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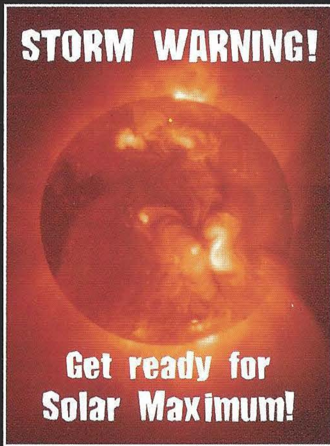

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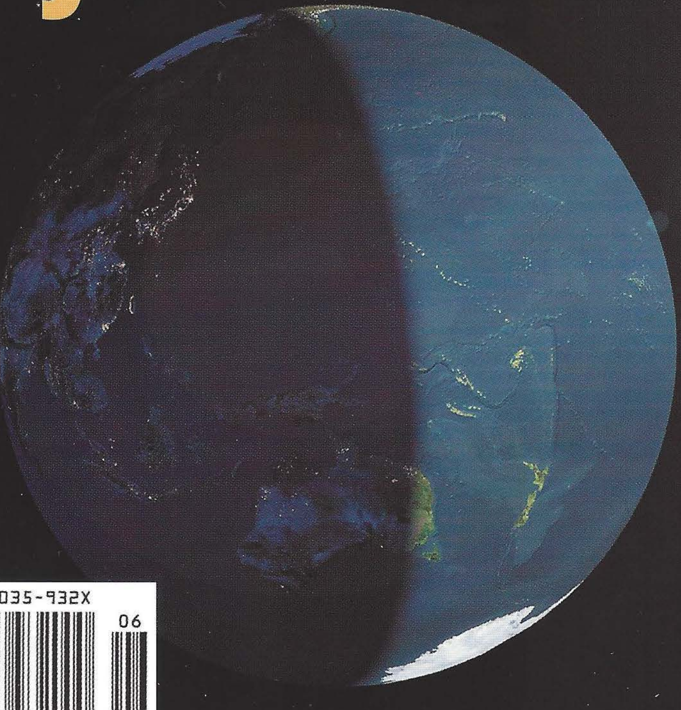

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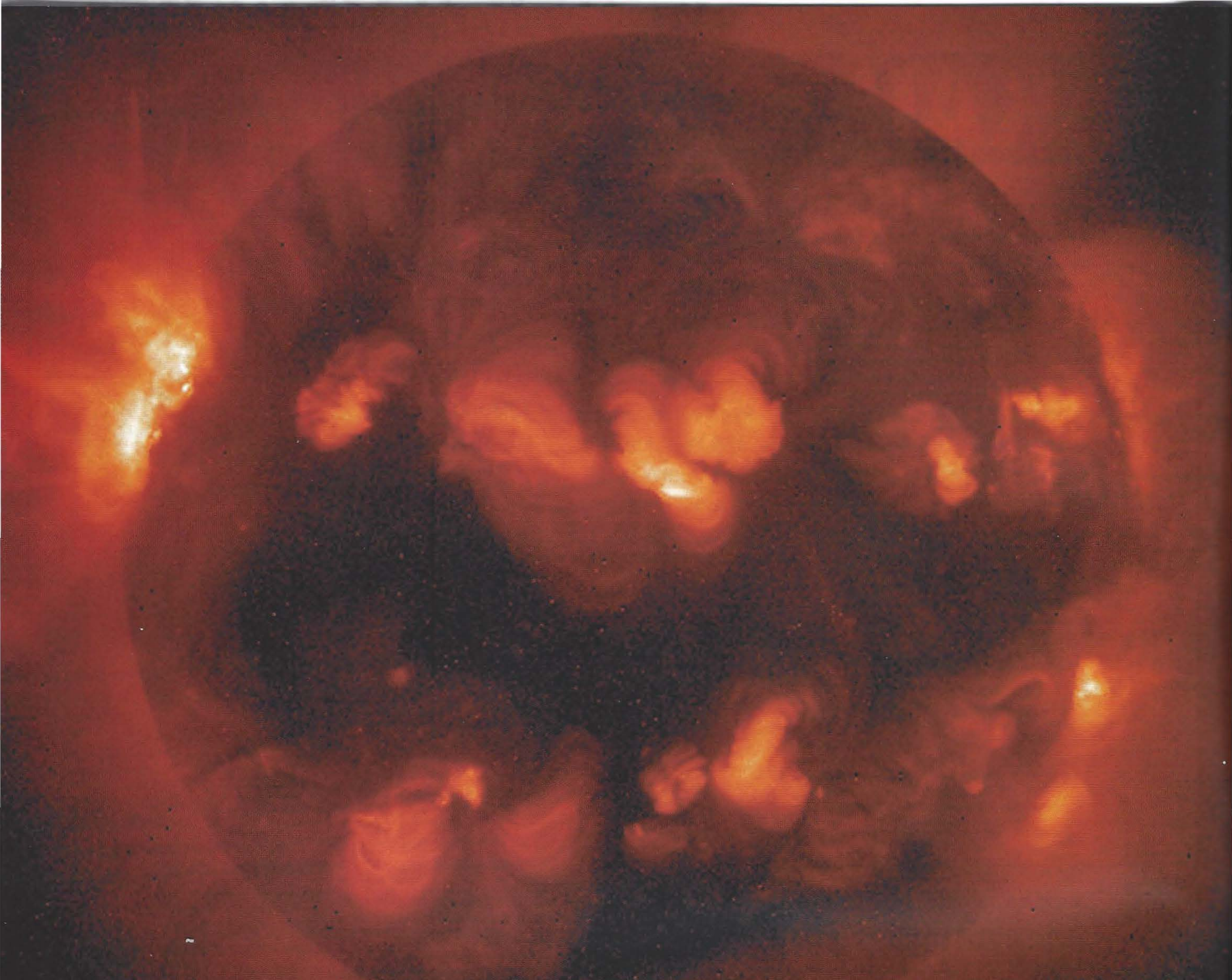


