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The Inconsistent Sun

Professor Claudio Vita-Finzi

Changes in the Sun's output can endanger health, power supplies and satellite systems. To prepare adequately for such events and to make judicious use of solar energy we need to investigate the Sun's 4.7 billion year history.

Why inconsistent?

Why should a ball of hot gas which uses up 7,000,000 tons of hydrogen a second be considered consistent? You might as well expect a souffle to rise evenly.

The widespread assumption that the Sun is reliable is a longstanding one which goes back to Aristotle and beyond. For him, and much later in Catholic teachings, the Sun was a perfect object. When in 1610 Harriot and Galileo showed it was spotty the myth was destroyed.

The spots (which are substantial objects 40,000 km across) came and went. But they did so every 11 years. So we had consistency again. In 1795 the astronomer John Herschel argued that the sunspot cycle governed the price of wheat, that is to say influenced the weather. (He also believed the sunspots were windows into a cool sun which was inhabited, the sort of idea that got Giordano Bruno burnt at the stake in 1600. Today you will get burnt academically if you suggest the Sun has anything to do with global warming.)

The sunspot cycle then turned out to vary from 9 to 15 years, so we had a rather approximate consistency. What is more, the spots showed Galileo that the sun rotated with a period of about 27 days and that the rate of rotation was faster at the equator than at the poles. Although this differential rotation eventually yielded an explanation for the spots (the Babcock model, in which lines of magnetic force are progressively tangled up) it totally undermined the notion of a homogeneous body.

Morerover evidence emerged for periods almost devoid of spots, the most famous being the Maunder Minimum of approximately 1645-1715. Others since emerged from the study of radiocarbon in tree rings including the Spörer Minimum (1450–1540) and the Dalton Minimum (1790–1820).

Fortunately the astronomers could focus on the solar constant – the amount of radiation received from the sun. Artificial satellites soon showed that it varies by 0.1 % over the 11-yr cycle, which was reassuring, but dedicated instruments then revealed that it varies by 200% or more in the UV range. And once the fusion model for generating the Sun's energy was accepted it became clear that, as hydrogen is 'burnt' to helium, the Sun gets hotter – so much for the solar constant – and will eventually run out of fuel.

Does this variability matter?

Consider the health angle. Too little Sun and we risk suffering from rickets through lack of vitamin D, essential for the absorption of calcium and phosphorus, which is manufactured in the skin by the action of UVB. Too much UVA and we risk cataracts, sunburn and skin cancer ; indeed a recent study suggests that if you are old your mind may deteriorate from exposure to UVB.

The story is equally complex when it comes to race. Many of us assume that dark skins represent adaptation to high UV levels by melanin. Recent studies which accept an African origin for humans is that the melanin shields the B vitamin folate, which is essential for DNA formation especially in the foetus. But as we moved polewards this benefit was outweighed by vitamin D deficiency and we had to become paler.

The solar wind – a stream of particles travelling at about 400 km/second – shields the Earth from lethal cosmic rays. When the Sun is weak the cosmic rays can penetrate more freely but fortunately our magnetic field also acts as a shield and we and we can safely enjoy the resulting auroral displays. In space, however, there is no such protection and astronauts are left exposed. What is more the Sun itself can unleash violent storms with high energy particles that can destroy satellites, penetrate spacecraft and endanger airline passengers and crew at high altitudes.

Similar uncertainties attend the exploitation of solar power. An area of solar panels with 20% efficiency measuring 600 km by 600 km in a sunny clime could supply the world's energy needs. But the requisite power lines would be exposed to the kind of surges induced by geomagnetic storms that destroyed the electricity network of Quebec in 1989 leaving 6M customers without power. The communication and GPS satellites on which we all depend can be destroyed by solar storms or brought down when their orbits are sabotaged by a change in atmospheric density caused by solar fluctuations.

