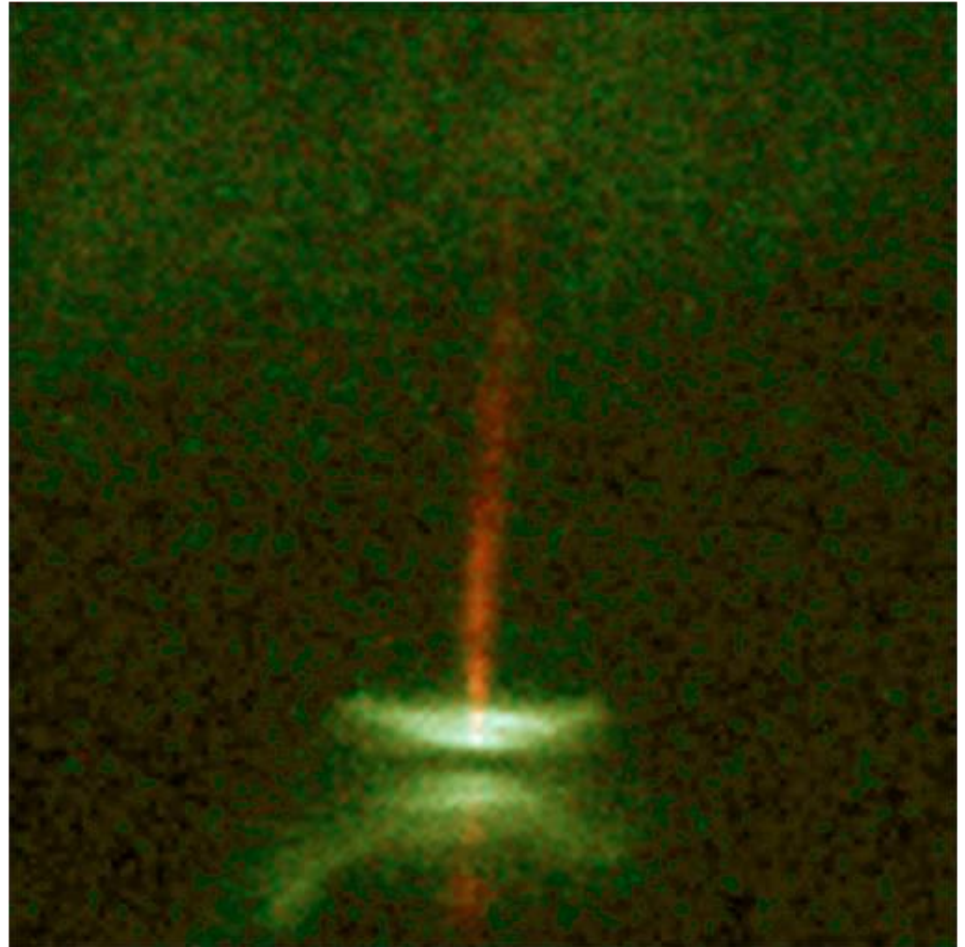


# Planet Formation

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

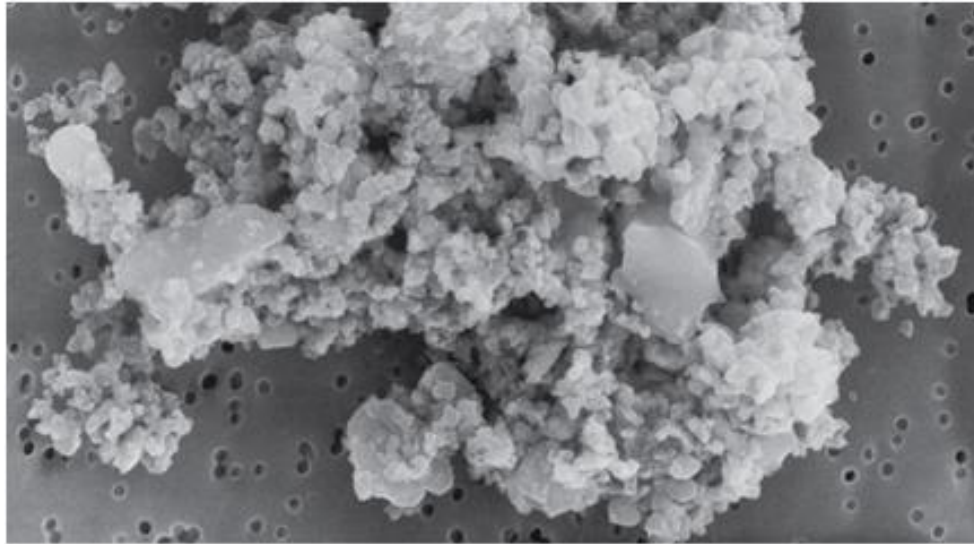
