Astronomy Cast Episode 72:
Cosmic Rays

Fraser Cain: We're going to return back to a long series of episodes we like to call: Radiation that Will Turn You Into a Superhero. This time we're going to look at cosmic rays, which everyone knows made the Fantastic Four.

These high-energy particles are streaming from the Sun and even intergalactic space, and do a wonderful job of destroying our DNA, giving us radiation sickness, and maybe (hopefully!) turning us into superheroes.

Pamela?

Dr. Pamela Gay: No.

Fraser: All right.

[laughter]

I guess we'll have to wait for the next episode – perhaps gamma rays. We'll keep moving.

So where do cosmic rays come from?

Pamela: They come from as near as our Sun, and as far away as some of the most distant angry, active galactic nuclei. Wherever we have strong magnetic fields you have particles getting accelerated. In fact, in some cases we also get what are not cosmic rays, but they look similar. They're cosmic ray-like things from granite and other rocks that are embedded with radioactive materials here on the planet Earth.

Fraser: What is a cosmic ray? Some come from the Sun, some come from deep space… break it down for me.

Pamela: It's basically a fast-moving, subatomic particle. You get protons, electrons and in some cases you even get alpha particles, which are helium nuclei. If you accelerate them at high rates, when they collide with things they expend all their energy. If the thing they're hitting happens to be DNA it can do damage. If it happens to be a digital imager such as a CCD detector it creates streaks in your image (in graduate school cosmic rays were the bane of my existence and I learned to hate them with great vigour.

Fraser: You're saying the word particle. That doesn't sound to me like a ray. When I think of a ray, I think of a piece of the electromagnetic spectrum, but it doesn't even fit on the spectrum, right?

Pamela: Yeah, that's one of the weird things about this. Cosmic rays are flying particles: they're a single thing that gets flung at you, or the planet Earth, or something that can detect them, at high velocities.

Fraser: So think bullets, not waves.

Pamela: They're bullets not rays.

Now, I have this sneaking suspicion, and I have no way of confirming this that I know of, that the name cosmic ray may have come from the fact that they leave streaks on detectors. So you get one basically coming to a grinding halt across your photo-detector, across your photo-sensitive whatever it is you're working with. When they come grinding to a halt, their energy creates a streak on whatever image you're trying to take, that looks like a ray.

Fraser: All right, so give me the origin of a cosmic ray. What kind of conditions exist and what will happen to actually generate one of these?

Pamela: So you have a proton minding its own business happening around the universe – perhaps in a star, perhaps somewhere else.

Fraser: Sure – lets start with the ones that come from our Sun. will you have a free-floating proton?

Pamela: A free-floating proton is nothing more than the hydrogen atom that's been stripped of its electrons.

Fraser: Okay, so how did it get stripped of its electrons?

Pamela: You heat it up and it gets naked . it's kind of cool that way.

Fraser: All right. And a star is known to heat things up – so a star can strip a proton of its electrons so you just have a naked proton.

Pamela: So you have this naked proton wandering around in the extremely hot outer, outer atmospheres of the stars. They get trapped in magnetic loops.

When you look at the Sun through and H-alpha filter, you'll sometimes see these loops – these different neat filamentary structures on the edges of the Sun. you can't see them face-on, because they get lost in the glare of the Sun. they're getting accelerated through these magnetic loops, and when these loops break, we get all sorts of particles flung at our planet. When they hit, we get things like the northern lights.

Fraser: so the magnetic loops we see on the Sun, those are almost like if you take a magnet and put it in a bunch of iron filings, the filings will move in the shape of the magnetic field lines that are coming out of the magnet. So those loops on the Sun are kind of the same thing?

Pamela: They're very similar. Another way to think of it is as an electromagnet. If you take a wire and loop it around a piece of PVC pipe (use the thickest wire you can find and a skinny pipe), attach it to a car battery, you can use it if you attach and detach it quickly to fling small objects that are metal. Don't do it with sharp objects, but it's fun to do with little BB's or something in an open space. This is a project I like to give to students.

Fraser: So in that situation you're turning on the magnetic field and the BB or whatever is trying to align itself into the magnetic field, and just as its about to get there and be slowed down and pulled into its correct position, you turn off the magnetic field and its just got the momentum to carry it along.

Pamela: In particle accelerators here on the planet Earth, like CERN which we talked about in our show about the Large Hadron Collider, they have pulsed magnetic fields where they're constantly turning the magnets on and off in sequence to drag the particles in circles around and around in these loops.

