Solar System Fundamentals

What is a Planet?

Planetary orbits

Planetary temperatures

Planetary Atmospheres

Origin of the Solar System

Properties of Planets

What is a planet?

Defined finally in August 2006!

- A Planet:
  - Orbits the Sun
  - Has enough mass so that gravity overcomes the strength of the body and it becomes round – it is in hydrostatic equilibrium.
  - Has “cleared” its orbit – the only body of its size at that distance from the Sun.

8 Solar System Planets

- Mercury
- Venus
- Earth
- Mars
- Jupiter
- Saturn
- Uranus
- Neptune

Dwarf Planets

- A Dwarf Planet:
  - Orbits the Sun
  - Has enough mass so that gravity overcomes the strength of the body and it becomes round – it is in hydrostatic equilibrium.
  - Has not "cleared" its orbit – other similar sized bodies will orbit the Sun at a similar distance.
  - Is not a satellite of another body.

“Dwarf” planets

- Ceres
  - Was classified as a minor planet
- Pluto
  - Has been demoted
- Eris
  - Discovered in 2003, Eris is slightly larger than Pluto

SSSB's

- All other bodies in the Solar system are called SSSB's – Small Solar System Bodies
- These include:
  - Minor Planets or Asteroids
  - Kuiper Belt Objects (KBO's) also known as Trans Neptunian Objects (TNO's)
  - Comets

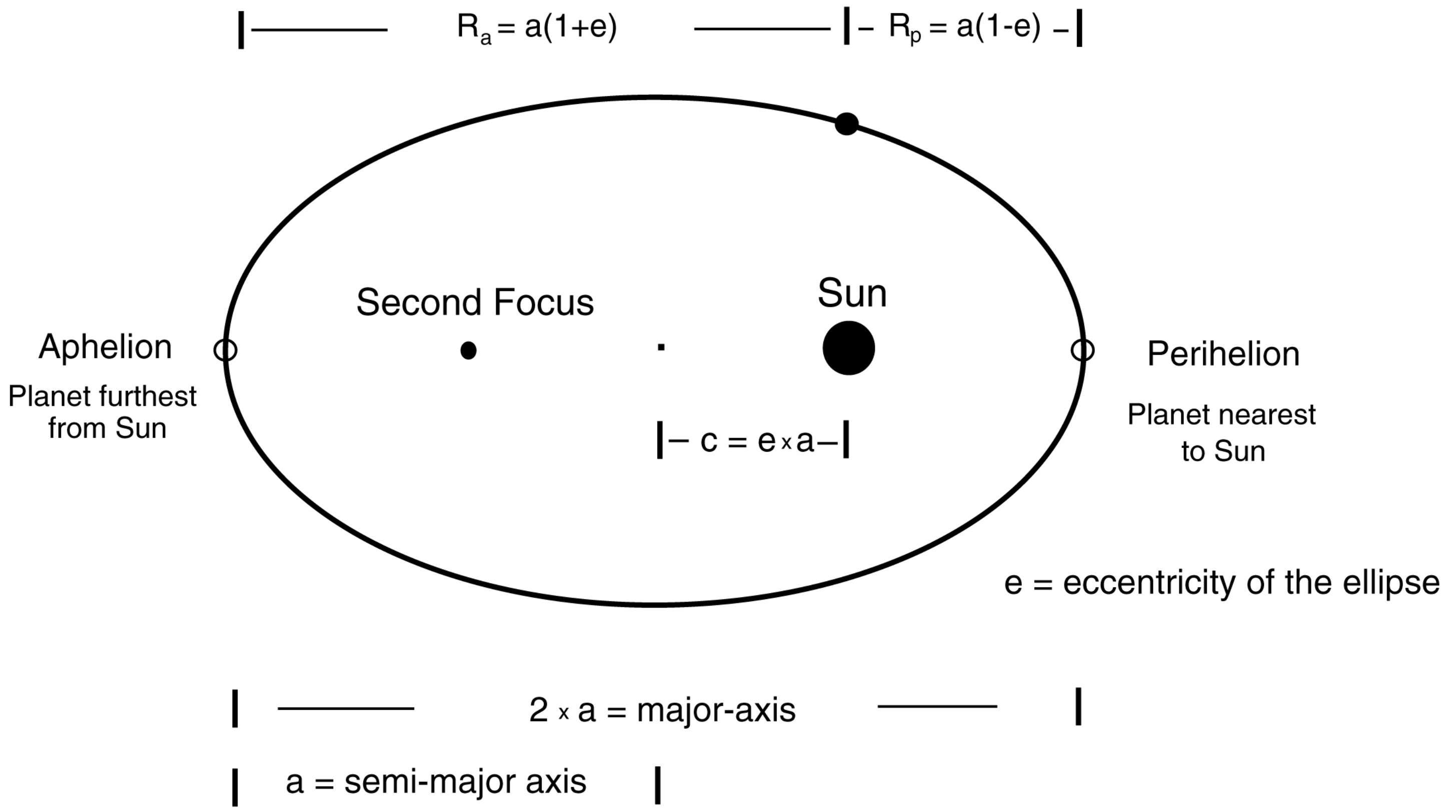
“Plutoids”

- The International Astronomical Union has decided on the term plutoid as a name for dwarf planets like Pluto.

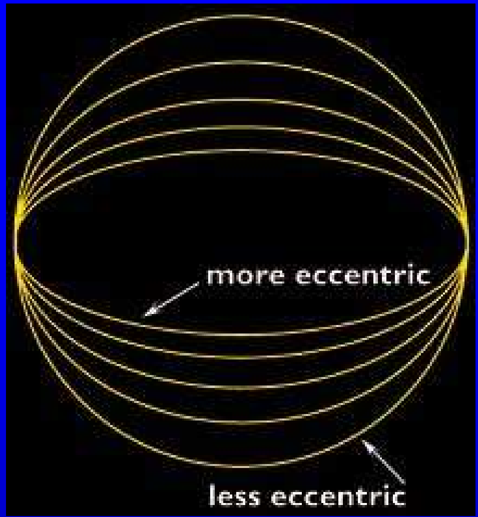
- This is a category of dwarf planets which orbit beyond Neptune and similar to Pluto.

