Aurora special: The science of the aurora

Ezzy: Greetings, listeners, and welcome to our special four part series all about one of nature's most beautiful spectacles, the aurora. Brought to you by Sky At Night Magazine and Hurtigruten Episode 2, the science of the aurora.

Today, I'm speaking with Melanie Windridge, whose background is in plasma physics and is a fusion energy and aurora expert and author of 'Aurora in Search of the Northern Lights.'

Hello, Melanie. And thank you for joining us.

Melanie: Hello, Ezzy. It's a pleasure to be here.

Ezzy: So today we're talking about the science of the aurora. So what is it that actually causes the aurora to appear in our skies?

Melanie: So the aurora is caused by charged particles which are accelerated into the Earth's upper atmosphere.

And when they have a lot of energy and they hit the atoms and molecules that are in the Earth's atmosphere, they give up some of their energy to those atoms and molecules and they cause them to then release that energy as light, which is the glow of the aurora that we see.

And these charged particles, we normally hear from people who talk about the aurora for tourism and travel, we often hear that these charged particles come from the Sun and they're caught up in the Earth's magnetic field and funneled to Earth.

But this is something that I always try to challenge a little bit because I think that that is too simplistic. An explanation and the charged particles don't actually come directly from the Sun. The Sun, of course, is involved because the Sun provides all the energy that drives this process, but it's not actually particles coming directly from the sun.

So, Do you mind if we unpick it a little bit and talk about what's really happening?

Ezzy: Go ahead. It sounds fascinating.

Melanie: Thank you. What is actually happening is you've got, well, first of all, let's talk about like why these particles can't be coming directly from the Sun. So if the particles were coming directly from the Sun, they would be hitting the earth on the sun side.

So that's on the day-side of the planet. And so if they were coming in directly on that side, we wouldn't actually see the aurora, because the daylight just obscures any light that would be created in the atmosphere .

We are seeing aurora on the night-side of the planet. So somehow charged particles are coming from the Sun, but they're getting around the back.

Ezzy: That's a really good point. How can you have charged particles from the sun if they're coming from the wrong direction?

Melanie: Exactly. They're getting around the back somehow. So that's number one.

And the second thing is they are getting more energy. Because we do actually get... some charged particles do actually come in the front a little bit. They kind of trickle in down the field lines. But any aurora that is created, which is called the day-side aurora, is only visible in places where they have 24-hour darkness. So at certain times of the year in places like Svalbard or Antarctica. And also it's very, very faint, so it's very hard to see. So to see the bright, dynamic auroral displays, that we're used to seeing at night time, the particles are getting more energy.

So they're getting around the back of the planet and they're getting more energy. So they're being accelerated and this is the key thing about the aurora. So the Sun and you hear about something called the solar wind and that's what drives this process. So the Sun is always throwing off charged particles, a plasma.

It's called the solar wind. It's like the sun's atmosphere, like bleeding off into space, this sort of background of charged particles. So all the planets sit in this sort of sea of charged particles from the Sun, which is called the solar wind. But then the Sun also, <u>occasionally</u> throws off more particles, so it's quite active.

If you look at pictures of the Sun or videos of the Sun, you could see that there are sort of twisted loops, which are caused by magnetic fields on the Sun kind of coming off. Sometimes these loops break and they kind of throw out charged particle and matter out into the Solar System. And the biggest of these is called a coronal mass ejection.

And for events like this, the Sun can throw out billions of tons of matter traveling at millions of miles per hour. And if that hits the Earth, then it really kind of energizes the Earth's magnetic field because the charged particles are actually stopped, prevented from getting to the earth by the Earth's magnetic field, which acts as a kind of shield, but the shield is sort of energised by the battering of this solar wind. Ordinarily at a lower level but if you get one of these big coronal mass ejections, then at a very big high level.

And so this energising, it sets up currents in the magnetic field of the Earth that accelerate these charged particles around the back of the Earth into the atmosphere of the Earth, and that's what causes the aurora.

So, yeah, a little more complicated than the nice, simple one, but I would say if you wanted to, like, summarise it in a nutshell, I'd say the aurora is caused by charged particles that are accelerated into the Earth's upper atmosphere, and this is driven by the energy of the Sun.

Ezzy: So, this is me just trying to make sure I've got this right.

