Transcript of 'Space Weather'

Season 3, Episode 1, Transforming Tomorrow

[Theme music]

Paul: Hello and welcome to Transforming Tomorrow from the Pentland Centre for Sustainability and Business. I'm Paul Turner.

Jan: And I'm Professor Jan Bebbington.

The forecast in Lancaster is for rain. But what is the forecast in space?

It's a new season, so of course we're back in space, but this time it's all about space weather. And we're answering a very important question. How in the world did the Northern Lights showing up in Lancaster in 2024 impact farmers in America?

[Theme music]

Paul: And we are back again, Jan. They didn't cancel us. [Jan giggles] We've managed to avoid the whole cancel culture over the summer and they brought us back for a third series.

Jan: Well, it makes me worry that we didn't say things that were interesting enough, but I'm pleased not to be cancelled.

Paul: Yes, we've not insulted the right people. Is that what you are, you are suggesting?

Jan: Yes, I think so. We could work on that though.

Paul: Yeah, I can certainly be more insulting. You may find that hard to believe, [Jan laughs] but I *can* be more insulting.

Jan: Hopefully not to me. [Paul laughs] So yeah, season three. Wow.

Paul: Yes. I think it's gonna be a season where we're gonna go off on many new pathways, but also go back to areas that we've discussed before and discover new areas to them.

Jan: Absolutely. So, a bit of continuity, bit a new stuff. Uh, we're going to sharpen up our show notes, so we'll have more materials, um, below each one of the episodes that you'll be able to pick up and delve into as well.

Paul: And. We'll be setting up a blog this, this term.

Jan: Yeah, we are too.

Paul: I say this term, I'm obviously being indoctrinated into the life of the university 'cause the, the word term means no sense.

This series, we have started, we're gonna start a blog. The first one has come out already, and there'll be about one a month, just picking up on some of the topics that we discuss in the podcast.

Bringing topics that have been discussed in one podcast together with other topics that we've discussed in the past, seeing how they all unite, seeing how it all fits in. And for the first one, seeing how it all fits in with my travels in Denmark.

Jan: Excellent. That sounds, that sounds very good. Blogging it is.

Paul: Blogging it is. That's the way, that's the future. It's not podcasting, it's blogging. We're going back, to go forward.

Jan: [Laughs] Well, that sounds very, very, uh, sort of physic-y and you know, back to the future, and space travel, and time travel.

Paul: No, I wanna talk about the weather. I'm British. I wanna talk about the weather instead.

Jan: [Laughing] Okay. Well, could we combine the two do you think?

Paul: What space weather?

Jan: Yeah.

Paul: Surely that's not a thing.

Jan: Surely not. Well, maybe? You tell me.

Paul: I don't know. I dunno. I don't dunno anything about space weather…

Jan: …well…

Paul: …it's not, it's not what I check the forecast, generally.

[Jan laughs]

Paul: What's the forecast like in Barrow? What's the forecast like in Lancaster? I'm not checking the forecast at Alpha Centauri.

Jan: Oh no, I do check the space weather. Particularly if there's gonna be an aurora. Um, so, so I'm on, I get alerts if things are happening that might make the sky look pretty at night.

So I am interested in space weather, as well as whether or not it's gonna rain in Lancaster…

Paul: …is that what space weather is? Is it only the aurora?

Jan: I have no idea.

Paul: So you, you, started off sounding like you knew what you were talking about and unfortunately …

Jan: …I don't…

Paul: …shall we find someone who does know what they're talking about when it comes to…

Jan: …I think it would be much better than me talking about it, I agree.

Paul: [Laughs] Well, we've got with us today, Professor Jim Wilde, who's a professor of space physics here at Lancaster University. He's also President Elect, so there's still time for it all to go wrong during the course of this podcast, of the Royal Astronomical Society.

Welcome, Jim.

Jim: Hello there.

Jan: Yeah, we should curtsy, President Elect. Ready? Curtsy,

Paul: Do you have to curtsy if they've not actually been put in place yet? I don't know.

Jan: Are you in place yet, Jim, or…

Jim: Uh, I will start my term as president in May 2026. So, no, no curtsying required.

Jan: My goodness, though. There must be a long lead in for such a responsible thing, clearly.

Jim: That's right. Uh, in the, the Royal Astronomical Society, the, the President Elect serves alongside the current President for a year to get a really good handover…

Jan: Oh, that's really smart…

Jim: …there's a bit of forward planning going on….

Jan: …yeah, no, that's, wow. Yeah, that sounds very sensible.

Paul: You don't get that in government do you?

[Jan laughs]

Paul: That would be useful. You know, actually learning from the people who've come before you.

Jan: Yeah.

Paul: It's a crazy suggestion. Crazy. The Royal Astronomical Society, they've just gone off on a, oh.

Now Jim, your research focuses on space weather.

Jim: That's right, space weather.

Paul: It does. So can you tell us a little bit about yourself, really, and a little bit about your background and then we'll get into what space weather is, 'cause I'm fascinated how you come to be someone who deals with space weather.

Jim: Yeah. So, so as you've already said, I'm the Professor of Space Physics, uh, here at Lancaster University.

And so, really my research is about understanding the space environment around the earth. And that's primarily driven and controlled by, uh, the effects of the Sun.

Um, and sort of my journey into, into understanding that started off as, you know, as a, as a kid, I was hugely, I was just a massive space nerd, you know, space Lego, space everything.

And that led me into studying, um, space physics at university and doing a PhD studying the Northern Lights. Basically how electrical currents flowing in the upper atmosphere create the Northern Lights and, and the dynamics that go on to do that.

But, and that was coming from a very much of a point of view, sort of curiosity-driven research. It's sort of a branch we might call solar-terrestrial physics, if you like, the links between the Earth and the Sun.

But nowadays it's, it's more acknowledged that as well as creating these beautiful lights in the night sky and, and other, uh, interesting effects in the region around the Earth, some of the, the physics can drive processes that can be really societally impactful and can affect technologies here on Earth.

