Astronomy Cast Episode 282 for Monday, November 26, 2012: Seasons

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. Hi, Pamela. How are you doing?

Pamela: I'm doing well, just shivering a little bit, which somehow seems appropriate for discussing the seasons.

Fraser: Yes. We are recording in very cold places in our houses, and that's going to come through in the recording, so we're going to try to keep the energy level up. Ask very warm questions.

Pamela: And we're acutely aware of the changing seasons in our northern hemisphere homes today.

Fraser: Yeah, so one thing I would like people to know is, as always, we are recording this episode as a live hang-out on Google Plus, and so you can come, you can watch us record the episode live, and one of the cool things that we do is we stick around after we do our recording for about a half an hour or so and answer questions, and you know, sort of continue the conversation, and we're happy to both answer and discuss the topics that we're talking about in this show, but also just anything about space and astronomy. If you have some weird "what if?" scenarios that don't require too much math, we can throw them at Pamela and just demonstrate her massive brain, so…

Pamela: And traumatize me in the process.

Fraser: Exactly, yeah, yeah. We don't go easy on Pamela during that second segment, but if you want some more of the show, more of us, and more space silliness, then that's a great way to kind of get more of it. And you can always, if you miss it live, you can always watch it on YouTube as well, so…although the podcast, the tight 30-minute, 25-minute podcast goes out on our podcast feed, the full video is recorded on YouTube, and you can find that there, and I think people can find it on the Cosmoquest site, right?

Pamela: Yes, it's archived through Cosmoquest, and if you search on Cosmosquest in YouTube, you'll see a channel called "Astrosphere vids," and that's our host channel for everything we do at Cosmoquest.

Fraser: Yeah, and there's a beautiful archive of all the different projects that we work on so I highly recommend if you want more of the Astronomy Cast, then that's a way you can get more of it. OK, great! Alright, well, let's get rolling!

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Fraser: So spring, summer, autumn, and winter -- these are the seasons that we experience here on Earth as our planet completes an orbit around the Sun, but what's going on? Why do we experience such different temperatures and weather over the course of 365 days? Do other planets experience the seasons like we do? So, if I recall correctly, the seasons happen because the Earth is moving closer and further away to the Sun?

Pamela: No.

Fraser: No, that's wrong, but that's what most people believe.

Pamela: I know! And it's such a disturbing idea because how does that work with the northern and southern hemispheres? Because really, we can't…that…yeah, it just doesn't work, so I think people are just not aware that there's two halves to our planet or something?

Fraser: Right. People don't think through the implications of what's really going on. OK, fine, so that is not what's going on. It is not the Earth getting closer and further from the Sun over the course of its orbit.

Pamela: It's not. We're actually closest to the Sun in the beginning of January, so those of us in the Northern Hemisphere, when we're shivering after the New Year's, we're closest to the Sun at that point.

Fraser: That's true. OK, so then what's really going on? What is the cause of all of this seasonal madness?

Pamela: At its most simple, it's a matter that as the planet orbits around, we're keeping our northern pole always pointed at the same star in the sky, Polaris (plus or minus a degree), and the butt end of the planet (sorry, southern hemisphere)…

Fraser: The important half of the planet, our wonderful southern hemisphere listeners…

Pamela: [laughing] …always pointed at the same set of stars in the Southern Hemisphere, and in order to maintain the planetary alignment relative to the stars other than our sun, as we go around the Sun, we're actually orienting different parts of our planet toward the Sun. So if you live in the extreme north or the extreme south, you know that during your summer the Sun may never set, and this is because your part of the planet is pointed toward the Sun, such that as the planet rotates, the Sun never gets below your horizon, and in the winter the Sun may never come up, or it may only come up for a brief period of time because you're almost exclusively in shadow. So this is the problem that…you have planetary tilt, and then you have that dividing line of where the sunlight is hitting, and the sunlight hits the half of the planet that is oriented toward the Sun, and if the North Pole is in that half that's oriented toward the Sun, that half that is being illuminated by the Sun, well, that's where the Sun will never set. Now, two days of the year – the equinoxes in March and September – these are the days when the North Pole lines up with that line between sun and shadow cast on our planet, and the South Pole lines up with that same line, and this means that our North and South Poles are exactly at a right angle to the sunlight coming at our planet, and that means that on those days, you get both sunrise and sunset on the two poles, you get equal amounts of daylight and nighttime, but the rest of the year -- pick a pole, it's going to be pointed at the Sun if you pick the right one.

