Episode 17: See Spot Sun
Physicists: Brian Sullivan, Jennifer Garst

Transcribed by Denny Henke

Ben: Over the course of my studies in theoretical physics I've traveled across the continent and around the world sampling new ideas and tasting different answers to the questions of how and why. And still I find there remains a deep hunger which lives within me, a burning desire to share these great ideas with the people around me. And so, I have assembled a team of some of the greatest, most lucid, most creative minds, I have encountered in my travels and I call them my Titanium Physicists. You're listening to the Titanium Physicists Podcast and I'm Ben Tippett. And now allez physique!

[1:49]

Ben: June 5th was a fun day. It was notable in part because the planet Venus passed between us and the sun. The Venus transit is a fairly rare event and it won't reoccur until 2117. Now, it was super cloudy where I live so I watched the event off of the NASA website and it was marvelous watching the perfectly circular shadow of Venus cross the perfectly circular image of the glowing sun. But the surface of the sun wasn't all that perfect. It looked kind of dirty. There were even little dark spots on it. Now, the spots I was noticing are called sun spots. They are dark spots on the sun and I'm obviously not the first person to notice them. In fact, people have been recording sun spots for thousands of years. Galileo in fact is famous for using his telescope to study them. So, here are some basic facts about sunspots. Firstly, they are little dark spots on the surface of the sun, like solar acne. But, because the sun is so big and so far away some of the big ones can be six or seven times the width of the earth. Second, they always occur in pairs. Over time, one of the two always moves towards the North or the South Pole and the other always moves towards the equator. Third, they are related to solar flares. Solar flares usually begin at sunspots. Fourth, the number of sunspots isn't constant. There's something called the solar cycle. Sometimes there's more of them, sometimes there's less of them. So, it goes from solar minimum where there's no sunspots to solar minimum in about 11 years. In fact, this year should be a solar maximum, there should be a ton of sun spots but it's been kind of disappointing so far. Now, we can deduce from this fairly periodic nature that there are very few simple elements involved in making sun spots. But, we can also deduce from the fact that this eleven year rule is kind of a rule of thumb. Sometimes it's 12 years, sometimes it's 10, we can tell from that that the elements involved in generating sunspots are also kind of complicated themselves. In fact, sunspots come from an interplay between the sun's magnetic field and the rotating fluid plasma that composes our star. In fact, explaining sunspots requires a mastery of a number of different fields. Speaking of mastering different fields, today my guest is a master of multiple fields. It's David Malki. David Malki is the Leonardo deVinci of stuff on the Internet. You might know him from his very silly web comic called Wondermark wherein Victorian era drawings of people posit that the proper way to eat Cheetos involve the use of chopsticks. See, using chopsticks will keep you from getting the sticky orange gunk on your hands. Now Wondermark has been nominated for Web Cartoonists Choice Awards, Ignatz Awards and Eisner awards. And you might also know David from his collaboration with Kris Straub on the Tweet Me Harder podcast. It's the world's first, best, only and last talkback enabled, interactive audio pod blast. And you might also know him from his collaboration with our old friend Ryan North. On calling for submissions for and editing the Machine of Death short story collection. The Machine of Death was the number one best seller on amazon.com and it displaced Glen Beck's book from the list. In other words David Malki is Glen Beck's personal enemy. He's also the supreme commander of publicity and promotions for the TopatoCo website and he's even been a volunteer search and rescue pilot. So, today our guest is David Malki. Welcome maestro.

David: Thank you very much. I'm very pleased to be here. I don't know where we are but as soon as I find out I'm just going to love the heck out of it.

Ben: Oh great. Well, I'll open the window to your box in a couple minutes. But first I need to tell you about the Titanium Physicists I have assembled for you today. Now arise Dr. Brian Sullivan!

Brian: Bazinga!

Ben: Right. Dr. Brian got his PhD from Dartmouth College in Hanover and he studies plasma physics and he wrote his PhD on magnetic reconnection. He's currently the physics instructor at the Maine School of Science and Math. Now, arise Jennifer Garst! Jennifer is a masters student at the University of Memphis where she studies the coronal heating problem. Alright you guys, let's start talking about sunspots. Alright David, you've played with magnets before, right?

David: Sure. Yeah. I do know like, what magnets are, clearly. I have used magnets to pick up a screw that fell on the ground. I've used magnets to degauss video tapes.

Ben: Right. Evidence.

David: Which is, entirely separate application for magnets and I have used magnets to, I don't know, I'll say, like hold a thing on the fridge. Like, that's a magnet thing to do.

Ben: Yeah. Sweet. Alright, let's make this really simple for the people imagining things at home. Remember those bar magnets that you get in science class. They were like little metal rectangular bars. One part of it said north and the other part said south.

David: Sure, yeah, yeah.

Ben: And did you ever have to sprinkle magnetic filings around them?

David: This is a thing where they are drawn in sort of in like an arc shape?

Ben: Yeah. They form these kind of ears around the magnet.

David: Yes, I do remember this.

[6:40]

Ben: So, essentially, what all those iron filings are doing is they are lining up with the direction of the magnetic field. So, magnetic fields are kind of invisible. And what they are kind of, is they're essentially shaped like rings. Imagine a very thin loop of wire and the loop of wire goes down the middle of the magnet and then it comes down around the outside and then back in the middle. So it's always a loop. There's never any free end, it's always like an elastic band.

David: So is the magnetic part of this hypothetical bar magnet just the end of that magnet? Or what is the actual magnetic part that the field emanates the from?

Brian: The magnetic field lines come out of the North Pole and go into the South Pole.

David: So it sort of loops through the magnet and then out in a ring shape and then back in the other side of the magnet in a continuous...

Brian: Yeah, that's right. Every magnetic field line is like a serpent that bites it's own tail. So, it's closed.

David: Well I know a lot of classical mythology so I understand that analogy.