# Proto-planetary discs

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



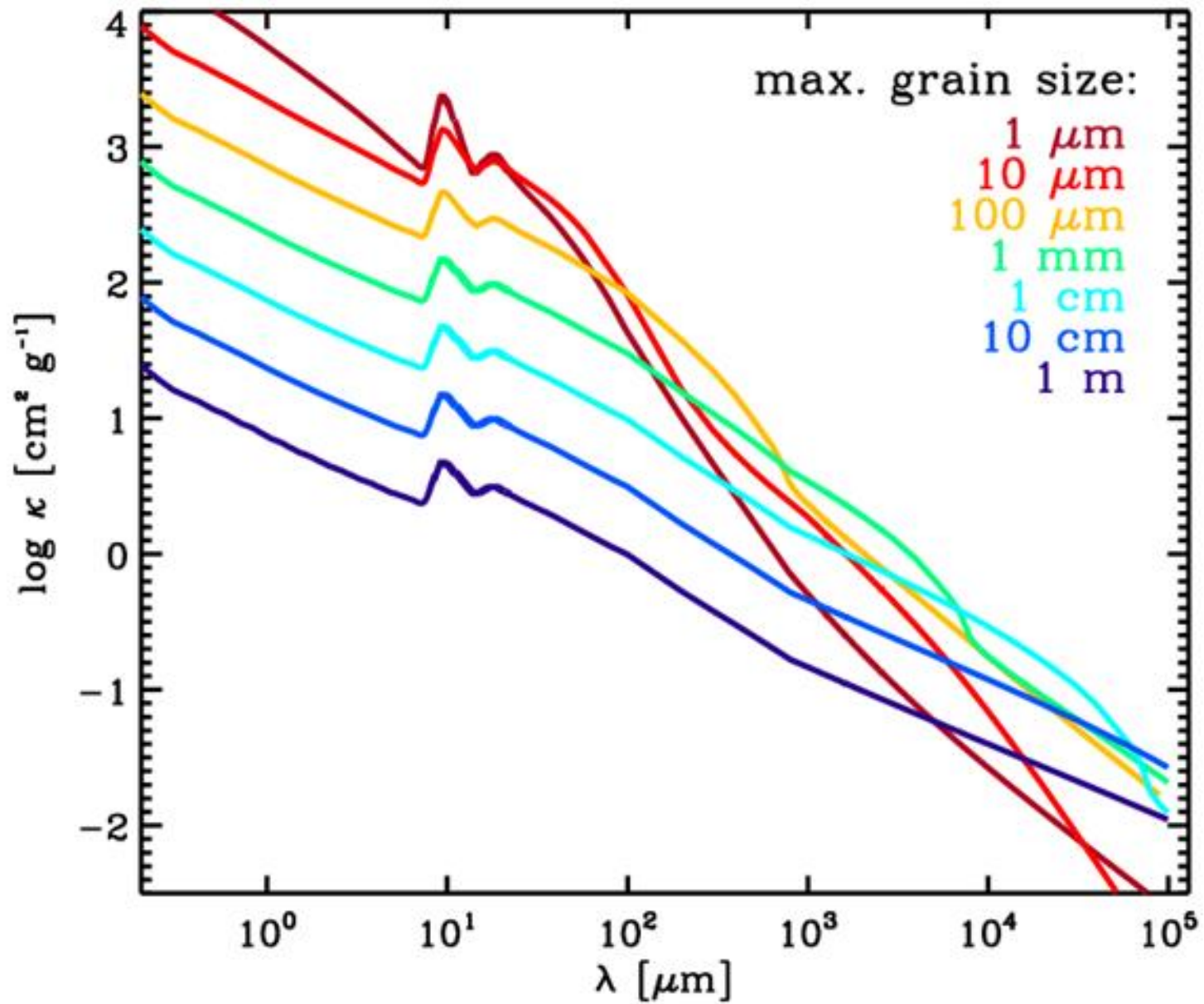
# Grain Growth

