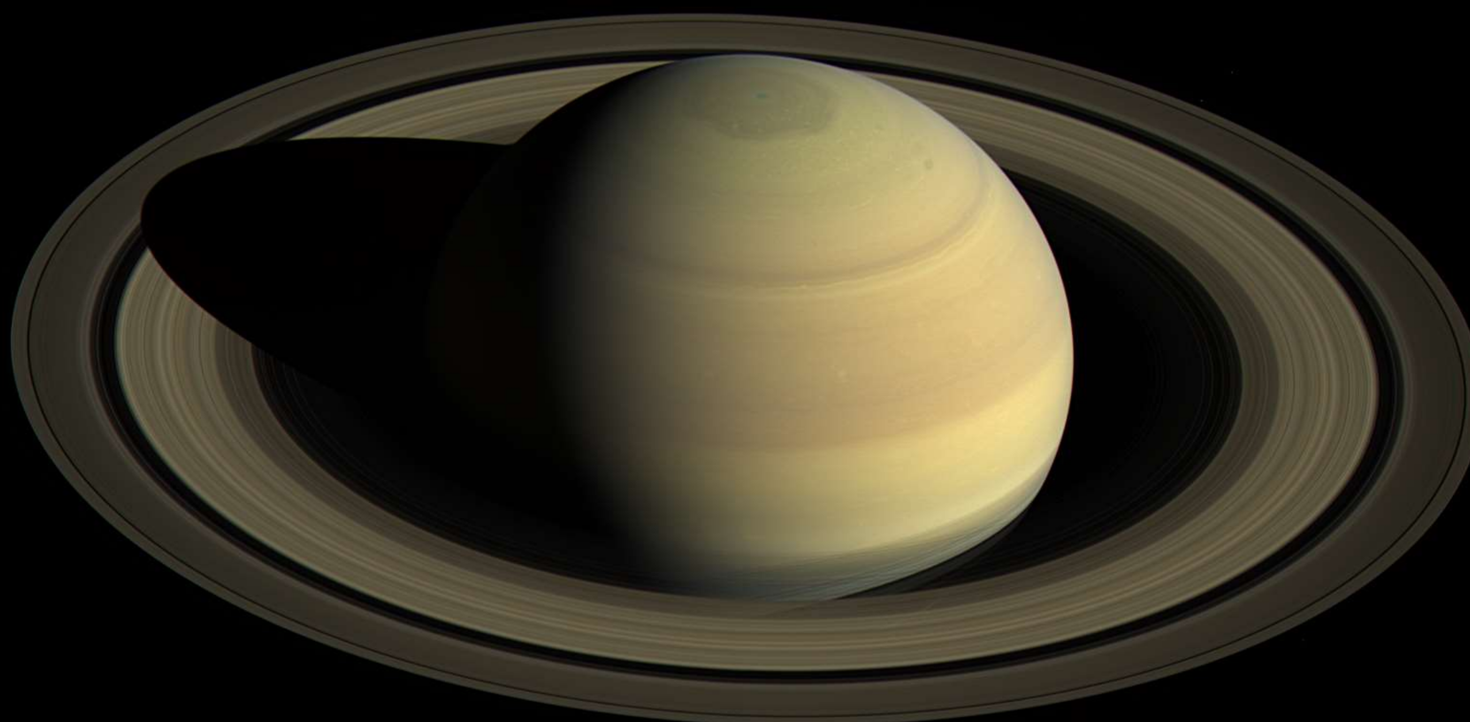
AST 2002
Introduction to Astronomy



A Few Quick Things…

E-mailing me: Must have AST2002 in the subject

Mary Hinkle, Graduate Teaching Assistant:
Office Hours: Mon 1:30-3:00pm. PSB 316

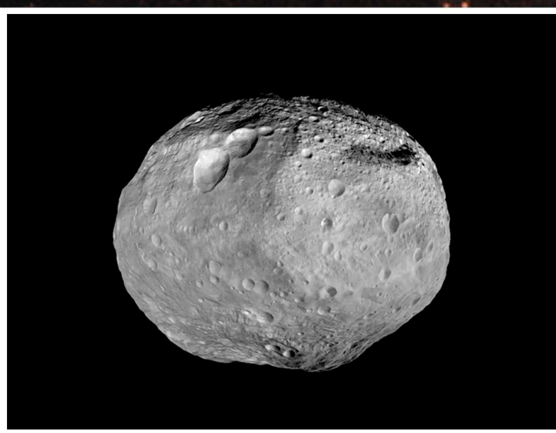
My office hours: Mon 3:00-4:00pm. PSB 308 – Mon Mar 5th I'm in a meeting 3:30-5pm
Tue 3-4 pm. PSB 308

First Mid-term : Will be having more regular homework
Will start going over some of the exam questions…

Next Mid-Term: Wed 7th March. Study Guide On Webcourses & Website Later Today

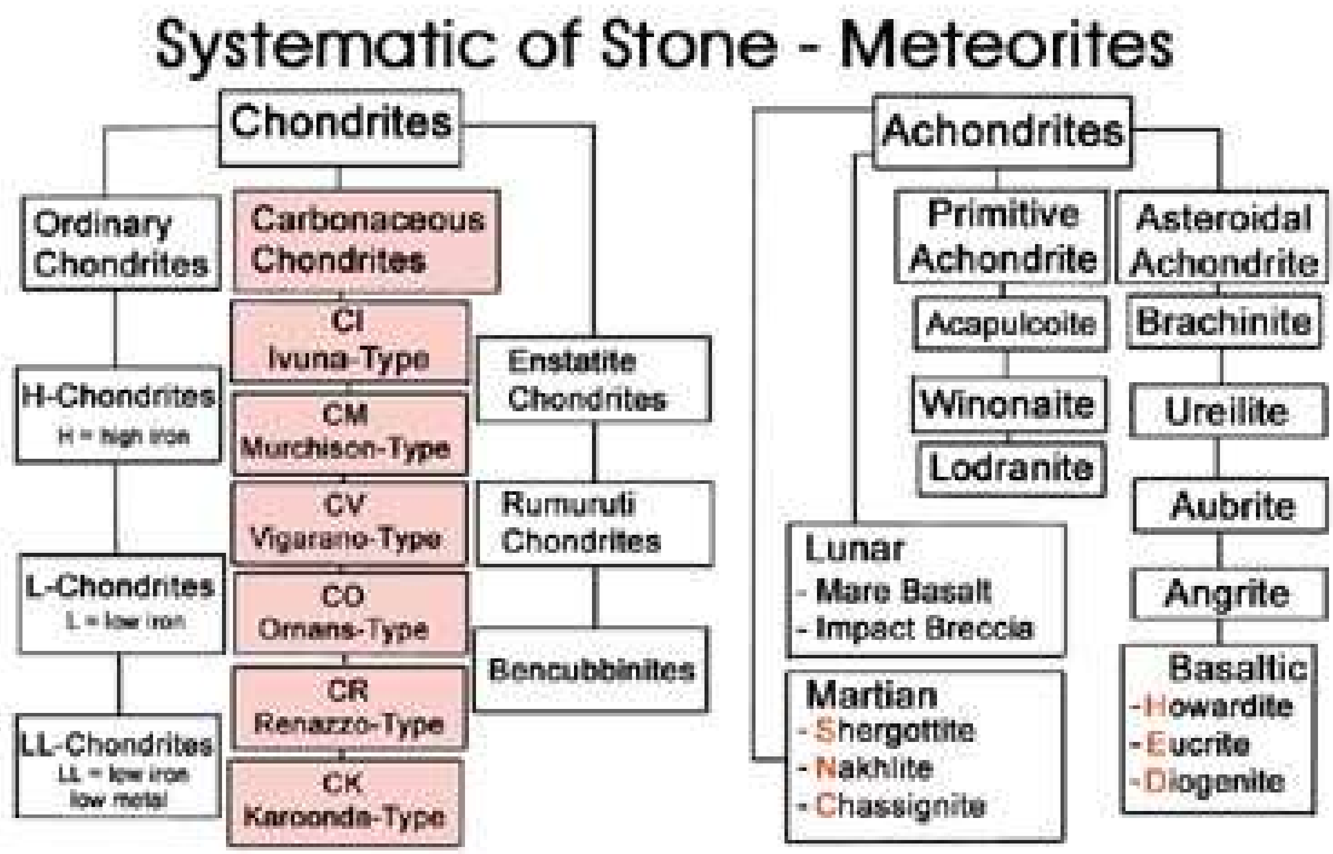
Next Knights Under the Stars Event – Thu 22nd Mar 8:30-10:00pm

Classification of Small Bodies
1. Asteroids



- Rocky, inner-solar system remnants.
- Asteroids leave trails in long-exposure images because of their orbital motion around the Sun.

There are Many Classes of Meteorite



Some are primitive (i.e. resemble solar nebula),
Some are processed (e.g., been differentiated).

How do we know ALH84001 is from Mars?

This is Alan Hills 84001. The most famous Martian Meteorite. It was found in Antarctica in 1984 and thought to have originated from Mars ~4 billion years ago and only landed on Earth about 13,000 years ago.

But - How do we know it was from Mars??

There are trapped bubbles of gas inside and these match the composition and isotopic ratios of Mars!

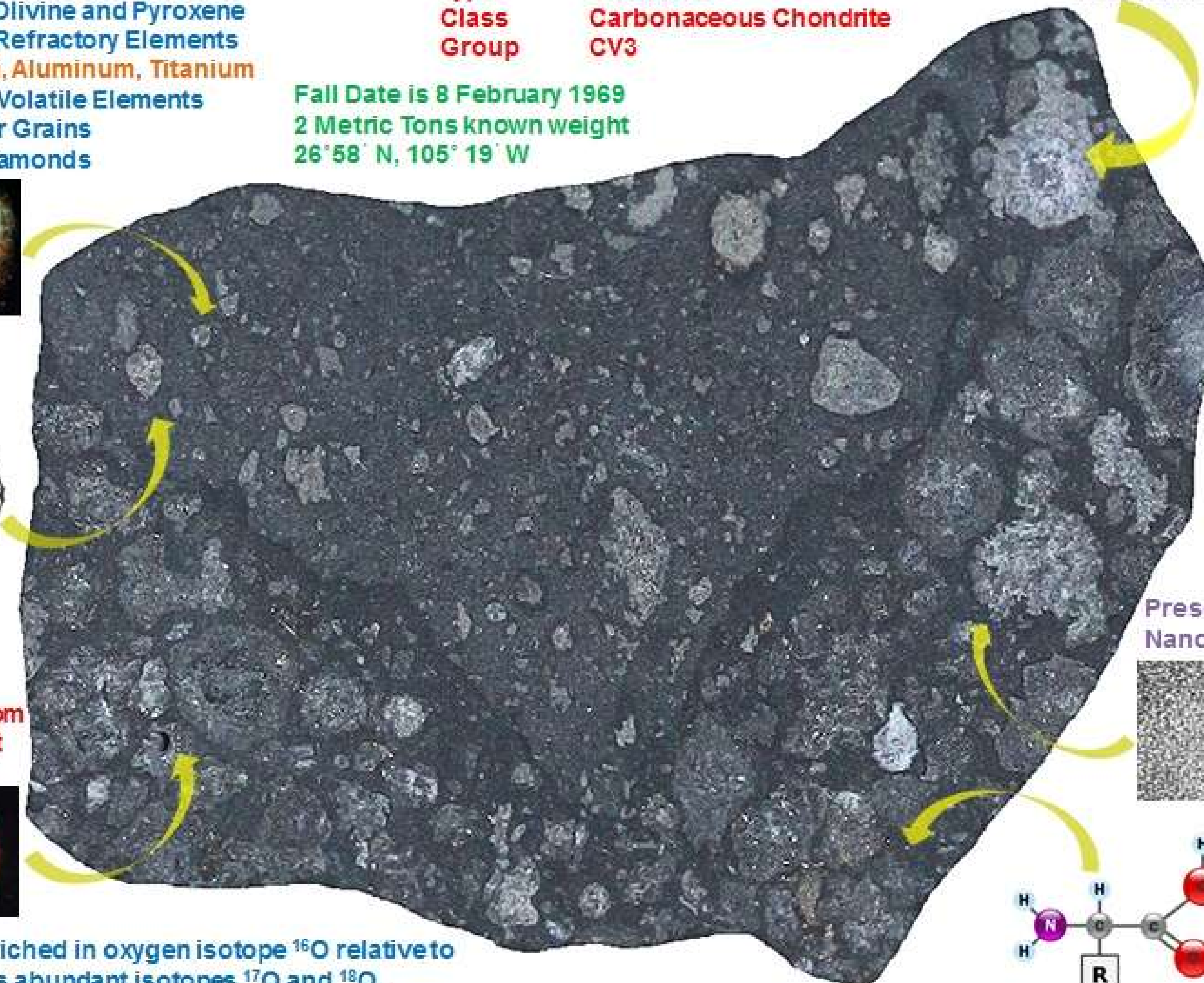
The Allende Meteorite – A "Messenger from Space"

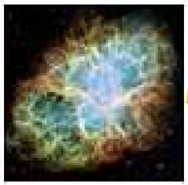
Matrix and Chondrules
Mostly Olivine and Pyroxene
Rich in Refractory Elements
Calcium, Aluminum, Titanium
Poor in Volatile Elements
Presolar Grains
Microdiamonds

Type	Chondrite
Class	Carbonaceous Chondrite
Group	CV3

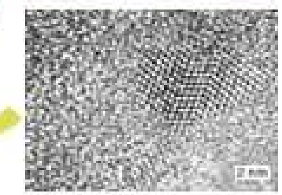
Fall Date is 8 February 1969
2 Metric Tons known weight
26˚58΄ N, 105˚ 19΄ W

Calcium-Aluminum Inclusions (CAI)





Presolar Nanodiamonds



Presolar Grains from Red Giant Stars

Enriched in oxygen isotope ^{16}O relative to less abundant isotopes ^{17}O and ^{18}O.

How to Identify a Meteorite

- Usually surprisingly heavy – more dense than most terrestrial Rocks (which have undergone differentiation)

- Has a fusion crust from being burnt traveling through the atmosphere
    - May also have aerodynamic pits (lower picture)

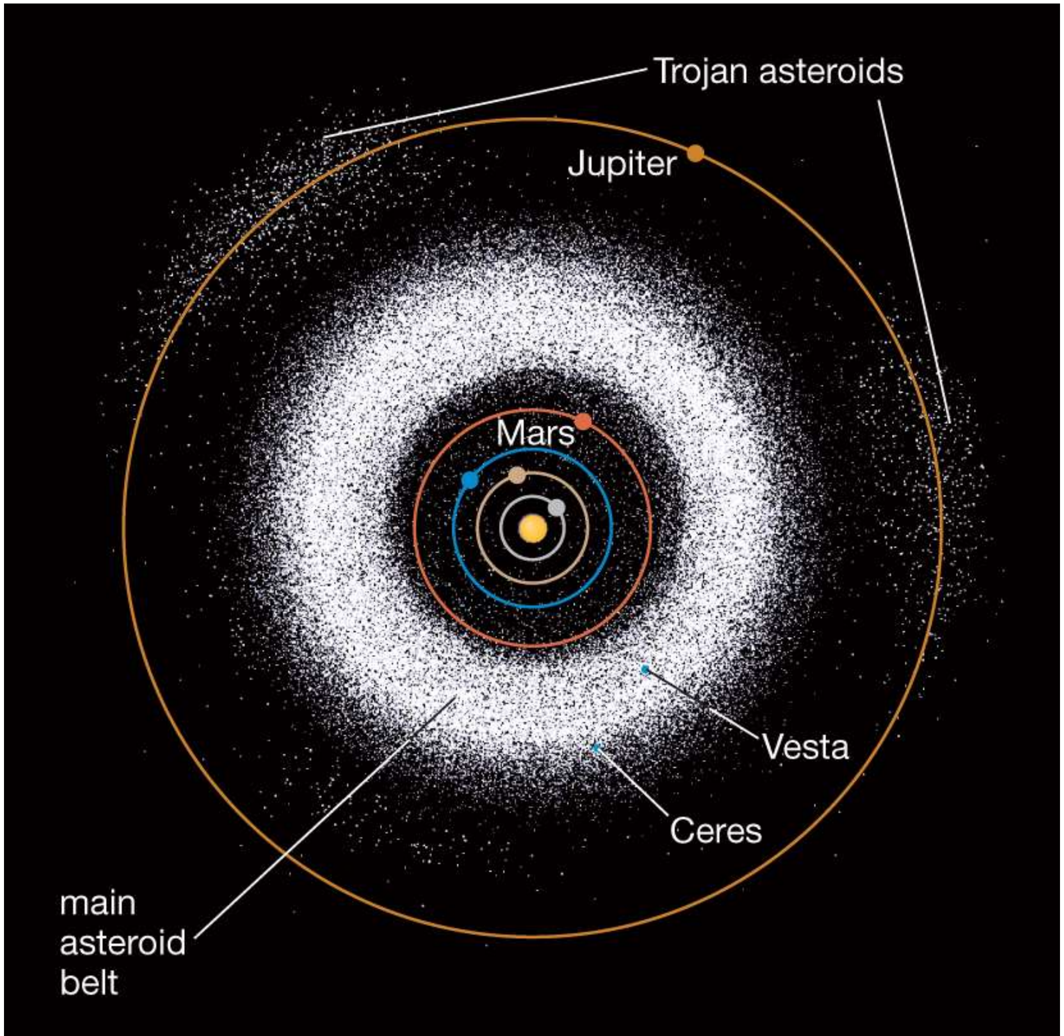
- If stony or carbonaceous will have round ‘chondrules’ in it, and most will be covered with shiny metal flakes

- Often Magnetic

What can we learn from Meteorites?

