SPASH ASTRONOMY
CHAPTER 13: COMETS, METEORS, ASTEROIDS, AND METEORITES
OVERHEAD LECTURE NOTES

1. What is a shooting star?

A shooting star is a meteor, that is a tiny dust or ice grain that burns up in the atmosphere before hitting the ground. Here's a table showing major meteor showers (times when you have the best chance of seeing several shooting stars)

Table of major annual meteor showers:

This table of meteor showers is by no means complete.
Lists only major showers with ZHRs >or=20.

Shower	Period of Activity	Maximum	ZHR	Velocity (km/sec)
Quadrantids	Jan 1 - 5	Jan 3	120	42
April Lyrids	Apr 16 - 25	Apr 22	15(90)	48
Eta Aquarids	Apr 19 - May 28	May 5	60	66
Arietids	May 29 - June19	June 7	60	37
z-Perseids	May 20 - July 7	June 9	40	30
d-Aquarids	July 12 - Aug 19	July 28	20	41
Perseids	July 17 - Aug 24	Aug 12	>100(400)	60
Orionids	Oct 2 - Nov 11	Oct 21	20	66
Leonids	Nov 14 - 21	Nov 17	20	71
Geminids	Dec 7 - 17	Dec 14	110	35
Ursids	Dec 17 - 26	Dec 22	>12(90)	34

2. What is the difference between a meteor and a meteorite?

A meteorite makes it to the ground where a meteor is the smaller meteoroid that burns up before hitting the ground. Most meteors are bits of debris from comets (ice), while most meteorites are fragments of broken asteroids.

3. What is the difference between a comet and an asteroid?

Comets are interplanetary bodies that come from beyond Neptune's orbit thus contain abundant ices as well as dark carbon-rich soil; when their ices evaporate away into space, that is, sublime, they give off gas and dust and form a tail. So comets form tails and asteroids do not.
Asteroids are interplanetary bodies that are found in Jupiter's orbit or closer composed mainly of rocky and metallic material; they do not give off gas.

An asteroid with enough ice can turn into a comet momentarily if it approaches the sun close enough to start a tail and then becomes an asteroid again if it gets toofar away from the sun to sublime.
Example: Asteroid 2060 Chiron (discovered in 1977, 200 km across) is the only asteroid known beyond Saturn's orbit. In 1987, 2060 Chiron developed a coma because it contained ice which warmed as it approached the Sun and became a comet.

COMETS

4. Writers sometimes describe comets as "flashing across the sky" like shooting stars. Can this be?
Comets don't even appear to move over the course of hours. Instead they seem to hang motionless and ghostly among the stars and can take several months before they pass out of view.

5. Describe the main parts of a comet:
The brightest diffuse part is the comet head, sometimes called the coma. The comet tail is a fainter glow extending out of the head as far as 2 or 3 A.U.'s, usually pointing away from the sun. A telescope reveals a brilliant, star like point at the center of the comet head. At the center of this bright point is the comet nucleus, which is the only substantial, solid part of the comet, but it is too small to be resolved by telescopes on Earth. The typical comet nucleus is just 1 to 20 km across.

6. What causes the comets tail and which way does it point?
As the comet nucleus moves through the inner solar system, the sunlight warms it and causes the ice to sublime into the form of gas. This gas, together with dislodged dust grains from the dirt in the nucleus, is then carried away from the nucleus by the pressure of radiation and thin gas rushing outward from the Sun. This out-rushing solar gas is the solar wind. Only microscopic grains get blown outward by it; larger grains are too heavy to be caught in the solar wind.

7. Who discovered the shape of a comets orbit and when did he discover it?
In 1704 the English astronomer Edmund Halley discovered that comets travel on long, elliptical orbits around the Sun and that certain comets reappear. Halley found that four comets seen in 1456, 1531, 1607, and 1682 had the same orbit and thus may be the same comet. Halley predicted the next occurrence of the comet correctly. Halleys' comet was last seen in 1984 so might you get a chance to see it on its next trip around?

8. Describe the two groups that comets are divided into?
Long-period comets take centuries to go around the Sun, and their orbits extend to thousands of AU's from the Sun. Pluto is less than forty AU's away.
Short-period comets like Halley's take about a century or less to go around the Sun, and their orbits are mostly inside the region of Pluto.