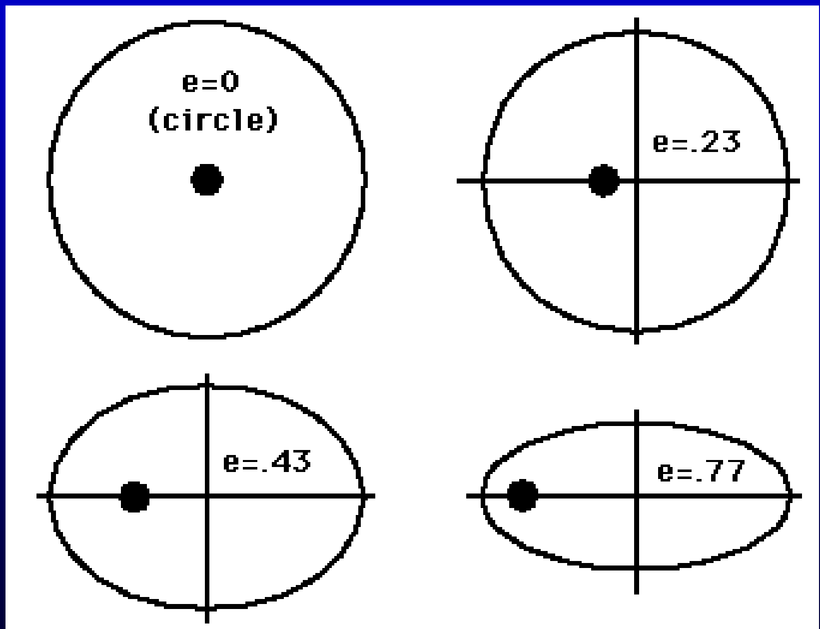
- Plutoids are celestial bodies in orbit around the Sun at a semimajor axis greater than that of Neptune that have sufficient mass for their self-gravity to overcome rigid body forces so that they assume a hydrostatic equilibrium (near-spherical) shape, and that have not cleared the neighbourhood around their orbit.
- The two known and named plutoids are Pluto and Eris. It is expected that more plutoids will be named as science progresses and new discoveries are made.