What can we do about it

The essential is to understand the problems and prepare to counter them. Many of the health hazards are a matter of prejudice or ignorance. Increasingly we can avoid dangers to human in space, as airlines already do by rerouting their planes for the benefit of their aircrews. Monitoring the Sun and the atmosphere -- space weather forecasting – has made great progress thanks to dedicated satellites. The Solar and Heliospheric Observatory (SOHO) launched in 1995 was intended to have a life of 5 years and is still at work. Ulysses orbited the Sun over the poles for 19 yr. The Solar Dynamic Observatory (SDO), launched in 2010, sends downs 150 million bits of data per second 24 hrs a day. And whereas light from the Sun takes 8 minutes to reach us, most of the particles blasted towards us by solar flares travel at a mere 1000 km/s and take a day or two to hit us, so that we have time to prepare. But a few particles travel at close to the speed of light, and to guard against them we need scientific understanding. The Sun appears inconsistent only because we are ignorant.

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Thank you very much. This is an anniversary because, in 1639, Nathaniel Horrocks, regarded by many as the father of astronomy in England, wrote to Samuel Foster at Gresham College telling him to prepare to watch the transit of Venus. Unfortunately, the mail was not very good then and the letter got there too late, so that Foster missed it, but Horrocks observed it, and of course on the tenth of next month, we will be witnessing the transit of Venus and I hope you will all be there watching the unusual event unfold.

My theme today is that the Sun is inconsistent, or it appears inconsistent because we are ignorant. Whenever we think something has gone wrong, it is because we did not know enough, not an uncommon failing, but in the days of Galileo, early seventeenth century, you got into trouble for saying things like that because the Sun was regarded as perfect, and any blemish on it was in the eyes of the beholder, not in the Sun itself.

Galileo was one of the first to observe sunspots, and here we have a little modest movie showing what it was that alarmed Galileo's contemporaries, that these blemishes going across the face of the Sun, they must be planets passing in front of it, or perhaps clouds, but it took some convincing for the Church and scientists to realise that what they were, were holes, gravitational holes, magnetic holes, 30 or 40 thousand kilometres across, active, bubbling with energy, and changing constantly, as they cross the Sun.

This the beginning of the realisation that the Sun is not perfect, but immediately, as we all tend to do, scientists tried to impose some kind of order in this inconsistency and they realised that there was a periodicity about the sunspots, that they tended to increase in number and then fall in number every eleven years. So, order was restored: we have an eleven-year cycle. In fact, today, if you look at an elementary textbook of astronomy, that is the phrase, it is an eleven-year cycle, but the cycle varies from eight to fifteen years, so it is highly inconsistent. And that was another worry, because if you see the last ones, we do not know what is going to happen at 24 or 25 – it could be tiny, or it could disappear completely.

So our knowledge of this periodicity is highly incomplete and worrying because the thought is that, if the Sun's spots disappear, we will have what happened in the eighteenth century, which is a little Ice Age. The Sun was devoid of spots, its energy levels fell, and it was a disastrous period for agriculture and for humanity throughout the world.

The rotation of the Sun, which is depicted by the movement of the spots, even that is irregular. The equatorial zone moves faster than the polar zones, so what happens is that lines of magnetism get knotted up and twisted and then you get short-circuits, as indicated by those red marks there, and this is what produces solar storms. But also, it accounts for the fact that the spots are magnetic, and they have a north and south pole. So the Sun itself is subject to a variety of cycles, some of which we understand and some of which we do not.

In despair, looking for some consistency in the Sun, people looked at what they call the Solar Constant. The amount of energy coming from the Sun, surely this is the same all the time – it is shining? And then, only in the last 30 years have we had satellites orbiting the Earth, in a convenient position to observe the Sun, to realise the Solar Constant is not constant. It varied substantially.

These are – the different colours represent different satellites, but they are all showing the same thing: that there is quite a dip. So the eleven-year cycle is not just a lot of spots moving across the Sun, it is to do with the energy levels. So, again satellites came to our aid and they said, "No, it is only 0.1% of the energy that fluctuates during the eleven-year cycle – 0.1% is nothing".

