



**H**ello, and welcome to Our Solar System and Beyond,  
created by The JLR Group, Inc.!

### **Introduction...**

**T**his disc is filled with an incredible number of multimedia articles on a wide variety of topics, from the center of our Sun to the farthest known reaches of the Universe. There is information for both the beginner and the sophisticated amateur astronomer. In addition to the multimedia articles, you'll discover stunning photography, an Interactive Dictionary of Astronomy, movies, illustrations, music, and interactive text.

**P**lease take a few minutes to read the short descriptions below. The following quick overview of the contents will help you to find your way around this large multimedia collection, and will help you to have more fun using the product!

### **Blast Off!**

**T**he Blast Off! section provides fast access to a dazzling array of exciting topics. You can read about the history, present, and future of subjects such as Extra Galactic Space, Stars, and Planets. You can even read about "Inner Space," which provides an insider look at the human element. If you're looking for Interactive Solar System graphics, click on the Guided Tour of the Universe button. As you get into the Blast Off! section, you'll be surprised at just how much information there is!

### **The Guided Tour of the Universe**

**T**ake your own special Guided Tour of the Universe! You'll zoom from Tour Stop to Tour Stop visiting such exciting destinations as White Dwarfs, Black Holes, Asteroids, Comets, Planetary Rings, Gas Giants, and much more. You'll find the answers to questions such as "What is the Sun?" and "What is Solar Wind?" along with learning about subjects like the Scale of the Universe, and the Magnetic Fields of the Solar System. You can take side trips from the Tour at any time, and then easily continue from where you left off.

### **Special Topics**

**T**he Special Topics section provides additional exploration into other Solar

System-related topics. Here you can learn about one of the world's greatest astronomers, and browse through various Overviews of Interest. You can also explore the Search for Life Beyond Earth, which includes general topics such as Life in the Universe, and Life in the Solar System, as well as detailed topics like the History of Exobiology. You don't know what Exobiology is?! Look it up!

### **I Didn't Know That!**

**I** Didn't Know That! is a feature of this CD-ROM which will be of interest to people of all ages, from very young children to adults. With its bright-colored cartoon-style illustrations, it will appeal especially to young astronomers. Interesting facts about our Solar System are presented with spoken narration and music.

**A**fter the narrator speaks the quote, the music continues for about one minute more. This is a feature specifically designed for parents using the product with their children. The continuation of the music provides the parent and child some time to discuss the interesting fact that they have just learned, and relate it to the picture they are seeing.

### **Explore the Space Shuttle Voyager Up Close**

**I**n Explore the Space Shuttle you'll see many exciting, full-color photographs of this amazing spaceship. In addition, you can watch detailed movies of the Space Shuttle in action, as you learn about our exploration of space. There's even an Interactive Graphic of the Space Shuttle controls!

**I**n Voyager Up Close there's a whole book's worth of information, along with many fascinating photos, movies, and more. You'll learn about Voyager's problems, successes, its exploration of the outer planets, and its journey as it heads for the stars.

### **High-Quality Photographs**

**O**ur Solar System and Beyond is packed with hundreds of high-quality, authentic photographs of everything from astronauts to astronomers, rocket ships to rocket scientists, the Sun, the Moon, and the Stars, and everything in between. The subjects that these photographs illustrate are all carefully indexed, and available at the click of a mouse.

### **A Video History of Space Flight, And More!**

**S**pread throughout this CD-ROM is the story of the history of space flight, told through videos. From the First Launch all the way to the Space Shuttle, you'll see and hear all about the technology of our space program, and the men and the women behind it. As you watch these videos, you'll learn all about our Solar

System, Voyager, and the fascinating history of our "reach for the stars."

## Dictionary of Astronomy

**I**n addition to all the other fascinating and fun multimedia materials on this disc, the Our Solar System and Beyond CD-ROM includes an interactive Dictionary of Astronomy. This feature defines over 150 astronomy-related words, names, and phrases. Every one of these items is available for direct look-up in the Index. Included in this Dictionary is a set of Interactive Solar System graphics!

## All The Most Interesting Topics!

**I**f it's out in the Universe, it's in this CD-ROM! There's information on all your favorite topics, subjects like Black Holes, Quasars, Anti-Matter, the Theory of Relativity, Neutron Stars, Life on Other Planets, and much more! Use the Index or the Search feature to find information on specific topics, or just use the Blast Off! and Guided Tour features to browse around.

## Search

**T**here's a powerful Search feature which you can easily use to look up any subject you want. Search is available at nearly all times. All you have to do is type the "S" key (upper or lower case). Then, simply type in any word or phrase you want to look up, for example star, Earth, quasar, etc. You'll get a list of all the sections that have what you're looking for. Select any name on the list, click the Go To button, and you'll automatically zoom to that article.

NOTE: There are many items that Search will not find, since these items are located not in text but in narrations, movies, graphics, and so on. If you don't find what you're looking for with Search, try using the Wildcard feature described below. If you still don't find it, check the Index!

**S**earch has many sophisticated features, and has additional Help Information built right into it. You can use the asterisk \* (shift 8) as a "wildcard" to fill in for one or more missing letters. For example, searching for the word "magnet\*" will find not only magnet, but magnetic, magnetosphere, and so on.

**A**lso, you can combine your search words in any way you want. For example, if you want to know which planets have rings, you can type "planet\* AND ring\*" and you'll discover that there are 22 topics that fit this description!

**I**f you wanted information on stars, but not the Sun, you could type "star\* NOT sun\*" and you would find dozens of matching entries and topics.

## Index

**T**he Index is available at nearly all times. All you have to do is type the "I" key

(upper or lower case). Included is an extensive Master Index with hundreds of entries, and many of those entries have sub-entries. Especially notice the Dictionary of Astronomy entry, with over 150 sub-entries! The Index provides an easy, quick way to zoom to any specific topic that you're interested in. The entries aren't limited to just objects -- you can also find subjects and subject-groups as varied as The Big Bang, G-Forces, Northern Lights, and Christopher Columbus.

NOTE: There are many items that are in this collection, but are not specified in the Index. If you don't find what you're looking for with Index, try using Search, especially with the Wildcard feature described above!

**W**e hope you enjoy  
The JLR Group, Inc. CD-ROM  
Our Solar System and Beyond,  
and that you will have many  
exciting explorations!

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## Credits and Acknowledgments...

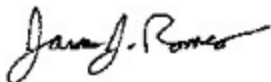
### The Creation of Our Solar System and Beyond

**T**he Our Solar System and Beyond CD-ROM was created over a long period of time by a core team of employees of The JLR Group, Inc. In addition, hundreds of people worked to create many of the photos and other media that are included in this product. It's impossible to list all of the individuals, corporations, government agencies, schools and universities, and other people who were involved. We would like to thank certain people and groups by name for their contributions to this effort. We hope you enjoy Our Solar System and Beyond, and we hope you take a few moments to read through the Credits and Acknowledgments.

### Our Solar System and Beyond

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Laura E. Romeo, V.P. of Production  
Peter Vantine, Director of Special Projects

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**Laura E. Romeo, V.P. Production**



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**L**isted below are some of the Media Artists, Technology Experts, Corporations, Writers, and Special Assistants who contributed to this product.

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Thank you for the wonderful original paintings you did for the "I Didn't Know That!" Special Topic. They have added a lot of fun and charm to our CD-ROM.

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**G**igi Abraham, Voice Over Talent.

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**A**dobe Systems Incorporated, for Photoshop.

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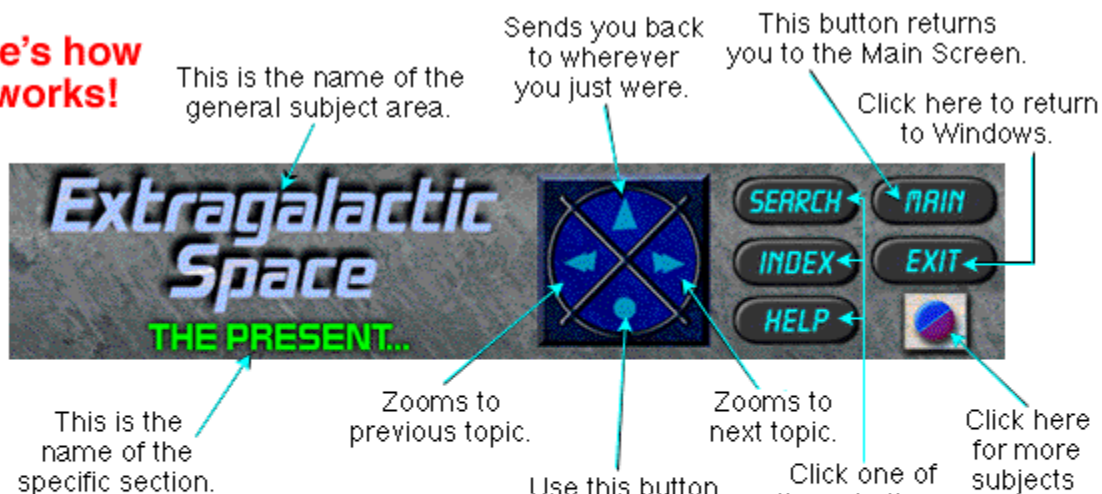
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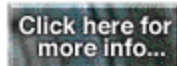
**The JLR Group, Inc.  
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Framingham, MA 01701**

## Here's how it works!



## Great Shortcuts!

type B to return back to your previous location  
type C to return to the Main Contents screen  
type I or S to access the Index or Search  
type < or > (comma and period) to browse left and right  
type T to trace all the places you have been



*Click here to hide me...*

## Note:

Click on green type to zoom to a related topic.

**I**f you are looking for interactive graphics of the Solar System, check out the Guided Tour Introduction.

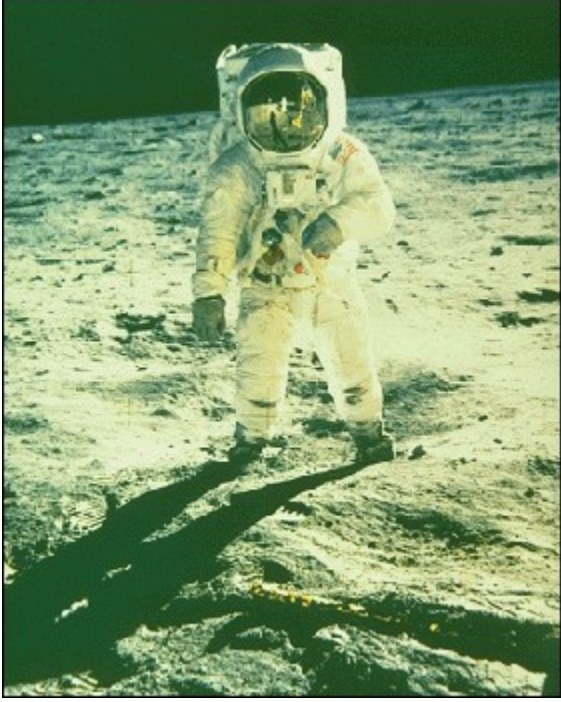
**I**f you want to look up a specific topic, click on the Index button.

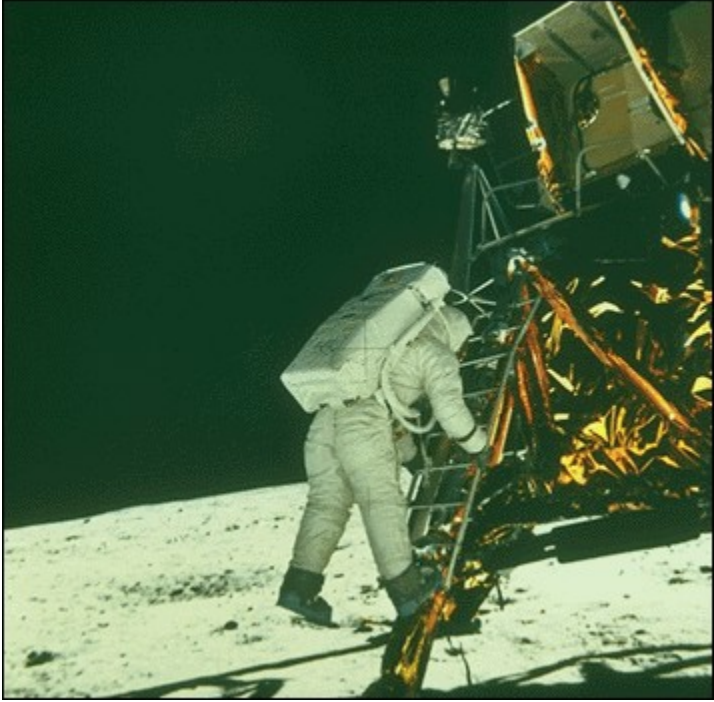
**I**f you want to browse around, click on Blast Off!

**I**f you want a general introduction to the contents of this CD-ROM, be sure to click on the About button.

**NOTE:** Not all of the blue 4-way Navigator buttons (up, down, prev, next) are always available.

*Press the Escape key to hide me...*

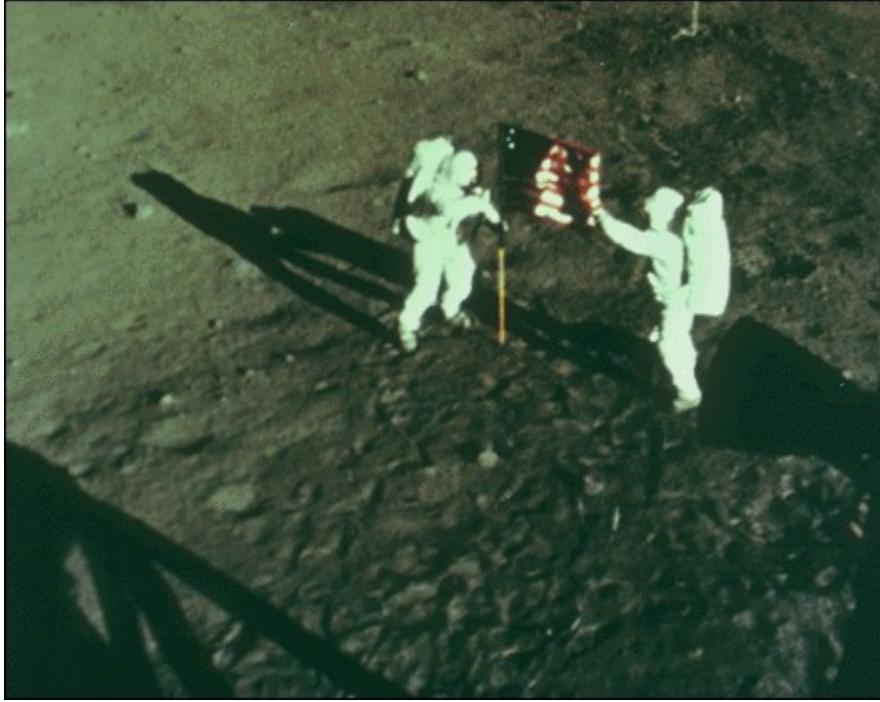




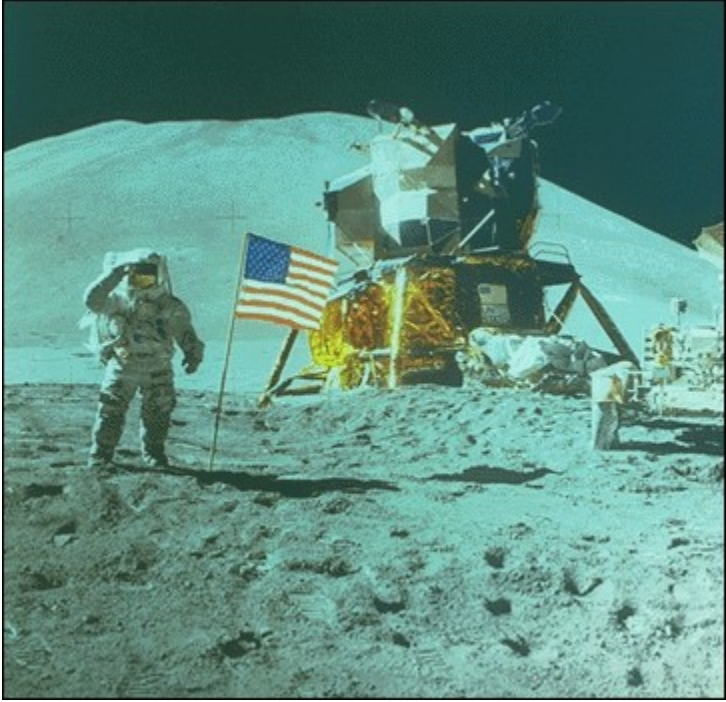






















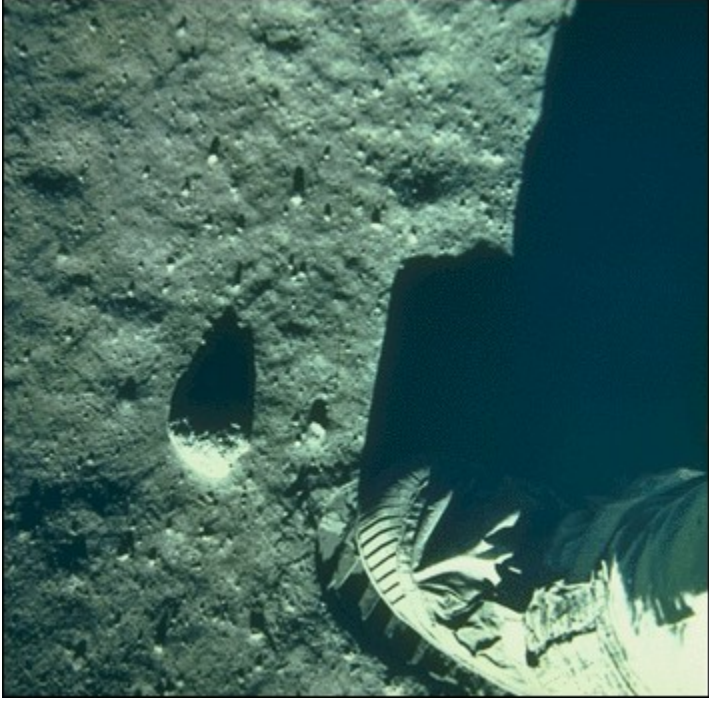


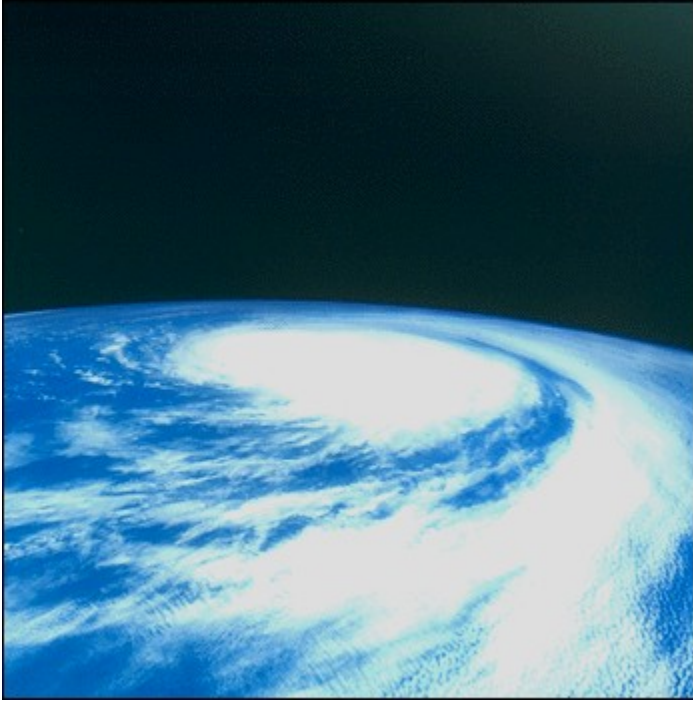




























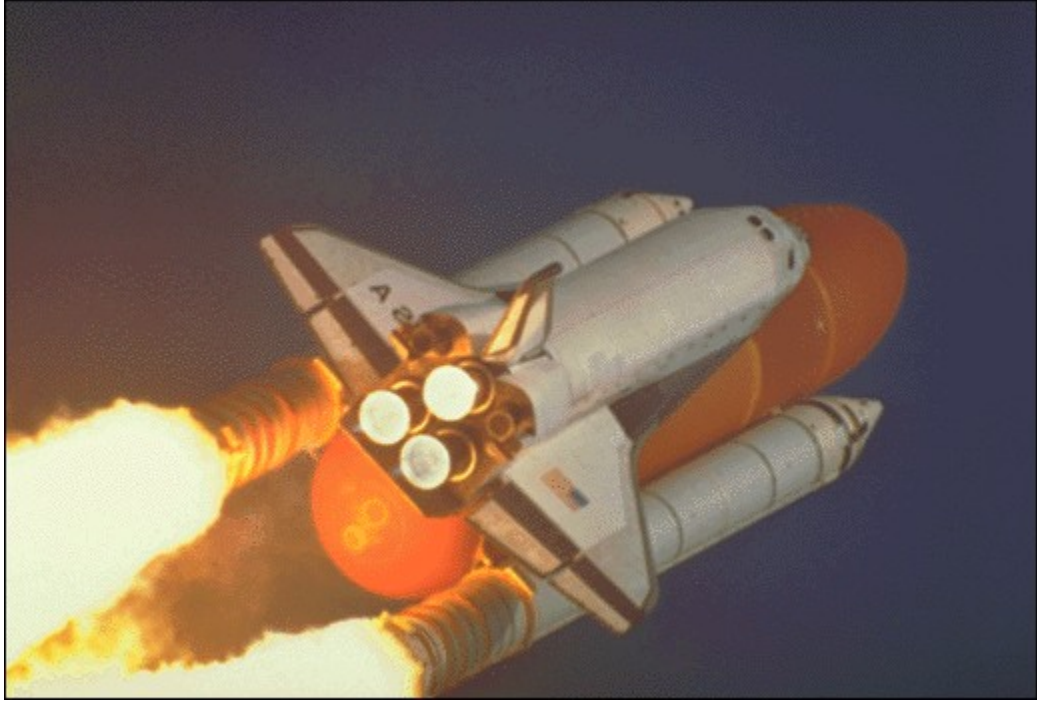


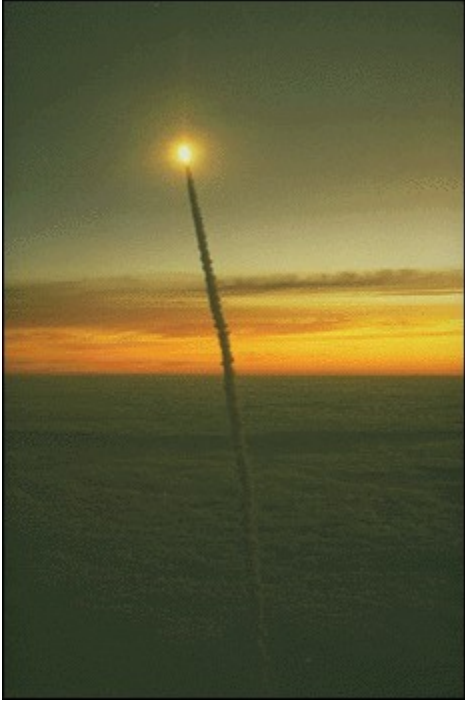










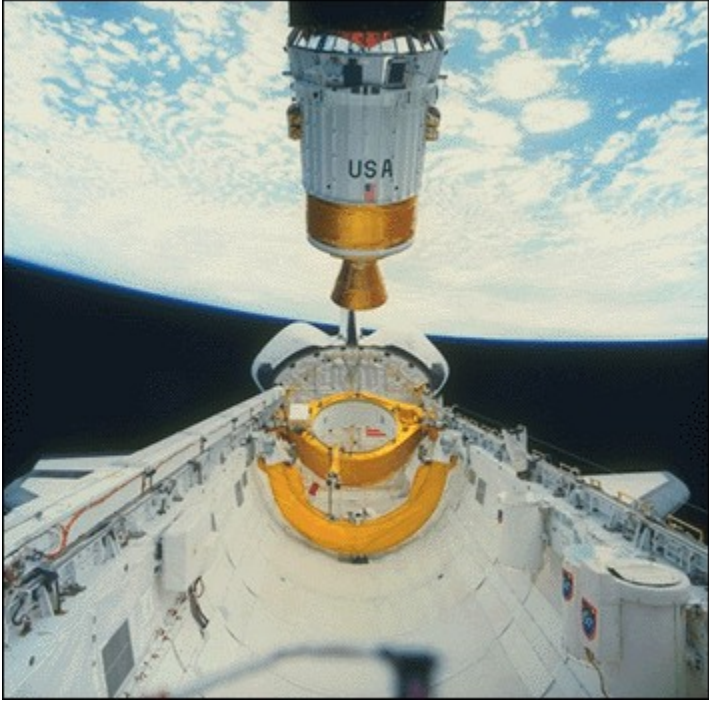




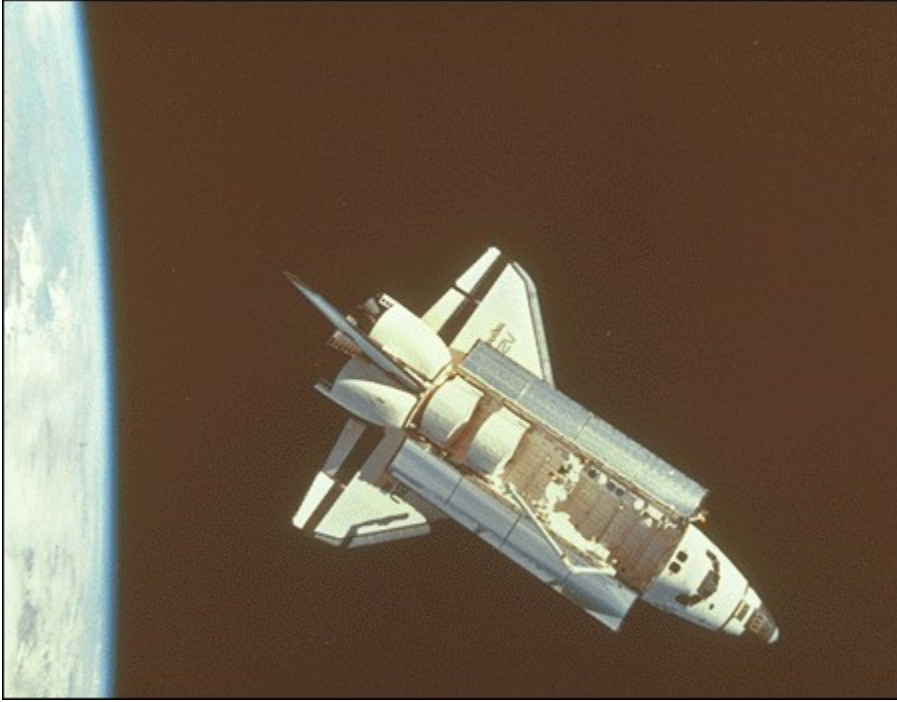


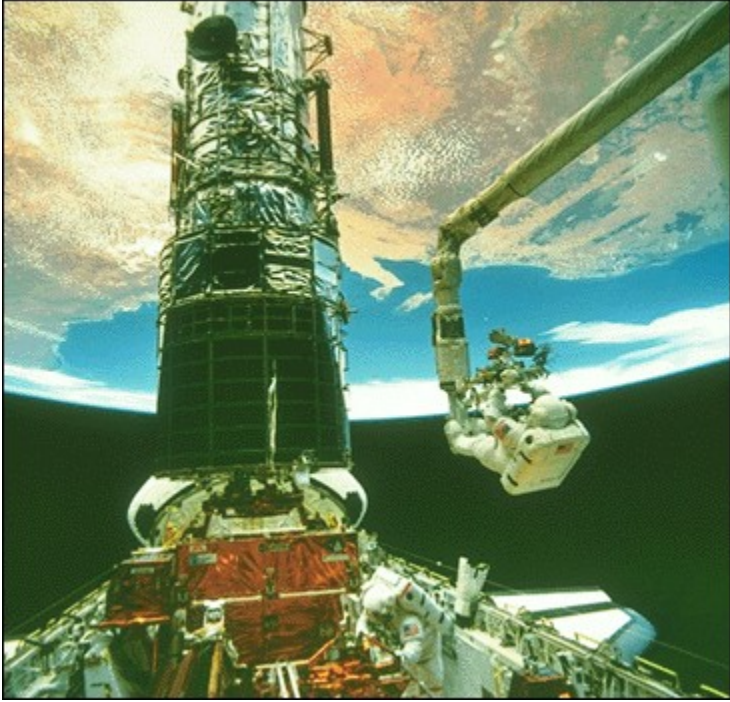






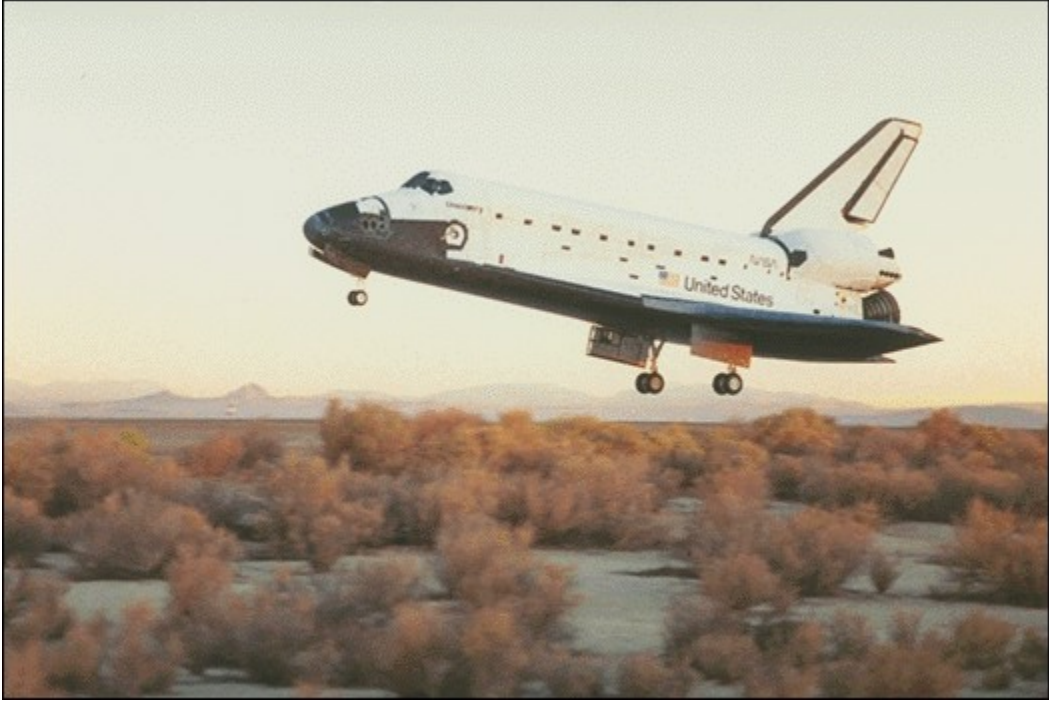




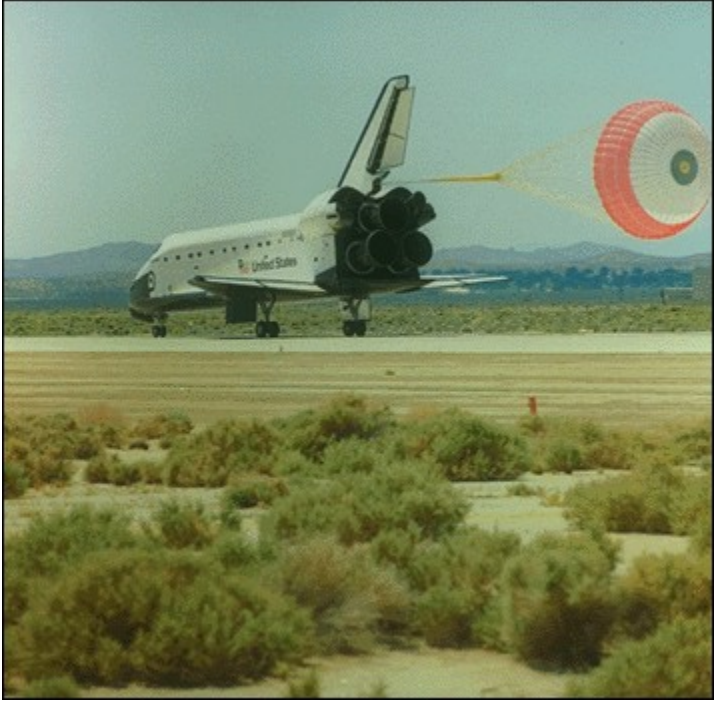








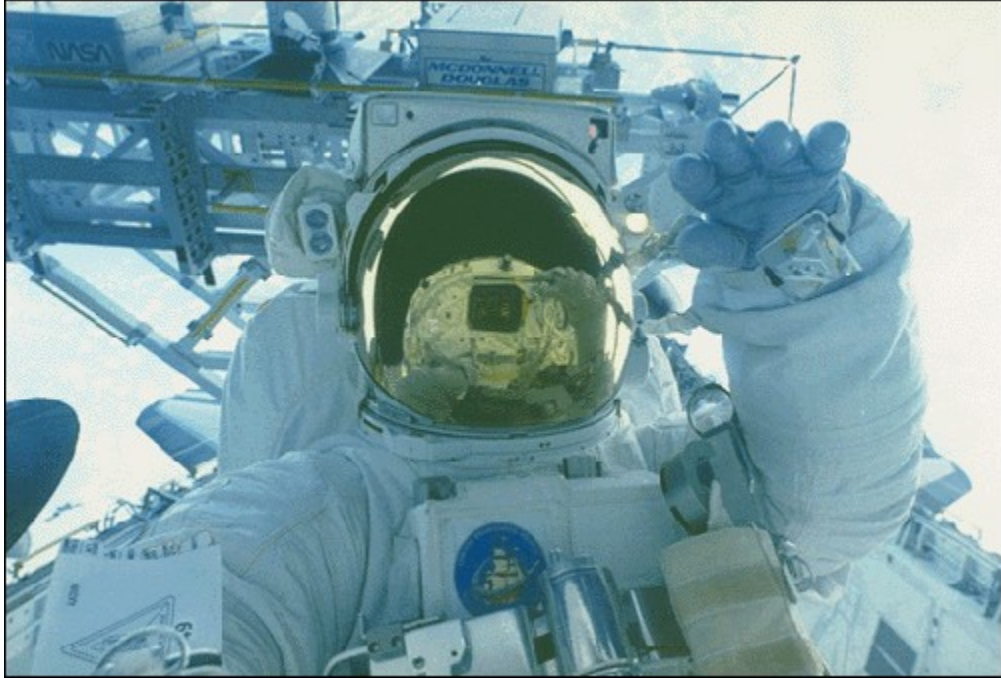






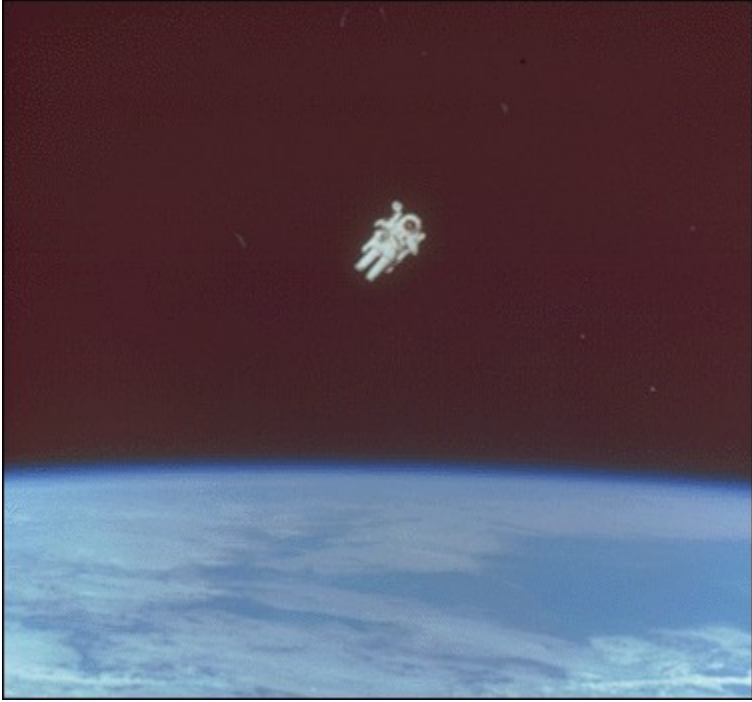








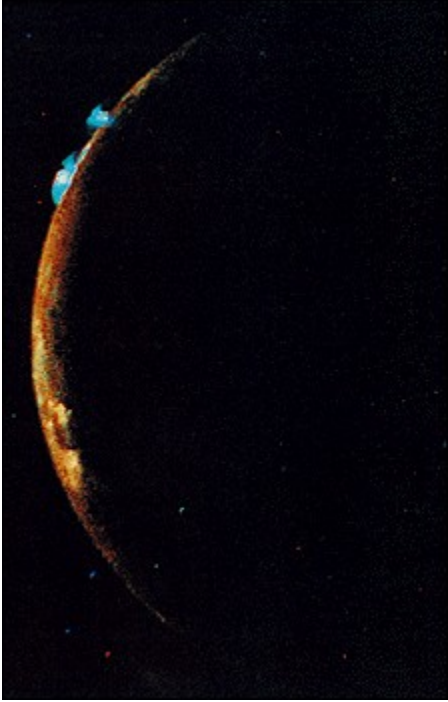


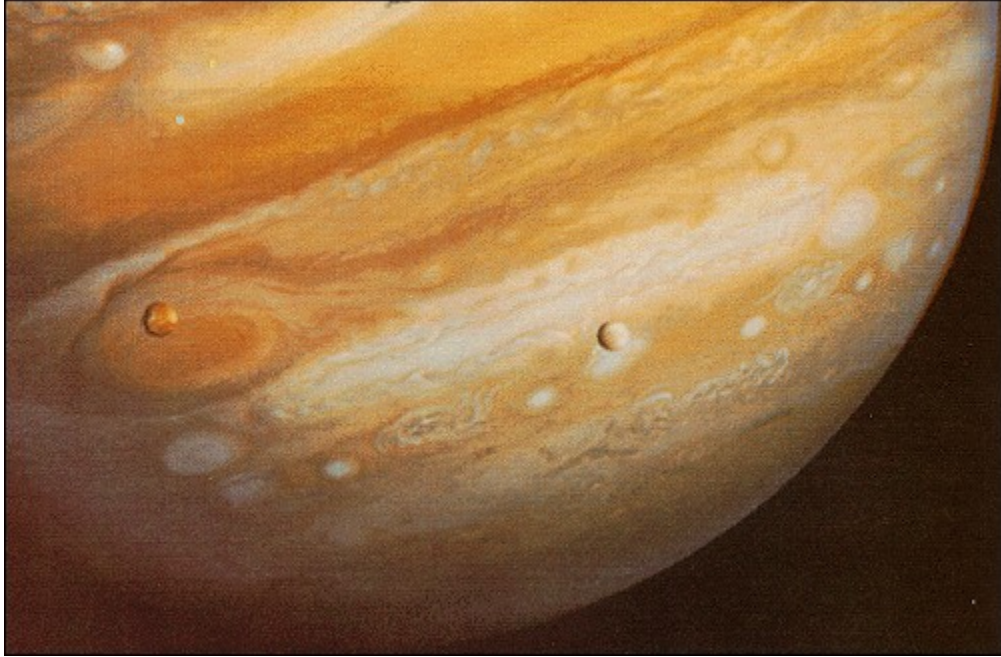








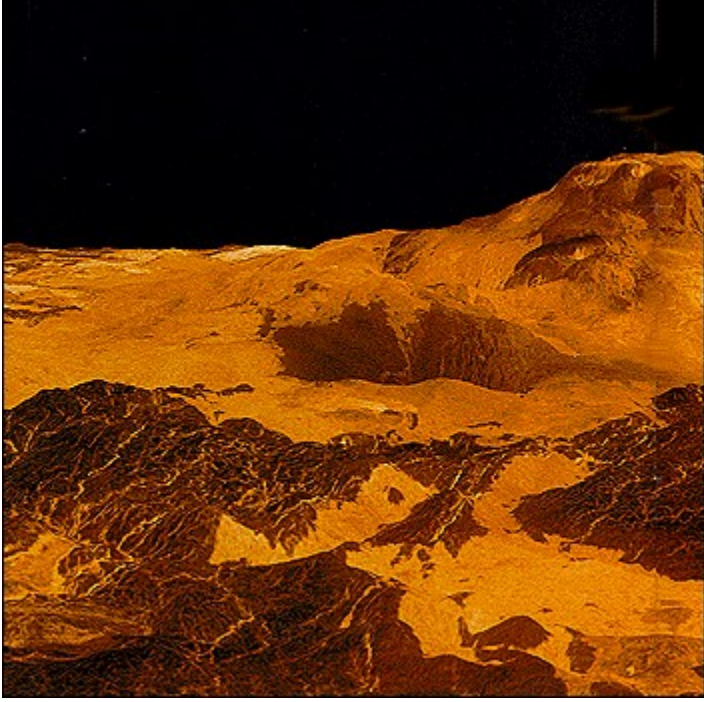








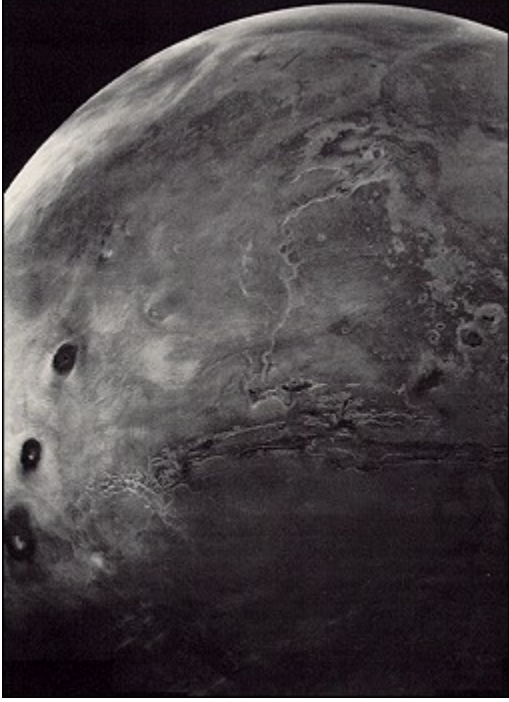












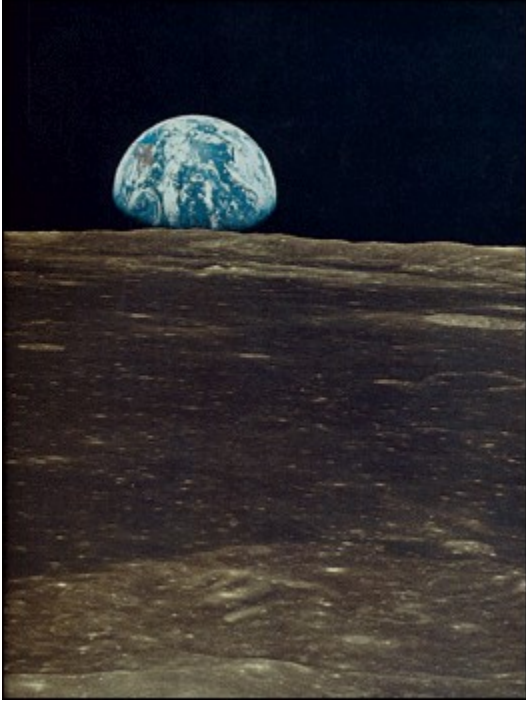


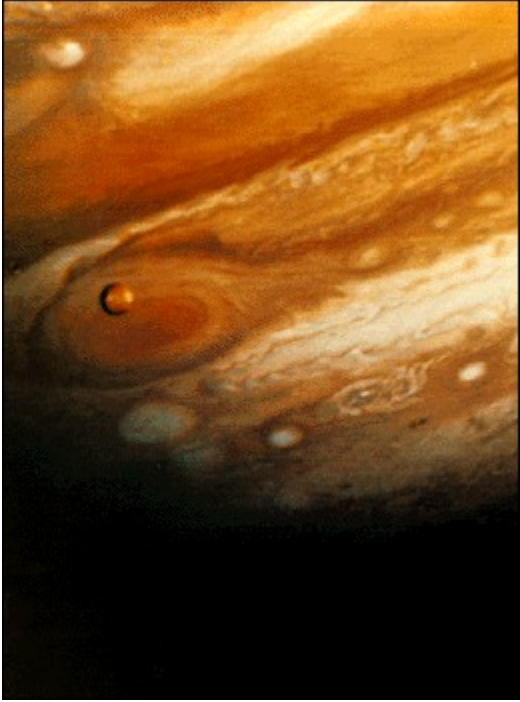


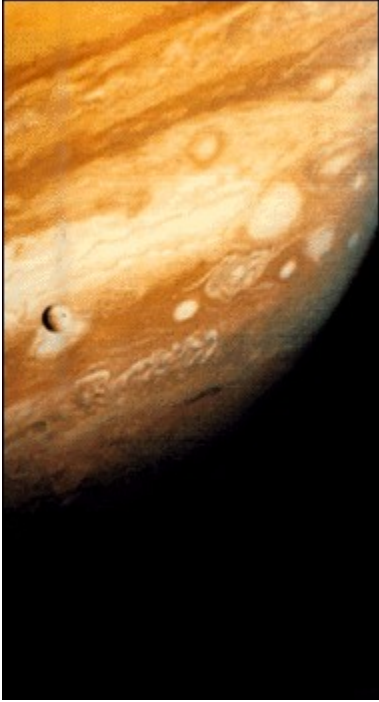












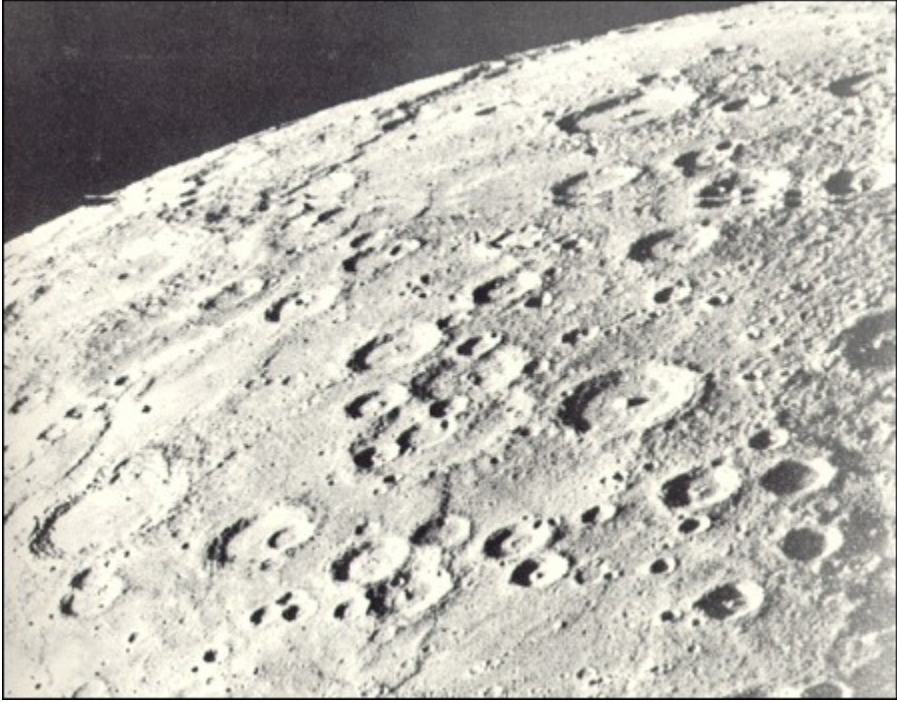




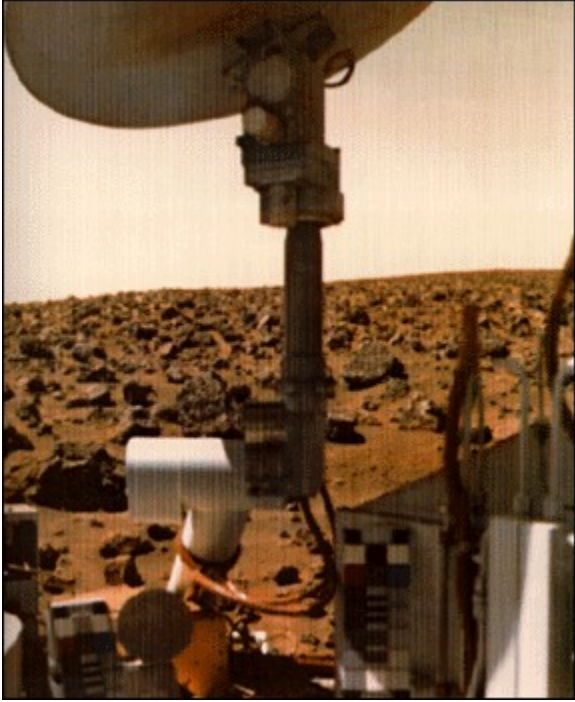










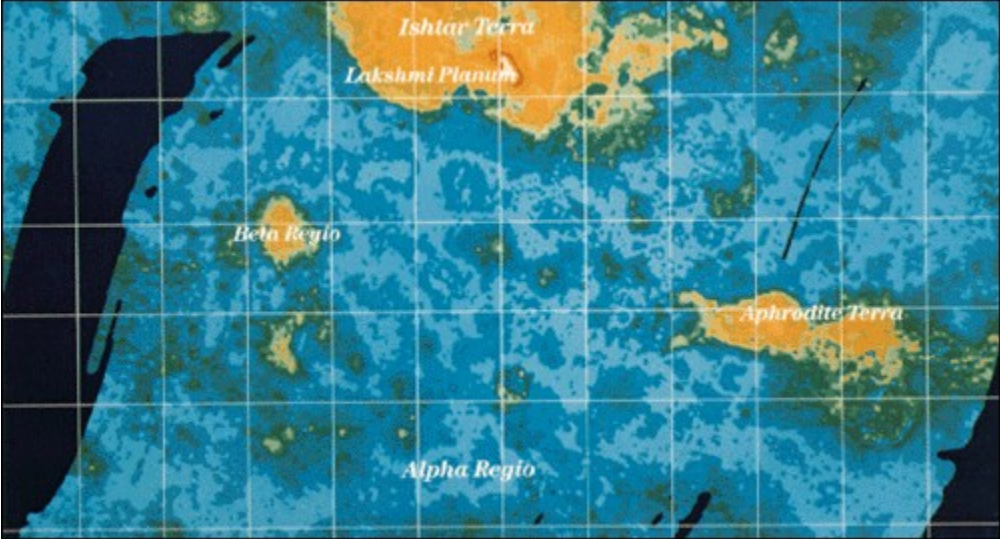








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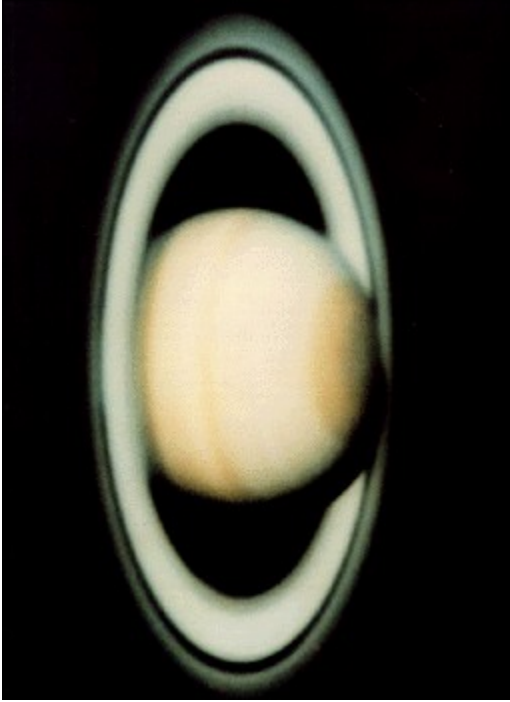
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*Europa*

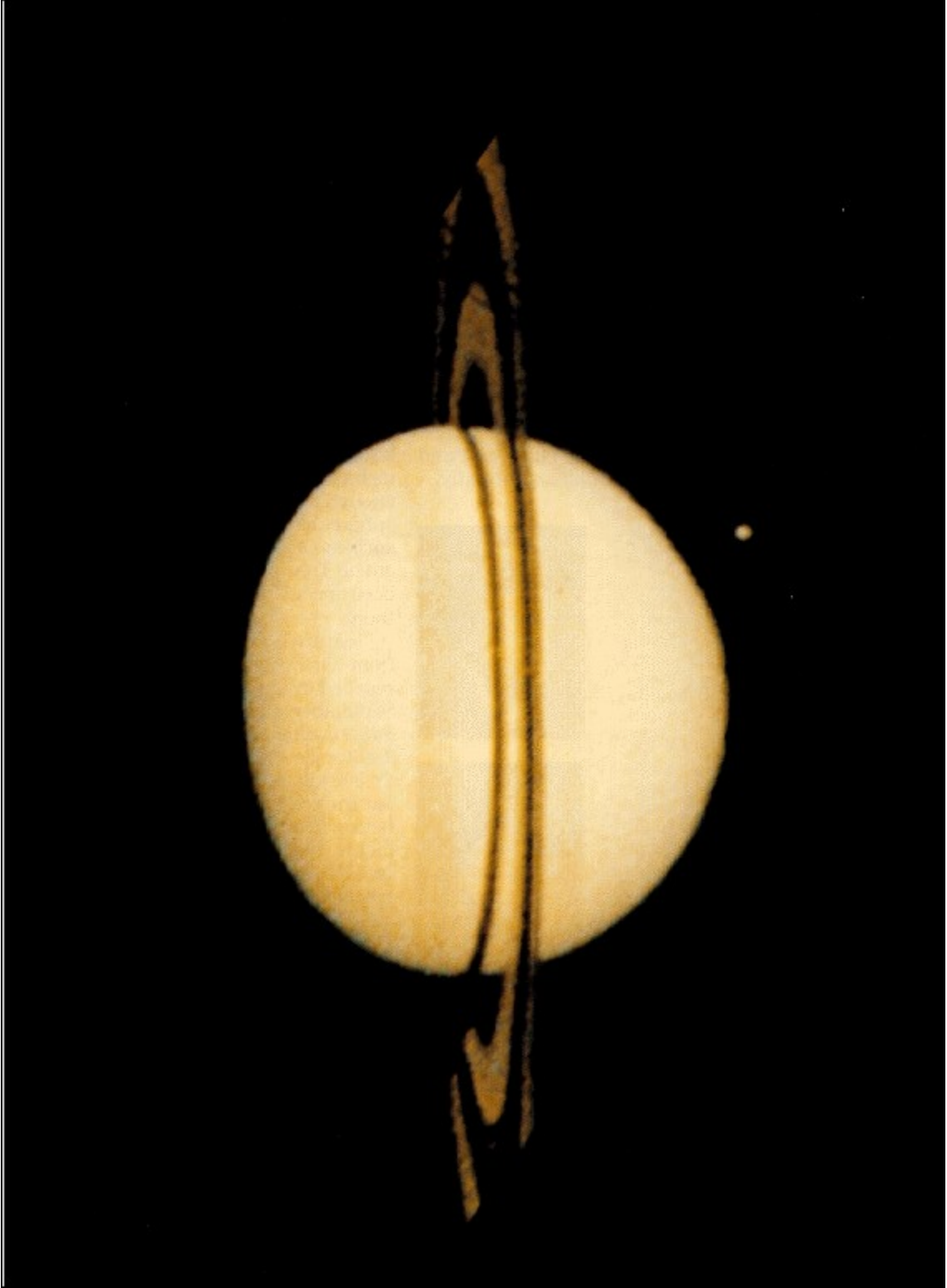
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*Callisto*

