<u>AirSpace Season 6, Ep. 3: Here Comes The Sun</u>

Music up then Under

Matt: Welcome to AirSpace from the Smithsonian's National Air and Space Museum, I'm Matt.

Nick: I'm Nick.

Emily: And I'm Emily.

Nick: In 1859 there was a huge geomagnetic storm that caused aurora to be visible almost down to the equator and sparked fires at several telegraph offices. This storm was called the Carrington Event, and it's still studied today as an example of the damage that the sun can do when it's in a mood.

Emily: More than 160 years later, space weather is predicted and prepared for by agencies across our government and international bodies around the world.

Matt: With our modern reliance on electronics, and satellite technology, monitoring space weather is an ever evolving and incredibly important job. We talked to a couple of people who do it today on AirSpace presented by Olay

Music up and out

Matt: Space weather is radiation and charged particles emitted from the sun that sometimes impact life here on Earth.

Nick: So let's talk about what space weather isn't. It's not rain and snow. I made a reference a second ago about the sun being in a mood and all space weather for the purposes of this conversation has to do with the sun.

Emily: Yeah, I think it's misleading to call space weather 'weather.' Here on Earth, weather is stuff that originates in our atmospheres, right? There's this complex network between our atmospheres and ocean circulation and snow, rain, hurricanes, tornadoes, all of that is weather. This space weather is not that. And so it's really misleading because there's no atmosphere in space to be interacting with oceans to create weather. But it is a phenomenon that gets generated by the sun, and it does affect the Earth in similar ways to weather events affecting the Earth. So there is a parallel but it's terrible.

Matt: But it is this interaction of systems. If you want to think about all of the different forms of radiation that are being expelled by stars. And the sun is, of course, the dominant star that we deal with. And it is, you know, pushing charged particles and and radiation towards the Earth and towards all of the the planets and into deep space. So when those things then encounter magnetic fields or atmospheres or other things, they cause phenomena to happen and we often call those phenomenon different types of storms, geomagnetic storms, etc. So yeah, it's it's attached to phenomena that are in ways very similar to weather phenomena. I don't know. Was that too convoluted?

Emily: Kinda? Kind of…

Nick: Emily, I feel like you've got something

Emily: I well, part of me is like wanting to simplify, but also wanting to flip to page two. But what I, what I think I want to try and say is space weather is driven by the sun and it can affect us on Earth in small ways, like static on your radio to really big ways like your flight might get diverted if it's on the wrong pathway and it's going to have an interaction with a space weather phenomenon that's going to be affecting Earth, right? It can it can be your radio. It could be your airplane that you're in everything down to maybe the power grid that is supplying energy to your house. But fundamentally, on a larger scale, space weather is the kind of thing that's going to create the Aurora Borealis. Have you ever seen the northern lights? Right. That's what we're talking about. These kind of light shows that are happening mostly at Earth's pole, which is caused by solar wind, which is sort of charged super energetic particles that are coming from the sun that have made their way to Earth. And a lot of those charged particles get blocked by Earth's magnetosphere. If you've ever seen the movie *The Core*,

Movie clip from The Core
Zimsky: the Earth's E.M. Field shields us from the solar winds, which are a lethal blend of radioactive particles and microwaves when that shield collapses microwave radiation will literally cook our planet.
Fades out

Emily: You know what? If you haven't seen the movie *The Core*, go watch it. You'll know what I'm talking about. If you have if you have seen it, then you know how important the magnetic field of of Earth is. So the Earth will block some of those charged particles, but some of them get trapped and create the northern lights, which are really beautiful. If those particles are too intense, there's too many of them. That's where we actually start to get negative effects of space weather.

Matt: Yeah. If you think of the Earth as a spaceship, right? Totally metaphorical. You're thinking of the Earth as a spaceship and the magnetic field as being like the shields that they're able to

Emily: Ooooo like a force field!

Matt: put up, like in Star Trek around the Enterprise, the shields that protect you from from the photon torpedoes. Right?

Star Trek Clip: locking phasers on target, they're locking phasers. FIRE!

Matt: That's kind of like what the electromagnetic field of the earth does when it comes to the solar winds and the charged particles that are coming from from the sun. And you're right, if those things become too intense, those shields, they don't fail but they start to let a little bit of that stuff in right now. Nothing's going to take our shields down completely

Emily: Unless the core stops spinning…

Matt: You know, unless the core stops spinning like you were saying. Yeah.