And so that whole field is generally known as space weather. And we're trying to understand the short-term fluctuations in the space environment that can have an impact on, on society, the economy, and technology here on Earth.

Paul: So to be clear then, it's not about whether it's raining on Mars or whether there's, you know, a force nine hurricane on Neptune.

Jim: No. Those things all happen, and there are astronomers and planetary scientists very interested in them, but they're not generally what we would call space weather.

Um, we're really focusing in on the, the solar activity and the changes it creates in the space environment that will have an impact on, on human technology.

There is a little sub-branch. I mean, if we, we're talking about Mars, we obviously fly things to Mars, we take probes to Mars. Maybe one day there'll be human beings on Mars, and then space weather will be an issue there. Will the space environment, the radiation environment, affect those instruments, those spacecraft, those people, those astronauts?

So space weather isn't strictly limited to Earth. But most of it's on Earth at the moment 'cause it's about our technology and the people in society.

Paul: So in a hundred years, Michael Fisher's successor might be giving us a forecast that doesn't just cover Earth, it might cover Mars.

Jim: That's right, that's right. And, and actually, you know, today, uh, the UK Met Office produce twice- daily updates to their space weather forecasts.

So the UK Met Office provide forecasts for industry and government about what is on the way coming from the Sun, so it's not as strange as you might think. There are daily weather forecasts you can go and look at.

Jan: That's so cool. I wish I was a space nerd. [Giggles]

Paul: I mean, they have the shipping forecast on Radio Four. It sounds to me only fair that you should have the space forecast.

Jan: And here you're talking about like the effects on Earth, but how far out does the effects on Earth go because, because it's not just the ground, I'd imagine, 'cause there's a bit around us as well?

Jim: That's right. So, uh, space weather will impact things on the surface of the Earth and indeed below the surface of the Earth as well. But then it extends all the way out through the atmosphere and into the region around our planet. And that's where most space weather research and, and, and the impacts on society and, and the economy are, are focused.

However, we do fly some spacecraft further out than that, as we already said, planetary probes and things like that. So understanding how they're going to be impacted is very important.

And to make some of the measurements we need to understand space weather that impacts the Earth. We need spacecraft that are actually a long way away from the Earth. They're actually much close to the Sun or on the, on the sort of the journey of anything that's heading from the Sun to the Earth.

They sit on that line between the two and, and make measurements. So, so it can stretch almost out to the surface of the Sun, if you like. We, we study with remote sensing instruments, telescopes, and images the upper atmosphere and the lower atmosphere and the solar surface. So even as far out the surface of the Sun, that's sort of the, the, the hatching ground for space weather. And, and we are feeling the consequences here on earth.

Paul: So, you've mentioned this one then. Is essentially all space weather related to the Sun or are there other factors that play into it?

Jim: Fundamentally, it, it all has its origins in the Sun. I mean, as with so much, if you boil virtually everything we do on planet Earth, it starts at the Sun.

So the, the energy and the material that drive space weather effects start at, at the Sun. Uh, some of those processes, some of that energy, some of that material, uh, comes to us as, as electromagnetic radiation. So light, X-rays, ultraviolet light, that sort of thing. And some of it comes as, as material. So subatomic particles, usually electrically charged subatomic particles, which stream out from the Sun and cross into planetary space and arrive at the Earth a couple of days later.

Jan: I see. That was a, that was exactly what I was wondering about is that, so we get some notice, don't we? Because it doesn't, suddenly, it's not here. You can maybe see something or observe something happening on the, the surface of the Sun and then think well, two days later, we are going to be in a position to respond in a particular way or to be affected.

But what, what's the shortest time between something happening at the Sun and us thinking about doing something about it, if we can?

Jim: It's a little bit complicated, but in some cases we have absolutely no warning. And in others we do have a, we have a couple of days, a few days notice. And so in terms of the no warning, something a lot of people have heard of is a solar flare. And a solar flare is basically a, a big outpouring of, of electromagnetic radiation.

Imagine a flash bulb going off, putting out a load of light. Some explosion, some, some process on the surface of the Sun can cause a solar flare, which emits huge amounts of, of radiation out into space. Now that travels at, towards us at the speed of light. So, the first clue we have that something has happened is when that arrives.

Jan: Ah, yeah...

Jim: … before that happens, we can't...

Jan: …you can't see, you can't see...

Jim: …if you've got a spacecraft closer to the Sun, you might think, well, what I'll do is I'll put a spacecraft closer to the Sun that monitors this thing 'cause it's closer. But of course it sees the solar flare happening. If it wants to transmit that signal back to Earth to let us know, that travels at the speed of light. You can't outpace the speed of light.

[Jan laughs]

So for solar flares, the first we know of is, we see the solar flare. You can see them visibly, so you can see literally a brightening of a region of the Sun. It pours out more light, but also the number of X-rays we start receiving, gamma rays, ultraviolet light, they all go up.

So if the space weather you are interest, is space weather effect that you might be interested in, is going to be controlled by radiation from the Sun, sometimes we have, we have no warning.

Jan: Wow.

Jim: So, so if you were interested in, for example, if you were operating a spacecraft that might be sensitive to very extreme flashes of, of radiation, of X-rays, a pulse of X-rays going past you, then you wouldn't really have any notice of that happening.

What you might do is you might look at an active region on the Sun, because we can view the Sun in lots of different wavelengths, or colours of light, and it tells us about the activity, and we might see a region on the surface of the Sun moving into view that's crackling and spitting and firing out solar flares.

And so we might think, well, we need to keep our eye on that region. Because, unbeknownst to most people, the Sun is actually rotating. It takes 27 days to rotate roughly. So as a feature rotates over the horizon of the Sun, the edge of the, or what astronomers call the limb, and you can see it, and perhaps it's firing and crackling and sending out lots of solar flares, we can keep our eye on it, because about a week later that will be pointing towards the Earth. And if it's still firing things out, they're coming our way.

So while we might not know that a particular flare is arriving until it is en route, until it arrives we can say there's an active region which we can keep an eye on. So the space weather forecasters will be tracking and watching that, and if they can see there's an absolute monstrous re, you know, a region on the surface of the Sun many times larger than as our planet firing out flare after flare after flare, you could notch up your forecast to say, well, space operators, this is on our way, on its way. You may need to be aware of this.

