# Descriptive Chapters

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# Contents

# Chapter 1

# Descriptive Chapters

## 1.1 Description

This database contains a series of descriptional chapters, linked into by other documents. As a result, no table of contents exists for the file.

## 1.2 Comets

The following information about comets is available:

What are comets?
Where do comets come from?
What do comets look like?
How do I get recognition for discovering a comet?.
Exploration of comets
Comet Halley
Comet Shoemaker-Levy 9
Pictures

## 1.3 What do comets look like?

Some comets become bright enough so that they can be seen by the naked eye. When this occurs, a comet can look quite spectacular.

However, most comets never reach that level of brightness, and can only be seen through binoculars or a telescope. A dim comet is often described as appearing like a "fuzzy star". Even when looking through a telescope, a comet may look just like a deep sky object. In fact, this is what prompted Messier to create his famous catalog of deep sky objects.

If a comet becomes brighter, some hint of a tail can often be seen through the telescope. However, as with all astronomical objects, long exposure photography is usually required to bring out much detail.

## 1.4 What are comets?

Of all the objects in the night sky, comets can be some of the most spectacular. The first recorded sighting of a comet was that of Comet Halley, by Chinese astronomers in 240 BC. As of January, 1995, 878 comets have been observed and recorded.

Comets are composed of a mixture of dust and ices (water and frozen gases). This has given them the appropriate description of being a "dirty snowball". It is thought that the material composing comets was not incorporated into planets when the solar system was formed. For this reason, the study of comets provides valuable clues about the early history of our solar system.

In 1990, Jacques Crovisier, of the Paris Observatory used the IRAM telescope in Spain to make spectral measurements of comets Austin and Levy. Among other compounds, he discovered hydrogen cyanide, formaldehyde, hydrogen sulfide, and methanol - frozen as ices. The finding was significant because hydrogen sulfide and methanol do not remain frozen at temperatures above -170 degrees C. If, at some point in the comet's history, it was warmed to a higher temperature than this, the gases would have been lost to space. Their presence implies that comets have stayed cold from the moment they were created.

Comets often travel in highly eccentric orbits, carrying them far from the Sun at some times, and near to the Sun at others. When they are near to the Sun, comets are the most active, and may exhibit some or all of the following features:

1. Nucleus - This is found at the heart of the comet, and is composed of mostly ice and gas with a small amount of dust. It is relatively solid and stable. When a comet is far from the Sun, the nucleus is often the only part which survives. It is typically less than 10 km in diameter, and covered by a dark coating of dust.
2. Coma - This is a dense cloud of water, carbon dioxide, and other gases surrounding the nucleus. The coma and nucleus together constitute what is often called the "head" of the comet.
3. Dust tail - This is composed of smoke-sized dust particles originating from the nucleus. It can be up to 10 million km long, and is the most prominent part of a comet to the naked eye, but only exists when the comet is relatively near the Sun.
4. Ion tail - This is composed of ions, and can be up to 100 million km long. It is often laced with rays and streamers, as a result of interactions with the solar wind.
5. Hydrogen cloud - This is a huge envelope of neutral hydrogen, often extending millions of kilometres in diameter. As a comet absorbs ultraviolet light from the Sun, chemical reactions release the hydrogen. It cannot be seen from the Earth, but has been detected by spacecraft.

As a comet travels in its orbit around the Sun, it often leaves tiny dust-sized particles behind. If the Earth happens to pass through such an orbit, we typically experience an annual meteor shower.

Comets are only visible when they are relatively near the Sun. As they approach, the ice evaporates and forms the coma and tails. It is very hard to predict how bright a comet will become, since it depends on how much ice melts.

Most comets are rather dim and can only be seen with binoculars or a telescope. But periodically, a comet is detected which becomes so bright that it can be seen with the naked eye.

Sometimes, a comet can be seen to have two tails - the ion tail and the dust tail. Since the dust tail is composed of much heavier particles than the ion tail, the solar wind has a harder time pushing the particles. As a result, the ion tail tends to point almost directly away from the Sun, whereas the dust tail tends to slowly curve away.

The following picture was taken of Comet West, and shows the two distinct tails. The thin ion trail appears blue, whereas the dust trail is much more broad and appears white.

View picture of Comet West

When a comet is in orbit around the Sun, it loses some of its gas and dust every time it approaches perihelion. As a result, comets are relatively short-lived objects. Eventually, only a rocky object resembling an asteroid remains.

Most comets are discovered by amateur astronomers, as the large observatories do not often have the resources to carry out time-consuming sky surveys. For more information, see the chapter entitled
How do I get recognition for discovering a comet?.

## 1.5 Where do comets come from?

In 1950, Jan Oort theorized that a giant cloud of a trillion or more comets orbited the Sun, thousands of times further than Pluto. Periodically, through the result of collisions within the cloud or the gravitational effects of nearby stars, the orbits of some comets are altered so that they pass into the inner solar system. Such a comet would be observed as one of the "long period" comets, taking many thousands of years to go around the Sun. The Oort cloud is still just a theory, but many astronomers believe in its existence. It might contain enough mass to rival Jupiter.

Some astronomers believe that a dim companion star to our Sun, known as Nemesis, may be responsible for diverting the orbits of comets in the Oort cloud towards the inner solar system.

Another cloud of comet material is believed to exist just past the orbit of Neptune, extending out to perhaps 50 AU. Known as the Kuiper Belt, it is believed that most short and medium period comets originate in this region.

Periodically, the gravitational effects of the outer planets in our solar system may modify the orbit of an object in the Kuiper belt enough to cause it to swing near Neptune. When this occurs, Neptune's gravitational field may divert the comet into the solar system. Four objects have been detected orbiting between Jupiter and Neptune, believed to have originated from within the Kuiper Belt, and known as "2060 Chiron", "5145 Pholus", "1993 HA 2" and "1994 TA". The IAU has designated this class of objects as Centaurs.

As of November 1994, 18 Kuiper Belt objects were known. It is estimated that at least 35,000 objects with a diameter of greater than 100 km exist in the

Kuiper Belt.

Spectral studies of these objects have shown them to be unusually red.

The following picture shows part of the discovery frames for 1993 SC. Obtained 4.6 hours apart by the 2.5m Isaac Newton Telescope on La Palma by Alan Fitzsimmons, Iwan Williams, and Donal O'Ceallaigh on September 17th, 1994, the two frames clearly show the motion of the object. 1993 SC is believed to be located approximately 34 AU from the Sun, and have a diameter of about 300km.

