4.2

THE SOLAR SYSTEM & THE EARTH

0:00–0:31

RISING COMPLEXITY

Hi, I'm John Green, this is Crash Course Big History. Today we're going to be talking about the formation of the Solar System, approximately 4.567 billion years ago. Four, five, six, seven. Could that possibly be a coincidence? Yes.

So if you weren't asleep during like every minute of grade school, you're probably familiar with the basic layout of the Solar System and the eight — formerly nine — planets. What you may not know is how the planets fit between the stars and life as the lynchpin of rising complexity.

Mr. Green, Mr. Green, what about Pluto?

0:32–1:29

PLUTO

Oh, me from the past, I know people like to root for the underdog, particularly when the underdog shares a name with Mickey Mouse's dog. Off-topic, but how come Mickey Mouse has a dog who is a dog and also a friend, Goofy, who is a dog?

But just remember that Pluto also shares a name with the Roman god of the underworld, who was very unlikeable. But regardless, the word planet is a manmade classification for a natural phenomenon. We use it because it makes it easier to do science.

Pluto hasn't cleared the rocks within its neighborhood orbit like planets usually do, and there's even a dwarf planet on the edge of our Solar System, Eris, that's bigger than Pluto, and there are hundreds of others that are comparable to Pluto. The nature of the Universe has not changed. It's just that we learned that Pluto was not acting like a planet, so can we please just drop the Pluto thing?

1:30–1:44

MOVING CLOSER

So we're now moving from the scale of galaxies, which involve millions of light years to a neighborhood that's only a few light hours from the Sun to Neptune, the farthest planet. Or at most, a light year or two to the distant Oort cloud of billions of comets held by the gravity of our Sun.

1:45–2:07

PARENTS OF THE SUN

So last episode we talked about how the stars are like our great-great-great many, many times over grandparents. Well, our Sun actually had stars as its parents, too. It's most likely a second-generation star, which means that the Sun was formed from the wreckage of previous dead stars, and that it contains elements other than just hydrogen and helium — heavier elements that are forged in the bellies of stars. And some of which are like flung out by supernovae.

2:08–3:03

FORMING THE SUN

When our star formed, its immense gravitational pull sucked in 99.99% of all the matter in the Solar System. So in this case, we are all the 0.01%. But essentially the rest of the Solar System is made up of the debris, like the crumbs, the dregs in the bottom of your coffee cup.

Our Sun formed over the course of about 100,000 years in what's called a solar nebula, which is like a fiery cradle of wisps of dust and gas. Then the solar nebula began to compress into a star, probably triggered by a nearby supernova that also, usefully, peppered the Solar System with even more heavy elements. And then as the Sun slurped up like almost all the matter in the Solar System, pressure made the core of the Sun heat up and it came to life. The usual fusion of hydrogen and helium began to happen, and continues to happen, which is nice, because otherwise the Earth would be extremely cold and also very dead.

So how do we know all of this is true? Well, let's talk to Emily from The Brain Scoop.

3:04–3:37

METEORITES

Well, a good piece of evidence is the construction site rubble from that time. Meteorites form a sort of fossil record. Meteorites fall to Earth, and some of them are primitive clumps of nebular dust. Careful investigation reveals them to be around 4.568 billion years old. The point is there can only be two environments where iron-60 came from: one is inside a very old, giant red star, and the other is within a supernova. Elderly red giants move away from star-forming regions in the galaxy. Chances are, the Sun wasn't formed near one of those, so it's much more likely that our Sun's formation was triggered by a supernova blast.

3:38–4:02

GAS GIANTS

So in the early days, the heat from the Sun blasted lots of gassy materials away from the inner regions of the Solar System, encompassing Mercury, Venus, Earth, and Mars. Further out in the vicinity of where Jupiter is now, it was cold enough for volatile gases to hang around, and even become liquids or solids. That's why the inner planets like us are rocky, and the outer planets — Jupiter, Saturn, Uranus, and Neptune — are all these humongous gas giants.

4:03–4:45

ELECTROSTATIC FORCES

So what happened to the remaining 0.01% of our Solar System and what does this have to do with the rise of complexity? Well, the dust floating around the baby Solar System wasn't just elements. Like heating in the stellar nebula allowed this dust to sometimes form more complex configurations of elements. Like for one thing, around 60 different kinds of minerals.

So then the dust began to stick together. Why do I have balloons, by the way? Well, obviously, I'm going to tell you shortly.

So you may have noticed that if you rub a balloon onto your head for long enough, it will stick. That's because of electrostatic forces. Precisely the same forces that allowed the dust in the Solar System to gently collide and stick together. And then as those clumps of dust got bigger and bigger, the collisions ceased to be so gentle.

