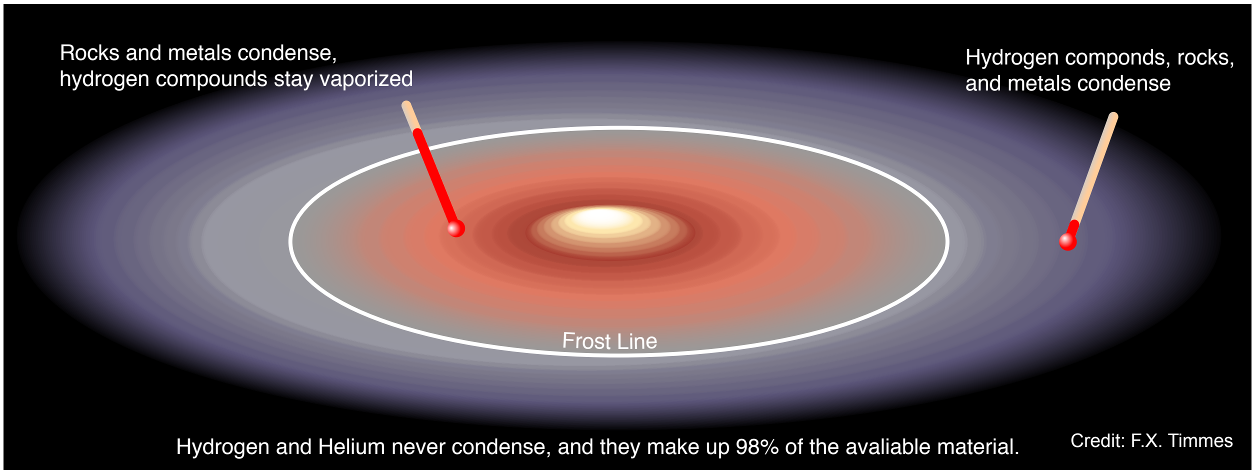
The Sun, with all the planets revolving around it, and depending on it, can still ripen a bunch of grapes as though it had nothing else in the Universe to do.

Galileo Galilei

Frostline

Hi AST 111. In this module we'll explore the second major pattern in our solar system, namely, why there are two classes of planets, terrestrial and Jovian.



So far we've turned our large diffuse cloud into flattened, rotating disk - which explains the orderly direction of the orbits and generally the direction of rotation of the planets.

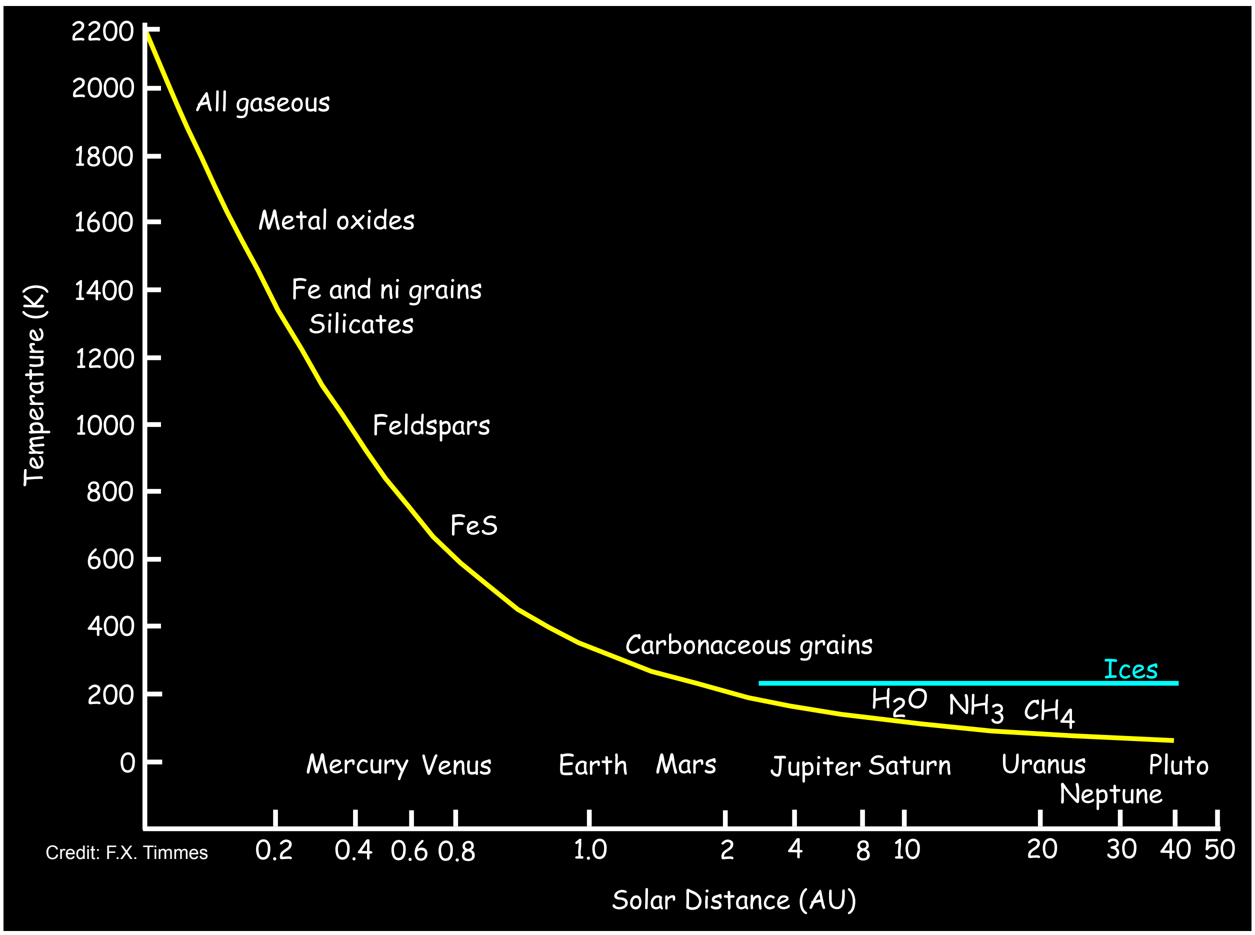
Within that disk, it's hotter in the middle. That's where the protosun is. That's the region where gravity is causing material to go, causing more collisions and more heating. It gets cooler as you go from the central regions to the outside regions of the disk.

