Summary: Asteroids, Comets and Impacts

- **Asteroids**
  - **Where are they found?** Asteroid belts, Trojans at Lagrange pts., and as moons.
  - **Basic Properties:** How many? Composition, Size, Density, Appearance. How much total mass?
  - **Some Terms:** Kirkwood Gaps, Apollos, Atens, Amors,...

- **Comets**
  - **Basic Properties:** Comp., Size, Density, Changing appearances, Dust and Ion tails, Total mass < 1 Earth.
  - **Where do they come from?**
    - » **Orbits are parabolic, just bound.**
    - » **2 Origin theories:** Oort Cloud, Kuiper Belt
  - **How do they fit into the Solar System?**

- **Meteors** What are they? Where do they come from. What's a meteor shower?

Physical Properties

	Comets	Asteroids	Meteoroids
Mass (Earth masses)	10^{-6} - 10^{-12}	< 0.0002	-
Radius	1 - 50 km	from 300m irregularly shaped, to Ceres = 410 - 570 km.	≤ 30m, most are dust grains
Composition:	ices, silicates, carbonaceous. Dirty Icebergs	• carbonaceous & rocky • iron & silicates	• irons • c. chondrites (C, SiO, no Fe) • ordinary chon. • Achondrites • Stony-irons
Total Mass in Solar Sys.	1 Earth?	0.0005 Earth Mass.	

Comments:

Comets: < 1000 known, Oort Cloud? Kuiper Belt?

Asteroids: ≈ couple thousand with known orbits + several thousand sightings. Most in belts.

Meteoroids: Earth collects 100,000 kg. per day. Carbonaceous chondrites have solar abundance of nonvoloatiles & date to 4.6 billion years ago. Showers from dead comets. Asteroids as parent bodies?

chondrite - a meteorite with chondrules.

chondrules - solidified mineral droplet.

