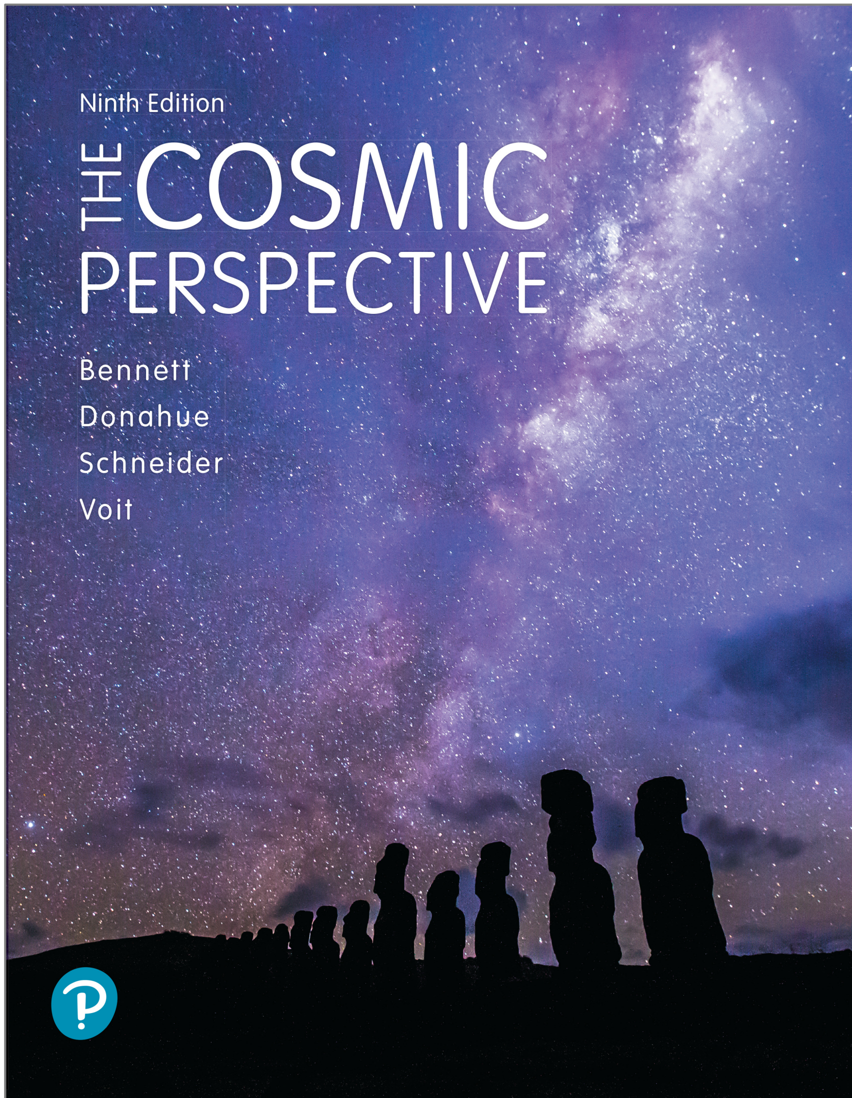
The Cosmic Perspective

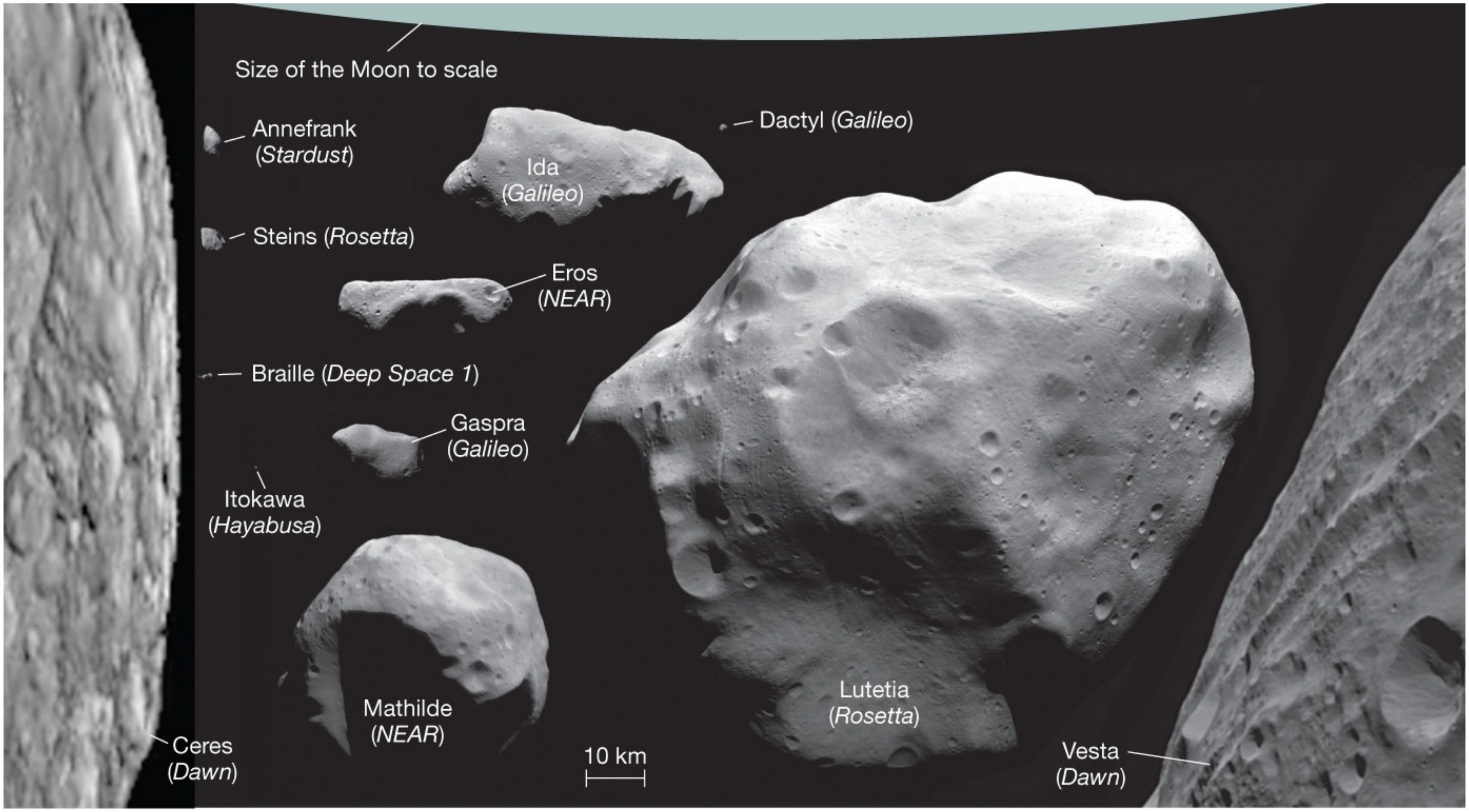
Ninth Edition



Chapter 12

Asteroids, Comets, and Dwarf Planets

Figure 12.8


Size of the Moon to scale
Annefrank (*Stardust*)
Ida (*Galileo*)
Dactyl (*Galileo*)
Steins (*Rosetta*)
Eros (*NEAR*)
Braille (*Deep Space 1*)
Gaspra (*Galileo*)
Itokawa (*Hayabusa*)
Mathilde (*NEAR*)
Lutetia (*Rosetta*)
Ceres (*Dawn*)
10 km
Vesta (*Dawn*)

Various asteroids at the same scale

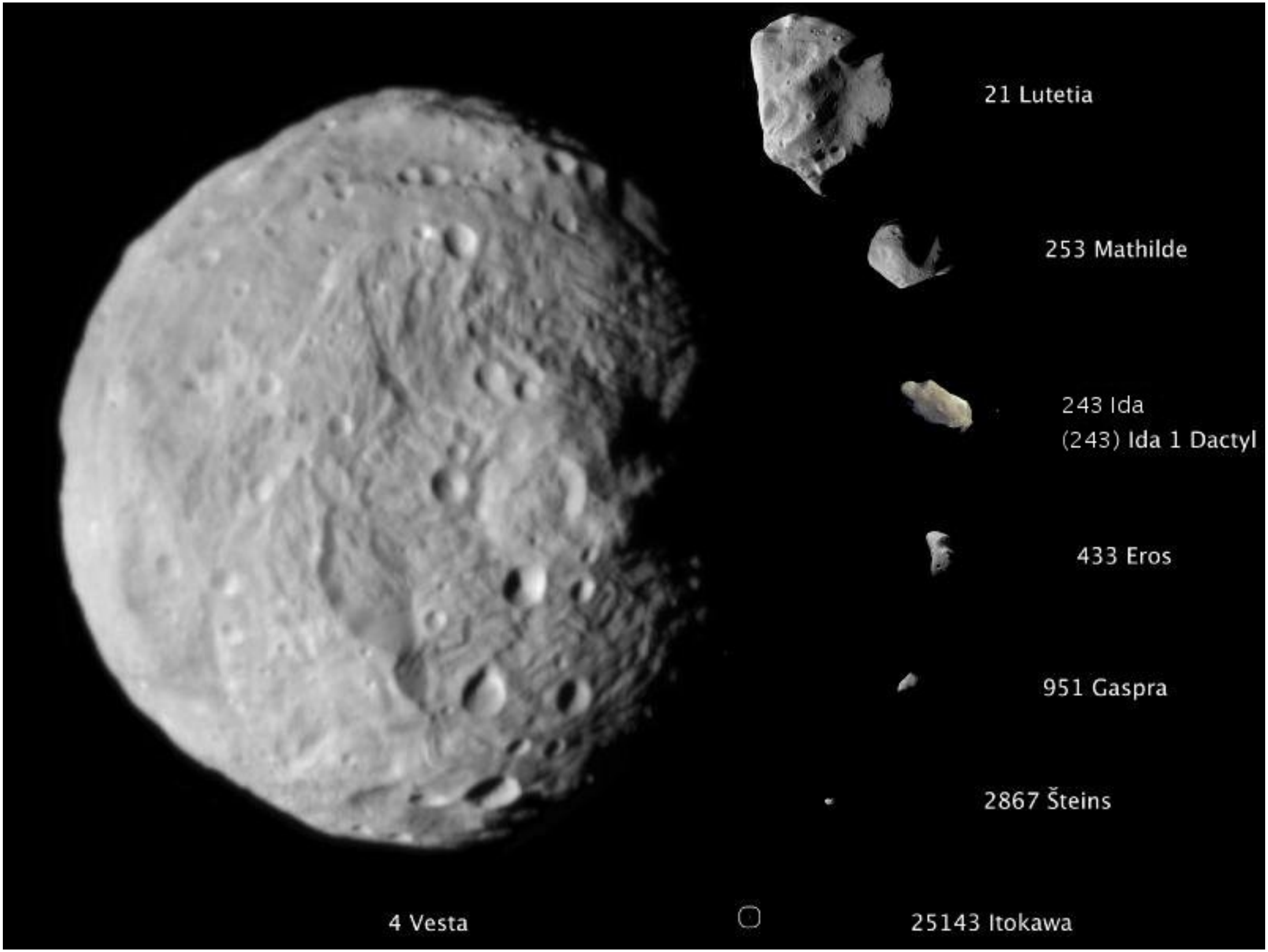
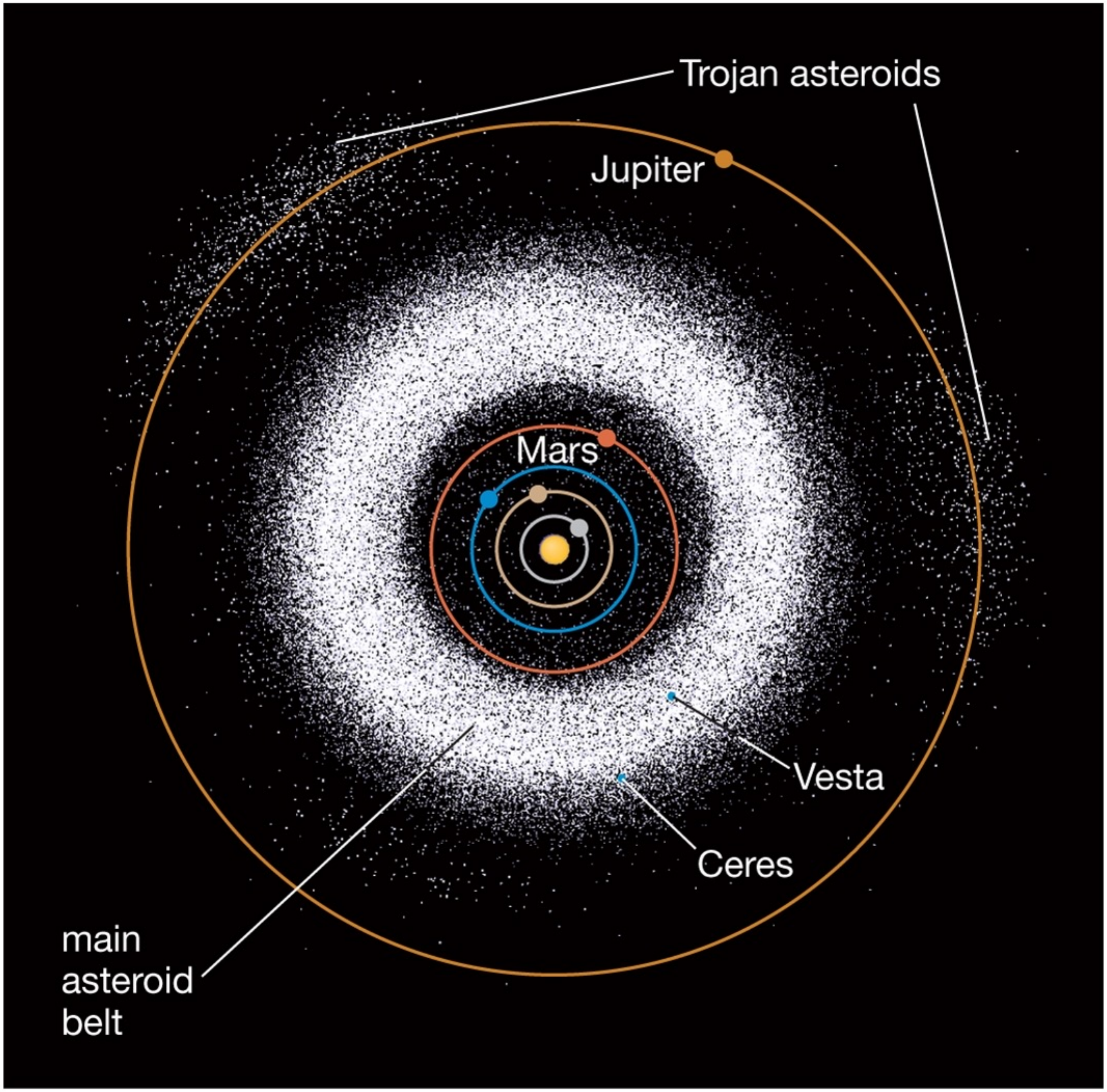


Figure 12.13


Trojan asteroids
Jupiter
Mars
Vesta
Ceres
main
asteroid
belt

Asteroids are unlikely to be fragmented planets because

1. the combined mass of all the asteroids is insufficient
2. asteroid orbits are not near the ecliptic
3. asteroids are typically only a few kilometers across
4. asteroids can have different colors
5. asteroids are composed of different materials than planets

