

## Astronomy 311: Lecture 10 - Asteroids, formation of the Moon and some other solar system specifics.

- Vast majority of material in Solar Nebula was swept out into space by the solar wind: this ended the era of planetary formation.
- Winds are much stronger in younger stars.
- If gas had not been cleared out, might even have had jovian type planets in inner solar system. But this could happen in other solar systems
- Clearing of excess gas still left many planetesimals between the newly formed planets.
- Asteroids are the rocky leftovers of the inner solar system.
- Asteroid belt between Mars and Jupiter probably contained many more planetesimals earlier but most crashed into inner planets or ejected from Solar System.
- Comets are the icy-rich leftover planetesimals from the outer solar system. Total mass of the asteroid belt is only a tiny fraction of the mass of any terrestrial planet.
- Comets beyond Neptune able to grow large without disruption - they would have stayed in their original orbits on the same plane as the planets. These therefore became the objects of the Kuiper belt.
- Comets further out suffered strong gravitational encounters which kicked them further out and gave them all sort of orientations - the Oort Cloud objects.
- Analysis of meteors supports this.
- Solar nebula theory predicts the existence of both KBO's and OCO's.
- Exceptions?
  - Earth's moon is very large compared to the host planet. Why? How?
  - Largest leftover planet collided with the Earth after iron had settled into core of planet.
  - If this impact had blasted away material from Earth's outer layers and sent this material into space. Orbiting material could then have accreted into a spherical shaped moon.
  - Overall composition of the moon is similar to the composition of the Earth's outer layers. Also the moon has a much smaller proportion of easily vaporized ingredients - the heat of the impact would have vaporized such ingredients.

- Other giant impacts could explain why Uranus is tilted almost on its side and why Charon is so big compared to Pluto.
- Asteroids
  - Today about 150,000 asteroids catalogued: largest is Ceres - about 1000km in diameter.
  - Asteroid shapes depend on their gravity.
  - Shine by reflected light.
  - Made up of mostly metal and rock (from spectroscopy) because they condensed within the frost line. Those near outer parts of asteroid belt are made of more carbon-rich material.
  - Vast majority located between Mars and Jupiter.
  - Orbit Sun in same direction as the planets but their orbits tend to be more elliptical and inclined between 20-30 degrees to the ecliptic plane.
  - Trojan asteroids share Jupiter's 12 year orbit around the Sun: one clump always stays 60 degrees in front/behind in its orbit.
  - A small group of asteroids (Near Earth asteroids) have orbits that pass near the Earth's orbit.
  - Orbital resonances are the key to understanding why there is an asteroid belt.
  - Orbital resonances mean two objects eg Jupiter and the asteroid will periodically line up in the same direction and get an "extra nudge" which can build up over time.
  - Such resonances more often responsible for clear areas: Kirkwood gaps - a lack of asteroids with periods exactly  $1/2$ ,  $1/3$ , or  $1/4$  of Jupiter's.
  - Why didn't a planet form in the space occupied by the asteroid belt?
  - Resonances with Jupiter disrupted the orbits of the region's planetesimals.
- Meteors burn up in the atmosphere.
- Meteorites are meteors that strike the ground.
- Types of meteorites
  - Primitive meteorites - remnants from the birth of the solar system: radiometric dating puts them to be about 4.6 billion years old. Can be stony or carbon-rich.

- Processed meteorites - once part of a large object that "processed" the original solar nebula material into another form. Generally younger than primitive meteorites. Can be metal-rich (high density iron, terrestrial planet cores) or rocky (terrestrial mantles or crusts).
- Primitive meteorites: accreted in the solar nebula and orbited the Sun for billions of years before falling to Earth. Carbon-rich/stony meteorites formed in the outer/inner solar nebula material respectively.
- On Earth, get mostly stony meteorites though carbon-rich are more prevalent in space - because of orbital resonances.
- Processed meteorites must be fragments of larger asteroids that underwent some sort of differentiation: interiors melted so that metals sank and rocks rose.
- Comets
  - Ice rich because they formed beyond the frost line where hydrogen compounds are abundant.
  - Nucleus plus tail.
  - Study spectra of comets: ice mixed with rocky dust plus some more complex chemicals, including some organic molecules,  $CO_2$ ,  $H_2O$
  - Far from the Sun, its frozen, just the nucleus chunk of ice is present - but still look pretty dark as they have a low reflectivity (less than 5 percent).
  - Halley's comet has a density much less than water. Comet nucleus is about 20km across.
  - As the comet gets closer to the Sun, its surface temp. increases and gases sublimate into gas that escapes the comet's weak gravity.
  - This creates a dusty "atmosphere" called the coma.
  - Larger than the nucleus it surrounds.
  - Coma grows as the comet continues into the inner solar system.
  - Comet tail forms as an extension of the coma: many hundreds of km in length, generally point away from sun.
  - Comet tail can be millions of km long with material shooting out at hundreds of meters per second.
  - Two comet tails, one made of ionized gas - the plasma tail and one made of dust.
  - UV light from Sun ionizes gas escaping from the coma. Plasma tail always points directly away from Sun at all times.