Bill Murtagh: So space weather for all practical purposes, variations on the sun and and the space between the sun of the Earth.

Emily: So since none of us are space weather experts or Helios, helium physicists, helio physicist, heel-ee-oh physicist,

Nick: Heliophysicists. That's a satisfying word.

Emily: It's hard, though. We decided to talk to people who are experts in these things.

Bill: My name is Bill Murtagh and I'm the program coordinator at the Space Weather Prediction Center. My responsibilities largely involve the external engagements. I do a lot of work with the end user community, the people that rely on the space weather information, may it be industries such as satellite companies, aviation, emergency responders, etc. But I also do a lot of the policy work, so I work with Congress and the White House and try to establish good and appropriate policy to address these risk associated with space weather

Emily: And the space Weather Prediction Center, where Bill works, is part of the National Oceanic and Atmospheric Administration, also known as NOAA

Bill: We've get lots of different types of eruptions emissions from the sun that can affect technologies here on Earth. So at the Space Weather Prediction Center, we're monitoring the sun. 24/7 watching for these eruptions. When these eruptions occur, we predict when the the effects will be felt here on Earth and in some cases what kind of effects will be felt and where they will be felt. Space weather has become a much more prominent issue of late because, largely because of our reliance on advanced technology for everything we do. And so much of that technology is vulnerable to space weather.

Emily: This is where I feel like there needs to be a bit of a vocabulary pit stop, because I think when you talk to experts about space weather, they're so familiar with everything that's going on on a really fundamental level they kind of skip to the cool stuff. For me, things started getting very muddied because I feel like there's a lot of mixing of terms because everybody kind of knows what you're talking about. And then I was like, I don't I don't know what we're talking about. Remember, I study planets, not stars. So I think we should go through a couple definitions of things that I think are really going to help.
And the first one being sort of sunspots, I think of sunspots is like the freckles you see on the I'm using air quotes, "surface" of the sun. And that's kind of this indication to people who are observing the sun that something might start happening in the location where there's these little sun freckles or sunspots.

Nick: Yeah. And something that I didn't know this morning but found out is that space weather requires a pair of sunspots interacting. It's it's the way that these two sunspots form a magnetic field between themselves and the way that it pulsates back and forth that's actually going to create the measurable phenomenon that we're talking about today. And if you want a really fun visual, our producer pointed out that that sounds a lot like the Harry Potter spell priori incantatem, where the the wands kind of formed this stream and they just duel back and forth and they're talking to each other and then something blows up

Movie clip from Harry Potter and the Goblet of Fire
Harry: Expelliarmus!
Voldemort: Avada Kedavra!
Dramatic wand noises

Nick: The something blows up is when we're going to have a bad time. But it all starts with sunspots, and not just one, but a pair of sunspots basically talking to each other.

Matt: Right. So the sunspots usually happen in pairs or clusters, never on their own. And there's always that magnetism going back and forth between the sunspots. In fact, if you look at like some of the really cool images that we've gotten of the surface of the sun. Right? You know, you can see that solar plasma, you can see those dark spots there. And you can also kind of see the arcs going between the sunspots. It's really kind of cool to look at, but sometimes something goes a little bit haywire.

Nick: So we've got two sunspots talking to each other and to resort to another movie metaphor, they cross the across the streams on their proton packs, except in this case, their photons

Clip from Ghostbusters
Egon: We'll cross the streams.
Peter: Excuse me Egon, you said crossing the streams was bad
Ray: Cross the streams.

Nick: So the solar flare that results from these crossed streams comes at us at, as a visible solar flare. And because they're photons, they reach the earth at the speed of light. And if we can see them, they're happening to us. And that's kind of the next escalation from where sunspots appear on the sun, they start talking to each other, they get a little bit more active, and we're going to start experiencing those those effects here on Earth. That's a solar flare.

Matt: Yeah. And then if those magnetic field lines really get twisted, you can actually get some of the plasma that's being held on the surface of the sun ejected. Right. And are basically an eruption of solar plasma. And that is a coronal mass ejection, which is kind of literally the sun ejecting part of itself with force out into space. And the solar wind can either speed up or slow down that process, but its trajectory is usually about the same. And if these head towards Earth, they can be even more damaging than those solar flares.

