Astronomy Cast Episode 277 for Monday October 22, 2012:

Orbit

Fraser: Welcome to Astronomy Cast, our weekly facts-based journey through the Cosmos, where we help you understand not only what we know, but how we know what we know. My name is Fraser Cain; I'm the publisher of Universe Today, and with me is Dr. Pamela Gay, a professor at Southern Illinois University – Edwardsville. Hey, Pamela, how are you doing?

Pamela: I'm doing well. How are you doing, Fraser?

Fraser: Good. So a bunch of people asked me if I had gotten hit by this recent earthquake that happened off the coast of Prince Rupert, and totally fine, didn't even feel it, no tsunami was generated, so I don't think there were any injuries, no damage; it was a pretty tame 7.7 magnitude earthquake, which is quite surprising.

Pamela: It's always good when they're in largely unpopulated areas – like Canada.

Fraser: Like Canada, which is largely unpopulated… Now you had a couple of things that you wanted to mention and kind of shamelessly promote?

Pamela: Well, I did! So Christmas season is fast approaching, according to my local department stores, which are all terrifyingly filled with Christmas stuff. We would like to remind all of you that one of the ways that we pay our bills is we sell t-shirts, and if you can please, please, please buy our t-shirts, this will help us pay all our server bills. We're actually running short on funding for our server bills right now, so and if you want to donate specifically for server bills, don't donate to

Astronomy Cast, go to Astrosphere because Astrosphere pays for the servers, so buy t-shirts, donate to Astrosphere.org, and we will hopefully keep our servers turned on, and that's always a good goal.

Fraser: That is the umbrella organization that holds Astronomy Cast and 365 Days of Astronomy, Cosmoquest, and all the fun stuff we do.

Pamela: So Astronomy Cast is a joint production of Astrosphere New Media, Southern Illinois University-Edwardsville, and Universe Today, and when you donate to Astronomy Cast that goes through Southern Illinois University – Edwardsville. That goes to help pay for our show notes, it goes to help pay for Preston to do all of our editing, that does not pay for the servers. Astrosphere pays for the servers, so if you want to donate for the servers, donate to Astrosphere -- and we really need money for that!

Fraser: OK. Alright, well let's get rolling then.

[advertisement]

Fraser: So when an object is orbiting the Earth, it is really falling. The trick -- as described in The Hitchhiker's Guide to the Galaxy, the trick is how to throw yourself at the ground and miss. There are several different kinds of orbits, and they're good for different reasons -- from suborbital jumps to geostationary orbit. Time to learn everything there is to know about going around and around and around.

Pamela: [laughing] So I never get to see your intros before we start, and I love the quote from Hitchhiker's.

Fraser: I know, I know. It's a great… I sort of stole it, right, because it's this quote about flying. The trick to flying is to just fall at the ground but miss, and the lead character in the books at one point finally figures out how to do this and flies around, but that's really what orbit is, right? Orbit is falling and missing the ground.

Pamela: It is! It helps to start from a large altitude.

Fraser: So, you know what, I want to go back a bit. We did a bunch of shows on Newton, and I don't think we gave Newton…Newton's thoughts on orbit kind of short-shrift, so can we have a quick conversation about how Newton figured out what orbit is and piece together what the Moon is doing with cannon balls, and…right?

Pamela: It wasn't so much Newton that figured out orbits as Kepler, and then Newton figured out the "why" of orbit. So what Kepler figured out was orbital periods, that orbits are ellipses, and then Newton figured out that there's this crazy force, called gravity, that causes keys to fall to the ground and causes moons to fall towards the Earth and miss, and the trick is if you simply drop a set of keys straight down, applying no force on them, just releasing them, they're going to fall straight toward the center of mass of the Earth. The center of mass of the keys is attracted toward the center of mass of the planet. Now if you instead toss the keys, they're going to move with a certain amount of horizontal velocity, and ignoring air resistance, ignoring friction, things like that, they're going to maintain a constant horizontal velocity while falling toward the center of the Earth vertically. Now, the catch is if you throw those keys hard enough, they're going to keep going further and further and further, getting further around our curved planet.