View picture of 1993 SC

Some people believe that Triton, Pluto, and Charon are just the largest examples of Kuiper belt objects.

## 1.6 Exploration of comets

There is a limit as to how much information astronomers can obtain about comets from their telescopes on Earth. Since the nucleus of a typical comet is no larger than 10 km across, much of our current knowledge about the structure of comets has come from spacecraft.

A chronological list of these probes, sorted by launch date, follows:

```
  ICE      - Aug. 12/78, Comet Giacobini-Zinner
        Vega 1   - Dec. 15/84, Comet Halley
        Vega 2   - Dec. 21/84, Comet Halley
        Sakigake - Jan.  7/85, Comet Halley
        Giotto   - Jul.  2/85, Comet Halley & Grigg-Skjellerup
        Suisei   - Aug. 18/85, Comet Halley
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## 1.7 How do I get recognition for discovering a comet?

Most new comets are discovered by amateurs, usually using large binoculars or moderate-sized telescopes. The only qualification you need to discover comets is to be quite familiar with the night sky. Galaxies, nebulae, and clusters all look remarkably like dim comets. In fact, this is what prompted Messier to create his famous catalog of non-stellar objects. So you must first be sure that the object you are viewing is indeed a new comet.

Since comets are named after their discoverers, it is important to follow the proper channels in claiming your right to its name. Note the comet's right ascension and declination, as well as an estimate of its magnitude.

Then, send the information, along with your name, address, and telephone number to:

The Central Bureau for Astronomical Telegrams
International Astronomical Union
Smithsonian Astrophysical Observatory
Cambridge, MA 02138
USA

Since speed is critical if you want to ensure that you get the credit for having discovered the comet, do not use postal mail. If you have access to the Internet and the World Wide Web (WWW) you can submit the information with the following URL:

http://cfa-www.harvard.edu/cfa/ps/DiscoveryForm.html

Alternately, you can send email directly to marsden@cfa.harvard.edu and green@cfa.harvard.edu, notifying them of your discovery. For emergency use, you can telephone them at (617) 495-7244, (617) 495-7440, or (617) 495-7444.

If there are near-simultaneous independent discoveries of the same comet, the IAU will name the object after up to two people.

## 1.8 Comets - Pictures

Though links to these pictures occur in various places throughout the document, they are provided here as well for convenience.

Comet West, showing dust and ion tails
1993 SC, an object in the Kuiper belt
Nucleus of Comet Halley, from Vega 2 spacecraft
Comet Shoemaker-Levy 9, before collision with Jupiter
Fragment 'W' impact of Comet SL9, as viewed from Galileo
Fragment 'G' impact site of Comet SL9, viewed from HST

## 1.9 Asteroids

The following information about asteroids is available:

What are asteroids?
Where are asteroids found?
Dangers of collision with Earth
Exploration of asteroids
951 Gaspra
243 Ida
Pictures

## 1.10 What are asteroids?

Literally thousands of small bodies orbit the Sun in the space between the planets. Typically ranging in size from 1 kilometre to hundreds of kilometers, these objects are known as asteroids or minor planets.

The first asteroid was discovered on January 1, 1801. Orbiting the Sun between Mars and Jupiter, it was thought to be a new planet. Eventually, astronomers realized that they were dealing with a much smaller class of object, and classified it as a minor planet, or asteroid. The object became known as Ceres. There is currently no strict definition classifying an object as a planet, satellite, asteroid, comet, or meteoroid. As a result, sometimes an object's designation is subject to debate.

Since 1801, over 6000 asteroids have been discovered, with 100-200 more discovered each year. 26 have diameters of more than 200 km, and it is generally believed that we have discovered 99% of all objects larger than 100 km. It is estimated, however, that there may be more than a million asteroids with diameters smaller than 1 kilometer which have not been detected. Despite all these objects, the total mass of all the asteroids is believed to be less than that of the Earth's moon.

The IAU is responsible for the naming of asteroids. The official designation of an asteroid consists of a name (chosen by the discoverer), prefixed by a number, generally in increasing order of date of discovery.

The 15 brightest asteroids are given in the following table:

| Asteroid | Maximum Magnitude | Diameter (km) |
|---|---|---|
| 4 Vesta | 5.1 | 555 |
| 2 Pallas | 6.4 | 583 |
| 1 Ceres | 6.7 | 1025 |
| 7 Iris | 6.7 | 222 |
| 433 Eros | 6.8 | 20 |
| 6 Hebe | 7.5 | 206 |
| 3 Juno | 7.5 | 249 |
| 18 Melpomene | 7.5 | 164 |
| 15 Eunomia | 7.9 | 261 |
| 8 Flora | 7.9 | 160 |
| 324 Bamberga | 8.0 | 256 |
| 1036 Ganymed | 8.1 | 40 |
| 9 Metis | 8.1 | 168 |
| 192 Nausikaa | 8.2 | 99 |
| 20 Massalia | 8.3 | 140 |

Asteroids are classified into one of four different types, depending on their composition and albedo:

- C-type: Extremely dark (albedo<0.1). They are somewhat like carbonaceous chondrite meteors, and are similar in chemical composition to the Sun (without the hydrogen and helium). 75% of the known asteroids are of C-type.
- S-type: These are relatively bright asteroids (albedo between 0.1 and 0.22). They are composed of nickel and iron, mixed with iron and magnesium silicates. 17% of the known asteroids are of S-type.
- M-type: These are also fairly bright asteroids (albedo between 0.1 and 0.18). They are composed of pure nickel and iron. Most of the rest of the known asteroids are of this type.
- D-type: These are rich in carbon and clay compounds. They have a low albedo of about 0.1.

In addition, about ten asteroids have been discovered which do not fit into any of these categories. But since they are quite rare, specific classification categories have not been developed for them.

It should be remembered that since the C-type asteroids are darker (and hence harder to see), the relative proportion of these asteroids is likely higher than the observed 75%.

Asteroids contain material left over from the formation of the solar system. There are two theories on how they came to be. One idea is that they are the remains of a planet that was blasted apart in a massive collision long ago. Another, more popular, notion is that they are simply the result of material which never formed into a planet. Since most asteroids lie between Mars and Jupiter, it is felt that the large gravitational influence of Jupiter might have prevented such a planet from forming.

## 1.11 Where are asteroids found?

Asteroids have been detected virtually throughout the solar system, though there are particular regions where they are concentrated:

