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Welcome to IFL Science, The Big Questions. The podcast where we invite the experts to explore the biggest mysteries of science with your host, Dr Alfredo Carpineti.

I: Life on Earth wouldn't exist without the Sun. Its light is the energy that powers so much of our planet from photosynthesis to the changes in the atmosphere. Like everything else in the universe, the Sun is not static, it changes. Its better-known cycle lasts round 11 years and is marked by a period of intense activity, dramatic ejection of plasma, and energetic eruptions such as solar flares. Solar flares can often mess up our technology and historically have caused massive damage as well as spectacular aurorae. In a world relying more and more on tech, the big question we have is: Are we ready for the next massive solar flare? To answer it, we are joined by Dr Ryan French from the National Solar Observatory.

Dr French would you like to introduce yourself and tell us a little bit about who you are and what you do.

R: Of course. Hello everyone, my name is Ryan. I am a solar physicist which means I'm an Astrophysicist who specialises in just one star in particular, the Sun, in this case. In particular, I research these explosive events on the surface of the Sun called solar flares, trying to understand how they work and how they can affect us here on Earth. I am also an author and my first book was published earlier this year, called *The Sun, Beginners Guide to our local star*. And as the name suggests, that's just an introduction to the Sun which is accessible to everyone.

I: Thank you very much for that introduction. The big question for this episode is, as we have heard, are we ready for the next massive solar flare – and that is the topic of your research. Can you start us by telling us what is a solar flare?

R: Sure. A solar flare is essentially a release or a conversion of energy in the atmosphere of the Sun. In the atmosphere of the Sun, everything is dominated by magnetic fields. It's far away from the nuclear fusion that dominates in the centre of the Sun so above the Sun's surface, in its atmosphere, it's all magnetism. Solar flares, eruptions, sunspots, any of these fun processes you might have heard about on the Sun, its all to do with magnetic fields. And in the case of solar flares, a solar flare occurs when you have this build-up of energy within these magnetic fields that want to relax. They want to get rid of this energy but they can't and if you continue to build up this energy enough, essentially you can picture these magnetic field lines breaking and snapping and as this happens, that energy is released from the magnetic fields to the heating of plasma, light, the acceleration of particles and essentially that is what we see as a solar flare, this burst of light that reaches us from radio waves sometimes to gamma waves, reaches us at the speed of light, because it's just light. Solar flares are associated about half of the time with what we call coronal mass ejections which are eruptions of plasma from the Sun. These are different, they only correlate about half of the time. You can have flares without eruptions, you can have eruptions without flares but these eruptions, they travel a lot slower and they take around 12 hours to 36 hours to reach us here on Earth.

I: How often do solar flares happen?

R: The short answer is pretty much all of the time. The longer answer is it depends how big of a solar flare you are talking about. We have different categories of solar flares: the largest category is what we call an 'X' class solar flare; below that is an 'M' class, you can think of mid-class; and below that you have 'C', 'B', and 'A' classes. Now, the other thing to consider is that the Sun actually follows a cycle of how often these flares occur, has an 11-year cycle of increasing and decreasing activity. So, towards the peak of this solar cycle, which we call solar maximum, we have solar flares every day, C class every day, M class flares every week, maybe an X class flare once a month or so. At the minimum of this solar cycle, solar minimum, flares basically don't happen for months at a time, at least not to any observable level. What we believe is that if we keep going smaller and smaller, below levels that we are able to actually observe, there still are solar flares happening down there, they're just too small for us to observe currently.

I: Interesting. So, as we are approaching a solar maximum, we are seeing an uptake of activity on the Sun and in particular, not just solar flares, all kinds of very energetic activity, right?

R: Yep. Increase in everything. So fundamentally, the cycle is just a cycle of basically magnetic complexity in the atmosphere of the Sun. If you have a lot of complex, concentrated magnetic fields they interact a lot more, they release energy a lot more, so as you say, not only do we get more flares, we get more eruptions, we have a lot more sunspots, a lot more quiet Sun eruptions as well, which are eruptions that don't occur over sunspots too. So, everything is picking up at the moment and we expect maximum to occur sometime between next year and 2026.