Ben: One way to imagine this bar is that it's not really emitting the magnetic field. What it's done is kind of gathered up magnetic fields. So, each magnetic field is a loop and the property of this iron, magnetized bar is that it's gathered a whole bunch of these loops together and it's kind of bunched them up so they are really, really dense down the middle of the bar. And then, floating out around the outside and then looping back in.

David: This is sort of magnetism that exists in the world in an unorganized fashion but a magnet's special super power is to sort of grab them and gather them to itself.

Ben: Yeah.

Brian: Well, the atoms in the iron, each of them is like a little magnet, and iron in particular, the atoms want to line up with each other. So we call a material like that a ferromagnetic material. And it has an effect that it creates a large...

David: Because it mainly occurs in large fairs, like county fairs and...

Brian: Ferro like iron...

David: Oh, no, no. Ferro, it means it's fair, like it's impartial, I get it.

Laughter.

Ben: It's not Egypt either. So, one of the fundamental attributes of a magnetic field is there is an interplay between electric charges and magnetic fields. So, you know, like electric charges, you rub your head on a balloon and then you give something a shock. Some particles, electrons have negative charges on them and some of them have positive electric charges on them.

David: Just depending on their attitude, sort of how they feel that day.

Ben: Well, they're stuck that way, but, essentially, yeah. Some are negative some are positive and two electric charges with the same charge sign, so if they're both positive, will push each other apart. And if they have opposite signs they'll attract each other. So, the center of each atom has a positive electric charge and that positive electric charge has attracted electrons. Electrons will have negative charge. And so the electrons all kind of swarm the center of these atoms and make it so that if you go far enough away from it the negative electric charges and the positive electric I charges all cancel out and so atoms are electrically neutral because positive electric I charges and negative electric charges attract.

David: Sure. But this is where we get into ions, huh?

Ben: Yeah, that's right. So, ions are when you've taken the electric charge in an atom and you split them up so they're free floating, positive charges and free floating negative charges.

David: Right, so you have two of them and you can put them in some engines and make a twin ion engine tie fighter. Right? Is that where we're going with this or not.

Ben: No, we're not going to tie fighters yet.

David: Sorry, I jumped ahead.

Ben: That's alright. We're going to do electromagnets right now. The fundamental feature of electric charges is that they interact with these loops of magnetic field that I've been describing in a really specific way which is that if you take a moving electric charge. So, you take an electron, and you have a magnetic field handy, so you imagine this rubber band. The electric charge will circle the magnetic field line.

Brian: It's gyrating around the string. It orbits it.

David: Okay, so the is like walking on the rubber band. Around and around and around.

Ben: No, no, it doesn't walk around. So, if you imagine the rubber band was shaped like a donut, blown up like a donut, where it goes from the outside through the middle back to the outside.

David: Got it, yeah, yeah. It rings around the length of this band.

Ben: That's right. So, it's circling the string. So, what happens is magnetic fields are produced when the charged particles circle and magnetic field lines cause charges to circle. Let's break this down into some phenomena. I want you to imagine an electromagnet and all an electromagnet is, it's a piece of wire that's been coiled. You have a piece of wire and you feed it into your fishing reel. So, it goes around and around and around and you end up, essentially, a tube of wound wire.

David: Sure, yeah. This is like the deal where you wind the copper wire around the nail.

Ben: Yeah, you got it. And then, if you put some charges in there. So, if you hook that up to a battery so the electrons flow down and go around that nail, what happens is that gathers magnetic field lines in and you imagine each magnetic field as a loop, the more charge you have going around that electromagnet the more field lines get gathered in.

David: So, does the loop widen or strengthen?

Ben: They kind of get denser, right.

David: Okay, so rather than a few, you have, sort of, a bunch of them, kind of like a slinky, kinda spread around your hands.

[11:46]

Ben: Yeah. Okay, so, I want you to take your hand and I want you to touch the tip of your index finger to your thumb.

David: Okay.

Ben: So, we're going to imagine that the electron is traveling in a loop that is following your finger and thumb so it's going around and around and around. As we force more and more charges to go around this loop, it gathers more and more magnetic fields. So, I want you to imagine, you have one electron going around that circle and that's like having one elastic band where you've taken an elastic band and you've hooked it around your index finger. And then, if you put two electrons in there and have them circling that's like taking two elastic bands and hooking them around your index finger and then if you have a whole bunch traveling around really, really fast that's like having a thousand elastic bands looped around your index finger that you're trying to clench. Effectively what happens is the more charge you flow through a ring the more magnetic fields that ring will kind of gather and the denser the magnetic fields are the more you've kind of squished into that little loop between your index finger and your thumb the stronger the overall magnet will be. So, you imagine those big ones at the dump that pick up cars?

David: Sure, I know a lot about the dump.

Ben: You put a little bit of current through that and it gets a little bit of magnetic fields and then they crank it all the way up and suddenly the magnetic fields all gather and that electro magnet becomes strong enough to pickup a car.

David: Yeah, got it. I'm totally following you.

Ben: So, there's an interplay. If a stray electric charge comes across a magnetic field it will circle it and the more charges you have going in a circle the more magnetic fields that circle will gather inside of it.

David: So it makes that magnet more attractive.

Ben: More attractive. You got it.

David: Sure. Just like being at a bar late at night. The lower the lights the more attractive everybody is.

Ben: Just like a bar. A bar magnet.

David: A bar magnet, yeah. Yes, I know, this is a 100% my wheelhouse.

Ben: Okay, so, now we have to talk about how magnetic field lines work. You know how there is like a North Pole and a South Pole to your bar magnet?

David: Yes.

Ben: I'm sure you've tried to press them together. You can't press the two South Poles together and you can't press the two North Poles together but the North and the South Pole will pull each other in, okay?

David: Yeah.

Ben: So I've described before how your electromagnet, you imagined holding your index finger to your thumb and passing electrons in that loop.

