Physics Seminar

February 25, 2019

>>DR. GARRISON: All right. Can I get everyone's attention? I'd like to introduce our speaker today. I know, you know, the weather tonight, it's not (inaudible) before. But we're lucky enough to have David Alexander here from Rice University. He is a professor of physics and astronomy there as well as the director of the space planetary --

>>DR. ALEXANDER: Space Institute.

>>DR. GARRISON: Space Institute at Rice and he's got expertise in the area of exoplanetary physics and (inaudible). He's had many honors including Officer of the Most Excellent Order of the British Empire by her Majesty, Queen Elizabeth. He's won the Presidential Early Career Award for scientists and engineers. He's won the Kavli Frontiers Fellow for the National Academy of Sciences. He is currently chair of the (inaudible) solar observatory, and former chair of the (inaudible) interplanetary environment.

Also we're lucky enough that he's here in Houston, and he also is doing a lot of really interesting things. So you know he is somebody you can talk to, you can find out more about what they're doing not only at Rice that might be of interest to you guys in the future, some of you guys are under grads. So with that I'll turn it over to David Alexander.

(Applause.)

>>DR. ALEXANDER: Thank you. So as you get older, your bio gets longer, so you don't have to read much into that.

So apparently we're being captioned tonight and I don't know if you've ever seen those YouTube videos about voice recognition with Scottish accents. I recommend you YouTube it. As you can tell, I'm from Scotland originally. I've been in the U.S. for the past 15 years.

This is, like, a two hours class and I can do all these slides in about five minutes if I wanted to, but I talk, too. But I'd like to do is maybe have you feel free to interrupt, ask questions, you know, clarify or -- what was that, again -- if the accent is proving problematic. And so we'll fill this out.

If we go through it reasonably quickly, Professor Garrison mentioned we're doing exoplanetary stuff. What we're actually doing is taking what you're about to see and hopefully discuss, and we understand how the sun reacts with the world pretty well. What we're trying to do is take that knowledge and transfer it to these new systems that are being discovered.

And so we're starting talking about the space weather of exoplanet systems. And that becomes quite important because the planets that we've discovered so far, at least the earth-like planets that are in the habitable zone -- do you know how it works out? It's with water, basically.

But because of the limitations of how we can observe each planet because they're so far away, we observe the signature of the planet. And the star has to be pretty small. And so what that means is most of the earth-like planets that you may have read about are very close to what's called an M dwarf star. And a lot of M dwarf stars are many times more active than the sun. And so now you're closer to the star and you have a star that is far more active. That's a pretty intense environment.

And astronomers -- (inaudible) astronomers don't know that much about magnetic fields. We and the sun, studying the sun, we have to understand magnetic fields and how it interacts with plasma and gas and so on. And so we're trying to define a way of what a space weather habitable zone would look like. Because even if you have liquid water, if you don't have a magnetic field or if the planet's magnetic field can't protect it from that activity, then any life at that planet will be at the bottom of the ocean. So it's not going to look like ours. It's not going to develop the kind of technologies we're interested in, unless you've watched Aquaman.

So what I'm going to try to do is talk about what we're studying, the sun earth system. Have any of you heard of the phrase space weather before? Anybody want to tell me what space weather is? Don't be shy.

>>STUDENT: Solar activity (inaudible) within our solar system interacts (inaudible).

>>DR. ALEXANDER: Basically -- I don't know if you heard that because -- what's your name? Because Katherine doesn't have a microphone. But essentially it's the interaction of the sun with the earth, and it's typically a magnetic interaction. There's some particle radiation and some other stuff that we'll talk about. But it's essentially a phrase that we use to try and understand what the space environment around the earth looks like because of the presence of an active star, which is the sun.

The -- some of the effects actually felt on the ground -- we'll talk about that briefly. What I'm going to do is define space weather a little bit and then we'll actually -- most of this talk is movies. We'll show you what's happening. Pretty much -- I think every single movie is a real observation. It may look like it's CGI but it's real observations. And we'll talk a little bit about that and how it feeds into how we understand this.

When you think about terrestrial weather, the kind of stuff you drove through today, we're pretty good at telling you -- although today we were not supposed to rain. It was supposed to rain tomorrow. So we don't always get it right. But you're pretty good at saying what the weather system is going to look like. We can fold it into models and predict a certain amount of time in the future. We're pretty good at having weather prediction.

When you think about how we can predict space weather, looking at what the sun might do, and again we'll go into a little bit more detail in that, rule of thumb is we were roughly aware of what terrestrial weather was in the 1950s. We've got a little bit of knowledge, we understand the physics. It's so complex that we can't really tell you.

We know, for instance, if there's no sunspots on the sun, there's not going to be a lot of space weather. So that's something. Even if there are sunspots on the sun, the chances of space weather picks up. Extreme space weather picks up. But being able to predict an event is difficult if not impossible. Even if you can predict an event, predicting what it's going to, say, do to the earth is impossible.

The one thing to remember is even though the sun is very close, it's 150 million kilometers away, the earth is really, really small. So it's not a really big target. So we'll talk a little bit about that as we go.

This is today's space weather. So you can go online and you can take a picture of the sun today. There's many, many different images you can get, different wavelengths. This, I believe, is three or four which is single ionized helium. So what you're looking at here is what we call the chromosphere.

You know about the solar atmosphere? So the surface that you see, the photosphere, it's what you would see if you were to look with the right goggles on. Like, don't look at the sun directly. But if you were to look through a filter with your naked eye, you would see the surface called the photosphere.

Because this is single ionized helium, we're looking at surfaces of about -- the surface of the sun is about -- we're looking here at about 50,000 degrees Kelvin. And it's hot enough that you can take an electron off helium. And when you do that it gives out photons at 30.4 nanometers. And typically again -- it looks pretty boring. Right? I mean, if you look at it, there's next to nothing. You can see a lot of mottling. That's a flexion of the granulation on the surface. That's something else we could talk about later.

There's this little fuzzy blob over here. It's called a plage. Plage is the French word for beach. It looks like a sandy beach. Underneath here is probably a little baby sunspot. So the sun is not very active right now. So we're not getting a lot of space weather effects at the earth right now. We're in a period called solar minimum. We'll come back to that in a few slides.

So that's what the sun looks like this morning. And if you can see the screen, it looks a lot nicer than it does -- if you can see the computer screen, it looks a lot nicer here. You can see a little thing called a prominence, another one up here. And there's a lot of interesting structure on the surface of the sun.

We also have, if you go to NOAA, the space weather prediction center, it has all of its data. We have a couple of satellites upstream at what's called the Lagrange point. And so we've got all this data. And you can take that data and with all this knowledge and some modeling, you can predict what the space weather is going to look like. If you -- if I had to ask you, if that's what the sun looks like, what's the weather going to look like tomorrow? I'm asking you. What would the weather look like tomorrow? That's the sun. Everything happens from sunspots and energy. What's going to happen tomorrow?

>>STUDENT: (Inaudible).

>>DR. ALEXANDER: Hmm? Don't be shy. This is all new to you, so you can't be wrong. Well, you can be wrong, but nobody's going to make fun of you for it.

>>STUDENT: (Inaudible).

>>DR. ALEXANDER: Right, nothing much is going to happen. And if you look at the predictions, this is a chart to try and show you, which is what the solar x-ray flux is going to look like. The surface of the sun is so hot that it produces x-rays instead of visible light. Nothing. Right?

The sun is doing nothing right now. If you look at the solar photons (inaudible) it's a low energy version that we look at, ABCMX. Don't ask me why but that's the classification for solar flares. A B flares is ten times stronger than an A flare, a C flare is ten times stronger than a B flare. And you think you've got a nice trend going, and then we call it M and X. X flares a giant flares. When some of these biggest flares happen -- has anyone seen an aurora? Northern lights? Southern lights? Where did you see it?

>>STUDENT: I used to live in (inaudible).

>>DR. ALEXANDER: So (inaudible) so we see them in Scotland a lot when you're not in the city. The year I arrived in Rice, there was a big storm, a huge X40, which means it's 40 times the M flare. It was so strong that there was aurora seen outside of Houston. So if you were away from the city lights of Houston, you would see an aurora, which is quite amazing given that we're at 30 degrees latitude. 2003, November, October. They called it the Halloween Flares. There was a series of three or four days producing these flares.

And so that tells you something about how the sun can affect the earth. The fact that you can compress the earth's magnetic sphere so much that the particles are coming in to create the aurora are actually coming in at latitudes as low as 30 degrees.

An 1989 story -- most of you are all too young to know this, but garage doors used to operate on radio not infrared. Way back 30 years ago, it was a radio transmitter. And the flare was so big that day in Los Angeles, doors were openings and closing at random.

But that was because the particles streaming into the earth's atmosphere were changing the properties of the ionosphere and adjusting radio emissions in the ionosphere at roughly the right frequencies to make garage doors think that they were getting a click.

So there's a lot of backdrop to that, but (inaudible) proton flux. These are from satellites. So this is in earth orbit measuring protons coming from the sun. Just background noise. And then this is a thing called the KP index, which is to do with changes in the magnetic field on the surface of the earth, and you average them over three hours. You do a bunch of stuff.