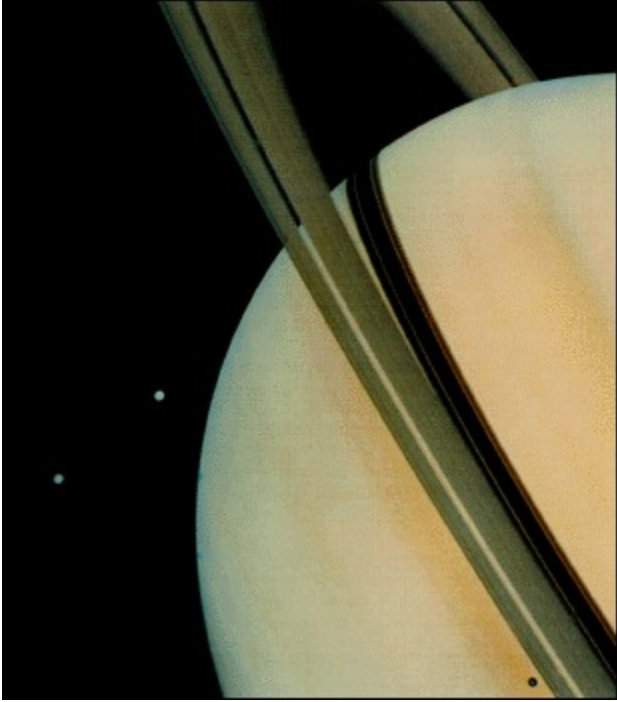


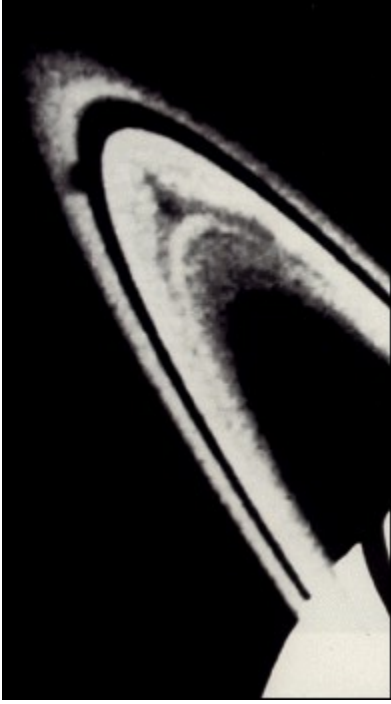


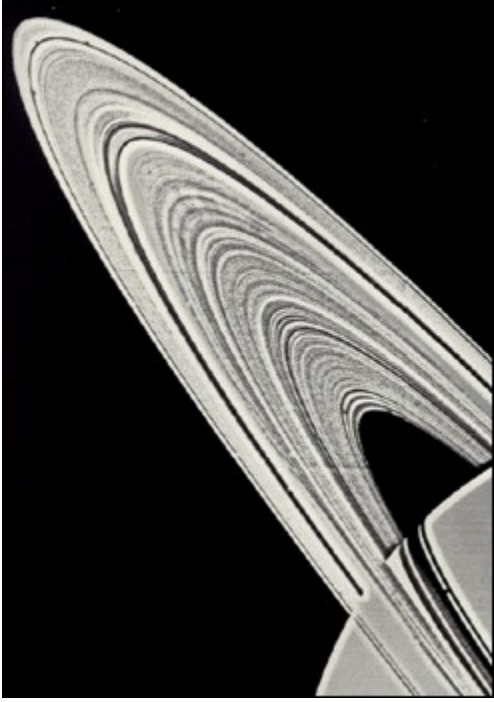








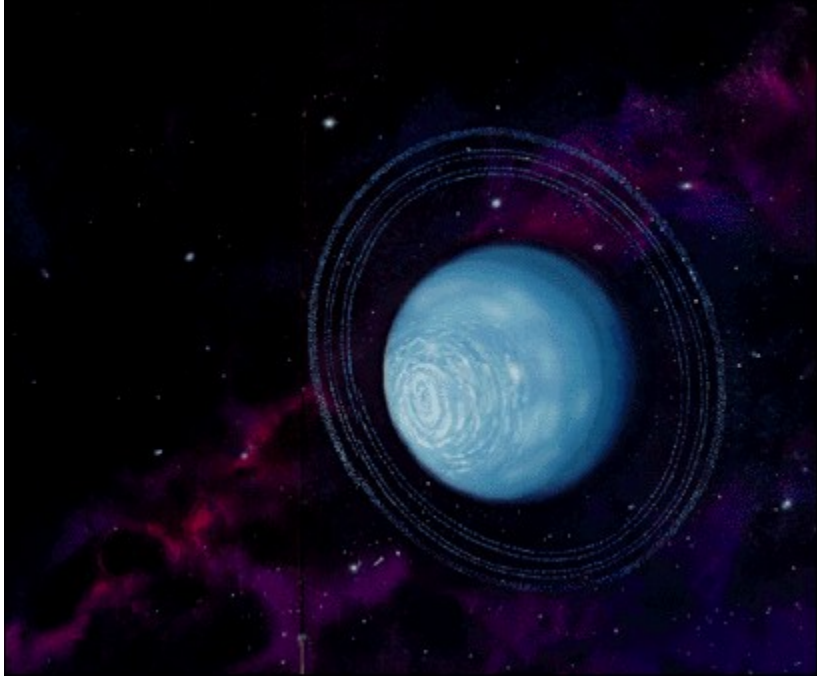


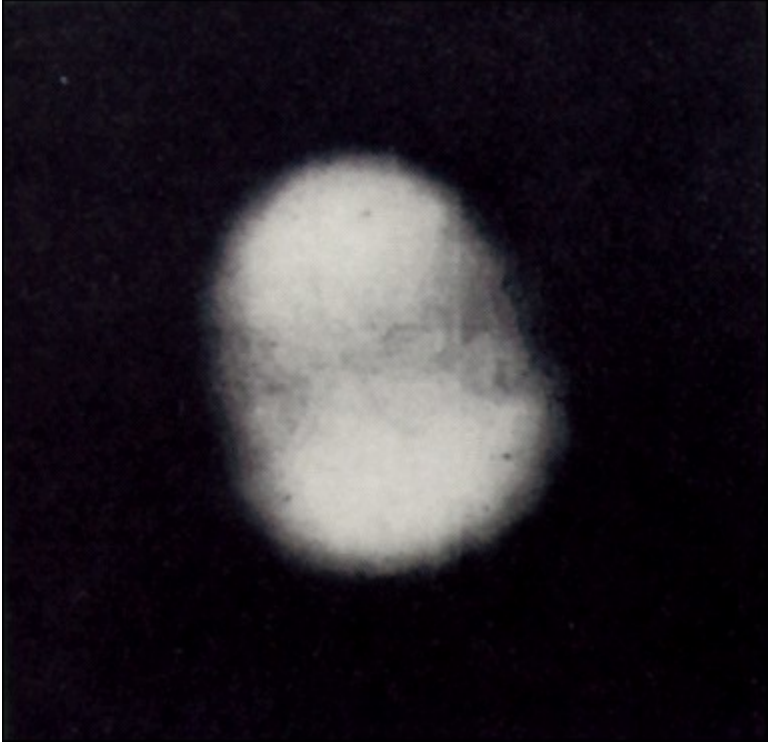


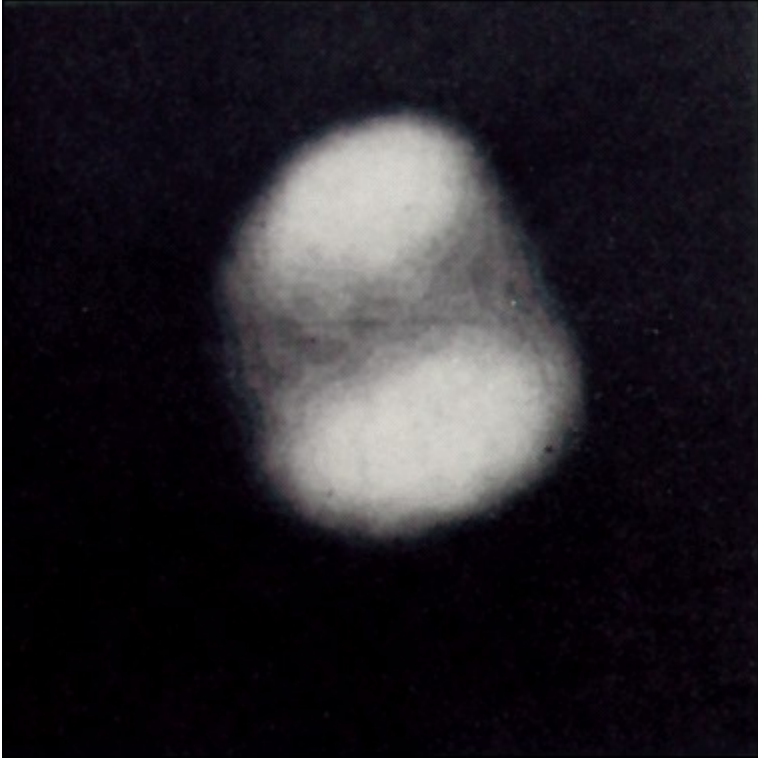


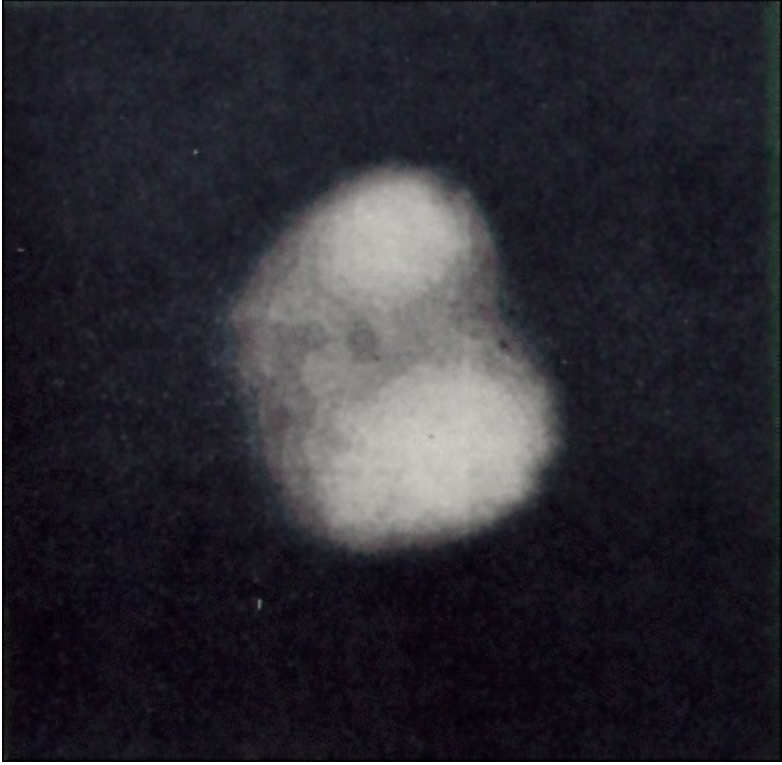


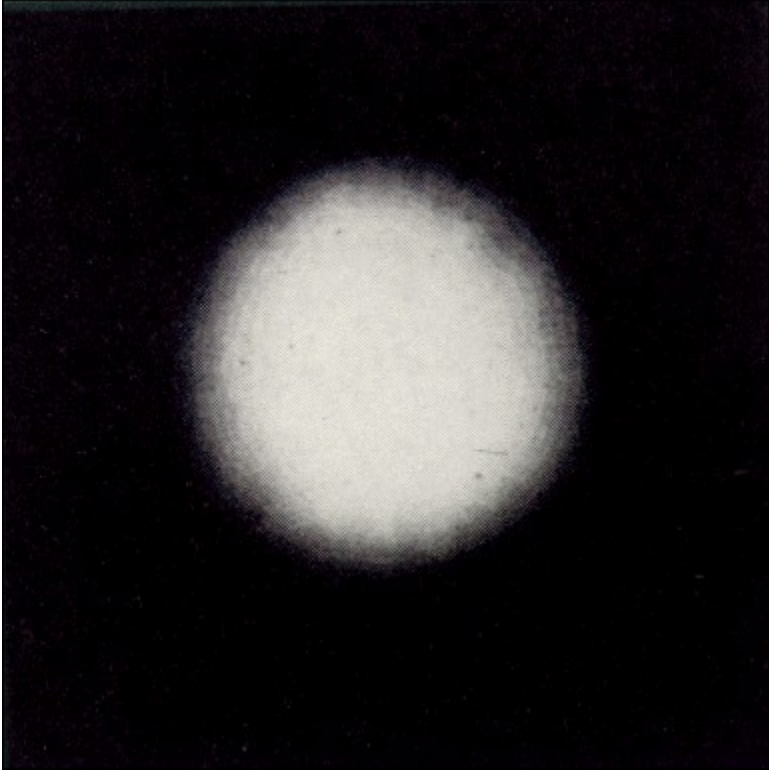












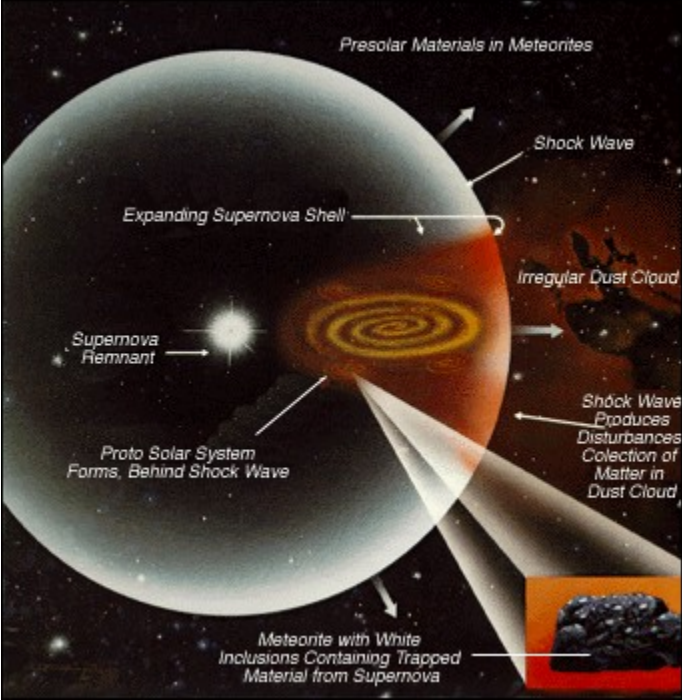




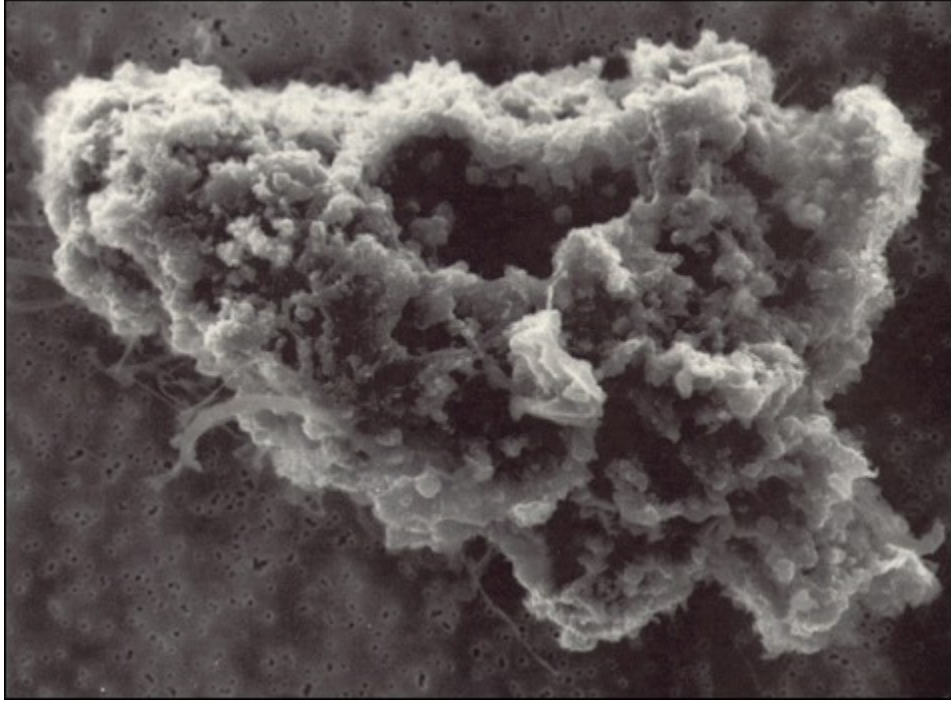


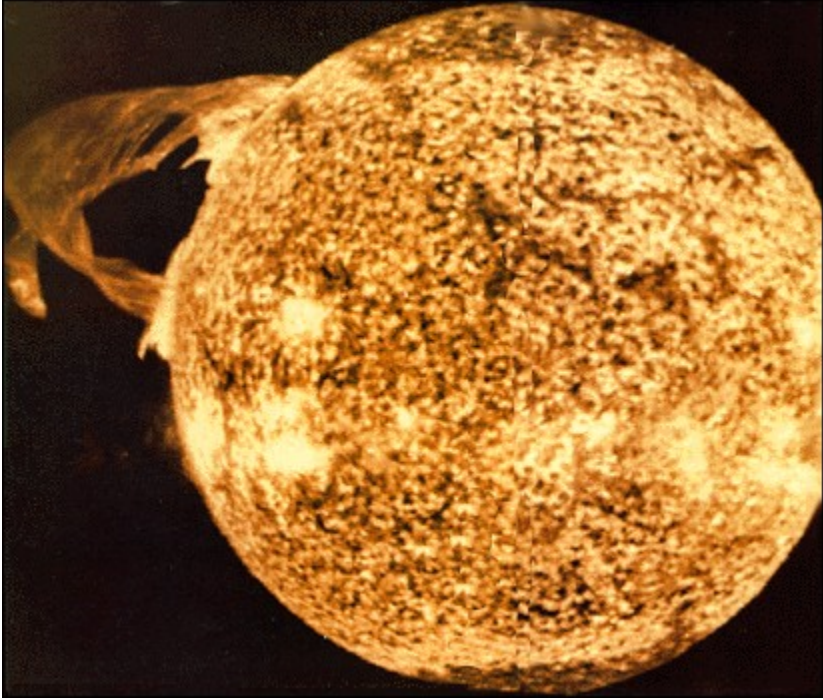








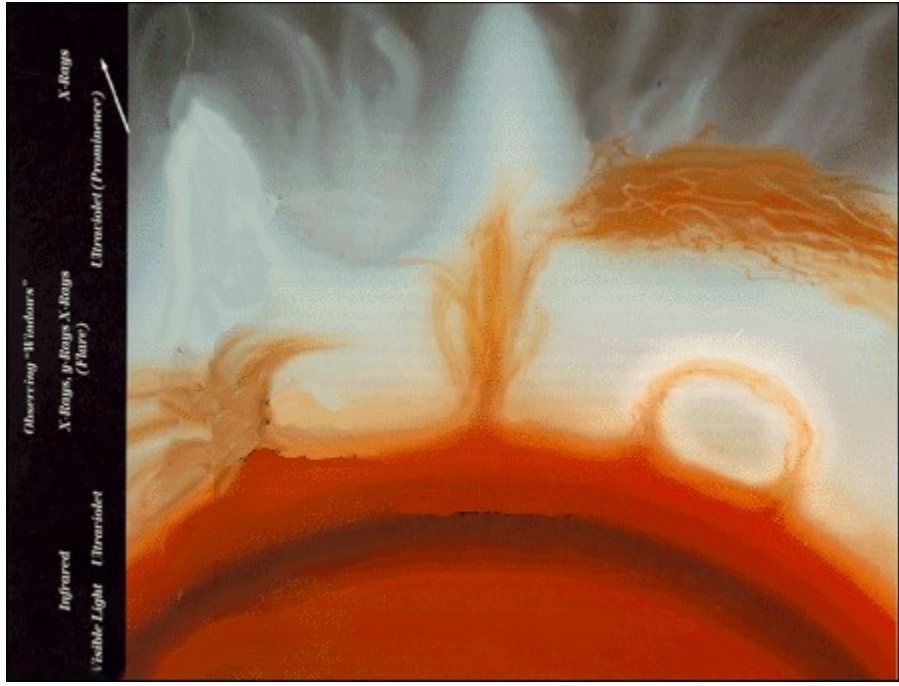


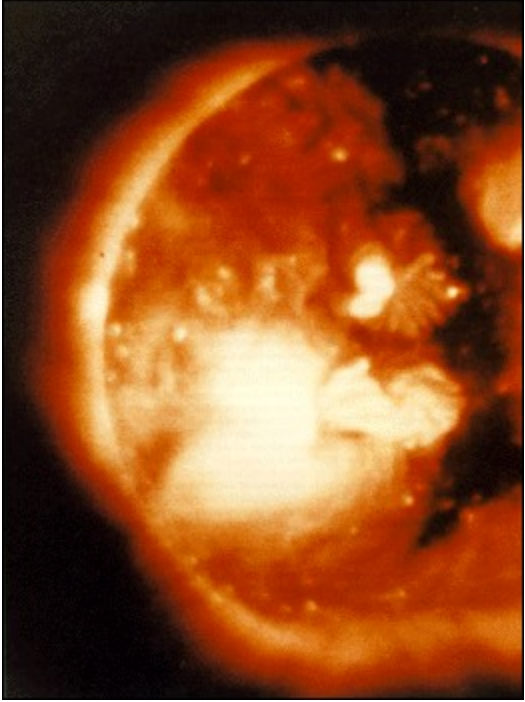




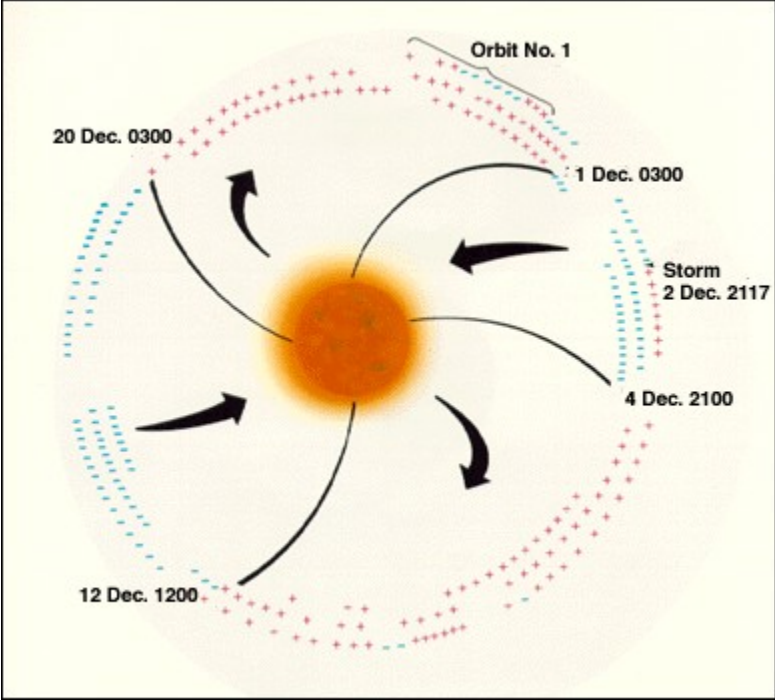


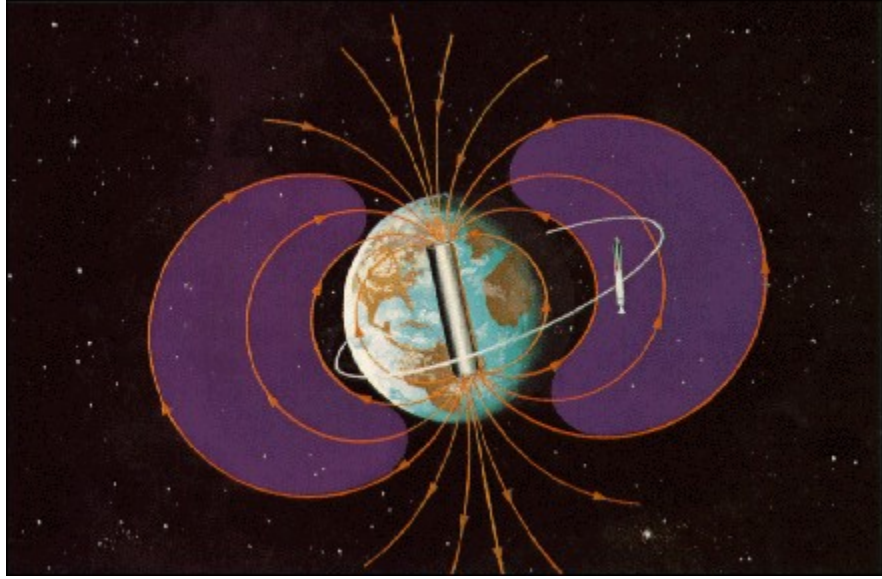








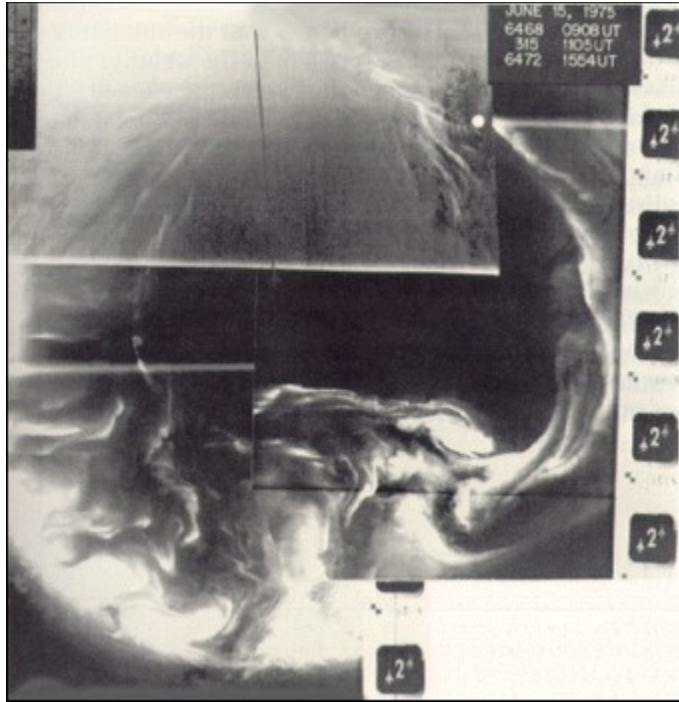


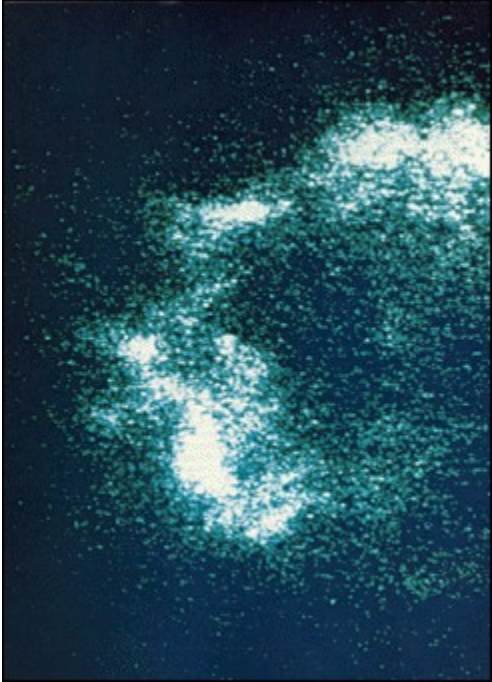














Stellar Evolution

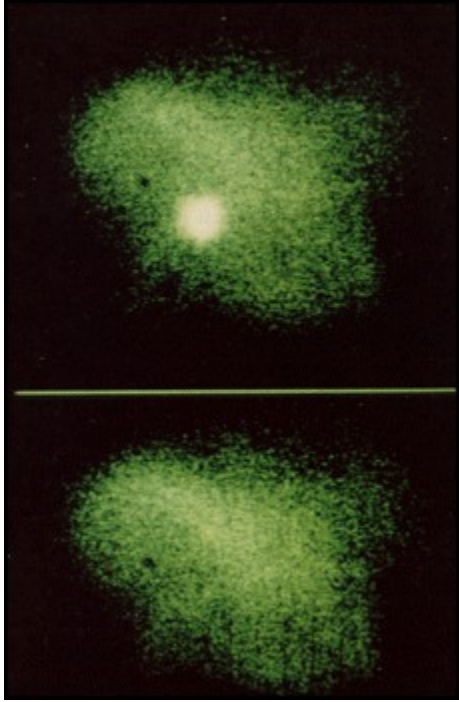
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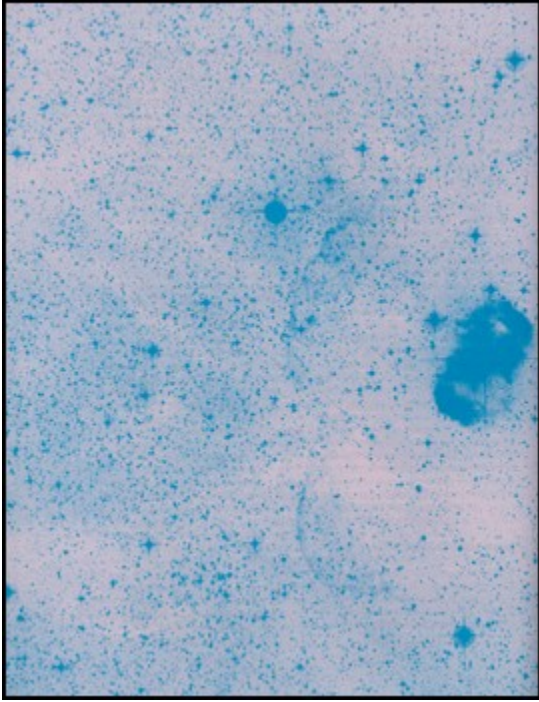
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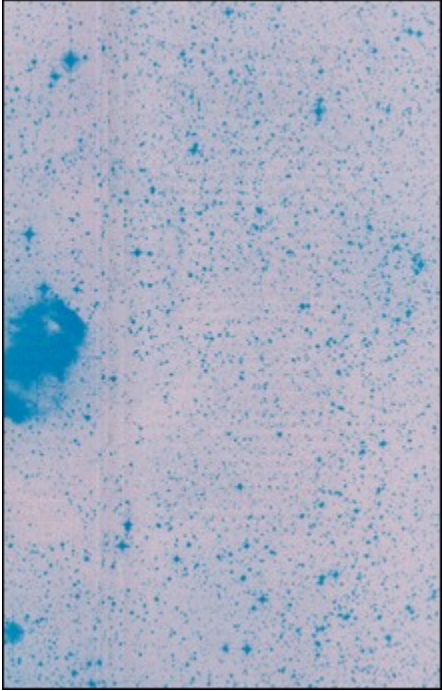