David: Right. And this is a magnet that comes on only when you apply an electric field to it, right?

Ben: Yeah, that's right. So you force...

David: Kind of like how you sort of love your wife only when you're in public.

Laughter

Brian: So, you hook up the battery and that drives the current...

Jennifer: Is this true? (Chuckles)

Brian: And the current causes the magnetic field. The current is just the motion of the charge.

David: You can only turn something on with the aid of a battery powered device. I know a lot about this.

Ben: Right. So, the uh, so the problem with my description like that is that there is no obvious north and south in that picture. There's just rubber bands, right.

David: There's no obvious top or bottom.

Ben: So, we need to add a north and south to this picture. So, I want you to imagine that instead of rubber bands that you're grasping, imagine that you have road bike tires. You know how the treads on road bike tires are kind of arrowed forward.

David: Right that way the cops know which direction the bike was riding.

Ben: That's right!

David: From the crime scene.

Ben: That's exactly right. In this case you look at it and the wheel is always counter clockwise, right?

David: Okay.

Ben: In just the same sense magnetic fields have clockwises and counterclockwises to them. So, if you imagine holding your ring that you're putting charge around and you're gathering up magnetic fields and you're packing in bike tires where these bike tires all have these arrows on them. All of the bike tires are oriented so that up is through the circle, in essence, right.

David: Okay.

Ben: And so there is a directionality to that so that we could say the north is where the bike tires are coming out of the hole and the south is where the bike tires are going in to the hole.

David: Yeah, I'm having to sort of translate all of these to sex metaphors but once I do I'm on board.

Ben: And so imagine your hand again where you've got your index finger and your thumb touching and your bike tire's going through it. If we pass electrons through your index finger, touching your thumb, the issue is how these tires are oriented with respect to this little ring of circulating charges. If we pass electrons through clockwise then the tires will end up pointing in towards your palm. If you have the electrons circling counter clockwise then they'll all be moving in the opposite direction. And if you have positive charges, the electrons have negative electric charge, if you have positive charges then everything I said is reversed. And the moral of the story is whether it's a positive or a negative charge and also the direction that they are circling will determine the orientation of the magnetic fields.

David: So, north versus south.

Ben: North versus south. Okay?

David: Got it.

Ben: So now, we can start talking about the sun. In the sun this magnetic field thing gets totally awesome.

Brian: Suppose you have an ice cube

David: Okay, I do have an ice cube here.

Brian: Okay, you have the ice cube.

David: I have it here.

Brian: Now, you add some energy to the ice cube. You raise it's temperature.

David: I'm crushing it in my hand.

Brian: So, what does it become?

David: Water.

Brian: So, that's a liquid.

David. Yes.

Brian: Now, if you boil the liquid that becomes.

David: Hold on, let me do that. Okay, I'm doing that. It becomes steam.

Brian: Right. Steam is a gas.

David: It is.

Brian: So, gas expands and doesn't have a definite volume or shape. The gas is composed of molecules. The H_2O, two hydrogens and the oxygen, now if you heat that up further the hydrogens will disassociate from the oxygen...

[16:50]

David: Too hot to handle.

Brian: They get broken up, yeah, too hot to handle.

David: I've been in this relationship many times.

Brian: Now, if you heat it up even further each of those atoms has an electron or several that are orbiting around the ions that are in the nucleus of the atom. But, if you heat things up enough, what happens is the atoms collide with each other and they knock the electrons off. They're just floating free. If it's hot enough then getting knocked off happens more often than getting reattached so now you have a gas that's made up of electrons and the positive ions. So, that is called a plasma.

David: So, it's just ions. It's not actual molecules.

Brian: That's right.

David: Okay.

Brian: It's two separate gases that coexist in the same space. One is made of positive ions and one is made of electrons.

David: And this is brought about by the extreme heat that causes it to become unstable.

Brian: That's right. It's very high temperature.

David: Cool. Alright.

Brian: The sun is a plasma. It's made up of charged particles and when charged particles move, connecting us back to what we were saying, they create...

David: Magnetism.

Brian: Yes. Magnetic fields.

David: Is that right. Okay, good. So, these other, moving in these predictable patterns because of, does the magnetic field cause them to move in this pattern do they intuitively form a pattern that generates a magnetic field.

Brian: So, that's the great thing. They create a magnetic field and that magnetic field evolves and their pattern of motion evolves and it evolves to a point where the magnetic field that they created causes them to move in the motion that they have. So, it's self consistent.

David: Oh, I see. It's like, it's self perpetuating.

Brian: That's right. And we call that a magnetic dynamo.

Jennifer: Okay, so, the sun has this magnetic field that is rotating. Now the sun is pretty fluid so, yeah, the earth rotates but all of the parts of the earth rotate at the same time because the earth is solid. But the sun, when it rotates, the equator of the sun actually rotates faster than the part around the poles.

Ben: The sun is kind of like a, imagine, I don't know, a water balloon. You've filled it with water and you've thrown it into the air and spun it. There's all sorts of weird fluids flowing around inside this sphere even though it's still kind of spherically shaped. So, what happens is there are a lot of different processes causing the fluids to flow in the sun. So, one of them, Jennifer mentioned, it's that you have this ball and the ball of fluid is rotating. Unlike the earth, so, like the earth is like a nice, rigid solid so it's all rotating in step, right.

David: We're all moving together.

Ben: We're all moving together, right. The surface of the sun doesn't do that because it's a fluid. The equator of the sun is moving faster than rings of latitude would above the equator and below the equator. So, the closer you get to the North Pole the slower you're spinning.

David: Got it.

Ben: So, that's one of the effects driving the motion of this fluid . Another one that's actually really neat, it's convection. Imagine, you take water and you put it in a pot and you put the pot on the stove.

David: Okay, I can do that.

Ben: You turn on the stove.

David: Okay, got it.