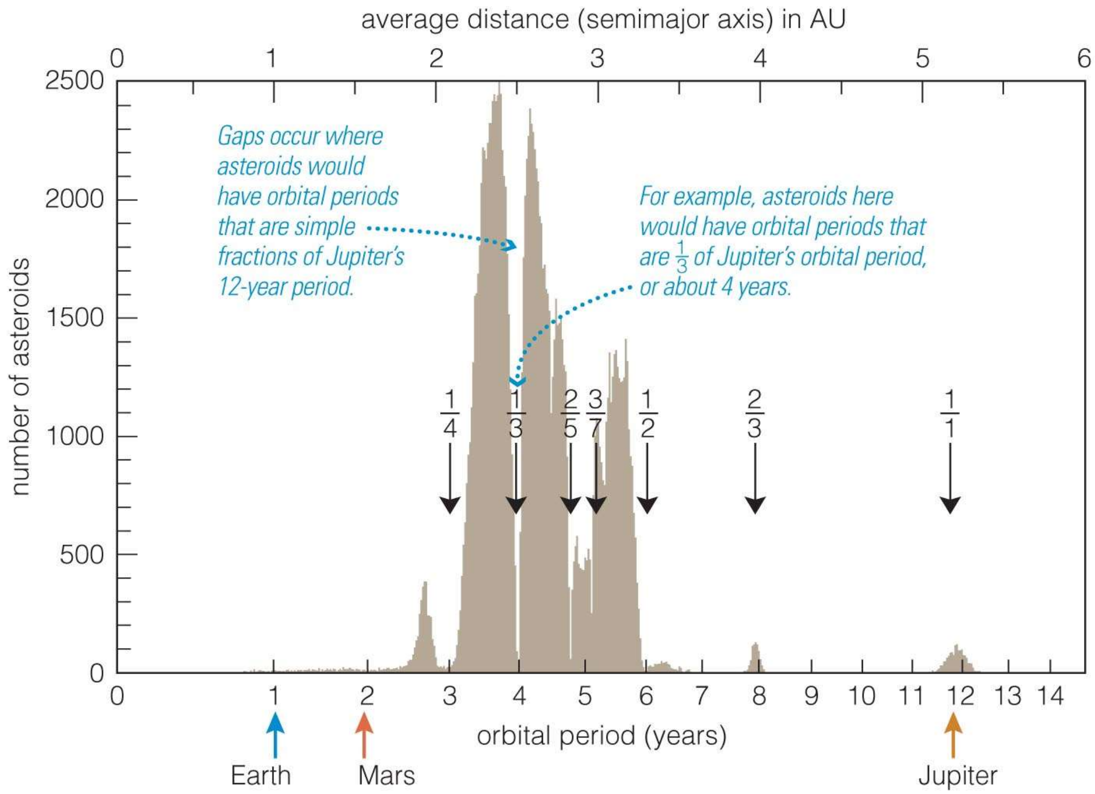
- What the original planetesimals were like.
  - Many are thought to be close to their pristine state.
- When solar system formation began.
  - We can tell from their age and compositions.
- What asteroids are like on the inside.
  - What compounds they may have bought to the early Earth…
- Proof that differentiation and volcanism happened on asteroids.
  - Particularly from HED asteroids.

Asteroid Orbits



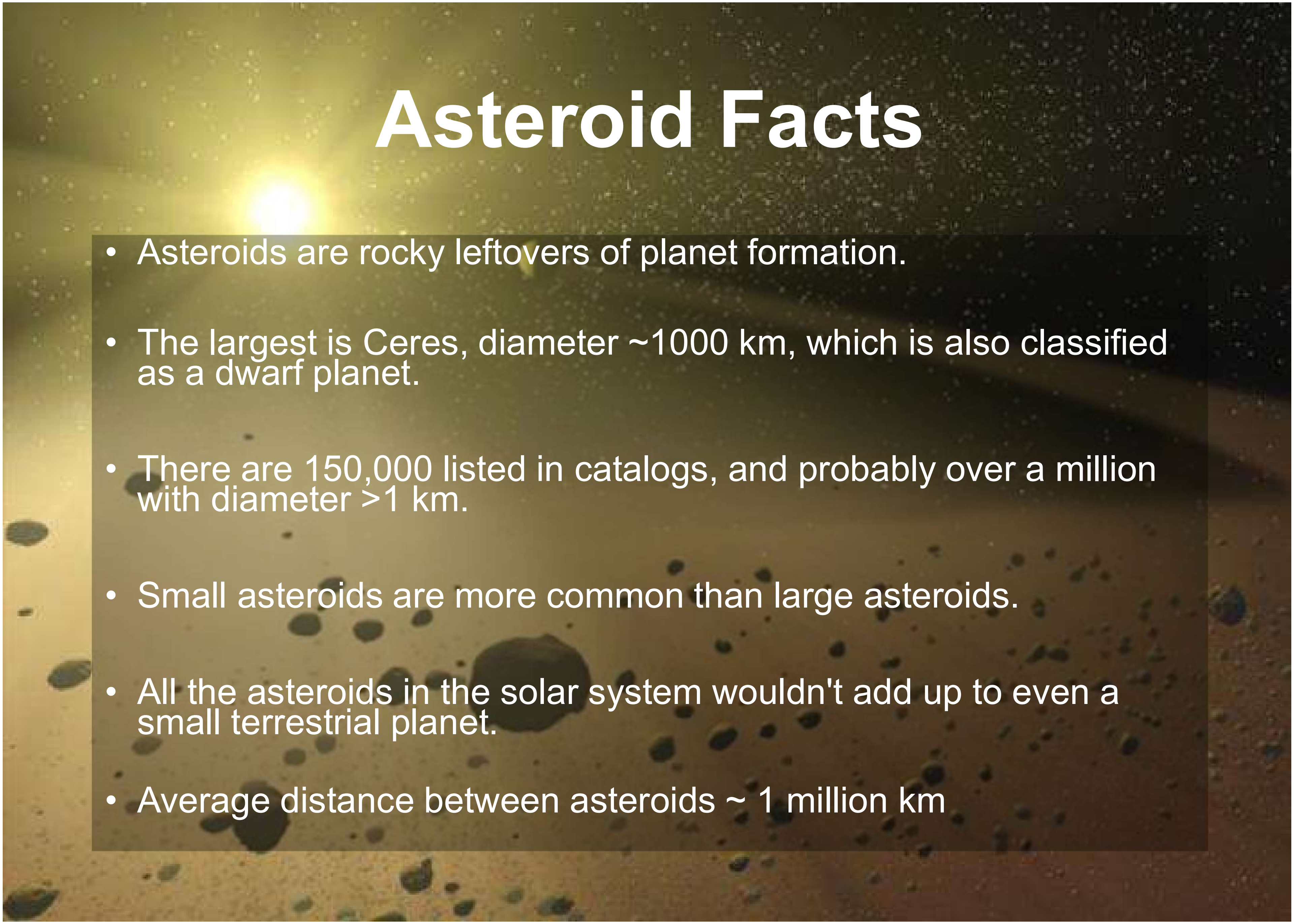
- Most asteroids orbit in a belt between Mars and Jupiter.
- *Trojan asteroids* follow Jupiter's orbit.
  - Lie in L4 and L5 Lagrangian points
- Orbits of *near-Earth asteroids* cross Earth's orbit.

Why didn't a Planet form in the Asteroid Belt?

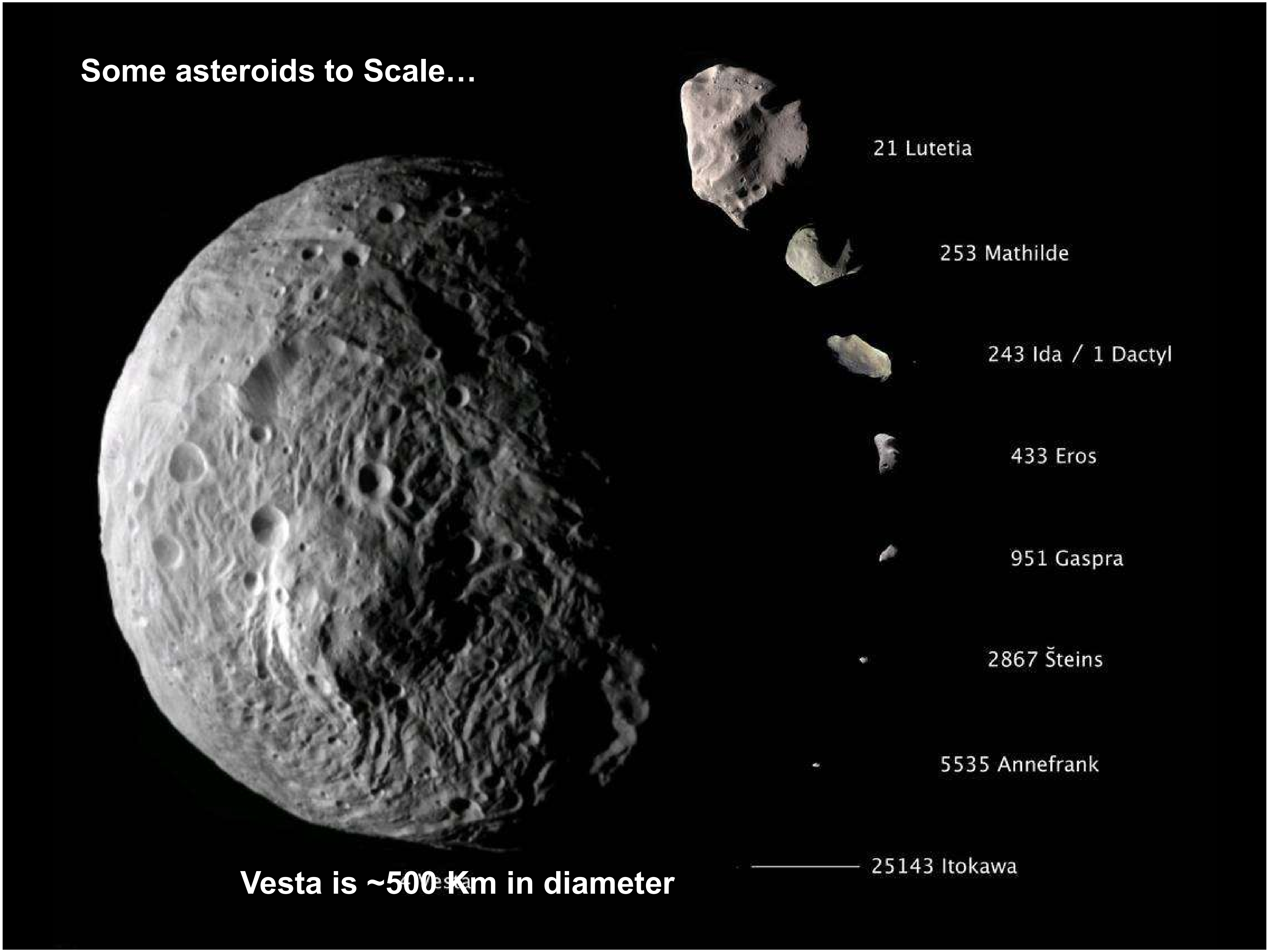


Orbital Resonances

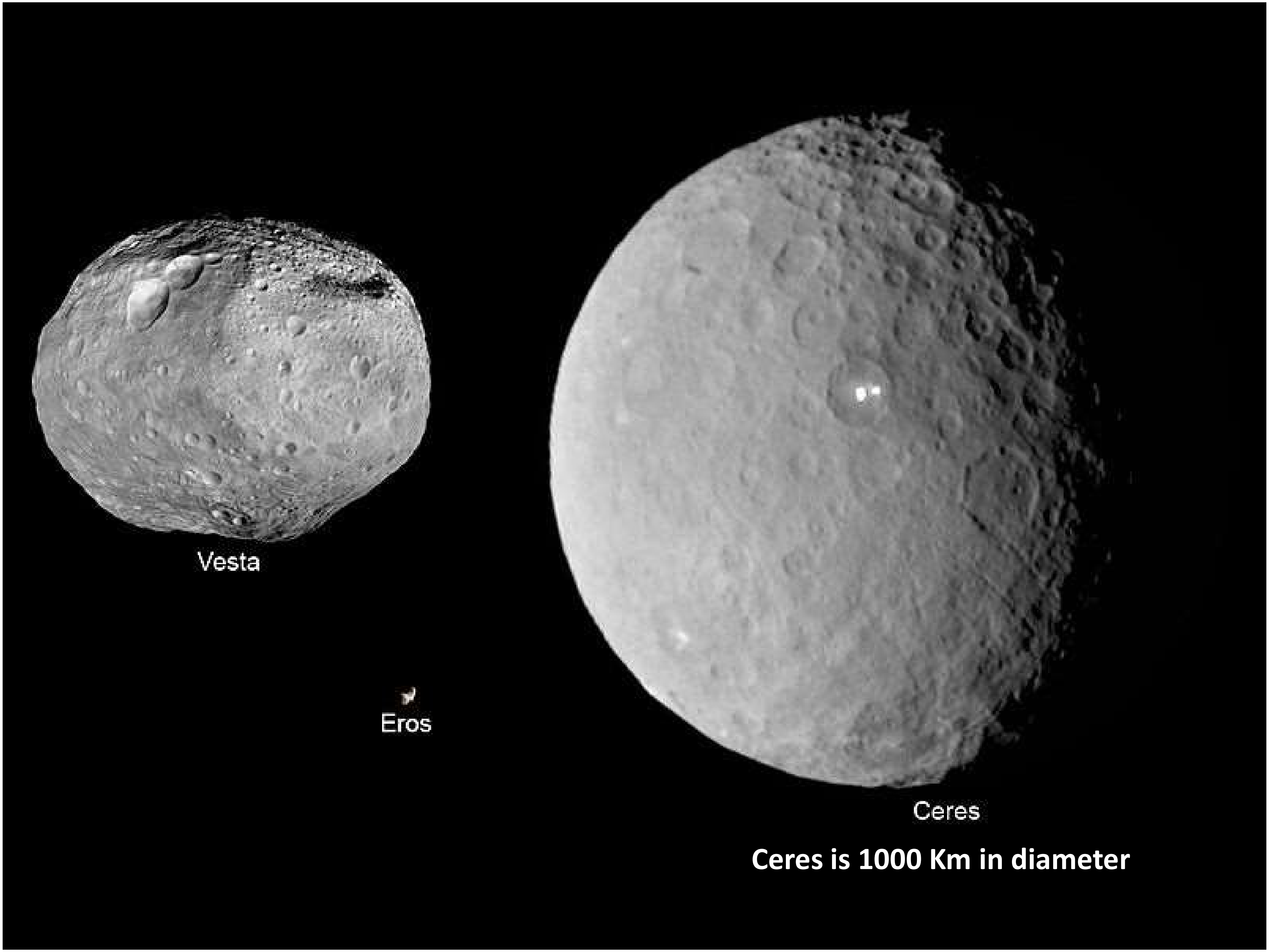
- Asteroids in orbital resonance with Jupiter experience periodic nudges.
- Eventually those nudges move asteroids out of resonant orbits, leaving gaps in the belt.
- Jupiter's gravity, through influence of orbital resonances, stirred up asteroid orbits and prevented their accretion into a planet.


Asteroid Facts
• Asteroids are rocky leftovers of planet formation.
• The largest is Ceres, diameter ~1000 km, which is also classified as a dwarf planet.
• There are 150,000 listed in catalogs, and probably over a million with diameter >1 km.
• Small asteroids are more common than large asteroids.
• All the asteroids in the solar system wouldn't add up to even a small terrestrial planet.
• Average distance between asteroids ~ 1 million km

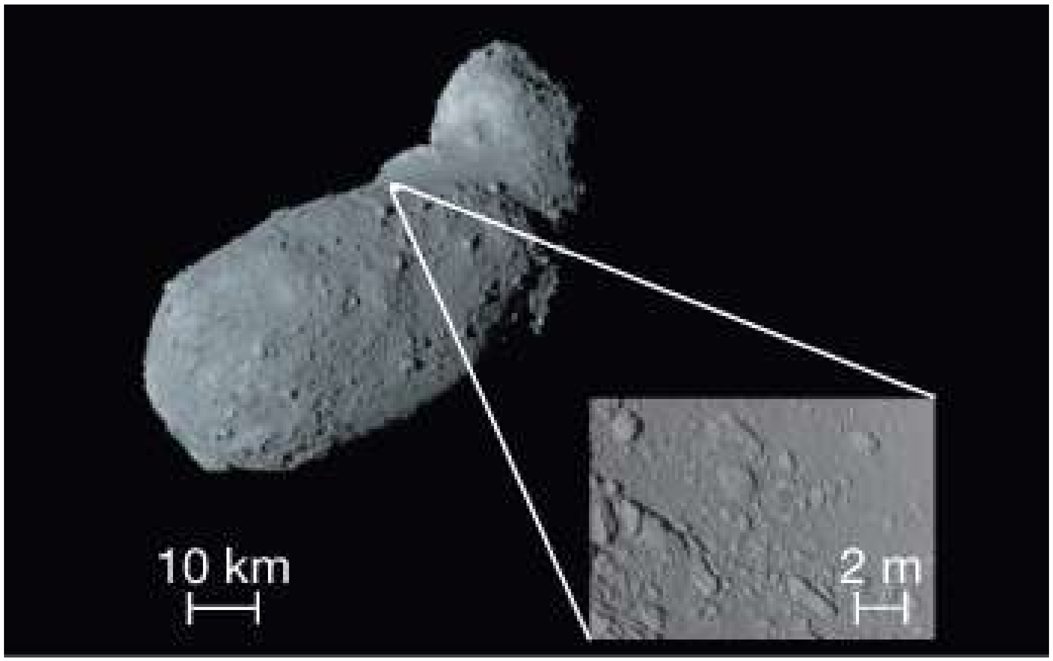
Some asteroids to Scale…



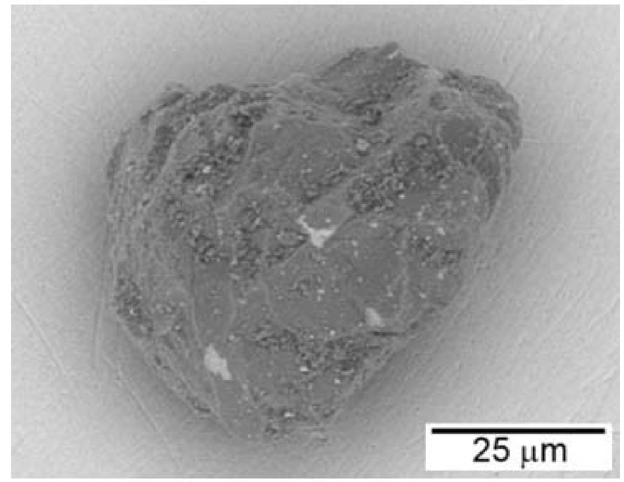
Vesta is ~500 Km in diameter


Vesta
Eros
Ceres
Ceres is 1000 Km in diameter

Asteroids visited by Spacecraft

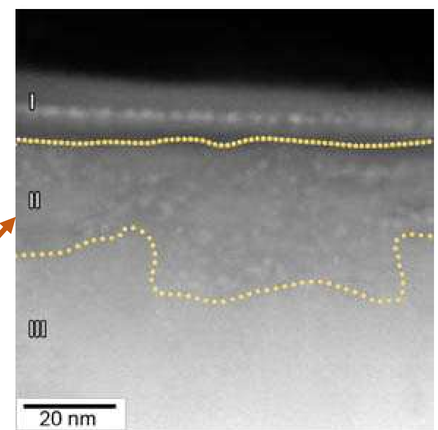


d Itokawa, photographed by the Japanese *Hayabusa* mission, which landed on the surface and captured a sample that it returned to Earth.



