

Chapter 12

Remnants of Rock and Ice
Asteroids, Comets, and Pluto

Motivation

- Asteroids and comets--“junk of the solar system”—are pristine samples of the early solar nebula
- Their study can tell us about what the solar system was like 4.5 Byr ago
- Impacts had a large effect on planets in the past, and may still occur
- Pluto, discovered only in 1930, is better understood as an icy planetesimal from the Kuiper belt rather than a planet

Definitions

- Asteroid: a rocky leftover planetesimal orbiting the Sun.
- Comet: an icy leftover planetesimal orbiting the Sun—regardless of its size or whether or not it has a tail.
- Meteor: a flash of light in the sky caused by a particle entering the atmosphere, whether the particle comes from an asteroid or a comet.
- Meteorite: any piece of rock that fell to the ground from space, whether from an asteroid, a comet, or even another planet.

Asteroids

“Starlike”

Discovered starting ~200 yrs ago

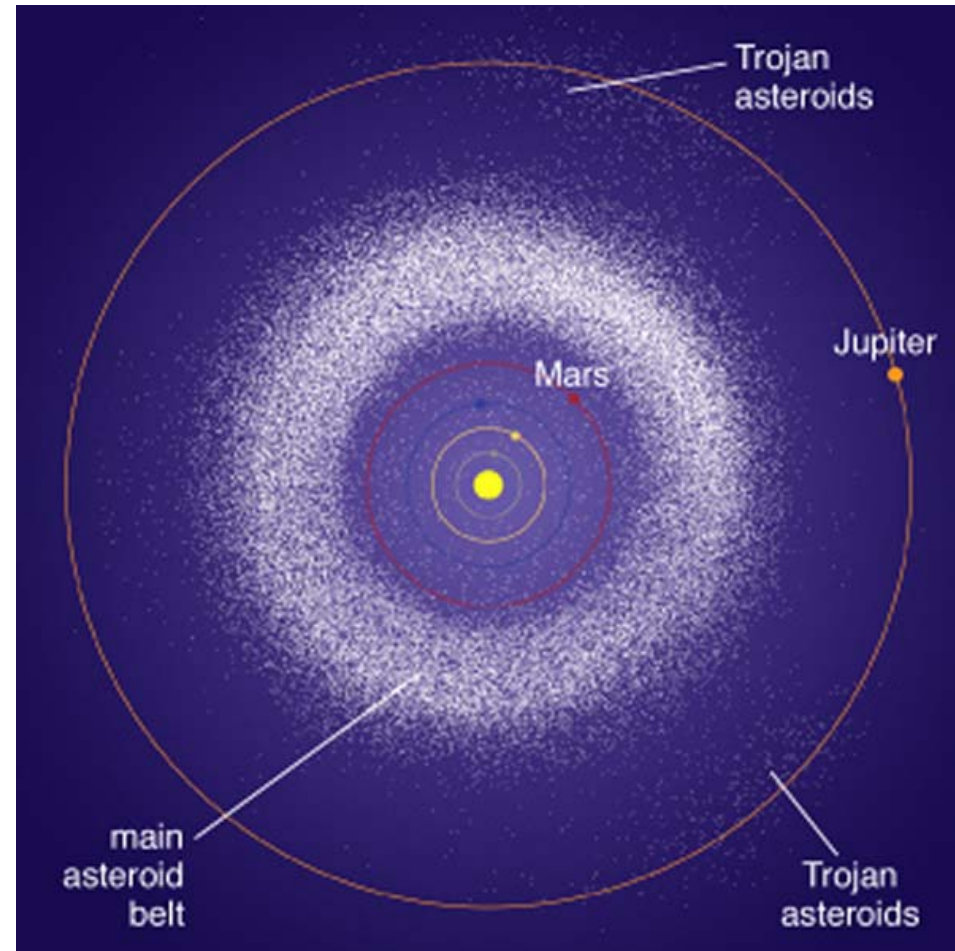
Located in the asteroid belt between Mars and Jupiter

Trojan asteroids precede and follow Jupiter in its orbit

About 100,000 with size > 1 km

Largest is Ceres, $d=940$ km

Next largest is Pallas, $d=540$ km



Asteroids Up Close

a Gaspra (16 km across). Photographed by the Galileo spacecraft on its way to Jupiter.



16 km

53 km

b Ida (53 km) and its tiny moon, Dactyl. Photographed by the Galileo spacecraft.



59 km



c Mathilde (59 km). Photographed by NEAR on its way to Eros.



40 km

d Eros (40 km). The NEAR spacecraft orbited Eros for a year before landing on it.