	Condensation Temperature	Abundance
H, He gas	never	98%
H compounds	< 150 K	1.4%
Rock	500 - 1300 K	0.4%
Metal	1000 - 1600 K	0.2%

The formation of a solid from a liquid or gas is known as condensation. But the pressures in space are so low that liquid drops rarely form. Instead, snowflakes form directly from the gas and dust. In our atmosphere we can also go directly from a gaseous state into a solid state, such as the formation of a water snowflake. Water condenses at around 32 °F or °0 C or 273 K. Other materials condense at different temperatures.

The table above shows hydrogen and helium never condense. Hydrogen compounds condense, like methane snowflakes, around 150 K. Silicates, basically rocks, form snowflakes between 500 K - 1300 K depending on the type of rock. Metal snowflakes, such as iron snowflakes, form between 1000 K - 1600 K depending on the type of metal. So metal flakes will form at higher temperatures than methane flakes.

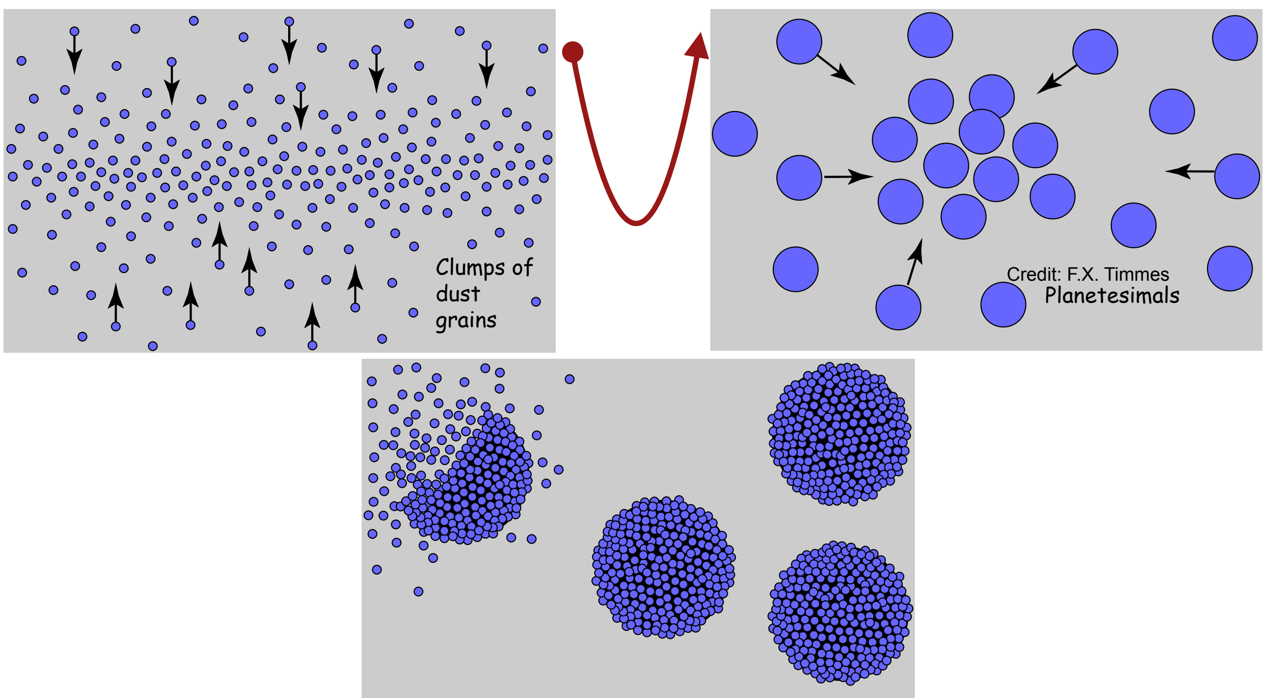
What type of snowflake, what type of planet you will ultimately get, depends on the temperature. Within the frost line, the temperatures were high enough that only metals and rocks could form snowflakes. Beyond the frost line, the cooler temperatures allowed hydrogen compounds snowflakes This idea of a frost line is going to be key to for determining what type of planet, terrestrial or jovian, you're going to form. The temperature of course depends on the distance from the protosun:



