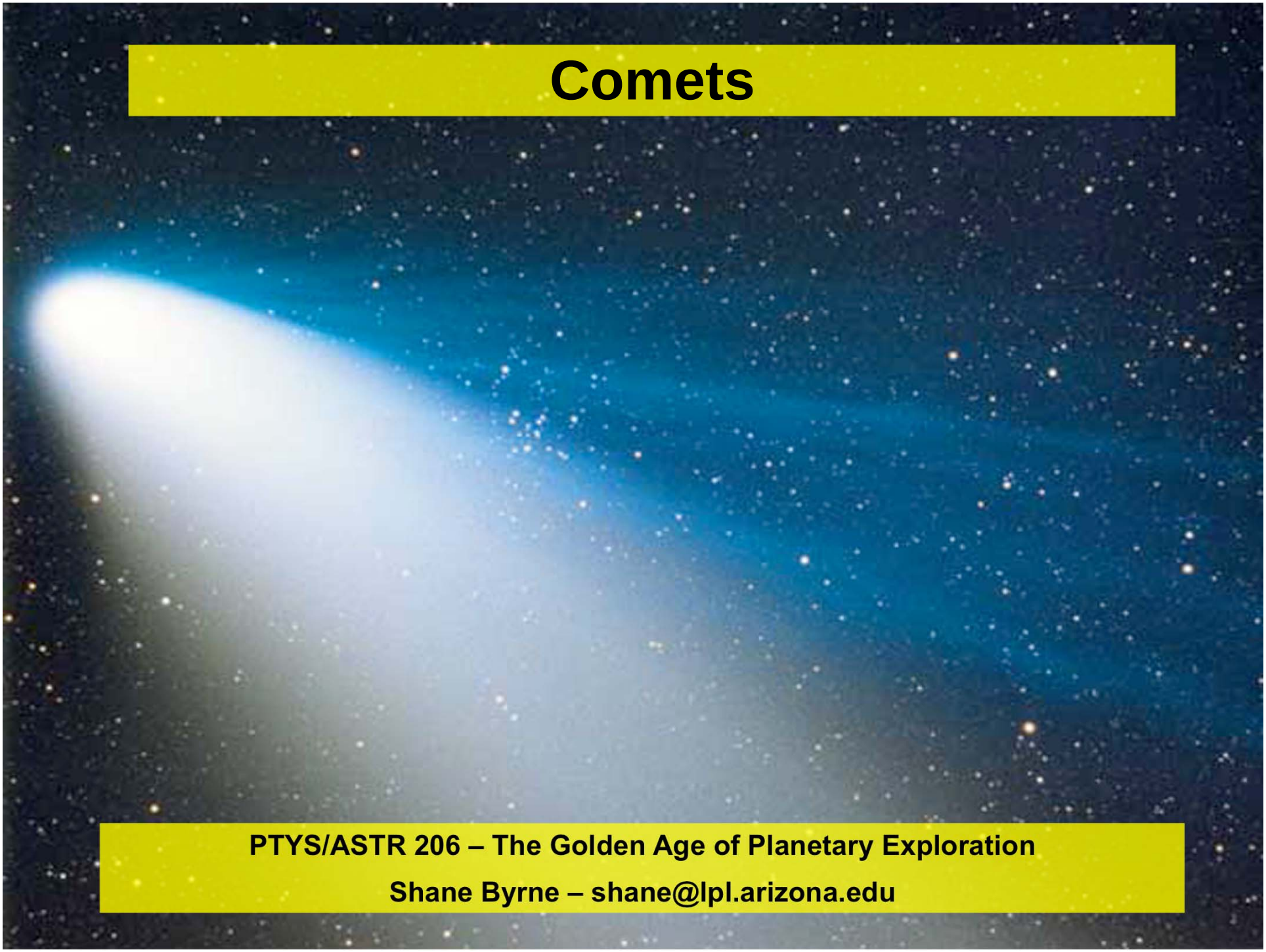
- **Announcements**
  - **HW6 available today, due in a week**
    - **Use Kevin as the TA for this one**
  - **2 In-class assignments left in 3 lectures**

Comets



PTYS/ASTR 206 – The Golden Age of Planetary Exploration

Shane Byrne – shane@lpl.arizona.edu

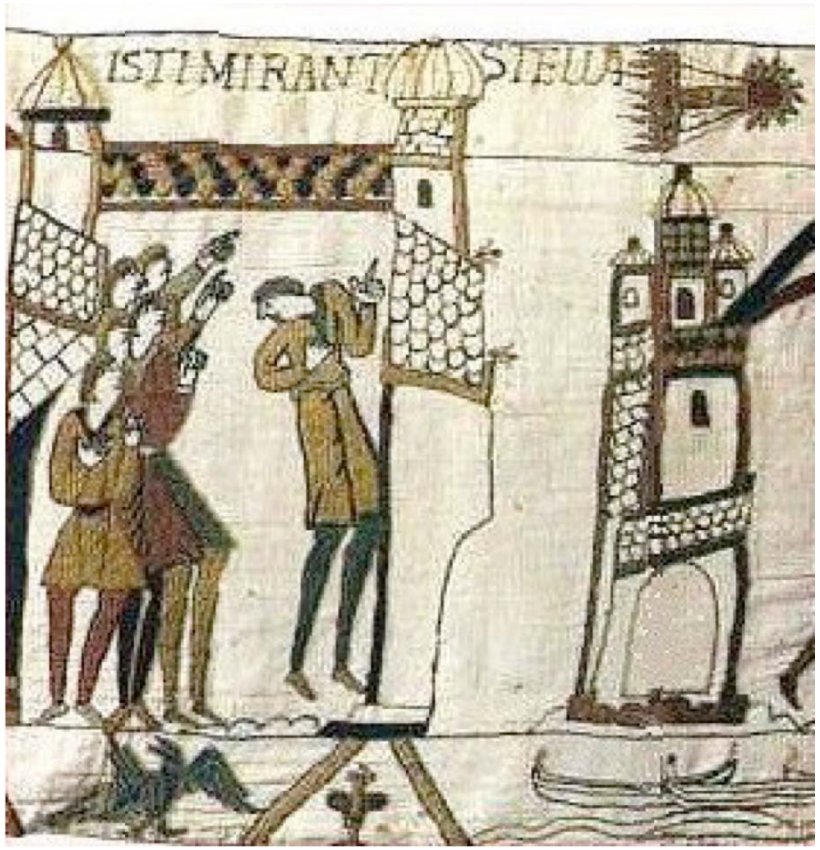
In this lecture…

- Observations of comets
- What are comets?
  - Composition and structure
- Cometary tails
  - Ion and dust tails
- Where do comets come from?
  - Orbits of comets
  - Oort cloud
  - Scattered Kuiper Belt

Observations of comets

- Comets have been known from ancient times
  - Thought to foreshadow disasters and major battles

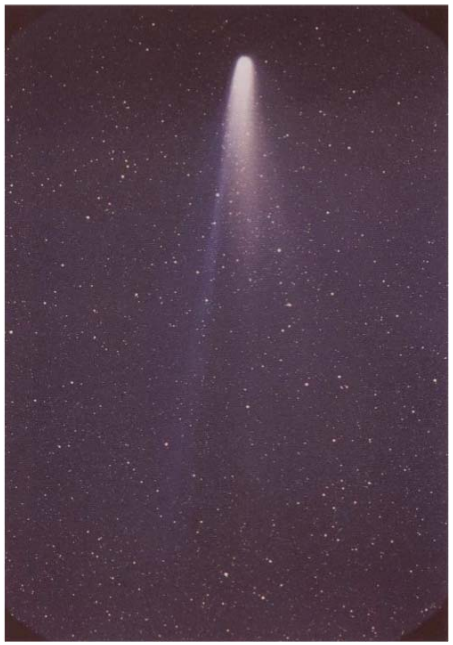
- Pre-telescopes the known solar system was a pretty empty place
  - Moon and the Sun
  - Mercury, Venus, Mars, Jupiter, Saturn
  - And COMETS
  - No Uranus
  - No Neptune
  - No planetary Moons (except ours)
  - No Asteroids
  - No Kuiper Belt Objects



- **People have recorded comet sightings for millennia**

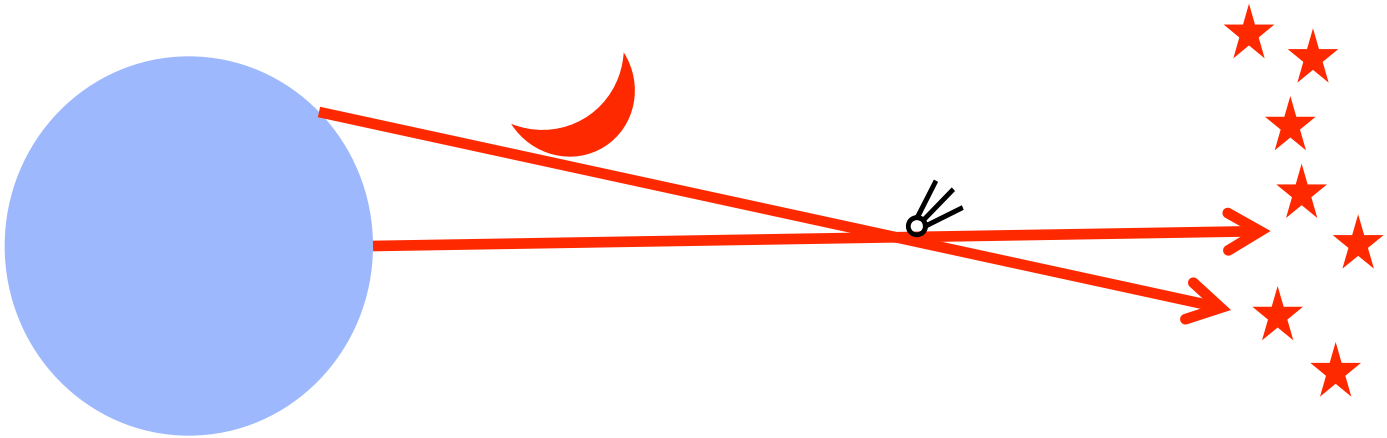
167 BC

687 AD



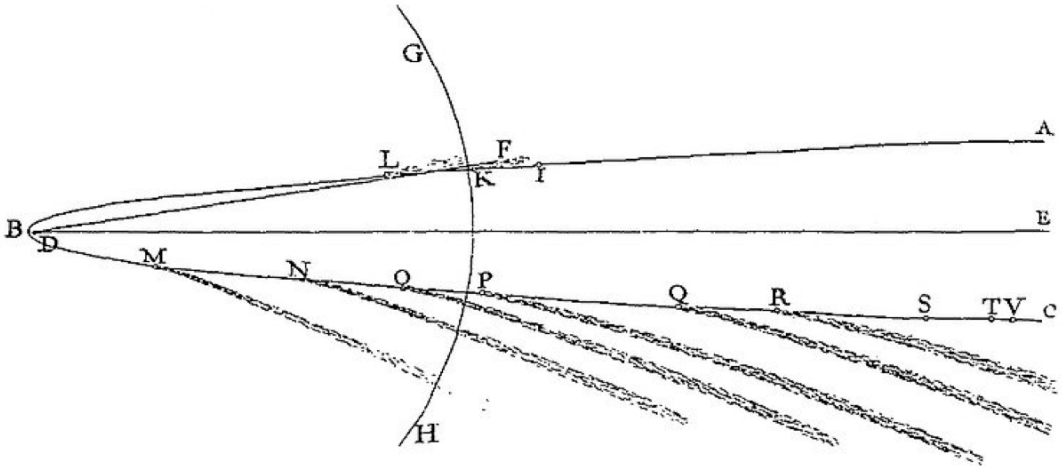
1986 AD

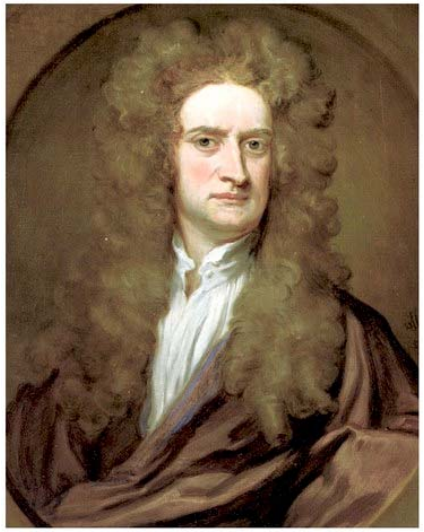
- **Ancient Greeks thought comets were atmospheric phenomena**
  - **In the west this went unchallenged until telescopes came along**
  - **Tycho Brahe's parallax measurements proved this wrong**
    - **Comets were much further away than the Moon**

