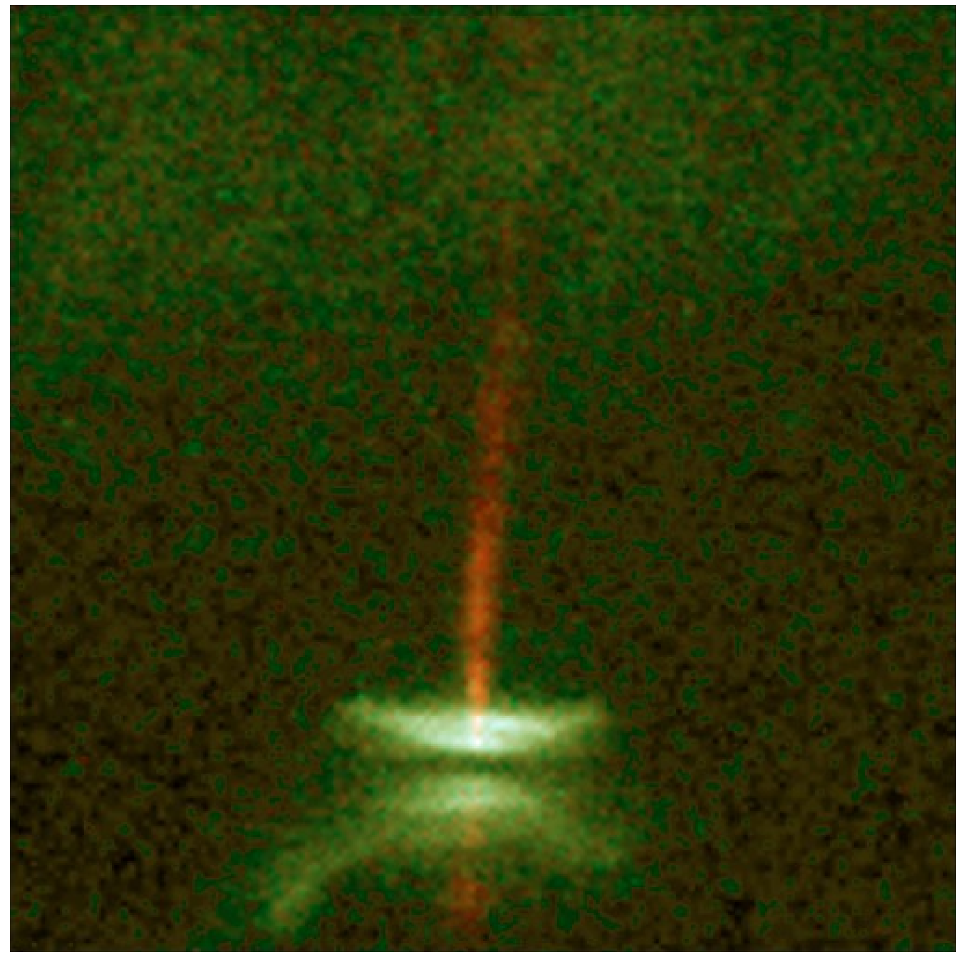
Planet Formation

- Proto-planetary discs
- Grain growth
- Snow line
- Terrestrial planet formation
- Jovian planet formation