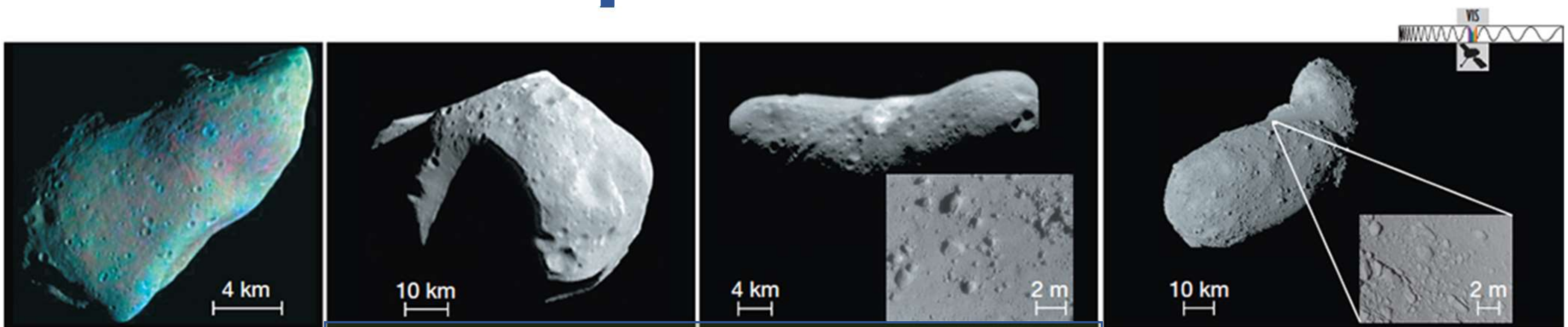
(From Noguchi et al., 2011, Science, v.333(6046), p. 1121-1125, Fig. S1, doi: 10.1126/science.1207794.)

Outer Layers are "Space Weathered"



(From Noguchi *et al.*, 2011, *Science*, v.333(6046), p. 1121-1125, Fig. 2, doi: 10.1126/science.1207794.)

Asteroids visited by Spacecraft



a Gaspra, photographed by the *Galileo* spacecraft. Colors are exaggerated to show detail.

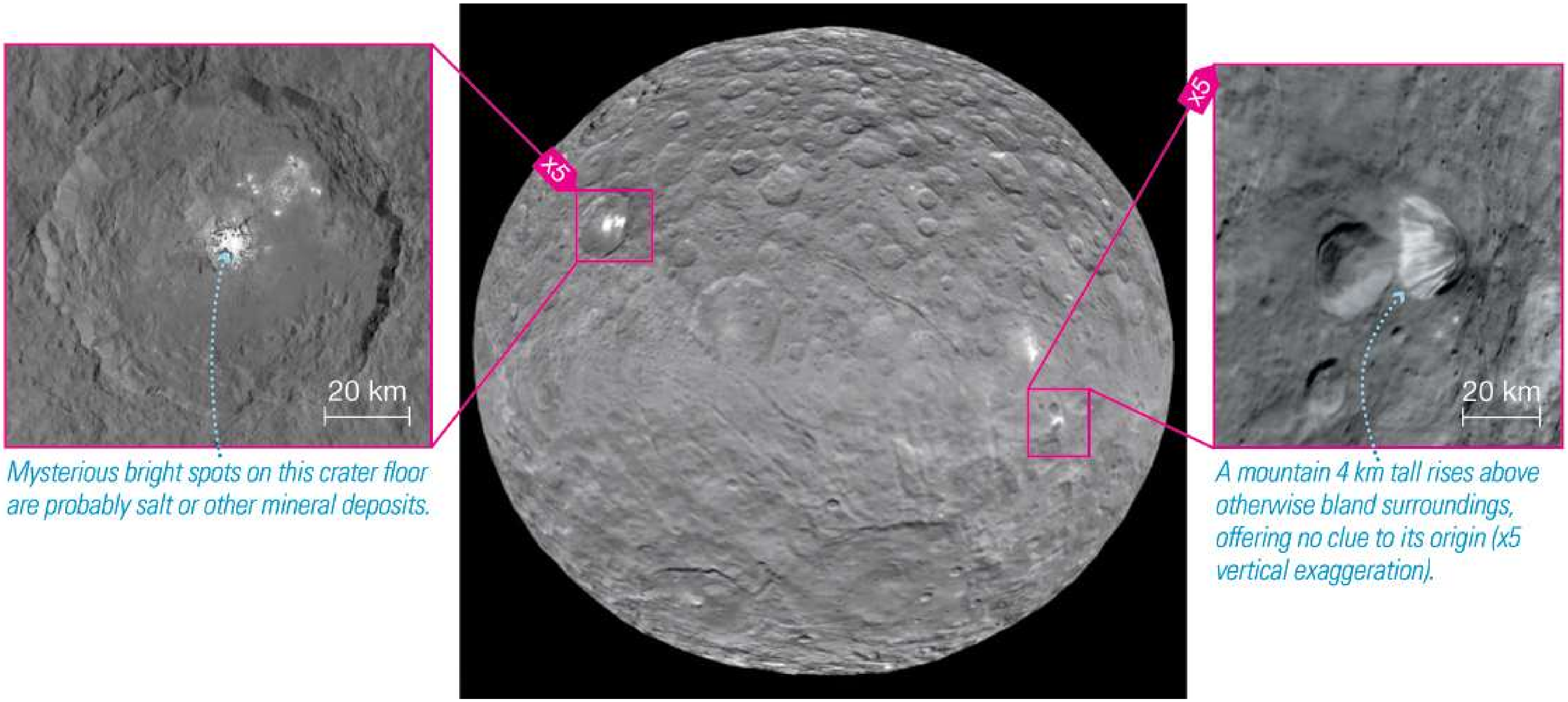
b Mathilde, photographed by the *Near-Earth Asteroid Rendezvous* (*NEAR*) spacecraft on its way to Eros.

c Eros, photographed by the *NEAR* spacecraft, which orbited Eros for a year before ending its mission with a soft landing on the asteroid's surface.

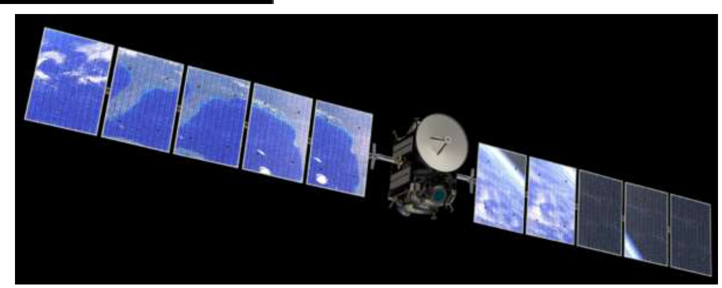
d Itokawa, photographed by the Japanese *Hayabusa* mission, which landed on the surface and captured a sample that it returned to Earth.

The Near Earth Asteroid Rendezvous (NEAR) spacecraft launched in 1996 and landed on Eros in 2001 after visiting several asteroids

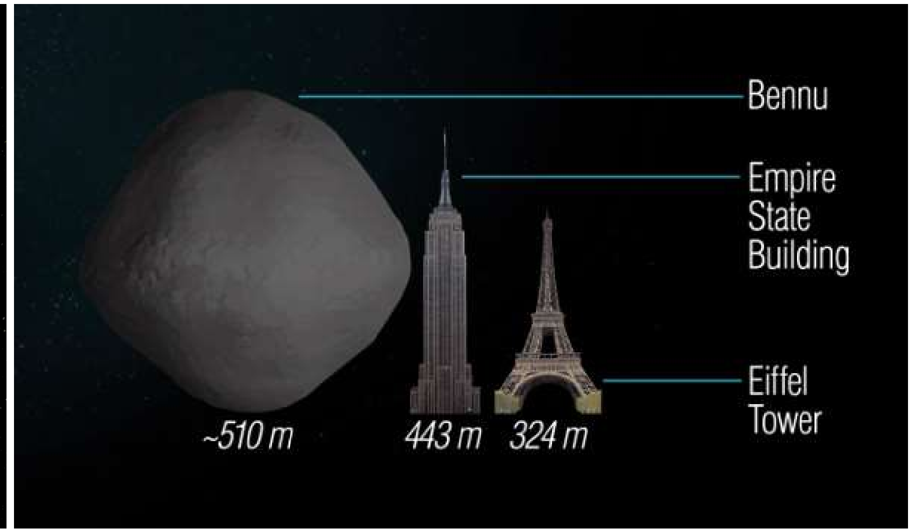
Asteroids visited by Spacecraft



The DAWN spacecraft is currently in orbit around Ceres (also visited Vesta), and has been there since March 2015



OSIRIS-REx Mission to Bennu



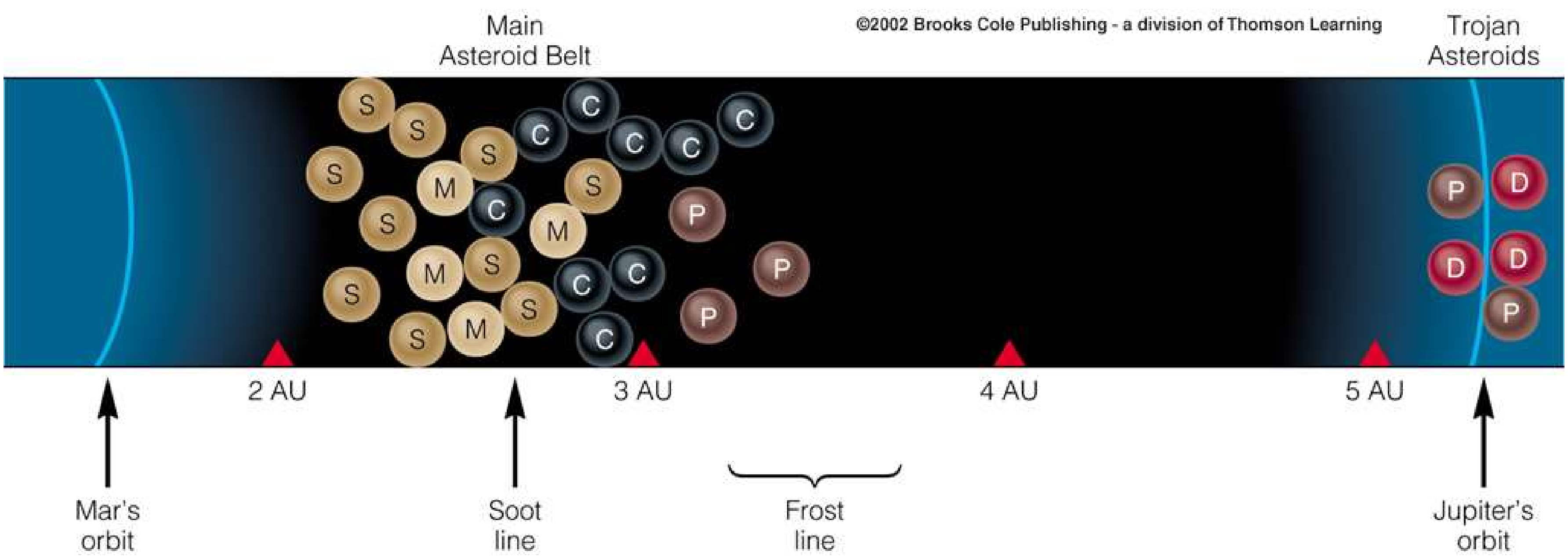
Launched in 2016, will arrive at a primitive carbonaceous chondrite in August 2018, and collect samples to return to Earth in 2021.

This should help inform us of the primitive conditions of the Early Solar System..

Asteroid Composition

Three categories:

1. very dark asteroids which contain Carbon-rich materials
   - found in outer regions of the asteroid belt (C-, P-, and D-type)
2. brighter asteroids which contain rocky materials
   - found in inner regions of the asteroid belt (S-type)
3. asteroids which contain metals such as Iron (M-type)



Martian Moons, Phobos & Deimos, are likely captured (D-type?) asteroids

What have we learned?

- What are asteroids like?
  - Asteroids are rocky leftovers from the era of planet formation.
- What do meteorites tell us about asteroids and the early solar system?
  - Most meteorites are pieces of asteroids.
  - Primitive meteorites are remnants from solar nebula.
  - Processed meteorites are fragments of larger bodies that underwent differentiation.
- Why is there an asteroid belt?
  - Orbital resonances with Jupiter prevented rocky planetesimals between Jupiter and Mars from forming a planet.

iClicker Question

Question: If all the asteroids in the asteroid belt were put together to make a planet, about how large would it be?

A. Half the size of the Moon
B. The size of the Moon
C. The size of Mars
D. The size of the Earth
E. Twice the size of the Earth

iClicker Question

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Mid-Term #1 Solutions

Earth is made mostly of metals and rocks. Where did the elements (carbon, silicon, iron, etc.) that make up these materials come from?

A. They were produced by the Big Bang

B. They are a product of chemical reactions in interstellar dust clouds

C. They were produced by nuclear fusion in stars

D. They were produced by nuclear fusion in our Sun

E. They were produced by nuclear fission of uranium and other radioactive materials in space

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Mid-Term #1 Solutions

Newton's second law of motion states that:

A. The acceleration of an object is equal to its mass times the force acting on it

B. The acceleration of an object is equal to its mass divided by the force acting on it

C. The acceleration of an object is equal to the force acting on it divided by its mass

D. The acceleration of an object is equal to the force acting on it divided by its mass

E. The acceleration of an object is equal to its velocity divided by its mass

Mid-Term #1 Solutions

Newton's second law of motion states that: $F = ma$ or $a = \frac{F}{m}$

A. The acceleration of an object is equal to its mass times the force acting on it. $a = Fm$

B. The acceleration of an object is equal to its mass divided by the force acting on it. $a = \frac{m}{F}$

C. The acceleration of an object is equal to the force acting on it divided by its mass (37%)

D. The acceleration of an object is equal to the mass times its velocity

E. The acceleration of an object is equal to its velocity divided by its mass

What have we covered, and what is next?

Chapter 9: Asteroids, Comets, and Dwarf Planets

9.1. Classifying Small Bodies

- How do we classify small bodies?

9.2. Asteroids

- What are asteroids like?
- What do meteorites tell us about asteroids and the early Solar System?
- Why is there an asteroid belt?

9.3. Comets

- Why do comets grow tails?
- Where do comets come from?