The plot above shows the temperature versus distance from the Sun. The curve shows how temperature falls off with distance. Also marked on the curve is the temperature where snowflakes form. What kind of stuff is going to condense at what distance?
Closest in to the Sun, it's too hot to form snowflakes. Its all gas. But as you move away from the protosun you get to cooler temperatures. At the distance of Mercury, metal snowflakes fall out of the gas Out to Mars you get different types of metal and rock snowflakes to fall out of the gas.

Once you go beyond the frost line, around Jupiter and beyond, then you can start getting hydrogen compound snowflakes to fall out of the gas -- water, methane, ammonia.

This idea of the frost line -- and you can see it's a pretty sharp boundary between rocks and hydrogen compounds -- that's going to explain why there are the terrestrial planets inside the frost line, Jovian planets outside the frost line. It's really just a temperature effect.

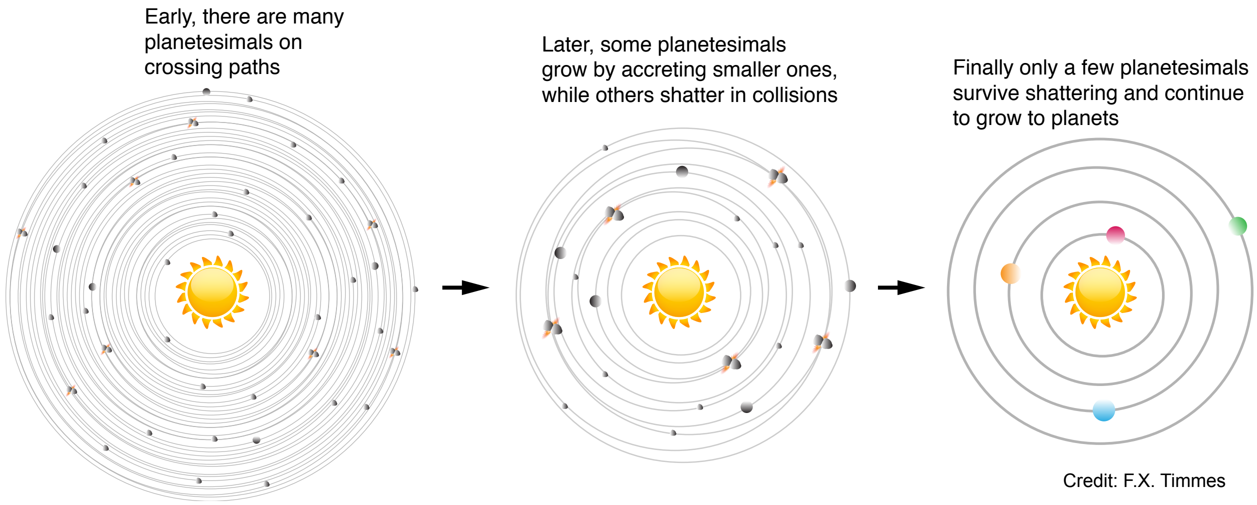


OK we get different snowflakes at different distances. Then what? Well, those snowflakes are going to collide with other snowflakes. Some will stick together.