But then if you look at the ultraviolet part of the solar spectrum, that changes by up to 400% and sometimes by 1000%, and the ultraviolet part of the solar spectrum is the part that makes us ill, that heats the stratosphere and produces climatic zonation. It is the crucial part of the solar spectrum, and that is the one that changes the most over the so-called regular eleven-year cycle.

Having said order has gone, we now have what some people call chaos, in the modern parlance of chaos, meaning it is some kind of order which is difficult to fathom, we then say: does it matter? Does it matter to us in the matter of health, or does it matter in a matter of economy, or in a matter of climate?

In the question of health, it really does matter a lot because uptake of Vitamin D is mediated mainly by solar ultraviolet, and the ultraviolet rays which act on our skin, then generate the vitamin, which is absorbed into our system and which avoids and pre-empts, rickets, other forms of bone weakness, and all sorts of other ailments. Some cancers are thought to be linked to a deficiency of Vitamin D.

And as you can see, in some cases, the cultural habit limits the amount of solar ultraviolet that an individual receives, and this is something which is beginning to cause anxiety in the Midlands of England and in many other parts of the world. In fact, one statistic I saw last week, which was that 50% of the population of the world has a Vitamin D deficiency. But certainly, we can see now that with the return of rickets, the scourge of Victorian England has now come back to the tenements and probably some of the more luxurious homes of areas where sunlight is in limited supply and any restriction on its uptake is injurious to health.

This is someone who is a victim of this phenomenon. Apparently, even children who have spent too much time in front of their computers are liable to this – do not go out, always indoors, fed by artificial light, and unable to benefit from sunshine, and have this crippling bone disease. Rickets has made a shock comeback, and this is 2010.

So there is something that we can guard against, and the point about the inconsistency of the Sun as regards health is that it is very difficult to get the balance right.

Cataract – if you have too much ultraviolet, all sorts of ailments come to the fore. Cataract is one of them, and cancer of the skin. This is a trooper who died of skin cancer after serving in Iraq in his last engagement. So, you can be fit and hale and hearty, but the Sun can get you. With skin cancer, we have seen some horrific disfigurements.

How much of the Sun can you tolerate? The line is fine. The Australians have probably gone too far the other way now – the slip-slap-slop, wear a hat, put on lots of lotion, wear a shirt, and do not expose yourself to the Sun at all. Rickets is making a comeback, even in the sunny continent of Australia.

It is a difficult thing to do, to judge the extent to which your children, as well as yourself, should be exposed to the Sun. Dermatologists who advised me on the book I was writing about this problem said that, if your child is burnt, not seriously, but burnt, painfully, at the age of under ten, three times, then the probability of getting some kind of cancer later in life was increased two-fold. So this lurks, the problem can lurk. It is not a matter of saying, "Oh, poor dear, you have got yourself burnt – it will be alright." You have already inflicted some potential damage on that individual.

There are all sorts of aspects of our ignorance that are constantly being corrected, and I think this is the positive message that I wish to convey: that although we are ignorant, we are getting better.

For example, for a long time, I suspect some of you, certainly I, used to think that dark-skinned people have adapted to ultraviolet rays by having more melanin in their skin, so it is a protective, it is a shield against excessive insulation. And then, some research being done in the United States in the last three or four years suggests that what is really the problem is that ultraviolet will destroy folate, which is a vitamin, which is essential for the development and survival of DNA, especially in the foetus. So, the argument there is that we came from Africa – that is the accepted view, certainly by most people – and there we had this protective colouration that protected not ourselves from skin cancer but our newborn, in fact the foetus, from developmental deficiencies, and then, as we moved into cooler, less sunny climates, we lost the colouration because the need for Vitamin D outweighed it. So there, again, you have this delicate balance between good and bad, and it is very difficult to get it right.

The question of health is something that is particularly topical when we talk about progress in monitoring the Sun by satellites because it is space travel, which has now been exposed to the greatest risk that has currently been encountered by humanity with regard to solar flares. Now, the Sun is a highly irregular omitter of energy. We have seen that the eleven-year cycle is itself subject to different degrees of fluctuation according to wavelength, and in addition to these fluctuations, there are these very short-term events called flares or solar storms. These may last a few seconds, but they release millions of tons of matter, which traverse the space between the Sun and the Earth, at speeds of up to 1,000km a second, probably more. Now, the advantage is that we can see the signal before the bad news arrives, because we see the signal from the light, which it takes eight minutes to reach us from the Sun, but the matter, the dangerous matter, the radiation, the particles, may take two days to reach us, so there is time to prepare for the emergency.