It's the charged particles from the Sun energise our magnetic field, and then that magnetic field accelerates our own atmosphere's particles in, which then cause the atmosphere to glow.

Melanie: Yeah, so they're not in our atmosphere. They're in what's called the magnetosphere, which is further away. The atmosphere is really kind of close to the Earth.

So, very close in, sort of, well, the edge of space, they say, is about a 100km up. So the atmosphere is kind of bleeding out that way. Whereas the magnetosphere is much further out. It's the region that's dominated by the Earth's magnetic field. And so there are particles up there. There are radiation belts called the Van Allen belts, where there are lots of electrons and charged particles.

And yeah, there are particles that are out there that ultimately, once upon a time, probably did come from the Sun, but it's all kind of mixed up out there. It's like, you know, you might have a few molecules of your body that were once in Shakespeare's or something, you know, all the atoms and molecules get all mixed up.

So it's hard to say where they're directly coming from.

Ezzy: So it sounds like we've got a lot of particles flying around all over the place. How does that correspond to the wonderful shapes and colors that we see in the aurora in the night sky?

Melanie: So when the particles come into the atmosphere, they hit against oxygen and nitrogen predominantly, there are others, bits of hydrogen, you know, some others.

And the electrons that are coming in excite the atoms in the atmosphere, so they give them a little bit of extra energy. And then after a certain period of time, the atoms then release that energy as light, and that's what causes the colours of the aurora. And so, the different colours depend on the different atoms or molecules that are being hit, so they all have characteristic colours.

So oxygen creates that green that's the most common colour in the aurora that you will have seen if you've ever seen the aurora or looked at pictures. Oxygen also creates a red colour but that is seen much higher up in the atmosphere and it's much more difficult to see with the naked eye but you might see it in pictures where it's like a curtain rail at the top of the green curtains of the aurora.

We also see, so nitrogen is lower down in the atmosphere, nitrogen produces sort of purplish pinky colours or a bit of turquoise, and so you can often see those at the bottom of an aurora display. If it's a very active one you might see those extra colours coming in. So yeah, the different colours depend on the different atoms that are being hit upon by the electrons as they come into the atmosphere.

So that's the colours. And the shapes and things that you get, well, plasmas are charged gas, electrically charged gas, so charged particles, and so up high in the atmosphere, the atmosphere becomes a plasma, so the atoms are disassociated, if you like, so the electrons are separate from the nuclei of the atoms. So you have a plasma up there.

And plasmas are very dynamic and complicated in the way that they move because they're a fluid like a gas which the particles can move as a fluid but the particles can also be affected by electric and magnetic fields, because they're charged particles, and so you get lots of like things Feedbacks and different particle movements can affect each other. And that's why you get things like the twists and the curls in the aurora.

And the wider dynamics are due to the magnetic field of the Earth, and how the magnetic field of the earth is changing, and how that is funneling the particles down to earth. So that's why you can get big arcs or bands across the sky, which can stretch thousands of kilometers across. But then in width, they might only be a few tens of kilometers, so they're kind of very long, thin structures. And that's due to what's happening up in space, and how the magnetic field is changing up in space.

So you have, yeah, these sort of like, long, kind of, Earth scale structures, but then within that you also have like smaller scale structures where these can get like twisted and feedbacks can cause the plasma to move.

And you can also see this, we call it a rayed structure. So like, yeah, rays coming down or lines in the aurora. And that's because as the particles come into the atmosphere, they hit at different depths. And so you can kind of see these like columns or pillars building up as well. So there's a lot of different parts of structure on different scales, I'd say.

Ezzy: So it's predominantly the magnetic field that affects their shapes. It's not got very much to do with what's going on with the weather at that altitude then?

Melanie: No, it's not so much to do with the weather. The weather is much lower down. So the aurora happens from about a 100km up or 60 miles above the Earth.

And then it stretches up hundreds of kilometres more. And the weather, most of the weather that we see is, you know, below about 20km. So although there is some interaction between the two and it's something that's studied, most of ordinary weather that we know and experience is much lower down, so the aurora is happening much higher.

Ezzy: One of the other things I've always been a bit curious about is why is green the predominant colour in the aurora? What's the sort of main factor that makes green the one that stands out?

Melanie: I think there are a couple of factors but it's mostly to do with atomic physics and the density of the atmosphere.