So this is the flare classification. Sorry this is the flare classification. This is the proton flux classification. This is the geostorm classification. If you're here, that's a big storm.

Again, this is where we are right now. Next to nothing happening. Sun is pretty boring right now.

So the previous one I showed you helium, the chromosphere. So you can see up in the top right corner, there's a tiny little sunspot. So again, there's a tiny little one up there and I think if we went back, if the -- see, I know I've got two hours so I'm just bumping my gums and taking my time.

So that sunspot is here, not much going on. So again, sunspots are very important and we don't have any right now. And then this is -- if you actually go to the website for this, this is a depiction. This actually happened. This was 4:00 p.m. UT, which is 10:00 a.m. Houston time. So this is this morning, like I said. And so this is the kind of prediction for the aurora. You can see, this is the United States. Michigan is in here. There's Greenland. There's Scotland. And these are particles that are coming in.

You know a bar magnet? You've played with bar magnets before? So if you think of the earth, it has a large scale magnetic field, north pole, south pole. Just like Rice, you guys (inaudible) can you? (laughter). I hope you get (inaudible) for this.

All right, thank you. So you have a -- they are washable, right?

So that's your bar magnet, right? And for the earth -- so the sun will be over here. There's a thing called the solar wind comes in and that gets dominated also in these big events that you see the movies of. And what happens is, it's very hard for charged particles, protons and electrons, maybe some alpha particles, helium nuclei, to cross magnetic fields. So these particles come in and they interact here, but they can't cross the magnetic field. It has to do with conduction and then how (inaudible) forces and so on.

So what happens is they get deflected. And where they can come in, where they come in is at the poles. So here's the earth. There's your north pole and southern lights. It's a lot more complicated than that and my drawing is not all that good but it turns out because there's a constant streaming solar wind. The magnetic field -- let me see if I can do the green -- what happens is the magnetic field gets compressed by the pressure in the solar wind. So where it was red it gets pushed into green and out back because this stuff gets pushed out this way.

The magnetic field at the anti-sun side gets stretched out so it looks like an eyeball. This is called the geomagnetic tail. And so what happens is the field lines are going north and south, are oppositely directed. And so what happens is when you get an event that comes into the system essentially squeezes this side in further. And because you've got oppositely directed fields, you get some interesting things happen. In other words you get fields connecting and springing back under tension.

And what they do is they drive particles back into -- so a typical quiet aurora like the picture over there are from particles energized in the geomagnetic field. But they're being energized because of the interaction with the sun with this big bubble of the earth's magnetic field.

When you have a solar storm, you have essentially another bubble coming, coming in. We'll talk about that, even show you some observations. And they can puncture the front side of this and they can inject particles directly from the interplanetary medium directly into the earth's system. When that happens you get a much stronger aurora. It comes with a bigger compression. If you have a bigger compression, the particles come in at lower latitudes and you get all the things we just talked about.

So in a nutshell, that's the whole lecture. That's what happens. If you won't mind, I will do this. Don't forget to take them back because we do need pens at Rice, too.

So why is space weather important? Because of how it affects the earth system. Not just the earth. We have stuff in that earth system. For example, most of us if not all of us now rely on space for our cell phones, for GPS, for all sorts of information. Those satellites are up in a region 300, 400 kilometers above the earth that are being directly affected by these interactions.

And so what can happen, and I'll show you a couple things, you can enhance the charging on a spacecraft. Spacecraft naturally charge because some parts of them are dark and the dark side of the (inaudible) side, so some of the spacecraft is in shadow, some are in sunlight. Metal, that allows some conduction, you get some charging going on.

You can have what's called single event upsets. We'll talk about that in a second, too. You can damage solar cells. I'll show you a picture of that. And so all these things -- this is a bit more generic. It's not micrometeorites in there. If you're an astronaut, if you're in the space station, you're generally okay. If you're on a space walk, you're not.

And even though astronauts have (inaudible) even though astronauts are technically classified as radiation workers, if they're out on a space walk during one of these storms when it gets to the earth, they can get an equivalent to one year's worth of dosage in a couple of hours. And because of that, when they came home they would not be allowed to fly again. So I've heard some stories. They take (inaudible) and stick them in a metal drawer inside the shuttle so they don't get registering as having extra radiation. Now the big discussion is about how much radiation we can allow for astronauts to go to Mars, for example.

So up in low earth orbit where you have them interacting with these particles. You have all sorts of interesting effects on your spacecraft. This is costly if you happen to be a telecommunication company. So it can cost lots of money in terms of lost business and so on.

We would love to be able to predict when all this is going to happen and we can't so right now it's a little like a Dutch boy with his finger in the dike or the little boy crying wolf. If we keep saying the sun is doing something and they shut down they're systems to protect them, they spent a lot of money shutting down their systems. So there's a lot of to and fro between NOAA, space weather prediction center, and the satellite operators.

When you come down a little further, we have the earth's ionosphere. Cool thing about the ionosphere is ozone. Ozone is really good at absorbing ultraviolet light. You essentially ionize that layer of the atmosphere, which is why we're really good at names, that's why we call it the ionosphere, right?

Well, when the sun is much more active and you get solar flare or coronal mass ejections, the UV goes up as well. And so you generate currents in the ionosphere.

I'm going to show you a really complicated picture in a few slides just to make it sound like we're really clever because of all the interesting physics that happens. But what happens is when you dump energy up here, you essentially create a potential difference between the ionosphere and any conductor on the ground. Power cables. Ion gas pipelines. Anything that's conductive. And so you set up a big potential difference and that can lead to effects on the ground, and I'll show you some pictures of that.

That big flare in 1989 I mentioned actually wiped out the power grid in Quebec in northeast Canada. And there's a whole book on this event where an operator in the -- so the Canadian grid and the U.S. grid are connected, particularly in that northeast corridor. Texas has their own grid, so, we're okay. We're south, and we're separate from the rest of the U.S. grid.

But some operator, I don't know if it was in Maine or Boston, saw some weird stuff happening and so decided to stay on the safe side and flick a switch to disconnect. Turns out if he had waited another .3 or .4 seconds, the Canadian grid would have started drawing power from the northeast coast. So Boston would have gone out, New York would have gone out. They would have drawn power up into the sinkhole. Essentially a big transformer blew because of the currents up here.

You can -- if you change the ionosphere, your signals where you're getting -- if you're watching football or something, or you're watching some game or you're communicating with your friend, you're actually bouncing your signal off the ionosphere. Nowadays what you're really doing is you're bouncing off a spacecraft. But the signal from your phone to your friend's phone is going through the ionosphere.

And if the ionosphere changes, (inaudible) just to give you an analogy. And so it takes a difference in path, your GPS gets off, you could be off by maybe ten, 20, 30 meters. And if you're flying an airplane -- and nowadays airplanes are using GPS all the time. That's not such a big deal unless you happen to be landing. Maybe even taking off. If you're landing and using GPS and GPS is off by 30 meters, you might want to worry about that.

If you have a self-driving car, and your GPS is off by 10 meters, you're traveling at 75 -- well, 45. Imagine you could drive 75 miles an hour on 45. That 10-meter difference is a huge thing.

So we have to not only understand this from the science point of view and the operations point of view, but we have to know how to mitigate the fact. You can't tell the sun to stop it. You can't tell the ionosphere not to respond. So you have to develop systems that are resilient to this effect. If you've overland pipelines like in Alaska, maybe in Texas, too, but Texas is quite far south. You can basically have currents running across those pipelines and so you increase corrosion. And so that becomes obviously a cost issue and potentially an environmental issue. A whole bunch of different things goes on there.

If you're flying to Japan and you're going over the pole, that's where all the effects happen. Flights get -- if they know there's a big solar storm coming, flights will be rerouted away from the solar regions. Flight attendants who regularly travel across the poles will wear (inaudible) so they can measure how much radiation they're getting. So all sorts of very interesting things happen.

I keep bumping my gums as long as you'll listen, but is there any questions about this so far? The cool stuff is still coming. This is verging on the physics without giving you the physics.

So tell you one last story about this effect. In 18 -- (snaps) I've forgotten my years. Eighteen -- it was either 1869 or 1859, was the first ever recorded solar flare at the earth. And it was recorded by a guy called Richard Carrington and another guy called Richard Hodson at the same time in England. It was such a bright solar flare that they could actually see it through the telescope. Do not look at the sun through a telescope. These guys didn't know any better.

Then a Scotsman who happened to be looking in Kew Gardens, (inaudible) and he saw a huge jump roughly -- some delay between when these guys saw -- it takes light (inaudible) seconds to get from the sun to the earth. So shortly after these guys saw the light, this guy measured this wiggle. At that time, the technology was the telegraph. If you watch cowboy movies, right? And it turned out that -- and again there's many examples of this.

And again if you think of the northeast U.S., used telegraph a lot. They could run the telegraph without batteries. So there was enough power in the cables, there was enough power that they could actually transmit the signal that the telegraph operator was sending. So that was kind of an interesting effect. 170 years later, we don't use telegraph but we do use satellites and we do use things in space that get affected by solar -- solar activity.

