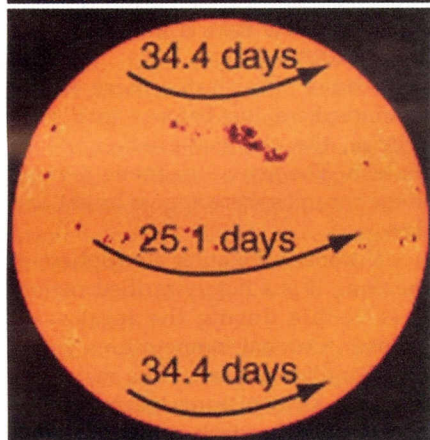


Prominence eruption with a flare observed on 8 September 2010

# Dangerous Face of the Sun

**Are we going to be roasted alive by killer solar storms that may arrive during the next solar maximum in 2012? Why and how do these solar flares occur and how do they affect the earth? Read on to find out.**



Sun in white light shows the presence of 'sunspots' (top)  
Differential rotation of the Sun (above)

**A**LTHOUGH the Sun is only an average star among 100 billions stars in our galaxy, its close proximity to the Earth helps us in studying the Sun in great detail. But the more we study it the more questions crop up in our minds.

First, how is the outer atmosphere of the Sun heated to million degrees compared to the surface temperature of 6000 K? Since heat can't run from cooler to upper regions, something other than heat and light from the surface may be responsible for the high temperature in the outer atmosphere.

Next, we wonder about the continuous flow of solar wind at speeds as high as 600 miles per second. This gusty wind produces auroras and geomagnetic storms, events in which

the Earth's magnetic field takes a terrific buffeting. But how are these solar winds accelerated to such high speeds?

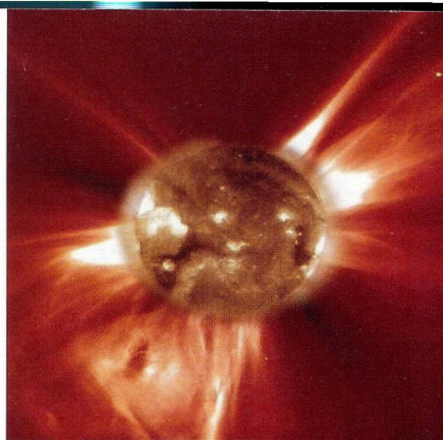
Then there are the solar flares, associated with the magnetic activity, producing deadly ultraviolet light, X-rays and solar cosmic rays. A medium sized flare can release the energy equivalent of a billion megatons of TNT in a few minutes. Solar astronomers are trying to understand the energy storing mechanism involved in such events. It is also interesting to find out how this energy is suddenly released.

The next curious phenomenon is that of the coronal mass ejections (CME) that occur almost every day from the outer solar atmosphere. We still have fuzzy ideas on how such a huge amount of mass made up of electrified gas is expelled from the Sun.

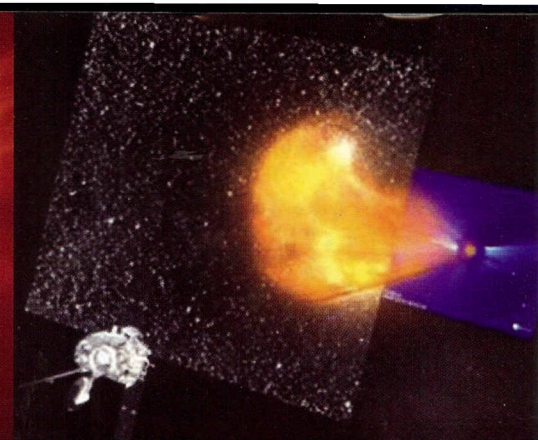
This aspect of study that tries to look into the Sun's dangerous face is



X-ray Sun by 'YOHKOH', a Japanese spacecraft. The bright and dark regions are the active regions observed in the corona



Coronal Mass Ejection



Artist's impression of a CME reaching the Earth

*What is going to happen in 2012? Is the Earth really nearing its end due to a severe solar storm that could cause devastation in 2012 as predicted by doomsayers and propagated by news channels?*

**Well, compared to the previous solar cycles, the sunspot activity during this cycle has not picked up rapidly.**

called 'space weather'. It becomes important to study and probe this aspect of the Sun in order to avert the huge damages that we on Earth may have to face during the course of such events.

### Solar Structure

The internal metabolism of the Sun is not just a passive lump of gas. The interior is made of a hard core functioning as a nuclear furnace. A misty radiation zone envelops the core and the energy produced in the core is slowly oozed or diffused out to the next layer of convection zone. The convection zone works as a powerful generator (Bray and Loughhead 1964) producing magnetic activity.

