Astronomy Cast Episode 17: Where Does the Moon Come From?

Fraser Cain: One of our listeners, Dave Hine, asked a great question: how did the Earth get its Moon? Instead of answering this on the forum, we have turned it into an entire show. So, Pamela, why do *you* think that this is a great question?

Dr Pamela Gay: Well, our Moon is a big mysterious object. It's not an asteroid, as so many other moons in the solar system are, nor a big potato-shaped thing that was captured and held in place, but it's not the same as Earth: its density is lower, its contents slightly different, and it does not have things like water.

But at the same time, some of the isotopes that we can use to figure out where things formed in the solar system - like the oxygen isotopes – are absolutely identical to the Earth's, and these things don't all fit together in a nice neat way. So the moon is not like many of the other moons, it kind of stands out, and its composition is really confusing. It's had people scratching their heads for as long as people have been trying to figure out what put it there.

Fraser: So what were the main theories for where the Moon came from?

Pamela: Initially there were three main theories. The first was a fission theory, that said that the Earth formed and was spinning really fast, and it just happened to fling off part of its surface. People point to the Pacific Ocean trench as where the Moon could have come from.

But it doesn't explain everything we see. This idea means that the Moon should be similar in composition to the Earth. I mentioned that the Moon lacks water, and water is a volatile. To get rid of volatiles, you have to heat something up, and the theory of a fast-spinning Earth flinging off the Moon doesn't explain how the moon lost its volatiles or how the heating took place to make the Moon the way it is.

Fraser: Did the Earth spin fast enough when it was forming that this would be plausible?

Pamela: We don't know how fast it was spinning initially. It does spin unusually fast, but there's no reason to suppose it was spinning much faster in the past using modern theories. We can't get there from here.

Fraser: And something would have to have slowed it down to its current rate of rotation.

Pamela: Well, there are tidal forces that are slowing down all the planets; Venus rotates remarkably slowly because it's so close to the Sun compared to the Earth. So we *are* getting slowed down, but we don't know how to get from spinning so fast that we heave parts of the planet into space, to our current, more sedate 24 hour rotation.

Fraser: So the problem with this theory is that it would mean that the Moon would be formed from the same constituents as the Earth, but it's not.

Pamela: It has many of the same things, but it's missing the volatiles. It has the same oxygen isotopes but the water isn't there. So we have to figure out how to bake the Moon, and this doesn't explain it.

Fraser: So it's as if, once the Moon had formed, nothing would have been hot enough to give it that final baking to remove the volatiles.

Pamela: It needed to be put under a sun lamp that didn't also affect the Earth.

Fraser: ...because we would have lost our volatiles as well. OK, so next step!

Pamela: So then there's the capture theory: you have the Earth and Moon formed near to each other so that they are made of similar things and they gravitationally pass and somehow the Moon grabs on to the Earth and starts orbiting.

This all sounds good, but it doesn't quite work when you try to figure out how the orbits work. If there's something as big as the Moon that's coming towards the Earth, it must be moving really slowly in order for the earth's gravity to be able to grab hold of it. To get the Moon moving that slowly if it's on a normal orbit, you require a third large object nearby that gravitationally slows the Moon, and there's no third object.

Fraser: I see. If the Moon was coming towards us so slowly, in most situations it would just be flung away, so you need a third big body and in the interactions between the three you can end up with the Moon going around the planet.

Pamela: And that third body isn't there. The Earth and Moon had to be formed at very close to the same distance from the Sun in order for them to have the same isotopic abundance of oxygen in both worlds. This [theory] doesn't take into account how the Earth and the Moon could have the same oxygen isotopic abundances, nor is there any third body.

Fraser: So that's out! Next?

Pamela: The next theory's the condensation theory: the Earth and the Moon formed where they are, out of the same stuff and they're in the same place and everything seems to be accounted for, but it's not. The problem is, that you end up with the Earth and the Moon having the same isotopic abundances, but you still haven't baked the moon, so our problem with the lack of water in the Moon is still there.

You also create a new problem: the Moon does not have an iron core like the Earth does. It has a really low density compared to the Earth, and if you have two things forming out of the exact same distribution of materials, how do you get two things that don't have the exact same composition? How do you form the Earth with an iron core but the Moon without an iron core?

Fraser: So if they had formed out of the same cloud of material, some would have ended up on the Moon, and some on the Earth, but they would have been distributed quite equally.

Pamela: Exactly!

Fraser: But then you're still not explaining why the Moon got baked and the Earth didn't.

Pamela: Yes, so with the condensation theory you get the same isotopic abundances, you get them in the right place, but how do you form it such that they don't have the same composition in terms of iron, and how do you bake it to get rid of the water?

So, three theories, and none of them match all of the observables. We have a lot of the scientific community scratching their heads.

Fraser: OK, so how did our current thinking come about then?