And so that means that we are far more sensitive to solar storms than they were in the 19th century just because we're so reliant -- everything -- some of it, so you miss the big fight because the satellite goes out. Not such a big deal. But if you're fighting a wildfire in California and you're relying on data from space, that's a problem. If you're flying a plane with GPS, that's a problem. If you happen to be launching a rocket from Cape Canaveral, that's a problem.

So there's so many things going on, we really have to be thinking about space weather.

I've mentioned this storm already. This is Quebec going out. There's a nice video that NASA put together. I was going to show it, but I decided not to, called "What if." And the what if is if you didn't have this half a second, it just shows all the lights going out on the eastern seaboard and then working it way across the United States. In other words you could have a national blackout because of this.

I don't know if you can see this but this is one of those giant transformers. I think is person is about this high. And again, it's much better on the computer screen. This is fried. This whole thing. This is a thing that basically exploded because it was so much -- just a potential difference on it, that bust. And that started this whole triggered relationship that took out the whole of Quebec province. We even lost the Mars probe because it was affected by a solar storm.

This is, like, 400 kilometers, (inaudible). But in here, you're still protected by the earth's magnetic field. We can talk about this more if you ask questions. It turns out Mars doesn't have a large scale magnetic field, either. So that becomes a large scale hazard for not just equipment but people, as well. And so we've lost satellites around earth. We lost a probe going to Mars.

(Inaudible) there's much better images than this one. I don't know why I kept this one. But there's a lot of spacecraft up there. I mean, think of these 4,000 objects that are listed here. Space debris is another interesting issue. There's something like 1600 operational satellites now. Some of them we're not supposed to know about. But telecommunications, and then there's a bunch of junk.

The two biggest components of space debris, it's Russian second stages, just these giant things still floating around in space. Floating isn't the right physics term, by the way. And then there's a whole bunch of really small clouds of material caused by two things. One was the Chinese tested an anti-satellite missile on one of its own satellites. It created a cloud of debris. And then there was an accidental collision by a satellite with a Russian satellite. So by number, those two created part of the problem. By mass, it's the Russian -- I'm not sure which rockets, but Russian second stages.

So every so often, the rocket has to move up or down and it does that by slowing down or speeding up. But it moves up or down to avoid these clouds of material.

We're launching (inaudible) now and so that number of objects is going up. We can measure things to 10 centimeters. So if an astronaut loses a glove, drops a spanner, you can detect that from the ground. A fleck of paint you wouldn't see from the ground but if you're an astronaut, it's moving fast. That's a problem.

And so that goes on. All of this is affected by space weather in an interesting way. And so the interesting way is No. 1, here.

So a couple effects that you have. Now, the top one is the most interesting, I think. But obviously you charge your spacecraft. There's more charged particles coming in, these are usually made of aluminum. And so you charge spacecraft.

You get single event upsets. The spacecraft have lots of computers on them. All you need is one particle to pass through, hit your board, and you can get a glitch. And sometimes that glitch is big enough to shut down the spacecraft. Sometimes it's just like your computer freezing. So your teacher is here so I shouldn't say this, but you couldn't finish your homework because there was a solar event and you lost everything. So blame the sun.

What's really interesting is this thing, a secondary effect. In fact, we're talking at Rice with some students about trying to fly a (inaudible) to measure this. So we're talking mostly about particles and how they affect spacecraft but those charged particles come with a release of energy in all wavelengths of the electromagnetic spectrum, as well as producing particles. When I show you the movies, we'll talk about that.

That enhanced ultraviolet radiation, that means the earth is a catcher's glove and now you've got more than one baseball coming and coming faster than usual. And so what happens is the earth's atmosphere gets heated more. That layer of ozone absorbs a lot of this radiation and heats up that layer of the atmosphere.

So what happens when you heat something up? It puffs up. And so even though the particles up here, there's, like, five particles per cubic centimeter. That five particles is really small but when you puff up the atmosphere, that can move to maybe five and a half. But that's enough, an extra bit of drag on the spacecraft and it slows down. But you don't just slow down. You have to change your orbit. And so it turns out when you get one of these big storms, this kind of thing happens.

So what this is, this is going back. These big giant events are not that common. I should update this to the 2003 one. Sorry, a few years ago.

What this is, this is NORAD, North American -- you know what NORAD, means, right? They're monitoring everything in space. They're tracking all these objects. And the way they track them is -- (mic cuts out) two hours later -- and you just may want out. And then what this is is a measurement of how many of those objects they lose. Typically (inaudible) something like 2,000 objects.

Typically they're losing a couple of hundred. Now, that doesn't mean they're losing them. It's just they lost them from signal. Maybe the orbit changed because it's a piece of junk that broke up. So these are not separate spacecraft. Just anything above 10 centimeters. So that's your background.

Look what happens when there's a solar storm. So this is a big magnetic storm, the eighth of March, 1989. They started losing 1500 of them. What was happening is, the atmosphere is puffing up. The spacecraft is seeing more particles, there's a drag on it so it's slowing down and dropping in its orbit.

And so the recovery here is it finally worked out and they've gone around and looked for it and found the object but in its new orbit. So that's fine. No big scare story there, right? The things have been found, they're just a lower orbit. So even though the earth's atmosphere recovers, these satellites are now lower than they were.

If they have propulsion, you can boost them back to their original orbit which is what we do with the space station a lot. But if they don't have propulsion, they're in a lower orbit with a thicker atmosphere and so their whole lifetime gets degraded. That may or may not be a problem depending on the nature of the spacecraft, how long you plan for it to be there anyway. But it does raise (inaudible) reboost them.

So that's an interesting thing because you wouldn't necessarily think of that as a secondary effect. But it's actually more important in some respects, degrading the lifetime of a satellite.

This is just to show you this is a picture of what happens to solar panels because of the enhanced charging and this just looks at the different kind of panels, (inaudible) phosphorus, something. And you can see the ability to generate energy drops over time. And a lot of it is caused by damage of particles hitting these panels. Remember, these panels are huge, typically. So they're taking the hit.

And so essentially you could lose your satellite catastrophically, you could lose it over a long time because its orbit changed, but you could also have it not work because it can't generate enough power to power its systems because of damage to the solar panels.

And then the last thing I wanted to show you was if you're an astronaut, here's what I talked about in terms of radiation. There's a whole vernacular around how you do this. There's equivalent dose. There's all sorts of stuff. Some of it is just how much radiation you're getting and some of it is how much your system is responding and then there's all these different things. So it's cutting that out a little bit.

So if you're behind a typical size of a spacecraft, running through it is roughly 10 grams per centimeter of aluminum. So, these are the kind of numbers you get behind that shielding. So this is not if you're in a space suit but if you're in the spacecraft.

These are different limits that NASA puts in. The average person, you or me, this is typically what we get per year, 360 mrems. This is called -- have you heard of Roentgen? Discovered X rays? And I apologize to the ladies in the room, but this is the roentgen equivalent man. So this is 360 mrems. So .36 rems is what we're expecting. If you're living in a place that is higher than that, move.

If you're Homer Simpson, you're allowed up to five rems a year. So roughly 15 times this, 12 and a half, 13 times this. If you're an astronaut, you're allowed 50. 150 times you or me.

And as I said, when you get one of these big events, notice we're going back to 89 again, this is what they're allowed per year. They can get that in two hours with one of these big events. And what this is showing you, when it comes to -- it's a whole other topic talking about radiation for astronauts. Radiation damage. Are you in low earth orbit? Are you on the moon? Are you at Mars?

There's two main components to that exposure. One is the sun. Again, I'm going to show you a bunch of stuff with the sun. And the other is a thing called galactic cosmic rays. Colliding black holes do all sorts of stuff. The difference in those particles is from the sun, there's lots of them. We're close to the sun. But the typical energy, this is in mega electron volts, it may be around a billion electron volts or so.

There's lots of them. This is a spectrum, so you can see there's lots of low energy, few high energy. But they're all there. You would integrate everything over this curve. That sounds like a lot, a gigavolt, but it turns out it's not that much. A typical spacecraft, 10 grams per square centimeter can protect you from this. So if you've heard about the Orion capsule for going to the Moon and Mars eventually, in the capsule they have a little metal grid all the astronauts have to hide behind. So they think they can stop it fairly well.

A galactic cosmic ray is a tera electron volt. So it's a 1 million times as energetic as a solar particle. But there's very, very few of them. The trouble is one of them can pass through almost anything. They can generate secondaries and you can't stop them with 10 grams per square centimeter.

So NASA are very, very worried about galactic cosmic rays because they can't stop them. So they want to understand the spectrum. They want to understand how much shielding do we need? What is it going to look like? Is it going to be aluminum? Is it going to be water?

What this shows you is there's very, very different effects. This is a big storm from April 1998. It cuts off, 300MEV? No worries. This one from September gets up to 4GEV. Small fluxes. You can see the range here. But these are the things that we understand. These are the things we can tell from the sun and we can start to put them into play in terms of calculating how an astronaut may be affected.

>>STUDENT: The (inaudible).

>>DR. ALEXANDER: Well, almost. Anything with mass can't move at the speed of light. But they move -- they're close to the speed of light. Yeah.

>>STUDENT: Well, with that in mind, how do we (inaudible) by the time we see it, it's going to be nearly on us.

