Announcements

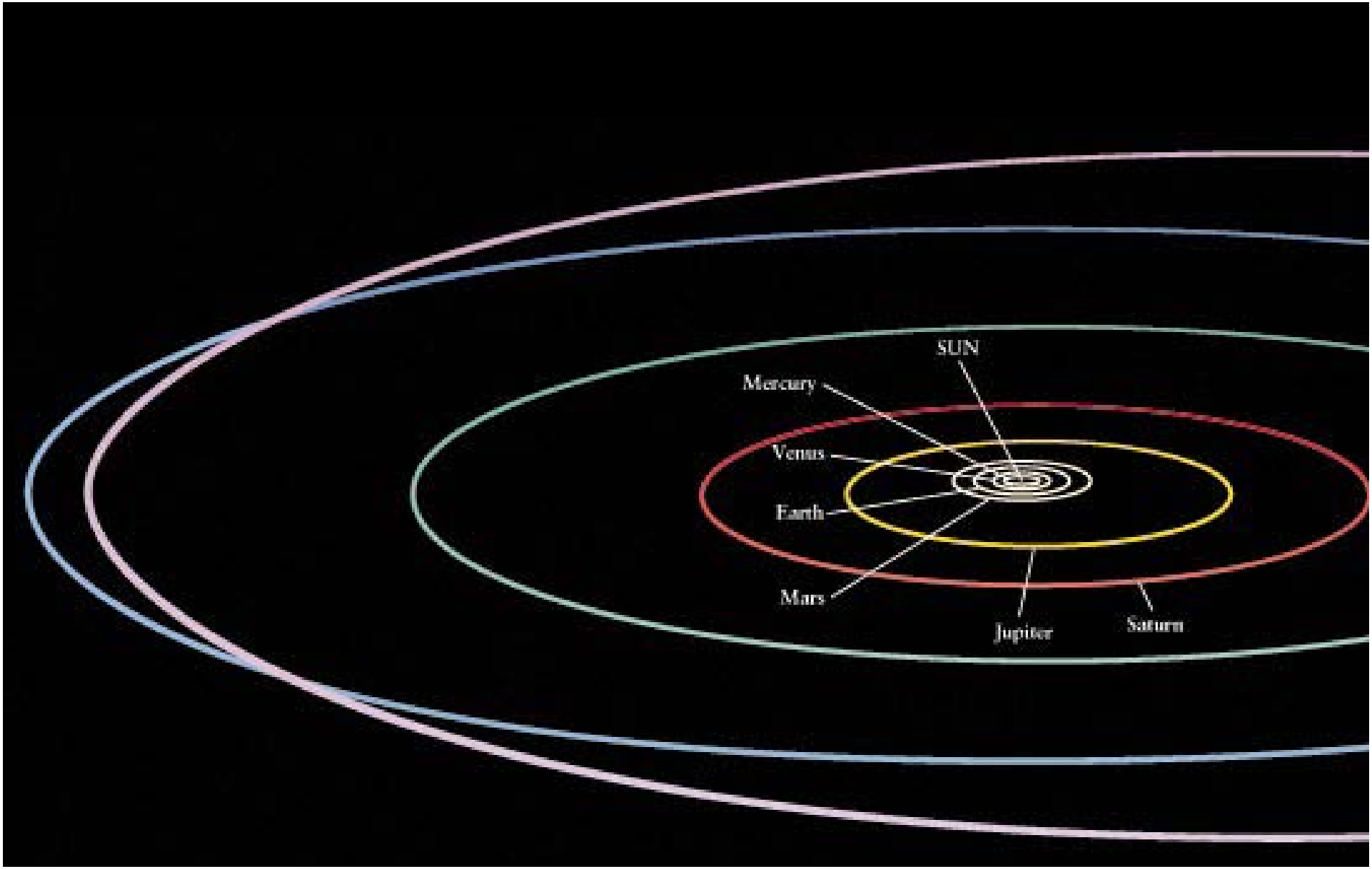
- Midterm grades available next week
- Quiz 8B on Chapter 13 due Monday, practice problems in Problem Set 8B
- Next topic: the **Solar System** (Chapters 4-8, but we won't cover all of it)
- Upcoming schedule:
  - Today: Chapter 4 Sections 4.1 and 4.2
  - Monday March 31: Section 4.3
  - Wednesday April 2: Start Chapter 6 (+ a bit of Ch 5)

Astronomy 103

The Solar System

Please read chapter 4

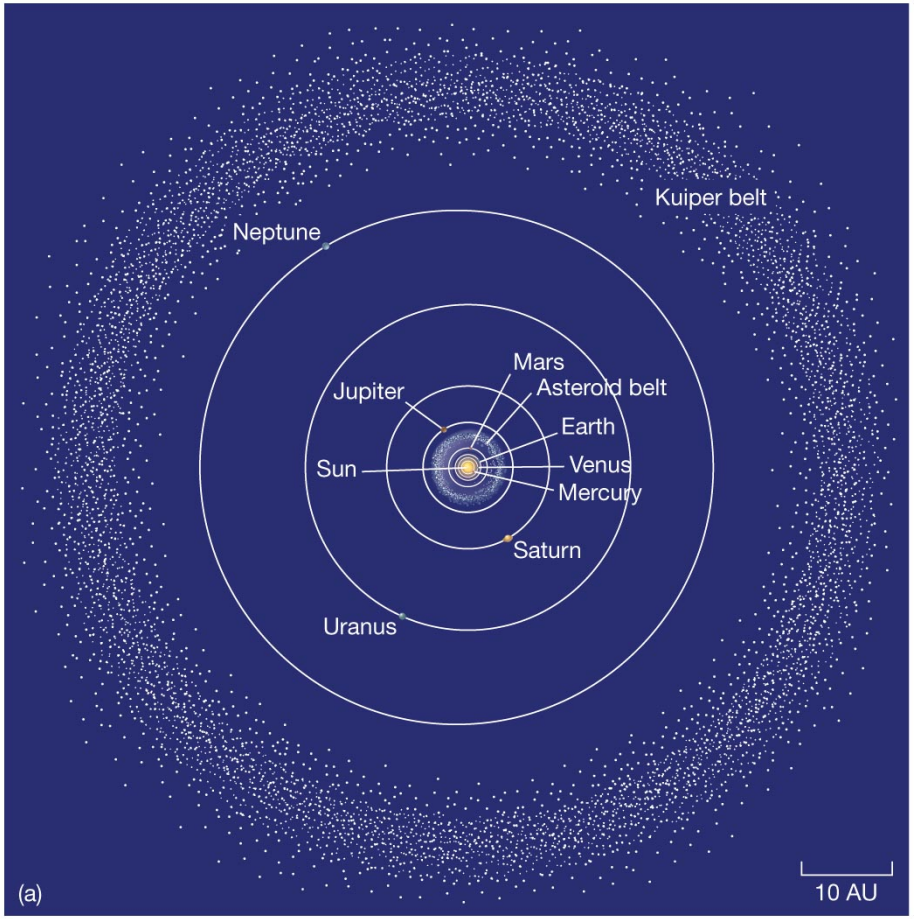
Inventory of the Solar System



An Inventory of the Solar System

Early astronomers knew Moon, stars, Mercury, Venus, Mars, Jupiter, Saturn, comets, and meteors.

Now known: Solar system has 166 moons, one star, eight planets (added Uranus and Neptune), asteroids, comets, meteoroids, dwarf planets, and Kuiper Belt objects.



An Inventory of the Solar System

- The Solar System consists of the sun and everything in orbit around it.
  - Nearly all the mass is in the Sun (~ 99.8%)
  - Nearly all the rest is in the planets and moons
  - The rest are
    - Plutoids – balls of ice and rock in the Kuiper belt
    - Asteroids – rocky piles mostly between Mars and Jupiter
    - Comets – Piles of ice and rocks
    - Meteoroids – pebbles from comets that got ejected when comets came close to the Sun and fragments of asteroids

An Inventory of the Solar System

TABLE 4.1 Properties of Some Solar System Objects

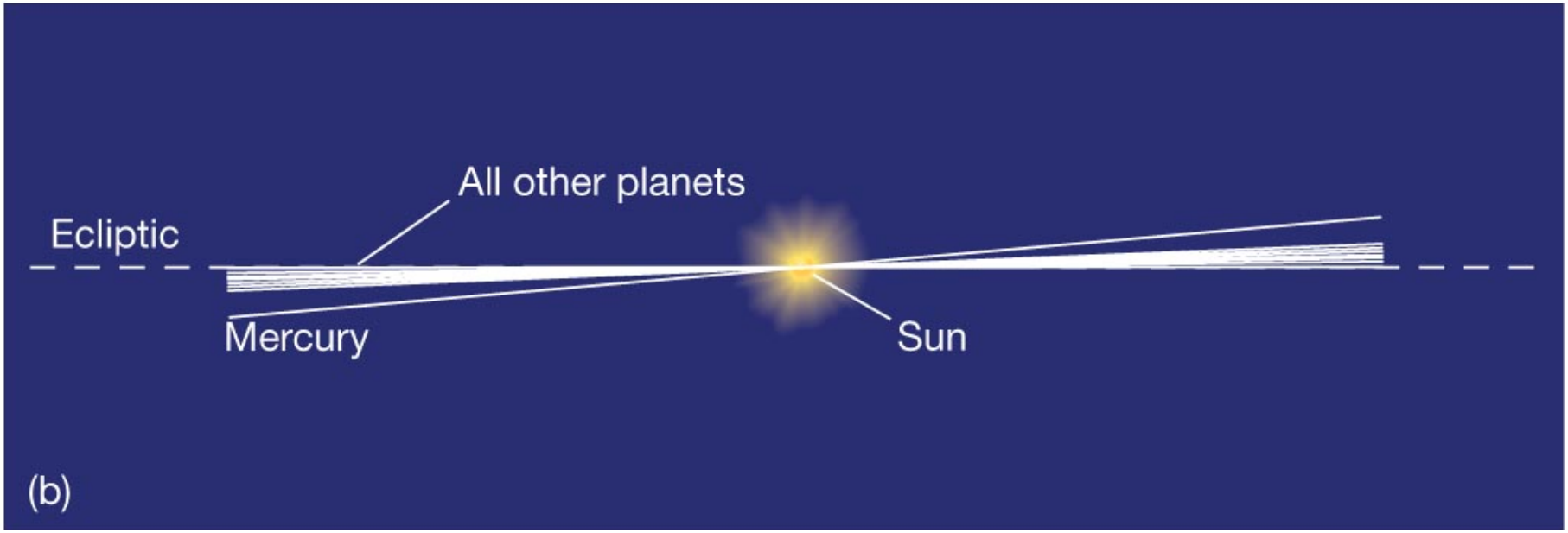
Object	Orbital Semimajor Axis (AU)	Orbital Period (Earth Years)	Mass (Earth Masses)	Radius (Earth Radii)	Number of Known Moons	Average Density (kg/m^3)	Average Density (Earth = 1)
Mercury	0.39	0.24	0.055	0.38	0	5400	0.98
Venus	0.72	0.62	0.82	0.95	0	5200	0.95
Earth	1.0	1.0	1.0	1.0	1	5500	1.00
Moon	—	—	0.012	0.27	—	3300	0.60
Mars	1.5	1.9	0.11	0.53	2	3900	0.71
Ceres (asteroid)	2.8	4.7	0.00015	0.073	0	2700	0.49
Jupiter	5.2	11.9	318	11.2	63	1300	0.24
Saturn	9.5	29.4	95	9.5	50	700	0.13
Uranus	19.2	84	15	4.0	27	1300	0.24
Neptune	30.1	164	17	3.9	13	1600	0.29
Pluto (Kuiper-belt object)	39.5	249	0.002	0.2	1	2100	0.38
Comet Hale-Bopp	180	2400	1.0×10^{-9}	0.004	—	100	0.02
Sun	—	—	332,000	109	—	1400	0.25

An Inventory of the Solar System

- **How do we measure the Solar System?**
- **Distance from Sun known by Kepler's laws**
- **Orbital period can be observed**
- **Radius known from angular size**
- **Masses known from Newton's laws**
- **Rotation period known from observations**
- **Density can be calculated knowing radius and mass**