Fraser: And I think one of the things that causes people a lot of problems is just this concept of…I mean, they can understand that the Earth's axis is tilted, so they can imagine center of the Earth spinning straight up and down that you actually… you know, like a gyroscope. Have you ever played with a gyroscope? Or have you ever been in one of those experiments in like a science museum, and they give you a big bicycle wheel to spin…?

Pamela: And you try to spin it and the chair you're on moves instead? Yeah.

Fraser: Right, and so you can turn it one way, or you can turn it another way, and you can feel the centrifugal force, and you can also sort of see that's what it's going to be like. If you held that bicycle tire where the handles were pointing up and down, that would be as if the Earth had no tilt. Turn it a bit to the side, and now you've got that slight tilt for the Earth's axis, but I think the part where people really go wrong is how it's on the one side of the Earth's orbit, you know, of the Sun, it's pointed toward the North Pole, towards Polaris, and then on the other side of the orbit, it's still pointed in that same direction.

Pamela: Right, Earth is always pointed in the Northern Hemisphere roughly toward Polaris, and in the Southern Hemisphere toward a small triangle of stars. And the other place where they get very confused is when we say that the seasons are because we are oriented with a pole more closely aligned toward the Sun than during the other season. Well, if the North Pole is at its most aligned toward the Sun in the summer, doesn't that make it closer to the Sun? Well, yes, but it also makes me closer to New York if I lean backwards in my chair because I know that New York is in that direction. Now, the difference between here and here and my head and New York City – not a noticeable amount, and the difference in distance between New York City and the Sun, between winter and summer -- it's not defined by the tilt. The distance is much more defined by the "ellipticity" of the Earth's orbit, so it's a matter of proportion; it's a matter or what matters, and that distance change between being pointed toward the Sun and being pointed away from the Sun, it really doesn't add to a noticeable amount. So this leads to the whole confusion of: why is it colder in the winter?

Fraser: Mmhmm! There is a great science experiment that you can do that really nicely illustrates that is to take a flashlight and to aim it straight toward, say, like a piece of paper, and then you call that summer, but then aim it at an angle and you call that winter, but you can see that the amount of space that the flashlight is illuminating is much larger, but it's still the same amount of light coming out of the flashlight.

Pamela: And this is somewhat not as easy to understand with modern LED flashlights. With the old incandescent ones you could hold them close to your hand and you could actually feel the warmth, and as you tilt the light and spread the light over more of your hand, it's not hot anymore, but you can actually, if you have a green laser pointer (that is illegal), one of those that you should absolutely not point at the sky, but you can buy on the internet, if you take one of those green…and I know that you…

Fraser: I have one. I love my green laser!

Pamela: If you take one of these green laser pointers, and you take a bar of chocolate, a nice smooth bar of chocolate, if you hold the laser pointer so that the beam is as small as possible, so the pointer is exactly perpendicular to the chocolate, you can melt a divot in the chocolate because of the heat of the green laser beam. Now, if you tilt the laser so that it's almost a glancing blow and you see this large, green blob of the light getting spread out across the chocolate, you might eventually be able to melt some chocolate, but the intensity of the light, it's just not concentrated enough to have a quick-melt effect. So this is a meaningful experiment using a laser that you shouldn't let children play with. This is a meaningful experiment that allows you to see if the light is focused over a small area, all of that heat is concentrated and it warms it up. If that light is spread over a larger area, you're trying to heat a larger area, and it's just not going to be as effective. And it's that efficiency in heating that goes down in the winter.

Fraser: Right, and so the Sun is only putting out a set amount of photons, but those photons are having to spread across a wider area of the Earth, and so you're getting just less heat.

Pamela: And in this particular case, the light coming out from the Sun is far bigger than the planet Earth, and so what's happening is at the pole -- not at the pole, at the line where it's the midpoint of where the sunlight is hitting the Earth on the equinoxes -- this is the equator of the planet. Right there the sunlight is hitting straight down, so it's getting concentrated nicely, but as you hit the more and more curved parts of the planet, the light has to spread out to cover that tilting surface, and you can do this experiment with a big light if you hold the board straight up as you tilt it more and more and more in that light, you'll see that it gets fainter and fainter.