>>DR. ALEXANDER: Well, if you're worried about it hitting you, you're too late. We know these things are there because we detect them in all sorts of ways. When they hit the earth's atmosphere, you get all kinds of things that slow down as they work through. There's all sorts of ways of detecting them. We can't say -- for the sun, we could in principle -- give us another 50 years, we could in principle say there's a big red curve coming. Okay? Get yourself locked away. Forget your EVAs, do whatever you need to do. Turn your spacecraft so it's pointing at the -- whatever you need to do. The galactic cosmic rays you can't do that. Also we know where these are coming from. They're come from the sun. So if they're coming from over there, just make sure your shielding is pointed in that direction.

What we'd like to do is understand typically how many of them there might be. If we added them up -- because again, if you think about this, I'm using big numbers here but these are all mostly (inaudible). Now, I don't know what any of you weigh, I'm a little over (inaudible)kilograms. A proton is not going to do me much damage. But what it does, it can damage cells. It can do stuff internally.

So we need to try and understand how many of these things we expect. If the mission is a two year mission, how many of those particles would you typically expect an astronaut to be exposed to given the conditions they're working in? One of the things we do know, this is -- usually I use this as a trick question but I'll just give you the answer. Actually, let me ask you the question.

Galactic cosmic rays are huge energy but very few of them. And you don't have enough information to answer this. But we'll do it anyway. Lots of particles from the sun. You get these particles at solar maximum, I'll show you in a second, when there's lots of sunspots you get lots of coronal mass ejections, you get lots of particles. When would you prefer to go to Mars? During solar maximum when there's lots of sunspots or during solar minimum when there's hardly any sunspots? Katherine?

>>STUDENT: (inaudible) that way you're on the other side of Mars, I guess, theoretically in coming back at the beginning of another solar (inaudible)?

>>DR. ALEXANDER: And what's your rationale for doing that?

>>STUDENT: Well it would take six to nine months to get to Mars roughly. I don't know. I don't remember (inaudible).

>>DR. ALEXANDER: Sure, sure. So you're trying to minimize the number of solar particles.

>>STUDENT: Right.

>>DR. ALEXANDER: Okay. Anybody want to agree or disagree with that? Please disagree.

>>STUDENT: The more solar particles we've got coming from the sun, (inaudible).

>>DR. ALEXANDER: Right. That's -- so your reasoning -- so here's where I get to ding both of you. You're wrong but your reasoning was good. You're right but your reason for being right was wrong. So what you were trying to do, Katherine, was basically say how do we minimize the solar particles? I didn't give you enough information for the right answer. But I've already said that these are low enough energy, even though there's lots of them you can protect yourself from them. So it turns out they're not so bad. You don't want to be out there walking around the surface of Mars where these things are going off but you can sort of handle these energy.

You can't handle the -- and it turns out when the sun is more active -- so another way of thinking of -- I'm going to redo this drawing. Because you talked about the particles coming from the sun, right? So if you take this drawing a little bit differently, we have the sun which I probably should use red, right? We have the sun. And I'm sure you-all know the sun has a smiley face on it, right? And the sun is sending out radiation and is sending out solar wind in all directions.

When I put the earth -- well the earth has this magnetosphere and gets balances and holds off this solar wind. Well similarly over here, this is called the interstellar medium. And my writing is almost as hard to follow as my accent. And so there's a pressure essentially the same from all other stars. And at some point there's a balance between the pressure of the sun. The sun's pressure -- and this is called the heliosphere -- and the accumulated pressure of the interstellar medium.

When the sun is very active this whole magnetic field puffs up and so this moves out. And so this is populated -- the sun has a large scale magnetic field, as well, that goes all the way out to the heliosphere. And remember, charged particles don't travel across magnetic field very well. So if you're a galactic cosmic ray out here, you're moving fast enough that you can punch your way through quite a lot. And, in fact, if this is your space station, this is your problem.

But when it's solar maximum, the whole sun's magnetic field is puffed up. And so this same particle doesn't get so far. And so it's better to travel at solar minimum because even -- sorry, better to travel at solar maximum because even though you have potentially a lot of particles from the sun, you can handle them. It's a bit like Scottish rain versus Houston rain. You're going to get wet anyway. You're not going to get beaten into the ground. Houston rain, a little bit different.

So, you want to travel during solar maximum because you can prevent -- you can reduce -- it's called the (inaudible) decrease. You can prevent some of those galactic cosmic rays getting to you. We still don't fully understand how much (inaudible) because each cycle is different, which is -- how am I doing on time? Okay. I could be talking all night. And we haven't even gotten to the cool movies yet.

So this is the thing. It's a trick question because we didn't talk about the earth's magnetic field. But your logic was good. And so there is this physical interaction between the solar medium, the planetary medium, and the interstellar medium. And it's magnetic interactions. Magnetic fields have a pressure as well. So think about a pressure interaction. All these different things.

Okay. The sun. The sun, what we're looking at in the top here, actually in both cases but let's focus on the top for a second. We've been systematically measuring sunspots since about 1610. Galileo likes to say he discovered sunspots. He did not. It was a bishop. But what he did do was show it was on the sun. Some people thought it was high clouds in the earth's atmosphere. Remember, we're going back 400 years here.

So if all you do is look at the sun on a given day and just count how many sunspots you see, today you would see one. A half. You might see one today. And you count the sunspots and you do that for 400 years. This is what you get. And notice, we'll talk about this in a second, although it'll probably take me more than a second but we'll talk about this.

Notice what you see. A regular beat. The sun has an 11 year cycle, which corresponds to a 22 year magnetic cycle, but it's an 11 year sunspot cycle. So this is an interesting thing. It tells us a lot about the star because you could fit a million earths inside the sun. It is a very clear path. And that tells you something about the machine that is the sun. That's a whole other lecture because it involves other things with how the sun rotates and other stuff.

So a couple other things. Notice the maximum are not all the same. So think about trying to predict -- if you're thinking about going to Mars, 2040 or whenever NASA gets around to it, that's 20 years away. But it's solar minimum right now. So 20 years from now, in a 11 year cycle, we'll be at solar minimum. Maybe you don't want to go. Or maybe it will be one of these cycles. You know? Maybe maximum is not that different from minimum and so it sort of doesn't matter. Or maybe it's one of these giant ones. So not only do you want to be able to predict -- an 11 year cycle is pretty predictable. It can be as low as eight or as high as 15. You don't know how many sunspots it's going to be. People are trying to predict this. They're trying to use all sorts of clever physics (inaudible) they're trying to work out what the maximum is going to be and there's some success. There's a big jet stream under the surface of the sun that's moving magnetic fields around -- a whole bunch of stuff. But it's regular in time, not regular in magnitude. And then you get stuff like this.

So remember, this is systematic regular observations, looking for sunspots. If you go back -- if you know that this pattern exists, you can go back into Chinese records and find observations of sunspots. Maybe even some Arabic records. They're sporadic. And people were looking but nothing was there. Not only were they looking, they had telescopes. They had all the things they needed. This is called the Maunder minimum. I think it was his wife, but he took the credit. You know how it goes. And there was no sunspots for seven cycles, to the year 1750. This coincided with Europe, in fact, in the U.S., too with extended winters. The Hudson River froze over later than it normally did. There was all these artists painting pictures -- we didn't have selfies in those days -- of people (inaudible).

One of the things I would point out is that there's a physics thing I want to mention in a second, but the -- if you take this 11 year cycle, so, if you think of the sun as a Starks you know what the (inaudible) magnitude is? You don't care what the wavelength is. You just add all the light coming from the star.

Over the course of a solar cycle, maximum to minimum, the sun's brightness changes by one tenth of 1 percent. Okay? Now, the sun is pretty big. It's pretty close but it's one tenth of 1 percent in the optical, which is the bulk of the radiation coming from the sun. So that's not a huge effect. You're not necessarily going to see that effect on the earth's climate. Not weather, but climate.

If you go into higher wavelengths, it's more like a hundred. And EV is more like ten. But the bulk is in optical and that only change by a percent.

But when you don't have sunspots for 17 years, then you're no longer inaugurate energy into -- even at 1 point percent change, you basically have a diminished sun. And so the earth -- that affected the earth's climate for a short amount of time. I mean, several years we're talking about. Maybe a few decades.

So the there's some interesting stuff. So the physics part S remember it's a giant machine, the sun is churning away. Think of this as a clock. It's very easy to stop a clock. Right? You can drop it, you can throw it against a wall. It's a lot harder to get it started again. You have to wind it up, do all this stuff. You have to go and buy a new battery. So you've switched it off. That's one physics problem. How do you switch it off? The bigger problem is once it's off, how do you switch it on again? And we're still uncertain about that. People have tried using chaos theory, it allows you to go to this -- these attracters and bifurcations. Even though you don't see a signal, the information is embedded in there.

The other thing I want to say at climate change, I don't want to get into it too much. This is not what we're talking about here. People have argued that the sun, since its inception has been getting brighter, and if it's getting brighter the earth could get warmer. And that's true. The difference is we know so much about the sun and we know, we've been able to monitor this for 400 years. There's other things that we can look at in tree rings and ice cores. But we've been visually monitoring the sun really, really well. And all the calculations suggest that that brightening of the sun contributes about 25, 26 percent of the climate change. So it's not producing a hundred percent. It's not the sun doing that. And I'll leave it at that.