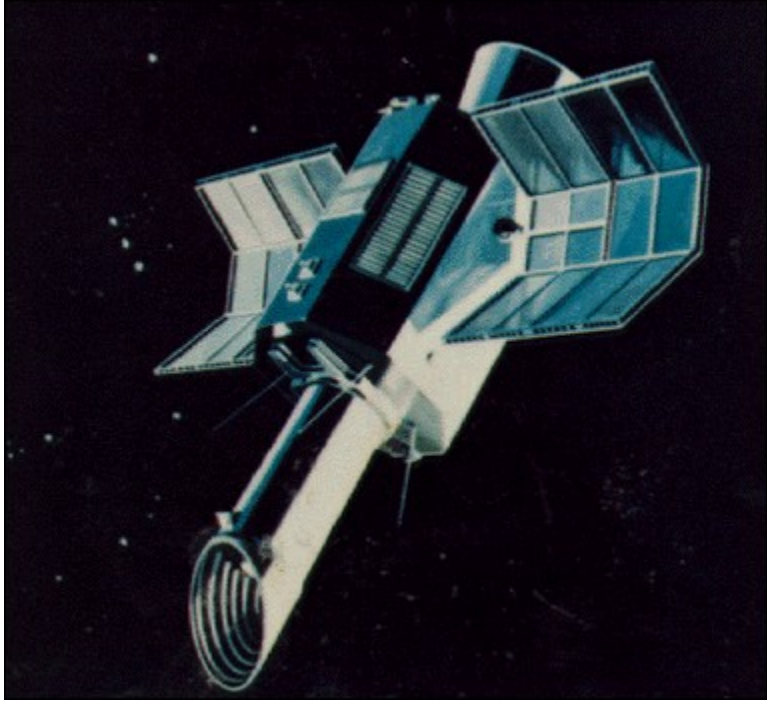






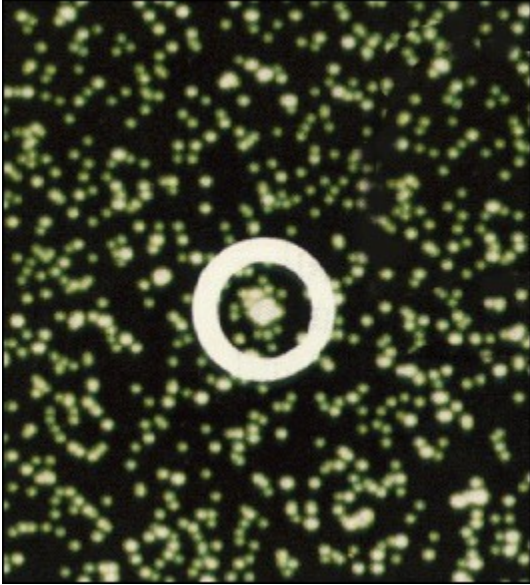


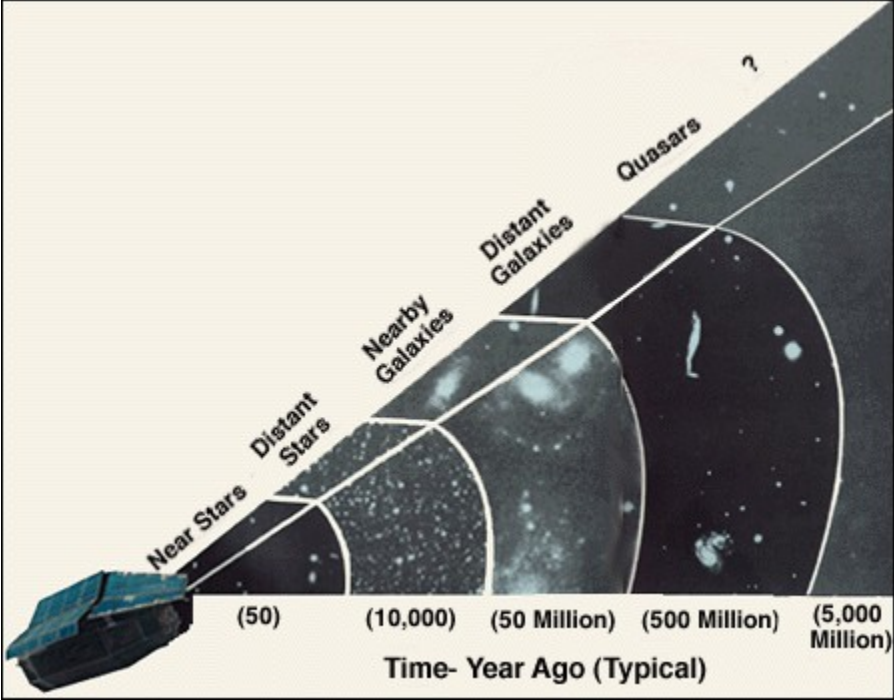












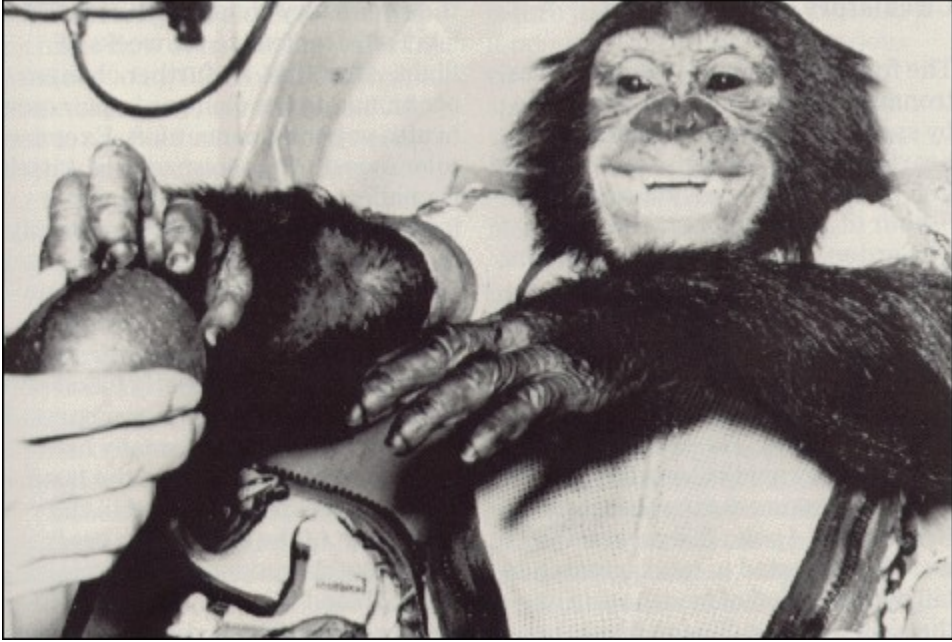




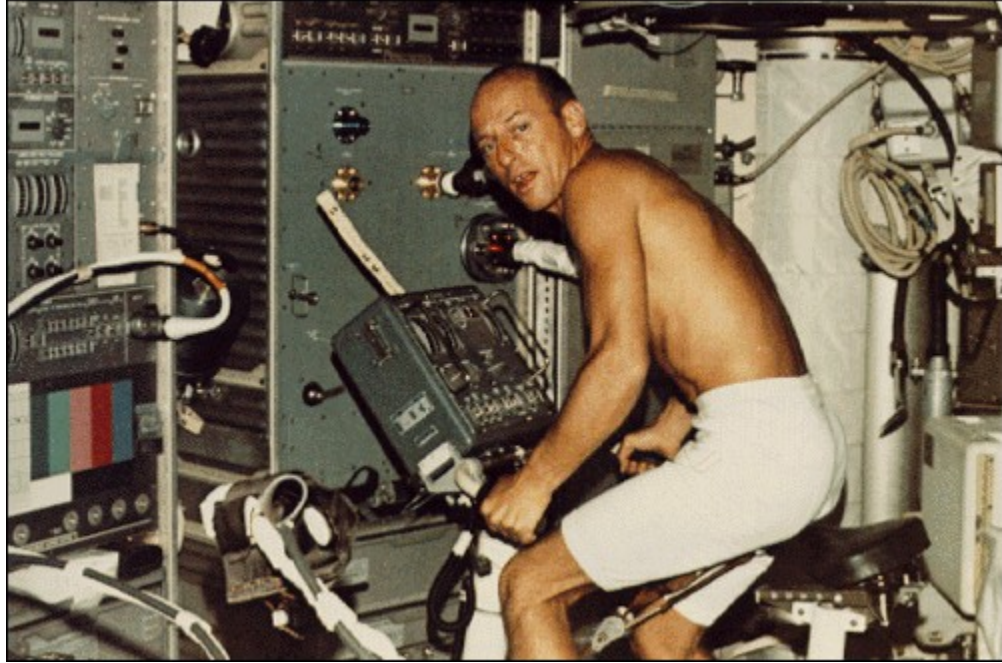








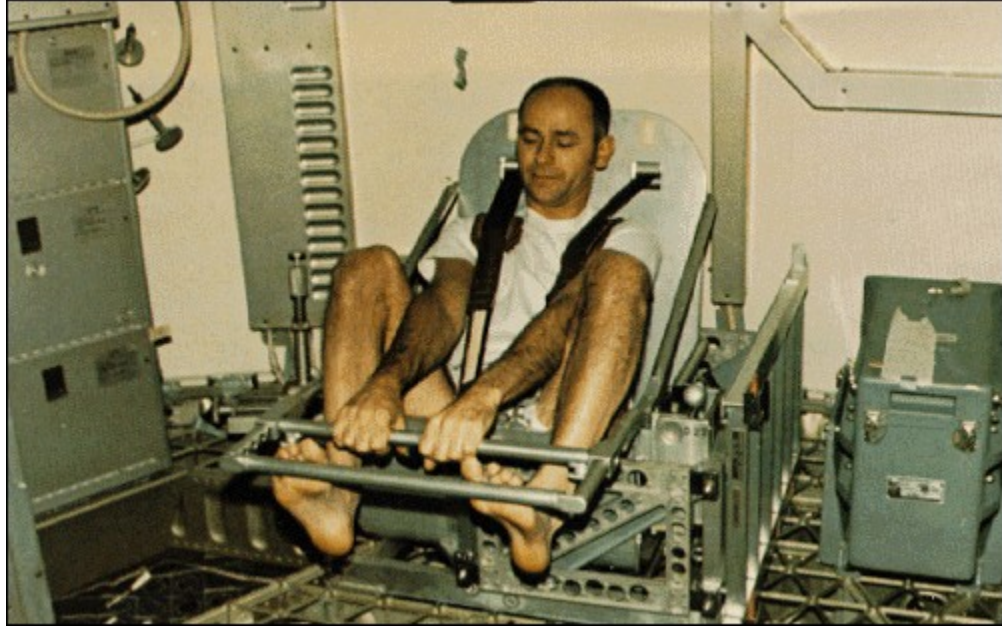




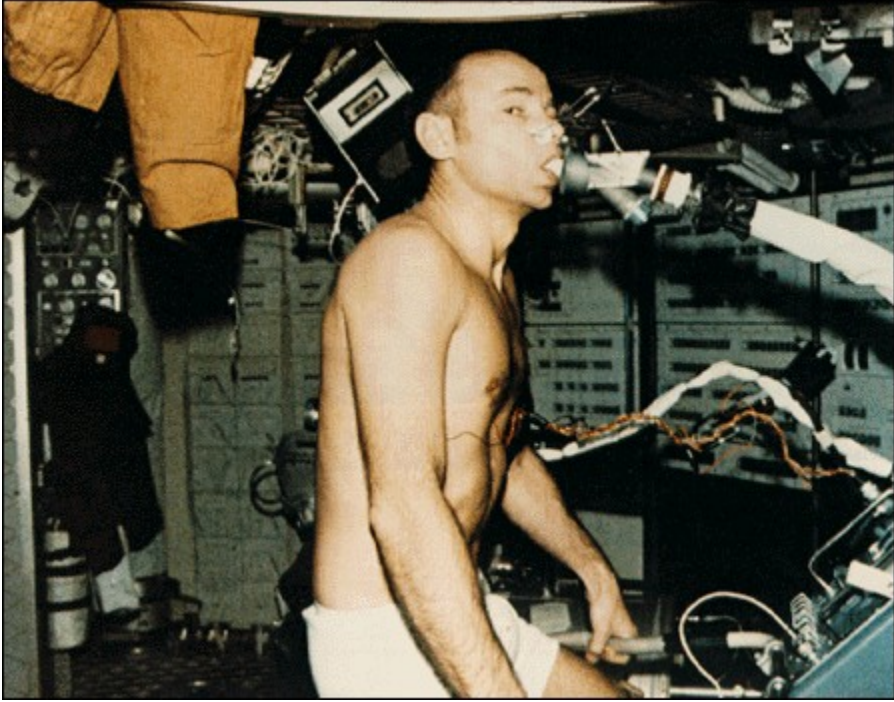














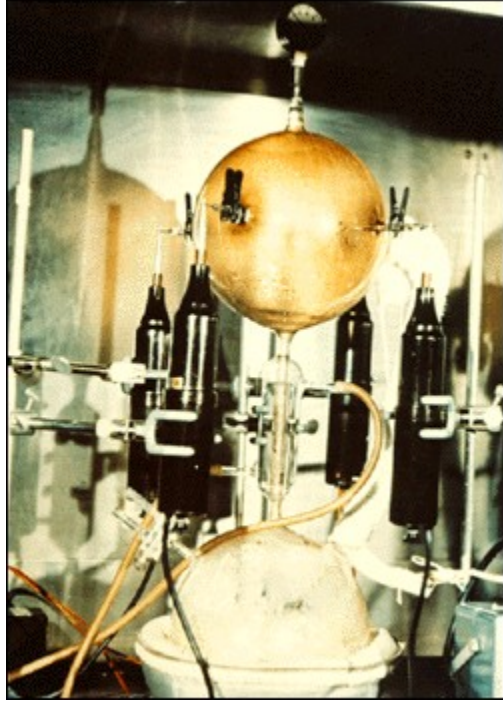




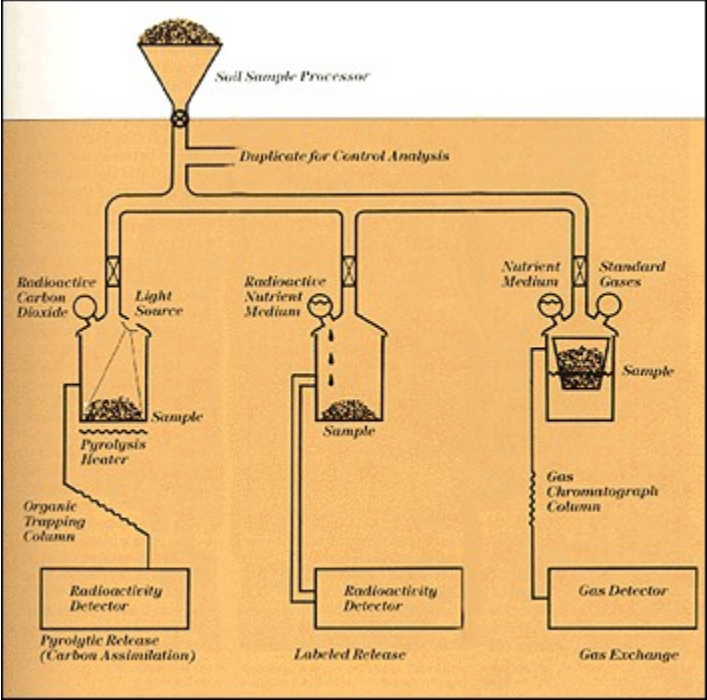




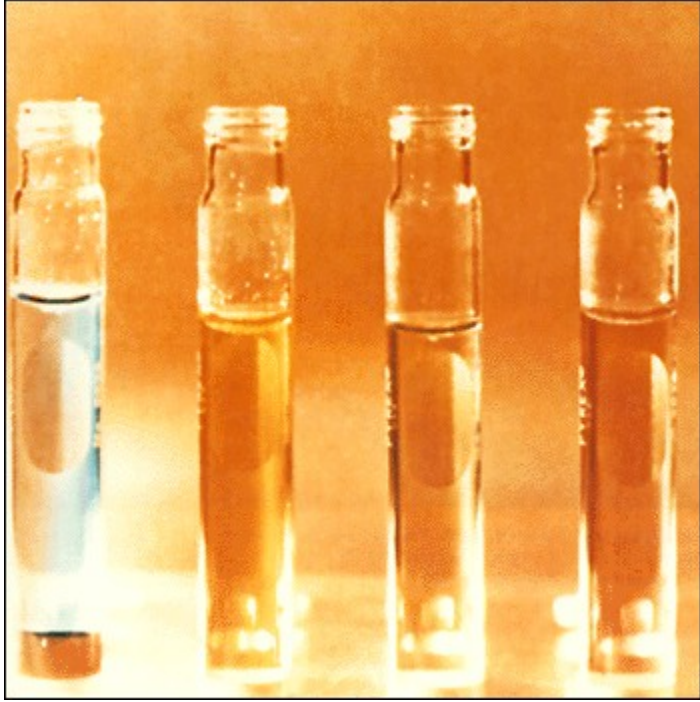


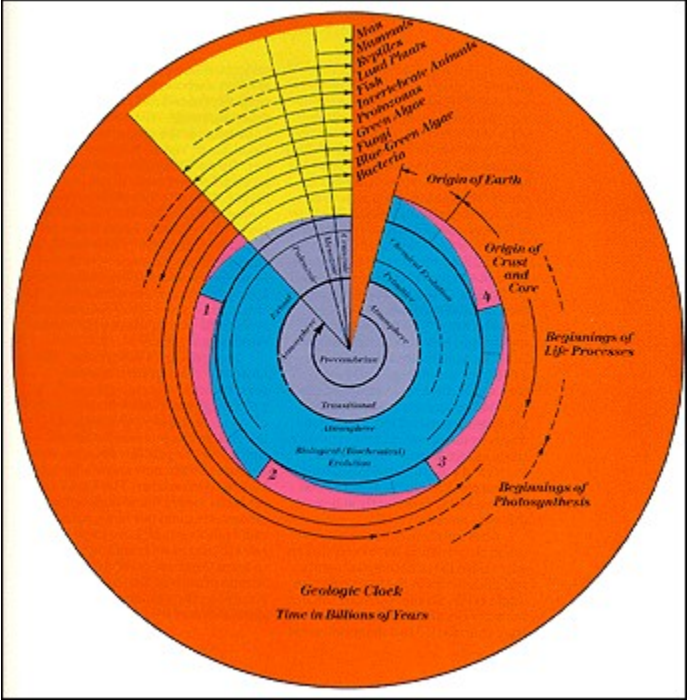




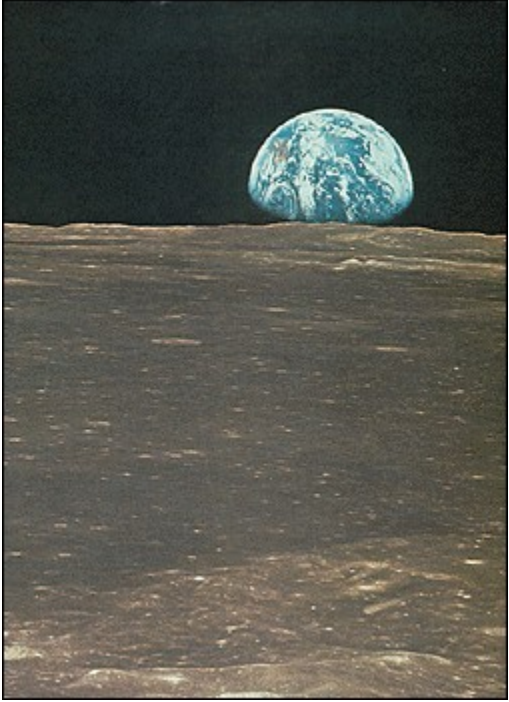








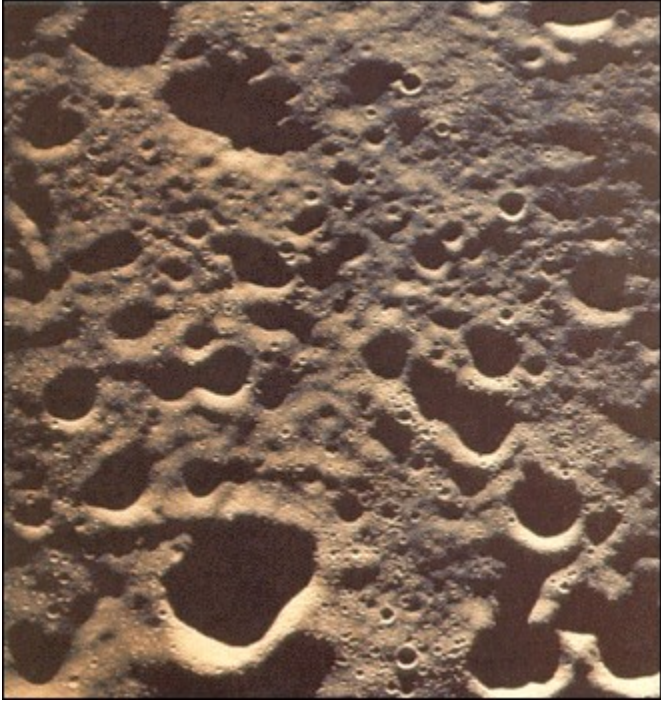


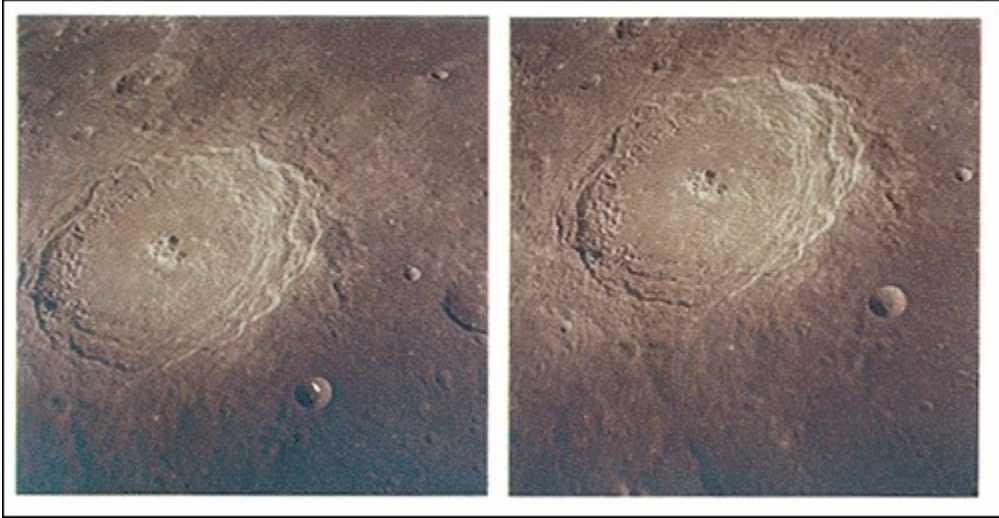


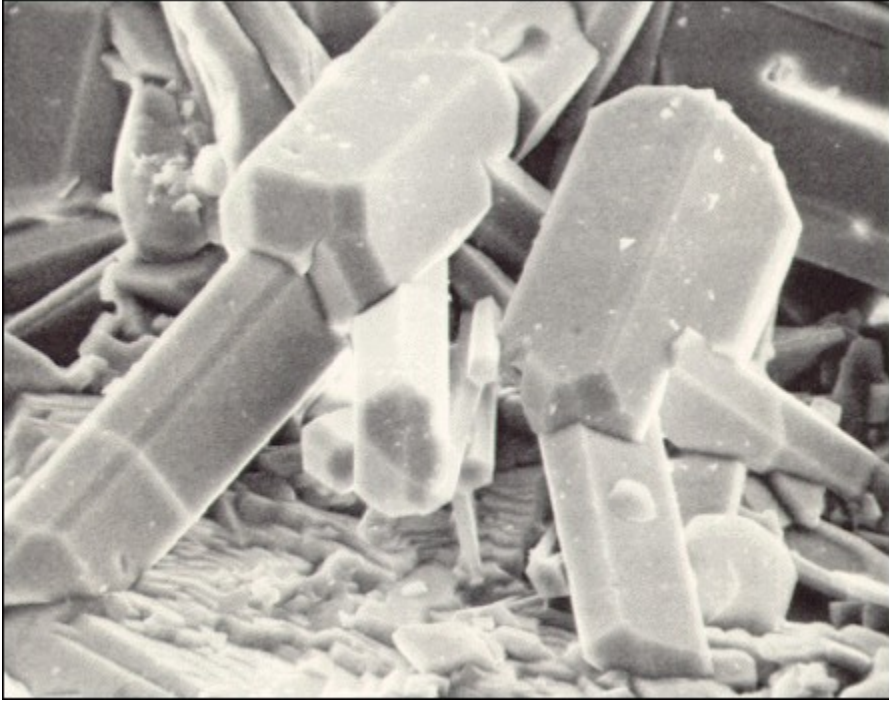


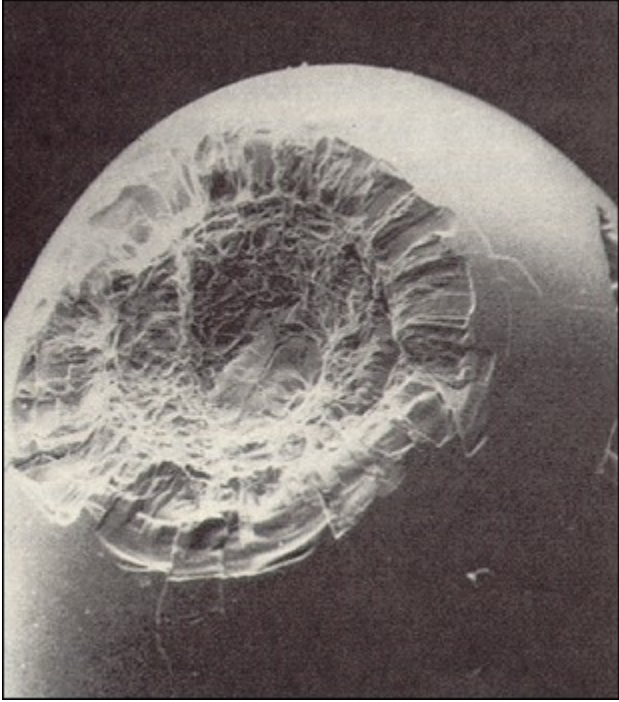


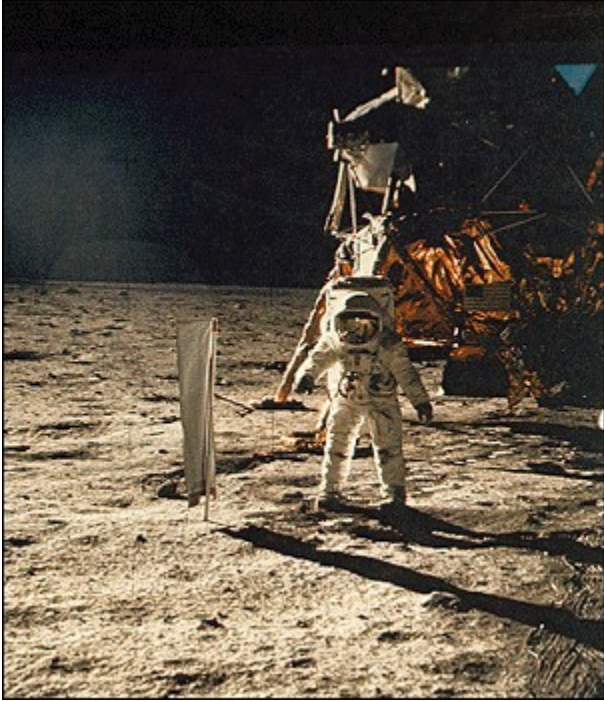










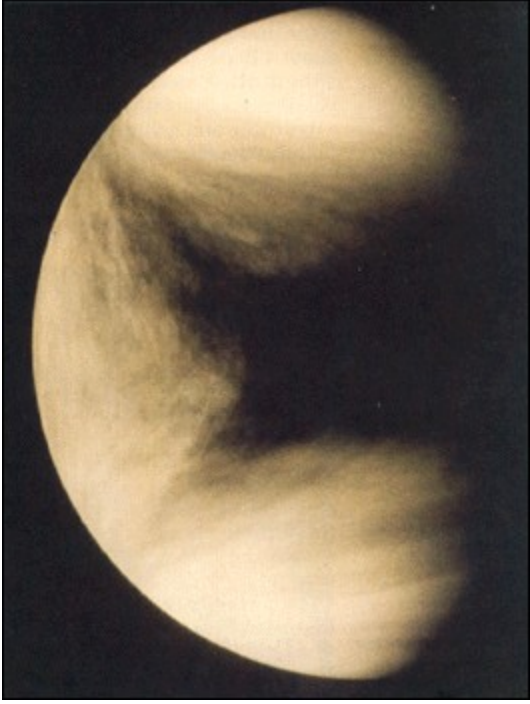


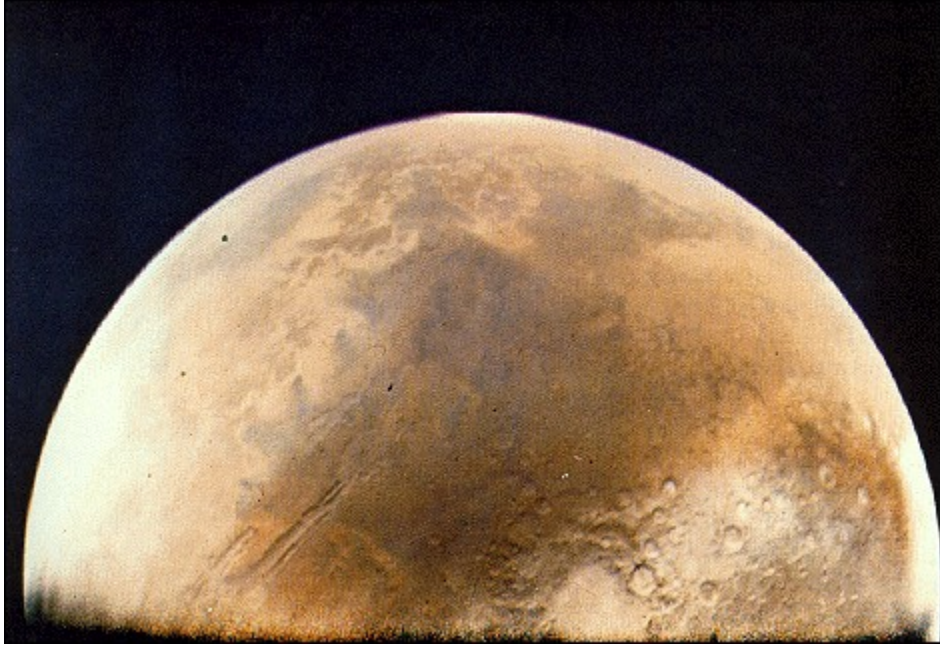


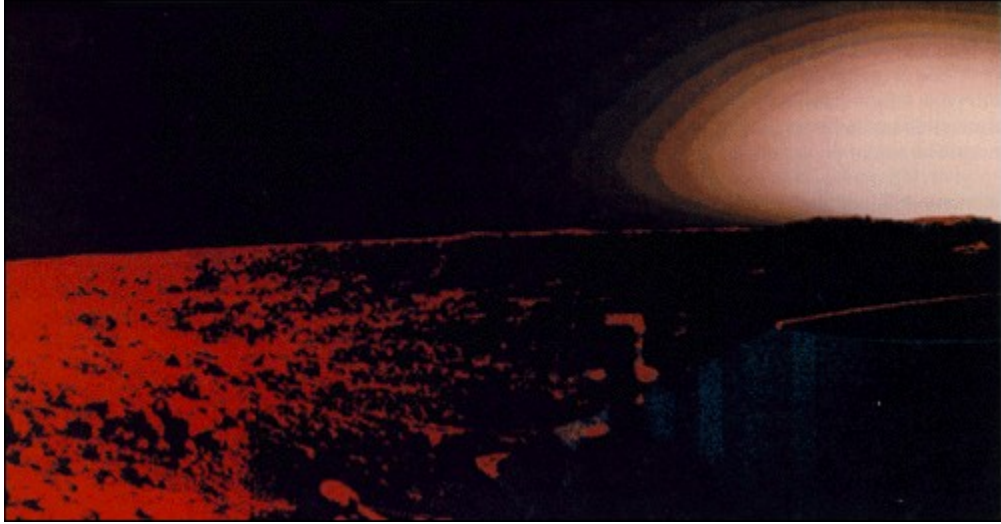


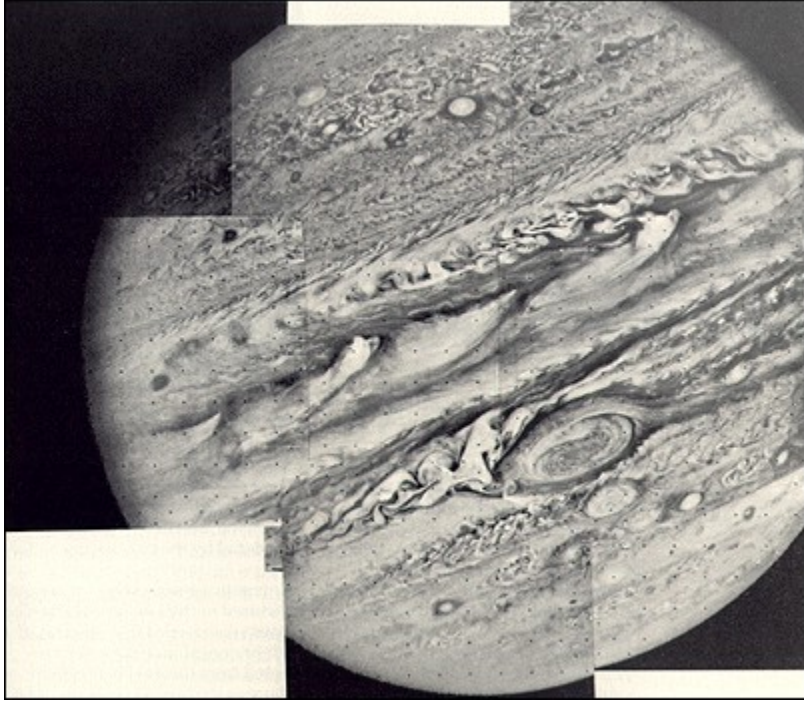








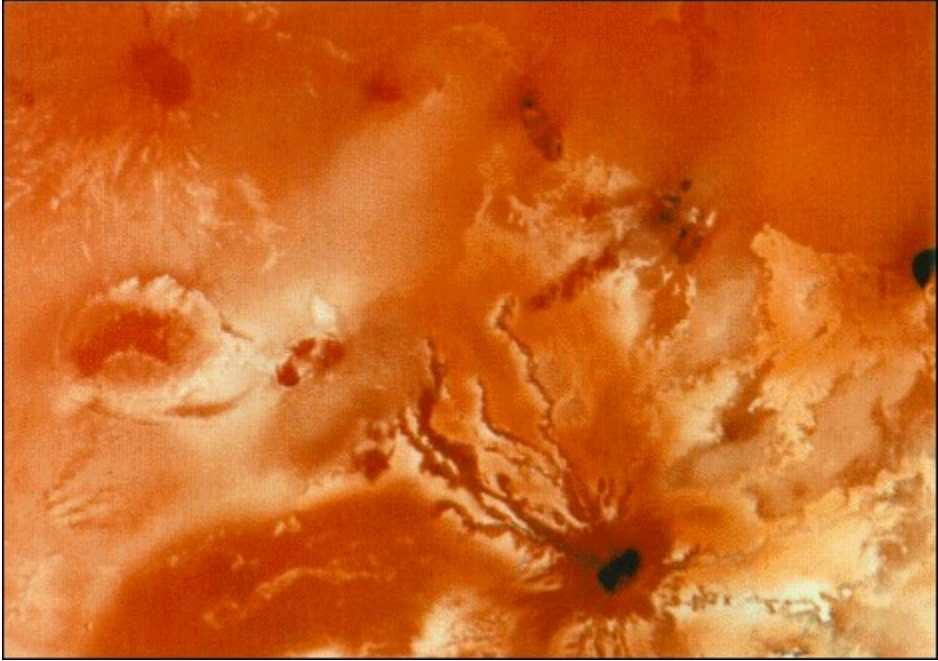












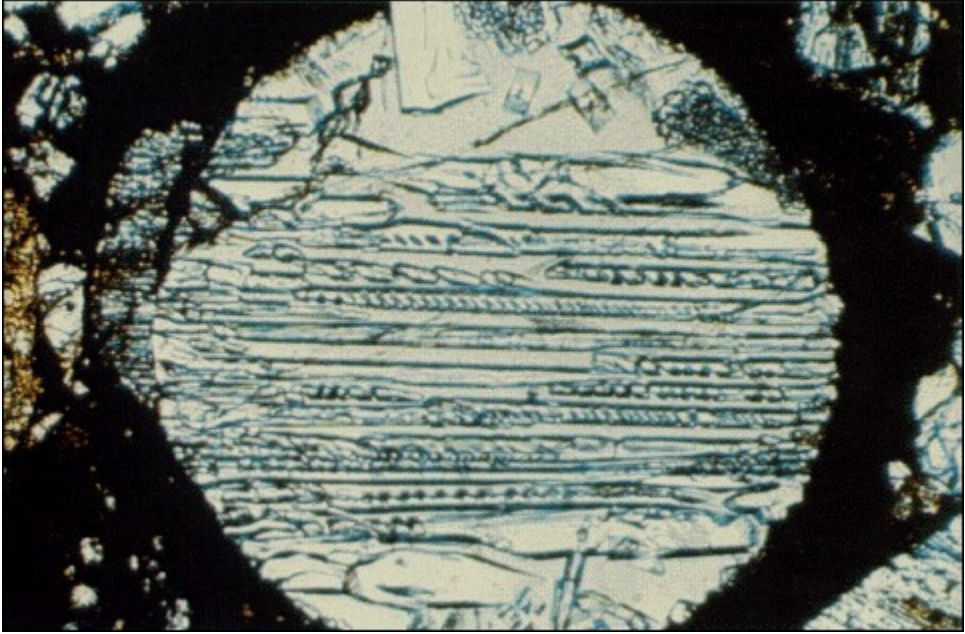




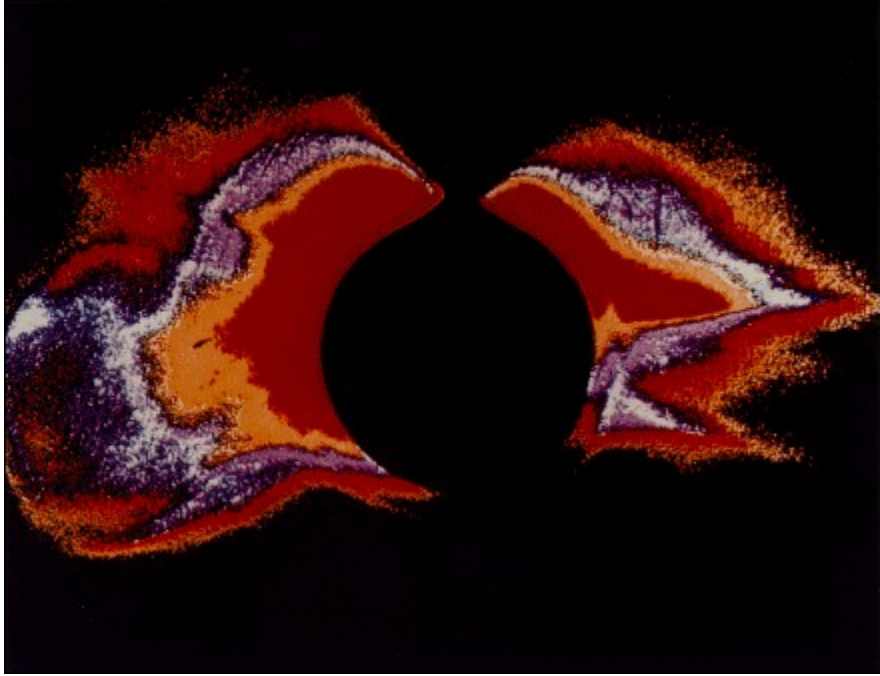


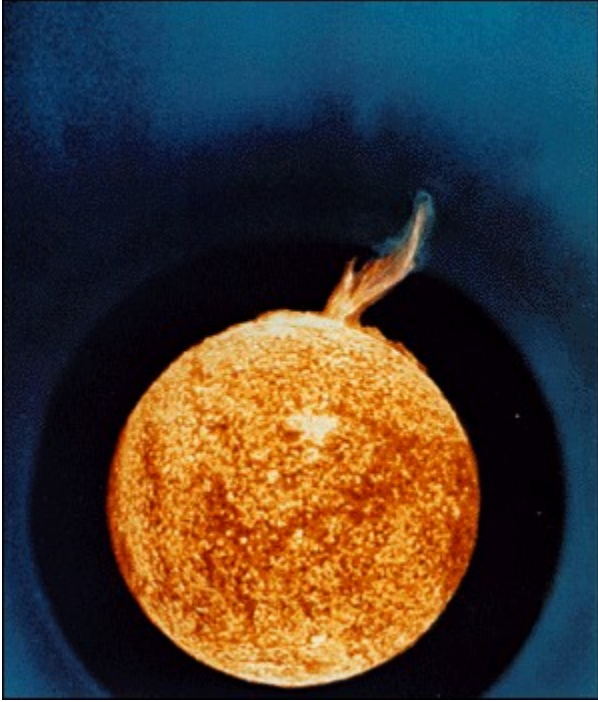


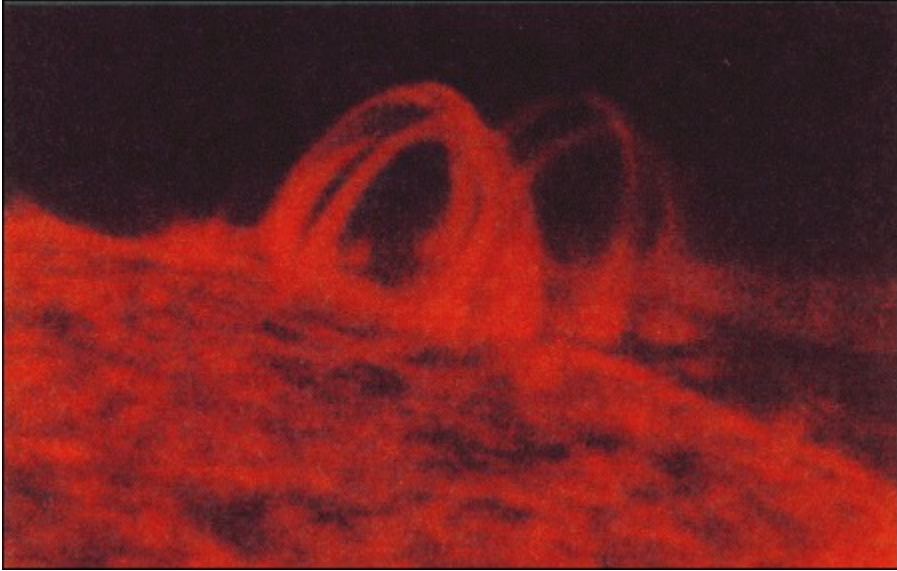


















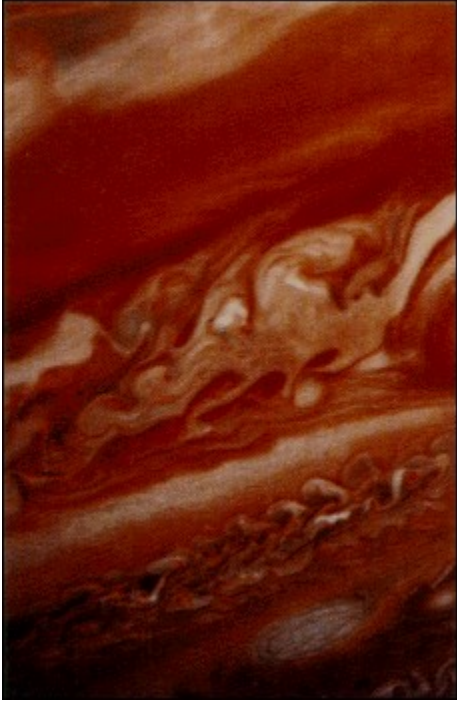


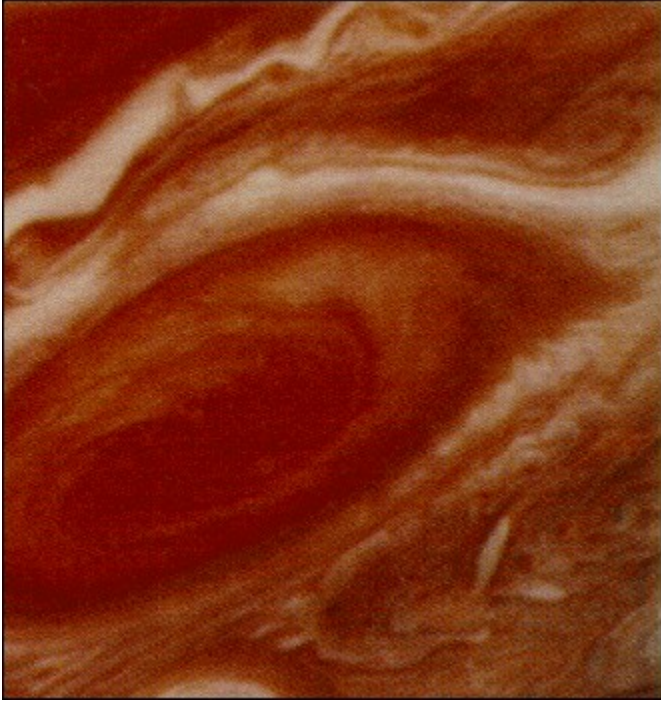




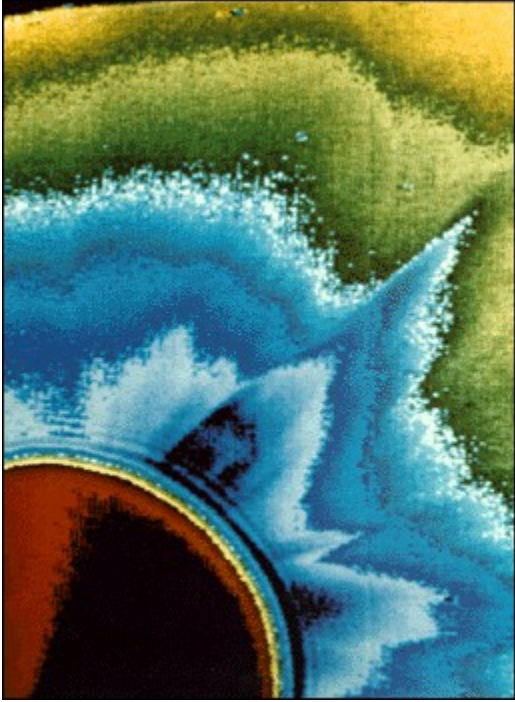








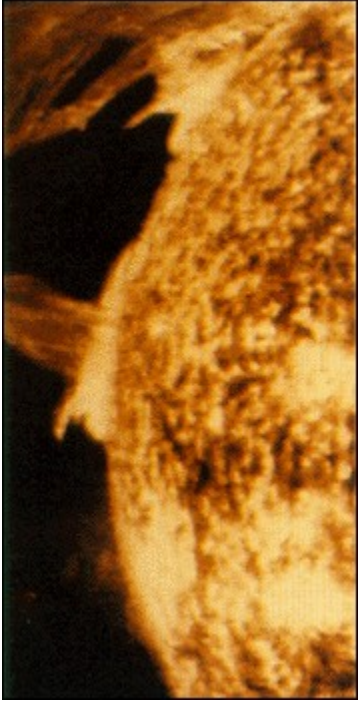


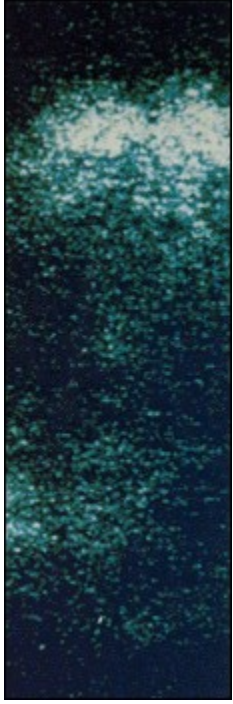




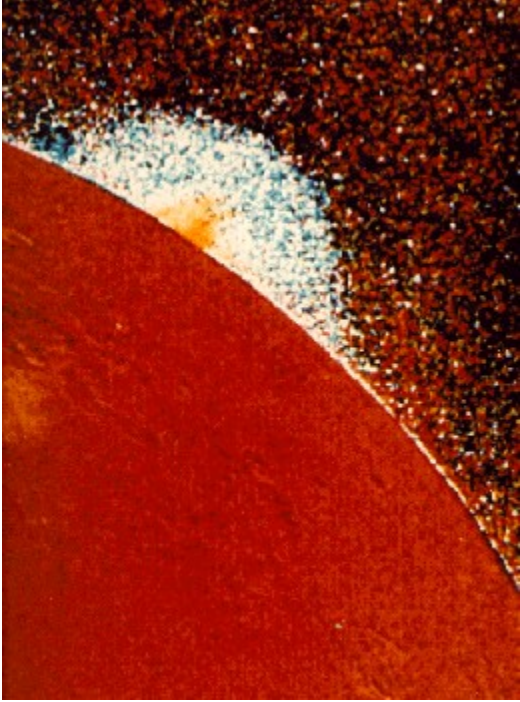


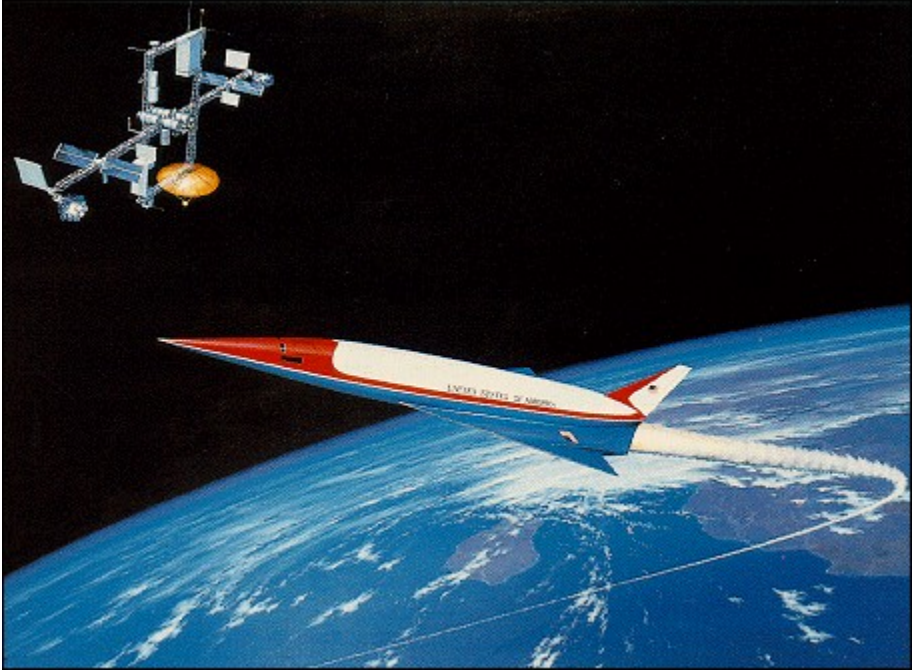








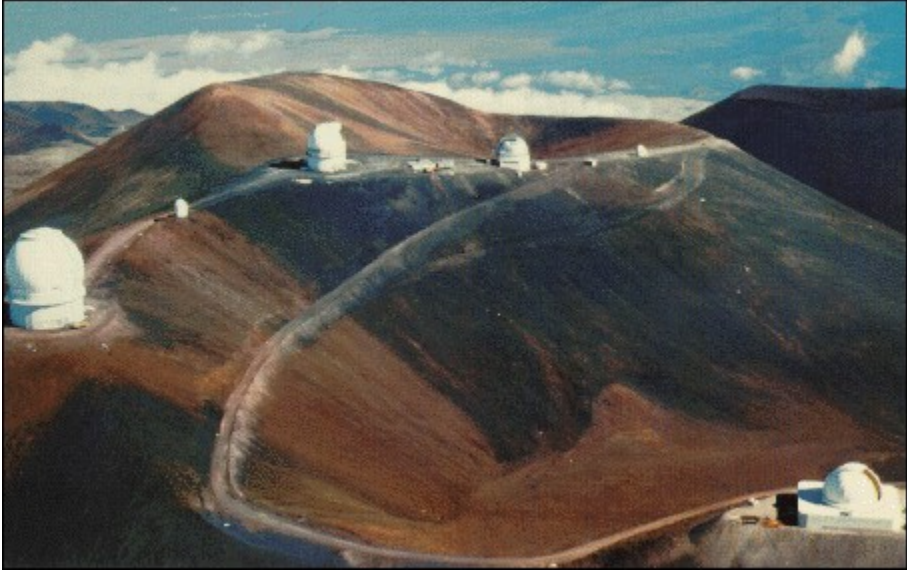




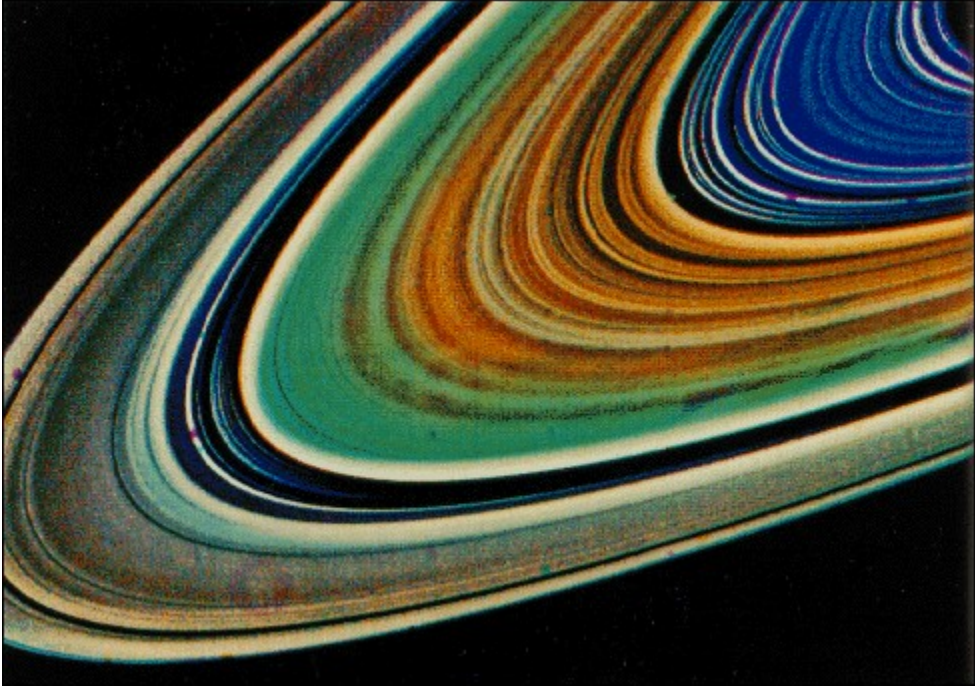


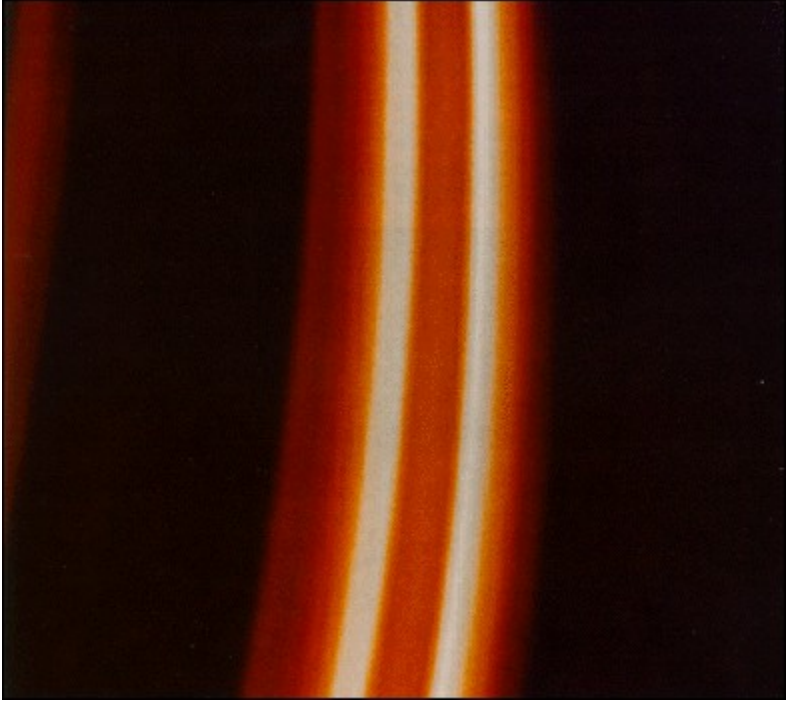




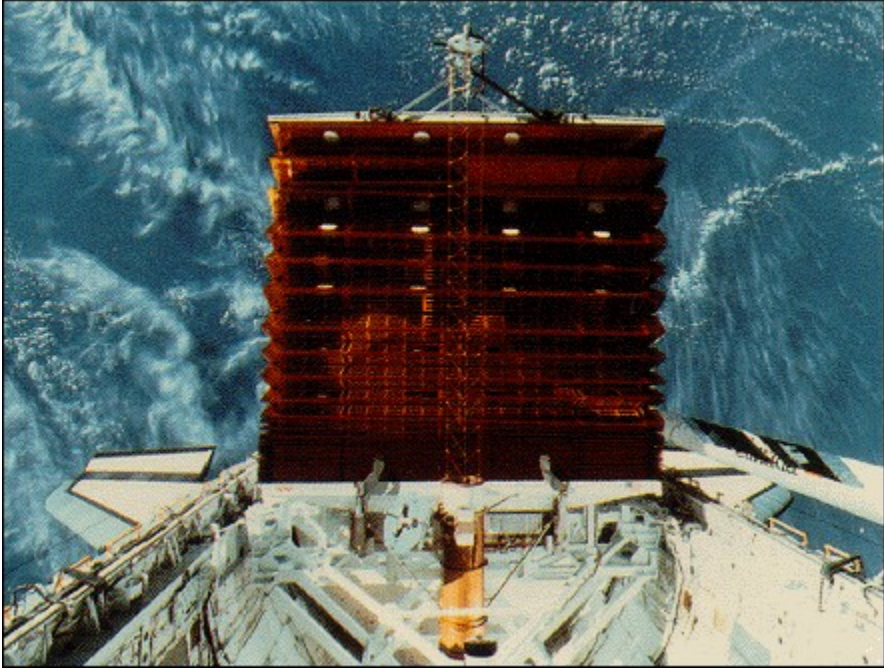


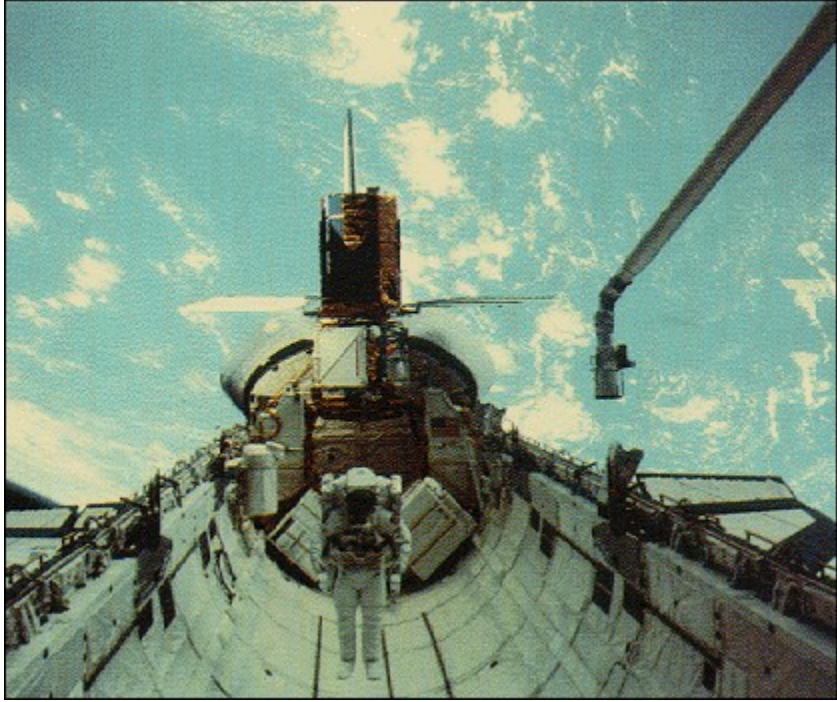




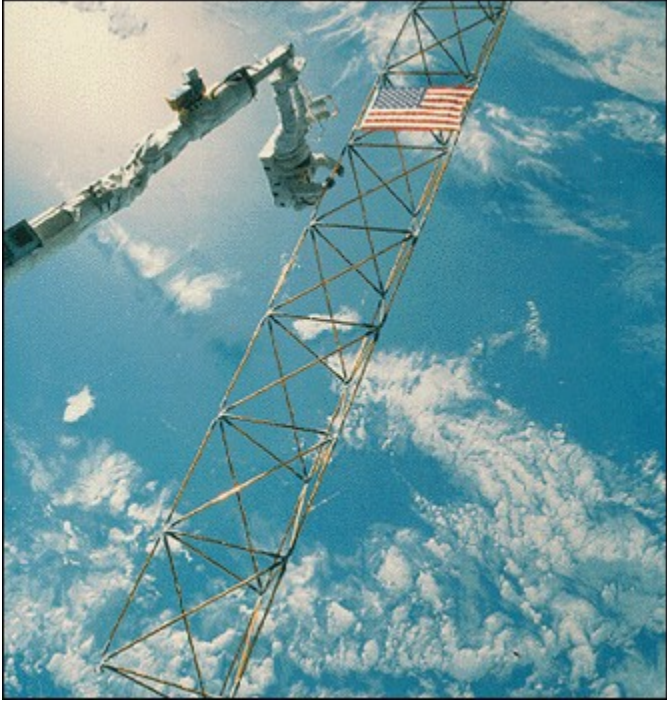


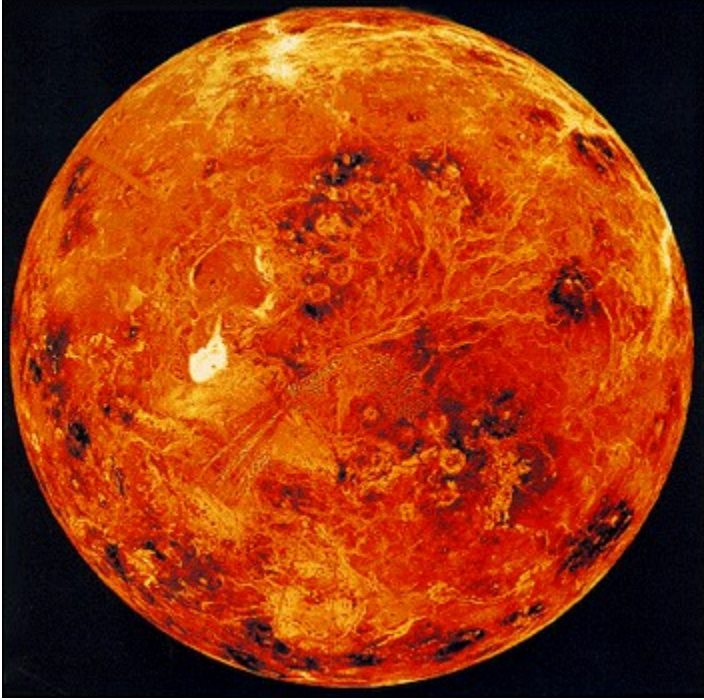






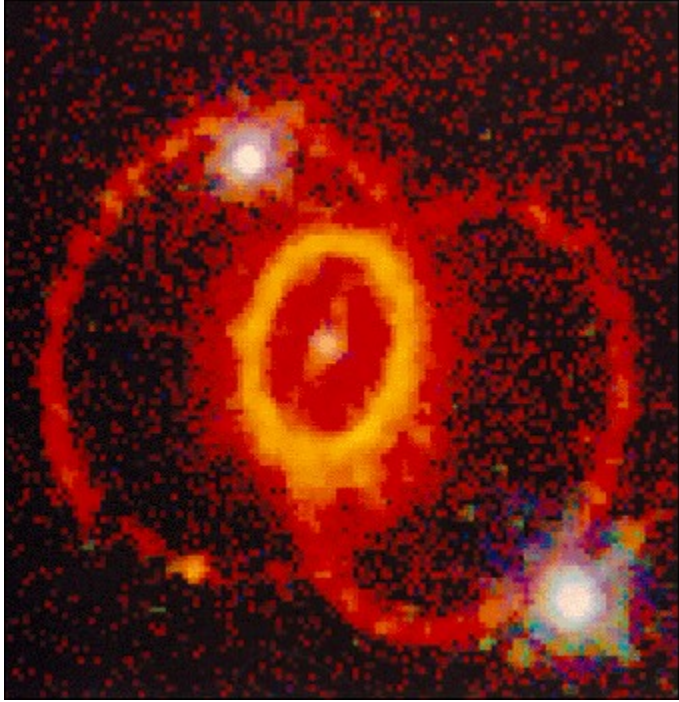






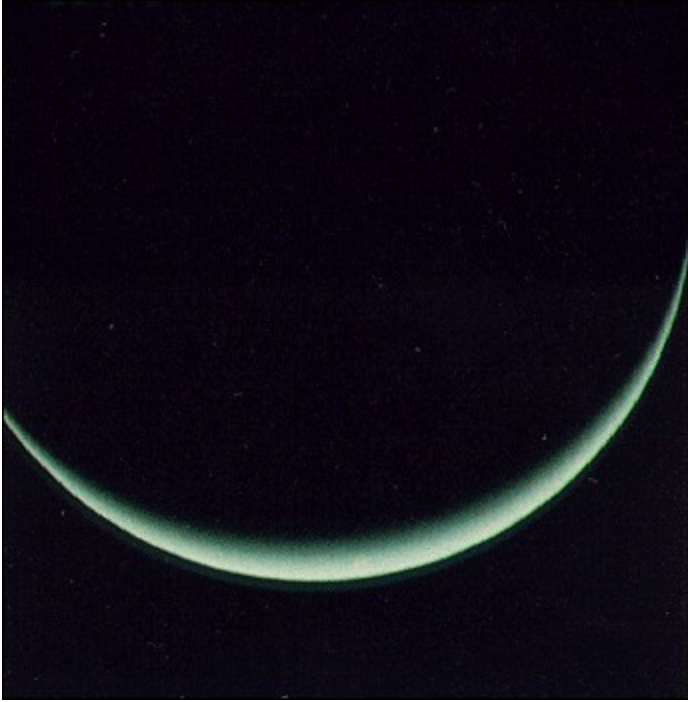




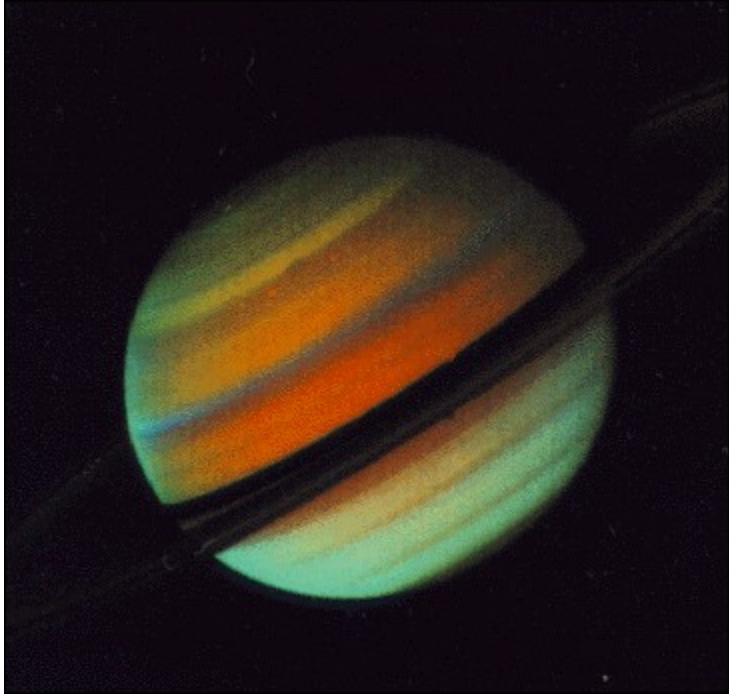


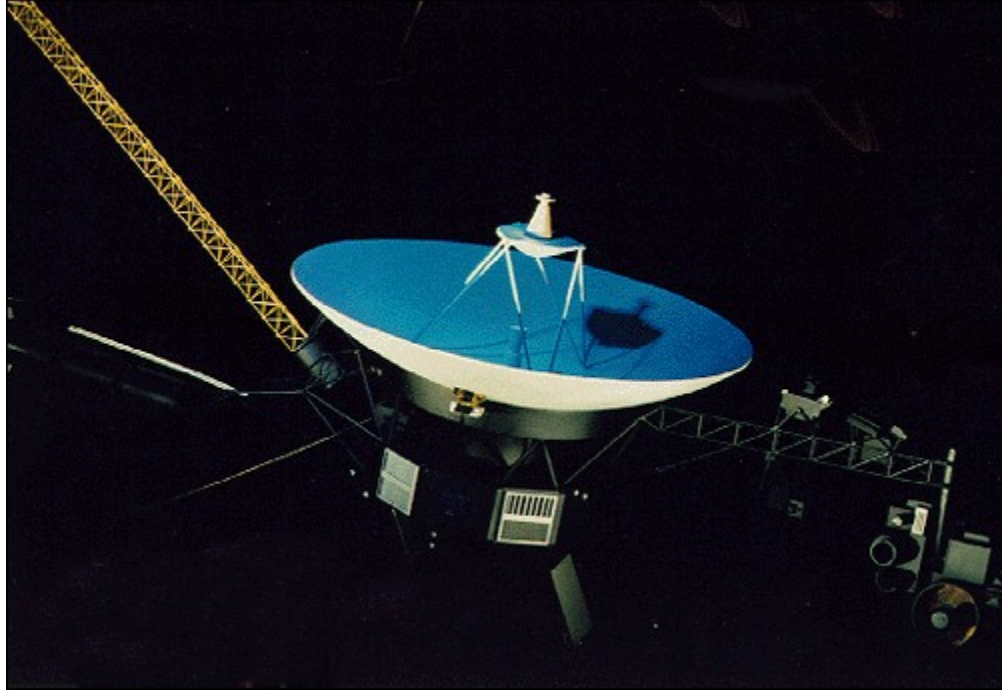






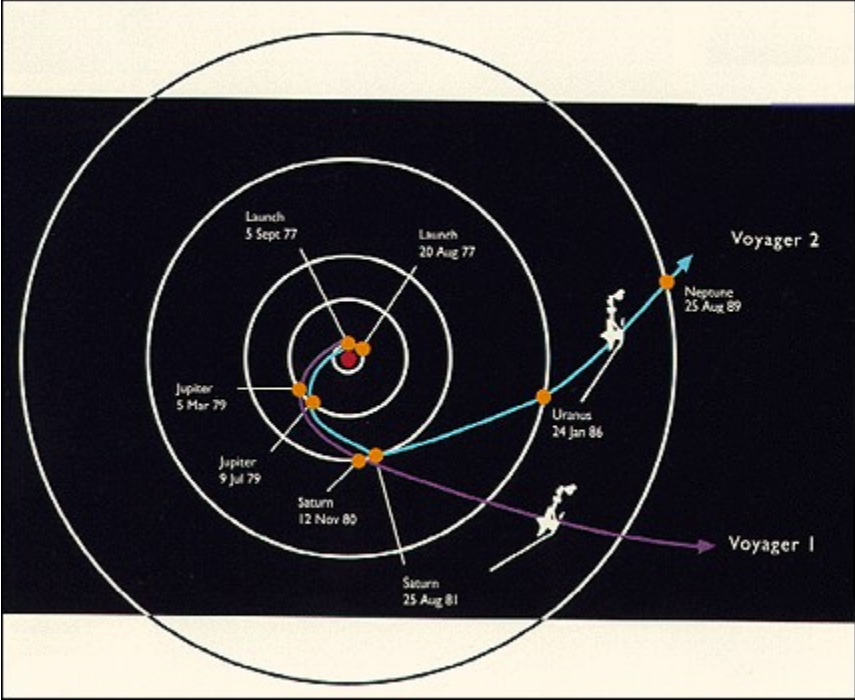


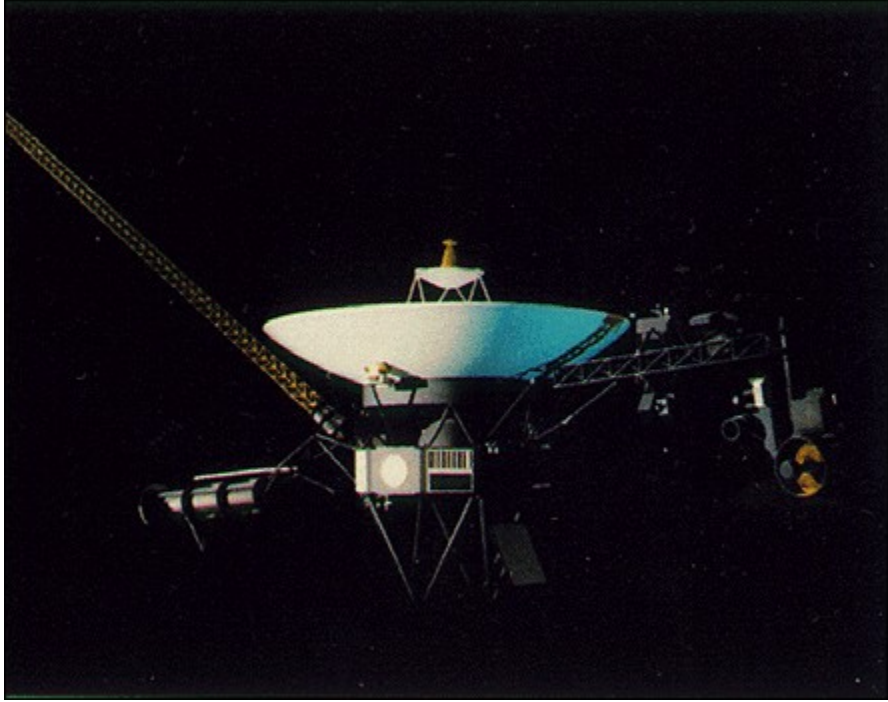








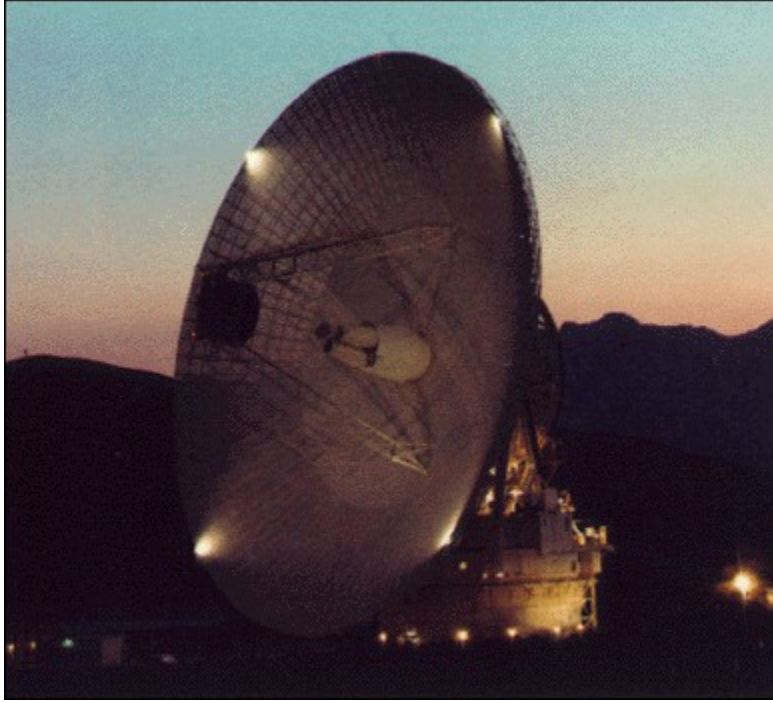






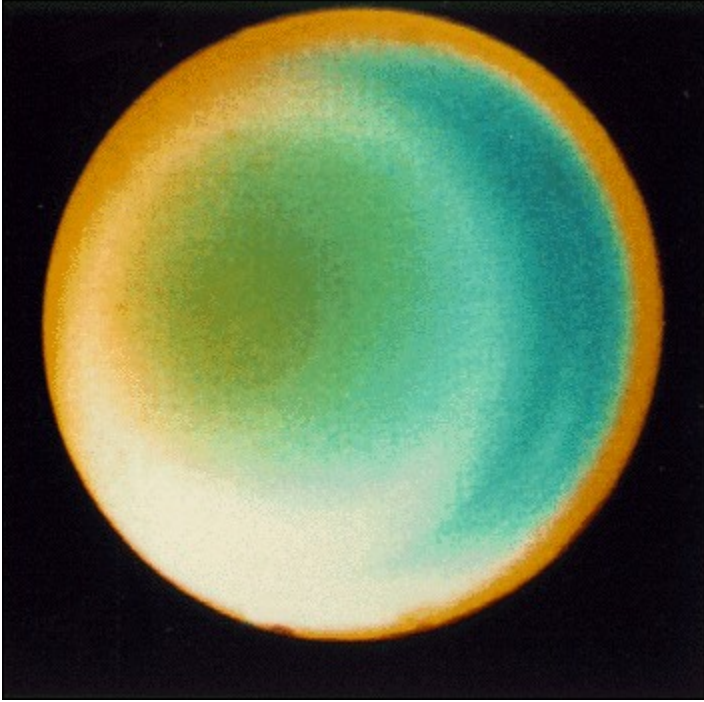


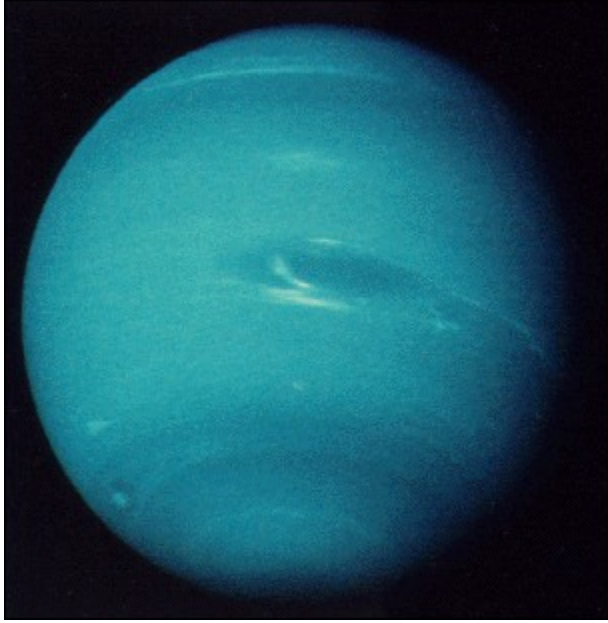


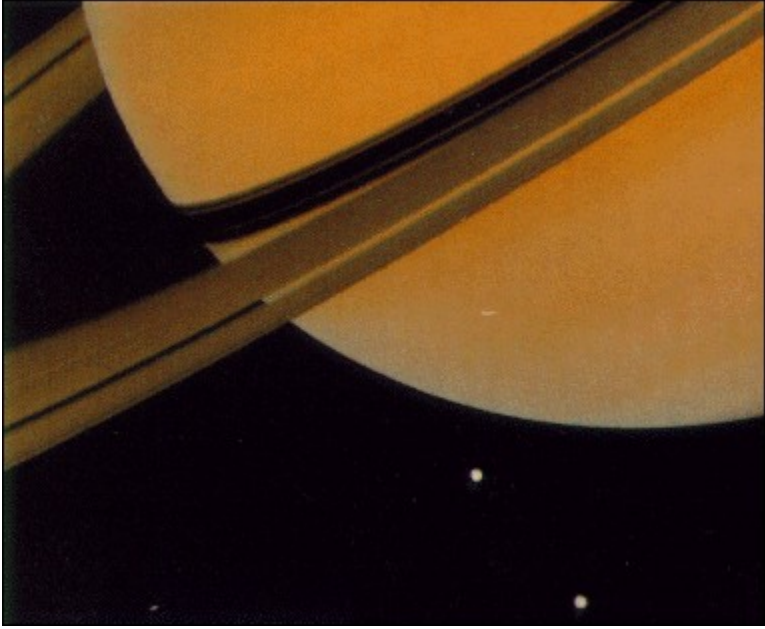
























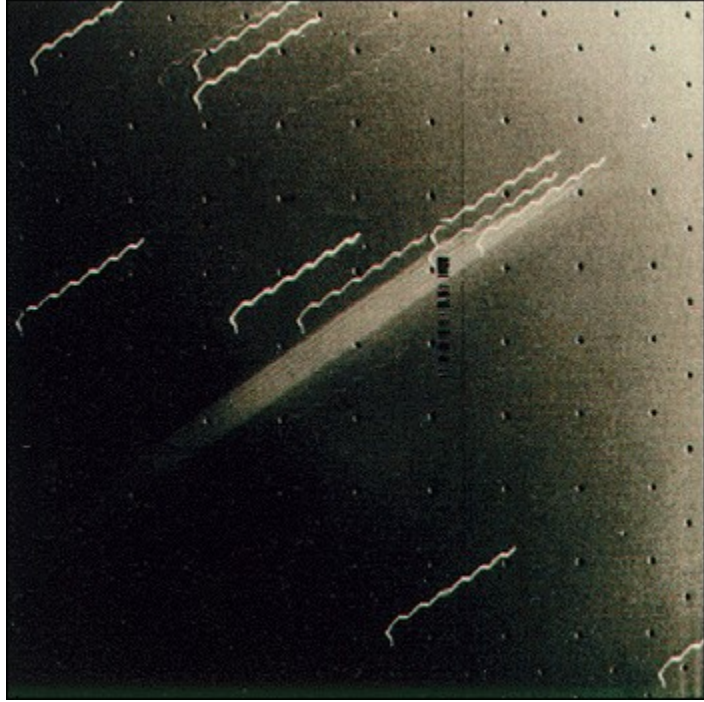


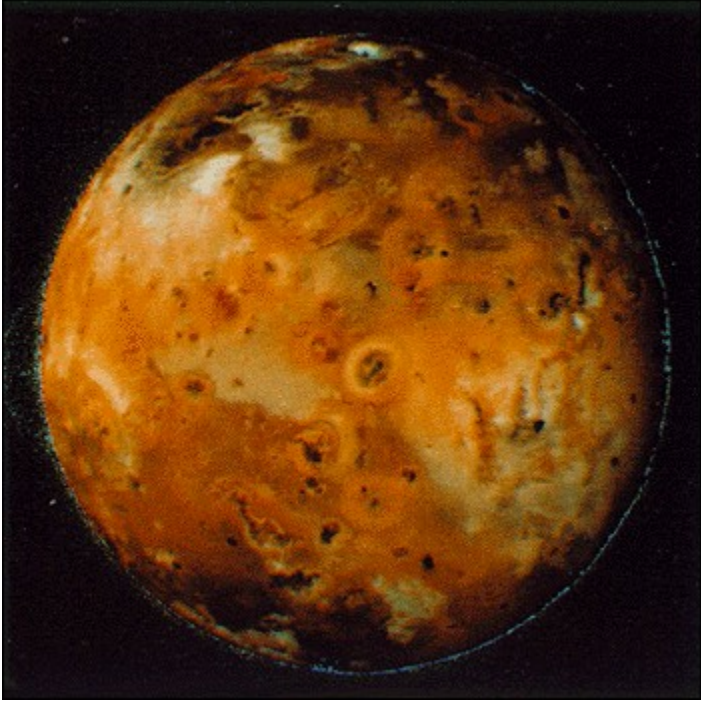


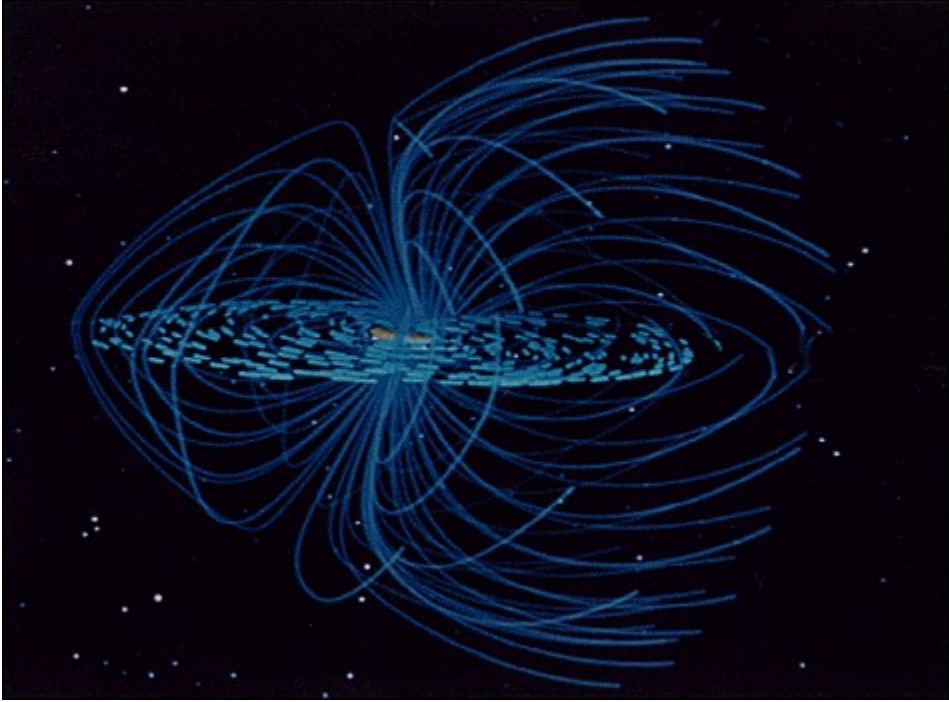




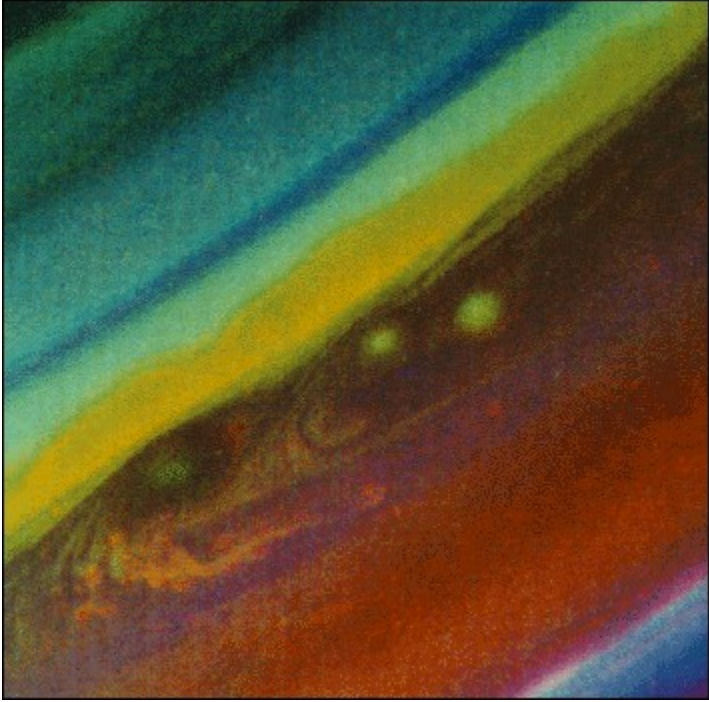






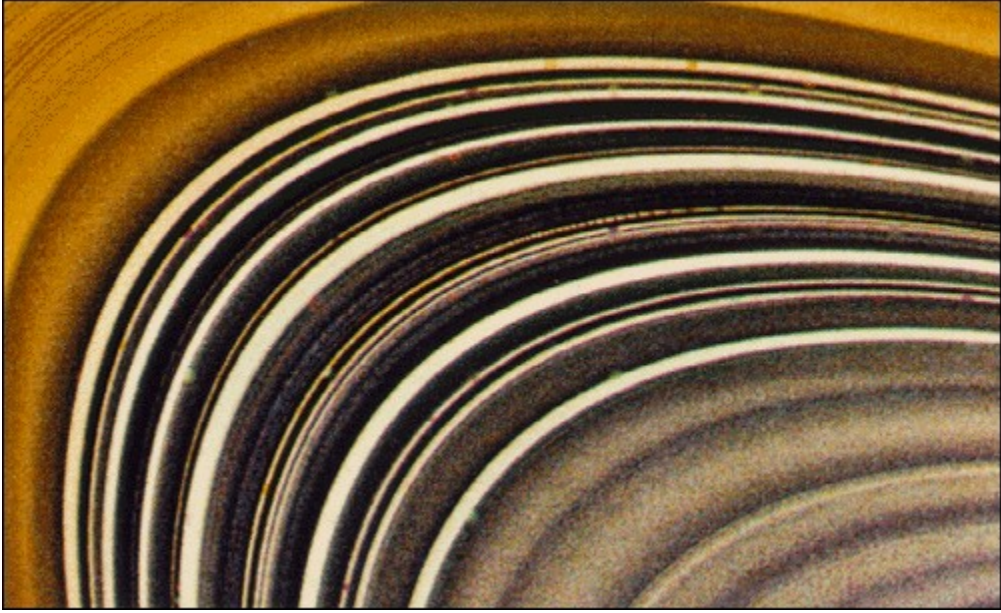




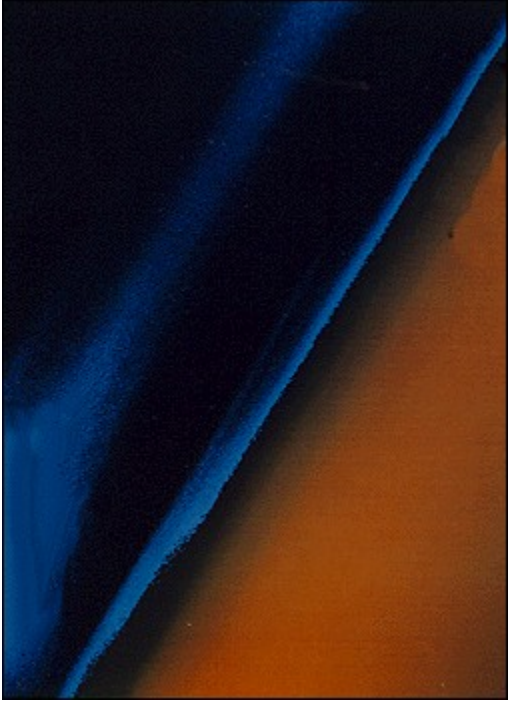


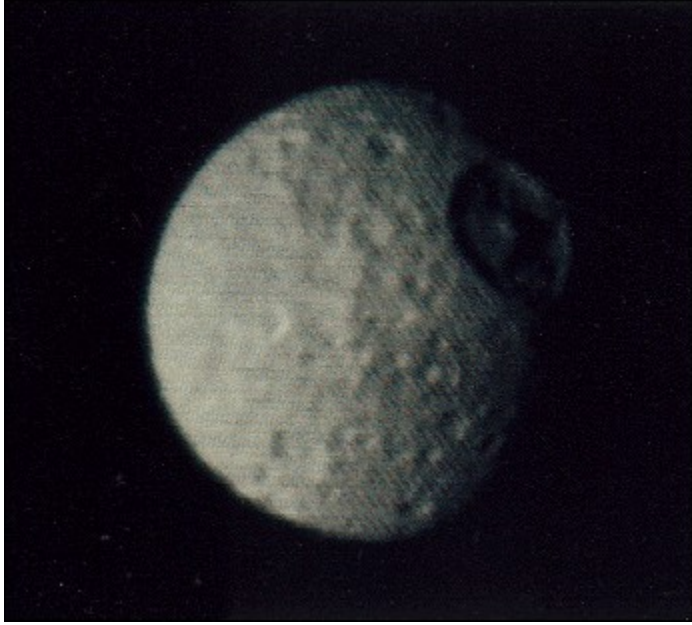


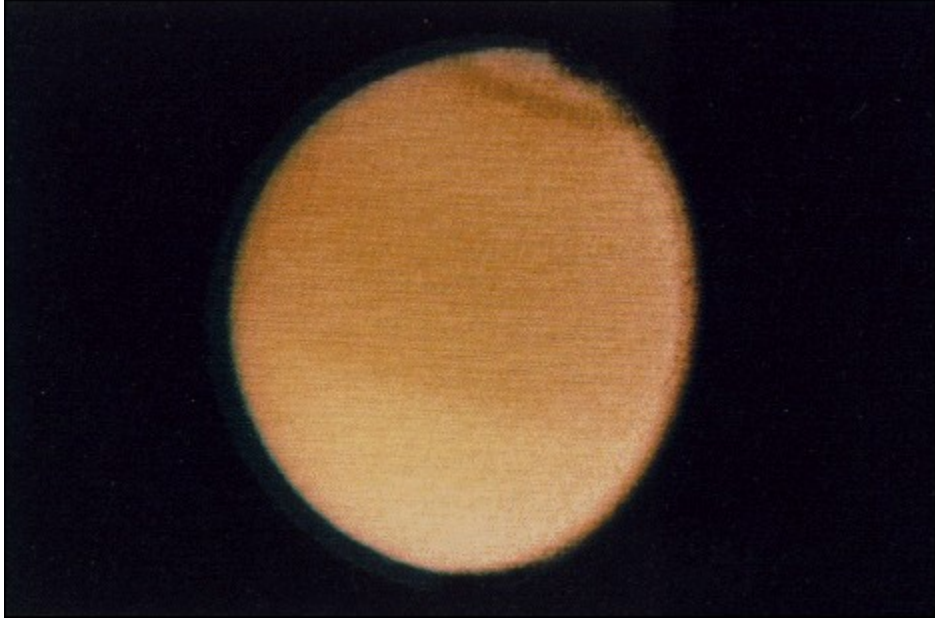






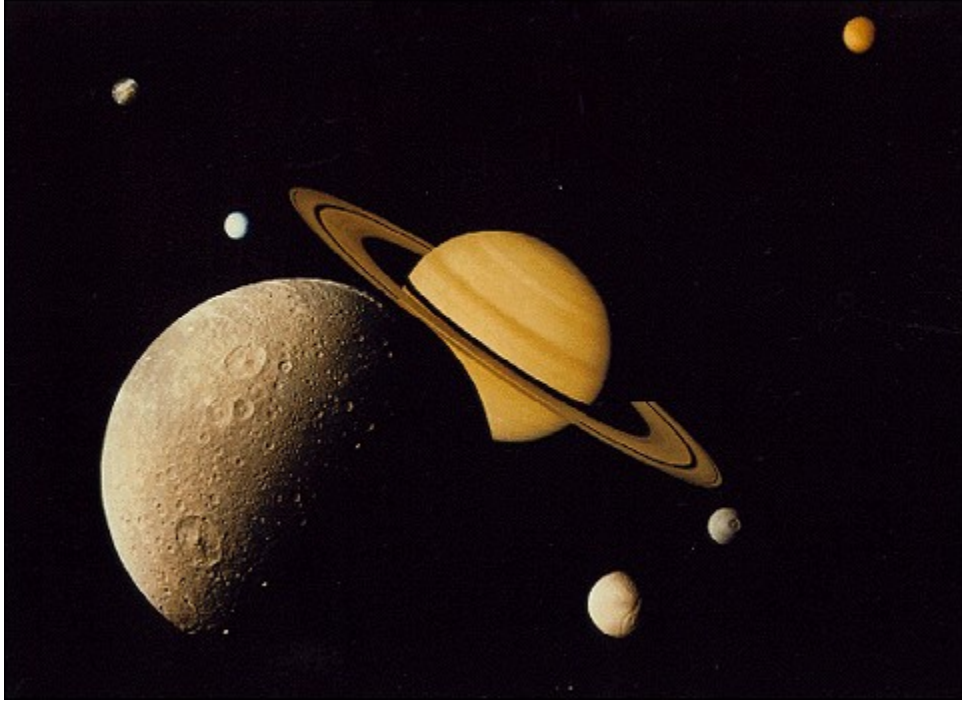




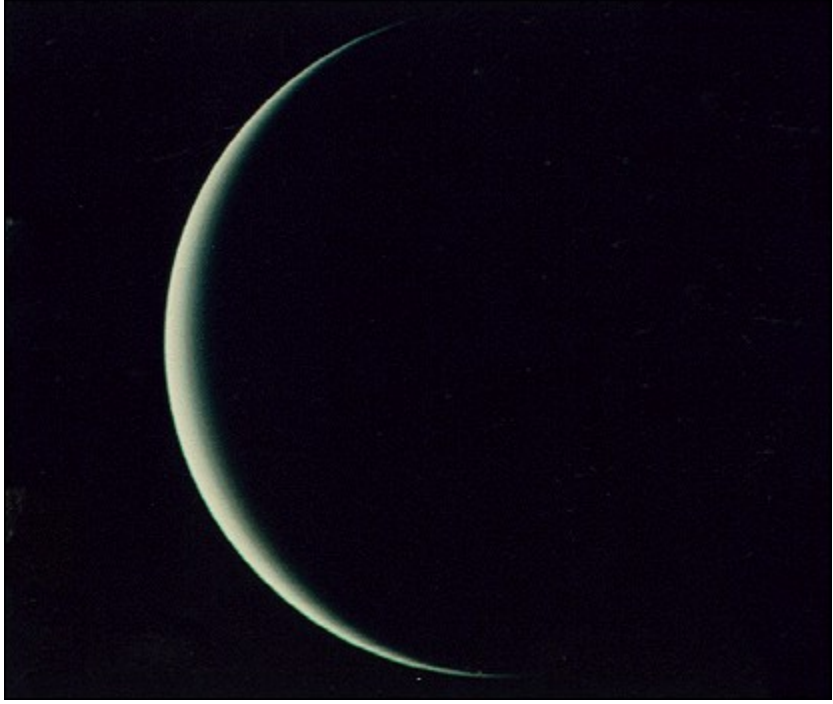


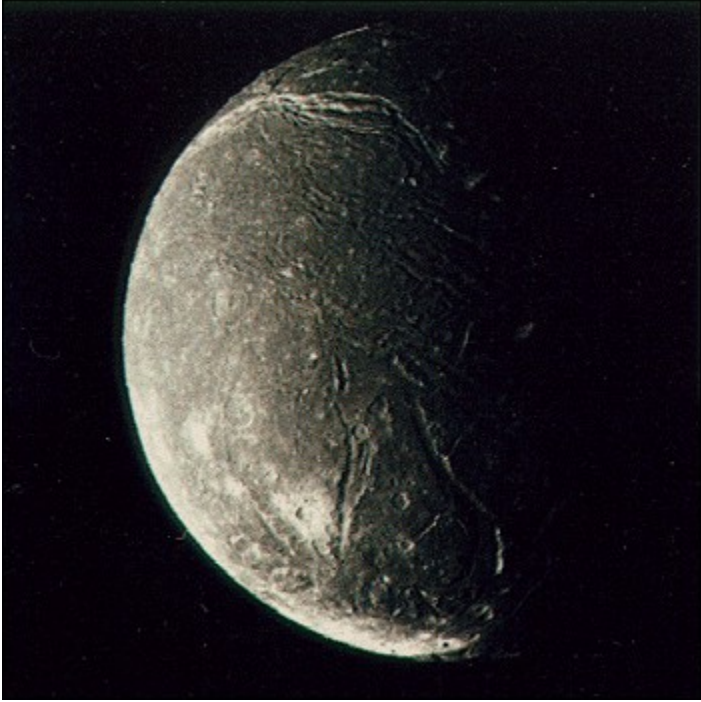


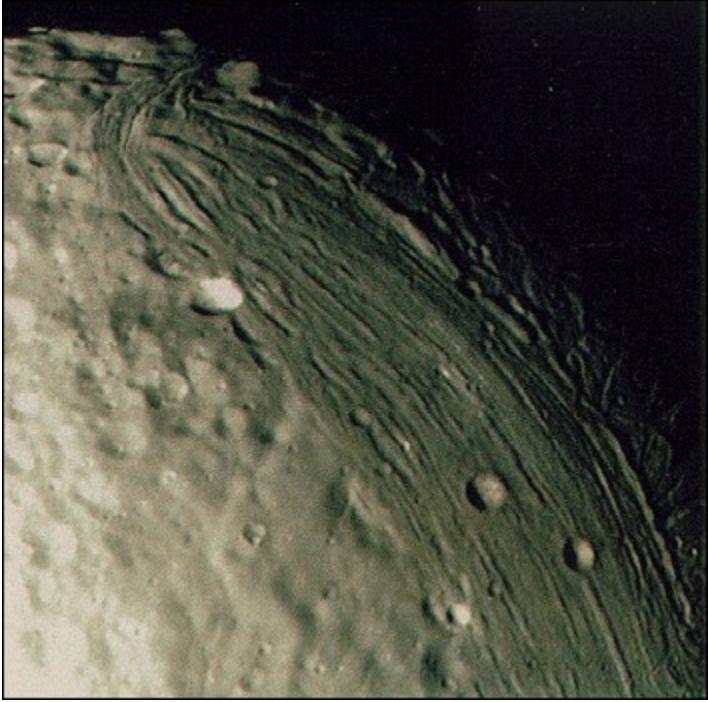


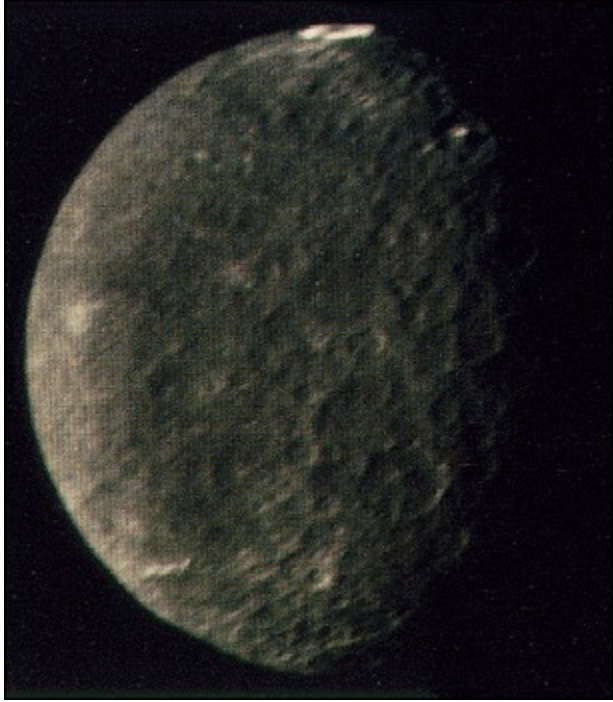






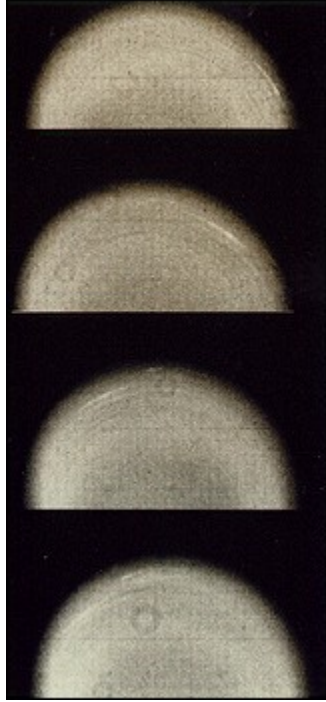


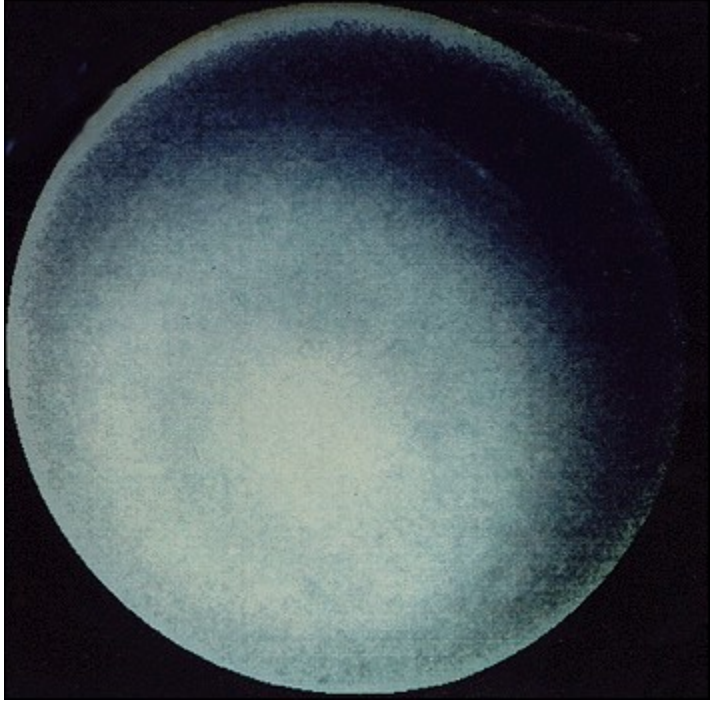


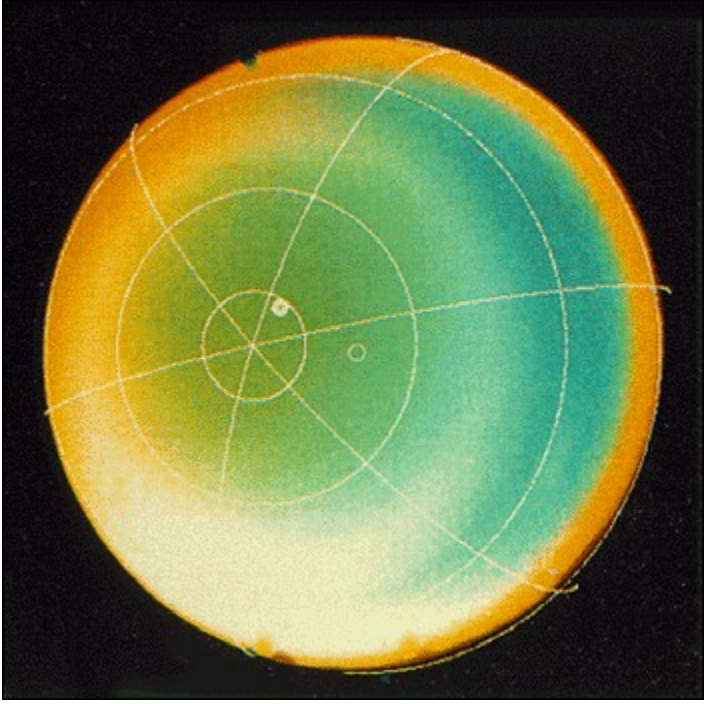


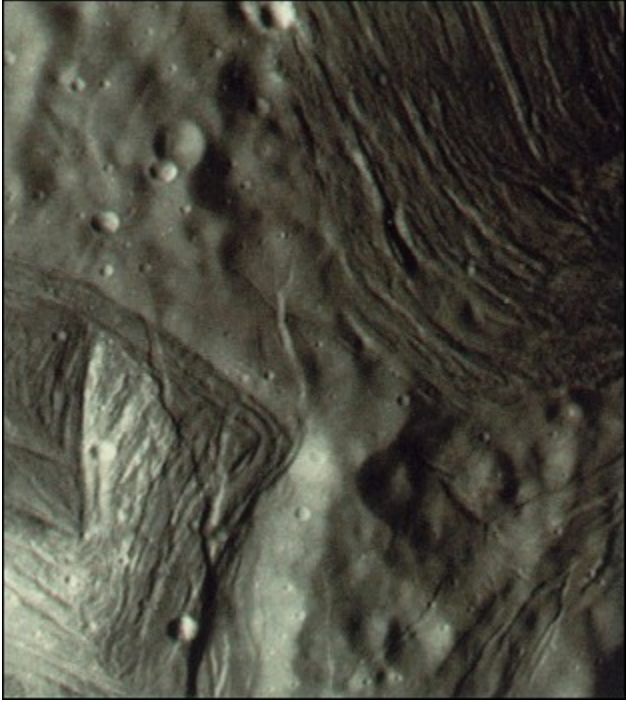


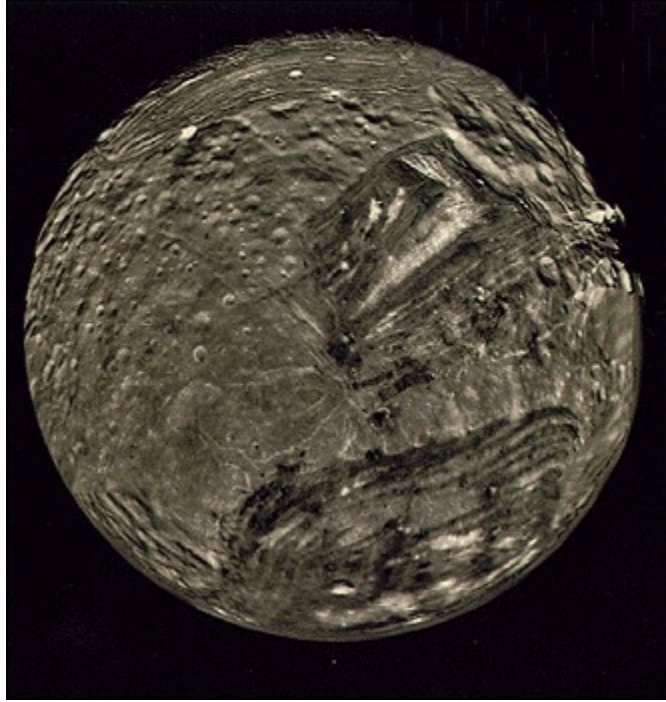


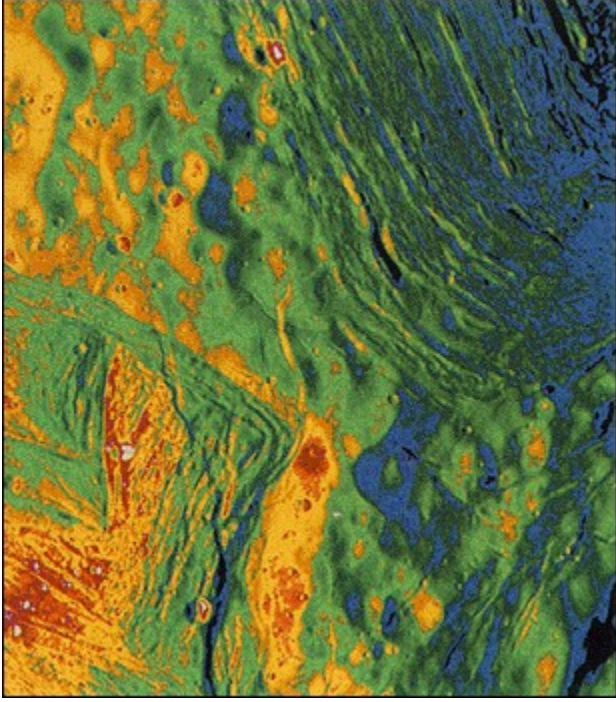




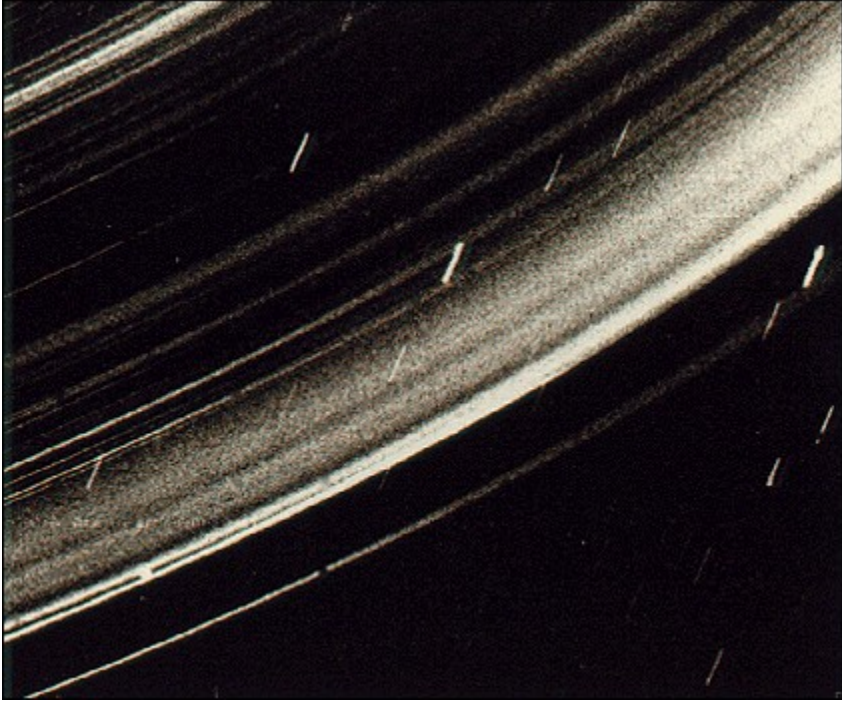




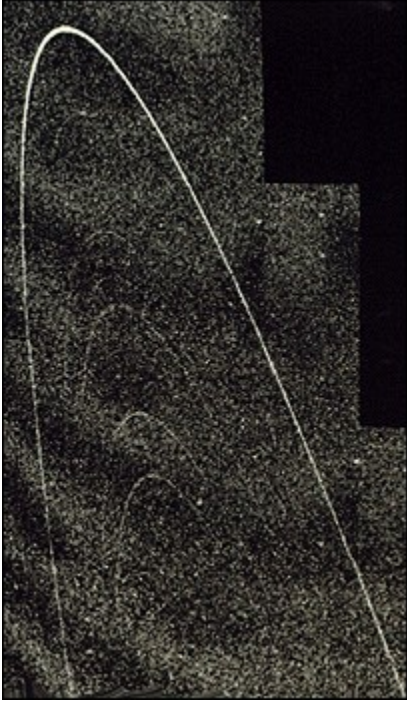




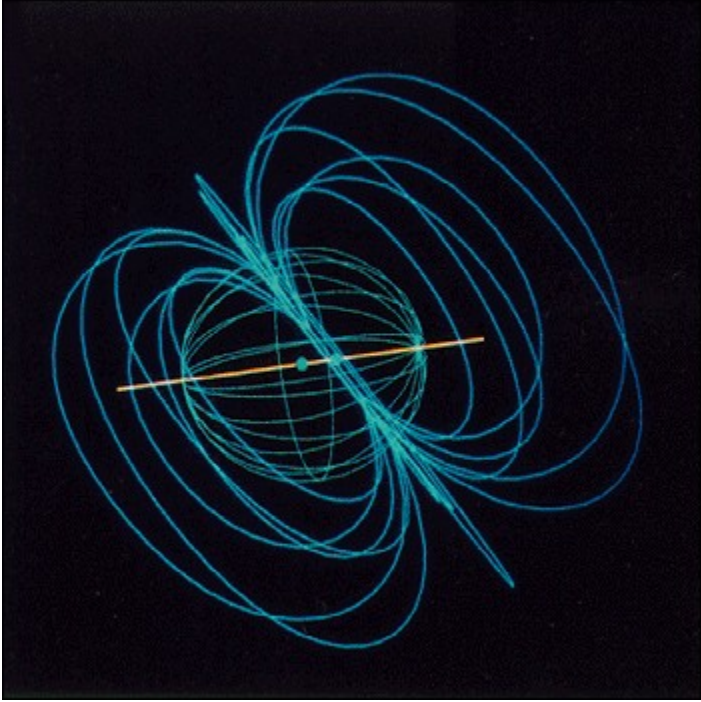


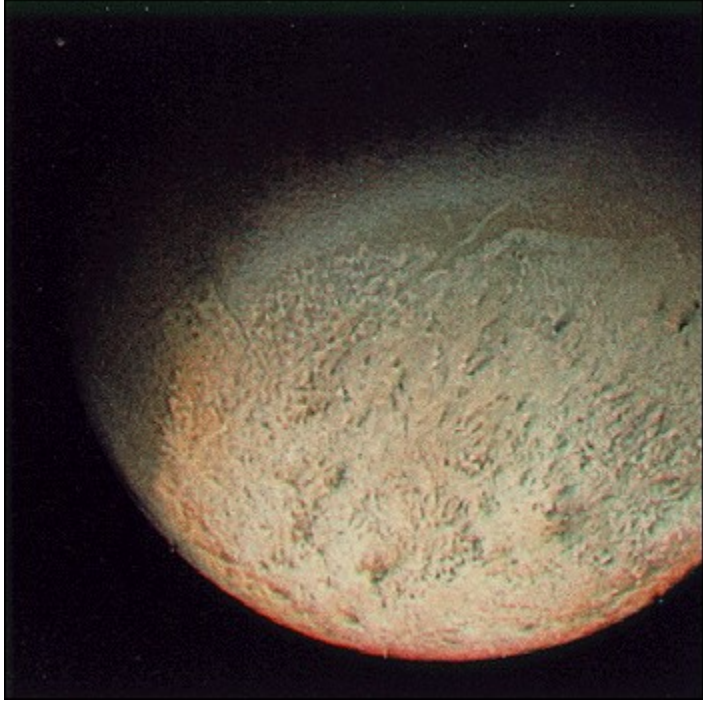


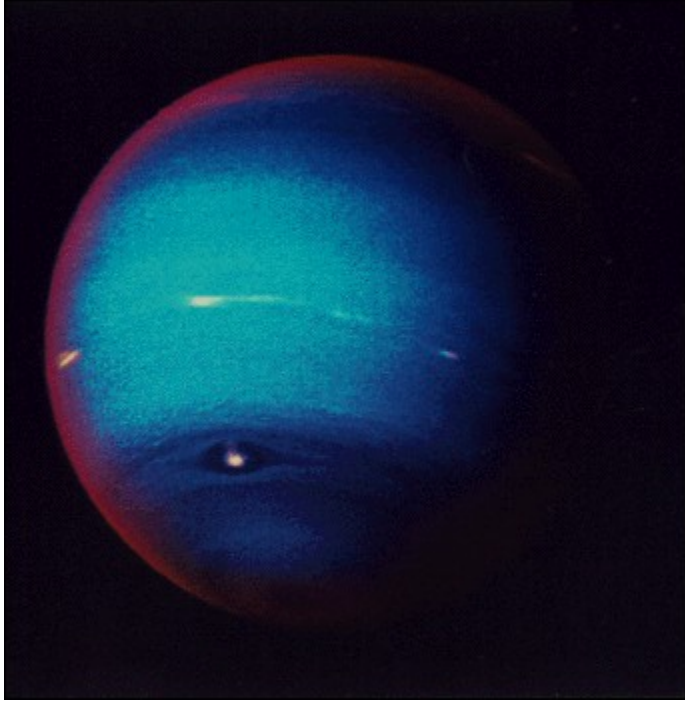


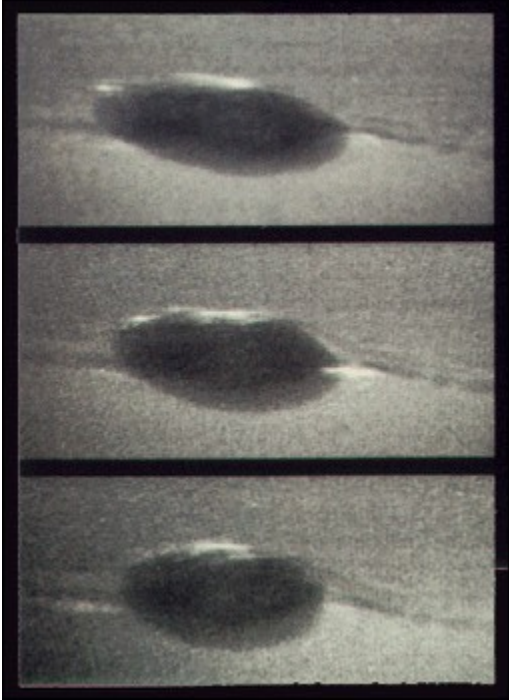






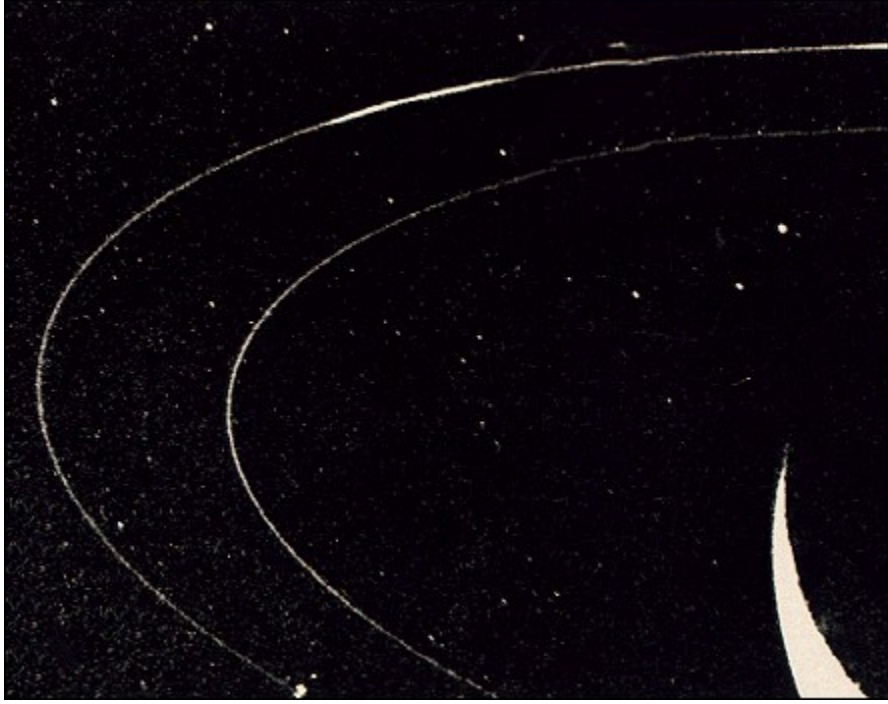


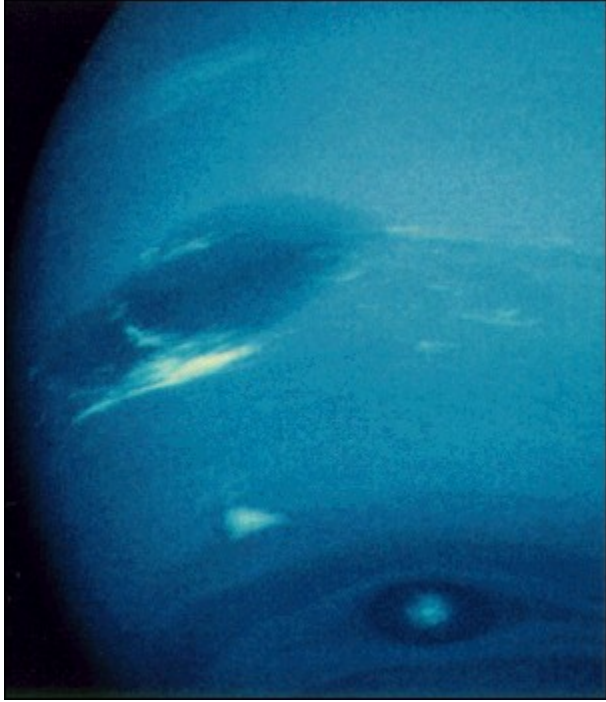


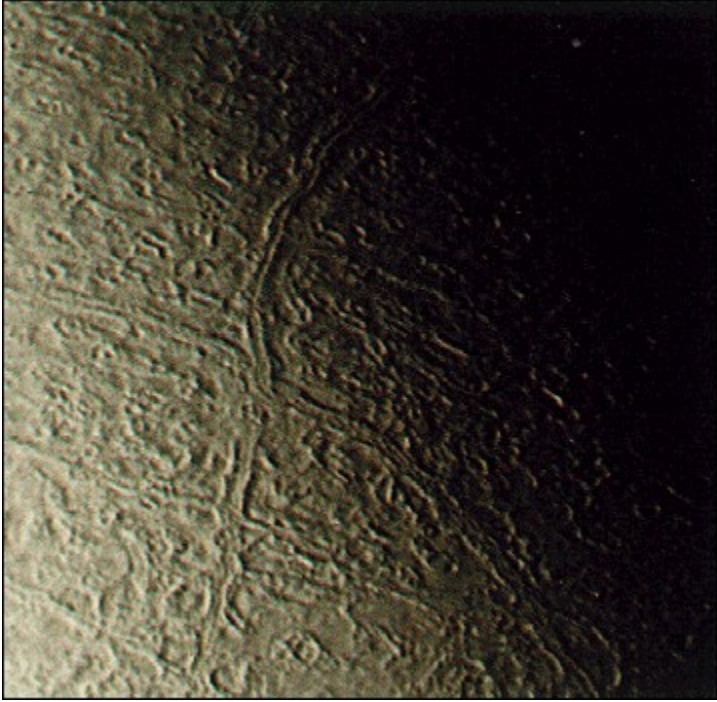


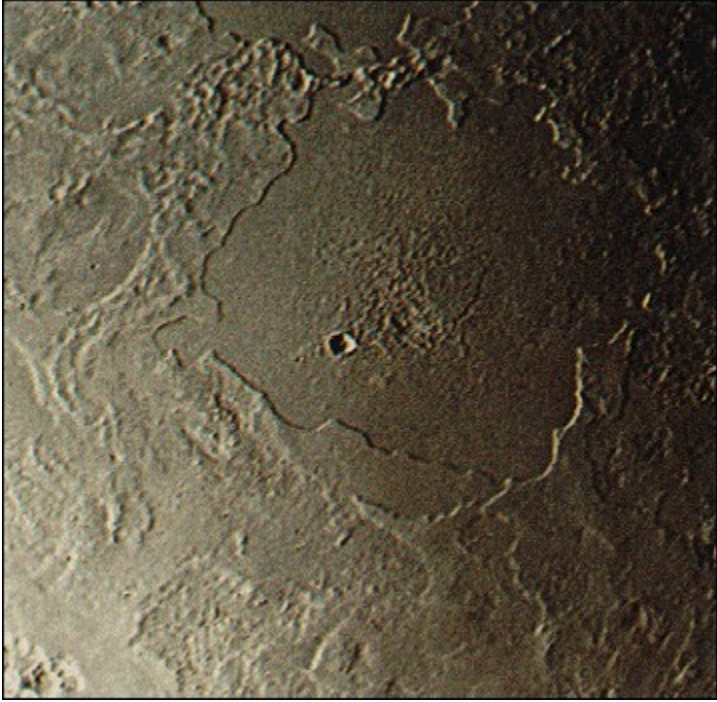


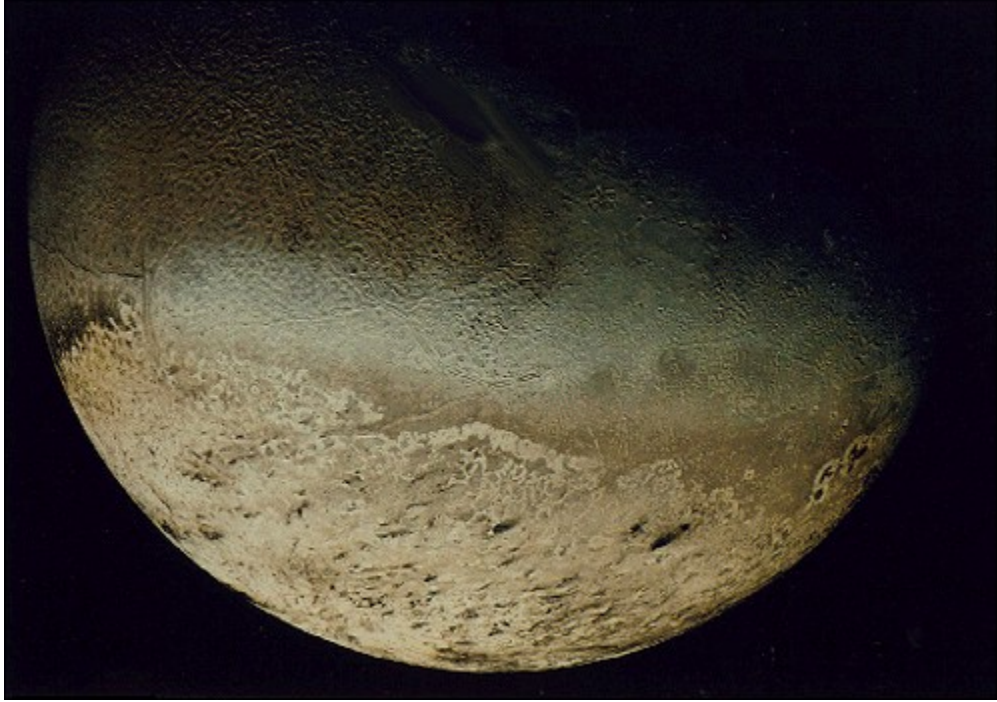


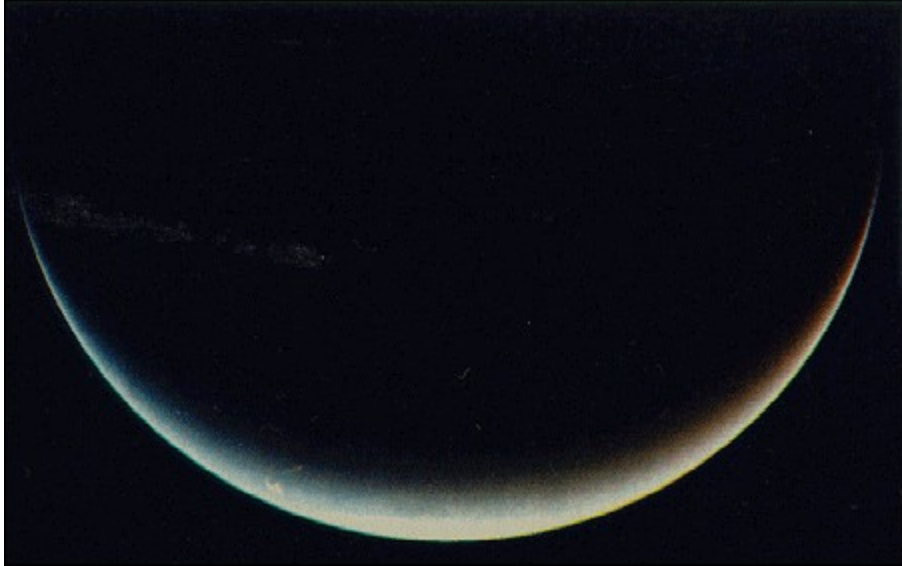




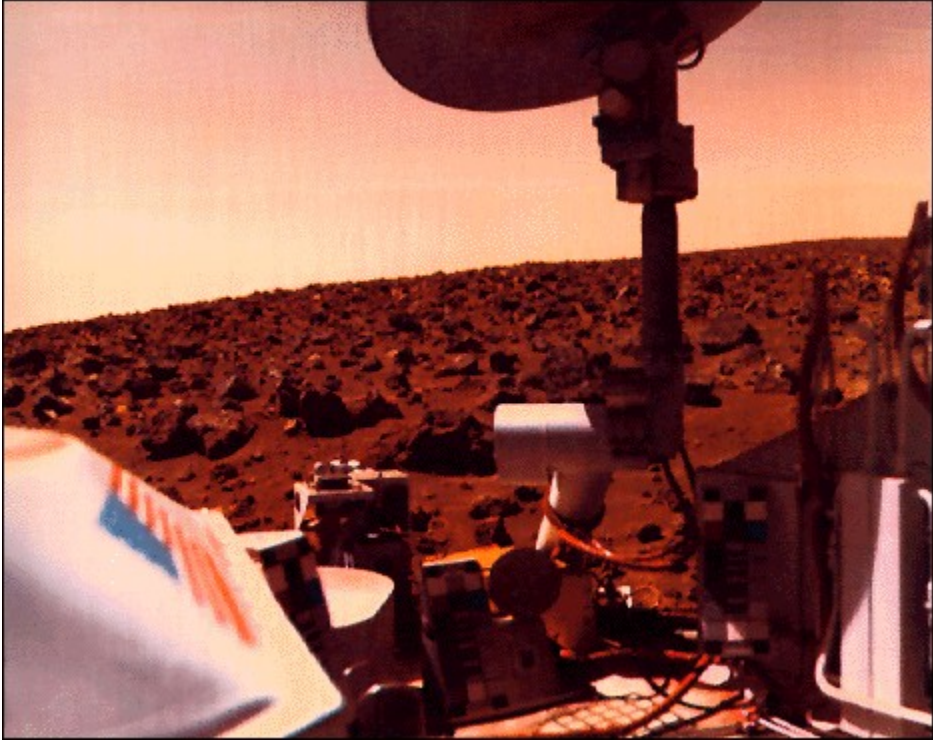








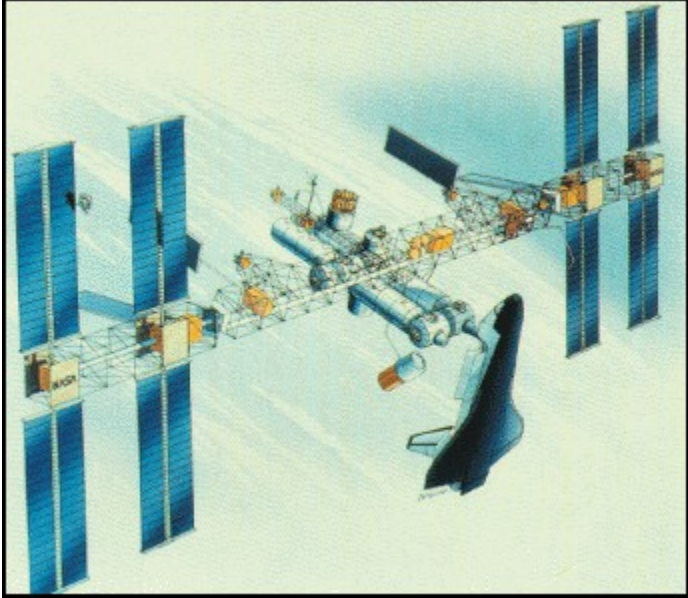


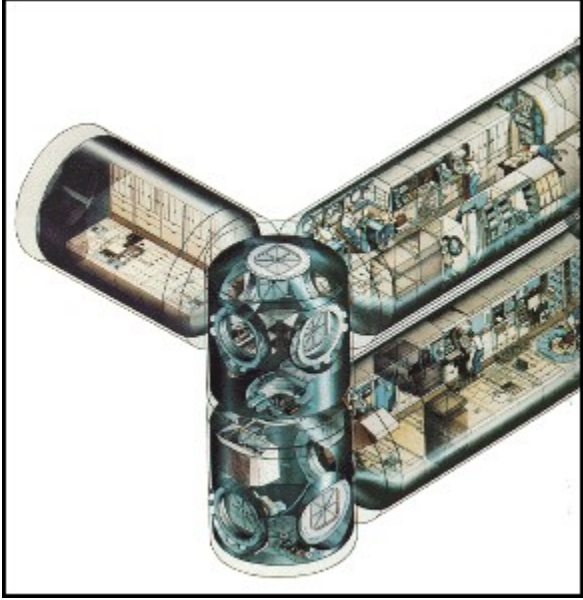


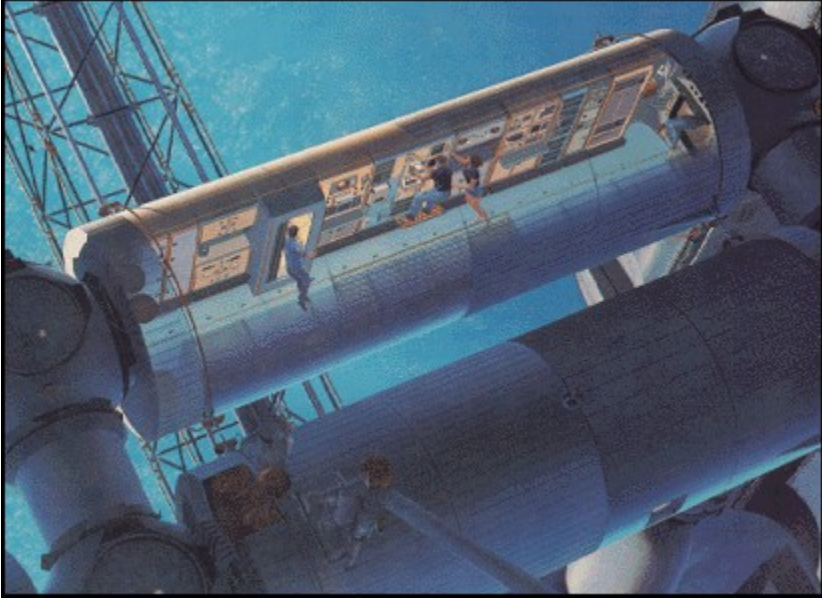


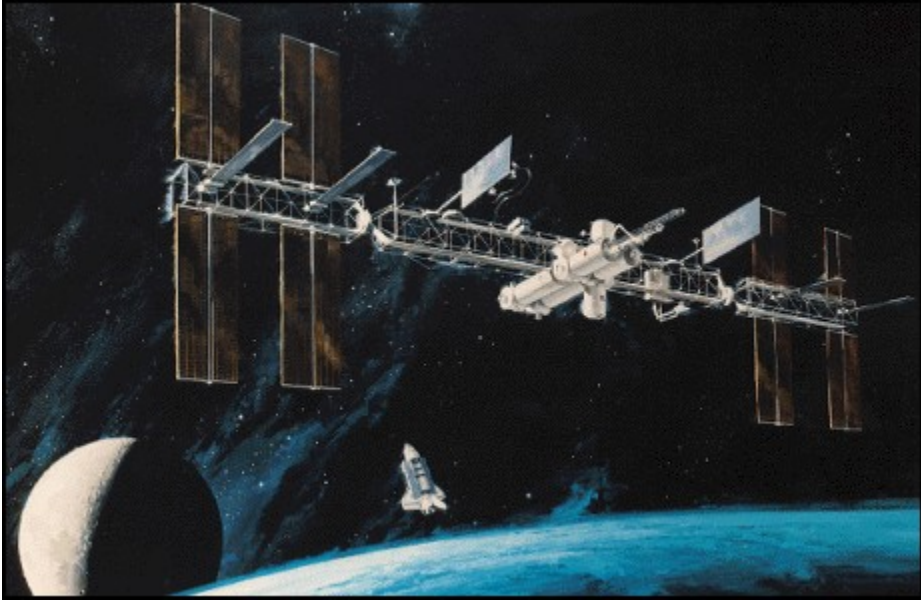















# Our Solar System

*and beyond...*



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Earth

Moon

Mars

Jupiter

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Neptune

Pluto

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New Windows in the Sky

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**THIS IS THE END OF THE TOUR!**

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**T**his is the beginning of the Guided Tour of the Universe. To advance to the next Tour Stop, click on the ***Begin Tour*** button below.

