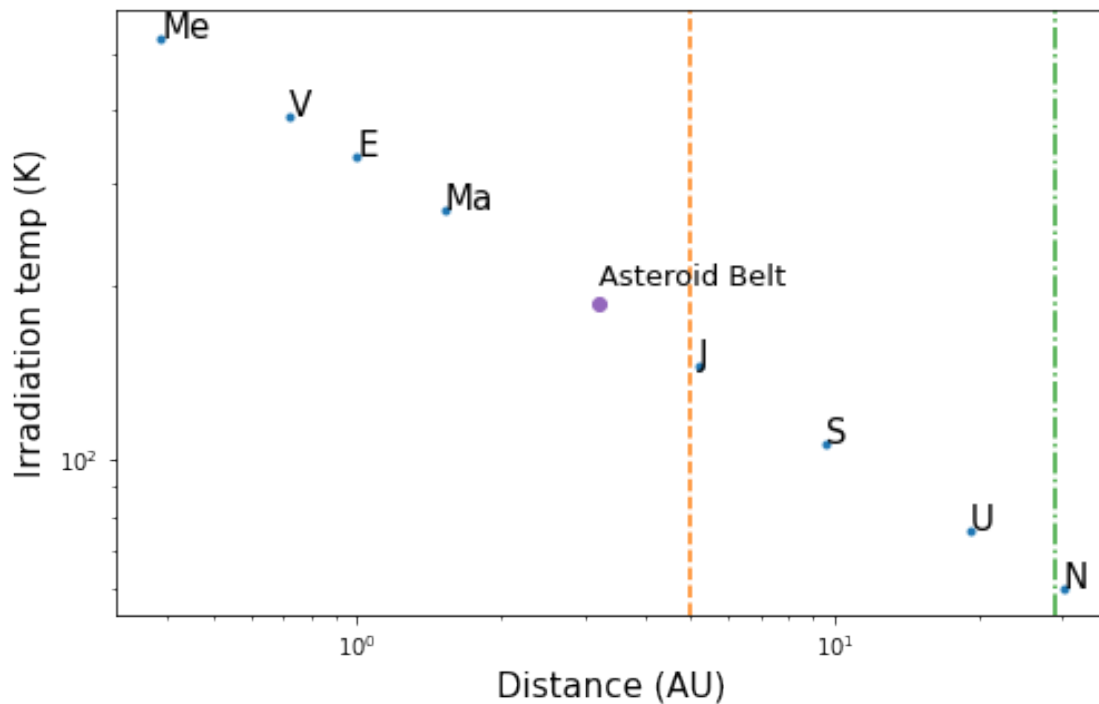


Lecture_19

March 21, 2022

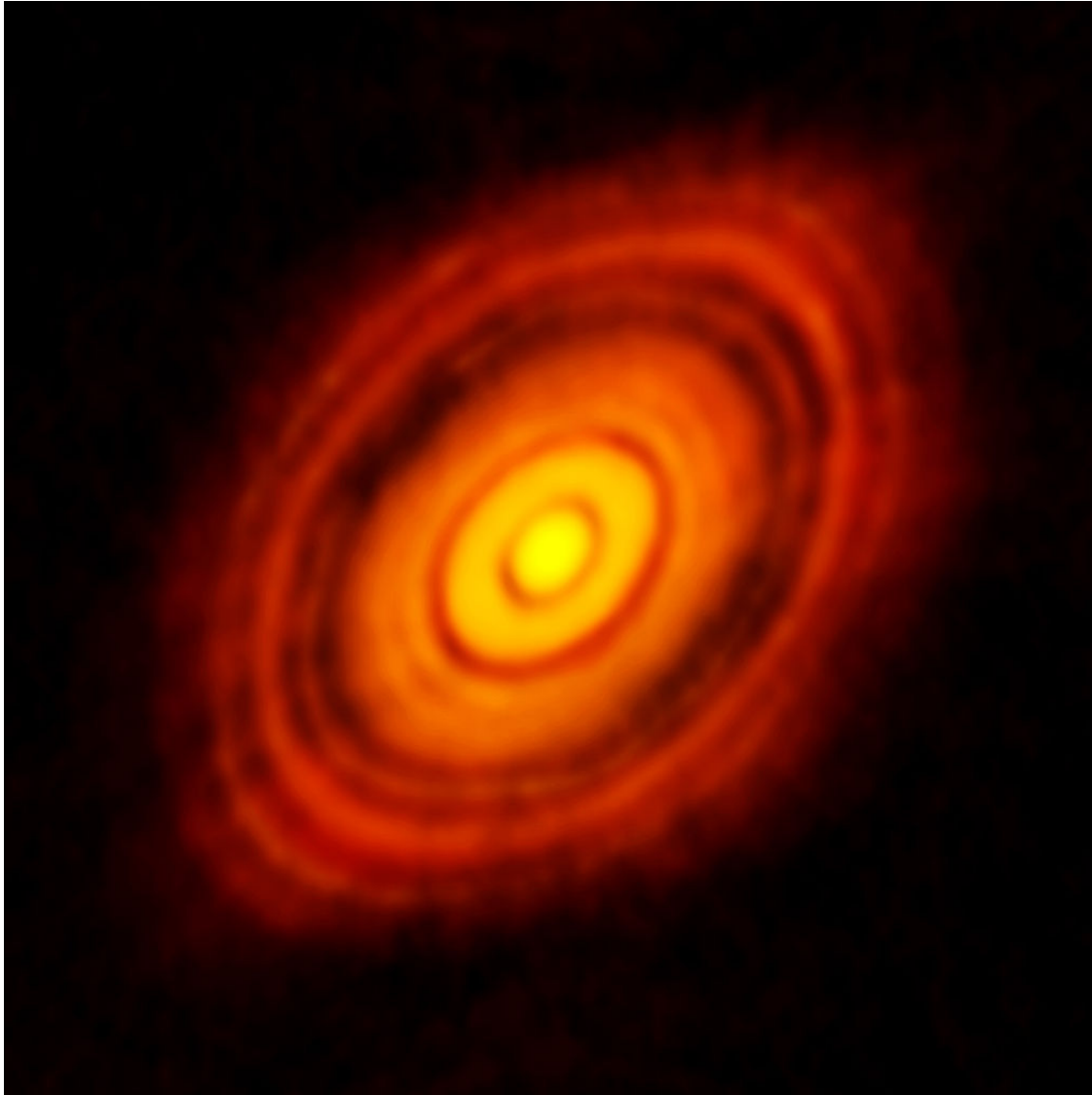
1 Terrestrial versus Gas Giant Planets

So why do we have these two types of planets? And how does this feed into a model of forming the solar system? First, let's propose a model. - As the protosolar nebula contracted and formed a disc, heavier elements condensed out first. - Water had not yet condensed when terrestrial planets formed. It's suspected most water on Earth comes from collisions with cometary nuclei. - Water could condense beyond some distance from Sun, near orbit of Jupiter (as shown below, where we've calculated the irradiation temperature for different distances from the Sun, and found where the snow line (condensation temperature for water = 150 K) lies.