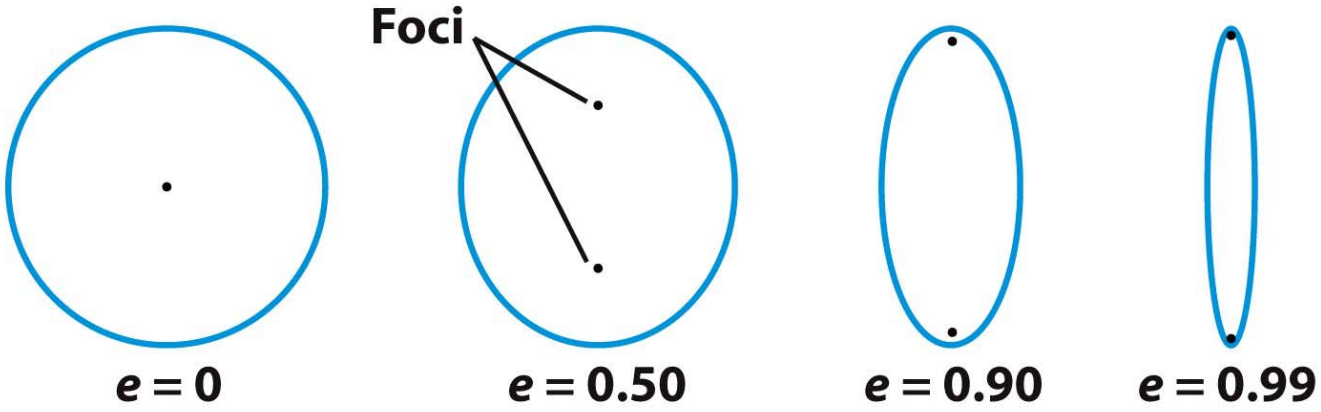


- **Renaissance astronomers thought comets moved in straight lines through the solar system**
  - **Even Kepler argued they shouldn't follow elliptical orbits like the planets**
- **In the 1680s astronomers tracked a comet and showed it had an elliptical orbit**
  - **Comets were solar system objects – just like planets**

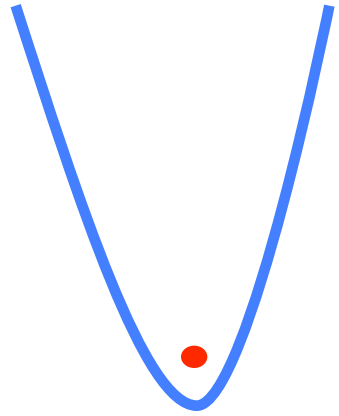
- **Newton finally settled this in his 'Principia Mathematica' (1687)**
  - **Showed that comets moved in parabolic or elliptical orbits by the Sun's gravity**







Ellipses with different eccentricities

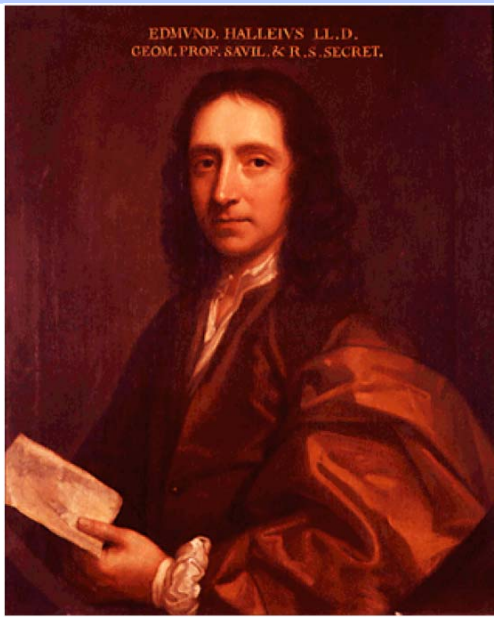


***e* = 1**

A parabolic orbit

Figure 4-10b
Universe, Eighth Edition

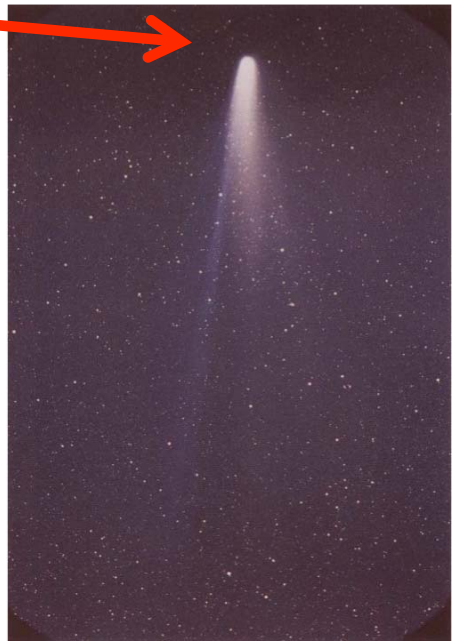
- If they have orbits… then they're periodic
  - The same comet should come back
- In 1705 Edmund Halley connected the dots…
  - Used Newton's laws to figure out the orbit of many comets
  - Comets seen in 1531, 1607, and 1682 were the same object
  - Predicted a return in 1759



- Halley's comet has been seen ~30 times

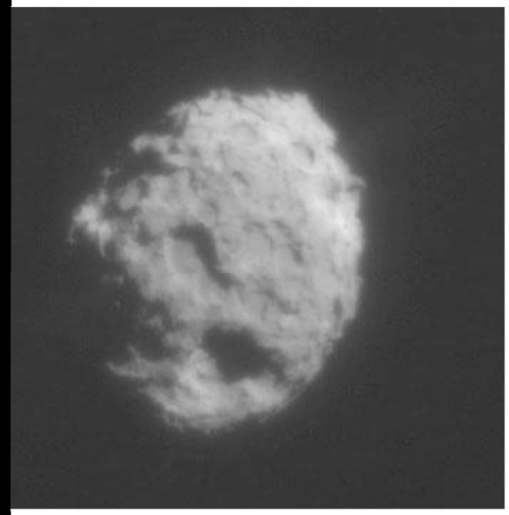
167 BC

687 AD



1986 AD

- Many telescopic observations of comets (including Halley's comet)
- Even a few spacecraft missions
  - Giotto & Vega
    - Comet Halley
  - Deep-space 1
    - Comet Borrelly
  - Stardust
    - Comet Wild 2
  - Deep Impact
    - Comet Tempel 1



What are comets?

- Comets have several parts
  - Nucleus
    - ~10 km
  - Coma
    - ~1,000,000 km
    - Almost as big as the sun!
      - 1,400,000 km
  - Hydrogen envelope
    - ~10,000,000 km
  - Tail
    - Ion tail
    - Dust tail
    - ~100,000,000 km
    - About 2/3 of 1AU!

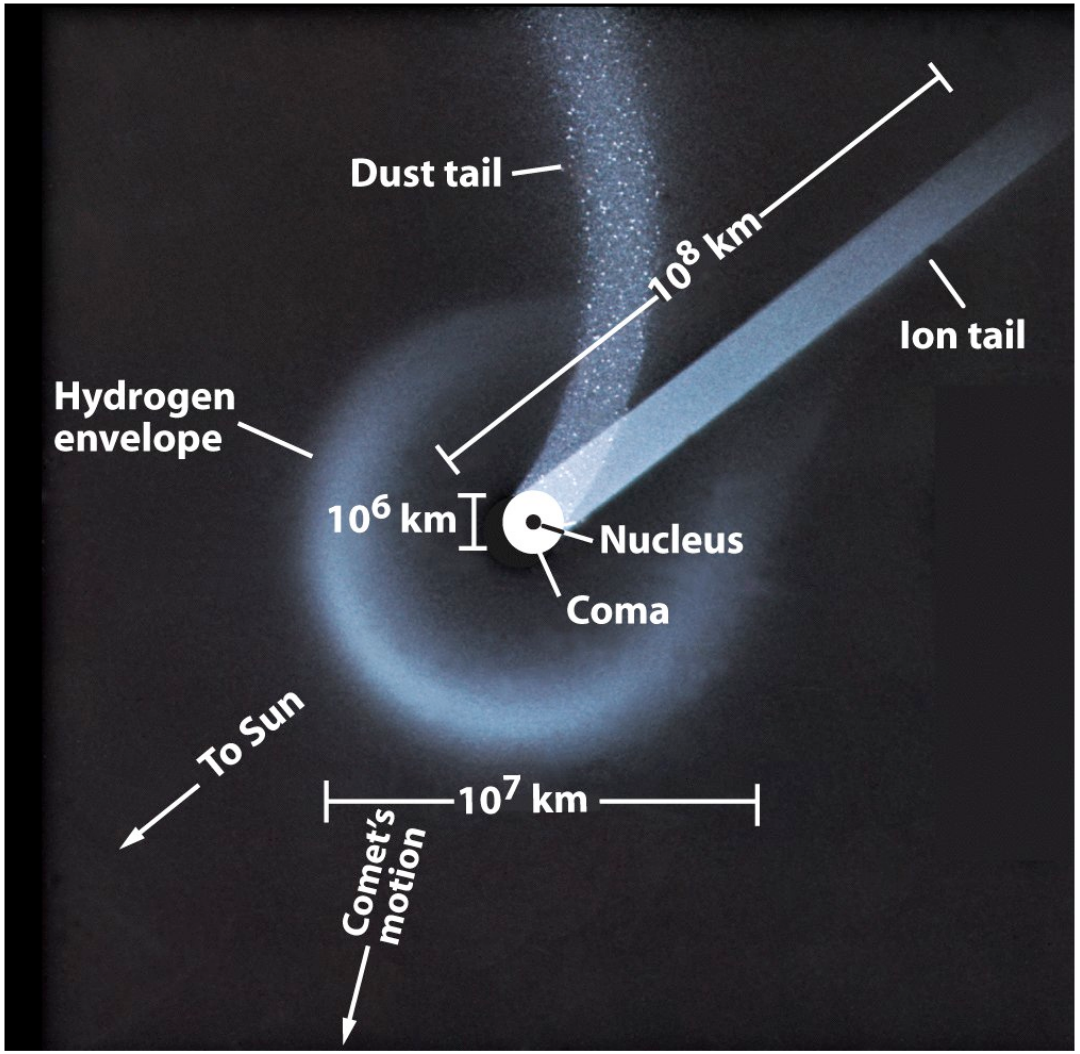
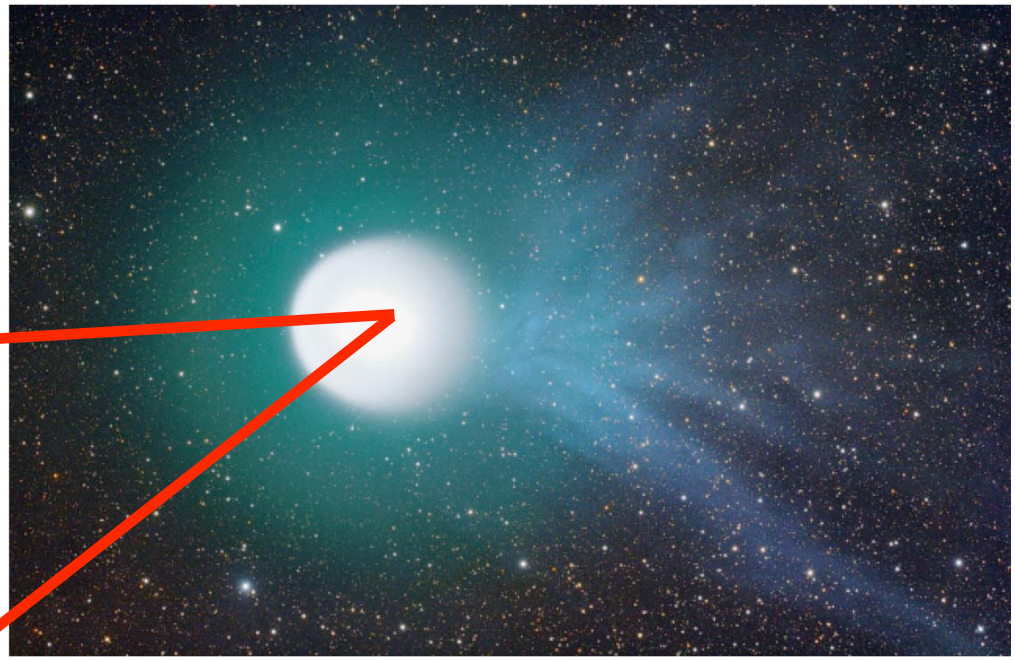
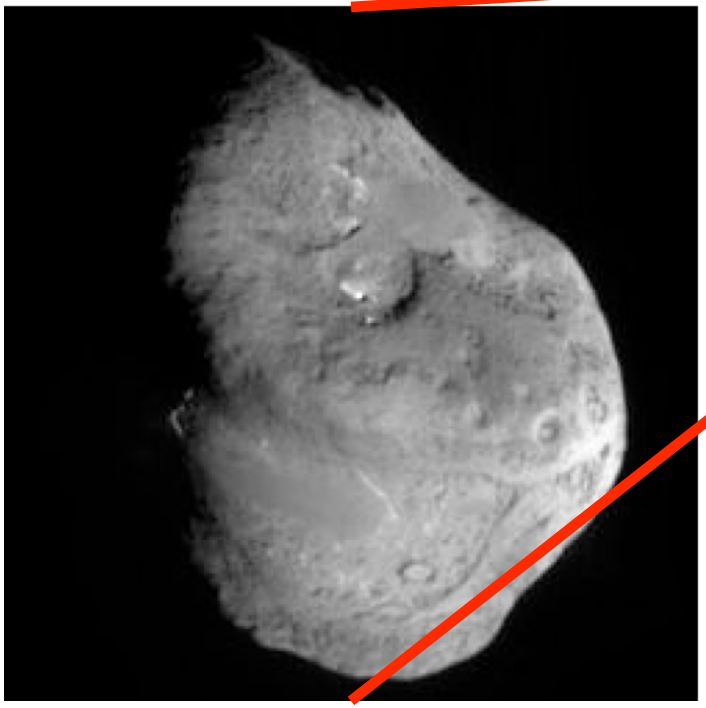