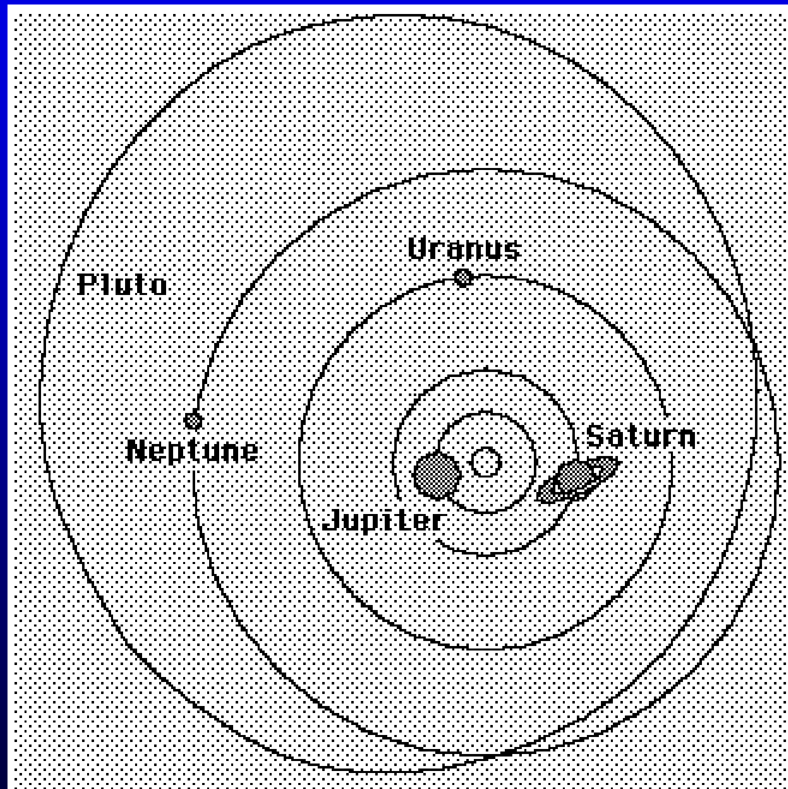
Planetary Orbits



Eccentricity





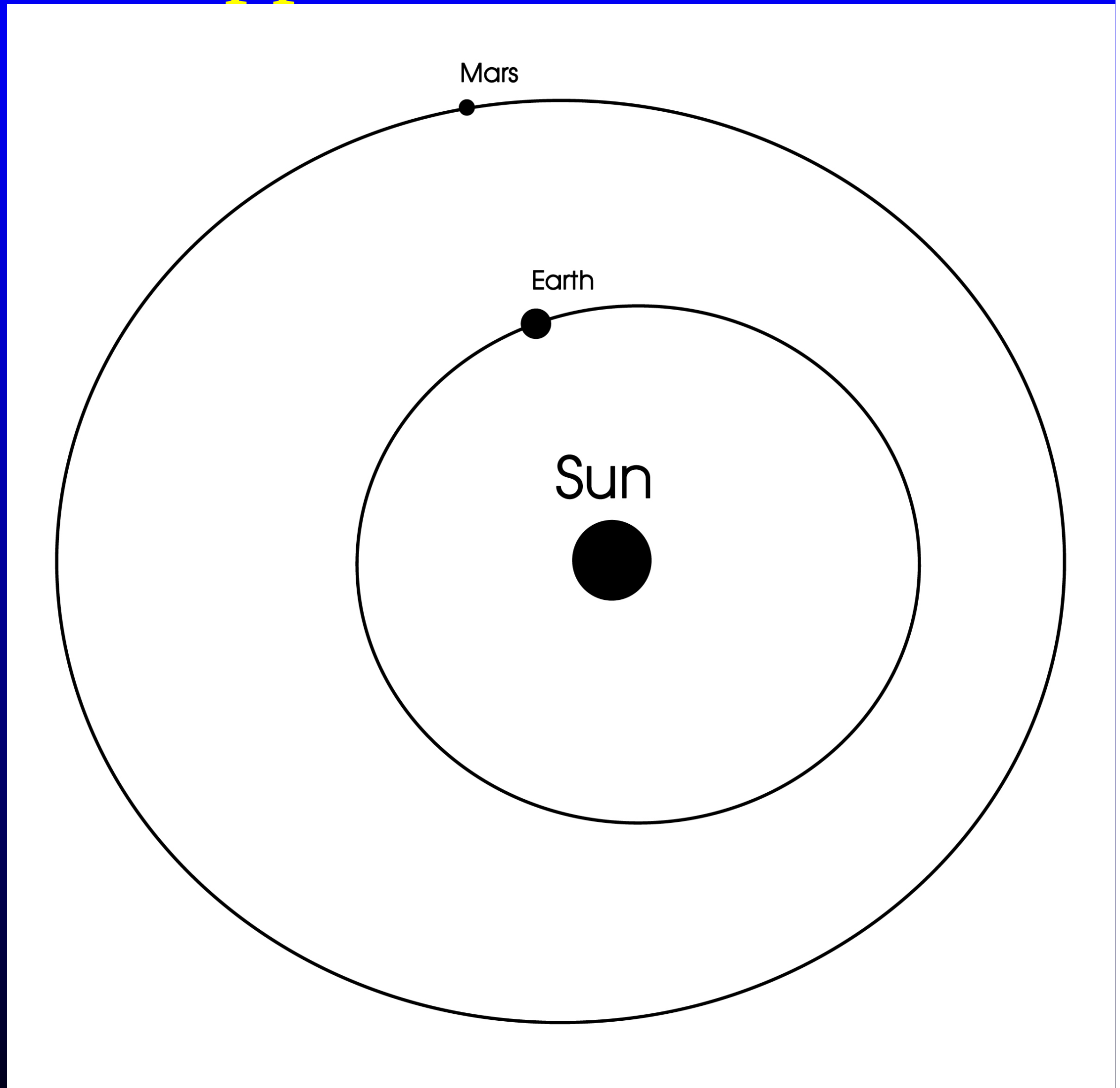


Eccentricity of Planetary orbits

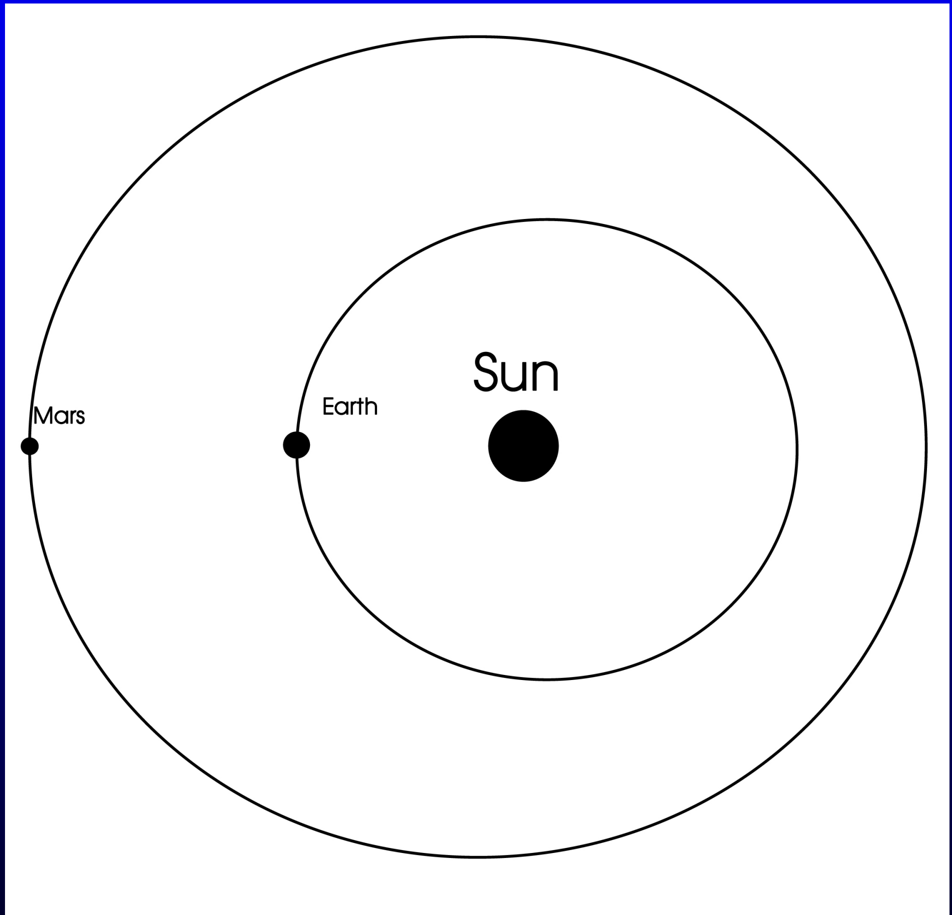
- Venus at 0.007 is virtually circular
- Neptune is next at 0.01
- Earth at 0.017 is next
- Mars is 0.093
- Pluto and Mercury have the most eccentric orbits with 0.249 and 0.206 respectively.

Effect on Closest Approach of Mars

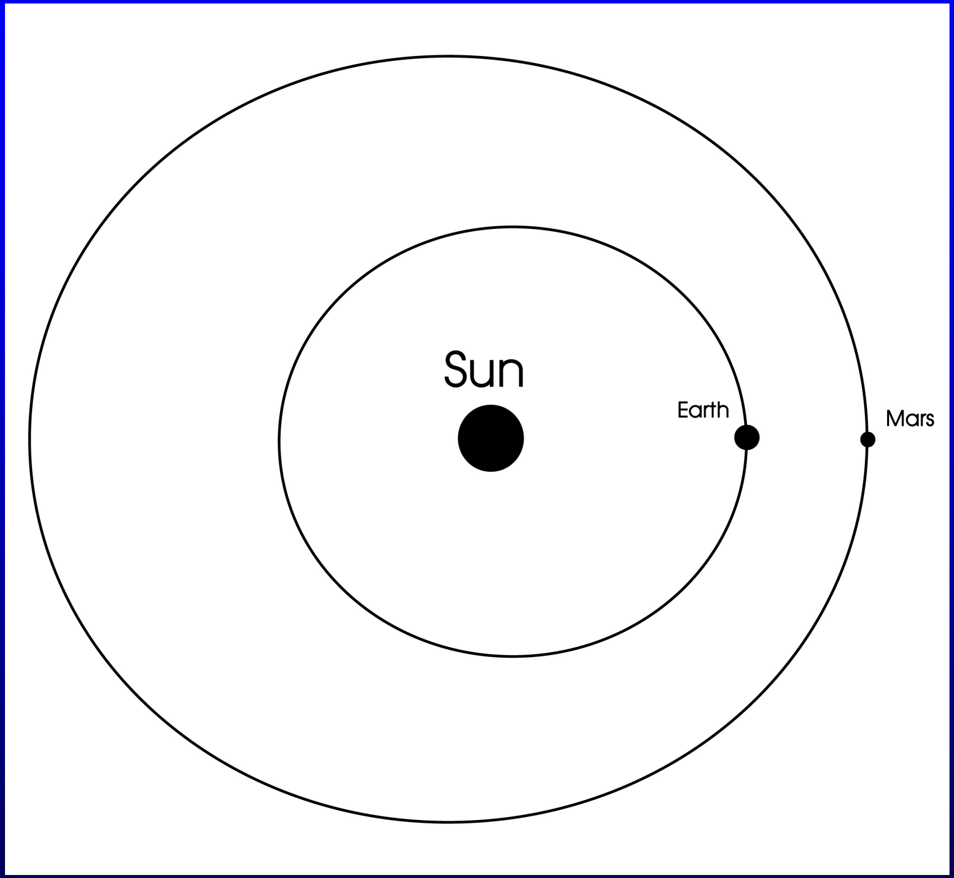
- A planet, like Mars, is closest to us at Opposition – when the planet, the Earth and the Sun all line up.
- NOTE the planet will be seen due south at midnight.
- The Earth passes Mars on the “inside track”.