I: Very interesting. And we mentioned the X class flare which are the most powerful. How bad does it get? How powerful is the most powerful that we have on record?

R: It's a great question. It's worth noting as well that X class flares, it's the largest category of flares. So, unlike an M class flare, where the top cap of an M class is the bottom of an X class, X class, there is no cap. So, we can have what we call an X1 class flare, or we can have X10 class flares, or even X50 class flares. The biggest solar flare we have since we've been able to measure them directly from space is something like an X28 class flare. That was way back in 2003. The largest flare we have on human record actually occurred long before we had telescopes in space. This was way back in 1859. It's quite a famous flare, it's called the Carrington Event named after a man called Richard Carrington who was, a great job combination actually, he was a part time astronomer and a part time brewery owner, so like, the dream!

I: **That is certainly an interesting job combination.**

R: Yeah. He would observe the Sun every day and one day he saw this bright light in this little sunspot that he had been observing and it wasn't a flash. He saw it slowly brightening over tens of seconds and slowly decay over minutes and we now know that this was a solar flare, because that evening, the aurora, or the Northern Lights was basically seen all the way down to the tropics. It was seen in the South of France, it was seen down in Florida, it was seen everywhere. Kind of crazy, and as well as just this weird Northern Light phenomena, telegraph machines, which were the peak of technology at the time, were acting really strange. They were giving electric shocks to operators, they were sending messages without being plugged in to a power source and all this weird wacky stuff was happening with telegraph machines and what we know today, looking back at that, is that solar flare event that we don't really have an estimate we have for how big of an X class that was, but a lot bigger than anything observed in recent years triggered a very powerful eruption and as that eruption of plasma moved through the solar system towards the Earth, it carries with it a very concentrated magnetic field. If any of you did A level physics, you will know that if you change a magnetic field over a conducted material, you induce an electrical current. If you start inducing electrical currents over things that already have a current, you're going to start overloading the system, you're going to give electric shocks, you're going to break stuff and that's basically what happened back in 1859 in this Carrington event. Now, if that happened today, which was your question, it would be a very different kind of story. Clearly, we have far more superior technology than just telegraph machines.

I: **So, the telegraph machines, what happened is because of the cables, right?**

R: Yeah, so if you imagine telegraph machines are basically these long cables of conductive material, so as this magnetic field from this eruption interferes with the Earth's magnetic field, that causes a temporary variation in Earth's magnetic field and that changing magnetic field induces electrical current over…

I: **At the ends where the machines are.**

R: Yeah.

I: **Fascinating.**

R: So that's why they were also able to send and receive random messages without being plugged in because this magnetic field from the Suns interaction with the Earth was causing the power to send just random messages, like really weird stuff.

I: **Cool. So, lets imagine we get that today and it's not just electrical cables, it's pretty much every way we shape our modern lives [unclear 0:09:58] very much about space and satellites. What would happen?**

R: We consider that to be the worst-case scenario. This is the scenario that we plan for, prep for, that is listed in government risk registers and everything and basically what we consider the worst-case scenario to be is possibly up to one in five satellites will break, they will stop working. Maybe some of them you might be able to get back online, but a large amount of satellites you are possibly losing connection to permanently. Down on the ground, you would have temporary loss, for maybe a couple of days in both radio communication, because radio waves, the way they work is they bounce off the upper atmosphere, that's how radio waves propagate and from the solar flare you actually get an expansion of this upper atmosphere. So, radio waves can't propagate as normal. You can't have communication with airlines, with ships, so you have flights grounded for maybe a few days, maybe a week. I think we spoke about this before, back in 2010, there was this Icelandic volcano and no one could fly anywhere and that uses a similar scenario for airlines today. GPS satellite navigation, forget about that for a few days too whilst that radio propagation isn't working. Perhaps the biggest concern is actually power grids. Not all power grids are at risk, the ones that are most at risk are ones that are very centralised, generate their electricity in one place and transport that long distances, because it's that long conductive medium that are most at risk. So, if you have a very localised, decentralised power grid, maybe you have lots of solar power, I don't know, different sources, then you are less at risk but if your systems are older, you could have loss of transformers which could cause power outages in certain regions of the world, maybe for a couple of weeks before you can replace those transformers. So long story short, no one physically, health wise, is at risk from these events. It's also not going to send us back to the Stone Age, you see a lot of quotes all the time. It's not going to fry your phone for instance, but it's the larger electronics that are at risk and current estimates, it would cause similar amounts of financial damage to any other natural disaster. So, the biggest earthquakes, the biggest hurricanes would be similar financial damage to that.