- The dust tail is made up of dust-size particles escaping from the coma.
- These particles are not affected by the solar wind and instead pushed away from the Sun by radiation pressure.
- Dust tail also generally points away from the Sun but with a slight curve in the direction the comet came from.
- After the comet loops around the Sun and begins to head back out of the Sun, sublimation declines, coma dissipates and the tails disappear.
- Gas escaping from coma also has pebble-sized material. Too big to be affected either by the solar wind or radiation pressure - forms a third, invisible tail.
- Meteor showers occur when such comet dust enters our atmosphere: when the Earth crosses through a comet's orbit. Examples are the Perseids (August 12, Swift -Tuttle) Leonids (Nov. 17, Temple-Tuttle).
- Most comets come from the Oort cloud - a collection of many individual comets: perhaps  $10^{12}$  comets orbiting the Sun at distances of about 50000AU.
- Some comets that visit the inner solar system come from the Kuiper Belt (orbits beyond Neptune).
- Left-over planetesimals in jovian region had a good chance of suffering a collision with one of the gas giants. Small object passing close to a large object - the small object's orbit is most affected. Those that escaped crashing into the planet were flung off in all directions.
- Some escaped the solar system.
- Random directions explain the spherical shape of the Oort cloud. Oort cloud objects can be affected by the gravitational pull of nearby stars.
- Such gravitational encounters were much less likely for KBO's: those comets beyond the orbit of Neptune. KBO belt extends to about twice the orbit of Neptune. Beyond this the density of the solar nebula was too low for the formation of planetesimals.
- Thus KBO's still orbit close to the plane of the ecliptic.
- OC's formed closer the Sun than KBO's but are now much more distant.
- Quaoar, more than half the diameter of Pluto discovered in 2002. 2004DW, Sedna are more than three quarters the size of Pluto.
- Planet X, discovered in 2005, is larger than Pluto, has a 560 year orbit, has a greater inclination to the ecliptic than Pluto and is so eccentric that it sometimes comes closer to the Sun than Pluto.
- Comet impacts

- \* Not witnessed a major impact on Earth, but one on Jupiter: 1994, comet Shoemaker-Levy crashed into Jupiter (SL9). Such an impact occurs every 1000 years or so.
- \* In 1978, geologists found a layer of dark sediments deposited about 65 million years ago (about the time of the extinction of the dinosaurs). Such a layer was very rich in iridium - rare on Earth's surface but common in meteorites. Iridium sank to the Earth's core during differentiation.
- \* Such an iridium rich layer was found throughout the world.
- \* Fossil record suggests that 99% of all living organisms died around that time and 75% of all species were driven to extinction.
- \* Evidence
  - Unusually high abundance of osmium, gold and platinum
  - Grains of shocked "quartz" with a distinctive structure which can only be created under high pressure
  - spherical rock droplets of a type known to form when molten rock cools and solidifies in air.
  - soot - perhaps produced by widespread fires.
- \* Metal abundances are similar to what is found in meteorites.
- \* Shocked quartz is found at other impact sites.
- \* There is a large impact crater, about 200km across in the Ucatan peninsula near Mexico.
- \* "Rock" hit at a slight angle sending shower of debris across N. America. Tsunami came 1000km inland
- \* N. American life probably wiped out immediately.
- \* Hot debris around the world rained down - killed many living organisms.
- \* Dust/smoke in atmosphere for months, blocking sunlight and causing temperatures to fall.
- \* This stopped photosynthesis for upto a year - again killing a large number of species.
- \* Global winter followed by global summer due to release of  $CO_2$  into the atmosphere.
- \* 25% survived - mostly small mammals.
- \* Appear to have been at least 4 mass extinctions over the past 500 million years.