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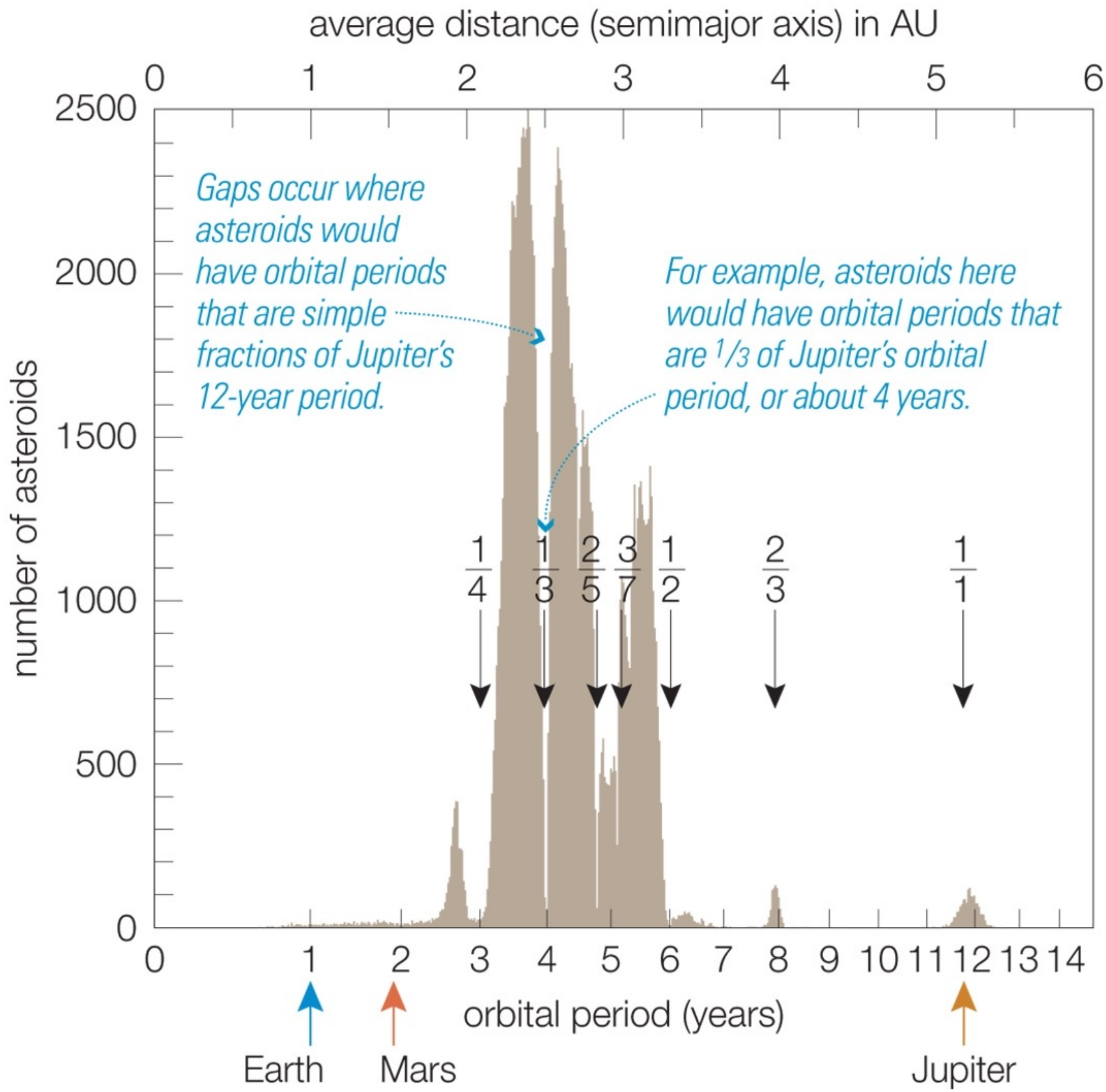
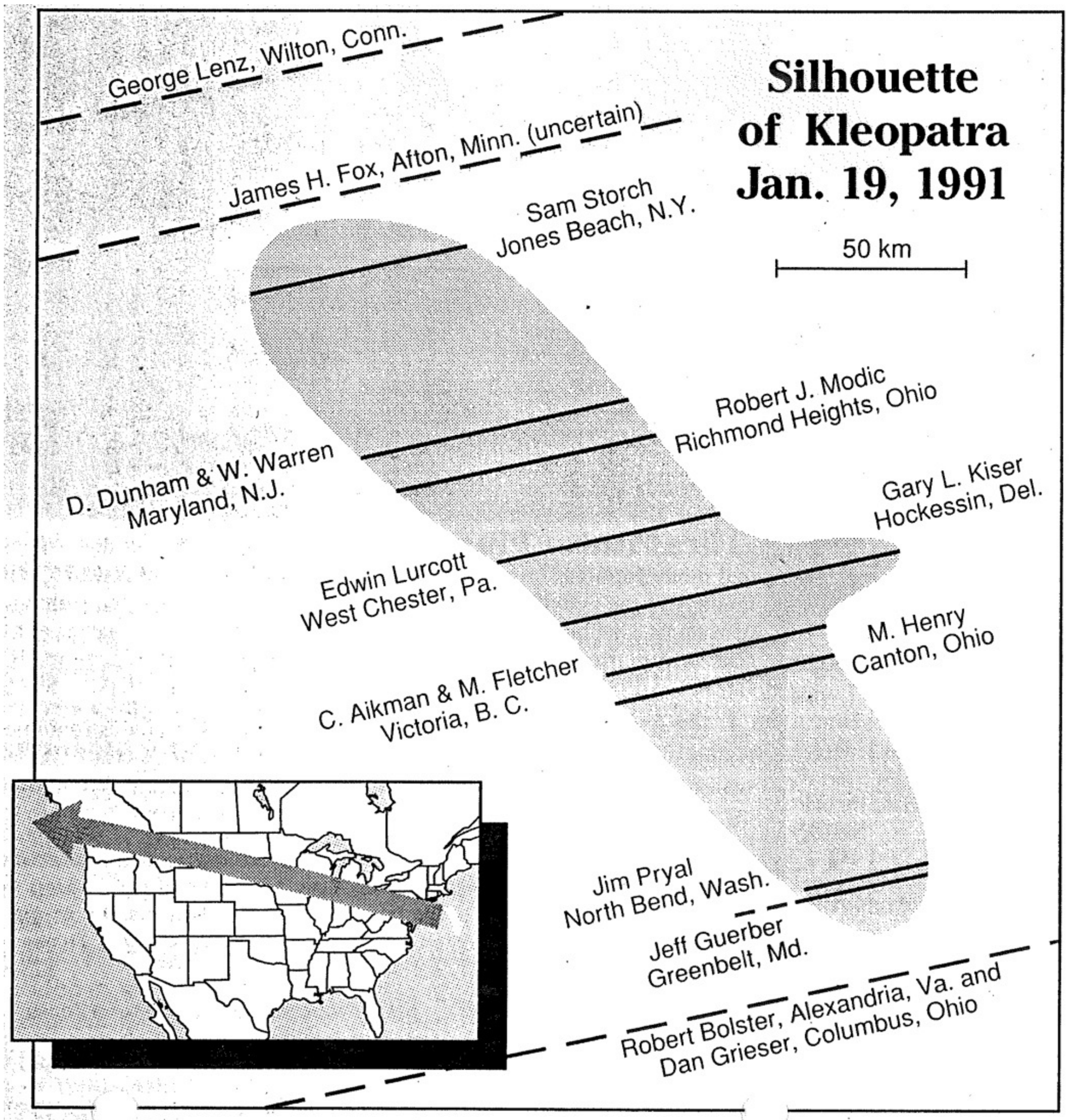
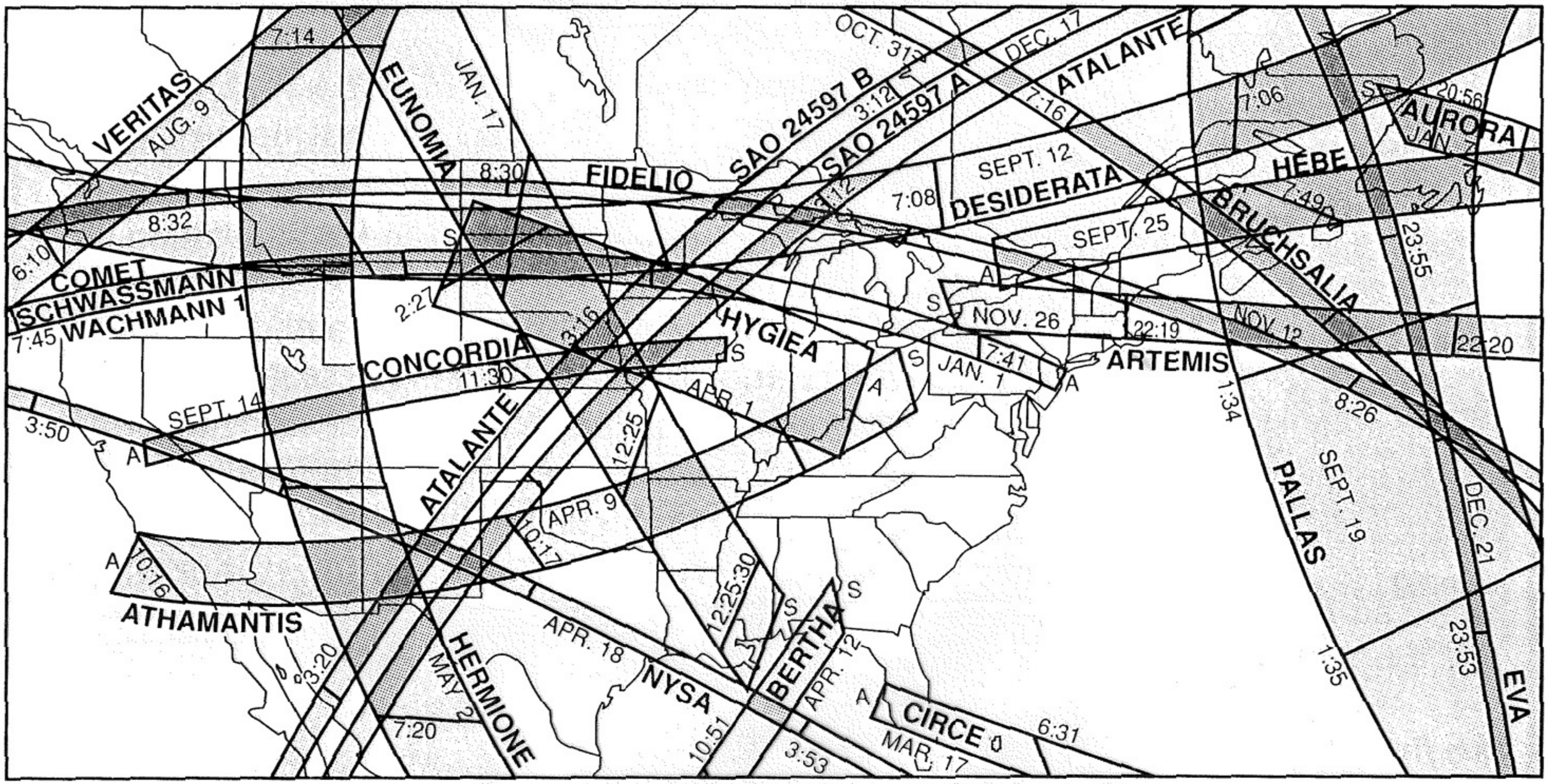
Figure 12.14


average distance (semimajor axis) in AU
0
1
2
3
4
5
6
2500
2000
1500
1000
500
0
number of asteroids
Gaps occur where asteroids would have orbital periods that are simple fractions of Jupiter's 12-year period.
For example, asteroids here would have orbital periods that are 1/3 of Jupiter's orbital period, or about 4 years.
1/4
1/3
2/5
3/7
1/2
2/3
1/1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
orbital period (years)
Earth
Mars
Jupiter

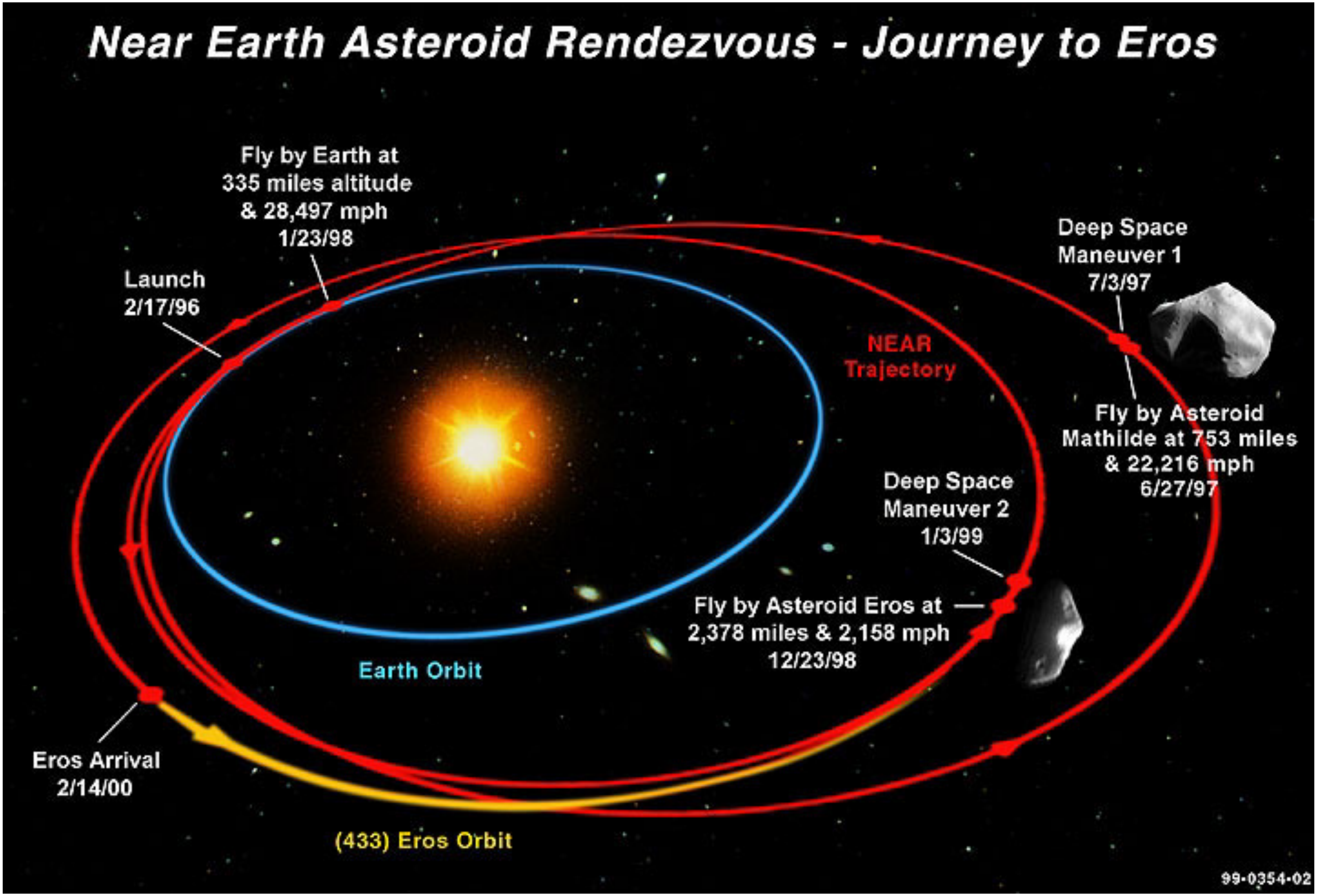
Asteroid sizes determined by coordinated observations of "stellar eclipses"



Asteroid sizes determined by coordinated observations of "stellar eclipses"



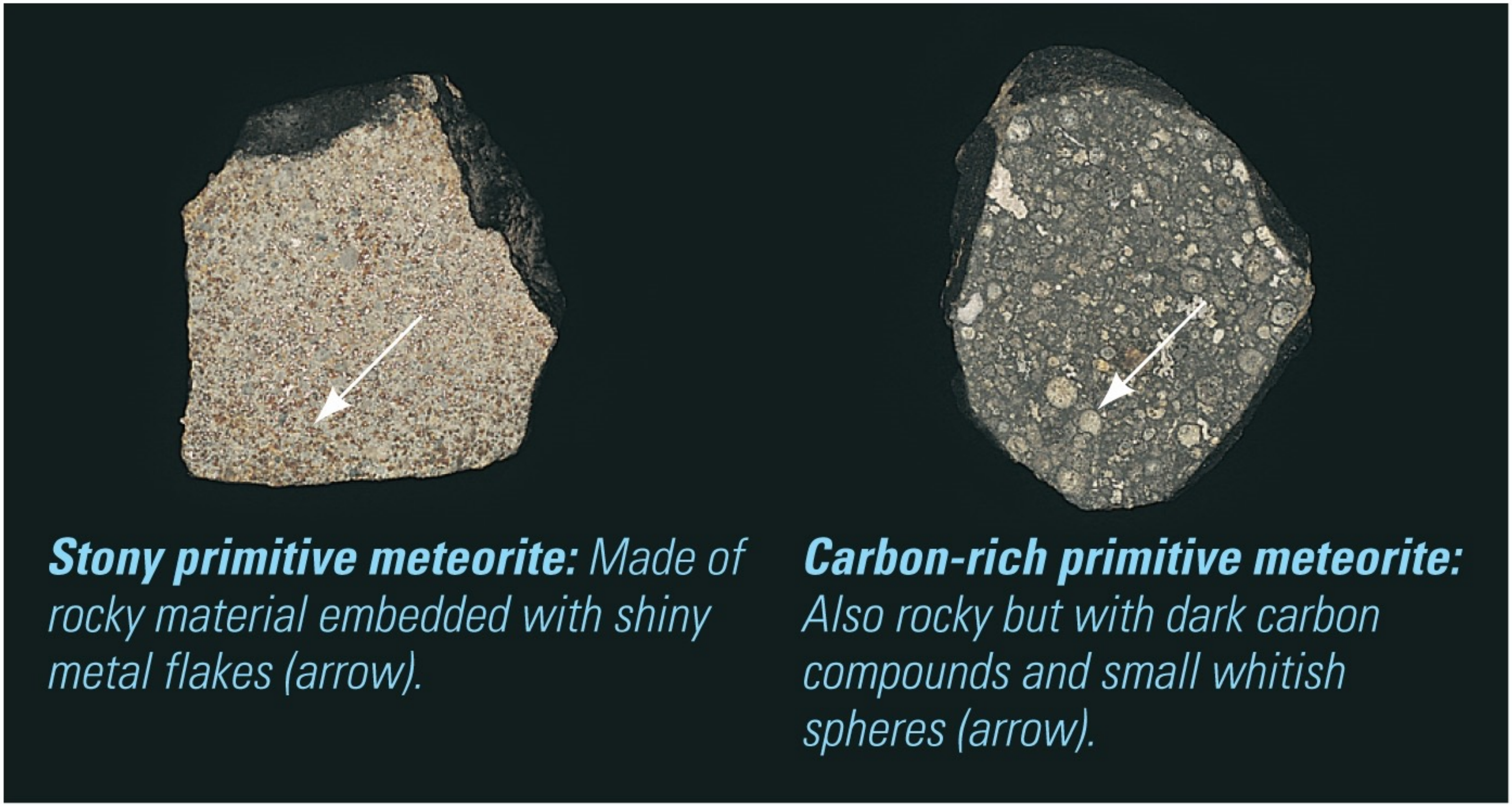
Getting to an asteroid is challenging?