Fraser: You can imagine like shooting those keys out of some kind of gun that shoots keys.

Pamela: Yes. Exactly.

Fraser: A key gun, yeah.

Pamela: Which, in some ways seems more dangerous than cannonballs, but if you get enough velocity on those keys, they're going to come all the way around and hit you I the back of the head, and so the catch is they're falling at the same rate that the Earth is curving, and if you get the velocity horizontally just right, they're going to keep falling all the way around the planet and come back to where they started.

Fraser: Right, and I was actually just going to go into that exact question, which is if you don't add quite enough force, they're going to spiral inward, but if you add more force, that perfect balance, then they spiral outward, right?

Pamela: Exactly. So you have…this is the difference between a ballistic trajectory, which is one that hits the planet again somewhere else, orbital velocity, which is one where you end up with anything from a circular to an elliptical orbit, to an escape orbit, which is kind of like Voyager, or any other of those interplanetary space probes that got away from the Earth and kept going.

Fraser: Right, right, and of course these are all…all of these are different kinds of orbits that scientists are…they have use for -- for different reasons. So we'll talk about some of those. So let's go back to the beginning. So what was the big leap, maybe, that Newton made about the Moon and gravity?

Pamela: Well, Newton's big leap was: "The Moon is falling around the planet." Up until then we knew things orbited, we had no clue why they orbited, we had no clue what held the planets around the Sun, no clue what held the Moon around the Earth. This was all highly mysterious, and it was Newton coming along and saying, "Whoa! Gravity!" and putting this idea of forces together, and every action is due to a force, for every action there is an equal and opposite reaction, putting all those pieces together -- that was what Newton's big breakthrough was.

Fraser: Right, right, and so you've got the situation where the Moon is falling toward the Earth, and at the same time, it's falling around the Earth, and it's this perfect balance: it's always continuously missing, but it's not spiraling inward, and it's not…I guess it's slowly spiraling outward.

Pamela: It's slowly spiraling outward.

Fraser: Yeah, yeah, but that's a different force that's going on. OK, great! So let's talk about the kinds of orbits that maybe we'll use, and let's get Low to Earth first. And I think something that's actually not an orbit at all is the kind of flight that, for example, Felix Baumgartner just did, right? He didn't orbit at all, but he, you know, travelled to the edge of space (I am holding up my air quotes). So what's that?

Pamela: So basically, there's a certain point where you get high enough above the atmosphere, or high enough into the atmosphere (depending on how you want to mince your atmospheric levels)...

Fraser: I thought you were going to say mince your astronauts!

Pamela: [laughing] Let's not mince astronauts! No, mince our atmospheres! So as you get higher and higher into the atmosphere, the density of the atmosphere drops. This is something you start to experience just by going to the city of Denver. It gets worse as you do things like climb Mt. Everest. As you keep going up you begin to run out of air, and one of the side effects of running out of air is you run out of stuff to scatter the sunlight and create the pretty blue sky above you. So as you get sufficiently high up at weather balloon altitudes – 50 km and higher, basically -- you start to reach the point where you can see where the blue sky ends and the blackness of space begins, and you aren't actually necessarily in space at the point that you can see that transition. That's one of the funky things is how do you define what space is? And it's not defined by where you go from pretty blue sky above you to stars above you; it's actually defined based on energies because that's much more mathematical. So when we first start talking about where does space begin, we start with thinking about, well, where do we start to see the starry blackness of space? And that's once you start getting to weather balloon, or crazy-dude-jumping-out-of-capsule altitudes, which is roughly 50 km or higher.

Fraser: So you can see…I don't know if anyone actually had a chance to watch this live or see what happened, but he tumbled out of a capsule and was totally out of control for the first, probably, minute or so.

Pamela: That was terrifying!