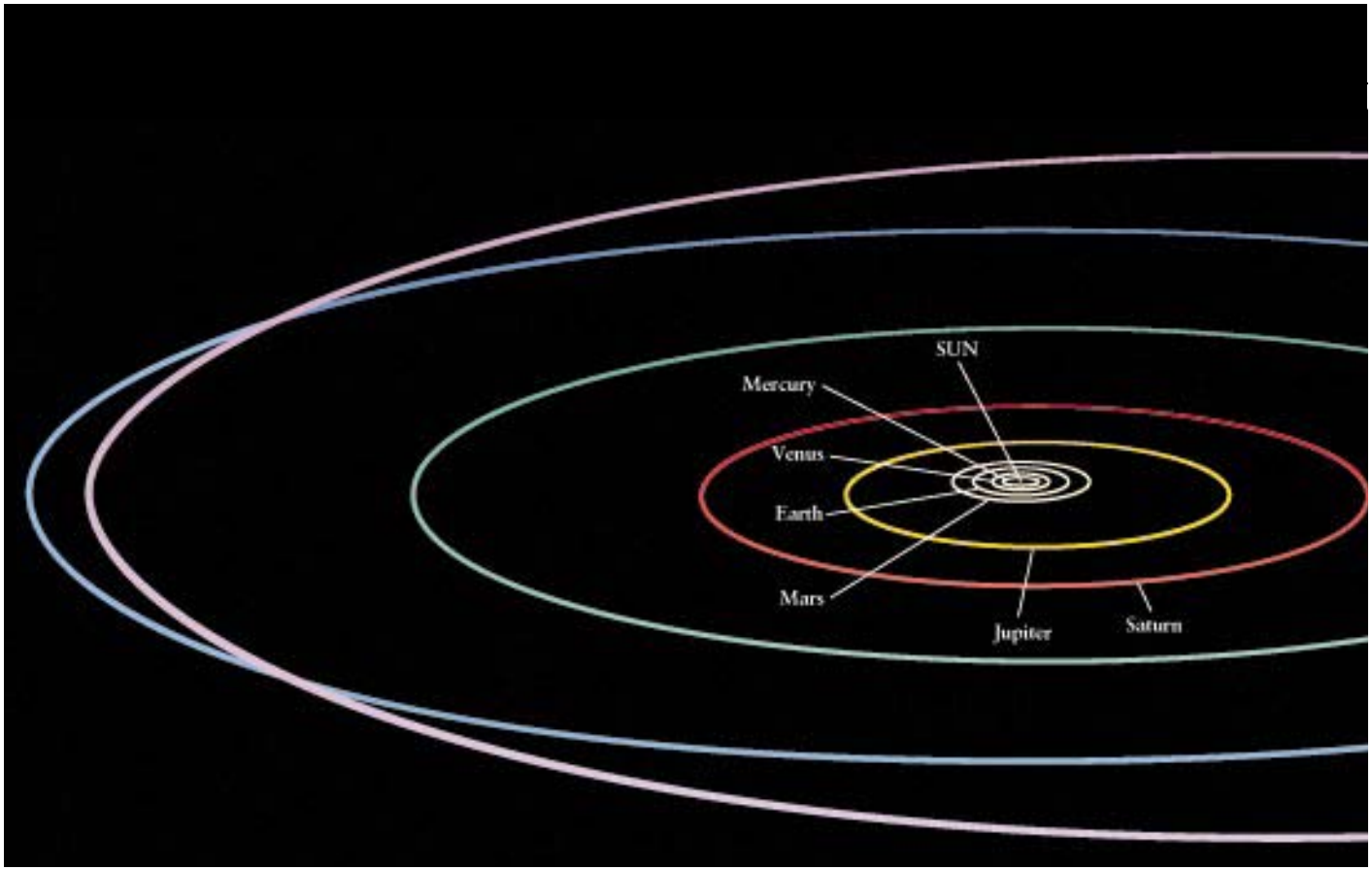
An Inventory of the Solar System

All planetary orbits except Mercury's are close to the same plane.



An Inventory of the Solar System

- The planets orbit the sun from W to E along the plane of the ecliptic – looking down from Earth's North pole, planets orbit counterclockwise.

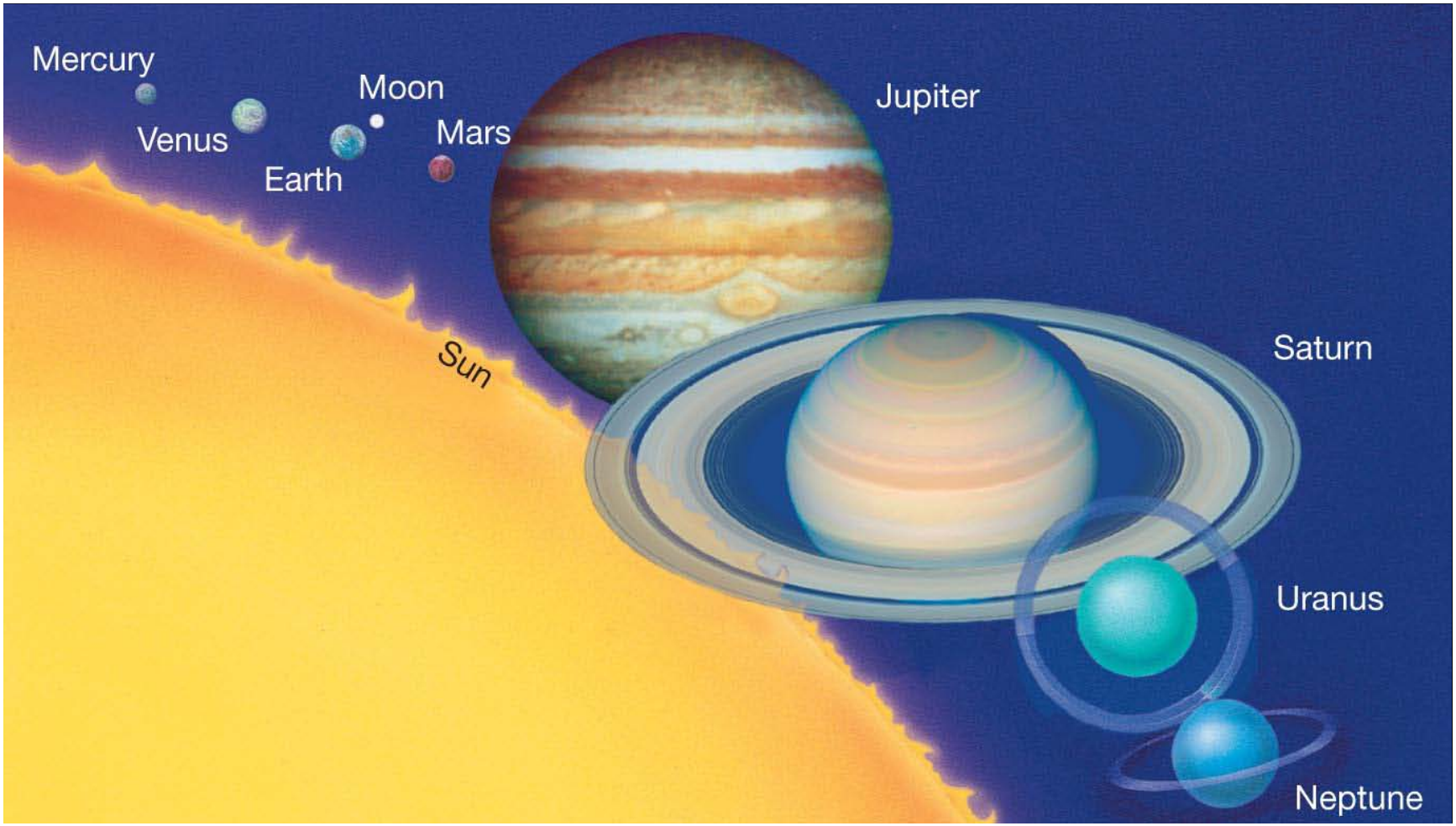


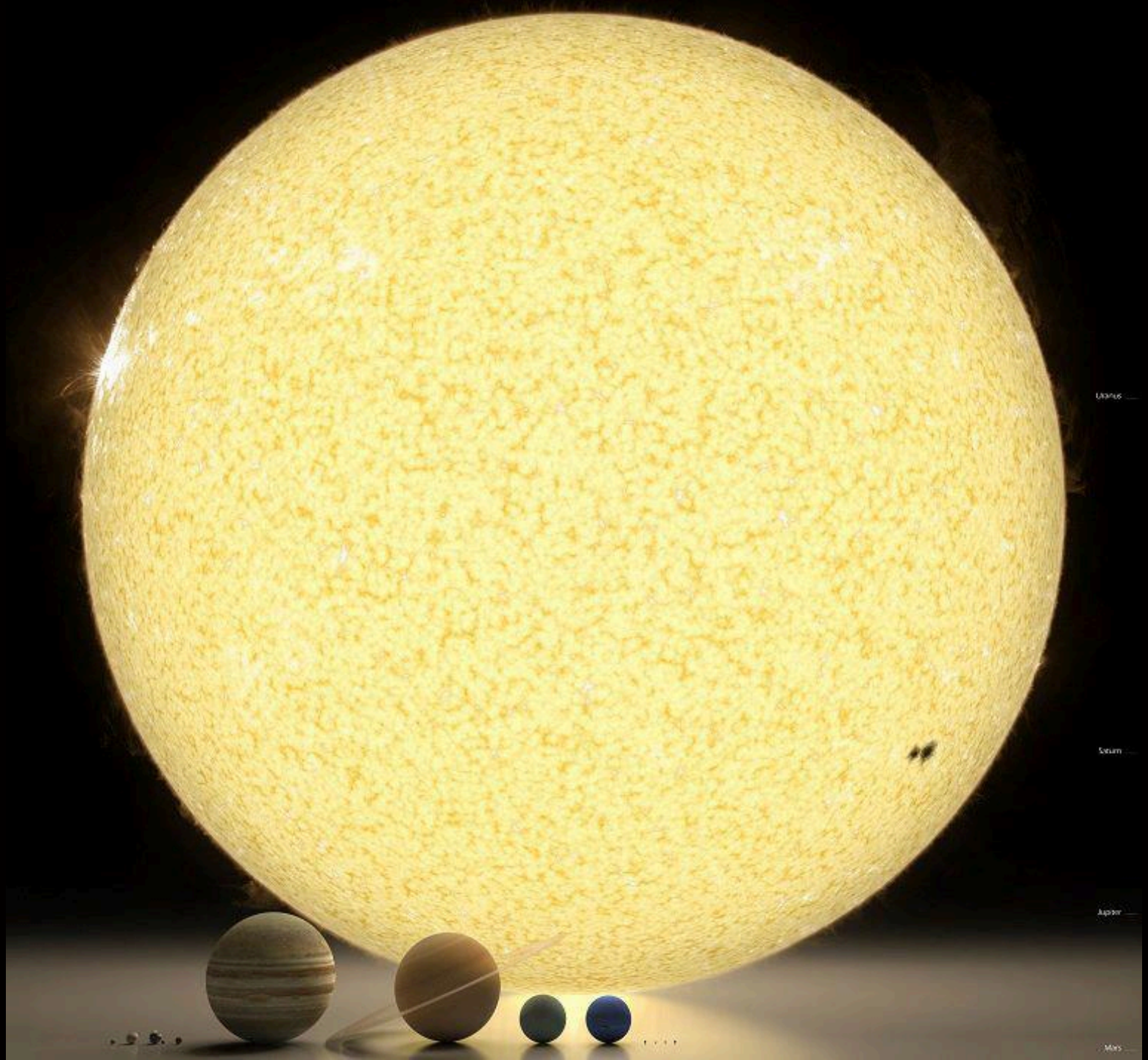
An Inventory of the Solar System

- The planets orbit the sun from W to E along the plane of the ecliptic – looking down from Earth's North pole, planets orbit counterclockwise.
- Orbits are nearly circular – yes, Kepler says that they are ellipses, and they are, but they are nearly perfectly circular ellipses
- Nearly all in the same plane – without Pluto, they are perfect to 1%
- Inner planets are called terrestrial planets
- Outer planets are called Jovian planets

Planets of the Solar System

- Planets vary a bit in size
- Jupiter is 1/10 the diameter of the sun
- Earth is 1/10 the diameter of Jupiter




