AstronomyCast Episode 238 for Monday, November 11, 2011: Solar Activity

Fraser: Welcome to AstronomyCast 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. How are you doing, Fraser?

Fraser: Good…and we're once again recording this as a live Google plus hang-out. Hello to all of our Google plus friends. They're all waving; you can't see it…joke never gets old. Alright, so we don't have a lot of time for chitchat; you have an airplane to catch so we're just going to roll. The Sun looks like a harmless ball of fire in the sky: warm, life giving and forever unchanging, but we know better, don't we? It's really a massive ball of churning hydrogen plasma encased in twisting magnetic field lines, speckled with sunspots and constantly disgorging vast balloons of radiation and charged particles. The Sun is very active indeed. And you know what's cool, Pamela? We are nearing the solar maximum.

Pamela: Well, we hope we are nearing the solar maximum.

Fraser: Yeah, It's very weird this year, very weird…strange times we live in.

Pamela: Yeah, yeah, so we're recording this in November of 2011, and they keep changing when they think our current solar cycle is going to peak just cause it's such a weird one. It's behaving oddly, and so the Gaussian fits aren't working so well. We're currently looking at a maximum probably around May of 2013, which for an 11-year cycle is right around the corner.

Fraser: Right. Alright, so I was getting ahead of myself, so let's go back, go back. So, the Sun is a ball of plasma hydrogen pulled together by its gravity in a nice state of equilibrium with the light pressure pushing out and the gravity pulling inward, and that would seem to be the sort of state of perfect balance, but the Sun is very active, so what's going on?

Pamela: Well, on the grand scheme of stars, the Sun is actually very boring and very inactive, but what we're realizing…

Fraser: Well, the show's over then. Thank you very much.

Pamela: [laughing] What we're realizing is when you look at any star, even our boring Sun, in enough detail you start to see all kinds of crazy variations, and our sun's most notable variation is its sunspot cycle, so if you watch the Sun for 11 years, you'll see it goes from having no or virtually no sunspots to having those really pocks-mark covered face that's just covered in sunspots, and what's interesting is as you watch over time, *where* the sunspots appear also varies. And this entire cycle repeats every 11 years, and if you have the right tools to watch, you'll actually realize that what's happening is for one set of 11 years, you have a north magnetic pole on the top of the Sun and the south magnetic pole on the bottom of the Sun, and then for the next 11 years, that will switch, and so what we're watching is, over time, the Sun's magnetic field is tying itself literally in a knot and flipping itself over, and in the process we end up with magnetic field lines poking through the Sun, and those magnetic field lines poking through actually change how much light that we're getting here on the planet Earth.

Fraser: So just to sort of think of this as an analogy here on Earth, it would be as if your compass pointed north, and then 11 years later it flipped around and started pointing south.

Pamela: That's exactly what we're seeing with the Sun, and what's cool is along the way we see this change in, well, the amount of light that we get that tracks beautifully with the sunspots, so the more sunspots we get, the more energy we get. It's a very small effect, just a little over a watt per square meter across the planet, but that little variation that we see, that's enough that, well, it actually slightly changes the temperature on the planet.

Fraser: Well, I guess the part that I find kind of confusing is why does the Sun even have this activity, this cycle? I mean, as I mentioned earlier on, I mean, it's compressed down, it's got this balanced state -- shouldn't it have figured out these fluctuations over the course of 4 and a half billion years?

Pamela: So the problem with astronomy is there's basically two things that we're trying to get a handle on: one of them is dust, which luckily isn't a huge problem when looking at the Sun, and the other one is magnetic fields, and that one is a huge problem when looking at the Sun. So, we know that (we think we know, at least) that the Sun's magnetic field is generated somewhere at the interface between where energy is getting transported via convection, via big blobs of hot material rising, giving off their energy at the surface of the Sun, and then sinking back down, and via radiative transfer, which is where you just have the light radiating through the material and transporting energy along the way, and exactly what causes this magnetic field to arise at this particular point in the Sun, we don't fully understand. What causes it to turn itself inside out and flip over on a not-precisely-but-pretty-close-to 11-year cycle, is also something that we haven't quite figured out. I mean, we know in big brush strokes that it has to do with differential rotation of the Sun. This is where you have giant ball of, well, plasma gas; that's not a solid. Here on the Earth, the equator, it rotates in lockstep with Massachusetts, in lockstep with Siberia, in lockstep with South Africa…

Fraser: Right, cause it's a solid.