STORM WARNING!

by Dr Alister Graham

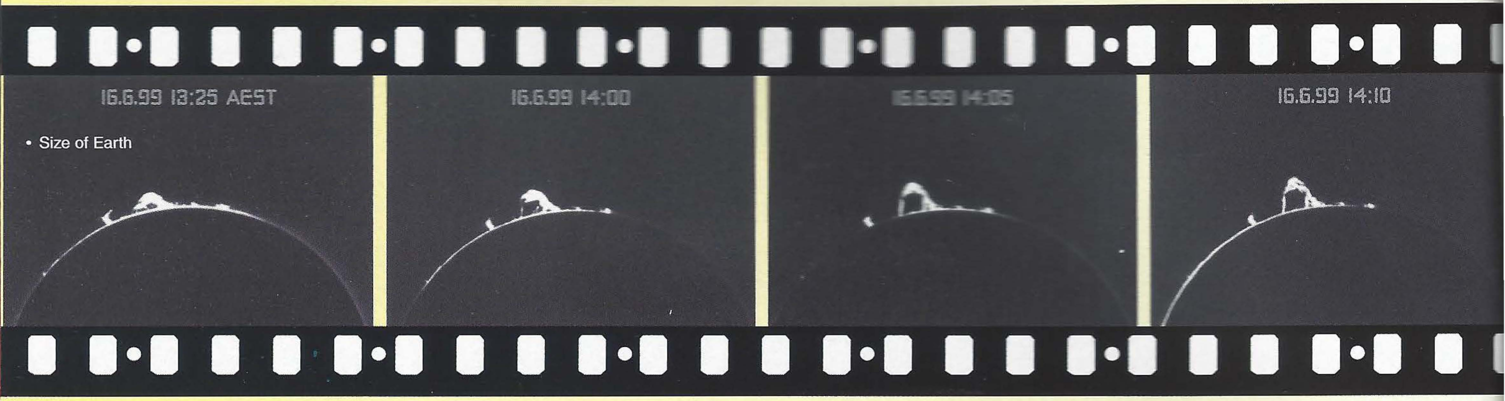
The Sun is the source of Earth's life-sustaining energy, but it is also one of our nearest and most dangerous enemies. With 'solar maximum' due sometime in the next 18 months, Alister Graham takes a look at how our Sun affects the Earth.

The Sun, and many other stars, are known to eject gigantic flares of intensely hot gas and lethal radiation into space. While the Sun can do this at any time, it actually cycles through periods of minimum and maximum activity. The last 'solar maximum' (1989) broke several records and resulted in the loss of satellites and interruptions to radio communications. It even blacked out an entire power grid here on Earth, producing a damage bill that reached into the hundreds of millions of dollars. The next solar maximum is due in the period 2000 to 2001, and that one is expected to be even stronger.