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



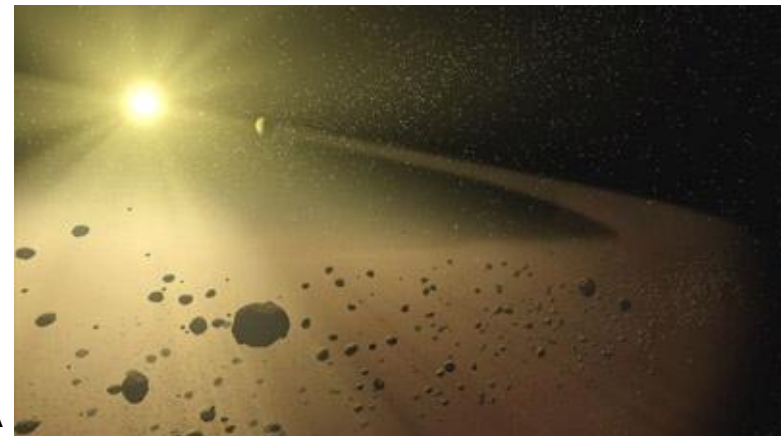
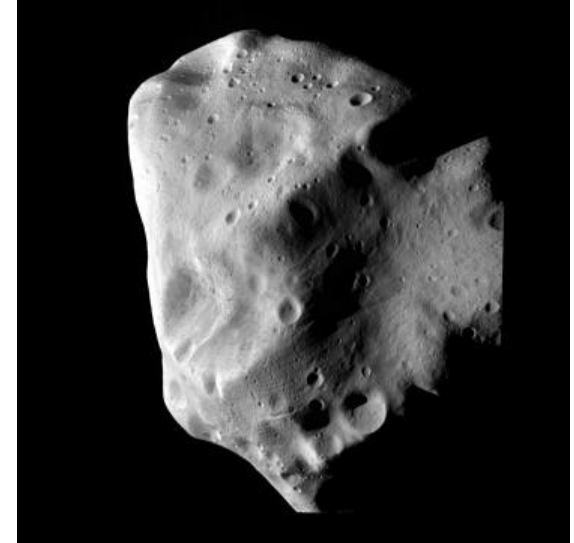
10  $\mu\text{m}$  = 0.01 mm

