The Sun Kings

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It is a genuine pleasure, if not a thrill, to be lecturing in Gresham College (that is an academic thrill of course), the birthplace of academic astronomy in the UK, and let me also add my endorsement of Ian Morison, who is a superb lecturer, and I am sure that he will teach you many things over the coming series of lectures here.

I am going to talk to you tonight about the Sun Kings. Being in a historic place, I thought we would look at some history, and over the course of the next three-quarters of an hour or so, I am going to sweep you back into the Nineteenth Century and look at the way in which the astronomers of those times replaced every bit of myth and speculation about the way the Sun works and how it affects the Earth, and put in place the foundation stones of our modern knowledge about the Sun.

Before I take you all the way back there though, let us step back just to Halloween 2003. The SOHO satellite is an electronic watchdog that sits between the Earth and the Sun and constantly monitors the Sun. The Sun is this ever-changing powerhouse of the solar system and it is a huge nuclear furnace that generates all the energy that then radiates into the solar system and keeps the Earth and all the life on it going. It is an extremely changeable place, and SOHO is there to watch for these changes. It changes on a daily basis in a number of ways.

The most obvious way in which the Sun changes is that, periodically, dark blemishes appear on its surface, and these are called the sunspots. We now know that the sunspots are caused by magnetic fields that well up inside of the Sun and burst through the surface. If you could see them, they would look rather like the pulled thread on a woollen jumper, and as these great structures rise into the solar atmosphere, so you see these dark features, the sunspots, on the surface. The sunspots are the sight of solar activity, and at Halloween 2003, for about a fortnight period, the Sun went through one of the most active periods we have ever known it to go through. In the course of that fortnight, something like seventeen solar flares exploded. The solar flares are the energy that gets released when these huge tottering loops of magnetism collapse into smaller, more stable structures.

Every time one of these flares explodes, it releases colossal quantities of energy - over a billion times the energy of the Hiroshima bomb in each explosion. They are cataclysmic events, and because of the way that SOHO works, we actually have a movie which shows the Sun during that period, in which you can see the flares. This movie covers a period of about a fortnight. It was taken at ultraviolet wavelengths, and so, instead of seeing the sunspots as dark, you see the hot gas in the magnetic loops above the sunspots which appear bright. On this movie, the really enormous flares seem to cover the screen in static. There is a big flare there, and suddenly this whole sort of static overcomes SOHO. Which gives on indication of how large the solar flares are.

All of these events contribute to what we call space weather, and not only is this releasing energy in the form of x-rays and gamma-rays, but it can also cause giant eruptions. The Sun is surrounded by this enormous atmosphere of gas, and when these explosions take place, it can actually launch huge clouds of this gas into space. A billion tons of solar material can be thrown off. So, each one of these flares can trigger these enormous eruptions of this solar material.

So, in 2003, we saw the solar flares began on October the 25th. But October the 28th was when the first of the massive flares and eruptions struck. We saw head-on collisions between this billion tons of million degree gas and the spacecraft, SOHO, and then of course it is swept on and hit the Earth afterwards. You always know when you are getting a big one by the amount of static that you get, and the largest solar flare was on November the fourth, which was actually directed away from the Earth, which was lucky.

I mentioned that they were hitting the Earth all the time, so, as you might expect, there were some effects from all of this, the first of which was that these huge clouds of electrified particles can charge up spacecraft, and as the charges build up on the spacecraft, so they can short-circuit and that damage the electronics. In fact, the Japanese lost the Meduri II weather satellite - it went silent during the storm on the 28th of October, and has not been heard from since. Half of NASA's spacecraft reported malfunctions in some way but, they were not fatal. What most of these faults were was a matter of their positioning mechanism. The satellites of today hold themselves upright and in fixed orientation in space by having little telescopes on them called star trackers. These star trackers watch the night sky and they monitor the positions of the stars, and if they notice any slight movement in the stars, then they fire little thrusters to keep the satellite stable. When the satellites are surrounded by these great big clouds of electrified gas, however, it blinds the star trackers and they lose sight. However, the spacecraft will try to correct for that - it thinks, 'Oh goodness, where has the stars gone? I need to try this, I need to try that,' and it will just dangerously fire all these thrusters. So what spacecraft do is simply recognise that something has gone wrong like that and shut themselves down, and then they wait for ground controllers to send up resuscitating signals saying, 'The danger is over. Turn on - see if you are okay or if there really is anything wrong with you.'