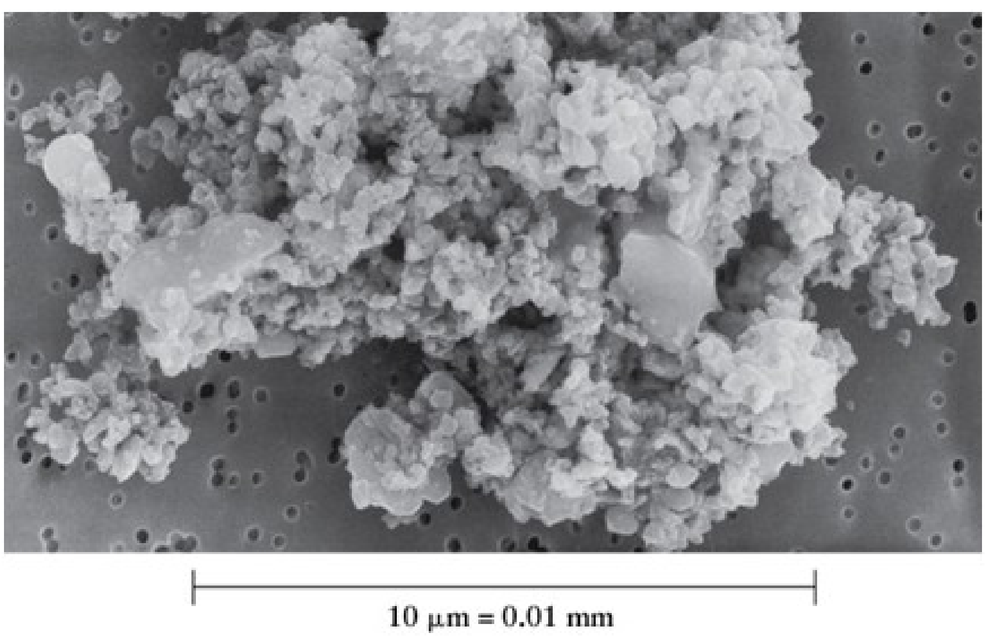
Proto-planetary discs

- The accretion discs that form stars are also the sites of planet formation



Grain Growth

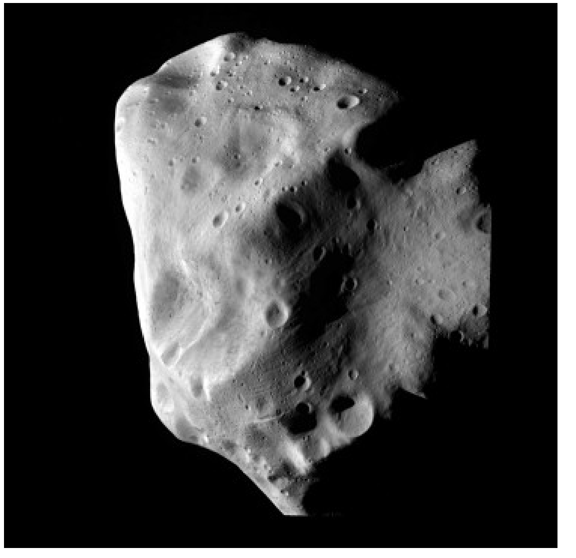
- In the dense mid-plane of the proto-planetary disc the dust grains collide and some stick together – coagulate
- Held together by chemical bonds

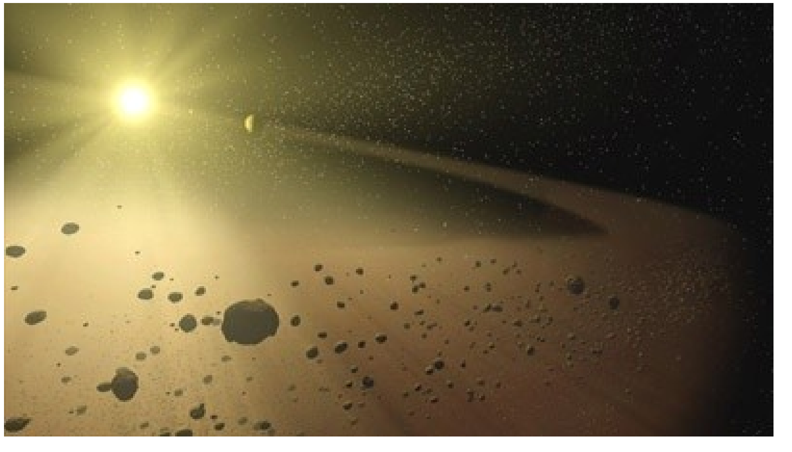


Interplanetary dust grain
Brownlee, U. Washington

Planetesimals

- Over a few million years these grains grow from a few microns to about a kilometre in size
- These are called planetesimals and are similar to asteroids
- Held together by gravity





NASA

Snow Line

- In the outer regions where temperatures are <200 K, ices coat the rocky grains made up of water, ammonia and methane frozen out from the gas phase
- In the inner regions the ices sublimate and the grains are bare silicate and carbon

- The dividing line between the rocky and icy grains is the snow line (frost/ice line)