Interplanetary dust grain  
Brownlee, U. Washington



# Planetesimals

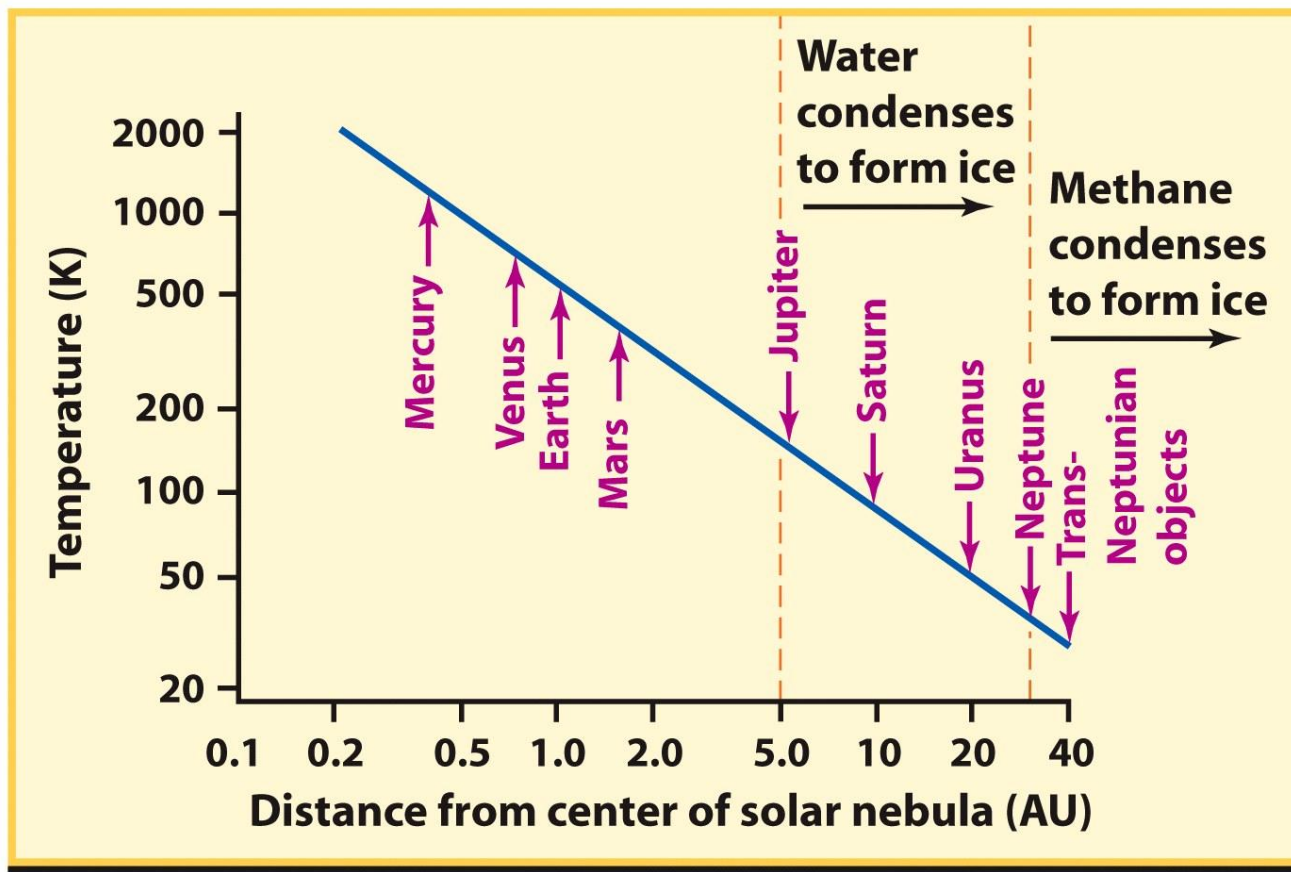
- Over a few million years these grains grow from a few microns to about a kilometre in size
- These are called planetesimals and are similar to asteroids
- Held together by gravity