Perhaps the best example of just how powerful these storms were is that NASA also had the Mars Odyssey spacecraft out in orbit around Mars, and it carried with it a radiation monitor. The radiation monitor was designed in order to measure the amount of exactly this kind of solar radiation that would reach Mars, because Mars has a very thin atmosphere, it has no ozone layer. In fact, this is one of the biggest problems: if you are going to send astronauts to Mars, that you do not have this big bountiful atmosphere like the Earth has protecting you from the radiation. Well, the Mars Odyssey radiation monitor was burnt out by the Halloween storms. NASA had completely miscalculated just how much radiation it was possible to receive at Mars.

On the Earth, there were all sorts of communications blackouts. All of the expeditions on Mount Everest were lost contact with. There were forest fires in California at the time, and the radios would not work properly so they could not correctly coordinate their efforts to fight these fires. The marine disaster network, the emergency network there, was blacked out as well. Then there were other somewhat more trivial communications issues, such as mobile phones and satellite television being blacked out for people. Perhaps most seriously of all was that this was the first time that passenger aircraft were diverted because of the risk of high altitude radiation. The solar flares on the 28th of October and again two days later on the 30th were so large that the FAA decided that they would move all aircraft away from the Polar Regions. These have been becoming increasingly popular as routes, to go over the poles of the planet. The trouble is, that is where the magnetic field of the Earth funnels all this solar radiation down into the Earth's atmosphere, and so, when these storms hit, as a precaution really and nothing else, they diverted the planes down to below latitude 54 and brought them down lower into the atmosphere so that there was more air above them to provide some protection.

But a question that occurs in my mind for all of this is: 'Did we have really quite a lucky escape?' All those things that I have mentioned to you, if the flare of November the fourth had hit the planet, it could have been much worse. Perhaps it could have been GPS that was badly affected. Certainly, over that Halloween period, all the GPS signals became much more inaccurate than normal. I think the clue as to what might have happened is if we look back 150 years into the past, to the time when we know that there was the biggest flare and subsequent magnetic storm in recorded history.

Let me take us back then; we are in 1859, it is September, and we were on board the clipper ship, the Southern Cross. The Southern Cross is designed simply to go from East Coast America all the way down, round South America, and back up to Gold Rush California. It just simply shuttles backwards and forwards. On the night of September the second, it was in temperate Pacific southern waters, off the coast of Chile, and the crew were fighting a gale that night. As the water whipped against the side of the ship and the spray sort of fell away to leeward, the sailors would be turning their backs into the wind, and they began to notice that over towards the other side of the ship, the whole ocean appeared to be the colour of blood. They wrote in the ship's log, 'We were sailing in an ocean of blood.' As the storm started to abate a little, and they looked up, they saw, even through the covering of cloud that was left, that '...the whole heavens was glowing red as well. It was the most unearthly sight.'

The thought immediately struck them that these could be aurora; these could be the southern lights. They were used to seeing them down near the Straits of Magellan, but never had they seen them this high up, near the Equator, and certainly never had they seen them encompassing the whole sky in this way.

The next thing that they noticed was all the masts and the lanyards began to glow with electricity. They knew what this was as well - it was the St Elmo 's fire. It was a sure sign that there was electricity, and it is usually a sure sign that there was thunder and lightning storms around. However, despite the weather that night and the squalls, there had been no electrical activity of that kind that they sailed through.

Getting towards dawn, the clouds began to clear and they started to see through to the night sky, and here, not just was the sky still enwreathed in red, but vivid white bolts of light seemed to be flying upwards from the horizon to burst above them at the zenith. They wrote: 'It was as if the very souls of all humanity were fleeing whatever cataclysm had engulfed the Earth.'

A little while later, they arrived at San Francisco, and they rushed to tell their story of this extraordinary night. But they discovered that they were by no means the only people that had seen these. In fact, around two-thirds of the whole Earth was covered in this blood red glow.