Uranus
Saturn
Jupiter
Mars

Density

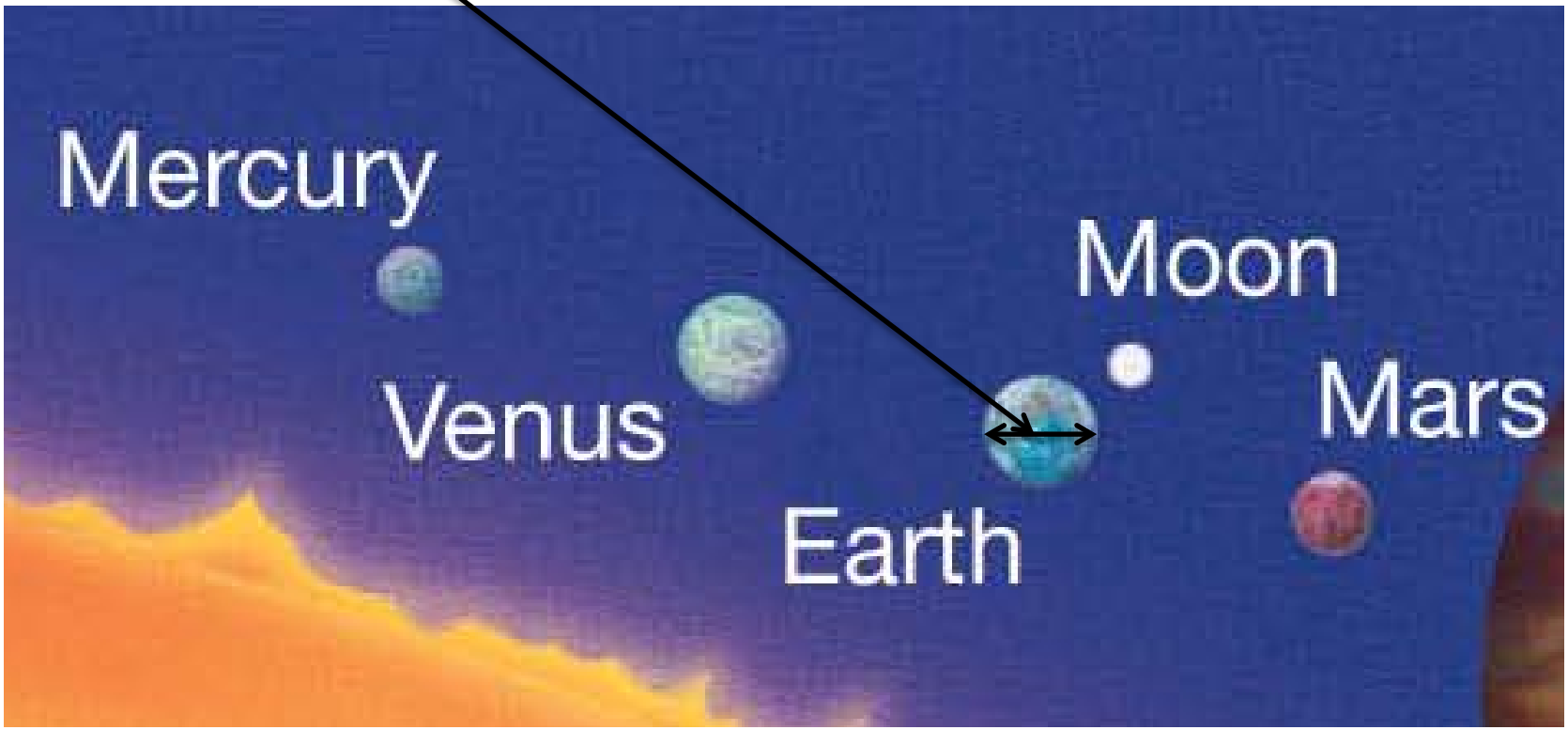
Density of a object is:
Density = mass / volume

Density of some common materials:
Water ~ 1000 kg/m^3
Rock ~ 2000-3000 kg/m^3
Iron ~ 8000 kg/m^3

For objects like the Sun, Jupiter, Saturn: density is ~ 1000 kg/m^3
For terrestrial bodies like Earth, Mercury, Venus: density is around 5000 kg/m^3

Terrestrial Planets

- Close to the Sun
- Made of rocks (silicon) and iron
- High density
- Small (~10,000 km in diameter)



Terrestrial Planets

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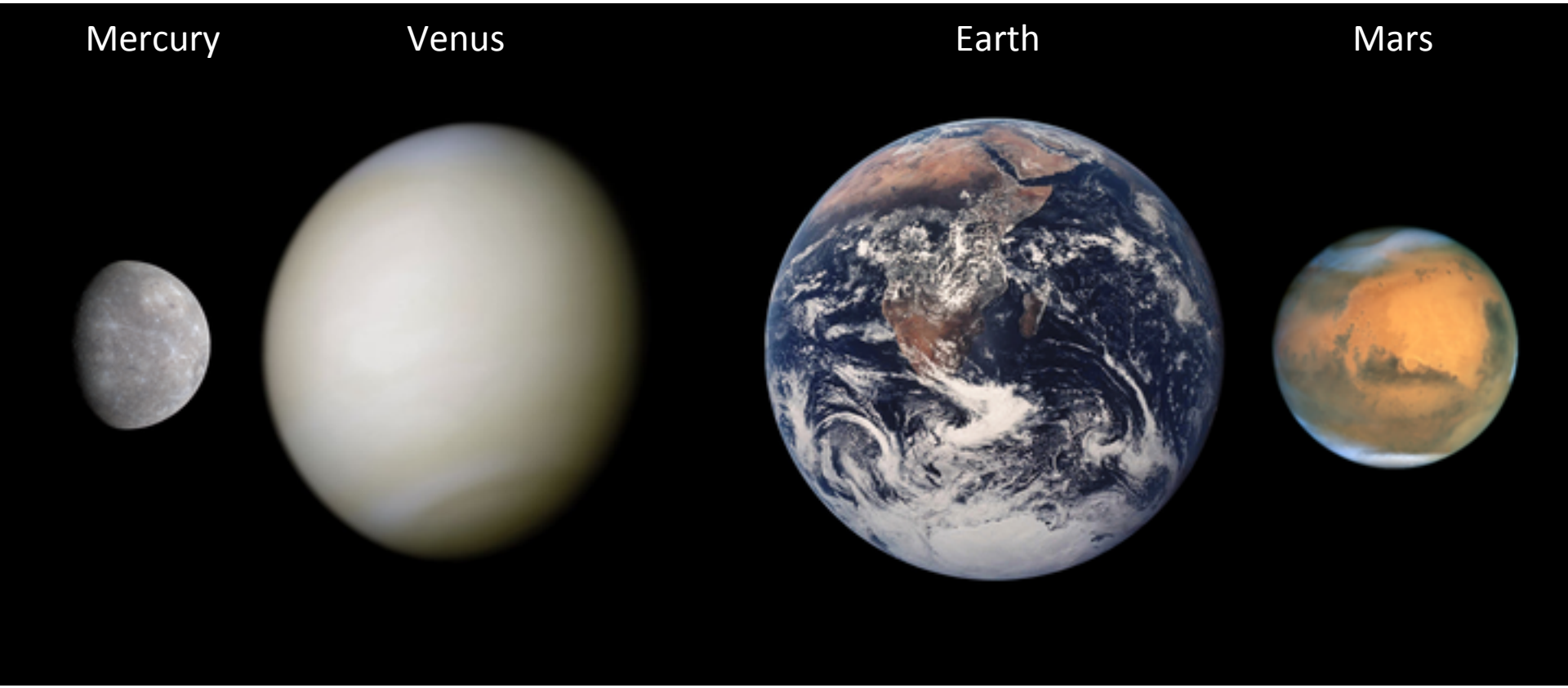
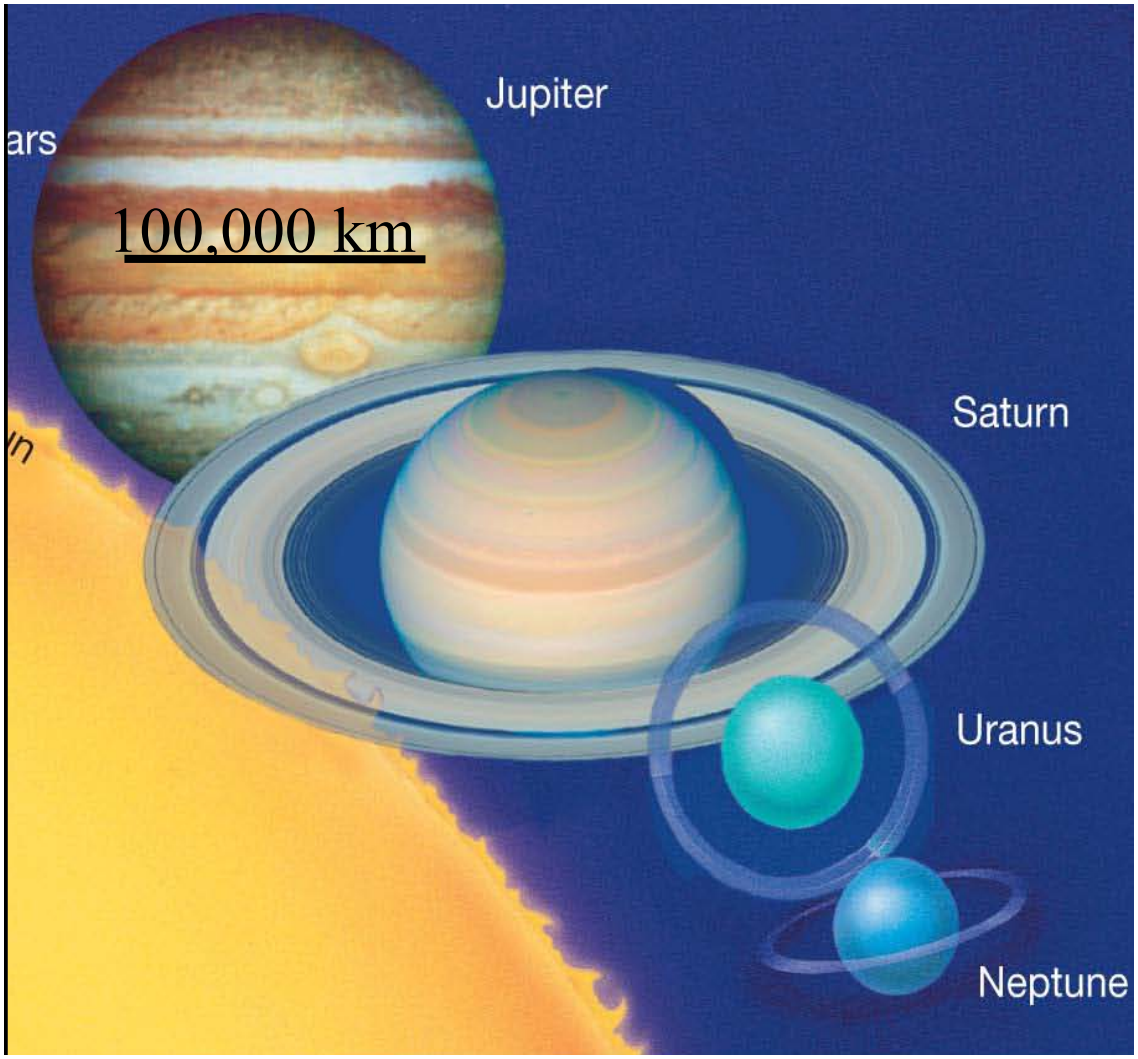
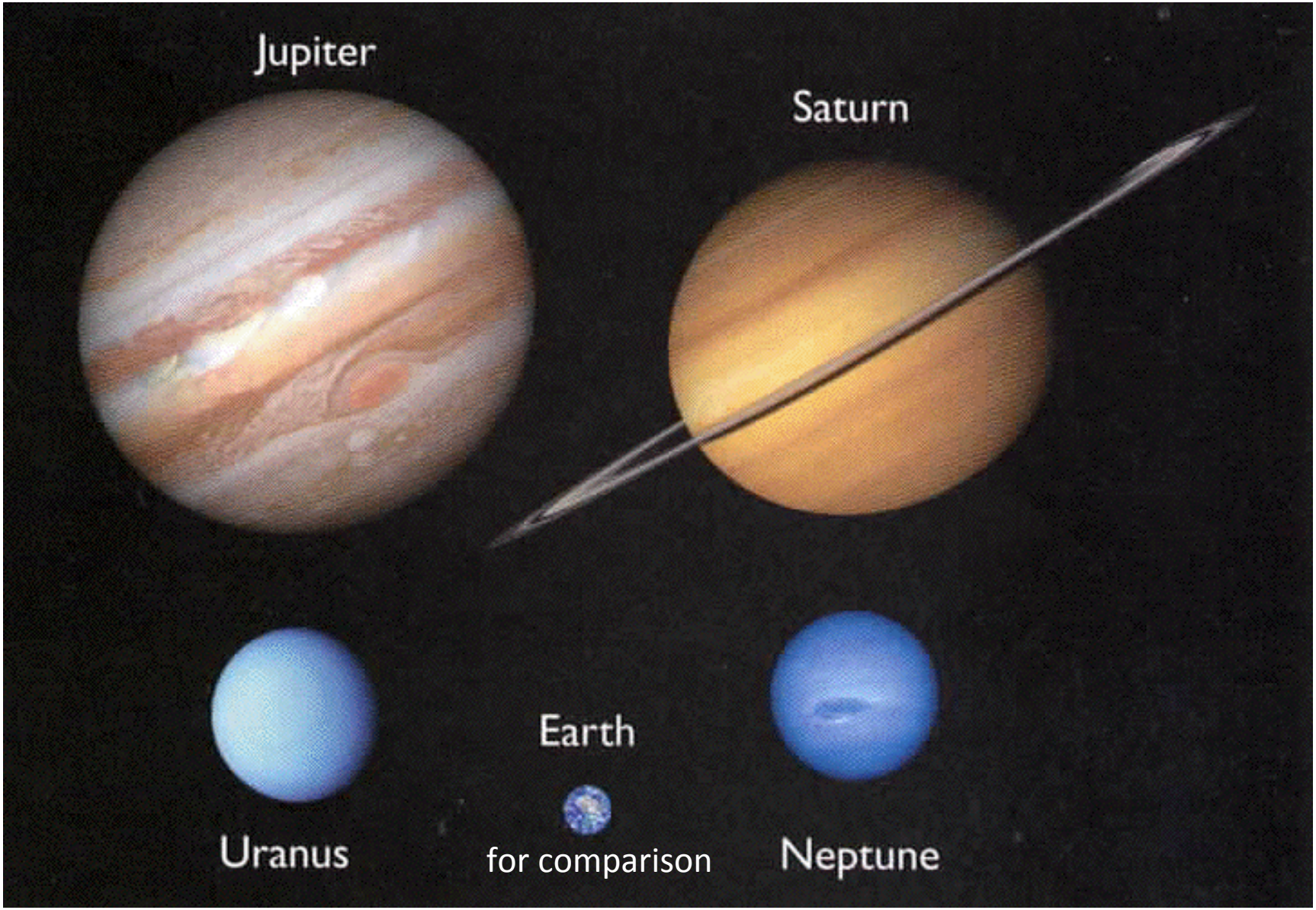