**Y**ou can zip around the Tour, start it and stop it, continue it or start it over, by clicking on the Tour Stop button.

**A**lso, you can click on the ***Solar System Explore*** button below, to zoom to various Solar System topics in the Dictionary of Astronomy.

**H**ave fun exploring!

***Begin Tour...***

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## The Terrestrial Planets, An Introduction



**T**he terrestrial planets (Mercury, Venus, Earth, and Mars) lie in the inner solar system, close to the Sun. They take from almost three months to almost two years to orbit around it.

[click here to see picture...](#)

**T**hey are relatively small, from less than 5,000 kilometers to almost 13,000 kilometers (less than 3,100 miles to almost 8,100 miles) in diameter, and they are solid and rocky, as if they had formed in a hotter part of the original dust cloud from which most of the gases were lost.

**T**he samples we have from the Earth, the Moon, and meteorites suggest that all the terrestrial planets are composed largely of fairly heavy elements such as silicon, aluminum, calcium, magnesium, iron, and others, combined with oxygen to make solid minerals and rocks.

**D**espite their common composition, the terrestrial planets are very different. Consider their atmospheres: Mercury has none, the Earth and Mars have modest atmospheres, and Venus has air so thick, dense, and cloud-filled that it forever conceals the planetary surface.

**T**he magnetism of terrestrial planets also varies strikingly. The Earth has a fairly strong magnetic field, Mercury has a weaker one, and Venus and Mars apparently have none at all. Even more curious, the rates of rotation vary widely: Earth and Mars each spin on their axes in about one day, but Mercury takes two months to rotate once and Venus takes a full eight months. (Venus also rotates opposite to the direction of rotation of the other planets.)

**T**he critical chemical water (H<sub>2</sub>O) varies greatly among the terrestrial worlds. The Earth has vast quantities of liquid water, so much so that it often is referred to as "the water planet." Mars has a much smaller amount,

present as ice. Venus may have almost none; only a trace of water has been found so far in its atmosphere.

**N**o water has been found on the Moon or in its rocks, although some scientists speculate that frozen water may exist in permanently shadowed regions near the lunar poles. A final mystery is that life, so far as we know, exists and has existed only on the Earth.

**F**urther out in the solar system are the gas-giant planets: Jupiter, Saturn, Uranus, and Neptune. Great globes of dense gas, with little or no rocky material, they formed in cooler parts of the protosolar cloud, so gases and ices were preserved. These planets take from almost 12 years to almost 165 years to circle the Sun, but they spin on their axes remarkably rapidly, in 10 to 16 hours, rather than in days or months.



## The Gas Giants, An Introduction



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**T**he giant planets are virtually all atmosphere. On Jupiter and Saturn, we see spectacular banded patterns of swirling, brilliantly colored clouds. At high altitudes, the clouds probably are composed of frozen ammonia crystals; in effect, there is a high layer of ammonia clouds like the high-altitude cirrus clouds of Earth.

[click here to see picture...](#)

**A**t lower altitudes Jupiter's clouds are probably made of water and complex molecules. The atmospheres of far-off Uranus and Neptune are hard to study, but show faint traces of clouds as well.

**W**e can only make informed conjectures about the interiors of the gas giants. They may have small rocky cores; if so, the cores are surrounded by layers of solid ice. Around this ice, in Jupiter and Saturn, the enormous pressure of the overlying material has reduced the molecular hydrogen gas (which makes up most of the atmosphere) to a liquid state in which the hydrogen behaves electrically like a metal.

**I**n Uranus and Neptune, the hydrogen is dense but may not reach the metallic condition. Currents circulating in the metallic fluids of Jupiter and Saturn generate powerful magnetic fields that surround the two planets in space and trap atomic particles from the "solar wind" that streams outward from the Sun.

**T**he gas giants have solid moons orbiting around them. Not just one or two moons, like Earth and Mars, but whole families; Jupiter and Saturn have more than a dozen moons apiece.

**T**heir moons, photographed by the Voyagers 1 and 2 spacecraft, have been revealed as an astonishing collection of distinct individuals: large irregular rocks, worlds of cratered ice, and one moon of incessant glowing volcanic eruptions.

**T**he largest of Saturn's moons, Titan, is covered by a dense brownish atmosphere of nitrogen and methane, with minor amounts of other organic molecules.

**W**ithin each of the two planetary groups -- the terrestrial planets and the gas giants -- our space probes have revealed tremendous diversity. Each world is unique, but each also has something in common with the others, so that by studying one, it is possible to discover basic truths that relate to them all.





## The Moon



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**I**s the Moon a planet? Technically no, for it revolves around the Earth rather than directly around the Sun. But the Moon is a large world, comparable in size to the planet Mercury. In composition, origin, and history, the Moon is like a terrestrial planet, resembling the Earth in many ways, different in others. These similarities and differences make the Moon an important starting point for the study of other worlds.

[click here to see picture...](#)

**B**ecause it is close to the Earth, the Moon is our most intensely studied "new" world. It has been reached by many spacecraft from both the United States and the USSR. On each of six missions, two American astronauts landed and studied the lunar surface.

**M**anned and unmanned satellites placed in orbit around the Moon have made detailed photographs and mapped the gravity, magnetism, and chemical composition over much of its surface. Instruments placed by our astronauts on the surface have investigated the once wholly inaccessible interior of the Moon.

[click here to see picture...](#)

**E**specially important has been the return of actual lunar samples from nine sites (six American, three Russian) on the Moon. By analyzing these samples in laboratories on Earth, we have measured the Moon's precise composition, deduced its history, and inferred the nature and variations of

the space environment around the Moon over long intervals of ancient time.

**T**he composition of the Moon is much like that of the Earth. Its rocks are similar to Earth rocks and contain many but not all of the same minerals. However, the Moon has no atmosphere, it shows no trace of past or present life, and its rocks contain no water.

[click here to see picture...](#)

**T**he Moon rocks show that the lunar surface is very ancient. Its rocks are older than most of the rocks now found on Earth, and the Moon has preserved a record of the earliest history of the formation and development of the planets.

**I**n its oldest rocks, we detect indications of an intense primordial melting that left the newborn Moon covered with a seething ocean of molten lava hundreds of kilometers deep. Gradually, the lava ocean cooled and solidified, forming the light-colored crust we call the lunar highlands, which still covers 80 percent of the Moon.

**T**he newly formed lunar crust was subjected to long-term catastrophic bombardment by meteoroids and asteroids, some as large as Rhode Island or Delaware. These violent impacts formed overlapping craters and huge circular basins that can still be seen on the Moon.

**T**hen, when the bombardment subsided, about 4 billion years ago, radioactivity began to heat the inside of the Moon. The lunar rock melted at depths of hundreds of kilometers, and fresh lava rose to the surface, spreading to form the great, dark regions, or maria, of the Moon.

**T**he lavas from these eruptions resemble lavas found on Earth in places like Hawaii and Iceland. But, unlike terrestrial lavas, they contain no water, and the crystals in them are as clear and gemlike as if they had been erupted yesterday rather than 3.5 billion years ago.

[click here to see picture...](#)

**F**or the last 3 billion years, the Moon has been a very silent world. A steady, gentle bombardment by tiny meteorites has gradually chipped away at the lunar bedrock, creating a slowly stirred surface layer of powdery rubble, the lunar "soil."

**D**uring these billions of years, the soil particles have been recording the space environment, retaining traces of the steady bombardment of the Moon by cosmic dust, by charged atomic particles from the Sun, and by cosmic rays from the stars.

**U**nlike the geologically active, continually changing Earth, the Moon has been a virtual "museum world," a key to understanding the history of the Sun and the planets.



## Mercury

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**O**nly 40 percent larger in diameter than the Moon, Mercury is the closest planet to the Sun, and its sunlit surface is hot enough to melt lead. The planet is so small and so far away from Earth that it was only a dull white blur in telescopes before the Space Age. Its surface finally was revealed during three flybys of a single space probe, Mariner 10.

[click here to see picture...](#)

**M**ercury is a planet much like the Moon. It has no atmosphere, and its surface is covered with circular impact craters and huge, round basins. Most of Mercury looks much like the lunar highlands; apparently it was subjected to the same bombardment that shaped the Moon in primordial times.

**Y**et Mercury is different. It seems to lack the dark deposits of lavas that engulfed much of the Moon between 3 and 4 billion years ago. Unlike the Moon, Mercury has great Cliffs, thousands of kilometers long, that may be wrinkles formed as the planet cooled and shrank.

[click here to see picture...](#)

**M**ercury is denser than the Moon, and it seems to have a large iron core, the source of a weak but detectable magnetic field, a feature the Moon lacks. Mercury is a scorched, primordial world which must retain traces of how planets were formed in a part of the solar system remote from the Earth and Moon.

[click here to see picture...](#)

**B**ut we cannot reach it yet for detailed exploration. Deep in the gravity field of the Sun, Mercury lies beyond the reach of even today's most advanced spacecraft. To send orbiters and landers there, more powerful

interplanetary spacecraft will be needed. Until then, Mercury waits just out of reach, its secrets baking in the light of a huge and searing Sun.



## Mars

[click here to see picture...](#)

**M**ars is larger than Mercury, slightly over half the diameter of the Earth. For centuries it has been a mystery planet, a blurred red globe in the telescope, splashed with patches of white and dark. Even before spacecraft ventured there, we knew that Mars had a thin atmosphere, winds, water, clouds, and polar ice caps.

[click here to see picture...](#)

**T**here was a continuing debate over whether the so-called "canals" were really there and whether Mars might in fact have life. In science fiction, Mars was the destination for spacefaring humans and also the main source of extraterrestrials, hostile or friendly, who visited Earth.

**A** new Mars has been revealed by several unmanned spacecraft: flybys, orbiters, and finally landers. Mars is now recognized as a kind of "halfway" world. Part of the Martian surface is ancient like those of the Moon and Mercury, and part is more evolved and Earth-like.

**T**he southern Martian hemisphere is heavily cratered, so it too bears the traces of the primordial bombardment that engulfed the Moon and Mercury. But the Martian craters are different: Their rims are low; they are shallow, eroded, and filled with wind-blown dust accumulated over millions of years.

**T**he northern half of Mars is more like the Earth. Huge volcanic mountains climb as much as 25 kilometers (15 miles) into the sky, three times as high as Mount Everest, and the remnants of ancient lava are seen on their slopes. A huge chasm, wider in places than the Grand Canyon is long, runs east-west for about 4,500 kilometers (2,800 miles).

[click here to see picture...](#)

**E**lsewhere on this younger half of Mars, surprising, twisted channels meander across the surface. These are not the straight "canals" once seen from Earth; those turned out to have been tricks of perception produced by viewing Mars at the limit of Earthbound vision. The real twisted, braided channels seem to have formed catastrophically in huge, sudden floods more than a billion years ago.

**T**he water has vanished; no liquid water is now found on Mars. But huge reservoirs of frozen water apparently remain in the Martian polar caps, and in permafrost beneath the Martian soil. The white polar caps are largely made up of water, with a frosting of "dry ice" or frozen carbon dioxide. The caps themselves lie on layered sediments, perhaps the evidence of past ice ages on Mars.

**T**wo places on Mars have been examined on the surface by the two Viking landers (one of which is still operating since its landing in 1976). The robot spacecraft sent back pictures of a pink sky, colored by fine, red, windblown dust. Lander instruments measured mild winds in the thin Martian air and detected a thin frost that formed on rocks and soil during the Martian winter.

**T**he atmosphere of Mars is very thin; the barometric pressure is less than one percent that of the Earth at sea level. Unlike our air, Mars' atmosphere is not predominantly composed of nitrogen and oxygen, but consists almost exclusively of carbon dioxide (CO<sub>2</sub>), with minor amounts of nitrogen and argon and just a trace of oxygen.

[click here to see picture...](#)

**T**he rocks of Mars are porous and jagged, like the volcanic lavas of the Earth and the Moon. The Martian soil, analyzed by the Viking landers, has a composition very much like weathered lava. The red color of Mars is in fact caused (as generations of science fiction writers had written) by the presence of oxidized iron, a kind of exotic rust.

**T**he greatest mystery of Mars: Is there life? remains a mystery. Several experiments on the Viking landers tried to detect life in the soil, and some unusual reactions were encountered. But the reactions probably were due to the unusual chemistry of the soil rather than to the presence of any microscopic life forms.

**I**t seems that we will need to carry more sophisticated experiments to Mars -- or bring a sample of Mars back to laboratories here on Earth --



before we can answer the question with certainty.

**M**ars is a more developed planet than the Moon and Mercury. The evidence of massive volcanism is obvious. In addition, some geologists consider the vast chain of canyons in the northern hemisphere to be the result of rifting, perhaps the beginning of continent-building.

**M**ars has made and retained an atmosphere. But, like the Moon, Mars apparently stopped evolving 1 or 2 billion years ago and has not gone as far geologically as the Earth. On the other hand, like the Earth, it is a world with weather and climate. The records of its past climates, floods, and ice ages remain in the layered sediments of the polar regions, photographed in detail, but as yet unreachable.





## Venus

[click here to see picture...](#)

**S**econd from the Sun, closest planet to the Earth, Venus has long been known as the bright morning and evening star. Called "Earth's Twin" because it is almost the size of Earth, Venus is surrounded by a thick, yellowish -- white, opaque atmosphere. All we can see in telescopes are fuzzy images of its perpetual cloud cover.

**P**robed and scanned by spacecraft, however, Venus has revealed itself as no twin of Earth, but rather as a strange and hellish inferno. Its thick atmosphere is composed mostly of carbon dioxide, with a little nitrogen and traces of water, oxygen, and sulfur dioxide.

**A**t the surface, the pressure of Venus' atmosphere is 90 times that of Earth's, equal to the pressure half a mile down in the ocean! The thick atmosphere traps the Sun's heat, producing a "greenhouse effect" that keeps the surface of Venus at a scorching 480o C, literally hot enough to fry eggs. Above the surface, entry probes of the Pioneer Venus mission detected several distinct regions, two of them, and possibly even four, constituting separate cloud layers.

**T**he topmost cloud layer, revealed in photos made from spacecraft and dimly perceived from Earth, consists not of water clouds as on Earth, but rather of sulfuric acid droplets, far more potent than the mild "acid rain" that concerns us now in the United States. A haze of aerosol particles extends upward from this layer and sometimes even veils the clouds themselves from view.

[click here to see picture...](#)

**T**he surface of Venus has been photographed at two locations by Russian Venera landers that briefly survived the hot, high -- pressure environment and photographed the surrounding rocky slabs and rubble. Another Venera lander gave us our first chemical analysis of the surface of Venus,

indicating a unique composition resembling that of terrestrial granite.

**U**ntil other camera -- carrying spacecraft land and survive, the rest of the surface of Venus will remain unseen. But the clouds that block telescopic investigation do not stop radar waves. Powerful radar transmitters, both on Earth and on a Pioneer Venus spacecraft in orbit around Venus, have scanned and located the major topographic features of the veiled planet's surface.

**V**enus revealed by radar apparently lacks the great number of high mountain ranges and the interlocked systems of deep oceanic trenches that run for thousands of kilometers on the Earth. But it has its own remarkable features. Among them are two great plateaus, each as large as a small continent, which rise as high as 17 kilometers (11 miles) above the surface.

**O**ne, called Ishtar Terra, is about the size of the continental United States and contains a more elevated region that is higher than Earth's Tibetan plateau and more than twice as large. Elsewhere on Venus is Beta Regio, a prominent land form that contains two huge, adjoining shield volcanoes, together more extensive than the Hawaii -- Midway chain.

**A**mong the rifts found in the Venus crust are a canyon deeper and longer than the Grand Canyon of Arizona and a long valley that apparently is flanked by large mountains. Do these chasms of Venus indicate that its continental masses are separating?

**T**here also are large circular depressions, perhaps great meteorite craters like those found on other terrestrial planets. However, these basins are unusually shallow, as though the hot crust of Venus has flowed into them like hot, soft wax.

[click here to see picture...](#)

**T**he surface of Venus seems to have been shaped by internal geological activity, but we do not know what kind of phenomena were involved, nor how long they went on. Is Venus now dead and quiet, as Mars appears to be? Or is it more evolved, and still geologically active, perhaps approaching Earth in its development?

**W**e have no detailed maps of Venus to guide our thinking, unlike the case of the other planets. The surface of Venus, the nearest planet to Earth, is still one of the largest unexplored lands in the solar system.





## Jupiter

[click here to see picture...](#)

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**J**upiter is where the action is. The planet is big enough to hold 1,400 Earths and is almost 2.5 times more massive than all of the other planets put together. It is a huge, rapidly spinning blob of cold gases -- hydrogen, helium, a little methane, water, and ammonia -- all colored by traces of more complex but largely unknown chemicals.

[click here to see picture...](#)

**T**he outer part of the atmosphere is all that we see of Jupiter. There, clouds form in belts and stripes, in consequence of the fast rotation. This planet, 111 times the diameter of Earth, spins on its axis in less than half an Earth day.

**D**eep inside Jupiter's atmosphere, the pressure becomes enormous, and hydrogen, a gas at the higher altitudes, is condensed to a liquid. At about 25,000 kilometers (16,000 miles) below the cloud tops, the pressure attains a value 3 million times that of the Earth's atmosphere at sea level. At this pressure, the liquid hydrogen transforms to a metallic state.

**C**urrents circulating through the metallic hydrogen fluid generate a magnetic field that is about 14 times stronger at Jupiter's cloud tops than the field at the surface of the Earth. Disturbances in the magnetic field around Jupiter produce powerful bursts of radio waves, making Jupiter the noisiest radio transmitter in the solar system, other than the Sun.

[click here to see picture...](#)

**J**upiter's magnetic field is much stronger than the Earth's, and it is much less compressed by the solar wind, the stream of charged atoms that pour out from the Sun. Jupiter's field forms a huge magnetosphere around the planet, and the field sweeps out on the side opposite the Sun to give

Jupiter a fat "magnetic tail" at least 150 times wider than the diameter of the planet itself.

[click here to see picture...](#)

**J**upiter's composition of hydrogen and helium is the same as the Sun's. Recent theoretical studies have carried the similarity even further, suggesting that if Jupiter had been only a little larger, it might have become another Sun, the gas at its center compressed so much that nuclear reactions would have begun.

**T**hus, Jupiter is a sort of "star that failed," although it still radiates, by compressing its own core, twice the amount of energy that it receives from the Sun. The most striking resemblance, however, is that Jupiter is the center of a miniature solar system, surrounded by an array of at least 16 moons, just as the Sun is surrounded by planets, comets, and a belt of asteroids.

**J**upiter, remarkable even as observed from Earth, revealed even more wonders as our spacecraft sped past it in recent years. Cameras gave us a close view of its banded atmosphere, and we learned that the seemingly smooth belts of color were actually separated by zones of violent turbulence.

[click here to see picture...](#)

**E**arth-sized blobs of colored gas travel along huge "jet streams," spin, and collide. Great plumes rise from deep in the atmosphere and leave trails 10,000 kilometers (over 6,200 miles) long across the planet. The great Red Spot, a long-lived oval as big as three Earths (it was first seen at least 300 years ago), is a complex, swirling hurricane. Even the night side of Jupiter is alive with the flash of lightning superbolts and the glowing bands of huge aurorae.

[click here to see picture...](#)

**T**he spacecraft passing Jupiter discovered three new moons, adding to the 13 already observed from Earth. Inside the orbit of the innermost moon they found a ring, a thinner version of the rings of Saturn, never seen from Earth. The ring, made of tiny particles, apparently reaches right down to the cloud tops of Jupiter, and it has stimulated a major debate about how it formed and how it continues to exist so close to Jupiter.



## Jupiter's Moons

[click here to see picture...](#)

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**T**he moons of Jupiter are equally spectacular, remarkably different from our own Moon and from each other. The two Voyager spacecraft discovered that they are very unlike what astronomers expected. Amalthea, once considered Jupiter's innermost moon, is an irregular rock about 270 kilometers (170 miles) long, but only about 155 kilometers (96 miles) wide along one axis.

[click here to see picture...](#)

**B**eyond it are the four Galilean satellites (so-called because Galileo discovered them). Three of them are larger than our own moon, including Ganymede, which is even bigger than the planet Mercury.

[click here to see picture...](#)

**I**o, the innermost Galilean satellite, was one of the biggest surprises of the Space Age, a brilliant red-orange world with more than 100 volcanoes. The two Voyagers saw seven of the volcanoes in continual eruption, shooting umbrella-shaped plumes of sulfur particles high above Io's surface.

[click here to see picture...](#)

**T**hese unique volcanoes, the only active ones known outside the Earth, seem to be ejecting molten sulfur at a temperature of a few hundred degrees, not molten rock at more than 1000oC. The heat comes, not from radioactivity as in the Earth, but from tidal forces and perhaps also huge electric currents that act on Io as it swings around Jupiter.

**E**uropa, the next moon out, resembles a smooth, yellowish billiard ball and comprises perhaps the flattest real estate in the solar system. It is

crisscrossed with thin lines, some several thousand kilometers long, that remind some observers of a kind of modern art. The lines may be the traces of a shifting icy crust, but we have no idea of what forces have acted, and continue to act, to keep this world so flat.

[\*click here to see picture...\*](#)

**G**anymede, the largest of Jupiter's moons, looks a little more familiar. Like our own Moon, its surface is divided into light and dark regions, and we can see craters. There the similarity ends. Ganymede is a lightweight moon, a "snowball" of mixed ice and rock. Bright rays extend from the craters, perhaps consisting of fresh ice. The light areas of Ganymede display long bands of parallel grooves, unique and puzzling structures which indicate that internal forces have shaped the surface.

**C**allisto, the outermost Galilean moon, is a heavily cratered, brownish world. It seems to be a snowball moon like Ganymede, but its surface is uniformly cratered and preserves a long history without any disruption. Callisto may have the oldest surface yet observed in the solar system, its craters perhaps dating back to an ancient era of bombardment, which ended about 4 billion years ago. Callisto also bears what may be the largest crater anywhere in the solar system, a huge, multi-ringed basin more than 2,500 kilometers (1,600 miles) across.





## Saturn

[click here to see picture...](#)

**T**o ancient astronomers, Saturn was a wandering light near the edge of the known universe. The planet and its rings have been objects of beauty and wonder ever since Galileo noticed the "cup handles" that seemed attached to a round world.

[click here to see picture...](#)

**S**aturn is a smaller version of Jupiter, made up of a similar mix of gases, mostly the very light hydrogen and helium. Like Jupiter, all we see of Saturn is the tops of its clouds. With their subdued hues of yellow, gray and brown, they lack the sharp, brightly colored belts of Jupiter.

**A**bove the clouds there seems to be a high haze of frozen ammonia crystals. Saturn's rings, its best known feature since Galileo's time, stretch far out around the planet, extending to more than half the distance from the Earth to the Moon. They actually consist of a series of individual rings separated by small gaps and composed of huge numbers of small particles.

[click here to see picture...](#)

**S**aturn has at least 15 moons, some only recently discovered by passing spacecraft. Among those that have long been known is Titan, one of the largest moons in the solar system, massive enough to retain a thick, cold atmosphere that obscures any view of its surface. Organic compounds are present on Titan, and it has occasionally been speculated that life may exist there.

**S**aturn is far out. A billion miles from Earth, the planet was not reached by any spacecraft until September, 1979, when Pioneer Saturn, after a six-year trip by way of Jupiter, flew past the rings to within 21,000 kilometers (13,000 miles) of Saturn's cloud tops. Voyager 1, with better, more sophisticated instruments (which had explored Jupiter in 1979) reached



Saturn slightly more than a year after Pioneer.

[click here to see picture...](#)

**O**n November 12, 1980, Voyager 1 ducked under the rings, passed Saturn at 124,000 kilometers (77,000 miles) above the cloud tops, crossed the ring plane again, and headed out of the solar system at 90,000 kilometers per hour (56,000 miles per hour). In a few hectic days, the television cameras and other instruments of Voyager 1 told us more about Saturn, its rings, and its moons than was learned in all the centuries that people have studied this strange and beautiful world.

[click here to see picture...](#)

**T**hese close-up looks at Saturn revealed several properties that the ringed planet shares with Jupiter, as well as some differences. Like Jupiter, Saturn is radiating away about twice as much energy as it receives from the Sun, but its frigid cloud tops have a temperature of about -183o C. Pioneer Saturn discovered that Saturn has a magnetic field.

[click here to see picture...](#)

**T**he field is much weaker than that of Jupiter, but it is probably produced in the same way, by circulating flows of liquid metallic hydrogen deep within the planet that generate electric currents and thus create a magnetic field. Saturn's magnetic field fills a smaller volume of space than does Jupiter's, and its radiation belts are correspondingly weaker. In fact, Saturn's radiation belts are comparable in intensity to the Van Allen Belts of Earth.

[click here to see picture...](#)

**A**s Voyager 1 approached Saturn, the planet's atmosphere began to show structural details within the indistinct, faintly colored bands. The television cameras peered through the frozen ammonia haze, down to the thicker clouds. At this still fairly distant range, Saturn looks more like Jupiter.

[click here to see picture...](#)

**T**urbulent belts and streams of clouds stretch east-west across the planet. Cloudy jet streams were photographed that move four times as fast as the winds of Jupiter, as much as 1,500 kilometers per hour (930 miles per hour). A red oval was found in the clouds, a swirling storm like Jupiter's Red Spot, but much smaller (only about the size of the Earth!).





## Saturn's Moons

[click here to see picture...](#)

**I**n its dash past Saturn, Voyager 1 photographed seven of the planet's large moons, previously unexplored worlds that had been only tiny spots of light in earthbound telescopes, despite their fanciful mythological names: Mimas, Enceladus, Tethys, Dione, Rhea, Titan, and Iapetus. Even before Voyager 1 arrived, we thought that these moons would be different.

**I**n this cold, distant region of the solar system, water does not exist as a liquid but as ice, in effect a brittle kind of rock. Saturn's moons are huge icebergs, perhaps with small cores of true rock, and they may be more like huge versions of the nucleus of a comet than like our own rocky Moon.

**J**ust like the moons of Jupiter, Saturn's moons displays a variety of weird landscapes. Mimas, Dione, Tethys, and Rhea all have heavily cratered terrain, presumably the result of bombardment by smaller objects shortly after the moons formed about 4.5 billion years ago.

**O**n Mimas there is one large crater that makes the moon resemble a huge, staring eyeball. The crater is so big that the impact that formed it must almost have shattered Mimas into pieces.

**T**he landscape of Rhea, photographed close up as Voyager 1 skimmed past only 72,000 kilometers (45,000 miles) above its north pole, resembles the cratered lunar highlands and the battered surface of Mercury, but Rhea's craters have been cut in ice, not in rock. The craters are caused by an external force, the cosmic bombardment of Saturn's moons, but some of the moons have clearly also been modified by internal forces.

**T**ethys has a huge trench, 60 kilometers (37 miles) across and about 750 kilometers (470 miles) long, perhaps a great crack in a spreading crust. Rhea and Dione display strange streaks and swirls, side-by-side with heavily cratered regions, as though the icy crusts shifted and deformed after the craters were made.

[click here to see a picture of Dione...](#)

**T**he moon Enceladus was a surprise of a different kind; its surface is smooth and crater-free, even though it orbits Saturn between the heavily cratered moons Mimas and Dione. Perhaps Enceladus is heated by tidal forces imposed by nearby Dione. (Similar tidal heating of Jupiter's moon Io is strong enough to power Io's constantly erupting volcanoes.)

**S**uch heating could warm Enceladus' icy crust, deforming it and removing the traces of once-present craters. Perhaps the heating is so strong that icy volcanoes erupt from time to time and floods of molten "lava" in this case just waterpour briefly across the surface of Enceladus.

**S**aturn's distant moon Iapetus, photographed at long range by Voyager 1, is even more of a mystery. Telescopic studies from Earth show that Iapetus has two different sides one dark and one bright. Voyager 1 pictures showed the two regions and their sharp boundary but as yet provide no explanation of the mystery.

**T**itan is a unique, giant moon, a world about the size of the planet Mercury. It is the only moon in the solar system known to have an atmosphere. Already from Earth we had detected methane and other organic compounds, so Voyager 1 was carefully programmed to take an especially close look at Titan.

**I**t flew past Titan only 4,000 kilometers (2,500 miles) above the atmosphere, the closest flyby past any cosmic object in the history of space exploration. The accuracy involved is comparable to shooting a billiard ball 3,200 kilometers (2,000 miles) across a giant table and sinking it in the right pocket.

**T**itan's atmosphere is so thick, perhaps more than 200 kilometers (125 miles) deep, that the Voyager 1 cameras could not see to the surface. Surprisingly, the atmosphere is not rich in the methane detected from Earth. Instead, the most common gas is nitrogen, just as on the Earth itself. Methane makes up only about one percent of the air of Titan.

**M**ore complex organic molecules, formed by the action of sunlight on the atmospheric gases, produce a natural smog not too different from the choking haze found over many of our cities. At Titan's surface, the atmospheric pressure is two or three times that on Earth, but the temperatures are as low as -150o to -200oC.

**T**he unseen surface of Titan may be a bizarre, frozen swamp, with murky streams and lakes of liquid nitrogen and a cold rain of nitrogen and organic chemicals sleeting down. There may be no life in that incredible cold after all, yet Titan may preserve in its deep freeze a sample of what other primitive atmospheres (including Earth's) resembled before they were changed by phenomena that probably have never affected Titan: volcanoes, oceans, and life.

**S**aturn and its moons still have much to tell us and doubtless more surprises in store.



## Uranus

[click here to see picture...](#)

**T**he ancients knew of five planets in the sky. In less than a generation, all five have been brought close to us by spacecraft. Further out in space, three more planets await our inspection.

[click here to see picture...](#)

**U**ranus, the first outward beyond Saturn is nearly 3 billion kilometers (nearly 2 billion miles) from the Sun and takes 84 years to make one orbit around it. Pioneer 10 passed the orbit of Uranus, but did not come near the planet. Uranus is another gas giant, smaller than Saturn, a cold world that is a distant greenish disk even in the largest telescopes.

**F**rom Earth, we can see five moons circling the planet. Uranus has one unique property: its axis of rotation lies in the plane of its orbit rather than nearly vertical to it as is the case with the other planets. Because of this curious orientation, Uranus moves around the Sun, not so much like a top spinning on its end, but like a barrel rolling along on its side.

**T**he greatest Space Age discovery about Uranus was made in 1977, not from a spacecraft but rather with a telescope mounted in a high-altitude jet aircraft, the Kuiper Airborne Observatory.

**L**ike many great discoveries, it was entirely unexpected, and the scientists were looking at Uranus for something entirely different. They intended to study Uranus' atmosphere by measuring the light from a distant star as the planet passed slowly in front of it. What happened was that the star seemed to flicker on and off several times, long before and long after the planet had passed in front.

**T**he only explanation was that Uranus -- like Saturn and now Jupiter -- has rings! The planet is surrounded by at least five and perhaps nine rings. The rings are dark, thin, narrow, and invisible from Earth, but they were

thick enough to block out the light from the star.

**U**ranus soon had its first visitor from Earth. The spacecraft Voyager 2 followed a path that took it past Uranus in 1986.



## Neptune

[\*click here to see picture...\*](#)

**N**eptune, the most distant gas giant planet from the sun, is so far away that it is only a tiny, blurred image in the 154-centimeter (60 inch) telescope at the Catalina Observatory.

[\*click here to see picture...\*](#)

**T**he top three images show dark absorption bands, due to the presence of atmospheric methane (CH<sub>4</sub>), across the planet's equator. The bright regions at the poles are produced by a high haze of ice crystals.

[\*click here to see picture...\*](#)

**T**he following image shows the uniform, featureless appearance of the planet when seen in visible light.

[\*click here to see picture...\*](#)





## Pluto

[click here to see picture...](#)

**P**luto is a planetary oddball, a strange world that has baffled scientists ever since it was discovered in 1930. It is not the large gas giant that one might expect to find in the outer reaches of the solar system.

**I**nstead, it is a small world, much smaller than the Earth, and in fact roughly as large as our Moon. It is probably composed of a mixture of rock and ice. It even has been suggested that Pluto is not a genuine planet, but simply a moon that somehow escaped from Neptune.

**P**luto is usually the farthest known planet from the Sun, its mean distance almost 6 billion kilometers (almost 4 billion miles) out. It takes 248 years for Pluto to complete one orbit around the Sun, but the orbit is so elongated that it actually spends about 20 years of this time inside the orbit of Neptune. (In fact, Pluto is inside Neptune's orbit now, and will be until 1999, so that Neptune is temporarily the furthest planet from the Sun.)

[click here to see picture...](#)

**D**espite Pluto's distance and the extreme difficulty of observing it, our view of the faraway planet has changed greatly in the last few years. As we have looked more carefully, Pluto has become an even smaller and brighter object than we thought it was. It seems to have a bright layer of frozen methane ("marsh gas," chemically CH<sub>4</sub>) on its surface.

**E**ven more surprising, reexamination of old photographs revealed that Pluto is not alone; it has a moon. Pluto now seems to be about 3,000 to 3,500 kilometers (1,900 to 2,200 miles) in diameter. Pluto's moon, Charon, is large by comparison, about 1,200 to 1,500 kilometers (750 to 930 miles) in diameter, so that the two bodies form a kind of unique double planet.

**P**luto will hold its secrets for a long time yet. It is simply too far away for our current spacecraft to reach it in a reasonable length of time. It will be

many years before any machines or humans see Pluto up close, dimly lit by a Sun so distant that it seems like just a rather bright star in the blackness of space.



## Minor Objects in the Solar System

[\*click here to see movie...\*](#)

**T**he nine planets and at least 39 moons are only a tiny part of the population that circles the Sun. There are huge numbers of smaller objects: comets, asteroids, large cosmic rocks and small pebbles, and innumerable particles of dust. Each object makes its own contribution to the solar scenery, and each has its own secrets to reveal.

**T**hese small objects have been less studied, and none have yet been visited by a spacecraft. Our main source of information has been observations through the telescope and study of meteorites, which are part of the extraterrestrial materials that fall to Earth at a rate of several hundred tons per day.



## Asteroids



**T**here is no planet between Mars and Jupiter. Instead, there are a great many small objects called asteroids where a planet might have formed. About 2,000 have been observed sufficiently so that their orbits are known. Most of them are irregular rocks a few kilometers across, but a dozen are about 250 kilometers (160 miles) or more in diameter.

[click here to see picture...](#)

**T**he largest, Ceres, has a diameter of about 1,000 kilometers (about 600 miles) and is roughly the size of Texas. It has been estimated that there may be a half-million asteroids larger than one kilometer (0.6 miles) in diameter, nearly all too small to be observed by current methods.

**M**ost asteroids have orbits that remain between Mars and Jupiter, in a region called the asteroid belt, but a few have orbits that cross the orbit of the Earth. These "Earth-crossers" are called the Apollo-Amor asteroids (named after two of their number).

**T**he most famous member of the group is Icarus, discovered in 1949, and so named because it actually goes closer to the Sun than Mercury. It came within 6.5 million kilometers (4 million miles) of the Earth in June, 1968.

**R**ecent observations have detected other members of this Apollo-Amor group in the sky. The geological record on Earth also bears witness to these Earth-crossers, for about 100 ancient meteorite impact craters have been detected, each one possibly representing an asteroid that didn't quite make it past the Earth.

**S**ome of these collisions must have been unbelievable catastrophes; the two largest known craters, one in Canada and one in South Africa, are more than 100 kilometers (60 miles) in diameter.

**S**mall bits of asteroids also collide with the Earth, although less violently and more frequently. These objects, called meteorites, have provided us with extraterrestrial samples for centuries, long before we were able to collect rocks from the Moon. We think that they come from the asteroid belt.

**I**f this is right, then there must be a great variety of objects out there, for meteorites are very different. Most meteorites are stones containing many glass droplets, but others are pieces of lava flows, chunks of solid nickel-iron, and even bits of dark, carbon-rich materials containing significant amounts of water.



## Meteorites

[click here to see picture...](#)

**M**eteorites are among the most ancient solar system samples we have. They date from the formative stages of the solar system 4.5 billion years ago, and they are the only source of direct information about the physical and chemical processes that went on as the Sun and the planets grew from a collapsing cloud of dust and gas.

**S**tudies of meteorites during the Space Age provide specific details about the solar system's birth and early years. Some meteorites seem to be pieces of actual lava flows that poured from ancient volcanoes on small asteroids heated by primordial radioactivity.

**T**he carbon-rich materials in some meteorites contains amino acids -- so-called "building blocks" of life -- which give us new insight into the possible occurrence of life in the universe. White rock fragments from a meteorite that fell in Mexico in 1969 are composed of high temperature minerals that may have been the first materials to form as the solar system came into being.

[click here to see picture...](#)

**T**he white fragments document more than just the beginning of the solar system: They may contain records that actually date from "before the beginning." Some of the fragments contain anomalous material that is chemically unlike the matter that makes up the solar system. (The chemical elements are the same, but the abundance patterns of certain elements are different.)

**T**his chemically unusual material did not come out of our own Sun. It may have come from another nearby star, perhaps flung out in a violent supernova explosion to enrich the cloud of gas and dust where the solar system later formed.



**T**he discovery also suggests that shock waves from the supernova passed through the cloud, triggering the condensation that eventually produced the Sun and the planets. Thus, through laboratory analyses of the meteorites, we can now see back in time beyond the formation of the solar system itself.

**M**eteorites also tell much about what the asteroids are like. Using ground-based telescopes and spectrometers, we are able to make crude chemical analyses of individual asteroids by analyzing the light that they reflect.

**C**omparing these data with the results of meteorite studies, we have determined that the asteroids can be divided into families that are similar to the different groups of meteorites, although we have not yet been able to link a meteorite group uniquely to a specific asteroid.

**T**he origin of asteroids has also been illuminated by meteorites. The asteroids were once thought to be the remnants of an exploded planet. Meteorite studies have disproved this idea, and the asteroids are now thought to have formed as small objects in a region where the gravitational tug-of-war between Jupiter and the Sun prevented a larger body from coming together.

**W**e now know enough about asteroids to ask some exciting questions. Do they hold records of the actual formation of the solar system? How can such small bodies have developed with such a variety of compositions and histories? Among the unanswered questions are some that may be of more than scientific importance. How many asteroids are there? How many undiscovered ones cross the Earth's orbit? When might another catastrophic collision occur?



## Comets



**C**omets are the shining wanderers of the solar system. With their glowing tails that may stretch 100 million kilometers (60 million miles) through space, they are conspicuous, remarkable, and exciting objects. Their appearances often have been superstitiously associated with disasters and (more recently) with brief periods of intense scientific study.

[click here to see picture...](#)

**M**ost comets reside in the outer fringes of the solar system, far beyond Pluto. In fact, the solar system probably is surrounded by a huge cloud of more than a hundred billion comets that may stretch a third of the way to the nearest star.

**A**lmost all remain there in the frozen darkness, but on rare occasions they are perturbed (perhaps by the gravity of a nearby star) and a comet may be sent on a long trip down to the Sun and back out again.

**F**or all their apparent size in the sky, comets are actually fairly small objects. When a comet begins its trip down past the Sun, it is probably a chunk of "dirty ice," a mixture of rock dust and ice a few kilometers across, much smaller than the typical observed asteroid.

**A**s it speeds toward the Sun, the heat from the Sun evaporates the ice, and the gases thus released blow dust particles outward from the solid body or nucleus. Radiation from the Sun ionizes the released atoms, producing a tail that glows in the sky like a neon sign; the dust particles reflect sunlight and form another, smoother tail.



**T**he tails seem white to the eye, but color photography reveals that the ionized gas tail is blue and the dust tail yellow. Although the tails may be bright, they are thin, and stars show through.

**T**he small nucleus, the only even near-permanent part of a comet, is surrounded by the coma or head of the comet, a large, hazy structure formed by the liberated gas and dust. From the coma, the tails sweep back in the direction opposite the Sun, driven by the pressure of sunlight and by the solar wind.

**I**n 1970, an instrument on the Earth-orbiting satellite OAO-2 (named the Orbiting Astronomical Observatory) revealed that comets are surrounded by huge clouds of hydrogen gas, produced when ultraviolet light from the Sun decomposes the cometary gas.

**L**ater, the hydrogen cloud of the bright Comet Kohoutek was scanned by a photometer on Mariner 10, and the comet was photographed in ultraviolet light from Skylab. Aboard Skylab, astronaut Ed Gibson was able to view the comet when it was very close to the Sun, and he discovered a unique "anti-tail" pointing toward, rather than away from, the Sun.

*[click here to see movie...](#)*

**O**f the 100 billion comets that may exist, less than 1000 have been observed thus far as they make the long journey down to the heat of the Sun. Some comets now are trapped in smaller orbits, taking from a few to a few thousand years to complete one lap.

**E**ven so, most of them spend the bulk of their time in the cold, dark, outer solar system and just a tiny portion of their lives speeding in glowing splendor past the Sun.

**C**ometes probably formed in the freezing darkness beyond Jupiter and perhaps beyond Pluto where they spend most of their lives. As a result, comets are probably the most primitive and the most unchanged original solar system materials that we can ever hope to sample and to study.

*[click here to see picture...](#)*

**W**e have never yet sent a spacecraft to a comet. What we have learned during the Space Age has come from ground-based telescopes, from a few

unmanned satellites and sounding rockets, and from studies made in the Skylab space station.

**E**xcitement built for a major event that occurred in 1985: the reappearance of Halley's Comet. Swinging on a long orbit that brings it by the Sun every 76 years, Halley's is one of the best-known and brightest comets, and during its reappearance scientists executed many observing programs that removed much of the mystery from this famous visitor.



## Dust

[click here to see picture...](#)

**T**here is no lower limit to the sizes of the solid particles that move around the Sun. Small asteroids grade downward into large meteoroids and then into smaller pebbles and so on down to the tiniest particles of dust. The most numerous particles are the smallest ones.

**A** particle larger than a millimeter (about one twenty-fifth of an inch) in diameter is a relative rarity in space, but even smaller particles exist by the uncountable billions. There are enough of them to reflect sunlight in a faint glow, called the zodiacal light.

**U**nlike planets and other large objects, dust particles are not permanent residents of the solar system. They spiral slowly inward toward the Sun. Over a million years or so, a typical particle will fall into the Sun, so that the current dust population must consist of fairly new arrivals, presumably shed from comets.

**B**ecause interplanetary dust particles may be actual samples of comets, strenuous efforts have been made to collect them. Many efforts failed because of the rarity of the particles and the contamination of collecting devices by terrestrial dust. Recently, however, extraterrestrial dust particles have been successfully trapped with collectors mounted on high-flying aircraft.

**T**he yield has been small so far: only about a hundred particles a few thousandths of a millimeter across. But recently developed instruments are so sensitive that even these tiny objects can be usefully studied.

**T**hey are definitely extraterrestrial, for their chemical composition is like that of common meteorites (and not like that of the Earth), but they are fluffy, fragile objects, each particle a mosaic of millions of tiny crystals.



## The Planetary Connections

**I**f our goal in planetary exploration were simply to accumulate a list of impressive discoveries, then we have succeeded beyond our wildest expectations. But there is a larger purpose to our search through the solar system: to discover not just what planets are like, but also how they got that way.

**W**hat forces formed and shaped young planets in the ancient past? What processes sculptured their surfaces, made or failed to make atmospheres, and brought forth or failed to bring forth life?

**W**e cannot discover the general laws that govern all planets by studying only the Earth. We would never know whether things that are common on Earth (oxygen, water, and life) were abundant or absent elsewhere, and so we have gone to other worlds to find out.

**A** new scientific discipline has arisen, comparative planetology, in which we study as many worlds as possible, looking for common characteristics amid the riot of individuality.

**F**inding how planets form and grow is motivated by more than just scientific curiosity. The Earth is a planet too. Our world and its life are the results of complex forces operating for billions of years. The more we learn about all planets, the better we can understand our own: its geologic past, the behavior of its atmosphere, and future climatic trends.

**B**y going into space, we have discovered that certain basic planetary characteristics occur throughout the solar system, manifesting themselves in different ways on different planets. These general features include phenomena that affect the Earth itself, volcanism, meteorite bombardment, magnetism, atmospheric evolution, and weather and climate.



## Volcanism

[\*click here to see picture...\*](#)

**V**olcanic eruptions seem to be a normal process in the development of terrestrial planets. The Moon is covered with dark lavas that have been identified, analyzed, and age-dated through samples brought to the Earth. Photos of as-yet-unsampled Mars reveal both huge volcanoes and surface rocks that resemble lavas. Mercury shows large surface features that also could be lava flows.

[\*click here to see picture...\*](#)

**O**ur blurred and indistinct radar views of Venus show some land-forms that probably are large volcanoes. The asteroids also seem to have volcanic histories, for some of the meteorites that we find (themselves presumably asteroid fragments) are pieces of ancient lava flows erupted at the very beginning of the solar system. Even Jupiter's moon Io has its own collection of strange, sulfur-spouting volcanoes.



## Meteorite Bombardment

**B**efore we went into space, meteorite bombardment seemed an unimportant process. Only about a dozen small meteorite craters were known on the Earth, and many scientists thought that the Moon's craters were all ancient volcanoes.

**N**ow we know that intensive bombardment by meteorites in the past was the rule, not the exception, among the planets. The Moon suffered a violent bombardment in its earliest years, more than 4 billion years ago, and the traces are still seen in the heavily cratered lunar highlands.

**O**ther planets show traces of the same ancient cosmic battering. The whole surface of Mercury resembles the lunar highlands, saturated with overlapping craters. The southern half of Mars likewise was battered, although its large craters have been deeply eroded. Venus bears traces of what may have been large impacts. Even Callisto, the icy moon of a gas giant world, displays much the same cratered surface that Mercury does.

**I**s the Earth unique? It shows no obvious large meteorite craters. Did it somehow escape the bombardment? No. The ancient Earth must have been pounded and shaped by meteorite impacts just like the worlds near it.

**B**ut the ancient craters, like the Earth's oldest rocks, have been destroyed by the continuous volcanism, erosion, and mountain-building that characterize our planet. Nearly 100 ancient craters, now identified in the geological record, show that the Earth has been, and still presumably is, subject to meteorite impacts.

**M**eteorite impact has continued through time, though at a much lower rate than in the early bombardment. Smaller craters occur in profusion on the relatively young, dark, lava flows on the Moon, and even tinier microscopic craters, made by bits of cosmic dust, dot the surfaces of exposed lunar rocks.

**O**n the Earth, Meteor Crater in Arizona, the best-known impact scar, is less than 50,000 years old. The Tunguska event in Siberia, a violent explosion probably caused by the entrance of a comet into the Earth's atmosphere, occurred within living memory, in 1908.





## Planetary Magnetism

**W**e have studied and used the Earth's magnetic field for centuries, but it remains a mystery in many ways. It surely is caused by huge electric currents in Earth's iron core. But we still do not know the details of how it is produced, why it varies, and why it completely reverses itself every million years or so.

**S**pace probes have discovered magnetic fields elsewhere in the solar system, extending outward from the Sun and surrounding both some terrestrial and some gas giant planets.

**W**here these fields are present, they shield the planet from the solar wind that pours out from the Sun, and in the region where the solar particles encounter the planetary fields, there arise other remarkable effects: trapped radiation belts, planetary magnetic tails, magnetic storms that cause aurorae, and bursts of radio noise that can be heard across the solar system.

**I**n truly great magnetic fields like those of Jupiter, atomic particles may be heated to millions of degrees, and a great electric arc flows between the planet and its moon Io.

**I**ndeed, one of the curiosities of the solar system is that two planets as different as Jupiter and the Earth—one terrestrial, one a gas giant should have similar magnetic properties. Each has a magnetic field, aurorae, radiation belts, and naturally-generated radio noise.

**M**agnetic properties vary widely and unpredictably among the terrestrial planets. The Earth has a metal core and a strong magnetic field. The Moon, with no detectable metal core, has no field, but it may have had a strong field in the past because a strange "fossil" magnetism has been detected in many lunar rocks.

**M**ercury has a large metal core, but only a weak magnetic field. Venus



probably has a metal core, but it has no field. Mars, which may or may not have a metal core, has no field. The gas giant planets, at least the two visited by spacecraft, seem to be more uniform.

**B**oth Jupiter and Saturn have strong magnetic fields, although their "metallic" interior regions probably are made of hydrogen rather than of nickel-iron.

**O**ur studies of planetary magnetism have so far produced more questions than answers. Why do some terrestrial planets with metal cores have magnetic fields (Earth, Mercury) while others (Venus, Mars) do not? If the planet's rotation rate is a factor, why does one slow rotator (Mercury) have a magnetic field while another (Venus) does not? More puzzling is the evidence from Moon rocks that the Moon's magnetic field "turned off" about 3 billion years ago. How could this happen? Might the Earth, or another planet, lose its magnetic field in the future?



## Atmospheres

**L**ong before the Space Age, we knew that other worlds have atmospheres. But only recently have we been able to make accurate analyses of these atmospheres or to understand something of their histories.

**T**here seem to be two types of atmospheres: original ones, formed from gas present in the primordial dust cloud, and evolved or outgassed ones, whose gases have gradually come out of the interior of the planet, probably as the result of volcanism.

**T**he atmospheres of the gas giant planets are largely original. Their compositions are close to that of the Sun itself (largely hydrogen and helium), and the crushing gravity of these huge worlds would prevent any original gases from escaping. The gases that collected into Jupiter 4.5 billion years ago must be there still.

**T**he terrestrial planets seem to have atmospheres of the outgassed type. Somehow, most of the original gas seems to have been swept away from the terrestrial planets and replaced by other gases from their interiors, such as nitrogen, carbon dioxide, and water.

**T**hese outgassed atmospheres differ greatly. Mars and Venus have atmospheres rich in carbon dioxide, but the pressure of Venus' atmosphere is 10,000 times that of Mars. Although Venus has a thick, heavy atmosphere, its composition suggests that the planet has not outgassed as much as has the Earth. The atmosphere of Mars has been modified continuously since formation because the low gravity of the planet has allowed much of the nitrogen to escape into space.

**E**arth's oxygen-rich atmosphere seems unique, but we know that it has been drastically modified by an agent not detected on the other planets: life. Studies of other planets suggest that, just before life developed, Earth's atmosphere may have been much like that of Mars and Venus: probably rich in carbon dioxide and nitrogen.

**I**n such an atmosphere, with oxygen lacking, simple organic molecules could combine into more complex ones without being destroyed by oxygen. Eventually, about 4 billion years ago, these complex molecules united to produce simple life forms. At some later time, simple plants began to turn the carbon dioxide into oxygen, and the process has continued to the present, producing the air we now breathe.

**I**t is ironic that the development of life on Earth has finally produced an atmosphere so rich in oxygen that the original chemical reactions that led to life can no longer occur. If life suddenly vanished from the Earth, it might not reappear again. Because living things produced the atmosphere in which we now live, there is a real cause for concern that another kind of life (human beings) could change the atmosphere even further. It happened once before.



## Weather

[click here to see picture...](#)

**E**arth is probably the worst place to learn the laws that govern Earth's weather. Our weather patterns are complicated; they are modified by the planet's rotation, by high mountain ranges, by the huge oceans, and by the water that rises as clouds and falls again as rain. Because of these complications, it is difficult to study the weather and almost impossible to predict it.

[click here to see picture...](#)

**W**e have to examine other worlds with simpler weather patterns in order to learn about our own. Fortunately, the solar system provides a wide variety to study. There are planets that rotate slowly (like Venus) and rapidly (like Jupiter).

**T**here is a flat world (Venus), a somewhat mountainous world (Mars), and a world that may have no solid surface whatever (Jupiter). There are thick, dense atmospheres (Venus, Jupiter) and thin ones (Mars). There are atmospheres of carbon dioxide (Venus, Mars) and of hydrogen and helium (Jupiter, Saturn). The atmospheres range from superheated (Venus) to freezing (Mars).

**W**e have found similarities to Earth's weather in unlikely places. The circulation of the thin Martian atmosphere is similar to the effects found over Earth's deserts. High-velocity jet streams like our own also run along the belts of Jupiter's atmosphere. Jupiter's Red Spot, three times the size of Earth, bears a strong resemblance to an overgrown terrestrial hurricane.

**T**he atmospheres of other planets give us another important opportunity: to learn how our own atmosphere might change in the future. We can look at other worlds to see how their atmospheres are affected by certain important substances: dust, carbon dioxide, sulfuric acid. In this way, we can understand what will happen to Earth's atmosphere if natural or human

activities continue to introduce these materials into it.

[\*click here to see picture...\*](#)

**W**e have already found several examples worthy of study and concern. Dusty Martian sandstorms may imitate the heating or cooling effects of dust, produced by volcanoes or by human beings, in our own air. The fine particles (aerosols) of sulfuric acid that form the corrosive clouds of Venus may help us to understand acid rain and other kinds of sulfur pollution here on Earth.

**T**he atmospheres of Mars and Venus, rich in carbon dioxide, may teach us to predict what will happen to our own atmosphere as the burning of fossil fuels continues to pour more carbon dioxide into the air. Will Earth warm considerably or not at all?



## Climate

**C**limate is simply the weather of a planet over long periods of time. We know that the Earth's climate has not been stable. It has been both hotter and colder in the geological past, and the recent Ice Ages are only the latest events in these variations.

**W**e do not know what caused these climate changes: gradual changes in the Earth's orbit around the Sun, changes in the Earth's oceans and atmosphere, or perhaps even changes in the Sun itself? We know even less about what climatic changes may occur in the future.

**Y**et civilization is dangerously vulnerable to these changes. Will the climate grow warmer, melting the ice-caps and flooding our seacoasts? Or will it grow colder, freezing the seas and wiping out agriculture?

**A**gain, other planets can help us find the answers. We now know that other planets have experienced climate changes, so that the Earth is not unique in this respect. Mars shows the traces of a warmer, wetter time, a period when its atmosphere was thick and great floods scoured channels across its surface. Mars may also have been colder in the past than it is now.

**T**he layers of sediment around the polar caps suggest that those caps may have been larger in the past. If we could show that Mars' hot and cold climates had occurred at times responding to the Earth's, then the underlying cause might be ascribed to variations in the light from the Sun itself

**V**enus, our other neighbor world, is not too helpful yet. We do not know enough about its surface to understand if there are traces of previous climates. In a cooler time, Venus might really have been "Earth's Twin," with rivers cutting winding channels across it; those channels may remain. We need to explore in great detail both Mars and Venus, those worlds that bracket the Earth, before we will fully understand the development of the Earth's climate.

**T**he flood of data and discovery in the Space Age has given us our first glimpse of the mechanisms that control the birth and development of planets. We have found that worlds which seem totally different at first glance are actually linked by common bonds: volcanoes, meteorite craters, magnetism, and atmospheres. But further investigation and exploration are required to clearly define the forces that make planets what they are.

**F**rom what we have already done and learned, we can suggest and plan the next steps:

**W**e should map the hidden surface of Venus, so that we can compare it closely with the other terrestrial worlds.

**W**e need to return to Mars, a world which we now see as tantalizingly Earth-like in some ways, strangely different in others. We should monitor its weather in detail, bring back rock samples to study, and carry out a more thorough search for life.

**T**he outer gas-giant planets are still largely unexplored. Jupiter's huge atmosphere and its strange and varied moons are now ready for close inspection and study.

**W**e should expand the investigation of comets and asteroids to study these strange, small objects at close range, and to seek in them a more complete record of how the solar system, and ourselves, came to be.





## Learning About Earth

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**T**he more we understand about other worlds, the more we will learn about the past and present nature of the Earth. Did huge meteorite impacts begin the process by which the Earth produced continents and ocean basins?

**W**hy is the Earth a highly evolved planet, with active volcanoes and mountain-building, while the other terrestrial planets seem quiet and dead? Why has the Earth developed a temperate environment where life has flourished, while nearby Venus and Mars seem lifeless and inhospitable?

**T**here are other questions about the Earth's future that we must also answer. How are we changing our atmosphere, and what will these changes do to us? Will the Earth's climate change soon, and how? Is the Earth's magnetic field decreasing?

**W**hat will happen to us if it vanishes, even for a short time? When will an asteroid hit the Earth, as many have done in the past? These are questions of more than just scientific interest. Their answers may determine the survival of people and civilization.

**T**he Space Age has given us a new view of many worlds, but most especially of our own Earth. On our first trips to the Moon, the Earth suddenly appeared to human eyes as a tiny blue world of life, isolated in a vast, uncaring blackness. Now that we have explored further, we see that the Earth is not alone.

**I**t is one of a family of worlds, all different, each an individual, but all formed at the same time, shaped by the same forces, and developing in related ways. We can no longer hope to understand the Earth, its past, and its future, without studying and understanding its companions in space around the Sun.







## The Sun and Us

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**N**othing is more important to us on Earth than the Sun. Without the Sun's heat and light, the Earth would be a lifeless ball of ice-coated rock. The Sun warms our seas, stirs our atmosphere, generates our weather patterns, and gives energy to the growing green plants that provide the food and oxygen for life on Earth.

**W**e know the Sun through its heat and light, but other, less obvious aspects of the Sun affect Earth and society. Energetic atomic particles and X-rays from solar flares and other disturbances on the Sun often affect radio waves traveling the Earth's ionosphere, causing interference and even blackouts of long-distance radio communications.

**D**isturbances of the Earth's magnetic field by solar phenomena sometimes induce huge voltage fluctuations in power lines, threatening to black out cities. Even such seemingly unrelated activities as the flight of homing pigeons, transatlantic cable traffic, and the control of oil flow in the Alaska pipeline apparently are interfered with by magnetic disturbances caused by events on the Sun.

**T**hus, understanding these changes -- and the solar events that cause them -- is important for scientific, social, and economic reasons.



## Early Fascination

**W**e have long recognized the importance of the Sun and watched it closely. Primitive people worshipped the Sun and were afraid when it would disappear during an eclipse.

**S**ince the early seventeenth century, scientists have studied it with telescopes, analyzing the light and heat that manage to penetrate our absorbing, turbulent atmosphere. Finally, we have launched solar instruments and ourselves into space, to view the Sun and its awesome eruptions in their every aspect.

**O**nce, when we looked at the Sun by the visible light that reaches the ground, it seemed an average, rather stable star. It was not exactly constant, but it seemed to vary in a fairly regular fashion, with a cycle of sunspots that comes and goes in about eleven years.

**N**ow the Space Age has given us an entirely different picture of the Sun. From space we have seen the Sun in other forms of light-ultraviolet, X-rays, and gamma rays that never reach the ground. This radiation turns out to be far more responsive to flare eruptions and other so-called solar activity.

**W**e now see the Sun as a place of violent disturbances, with wild and sudden movements above and below its visible surface. In addition, the influence of solar activity seems to extend to much greater distances than we had believed possible. New studies of long series of historical records reveal that the Sun has varied in the past in strange and unexplained ways. Scientists wonder how such variations might affect the future climate on Earth.



## New Techniques

**W**e have obtained a clearer picture about the scope of the Sun's effects. Its magnetic field stretches through interplanetary space to the outer limits of the solar system. Steady streams and intense storms of atomic particles blow outward from the Sun, often encountering the atmospheres of our Earth and the other planets.

**T**he spectacular photos of the Earth from space show only part of the picture. Instruments carried on satellites reveal a wide variety of invisible phenomena -- lines of magnetic force, atomic particles, electric currents, and a huge geocorona of hydrogen atoms -- surrounding the Earth. Each is as complex and changing as the visible face of the globe.

**T**he Earth's magnetic field extends tens of thousands of miles into space, and many different streams of electrons and protons circulate within it. Huge electric currents flow around the Earth, affecting their high-altitude surroundings as well as our environment at ground level.

**S**pace observations have greatly expanded our ability to look at the Sun, at interplanetary space, and at the immediate surroundings of the Earth itself. We can now "see" many phenomena that are completely undetectable from the Earth's surface, and we now have a much better, more complete and more coherent picture of how events in one part of our solar system relate to activity in another.



## What is the Sun?



**H**uman beings have always looked upon the Sun as the most important celestial body. Even primitive people realized that the light and heat from the Sun sustain all life on Earth, and they knew that any disturbance to the Sun's daily motion through the sky would have serious effects.

[click here to see picture...](#)

**O**ver the years, they devised many rituals to ensure the reliability of the Sun. Later, Greek philosophers declared that the Sun is a flawless sphere, its motions governed by perfect perpetual clockwork. Sunspots glimpsed dimly by the ancients when thin cloud or thick mist made it possible to stare at the Sun were dismissed as unrelated objects passing in front of the glowing sphere.

**T**his idea was accepted throughout the Western world until after the invention of the telescope, when Galileo proved that sunspots were true markings or structures (hence, "blemishes") on the surface of the Sun. Not only was the Sun imperfect, but it was changeable; the spots came and went over days and weeks. Later, astronomers discovered that the number of sunspots varies in a cycle, showing a maximum and a minimum about every eleven years.

**M**ore recently, the combination of nuclear energy theory, laboratory experiments, and better solar observations has enabled scientists to obtain a good picture of the overall structure of the Sun. It is a ball of gas, composed of about 90 percent hydrogen, 9 percent helium, and only 1 percent of all the other elements such as carbon, nitrogen, oxygen, silicon, and iron. The diameter of the Sun is about 1,390,000 kilometers (865,000 miles), or about 109 times that of the Earth, and the Sun is 300,000 times

as massive as the Earth.





## The Center of the Sun

**A**t the Sun's center, theory predicts that the temperature reaches an incredible 15 million o C. This is the temperature of an exploding hydrogen bomb; it is hot enough to sustain the thermonuclear reactions that convert hydrogen atoms into helium, thus powering the Sun.

[click here to see picture...](#)

**I**n this way the Sun consumes about 5 billion kilograms (5 million tons) of its nuclear hydrogen fuel every second. Yet the Sun is so large that it has been burning hydrogen at this rate ever since it formed some 5 billion years ago, and it will continue to burn steadily for at least another 4 billion years.

**T**he energy released by nuclear fusion in the heart of the Sun is eventually radiated away in all directions into space. A tiny fraction reaches the Earth, powering every process necessary for life. Even this tiny fraction is enormous. The solar energy striking the Earth is equal to 800 billion, megawatts of power, an amount vastly more than the entire capacity of all of our power plants. Someday, we will learn to harness it effectively.

**T**he solar interior may burn hydrogen at a steady rate, but a close look at the surface and outer layers shows that the Sun is not stable at all. Examined with modern techniques -- especially space instruments -- the solar atmosphere is seen to seethe with constant motion and violent activity. Solar disturbances of diverse kinds occur on time scales ranging from years down to thousandths of a second, involving regions ranging in size from the entire solar atmosphere to the smallest detail visible in our most powerful telescopes.

**S**pace observations allow us to see the Sun in many wavelengths, or "colors," of light that are totally absorbed by the Earth's atmosphere and cannot be seen from the ground. High-energy gamma rays and X-rays, ultraviolet light, and much of the infrared and radio regions of the

spectrum can be observed only from above most of our atmosphere.

**E**ach of these newly explored spectral regions, or "windows," yields unique information about physical processes and phenomena on the Sun which are inaccessible with ground-based telescopes.

**T**hrough these new windows that open for telescopes above the Earth's atmosphere, we can see radiation emitted from many different parts of the Sun. Each solar region has its own temperature, density, and other characteristic physical conditions and emits its own kind of light. We have measured temperatures on the Sun ranging all the way from a mere 4,200 C in the coolest regions to over 50 million C in the hottest solar flares.





## The Photosphere

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**T**he apparent surface of the Sun, the photosphere, has a temperature of about 6,000o C, which decreases with height to a minimum value of 4,200o C. The solar gas in this region shines mostly in visible and infrared light. Above the minimum temperature region, the gas gets hotter.

**T**he chromosphere (the next higher part of the Sun's atmosphere) has a temperature of about 10,000o C and glows brightly in ultraviolet light. The million-degree corona, farther out around the Sun, is best seen by the X-rays it emits.

**T**he very highest energy radiation given off by the Sun is not due to a hot gas but is actually produced by erupting streams of very-highspeed electrons and protons which strike the ordinary atoms of the Sun's atmosphere with sufficient force to generate X-rays and gamma rays. On Earth we use a very similar process on a vastly smaller scale to generate X-rays for medical examinations.

**I**n addition to the X-rays, ultraviolet, and other forms of light from the Sun, satellite-borne instruments have observed pulses and streams of atomic particles that are emitted from the Sun and travel outward to the Earth and beyond. These particles provide actual samples of solar material. Their composition tells what the Sun is made of and how matter is ejected from its atmosphere. From space we can even detect the solar magnetic field, which stretches out into the far limits of the solar system.



## The Sun as a Star

**W**e sometimes forget that there is one star that is easily visible in the daytime: our Sun. The Sun is the only star close enough to be studied in detail, but we are confident that all the processes in the Sun must also occur in billions of distant stars throughout the universe.

**T**o understand the nature and behavior of other stars, we must first understand our own. At the same time, observations of other kinds of stars help put the Sun in perspective.

**T**he Sun is a relatively typical star among the approximately 100 billion stars in our Milky Way galaxy. The masses of most other stars that we see range from approximately one-tenth the mass of the Sun to about 30 solar masses.

**T**he surface temperatures of most stars range from about 2,000o C to 40,000o C. Although the Sun is somewhat on the cool side at about 6,000o C, hot stars are rare, and most normal stars are cooler than the Sun. Compared to some of the explosive starsnovae and supernovaewhich sometimes appear in the sky, the Sun is stable and ordinary.

**T**his long-term stability of our Sun probably was crucial for the development of life on Earth. Biologists believe that a relatively stable average temperature had to prevail on Earth during the past 3 billion years, in order for life to evolve to its present state.

**T**he relative stability of the Sun is also important to astronomers trying to understand the basic nature of it and other stars. Violent activity in the Sun could mask the more subtle and long-enduring processes which are the basic energy transport mechanisms of our star. Fortunately, they are not hidden, and we have been able to map the trend in solar properties with height above the visible surface.

**A**bove the minimum temperature region in the photosphere, we have

measured how the gas gets hotter as it thins out with height. The chromosphere and corona, each hotter than the layer below, are warmed by the transfer of energy from below, by processes that still are not well understood.

**U**ntil space observations became possible we knew nothing about coronae in any other stars, and had only marginal information about the properties of stellar chromospheres. Now, space observations have shown us that a large fraction of the stars in the sky have chromospheres and coronae.

**O**n several dozen stars, we have even detected activity which may be connected with sunspot (or "starspot") cycles like those of our own Sun. X-ray telescopes carried on satellites have recorded flares in other stars that are far more powerful than the already impressive flares of the Sun.

**B**y observing the strength and frequency of these events on stars with masses, ages, and rotation rates which differ from those of the Sun, we search for answers to such basic questions as: "How does the sunspot cycle period depend on the star's rotation rate?" or "What is the relation between the temperature of a star's corona and the strength of its magnetic field?" By deciphering the general pattern of stellar properties we can better understand what makes things happen on the Sun.

**T**he Sun presents us with a bewildering variety of surface features, atmospheric structures, and active phenomena. Sunspots come and go. The entire Sun shakes and oscillates in several different ways at the same time.

**G**reat eruptions called prominences hang high above the Sun's surface for weeks, suspended by magnetic force, and then sometimes shoot abruptly into space from the corona. The explosions called solar flares emit vast amounts of radiation and atomic particles in short periods of time, often with little or no warning.



## Space Observations

**S**pace observations have discovered many new aspects of solar events that were hidden from ground-based observatories. The hottest spots on the Sun shine primarily in ultraviolet and X-rays, rather than in visible light. Thus, only from space can we map the true structure of high temperature solar flares and determine their physical conditions.

**S**pace observatories have shown us the higher, hotter layers of the Sun's atmosphere that normally are invisible from the ground. Instruments on satellites revealed that in flares and other violent disturbances the Sun acts like an atomic accelerator, driving electrons and protons to velocities approaching the speed of light.

**A**t such high speeds, the particles emit the high-energy X-rays and gamma rays measured by our satellites. Sometimes they even induce nuclear reactions on the surface of the Sun.

**T**wo aspects of our improved knowledge of the Sun deserve special attention. One is the role of magnetic fields in determining virtually all aspects of the structure and behavior of the Sun's upper atmosphere. The other is the discovery of the solar wind, a stream of atomic particles that constantly evaporate from the Sun's atmosphere and are accelerated to speeds of hundreds of kilometers per second, escaping into space in all directions.