The blood red aurora of September the second 1859 is the largest and most widespread of an auroral storm ever witnessed. It stretched down into the northern tropics. People gathered on the shores of the Caribbean islands, convinced that the neighbouring islands were on fire. It is very usual for the aurora to be green. It is very unusual for them to be totally red, and this is another sign of just how extraordinary the 1859 one was. In the Midwest, in America, they thought that there were enormous prairie fires engulfing the states there. You could read by some of these lights. People were woken up by the brightness of the aurora and could read newspapers by it.

There was a sinister side to this great auroral display. It was not all just light shows. The telegraph system was the internet of its day. It was the high tech communication - everything that you use the internet for today, so was the telegraph used by the Victorians. As the aurora erupted into the sky that night, so the telegraph system around the world went down. It crashed spectacularly. Not only did it cease functioning, but enormous currents surged along the wires, setting fire to equipment in the telegraph offices, causing huge sparks to fly out of the equipment that was being used, stunning operators unconscious. It was as amazing and as frightening just as surely as if the internet were to go down today, and in this time period, what happened was that the politicians turned to the scientists and they said, 'What happened to our planet?' and the scientists had to say, 'We have no clue - this is completely beyond our understanding. It is completely beyond our knowledge. There is something that has engulfed our world that we are helpless in its grip and we simply do not know what it was.'

They did, however, have just a couple of clues. It was certainly known that the aurori were linked with magnetic effects, because in the 1700s, Professor Celsius and a student called Hiortner, investigated the aurora. They had equipment out in front of them, and Hiortner recalls later in his writings that as a great aurora burst over their heads, he noticed that the compass needle was wildly oscillating around, its lock on magnetic north was totally lost, and he said to Professor Celsius, 'Look what's happening to the compass - somehow these lights are magnetic.' The Professor, the wily old Professor, turned round and said to Hiortner, 'Ah yes, I noticed that too, but I thought I wouldn't say anything just to see if you noticed it!' Commenting on this comment, historian of astronomy, Jack Meadows, wrote in a footnote in one of his papers that says: 'I notice that the relationship between professors and their students has not changed greatly down the ages.'

So somehow the aurora were magnetic. There was also one other clue, and that was what I have called the solar lockstep. General Sabine was an adventurer and scientist, and he tracked the compass readings across the globe in his quest for magnetic north, and he noticed that the compass needle points in a slightly different direction at the end of the day than it does at the beginning of the day. He tracked this, and what happens is that, when you get up in the morning and take your compass reading, it points in a direction north; over the course of the day, the direction that it points drifts very slightly, and then, at night, it sinks back again and starts its daily trek all over again the next morning. Sabine noticed that the amount of this deviation changed every year, and it went in an eleven year cycle. Sometimes it was very small, and year on year, it got larger and larger, until it reached a maximum, and then it shrank back to a small deviation again.

Now, Heinrich Schwabe was a chemist who decided he did not like chemistry anymore so he sold the family business and spent all his money on telescopes, and made an extraordinary discovery. The sunspots that I was talking about earlier are not constant in how they appear, in their position or their number, on the solar surface. Schwabe decided to keep a track of these fickle blemishes to see if he could build a catalogue of them. He noticed that they began as being relatively few in number and only appearing at higher latitudes. As the years progressed, so the number of sunspots that appeared increased, and they moved down in latitude, towards the Equator. When Schwabe's solar cycle of sunspots was put in a the graph underneath Sabine's graph of the magnetic deviation, they moved in lockstep with one another. When there were more sunspots, so the compass needle moved more every day. That was an extraordinary discovery! How could the Sun, 93 million miles away, be responsible for compass readings on the Earth?

The astronomer John Herschel wrote to the physicist Michael Faraday, talking of this, and he said, 'I think we stand on the verge of a vast cosmical discovery the like of which hitherto has never been seen before.' The reason he thought this is that since the late 1600s, when Newton had developed his Law of Universal Gravitation, the philosophers and the scientists of the time believed that the universe moved in the gentle grip of gravity, that this was the system of the universe, and yet, here was evidence that somehow a magnetic force could also reach across space. The question was how to prove it?