Jovian Planets

- Farther from the Sun
- Made of gases (hydrogen, helium, methane, water, ammonia)
- lower density
- large (~100,000 km in diameter)



Jovian Planets



Comparison of Terrestrial and Jovian Planets

	Distance from Sun	Composition	Mass	Radius	Density	Spin	Number of moons
Terrestrial	close	rock and iron	Earth or less	Earth or less	high (rock)	slow	few or none
Jovian	far	Gas: H, He, H_20, NH_4, CH_4	larger	larger	low	fast	many

An Inventory of the Solar System

Terrestrial planets:

Mercury, Venus, Earth, Mars

Jovian planets:

Jupiter, Saturn, Uranus, Neptune

TABLE 4.2 Comparison Between the Terrestrial and Jovian Planets

Terrestrial	Jovian
close to the Sun	far from the Sun
closely spaced orbits	widely spaced orbits
small masses	large masses
small radii	large radii
predominantly rocky	predominantly gaseous
solid surface	no solid surface
high density	low density
slower rotation	faster rotation
weak magnetic fields	strong magnetic fields
no rings	many rings
few moons	many moons

Compared with terrestrial planets, Jovian planets have all of the following characteristics EXCEPT

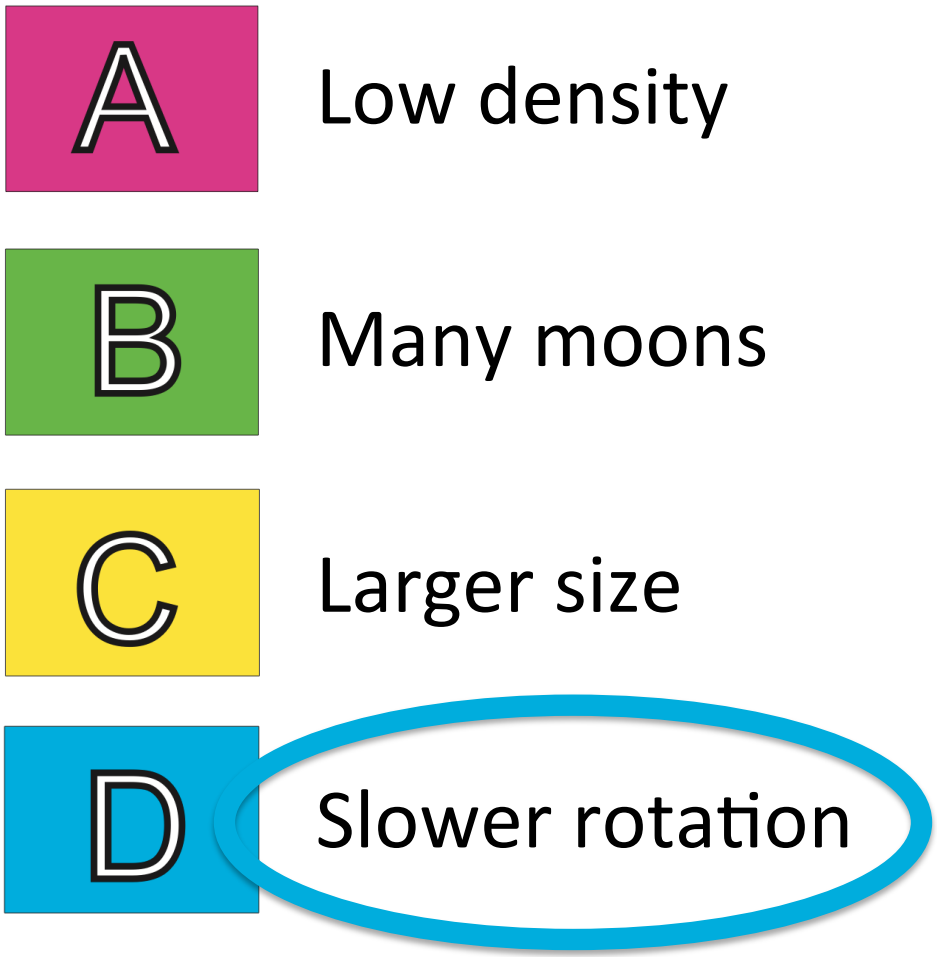
A Low density

B Many moons

C Larger size

D Slower rotation

Compared with terrestrial planets, Jovian planets have all of the following characteristics EXCEPT



An Inventory of the Solar System

Differences between the terrestrial planets:

- **Atmospheres and surface conditions are very dissimilar**
- **Only Earth has oxygen in atmosphere and liquid water on surface**
- **Earth and Mars rotate at about the same rate; Venus and Mercury are much slower, and Venus rotates in the opposite direction**
- **Earth and Mars have moons; Mercury and Venus don't**
- **Earth and Mercury have magnetic fields; Venus and Mars don't**

History of the Solar System

- We want to understand the history of the solar system
- However, large bodies like planets evolve
  - Volcanism, erosion, plate tectonics…
- So it is important to look at things that hold a better record of the past: small bodies that don't change much
- The small bodies that have the best clues are **asteroids, comets, meteoroids** (coming from asteroids and comets) and **plutoids**
- The age and chemical composition of these things can tell us about the early solar system

Asteroids

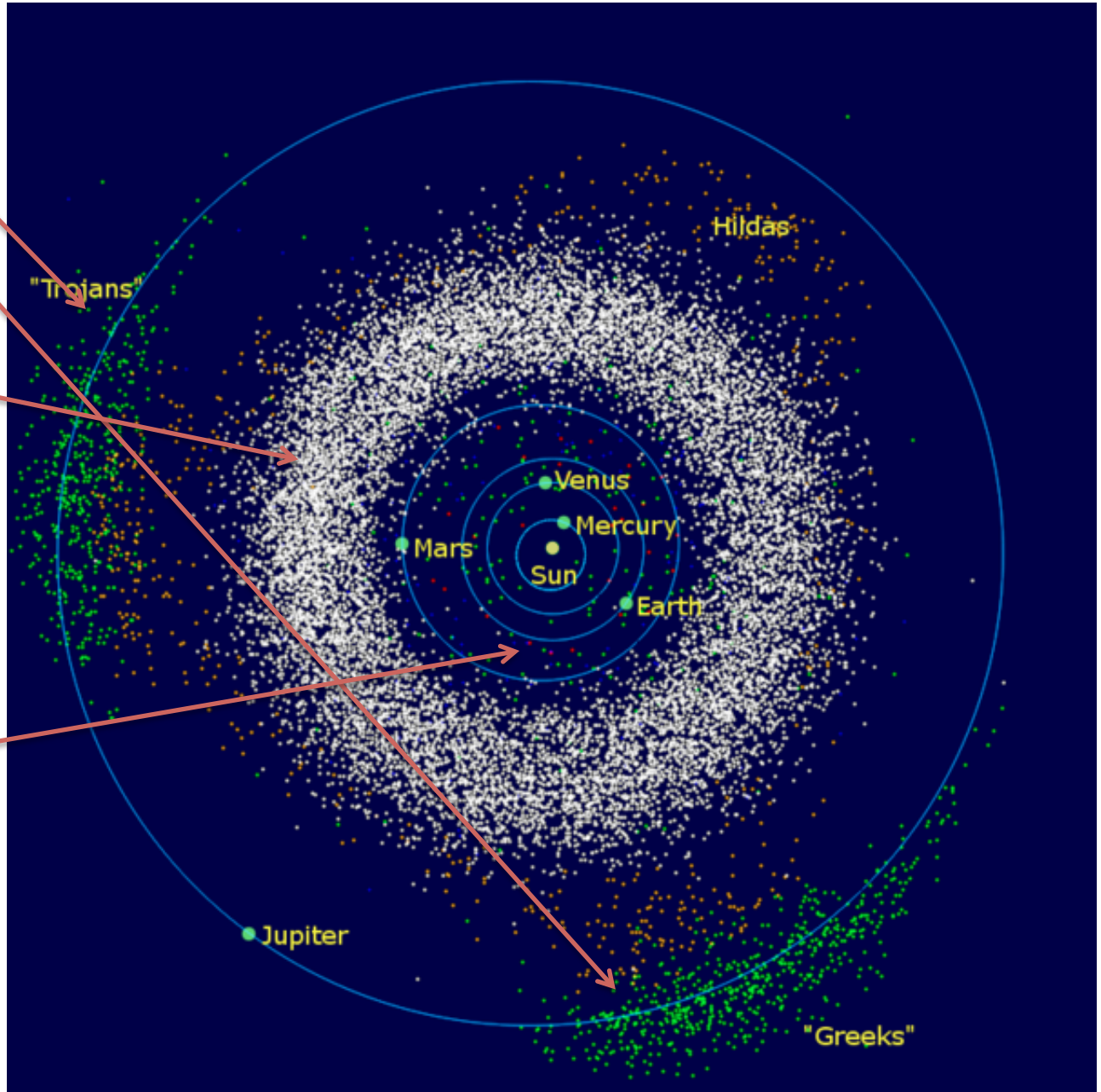
- Rocky bodies that are held together by gravity
- Most live in a belt between Mars and Jupiter at 2.8 A.U. called the asteroid belt
  - about 100,000 rocky objects bigger than 1km exist
- Ceres is the largest asteroid with a diameter of ~1000 km
- A few thousand have orbits that cross Earth's orbit – called near-Earth asteroids (NEAs)
- Some are near Jupiter (60 degrees ahead and behind) and are called Trojans