```
 Main Belt: The majority of asteroids are found in the "main belt", or
            simply the "asteroid belt".  This region is located between
            Mars and Jupiter, at a distance of between 2 and 4 AU
            from the Sun.  The main belt is divided into several
            subgroups, each named after a prominent asteroid in the
            group.  The different subgroups are Hungarias, Floras,
            Phocaea, Koronis, Eos, Themis, Cybeles, and Hildas.
            Between these subgroups are regions with relatively few
            asteroids, known as "Kirkwood gaps".
 Atens:     These asteroids have semimajor axes less than
            1 AU, and aphelion distances greater
            than 0.983 AU.  They have the characteristic of spending
            most of their time nearer to the Sun than the Earth, but
            have the potential of crossing the Earth's orbit.
 Apollos:   These asteroids have semimajor axes greater than 1 AU, and
            perihelion distances of less than 1.017 AU.  They
            spend most of their time further from the Sun than the Earth,
            but have the potential of crossing the Earth's orbit.
 Amors:     These have perihelion distances of between 1.017 and
            1.3 AU.  Though they don't cross the Earth's orbit, they
            are nearer to the Sun than the asteroids in the Main Belt.
 Trojans:   These are located at stable positions 60 degrees ahead and
            behind of Jupiter in its orbit (known as Lagrange points).
            More than 1000 trojan asteroids have been discovered.  A few
            asteroids have been discovered in similar points of the
            orbits of Venus, the Earth, and Mars as well.
A few asteroids have been detected in the outer solar system, beyond the orbit
of Saturn.  The composition of these objects is thought to be similar to comets
or Kuiper Belt objects.
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## 1.12 Exploration of asteroids

Though astronomers have had some remarkable successes with using radar or the Hubble Space Telescope to generate pictures of the surface of asteroids, there is no comparison to observations made from spacecraft. However, to date there has only been one spacecraft to approach an asteroid - Galileo. It returned a great deal of scientific data, including pictures of two asteroids - Gaspra and Ida.

## 1.13 Dangers of collision with Earth

Earth's thick atmosphere protects us from many smaller meteors. As an object strikes the atmosphere at unimaginable speeds, the force of friction often causes it to vaporize or explode before reaching the surface. It is estimated that most stony meteoroids smaller than 10 metres in diameter explode in the atmosphere. They often release many of the small fragments found in today's museums.

Sometimes these fragments hit with enough force to cause some damage. On October 9, 1992 a 12 kg meteor crashed through the rear end of a parked car in Peekskill, New York. There have been reports of meteors falling into a Connecticut dining room and an Alabama bedroom. However, there is no record in modern times of a person being killed by a falling meteorite.

We are lucky that the atmosphere breaks up these 10 metre meteoroids into smaller pieces. If they were to hit the surface intact, they would release the energy equivalent to five Hiroshima bombs.

However, periodically an object larger than 10 metres in diameter strikes the Earth. Since meteors of this size do not typically explode in the atmosphere, they carry their energy with them to the surface. 50,000 years ago a nickel-iron meteorite only 60 metres in diameter fell in northern Arizona at a speed of 60,000 km/hour. It created a huge crater 1200 metres in diameter and 200 metres deep, as the impact released the energy equivalent of 15 million tons of TNT. It is estimated that on average, every thousand years an object hits the Earth releasing the same amount of energy as that held in a 50 megaton nuclear bomb. Based on the number of known asteroids, every 300,000 years we should expect a meteor impact to create a crater 10 km in diameter or more.

The Earth has been hit in the past by even larger objects. The Manicouagan crater in Quebec, Canada is the result of such a collision. Blasted out of the landscape 210 million years ago, the feature is approximately 100 km in diameter.

View shuttle image of Manicouagan crater

Over 120 impact craters have been identified on the surface of the Earth so far.

It is thought by many scientists that such collisions can cause mass extinctions. 65 million years ago, 70% of all species living on Earth at the time (including dinosaurs) vanished. In 1980, geologists discovered that a large concentration of an element known as iridium was laid down in sedimentary rocks of the time. The finding was significant since iridium is a rare element on the surface of the Earth - most is believed to have sunk to the core when the Earth was being formed. However, they have found a relatively high concentration of this element in meteors. In 1990, geophysicists found evidence for a huge crater in Mexico, 300 km in diameter. Known as Chicxulub, the crater was dated at 65 million years old. Fitting the pieces of the puzzle together bit by bit, many scientists feel they are now beginning to have evidence that the dinosaurs were in fact killed by a large (10 km in diameter) asteroid impact.

There are more than 150 known asteroids, ranging in size from a few metres to 8 kilometres in diameter, which pose a threat to the Earth. Most asteroids are still undiscovered, but some scientists believe that more than 2000 objects larger than 1 kilometre in diameter, and 320,000 objects larger than 100 metres may have the potential to impact with the Earth at some point in the future.

The impact of an object several hundred metres in diameter would be catastrophic, but not threaten civilization. On the other hand, a collision by an object a kilometre or more in diameter might stretch the resources of humankind to the limit.

Close encounters periodically occur. On May 20, 1993 Tom Gehrels discovered a new asteroid (which became known as 1993KA2). When another picture was taken the following evening, enough information was obtained to determine its orbit. It was calculated that the asteroid had passed within 150,000 km of the Earth's surface, and that it had been detected after it had made its closest approach. If it had impacted with the Earth, we would have had no advance warning. This distance was less than half of the distance between the Moon and Earth, exceptionally close by interplanetary standards. The asteroid is thought to have been no larger than 5 to 11 metres in diameter, but it is obvious that larger objects must periodically pass this close (or closer).

On December 9, 1994 at 4:50 Universal Time, James V. Scotti discovered a 17th magnitude asteroid with the 0.9 metre Spacewatch telescope at Kitt Peak in Arizona. Thought to be 6 to 13 metres in diameter, this asteroid (denoted 1994XM1) missed the Earth's surface by only 100,000 km 14 hours later, claiming the record for the closest near miss.