Ben: So, before it starts boiling, before you see little bubbles rise up, what's happening is the heat is moving up through the bottom, and it's doing it through diffusion. So it just kind of, the heat kind of trickles up and slowly the heat rises from the bottom to the top. And what happens is if the temperature on the bottom is hot enough you get big bubbles forming that loop up to the top. I was telling you earlier about how you smash these atoms together and that essentially creates little particles of light that then want to escape the sun and for the first two thirds of the way out of the sun they travel by diffusion and it takes them hundreds of thousands of years to go from where they started out to the edge but if they get close enough to the edge they get into a region where there is convection bubbles. Bubbles of hot gas actually rises up like a lava lamp or like a big blob of convection in your porridge. It turns out it's faster, it's more efficient for heat to travel in these big convection bubbles than it would be for to travel by diffusion. And so the last, say third of the sun, as these photons are making their way out from the center they travel in these convection bubbles. And so what it means is the outer jacket of the sun is always bubbling, this fluid in it is always churning as big globs of heat come up from the center. Just imagine the sun as an initial state so it's like a bar magnet. So you have this big glob of fluid and then there are magnetic field lines like the tires. They go out, out through the middle, through the North Pole and then loop down back through the bottom. And you can see all the rings coming out.

David: Okay, alright.

Ben: So, now imagine that they're elastic bands. Now, imagine that instead of fluid, so, imagine that instead of fluid moving, because this fluid is a plasma the magnetic field lines are trapped in it. They are stuck where they are. In other words, you can't change the magnetic field lines without changing the flow of the fluid. You need to change the way all the fluid is flowing. So, I want you to imagine, instead of a big fluid flowing, essentially you just have this big sphere and then there are a whole bunch of dogs. Okay. And each of the dogs bites one of the magnetic fields and drags it along with it but luckily these magnetic field are made of rubber so we can stretch them as long as we want.

[22:00]

David: Okay.

Ben: So, the fluid is rotating around the sun as these dogs are running around the edge of the sun they are wrapping the magnetic fields, they are stretching it and wrapping it around the center in a really twisty kind of way.

David: Okay, yeah.

Ben: Imagine if you had an apple with a rubber band sticking out through the middle of it and then you took your finger on the equator of the apple and then drag your finger around the edge of it a couple times so you're wrapping the elastic band around the edge.

David: Hold on, I can do this. Hold on just a second. I can set that up.

Ben: Right, get your apple.

David: I have a rubber band apple already so let me just stretch it around there. Yeah, I see what you mean. For sure.

Ben: So, it gets all tangled up, it get's all looped around itself. And, also, there's all this weird convection so, in essence, some of the dogs biting the magnetic fields and then are running down the street towards the center or running up straight out of it.

David: They are pulling all kinds of weird directions.

Ben: Yeah, so all these dogs are taking these neatly arranged magnetic fields and they are making it one big crazy tangle. Okay?

David: Okay.

Ben: So, sometimes what happens is, it doesn't really happen with elastic bands, you take an elastic band and you twist it so that it becomes two rings separated by a twist and then you twist that again and you keep twisting it. Twist it and twist it, eventually what happens to the magnetic field is sometimes the end part will pinch off so you get a little pinched off ring of magnetic field and it's not attached to anything. It doesn't go through the middle and out through the outside anymore, it doesn't have any configuration that looks like, it's just a little ring.

David: Homeless.

Ben: Homeless. Okay.

Brian: So, we've got these magnetic fields, they're twisty. They get twisted enough, they kink and we form a closed loop that's no longer attached to the sun, okay.

David: Yeah.

Brian: So, the loops rise up and they twist, they pinch off and now we have a free blob of plasma that's wrapped up in its own magnetic field. Sometimes it's called a plasmoid. These things get pushed out into space violently by the tension in the magnetic field which snaps and the blob which is called a coronal mass ejection can be launched off the sun carrying lots of plasma with it. And if one of these is directed towards the earth and it pinches off and heads our direction then we can get auroral activity, the northern lights, the southern lights, glowing in the sky. That's the link between what happens there on the sun and what we experience here as a result.

David: But that would be different from a solar flare.

Brian: There can be solar flares that don't have coronal mass ejections and then there are solar flares that are associated with coronal mass ejections.

David: Is that because the coronal mass ejection is like an ionic thing and the solar flare is radiation?

Brian: The solar flare is radiation like invisible light, X-rays, and it gets to the earth in about eight minutes. And then the coronal mass ejection takes between a day and three days, typically, to get to the earth.

David: So, I'm thinking of the pictures I've seen of the sun where there's like a big splashing thing coming off of it.

Brian: That's what we're talking about. So, there's a flash at the time that the spalshy thing ejects. The flash is the flare and the blob is the coronal mass ejection.

Ben: Let's back this truck up because there is a neat little bit of insight here. Back it up to where there's a ring of magnetic field inside the sun. So, it starts out inside the core of the sun and it's like a bubble or something, right? It has a lower density, it pushes itself up through the sun, and then as it crosses the surface of the sun if you imagine this ring as this tire then it will intersect the sun in two places right. One part where the tire tread is coming out, pointing out of the sun and the the other where the tire tread is pointing into the sun. Those two spots, those are sun spots. And then as the blob of the magnetic field emerges from the sun it goes off into space, that ring of magnetic field, it's kind of becomes an elongated ring, that's essentially that long coronal mass ejection tail shape you see.

David: And so the sunspots are the points at which that ring shape intersects with the surface of the sun.

Ben: Than's right.

Jennifer: Right

Brian: The complicated thing about the plasma is that it has the same kind of pressure that a gas has. So, if you watch the weather channel you see the high pressure and the low pressure and air in the atmosphere will move from high to low pressure, right?

David: Sure.

