Astronomy Cast Episode 76:
Lagrange Points

Fraser Cain: Gravity is always pulling you down, but there are places in the solar system where gravity balances out. These are called Lagrange points and space agencies use them as stable places to put spacecraft. Nature is on to them and has already been using them for billions of years.

Before we get on to it, let's talk about pronunciation. I said it Lagr-ahunge points. Is that okay?

Dr. Pamela Gay: I have heard it said Lagr-ahunge points, Lagr-ahungian points, Lug-range points and Lug-range-ian points. So you know – go with it. Say whatever your local dialect dictates is correct.

Fraser: They're acceptable.

Pamela: They're all acceptable.

Fraser: All right. Maybe someone from France can jump in and give us the most correct pronunciation.

So, where do these come from?

Pamela: The basic idea is if you have a two-body system with two giant things – where giant can be defined on small scales, such as the Moon and the Earth would qualify, the Earth and the Sun would qualify – then you throw in something small (a test particle, a frozen pea, a satellite), you can look to see how the smaller object is going to gravitationally interact with the larger object.

Fraser: The point being this object isn't going to be pulling at the other two objects with its gravity. Its gravity is negligible in the situation.

Pamela: Yeah. It has no pull on the Earth or the Sun – no pull on the two giant objects that we're worried about.

When you start to probe all the different places you can stick this test particle, there are some places that when you stick it there, it stays. In general, if you take an object and you put it on an orbit around the Sun that's bigger than the Earth's orbit, it's going to go around the Sun a little bit more slowly. When you stick it on an orbit that's inside of the Earth's orbit from the Sun, it's going to go around the Sun more quickly than the Earth.

Fraser: If you have an object, which you've got the Sun and the Earth, the interaction of the Earth is going to mess with it, right?

Pamela: That's where the magic happens. There are a few specific points – five of them to be exact – that if you stick an object exactly in one of these five points, the combined gravitational attraction of the Earth and the Sun gang up on this object to keep it moving in lockstep with the Earth as it goes around the Sun. If you're dealing with the Moon-Earth system, you can stick things in the five specific spots that come from the combination of the Earth and the Moon so that it sticks there, following the Moon in its orbit around the Earth in lockstep.

Fraser: Hold on, so you're already said places where its stable. What if you're not in one of those places?

Pamela: if you're not in one of those places, you're happily going to end up in some sort of orbit going around the object, but you're not going to be synced up with anything. For instance, the space shuttle at the space station right now is zipping around the planet every 90-100 minutes. The moon, on the other hand, takes 20-some-odd days to go around the planet.

If I move the space shuttle and the space station its attached to, out into gradually further and further orbits, and position it in just the right orbit in just the right period of time, even though it's not as far away from the Earth as the moon, it would still go around the Earth with the same orbital period as the moon. It's in one of these magical Lagrangian spots where the potential and kinetic energies of the systems balance out just right to keep it there.

Fraser: Right. If you slowly move it out and don't necessarily have it in a perfect circular orbit, it might get caught into some weird, gravitational dance, and get thrown out of the system or hurled into the Earth or sent into orbit around the Sun, or…

Pamela: Most likely it will just end up in a very elliptical orbit around the Earth.

Fraser: Right, get turned into very elliptical orbits. So if you have a little space rock that comes into our system, in most situations it's going to crash into the Earth, crash into the Moon, get skewed away into an elliptical orbit or…

Pamela: It's just going to be another satellite.

Fraser: Yeah. It's not going to stop and pause and stick around. Let's talk, then, about these Lagrange points. How do they work?

Pamela: There are five of them that are ever so creatively named: L1, L2, L3, L4 and, well, L5.

Fraser: And that's Lagrange-1, etc. Right?

Pamela: Right. So Lagrange-1 is the point between the two masses that stays in sync with the smaller object. For instance with the Earth-Sun system, this is the point in space nearer the Earth that, if an object is plunked down in L1, it goes around the Sun in the same just about 365 day period that the Earth has. We will always have this constant line going Sun-object-Earth lined up like little soldiers.

Fraser: So if we take that object and put it closer to the Sun, it's going to be travelling at a faster orbit like Venus, so it will go around the Sun faster than the Earth will.

Pamela: Normally.

Fraser: Yeah. If we move a little more toward the Earth from that point, it will still be going faster than the Earth will, but it will actually be going slower than that point. Right? If that makes any sense. You're saying it goes in lockstep with the planet, so…

Pamela: Here's a different way of looking at it that's a little bit weird. If I take an object and put it the exact same distance from the Sun as L1, but I plunk it down so the Earth, Sun and this object form a right angle from above, that object is going to start going around the Sun with its own period that is way shorter than one Earth year.