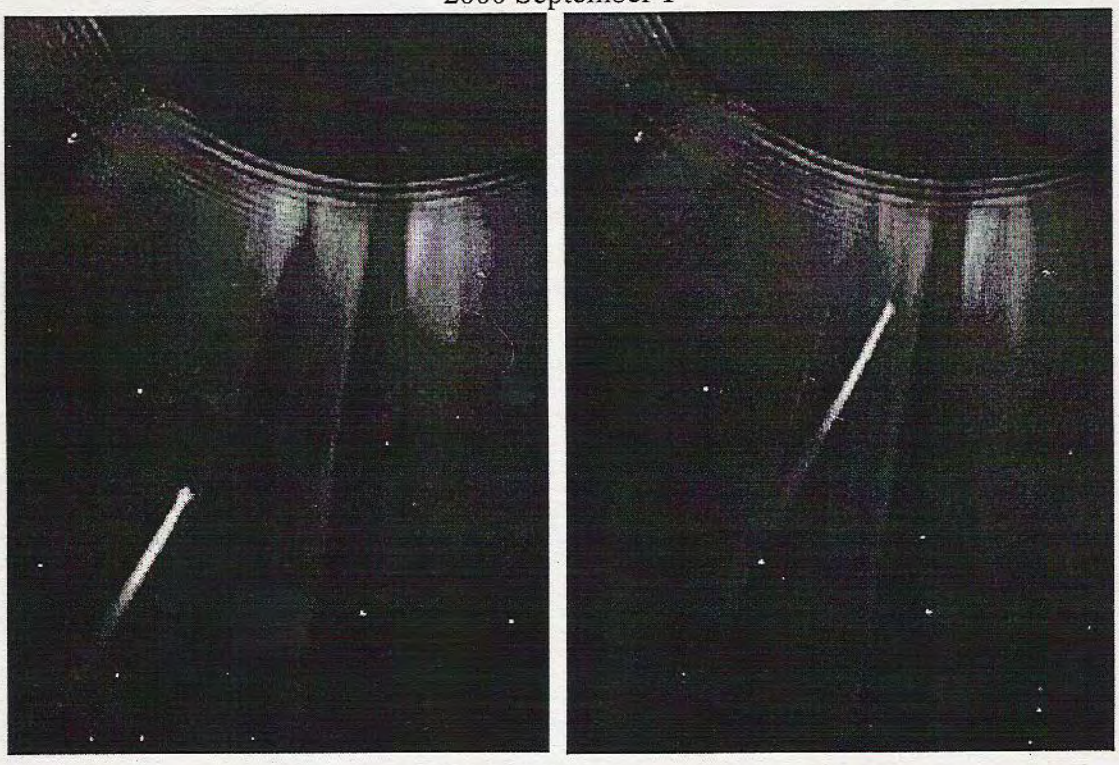
Halley Results

- **Single nucleus, but peanut shaped!**
  - Dimensions 8 x 8 x 16 km, period ≈ 52 hours.
- **Variety of surface features observed: hills and valleys.**
  - Probably not a result of sublimation, primordial.
- **Density ≈ 0.6 g/cm^3**
- **Albedo < 0.04.**
- **Surface temp. > sublimation temp.** ------> ice covered by insulating crust.
- **Dust streamers observed out to 100 km.,** diameter ~ 0.5 km near nucleus, strongly collimated.

Astronomy Picture of the Day

Discover the cosmos! Each day a different image or photograph of our fascinating universe is featured, along with a brief explanation written by a professional astronomer.

2000 September 1



SOHO Sungrazer
Credit: SOHO - LASCO Consortium, ESA, NASA

Explanation: SOHO, the space-based SOlar and Heliospheric Observatory, has become by far the reigning champion facility for discovering comets, its total having recently reached 200. As might be expected of a solar observatory, most of the SOHO discovered comets are sungrazers, destined to dive within a mere 50 thousand kilometers or so of the solar photosphere. At that range the intense heat and gravitational forces make it unlikely these primitive chunks of ice and dust will survive. Based on their similar orbits, as first worked out by 19th century German astronomer Heinrich Kreutz, all sungrazers are believed to originate from a single large parent comet which broke up during a perihelion passage perhaps 2,000 years ago. Over time, pieces have continued to split off producing a family of smaller comets which seem to travel in the same orbit. These frames from SOHO's coronograph were taken two hours apart on April 29 of this year. They show a sungrazer (SOHO comet discovery number 111) with a long, bright tail headed toward its fiery encounter. The sun itself is hidden behind the coronograph's occulting disk at each frame's upper right.

Tomorrow's picture: Pixels In Space

III. WHERE DO THEY COME FROM?

A. Oort Comet Cloud

- **There are about 600 known comets**
  - 500 have periods longer than 200 yrs. with a wide range of inclinations.
  - About half are on slightly hyperbolic (unbound) orbits, so they are on the first and only pass of the inner solar system.
  - Can only see a comet if it comes within about 3 a.u. of the Sun.

- **These facts led Jan Oort** to suggest in 1950 that the comets we see are only a small fraction of a much larger population distributed in a volume with radius ≈ 100,000 a.u. (i.e. about a light year).
  - Disturbances by passing stars drive some comets inward.
  - Oort suggested that there might be of order 10^{11} comets.

B. Kuiper belt: hypothetical cometary equivalent of asteroid belt.

- located between 40 and 50,000 a.u.

Large Impacts (on Earth)

What effects?

- **1. A big hole!!!**
  - E.g. craters around the globe.
- **2. A strong shock wave,** capable of much damage in the immediate vicinity.
  - E.g. Tsunguska event
  - Tsunamis
- **3. Much dust thrown into the atmosphere**
  - Little grains will float on high altitude winds ----> "nuclear" winter.
  - Bigger particles ballistically launched ,.... and can come back....
- **Hence the dinosaurs.....**

How often? (See transparency.)

- **Impacts** (especially giant impacts)
  - **Size Range:** from meteors to moons
  - **Source:** Earth-crossing comets and asteroids
  - **Dangers from giant impacts:**
    - » Direct hits
    - » Strong shock wave or tidal wave
    - » Forest fires
    - » Much dust thrown up - "nuclear winter"
    - » Bigger particles reform, launched ballistically, re-enter with "broiler" effect.
  - **Comet showers and mass extinctions:** the galactic connection.

(1994) in Hazards Due to Comets & Asteroids.