Brian: As a pressure gradient, a difference in pressure. So that same thing exist is in the plasma and that kind of pressure is called plasma pressure. It's a measure of the average kinetic energy which is the energy of motion, of the particles in the gas or plasma. Their average speed, roughly. But there's a second kind of pressure in the plasma which is called magnetic pressure and it's kind of like the pressure you feel when you push two north ends of magnets towards each other, you feel a pressure pushing back against you. And, in general, the two things compete with each other. So you'll have a region with really high magnetic pressure then the regular pressure will be low there.

[26:55]

David: This is what causes things to sort of be turbulent within the sun because these pressures are sort of waring with each other.

Brian: Right. The interplay of these two pressures is the thing that causes the motion of plasma in the sun. And if you have really densely packed magnetic field lines, like the elastic bands going through the plasma are very densely packed, that corresponds to high magnetic pressure which is lower conventional pressure. So that means, in general that area is lower temperature than the region that has higher conventional pressure and lower magnetic pressure.

David: So the higher conventional pressure is generating more heat because, is that because things are more agitated.

Brian: It's a higher temperature because the average speed of the particles there is higher.

David: Okay, so, in the parts where there is a higher magnetic pressure there is a lower conventional pressure meaning that the elements are moving more slowly meaning that their relative temperature is lower.

Brian: That's right. Exactly.

David: But they are darker because light and heat are associated so if you have more heat you have more light and vice versa- and less heat, less light.

Brian: And like you were saying, you've seen the false color images that are different wavelengths. So, each of those corresponds to a particular temperature. We can tell a color in astronomical terms, corresponds to a particular temperature.

David: So, this is where you get, like, red giants or ...

Brian: That's right. A blue star is hotter than a red star.

Ben: Or it's like, you know how in the middle of the fire it's blue because it's hotter and white's even hotter than that. And then the outside of fire it's red so it's cooler.

David: Sure. And you know there's also color temperatures which I know from color theory where 5500° K is a bluish color.

Ben: Right.

David: And 3000° is an orange color and so on.

Ben: Right.

David: See. I know something.

Ben: We're impressed.

David: Okay, so the reason we see these sunspots is because they are darker and the reason they're darker is because they're cooler and the reason they're cooler is because they have a higher magnetic pressure and the reason they have a higher magnetic pressure is because of that tire shape rising through the sun is being pushed by this more densely packed magnetic field within the sun itself.

Brian: You might actually be ready to teach freshman physics.

Ben: Yeah, that's, that sounds pretty great.

David: You see how I put it in layman's terms really simply.

Ben: Right.

David: Ahhhh. Alright. Okay, so now as this shape rises and the points of it spread farther apart, this is where you see the sunspots diverge. But eventually it's not an actual ring where as it rises out they converge again, its just, does it just dissipate as it gets wider and wider and wider.

Ben: So, I guess the magnetic field on the inside of the sun eventually reconnects with other magnetic fields and then it dissipates and then the ring on the outside gets flung out into space. Is that it?

Brian: That's right.

David: Okay, so those sunspots just sort of drift farther apart until the thing that is connecting them, that sort of external portion is either detached from the sun or pieces of it are dragged back in. The sunspots themselves, do they then disappear.

Jennifer: They'll eventually dissipate as they evolve they move apart from each other and they will eventually dissipate.

David: Just like a relationship.

Ben: Just like a relationship.

Jennifer: I guess so, yeah.

Ben: You start off close together and then they, one moves...

David: This has been real instructive.

Jennifer: They just drift apart.

Ben: The other moves to the equator.

David: Clarified a lot of things. It's okay, so you have a pair of sunspots that appear and diverge from one another and that correlates with this magnetic field that is emerging from the sun. So the result of that is that you have an ionized portion that is independent of the body of the sun at some point.

Brian: That's right.

David: Is that what causes this coronal mass ejection or is that a separate thing.

Brian: No, that's exactly right.

Ben: Yeah, oh so...

David: Yeah, so these ions are now coming towards the earth and causing the northern lights.

Ben: Yeah, that's right. Earlier I was telling you about how if you have a charged particle and it runs into a magnetic field it will start to circle it. So, essentially you have these charged particles in the plasma of the sun and they come across this big magnetic field sticking out through the sun, and they start riding that riding that magnetic field off of the surface of the sun.

David: Mmmmmhmmmm. So, like, I'm getting out of here man, finally, this is my ticket out of this joint.

Ben: That's right. And so as the magnetic field blows off the sun all of these particles are riding the magnetic field off into space.

David: Finally, yeah. You can't tell me what to do dad, I'm on my own.

Ben: Right.

David: And so then, that's when you hear, like, well there's a lot of sunspot activity that's causing, whatever, radio interference just because we have a higher number of charged particles our atmosphere.

Ben: Right.

Brian: I guess, a kind of interesting thing is that, do you know what a tokamak is? Have you seen Iron Man?

David: It does sound like another superhero character.

Brian: So Iron Man builds this donut that has plasma inside.

David: Sure, yeah.

Brian: That's called a tokamak. And he has a mini one in his chest. So, that's our attempt to use these magnetic fields to contain fusing plasma for fusion so we can get power out of it.

[31:55]

David: But that's a fake thing, right? That's a movie.

Brian: No, that's something we're really trying to do.

Ben: It's kind of a fake thing. So, the deal with it is that in the movie Iron Man gets all his power from this. In real life we haven't been able to get one that works so well that we can, that it can power itself.

Brian: Right.

David: Is it palladium, is the shield source in the movie? Is that just a made up thing or is that, like there's some property that makes it actually relevant.

Ben: I think he says it sometime. But, in essence he's doing a nuclear fusion inside his little reactor that he's getting energy from and then the palladium's helping him do it really efficiently.

Brian: Like a catalyst.

Ben: Yeah. Or something.

David: It seems like that is, at least in the second movie it's a thing that is being expended by this reactive force.

Ben: Yeah. Yeah, no. Yeah, yeah. So it's some kind of...

