# The Sun-Earth System

CORONAL MASS EJECTION

## DESIGN, BEAUTY AND PROTECTION IN THE SUN-EARTH SYSTEM

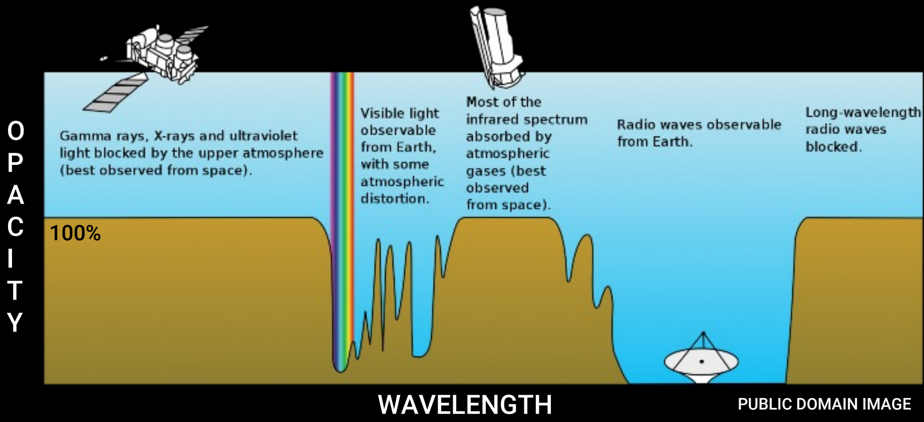
The Sun provides all the light and heat we need to live. Plants use that energy to convert carbon dioxide, water and minerals into bio-matter through photosynthesis, and this provides the basis of the food chain that is essential for life. We couldn't live without our star and the wonderful creation of living plants. And yet, satellite images of the Sun reveal a violent place where very hot plasma is in constant motion. We tend to think of the Sun as a constant light bulb where not a lot of change happens, but that is not the case. As well as being a very hostile place for life, the Sun releases electro-magnetic radiation at multiple wavelengths, high energy X-ray and EUV flares, and high energy particles.

We are thankfully at the perfect distance from the Sun for life: much closer and the energy would be too strong, further away and things would turn too cold. We are in what is termed the 'Goldilocks Zone': not too hot, and not too cold. It is just right and a place where water can exist widely in a liquid state. And the Earth's atmosphere and magnetic field are ideally designed to protect us.

## CORONAL MASS EJECTIONS

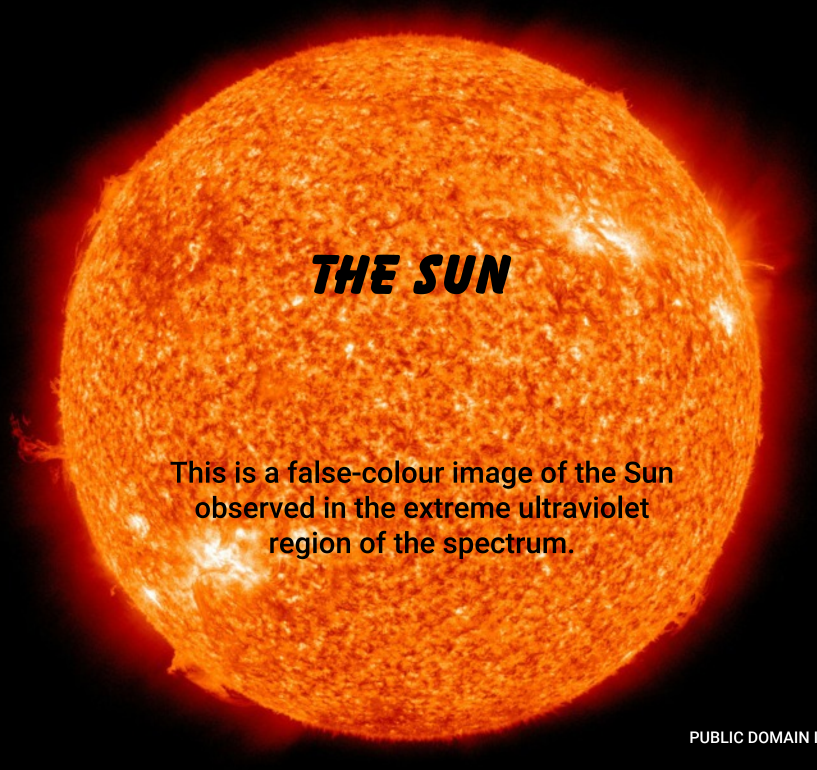
The Sun goes through an eleven-year cycle where sunspot activity reaches a peak, and then falls away again. The last peak in 2014 was relatively weak compared to previous solar cycles in the last 100 years. Sunspots are formed by the strength and twisting of the magnetic field on the Sun. The magnetic field twists and turns as the Sun rotates about its axis, and faster at the solar equator than the poles. And because the magnetic field about a sunspot region is twisting it sometimes breaks and recombines with tremendous energy. If you hold two bar magnets together you can feel powerful forces of attraction or repulsion. Imagine the strength of the magnetic field on the Sun.