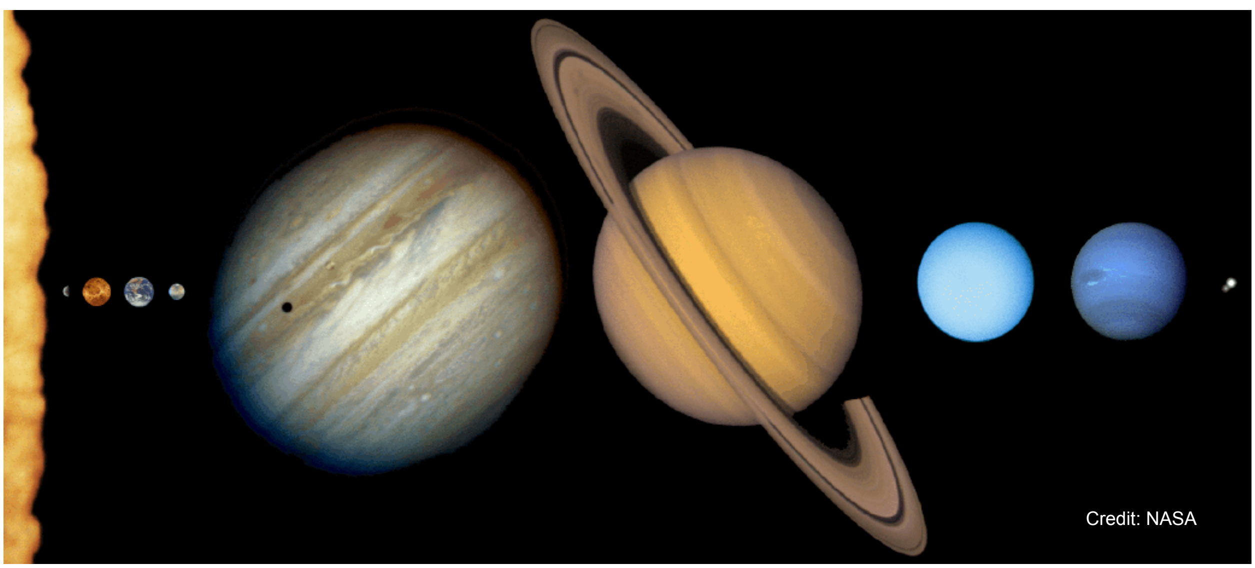
This process of adding material is called accretion. You accrete material onto other material.

Initially the snowflakes stick together not because of gravity but because of electrostatic forces -- basically static electricity. You begin to make snowballs one snowflake at a time! Now that the snowball is a bit bigger, its got a bigger area. So it can start accreting even more snowflakes. Its kind of a runway process - the big get bigger. Eventually the now massive snowballs are big enough to be called planetesimals - little baby planets.