Ida Animation

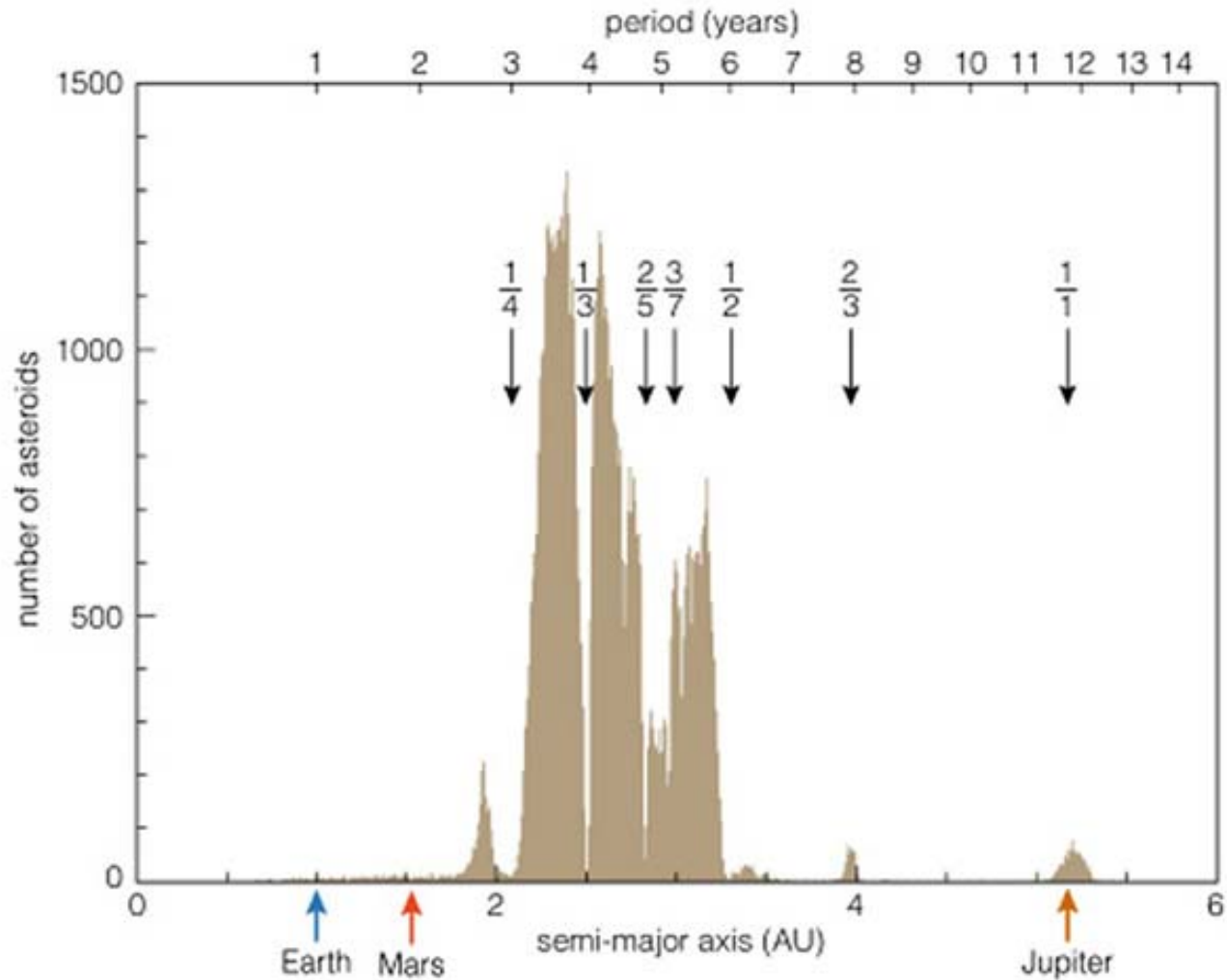


<http://solarviews.com>

Origin of Asteroid Belt

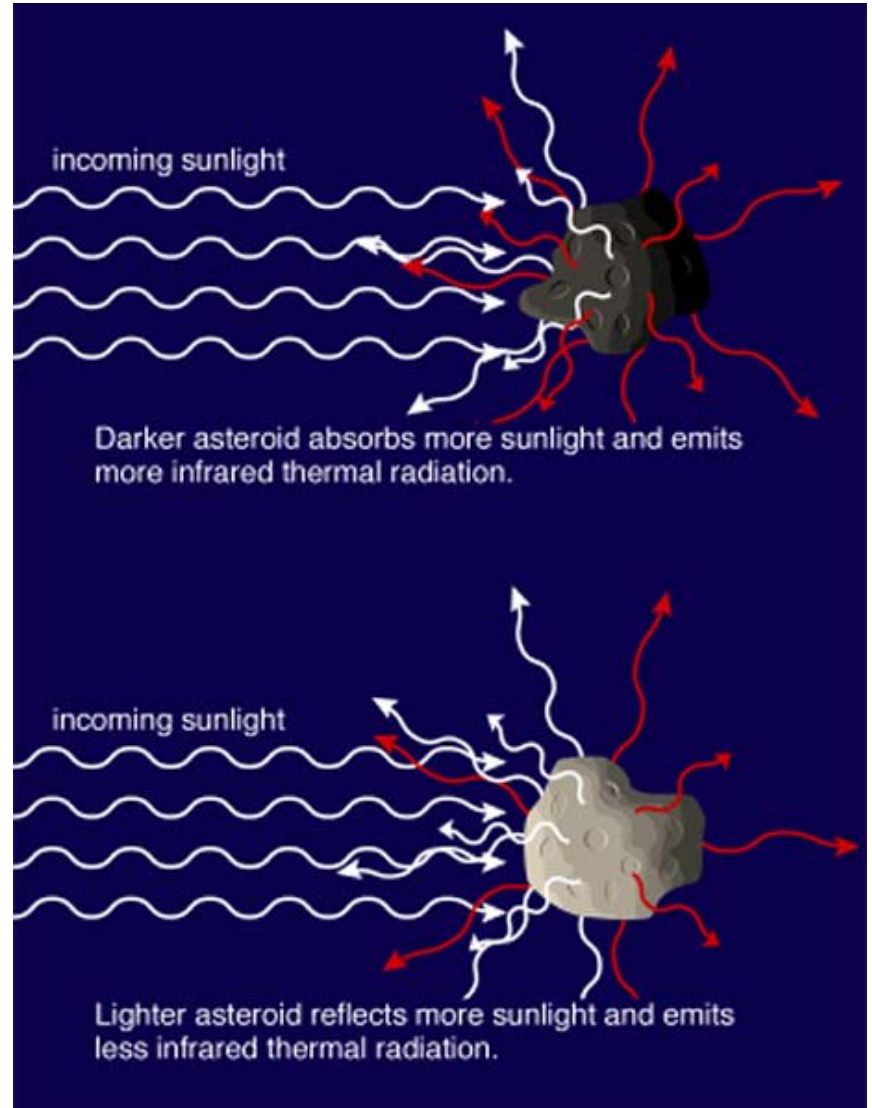
- A **planet that failed** or **shattered planet**?
- Evidence points to the former, although it may be both (cf. Meteorites)
- Gravitational perturbations by Jupiter kept the planetesimals “stirred up”, preventing coalescence into large protoplanet
- Evidence of this are the **Kirkwood gaps**

Kirkwood Gaps



Determining Asteroid Composition

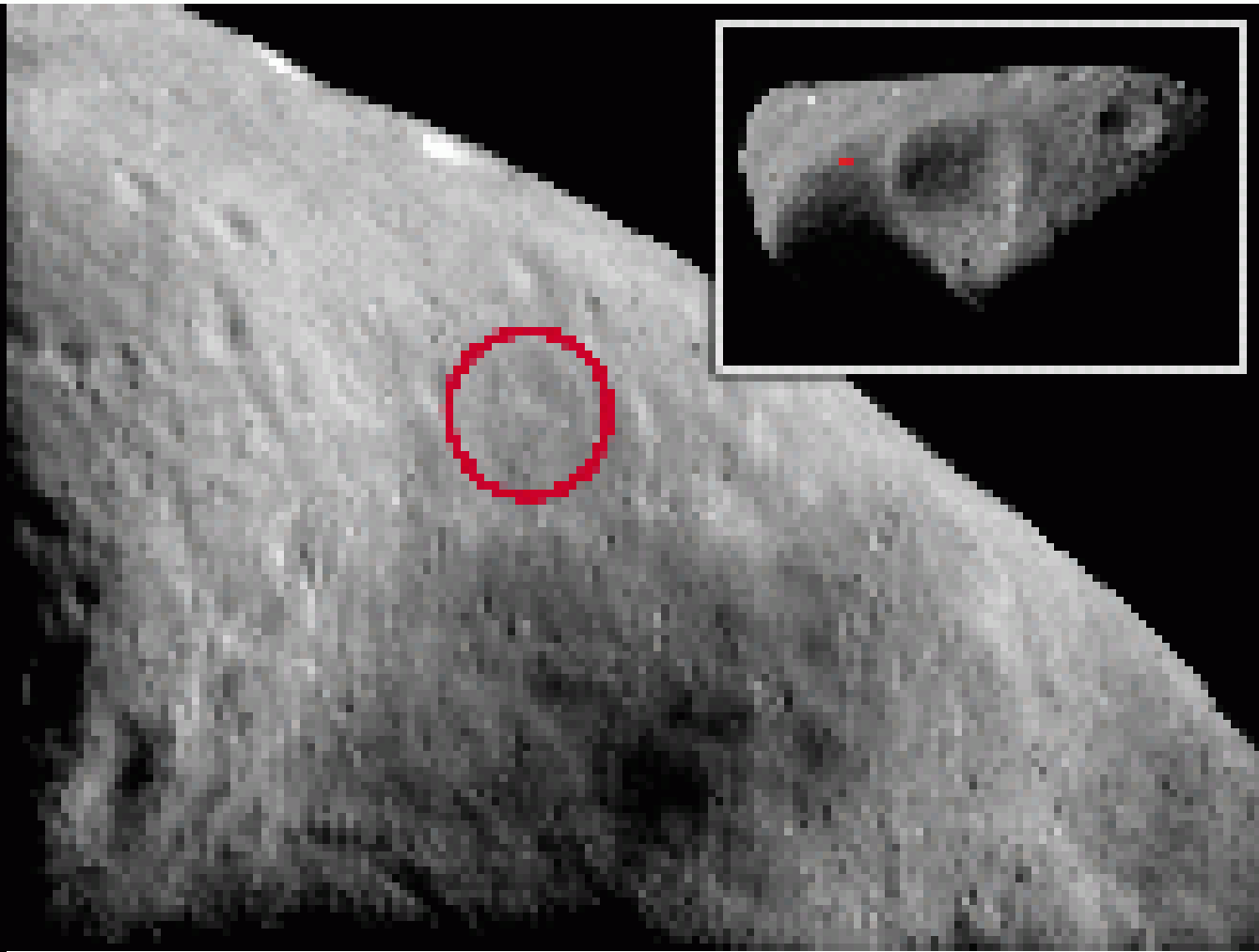
- Measure brightness of asteroid at optical and infrared wavelengths
- Ratio of brightnesses indicates composition
- Three classes:
 - Carbonaceous
 - Rocky
 - Metallic



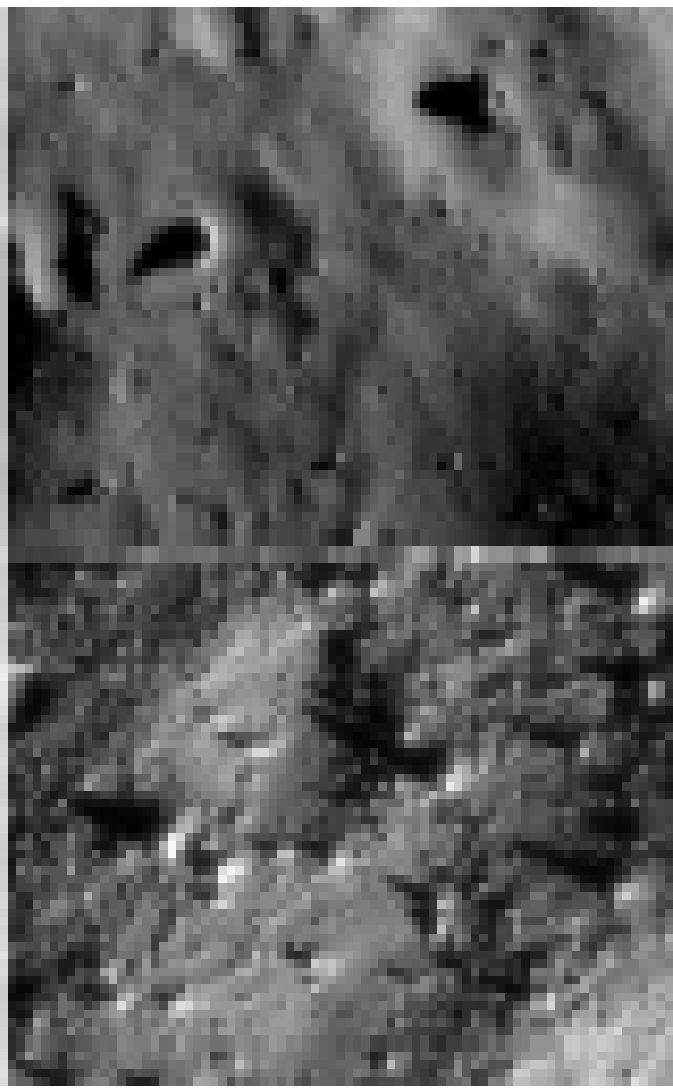
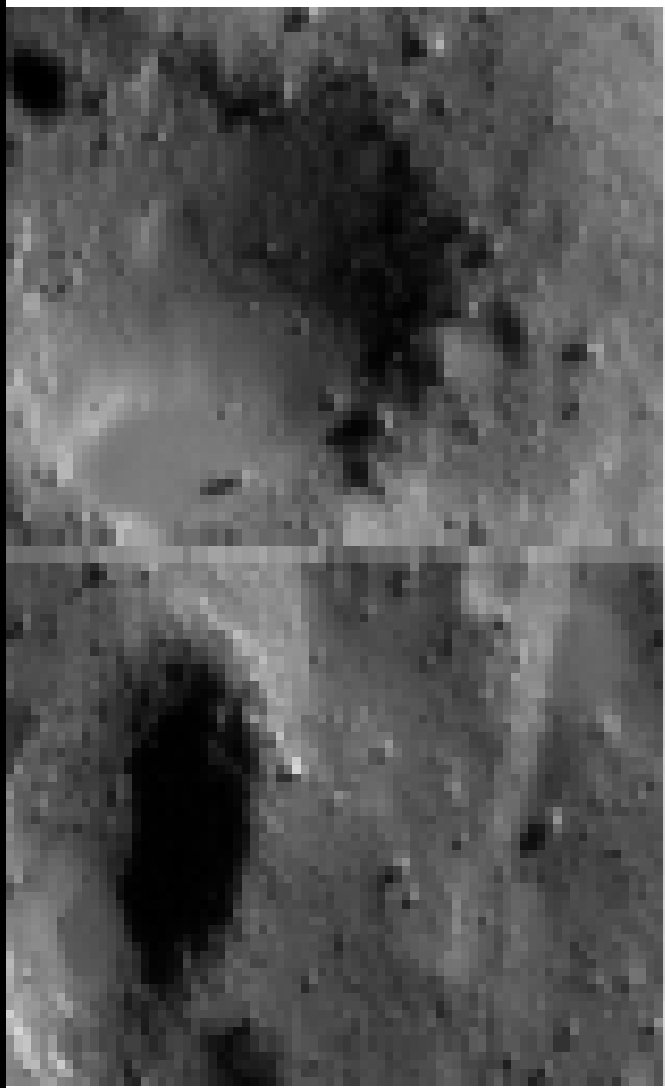
Landing on an Asteroid: NEAR

