Tracey: [00:01](https://www.rev.com/transcript-editor/Edit?token=IRvJnilo5prvjwCdzweAUMU87myvM4s5cYFgM-f-KVTD6y7aCiwJiKPofalo_uV4o9R_evztZw01C_NxD1F2idtad48&loadFrom=DocumentDeeplink&ts=1.29) Hello, and welcome to NC State's Audio Abstract. I'm your host, Tracey Peake. You may have heard that our sun's activity is getting much quieter lately as it enters a portion of its cycle called the solar minimum, but what does that mean? We're speaking today with Steve Reynolds, alumni distinguished professor of physics, here at NC State, about our favorite star, the sun. Welcome, Steve.

Reynolds: [00:27](https://www.rev.com/transcript-editor/Edit?token=5wB7jhmKwxv7G9VNsCf4kSc4oQAtYPBNAokR7qFIcavLVJPXE5uiP8SB3A-e8FG3PcRlkPHBq3Wq-lgM3z6NftNtcas&loadFrom=DocumentDeeplink&ts=27.48) Hey, happy to be here.

Tracey: [00:28](https://www.rev.com/transcript-editor/Edit?token=ojpimhcc3awj79dJOSXnfw1hYAAZSZcXkLDztKRQUA2c47nFBphDUFQjob4B2evyuGOevlMkxkzvRTItDxyXl6nYsls&loadFrom=DocumentDeeplink&ts=28.46) Glad to have you. So, first of all, let's talk about the sun is just a regular star, how does it compare to other types of stars in the universe, and how do we know what we know about our sun?

Reynolds: [00:43](https://www.rev.com/transcript-editor/Edit?token=HP57u13M74AK_hlxL5SUfnfspETW1R1YkdoBWDQRU3dA661xMmENp_I0Ie7U0VQOt1j-FlcVurKdPlHA-y4nswTdTMo&loadFrom=DocumentDeeplink&ts=43.81) Well, that's a great question. The stars are the most common producers of light in the universe. In general, a star is just a ball of gas held together by gravity and conducting, at the moment, or had conducted in its past, nuclear reactions. So, what's going on in a star is the gravity of a huge amount of stuff, and I mean huge. The mass of the sun is a thousand times the mass of Jupiter, the largest planet in the solar system. All of that gravity would just pull a gas cloud together and collapse into a black hole if there were nothing to impede it.

Well, as you probably know, last time you tried to inflate a bicycle tire with a pump or something, if you compress gases they get hot. If you have the whole mass of the sun at your disposal, to compress yourself, you'll get so hot that eventually you'll be smashing nuclei of atoms together with such violence that you make nuclear reactions, in particular, you turn hydrogen into helium, releasing energy. So, suddenly gravity has an opponent in the center of the star, namely the pressure from all of this newly released energy. And so, there is a standoff that sets on, so that is what's going on in the sun and all the other stars you can see it at night, they are in an uneasy equilibrium between gravity, which is forever, and the hot gas, kept hot by the release of nuclear energy.

So, that's fine as long as the fuel holds out. For in the case of the sun, its fuel is good for about total of 10 billion years. It's burned through about half of that. Our earth is about the same age, about 5 billion years. At the end of that time, that'll be 90% of its whole life. Some other cool stuff happens, but the short version is that the sun will swell up, get very much brighter, incinerate the earth, by the way, and lose most of its outer layers. It will be a white dwarf star.

Reynolds: [03:33](https://www.rev.com/transcript-editor/Edit?token=PTDQwD1Wt7ZRiYhGuNH_WocZ7gCdaljQijrOG-dUS4mFLJ98FWXlZJ-IWMcdDSWqKai-HENym2uTeC0CQdKpt6OZauc&loadFrom=DocumentDeeplink&ts=213) Stars like the sun are littered throughout the galaxy. More massive ones get less common quickly. And all of the cool stuff you read about stars blowing up and making black holes and pulsars and things like that, that's just the very, most massive stars, which are extremely less common than the sun.

Tracey: [05:17](https://www.rev.com/transcript-editor/Edit?token=6_RVk9e-VtB3cnvN7C5tO1pX41w0yWKOM42fP1PsDNslwBMzC90dRUzQq3s16BINKSeJkEvctqPQPWwzQgJRkcu3VO0&loadFrom=DocumentDeeplink&ts=317.31) Well, how do we know what we know about the sun? How do we study it, when we're here and the sun is very far away and stars are even farther away than that?