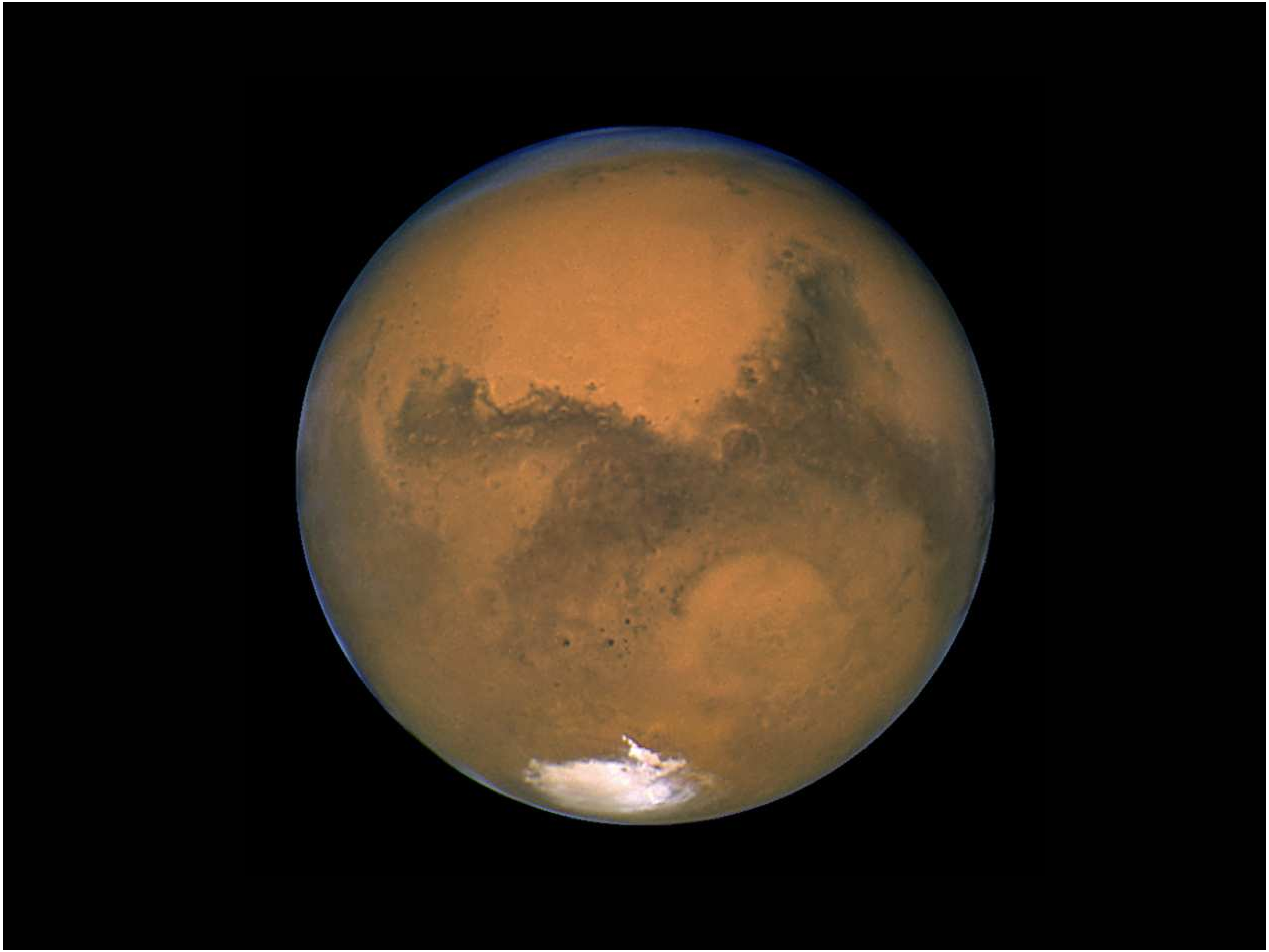


- A poor opposition occurs when the Earth is nearest the Sun (near perihelion) and Mars is furthest from the Sun (near aphelion).