Fraser: I know! It was really scary! And then you could see he was able to sort of get some air or wind resistance, and he was able to get under control until he was in this nicely controlled flight, and you could really see where he had no atmosphere, and then he had enough atmosphere to start to orient himself and that spin, but yeah…it sounds like it really scared the pants off him! OK, so that's your first situation. The next one is you've got Spaceship 1, and the upcoming Spaceship 2, which is again…

Pamela: Well, there's actually many more layers to go through before you start getting that complicated.

Fraser: What do you mean?

Pamela: So Spaceship 1 and Spaceship 2 -- that's just suborbital flight, but then you have to look at (and I'm going to mispronounce this because, really, there has to be at least one mispronounced word per show) -- it's the Kármán line? It's at an altitude of 100 km above sea level, and this is another one of those places where we start defining "what is spaceflight?" And in this case, it's where we're looking at a lot of energy boundaries. We're starting to look at: so how do you travel? Do you travel using the lift generated by your wings? Do you travel using thrusters and orbital velocities? And it's at this line that the atmosphere gets sufficiently thin that you are now a rocket and not an airplane.

Fraser: Right, and but I think that's really important for people to understand is that like with Spaceship 1, they just go up to this line (the 100 km line), and then come back down, and that is…it requires a lot of energy, but it still uses a fraction of the energy to actually go into orbit. I mean is that really suborbital?

Pamela: Well, suborbital is any time you hit the international boundary for space, which is 100 km.

Fraser: OK, yeah.

Pamela: So by definition, since they hit the 100 km, since they get past the altitude at which you are no longer travelling as a plane…

Fraser: Yes.

Pamela: They do count as suborbital, and the reason that the "sub" word is there is because there's no orbiting involved. There's simply the going up and the coming back down part. It's ballistic.

Fraser: Right – ballistic, and it's using a fraction of the energy. Now, what would scientists…I know scientists like to use, they'll use like sounding rockets and things like that. There's some value in going into a suborbital flight. Even like straight up and down, right?

Pamela: Right, so there's lots of different advantages for when you need just quick data. You can do things to measure radiation levels, you can do things to measure thicknesses of the atmosphere at different altitudes, you can take quick x-ray measurements, so instead of having to launch an orbiting x-ray satellite, you can get basic x-ray, you can also get basic microwave data by launching yourself up into the atmosphere. Now, instead of using sounding rockets, another cheaper way to go is to actually use the equivalent of weather balloons -- just swap out the sensor package, get high enough up and float around, and whereas you have a few minutes with a sounding rocket, you can get many hours out of a weather balloon.

Fraser: Right…until your balloon pops.

Pamela: Well, yes, that is a problem.

Fraser: Yeah. OK, cool. So that's straight up and down, and it's really important for people to understand this distinction that the energies required to go up and then come back down are a fraction of the energy to actually go into orbit. So let's talk about some more ballistic flight now. I think a great example was the first American man in space, Alan Shepherd. He went on a ballistic trajectory.

Pamela: Right, and in fact, he and many animals that we'll be talking about in the next show…so the what they did is they basically went up, went up high enough that they could experience zero-G, that they wouldn't be up there long enough that they had to worry about food and water because they didn't know people could eat in space initially, and then just bring them straight back down. And this is what we're looking at for Spaceship 2; this is what we're looking at for a lot of the X-Prize commercial stuff. Many of these different tourist flights are going to be these suborbital flights that go up just long enough that you can see the starry night, that you can experience zero-G, that you can make some distance across the ground (luckily the planet's also rotating beneath you), but you don't have to get all the way up and all the way around the planet as you do with orbit.

Fraser: Right, and then I think you can take that concept even further. I mean, you've got the horrible intercontinental ballistic missiles, or futuristic…

Pamela: You see, you say "horrible," and I'm looking forward to the day that we have, I don't know, Spaceship 3, and we can fly to Australia suborbital. I want to be ballistic to Australia!

Fraser: Of course!   Of course! And that's the whole point. Let's remove the nuclear payload, and let's replace that with a nice scramjet or ramjet.

Pamela: And decrease the velocity of re-entry.