Reynolds: [05:38](https://www.rev.com/transcript-editor/Edit?token=Ngcyzm-9QwKF2paZG-sDKAo_hVdY7inIqlPO2Bj0E8v03GVUrzJiLD4yTHBcScH3rv5C4F2GDYHd8_ZSmM1yB2PqNJE&loadFrom=DocumentDeeplink&ts=338.1) Well, this is really a great story. What we can observe, what we can infer from where we are from the ... We get the distance to the sun, actually, nowadays we can get the distance to it by bouncing radar off it. The story of how people learned the distance to the sun before radar is a fascinating one, which would take us way too far afield, but once you know the distance, we know how fast we're going around the sun. It takes a year, and that allows us to infer the total gravitational force and therefore the mass of the sun. So, we learned its mass. We know its brightness, because we know how far away it is. So, we know that we get, it turns out we get about 1.4 kilowatts for every square meter, by the way. So, if you go up above the atmosphere and unfold about a 10 square foot detector of some kind, you will pull down 1.4 kilowatts.

So, if that's the same amounts going in all directions, you can work out the luminosity of the sun. It's a gigantic number, it's like four times 10 to the 27th watt, it' one of those numbers we call astronomical, because they're astronomical, but it's so common that we actually, astronomers, use that as a unit of measuring solar luminosity. So, that's really what we know. We know its size too, because we know its distance. We know how big it is. We know its total mass and we know its luminosity. That seems like thin material to go on, but we can say, "All right, we know how gasses work on earth. We know how gravity works." You can write down five, it turns out, relatively simple equations that involve how a ball of gas might work.

And you can write down a simple computer code and 20 or 30 lines that solves these. And it turns out, you can describe something like the sun pretty well. Now, it tells you all kinds of things that you think, how can you ever know the central density and temperature of the sun? We're never going to go in there and measure it but this model predicts it, but it comes out, what winds up at the end is something that works like the sun, it's the right size. It takes the mass, produces the luminosity we observe. It turns out nature has provided us two fascinating ways to learn about what's inside the sun.

One is, that those nuclear reactions don't just produce energy. They don't just turn hydrogen into helium, but they produce as a byproduct, every helium atom that's produced, is accompanied by two neutrinos, they're called. These are electrically neutral particles. Their mass is not quite zero, but it's as close to zero as any particle known in nature and they interact almost with nothing. Once they're born, they travel through the sun as if it were just completely not there. They radiate out into space, they travel through the earth as if it were not there. They travel through you and me. But if you really set out to work at it, you can grab one out of a trillion of those with the appropriate detector and measure it.

So, these are coming straight from the center of the sun. They're not banging into anything. They can be produced only in nuclear reactions, and that confirms for us, that these reactions are going on in the center of the sun. And the interesting thing about it, if you turned off the energy source in the center of the sun, if you could somehow magically keep it from collapsing on itself, the sun would not turn off for 10 million years. That's how long it takes the energy that's produced in there, it's produced in the form of these gamma rays, and they go a centimeter or something and bang into something else and turn it into other stuff and slowly pingpong their way out of the sun, it takes 10 million years to get out.

The neutrinos get out instantly and they get here eight minutes later, the sun is eight light minutes from us. And so, they are telling us that right now the nuclear furnace is burning. Now, the other thing, actually, that would happen if you really did turn off the nuclear furnaces, is the sun would start to shrink almost immediately. The forces, the balance between gravity and pressure is such that even a small deviation would cause a significant change in the radius of the sun. So, that means also, that the sun does something else. Well, it varies, as you mentioned at the beginning but it also turns out that the sun is constantly quivering. It's vibrating and shaking in a constant, very, very tiny amplitude of oscillations at a whole range of frequencies, which can be measured carefully, and that is telling us about how the interior of the sun behaves.

Now, we learned about the interior of our own earth in a similar way. If an earthquake happens, it causes waves in the solid and molten earth's interior and they race through, and we detect them elsewhere and they tell us about the inside of the earth. Well, these quiverings of the sun tell us about the inside of the sun and that simple description that I told you, those five simple equations, turn out to be an amazingly good description of what these quivering actually tell us. So, we have some simple theoretical calculations, but then we have two forms of direct information. Well, it's not quite direct, but actual data, which tell us about the center and the interior of the sun, the neutrinos and the oscillation. So, it's called Helioseismology by analogy with terrestrial seismology, and it can even be done for other stars. So, we learn about how they're built. So, our picture of the interior of the sun is really remarkably well founded.