Asteroids

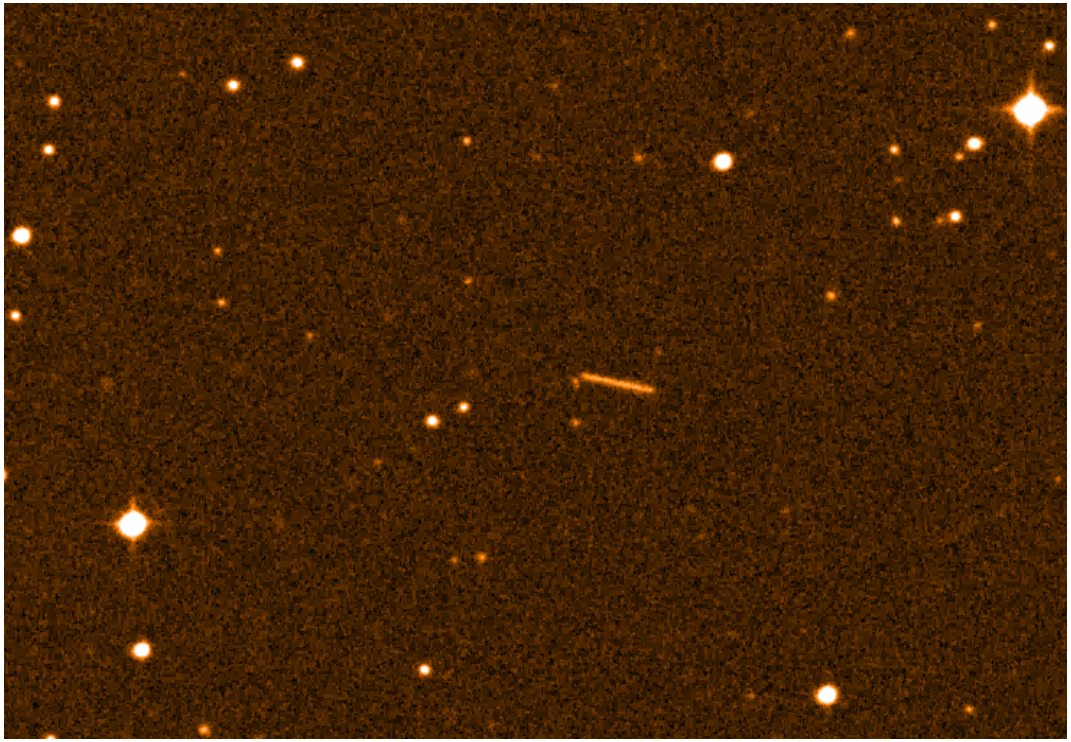
Trojans

Asteroid Belt

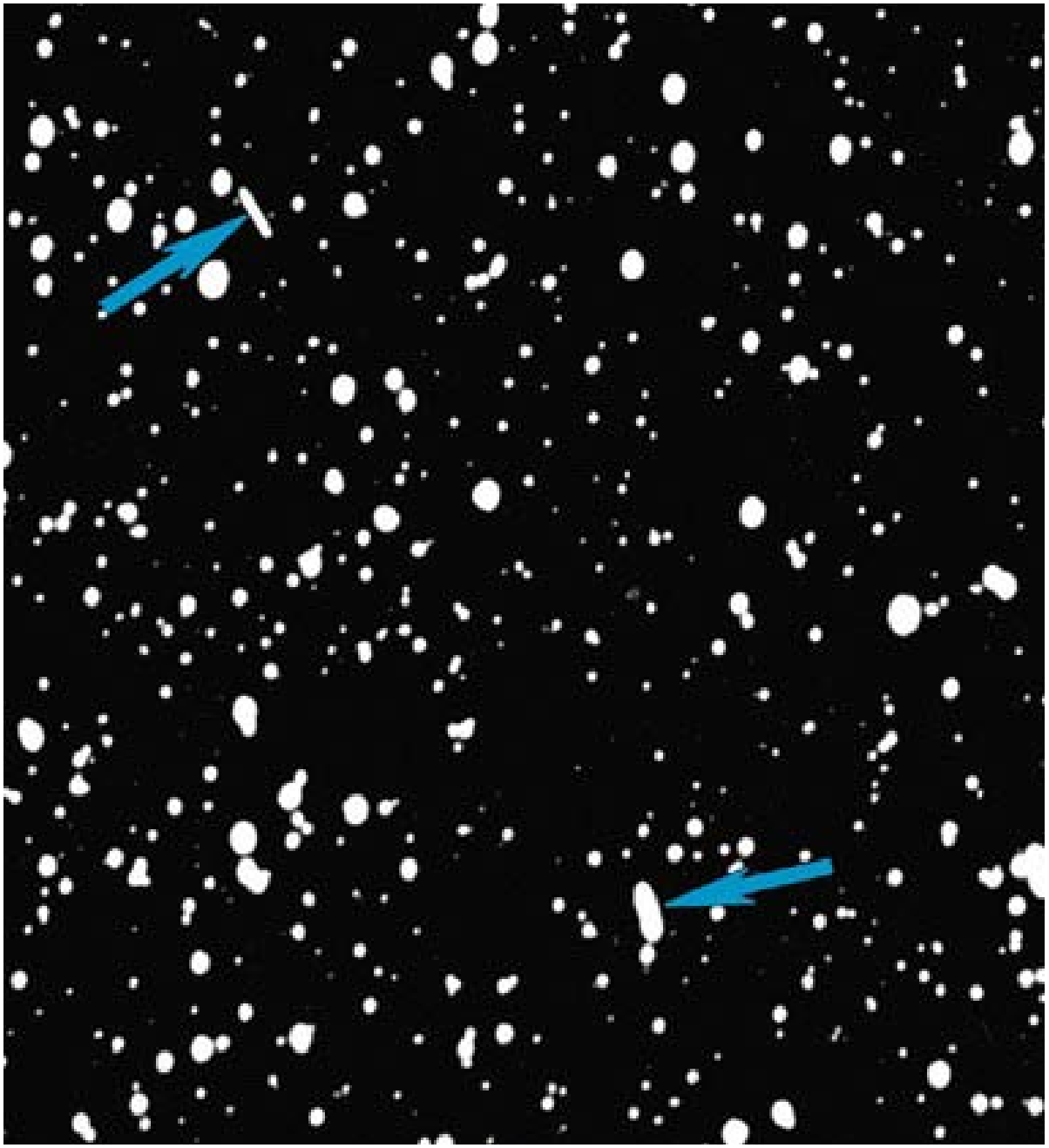
Near Earth Asteroids



Asteroids are faint because they shine only in reflected light and they are small. But they can be differentiated from stars because they move.



Over a long exposure, they appear as streaks.