- Landed on near-Earth asteroid Eros (d=40 km) on 12 February 2001
- Images and movies available from website
- <http://near.jhuapl.edu/>

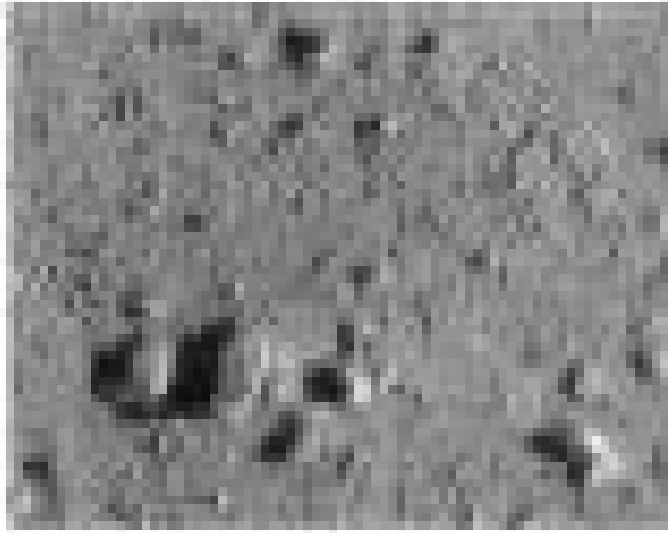
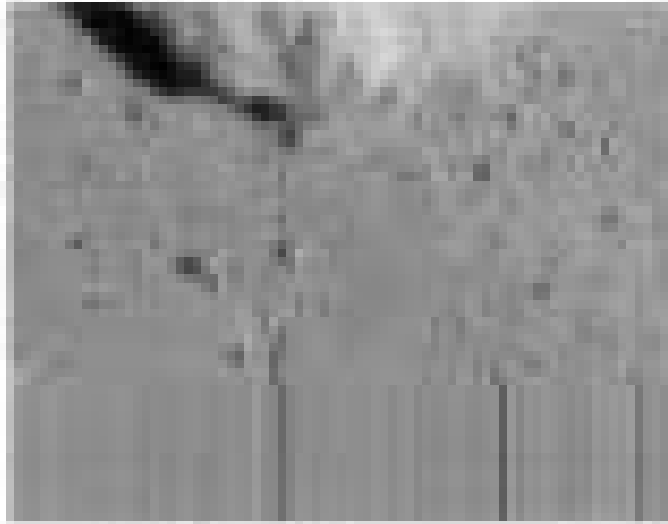
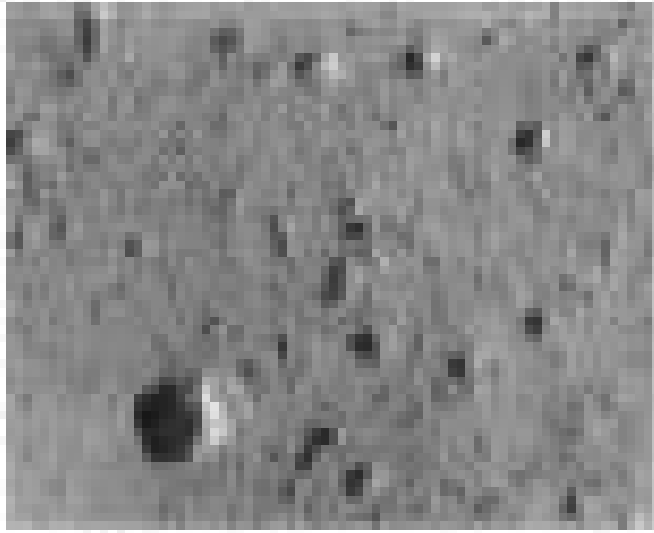
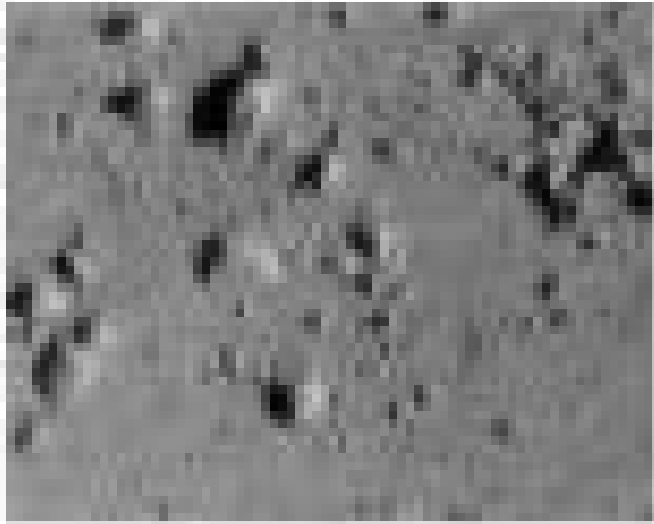
Discovery Is NEAR



Discovery Is NEAR



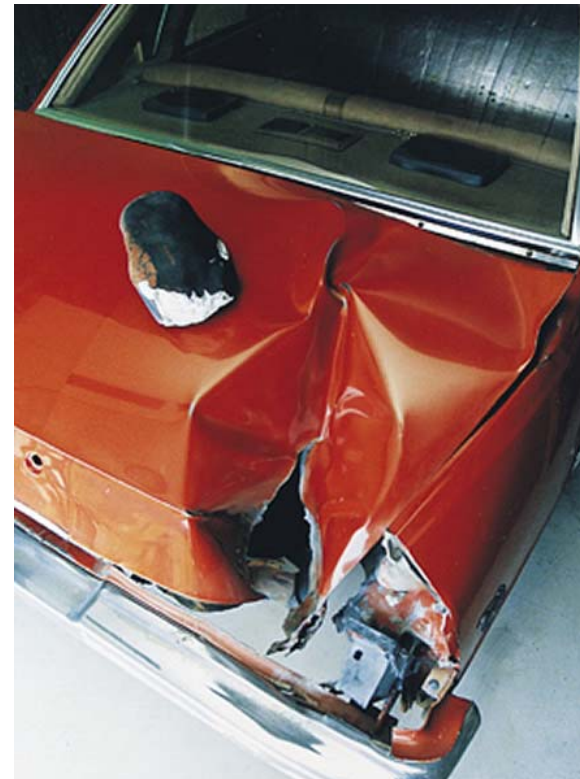
Discovery Is NEAR



Meteorites

“of the air”

- Meteors are rocks from space
- Largest ones originate in the asteroid belt
- Smaller ones come from comet tails
- Most burn up in the atmosphere before reaching Earth
- Those that survive are called meteorites



A Giant Meteorite

www.meteorites.com



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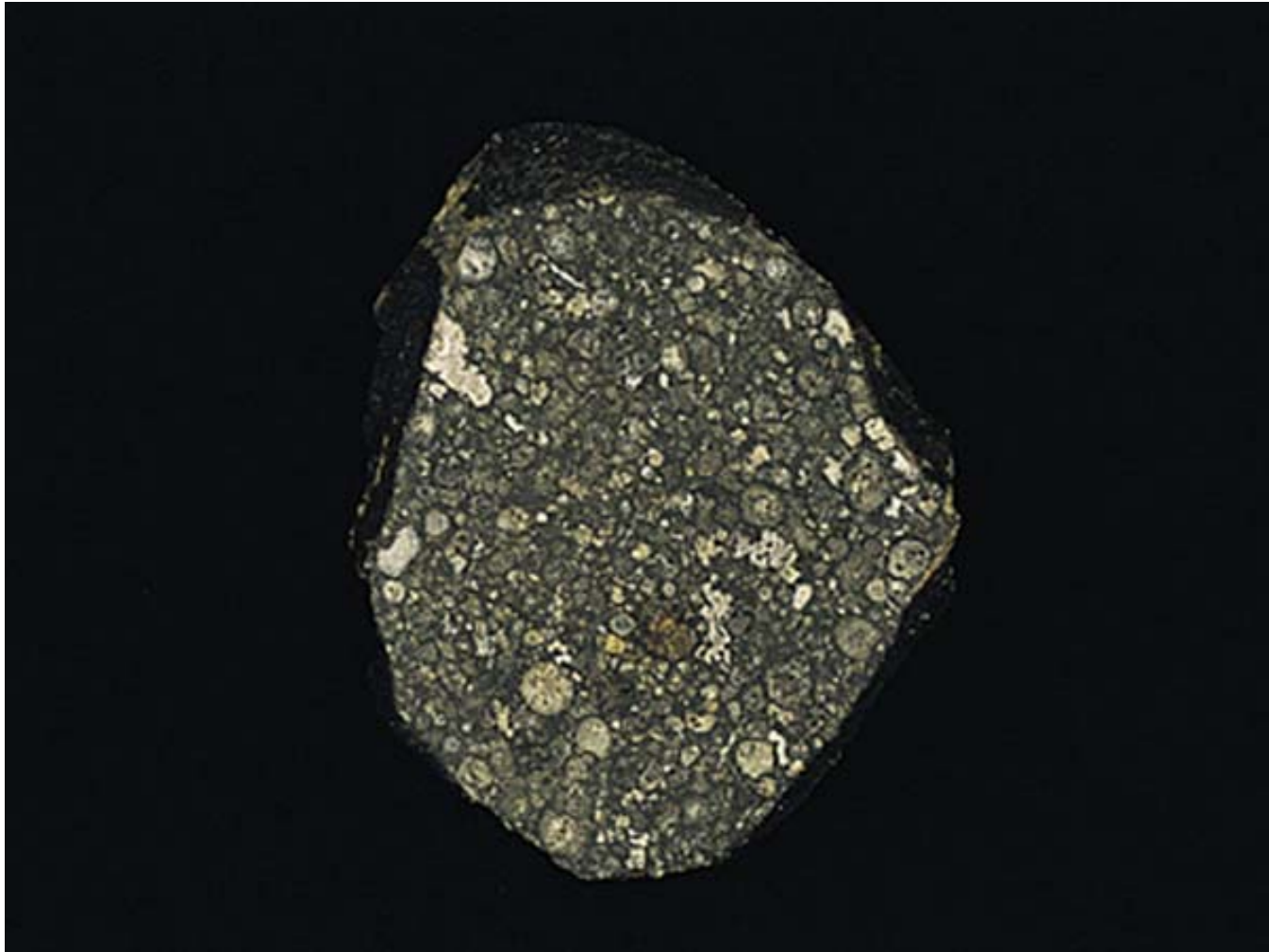
3-31