## The Sun as a Magnet

[click here to see picture...](#)

**W**e have known since 1912 that there are powerful magnetic fields in sunspots. In fact, the sunspot cycle could just as well be described as a periodic increase and decrease in the amount of solar magnetism. The magnetic fields are generated deep within the Sun by a natural dynamo that reverses itself every eleven years. This dynamo action may result from an interaction between the Sun's 27-day rotation and the rising and falling of huge blobs of gas in a layer just below the solar surface.

[click here to see movie...](#)

**W**hen the Sun was photographed from Skylab, we learned that the whole atmosphere above the surface of the Sun is structured by the presence of changing magnetic fields. The solar corona often appears smooth when glimpsed from the ground during total eclipses of the Sun.

**H**owever, Skylab X-ray photographs proved that the corona is composed almost entirely of individual loop structures, formed by streams of hot gas channeled along lines of magnetic force. Some loops are small and isolated; others are so large that their two feet may be separated by half the solar surface. The majority of the loops are arranged in long rows or arcades, which frequently cover a large fraction of the surface.

**I**n addition to the prominent loops in the corona, many very small magnetic loops appear suddenly at random locations on the solar surface, where they emit intense X-rays for a few minutes, and then fade away in an hour or two.

**T**hese loops, identified as "X-ray bright points" in Skylab photos, are generated when magnetic fields emerge from inside the Sun. For some unknown reason, this type of magnetic activity grows to a maximum when sunspots are at a minimum. An explanation of this unexpected anti-correlation remains as a challenge to solar researchers.

**P**erhaps the Sun's most remarkable magnetic features are the coronal transients. These objects were discovered by the seventh Orbiting Solar Observatory satellite (OSO-7) and later were studied intensively by Skylab. A typical transient begins as a gigantic bubble that appears near the solar surface and flies out through the corona at a velocity of hundreds of kilometers per second.

**T**hese transients usually are caused by solar flares or by the eruption of a type of solar prominence known as a cool loop. The bubbles, consisting of high temperature plasma, carry along magnetic fields from the lower corona and disrupt the upper corona as they expand outward.





## The Solar Wind Blows on Earth



**B**efore the Space Age, people thought that the material that makes up the Sun stays with it. The solar corona was thought to merge gradually into interplanetary space, a static gas of low density.

[\*click here to see picture...\*](#)

**T**here were some problems with this "quiet sun" concept. It was known that the violent solar flare explosions are often followed by brilliant displays of aurorae (the Northern Lights and Southern Lights) in the Earth's atmosphere and by disturbances in the Earth's magnetic field.

**S**ome physicists speculated that these effects might be due to streams of atomic particles from the Sun, but even these scientists felt that these events were rare and not part of the day-to-day behavior of the Sun.

**G**eophysicists who studied the Earth's magnetic field were faced with a mystery. They often found disturbances in the Earth's field that did not coincide with solar flares but which repeated at intervals of 27 days, the period of the Sun's rotation on its axis.

**B**ecause of the coincidence in timing, the geophysicists thought that some solar influence was at work. The influence was ascribed to so-called "M-regions" ("M" standing for "mystery") on the Sun, but attempts to locate the M-regions as sunspot groups or other specific visible features on the solar surface were unsuccessful.

**T**he first step in solving these puzzles was taken in 1957, when a University of Chicago physicist, Eugene Parker, demonstrated that the

solar corona, which has a temperature of two million degrees, cannot be static. The corona is so hot, Parker explained, that its gas is constantly evaporating away from the Sun at supersonic speed.

**H**e predicted that there must be a solar wind, with a density of about 10 atoms per cubic centimeter (160 atoms per cubic inch), continuously blowing away from the Sun and passing the Earth at the high speed of several hundred kilometers per second. The theory would also account for the behavior of certain comet tails, which acted as though they were blowing in an electrified wind.

[\*click here to see picture...\*](#)

**S**everal early interplanetary spaceprobes detected the solar wind around 1959-1961. In 1962, Mariner 2 made a detailed survey that showed that the properties of the solar wind agreed with Parker's predictions. Instruments carried on Mariner and other spacecraft also found that the solar wind actually is guided along an interplanetary magnetic field which originates at the Sun.

**T**he magnetic field is stretched outward by the flowing wind and warped by the turning of the Sun, so that it has the spiral shape of a gigantic pinwheel. The field begins to be stretched at a height of about one solar diameter above the surface of the Sun.

**T**his stretching explains the elongated and nearly radial appearance of the streamers seen in the outer corona during eclipses of the Sun and which also have been photographed by solar telescopes on Skylab and other satellites.





## The Magnetosphere: Our Shield in Space

**I**n the plane of the Earth's orbit, the interplanetary magnetic field often is divided into sectors of alternating inwardly (i.e., toward the Sun) and outwardly directed fields. This magnetic pattern will persist for months as the Sun rotates and sometimes lasts for as long as two years.

**W**e have recently discovered that the magnetic fields which originate in the northern hemisphere of the Sun will point in one direction (inward or outward) while fields originating in the southern hemisphere point in the opposite direction.

**T**he boundary between the two magnetic hemispheres consists of a thin neutral sheet, in which the magnetic directions are not consistent. The neutral sheet is slightly warped, so that it does not lie quite flat in the plane of the Earth's orbit.

**A**s the Sun rotates, the sheet turns too, so that the Earth is alternately on one side of the warped region and the other. As this happens, satellites near the Earth observe the change in the direction of the interplanetary magnetic field as the sector boundaries pass the Earth.

**S**tudy of the solar wind revealed the identity of the mysterious M-regions on the Sun, which cause the recurrent disturbances (geomagnetic storms) in the Earth's magnetic field. The geomagnetic storms are found to coincide with streams that are much faster than the normal solar wind.

**B**y comparing the arrival times of these high-velocity streams with pictures of the Sun's corona taken by Skylab X-ray telescopes on known dates, the highspeed streams were traced to parts of the corona which emit no X-rays, the so-called coronal holes.

**T**he temperatures and densities of coronal holes are much lower than those of other parts of the corona. Investigations show that in the holes, the magnetic field has no loops, but extends directly out into the solar wind.

We do not yet know how and why coronal holes form, but we do know that they are a major source of the solar wind. Two apparently permanent coronal holes exist at the north and south poles of the Sun, and it may be that much of the solar wind that leaves the Sun originates in these two polar coronal holes.



## The Earth-Sun Battle

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**I**n order for any solar particle to reach the Earth, it must first pass through the Earth's magnetic field. Before the solar wind was discovered, the Earth's field was thought to be symmetrical, resembling that of a huge bar magnet, fading off indefinitely into space.

**H**owever, we now know that the solar wind shapes the outer regions of the Earth's magnetic field, and that the field is sharply bounded. Outside the boundary, space is dominated by the solar wind and the interplanetary magnetic field. Inside the boundary is the region or magnetosphere dominated by the Earth's magnetic field.

[click here to see picture...](#)

**T**he measurements from many space missions have been combined to reveal that the Earth's magnetosphere is blown out by the solar wind into a teardrop shape. The head of the drop extends only about 10 Earth radii, or about 65,000 kilometers (40,000 miles) "upwind" toward the Sun.

**T**he tail of the drop stretches away in the direction opposite the Sun, actually reaching beyond the Moon's orbit. This long magnetotail extends more than 600,000 kilometers (370,000 miles) from the Earth.

**A**t the boundary of the magnetosphere, there is a constant struggle between the magnetic field of the Earth and the forces of the Sun. Buffeted by fluctuations in the velocity and density of the solar wind, the magnetosphere's size and shape are continuously changing. At the point where the solar wind strikes the magnetosphere, a shock wave forms, analogous to the sonic boom that precedes a supersonic airplane.

[click here to see picture...](#)

**I**nside the boundary with the solar wind, the magnetosphere remains an

active region. It contains two belts of very energetic charged atomic particles that are trapped in the Earth's magnetic field hundreds of miles above the atmosphere.

**T**hese belts were discovered by Professor James Van Allen of the University of Iowa and his colleagues in 1958, using simple radiation detectors carried by Explorer 1, the first U.S. satellite.



## The Northern and Southern Lights

[click here to see picture...](#)

**T**he structure of the Earth's magnetosphere also controls the behavior of aurorae, seen in our night skies. Pre-Space Age textbooks stated that aurorae are produced by protons which are emitted from the Sun and reach the Earth's upper atmosphere through gaps that exist in the Earth's magnetic field at the north and south magnetic poles. According to the theory, these protons strike oxygen atoms in the atmosphere, and the collisions cause the glow which we call the Northern Lights.

**T**his view has changed in the Space Age. The data collected by many spacecraft showed that the situation is more complicated. Particles from both the solar wind and from the Earth's atmosphere apparently are stored in the magnetotail.

**F**rom there, they periodically are violently ejected into the northern and southern polar regions of the atmosphere along the Earth's magnetic field and are accelerated to high speeds by a process not yet fully explained. The magnetotail is in effect a reservoir of particles that is periodically refilled. When the Sun is active during maximum sunspot years, this process is especially intense and frequent, and the aurorae are brighter and move closer to the equator.



## Other Planetary Magnets

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**S**paceprobes have discovered that three other planets besides the Earth have magnetic fields strong enough to form magnetospheres around them. The magnetospheres of these planets, tiny Mercury, giant Jupiter, and ringed Saturn, are as different as the planets themselves.

**M**ercury's magnetosphere is much smaller and weaker than the Earth's, while Jupiter's very strong magnetic field has trapped particles in a violently active magnetosphere so large that, if visible from Earth, it would appear as big as the full Moon. Saturn's magnetosphere is intermediate between those of the Earth and Jupiter.

**C**omparative studies of the magnetic fields and magnetospheres of the planets should help us interpret the origin of the Earth's magnetosphere and its associated phenomena, and to understand why some planets apparently do not generate their own magnetic fields.

**J**ust as there is a sharp boundary between the Earth's magnetosphere and the solar wind, there must be a limit to the much larger region filled by the solar wind and the interplanetary magnetic field. This region, called the heliosphere since it is dominated by particles and fields that originate in the Sun, has "upstream" and "downstream" directions just as the Earth's magnetosphere does.

**I**n the case of the heliosphere, this streaming is caused by the motion of the Sun through interstellar space at a velocity of about 20 kilometers per second (12 miles per second) with respect to the surrounding interstellar gas. The distance to the edge of the heliosphere is unknown, because no spacecraft has yet gone far enough.

**H**owever, we do know that the heliosphere extends at least as far out as the orbit of the planet Uranus [almost 3 billion kilometers (1.9 billion miles) away], because the outward bound Pioneer 10 spacecraft passed

Uranus' orbit in September 1979, and has still not found the boundary.





## The Sun-Weather Connection

**T**he energy that the Earth receives from the Sun is the basic cause of our changing weather. Solar heat warms the huge air masses that comprise large and small weather systems. The day-night and summer-winter cycles in the weather have obvious causes and effects.

**A**re there other, more subtle ways in which the Sun affects weather and climate? Will the future climate—even our survival—depend on sunspots, flares, coronal holes, or other forms of solar activity? If so, can future trends be predicted?

**T**he effects of currently observed changes in the Sun—small variations in light output, the occurrence of solar particle streams and magnetic fields—are very small in the Earth's lower atmosphere or troposphere where our weather actually occurs. However, at higher altitudes, the atmosphere reacts strongly to changes in solar activity.

**T**he ozone layer, at an altitude of 25 kilometers (16 miles), and the ionosphere, which extends upwards in a series of layers above 60 kilometers (37 miles), are produced by solar ultraviolet light and X-rays which ionize the thin air at these altitudes. Although the visible light of the Sun is stable, large variations in X-ray and ultraviolet radiation accompany solar activity, and these variations on the Sun cause major changes in the ionosphere.

**S**ome meteorologists believe that the ionospheric changes in turn influence the weather in the lower atmosphere, but the physical mechanism by which this may occur has not been definitely identified. There is much research under way on possible relationships between solar activity and the weather.

**A** study of short-term weather patterns by Walter Orr Roberts of the University Corporation for Atmospheric Research and Roger H. Olson of NOAA suggests that weather may be affected as the spiral-shaped interplanetary magnetic field rotates past the Earth.



**T**hey found that about a day after the boundary between inward-pointing and outward-pointing sectors sweeps by, there is a decrease in the number of low pressure weather systems forming in the Pacific Ocean off the western United States and Canada.

**B**ecause these low pressure systems give rise to most of the storm centers that pass over North America, an understanding of this effect may ultimately assist in making weather predictions.

**L**ike most suspected Sun-weather connections, the effect seen by Roberts and Olson is hard to explain. The problem is that the amount of energy present in the weather phenomena themselves far exceeds the energy that apparently is available from the variations in solar activity.

**I**n this case, the low pressure storm systems in the Pacific contain far more energy than do the particles and magnetic fields which enter the Earth's magnetosphere from the solar wind. If the Roberts-Olson effect is real, then there must be an amplifier mechanism, whereby the magnetic variations trigger the changes in the weather. But the nature of the amplifier mechanism is currently unknown.

**T**he search for Sun-weather relations is further complicated by the presence of many non-solar influences on both short- and long-term weather patterns. Volcanic eruptions can inject huge amounts of dust and ash into the atmosphere, cutting off some of the Sun's light and heat.

**C**hanges in the amount of carbon dioxide in the atmosphere, as a result of volcanic eruptions or the burning of coal and oil, affect the amount of heat absorbed by the atmosphere. Even small variations in the Earth's orbital motion around the Sun from year to year may cause significant changes in the weather.

**I**n looking for direct effects of solar activity on the weather we must first disentangle the many nonsolar effects that are going on simultaneously. It is a challenging task.



## Climate Through the Ages

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**C**limate is the state of the weather over long periods of time, tens to thousands of years. Long-term effects of the Sun on the Earth's weather are called climate effects.

**I**f the total output of radiant heat and light from the Sun (the solar constant) changed with time, rather than just the X-rays, ultraviolet and other fringe effects of solar activity, the variations would affect the lower atmosphere directly and surely would change the Earth's weather and climate.

**B**ut we still do not know whether the solar constant has changed in the past or even if it is changing today. The necessary measurements are very hard to make with the required accuracy. Because of absorption and scattering of sunlight in the Earth's atmosphere, these measurements are unreliable if made from the ground. Recently, techniques have been developed to measure the solar constant from space vehicles.

**T**here are now several instruments in orbit that are measuring the Sun's output with an accuracy that should be sufficient to detect variations capable of changing the climate.



## Study of the Sun from Space

**T**he spacecraft measurements of the solar constant that we are accumulating now will enable us to determine the day-to-day and month-to-month changes in solar output. It should eventually be possible to find out whether the Sun varies, not only during its 11-year sunspot cycle, but perhaps even over longer periods as well.

**O**ur studies with spacecraft are motivated in part by indirect evidence that long-term variations in the Sun's light have actually occurred. Observational records show an almost complete absence of sunspots between the years 1650 and 1715.

**D**uring this period, named the Maunder Minimum for the English astronomer who first pointed it out, the sunspot cycle apparently ceased to exist. Historical sources attest to the fact that the weather in Europe was particularly cold during these years, a fact which would follow logically if the light from the Sun decreased significantly during years when the sunspot count was low.

**W**e have made much progress in using observations from space to discover basic properties of the Sun, its magnetic field, and the Earth's magnetosphere. But we have only just begun to see the Sun as it really is, and many very important questions remain.

**F**or instance, we still have no adequate theory to explain why the period of the sunspot cycle is 11 years rather than, say, 2 years or 50 years. And we are far from being able to predict when (or even if) another long interval with few if any sunspots will occur. To answer such questions, we will need a program of systematic new space observations and much intensive theoretical work in the years to come.

**N**ew techniques of observation will enable us to probe the convective, oscillatory, and rotational motions that take place deep inside the Sun. These studies will be crucial for understanding how the solar magnetic field is generated.

**T**elescopes, mounted on spacecraft, will give us detailed pictures of the fine structure of the Sun's surface. Currently anticipated instrumentation can reveal details a fifth as large as can be perceived (due to blurring by the Earth's atmosphere) from the ground. Spacecraft could be launched into trajectories that would carry them far out of the plane of the planetary orbits, so that they could look down over the poles of the Sun.

**M**oving along these paths, the spacecraft could pass directly through the streams of solar wind that originate at the Sun's north and south poles. We would thus obtain our first information on the full three-dimensional structure of the solar wind and the Sun's magnetic field.

**T**o better study the Earth's magnetosphere and ionosphere, the next major advances will require measurements made simultaneously by perhaps five different spacecraft located around the magnetosphere and in the solar wind just upstream from the Earth.

**W**ith coordinated measurements like these we can accurately trace the changing motions of the magnetosphere and follow disturbances in the streams of solar particles as they travel through space around the Earth.

**A** basic new type of investigation will be possible with future large orbital laboratories such as Spacelab, which will be launched on the Space Shuttle. These laboratories will allow us to make active experiments in space, in contrast to the earlier passive measurements.

**B**y injecting known amounts of radio waves or atomic particles into space and observing how they travel away from the spacecraft, we can answer questions about space around the Earth in much the same way that Earthbound physicists determine physical conditions in laboratory vessels. The future missions will be logical extrapolations from previous space- and ground-based studies of the Sun and the Earth's environment.

**W**e now know enough to frame the questions that we believe they will answer. These explorations will bring closer the day when our understanding of the phenomena around us is complete enough to tell how the entire Sun-Earth system works and how we can anticipate its future behavior.



## New Windows in the Sky

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**S**ome of the greatest studies of earth and our universe has been done from space. Ever since John Glenn's first orbital mission around the Earth have we tried to learn more of the ever growing universe we live in.

**A**stronomy has undergone a tremendous burst of discovery thanks to our new ability to study the universe through "windows" available to telescopes flown above the Earth's atmosphere. We are observing radiation that never reaches the ground: X-rays, gamma rays, ultraviolet, and infrared light.

**E**ach new telescope in space brings the universe into clearer focus and reveals objects and phenomena not even imagined when the telescopes were planned. We are seeing further than before, with greater sensitivity, and at wavelengths of light that are utterly invisible to observatories on the ground.

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**O**bserving this heretofore unseen radiation, we are exploring what amounts almost to a new universe. X-rays and gamma rays from matter heated to millions of degrees tell us of violent explosions both in our own galactic neighborhood and as far away as the edge of the known universe. At the other extreme, infrared telescopes discern clouds of dust in interstellar space whose temperatures are scarcely 50 degrees above absolute zero (-273o C).

**W**e have found places in our own galaxy where enough matter to make a planet apparently disappears into a black hole each day, and there are far-off galaxies where more ravenous black holes may consume whole suns every day.

**A**t the very edge of the observable universe is a wall of frozen fire, the remnant of the Big Bang of creation, which appears to us as a whisper of radiation just a few degrees above absolute zero. No light from behind that wall can ever reach us, but the wrinkles in the wall remain to tell us the very details of creation itself, if we are clever enough to understand them.





## The Scale of the Universe



**T**o discuss the universe, we must abandon our ordinary frames of reference and think along almost unimaginable scales of distance and energy, and we must consider unusual, even fantastic, states of matter.

[click here to see picture...](#)

**T**True, our own horizons have expanded through space exploration. Humans have gone higher and faster than ever before. But our experience is still drastically limited by comparison to the immensity's of structures in the universe.



## Speed and Distance

**T**he scale for speed in the universe is set not by space flight but by light waves, which travel at 299,800 kilometers per second (186,000 miles per second). This velocity is a fundamental constant of the universe, and it provides a standard for judging our progress into space.

**A**t the beginning of the Twentieth Century, the speed of light was more than 5 million times faster than any human had ever traveled. Now it is only 25,000 times faster than astronauts have flown on their way to the Moon. As space travel develops, it is no longer inconceivable that humans may someday travel at such high speeds that trips to the stars may become possible.

**D**imensions in space are most conveniently expressed not in miles or kilometers, but in terms of the time it takes light to travel the distances involved. The distance from the Earth to the Moon (385,000 kilometers or 240,000 miles) is 1.3 light seconds. The distance from the Earth to the Sun is 8 light minutes, or 150,000,000 kilometers (93,000,000 miles).

**T**he spacecraft Pioneer 10, launched in 1973 and now past the orbit of the planet Uranus, has gone more than 3 light hours from the Earth. Even the nearest stars are light years away. It takes 4.3 years for light from the nearest star beyond the Sun, Proxima Centauri, to reach the Earth, traveling 41 million million kilometers (25 trillion miles) in the process.

**G**alaxies, which are irregular, ellipsoidal, disk- or spiral-shaped systems of billions of stars, are aptly termed "island universes." Our own galaxy, the Milky Way, is a flat spiral that is 100,000 light years across and almost 1,000 light years thick, with a large central bulge. The distances between galaxies are greater still, often measured in millions of light years. And the universe itself extends at least 10 to 20 billion light years in every direction from the Earth.





## Energy

**T**he amounts of energy involved in celestial processes are equally difficult to appreciate from our own experience. A typical unit of human energy is the joule, about the amount of energy needed to lift a glass of water from the dinner table to your mouth.

**O**n earth, energy releases can reach a quadrillion (a thousand million million) joules, about equal to a megaton, the energy produced by the detonation of a million tons of TNT. This is also roughly the amount of energy contained in a tornado or in a small earthquake. A very different scale is needed for astronomical power.

**A** useful unit is the energy released by one star -- our Sun -- which emits the equivalent of 100 billion megatons in the form of light every second. Even this immense quantity is tiny by cosmic standards. An average galaxy may contain 100 billion stars, many comparable to the Sun. The strange, distant objects called quasars are even more powerful, some individually releasing as much energy as a million galaxies.

**E**nergy has many different forms in space. Energy is present in light, in the motions of particles, in magnetic fields, and in gravitational attraction. The temperature of atoms and molecules moving randomly in space is proportional to the energy contained in each particle. As each particle moves, it radiates energy. By detecting and measuring this energy, we can measure the particle temperatures at distances of thousands of light years.

**T**he scale of temperatures found by space astronomy runs from a few degrees above absolute zero, with particles moving at a slow 30 kilometers per hour (19 miles per hour), to almost 10 billion °C, where electrons move at close to the speed of light.

**M**ost of the universe is made of hydrogen, and for this reason the temperature of 10,000° C is a critical threshold. At this temperature, the energy of a moving particle is enough to knock the electron from a hydrogen atom when they collide. If energy is added to interstellar

hydrogen, the gas will heat up until it reaches 10,000o C and then will stay at 10,000o C, even though energy is continuously added, until the hydrogen is completely ionized.



## Density

**T**he density of matter in space is very different from conditions on the Earth. The best vacuums are found in space, especially between the stars, where there often is only one atom in more than a thousand cubic centimeters (60 cubic inches). An average star, with about a trillion trillion atoms in each cubic centimeter, is about as dense as water.

**A**t the extreme of astronomical density, however, are the neutron stars that form in supernova explosions. Their matter is so compressed that the individual atoms collapse into neutrons. A single cubic centimeter of a neutron star contains enough material to make a cubic kilometer of a normal star and may weigh as much as several billion tons.



## The New Astronomy

**O**ne cannot perform laboratory experiments on stars and galaxies. For this reason, astronomy has always been a science of careful observation. Our two main sources of information about the universe are electromagnetic radiation (light, radio waves, infrared, X-rays, gamma rays, etc.) and cosmic rays, which are atomic particles that have been accelerated to high velocities and carry great amounts of energy.

**E**ach kind of electromagnetic radiation moves at the speed of light, while cosmic rays are slightly slower. Electromagnetic radiation is electrically neutral, but cosmic rays carry an electric charge. As a result, light can travel through space in essentially straight lines, but cosmic rays spiral along the weak lines of magnetic force that permeate space. We can see where a beam of light or of X-rays has come from, but because of their spiraling, cosmic rays cannot be traced to their points of origin.

**B**efore the Space Age, all astronomy was performed on the ground, limited by the Earth's atmosphere. Cosmic rays could not be observed directly, but it was possible to study the showers of energetic charged particles that they produce when they strike the atmosphere.

**T**he atmosphere absorbs almost all of the radiation that reaches the Earth from space, so stars and galaxies could only be seen at the limited wavelengths to which the atmosphere is transparent, primarily visible light and radio waves. Large telescopes were built to "see" at these wavelengths. Diameters of optical telescopes are measured in meters, while some radio telescopes are hundreds of meters across.

**G**round-based observations discovered star clusters, galaxies, cosmic radio sources, and the expansion of the universe. Optical and radio telescopes also discovered quasars and pulsars, two types of energetic objects that have gained in interest through studies from space.

**P**erhaps the most significant discovery of ground-based astronomy was that the universe is expanding, a result which led directly to the Big Bang

theory of creation. As fragments fly apart from any explosion, the faster-moving pieces leave the slower moving pieces behind.

**A** simple law applies to the various exploded parts: the further apart they are the faster they are moving apart. From the ground, we could see that galaxies as far away as 40 million light years were receding from us in accordance with just such a law.

**T**his law -- that the velocity at which a galaxy recedes from us is 20 to 40 kilometers per second for each million light years of distance away from us -- lets us determine the size and age of the universe. At great distances, everything is moving away; nothing is approaching us. About 10 to 20 billion light years away, the receding matter would have the speed of light, and observation to greater distances is impossible.



## Alternatives to the Big Bang Theory

**T**here are several alternative versions of the Big Bang theory and also some competing theories about the nature of the universe. We hope to learn whether the universe is "open," meaning that the expansion will continue forever, or if it is "closed," in which case the expansion will some day come to an end.

**I**n that event, the end of the expansion will be followed by a collapse phase, in which all the galaxies in space approach each other and eventually coalesce in a fiery end to the universe as we know it. To discriminate among these alternatives, we need to see further and make measurements of distant phenomena at appropriate wavelengths and with higher precision than heretofore.

**H**opefully, we can then resolve the uncertainties we face in applying the laws of physics at the very largest scales of energy and distance.

**A**stronomy will advance greatly in the future as we launch large more optical and radio telescopes above the interfering atmosphere, but the main achievement of space astronomy so far has not been in these traditional areas.

**T**he Space Age has made it possible to see the universe in new kinds of light, not just the visible light and radio waves that reach the ground. The most dramatic discoveries have come from the telescopes that observe ultraviolet radiation, X-rays, and gamma rays. Small telescopes to study cosmic rays have also been flown, and the first large cosmic ray telescopes were launched on the third High Energy Astronomy Observatory (HEAO-3) in September, 1979.

**F**rom these telescopes in space has come a burst of discovery that rivals the revolution produced by the invention of the telescope itself in the early 1600's. We are reaching toward a new understanding of the components of the universe: the stars, the galaxies, the strange pulsars and stranger quasars, even the almost-empty space that lies between the stars.







## Normal Stars

**B**efore the Space Age, most astronomy concerned stars and systems of stars. The reason for this is that stars emit much of their energy as visible light, and this light can penetrate our atmosphere and be detected easily from the ground.

**E**ven though scientists were limited to studying this kind of starlight, much was learned. Stars were counted, analyzed, measured, weighed, and sorted into groups. Their nuclear energy sources were deduced. Their life histories, from birth to death, gradually were deciphered.

**T**he so-called "normal" stars, such as our Sun, shine steadily. They have a variety of colors: red, orange, yellow, white, and blue. Most are smaller than the Sun, many resemble it, and a few are much larger. In addition, there are several types of "abnormal" stars: giants, dwarfs, and a variety of variable stars.

**T**he Sun is about 1.4 million kilometers (865,000 miles) in diameter -- about 109 times the diameter of the Earth -- and has a surface temperature of about 6,000o C. It is a natural hydrogen-fueled nuclear power plant. Deep inside, the hydrogen that makes up 90 percent of the Sun is fused into helium atoms, releasing an intense flood of energy that finds its way to the surface and so out into space. Today the Sun is in a state of balance between two forces: gravity, which pulls it inward, and the pressure of the hot gas and outward streaming radiation from the central nuclear furnace.

**T**he diameters of most normal stars range from one tenth to ten times as much as the solar diameter. The larger, more massive ones are blue or white, and notably hotter than the Sun. Sirius, in the constellation Canis Major, and Vega, in Lyra, are examples of hot, massive normal stars that are fairly close to the Sun (8.6 light years and about 26 light years away, respectively). They are white, several times more massive than the Sun, and have surface temperatures about 10,000o C.

**O**ther, more distant normal stars have temperatures up to about 40,000o



C. There are many normal red stars near the Sun, with temperatures of a few thousand degrees and masses much less than that of the Sun. None, however, is bright enough to be seen without a telescope. All of the bright red stars in the night sky are red giants and supergiants, counted among those we term abnormal stars.

**E**xamples are the supergiants Betelgeuse in Orion and Antares in Scorpius (each about 520 light years from Earth) and giant Aldebaran (68 light years) in Taurus. The Sun is slightly unusual in one respect: It has no companion star. Most stars seem to have companions, with which they orbit in binary, triple, or larger systems, and some stars are members of clusters, with from a few dozen to a few million members.



## The Life-Cycle of Stars



**I**n the first half of the Twentieth Century, astrophysicists worked out the life cycle of the stars. Stars are born out of giant clouds of gas and dust called nebulae. We can see the young stars in such clouds as the Great Nebula in Orion. (This nebula is visible to the eye, and even with small binoculars one can see that it is a diffuse object and not a star.)

[click here to see picture...](#)

**T**he large blue supergiant stars have up to 100 times the mass of the Sun, while small, red dwarf stars have less than one-tenth the mass of the Sun. (For comparison, the planet Jupiter has slightly less than one thousandth the mass of the Sun.) The biggest stars burn hotly and rapidly, consuming all their nuclear fuel quickly, sometimes in less than a million years.

**S**tars like the Sun, on the other hand, burn slowly and steadily; their hydrogen fuel may last for 10 billion years or more. The red dwarf stars burn up so slowly that trillions of years would have to elapse before their hydrogen is exhausted. When a star has used up its hydrogen fuel, it leaves the "normal" state. This occurs when the core of the star has been converted from hydrogen to helium by the nuclear reactions.

**N**ow the burning process moves outward to higher and higher layers. The atmosphere of the star expands greatly and it becomes a red giant. "Giant" is an apt name; if a red giant were placed where the Sun is now, the innermost planet, Mercury, might fall inside it, and a larger red "supergiant" might extend out past the orbit of the planet Mars.

**A**s nuclear evolution continues, the star may become a variable, pulsating

in size and brightness over periods of several months to a year. The visual brightness of such a star may vary by a factor of 100, while its total output of energy changes by only a factor of two or three.



## Stars in a New Light

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**S**pace astronomy has allowed us to understand some of the really hot stars in the universe. When a star shines with a temperature of about 6,000oC, like the Sun, most of the energy is emitted as visible light. A 10,000o C star produces much ultraviolet radiation.

**U**nusual, very small stars, with temperatures around one million degrees, generate X-rays. But we can never see these extremely hot stars from the ground. The X-rays are absorbed by our atmosphere. In fact, they were discovered with instruments flown in space.

**U**ltraviolet telescopes in orbit have observed hot blue supergiants, such as Rigel in Orion (about 900 light years away), that are much more massive than the Sun. To our surprise, these massive stars turned out to have intense stellar winds, streams of atoms that boil off the top of the star's atmosphere and race into space.

**A**lthough the winds from the hot supergiant stars are invisible to telescopes on the ground, they are hundreds of millions of times more powerful than the wind from our own Sun. These winds sweep away the interstellar gas and dust around their stars, sometimes producing an "interstellar bubble" over 10 light years in diameter.

**T**he wind "blows" at thousands of kilometers per second and carries away enough of the star's mass to make a whole Sun every million years. In the lifetime of a blue supergiant, which may be 10 million years, a substantial fraction of the original mass of the star may be expelled into space.

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**S**tudying the X-rays from stars has given us more surprises. With the X-ray telescope on the second High Energy Astronomy Observatory (HEAO-2), stars of all kinds have been observed through the X-rays they produce.

Contrary to what scientists expected, massive stars were found to have coronae: thin, hot gaseous envelopes surrounding their lower atmospheres.

**T**hese coronae, with temperatures up to several million degrees, generate the X-rays. Normal yellow stars like the Sun seem to make much fewer X-rays. Even some cool stars make more X-rays than the Sun. New theories are being developed to account for this discovery.

**T**he space observations indicate that the speed of a star's rotation may play a more important role than its temperature in determining its X-ray luminosity, and indeed the Sun is a slowly rotating star. Faster-turning stars seem to outshine slower ones of the same type in X-rays.



## The Mystery of SS 433

**T**he interplay between space telescopes and ground-based astronomy has not only given us a new look at familiar objects, it has also turned up a number of very strange and unfamiliar ones. One example is the remarkable, still somewhat mysterious object known as SS 433.

**T**he light from SS 433 was observed to have spectral lines that did not correspond to the spectra of any known stars. More detailed observations revealed that these lines moved very quickly from one wavelength to another, indicating a surprising change in the velocity of the gas emitting the light.

**O**ver several months, the range in velocity amounted to nearly one-third of the speed of light. This was sufficient to shift some infrared and ultraviolet wavelengths alternately into the range of visible light. No wonder the spectral lines were hard to identify!

**T**he high-speed movement is characteristic of gas at a temperature of close to a billion degrees. The width of the lines, however, showed that the gas is cool, with a temperature of only about 10,000o C. How the gas in SS 433 can move so very fast and still remain cool is one of the outstanding mysteries of the 1980's in astrophysics.

**X**-ray observations from satellites first called our attention to this star, stimulating the spectral studies that revealed the enormous velocities.





## White Dwarfs

**P**erhaps the greatest surprise of the Space Age has been the realization that "dead" stars that have used all their nuclear fuel can sometimes produce more energy than they did when "alive." We have discovered that there are three possible ends for a burnt-out star.

**I**f the star has about the mass of the Sun, it will collapse under its own gravity until the collective resistance of the electrons within it finally halts the process. The star has become a white dwarf and may be comparable in size to the Earth. A star with a mass of about 1.5 to 2 or 3 times that of our Sun will collapse even further, ending up as a neutron star, perhaps 20 kilometers in diameter.

**I**n neutron stars, the force of gravity has overwhelmed the resistance of electrons to compression and has forced them to combine with protons to form neutrons. Even the nuclei of atoms are obliterated in this process, and finally the collective resistance of neutrons to compression halts the collapse. At this point, the star's matter is so dense that each cubic centimeter weighs several billion tons.

**F**or stars that end their life weighing more than a few times the mass of the Sun, even the resistance of neutrons is not enough to stop the inexorable gravitational collapse. The star ultimately becomes a black hole, a region in space so massive that no light or matter can ever escape from it.

**T**he existence of white dwarfs has been known for some time, and many have been detected with ground-based telescopes. However, neutron stars and black holes existed only in much-disputed theory until the Space Age.



## Supernovae

**T**he discovery and understanding of neutron stars involve studies of two poorly understood types of space objects, supernovae and pulsars. Supernovae are extremely violent explosions, in which a star suddenly detonates, pouring out so much energy that for a few days it may outshine all the other stars in its galaxy put together.

**P**ulsars, first detected by radio astronomers in 1967, are sources of very accurately spaced bursts of radio waves. These bursts were so regular, in fact, that the scientists who detected them wondered briefly if they had found artificially generated signals from an interstellar civilization.

[click here to see picture...](#)

**T**he discovery of a pulsar in the Crab Nebula supernova remnant led to a great synthesis in our understanding of pulsars and supernovae. Supernovae occur at the end of a massive star's life, when it is a red supergiant, with its nuclear fuel almost spent. When the central core becomes so dense that electrons and protons begin to form neutrons, it collapses catastrophically to form a neutron star.

**I**n the process, more energy is released than the star ever generated from its nuclear fuel, producing an explosion in which every atom in the outer parts of the star is heated to well over a million degrees. The star is literally destroyed in an instant, but the debris from the explosion shines briefly with the energy of a billion suns.

**B**esides splattering stellar debris into space, supernova explosions leave behind a "cinder" -- the dense, collapsed core, made of neutrons -- where there once was a star. The weak magnetic field of the original star is greatly enhanced in the collapse, and the remnant core -- the neutron star may have a magnetic field trillions of times stronger than the magnetic field of the Earth.

**T**he rotation of the star also increases dramatically during collapse, and



the resulting neutron star spins many times a second. Beams of radio waves, X-rays, and other radiation, perhaps focused by the powerful magnetic field, sweep through space like the revolving beam of a lighthouse. The neutron star has become a pulsar.



## Pulsars

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**P**ulsars were discovered accidentally during a study of "twinkling" radio sources in the sky. This twinkling is not due to our atmosphere, as is the twinkling of stars. Instead it is caused by the highly rarefied interstellar gas, which affects the passage of radio waves. As the study went on, the scientists at Cambridge University noticed that in some sources the twinkling was periodic, the signals came at regular intervals of 1 or 2 seconds or less.

**G**radually, more pulsars were discovered. The fastest one known so far, which rotates at 30 times a second, is in the Crab Nebula, the remnant of a supernova explosion that was observed in 1054 A.D. When this rapid pulsar was found, it was quickly realized that it must be a neutron star. Only a neutron star could remain intact under such rapid rotation without breaking up. (A rotating black hole would remain intact, but it would not produce a regular signal.)

**N**ow that we can see the universe by the light of X-rays and gamma rays, further unexpected properties of pulsars have been found. The theories that were rather successful in explaining the Crab Nebula pulsar failed to predict or account for phenomena found in the brightest gamma ray pulsar, located in the constellation Vela. New theories are needed to explain how pulsars can create intense radio waves, visible light, X-rays, and gamma rays, all at the same time.



## Neutron Stars

[click here to see picture...](#)

**M**any neutron stars of another kind have been found with orbiting X-ray telescopes. We usually cannot detect the heat left over from their collapse, but instead we detect X-rays from matter that is heated intensely as it falls rapidly towards the surface of the star.

**T**he realization that neutron stars suck up surrounding matter came from the discovery in 1971 of an X-ray pulsar, Hercules X-1. Detailed study of this X-ray source revealed very small variations in the 1.2 second period of pulsation. More study proved that these small variations were caused by motion of the neutron star in orbit around another star.

**W**e have now learned that most X-ray emitting neutron stars are in orbit around other, otherwise normal stars. In some cases the stars are so close that the intense gravity of the neutron star actually pulls gas away from the atmosphere of its companion. Even when the stars are farther apart, the neutron stars may collect material from the stellar winds of the companions.

**A**s the gas is pulled from the normal star down to the surface of the neutron star, the gravitational energy of the neutron star heats the gas to millions of degrees. The hot gas gives off X-rays that mark for us the location of the otherwise invisible neutron star. X-ray pulsars derive their energy from the accretion of matter; the pulsars discovered by the radio astronomers are mostly single stars that are using up their energy of rotation and thus are gradually slowing down.



## Black Holes: The End Point



**W**hen the gravity of a collapsing star is too strong for even neutrons to resist, a black hole may be formed. A black hole is a point mass in space, surrounded by a literally black region in which the gravity is so strong that no matter, nor even light, can escape it.

**B**ut, just as in the case of a neutron star, matter that falls toward the black hole is intensely heated, producing copious X-rays that can be detected with telescopes flown above the atmosphere.

**A** few of the brightest X-ray sources in our galaxy are probably black holes orbiting closely with relatively ordinary stars. The X-ray source called Cygnus X-1 is a famous example. In 1971, astronomers learned that Cygnus X-1 was associated with a visible star that also is a radio source.

**T**his discovery is an important example of how ground-based optical and radio telescopes work in consort with orbiting X-ray telescopes to solve the problems of Space Age astronomy. The identity of the stellar companion was confirmed when both the radio source and the X-ray source were observed to change dramatically and simultaneously in intensity.

**O**bservations of the spectrum of the visible star and its changes in velocity as it and its X-ray source companion followed their orbits led to an estimate of the mass of the X-ray source. This unseen star that does produce X-rays appears to have at least six times the mass of our Sun, much more than can possibly be supported by the resistance of neutrons.

Comparing the deduced mass with the theoretical limits on the masses of neutron stars, we conclude that the unseen X-ray source in the Cygnus X-1 binary star system must be a black hole. However, the proof necessarily is limited—you can't see a black hole and further studies of this and other cosmic X-ray sources are needed.



## First Contact with Interstellar Space

**O**ur first exploration of the deep space beyond the solar system is approaching. Our spacecraft -- Voyagers 1 and 2, Pioneers 10 and 11, and still others to come -- are moving out toward the space between the stars.

**T**hanks to Space Age astronomy, and especially to observations made in ultraviolet wavelengths from satellites, we already know something about what to expect there.

**O**ur view of the interstellar space that they are approaching has changed completely since the Pioneers and Voyagers were launched for solar system studies several years ago.

**F**or one thing, we now know that "empty" space isn't empty and quiet. True, you can count on your fingers the number of atoms in a cubic inch of interstellar space, but these atoms are subjected to violent processes.

[click here to see picture...](#)

**S**ome are heated to more than a million degrees, while others may cool to within fifty degrees of absolute zero. Within this thin gas, winds blow and bubbles are formed, expanding and sometimes popping out of our galaxy altogether.

**A**s the spacecraft move out, they will first enter a region of warm gas that surrounds the solar system to at least 10 light years in all directions from the Sun and which contains our nearest neighbor stars such as Alpha Centauri and Sirius. We have been able to measure the temperature of the cloud (about 12,000o C) and its density, about 100,000 atoms per cubic meter (1.6 atoms per cubic inch).

**S**ince the Sun is moving through the cloud, we observe the gas streaming through the solar system. It will take Voyager 1 more than 200,000 years to leave this cloud, but when it does it will enter a region of much higher



temperature and much lower density, a bubble of very fine vacuum in space. The bubble extends at least 100 light years in all directions around the smaller "warm" cloud.

**I**t will be millions of years until Voyager leaves the bubble and enters another zone of denser interstellar gas. The high temperatures in the bubble more than 10,000o C pose no threat to the spacecraft (which will have ceased operating several hundred thousand years earlier) because the gas is an almost-perfect vacuum.

**T**here are less than 10 atoms per cubic meter (1 atom in 6,100 cubic inches) in the bubble. Even if the temperature of the gas is a million degrees, the energy the gas conveys to the spacecraft will be quickly radiated into space. The greatest danger to the spacecraft in interstellar space will be that of getting too cold.



## New Discoveries

**T**he recent discovery of large bubbles of hot, very thin gas has produced a radically new view of what's going on in the space between the stars. In the old view, gas in interstellar space was either warm or cold. Now, with X-rays and ultraviolet light, we find that most of the space between the stars is much hotter than we had suspected.

**I**n the old view, pressures of thin, warm gas were balanced against those of denser cold gas, and the situation was stable. Our telescopes in space now tell us that this is not true; pressures are out of balance. There is a great deal of interstellar pushing and shoving going on.

**M**atter gathers and cools in some places because matter elsewhere is heated and dispersed. Besides discovering the very hot gas, the orbiting telescopes discovered two sources of the gas: the intense stellar winds that boil off hot stars, and the rarer but more violent blasts of matter from exploding supernovae.

**T**he hot bubbles of very thin gas pile up colder matter at their boundaries as they spread out into space, much as a soap bubble collects a film of dust from the air. All over the galaxy, these bubbles have piled up matter and swept it into clouds. Some of these cold clouds are enormous and contain enough matter to make millions of suns.

**O**ur own solar system formed out of just such a cloud. We have even found evidence in meteorites telling us that the solar system itself formed only a few million years after the very first stars had formed in the cloud that was to be our Sun's nursery.

**A**lthough infrared astronomy research satellites have not yet been launched, infrared astronomy conducted from balloons, airplanes, and mountain top observatories has given us important new information about the cool interstellar clouds.



**I**t has been discovered that the tiny interstellar grains contain silicon compounds similar to clay minerals. These particles can survive temperatures up to 1,500o C and may possibly come from the atmospheres of red giant stars.

**T**he origin of the interstellar grains is one of the great questions of astrophysics that we can investigate by space astronomy. Very recently, ultraviolet telescopes in orbit found evidence for a covering of graphite (a form of carbon) on the silicate grains.

**O**ur best picture of interstellar space is that half its matter (other than the predominant hydrogen gas) is in the form of sooty sand grains the size of tiny smoke particles. It is possible that comets are made of accreted interstellar material, and so we hope that someday grains like this will be brought back from a comet sample-return mission.



## Beyond the Milky Way

**S**tars are not scattered uniformly across the seas of space. They are collected into huge disks, spirals, and globular forms that may contain billions of stars. These may be more than 100,000 light years across, but they are often millions of light years apart. Hence, they have occasionally been called "island universes."

**A**stronomy before the Space Age was mostly concerned with stars and star clusters. It was not until 1924 that the existence of galaxies beyond our own Milky Way was firmly established by the then-new 100-inch telescope at Mount Wilson. Once scientists were convinced that those dim, fuzzy patches in the sky actually contained hundreds of billions of stars, a new astronomy was started.

**I**t was quickly realized that galaxies come in different shapes and sizes. The most numerous ones are dwarf galaxies like the Magellanic Clouds, two satellites of our own galaxy. Dwarf galaxies are small and often irregular, but even they can contain a million to a billion stars.

**A**t the other end of the scale, some of the very biggest galaxies are elliptical in shape, ranging from almost spherical to very elongated like a football. Many people, scientists and nonscientists alike, feel that the most beautiful galaxies are the spirals, such as the famous Andromeda galaxy, whose mass amounts to half a trillion suns.

**O**ur own galaxy, the Milky Way, is a comparable spiral, although the details of its structure are hard to determine from within. Besides the normal spiral galaxies such as Andromeda, there are spiral galaxies with a bar across the middle, the spiral arms trailing like pennants at the end of the bar.

**A**s ground-based investigations of galaxies proceeded, it was soon learned that far-off galaxies are receding, and that the more distant the galaxy, the faster it is moving away from us. This discovery was a major achievement of the 100-inch telescope at Mount Wilson, and it provided

the impetus for the Big Bang theory of formation of the universe.

**S**tudies of the detailed appearance of galaxies also revealed several new types. Among these are the Seyfert galaxies (named for the American astronomer Carl Seyfert), which have very bright central nuclei. The spectra of these nuclei reveal the presence of hot gases in rapid motion.



## Study of Galaxies, with Radio Telescopes

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**O**ther remarkable aspects of galaxies were found when radio telescopes were developed. After some galaxies were found to emit intense radio waves, more detailed observations of these radio galaxies showed a characteristic double-lobe structure of the radio-emitting regions. These lobes typically are located far beyond the visible structure of the galaxy.

**T**he amount of energy required to produce the lobes is immense, sometimes equal to the output of a galaxy over its entire life. Later it was found that at the centers of some radio galaxies there are very intense radio-emitting cores which could not be spatially resolved even with the biggest radio telescopes.

**T**he character of the radio waves showed that these sources must be very small -in some cases as small as the solar system and yet somehow they produce enormous amounts of energy. This has been further corroborated by infrared measurements.

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**A**nother unusual galaxy, known as Centaurus A, has been the subject of some exciting space observations. Centaurus A has a typical double-lobe radio source, but in addition there is an inner pair of lobes, spaced along the same axis as the outer lobes. Within these inner lobes there is yet another, unresolved source of radio emission. In addition, Centaurus A produces a tremendous amount of high-energy radiation.

**T**he gamma ray telescope on HEAO-L revealed that Centaurus A emits gamma rays with energies up to 1 million electron volts. Another experiment detected gamma rays from Centaurus A with even higher energies of 100 billion electron volts. The latter, very high-energy gamma rays produce showers of electrons in the Earth's atmosphere.

**X**-rays are also emitted from the inner radio lobes of Centaurus A. In addition, there is a jet, visible to X-ray telescopes, that extends from the innermost core to the northern inner lobe. The existence of the jet indicates that the lobes are constantly being resupplied with energy from the active, but still mysterious nucleus of the galaxy.



## Normal Galaxies

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**T**he nearest neighbors to our own Milky Way galaxy are the Magellanic Clouds, about 150,000 and 190,000 light years away. To observers in the southern hemisphere they resemble luminous clouds several times the size of the full Moon, but the Magellanic Clouds were not well explored until recently, when large telescopes were built in the Southern Hemisphere and airborne telescopes conducted far-infrared observations.

[click here to see picture...](#)

**I**n the Magellanic Clouds, our satellite observatories are finding the kinds of X-ray sources that we earlier discovered in our own galaxy: binary stars, supernova remnants, and others. In addition, the most intense gamma ray burst yet observed, the event of March 5, 1979, apparently came from the Large Magellanic Cloud.

**G**amma ray bursts are a relatively new discovery from orbiting satellites. Many objects in the universe emit gamma rays fairly steadily, but these sudden eruptions of gamma rays from a single point typically last a few seconds to tens of seconds, during which they outshine the rest of the universe in gamma rays.

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**W**e think that the sources of typical gamma ray bursts are somewhere in our own galaxy, perhaps as close as 20 to 50 light years from Earth. But if the intense burst on March 5, 1979 came from as far away as the Large Magellanic Cloud, the release of energy must have been truly enormous for the event to seem so bright at a distance of 150,000 light years.

**T**he direction of the source of this burst has been determined with great precision by combining measurements from nine different spacecraft, and it lies near the heart of a supernova remnant in the Large Magellanic

Cloud. Perhaps an unusual neutron star left behind by the supernova explosion was the actual source of the gamma rays.

[\*click here to see picture...\*](#)

**O**ur next neighbor galaxy is the Great Spiral Galaxy in Andromeda, the most distant object visible to the naked eye. It is as large as or larger than our galaxy and is about 2 million light years distant, yet emits only about one-tenth as much energy in the form of infrared radiation as our galaxy. X-ray images taken with a telescope on the HEAO-2 satellite revealed more than 70 X-ray sources, which appear to be binary stars and supernova remnants in this neighbor galaxy.





## The Corona



**W**e have just discovered that our own Milky Way is surrounded by a corona, a very thin atmosphere of hot gas. The sources of the corona probably are the bubbles of hot, thin gas that pervade the interstellar space in our galaxy.

[click here to see picture...](#)

**S**ome of the bubbles probably expand to such enormous sizes (thousands of light years in diameter) that they must actually break out of the disk of the galaxy altogether, injecting hot gas into intergalactic space.

**M**uch of the hot gas remains bound to the galaxy by gravitation and thus forms the invisible corona at a temperature of about 100,000o C. Because the galactic corona produces no visible light, it could not be seen until the launch of the International Ultraviolet Explorer (IUE) satellite in January, 1978.

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**I**UE found evidence of the corona in the form of ultraviolet absorption lines in the spectra of bright blue stars in the Magellanic Clouds. The measured Doppler shifts of the lines proved that they are produced by foreground gas around the Milky Way, rather than in the Clouds.

[click here to see picture...](#)

**S**ome coronal gas is not gravitationally bound to our galaxy and must



expand into the space between the galaxies. The scales of distance here are immense. Galaxies are tens to hundreds of thousands of light years across, but the distance between galaxies is typically a few million light years, a million times the average distance between stars in our galaxy.

**E**ven if Voyager, with its great speed, could escape our galaxy, it would take 30 billion years for it to reach the Andromeda galaxy, much longer than the present age of the universe!

**I**n places where galaxies cluster together to form a group millions of light years across, the escaping hot gas between the galaxies is revealed by its X-ray emission. With the X-ray telescopes of HEAO-2, we obtained images of the gas in such clusters of galaxies. We have even found clues to the age of the gas. For example, in clusters where the gas has only recently emerged from its parent galaxies, it is still clumped around them, as revealed by the patchy appearance of the X-ray images.

**I**n more evolved clusters, the images are smooth, showing a diffuse, centrally-peaked distribution of hot gas. These differences in the X-ray images of clusters of galaxies are correlated with differences in the types of galaxies involved. Spirals seem to be associated with the patchy X-ray emission. Thus, X-ray observations are providing basic clues to the evolution of giant systems of galaxies. We have only a few tantalizing clues just now.



## Quasars and the X-Ray Background

[\*click here to see picture...\*](#)

**A**s NASA launched successively more powerful X-ray observatories, more and more cosmic X-ray sources were found. In addition we investigated a background of cosmic X-rays that seem to come from all directions in space.

**A**s it became quite clear that these background X-rays were very uniformly distributed, astronomers wondered whether they were produced by a vast collection of point sources at great distances, so numerous that individual ones could not be seen, or whether the emission source is genuinely spread out over all of intergalactic space.

**T**o answer this question, the X-ray astronomers took very long exposures of portions of the sky. With one type of instrument they confirmed that the background radiation is remarkably uniform; with another they found a surprisingly large number of quasars that emit X-rays.

**Q**uasars, first discovered in the early 1960s, appear almost like stars, although vastly more distant than any individual star that we can see. They were called "quasi-stellar radio sources" (shortened to "quasars") when they were detected with radio telescopes. They emit tremendous amounts of energy from very small volumes.

**T**he most distant quasars seen are so distant that they are receding at more than 90 percent of the speed of light. As bright, concentrated radiation sources, they resemble the nuclei of Seyfert galaxies, but are far more luminous.

**R**emarkably, the visual brightness of some quasars can change by a factor of two in about a week, and noticeable changes can occur even in one day. Since a source of light cannot change brightness significantly in a time shorter than it takes light to cross it, these quasars cannot be much bigger than one light day across, only twice the size of our solar system. The

problem, then, is to explain how a quasar can produce vastly more energy than a galaxy in such a small region.

**T**he brightest quasar as seen from Earth, 1.5 to 3 billion light years away, is called 3C273, from its number in a catalogue of radio sources. It is speeding away from us at nearly 16 percent of the speed of light. It has been detected as a source of radio, infrared, visible light, ultraviolet, X-ray, and even gamma ray emission. Some of the new quasars found by the HEAO-2 satellite are much further away, with recession velocities of two-thirds the speed of light.



## BL Lac Objects

**A**nother distinctive type of X-ray source is closely related to the quasars and may even be an unusual type of quasar. They are called "BL Lac" objects after the first known member of the class, BL Lacertae, which for years was listed as an ordinary variable star of the Milky Way in astronomers' catalogues.

**M**ore recently, we learned that it is in fact a distant object in extragalactic space, which resembles a star until studied in detail. The visible light of BL Lac objects is dominated by radiation from high-velocity electrons spiraling in magnetic fields. By contrast, in ordinary quasars there are prominent visual emissions from hot gas.

**H**owever, in their compact dimensions, rapid intensity variations, and emissions of X-rays, gamma rays, infrared and radio waves, the BL Lac objects resemble quasars and constitute yet another mystery of distant space that we are only beginning to explore.



## Accounting for Background Radiation

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**Q**uasars, galaxies, and the X-ray background seem to be linked together. By making some reasonable guesses about how quasars and galaxies evolve—that is, how they change their X-ray brightness as they grow older—it is possible to account for all of the observed background radiation. But this idea is not easy to confirm.

**T**he imaging X-ray telescopes launched thus far are sensitive only to relatively "soft" X-rays, with energies of about one kilovolt, in physicists' terms. At higher energies there is a "bump" of enhanced intensity in the X-ray spectrum of the X-ray background near 40 kilovolts, but none of the quasars observed so far have such bumps in their spectra. If this bump is not from quasars, what is it from?

**O**ne suggestion is that very young galaxies formed shortly after the creation of the universe would have a great many pulsars and neutron stars in them to supply the necessary X-rays. There is also a diffuse background of gamma rays, with a bump at the energy of 1,000 kilovolts. Is it due to the quasars once again or to something even more exotic?

**T**here is no place in the universe that is truly empty, but the space between clusters of galaxies comes close. These regions contain less than one atom in every 10 cubic meters (350 cubic feet), or only three atoms in a space about the size of a small room. Although galaxies continually supply new material to intergalactic space, the continuous expansion of the universe makes the net effect nil. Intergalactic space is very empty, and it is getting emptier as the universe expands.

**T**he more we learn about it, the more complicated the expansion of the universe seems to be. In the region near our galaxy, the expansion seems less rapid than for the universe as a whole. In fact, it appears that the combined gravitational pull of a very large cluster of galaxies in the constellation Virgo is actually retarding the local rate of expansion to half

the rate for the universe as a whole. We're finding evidence of how gravity attracts even over distances of hundreds of millions of light years.

**A**lthough there must be many very distant galaxies and quasars that we are not yet able to detect, astronomers have observed radiation from an even more remote source, literally at the edge of the observable universe. As we look far out in space, we are looking back in time, since light waves take time to cross space from their source to the observer. Hence, we view distant regions of the universe as they were long ago.

**A**ccording to the Big Bang theory, the universe originated in a great explosion and has been expanding ever since. At a very early epoch, before galaxies and stars formed, the universe was filled with hot glowing gas, and it was opaque.

**A**t some point during the first million or so years after the Big Bang occurred, the expanding and cooling gas became transparent. Hence, we can see out into space and back in time only until we come to the distant region that we observe as it was in the era when the universe cleared.

**B**eyond that point, space is opaque so light waves cannot reach us. We see the glow from the hot gas that cooled to about 10,000° C and then cleared, but we cannot see further. This glow was emitted as ultraviolet light, but has been shifted to longer wavelengths by the expansion of the universe, so that we observe it today as a diffuse background of microwave (short-wavelength radio) and infrared radiation.

**T**his microwave background is thus the radiation that comes to us from the limits of the observable universe. We can never see beyond it to more distant regions or earlier times. Due to the red shift, the background radiation resembles the emission from a dense gas at only 2.7° C above absolute zero.

**Y**ou can think of the source of the microwave background as a distant, spherical wall that surrounds us and delimits the observable universe. If an observer is moving with respect to the wall, then the spectrum of the radiation coming from the region of the wall that he or she is approaching will be shifted toward shorter wavelengths, while radiation from the opposite direction will be shifted toward longer wavelengths. Thus, the existence of the microwave background allows us to determine whether the solar system is moving with respect to a basic frame of reference in the universe.

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**A**ccording to the results from recent measurements with telescopes on high-altitude aircraft, balloons, and sounding rockets, we appear to be moving at about 300 kilometers per second (190 miles per second) toward the constellation Leo.

**W**hen we launch additional infrared and microwave telescopes on orbiting satellites, it will be possible to make more sensitive measurements and to search for structure in the spatial distribution of the microwave background that may reveal fundamental aspects of the nature of the universe.





## What's Coming

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**T**he next major development in Space Age astronomy was the launching of the Space Telescope. We finally had an optical telescope above the disturbing influence of the atmosphere, thus increasing the sharpness of images and allowing us to see more distant galaxies than can be photographed, even with larger telescopes, from the ground.

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**T**he Space Telescope is able to tell a spiral galaxy from a barred spiral galaxy at a distance of 5 billion light years, or take photographs of Mercury from Earth orbit that show as much detail as those made from Mariner 10, when it flew past the planet.

**A**fter Space Telescope, the next major astronomy mission planned is the Gamma Ray Observatory (GRO). This satellite will carry instruments designed to detect gamma rays over the entire range of energies from a few hundred to several hundred million kilovolts. The GRO will be a powerful tool for investigating the most baffling and puzzling objects in space: pulsars, quasars, and active galaxies.

**T**o learn more about dust in the universe and about the whisper from the Big Bang, we are developing orbiting infrared telescopes. There are still some technical problems. For example, infrared detectors have to be kept very cold, which is surprisingly difficult on an Earth-orbiting spacecraft.

**T**he first planned NASA mission is called IRAS (for Infrared Astronomy Satellite); it will carry a small telescope in a low-temperature chamber. Later, a Spacelab Infrared Telescope Facility (SIRTF) will be deployed on the Space Shuttle.

**W**ith these instruments, we can study for the first time the coolest matter in our galaxy: the clouds of interstellar molecules and the dense



condensing masses of dust and gas from which stars are born. The Cosmic Background Explorer (COBE) will concentrate on the study of the microwave background and other sources of widely distributed infrared and microwave radiation.

**T**he advance of Space Age astronomy is being supported by new instruments on the ground, notably the Very Large Array (VLA) of radio telescopes in New Mexico. The VLA consists of 27 radio dish antennae that simulate a single radio telescope 31 kilometers in diameter.

**T**his same principle, that a set of small radio telescopes can be designed to act like a very large telescope, may eventually be exploited in space. Operating a radio telescope in orbit in conjunction with radio telescopes on the ground would produce a system that acts in some respects like a radio telescope larger than Earth!

**A**t the same time, new techniques in photography and in electronically recorded optical images are greatly improving the speed and sensitivity of astronomical observations made on the ground. Space Age astronomy is a joint effort of all astronomers to elucidate the nature of the universe. In spite of all that we have learned in the last few years, we have only just begun to see.



## Our New Domain

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**S**carcely thirty-four years have passed since Russian cosmonaut Yuri Gagarin became the first person to orbit the Earth. In less than a single generation, human beings have extended their domain from the upper fringes of the Earth's atmosphere to the mountains of the Moon.

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**I**f this human progress continues, we can expect that some of those already born since Gagarin's 1961 flight will walk on Mars and that some of their grandchildren will be born, live, and die in colonies beyond the Earth. There has always been a human drive to expand and explore.

**T**he last thirty years have shown that space travel is feasible. Now a more profound question faces us: Will our own biology permit us to become full-time residents of outer space?

**S**paceflight produces many severe stresses on the body and mind. The astronaut is subject to high accelerations (G-forces) on launch and reentry; in between these are long periods of weightlessness. In space, there is radiation more intense, dangerous, and sometimes quite unlike anything encountered on Earth.

**I**nside a spacecraft, high noise levels are produced by the powerful rocket motors and by the continuous operation of life support machinery. Spaceflight involves long periods of isolation, nagging vibrations, and disturbances in normal day-night cycles.

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**B**eyond these specific problems is the ever present element of physical danger. Only the thin wall of the spacecraft separates the occupants from

an environment more hostile than any on Earth. Above the atmosphere, the unfettered energy of the Sun scorches anything that it strikes, and the temperature of shaded objects approaches absolute zero. In the almost perfect vacuum of space, an unprotected human would survive less than a minute before his blood would boil.

**W**e are already quite familiar with many effects involved in space flight. Exposure to highly accelerative forces has become commonplace to the pilots of experimental jet and rocket aircraft. The same forces are produced on rocket-propelled sleds and in centrifuges, where their biological effects can be studied in great detail.

**T**he dawning of the Atomic Age, combining the threat of nuclear devastation with the promise of unlimited useful energy, has given great emphasis to studies of the effects of ionizing atomic radiation on living things.

**I**ncessant noise, vibration, and jet lag are common accompaniments to modern civilization, and despite all the teeming billions of humanity we need only to recall that people live and work in isolation on the polar icecaps, under the oceans, and on the windswept slopes of the Himalayas to be reassured of our capacity to adapt to the most lonely environments.

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**T**he unique aspects of spaceflight, so far as the human body is concerned, are weightlessness and the heavy, energetic atomic particles (known as HZE radiation) that are sprayed out of the Sun and other stars and that fill the space around us. The key to understanding the effects of spaceflight on humans comes from the reactions of astronauts to weightlessness and HZE radiation, and the evaluation of how much of each they can tolerate.



## Weightlessness

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**F**ossils in the geological record reveal that humans have existed on Earth for over three million years. Further, we know that vertebrates roamed the Earth for hundreds of millions of years before the emergence of Man. Throughout these eons, all evolution and human development have been influenced by the Earth's gravitational field.

**I**n countless subtle ways, humans have responded to this ubiquitous force and have learned to cope with it. Not only are we molded and constrained by gravity, but Earth's whole blanket of life, the biosphere, with all its component species, is in some respects a product of the effects of gravity.

**S**o intimate is the relationship between gravity and life that, before the advent of spaceflight, no one could predict precisely how or even whether any particular biological process would function in the absence of gravity. Weightlessness cannot be experimentally produced within the Earth's atmosphere for more than a few seconds at a time in aircraft. We had to wait until spacecraft could be launched into orbit around the Earth before the effects of prolonged weightlessness could be investigated.

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**B**efore the Space Age, scientists predicted many dire consequences if a human being were suddenly thrust into weightless flight. Often, the predictions contradicted each other. Various specialists said that the heart would race or that it would stop, that a person could not sleep or would sleep constantly, and that an astronaut would become euphoric or profoundly depressed. It was said that the bones would soften, that eating would be impossible, and that the ability to think would be impaired.

**S**o acute was the concern for the unknown medical effects of weightlessness that numerous animals were flown, first in ballistic

suborbital trajectories and finally in complete Earth orbits, before either Yuri Gagarin or Alan Shepard first flew their Vostok and Mercury spacecraft. Happily, most of the predicted dangers did not occur.

**W**eightlessness in general turned out to be surprisingly benign and tolerable. However, some significant changes in the human body were noted, even in the earliest flights. How long these changes last, and how serious they are in the long run, continue to be the subjects of intense investigation by space medicine specialists in both the United States and the Soviet Union.



## Circulatory Changes

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**T**he first impairments observed in astronauts that were definitely caused by space flight were the changes in heart rate and blood pressure exhibited by Walter Schirra following his 9-hour flight in October, 1962 and by Gordon Cooper after a subsequent 34-hour flight, each in a Mercury spacecraft.

**I**mmediately after returning to Earth the astronauts tended to become dizzy on standing, and each showed a decrease in the total volume of blood. These effects were confirmed by medical studies of other astronauts during the later Gemini and Apollo flights, and they were investigated in much greater detail over a period of months during the long-duration Skylab flights in 1973-1974.

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**T**he Skylab studies showed that the circulatory changes which occur level off after four to six weeks of flight. After that, no further changes occur, nor do the changes impair crew health or performance aloft. Exercise tolerance during the space flight itself is unaffected, but the ability to perform vigorous exercise is temporarily diminished after return to Earth.

**S**cientists and doctors are beginning to understand these changes. When a human is suddenly thrust into weightlessness, apparently blood shifts from the legs and lower parts of the body, where it is normally held by gravity, upward toward the head. Sensitive receptors, located in the upper part of the body, mistakenly interpret this sudden and sustained shift of blood as an increase in total blood volume.

**T**he body then tries to reduce the blood volume to its "normal" value by eliminating fluid and some electrolytes, either by increasing urine flow or by cutting water intake (reducing the feeling of thirst). These changes lower the blood volume to a level that is perfectly compatible with

weightless life in space but that is too low to support vigorous activity back on Earth.

**J**ust after return, the astronaut is like someone who has just given a blood transfusion and cannot immediately engage in heavy exercise. This diminished performance after return from space continues for a few days until the missing blood volume is restored; there seem to be no long-term effects.

[click here to see picture...](#)

**I**f the circulatory changes, technically called "cardiovascular deconditioning," are caused entirely by lowered blood volume, simple precautionary measures can be used to correct the problem during critical reentry maneuvers and immediately after return to Earth.

**H**owever, because it is possible that other, more serious circulatory changes may occur in space, scientists monitor the cardiovascular system of an astronaut in flight as well as the red and white cells and other components of the blood.

[click here to see picture...](#)

**T**he opportunities to study humans in space are still somewhat limited and can involve only a few subjects, so methods have been devised for simulating some of the physiological effects of spaceflight here on Earth.

**B**y immersing humans and animals in water baths for extended periods or by confining them to bed or in plaster casts in a slightly head-down position, many of the same cardiovascular changes that occur in space can be produced on the ground and studied in detail.





## Bone and Muscle Loss

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**W**hen they are not used to work against the gravity field of Earth, bones tend to deteriorate and muscles tend to atrophy, that is, to shrink or waste away. Similar problems occur in space.

**T**he limited mobility within the small earlier spacecraft and the lack of appropriate stress, even in the larger Skylab and Salyut space stations, produced a continuous loss of bone and muscle tissue in the astronauts.

**T**he loss appears slow enough to enable space missions of from six to twelve months to be undertaken without instituting any preventive or remedial measures. On longer flights however, steps must be taken to prevent these losses.

[click here to see picture...](#)

**I**n-flight exercise was tried on the Skylab and is being used by the cosmonauts aboard Salyut missions, but so far the correct combination of measures to be applied to prevent bone and muscle loss has not been found. The search is continuing in the Space Shuttle missions as well as in laboratories on the ground.





## Motion Sickness

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**S**tarting in 1968, eleven missions involving astronauts were undertaken during the five-year span of the Apollo program. These missions added motion sickness (the "space sickness" of generations of science fiction writers) to the significant biomedical problems produced by space flight.

**A**lthough nausea had been noted earlier by Soviet cosmonaut Gherman Titov during his one-day Vostok 2 flight on August 6, 1961, as well as by some crew members of subsequent Soviet flights, no American astronauts had yet experienced the symptoms. (In retrospect, however, the lack of appetite observed on certain Gemini flights may have been an early sign of this illness.)

**T**he crewmen of Apollo 8 and 9 were especially plagued with stomach uneasiness, nausea, and vomiting. In Apollo 9, an Earth orbit mission, astronaut Rusty Schweickart was sick for a considerable time and had to postpone the first test of the Lunar Module in space.

[\*click here to see picture...\*](#)

**T**hroughout the remainder of the Apollo program, during subsequent Skylab missions, and during Soviet missions, symptoms of motion sickness continued to manifest themselves. It is a serious problem; almost half of the astronauts sent into space have been affected.

**T**he illness appears to last for only the first two or three days in space and in almost all cases disappears within a week. The occurrence of motion sickness during the first few days of space flight is of great operational concern during Space Shuttle flights, many of which last only a few days.

**U**nfortunately, at the present time, the factors responsible for motion sickness are unknown. Scientists believe that the vestibular apparatus, or machinery of the inner ear which controls our sense of balance, is

profoundly influenced by weightlessness. Humans are not the only creatures affected.

**E**xperiments carried out on the Skylab spacecraft produced pictures of disoriented fish swimming in loops in their containers. Furious nervous activity was recorded from the brain of a frog that was suddenly rocketed into weightlessness.

**I**n humans, the disorientation arises when sensations from the eyes and from other parts of the body conflict with those from the vestibular (inner ear) apparatus and with information stored in our brains as a result of experience at "1 G." This condition apparently can be overcome. After a few days in space, a repatterning of the central memory network occurs so that unfamiliar sensations from eyes and ears start to be correctly interpreted and the person adjusts to his new environment.

**M**ore effective means whereby adaptation can be accelerated and motion sickness symptoms suppressed are being sought in many laboratories. Hopes are high that this search will be successful and that, unlike so many hapless sailors, aviators, and other travelers, future astronauts will be freed of space motion sickness as an occupational nuisance.



## Food and Diet

[click here to see picture...](#)

**I**t is almost always true that an astronaut or cosmonaut who returns from space to Earth weighs from one to ten pounds less than upon launch. Spring-loaded mass measuring devices, carried aboard the American Skylab and Russian Salyut spacecraft, were used to "weigh" the astronauts in the absence of gravity.

**T**hese records showed that about half of the weight loss occurs within the first few days of flight while the remaining loss takes place much more slowly. Scientists believe that, just as in any person who starts to lose weight, the early losses consist mainly of water, while muscle, fat, and bone comprise the later losses.

**W**eight loss can be reduced by combining appropriate exercise with a complete and balanced diet. However, most of the early astronauts paid little attention to the dietary advice they received prior to flight and could not be convinced that life in weightless flight required just as much food energy as it did on Earth.

**T**he commander of one lunar flight insisted that he wanted nothing but a few candies on the way to the Moon. Some Gemini astronauts traded their individually planned metabolic rations with each other, much to the consternation of the dietitians. In later long-term flights such as Skylab, food was taken more seriously. Daily intakes were calculated by computer, and supplements were automatically prescribed to each astronaut to make up deficits incurred the previous day.

**E**nsuring that the space food tastes good is one way to promote eating enough. This always has been difficult because of the need to process the food to save as much space and weight as possible, but the individual meals on Skylab were a major advance over the primitive edibles available to the Mercury astronauts. Food preparation and use will provide increasingly complex challenges in the future, when "closed ecology" food

systems will generate food from the waste products of human metabolism.



## Ionizing Radiation

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**B**eyond the protective blanket of the Earth's atmosphere, space is filled with radiation of all kinds: the light and heat from the Sun, radio waves from Jupiter, X-rays and gamma rays from the Sun and from energetic, poorly-understood objects beyond our solar system.

**T**his radiation not only spans the electromagnetic spectrum, but also includes atomic and subatomic particles of all dimensions and energies. Much of the radiation is similar to that which can be produced on Earth, using radar, cyclotrons, or radioactive materials. The biological effects of these radiations can be studied in great detail.

**O**ther space radiations, such as the highly energetic HZE atomic particles, or cosmic rays, are unique to space and can be duplicated only imprecisely and with the greatest difficulty on Earth.

**C**osmic rays have been studied in great detail, using a variety of detectors carried into space. One very sensitive detector turned out to be the human eye. Cosmic rays apparently are the cause of the "light flashes," bright streaks seen by the astronauts when their eyes were closed. Some of the displays were striking. On one lunar trip, brilliant green flashes were seen, causing the astronauts to report, "It looks like St. Patrick's Day."

**T**here is no doubt that such penetrating radiation can produce biological damage. It is not yet clear that this radiation is any barrier to our progress into space, but we will need to be protected against it. How the radiation causes damage, what the dangerous exposure times are, and what the possible protective measures may be are all subjects of intense scrutiny.



## Conclusion: We Can Go On

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**T**here no longer is any doubt that humans can both survive in space and work hard and productively in this exotic environment for periods of many months. A sizable number of biological responses to weightlessness do take place fairly promptly but are reversible when the space traveler resumes his or her accustomed place on the surface of the Earth.

**Y**et it is equally clear that some of the adjustments are slow and do not reach equilibrium even after many months of weightlessness. There also is concern that a few of these processes, if allowed to go on long enough, may produce irreversible changes.

**T**his could be particularly worrisome when older individuals or persons in different physical condition from the astronauts travel into space. Many scientists are seeking to detect, to understand, and ultimately to prevent these changes, so that long voyages into space will be both safe and feasible.