4:46–5:25

OBJECTS COLLIDE

So within 100,000 years there were many objects of up to ten kilometers in diameter in the Solar System, and the force and heat of those violent collisions allowed the formation of still more celestial bodies. Objects continued to collide, the larger objects sucking in the smaller ones with their gravitational nets, and then the largest in each orbit began bulldozing its way through the remaining material. So after about a million years, the Solar System consisted of a few dozen or so protoplanets. They were roughly between the size of Mars and our moon. And then over the next ten to 100 million years, the game of pool continued. Each collision being something terrifying to behold until we wound up with the eight massive planets we are familiar with today.

5:26–5:58

OTHER OBJECTS

But, of course, there's more than just planets in our Solar System, there's an asteroid belt between Mars and Jupiter, for instance, which may be a failed planet messed up by Jupiter's gigantic gravitational pull. And then on the edge of the Solar System there's the Kuiper Belt, a region of planetary shrapnel like poor old Pluto. And even further out in the boonies, there is the Oort cloud. It's like this huge borderland teeming with billions of comets, but it's still within the Sun's gravitational pull. And the Oort cloud is a light year away. That's how massive our Sun is, and it's a pretty modest-sized star.

5:59–6:57

DIFFERENTIATION

So this was a pretty intense time in terms of energy transference. Like all those protoplanets smashing together converted huge amounts of kinetic energy to heat. In fact, it was so much heat that when combined with the heat put off by radioactive materials in the early Solar System, the Earth was a molten ball of lava. Basically, the entire planet was as hot as Houston, Texas. What's that? Apparently it was much hotter than Houston, Texas.

6:58–7:37

THE EARLY ATMOSPHERE

Anyway, the Earth underwent a process of differentiation, whereby heavy elements sank to the center, and many lighter elements floated to the surface. A lot of the metallic elements like iron and nickel sank through the hot sludge to the core, where they still are. And the lighter silicates floated upward, forming the Earth's mantle, a region about 3,000 kilometers thick. The even lighter silicates floated to the surface, where they eventually cooled into the Earth's crust, about 35 kilometers thick in some places, and at the bottom of the deepest oceans, about as thin as seven kilometers.

You can think of the crust as like the thin layer of skin that forms on a bowl of hot clam chowder and you wouldn't be far from the truth. By the way, I could use some delicious geological clam chowder right now, just like my mom used to make, but with more nickel.

The lightest materials of all, including gases, like hydrogen, helium, methane, water vapor, nitrogen, ammonia, hydrogen sulfide, they bubbled to the surface, and were kind of belched out of volcanoes to form the early atmosphere of the Earth — the steam off the soup. And then even more water vapor was brought in my comets falling to Earth. Which we appreciate comets, but even though we do have a water shortage, we don't need you to come back.

7:38–8:09

HADEAN ERA

Much of the methane and hydrogen sulfide in the early atmosphere was converted into carbon dioxide, which turned the sky into like a terrifying red, rather than our friendly blue of today. So basically you've got an Earth with a red sky, volcanoes that are thousands of feet high, a black, barren, rocky surface, the foul smell of sulfur everywhere, scalding hot steam, constant collisions of fire and brimstone from above occasionally splitting the crust open and creating entire oceans of lava. That's why we call this period in Earth's history the Hadean Era, after Hades, the Greek god of the underworld.

8:10–8:27

MINERALS INCREASE

But a couple nice things about this crazy, terrifying, ball of fire. One: we weren't there, so it's not bothering us. Two: all of this intense heat and pressure allowed mineral combinations to increase dramatically. In fact, there were a whopping 1,500 different combinations, and that would only increase as plate tectonics and life got involved.

8:28–9:02

THE MOON

So during this terrible toddler phase for the Earth, a Mars-sized object dubbed Thea collided with the newly formed Earth in a vigorous kind of body check, or I guess more of a planet check. This knocked out a huge chunk of the Earth's materials, and then over time, those materials accreted into, you guessed it, the Moon.

The Moon of course is best known today for inspiring the Moons Over My Hammy sandwich at Denny's, but it also inspired the space race and millions of poems, and paintings, and it also created tides. But putting aside the tides, which are admittedly a pretty big deal, without the Moon what would wolves howl at in all of those t-shirts?

9:03–9:29

THE FIRST OCEANS

All right, so as the Earth cooled, the water vapor that had accumulated in the atmosphere fell in torrential rains, like downpours that lasted millions of years. It was like Seattle, but instead of like coffee and grunge music there was just ammonia.