9. Describe at least three ways that the Oort Cloud differs from the Kuiper Belt?

Comets reside or originated in only two regions of the solar system.
The closer region is the Kuiper Belt which is in the same vicinity as Pluto (so roughly 30 to 100 AU's distance from the Sun), and is in a 2-D elliptical orbit, basically the plane of the solar system. The Kuiper Belt may contain around a billion comet nuclei and is where the short range comets come from. At the beginning of the solar system this debris was probably slung shot out from the terrestrial planets.
The farther region is the Oort Cloud which is 50,000 to 150,000 AU's from the Sun in a spherical 3-D orbit. It is estimated that roughly 100 billion inactive comet nuclei lie in this area that overlaps the Oort Cloud of our nearest star neighbors and thus like electrons swarming around atoms can trade stars if they like. This is where the long range comets come from. At the beginning of the solar system this debris was probably slung shot out from the gas giant planets.

10. When and who discovered the true nature of the comets' nuclei and what did he discover about it?
Around 1950, Harvard astronomer Fred Whipple first predicted the ice to be mostly frozen water with certain amounts of frozen methane, carbon dioxide, and frozen ammonia. Thus Whipple's theoretical picture of a comet nucleus came to be called the dirt iceberg model and it has been confirmed by modern data.

METEORS

11. Why does one see more meteors after midnight than before?
After midnight you are located on the leading edge of the Earth as it moves forward in its orbit, sweeping up interplanetary debris. Note Mr. Konichek's model Earth demo. Note figure 13-7 on page 253 (the Leonids 1966)

12. How is a meteor shower named?
A shower is named for the constellation most prominent in the area of the sky from which the shower radiates. Note the table on page one of these notes for some of the names. Also note that one does not actually look in the originating constellation to see the shower but 30° to 40° radius around the spot as they do not start lighting up until they are further away from where they entered the atmosphere.

13. What is the connection between meteor showers and comets?

In 1866 G.V. Schiaparelli (of Martian canal fame) discovered that the Perseid meteor shower occurred whenever the Earth crossed the orbit of Comet 1862 III. In 1983, an infrared astronomical telescope in orbit (called IRAS) discovered the thermal infrared emission from a swarm of meteor dust spread along the orbit of Comet Tempel 2. Therefore, most meteors must be small bits of debris scattered from comets.

14. How close to the earth do meteors come and what is a fireball?
Most meteors are far too small to reach the ground, "burning" at altitudes around 75 to 100 km up. That's over six times higher than the highest passenger planes fly. Occasional large ones (grain of sand instead of microscopic dust size) called fireballs (sometimes reported as UFO's), are very bright and spectacular. The fireballs generally explode in the air instead of hitting the ground, again indicating that they are too fragile to survive atmospheric entry.

ASTEROIDS

15. What is an asteroid?
Asteroids are rocky and metallic interplanetary bodies. Because of their small size, they came to be called minor planets, a name that now applies to any interplanetary body that is not a comet (that is having no ice or insufficient ice to make a coma or tail).

16. What is the story behind the discovery of asteroids?
Bode's rule, confirmed by discovery of Uranus in 1781, called for a planet at 2.8 AU from the Sun in the large space between Mars and Jupiter. Therefore, astronomers set out to find the "missing planet" in 1800. On the first day of January 1801, Giuseppe Piazzi discovered an object which he first thought was a new comet. But after its orbit was better determined it was clear that it was not a comet but more like a small planet. Piazzi named it Ceres, after the Sicilian goddess of grain. Three other small bodies were discovered in the next few years (Pallas, Vesta, and Juno). By the end of the 19th century there were several hundred. Several hundred thousand asteroids have been discovered and given provisional designations so far. Thousands more are discovered each year. There are undoubtedly hundreds of thousands more that are too small to be seen from the Earth. There are 26 known asteroids larger than 200 km in diameter. Our census of the largest ones is now fairly complete: we probably know 99% of the asteroids larger than 100 km in diameter. Of those in the 10 to 100 km range we have cataloged about half. But we know very few of the smaller ones; there are probably considerably more than a million asteroids in the 1 km range. The total mass of all the asteroids is less than that of the Moon.

17. How are Asteroids named?

Asteroids are known by numbers (assigned in order of discovery, but only after the orbit has been accurately identified) and a name (chosen by the discoverer).

Examples include writers: for example, we have (2106) Hugo, (2984) Chaucer, (2985) Shakespeare, (4370) Dickens and (5231) Verne among "older" authors, and for those who look for more modern works, we have (2675) Tolkein, (4923) Clarke and (5020) Asimov.