And what's actually in the atmosphere. So I said that predominantly our atmosphere is oxygen and nitrogen. So they are predominantly going to give whatever their characteristic colours are. And oxygen kind of wins out because the nitrogen is actually lower in the atmosphere.

As we go higher up in the atmosphere, the concentrations of these different elements sort of changes a bit. And so nitrogen is predominantly lower in the atmosphere and the oxygen is going higher up. And so there's just more oxygen for the particle, the electrons that are incoming to hit into. From about a 100km up and stretching up to like 500 or 600 km, it's mostly just oxygen.

And so that's why you see the oxygen colours and why you see the green colour over the red colour that has to do with atomic physics and that's to do with how quickly or slowly the atom releases the energy that it got from the incoming electron. So the electron comes in from space bang, hits against an oxygen atom. Excites it.

And the oxygen atom has various different 'energy levels', we call it, for its own electrons to be in and so the way you get these different colours is an electron from a lower shell, shall we say, gets kicked out to a higher shell or energy level and then when it drops back down again to the original energy level it releases that extra energy that it was given from the incoming electron and these shells or energy levels are fixed.

So there's one for red and there's one for green in oxygen. Now the green one, when the electron gets kicked up to the green level, it drops down again quite fast. And so then it releases that energy as green light. The red one, when it gets kicked to a red level, it can actually stay in that red level for quite some time, before it drops down and releases the red light.

If, during that time period, something else hits the atom, then it will just kind of fizzle away that energy and it won't release the red light. So we don't see that. So the only way that we can see the red light is if there's very little chance of anything else hitting the atom before it releases the red light.

So that means it needs to be very, very high in the atmosphere where there's very little stuff actually there at all, and an atom can travel for maybe like a second or so without actually hitting another atom. And that's a long time. And so that's why you only see the red light very high up in the atmosphere, where it's not very dense up there at all.

So it depends on atmospheric density and it depends on atomic physics. And I've, it's probably like gotten very complicated for a podcast and everyone's a bit like, oh my god, I need to see pictures.

Ezzy: So it definitely seems like where things are in terms of altitude depends on what you're going to see when it comes to aurora.

But we know from the last episode that You're also more likely to see the aurora at certain places on the globe. What is it about the science of how the aurora happens that causes that?

Melanie: So the places on the globe are generally closer to the poles. But not absolutely at the poles. A little bit away.

Because the aurora generally happens in rings around the poles. So the North Pole or the South Pole. But more people see the aurora in the North because there's just not very many people in the South. Or rather the ring, the auroral oval in the South goes mostly through the sea and a little bit through Antarctica. And so, like, more penguins see the Southern Lights than people do. They get a great view of it, they do.

But the Northern Lights the auroral oval in the north, goes through a lot of land. So, places like Alaska, northern Canada, Iceland, Greenland, northern Scandinavia, Russia, you know, there's mostly land under the auroral oval in the north, which is why we know a lot more, in folklore at least, there's a lot more, you know, stories in folklore about the northern lights than the southern lights just because people saw it a lot more.

So yeah, it happens in these rings around the poles and so it's predominantly in the regions I just said, but it can, this ring, this auroral oval can expand and it does that if we get a lot of energy hitting the Earth's magnetic field. So if the Sun releases a coronal mass ejection and we get bombarded by a lot of matter, then this really energises the Earth's magnetic field.

It accelerates a lot more particles into the Earth's atmosphere and the auroral oval actually expands southwards in the north, northwards in the south. And so you see it in more like mid latitudes, but that's a rare event. We don't often see it in the lower latitudes. So yeah, the geography of the aurora is really to do with what's happening up in the magnetosphere with the Earth's magnetic field.

Ezzy: I think that is one of the things that I struggled to get my head around when I first sort of started getting interested in the aurora, which is that a bigger event in space doesn't necessarily mean a more spectacular aurora. It just changes where you might be able to see it. And anybody who does start getting interested in aurora are very quickly going to come across something called the KP index.

What actually is that? And how does it relate to the aurora and the aurora oval?

Melanie: So the KP index is a measure of the disturbance in the Earth's magnetic field. So the Earth has a magnetic field, a little bit like a bar magnet, you know, like at school, if you used to use iron filings with a bar magnet, you'd see it had this kind of butterfly wing pattern around it.