Though it might sound as though meteor impacts pose a serious threat to human civilization, the chances of any individual being killed by a meteorite or asteroid collision are incredibly small. But nevertheless, astronomers are expanding their searches for the larger asteroids that could pose a potential threat to the Earth. If they are discovered early enough, many people believe that a space mission could be organized to divert the object away from its collision course.

## 1.14 951 Gaspra

View Gaspra

In August 1991, Galileo entered the asteroid belt. On October 29th, it became the first spacecraft to encounter an asteroid. Passing at a distance of approximately 1600 km at 2:40 pm PST, at a relative speed of about 29,000 km/hour, the spacecraft frantically collected data and images of 951 Gaspra, storing everything to its onboard tape recorder. Over the next few months, this information slowly trickled back to Earth over the low gain antenna. It was found that Gaspra is a very irregular body about 19 x 12 x 11 km in size, with a rotational period of 7.04 hours.

Gaspra was discovered by Grigoriy N. Neujmin in 1916, and was named for a resort on the Crimean peninsula. As a result, many of the asteroid's craters have been named for resorts and spas around the world.

Gaspra is believed to be an S-type asteroid, and is a member of the Flora subgroup of the main asteroid belt. Its surface is covered with craters, and is estimated to be about 200 million years old.

Some slight variations in the solar magnetic field were measured by Galileo as it flew past Gaspra. This indicates that the asteroid contains some magnetic material, though its density is too low to be similar in composition to an iron or stony iron meteorite.

## 1.15 243 Ida

On August 28th, 1993, Galileo had its second encounter with an asteroid. As with the encounter at Gaspra, images of 243 Ida were taken, recorded, and then slowly sent to the Earth.

At a distance of only 2480 km, the spacecraft managed to take the highest resolution image of an asteroid's surface. Each pixel in the photograph covered a square only 25 metres to a side on the surface of Ida. Since the exact location of Ida in space was not well known prior to its encounter with Galileo, mission controllers were not able to tell Galileo ahead of time which direction to point its cameras. Instead, they took some 15 images during closest approach, moving the camera slightly between each image, with the hopes of capturing the asteroid in at least one of the images. There was only a 50% chance of obtaining an image at all in this mosaic, but luckily part of the asteroid was photographed at the bottom of one of the frames.

View high resolution image of 243 Ida

Ida is approximately 56 x 24 x 21 km in size, and rotates about its axis once in 4.63 hours. Its density is estimated to be between 2.2 and 2.9 grams per cubic centimeter.

As the images slowly trickled back to the Earth, scientists were in for a surprise. It appeared as though the cameras had managed to catch a tiny moon orbiting around the asteroid. At a distance of 10,500 km, the following image was obtained (the moon is to the right of Ida):

View Ida & its moon

The moon, later to be known as "Dactyl" appeared from spectral data to be made of basically the same material as Ida, though not exactly. In the most detailed image received from Galileo on June 8, 1994, Dactyl appears at a distance of only 3,900 km. In the picture, each pixel covers a square of about 39 meters on a side. More than a dozen craters are evident, with the largest crater on the terminator (day/night dividing line) about 300 metres in diameter. Dactyl measures approximately 1.2 x 1.4 x 1.6 kilometres.

View closeup of Dactyl

Data playback from the Ida encounter was completed June 6, 1994. Despite the problems with Galileo's high gain antenna, 98.7% of the data transmitted by the spacecraft was successfully received.

It is thought that Ida is similar in composition to a chondrite meteor. It is a member of the Koronis subgroup of the main asteroid belt.

Some slight variations in the solar magnetic field were measured by Galileo as it flew past Ida. This indicates that the asteroid contains some magnetic material, though its density is too low to be similar in composition to an iron or stony iron meteorite.

## 1.16 Asteroids - Pictures

Though links to these pictures occur in various places throughout the document, they are provided here as well for convenience.

Gaspra
Ida and its moon Dactyl
High resolution view of a portion of Ida
Highest resolution view of Dactyl
Shuttle image of Manicouagan crater

## 1.17 Meteors

The following information about meteors is available:

What are meteors?
Observing meteors
Annual meteor showers
Dangers of a serious catastrophe
Pictures

## 1.18 What are meteors?

For some unknown reason, we have developed four different names for objects which are essentially the same thing - asteroids, meteoroids, meteors, and meteorites. The only fundamental factor in deciding what to call an object is where it is. The following definitions might help to clarify things:

Asteroid: An object in the solar system, smaller than a planet or moon, and in orbit around the Sun.
Meteoroid: An asteroid on a collision course with the Earth.
Meteor: A meteoroid which has entered the Earth’s atmosphere and is glowing brightly from heat due to friction.
Meteorite: A fragment of a meteor which has landed intact upon the surface of the Earth.

In particular, the distinction between asteroid and meteoroid is rather ill-defined, and several different opinions on their distinction exist. A different popular notion is that meteoroids are fragments from a larger asteroid, but that raises problems in that it is often impossible to tell if an object was broken from a larger body at some point in time, or was formed that way to begin with. Perhaps a classification system based on the size of an object would be helpful, but no such classification system exists. Many people feel that it would be sensible to abandon this artificial four-way "distinction" between objects, and call them all the same thing (after all, a meteorite would have been called each of the four names at different stages in its life).

Whatever nomenclature given these objects, they are extremely interesting and useful to science. They provide evidence of the universe beyond our Earth. Some meteorites are even thought to have originated from the Moon or Mars!

View picture of Martian meteorite

A meteorite may be classified into one of several different categories:

| | |
|---|---|
| Carbonaceous Chondrites: | Similar to the Sun in composition, without the hydrogen and helium. These rare meteors are similar to C-type asteroids. |
| Ordinary Chondrites: | Similar in composition to the mantles and crust of the terrestrial planets. These types of meteors are the most common to fall, though since they often look like rocks on Earth, they are frequently overlooked. View picture of ordinary chondrite |
| Achondrites: | Similar to basalt in composition. The meteors thought to have originated on the Moon or Mars are Achondrites. View picture of achondrite |
| Irons: | Contain a mixture of iron and nickel. Similar to M-type asteroids. View picture of iron meteorite |
| Stony Irons: | Mixtures of iron and stony material. They are similar to S-type asteroids. |

Many meteors are believed to originate from matter in the tails of comets. If the Earth passes through such a stream, we are treated to spectacular meteor "showers".