TABLE III
Impact Magnitude for Effects to Occur

Energy Effect	10^4 Mt	10^5 Mt	10^6 Mt	10^7 Mt
Dust		Nuclear winter cooling	Photo-synthesis ceases	Vision ceases (UV)
Fires			Global ejecta, regional fires broiled	Global fires
NO		Loss of O_3 shield		
Blast	Local			Regional
Tidal waves	Regional			
H_2O injections	Global			

fraction is higher than we have suggested, then dust injection could also be important in this energy range.

The energy range from 10^5 to 10^6 is transitional. The dust lifted in this energy range can produce optical depths from 1 to 10. Such optical depths equal or exceed those of historical volcanic eruptions and approach those having optical effects comparable to the optical effects of smoke generated by a nuclear war (Figs. 3 and 4). Cometary impactors in this energy range may throw material out across the globe (Fig. 6). The ejecta plumes of impacts between 10^5 and 10^6 megatons may produce enough NO to destroy the ozone shield (Fig. 10).

Between 10^6 and 10^7 megatons light levels drop below those which can support photosynthesis (Fig. 5). Ballistic ejecta re-entering the atmosphere will set fires over regional scales (above 10^6 km^2) and significant injections of water vapor into the upper atmosphere will occur.

At energies beyond 10^7 megaton light levels are too low to support vision, blast damage reaches the regional scale and fires are set globally.

Many of the mechanisms that have been discussed in this chapter have been investigated by only a single researcher, often in a preliminary fashion. Further studies will undoubtedly narrow many of the uncertainties that we

Astronomy Picture of the Day

. day a different image or photograph of our fascinating universe is featured, along with a brief explanation written by

2002 November 18

Explanation: The Peekskill meteor of 1992 was c
and then struck a car. Documented as brighter tha
fireball crossed parts of several US states during
landing in Peekskill, New York. The resulting mete
of dense rock and has the size and mass of an ext
are lucky enough to find a meteorite just after imp
are likely to be either very hot or very cold. In toni
meteor shower, few meteors, if any, are expected

Jovian Moons ~~and Rings~~

- **Jupiter's Galilean Moons:** already covered a bit, but a few slides, additional comments on Io, and ice tectonics on Europa, Ganymede.

- **Saturn's Moons**
  - Titan
  - The "resonance" moons
  - Other little-uns

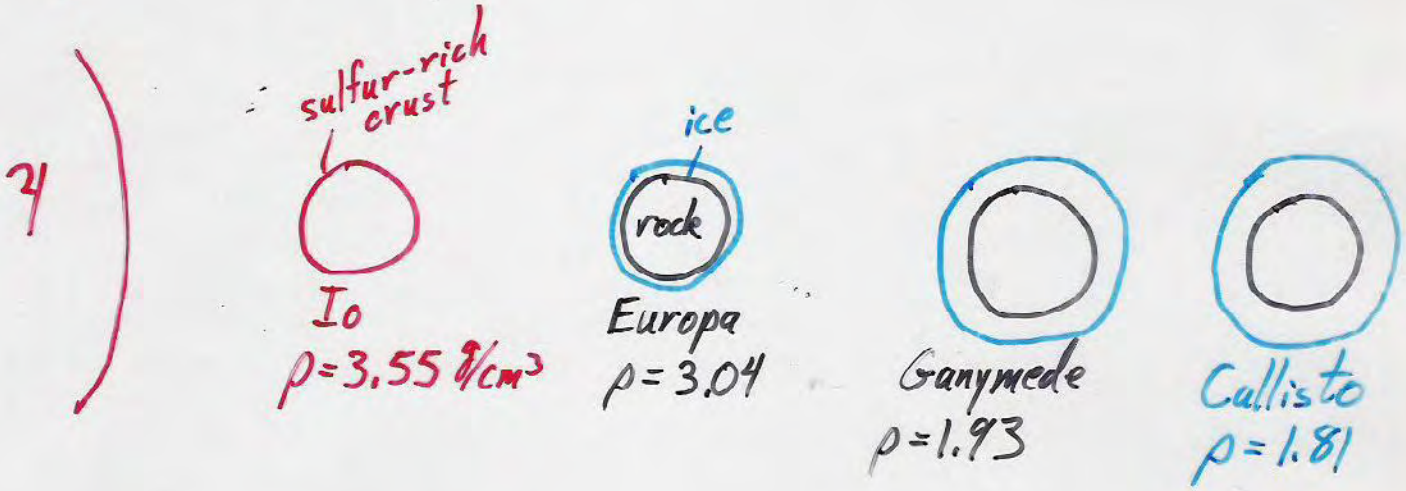
- **Uranus'**
  - Ariel: Ice tectonics
  - Miranda: chaotic geology

- **Neptune's**
  - Triton: retrograde orbit ----> captured?