This is just showing you what the current -- this is the last cycle and the current cycle. This one is interesting, it was double peaked. Again, this is the kind of thing you have to deal with. You couldn't have predicted that. Then you get your solar minimum. And these individual spikes are, like, if you get one big sunspot -- you have to look at the average. And eventually there's another little double peak. Just so you know right now, we're about here. We're turning around here.

So that's the large scale. There's positive, negative magnetic field patterns, and again that's a whole other talk.

In and out cool movies. So I've just shown you this set of peaks. Sunspots. What we're looking at here is two sequences of observations from the solar dynamics observatory. This is at 17.1 nanometers which is a transition in iron that's been ionized eight or nine times. So there's eight or nine electrons picked off the iron. There's a whole other lecture on why the surface of the sun is 6,000 and the atmosphere is a million. Try keeping hot water (inaudible) when you're pouring cold water in the other. Try that experiment for yourself. Or with a friend, but try it anyway. It's an interesting problem.

This is solar maximum period. There will be a few days near solar maximum. This will be a few days near solar minimum. So these are the same kind of observations, just as different phases of the sun. We're looking at the atmosphere above. There's sawn spot under here, there's a sunspot under here. Maximum. Minimum. Right?

What you'll see is the sun -- probably know this already, too but the sun rotates. So you'll see the rotation and you'll see there's lots of activity. Typically we call this -- these regions the active sun, and we call everything else the quiet sun. If you look, nothing is quiet. It's never quiet. It's always moving and doing interesting stuff. And these are real observations of a star.

Okay, here's my other question. If you look at the a star with your naked eye -- not the sun -- what do you see? Isn't a trick question.

>>STUDENT: (inaudible).

>>DR. ALEXANDER: If you look at that same star through a telescope, what do you see?

>>STUDENT: Still a dot.

>>DR. ALEXANDER: Maybe two or three dots. Okay, this is a star. There's a million (inaudible) fit in here. If this was the earth from the distance of the sun, you could separate hobby airport from bush airport. You could almost separate UH Clear Lake from Rice. The resolution is 56 kilometers. So we're observing a star in space, a spatially revolved star at 50 kilometers. You know what I'm trying to do.

Not only that, as you'll see, we're observing it in time. We see (inaudible) we see flares happen, we see dynamic changes in the atmosphere. We see sunspots come and go. We can observe the star in time. And this is just one wavelength. I already showed you the 80,000 Kelvin image from helium. That's a different wavelength. I'll show you visual light wavelengths and so on. We can basically differentiate this star (inaudible).

Now, we have to go to space to do this because this doesn't make it to the surface because of ozone. We wouldn't be here if it made it to the surface. It (inaudible) and it would break up molecules. We would not be here. So we have to go to space to do this. But this is a star. All other stars should look something like this but this is our own star.

That's the kind of used car sales man version.

And of course we can make it any color we like. So we have blue for -- we have green for 17.1. So there's a lot -- you can spend a lot of time talking about this. You know the sun is rotating.

One sunspot, just the one spot, it jumps a little bit. Notice the magnetic field ones. Each sunspot you can think of as -- you can think of as its own little bar magnet.

You look at the maximum but just much, much more of it. Most of the concentrated in what we call the activity belt, which is roughly plus or minus 30 degrees latitude, it looks more because it's a sphere and so it's projection effects. Lots and lots of dynamic activity. Field lines connecting two different hot spots. Positive and negative polarity. Doesn't have to be right, left. It could be the other way around. There's lots and lots of stuff going on.

Say that again?

>>STUDENT: (inaudible).

>>DR. ALEXANDER: So -- yeah. Okay, thank you. So what we're seeing -- the atmosphere is so hot, a million degrees, 2 million degrees, 3 million degrees, that it's completely ionizing everything, which is mostly hydrogen. So what we're looking at is iron. There's one ion for every million or so hydrogen. But because we can select using our technology for (inaudible) and stuff, we can select individual emissions. We can ignore all the hydrogen and focus on the iron.

What you're looking at, everything gets ionized. This is iron with eight of them kicked off. So it's a hot temperature. And so the gas is no longer called a gas, it's called a plasma. And so it's a gas of charged particles. Mostly hydrogen. Quite a bit of helium and then trace elements of iron.

Because the charged particles, going back to this, the physics is such that the particles don't cross magnetic fields very well. So each one of these sunspots, my students at rice in the solar physics class get tired of me doing the same drawing. I do this, like, a hundred times over the course of the semester. Negative and positive or positive negative, doesn't matter. There's a whole bunch of field lines coming out between these two polarities.

There's a thing called (inaudible) in the middle. And what's happening is, so this is all full of gas. The key thing you should notice and I should have pointed out, actually, if I had to ask you, most people would say that the sun is a big ball of gas. It's ionized gas, so you could be refined and say it's a big ball of plasma. But notice it's not a big fuzzy blob. There's a whole lot of structure nit and the structure tends to be in the number of these -- we call them coronal loops. And they're just magnetic field lines that happen to be delineated by heated plasma.

And what's interesting about -- so there's two problems with the coronal heating problem. How do you make it hot when the surface -- so the energy is coming from the core of the sun where it's 50 million degrees. That energy spreads out, so the core is the campfire. As you get further away from the campfire, it gets colder. We all know that. When you get to the surface, it goes to 6,000 degrees Kelvin. Anyway, 6,000 degrees. Then it starts to pick up again. So the farther you get away from the campfire, the hotter it gets. That's one problem.

The second problem is why is it structured? Why is it not this fuzzy ball of gas? It's because each structure, the field is everywhere. You know field lines don't exist, right? They don't really exist. They're just this volume filling magnetic field. But certain chunks of them get more energy than others. And there's that day that energy going in, heats the plasma, heats the gas, makes it dense enough. There's enough of it to produce one of these structures. One of these loops.

Now, why is it structured in such a way in you know you've got field lines going be between two parts of the sunspot, the positive and negative. But why is there a gap? We think it's something to do with the pointing flux at the surface. So what happens is this plasma is being heated by some process that's dumping it into the plasma and lighting it up and it can light up for three reasons.

One, there's more of it. So you increase the density. So you're maybe bringing hot plasma up from the surface. Two it was cold and you're heating it up so you see it brighten because it went from -- this day if this can only see a million degrees, maybe it went from a hundred thousand to a million. Or it could have cooled. And it would power plant here.

Or because there's a thing -- I'm giving you all these little tidbits here. The corona is what we call optically thin, which means if you were all optically thin, I would know you had two eyes and a nose and lips but I wouldn't know whichever which way you were facing because I wouldn't be able to tell the front of your head from the back of your head. I wouldn't know which way it was pointing. No 3D opportunity. So the sun is the same way. Every piece of plasma along here is adding up to what you could see. So when it's bright, it could be bright, or that it got denser, it's just you're looking through lots of structures. Right now I could see you individually. If you were all optically thin and I went to the side, you would all add up.

That's a challenge if you're trying to take these observations and turn them into real numbers. But we're getting good with it. We've got lots of different wavelengths. We use lots of different tools.

Okay. This is just to show you the same -- this is the same thing but a little more close in. So here what you're going to see is the sun's going to rotate. Here's a sunspot in what we call the limb of the sun. And it just shows you that they're not all stationary. They're constantly changing and moving.

I don't know what you call that color. But it's just -- and again if you could see it on the screen, I think it will be available. You can get all these from the solar dynamics website. So it's just beautiful. Just these wonderful structures. Changing and going -- again, think about. There's a sunspot underneath here. These are magnetic field lines.

>>: (inaudible) combination of the gravitational force of the sun (inaudible) the energy that's being generated by (inaudible).

>>DR. ALEXANDER: Well, what we think it is, for why it gets hot? So what we think it is is essentially -- oh, I meant to put one in my pocket so I wouldn't forget. Anybody got a rubber band?

>>STUDENT: Yes.

>>DR. ALEXANDER: Thank you. Okay. So thank you think of this as magnetic field, it doesn't go in a complete circle but it's a magnetic field (inaudible). It doesn't do anything. These field lines are (inaudible) in the surface of the sun and the surface of the sun is moving around. So what's happening is you're stretching the magnetic field. What happens when you stretch a rubber band? I just added energy to it. And I'll try not let it go but if I let it go, it would fly across the room. If I stretch it so much, I can snap it. And it'll come back. If I stretch it so much, I can snap it. You're going to see that in some of these observations. So what we think is happening is because of all those observations, you're stretching the magnetic field and when you stretch the magnetic field, you've added potential energy to the field. That's energy you can tap into.

How? That's a good question. So for example, if you had an incandescent light blub (inaudible) the sun's sates almost a perfect conductor but not quite. So it's a little bit of -- it's actually (inaudible) there's a little bit of resistivity. So the currents can flow because of the resistance. They can take some of the energy out of the field, put it into the particles in the form of heat and motion. And when it snaps you can get particle acceleration. So that's the analogy you should think about and it's a very good analogy.

