We're Ready... How about you? Join us as we Explore Jupiter

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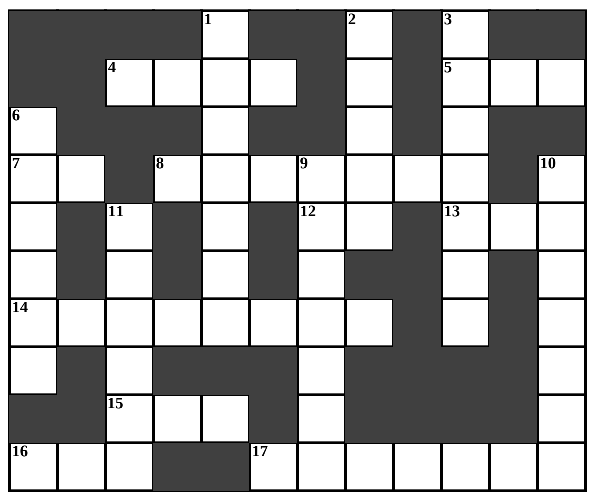
Welcome to the first issue of the Galileo Curriculum Module! 1995 is a very exciting year for all of us. The Galileo spacecraft, after a 6-year journey, will arrive at Jupiter in December and begin a tour of the planet and its system of moons. Let us help you and your students understand and appreciate WHY we're going and WHAT we hope to learn there.

We've provided dashed lines as guides for cutting out single exercises. Each exercise's level of difficulty is expressed as:

- ☞ *easy (no math or writing required)*
- ☆ *challenging (some math, writing or fairly difficult concepts to understand)*
- ☆☆ *advanced (higher math skills and / or background knowledge required)*

☆

Here's a crossword puzzle that tests your knowledge of Jupiter. If you can't do it already, you should be able to completely fill out the puzzle after you've completed the other lessons in the Module.



DOWN

(1) The King of Planets
(2) Jupiter was hit by one (Shoemaker-Levy 9) in 1994
(3) Number of moons at Jupiter
(6) On Jupiter it's 9 hours 48 minutes (2 words)
(9) He's credited with first having observed Jupiter's largest moons
(10) On Dec. 7, 1995 an atmospheric Probe will provide this kind of report from Jupiter (Hint: think of local TV news)
(11) Jupiter's nearest "Gas Bag" planetary neighbor

ACROSS

(4) "Jupiter" Greek-style
(5) Jupiter's outermost moons are covered with this substance often associated with Wayne Gretzky.
(7) Are there mountains on Jupiter?
(8) In terms of planet size how does Jupiter rate?
(12) The Galileo spacecraft arrives __ Jupiter in December,1995.
(13) Common instrument used to view Jupiter at night: the naked ___.
(14) In our Solar System, this "belt" separates the 4 inner planets from the 5 outer planets.
(15) Short for Radio-isotope Thermoelectric Generator, the power source on the Galileo spacecraft
(16) Jupiter is 5 times farther from this than the Earth.
(17) In 1979, this spacecraft flew past Jupiter and discovered a ring!!

What do YOU Know About Jupiter Already? Find out ...

"My Very Educated Mother Just Served Us Nine Pizzas"
this is an example of a mnemonic (nee-mon-ik), a simple way to remember complicated things.
What does this mnemonic help us remember? (next page)

☞ TRUE OR FALSE: JUPITER, SATURN, URANUS AND NEPTUNE ALL HAVE RINGS.

☞ THE "GREAT RED SPOT" IS :
(A) a huge volcanic plume.
(B) an ocean similar to Earth's Red Sea.
(C) where sunburned people go to meet each other.
(D) a big storm.

☆ WHICH STATEMENT(S) IS / ARE LIKELY TO BE UTTERED BY JUPITER'S FIRST TOURISTS (there could be more than one):
(A) "This rock looks really old"
(B) "The air sure smells great!!!!"
(C) "I've lost a lot of weight since leaving Earth!"
(D) "Looks like it might rain later"
(E) "It's cool but there's a lot of pressure to deal with"

☆ WHICH OF THESE STATEMENTS ARE TRUE?
(A) Jupiter has 16 moons.
(B) Jupiter has a moon named Warren.
(C) About 400 years ago, Galileo saw 4 of Jupiter's moons.
(D) Jupiter's moons are all about the size of the Earth's Moon.
(E) One of Jupiter's moons has active volcanoes on it.

☆☆
YOU'RE ABOUT TO BE STRANDED AT JUPITER! IN ORDER TO SURVIVE, WHICH OF THE FOLLOWING ITEMS (choose A or B from each line) WOULD YOU PREFER TO HAVE? WHY?
(This exercise is best done as a group activity)

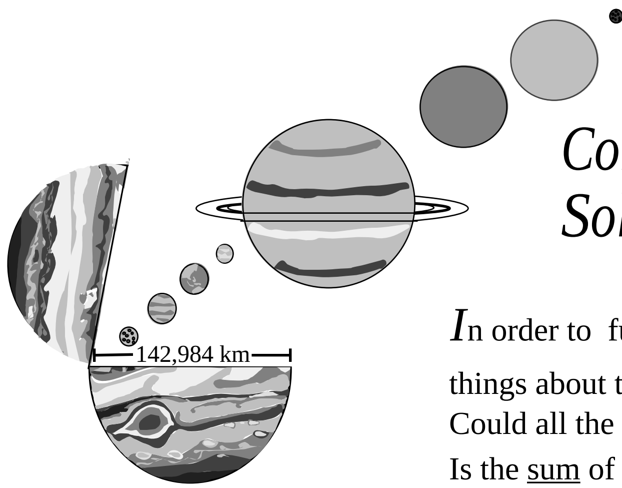
A	B
SOLAR-POWERED ENGINE	NUCLEAR-POWERED ENGINE
SCUBA GEAR	FIRE-PROOF CLOTHES
HOT-AIR BALLOON	DUNE BUGGY
MATCHES	COMPASS
WATER	FOOD
CHAPSTICK	SUN TAN LOTION

---

aturn, Uranus, Neptune, and Pluto (The word "nine" reminds us of how many planets there are and the sentenc
BUT BE CAREFUL... because of its non-circular orbit sometimes Pluto is closer to the Sun than Neptune)

☆ *The volume calculation exercise can be lead by the teacher (see the answer key).*

☆☆ *The volume calculation exercise can be cut out and done by the students, too.*



Compare the Planets in our Solar System: Size and Volume

In order to fully enjoy this adventure you should learn a few things about the King of Planets. For one, it's **HUGE**... Could all the planets in our solar system fit INSIDE Jupiter? Is the <u>sum</u> of their volumes less than that of Jupiter?

	Diameter (D) at equator (km)	Radius (R) 1/2 D (km)	Volume $4/3\ \pi\ R^3$ (km^3)
JUPITER	142984	0.7×10^5	1.4×10^{15}
MERCURY	4878		
VENUS	12102		
EARTH	12756		
MARS	6786		
SATURN	120536		
URANUS	51118		
NEPTUNE	49528		
PLUTO	2300		
TOTAL VOLUME OF OTHER PLANETS			

Add these and compare to Jupiter's volume

A pretty accurate way to do this is by using scientific notation and rounding to 2 significant digits. For example, Jupiter's diameter can be rounded to 1.4×10^5 km. Half of that is 0.7×10^5 km, Jupiter's radius. You can calculate R^3 by multiplying $0.7 \times 0.7 \times 0.7$ (= 0.34) and multiplying the exponent by 3 ($5 \times 3 = 15$).... $R^3 = 0.34 \times 10^{15}\ km^3$. The term ($4/3\ \pi$) can be simplified to 4 since π is about 3 ($4/3 \times 3 = 4$). Jupiter's estimated volume is $1.4 \times 10^{15}\ km^3$ ($4 \times 0.34 \times 10^{15}$). Without the short-cuts the answer you get is $1.5247 \times 10^{15}\ km^3$.