Pamela: Well, in the mid '70's, after all the lunar rocks dashed all of our hopes (because now we knew what the moon was actually made of), scientists sat around, scratched their heads and started talking to one another and the idea of a giant impactor came up.

So, what if you take a giant hunk of planet about the size of Mars or, for instance, take Mars' evil twin and put it on an orbit very similar to the Earth's orbit but not identical, such that the two of them end up colliding with one another?

Well, assume this Mars object hits the side of the Earth with a speed relative to the Earth of 10 kps (so they're both orbiting the Sun going at a bazillion miles an hour, but the difference between their two velocities is such that the Mars object catches up to the Earth at a closing rate of 10 kps), then you can end up with a giant splash.

The heavy parts of the two planets collapse down, form a big iron core, and the light parts of the planets – the mantle, the crust – get flung up and form a disk around the Earth and - over time - that disk coalesces into a moon.

Fraser: Right, so I guess that solves some of your problems, because you can keep the heavy material in the Earth, and you've got the lighter material that splashed out, and a reason why the Moon got baked.

Pamela: It's the energy from the collision that baked out the water from the parts that got splashed. So, basically, the high energy got the *expletive* smashed out of its stuff, thrown into space, all of the water, all the volatiles come out of it, it forms a disk and that disk – over time – builds itself into the Moon. And the time period over which this happened was probably only about a year.

Fraser: So what would have happened to the Earth then?

Pamela: The entire surface of the Earth would have gotten redone. The core of the Earth would have been redone. Our entire planet changed itself when this happened: we went from being smaller to being suddenly larger, we became much denser in the centre and we lost some of our mantle – it became the Moon. It was a point at which the Earth was essentially erased and started over.

Fraser: So it would have been absolutely catastrophic if there had been life on Earth.

Pamela: This was potentially the biggest impact that has happened in our entire solar system in terms of the effects of what happened. This was during the period of the Great

Bombardment, or Heavy Bombardment (most likely the Late Heavy Bombardment).

While everything was going on, you have comets and asteroids crashing into things, and in this case we had another planet crash into us, which is rather catastrophic. It hit the reset button, and everything on Earth got to start over again at that moment. But what was cool, was that the Moon that we were given potentially allowed life to exist on our planet.

Our Moon is basically the great attractor of all things that want to hit the Earth. Its is completely covered in craters, most of which represent the catching of some object that might otherwise have hit the planet Earth.

We also have tides, which aren't just fun to play in and surf on, they also slosh about the oceans, and who knows what effect that has on the evolution of biological life on the Earth.

So, not only did it hit the reset button, it started the planet Earth on a completely different direction.

Fraser: Now, apart from not looking so battered, would the Moon have looked very similar to what we see today?

Pamela: Well, it would have been much smoother, it wouldn't have had the Old Man in the Moon lava basins that we see now. It took time for all of those things to form.

No one is exactly sure why the lava flows on the Moon are the way they are, lots of people have tried to figure out why the dark features that we see as the Old Man in the Moon are predominantly on the side of the Moon that faces the Earth, and no one can really explain why that is the case.

They're not the lowest points on the planet, and basic physics does not allow us to get an exact solution that says it's because that's where there is higher gravity from the earth; there's just not that much difference in gravity. But it took time for all those volcanoes to erupt for unknown reasons predominantly on the side of the Moon that we see all the time.

We also would have had a completely smooth Moon initially; it took time for all the craters to build up on the surface.

Fraser: Why do we see only one side of the Moon?

Pamela: It's because of something called tidal locking. The Moon creates tides on the Earth. Its gravity pulls on the Earth such that the gravitational pull is higher on the side closest to the Moon and lower on the side furthest from the Moon, and this squishes our planet a little bit.

The same thing is happening on the Moon; the Moon is getting squished a little bit and, if the object is rotating, the rotation carries the bulged part (the squished-out, flat part) away from the other object. So as we rotate, the high tides are slightly ahead of the Moon's position.

Now, the Moon is pulling on those bulges, trying to prevent them from rotating away. The Moon is a smaller object, so the effect of a pull on a bulge on the Moon is much more dramatic and so initially the Moon was probably rotating compared to where we stand on the Earth. Currently, it does rotate relative to the stars, so the Sun gets to see every face of the Moon during every lunar cycle, but we only see the exact same side because our gravity has locked it in the place. If it was rotating, it would squish out and we would grab the bulge and pull on the bulge so that the bulge was always faced towards us.

The Earth is getting slowed down currently; as we rotate, the Moon pulls on our tides. It pulls on the high tides,even the rocks have tides: did you know that mountains can move by as much as 30 centimetres as they get pulled towards the Moon?

Fraser: I had no idea!

Pamela: It's one of those cool things. We see the ocean tides, but the mountains are moving as well.

Fraser: So was there a time, long ago, when the Moon freely rotated? I guess it would have been a lot closer to us, right?