And then space operators can decide how they, how they, how they deal with it. Now, they might think we, that's fine, our spacecraft's great, it's very shielded. But they might think, well, this particularly tricky manoeuvre we were going to do that was especially delicate, we'll delay that for a week. Or we might put the spacecraft into a safe mode. So some of the systems shut down and others operate a bit more robustly with more error checking, which is perhaps gives you a slight reduction in, in performance, but it's safer.

Um, because the thing about spacecraft is if they break, you can't fix them if it's in, if it's in high Earth orbit, geostationary orbit, you are never sending a repair crew out to do anything with it. So if it's damaged, it's gone. And, you know, the, the not only is the, the cost of building and launching the spacecraft, but loss of revenue is, is astronomical. To, to just make a pun out of it, you know,

Jan: [laughs] Well done, well done. I expect lots more of that.

Paul: It sounds very similar to me to the way traditional forecasts, weather forecast goes, say that there's a storm coming, but you don't necessarily know exactly where the storm's going to hit and where the main damage is gonna be, but you can see a storm developing and it's gonna be pushing in that area.

Is that a, a decent…?

Jim: …that's basically it, yeah. So the, the, the forecasting you, you'd use some similar approach to forecasting, um, and, and obviously we all like to joke about, uh, British people love to joke about the weather [Jan laughs] and how terrible forecasts are.

But actually if you look back 10, 20, 30, 40, 50 years, weather forecasts now have, have come on hugely since, since those earlier times because forecasting techniques have got better, we can run large models, computer models, very quickly with just slightly different starting parameters.

You know, if, if the direction of this weather front is slightly different than we expect, or it's moving slightly faster or slightly slower, and it's move, it runs into a different weather front, will it combine? You know, and you can run all those scenarios and go, well, well, you know, in most scenarios it's gonna arrive on Tuesday lunchtime and this is what, that's the most likely outcome.

And so there are some of those tools you can start to do. Terrestrial meteorological weather forecasting has the benefit of a longer track record and much more data, many more measurements.

So you have literally thousands of, of atmospheric balloons, buoys in the ocean, all these sort of things feeding into this, uh, and, and satellites orbiting the Earth.

Space weather is much more in its infancy compared to that. But again, much better than our capability was even 10 years ago or 20 years ago, so…

Jan: There's been a, you know, from what you've said already, there's a sense in which space weather might impact technology, which is in orbit, and so that's quite important. But does it impact technology elsewhere? So like, on the surface of the planet and, and here, I'm, I'm I've, uh, on my, my pre-work, 'cause that sound pretty interesting, is I had, I've been reading up about the Carrington event in, in 1859 where I, where I, where it did have impacts on the ground.

And so maybe saying something about that event, but then also, we obviously [laughing] have a lot more technology than we had in 1859 as well, so I suspect the complications have got larger.

Jim: That's quite right. So, so the Carrington event is, is uh, something that space weather researchers spend a lot of time thinking about.

And so back in 1859, Richard Carrington was a, a gentleman astronomer, another Fellow of the Royal Astronomical Society, and he was making some observations of the Sun from his observatory at home, um, and that he had an instrument, which basically we all know, um, everyone at home, don't look at the Sun through a telescope or a pair of binoculars, but you can build instruments that will basically project a magnified image of the Sun onto, onto a screen.

And he was using that to make observations and draw sunspots, which are active regions on the surface of the Sun, that appear to be a bit darker than the rest of the Sun. And you can, you can, you can see them very clearly and, and humans have been able to do this for hundreds of years, and we've been able to look at sunspots and count how many there are and look at the trends in those, et cetera.

And so Richard Carrington was observing a sunspot group when suddenly his, his room brightened and he was probably, he was the first recorded astronomer to see a white light solar flare. So this, a solar flare happened at the region of the Sun happened to be looking out with his instrument and the room brightened.

Um, the story is he ran off to tell the maid to come and have a look 'cause he realised, he originally had thought the maid had come in and opened the shutters on his observatory and was about to turn and scold her, and he realised that it was actually light coming from the instrument…

Jan: …wow…

Jim: …and so the instrument brightened up, he ran off to tell maid to show her, brought her back, and by the time he brought it back, it, it has stopped apparently. So there's a, a good rule, which is don't stop observing when interesting things are happening.

So, um, of course, in Carrington's times there were no, no satellites orbiting the Earth. However, there was, you know, we're thinking about the Victorian era, there were, there were observations around the Earth that were, observatories that were measuring the Earth's magnetic field. And actually the Earth's magnetic field, if we think back to our high school science, you can imagine it to be a large bar magnet at the centre of the Earth.

It's a bit more to it than that, but effectively we get a, a dipolar field emerging from one hemisphere and going into the other one. We have a north pole and a south pole, and we get a magnetic field structure. Um, but actually it's not fixed. It, it's slowly wobbling over time. It's moving around, it's drifting around.

And actually just the process of the Sun coming up in the morning irradiates the upper atmosphere and allows electrical currents to flow, which can add to or subtract from the Earth's magnetic field depending on where you are on the surface of the Earth.

And so actually if you measure the direction of the Earth's magnetic field, it's got a daily drift in it. It goes back and forth sort of once a day. And the amount of back and forth is linked to the season it is, because that's the amount of daylight and the amount of time the Sun's in the sky. Um, it's due to where you are on the surface of the Earth, the geology, or location.

So there was a whole set of reasons why it was useful to understand variations in the Earth's magnetic field because at the time the magnetic field was one of the principle mechanisms with which you'd navigate a ship.

So with all that preamble, Richard Carrington observes in 1859 a solar flare and just down the road in, in London, um, at, uh, at the observatories, the magnetic field observatories at Kew, it was noticed that there was a very slight wobble in the Earth, in the Earth's magnetic field observed, but not very much, at the same time that this flare is recorded.