# 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)

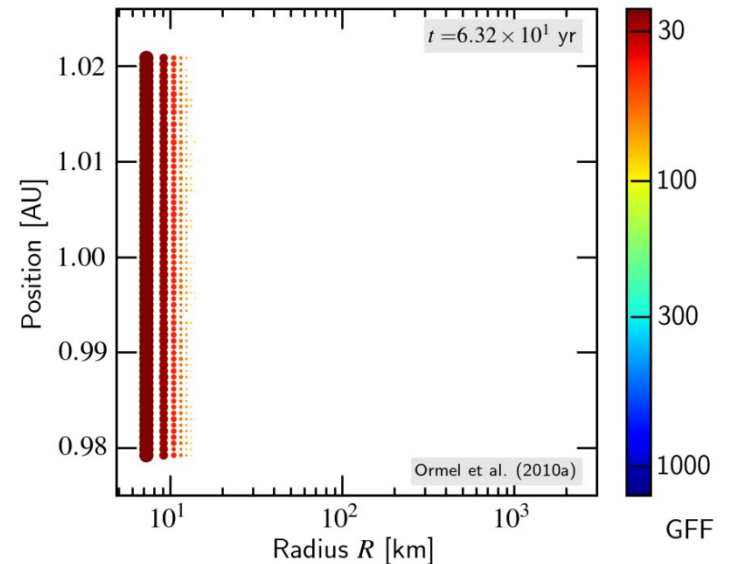


# Proto-Planets

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



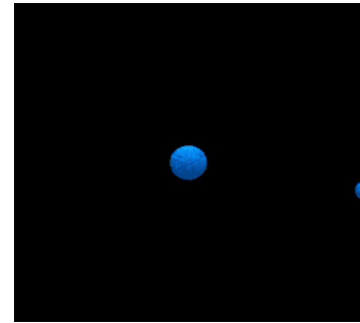
Vesta, Pallas and Ceres  
[sciencewise.anu.edu.au](http://sciencewise.anu.edu.au)



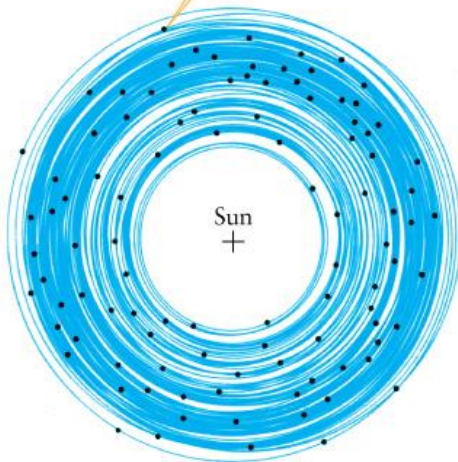
Ormel et al. (2010)

# Terrestrial Planets

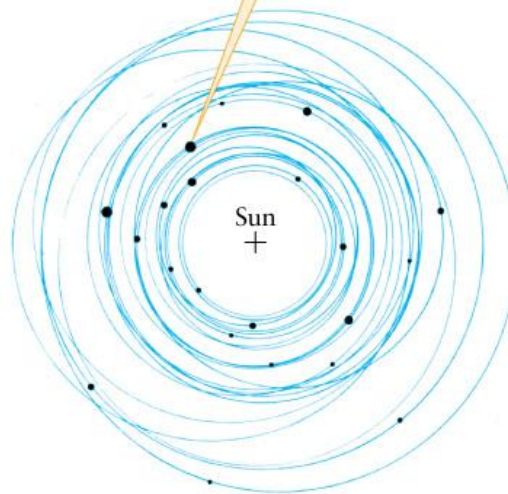
- Collisions & interactions continue until the neighbourhood of the largest bodies are cleared, i.e. a planet



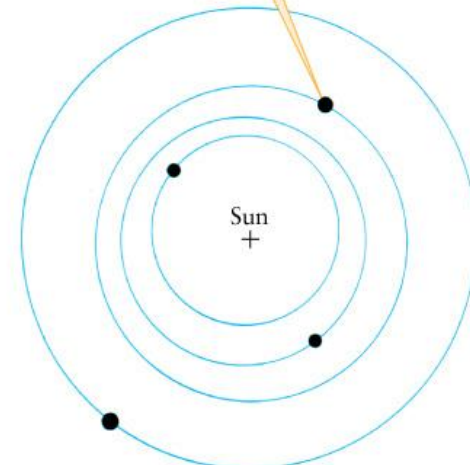
The computer simulation begins with 100 planetesimals orbiting the Sun.



