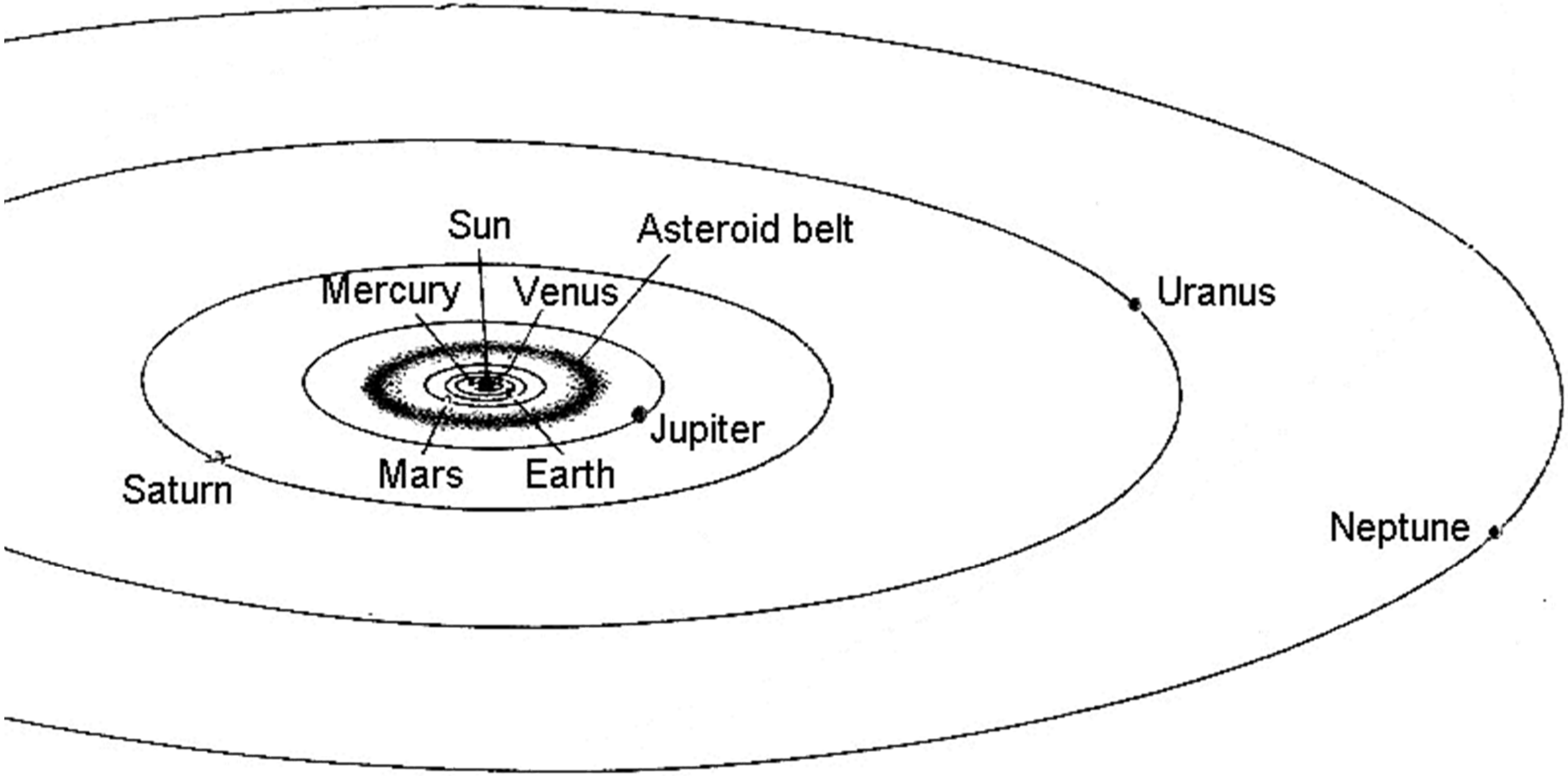
Chapter 5

The Solar System

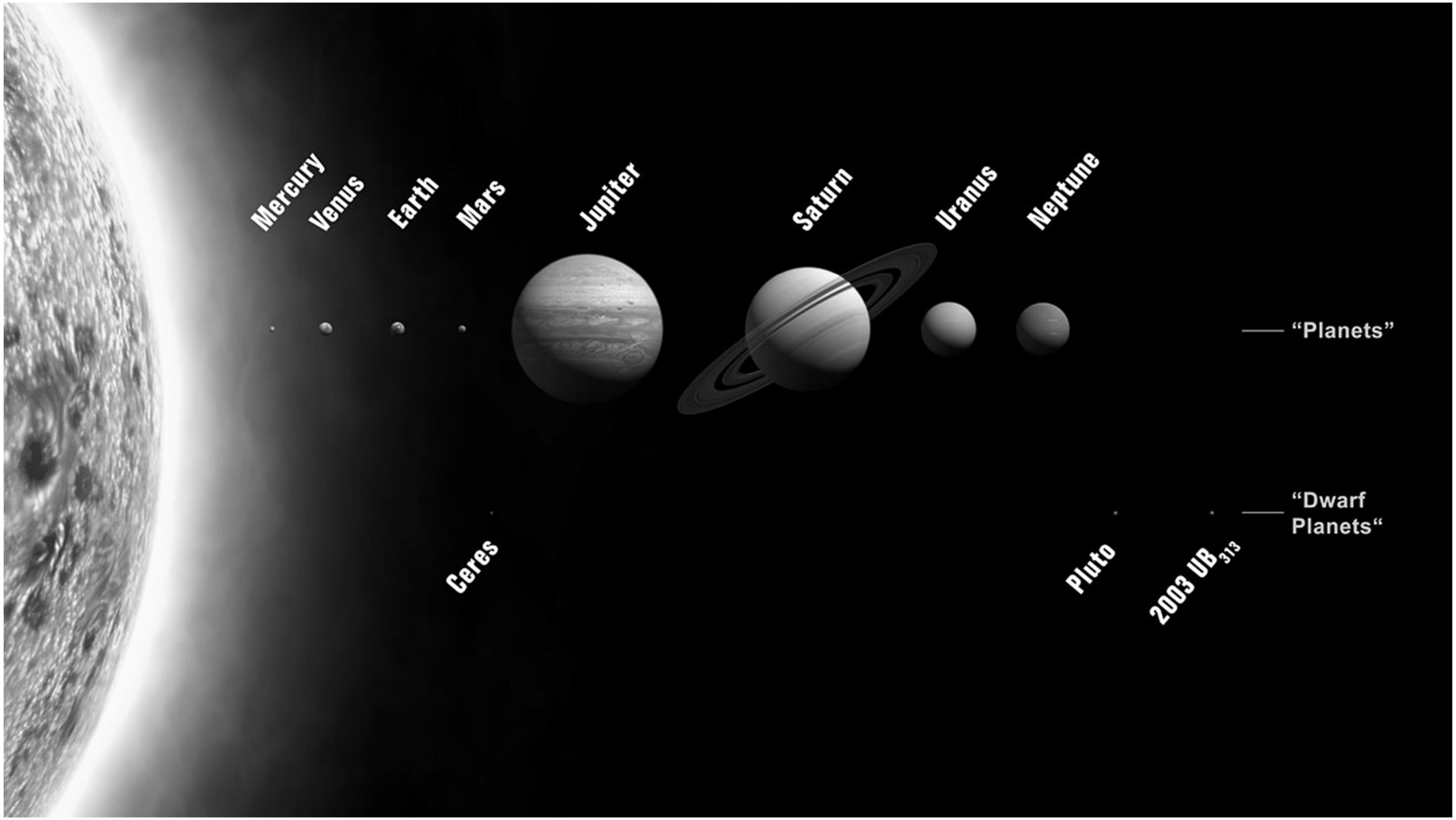
The Solar System

5.1 A quick survey

The Sun and the 8 major planets in the Solar System



Mass of *Sun* ~99.8% of the whole Solar System



Classification of planets and other bodies in the Solar System into three categories, namely, *planet*, *dwarf planet* (矮行星) and *small Solar System bodies* as proposed by the International Astronomical Union (國際天文聯合會) in 2006.

5.1 A quick survey

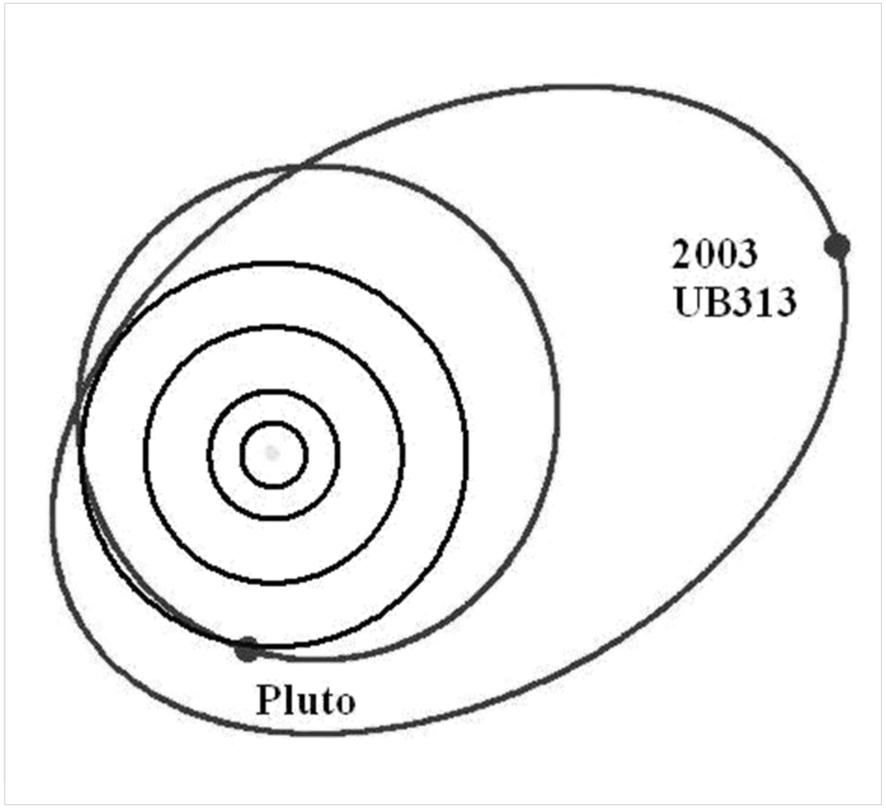
Planets

- ✓ 8 *planets* with their satellite lying almost on the same plane.
- ✓ Orbital motion in counter-clockwise sense; self-rotation also in counter-clockwise sense, except Venus, Uranus. Orbits of the planets *not* evenly spaced.

5.1 A quick survey

Dwarf planets

- ✓ The first members are Ceres, 2003UB$_{313}$(Eris), and Pluto.
- ✓ Pluto became a dwarf planet in 2006.
- ✓ Currently 5 members.



5.1 A quick survey

Small Solar System bodies

- ✓ Refers to all other objects except satellites orbiting the Sun.
- ✓ These currently include most of *asteroids* (小行星), most *Trans-Neptunian Objects* (TNOs，海外天體), *comets* (彗星), and other small bodies.

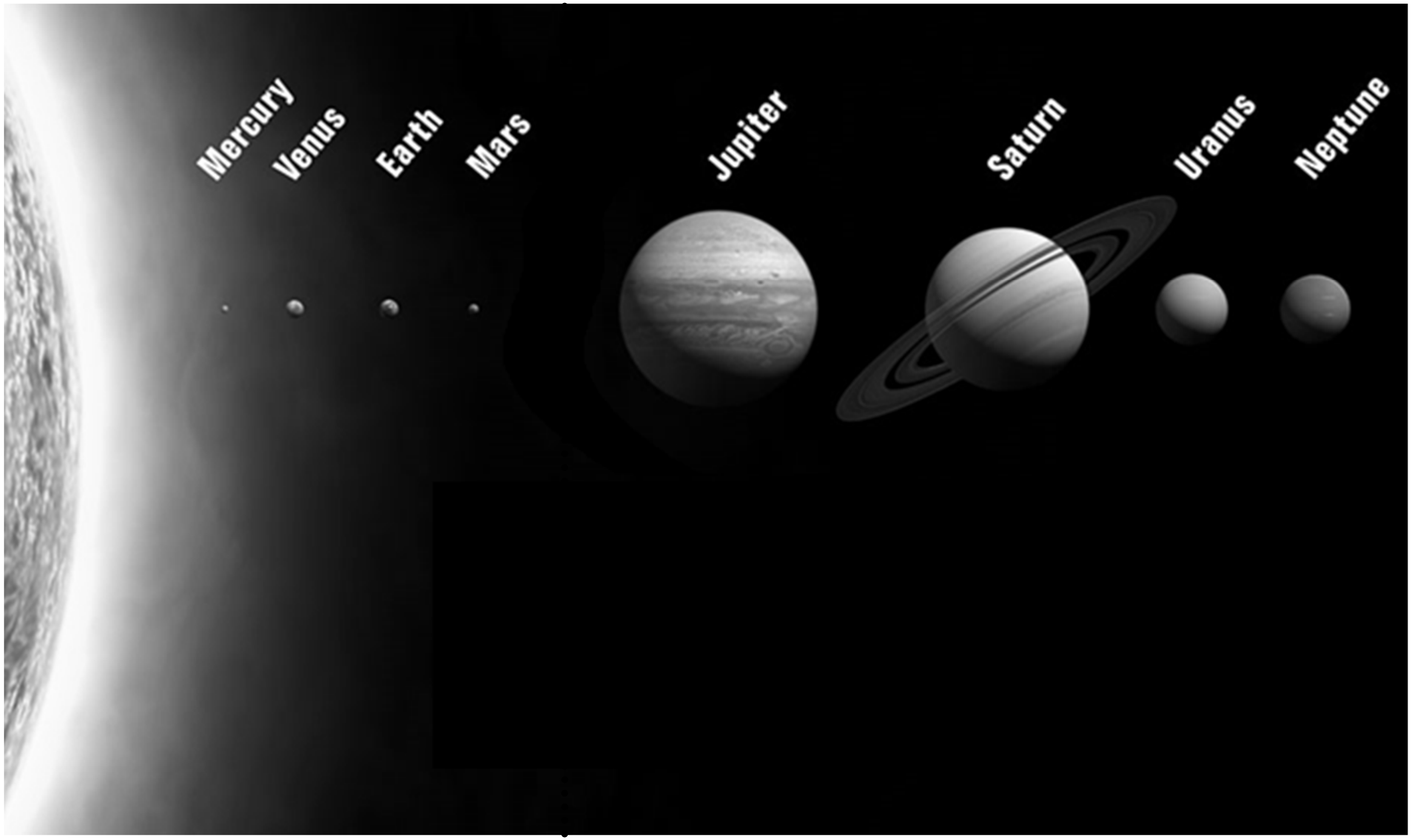
5.1 A quick survey

- ✓ *Asteroid belt* (小行星帶) consists of minor planets (*asteroids*), most are rocky debris < 0.1km
- ✓ *Meteor* (流星): the streak of light across the sky

  Meteoroid (流星體): the object in space

  Meteorite (隕石): any part that survives its entry
  - ➢ about 4.6 billion years old ~ age of the Solar System
- ✓ *Comets*: "Dirty snow balls" moving in highly elliptical orbits around the Sun
- ✓ *Solar wind*: High energy charged particles blown off from the Sun

5.1 A quick survey



Terrestrial planets *Jovian planets*

5.2 Physical Processes

Tidal forces

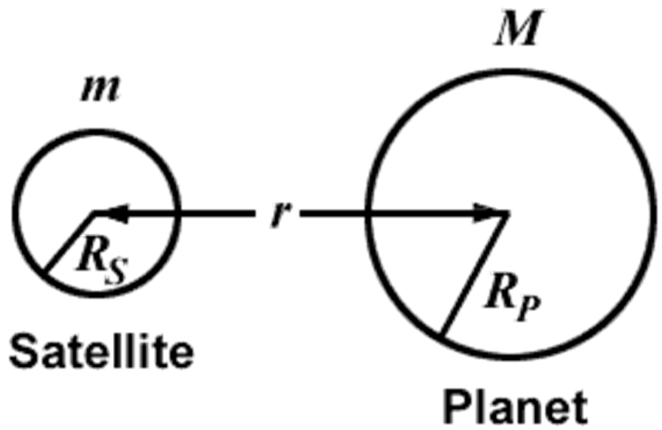
- ✓ Effects on Earth-Moon system
  - – tides; tidal coupling; slowing down of the Earth's spin; increase of Moon's distance
- ✓ Tidal coupling of spins and orbital motions in are common
  - – Two moons of Mars, Galilean moons of Jupiter, most moons of Saturn, etc
  - – Pluto and Charon: Mutual synchronous rotation (as known as tidal locking)

5.2 Physical Processes

✓ Tidal disintegration of a satellite

– Tidal force > self-gravity

$$F_{\text{tidal}} \sim \frac{2GMR_S}{r^3} \qquad F_{\text{self}} = \frac{Gm}{R_S^2}$$



If the satellite is close to the planet, $F_{\text{tidal}} > F_{\text{self}}$, the satellite may be torn into pieces!