Nick: Yeah, the coronal mass ejection, instead of just the light from the sun reaching us, it's actual material from the sun that supercharged plasma particles. It's the difference between standing on the beach and getting a nice fresh salt breeze and then the wave actually crashing on you. Like it's a, it's a much more disruptive experience.
So what do we do about all of this? They they tell us never to look at the sun, but if we followed that advice as a species, we might be out of luck. But there are people that watch the sun 24 hours a day.

Matt: Right. Not literally, like with their eyes the way. Yes. We're not supposed to do, but with technologies that allow them to monitor the sun's surface and look for those sunspots as indications that something might be about to happen. And after decades of watching the sun with these technologies in the space age, there's actually people who have gotten very good at predicting what will happen and using different tools to try and keep us prepared for these types of events.
So we've told you what space weather is, but how do you actually predict it? So we talked to Bill about this, and he was able to tell us how you go from basically understanding the surface of the sun to actually predicting what might happen when something happens on the surface of the sun,

Bill: It essentially begins this whole forecasting process. Looking at the surface of the sun, looking for sunspots, sunspots to the space weather forecast. So it's kind of like the nor'easter for a meteorologist. If we don't see sunspots in the sun, typically we're not going to see much in the way of space weather. But when we do see those sunspots, we know something can happen, especially if those sunspots grow to large, complex magnetic structures. They can grow as big as ten to 15 times a lower the size of Earth. And what they are is essentially the visible manifestation on the surface of localized stressed magnetic fields, and that's when the eruptions are going to occur. So with the Space Weather Prediction Center, as soon as we see those sunspots develop, we started monitoring them closely because when they're small and simple in magnetic structure, not a big deal, but as they grow into large complex structures, then we have the ability to assess just how likely they are to produce big eruptions.

So we'll go from, say, a quiet day when nothing's happening. We'll say 1% chance of that of a flare because we never say never. And then when we see a big, big sunspot cluster evolve over the course of a couple of days, then you'll see those numbers going up and you'll see 60, 70% chance of a large flare and we'll get that information out to all those users that need to know that this is now happening on the sun and there's potential for emissions, eruptions from the sun that's going to disrupt their technology.

Emily: Dr. Michele Cash also works for NOAA at the Space Weather Prediction Center.

Dr Michele Cash: I'm Dr. Michele Cash, and I am the lead for the research section at the Space Weather Prediction Center.

Emily: Her team creates and study is the computer models that they use to predict space weather events and you know, get a sense of what's going to happen when it's going to happen. How big is that event going to be? And this is where I think that the analogy of space weather, which we all decided is a terrible thing to call it, actually holds up with how we make weather predictions. Because we understand how weather works. But there's a lot of things that feed into how a weather system is going to behave, for example, and we can't know all the things, right? So all models are wrong. Some models are useful. And so Michele is one of those people who's really helping to sort of dig into the science continually to improve the models and continually trying to understand how to interpret the results from those models so that they can do a better job of saying what's going to actually happen and how big the impact is actually going to be.

Michele: Even ten years ago when we were forecasting geomagnetic storms, we can only say there's going to be a geomagnetic storm. It will impact, you know, might impact Earth. The equivalent would be with terrestrial weather saying it's going to rain someplace on Earth tomorrow. And we've been able to evolve and improve our modeling capabilities. We're now with our geospace model. That model now lets us instead of giving a global forecast, we can do more regional forecast. So now we can say instead of it's going to rain someplace on planet Earth, it's going to rain maybe in Seattle, but not in Washington, D.C. So these are some of the advances that we're working with the the research community. And as they develop better models, we can transition those into operations. And that's one of the things that's really helping to improve these forecasts.

Nick: So as the models get more accurate and the forecasts get more robust, Michele is out there doing the yeoman's work of making space weather a less terrible thing to call it.

We're getting more and more like the prediction systems that we're actually used to in the atmosphere.

Emily: Well, and I think one of the reasons we've gotten so much better at predictions are folks like Michele, who are doing that modeling work and improving those prediction capabilities. But along with that is the improvement in technology and the improvement of observations that has been really critical because a model is only as good as the data you put into it. And if the data that you put into it is terrible, then the results that you're going to get out of your model are also going to probably be similarly as terrible. So what's been really important is how models are getting better and better because they've been able to get data directly from space, which is where the space weather happens, rather than just using earth based observation methods to observe events in space.