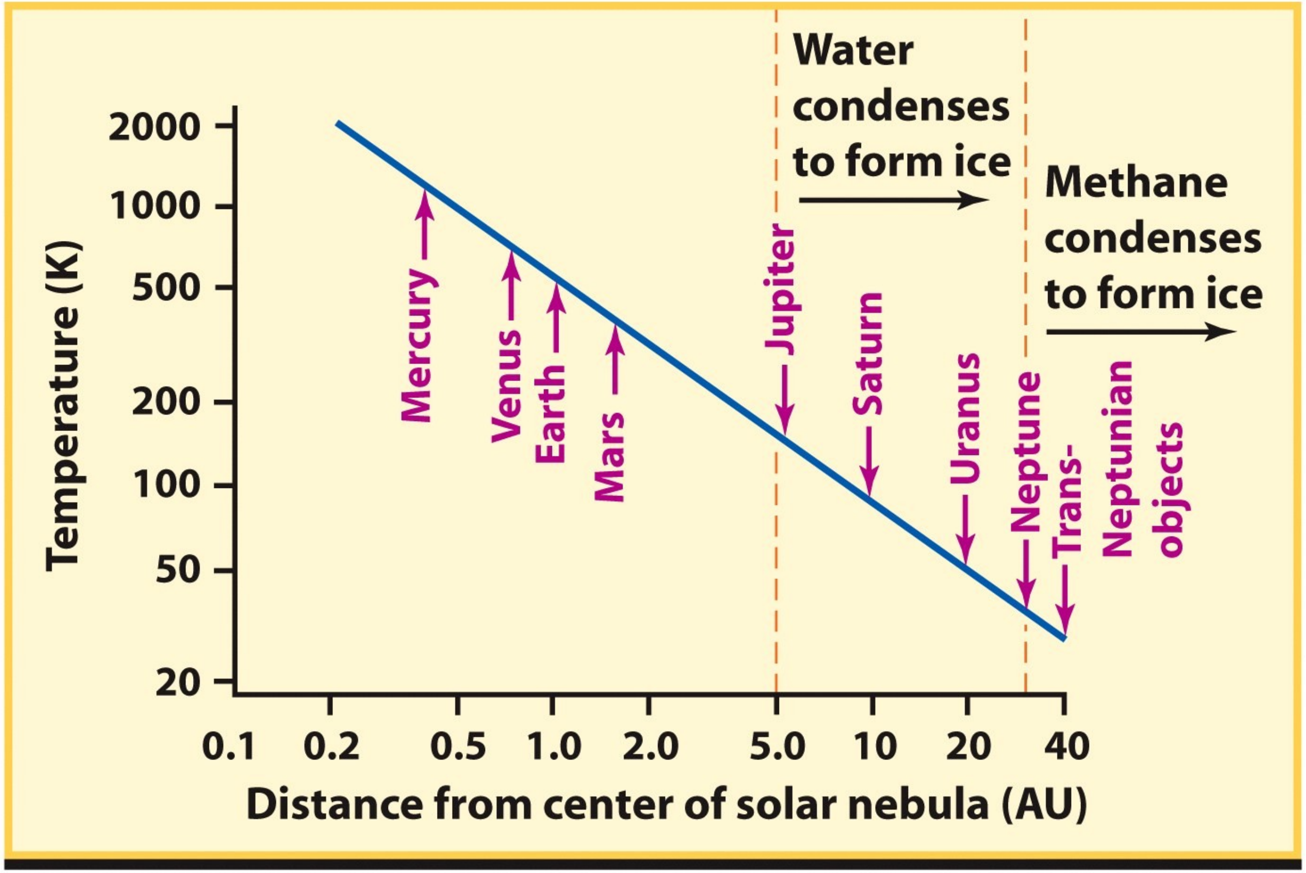


Figure 8-10
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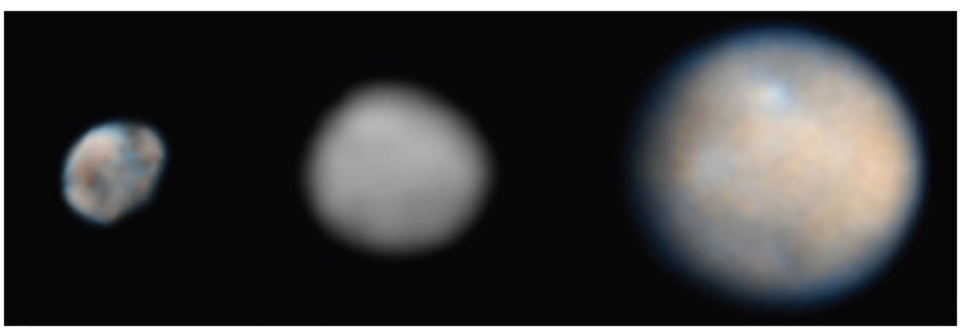
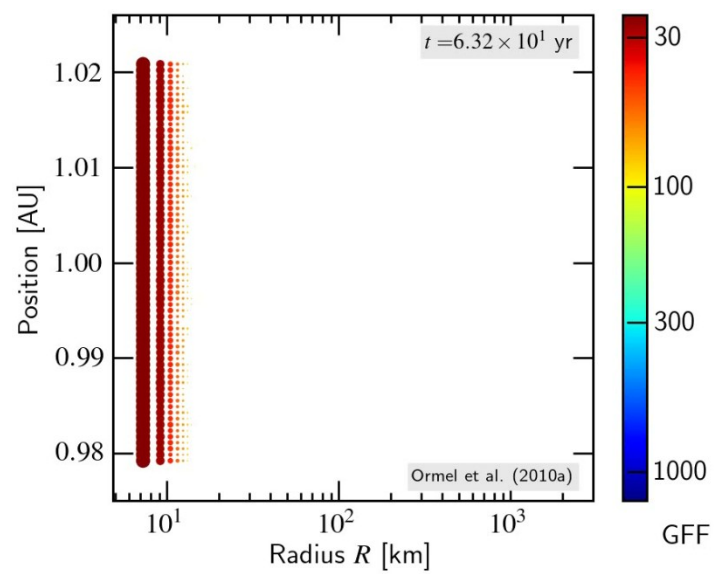
Proto-Planets

- Planetesimals have enough gravity to attract each other, collide and merge
- This forms proto-planets with sizes similar to the Moon and dwarf planets



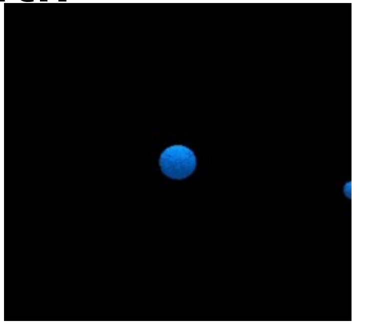
Vesta, Pallas and Ceres
sciencewise.anu.edu.au