☞ *A fun way to teach about shapes and volumes is to use modeling clay. Make a sphere for each planet at a manageable size (for example 1 mm per 1000 km of diameter). First compare the volumes as spheres. Would they fit inside Jupiter "as is"? Then "mash" the non-Jupiter spheres together into a ball and compare with Jupiter.*

Using this technique the Jupiter sphere will be 14.3 cm in diameter:

The Pluto sphere will be 2.3 mm in diameter: ■

☆ *The "Planet & Interior" section can directly used by students or presented by teachers. The cross-sectional diagrams of Earth and Jupiter can be used by students to compare the structure and size of a rocky inner planet and a gaseous outer planet.*

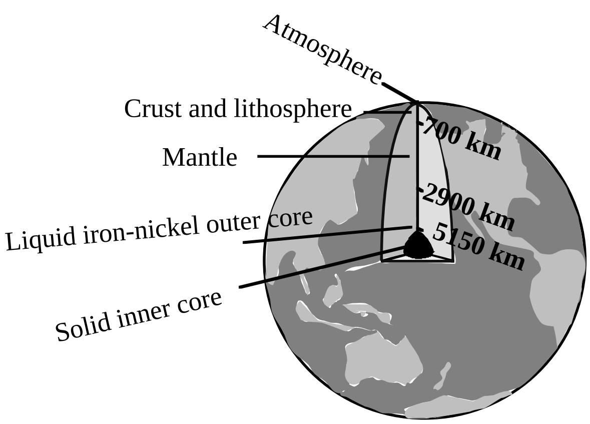
The exercise to calculate the ABSOLUTE spin rate (at the bottom of the page) is rated: ☆☆

The exercise to calculate the RELATIVE spin rate (at the bottom of the page) is rated: ☆

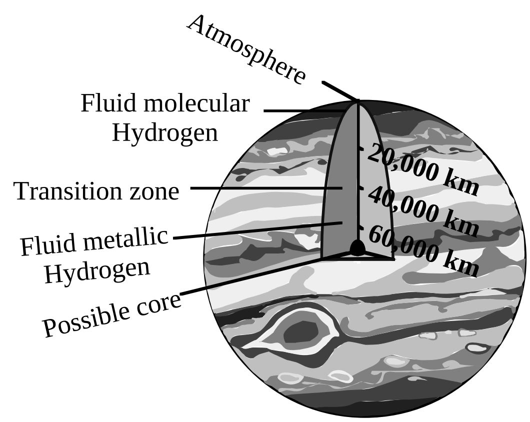
Planet Structure & Interior

*T*he familiar brown, white and orange clouds that we can see on Jupiter make up only the thin outermost layer. Like every substance, the molecules and atoms in Jupiter's cloud tops emit and absorb radiation at certain characteristic wavelengths, just as a guitar string will vibrate only at given frequencies. The wavelengths that characterize individual chemicals are accurately known from laboratory experiments. Earth-based studies revealed that Jupiter's atmosphere is composed mainly of hydrogen with small amounts of ammonia and methane. There is also a significant amount of helium in the atmosphere; the ratio of hydrogen to helium is close to that found on the Sun!

*A*lthough Jupiter is extremely massive (1.9 X 10^{27} kg), its mean density is only 1.33 grams per cubic centimeter (slightly greater than water's density). The mean density of the Earth is about four times that of Jupiter! The large size and low density indicate that Jupiter is made up of lighter elements, in particular hydrogen and helium; these are present mainly in the form of gas and liquid.



EARTH (radius = 6378 km)



JUPITER (radius = 71492 km)

Q and H (for "Hints")

*J*upiter and the Earth spin in the same direction (counter-clockwise if you're looking down at the North Pole). Even though it doesn't feel like we're moving, we actually travel the distance around the Earth (its circumference if we're at the Equator) every day. If you were "sitting" on a cloud in Jupiter's atmosphere you'd move faster than you move "sitting" on the Earth's surface.

Q: One Jupiter day is 9 hrs 48 min. How much faster would you be moving on Jupiter than on Earth?

H: To know the ABSOLUTE rate you're moving you need to know two things about each planet: the length of its day and its circumference ($2\pi R$). To estimate the RELATIVE speed between Earth and Jupiter you simply need to know the following: Jupiter's day is about $2^1/_2$ times **shorter** than one Earth day. From page 3 we know that Jupiter's diameter is about 12 times that of Earth. Radius and circumference are LINEARLY related to diameter (no exponents used in the equations) thus Jupiter's circumference is also 12 times **greater** than Earth.

The "Jupiter's Monstrous Magnetosphere" and "Radiation" sections can directly used by students or presented by teachers. Use the cross-sectional diagram and accompanying scale to help students visualize the magnetosphere's shape and its size relative to that of the planet .

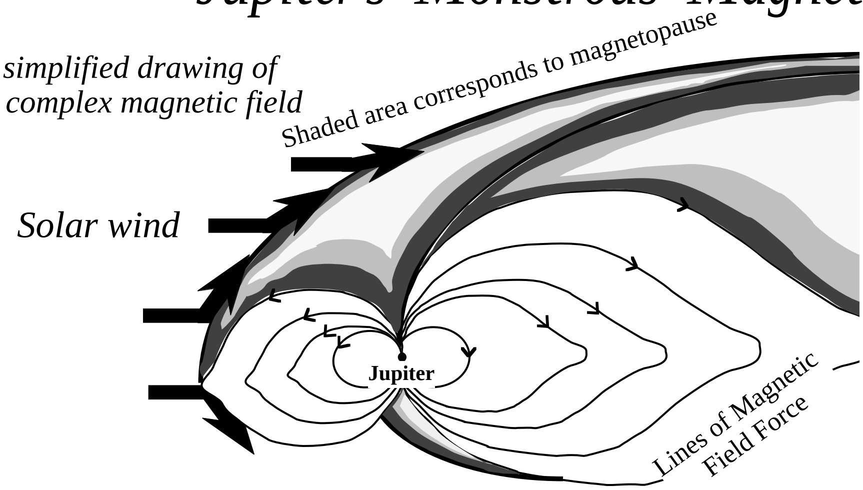
☆ *Q:* Why do we think Jupiter has a metallic fluid hydrogen layer deep inside the planet?
H: What special characteristic about the Earth is associated with Earth's iron-nickel liquid outer core?

Frank & Ernest, 1/6/95
Used with permission
from Bob Thaves

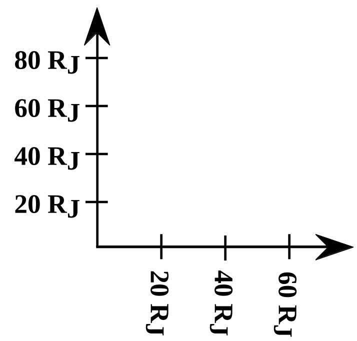
Earth's magnetic field comes from its electrically-conducting liquid iron-nickel outer core starting at depth of 2900 km (see diagram on page 4). Jupiter's magnetic field is ten times stronger than the Earth's and Jupiter's magnetosphere is immense; if it were visible from the Earth, it would look twice as large as a full moon! The presence of a gigantic magnetic field around Jupiter is why we think there's <u>a lot</u> of swirling metallic hydrogen within the planet.

Jupiter's "Monstrous" Magnetosphere

Here's a simplified drawing of Jupiter's complex magnetic field

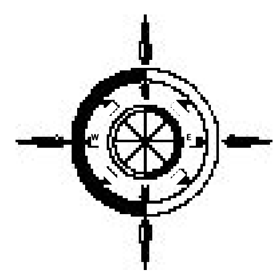


Scale in units of R_J (radius of Jupiter; 1 R_J equals 71,492 km)



A magnetosphere is the region around a planet where its magnetic field predominates over the magnetic field of the surrounding interplanetary region. Despite its name, Jupiter's magnetosphere is not spherical, but has a long "magnetotail" streaming away like a windsock from the Sun's solar wind . The solar wind itself is made mostly of protons and electrons. The magnetotail stretches beyond the orbit of Saturn! A shock wave (like the bow wave of a boat) is formed where the solar wind particles are slowed by the magnetic field causing a turbulent region to form ("magnetopause"). In the outer reaches of Jupiter's magnetosphere there is a disk-shaped region ("magnetodisk") within which electric currents flow, carried by low-energy "plasma". Plasma is matter which is heated up enough not only to break the bonding forces between its molecules, but also to free the electrons from their atoms!

Arrows located on the magnetic field's "lines of force" show the direction that an Earth-made compass' "North" arrow would point. On Jupiter, the "North" arrow would point toward geographic SOUTH! On Earth, rocks with magnetic minerals show that the "polarity" of the magnetic field has changed throughout geologic time. This is probably also true for the magnetic fields of other planets... so if you're planning a trip to Jupiter in the future don't throw away your compass !!