Fraser: Yes. Yes. So, you know, I mean, in these situations, like, what kind of trajectory will an ICBM take? If you want to destroy Russia, which we don't want to destroy Russia, but let's say the Americans did plan to do that…

Pamela: Yeah, let's say…I don't know…let's not destroy anything. Let's say that we uh…

Fraser: Let's send flowers to Russia on a missile.

Pamela: No! I want to send, like, news reporters overnight to Australia! This is what I want to do!

Fraser: Sure.

Pamela: No. You pick the…it's not so much an orbit at this point as throwing a football. You have three different things that you need to take into consideration, and each of them plays a different role. At the most simplistic level, you're trying to pitch it so that it goes up and then comes back down, and time up is roughly equal to time down -- it's that whole football arc. There's usually two different angles that you can pick to get to the same location, so you can go really high and have this nice gentle arc, up and over. You can go low and you have to get much more horizontal velocity to be able to get there before you crash into the ground if you take the lower angle. Both of these are fairly straightforward to calculate. It's one of those things we torture freshman physics students with. The second thing you have to take into consideration as you're calculating these trajectories is our planet is rotating. So the point you're aiming at now is not going to be there later, so you have to figure out where the point you're aiming at is going to be as the planet rotates, and in the process of figuring this out, the third thing that you have to take into consideration is that you're moving as well, so as your rocket is getting taken off from the ground, the ground is moving, giving you initial velocity. This is part of why we like to launch from places like French New Guinea, from Cape Canaveral, from near-equatorial regions is because those parts of the planet are rotating about the center of mass of the Earth the fastest. If you were aiming from Cape Canaveral, or New Mexico, and you're trying to land in South Africa, well, South Africa is going around at a different rate, and you have to take all of these things into consideration in trying to figure out how to get from here to there, and Coriolis forces end up playing a role in all of this because of those differences in rotation rates.

Fraser: Well, and this really is the "big frontier." If people are working on these different kinds of technologies – scramjets and ramjets, you know, if they can come up with something that can go Mach 20 or so, and be able to handle the atmospheric re-entry, then we will be able to do flights from, say, you know…from Los Angeles to Sidney, Australia in just a couple of hours. It will be a dramatic change.

Pamela: Well, the things with the scramjets and stuff is they're still doing those at fairly low altitudes compared to the suborbital flights, so I think the suborbital flights, in some ways, have a much easier way to go. The only trick is if you want to get from America to Australia…

Fraser: Landing…

Pamela: Well, that and trying to get from America to Australia, the planet's rotating in the opposite direction that you want it to be for that particular journey, so you can almost imagine a future where it's easier to go from New Mexico to South Africa to Australia, or…that's probably bad…from new Mexico to Morocco to Australia.

Fraser: Right, break up the velocity changes a bit.

Pamela: And you're going in the correct direction around the planet when you do it that way. As long as everyone's going in the same direction it becomes a lot energetically easy.

Fraser: Alright, so we're going to kick things up to the next level then and actually go into orbit. So you know now we've got a rocket. I think what's really important here is that it's not about velocity upwards it's about velocity sideways.

Pamela: Yes. And this is the tricky part, so you have to get high enough up that well Low Earth orbit, you're traveling at about 8000 meters/second, so that's… compare to an airplane that goes maybe 1500, 2000 meters/second for the fastest ones we build, so you're looking at four times faster than our fastest airplanes in order to orbit. That's…it's harder than you would think to double your speed twice.

Fraser: Right, and so you're looking at, I mean, yeah, what -- 20,000, 25,000 km/hour to get into orbit.

Pamela: It's about 30,000 km/hour, about 20,000 mph.

Fraser: Yeah, and that's as you say many…almost an order of magnitude more than just to try and just go up and come back down. It's a phenomenal amount of energy, so really only rockets have the energy output to be able to do this and in many cases a rocket is all fuel, so it burns up all its mass, all its fuel, to get into that velocity.

Pamela: And this is one of those things we're trying to figure out. What is the most energy efficient way to launch things? It's such a difficult challenge without a space elevator. You have people who are trying to use magnetic cannons, where essentially you use magnetic fields to accelerate things along rails, you have people who are considering various slingshotting things, although really this is best expressed in "Moon is a Harsh Mistress," rather than in science reality. You then have all the different rockets.