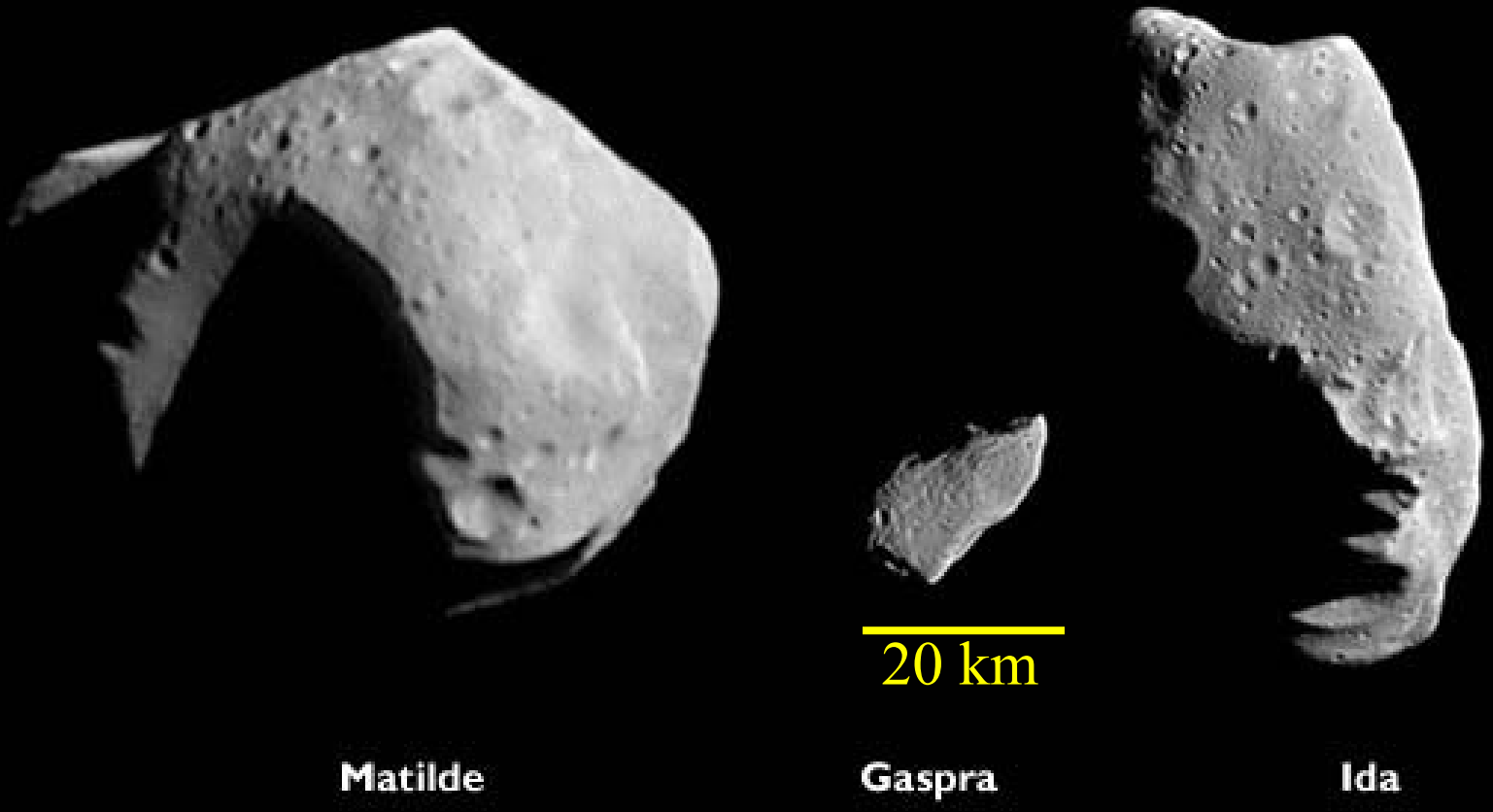


Asteroids

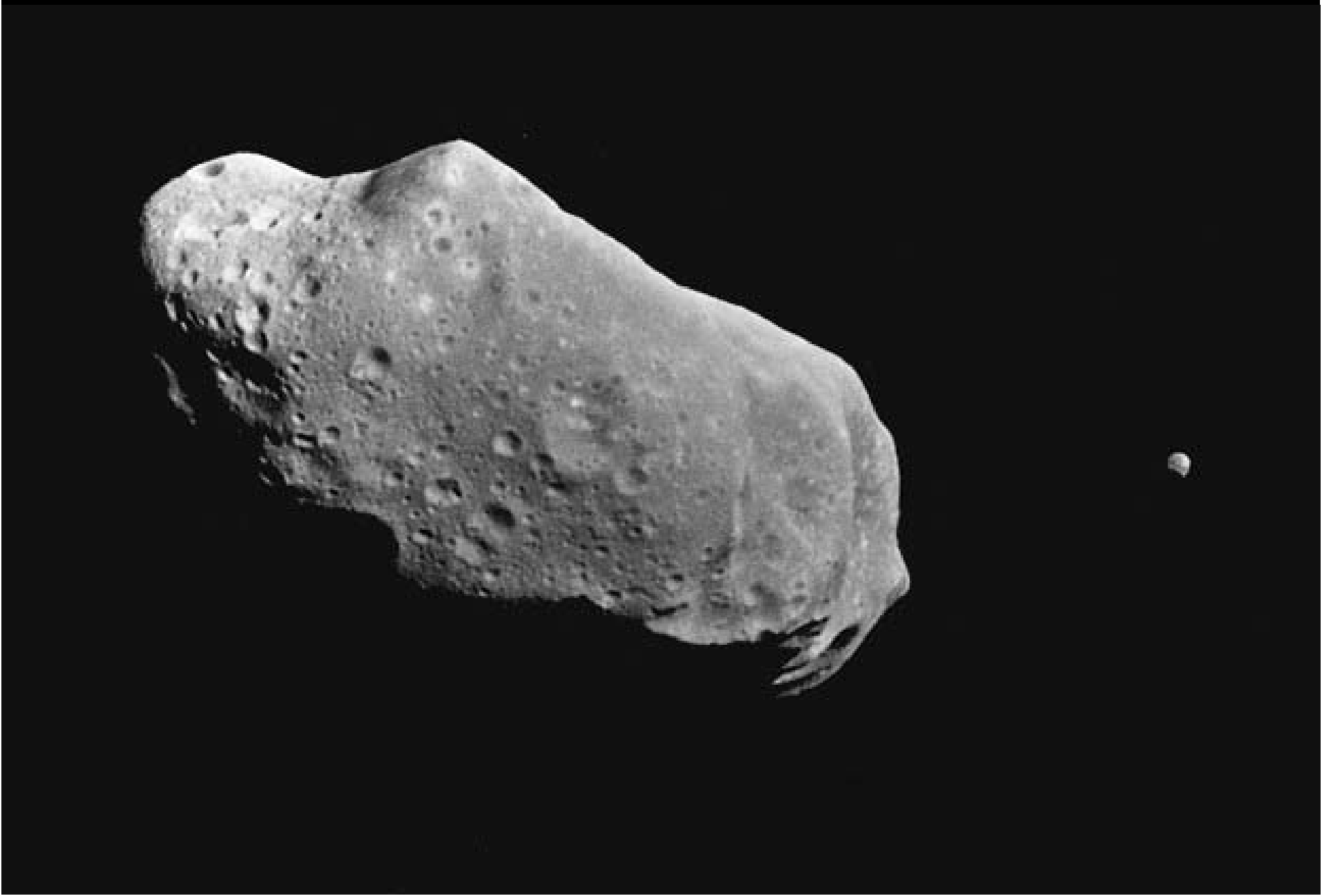
- Their composition is not well known, but it is believed that some of them have iron cores and rocky or icy exteriors, or are rocky all the way through.
- Some are dark and have lots of water ices and organic material on the surface – known as carbonaceous asteroids
- Others are more reflective and are mainly bare rock – known as silicate asteroids
- Total amount of mass in asteroids is about the mass of the Moon

The first close-up photos of asteroids

(photos taken by Galileo in ‘91, NEAR in ‘97)



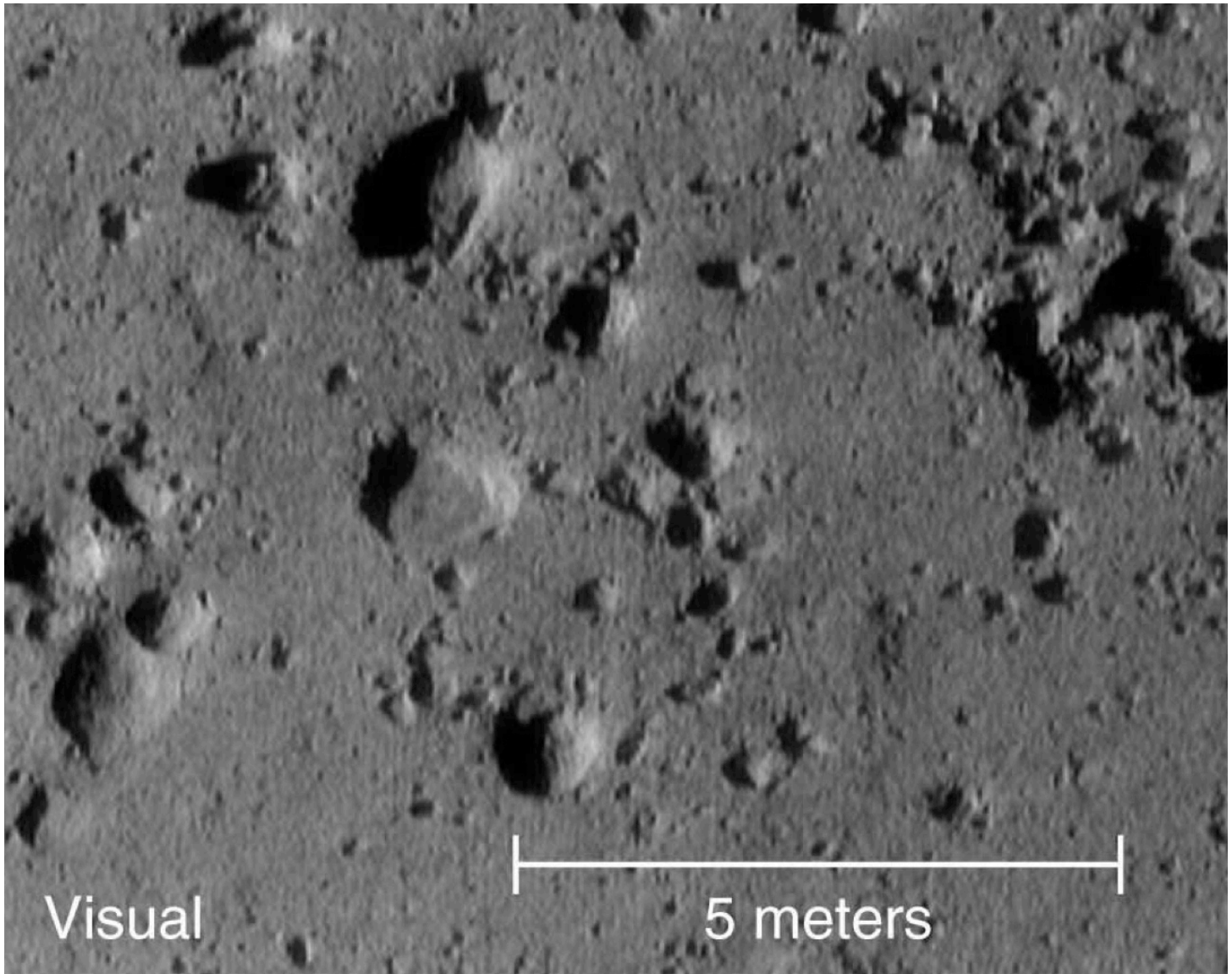
Ida and its moon Dactyl (Dactyl is about 1 km across)



More Asteroid Properties

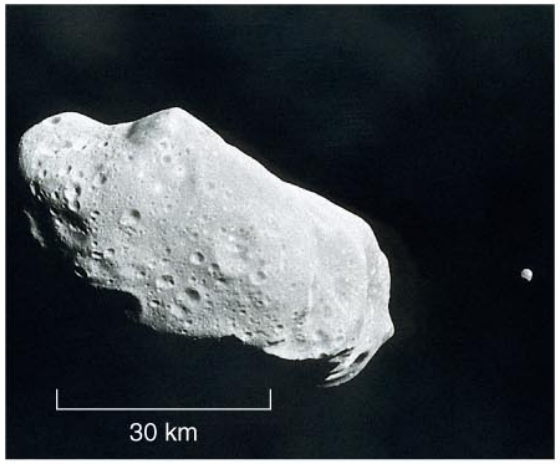
- Measurements of their density from Galileo (the space probe) and NEAR (Near Earth Asteroid Rendezvous) gives asteroid densities from 1000 – 3000 kg/m^3
- Remember that the terrestrial planets have densities of about 5000 kg/m^3
- This means that while these object are rocky, they are probably very porous – sometimes referred to as “rubble piles”
- Might be important to know if you want to stop a killer asteroid

Picture from NEAR/Shoemaker spacecraft right before landing/crashing on an asteroid



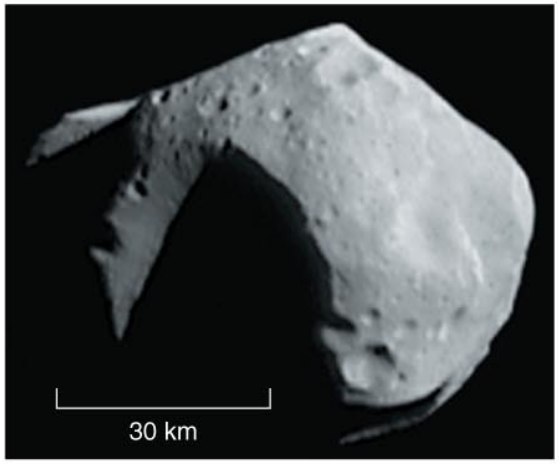
Asteroids and Meteoroids

Asteroids and meteoroids have rocky composition; asteroids are bigger.

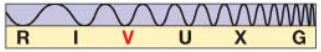


(b)

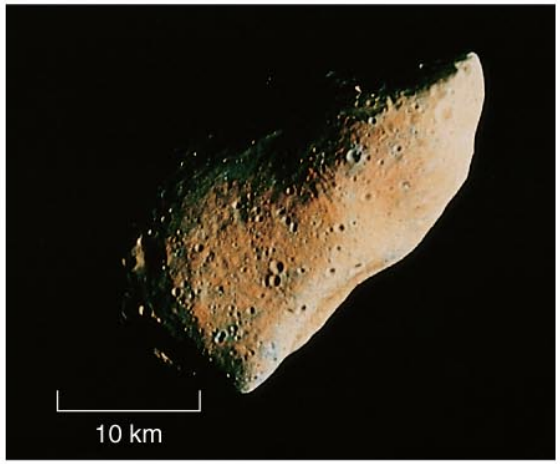
(below) Asteroid Gaspra



(c)



(above) Asteroid Ida with its moon, Dactyl



(a)

(above) Asteroid Mathilde

Comets

- Icy bodies – called “dirty snowballs” – made of rocks, water ice, frozen methane, frozen ammonia, and frozen carbon dioxide
- ~1 – 10 km in size.
- When they pass close to the sun, the ices sublimate: solid -> gas. Blows out a halo of gas and rocks (pebbles), which is called a **coma**
- Sunlight and the solar wind push on the gas and dust blowing the tail away from the sun
- Comet tails point away from the sun, NOT opposite of direction of motion