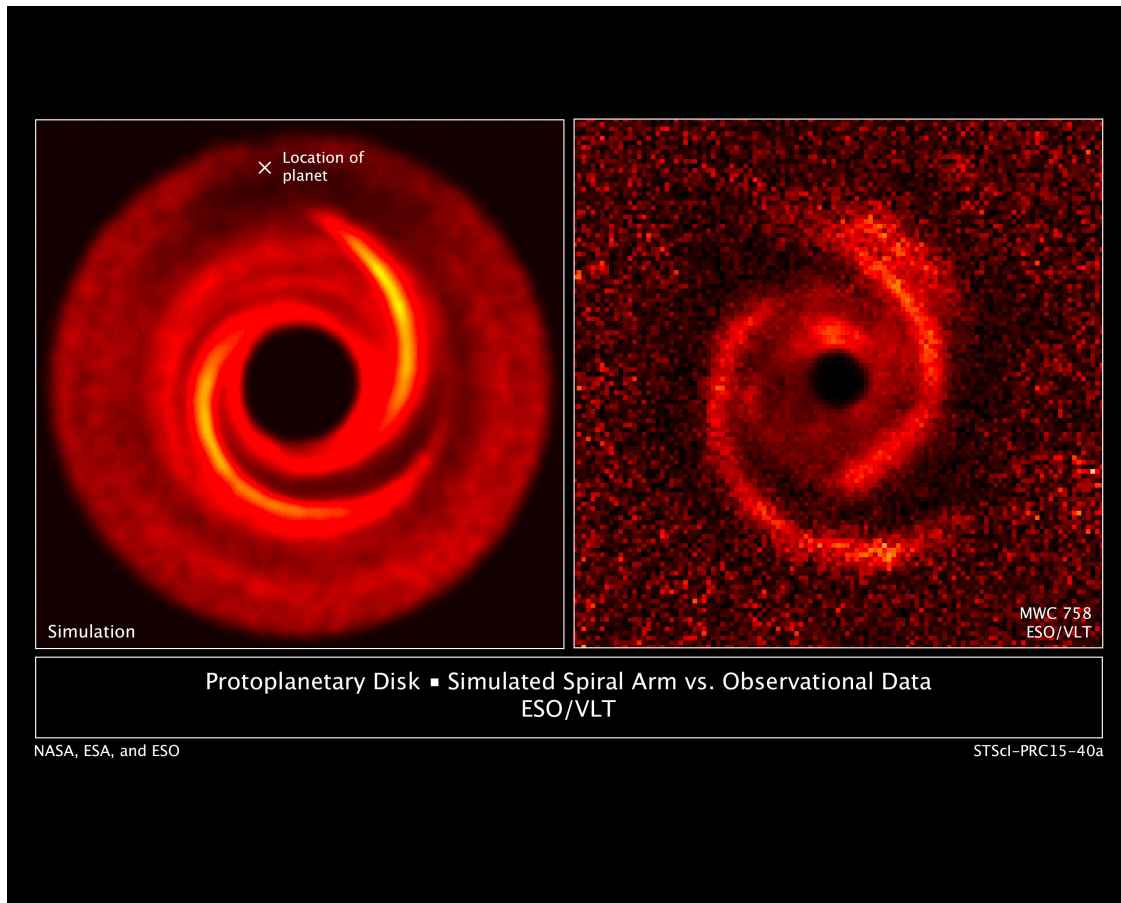


- When fusion began in the centre of the Sun, it led to a very strong solar wind. This pushed matter not bound in the inner planets away from the Sun.
- Water pushed beyond the snow line. There, it condensed onto Jupiter, increasing its mass. This enabled Jupiter to capture H and He, further increasing its mass.

2 Protoplanetary discs



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3 Quirks of planets

3.1 Mercury

- Its rotation is studied using radar signals transmitted by the Arecibo radio telescope (which has since collapsed) in 1965, using the Doppler effect. The rotational period is $P_{\text{rot}} = 58.65$ d.
- This is exactly $2/3$ of the orbital period of the planet ($P_{\text{orb}} = 87.97$ d). Since Mercury feels the strongest tidal force at perihelion (point of closest approach to the Sun), this means that the tidal bulges always line up with the Sun at this time (as there is 1.5 rotations per orbit, see figure).
- Gravitational influence of other planets causes the perihelion to shift in a counter clockwise rotation by $574''/\text{century}$. Newtonian gravity can only explain $531''/\text{century}$ - the remaining $43''/\text{century}$ explained using Einstein's theory of general relativity.

3.2 Mars and the asteroid belt (between Mars and Jupiter)

- Mars has a low mass of $0.107 M_{\oplus}$.
- To explain this, it may be that Jupiter became very massive before Mars finished forming, which perturbed orbits of planetesimals near Mars.
- This would mean the “missing mass” of Mars has ended up in the asteroid belt.
- Numerical simulations suggest Mars' rotational axis may vary chaotically with tilts between

11-49° on timescales as short as a few million years (due to its low mass and gravitational influence of other planets).

3.3 Venus

- Also studied using radar signals sent from Earth, but also using Doppler shifts of reflected sunlight.
- Venus rotates in a retrograde direction, with $P_{\text{rot}} = 243$ d and $P_{\text{orb}} = 224.7$ d.
- Main gas in atmosphere is CO₂ (96.4%). At the base of its atmosphere, it has $T = 740$ K and a pressure of 90 atm.
- This temperature is 2-3 times higher than the irradiation temperature we get when we use the formula from last week - due to the greenhouse effect.
- Surface accurately mapped by the Magellan spacecraft. The frequency of the radio signals sent to Earth were Doppler shifted depending on the speed of the spacecraft as it passed over regions of higher/lower mean density.
- It also potentially has traces of phosphine in its upper atmosphere (which **may** be due to life).

3.4 Gas Giants

All planets produce heat due to the decay of radioactive nuclei, including the terrestrial planets, but the Gas Giants show excess heat on top of this. This is partly due to the gravitational potential energy released by gases as they collapse onto the planets during their formation:

$$\langle K \rangle = -\frac{1}{2} \langle U \rangle$$

$$\langle E \rangle = \frac{1}{2} \langle U \rangle$$

Now, using $\langle U \rangle = -\frac{3}{5} \frac{GM^2}{r} = -\frac{16}{15} \pi^2 G \rho^2 r^5$. Also, say that the cooling time scale is given by the total energy divided by the loss rate:

$$\tau_{\text{cool}} = \frac{\text{total energy}}{\text{energy loss rate}} \sim \frac{V}{A} \sim \frac{r^3}{r^2} \sim r$$

Jupiter's heat production can be explained in this way - that is, the excess we see matches what we'd expect from this cooling time for an object of Jupiter's radius. However, Saturn's heat production is too high. - The action of the virial theorem continues as He sinks slowly through the H₂ atmosphere.