Even in the days of Apollo, early space travel – in fact, we had a conversation with the first man on the Moon and we asked him, "Were you warned about solar flares?" He said, "Oh yes, NASA knew about them, they did nothing about it, but they said, "Well, if one is on its way, just rotate the spaceship so that the fuel tank is between you and the Sun and that will give you some protection."" That is all that Armstrong was told about this event.

Of course, we have much more advanced warnings now, but the skin of the landers or the orbitals is unable to protect the individuals from a massive solar flare. These protons, these particles, travelling at very high velocity, with huge energies, can penetrate quite easily into the space cabin.

And if we are not worried about man travel, we are simply thinking about the instruments that we rely on for GPS, for telecommunications, for weather forecasting and so on, all those are liable to damage, serious damage, or destruction, because of these missiles from the Sun.

In fact, there are all sorts of new problems that we are learning about which are much more subtle than a bolt delivered from the Sun. As the Sun goes through its cycle, the amount of heat it is giving out is reduced or increased, so the atmosphere, the upper atmosphere, is either heated or cooled, and so spacecraft are faced by either greater drag or less drag, and so the orbits are changed by solar action, and in some cases, the spacecraft loses sufficient elevation to be totally destroyed. So we are faced by the understated risk that a lot of our space equipment could be destroyed or seriously damaged from one day to the next.

I now turn to the promise of solar energy, which many of us think is the right way to move. It has vast quantities being omitted and, although, in some cases, you have these elaborate sets of mirrors which focus the Sun's beams onto some kind of device at the top of the tower, the amount of solar energy that would be required to power the Earth, the present population of the Earth, close to three million, would be supplied by solar panels occupying these patches. Now, they are substantial. I think one patch could be 6km a side, and that would do it, but of course, we then have the problem of getting the energy to where it is needed, which is why, on this map, we have shown one for North Africa that would do the whole of North Africa, there you have Arabia and the Near East over there, and then you have Turkey and this part of Eurasia, and then we have Russia and its neighbours. So, it could be done, but who is going to do it?

On top of the problem of investment – and the investment is of course the primary cost because maintenance is very low on solar capture – there is the problem of transmission. You can imagine the power lines required for this little power station to power the whole of North Africa. The power lines not only are expensive and technically problematic, but they are exposed to a danger from the inconsistent Sun, which we have learnt about primarily in Canada. In 1989, the whole of Quebec province was plunged into darkness because a solar flare had induced a power surge on the power stations of that part of Canada, and that melted transformers, destroyed miles of wire, and completely shut six million consumers from power for a long time, and of course replacing transformers can take weeks or months or possibly years. Now, there are all sorts of trip switches that have been put in place, but they just cannot manage.

This is happening all the time, and if the Sun is facing towards us, we are in trouble. Fortunately, the Sun is rotating every 27 days and so it generally misses.

So that is millions of tons of matter, all temperatures of billions of degrees Kelvin, and it is constantly threatening us.

Now, the way forward to understand and pre-empt all those things, you need to understand what it is that is coming our way, and at the moment, we have 400 years of sunspot records, since Galileo and his friends started observing – that is 400 years. We have about 35 to 40 years of satellite observation. Some of the satellites now are extremely busy. The SDO, which went up in 2010, sends down 150 million bits of data every second, 24 hours a day. So the amount of information that we are getting since 2010 totally swamps anything we knew before. The satellite before that, Soho, which went up in 1995, with a predicted life of five years, it is still working, and it is sending out, but it is sending out a few thousand bits of data every day. So the multiplication of the data does, on the whole, mean that we understand better, because we can see events like that flare before they happen, as opposed to when they are on their way to Earth and we have got a couple of days to install some switches.