Tracey: [12:10](https://www.rev.com/transcript-editor/Edit?token=dBhrk5HG0UWwXzeuXyWJb-wNX3QAYD9D6jXDhNanoFq1q1P8VvdXpdQkqHCqwzu3qW6fCY_k2wWRT5HTAu-k3ReuDZE&loadFrom=DocumentDeeplink&ts=730.99) That's amazing. I did not know that the sun vibrated.

Reynolds: [12:17](https://www.rev.com/transcript-editor/Edit?token=aLTBxB_5OsA1Tvh10WmlUjjem-AiowcmFAvfxb3XNNNmsuar9N8F-g1mObA282CF8kEdjkwmIjj3GifUzLgZ2VLAsJ0&loadFrom=DocumentDeeplink&ts=737.57) Yeah, it's not easy to see. It was not discovered until the 1970s.

Tracey: [12:21](https://www.rev.com/transcript-editor/Edit?token=RWlt3eIK3zdnvorFwNC5UQ0zEVK438L4UnjAoDlAl6xhD8ZJdwbXO07zCcIw8bN0XeXyI8FrCZPSUVQRQ4wRnV_Wjao&loadFrom=DocumentDeeplink&ts=741.96) Wow.

Reynolds: [12:22](https://www.rev.com/transcript-editor/Edit?token=vhL1GunTeL28XFvaEHFNXs4_6gX8x-muIh1WgnSd-XbiK2zM_EdNKBymTSTA4yc05bCKhkYNJxx3TqMzBNncJe2xh1M&loadFrom=DocumentDeeplink&ts=742.36) Now it's a whole area of research.

Tracey: [12:25](https://www.rev.com/transcript-editor/Edit?token=sSgZUSDriSqWkLl-FP-x-hK7mDMRnP6tm8cj8Lwu89pA6flUVAKoU0ouVJk6rvv_qwhqXVtFysc0IznRO4d6I7kxVv8&loadFrom=DocumentDeeplink&ts=745.93) When people talk about solar cycles, what does that mean? We know that we're entering what they call a solar minimum or a minimum part of its cycle. So, let's talk a little bit about solar cycles. Why does the sun have periods of more or less activity and do they occur at regular intervals? What's going on with solar cycling in general?

Reynolds: [12:51](https://www.rev.com/transcript-editor/Edit?token=ohcy3thfBA7x6T5hahS-A1JL1Eip5mAa7ucDE5FMpAwNM82Endl4LB4QyWCBMFkiQ3VmYAyqugj9JegK_irUMtqri-8&loadFrom=DocumentDeeplink&ts=771.72) Okay. Let me begin by saying we don't actually know as much as we'd like to about why it happens, but now I'll tell you what it is. The sun has spots, and these spots, they come and go and they were first detected, I guess, in the 17th century, I believe that might be one of the incredible list of achievements that Galileo has to his credit, once he had a telescope. But you can actually, when they're very strong spots, they are darker features on the sun. They are dark by contrast with the rest of the solar disc, which is incredibly bright, of course, and it will blind you if you look at it, even if it's not an eclipse.

But people, once they realized that they existed, folks could use various techniques. It turns out you don't need a telescope, when there are very prominent spots you can just make a pinhole camera, take a pin and poke a hole in a piece of paper and hold it up and project the image of the sun on another piece of paper behind it. And when there's a very prominent group of sunspots, you can actually see them with the naked eye. So, people have been doing this for 400 years and they discovered that the numbers come and go in an 11 year cycle. That's the solar cycle. Originally sunspots, the fact that some parts of the surface of the sun are a little darker means that they're a little less luminous. So, there's a tiny fluctuation in the sun's brightness. It's like a 10th of a percent overall, but nowadays that can be measured.

So, since the days of photography and the possibility of recording things, and even more recently, space detection and monitoring of the sun, we've been able to refine this, but there is an 11 year cycle by which the number of spots rises and falls. Other things go along with that, when there's more sunspots, the solar wind of outflowing material particles and magnetic field from the sun, which is constantly going on, is stronger. And that has implications for terrestrial satellites, communication, things like that, so it's important for us to keep track of it. It's called space weather. Let me put in a plug here for spaceweather.com, a very interesting website that tells you all about this.

So, the sun not only produces a steady stream that rises and falls with an 11 year cycle, but it also produces explosive events called coronal mass ejections. And when there's a big one of those, it takes a couple of days for the particles to get here, we're now warned, we can put our satellites in safe mode. We can take other precautions to keep from communications blackouts, but when those are bad, they can really be a significant problem on earth. So, something causes this low variation. Another cool thing, is the sun is a big magnet and its North and South Poles reverse during the solar minima, so that it's actually a 22 year cycle. 11 years where the north pole of, magnetic pole of the sun, is in the north side of corresponding to earth's North Pole and then 11 years where it's the other way.