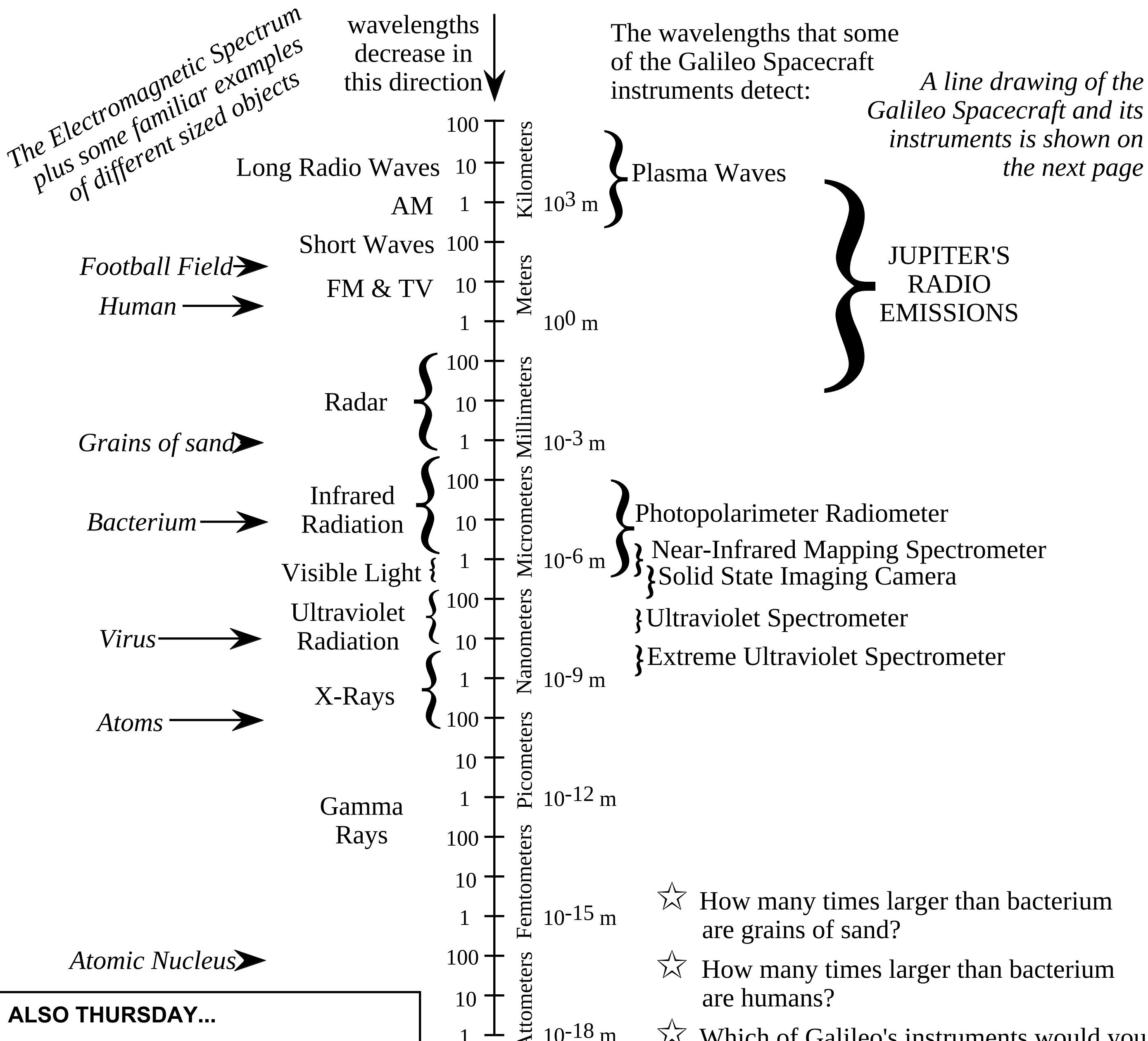


High-energy particles are trapped in Jupiter's magnetic field and form belts of intense radiation aligned with the magnetic axis. There are similar belts of radiation on Earth (Van Allen belts) but Jupiter's can be up to 10,000 times more intense! These levels of radiation near Jupiter's moon Io are so high that a human would absorb a lethal dose in just minutes. This level of radiation also is a serious hazard to spacecraft. Lessons learned from earlier missions, which were seriously jeopardized by radiation effects, were taken into account when scientists and engineers designed later missions.

Catch a Wave.....

*L*ight is electromagnetic radiation whose wavelength can be sensed by the human eye. There are many other wavelengths that can be detected using instruments. The study of electromagnetic wave spectra is called "spectroscopy". Spectroscopy can provide information about the chemistry of planets, the speed of comets, the temperatures of stars, and much more. For example, at infrared radiation wavelengths a heat-generating body is easily detectable against a non-heat-generating background*. Photographs of other planets and stars are only part of the whole picture!!

*T*his chart shows the types of waves and their sizes on a logarithmic scale... that's why the distance between 1 and 10 is the same as the distance between 10 and 100. Each tick mark represents a factor of 10 increase or decrease from the one next to it. For example, Short Waves are 10 times longer than FM & TV waves and visible light is 100 times (two tick marks =10 X 10) shorter than infrared radiation.



☆ How many times larger than bacterium are grains of sand?

☆ How many times larger than bacterium are humans?

☆ Which of Galileo's instruments would you use to take photos of the Great Red Spot? Why?

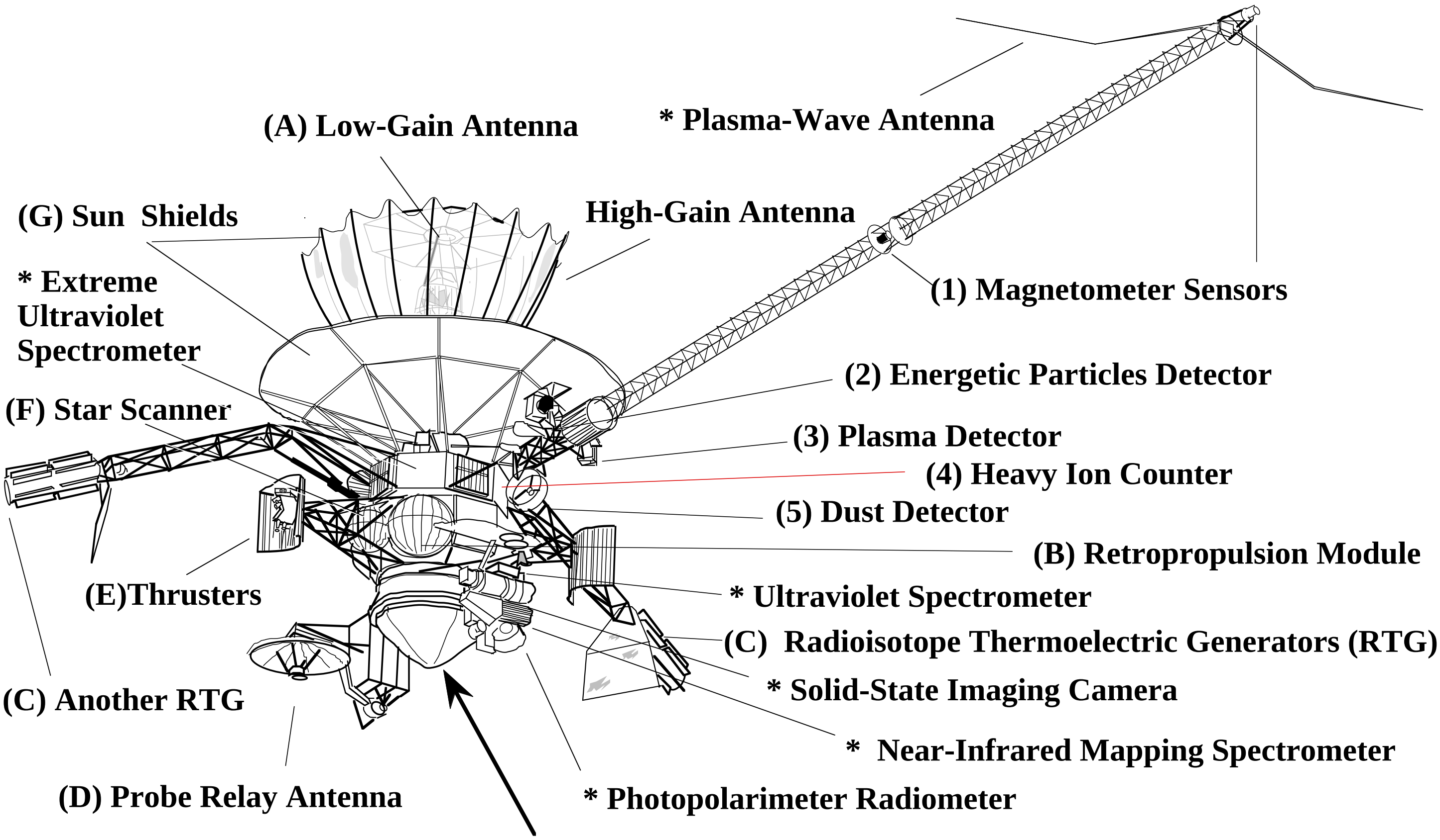
☆ Could we hear Jupiter's radio emissions?