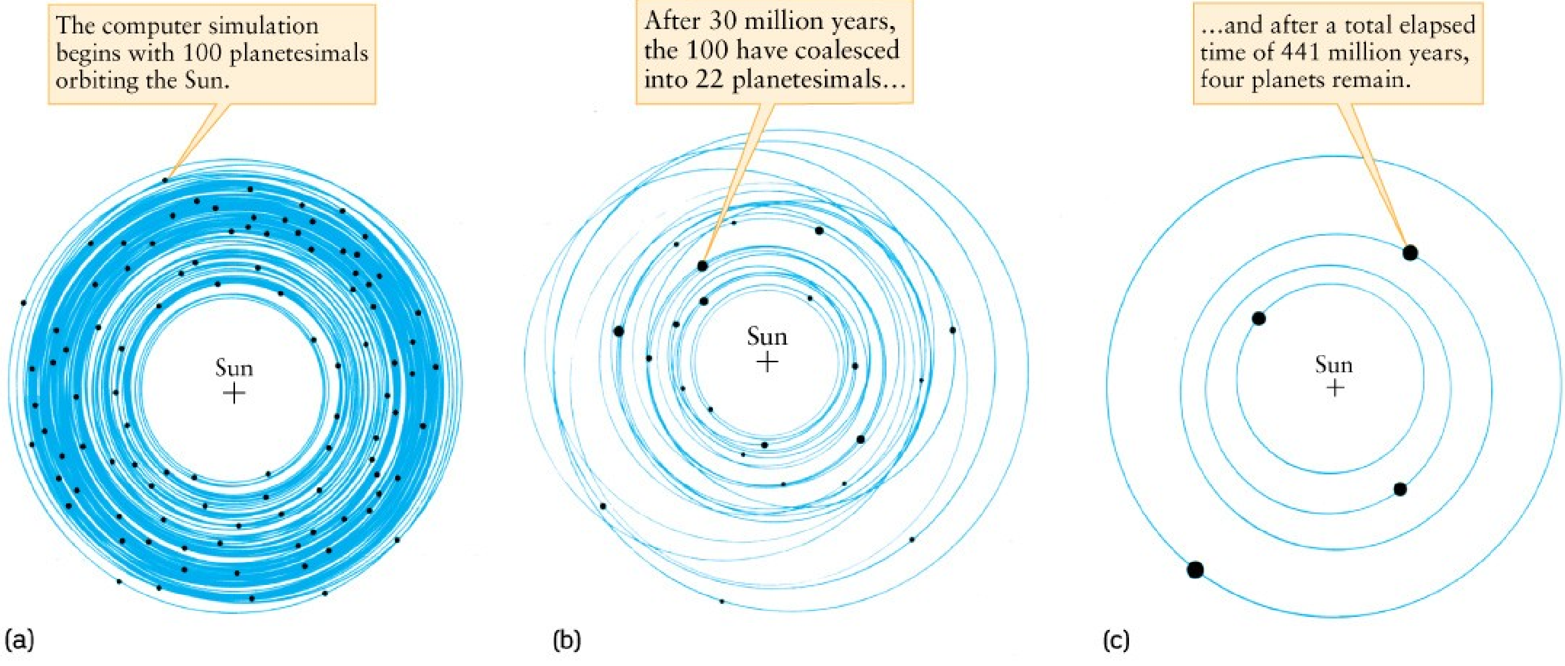


Ormel et al. (2010)

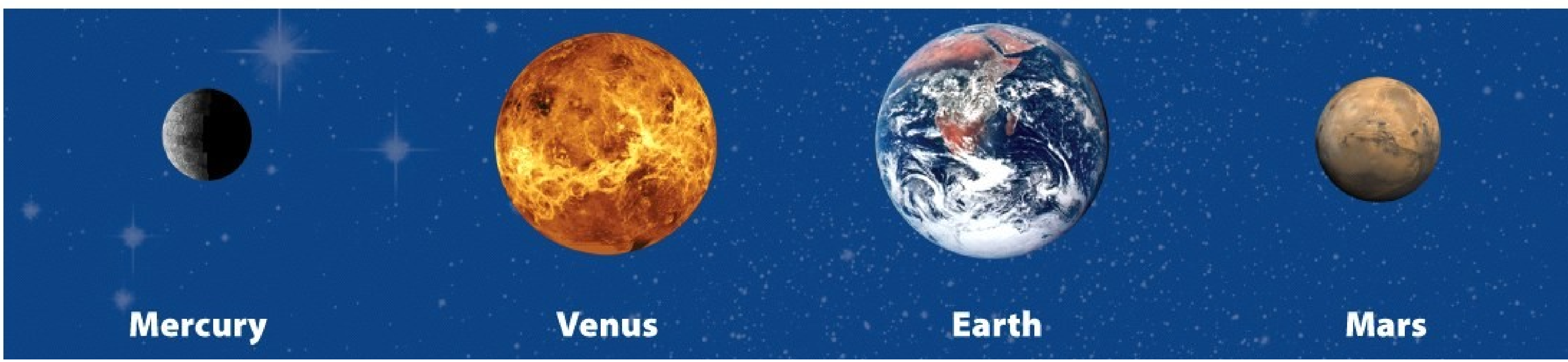
Terrestrial Planets

- Collisions & interactions continue until the neighbourhood of the largest bodies are cleared, i.e. a planet