The Sun is a huge nuclear reactor, 330,000 times heavier than the Earth and 100 times larger in diameter. Its average total radiated power is a somewhat incomprehensible 380 billion trillion kilowatts, while solar flares alone are equivalent to roughly 100,000 nuclear bombs detonating every second. In addition, through a process that is not yet fully understood, the relatively mild 'solar wind' blasts charged particles into space at speeds in excess of three million kilometres per hour. This wind continues way out beyond the Earth, perhaps up to 100 times further out. In addition, coronal mass ejections (CMEs) — huge bubbles of hot gas expelled from the outer atmosphere of the Sun — have recently been seen to spew into space, ten thousand billion kilograms of material in a single event, growing to a size larger than the Sun in a matter of hours.

Solar outbursts roughly follow an 11-year cycle of maximum and minimum activity, although the cycle has been known to vary from ▶

• ☚ Size of Earth compared to Sun. At this scale, our planet would actually be over 20 metres away.



Western Australian amateur astronomer and solar photographer, Barry Reynolds, took this amazing sequence of photos. They show a huge solar prominence flinging billions of tons of hot gas into space. Prominences and other violent solar phenomena are so huge that they completely dwarf the Earth (see scale on first image).

▶ 8 to 15 years. (A magnetic polarity flip between northern and southern sunspots means one complete cycle is actually 22 years.) Part of this activity is the enhanced prominence of sunspots, which are dark, cooler regions on the Sun — a mere 3,000°C, compared to the average 6,000°C surface temperature. Sunspots have been regularly observed since around 1610, when Galileo and others first turned their telescopes to the Sun.

These cooler sunspot regions occur because, in certain areas on the Sun's surface, the magnetic field inhibits the escape of heat from the interior, trapping the hot gas beneath the surface. However, the combined effect of the Sun's rotation and internal dynamics often leads to a region of hot plasma bubbling up and breaking free, shooting out vast quantities of energetic gas. This is called a solar flare. A typical flare is so big that it would easily engulf the Earth if our planet was positioned next to the Sun. Flares can arise in a matter of hours and grow to be tens of thousands of kilometres across — they are literally jets of fire spewing forth billions of tons of nuclear material into space.

Somewhat worryingly, we do not understand several fundamental factors as to how or why these and other outbursts occur. What we do know is that strong, turbulent magnetic fields are frequently observed to loop up from the solar surface, inflated by ejected hot plasma that is forced to flow along magnetic field lines. While the magnetic loop remains anchored to the surface, the hot plasma sometimes breaks free and escapes into space.

As recently as last year, astronomers were quite confident that large magnetic loops could not occur in certain types of hot stars. Subsequently, however, scientists detected a huge magnetic loop — 150 times the radius of the Sun — being ejected from the bright star, Rigel. This discovery has sent the theorists back to their blackboards, and highlights the fact that we really don't know if such behaviour can occur on the Sun.

Flares on scales not recorded on our Sun, but seen in stars very similar to our Sun, have been dubbed 'superflares' because of their tremendous power. Their energy output is up to one million times greater than any solar flare measured to date: if they were to occur in our Sun they might be capable of causing mass extinctions of life here on Earth. Rather unnerving is the fact that we do not know exactly why our Sun has not produced such flares in the past, or whether it will in the future.

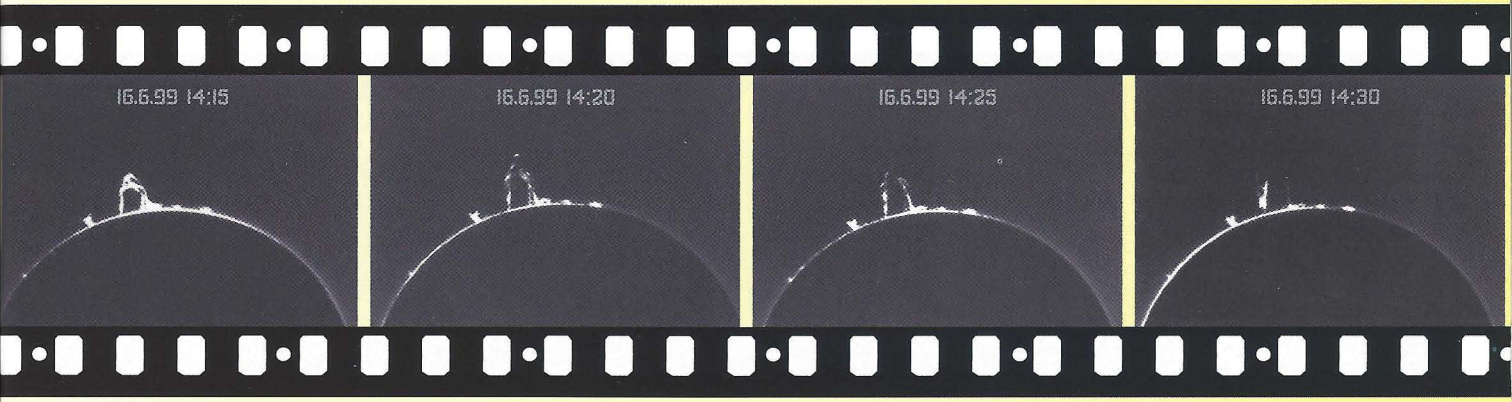
What we do know is that periods of enhanced solar activity do affect life on Earth, sometimes quite dramatically.