Very small asteroids are “meteoroids”

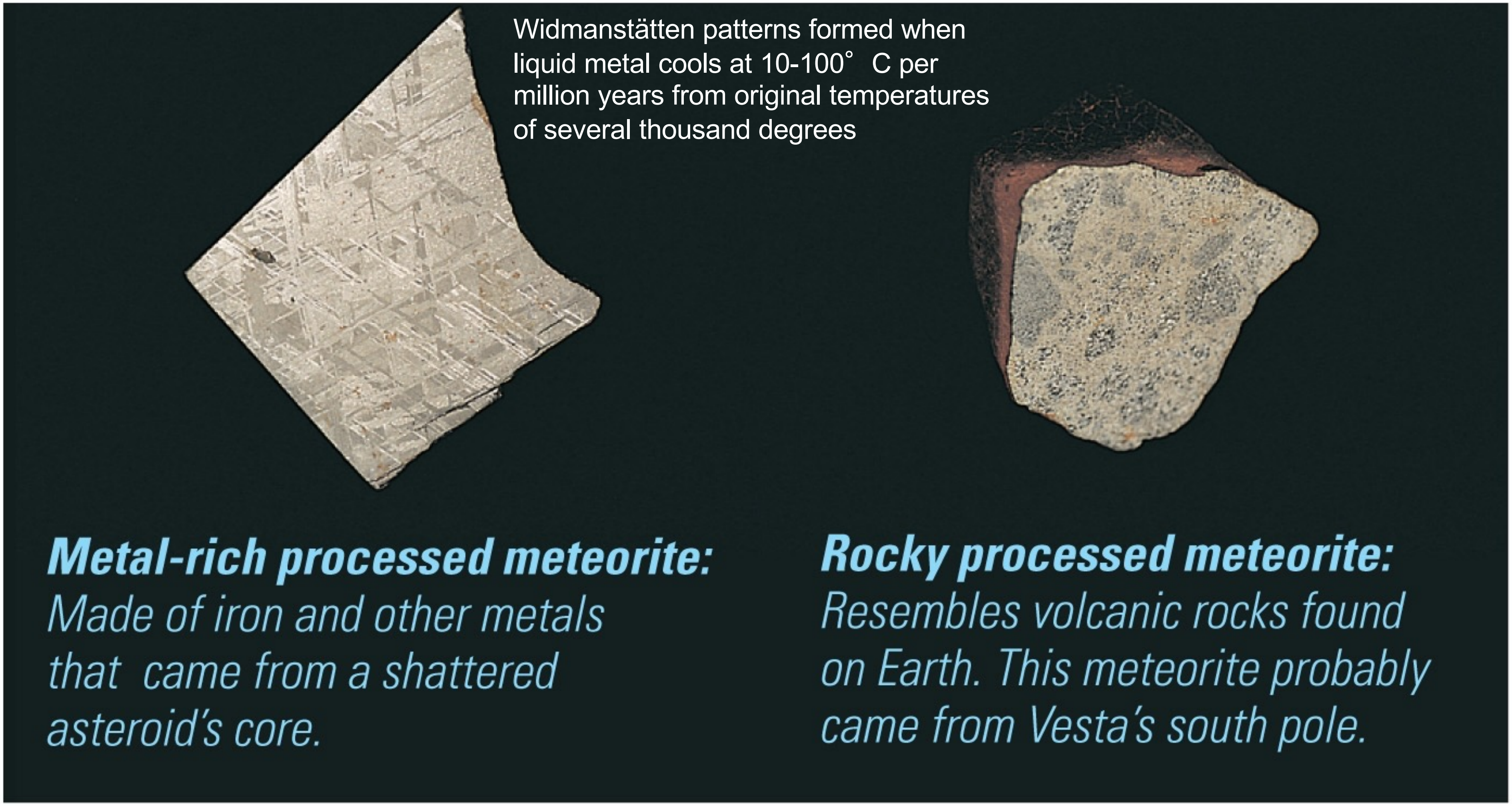
- Typically not identified while in orbit around the Sun
- Entering Earth’s atmosphere at ~ 30 km/s, they heat due to friction and glow very brightly but very briefly
- These shooting stars are properly called “meteors”
- Most are essentially grains of sand and vaporize rapidly
- Pieces that survive to the surface are called “meteorites”
- Basic types of meteorites:
  - Metallic
  - Stony
  - Combination
  - Carbonaceous Chondrites

Figure 12.12a



a Primitive meteorites.

Figure 12.12b



b Processed meteorites.

Why are some meteorites metallic while others are rocky?

1. In the early solar nebula, matter accumulated according to how similar the elements were, so metals like iron and nickel collected in one region while rocky elements made of silicates (silicon-based molecules) collected elsewhere
2. In the early solar nebula, different elements formed into solids at different times because of the temperatures required for them to cool sufficiently.
3. All elements present came together into large bodies, but the heat of their formation caused elements to separate according to density

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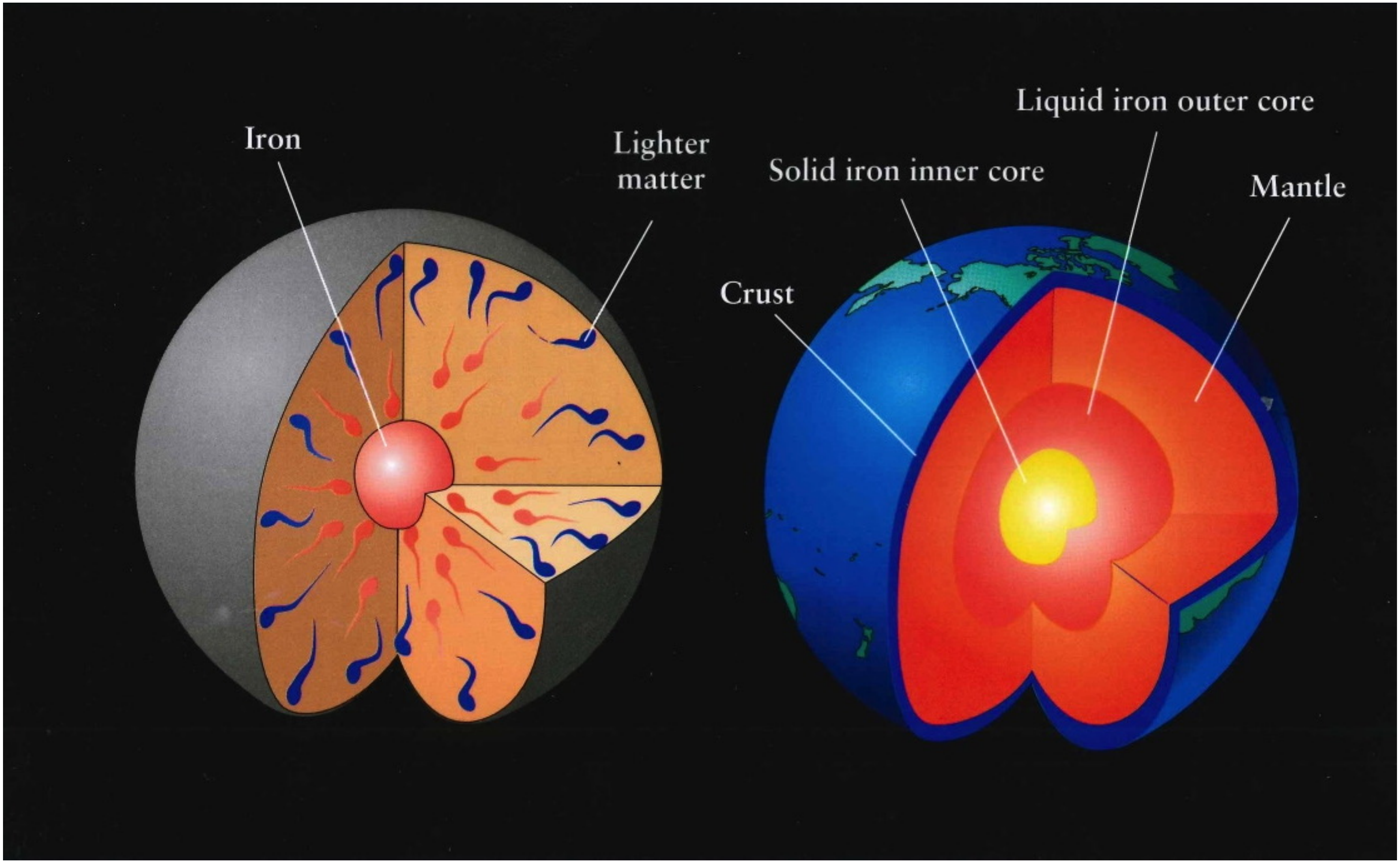
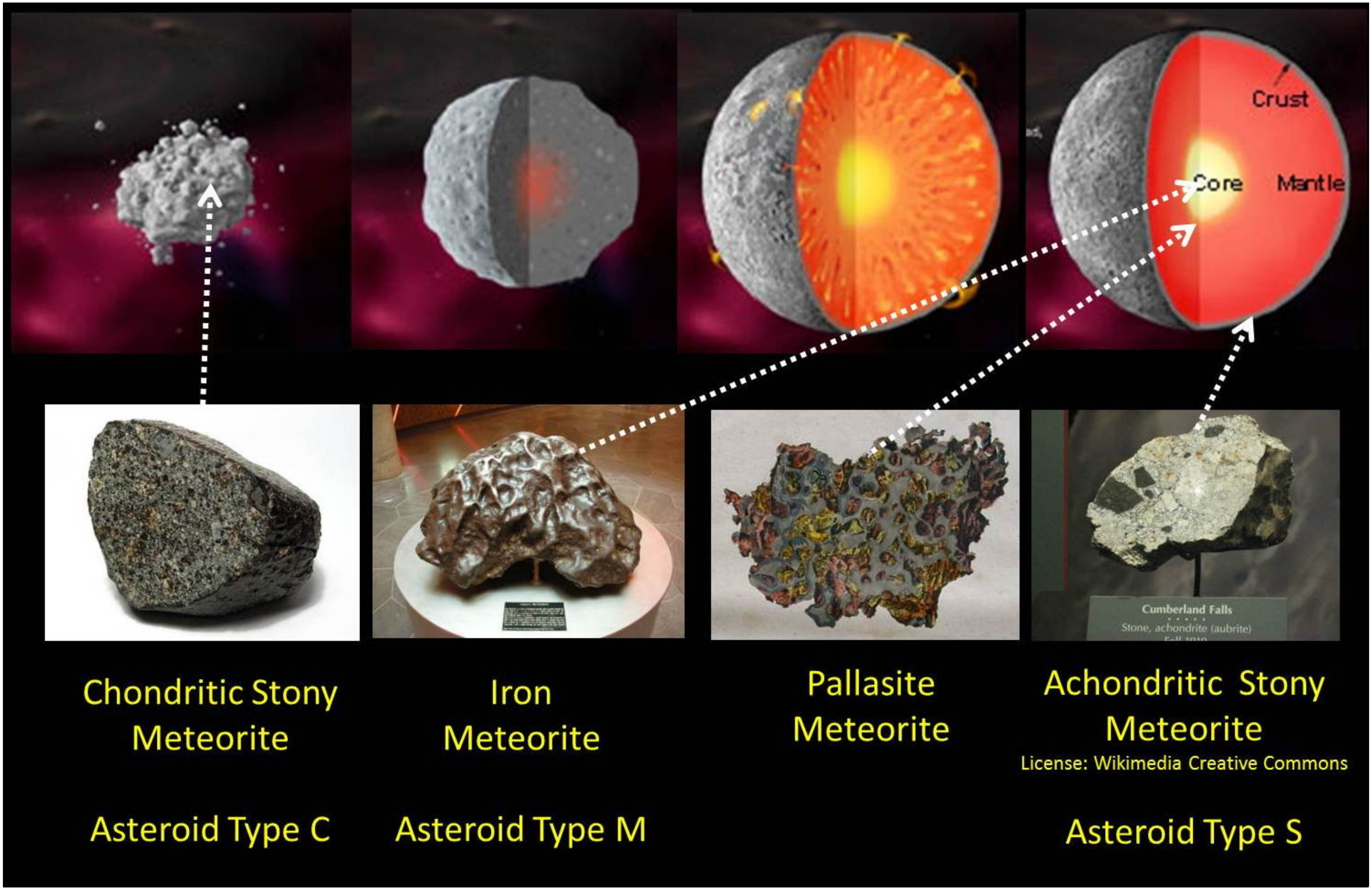
Differentiation



Meteorite classification originates in breakup of differentiated asteroid



On a given day, when is one likely to see the most "shooting stars" (meteors)?

a. dawn
b. morning
c. afternoon
d. dusk
e. before midnight
f. after midnight
g. it doesn't depend on the time of day

*tip: think about the Earth’s path through space

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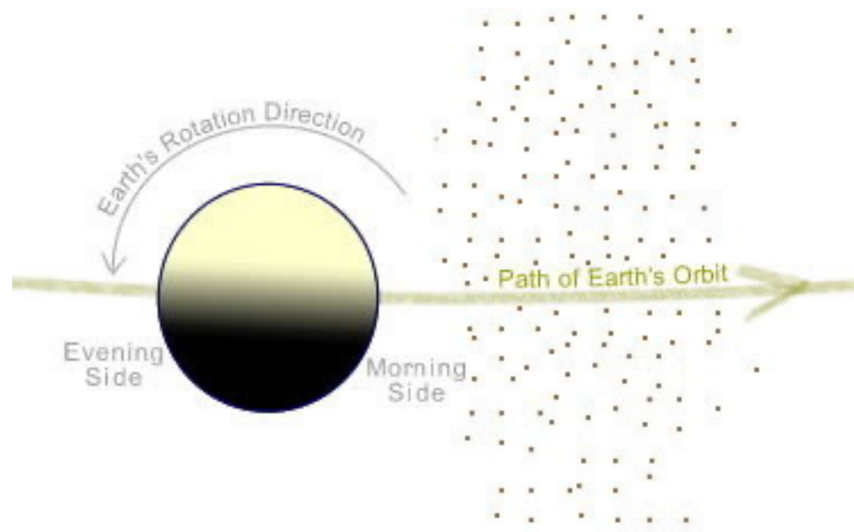

*tip: think about the Earth's path through space

Which of the following could cause a meteor shower?

a. A meteoroid hits a cloud in the atmosphere, and creates a thunderstorm.
b. Earth crosses the debris-filled orbit of a comet.
c. Asteroids in the same orbit as the Earth.
d. A small constellation of dying stars disintegrates.