Nick: Yeah, and those space based instruments are put at LaGrange points, which are spots in space that are gravitationally stable so the spacecraft stays put with minimal effort.

Bill: We currently have a spacecraft at LaGrange Point one, so it's a million miles out from the Earth along the Sun-Earth line. It acts as our sentinel in space. So when that CME barrels out from the sun takes a day or two to get to Earth, hits that space craft first. That's really the first time we know the magnetic structure within that CME, and we have to know that to be able to accurately forecast a geomagnetic storm. So we have to make sure we have that measurement there. So the continuity is critical too. And NASA's going to be flying the IMAP, which is the interstellar mapping and acceleration probe mission in 2025, and on board that will be the NOAA's space weather follow on. So we currently rely on the Discover spacecraft in L1, but we're very much now on the road to getting their next spacecraft up at the L1 point to ensure the continuity of those critical observations. But space where there is a global threat. We've got to work with our partners around the world and we do. The European Space Agency are planning on a 2028 launch to the LaGrange Point three. So we will put a spacecraft out essentially off at an angle which should give them essentially a cross-section. And so we can see the CME leaving the sun and making its way to Earth so we won't be stuck with this single measurement that we have right now. With a CME coming down that Sun-Earth line that will have a spacecraft off to the left, if you will, giving us that side view. So we'll have L3 by the Europeans, L1 by the United States. So monitoring these CMEs. So in the next five or six years, if this all works out right, we'll be in a better position, a better place to observe and predict these geomagnetic storms because of these observations.

Michele: And then those observations are what we use to drive the models. So we have side imagery of that coronal mass ejection. We can get a better sense of the shape. And then as Bill mentioned, when it gets to the spacecraft at L1, that first LaGrange point we can then measure what the magnetic field is within the coronal mass ejection. And this is going to impact if we're going to have a really large magnetic storm or if it's not going to be as large because the Earth has a magnetic field. And so the CMEs magnetic field is in the same direction as Earth, we're not going to get as large a storm, but if it's in the opposite direction of Earth's magnetic field, that's when you're going to get a magnetic reconnection, you're going to get a lot more interaction and a much stronger geomagnetic storm.

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Matt: One of the interesting things that we've learned about the Sun is that it actually has cycles and these cycles last roughly like nine to 14 years, usually around 11 years, but they can range between nine and 14 and space weather is least active at the beginning of those solar cycles. We're currently in Solar Cycle 25. It started back in at the end of 2019 so we're near the beginning right now, so we kind of know how to expect activity to ramp up from here.

Emily: You can actually, and this is what this is one of like maybe the most basic ways in which the sun is observed, you can actually track sun activity even if you just track the number of sunspots on the sun over time you can actually see the number of sunspots increase with time. And so scientists can start to tell whether we're talking about a nine year cycle or a ten year cycle or an 11 year cycle. Depending on where that peak goes. And then the work that, you know, folks like Michele are doing. That's where you start to get into that level of detail where the models are really helpful to start talking about how much activity and what the effect of that activity is going to have on the earth. And that's one of my favorite things about places like the Sun. Stars seem really volatile and yet you can kind of fit them in these little like cyclical boxes. I think it's very satisfying.
So we talked about space weather and space weather predictions and one of the newer things to come out of the last few decades of studying the sun with respect to space weather is that they've started to develop different kinds of scales for the severity of the storm that's predicted. And this is where I think the space weather terminology truly works. If you live in a hurricane prone or a tornado prone area, as storms become predicted and as they start to track storms that are developing, they're starting to

communicate with people who live in particular regions of our country to say we're predicting a category three hurricane or a category four hurricane. And what's important about it is that it's not that they're going to stop the storm, right? Everybody knows you don't stop a hurricane, but it's really helped change how folks mitigate and live in weather prone areas. We're going to stick with hurricanes because it's one of the more familiar with. Right. You've got impact resistant glass. You've got shutters that people start to put up. They start putting in sandbags and coming up with ways of mitigating the flooding. And the rainfall that's going to happen in the high winds in the same way that different scales for different kinds of space weather events really help organizations like NOAA talk to and communicate with the general public about the kind of space weather event that's happening and how it's going to affect them. And so there's three different kinds of scales that they've developed so far that they've been using as a way of trying to communicate with folks about what to expect.
So R-scales are, that’s R the letter, R-scales are for radio blackouts associated with solar flares. And these are the most common events. S-scale events are radiation storms. And then G-scales are for geomagnetic storms. All three are labeled one through five, with one being the least severe and five being, you know, the biggest.