9.4. Pluto and the Kuiper Belt

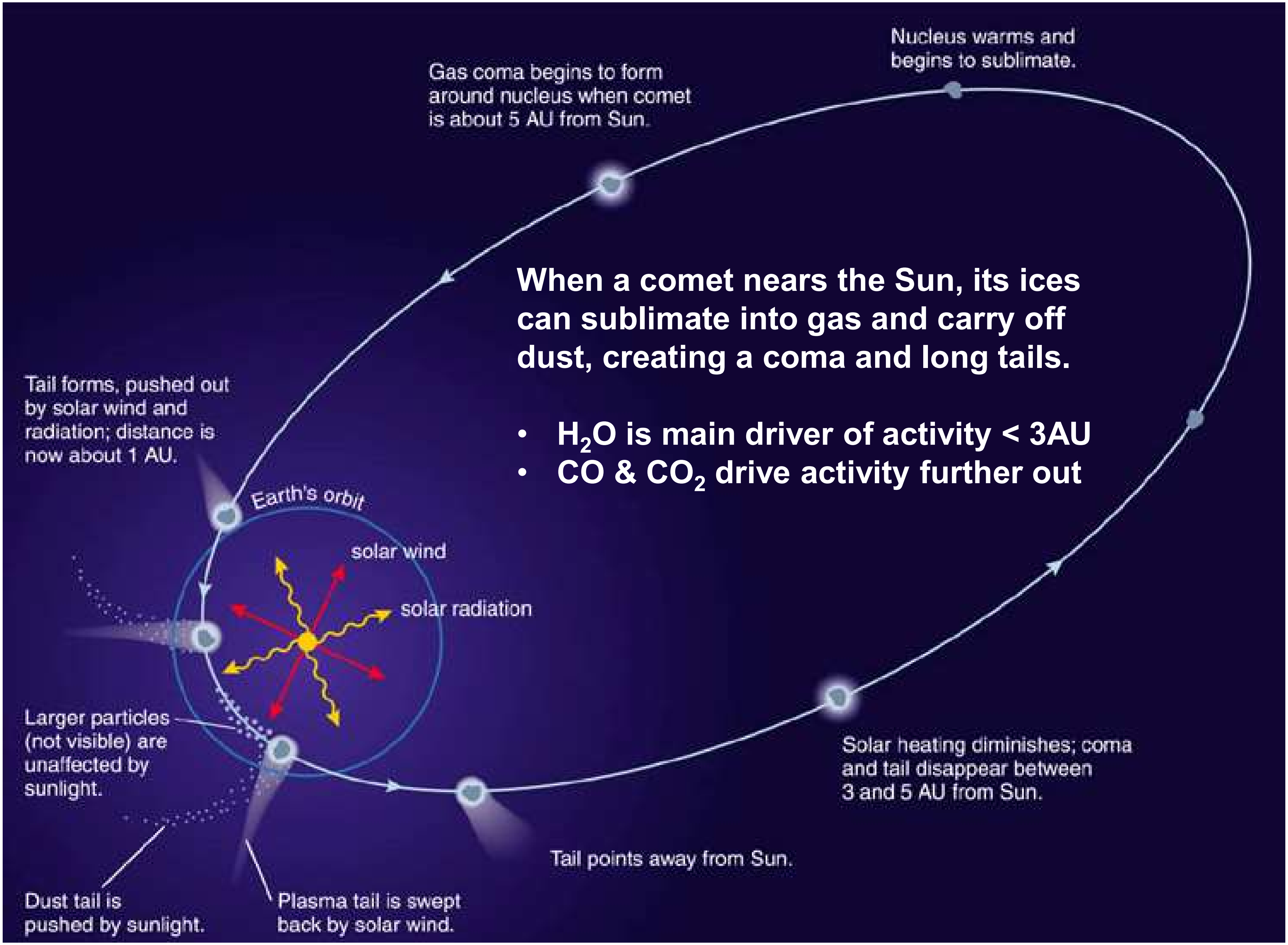
- What is Pluto like?
- What do we know about other Kuiper Belt Objects

9.5. Cosmic Collisions: Small Bodies Versus the Planets

- Did an impact kill the dinosaurs?
- How great is the impact risk today?
- How do the Jovian planets affect impact rates and life on Earth?

Comets

- Formed beyond the frostline, comets are icy counterparts to asteroids.
- "Dirty snowballs" = the nucleus
- Most comets remain perpetually frozen in the outer solar system. Only a few enter the inner solar system, where they can grow tails.
- A comet can only visit the Sun a few hundred times before losing all its ice to sublimation.
    - the comet may then disintegrate
    - or the rocky remains may stick together as an asteroid



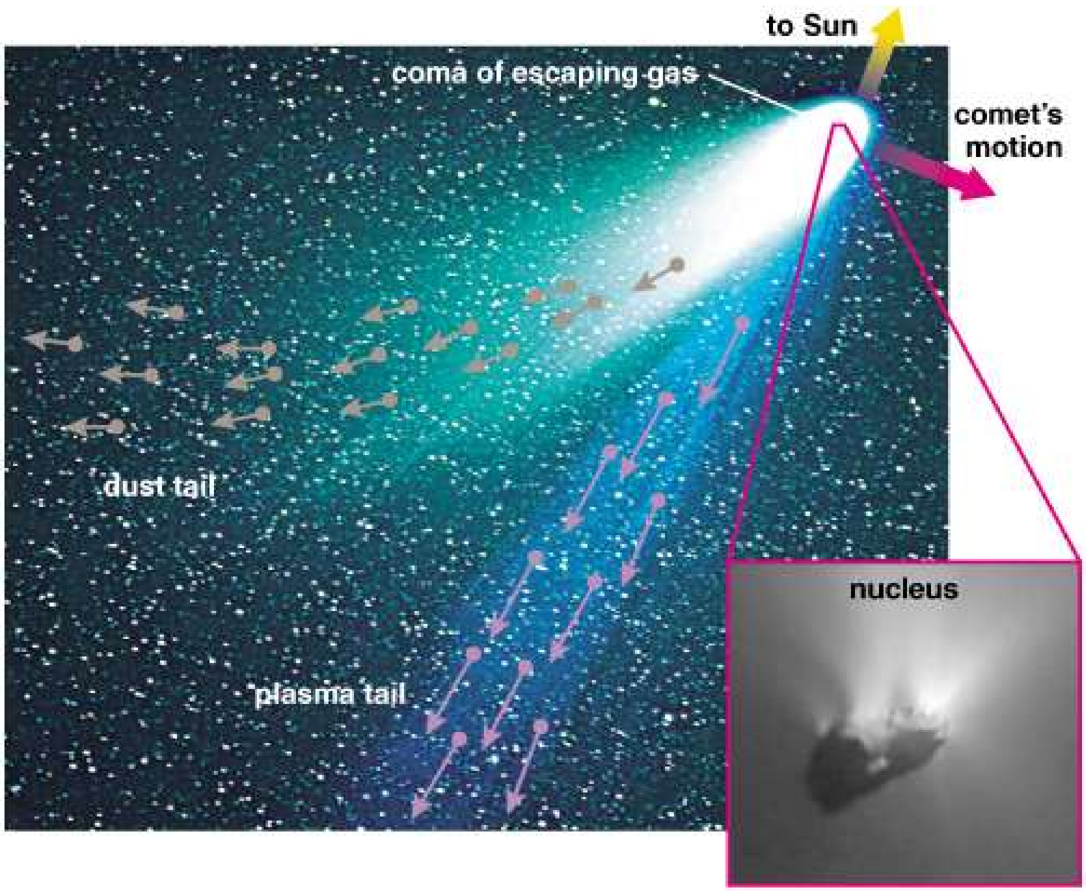
When a comet nears the Sun, its ices can sublimate into gas and carry off dust, creating a coma and long tails.

- **H_2O is main driver of activity < 3AU**
- **CO & CO_2 drive activity further out**

Comets: A Tale of Two Tails

Comets are "dirty snowballs"…ice mixed with rock and dust.

- Ice is H_2O, CO_2, CO, with other compounds ~% levels (e.g., NH_3, CH_4)



Nucleus

- the "dirty snowball"
- how the comet appears far from the Sun

Coma

- surrounds nucleus when near the Sun
- sublimated gas & dust

Plasma tail

- ionized gas swept back by Solar wind

Dust tail

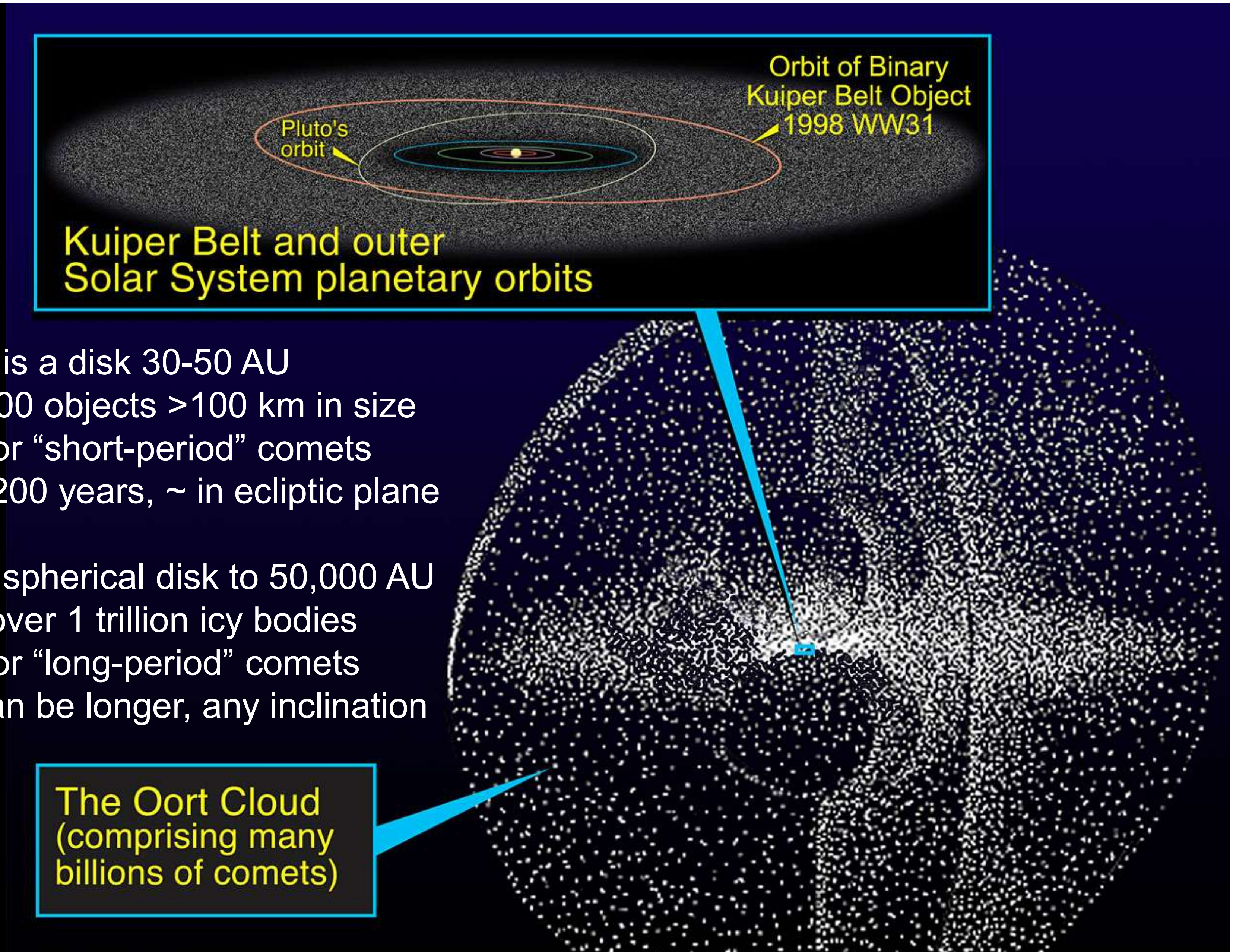
- dust particles swept back more slowly by radiation

Kuiper Belt is a disk 30-50 AU
Over 100,000 objects >100 km in size
Reservoir for “short-period” comets

- Orbits <200 years, ~ in ecliptic plane

Oort cloud, spherical disk to 50,000 AU
Estimated over 1 trillion icy bodies
Reservoir for “long-period” comets

- Orbits can be longer, any inclination

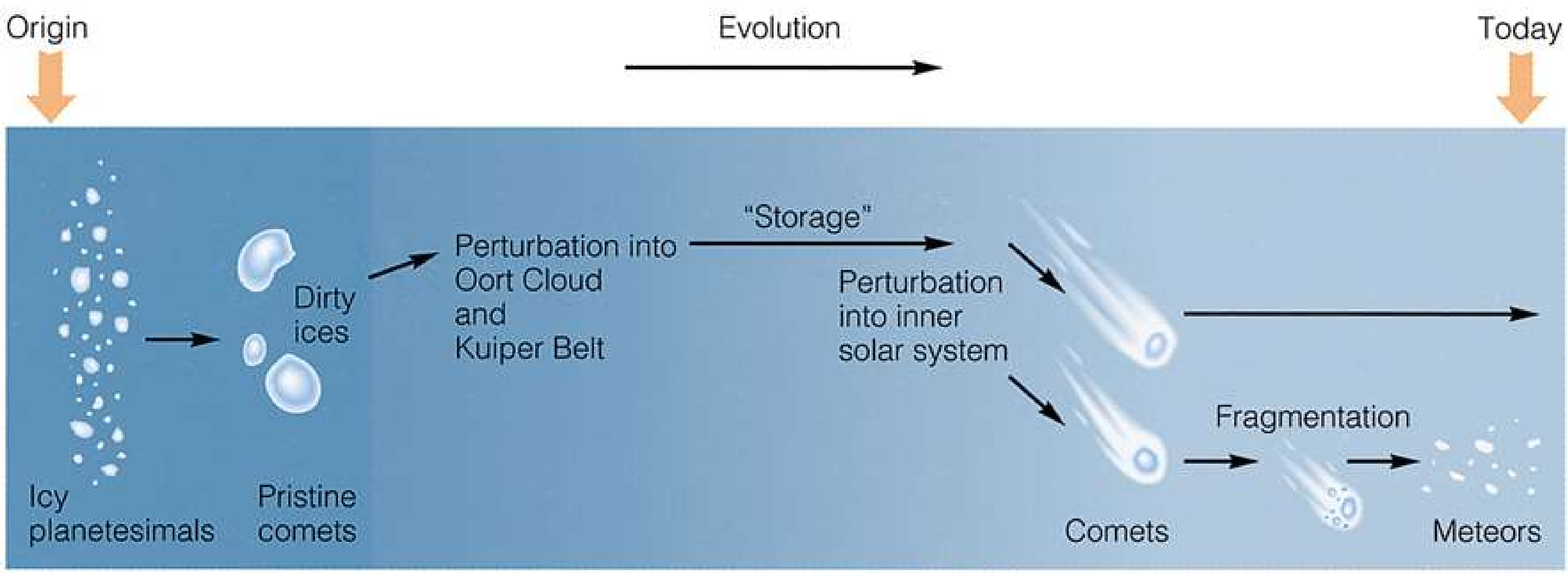


Oort Cloud cutaway drawing adapted from Donald K. Yeoman's illustraton (NASA, JPL)

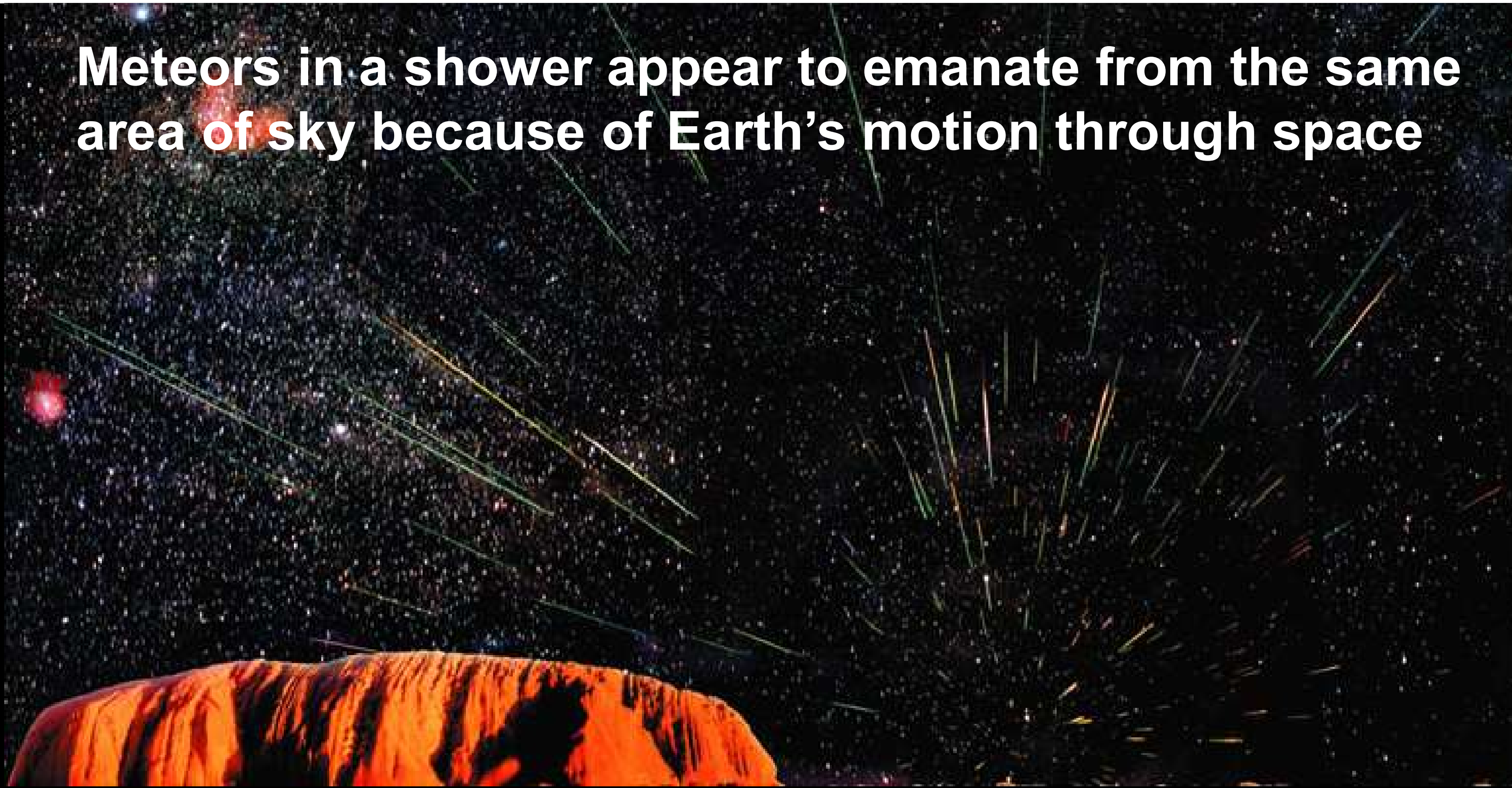
How did they get there?

