Astronomy Cast 226 for Monday, March 28, 2011:

Weather

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, 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. How are you doing, Fraser?

Fraser: I'm doing great. Now, I know you wanted to pump up the store today.

Pamela: Yes. It's actually t-shirt season, even in like the places where it refuses to ever stop snowing, it's starting to be t-shirt and giant mosquito season, and while Astronomy Cast t-shirts will not protect you against mosquitoes, you will at least look really good and nerdy while you're getting eaten by the bugs, so go buy a t-shirt.

Fraser: I've had lots of people stop and say, "Cool shirt! What's Astronomy Cast?" and then I have a new listener, so…yeah, definitely, if you wear the shirt, you have the responsibility of promoting the show, just so you're clear.

Pamela: But you'll look cool.

Fraser: But you'll look super-cool and people love the shirt. So how could a person purchase these wonderful items?

Pamela: Well, that's a wonderful question, Fraser. So all you have to do is go to astrogear.com will get you there, and we have not just t-shirts, but we also have pins and CDs and posters, and all the proceeds go to paying the happy people that make the show go that aren't Fraser and I, who do this because we love you all.

Fraser: Yeah, yeah, we don't get paid. [laughing]

Pamela: [laughing] …but we have Joe who helps keep everything up-to-date on the websites, and Nancy Atkinson, and a woman named Romayne, who does the transcripts…

Fraser: Preston…

Pamela: Preston, Preston…Preston is awesome, and he's the reason you hear us right now.

Fraser: Correct.

Pamela: …and we want to pay them, so buy t-shirts and look awesome, please.

Fraser: Alright, let's get on with the show then. So, how's the weather? Well, maybe a better question is "*why's* the weather?" What is it about planets and their atmospheres that create weather systems? What have planetary scientists learned about our Earth's weather, and how does this relate to the other planets in the solar system, and what is the most extreme weather that we know of in the whole universe? Alright, Pamela, so why's the weather?

Pamela: Because there are thermal gradients.

Fraser: So if we were gonna like, "Webster's dictionary says…" what is the weather?

Pamela: [laughing] So the weather is the change in various atmospheric properties: humidity, dense pressure -- all of these different things as a function of altitude, as a function of time, as a function of where you are located on the planet.

Fraser: And as you said, it's thermal gradients that because thermal gradients exist, because there are differences in temperature at different places in the atmosphere, we get weather.

Pamela: Exactly. It all comes down to the Ideal Gas Law at a certain level because as you have variations in temperature, it causes the gas to contract, expand, depending on what that change in temperature is, and if you have a gas contracting, well, more gas is going to flow in, it's a giant system, everything's connected. If you have the gas expanding, it's going to push on things. And all of this has an effect: it drives wind, it drives floes; you can have changes that cause snow, cause rain, cause tornados (if you're unfortunate), and it's all about that difference in temperature from one place to another.

Fraser: And so you're getting these differences in temperature from one physical location to another one, you're getting these temperature differences depending on altitude, so you could be at one place and it's warmer, higher up and it's colder. So, what is the cause of these temperature variations (he says, knowing the answer)?

Pamela: [laughing] Well, at the most fundamental level, the sun is only on one side of the planet a given moment.

Fraser: And so that is the fundamental driver of all of these variations.

Pamela: Right, and this is why all the different planets have some sort of…if you took a planet and you were able to quite happily put it inside of a star sphere where every single point received the exact same amount of illumination…

Fraser: But why would you do that?

Pamela: Because you could get rid of the weather!

Fraser: Well, good! Alright, and the planet…

Pamela: Well, if it was a sufficiently large enough sphere…[laughing]

Fraser: Fine. No problem, you go ahead, put your planet in your atmosphere and see how that works out for you.

Pamela: So, if you were able to create this artificial "sphere-o-star" and make it sufficiently large so to not fricassee a planet, and you were able to take that planet under constant illumination, and just sit it there and have constant surface features so every place on the planet absorbed and emitted light in exactly the same way, then you could have a weather-less planet, but as long as there's any variation anywhere -- even in that "sphere-o-star," if your planet was white on one side and black on the other, that would be enough to drive some sort of weather in the atmosphere.