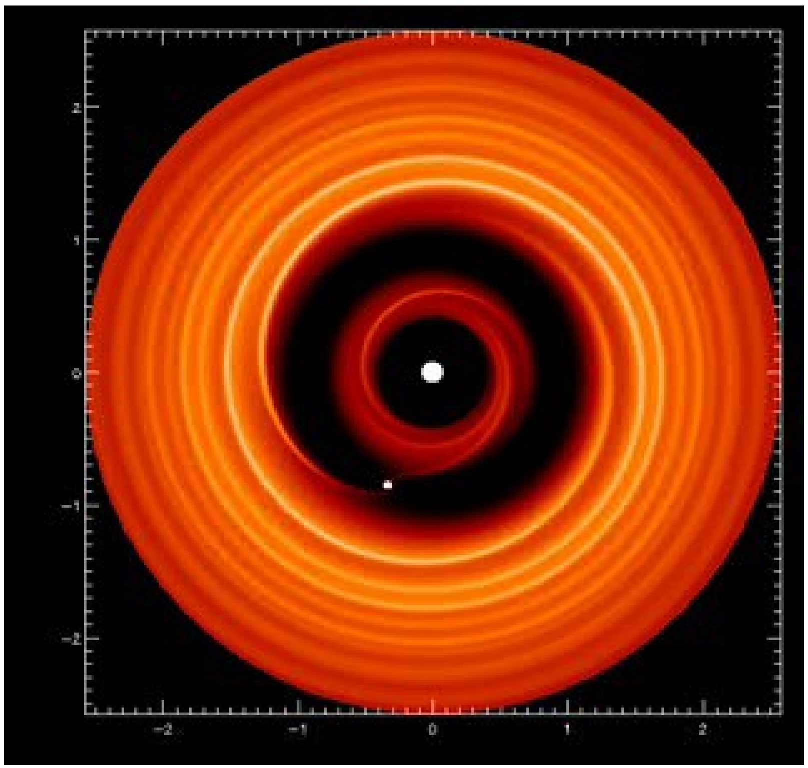
- Results in the rocky terrestrial planets
- These inner solar system planets never get massive enough to capture the hot gas from the accretion disk

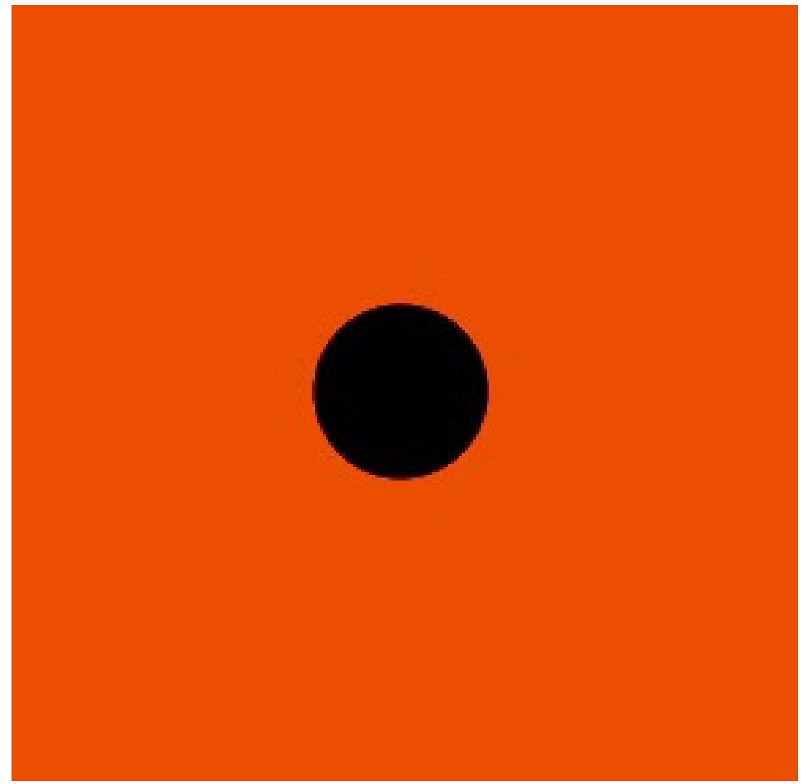


Jovian Planets

- Outside of the snow line the icy grains stick together more easily and there is a larger mass of solid material
- Here the rocky cores can build to about 10 times the Earth’s mass
- The gas in the disc is also cooler and easier to capture – core accretion model

- Rapid gas capture opens a gap in the disc
- Multiple gas giants stop accreting when gaps merge