Kinds of Meteorites [1]



Stony primitive meteorite: age 4.6 Byr

Kinds of Meteorites [2]



Carbonaceous primitive meteorite: age 4.6 Byr

Kinds of Meteorites [3]



Differentiated iron meteorite: age <4.6 Byr

Kinds of Meteorites [4]

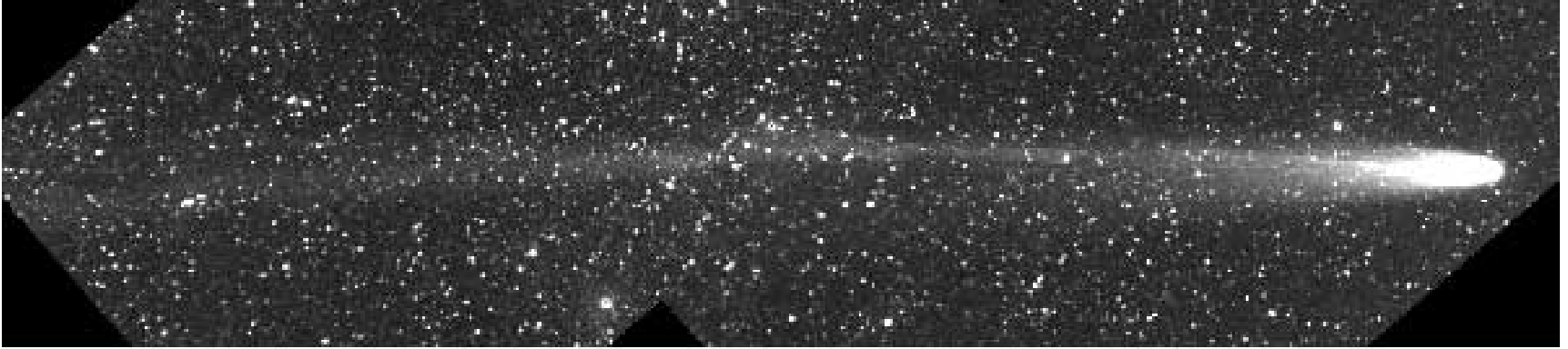


Differentiated stony meteorite: age <4.6 Byr

Origin of Meteorites

- **Primitive meteorites** have compositions similar to asteroids, and presumably formed there
- **Asteroid collisions** knocked them out of orbit
- **Processed meteorites** have compositions similar to planet cores, mantles or crusts
- **Remnants of a shattered planet** large enough to have differentiated

Comets "hair"



Hyakutaki 1996

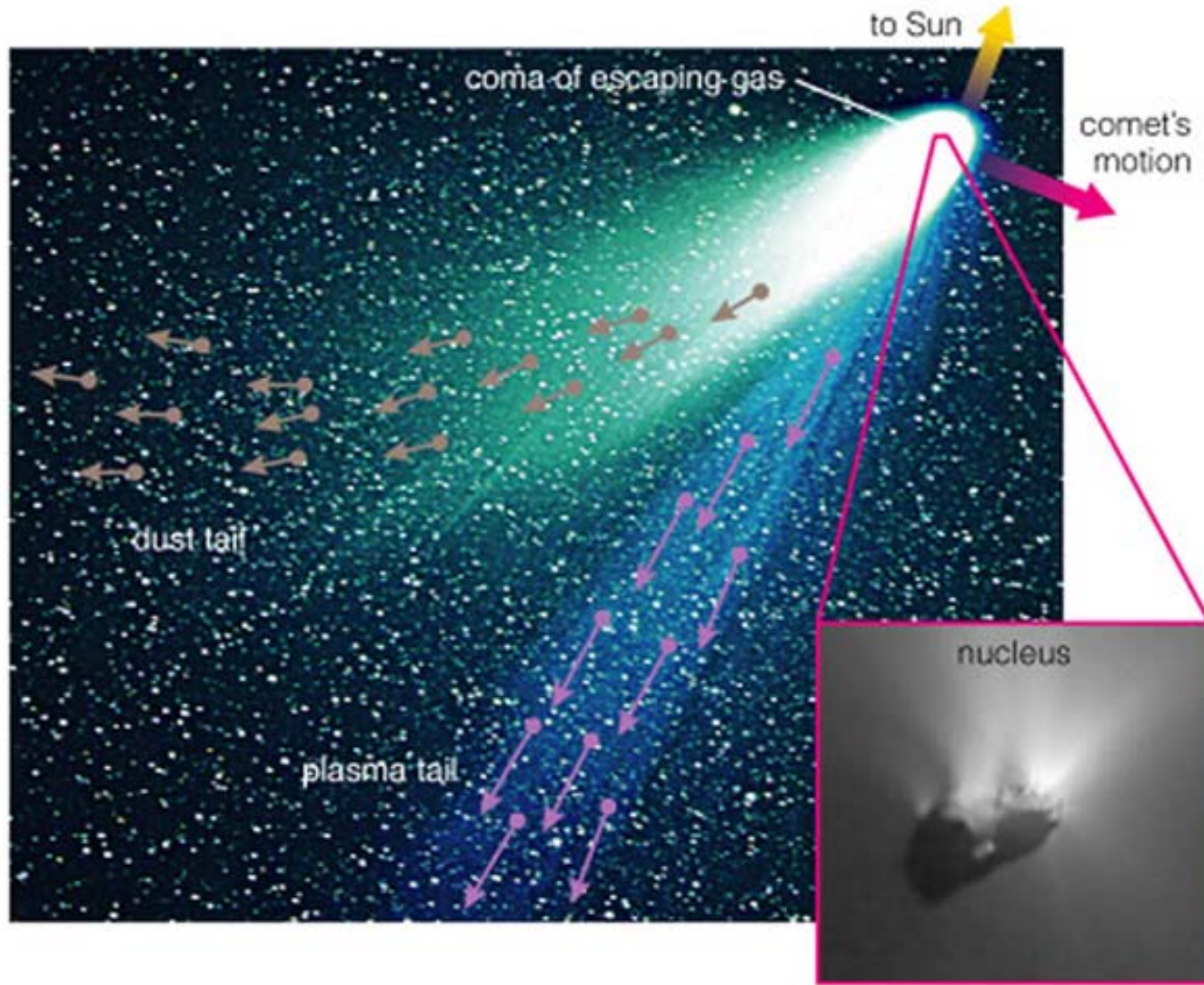


Hale-Bopp 1997

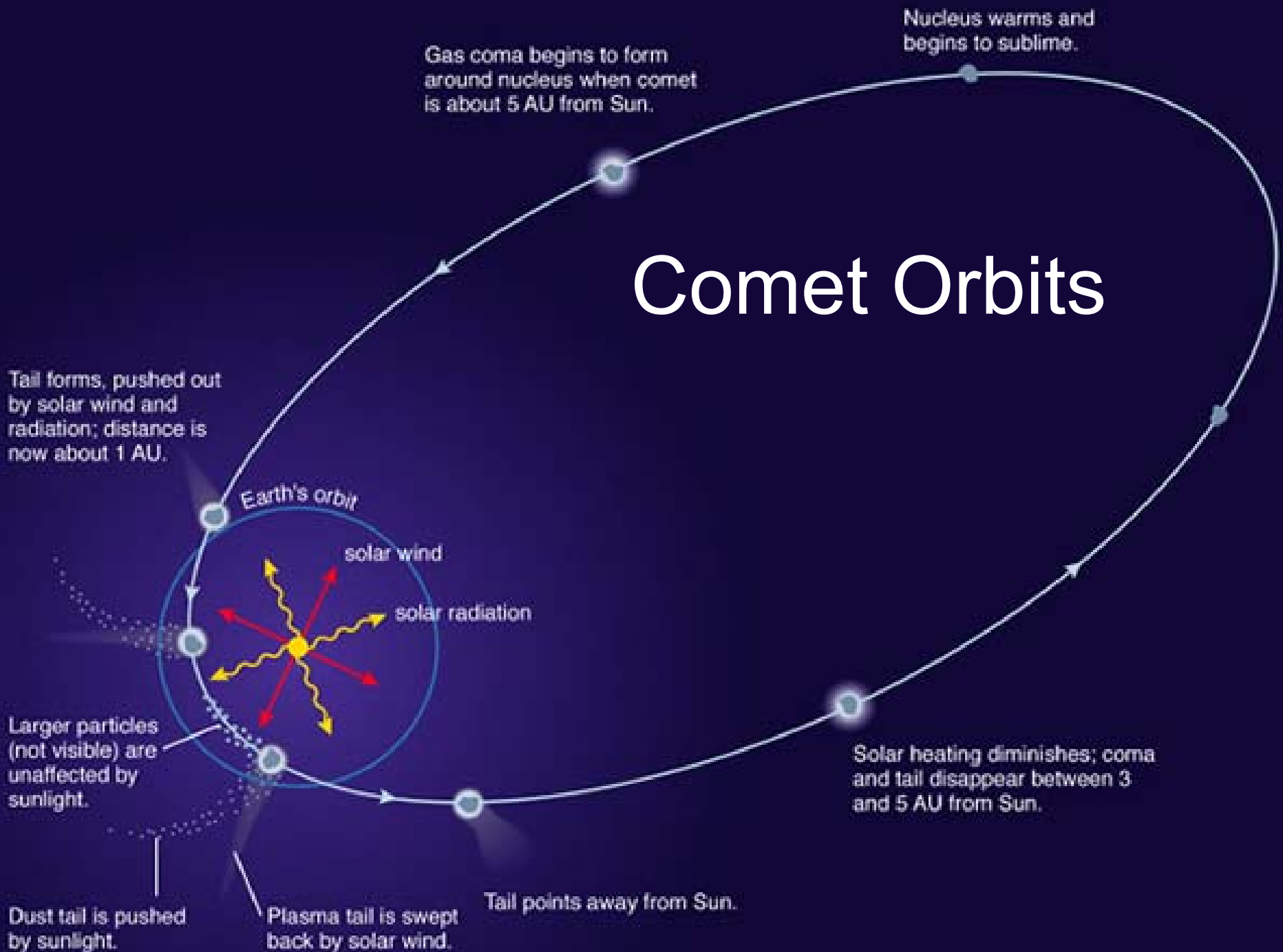


Ikeya-Seki 1965

Anatomy of a Comet



Comet Orbits



Gas coma begins to form around nucleus when comet is about 5 AU from Sun.