David: I just figured it was baloney.

Brian: But the thing that makes a big problem with the actual tokamaks that we're trying to build is the same magnetic reconnection that causes coronal mass ejections it's just the sun can handle having coronal mass ejections and the tokamak can't deal with that. Once you have a kink in the magnetic field you just loose, you loose it.

David: Lose it's integrity.

Brian: No more fusion, right.

David: Just like when you, when you make one compromise in your soul, it's like, you feel like it's no big deal but you're no longer that perfect ring of goodness that you once thought you were and you realize the more, the more kinks that come to the surface the more energy you waste just trying to be a powerful person. And trying to keep that purity about yourself.

Brian: Right, there are so many life lessons in plasma physics.

Laughter.

Brian: It's like listening to John Tesh.

Ben: I'm going to... Well anyway, I think we have half an hour of content...

Laughter.

Brian: I'm not sure. We might have to do a sequel.

Ben: That was... I think that was, I think we should end on the fact that there are lots of life lessons in plasma physics.

Well, okay, well that was wonderful. Thank you Brian, thank you Jennifer. You've pleased me. You're efforts have born fruit and that fruit is sweet, here's some fruit. So, Brian, you get a donut peach. And Jennifer you get a star fruit.

Jennifer: Aw, thank you. Nom not nom nom.

Ben: Ahhh, wonderful. So I'd like to thank my guest, David Malki. Thanks David for coming on the show.

David: Oh, it's been my pleasure, thank you for telling me about sunspots, temporary phenomena in the photosphere of the sun that appear visibly as dark spots converging in surrounding regions.

Ben: Wow.

So, my friends, if you want to email us you can email us at barn@titaniumphysics.com or you can follow us on Twitter at @titaniumphysics or visit our website at www.titaniumphysics.com or you can look for us on Facebook. If you have a question you would like my Titanium Physicists to address email your questions to tiphyter@titatiumphysics.com and if you are a physicist and would like to become one of my Titanium Physicists email physics@titaniumphysics.com we're always recruiting. So, let's talk about how you listen to Titanium Physics. If you like listening to us on iTunes that's great. You should leave us a review because the only way people find us is if people write us reviews. So, if you write us a review this week our ranking will improve. Please do so. And if you don't like to listen to us on iTunes, why not try Stitcher Radio. Titanium Physicists is on Stitcher Radio and it makes it really easy to listen to us because you can subscribe to it and listen to us every week without having to go to our webpage. So, the Titanium Physicist podcasts is a member of the BrachioMedia if you enjoyed our show you might also enjoy Science Sort Of or the Weekly Weinersmith, please check them out! The intro music is by Ted Leo and the Pharmacists and the end music is by John Vanderslice. Good day my friends and remember to keep science in your hearts.

[37:13]

David: I almost got some caught in my intestines but then I didn't eat them. So it turned out to be fine.

Ben: Never eat the magnets.

Brian: You know they feed those to cows?

Ben: Do they?

Brian: Yeah, to keep the shrapnel they pick up in the field all in one stomach.

David: All, man, that's such a great idea. I should keep all the shrapnel I eat in one stomach.

Brian: Yeah, it's less harmful that way. The shrapnel's not.

David: I am actually, I've learned something already.

Ben: Me too. Golly.

Jennifer: Yeah.

David: It looks like a pill.

[37:44]

David: So magnetism and circulation are mutually exclusive. No, I'm talking about your blood circulation. Because you're going to have those rubber bands are going to start choking off that skin, could get gangrenous. It's a real problem. I know we're not talking about medicine here. I just wanted to bring that up now in case that becomes a problem later.

Ben: Right. No, it's true. Circulation is important. Um, so, take a break whenever you're passing electrons through your...

David: It's just the sort of thing, like, every 15 minutes you should like take them off for a minute and just do some exercises. I just want the kids at home to be prudent about it.

Ben: Yeah

[38:17]

David: I really don't want this to turn into a gay marriage debate because I don't feel like it is the appropriate venue.

Brian: But it is a Paula Abdul song, "Opposites Attract".

David: I feel like we should be more inclusive. Like is there anything we can do to allow magnets to, if they want to, like north and north, like, I'm totally in favor of that, like how can we make that happen?

Brian: You can push on it them but they don't like it.

Ben: Yeah.

Brian: They push, they repel each other.

David: This is getting real political guys. Um, okay, alright. Fine, I'll hear you out. So, only north and south can be attracted to one another, fine. Alright, let's see where this goes. If it holds up to any intellectual rigor because they my counter argument about basic human rights. But go on.

Ben: Um, ah, okay. I'm going to go with my really good magnetic field metaphor. Okay. You've got an electromagnet. It's kind of like a fan, there's a direction to it, okay? Imagine a big round floor fan.

David: Sure.

Ben: It sucks air in the back and then the air comes out the front then the air loops around and it goes in the back again. Imagine if you have two fans, if you take those two fans and press them so that they are blowing air towards each other you won't be able to press them together.

Because, we imagine the air coming around in a loop. So the loop goes through the back of the fan, out of the front of the fan and then loops around to the back. Those loops got to get all compressed if you try to press them front to front or back to back So, you won't be able to press two fans together, unless you press them together, back to front. Press a fan back to front, the air coming out the front of the fan will get sucked in the back of the other fan and they'll just kind of pull each other together.

So, there's a charge to magnetic fields, there's a north and a south to magnetic fields and they're named like that

David: After their inventors. Ryan Northland

Ben: Ryan Northland

Brian: Interestingly, though, the earth's north geographic pole is the south's magnetic pole.

Ben: Right

Brian: We named it before we understood.

David: This like, like north, it's like Eurocentrism, like I'm tired of imperialism infringing on science.

Brian: The direction of the magnetic field is the direction the compass would point and the north end of the compass is attracted to the south end of the earth But it's the direction that the north end of the compass points so we call it north.