The other thing that can happen, and you'll see this, is if you were to twist this up, if you were to twist this up and almost if you had done, this hopefully nobody has done this in this class. And what happens sometimes is it would jump -- what we used to call a nobody but it would wrap around itself. That's breaking (inaudible) and it's called a kink instability.

>>: (inaudible).

>>DR. ALEXANDER: You will see. Yes. So you can (inaudible) to get heat. This is all very (inaudible) dynamics. It's changing a little bit. You can see loops come and go. And so once you heat, it can cool. The very fact that you're seeing this means it's losing energy. It's also conducting because the surface is cooler. Again, go back to your bathtub. Hot water, cold water.

And so you're losing energy, and so things come and go. When it gets more dynamic is where you put so much energy into the magnetic field that it can't handle it. In the same way a magnetic field would snap or kink.

So this is just your average, everyday sun. This is what it does all the time. This is a corona. Except at solar minimum, you'll have not so many of these sunspots. But even at minimum, it would do the same thing that this guy does.

Now what you're going to see is something similar. It is different. We'll talk about these things different. This band is called a filament. Up here we have another sunspot. You can see some loops. What you're going to see is not as dramatic as some of the other ones I'm going to show you. What you're going to see is the rubber band snapping and what happens is you release a whole bunch of energy. Some of it will push the material outwards. The view isn't that big so you'll see it leave the scene. But look at what happens back at the sun. Everything will get brighter and stronger. This is a solar flare.

As seen in 17 nanometers. You could look at it forever and see all these details. And there's your explosion coming out. So the rubber band has snapped. You saw that it went so bright that you had a detection pattern. It couldn't keep up with how the levels were changing. So you can sort of see.

And the size of earth -- actually, see the little clumps up there? That's about the size of the earth in this scale here. You get these tiny loops, become giant loops. So something breaks -- boom. And you get all of this activity across this huge volume.

>>STUDENT: (inaudible) spread out across the surface, too.

>>DR. ALEXANDER: Right. So two things about that. One is, yes. And two is optically thin. Right? So the optically thin thing means that it may not actually be moving across the surface. It may be up here but what it's done is moved laterally. It may actually be, depending on the angle, up here. But when you look at it, you're projecting down here. That's one thing.

But what happens is these things snap in a really interesting way. So what you have is you have -- this is where the filament comes in. So this is in cross section. The filament is a slinky. And there's magnetic fields on either side of it. And what happens is it pushes up against this field. This field then looks like this. This is a the surface. And that's -- you'll see there's a slow evolution, when I show you the filament movies. Look at what's happening. And so what happens then, these two fields come together because of the finite conductivity. This is called a diffusion region. Magnetic fields pass through it and you end up with this structure and this structure. And there's a big explosion. I should probably do that in red. Right?

This is your cartoon. This thing this s your coronal mass ejection. All the energy gets dumped into that structure and that's what you see. But because this is a height varying thing, as it moves up it redirects different field lines every time. And so what happens is you'll see the base of these structures move out. So it is moving across the surface. They're called flare ribbons is what they're called.

Okay. Whoops. Need to stop using the mouse. I think the recorder will probably show the -- NASA really is bad at music. Luckily you can't hater. But this is a nice little movie where you saw nothing at the beginning and then this goes on for hours and the music drives you nuts after about ten seconds. There's the earth to scale. Now you get your (inaudible) you can see the thing, it's called coronal rain. It was heated and brought up in here. And then once the energy has stopped, the energy input has stopped, it just rains. It's an interesting 3D instrument. There's a bunch of stuff happens out here. You can see stuff here. Sometimes you don't see the whole structure. You only seat part that's lit up. And so it becomes really beautiful and strange. Try and predict one that looks -- right? Every one looks really different.

And again, it's not my fault when you hear the music.

>>STUDENT: You're saying there's no (inaudible).

>>DR. ALEXANDER: So, no. The gravitational -- I mean, obviously gravity is pulling this stuff down. But the amount of -- the difference -- the sun is 700,000-kilometer radius. This is pretty high. This is maybe a hundred thousand kilometers but the change is gravity is not that much. And you're not converting -- used to think that the sun was powered by gravitational contraction. It's not. Nuclear fusion in the core, but (inaudible) into helium. Jupiter radiates twice as much energy as it receives from the sun and it's because of gravitational contraction. But it's in the sun it's minuscule compared to these other things.

Okay. Solar filaments. It takes a second to explain this. (inaudible) heard of solar prominences? So a prominence and filament is the same thing. Nobody knew that they were the same thing. So it's a filament because it's filamentary. What it turns out to be is if you think of -- it really is -- well there's different models. I'll do the simple one. If this is the surface of the one, a solar filament looks like this. It's like a slinky.

What's interesting about filament, down in here and in here, you have hydrogen and helium and it's 6,000 degrees. Or actually, sorry, for the helium, (inaudible) in the chromosphere, you have this 50,000 degrees Kelvin. It turns out a filament is a whole bunch of hydrogen and helium that collect against gravity in the kind of concave up parts of the slinky. This stuff. And if you draw it right you end up with a continuous structure.

This stuff is hydrogen and helium at 50,000 degrees. So what does that do? Remember your Bohr atom or any of that stuff? What's happening is first of all the rest of the corona up here is a million degrees. So what does not what this does is it creates a cool, dense cloud of material embedded by the magnetic field in the solar corona. Why do I say all of that? Because what that means is if you are looking from up here, if you're looking from up here, right, then the radiation coming from the surface at 50,000 degrees, it's hot, it's orange, is being absorbed at the same temperature. So it absorbs the light from below and (inaudible) it in all direction. Which it's called, so. You're absorbing the light from below and therefore it shows up as dark.

If you're looking from over here, there's no surface to look at. You're looking right through the material. And what's the material? It's hydrogen and helium at 50,000 degrees. It's bright. There's nothing to absorb. There's nothing behind it to absorb. So what happens is a prominence is this structure seen from the side and a filament is this structure seen from above. The same thing. And, of course, the sun rotates. Here is an absorption. Here is an emission. When you didn't know that, this is a prominence. That's a filament. Okay?

So what we've done here is provided three different observations together. 13.1 nanometers, which I think is, like, two and a half million degrees. 19.3, 17.3. May even be the same event I showed you earlier. Here's your nice sunspot, here's your nice filament. Think about the rubber band. It's expanding. You'll see it slowly evolve and then something will happen.

For some reason it doesn't let me play it. Hopefully that doesn't mean all the other movies won't play. Say that again?

>>DR. GARRISON: (inaudible).

>>DR. ALEXANDER: Uh-oh.

>>DR. GARRISON: Try righted clicking it.

>>DR. ALEXANDER: Oh, I'm sorry. I'm used to -- no. All right. It says cannot play media. Okay. It was pretty cool. This is cooler, if it works. Okay. Helium, orange. We use orange for helium. Little sunspot. Here's your plage. Here's your beach. See this -- well, here's a prominence. See this thing that looks like a scratch? It's a filament. It's about 50,000 kilometers long. And with a buildup, I want you to watch that tiny little scratch, and I hope this plays. Boom. I need some drum music for that. How are you going to predict that? It's this tiny little thing that somebody says oh, you've scratched the lens. Can you get the handy wipe? And it does this. We use it out of the field of view. It suddenly went from -- you see a slow evolution and then boom. Gravity pulls it back. You start to see splashes over here. This should all be constrained or entrained by the magnetic field. So the magnetic field has been blown off with the plasma and it's just this huge thing that comes back.

You can see other little filaments, up here, for example. And again, I told you we're good at names. The ones that erupt, we call them erupting filaments or erupting prominences. But which one is going to go? If I had told you about how filaments do this, you may have picked some of bigger ones or the ones sticking over the edge already. I doubt you would have picked the little one.

>>STUDENT: (inaudible).

>>DR. ALEXANDER: Good question. But we think what this is doing, my little cartoon here. So if you think of this as the filament, this is a cross section, this slow evolution is pushing up -- think of this as a hot air balloon. My other analogy is this is a hot air balloon. These are the guy ropes holding it down. But you're pumping hot air into the balloon. When one of those guy ropes breaks, you've now got less ropes holding on the balloon. So you create a sequence, boom, boom, boom, they all erupt. So you have a small evolution. This takes off. This red stuff I was trying to do, that's the energization back at the star, which is a flare. So we think the standard model, if you can really push that kind of thing, the standard model is that the erupting filament creates a flare in the -- back at the sun, a coronal mass ejection in interplanetary medium. And I'm going to show you that now.

>>STUDENT: (inaudible).

>>DR. ALEXANDER: So there was a big thing called the myth, because he didn't like flares. He liked coronal mass ejections. I would argue they're different manifestations of the same process. What he was right about that was the they're (inaudible) and I'll tell you about why that is in a second. But the flare itself, because -- I don't know. You don't want me to go past 9:00 o'clock. So let me not explain the Parker spiral. But the flare produces all the photon, the electromagnetic radiation. So that EV enhancement is what can affect the atmosphere. It also generates particles, very high energy particles that can travel along the magnetic field coming into the sun and interact with the earth as well.