Fraser: Yeah, so that's sort of why the seasons are happening, but yet we don't really experience the seasons here on Earth in this really sort of absolute, stark way like the coldest, I guess, like for example, the longest day of the year, the day that's getting the most sunlight for the Northern Hemisphere is, what, June 21, the summer solstice, and yet that's not the hottest days of the year. The hottest days are usually coming in July and August. So why is that delay happening?

Pamela: It's the same reason that I can walk up to my steam radiators in this old house I live in and even though the heat is off, they're still warm. It's because our planet is able to hold on to that heat and continue radiating it out. Now, at the same time, it absorbs some of the heat, so what ends up happening is we have the sunlight coming down, hits the planet Earth, Earth absorbs a lot of the different colors of light, re-radiates it as infrared, which we perceive as warm. Now, in the winter, it's radiating away the heat faster than it is absorbing heat, so this means that it's basically going to end up giving up all of its heat by the end of winter in some places, or at least a lot of its heat. It doesn't become like a Bose-Einstein condensate and hit absolute zero; it simply gets cold.

Fraser: That would be bad!

Pamela: [laughing] It would be bad. It really would be bad. So the soil, the bodies of water, many different heatsinks, they radiate away the summer's heat during the winter, during that first part, allowing us to have fairly mild falls, allowing the longest day of winter to not be the coldest day of winter because the ground is still radiating out that summer heat it absorbed. But by the time the end of February and March comes along, a lot of that heat has been given up to the air. So when the days start getting longer again after the March equinox, we're now at a point when the soil is trying to warm back up, trying to warm back up, but it's not re-radiating a lot of heat. Come August, we have sunlight coming down, and then we have the ground re-radiating up at us, and so it's that combined heat of the planet and the sun that makes August such a miserable month.

Fraser: It's a wonderful month.

Pamela: It's the dog days of summer. It's the dog sitting in the grass, tongue lolled out being lazy that is my image of summer.

Fraser: Yeah. So now, for you and I in the northern hemisphere, we've got these really distinct seasons. We've got a…well, I guess maybe not me on the west coast.

Pamela: Those of us who are far enough north.

Fraser: I have a rainy fall, a rainy winter, and a rainy spring, and then a hot dry summer, so that's the best I can do, but for a lot of people in the Northern Hemisphere and far enough in the Southern Hemisphere, you get these distinct seasons, but for a lot of places closer to the equator, they really don't experience seasons in the same way that folks like us do. So what's going on there?

Pamela: So here you basically the Sun bouncing back and forth between a narrow set of angles in the sky, so in the northern hemisphere, where we are north of the Tropic of Cancer, north of Florida basically. Where we are, the Sun never becomes straight overhead, but it goes from fairly low on the horizon to mid-way up the horizon to slowly getting closer and closer to straight overhead as you move further south, so for us the seasons are defined as in summer the Sun is at its highest point in the sky, in winter the Sun is at its lowest point in the sky, so this argument that the seasons are caused by how directly the sunlight hits the Earth makes perfect sense. Now, if you happen to live on the equator, on those equinoxes, on those days in March and September, you have the Sun straight overhead, and as you go into the extreme Southern Hemisphere, you end up with the Sun lower on the southern horizon. As you go into the extreme northern summer, you end up with the Sun low on the northern horizon, and so you actually find that in your December and June, that's when the Sun is lowest on the horizon, so the Sun is constantly bouncing between these two points that are both pretty high in the sky and you just never get any relief, so when you live in the…

Fraser: It's always sending out energy.

Pamela: Yeah…it just makes for a miserable lack of geometric relief from the Sun.

Fraser: I think I can remember being in Mexico one time, I guess it was in December, and seeing the Sun that high up still was really unnerving to me.

Pamela: It's confusing.

Fraser: Right, because I'm so used to the Sun taking this long, low path across the southern horizon, you know? Especially like now, as we're nearing December, we don't get much sun. Sun gets up in Canada, right, the Sun rises around 9:00 and does this slow, you know, very low to the horizon across the entire day, and then probably sets around 4:30 or so, so very little sun.

