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SPACE

Vanishing sunspots

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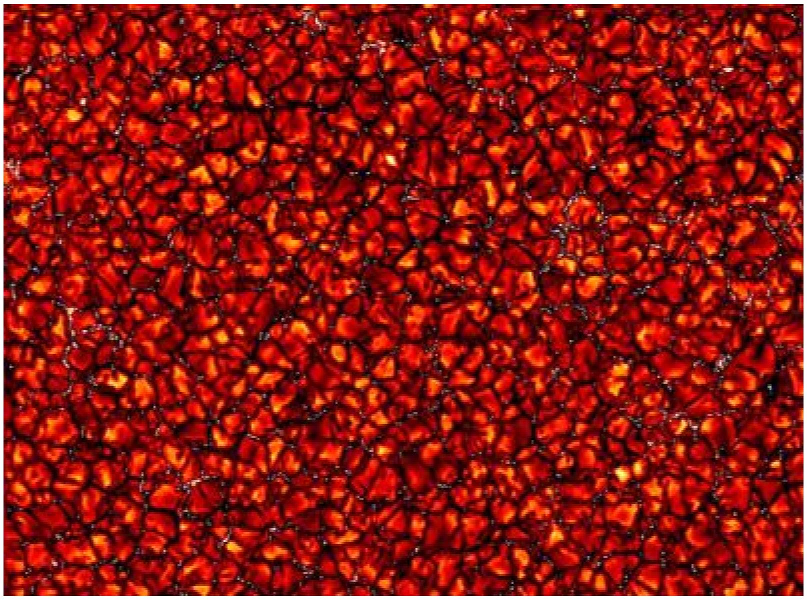
A solar storm brings hope to scientists who were worried about the lack of sunspots and the consequences of this for the earth.

PICTURES: BY SPECIAL ARRANGEMENT



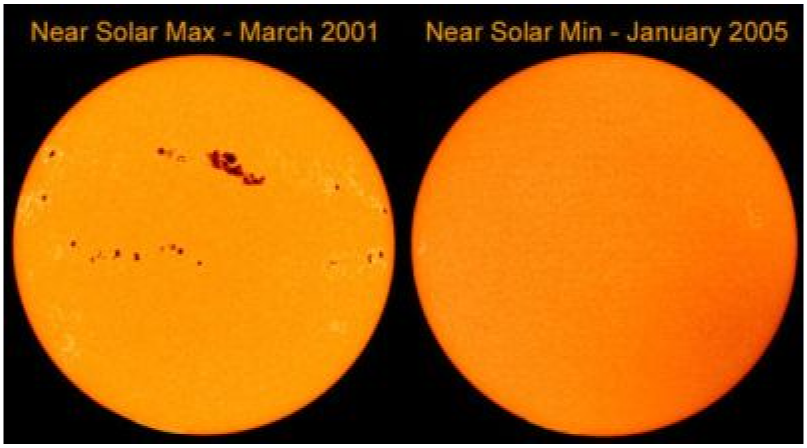
Granules on the surface of the sun. Gas in these 'grains' is constantly rising and falling.

THE sun finally appears to be coming out of a long slumber. A huge storm was reported to have erupted on the surface of the sun in the first week of August. The storm threw out a large amount of solar gas in a spectacular display. Some parts of this gurgled gas came hurtling towards the earth and, within a couple of days, began to whip the atmosphere. People saw aurora even at low latitudes, far away from the poles, where one does not normally get to witness such display of colours.

And along with the fierce storms, a few large spots emerged on the solar surface. This onset of sunspot activity on the sun's surface after it remained almost spotless for a prolonged period was greeted with relief by scientists. They had been worrying about the phenomenon of vanishing sunspots for the last couple of years.

Then there were rumours that the immaculate sun probably had something to do with the unusual winter of 2009. Perhaps, the lack of spots had caused in some yet unknown way a heavy winter on the earth. Perhaps, blemishes are not bad omens after all, at least for the sun and the earth.

But why worry at all about some random spots on the sun? Are they manifestations of some random events inside the sun or do they carry some information at all?