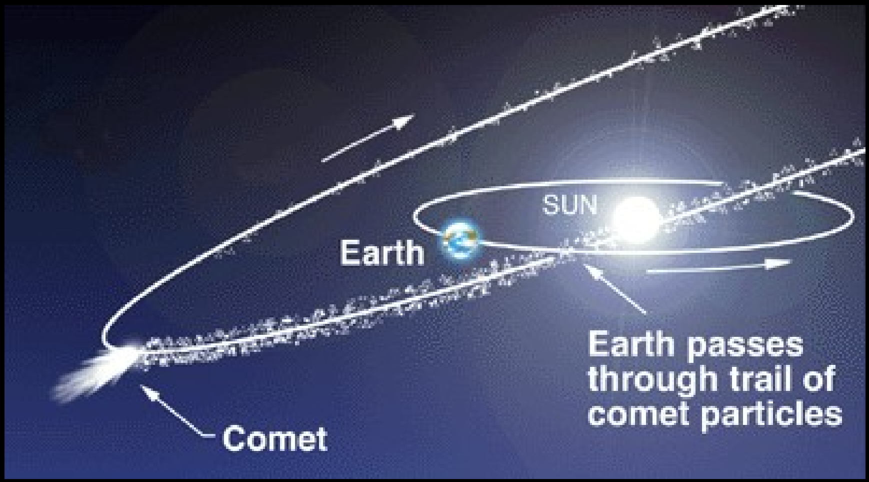
- **Kuiper belt comets formed in the Kuiper belt:** flat plane, aligned with the plane of planetary orbits, orbiting in the same direction as the planets.

- **Oort cloud comets formed closer to the Sun**, but they were kicked out there by gravitational interactions with Jovian planets: spherical distribution, orbits in any direction.



Meteors in a shower appear to emanate from the same area of sky because of Earth's motion through space



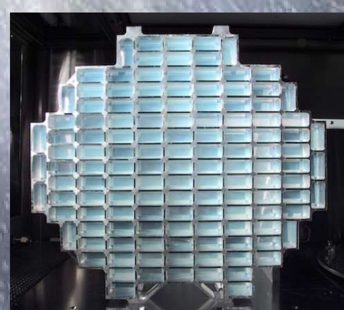


Shower Name	Approximate Date	Associated Comet
Quadrantids	January 3	?
Lyrids	April 22	Thatcher
Eta Aquarids	May 5	Halley
Delta Aquarids	July 28	?
Perseids	August 12	Swift-Tuttle
Orionids	October 22	Halley
Taurids	November 3	Encke
Leonids	November 17	Tempel-Tuttle
Geminids	December 14	Phaeton
Ursids	December 23	Tuttle

Missions to Comets

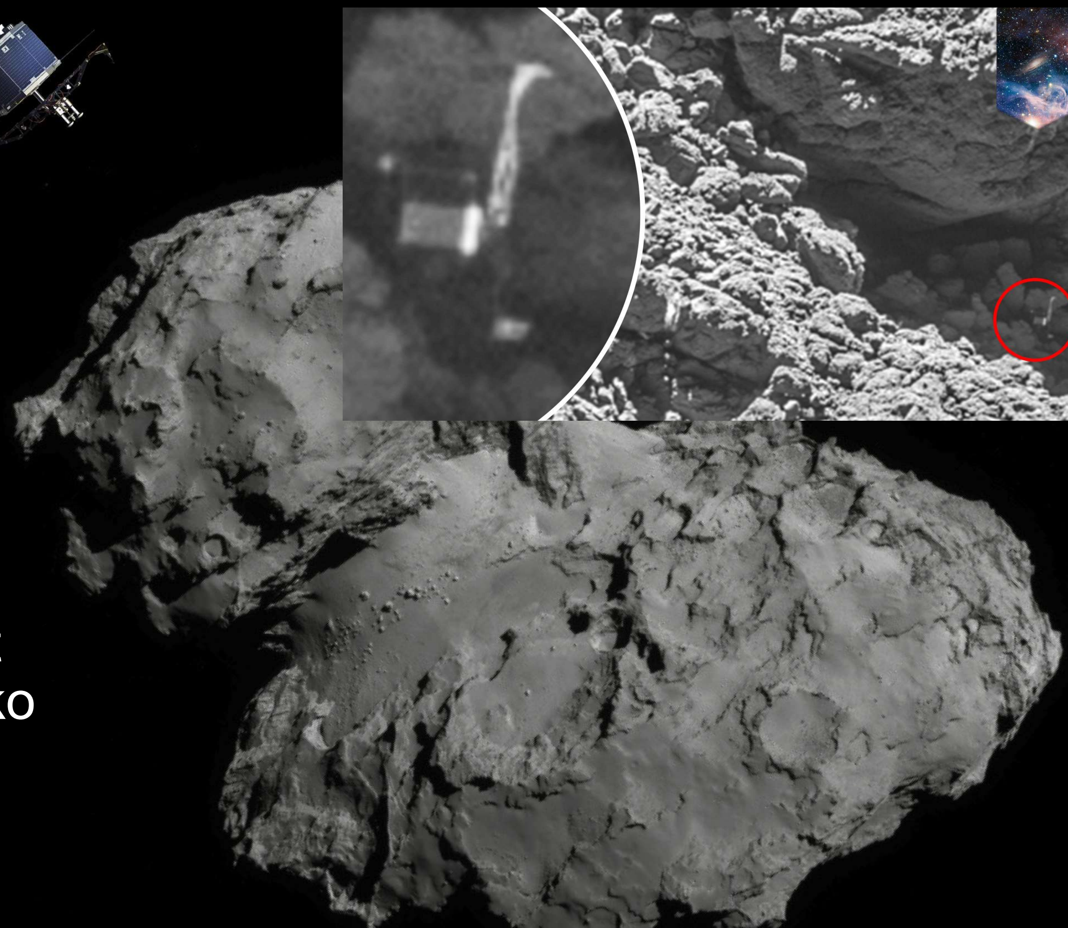
Stardust spacecraft returned samples from comet Wild 2 in 2006

- Dust captured in Aerogel
- Evidence of non-terrestrial glycine
- Captured evidence of interstellar dust as well as cometary dust



Missions to Comets

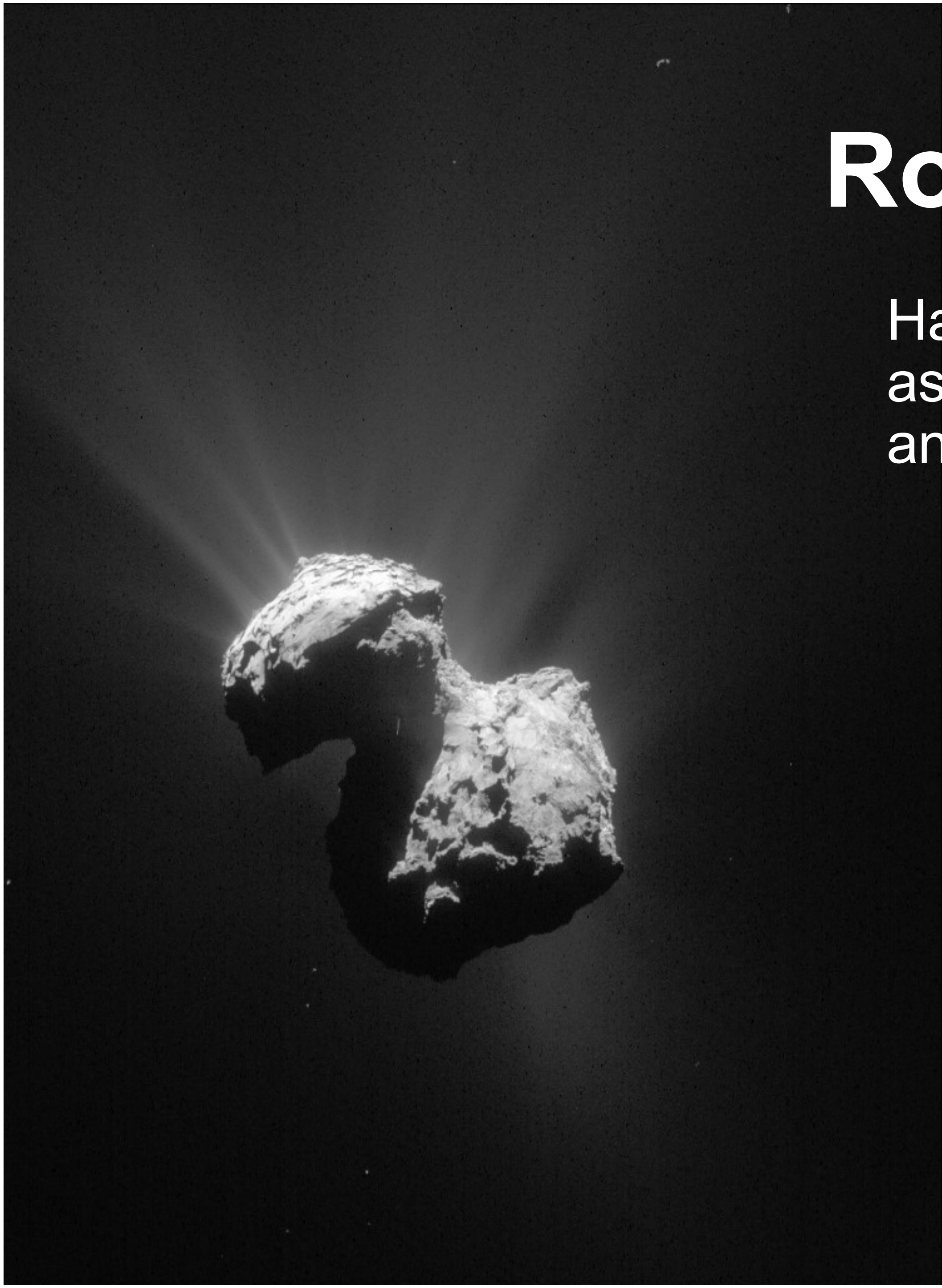
The mission also had a lander called Philae, unfortunately didn't work quite as well…



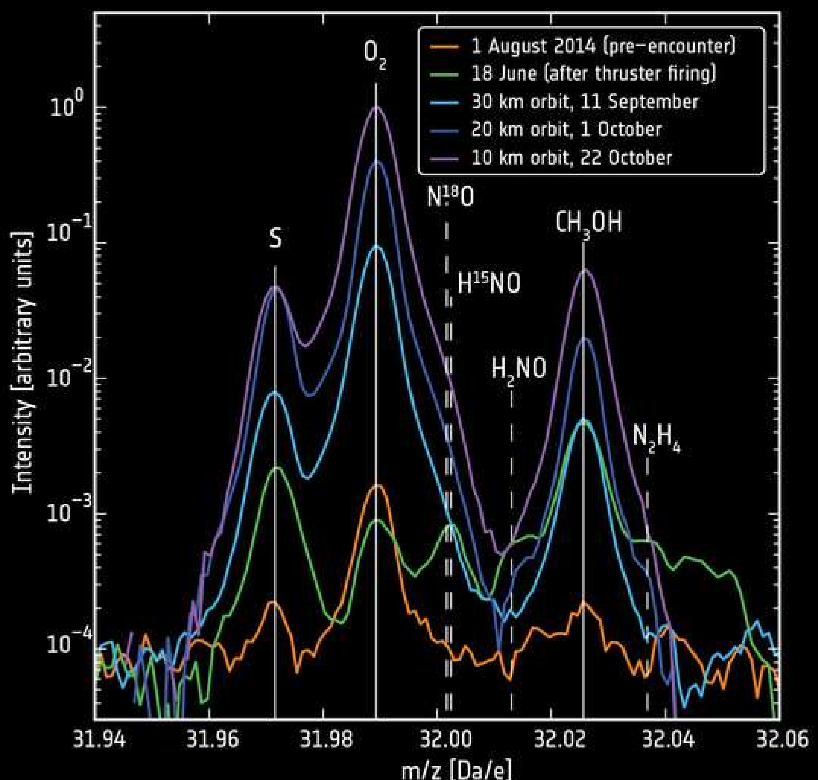
Rosetta Spacecraft

- Launched in 2004
- Went into Orbit around comet 67P/Churyumov–Gerasimenko in 2014

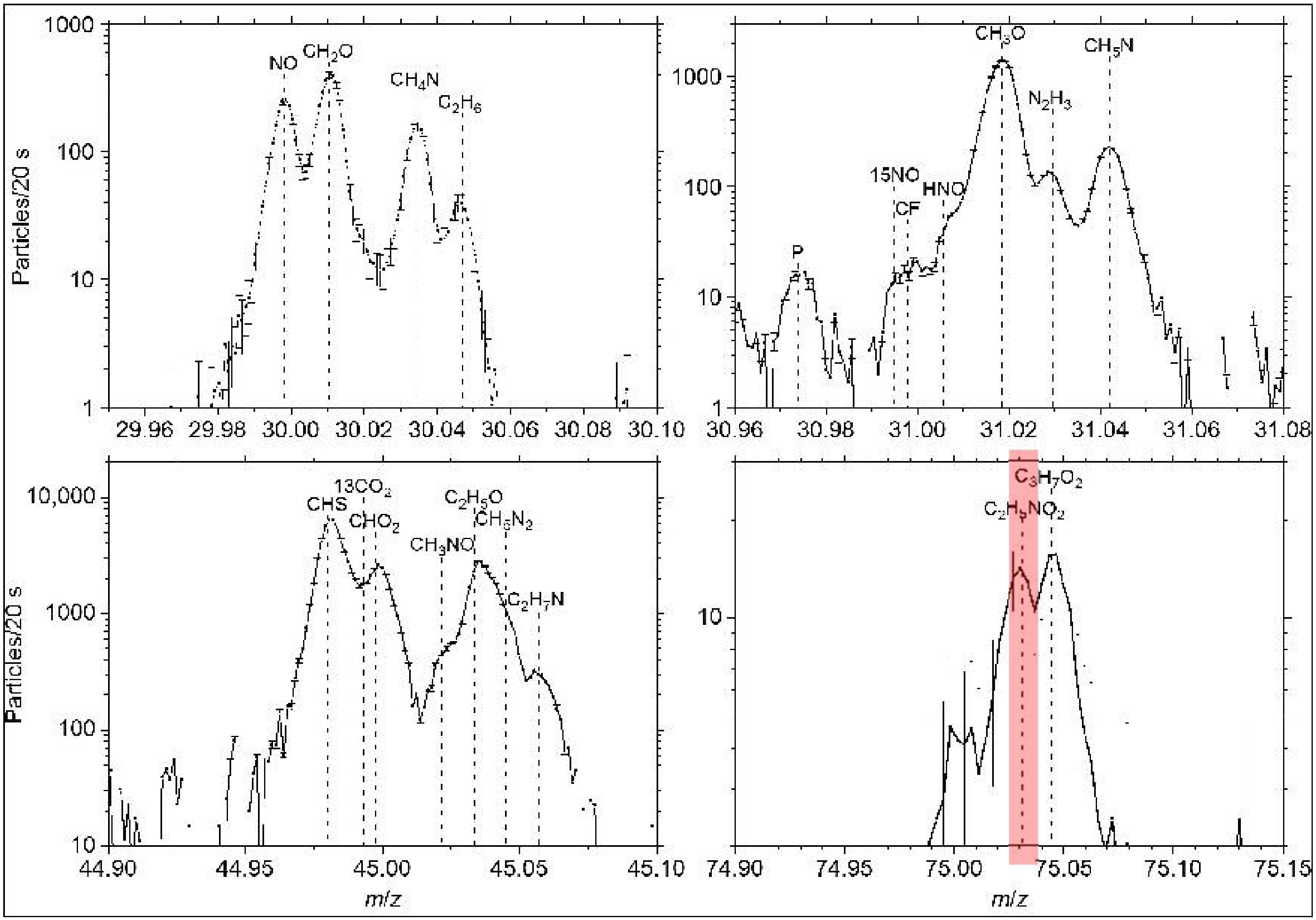
Rosetta Results



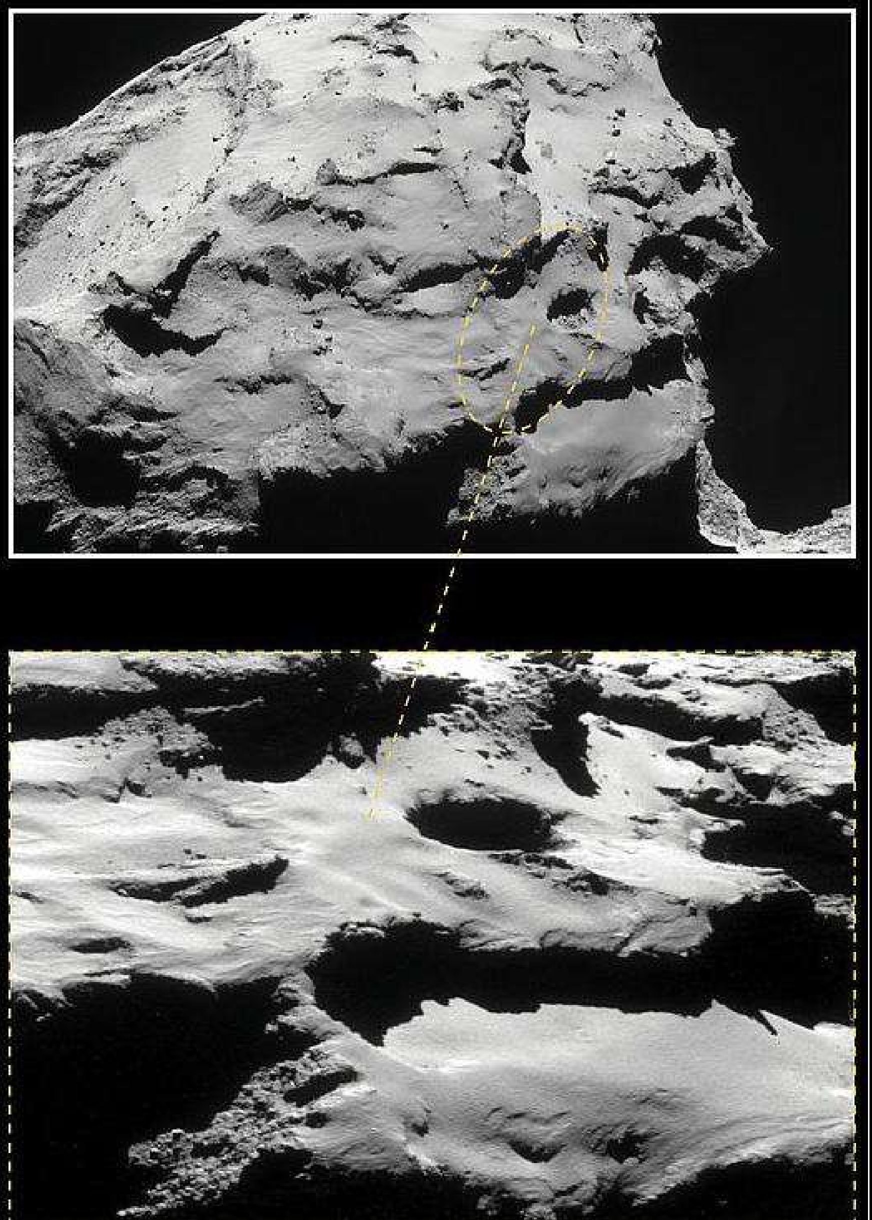
Has also detected glycine, as well as high levels of O_2 and N_2



ROSETTA: Organics and Glycine



ROSETTA: Images of Comet 67P Better than 1m/pixel!