This may occur when $r^3 < 2\dfrac{M}{m}{R_S}^3$

Therefore, if $r < 2^{1/3}\left(\dfrac{\overline{\rho}_P}{\overline{\rho}_S}\right)^{1/3} R_P \qquad 2^{1/3} \approx 1.3$

the satellite may be disintegrated.

5.2 Physical Processes

More careful analysis by Roche: Oscillations developed at greater distances may disintegrate the satellite

$$\boxed{r < r_c \equiv 2.46 \left(\frac{\bar{\rho}_P}{\bar{\rho}_S} \right)^{1/3} R_P}$$

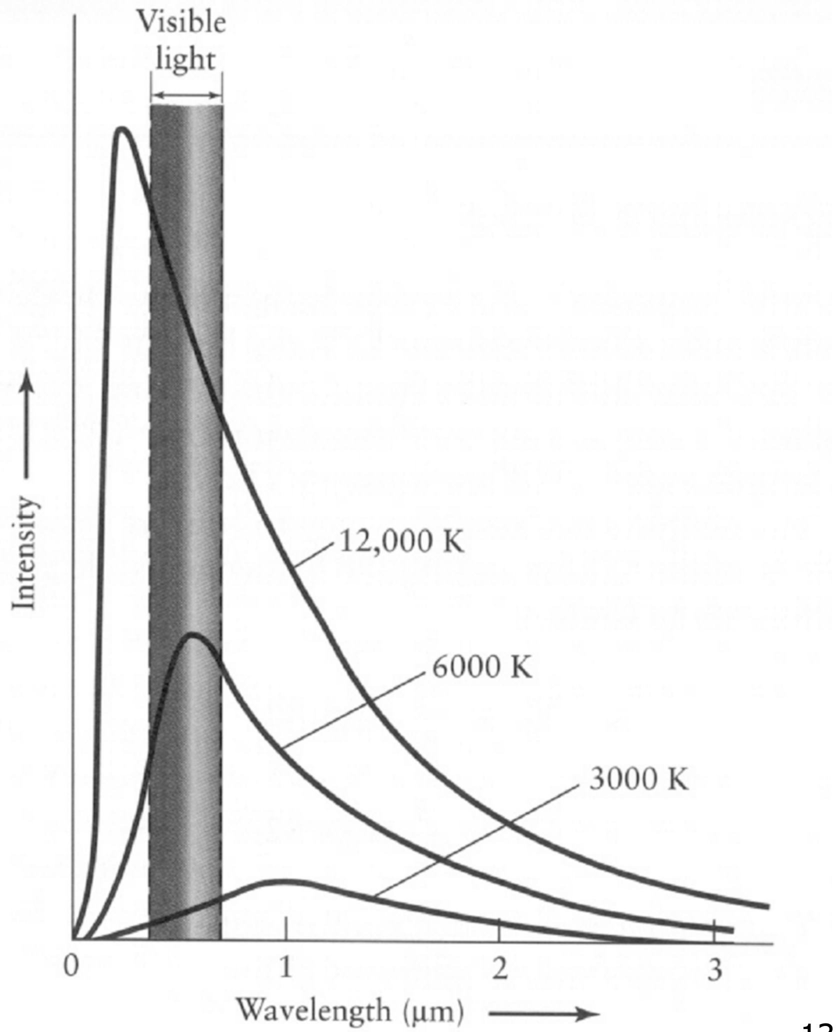
Roche limit : Maximum orbital radius inside which a satellite might be disintegrated. It is an *upper limit*. The actual situation depends on the satellite's internal cohesive force.

5.2 Physical Processes

Physics of planetary atmospheres

- ✓ Average temperature of the Earth

  Assume the Sun and the Earth are perfect absorbers and emitters, called *Blackbodies.*
- ✓ Many celestial objects behave like a blackbody
- ✓ Shape of spectrum depends on its temperature



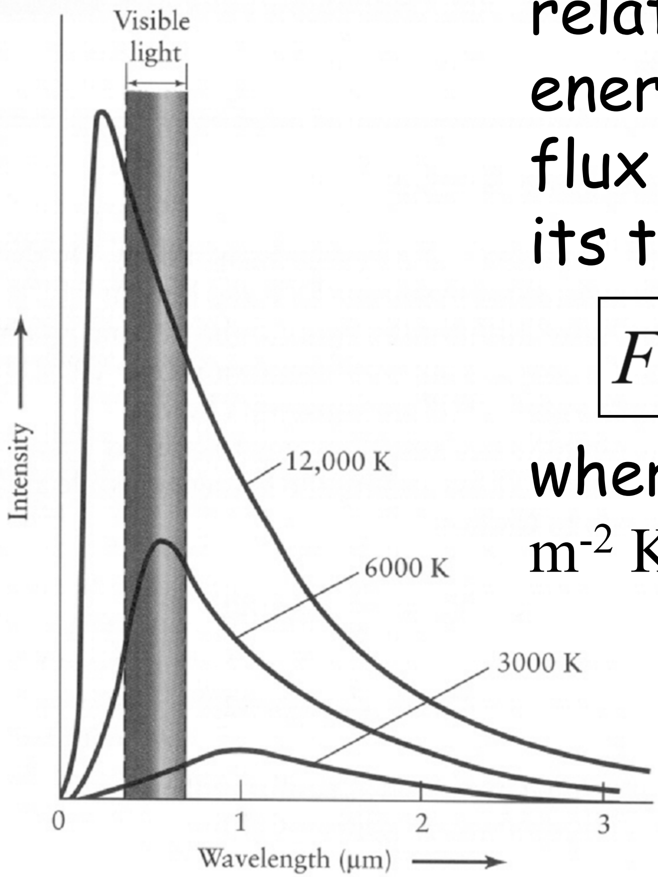
5.2 Physical Processes

Important results about blackbody spectrum

Wien's law: relation between the wavelength at max emission and the temperature

$$\boxed{\lambda_{max} = \frac{0.0029}{T}}$$

where λ_{max} in meter; T in K



Stefan-Boltzmann law: relation between the energy (all frequencies) flux (per unit area) and its temperature

$$\boxed{F = \sigma T^4}$$

where $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}

Luminosity:

$$\boxed{L = 4\pi R^2 \sigma T^4}$$

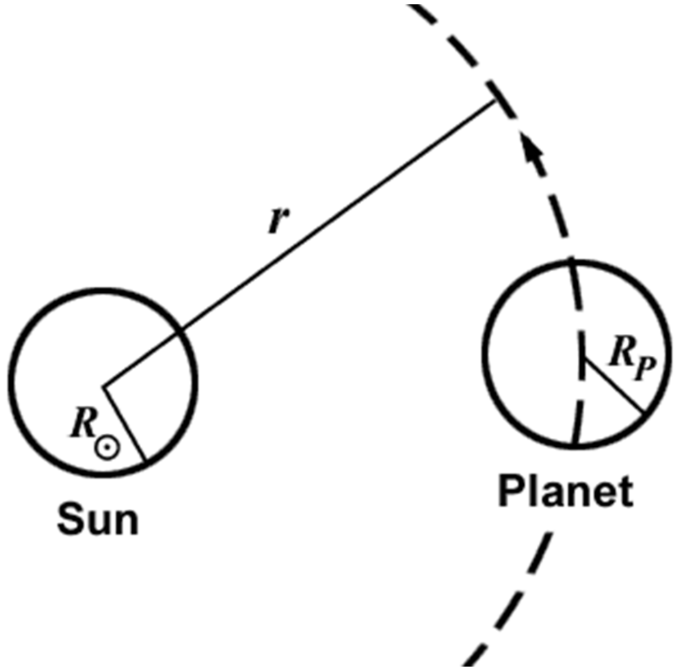
5.2 Physical Processes

Question: Estimate the surface temperature of the Earth?

- ✓ flux of energy falling on Earth:

$$F_s = \frac{4\pi R_{sun}^2 \times \sigma T_{sun}^4}{4\pi r^2} = \sigma T_{sun}^4 \left(\frac{R_{sun}}{r}\right)^2$$

- ✓ Given that $r = 1.5 \times 10^{11}\,\mathrm{m}$, $R_{sun} = 6.96 \times 10^8\,\mathrm{m}$, and $T_{sun} = 5{,}770\mathrm{K}$, then energy flux is $F_\mathrm{s} = 1360\ \mathrm{W\ m^{-2}}$ (the *solar constant* for the Earth).

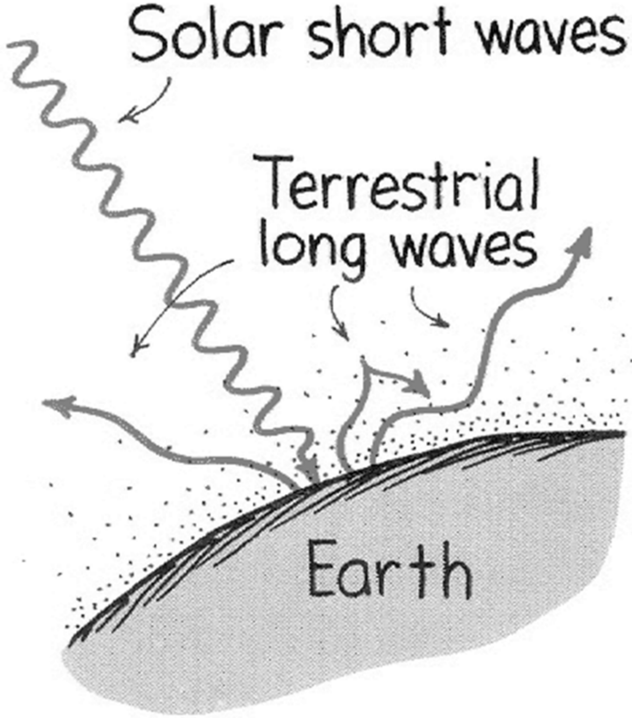


5.2 Physical Processes

At thermal equilibrium,
rate of absorption = rate of emission by the planet

$$F_s \times \pi R_E^2 \times (1-\alpha) = \sigma T_E^4 \times 4\pi R_E^2$$

$$\frac{1}{4} F_s (1-\alpha) = \sigma T_E^4$$



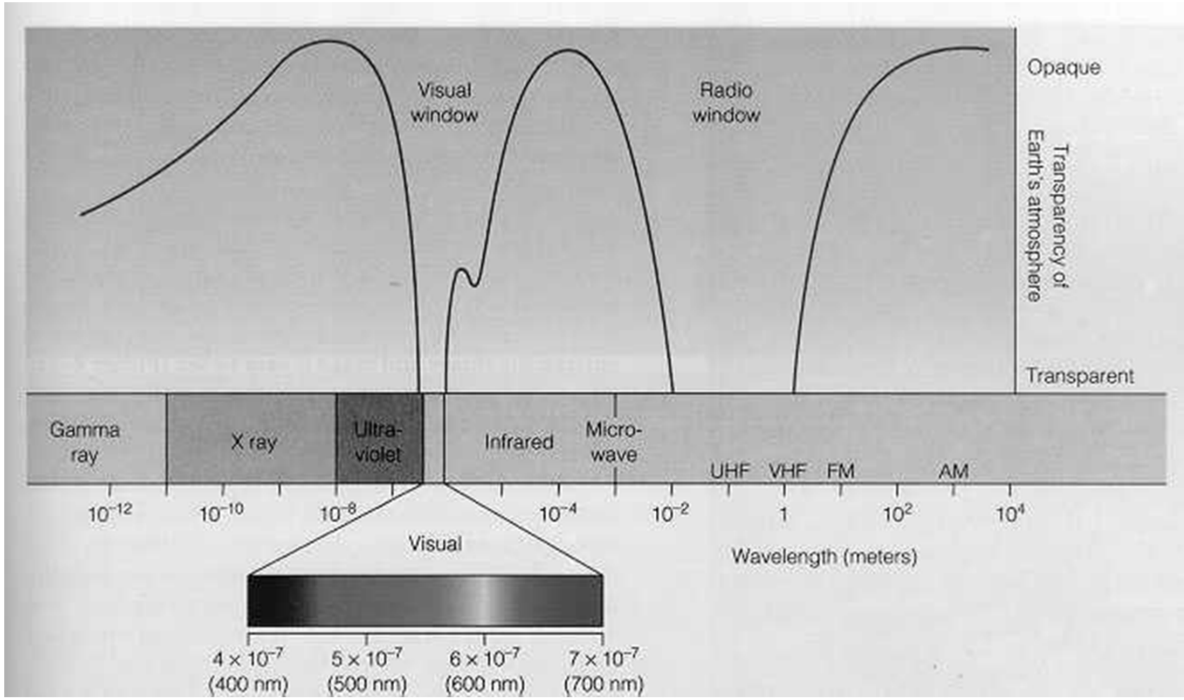
A fraction α (called *planetary albedo*) of the energy is reflected, a fraction 1-α is absorbed.

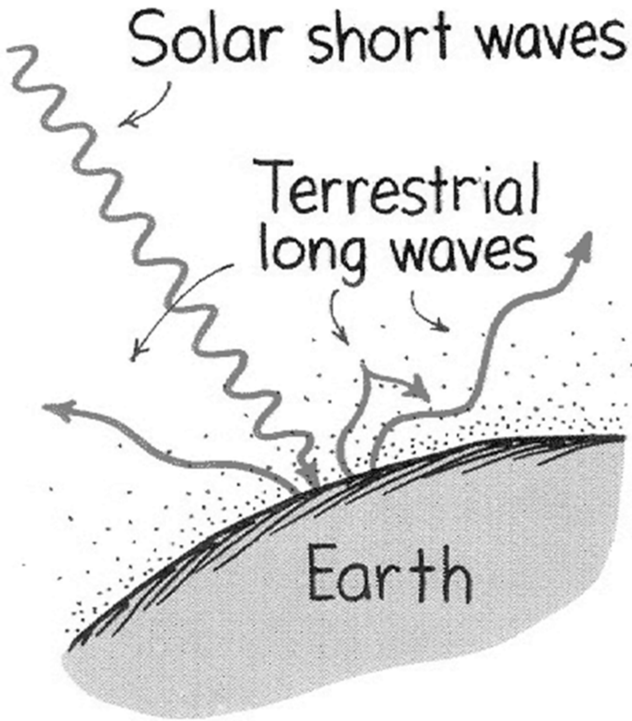
Suppose $\alpha = 0.3$,
then $T_E = 254$ K = -19°C.