The atmosphere of the Sun is divided into three regions—

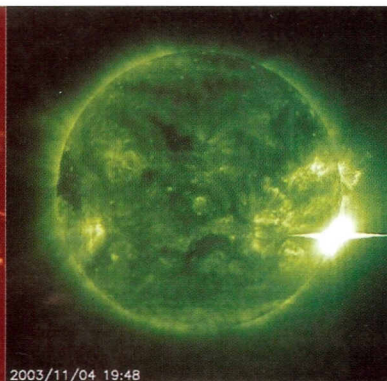
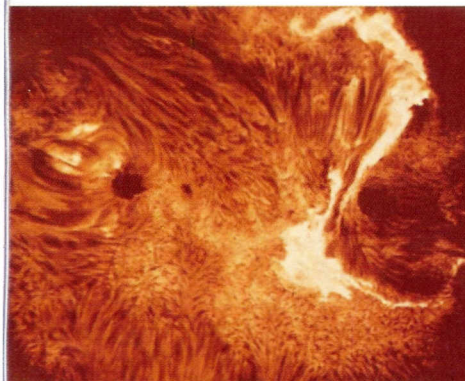
photosphere, chromosphere and corona. When the image of the Sun is projected on a screen, we can observe the photosphere and the surface features. Watching the Sun through the naked eye is harmful and may permanently damage the eyesight.

White light image of the Sun shows the presence of dark sunspots. Sunspots are the strong magnetic field regions observed in the photosphere. These are cooler compared to the surrounding regions and so appear darker. The strong magnetic fields of a sunspot exert pressure on the gas trapped beneath the sunspot and prevent the gas from reaching the surface. Therefore the material density in the sunspot becomes low, causing lesser temperature. A sunspot may be 30 times the size of the Earth.

Sunspot numbers wax and wane rhythmically every 11 years. This is called the 'Solar Cycle'. Sun, unlike the Earth has a differential self-rotation. This differential rotation coupled with the convection is thought to be responsible for the formation of sunspots. The Sun is currently in its 24<sup>th</sup> solar cycle that is likely to peak during 2012.

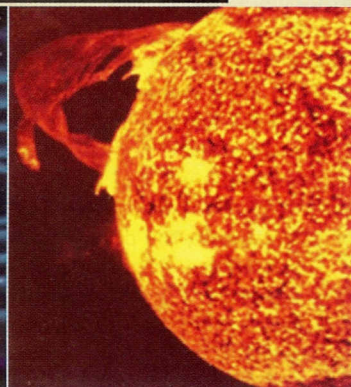
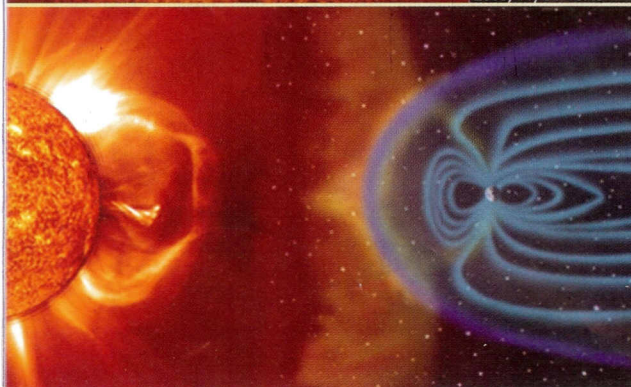
Above the photosphere is the chromosphere. Just before a total solar eclipse, the chromosphere appears pinkish. The active magnetic regions in the chromosphere appear bright and dark.

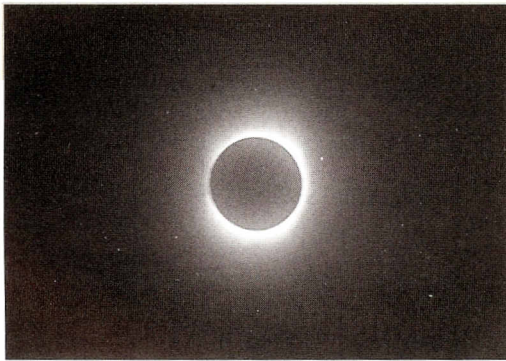
Corona is the outer atmosphere of the Sun. It is a highly rarified region. It is visible during the total solar eclipse. Coronal temperatures go up to 1-5 million degrees thus making it visible in X-ray pictures taken from the space lab. The dark region is called 'Coronal Hole' from where the solar wind originates.



Solar Flares. The right side image in green is by spacecraft SOHO.