Figure 15-20
Universe, Eighth Edition

- **Cometary nuclei are usually invisible from the Earth**
  - **Hidden by the coma**
  - **Spacecraft missions can visit far from the Sun when the coma is inactive**



Comet Holmes



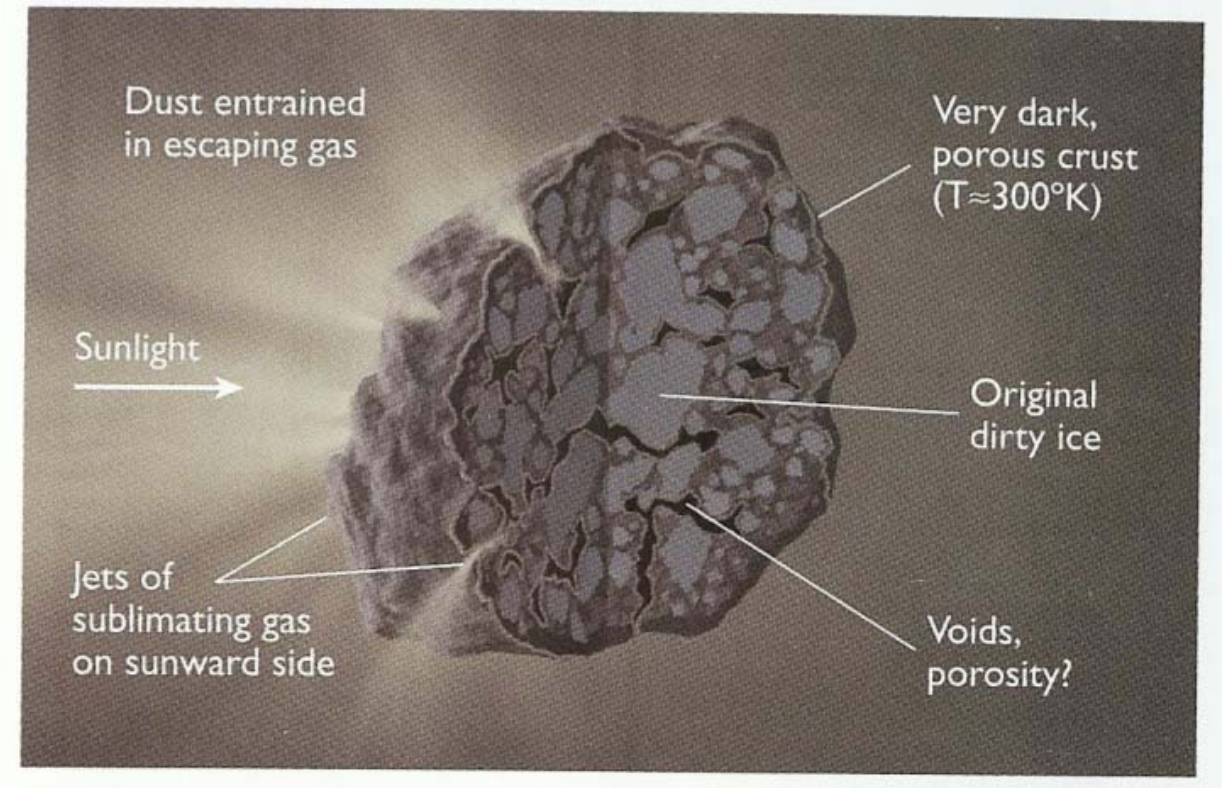
Comet Tempel 1

- **Comet Nuclei are 'dirty snowballs'**
  - **Random mixtures of ices and dark stuff**

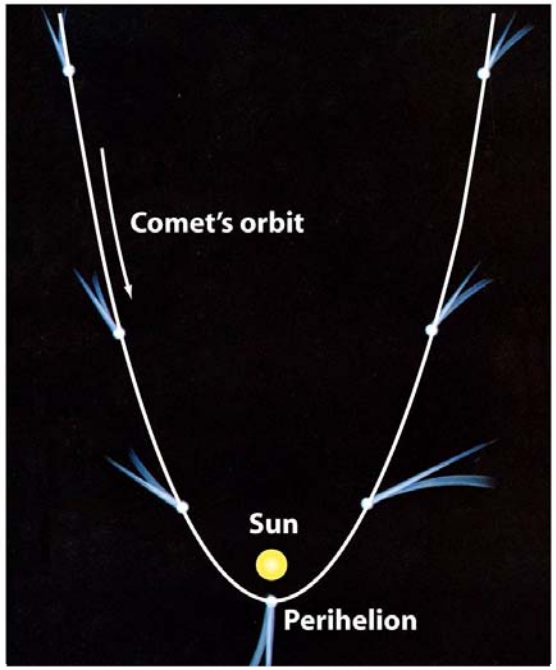
  - **Ices**
    - **Mostly water ice**
    - **A little CH4, CO, CO2 etc**

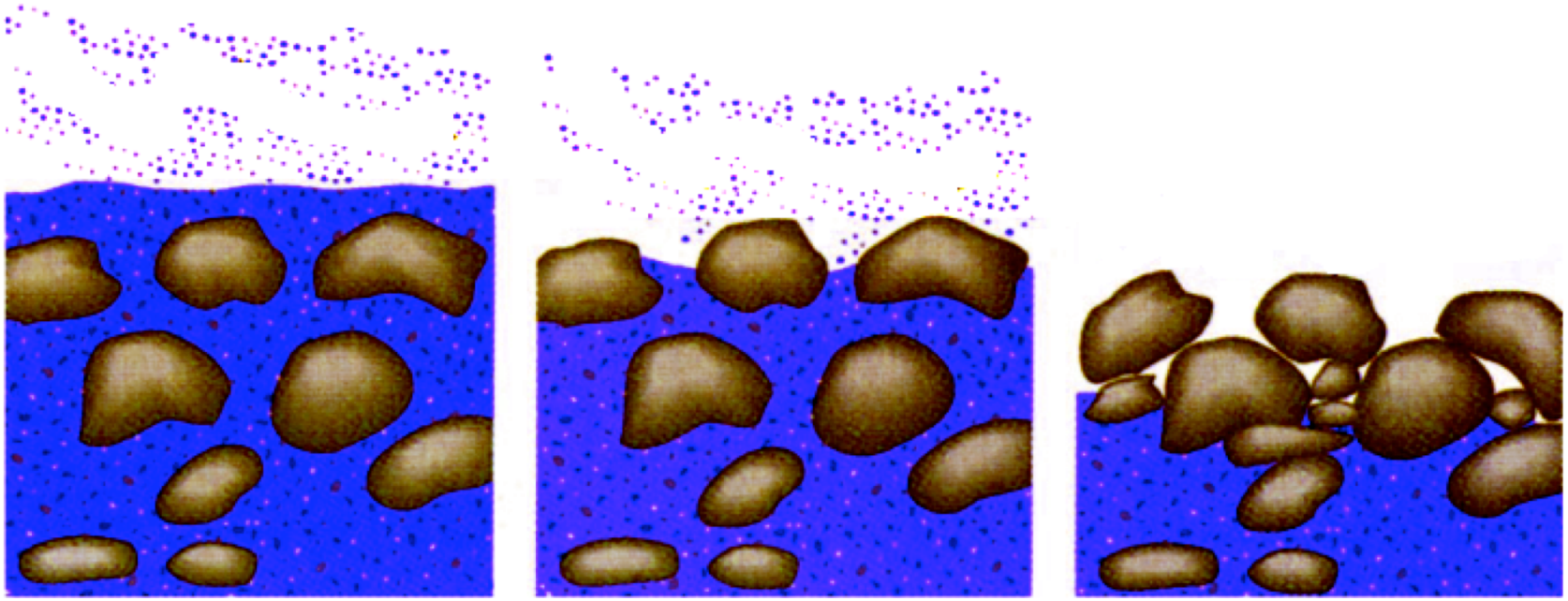
  - **Dark 'stuff'**
    - **Organic compounds (H,C,O)**
    - **Rock-like material**
      - **Like asteroids**

  - **Very small objects**
    - **Not enough self-gravity for a round shape**



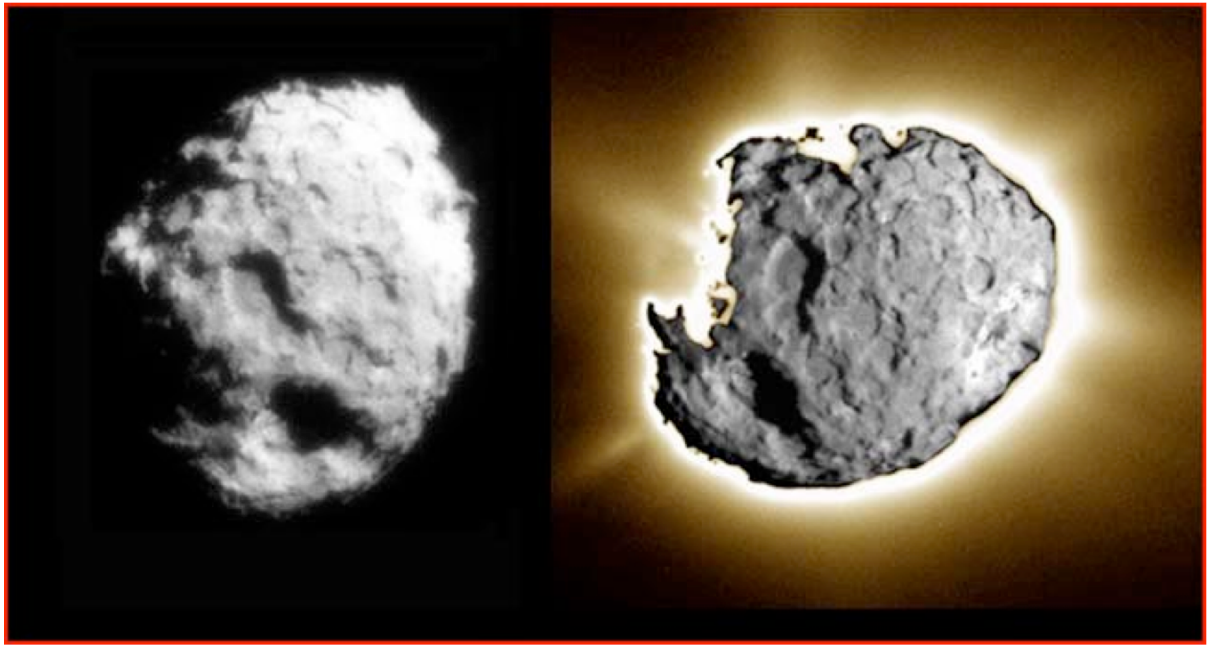
- **When comets are close to the sun**
  - **Surface heats up**
  - **Ice sublimates (turns to vapor)**
  - **Dark organic stuff gets concentrated on the surface**