* **ALSO THURSDAY...**

TIGER SEARCH: Gov. Frank Keating called on the Oklahoma Air National Gaurd to use its OH-58 helicopter, which contains infrared radar, to search for the missing tiger near Hugo. The 200-pound tiger escaped more than a week ago from the Carson and Barnes Circus.

USA TODAY • FRIDAY, FEBRUARY 10, 1995 • 3A

What Does the Galileo Spacecraft Look Like?



*T*he Galileo spacecraft has many instruments and features that can be divided into four categories: Atmosphere Probe, Fields and Particles Science, Imaging or Remote Sensing Science, and Engineering. The five Remote Sensing Science instruments (shown as *'s in the diagram) "see" wavelengths between 1 nanometer and 100 micrometers (see the "Catch a Wave" chart). The plasma wave antenna is also starred and its wavelength range is shown on the "Catch a Wave" chart.

*F*ields and Particles (F & P) Science is the study of Jupiter's magnetosphere and associated fields. One F & P instrument is shown on the "Catch a Wave" chart: the Plasma Waves antenna (at radio frequencies). The other five F & P instruments are shown as (1) through (5) above.

Magnetometer Sensors (1) sense the magnetic field in the spacecraft's immediate environment.

Energetic Particles Detector (2) measures the velocity and energy of helium, oxygen, sulfur and iron **ions.**

Plasma Detector (3) measures the velocity and energy of hydrogen, oxygen, sodium and sulfur **electrons.**

Heavy Ion Counter (4) is a radiation monitor: a Jupiter-bound Geiger counter.

Dust Detector (5) measures the mass, speed, flight direction and electric charge of dust as it interacts with the magnetic, radiation and gravity fields.

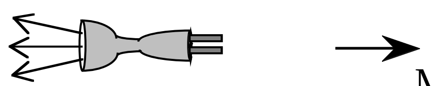
What Does the Galileo Spacecraft Look Like? (continued)

☆

LEARN ABOUT GALILEO'S <u>ENGINEERING</u> INSTRUMENTS by filling in the blanks with the correct letters (A - G) from the Galileo spacecraft diagram:

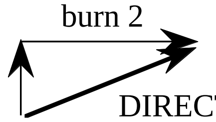
All spacecraft need to know where to go and have a way to get there. The "map" the spacecraft follows is based on celestial navigation; it steers by *looking at the stars (__)*. Using *propellant (__)*, the spacecraft moves around in 3-dimensional space by *spewing fluid through nozzles at high speeds (__)* oriented in 3 different directions. The power needed to operate the instruments and computers onboard is *generated from the heat of radioactive sources (__)*. The hot environment (extreme temperatures, unfiltered sunlight , etc.) encountered during the trip to Venus on the way Jupiter required extra protection in the form of __. *Communication (__)* between the spacecraft and Earth is one of the key challenges we have to face because the High-gain Antenna did not open properly during flight (the shape shown above is what we think it looks like...it was supposed to unfold so that it would look like an upside-down umbrella) and thus we must rely on other equipment and new data-handling techniques for communication. Upon Jupiter arrival, the Atmosphere Probe will send data to the Galileo Orbiter *using a dish (__)* oriented toward the planet (and away from the Earth).

☞ *Spacecraft have 2 ways of moving using thrusters. One way, called "Turn & Burn", is to turn the spacecraft so that its thrusters are pointing along the direction we want it to go:*



During "Turn & Burn" maneuvers we often lose communication with the spacecraft because its antenna is not pointed towards Earth.

Another choice is doing a "Vector" maneuver. This maneuver involves doing burns in 2 different directions to get the spacecraft going the correct way:



Draw a 10 by 10 square grid on the ground using chalk or use floor tiles. Designate a few students to be planets and have them stand on different parts of the grid. Make up a list of planets and an order in which to visit them. Review this list with a designated "human spacecraft" before he or she begins their "Planetary Tour". For the "Vector mode" Tour, the spacecraft can only move along the grid lines. The spacecraft is allowed to talk to "home" (i.e., ask the teacher for directions). Count the number of steps used during the Tour.

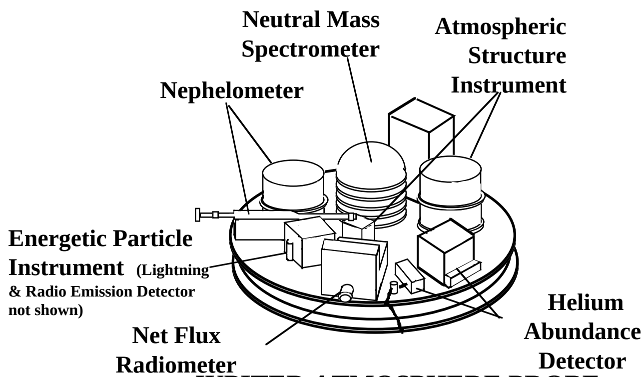
Re-create the Tour in "Turn & Burn" mode by walking directly toward each planet in the same order. The spacecraft is not allowed to "phone home" for directions. Count the number of steps used and subtract from it the number of steps used during the "Vector" Tour...this is the amount of "propellant" saved.

Did the spacecraft get lost during the second Tour? Can the students think of ways to save propellant AND "phone home" periodically?

Jupiter's Weather Forecast

One-hundred forty-seven (147) days before the Galileo Orbiter reaches Jupiter it will release an Atmospheric Probe. Soon after release, the orbiter will burn its big engine for 5 minutes and end up on a path to Jupiter that is slightly different from the path the Probe is taking. The Orbiter and Probe will reach Jupiter at the same time (December 7, 1995) but will be out of communication until a 75 minute period called "Probe Relay". During "Relay", the Probe will deploy a parachute and then descend about 150 km into the planet's atmosphere. The Probe will send atmospheric data up to the Probe Relay Antenna and the data will be recorded onboard the Orbiter. The data will be played back to Earth soon after the Jupiter encounter.

During the Probe's "pre-entry" phase, it will study the energetic particle population in Jupiter's innermost magnetosphere (Energetic Particle Instrument). During descent, instruments on board the Probe will measure temperature and pressure (Atmosphere Structure Instrument), locate major cloud decks (Nephelometer and Net Flux Radiometer) and analyze the chemistry of atmospheric gases (Helium Abundance Detector and Neutral Mass Spectrometer). The Probe will attempt to detect lightning by looking for flashes of light and by listening for the radio "static" they generate (Lightning and Radio Emission Detector).



JUPITER ATMOSPHERE PROBE

Photographs from space show how different weather is on Earth and Jupiter. On Earth, the cloud patterns are mostly spiral-shaped storms. Jupiter's weather pattern is dominated by bands of clouds that are aligned with its spin direction.

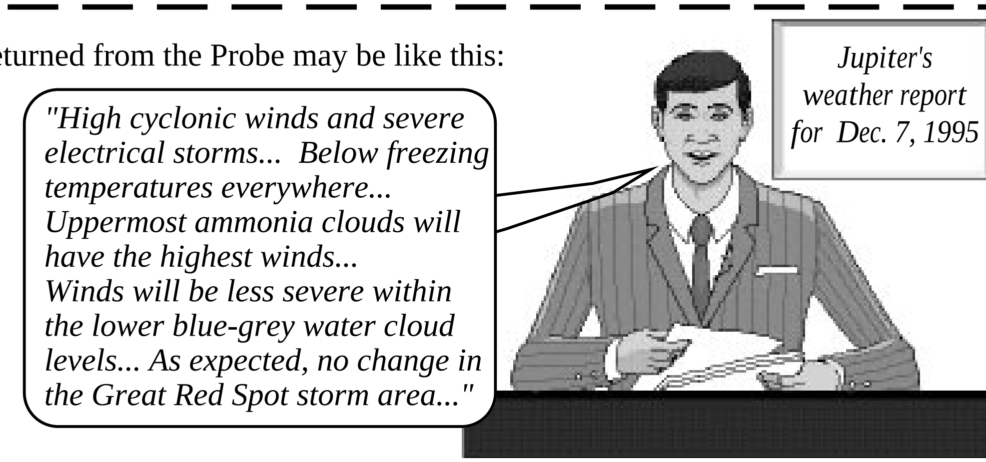
☆

Several factors that contribute to the differences in weather on each planet are shown in the chart below. Compare the two planets by filling in the rest of the blanks (use general descriptions, not quantitative values).