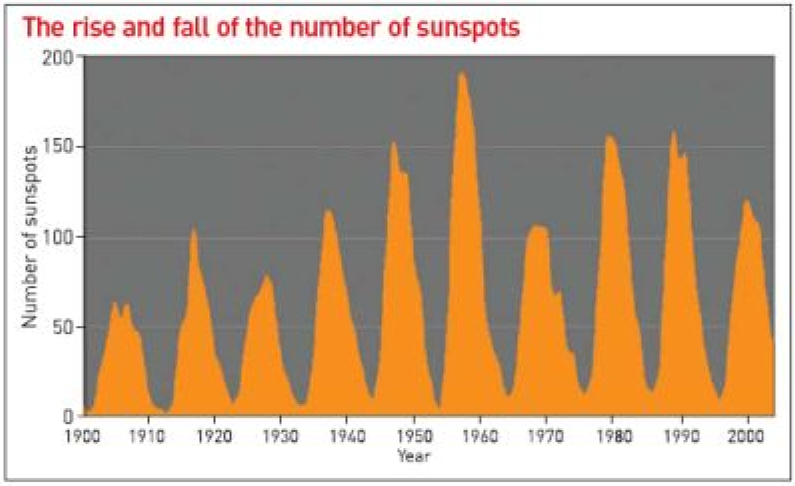
THE FACE OF the sun during its maximum and minimum activity. The face on the right is near-spotless.

The sun is a ball of hot gas whose central temperature, about 15 million degrees Celsius, is enough to trigger nuclear fusion reactions. The density of the gas there is also rather high, about 10 times that of lead. This dense and hot gas provides the perfect setting for a fusion reaction involving the nuclei of four hydrogen atoms. The nucleus of a hydrogen atom, the simplest of all atoms, contains a lone proton, a positively charged particle. When four protons combine, one after another, they create the nucleus of a helium atom with two protons and two neutrons. This helium nucleus weighs a trifle less than the combined weight of four protons, which implies that the reaction has removed a certain fraction of mass from its constituent elements. This extra mass appears as energy, or light in this case, courtesy Einstein's equation ($E=mc^2$), which says that mass is equivalent to energy.

The sun is, therefore, constantly turning a bit of its mass into energy, and this energy comes out of the sun as light. Initially, near the core, this radiation is in the form of intense gamma rays, which pack more energy than X-rays or ultraviolet radiation. Slowly the photons advance outward, amidst the crowding of the constituent material of the sun, colliding with them often and losing their energy during the process. The photons travel inside the sun almost like a drunkard tottering out of a pub late at night. When the radiation finally emerges out of the surface of the sun after a few hundred thousand years, it is rather enfeebled, a mundane yellow light in the visible part of the spectrum, its energy much short of its original strength.

But something extraordinary happens when this radiation reaches the bottom of the outer layers of the sun. There are three ways in which heat can be transported from one place to another. One way is conduction, which is the reason a metallic vessel kept on a stove feels hot on the outside. The atoms of the vessel material interact with their neighbours and conduct heat from one spot to another. Another way is radiation, when atoms at one place radiate photons that travel to a different place and thereby transport the heat. The third way is convection.

An example of this is – when one place on the earth becomes hot the air above it rises up and creates a region of low air pressure. Then air from the neighbouring places rushes in to this place and causes a storm. In this case, the rising parcel of gas takes heat from the bottom layer of the atmosphere and delivers it to the top layers by moving itself in bulk.



The transport of heat from the inner to outer regions of the sun involves all these processes. Just outside the core, conduction and a bit of radiation help transport the heat outward. The gas in these regions is very hot, although somewhat cooler than the core temperature, and electrons are not attached to any atoms – they move about freely. These free electrons absorb the photons from the core and radiate them again and in the process pass on the energy to their neighbour. The electrons do not completely absorb the photons but regurgitate them out after a while. So the photons keep bumping into electrons, get re-radiated by them and slowly advance outward.

The temperature drops drastically near the outer surface. The temperature of the outer skin of the sun is about 6,000 degrees Celsius. At these relatively low temperatures, atoms can capture electrons. The interaction of light with these captured electrons is very different from that with free electrons. In some cases, these atomic electrons absorb the radiation, which makes the gas in the outer layer of the sun hot and, therefore, it begins to rise upward, just as it happens at a place of low pressure on the earth. This causes the gas from the nearby regions to rush in. So the gas in the outer layer of the sun keeps rising and falling in a cycle. Like water in a fountain going up and then falling back, gas in this region is constantly recycled, and in this process the inner heat is transported to the outer layer.