Well, on the first of September 1859, Richard Carrington, an amateur astronomer, was in the right place at the right time. In his observatory and house at Redhill, he decided to take up the baton from Schwabe. Indeed, he would take on the work and he would make the biggest, the most accurate, and the most detailed catalogue of the sunspots that had ever been taken. And so it was that this day, just after noon, he had finished his sketches and he was starting to time the movements of the sunspots.

Carrington drew sketches of the sunspots that day. Carrington's sunspots were around about ten times the diameter of the Earth, and as he was timing the movement of this spot. He was projecting the Sun through his telescope and down onto a board, and on this board, where he saw a full image of the Sun, so appeared two brilliant kidney bean shapes of light. They were so searingly bright that he instantly realised he was seeing something that no one else had ever described; that this was something totally new and totally unique.

He writes that he was rather flurried by the surprise of it all. That did not, however, stop his scientific instincts kicking in, and in taking down the precise time at which this happened, he then ran out of the observatory into his house, looking for a servant. He tried to find somebody to come back and witness what he had seen. He does not actually say whether he succeeded in finding anybody to come and witness, but he does say he returned no more than thirty seconds later and was most disappointed to see that the lights had already significantly diminished.

He tracked them for the next several minutes, and they moved across the sunspot group and finally disappeared as two tiny points of light, which he marked on his drawing. Do not forget that the distance that they had moved in a few minutes was several times the diameter of the Earth. When he was doing the calculations later that evening, he realised that these things had been moving at colossal speed, speeds that were just frankly unbelievable, and so he then went on a concerted effort to see if somebody else, another astronomer, had witnessed the same event. He simply knew he would have a hard job persuading anybody if he could not find an independent witness.

He went first to the Kew Observatory in Richmond, built by George III, and here, one of Carrington's colleagues was engaged in the daily photography of the solar surface. It was an experimental device, and when Carrington got there that day, he asked if anything had been seen, and unfortunately, no picture had been taken that day. But the Director of the Kew Observatory said, 'We do have something strange to show you.' He took him down into the basement of Kew, into a pitch black room, and in this pitch black room was hung a magnet on a silken thread, and pasted to the front of the magnet was a mirror. This was suspended in the room, and a beam of light was shone onto the magnet. This beam of light bounced from the magnet and hit a rotating drum, and the drum clockwork device had a piece of photographic film placed around it and would gradually turn every day. Any changes in the magnetic field of the Earth would cause the compass to wobble. That would make the light deflect, and so it would trace a path on this photographic film. When they unrolled the film to show him from the day before, there, at exactly the time that Carrington saw the flare, was a spike. It was as if the Sun had reached out and struck the Earth and set the magnetic field ringing like a bell.

As Carrington stood in the Observatory, so the magnetic field of the Earth was still jittering, and in fact, it was not diminishing but it was getting stronger and stronger, far exceeding the spike that coincided with his flare that he had seen. This was the night of the giant aurora. Unwittingly, Carrington had been in the right place at the right time to see the flare that precipitated this giant eruption of material that would then engulf the Earth and produce the largest magnetic storm and aurora the Earth had ever seen.

He presented his case at the Royal Astronomical Society, and a vigorous debate erupted about this. What was at stake here was the belief that they had an almost complete knowledge of the way the universe worked. If it was not just gravity at work, it was magnetism as well, then in a sense they had to go back to the drawing board. There was much more still to learn. There was no full theory of what magnetism was at this stage, and so there were a number of people that simply could not really believe what Carrington was saying.

One of these people was George Airy, the Astronomer Royal. He was fully convinced that there could be no way for magnetism to leap out across space, and he was vigorous and pointed in his rejection of this as an idea, and as you might imagine, the Astronomer Royal carried great weight at that time, as he still does.

A further clue was missed the year after, and this is a picture to set the scene. In Spain there was a total solar eclipse. Eclipses were phenomenally valuable, because, in those few moments where the Moon sits in front of the Sun, so you see the solar atmosphere. We now constantly monitor what is going on via the SOHO satellite so it is hard to imagine how years would pass and you would just get a few minutes to see what was going on.