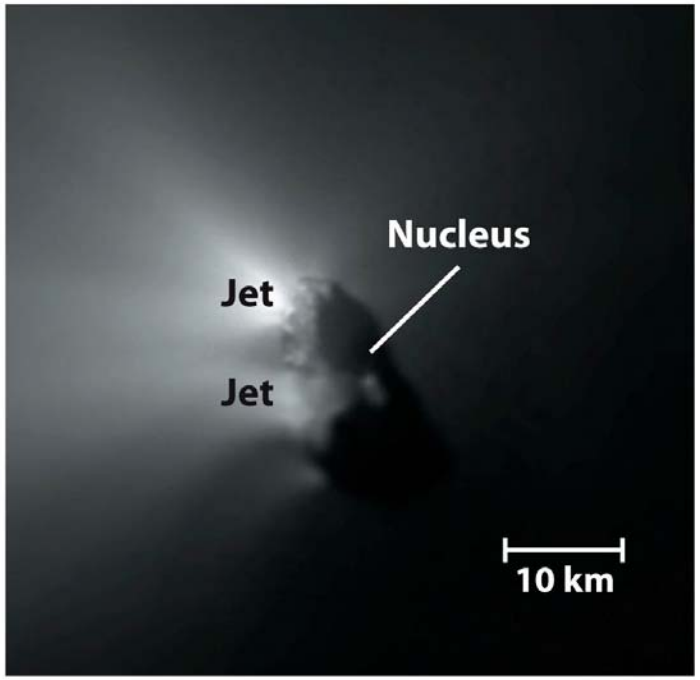




- Comets are ice rich
- …but among the darkest objects in the solar system
  - Albedo of 2-4%
  - Like tar
  - Comet nuclei are very hard to see without their comas

- **This thick crust builds up over many orbits**
  - **Sublimating ice comes out in jets**
  - **Collapse pits form on the surface from removal of sub-surface ice**
  - **Jets act like rocket engines – can alter the orbits of comets**

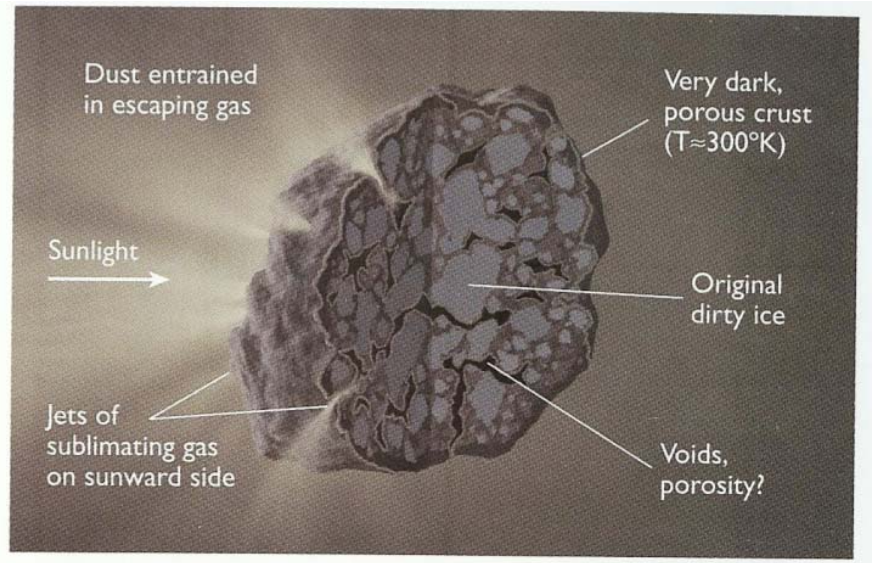




Comet Halley

Figure 15-21a
Universe, Eighth Edition

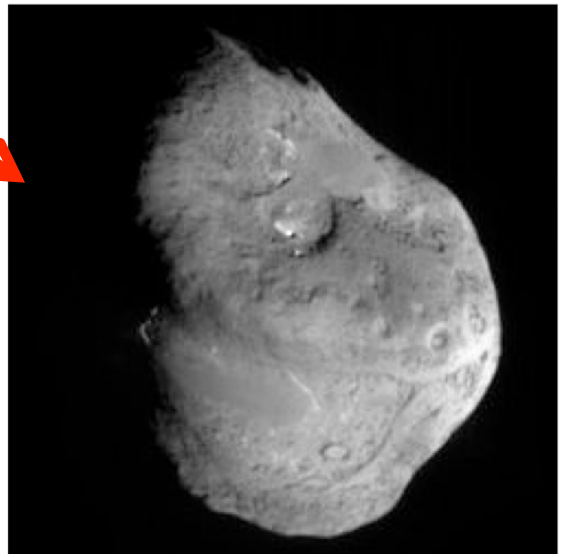
- **Comet nuclei are typically small < 40km**
- **Mass estimates come from spacecraft flybys**
- **Comets are very low density**
  - **Contain significant internal voids**



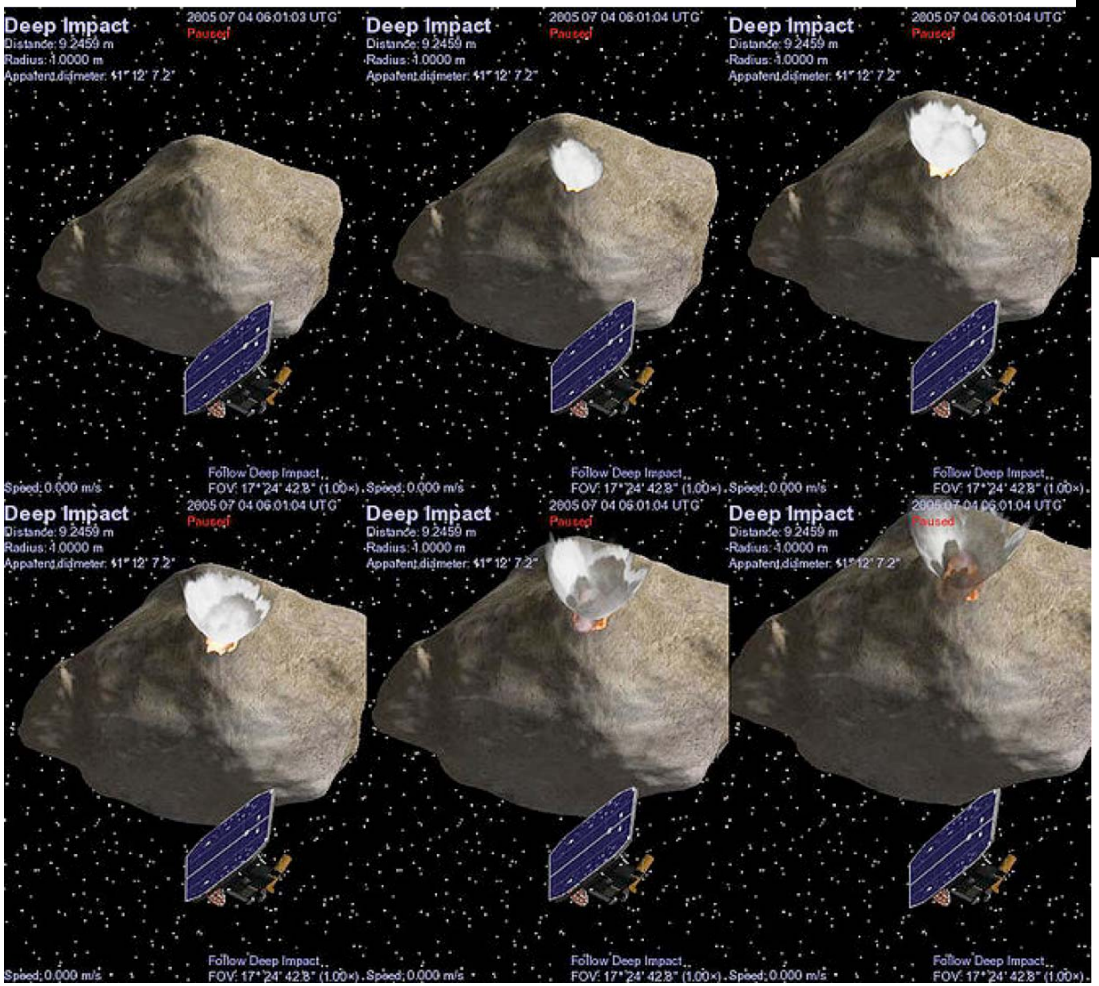
Water ice ~0.9 g/cm³

Name	Dimensions km	Density g/cm³	Mass kg[11]
Halley's Comet	15×8×8[7][2]	0.6[12]	3×10^{14}
Tempel 1	7.6×4.9[13]	0.62[10]	7.9×10^{13}
19P/Borrelly	8×4×4[8]	0.3[10]	2×10^{13}
81P/Wild	5.5×4.0×3.3[14]	0.6[10]	2.3×10^{13}

From Wikipedia



- The Deep Impact mission
  - 370-kg (815-lb) copper impactor
  - Analysis of vapor plume
  - Crater 100m wide, 30m deep



- Composition was ‘dirtier’ than expected
  - Data analysis still in progress

- **Sublimation jets produce cometary atmosphere**
  - **Mostly water ice crystals – some dust**
  - **Comet's gravity can't hold onto this material**
- **Occasionally a big piece of the comets surface will break off exposing fresh ice**
  - **Comet Holmes brightened by a factor of 1 million within a few days**

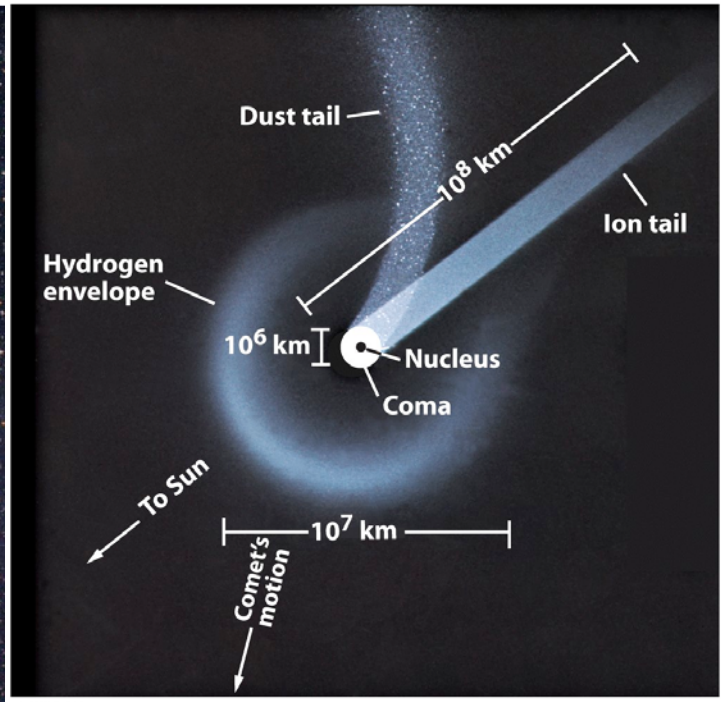
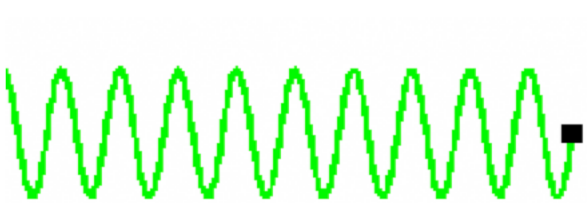
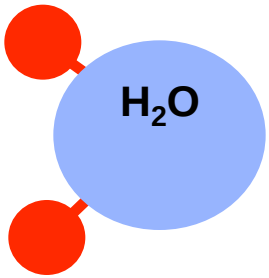


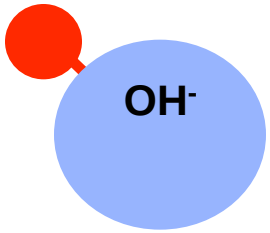
Figure 15-20
Universe, Eighth Edition

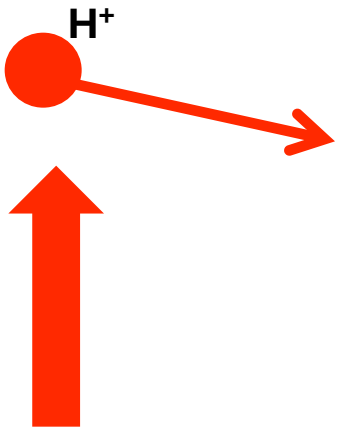
Coma of Comet Holmes

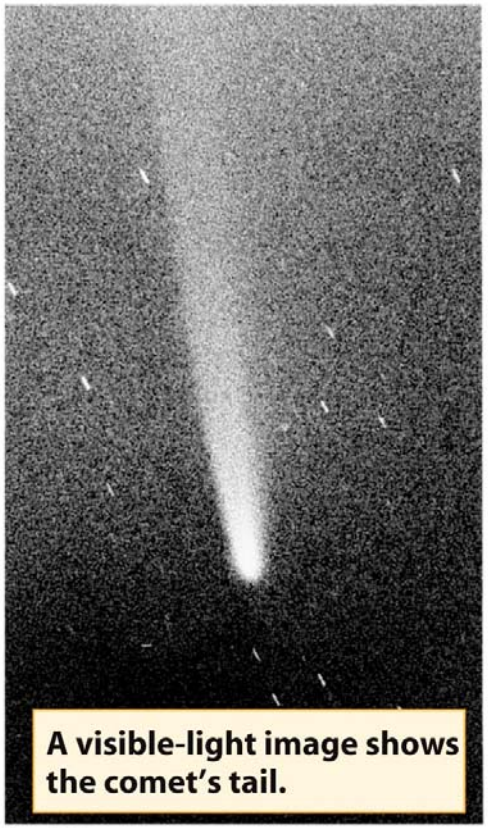
- **What happens to the water ice crystals?**
  - **UV solar radiation breaks up the water molecules**