	EARTH	**JUPITER**
PLANET TYPE	Terrestrial (continents & oceans)	Gaseous
SPIN RATE		
DISTANCE FROM THE SUN		
INTERNAL HEAT RELEASED	a little	a lot
SIZE		
MASS / GRAVITY		
SPIN AXIS ORIENTATION	23 degrees	3 degrees

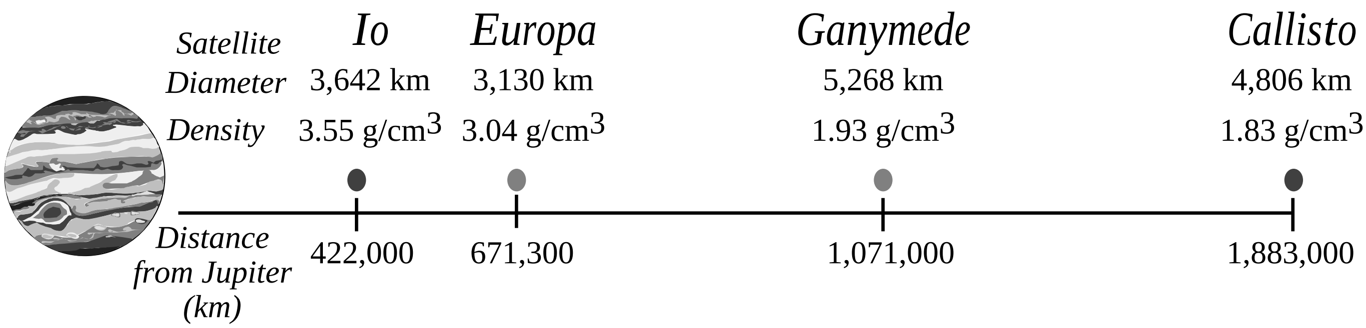
Does this chart help you understand WHY the weather on Earth and Jupiter look so different?

The weather report returned from the Probe may be like this:

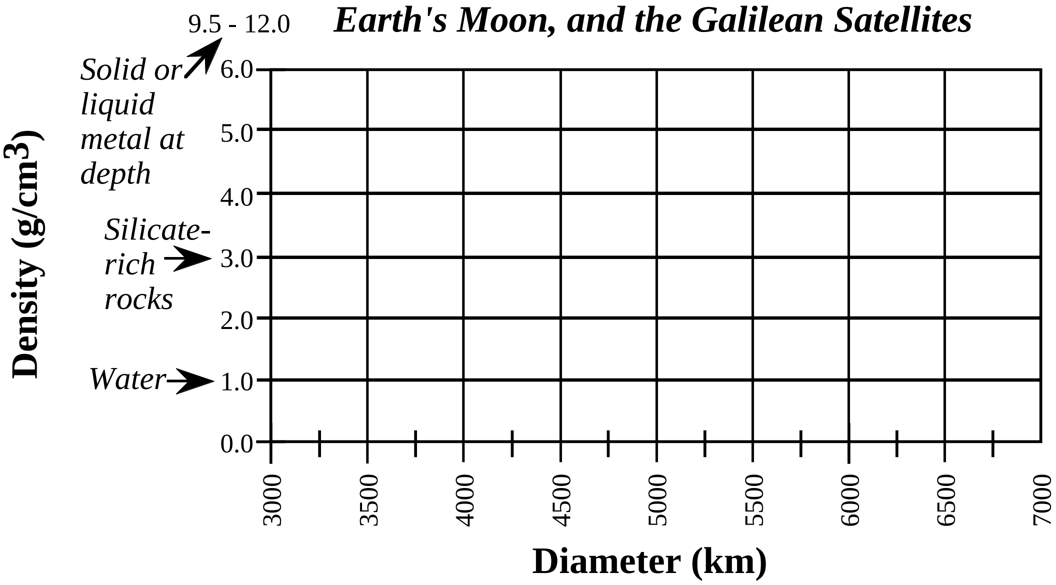


❍❍❍❍❍❍❍❍❍❍❍❍❍❍❍ *The Moons of Jupiter* ❍❍❍❍❍❍❍❍❍❍❍❍❍❍❍

Sixteen moons have been found at Jupiter. The four largest were discovered by Galileo himself in the year 1610! That's why they're called "The Galilean Satellites". There are four smaller satellites in near-circular orbits that are closer to Jupiter than the innermost Galilean Satellite (Io, see below): Amalthea (discovered in 1892) and 3 others (discovered in 1979). The remaining eight satellites have elliptical orbits and are found far beyond Callisto (at 11,000,000 km and 22,000,000 km!) in 2 groups of four satellites. And, if that isn't enough, the Voyager mission also discovered a RING around Jupiter!!



Density versus Diameter of Mercury, Mars, Earth's Moon, and the Galilean Satellites



The density of Mercury is 5.43 g/cm^3 and the density of Mars is 3.93 g/cm^3. Their diameters are given on page 3. Earth's moon has a diameter of 3,476 km and a density of 3.34 g/cm^3.

☆ Plot the density versus diameter of these and the Galilean satellites on the chart provided.

☆ How do the Galilean satellites compare to these bodies in terms of size?

☆ Based on density, can you guess anything about the composition of Jupiter's moons?

☆ Based on density, can you guess anything about the other bodies? For example, why is Mercury so much denser than Mars?

☆ Do you see any trends that correspond to distance from Jupiter?

The Moons of Jupiter (continued)

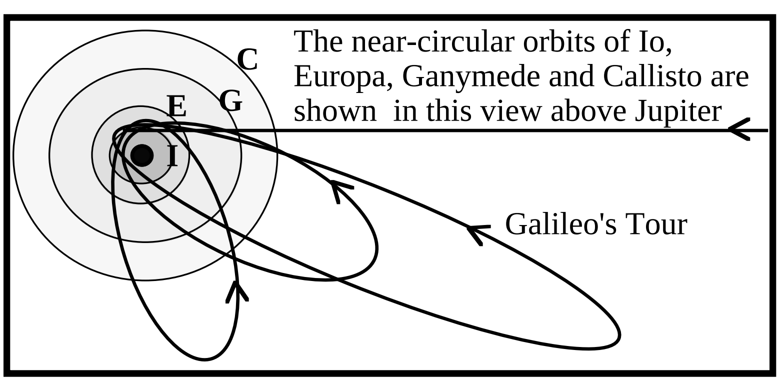
Comparative Planetology is used to infer things about less-explored planetary bodies by comparing them to better-known ones (and vice versa). The Earth and its moon are well-known...they're the only planetary bodies that we've stood on! Earth is a geologically ACTIVE planet: volcanoes, fault lines and mountains are proof of that. The Moon is INACTIVE; no short-term (less than millions of years) processes such as weather, volcanic flows or mountain-building are operating to destroy the record of crater impacts that has built up over billions of years.

Satellite	*Io*	*Europa*	*Ganymede*	*Callisto*
Description	A LOT of volcanoes & lava flows No impact craters	Abundant fractures & cracks Some impact craters	Some ridges & grooves Many impact craters	Craters everywhere!
Distance from Jupiter (km)	421,600	670,900	1,070,000	1,880,000

☆
Based on this information, can you use the technique of Comparative Planetology to determine whether the Galilean Satellites are geologically active or inactive?

☆
Do you see any trends that correspond to distance from Jupiter?

From December 1995 through December 1997, the Galileo Spacecraft will be on an 11-orbit tour of the Jupiter System. This tour will bring us closer to Jupiter's moons than we've ever been before. The Io encounter is first and one of the most exciting. We'll be within 1000 km of what many think is the most volcanically active body in the Solar System! Throughout the next 2 years we'll have close encounters with Europa three times, Ganymede four times and Callisto three times. We'll also image the ring and smaller satellites during most orbits. Stay tuned........



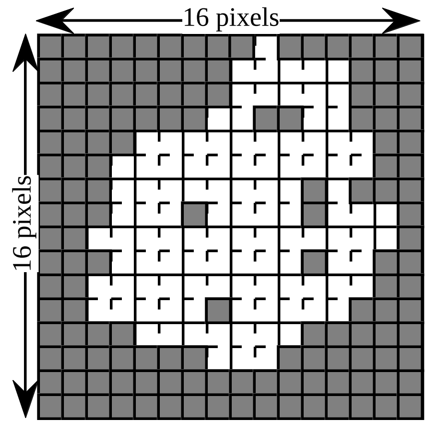
This sketch is a simplified view of the tour that Galileo will take during its 2-year journey. Notice that the tours' orbits have different shapes. That's because we will use the moons' gravity fields to deflect the spacecraft into orbits that provide the best "views" of each of the Galilean satellites. The method of using gravity to change the path of a spacecraft is called a "gravity assist".