Storm warning

Short-wave radio transmissions (used by search-and-rescue organisations, police, the military and so on) travel further at night, when the Sun is not shining overhead on the ionosphere (a region of the atmosphere containing ionised particles). Similarly, you may have noticed that medium-wave transmissions (the AM dial on your radio) are better received at night — partly due to less ground-based interference from machinery, but also because the night-time ionosphere becomes more capable of reflecting these wavelengths greater distances. This is because the absence of the Sun's ionising radiation results in a significant reduction in the number of radiowave absorbing particles in the 'D-region' of the ionosphere.

Conversely, during times of enhanced solar activity, short-wave radio communication on the daylight side of the Earth has been known to experience complete black-out from the disturbing affects of solar flares. (Ultraviolet and X-ray emission from the flares, collides with the Earth's atmosphere and strips electrons from the atoms — the resulting ionised particles absorb radio transmissions.) This common phenomenon is potentially dangerous, as it interferes with

Our Sun goes through an 11-year cycle of maximum and minimum activity (actually, it's 22 years if sunspot magnetic polarity is taken into account). This amazing montage shows the evolution from 'quiet Sun' to 'violent Sun'.



emergency communications. Known as 'Short Wave Fadeout', it can last for up to several hours, typically occurring in regions near the equator.

Short Wave Fadeout also occurs at the poles of the Earth, the result of bombardment by solar protons which arrive hours to days after the initial solar flare. While ultraviolet radiation and X-rays travel at the speed of light, taking roughly eight minutes to reach the Earth, protons travel at a somewhat reduced speed. Radio blackout in the polar regions can last for days — in November 1960, supply planes were prevented from flying to the South Pole for a whole week as they could not obtain reliable weather reports from McMurdo Station.

Additionally, satellite communications become increasingly difficult as solar outbursts produce irregularities in the Earth's ionosphere that hamper the transmission of UHF and VHF satellite signals.

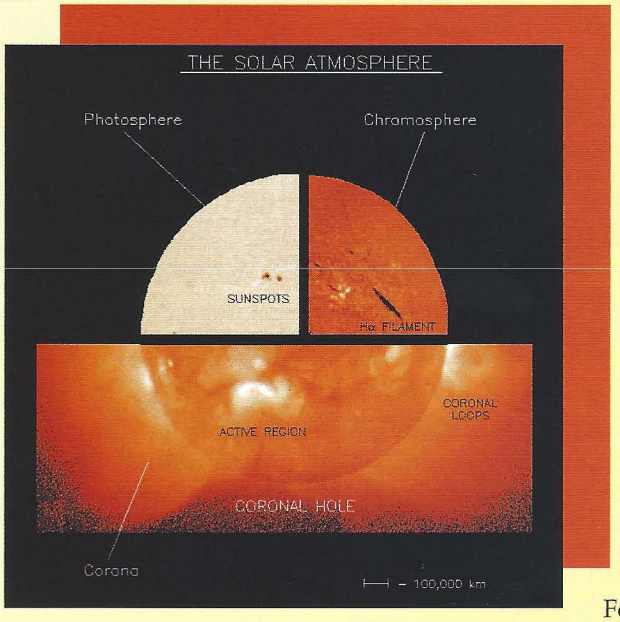
Corruption of power

The flow of charged solar particles through the Earth's upper atmosphere is strong enough to ionise atmospheric particles, resulting in the eerie glow in the twilight sky known as the aurora, or southern and northern lights. Because the interaction of both magnetic fields and charged particles is greatest near the Earth's magnetic poles, aurorae are far more prevalent there than at middle latitudes. Fluctuating magnetic fields are created by this phenomenon, which are known as 'geomagnetic storms', which in turn induce electrical currents in the Earth's oceans and surface rocks. However, electricity being what it is, it prefers to flow though man-made metal pipelines and power lines rather than through the somewhat more resistant rocks.