Nucleus warms and begins to sublime.

Tail forms, pushed out by solar wind and radiation; distance is now about 1 AU.

Earth's orbit

solar wind

solar radiation

Larger particles (not visible) are unaffected by sunlight.

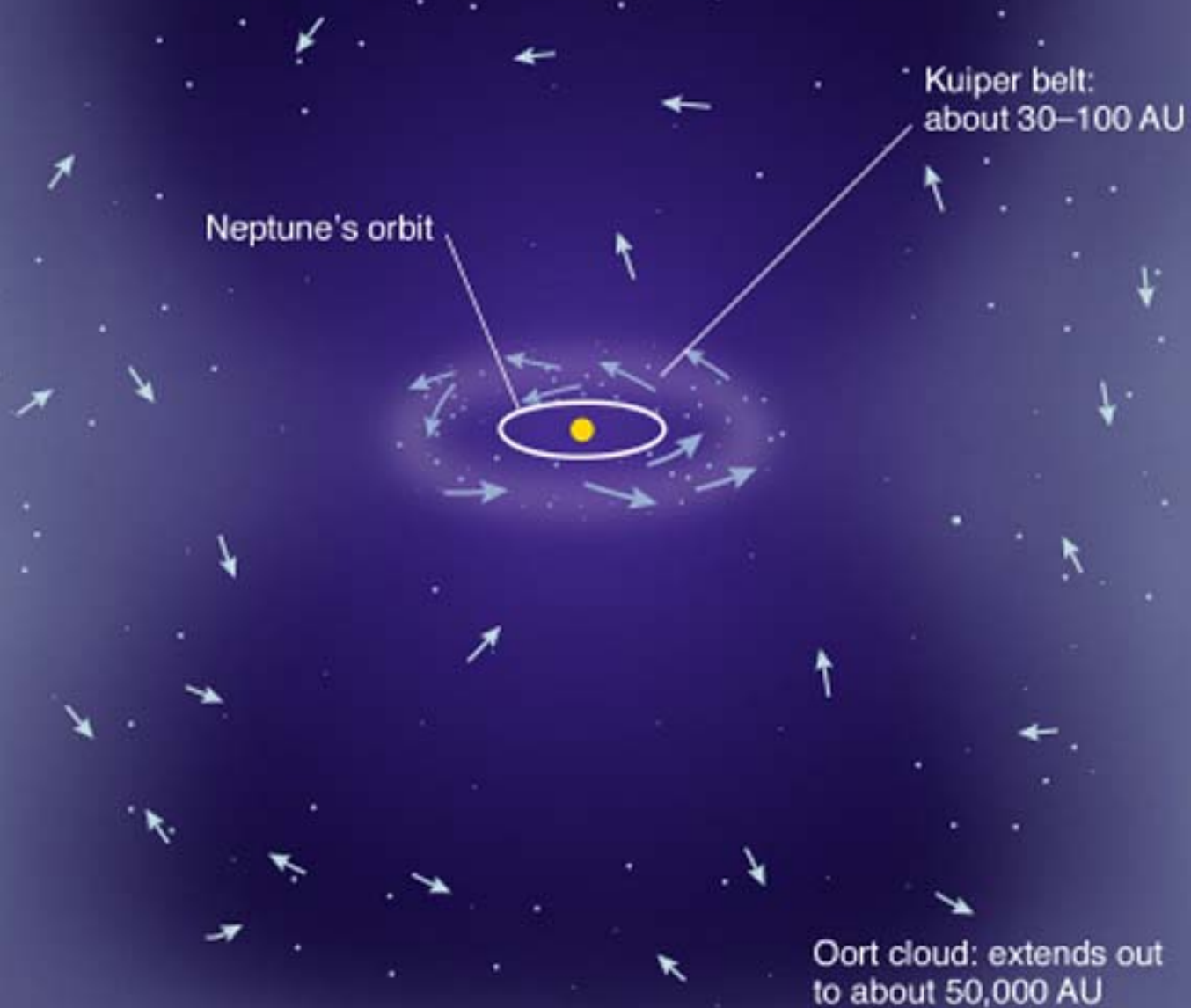
Dust tail is pushed by sunlight.

Plasma tail is swept back by solar wind.

Tail points away from Sun.

Solar heating diminishes; coma and tail disappear between 3 and 5 AU from Sun.

Comet Reservoirs

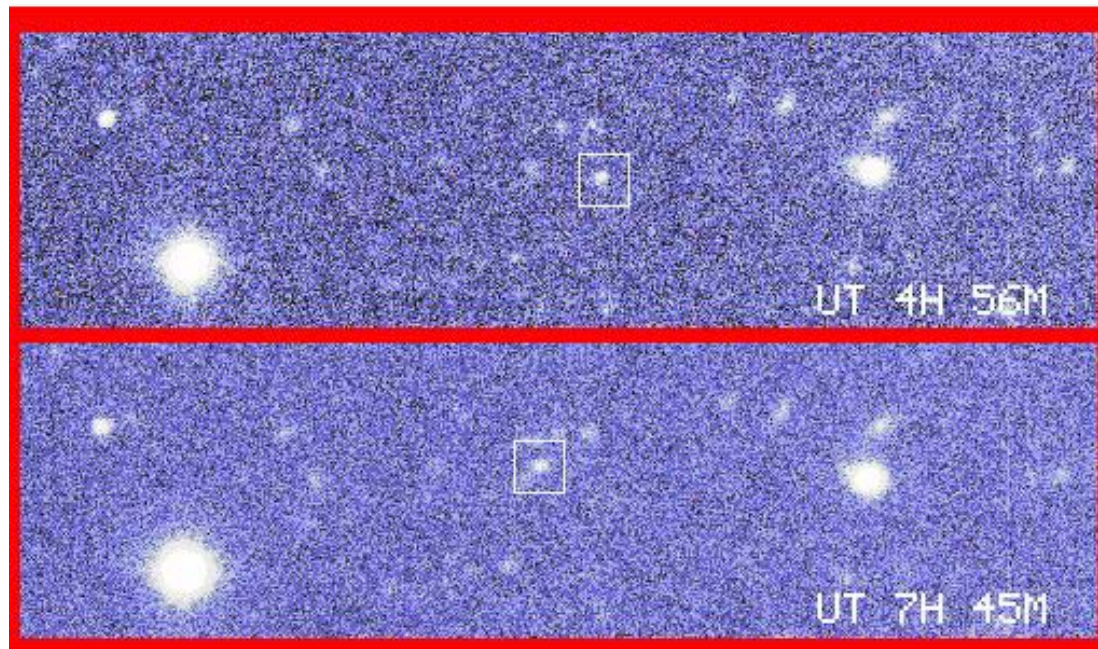


Kuiper Belt and Oort Cloud

- Existence inferred from orbits of comets
- Two classes:
 - Kuiper Belt: (30-100 AU)
 - roughly coplanar with SS, orbit Sun in same direction as planets
 - Make frequent returns
 - Estimate 100,000 objects with $d > 100$ km
 - Oort Cloud: (up to 50,000 AU)
 - orbits in random planes and directions
 - May make only one pass
 - Estimate 1 trillion comets