We can see this using ultraviolet light

Figure 15-22
Universe, Eighth Edition

- Comets have two tails
  - Ion tail of OH^- and H^+
  - Ions are swept up by the solar wind
  - Ion tails point away from the Sun
  - Blue-ish in color

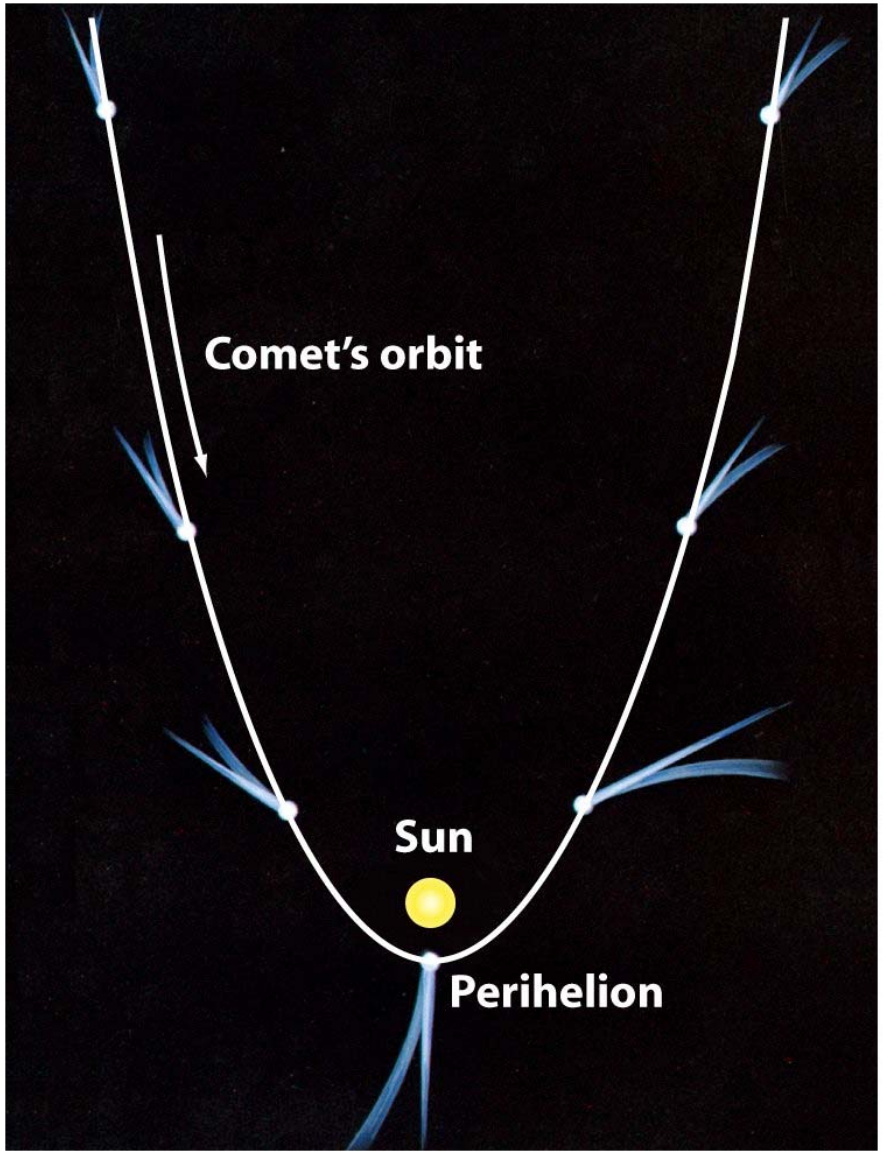
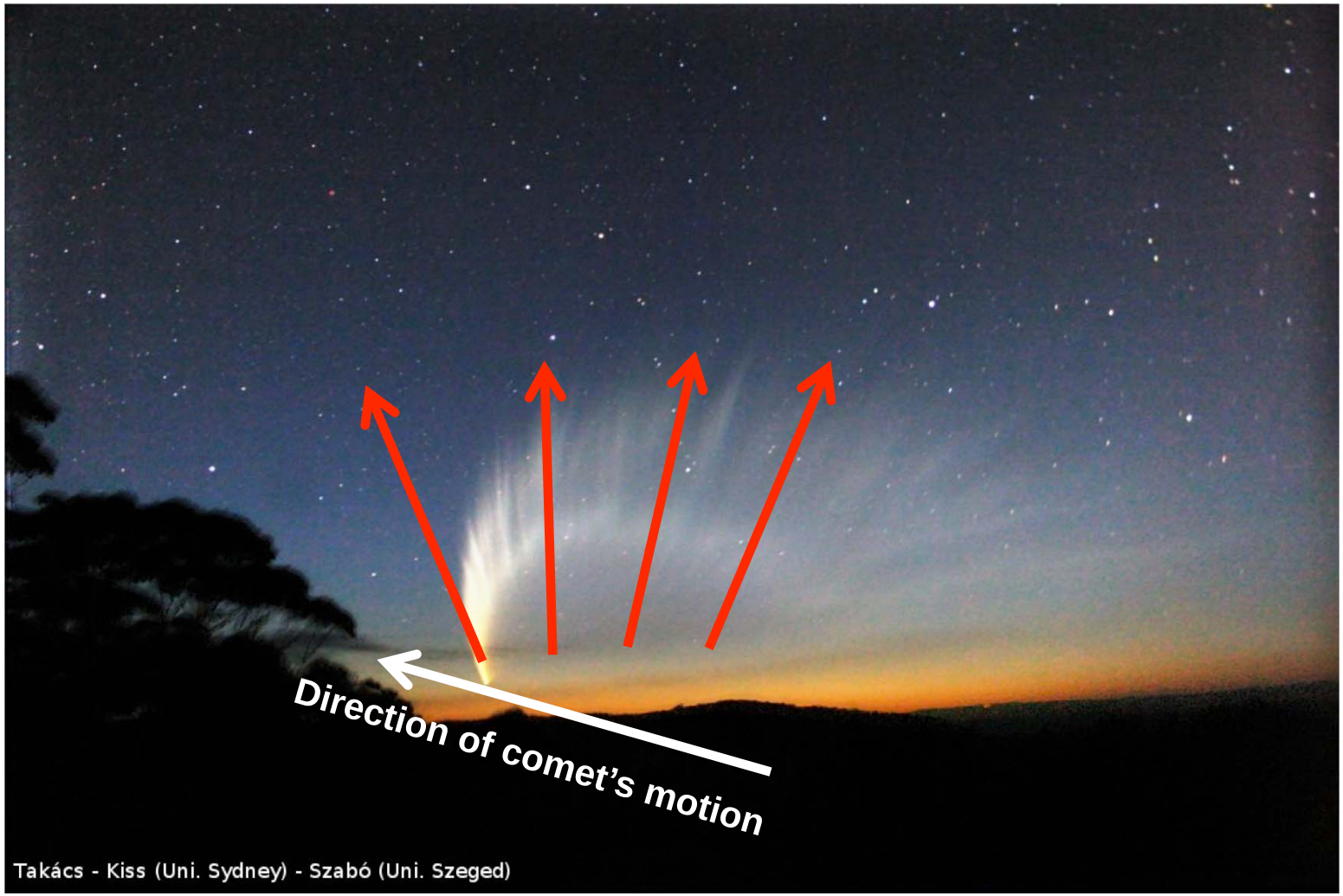


Figure 15-23
Universe, Eighth Edition

- **Dust tails**
  - **Also swept by the solar wind but less efficiently**
  - **Dust tail is brighter and whiter**
  - **Tail direction affected by the comets motion and is curved**



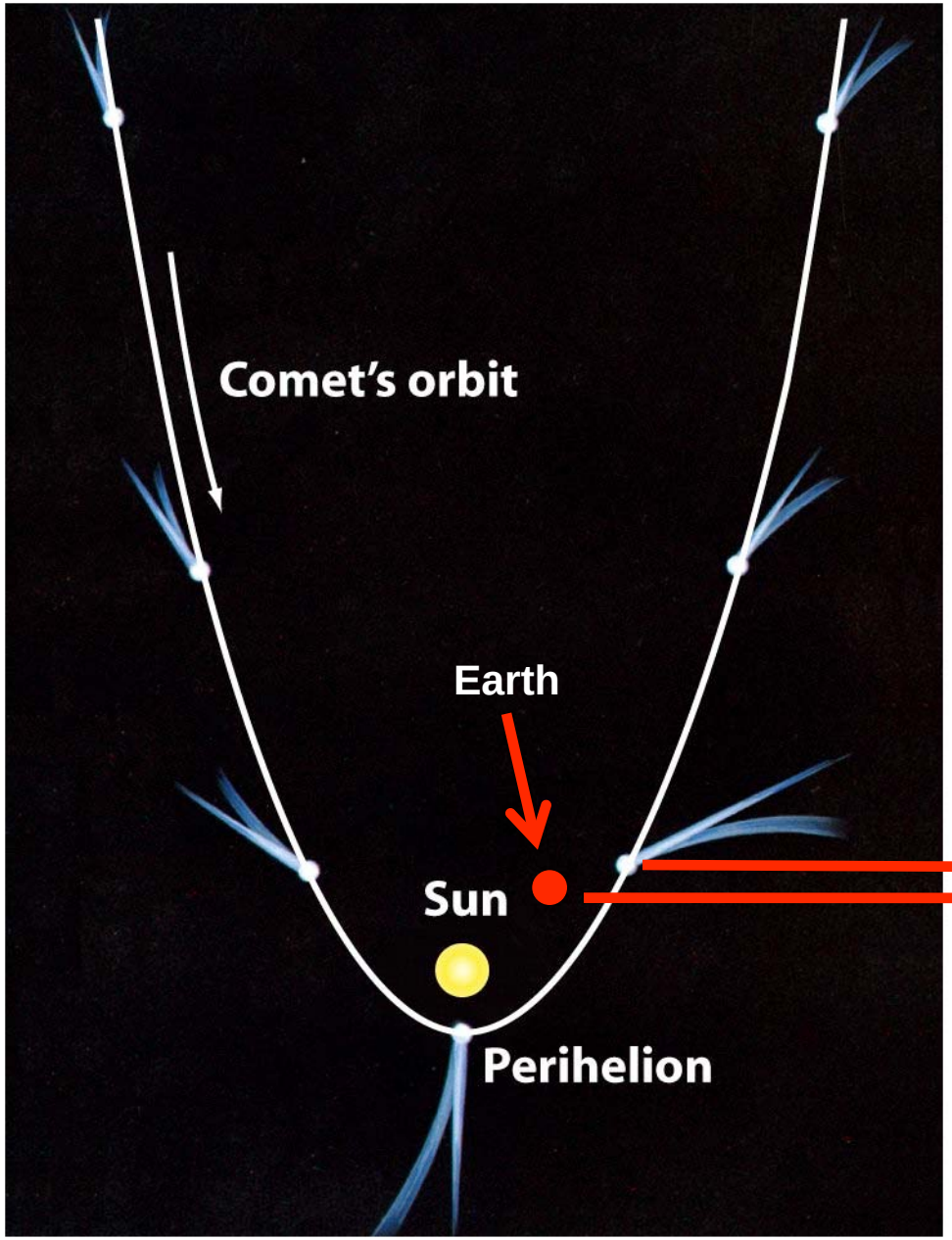
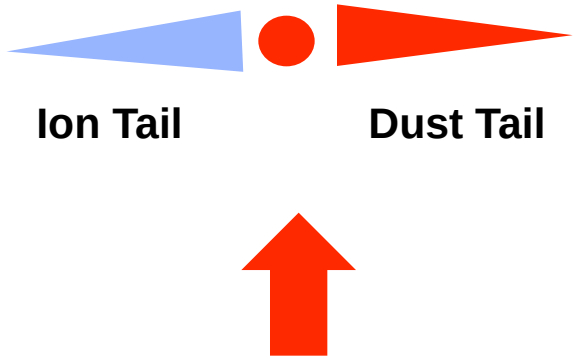