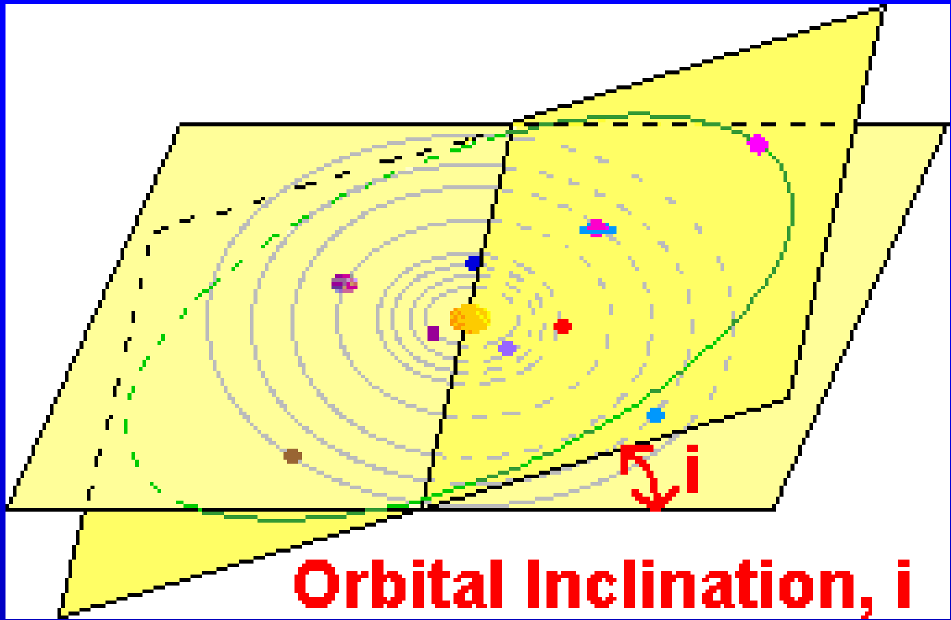


- A close opposition occurs when the Earth is furthest from the Sun (near aphelion) and Mars is nearest to the Sun (near perihelion).
- The Earth is furthest from the Sun in August.
- So a very close opposition of Mars MUST happen in August.
- In August 2003 , Mars was closest for 60,000 years!



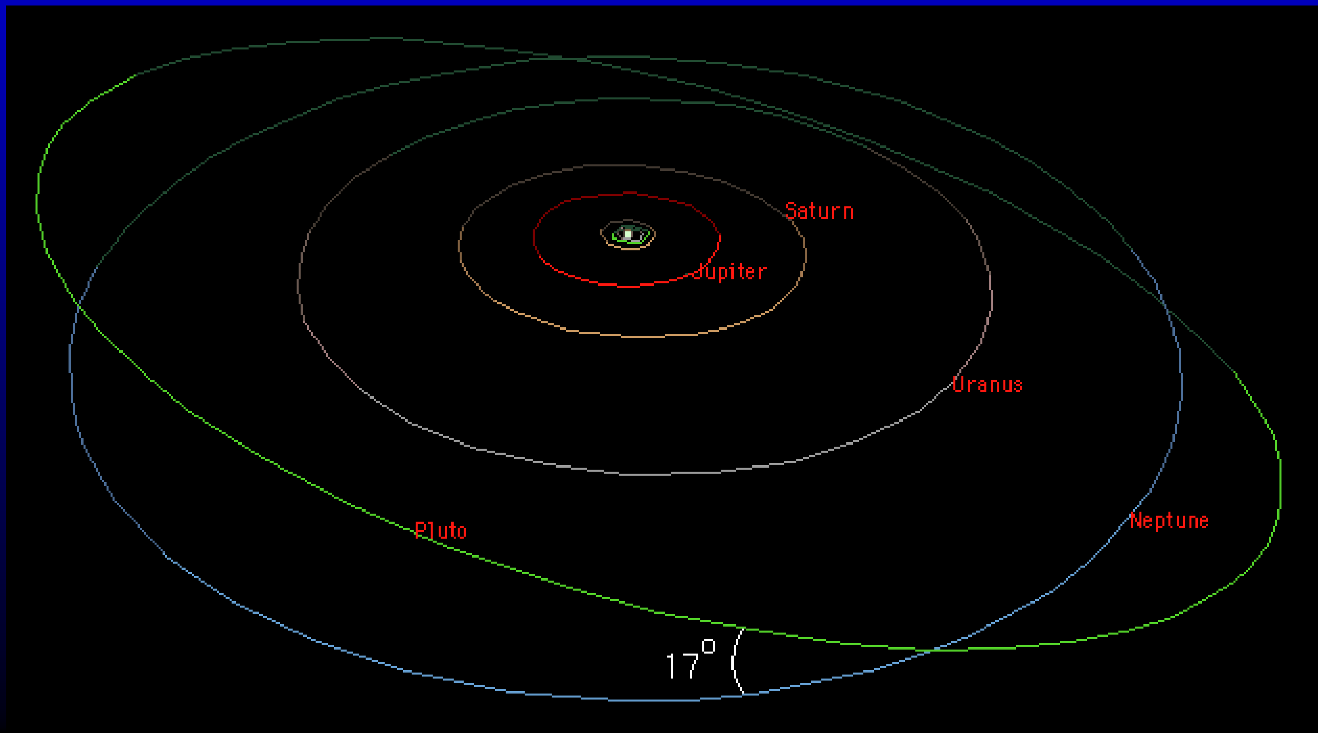


Orbital Inclination



- The Earth's is defined to be zero so the plane of the Solar System is defined by the plane that includes the Earth's orbit.

- Mercury 7 degrees
- Pluto 17 degrees



Properties of Planets

Planetary Masses

- Can only be found if the planet has a satellite or is flown by or orbited by a spacecraft.
  - Mercury Fly-By by Mariner 10
  - Venus orbited by Pioneer Orbiter
  - Other planets have natural satellites
- Use Newton’s Law of Gravitation

Finding the Mass of a Planet

- Force between Planet and satellite
  $=MmG/a^2$ (M = mass of Planet, m = mass of satellite)
  Centripetal acceleration = $\omega^2 = v^2/a$
  Centrifugal Force = mv^2/a
  So $MmG/a^2 = mv^2/a$

  $M = v^2\, a/\, G$
  But $v = 2\, \text{pi}\, a/P$ where P is the period of the satellite,
  so substituting,
  $M = 4\, \text{pi}^2\, a^3/\, GP^2$ (Units: kg, seconds, m)

Finding the Density

- From angular size and distance one can calculate radius and hence volume.
- Mass / Volume = Density

Finding the Rotation Period

- For some planets, such as Mars, Jupiter and Saturn one can observe the rotation of a marking on the surface – such as the “red spot” on Jupiter.
- For cloud shrouded Venus and Mercury planetary radar was used to measure the rotation period using the doppler shifts in the returned echoes.