## 1.19 Observing Meteors

Millions of meteoroids enter the Earth’s atmosphere each day. Though most of these are extremely small (less than the size of a grain of sand), the Earth accumulates several hundred tons of meteoritic material every day.

A typical meteor would enter the Earth’s atmosphere at velocities of between 40,000 and 250,000 km/hour. If the particle is small, it will burn up by the intense heat generated by atmospheric friction. Most of the meteors, or "shooting stars" seen by people are the size of a grain of sand, ending its life 100 km above the surface of the Earth.

As an interesting side note, it is precisely this atmospheric friction which require spacecraft to have heat shielding. If a spacecraft returning to Earth did not have such a shield, it would be destroyed in the atmosphere much like a meteor.

If the object is a little bigger, some of it may survive its descent to the Earth. These larger objects can often cause spectacular displays called ‘fireballs’. Sometimes, fireballs can even be seen to send off sparks, or explode during their descent. Most small meteorites which are collected and displayed in museums originated from such a display. Usually, atmospheric friction slows the objects down to only a few hundred kilometers per hour before they hit the surface. As a result, they do not typically leave craters.

But if the objects are larger than a few hundred tons, they do not break apart or slow down significantly before impacting with the Earth. These leave craters, but fortunately are extremely rare.

More than 2000 meteorites have been found on Earth. The largest is known as the "Hoba" iron meteorite, and weighs 60 tons.

Sporadic meteors
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Provided that the Moon is not too bright (so that the sky is dark), meteors may be seen on any night of the year. On average, about 7 meteors per hour can be seen from any given location on Earth, originating from random directions. These are known as "sporadic" meteors, and most are thought to have originated from fragmented asteroids.

Meteor showers
==============

Material from a comet's tail remains in the comet's orbit, but tends to get spread out along the path. If the Earth happens to pass through such an orbit, we see a large number of meteors all seeming to originate from the same general location in the sky, or radiant. Since the Earth returns to the same spot at the same time each year, the showers are usually annual events.

Far more meteors can be seen during a typical annual shower than on any average night. See Meteor Showers for a general timeline.

Observing meteors
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Since meteors generally move quickly through the sky and are only visible for a few seconds, it is usually best to observe them without optical aid (you would never be able to move a telescope quickly enough to see a meteor).

Most people wait for meteor showers to intentionally observe meteors. However, sporadic meteors are frequently seen while routinely stargazing.

If you are interested in observing a meteor shower, wait for a moonless sky (within the confines of the date of the predicted shower, of course!). Far more meteors can be seen when the absence of the moon makes the sky nice and dark. In addition, more meteors can usually be seen in the early morning hours (between midnight and sunrise), since this is when you are located on the leading side of the Earth in its orbit. Just as more raindrops hit the front windshield than the back window of a car when it is moving, more meteors 'smash' into the 'front' side of the Earth.

Lie on your back, or in a lawn chair, while keeping your general attention directed towards the radiant. Most meteors will not be visible at the radiant, but instead will appear when some distance away, so pay attention to the edges of your field of vision. If you trace its motion back, and it appears to have originated from the radiant, it was part of the shower. If not, it was a sporadic meteor.

If attempting to photograph a meteor shower without a very wide angle lens, most meteors will appear out of the frame if you have the camera directed at the radiant. For this reason, better results are often obtained when the camera is centered 20 to 40 degrees away from the radiant.

It is both interesting and useful to keep records of your meteor observations. If you keep track of how many meteors are observed per hour, along with the magnitude of the dimmest star you could see (to give an estimate of the sky conditions and the dark adaptation of your eye), you can use the data to get an idea of how the strength of the shower varies with time. It is helpful to make a note of how many meteors you observed that were sporadic, and how many were part of the actual shower.

If you would like to see your data used by amateur and professional astronomers worldwide in studying the density of annual meteor showers, you may want to consider reporting your observations to one of several central authorities. The following organizations collect such information, and can be of further assistance in meteor observations:

American Meteor Society
Department of Physics and Astronomy
SUNY
Geneseo, NY 14454
USA

British Meteor Society
26 Adrian Street
Dover, Kent
CT17 9AT
England

Meteor Section
British Astronomical Association
2 Hyde Road
Denchworth, Wantage, Oxfordshire
OX12 0DR
England

## 1.20 Annual Meteor Showers

Though many sporadic meteors can be seen on a nightly basis, annual meteor showers can be seen on several dates throughout the year. Most showers are named for the constellation in which the radiant is found, or for a star near the radiant. The following table gives a summary of these showers. It should be kept that the exact dates of maximum can fluctuate by up to a day in any given year.

Also remember that the quoted rates for ZHR do not anticipate any storm activity. Almost every shower is capable of unpredictable "meteor storms" exceeding 1000 meteors per hour.