But about 24, 36 hours later all the instruments around the Earth went off the chart, quite literally. So, so the Earth's magnetic field started wobbling backward and forth, huge disruptions to the Earth's magnetic field. And what had happened was the geomagnetic storm had been kicked off. And what we hadn't known at the time, and what Richard Carrington wouldn't have known is, he'd have seen the flare, but the flare was accompanying the launch of an eruption of material towards the Earth, which we call a coronal mass ejection. So called because some material, some mass of the corona, the outer atmosphere of the Sun is being ejected.

We couldn't see that from the Earth. And about 24 hours later, it had transited the 150 million miles between the Earth and the, the Sun and the Earth and had and sort of crashed into the Earth's magnetic field. Which… it's like a bell being hit with a big hammer. It just wobbled and vibrated and ring, and started ringing. Electrical currents were set up in the Earth's atmosphere, which started to make disturbances on the ground, which the observatories at Kew, and in Mumbai, and all around the world started to observe.

And what we now know is that this was an enormous coronal mass ejection, and this was one of the biggest geomagnetic storms on record. At the time, this was not very well understood. It wasn't really understood how the Sun's activity could affect the Earth in this way.

But again, back in those days, we didn't have, we didn't have satellites. We weren't trying to, you know, land large aircraft in the fog at an airport using GPS. But there was the Victorian telegraph system, which was the Victorian instrument, um, internet, if you like. And actually, lots of telegraph signals were, were really disrupted by this geomagnetic storm.

The wobbling of the earth magnetic field, because of this impact, 'cause of this ongoing storm that lasted three or four days, meant that anything at the ground level was bathed in a, in a varying magnetic field. Well, again, if you go back to your high school physics, if you are put in a conductor in a varying magnetic field, that's how you generate an electrical current. That's how a dynamo works or a generator works.

And all the long copper wires of the telegraph system were bathed in varying magnetic fields, and electrical currents were induced in them. So some telegraph operators were able to, unable to have a conversation hundreds of miles apart because of interference in their sets.

And what they did is they, um, unplugged their, their sets from the batteries that were powering them, and then actually the electrical current that was induced in the line from the space weather event was enough to allow them to then carry on using the sets...

Jan: …Oh, Lord… [laughs]

Jim: …while they were completely disconnected. Other telegraph operators were electrocuted, some telegraph huts burnt down, all sorts of things happened.

But at the same time, you had ships' captains in the Caribbean making records of the Northern Lights in their logs. The Northern Lights were out over San Francisco for three nights running. So this was a major space weather event that predated almost all modern technologies.

And so the obvious question is, if one of those happened today, how would we fare?

Jan: How would we fare?

Jim: So this Carrington event is often taken as being a sort of reasonable worst case scenario. Um, research suggests it, that's probably not a bad, a bad starting point.

What we do know about space weather events is, uh, they all look different, just like all big storms tend to be. You know, some of them come with lots of rain, some of 'em come with wind in a particular direction. Then another one will come with a, you know, a, a rain coming from a different direction. You know, the wind will move round, or it might have a different intensity. It might be not quite as strong but last longer. All these storms are different.

It's just the same in space weather. But it's a reasonable analogue. If we want to say, well, how bad would things be, um, to take what we have observed in the past and apply it to, to today. And so there's a whole industry in your like, in trying to understand that.

And what we know is that it, it depends a little bit on the preparedness of the industry. So, um, I do a bit of work with infrastructure operators, for example, power, um, in, in the UK. And so, you know, in the UK there's quite a long history of being, trying to look at what these risks would be and be prepared for it.

So in a power grid, what will happen is electrical currents can be induced in the lines and go through the transformers of the grid. And our power grid operates on an alternating current system. So the current fluctuates in directions 50 times a second. And the currents that are imposed from space weather. Are direct currents, they're kind of quite steady. So they basically put an offset in which, which interferes with the operation of transformers and, and can damage them.

And so what you wouldn't want is to lose lots of pieces of grid-scale infrastructure, because these are not the sort of thing you can just replace easily, these are pieces of equipment that last multiple decades, cost millions of pounds and have many, uh order times.

So, you know, the, the, so the grid operators in the UK I know have done a lot of work trying to understand the risk and, and identify which parts of their network are most likely to be impacted.

Now the honest answer will be, I'll tell you when we get one…

[Jan laughs]

Jim: …because we haven't seen a one on that scale for 160 years. However, the current work is suggesting that, say for example, a grid infrastructure in the UK should be relatively resilient. There would probably be some impact, some loss of some equipment, but not huge amounts of it. In fact, very small amounts of it.

And it would probably locate, you know, you'd imagine that it will be, um, you know, you, you that it would come on infrastructure that is perhaps slightly older. So what you can do is you can then have a plan, such that when the space weather alert is looking like something really big might happen, you implement your plan and configure the grid so that the more vulnerable equipment is, is put under less stress than perhaps newer, less vulnerable equipment.

So you can, you can manage, if you have a plan, is basically the, the forward look.

Paul: Thinking on a more, on a personal level. Would it have an effect on, say, someone with a mobile phone, um, and all the technology that's in there? Is that something that people, as individuals, would need to consider rather than companies thinking about big infrastructures?

Jim: That's a really good question. So, things like GPS are likely to be affected, so satellite positioning systems will likely be affected. Um, in that, in that the, at the atmosphere through which the signals have to pass, between the satellite and your device, that can be altered by space weather.

And it can become more dynamic. It can become less transparent. And so the same effect that you see when you look through the night sky and you see a star twinkling, it's because, it's because of scintillation going on in the atmosphere. The light coming through, the atmosphere to your eyes is actually being just slightly shifted by motion, uh, in the upper atmosphere, density, irregularities in the atmosphere that are, that are passing into or out of your field, your line of sight. And so, your star appears to twinkle.

In a similar way, GPS signals can twinkle, and it might cause the phone to lose lock or your GPS receiver. Now, for most things such as that, we use our mobile phones for, for say GPS, it's going to be hard to say. It's most likely, I would imagine that the effects will be relatively light, but if you want very precise navigation and timing information, that could be more challenging.