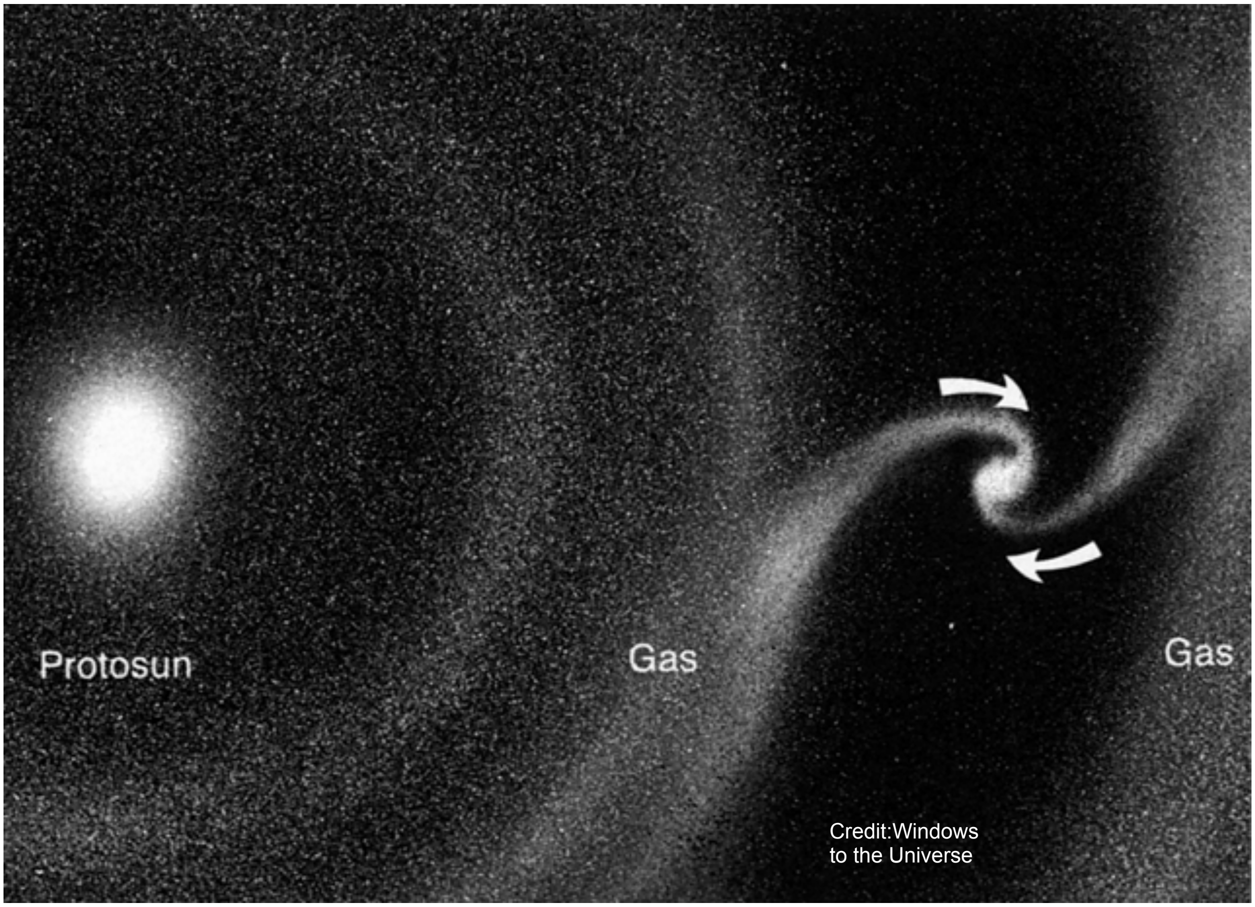
This sequence is illustrated by the image above.



The protonsun, meanwhile is still accreting material and getting hotter on its way to firing its nuclear engines. Let's first focus on inside the frost line By now we have maybe thousands of planetesimals inside what is now the orbit of Mars. And they continue to merge and collide with each other. Except now the collisions and mergers are more violent. Entire worlds can be shattered. Its a wild pinball game as the planetesimals compete for orbits. After a few hundred thousand years our solar system ended up with four survivors. Other solar systems probably end up with a different number of terrestrial planet survivors.



Remember that all the heavier elements - the carbon, the oxygen, the iron - makes up only 2% of the material. Take a look again at the Table on Page 1. Most of these heavier elements, 1.4% have bonded with hydrogen to form hydrogen compounds. Only the remaining 0.6% are in the form of rocks and metals. This means the planetesimals in the inner solar system could not grow very large. There is just not a lot of material. This explains why the terrestrial planets are small relative to the Jovians - because the amount of material from which you could build terrestrial planets out of was just less.