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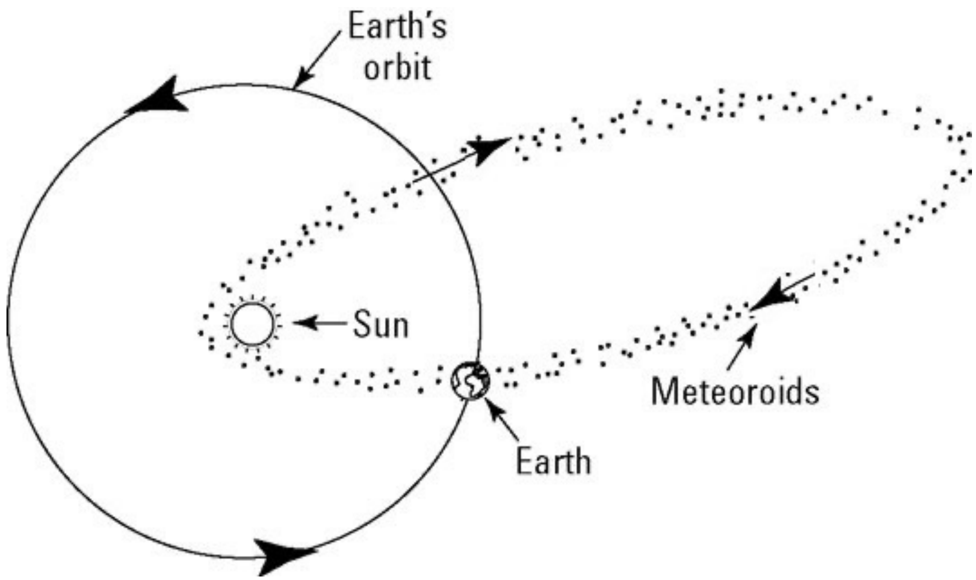
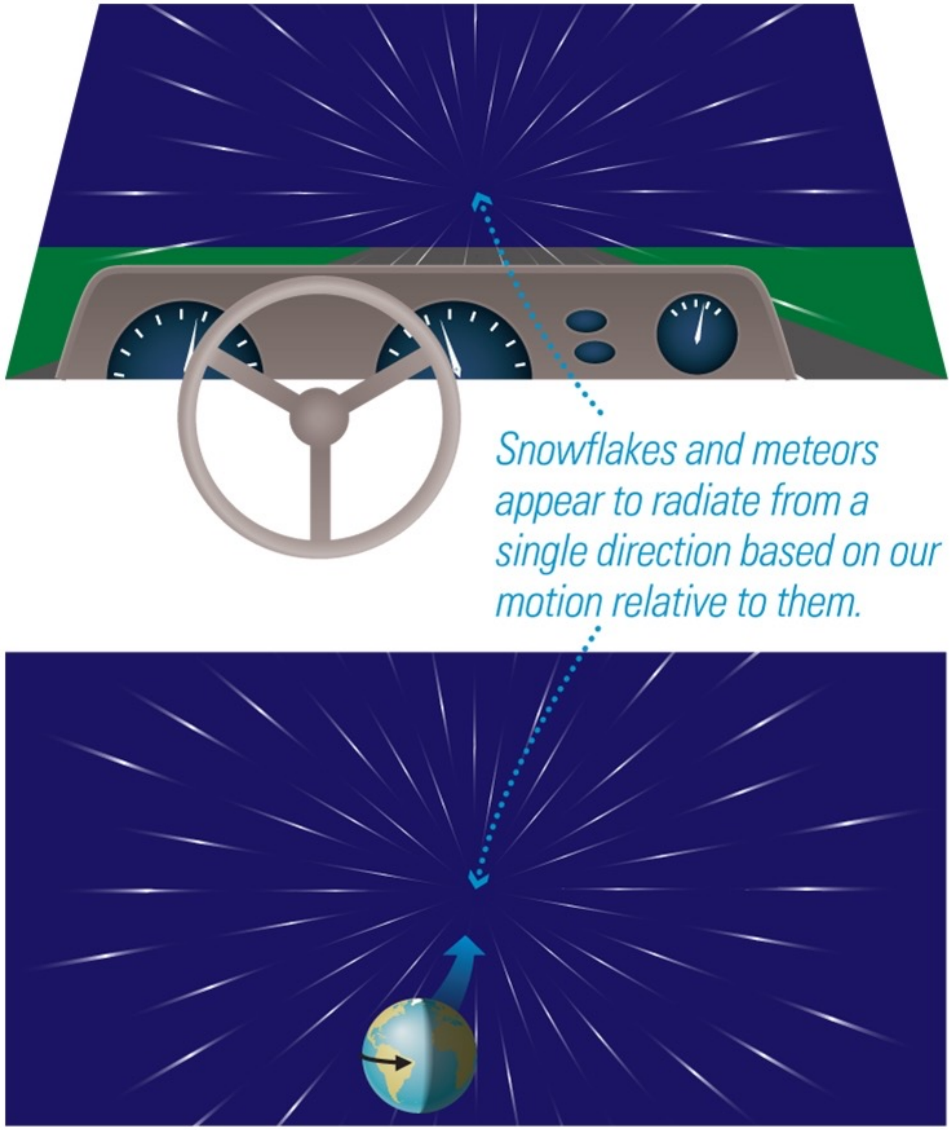


Figure 12.20a



a Meteors appear to radiate from a particular point in the sky for the same reason that we see snow or heavy rain come from a single point in front of a moving car.

Composite image of meteors from the Geminid meteor shower of 2007 - Erno Berkó.

Table 12.1

TABLE 12.1 Major Annual Meteor Showers

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

Figure 12.2a

a Comet Hyakutake.

Comets

- Similar objects to asteroids, except formed beyond the “frost line” where sunlight is weak and ice can persist
- Basic structure
  - Nucleus: loose, dirty iceberg ~ 0.1-100 km across
  - Coma: thin ice & dust envelope around surface, can grow as large as a planet or even the Sun!
  - Tails: escaping dust & gas stretching up to 4 AU!
- Comets are classified by their orbital periods
  - “short” (100’s of years)
  - “long” (10,000’s of years)
- Period corresponds to origin and recent location

The “Frost Line” or “Snow Line”

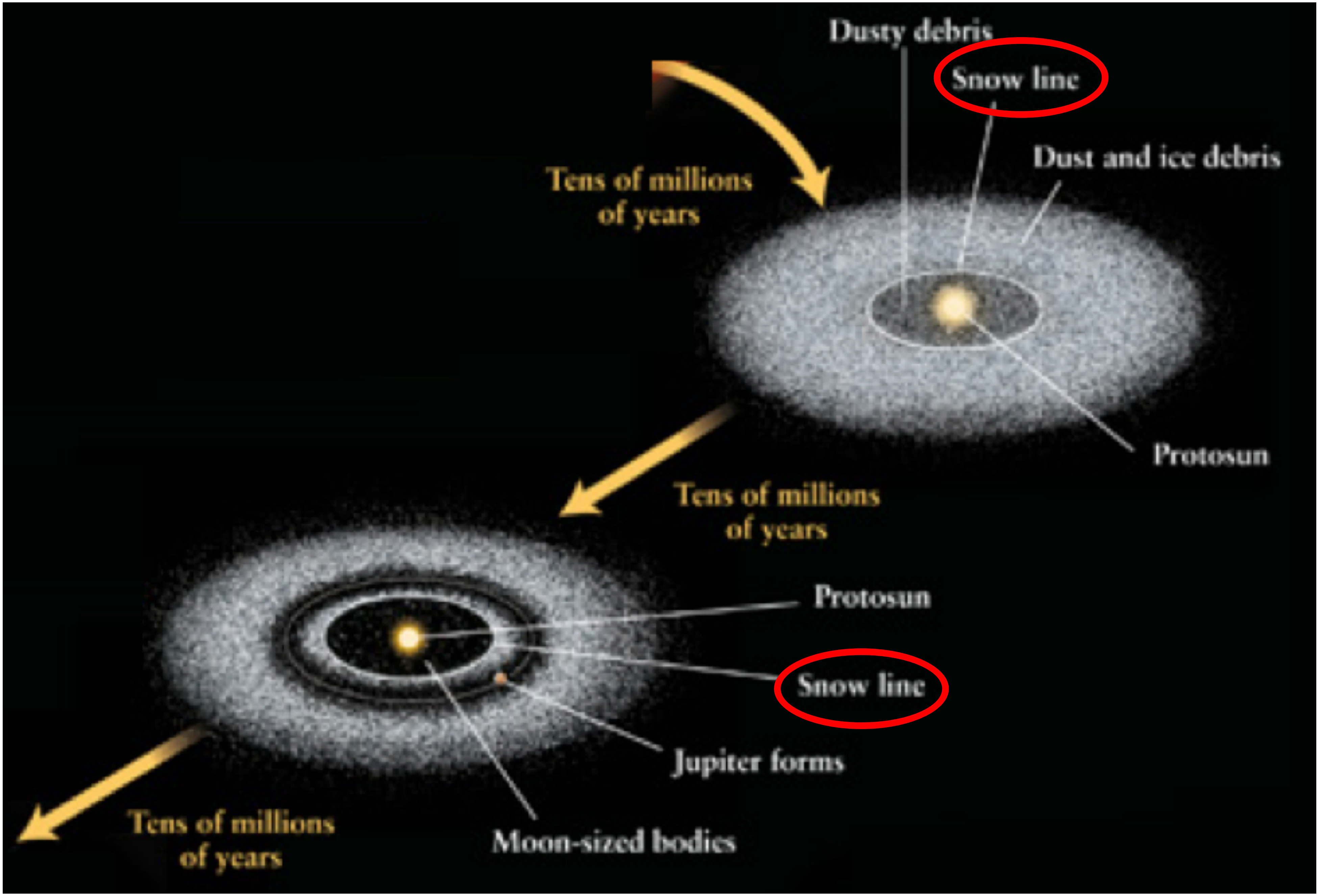


Figure 12.2b

b Comet Hale-Bopp, photographed over Boulder, Colorado.

The tail of a comet is generally directed

a. away from the Sun because of the solar wind and radiation pressure
b. opposite the direction of motion as the comet passes through interplanetary matter
c. toward the Sun because of the Sun's gravitational force
d. along the comet's magnetic field lines

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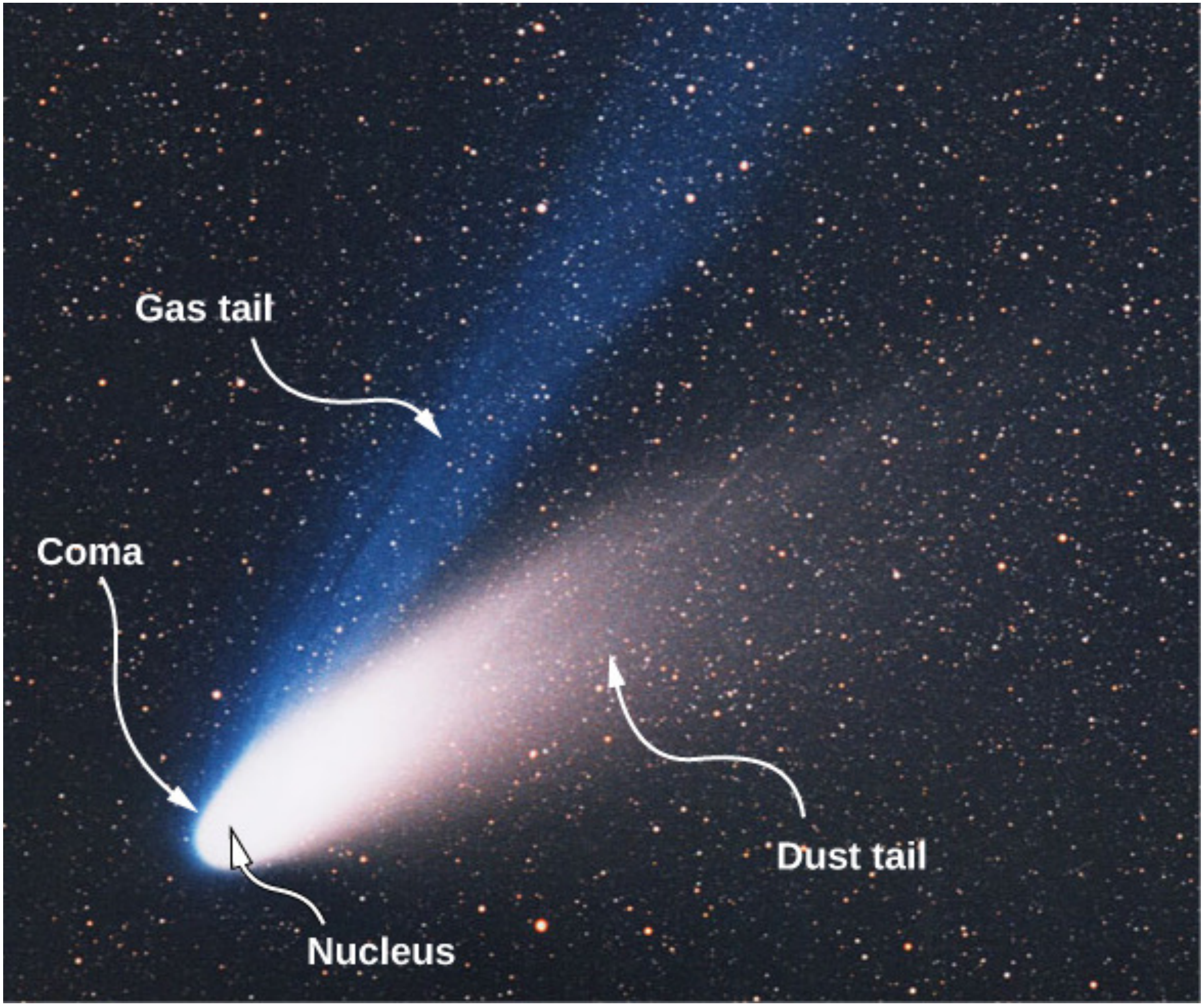
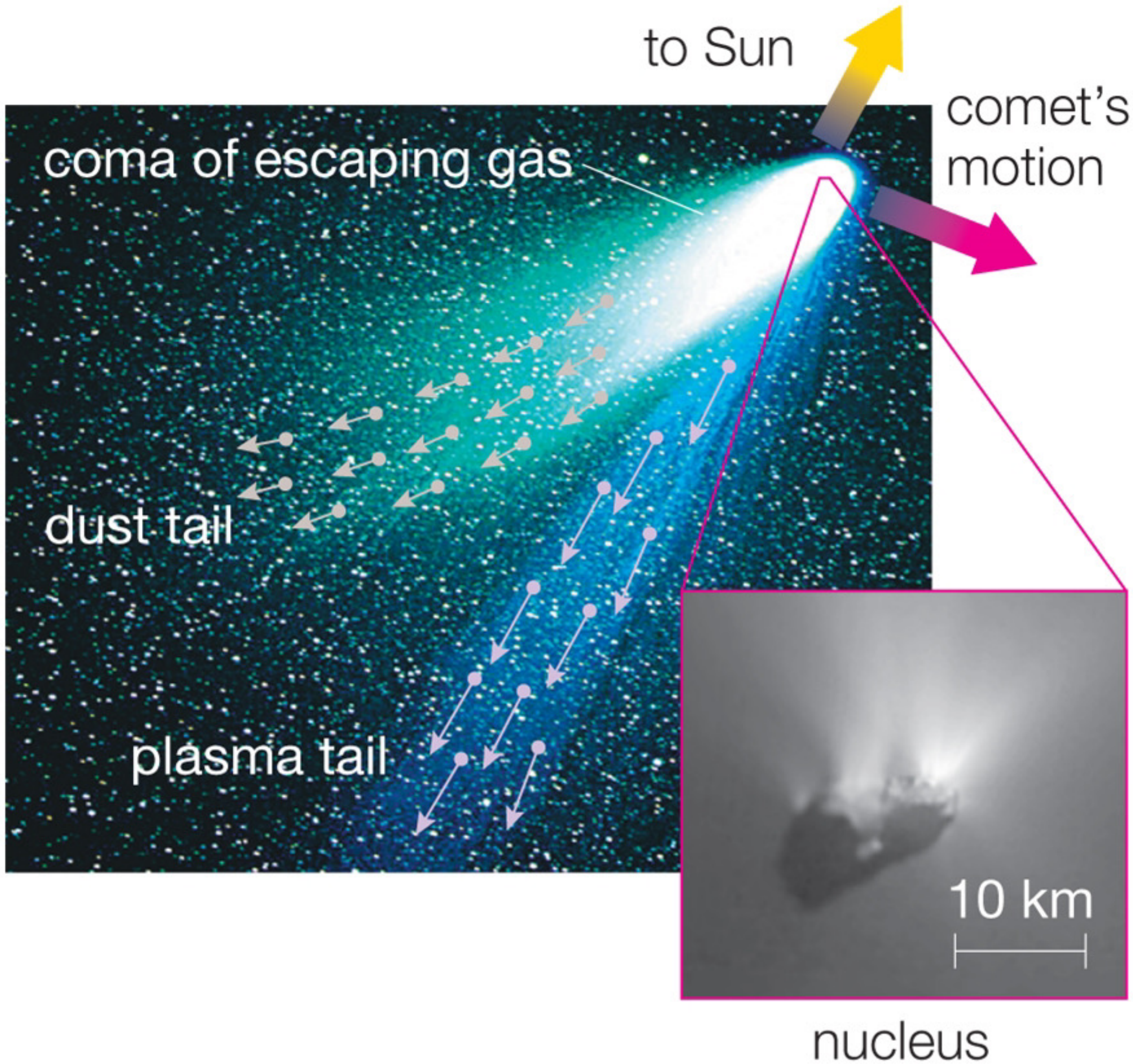
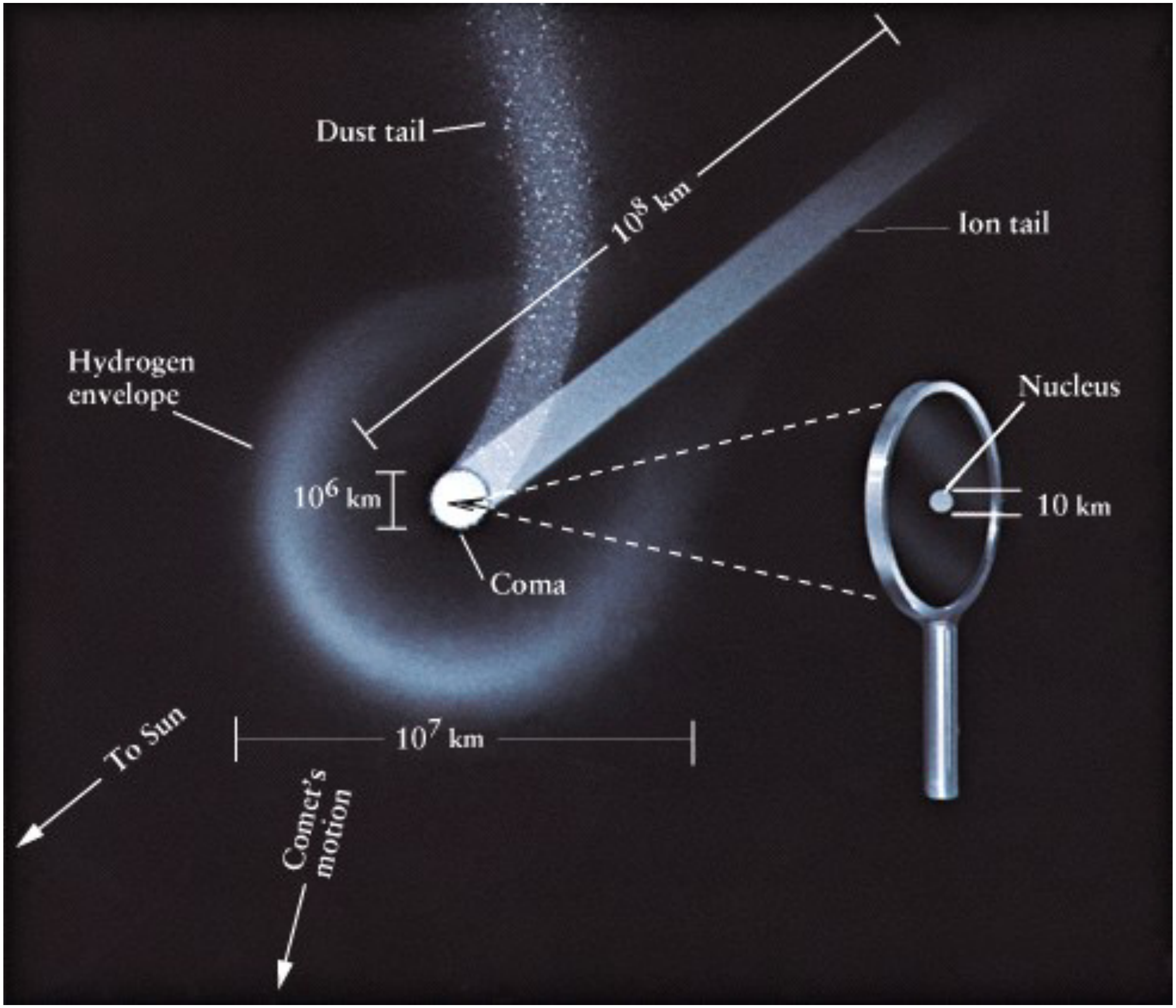
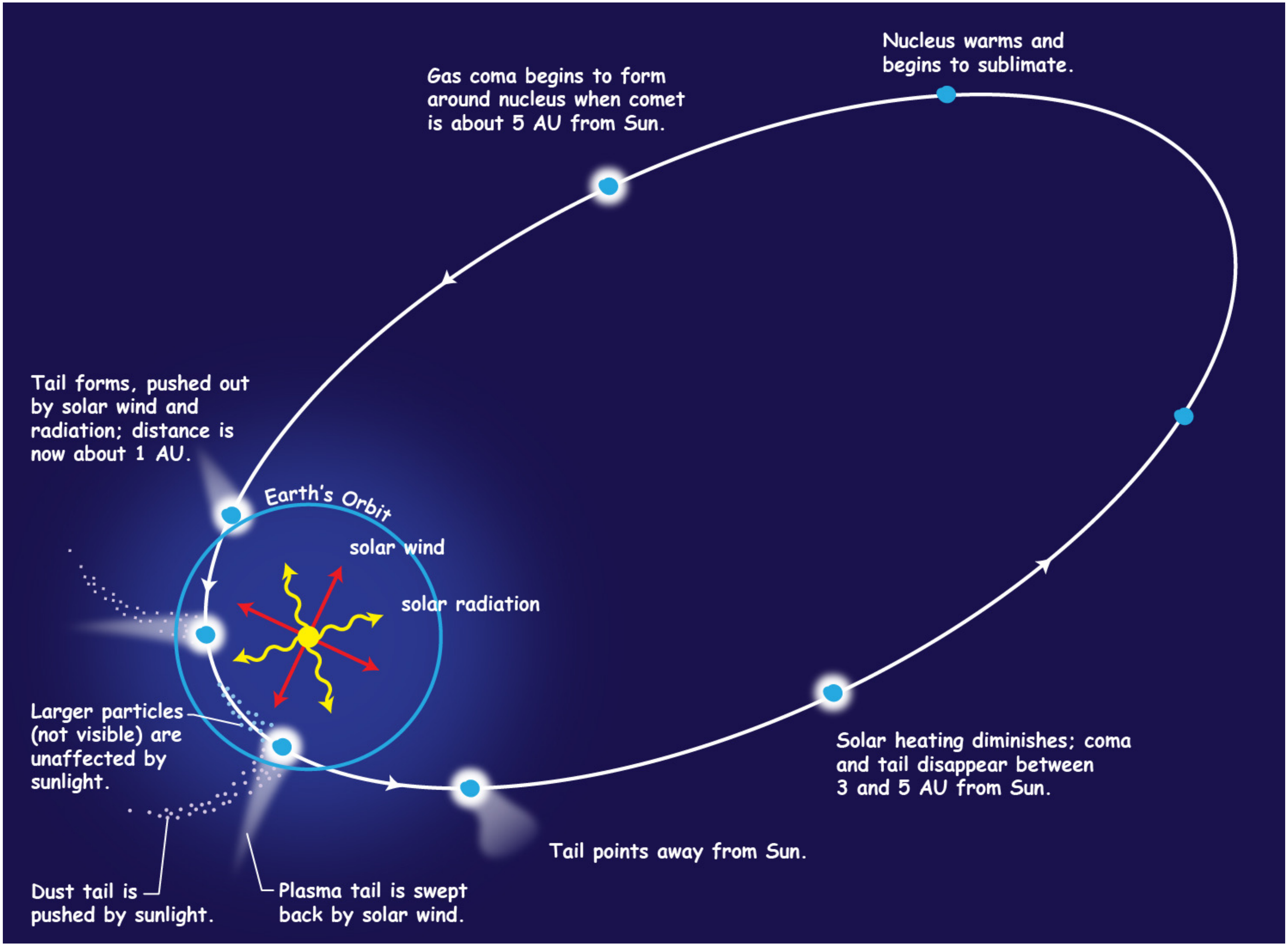