That's a little bit like, well, that's like the basis of the Earth's magnetic field. But then it gets changed by the fact that it's getting hit by the solar wind all the time because magnetic fields can't cross and the solar wind, which is a plasma made up of charged particles, has its own embedded magnetic field.

And so when these two magnetic fields hit upon each other, The magnetic field on the Sun side of the Earth gets squashed up a little bit towards the planet and on the back side of the Earth it gets sort of stretched out a little bit like a wind sock. So we have the magnetosphere, which is the magnetic environment around the Earth, looks a bit squashed up on the front nearest the Sun and a bit like long stretched out tail on the back away from the Sun.

So when the solar wind is coming at the Earth and particularly if there's a bigger disturbance like a coronal mass ejection, then this is going to affect the magnetic field of the Earth and the position of the magnetic field of the Earth. And so the KP index is a measure of how this is changing. It's a measure of the disturbance in the Earth's magnetic field. And so then that correlates generally with auroral activity as well.

And so Kp index, it's a planetary index. And so it's made up of measurements that are taken on the ground from lots of different observatories or auroral stations all around the planet. And so they're all measuring the magnetic field and it's all put together and sort of averaged, if you like, in this planetary index. So it gives a sort of average idea of how disturbed the magnetic field is, and therefore where the auroral oval might be. So it gives you an idea of where, over the planet, we should be seeing auroral activity.

So that's what it's useful for. But what it's less useful for is you sometimes don't see the aurora because it's not as simple as that. It's a very complicated process that's involving magnetic fields and electric fields and incoming plasma.

And also sometimes how much aurora we see also depends on the magnetic field that's in the solar wind. And that can change. Sometimes it's facing northward, sometimes it's facing southward. And depending on the orientation of the magnetic field in the solar wind, it will interact in different ways or to different levels with the Earth system.

And so if it's pointing northward, it just doesn't interact very strongly. If it's pointing southward, it's like opening a key to a lock and suddenly all this activity starts happening. It starts opening up field lines on the Sun side of the planet, stretching them up over the planet, pushing them down on the tail side, causing magnetic reconnection, which accelerates particles.

So it's really like the southward magnetic field, which is referred to as Bz if people are watching the forecasts. Southward Bz is when things can really start happening. So you kind of need a combination of high density in the solar wind, high particle speed in the solar wind, a south facing magnetic field in the solar wind and that's going to really like unlock the good auroral displays for you, as opposed to just the Kp index which tells you how disturbed the field is.

Ezzy: I think that's one of the things that makes the aurora so magical and why people get so invested in trying to see it is that it is really unpredictable. As much as we try to. So is there ways to predict when it's likely to be a good display as opposed to sort of more of a damp squib or is it just you have to go out there and wait and hope?

Melanie: Alas, you mostly have to go out there and wait and hope. I mean there are indications of when it's going to be amazing. Like if you know that there is a coronal mass ejection that happens to hit Earth, because the Sun can send these things out in any direction, it doesn't have to hit Earth, but if there is one that's looking like it's coming towards us, then you get a bit of warning and people might be saying, oh, you look, you know, the Sun's just released something, so maybe in a day or two, it's going to hit us.

And if it does, it could be good. And so then people will start going out and trying to see it. But yeah, there's still no guarantee. As I said, you might have great high density, you might have great solar wind speeds, and you might be thinking, yeah, this is going to be amazing. And then the magnetic field just doesn't align properly and you don't really see much. So there are times, yes, when you can see from the forecast that it's going to be good, but there's still no guarantee and you don't know exactly when it's going to happen. So you might go out at 9:00 and wait until 12:00. You know, it's just one of those things.

Ezzy: You mentioned that there's lots of stations that are monitoring all aspects of the aurora. What can we learn by studying the aurora?

Melanie: Ooh, that's an interesting question. There's lots of things you can learn by studying the aurora. But predominantly on Earth, we learn about what's happening out in space.

So we learn about the dynamics of the magnetosphere or the magnetic environment of space, and you can kind of put together things like looking at the shapes and the forms and the colour of the aurora, you can actually kind of extrapolate that to further out. So the aurora is like the screen that this activity is playing out on. The events that are causing it happen way out in space. So, by looking at the aurora, you can learn about what's happening way out in space, in the Earth environment.

So, yeah, so that's interesting, and also, from a planetary perspective and a human perspective- the aurora looks amazing, we love it, it's brilliant. But actually, it's a manifestation of a disruption in our upper atmosphere, and that has consequences for technology.