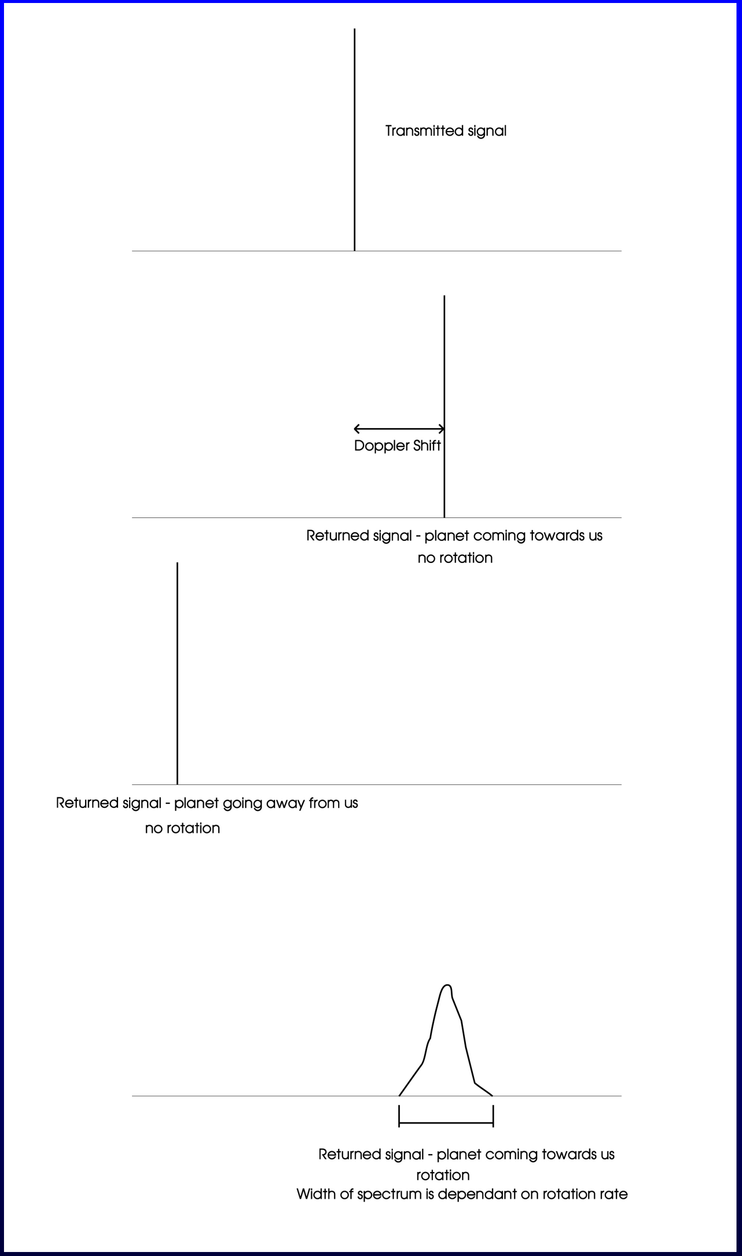
Radar Determination of Rotation Period

Doppler Formula:

$$\Delta f/f \quad = \quad \Delta v/c$$

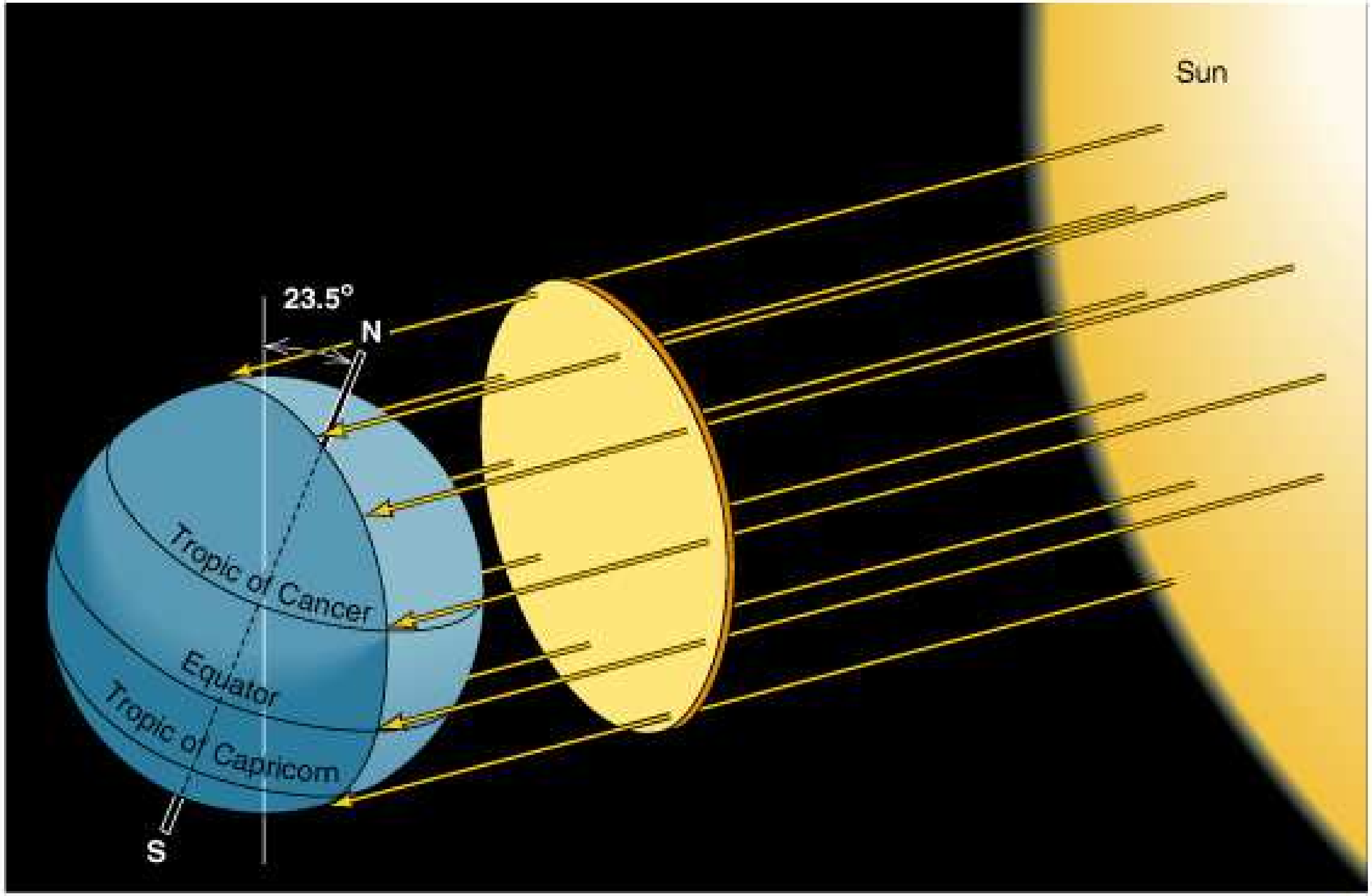
(Δf and f must be in same units i.e., Hz)