But it will depend very much on the application. There was a, there was an event, um, there was actually a reasonably punchy space weather event in May of 2024, uh, which brought the Northern Lights to the UK. You could see them beautifully from here in Lancaster. That struck at sort of early evening time in the UK.

Actually at that time it was, it was, uh, sort of in daylight hours in North America. Now, that meant that when that event happened, it was dark in the UK, or going dark and we could start to see the Northern Lights, which had been pushed further south from their more polar latitudes by the space weather winding up the, all the electromagnetic processes going in the Earth's upper atmosphere.

However, on the side of the Earth that was pointing towards the Sun at that time, they had slightly different effects in that the, the GPS signals started to be disruptive. Now what was interesting there is have seemed to impact the agricultural sector.

So if you have an enormous farm and you have a tractor, these modern tractors, they have very precise GPS location on them 'cause it tells them where they planted the seeds and then they know to go back and put fertiliser or weedkiller on the same spot, and then they know to where to go back and they can, they can harvest at the same spot.

Now, of course, also over years you build a map of your field and it tells you where you need to put more weedkiller or more fertiliser or whatever. So, and, and when you have an enormous site, these numbers start to add up if you're using more than you should. And, and there was some hardware that, um, farmers would use to navigate around their fields, which actually stopped working.

They just said, you know, this will not work today. And you, you can't use this kit to go and put weedkiller on your field. Now, you know, if, if that was the day you had to do it or the day you had to harvest it, that could be problematic.

And so there are sort of these slightly more convoluted effects. It's not like the mobile phone in your pockets going to get hot and start melting and emit smoke, but all of these things, which we just assume will be there all of the time and will be working all of the time, if you take them away, suddenly there's knock on effects that we often don't consider.

So there's some quite interesting and subtle impacts of this.

Paul: Is there any indication that how common something like the Carrington event might be? You, if we have storms or such over on Earth, we'll say it's a one in 100-year event or something like that…

Jim: …yeah…

Paul: …is there any indication like that for the Carrington event? Or are you gonna need to wait until there's another one to be able to say?

Jim: Yeah, so that's, that's, uh, you know, and if we, if we had the answer to that perfectly, then it would be very nice.

There are two ways of doing it. The last one we saw was about 160 years ago, so you could very quickly say, okay, things like this are about perhaps one in 200 years.

We don't know. I mean, it could be one in 10,000 years. And then, and then, you then, and we've, we just saw the last one, and there'll be 10,000 years before we see the next one.

In reality, we can do a bit better than that. So there's a whole branch of, of mathematics and statistics that deals with extreme events. So in, in things, in environmental sciences, for example, um, or environmental studies, you might look at river height and obviously most of your measures will show you what the average river height is, and it will show you what the typical range of the river height is over a year, or over a 10 year period.

But there are ways you can do, you can do some analysis that tell you what, based on that, if you've got a handful of outlier events, if you've got a couple of data points at the storm, you get once every 20 years and you get a couple of, you know, this is a one in 50 year storm and this is the biggest one we ever saw.

You can start to, to constrain the extremes a little bit better. And so that's how you do things. For example, you might do river height or rogue wave height. How, how high do you need to build the wall that put, you put around a power station or to protect it from a rogue wave or, or you know, what sort of, what does an oil rig need to operate in?

So there are branches of environmental science, which are directly analogous to this, that use some really interesting statistical methods. And if you do that, the numbers come back out about the same, that the Carrington level storm is probably a once every century, once every couple of centuries events.

But we do have to be a bit careful 'cause that is a statistical interpretation. Every day you wake up and you think, well, it's a one in 10,000 year event, but it only has to roll, the dice only just has to roll appropriately, yes today is the day and it's on its way.

So yes, it is statistically unlikely to occur very commonly. But that every day you roll the dice again, so you, you know, you take your chance. Um, so, so yeah, we think once every couple of centuries is, is that that sort of limit.

What is also an interesting question though, is, is that the worst it could be? Uh, and, and there is a lot of work going on as well. How big a storm can, can you get? How much, you know, how big an electrical current can you set up in the surface of the Earth from these things?

And there, there are, it's not gonna be infinitely large. There is system-wide limits on, on what can happen. So there's a lot of work going on to think about that.

And then of course, you're looking back over longer-term scales where we don't have modern records and you're looking in tree rings, because you can look at isotope composition that tells you about solar flux and all this sort of thing to try and get a feeling of it.

But some interest, some industries would find that very helpful though. Um, we've done a bit of work with, uh, nuclear generators and in the nuclear industry, you tend to want to understand risks or events that are happening on a one in 10,000-year level. So, you know, if you're building a power station, a nuclear power station by the coast, you would want to know what is the highest tide we're gonna see once every 10,000 years, or the biggest tsunami you're gonna get once every 10,000 years, because that's an industry that's very rooted in safety and has very long timescales.

Whereas if you were interested in talking to, say, a rail operator about whether their operations might be impacted by space weather, they're probably thinking about shorter timescale risks, you know, and they've got other things to worry about, leaves on the line and, and other things that are more immediate.

Paul: You talked there about the potential evidence being there in tree rings. I'm wondering if there's trees on this Earth that go back a lot further than the Carrington event in 1859. Is there any evidence from trees that have maybe been analysed that are older than that of a similar event having taken place in those 200 years before?

Jim: Yes. So there are so-called Miyake events named after the, the, uh, author who, who first proposed them. And yes, you can use isotopic measurements from trees and in other, and ice cores. And as you might do in climate science, you can start to see, because, because very strong solar flares ionise the upper atmosphere and create interesting isotopes, if those then make it down into, and they're taken up by trees or into the ice, you can start see those.

So yes, we do know that there are some very large events that have happened on over 10,000 year timescales. So, what if one of those hits is, is another question. So, but trying to get, what we then need to think about if one of those big events hits, how would we characterise it? What, what is it likely to look like?

And this is where it starts to get, you know, your uncertainties getting larger and larger and larger as you extrapolate further and further back. But yeah, the big events can happen, bigger than Carrington is possible.

Paul: Evidence would at least suggest that life on Earth will survive.