Fraser: You've got tethers…

Pamela: Tethers isn't so much a good way to get off the surface of a planet. Space elevators...

Fraser: Yeah, space elevators, boost your orbit.

Pamela: Yeah, and then there's matter of do you start from the ground, or do you start from an airplane? So there's all different ways to look at doing this and when you look at our early suborbital testing, it was drop something off the bottom of an aircraft that is 2/3 fuel and pretends to be an airplane, and see how high it can go.

Fraser: Yeah, so then what are the different kinds of orbit? I mean, what's… I guess the first one was the Low Earth orbit.

Pamela: So here you're looking at a few 100 miles up, orbiting the Earth every hour-and-a-half or so, and in these Low Earth orbits, one of the things you have to worry about is you're still in the thick enough part of the atmosphere (you're still in the thermosphere up until you get to about 700 km up) that you have to not constantly, but on a regular basis boost yourself back up because there's sufficient drag from this very, very thin diffuse part of the atmosphere that it's still pushing on you enough to slow down your orbit, and will eventually, like it did with Skylab, pull you out of space, and that's a bad thing when you're trying to stay in space.

Fraser: Right, so I know that the Space Station is constantly being having its orbit boosted back up.

Pamela: And it's constantly also doing things like dodging space debris, so they're moving that giant spacecraft way more than you would think about.

Fraser: So it's really an inherently unstable orbit…that any object placed in low Earth orbit is really just on a…it's just a matter of time before it de-orbits itself and crashes somewhere.

Pamela: Yeah, yeah, and so…yeah, it's just, it's just bad.

Fraser: Yeah, so then what's a more stable orbit? Where do they go next?

Pamela: Once you start getting about 10,000 km up, then you start hitting the point where there's sufficiently little atmospheric leftover bits that you're pretty much good to go up that high, but that's pretty high up. You're still not geosynchronous, but you're starting to get there.

Fraser: So now what are the advantages of placing a spacecraft into that kind of orbit?

Pamela: Well, at a certain level, there's…you need less fuel to stay put.

Fraser: Right. Stability.

Pamela: But beyond that, at that sort of altitude, it's a kind of weird timing -- you're not geosynchronous, so you're just slowly drifting over the planet, you're not synchronous with shadows, it's stable, but it's kind of…I don't know what you're trying to do at that orbit.

Fraser: Well, I know that in some cases, there's like a funny orbit where you can be sort of geostationary at the same time every day.

Pamela: Oh, that's the Molniya.

Fraser: Yeah, right? So there's a special kind of orbit you can do that doesn't require as much energy to get to geostationary, but it still gives you a fairly stable orbit, and there's also more elliptical orbits, so they're lots of orbits that aren't perfectly circular. They go in elliptical orbits where they go way far out. We actually talked about this last week with the XMM satellite.

Pamela: And the orbit you were talking about a moment ago – the Molniya orbit – it's an orbit that gets used for communications with very northern and very southern latitudes. It comes close to the Earth on one part of its orbit and then goes sufficiently far out on the other side of its orbit that it's moving at roughly the same rate that the planet is rotating, and so this highly elliptical orbit allows it to act like a communication satellite when it's over extreme northern or extreme southern latitudes on the planet. Zip around the other side of the planet and one of the problems we run into with normal geosynchronous satellites is they're happily straight above the equator, and if you want to watch television from Juneau, Alaska, or…I don't know, somewhere in Siberia, that's not going to help you because the satellite is so close to the horizon, you're looking through so much atmosphere. So it's with these highly elliptical orbits you're able to get some sort of television station or something up over these extreme northern and southern latitudes.

Fraser: And also, as you mentioned, there's the elliptical orbit where the satellite is orbiting around the equator, but you've also got these polar orbits, where the satellite is going pole to pole, and that gives you a chance to get complete coverage of the whole planet.