I: Thank you for that. So, that is how bad it could get. Can you give us a few examples of the kind of stronger solar flares that have disrupted technology in more recent years?

R: Yeah of course. So, it's obviously a spectrum, that's the worst-case scenario. That's one end of the spectrum and we expect an event that size to happen maybe every 200 years or something like that. On the smaller end of the spectrum, if you are a satellite operator or in the military logistics or something, you care about even the small events that happen a lot more often. Sometimes every few weeks and as members of the general population we don't really notice those day to day. But there have been a few cases in recent decades where there have been middle sized events that have affected everyday life. A very recent example, just off the top of my head, I think it was last year, Elon Musk and SpaceX launched some Starlink satellites, and I think it was 60 Starlink satellites, an entire launch worth, didn't make it to space because there was a solar flare and that expanded the atmosphere slightly that it changed the trajectory and these satellites didn't make it to space. So, that's a very recent example. Back in 1989, the East Coast of Canada, Quebec area, a hydro-electric plant, I think it was, lost power for about 13 hours because of an eruption from the Sun and this caused millions of people to be without electricity for 13 hours. There were a few other cases like that in recent decades too, and a really interesting one which I wrote about in my book very briefly is, back in 1967 a solar flare almost caused the end of the world. 1967, height of the Cuban Missile Crisis in Cold War era, there was a US naval ship which I can't remember if this ship specifically was carrying nukes or not, but essentially lost communication with the rest of the network and their first thought was hang on, we've lost communication, this must be an attack, this must be an EMP, something like that, we should ready for a counter-strike and the story goes there was one guy on board who knew about solar flares, knew about what we call space weather and said, “hang on, let’s just check before we react. Let’s just check that this isn’t the Sun.” They made some phone calls and as we know now, there had been a massive solar flare at the time and so that was the reason for that communication outage, not the alternative. So, it’s important that we understand solar flares certainly, and can mitigate their impact.

I: I remember there was also something about a Canadian radar system that was used by the US that also had a similar problem but I think they were seeing something weird and still due to the activity of the Sun. So, I think we are asking our big question, if there is a massive solar flare what are we going to do? What are the contingency plans that are in place to keep us and our technology safe?