| | | | | Radiant | | |
|---|---|---|---|---|---|---|
| Name | Range | Maximum | ZHR | RA | Dec | Notes |
| Quadrantids | Jan 01-Jan 05 | Jan 03 | 110 | 15.3 | +49 | |
| Pi Puppids II | Jan 06-Jan 14 | Jan 10 | | 07.5 | -43 | |
| Delta Cancrids | Jan 05-Jan 24 | Jan 17 | 5 | 08.7 | +20 | |
| Alpha Crucids | Jan 06-Jan 28 | Jan 19 | 5 | 12.8 | -63 | |
| Lambda Velids II | Jan 18-Jan 26 | Jan 21 | | 08.9 | -46 | |
| Alpha Carinids | Jan 24-Feb 09 | Jan 31 | | 06.3 | -54 | |
| Virginids | Feb 01-May 30 | several | 5 | 13.0 | -04 | (1) |
| Theta Centaurids | Jan 23-Mar 12 | Feb 01 | | 14.0 | -40 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Alpha Centaurids | Jan 28-Feb 21 | Feb 07 | 25 | 14.0 | -59 | |
| Omicron Centaurids | Jan 31-Feb 19 | Feb 11 | | 11.8 | -56 | |
| Delta Leonids | Feb 05-Mar 19 | Feb 15 | 3 | 10.6 | +19 | |
| Gamma Normids | Feb 25-Mar 22 | Mar 14 | 8 | 16.6 | -51 | |
| Beta Pavonids | Mar 11-Apr 16 | Apr 07 | 13 | 20.5 | -63 | |
| Scorpid/Sagittarids | Apr 15-Jul 25 | several | 10 | 17.3 | -30 | (2) |
| Lyrids | Apr 16-Apr 25 | Apr 22 | 90 | 18.1 | +34 | |
| Pi Puppids | Apr 15-Apr 28 | Apr 23 | 40 | 07.3 | -45 | |
| Alpha Boötids | Apr 14-May 12 | Apr 27 | 3 | 14.5 | +19 | |
| Eta Aquarids | Apr 19-May 28 | May 03 | 50 | 22.4 | -02 | |
| Alpha Scorpids | Mar 26-May 12 | May 03 | 10 | 16.0 | -27 | |
| Ophiuchids N | Apr 25-May 31 | May 10 | | 16.6 | -14 | |
| Beta Corona Australids | Apr 23-May 30 | May 15 | | 18.9 | -40 | |
| Kappa Scorpids | May 04-May 27 | May 19 | | 17.8 | -39 | |
| Ophiuchids S | May 13-May 26 | May 20 | | 17.2 | -24 | |
| Omega Scorpids | May 23-Jun 15 | Jun 04 | | 16.2 | -22 | |
| Chi Scorpids | May 24-Jun 20 | Jun 05 | | 16.5 | -14 | |
| Gamma Sagittarids | May 22-Jun 13 | Jun 06 | | 18.1 | -28 | |
| Theta Ophiuchids | Jun 04-Jul 15 | Jun 13 | | 17.8 | -20 | |
| Lyrids (Jun) | Jun 11-Jun 21 | Jun 16 | 5 | 18.5 | +35 | |
| Boötids (Jun) | Jun 26-Jun 30 | Jun 28 | 2 | 14.6 | +49 | |
| Lambda Sagittarids | Jun 05-Jul 25 | Jul 01 | | 18.4 | -25 | |
| Pegasids | Jul 07-Jul 11 | Jul 10 | 8 | 22.7 | +15 | |
| Phoenicids (Jul) | Jun 24-Jul 18 | Jul 15 | | 01.4 | -43 | |
| Delta Aquarids S | Jul 08-Aug 19 | Jul 28 | 20 | 22.6 | -16 | (3) |
| Piscis Austrinids | Jul 09-Aug 17 | Jul 28 | 8 | 22.7 | -30 | |
| Alpha Capricornids | Jul 03-Aug 25 | Jul 30 | 8 | 20.5 | -10 | (4) |
| Iota Aquarids S | Jul 15-Aug 25 | Aug 04 | 3 | 22.2 | -15 | (5) |
| Delta Aquarids N | Jul 15-Aug 25 | Aug 12 | 5 | 22.5 | -05 | (6) |
| Perseids | Jul 17-Aug 24 | Aug 12 | 95 | 03.1 | +58 | (7) |
| Kappa Cygnids | Aug 03-Aug 31 | Aug 18 | 5 | 19.1 | +59 | |
| Iota Aquarids N | Aug 11-Sep 20 | Aug 20 | 3 | 21.8 | -06 | (8) |
| Pi Eridanids | Aug 20-Sep 05 | Aug 29 | | 03.5 | -15 | |
| Alpha Aurigids | Aug 24-Sep 05 | Sep 01 | 15 | 05.6 | +42 | |
| Delta Aurigids | Sep 05-Oct 10 | Sep 09 | 7 | 04.0 | +47 | |
| Piscids S | Aug 15-Oct 14 | Sep 20 | 3 | 00.5 | 00 | |
| Kappa Aquarids | Sep 08-Sep 30 | Sep 21 | 3 | 22.6 | -02 | |
| Puppid/Velids | Sep 28-Dec 30 | several | | 07.7 | -44 | (9) |
| Capricornids (Oct) | Sep 20-Oct 14 | Oct 03 | 3 | 20.2 | -10 | |
| Sigma Orionids | Sep 10-Oct 26 | Oct 05 | 3 | 05.7 | -03 | |
| Draconids | Oct 06-Oct 10 | Oct 10 | | 17.5 | +54 | |
| Epsilon Geminids | Oct 14-Oct 27 | Oct 20 | 5 | 06.9 | +27 | |
| Orionids | Oct 02-Nov 07 | Oct 21 | 25 | 06.3 | +16 | |
| Taurids S | Sep 15-Nov 25 | Nov 03 | 10 | 03.3 | +14 | (10) |
| Taurids N | Sep 13-Nov 25 | Nov 13 | 8 | 04.0 | +23 | (11) |
| Leonids | Nov 14-Nov 21 | Nov 18 | | 10.1 | +22 | |
| Alpha Monocerotids | Nov 15-Nov 25 | Nov 21 | 5 | 07.8 | -06 | |
| Chi Orionids | Nov 26-Dec 15 | Dec 02 | 3 | 05.5 | +23 | |
| Sigma Puppids II | Nov 27-Dec 12 | Dec 06 | | 06.8 | -45 | |
| Phoenicids (Dec) | Nov 28-Dec 09 | Dec 06 | 100 | 01.2 | -53 | |
| Monocerotids (Dec) | Nov 27-Dec 17 | Dec 10 | 5 | 06.7 | +14 | |
| Sigma Hydrids | Dec 03-Dec 15 | Dec 11 | 5 | 08.5 | +02 | |
| Geminids | Dec 07-Dec 17 | Dec 14 | 110 | 07.5 | +33 | |
| Coma Berenicids | Dec 12-Jan 23 | Dec 19 | 5 | 11.7 | +25 | |
| Ursids | Dec 17-Dec 26 | Dec 22 | 50 | 14.5 | +75 | |
| Tau Puppids | Dec 19-Dec 30 | Dec 23 | | 06.9 | -50 | |

```
 Notes
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  (1) The radiant moves from RA=10.6, Dec=+15 to RA=14.4, Dec=-13
  (2) The radiant moves from RA=14.9, Dec=-18 to RA=20.4, Dec=-20
  (3) The radiant moves from RA=21.4, Dec=-21 to RA=23.4, Dec=-12
  (4) The radiant moves from RA=19.3, Dec=-14 to RA=21.6, Dec=-04
  (5) The radiant moves from RA=20.7, Dec=-18 to RA=23.5, Dec=-02
  (6) The radiant moves from RA=21.1, Dec=-10 to RA=23.1, Dec=-02
  (7) The radiant moves from RA=00.8, Dec=+51 to RA=04.3, Dec=+60
  (8) The radiant moves from RA=21.5, Dec=-07 to RA=22.1, Dec=-05
  (9) The radiant moves from RA=06.9, Dec=-44 to RA=09.4, Dec=-44
 (10) The radiant moves from RA=00.7, Dec=+01 to RA=04.6, Dec=+17
 (11) The radiant moves from RA=00.5, Dec=+06 to RA=04.8, Dec=+24
The table above was derived from information obtained from the International
Meteor Organization.  For details on membership with the IMO, write to:

 Ina Rendtel
 IMO Treasurer
 Gontardstrasse 11
 D-14471 Potsdam
 Germany
```