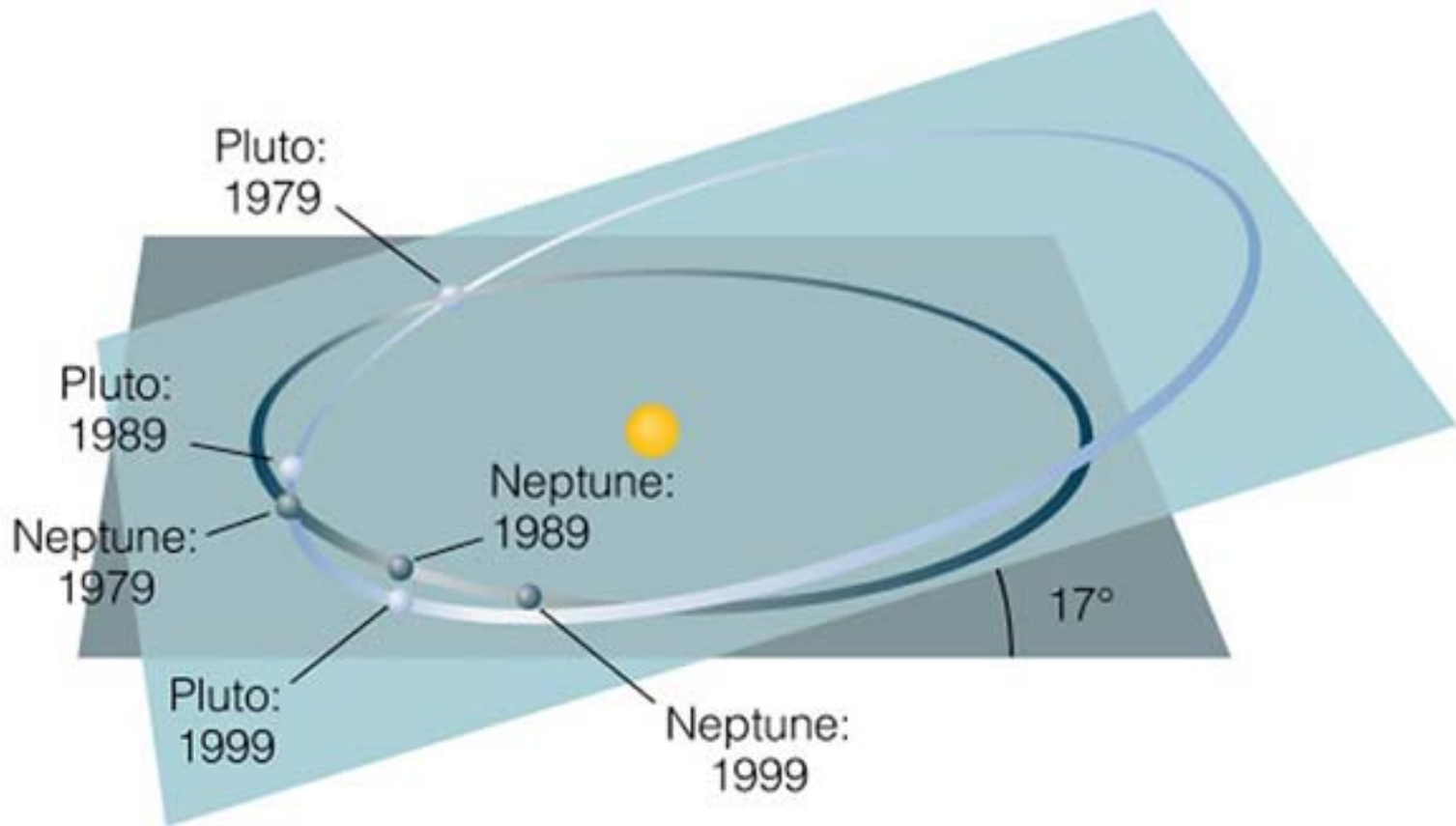
Kuiper Belt Web Site

- <http://www.ifa.hawaii.edu/faculty/jewitt/kb.html>



- Over 400 objects now known
- Largest: $d > 1000$ km

Pluto: Planet or KB Object?



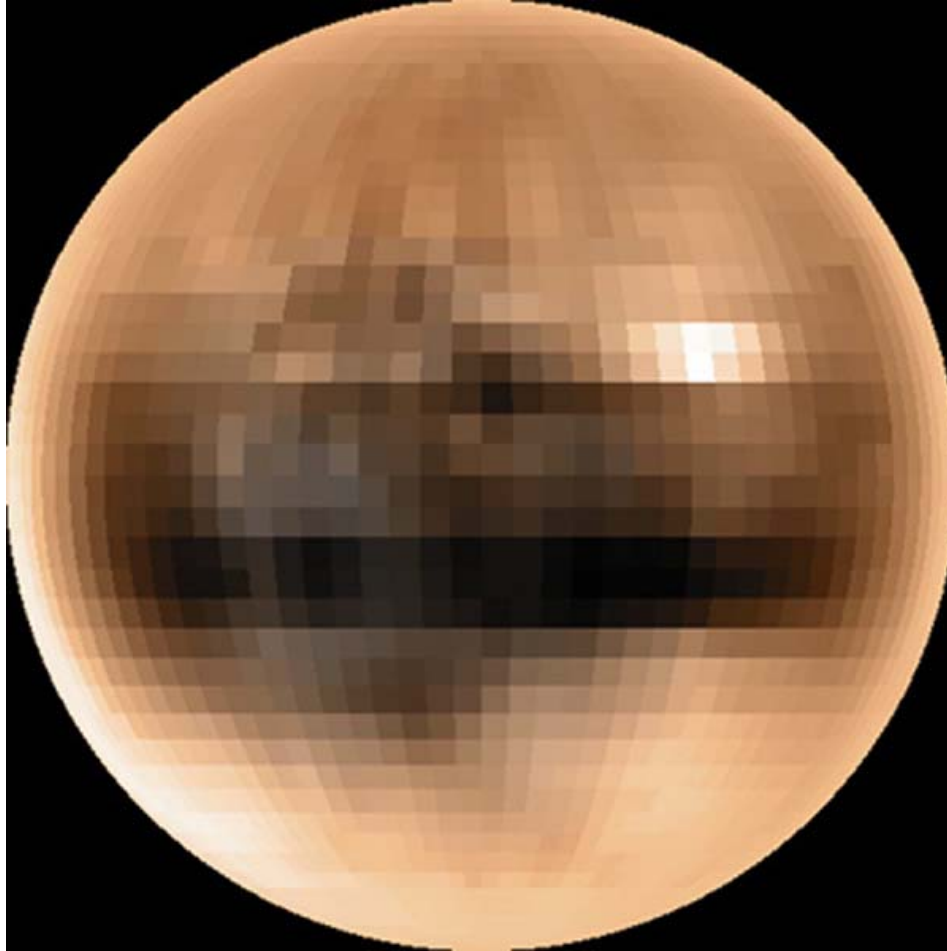
Orbit, mass, and composition similar to largest KB objects

Pluto's Moon Charon



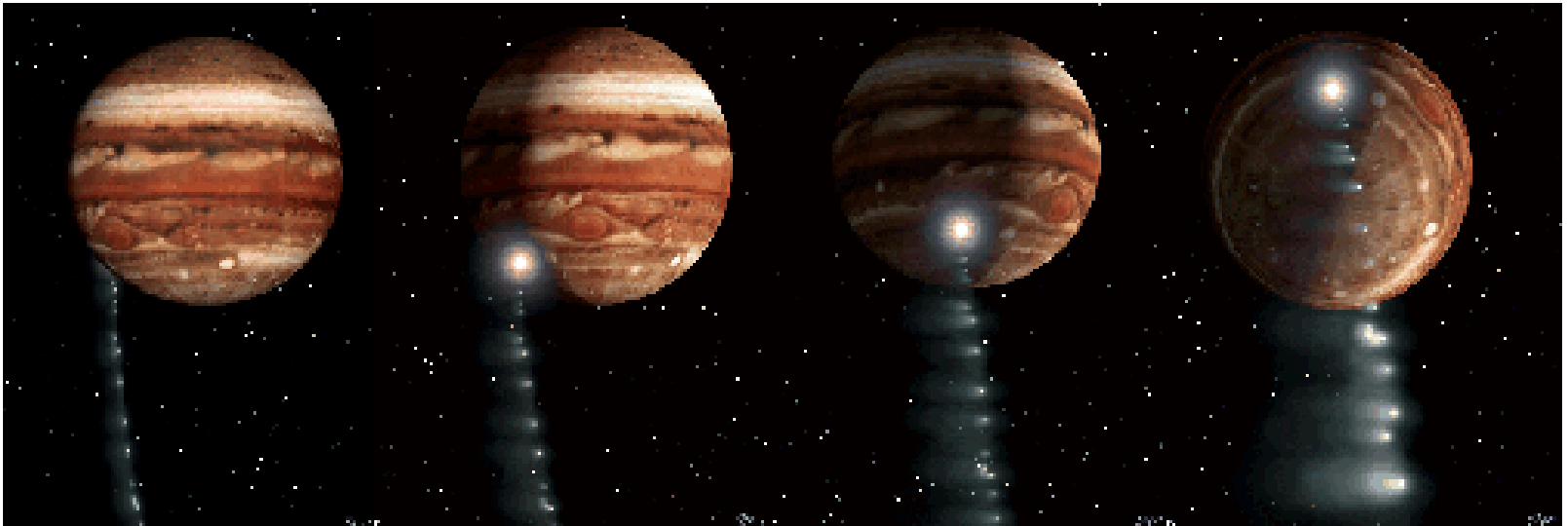
Hubble Space Telescope image

Pluto Surface Features



Pluto is only planet not visited by space probe

Cosmic Collisions



Comet Shoemaker-Levy 9 Impact with Jupiter, July 16-22 1994

<http://www.jpl.nasa.gov/sl9/>

Cosmic Collisions

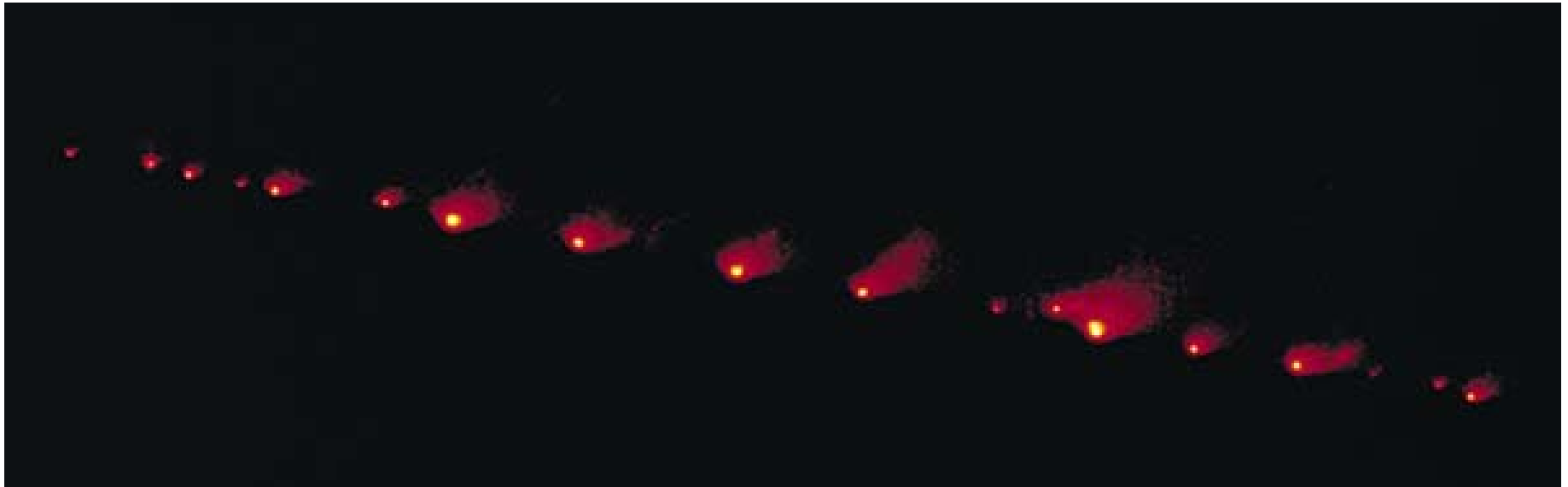
- With so much debris in the solar system, collisions with planets occur
- In 1994, comet Shoemaker-Levy 9 collided with Jupiter with an energy of a million H-bombs
- In 1908, something (a comet) struck Tunguska, Siberia, flattening the forest for miles around
- 65 million years ago, a 10 km object struck Yucatan, Mexico, leading to mass extinctions including dinosaurs