Music is also very popular; (1034) Mozartia, (1814) Bach, (1815) Beethoven, (2055) Dvorak, (3784) Chopin and (4559) Strauss represent some of the "older" musicians found in the asteroid belt. Younger astronomers may appreciate the quartet (4147) Lennon, (4148) McCartney, (4149) Harrison and (4150) Starr, along with (3834) Zappafrank, (4305) Clapton and (4442) Garcia (from Jerry Garcia of the Grateful Dead). Those whose tastes don't quite tend towards rock 'n roll may prefer (6354) Vangelis or, possibly, (6433) Enya. Also orbiting the sun we find journalists such as (6318) Cronkite, entertainers like (3252) Johnny (from Johnny Carson), pioneers like (3895) Earhart, and sports heroes such as (6758) Jesseowens.

The largest asteroid by far is 1 Ceres. It is 933 km in diameter and contains about 25% of the mass of all the asteroids combined. The next largest are 2 Pallas, 4 Vesta and 10 Hygiea which are between 400 and 525 km in diameter. Note the number doesn't necessarily correspond to the size.

The highest-numbered asteroid I could find on the internet 8/7/02 was 37608 Lons (1992 SY16). There may be as many as 100,000 observable ones remaining uncharted.

18. Beside the Asteroid Belt describe the other two places asteroids are found in our solar system.

1). Earth-approaching asteroids are ones whose orbits come much closer to Earth than Mars or Venus do. Apollo asteroids are a subgroup of the Earth-approaching asteroids whose orbits actually cross Earth's orbit. They are named after 1862 Apollo, first of the group to be discovered.

The Apollo asteroids are a class of asteroids with Earth-crossing orbits. The first Apollo asteroid was discovered in 1918 by Max Wolf observing from Heidelberg, Germany. A table of large Apollo asteroids is contained in *Sky & Telescope* (March 1990). There are 240 known Apollos (Minor Planet Center), but it is believed that there are at least 2000 Earth-crossers with diameters of 1 km or larger, 100,000 larger than the Rose Bowl, and 70-80 million larger than a typical house (Ostro 1997). One of the largest Apollos is Geographos, which is 5.1×1.8 km in size and was discovered in 1951.

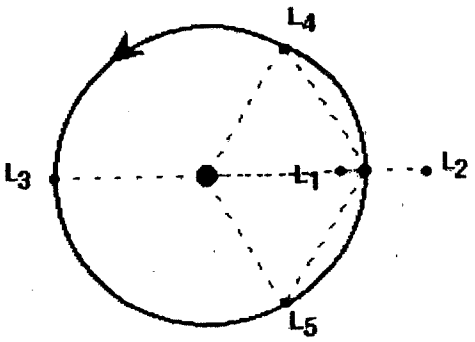
These are considered Earth's number one threat to human extinction.

2). Trojans: located near Jupiter's Lagrange points (60 degrees ahead and behind Jupiter in its orbit). Several hundred such asteroids are now known; it is estimated that there may be a thousand or more altogether. Curiously, there are many more in the leading Lagrange point (L4) than in the trailing one (L5). (There may also be a few small asteroids

n the Lagrange points of Venus and Earth (see Earth's Second Moon) that are also ;ometimes known as Trojans; 5261 Eureka is a "Mars Trojan".)

Lagrange points

Lagrange showed that three bodies can lie at the apexes of an equilateral triangle which rotates in its plane. If one of the bodies is sufficiently massive compared with the other two, then the triangular configuration is apparently stable. Bodies at such points are sometimes referred to as Trojans. The leading apex of the triangle is known as the leading Lagrange point or L4; the trailing apex is the trailing Lagrange point or L5. Collinear with the two large bodies are the L1, L2 and L3 unstable equilibrium points which can sometimes be useful places for spacecraft, eg SOHO.



19. Would it be safe to take your spaceship into the asteroid belt?

In spite of the apparently dense crowding in the asteroid belt the distances are so vast and asteroids so small by comparison, that if you were riding a spaceship through the belt you would rarely see another asteroid passing close by. Several unmanned spacecraft have already flown through the belt with no serious consequences.

20. Name and describe the three different compositional classes of asteroids:

Asteroids are classified into a number of types according to their spectra (and hence their chemical composition) and albedo:

albedo

the ratio of the amount of light reflected by an object and the amount of incident light; a measure of the reflectivity or intrinsic brightness of an object (a white, perfectly reflecting surface would have an albedo of 1.0; a black perfectly absorbing surface would have an albedo of 0.0).