Δv will be twice the rotational speed of the surface about its axis of rotation



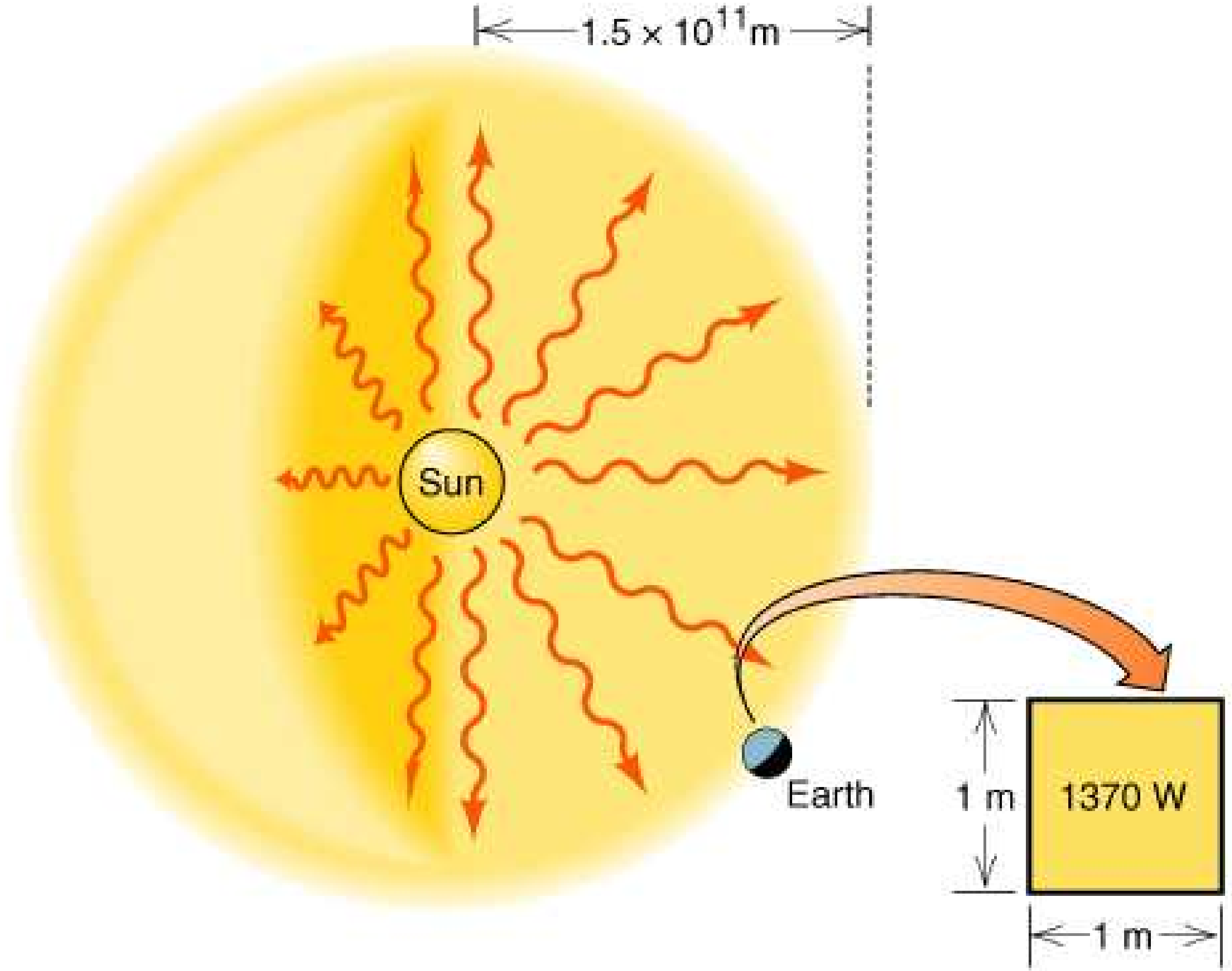
Surface Temperatures

- By landers on the surface.
  - Venus, Mars
- Intensity of radio emissions
  - Mercury
- Calculation based on energy received from the Sun and emitted by the planet.
  - On average these must be equal! (Except for Jupiter which is contracting and gravitational potential energy is being converted into heat)


Sun
23.5°
N
S
Tropic of Cancer
Equator
Tropic of Capricorn

The Solar Constant

How much energy falls per square metre on the “surface” of the Earth at the sub solar point in Watts?


1.5 × 10¹¹m
Sun
Earth
1 m
1370 W
1 m

The Solar Constant

The Solar Constant is the amount of energy that passes through each square metre of space at the average distance of the Earth

It is 1368 watts/sq metre

Inverse Square Law

- Note that the solar constant must fall off with the inverse square law. The solar constant at a planet that was two times further away from the Sun than the Earth would have a solar constant that was 4 times less than that on Earth.

$= \quad 1368/4 \; = \; 342$ Watts per square metre

Planetary Temperatures

- To do calculations regarding the temperatures of planets:

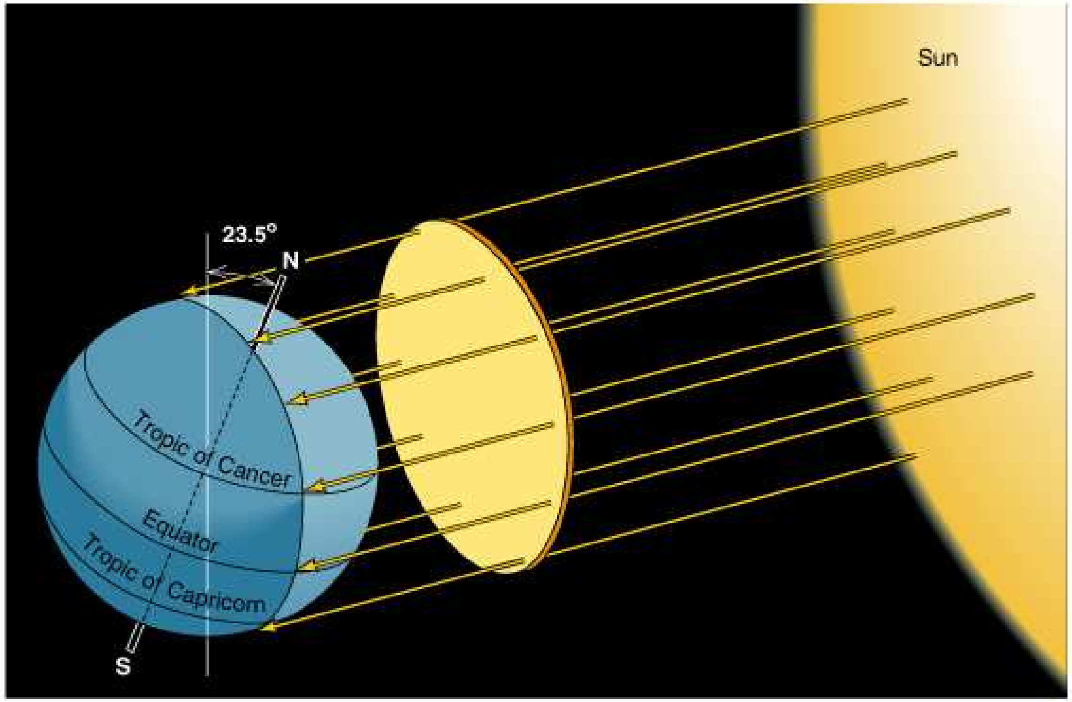
  1) we can assume that they act like black bodies.