SL9 Impact: Artist Conception



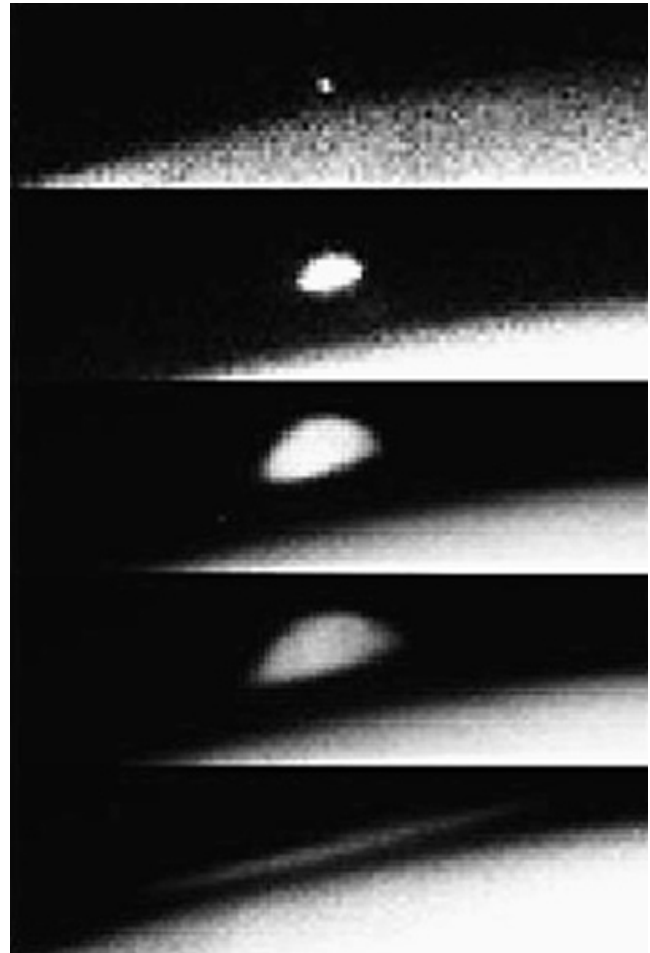
SL9 Comet: Multiple Nuclei

- Close encounter with Jupiter in 1992 broke up comet nucleus into chain of fragments



Hubble Space Telescope Image

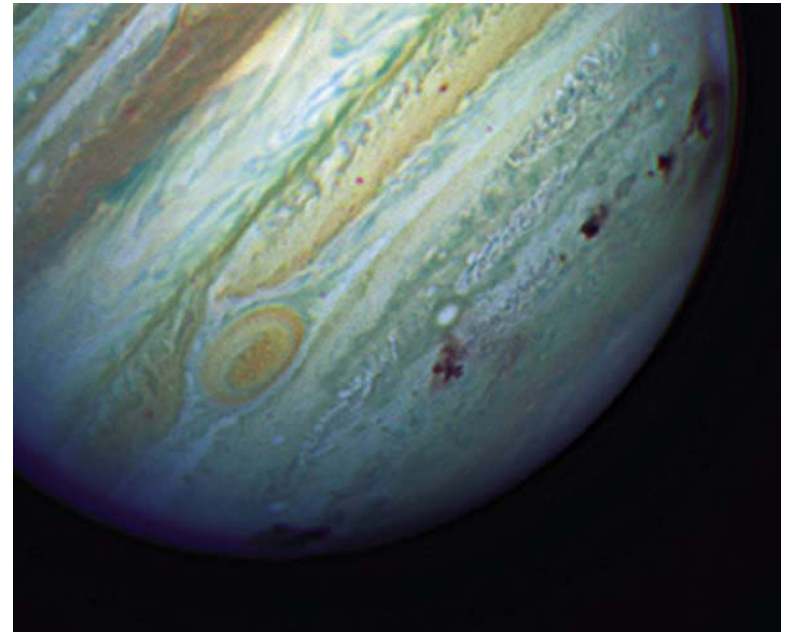
SL9 Impact Fireball



Infrared Image Shows Heat Generated by Impacts



Aftermath: Scars in Cloud Deck



8 yr later, these blemishes have disappeared

Terrestrial Impacts

Meteor Crater, AZ

Happened 50,000 yr ago

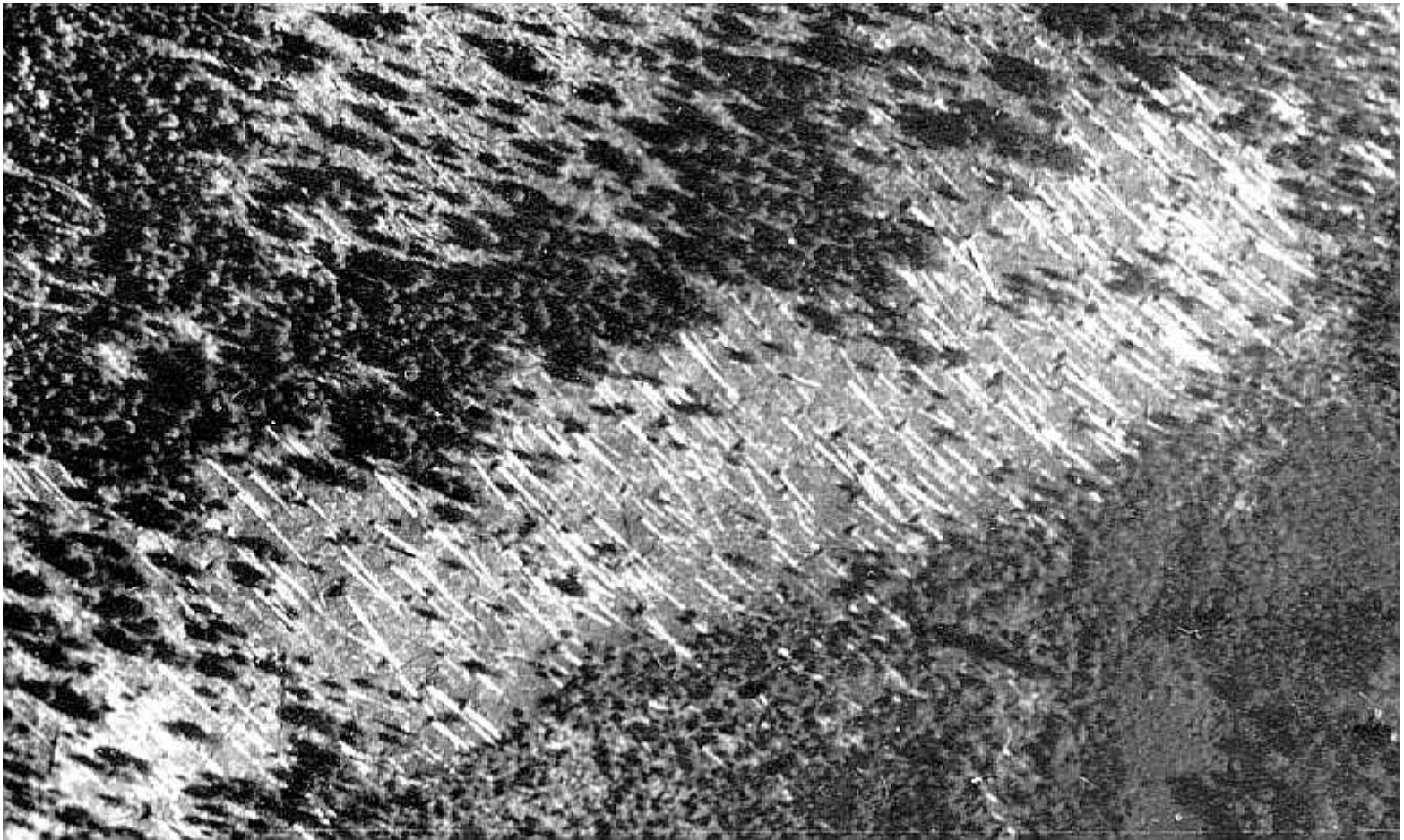
Crater 1 km across,
200 m deep

50 m diameter object (est.)

Impact energy similar to a
20 megaton H-bomb



Tunguska, June 30, 1908



<http://www-th.bo.infn.it/tunguska/>

Size Matters!

- $K.E. = \frac{1}{2} M V^2$
- M is proportional to volume $\sim D^3$
- Therefore, a 500 m object would have 1000 times the impact energy of the 50 m Meteor Crater object
- Q: Has anything like this ever happened?
- A: yes, the dinosaur killer!