Jim: That's the good thing. That is the good thing I, you know, so. So, so the Earth's we, we rely, life on Earth in many respects, relies upon our magnetic field. The planet's magnetic field is what holds most of the everyday space weather at bay.

So space weather, you know, the, the Sun emits material 24 hours a day, seven days a week. It forms the solar wind that blasts past our planet at 500 kilometres per second, every second of every day. So, so if we didn't have a strong, a strong magnetic field, our atmosphere would be actually open to that. And, and that blast of material coming past would slowly erode it and, and we'd lose our atmosphere.

So actually our magnetic shield, our magnetic field is, is a force field. It is Starship Enterprise time, you know, with, with up shields. The, the magnetic field of the earth shields the Earth's atmosphere from much of the, of the interplanetary environment that, uh, which contains the solar wind that's streaming past us.

And the atmosphere does a lot of the heavy lifting that then shields us from radiation from the Sun. So, you know, ultraviolet light, we know, gives us a suntan. If we didn't have an atmosphere, the extreme ultraviolet light, which currently gets absorbed by our atmosphere, would make it to the surface of the Earth and, and would cleanse it.

So actually, you know, we, our, our atmosphere is essential to protect us from radiation. Our planet's magnetic field is essential to protect the atmosphere.

So, you know, we know that, that this is really important, but also we know that the Earth's magnetic field varies over millennia. So several times, every million years, the Earth's magnetic field seems to decay away and reverse and come back in a new configuration.

So we know…

Jan: …that's more, that's more of worry… [laughs]

Jim: …yeah. Well, in, from a, from a life on Earth scenario. It seems to be that that's not a problem. You know, life has evolved over hundreds of thousands of millions of years. Um, so, so the Earth is not sterilised every time the Earth's magnetic field reconfigures.

But the last time it happened, we didn't have all of the technological infrastructure we have now 'cause it was, you know, say it was a hundred thousand years ago. So, so what would be interesting is when that inevitably happens at some point. What impact will it have? Will it happen quickly? Will it happen slowly?

And again, that's another area of open research, not one I'm especially versed in, but you know, does it happen quickly on geologic terms, which would, could be perhaps hundreds of thousands, hundreds or thousands of years? Or is it slow? Um, and I think there are folks in both camps there.

Jan: In terms of the business-centric effects, some of them is like basically turn everything off until you can turn it all back on as, as my broad thing or…

Paul: …the whole world will become computer technicians…

Jan: [laughing] …yes.

Or you know, this is not the day for your precision agriculture because you can't, you can't put it in the right place. And, and with mining it would be in the same kind of position as well. Are there things that wouldn't go back to normal after being exposed to that kind of flux?

Jim: So in terms of the radiation flux and spacecraft, I mean, yeah, so, so if you, you can physically damage spacecraft.

So the, so the solar cells that provide the power to most, most orbiting spacecraft, uh, they're designed to absorb radiation, they absorb light and they turn it into electricity that the spacecraft uses.

Now because of that, it's very hard to build, to build those that are completely shielded from radiation, 'cause they're designed to absorb radiation. So what you find is that the amount of energy you get out of your solar panel, when you get a lot of damaging radiation from a space weather event, it effectively shortens the lifetime of your, of your spacecraft. So that obviously isn't great if it pushes the spacecraft over the edge and it can no longer generate enough power.

But even on a more, more moderate, you know, you will have had a business plan that, that assumed you would get a certain lifetime out of the spacecraft and you know what its revenue worth was. And if that fell short, then obviously you'd be, you'd be losing revenue on that. So that can be interesting.

And also that, um, electrically charged subatomic particles blitzing through the spacecraft can deposit energy into, into, um, silicon chips, into charge, into devices, and that can actually flip memory states. So you leave a little bit of charge behind and something that should have been a zero is now a one. So you're basically perhaps putting a binary instruction into a, randomly into a bit of memory on a, on a computer.

Now, if that happens to do something damaging, it can be very hard to go back. If it says shut down or, you know, point away from the Earth, or whatever it is. So usually you'd have systems that would mean that one error like that wouldn't cause something catastrophic to happen...

Jan: …yeah…

Jim: …however, there are instances of satellites, and indeed aircraft where mishaps have come, have been ascribed to what they call these single event upsets, where, um, uh, a, a cosmic ray, if you like, a subatomic electrically charged particle coming from the Sun has, has done some damage and caused some, a piece of electronics to behave oddly, um, in an unpredictable way.

So, so again, you want to make sure that, that those sort of, you know, you build your spacecraft, you build your aircraft, you build your electronics to be hard to that kind of, that kind of damage.

And the electronics are not stationary. You know, the chart, the, the devices that we are building for the next generation of aircraft or spacecraft, they're much smaller. So potentially they could be more vulnerable. The, uh, the circuitry on board them is smaller. You can, you can pack more circuitry in the same size chip.

And so our risk is actually changing as well as we as, as time progresses.

Paul: That's...lots of risks to things up in space. And you mentioned aircraft as well, which are flying course to the atmosphere.

Businesses, closer to the ground, you've talked about railways and that, you know, it, it's crazy to think that space weather could affect railways. Could it affect just general businesses all across the world in some way or other, or does the magnetic field, the atmosphere, et cetera provide a level of protection that should mean that most businesses, their day-to-day operations aren't gonna be affected by similar things that you're talking about. What's going on in space.

Jim: Yeah, I think, I think most businesses would not notice. It will probably be, I mean, we, we'd mentioned farmers, you know, so that might be a very, a very direct example. If you are doing something that requires very precise satellite measurements, then, then those, those systems would potentially be impacted.

Big transport, as we already mentioned, you know, if there is a large geomagnetic storm, aircraft will reroute to different lower latitude routes to stay away from the polar regions. You get a lower radiation dose, better radio communications, et cetera. Of course, those routes are usually longer and mainly aircraft are in the wrong place at the wrong time, you've used more fuel, you can carry less cargo. Prices go up, things, you know, there is knock on effects like that.