## 1.21 Quadrantids

This meteor shower, visible primarily from the northern hemisphere, is one of the most spectacular of the year. A ZHR of up to 110 is frequently observed, though it seems to fluctuate from year to year. Meteors from this shower tend to have a blue tinge.

The peak of the shower rarely lasts more than a few hours, so it can be easy to miss. There is some evidence to suggest that the size of the radiant is smaller during the peak, and larger at other times.

This shower is named after "Quadrans Muralis", a constellation proposed by J. E. Bode in 1801. The constellation was not accepted, and the region now lies in Boötes.

## 1.22 Lyrids

Though best viewed from the northern hemisphere, the Lyrids can be seen almost everywhere in the world. The ZHR is variable and erratic. In most years, 15-25 meteors per hour are seen. However, in 1982 observers were treated to a short burst of 90. We cannot tell when another burst like this can be expected, so they are always interesting to watch.

The Lyrids originated from the tail of comet 1861 I Thatcher.

## 1.23 Pi Puppids

This meteor shower is composed of material originating from the tail of comet Grigg-Skjellerup (which was explored by the spacecraft Giotto).

It is a rather young shower, with the first activity detected in 1972. Its ZHR varies wildly, with 40 meteors per hour recorded in 1977 and 1982, and little activity at other times.

The Pi Puppid meteors are usually bright and relatively slow moving.

## 1.24 Eta Aquarids

These fast and bright meteors originate from the tail of Comet Halley (as do the Orionids). Many meteors associated with this shower have been reported to leave bright, persistent trains behind them.

The shower is generally active for a few days on either side of its peak.

## 1.25 Southern Delta Aquarids

This shower exhibits a combination of both faint and bright meteors. It is best situated for observations in the southern hemisphere, though northern hemisphere observers should not have much difficulty in identifying the meteors travelling north of the radiant.

## 1.26 Alpha Capricornids

Extremely bright, yellow meteors (approaching fireballs), travelling at relatively slow speeds, have been associated with this shower. Though best suited for observations from the southern hemisphere, northern hemisphere observers can usually detect a substantial amount of activity as well.

## 1.27 Orionids

In 1993, the Orionids produced a brief, unexpected burst of meteors, at ZHR rates equivalent to its normal maximum of 25 meteors/hour, but some four days before the predicted peak. This was in addition to its normal peak at the usual time. Observations in the coming years will help to explain the characteristics of this "double peak" phenomenon.

The shower is well-situated for good viewing in both the northern and southern hemispheres. Orionid meteors are fast, and have fine trains.

The Orionid meteors originate from the tail of Comet Halley, as do the Eta Aquarids.

## 1.28 Leonids

The Leonid meteors originated from the tail of periodic comet Tempel-Tuttle. At roughly 33 year intervals, when the comet reaches perihelion, the ZHR increases dramatically (to storm levels) from its current rate of 10-15 meteors/hour. This is due to happen again in the years 1998-2000, though rates are expected to increase as the time approaches.

Leonids are fast and bright meteors, with fine trains.

## 1.29 Alpha Monocerotids

Though the ZHR of this shower is typically a low 5 meteors/hour, very short lived bursts have been observed. These bursts seem to recur with a ten year period, with a burst expected in 1995.

It should be remembered that we simply do not know enough about the particles composing most meteor showers to accurately predict periods of high activity. Nevertheless, it is interesting to use past trends in an effort to predict future activity.

## 1.30 Ursids

This shower usually consists of several faint meteors, reaching a ZHR of 15 meteors/hour. However, in 1945 and 1986, bursts exceeding 50 meteors/hour were observed. It is not known if there is a periodicity associated with these outbursts, so future observations of the shower are valuable.

Due to the position of the radiant, the shower is only visible from the northern hemisphere.

The meteors composing this shower come from the tail of comet Tuttle.

## 1.31 Virginids

Though this meteor shower is usually pretty faint, fireballs have been reported to originate from it. Several maxima are thought to exist.

The shower is visible from both the northern and southern hemispheres.

## 1.32 Alpha Centaurids

Only visible from the southern hemisphere, this meteor shower is not particularly active, with rather low ZHR rates. However, the meteors which appear are frequently very bright, often approaching the status of fireballs. Almost one third of the meteors associated with the shower leave glowing trains behind them. As well, unpredictable bursts of up to 25 meteors/hour sometimes occur, lasting for several hours.

## 1.33 Beta Pavonids

Several peaks of this shower have been observed to exist. As well, the ZHR varies markedly from one year to the next, so data taken of Beta Pavonid activity can be rather interesting.

This meteor shower is only visible from the southern hemisphere.

## 1.34 Perseids

The Perseid meteor shower has been particularly exciting in recent times. In 1991 and 1992, bursts of over 400 meteors/hour were observed.

Perseid meteors are bright and fast, and often display a glowing, persistent train. They are associated with comet 1862 III Swift-Tuttle, which appeared in 1737, 1862, and 1992.

Since bursts are difficult to predict, observers are suggested to pay close attention to the Perseid meteor shower in the coming years.

## 1.35 Alpha Aurigids

Despite a rather low ZHR, the Alpha Aurigid meteors have resulted in bursts of 30 to 40 meteors/hour, reported in 1935 and 1986. Since it is not known when further bursts can be expected, it is of good scientific value to record data about this shower.

## 1.36 Taurids, South and North

The meteors constituting the North and South Taurids originated from the tail of comet Encke. The radiants are difficult to define precisely, and since the showers occur at a similar time, it is often difficult to differentiate whether a meteor is part of the South or North Taurids.

The maxima for both showers are not exceptionally high, but last for a week with nearly constant ZHRs.