- C-type, includes more than 75% of known asteroids: extremely dark (albedo 0.03); similar to carbonaceous chondrite meteorites; approximately the same chemical composition as the Sun minus hydrogen, helium and other volatiles;

- **S-type, 17%: relatively bright (albedo .10-.22); metallic nickel-iron mixed with iron- and magnesium-silicates;**
- **M-type, most of the rest: bright (albedo .10-.18); pure nickel-iron.**
- **There are also a dozen or so other rare types.**

Because of biases involved in the observations (e.g. the dark C-types are harder to see), the percentages above may not be representative of the true distribution of asteroids. (There are actually several classification schemes in use today.)

21. How can scientist study asteroids?

By means of radar signals bounced off them from large radio telescopes as asteroids pass close to Earth. There is little data about the densities of asteroids. But by sensing the Doppler effect on radio waves returning to Earth from NEAR owing to the (very slight) gravitational tug between asteroid and spacecraft, Mathilde's mass could be estimated. Surprisingly, its density turns out to be not much greater than that of water, suggesting that it is not a solid object but rather a compacted pile of debris.

METEORITES

25. What is the key to the story behind meteorites?

Meteorites are fragments of asteroids that collided and blew apart at various times during the history of the solar system.

26. Do Meteorites Ever Hit People?
The answer is yes, but very rarely!

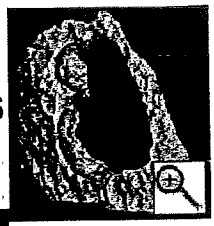
Sylacauga, Alabama in 1954:
A woman was resting on her sofa when an 3.9 kilogram (8.5 pound) meteorite crashed through the roof of her home, bounced off a radio, and struck her leg, leaving a bruise the size of a football.

Wethersfield, Connecticut in 1971
During the night a 284 gram (0.6 pound) meteorite crashed through the rood of a home. The next morning the owners noticed the black rock sticking out of the ceiling.

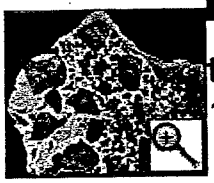
Wethersfield, Connecticut in 1982
Oddly enough, just 11 years after the 1971 Wethersfield crash, another meteorite struck a different house just across town. This one slammed through the roof and into the living room, bounced into the dining room, and landed under a table -- all while the surprised occupants were watching TV.

27. Name the three main groups and three sub-groups of meteorites and briefly describe each group and sub-group.

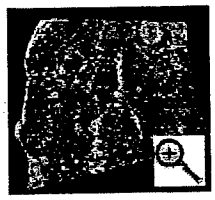
Meteorites are classified into three main groups: iron, stony, and stony-iron. Stony meteorites are also separated into three sub-groups: chondrites, achondrites, and carbonaceous chondrites.



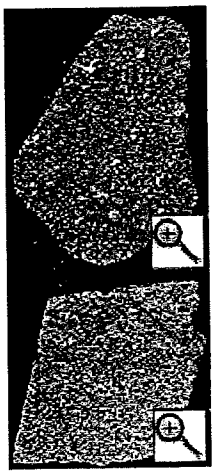
Irons: These meteorites are made of an iron-nickel alloy that is like a lot of rocks found in the outer crust of the Earth. Out of every 100 meteorites, 5 or 6 are irons.



Stony-Irons: These meteorites are mixtures of an iron-nickel alloy and non-metallic minerals called *silicates*. Scientists believe they are like the inside of the earth, near the earth's core. Only 1 or 2 of every 100 meteorites are stony irons.



Stony Chondrites: These meteorites are the most common, about 85 out of every 100 meteorites found. When cut apart you can see chondrules: small (1 milimeter) spheres of minerals that were melted together to form a solid rock. Scientists think chondrites are some of the oldest rocks in the solar system.



Stony Carbonaceous Chondrites: These meteorites are very rare and are like chondrites but also contain carbon, the basic building block for life on earth.

Stony Achondrites: These meteorites are like stony meteorites without chondrules. About 7 out of every 100 meteorites are achondrites. Scientists believe that some of these meteorites come from the surface of the Moon or Mars.

Note Figure 13-11 page 258 of where asteroid classes are located in our solar system.

