Hi this is Steve Nerlich from Cheap Astronomy www.cheapastro.com and this *How to build a solar system*.

*Planetary systems are thought to form from rotating dust clouds which collapse inwards towards a growing proto-star. Like ice skaters pulling their arms in, the cloud spins faster and its angular momentum reorganises the cloud into a flat accretion disk.*

Most of the rotating dust cloud's contents just provides mass to build the star, but a scant remainder is available to form a protoplanetary disk. However, while planets can obviously form out of a protoplanetary accretion disk, the physics of exactly how it happens remains a bit of a puzzle for astrophysicists.

In the traditional solar nebula model we imagine a rotating protoplanetary disk within which loosely associated objects slowly build up into planetesimals, which then become gravitationally powerful centres of mass, capable of clearing their orbit – and then *hey presto, planet*!

It's generally agreed now that this just can't work since a growing planetesimal, in the process of constantly interacting with protoplanetary disk material, will have its orbit progressively decayed so that it will just spiral inwards, potentially crashing into the Sun unless it can clear an orbit before it has lost too much of its angular momentum to the surrounding protoplanetary disk.

This orbital decay effect probably explains the existence of hot Jupiters which have been detected around a number of stars in our ongoing hunt for exoplanets. There is no way a gas giant could form at such close proximity to its star, since there wouldn't be enough material in the narrow radial orbit it occupies to build a planet of that size. The solution, both for alien stellar systems and for ours, is to accept that most planets probably do form in different regions to where they orbit now.

*It's likely that the rocky planets of our inner solar system formed further out from the Sun and have moved inwards through a process called planetary migration.*

It's theorised that in a dusty protoplanetary disk, small boulder sized objects are likely to herd together behind a lead boulder which creates a kind of slip stream through the dust and gas of the protoplanetary disk so that other boulders, also falling towards the Sun in decaying orbits tend to fall in behind that first boulder - and since the first boulder is the one experiencing the most friction - the other boulders tend to catch up with it, forming a tightly packed conglomerate - and ultimately a single object if enough mass is gathered together through this process to compress it all together by self-gravity.

*It was probably the new Sun's powerful solar wind that blew out most of the gas and dust from the inner solar system and saved these planets from having their orbits decayed completely.*

It is likely that within 100 million years of the Sun's ignition, the inner solar system became populated by a large number of rocky protoplanets, in eccentric and chaotic orbits, engaged in multiple collisions even while they still migrated inwards - until finally the last four planets left standing had their orbits stabilised into the almost circular, and only marginally eccentric, orbits we see today.

Meanwhile, the gas giants were forming out beyond the 'frost line' where it was cool enough for ices to form. Since water, methane and $CO_2$ were a lot more abundant in the protoplanetary disk than iron, nickel or silicon - icy planetary cores could grow fast and grow big - reaching a scale where their gravity was powerful enough to hold on to the hydrogen and helium that were also present in abundance in the protoplanetary disk. This combination of factors allowed these outer planets to grow to an enormous size.

Jupiter probably began forming within only 3 million years of solar ignition, clearing its orbit relatively quickly, which then stopped it from migrating further inward. Saturn's icy core grabbed up whatever gases Jupiter didn't - and Uranus and Neptune soaked up the dregs. Uranus and Neptune are thought to have formed much closer to the Sun than they are now - and in a reverse order, with Neptune closer in than Uranus.

*It is thought that around 500 million years after solar ignition, something remarkable happened.*

Jupiter and Saturn settled into a 2:1 orbital resonance - meaning they would line up at the same point once around every orbit of the slower moving Saturn. This created a kind of gravitational pulse that kicked Neptune out past Uranus, so that it ploughed in to what was then a much closer and much denser Kuiper Belt.

The result was a chaotic scattering of Kuiper belt objects, many being either flung outwards towards the Oort cloud or flung inwards towards the inner solar system. These objects, along a rain of asteroids from an also gravitationally disrupted asteroid belt - delivered the Late Heavy Bombardment, in which the planets of the inner solar system were pummelled by multiple comets and meteors for several hundred million years - the devastation of which is still apparent on the cratered surfaces of the Moon and Mercury today.

But then, as the dust finally settled around 3.8 billion years ago and as a new day dawned on the third rock from the Sun – clear skies meant early forms of life were able to start using photosynthesis for energy – and the rest is, of course, history.

*A disk-shaped planetary system naturally arises from conservation of angular momentum - just like spinning pizza dough in the air forms a disk.*

But a somewhat surprising feature of our solar system is that the Sun has over 99% of the solar system's mass, but only 2% of its angular momentum. In fact, a point on the Sun's equator will complete a full rotation in 27 days rotates at a speed of 1.9 kilometres a second. This is slower than even Neptune’s orbital speed of 5 kilometres a second - and much slower than Mercury's 48 kilometres a second orbital speed.

However, from the observation of other stars there is a clear correlation between a star’s age and its rate of spin - which may result from interaction between the star and the solar wind particles it pumps out - so that the star transfers some of its angular momentum to those solar wind particles via a mix of gravitational and magnetic forces - arcing those solar wind particles around into a curving trajectory and reducing the star's own spin in the process. Day by day, the effect is minute, but after billions of years it does start adding up.

Another way to look at the angular momentum problem is to consider that if the Sun did have 99 or 100% of the angular momentum of the solar system, it would spin itself apart.

Angular momentum must be conserved - and for the solar system, it is. It has to start off as a spinning accretion disk and the only way a central star can form is by giving up its angular momentum to the disk – just like a spinning ice skater can spread his or her arms out wide to slow down.

Thanks for listening. This is Steve Nerlich from Cheap Astronomy, www.cheapastro.com. Cheap Astronomy offers an educational website where we can even do podcasts on ice. No ads, no profit, just good science. Bye.