R: The last 10 years in particular, there has been massive investment to understanding solar flares and the eruptions that are associated with solar flares and understanding their impact here on Earth. There are actually two organisations in the world, civilian organisations I should say, that are monitoring the Sun 24 hours a day, seven days a week, just like regular weather forecasters they have space weather forecasters. People sitting behind a desk watching the Sun, waiting for it to do anything. The United Kingdom actually has one of those two groups, it’s down at the Met Office. So, Met Office, famous for regular weather forecasting, as I say, they also do space weather forecasting. There is one in the US as well and I think the US Military does something similar too but that’s not as publicly accessible. So, essentially, if these space weather forecasters see anything happening, or even if they don’t see anything happening, they send daily alerts to airlines, to satellite operators, to the military who are aware all the time of anything that is happening. So, you probably wouldn’t organise something very sensitive military wise if there was a large solar flare coming that might damage the radio communications. You wouldn’t launch some satellites into space, like SpaceX did, if there was a large solar flare that had just happened, for example. Currently, forecasting, we’re forecasting events on the Sun, statistically wise success rate wise, we’re probably where we were with regular weather 50 years ago. So, it’s still got a long way to go, we can’t specifically forecast when a solar flare will occur. We can give probabilistic forecasts of when they will happen, but more importantly after that flare has happened we can check to see if that flare has caused an eruption because it’s actually the eruption that causes the most damaging parts to power grid and satellites and everything, and we model those eruptions to see if it’s going to be directed towards Earth, what we think the impact might be from that, what the effects might be from that and essentially, if there is anything really severe which hasn’t happened yet, since these forecasts have been going, the plan essentially is to turn off the power grid manually. Sounds strange, why would you turn off the power grid manually? Well, if you remember, the damage comes from this magnetic field that’s created by the interaction from the eruption with the Earth’s magnetic field generates that current. So, the damage comes when you have electrical currents that are conflicting with the electrical currents that are already in those power grids or those satellites, that’s what breaks the stuff. If you turn off the system, let the electricity get generated and pass through, wait for everything to pass and then you can turn it back on again and mitigate that damage. So, there are preventative things that we can do if something really bad looks like it’s going to come to us and that’s just one example. Another part is future research as well, and maybe we will talk about this in a minute, but we are always trying to improve models, improve our understandings and make better progress but at the moment, it's not the same scenario it would have been 20 years ago if one of these large things happens.

I: **That is reassuring that we are improving on how to react to a massive solar flare and it's great that it's not going to be back to the Stone Age with humanity. So, you mentioned space weather forecasts is a bit behind regular weather forecasts and you are eager to talk about future and current research. So, tell us what are we doing to better understand our star and also it affects the interplanetary space around Earth?**

R: Yeah, great question. There are a whole bunch of scientists working at different points through this system. I, myself, work on solar flares, so I am trying to understand the processes that happen on the very small scales that trigger a solar flare and cause a solar flare to erupt and we have a large suite of telescopes both on the ground and in space that can do this, but that's my area of focus. There are other people that look at how this eruption, once it's triggered, how it moves into the solar atmosphere, how it evolves as it travels through space. You have other people that look specifically at this eruption as its travelling towards Earth, how it changes, and you have other people that look at when it arrives at Earth, what happens there. So, there are lots of different parts of these systems that are being worked on by different scientists and hopefully some, or if not all of those parts of that system, will be put together incrementally to improve the models that we do have. At the moment we can't say when a flare will occur but if we can fully understand what triggers a solar flare maybe one day, we will be able to say that. We're currently living in a great time to research the Sun. It's been called, informally, the golden age of solar physics. We have a bunch of different telescopes. Back in 2018, NASA launched the Parker Solar Probe which is a spacecraft that is orbiting the Sun in a very elliptical orbit, getting as far as 95 percent of the way to the Sun, flying through its atmosphere. Literally measuring and tasting these eruptions as they launch off the Sun. We have the European Space Agency's solar orbiter spacecraft which is also orbiting the Sun with telescopes, looking at the Sun from different angles giving a great perspective, again, on how eruptions are triggered and evolve and we also have just starting this year, operationally, the National Science Foundation in the US have built a telescope called the Inouye Solar Telescope, which is a 4 metre [13 foot] wide solar telescope, which might seen not that big compared to some of the night sky telescopes, but think about how bright the Sun is, how much light you're covering from a 4 metre photon bucket, essentially. So, expect some very exciting results to come from that telescope and coordination between all these instruments from scientists in the next few years, so a very exciting time to research the Sun.

I: **Wonderful. Thank you so much for taking the time to tell us all about the Sun, the solar cycles, and what might happen when the next massive solar flare hits.**

R: Yes, thank you for having me and if anyone wants to learn more about the Sun, solar flares, their effect on Earth, you can check out my book called *The Sun, Beginners Guide to our Local Star* by me, Dr, Ryan French, available wherever you buy books. Thank you for having me.

I: **Have a good day.**

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