Fraser: Or if there were mountains, or you name it. OK, alright. Well, we kind of have some planets, though, in the Solar System, well, we have one planet that doesn't experience very much weather at all: Venus.

Pamela: Well, Venus pretty much does have constant misery, but that constant misery that it experiences, you see in the cloud patterns of the winds, you see these banding jet streams, you see the vortex at the poles -- all of this is driven by…there are thermal gradients in this overall misery that is the planet Venus.

Fraser: Alright, so back to Earth then, so we've got these temperature gradients, we've got differences in location depending on where the Sun in shining, we've got differences in altitude about how high up in sea level you are, and also just differences in latitude, right? If you're more north, you experience less sunlight, and if you're in the south, or if you're near the equator, you experience more sunlight, and then I guess as you get down to the southern pole, less sunlight, so what does this turn into for our planet?

Pamela: So we have the major thing that dominates our weather is the difference between tropical heating, so this where between roughly Florida and the southern equivalent of where Florida is located, which is part-way down Africa: tropical band, and within the tropical band, lots of sunlight, lots of heating, oceans get much warmer because of all of the heating, and this one temperature extreme. Then, at both of the poles you have very, very little sunlight, some parts of the year, pretty much no sunlight at all, and that's a very, very cold region of the planet, and this difference between the two regions sets up what is called the jet stream, which is the predominant blowing wind at higher altitudes, and in fact hurricanes are what happens when the jet stream behaves badly.

Fraser: And so you can kind of explain all of the weather systems, you know, the jet stream is some of the big ones, but then we see these small, localized weather systems…you know, we're having a particularly cold spring here.

Pamela: Right.

Fraser: What's driving that?

Pamela: So I have to admit I don't know exactly what is driving Vancouver right now…

Fraser: No, no, I mean, no, but just, in general, the local weather conditions, right?

Pamela: So local weather conditions -- what you end up with is things like long lasting snow cover, that's an Albedo difference, and that's an insulating factor, so rather than letting nice, dark land heat up and trap in the heat which is part of why the hottest days of summer lag behind the longest day of summer, so without getting all of your snow melting, which I know is a problem you're having, the snow that is still there is able to not let the land warm up, and not let the land help warm up the air. You also can end up with local oceans trapping in more cold, and again, this is in this case, it's not a heat reserve, but it's a heat sink, so energy that might not otherwise be needed to help heat up the waters…still needed to heat up the water. You can end up with all sorts of local effects that also depend on how much foliage is around, so maybe the farmers planted something different or maybe the roofing materials have changed. All of these different things can have effects that aren't necessarily anticipated when people are necessarily choosing what crops to plant and inadvertently changing the local regional temperatures.

Fraser: And so then how well do scientists understand the weather process? I mean, you know, they always say that predicting the weather is an inexact science. I think that's kind of giving it…that's generous.

Pamela: [laughing] That's true. We're starting to get to the point that five days out at least using the set of satellites that we have over the North Americas, we're able to say fairly well, "OK, really, really bad (expletive) storm coming. Prepare to hide." They were able to actually give with the massive band of tornadoes that recently went through the American South, they were able to give several days warning, that something really, really bad was coming. So we're able to look at the planet, we're able to look at the high pressure zones, the low pressure zones, we're able to know the ocean is containing this much heat, we're able to know the land is containing this much heat, and run complex computer simulations that takes into effect all of the topography and all of the atmospheric conditions and say, "Five days out, roughly, what's coming, but beyond that, it starts to get too difficult, and things break down very quickly.

Fraser: Do you think that they're, I mean, are they going to be getting better at this? What's needed?

