Constructing the Solar System: A Smashing Success!

Lecture 4: Building the Planets

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1 Introduction

So far in the lecture series, we have seen how a cloud of gas and dust led to the birth of the Sun, and the evolution of the Solar Nebula, a spinning disk of gas and dust around the young Sun. We have seen how the dust particles collided and stuck together, leading to the growth of planetesimals, up to around 100 km in size. Today, we will examine how those planetesimals grew further — into planet sized objects.

2 The Terrestrial Planets

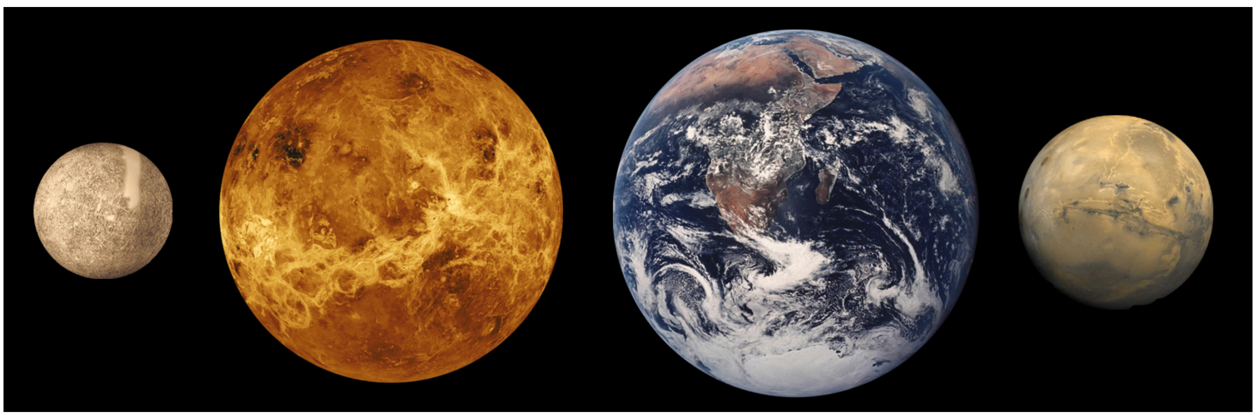

Figure 1: The terrestrial planets (Mercury, Venus, Earth and Mars) are small, dense rocky worlds which orbit close to the Sun. Image courtesy of NASA.

The terrestrial planets (Mercury, Venus, Earth and Mars) all formed near to the Sun. Their growth was the result of pairwise collisions between planetesimals. Gravitational focusing of smaller planetesimals onto the surface of the larger planetary embryos led to the growth of the few terrestrial planets. Computer models (*N-body simulations*) have been able to reproduce the formation of 3–4 rocky planets on stable orbits in the region of 0.5–2 AU, matching the current locations of the inner planets.

3 The Gas and Ice Giants

The outer planets, including the gas giants (Jupiter and Saturn) and the ice giants (Uranus and Neptune) are very different physically when compared with the terrestrial planets. They have radii between 4 and 11 times larger than the Earth, and densities of 3–8 times lower that of the Earth. Why are they so much larger and less dense than the terrestrial planets?

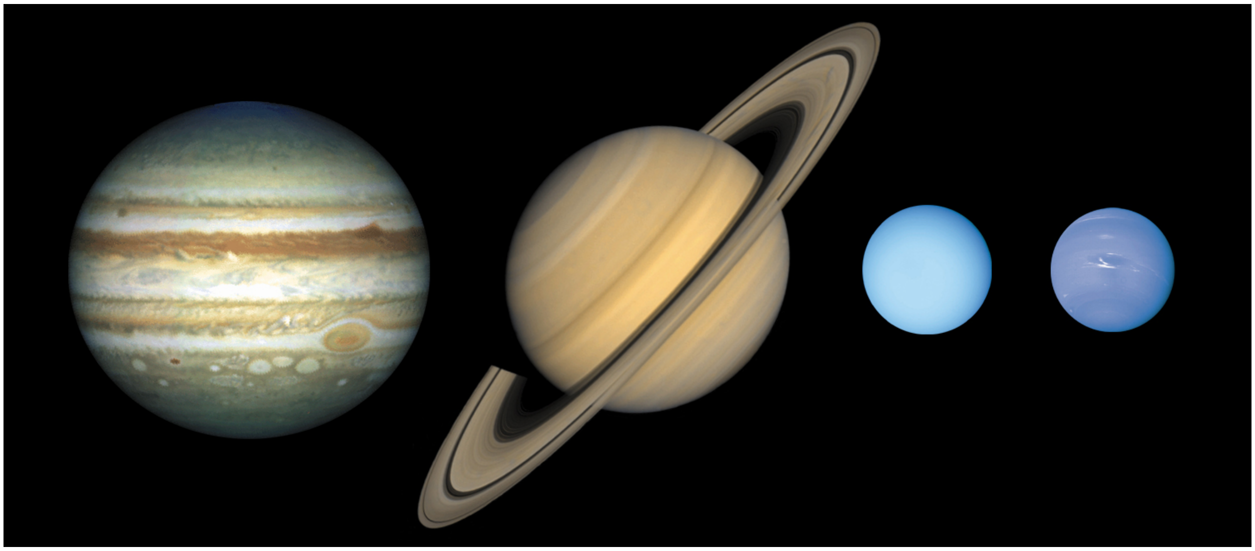

Figure 2: The gas giants (Jupiter and Saturn) and the Ice Giants (Uranus and Neptune) are much larger and much less dense than the terrestrial planets. Image courtesy of NASA.

The formation mechanism of the outer planets differs slightly to that of the inner planets, which leads to the differences between the inner and outer planets:

- The outer planets formed much further from the Sun (beyond the *snowline*)
- Temperatures were lower in that region, so ices (e.g. water, ammonia, etc.) were able to condense much more readily
- Extra solid material available at these greater orbital distances meant more collisions between small objects could take place — leading to more rapid growth of planetary embryos
- Once a solid *core* had formed, the embryo was able to sustain a gas envelope (atmosphere)
- The core grew as planetesimals impacted its surface; the increased gravity was able to attract more gas into the atmosphere
- Once the gas became more massive than the core, a period of runaway growth was entered; a large amount of gas was quickly accumulated, leading to the gas giants we see today

4 Open questions

While this model of planet formation seems to explain many of our observations of the Solar System, some open questions still remain, for example:

- How could Uranus and Neptune form so quickly in their current locations?
- Why do the gas giants all have non-trivial orbital eccentricities and inclinations?
- How did Pluto and the dwarf planets form in the Kuiper Belt (beyond the orbit of Neptune)?
- Why is Mars so small (one might expect it to be at least as large as the Earth)?

Computer models of the dynamical evolution of the orbits of the gas giants have provided some possible answers to some of these questions, and we will take a look at some of the most recent developments, such as the *Nice Model* and the *Grand Tack* scenario.

5 Next lecture

Next week we will start to look in detail the role of impacts on the evolution of planetesimals.