Ezzy: That does make it sound a bit more ominous: it's a manifestation of a disruption.

Melanie: Exactly. In our upper atmosphere. Yeah, well, it's true. It is ominous. Like, bad things are happening in the atmosphere. So for satellites, it can be very disruptive to satellites. It can be disruptive to airlines and flights have to be diverted sometimes if there's a big solar storm because of the extra radiation that's coming into the Earth system, which would be bad for pilots.

Astronauts, of course, have to think about radiation when they're going to the International Space Station and things like that. And also, on the Earth, these big auroral displays, it's a lot of changing magnetic and electric fields in the atmosphere. They can actually induce currents in power lines, they can cause big power cuts.

So there's a lot of, let's say, like, darker sides to the Northern Lights. And so people need to monitor this and people want to understand better what's going on in space so that we can better protect ourselves. Because when we didn't have so much technology, it wasn't so much of a big deal. But now we have, yeah, things like GPS, communications, so much that we rely on all the time that can be disrupted by what we call space weather.

And so learning more about the aurora and the processes that are happening out in space can actually help us to better protect ourselves from the downsides of space weather.

Ezzy: So there's lots of ways that we can monitor when this stuff is coming in, but are we able to predict when the aurora might look better?

Are there certain times of year when the aurora looks better?

Melanie: It's never entirely predictable, but in terms of probability, yes, things change that make it more likely that you might see a good aurora display. There are a couple of things. Firstly, seasonally, they say that often you can see better aurora around the equinoxes.

So around sort of springtime, March time and September, October, you can sometimes see better aurora. And that's because of the alignment of the magnetic fields. So I mentioned that the southward facing magnetic field in the solar wind opens up the field and energises it more. And it just so happens that because of the tilt of the planet, it's more likely that you're going to get that sort of favourable coupling, shall we say, around the equinoxes.

So that's one time where you might get lucky and see more aurora. But also the Sun has an 11 year cycle of activity. The Sun rotates, but it also rotates not as a solid, it's a big ball of plasma or fluid, and so it's got this sort of differential in it where the outer layers can rotate at different speeds to the inner parts of the Sun, and this causes the magnetic field to get like it's all twisted up and so it kind of like knots up and gets very twisted and then it sort of like pings and resets and gets less twisted and then the cycle repeats over an 11 year period.

So from a very twisted active Sun to the next time it's a very twisted active Sun, that's about 11 years, give or take. And when it is more active, when the magnetic field is more twisted, you've got much more chance of, that it will release one of these big coronal mass ejections, and it will send a lot of matter our way.

And if that happens, you're going to see much bigger solar storms, they would call them. And so, that's not to say that you don't get aurora in the lower times, because the Sun is always sending off a solar wind. So if you live in the locations under the auroral oval or in the auroral zone, then even during low activity, you're still going to see the aurora, but it will probably be the sort of quieter, and by that I mean like slower moving, less active, just oxygen green kind of auroras. And you'll see that anyway, probably, if the conditions are right.

But yeah, as the Sun's activity ramps up, you get more chance of coronal mass ejections, more chance of fast pockets of solar wind coming out. And if you've got fast solar wind, or if you've got coronal mass ejections, then you've got much more chance of a nice, big, colourful, active aurora display.

But you still don't know when it's gonna be! It's just there's more chance that it'll happen, but you don't know when.

Ezzy: One of the reasons why we're doing this series now and why people are getting so interested is because we're actually at the peak of our current Solar Cycle, Solar Cycle 25, which is such a fascinating topic that we're actually going to give the Solar Cycle its entire own episode.

So please do tune in next time where we'll be talking to Lucie Green to get all of the details. on what's going on with Solar Cycle 25. But for now, thank you so much for taking the time to talk to us, Melanie. It has been absolutely fascinating to learn about the aurora.

Melanie: It's a pleasure. Thank you for having me.

And if it has been really confusing, then do read the book and get like more of the details because it's a fascinating topic and there's so much that goes into it. And you do sometimes get really good aurora on the declining side of the solar cycle too. So we should be seeing good aurora for a good few years yet.

Ezzy: Well, thank you very much.

Melanie: Thank you.

Ezzy: Thank you for joining us for this episode of our special series, all about the Aurora. We'll be back soon with episode three, the Solar Maximum.