Pamela: The problem with weather is it's a chaotic system, which means that slight differences of maybe a degree, of maybe a couple of new skyscrapers, of maybe just a boat blowing its horn, those slight differences, the butterfly in the wind that you've always heard about on TV -- those things cause huge effects that blow up over the timescale of about a week. So it's the rate at which the errors in our measurements double, and it's not the fact that we're making errors in our measurements, it's the fact that there's chaos in our measurements that we can't say the drop in Jurassic Park is going to go to the left or the right, so without being able to *control* our weather better, we can't *predict* our weather better.

Fraser: I mean it's kind of surprising that when you think of the movements of the Earth around the Sun are known within centimeters, you know, the, I guess, the angle of the Sun's radiation hitting us is known, the amount of radiation coming out of the Sun is known, the topography of the Earth is known, the amounts of cover in ice and all that is all fairly known…it's interesting that the chaos comes in there somewhere, you know?

Pamela: And part of the problem is trying to take into account of all of the little moving heat sources, and so think about something as simple as trying to keep an auditorium at a convention center at constant temperature. If you arrive for some sort of a large, plenary speech -- say you're going to hear Steve Jobs announce the latest, greatest whatever-it-is from Apple (that I know I will probably purchase because I'm just that type of a person) -- if you show up early, the auditorium that might hold a couple thousand people is going to be frigid cold, but by the time everyone gets into the room and everyone flips open their technology or their *technologies* -- and all those little things are heat sources -- that room is going to end up overheating, and people going to end up taking off their jackets and loosening their ties, trying to deal with the fact that that once frigid room, which is now filled with all these little tiny heat sources, is now a much warmer room. And so, OK, you want to compensate ahead. You need to figure it out: how do you pace this system? It starts to become very complicated because you have to figure out something as stupid as: how many pieces of technology that produce how much heat are people going to bring with them? Because compensating for a MacBook Pro, which is a really good space heater in winter vs. compensating for an iPad, which won't keep anything warm – those are two different problems. Now, that's just an auditorium…now, if you're instead trying to figure out how to compensate for understanding intricacies of the weather over a city, you have to be able to deal with such things as: well, how many aerosols are going to be produced by all of the cars, by all of the airplanes? We saw during the days after "9/11" massive changes in cloud cover just because there were fewer airplanes, so the simple act of saying, "OK, there are thunderstorms over Louisiana, let's send all the airplanes north," -- that's going to change the weather.

Fraser: But there were variations in weather before there were humans. You're not saying, you know, it's not our fault.

Pamela: No, it's definitely not our fault, but you still have to be able to take into account all sorts of random things. There's always been forest fires, there's always been just herds of buffalo [missing audio] a field that has been completely eaten down by sheep vs. a field of knee-high prairie grass -- those are going to impact the weather.

Fraser: Right, plankton blooms, volcanoes…

Pamela: Volcanoes seriously impact everything.

Fraser: Yeah, big snowfalls, I mean it all…it goes on and on, flooding…so, yeah. So then, what lessons, I guess, have the scientists learned about the weather we see on Earth and then compare it – what kinds of weather do we see on the other planets? Obviously, we need an atmosphere, so Mercury is out, and Venus is surprisingly out because it just has very little weather.

Pamela: It has very little differentiation in its weather. It has wind.

Fraser: Very little temperature gradients. It has horrible sulfuric acid rain, and other nasty stuff.

Pamela: So the types of things that we've been able to look at and understand are when we look at planetary atmospheres, you're dealing with differences in heating on the two different front and back sun-facing/not-sun-facing sides of the planet, and you're dealing with the fact that the surface of the planet is rotating underneath the atmosphere, and so you have energy going into the system, and this chaos of differential rotation -- because the equator is going to be rotating much faster than the pole and what this ends up doing is setting up cells in the atmosphere -- and so when you look at planets like Jupiter, this banding of the cells is extremely obvious, where what you see are these beautiful stripes around the planet, but what each of these stripy bits actually are is just areas where you have circulation in the atmosphere where on one side of that band, hot atmosphere is rising, and on the other north-to-south side of the band, the cold air is sinking, cold atmosphere is sinking, and so you have the bands north-to-south going through different circulation while also rotating around and around and around the planet in an east-to-west sort of direction.