Space Weather (below left) Prominence (below)





*Solar corona during total eclipse observed from China on 22 July 2009*

## Stormy Flares

Solar flares are also called 'Solar Storms'. They are explosions in magnetized plasma. These explosions push light of all wavelengths in every direction. In a matter of just few minutes, an active region in the solar atmosphere is heated to many million degrees and sudden outburst of energy as high as  $10^{32}$  ergs/s is released. They are always associated with one or more active regions on the Sun. They generally occur above sunspots.

Solar flares form 15,000 miles from the surface of the Sun. Common to all the flares is the heating of parts of the outer atmosphere of the Sun. Sometimes the flare is so powerful that the storm accelerates particles like electrons and protons to tremendous energies. Most powerful storms produce proton particle events. These particles are released like bullets with tremendous energies.

The primary condition for a flare to occur is the presence of one or more active regions on the Sun. Within an active region too flares do not occur at random locations, but invariably are related to boundaries between positive and negative magnetic fields. These boundaries are often referred to as 'neutral lines'. Flares derive their power from the magnetic fields of the active region because other energy sources are totally inadequate in those regions. These active regions are deeply anchored in the photosphere or even below and so the flare triggering mechanism may start from these places on the Sun though flare is a coronal phenomenon.

The magnetic stress gradually stores energy in the active region. The accumulated stress develops twisted magnetic field structures irrespective of the size of the active region. Once the magnetic twist exceeds a threshold

limit, the magnetic field in the active regions gets uncoiled releasing energy in the form of a flare.

## Coronal Mass Ejections

Large coronal loop-shaped eruptions having diameter more than 2 solar radii moving away from the Sun were discovered in the early 1970s from the 'Skylab' coronagraph observations. Because these events are often associated with flares, they are thought to be the consequences of the solar flares. The Skylab results show that CMEs are eruptions of coronal material flowing with very high-speed solar wind causing geomagnetic effects.

CMEs involve transport of mass as high as 200 million tons of plasma per second at speeds ranging up to 600 miles per second. They comprise roughly one tenth of coronal material and tremendous energies of the order of  $10^{32}$  ergs/s may be liberated. A flare eventually produces mostly thermal energy, whereas CMEs are bulk motions in the form of kinetic energy. They produce a magnetic shockwave that extends billions of miles out into space. A magnetic shockwave from Earth-directed CME could cause the alignment of the Earth's magnetic field to shift unpredictably.

The frequency of occurrence of the CME is at least one event on a day during the period of solar minimum and 6 events during solar maximum. They are mostly associated with flares and prominence eruptions. CMEs aimed towards the Earth are called 'halo events' because of the way they look in coronagraph images. As the expanding cloud of an Earth-directed CME looms larger and larger, it appears to envelop the Sun, forming a halo around it.

## Past Solar Events

Solar flares are known to disrupt ground communication, cell phone activity, power grids, air travel and satellite activity. Places in high latitude belts like USA and Canada are highly vulnerable to solar flares and coronal mass ejections. The high power grids that transmit power could attract currents from these highly ionized plasma, which in turn could ruin transformers. As power is needed for sewage treatment, running water and many other life-supporting infrastructures, the loss of power for days or weeks could be deadly for life on Earth.

A number of such turbulent events have been recorded in the past.

One of the greatest solar storms, called 'Carrington Event', occurred in 1859, causing a major fire in USA and Europe by short-circuiting the telegraph wires.

A huge solar flare on 4 August 1972 knocked out long-distance telephone communication across Illinois. AT&T, the largest telephone provider in USA, had to redesign its power system for transatlantic cables.

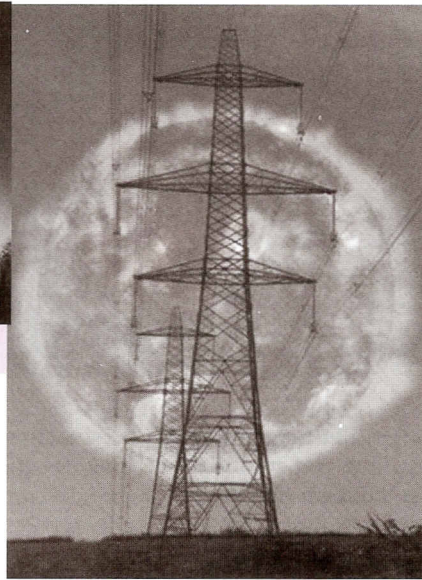
A similar flare occurred on 13 March 1989 disrupting hydroelectric power transmission from Quebec, Canada and millions of people were left without power for nine hours. Aurora-induced power surges even melted power transformers in New Jersey.