David: It's like a functional north. And a scientific south.

Ben: Right.

Brian: That's right.

Ben: Magnetic south. Okay.

David: There's a lot of things in life that are like that though. So. Like, socially speaking.

Ben: That's right.

David: Like you can have a functional wife, just like, goes out to parties with you, but, scientifically speaking it's usually more complicated than that. And you don't want to let your friends in on that because it's like, they all came to your wedding, you know, it's just super awkward to explain, like, alternate lifestyles... No, so okay, I think I have a good handle on where this is going.

Ben: Okay, um. Right.

[41:07]

Brian: What's the water molecule look like.

David: It looks like a chevron shape.

Brian: It's like a Mickey Mouse. Mickey Mouse face.

David: Sure.

Brian: It's got the two hydrogen ears and an oxygen face.

David: Sure. Is this like a sponsored thing because I don't believe that corporate branding is infiltrating every part of our

Ben: Do you think that physics pays for itself David Malki?

David: Is there like a non-trademark version of Mickey Mouse ears? Can we just call it like generic carton mouse head shape?

Brian: That sounds good.

David: Okay, let's stick with that. Maybe edit that back in.

Laughter.

Brian: The new mouse, the open mouse.

David: The open mouse. Yeah. Open mouse.

Brian: The open mouse project.

David: So we have...

[41:58]

David: Okay. H is typically, what is it, one electron, one proton, right.

Brian: That's right. Most of the time. That's normal hydrogen.

David: But there's like poly-hydrogen. Where it's like...

Brian: There's deuterium

David: Come on baby, livin' the... Okay. So...

Brian: So that's a radioactive sort of hydrogen, that's from the sun. There's tritium that's like triple hydrogen and it has two neutrons. Much heavier.

[42:30]

David: Like a 100°, a 110° sometimes seems ... to me, or...

Brian: So, the sun has a very wide range of temperatures and the surface is something like 6000° K which is like 6000° C, roughly, give or take.

David: In Fahrenheit that's like a 110° or a 120° or...

Jennifer: About 10,000° F.

David: I'm sorry, I just fell off my chair, okay.

Brian: But some parts of the sun are much hotter than that.

David: How is that possible.

Brian: The surface, well, that's complicated. I think Jennifer's an expert on that part.

Laughter

David: I demand to know in detail why that is because otherwise I can't accept it.

Ben: You got a, have you ever eaten pizza pockets?

David: I have.

Ben: Like pierogis and you bite into the middle and the middle's really hot and the outside

David: Much hotter than the outside.

Ben: ...is touchable. Yeah. So...

Brian: What happens with the sun, there was a cloud of gas long ago and as gravity, all the particles are attracting each other. So all this gas was attracted to itself and it compressed into a star and it compressed so much that it heated up to the point where the electrons and protons are now free, roaming about in an orgy of moving ions and electrons.

David: Just, abandon, just like I'm...

Brian: Right.

David: I'm like, here to do what I want to do.

Brian: Ions gone wild.

David: Yeah. I have that. It's not great. It's okay. I do know it.

Brian: So, the ions are so hot that they actually slam into each other and create new elements. Hydrogen becomes helium, helium becomes lithium, if the sun gets depressed it's in good shape.

David: Sure.

Laughter.

Ben: Oh, I get it.

Brian: That's going on in the sun.

David: These are all like, they form certain types of elements. Like, you're not going to get, I don't even know what, there wouldn't be in the sun.

Brian: Well, the heaviest one you can make is iron. So, there's no gold.

David: There's no gold in the sun.

Brian: That's right.

Jennifer: No gold.

Brian: The only way you ever get gold is a supernova. So, at the very end when a star explodes you can get those, those heavier elements.

David: And then the gold comes flying out. It's like when you kill a boss and the coins...

Ben: That's right.

Brian: It's exactly like that.

[44:44]

David: A magnetic dynamo. That's a really great phrase. Like you feel like

Brian: It sounds like...

Ben: That's a golden age of physics phrase.

Brian: I think Stan Lee came up with that, right.

Ben: He's still...

David: The magnetic dynamo. He was struck by the sun.

Laughter

David as Stan Lee: One day a stone fell from the sun, burning white hot, he grabbed it and then thought, oh know, I'm going to be late to my paper boy job.

Laughter.

David as Stan Lee: But, it turns out his hands had the power of sunlight so no alley was dark enough for crime.

Laughter

David as Stan Lee: He will have to somehow deliver these papers so he grabs them from his satchel. They burn at 6,000° K and now he has to pay for all the papers he ruined.

Laughter.

David: It writes itself.

Brian: Where do we go from there?

Laughter.

David: I feel like I have a good handle on this guys, I can take it from here.

Laughter

[45:56]

David: I understand that the earth has a, it's like a ball that's like spinning, but what causes the sun to rotate. Is it just that magnetism or is it gravity or is it.

Ben: The sun's always been rotating. The gas that created the sun was rotating so the sun started out rotating.

Jennifer: Conservation of angular momentum is what we call it.

Brian: Just like when an ice skater pulls his or her arms in, the ice skater rotates faster. The gas coalesced into the sun and it spun up because it was already spinning a little bit, now the sun is spinning.

David: So, is this motion what keeps that, the gases and plasma in the sun compressed an heated, like is this when we talk about the sun dying is that when it slows down and all those electrons don't move as fast?

Jennifer: Well, it remains heated because the nuclear processes going on in the core of the sun.

Ben: Right, okay, so, you have this big cloud and it collapses down on the center and it turns into a big ball and the deal is that at the center of this ball it's so hot that different atoms are fusing together so hydrogen is sticking to hydrogen atoms and making helium atoms and the way nuclear physics works, is that when you do that, when you stick two hydrogen atoms together to make a helium atom you end up with energy. And so, as this thing is compressing all these atoms together it's liberating a lot of energy and that energy is what's causing the sun to be, you know, really, really hot. So, that energy's kind of escaping, boiling off the sun, in essence what happens it's kind of like a log where the center of it is burning and the outside of it is just conducting the heat out.