  2) they have a uniform surface temperature

  (atmosphere and rotation tends tomake this true)

What would we expect the temperature of the Earth to be?

The energy received by the Earth is given by the solar constant multiplied by the Earth's cross sectional area.



$= \text{pi} \times R^2 \times SC$

where R is the radius of the Earth and SC the solar constant

Energy emitted by the Earth is given by :

Surface Area of Earth $\times \sigma \times T^4$

$= 4 \text{ pi } R^2 \times \sigma \times T^4$

As this must equal average energy input

$$\text{pi} \times R^2 \times SC = 4 \text{ pi } R^2 \times \sigma \times T^4$$

$$SC = 4 \times \sigma \times T^4$$

$$T = (SC/(4 \times \sigma))^{1/4}$$

$$= (1368 / (4 \times 5.7 \times 10^{-8}))^{1/4}$$

$$= 278 \text{ K}$$

This is quite close. But should it be?

The Earth is, on average, 50% cloud covered and absorbs only 77% of the Sun's radiation. This would make T_{earth} only 260K.

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But those same clouds, and the carbon dioxide, water vapour and methane in the atmosphere prevent the Earth radiating as much as a black body – the Greenhouse Effect.

This increases the Earth's temperature above what it would be, so the two effects tend to cancel giving a T_{earth} of 288 K.

The temperature of a planets surface is affected by the albedo of the planet and the effect of greenhouse gasses if any.

(Albedo (a) is the fraction of the Sun's energy reflected by the planet so (1-a) is the fraction absorbed.)

Earth 0.23

Venus 0.77

Mars 0.14

What determines the atmosphere of a planet?

- The atmosphere it is given:
  - From the Solar nebula
  - From out-gassing from Volcanoes if any
    (Venus, Earth and Mars)
- What gasses the planet can hold on to given the temperature of the atmosphere and its gravitational pull on that atmosphere.
- Effects of chemistry or life.

Temperature and Gravity

- Think of Molecules of different gasses in the atmosphere of a planet (or satellite) .
- All have equal average energies – Law of Equi-partition of Energy.

  = 3/2 kT where k is Boltzmann's Constant

- Kinetic energy = $\frac{1}{2}\, m\, v^2$

- So $\frac{1}{2}\, M\, v^2 = \frac{1}{2}\, m\, V^2$

  Where M and m are the masses of a heavy molecule and a light molecule and v and V are their average velocities.

- If the average velocity of a molecule is close to the escape velocity of the planet or satellite, then over time it will escape into space.

- The effect of this is that hot, light planets or satellites will lose all lighter molecules that they might have had.

  – Mercury, Moon and all satellites except Titan (a satellite of Saturn) have effectivly no atmospheres.

  – Earth cannot hold on to Hydrogen or Helium

Heavy Planets such as Jupiter and Saturn, Uranus and Neptune are both massive and cold so they have kept the light gasses from the Solar Nebula.

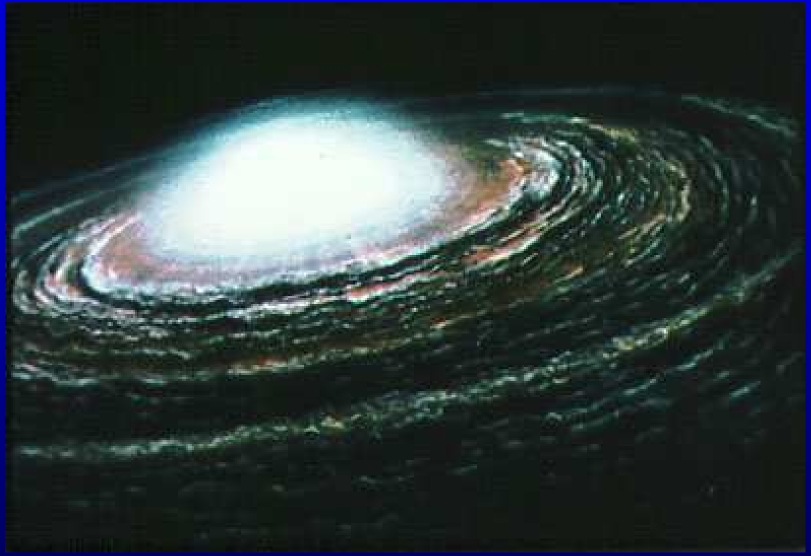
Because Titan, at the distance of Saturn, is so cold it has also kept an atmosphere.

Earth’s Atmosphere

1) Lost original light atmosphere of H and He as too little gravity to keep hold of them.
2) Was given a new atmosphere by out-gassing from Volcanoes.
3) Has kept the heavier molecules.
4) CO_2 reacts with elements like Calcium and is removed from the atmosphere into the Ocean Floors.
5) These are subducted under the continental plates and volcanoes recycle CO_2 into the atmosphere.
6) Life has produced free Oxygen!

The Origin of the Solar System

Formed along with our local star – The Sun, some 4.5 billion years ago from a gas cloud in the Milky Way



The early Solar Nebula collapses to a rotating disc within which the rocky cores of planets form from dust particles and grow by collision

As the Sun turns on, winds sweep the inner solar system of any remaining primordial gas