Fraser: Right.

Pamela: It's just going to be heading around following Kepler's laws.

Fraser: Right.

Pamela: Now if I take that object and take it at that specific distance from the Sun at just the right moment so that you have Earth, Sun and this object in a straight line with the object between the Earth and the Sun, and then I give it just the right amount of momentum, it's going to travel around the Sun with the exact same orbital period as the Earth.

Fraser: Right. I'm going to make a guess here, but the point is the Earth is tugging on it and providing just that extra little bit of oomph to keep it going around at that speed.

Pamela: The Earth is giving it that extra pull. Well, not so much an oomph as it's combating the Sun's pull. It's because of the Sun's mass that the object would normally be zipping around so quickly. If you have the Earth pulling in the exact opposite direction, in a way philosophically, it's like you removed a chunk of the Sun. if you make the Sun smaller you can orbit it more slowly.

By having the Earth there, pulling away with its own gravitational pull, it slows down the velocity that's needed to stay in a nice stable orbit around the Sun.

Fraser: I've got an analogy. If you're diving and you're going to wear a weight belt to keep yourself perfectly stable, then if you want to go back up you could attach a balloon behind you that would start pulling you back up. You could balance it out with weights and balloons, with the Sun being the weights and the balloons being the Earth. The right spot is your Lagrange point. 1

Pamela: Just like with the weights and the balloons, you have to get it exactly right or you're either constantly floating or constantly sinking. With the Lagrange points, especially with the first three, you have to get it exactly right, or you're going to go flying out of it. These aren't stable locations to be. The spaceships we stick there have to have their own engines and they're constantly making their own corrections to stay in these places.

Fraser: Okay, so these spots, although you can keep going at that same orbital speed, they're not stable. It's almost like you're at the top of the point of a needle, and you can fall any direction and have to fall out of that Lagrange point. The only way to stay there is to keep using your rockets.

Pamela: Mathematically they're what we call saddle-points. In certain directions, you're going to fall right back down to the Lagrange space. If you're taking a marble and trying to balance a marble on a western saddle, if you move it toward the head or butt of the horse, the marble will roll right back to the centre of the horse's back. If you bump the marble left or right, it's fallen off the horse. I know people (including myself) who have had the same experience of falling off the horse.

These are semi-stable positions. The spaceships we stick there have engines that make corrections to stay put. At the same time, it's so convenient to have something that isn't in the Earth's orbit, and is following us around the Sun. it makes communications easier. It's worth the expenditure of energy.

Fraser: Right, if you wanted to put a spacecraft there and didn't have the help of the Earth's gravity, you'd have to fire your rockets non-stop, using tremendous amounts of fuel. Even though you've got to do minor corrections to stay at that sweet spot, it beats having to fire your rockets non-stop o stay in that kind of position.

Pamela: So with the L1 spot, which is between the Sun and the Earth, that's someplace we stick things that are observing the Sun for us. What's cool is they're just enough closer to the Sun that in a lot of cases, when there's a particle spray – a bunch of electrons headed our way from the Sun – they might hit SOHO that's hanging out at L1 a little bit before they hit Earth, about an hour earlier. That gives us extra time to protect our astronauts and put satellites into safety mode, because SOHO can send us radio signals at the speed of light that these electrons are coming toward us at less than the speed of light.

Fraser: Right. Okay, so that's L1. What's L2?

Pamela: If you have a position between the Earth and the Sun, there's also a point that's on the same line but it's beyond the Earth. So you go Sun-Earth-object, and that we call L2 (ever so creatively).

Normally if you stick an object on an orbital path bigger than the Earth's orbit, it will orbit a little bit slower. Since you have the added pull of the Earth, it's like making the Sun a little bit bigger, so an object can orbit faster and still be stable at that greater distance. It's not entirely stable: just like L1, it's saddle shaped and you can fall off the Lagrange point. It's still a great place to stick things that have to make corrections because it makes the communications easy.

For instance, the Herschel satellite, the Planck satellite, the James Webb Space Telescope are all candidates for the Lagrange-2 point. WMAP, the microwave anisotropy probe that has given us such wonderful information about the cosmic microwave background is hanging out at the Lagrange-2 point.

This is a good place to put things that is protected a little bit from the Sun's light, by the Earth hanging out there. It's in a nice safe place beyond the Earth, following us around an orbit, and because it's not orbiting us, instead orbiting the Sun, all the random junk that orbits the Earth is not in any danger of hitting these things in the Lagrange points. The radiation doesn't get there. It's a nice safe place to stick things that work in the infrared and radio that need it a little bit quieter and a little bit darker.