Pamela: It would have been a lot closer. Due to conservation of momentum and a lot of other neat stuff, the Moon was initially closer but, as we've been slowing down its rotation, it has been been moving faster in its orbital velocity, so its been slowly creeping further and further away from the Earth.

Fraser: How fast is it moving away from us?

Pamela: Only a couple of centimetres a year, but it adds up in time, and what's neat is that we can actually measure this using lasers. There's a group out at McDonald Observatory in West Texas out in Fort Davis, that shoot giant green lasers off the mirrors that the Apollo astronauts planted on the Moon, and they measure the amount of time it takes the laser light to go up to the Moon and come back, and they an measure the distance to the Moon to just millimetres and they can measure changes in the orbit and very minute changes in the distance of the Moon from year to year.

Fraser: But if the moon is moving away from us, how is it that the Moon and the Sun are the same size in the sky? We can have a total eclipse of the Sun and the Moon just perfectly covers the Sun.

Pamela: This is one of those strange coincidences. In general in science we say that we do not live in a special time or place, but when it comes to the Moon and the Sun, we actually do live in a special time.

In the far distant past, when there were probably no human beings walking on the Earth, the Moon appeared much larger in the sky and could more than cover the face of the Sun when it passed in front of it but now, as the Moon's moving further and further from the Earth, it's getting smaller in size.

Currently we have two types of solar eclipses: one is a complete, and the other is an annular eclipse.

With an annular eclipse, the Moon is further away from the Earth in its orbit, and it only sort of covers the Sun, and you end up with this small annulus of the Sun visible around the Moon. In time, that's going to be the only type of solar eclipse we ever get.

Currently, when the Moon is on the closest part of the orbit, if it happens to be a new moon that exactly lines up with the Sun, you get a full solar eclipse, but eventually, when the Moon is at its closest position to the Earth, it will no longer be able to block the Sun, so we'll always have this doughnut of Sun left behind during a solar eclipse.

Fraser: Have there been any other examples of these kinds of large collisions in the solar system that might explain other moons?

Pamela: Well there are all sorts of examples of collisions all over the place. When we look at the asteroid belt - which is fairly close - some of the larger asteroids have small chunks of rock which orbit them. In some cases, those small chunks have been knocked off the parent asteroid and now orbit it.

If you look at the distribution of what asteroids are made of, you see clumps where all of the asteroids are made of very similar materials, and were probably once a larger body that got broken up during collisions.

As we look further out across the solar system, when we look at Pluto and Charon, there's a chance that there's another example of a place where something big got hit and turned into two smaller bodies.

Fraser: So we've got a very similar situation there with the non-planet and the moon...

Pamela: ...the dwarf planet and the other dwarf planet!

Fraser: Yeah, where they have a similar type of material but one is lighter than the other. I guess we're going to wait for New Horizons to make it out there and help answer...

Pamela: ... And the more we can learn about the other moons of Pluto and Charon, the more we'll know about that particular system.

Fraser: So what does the future hold for our Moon? It's moving away from us, so what's in the far future?

Pamela: Well, eventually the Earth is going to become tidally locked with the Moon as well. So if I can see the Moon and it's low down on my eastern horizon, you - who live further west – may not be able to see the Moon at all because it's over your horizon. So only half the planet will ever be able to see the Moon.

It's also going to be rough on those of us who like 24 hour days, because when this happens, the Earth is going to rotate once for every time the Moon orbits the Earth, and that's going to take a thousand hours or so. So the days are going to be substantially longer.

Luckily it's going take about a trillion years for that to happen, so we have a good long wait but, until then, our days are slowly going to get a little bit shorter each year and the Moon's going to get a little bit further away each year, until at some point the Earth and the Moon are completely locked together, at which point they stop moving apart and the days start lengthening, and we're trapped looking at the exact same aspects of one another.

Fraser: Wow! That's quite a future. I think that it's interesting to see that what we see right now is just a moment in time. The Moon is getting further away, our days are getting longer, and what we think has always been is something that is happening on scales which are so long that we just can't comprehend it.

Pamela: Everything is always evolving and changing and we don't live in a stagnant place; it's a very dynamic universe. Saturn's rings could disappear, it's possible that Mars will develop rings. Everything is changing and we just happen to live in a unique time when we have a 24 hour day and full solar eclipses. It's a pretty good to time to live in, I think.

Fraser: So, there you go Dave Hine, I hope that answers your question, and I hope that gives the rest of you some hope that, if you ask us questions, send us e-mails, suggest show topics, or post in the forums, we'll try to turn them into shows if we think there's enough material there.

Next week we'll be tackling black holes, big and small. Thanks again Pamela.

Pamela: See you later, Fraser.

This transcript is not an exact match to the audio file. It has been edited for clarity.
Transcription and editing by Colin Humphries