After 30 million years, the 100 have coalesced into 22 planetesimals...



...and after a total elapsed time of 441 million years, four planets remain.



(a)

(b)

(c)

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



**Mercury**



**Venus**



**Earth**

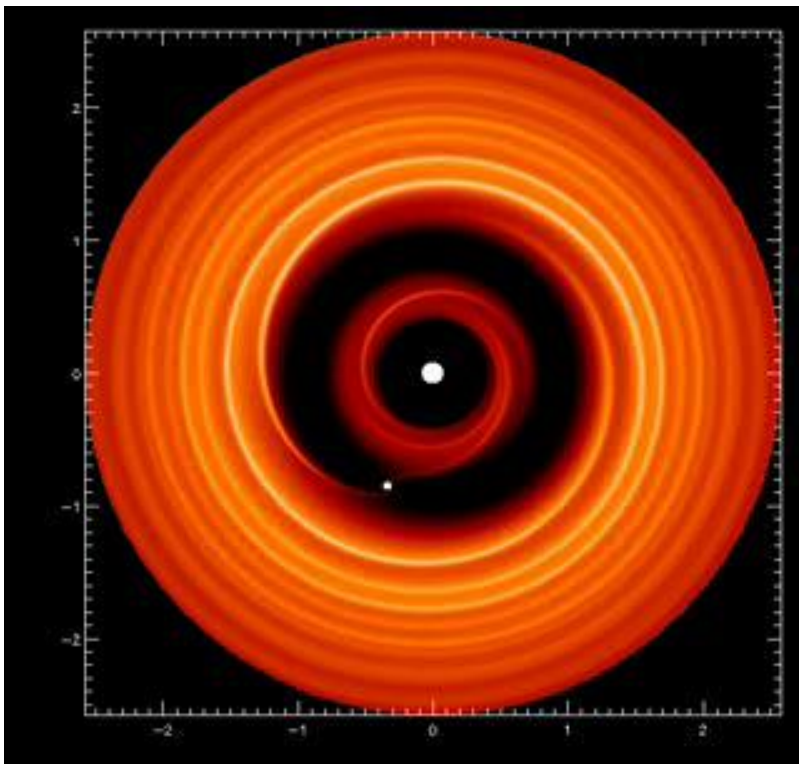


**Mars**

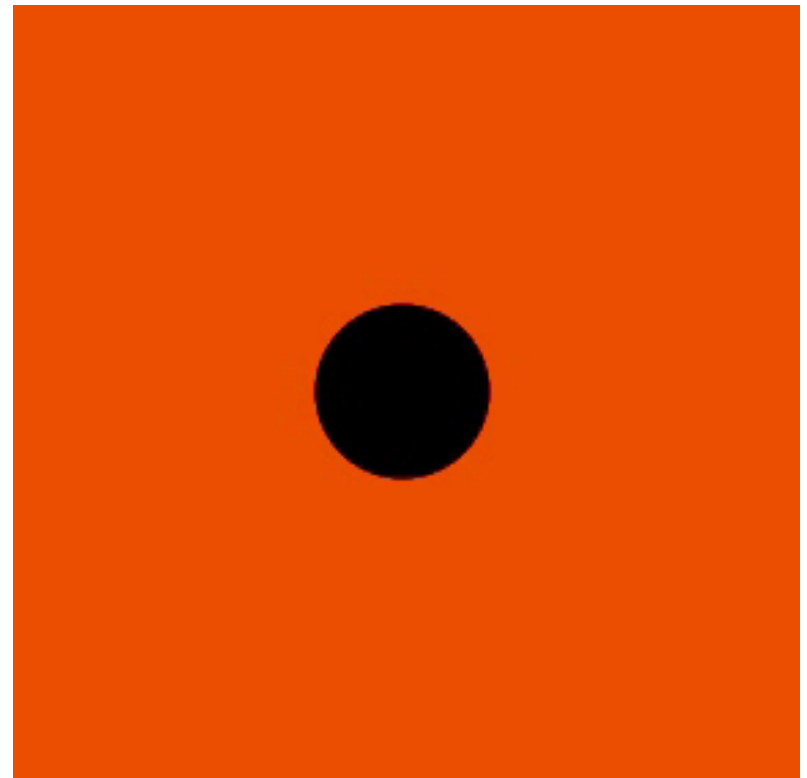