Pamela: Yeah. Travel opens you up to understanding the sky. Last Christmas my husband and I made the discovery that the transatlantic cruises aren't that expensive (compared to a lot of other things) during the Christmas period, and so we ended up sailing from Gibraltar down to Rio de Janeiro, and as we made this journey that crossed the equator, we watched Orion going from standing up to standing on his head, we watched our days go from short to long, and the temperatures changed, and it was just this dramatic example that we live on a globe, and you have to just imagine how confusing and perhaps even terrifying this was to early sailors as they took off from northern latitudes, like England, and then sailed the Cape of Good Hope. It's our planet is extremely varied, and you can find almost everything on any given day of the year.

Fraser: Now, like with many things in astronomy, our current experience of the ways things are is not the way things have always been. There are cycles going on that actually change the way seasons are experienced. I forget…is it like the Milankovitch cycle?

Pamela: There's a lot of these different cycles, and they have many different names, and they basically boil down to three different things: one, there's some sort of cyclic cycling of our atmosphere that we don't understand that's probably some interplay with volcanoes and other things like that, that are our Earth affecting our atmosphere. There are additional cycles, however, that are caused by our Earth's poles slowly precessing, just as tops precess, but then our planet is also getting torqued (which is a fun word to say)… is also getting torqued by its interactions with other worlds. So over time, the orientation of our rotational axis is changing, and as that orientation changes, that changes the geometry between us and the Sun. It changes the angle at which the sunlight hits the planet Earth, and in effect, it changes how intense the light is on different parts of our planet throughout the year.

Fraser: Right, and so like that cycle, you know, some of those cycles are quite long, you know, right? Like thirteen thousand years…

Pamela: Hundreds of thousands years.

Fraser: Yeah, I think one is like 13 thousand years, essentially for the seasons to flip.

Pamela: Well, they never completely flip, but they do change radically.

Fraser: Now, you mentioned like right at the very beginning that, in fact, the Earth is at the Northern Hemisphere is at its closest point to the Sun in January.

Pamela: The first week of January…

Fraser: And then it's at its most distant point at, what, in the Northern Hemisphere's summer.

Pamela: And it actually does have a small effect on how different our two poles are, so the southern pole is not undergoing the same complete glacial melt that we're seeing in the northern pole, where you can now safely take cargo from Russia to Alaska in the summer, so yes, we do…

Fraser: So this is one of the reasons why Antarctica is just a lot colder, a lot more, you know, more temperature extremes than the northern pole?

Pamela: And the fact that it's land also changes the thermal capacity. Where we really see this much more markedly is on Mars, which has a tilt not too different from the Earth's tilt, but its seasons are more exaggerated because its tilt is just a bit more exaggerated, and the entire world, well, it doesn't have oceans the way we do, at least not today, and so we do see much more difference between its northern and southern poles.

Fraser: And, you know, this is perfect. I want to talk about some of the other planets in the Solar System because, as you said, Mars has a very similar axial tilt to the Earth, so they do get these same kinds of seasons, but some of the other planets are a little more extreme. Saturn has seasons, right?

Pamela: Saturn has seasons. The Cassini data has been absolutely fabulous because we've now gone through equinox, and so we've been able to see storms spin up and spin down in the hemispheres; we've been able to see what we think might be the equivalent of moisture fall, for lack of a better phrase, on Titan as the seasons changed on Titan. Our…thermodynamics shows no mercy. If you have a tilt, you have seasons – and that's kind of awesome!

Fraser: But then you get a weird situation like Uranus, right?

Pamela: Well, so Uranus is the planet that fell over basically. This is a world that twice a year for its years, which are tens of Earth years long, it will point its north pole pretty much exactly at the Sun, and then it will point its south pole pretty much exactly at the Sun, and this leads to massive storm differences; it leads to very strange dynamics in how you have to try and model its atmosphere, and it's just a very different world, where imagine half the planet went to night and half the planet went to day, and you're still rotating, so you're still getting the winds that are driven by planetary rotation. It's just a very different, very interesting world. And then, just to mess with us, there are worlds like Pluto, where the seasons are defined not by axial tilt, but by the fact that it actually does get significantly closer and further from the Sun, so yeah.

Fraser: Right, right, so that does play an effect. If you've got a really elliptical orbit, you're going to get this situation where the distance to the Sun is going to play into your temperature extremes with your seasons.