It is too low. How to explain? *Greenhouse effect*

5.2 Physical Processes

Greenhouse effect





The Earth's atmosphere is opaque to infrared

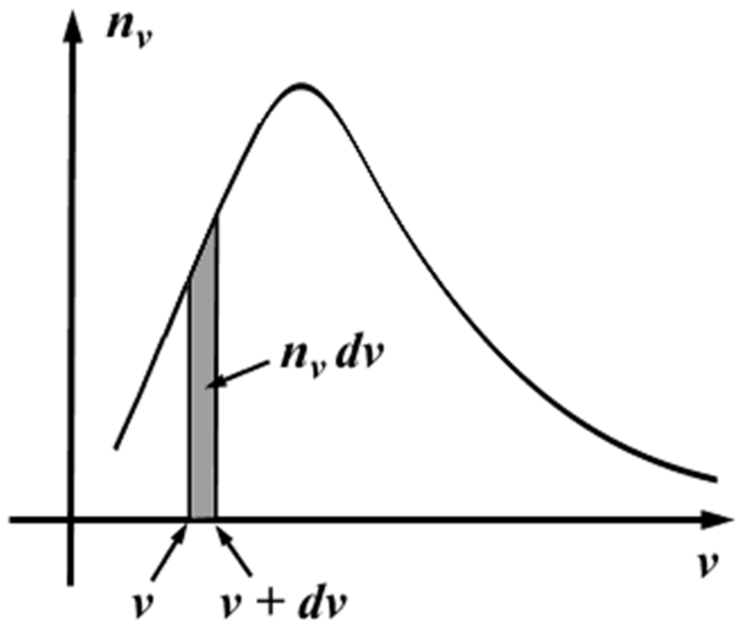
Re-emitted radiation is trapped!

5.2 Physical Processes

Compositions of planetary atmospheres

✓Mercury and Moon have no atmosphere; Earth's has O_2 and N_2, but not much H_2 and He; Jupiter and Saturn retain all gases. Why?

✓Speeds of atmospheric particles are distributed according to Maxwell-Boltzmann distribution.

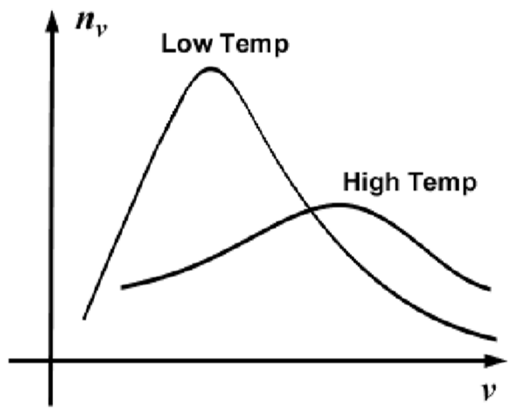


5.2 Physical Processes

✓Shape of distribution depends on temperature

✓Average KE: $\boxed{\frac{1}{2} m v_{\mathrm{rms}}^2 = \frac{3}{2} kT}$

✓Root mean square speed: $\boxed{v_{\mathrm{rms}} = \sqrt{\frac{3kT}{m}}}$



✓if $v > v_{\mathrm{esc}} = \sqrt{\frac{2GM}{R}}$, a gas particle escapes

✓Suppose that a gas will stay in the atmosphere

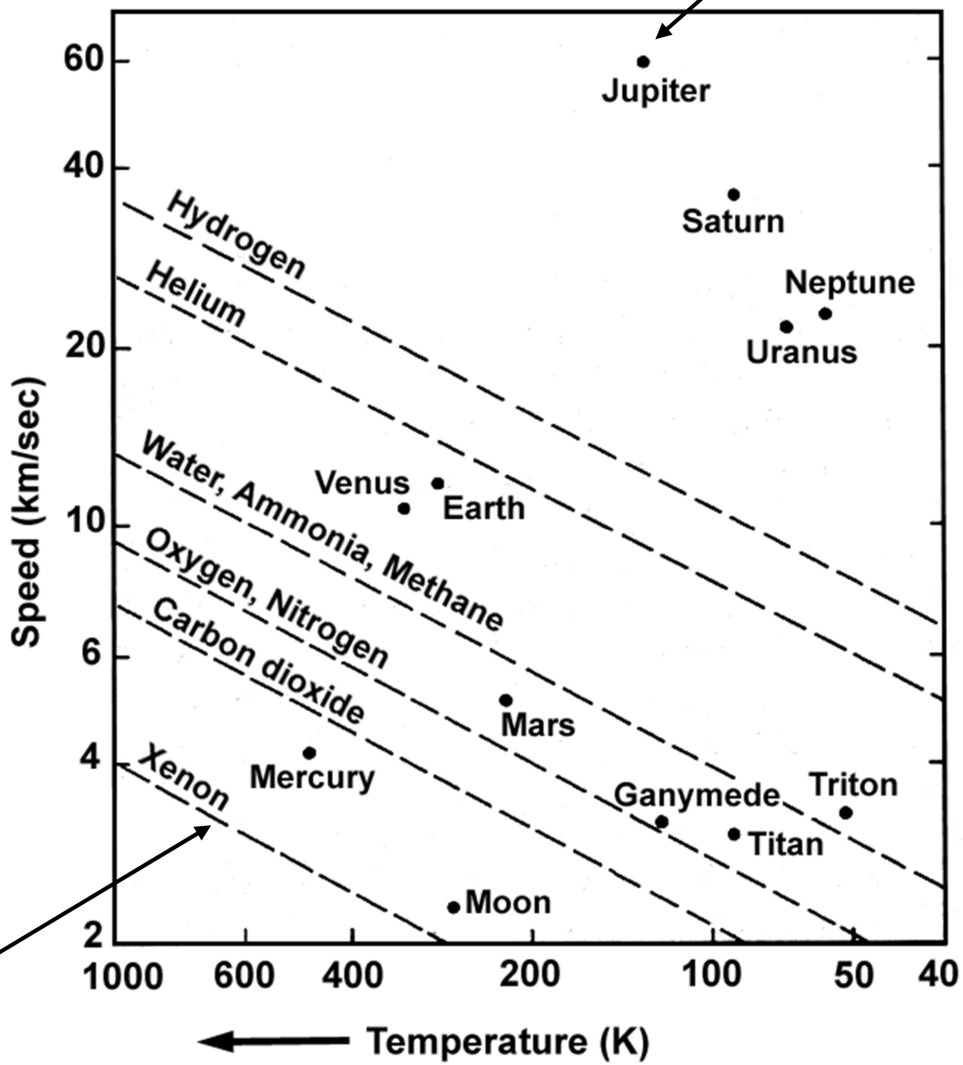
for billions of years if $v_{\mathrm{esc}} > 10\, v_{\mathrm{rms}}$, or $T < \frac{GMm}{150kR}$.

5.2 Physical Processes

✓Retain gas if $T < \dfrac{GMm}{150kR}$.

✓Mercury and Moon have almost no atmosphere; Venus, Earth and Mars are unable to retain H_2 and He; Jovian planets retain all gases including H and He

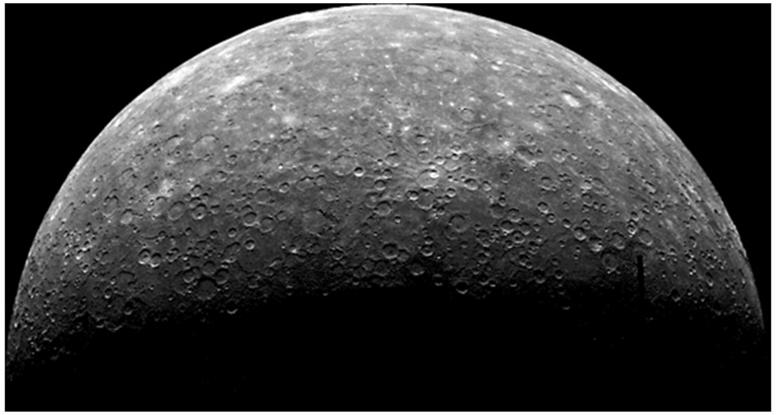
v_{esc} of the planets

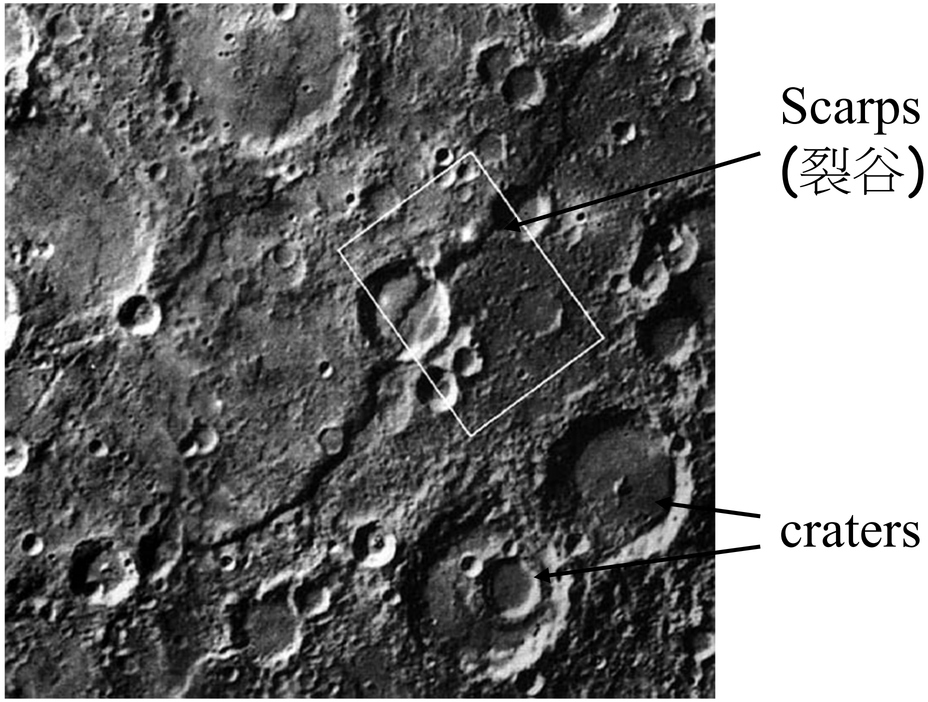


$10\ v_{rms}$ for certain type of gas

5.3 Features of the planets

A. Mercury



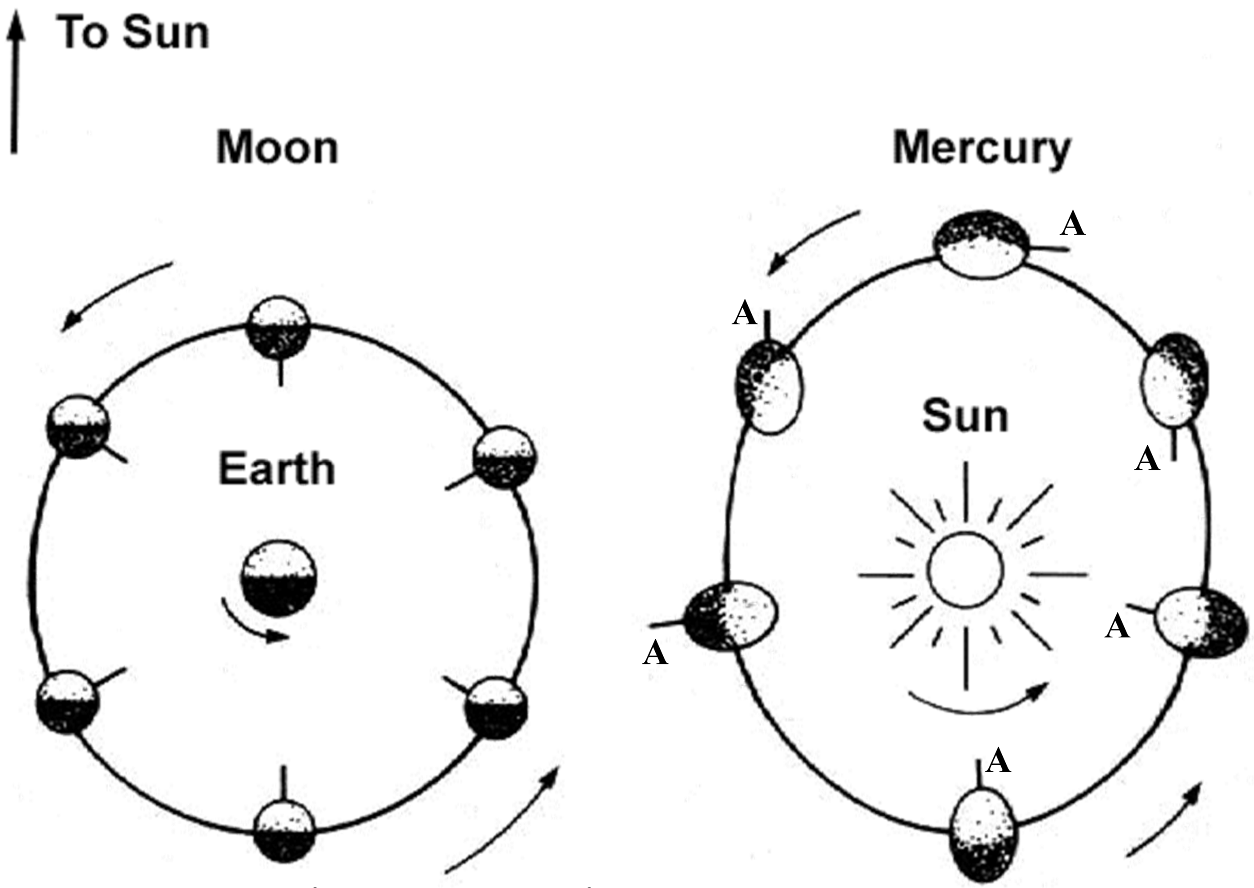


- ✓Small, dense, large iron core
- ✓-173 to 430 ^{o}C
- ✓No atmosphere
- ✓Lots of craters (with some differences to the Moon)
- ✓Very weak magnetic field