Data Handling Techniques

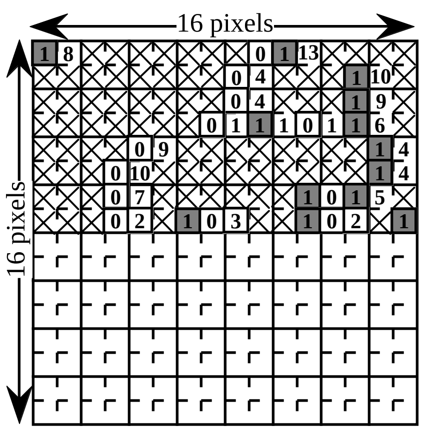
On-board data compression and data editing are also being used to reduce the volume of data being sent to Earth from the Galileo spacecraft while keeping as much of the interesting information as possible. Here are two simplified ways to handle data on a spacecraft BEFORE it is sent to Earth. The first is "lossless"; data are changed onboard the spacecraft before being transmitted. These data need to be reformatted back to their original state after reaching the Earth. The second is called "lossy" because some original data is lost through mathematical averaging of the data.

EXAMPLE: ORIGINAL IMAGE OF AN ASTEROID

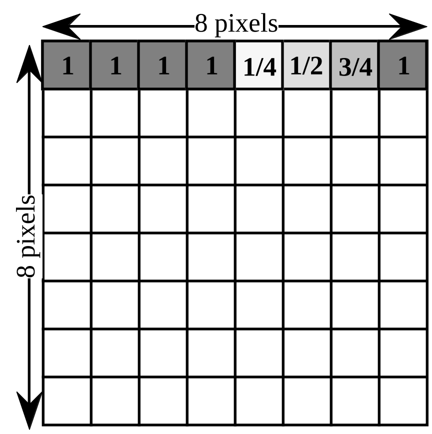
"Asteroid" image made up of 256 squares (pixels).
We can assign a "1" to the filled pixels and a "0" to the unfilled ones.



"Lossless" technique: Recreate the Asteroid



"Lossy" technique: Recreate the Asteroid



This technique makes use of the fact that the "asteroid" is made up of patterns of "1's" and "0's". These numbers can be easily summed up and reconstructed if you know the row length and pixel size. In this example, the first filled pixel (upper left corner) represents itself. The following pixel gives the number of pixels (8) that are identical to the first one. Instead of using 9 pixels of data you only use 2. The "X's" show unused pixels. The 10th is unfilled (equal to "0") and followed by a series of 14 filled pixels.

☆ Continue this exercise and determine how many pixels you save using this technique (the total number of "X's").

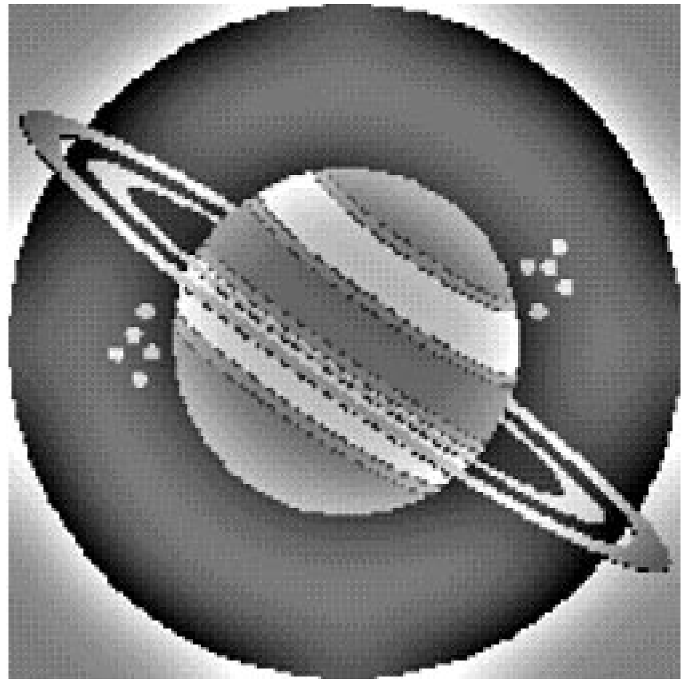
This is a simple example of one type of on-board averaging. The original image is 16 by 16 (256 total) pixels. The "new" (reduced) image is 8 by 8 (64 total) pixels. You can mathematically average the number in 4 adjacent pixels and use one value for the "new" reduced pixel. In this example, the first group of 4 pixels had a value of "1" thus the averaged pixel also is "1" (1+1+1+1 divided by 4). The 5th pixel in the first row of the reduced image has a value less than "1" and is shaded to show this. Likewise, the next two pixels are shaded 1/2 and 3/4 as much as the filled ones.

☆ Continue to average these pixels and shade them in a similar way. Does this look like the original image?

Unlike the "asteroid" shown on the previous page which only has 8 pixels per inch, most images have A LOT of data!

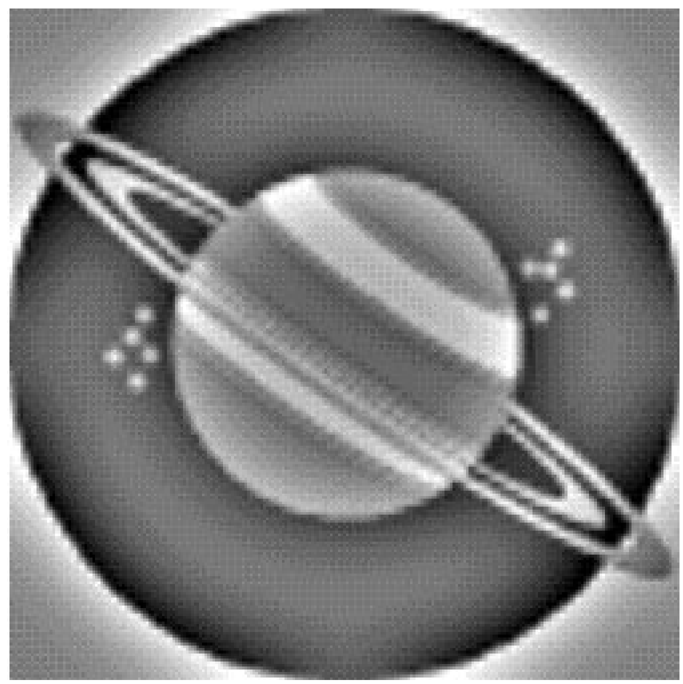
On the top is an image of a ringed planet. There are 96 pixels per inch in this full-resolution image. >>

full-resolution (lossless)



The image on the bottom has one-quarter of the resolution of the other image. It has 24 pixels per inch. >>

one- quarter resolution (lossy)



☆ How different do they look from one another?

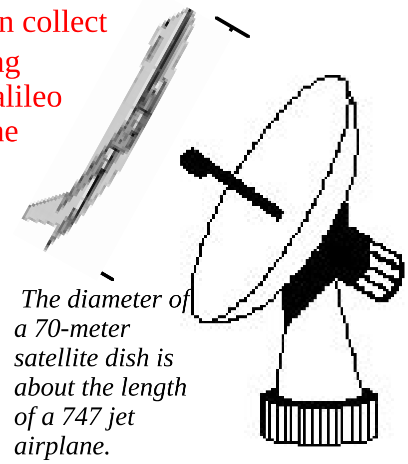
☆ Look at the small stars in each image...do they look the same in both images?

☞ *Images of planets are made up of squares or "pixels" of data. Each pixel has one piece of information in it even if the original is very complicated.*
Have different students draw pictures of a planet in dark sky using either 1, 2 or 3 different colors per planet. Each person should then fold their picture into 8 by 8 squares. Then take a similar blank piece of paper that's already folded into 8 by 8 squares. Color the blank squares with the color most used from the corresponding square of your original artwork, filling the new squares completely with the dominant color.

Do these "copies" look like the originals? Does it depend on the number of colors used? Do "striped" planets translate differently than "spotted" ones?

Hearing Galileo's Whisper Across the Solar System

The larger the collecting area of an antenna, the weaker the radio signal it can collect and focus, and the faster the spacecraft can send down its data without getting "garbled". Very large Earth receiving satellite dishes are needed because Galileo is very far away and the amount of electromagnetic energy decreases with the square of the distance from the source.



The diameter of a 70-meter satellite dish is about the length of a 747 jet airplane.