28. Explain what zodiacal light is?

The dust released into our solar system by comets and asteroids undergoes a complex evolution. Initially distributed in the trails that cause meteor showers, the dust eventually disperses into the ecliptic plain (is the plain in which the planets move around the sun). The smallest dust particles are blown out of the

solar system by the solar wind. The larger ones gradually spiral inwards towards the sun, and together form a flattened disc in the ecliptic plain in the inner part of the solar system. This disc of dust is composed of dust particles with sizes between 0.1 and 100 micrometer.

From a dark secluded location, this disc of dust is visible from earth at night. A very faint band of light stretches over the sky following the path of the ecliptic ("zodiac"). This is the Zodiacal Light. Just after the end of evening twilight or just before the start of morning twilight, the main light (morning light and evening light) is best visible as a faint pyramid of light spread out over a very large area of the sky. Near its base at the horizon it measures some 40 degrees, and it stretches for 60-80 degrees under good conditions, as a ghostly glow. The brightest parts are as bright as the brightest parts of the Milky Way, but the nearness to the horizon with its atmospheric extinction effects (and sometimes increasing light pollution) makes it much harder to observe than the Milky Way. It is best seen from the tropics, where usually it is not too much of a difficulty to see it due to the favorable steep angle of the ecliptic for most part of the year. From our latitudes the best times of the year are March-April in the evening, and October-November in the morning. A very dark observing location with a dark horizon lacking light pollution, and a moonless night are absolutely necessary.

29. Could an asteroid hit the earth?

Earth-crossing asteroids pose a very real (if statistically unlikely) danger to the Earth. An impacting asteroid makes a crate about 10-20 times its size. An asteroid 1 km in size kicks so much dust into the atmosphere that sunlight would be blocked for several years, resulting in a global agricultural catastrophe. Such events are estimated to happen every 100,000 years or so. 10-km asteroids are so large that their impact could result in the destruction of most animal life on Earth (Ostro 1997). The Tunguska event was caused by an asteroid roughly 60 meters across (Ostro 1997). These events happen once every several centuries. There has recently been a great deal of interest (and concern) in the dangers of an Earth-crossing asteroid hitting the Earth. While the probability of such an event is relatively small, the consequences could be globally catastrophic. After all, a Tunguska-like even occur in Los Angeles or New York would be enough to spoil the day for many millions of people. For many years, however, there was a pronounced lack of interest in locating Earth-crossing asteroids. An observing program called spacewatch is now underway under the auspices of Drs. Tom Gehrels and Bob McMillan at the Lunar and Planetary Lab of the University of Arizona. At the time this survey was begun, no more than a dozen or so Earth-crossers were known. This number has since been pushed into the hundreds.

30. How could I possibly be of any help in saving Earth from an impact?

"The following is a list of examples of recently observed asteroids:

* An asteroid about 300 meters in size crossed a near-Earth orbit about 500,000 miles from our planet in October of last year (2001).

* An asteroid about the size of three football fields made its closest approach to the Earth (roughly the same distance: twice the Moon's distance from the Earth) on January 7, 2002.

* An asteroid reportedly the size of an 18-story building on a close approach to Earth (just a bit farther out than the Moon) was observed on March 8.

The disturbing point about this asteroid is that it was seen from Earth again only after it had moved out of the glare of the Sun and into the night sky on March 12.

For each nearby asteroid that is spotted there are several that pass entirely unnoticed. Some researchers estimated that there are roughly 25 asteroids, roughly the size of the one observed on March 12, cross a near-Earth orbit that is closer than the Moon. Astronomers believe that the number of undiscovered asteroids far exceeds the known list currently available to the scientific community. We need to know if there is a threat coming at the world. And having our young people, giving them awards, having amateur astronomers look into the sky to help us find those objects is something that we are mobilizing the people to help us discover that possible threat. If we see something coming at us that is years away, then we can handle that. We can do something about it. If we do not find out until a mere month or two beforehand, the Earth could be in real danger."

30. How can an asteroid be an opportunity?

Mine them. Since we live in an Earth-bound society, depletions of many natural resources will begin to alter society in the middle of this century. Masses of metal worth billions of dollars – enough to supply Earth's needs of certain metals for decades – should be obtainable from km-scale and smaller asteroids.

The ability to reach asteroids and deflect them from one orbit to another would emerge as a byproduct of such a program and would thus solve the problem of the asteroid threat.