Size comparison

Image: Wikimedia Commons

5.3 Features of the planets

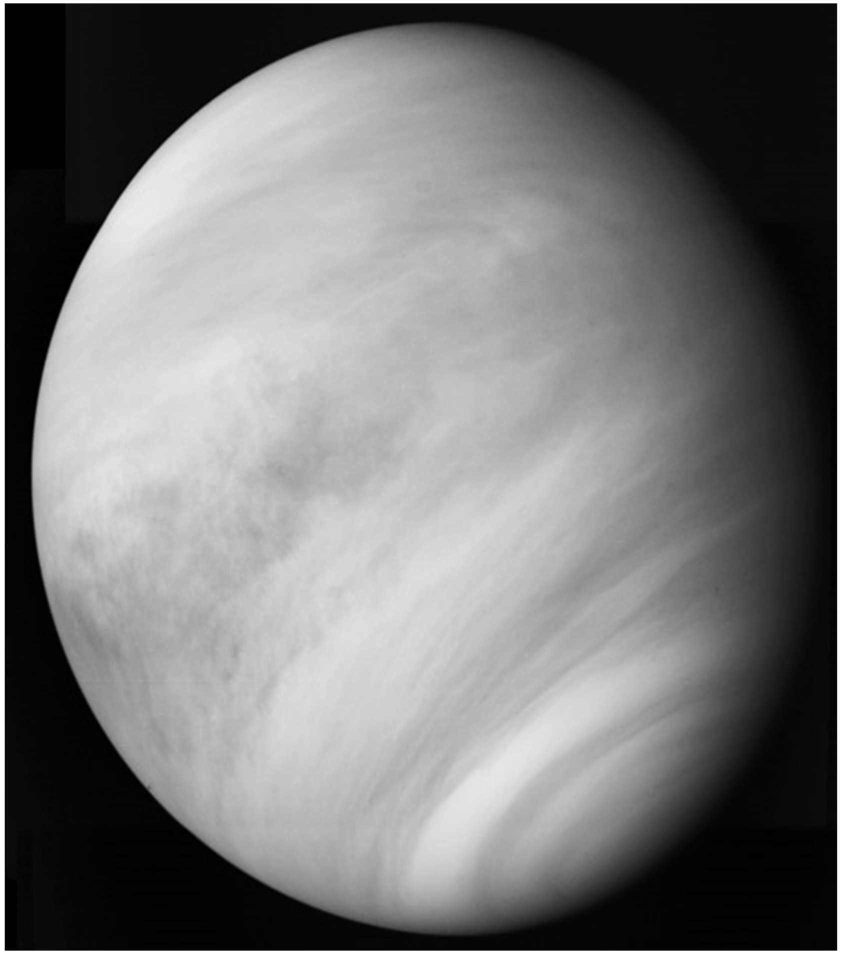


Moon's orbit almost circular, observe the same face of Moon

- ✓Mercury's orbit rather elliptical (e = 0.21).
- ✓Tidal budges along direction of the Sun at perihelion
- ✓1 orbital period ~ 1.5 self-rotation period

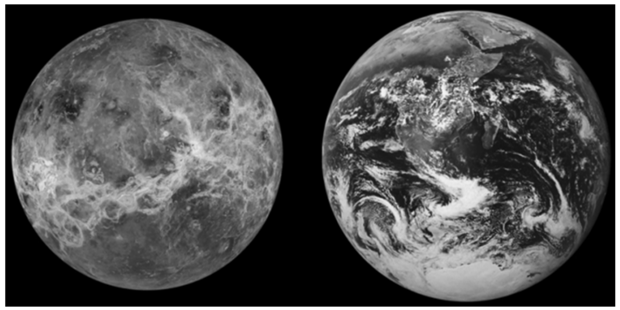
5.3 Features of the planets

B. Venus



- ✓Spins in clockwise direction.
- ✓Hot surface (750K)
- ✓Dense and stable layer of clouds (contains sulphuric acid!)
- ✓Thick atmosphere (~90 times of the Earth's), with mainly CO_2
- ✓Strong greenhouse effect
- ✓Weak magnetic field

Size comparison



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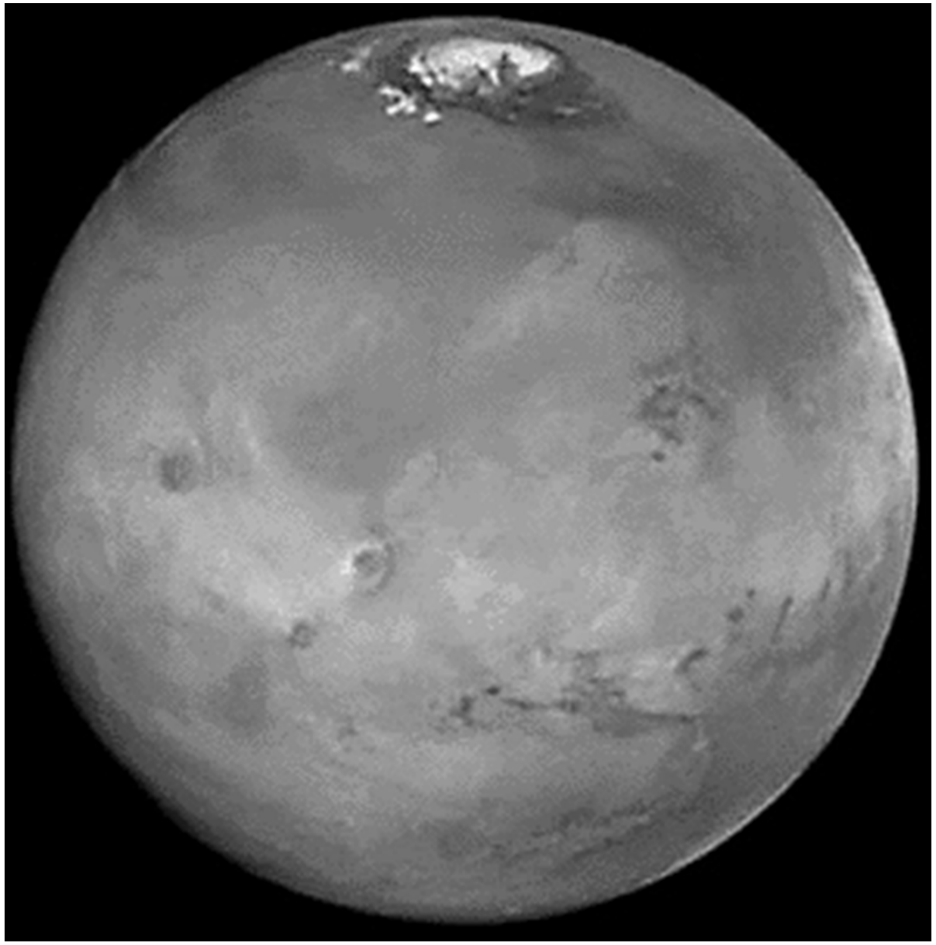
5.3 Features of the planets

C. Mars



✓Red (lots of iron oxide, or rust)

✓-140 to 20 ^{o}C

✓Thin atmosphere (~1/100 of the Earth's), with mainly CO_2

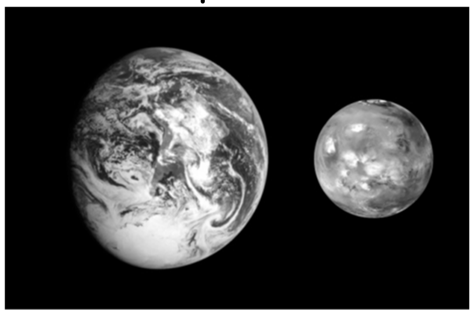
✓Gigantic volcanoes, deep canyons

✓No global magnetic field

✓Used to have lots of liquid water. Now only a tiny amount is left (confirmed in 2015)

✓Polar cap

Size comparison



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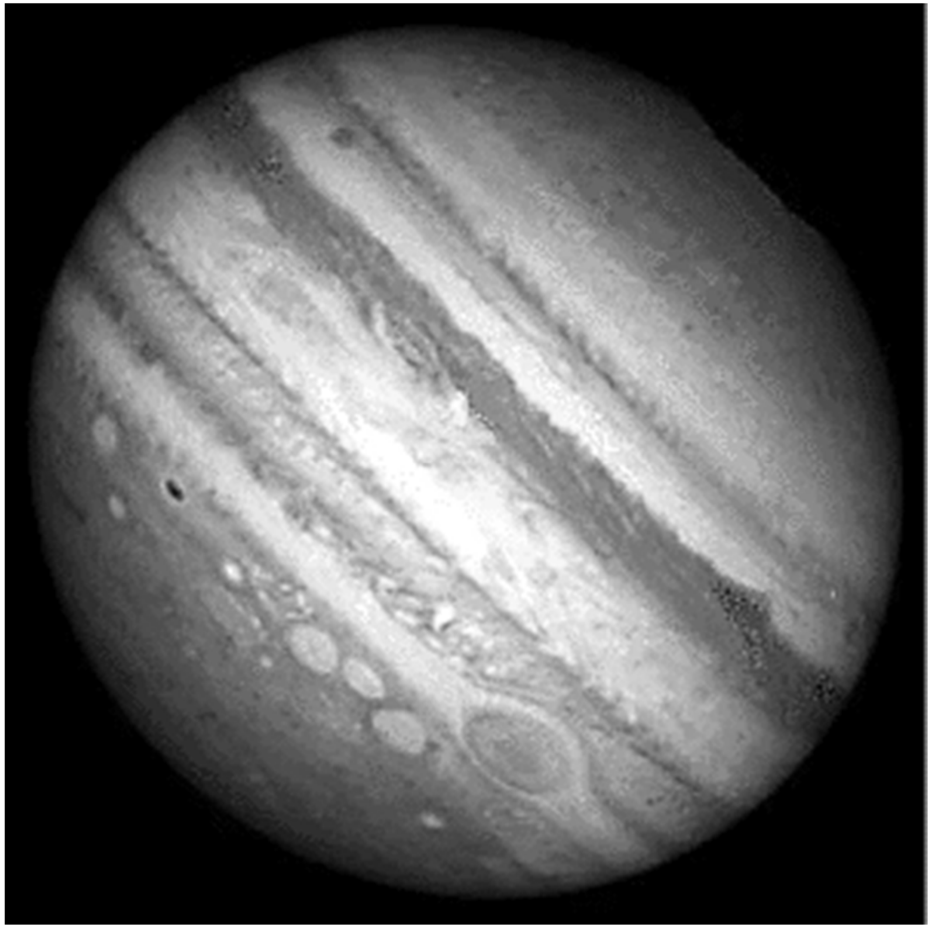
5.3 Features of the planets

D. Jupiter



- ✓The largest planet
- ✓-100 ^{o}C
- ✓Rapid rotation (period ~ 10h)
- ✓Gaseous (actually, liquid)
- ✓Stripes on surface
- ✓Great Red Spot: a great cyclone
- ✓Liquid metallic H core; strong B
- ✓66 satellites (50 confirmed)

Size comparison

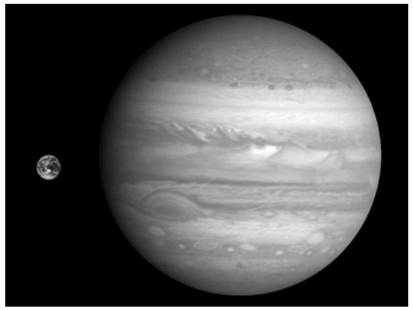
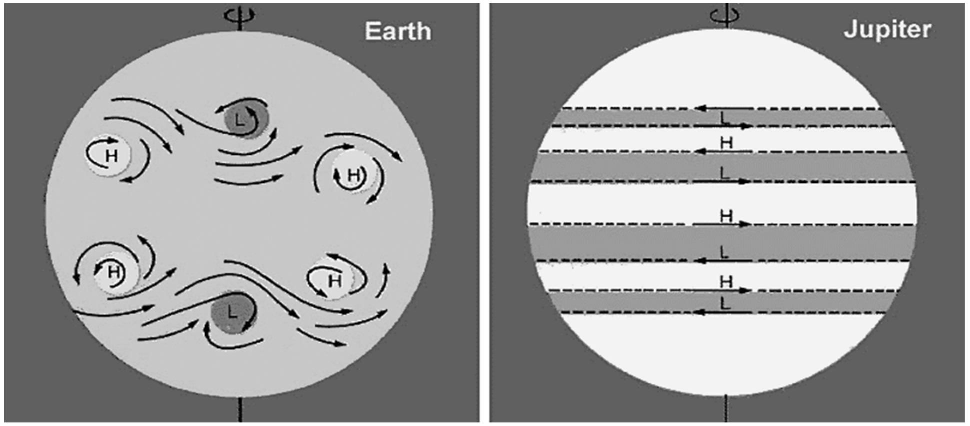
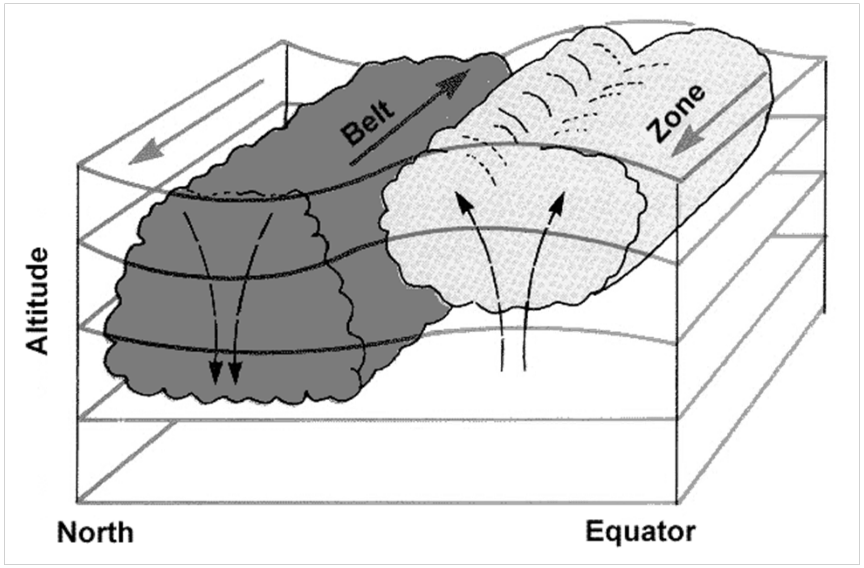