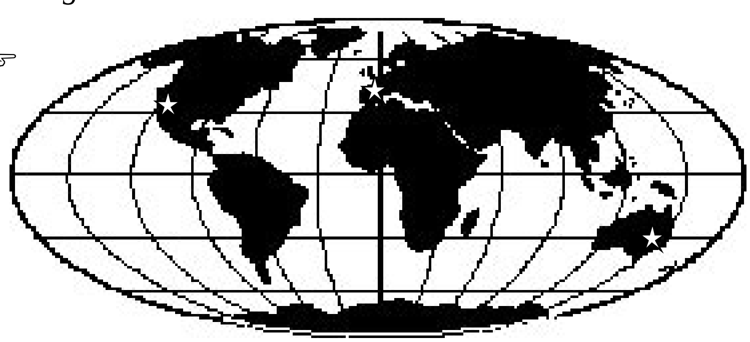
✔ How many Galileos does it take to turn on a light bulb??
✔ With the existing Earth receiving stations , it would take energy collected from 10 BILLION GALILEOS OVER THE LIFE OF THE SOLAR SYSTEM TO LIGHT ONE 100-WATT LIGHT BULB FOR 1 SECOND!!!!
And yet, we can detect this very weak signal and send back pictures and other information with it.

The antenna "hears" both signal (data) and noise (static) and uses hardware and software to maximize signal and minimize noise. The data rate or number of data bits per second (bps) a spacecraft can transfer to an Earth station depends on the communications capabilities of both systems.

Galileo will record and later transmit all of its data through its low gain antenna (see spacecraft diagram on page 7). The Deep Space Network, with its 70-meter antennae, can receive data from Galileo at Jupiter at the rate of 10 bps (equal to about 1 letter per second). Several new capabilities will be ready by 1996 to increase the rate to 160 bps (about two sentences per second). These include connecting the ground antennas together in arrays (increases received signal), use of an Ultracone (decreases communications noise) and improved receivers (makes more effective use of available received signal).

☞ *Compare the "fast" rate of 2 sentences per second to the "slow" rate of 1 letter per second . Use the first 2 lines of a favorite story or poem. It would take one second to recite using the faster rate.... how long using the slower rate?*

☞



Q: The Deep Space Network has 70-meter antennae at stations located in Spain, Australia and the U.S. (California). Why do you think these places were chosen?
H: Stars on this map show where they're located.

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The Galileo Mission, 1992, Space Science Reviews, Volume 60, Numbers 1/4, Kluwer Academic Publishers.
Yeates, C. et al, Galileo: Exploration of Jupiter's System, 1985, NASA publication SP-479.

Along with this Module (and others to follow), the Galileo Outreach Team has a new poster available and maintains a World Wide Web homepage (http://www/jpl.nasa.gov:80/galileo/). The Project's newsletter, the Galileo Messenger, is available through the address shown on the first page.

We Want Your Opinion!

Suggestions and ideas to improve the Galileo Curriculum Module are always welcome. Please let us know how we're doing by contacting us through electronic mail or written mail. The e-mail address to use is: annette.v.decharon@jpl.nasa.gov. The mailing address is given on the first page.

THANK YOU!!!!!!

Answer Key for Galileo Curriculum Module: Volume 1

Answers to Jupiter crossword puzzle

				1 J			2 C		3 S		
		4 Z	E	U	S		O		5 I	C	E
6 O				P			M		X		
7 N	O		8 B	I	G	9 G	E	S	T		10 W
E		11 S		T		12 A	T		13 E	Y	E
D		A		E		L			E		A
14 A	S	T	E	R	O	I	D		N		T
Y		U				L					H
		15 R	T	G		E					E
16 S	U	N			17 V	O	Y	A	G	E	R

What do YOU Know About Jupiter Already? Find out...

The statement "Jupiter, Saturn, Uranus and Neptune all have rings" is TRUE.

The "Great Red Spot" is (D) a big storm.

The best answers to the "Jupiter tourist" question are (D) and (E). The generally cloudy conditions (and frequent lightning) would suggest rain is on its way. Cool temperatures and high pressure also describe the conditions at Jupiter. Because the planet has no solid surface the "tourists" would need a spacecraft / submarine to explore within the clouds and below the clouds. By the time they reach 130 km below the cloud tops the pressure would be 20 times the pressure felt at sea level on Earth. The other answers are incorrect for these reasons: there are no rocks on this Gas Giant planet, the air smells like ammonia and one would gain weight in Jupiter's gravity field.

The true statements are (A) Jupiter has 16 moons, (C) About 400 years ago, Galileo saw 4 of Jupiter's largest moons and (E) One of Jupiter's moons has active volcanoes on it. (B) is incorrect because Jupiter's moons are named: Metis, Adrastea, Amalthea, Thebe, Io, Europa, Ganymede, Callisto, Leda, Himalia, Lysithea, Elara, Ananke, Carme, Pasiphae and Sinope. (D) is incorrect because only the 4 largest moons are comparable in size to Earth's Moon (the rest are much smaller).

For the "Stranded at Jupiter" exercise the better items to have from the list are:

(B) Nuclear-powered engine: there's very little sunlight at Jupiter with which to run a solar-powered engine
(A) Scuba gear: the lack of oxygen at Jupiter makes it a good idea to bring your own; for the same reason fire is not a big worry
(A) Hot-air balloon: there's no solid surface on which to drive a dune buggy
(B) Compass: Jupiter's huge magnetic field would make a compass useful; the lack of oxygen would prevent matches from lighting
(B) Food: there's water but no food
(A) Chapstick: the windy conditions would be hard the lips; there's not enough sunlight to require sun-tan lotion; just being at Jupiter's distance is equivalent to a Sun Protection Factor of 27!

Compare the Planets in our Solar System: Size and volume

Jupiter's volume is about 1.4 times the sum of the volumes of the other planets in the Solar System.

Expressing the volumes of all the planets as __X 10^{12} makes adding the column of numbers easier. It also gives a good sense of the difference in size between the inner planets (Mercury, Venus, Earth & Mars) and the outer planets (except "teeny" little Pluto, that is)

	Diameter (D) at equator (km)	Radius (R) 1/2 D (km)	R^3 (km^3)	Volume 4/3 π R^3 (km^3)	Volume 4/3 π R^3 (km^3)
JUPITER	142984	0.7×10^5	0.34×10^{15}	1.4×10^{15}	$\boxed{1400 \times 10^{12}}$
MERCURY	4878	2.4×10^3	13.8×10^9	55.2×10^9	0.06×10^{12}
VENUS	12102	0.6×10^4	0.22×10^{12}	0.88×10^{12}	0.88×10^{12}
EARTH	12756	0.6×10^4	0.22×10^{12}	0.88×10^{12}	0.88×10^{12}
MARS	6786	3.4×10^3	39.3×10^9	157.2×10^9	0.16×10^{12}
SATURN	120536	0.6×10^5	0.22×10^{15}	0.88×10^{15}	880×10^{12}
URANUS	51118	2.6×10^4	17.8×10^{12}	71.2×10^{12}	71.2×10^{12}
NEPTUNE	49528	2.5×10^4	15.6×10^{12}	62.4×10^{12}	62.4×10^{12}
PLUTO	2300	1.2×10^3	1.7×10^9	6.8×10^9	0.007×10^{12}
			TOTAL VOLUME OF OTHER PLANETS		$\boxed{1016 \times 10^{12}}$

Planet Structure & Interior

Jupiter's equatorial surface moves at a rate of: 2 X 3.1 X(0.7 X 10^5 km) / 9.8 hr = 4.4 X 10^4 km / hr

Earth's equatorial surface moves at a rate of: 2 X 3.1 X (0.6 X 10^4 km) / 24 hr = 0.16 X 10^4 km / hr

The ABSOLUTE difference is (4.4 X 10^4 km / hr) - (0.16 X 10^4 km / hr) = 4.2 X 10^4 km / hr

=> *42,000 km / hr*

On Jupiter's equator, it takes 2.5 times LESS time to travel 12 times GREATER distance.
The RELATIVE difference between Jupiter's equatorial surface speed and that of Earth is: 12 X 2.5 = 30

=> *You'd move 30 times faster on Jupiter's surface*

Jupiter's "Monstrous" Magnetosphere

The existence of a very large magnetic field is why we think that there is a lot of swirling metallic material at Jupiter's core.

Catch a Wave....

Grains of sand are 100 times (2 tick marks = 10 X 10) larger than bacterium.

Humans are greater than 100,000 times (5 tick marks = 10^5) larger than bacterium.