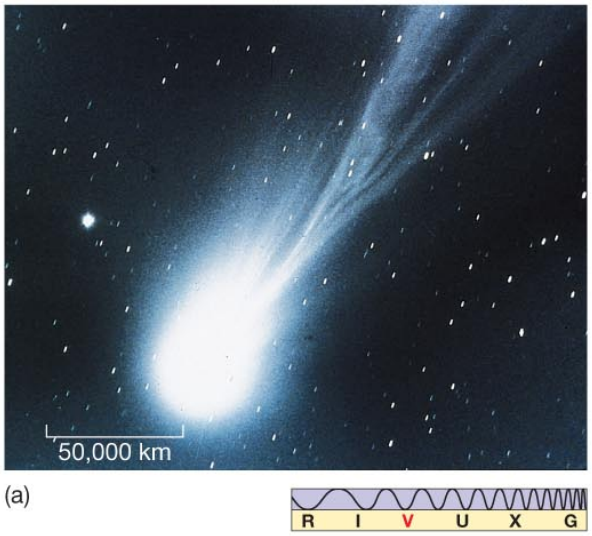
Comets

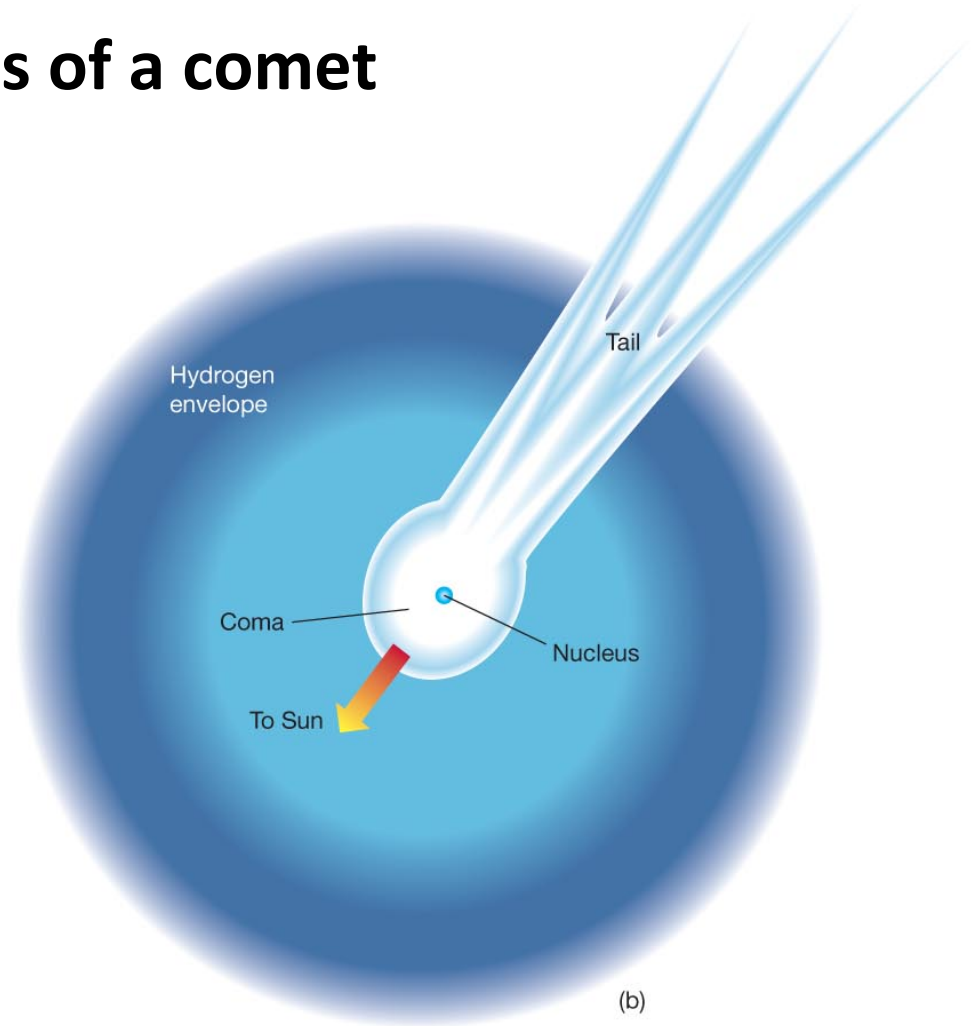
- Consist of the **nucleus** – main solid body of the comet
- And the **coma** – diffuse halo of gas and dust around it
- Very low density ~ 100 kg/m^3 << water ice (1000 kg/m^3), so they are loosely packed *snowballs*
- Orbits are typically 1000s of years and originate far beyond the orbit of Pluto in the Oort cloud.
- Short period comets (<200 years) originate in the region near Pluto known as the Kuiper belt

Comets

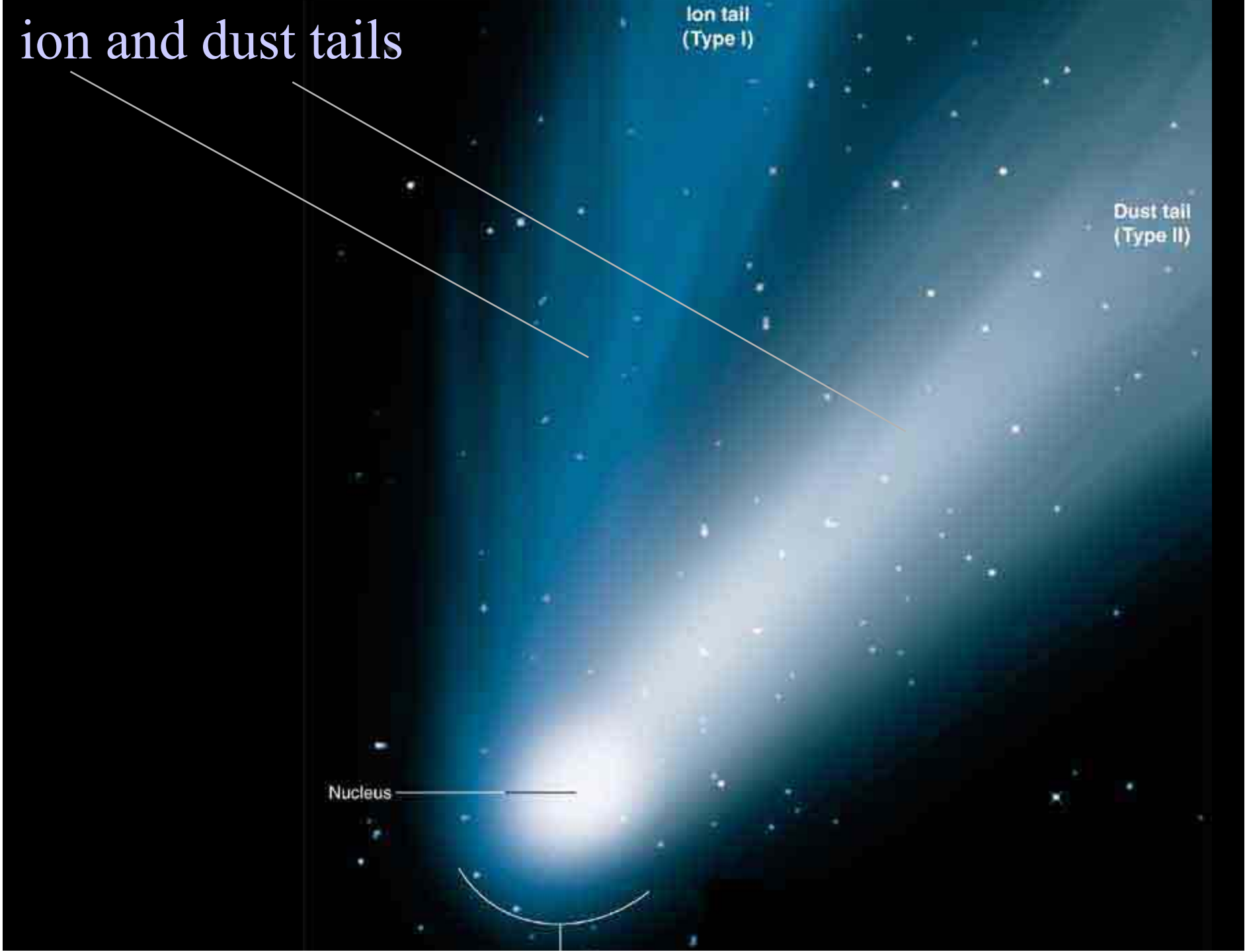
Comets are icy, with some rocky parts.

The basic components of a comet

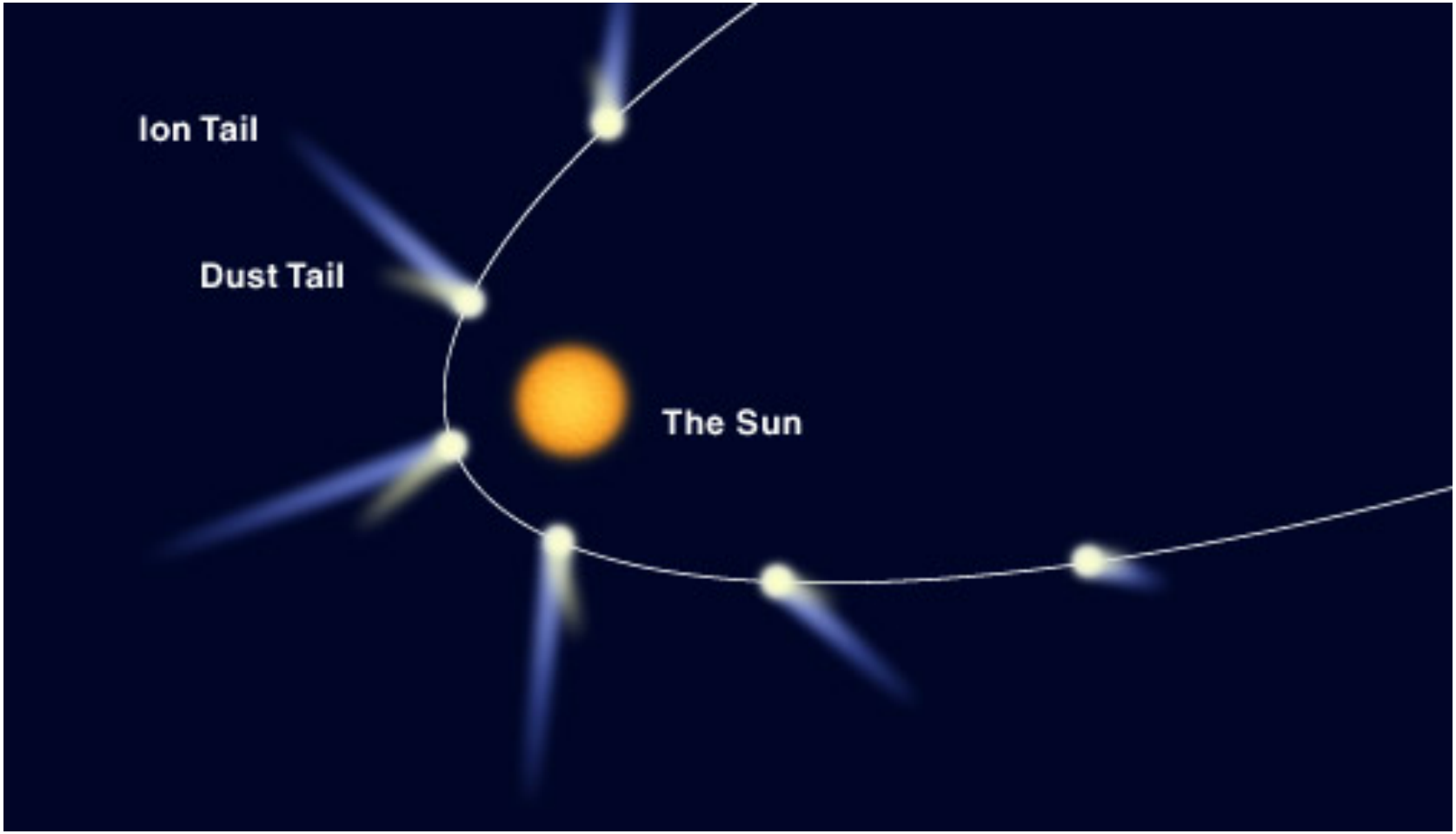





Comet Hale-Bopp,
March ‘97


ion and dust tails
Ion tail
(Type I)
Dust tail
(Type II)
Nucleus

Comet's tail

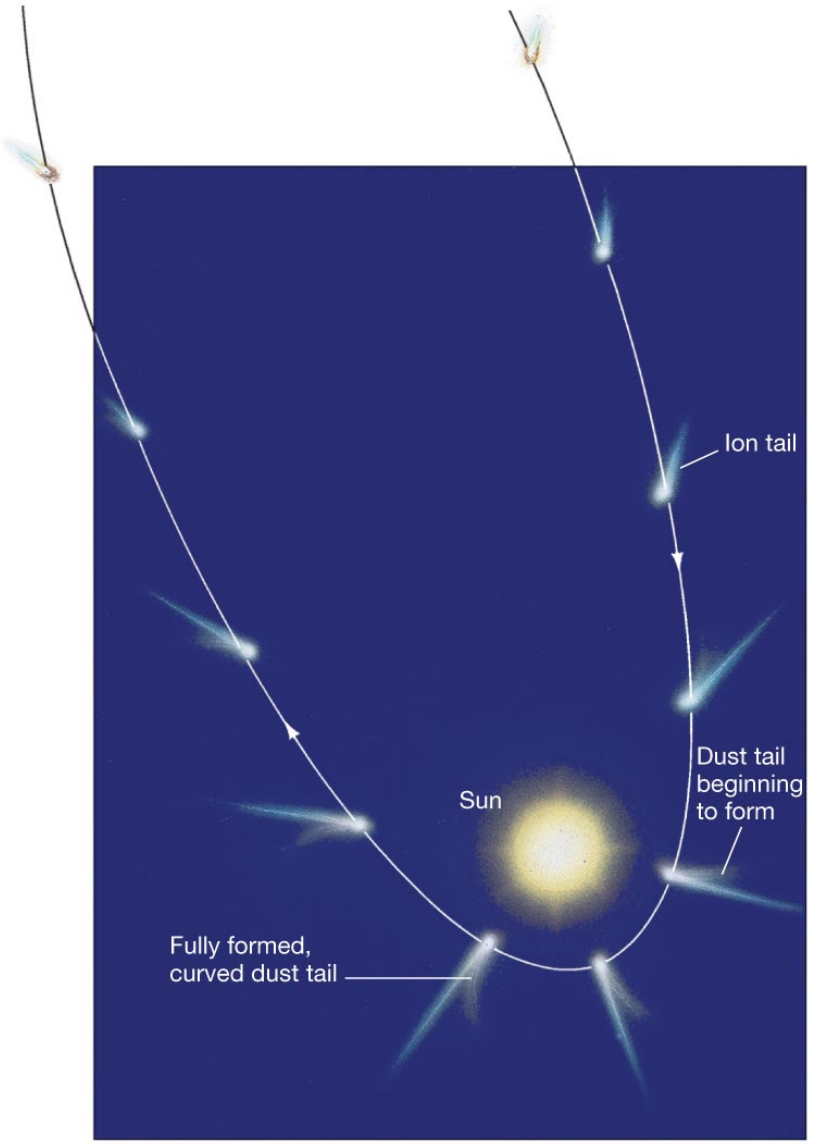


Comet tails point away from the sun due to the solar wind and the light from the Sun.