Pamela: No matter where you are, because it's a solid, everything rotates together. Sun's not like that. With the Sun you end up with different parts of the planet rotating at different velocities and as a result, well, different parts get carried ahead while others lag behind, and this seems to be partially if not fully responsible for the magnetic field becoming a tangled mess over time, and as the magnetic field tangles itself up, it ends up turning itself inside out, and we don't fully understand the details -- we just know it happens. I love observational astronomy; theorists have a challenge.

Fraser: Yeah, and I've seen some really interesting animations, maybe it was on a Nova episode… We'll try to link to something in the show notes where you can see these animations of, or simulations of what the magnetic field lines look like over time. And you start with these nice, clean magnetic field lines from the top to the bottom, and then over time they get all twisted and turned out and not connecting sort of top to bottom. And then you get this point where it's all jumbled, then it flips over and balances back out again. It's quite amazing, and it's…a lot of this kind of theory, this only came together fairly recently, I mean, we're in modern history and the people really figured out what's causing this cycle, the sunspot cycle, and how it connects the field lines and really what's going on. It's quite a fascinating process. And, I mean, there's a version of it that happens here on Earth, although it's different.

Pamela: Now, we don't fully understand the time scales for the Earth. We just know the Earth does flip occasionally, but the Sun's pretty much like a confused clock that is sometimes ahead and sometimes behind, but averages out to on time in the end.

Fraser: And so this is the situation that we talked about. So we are nearing the solar maximum in 2012/2013, and what does the solar maximum mean?

Pamela: Solar maximum is that point when the Sun's magnetic field is its most tangled, when you have field lines that are poking through the surface, and when you see sunspots. The sunspots often come in pairs, and one of them is the point where the field line is coming *through* the surface, and other one is the point where the field line is going *back into* the surface, and as the field line twists itself around, it actually channels plasma, and so these footprints can be connecting plasma loops, they can be the cause of giant coronal mass ejections…all sorts of activity is associated with these places of magnetic entanglement. And when the field lines break, as they sometimes do, and rearrange themselves into lower energy configurations, that energy can get flung straight at us here on the planet Earth, so we actually really have to pay attention during solar maximum because, well, sometimes we get lucky we just end up with amazing northern and southern lights – the aurora borealis that you can…well, last week there was one that was visible as far south as Arizona. You only get that with big solar flares, but if you get unlucky, you're not paying attention, when all that energy, when all those ionized particles hit the Earth's magnetic field, they generate electricity in the Earth's power grid, and this is something we've talked about in "Various Ways to Destroy the Earth" shows, and that excess energy in the Earth's power grid isn't exactly free energy. It is actually sometimes a cause for lack of energy because it can, well, overwhelm the system and take down the grid.

Fraser: And there's, you know, those magnetic field lines coiling out of the sun – it's a really powerful analogy in my mind, and you can see these amazing videos taken by some of the recent spacecraft -- the SDO mission, right? You can see these videos, time-lapse videos of the surface of the Sun. And you see the solar material following the field line from one sunspot to another sunspot, and you can see how it's sort of wriggling, like writhing, like snakes on the surface of the Sun, and then you can see them snap like someone has coiled up too far, and the, you know, the coil just can't handle it anymore and it just snaps and releases, and you see this material flung out like the end of a whip, like a bullwhip, is being sprayed out into space, and then you can see the sunspots disappear. The videos, the time-lapse videos of the Sun, of the solar activity is just mind blowing. Some of those beautiful space-related video, like, time-lapse footage that you'll ever see…I could just watch that stuff all day. So that's the solar maximum. The solar minimum is this opposite situation, right? Where there are no sunspots, the magnetic field is not coiled. Is there like a great big sunspot at the north and south poles of the Sun where the magnetic field lines are coming out?

Pamela: [laughing] No. What's actually kind of amazing is that during solar minimum, you end up with most of the sunspots at the equator, of all places, so as you hit solar maximum, you end up with sunspots towards more southern and northern latitudes of the Sun. They really only get as far north and south as about 30 degrees, but it's still neat to watch them back and forth. And we're talking averages here -- sunspots can poke out anywhere they please.