Fraser: So you've got these protons hanging out on the Sun, they get accelerated or they get pulled into these magnetic field lines, and then the magnetic field lines change and you get this snap and the particles are flung out. Is it just protons? How fast are they going? …I just asked two questions there. Is it just protons?

Pamela: It's not just protons. It's protons and electrons, its even helium nuclei (alpha particles) in some cases.

Fraser: It's whatever was trapped in the magnetic field line when it snapped.

Pamela: It's always ions

Fraser: Water at the end of your wet towel.

Pamela: The key is its always something that has charge. It's going to be a light atom because it takes a lot more energy to accelerate a heavy atom.

Fraser: Oh, because they have to have charge to be picked up by the magnetic field line anyway.

Pamela: Exactly. So you take a charged nuclei, interact it with a magnetic field, snap the magnetic field and off flies the charged particle, the charged ion… and you have a cosmic ray.

These things vary in energy. You can get pithy little tiny ones, but you can also get some where you have a single proton that is carrying as much energy as a tennis ball going 50-60mph. That's a lot of energy.

Fraser: Especially if it hits your precious DNA.

Pamela: Yeah. Imagine how much it hurts your skin if you get hit by a baseball. Imagine instead all that energy being focused and nailing a piece of your DNA.

Luckily, these are itty-bitty little tiny things. They're parts of atoms. Even though we look like solid objects, human beings are mostly empty space – everything is mostly empty space. Most of the time these protons will happily sail through your entire body and not interact at all. Occasionally, damage can occur.

Fraser: Right, but aren't we protected by the Earth's atmosphere?

Pamela: We're mostly protected by the Earth's atmosphere. The magnetosphere is what's doing most of the protecting. Our planet has its own magnetic field, and when these charged particles interact with the magnetic field, in many cases these particles get their direction changed and they veer off so we don't get hit by the majority of them. Some of them do make it through the magnetic field of the Earth and hit us down here on the planet Earth. There's actually been some possible relationships between spikes in the number of cosmic rays hitting the planet Earth, and the frequency of cancer.

Fraser: So when the cosmic rays hit the Earth, they don't stream straight in – they get stopped by the atmosphere. Could we talk about our natural defences – how is our planet protecting us from those awful rays?

Pamela: It's primarily our magnetic field. Just like magnetic fields can accelerate these particles, they can decelerate them and change their direction. They can funnel them into the Van Allen Radiation Belts.

Our atmosphere can help as well. When these cosmic rays hit the atmosphere, they end up reacting with things in the atmosphere, creating Cherenkov Radiation. We get streams of different types of particles that we can then detect with different telescope facilities that are specially built to detect these cosmic rays.

There are still some that make it through, completely unaltered, waiting to nail my CCD when I'm trying to take high-resolution images of the cosmos.

Fraser: That's what you talked about next. You're using your CCD and not trying to detect them… but what's the method astronomers use to detect them when they go looking for them?

Pamela: There's a few different ways. One method you can use is you can take a large tank of often heavy water. You can actually get muons produced when cosmic rays hit the heavy water. We can detect these through their child particles and the flickering of light they give off.

Another way that we can detect this is through the chain of particles they produce in the atmosphere. You can have a high energy proton coming in and it collides with a molecule in the atmosphere and gives off what are called pions which then decay into things like muons and gamma rays and neutrinos. Through all these different chains of events, we eventually get things we can actually detect. There are different observatories like the Whipple Observatory.

There's a new facility, the Pierre Ojet Observatory, which is actually a pair of observatories, one in the United States and another in Argentina. They're working to use a whole different array of methods so they can compare how they're detecting cosmic rays and hopefully work to figure out where on the sky these cosmic rays are coming from.

Figuring out where cosmic rays originate is actually a real problem. As they're flying through the cosmos, every magnetic field they interact with is going to change their direction. Some cosmic rays we'll never be able to figure out where they originated.

Fraser: That's part of the mystery. You talked about the fact that we know most of the cosmic rays hitting the Earth are coming from the Sun. That's not all of them – where are the rest coming from?

Pamela: Some are coming from galactic origins. Unfortunately, the galactic ones we have no way of figuring out where they came from. The galactic magnetic field scrambles all of that information.

Based on their energies and based on the shocks we see around things like supernova, we believe most of the galactic cosmic rays originate in supernova blasts. Some of them though have such high energies we can't really find anything in our galaxy that they could be coming from. We're still trying to find all the origins.

