[Voice of Troy Cline]
The core of our sun has a temerapture 15.7 million degrees Kelvin. However, the solar surface of the p photosphere is only 5,770 degrees Kelvin. But then something very interesting happens. The temperature starts to increase again as we enter the outer atmosphere of the Sun or the Corona where it can reach nearly 2 million degrees Kelvin. So what's up with that. I'm Troy Cline and in today's podcast we'll be hearing from Dr. Sten Odenwald. Sten is the chief author and editor of the Technology Through Time series. Sten is going to fill us in on this year's first Technology Through Time mystery, “Why is the Sun's Corona So Hot?

[Voice of Dr. Sten Odenwald]
It's turns out to be very interesting question for astronomers...actually, an embarrassing one sometimes. Ah, you know we've been looking at total solar eclipses for literally thousands of years. Anybody that's actually seen a total solar eclipse know that the most dramatic thing about is not only that the moon blocks out the Sun, and that's kind of a good thing, but you also see the spectacular Corona that surrounds the blacked out sun. And so the Corona is something that people have observed going all the way back to ancient Chinese astronomers. So now we're in a situation where, OK. Let's learn more about the Corona. When people did that in the 1800s with a new instrument called the spectroscope, they discovered that, well, you know there we things that they found in the Corona that they didn't find in the light from the rest of the Sun. One of those things was a whole bunch of mysterious atomic lines that simply nobody could figure out what these were all about. The way things work is that when you take an atom and heat it up or have it collide with other atoms, the electrons get excited, they gain and loose energy, and each element produces it's own fingerprint set of lines of light in the spectrum. These lines can identify an element very uniquely because they're so unique to the element. Now, what happened was that in the 1800s people went through and cataloged all the lines and said, OK, those lines come from the element iron and those lines come from the element calcium,and these other ones over come from the element sodium ...and so forth and so on. They good at matching up lines on the Sun with things that they could see under laboratory conditions. But then when they looked at the Corona, they found lines that didn't match up with anything they had seem in the laboratory and so they called these things the Coronium lines and they actually thought that there was a band new element called Coronium that was present in the Corona of the Sun that was producing these atomic lines.

Well in 1942 a Swedish astronomer spent some time looking at this whole problem...scratching his head about what these Coronium lines could possibly be, and he figured out that if take an element like iron and you strip off something like 13 of its 26 electrons, it will produce a fingerprint in lines that looks nothing like ordinary iron. In fact, many of those lines turned out to match up very nicely with the lines that were seen in the solar corona. So, this was a major discovery that, WOW, we've got not only atoms that can produce these lines but if you take some of the electrons out of the atoms, those produce a whole different set of lines, ah, and in this case they matched up very nicely with what was found in the Corona.

Well if was kind of a neat discovery but the only problem was that it raised a fairly ugly question. If you look at that surface of the Sun and you stuck a thermometer into the surface, it might measure something like 5700 degrees Kelvin or 6000 degrees Centigrade or 10000 degree Fahrenheit depending on what temperature scale you want to use. If you stuck that

same temperature thermometer up in the Corona, these lines of iron suggested that the Corona was a temperature of over 2 million degrees. So how in the world could you have a cold solar surface at 6000 degrees producing an atmosphere above it that was at 2 million degrees?

By 1942 and the work by Bengt Edlen who was the Swedish astronomer, this great mystery sort of came up! Why is the corona of the Sun so hot? Where does it become 2 million degrees when the surface of the sun is only at 6,000 degrees? It was kind of like of you were standing in your kitchen and you've got this hotplate that's boiling water and the hotplate is maybe 200 degree Fahrenheit and then if you were do back away from that hotplate, instead of things getting colder and colder, things got hotter and hotter until in the middle of the room the temperature was 3000 degrees. I mean it's completely a ridiculous situation. Since 1942 solar physicists and astronomers have spent a lot of time trying to understand why the Corona of the Sun is so hot. The problem is that you only have a few things to work with aside from space aliens with ray guns and electric heaters...there's no real easy way to heat up a gas to 2 million degrees and keep it that way all the time. The temperature of the corona stays hot throughout the entire solar activity cycle. It doesn't go hot and cold with the 11 year sunspot cylce...it stays hot throughout the entire cycle. So whatever is going on to heat up the Corona of the Sun really doesn't have a whole lot to do with sunspots and what looks like the obvious activity on the surface of the Sun.

the physicists came up with a couple of ideas. One has to do with sound waves. Here's a way of thinking about it. If you take a whip, a bull whip which is real big one, has a really thick handle, usually about 1 inch in diameter and the whip is a tapered thing that goes out to a tip that's only about a millimeter or less in diameter. What you do when you crack a whip is you put a big pulse of energy into the base of that thing and this wave travels out into the tip of the whip going faster and faster and faster as it goes out into the tip until finally when this energy gets to the end of the whip, it moves the end of the whip at the speed of sound and you hear the crack. If you have a situation where you take energy and put it an area that is at high density and that energy flows into and area that is at low density, you and actually get the low density stuff to move faster. So people thought, wow, that's kind of how sound waves work and maybe there a lot of sound waves being produced by the surface of Sun from all the connection and turbulence. Basically if you take a pot of water and put it on the stove and you get it boiling,the first thing you actually do here and notice about the boiling water is that it's making the sound of boiling water. So there's sound energy involved when you have stuff boiling. The surface of the Sun certainly is boiling like crazy. You can actually see the boiling of the surface in photographs. The only problem is that people have looked very carefully for sound wave energy going into the corona and the first thing that they noticed theoretically was that the sound waves tend to get reflected back to the sun, they never really quite make it deep into the corona. They certainly don't get as far out as where the hot stuff if found which is almost a million miles above the surface of the Sun. Particular measurements that have now been done can actually see some of these sound waves in progress and unfortunately it looks there just simply not enough energy in the sound waves to heat up the corona. So that was a real disappointment.