Fraser: So you wouldn't necessarily want to have one of those satellites orbiting the Earth, because of our radio static.

Pamela: Our heat.

Fraser: Our heat. Right. That would actually cause them some problems. So if you keep them away from the Earth, they'll be cold, and will have fewer radio waves blasting them. They'll have a chance to observe better the state of what the universe really is. At the same time, you want to put them some place where you're not going to have them firing their engines non-stop. You also don't want them somewhere you can't communicate with them.

Yeah, I can imagine if you pushed one of those telescopes out to a larger orbit than the Earth, it'll slip behind us in orbit and there will be times like when we're trying to communicate with the rovers on Mars, right? They're on the other side of the Sun and there's no way to communicate with the rovers. If we put them in the L2 point, then it's there in the exact same spot in the sky – which probably makes communication a lot simpler, less power on the spacecraft than the kind of thing the rovers need to communicate with (though they relay stuff through satellites).

So I can see it makes a lot of sense. Okay. What's the next point?

Pamela: Then there's L3, and we don't have anything hanging out there. L3 is the one that's opposite us, so that it goes Earth-Sun-object. If you can imagine an object that has an orbit on the exact opposite side of the Sun from us where it's getting pulled on by both the Sun's gravity and the Earth's gravity. Even though it's not the same distance as the Earth from the Sun, it's orbiting with the same period, constantly staying in lockstep with us, always out of sight.

Fraser: So if I imagine this right, you've got the Sun and the Earth and I guess the combined gravitational force is pulling on this object. That feels to me like it would fall into the Sun.

Pamela: Here we're talking about an object that has an orbit that's again, a snert bigger than the Earth's orbit. It's trying to head off in a line to get away from the Sun, but it's the combined gravity of the Earth and Sun that's keeping it on its circular orbit, chewing around in lockstep with the Earth. This is very similar to L2, but it's beyond the Sun from us.

Fraser: So if you were to look at the line from above it would be like this object will be almost the same distance from the Sun as the Earth…

Pamela: Almost.

Fraser: Hard to calculate or see, but a little bit more. Instead of just going into a larger orbit, the way it should if it's further away from the Sun, the Earth is almost increasing the mass of the Sun and keeping it at that exact same orbit.

Okay. Is it stable?

Pamela: Again, it's a saddle point. The objects are going to want to fall out of that spot. If it can balance just right, or has engines to keep it balanced, it will stay there.

Fraser: There are no spacecraft planned for that, are there?

Pamela: No, because the communications isn't possible.

Fraser: But I can imagine it would be great. If you ever had SOHO, you could put another SOHO on the other side of the Sun and observe it at all times.

Pamela: The trick is you start needing to have things at the right angles between the Earth, Sun and the object so that you can relay the communications around the Sun, just like we have satellites that allow us to relay communications around the planet Earth. We can't talk directly to a satellite that's through the planet, on the opposite side of the Earth in its orbit. Instead, satellites can relay communications from one satellite to the next to get from Australia to Washington DC.

Fraser: Right, so if we had other satellites going around Venus or in some of the other Lagrange points, you could actually get this communication. So you could always observe the front and backside of the Sun at the same time.

Pamela: Then just relay the information all the way around and put it together in the lab later.

Fraser: There might be uses for those. Would they be useful going around the Moon, in the Earth-Moon system?

Pamela: This is where you start to get into space elevators and other crazy stuff. Let's talk about L4 and L5 to get them out of the way first.

Fraser: Sure, yeah.

Pamela: There are two more Lagrange points left, just two. These are the most stable. They are points that lag behind the Earth in its orbit and ahead of the Earth, such that if you drew an angle from the Earth to the Sun to either L4 or L5, both of those angles are 60-degree angles.

There are these hills that it's capable to stand on top of and just hang out there and be gravitationally balanced.

Fraser: So it's the combination of the gravity from the planet pulling you forward, and you're still going around the star, keeping you in that orbit. If you fall too far back, the gravity of the planet pulls you back in. this is the opposite of that saddle. It's very stable – it requires energy to get out of this orbit.

Pamela: The objects are hanging out here. They're getting tugged forward by the Earth, or pulled back from the Earth, because their natural inclination is going to have different periods than what they are. It's really neat that if you have a map of your potential of hanging out in any particular point, these are actually at the tops of hills. They're fairly flat tops of hills. Once you're up on top, you have to take effort to fall off. What's cool is you can actually end up with things inside these larger L4 and L5 points on little tiny circular orbits, where they're going around within the L4 or L5 point and also going around the Sun. that's just kind of neat.