Gas tail
Coma
Dust tail
Nucleus

Figure 12.15b



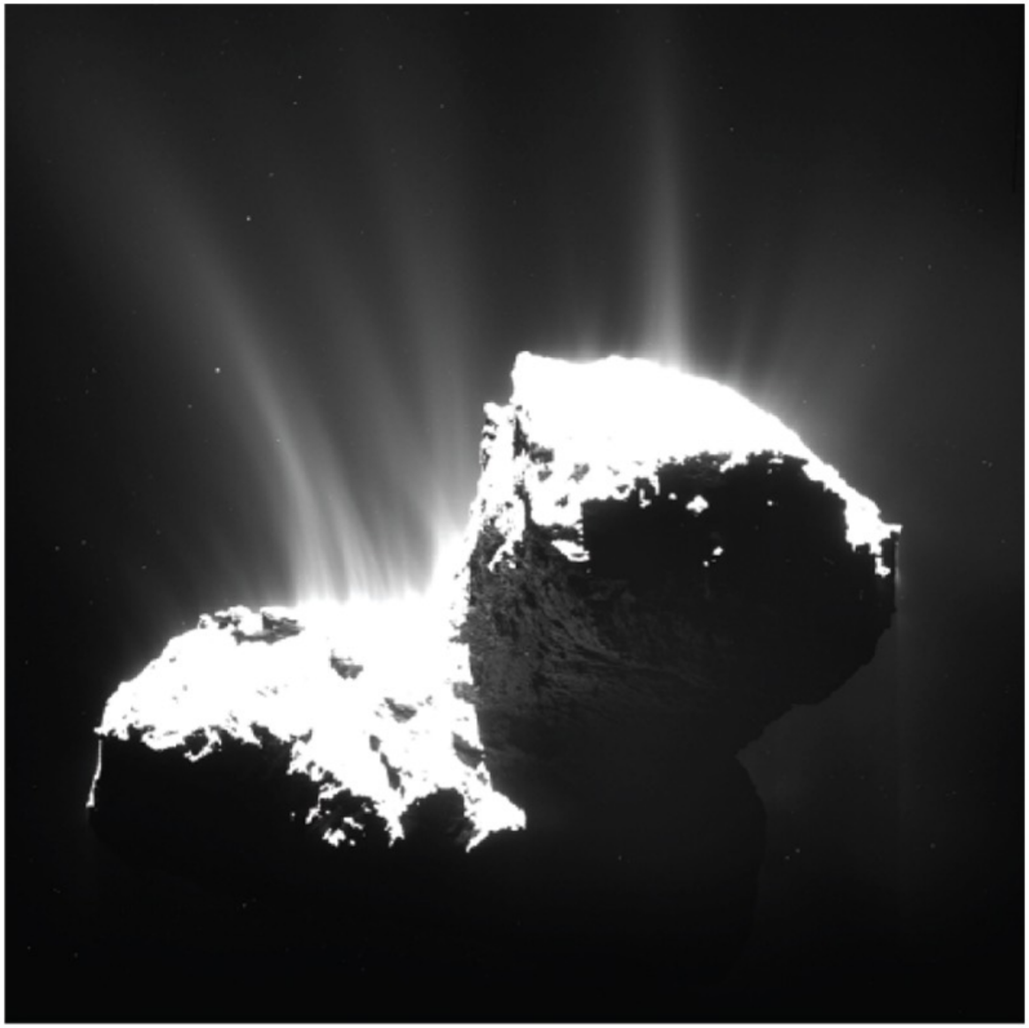
b Anatomy of a comet. The larger image is a ground-based photo of Comet Hale-Bopp. The inset shows the nucleus of Halley's Comet photographed by the *Giotto* spacecraft.


Dust tail
10^8 km
Ion tail
Hydrogen envelope
Nucleus
10^6 km
10 km
Coma
To Sun
10^7 km
Comet's motion


Nucleus warms and
begins to sublimate.
Gas coma begins to form
around nucleus when comet
is about 5 AU from Sun.
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.
Solar heating diminishes; coma
and tail disappear between
3 and 5 AU from Sun.
Tail points away from Sun.
Dust tail is
pushed by sunlight.
Plasma tail is swept
back by solar wind.

Comet Churyumov–Gerasimenko

Figure 12.18a

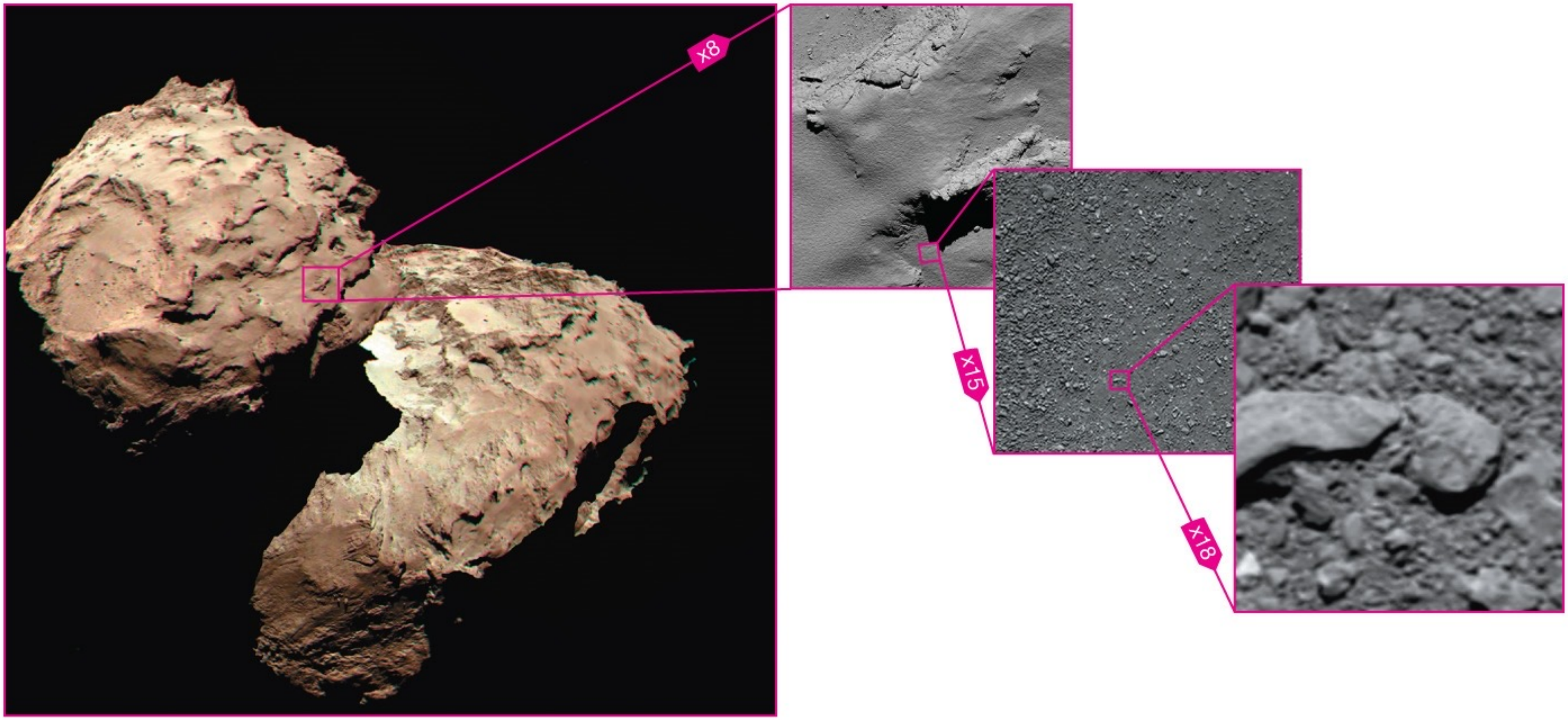


a This image (from November 2014) shows jets of material vaporizing into space.

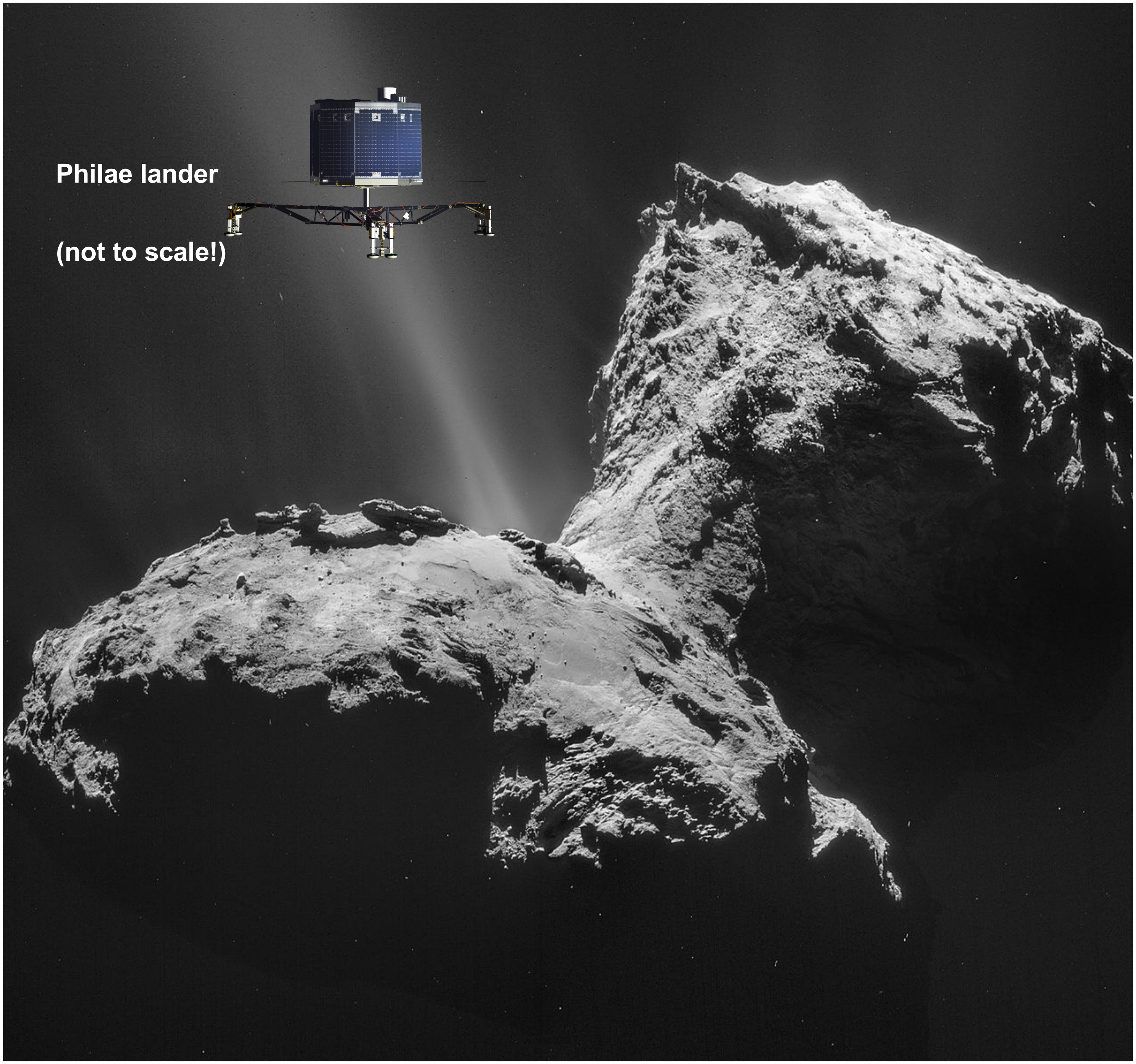
Figure 12.18b

b Close-up of a jet shortly before the comet reached perihelion in August 2015.