This creates problems for power grids which use transformers to manage current flow and voltage differences. They are not designed to withstand the effects of such ground-induced currents. Indeed, transformers have been known to catch fire because of this — and not just one, but all of the transformers in a grid. Parts of North America with significant amounts of igneous rock are particularly susceptible to the effects of ground-induced currents on man-made structures.

During the last 'solar maximum' period, a particularly large sunspot (54 times larger than the Earth, yet still it covered only 0.3% of the solar disc) threw out, over several days, a number of extreme solar flares with temperatures of around 20 million degrees. One such flare, on March 6, 1989, was the second-strongest X-ray flare to have been measured since X-ray monitoring began in 1976. Seven days later, ground-induced currents caused by these flares resulted in a transformer failure on one of the main powerlines in Canada's HydroQuebec power system. The overload-induced shutdown that followed took just 90 seconds — there was no time for action to be taken — and six million people lost power for at least nine hours.

The cost of this failure was estimated to be in the hundreds of millions of dollars, on a par with damage from earthquakes and cyclones. The same event also caused power outages in Europe and Central America. During winter, such blackouts are life-threatening due to the loss of heating systems and essential services; they also disrupt other vulnerable areas, such as public transport and security systems. Today, power grids are larger, longer and more complex, and so are more liable to interruption from geomagnetic storms.



The solar atmosphere is made up of a number of different levels, many of which are far from being completely understood.

However, our early warning systems are also much better than they were back in 1989. In comparison with ground-based optical monitoring of the Sun, newer space-based X–ray (eg. the Yohkoh satellite) and ultraviolet (SOHO satellite) data provides superior observations and insight into solar magnetic activity. This gives authorities more time to take preventative measures before a flare reaches us. In 1994 a US National Science Foundation sponsored committee, which was comprised of representatives from the fields of research, commerce and even the military, met to outline a plan to deal with any future geomagnetic storms induced by the Sun. They highlighted the need for advanced warning systems. One can now obtain real-time data, even off the internet at (http://sec.noaa.gov/ace/ACErtsw_ home.html), from the Advanced ▶

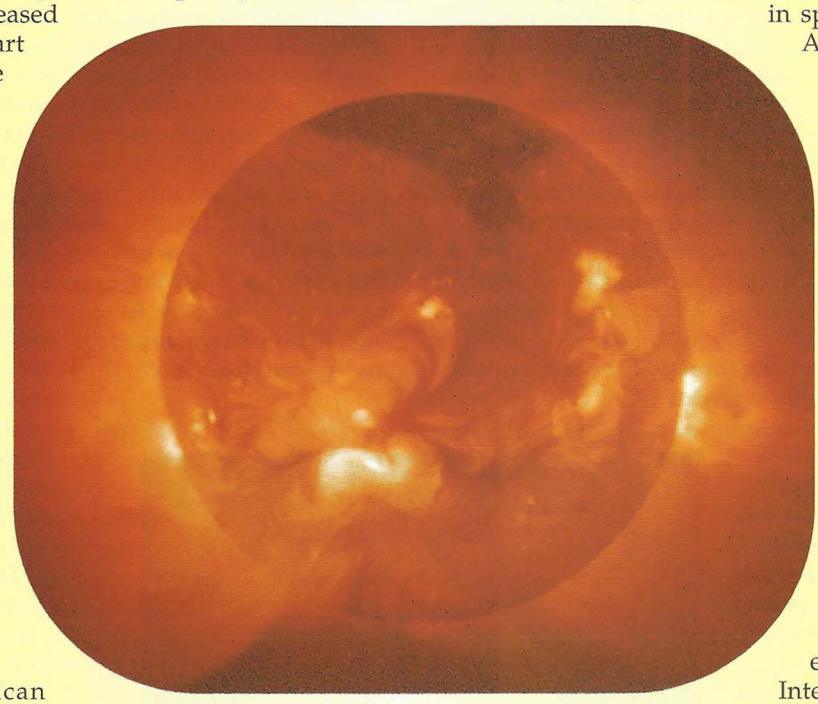
Composition Explorer (ACE) satellite. Located one million miles upstream of Earth, this satellite detects high-energy particles and measures other solar wind parameters before they reach our planet. It then radios this data back to Earth, providing up to 60 minutes vital warning of an impending magnetic storm.