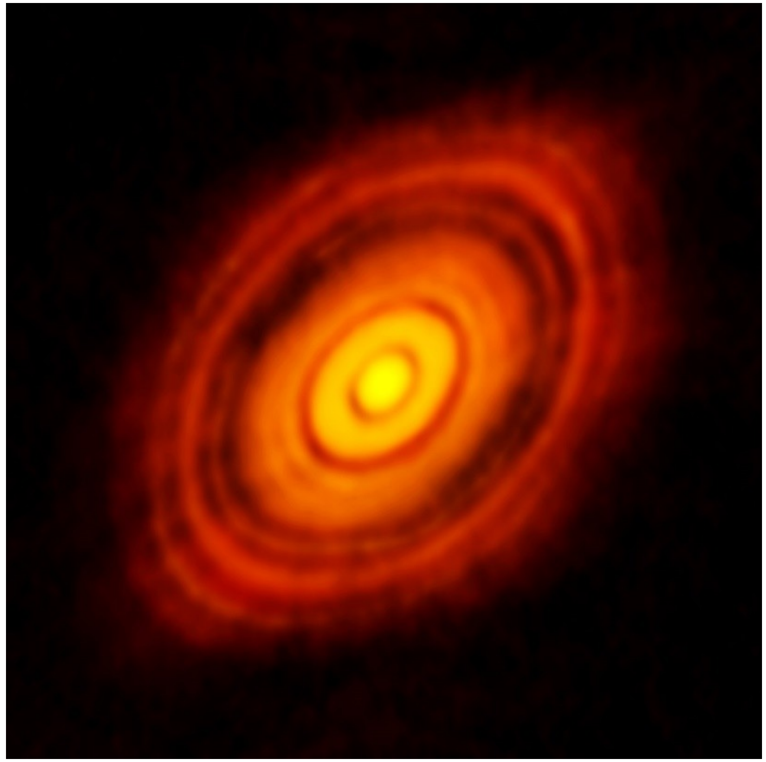




www.maths.qmul.ac.uk/~rpn/projects/mhd/

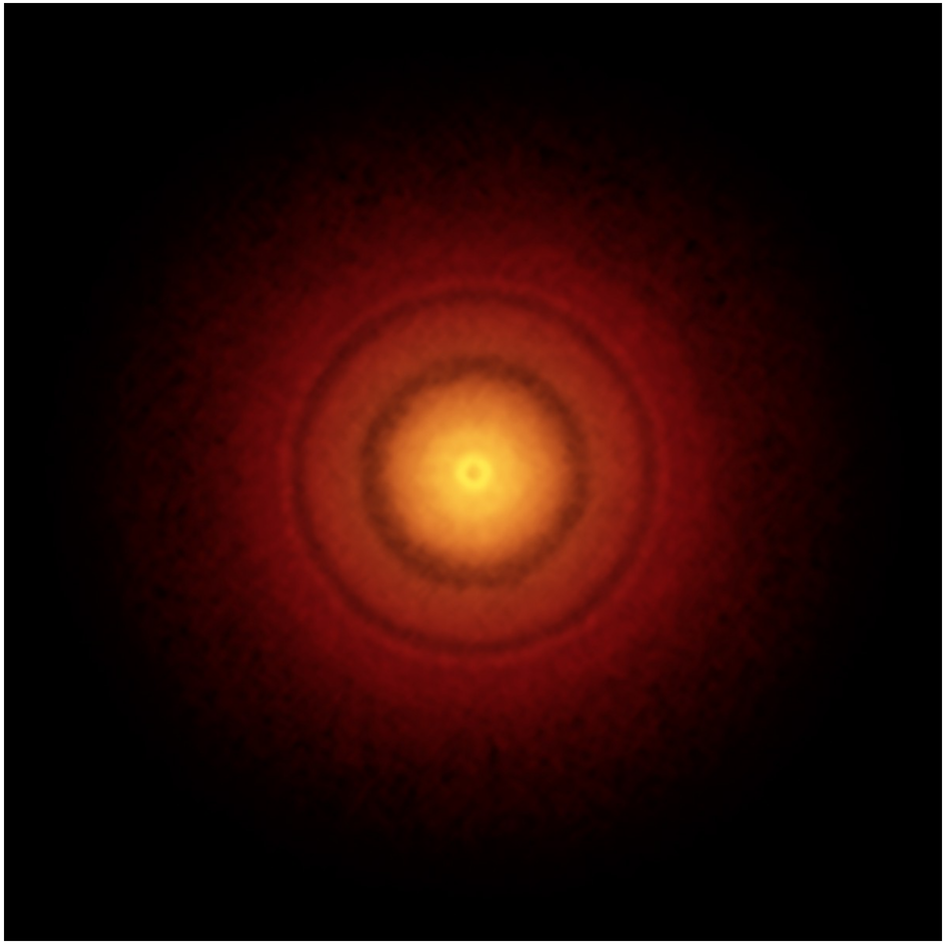
www.maths.qmul.ac.uk/~masset/moviesmpegs.html

ALMA mm-wave image of protoplanetary disk



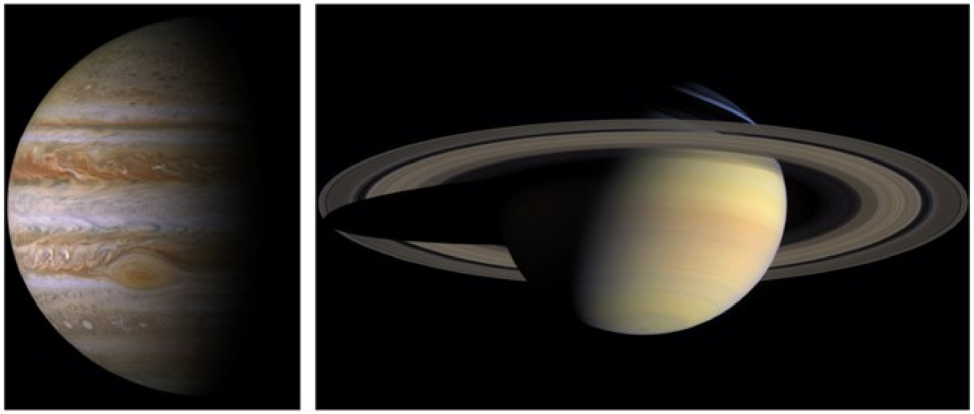
Explanation: Why does this giant disk have gaps? The exciting and probable answer is: planets. A mystery is how planets massive enough to create these gaps formed so quickly, since the HL Tauri star system is only about one million years old. The picture on which the gaps were discovered was taken with the new Atacama Large Millimeter Array (ALMA) of telescopes in Chile. ALMA imaged the protoplanetary disk, which spans about 1,500 light-minutes across, in unprecedented detail, resolving features as small as 40 light minutes. The low energy light used byALMA was also able to peer through an intervening haze of gas and dust. The HL Tauri system lies about 450 light years from Earth. Studying HL Tauri will likely give insight into how our own Solar System formed and evolved.