And another interesting thing is we don't know if other stars have these. There are satellites. They look for planets around other stars by the tiny dip in brightness when the planet passes in front of the star, but you wind up collecting huge amounts of data on just the overall brightness of stars.

So, people are combing through this, and one of the interesting things they found is that stars like our sun, mostly, are a lot more variable than our sun. Stars that are matched to our sun in mass and temperature, and every other way, we know how to match stars, turn out to be a lot less quiet. Their luminosity's changed by tens of percent, rather than this 10th of a percent, in the case of the sun, nobody knows why that is. We've been able to track ours back from counting sunspots for 400 years, and the particles from the sun also do other cool things. They make more carbon 14 in the atmosphere. So, we can actually use that and learn that our sun has been fairly stable for the last say, 10,000 years. And during all that time, the stars that are like the sun, as like as we can get, something like a sample of three or 400 recently published, turn out to be more active. We don't know why.

Tracey: [17:46](https://www.rev.com/transcript-editor/Edit?token=gmq4cju7BV74W1A3saZvmG1wRJxK7VjN6zLJTVTjP3-hPwZiXe47idtDIzElDUimeke-xG9KN8XwRZKPXNyYbIcgVL0&loadFrom=DocumentDeeplink&ts=1066.37) Well, that's a good thing, right? That our sun is not quite as active as perhaps some of these other stars, I mean, in terms of life on earth, is it good that we have a quiet sun?

Reynolds: [17:56](https://www.rev.com/transcript-editor/Edit?token=sm7qTQGiZ4H8Do5vq5gCkxWvg-sD9j0qjKsAoC2rXtTexFE3TZrhZIfRtZbQNfMIF5uY8gpHAKFSy3Qz8l9O_UMiAo4&loadFrom=DocumentDeeplink&ts=1076.3) Absolutely. It has all occurred to us that this might have something to do ... If this is the way the sun has been for millions of years, this might have a lot to do, that we are actually protected from much of the effect of solar radiation from the earth's magnetic field. But the occasional effects on the earth's power grid show that when there's a real big eruption on the sun, it can make a difference. And if that happened all the time, you can imagine it might make it hard for the terrestrial slime to evolve into human beings.

Tracey: [18:31](https://www.rev.com/transcript-editor/Edit?token=QSTye4bip2sgHw0ybdlnNnNWRy9cNwrWptE1FvW3O-JjGxgw8O5gWfZRrqoL-hnTn1MSARn57c_jLXUUG8l9r82jby0&loadFrom=DocumentDeeplink&ts=1111.5) Indeed. We know that when there's a solar maximum and there's a lot of sunspot activity, it has very observable, immediate effects on earth. It can affect satellites data, the way our electronics work, things like that. What happens during a minimum?

Reynolds: [18:57](https://www.rev.com/transcript-editor/Edit?token=IP5oA-07U6RYppqKAceK-QKUz7JgJzh2ZS42ctFnHykS-_gBkhqpApLW2sZfaZDN0iXIKkfRVaZXfaIemYSgkAEWPSo&loadFrom=DocumentDeeplink&ts=1137.1) It's just quiet.

Tracey: [18:57](https://www.rev.com/transcript-editor/Edit?token=ArJOkaLgGLmB95b0fnq-NntnepUoYCm4ZYeaTMX2DPk2GslGqM-PWtRYtJjG0Xt8AETYxw3Wk95Ksfl0umW9i-RyimA&loadFrom=DocumentDeeplink&ts=1137.45) Just nothing? Some of the crazier things that you'll hear online are, "Oh, no, it's a solar minimum. We're all going to have an ice age." Is there any truth to that? Is there a correlation there at all or is it just, "Hey, our satellites are cool."

Reynolds: [19:21](https://www.rev.com/transcript-editor/Edit?token=SMQUdE4Qu5-qFBdd1Ld63P8FJ-S3nQOzaFyFkQWsJaTm60gw_o8wVZDGPrEcvh6PMdyckBVGDT95C4VfxgfbSlQhqzM&loadFrom=DocumentDeeplink&ts=1161.33) Yeah, no. I think, the minimum is, I mean, these are very broad effects. It's not like something that's going to happen tomorrow, the solar minimum is at 11:30 tomorrow. There are more conjectural associations of solar activity with actual weather, seeding, thunderstorms, things like that. I don't think there's really good evidence right now, but it's not crazy to imagine, and people are still studying that kind of thing. But again, the total effect is pretty small compared to the average, I mean, it's a cycle all right, but the amplitude is just not very big. So, huge, dramatic effects are not likely.