Fraser: Weren't some of the energy levels in the cosmic rays higher than physicists thought was even possible? Wasn't it more than was theoretically predicted by the most extreme events anyone could imagine?

Pamela: Oh, totally.

So sometimes (not often, but occasionally), you get physicists that come up with humorous names for things. The Higgs Boson is nicknamed the God Particle.

It's the one we're looking for that will give mass to everything, and we need to know where mass comes from.

After finding these ultra, oh-my-god-high energy cosmic rays, they got nicknamed the "oh my god" particles, because nothing can explain what created these things.

We're starting to get some clues. We think many of them have extragalactic origins, so they're travelling to meet us from other galaxies. We think it might just be that they're coming from super massive black holes that are angrily feeding in the centres of galaxies. These are active galactic nuclei. It's a family of galaxy related to quasars.

Fraser: What might be the process that's whipping up these particles with that much energy?

Pamela: It's all about the magnetic fields. Active galactic nuclei, in many cases, have these amazing jets. They appear as radio lobes in surveys like the first NVSS surveys done with the VLA in Mexico. You look at these images and when you super-impose the radio images on the optical images, the optical part of the galaxy might be 20 pixels across, down in the centre of the image. Then you get these huge radio lobes that will go out a couple hundred pixels in either direction.

Fraser: When you say lobes… what is a lobe?

Pamela: We call them lobes. It's the name we gave the shape. Take ice cream cones and attach them to the top and bottom of a spiral galaxy. At the end, have the material coming out billow as it hits the intergalactic medium.

We have these jets of material in some cases very tightly wound and we can actually see twisting and winding of the material. As the material travels away from the galaxies, it eventually ends up colliding with the dust and gas between galaxies and it billows out when it hits, sort of like a waterfall hitting the ground and creating a cloud of splashing water.

Fraser: So when you see the picture from a telescope of a quasar or active galactic nuclei, the visible part may be a small little part of the screen, but then the part that's actually radiating radio waves is gigantic around the galaxy, and that's coming from the jets that are interacting with its surroundings?

Pamela: They originate from the jets. So these quasars have powerful magnetic fields being generated in the accretion disk of in-falling material around them. You have this spiralling charged material driving huge magnetic fields. Sometimes, particles get flung out the poles of the magnetic fields. This acceleration creates the jets, and it can also help create, in this chaos of magnetic fields, these ultra high-energy cosmic rays that are packing a wallop of a high school student's tennis ball that's getting hit at 50-60mph.

Fraser: There's actually some brand new research that we reported on at the AAS, where astronomers are now calculating that many super massive black holes are spinning at the very limits of relativity as predicted by Einstein. You can just imagine something with hundreds of millions of times the mass of our Sun spinning close to the speed of light.

Pamela: Yeah.

Fraser: In a disk of material and with a giant magnetic field it's building up. You can just imagine the forces its building up. Just like the Sun, it's scooping up particles in these magnetic fields and snapping them like a towel at us? Maybe.

Pamela: That's pretty much exactly what's going on. One of the numbers I found in preparing for the show was that in some cases, these high energy accelerated particles are moving so fast, at so close to the speed of light, that if one of these high energy cosmic rays – a proton – left a supernova at the same time as a photon and they travelled for one year, the proton, which because it has mass can't travel at the speed of light, will only be about 46nm behind the photon that is travelling at the speed of light.

Fraser: That's what I heard – that one of the important things astronomers were able to, with their latest research they were able to see some event at a super massive black hole in a galaxy far away, and then later, see the associated cosmic rays from it.

Pamela: This is one of the neat, new, forefront areas of science where we're just starting to build the detectors, we're just starting to figure out how to detect these things and how to triangulate where they're coming from, and in may cases we can't tell where the cosmic rays are coming from, but with our optical, radio, gamma ray, x ray telescopes we can see that a really cool event went off and then a few minutes later, with our cosmic ray detectors, we see this flood of cosmic rays. So we're using the probability alignment of "if we see this and then we see this over and over, then they're probably related".

Fraser: That makes sense.

Pamela: Works for me.

Fraser: Now, what kind of an impact do cosmic rays have on spaceflight for astronauts heading to the Moon? If humans are going to be buzzing around the solar system in the future, are these pretty dangerous?