Fraser: And you can have times where there's not a single sunspot on the surface of the Sun.

Pamela: You can actually have months, occasionally years, with no sunspots at all, and this is one of the things that we've recently been dealing with. This was kind of the solar minimum that refused to end, and we're still trying to figure out what causes this to happen sometimes. As you look at long-term maps of solar cycles, you see that there's amazing variation, and sometimes the Sun just stops, and we don't know why – for twenty thirty, fifty years. And one of the problems that we deal with is things like the modern minimum from 1650 to about 1700. That was a period of negligible sunspot activity. There were sunspots, but very, very few. And during that period, we actually had a mini-ice age where planetary temperatures dropped, where one of the problems associated with this is you end up with much stronger winter storms in New England and in northern Europe; you end up with much hotter seasons in the central regions of America and in Canada. Southern Europe is also hot. We don't have as good of records for some other parts of the planet, and so when we see the Sun going into quiet times, it's sort of a warning that, "Wow! We could have severe northern storms." So looking at things like last year and the year before where it decided to just snow in England on a regular basis, there are those who attribute that random, non-normal snowing in England to it actually being a really quiet sunspot time.

Fraser: Hmm…interesting. I wonder if there is a larger cycle that could last over thousands of years, and maybe…that sits on top of that 22-year cycle of the sunspots coming, coming, going away, coming back that has these highs and lows, you know, more modern minimums, but the problem is that we've only been observing sunspots for the last few hundred years, and so we just don't have any accurate observations before that.

Pamela: We do have hints at longer-term cycles, and the hints come from ice cores. One of the things about the sunspot cycle is it's tied to the whole magnetic behavior of the Sun, and so when you have a really active Sun, you actually have the solar winds and other factors pushing past the planet Earth, and actually making it harder for things like cosmic rays to hit our upper atmosphere, and with fewer cosmic rays hitting our atmosphere, we end up with fewer aerosols. There's also various chemical productions that we see in our own atmosphere as a result of interplay with space weather, and so when we take ice core samples, we can actually look back in time and get a feel for what the Sun has been doing over, well, thousands of years, and so there are those who study this and are saying that we're actually heading back towards a cooling cycle with the Sun, where perhaps for the next 500 years, we're going to slowly work ourselves down to a point where the planet cools off to a lot like it was during the Holocene period before it again begins to warm back up where we're looking at a much longer, 1000s of years cycle.

Fraser: So isn't the rise and fall of the solar activity what's driving, like, things like the ice ages?

Pamela: In the past. Um, right now we have to worry about the effects of man on the atmosphere, and that's a whole can of worms for an independent show.

Fraser: And that makes the whole thing more complicated, which is that you've got the inputs of man pushing against the activity of the Sun, and the whole thing is super-complicated and takes, you know, people who specialize in it to argue about it, so definitely not a can of worms we're going to open on *today's* episode, needless to say…you know, we understand that it's complicated, so we'll move on. So I guess there's like a longer-term variation in climate that can be attributed to the solar activity, the solar maximum, the solar minimum and some kind of cycle over a long period of time.

Pamela: Right. So what we do see is due to solar activity, which is just one of many effects, but there are specific points, such as the mini-ice age during the modern minimum that can be tied directly to the sunspot cycle. What's interesting is we can also see planetary heating tied to the sunspot cycle, and that has some interesting sociological impacts.

Fraser: I'm intrigued! Please tell me more about the sociological impacts.

Pamela: [laughing] So I have to admit I need to do more research on this because there's statistics, and then there's statistics that are really, well um, couched in what is the differentiation between this and random.

Fraser: Yeah, but you found some really cool research.

Pamela: I did find some really cool research. So one of the things that I think all of us know is that when you're hot, you're grumpy, and it turns out that when the planet is hot, societies get grumpy. And so there was a recent study coming out of the Earth Institute at Columbia University in New York that found that there appears to be a link between El Nino, which is a warming of the oceans that's tied to warmer seasons, that, well, when there's El Nino, there's also a lot of world conflict, so they were able to tie roughly a fifth of world conflicts to warmer temperatures, so, yes, if you want a civil war, wait for an El Nino and it may just happen on its own.