Pipeline networks do not suffer quite as much as power grids, with damage mainly taking the form of increased corrosion. The longest pipeline in the USA is 3,200 kilometres in length and has 12,000 kilometres of branch piping (it carries natural gas). The former Soviet Union has the longest pipelines in the world (6,100 and 4,000 kilometres long), which are even more susceptible to damage because of their location at higher latitudes where solar-induced magnetic storms are more common.

Susceptible satellites

Solar ultraviolet and X-ray emissions heat the Earth's atmosphere and cause it to expand; consequently, low-Earth-orbit satellites suffer increased drag and their orbits start to slowly decay. Due to the complex and chaotic behaviour of the Earth's atmosphere, it is actually not possible to determine this effect accurately. In 1979, the US space station Skylab crashed back down to the Earth because of increased solar activity. Scientists were unable to predict either when or where it would hit — in the end, it burned up in the atmosphere over the Indian Ocean with bits of it landing in Western Australia, but it could have landed in a populated area.

The US North American Aerospace Defence Command (NORAD) is responsible for tracking literally hundreds of pieces of the man-made debris in Earth orbit. After the March 1989 geomagnetic storm, 'space-junk' orbits were observed to decrease as the satellites slowed down due to an increase in atmospheric drag. The SMM (Solar Maximum Mission) satellite was said to have 'dropped as if it hit a brick wall'. Over the following days the number of lost satellites and debris rose from 300 to 1,300, until they were later found at lower altitudes.



Scientists do not have as yet a thorough explanation of the solar cycle, and as we become more and more reliant on electronic wizardry, so too will we become more vulnerable to solar outbursts.

Satellites in higher orbits are not safe either. They are subject to bombardment by high-energy charged particles, which can pass through computer chips and memory cells, corrupting stored data and burning out circuits. During times of heightened solar activity, increased fluxes of electrons can result in a build-up of electric charge on satellites. These electrons are capable of penetrating deep within the material used for wiring, circuit boards and other electronic components, and have been known to induce random triggering of circuits and 'phantom' commands. On January 20 and 21, 1994, the Canadian telecommunications satellites Anik E-1 and Anik E-2 were actually lost due to this effect. Control of Anik E-2 was not regained until several months later. On October 7, 1995, the Intelsat 511 spacecraft was swamped by a cloud of high-velocity electrons that caused an electrostatic discharge which actually fired the thrusters, changing the altitude of the satellite and resulting in a loss of 'Earth lock'.

Furthermore, solar panels can be damaged by high-speed ions ejected from the Sun. During the 1989 solar maximum, the panels of a Geostationary Operational Environmental Satellite (GOES) were damaged so much that six years of operating lifetime were lost in just a few days.

Don't forget the sunscreen

It was pure luck that one of the largest solar proton outbursts on record occurred in the gap between the Apollo 16 and 17 manned spaceflights. If the crew of either mission had been in space during this event in August 1972, they would have received lethal doses of radiation, despite the (somewhat) protective walls of the spacecraft.

Coronal mass ejections from holes in the solar corona can blast huge quantities of plasma into space. This material slams right into and 'shocks' the slower-moving solar wind, accelerating particles which then race ahead of the other material to reach the Earth first, creating a kind of double-wave effect. Today, astronauts are still at risk from such events. Construction of the International Space Station is continuing right on into the period of the next solar maximum — therefore constant monitoring will be needed to give some advance warning to the astronauts, either to get them back into the space shuttle for some protection or back down to Earth.

The upshot of all this is that scientists do not have as yet a thorough explanation of solar activity and the solar cycle, and to this day it remains to be fully understood. What we do know is that magnetic loops, flares and mass ejections do occur in our Sun and that they will continue to influence the Earth and our lives. It is the troublesome affect they have on our technology which we feel the most — as we become more and more reliant on electronic wizardry, so too will we become more vulnerable to solar outbursts. S&S

Dr Alister Graham obtained his PhD at the Australian National University, and presently works as an astronomer at the Instituto de Astrofisica de Canarias in the Spanish Canary Islands.