This up-and-down motion is readily observed on the sun. Observation through a telescope shows that the surface of the sun is covered with grain-like features that seem to vanish and reappear constantly. By tracking the movement of gas in these granular regions, one finds that the grains are actually cells, localised fountains, in which the gas keeps bouncing up and down. These stormy grains, however, do not completely cover the surface of the sun. There are patches on its surface where this current of rising and falling of the gas is inhibited. These regions harbour a different type of energy – other than the inherent energy of the hot gas – that blocks the normal movement of the gas there. The gas fails to rise upward in these regions and, therefore, cannot transport the heat to the very outer layer. The surface in these parts appears cooler than the surrounding regions and, therefore, less bright. They appear rather dark and black compared with the other luminous parts of the disc of the sun.

ULTRAVIOLET IMAGES TAKEN by instruments aboard a satellite named TRACE show the radiation from electrons around the magnetic field lines above the surface of the sun.

The mysterious, dark force that lies beneath these patches is magnetic in nature. An abundance of magnetic energy in these parts causes them to appear as sunspots. What causes the magnetic field in the first place?

The twin forces of electricity and magnetism are intimately connected. Whenever there is a change in the electric current at a place, magnetic energy is bound to pop up there. And one can create an electric current in a wire by moving a magnet near it. In a simple bicycle dynamo, one can produce electric current by tagging a magnet to the rotating wheel of a bicycle.

MAGNETIC ACTIVITY

The gas inside the bowel of the sun is hot and at these temperatures atoms cannot hold on to their lightweight electrons. Heat causes the particles of matter to move around: the hotter a gas, the faster its particles move around, aimlessly as it were. Consider an atom moving around chaotically in a hot gas, carrying its heavy nucleus and its lightweight electrons. The nucleus and the electrons are usually bound by mutual electrical attraction. But when atoms are being constantly hit by other atoms, this attractive force has to compete with the destructive effects of the collisions. These atoms tend to lose their electrons when the temperature of the gas rises beyond a certain point.

The gas in this state consists mostly of charged particles such as protons and electrons. And what is electric current if not the movement of charged particles? Movement of this hot and charged gas causes electrical current and, therefore, gives rise to magnetism in the gas. This magnetic force is hardly a constant feature, unlike in the case of a bar magnet, because of the constant movement of the gas. Its strength and direction are changing all the time, and from place to place. Wherever it is strong in the outer layer of the sun, it blocks the gas from rising up. The gas in these parts fails to deliver the heat to the top layer and these parts show up as spots on the sun's surface.

Sunspots are, therefore, related to magnetic activity inside the sun. It is no wonder then that sunspots always come in pairs, as though they were the opposite poles of a magnet. In a bar magnet one cannot separate its north and south poles even if one breaks the magnet into two – they always appear together. The two sunspots in a pair have opposite magnetic polarity, and there is a magnetic field between them. It is not a figment of imagination of a theorist anymore. There are direct and visual evidences for this. When we sprinkle iron filings around a magnet, they arrange themselves according to the lines of the invisible force – their alignment helps one to visualise these lines of force. The magnetic lines of force around sunspots are also made apparent in a dramatic fashion by the electrons in the solar gas.

Charged particles such as electrons tend to spiral around magnetic lines of force, like beads on a wire. As they spin around it, they radiate photons whose energy depends on the electron's energy. For the energetic electrons, which are whipped up in storms on the sun's surface, these photons show up as ultraviolet light. Images of the sun's surface taken recently by ultraviolet telescopes have detected these emissions. This radiation traces the movement of the energetic electrons near sunspots, and they clearly delineate the magnetic lines of force in those regions.