ALMA mm-wave image of protoplanetary disk



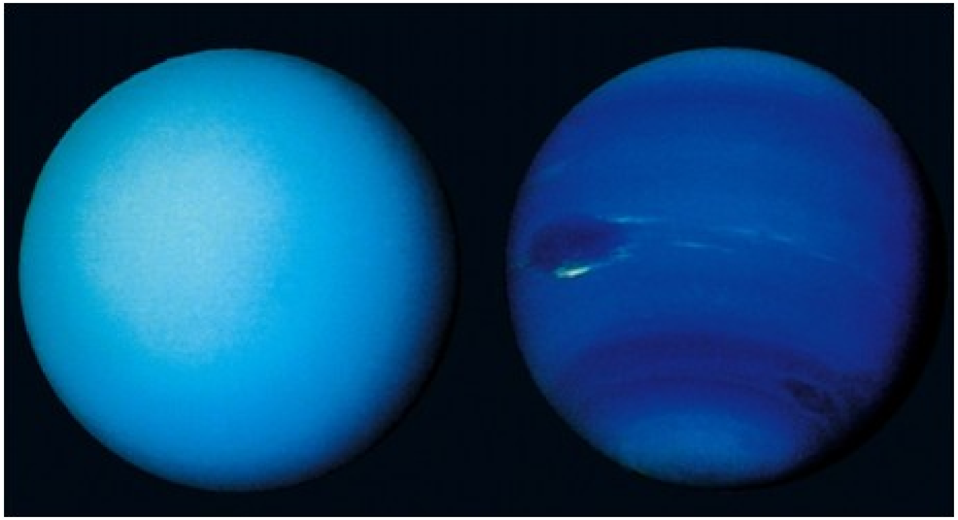
The star, TW Hydrae, is a popular target of study for astronomers because of its proximity to Earth (approximately 175 light-years away) and its status as a veritable newborn (about 10 million years old). It also has a face-on orientation as seen from Earth. This affords astronomers a rare, undistorted view of the complete disk.

- This leads to formation of the massive gas giants Jupiter and Saturn



Chapter 12 Opener
Universe, Ninth Edition

- Further out there is less gas available and here the ice giants Uranus and Neptune formed



Small Bodies

- Jupiter cleared most of the rocky planetesimals near it leaving the asteroids
- Icy planetesimals outside the Jovian planets were scattered outwards to form the Kuiper Belt
- Planetesimals that closely encountered the Jovian planets were flung out into the Oort cloud