Image: Wikimedia Commons

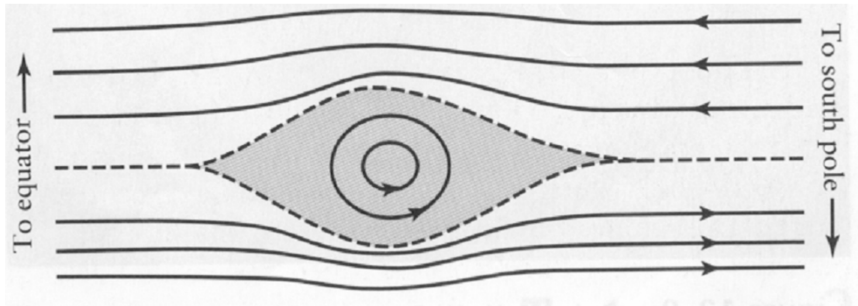
5.3 Features of the planets

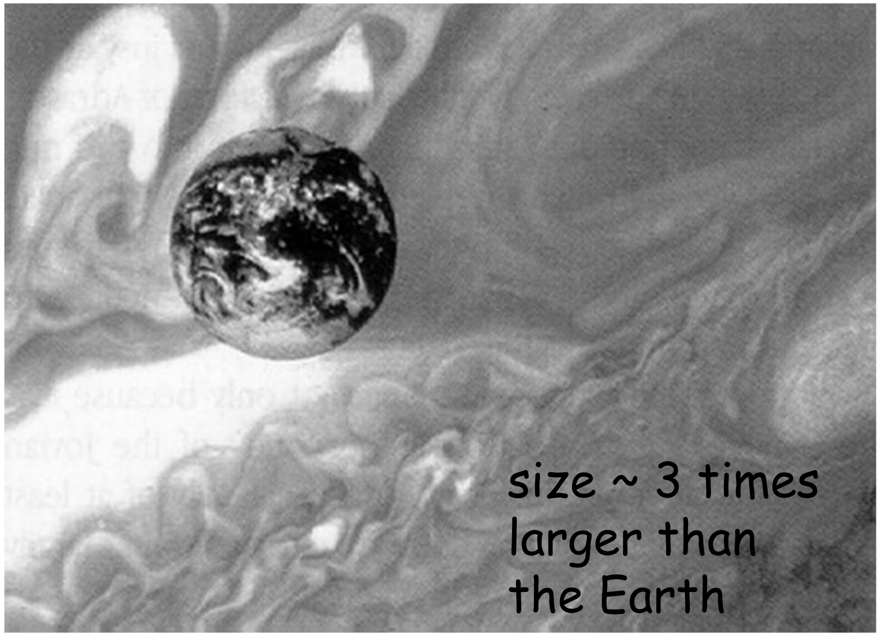
Stripes





Great Red Spot

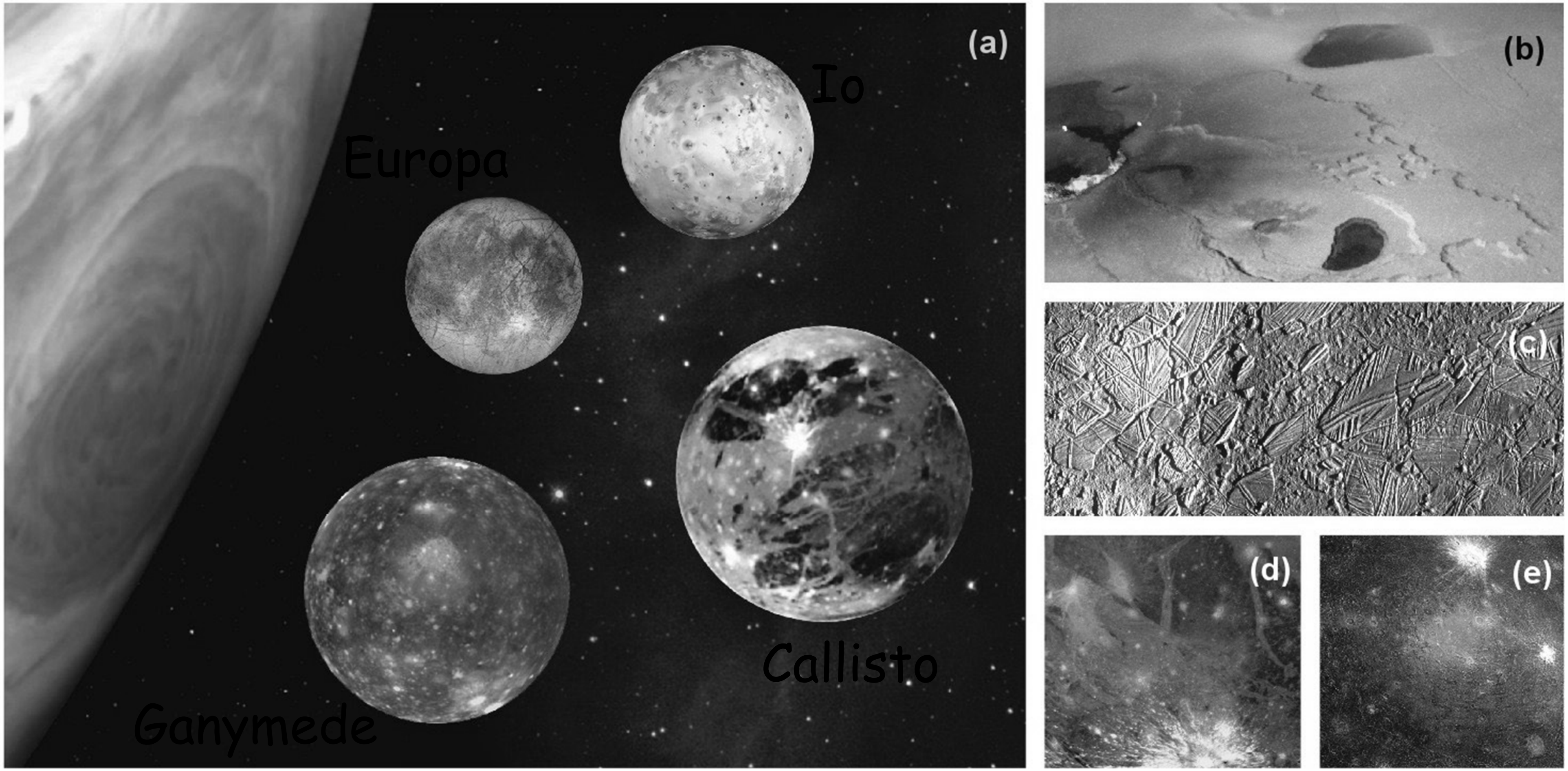




5.3 Features of the planets

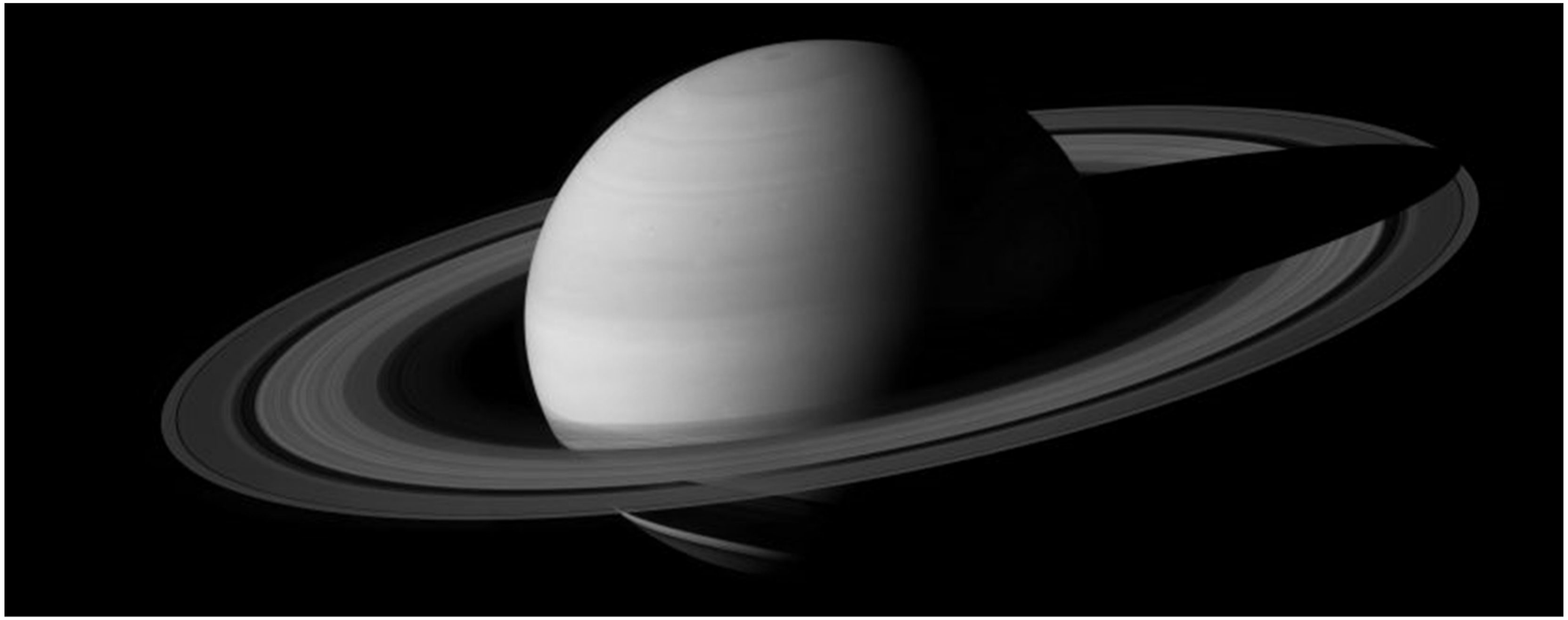
Four Galilean Moons

Image: NASA



5.3 Features of the planets

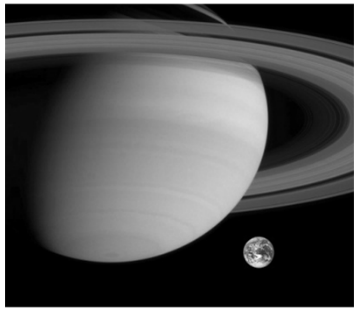
Image: NASA



- ✓Bright ring system
- ✓-180^{o}C
- ✓Lower average density than water (0.7 g/cc)
- ✓Even stronger winds than Jupiter
- ✓62 satellites (53 confirmed); Shepherd satellites

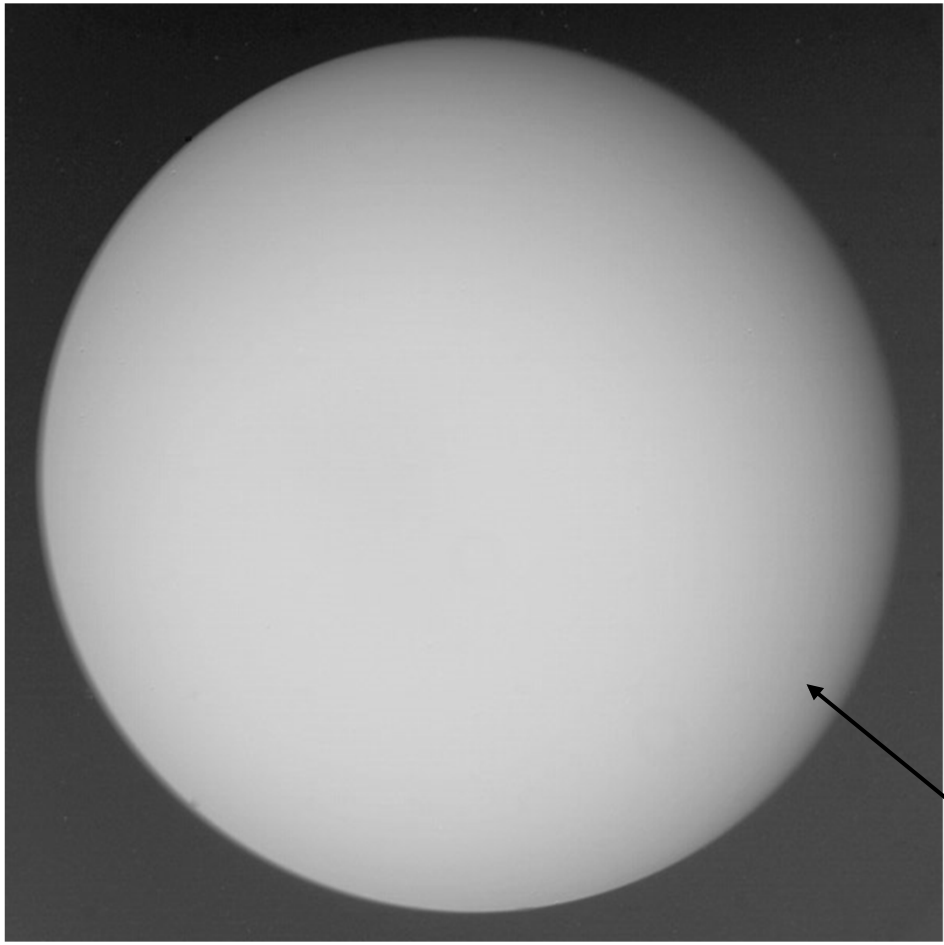
Size comparison

Image: Wikimedia Commons

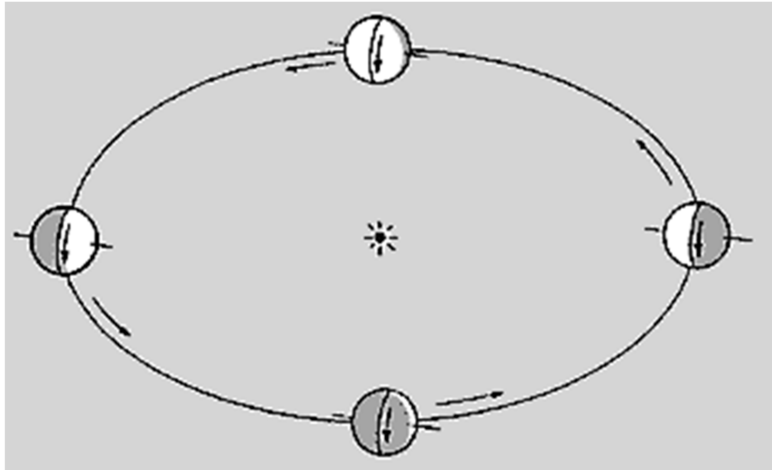


5.3 Features of the planets

F. Uranus



✓Spin axis almost lies on its orbital plane (tilt 97.9°)



✓Magnetic field tilt 60° from spin axis; 30% off center

Mostly H, 15% He, a few % CH_4 (methane). Blue due to methane.