Dinosaur Killer



Don Dixon

Evidence for Worldwide Catastrophe 65 Myr ago

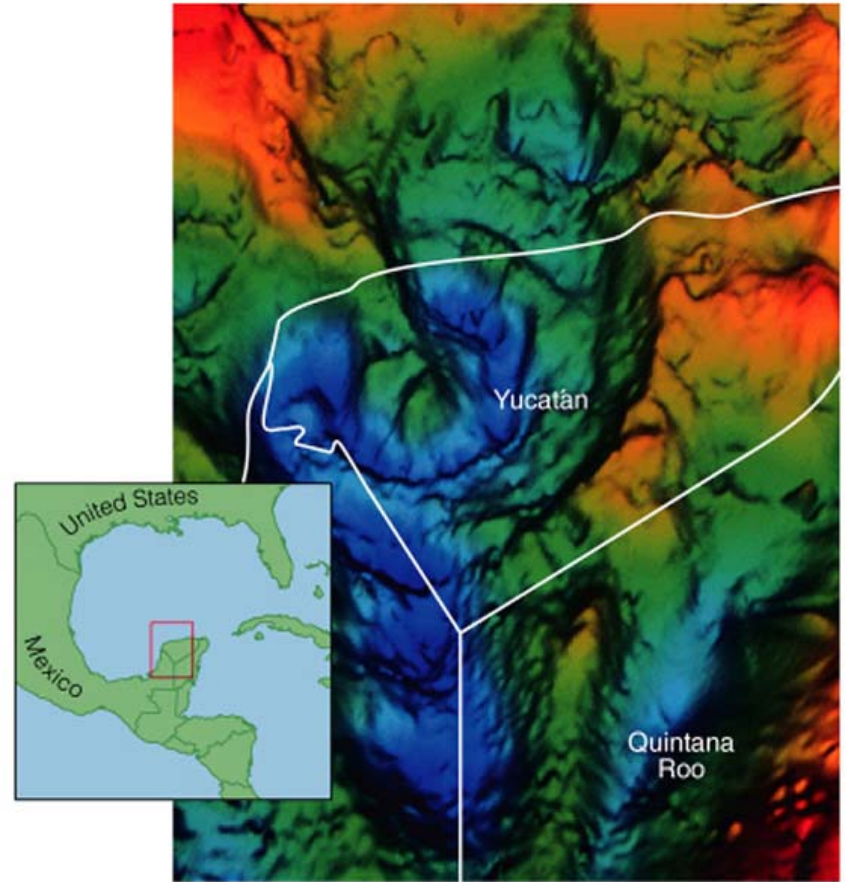


Sedimentary layer of ash and soot rich in Iridium found worldwide

Age dating: 65 Myr coincides with disappearance of dinosaurs

Impact Site: Yucatan

- Map shows gravitational anomalies and a circular depression
- Size suggests a 10 km object punctured Earth's crust



Artist Conception



Don Dixon

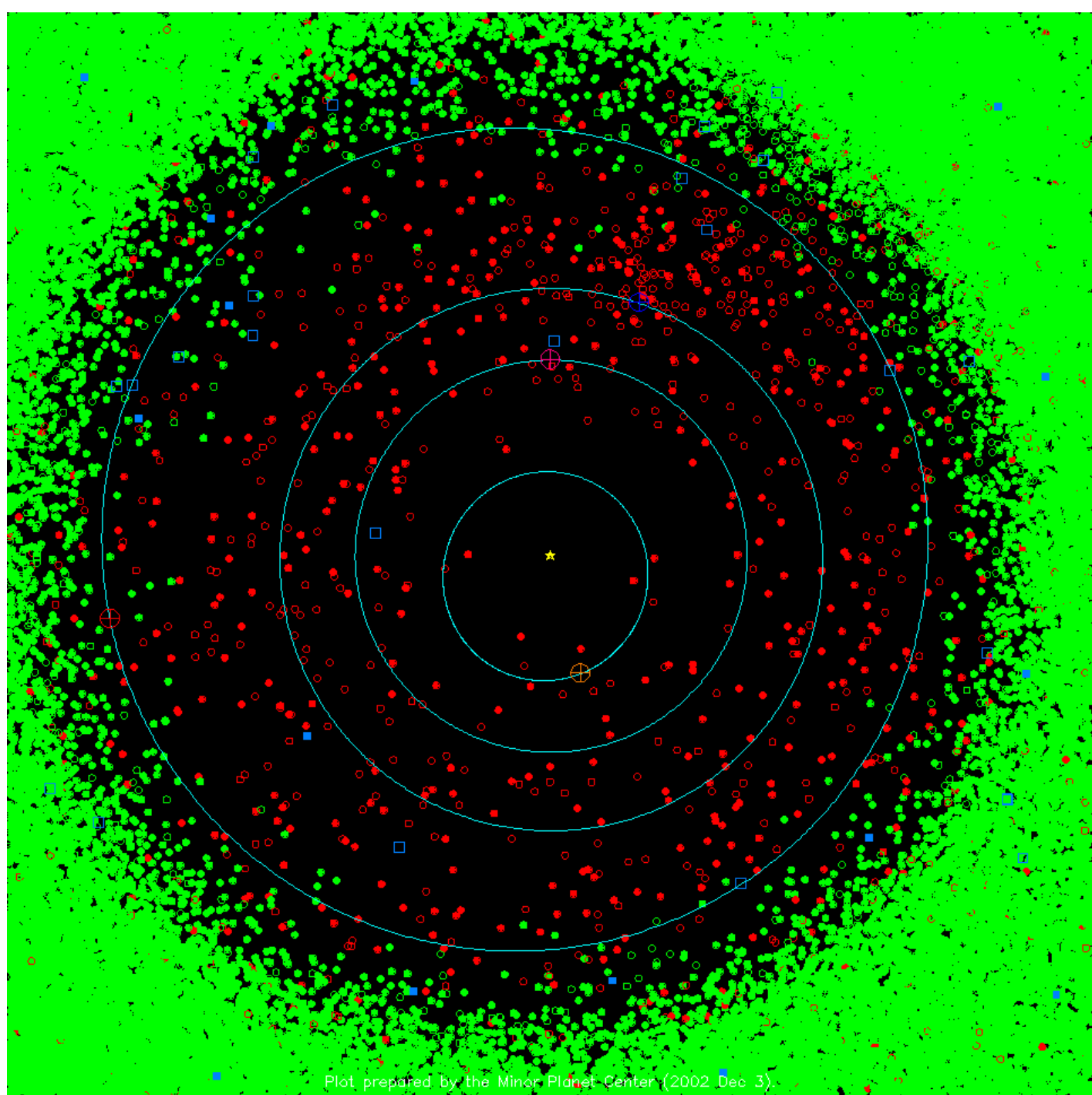
NEO Impact Hazard

- NEO=Near Earth Objects
- NEO Website: <http://impact.arc.nasa.gov>
- How likely is a catastrophic collision with a rogue asteroid?
- Very unlikely
- However, Tunguska event predicted once per millenium

Over 1000
NEOs (red dots)
cataloged and
tracked

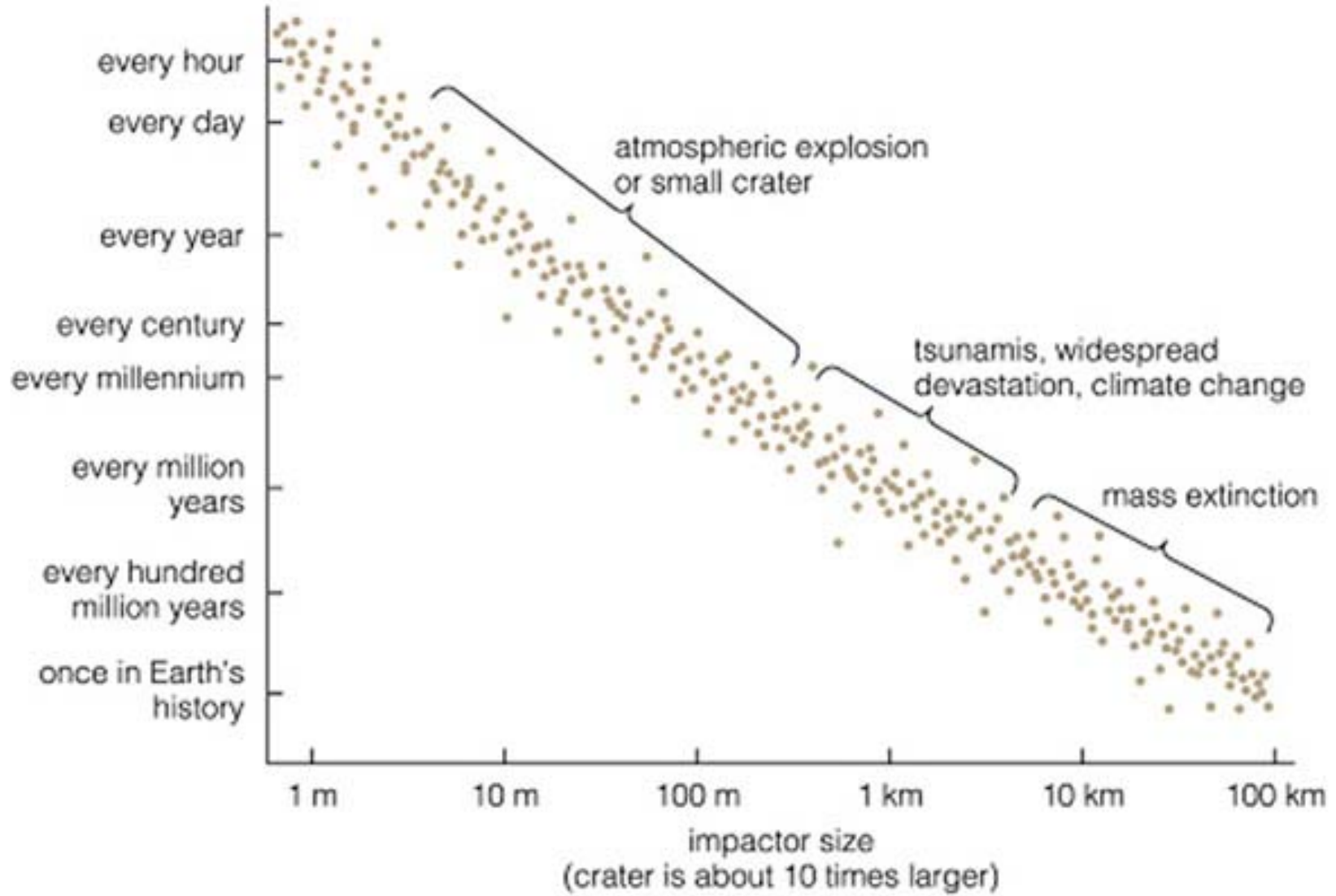
List of PHA
(potentially
Hazardous
asteroids) is
maintained

List of close
approaches is
posted



Plot prepared by the Minor Planet Center (2002 Dec 3)

Size-Frequency Distribution



A Catastrophic Event