Comets

The solar wind means the ion tail always points away from the Sun.

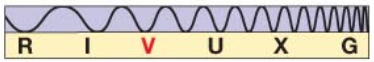
The dust tail also tends to point away from the Sun, but the dust particles are more massive and lag somewhat, forming a curved tail.

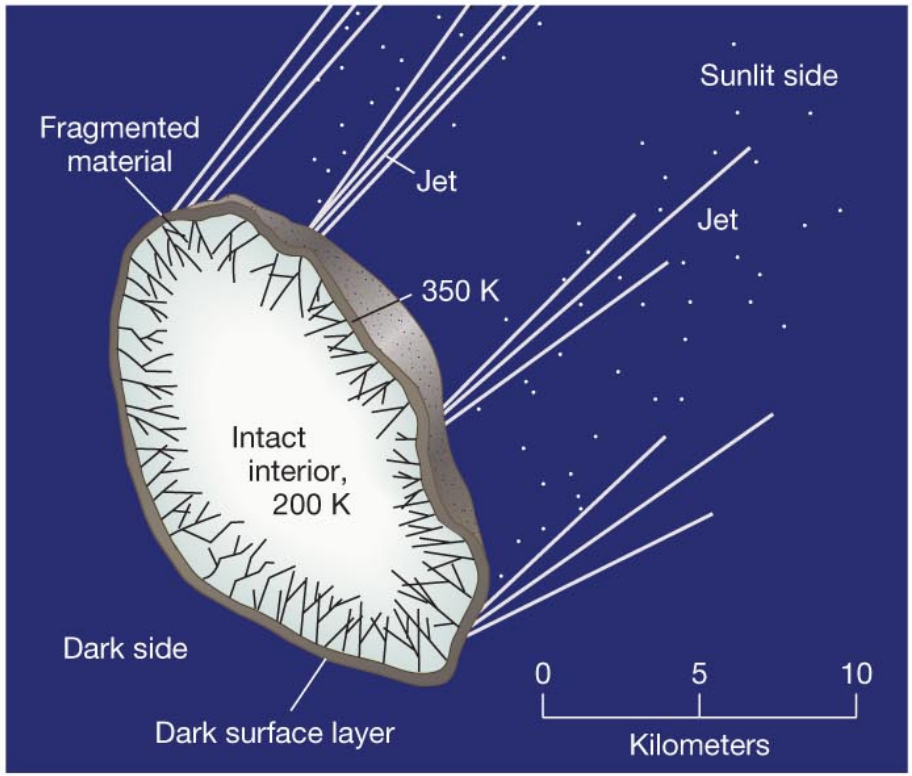


Comets

The internal structure of the cometary nucleus

(a)





(b)

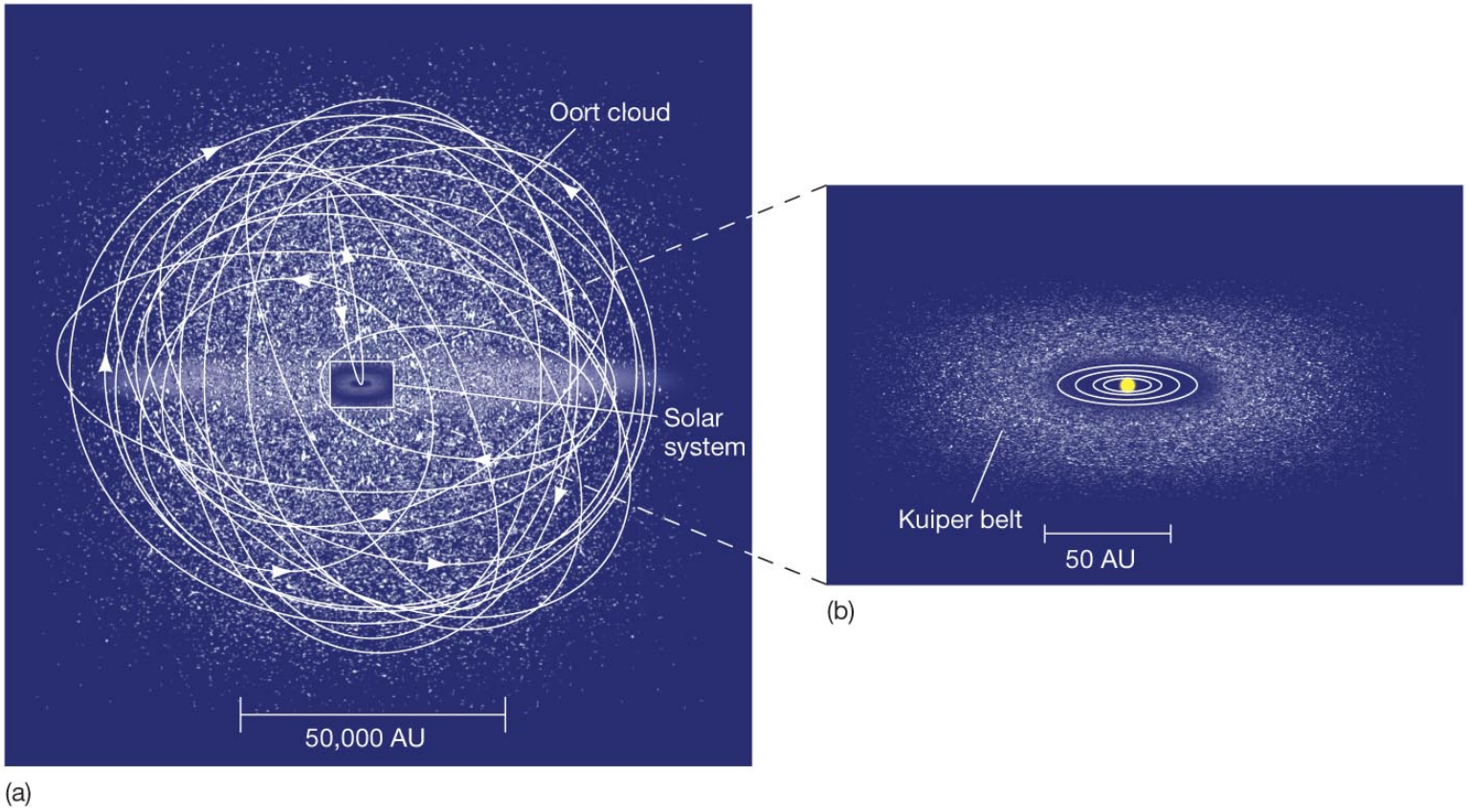
Comet Hartley 2 – showing plumes of material from Deep Impact spacecraft

Halley's Comet

Nucleus ~ 10 km across

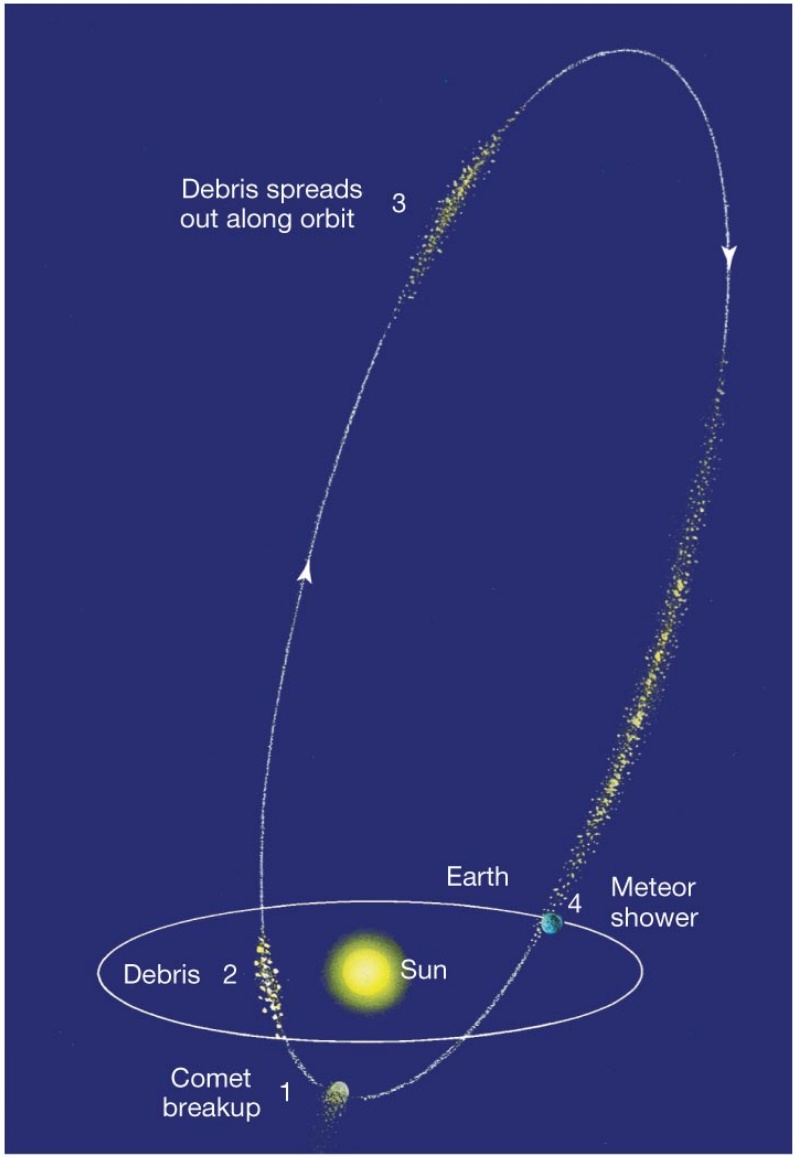
Orbits of Comets

The size, shape, and orientation of cometary orbits depend on their location. Oort cloud comets rarely enter the inner solar system.



Comets and Meteor Showers

Meteor showers are associated with comets – they are the debris left over when a comet breaks up.



Comets and Meteor Showers

TABLE 4.3 Some Prominent Meteor Showers

Morning of Maximum Activity	Shower Name/Radiant	Rough Hourly Count	Parent Comet
Jan. 3	Quadrantid/Bootes	40	—
Apr. 21	Lyrid/Lyra	10	1861I (Thatcher)
May 4	Eta Aquarid/Aquarius	20	Halley
June 30	Beta Taurid/Taurus	25	Encke
July 30	Delta Aquarid/Aquarius/ Capricorn	20	—
Aug. 12	Perseid/Perseus	50	1862III (Swift–Tuttle)
Oct. 9	Draconid/Draco	up to 500	Giacobini–Zimmer
Oct. 20	Orionid/Orion	30	Halley
Nov. 7	Taurid/Taurus	10	Encke
Nov. 16	Leonid/Leo	12[1]	1866I (Tuttle)
Dec. 13	Geminid/Gemini	50	3200 Phaeton[2]

[1]Every 33 years, as Earth passes through the densest region of this meteoroid swarm, we see intense showers that can reach 1000 meteors per minute for brief periods of time. This occurred most recently in 1999 and 2000.
[2]Phaeton is actually an asteroid and shows no signs of cometary activity, but its orbit matches the meteoroid paths very well.

Meteoroids

- Small rocks in the solar system
- **Asteroid: >100 m in size**
- **Meteroid: <100 m in size**
- If they enter the Earth's atmosphere and burn up they are called **meteors**
- **Meteorites** are meteors that penetrate though the atmosphere to hit the ground

Most meteorites (95%) are rocky

Most of the rest are iron

The rarest are carbonaceous chondrite – lots of carbon and hydrocarbons