Pamela: But you have to have a seriously elliptical orbit -- comets are an example of the extreme of this, where they don't exactly have tails in the outer Solar System, and you can view their heated up and expelling a tail as summer. They may have tilt, depending on which one you look at, but that doesn't matter. What matters for them is distance from the Sun, so planets for the most part (planets according to the modern definition of planets) don't have very elliptical orbits, with the exceptions of Uranus and Neptune. They're pretty much round. Mercury's another annoying, not-as-round-as-one-would-want, but round enough.

Fraser: Yeah, I think it has one of the most roundest orbits, so…and not a lot of tilt. And, of course, now we're in this modern age, where, what, like five hundred extra-solar planets have been discovered, and so…

Pamela: And there's evidence for upwards of 1000 that still need to be confirmed.

Fraser: Yeah, so we're finding, again, these concepts of seasons are starting to extend out into these extra-solar planets. You've got worlds, these hot Jupiters, which are tidally locked to their sun. I mean, what would a season feel like on a planet like that? No season, right?

Pamela: Yeah, not so much. If you're tidally locked, the part of your planet that is getting crispied is going to stay the part that's getting crispied, and the part that is pointed away is probably going to have its own effects to deal with. So tidal locking is definitely one of those bad things for seasons when you're tidally locked to a star. Much better to tidally lock yourself to a planet like our moon has done.

Fraser: Right, right, and then imagine some of these worlds that are in binary star systems. You know, the Tatooines, where you'd probably get these really complicated seasons with… you know?

Pamela: Well, it depends on how the orbit is. If you think about it, as you get significantly far away from the other stars, they aren't going to really impact your seasons, so if you're orbiting close in to your host star, and the other two stars (or one star) are significantly far away, it won't play any more of a role in the seasons than, I don't know, the Moon's reflected lights plays in the seasons.

Fraser: Right so there's just not a lot of energy coming out of these other stars in the system.

Pamela: And the other situation is you have close-in binary stars with planets orbiting the set. So in that case, again, if you're orbiting both stars at once, yes, the amount of light that you get will depend on how those two binary systems are or aren't eclipsing one another, but again, that's not going to be necessarily what dominates your seasons, depending on distances. Geometry allows all options, and so you can have crazy seasons if the stars are close in and you're between the two of them in a chaotic orbit, but then you can also have nice, stable seasons that have some variation, but not that crazy simply because the stars are significantly far apart, or significantly closer compared to the distance to the planet.

Fraser: And you can have a situation like Venus, where the atmospheric effects are so powerful that they really just override any seasonal variations you would feel.

Pamela: So this is the case of everything that comes in does not get given back up to space. So you have such good, essentially one-way insulation on Venus that the sunlight passes through the clouds, and then when the infrared radiation tries to escape back into space, that atmosphere says, "No," and that atmosphere causes the entire planet to basically remain as a giant heatsink that keeps the atmosphere hot beyond what you would get without the atmosphere – 900 degrees Fahrenheit.

Fraser: So I've got one last weird question for you here, which I know are your favorites: Does the Moon experience seasons?

Pamela: It doesn't really have that much of an atmosphere.

Fraser: Right, so it doesn't have the atmosphere to trap the heat, but if you lived on some base on the Moon that maybe wasn't in one of these permanently dark craters, would you experience seasons in the same way?

Pamela: So the thing with the Moon is it goes around the Earth every month, and it's during that month that it changes how it's oriented toward the Sun, and there are slight librations that cause some of it to point more toward the Sun, some of it to point less toward the Sun. And when you do thermal maps, this can crop up in how heat is dissipated, but we're still trying to understand this, we're still doing the thermal maps, we're still trying to figure out what heats up, what retains its heat longer, what doesn't, how do all of these things interplay, so stay tuned for more data to come down.

Fraser: Definitely would want to go into your calculations if you wanted to set up solar panels and collect energy on the Moon.

Pamela: Well, so there it's a simple matter of you put your solar panels in an area that's eternally lit on either the northern or southern pole. That's an easy calculation. And for the majority of the planet, not planet, for the majority of the Moon, it's going to be half a rotation of sunlight, half a rotation of darkness, and you just don't get around that.

Fraser: Cool. OK, well thanks a lot Pamela.

Pamela: Thank you.