Warren De La Rue was another amateur astronomer and it was him who was the man responsible for the solar photography at the Kew Observatory. He took the solar camera that he financed to Rivabellosa in Spain to observe this eclipse. This was the first time anyone had ever attempted to take a picture of the fully eclipsed Sun. They had no idea whether they could do it. In fact, they thought they would probably fail. Warren De La Rue reasoned that the full Moon was probably about the same brightness as the solar atmosphere and so made test shots with his camera to see if it would work, and he registered not a single thing on the photographic plate. But he still went and took the chance.

They had to construct a makeshift observatory out of wood and covered it in tarpaulin to make a dark room. Over this they had to constantly throw buckets of water, because it is so hot that the photographic film simply fogged if they did not keep everything cool, and then they had to prime it, expose it, and develop it rapidly.

I am very pleased to say they got the picture. It sits today in the Library of the Royal Astronomical Society. This is the first image ever taken of the solar atmosphere, and its important feature was a solar flare launching a big eruption of gas into space, like we can see on the SOHO images.

The track of the eclipse passed from the East Coast of America, across the Atlantic, across Spain, across the Mediterranean, and down into Africa. It is interesting when you compare the descriptions of the solar atmosphere from observers at all these locations. On the Eastern seaboard of the States, an observer saw a bright flash that he could not be certain was real or not. Suddenly there was a boom, which was the flare gone. Then, as it comes across Spain, people saw this bubble opening up to become a tulip shape and moving off into space. The trouble is nobody knew really what they should be looking for in the solar atmosphere. They did not know if they could believe these stories of what was seen, and the fact that different observers saw different things. They were not sure they were all seeing the same thing.

The photograph was a double-edged sword in a way, because it said here's a photograph, here is something, in black and white, literally, that we can all agree on, but of course it did not take into account the fact that this structure changed and moved, and so they did not recognise the true dynamism of the solar atmosphere. Also, importantly, they did not link this up with a similar event to the bright light that Carrington saw.

Our story takes a little bit of a leap here, because Carrington didn't live long enough to pursue this research. What seemed to do for Carrington in fact was that he was a gentleman of leisure, had a very healthy living and income from his father's brewery in Brentford, but his father died prematurely and Carrington had to take over the family business. Working for a living seemed to come as quite a shock to the system for Carrington, but I do have some sympathy for him. He had begun an unbelievably punishing regime of scientific research. First, he catalogued stars, and he then also started cataloguing the sunspots, as we have talked about, and it was not just a case of making sketches and doing a few timings. He then had to reduce all his measurements into hard numbers that everybody could agree on, because he realised that he was seeing the sunspots as seen on a globe and he was projecting those onto a flat surface, so he had to make corrections and allowances, and he had to do all of this work by hand. So for every day that he observed, he had days' worth of mathematics to then do.

Essentially what happened to Carrington is that in trying to run the family brewery and trying to keep up his scientific research resulted in him having a nervous breakdown and he abandoned everything. He sold the brewery, he sold his observatory, and he tried to retire. He then made the most disastrous marriage you can possibly imagine. I had always wondered why Carrington seems to just disappear from history. You read about this amazing astronomer whose proposal to the Royal Society reads like a 'Who's Who' of Victorian astronomy. He was in the top echelons of science, and yet, you hardly ever hear about him today. After a little bit of digging, you find that this marriage resulted - I am not kidding - in scandal beyond belief. In fact, I joked at the very beginning of wanting to write this book, I said, 'I know what the title is: it is 'Sex, Drugs and Solar Flares'! Obviously, I will not air Carrington's troubles in public, but in the spirit of fair and complete journalism, I researched it and put it all in the book!