Size comparison

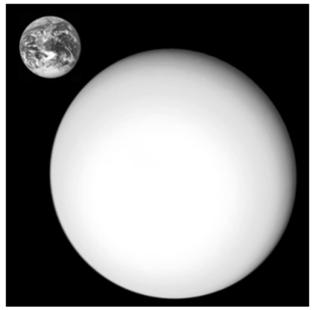
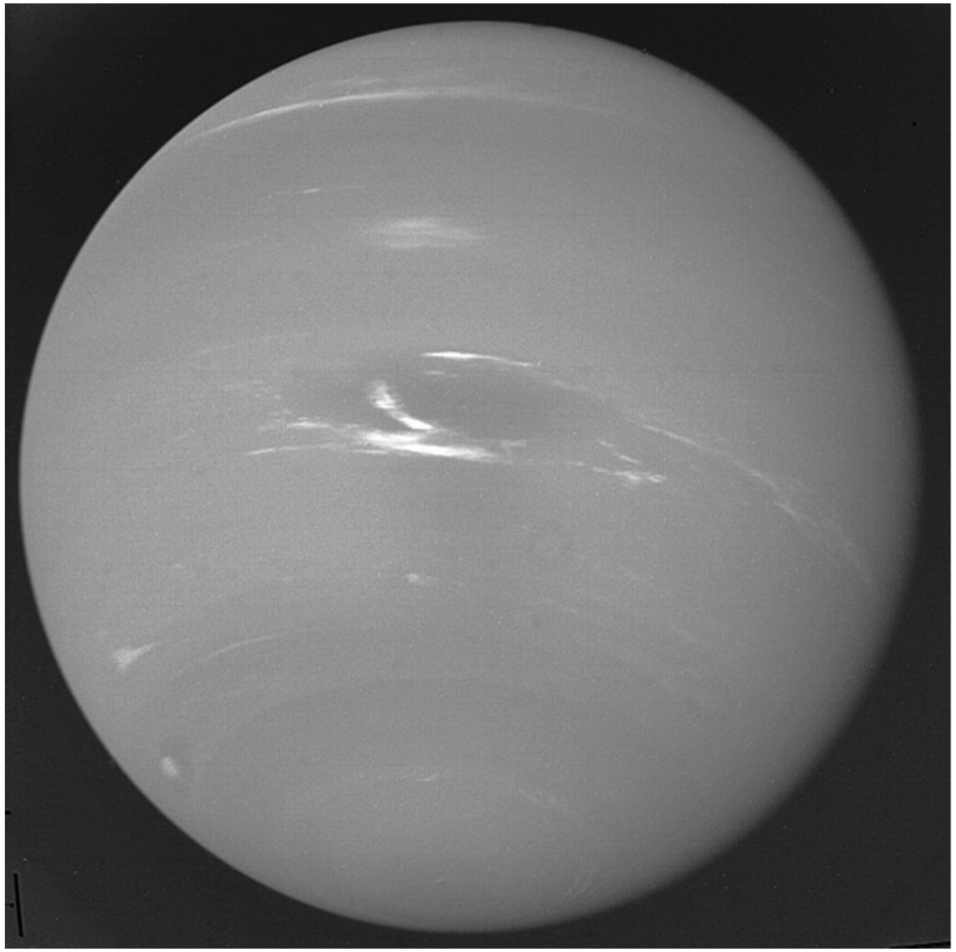


Image: Wikimedia Commons

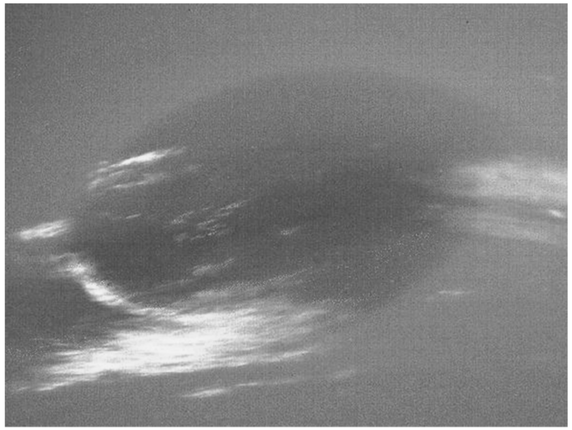
5.3 Features of the planets

G. Neptune



✓Orbit of Uranus was found to deviate from ellipse. Mass and orbit of Neptune were predicted by Newtonian mechanics

✓The Great Dark Spot (gone)



Size comparison

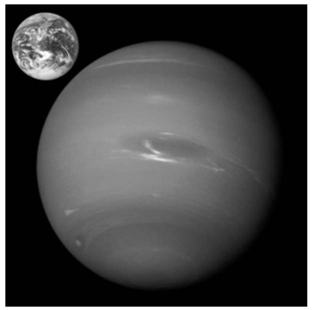
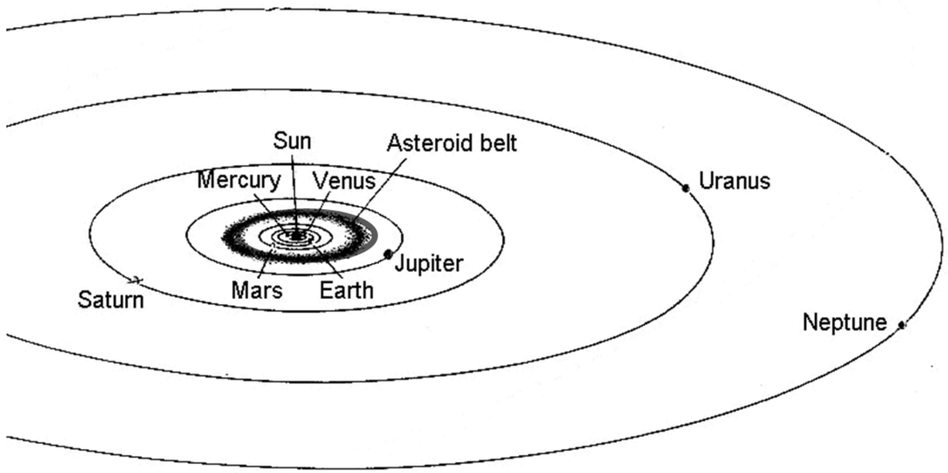
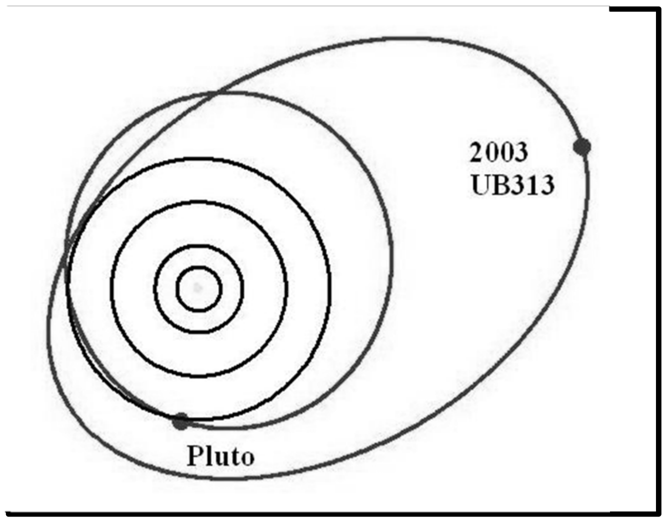


Image: Wikimedia Commons

5.4 Dwarf planets

- ✓ "Minor" planets
- ✓ New category since 2006
- ✓ First three members
  - Ceres (穀神星) in asteroid belt
  - Eris (2003 UB_{313})
  - Pluto
- ✓ 5 members right now





5.4 Dwarf planets

Pluto

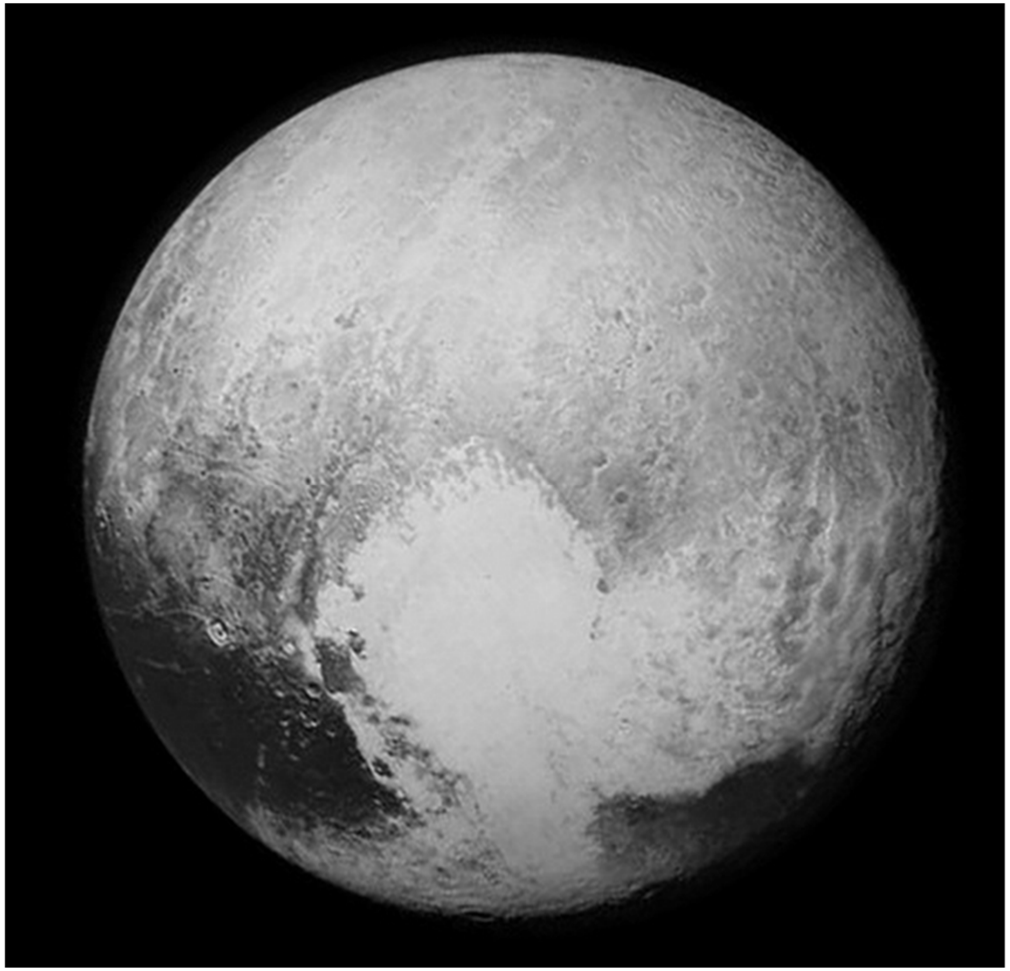
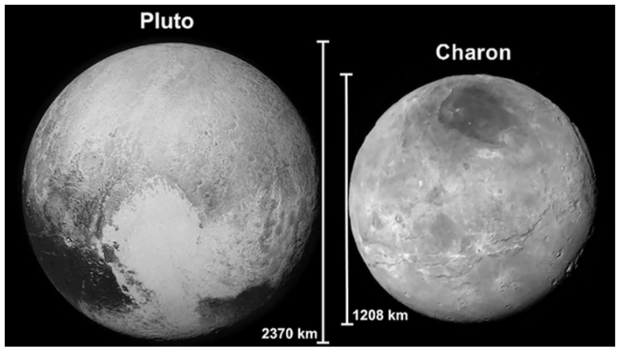


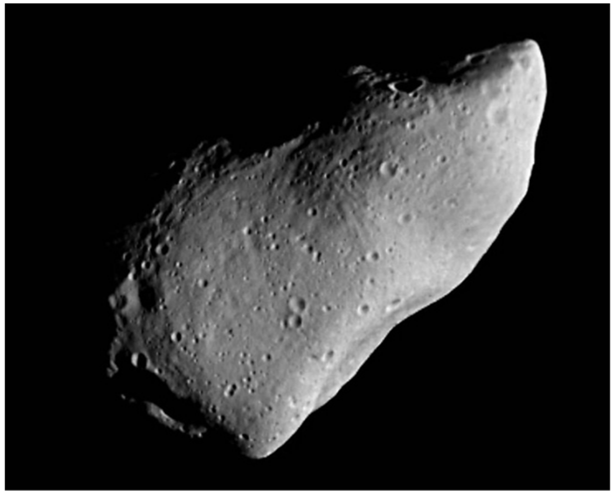
Image: NASA/APL/SwRI

- ✓Orbit is inclined (17^o) and elliptical (e = 0.24)
- ✓Go inside Neptune's orbit sometimes
- ✓No ring system
- ✓5 known satellites
- ✓Pluto and Charon have often been considered a binary planet.



5.5 Asteroids

- ✓ Small rocky debris revolving around the Sun
- ✓ Most orbits lie in the *asteroid belt* (小行星帶) between those of Mars and Jupiter
- ✓ Strong gravitational forces of Mars and Jupiter affect their orbits
- ✓ Only two dozens or so are larger than 200 km, most as small as ~0.1 km, irregular in shape.



Gaspra :

19 x 12 x 11 km

Spins once every 7 hours

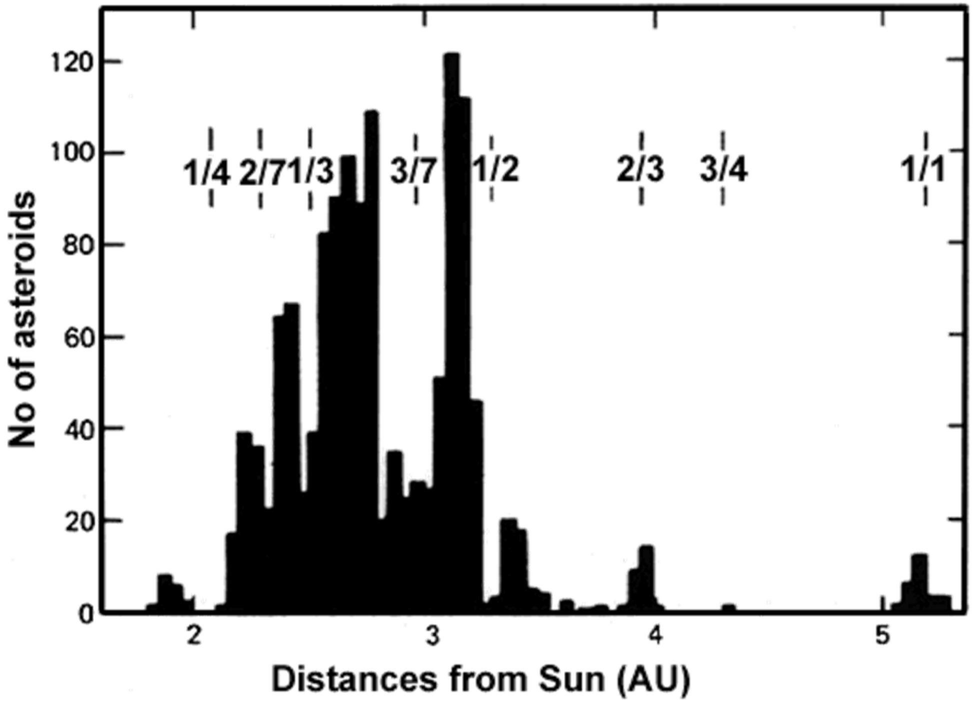
5.5 Asteroids

Kirkwood's gaps

✓Regions in the belt devoid of asteroids

✓Lie at orbital distances in resonance with Jupiter

✓Resonance occurs when orbital period of asteroid is equal to a rational fraction of that of Jupiter, e.g., 1/4, 2/7, 1/3 2/5, etc.



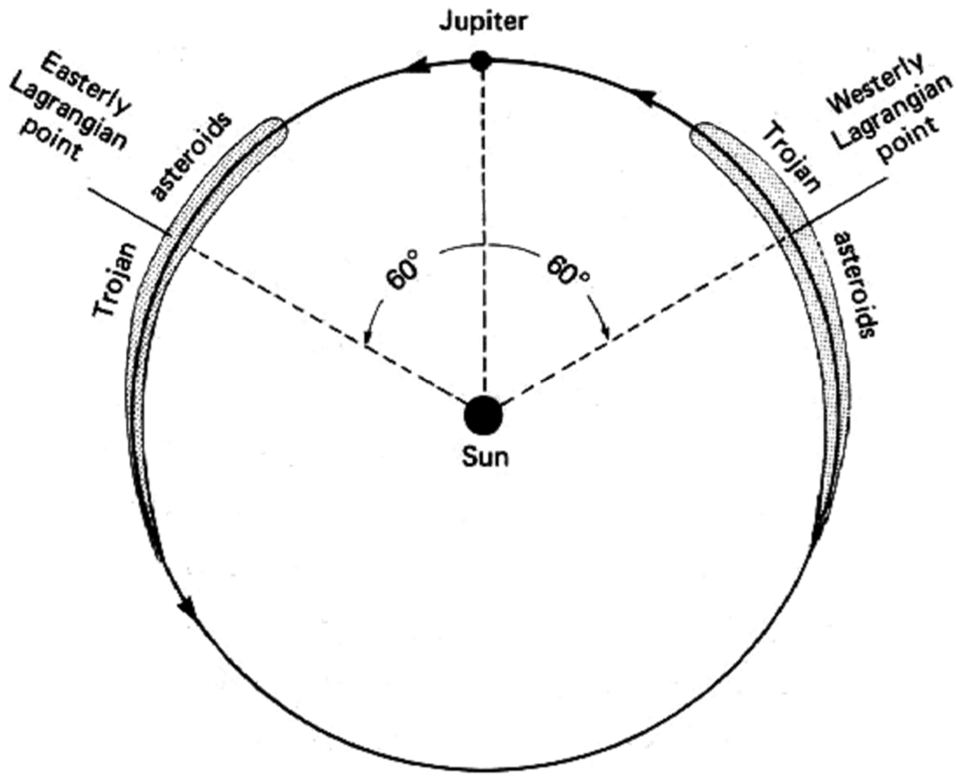
e.g., asteroid's period = 2 Jupiter's, asteroid find Jupiter in opposition in alternate periods. The cumulative perturbation changes its orbits a bit until no longer resonance

5.5 Asteroids

✓Not all asteroids are between Mars and Jupiter

✓Combined gravitational forces of planet (Jupiter) and the Sun hold asteroids at Lagrangian points

✓About 700 asteroids (called Trojan asteroids) are trapped at Jupiter's Lagrangian points



5.5 Asteroids

✓Apollo – Amor objects (阿波羅 – 阿莫爾物體) are a few dozens of known asteroids whose orbits carry them into the inner solar system, and many more are unknown.