But the flare is so small that its magnetic path to the Earth is very narrow. Which means if it's anywhere -- because the sun rotates, it spirals that way. If it's over here and you're the earth it would do this. So you wouldn't seat particles. But if I'm over here, you would see the parallels. So if the flare are over here, you don't see the direct particles. The coronal mass ejection is huge and what it does is it moves out. I'll give you an analogy when we get there and it generates particles over pretty much (inaudible) longitudes. So then it doesn't matter where the earth is, it's going to get hit before some of these.

So the flare, ground level enhancement, we all think those are to do with flare particles. (inaudible) will be coronal mass ejection created particles.

So we're going to put all that together in this movie. So there's three different telescopes -- let me go over here. Again, we pick any color we like. Three different telescopes. First telescope produces the green sun. That's everything you've seen so far. Sunspot, sunspot, sunspot. (inaudible). But don't worry about it. This black disk, it's an aluminum disk that you block out the sun and create an (inaudible) out to two and a half solar (inaudible) which is 2 million kilometers. So this is a the second telescope, produces this green annulus. This is called a helmet sphere. Why? Because it's shaped like a helmet.

And then there's a third telescope that's got a bigger aluminum disk that blocks out the inner part and extends out to 20 million kilometers. I've trimmed it, but what you're going to see, your filament erupts. But now we can observe it all the way out to two -- 29 kilometers. What's or not here is that you're the earth. The thing that you're going to see is going to the side so you don't have to worry about it. I'll show you what happens next. And the see thing, that green ball in the middle, that's a star. It's a million times the size of the earth. Okay, this is (inaudible) boom.

Now, this is called a coronal mass ejection. Remember what I said about names? It's the ejection of mass from the corona. Look at the size of that thing. If you add up all the mass that you see there, it's about the same as Mount Everest. It's typically moving a million miles an hour. The biggest one, I think (inaudible) the record for the fastest observed, I think somebody beat that. But this the fastest ones are about 5,000 kilometers per second. At those speeds, think about it as a giant bullet. Massive Mount Everest. A million miles per hour. At those speeds, it can take at a day to reach the earth. Typically a day to three days. We see this thing, takes three days to get to the earth. We're good, right? You can turn off your satellite.

>>STUDENT: What do you do about it?

>>DR. ALEXANDER: Well you put your satellite in safe mode. You can still have problems. The thing S that's not what causes the problem. Think of this million miles an hour bullet as being a speedboat or a jet ski and it's traveling -- I keep pointing at the screen. You can't see that. Sorry. Here's your big event. All these lines coming out here, that's roughly -- what you're looking at is the solar wind. There's a river of plasma called the solar wind. The speedboat passes through the river. The solar wind in the equatorial, these bigger events are going at 5,000 kilometers a second. What happens when you drive a speedboat in a river? You create a wake.

So what happens is (inaudible) is supposed to help answer that. What five or ten solar radii, you create a shock. And what shocks are really good at doing is accelerating particles. And so what happens is with a shock, the particles bounce back. It's like ping-pong paddles when you bring them close together. You can put energy into the ball. They're bouncing backwards and forwards and they get accelerated to close to the speed of light.

So now think about your time scale. The earth is 215 solar radii away from the sun. Let's just call it a day. These particles are created at five solar radii. So that's about a 40th. So what's a 40th of a day? Half an hour. Forty-five minutes. Close to the speed of light means it's another (inaudible) to the earth. So effectively from when you see this, you've got -- I forgot what my numbers were. You've got, like, 45 minutes. You have 45 minutes to do something, and that's not enough. So that's one of the problems we have.

Now, I don't have time to go into why these may or may not be a problem. Sometimes they're not, sometimes they are. But that's the thing that you're having to deal with. You've got limited time in which to know something is coming, know what kind of shape it is and where it's headed and to do something with it.

So this, as I said, you're the earth. You don't have to worry about it it's going off to the side.

So same here, here's the big aluminum disk. Here's your solar wind. Here's your helmet streamers. Now, what you're going to see, remember in order to see these things, we have to block out the sun. So if I block out -- if I'm the sun, I'm blocking out my face. If it's coming at you, you don't see all that structure. So think about it coming at you like this. Now it's coming like this but you've got a big disk in the middle. So what do you see? Remember, we're good at names. You see a halo. It's called a halo CME.

When you see a halo CME, it's coming to you. Remember, the earth is a small target this is one of the problems. Even if it's coming at you, it may not be coming directly at you. You don't want to spend millions shutting down at your spacecraft when it's not going to affect you. This is taken from a satellite that's a million and a half kilometers up stream, not in earth orbit. There's your CME. And look at this. Each one of those little dots is a relativistic proton hitting your camera. That's the environment that your astronauts are in. Now, because it's (inaudible) and because we're taking a huge volume of space and making it 2 meters across, it looks like you can't breathe because these particles but particles are small and spread out over a lot of space. But the bottom line is it's the speedboat hitting the river, accelerating the particles.

Particles move along the magnetic fields at the speed of light and come in and hit your detector. Or your astronaut or your spacecraft or our ionosphere or your earth's magnetic field, all those different things. So that would be a halo CME. That's space weather right there. So if all that -- that was almost hours ago.

This is what space weather looks like. I was going to show you this (inaudible) movie. It's a four minute movie. Do you want me to take time for that?

So on March 6th, the chief scientist and the director of the (inaudible) division will be giving a talk at Rice on the Parker solar probe. You're all welcome. We even provide food and drink if you're old enough. It's part of the Houston space port lecture series.

Parker solar probe -- well, I don't have time to tell you all this. But, the thing about the Parker -- remember I said this we think acceleration is happening, this thing is going to nine solar raid why I. It's got four month orbit. Uses Venus every time to get closer and closer. Sometime, 2021, it'll at 3 million miles above the surface of the sun. And the reason that's a real -- if you think about what that means -- well, bottom line is the front of the spacecraft is 2500 degrees Fahrenheit. Where your instruments are is (inaudible). We couldn't do this -- I was first working on this when I first moved to the United States. People in the room had been working on it 17 years before that. And we finally launched it last year.

But the reason for that is if you're going to go that close to the sun, you better protect your instruments. And it's only now the technology is available. So you're welcome tot to come to the talk on March 6th. This movie will essentially finish the lecture. And you can't hear the sound though, can you? Can we -- hold on. Is it on there? Because this has got somebody telling you about the mission, and I can't do it all. (inaudible)? It's not coming on. There it is. Okay. Okay. Let's see if that -- see how loud it is. All right. This could deafen you, so --

>>DR. GARRISON: I don't -- (inaudible) I don't know if the sound on this computer works, unfortunately.

>>DR. ALEXANDER: Okay, it's not going to work. What this mission -- it's named after a man called Gene Parker. What it's going to do is essentially -- the original mission we're going to do was going to do a single fly past. But what this is going to do is skim into this region where all this is happening and we're hoping it will survive long enough to take the measurements that will tell us how many of these particles are being accelerated. There's the typical event. There's the orbit.

Again, you can find this on the NASA website. But it's already gone into its first (inaudible) which is about 36 million miles above the surface. You can see here it's got lots and lots of Venus assists to get close to the sun. These are some engineers building stuff -- spacecraft. Without sound, it's not all that great. But it doesn't have any annoying music. So that's good. Everything went well. It launched perfectly. Made its first Venus assist. On its way to its second Venus assist.

And just to finish, some of this stuff that we see is caused by the fact that the earth has a magnetic field. When I talked about the geomagnetic tail, this would not happen at Mars. As it crystal magnetic field in the southern high lands where there's (inaudible) from when Mars did have a magnetic field. So there's a little bit of a bubble there. But it's not enough to protect you. So any astronauts in interplanetary space heading for Mars are going to have to worry about all of these things.

And again, you can look at these pictures. You actually see aurora on Jupiter and Saturn. And that's the kind of thing we're also thinking about when it comes to planets around all the stars, and I'll save you that because we're already at time. Thanks a lot. I hope you learned something. And if you have questions, I'm happy to take them on board.

>>STUDENT: So how prepared are we and how much damage could we expect from another event similar to the 1859 Carrington one?

>>DR. ALEXANDER: So there was a big event that was observed by the (inaudible) spacecraft, a spacecraft, it went the wrong way. I think 2010, maybe. All the measurements suggested it was as big as the Carrington event. So what they did, they tried to reconstruct from all the data the event, and then in the computer turned it on the event. And the argument they came up with was essentially it was about a trillion dollars of infrastructure damage caused by the potential effects on spacecraft, the effects on the ground and power systems. We're not really that well prepared for these things on the ground. The good thing is that they don't have -- these are, like, one in a hundred year events. But we're not that prepared for them.

So I don't know if it's a dollar amount you wanted but there's all the sorts of individual stories. Hospitals losing power, fire fighters not getting data. Just all sorts of thing. The military part of most countries, particularly U.S., is really, really interested in the whole space weather problem. Situational awareness, knowing why your satellites are, knowing where your enemy satellites R. giving your troops on the ground positional information they need. Laser target -- it's a big conversation right now because of what's China's doing. So it was a huge amount of individual stories that would be really bad. But economically it could be quite catastrophic.

>>STUDENT: (inaudible)?