Figure 15-23
Universe, Eighth Edition

- **Comets can appear to have a tail and an anti-tail**

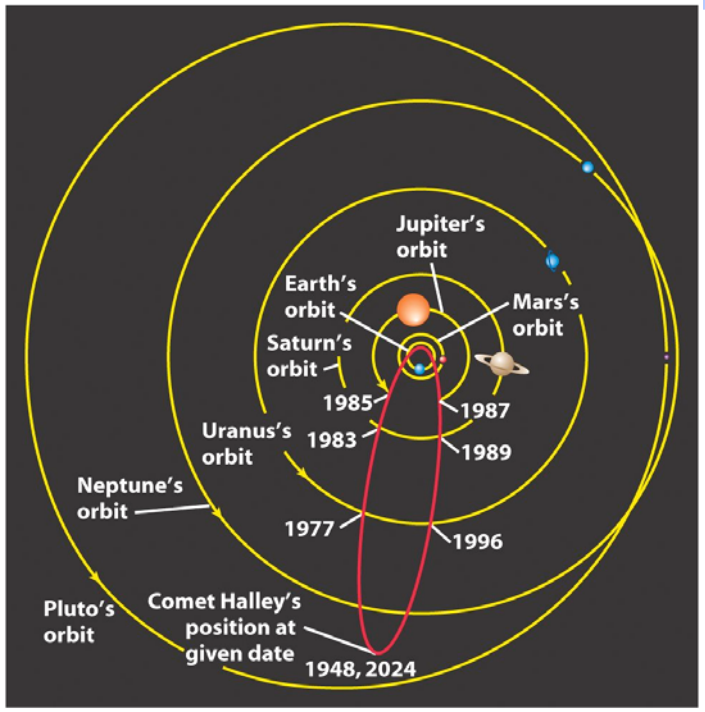


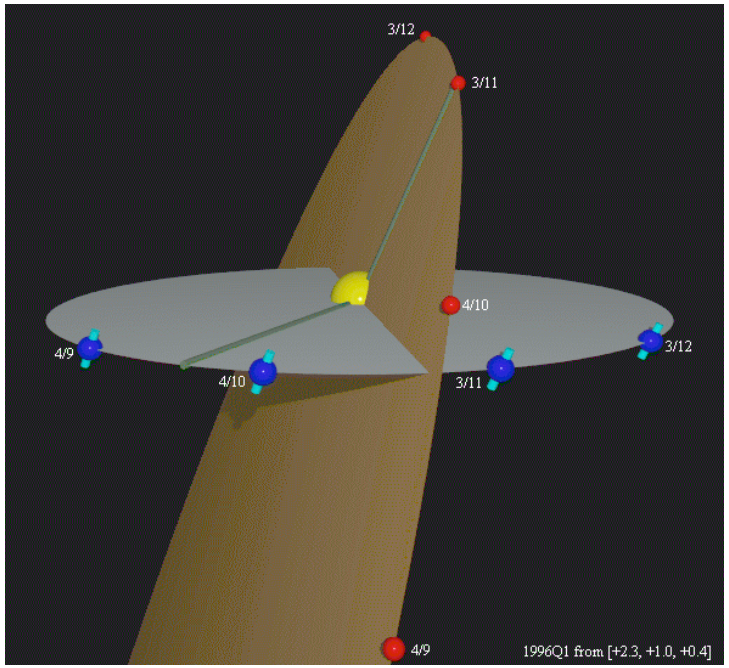
This observer sees the this comet


© 1997 Jerry Lodriguss

Where do comets come from?

- **Cometary orbits are very different from asteroids**
  - **Comets have very elliptical orbits**
  - **Comets have randomly inclined orbits**
  - **Comets have very large orbits**





- **Divided into short period (<200 years) and long period (>200 years)**
- **Short period comets**
  - **Jupiter family comets (Periods <20 years)**
  - **Orbits controlled by Jupiter**
  - **All low inclination**

  - **Halley family comets (Periods 20-200 years)**
  - **Come from the Kuiper Belt**
  - **Spread in inclinations**
  - **Eventually transition to Jupiter family comets**

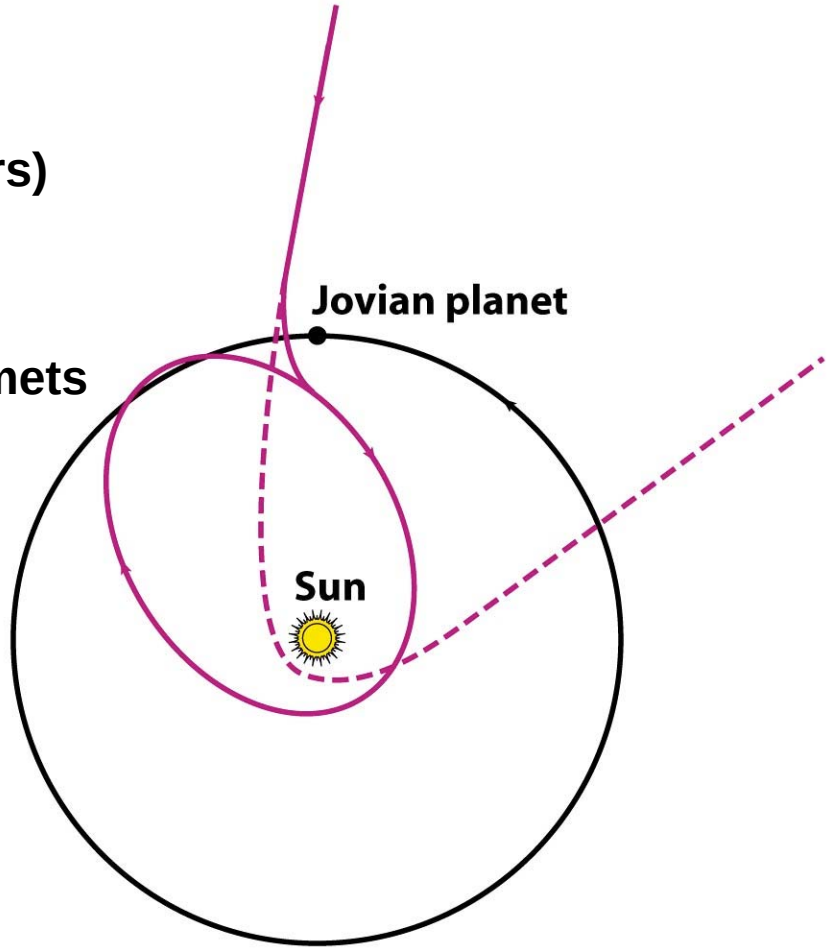
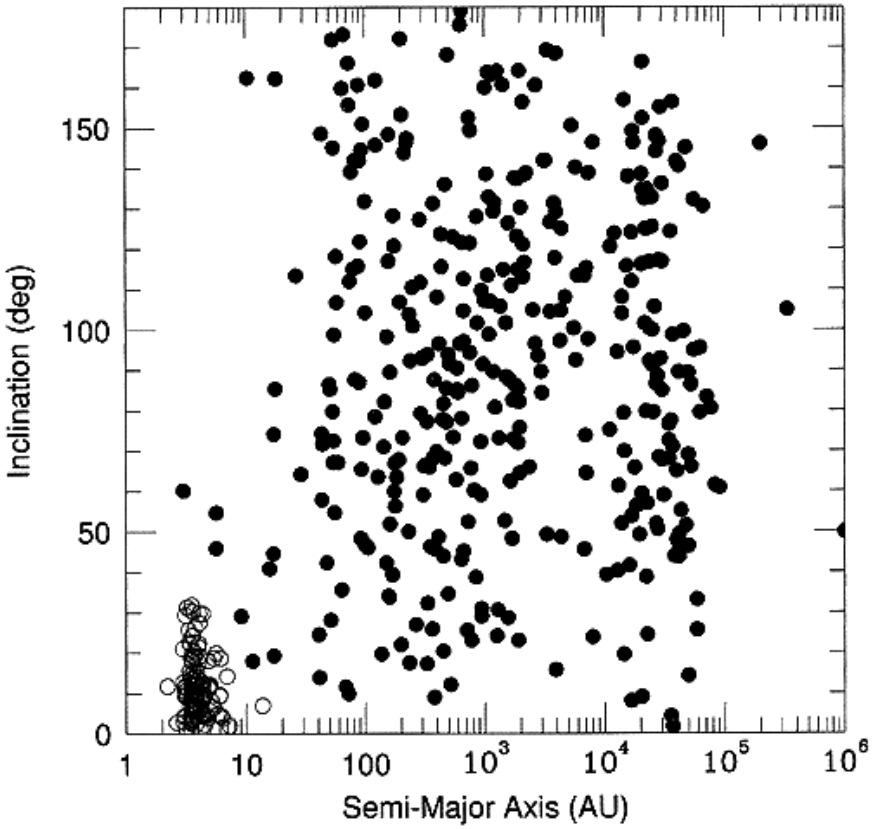
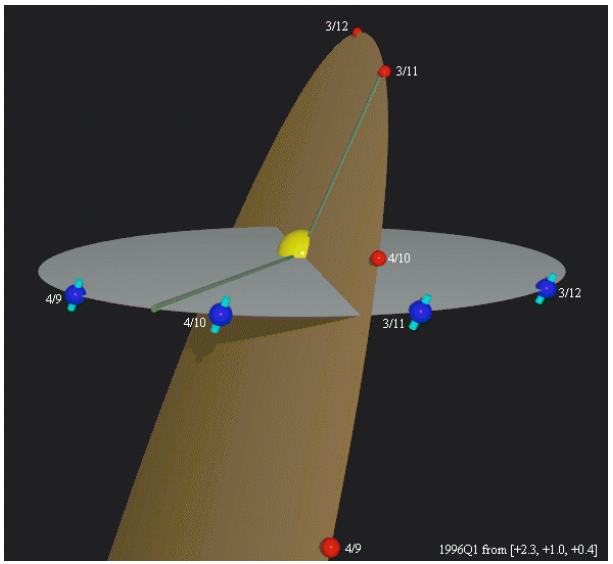