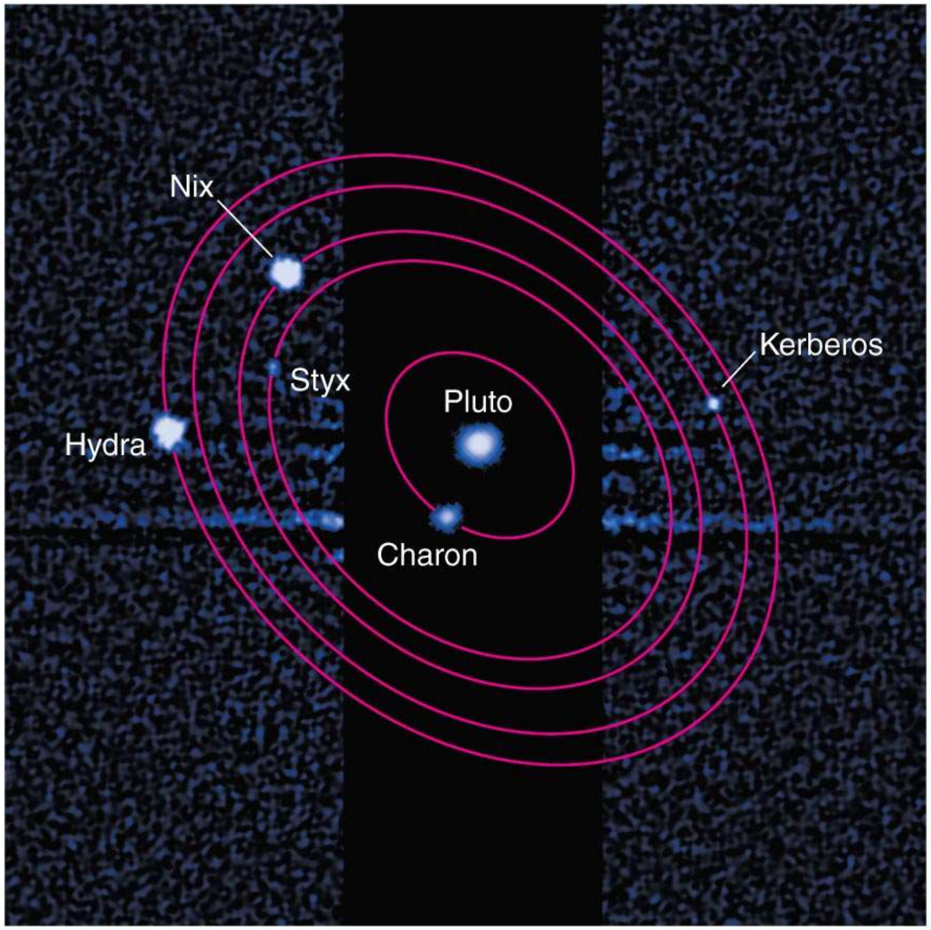


*Ex-planet** Pluto was visited by the New Horizons Spacecraft in 2015

**Classed as a dwarf planet since 2005*

1930
Lowell
Observatory

Pluto before *New Horizons*

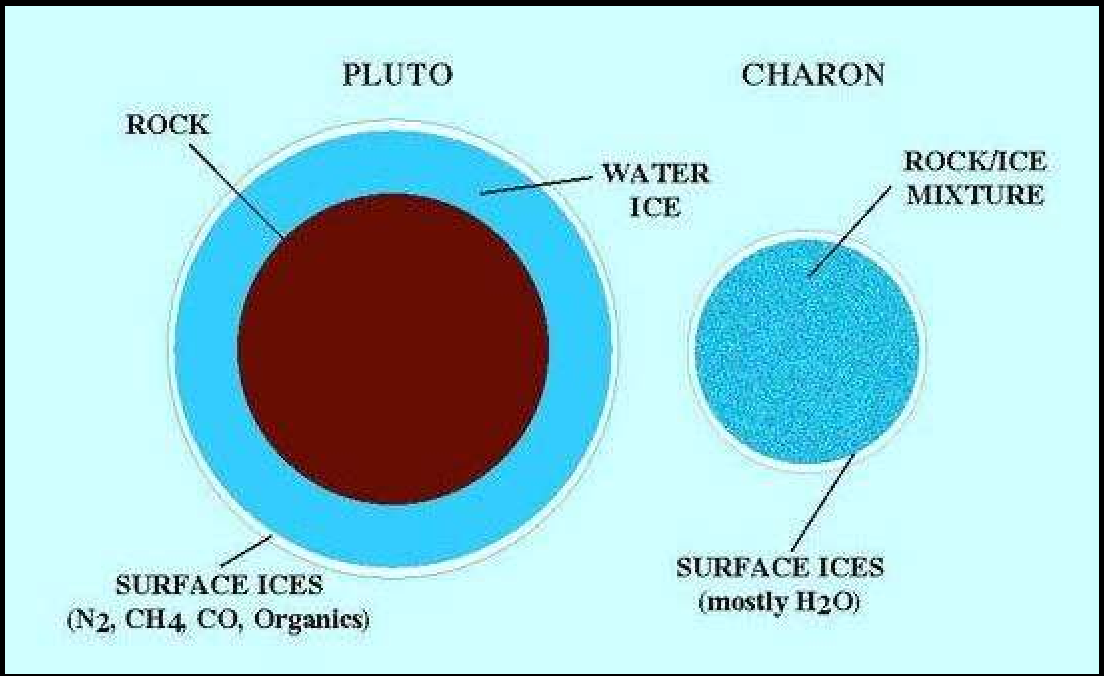


a This Hubble Space Telescope photo shows Pluto and its five known moons, along with orbital paths for the moons. Horizontal stripes are scattered light from Charon and Pluto in the long exposure.