- ~~**Rings....**~~

Also evidence of electric currents flowing between Jupiter's atmosphere and Io, contributing further heating.

In contrast to Io, the other Galilean satellites have ice mantles with fructional depths that increase with distance from Jupiter.

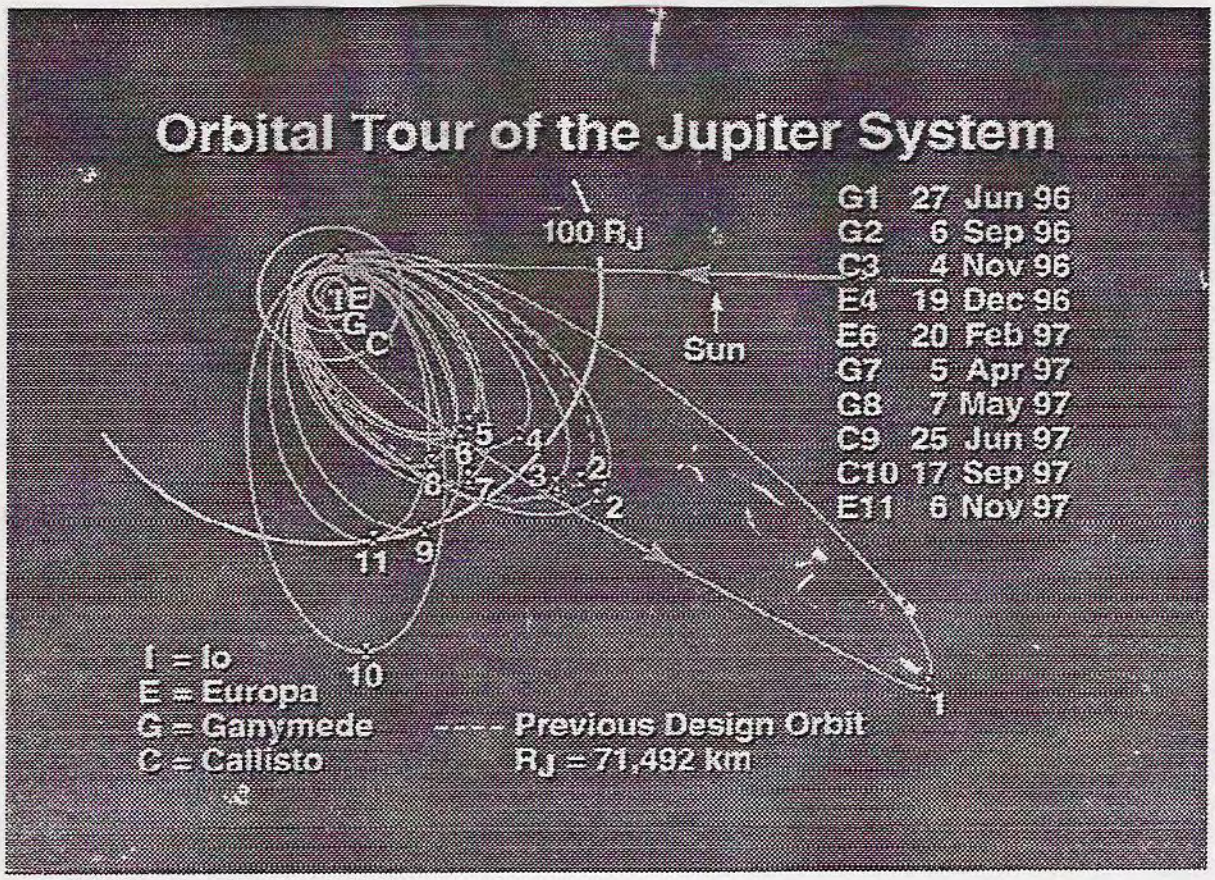