These downpours created the first oceans. Like as the Earth's surface cooled below 100 degrees Celsius, water vapor was able to stay in liquid form and somewhere between 3.8 and four billion years ago, we had oceans.

9:30–9:58

THE SURFACE OF THE EARTH

Let's talk about food again. This time, though, instead of Earth chowder, let's imagine the Earth as an egg. The crust is as thin as the eggshell, it's also brittle and fractured into segments called plates. Essentially these plates float on top of squishy, goopy rocks that are close to their melting point. As a result, the surface of the Earth has a history of its own, including the creation of mountains, the explosion of volcanoes, the forging of mighty super continents like Rodinia and Pangaea.

9:59–10:34

PLATE TECTONICS

Plate tectonics affects everything from the movement of continents to the distribution and evolution of species, and is one of the most vital principles of modern geology. It's also responsible for less fun things like massive earthquakes and super volcanic eruptions that have caused the deaths and even total extinction of millions of species.

Finally, the point should be raised that of all the possible scenarios that might kill off the human race, provided we don't kill off ourselves, a super volcanic eruption is among the foremost of them. In fact, on the scale of millions of years, a devastating eruption is almost guaranteed to happen.

And unlike an asteroid, one can't go all Bruce Willis and blow up a super eruption with a nuke. If we're still around, it'll be interesting to see how we cope.

10:35–11:19

GOLDILOCKS CONDITIONS

Throughout the birth of the Sun and the origins of the Earth, there was the chance formation of Goldilocks conditions for life. Like with the porridge and beds that our fairy tale sociopathic blonde pilfered from a baby bear in a break and enter job, the conditions for life on Earth were just right. This includes the placement of the planet relative to the Sun. The right chemicals were present on Earth to produce the first building blocks for life. More on that next time. Even plate tectonics were hugely important. First, they suck biotic waste — dead things, excrement — underground instead of remaining on the surface. If not for plate tectonics, we'd be more or less swimming in our own you know what. Over millions of years, this biotic waste could be transformed into coal or even diamonds.

Plate tectonics — we turn your poo into diamonds.

And if it wasn't for oceans and plate tectonics, there's a good chance that we'd have the same runaway greenhouse effect that Venus has, where the surface is hot enough to melt lead.

11:20–12:14

IMPACT ON HUMAN HISTORY

Plate tectonics were also crucial to human history. The gigantic landmass of Afro-Eurasia made trade networks possible, which facilitated the exchange of knowledge and technologies, along with sharing diseases to gradually build immunities. Something that would be grave news for the isolated inhabitants of North and South America. The distribution of copper, iron, silver, and gold influenced the growth and prosperity of countless societies, even the distribution of coal beds in Wales was a major ingredient for the Industrial Revolution kicking off in Great Britain.

All of these things, formed within the slimmest of margins of probability were Goldilocks conditions for the rise of complexity in the later story. The sustenance of life, the distribution of resources, and even the coal needed for the Industrial Revolution, which exploded into the tremendous rise of complexity in modern times. It's a transformation that continues to this very day.

12:15–13:07

EXOPLANETS AND PLANETS

So speaking of Goldilocks conditions, knowing about the formation of our Solar System and the conditions on Earth that were necessary for life is crucial to thinking about the possibility of life elsewhere. The first so-called exoplanet was discovered by Swiss astronomers in 1995. And in 2002 alone, 31 new exoplanets were discovered by independent astronomers. NASA has taken this several steps further. In 2009, they launched the Kepler probe to look at about 150,000 Solar Systems in the nearby galaxy. As of now, they've found hundreds and hundreds of confirmed planets with thousands more potential candidates. And estimates are that in the entire Milky Way galaxy, there could be as many as 40 billion Earth-sized planets orbiting their stars in the Goldilocks zones for life. And that's just in our galaxy. There are hundreds of billions of galaxies in the Universe.

13:08–14:00

OTHER LIFE FORMS

Now I'm not going to tell you that creating life is as easy as shooting fish in a barrel, but if you put 100 trillion bullets in that barrel, you are bound to hit a fish. But given the vast amount of space between Solar Systems and the fraction of time in which life — to speak nothing of the sliver of time so-called intelligent life has existed on our planet — we may never encounter other life forms.

But I find it tremendously exciting, as well as kind of comforting knowing that there may well be other forms of life out there even if we never run into them, from microbes, to multi-celled organisms, like, you know, us.

Maybe they're as astonished by their existence as we are by ours. And thinking about that, one begins to feel a little bit better about our tiny role in the cosmic play. We may never meet, but we're comrades in this strange phenomenon of rising complexity in the Universe.

More on that next time — I'll see you then.