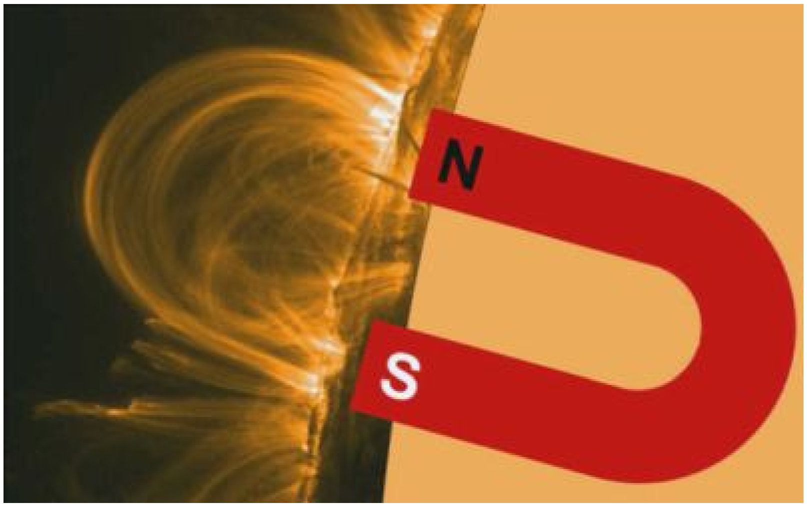
This magnetic field that shows up on the surface is produced deep underneath the surface of the sun, below the layer where the gas constantly moves up and down. This force is then carried upward by the movement of the gas, and when it reaches the surface, it wells up and beats the gas into a frenzy.

AURORAS

At times this welling up of the gas is so energetic that the sun's gravity cannot hold on to it – the gas is thrown out of the sun at a dizzying speed. This outflow of gas, called “solar wind”, consists of highly energetic charged particles and they are hurled into space like bullets from a machinegun. A part of this wind naturally hits the earth's atmosphere. The magnetic field lines around the earth are concentrated near the magnetic poles (which are near the geographic poles).

As the charged particles spiral down the magnetic lines of the force near the earth – again like beads on a wire – they are mostly guided down the north and south polar regions. The solar particles collide with the air molecules there and excite them into energetic states, making the air molecules fluoresce and glow. This is what is called aurora. When the magnetic activity in the sun increases and causes intense solar storms, often accompanied by an increase in the number of sunspots, the auroras on the earth also become particularly bright and frequent.

One of the biggest such storms in recent times appeared in September 1859. A day later, the dawn sky began to glow in brilliant colours even as far down south as the Bahamas in a spectacular display of aurora. An observatory in Colaba, Mumbai, also recorded unusual magnetic activity; the strength of the field there had plunged abnormally. There have been huge solar storms in 1921 and 1960, and they were also accompanied by the display of aurora at the low latitudes, as in 1859.



The diagram shows the magnetic polarity of these field lines and an analogy to the poles of a horseshoe magnet.

The solar wind particles can have other, and rather destructive, effects too. When sheets of such wind particles arrive on the earth in great numbers, they can alter the magnetic field around the earth in a significant way, what is known as a “geomagnetic storm”. They also affect the electrical circuits on satellites orbiting the earth by short-circuiting them, with disastrous consequences for telecommunication. At times, these particles cause failures of electrical power grids in places near the poles – there have been instances of power failures being caused by storms on the sun after a few days' lag.

Solar storms may not always be a bad omen though. The brightness of the sun decreases by a small amount when it goes through a lull in its magnetic activity. Although the change is very small – about a 10th of a per cent – it can have a palpable effect on the earth's atmosphere. The very outer layers of the atmosphere cool down a bit and the atmosphere contracts to some extent. This increases the density of air in those parts, and satellites orbiting at these heights feel an enhanced drag, which effectively pulls them down.

Some scientists have even speculated that particles in the solar wind may have other effects in the lower atmosphere as well. They might catalyse the formation of aerosol particles, which, in turn, may help seed clouds. These are still hypothetical ideas and the connections with solar activity, if any, are not yet clear. An ongoing experiment called CLOUD (Cosmics Leaving Outdoor Droplets) at the European Organisation for Nuclear Research (CERN), the particle physics laboratory in Geneva, is examining the possible effects of energetic particles on the earth's atmosphere, and preliminary results have shown that there may be some connections after all.

WELL-DEFINED LAW

Naturally, the sunspots, along with their variations and peculiarities, have been the focus of astronomers in recent times. The most interesting thing about sunspots is that they do not vary in a random manner. There appears to be a well-defined law that dictates the rise and fall in the number of sunspots and their places of occurrence. Their number varies (a period of about 11 years) in such a way that an epoch of maximum activity (implying a large number of sunspots and fierce solar storms) is followed by another such epoch after 11 years. There is a period of lull, or minimum activity, halfway between two solar maxima. For example, in April 2000, the number of sunspots stood at a peak, with about 120 spots on average. Before that, the number averaged to about 10 in the middle of 1996. Even earlier, in September 1989, the numbers stood again at a peak of about 150 on average.