The Solid State Imaging Camera is the best instrument to take photos of the Great Red Spot because it operates in the visible light part of the electromagnetic spectrum.

Jupiter emits waves at radio frequencies that are similar to the static that causes interference when a radio is playing in a lightning storm or near electrical equipment. The radio noise reaching Earth from Jupiter is greater than from any other extraterrestrial source except the Sun!

What Does the Galileo Spacecraft Look Like?

All spacecraft need to know where to go and have a way to get there. The "map" the spacecraft follows is based on celestial navigation; it steers by *looking at the stars* ***(F - Star Scanner)***. Using *propellant* ***(B - Retropropulsion Module)***, the spacecraft moves around in 3-dimensional space by *spewing fluid through nozzles at high speeds* ***(E - Thrusters)*** oriented in 3 different directions. The power needed to operate the instruments and computers onboard is *generated from the heat of radioactive sources* ***(C - Radioisotope Thermoelectric Generators)***. The hot environment (extreme temperatures, unfiltered sunlight , etc.) encountered during the trip to Venus on the way to Jupiter required extra protection in the form of ***G - Sun Shields***. *Communication* ***(A - Low Gain Antenna)*** between the spacecraft and Earth is one of the key challenges we have to face because the High-gain Antenna did not open properly during flight (the shape shown above is what we think it looks like...it was supposed to unfold so that it would look like an upside-down umbrella) and thus we must rely on other equipment and new data-handling techniques for communication. Upon Jupiter arrival, the Atmosphere Probe will send data to the Galileo Orbiter *using a dish* ***(D - Probe Relay Antenna)*** oriented toward the planet (and away from the Earth).

The maneuver exercise can also be done using a chessboard. Chess pieces can represent different planets. A key concept of this exercise is that the shortest distance between two points is NOT always the the best way to go. To get from one side of a forest to the other you'd probably use roads on the edge of it rather than going through the middle.
Maneuvering spacecraft involved even more complicated decisions. Spacecraft need to get directions (thruster firing values) from "controllers" on Earth. For safety reasons, the controllers want to know where the spacecraft is located as much as possible. Maneuvers are planned by keeping in mind the TRADEOFFS between saving propellant and staying in contact with the Earth.

Jupiter's Weather Forecast

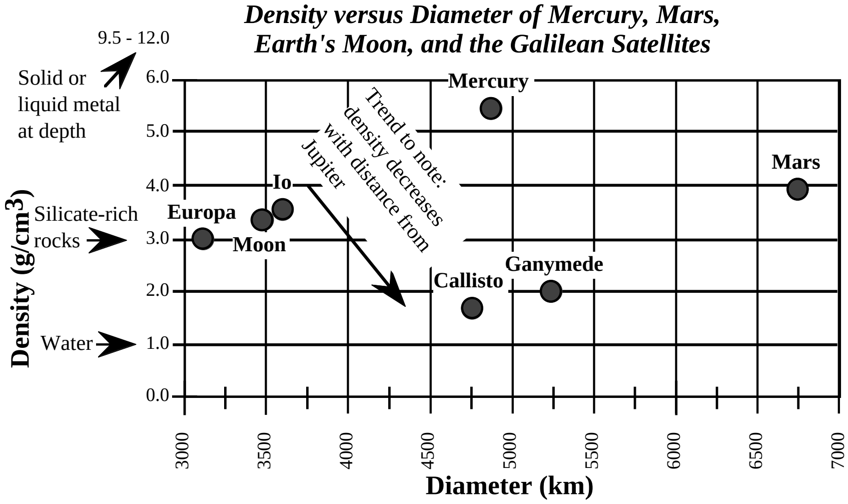
	EARTH	JUPITER
PLANET TYPE	Terrestrial (continents & oceans)	Gaseous
SPIN RATE	slower	faster
DISTANCE FROM THE SUN	closer	farther
INTERNAL HEAT RELEASED	a little	a lot
SIZE	small	large
MASS / GRAVITY	low	high
SPIN AXIS ORIENTATION	23 degrees	3 degrees

This chart shows that Earth and Jupiter are VERY different in these parts of the "weather equation". It's no wonder that their weather patterns look different. (More detailed information about Jupiter's weather is available on the Galileo Poster and also in these references listed on page 14: Beatty & Chaikin, Hunt & Moore and Yeates et al)

The Moons of Jupiter

The inner Galilean satellites, Io and Europa, are about the size of Earth's moon. The outer Galilean satellites, Ganymede and Callisto, are about the size of Mercury.

Density versus Diameter of Mercury, Mars, Earth's Moon, and the Galilean Satellites



The inner large Galilean satellites, Io and Europa, have about the same density as Earth's Moon and Mars. One guess is that the satellites are mostly composed of silicate-rich rocks and have no metallic core. This isn't the only possible answer. A combination of high-density and low-density layers such as an ice outer layer (it's cold in that part of the Solar System!) with a metallic core could give the same average density. However, other evidence (such as the existence of volcanoes on Io) supports the conclusion that Io and Europa are made up of silicate-rich rocks. Spectrometer data shows that there is a layer of ice (about 100 km thick) on Europa; this is reflected in the fact that it has a lower density than Io.

Mercury's high density implies that there is a high concentration of heavy metal (probably iron) within the planet. Conversely, Mars has a lower concentration of iron than Mercury.

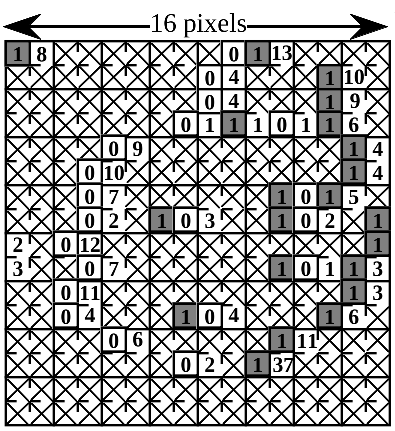
The outer Galilean satellites, Ganymede and Callisto, have much lower densities than the other bodies. Their densities are not much greater than that of water! Ice is exposed in young impact craters supporting the fact that there are thick layers of ice on these bodies.

Based on DECREASING crater coverage and INCREASING evidence of geologic activity (volcanoes, etc.) with proximity to Jupiter you can conclude that the inner satellites are more geologically ACTIVE.

In fact, Jupiter and its satellites may have formed in as a "mini" Solar System. In this theory, Jupiter was the central source of heat and gravity (remember its composition is very close to that of our Sun!), the inner satellites have relative high densities (like the inner planets of the Solar System) and the outer satellites have low densities (like the "Gas Giants" of our outer Solar System) and were not hot enough to "burn off" their ice layers (and still aren't).

Data Handling Techniques

"Lossless" technique

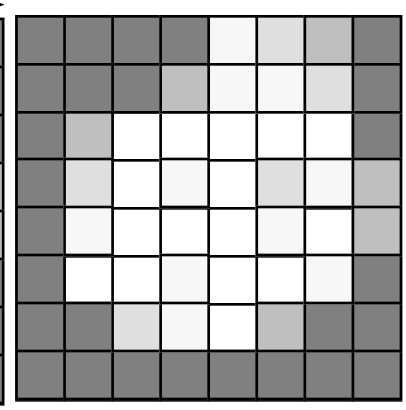


# pixels used	# pixels "saved"
5	11
4	12
4	12
8	8
4	12
4	12
6	10
9	7
4	12
8	8
4	12
7	9
4	12
4	12
0	16
0	16
75	181

"Lossy" technique

8 pixels × 8 pixels

1	1	1	1	1/4	1/2	3/4	1
1	1	1	3/4	1/4	1/4	1/2	1
1	3/4	0	0	0	0	0	1
1	1/2	0	1/4	0	1/2	1/4	3/4
1	1/4	0	0	0	1/4	0	3/4
1	0	0	1/4	0	0	1/4	1
1	1	1/2	1/4	0	3/4	1	1
1	1	1	1	1	1	1	1



The "ringed planet" images at the bottom of the page don't look very different from one another. The 2 sets of "star" clusters, however, are less bright in the quarter-resolution image. This is because the pixels in these images are too small and closely spaced for our eyes to easily see the loss in resolution EXCEPT for features that had very few pixels to begin with. That's why our original example "asteroid" (made up of a small number of large pixels) looks very different from its quarter-resolution counterpart (shown above on the right).

Hearing Galileo's Whisper Across the Solar System

DSN stations are located at California, Spain and Australia because these sites are spread roughly evenly around the Earth which allows a spacecraft very far from Earth to always be seen by at least one DSN station even though the Earth is rotating once per day.