**W**e still do not know whether weightlessness or reduced-gravity environments are suitable for indefinite lengths of time for any terrestrial species. All plants and animals not only are endowed with specialized gravity sensing devices, but also possess many cellular and sub-cellular structures whose orientation and perhaps even function will be influenced by the withdrawal of gravity.

**A**ctual spaceflight data are sparse, but so far gross anomalies in basic living processes have not been detected in the space environment. Much work, of course, remains to be done before the role of gravity in living processes is completely understood and before humanity can erect cities in the sky with the same impunity with which the spiders Arabella and Anita spun webs in Skylab.

**T**he physiological and psychological barriers to space flight are being

methodically and successfully challenged. A major dividend of these space medicine studies is that much of what is learned is directly applicable to ordinary people who may never leave the Earth.

**T**he technology that permits the flight surgeon to monitor the heart rate of an astronaut walking on the Moon can be used to keep a careful and continuous watch on cardiac patients going about their daily work. The space suits that cooled and protected astronauts during extravehicular activity have been adapted to treat the cancer patient and to guard the immune-deficient child from the germs against which it has no natural defense.

**E**ven an astronaut's adverse reactions to weightlessness are in many ways similar to diseases on Earth. Such diseases are thus seen in a different light from the viewpoint of space. Their underlying mechanisms may become more apparent, and effective treatment may be developed.

[\*click here to see picture...\*](#)

**M**uch must be learned, much must be done before humans can spend indefinite periods of time beyond the confines of the Earth. It is still conceivable that prolonged or repetitive exposure to space may ultimately present an impassable barrier to our survival in that environment.

**T**oday, however, from the vantage point of twenty years of space flight operations, many thousands of hours of flight experience, more than one hundred astronauts and cosmonauts, and many other living creatures, no such barrier is in view.





## Life in the Universe

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**P**lanets seem to be reasonable places for life. They are neither as hot and deadly as the surfaces of stars, nor as cold and empty as the space between them. The only life we know of in the universe has developed on a planet, the Earth.

**T**hus, other planets have always been the major focus of our search for other forms of life. If planets are abundant in the universe, life may be common. If planets are rare, we and our fellow Earthlings may be unique.

**O**nly thirty years ago, most astronomers believed that planetary systems were extremely rare. It was even thought that the solar system and the habitat that Earth provides might well be unique in the entire galaxy. At the same time almost nothing was known about the chemical basis for the origin of life. Since then, our view has changed drastically.

**N**umerous studies have eroded the reasons why planetary systems and the development of life on suitable planets should be unlikely. Today, the leading theories for star formation suggest that planets may be the rule rather than the exception and that the formation of planets is expected to accompany the formation of stars.

**A**t the same time, new discoveries have shown that the chemicals necessary for life are abundant beyond the Earth. Interstellar gas clouds have been found to contain biologically important organic molecules made of carbon, hydrogen, and other elements. Similar molecules have been detected in comets and meteorites.

**T**herefore, today's theories suggest that life could be widespread in the universe. Growing numbers of scientists are now convinced that extraterrestrial life must exist, and more and more people feel that contact with other civilizations is no longer something beyond our dreams but will be a natural event in the history of mankind.



**T**he existence of extraterrestrial life and the origin of life are two questions that are intimately related. The major problem is the origin of life. This topic is intrinsically fascinating. It is surrounded by mystery, philosophy, and religion, and it has been the subject of contemplation and speculation since the beginning of human history.

**O**nly in the last century has the question become recognized as a subject suitable for direct scientific inquiry. Individual researchers and groups of scientists have considered the problem for years, but NASA was the first organization to provide a cohesive, interdisciplinary approach, combining the various scientific programs that had investigated the question since the early 1960s.

**T**his integrated attack includes disciplines as diverse as astronomy, biology, chemistry, geology, and engineering. Ground-based laboratory research, astronomical observations, and space missions have all been brought to bear on the questions of the uniqueness of life on Earth, the origin of life in the universe, and the place of life in the general cosmology.

**W**e have come to the point that scientists can now devise experiments to answer such fundamental questions as: "Where did life come from?" "Why is life like it is?" "Are there other forms of life in the solar system or in the universe?" "Is there intelligent life elsewhere?"

**T**his new science of exobiology has several goals. It seeks to understand the origin, evolution, and distribution of life and of the chemicals necessary for life, both on Earth and throughout the universe, and it seeks to determine the relationship of life to the evolution of planets.

**T**hrough research in chemistry, geology, and biochemistry, and from our exploration of the planets, we have begun to pull together some parts of the origin-of-life puzzle. Pieces of the puzzle are being gathered from throughout the universe, from interplanetary and interstellar space, from other worlds, and naturally, from the Earth.



## From Molecules to Man

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**I**t now is generally accepted that the origin of life on Earth was closely tied to the origin of the solar system itself. From this concept, combined with experimental findings, a general model for the beginnings of life on Earth is emerging. It starts, almost immediately after the original accretion of the Earth, with a period of chemical evolution which resulted in the formation of small organic molecules that are essential for life.

**T**hese molecules were synthesized from the gases that made up the primitive atmosphere. This first atmosphere, which surrounded the newly formed Earth, is believed to have been reducing in nature. That is, it contained no free oxygen and was composed mainly of gases such as hydrogen, methane, ammonia, and water vapor.

**A**s time passed, these gases were activated by energy sources like lightning discharges and ultraviolet radiation from the Sun. The original molecules broke apart, and their atoms recombined to make new, more complex molecules, thus beginning the prebiotic synthesis of organic matter, meaning the reactions that preceded the development of life.

**U**nder the influence of primitive planetary environmental conditions the organic molecules combined to form larger, even more complex molecules. Finally, thousands and millions of molecules were assembled into structures exhibiting key properties of living things: metabolism, respiration, reproduction, and the transfer of genetic information. This stage was reached on Earth about 3.5 to 4 billion years ago, about 0.5 to 1 billion years

**A**fter the Earth and the solar system formed. From that point on, the record preserved in Earth's rocks constitutes the raw material for laboratory studies because it is the repository for all evolutionary information from the time of the first living cells through the evolution of today's complex life forms.

**A**s the details of this process are being unraveled in terrestrial laboratories by scientists using sophisticated instruments and experiments, we find ourselves also exploring an important related question: Are the same or similar processes producing life elsewhere, beyond the Earth?



## From Theory to Search

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**T**he first opportunity to search directly for extraterrestrial life was provided by the Apollo missions to the Moon. Rock and soil samples returned from the Moon were analyzed extensively, but neither living nor fossil life forms were found.

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**F**urther studies show that the Moon, which has no water, no atmosphere, and no protection from the radiations of space, probably never had the physical characteristics needed to begin the synthesis of organic matter, a required precursory step to the origin of life.

**M**ars provided our second opportunity. With its obvious atmosphere and polar caps, Mars was deemed (in both scientific papers and the popular press) a much more likely location in the solar system to harbor extraterrestrial life.

**T**he search for Martian life began in earnest when the Viking Project landed two robot spacecraft on the planet in 1976 to photograph the surface material and analyze it in detail. These missions increased our knowledge of the physical and chemical properties of the remarkable red planet tremendously.

**P**erhaps the most unexpected and fascinating findings, however, were returned by the two instruments designed to search for life and for life-related molecules. One instrument showed that, quite unexpectedly, the Mars soil samples contained no organic materials, not even traces of carbon from meteorites that must hit the planet's surface.

**T**his is probably due to the destructive power of the intense ultraviolet radiation from the Sun, which destroys any exposed organic material. The second instrument, intended to detect biological reactions in the Martian

soil, did not detect life on Mars. It did uncover an intriguing chemical property of the soil that, at least in part, does mimic some simple lifelike reactions. Among these are the breakdown of nutrient chemicals and the synthesis of organic matter from gaseous substances.

**A**ll in all, Mars remains a planet of extreme interest to exobiologists. Although Viking did not detect life, Mars continues to tantalize us. Why were no organic molecules detected? Were conditions in Mars' past history more favorable for prebiotic chemical syntheses than those present today? Are there other locations on Mars today where conditions are more conducive to life or to life-related chemistry?

**T**hese questions and more require continued exploration of Mars. After all, the Earth is not the most favorable place to look for clues about life's origin, since life itself has altered the planet so drastically that much necessary information has been obliterated. Mars, then, provides us an essential point for comparison with Earth: an environment not extensively modified by widespread life, and perhaps still harboring secrets about the relationship of the origin of life to the origin of the solar system.



## The Chemicals of Life

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**I**n addition to searching for extraterrestrial life, we pursue the search for extraterrestrial life-related molecules in order to establish the universal nature of prebiotic chemical synthesis. Recent discoveries show that comets, which seem to have remained unchanged since the formation of the solar system, may represent a unique storehouse of information about organic synthesis at the time of formation.

**W**e now have evidence that the organic molecules believed to be precursors of molecules essential for life are prevalent in comets. These discoveries have provided further support for the view that chemical evolution has occurred widely beyond the Earth.

**C**omets may even have played a major role in the organic chemical evolution of the primitive Earth itself. Significant amounts of important precursor molecules could have been deposited on the primitive Earth by cometary impacts.

**M**eteorites, which provide us with solid samples of extraterrestrial material, represent another source of information about the occurrence of prebiotic chemistry beyond the Earth. In 1969, meteorite analyses provided the first convincing proof for the existence of extraterrestrial amino acids, a group of molecules necessary for life.

**S**ince then, a large body of information has accumulated to show that many more of the molecules necessary for life are also present in meteorites, and it now seems clear that the chemistry of life is not unique to the Earth. Future studies of meteorites should greatly contribute to the eventual understanding of the conditions and processes during the formation of the solar system and should provide clues to the relations between the origin of the solar system and the origin of life.

**T**he atmospheres of the outer gas giant planets (Jupiter, Saturn, Uranus,

and Neptune) represent yet another extraterrestrial environment in which prebiotic chemistry can occur. In fact, from our knowledge of the composition of Jupiter's atmosphere, many scientists consider it to be a good model for the primordial atmosphere of the Earth.

**J**upiter's atmosphere contains the same gases (hydrogen, methane, ammonia) that may have been present when the Earth's atmosphere formed, and violent lightning flashes were detected in Jupiter's clouds by the Voyager spacecraft.

**W**ith its abundant organic molecules and electrical energy, Jupiter may be the site of extensive prebiotic chemical reactions that reproduce what occurred on our own planet 4 to 4.5 billion years ago. We expect that further important information on this question will be provided by the Galileo-type spacecraft as they make direct analyses of the turbulent atmosphere of this giant gaseous world.





## The View from Earth

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**W**e are actively exploring the origin of life on the surface of our own planet. Several recent discoveries have provided new insights into the mechanisms which may have acted to synthesize biomolecules on the primitive Earth.

**W**e have discovered that, under geologically reasonable conditions, the surfaces of certain clay minerals can select specific biomolecules (molecules necessary for life) from a dilute solution like sea water, can concentrate them, and can cause them to polymerize, or grow into chains of more complex molecules.

**M**odel systems based on this research simulate a primitive tidal basin and provide for the first time an attractive sequence of events to explain how large molecules, like proteins and nucleic acids, could form from simpler molecules present in small amounts in the primordial oceans. These findings indicate that clays could have played a vital role in the origin of life on Earth.

**W**e have also come to understand better the puzzling data sent to us from Mars by the Viking landers. During 1979, experiments conducted in several university laboratories finally reproduced the controversial measurements from one of the life detection instruments.

**S**pecially prepared clays, when mixed with salts in an amount determined by other Viking instruments to be present in the Martian soil, released carbon dioxide in a fashion like that observed in the Viking labeled release (LR) experiment. More recently, it has been shown that the activity of these same clay-salt mixtures can be destroyed by heat sterilization.

**T**his strong sensitivity to heat, also observed in the LR experiment, was the most lifelike response observed in the Martian soil, and it had been the most difficult feature to simulate on Earth up to this time. The discovery



on Mars that a non-biological system could exhibit life-like behavior was a significant finding with implications for the exobiological history of Mars that remain to be determined.

**T**hese findings highlight the need for continued exploration of Mars, including the return of samples for detailed study on Earth. The data also reinforce the central role that clays may have played in generating chemical reactions of exobiological importance, both on Earth and on the other planets.

**O**ur present knowledge of the Mars environment indicates that it is quite hostile as far as the survival of Earth-like microorganisms is concerned. Mars is cold, dry, and bombarded by ultraviolet radiation from the Sun. However, Earth-based research continues to discover microorganisms with unique abilities to thrive in environments previously considered to be too severe or extreme for life.

**T**he interior of Antarctica was once believed to be devoid of indigenous life forms because of its cold and dryness. But recent work in the dry valleys of the Antarctic has revealed native microbes of three different kinds. Algae, bacteria, and fungi were discovered living comfortably, embedded just below the surface of rocks strewn over more than 100 locations in these frozen deserts.

**T**he finding of life in Antarctica's dry valleys extends the known limits of life on Earth to its driest and coldest climates. At the same time, the discovery suggests that life may exist in similar environments on a planet like Mars, where the climate closely resembles that of the dry valleys of Antarctica. The surface of Martian rocks could provide an effective shield from the harmful radiation of the Sun for microbes dwelling inside.

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**A**nother new line of investigation was initiated in an attempt to decipher the long series of events that took place in early biological history after the formation of the first living cell. A multidisciplinary, international team of specialists assembled for a fifteen-month project to discover the details of some of the most significant events in the early biological evolution of the Earth.

**S**ome of these events include the origin of early microorganisms that did not use oxygen; the development of the photosynthetic capability to produce food-energy from sunlight; and the advent of oxygen-using or

aerobic microorganisms. This group is searching the Earth's ancient rocks for evidence of the chemical reactions which preceded the appearance of the first life forms.

**T**hey have already succeeded in pushing back in time the direct evidence for life on Earth by discovering microfossils in rocks that are 3.5 billion years old. This unique research team approach should have a major impact on future investigations of the organic geochemistry of early Earth.



## Things to Come

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**T**he new information on planetary formation, extraterrestrial chemistry, and the effect of the Earth's environment on the origin and development of life now provides a strong basis for looking for life (in fact, intelligent life) beyond the solar system. Such a search requires a much different approach than sending astronauts and spacecraft to nearby worlds.

**B**ecause of the incredible distances to even the nearest stars, we need to search for some long-range manifestation of life that can be detected from Earth. We need to detect radio signals rather than metabolic chemical reactions. We need to explore different stars rather than just the planets around our Sun. And finally, we need to use a different technology, radio astronomy, rather than spacecraft.

**W**e can now define a program to search for intelligent signals of extraterrestrial origin by using our existing radio telescope antennas with only a small amount of sophisticated auxiliary equipment. The technology needed for such a search is clearly at hand at this very moment.

**A**fter only three decades of active research, scientists have compiled an impressive list of accomplishments and discoveries in the search for the origin of life. Studies pursued under the auspices of the space program have contributed to a more universal understanding of the phenomenon of life as a whole.

**W**e now have considerably more details than we did thirty years ago. We have direct knowledge of the properties of the Moon, Mars, Venus, Mercury, and Jupiter. We have a wealth of information on proteins and cells, on the low likelihood of life on other planets in the solar system, and on the forces that led to the formation of the solar system and biomolecules.

**W**e have found simple organic substances, believed to be the precursors of life, in planetary atmospheres, in meteorites, in comets, and in interstellar space. We can also synthesize them quite readily in laboratory experiments.

**T**o discover an independent life form on another planet, or even beyond the solar system, still presents a challenge unequaled in the history of scientific inquiry. Although our knowledge has increased dramatically over the past few decades, our ability to obtain new knowledge has increased even more.

**T**he Earth's oldest rocks, newly found meteorites, our laboratories, and our huge, sensitive radio telescopes all have important roles to play as we continue our efforts to learn the chemical and biological secrets of ancient Earth and our studies on the existence, nature, and distribution of life in the universe.



## The View from the High Ground

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**T**he climb into space has made us unique. We are the first generation of human beings to study the universe directly from the high ground of space itself. From this new perch, we have made discoveries that would have seemed impossible to the ancients and unbelievable even to the scientists of a generation ago.

**F**or all our climbing, we have not reached the summit, only a ridge from which we can better glimpse the mountains beyond. We have reached a point from which to observe, a base from which to explore further, and we have learned how best to continue our investigation of the universe.

**B**ecause we have found so much, we now know how much more there is to learn and how to proceed to study it. The necessary tools exist or can be built. The spacecraft can be flown, and their data deciphered. A few new missions, already approved, are under development.

**M**any more are being intensively studied, so that they too may come to fruition. The future missions, and the research that they will undertake, concern the subjects that we have already begun to explore: the solar system, Earth-Sun relations, the outside universe, and life.



## The Worlds that Wait

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**T**he Voyager 2 Saturn encounter in August, 1981, marks the end of an era in planetary exploration. All of the planets known to the ancient astronomers have been visited by spacecraft; the reconnaissance of the inner solar system is finished.

**R**econnaissance is not enough, however. Many tantalizing questions cannot be answered by spacecraft flashing quickly past these worlds, and new and unexpected questions have been raised by the very data sent back to us.

**W**e are now ready to begin a different phase in the exploration of the solar system, a period of careful, systematic study. For this we will need heavier, more sophisticated spacecraft, longer observation times, and much larger data returns. Such missions and their new generations of instruments will be based on the immense knowledge that we have already obtained.

**T**he next generation of planetary exploration missions which was launched in the mid-1980s and beyond began with the Galileo mission to Jupiter, which was intended to begin the detailed exploration of the outer gas giant planets.

**T**he concept for Galileo is a two-spacecraft mission. One is a probe that would plunge into the Jovian atmosphere, measuring the chemical composition as it descends, until, more than 100 kilometers (62 miles) down, it succumbs to the intense pressure.

**T**he second spacecraft would go into orbit around Jupiter, continuously photographing the planet's clouds and weather, measuring the magnetic field, and taking close-up pictures of its moons. Galileo would study Jupiter in detail, not on a quick flyby, but over a period of a year or two, and would bring us a long way toward understanding this giant planet, its

huge magnetic field, and its mysterious moons.

**A**lthough we have explored the inner terrestrial planets in some detail, one remains hidden. The surface of Venus, beneath its thick, opaque atmosphere, is still largely unknown. We have some crude radar maps made by Pioneer Venus, but their resolution is only a few kilometers, not enough to let us compare the details of Venus with those of the other worlds whose surfaces are in full view.

**A** new spacecraft mission has been proposed to fill this gap. Called VOIR (for Venus Orbiting Imaging Radar), it would carry a large radar into orbit around Venus. The radar waves can penetrate the clouds and make accurate images of the surface, detecting features as small as a football field.

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**T**he resulting maps would cover almost the entire surface of Venus, an area four times as large as the total land area of the Earth, and would be adequate to show such features as volcanoes, meteorite craters, crustal fractures, and river channels. We will then be able to compare the geology and history of Venus in detail with what we have learned from other worlds, to discover how Venus fits in with the rest of the terrestrial planets.

**T**he year 1985 was a special occasion for the study of small bodies in the solar system. It marked the return of Halley's Comet to the neighborhood of the Sun. This bright comet, which returns about once every 76 years, has been sighted on over two dozen visits to the inner solar system since its first recorded appearance in the year 240 B.C. NASA coordinated a program of Earth- and satellite-based observations when the comet appeared in our sky.

**O**ther missions are under study for the more distant future. After Galileo explored Jupiter, Saturn should be the next step in our detailed investigation of the gas-giant planets. Plans are under discussion for a Saturn Orbiter, resembling Galileo, that would make a long survey of the ringed planet and its family of at least 15 moons. The Orbiter might also carry two probes, one to plunge into Saturn's atmosphere and a second to analyze the atmosphere of the large moon, Titan.

**C**loser to Earth, among the terrestrial planets, Mars still demands our attention. It is better understood and more hospitable than Venus, but it is still a puzzle in many ways. We need to find out the nature of its rocks and



soil and to search more thoroughly for possible life.

**A** more sophisticated lander, a sort of superViking, is one possibility. A more exciting and advanced, yet wholly feasible, idea is to send a robot spacecraft to land, collect a load of Martian rocks and soil, and return to Earth, just as the USSR Luna spacecraft collected samples from the Moon. It may be that only on Earth, with the full resources of our laboratories focused on returned Martian samples, can we finally settle the ancient questions about Mars: its composition, its history, and its life or lack thereof.

**T**he small bodies of the solar system—thousands of asteroids and billions of comets—are also important targets for future space exploration. None of them has ever been visited by a spacecraft, and their compositions and detailed natures are largely unknown. They are primitive objects that date back to the earliest days of the solar system.

**C**ometes, preserved in the cold regions beyond Pluto, may give us an unchanged sample of what the original solar nebula was like. The asteroids retain the history of how all the tiny bodies formed and grew in the original solar system, before they were collected into larger worlds like the Earth.

**E**ven after the quick flybys past Halley's Comet, we still need to send out more spacecraft to scan these objects at close range, to rendezvous with other comets and study them for long periods of time, to determine the exact nature and composition of asteroid surfaces, and even to collect and return samples of these bodies to Earth.

**T**o orbit distant worlds like Saturn and Uranus, or to go out to rendezvous with comets or asteroids, we need a boost, a more powerful means of propulsion than we now have. One possible solution is a propulsion system that would operate only in space, the Solar Electric Propulsion System or SEPS. SEPS could be used to carry spacecraft launched from the Space Shuttle even further and faster into space.

**T**he energy source for SEPS will be not fuel but sunlight. Large solar panels on the engine convert sunlight into electricity. The electricity is applied to a supply of atoms, perhaps of the element mercury. The atoms become ionized (electrically charged) and are hurled out of the engine.

**T**he reaction from this jet of departing atoms pushes the rocket infinitesimally forward. A SEPS engine can produce only a weak thrust,



but the thrust can be applied continuously for weeks or months, until the supply of mercury runs out. Even a very small force will accelerate the spacecraft to a surprisingly high speed when it acts over a long time.

**S**EPS, or something like it, is essential if exploration of the solar system is to continue. Without it, we can do little more than we have done, and many aspects of the solar system will remain a closed book. Our access to distant worlds, and our ability to make more thorough studies of nearby worlds, depend on the thrust that SEPS, or a comparable system, can provide.

**S**ome of the future of space exploration may lie closer to home, on the Moon. We have learned much about the Moon, but it remains mysterious in many ways. We actually have sampled only nine lunar locations. The nature and composition of the rest of the Moon are unknown and much debated. We have no samples at all from the far side of the Moon, that never faces Earth.

**W**e do not know what causes the mysterious glows and clouds that have appeared and disappeared on the Moon on various occasions over the past 200 years. We have not explained the fossil magnetism preserved in lunar rocks, nor unraveled the mystery of whether the Moon has an iron core. We have virtually no information about the Moon's polar regions, where water and other gases may still remain as frozen deposits in the permanent shadows.

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**A**pollo was a glorious beginning to lunar exploration, but we cannot answer the above questions until we study the Moon on a systematic global basis. The Russians have already demonstrated, with their automatic Luna spacecraft, how samples can be brought back, at relatively low cost, from additional regions of the Moon.

**A**nother method of global lunar exploration involves a spacecraft that would be placed in an orbit that passes over the Moon from pole to pole. In such an orbit, the spacecraft would eventually scan the entire lunar surface. A battery of instruments would map the chemistry, gravity, magnetism, and thermal properties of the whole Moon.

**O**ther instruments would search the polar regions for frozen water in the permanently shadowed areas. This project would complete the mapping begun by Apollo. It would give us the first thorough scientific data base

for a whole new world, with which we can better understand the global properties not only of the Moon but of other planets as well.

**N**ASA's consideration of such a mission has not proceeded beyond the study stage. Other countries, including the European Space Agency (ESA), are also considering the polar orbiter project.

**T**he Moon may some day be more than just a scientific treasure. A major concern of our long-term future in space is the question of resources. If we decide to build large structures, power satellites, research stations, or habitats-in space, where will we get the materials? Will we lift them up out of the Earth's strong gravity field at a great cost in fuel, launch facilities, and possible environmental impacts? Or can we use materials that are already present "up there" in space?

**S**tudies of moon rocks and meteorites tell us that the Moon and the asteroids do contain critical and necessary elements: aluminum, silicon, iron, titanium, and oxygen, and even hydrogen and carbon in some asteroids. There is a continuing controversy over whether, how, and when these materials can be mined and used in space.

**S**o far, no fundamental barriers have been identified, but there are a host of technical, economic, and social problems to be resolved before a new generation of "forty-niners" goes into space. These discussions and studies should continue, so that we will understand better what we can now do in space if we want to. Only a generation ago, the idea of going to the Moon was science fiction. A generation from now, the mining of the Moon might be routine.



## The Sun, the Earth, and "In Between"

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**W**e now know that the Sun touches the Earth not only with heat and light but with magnetic fields and streams of charged atoms that fill what we once thought of as empty space. In the near future, for both scientific and practical reasons, we need to study both the Sun itself and the dynamic phenomena in space that bind us to it.

**I**n the past, we have always had to look at the Sun sideways. The Earth's orbit lies near the plane of the solar equator, and from Earth we see clearly only the Sun's midsection. The higher latitudes are harder to see, and the polar regions of the Sun are extremely difficult to study from the Earth. The spacecraft launched from Earth generally are constrained to remain near the plane of the Earth's orbit, and thus are subject to the same viewing limitations.

**Y**et it is at the Sun's poles, as we learned from observations in space, that some of the most significant and unexpected solar processes occur. Above the Sun's poles, streams of charged particles pour out into space through the coronal holes. To understand the Sun and its effects on Earth, we need somehow to rise up and look at the Sun from above and below. But we do not have an existing propulsion system capable of carrying a spacecraft over the poles of the Sun.

**N**evertheless, a mission is now being planned to send spacecraft over the Sun's poles. The extra thrust needed will come, not from a new kind of thruster, but from the planet Jupiter! In this program to explore the Sun's polar regions, spacecraft would be launched, not toward the Sun, but toward Jupiter.

**O**n reaching the giant planet, the spacecraft would cross over its north or south pole and be flung by Jupiter's powerful gravity field back toward the Sun like a pebble whirled from a slingshot. (Similar gravity-assist maneuvers around Jupiter were used with the Pioneer 11, Voyager 1, and

Voyager 2 spacecraft to propel them toward Saturn.)

**W**ith the extra speed provided by Jupiter, the spacecraft would be aimed to pass over the Sun's north or south pole. A battery of instruments would be used to measure the streams of solar wind particles and to record the magnetic fields associated with the solar-wind.

[\*click here to see picture...\*](#)

**A** variety of other measurements would be carried out as well. This mission would give us our first indication of what the Sun and its surroundings are like in three dimensions, thus literally adding a new dimension to our understanding of the interactions between the Sun and the Earth.

**U**nderstanding all the details of the Sun-Earth interactions is a difficult problem. The volume of space that is involved is huge and filled with complex phenomena: magnetic fields, solar-wind streams, the Earth's magnetosphere, and belts of high-energy radiation.

**T**hese features change constantly, shifting positions and varying in intensity. To follow and understand these changes, we need to make continuous measurements at widely-separated locations simultaneously. So far, we only have data from a few isolated spacecraft moving on limited orbits.

**T**rying to comprehend the full complexities of the Sun-Earth interaction currently is like trying to reconstruct a motion picture from a few individual frames. Inevitably, there are still great gaps in our understanding.

**W**e now need to make a systematic study of the Sun-Earth region. A mission under study would involve the simultaneous launch and operation of four heavily instrumented spacecraft. One would be located between the Earth and Sun to measure approaching disturbances in the solar wind and the interplanetary magnetic field.

**T**wo more would be placed in orbits (one polar, one equatorial) around the Earth to observe the interaction of the solar-originated particles and fields with the Earth's atmosphere and magnetic field. The fourth would be located on the side of the Earth opposite the Sun, to record disturbances that take place in the Earth's magnetic tail downstream from the Sun.

**W**ith these spacecraft making simultaneous measurements, we would obtain the data to construct a "movie" of the Sun-Earth interactions. We could detect changes in the Sun's forces and see how the Earth responds to them. We could match the data with information from weather satellites and ground-based weather stations to gauge the effects of the Sun on the weather.

**T**his project would be an expedition to explore the space between Earth and Sun, but its discoveries would be used on Earth, hopefully to improve weather prediction, to understand and perhaps prevent communications interference, and to discover the Sun's long-term effects on our climate.



## The Violence Around Us

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**T**he universe beyond the solar system has become almost unrecognizable since the Space Age began. It is no longer viewed as the peaceful stellar background that earlier astronomers envisioned; instead, it is a region filled with strange forces, turbulent clouds of dispersed matter, and unexplained floods of energy. How can we begin to comprehend it all?

**F**irst, we need to observe the universe from space over longer periods of time. Much of our knowledge comes from instruments lifted above our atmosphere, on rockets or satellites, for short periods of time, a few minutes, a few months and, in a few cases, a year or two.

**E**ach instrument has seen only a limited spectral range-ultraviolet or X-rays, for example so that it has been difficult to observe different radiations from a single object at the same time. We have many fragmentary and exciting observations, but still no systematic view of the puzzling and awesome phenomena that have been discovered.

**T**his knowledge gap was partly filled in 1994, when we finally realized the age-old dream of astronomers to place a long-lived observatory outside the Earth's atmosphere, where it would command an unobstructed view of space. This project, the Space Telescope, was launched aboard the Space Shuttle. The spacecraft carried the mighty telescope 2.4 meters (94 inches) in diameter, highly automated, and capable of seeing, not only in visible light, but in ultraviolet and eventually in infrared as well.

[click here to see picture...](#)

**T**he launch of Space Telescope was a major event in astronomical history, like the construction of the great Mount Wilson and Mount Palomar reflectors several decades ago. It was truly a major observatory in space. Although the Space Telescope is only about half the size of the 200-inch (5-meter) Hale Telescope on Mount Palomar, it has no cloudy, wavering

air to look through, and it can see five times as far into the universe as well as obtain images of unprecedented sharpness.

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**W**ith the Space Telescope, we can study many other galaxies almost as easily as we now study the stars of our own Milky Way. We will see more clearly the distant, energetic objects that puzzle us: quasars, active galaxies, and neutron star binary systems.

**B**ecause we will see galaxies so much further away, we will view the universe as it was long ago, and we can begin to better comprehend how it has evolved. We will doubtless see many strange new things that we cannot now imagine because we have never been able to see so far or so well before.

**T**he Space Telescope cannot do everything, however. It cannot detect all the radiations and energies that astronomers need to examine. Although it will be the heart of astronomical research during the 1990s, other specialized space instruments are required to complement its work. Among these is IRAS (Infrared Astronomy Satellite), which is under development as a collaborative project by the United States, the Netherlands, and the United Kingdom.

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**T**his is a smaller telescope that can detect infrared radiation of types that the Space Telescope cannot observe. IRAS will give us a view of the cooler regions of the universe, the dust clouds that are the birthplaces of the stars, and the core of our galaxy, where intense and unseen energies apparently are hidden behind a screen of dust.

**T**he Space Age has shown us not only a universe of light and heat, but a universe of high-energy radiations X-rays, gamma rays, and cosmic-ray particles which come from violent and mysterious sources. To study this aspect of the universe, we need more sensitive and capable instruments in space.

**N**o single instrument or spacecraft can record all of these radiations at once, so a series of projects is under consideration. Each would observe a part of the complex array of radiation; together they would give us a better view of the energetic side of the universe.



**O**ne project would focus entirely on the highest -- energy radiations of all -- gamma rays. An Earth-orbiting spacecraft (the Gamma Ray Observatory) will carry several detectors to look at gamma rays of all kinds and energies. It will detect and observe new gamma ray sources in the sky, investigate the gamma ray background radiation that comes toward Earth from all directions in space, and analyze the "bursters", those mysterious powerfully erupting sources of intense gamma rays. During the few seconds of a typical gamma ray burst, its unknown source briefly outshines the whole universe in gamma rays.

**D**ifferent instruments, carried by other spacecraft, could make detailed observations of the other powerful radiations from space. A wide variety of possible programs could be pursued. For example, an advanced system for detecting X-rays would make a systematic study of the X-ray sky and its puzzling sources and explosions.

**A**nother spacecraft, carrying instruments to detect weak microwave and infrared radiation, would look even further out and much further back in time. It would look for radiation from the early expanding universe and would scan the sky for slight differences in the background that should give us clues to the details of exactly what happened shortly after the universe was born.

**W**hen such advanced instruments are finally placed in space, above the blanketing atmosphere in which we live, we will have made a major step forward in seeing the universe as it really is. We can then sense all of its energies, from the weakest microwave (radio) radiations to the strongest bursts of gamma rays.

**W**e will see faint and mysterious objects clearly, and we will be able to look steadily at objects that have only been seen in quick, snatched glances. We will then begin to accumulate the facts we need to answer the many questions about the universe, to plan future experiments and new missions, and to discover new mysteries and questions whose existence we do not now even suspect.





## Return of the Humans...

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**T**he 1960s were the first decade of Man in Space. The 1980s and 1990s are just as significant, but in a different way. The launch and operation of the Space Shuttle have begun a new kind of space travel. Large numbers of men and women, astronauts and scientists, will soon travel almost routinely into space, not to explore an unknown and possibly dangerous environment, but to observe, work, and live in space.

[click here to see picture...](#)

**T**he Space Shuttle flights, lasting from one to four weeks, provide time for long scientific and biomedical experiments that have not been possible since the Skylab flights of 1973-1974. In the natural or "shirtsleeve" environment inside the Shuttle, instruments can be operated, modified, and even repaired by scientists on the spot.

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**A**mong other missions, the Shuttle will carry a complete scientific laboratory called Spacelab into space. Chemical and materials-processing experiments will be done to investigate suitable applications of the weightless ("zero G") environment.

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**A** major advantage of the Space Shuttle is that it makes possible more detailed biomedical experiments on the human ability to adapt and function in space. These studies are especially important for the future, because they will provide the information we need to plan longer missions for humans in space.

**L**ooking beyond the Space Shuttle, there is much to be done before astronauts can set out for Mars, before we can staff permanent space station or build bases on the Moon. We must first discover whether people truly can live in space for long periods of time.

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**W**hat are the psychological effects of weightlessness? Can calcium loss from bones in space be controlled or reversed? What are the long-term effects of space radiations on human beings? Can humans readjust to Earth's gravity after long periods spent in space? Some of the answers can be found in studies on Earth. For most of them, however, we need the experience that flights of the Space Shuttle will provide.

**I**f humans are to live in space on a permanent basis, we must then design the systems that they will need. Our spacecraft systems to date Gemini, Apollo, even the Space Shuttle have all carried the full complement of supplies needed for their short missions, enough to allow for the consumption of food and the gradual exhaustion of oxygen. These systems are both wasteful and inadequate for long missions.

**F**or longer trips, we need to design life-support systems that will recycle water and oxygen over long periods of time. We also need to develop ways of producing food in space, whether from plants, from small animal farms, or even from the products of our own metabolism. We do not need these systems to operate the Space Shuttle, but we will need the experience from Space Shuttle to develop the systems for future use.

**B**ecause we have been so successful in going into space, serious consideration is now given to ideas that, not long ago, were found only in science fiction. Current scientific workshops and political debates focus on such possibilities as mining the Moon, building space-based solar power stations, even establishing sizable populations in space.

**W**e do not know yet if these things are possible. In the next few years, research, both on the ground and in space, should provide the answer to whether humans can be permanent residents of space and should illuminate the prospects for what can be accomplished there.



## ...And Others?

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**T**he discovery of extraterrestrial life, whether intelligent or not, remains for the future. The negative results from the Moon and the ambiguous results from Mars give no indication that we have company in the solar system, but the intense interest in this subject leads us to explore other possible habitats for life: Jupiter, Saturn's moon Titan, and certain as yet unexplored regions of Mars. Spacecraft observations or the return of samples to Earth may yield definite answers, even if they are negative.

**R**egardless of whether the solar system outside the Earth proves inhospitable and lifeless, there are billions of stars beyond it. Here we must deal both with speculation and with probabilities. A certain percentage of the stars are like the Sun, a fraction of those suns may have planets, a percentage of those planets may have life, on a percentage of those planets life may have evolved to the intelligent state, a percentage of those planets with intelligent beings may be the sites of technical civilizations....

**T**he odds against each individual step may be tremendous, but there are so many billions upon billions of stars in our galaxy and so many galaxies in the universe that the odds in favor of life -- even intelligent life -- somewhere else in space seem overwhelming. Just as the radio and television signals broadcast on Earth a few years ago now are spreading out past the stars in our own neighborhood, so might signals from other life-forms be passing us at this very moment.

**T**he stars are far away, and we can't go to them to look for life, not for awhile anyway. Even so there are methods that we can adopt on Earth, at modest cost, to look for life elsewhere in the universe. One thing we can do is look for planets around the nearer stars, to check our theory that the solar system is not unique, to verify at least one link in the chain of logic which suggests that intelligent life must be common in the universe.

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**W**e may not be able to see planets around the nearest stars, even with the Space Telescope. Planets are too small and dim, and the nearest stars are still too far. But we can detect other planets -- possibly even from the ground -- by making careful measurements of the motions of nearby stars. Planets orbiting around a star would cause tiny wiggles in its motion across the sky.

**W**ith high-precision observations, we perhaps can determine that a star has planets, even though we could not see them. Proof that the solar system is not unique would be a major scientific discovery in any case. It would also be an important step toward the eventual discovery of life elsewhere.

**A**nother way to discover extraterrestrial life is simpler: sit back and listen. The huge and highly developed radio telescopes now operating on Earth can be equipped to detect artificial signals amid the cacophony of natural radio sources in the sky. (Suitably instrumented antennas many light years away could likewise pick up and recognize the radio and video signals now escaping into space from the Earth.)

**A** few limited attempts to detect communications from other civilizations have already been made. We can begin now to listen more sensitively and systematically for such signals from other civilizations, and we could detect them whether they were addressed to us or not. Some ideas for doing this have already been developed, and most of the necessary equipment is already in place.

**W**ith a modest investment for improvements in existing radio telescopes, and some shrewd guesses about where and how to listen, a systematic search for other life could be started now. The "First Contact", about which so many science fiction stories have been written, may yet come in our own lifetime, if we take the trouble to listen.



## Space Science on the Ground

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**T**he future exploration of space will need more than spacecraft and astronauts. Much research and study can, and must, be done on the ground if we are to go further. Ground-based studies and observations provide the data needed to plan space missions, to support the missions while they are in progress, and to make detailed analyses of the data that spacecraft gather.

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**I**n many cases, ground-based observations are our only source of data about things that spacecraft cannot yet explore: the outermost planets, celestial radio sources, and some aspects of very unusual and distant objects in the universe.

**G**round-based astronomy will not die out in the Space Telescope era. There are still many aspects of astronomical research that cannot be accommodated by observatories free of the Earth's atmosphere. Our present radio telescopes are much larger and better equipped for many kinds of observations than anything we can send into space.

**T**hey not only can listen for the natural and artificial (if any) sources in the radio sky, but they also can transmit radio waves from Earth, to bounce off distant moons, asteroids, and planets, and even the Sun itself. Such measurements can yield hard information on the surface structure and gross physical properties of large asteroids, well before we can hope to explore them with a spacecraft.

**O**ptical and infrared telescopes are needed to carry out surveys, to analyze new problems, and to conduct cooperative observations in support of X-ray telescopes and other space instruments.

**T**he collections of extraterrestrial material that we now have -- moon

rocks, meteorites, and cosmic dust -- are still important sources of new data on problems that no spacecraft or telescope currently can properly attack: the physical and chemical nature of asteroids, the early history of planets, the past history of the Sun, and the nature of the solid materials in comets. Even past missions still have much to contribute.

**T**he data from our recent Pioneers, Vikings, and Voyagers, which arrived in such floods, are still being studied, sifted, and compared. The continuing analysis of these data is providing further information on the worlds that the missions explored, as well as insight for planning more extensive return visits.

**G**round-based scientific studies are the foundation on which all of our explorations of the universe from space have been built. This work is still essential in planning and carrying out future explorations. Just as a spacecraft should not be flown from a poorly constructed and badly maintained launch pad, so our future studies of the universe will necessitate that our ground-based facilities and research capabilities be maintained.





## The View Ahead

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**F**rom our new vantage point, the universe awaits us, still holding the answers to unexplored questions. What are the mechanisms that sustain the tremendous energy sources that we have found in space? What is the surface of Venus like, and why is it apparently so different from those of the other terrestrial planets?

**H**ow will the Sun affect our weather and climate in the future? What are we doing to our own atmosphere, and what are the consequences? Is there life on Mars? Or elsewhere? Can people live and work permanently in space?

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**F**inding the answers to these questions depends on us. We see no technical barriers to going further into space or to living there. How we proceed depends on our purpose, our will, and on economic, political, and cultural factors that are beyond scientific calculation. The lesson of space explorations so far is simple: We can go on if we want to. The future is in our hands.



## Lunar Exploration

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**F**irst spacecraft impact on the Moon: Luna I (USSR), 1959.

**D**iscovery that the lunar far side consists almost entirely of highland regions, with no maria (large dark basins): Luna 3, 1959.

**I**nvestigation of the details of the lunar surface by the U.S. Ranger 7, 8, and 9 spacecraft in 1964-1965 revealed a gently rolling terrain with no sharp relief; there is a layer of powdery rubble, with rocks and craters down to at least one meter in diameter everywhere.

**L**una 9 and Surveyor 1 landed on the moon in 1966, found that the surface is firm and capable of supporting machines and astronauts.

**S**urveyor 5, in 1967, found that the surface chemical composition of the maria resembles that of terrestrial basalt lava.

**S**urveyor 7, in 1968, found that the highlands composition differs from that of the maria and is aluminum rich.

**D**ata from five Lunar Orbiters showed in 1968 that mascons or concentrations of excess mass exist under circular maria. This showed that the lunar crust must be sufficiently cool and strong to support the extra mass.

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**T**he manned Apollo missions to the Moon from 1969 to 1972 succeeded in collecting and returning rock and soil samples, emplacing instruments, including sensors for long-term measurements, and performing remote sensing from lunar orbit. From 1969 to the present time, the samples and



data have been the subject of numerous scientific studies on Earth.

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## Nature and History of the Moon

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**T**he Moon was found to be a complex, evolved planet, with three basic rock types: (1) volcanic lavas in the maria; (2) aluminum-rich rocks in the highlands; (3) unusual rocks (called KREEP basalts) that are enriched in silica and radioactive elements.

**E**vidence was found relating to the early history of planetary development (4.6 billion to 3.0 billion years ago): extensive primordial melting, catastrophic meteorite impacts, and major volcanic eruptions. The Moon was formed 4.6 billion years ago, along with the Earth and the rest of the solar system.

**I**t appears that the lunar surface has been basically quiet and unchanging over the past 3 billion years.

**N**o life, past or present, was found on the Moon.

**T**he lunar surface material, or "soil," is a layer of powdery rubble, 10 to 100 meters (about 33 to 330 feet) deep, formed by meteorite impacts over billions of years.

**T**he lunar surface composition is fairly uniform over large areas, judged from the 20 percent of the Moon that has been analyzed from orbit. There is a basic division between iron- and magnesium-rich lavas in the maria and calcium- and aluminum-rich rocks in the highlands.



## The Rocks

**A**ll of the lunar rocks are igneous (formed by cooling from molten lava) or derived from igneous rocks. There are no sedimentary (derived from water-deposited sediments) rocks.

**T**he rocks are very fresh and chemically unaltered, due to the lack of water.

**T**he rocks are generally like those of Earth in chemistry and minerals, but are deficient in volatile elements such as hydrogen, sodium, and potassium.

**T**hree new minerals, never found on Earth, were discovered in the Moon rocks: tranquillityite, armalcolite, and pyroxferroite.

**T**he Moon rocks range in age from 3.0 billion to 4.6 billion years; the older ones thus are older than any remaining rocks on Earth.



## The Lunar Interior

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**T**he Moon was found to be slightly egg-shaped, with the small end pointing toward Earth.

**T**he interior of the Moon consists of a crust, a mantle, and perhaps a core. The possible core may be metallic.

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**T**he thick, rigid, outer portion of the Moon, the lithosphere, was found to lack the plate tectonic motions that occur on Earth.

**I**t was found that the Moon is not seismically active. There are weak, infrequent quakes, some triggered by tidal forces.

**F**ossil magnetism was found in lunar rocks, although the Moon has no magnetic field. The source of the fossil magnetism is still unexplained.

**A** large magnetic anomaly was found on the lunar farside, near the crater Van de Graff.

[click here to see picture...](#)

**T**here is some outgassing underway from the lunar interior, as shown by the detection of radon from lunar orbit.



## Solar History, and Space Environment Discoveries

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**B**ombardment by cosmic dust (which produces microcraters on the lunar rocks) seems to have occurred at a constant rate over the last few million years.

**R**ocks have remained exposed on the lunar surface for periods as long as 500 million years without being destroyed.

**S**pecific impact craters on the Moon have been dated: Copernicus was formed 900 million years ago; Tycho, 100 million years ago; smaller craters at the Apollo landing sites, 2 million to 50 million years ago.

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**T**he solar wind striking the Moon was found to have a higher hydrogen/helium ratio than the Sun itself.

**L**unar soil analyses show that major variations in the amount and isotopic composition of solar wind nitrogen have occurred during the past 2.5 billion years.

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**T**here do not appear to have been major changes in the intensity of solar flares and the composition of particles erupted from them over the past 100,000 years.

**S**tudy of the Surveyor 3 television camera lens, which was retrieved from the Moon by the Apollo 12 crew, revealed that there is a higher iron/hydrogen ratio in solar flare particles than in the Sun as a whole.

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**T**he flux of galactic cosmic rays has apparently been constant on the Moon over the past 1 billion years.



## Mercury

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**G**round-based radar measurements determined (1965) that the rotation period is 59 days, not 88 days as had long been believed.

**M**ariner 10 made the first spacecraft flyby of Mercury in 1974 (in fact, it flew past Mercury three times), and obtained several thousand photographs.

**A**mong the results of the Mariner 10 investigations were the following:

**T**he mass of Mercury was accurately determined.

**A**ny residual atmosphere has less than a million-billionths the pressure of the Earth's atmosphere at sea level. However, a trace of helium, perhaps derived by outgassing from Mercury's interior, was found.

**I**t was discovered that Mercury has an internal magnetic field, similar to but weaker than that of Earth.

**M**ercury's surface is heavily cratered and resembles that of the Moon.

**A** huge circular impact basin (Mare Caloris), about 1300 kilometers (810 miles) in diameter, was discovered.

**A** planetary feature unique to Mercury was found, consisting of long scarps, or cliffs, that apparently were produced by compression in a major shrinkage of the planet.

**F**lat plains, perhaps lava flows, were found.

**M**ercury was found to be closer to a perfect sphere than is the Earth.





## Venus

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**G**round-based radar measurements in the early and mid-1960s showed that the rotation period of Venus is about 240 days and that the rotation is retrograde, so that it spins in the opposite sense with respect to the Earth.

**T**he 1962 flyby of Venus by Mariner 2 led to an accurate determination of the planet's mass. This spacecraft, and ground-based observations, also measured high temperatures, around 300oC, in the atmosphere of Venus.

**G**round-based observations detected various minor components of the Venus atmosphere, including the gases hydrochloric and hydrofluoric acid (1967), carbon monoxide (1968), water (1972), and sulfuric acid (1978). In 1973, it was found that the upper cloud layer is composed of sulfuric acid droplets.

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**F**rom the USSR's Venera 7 in 1970, it was found that the atmosphere is largely carbon dioxide, with a pressure at the planetary surface about 100 times that of the Earth's atmosphere. Venera 7 also measured a surface temperature of about 500oC.

**M**ariner 10 flew past Venus in 1974. Among the results were:

**V**enus has no significant magnetic field.

**A** notable disturbance in the solar wind is produced as it flows past Venus.

**V**enus is closer to a perfect sphere than the Earth.

**U**ltraviolet images of the atmosphere revealed streamline and circulation patterns, including Y- and C-shaped structures.

**T**he upper atmosphere was found to rotate much more rapidly (once in about 4 Earth days) than Venus itself, a result also suggested by ground-based measurements.

**H**ydrogen and helium were detected in the atmosphere.

**I**n 1975, the Venera 9 and 10 lander spacecraft found that the surface of the planet is firm and rocky. Their other results included:

**T**he measured surface winds had velocities of about 3 to 13 kilometers per hour (2 to 8 miles per hour).

**A** significant amount of sunlight reaches the surface.

**T**he surface rocks vary in radioactivity and have compositions resembling those of granite and basalt.

**T**he 1978 Pioneer Venus mission included both atmospheric probes and an orbiting spacecraft. Among the results were:

**T**he atmosphere was found to circulate in large planet wide systems, much simpler than the circulation patterns on the Earth.

**A** collar of polar clouds was discovered, which may be part of a large atmospheric circulation vortex.

**A**t least four distinct cloud and haze layers were found at different altitudes.

**T**he haze layers contain small aerosol particles, perhaps sulfuric acid droplets.

**A**ccurate measurements of the atmospheric composition showed that it was about 96 percent carbon dioxide, 4 percent nitrogen, with small amounts of water, oxygen, and sulfur compounds. Rare gases such as argon and neon detected in the atmosphere suggest that Venus is richer in volatile elements than the Earth or Mars.

**T**he surface of Venus was found to be generally smooth, much less irregular than that of the Earth.

**R**adar measurements from the Pioneer Venus Orbiter and from ground-based observatories revealed the presence of two broad plateaus as well as apparent volcanic structures, craters, and canyons.

**L**ightning and thunder are present on Venus, according to results from the Venera 11 and 12 landers in 1978.

**I**n 1982 the USSR Venera 13 and 14 spacecraft land on Venus and return photographs and preliminary analysis of Venus' soil.

**I**n 1989 the space shuttle Atlantis launched the Magellan spacecraft for its mission to map the surface of Venus.



## Mars

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**G**round-based observations detected water vapor on Mars in 1964.

**M**ariner 4 flew past Mars in 1965 and photographed a heavily cratered, moonlike surface.

**M**ariner 4 found that the Martian atmosphere is thin, with less than 1 percent the pressure of the Earth's atmosphere, and is composed largely of carbon dioxide.

**T**he Mariner 6 and 7 flybys took place in 1969. Instruments on these spacecraft found that nitrogen is virtually absent from the atmosphere and that solid carbon dioxide ("dry ice") occurs in the clouds and near the polar caps.

**M**ariner 6 and 7 found that the dust particles in the Martian atmosphere probably consist of silicate materials derived from the planetary surface.

[click here to see picture...](#)

**T**he first soft landing on Mars was executed by the USSR Mars 3 spacecraft in 1971; the spacecraft ceased operating 20 seconds after the landing.

**M**ariner 9 became the first Mars-orbiting spacecraft in 1971. It obtained over 7300 photographs. Among the results of this mission were:

**M**ars is actually a two-part world, with an ancient cratered surface in the Southern Hemisphere and a geologically younger surface, with volcanoes, canyons, and dry river channels, in the Northern Hemisphere.

**T**he Martian volcanoes include a few huge ones, rising to heights of as much as 25 kilometers (16 miles), with fresh looking lava flows.

**M**ars has a huge valley (Vallis Marineris), about 5000 kilometers (over 3000 miles) long.

**S**inuuous channels, with braided and streamlined formations, appear to be former river beds.

**L**andforms resembling lava flows occur in flat regions.

**T**here are layered deposits in the Martian polar regions, perhaps indicating glacial periods in past times.

**S**olar ultraviolet light is not absorbed by the atmosphere and hence reaches the surface of Mars.

**P**eriodic global dust storms were observed in detail.

**T**he two small moons of Mars were photographed and found to be very dark and to have irregular shapes and cratered surfaces.

[\*click here to see picture...\*](#)

**T**he Viking 1 and 2 landers and orbiters reached Mars in 1976. Among their many findings were:

**T**he highly oxidized soil produced unique chemical reactions in the life detection instruments (see Appendix section on Exobiology).

**T**he reddish color of the soil is due to oxidized iron.

**T**he soil is fine-grained and cohesive, like firm sand or soil on Earth.

**T**he surface rocks resemble basalt lava, and the soil chemistry is like that of weathered, altered basalt.

**T**here are water and sulfur compounds in the soil.

**T**he sky is not blue but pink, its color caused by fine suspended particles of red dust.

**T**he polar caps are largely made of water ice.

**T**he winds at the surface of Mars are light, about 24 kilometers per hour (15 miles per hour).

**T**he surface temperature ranges from about -84° C (-120° F) at night to -29° C (-20° F) in the afternoon.

**F**og and clouds occur despite the fact that the water content of the atmosphere is less than 0.1 percent that of the air on Earth.

**T**he surface pressure of the atmosphere, only about 0.8 percent that of the Earth's atmosphere, varies seasonally in accord with the evaporation of the polar caps.

**T**he isotopic ratios of carbon and oxygen in the Martian atmosphere resemble those of the Earth's atmosphere.

**T**he atmosphere has been modified over time by the escape of nitrogen to space; this has produced nitrogen isotopic ratios that differ from those on Earth.

**M**ars may have had a much denser atmosphere in the past, and could have had liquid water on its surface.

**T**he abundance's of rare gases such as argon and neon suggest that Mars has a lower volatile content than either the Earth or Venus.

**T**he Martian moons are grooved, indicating that fracturing may have occurred; they may be asteroids that were captured by Mars.



## Jupiter

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**A**ccording to a theory formulated in 1958, the interior of Jupiter includes a large core of metallic hydrogen.

**P**ioneer 10, in 1973, and Pioneer 11, in 1974, made the first flybys of Jupiter; both spacecraft survived passage through the asteroid belt and through the Jovian trapped radiation. Among the findings from these spacecraft were:

**A**side from its polar flattening, Jupiter is very symmetrical and has no gravitational anomalies; it behaves like a liquid planet.

**J**upiter is slightly more massive than had been indicated from ground-based observations.

**A**s suggested from ground-based measurements, Jupiter emits twice as much energy as it receives from the Sun.

**T**he temperature at the center of the planet may be 30,000o C.





## Jupiter's Atmosphere

**F**rom ground-based studies, it was deduced that the atmosphere of Jupiter must consist mostly of hydrogen and helium, in an approximately 2 to 1 ratio. The bright bands in the atmosphere ("zones") are cooler than the dark ones ("belts").

[click here to see picture...](#)

**A** theory proposed in 1958 interprets the great Red Spot as the top of a rotating column in the atmosphere.

**A**mong the results of the Pioneer 10 and 11 missions were:

**T**he general banded structure of the Jovian atmosphere is not present near the poles; there, oval circulation patterns develop.

**A**t the poles, a thick, aerosol-free, or "blue sky", atmosphere was found.

**T**he bright zones consist of rising cloud masses at higher altitudes, while the belts are descending masses that allow a deeper view into the atmosphere.

**T**wo cloud layers are present; the thick, low cloud deck is topped by a thinner, clearer region.

**D**etailed study showed rapid motions among the clouds and changes in the wind speeds.

**B**right plumes of warm material were observed rising from deep in the atmosphere.

**C**hanges in the flow patterns of the Red Spot were observed between 1973 and 1974; the Red Spot and other features were interpreted as



hurricane-like storms.

**H**elium was detected, confirming the earlier deduction of the Jovian atmospheric composition.

**V**oyager 1 and Voyager 2 flew past Jupiter and its moons in 1979; among the findings from this pair of spacecraft were:

**E**ruptions of warmer material from below are signaled by brightenings followed by cloud spreading.

**A**long the boundaries of the belts and zones, there occur atmospheric jet streams, plumes, and extensive turbulence.

**T**here is actual mass movement, rather than simply wave motions, in the Jovian atmosphere.

**A**n east-west wind structure is present in the polar regions.

**T**he Red Spot rotates counterclockwise in about 6 days, as estimated from ground-based observations.

**T**he fraction of helium by volume in the Jovian atmosphere is 0.11.

**A**urorae were discovered in the polar regions and are related to the magnetic field lines and currents between Jupiter and its moons.

**L**ightning "superbolts" were detected in the cloud tops.

**T**here is intense ultraviolet emission from the atmosphere.

**M**inor components of the Jovian atmosphere that have been detected at various times include deuterium (heavy hydrogen) compounds; organic molecules such as ethane and acetylene; water vapor (found using the Kuiper Airborne Observatory in 1975); carbon monoxide; phosphine (PH<sub>3</sub>); and germane (GeH<sub>4</sub>).



## Magnetic Field and Tapped Radiation

**T**he discovery of naturally generated radio bursts from Jupiter was accomplished with a ground-based radio telescope in 1955. Theory indicated that a strong magnetic field must be present in order to account for the bursts, and additional radio observations showed that the occurrence of many bursts is related to the position of the Jovian moon Io.

**A**mong the findings of Pioneer 10 and 11 were:

**T**he magnetic field was detected and found to be huge. The bow shock of the Jovian magnetosphere had a measured width of 26 million kilometers (16 million miles). The Jovian magnetic tail extends to beyond the orbit of Saturn. If the magnetosphere were visible in the sky from Earth, it would appear larger than the Sun or Moon.

**T**he Jovian magnetic field is 10 times stronger than Earth's and contains 20,000 times as much energy.

**T**he axis of the magnetic field is tilted 11 degrees from the Jovian rotation axis and is offset from the center of Jupiter in a manner similar to the axis of the Earth's field.

**T**he Jovian magnetic field has the opposite sense to Earth's field; the "north" magnetic pole is at the south pole of Jupiter.

**T**he magnetic field fluctuates rapidly in size on the sunward side of Jupiter because of pressure variations in the solar wind, an effect studied in further detail by the two Voyager spacecraft.

**E**nergetic protons were found and measured in the Jovian radiation belt.

**I**t was discovered that streams of high-energy atomic particles are ejected from the Jovian magnetosphere and travel as far as the orbit of the Earth.

**E**lectric currents were detected flowing between Jupiter and some of its moons, particularly Io.

**A**mong the findings of Voyager 1 and 2 were:

**W**ithin the Jovian magnetosphere is a huge sheet of plasma (a gas of electrically charged atomic particles), 4.8 million kilometers (3 million miles) in diameter. The plasma sheet rotates along with Jupiter and its magnetic field.

**S**ome of the magnetospheric plasma has a remarkably high temperature, in the millions of degrees. Among the high energy particles in the plasma are ions of hydrogen, sulfur, and oxygen.

**A** sulfur-rich plasma, which was not present in 1973, was detected near Io, with a temperature of about 100,000o C.

**T**he electrical current between Jupiter and Io was measured at about 5 million amperes.

**I**t was found that radio emissions may be generated in the plasma near Io.



## The Moons and Ring of Jupiter

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**G**round based studies of the Jovian moons in the 1970's revealed the presence of two additional small moons and the existence of water ice on the surfaces of the three outermost Galilean satellites, Europa, Ganymede, and Callisto.

**F**indings about the Jovian satellites from Pioneer 10 and 11 included:

**T**he two outermost Galilean moons, Ganymede and Callisto, are less dense than the Earth's Moon.

[click here to see picture...](#)

**I**o was found to be 28 percent more massive than had been calculated from ground based observations and to be 1.22 times more massive than our Moon.

**A** thin atmosphere, about 1/20,000 of the density of Earth's atmosphere and extending to about 115 kilometers (70 miles) above the surface was discovered on Io.

**A** cloud of sodium vapor around Io and its orbit, detected from the ground, was detected and found to be immersed in a cloud of hydrogen as well.

**R**esults of the Voyager 1 and 2 missions included:

**T**hree additional moons were discovered.

**A**malthea, the small inner moon of Jupiter, was found to have an elliptical shape. In effect it is a big rock, about 265 x 140 kilometers (165 x 87

miles) in size.

[click here to see picture...](#)

**V**olcanic eruptions were discovered on Io, the first evidence of active volcanism found outside the Earth. The volcanism is probably induced by tidal heating. The erupted plumes extend up to 320 kilometers (200 miles) above the surface, and the volcanic activity varies over times of a few months.

**A** hot spot on Io, 150o C warmer than the rest of the surface, and associated with volcanic features, was discovered.

**E**uropa was found to be a world of essentially flat terrain, with virtually no topographic relief. It is marked by intersecting linear features, not cracks, and the surface is very young, as indicated by the lack of impact craters.

**B**oth cratered and grooved terrain's are present on Ganymede; the icy crust of this moon appears to have been globally deformed.

**G**anymede was found to produce distinct disturbances in the Jovian magnetic field and trapped radiation belts as far as 200,000 kilometers (124,000 miles) away.

**C**allisto's crust is ancient and heavily cratered, with large impact basins.

**A** ring around Jupiter was discovered inside the orbit of the innermost moon. It apparently extends down to the top of the Jovian atmosphere.

**I**n 1989 the space shuttle Atlantis launched the Galileo spacecraft for its journey to Jupiter. It is due to arrive during 1996.



## Saturn

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**A**mong important recent findings from Earth-based observations of the Saturn system have been the detection of a deuterium compound in the atmosphere of Saturn, indications that the small ring particles are composed of or covered by ice, the detection of ice on the moons Rhea, Iapetus, and Dione, and the discovery of methane in the atmosphere of Titan.

**T**he first spacecraft flyby was accomplished by Pioneer Saturn in 1979. Among the findings were:

**C**onfirming ground-based studies, Saturn has an internal heat source like Jupiter and radiates about twice as much energy as it receives from the Sun.

**A**s suspected, Saturn must have internal shells of liquid and metallic hydrogen, small amounts of helium, ammonia, and water, and perhaps a small rocky core.

**A** magnetic field was discovered around Saturn, larger than the Earth's, but smaller than that of Jupiter. It is five times as weak as predicted by theory.

**T**he axis of Saturn's magnetic field is aligned parallel to the planet's rotation axis, contrary to the circumstances in both the Earth and Jupiter.

**T**he boundary of the magnetic field varies due to changes in the pressure of the solar wind on the sunward side, as was found in the case of Jupiter.

**T**he atmosphere of Saturn has weak bands, rather than the conspicuous belts and zones seen on Jupiter.

**T**here is a high haze, perhaps composed of crystals of ammonia ice, above the clouds.

**A**pparent high-speed jet streams were detected in the atmosphere.

**C**onfirming ground-based measurements, the cloud-top temperatures were measured at about -200o C (-330o F), only about 73o C (130o F) above absolute zero.

**R**adiation belts were discovered that are weaker than those of Jupiter. The radiation is absorbed (cut off) by the rings and moons of Saturn. Cutoffs in the radiation data were used to infer the presence of additional rings and moons beyond those already known from visual observations.

**T**he Voyager I encounter (November, 1980) provided a closer look at Saturn and its surroundings. Some of the new discoveries were:

**T**he details of Saturn's atmosphere appear similar to Jupiter's, with alternating light and dark bands and circulating storm systems.

**W**ind speeds up to 1500 kilometers per hour (930 miles per hour) were measured near Saturn's equator; these winds are four to five times as fast as those measured on Jupiter.

[\*click here to see picture...\*](#)

**U**nusual atmospheric features include a ribbon-like wave feature, large and small clouds, and a red oval similar to, but smaller than, Jupiter's Red Spot.

**A**urorae were observed in the atmosphere above Saturn's poles.

**A**lthough lightning bolts were not observed on Saturn, radio signals typical of lightning flashes were recorded. The signals may be produced by electrical discharges in the rings rather than in Saturn's atmosphere.





## Saturn's Rings

[click here to see picture...](#)

**T**he Pioneer Saturn flyby in 1979 made several new discoveries about the rings:

**T**he rings consist largely of particles several centimeters in diameter. They are extremely cold and possibly composed of frozen water and other ices.

**A**n extensive cloud of hydrogen was discovered around the rings.

**T**wo new rings (called F and G) were discovered, and a gap between rings was confirmed.

**V**oyager 1 provided much more detail on the beauty, complexity, and sometimes baffling nature of the rings. Among the discoveries were:

**T**he six known rings are actually composed of hundreds of tiny, thin ringlets with intervening spaces, so that the whole ring system looks something like the grooves in a phonograph record. Even the Cassini division, once thought to be empty space between the A and B rings, contains several dozen ringlets. There are far too many rings to be explained by our present theories of how planetary rings form and remain stable.

**E**longated radial features that last for hours to days were observed in the B-ring. These "spokes" may be clouds of electrified dust rotating around Saturn above the plane of the rings.

**T**he thin outer F-ring, discovered by Pioneer Saturn, was resolved into three distinct but intertwined ringlets. This braided ring structure is very difficult to explain; it seems likely that both electrical and gravitational forces are at work.



**T**wo small moons, one on each side of the F-ring, may act as "shepherds," their gravitational attraction keeping the ring particles on track between the orbits of the two moons.



## Saturn's Moons

**N**ine (possibly ten) moons had been detected from Earth. The encounter of Pioneer Saturn (September, 1979) provided several new discoveries:

**A**t least two new moons were discovered by Pioneer and ground-based observations.

**A**ccurate masses were determined for the moons Rhea and Iapetus.

**T**he cloud-top temperature of Titan was found to be very low, about -200oC (-330oF), and a hydrogen cloud was discovered around Titan.

**A** much closer look at several of Saturn's moons was provided by Voyager 1. The new results included:

**S**ix tiny, unnamed moons were photographed, some of them for the first time. Satellites 10 and 11 share the same orbit and must frequently undergo some orbital "evasive actions" to avoid colliding. Satellite 12 shares the orbit of the larger moon Dione. The shepherd Satellites 13 and 14, on either side of the thin F-ring, may exert gravitational forces to keep the ring in place, while Satellite 15, located just outside the large A-ring, likewise may help keep that ring in place..

[click here to see picture...](#)

**T**he inner moons Mimas, Tethys, Dione, and Rhea all have heavily cratered surfaces like those of the Moon and Mercury, although Saturn's moons are composed largely of water ice. This shows that meteorite bombardment, even as far out as Saturn, has been a major process in shaping the solar system.

**M**imas is marked by a huge impact crater that is fully one-fourth the diameter of Mimas itself. This crater makes Mimas look like a staring eyeball, and the impact that formed it was almost intense enough to blast

Mimas into fragments.

**T**he inner moons also show traces of internal geological activity. Tethys has a rift-like valley that stretches 800 kilometers (500 miles) across its surface. Dione shows several sinuous, branching valleys. Both Dione and Rhea have bright, wispy streaks on their surfaces.

**A**lthough Enceladus orbits between two heavily cratered moons, Mimas and Dione, it seems smooth and entirely uncratered, as viewed from Voyager 1.

**T**itan, Saturn's largest moon, has a diameter of 5120 kilometers (3180 miles), which makes it smaller than Jupiter's moon Ganymede. Titan's dense, hazy atmosphere is at least 400 kilometers (250 miles) thick and completely shrouds the surface from view.

**T**itan's atmosphere was found to be mostly nitrogen (like the Earth's), with minor methane and other hydrocarbons. At the surface, the pressure of Titan's atmosphere is at least twice that on the Earth. The surface temperature, about -175°C (-280°F), is low enough to permit lakes and streams of liquid nitrogen to form on its surface.

**L**ong-range Voyager 1 photographs of Iapetus, an outer satellite, confirmed Earth-based observations by showing that the satellite has light and dark faces, but no explanation for this puzzling difference was found.



## Uranus

**A** wholly unanticipated system of thin and narrow rings was discovered around the planet Uranus in 1977 by telescopic observations from the Kuiper Airborne Observatory.

**T**here may be as many as nine of the very dark rings.

**I**n 1986 Voyager 2 made its closest approach to Uranus.

**D**uring that fly-by, detailed images of Uranus' surface, its ring system, and its five satellites were returned to Earth.



## Neptune

**C**loud patterns were detected in the atmosphere of Neptune by ground-based observations in 1978.

**I**n 1989 Voyager 2 passed Neptune and returned detailed photographs of Neptune's surface and moons.

**V**olcanism was discovered on the moon Triton.

**I**n addition, Voyager 2 discovered six new moons circling Neptune.



## Pluto

All studies of Pluto thus far have been done from the ground.

In recent years, a surface layer of frozen methane has been detected.

Also, a very important discovery took place: astronomers proved conclusively that Pluto has a moon; they subsequently named this moon Charon.

It appears that Pluto is much smaller, less dense, and less massive than previously believed.



## Asteroids and Meteorites

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**A**lthough nearly all asteroid observations thus far have been made from the ground, the asteroid belt was safely traversed by Pioneer 10 in 1973 and subsequently by other spaceprobes.

**B**ased on the study of reflected sun-light, asteroids have been classified into six major compositional families since 1970.

**S**ince 1970, diameters have been estimated for an increasing number of asteroids by means of infrared observations.

**I**n 1968, a radar echo was successfully obtained from the small asteroid Icarus during its close approach to the Earth. Another radar contact was made in 1980.

**S**ince 1976, several new Earth-crossing asteroids, i.e., those which cross the orbit of the Earth, far from the inner boundary of the asteroid belt, have been discovered. Among them was Ra-Shalom, discovered in 1979.

**M**ost asteroids have been found to be very dark, perhaps a symptom of carbon content, and chemically bound water has been detected on some of the darker surfaces.

**T**he mass of the large asteroid Vesta has been determined, and it has been found that the surface composition of Vesta resembles that of basalt lava.

**I**n 1979, a minor planet (Chiron) was discovered between the orbits of Saturn and Uranus, far outside the known limits of the asteroid belt.

**L**aboratory study of meteorites reveals that they typically have spent only



10 million to 100 million years exposed to the space environment, a finding that suggests that relatively recent collisions have occurred in the asteroid belt.

**S**ome meteorites are composed of lava, indicating that early melting and volcanic eruptions occurred on their parent asteroids.

**D**aughter products of extinct, primordial, radioactive isotopes, such as iodine-129, plutonium-244, and aluminum-26, have been found in meteorites. These isotopes, when still present in the parent objects of the meteorites, may have served as important heat sources.

**A**mino acids have been found in meteorites.

**W**hite inclusions of minerals formed at high temperatures have been found in the Allende meteorite. These may be samples of the first material to solidify in the original cloud from which the solar system was born.

**E**lemental anomalies found in the white Allende inclusions indicate that some matter may have been introduced into the solar system cloud from another star, presumably a supernova.

**T**he formation ages of meteorites date back 4.6 billion years, providing a firm estimate for the age of the solar system.

**G**ases from the solar wind have been found to be trapped and preserved in meteorites.

**T**he rates at which iron meteorites cooled from the molten state within their parent objects have been determined; they range from 1 to 20 degrees centigrade per million years. This cooling is too rapid to have occurred within the iron core of a large planet.





## Comets

**I**n 1970, the existence of huge hydrogen clouds around the comets Tago-Sato-Kosaka (1969 IX) and Bennett (1970 II) was discovered with the OAO-2 satellite. The clouds, also observed by OGO-5, are detectable only in ultraviolet light. The existence of such clouds had been predicted on the basis of the icy conglomerate or "dirty iceball" model of comets, and thus the discovery helped to confirm the theory.

**T**he predicted presence within the cometary hydrogen cloud of high velocity material, with speeds of about 20 kilometers per second (12 miles per second), was found to be consistent with the intensity distribution of the hydrogen clouds mapped by OAO-2 and subsequent spacecraft. It was recently confirmed by spectroscopic observations from the Copernicus satellite.

**T**he hydrogen clouds provide direct evidence for a rate of mass flow from the nucleus of a comet that is adequate to account for the so-called "nongravitational force" that disturbs the motions of comets.

**R**adio telescopes have observed the hydroxyl (OH) radical in several comets and have made apparent detections of the substances CH<sub>3</sub>CN, HCN, and CH in Comet Kohoutek (1973 XII).

**T**he first definite detections of carbon and oxygen atoms in a comet were made by ultraviolet spectroscopy from two sounding rockets launched to study Comet Kohoutek in 1974.

**I**nfrared measurements made from the ground have revealed the presence of silicate dust grains in several comets.

**R**adio observations of Comet Kohoutek and Comet West (1975) revealed the presence of transient microwave emission apparently produced by the icy-grain halo, a structural feature of comets that had been predicted to exist.

**O**bservations of Comets Seargent (1978) and Bradfield (1979) with the IUE satellite revealed the presence of atomic sulfur and CS in the coma and showed that these species are produced from an extremely short-lived (less than about 100 seconds) parent molecule, perhaps CS<sub>2</sub>. The forbidden neutral oxygen line at 2972 Å was identified; it is thought to come from photodissociation of water and thus provides a means of determining the spatial distribution of water vapor in the coma.

**U**sing IUE, the water vapor production rate of Comet Bradfield was determined over a range of heliocentric distance from 0.7 to 1.5 astronomical units, the first time this has been measured for a comet. The variation was inconsistent with the idea that the vaporization might depend only on the input of heat from the Sun.

**I**n 1978 the International Sun-Earth Explorer satellite was launched to intersect with the path of the comet Giacobini-Zimmer. Its path was redirected in late 1983 and the satellite intersected the path of the comet in the fall of 1985, sending back valuable information.



## Interplanetary Dust

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**P**egasus 1, in 1965, and other spacecraft showed that interplanetary dust particles are about 10,000 times less abundant than had been indicated by early space experiments.

**P**ioneer 10 and 11, in 1973 and 1974, found that Mars sweeps up the interplanetary dust near its orbit.

**P**ioneer observations also showed that the zodiacal light is produced by dust that orbits the Sun at great distances from the Earth.

**T**he first definite samples of interplanetary dust have been collected by high-altitude research aircraft since 1978.



## The Sun

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**T**he solar ultraviolet spectrum has been mapped and studied, first with sounding rockets in 1946 and later with the Orbiting Solar Observatories (OSO satellites).

**W**ith radio telescopes, it was found that radio bursts of many kinds are emitted by the Sun.

**G**round-based telescopes discovered "supergranulation," the existence on the Sun of convection cells with typical sizes of 30,000 kilometers (19,000 miles).