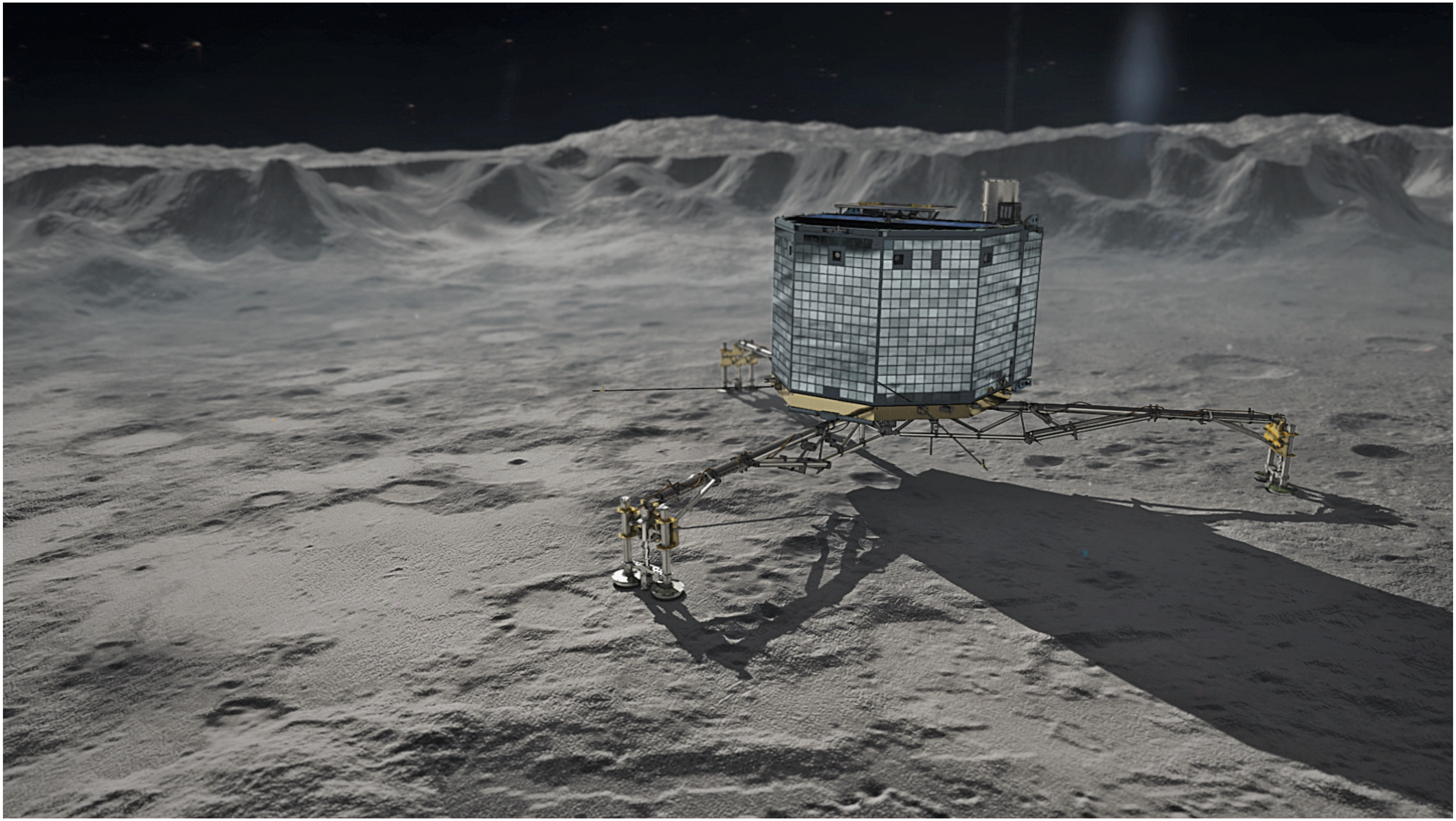
Figure 12.19



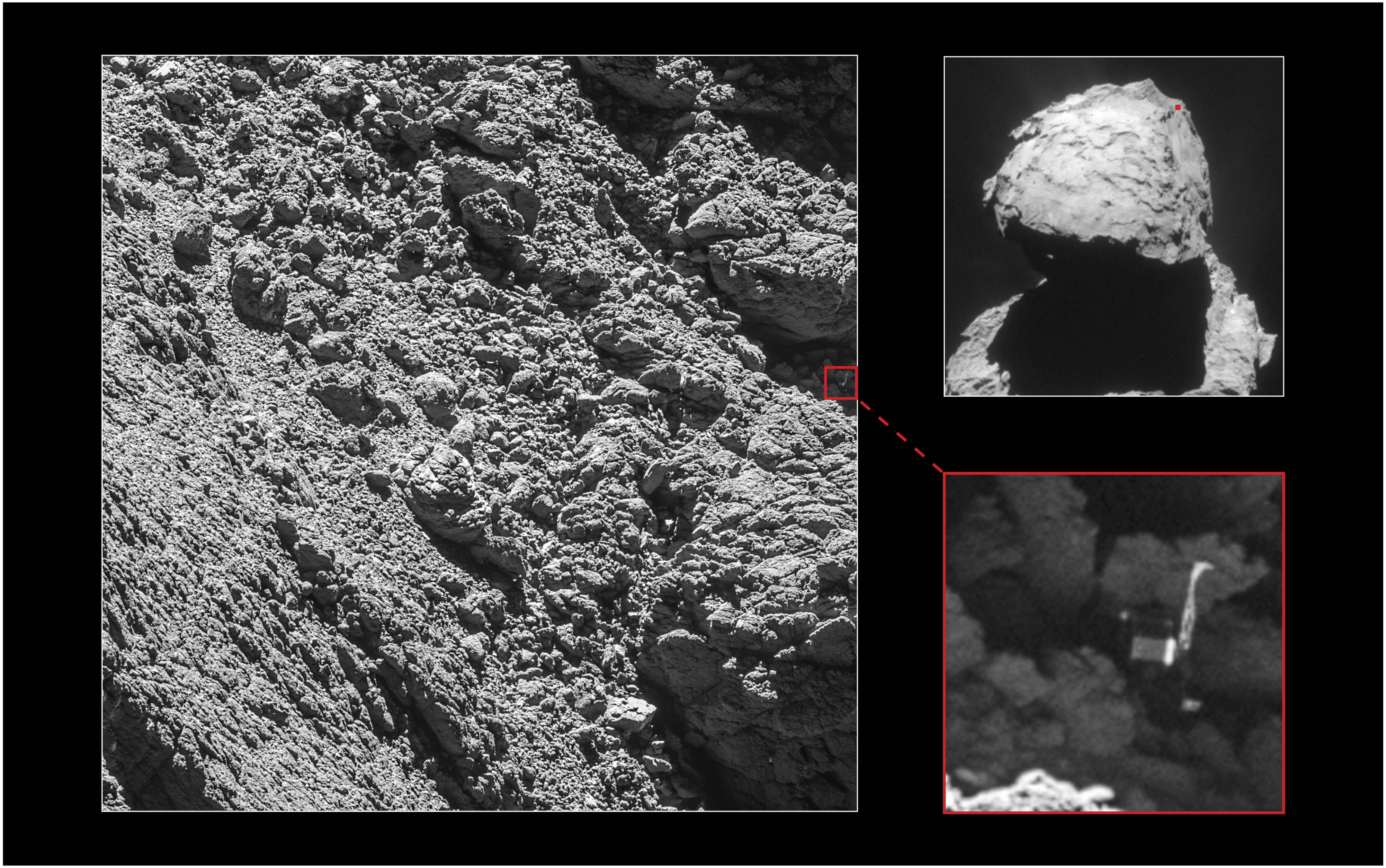
Comet Churyumov–Gerasimenko



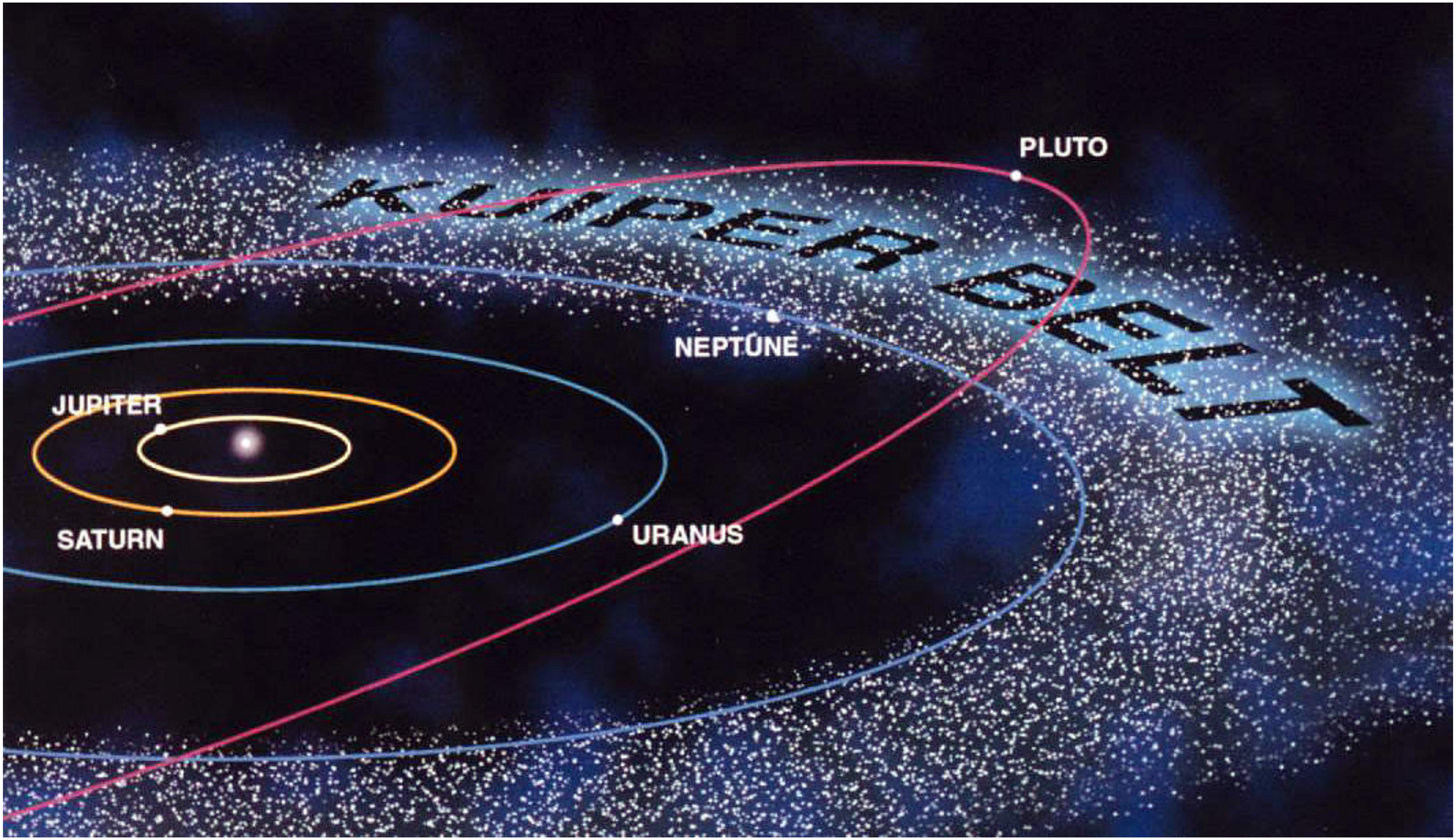
Philae landing – artist's impression



Philae found!



THE KUIPER BELT (about 2 million comets, 20-50 AU)



Long-period comets have orbits that are

a. the same as short-period comets, just longer
b. circular
c. always in the ecliptic
d. randomly oriented with respect to the ecliptic
e. of low eccentricity

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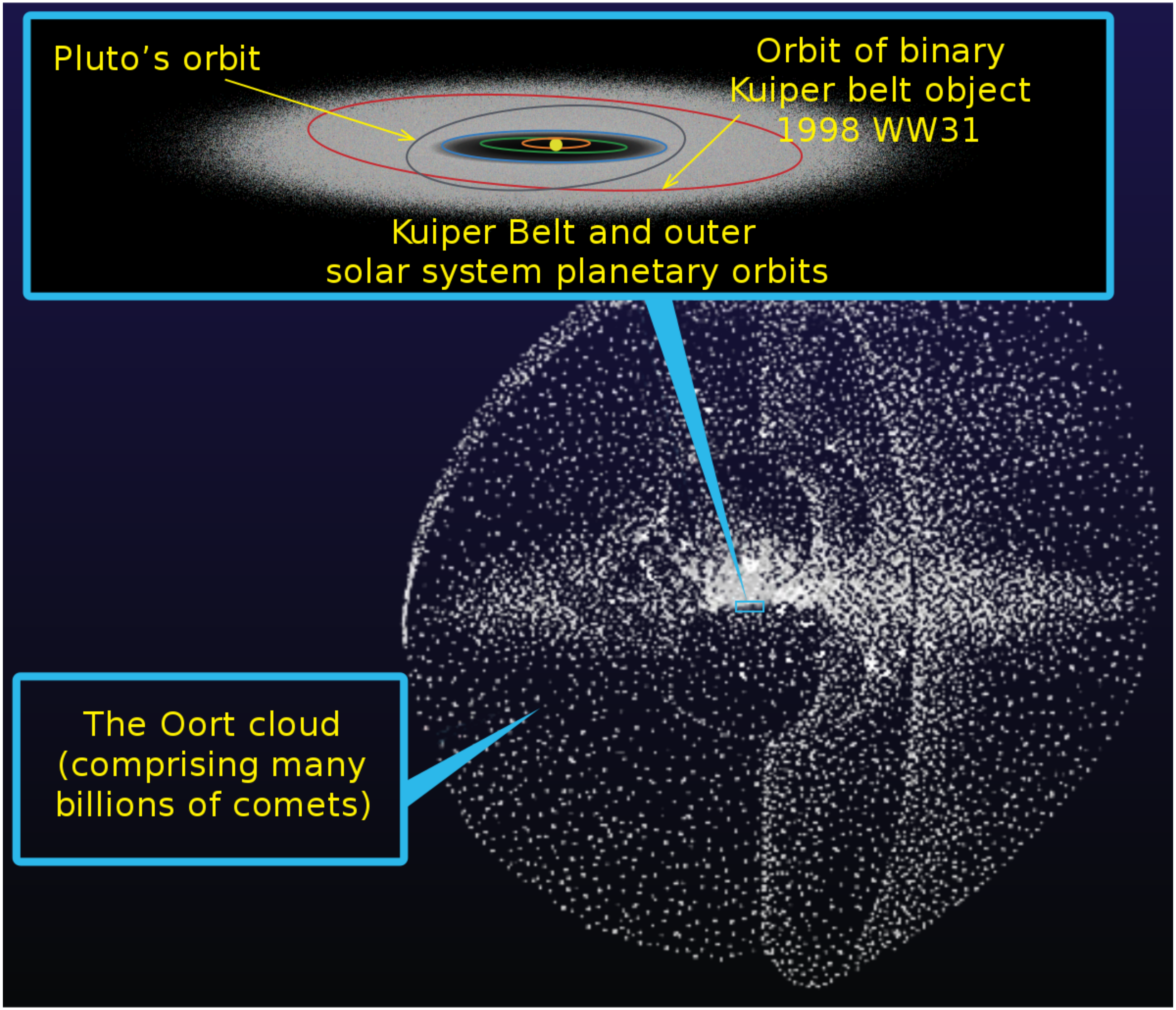

Pluto's orbit
Orbit of binary Kuiper belt object 1998 WW31
Kuiper Belt and outer solar system planetary orbits
The Oort cloud (comprising many billions of comets)