Tracey: [20:54](https://www.rev.com/transcript-editor/Edit?token=v3hf8QCzaf5grvLZipf1LpXgLYjqsOFeRjR9QyoP9FOsgtcHpKy7hIx5lzMjRbz9hOw23l4qXzJsHvg7NwAM16HodOQ&loadFrom=DocumentDeeplink&ts=1254.78) The other thing that you hear in conjunction with talking about the solar minimum is that, say people on the International Space Station or at very high altitudes, might inadvertently be exposed to more cosmic rays coming from other areas. How does that work? Does solar weather somehow protect us from other rays coming in from different areas of space?

Reynolds: [21:23](https://www.rev.com/transcript-editor/Edit?token=DV53H-02EMYf7vzli8JLqQ8clpEWBe6N35OQovq3JH2U1mRQNMeGik0cW8gc7mGKaI-FRLSqm3L8UHUR3Mz6339D3z0&loadFrom=DocumentDeeplink&ts=1283.52) Well, as a matter of fact, it does. Charged particles fill space, the ones in our neighborhood, in the neighborhood of our solar system, predominantly come from the sun. These are relatively low energy particles, but we also know that our galaxy is full of much more energetic particles, in addition to the stars, and gas clouds, and dust, and things. There are particles flying around, actually related to my own research is how they get these terrific energies, short answer is supernovae. At any rate, these galactic cosmic rays can be much more energetic and they can do all the same scary things that particles from the sun can do. And some of those come to earth, again, the earth's magnetic field protects us from a lot, but some of those are so energetic that they come and smash into atoms at the top of our atmosphere and make a shower of secondary particles.

So, again, this is something we're all exposed at the earth's surface is showers from cosmic rays, but the sun's solar wind, it's less energetic particles, but there's a lot more of them. And when the sun is near its maximum, there's just more of that and that sweeps out the galactic cosmic rays. So, the galactic cosmic rays have are suppressed by solar maximum. These things are called Forbush decreases in the cosmic ray flux. So, I have to admit, I don't know enough about potential radiation damage to say, pilots, or people in low earth orbit, to know which source of radiation is more important for health. The very much more energetic particles are much scarcer. So, my guess is that probably the sun is more of your enemy than your friend, if you're worried about radiation beyond the Earth's magnetic field. Low earth orbit is still pretty productive. It's the people you have to worry about are the ones, the astronauts that are going to Mars. They are going to be exposed to a lot of radiation for years.

Tracey: [23:27](https://www.rev.com/transcript-editor/Edit?token=2iQbIr0RXiO8q00QT2O_-984SMVyWFuHEVCc0mKE-ij1IDHnqHVYqnRVSBNZbr1OOlKE-rLyPVzAk7XWHF89xAXVHUc&loadFrom=DocumentDeeplink&ts=1407.91) What is your favorite or most interesting fact that you know about the sun?

Reynolds: [23:52](https://www.rev.com/transcript-editor/Edit?token=D8aapkrMYn_5VnEW598V0FQavp2xsX6tACFU936CWLIHq_xVaJ0dsnZKn9sZjcR2nzAci3KgaxsuafJm9RZTmBQZjuE&loadFrom=DocumentDeeplink&ts=1432.6) Golly, that's a tough one. I think the idea that it takes light 10 million years to get out from the center, and the neutrinos make it in a few seconds, is a pretty interesting piece of information. It's not only a cool fact, but it reminds us that we do have this interesting channel to study the sun as it is now and not just as it was 10 million years ago.

Tracey: [25:59](https://www.rev.com/transcript-editor/Edit?token=2kpa-YqOMDQuSw1KtwtjCoZRSi2ur0wsDLLvFyUJnsAMvKtmJlvp_661d_2XgHKDhuYmfdYbMCJQuY3veFWdsg9VJ8E&loadFrom=DocumentDeeplink&ts=1559.07) Well, that is fascinating stuff and I would like to thank you again for being here with us today and talking to us about our closest star neighbor, the sun. We've been speaking today with Steve Reynolds, alumni distinguished professor of physics here at NC State. This has been Audio Abstract. I'm your host, Tracy Peake. Thank you so much for listening.