Fraser: Well, aren't they going like in opposite directions?

Pamela: And that's one of the cool things is different bands do alternate in which direction you're going, and we have the same thing on the planet Earth to a certain degree. We have far *fewer* bands so we don't really notice it, but what we have is the Hadley Cell down toward the equatorial region, and the Ferrel Cell up above that and with the middle latitude Hadley Cell, you have this general I'm-gonna-track-slightly-south-and-west behavior, whereas with the more northerly Ferrel Cell, you have an I'm-gonna-track-east-and-north direction.

Fraser: Right, you get a situation like Jupiter where it's a perfect environment. There's a much higher temperature gradient between the center of the planet and space -- you've got no land masses to stop anything from happening, you've got massive gravity, and you know, so you can see that that's sort of in the perfect situation, you can even see it on the Sun, right?

Pamela: Yeah, exactly. You have convective cells on the Sun, and what's kind of amazing about the Earth's atmosphere is the atmosphere itself really extends more than 600 km up, but weather itself for the most part, is confined to just the first 15 km! And so just the very small, small height of our atmosphere contains all the interesting stuff that's going on, and, in fact, in winter, the interesting bits end up getting stuck even closer to the Earth because the cold air, of course, contracts, and you end up with the atmosphere shrunk even closer to the surface of the planet.

Fraser: So where else do we see weather in the Solar System?

Pamela: I think some of the most interesting weather that we see, in some regards, is the planet Titan, which has, like Venus, cloud cover above it, but we know from some of the images from the Huygens probe that there's definitely all sorts of fluvial, fluid-based geography beneath, so we think that these methane clouds are raining out methane rain that's leading to methane rivers on this world where methane is at its triple point that allows it to be liquid, solid and gas.

Fraser: And -- same situation -- you've got the Sun heating Titan from one side, and then Titan is rotating, or is orbiting Saturn, and so, you know, sometimes it's showing one face, and other times it's showing another face, but it's also….

Pamela: …blinking in and out as it goes into eclipse every once in a while, too.

Fraser: Yeah, yeah, exactly, and so you can see…and also it gets closer and further away from the Sun depending on whether where Saturn's on its orbit, so you can see that some of these changes are pretty dramatic. And how extreme is the weather on Titan?

Pamela: This is one of those things we're still trying to learn. It's unfortunate we're essentially looking strictly at the tops of, well, opaque clouds, so there's been various return signals when we've tried to send different wavelengths of light through the atmosphere of Titan that have led us to believe that there's rain going on, but we only have a few years' worth of data and it's not a lot of data, and…wouldn't it be glorious if we could put a weather satellite in orbit that would be constantly returning IR images, constantly returning radar returns, and allow us to really get a sense of what was going on?

Fraser: First spacecraft to orbit Titan…yeah, that'd be alright.

Pamela: I'm good with that one.

Fraser: Yeah! So, what about Mars, though? I mean, I know Mars has got some really interesting weather.

Pamela: Yeah, Mars…it's not the type of weather that we're used to thinking about. We don't think of dust as weather, but the reality is that with Mars the planet will undergo these massive almost entirely planet-wide dust storms. We're still trying to understand what triggers them; we know that they're seasonal. We also see that the icecaps -- they grow and recede from season to season just like we see our own ice grow and recede, especially now with the North Pole here on the planet Earth. We see that exact same growing and shrinking, but what's interesting is the growing and shrinking there actually affects the thickness of the atmosphere because the ice goes straight from being large, white, splotch -- beautiful from a ground-based telescope, even a nice 14-inch will let you see the poles of Mars -- to instead being an almost invisible polar cap, and a much thicker atmosphere.

Fraser: But you can just imagine, I mean, there's got to be some really interesting process that cranks up the wind across the whole planet and kicks that dust up into the air.

Pamela: And even when it's not massive dust storm season, we've caught on images from the Mars exploration rovers dirt devils just like you see racing across the American Southwest. Dirt devils!