# Jovian Planets

- 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

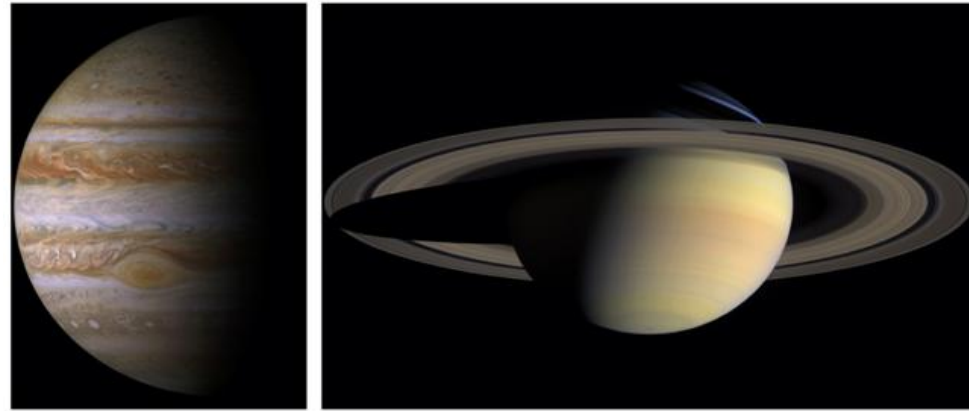


[www.maths.qmul.ac.uk/~rpn/projects/mhd/](http://www.maths.qmul.ac.uk/~rpn/projects/mhd/)



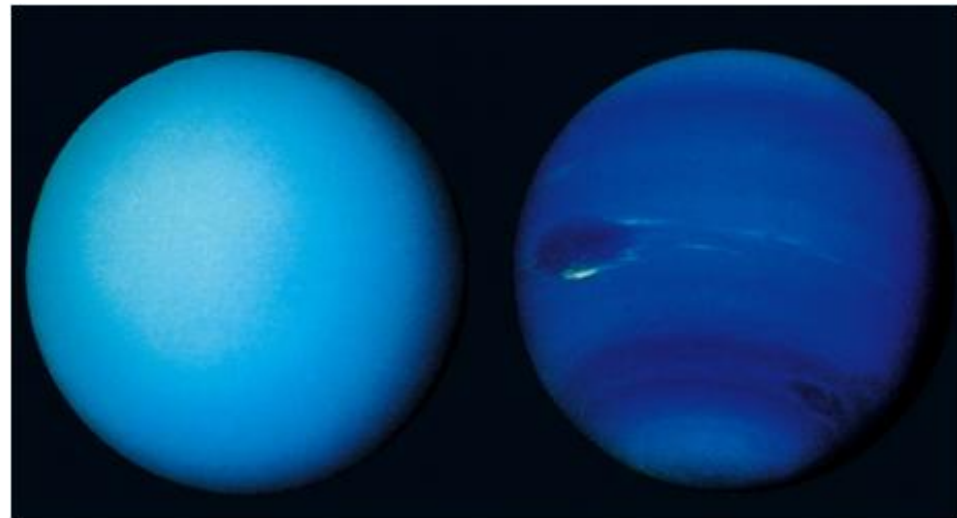
[www.maths.qmul.ac.uk/~masset/moviesmpegs.html](http://www.maths.qmul.ac.uk/~masset/moviesmpegs.html)