>>DR. ALEXANDER: Well, that's another interesting question. What we have found is sometimes some of the -- maybe not the biggest, but some of the biggest events in a given cycle can happen during minimum. Now, my argument for that, I always like to use students as an example. If you were walking between classes, you've got a lot of energy, it's a really good class that you're in, you want to get there, but everybody is going to class at the same time. You keep bumping into people. Or students walk more slowly than any other species on the planet. By the time you get to Clarks you're dragging your bag behind you.

That analogy in how it translates to the sun, if you have a lot of energy, a lot of sunspots, you're driving a lot of these things and you can get to an unstable position really quickly so you don't have time to build up a lot of energy. It's not just stretching the rubber band. You have to snap it. You build up the energy and you release it. So you get flare after flare. When you don't have many active sunspots, you're winding that rubber band up for a long time. So when it does go unstable, it's stored a lot of energy. That's the kind of an he can dolt argument for why this is. But we do see some of largest events during solar minimum. You have a question?

>>STUDENT: (inaudible) to ever colonize it or would we have to (inaudible)?

>>DR. ALEXANDER: Well I always like to say that Mars doesn't want it. It's a 96 percent carbon dioxides sates that's actually very thin. Hundred miles an hour dust storms. And it's dosed in radiation like crazy. So it's a tough question. The way that NASA's working this is the 500 day mission. Four months there, four months back and whatever difference is on the surface or in orbit.

They're going to have to be thinking of shielding. So in other words, colonizing if you are willing to live underground probably, or it's not feasible. So you have natural enclosures with a regolith above you, it's a very good protector. Otherwise your habitat is going to have to have a lot of shielding. So there's all these different scenarios, how long your mission S how long your travel time is, do you go at minimum or maximum, and whether you can literally dig underground -- I mean, there's a mission -- a thing called Mars one a few years ago, a one way trip to Mars. I actually knew one of the women who made it into the last hundred competitors for this. Good to say it's gone bye-bye because it's a stupid idea.

But they were thinking of sending up the first four people to build a habitat and cover it in Martian dirt and that would provide the radiation protection. So I wouldn't rule it out. The challenges are enormous. We're not going to (inaudible) Mars. Let's put it that way. But there's a new season of the expanse starting next week, so that's a good thing. And we may even have one of the actors come to speak in the lecture series at some point. But it's where we're supposedly headed. We're headed there really, really slowly. I mean, the space age isn't that old. It's a little bit older than me and we were on the moon in 1972 and we've gone nowhere else, not even the moon since. So it's a slow process. Unless you guys get your politicians to put money into the space program.

So even if you never get to Mars, solving those problems, think about it. It's a low resource environment in which you have to develop such as much sustainable technology as you can. That would be great on the Earth. If you can reprint stuff, reuse your materials, learn how to recycle water, all of those things that NASA is will go already doing. So the problems are worth solving whether you go to Mars or not. I think there was another hand up somewhere.

>>STUDENT: I was I have a question. A few years we had student (inaudible) where he was following the sun's magnetic field (inaudible) and was able to -- I think it was a little bit --

>>DR. ALEXANDER: Right. So the way to think about that, and it just depends how when it comes in. So if you think about, solar minimum looks like this. Give or take. And I have to -- this is supposed to be symmetric, but I ran out of space over there. It's a dipole field. So the solar wind stretches it out into these helmet streamers, right? This field like this. So that's your dipole field. No sunspots, just large field. And you can -- you've got three dimensional fields you can break it into. Dipole, quadropole, octopole, all the way up the field.

What it does is it pops up -- if you've got a lot of sunspots and so if you were to do that and then if you added up all of those field components, the structure of the atmosphere, right, looks like -- and so you have a strong quadropole component. Actually several years ago, using some data that we had for the magnetic field and observations of the streamers, at solar -- that's solar maximum. We were looking at the quadropole component was at strong as the dipole component. But it does disappear when you get to minimum. Frequently there will be sunspot so you have at least some quadropole component.

I don't think -- it may be that a lot of the models don't (inaudible) this quadropole component. So when you see predictions, you were predicting the next minimum and the next maximum?

>>DR. GARRISON: Yeah, I think the idea was to (inaudible), yeah, the space station in low earth orbit, and you can model what's going to happen as far as atmospheric drag.

>>DR. ALEXANDER: Okay -- yeah, and I wouldn't be surprised if from that -- for that application that any previous work did not include some real -- I mean, when we are thinking the solar corona and the structure, we have to think of those quadropole component. Very few out of us in the solar world think about the space station, for example. So it may be that when NASA does calculations, they take some basic backgrounds and they don't do everything (inaudible) wasn't in prior studies.

>>DR. GARRISON: (inaudible).

>>DR. ALEXANDER: No, as I said, when you get to maximum in some cases, the quadropole component is as strong as the dipole component. So you shouldn't ignore it.

You can even see it in the (inaudible) data. You see these amazing structures around the sun, just a little bit different than the basic structures.

Sir?

>>STUDENT: (inaudible).

>>DR. ALEXANDER: So, yes. And people have talked about -- they -- I used to work on things called solar sails. But there's also these things called magnetic sails and that's a kind of offshoot from what you're saying. So people have talked, because charged particles can cross fields, they go around them. The suggestion is if you create your own magnetic bubble, all that damaging radiation would never make to it your spacecraft. It would be deflected around your spacecraft. Some of the problems are that you also get a kick. So you get some propulsion that you have to counteract. You have to have a plasma to create a public of magnetic field. So you have a generate the plasma and have a continuous source of that plasma. That's also solvable. You just take helium and strip it as it moves out. So those are solvable.

I think the biggest problem is how much energy, how much power you need to maintain that level of magnetic field for the whole time. And so the power generation system defeats the purpose, in a sense. I'm sorry, it doesn't defeat the radiation purpose. It defeats the cost and some of these other problems. But it's still being actively discussed. Maybe if we get to the point of room temperature super conductors of a reasonable scale, there might be an option for using that. You also have to think when you're generating these fields, you're generating currents. That's not very good for electronics on a spacecraft. So you have to be able to isolate your electronics. All these different things. But it is being actively discussed as a protective mechanism.

>>STUDENT: So (inaudible) there's more talk about this (inaudible) hearing more about cosmic rays, other than being out in space for a very long time?

>>DR. ALEXANDER: I think the long time is the thing. In a basic sense, yes. Because the cosmic rays -- there will be more cosmic rays out there. Pluto is not that far away in the heliosphere. It's 60 (inaudible) or something? Something like that. So the field drops off somewhere between (inaudible) there's a dipole (inaudible) so the (inaudible) is dropping, if it's -- let's say it was a square. That's 3600 times smaller than it is at the earth. And so there will be a lot more penetration of these cosmic rays.

So yes, it will be a bigger issue. Whether it's the dominant issue, as opposed to the flight times for humans. I mean, it would be great. Right now we should be at Pluto given what we did in the 60 and is 70s. But, yeah, these are -- (inaudible) on a panel recently at Rice. I was on the radiation panel with a few astronauts and a few experts. And everybody got really annoyed with us because we said we shouldn't worry about radiation at all. And the reason we shouldn't worry about it is the way that NASA (inaudible), if NASA was to follow their guidelines, no woman or man younger than my age would get to go to space.

Because what they do is say given the exposure that you would and want too receive for a given flight, does the risk of you dying younger from cancer exceed 3 percent of what you would get normally? What that means is women live longer, so if over the course of 50 years you've got 3 percent chance, it's better to be 50 than 20 because you're probably not going to live to 105. It's better to be a man than a woman because woman's organs respond for severely to radiation. All of these things.

You talk to a man or woman astronaut, they come home after a flight, some of them climb Everest, some of them do test pilot stuff. So they're going to kill themselves before any radiation has a clans to affect them. So any astronaut, male or female, they say it doesn't matter. Unless you can bring an astronaut home and stick them in a protective bubble for the rest of their live, why bother? So, of course, it turns out all of our panel agreed.

(Inaudible) because I'm a solar physicist and we need to understand the radiation just from the point of view of understanding the sun. But from the point of view of protecting astronauts, nobody cared. NASA didn't adopt that strategy, they're still worried abut. But we have no real data of an astronaut who was exposed to a certain amount of radiation over a certain amount of time who has died because of that.

I mean, all the Apollo guys are 80 some odd years old. (inaudible) maybe that's got something to do with it. But he is 87 or 89 now. Don't tell -- don't put this on the web. But what I mean is that these Apollo guys, they're all in their 80s. And the one who aren't alive, most of them lived (inaudible). How much radiation were they exposed to? We don't know. So we don't know if they could have lived to 99 or maybe someone who died at 75 could have lived to 80. We don't really know.

And you can't do that experiment. I mean, how are you going to do that? NASA does follow all these astronauts. They come and add to that database. But we don't know. So the question is, is it such a big deal if it's a 3 percent increase that you'll die at 80 instead of 85? What does that mean to anybody who wants to go? It's a tough call. But that's one of the big issues. They're actually doing -- one of the biggest problems and challenges is radiation. And please strike the Buzz Aldrin thing, because I see him every so often, and he'll probably -- I'm not saying another word. So, yeah, if there's any other questions.

>>DR. GARRISON: Let's thank our speaker.

(Applause.)

>>DR. ALEXANDER: Cheers. Thanks a lot.

(End of class)