Oort cloud, a billion comets, 2000–200,000 AU

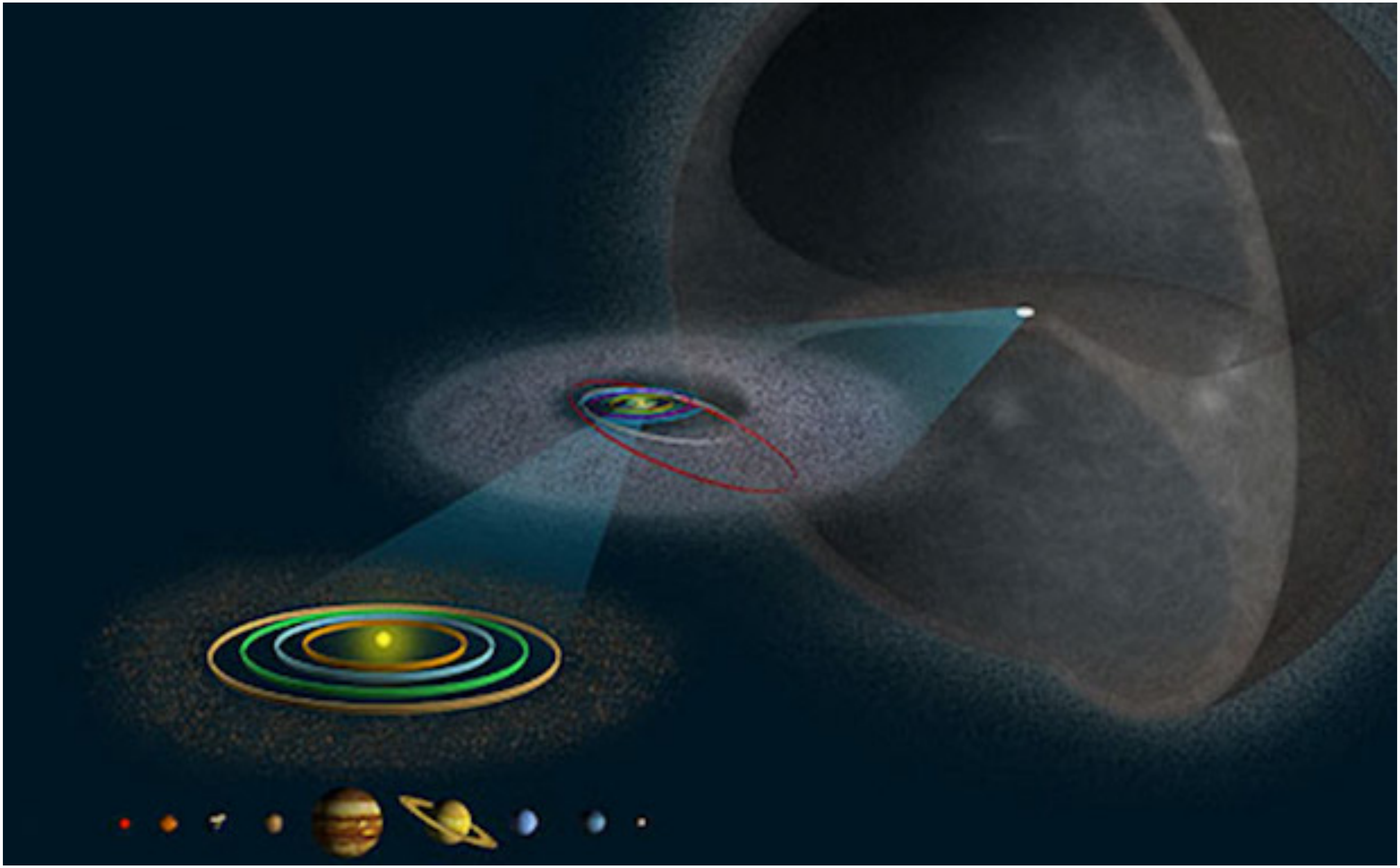


Figure 12.34

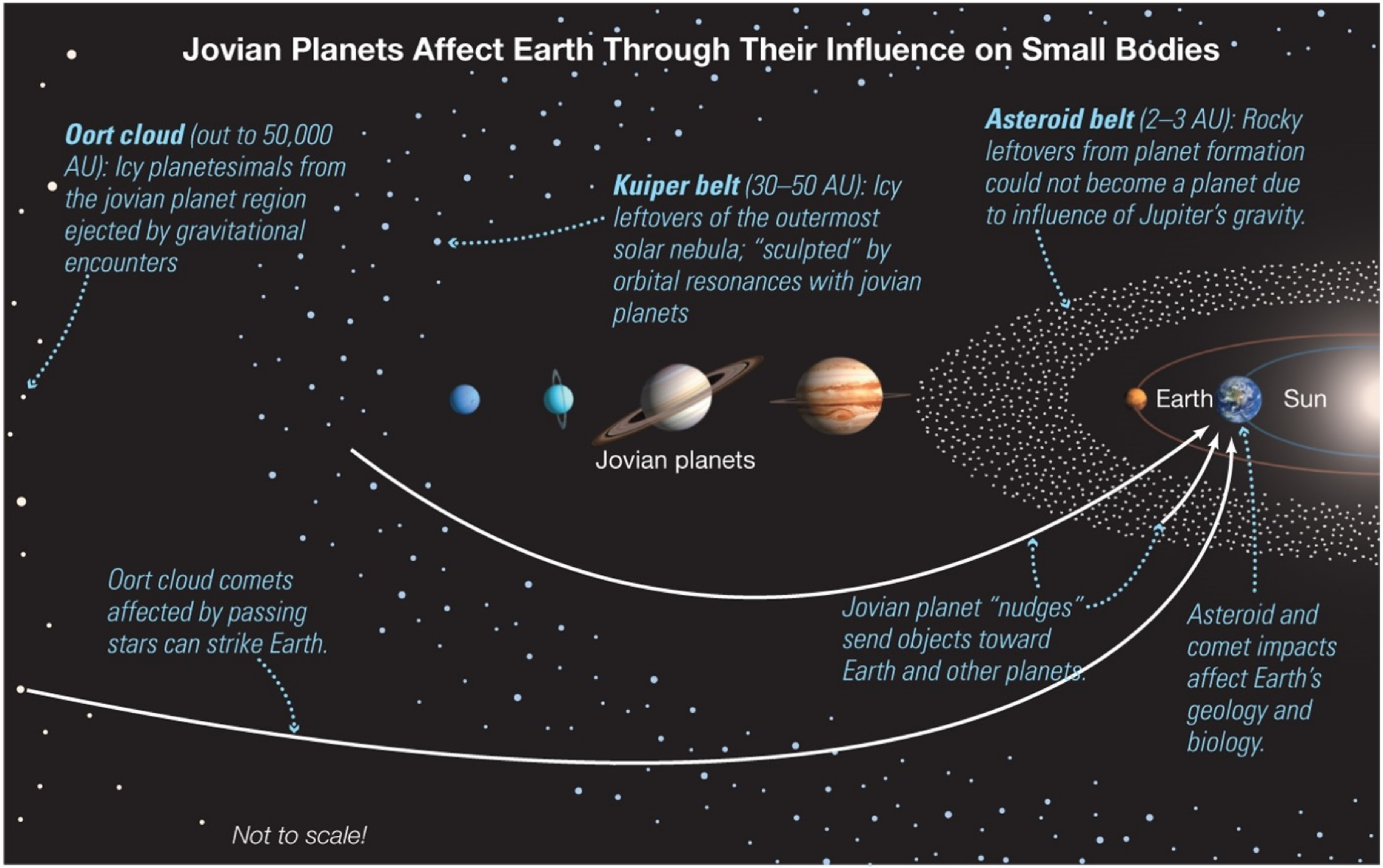

Jovian Planets Affect Earth Through Their Influence on Small Bodies
Oort cloud (out to 50,000 AU): Icy planetesimals from the jovian planet region ejected by gravitational encounters
Kuiper belt (30–50 AU): Icy leftovers of the outermost solar nebula; "sculpted" by orbital resonances with jovian planets
Asteroid belt (2–3 AU): Rocky leftovers from planet formation could not become a planet due to influence of Jupiter's gravity.
Earth
Sun
Jovian planets
Oort cloud comets affected by passing stars can strike Earth.
Jovian planet "nudges" send objects toward Earth and other planets.
Asteroid and comet impacts affect Earth's geology and biology.
Not to scale!

Figure 12.21

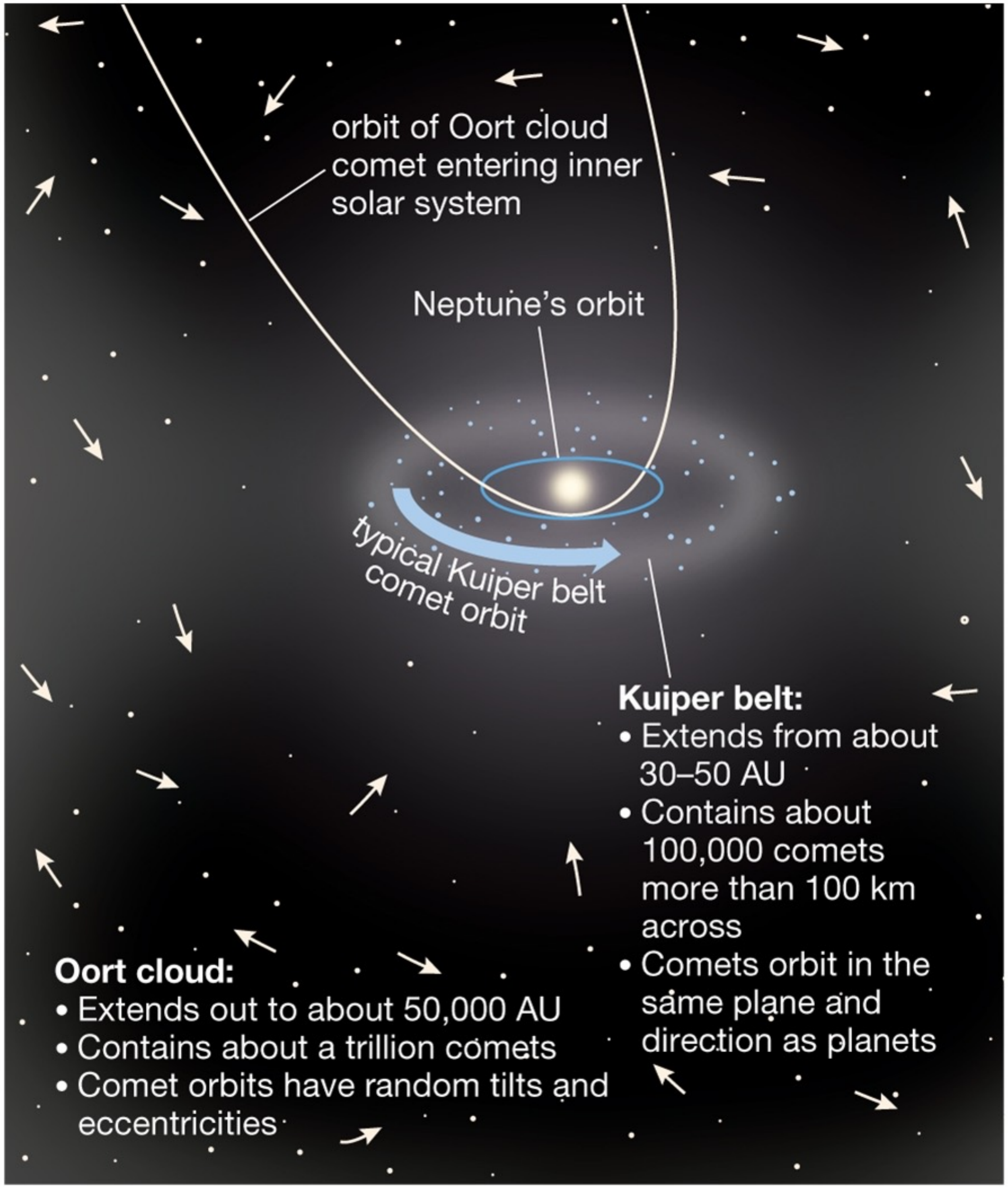
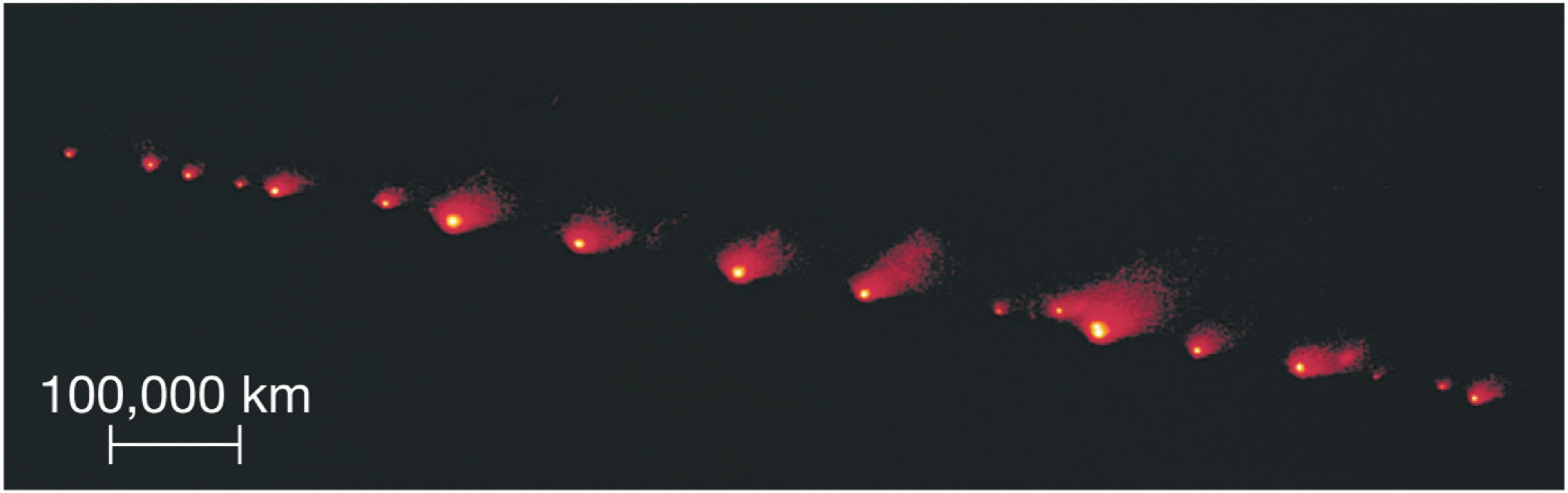
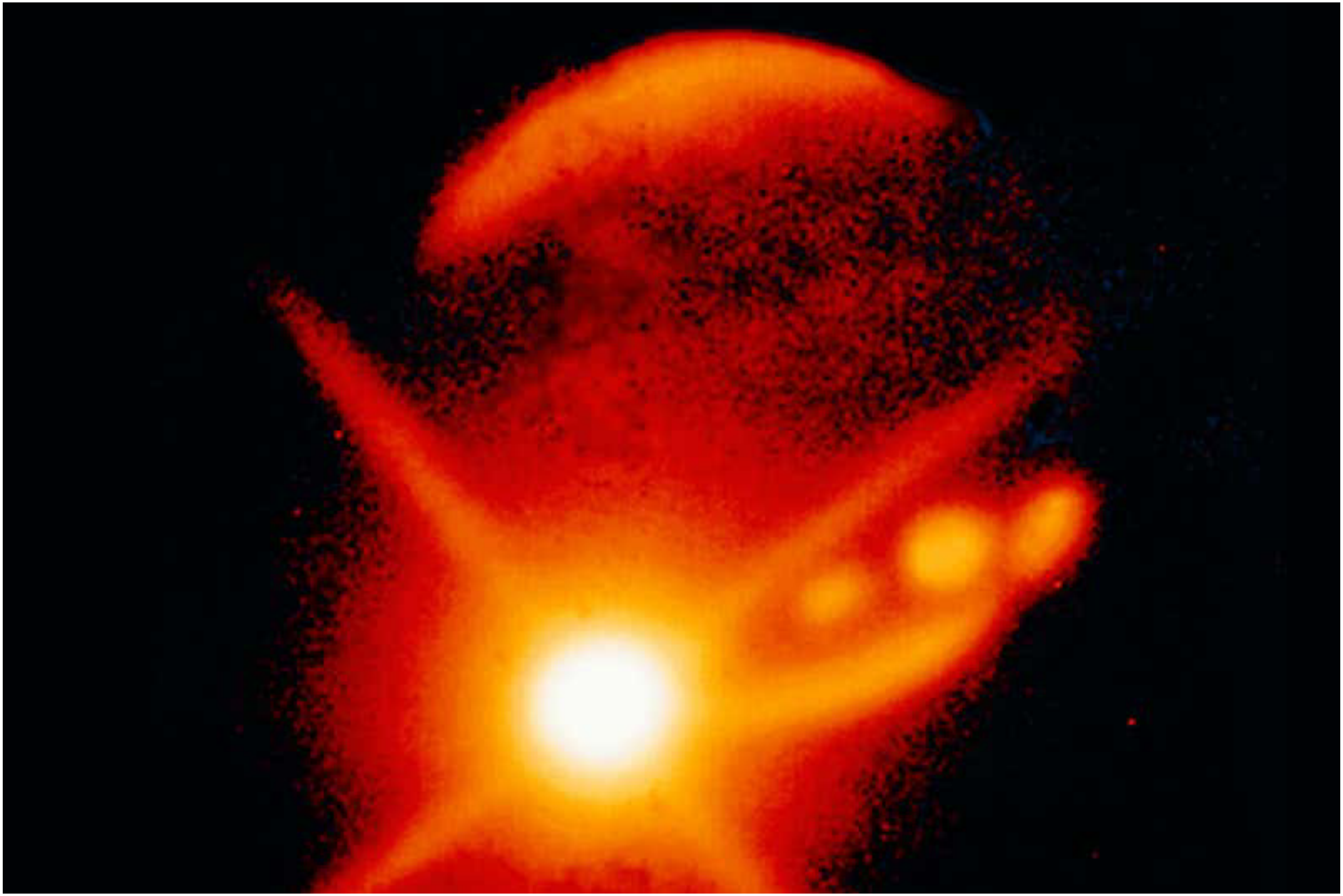

orbit of Oort cloud comet entering inner solar system
Neptune's orbit
typical Kuiper belt comet orbit
Kuiper belt:
• Extends from about 30–50 AU
• Contains about 100,000 comets more than 100 km across
• Comets orbit in the same plane and direction as planets
Oort cloud:
• Extends out to about 50,000 AU
• Contains about a trillion comets
• Comet orbits have random tilts and eccentricities