Now, 400 years and 30 years of satellite data. The Sun is about 4.6 billion years old – American billion, four point six thousand million, so we know a fraction, a tiny fraction, 0.0001% of the total history of the Sun, on the basis of data and observation. And so, we have to look elsewhere because how can you understand the history of anything when you only know a tiny proportion of the latter part of it? And so we look elsewhere for information, and the main clues that we have come across are enshrined in rather strange places. One of them is the meteorites.

The meteorites that land on Earth have been traversing the solar system. Some of them are as old as the Sun. They have within them small crystals of matter which were created at the beginning of the solar system, 4.6 billion years ago. So these meteorites have been sailing around and occasionally they land on Earth, and so they bring with them a history of the early days of the solar system. Some of them have been trailing around the solar system exposed to the cosmic rays and other effects in the solar system that leave tracks on the minerals, damage trails, so they tell us a history of the solar system while they were in transit. So, we have these two sources of data in meteorites.

Finding meteorites is a matter of chance. I think, recently, there was one where people were proudly holding up fragments, a few millimetres across. So, substantial meteorites, which are as old as the Sun and which contain this evidence are few, but they exist, and we are already beginning to get a history of flares. It is as if you had a history of battles. It is really rather like human history – we know a lot of battles, and we know very little about the common people. Here, we have a history of the Sun which is written in flares and explosions.

In addition to that, there is a lot of information to be had on the Moon. The men who walked on the Moon drilled into it, often with a simple corer and then, latterly, with an electric drill, down to three metres. That is several hundred thousand millions of years of the history of the solar system, written in the rocks, which have been accumulating on the Moon, so drilling into the Moon is a kind of archive of solar history and terrestrial history and of course lunar history too.

The Lunar Archive also contains a lot of information on flares because flares are flashy and they travel far and they leave a clear impression of what has been happening on the Sun, but they do, at the very least, tell us the extent to which the Sun has changed in its behaviour, and from that point of view, it has been consistent. The number of flares tends to increase as the sunspot ratio increases, and we seem to get the same kind of rhythm with a 200 year sunspot period that people have detected, and there is also a 1,500 year periodicity in sunspots, and the flares seem to echo that too. So it looks as if these flashy events in solar history are telling us that there is a uniformity in the events that have been taking place. The Sun therefore has left us some kind of information on its history.

In addition to threatening us, damaging minerals, for our scientific benefit, the Sun also protects us from cosmic rays. Cosmic rays are not rays. They were called cosmic rays because, at the time they were discovered, early in the twentieth century, people were looking for rays of various kinds, and the fact that there was this radiation coming from outer space, immediately evoked the idea of rays as in a cartoon. Cosmic rays come from outer space. Many of them, perhaps most of them, are remnants of supernovae that have exploded, and a supernova in explosion produces more energy in a few seconds than the Sun will have emitted, in the whole of its life. So they are tremendously powerful, and these cosmic rays are extremely dangerous to life and to us.

The Sun emanates, side by side with its violent behaviour, what is called a solar wind, which is not that calm because it travels at 400km a second, but relatively to the events that are happening out there, it is very peaceful, and solar wind protects us against cosmic rays. So we are bathed in this friendly kind of radiation that shelters us from cosmic rays. If the Sun is weak, as it is when the sunspots are few, then the cosmic rays can penetrate further. Fortunately, we are also protected by the Earth's magnetic field, so we are shielded.

But, the cosmic rays act on various minerals on Earth, carbon, produce carbon fourteen, varillion ten. They produce these elements, which are stored in ice-caps and ice-sheets, and in tree-rings, and there we have another archive telling us of solar history, but back to front – that is, what it tells us is when the Sun was weak or when it was strong, in the light of the damage produced by cosmic rays. So it is a reverse history of solar behaviour.