**S**ounding rocket instruments discovered that solar soft (lower energy) X-rays are produced primarily by active regions.

**O**SO instruments revealed that bursts of hard (higher energy) X-rays accompany solar flares.

**S**ounding rocket observations unexpectedly detected neutral hydrogen emission from the solar corona, allowing astronomers to measure the temperature of the coronal hydrogen and to infer the speed of the solar wind moving out through the corona.

**G**round-based telescopes show that the five-minute oscillations of the Sun are composed of superposed oscillation modes.

**A**n OSO instrument discovered gamma ray emission lines, indicating that nuclear reactions sometimes occur in solar flares.

**O**bservations from Skylab revealed that:

**T**he corona consists largely of arcades of magnetic-field arches.

**T**he basic structure of a solar flare is a magnetic arch or loop.

**C**oronal holes do not exhibit the differential rotation which characterizes the solar photosphere, but rotate as though they were solid objects.

**T**he top of a flare loop is hottest, and its foot points are relatively cool.

**T**here are numerous small regions of emerging magnetic flux, which appear as bright points on the Sun in soft X-rays, with lifetimes of three to six hours.

**O**bservations from OSO-7 and Skylab showed that large "solar bubbles" or coronal transients pass outward through the corona after flares and prominences erupt.

[click here to see picture...](#)

**O**SO-8 measurements showed that contrary to earlier expectations, acoustic waves do not carry sufficient energy to heat the corona. Perhaps the dissipation of magnetic energy is responsible for the high temperature of the corona.

**S**ounding rocket observations showed from week to week by amounts of plus that jets, perhaps related to the spicules seen with ground-based telescopes, are ejected from the solar surface and reach speeds of 300 kilometers per second (190 miles per second).

**C**ombining the results of observations from the Solar Maximum Mission (SMM) satellite and ground-based radio telescopes, it was found that hard X-rays are emitted at the foot points of flare loops, while microwave radio bursts are emitted at the tops of the loops.

**A**n instrument on SMM discovered that the total light of the Sun varies from week to week by amounts of plus or minus 0.05 percent and that there are some larger variations as well.

**S**M M observations revealed how solar flares occur after hot plasma fills preexisting magnetic loops, which then explode.

[\*click here to see movie...\*](#)

**I**n 1990, the space shuttle Discovery launched the spacecraft Ulysis toward the sun. Arriving during 1996, its mission is to explore the polar regions of the Sun.



## Heliospheric Physics

**G**round-based measurements found that there is an inverse correlation between solar activity and cosmic ray intensity.

**I**nterplanetary spacecraft including the Mariners detected and measured the solar wind.

**T**he abundance's of such atoms as carbon, nitrogen, oxygen, and iron have been measured in the solar wind.

**E**nhanced amounts of the isotope helium-3 were discovered in the matter ejected from solar flares and in high-speed streams of the solar wind.

**W**aves and discontinuities were discovered in the solar wind.

**T**he interplanetary magnetic field was found to possess sector structure that rotates with the Sun.

**S**kylab observations identified coronal holes as the sources of high-speed wind streams and showed that coronal holes are the cause of recurrent geomagnetic storms on Earth.

**C**orrelation of the interplanetary magnetic field with the magnetic field at the solar surface was accomplished.

**A** warped-disk model for the magnetic neutral sheet in interplanetary space has been developed.

**P**ioneer 10 has established that the heliosphere extends out beyond the orbit of Uranus.

**T**he International Sun-Earth Explorer (ISEE) mission discovered electron

bursts that originate in the outer corona and traced the paths of the bursts outward through the corona, along the spiral magnetic field.





## Magnetospheric Physics

**T**he Van Allen radiation belts of the Earth were discovered by Explorer 1.

**T**he magnetopause, or boundary between the solar wind and the Earth's magnetosphere, was located at a distance of about 20 Earth radii toward the Sun.

**T**he Earth's "bow shock, a collision less shock wave, was found to be slightly closer to the Sun than the magnetopause and separated from the latter by a region called the magnetosheath.

**T**he Earth's magnetic tail (magnetotail) was found to extend far into space, beyond the distance of the Moon.

**L**arge electrical current systems were found to flow through the magnetosphere.

**I**t was determined that significant numbers of charged, particles enter the magnetosphere directly from the solar wind.

**E**vidence was found for a magnetic field reconnection process in the magnetotail, which accelerates charged particles to high velocities.

**D**isplays of the aurora on Earth were found to originate from disturbances in the magnetotail.

**L**ow-frequency waves were detected in the magnetosphere.

**I**t was found that electric currents move along the magnetic field lines above the Earth's polar regions. These currents are maintained by electric fields aligned along the magnetic field, which once were thought to be impossible.





## Ionospheric Physics

[click here to see picture...](#)

**R**ocket-borne ion mass spectrometers showed that molecular ions predominate among the charged particles in the lower layers of the Earth's ionosphere, at altitudes of 90 to 200 kilometers (about 55 to 125 miles).

**R**ocket observations showed that the charged particles in the upper layers of the ionosphere, at altitudes of 200 to 800 kilometers (125 to 500 miles), are mainly ions of oxygen.

**M**etallic ions derived from meteorites were discovered in the E region of the ionosphere.

**M**easurements showed that the temperatures of the ionospheric electrons are higher than those of the ions; the ion temperatures are higher than those of the neutral gas.

**O**bservations by Explorer satellites showed a division between the polar ionosphere and the ionosphere over lower latitudes of the Earth.

**P**lasma instabilities were artificially excited for study in the ionosphere by means of radio-wave injection.

**E**xtensive satellite measurements solved the long-standing problem of why there are more electrons in the winter ionosphere than in the summer ionosphere at the low- to medium-activity phases of the sunspot cycle. (More electrons would be expected in the summer, since the Sun is then more nearly overhead.) Systematic measurements by the Atmosphere Explorers provided a large data base.

**T**his allowed variations associated with satellite height, latitude, time of day, and season to be statistically separated. Three factors were found to contribute to the winter anomaly. First, there is an increase in neutral

atomic oxygen due to atmospheric circulation and dynamics; this results in an increase in electron production due to more ionization by the Sun. Second, the temperature of the neutral nitrogen is lower in winter, so that the existing ionization is removed more slowly by a chemical recombination process. Third, there is a more rapid production of ionization in winter due to increased quenching of an intermediate excited state of atomic oxygen.

**C**onvective bubbles that cause the equatorial "spread-F" effect were detected. These involve electron density variations by factors of 100 within scale sizes of approximately 10 meters (33 feet). The bubbles move at speeds of hundreds of meters per second.

**A** "polar wind" of ions that are convected rapidly upward from the ionosphere above polar regions was discovered. The ions either travel out along magnetic field lines to interplanetary space or are transported into the magnetotail.



## Cygnus X-1

[click here to see picture...](#)

- 1964** Strong source Cygnus X-1 discovered with an X-ray telescope carried on a sounding rocket.
- 1971** Uhuru satellite monitored time dependence of Cyg X-1 and found periodicity matching that of visible-light spectral changes in a faint blue star in the direction of the X-ray source. A radio source also found at this position. The spectral changes revealed that the blue star has a dark companion star so massive that, according to current theory, it cannot be a neutron star and presumably is a black hole.
- 1973** X-ray telescope on a sounding rocket found very rapid intensity changes in Cyg X- 1 of type predicted to accompany accretion of matter onto a black hole.
- 1975** Analysis of X-ray intensity changes of Cyg X-1 showed that flares of about 0.5 seconds duration occur randomly, a phenomenon not found in other X-ray sources.



## Gamma Ray Bursts

[click here to see picture...](#)

**1973** Physicists announced that celestial gamma ray bursts of unknown origin, arriving from random directions in space, were discovered with the Vela satellites, a set of Earth-orbiting spacecraft designed to monitor the Limited Test Ban Treaty. The bursts were first recorded in 1967, but were not immediately recognized as extraterrestrial events.

**1974** Study of a gamma ray burst found in data recorded in 1972 by an instrument on Apollo 16 showed that it had more than five prominent intensity peaks. Earlier known bursts had one or two peaks.

[click here to see picture...](#)

**1978** Statistics of the occurrence of gamma ray bursts of weak intensity, as measured with balloon-borne instrumentation, showed that the bursts must arise in sources located inside our Milky Way galaxy.

**1979** Interplanetary network of gamma ray detectors on nine spacecraft observed the strongest gamma ray burst yet on March 5th, with a remarkably fast rise time of less than one thousandth of a second. The source was pinned down to the direction of a supernova remnant in the Large Magellanic Cloud, companion galaxy of the Milky Way. The implication, if this identification is correct, is that the burst came from a neutron star that remained from the supernova. An eight-second recurrence of intensity peaks was observed, perhaps to be interpreted as the rotation period of the neutron star. Astronomers cautioned that the burst's properties were exceptional and that it might represent a different phenomenon than the other observed gamma ray bursts.





## Cosmic Rays

- 1912** Cosmic rays discovered in a balloon experiment. However, it was thought that they were gamma rays rather than subatomic particles.
- 1929** Cosmic rays found to be electrically charged, thanks to measurements from the newly developed Geiger-Muller counter.
- 1936** Muon recognized as a cosmic ray that reaches the ground. The first discovery of an unstable subatomic particle, this finding launched the discipline of elementary particle physics and showed that the primary cosmic rays which don't reach the ground are something other than muons.
- 1939** Primary cosmic rays found to be positively charged, with the flux of particles from the west slightly greater than that from the east, as would be predicted for positively charged particles moving in the Earth's magnetic field.
- 1960** Balloon experiments at high altitude discovered that about one percent of the cosmic rays are relativistic electrons.
- 1964** The flux of cosmic rays studied over a complete solar cycle was found to vary so that the flux reaching the Earth is reduced by as much as 20 percent when the Sun is in its active phase.
- 1974** Balloon measurements determined the average amount of matter traversed by cosmic rays in space between their sources and the Earth (five grams per square centimeter) by measuring the ratio of the number of light nuclei in the cosmic rays (lithium, beryllium, boron) to the number of heavy nuclei (carbon, oxygen). Light nuclei are probably produced when the heavier ones collide with interstellar matter, thus the larger the ratio, the more matter has been traversed, by the heavy nuclei.

**1977** The age of cosmic rays was found to be about 20 million years from two kinds of experiments. First, the IMP-7 and IMP-8 satellites measured the ratio of the beryllium-10 and beryllium-9 isotopes in cosmic rays; both are produced by the interaction of carbon and oxygen nuclei with the interstellar matter, but beryllium-10 is unstable, with a half-life of 2.5 million years. Second, balloon-borne telescopes observed the energy spectrum of relativistic cosmic ray electrons and found it to bend at 20 GeV, a result predicted for a 20-million-year exposure to galactic magnetic fields and the microwave background radiation.

**1979** Launch of HEAO-3 satellite with two large cosmic ray experiments, one to study isotopes and one to observe very heavy nuclei. A new theory of cosmic ray variations due to phenomena of the solar wind and interplanetary magnetic fields was advanced on the basis of data from many interplanetary spacecraft.





## Quasars

[click here to see picture...](#)

- 1962** The position of radio source 3C273 was determined when it was occulted by the Moon, and a faint star-like object with a jet was photographed at the position. Its spectra showed unusual emission lines.
- 1963** The spectral lines were identified as familiar hydrogen lines, but redshifted by about 16 percent of their wavelength, so that 3C273 must be extremely far away and hence thousands of times more luminous than a galaxy.
- 1970** Sounding rocket telescope discovered X-rays from 3C273.
- 1972** Variability of infrared radiation from 3C273 was reported; the time scale of variation is too short for the radiation to arise from hot dust grains, so the emission mechanism must be nonthermal.
- 1978** COS-B satellite observations revealed a weak gamma ray source in the direction of 3C273. X-ray observations of the quasar OX 169 showed that its intensity changed by a factor of six in only six hours. If (as one theory maintains) the source of the X-rays is matter accreting onto a black hole, then this rapid change implies that the black hole has a mass at least a million times greater than that of the Sun.
- 1979** An X-ray quasar reported to have a redshift of 3.2, corresponding to a velocity of recession of 97 percent of the speed of light. (The most distant known quasar has a redshift of 3.5.)



## The Extent of the Universe

**W**hat is space?

**T**his is not such an easy question to answer. Is it simply the absence of anything? If so, then perhaps the Universe can be thought of as an enormous, empty container, which has sprinkled throughout it planets, stars, and others items.

**B**ut a container implies a boundary. A box or a bowl is a container, but they have boundaries. Does the Universe have a boundary? Also, if space was simply the absence of anything, then how can it be curved in some places, as Einstein proved it is.

**W**e know that even today everything in the Universe is expanding out from the Big Bang. But what is it expanding out *into*? If the Universe itself was created with the Big Bang, then where did the space come from that the Universe is expanding into?

**O**r is space continuing to be created as the universe expands? Or, did space exist prior to the Big Bang?

**A**stronomers, scientists, and philosophers have more questions than answers about the true nature of space at the present time. In many ways we know more about the quasars that are billions of light years away from us than we know about the nature of Space in our own bedroom.

**A**nd this brings up an even more intriguing question:

**W**hat exists outside the universe?

**H**ow can the space of the universe even have an end?

**I**f you try to imagine an infinite universe, you'll find that it's a very difficult thing to imagine. But it's just as strange to try to imagine it "stopping" -- after all, if the

universe stops, it seems that there would have to be a wall or something. And then that wall would just be another part of the universe.

**P**hilosophers, astronomers, and theologians have struggled with this question for ages.

**A**lbert Einstein made the interesting suggestion that the universe is both *infinite* and *bounded* -- that it is curved in on itself, and if you traveled in one direction long enough, you'd end up back where you started.

**S**tephen Hawking has made the fascinating proposal that the universe is perhaps *finite* and *without boundary* -- he talks about this at length in his book *A Brief History of Time*.

**D**ifferent cultures at various times have had different religious views on the subject as well. Maybe our universe is just one small part of a larger universe -- a universe of universes. Or maybe heaven is on "the other side."

**T**he most interesting aspect of the question is that it *has* an answer -- and a direct, unambiguous one, at that. The Universe either does end or it doesn't, in one way or another.

**W**e just don't know what the answer is. Yet...



## Pulsars

- 1967** Discovery of the first radio pulsar, CP1919, with a pulse period of 1.337 seconds and a pulse width of 0.04 second.
- 1968** Publication of theory that pulsars are rotating, magnetized neutron stars. Observations showed that the pulsars are gradually slowing down.
- 1969** Visible light pulses were discovered from the pulsar in the Crab Nebula. Then, discovery of X-ray pulses from this object showed that the power radiated in the form of X-rays is more than 10,000 times the luminosity of the Sun at all wavelengths.
- 1972** Gamma ray pulses at high energies observed from the Crab Nebula pulsar. There are two gamma ray pulses per pulse period, mimicking the X-ray pulse behavior, and they are exactly in phase with the radio pulses. Radio studies of many pulsars were sensitive enough to study them pulse by pulse; these investigations discovered a rich variety of phenomena, including drifting subpulses, so-called "giant pulses," and "nulling," when an entire pulse fails to occur.
- 1975** SAS-2 satellite discovered gamma ray pulses from the pulsar in the Vela X supernova remnant. Radio observations of this object had shown one pulse per period, although there are two gamma ray pulses in the same interval, neither one coinciding with the phase of the radio pulse. Also, the first radio pulsar in a binary system was discovered; continued monitoring over several years suggested that the orbital period is slowly changing, perhaps as the system loses energy in the form of gravitational waves, as predicted from the General Theory of Relativity.
- 1977** Optical pulses discovered from the Vela pulsar. Again, two pulses

seen per pulse period, but not coincident with either of the gamma ray pulses nor with the radio pulse.



## Interstellar & Intergalactic Media

- 1951** Detection of 21-cm (8.3-inch) wavelength radio emission from interstellar atomic hydrogen.
- 1956** Theory that there exists a galactic corona was proposed.
- 1969** Model of cold clouds and warm intercloud medium in pressure balance was proposed. The average density of interstellar matter was found to be one atom per cubic centimeter and thought to be equally divided between thin, warm gas and cool, denser clouds.
- 1972** Another Orbiting Astronomical Observatory (OAO-3), also called Copernicus, was launched, carrying the first instrumentation for ultraviolet spectroscopy of stars from Earth orbit.
- 1973** Copernicus results showed that: (1) The ratio of deuterium to hydrogen in interstellar gas is very low, a result that is evidence for the "Open Universe" theory, according to which the expansion of the universe will never end; (2) many of the heavier elements are much less abundant in the interstellar gas than in the stars that supply mass to the gas, which indicates that atoms of these elements have condensed to the solid state and are present in interstellar dust grains.
- 1974** Copernicus data lead to the theory that low-density cavities in interstellar space are caused by supernova explosions and are filled with hotter gas than the surrounding regions. It was suggested that a series of supernovae may cause cavities that connect to form tunnels of hot gas, threading through the cold clouds and warm intercloud medium.
- 1975** White dwarf stars were detected with an extreme ultraviolet telescope on the Apollo-Soyuz mission. The results show that

there is very little gas (less than 1 atom per 100 hundred cubic centimeters) in the vicinity of the Sun, out to at least 200 light years.

- 1976** According to Copernicus results, the bulk of the neutral interstellar gas is contained in small dense clouds rather than uniformly distributed.
- 1979** Discovery of an X-ray "superbubble" in the constellation Cygnus, made with an X-ray telescope on HEAO-L. Discovery by IUE of a corona of 100,000o C gas around the Milky Way galaxy, as theorized in 1956. The corona perhaps is fed with hot material by superbubbles expanding from the galactic plane. Discovery by IUE of coronae around the Magellanic Clouds; coronae must be very common around galaxies.





## Cosmic Background Radiation

- 1946** Prediction made that a cosmic background radiation exists due to the origin of the universe in the Big Bang.
- 1962** X-ray background radiation discovered by an instrument on a sounding rocket.
- 1965** Cosmic microwave background discovered with a radio telescope.
- 1968** Measurements of the isotropy of the X-ray background showed that the radiation must come from very great distances, because the universe is homogeneous and isotropic only on very large scales.
- 1977** Anisotropy found in the microwave background. The measurements indicate that our galaxy is moving at about 300 to 400 kilometers per second (190 to 250 miles per second) in the direction of the constellation Leo.
- 1979** The diffuse X-ray background at energies around 1 keV was found to be dominated by emission from many very distant individual objects, perhaps quasars and young galaxies.





## Biomedical Research

[\*click here to see picture...\*](#)

**T**he following articles are selected biomedical findings, not an all-inclusive list.

**R**esults are noted only under the first flight program in which they were found, except when significantly modified by data from subsequent flights.

**T**hus, although weight loss was observed after every flight, it is mentioned here for the first flight program and then, when modified by longer duration, for the last.



## Early 1960s: Mercury, Vostok

**C**onsiderable weight loss of 3.5 kg (8 pounds) postflight.

**1**2 percent increase in heart rate, normalizing after 9 to 19 hours.



## Mid-1960s: Gemini, Voskhod

**D**ecreased capacity to work postflight.

**1**2 to 15 percent decrease in bone density; bone decomposition potentially dangerous.

**H**ear rate as high as 180 beats per minute during extravehicular activity.

**B**lood abnormalities:

**L**oss of red cells and plasma volume.

**D**ecrease in important electrolytes (sodium, potassium).

**C**hanges in hormone levels.

**A**bnormalities in urinary excretion:

**P**rogressively increasing calcium loss.

**I**ncreased nitrogen, aldosterone, and catecholamines.

**R**educed sodium and chlorine postflight.



## Late 1960s-Early 1970s: Apollo, Soyuz

**A**daptation to weightlessness; high work capacity inflight, but significantly lower capacity postflight; two weeks needed to recover.

**M**uscle atrophy:

**D**ecreased strength, reflexes, and size of muscle.

**V**ariable complaints of muscle pain inflight and up to five days postflight.

**C**ardiovascular and hemodynamic adaptation:

**D**ecreased cardiac size and output.

**R**educed blood pressure postflight.

**D**ecline postflight in orthostatic tolerance (ability to stand without fainting).

**U**npredictable incidence of motion sickness, vomiting, and/or tumbling sensations; on occasion, functionally incapacitating.

**C**hanges in quality (types, viability) and quantity of bacteria normally associated with Man; significant implications for epidemiology of diseases, immunity, and digestion.

**O**bservations of visual light flashes by all crew members, resulting from the impact of cosmic rays.



## Mid to Late 1970s: Skylab, Salyut

[click here to see movie...](#)

**D**ecreased rate of weight loss with increased flight duration; pattern of weight loss indicative of early fluid loss and later tissue loss.

**R**oughly half the body volume loss occurred in the legs alone.

**S**hift of blood toward head region early in flight, contributing to a sensation of fullness in the head that persisted throughout flight.

**L**eg muscle atrophy; little or no change in sizes of arms and chest.

**R**igorous in flight exercises were successful in facilitating recovery postflight.

**N**o mineral loss in upper extremities, although significant loss in heel bone after 84-day flight.

**P**ostflight reduction in cardiac output and stroke volume and increase in heart rate.

**R**ed cell mass loss during first 30 days, but gradual recovery after 60 days. Thus, decrease in red cell mass immediately after 84-day flight was approximately one-half that of earlier (28-day and 59-day) Skylab flights.

**D**ecreases in various enzymes involved in red blood cell metabolism.

**E**levated white blood cell levels in flight, with rapid recovery postflight. Also, slight changes in humoral immunoglobulins.

**S**ensory changes, including slightly decreased visual acuity and depth

perception postflight and differences in taste of food samples between inflight and postflight periods.

**P**ostflight impairment of coordination and balance with eyes closed, although fairly normal with eyes open; implications for vestibular adaptation involving reliance on visual sensory input.

**L**evel of overall microbial contamination greater in 84-day Right than in previous flights, mostly due to increased population of fungi; implications for environmental control of future long-duration missions.





## The History of Exobiology

**A**mino acids have been synthesized non-biologically under conditions that simulate those postulated for the primitive Earth, followed by the synthesis of most of the biologically important molecules.

**A** laboratory model was developed for the evolution of cell structure from non-biological precursors.

**A**mmonia and water molecules were detected in interstellar space with radio telescopes, followed by the discovery of many more important organic molecules and precursors.

**A**mino acids and other biologically significant organic substances have been found to occur indigenously in meteorites and to be of non-biogenic origin.

**A**nalysis of rock and soil samples returned from the Moon provided no evidence for past or present life and only traces of the precursors of amino acids.

**S**imulations of the atmospheric chemistry of the outer planets showed that these atmospheres may be sites where extensive abiotic synthesis of organic molecules is presently occurring.

**S**pectroscopic observation of comets has revealed the presence of biologically important ions, molecules, and fragments.

**V**iking lander experiments found no existing life or organic chemicals in the soil at two locations on Mars.

**T**he Martian soil was found to possess intriguing chemical properties that mimic, in some respects, certain reactions of biological systems.

**A** third kingdom of microorganisms, the Archaeobacteria, was shown to be distinct from the prokaryotes and eukaryotes, thus altering concepts of the earliest lines of descent of species on the Earth.

**C**lay minerals were found to markedly influence the rate and direction of chemical evolution processes.

**A**lgae, bacteria, and fungi were discovered living inside rocks from the coldest and driest deserts of the Antarctic, which represent the closest terrestrial analog to the environment of Mars.

**M**icrofossils were discovered in rocks 3.5 billion years old, a finding that pushed back the estimate of the time when life originated on the Earth to within the first billion years after the Earth was formed.

**N**ucleic acid polymers in the biological size range were synthesized in a nonrandom manner, under geologically plausible conditions.





## Space Shuttle Missions

[click here to see picture...](#)

**1977** The US Space Shuttle makes its first test flight -- atop a Boeing 747 Jumbojet.

[click here to see picture...](#)

[click here to see movie...](#)

**1981** The Space Shuttle Columbia makes its first orbital test flight. Columbia was piloted by astronauts John Young and Robert Crippen.

[click here to see picture...](#)

**1983** The Space Shuttle Challenger, with astronauts Paul Weitz, Story Musgrove, Donald Peterson and Karol Bobko aboard, makes its first five day mission.

[click here to see picture...](#)

**1984** The first untethered astronauts become a reality when Robert Stewart and Bruce McCandless leave the Space Shuttle Challenger. Also during 1984, the first in-space repair of a satellite is made.

[click here to see picture...](#)

**1986** Disaster strikes the Shuttle Challenger, destroying it during launch, resulting in NASA's first mission fatalities. Future missions were put on hold until 1988.

**1990** The Hubble Space Telescope was released by the Shuttle. Unfortunately, the primary mirror of the telescope was polished to the wrong shape, resulting in unacceptable images. The

problem was later solved when a new "corrective lens" was sent up and installed on the telescope. Also in 1990 the Defense Department carried out its last classified mission. All future military missions were to be unclassified, the first one occurring during 1991.

[click here to see picture...](#)

**1992** The first African-American female, Mae Jemison, and the first married couple, Mark Lee and N. Jan Davis, were launched into space. Also during 1992, (1) the first extended mission of a Shuttle was made, lasting 14 days and (2) a satellite not launched by the Shuttle was captured and repaired for the first time.

[click here to see picture...](#)



## Earth

[click here to see picture...](#)

**T**he Earth, our home planet, is a complex environment of living animal creatures, living plants, microorganisms of all sorts, and of course inanimate resources, including volcanoes, oceans, and various landforms.

[click here to see picture...](#)

**W**e have studied the Earth for centuries, and we know more about the Earth than any other planet in our Solar System. Yet, even though it's our home planet, it still seems that we know only a small portion of everything there is to know. You can therefore imagine how much more true this is for the other planets and heavenly bodies in the Universe.

[click here for more information about the Earth...](#)



## Galileo Galilei, Life & Times

*[click here for contents...](#)*

### Introduction

**G**alileo Galilei: 1564-1642.

**T**his article briefly discusses the life and times of Galileo Galilei, one of the greatest astronomers in history. The focus is not only on his scientific achievements, but on his life, and on the society in which he lived.

**P**rior to the time of Galileo, and even during his time and for some time thereafter, it was commonly believed that the Earth was the center of the Universe, and that the Sun revolved around the Earth. This was the thinking put forth by Ptolemy.

**G**alileo believed differently -- he believed that the Earth revolved around the Sun. This opinion followed the thinking of Copernicus, and it was a very unpopular opinion during Galileo's day, since it seemed to challenge the importance of the Earth in the grand scheme of things.

**N**ot only did Galileo have this unpopular opinion, but he wasn't very sensitive in the way he expressed it. Of course, his opinion turned out to be correct, but his manner in trying to convince the other leaders of his day made them angry, and ultimately his personality hurt his chances for other people to accept his ideas.

**T**he following article tells this story in detail, focusing on his intellectual struggle, and his personal successes and failures, in addition to highlighting many of his scientific achievements.

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**G**alileo Galilei was an Italian astronomer, mathematician, and philosopher. He was born in Pisa on the 15th of February in 1564. His father, Vincenzo, was a poor descendant of a noble Florentine house.

**H**is father Vincenzo was a competent mathematician. He also wrote about music, and was a well known performer on the lute. He had a wife named Giulia Ammannati. They had three sons and four daughters; Galileo was their oldest son.

## **The Early Years of Galileo**

**G**alileo was famous for his intelligence and his skill at mechanical invention. His favorite hobby was inventing original and ingenious mechanical toys.

**H**e was also very good at literary studies. Galileo studied in a monastery called Vallombrosa, near Florence. He got most of his education there, where he studied Latin and learned to speak Greek well.

**O**ne of the monks gave him instruction in logic, but it wasn't a subject he enjoyed. He began to study to become a monk, but his father, who had other plans for Galileo, withdrew him from his studies.

**G**alileo's father wanted him to go into the field of medicine instead of mathematics or music. With the help of his father, Galileo was accepted at the University of Pisa. He graduated on the November 5, 1581, and immediately began to attend lectures by a well-known physician and botanist named Andrea Cesalpino.

## **The Studies of Galileo**

**G**alileo was gifted in many different areas of study.

**H**e enjoyed music and art, and probably would have chosen art as his field if it weren't for his father's influence.

**I**n fact, a famous artist during Galileo's time named Lodovico Cigoli said that he owed his own success in art to Galileo.

## **The Early Discoveries of Galileo**

**I**n 1581, while he was watching a lamp swinging in the cathedral of Pisa, he

noticed that, however far the lamp swung back and forth, it took the exact same amount of time to complete each full swing.

**A**fter he had tested his theory with experiments, he discovered how a pendulum works. Fifty years later he used this principle to design an astronomical clock.

**T**he technical name for his discovery is the **isochronism of the pendulum**.

**iso = same**                      **chronos = time**

**U**p to this time he didn't know much about mathematics. His father didn't encourage Galileo to study mathematics because he thought it would turn him away from the study of medicine.

**G**alileo happened by chance to have a lesson in geometry, from Ostilio Ricci. Afterward, he threw all his energies into the study of mathematics.

**W**ith Ricci's help, Galileo quickly learned all he could about geometry, and eventually got his father's permission to change from medicine to mathematics. In 1583 he withdrew from the university, and went back to Florence, where his family lived.

**H**e lectured at the Florentine Academy and afterwards published an essay on his invention of the hydrostatic balance. He became well-known throughout Italy.

## **The First Patron of Galileo**

**H**is first patron was the Marchese Guidubaldo del Monte of Pesaro who was an influential and well-respected scientist. The Marchese requested Galileo to write a book on gravity in solids. Because of this, he was hired by the Pisan University as a mathematics lecturer.

**D**uring the next two years (1589-1591) he did a series of experiments that helped him establish the first principles of dynamics.

**F**rom the leaning tower of Pisa he proved one of his most famous theories, having to do with the fact that things fall at the same rate no matter how heavy or light they are. Since his theories were new, he was unpopular with many of the other professors.

**D**uring this time he also lost the support of the Prince, and ended up resigning from his job as a professor. He went to live in Florence in 1591.

**G**alileo's father died in July 1591, and the Marchese Guidubaldo along with the Venetian Senate helped him to get a position as the Chair of Mathematics at the University of Padua.

## Residence at Padua

**H**is job in Padua lasted for eighteen years, from 1592 to 1610. Each time he was rehired, he was given an excellent raise. The university was so pleased with his performance that his salary went from 180 to 1000 florins.

**P**eople came from all parts of Europe to his lectures. The University eventually had to build a hall that could hold 2,000 people because of the large crowds who came to hear Galileo speak.

## Important Inventions of Galileo

**H**is invention of the proportional compass or sector is still used in geometrical drawing today. He invented it in 1597. Around that same time he invented the first thermometer, using a bulb and tube filled with air and water, which ended in a container of water.

**A** man named Rinieri, in 1646, improved it by hermetically sealing the liquid in glass. Then mercury was substituted for the water beginning in 1670. The mercury type of thermometer is still sold today.

Other discoveries and/or inventions include:

- formulating the basic principles of what Newton would formulate as the Three Laws of Motion (this includes the principle law of inertia)
- demonstration that the path of a "flying object" (like a bullet or arrow) is a parabola
- and above every specific discovery and invention must stand Galileo's general contribution to the concept of the scientific method, i.e., the notion that experimentation, and reproducible results, is the ideal way to prove or disprove any theory.

## Early Studies in Astronomy

**G**alileo believed in the Copernican theory of the solar system from when he was young. But, since he had no way to prove it, and since this was not the popular, accepted theory of the day, he was afraid people would make fun of him for it.

**S**o, he continued to teach the older, incorrect Ptolemaic principles based on the teachings of Aristotle in public, until the discovery of the telescope.

**G**alileo was not the original inventor of the telescope. An optician named Johannes Lippershey, from Middleburg, was. But after Galileo heard about the new invention, he succeeded in creating his own telescope in only one night!

## The Enhancement of the Telescope

**G**alileo made a lot of improvements on his telescope, until he had one that could magnify 32 times. He made hundreds of them with his own hands. Soon they were being requested all over Europe.

**H**e used two lenses--a convex one and a concave one. He ground the lenses himself. These same principles are still used in opera glasses today.

## Initial Astronomical Discoveries of Galileo

**T**here were many more discoveries after this. A publication called *Sidereus Nuncius*, published in Venice early in 1610, listed the first discoveries that had been accomplished with the help of this new invention (the telescope).

**H**ere, the mountainous surface of the moon was first described, and Galileo explained that the Moon did not shine on its own, but simply glowed due to the sunlight that it reflected.

**M**any of the stories and guesses about what the Milky Way was made of were cleared up by observations made by Galileo, after he studied it with his telescope.

**H**e said that it looked like an accumulation of smaller stars, while the great



nebulae were said to be the same.

**G**alileo was able to make all of these discoveries primarily due to his powerful telescopes.

**I**t's interesting to realize, however, that just about any decent pair of binoculars you can buy in a department store would be more powerful than the telescope used by Galileo to make all these important discoveries!

## Discovery of the Satellites of Jupiter

**B**ut one of the most important and revolutionary discoveries was of Jupiter's moons, first seen by Galileo on the 7th of January in 1610.

**H**e named his discovery *Sidera Medicea*, in honor of the grand-duke of Tuscany, Cosmo II, who had been his pupil, and was about to become his employer. Other moons of Jupiter were discovered after Galileo (some of them by Voyager I), but he discovered the first four.

## The Work of Galileo Continues

**I**n September 1610 Galileo finally left Padua to go to Florence. His research with the telescope was rewarded by the Venetian senate. They gave him a position for life as a Professor, at a very high salary.

**H**is discovery of the "Medicean Stars" was acknowledged by his nomination (July 12, 1610) as philosopher and mathematician extraordinary to the grand-duke of Tuscany.

**H**is new position allowed him to continue working on his research in the field of science. Since he had more leisure time, he was able to do this more easily. He discovered the triple form of Saturn (the ring formation was first recognized by Christiaan Huygens in 1655), the phases of Venus, and the spots on the sun.

**I**n the spring of 1611 Galileo visited Rome, and exhibited in the gardens of the Quirinal Palace. He showed how the heavens could be seen with this new invention of the telescope.

**H**e showed these wonders to the most important people at the pontifical court.

Because the court was so encouraging, he wrote in his *Letters on the Solar Spots*, many of the ideas he had believed to be true for much of his life.

**U**ntil this time, he had not been sure these Copernican ideas would be accepted.

## **A New View of the Solar System**

**E**ven in the time of Copernicus (who lived before Galileo) some well-meaning people had suspected a contradiction between the new view of the solar system and certain passages of the Bible. Many people thought these new views were anti-Christian, including a man named Giordano Bruno.

**G**alileo debated this issue, arguing that the new view was in fact compatible with Holy Scripture. This debate caught the attention of the authorities.

**I**n December of 1613 a Benedictine monk named Benedetto Castelli, at that time professor of mathematics at the university of Pisa, wrote to tell Galileo of a recent discussion at the grand-ducal table.

**C**astelli had been called on to defend the Copernican doctrine against theological (religious) objections. The monk was a good friend and disciple of the astronomer.

**G**alileo answered very forcefully. He offered to give proof that the Bible and the planetary system he believed in, were in agreement. He didn't realize that he had insulted many of the people he had hoped to win over to his own way of thinking, by implying that the people who didn't understand him were ignorant.

**P**eople got more and more upset about it. On the fourth Sunday of the following Advent, a priest called Father Caccini condemned the "new astronomy" and said his superiors did not approve of it either.

**O**n February 5, 1615, another Dominican monk named Lorini gave Galileo's letter to Castelli to the Inquisition.

## **A Warning for Galileo**

**C**ardinal Robert Bellarmine was at that time by far the most important faculty member of the Sacred College. He was very intelligent, schooled, and religious. Bellarmine was friendly with Galileo, but thought Galileo's teachings on science

were dangerous.

**A**fter a meeting between Cardinals Bellarmine and Del Monte, Galileo received a semi-official warning to avoid theology, and limit himself to scientific reasoning. "Write freely," he was told by Monsignor Dini, "but keep outside the sacristy."

**U**nfortunately, Galileo couldn't help himself, and he was headed for trouble. In December he traveled personally to Rome, full of confidence that his ability to debate and prove his points would win over the entire pontifical court to his own way of thinking.

**A**lthough the people he met with were friendly, and listened, Galileo was so overbearing about his views that once again he unknowingly offended the people he had wanted to impress.

## **The Injunction on Galileo: The Decree of 1616**

**O**n the 24th of February 1616 the consulting theologians of the Holy Office described Galileo's two propositions -- that the sun is immovable in the center of the universe, and that the earth has a diurnal motion of rotation -- in this way: the first as "absurd in philosophy, and formally heretical, because expressly contrary to Holy Scripture," and the second as "open to the same censure in philosophy, and at least erroneous as to faith."

**T**wo days later Galileo was commanded by Pope Paul V to come to the palace of Cardinal Bellarmine. At the palace he was officially ordered -- in this Decree of 1616 -- not to "hold, teach, or defend" the condemned doctrine.

**H**e promised to obey. It's important to realize that many church officials were sympathetic toward Galileo, and although officially they said one thing, in private many were encouraging and friendly toward Galileo.

## **Galileo Returns to Florence**

**A**s mentioned above, although the officials in Rome didn't embrace Galileo's ideas, they didn't really attack Galileo in any way, either. Galileo returned to Florence three months later, more or less satisfied with the result of his visit to Rome.

**H**e had been given a written certificate by Cardinal Bellarmine which would protect him from his enemies. It said that there had been no punishment as a result of his meetings. Also, during an audience he had with the pope, the pope said he thought highly of Galileo, and promised to protect him.

**G**alileo was a sincere Catholic, and although he didn't agree with the warnings of the Holy Office, he more or less followed their wishes.

**F**or the next seven years, he led a quiet life in the Villa Segni at Belosguardo, near Florence. He kept almost completely silent about his scientific beliefs.

## The Nature of Comets

**A**t the end of that time he appeared in public with his *Saggiatore*, a treatise written in reply to the *Libra astronomica* of Padre Grassi (under the pseudonym of Lotario Sarsi), the Jesuit astronomer of the Collegio Romano.

**T**he subject in debate was the nature of comets. Three of them had been seen in 1618, and they were what caused the controversy.

**G**alileo's views on the matter were not right, since he thought comets were just atmospheric reflections of sunlight like a halo or a rainbow. But he argued so sarcastically, and with such enthusiasm, that his opponent didn't even answer.

**T**he *Saggiatore* was printed in Rome in October 1623 by the Academy of the Lince (of which Galileo was a member). Galileo dedicated his treatise to the new pope, Urban VIII. Some passages contained a hidden defense of Copernican opinions.

**B**ut even so, the treatise was received very well by both religious and scientific authorities.

## The Later Years of Galileo

**E**verything seemed to be going well with Galileo's career. Maffeo Barberini, his best friend and admirer at the Sacred College, was on the pontifical throne, and Galileo received many favors.

**T**he pope admitted him to six long audiences in two months, and wrote an enthusiastic letter to the grand-duke praising the great astronomer, not only for his distinguished learning, but also because he was so pious.

**I**n addition, the Pope granted a pension to Galileo's son Vincenzo. Galileo had hoped to get the Decree of 1616 revoked by the pope, but did not succeed.

**Y**et there seemed to be reason to expect that it would at least be interpreted in a liberal way.

**G**alileo's friends encouraged him by telling him everything the pope said that could possibly be thought to be supportive of Galileo's ideas. Urban was reported to have said that the theory of the earth's motion had not been and could not be condemned as heretical, but only as rash.

**I**n 1630 the brilliant Dominican monk Tommaso Campanella wrote to Galileo that the pope had expressed to him in conversation his disapproval of the Decree of 1616.

## **The Completion of a Great Work**

**S**o Galileo left to go back to Florence full of anticipation thinking he would become more well known. He had no idea that there might be other consequences.

**H**e decided to complete his famous but ill-fated work, the *Dialogo dei due massimi sistemi del Mondo* (Dialogue Concerning the Two Main World Systems). He finished it in 1630, but it was not published until January 1632 by Landini in Florence.

**T**he book was originally intended to appear in Rome, but because of the collapse of the Lincean Academy and an outbreak of the plague, it was published two years later.

**I**n *Dialogo dei due massimi sistemi del Mondo*, three characters, named Salviati, Sagredo, and Simplicio, take part in the four dialogues. Salviati gives the views of the author (Galileo); Sagredo is an eager and intelligent listener; the third, Simplicio represents a well-meaning but dull person, whom the others treat at times with undisguised contempt.

**S**alviati and Sagredo were named for two of Galileo's early friends; Simplicio

supposedly got his name from the Cilician commentator of Aristotle. Galileo probably chose this name because of the double meaning of the word.

## **A Final Thought**

**I**t was evident that this treatise completely contradicted the Decree of 1616 that Galileo had promised to obey sixteen years before.

**T**he beginning and ending were written to somewhat soften the main part of the treatise, which clearly supported the new, Copernican principles, that the Earth revolved around the Sun.

**I**n the end, of course, Galileo's support of the theory of Copernicus was correct, and the Decree was eventually lifted.

**G**alileo will always be remembered for his discoveries and inventions, and as one of the greatest astronomers in history. Here, in conclusion, is a summary of just some of his discoveries:

- the mountains of the Earth's Moon
- the rings of Saturn
- sunspots
- the phases of Venus
- four moons of Jupiter
- Milky Way made up of stars
- law of inertia
- light and heavy objects fall at the same velocity

# *Galileo Galilei*

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Introduction

The Early Years of Galileo

The Studies of Galileo

The Early Discoveries of Galileo

The First Patron of Galileo

Residence at Padua

Important Inventions of Galileo

Early Studies in Astronomy

The Enhancement of the Telescope

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**SPECIAL TOPIC:**

# *I Didn't Know That!*



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EXIT

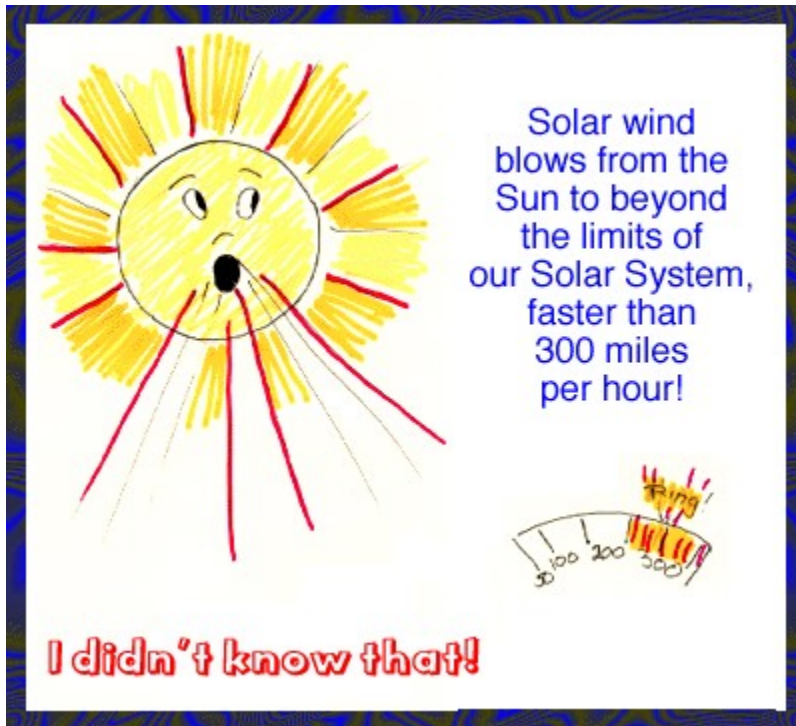
HELP



There's a Fun Fact in each folder!  
Click on any one to open it...







Solar wind  
blows from the  
Sun to beyond  
the limits of  
our Solar System,  
faster than  
300 miles  
per hour!

**I didn't know that!**

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How big is big?  
Well, the biggest stars are almost  
the size of our entire Solar System!

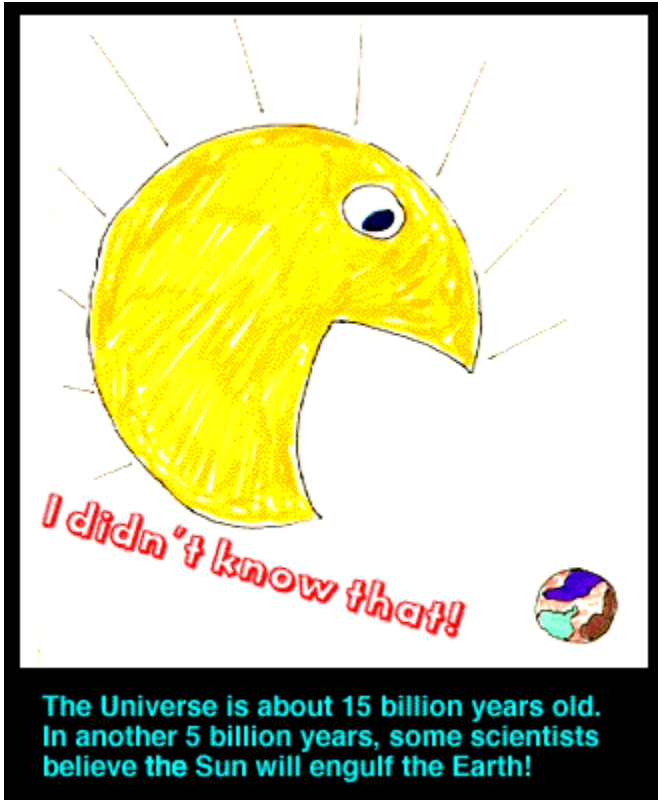
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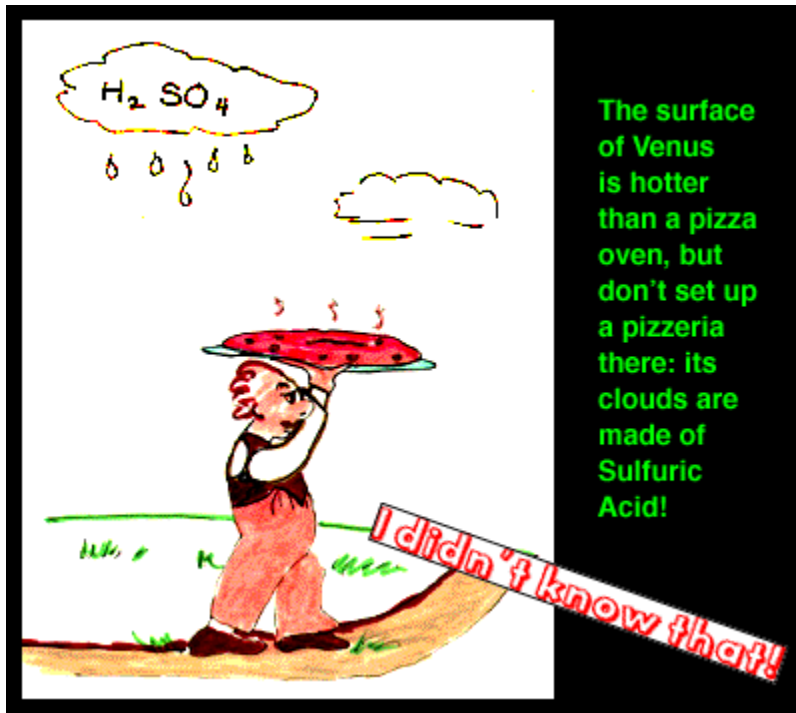
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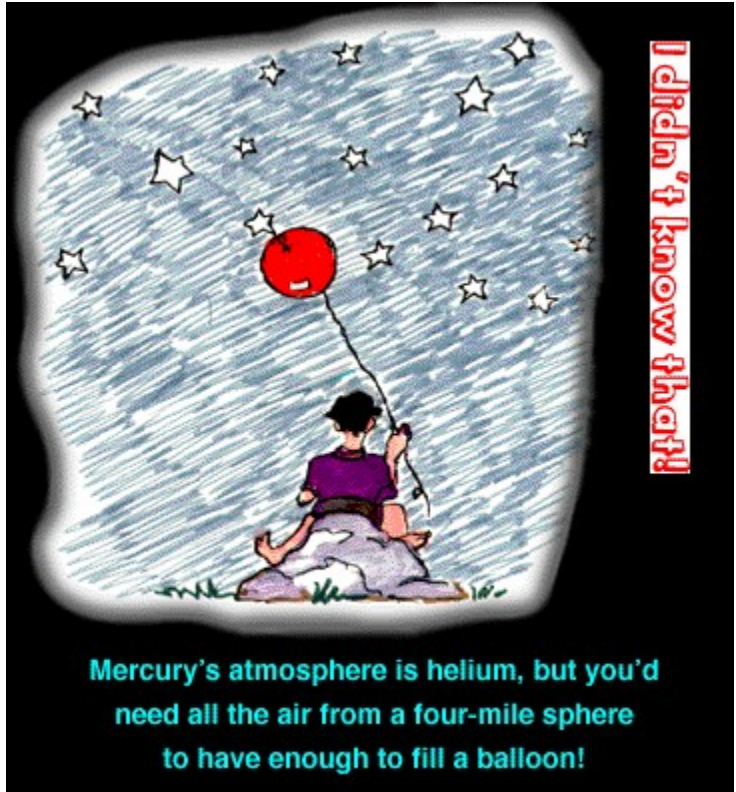
**I didn't  
know that!**

**If the Sun were the  
size of a beach ball,  
the Earth would be  
a small pea about  
200 feet away, and  
Jupiter would be a  
golf ball, almost  
1/4 mile away!**



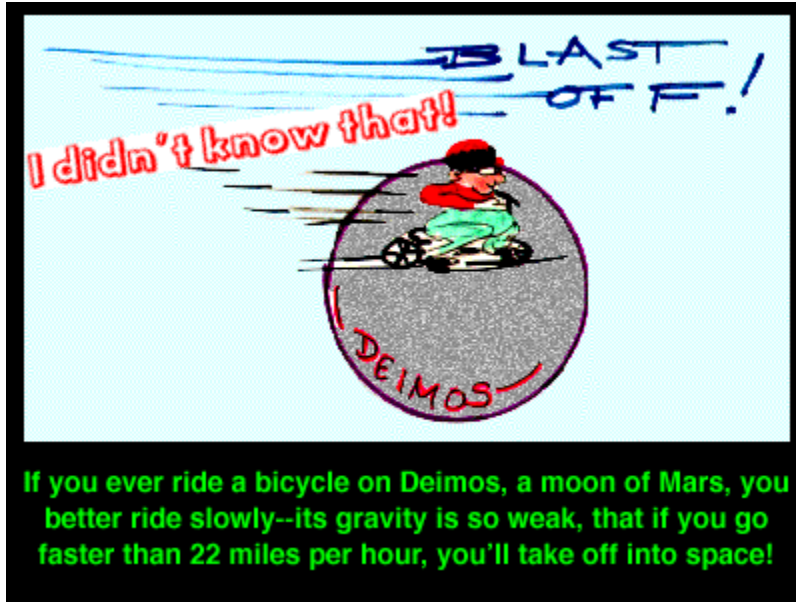
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If you ever ride a bicycle on Deimos, a moon of Mars, you better ride slowly--its gravity is so weak, that if you go faster than 22 miles per hour, you'll take off into space!

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[device WaveAudio][autostart][share Wave]wave.wav}





Saturn is made of gas.  
It's so light that if you could  
scrunch it down  
to the size of a tennis ball,  
it would float  
in a bowl of water!

*I didn't  
know that!*

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## I didn't know that!



A solar flare can erupt from the Sun and reach heights of over 200,000 miles. That's farther than the distance from here to the moon!

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WaveAudio][autostart][share Wave]wave.wav}

There's no wind on the Moon,  
so the footprints left during  
our first Moon landing will still  
be there millions of years from now!



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## Overview

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## The Quest For Answers

[click here to see picture...](#)

[click here to see movie...](#)

**Q**uestions, questions, questions... Human beings won't accept things as they find them. They ask questions, and they search for answers. What am I? Where am I? What is my past? What is my future? From earliest childhood, people want to know things. Why is the sky blue? What makes the Sun shine? What is the Moon made of? What are the stars?

[click here to see picture...](#)

**C**uriosity drives us to explore our surroundings. We want to see the unseen and to learn what lies over the next hill. People have always been bothered by blank areas on the map or in the mind, and they have studied and worked and strived and sometimes died to fill them in.

[click here to see picture...](#)

**O**ver the centuries, the urge to explore has taken human beings into unknown and unreachable places: to the New World, the South Pole, Mount Everest, and the Moon. The same urge has carried the human mind outward into the realm of the galaxies and into the microscopic domain of subatomic particles.

[click here to see picture...](#)

**T**hese explorations have always been profitable. They have produced tangible riches: gold, new lands, beneficial trade, and profitable technological advances. More important is the knowledge gleaned: a better understanding of our world, its mechanisms and processes, and the basic natural laws that govern them. It is knowledge, much more than riches, that makes modern civilization possible.

**W**hen we think of exploration, we think of individuals: Marco Polo, Columbus,

Lewis and Clark, Lindbergh, Neil Armstrong. But great explorations have also been an important part of the character of nations. To search for something new is an expression of a nation's confidence and enthusiasm, of its ability to organize and its willingness to innovate.

[click here to see picture...](#)

**I**t is no coincidence that the New World was discovered at the height of the Renaissance, nor that the colonization of North America accompanied the rise of Elizabethan England. In our own time, the Apollo Program manned landings and exploration of the Moon were the American response to the challenge of competition in the new ocean of space.

**T**he exploration of space may be only the latest episode in the long human history of wondering and seeking, but the sudden explosions of travel, new sights, and scientific discovery exceed anything that preceded them. New worlds have been discovered, not one by one, but by the dozen. Human beings have explored and sampled the Moon.

**R**obot laboratories have dug into and analyzed the surface of Mars. The video eyes of our spacecraft are providing close-up views of planets never seen by the ancients, and more than a dozen moons have emerged in our consciousness from tiny points of light to unique, mysterious, and changing worlds.

**G**reat as these steps have been, they have occurred in a remarkably short time. Only a single generation separates the flight of Sputnik 1 from the first spacecraft pictures of Saturn's moons; the first geologist to explore the Antarctic is still around to talk with the first geologist to go to the Moon!

**T**hanks to modern communications, all of us have shared in these voyages to an extent never possible before. Less than 100 people witnessed Columbus' landfall in the New World; half a billion watched on television as Armstrong and Aldrin stepped onto the Moon.

**W**e have flown into space, but from this high vantage point we still feel as curious as an earthbound child. How did the universe form? How will it end? How was the solar system created? What are the other planets really like? What lies in deep space beyond the Sun? How did life originate? Is there other life out there?

**I**n the last generation, we have come a long way toward the answers. But we still have farther to reach, more questions to ask, and much more to learn. Like earlier explorers, we have painfully struggled to a high plateau from which we see new

mountains and valleys beyond. The answers to our questions, the benefits from the new knowledge, still lie ahead, out of sight, but no longer out of reach.

## The Unfolding Universe

[click here to see picture...](#)

[click here to see movie...](#)

**O**nly 500 years ago, the universe seemed simple, orderly, peaceful, and well-understood. The Earth stood motionless at the center. The Sun, Moon, and planets circled it at no great distance. Slightly further away, the fixed stars were tiny points of light mounted on a sphere of pure crystal. It was a small, comfortable, and reassuring universe, and Man was at the center of everything.

**I**n only a few centuries, the scale of the solar system and of the universe expanded incredibly as a result of investigation and study. The telescope and the Copernican theory replaced the Earth with the Sun at the center of the solar system. The five wandering lights (called planets by the Greeks) became individual worlds.

**N**ew discoveries in physics and spectroscopy made it possible to analyze and even weigh the distant stars. Still larger telescopes moved the Sun from the center of things to the fringes of the Milky Way galaxy, a huge system of 100 billion or more stars.

**T**hen the Milky Way became only one of billions of galaxies in an expanding universe. New telescopes, sensitive to radio waves, probed the universe, discovering strange objects and powerful sources of energy that our eyes could never see.

**W**hen we suddenly entered the Space Age with the launch of Sputnik 1 on October 4, 1957, we broke through the last two barriers to our exploration of the universe: gravity and air. We now could escape from the pull of Earth's gravity, in which we had spent all of history, and reach other worlds.

**A**stronauts and machines could stand on other planets, study them at close range, and bring back samples to analyze on Earth. Robot spacecraft could fly past other worlds, sending back close-up video pictures that brought distant planets closer to us than our own Moon.

**W**ith the Space Age, a second barrier fell away: the blurring and dimming



caused by the Earth's atmosphere as we look outward from the ground. Out in space, instruments and human eyes could see the universe directly in all of its incredible violence, immensity, and variety.

## Knowledge Before the Space Program

[\*click here to see picture...\*](#)

[\*click here to see movie...\*](#)

**L**ooking back at the launch of Sputnik 1, we realize how much that we take for granted now -- only a generation later -- was unknown and in many cases not even suspected then. In the universe of 1957:

**T**he Sun seemed a basically stable, steadily shining star.

**M**ercury and Venus were just blurs in the telescope; there was no information on their remarkable geologic features.

**N**o one knew that the Earth was surrounded by belts of trapped radiation.

**M**ars, some astronomers thought, had "canals" perhaps it sheltered some form of life as well.

**T**he moons of Jupiter were no more than points of light, hardly more visible than they were to Galileo when he discovered them in 1610.

**A**mong the planets, only Saturn was known to have rings.

**P**luto had no known moon; the planet's size and mass were hardly more than matters of conjecture.

**T**he only known volcanoes were those on the Earth.

**N**o one knew what a moon rock was like; no one had touched or studied one.

**C**hemists had found traces of the origin of the solar system in meteorites, but no clues to earlier events.

**B**lack holes and neutron stars were creatures of the physicist's imagination.

**N**o one had even speculated that such objects as quasars and pulsars might exist.

**T**he "Big Bang " was just one of several theories for the origin of the universe; it seemed unlikely that evidence to clearly discriminate between them would be found.

**N**o one had gone into space.

**I**t was widely doubted that human beings could survive and work in space, given the dangers of radiation, weightless, and meteorites.

**A**mong science fiction writers, few predicted that there would be a man on the Moon before, say, the 1990's.

## **Developments Since Sputnik**

[\*click here to see picture...\*](#)

[\*click here to see movie...\*](#)

**D**uring a single generation, astronomers and space scientists have compiled a remarkable list of accomplishments and discoveries. Other planets have become individual, familiar worlds that we can see and touch, at least with the aid of remotely-controlled instruments.

**W**e have analyzed crystals from the Moon, measured the winds of Mars, and seen the violence of the volcanoes erupting unexpectedly on Jupiter's moon, Io. We have seen our own Sun in a new "light" -X-rays and ultraviolet and have gained new insights into the character of this star that makes life possible.

**W**e have sensed the turmoil in the huge, violent universe beyond: incredible energies and fantastic objects such as quasars, pulsars, and black holes. We have even caught the whisper of creation, the tiny echo of microwave radiation from the moment, billions of years ago, when the new universe was just expanding from the Big Bang.

**W**e have also gained a new viewpoint on ourselves and the Earth. We have found our own origins in the stars: carbon compounds in meteorites, organic molecules in interstellar space, the calcium and iron in our bodies that came from stars that died before the Sun was born.

**W**e have a new view of the Earth: a small, blue, habitable island in a vast, forbidding blackness. By studying the life-styles of other worlds, we are learning more about our own: its history, weather, climate, all the circumstances and conditions that are critically important, not only to science, but to our survival.

**I**n a single generation, we have learned more about the cosmos than we did in all the centuries that went before. It seems almost unbelievable that we have been able to discover so much about objects so huge, so ancient, so complex, and so far away.

**Y**et all this knowledge is just the basis for new explorations, discoveries, and understanding. Our current view of the universe probably is no more permanent than were the ideas people had five centuries ago. It will change just as radically as did the old concepts, as we do more and see further.

**A**ll that we have done is yet a beginning, and future generations may regard our view of the universe with the same amused tolerance that we reserve today for the ancients' crystal sphere.

## **A New Solar System**

[\*click here to see picture...\*](#)

[\*click here to see movie...\*](#)

**T**o the ancients, the solar system consisted of a few worlds wandering through a limited region of empty space. To us, it is a huge region containing uncountable bits of solid matter and filled with great magnetic fields and streams of electrically charged atomic particles from the Sun.

**O**ne of the most visible and exciting activities of the Space Age has been the detailed exploration of this astonishing collection of matter and energy around the Sun. The inventory of solid bodies in the solar family is impressive: nine planets, at least thirty-nine moons, thousands of tiny asteroids, billions of comets, and vast numbers of meteoroids and small particles of cosmic dust.

**I**n recent years, many spacecraft have explored the planets and their moons: over two dozen of these worlds have been studied at close range. This exploration is not a random process. It proceeds in systematic stages, each stage built on the results of earlier ones.

[click here to see picture...](#)

**F**irst, there are the reconnaissance or "flyby" missions such as those to Mercury, Jupiter, and Saturn. Next come exploration missions, carried out by orbiters and landers on the Moon, Mars, and Venus. Finally, there is a stage of intensive study, involving astronaut landings and sample return, which thus far have been accomplished only on the Moon.

**A**s of now, we have made intensive studies of only the closer worlds. Our spacecraft have not been powerful enough to push us very far out from Earth or very far inward toward the Sun. For this reason, most of our missions, especially the earliest ones, have involved the nearest worlds: the Moon, Venus, and Mars.

**W**e have only briefly surveyed Mercury, Jupiter, and Saturn. Although one interplanetary probe, Pioneer 10, has passed the orbit of Uranus, the outer planets beyond Saturn are completely untouched. Even plans involving definite missions included only a possible Voyager 2 flyby of Uranus. To return inward to survey Mercury in greater detail than heretofore, or to go outward to study the outermost planets, we will need more powerful spacecraft than exist today.

**A**ccording to current theory, the Sun and planets formed together in the collapse of a vast cloud of interstellar dust and gas (the protosolar cloud) about 5 billion years ago. The central part of the cloud collapsed to form the Sun, and the planets condensed in orbits around it.

**O**ne feature of the solar system that all the theories have to take into account is that there are two basically different kinds of planets: the solid terrestrial planets, like the Earth, and gas giants, like Jupiter and Saturn.



**W**elcome to Space Shuttle Explorer!

**T**his single screen tells the story of the Space Shuttle in pictures and movies.

**C**lick on any button below to start exploring!

[\*Movie 1\*](#)

[\*Movie 2\*](#)

[\*Movie 3\*](#)

[\*Movie 4\*](#)

[\*Picture 1\*](#)

[\*Picture 2\*](#)

[\*Picture 3\*](#)

[\*Picture 4\*](#)

[\*Picture 5\*](#)

[\*Picture 6\*](#)

[\*Picture 7\*](#)

[\*Picture 8\*](#)

[\*Picture 9\*](#)

[\*Picture 10\*](#)

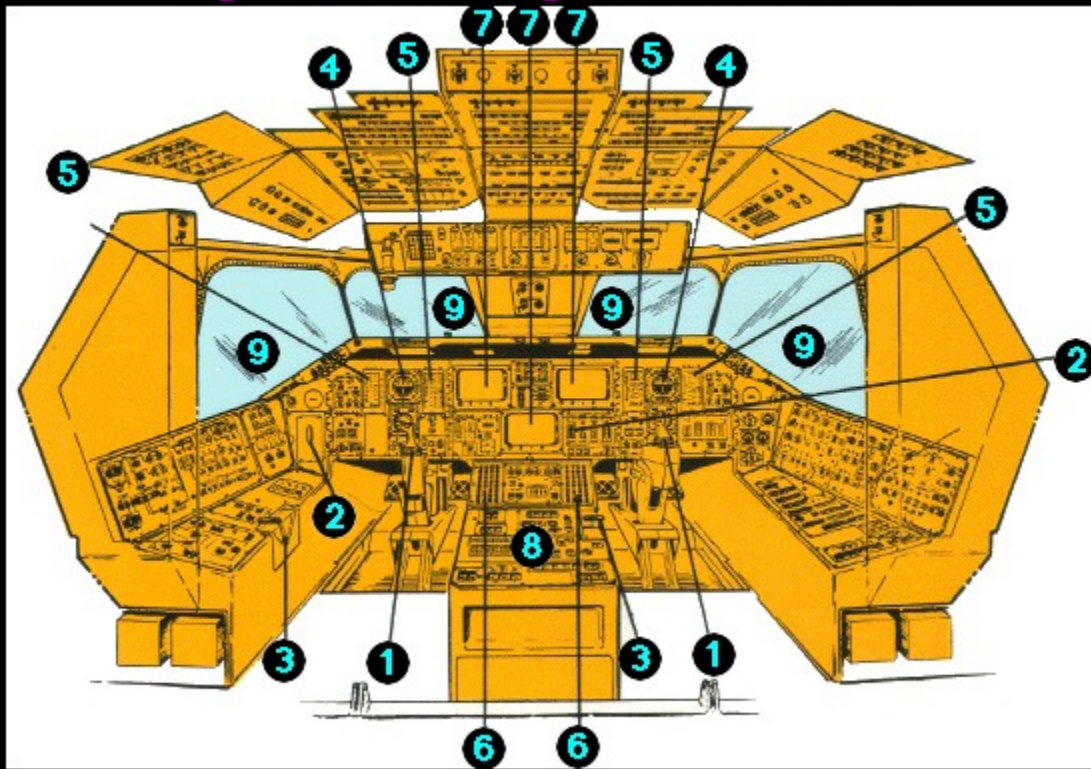
[\*Picture 11\*](#)

[\*Picture 12\*](#)

[\*Click here to see the Space Shuttle controls!\*](#)

*Press the Escape Key to hide any picture...*

## Space Shuttle Flight Deck Controls



*Click any button to explore...*

*Click here to return...*

## **Rotational Hand Controller**

[Click here to close this window...](#)

## **Translational Hand Controller**

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[\*Click here to close this window...\*](#)



## **Speed Brake**

[Click here to close this window...](#)

## **Attitude Direction Indicator**

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An artificial horizon -- a round black and white ball which tells which way is up.

[\*Click here to close this window...\*](#)

## **Air Speed and Altitude Indicators**

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[\*Click here to close this window...\*](#)

## **Keyboard**

---

Runs flight computer, which in turn runs the automatic pilot.

[\*Click here to close this window...\*](#)

## **Cathode Ray Tubes (TV)**

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These CRTs provide displays from flight computers.

[\*Click here to close this window...\*](#)

## **Radio Panel**

[Click here to close this window...](#)

## **Windows**

[Click here to close this window...](#)



## Absolute Star Magnitude

**T**he brightness of a star as it would appear to an observer on Earth if it were exactly 10 parsecs (32.6 light years) from Earth.

**T**he Sun's absolute magnitude is approximately 5M. (The upper-case M denotes absolute magnitude; this is different from lower-case m, which denotes apparent magnitude).





## Achromatic

**A**ppplied to an glass object in which rays of different colors are brought to the same focus.



## Acid Rain

**W**hen a gas such as sulfur trioxide,  $\text{SO}_3$ , dissolves in the moisture in the atmosphere, sulfuric acid,  $\text{H}_2\text{SO}_4$ , results.

**T**his acid then falls to the surface of a planet in the form of rain.



## Albedo

**T**he degree of whiteness, or proportion of incident light reflected by a non-luminous body.

**W**hen the albedo of a body is said to be 0.6, it means that it reflects  $\frac{6}{10}$  of the incident light.



## Altitude

**T**he apparent angular elevation of a body above the horizon, usually expressed in degrees and minutes.

**A**t the horizon the altitude is zero, at the zenith, it is  $90^\circ$ .



## Altazimuth Telescope Mount

**T**he simplest type of telescope mounting. This type of mounting is basically a tripod that can be rotated horizontally to adjust for azimuth and vertically to adjust for altitude.

**W**hile inexpensive, this type of mount is somewhat inconvenient to use as both the horizontal and vertical settings need to be continually changed.



## Amino Acids

**W**hen linked together, amino acids form proteins.

**T**here are about 20 amino acids common to all living organisms.

**S**ome of these amino acids have been found on meteorites.



## Andromeda

**I**n Greek mythology, a maiden rescued from a sea monster by Perseus; in astronomy, a northern constellation.

**T**he Andromeda Galaxy is one of the most well-known of all the interstellar objects. It has been mentioned in movies and novels, and many TV shows as well.

**A**ndromeda is the closest spiral galaxy to the Milky Way. In fact, it is so close that it can be seen without a telescope.

**A**ndromeda Galaxy is over 100,000 light-years in diameter, and has well over 200 billion stars.

**I**t is, of course, located in the direction of the constellation Andromeda, in the North Sky.





## Anti-Matter

**D**espite what many people think, anti-matter is not a science fiction fantasy. It is real, and does exist in our Universe. In our world, atomic particles have certain charges; for example, electrons have a negative charge, and protons have a positive charge.

**A**nti-matter particles have opposite charges--electrons are positive (called positrons) and protons are negative (called antiprotons).

**M**atter and anti-matter cannot come into contact, otherwise an explosion greater than a supernova would take place. Some astronomers believe that in the outer reaches of our Universe, there may be entire galaxies made up of anti-matter!





## Aperture Of A Telescope

**T**he diameter of the glass or mirror which admits the rays of light, clear of all obstacles.



## Aphelion

**T**hat point in the orbit or path of a planet or comet which is farthest from the sun; opposite of perihelion.



## Apogee

**T**he point of an orbit in which the planet is farthest from the earth.

**I**n ancient astronomy the planets were said to be in apogee when beyond the sun, and therefore at their greatest distance from the earth.



## Apparent Star Magnitude

**T**he brightness of a star or other light-emitting heavenly body, as it appears to an observer on Earth.

**T**he Sun has an apparent magnitude of  $-27m$  (The lower-case  $m$  denotes apparent magnitude; this is different from capital  $M$ , which denotes absolute magnitude).



## Asterism

**A** constellation that is contained within another constellation, e.g., the constellation Big Dipper is contained in the constellation Ursa Major.



## Asteroid Belt

**C**onsists of 2000+ asteroids located in an orbit between Mars and Jupiter.

**T**hey range in size from a few kilometers in diameter to over 1000 kilometers (600 miles) in diameter.



## Asteroid

**O**ne of the many small planets between Jupiter and Mars.

**T**he first asteroid to be discovered was Ceres, discovered on January 1, 1801.





## Astronauts

**T**he first astronaut was Yuri Gagarin (1961) who flew the Russian spacecraft *Vostok*.

**T**he first American astronaut was Alan Shepard who flew the *Mercury* spacecraft.





## Astronomical Unit

A measure of the average distance from the Sun to the Earth, about 93 million miles (150,000,000 km).



## Astronomy

**T**he science concerning the heavenly bodies, *e.g.*, their composition, their distances, their motions, and the laws which control them.



## Astrophysics

**T**he science resulting from the combination of astronomy and physics.



## Atmosphere

**T**he envelope of gas around any heavenly body.



## Aurora

**I**n Roman mythology, the goddess of dawn; in astronomy, the rising light of day.



## Aurora Australis

**T**he night lights of the southern polar sky, probably due to electrical disturbance in the upper atmosphere; also called the *southern lights*.



## Aurora Borealis

**T**he brilliant radiance of the sky in the far northern latitudes at night, probably due to electrical disturbances in the upper atmosphere; also called the *northern lights*.





## Autumn

**T**he season between summer and winter, beginning about September 22, and ending about December 21; often called *fall*, because of the falling of the leaves off trees.





## Autumnal Equinox

**T**he time of the sun's southward passage across the equator, about September 22.



## Axis

**A**n imaginary line running through the Earth from pole to pole.



## Azimuth

**T**he angular distance of a point of the horizon from the north or south.

**T**he azimuth of a horizontal line is its deviation from the true north and south direction.

**T**he azimuth of the east and west points is  $90^\circ$ .



## Big Bang

**T**he explosion that occurred 10-20 billion years ago that resulted in the formation of our universe.



## Binary Star

**A** double star, in which the two components are found to revolve around each other.



## Biosphere

**T**he layer surrounding the Earth capable of supporting life.



## Black Hole

**B**lack holes are one of the most captivating mysteries of modern astronomy. A black hole can be visualized as a colossal vacuum that destroys anything that comes within its control.

**B**lack holes are considered by many to be the cause of quasars, the most powerful sources of radiation that we know of.

**W**hat is a black hole? According to scientists, when a large star ages it contracts.

**E**ventually, the star collapses, leaving behind it this incredible gravitational field -- a black hole is born!

**T**he name black hole was coined by John Wheeler in the late 1960s.





## Blue Supergiant Star

A large star with a mass approximately 100 times that of the Sun.





## Catadioptric Telescope

A telescope that uses both mirrors and lenses to obtain the image.



## Celestial Equator

**T**he projection of the Earth's equator onto the celestial sphere.



## Celestial Latitude

**A**nalogous to the Earth's latitudes on the celestial sphere.



## Celestial Longitude

**A**nalogous to the Earth's longitudes on the celestial sphere.



## Celestial Meridian

**A** line on the celestial sphere running for a point due North of you, through the zenith, and continuing due South.

**I**t effectively divides the sphere into East and West.



## Celestial Poles

**T**he projection of the Earth's North and South poles onto the celestial sphere.



## Celestial Sphere

**A**n imaginary sphere that surrounds the Earth, holding all of the heavenly bodies.





## Chromosphere

**T**he luminous envelope of incandescent gasses surrounding the sun; seen at times of a total solar eclipse.





## Comet

A heavenly body moving about the sun and often having a long blazing tail.



## Conjunction

**T**he nearest apparent approach of two heavenly bodies which seem to pass each other in their course.

**T**hey are commonly considered in conjunction when they have the same longitude.



## Constellation

**A** group of fixed stars, having a special name.

**T**hese special names were not uniformly agreed upon until 1930.

**T**here are 88 universally recognized constellations, each with a Latin name.



## Coordinated Universal Time (Utc)

**A**n older time referring to the time in Greenwich, England.



## Corona

A halo surrounding a heavenly body.