This interesting law was discovered by astronomers after tracking the rise and fall of sunspot numbers over two centuries. There have been memorable exceptions to this apparently well-defined rule. There was a prolonged period of low activity in the 17th century, roughly between 1645 and 1715. For almost half a century the sun appeared almost unblemished. Interestingly, this period also coincided with one of the coldest periods in the history of Europe and North America, known as the Little Ice Age, when the river Rhine had frozen. Such exceptions have never occurred in the last 200 years, although the period of minimum activity in 1913 was rather protracted.

The recent observations of the spotless sun had naturally caused concern among the scientists. It was not clear if the sun was heading towards another long period of lethargy. Initially, the solar cycle had begun in a normal way; the number of sunspots had begun to decline after the fireworks of 2001, which was a period of maximum activity. But soon there were reports that there was something wrong with the cycle.

The sun remained almost without spots during 2008. Even in 2009, it remained mostly without spots, whereas there should have been ample sunspots then, rising to about a 100 odd spots on average by the middle of 2010. Incidentally, the unusual low level of activity hampered the working of X-ray spectrometer C1XS aboard Chandrayaan-1. It was designed to analyse X-rays from the sun scattered by lunar material, but the rather low X-ray output of the sun in 2009 made this task difficult, although the scientists did manage to gather some data.

This unusual deviation led to astronomers focussing attention on the actual reason behind the solar cycle. Why is there a cycle at all? In fact, it is not just the number but also the location of the sunspots that vary periodically. During the minimum activity period, most sunspots, if any, appear away from the equator, and then they spread towards the equator as the activity ramps up towards the maximum, during which sunspots may appear close to the equator.

DIFFERENTIAL ROTATION

Scientists think that the answer to these cycles lies deep beneath the surface of the sun, where the gas rises upwards as a result of convection. The main driving force behind the cycle is the peculiar way the sun rotates around its own axis. The sun does rotate, just like the earth, but the speed of rotation is not equal at all latitudes: the gas near the polar regions of the sun rotates much slower than the gas near its equator. This differential rotation causes the magnetic lines of force inside to be stretched and pulled in different directions. In a span of 11 years, the magnetic lines, which act much like rubber bands, are wrapped around the sun many times because of its rotation. The differential rotation causes theses lines to be twisted and folded into bundles, and they occasionally poke through the surface of the sun, causing sunspots.

It is possible that something has happened deep inside the sun causing the passive state to be prolonged. Astronomers are still debating about the physics of this odd event. They had discovered, in 1980, a “jet stream” that originates near the poles and pushes towards the equator, lying deep below the surface. It has been observed that magnetic flux tubes begin to rise up in earnest when this “jet stream” reaches a critical latitude near the equator so all depends on how fast it migrates from the polar region to the equator. This time around the “jet stream” appears to be moving rather slowly, giving rise to the slow recovery of the sun, but why it is doing so is anyone's guess at this moment.

Scientists are now eagerly waiting to see how the solar activity will proceed in the next few years. There have been a few contrasting predictions about how sunspot activity may ramp up to its maximum. A group of Indian and Chinese scientists, led by Arnab Rai Choudhuri of the Indian Institute of Science, Bangalore, have predicted that the next maximum will not be as spectacular as the earlier one, which means a smaller number of sunspots on average. David Hathaway of the Marshal Space Flight Centre, National Aeronautics and Space Administration (NASA), Huntsville, has also made a similar prediction. On the contrary, another group based at the National Centre for Atmospheric Research, with Peter Gillman and Mousumi Dikpati (who had earlier studied under Prof Arnab Rai Choudhuri), has predicted more fireworks during the next solar maximum. Their predictions are different because their assumptions for the interaction of gas and magnetic fields have subtle differences, the details of which are still unknown.

The observations of the next few years will be crucial to our understanding of the sun. Will the sunspot activity ramp up steadily or will there be hiccups? Will the solar maximum be more spectacular, or less, than the earlier ones? Clearly, the sun is not as uninteresting a star as it is often made out to be. There is more to the sun than what appears on its surface.

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