We then have 4.6 billion years of flare history, we have several million years of cosmic ray damage and minerals stored in ice-sheets, tree-rings, and so forth, and then we have the millennial fluctuations in sunspots. We know that when the sunspots were almost absent for a long period of time, we had the little Ice Age. So this is one reason why some solar scientists are besotted by sunspots, to the detriment of the rest of the science, because they think that the sunspot cycle will tell us when the next minimum will happen, and if a minimum of some decades long enough for the Sun's weakness to be manifested, the ice-sheets will swamp Northern Europe again and spread down from all the mountain ranges of the world.

The satellites are both warning us of what is going to happen, measuring what is happening, but also exposing themselves, with their solar panels, to damage by storms, particles and all the other things – and other satellites. Of course, collisions in space are now becoming quite commonplace because there is a crowd of wrecked and functioning craft orbiting the Earth and getting into each other's way.

The need is, therefore, to prepare both astronauts and spaceships and warn them in time. You see this individual here is highly exposed. A few protons from a solar proton event would kill him instantly, and there is no way in which he could wear sufficient protective clothing to get out of the way, so we have to know in advance, and so the satellites, like the SDO, which is sending masses of information down, will give us a lead. We now have spacecraft that are reading every second what is going on on the Sun, whereas, before, we could only read at separations of days or weeks.

So what can we do about it? Well, the need for more spacecraft, intelligent spacecraft, is something that, in a time of austerity, is not going to go down very well, but let me just mention a couple of success stories.

Ulysses, for example, was a spacecraft that went round the Sun over its poles. It took 19 years to perform its work. Now, it is quite an achievement because, before we could only see the Sun face-on, and so we now know what is going on at the poles, and that was something that NASA was able to push through the budget problems because the solar problem is becoming serious, especially for the spacecraft. So, in a way, creating your own problem, but at the same time, being able to combat it.

This is to show you how spacecraft are looking at the Sun in different wavelengths, in the same way as, when you wear dark glasses, you see different colours. So, we have different filters and showing different temperatures as a result. Not only are we able to watch things as they happen, but we can see what it is that is going on. It is not just a flare, but it is a flare which achieves temperatures of a million degrees, but parts of it produce these loops, and you see the cooler parts, the relatively cool parts, produce this loop, which probably represents two poles, a positive and negative pole, and an arc of magnetism shorting across.

You can also see that the Solar Dynamics Observatory, the one that went up in 2010, is able to observe all these events as they happen, all over the Sun, constantly. So if you ever feel like it and you want to go and watch this happening, type SDO in your Google, and you will get a movie, a NASA movie, showing some of these things happening. Expensive, but vital to our wellbeing.

Then there are all sorts of things you have heard about. Probably, some of you probably know more about than I do – the neutrino. The neutrino was named when there was something missing from an equation – must have been a small neutron, so an Italian called it the neutrino, this rather sweet name.

There are billions of neutrinos passing through us every second. They come from the Sun, mainly. Some come from outer space. And these neutrinos, being neutral, or almost entirely neutral in charge, do not react with matter, so they go through matter ignoring it completely.

The neutrinos were theorised, were hypothesised, but nobody could see them because there was no way of detecting them, so it remained a fiction until a man called Ray Davis thought that perhaps there were certain liquids where the neutrino might possibly interact with something and leave a trace. The first liquid that was tried was dry-cleaning fluid, so a huge tank of I think 80,000 gallons of dry-cleaning fluid, where the neutrinos penetrate through the Earth's crust, because the Earth's crust is trivial, into this deep mine, and produce a small number of reactions with chlorine which you can count them. You are talking about ten or twenty in a year, a minute number. There were too few. Despair – physicists tearing out their hair because they predicted it, they found it and it was wrong. The solution, which some of you may think is a great fiddle, but others may admire the ingenuity of the physicists, is that as the neutrinos travelled through space towards the detector, the dry-cleaning fluid, they changed character, so some of them are consistent with what we expected and some are not. So different detectors have been put up, using Gallium in Italy, and Super-Kamiokande in Japan, using very, very pure water, and so these different detectors are identifying the missing neutrinos. Now, you may think this is all a bit of a nonsense, that the physicists are indulging their whims at enormous expense and then fiddling the results. It is very important because the neutrino is a demonstration of what is happening in the Sun. It is as if you were witnessing the furnace in the Sun, where hydrogen is being converted to helium, at a rate which I wrote down because it is so enormous I always forget: seven million tons of hydrogen a second are being consumed to produce helium, which occupies the smaller mass, so the energy, the excess mass becomes energy. We can see this happening now because of the neutrino flux. So that is one way in which we can amplify our images - we can understand our images of the Sun and its surface manifestations by seeing the core of the Sun.