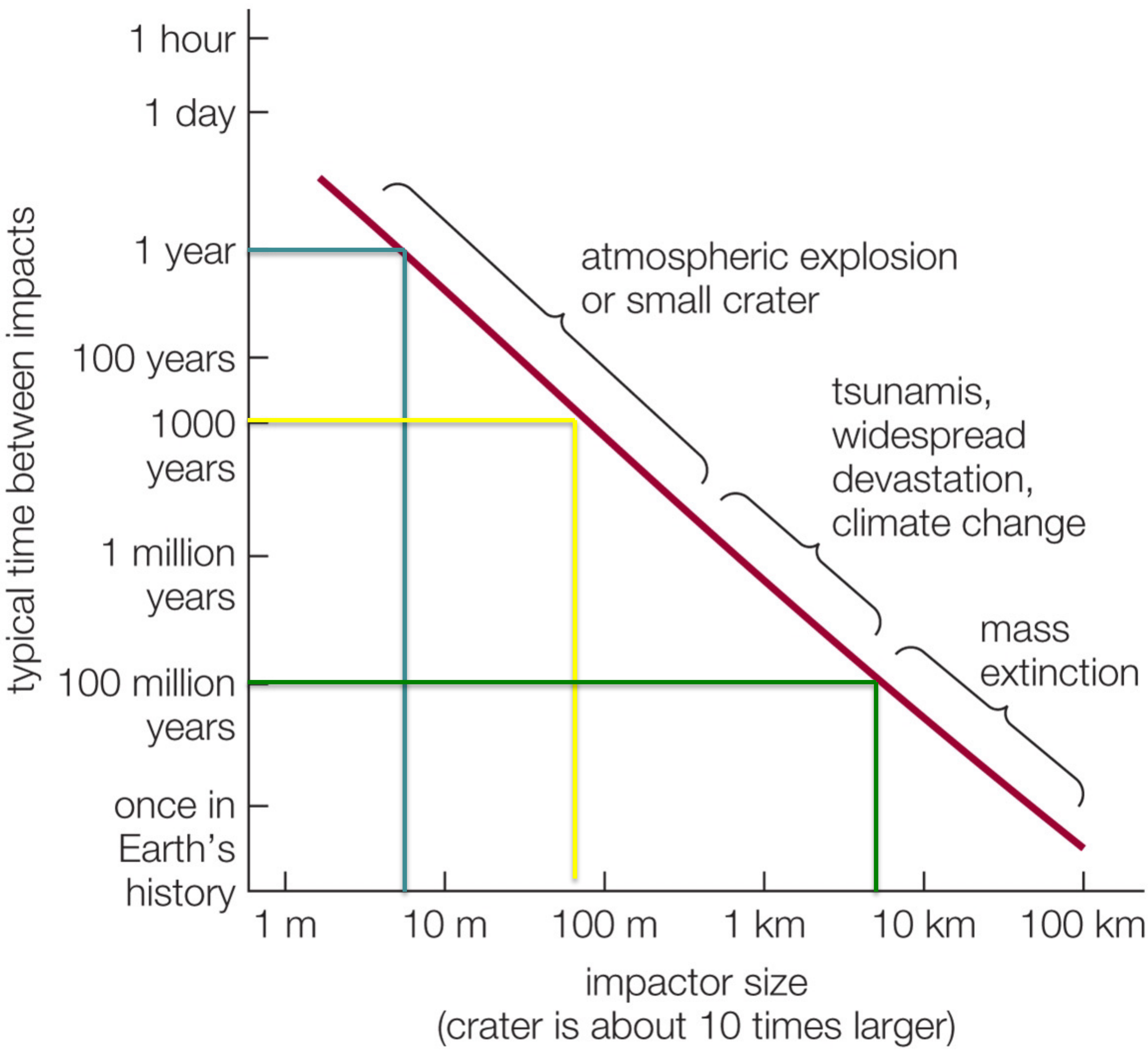
Figure 12.27a



a Jupiter's tidal forces ripped Comet SL9 apart, breaking its nucleus into this chain of smaller nuclei.

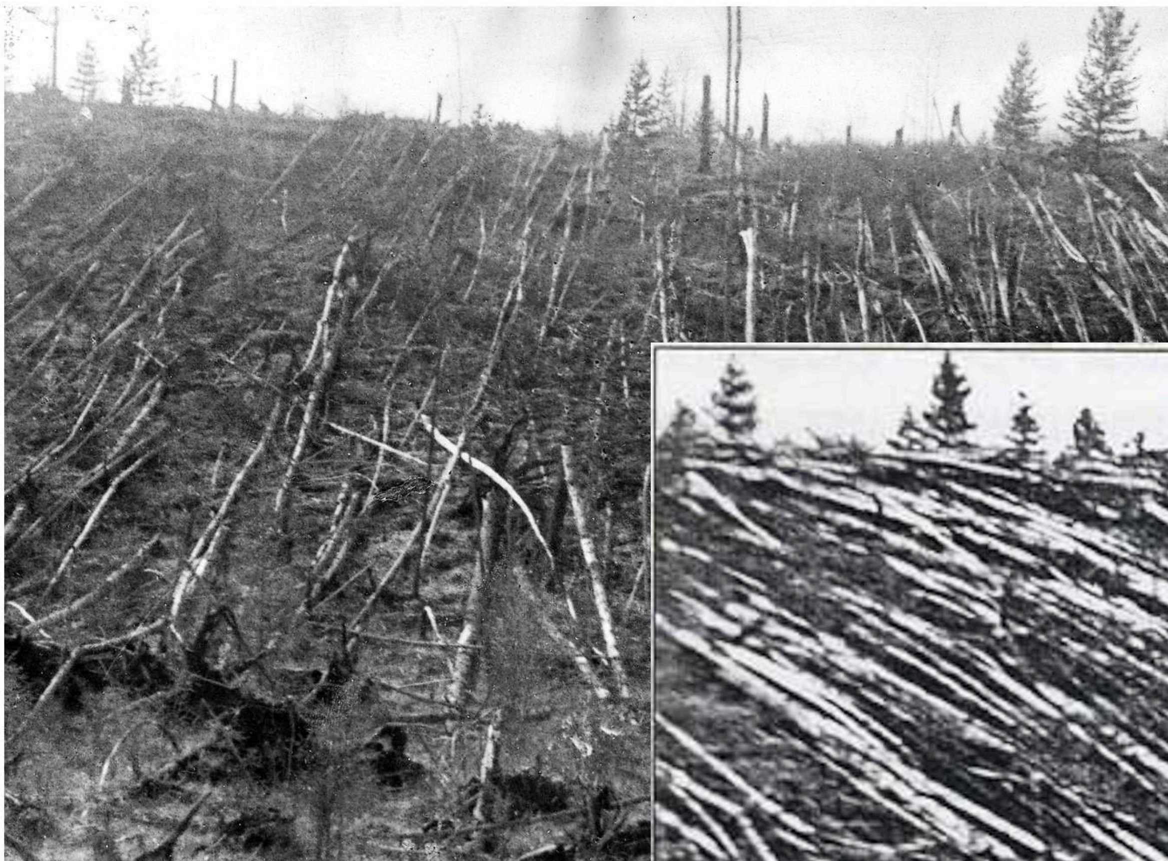
Shoemaker-Levy impact




typical time between impacts
1 hour
1 day
1 year
100 years
1000 years
1 million years
100 million years
once in Earth's history
atmospheric explosion or small crater
tsunamis, widespread devastation, climate change
mass extinction
1 m
10 m
100 m
1 km
10 km
100 km
impactor size
(crater is about 10 times larger)

The Tunguska Event - 30 June 1908

The Tunguska Event – the aftermath 19 years later!



Pluto and other Kuiper Belt objects

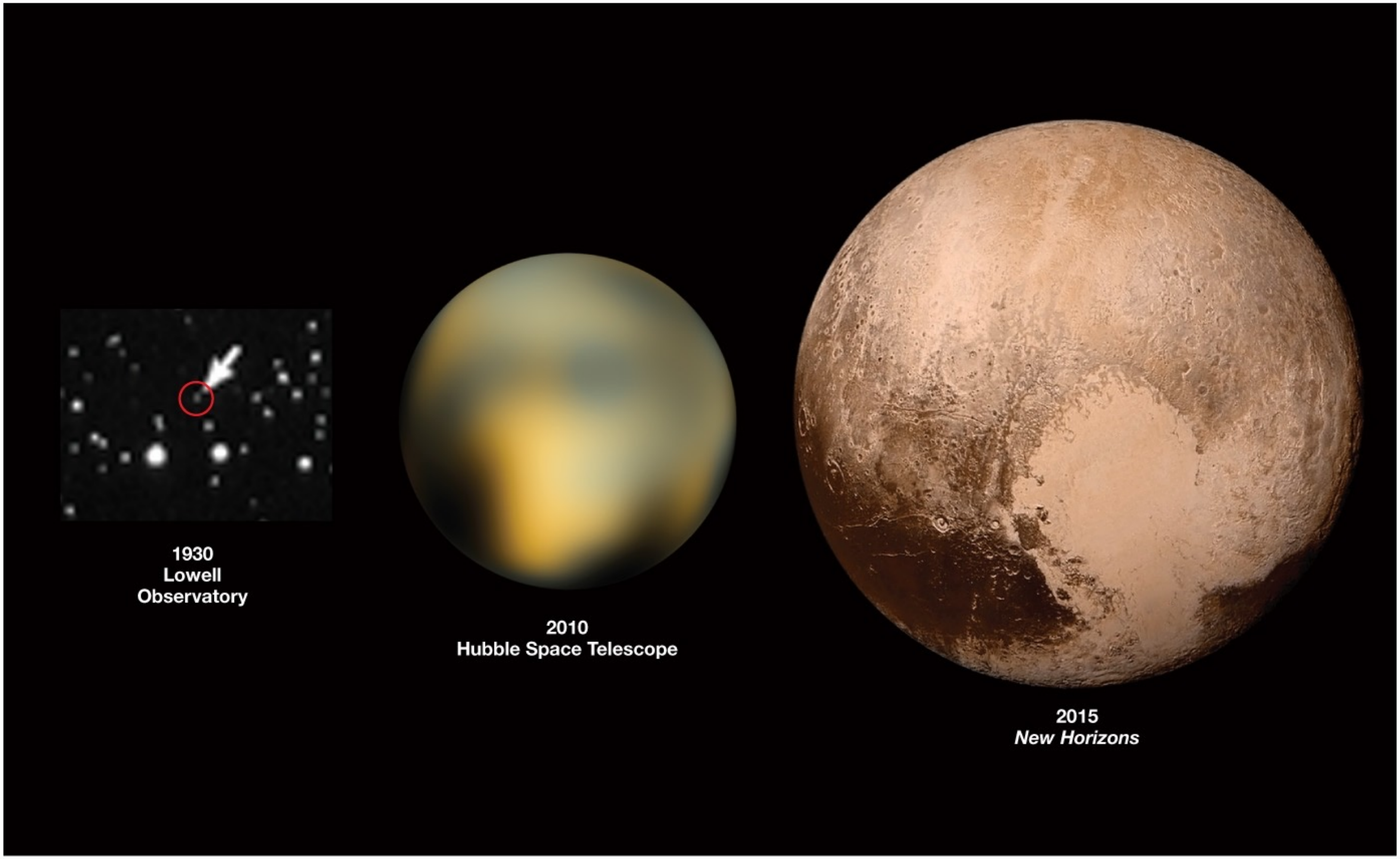


Figure 12.4

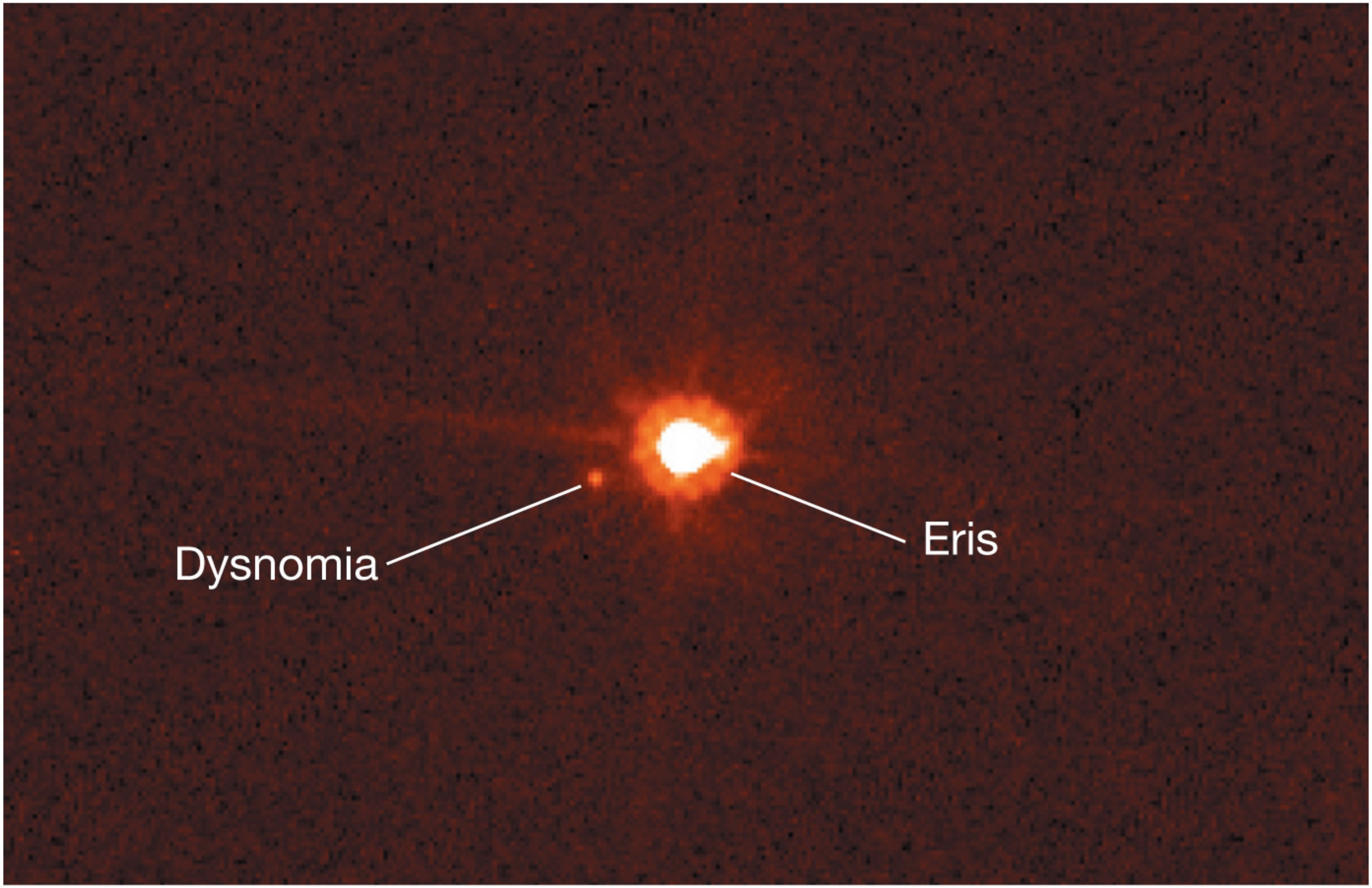


Figure 12.5


Dysnomia
Nix
Kerberos
Styx
Charon
Namaka
Hydra
Hi'iaka
Eris
Pluto
Makemake
Haumea
Weywot
Vanth
Sedna
2007 OR10
Quaoar
Orcus
Ceres (asteroid)
Vesta (asteroid)
1000 km

Ultima Thule