The next possibility is to do what the Sun does best; and that is: The Sun produces magnetic fields and those fields get tangled up. When they re-arrange themselves they basically take the energy that's in the magnetism and convert it into heat. It's a process that's called magnetic reconnection. One possibility is you can have all kinds of flares going off on the

surface of the Sun and the magnetic energy then heats up the gases and those gases go into the corona and you end up with a hot corona. That's a real exciting prospect, the only problem is that these events can't really have a whole lot to do with the big sun spots and the big huge flares that we see all the time because these flares happen at times when you have a lot of sun spots and you have a high state of activity; the problem is the corona is hot all the time, even with no sun spots on the surface or big flares going on.

It turns out that the SOHO satellite, and now recently, the Hinode satellite have measured what are called micro and nano flares going off on the surface of the sun. These are really teeny tiny flares; but there are so many of them. There are literally thousands and thousands of them all across the solar surface. It's hoped that when we understand these better we might discover that they are actually the source of the heating of the corona. There are so many of these micro-flares going off all the time, day and night, during the entire time of the sun spot cycle. But maybe added together they will be enough to heat up the corona. And right now those observations are in progress and maybe we'll know in a year or so whether or not that is the process.

So far we only have Two horses in town. One horse has a broken leg and the other one is about magnetic reconnection. We're hoping that one can move to the finish line. If it doesn't then we're really going to have to scratch our heads and come up with a third way of heating the corona and hope that one works. Of course the way things work in nature, nature decides to do everything. There might not be just one thing going on, but maybe two or three or four different things going on that actually heat the corona. Maybe that is the way to solve the problem. A little bit of this, a little bit of that and it all adds up to a hot corona. Anyway, that is for the future. Right now we have plenty more mysteries to come. The next mystery is going to be "The mystery of the solar neutrinos". For a long time people wondered where all the neutrinos went from the center of the sun which is converting hydrogen into helium to produce the solar energy. That turned out to be a really big mystery for about 30 years. So we're going to explore what the mystery is all about and how that mystery was solved. Probably one of the few mysteries that we think we have solved completely. Beyond that there are other mysteries to come in future essays. So stay tuned and keep watching our page.

[Voice of Troy Cline]
When visiting our website you'll be able to browse through all of our technology through time essays and the new sun-earth day image gallery. That gallery also contains all images associated with the technology through time series. I asked Sten to give us a brief explanation of the three images he chose for this article.

[Voice of Sten Odenwald]
The first image in the gallery is a lovely photograph taken of the total solar eclipse as seen from Monchaia Hawaii in 1991. You will see the black disk of the moon covering the brilliant disk of the Sun and of course what your eyes are drawn to is the wonderful detail of the corona of the sun. Those loops and streamers that you see are very high temperature gases that are trapped in magnetic fields near the Sun. Magnetic fields tend to have a loopy shape to them. So whenever you see loops and things like that in the corona you know that magnetic fields are somehow involved in making them see that way. Without magnetic fields all you would see here is a featureless bright glow and that would be it. So magnetic fields are like nature's paint brush. They actually put details in things that would ordinarily would be without any real features at all.

The second image is a really spectacular image taken by the Yokoh satellite. What you're seeing here is hard to describe. You're seeing very high temperature gases that are almost up to one million degrees hot. And these gases that you see here, especially in the bright yellow areas, are anchored to the Sun's surface. So the gases there tend to stay around in a small area of space so you can see them very intensely by the x-ray light that they produce. Those black areas don't mean that there isn't any light being produced by the sun. What it means is there are very few x-rays being produced by the those parts of the Sun's surface. To produce x-rays you have to have gases that are at 100,000 degrees temperature. But the surface of the sun is only at 6,000 temperature; so it's simply not hot enough to produce x-rays over it's entire surface. So that's why you'll see areas that are black. The black just means that yeah there's very hot gases down there but in x-ray light those gases are not producing any x-rays at all. The only x-rays coming out are from the very very hot gases that are trapped in the magnetic fields that you see in the picture.

The third and final image is actually not a photograph of anything. It's actually a computer model that is meant to represent the magnetic field of the Sun for a particular time. This turns out to be March 24, 2006. This is what is called a physics base calculation. There is no artwork involved here at all. Every one of those lines are meant to represent an actual magnetic field line computed from physical equations that control how gases produce magnetic fields on the surface of the Sun and how those magnetic fields spread out into space. You'll notice there are a lot of loopy things that are closed and if you will remember what the total solar eclipse picture looked like, it also had the same kinds of loopy things. That is what I was saying before that those loops that you see in the pictures are things you can match up with magnetic fields in the Sun. This third picture actually shows you what those fields would look like that would make the corona have that kind of shape. But you'll also notice that there are lines that go off into space without coming back to the surface. Those lines are places where hot gases can stream out from the Sun and go out into inner planetary space beyond the orbit of Earth and even Pluto. So those are like water pipes into infinity [laughing]. Where gases can freely go out into the rest of the solar system. So that's a little bit about this gallery. I hope you enjoy the pictures and there are more to come in future episodes.

[Voice of Troy Cline]
We are very interested in hearing your questions and comments about the Sun-Earth Day podcast. If you have something to say, send an email to sunearthdaypodcast.mail.630.gsfc.nasa.gov . For all other details about Sun-Earth Day program including information about our past Sun-Earth Day themes and all podcasts. Be sure to visit our website at http://sunearthday.nasa.gov . Sun-Earth Day is a program sponsored by the NASA Sun-Earth Connection Education Forum at the Goddard Space Flight Center, and at the UC Berkely Space Sciences laboratory. This is Troy Cline, signing off.