Pamela: Yeah. This is actually a fairly serious problem we have to figure out how to address as we look to send men and women further and further across the solar system. Today on the International Space Station, they actually have one part that is much better protected than others. When there's a solar storm, they lock everyone in that one area because it will protect them better.

As we start heading out… Mars doesn't have a magnetosphere. The Moon doesn't have a magnetosphere. We're going to have to develop spacecraft that will allow astronauts to not only survive solar storms but as they spend longer and longer periods of time in orbit, they're going to need to not get blasted with too many REMs of radiation.

Alpha particles are one of the forms of cosmic rays. They're also one of those things that can cause radiation poisoning if you encounter too many of them. So we need to protect them, and we need to worry about how long people spend in space.

Anyone who's worked in a lab with radiation knows you can experience a certain amount of radiation before you have to start worrying about the consequences of the radiation. All of us can get our teeth x-rayed, all of us can go down to the granite quarry now and then. But if you live in new England, you've probably done a radon test in your basement because you don't want to live in a house that's filled with radon. It will eventually cause increases in cancer rates.

Going into space is the same as building your house inside the granite quarry, where your entire house is filled with radon.

Fraser: What kind of warning will we get? Do we have mechanisms for detecting a solar storm coming past, and a way for the astronauts to run and hide? How much time do they have?

Pamela: People are trying to figure out ways to do this. Luckily for the solar ones they're not going at the speed of light. Often we have a day or so – a few hours, to get people prepared. It depends.

At last year's AAS, or perhaps over the summer, someone was talking about ways you can tune in to coronal mass ejections, and depending on the radio spectrum, depending on all the different colours of light and how they come off of the Sun, you can say, "this one is going to hit us with a blast of particles, and this one isn't." that's useful information. It allows us to do things like put telescopes into safe mode when we know they're in trouble.

Now, the problem is there are these ultra-high energy cosmic rays that are coming from beyond the Sun that we have no way of predicting. As you get out of the Earth's magnetosphere, the number of those that are going to hit your body are increasing.

Fraser: The astronauts in the space station, they're protected because they're within the magnetosphere.

Pamela: In many cases yes.

Fraser: Right. But if you get out of the magnetosphere and off to the Moon or off to Mars, then you're on your own.

Pamela: Exactly.

Fraser: I think that's going to be a pretty big problem, and I can imagine us having these heavily armoured (and, I guess, heavy) spaceships trying to minimize the radiation risks the astronauts are going to be facing. That's just going to increase the expense of getting things into orbit.

Pamela: Yeah, and people in the international space station are only up for a few hundred days. Going to Mars, you're looking at 3 years.

Fraser: Right, and it's not like once you get to the planet you can sit there and be safe. It's just as dangerous down on the surface of the planet as you are in space.

Pamela: So we have to figure out how to effectively protect people, lower the risk of cancers and mutations. One of the problems with this is it's not necessarily the astronauts that get the cancer, but it could also be their children. You don't want to say astronauts can't have children, but we have to consider the generations of damage we can do.

Fraser: There's one last thing that was quite interesting. One of the writers on Universe Today did an article, and scientists had been able to track the link between cosmic rays and cancer rates.

Pamela: Yeah, this is what I was hinting at. There was a cycle determined using ice core samples. It's possible to go through and determine where and when in the past there were increased numbers of cosmic rays. In the United States, Canada, the UK, and Australia, we have fairly good data for who had cancer and died of cancer in the past 100+ years. Going through this data, they were able to find there's basically a 28 year lag between a peak in cosmic rays and a peak in cancer deaths.

They also found that when there was extremely low rates of cosmic rays, 28 years later there was extremely low rates of cancer. All because there's a link doesn't mean cosmic rays are causing the cancer – it could be something else. It could be that cosmic rays are causing something else. But there is this relationship we're noticing.

One of the ideas they put forward is you have a woman who's pregnant. While pregnant she gets blasted with cosmic rays. She has millions of cells – she's' okay. But her unborn child might be a few dozen cells at the time. When you damage one of those few dozen cells, that damage propagates to the entire future human being. Then that future human being has a child, and it's that child that ends up getting and dying of the cancer.

Fraser: Wow. So is there a Suntan lotion I can get when the cosmic rays are on the increase? Lead, right?

Pamela: Or glass – glass in some cases can be useful.

Fraser: Glass, lead, underwater.. live in a subterranean home…

Pamela: That little room the x-ray technician goes into.

Fraser: Yeah, that should be safe.

This transcript is not an exact match to the audio file. It has been edited for clarity.