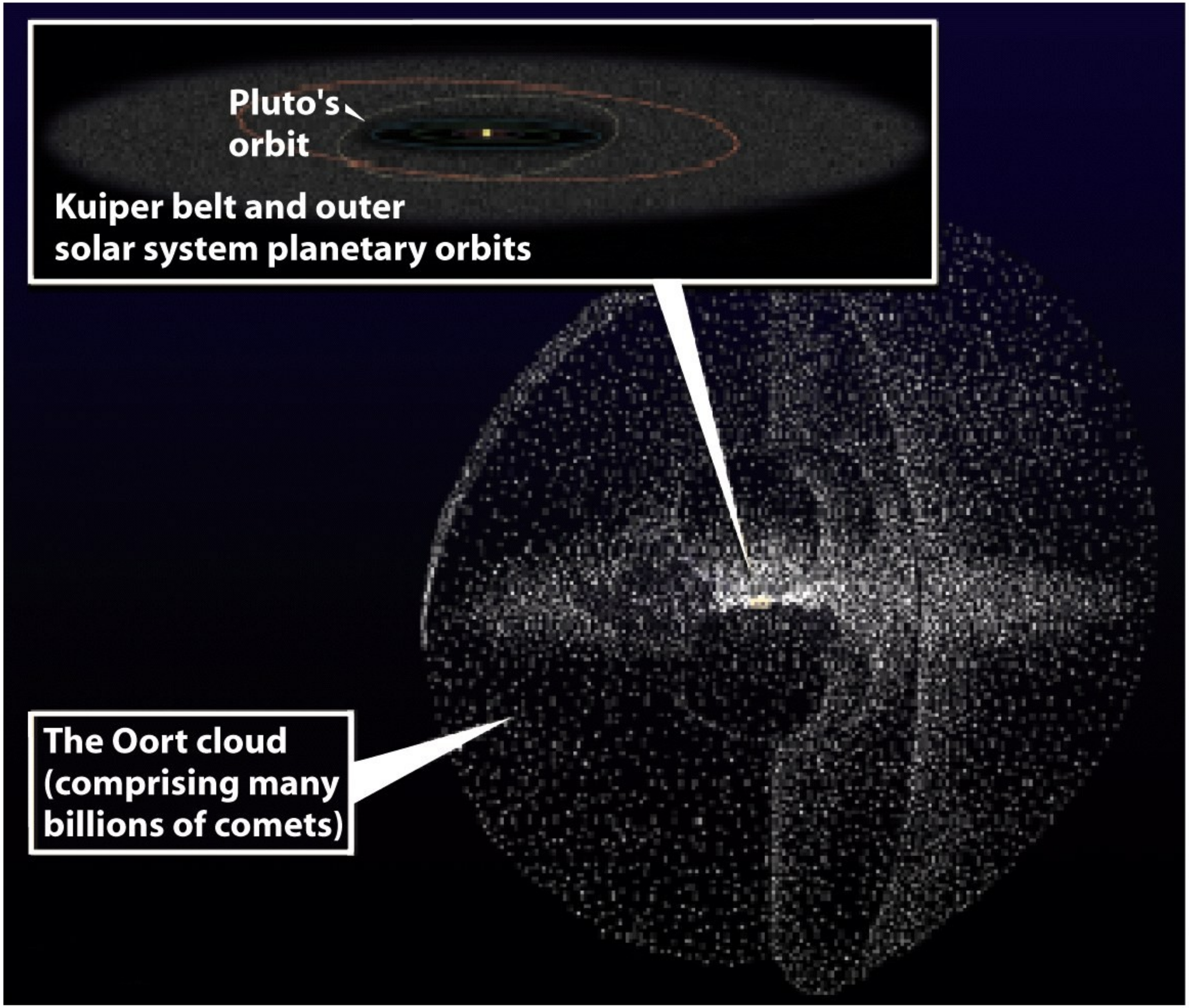


Figure 15-27
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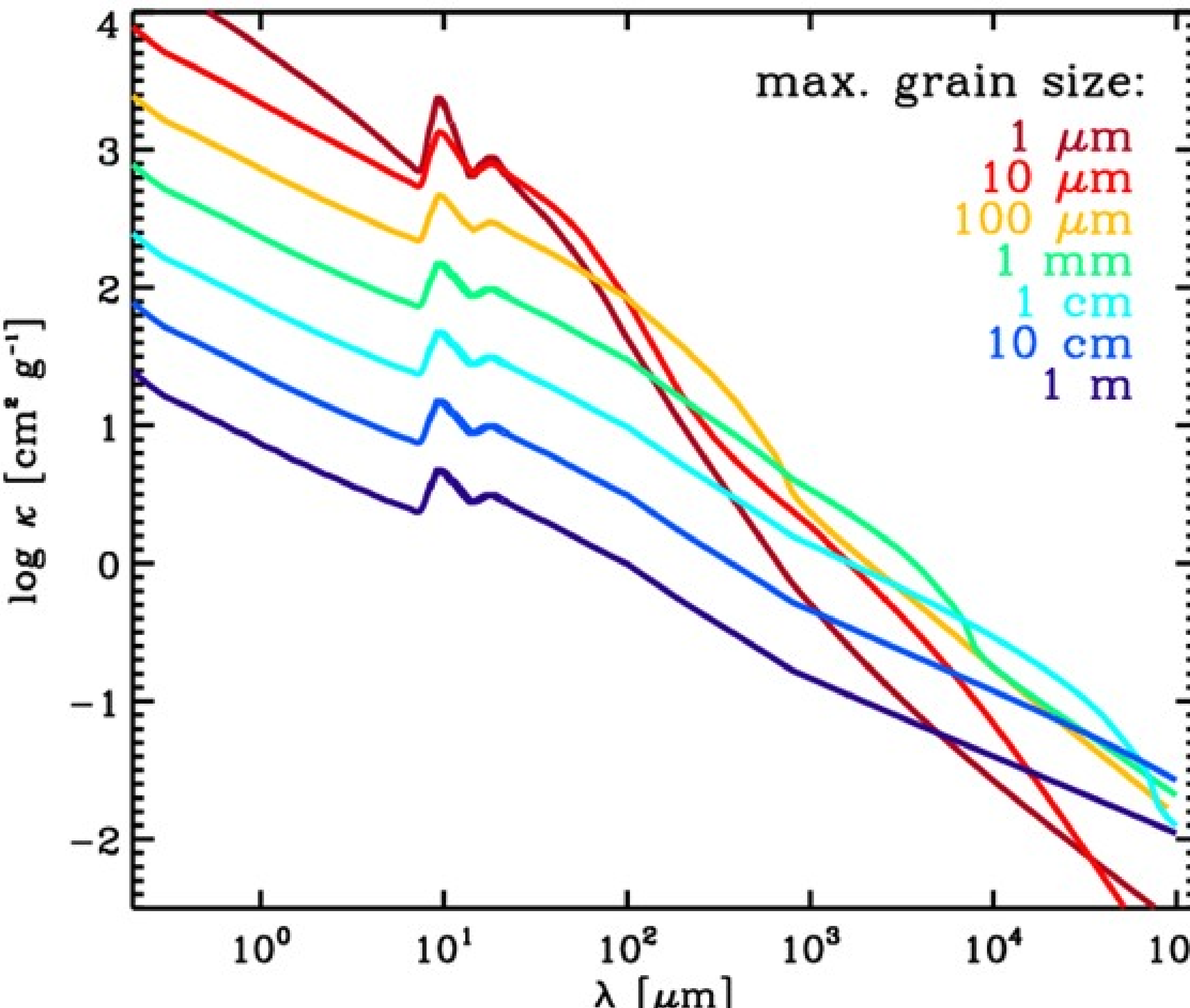
Summary

- Planet formation in a disc is a natural by-product of star formation
- Dust grains enable molecular clouds to cool and collapse and planets to form
- The main features of the solar system are explained by the core accretion model
- Rocky planets form inside the snow line
- Jovian planets form outside the snow line

END


max. grain size:
1 μm
10 μm
100 μm
1 mm
1 cm
10 cm
1 m
log κ [cm² g⁻¹]
λ [μm]
4
3
2
1
0
−1
−2
10^0
10^1
10^2
10^3
10^4
10^5