Michele: So we have different effects from space weather. Solar flares can produce radio blackouts, and we don't have much warning for those at all. So those are traveling at the speed of light. We can put out a probabilistic forecast, but there isn't much advance warning. And then the next thing that would come is our solar energetic particles and the solar energetic particles are what result in radiation storms. So these are S-scale events. Radiation storms are the ones that affect HF communication, satellite electronics. These are the ones that the astronauts in Space are concerned about and the airlines.
And then the third effect is the magnetic field and the currents that caused the geomagnetic storms. So these are the ones that are going to impact the electric power grid. Again HF comm can be impacted, navigation. But these ones, because they result from this coronal mass ejection on the sun, they come much later. So you have, you know, one to three days warning and depending on the speed at which the coronal mass is traveling before you see those effects.
So the minutes is your your solar flare, your solar energetic particle, you know, hours and then magnetic fields and the geomagnetic storms in terms of days.

Matt: Bill mentioned before that NOAA collects all this information and makes these predictions for its end users. And what that typically means is, you know, businesses like airlines or like companies that operate power grids who need to react to this stuff as quickly as possible if they know an event is coming. So for example, an airline might divert your flight so it's not flying over the poles because that's where this activity is most intense to minimize the amount of of radiation you're going to be exposed to as an airline passenger, but also protect the plane's electronics. And then, you know, if you're operating a power grid, you might take part of the power grid if it's older and more susceptible out of service for the day or for a few hours just to sort of wait out this event so that that equipment doesn't get fried, it saves money. And it also means that that infrastructure lives to serve another day.

Emily: Right. And not everything that the sun throws off is necessarily coming to Earth. And those that are only impact part of the Earth. And the really severe events are very rare.

Michele: So your, your G1, which is the bottom of the scale, that's your minor event. You know, you'll have, you know, maybe a thousand per solar cycle on that one. You have a lot of these smaller events. And then as you get to G2 those are moderate events. So you'll see less of those maybe like 600 per solar cycle. G3 these are your strong events, maybe 200 per solar cycle by the time you get up to G4 which is your severe these you're seeing maybe 100 per solar cycle and then G5 is extreme these are much more infrequent. So you know, only one or two per solar cycle.

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Nick: At the top of the episode we mentioned the Carrington Event. This was one of the biggest space weather events in history. The biggest that we know about happened in 1859. It was named after Richard Christopher Carrington, who was one of the scientists that observed the solar flare that caused this geomagnetic storm the following day. The aurora that we mentioned, normally the northern lights stay up north, but they were so bright and so pervasive that you could see them almost all the way down to the equator. There are stories about people in New England reading newspapers by the lights of the aurora, and a particularly colorful story that I love, where some gold miners in the Yukon got up in the middle of the night and started making breakfast because the sky was so bright they thought the sun had risen and the day had started. And in addition to the dazzling display of aurora around the globe, which I think we would all get a kick out of, it fried the technology of the time, which the most sophisticated example is telegraph booths, like a telegraph lines. There were sparks, fires started like this is kind of a taste of the idea that it's not all pretty lights in the sky. This geomagnetic storm had consequences for the technology that we had at the time. Took some things offline and, oh boy, if that happened to us today which is kind of the thesis of tracking space weather.

Matt: Yeah if you want to think about what happened with those telegraph wires catching fire. Right I mean telegraph wires work because of electricity because the current is running through the telegraph wire carrying the signal from one telegraph to another. And you know that current is directional. And when a geomagnetic storm happens and you get another current starting to interfere with the current that's running through the wire, then that's when you get sudden fires and thinking about how electronics dominate life today. You can imagine, right, a storm like that would potentially, if it caught us unawares, take out quite a bit of our existing communications infrastructure, our power infrastructure, everything we take for granted when we, you know, walk out of the bedroom in the morning and think, I'm going to turn on the light, make coffee, turn on my computer, get going. Right? If it were to take out all of these things, we we might not be able to live the lives we've gotten used to.

