76th Arthur H. Compton Lecture Series

Constructing the Solar System: A Smashing Success!

Lecture 2: Making Planetesimals — The building blocks of planets

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1 Introduction

Last week, we learnt how the Sun formed from the nebula, leading to a spinning disk of gas and dust surrounding our young Sun. This week, we will look at how that disk of gas and dust evolved through time, resulting in the growth of solid bodies, up to the size of planetesimals. Planetesimals are small rocky objects that orbited the Sun in the early Solar System, which we define as a solid object that:

- formed during the accumulation of planets
- has an internal strength that is dominated by self-gravity
- was not affected by gas drag
- is larger than approximately 1 km

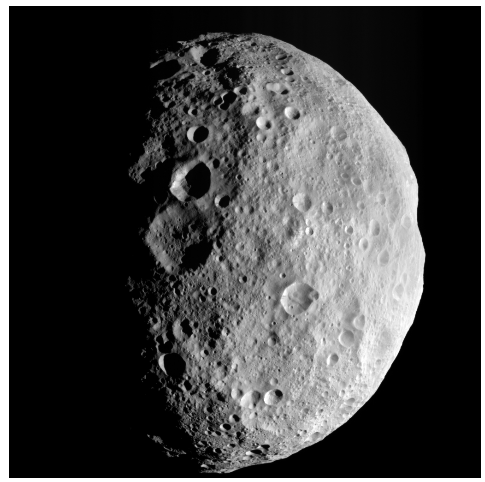

Figure 1: Asteroid 4 Vesta — a surviving planetesimal? Image courtesy of NASA/JPL-Caltech/UCLA/MPS/DLR/IDA

2 The first solid objects

The physics of the solar nebula meant that most of the material surrounding the young Sun settled to a thin disk. As the density of this disk increased, low velocity collisions between the dust particles would have led to growth of larger objects. Velocities must have been low to allow the colliding particles to stick together rather than smash each other apart—this resulted in the growth of porous objects, up to around a meter in size.

3 Further growth impeded by the meter-sized barrier

This collisional mechanism for growth could only have continued up to around a meter in size:

- The gas in the disk would have orbited the Sun slightly slower than the velocity predicted by Kepler because of a pressure gradient
- Particles smaller than a meter would have been swept along with the slow moving gas
- Objects of around a meter in size would have been too large to be entrained in the gas
- As they moved through the gas, they would have experienced a headwind, slowing them down
- If this continued unchecked, meter-sized objects would have spiralled into the Sun within a few hundred years!

4 Planetesimals formed rapidly

Several theories describe possible mechanisms of how objects broke the meter-sized barrier, but none have reached a full consensus yet. One possible explanation requires an overdensity in the disk, allowing for gravitational collapse to form a planetesimal. Whatever the mechanism, the growth of planetesimals must have been rapid, and is likely to have formed a swarm of porous planetesimals of sizes up to 100 km. This may have taken just a few thousand years.

5 Growth into protoplanets

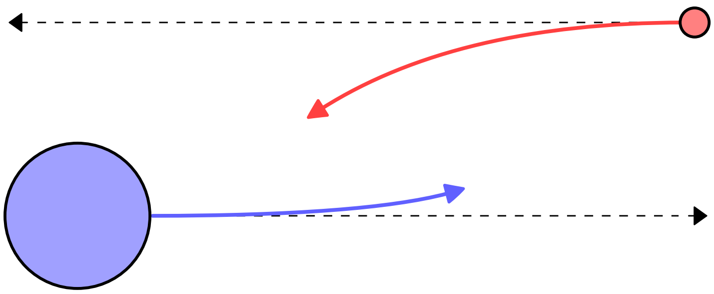

Figure 2: Gravitational focusing of planetesimals. Large protoplanets could focus the paths of smaller bodies, increasing the number of collisions they experienced, and thus speeding their growth.

Planetesimal sizes increased during a period of collisional growth.

- As some bodies grew larger than others, they were able to attract the local population of smaller planetesimals using gravitational focusing (Figure 2)
- Larger planetesimals grew more rapidly than smaller ones in a phase we call *runaway growth*
- This phase resulted in a bimodal population, with some large bodies that we call protoplanets, and a swarm of smaller planetesimals
- Once the local neighborhood of planetesimals was used up, growth slowed down as collisions became less frequent
- *Oligarchic growth* allowed protoplanets to attract bodies from outside their feeding zone—the growth during this period was less rapid than during runaway growth.
- The result of the oligarchic growth phase was the formation of planetary embryos—these bodies were the final stage before the formation of the planets

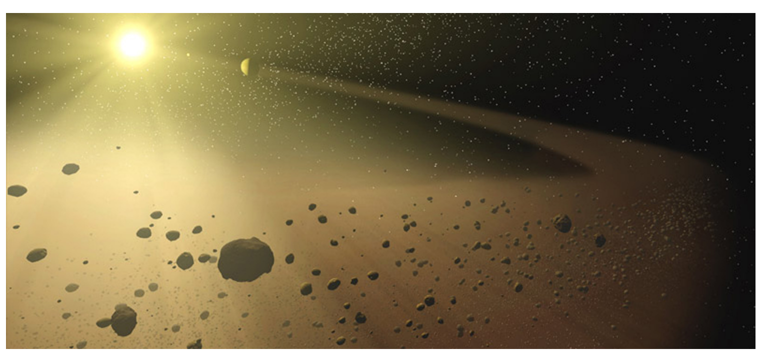

Figure 3: A swarm of solid bodies known as planetesimals would have orbited the young Sun. Collisions between these bodies led to the growth of planetary embryos—bodies capbable of going on to form planets. Image courtesy of NASA/JPL-Caltech

6 Next lecture

In the next lecture, we will discuss how we use asteroids and meteorites to infer details about the conditions of the early Solar System.

Correction: In last weeks handout, the date of the final lecture was given incorrectly as 12/18/12. It should have been 12/15/12.