Interestingly enough, in the year that Carrington dies, under suspicious circumstances, Walter Maunder was just taking a job at the Greenwich Observatory. Walter Maunder was one of the first to be employed in an open and fair system based on ability and not the old-boy network, and this drove George Airy absolutely mad! The Astronomer Royal could not stand Walter Maunder and seems to have terrified him. Maunder was carrying two vials of photographic developing fluid one day through the Observatory, caught one sight of Airy stalking towards him, and dropped the lot - just the thing you don't want to do when you are trying to impress a boss who has already not convinced about you! That very day, probably a few minutes after I suspect, Airy dashed off a letter to his superiors saying, 'Walter Maunder is the veryest dummy I've ever come across.' He said, 'The wrong man was chosen for this job.'

Anyway, Maunder managed to survive, he kept his head down, he persevered, and what he did was to take over Carrington's work and the work of Warren De La Rue at Kew. He took daily photographs of the Sun, he monitored the sunspots, and he also kept a lookout for when there were magnetic storms on the compasses at Greenwich as well. Together with his wife, at an eclipse in the 1890s Annie Maunder took an image of the Sun which showed the most amazing streamers in the atmosphere.

The problems of trying to prove that sunspots could somehow give up magnetism that could hit the Earth was made much worse when Maxwell developed his theory of electromagnetism, and the concept of the force field was born into physics for the first time. This imagined that if the Sun was a magnet, then somehow it was surrounded by magnetism, and the biggest cataclysm you could imagine that could happen is for it to reverse polarity up and down. If you were to do that, if you do the calculations of how much magnetic energy that would release and radiate all through space, it was not anything like the quantity of magnetic influence that you were seeing on the magnetic storms. Thus went the reasoning from all the people that believed in the mathematics of Maxwell wholly: it proved that magnetic storms could not come from the Sun.

But after thirty years, Maunder knew that when you had sunspots, you were likely to get magnetic storms. When you looked at the data of when you had magnetic storms, and there appeared not to be any sunspots, if you just tracked back, the last time the Sun rotated round in your direction, there had been a sunspot there. So he was starting to think that sunspots were just a sort of visual manifestation of an overall magnetic blemish, that grew and then produced a sunspot, and as the sunspot died away, so the magnetism followed it at a later time and died away.

He said, 'Look at these big beams! What if magnetism could somehow be projected like a searchlight beam, or a big magnetic cannonball could be somehow thrown off the Sun and strike the Earth? Then you would be able to have enough energy, because you would not be radiating wastefully all the way across the universe.' Now remember, this is like saying you do not believe in gravity or something like that. He simply said, 'I know there's a theory, and I know it seems to work for a lot of applications, but I think there is more to find. I think this is a signpost that there is new physics that we do not understand,' and indeed, soon, in the twentieth Century, they discovered the Quantum Theory and the idea of particles carrying electricity and magnetism, and essentially proved Maunder's idea about the magnetic cannonballs.

Now, doubtlessly - I am going to get asked the question of whether sunspots cause global warming, so I best address it now.

The Victorians were principally interested in whether the sunspots could affect the temperature and the climate of the Earth because there was some reason to believe that the number of sunspots also seemed to coincide with good and bad years of harvests and things like that. That is one of the reasons they began to look into the Sun.

The modern view is that the Sun is not responsible for global warming, that manmade emissions are the driving force. If you look back, however, at the records, manmade emissions probably only rose to dominate the magnetic influence of the Sun on the Earth's climate within the last few decades. So up until around between 1970 and 1980 or so, the surface temperature of the Earth and the climate could very well have been driven by magnetic activity on the Sun. This raises an extremely interesting point: how much now is due to manmade emissions and how much is due to the Sun?

According to a number of lines of research, it would suggest that perhaps up to about a third of modern warming is still caused by the Sun. We know that the Sun is in a very unusually active time, magnetically active time, and although the pathways are not fully understood, about how this magnetism can affect the surface temperature of the Earth, there seems to be some evidence for it. The worry that I have in all of this, is that if we steadfastly refuse to believe that the Sun has even a small influence on global warming, if the magnetic activity of the Sun were to lapse, then it is possible that what we perceive as global warming could change, and it may even go down slightly. If we are not willing to believe that there could be a natural force involved here as well, then we play into the hands of the people that say, 'You do not understand global warming. We do not need pollution controls. We do not need to worry. Go away and understand global warming more before you bash us over the head with green taxes!'

So, on that depressing note, I shall leave you there!