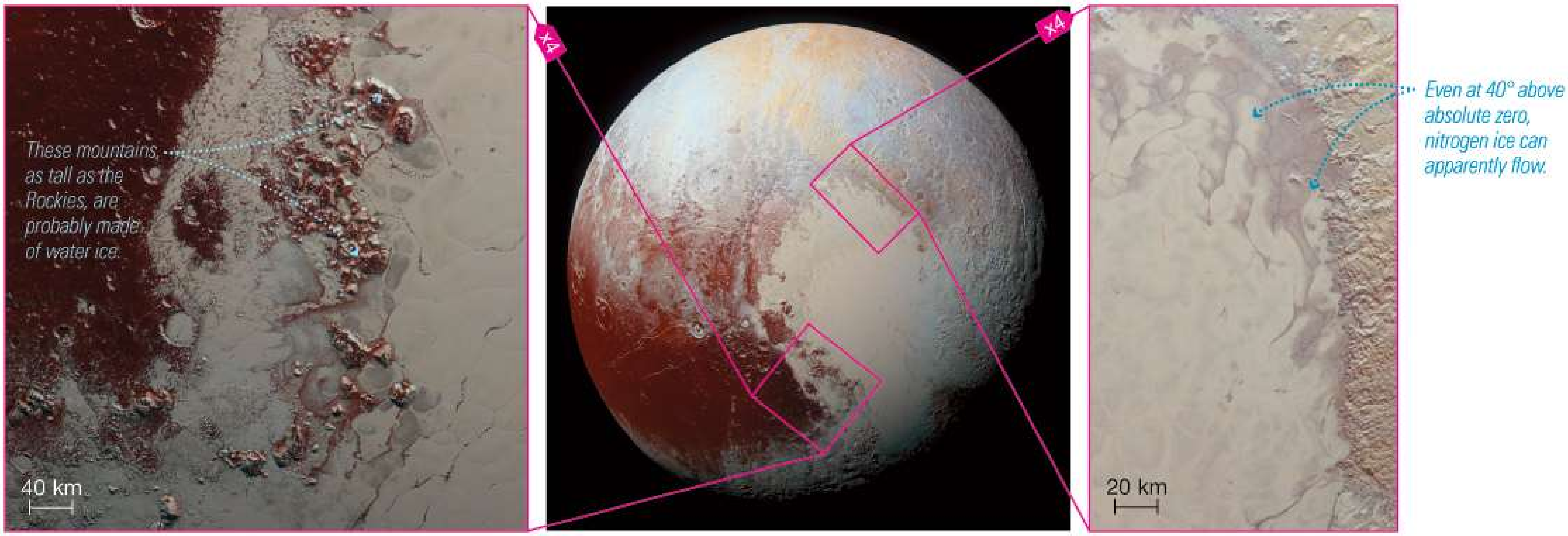
After: Pluto and Charon

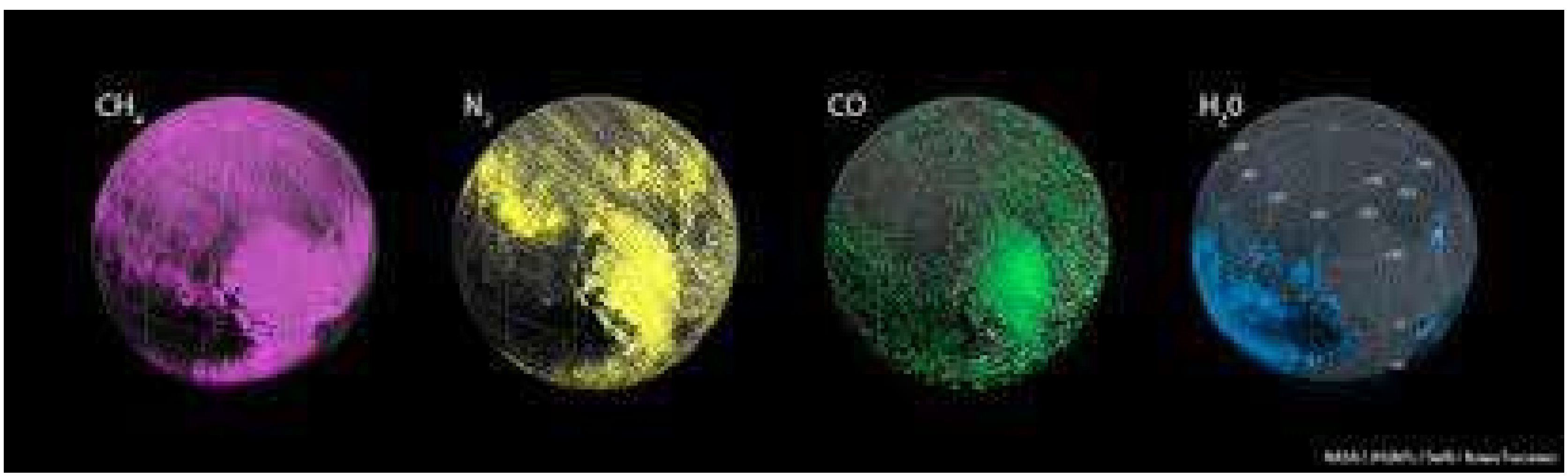
~600 km radius

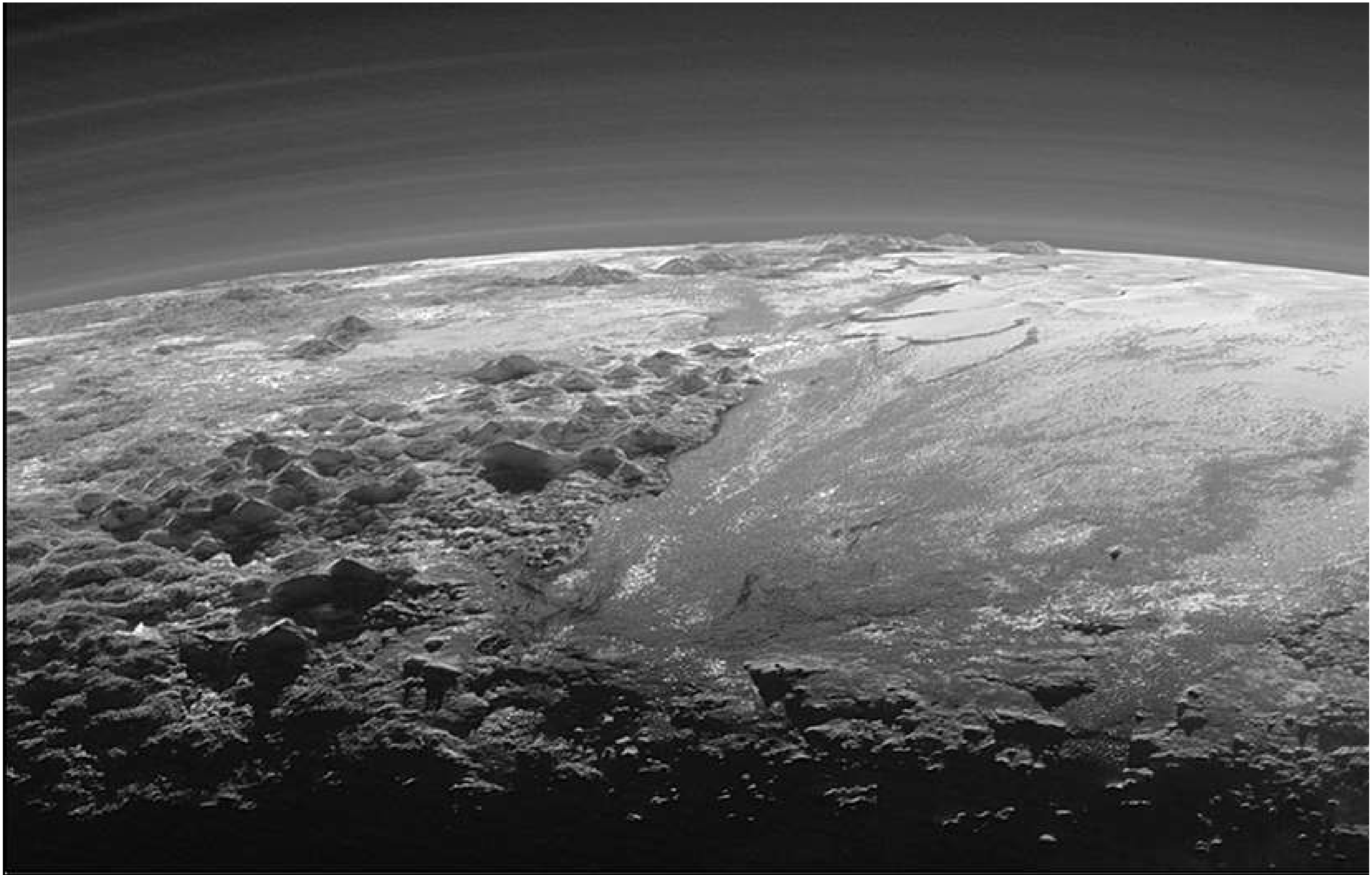
~1200 km radius



New Horizons at Pluto

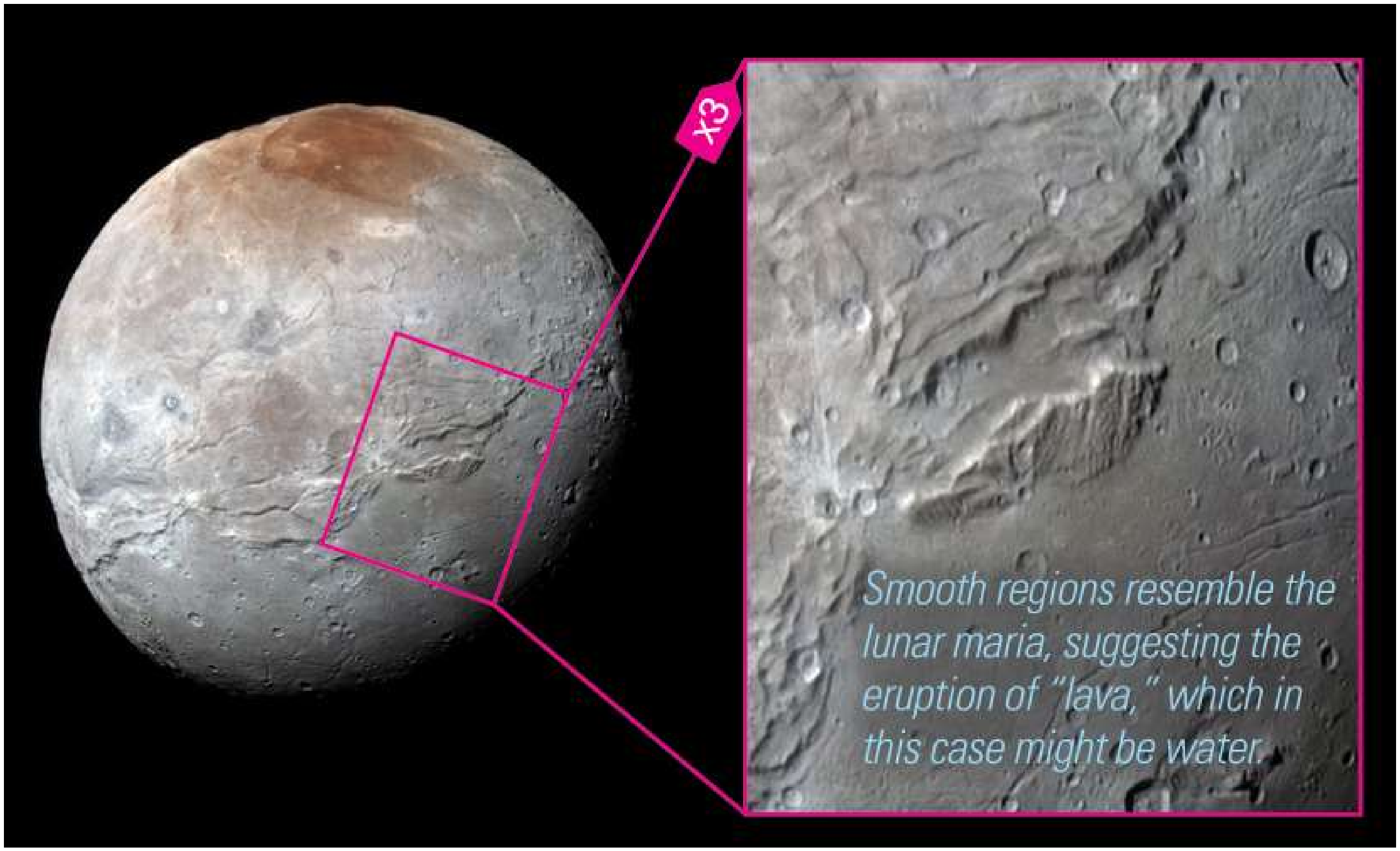






Pluto has large km-sized mountains of water covered in *"Tholins"*, which form from irradiated methane precursors, and has 'lakes' of N_2 and CO

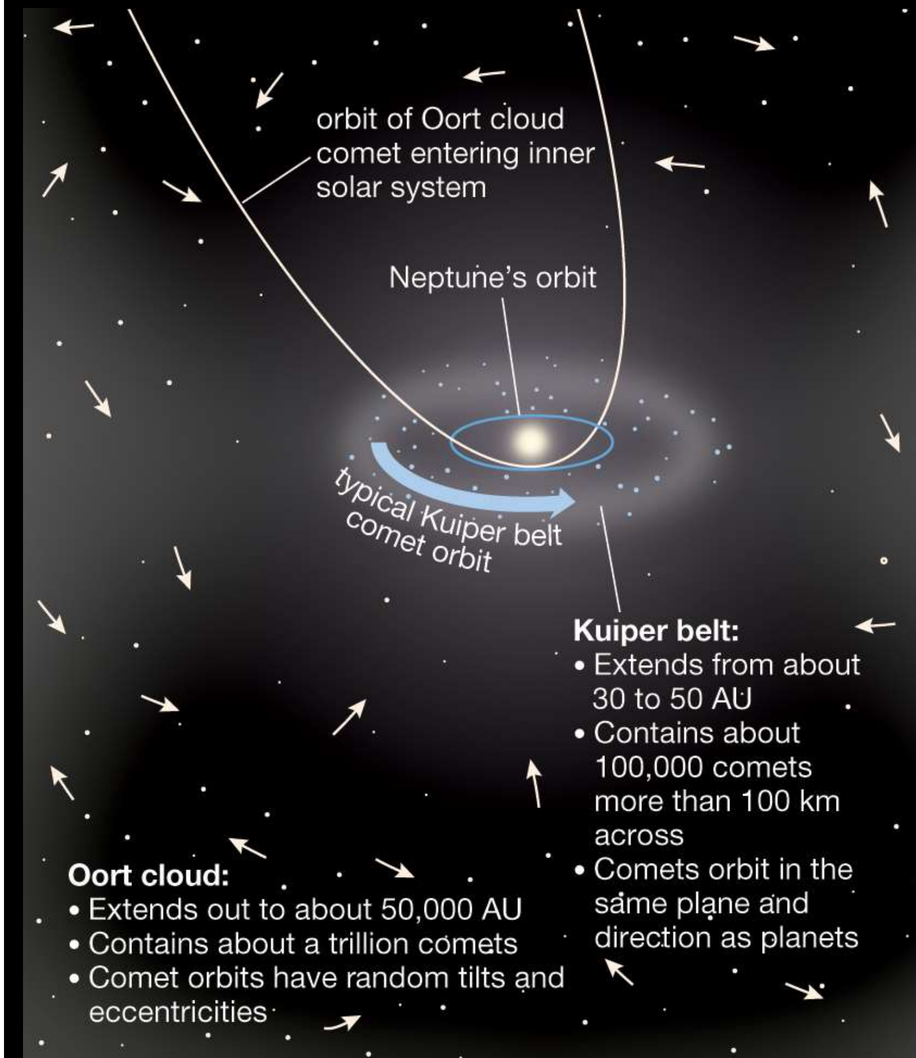
New Horizons at Charon

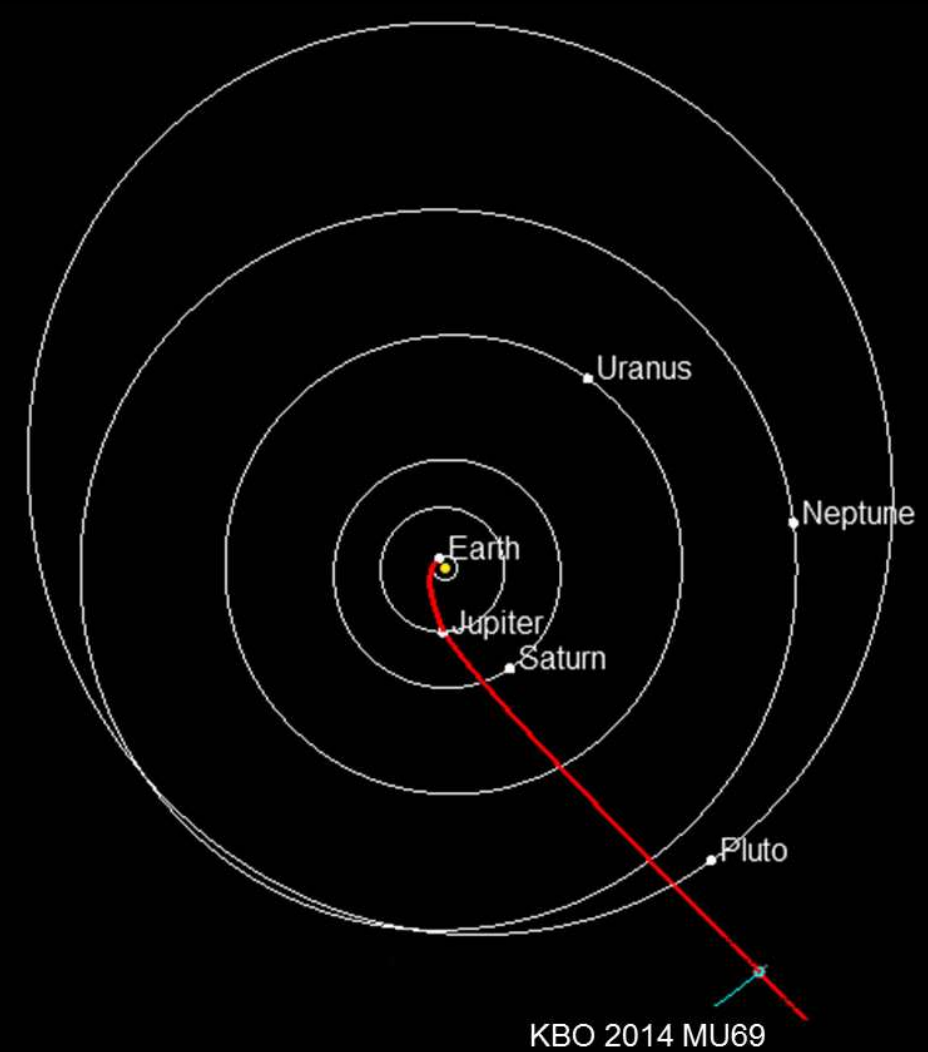


The surface of Charon also shows evidence of recent geological activity.

We expect many Kuiper Belt Objects (KBOs) (and comets) to resemble Pluto

New Horizons is currently heading towards another KBO!





Largest known trans-Neptunian objects (TNOs)

TNOs includes KBOs

What have we learned?

- What is Pluto like?
  - Pluto has a tilted and elliptical orbit and a system of moons.
  - Pluto's surface shows evidence of ongoing geological activity, as revealed by *New Horizons*.

- What do we know about other Kuiper belt comets?
  - Likely similar compositions to Pluto

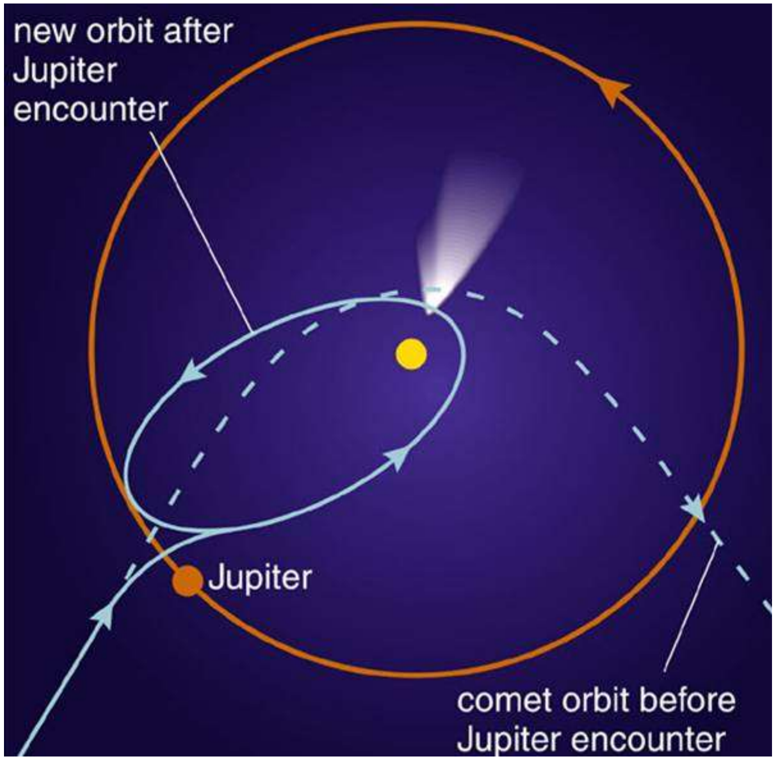
9.5 Cosmic Collisions: Small Bodies Versus the Planets

Our goals for learning:

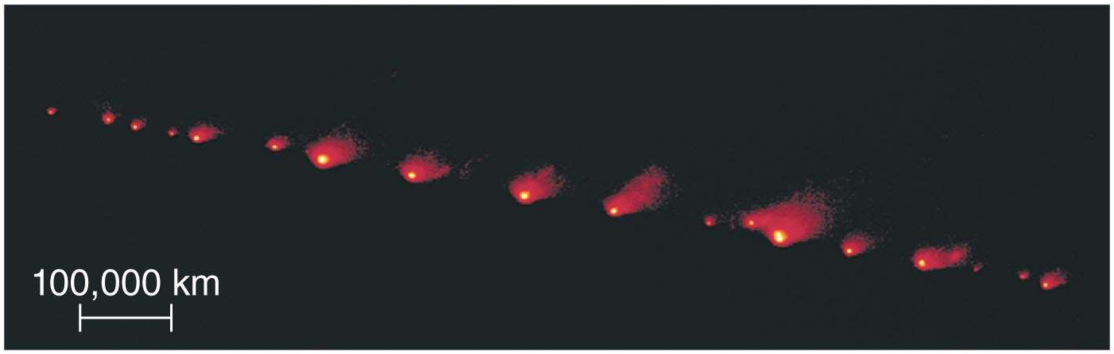
- Did an impact kill the dinosaurs?
- How great is the impact risk today?
- How do jovian planets affect impact rates and life on Earth?

Major Impacts – The Role of Jupiter

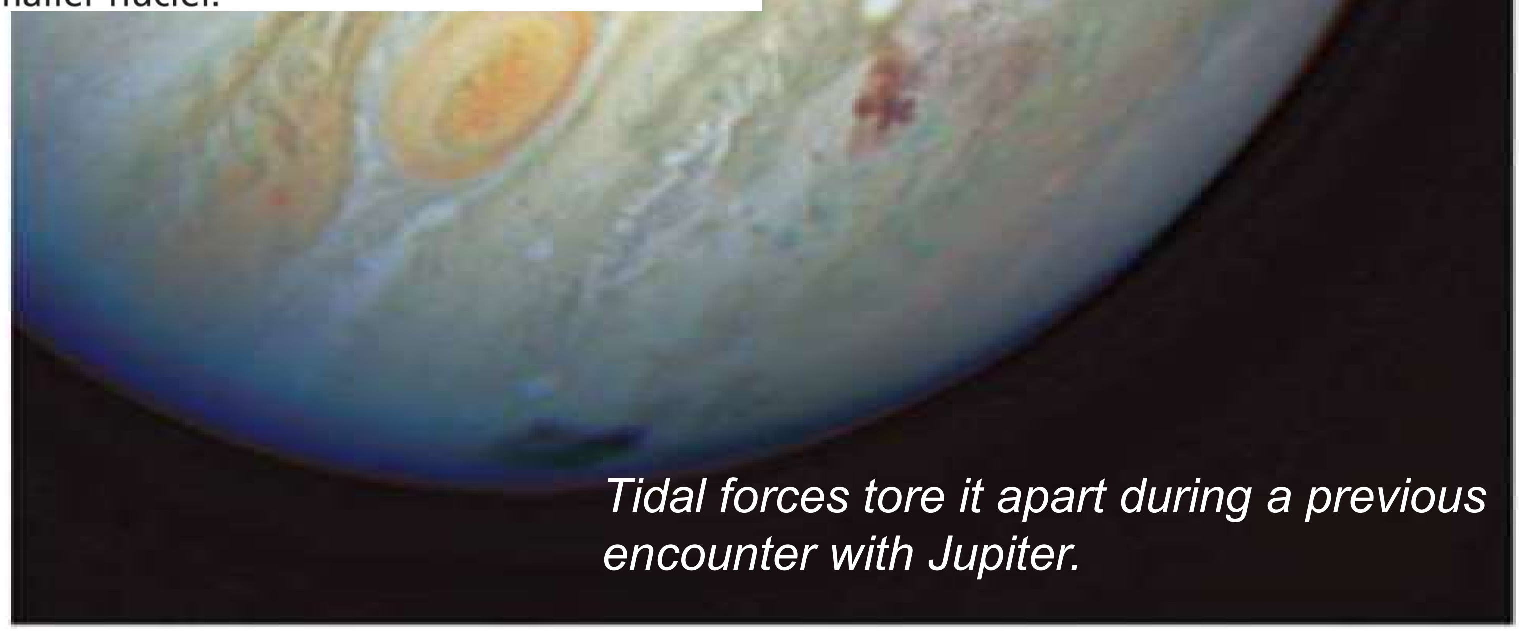
- Small objects impact all of the planets every day.
- Evidence suggests larger impacts are also still occurring, such as the impact of comet Shoemaker-Levy 9 into Jupiter in 1994.
- A Large number of Earth-bound objects run into Jupiter instead
- Jupiter can also deflect their orbits sending them into the Oort cloud
- But Jupiter can also change the path of objects and direct them towards Earth