Nick: Yeah. And let's paint a little bit more historical doom and gloom and then we'll talk about how messed up we might not be. So there was the Carrington Event. Less significant events have happened over the years. In 1921 there was the New York Railroad Storm that sparked some fires in New York's central terminal. There was the radiation storm of 1972, that would have been disastrous for astronauts aboard the ISS, for example. But it was falling between the Apollo 16 and 17 missions, so there was no harm done. But that's the kind of thing that NASA looks out for, for its astronauts and satellites in space technology. There was a solar flare in 1989 that triggered a nine hour blackout in Quebec. We're starting to get a taste of the consequences for our power grid if it's not properly hardened. And then one big wakeup call was in 2012 in July. A huge coronal mass ejection just barely missed us. It did cross the Earth's orbit where we had been about a week before. So that served as a wake up call, got a lot of people thinking about what it might mean. And in the worst case scenario, pandemonium, bedlam. But, Matt, maybe not all that bad because we could potentially have a couple of days heads up. What do you think?

Matt: Well, I mean, it could be bad right? I mean, it could take out a lot of the stuff we have in orbit, which were not really that great at protecting. So imagine all of your GPS shut down for a while. And maybe satellite communications shut down for a while. But in terms of infrastructure on the ground, we, you know, have pretty good ways of protecting at least parts of that infrastructure. So when, you know, a space weather event is predicted and the people who run power grids or who run the airlines, etc., get that information, they're able to react to it. They're able to take certain things out of service, they're able to divert flights or in the case of a Carrington level event, probably just ground all flights. And typically, if electronics aren't in use during one of these events, they're not fried. Right. It's mainly the stuff that's operating and that has current running through it at that moment that gets fried by these storms. So yeah, it could be bad, but it probably wouldn't knock us back into the Dark Ages or anything like that.

Emily: Well, and I think the other thing that's really important to talk about is that a lot of these space weather events that can affect the Earth, they may have a global effect, but there's going to be an isolated region that's going to bear the brunt of the impact, right? If you go back to the list of historical events that Nick went through, right. The New York Railroad storm that was in New York Central Terminal. Right. The 1989 solar flare, nine hours in Quebec. Right? I mean the largest impacts are really pretty isolated. And as a result, if we can understand how large the storm is going to be and what part of the Earth is going to receive the greatest impact from that storm, it's not like we have to shut down and harden the grids across the globe. Right? Like, again, it goes back to we hate the term space weather, but in terms of mitigation strategies, space weather holds up really nicely because we have a sense of who's going to feel the greatest effect from the storm. Here on Earth, there are mitigation techniques of 'you're in the path of this storm. You have four days to prepare, unplug all of your devices' right? Like I'm not saying mitigation is necessarily that simple, but I think the point is it like we're not talking apocalyptic level global meltdown of our infrastructure.

Nick: Yeah. A Carrington Event could potentially mess up good. But Emily, to your point, in our continued efforts to redeem the term space weather and make it less inaccurate as we get more weather stations in space, as we get more data, as we get better at modeling the data, we're ending up with something that is more precise that you can say a region in North America is going to experience high geomagnetic activity today. Maybe be careful and understand that's why your radio isn't working. So we're getting, we're getting more precise and we're getting more day to day. And yes, certainly a Carrington level event would be wildly disruptive. But we're also getting to a point where we might be able to salvage much of our infrastructure, even in that case.

Bill: Department of Energy and the Federal Energy Regulatory Commission in particular have mandated a lot of activities across the grid with the grid owners and operators to look at this vulnerability and to do something about it. And that has made a big difference. We still have a long ways to go to be fully to, I don't will ever be fully protected, but we certainly have a long ways to go to get to the place where we want to be, that state of preparedness for one of these big geomagnetic storms. What I will say this that we are certainly better off today than we were 20 years ago because of this awareness and because of these new rulings, because the grid owners and operators are doing so much to assess their vulnerability and then address that vulnerability.

Matt: Right. And it's, you know, now a problem that not only scientists and NASA are interested in. NASA and NOAA are interested in. So ever since 2015, the U.S. government has really been interested in coordinated efforts to prepare for solar storms. So to get beyond just predicting but actually preparing and protecting especially the electrical grids. So that if a storm like that did happen, it would not knock the United States or parts of the United States out of commission but instead we would have a plan and protections in place for the infrastructure

Music up and under

Emily: AirSpace is from the Smithsonian's National Air and Space Museum. It's produced by Katie Moyer and Jennifer Weingart, mixed by Tarek Fouda.

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Music up and out

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