So you might expect a large, if there was a very large space weather event, if you are relying upon global shipping and things like that, you might start to see disruption. In the same way you might, if there was an enormous snowstorm that affected things.

I mean, a really good analogy would be in 2010 when an Icelandic volcano shut down British airspace for basically a week. Now, you might think, well, you know, um, you know, I'm at home, I've got a crocheting business, I sell stuff on the internet. How's it gonna affect me?

Well, if you are needing to fly stuff somewhere, it, it will affect you and it might be a disruption and there's a delay and everyone can live with it, and you say, look, the volcano erupted, I'm sorry, you, your plushy's gonna be late, when it, when it gets delivered to you. But, and people will understand.

But obviously there are more, more significant things. So it'll be how those, it would, for a lot of businesses it would probably be around how those, sort of system effects would affect your business. And so it might be, you know, perhaps it might be, you know, some of the, some of the power system type scenarios might be, well, let's just say a, you know, um, you lost a transformer and a and a and a region or a city was without power for some time. And, and, and perhaps if a transformer is very badly damaged, it might take days or weeks or months to get a replacement.

Now, what's very interesting of course, is whenever I hear myself saying this, I reflect on the experiences of the community in the city of Lancaster, which in 2015 suffered a regular meteorological weather event in Storm Desmond, which took power out in the city for best part of a week, you know, several days, and you know.

And in some ways that was very much like a space weather event. Power went, very shortly afterwards, the cell phone mast, we went down because they need the grid as well, and sort of very quickly you realised, oh, well your shop couldn't open 'cause you didn't have power or you couldn't sell things 'cause your tills wouldn't work, your registers wouldn't work.

And so, so that was very much like a space weather event. A large meteorological event can cause the same things. So probably for businesses, and, uh, it's probably thinking about your business continuity and your resilience. In some ways it's, it's irrespective of what is, that actually it's some activity on the Sun that's caused maybe a power cut or delays to shipping or things like that. You, you could just apply your, what is your business continuity plan? How do you manage that?

What is interesting is space weather, perhaps has slightly different interdependencies, um, than, than some other things. So, um, what I always think about is if, for example, um, I do a bit of research that into the impacts of space weather on, on railway signalling. So I'll just use this as an example.

If there was some problem with the signalling, which caused the train to be stranded, have to stop in the middle of a line, um, far away from the station for five or six hours. Then, then, as we know from our newspapers, passengers start to get off trains. After a couple of hours, they will, you know, the, the toilet stopped working, the air conditioning stops working, you can't buy a Cup of tea, everyone is very grumpy. Your mobile phone might have stopped working as well. Um, people will force the doors and get off the train. And then you potentially have people wandering around on a, on a railway line, which is terrible.

And so, if your business continuity plan happens to be, well, in that case, we'd have to get the police and the fire brigade to escort people off the line. And indeed, when you see the pictures on the TV and the news, that's kind of what you see. If that's your plan, then, then that's great, and it's been used many times.

If, however, this was because of a space weather event and at the same time power had been lost to a city centre on a, you know, on a Friday evening at the height of the rush hour, the police are probably gonna be quite busy dealing with that and they may not be coming.

So, so how does your resilience, how does your getting back to business depend if perhaps you lost several space weather, vulnerable systems or services at the same time? Gets quite interesting, quite quickly.

Paul: We're coming towards the end here, but I do want to go back to Mars, 'cause you did, well, not literally, I'm not physically expecting to go back, and saying going back suggest I'd been there once before, but I want to cover again the topic of Mars and just say. When it comes to the weather on Mars, what can that tell us about what's happening elsewhere in the solar system then, and what sort of analysis is going on?

Jim: So Mars is really interesting. So when Mars was formed, our best understanding and all the evidence seems to suggest it, it was kind of earth-like. It's a rocky planet. And at the centre, it had a molten metallic core, iron and nickel, and the churning round of that hot core caused it to have a strong magnetic field just like the Earth does, even now.

But Mars is a bit smaller than the Earth, so it's basically cooled down much quicker. Small things cool down quicker than big things. Your mug of tea will cool down quicker than your bath of water, even if they start at the same temperature. Um, so Mars has cooled down. Its molten core has gone cold. It's frozen, it's now a solid lump of nickel and iron. It's not generating a strong magnetic field, so Mars doesn't have the magnetic force field around the atmosphere and the planet that the Earth has.

And so for the last, well, the planet's probably about four and a half billion years old. For the past 3 billion years or so it's not had a magnetic field, and the solar wind, this material that's constantly flowing out from the Sun, as the Sun is burning at the centre of the solar system, has just stripped away Mars' atmosphere.

So the reason why Mars has a very thin atmosphere, and a very dry atmosphere and a very cold atmosphere is most of the good stuff has just been stripped off over time. A bit like a dandelion in a, in a hair dryer. It's just been blasted away by the solar the wind over billions of years.

So the way, the reason Mars looks the way it does today. Cold, dry with very thin atmosphere, is because it's not been shielded from space weather for most of its lifetime. So that's a really interesting juxtaposition of why this is kind of relevant to, to life on Earth.

But also we are ever to put astronauts on Mars the space weather hazard on the surface is very different from Earth, because of that thin atmosphere. So they're much more vulnerable to space weather events, these big solar storms will be much more impactful for a human being standing on the surface of Mars. On the surface of Earth, you don't even know it's happening.

So understanding that risk will be very important and having forecasting that might say tomorrow is not the day to go and do that, that trip in the rover, that's gonna take three days. Today, tomorrow is the day where we go into the, the, you know, the basement we've dug and we stay in there and play draughts for a couple of days, because it's gonna get a bit, a bit un unpleasant.

And of course, radio communications on the surface and between the surface and the Earth, they're all gonna be really impacted by, by space weather.

So space weather forecasting is gonna be really important for, for anyone who's thinking of going out that far.

Paul: So for this series, we're gonna be asking people,, just as our last question, just to look to the future a little bit, but not too far to the future, just the, the next year or two, the next steps.

And so, with that in mind, what do you think is coming next when it comes to space weather and the research and analysis around it? And do you think there's still things that are going to be discovered?