Fraser: Right, so we've talked about sunspots and twisting magnetic fields, but there's a lot of other really cool stuff that the Sun throws at us, like, we hear about flares, and coronal mass ejections, and solar storms, and proton storms, and things like that, so what are all these? Let's kind of run through these. What are the kinds of things that the Sun can emanate during these periods of solar activity?

Pamela: So, solar flare is usually nothing more than…it's a energetic outburst that probably isn't going to destroy anything, or cause astronauts to have to go into hiding, or anything particularly exciting, but it's just when a field line breaks, and a bunch of material is released into space, so this is…

Fraser: That's that snapping that we talked about earlier…

Pamela: It's that snapping, and all of that material that's tangled up inside of that magnetic field, well, it just keeps going in a straight line along whatever direction it was heading in originally.

Fraser: But why do we see a blast of x-ray radiation?

Pamela: There's some things we're still trying to figure out. One of the things that has amused me in recent years is at the American Astronomical Society meetings, about every two years there's a major press release on, "We have now figured out why…" and it's going to be either coronal mass ejections, or why some parts of the Sun's atmosphere are hotter than they logically seem to be, or any number of different things, and the x-ray emission comes from the high-energy particles that are tangled up in the magnetic fields, but that doesn't explain all of the high energies that we see, so we're still figuring this out. It's awesome to have the stars so close to study, but when something gets studied in sufficient detail, you realize it's a much uglier problem than you thought.

Fraser: Well, didn't you say that solar hydrodynamics is the most complicated science and mathematics that you could possibly envision, that trying to understand how plasma works in three dimensions…?

Pamela: Yeah, it's hydro-magneto dynamics.

Fraser: Hydro-magneto dynamics.…sorry, I forgot the magneto part.

Pamela: It's just nasty.

Fraser: If you want to choose the most complicated path in science, in astronomy, there's your career path.

Pamela: So the broad brush strokes answer is the magnetic field lines have a whole lot of energy in them, and when they break its because they're rearranging into a lower energy state, and all that energy has to go somewhere and sometimes it gets thrown straight at us.

Fraser: [laughing] Right. Right. And so the solar flare is that momentary release of energy that is a blast of radiation. Um, the coronal mass ejections are these particles that are thrown out in some random direction -- sometimes right at Earth.

Pamela: Now, so coronal mass ejections are basically the big, angry brother of solar flares. So solar flares are fairly well understood; they're tied to magnetic field lines, they're rearranging. Coronal mass ejections we're still trying to sort all the things that trigger them. They're also triggered at times by breaking the field lines, breaking the tangled up field lines, clusters of sunspots, and when these go off, we also can get a blast of particles heading towards us at various different velocities. So sometimes we'll only get half a day's warning that there's this cloud of particles heading toward us, and sometimes it's a couple of days, and these are the things that we do have to worry about because, well, all of those ionized particles, those can pose danger to astronauts. All of the high energy radiation tangled up with this -- that can pose danger, well, to just about everything on orbit. Luckily, the light gets to us before the particles, so thanks to spacecraft like STEREO and SDO that are watching the Sun for us… SDO actually takes an image of the Sun every 10 seconds. These spacecraft are allowing us to do better modeling, are allowing us to see the stuff on our way, and as we continue to watch these things, it's a matter of building up models, of "if we see this, then *this* is going to occur; if we see this, then this *other* thing is going to occur." And between STEREO and SDO's constant vigilance, we're getting better at predicting when large solar flares are coming our way.

Fraser: That's really cool. STEREO, you know, particularly has this 3-dimensional view of the Sun, so one of the big problems with a lot of the spacecraft before now was they took a picture of the Sun and they could see a coronal mass ejection, but they wouldn't know if it was actually directed right at Earth, so they would say, "Well, we kind of probably think that maybe this one's coming toward Earth," but STEREO sees it in 3-D, so it can see the alignment of the coronal mass ejection and tell with a lot more accuracy exactly where that gun was pointed, and…

Pamela: And the way it's seeing in 3-D is one of the two spacecraft is in an orbit that's slightly bigger than the Earth's, and the other one is in an orbit slightly smaller than the Earth, so this is causing them to lag behind the planet, and move in front of the planet and actually look at that space between the Sun and the Earth. Now, unfortunately…

Fraser: It's binocular vision of the Sun.

Pamela: Exactly. Now, unfortunately, they're eventually going to pass behind the Sun, which isn't a useful place for them to be, but they come back around, and assuming these spacecraft are still healthy, once they come back around we'll be able to use them again.