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



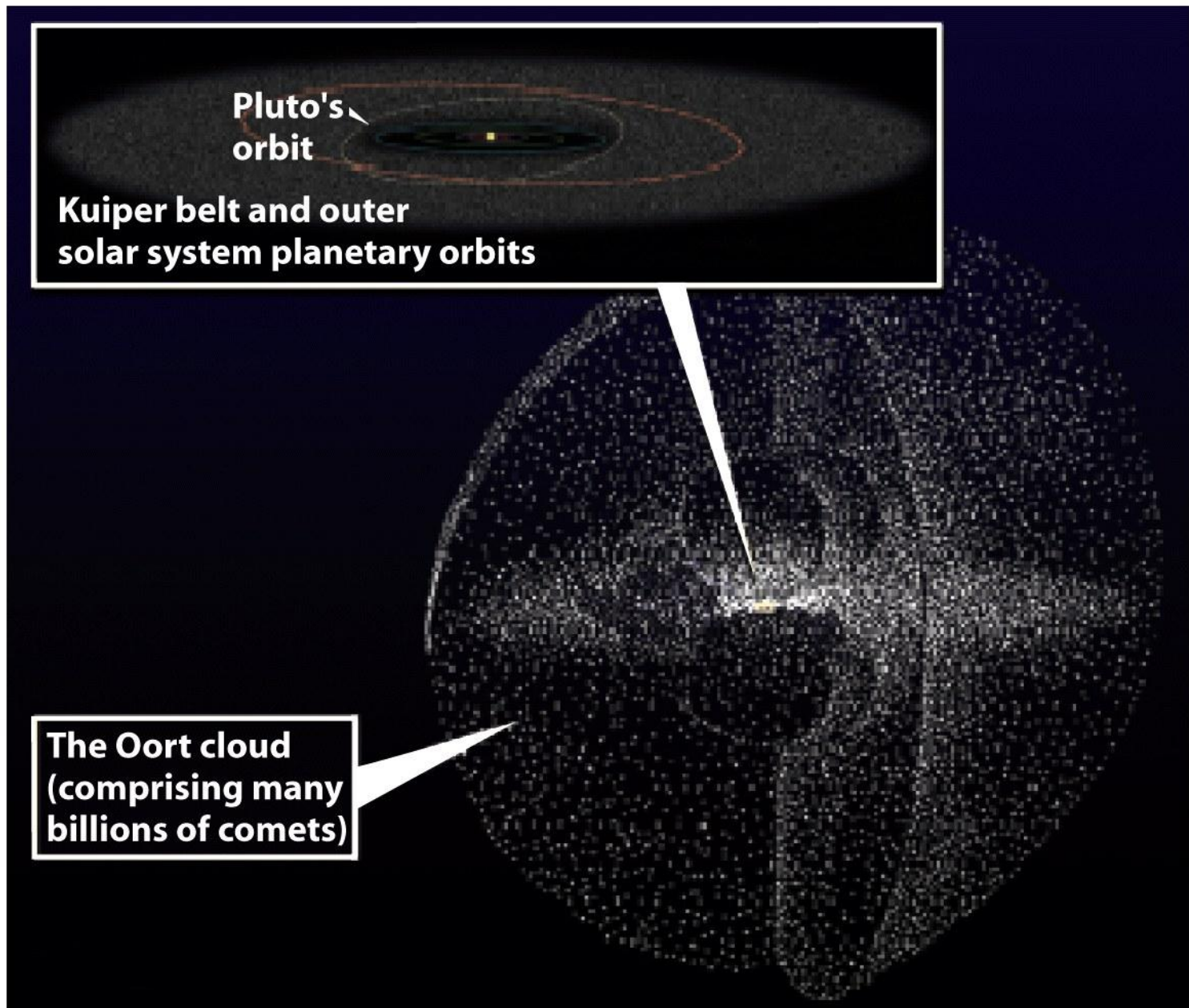
Chapter 12 Opener  
Universe, Ninth Edition  
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- Further out there is less gas available and here the ice giants Uranus and Neptune formed



# 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**  
*Universe, Ninth Edition*  
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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