Fraser: Well, they were cleaning up the rovers!

Pamela: Exactly. Exactly. And what's amazing is some of the high-res images…you look down and you see these crazy paths of exposed lower-level dirt on Mars, and it's just like, "what the heck caused that?" And then you realize that what you're actually seeing is the path of destruction of a dirt devil.

Fraser: Yeah, that's great…so it's the same process, right? You look at Earth, you look at Mars, you look at Titan, you look at Jupiter – all the same process going on. What about places like Pluto, I mean, I know that Pluto has a bit of an atmosphere during its summer, right?

Pamela: Right, so what happens with Pluto is it's not so much that the polar caps sublimate and make an atmosphere, but a certain amount of the entire planet…well, we don't know if it's the entire planet…we don't know if Pluto's…we don't know that much yet.

Fraser: I wish there was a mission going there right now.

Pamela: You know there just might be. I think it might [missing audio] like New Horizons or something?

Fraser: Come on 2015!

Pamela: So we don't entirely know what's happening, but what we do know is part of Pluto's surface sublimates and becomes a very thin atmosphere that causes stars that are getting occulted by Pluto to flicker as they get ready, and you see a change in the brightness, the change in the light of the stars, and what's neat is while the date for this episode is quite a while in the past because we are trying to catch up on back episodes right now, in June of 2011, there's going to be an occultation visible for different parts of the planet of Pluto, so Pluto's going to pass in front of a star, and right now it's entering its summer months (or summer years as the case may be), and so, hopefully, we'll be able to see some of that flickering of starlight as it's behind the atmosphere of Pluto.

Fraser: Well, enough about our boring solar system. There is some crazy weather out in the universe. I mean, you think of some of the extra-solar planets that have been discovered, you know, let's hit some of the highlights because there's some really neat planets out there.

Pamela: Well, I think the highlights are all with the planets that are sufficiently close to their parent star that they're tidally locked, so you have this whole family of planets that one side of the planet and only one side of the planet always faces the Sun, just like our own moon only shows us the "Old Man in the Moon," and never lets us see the pockmarked other side of the Moon. Now, if you only have one side of your planet ever facing the Sun, that one side is going to get pretty, pretty hot and that sets up massive convective zones that instead of being bands that run parallel to the equator, you instead get convective zones that have cells that are passing the air from the sun-facing to the non sun-facing side of the planet, and we have models that are trying to understand what's going on, but this is something we've never seen before outside of our computer simulations.

Fraser: Yeah, it was actually surprising…I know that when these planets were discovered it was surprising how well they actually did move the heat from the face that, you know, the one that's facing the star to the other side. They actually found that the global temperature differences weren't as extreme as they thought, so you can just imagine there must be some ferocious winds, like, what, faster than 1000 km/hour -- just incredible winds blowing from one side of the planet to the other side to circulate this heat around. Just amazing!

Pamela: And one of the things about, at least I think, one, maybe more of these planets (you always have to say "maybe more" because they're finding new planets every time you blink), but one of these suckers is within the region of its solar system where liquid water can exist on the surface of the planet. So you have this planet orbiting a red dwarf star so close that it's tidally locked, but were it able to behave like a happy, normal rotating planet, it might have had oceans, but now it instead has insane weather instead.

Fraser: And this is going to be one of these things, you know, the more of these planets that we find, the more of these crazy extremes. I just wish that we could see them closer, better, but we just can't.

Pamela: Yeah, it's one of those frustrating things, but what's kind of cool, though, is at least if they are polite enough to transit in front of their star, we can get a measure on what's in their atmosphere, so that's at least something.

Fraser: That's pretty amazing when you think about it. Alright, well, that's great, Pamela. Thank you very much. Now we know "why is the weather," and I'm going to go out and enjoy it.

Pamela: That sounds great. I hope you're having a slightly warmer day today.

Fraser: Yeah, it's a total, horrible spring, but I'll do the best I can. OK, we'll talk to you later Pamela.

Pamela: OK, bye-bye.