Io Flyby Results

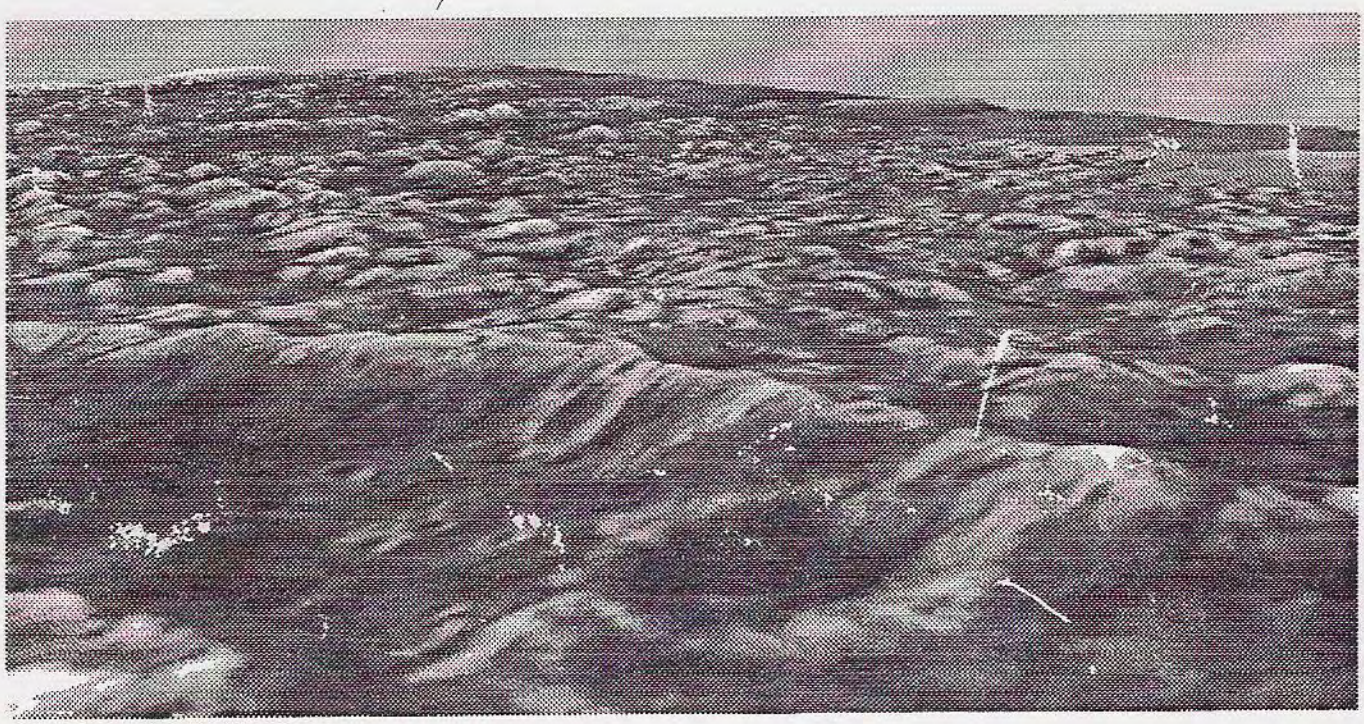
- Large iron core, deduced from satellite deflections.

- Hole in J.'s magnetic field near Io. Does Io have a field of it's own?

- Io is source of mysterious high velocity (40-90 km/s) dust streams. Electrically charged grains??