Fraser: Yeah, that's amazing. And so we get this binocular view, so you get this chain, right? You get an X-ray flare, the spacecraft can spot the direction that the coronal mass ejection has been blasted out, and then predict that a storm of particles is going to pass by the Earth within "x" minutes because the light from the Sun takes 8 minutes to get here; the particles take only a little longer than that, and so the astronauts have a few seconds or minutes to get into cover before they sweep past the Earth.

Pamela: And most of the time the particles do take hours to days to get here, so that's a good thing.

Fraser: But some of them can be really energetic and can get here really fast, and they're worst ones, right?

Pamela: Yeah, it's a difficult situation because the more dangerous, the less warning.

Fraser: So, we're kind of running out of time, but I just wanted to compare and contrast what we see with our Sun with some other stars out there, and maybe this is a whole other show on its own where we can talk about solar activity or the star activity on other stars are, but how does our Sun compare to other kinds of stars? If we could get up close and watch, you know, Betelgeuse or a red dwarf star, or…you know what I mean?

Pamela: Right, so we do see other stars, Betelgeuse being one of them, that have much larger sunspots that – well, we don't know for certain if it's individual sunspots that are much larger, but have large percentages of the side facing us covered in sunspots, so we're able to map over time using interferometric telescopes the patterning of the sunspots. This is one of the amazing things that we've started to be able to do by linking together multiple optical telescopes is actually tell how sunspots appear on the surfaces of stars that were just able to resolve. We're also able to look at minor variations over time, and using high-speed imaging start to get hints at, well, this is actually a variation that goes with the rotation period of the star. Well, that's likely sunspot behavior as well. We also see violent, violent flares from some types of stars. The type of flares that would just casually destroy our atmosphere on a regular basis, so we both have more run-of-the-mill sunspots; we also have much less flare activity, and all of this makes our planet a fairly safe place to be. Now, this has a lot to do with where we are on the diagram of stars -- we're not too cold, we're not too hot, we are happily burning hydrogen…all of these things are good things to be doing.

Fraser: Right. But we could have things a lot worse …

Pamela: We certainly could.

Fraser: …as far as stellar activity goes, but then we wouldn't be here to talk about that, so there you go. Alright, awesome! Alright, well thank you very much, Pamela, and…Oh, just one last thing just to mention is one of the big side effects of all this solar activity is the auroras that we see here on Earth, and so we've done a whole episode just on auroras that you can listen to that gives you a lot more information on exactly what's going on, exactly how the interactions are with the Earth's magnetic field, and how you can see them, and so on…So we are, as we said, we're entering this period of high activity and over the next few years, we're going to have multiple opportunities to see auroras, and if we're lucky they're going to be fairly far south, so stay tuned to spaceweather.com. They probably have the most comprehensive alerts, and anything that's going to be really interesting, we'll mention it on *Universe Today*, but definitely try to go out and see some auroras over the next couple of years because then you won't be able to see them again for a long time.

Pamela: And in general, the best aurora curve, for whatever reason, of the alignment of the magnetic fields around October and March of each year, around the equinoxes, and so in the couple of months around equinox, that's when you really need to stayed tuned to, "Oh, there's a solar flare! Oh, there's a coronal mass ejection!" Good chance of good aurora.

Fraser: Yeah, get outside, take some hot chocolate, stare into the sky and hope that you'll be able to see it because if you do see an aurora, it's one of the most amazing things that you'll have ever seen in your life so, and you know, some of them have gone really far south; I mean, I remember hearing with a storm people were seeing them in like Florida, so it's not impossible with this solar cycle.

Pamela: And one of the amazing things is you can actually see them from spacecraft, so if you're flying Trans-Atlantic or trans-pacific where the airplane is likely to cut near one of the poles, try to sit on the side of the aircraft that's going to put you on the pole-facing side, so Chicago to London sitting on the north side of the plane, Cape town to Sidney sitting on the south side of the plane, and you'd be surprised. I saw some absolutely amazing aurora a couple weeks ago on a flight over to London.

Fraser: Cool pro tip! I love that! OK, well, thanks a lot, Pamela. I know you've got to run to a flight. Thanks again, and we'll talk to you next week.

Pamela: Sounds good. Talk to you later, Fraser.