✓Asteroid 2012 DA14 (it passed by the Earth on Feb 15, 2013) <u>was</u> in the Apollo class.

✓Oh! collision with the Earth is possible?!


DON DAVIS

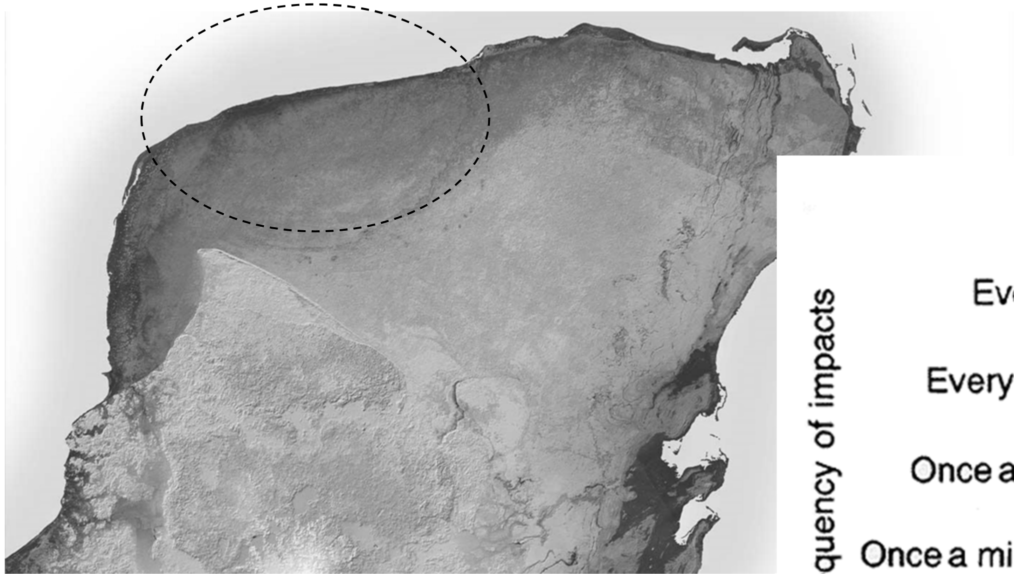
5.5 Asteroids

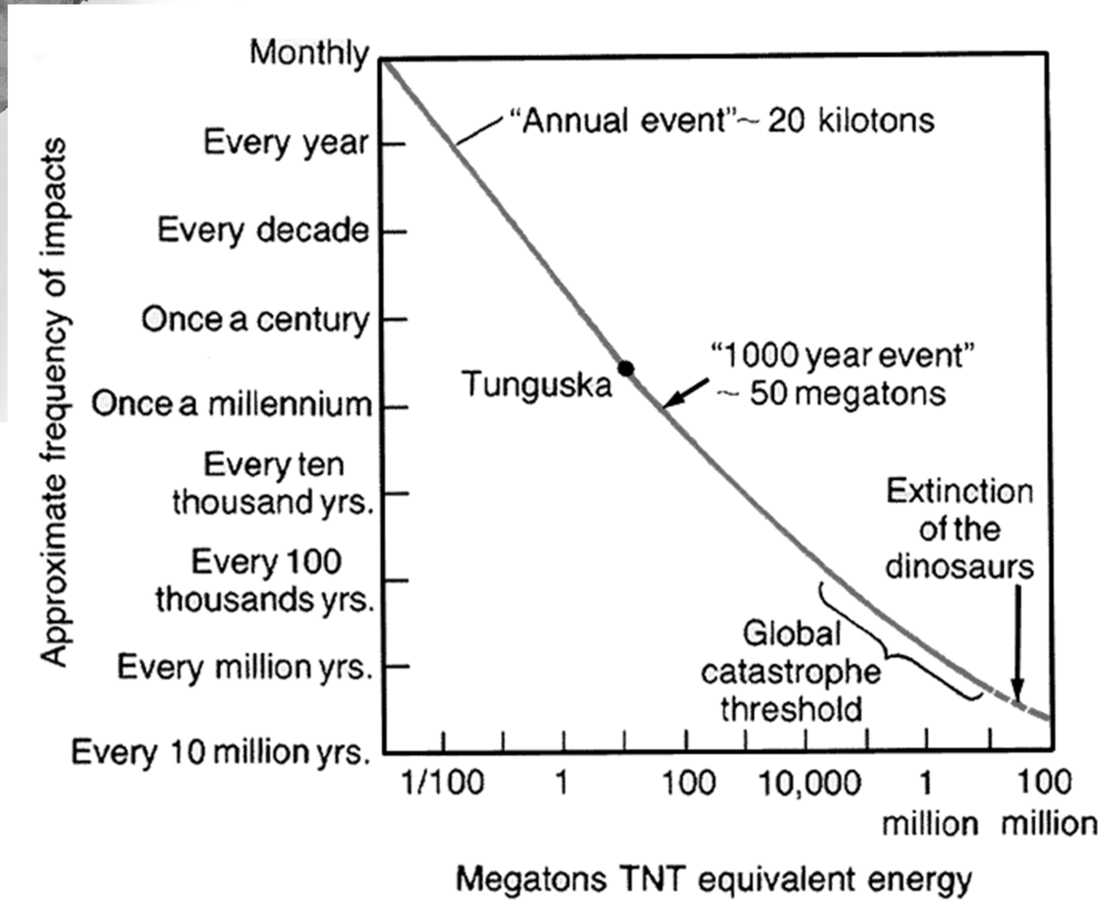
A theory of extinction of dinosaurs

A large asteroid or comet hit the Earth 65 million years ago ...,

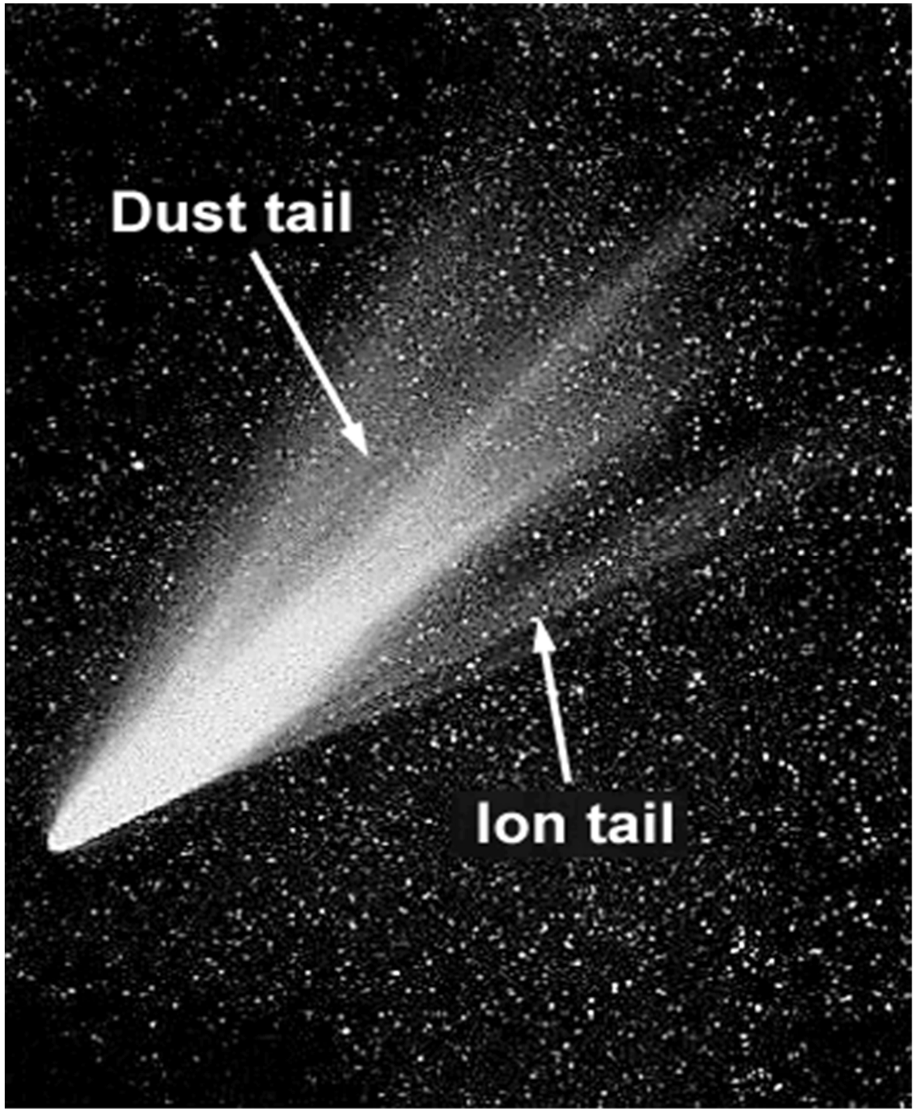
Dust of explosion shrouded our planet for years, extinguishing Sun’s ray ➔ plants died ➔ food chain disrupted ➔ dinosaurs died

Yucatan Peninsula, Mexico; crater ~ 180 km

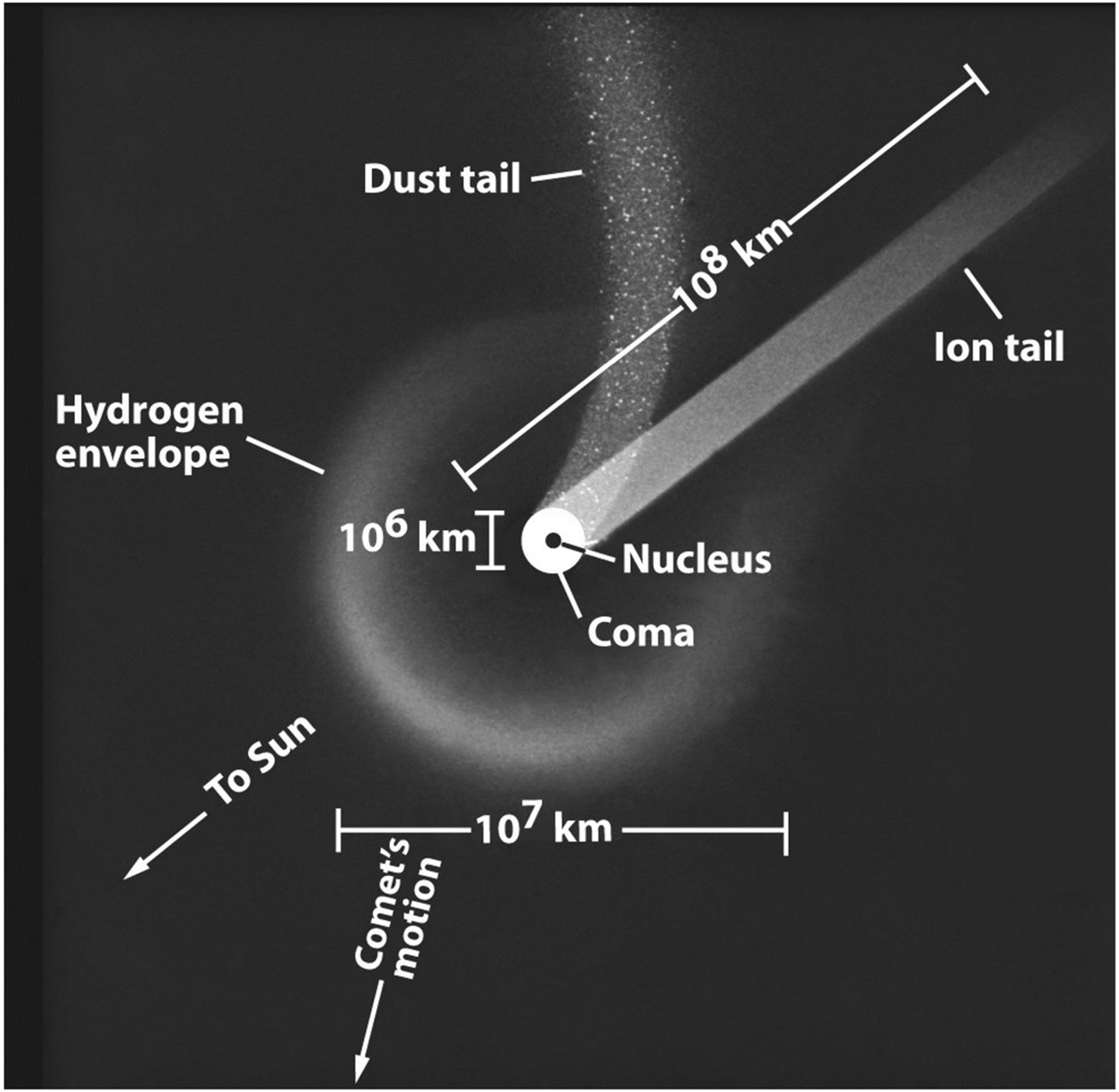




5.6 Comets



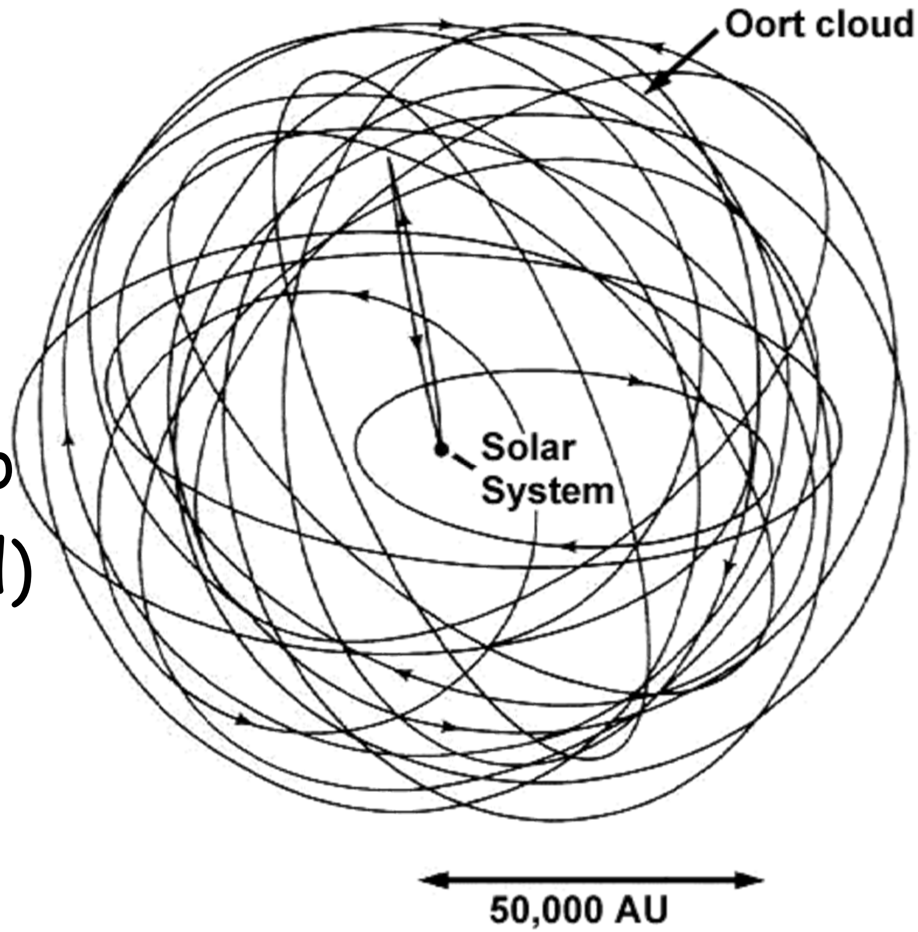
- ✓Low-density dirty snowball
- ✓Highly elliptical orbits around the Sun. Many were from far beyond Pluto, probably as far as 50000 AU
- ✓Short-period vs long-period
- ✓Orbits could change significantly when approaching the Sun