Fraser: So it's like a volcano. You've got a mountain where it's quite hard to get into that point, but once you're at the top, there's actually a crater inside that's easy to roll down into.

Pamela: Sort of like that, yeah.

Fraser: Not that there's actually volcanoes in space, but that's the way the gravity works.

[laughter]

So if we were to put a spacecraft into one of these L4 or L5 points, same deal – they'd just sit there, no energy required, right?

Pamela: What's cool is there are asteroids hanging out in the L4 and L5 points of Jupiter. We call these the Trojan asteroids. It looks like Neptune also has its own Neptunian version of Trojan asteroids that may even be more populated than Jupiter's. Mars is tugging on asteroids as well, holding them locked in its Trojan points. These are places where the solar system likes to store its rocks.

Fraser: We don't have any going around the Earth?

Pamela: Not as much as these bigger things like Jupiter and Neptune.

Fraser: I wonder, if you could fly some asteroid observing telescope out to the Earth L4 Lagrange point and place it there, would it see rocks and debris and stuff in a cloud?

Pamela: I'm sure the density of rocks and pebbles and pea-sized bits of gravel in the Earth's Lagrange points is probably higher than they are elsewhere in the solar system. These are just good places to store things.

Fraser: If you were sitting on Jupiter's orbit, maybe standing still on Jupiter's orbit while it and its Trojans go around, you'd be standing there and a whole pile of asteroids would go past you, then Jupiter, then a whole pile more asteroids.

Pamela: Oh yeah. That's the really cool thing. If you look at a plot of where rocks are in the solar system, if you look at a plot of where all the asteroids are located, there are just piles of them in Lagrange points for Jupiter, Saturn and Neptune. That's just neat to look at.

Fraser: We talked a bit about spacecraft we might put in some of those Lagrange points. I've heard ideas of putting spacecraft into the L4 and L5 points as well – space colonies, space stations. It's so stable it doesn't require energy once you put it in there.

Pamela: That's one of the places they have at various points talked about, with the Earth-Moon system, sticking space stations.

What's also cool is with the not particularly stable, but we have engines to fix it L1 and L2 points in the Earth-Moon system, you can start to think about building space elevators with regard to the Moon.

The moon is facing the Earth the exact same way all the time. It's going around the Earth at the same rate that it's rotating about its axis. So if you have something in the Earth-Moon system's L1 or L2 point, it's essentially in geostationary orbit around the Moon. It maintains the same orientation with the same plot of land on the surface of the Moon all the time.

It's not the same way with the Earth. The Earth rotates about its axis fairly quickly. There are specific geostationary orbits that we stick communications satellites in. With the Moon, you can use the L1 and L2 points. So you can conceive of potentially some day sticking some sort of space station in geosynchronous orbit above some point on the equator where there's land and building a carbon nanotube space elevator tether and dropping it down to the surface of the Earth.

You could have an elevator to get to geosynchronous orbit (which is pretty high up). Then you fly your little rocket from that craft to something that is in the L1 orbit between the Earth and the Moon and you take a different elevator down to the surface of the Moon. Hang around, walk to the exact opposite side (you'd probably actually want a vehicle of some sort) and then take an elevator up to the L2 point which is pointed away from the Earth-Moon system and could be pointed away from or toward the Sun, or at right angles. You could use that as a jumping off point to escape the Earth-Moon gravitational system.

Fraser: that would be awesome. Like heaven! How cool would that be?

Pamela: It's a brave new sci-fi universe.

Fraser: Let's get on that, people!

[laughter]

Pamela: It's a bit expensive.

Fraser: I want my space travel!

[laughter]

I actually did an article on that space elevator concept. The advantage is since you attach the elevator to the surface of the Moon, you don't have the problem with the instability of the L1 point, because it's tied to the ground. Just like a balloon really wants to float away, you'd be able to tie your ribbon down to the

Moon and even though it'd be trying to get out of that orbit, it would be continuously held there.

Pamela: The only thing that's a bit scary, and anyone who's read Kim Stanley Robinson's Red Mars series has read about this, is what if the cable breaks?

Fraser: It would come toward the Earth.

Pamela: Yeah, and you can end up with a ribbon of destruction wrapping itself around the planet. That's a rather bad thing. So yeah, there are all sorts of safety things to be figured out. It's still a cool plot point and a cool thing to dream about and imagine. The future has so many possibilities. It's fascinating to think about what's possible thanks to these neat gravitational holes in space.

Fraser: So now hopefully, if you hear someone bring up Lagrange points, or if you read it in an article, you'll know what they're talking about. Thanks Pamela!

This transcript is not an exact match to the audio file. It has been edited for clarity.