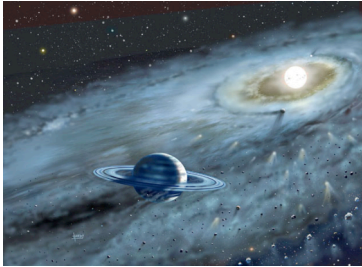


The Formation of the Solar System



How did it get to be this way?

Formation of the solar system

- First question: how long ago did this happen? ←
- Nobel Prize winner Hannes Alfvén: “the study of the origin of the solar system is archaeology, not physics”.
- Second question: what is the principal object in the solar system?
- The answer to the second question explains the title to the chapter in the book which covers this topic, chapter 18

An important way in which Alfvén's statement is wrong



Star formation, and planet formation, are going on **right now** at other places in our Galaxy. Some of these new star systems are relatively close

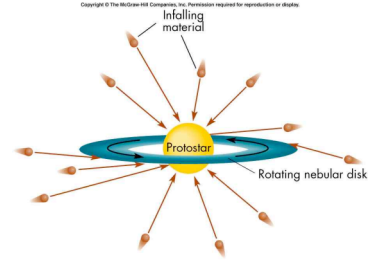
The Orion Nebula...a stellar nursery



Our understanding of stars, and star formation, means that the solar system began as a huge cloud of (mainly) hydrogen and helium collapsing under its own gravity. Most of this matter went into the Sun. Some tiny part of it ended up as the rest of the solar system.

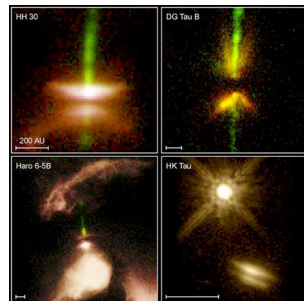
Leads to the concept of the **solar nebula** for the cloud of matter that surrounded the "proto-Sun"

The cloud would have been rotating (even a little bit). This means the inflowing material would have formed an accretion disk in the plane of the Sun's equator

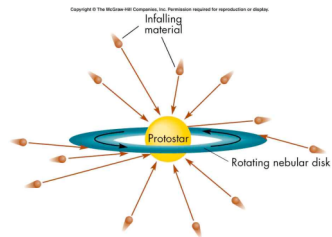


With today's astronomical instrumentation, we can see this in young star systems called Herbig-Haro objects

What do these disks remind you of in the solar system?



The idea of an accretion disk in the solar nebula 4.6 billion years ago, from which the planets formed, is consistent with the observation that all of the planets revolve in the same direction, that of the rotation of the Sun



How do we account for one of the most basic properties of the solar system; the difference between the Terrestrial and Jovian planets?

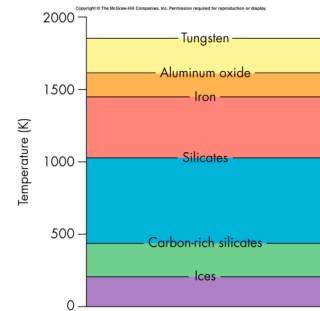
We think this is a consequence of different temperatures in different parts of the solar nebula

"the solar nebula was heated by release of gravitational energy...it was hottest near its center, where temperatures may be been 2000K..."

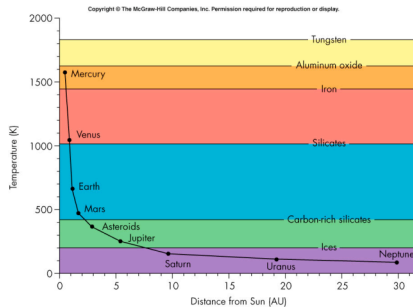
Consider what substances would have condensed out of the solar nebula at different temperatures

Condensed out -> going from vapor state to small pieces of solid matter

Small particles called "dust"



Now consider what we think the temperatures were at different parts of the solar nebula



There appears to be a connection between the types of materials which were condensing (precipitating) in the solar nebula, and what sort of planets formed there

At the position of the Earth, only silicates and other more "refractory" substances would have precipitated from the vapor state. At Jupiter and beyond, ices of water, ammonia, methane, would have condensed.

The idea of **planetesimals** and the origin of the solar system

Everywhere in the solar nebula, tiny pieces of matter started condensing from the gas



At different places in the solar nebula, these "little bits of grit" were different compounds



Eventually, these planetesimals collected into objects the size of planets. Gravity got into the act when the planetesimals got big



These small pieces of matter stuck to others, making larger sized blocks (the planetesimals)

An artist's conception of the early solar nebula



Artist is William K. Hartmann, solar system astronomer

The different compositions of the major planets

- At the location of the terrestrial planets, there was not much mass in the planetesimals, since they were formed of non-abundant elements
- In the outer solar system, there was more mass in the planetesimals, since they were formed of hydrogen-bearing compounds. Apparently, they produced more massive planetesimals. They also had to incorporate the hydrogen and helium gas that makes up most of Jupiter and Saturn. See Figure 18.19

A question of timing in planetary formation

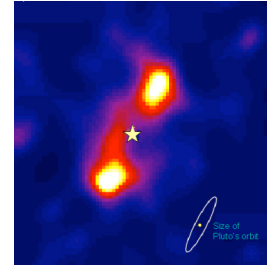
- As the star system forms, the protoplanetary nebula has to cool enough for dust formation to start
- Planetesimal formation and growth then can begin
- A planetary system does not have unlimited time. As the young star develops, it produces a strong stellar wind that would carry away into space the dust that has not formed into large planetesimals

A test of these ideas

When small particles condense, they are heated by the starlight, and radiate in the infrared. A star at the beginning of the planetesimal formation process will be bright at infrared wavelengths as well as in visible light

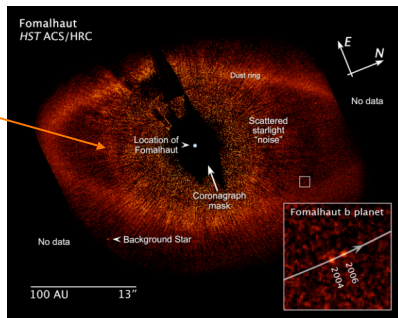
The case of Fomalhaut

- See Appendix 13
- Star about 25 light years away
- Is a young star
- Shows an infrared “ring”

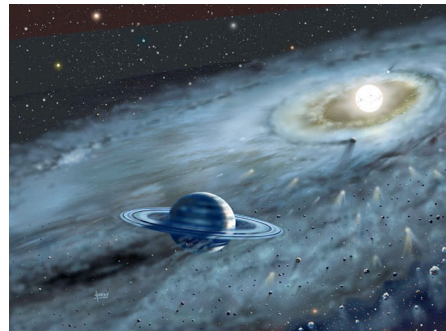


The Hubble Space Telescope image of Fomalhaut

Large planetesimals have probably already formed in here



Fomalhaut... a replica of the early solar system happening right now



A final question: where can we see evidence that the planets “swept up” the planetesimals 4 - 4.5 Gyr ago?

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