Taurid meteors streak across the sky slowly when compared to those in other meteor showers.

## 1.37 Geminids

The Geminid meteor shower is one of the most active. Usually, ZHRs of 110 or more are reported.

The Geminid shower usually provides many bright meteors, but few leave glowing trains.

## 1.38 Meteors - Pictures

Though links to these pictures occur in various places throughout the document, they are provided here as well for convenience.

Shuttle image of Manicouagan crater
Picture of an Achondrite meteor
Picture of a Chondrite meteor
Picture of an Iron meteor
Picture of a Martian meteor

## 1.39 The Interplanetary Medium

Though the space between the planets is usually considered to be a vacuum, it is in fact far from being empty. It is filled with photons (carrying heat and light from the Sun), the solar wind, microscopic dust particles, and magnetic fields.

The density of these particles is, however, quite low. In space near the Earth, there are approximately 5 particles per cubic centimeter, with the density generally decreasing with increasing distance from the Sun. But this density is highly variable, with concentrations of as much as 100 particles per cubic centimeter in certain places.

The temperature of the average particle in the interplanetary medium is an incredible 100,000 degrees C. However, water (and in fact most gases) would freeze rock solid if not in direct sunlight. This is because that although the average particle has a high temperature, there are few particles to give up that energy. As a result, the overall heat gained by an object from particles in the interplanetary medium would be incredibly low.

Though the density of the interplanetary medium is low, it has measurable effects on the paths of spacecraft. Due to a combination of travelling at high speed and travelling for a long time, even slight forces originating from collisions with these particles accumulate to create an observable effect on the spacecraft’s motion.

The magnetic fields of the Sun and planets significantly modify the nature of the interplanetary medium surrounding them. In particular, the relationship between these fields and the solar wind is extremely complex, but important for life as we know it. The Earth’s magnetic field keeps dangerous radiation away from the surface. For objects in the solar system without a magnetic field (such as the Moon), these energetic particles reach the surface unimpeded.

When the solar wind is overcome by the "stellar wind" (high energy particles originating from other stars), a region known as the heliopause is reached. Little is known about this region, since it is believed to be situated at a distance of about 100 AU from the Sun. It is hoped that the Pioneer 10, Pioneer 11, Voyager 1, or Voyager 2 spacecraft will survive long enough to return information about this region. If it is indeed located at a distance of 100 AU, they are only about half way there.

## 1.40 Our Expanding Universe

While working at the Mount Wilson Observatory in California, Edwin Hubble realized that most galaxies were red shifted, or travelling away from us. He then used the large telescope to identify Cepheid variable stars in these galaxies. Cepheid variables have a very useful property which enables astronomers to determine how far away they are. The less light a Cepheid gives off, the shorter its period of variability. By measuring its period, we can therefore determine how bright the star is. We can then calculate the distance required for the star to appear as bright as it does from the Earth. If a Cepheid variable is located in a distant galaxy, this effectively gives us the distance to the galaxy.

By comparing his red shift data with the distances to galaxies derived from Cepheid variables, Hubble made a startling discovery. It appeared that, in general, the further away a galaxy was, the faster it was receding from us. It didn't take long to realize that this observation could be explained by assuming that we were in an expanding universe. Astronomers advanced the theory that the universe had started from a single point long ago, which had 'exploded' (and is still exploding) into the universe that we see today. The theory became known as the "Big Bang Theory", and is now generally accepted by astronomers.

Astronomers began to talk about a "Hubble Constant". This is simply a measure of how fast the universe is expanding, given in the units of kilometers per second per megaparsec (1,000,000 parsecs). If a Hubble Constant of 75 were assumed, it would mean that a galaxy 1 megaparsec away traveled at 75 km/sec, one 2 megaparsecs away would move at 150 km/sec, and so on. If astronomers were able to calculate an accurate value for the Hubble Constant, they would be able to determine distances to galaxies merely from their red shift, and wouldn't have to rely on the difficult business of detecting Cepheid variables. In practice, determining the Hubble Constant was not easy, and estimates ranged from 50 to 100 kilometers per second per megaparsec.

By "winding back the clock" in their equations for the expansion of the universe, scientists attempted to determine how long ago the Big Bang occurred. Due to various uncertainties (telescopes of the time were not big enough to find Cepheid variables in very distant galaxies, nor did scientists have a very accurate idea of the amount of mass in the universe), the best they could do was determine an age of between 10 and 20 billion years.

As well, scientists used other methods to determine the age of the universe. Through our understanding of the nuclear processes going on inside stars, we can derive an estimate as to how long a star will be able to remain shining. The length of time is dependent upon the star's mass - the heavier a star is, the faster it lives out its life. When astronomers looked at globular clusters, they found a noticeable absence of massive stars. It was assumed that the stars had existed long ago, but had exhausted their nuclear fuel supply and are no longer visible. By determining the masses of the heaviest stars in the clusters they could determine an estimation of the cluster's age. Typical values were calculated at about 16 billion years, in excellent agreement with the age of the universe calculated through the use of the Hubble Constant.

However in 1994, Wendy Freedman of the Carnegie Observatory in Pasadena, California made a surprising discovery that has upset the agreement between the two methods for determining the age of the universe. By using the Hubble Space Telescope to take images of a galaxy known as M100, her team was able to identify 20 Cepheid variable stars (ground-based telescopes are not large enough to be able to detect individual stars in galaxies this distant). The distance obtained from these Cepheid variables turned out to be 56,000,000 light years. When the red shift for the galaxy (and hence its velocity away from us) was measured, a more accurate value of 80 kilometers per second per megaparsec was calculated. However, this value implied an age of the universe of between 8 and 12 billion years old. If both methods of measuring age are correct, this would imply that the universe is younger than the stars within it!

There is clearly something wrong with the methods by which astronomers are calculating the age of the universe. Perhaps there is more error inherent in the methods than astronomers believe - if so, the ages might still agree. The age of the universe as determined by the Hubble Constant is dependent upon the amount of mass within the universe. Through a variety of observations, astronomers believe that there may be a great deal of matter within the universe which cannot be seen. They call this "Dark Matter", and there is a worldwide effort to try and determine the amount of it. Better estimations of the mass of dark matter will yield more accurate calculations for the age of the Universe based on Hubble's Constant.

See Steps to the Hubble Constant for further details.