The second main source of information that has come about in the last few years is called helioseismology, like seismology, like earthquake research on Earth, but looking at sound waves in the Sun. It was discovered some years ago, just looking at the Sun through a reflecting telescope – obviously never directly – that there are little waves, oscillations, in the Sun, of five second frequencies, and so that led to the idea that perhaps these represented something that is going on in the Sun, some kind of oscillation. This helio-seismology now allows us to see how much hydrogen is left, where the depth of mixing is taking place, where the core is.

We now have two new windows into the Sun to complement what the satellites are telling us. Of course, there are trillions of suns, most of them with planets, and individuals on them. If you remember that, in 1795, Herschel, the astronomer, who was very concerned to understand sunspots, he believed sunspots were windows into a cooler Sun, which was inhabited, so where the cool air is – he was right about that – looking down onto the surface of the Sun, which was cooler and populated by solar individuals.

It is probable that many of these suns have planets around them, and, for us, they have the additional benefit that they have different ages. Some of them are young suns, like our Sun, 4.7 billion years ago. Some of them are suns, which are about to conk out, turning into red giants, because they have run out of fuel. By looking at parallel suns, the astronomers can tell us the likely fate of our Sun. We are not talking about four billion years ahead; we are talking about the near future, because the way the Sun is fuelling itself is reflected in these earthquakes. These are sonar-waves, some of the thousands of different waves that are produced by sound within the Sun.

The lifecycle of the Sun, which we will read from our own history, the history of other stars, is something like that. We are here, halfway, and then it will become a red giant, and then it will disappear into a cloud of debris. So there is plenty of time to understand it and to move to another solar system when time is running out.

The meteorites are very unprepossessing. This meteorite has it flare history going back two billion years. Some of the events that we are witnessing in historical times, or in prehistoric times certainly, have something to do with our position in the galaxy. Astronomy suddenly becomes part of human history because, as the Sun rotates, it rotates around a centre of gravity in the solar system – it is not the centre of gravity in the solar system, but there is a centre of gravity, to which it has to pay homage. As it rotates, it passes through different parts of the nebula, so passes through clouds of debris which may be responsible for the Ice Ages and may be responsible for some of the interference that you get on your radio.

This is T-Tauri. Tauri is a set of stars, which are thought to represent the young Sun, so we can actually see, a long way away but visible optically, what our early Sun looked like.

In the Ice Ages, then, it could well be astronomically mediated, that as the Sun changed its output, either directly or by passing through clouds of muck, we had a glacial period.

We have these many waves on which are super-imposed. Long-term averages here are shown, and we have the present day, which is causing much anxiety, but once you look at this sort of thing, you realise that we are doomed to having events of great seriousness thrust upon us.

These are some of the minima I was telling you about. The maunder is the big one. There was a Dalton. We are now at a maximum. Is it all humanly produced? Is some of it due to the Sun? I suspect it is a bit of both. We cannot do much about the Sun, but we certainly should know about it. So we have these – the Medieval Maximum, warm, wine growing in Hampstead Heath…the good old days! And then, followed by these freezing periods, glaciers wiping out ski lodges…

We have the message really of today, apart from the optimistic one that we have got to find out what is going on, what we can, is that we have all sorts of cyclicities superimposed on each other. We have the long-term solar decay – it is getting hotter, but it is running out of fuel. On top of that, we have the flares and other meteoritic, signs of meteoritic change. Then we have the effects produced by moving through the nebula, which may be leading to climatic disasters. And then we have the eleven-year cycle, the 22-year cycle, the 200-year cycle, the 1,500-year cycle, that sunspot experts have identified.