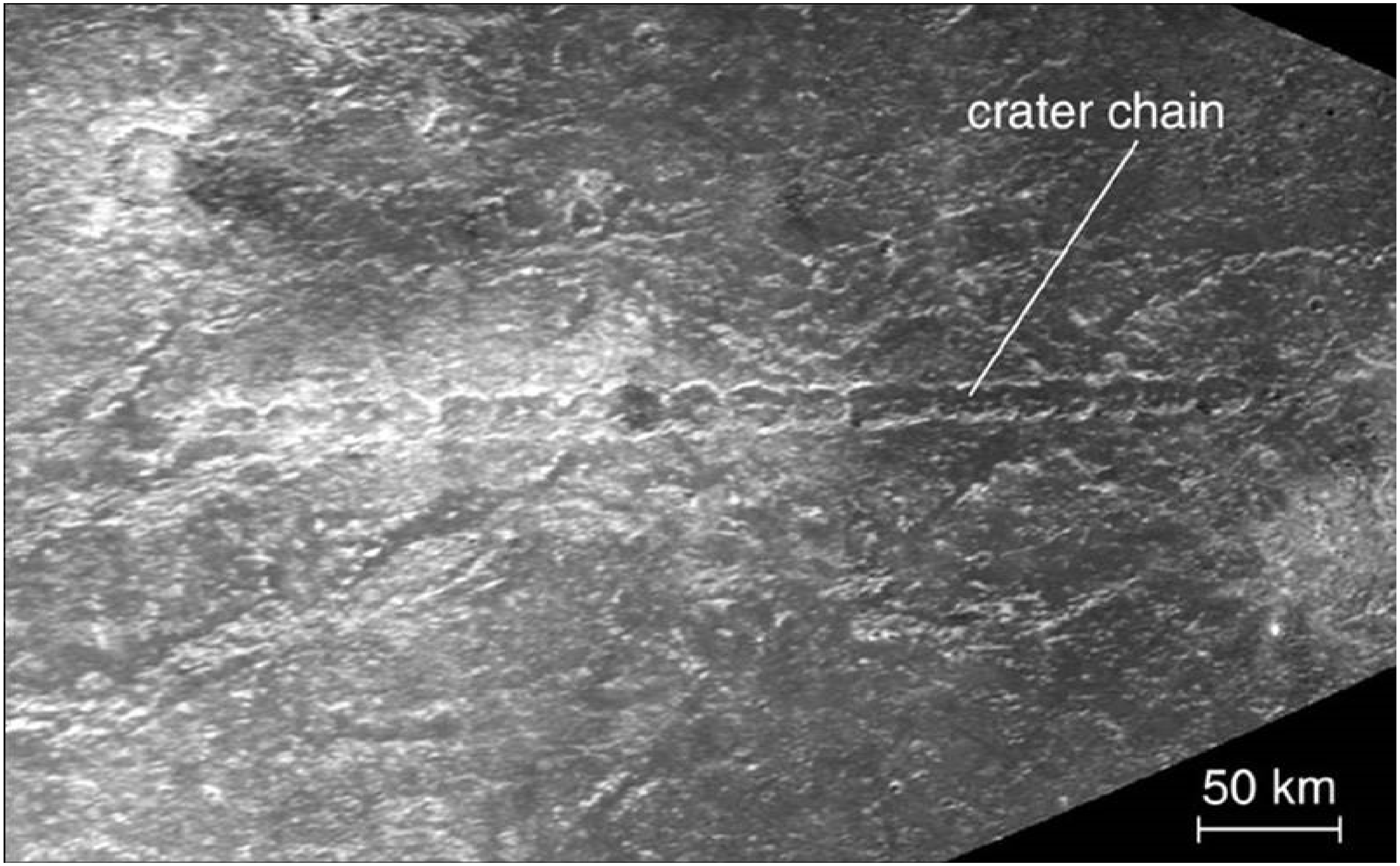
The impact of comet Shoemaker-Levy 9 into Jupiter in 1994



a Jupiter's tidal forces ripped apart the single comet nucleus of SL9 into a chain of smaller nuclei.



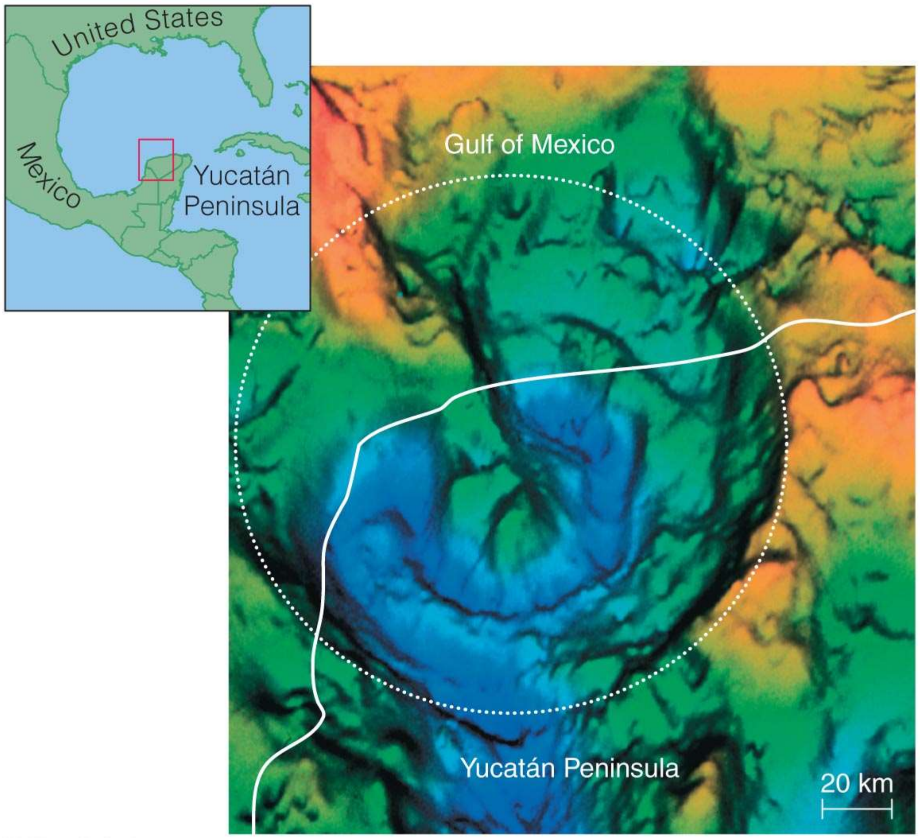
Tidal forces tore it apart during a previous encounter with Jupiter.



This crater chain on Callisto probably came from another comet that tidal forces tore to pieces.

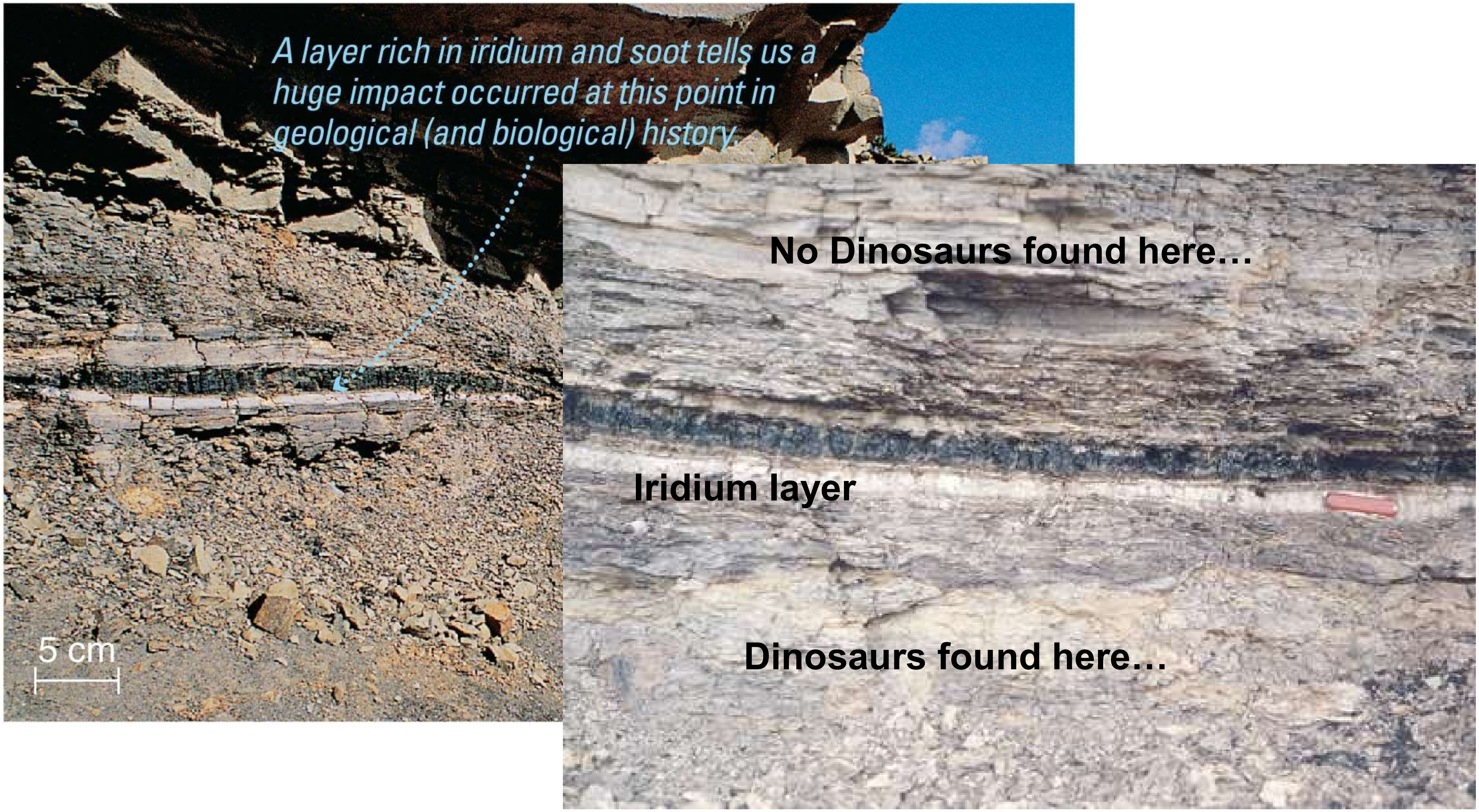

Did an Impact Kill the Dinosaurs?

Probably: Likely Impact Site

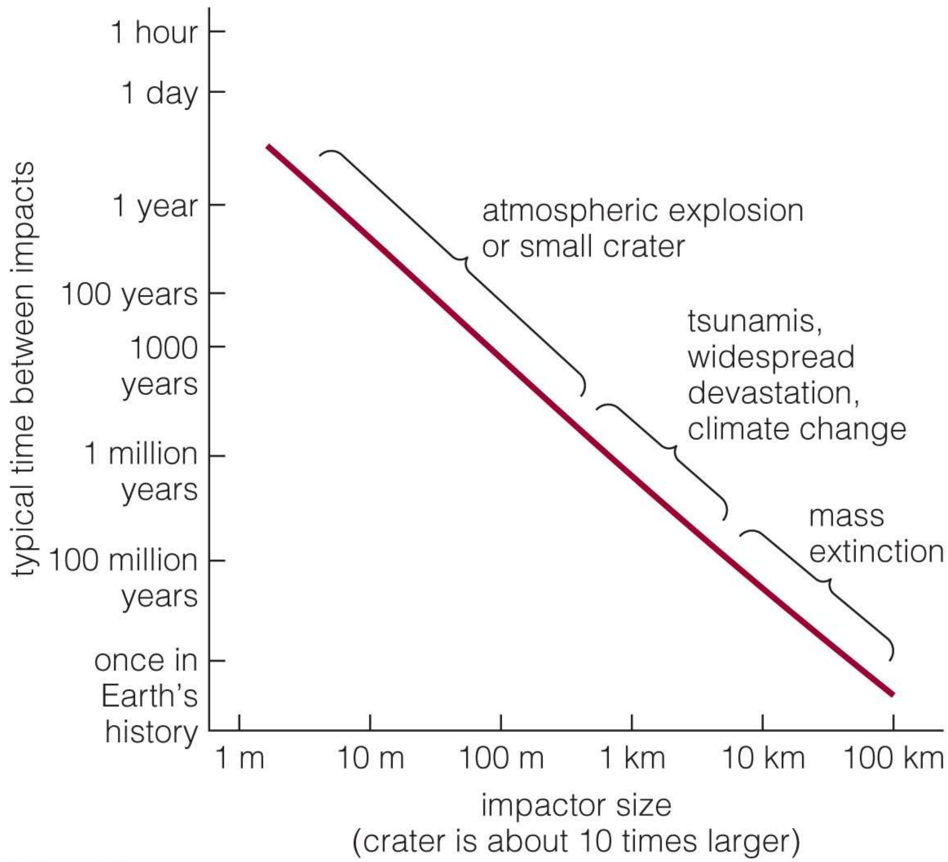


- Geologists found a large subsurface crater about 65 million years old in Mexico.
- Size of crater suggests impacting object was ~10 km in diameter.
- Impact of such a large object would have ejected debris high into Earth's atmosphere.

Iridium Layer Found World-wide
K-T boundary (Cretaceous-Paleogene; 65 Myrs ago)

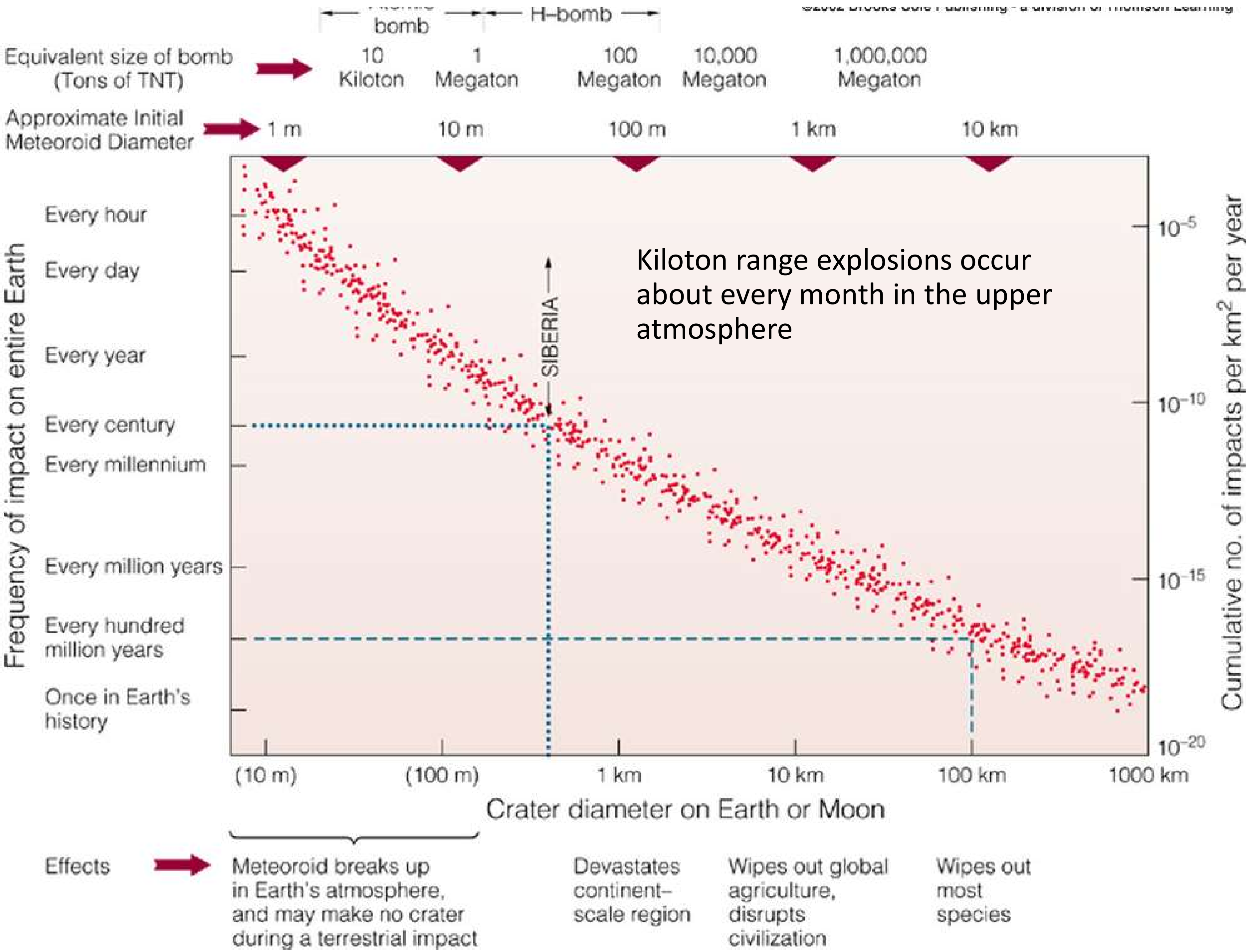


How Frequent are Impacts?



- Small impacts happen almost daily.
- Impacts large enough to cause mass extinctions are many millions of years apart.
- Impacts the size of meteorite crater occur around every 50,000 years

Kiloton range explosions occur about every month in the upper atmosphere



Meteor Crater, Arizona: 50,000 years ago (50-100 meter object)

An asteroid detonates in the sky above Chelyabinsk, Russia in February 2013, releasing energy equivalent to a 500 kiloton nuclear bomb.

Tunguska, Siberia: June 30,1908 A ~40-meter object disintegrated and exploded in the atmosphere.

Thought Question

Is there an asteroid/comet heading for Earth?

How would we know?

What can we do about it?

- Possibly… We haven't seen it yet…
- Deflection is more probable with years of advance warning (at least 1 or 2 years, practically!)
- Control is critical: Breaking a big asteroid into a bunch of little asteroids is unlikely to help (much).
- We get less advance warning of a killer comet.

What have we learned?

- Did an impact kill the dinosaurs?
  - An iridium layer just above dinosaur fossils suggests that an impact caused mass extinction 65 million years ago.
  - A large crater of that age has been found in Mexico.
- How great is the impact risk today?
  - Large impacts do happen, but they are rare.
  - They can cause major extinctions about every 100 million years.
- How do jovian planets affect impact rates and life on Earth?
  - Jovian planets sometimes deflect comets toward Earth, but send many more out to the Oort Cloud.

End of Todays Lecture