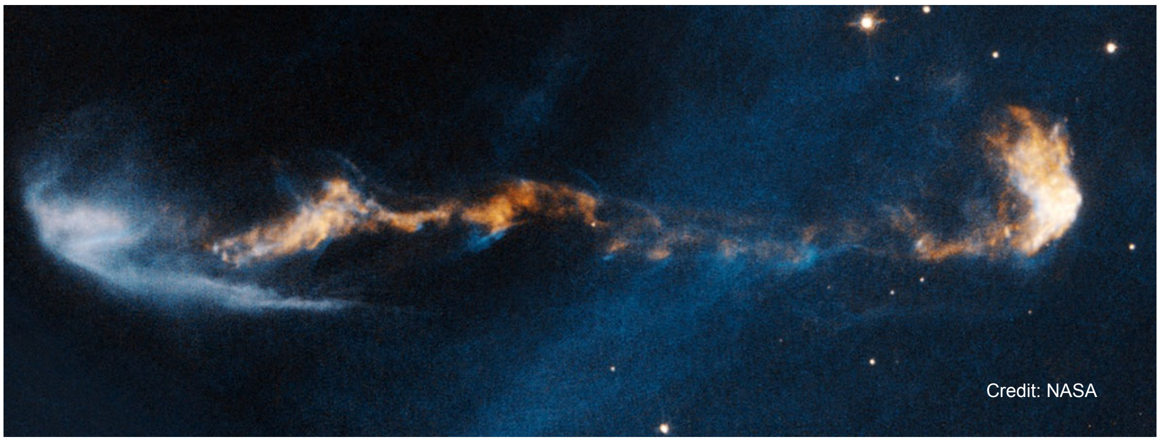


So how did the Jovian planets form? Well, the Jovian planets also formed rock and metal cores, but they were out beyond the frost line. There's a lot more snowflakes of hydrogen compounds out there so they had a lot more material that they could start accreting. Once they start getting above a certain size -- about 200, 400 kilometers or so -- then their gravity starts to act. Then they can start accreting and holding hydrogen and helium gas, thus building the Jovian planets. In some sense -- like the image above shows -- the Jovian planets become like mini solar systems within a solar system because they have enough gravity that they can start taking in the gas that surrounds them.

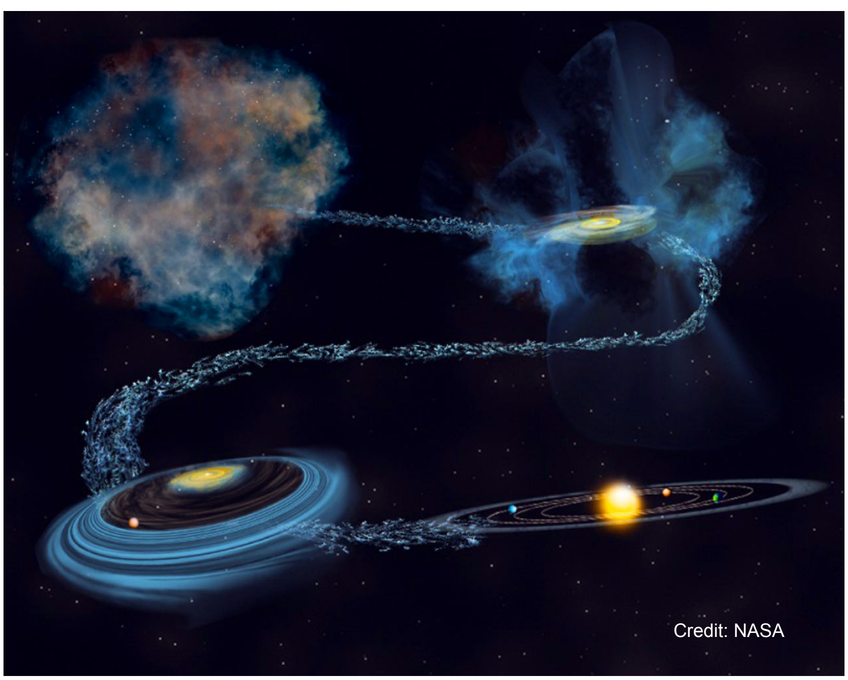
This combination of temperature and accretion explains the general differences between the terrestrial and the Jovian planets.

Planet formation doesn't go on forever. In fact, you've got a relatively small time from when you flatten out the disk because, material is still falling into our protosun. About 10 million years after the cloud collapses, our protosun ignites hydrogen in its core to become a star. And young stars generally send out a very strong solar wind - the pangs of birth if you will. That wind is still with us today. That's what creates the space weather. It's what creates the northern and southern lights. But when the Sun was first born, that wind was a lot stronger. And that wind clears out the loose debris from the solar nebula. About 100,000 after ignition,there's no more snowflakes, there's no more gas from which you can accrete. The era of planet formation ends.

We can see this process strong winds blowing from other young stars, other new solar systems, because stars aren't shy about sending out their birth announcements. The image below is just one example of jets - the long structures going left and right - emanating from the central new born star near the middle. Over timescales of 10-20 years one can make movies showing the dynamics and interactions of such jets. Nifty!



Below is our now familiar illustration of the evolution of the solar nebula. Hopefully this image is making more sense to you. We start with a large, diffuse cloud, collapse it down to a rotating disk, go through the planet formation process we discussed above, and then turning on the Sun to clear out the debris.



Thanks! Bye Bye.