A prominence extending over 200,000 miles, about 28 times the diameter of the Earth erupted during 1997 associated with both a solar flare and CME causing colourful auroral lights.

On 13 July 2000, an intense solar storm nicknamed 'Bastille Day Event' caused energetic proton shower disrupting satellite functions. A G5 geomagnetic storm raged for nearly nine hours after the solar shower's impact. G5 is the most intense level. Cameras and star-tracking navigation devices on several satellites were flooded with solar particles. Satellite functions were degraded and temporarily shut down. On the ground, aurora lights were seen as far south as El Paso, Texas. Power companies suffered geo-magnetically induced currents that tripped capacitors in the transformers. Global Positioning System (GPS) accuracy was



Aurora (top), Solar events could impact power grids (right)



High altitude polar flights and persons on board may also be affected. Astronauts in space will also be exposed to high dose of radiation and energetic particles.

degraded for several hours. The flare coincided with a CME from the Sun, releasing billions of tons of plasma into space traveling at 4 million miles per hour.

In 2003, a massive solar flare hobbled over the Japanese Advanced Satellite for Cosmology and Astrophysics (ASCA) making it tumble in orbit.

One of the largest solar flares reported in 2006 created a complete blackout of high-frequency communications on the side of Earth facing the Sun causing disruption in satellite TV reception and GPS activities in the entire USA.

### Devastating Effects

When energetic phenomena like powerful solar flares or CMEs are directed towards the Earth, the radiation takes slightly more than eight minutes to reach the Earth whereas the particle events may take 3-4 days. The Earth's magnetic field provides protection through its invisible layer. Though it is relatively weak, the extrapolation of this magnetic field around the volume of the Earth provides a bubble shaped shield deflecting the charged particles. Thus cosmic solar electrons and ions are driven away from the most heavily inhabited areas of the Earth's surface in spite of the influx of particles toward the magnetic poles getting enhanced.

But the topology of the magnetic field is such that high-energy particles can be trapped in belts circling the globe, with major consequences for the

orbiting spacecraft. Also when a sudden transient event like a magnetic storm from the Sun arrives, the protection from the Earth's magnetic field breaks down and life on the ground gets affected. These magnetic storms may shake the Earth's magnetic field and produce huge amounts of power amounting to million mega watts. That power may be sufficient for a huge country like India for a week or so.

Thus, a powerful CME could induce electricity in large overloading electrical systems and cause massive damage. Sometimes, a powerful event may even cause damage to the power grids in the low latitude belts. It has now been realized that the power grids could be safeguarded by configuring them with the direction and speed of the electric currents induced due to space weather. Since CMEs take days to reach the Earth, we could have enough time to adjust power grids so that they are less vulnerable to the surge in current produced by the CME.

Long distance telephone communications through cable distribution and GPS operations could be disturbed. Once the energetic particles from these events reach the Earth, they interact with our atmospheric particles and produce colourful skies that are known as 'auroras' and are mostly observed in high latitude regions.

Since CMEs are huge plasma eruptions consisting of charged particles and also since electronic technology has become more

Once the energetic particles from these events reach the Earth, they interact with our atmospheric particles and produce colourful skies that are known as 'auroras' and are mostly observed in high latitude regions.

sophisticated and embedded in every day life, they have become more vulnerable to solar activity. A Carrington type flare may damage 900 plus satellites in orbit that could cost around \$70 billion. The solution would then be to be ready with a pipeline of satellites ready to launch. Fortunately such a Carrington event will be rare to happen may be once in half a millennium.

High altitude polar flights and persons on board may also be affected. Astronauts in space will also be exposed to high dose of radiation and energetic particles. Earth's ionosphere will be further ionized creating an ionospheric storm and long distance radio communication could be disturbed. Chances of these geo-effects are expected frequently during the period of solar maximum.

Finally, what is going to happen in 2012? Is the Earth really nearing its end due to a severe solar storm that could cause devastation in 2012 as predicted by doomsayers and propagated by news channels? Well, compared to the previous solar cycles, the sunspot activity during this cycle has not picked up rapidly.

Sunspots started appearing slowly from 2009 onwards and we could hardly spot a group or two during 2010. The slow pick up of the solar activity may not give rise to powerful storms or CMEs contrary to media reports which say that a severe killer storm may arrive from the Sun during the next solar maximum 2012. To emphasise, there is not going to be a massive life-killing solar flare in 2012. So, keep enjoying the bounties of the Sun!

Prof. K. Sundara Raman is with the Indian Institute of Astrophysics, Kodaikanal-624103; Email: ksmkodai@yahoo.co.in, sundar@iiap.res.in