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

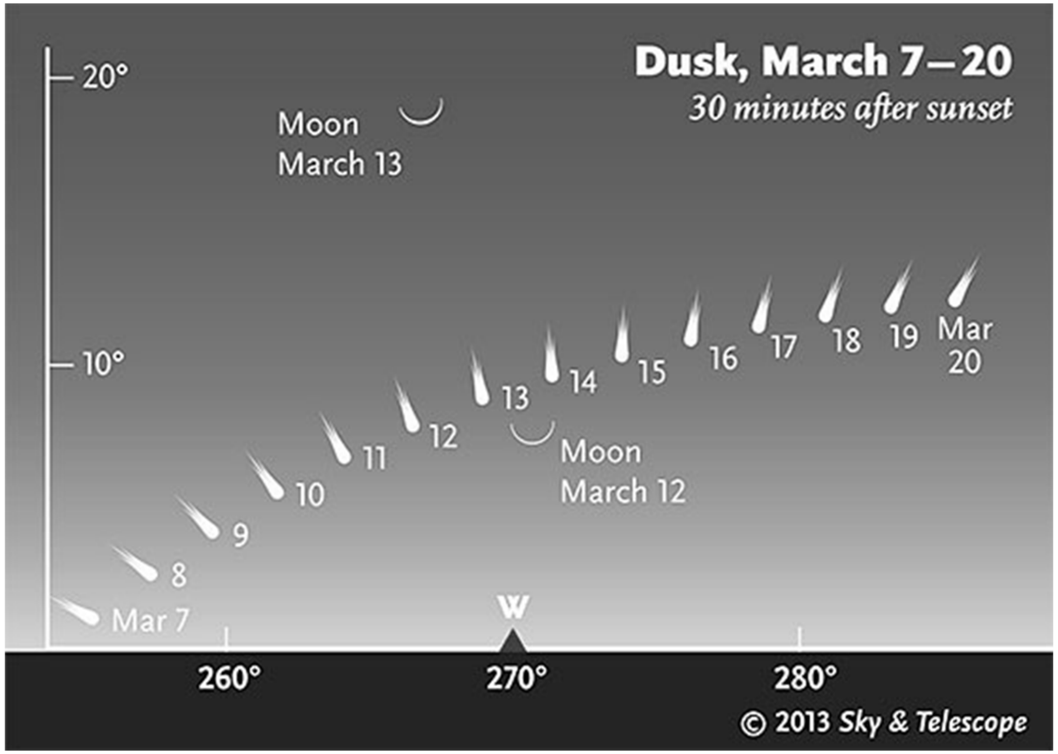
5.6 Comets

Oort cloud (奧特雲)

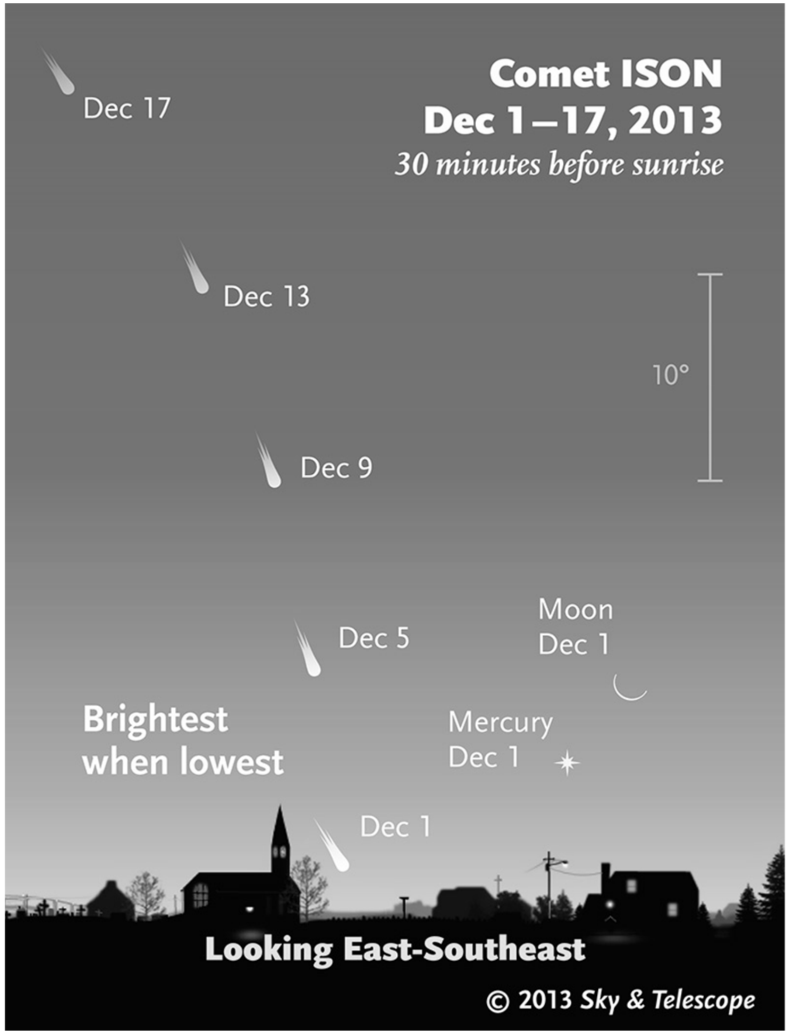
- ✓ a vast and distant reservoir of inactive comets. Up to a trillion comets orbit the Sun from about 30,000 AU to 1 light year. (long-period)
- ✓ only a few are disturbed and enter the Solar System.



Some comets are bright enough for naked-eye observation



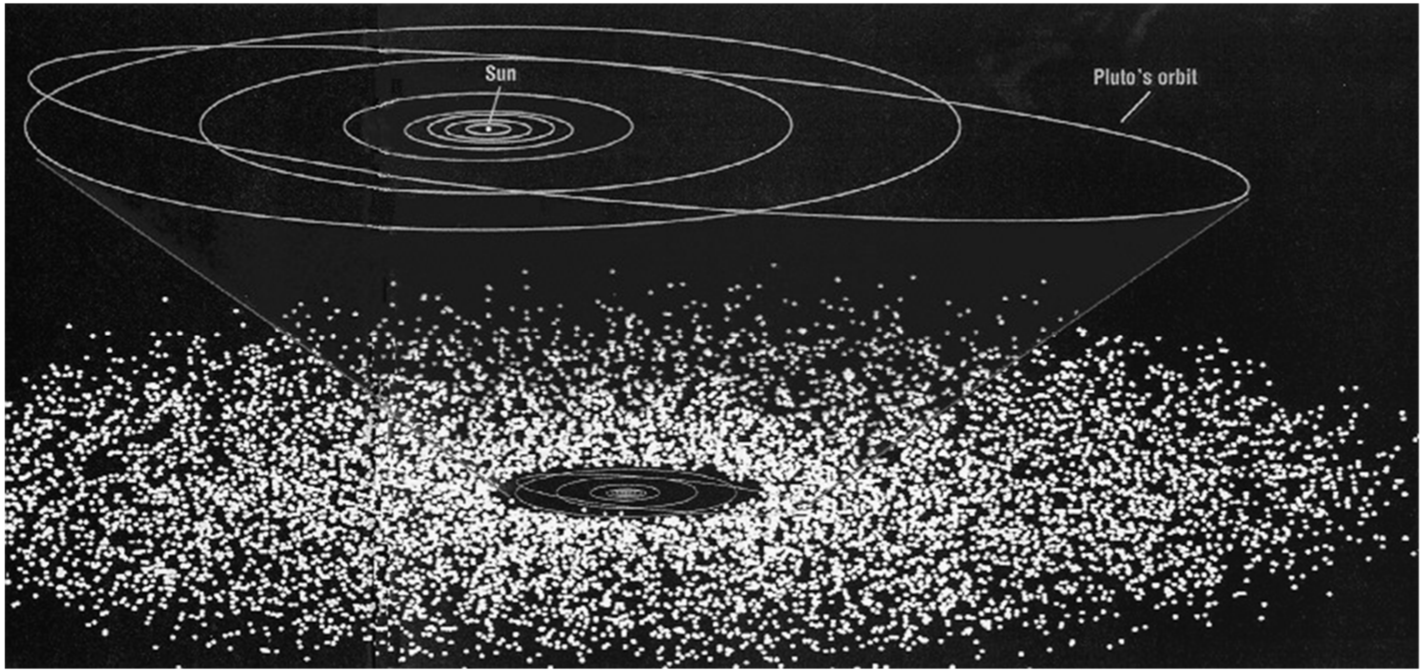
Comet PanSTARRS
– the diagram is drawn for a viewer near 40°N, 30 mins after sunset



Comet ISON
– the diagram is drawn for a viewer near 40°N, 30 mins before sunrise

5.7 Kuiper Belt

- ✓ Small icy objects outside of Neptune's orbit (30-100 AU), possibly the source of many short-period comets.
- ✓ Pluto, Charon, Triton could be just KBOs



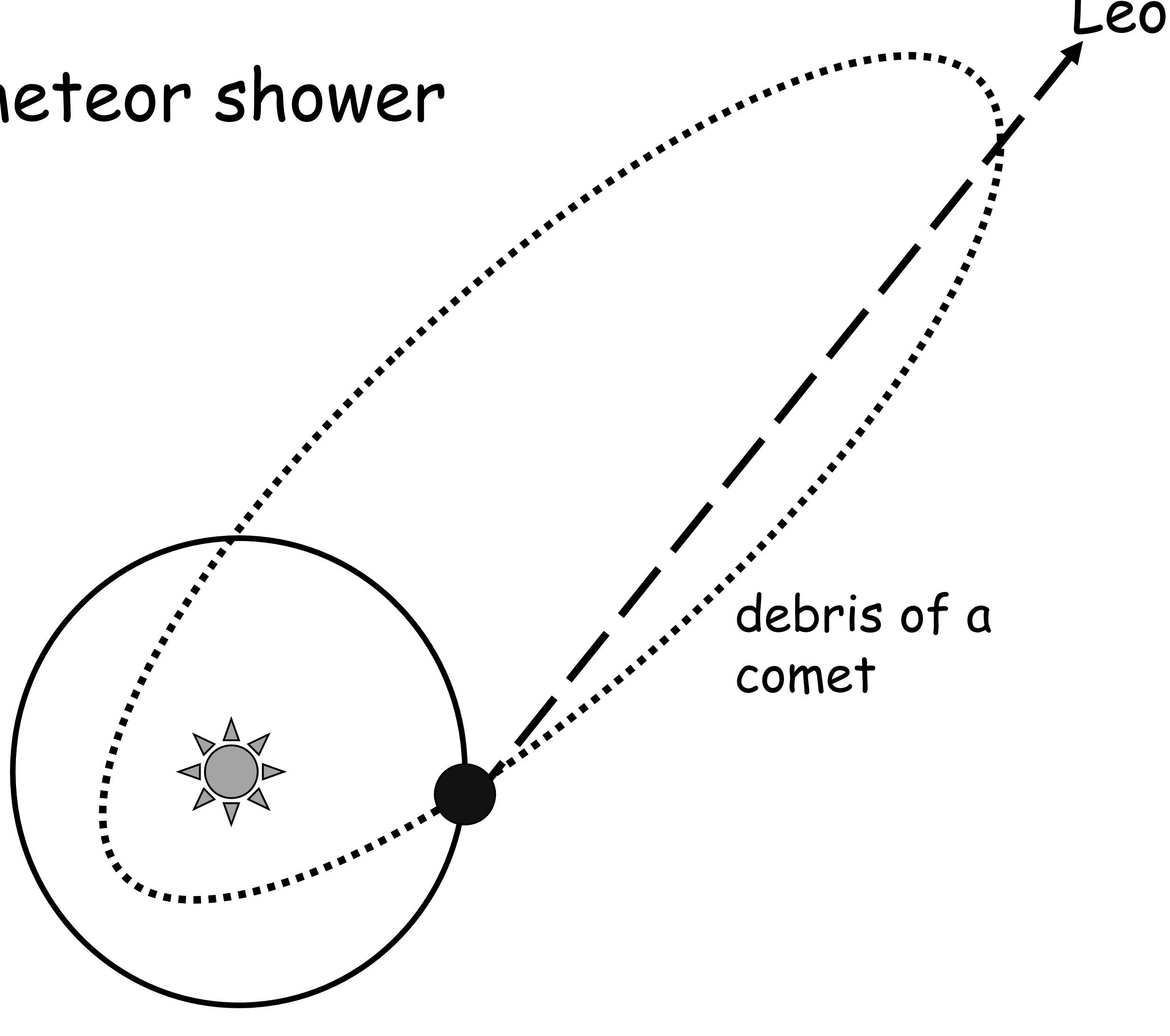
5.8 Meteoroids

5.8 Meteoroids

- ✓ Interplanetary debris hitting the Earth, heated up by friction in the Earth's atmosphere.
- ✓ appear as bright streaks of "shooting stars" called **meteors (流星)**
- ✓ Most meteoroids are destroyed in the atmosphere; any parts reach the ground are called **meteorites (隕石)**
- ✓ Some are fragments dislodged from comets, spreading along the comets' orbits.
- ✓ a spectacular **meteor shower** 流星雨 (cluster of meteoroids) results when the Earth crosses a given comet's orbit

5.8 Meteoroids

Leonid meteor shower



5.8 Meteoroids

The meteorite crater in Arizona, formed 50,000 years ago, by the impact of an iron meteorite, 1.2 km in diameter.

5.9 Formation theory (Solar nebula hypothesis)

- ✓ interstellar medium (ISM): mixture of hydrogen, helium and other elements (remnants of dead stars)
- ✓cloud of ISM contracted
- ✓ rotation of the cloud becomes more rapidly

5.9 Formation theory (Solar nebula hypothesis)

Because of centrifugal force, it did not contract into a ball but a disk.

5.9 Formation theory (Solar nebula hypothesis)

- ✓very high temperature at the centre, becoming a star.
- ✓Mass of the Sun ~ 99% of the whole Solar System!
- ✓Radiations from the Sun pushes gas, dust outwards