Jim: I think there's a lot still to be discovered. Our space weather capabilities are, are quite rudimentary compared to what we were able to do in meteorology.

Um, and we're gonna be seeing new missions, which are designed specifically to look at space weather. A lot of space weather in the data in the past has come from scientific missions, which are, you know, they're meant to study solar processes. Astronomers basically wanting to understand things.

And that data we realise is very useful, but scientific data tends to come back from spacecraft over a couple of days and it sits on a server and it gets processed and maybe your PhD or your postdoc does something to process it, and then months after it's taken, you can start to analyse it.

Whereas space weather forecasting data, you need real-time. So understanding that and having that real-time connection to the data is really important. Um, and we're having new missions coming forward that are designed specifically to do space weather that, might maybe give you some good science as well, but they're really about operational forecasting.

And so for, for, I think for a long time we've been working to do things to get from research to operations. You know, there's the scientists just curious how things work, and then realising how it can affect operational stuff like space weather forecasting. And I think we're now in the era of that operational perspective, coming back. To loop back, to help with then the research that we need to understand better to be able to do the operational stuff better.

So it's a virtual circle. We originally, we, we now need to figure out what the holes are, and we are, we're understanding some of them, in our ability to forecast and what science and what physics we don't understand in order to improve the forecast, which is what's been going on in meteorology for decades.

So it's just that being applied to just a whole new scale.

Paul: Sounds to me like in 10 years' time there won't be any space weather instances of Michael Fish saying, no, there's not a hurricane coming today.

[Jan laughs]

Paul: Just before the great storm hits.

Jan: I, I mean, just it's, it's fascinating and that sort of resilience, disaster planning end for companies becomes really, really important.

Paul: Yeah. Jim, thank you very much. It's been fascinating. Thank you very much.

[Theme music]

Jan: One of the things that I looked up after talking with Jim was the UK government's risk register. Space weather is on it. So this isn't some crazy, sort of marginal thing. It's a key safety, uh, resilience issue that, that governments address. It's very important stuff.

Paul: It really is, and you can see from everything Jim was saying, how the effects could be from a, a major event. We don't know for certain because there hasn't been that major event since 1859. And so, you know, in the 165 years since then, 166 years since then, we've been almost waiting for it to happen again, to see what might happen as technology, uh, has grown.

But that's the reason it's got the potential to have such an impact because of the growth of technology and electronics and all the like, like that.

Jan: And I'm always struck in, in all of our podcasts that the detail of, uh, of the stuff, whether it be, you know, systems or knowledge or understanding or complexities. All that stuff that's behind the scenes of our everyday life matters enormously. And each individual bit of it is a huge field of complexity and knowledge in itself.

So every time you use a GPS service, you think, thank goodness for the magnet [laughing] that is the Earth, but through to realising that actually that might not always be in play, particularly when he gave the example of precision agriculture had to hang fire for a few days until the GPS settled back down again.

Paul: Yeah. And that's from a not particularly major event. Major enough that we noticed it here with the Aurora Borealis in the skies above Lancaster, Cumbria, and various other places that wouldn't normally get to see it. But otherwise, pretty negligible, and that happens every once in a while that you get to see the Northern Lights.

So, imagine what the potential is for impact on GPS, say, if there's a big, big event. How long will the repercussions of that last?

Jan: And, um, physics is not my strength [laughs] but I kind of thought you, maybe you could see it coming, but of course if it's moving at the speed of light, [laughing more] you can't see it coming.

Paul: I think you've been watching too much science fiction where they managed to somehow communicate faster than the speed of light…

Jan: …yeah….

Paul: …communicating across the galaxy, you know, at the drop of a hat, which doesn't really happen.

Jan: Well, it also, um, not that I was ever thinking I might, uh, move to Mars with, with the other people who are going to Mars, whoever they might be. But it really tells you about, you know, the impossibility of actually perhaps being elsewhere, but the importance of really cherishing and nurturing the Earth we're on. That's what came across to me as well.

Paul: Yeah. Uh, saying, you know, that, Mars used to have, um, the magnetic core, used to have the atmosphere that we have, and then it lost it, albeit billions of years ago. And look at it now. Yeah. It's like this is what could happen to us. It's… oh, delightful.

Jan: [short laugh] Yeah. Actually billions of years in the future.

Paul: Yeah, oh yeah. You don't care, you'll be long gone. That's it, isn't it?

[Jan laughs]

Paul: Never mind the future generations. All your talk about the next generation, and all this lot, no, no, no. It's as soon as you are gone.

Jan: [laughs] Unfortunately, the, the moment at which I might be gone feels much closer than the 30-year generational effect. [laughs]

Anyway, we'll see. We'll see. That's not for today.

Paul: No. Well. Yeah, it's been a great way to start the series. It's space for the second year in a row at the start of the series. I don't think you thought I was going mad when I suggested space and weather.

Like I thought you were going mad when you suggested mining asteroids last year, but eh, you know, it's, it's good to keep up the standards and we'll have to find someone else with space for next year now, that's the only challenge.

[Joking] So, anyone who's a specialist on Jupiter's influence on the rainfall patterns in Lancaster…

Jan: No… but I happen to know dear, dear listeners, that we are going to have some more spacey things, um, in this, in this season.

Paul: We will, we will, but we'll get to them when we get to them.

Jan: Yes, indeed.

Paul: Before that, next week, we're gonna be coming back down to Earth with some more talk about modern slavery.

Jan: A recurrent interest on this podcast and a topic to keep on digging into. I think.

Paul: Yes, we're gonna be welcoming Kyla Raby from Australia. She's coming in from the University of South Australia, and she's gonna be talking to us about modern slavery regulations in her homeland, but also comparing them with here in the UK, and other countries around the world.

Jan: And the great thing about having her here in person is she's on a study tour of the UK, and so has come to the UK to research aspects of the modern slavery legislation and how it's operationalised over here.

So it's always nice to welcome visitors to the Pentland Centre.

Paul: Until then, thank you very much for listening. I'm Paul Turner.

Jan: And I'm Professor Jan Bebbington.

[Theme music]