## Cosmic Rays

**R**adiations similar to X-rays, but of greater penetrating power.



## Crab Nebula

**R**esulting from the explosion of a supernova in 1054 AD, this large nebula measures about 10 light years in diameter.

**T**here is evidence that it is continuing to expand even today.





## Dark Matter

**D**ark matter, in the words of the astronomers, is completely invisible.

**B**ut even though we can't see it, it may account for a large percentage of the mass of the universe.

**I**t is believed to be made up of atomic particles that we haven't discovered yet, or maybe matter from dead stars.

**S**cientists can't see dark matter.

**B**ut many scientists infer its existence, primarily by analyzing the gravitational pull of one galaxy on another.





## Daylight Savings Time

**F**rom the first Sunday in April until the last Sunday in October, the clocks for most of the US are advanced by one hour.

**C**alled Daylight Savings Time in the US, this is referred to as Summer Time around the rest of the world.



## Declination

**T**he angular distance of a heavenly body from the celestial equator.

**W**hen north of the equator, it is said to be in north declination; otherwise, in south declination.



## Deep-Sky Object

**H**eavenly bodies that are outside our solar system.



## Density

**A** measure of the amount of matter in an object, as measured by a ratio of mass to volume.



## Ecliptic

**T**he great circle which is the apparent path of the sun, or real path of the earth in the heavens during a year.

**L**unar and solar eclipses can occur only when the Moon is near this line.



## Eclipse

**T**he total or partial darkening of the light of the sun, moon, or other heavenly body caused by its entering the shadow of another body.



## Electromagnetic Radiation

**C**onsists of light rays, radio waves, infrared rays, X-rays, and gamma rays.





## Elliptical

Shaped like an ellipse.





## Ephemeris

**A** table giving the position of a heavenly body from day to day, in order that observers may know where to look for it.

**A**ppplied also to an astronomical almanac giving a collection of such tables.



## Equator

**T**he imaginary circle around a heavenly body, everywhere equally distant from the poles.



## Equatorial Coordinates

**T**he celestial coordinates that uses the celestial equator as its reference point.



## Equatorial Telescope Mount

**A** better type of telescope mount than the altazimuth mount.

**O**ne axis of the mount is adjusted to be parallel to the Earth's axis.

**T**he other axis is then the only one that needs to be adjusted to locate the heavenly body in question.



## Equinox

**E**ither of the two points in which the sun, in its apparent annual course among the stars, crosses the equator.

**S**o called because the days and nights are, when the sun is at those points, equal.



## Exobiology

**T**he science of life, both on the Earth as well as elsewhere in the universe.



## Extraterrestrial

**P**ertaining to anything off the planet Earth.





## Extravehicular Activity

Any activity, e.g., a spacewalk, that occurs outside a spacecraft.





## Eye Piece Of A Telescope

**T**he small glass nearest the eye, which magnify the image.



## Fall

**T**he season between summer and winter, beginning about September 22, and ending about December 21; called *fall*, because of the falling of the leaves off trees.



## Flybys

**A** space mission that endeavors to have a type of reconnaissance purpose.

**Q**uite often this type of mission is carried out before other types of missions, e.g., orbitals.



## Focus Of A Telescope

**A** point in which converging rays all meet.

**T**he focus of a telescope is the point at which the image is formed.



## Galactic Corona

**A** very thin atmosphere of hot gases that surrounds a galaxy such as the Milky Way.



## Galaxy

**I**n Greek, galaxias means milky, hence the Milky Way galaxy.

**A**n aggregate of gas, dust and stars.

**T**hese entities are held together by mutual gravitational attractions.



## Galileo

An Italian physicist and astronomer who lived from 1564 until 1642.





## Gas Giant (Jovian)

**M**any of the larger planets, e.g., Jupiter and Saturn, appear to be composed primarily, if not totally, of gaseous materials.





## Geocentric

**R**eferred to the center of the earth.

**T**he geocentric position of a heavenly body is its position as seen or measured from the earth's center.



## Geocentric Orbit

A satellite orbiting a planet, moving in its orbit at the same rate that the planet rotates, thereby remaining directly above the same point on the planet.



## Greenhouse Effect

**T**he trapping of the Sun's heat by a heavily CO<sub>2</sub> laden atmosphere.

**T**he temperature on a planet that exhibits a greenhouse effect, e.g., Venus, may have surface temperatures of 400-500°C.



## Greenwich, England

**T**he city in England that is the reference point for measuring time zones.

**F**or every 15°, there is a difference of one time zone (hour).



## Greenwich Mean Time (GMT)

**T**he time in Greenwich, England.



## Halley's Comet

**A**lthough unknowingly sighted several times earlier, this comet was first seen on August 19, 1682 and remained visible for about a month.

**H**alley computed the position of its orbit, and, comparing it with previous orbits, found that it coincided so exactly with that of a comet observed by Kepler in 1607, that there could be no doubt of the identity of the two orbits.

**T**his comet is visible approximately every 76 years.



## Heliosphere

**T**he theoretical boundary between the solar wind and the interplanetary magnetic field.





## Index Catalog (IC)

**A** supplement to the New General Catalog of stellar and nonstellar objects.





## Interplanetary Dust

**T**he space between the planets is not totally without matter.

**I**n this interplanetary space, dust particles may be found.



## Interplanetary Magnetic Field

**O**riginating at the Sun, this magnetic field stretches well past the Earth.

**T**his magnetic field guides the solar wind.



## Interstellar Bubbles

**A**n area around a star devoid of interstellar gas and dust.

**T**his bubble is caused by stellar winds.



## Interstellar Gas

**C**ontrary to popular belief, space is not a vacuum.

**B**etween the stars is a very thin gas, perhaps formed from the remnants of dead or dying stars.



## Io

**O**ne of Jupiters moons. Along with Europa, Ganymede and Callisto, Io was originally discovered in 1610 by Galileo.

**T**he great amount of volcanic activity on Io make it the most volcanically active body in our solar system.



## Ionosphere

**T**hat portion of our atmosphere (100-500 miles) composed predominantly of ions.



## Jovian (Gas Giant)

**M**any of the larger planets, e.g., Jupiter and Saturn, appear to be composed primarily, if not totally, of gaseous materials.





## Keplers First Law Of Planetary Motion

**T**he shape of the orbit of a planetary system is an ellipse.





## Keplers Second Law Of Planetary Motion

**I**f one were to draw a line from the Sun to a planet and let it sweep over any period of time, given an equal amount of time, it will sweep over the same distance.

**T**he only way for this to occur is for a planet to travel faster when it is closer to the Sun than when it is further away.



## Keplers Third Law Of Planetary Motion

**T**he square of the sidereal period of a planet is proportional to the cube of the planets average distance from the Sun.

**U**sing this relationship enables astronomers to precisely calculate the distance the planet is from the Sun at any point in time.



## Latitude

**D**istance on a heavenly bodys surface as measured by degrees North or South from the equator.



## Light Year

**T**he distance traveled in one Earth year by a wave of light, with a velocity of about 186,000 miles per second (300,000,000 meters per second); approximately 6 trillion miles.



## Longitude

**D**istance East or West measured by the angle between the meridian of a given point and the meridian of Greenwich, England.



## Lunar Eclipse

**A**n eclipse wherein the Earth comes between the Sun and the Moon.



## Lunar Month

**T**he interval from one new moon to the next, approximately 29.5 days.





## Lunar Year

A year of twelve lunar months, or about 355 days.





## Magellanic Clouds

**T**here are two Magellan Clouds: the Large, and the Small.

**T**hey orbit the Milky Way galaxy.

**T**hey are very bright objects in the sky, but since they are located in the south sky, they can't be seen from the U.S., or anywhere else in North America.

**T**hey are named after the explorer Magellan, who was the first explorer to travel the entire way around the world.

**T**he Magellan Clouds are favorites of astronomers, and people have discovered many sub-parts to them, and given these sub-parts colorful names, such as the Tarantula Nebula.



## Magnitude

**H**ow bright a star is. A small magnitude indicates a very bright star. Going from one magnitude to another, the brightness differs by 2.512 times, e.g., a star of the third magnitude is approximately 100 times (2.512<sup>5</sup>) brighter than one of the eighth magnitude.



## Magnetosphere

**T**he region around the Earth containing the Earth's magnetic field.

**O**riginally thought to be symmetrical in shape, it was later determined to be teardrop in shape.



## Magnetotail

**T**he highly extended base of the teardrop-shaped magnetosphere.

**T**his magnetic field extends some 375,000 miles from Earth.



## Mariner

**T**he class of interplanetary spaceprobes launched during the 1960s.



## Mass

**T**he quantity of matter contained in a body.

**M**ass differs from weight in that the latter is different in different places even for the same body, depending on the intensity of gravity, whereas the mass of a body is the same everywhere.



## Messier Catalog (MC)

**A** catalog of stars first compiled by the French astronomer Charles Messier in the late 18th century.

**T**his book lists approximately 100 celestial objects.





## Meteor

**M**eteorites are also known as "shooting stars." They aren't stars, however.

**A** meteor is a piece of space stuff that is most often smaller than a golf ball. It is usually some sort of rock, or rock/dirt/ice mixture, often a remnant of a comet.

**T**he meteor enters the Earth's atmosphere, and the friction of the air against the speeding rock causes the rock to heat up, and eventually burn up. The heating and burning create light, and since the meteor is zipping through space (much faster than a bullet), the rapidly moving light gives the appearance of a "shooting star."

**S**ometimes the meteor is so large that it doesn't burn up completely. In that case, it will reach the ground. It is then called a meteorite.

**B**y the way, if you're wondering how often meteors come around, the answer is that they are *not* infrequent, like comets. In fact, you can see them on any clear night. There are over six per hour on average, every night of the year.





## Meteorite

A body of matter which has fallen upon the earth from outer space.



## Meteoroid

**A** body of matter that is in outer space, but which may pass into the earths atmosphere.



## Nadir

**T**he point of the celestial sphere directly beneath our feet, or the direction exactly downwards.



## Neutron Stars

**T**he remains of a supernova. Incredibly small, but highly massive, star that emits light and radio waves.

**T**he original mass may have been five times that of our Sun, but it occupies a volume of Boston, MA.



## New General Catalog (NGC)

**A** catalog of stellar and nonstellar objects compiled around the turn of the century.

**T**his catalog contains thousands of entries, as compared to the Messier Catalog which contains but a bear 100.

**T**he supplement to NGC is the Index Catalog.



## Northern Lights

**T**he brilliant radiance of the sky in the far northern latitudes at night, probably due to electrical disturbances in the upper atmosphere; also called the *aurora borealis*.



## Occultation

**T**he disappearance of a distant body through the interposition of a nearer one of greater angular magnitude.

**A**ppplied especially to the case of the moon passing over a star or planet, and to that of a planet hiding one of its satellites.





## Orbit

**T**he path described by a planet around the sun, or by a satellite around its primary planet.





## Orion

**I**n mythology, a Greek hunter beloved by Artemis (Diana), who accidentally killed him and in sorrow placed him and his dog Sirius among the constellations.

**I**n astronomy, a large constellation near the celestial equator, noted for its group of three bright stars in a line.



## Ozone Layer

**A** layer of an allotropic form of oxygen found in the atmosphere.

**T**hought to protect living organisms from excessive exposure to ultraviolet light. (Ozone, with a formula of  $O_3$ , was first discovered by Schonbein.)



## Partial Eclipse

**O**nly part of the body being eclipsed is covered by a shadow, e.g., the earth's shadow partially covers the moon in a partial lunar eclipse.



## Penumbra

**A** partial shadowing. Applied generally in cases where light is partially, but not entirely, cut off.



## Perihelion

**T**hat point in the orbit, or path, of a planet or comet when it is nearest the sun; opposite of *aphelion*.



## Perturbation

**A** disturbance in the regular elliptic or other motion of a heavenly body, produced by some force additional to that which causes its regular motion.

**T**he perturbations of the planets are caused by their attraction on each other.

**U**sing these perturbations, astronomers are able to mathematically determine the position of a previously undiscovered planet.



## Photosphere

**T**he luminous, incandescent surface of the sun as seen from the earth.





## Planet

**A**ny one of the larger celestial bodies of the solar system, revolving around the sun in nearly circular orbit and shining by reflected light.

**T**he word planet means wanderer.





## Planet X

**T**here are many objects, conditions, and phenomena that we don't know about yet. One of these mysterious items is Planet X.

**P**lanet X, if it exists, would be in our Solar System.

**I**n fact, Planet X would be the tenth planet. No one has ever seen such a planet.

**S**ome people think there must be one, however. Uranus and Neptune don't orbit around the Sun exactly the way we expect them to. Some people think that this is due to gravitational effects by Pluto, but other people feel that Pluto is too small to be the cause.

**A**stronomers have tried quite hard to find Planet X. Over 70 percent of the sky was scanned in 1983 by the Infrared Astronomical Satellite, but no Planet X was discovered.

**O**ne thing that makes figuring it out so difficult is that events on this scale take a long time to unfold. For example, Neptune was discovered in 1846, and it takes over 160 years for Neptune to complete one orbit around the Sun. That means that, since we first discovered it, *Neptune it hasn't even made one complete orbit around the Sun yet!*

**I**f Planet X exists, it would probably be several times larger than the Earth.

**I**s it out there? Maybe some day we'll know for sure. Until then, Planet X will remain one of the mysteries of the universe.



## Polestar

A star nearly at the pole of the heavens, *e.g.*, Polaris; used as a guide by navigators and explorers.



## Precession Of The Equinoxes

**A** motion of the pole of the equator around that of the ecliptic in about 26,000 years.

**T**his phenomenon was first discovered by the Greek astronomer Hipparchus in the second century BC.



## Prime Meridian

A meridian by which longitude is measured, passing through Greenwich, England.



## Primitive Atmosphere

**T**he initial atmosphere of Earth. Composed primarily of  $H_2$ ,  $CH_4$ ,  $NH_3$ , and  $H_2O$ , it was not capable of supporting life.

**O**nly after the passage of time did the electrical storms and ultraviolet light from the Sun change this life-less atmosphere into one that would eventually support life.



## Prominence

**A** large loop of hot gases coming off the surface of a star during a solar disturbance.





## Pulsar

**A** pulsar (pulse quasar) has several characteristics:

- it is a small-sized cluster of energy, about 5 miles wide
- it spins rapidly
- it gives off energy in pulses, like an electric switch is being turned on and off and then on again

**P**ulsars are sometimes called neutron stars.

**O**ur Sun is a star, and weighs about as much as a typical pulsar.

**S**ince a pulsar is so small, and weighs so much, it is one of the densest objects in the Universe.



## Quasars

**Q**uasars are the things in the Universe that are farther away from us than anything else we know about.

**T**hese things are 12 to 14 billion light years away from us!

**T**hat means that the light we see from them is 12 to 14 billion years old. Since the earth itself is only about 5 billion years old, that means the light we see from the quasars in the Universe started out on its journey over 7 billion years before the Earth even existed.

**Q**uasars contain incredible energy -- they are more radiant than anything else. They were just discovered less than 30 years ago -- in the early 1960s.

**T**he word quasar is sort of a shortened version of the phrase "quasi stellar radio source." A quasar is so bright that it's about a trillion times brighter than our Sun.

**M**any people think that black holes are at the center of quasars, and that the black holes are responsible for the incredible amount of radio waves that a quasar generates. The truth is, we're still figuring out exactly what quasars are, and what makes them such radiant sources of energy.





## Red Dwarf Stars

**R**elatively small stars, having a mass of perhaps 10% of that of the Sun.



## Red Giant Stars

**T**he stage of stellar evolution reached when a star has finally exhausted all of the fuel at its center and begins to expand, with its surface getting cooler.



## Red Spot

**L**ocated on the surface of Jupiter, this is thought to be a massive storm system.

**I**t is the size of three Earths and has lasted for upwards of 300 years.



## Reflecting Telescope

**A** telescope that uses a series of mirrors to collect light and focus it to an image.

**T**he mirrors reflect the light to the focal point.



## Refracting Telescope

**A** telescope that uses a series of lenses to collect light and focus it to an image.

**T**he lenses refracts, or bends the light to the focal point.



## The Theory of Relativity

**T**he Theory of Relativity was first stated in a set of two publications by Albert Einstein. In these publications, Einstein set forth a remarkably new and revolutionary theory of space and time.

**T**he first part is called the Special Theory of Relativity, and was published in 1905; the second publication is called the General Theory of Relativity, and was published in 1915.

**R**elativity is famous for being difficult to understand, even for advanced scientists. The important fact of relativity is that things that were once thought to be absolute, such as space (distance) and time, were proven to be relative.

**I**n other words, my hour may be shorter than your hour, if for example we're traveling at different speeds. And my three-foot yardstick may be longer than yours, if we are traveling at different speeds.

**A**s startling as this is, it has proven to be true. But even the statements above are generalizations that are slightly inaccurate. Perhaps the best way to understand relativity is to read and understand the consequences of relativity.

**H**ere is a list of things that are true, and are known in part or primarily as a result of Einstein's work:

- 1.** Objects appear to get smaller as they move faster (they contract in the direction of their speed).
- 2.** Clocks move slower (i.e., time itself "moves slower") as speed increases.
- 3.** Two things that seem to happen at exactly the same time to one observer may not appear to happen at the same time to another.
- 4.** And perhaps the most famous statement: mass and energy are the same thing.

In other words, a hunk of stuff is really just a very tightly compressed amount of energy. Now, since energy is so light (try weighing electricity or a beam of light), it takes *a lot* of it to make even a small amount of "stuff," or matter. In fact, the equation is:

$$E=mc^2$$

**E** equals the total amount of energy;

**m** equals the amount of mass, and

**c** equals the speed of light (186,000 miles per second)

**N**ow, "c squared" means that you take c, which is 186,000, and multiply it by itself, which gives you 34,596,000,000. This is such an enormous number that you can see how even a small speck of matter, when multiplied by such a large number, will yield an incredibly large amount of energy.

**T**his is the principle behind an atomic bomb, which by transforming matter to energy creates an incredibly large explosion.

**H**ow do we know that Einstein's theories are true? Not only is his reasoning mathematically sound, but many of his statements are provable through laboratory experiments that offer reproducible results.

**A**lso, his theories predicted many and varied phenomena, all of which have so far turned out to be true, including: light is deflected by gravity, and space can be "curved" (confirmed during a 1919 eclipse of the sun); corrections to Newton's theory of planetary motion; and many others.





## Right Ascension (RA)

**A**nalogous to the Earth's longitudes on the celestial sphere.





## Shepherd Moons

**M**oons around Saturn and Uranus that help hold these planets rings together.



## Sidereal Period

**S**tarting at any point in a planets orbit, this is the time required for the planet to follow its orbit and return to this original starting point, that is, the time required to complete one of its orbits.

**T**his is not to be confused with synodic period, which is the time required for the planet to go from some point in the sky and to return to that exact same point.



## Signs Of The Zodiac

**T**he twelve equal parts into which the ecliptic or zodiac was divided by the ancient astronomers.

**T**hose signs, beginning at the vernal equinox, are: Aries (the Ram), Taurus (the Bull), Gemini (the Twins), Cancer (the Crab), Leo (the Lion), Virgo (the Virgin), Libra (the Balance), Scorpius (the Scorpion), Sagittarius (the Archer), Capricornus (the Goat), Aquarius (the Water-bearer), and Pices (the Fishes).



## Skylab

**T**he first long-duration space flights.

**T**he Skylab flew in 1973-74.



## Solar Day

**T**he time required for the Sun to pass across a meridian and return to it.

**B**ecause of the Earth's movement in the meantime, a solar day is not equal to a sidereal day.

**A** solar day is slightly longer than a sidereal day.



## Solar Eclipse

**T**he type of eclipse that occurs when the Moon comes directly between the Earth and the Sun.

**A** total solar eclipse occurs in the umbra of the Moons shadow, whereas a partial eclipse occurs in the penumbra.



## Solar Flare

**A** violent eruption of the Sun's surface.

**T**his large amount of matter and energy is spun into space, at times reaching the Earth and interfering with radio and television communication.





## Solstice

**T**hose points of the ecliptic which are most distant from the equator, and through which the sun passes about June 21st and December 21st.

**S**o called because the sun, having then attained its greatest declination, stops its motion in declination, and begins to return toward the equator.

**T**he two solstices are designated as those of summer and winter respectively, the first being in 6 hours and the second in 18 hours of right ascension.





## Southern Lights

**T**he night lights of the southern polar sky, probably due to electrical disturbance in the upper atmosphere; also called the *auora australis*.



## Sunspot

**O**ne of the dark, irregular patches or spots visible on the sun's disk.

**T**his spot is approximately 2000° C cooler than the surrounding area.



## Sunspot Cycle

**F**rom peak sunspot activity to the next peak sunspot activity takes approximately 11 years.



## Supernova

**A** supergiant star (perhaps the size of the diameter of the orbit of Jupiter) that explodes, releasing great amounts of energy and light.



## Synodic Period

**M**easures a planet's position relative to the Earth. One synodic period is the time required for a planet to leave and then return to a particular point in our sky.

**T**his is not the same as sidereal period which is the time required for the planet to complete one of its years.



## Titan

A moon of Saturn.

If one includes its cloud cover in making measurements, Titan is the largest moon in the solar system.



## Total Eclipse

**T**he entire body in question is eclipsed, e.g., the shadow of the Earth completely covers the moon in a total lunar eclipse.





## Umbra

**T**hat darkest part of the shadow of an object where no part of the luminous object can be seen.





## Universal Time (UT)

**T**he time in Greenwich, England.



## Vernal Equinox

**T**he time of the sun's northward passage across the equator, about March 21st.



## White Dwarf Star

**A** star with the approximate size as that of the earth, but with the approximate mass of the Sun.

**I**ts interior is very hot.



## Winter Solstice

**T**he beginning of winter, about December 21st.

**T**his is the shortest day of the year in the northern latitudes.



## Zenith

**T**he point of the celestial sphere which is directly overhead, and from which a plumb-line falls.



## Zodiac

**A** belt encircling the heavens on each side of the ecliptic, within which the larger planets always remain.

**I**ts breadth is generally considered to be about sixteen degrees - eight degrees on each side of the ecliptic.

**I**n the older astronomy, it was divided up into twelve parts, called *signs of the zodiac*.

**T**he term zodiac comes from a Greek word meaning circle of animals.



## Mercury [Click here for Solar System graphic...](#)

[Click here to zoom to a detailed chart of facts on Mercury and the other planets in our Solar System...](#)

**L**ike the Earth's Moon, Mercury lacks an atmosphere and its surface is saturated with craters from the same bombardment 4 billion years ago.

**I**t is 2.8 times the volume of the Moon but 4.6 times more massive.

**I**ts high density is surprising for such a small body.

**I**t has a large iron core and a magnetic field, despite its slow rotation of 59 days.





## Venus [Click here for Solar System graphic...](#)

[Click here to zoom to a detailed chart of facts on Venus and the other planets in our Solar System...](#)

**O**ur sister planet Venus is nearly the same size and density as Earth.

**V**enus, however, has retained an atmosphere of carbon dioxide which is 100 times thicker than Earth's.

**T**his atmosphere traps heat in the atmosphere causing the surface temperature to rise above 400°C.

**T**he yellow clouds which obscure the surface of the planet are composed of sulfur particles and concentrated sulfuric acid.





## The Earth-Moon System

*[Click here for Solar System graphic...](#)*

*[Click here to zoom to a detailed chart of facts on the Earth and the other planets in our Solar System...](#)*

**L**ife-sustaining water gives Earth its brilliant colors, while the harsh rocky surface of the Moon reflects the Sun's yellow light, revealing few color contrasts.

**T**he surface of the Moon is pocked by craters of an intense meteor bombardment which ended almost 4 billion years ago.

**F**ew such craters are seen on Earth because of the effects of continental drift and erosion which obliterate most such features in less than a half billion years.

**N**o other satellite is so close to the size of its parent body, making the Earth-Moon system a "double planet."



## **Mars** [Click here for Solar System graphic...](#)

[Click here to zoom to a detailed chart of facts on Mars and the other planets in our Solar System...](#)

**T**he red planet is a harsh desert-like planet with a thin atmosphere of carbon dioxide less than 1/100 as thick as Earth's.

**A**n early morning frost of frozen carbon dioxide covers meteor impact craters in the southern regions of the planet.

**M**ars is less dense (3.9) than the other inner planets, suggesting a different chemical make-up with relatively more light elements.



## Jupiter [Click here for Solar System graphic...](#)

[Click here to zoom to a detailed chart of facts on Jupiter and the other planets in our Solar System...](#)

**J**upiter's atmosphere is mostly hydrogen and helium, but the clouds may be made of ammonia ice and ammonia hydrosulfide.

**C**louds of an unknown composition provide a colorful panorama as the giant of the solar system rotates in just under ten hours.

**T**he white bands and reddish-brown and gray belts are constantly changing, yet the basic patterns remain unchanged for hundreds of years.

**F**ar below the clouds the atmosphere becomes so thick that it gradually becomes a liquid hydrogen ocean, and at the very center of Jupiter is a metallic hydrogen core.

**J**upiter has an intense magnetic field and 13 known satellites, 3 of which are larger than the Moon.



## Saturn

[Click here for Solar System graphic...](#)

[Click here to zoom to a detailed chart of facts on Saturn and the other planets in our Solar System...](#)

**O**ne and a half billion kilometers from the sun, the temperatures are so low that the water ice which covers Saturn's ring particles has remained since the beginning of the solar system.

**T**he ring particles are small, perhaps two inches in diameter.

**S**aturn is similar to Jupiter in composition, mostly hydrogen.

**I**t has the lowest average density of all the planets (0.7), less than that of water.

**S**aturn has ten satellites. The largest of them, Titan, has an atmosphere which may be as thick as Earth's.



## Uranus [Click here for Solar System graphic...](#)

[Click here to zoom to a detailed chart of facts on Uranus and the other planets in our Solar System...](#)

**U**ranus, the seventh planet from the sun, is the first planet to be discovered by telescope. It was discovered in the late 1700s.

**T**he planet Uranus is tilted so that its pole of rotation is nearly in the plane of its orbit.

**S**tudies from NASA's Kuiper Airborne Observatory revealed that Uranus has five or more rings.

**U**nlike Saturn's rings they are exceedingly dark and must be made of rocks similar to those found in carbonaceous chondrites, a type of meteor.



## Neptune [Click here for Solar System graphic...](#)

[Click here to zoom to a detailed chart of facts on Neptune and the other planets in our Solar System...](#)

**N**eptune is the eighth/ninth planet in our solar system.

**T**he orbits of Neptune and Pluto actually cross each other and Pluto will be closer to the sun than Neptune for the next 50 years.

**M**ethane gas absorbs red light from the sun, leaving only the blues and greens to be returned from the deeper layers of the hydrogen-rich atmosphere.

**V**oyager zoomed by Neptune in 1989, and based on information we got from that, it is currently believed that Neptune may have as many as eight or nine moons, and maybe even rings like Saturn, but fainter.

**I**t's interesting to note that Neptune's largest moon, Triton, revolves around Neptune in the opposite direction from most solar system objects.





## Pluto

[Click here for Solar System graphic...](#)

[Click here to zoom to a detailed chart of facts on Pluto and the other planets in our Solar System...](#)

**P**luto is not a gaseous giant like the other outer planets and it may possess a single satellite.

**I**t may be rocky, like the inner planets.

**I**t is known to be covered with an icy coat of frozen methane.

**T**he orbits of Neptune and Pluto actually cross each other and Pluto will be closer to the sun than Neptune for the next 50 years.

**P**luto is smaller than the Moon, and it takes about 250 Earth years to orbit the sun. Pluto is 365 billion miles from the sun.



## Asteroid Belt [Click here for Solar System graphic...](#)

**W**as there another planet between Mars and Jupiter, that exploded, leaving behind an orbiting swirl of rocks? Astronomers used to think so.

**T**he Asteroid Belt, located between Mars and Jupiter, is a large collection of space rocks of various sizes. Some are as big as 600 miles in diameter.

**T**he chart below is a partial list of eight of the larger asteroids, with year of discovery and approximate size.

<b>Name</b>	<b>Year of Discovery</b>	<b>Diameter in Miles</b>
Ceres	1801	500
Pallas	1802	300
Vesta	1807	250
Iris	1847	125
Juno	1804	120
Metis	1848	80
Flora	1847	60
Astraea	1845	50





## Our Moon

[Click here for Solar System graphic...](#)

**T**he moon is Earth's closest neighbor. It's about 240,000 miles from Earth.

**T**he origin of the Moon is unclear, with some scientists saying it was once a part of the earth itself that was somehow ripped apart from the earth.

**A**fter the moon formed, it went through several periods, including:

- a melted shell, about 4.4 billion years ago, and
  - bombardment from smaller space rocks, which created the craters, about 4.1 billion years ago.

**I**n general, planetary surfaces of the inner planets of the solar system are dominated by craters from impacting meteors.

**A**nalysis of lunar rocks has enabled scientists to learn that there was an intense bombardment of meteors for about a half billion years after the solar system was formed.

**T**he scars from this event have been completely erased from Earth's surface and we would not know that it had occurred if we did not see craters on every other terrestrial body.



## **Our Sun** [Click here for Solar System graphic...](#)

**T**he Sun is just one of the trillions of stars in the Universe. It's of course the most important star of all to us, since it's the source of our heat and light.

**O**ur Sun is a medium-sized star, with a temperature of about 25 million degrees Fahrenheit; the Earth is about 93,000,000 miles away.

**T**he outermost part of the Sun is called the corona. Sun spots, which are dark areas on the Sun, were discovered by Galileo in 1610.

**T**hey have been the object of superstitions over the centuries. They are now known to be simply solar magnetic storms.

**S**ince the temperature of the storm is lower than the rest of the surrounding sun's surface, the sun spot is not as bright.



## Space in the Solar System

*[Click here for Solar System graphic...](#)*

**T**wenty years of planetary exploration from space have revealed a rich and colorful array of planetary phenomena.

**M**eteor craters have been found throughout the inner solar system, and the outer planets have been found to have bottomless atmospheres. Planetwide dust storms envelop Mars and a carbon dioxide "greenhouse" smothers Venus, raising its temperature to over 400°C.

**T**he satellites of Jupiter are so light that they must be made of ices rather than rocks, while Mars' two tiny satellites look like derelicts from the asteroid belt.

**T**he age and early history of Earth is studied by analysis of Moon rocks. This tremendous burst of new knowledge has ushered in the age of Comparative Planetology. We no longer study one planet or another, but an entire system...the Solar System.



## Solar System Planets -- Detailed Chart

	MERCURY	VENUS	EARTH	MARS	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Mean Distance from Sun (Millions of Kilometers)	57.9	108.2	149.6	227.9	778.3	1,427	2,869	4,496	5,900
Mean Distance from Sun (Astronomical Units)	.387	.723	1	1.524	5.203	9.539	19.18	30.06	39.44
Period of Revolution	88 days	224.7 days	365.26 days	687 days	11.86 yrs.	29.46 yrs.	84.01 yrs.	164.8 yrs.	247.7 yrs.
Rotation Period	59 days	-243 days retrograde	23 hours 56 mins 4 secs	24 hours 37 mins 23 secs	9 hours 50 mins 30 secs	10 hours 14 mins	-15 hours retrograde	22 hours or less	6 days 9 hours
Inclination of Axis	< 28°	3°	23° 27'	23° 59'	3° 5'	26° 44'	82° 5'	28° 48'	?
Inclination of Orbit to Ecliptic	7°	3.4°	0°	1.9°	1.3°	2.5°	.8°	1.8°	17.2°
Eccentricity of Orbit	.206	.007	.017	.093	.048	.056	.047	.009	.25
Equatorial Diameter (Kilometers)	4,880	12,104	12,756	6,787	142,800	120,000	51,800	49,500	6,000 (?)
Mass (Earth=1)	.055	.815	1	.108	317.9	95.2	14.6	17.2	.1 (?)
Volume (Earth=1)	.06	.88	1	.15	1,316	755	67	57	.1 (?)
Density (Water=1)	5.4	5.2	5.5	3.9	1.3	.7	1.3	1.7	?
Atmosphere (Main Components)	None	Carbon Dioxide	Nitrogen Oxygen	Carbon Dioxide	Hydrogen, Helium	Hydrogen, Helium	Helium, Hydrogen, Methane	Hydrogen, Helium, Methane	None Detected
Atmospheric Pressure at Surface Bars	10-6	90	1	.006	?	?	?	?	?
Known Satellites	0	0	1	2	13	10 + 3 rings	5 + 5 rings	2-9	0



## Stars

**S**tars are very large bodies of burning gasses, that are traveling at enormous speeds through space. But, since they are so far away, they appear to be tiny lights in the evening sky that aren't moving at all.

**H**ere's an idea of how many stars there are in existence. The universe contains billions of galaxies. And each galaxy contains billions of stars.

**S**o, there are over a billion billion stars in the Universe.

**O**f all these stars, the only ones that we can see without a telescope are in our own Milky Way. But we can see clusters of other stars, i.e., complete other galaxies, with our naked eye. One example of this is the Andromeda Galaxy.

**S**tars live, and stars die. Since they are burning entities, eventually they burn up everything they have. Some stars undergo a supernova before completely burning out. This is an immense explosion where the star temporarily becomes as much as a billion times more radiant than normal.





## The Milky Way Galaxy

**A** galaxy is a large collection of stars. Most galaxies have billions of stars.

**O**ur Solar System is on the edge of the Milky Way Galaxy. So, it is possible to look in one direction and be peering through the vast thickness of our galaxy, or look in the other direction and be looking out into the vastness of space.

**W**hen you look into our own galaxy, there are so many stars in the core of our galaxy that their combined whiteness looks "milky," which is how the name came about.

**W**e're fortunate to be able to look in the other direction, too. Since we're on the edge of the galaxy, we get an unobstructed view of deep space.

**I**f we were in the center, then everywhere we looked we'd be surrounded by stars, which would cut off our view of the rest of the universe.

**T**he Milky Way Galaxy is a spiral galaxy, which is the most common kind. Other kinds include elliptical, and irregular.



## Our Solar System

### *The Inner Planets*

**T**he inner planets are similar to Earth in size and composition. They are rich in heavy elements such as magnesium, iron, silicon and oxygen.

**T**hese elements were only a tiny portion of the material which formed the sun and the planets.

**T**he more abundant light elements were not able to condense into solid form at the higher temperatures close to the proto-sun, and the gravity of these smaller, rocky planets was not strong enough to hold on to the light abundant gases such as hydrogen and helium.

### *The Outer Planets*

**T**he planets which lie beyond the orbit of Mars are known as the outer planets.

**E**xcept for Pluto, they are gaseous giants ranging from 5 to 1300 times the size (volume) of Earth.

**B**ecause they were formed far from the sun, they are made mostly of light elements which are abundant in the universe.

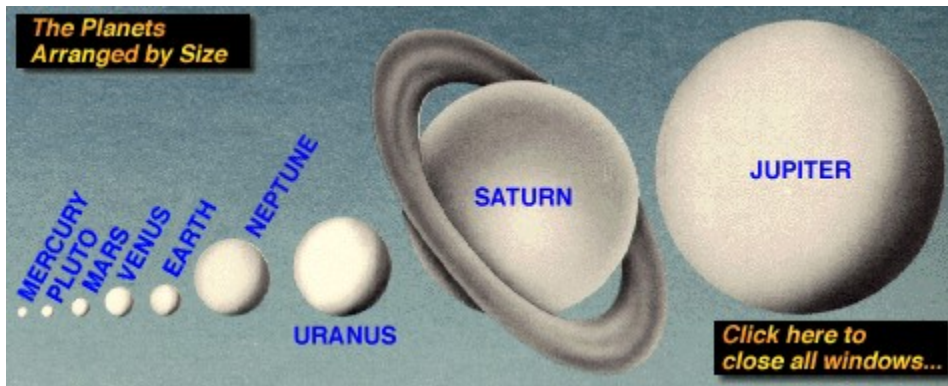
## Note:

**F**or a text chart listing the exact distance of each planet from the Sun, as well as additional detailed information, [click here...](#)

**F**or a graphic of the planets arranged in order of size, [click here...](#)

**F**or a graphic of the planets arranged according to distance from the Sun, [click here...](#)

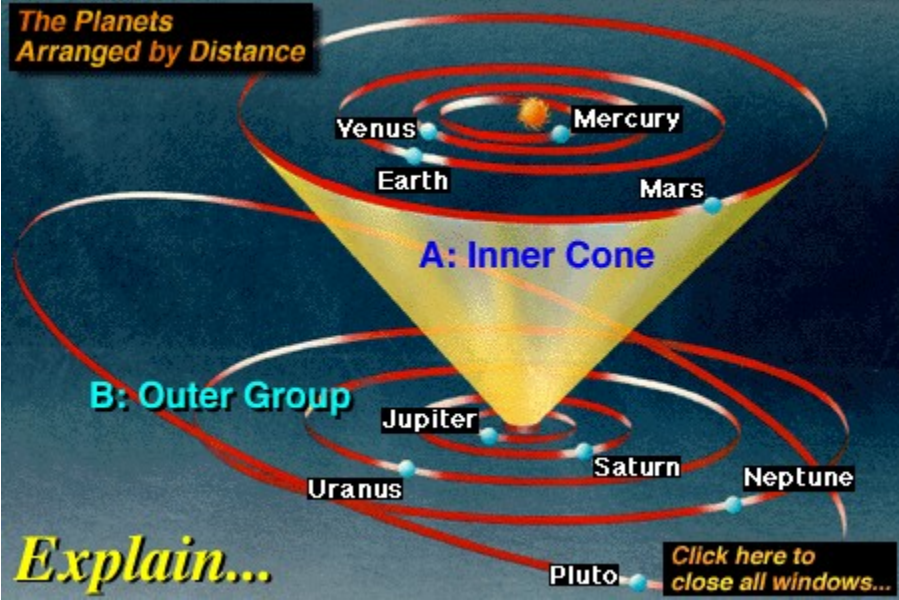
*Press the Escape Key to hide me...*



*Press the Escape Key to hide me...*



**The Planets  
Arranged by Distance**



**Explain...**

*Press the Escape Key to hide me...*



*Press the Escape Key to hide me...*

**T**his graphic is a bit complicated, but so is the Solar System! This is one of the very few places you'll ever see an accurate representation of the distances of the planets from the Sun. Most illustrations show a set of rings around the Sun, with the outer planets being way too close proportionally. Take a few minutes to understand this graphic, and you'll gain a new appreciation for the vastness of our Solar System.

*All* of the planets of the Inner Cone (labeled A) fit into the tiny center portion of the Outer Group (Labeled B). Notice that this drawing even shows the fact that Neptune and Pluto cross orbits.

*Press the Escape Key to hide me...*



## Voyager

[click here for contents...](#)

### Introduction

[click here to see movie...](#)

**W**ritten accounts have described them as loyal, fearless, intelligent and curious. They have been called intrepid. Indefatigable. Troupers, they are both still operating smoothly years beyond their planned lifetimes. One has even been dubbed the little robot that could.

[click here to see a picture of Voyager I...](#)

**T**he machines that have inspired such imaginative and sometimes anthropomorphic descriptions are the United States Voyager 1 and Voyager 2, a pair of gangly, instrument-laden spacecraft assembled from more than 65,000 parts made in industrial and research laboratories across the country. The Voyagers awkward looks belie the balletic grace with which they have conducted their explorations.

[click here to see a picture of Voyager II...](#)

**O**ver the course of 12 years, these spacecraft drew back the curtain on nearly half the solar system. They brought into sharp focus the faces of the four giant outer planets - Jupiter, Saturn, Uranus, and Neptune - and their families of disparate moons.

**T**he Voyagers shows us unimagined worlds: frozen beauty in the rings of Saturn, and molten violence in the explosive sulfur volcanoes on Jupiters moon Io. They brought us close-ups of the florid and intricate storms of Jupiter itself. Voyager 2 went on to reveal the peculiarities of cockeyed Uranus and its equally skewed rings and moons. Then finally, Neptune, nearly invisible from Earth, was unveiled in all its big, blue splendor, circled by shadowy rings and a bright pastel moon called Triton.

## Voyager's Success

**T**he Voyager spacecraft, originally meant to fly by just two planets and operate for five years, accomplished much more. In all, they explored four planets, tens of moons and the rings and magnetic environments of those planetary systems.

**T**he mission became one of those technological enterprises that actually delivered more than it promised. Together, the Voyagers and the men and women who built the spacecraft and choreographed their flight accomplished one of history's most ambitious and rewarding expeditions of discovery.

[click here to see picture...](#)

[click here to see picture...](#)

**T**he Voyager mission, managed for the National Aeronautics and Space Administration (NASA) by the California Institute of Technology's Jet Propulsion Laboratory (JPL) in Pasadena, California, was designed to take advantage of a rare geometric arrangement of the outer planets - one that occurs only once every 176 years.

**T**his layout of Jupiter, Saturn, Uranus and Neptune allows a spacecraft to swing from one planet to the next without the need for large onboard propulsion systems; the flyby of each planet both accelerates the spacecraft and bends its flight path. Aimed properly, the spacecraft can be sent on to the next planet. Without this gravity assist technique, the flight time to Neptune is 30 years; with it, only 12.

**W**hile a four-planet mission, promoted by planetary scientists as the Grand Tour, was known to be possible, it was deemed too expensive to build a spacecraft that could travel the distance, carry the instruments needed and last long enough to complete such an extended voyage. Thus, the project was funded to conduct intensive flyby studies of only Jupiter and Saturn.

**M**ore than 10,000 trajectories were studied before the two were chosen that would allow close flybys of Jupiter and its large moon Io, as well as of Saturn and its rings and large moon Titan. The chosen flight path for Voyager 2 also preserved the option to continue on to Uranus and Neptune.

[click here to see picture...](#)

[\*click here to see movie...\*](#)

## The Launch

[\*click here to see picture...\*](#)

**A**board a Titan/Centaur expendable launch vehicle, Voyager 2 was launched first, on August 20, 1977. Voyager 1 - also on a Titan/Centaur - was launched on a faster, shorter trajectory on September 5, 1977. Both launches were from the NASA Kennedy Space Center at Cape Canaveral in Florida.

**A**ll the unmanned spacecraft that came before them, whether they flew or failed, contributed to the mechanical stamina and electronic adaptability built into the Voyagers. The key to the Voyagers success lay in this heritage, and in the acknowledgment that things could go wrong.

**B**y installing backups, or providing what spacecraft engineers call redundancy, to take over in the event of the failure of critical components such as radio receivers and computers, Voyager engineers launched the spacecraft with the foresight of a driver who embarks on a cross-country trip having packed extra hoses, filters and a spare tire in the trunk.

## First Problem

**T**his prudence paid off early in the mission when Voyager 2's prime receiver failed. For the rest of its flight, telecommunications with Voyager 2, conducted through the Deep Space Network (DSN) operated for NASA by JPL, depended on a flawed but functional backup receiver.

**D**emands placed on the Voyager spacecraft grew with the distance they traveled from Earth. Commands from the DSN transmitters, traveling at the speed of light, took longer and longer to reach the spacecraft; correcting any mistakes or attempting to remedy a problem on the spacecraft entailed uncomfortably long delays before the spacecraft received and executed the necessary commands and then radioed back to Earth that the problem had been solved.

**A**t Jupiter, the Voyagers were less than an hour's light-time away, but by the time Voyager 2 reached Neptune, it took more than four hours to make

the radio connection from Earth. The spacecraft were programmed to orient themselves in a safe state - instruments pointed away from the Sun, radio dish pointed toward Earth ready to receive commands - whenever any spacecraft maneuver or normal operations did not go as planned.

**T**he ability to detect flaws in the execution of their programs and to place themselves in a safe state whenever anything went awry was of critical importance in keeping the Voyagers healthy over their long journeys.

## The Outer Planets

**J**upiter, Saturn, Uranus, and Neptune are giant planets with deep atmospheres made up primarily of hydrogen and helium. They and their moons and rings formed and have evolved in a much colder, darker region of space than the inner planets of the solar system. None of these outer planets has a solid surface. At their centers are spheres of molten ice and rock.

[click here to see picture...](#)

**W**ith a diameter of 88,846 miles, Jupiter is the largest planet in the solar system. Sulfur compounds and ammonia give its atmosphere its yellow and orange hues and white clouds.

[click here to see picture...](#)

**S**aturn, second largest with a diameter of 74,900 miles, lacks the chemicals in the upper atmosphere that give Jupiter its colors. Saturn has less inherent color, reflecting mainly the pale yellow of the Sun.

[click here to see picture...](#)

**U**ranus is 31,764 miles in diameter, making it the third largest. Neptune is close behind with a diameter of 30,776 miles. Methane in their atmospheres gives these last two planets their blue tones.

[click here to see picture...](#)

**B**esides studying them for their own sake, scientists consider other planets to be laboratories where different facets of the early history of Earth and the solar system as a whole can be explored and theories can be tested.



[\*click here to see picture...\*](#)

**A**s different as the outer planets and their moons are from Earth and other bodies closer to the Sun, they all share certain characteristics and physical processes. The field of comparative planetology investigates the common threads linking the pasts and futures of the planets, their systems of moons and rings and their magnetic environments.

**P**rocesses observed on one body can be extrapolated and applied to another. For example, studying and comparing the meteorology of the outer planets can help scientists understand the basic forces that control climate and weather on Earth.

**S**tudies of the large moons of the outer solar system help divulge the geophysical processes common to solid bodies. Studies of small moons and planetary rings reveal information about how the solar system formed and how it has evolved.

## **Jupiter**

[\*click here to see movie...\*](#)

**A**s the closest of the four giant planets, Jupiter was better known than the others before the Voyagers arrived. Studied through telescopes since Galileo, the broad, visible characteristics of the Jovian system -- the Great Red Spot and the latitudinal bands -- were apparent, as were the four Galilean moons, so-called because of their discovery by the 17th-century Italian astronomer.

[\*click here to see picture...\*](#)

**E**ight other moons also could be counted. Beyond the visible features of the Jovian system was the intense radio noise emitted from the planet. The noise, which is due to electrons spiraling in Jupiter's magnetic field, is long enough to make Jupiter the second noisiest radio emitter in the solar system, after the Sun.

[\*click here to see picture...\*](#)

**N**ASA's Pioneer 10 and 11 spacecraft preceded the Voyagers to Jupiter in the early 1970s and sent back important information about the powerful

Jovian magnetic environment, including measurements of the searing radiation belts around the planet. The Pioneer experience at Jupiter led Voyager engineers to take extra measures to harden the spacecrafts electronic components against radiation.

**V**oyager 1 took 18 months to reach Jupiter, 400 million miles away. The spacecraft made its closest approach on March 5, 1979, while Voyager 2 followed on July 9 the same year. A torrent of new discoveries began as the spacecraft neared the giant planet.

## Saturn

[click here to see picture...](#)

**F**or 2,600 years, sky watchers have observed the slow progress of Saturn in its orbit around the Sun. Through his telescope, Galileo noted strange appendages on either side of the pale yellow planet that he took to be attendant bodies. Christian Huygens in 1655 concluded that the appendages were not attendants, but a ring encircling the planet.

**L**ater, astronomers would discover gaps separating a multiple-ring system. Scientists have long sought to determine what the rings are made of, how they got there and what keeps them in orbit around Saturn.

[click here to see picture...](#)

**S**ome of the questions began to be answered when Voyager 1 arrived at Saturn on November 12, 1980, and Voyager 2 arrived on August 25, 1981. But the Voyager discoveries would soon present many more new puzzles than solutions.

**S**aturn is composed of the same constituents as Jupiter, but in different mixtures. Saturn radiates 80 percent more energy than it absorbs from the Sun. The Voyagers found that the amount of helium in the atmosphere is less than half that at Jupiter, consistent with the suggestion that the precipitation of helium out of the mainly hydrogen atmosphere could be supplying the internal heat that Saturn radiates.

**E**ven with its self-manufactured heat, Saturns atmosphere, compared to Jupiters, is much less turbulent and somewhat placid-looking. Given Saturns relatively bland appearance, scientists were surprised at the high-velocity equatorial jet stream that blows some 1,100 miles per hour.

## Voyager 1 Heads for the Stars

[click here to see picture...](#)

**W**hen Voyager 1 left Saturn, it left the planets forever, heading on a trajectory that took it northward, above the ecliptic plane in which the planets orbit the Sun. As it departed, Voyager 1 sent back stunning views of the dark side of Saturn, taken from a vantage point only a robot could reach.

**W**hen Voyager 2 made its closest approach to Saturn, the spacecraft's path was gravitationally altered by the ringed planet and directed toward Uranus, another billion miles away.

**N**ow left alone to continue into uncharted territory, Voyager 2 made a somewhat shaky start toward Uranus. After the closest approach to Saturn, the steerable platform holding many of its instruments (including the cameras) became stuck.

**E**ngineers diagnosed the problem as a loss of lubricant, which soon migrated back, allowing the balky platform to move again. But new rules were created to restrict the frequency and speed of movement, preserving the ability to point the instruments during the Uranus and Neptune encounters.

## Uranus

[click here to see picture...](#)

**U**ranus, the third largest planet, is known as the one that was knocked on its side. Scientists postulate that Uranus was permanently thrown off its normal axis when it was struck by a body at least the size of Earth. As a result, the planet's poles receive more sunlight than its equatorial region. As at other planets, rings and moons orbit around the equator, giving the entire Uranian system its odd, bulls-eye appearance.

[click here to see picture...](#)

**A**t a distance of two billion miles from Earth, Uranus is hardly an easy

target of study, even through powerful telescopes. Prior to the arrival of Voyager 2, five moons had been counted, and dark rings had been detected. Only broad characteristics of the planet could be discerned. With its polar regions exposed to sunlight or darkness for long periods, scientists were not sure what to expect.

## Adapting Voyager 2 for the Outer Planets

**N**o special equipment was placed aboard Voyager 2 for its Uranus and Neptune encounters, so the spacecraft had to be taught new ways of gathering, processing and sending data to obtain the information needed at these dark and distant planets. As a spacecraft flies farther away, its signal received on Earth becomes increasingly weaker.

**B**y lowering the rate at which Voyager 2 transmitted data, engineers increased the time devoted to the transmission of each bit of data. This is akin to speaking slowly to be better understood; less is said, but what is spoken has a greater chance of being heard clearly. Since this normally would result in less data received, a new method was devised for compressing the data gathered.

**N**ew software was radioed to the spacecraft. The programming enabled one computer, a backup, to be devoted to compressing and formatting all imaging data prior to transmission. Far fewer bits were needed to rebuild a picture received from Voyager 2. The process allowed the spacecraft to return thousands, instead of hundreds, of pictures from Uranus and Neptune.

## Improving Reception

**A**t DSN complexes around the world, multiple antennas were electronically linked together to improve the reception of Voyager 2's faint transmissions.

[click here to see picture...](#)

**H**igh noon on Uranus is not as bright as dusk on Earth, and Voyager 2's cameras were not designed to operate at such low light levels, so new techniques were developed to allow the cameras to track their targets while making long exposures.

**T**he entire spacecraft was moved with the cameras shutter open for exposures as long as 15 seconds. This engineering feat would yield sharply focused close-ups throughout the remainder of Voyager 2s journey.

**D**ue to the orientation of the Uranian system and Voyager 2s path through it, the spacecrafts discoveries there nearly came all at once.

## Neptune

[click here to see picture...](#)

**A** billion and a half miles beyond Uranus was Neptune - and Voyager 2s last encounter with a planet. At the time of Voyager 2s flyby, Neptune was the most distant member of the solar system. (Pluto once again will become most distant in 1999.)

[click here to see picture...](#)

**T**he astonishing discoveries made by the spacecraft at Neptune and its moon Triton would make the final flyby the piece de resistance of the Voyager mission.

[click here to see picture...](#)

**O**rbiting at the edge of the solar system, Neptune is the smallest of the solar systems giant planets. Very little was known about it before Voyager 2s arrival on August 25, 1989, so nearly everything the spacecraft observed was new.

## Hints of Pluto

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**P**luto may remain unexplored, but Triton gave scientists a glimpse of what to expect from that planet. Triton and Pluto share many characteristics: they are about the same size and have thin atmospheres. Both are about three-quarters rock and one-quarter ice; each has a layer of methane ice at its surface. Given these similarities, planetary scientists recognize that Voyager 2s flyby of Triton provided the best look we may have of Pluto for a long time.

## The Future of Voyager

**W**ith the planetary phase of its long mission accomplished, Voyager 2 took a sharp dive past Neptune, heading southward into a course that eventually will take the spacecraft out of the solar system.

**B**oth Voyagers are headed toward the outer boundary of the solar system in search of the heliopause, the region where the Sun's influence wanes and the beginning of interstellar space can be sensed. The heliopause has never been reached by any spacecraft; the Voyagers may be the first to pass through this region, which is thought to exist somewhere from 5 to 14 billion miles from the Sun.

**S**ometime in the next 10 years, the two spacecraft should cross an area known as the termination shock. This is where the million-mile-per-hour solar wind slows to about 250,000 miles per hour - the first indication that the wind is nearing the heliopause. The Voyagers should cross the heliopause 10 to 20 years after reaching the termination shock.

**T**he Voyagers have enough electrical power and thruster fuel to operate at least until 2015. By that time, Voyager 1 will be 12.4 billion miles from the Sun and Voyager 2 will be 10.5 billion miles away.

**E**ventually, the Voyagers will pass other stars. In about 40,000 years, Voyager 1 will drift within 1.6 light years (9.3 trillion miles) of AC+79 3888, a star in the constellation of Camelopardalis. In some 296,000 years, Voyager 2 will pass Sirius, the brightest star in our sky, at a distance of about 4.3 light years (25 trillion miles). The Voyagers are destined - perhaps eternally - to wander the Milky Way.

## *Voyager Contents*

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The Future of Voyager

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## Jupiter's Atmosphere

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**T**he ultraviolet spectrometer observed auroral activity so intense it was detected on the day side of Jupiter. As on Earth, the auroras are caused by charged particles plunging into the atmosphere.

**T**he complicated, swirling turbulence of the atmosphere and its beauty, reminiscent of works by Vincent van Gogh, awed scientists and non-scientists alike. The yellow, red and orange belts around Jupiter were shown to contain roiling, fluid-like storms. Huge cyclones moved through the upper atmosphere. A white jet stream of ammonia crystals clipped along at 350 miles per hour.

**T**he Great Red Spot, a hurricane-like storm three times the size of Earth, was seen surrounded by swirling currents that rotated around the spot and were sometimes consumed by it. The color of the spot, still unexplained more than a decade after the Voyager flybys, may be due to traces of sulfur or phosphorus compounds.



## Io and Europa

[click here to see picture...](#)

**N**othing in Jupiters realm was as exotic or more unexpected than the discovery of active volcanoes on Io; it was the first time these had been spotted on any object in the solar system besides Earth. In March, Voyager 1s cameras saw nine volcanoes spraying sulfurous ejecta above the surface of the innermost Galilean moon.

**W**hen Voyager 2 arrived four months later, eight of those volcanoes were still erupting. Ios volcanism explained its orange, red and black pepperoni-pizza appearance. The spots were not some kind of strange impact crater, but probably lakes of molten sulfur.

[click here to see picture...](#)

**I**o occupies an orbit that makes it the perpetual object of a gravitational tug-or-war between Jupiter and the moon Europa. In the same way that the Moon raises tides in Earths oceans, Jupiters gravity raises a bulge in Ios waterless surface. The tidal flexing of Ios crust heats the moons interior and creates volcanic eruptions of sulfur and sulfur dioxide.

[click here to see picture...](#)

**T**he next moon out is Europa. Its thin, icy crust is only weakly heated by tidal flexing, yet a tidally heated ocean may lie beneath the surface. The Voyagers found Europas face to be remarkable smooth and uncratered, yet striated with lines that are probably fractures in the ice surface.



## Ganymede and Callisto

[\*click here to see picture...\*](#)

**G**anymede and Callisto, both about the size of Mercury, are each half rock and half ice. When all the major moons in the solar system were finally measured by the Voyagers, Ganymede turned out to be the largest, with a diameter of 3,280 miles. Global tectonic processes appear to have been at work on this large body, creating crisscrossing ridges. These rifts, created by geophysical upheaval, surround other older, cratered terrain.

[\*click here to see picture...\*](#)

**C**allisto has escaped the geophysical transformation the other Galilean moons have undergone, and instead retains all of its original surface, still scarred by the rains of debris that littered the nascent solar system. This heavily cratered relic from the earliest days of the planets possesses one of the oldest surfaces in the solar system.



## Jupiter's Ring

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**M**uch to the surprise of Voyager scientists, a ring was found around Jupiter. Although suggested by Pioneer 11 data, the finding was unexpected; the theory explaining the long-term stability of planetary rings did not predict the existence of a thin, dusty, Jovian ring.

[click here to see picture...](#)

**T**wo of the three small moons the Voyagers found orbiting between Io and Jupiter appear to shed the dust-size grains that form the tenuous ring. Ultimately, new theories about rings were developed as the spacecraft found unique ring systems at each of the four giant planets.



## Jupiter's Magnetic Field



**T**he largest entity in the Jovian system is the invisible force of the planets magnetic field. Planetary magnetic fields are created by the motion of fluid interiors. Fifteen thousand miles deep within Jupiters interior, hydrogen undergoes a dramatic change.

[click here to see picture...](#)

**A**t a pressure three million times that at Earths surface, and at temperatures exceeding 19,000 degrees Fahrenheit, the hydrogen changes from molecular liquid to a state called liquid metallic hydrogen, an excellent electrical conductor.

**T**he liquid metallic hydrogen and the planets rapid rotation (9 hours 55 minutes) generate electric currents that create Jupiters magnetic field, which is more than 10 times stronger than that of Earth.

**J**upiters ring and moons are embedded in an intense radiation belt of electrons and ions trapped in the magnetic field. The Jovian magnetosphere, which comprises these particles and fields, balloons two or three million miles toward the Sun and tapers into a wind-sock-shaped tail extending at least 465 million miles behind Jupiter -- as far as Saturns orbit.





## The Magnetic Field and Io

[click here to see picture...](#)

**T**he relationship between the magnetic field and Io is unique. As the magneto-sphere rotates with Jupiter, it sweeps past Io, stripping away about a ton of matter per second and forming a torus -- a doughnut-shaped ring around Jupiter predominantly composed of electrified oxygen and sulfur glowing in the ultraviolet.

**A**s these heavy ions migrate outward, their pressure inflates the magneto-sphere to more than twice its expected size. Some of the more energetic ions fall into the atmosphere along the magnetic field to create Jupiters auroras.

**A**s Io moves through Jupiters magnetic field, it acts as an electrical generator, developing 400,000 volts across its diameter and generating an electrical current of three million amperes. The current flows along the magnetic field to Jupiters ionosphere.



## Saturn's Rings



**S**aturn's rings are a landmark of the solar system. They seem solid, but we have long known that they are made up of innumerable particles of water ice and perhaps frozen ammonia, a few centimeters to a few meters in size.

[click here to see picture...](#)

**N**evertheless, in close-up, the rings were one of the biggest surprises in the history of planetary exploration, far more numerous, complex, baffling, and beautiful than ever was expected.

**F**rom Earth, we could clearly see only three rings. Pioneer Saturn discovered three more. But as Voyager 1 drew close, the once seemingly uniform rings separated into dozens and then into hundreds of distinct, thin rings separated by narrow gaps.

[click here to see picture...](#)

**A**s Voyager 1 flew under Saturn, the rings stretched above the spacecraft like a huge rainbow and the Voyager cameras photographed perhaps a thousand separate rings, looking like the grooves of a cosmic phonograph record. Even in the Cassini division, a dark, seemingly empty band as seen from Earth, Voyager 1 photographed over 50 of the thin rings, floating within what had long been regarded as a permanent empty space in the ring system.

**T**he rings are far more complicated than anyone had imagined. For some unexplained reason, a few rings are not circular but appear elliptical, as though

some force has pulled them a little out of round. The thin, outer F-ring was resolved by Voyager 1 into several distinct strands that apparently are braided about each other.

[click here to see picture...](#)

**E**qually mysterious and unexpected are the so-called spokes, radial bands cutting right across the rings much like the spokes in a wagon wheel. They may be clouds of fine dust, held in place by electrical forces generated around the rings, but no one really knows.

**T**he Voyager 1 pictures demolished all existing theories about Saturn's rings. Previously, the structure of the few known rings and gaps was explained in terms of the gravitational influence of some of Saturn's adjacent moons on the small ring particles.

**I**ndeed, Voyager 1 did show how this mechanism may work on a small scale: Two small moons were discovered, one on each side of the thin F-ring. The pair may be shepherds, their gravity keeping the ring particles from moving in or out of their present orbits. A third small moon, discovered just outside the large A-ring, may have a similar stabilizing effect.

**T**hese examples are helpful, but they are not enough. No theory involving only a few moons can explain the presence of a thousand narrow rings, the elliptical rings, the ring braids, or the spokes. Nor can we yet explain how the delicate rings apparently have survived over the 4.5-billion year age of the solar system. The problems of the rings are now seen more fully and clearly, and unfortunately, they are more complex. New theories are needed to understand the entire fantastic Saturn system.

## **Saturn's Rings: As Seen By Voyager**

**C**omputerized enhancement of some of the Voyager images made apparent Saturn's faint banding through the planet's hazy upper atmosphere, and several hurricane-like storm systems could be discerned. Saturn's greatest beauty and mystery, however, were not in its atmosphere, but in its rings; by the time the Voyagers reached and photographed the rings, they were acknowledged as the most exquisite sight in the solar system.

[click here to see picture...](#)

**R**ather than being broad, featureless sheets, the rings were found to have an intricate structure. Scientists were amazed by strange shadowy streaks crossing



the broad B-ring and forming spoke-like patterns around the planet. These spokes, which appear to form, dissipate, and reform in a matter of hours, possibly are small grains of dust electrostatically levitated above the larger particles.

**I**n time-lapse movies of Voyager images, the motion of the spokes revealed the rotation of the rings around Saturn. We never thought we would be able to see the rings spinning like this, said one scientist. We thought we would see the planet turning with the rings as a still life. It now appears to be more nearly the reverse.

**T**he material in the rings ranges from dust to boulder -- and house-sized particles; the rings themselves are not much thicker than the largest particles and are thought to be the remnants of large moons that were shattered by impacts of comets and meteoroids. The irregular shapes of the smallest of Saturn's 18 known moons suggest that they too are fragments of larger bodies.

**T**he Voyagers found several narrow gaps, some occupied by slender rings unseen from Earth. Kinks and wavy edges were discovered in some of the rings and were associated with shepherding moons, small satellites orbiting within the ring plane.

**T**he elaborate and disordered structure of some of the rings is due largely to the gravitational effects of these moons, as demonstrated by the relationship between the F-ring and two small moons, Pandora and Prometheus, that orbit near one another but on opposite sides of the ring. These were the first of the many shepherding moons found orbiting the outer planets.

[\*click here to see picture...\*](#)

**M**oons embedded in the rings were found to sweep pathways clear of particles, creating the gaps between rings. In addition, the Voyagers found spiral waves in the rings, generated by the gravitational wake of moons orbiting outside the rings.



## Titan

[click here to see picture...](#)

**T**itan, the largest moon of Saturn, has a diameter of 3,200 miles. It is covered with an orange photochemical haze too thick to see through, but Voyager scientists hoped for some openings that would allow a look at the surface.

**A**lthough there were no such openings, instruments on the spacecraft provided intriguing glimpses of Titan that had scientists making early plans to send a probe to explore the terrain of the planet-size moon in the future.

[click here to see picture...](#)

**B**ecause of uncertainty about whether Titan's surface is composed of oceans, lakes, dry land or some combination thereof, the probe to be parachuted into Titan's atmosphere early in the next century is being designed to land or float safely on anything ranging from liquid seas to solid ground.

**T**itan has been described as Earth in a deep freeze. The chemistry in Titan's atmosphere may strongly resemble that on Earth before life evolved. Titan's surface temperature and pressure are -292 degrees Fahrenheit and 1.5 atmospheres, respectively.

**P**hotochemistry converts methane in the Titan atmosphere to other organic molecules, such as ethane, that are thought to accumulate in lakes or oceans. Other, more complex hydrocarbons form the haze particles that eventually fall to the surface, coating it with a thick layer of organic matter. Scientists believe this might be the kind of environment where, if it were warmer, primitive life might evolve.



## Saturn's Other Moons

**T**he satellite with a history of the most surface activity is Enceladus. The many valleys and faults of this moon attest to its tectonic vigor.

**L**ikewise, Tethys has undergone internal stresses, as indicated by a valley extending more than half the moons circumference.

[click here to see picture...](#)

**A**nother moon, Mimas, showed a crater so huge that the impact that caused it nearly broke the satellite apart.



## Saturn's Magnetic Field

[click here to see picture...](#)

**S**aturn's magnetic field is only 5 percent that of Jupiter. Of all the magnetic fields studies by the Voyagers, Saturn's was the most orderly; the axis of the field is almost perfectly aligned with the rotational axis of the planet.

**T**itan is often embedded in Saturn's magnetosphere and shed photochemically produced hydrogen to form a torus, somewhat similar to that produced by material swept off Io in Jupiter's magnetosphere. Ions from the surfaces of Saturn's icy moons form a sheet of ionized oxygen in the planet's equatorial plane. Bursts of radio emission from Saturn were heard at a frequency of 10 hours 39 minutes, giving the length of a Saturnian day.



## Uranus' Atmosphere

[click here to see picture...](#)

**A** high layer of smog-like haze was found around the sunlit pole of the planet. Scientists called ultraviolet light emanating from this day glow. The belted latitudinal pattern seen in the atmospheres of the other giant planets is maintained on Uranus despite its orientation.

[click here to see picture...](#)

**A** few methane clouds seen in the atmosphere revealed the presence of winds of nearly 374 miles per hour at the middle latitudes. Otherwise, the shallow hydrogen-helium atmosphere was found to be relatively inactive, with no visible hurricane-like storm systems.

**V**oyager scientists had thought the poles would be warmer than the equatorial region, but were surprised to find that most of the planet shows nearly the same temperature at the cloud tops.



## Miranda

[click here to see picture...](#)

**V**oyager 2's closest approach to Uranus on January 24, 1986, also brought the spacecraft near a little moon called Miranda. It would be the closest satellite flyby of the encounter with Uranus, but the Voyager team had no way of knowing in advance if Miranda would be of particular interest or pale in comparison to other, less accessible Uranian moons. Nevertheless, a series of close-ups of the moon was planned. Fortunately for planetary scientists, Miranda was the scientific equivalent of pay dirt.

[click here to see picture...](#)

**T**he smallest of the five Uranian moons known before Voyager 2, Miranda seems too diminutive and cold to possess the diverse geologic features it has. Giant faults have sliced canyons as deep as 12 miles into the surface. Rolling plains that are heavily cratered abut large patches of grooved and ridged terrain.

[click here to see picture...](#)

**T**hese characteristics suggest Miranda may have undergone strong tidal heating in the past, possibly during a time when the small moon occupied a chaotic orbit around Uranus. Whatever forces shaped Miranda, they seem to have stopped.

[click here to see picture...](#)

**P**lanetary scientists have theorized that Miranda was frozen in the midst of a geologic process that most terrestrial (solid, Earth-like) bodies are thought to have undergone at an early age, a process in which the body almost literally turns inside out. Still other theories put forth that Miranda is the reagggregated sum of the parts of one or more moons that shattered in a collision with a comet.





## Uranus' Other Moons

[click here to see picture...](#)

**T**he other large Uranian moons display the same variety found in Jupiters and Saturns collections. Ariel and Titania both have valleys formed by faults. Titania has fault lines that may be the result of the expansion of subsurface water as the moons interior froze. Oberon and Umbriel have old surfaces little changed since their formation.

[click here to see picture...](#)

**U**mbriels surface is darker than those of its companions and may have been blanked by a layer of dark debris. Any methane in its icy crust would have been darkened from the continual bombardment by ions trapped in the Uranian magnetic field.

[click here to see picture...](#)

**T**en new moons were found orbiting near the rings, bringing the total to 15. Based on the knowledge gained at Saturn, scientists predicted and found shepherding moons ushering the outermost of Uranus rings; the moons herding other rings may have been too dark or tiny for Voyager 2s cameras to record.





## Uranus' Rings

[click here to see picture...](#)

**V**oyager 2 counted two new Uranian rings in addition to the nine that were already known. From the Uranian rings, scientists have determined that planetary rings may be short-lived phenomena that come and go throughout a planet's lifetime.

[click here to see picture...](#)

**T**he particles in orbit around Uranus are thought to be pieces of a moon that broke up; the rings contain relatively little dust, in contrast to Saturn's E- and F-rings and Jupiter's ring.

[click here to see picture...](#)

**I**t is thought that atmospheric drag, due to the hydrogen corona that Voyager 2 observed around Uranus, causes dust particles to spiral into the planet. In time, the rings may vanish. New rings would form only with the breakup of another moon or a captured meteoroid or comet.



## Uranus' Magnetic Field

[\*click here to see picture...\*](#)

**P**erhaps the weirdest aspect of the Uranian system is its magnetic field. On other planets, including Earth, the axis of the magnetic field is nearly parallel to the axis of rotation, placing the magnetic poles near the geographic poles.

**B**ut Uranus magnetic axis is tilted about 59 degrees and offset from the center of the planet by 30 percent of its radius (4,500 miles), placing the magnetic poles nearer the equator.

**A**s it rotates with the planet, the field is forced back by the wind of charged particles from the Sun and would into a twisting magnetotail. Scientists believe the field is generated at an intermediate depth in the planets interior -- where the pressure is high enough for water to become electrically conductive.

**R**adiation belts at Uranus were found to be of an intensity similar to those at Saturn; irradiation would quickly darken (within 100,000 years) any methane trapped in the icy surfaces of the inner moons and ring particles. This may account for the darkened surfaces of the moons and ring particles.



## Neptune's Dynamic Atmosphere

**B**ecause Neptune receives so little sunlight (only 3 percent of Jupiters total), it was expected to be somewhat less active than the other giant planets.

**Y**et Neptunes atmosphere showed itself to be surprisingly dynamic, with winds blowing westward, opposite the direction of rotation, at more than 1,200 miles an hour - faster than winds on any other planet. Neptunes winds are not very turbulent, so less energy is needed to maintain their high speeds.

[\*click here to see picture...\*](#)

**E**arly in Voyager 2s approach, a giant storm the size of Earth peered out from Neptunes atmosphere like a giant eye. Called the Great Dark Spot, it resembles Jupiters Great Red Spot, with winds blowing counterclockwise and moving westward at almost 745 miles per hour. A small, irregularly shaped, eastward-moving cloud was seed darting around Neptune every 16 hours or so.

**T**his scooter, as Voyager scientists called it, may be the top of a cloud plume rising above a deeper cloud deck. Long, bright clouds similar to cirrus clouds on Earth were seen casting their shadows on lower level clouds in the atmosphere.



## Neptune's Magnetic Field

**B**efore Neptunes magnetic field was measured, scientists believed Uranus to be unique in its huge offset from the planets axis of rotation. But Neptunes field turned out to be highly tilted too -- 47 degrees from the rotational axis and offset at least 0.55 radius (about 8,500 miles) from the physical center of the planet.

**C**omparing the two magnetic fields, scientists think that the unusual orientations may be characteristic of flows in the interior of both Uranus and Neptune -- and not the result of magnetic field reversals, or, in Uranus case, of the planet being tipped on its side.



## Neptune's Rings and Moons

[click here to see picture...](#)

**L**ike its sibling giant planets, Neptune was found to be completely encircled by rings rather than surrounded by the partial rings or ring arcs that had been detected from Earth. Some of its rings are diffuse, dusty sheets; others have unevenly spaced clumps of dense material.

**T**hese concentrations of ring material are puzzling; the material should have spread uniformly throughout a particular ring in just a few years.

**T**wo moons, Nereid and Triton, were known to orbit Neptune, but Voyager 2 found six more. The new moons are all very dark and small, ranging from 30 to 250 miles in diameter. Like the rings, the smallest of these are probably fragments of larger, shattered moons.





## Triton

[click here to see picture...](#)

**V**oyager 2s close look at Triton did not disappoint a science team that had learned to expect surprises. This large moon, which has a thin atmosphere of nitrogen and methane, is the coldest object in the solar system, with a temperature of -391 degrees Fahrenheit.

**S**till, it possesses a remarkable range of activity, including geyser-like plumes. These eruptions carry dark hydrocarbons upwards several miles, where they are blown away in high winds.

[click here to see picture...](#)

**T**ritons relatively high density and its retrograde orbit (opposite to the direction of Neptunes rotation) indicate that the satellite is not an original member of the Neptune system, but is a captured object. If that is the case, tidal heating could have melted Triton during the time it had a more eccentric orbit. The moon might have been molten for as long as a billion years.

[click here to see picture...](#)

**F**ault valleys crisscross Tritons frozen, water-ice surface near the equator. The faults are filled by ridges of ice extruded from the interior. The volcanic craters have been repeatedly flooded and refrozen, forming bright, lake-like features.

**N**eptunes radiation belts encompass Triton, possibly producing the pink and reddish hues on the moons surface by irradiation. Fine-grained frost on Tritons surface appears blue.

[click here to see picture...](#)

**S**ome of the charged particles traveling along Neptunes magnetic field lines strike Tritons atmosphere, exciting atoms there and producing an auroral glow detected by Voyager 2s ultraviolet spectrometer. Triton and Saturns Titan are

among the few satellites in the solar system to have atmospheres, and the only two moons known to have auroras.