David: So there is this energy is just massive nuclear processes are spilling energy forth at an alarming rate (in new Stan Lee voice) "and somebody has to stop it!"

Ben: Nobody has to stop it!

David: "Before it destroys the city!"

Ben: Stan Lee, nooooo!!!!

Laughter

David: "We're going to put out the sun! Do you realize that 100% of super villains are nourished by plants from the sun..."

Ben: It's true.

David: "That gained their energy from the photosynthesis. If we can put out the sun no super villains will have the energy metabolized to create villainy.

Laughter

Jennifer: Yeah, there's a problem with that argument.

Ben: Yeah, no,

David: "Well I'd like to hear it."

Ben: That's right.

Brian: "A" problem?

Jennifer: Well we would all die.

Ben: Well, I mean...

David: "Sometimes a little sacrifice is required... To stop villainy from taking over New York City, singly."

Dog barking in background

Ben: The dog agrees

David: Alright, so the sun is. Guys, can we just like, let's be serious.

David: So, we're burning the hydrogen. We have this, this ball circling around, and plasma, plasmodically.

Ben: Right.

David: Gyrating.

[48:55]

Ben: Well if you look at the sun you see all these blobs of convection don't you.

Brian: Don't look at the sun.

Ben: Okay, so,

Ben: If people look at the sun with instruments they see big convection.

David: If people stare at the sun with their eyes wide open, what do they... What can they, I think...

Jennifer: They go blind.

David: Your eyes would adjust to it eventually.

Laughter.

Jennifer: It's not recommended.

David: Here's what I want to know, this is, this is a serious question. It seems like this is something that humans hard time of, right, looking at the sun.

Ben: Yes.

David: Why do you think we have evolved, I mean, like, the sun has been there as long as light has been on this planet, don't you think that we would have like, naturally selected for people who were able to look at the sun.

Ben: If there was food on the sun then we would but there is no food on the sun so...

David: Here's my suggestion. I think that there were some people who said hey, my eyes are adjustable enough, I have evolved a mutation that allows me to look at the sun and see incredible detail, it's just this ball of burning plasma.

Ben: Right.

David: And the other people said, ah, no, when we look at it all we see is this brilliant disk that we can't see any details on and we think it is a god. And they go no dude, it's just burning plasma. And the god people put those people to death for being heretics and they all died out.

Ben: That's possible.

David: And we are the descendants of the people who thought that the sun was...

Brian: If you're busy staring at the sun you're not likely to reproduce.

Jennifer: This is true.

David: Well, I'm not, they don't stare at the sun all day long. In the same way that I can see a tree but I don't stare at trees all day long. At least, not anymore. Ever since I got a job.

Ben: That's the worst thing about jobs.

David: Well they prevent you from staring at trees. That's what I told my boss. Can I have a tree break. I don't smoke, can I have five minutes every hour to go look at trees and he said "David I've been waiting for someone to say that for years, yes you can have a tree break. Have a tree break.

Ben: Yeah.

[51:05]

Brian: Sure, this works really well if you have a yo yo string.

David: Man, the metaphors are, we're piling on the metaphors here.

Brian: Yeah, it's physics.

David: So, a dog with a yo yo eating an apple on a rubber band in a bowl of porridge on top of the lighthouse with a friendly cat upside down in a box.

Brian: A dead cat.

Jennifer: The dogs

David: All jeeze.

Ben: You forgot the dogs but don't worry. You're almost there.

David: And the whole thing is on a boat that's on a stormy ocean that a monster is eating because of a galaxy upside down on a, the electro college.

Ben: I think you're ready to take Physics 101.

David: I'm ready to teach Physics 101.

[51:57]

David: It's causing radio interference because it's interfering with the free flow of radio waves which are part of the... There's only one type of wave right? Like, some of it's visible, some of its radio, some of its...

Ben: That's right.

Brian: There's only one electromagnetic kind of wave.

David: The electromagnetic spectrum. Right.

Brian: Right.

David: I was going to use that and I was not totally sure if it was right but now I know.

Brian: That's right.

David: So, I'm going to use it all the time, basically for everything...

Ben: Right

Brian: A sound wave is different and plasmas have several different.

David: All jeeze. Forget it, I'm out. Sound waves are different, no, too much.

Laughter

David as Stan Lee: "Sound wave was created from an experiment when a giant stereo speaker exploded all over a young pizza delivery person. Every time he went to deliver his pizza every footstep created a wave of sound that shattered windows in the area. But he couldn't pay for the repairs if he could never get his pizza's delivered."

Laughter.

Ben: All of Stan Lee's heroes these days are coming up pretty tragic. They're always deep in debt, trying to pay off the damage they create.

David as Stan Lee: "That's what makes super heroes relatable. They have to be someone that the audience feels like they could become."

Ben: There's lots of people with credit problems these days I guess.

Brian: It's funny though if you look at the end of Spider-Man 2, ah, Doc Oc has the ah, has the mini sun and it has all these loops on it, just like on the sun.

Ben: That's right. But somehow he's putting the loops back in with his claws isn't he?

Brian: That's right.

Ben: I don't know what that had to do with anything.

David as Stan Lee: "Doc Oc was driven to a life of crime when his home was foreclosed upon thanks to a mortgage from Bear Stearns."

Laughter

David: It became Gilbert Gottfried half-way through.

Ben: It did.

David as Gilbert Gottfried: "I hate superheroes!"

Laughter

Ben: Okay. Um.

David as Gilbert Gottfried: "My favorite superheroes are the ones that are unapologetically vulgar."

Laughter

Ben: Like "Fuckman"

David: You said it not me.

David as Gilbert Gottfried: "My favorite!"