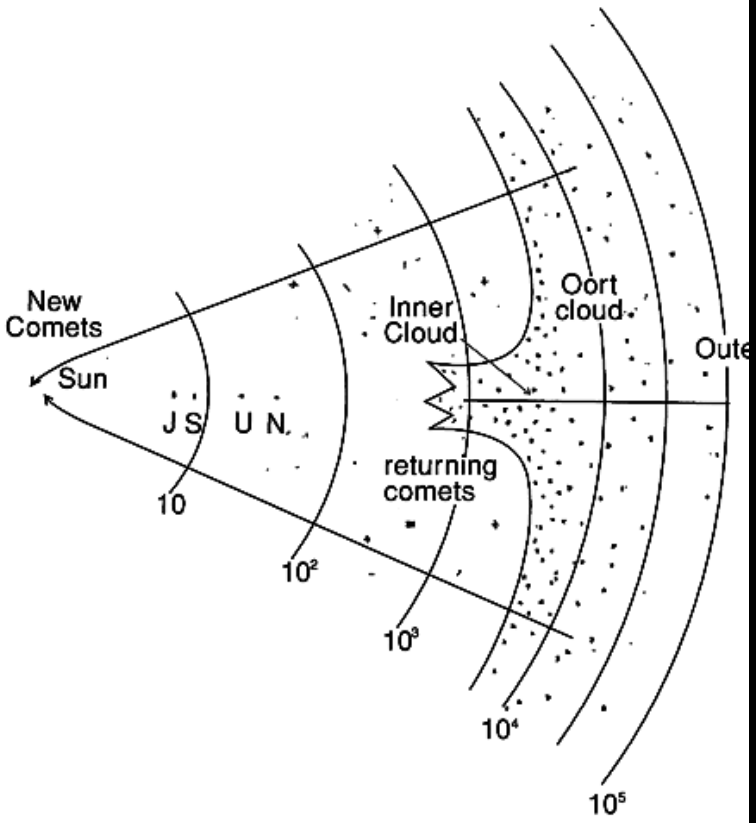
Figure 15-28
Universe, Eighth Edition

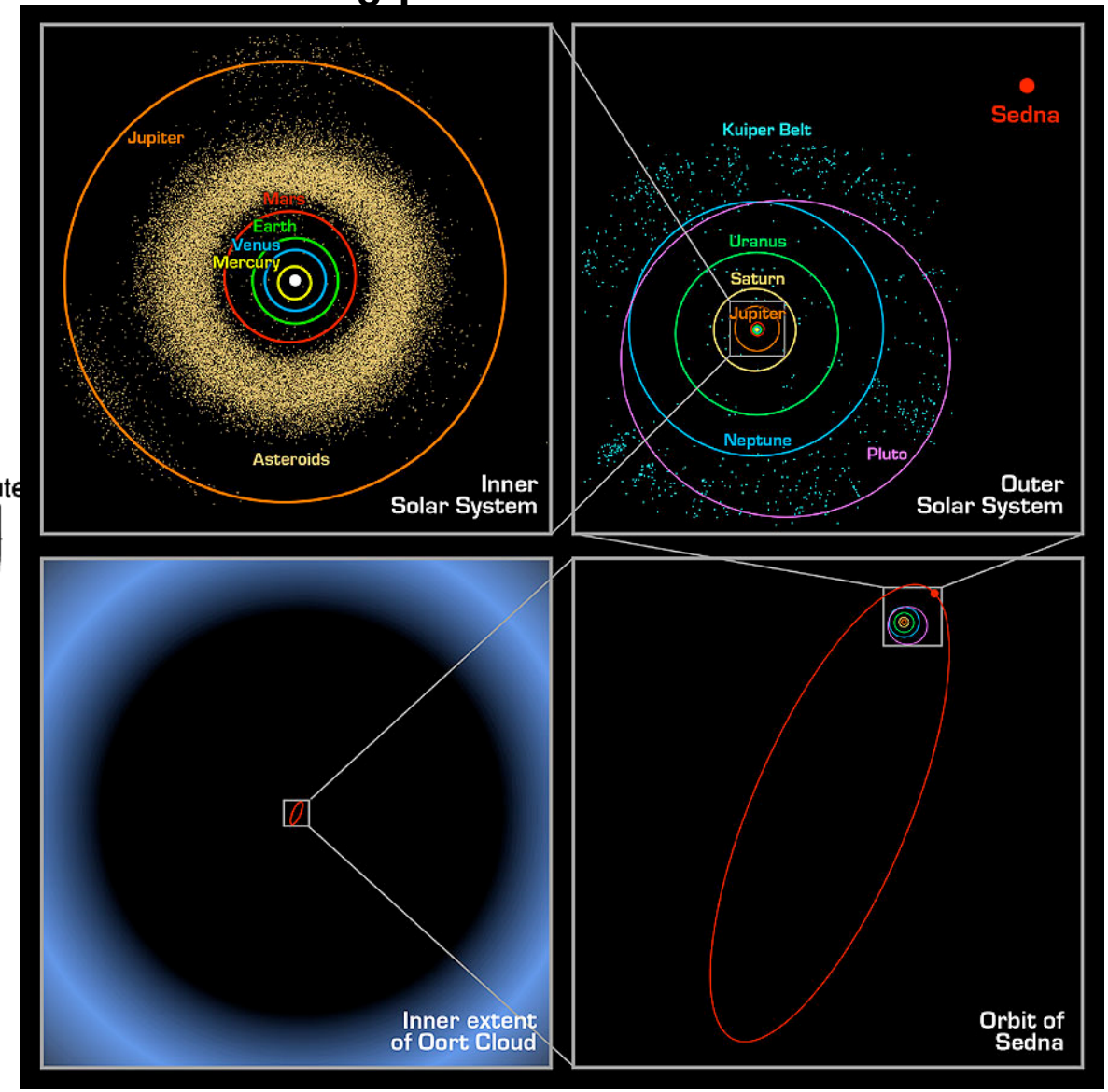
- **Long-period comets**
  - **Have totally random inclinations**
  - **Have very long periods/large orbits**
  - **Many of these appear to be on their first pass through the inner solar system**
  - **A body with a semi-major axis of 10,000 AU will orbit once every million years**



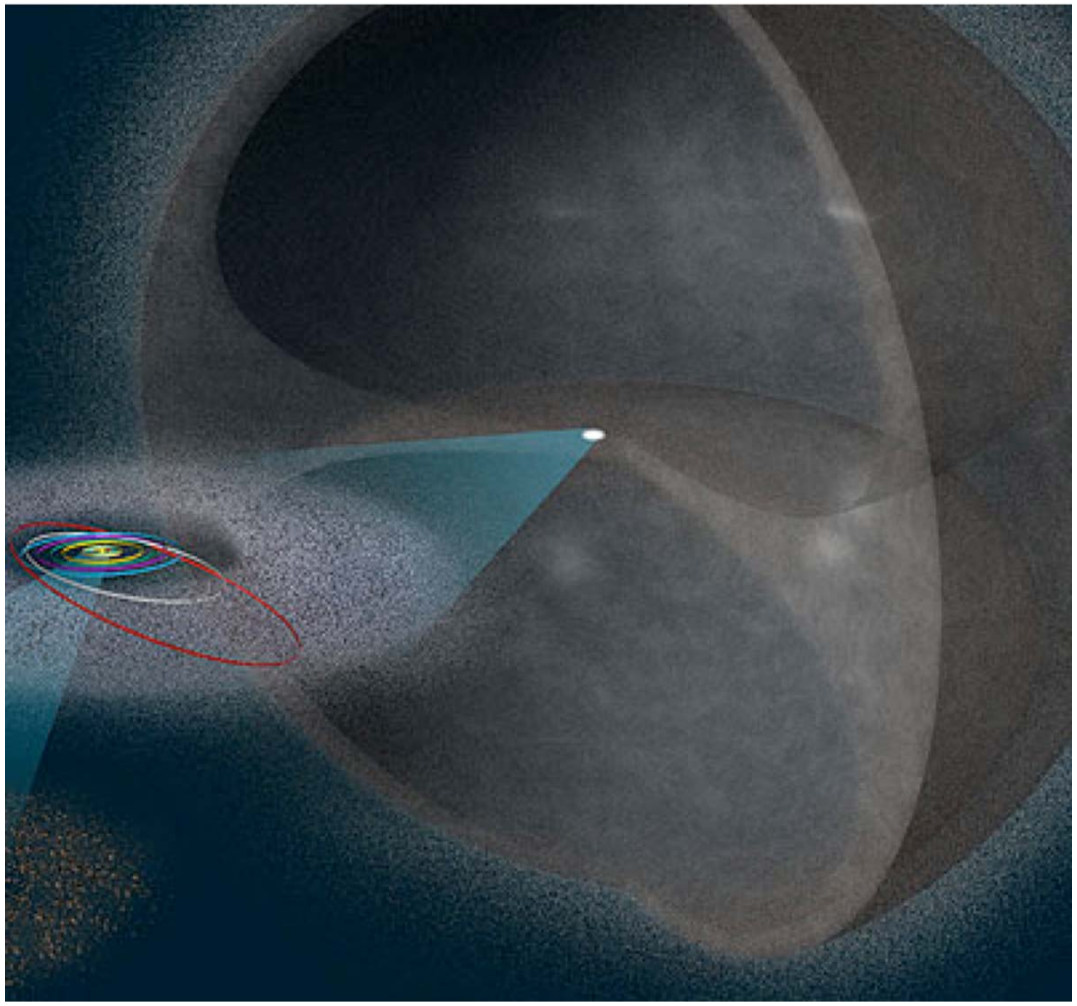


- **The Oort cloud**
  - **A spherical cloud of billions of comets far from the sun**
  - **Explains the random inclinations of the long-period comets**

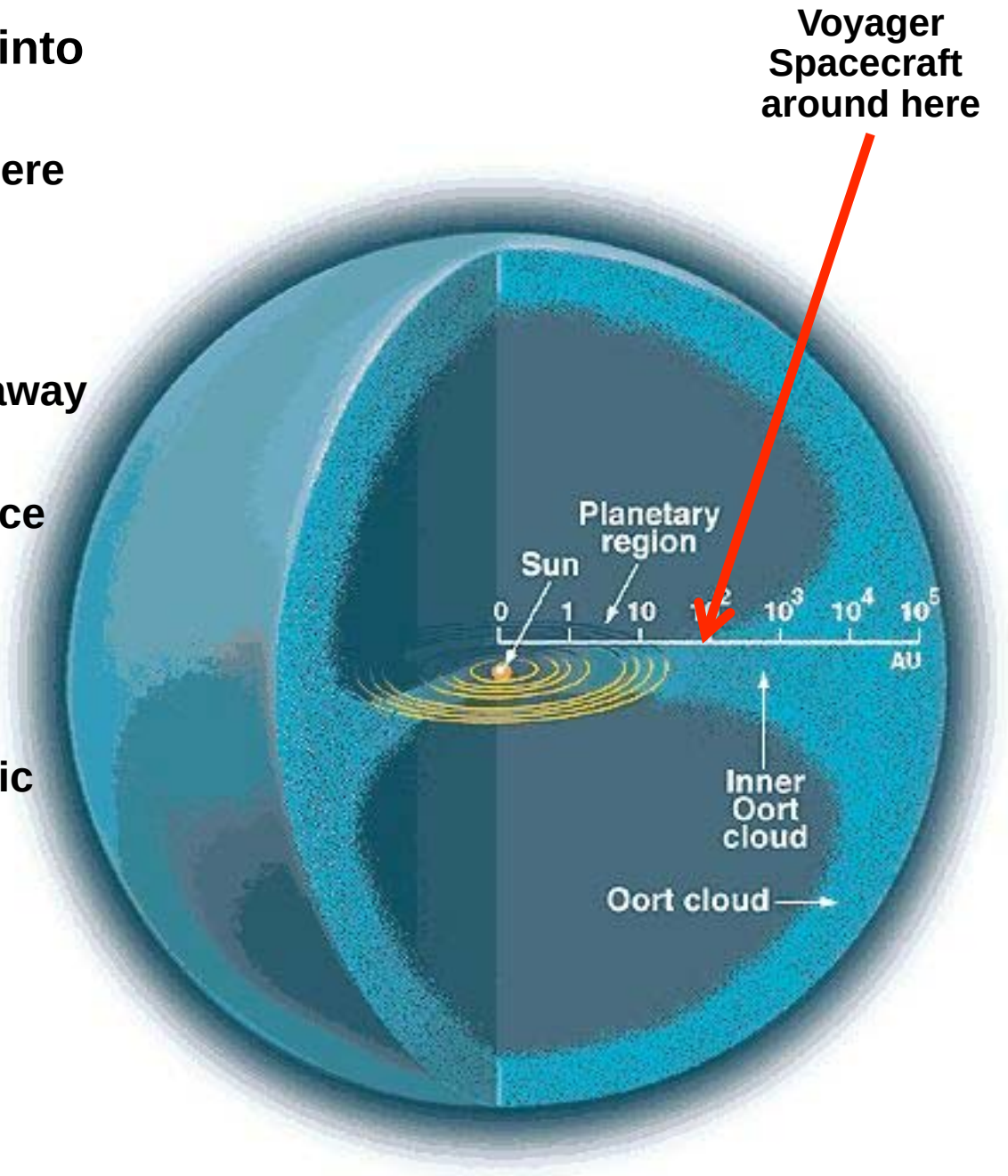




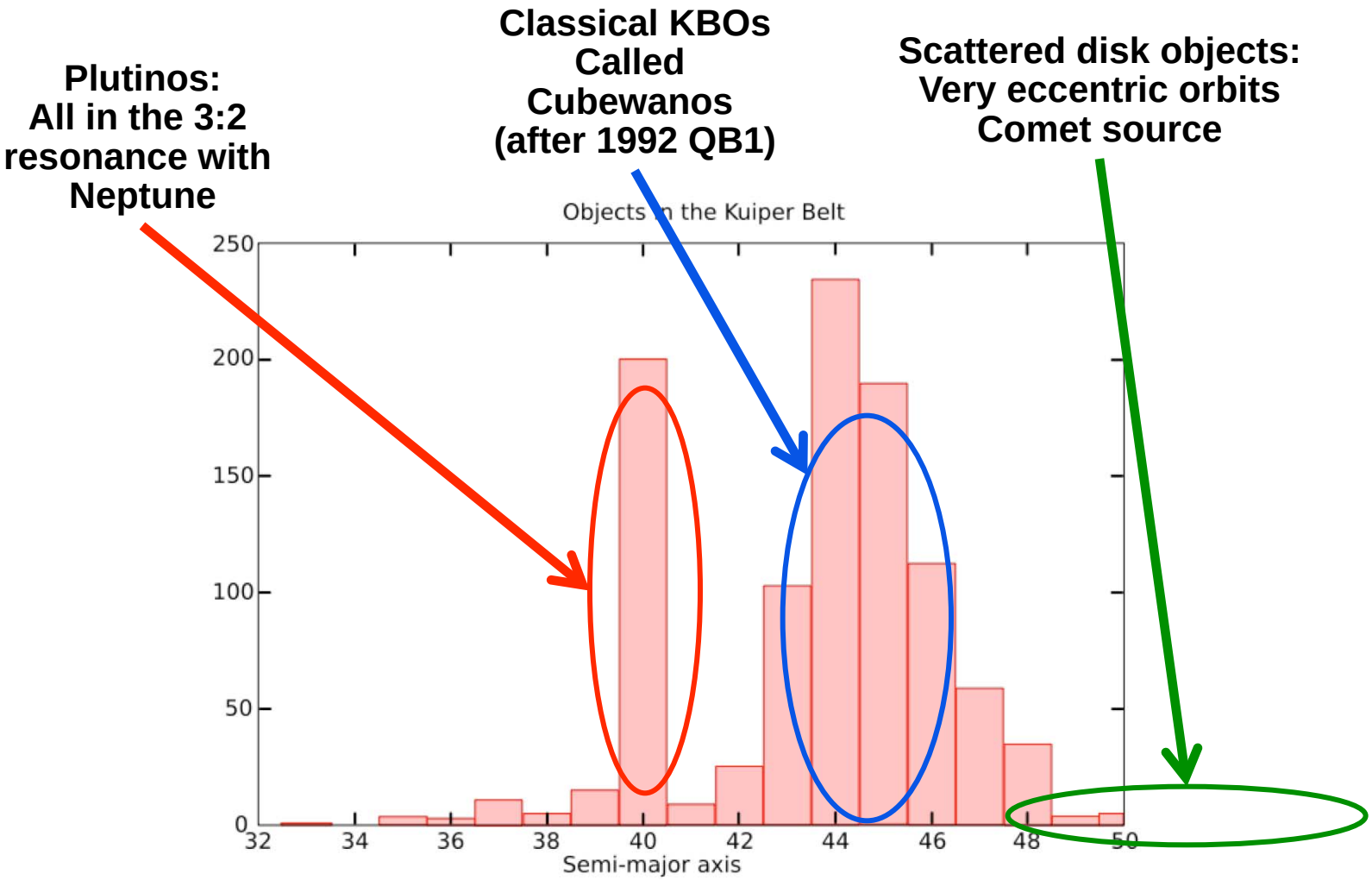
- Comets form closer to the giant planets
- Gravitational encounters
  - Fling them into very distant orbits
  - Allow the giant planet to migrate
- Passing stars randomize the orbital inclinations
  - Less so for objects closer to the sun
- Only a small fraction of the original objects survive
- Sharp outer edge of the Kuiper belt is not continuous with the Oort cloud