-Ganymede, Fall '96



Ice (Liquid) Tectonics and Cryovolcanism

- **Up to 10% of the ice moons' mass may consist of ammonia hydrates.**

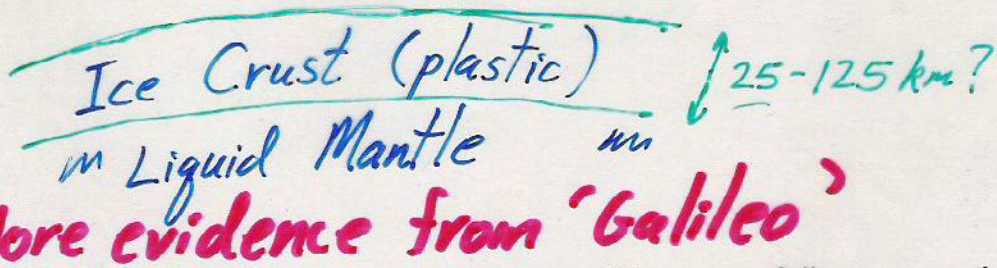
- **Properties of $NH_3 + H_2O$:**
  - melting T ≈ 174 K (Room temp. ≈ 300 K)
  - Density ≈ 0.94 g/cm^3
  - Neutral or negative buoyancy

- **Surface temperature:** 130-140 K measured at noon on Callisto (Mean 90 K on Europa)

- **Interior heating:** radioactive decay + tidal stresses

  -------> Subsurface Melting

- **Models of Europa (2nd out from Jupiter):**



More evidence from 'Galileo'

- **Ganymede:** wide range of crater densities and "grooved terrain", result of ice tectonics and cryo volcanism.

- **Callisto:** most heavily cratered of Galilean moons.

undifferentiated interior

Saturn's Satellites

- Dione and 1980S6 (Helene) have similar orbits with about a 60° separation relative to Saturn.

- 1980S13 (Calypso) - Tethys - 1980S25 (Telesto) are also each 60° apart on the same orbit.

In each case, probably the small moon(s) occupy the $L_{4,5}$ points relative to Saturn and the larger moon.

Titan is the 2nd largest and perhaps most interesting Jovian moon.

$\rho = 1.9 \Rightarrow$ equal parts ice and rock.

Both H_2O and CO_2 would be frozen if present. Has extensive atmosphere (relatively), but no magnetic field. Parts of the atm. have ρ, T near the triple (gas-liquid-solid) point of methane, giving rise to speculations that Titan has methane weather.

- Other large satellites have low densities, which imply large ice fractions:

	ρ (g/cm^3)
Mimas	1.2
Enceladus	1.1
Tethys	1.0
Dione	1.4
Rhea	1.3
Iapetus	1.2

- Iapetus has one dark (albedo 4-5%) red hemisphere, and one light hemisphere (albedo 50%)!

Moons of Uranus and Neptune

- **Uranus:**
  - **Ariel:** More ice tectonics? Young flows observed.
  - **Miranda:**
    - » Some older cratered terrain
    - » Chaotic terrain (gorges 10 km deep):
    - » Vigorous tectonics? Very small with d = 484 km, should be cold.
    - » Collision with Uranus?

- **Neptune:**
  - Triton: has polar caps H_2O, CH_4, N_2 ices? $T \approx 35$-45K, so most, but not all, N_2 frozen.
  - Tectonics? Cryovolcanism: big moon, $d \approx 2710$ km. Plumes, geysers observed with melting of polar caps (solar energy as well as interior energy?) Global albedo changes observed1977-1989.
  - Tenuous N_2, CH_4 atmosphere.
  - Was Triton captured? Retrograde orbit.
    - » If so models suggest global melting for as long as 500 million years due to tidal heating.
    - » No heavily cratered regions.

Pluto - Charon Summary

- **Orbit:**
  - a = 39.4 au, e ≈ 0.25, i = 17°.
  - Crosses inside Neptune's orbit, but no danger of collision.

- **Physical characteristics:**
  - diameters: Pluto: 2100 km., Charon: 1100 km
    - » i.e. Pluto's about 60% the size of the Moon, same size and composition as Neptune's moon Triton.
  - density: both about 2.1 gm/cm^3
  - bulk composition: 75% rocky, 25% water ice
  - surface/atmosphere: methane on Pluto (polar caps?), temp. ranges from 50-60 K, Charon a bit warmer? N_2, CH_4 atmosphere at warm phase. Albedo ≈ 0.20
  - Pluto's obliquity = 112°

- **Pluto/Charon System:**
  - Orbit radius: 19,000 km, i.e. 9 Pluto diameters
  - Sidereal rotation period: 6.4 days
  - Sidereal orbit period: 6.4 days, **synchronous**