Pamela: And one of the neat things that you can do with the polar orbits is you can time them just right so that you're always seeing the planet at the exact same elimination angle, and so that has the benefit (especially if you're a spy satellite) of allowing you to very easily make out differences from orbit to orbit in what you're seeing on the planet below you.

Fraser: Hmm…so a lot of spy satellites are launched into polar orbits?

Pamela: Yes. Yes, they are.

Fraser: Good to know.

Pamela: There are also weather satellites, so it's not just…it's also useful for weather.

Fraser: And let's go to the granddaddy of all the orbits, which is the Geostationary orbit.

Pamela: Right, so these are orbits that are always over the exact same point on the planet if they're above the equator.

Fraser: Why don't they fall into the Earth then? This is impossible!

Pamela: [laughing] Well, so they're orbiting at the same rate the planet is rotating. It's the same way the Moon is going around the Earth at the same rate that it's rotating about its axis.

Fraser: Right, so the satellite is going around, but you're seeing…it appears stationary overhead.

Pamela: Yes, so these are a little more than 40,000 km up, a little more than 25,000 miles up, and what's interesting is occasionally asteroids, including the week that we're recording this, occasionally asteroids come closer to the Earth than these Geosynchronous satellites, and it gives you an idea of how empty space is that so far we haven't lost any of our satellites to an interloping asteroid. I'm waiting for this to happen. That's going to be such a blast to watch how badly the television news covers it. It needs to be like some dead satellite that gets destroyed by an asteroid, but still it's on my bucket list of things to see.

Fraser: So why would you want to put a satellite into a Geostationary orbit?

Pamela: Well, if you put it into a Geostationary orbit, it's directly over the equator of the planet. It's going to happily stay over the same point on the planet as the planet rotates. This means that if you're a communications satellite, you're not budging. Someone points their satellite dish at you, you point your satellite at them -- it's a nice friendly uplink. Now, the problem is if you're not directly over the equator, you're going to be oscillating north and south as you go around, but you will stay over the same band as the planet, so you're just going to drift north and south as it orbits. This has its uses as well, but it's not generally what you're going for.

Fraser: Right. Now, are there any other orbits that are possibly used, especially around Earth? We talked about this sort of an increasing orbit, you know, getting further and further away?

Pamela: Things get thrown into all sorts of different orbits; it depends on what you're trying to do. There's transfer orbits of all sorts of various kinds, there's…it's useful to put things in elliptical orbits that keep them below the radiation belts where they can send back their signals back to earth easier, and above the radiation belts for doing astronomical observations, this is what x-ray satellites like to do, so there's all sorts of different things you can do depending on what your purpose is, but the big-named orbit that we haven't touched on so far is the Hohmann transfer orbit. It's a type of transfer orbit that requires the least amount of energy in order to get from one type of orbit to another. This is what we use to get from Earth to Mars most of the time.

Fraser: Yeah, and I've seen those animations. You can see the little spacecraft is a little dot, and it leaves Earth, and it's on this increasing orbit, and then its orbit matches Mars, and then it happens to be in orbit at the same place where Mars is, so that's how it gets to Mars.

Pamela: So the goal here is you just create an elliptical orbit, where one point on the ellipse is the planet Earth, and the opposite point on the ellipse…because with Earth to Mars you're increasing your distance from the Sun, so closest point to the Sun is Planet Earth, furthest point from the Sun is planet Mars, and the trick here is just timing it so that you end up with Mars and Earth at the points they need to be at the times they need to be at those points, and this is why we talk about "launch windows" that allow us to get to various planets with the correct low energy transfer orbits.

Fraser: Right, and that's really the trick is you want to use the minimum amount of fuel possible to get from point A to point B. You can always burn more fuel if you want to get there faster, but many cases there's a limit to how much…how heavy an object, I mean, at that point, the rockets are massive and the payloads are tiny because of the energies involved, so... Well, cool! Well, this was great, Pamela. Thank you very much, and I think we've covered orbit top to bottom, back to front.

Pamela: Sounds good.

Fraser: Alright, well, we'll see you next week.

Pamela: OK, bye-bye.

Fraser: Bye.