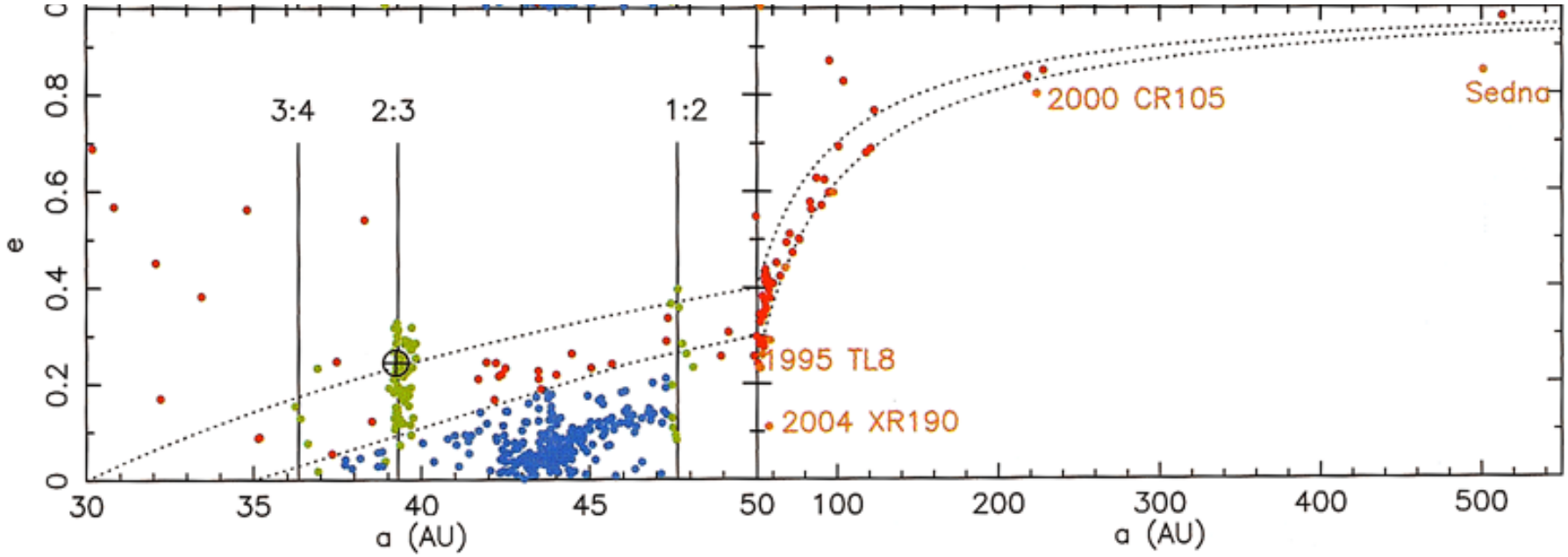
- **What knocks these comets into the inner solar system?**
  - **Planets have no influence here**
- **Passing stars?**
  - **Nearest star ~4 light years away**
  - **~250,000 AU**
  - **Twice the Oort cloud distance**
- **Galactic tides?**
  - **As the sun orbits the galactic center**
  - **Takes ~250 million years**



- **Why do all the short-period comets have low inclinations?**
  - **They come from a disk not a spherical cloud**
  - **This is why the Kuiper Belt was postulated**

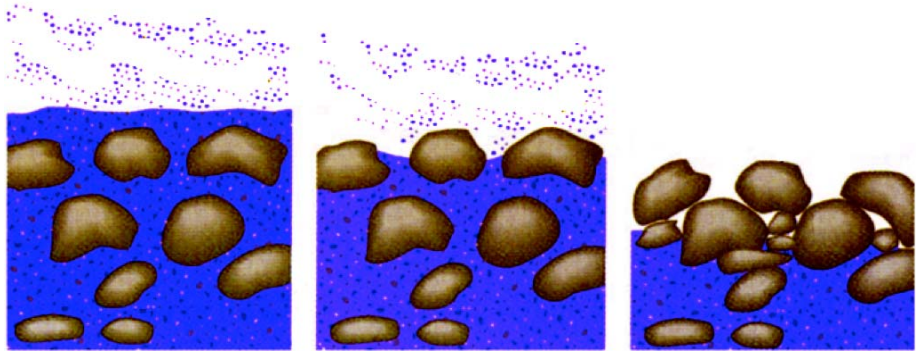


- **Scattered disk objects encounter Neptune**
  - **Are perturbed into smaller orbits**
  - **Wander among the gas giants as Centaurs**
    - **(half KBO, half comet)**
  - **About 1/3 make it to the inner solar system**
    - **Become Jupiter family comets**
    - **Other 2/3 are swept up by one of the giant planets**
    - **Takes 1-10 million years**



End of comets

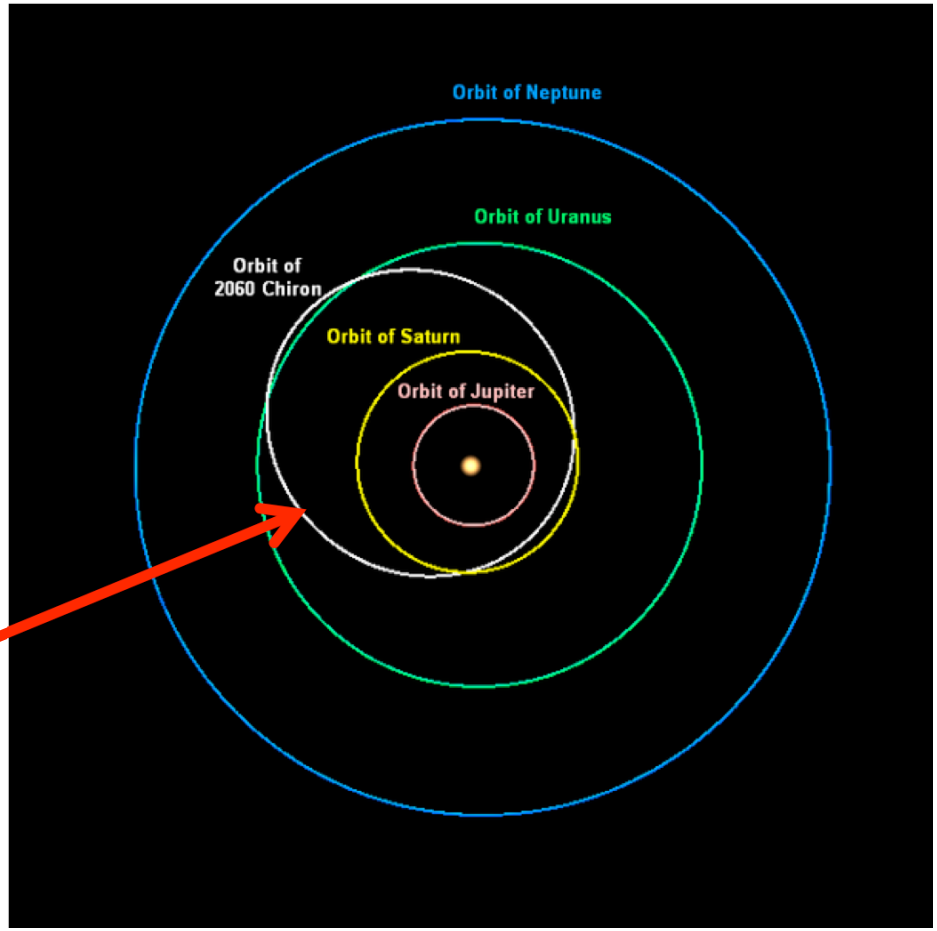
- Comets lose more ice on each pass close to the sun
  - Eventually the thick outer cover seals off the ice
  - No more cometary activity



- Some asteroid-like objects are in comet-like orbits

- Some asteroid-like objects suddenly develop comas
  - Impacts disturb surface cover

    or
  - Move closer to the sun
    - Chiron developed coma and tail
    - People were puzzled as this was before KBOs were known



- Another common fate of weak cometary bodies is to break up
  - Tidal forces from close approaches to planets

- Old debris corridors cause meteor showers when the Earth passes though them

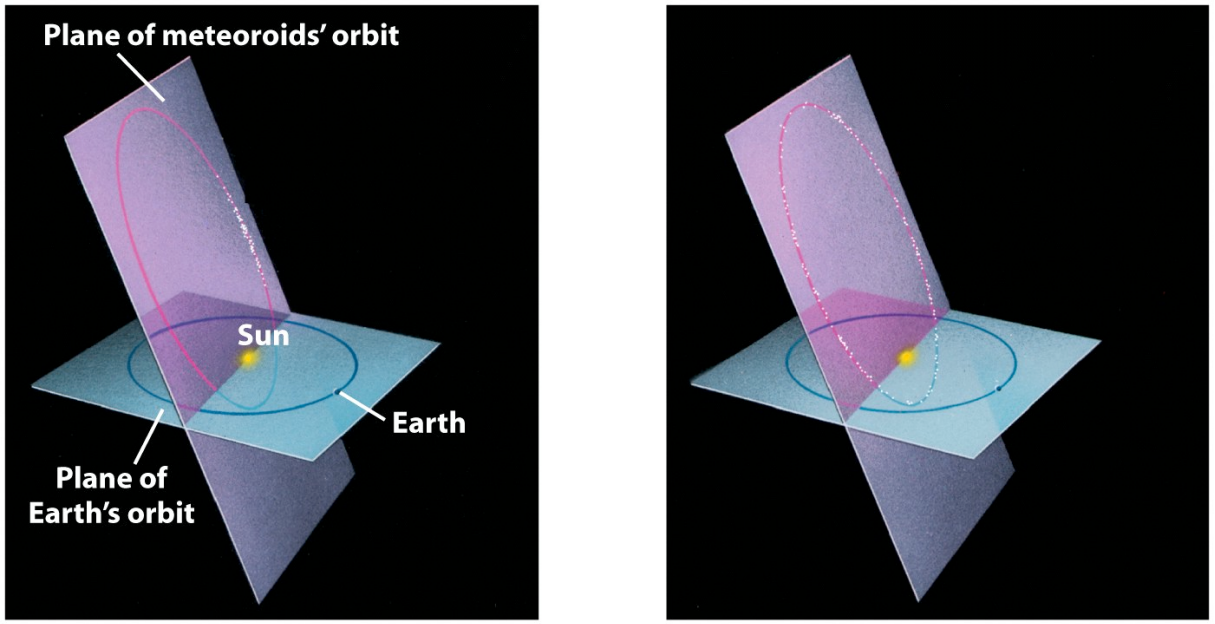


Figure 15-30
Universe, Eighth Edition

In this lecture…

- What are comets?
  - Dirty snowballs – removal of ice leave dirt on the surface
  - Ice sublimates in jets through a debris cover and produces a coma
- Cometary tails
  - Ions tails are bluish and point away from the sun
  - Dust tails move slower and so are curved due to comet's motion
- Where do comets come from?
  - Short-period comets are dominated by Jupiter
    - Low inclination orbits means resupply from a disk – the Kuiper belt
  - Long period comets have random inclinations
    - Resupply from a distant spherical reservoir – the Oort cloud

Next: Formation of the Solar System

- Reading
  - Chapter 15-7 to 15-9 to revise this lecture
  - Chapter 8 for next lecture