When this magnetic energy is released from a sunspot region a cloud of hot plasma is ejected at high speeds, perhaps as high as 3000 km/s in some cases – at that speed it would reach Earth in under a day. This is called a Coronal Mass Ejection (CME) and if it hits the Earth's system it can lead to an enhancement of the northern lights – the aurora borealis – with a disturbance of the Earth's magnetic field. A powerful geomagnetic storm can then induce DC currents in the ground and electricity system, and potentially lead to damage to electricity grid transformers that are connected to the ground. But no harm comes directly to living organisms from changes in geomagnetism. The largest known CME was on 2 September 1859 and followed a powerful white light flare observed by astronomer Richard Carrington the day before. With this Carrington event the aurora was seen as far south as the Caribbean and some telegraphic transfer stations caught fire.




PUBLIC DOMAIN IMAGE

This chart shows the opacity of the atmosphere to electromagnetic waves of different wavelengths. Visible light and the near infrared get through quite easily but almost all of the high energy, short wavelength energy does not reach us. This radiation would be an extreme health hazard! We can receive radio waves from space which does help our satellite communications.



# THE SUN

This is a false-colour image of the Sun observed in the extreme ultraviolet region of the spectrum.

PUBLIC DOMAIN IMAGE

The Sun is a swirling fireball in space with a surface temperature of about 6000K (about 5727°C)

## HIGH ENERGY PROTON STORMS

Most of the harmful particles associated with a CME are too weak to penetrate deep into the atmosphere and are deflected away by the Earth's magnetic field. But some of the protons and alpha particles have very high energies (of the order of 100MeV or above and travelling at perhaps a third of the speed of light) and these can lead to an enhancement of background radiation levels at the ground in high latitudes. These protons are directed towards the Poles by the Earth's protective magnetic field. Such ground level events (GLEs) are quite rare, and occur in cold places where few people live. They also sometimes affect passengers and crews on flights over the Poles. And even on routine flights without flares there is a noticeable increase in radiation at 7km height due to the thinner air, and an ongoing flux of cosmic rays from deep space. But without our own protective atmosphere and magnetic field the radiation received at ground level would be much greater. The atmosphere is at the optimum thickness for life, and helps to protect us from harm.

## X-RAY FLARES

When a CME occurs, there is often an intense burst of X-ray energy. The background flux is typically around $10^{-7}$ to $10^{-6}$ $Wm^{-2}$, but a powerful flare can increase the X-ray energy received at Earth by as much as 10,000 times. The highest recent flare was estimated at $45 \times 10^{-4}$ $Wm^{-2}$ (denoted as an X45 flare) on 4th November 2003. Such energy levels are rare, but thankfully absorbed in the Earth's upper air by a region called the ionosphere – the absorbing D-region of the ionosphere is about 60km high. While this can impact HF communications little direct harm comes to us living on the Earth's surface.

If the Sun were to spin much faster then larger flares would result. It currently rotates about once every 27 days. In fact, recently the NASA SWIFT satellite detected an X100,000 flare (about 10,000 times greater than the largest flare at Earth) on 23 April 2014 from a Red Dwarf binary star system (DG CVn) that is believed to be spinning at a much faster rate. Ironically, naturalistic scientists suggest the Sun was rotating at a far higher speed at a time when life was supposed to have got going several billion years ago – which is why some now claim life evolved in the deep ocean to avoid the very harmful solar radiation, and not in some warm pond of organic soup.

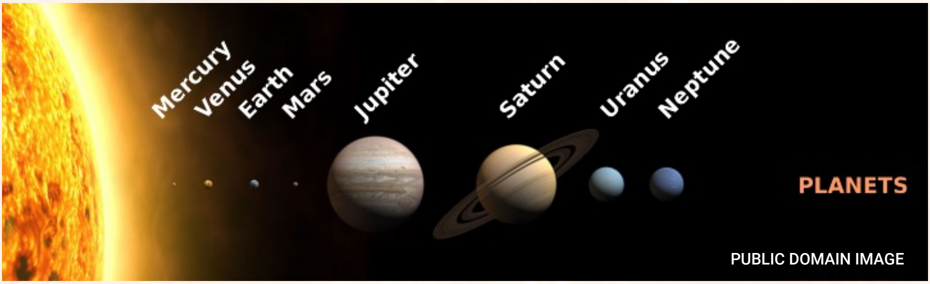
The Sun releases energy at multiple wavelengths, and at energies that are harmful to life including at the extreme ultra-violet (EUV) wavelength. Most of this harmful energy is absorbed by the ozone layer in the stratosphere at about 20 to 40km above ground level (although a little gets through due to holes in the ozone layer, which is why we need to take care not to over expose ourselves in northern latitudes where we have insufficient melanin in the skin).

And yet at slightly longer wavelengths visible light can get through the atmosphere. This is a wonderful design feature, where we are protected from harmful rays and yet able to see the beauty of the night sky, and the scattering of light (Rayleigh scattering) gives us a lovely tinge of blue during the day and sometimes colourful red sunsets. Refraction and the reflection of light are also responsible for the colours of the rainbow when raindrops separate light out. A diagram of the opacity of the atmosphere to different wavelengths shows the very narrow band where light can get through, and yet prevents more intense energy from reaching the ground – this is another wonderful design feature.

## ATMOSPHERE AND WATER

It is known that water is densest at 4 °C, which allows life to live in the bottom of ponds that are frozen on the surface. But water vapour in the air has the right properties to support 'moderate' rainfall. Given surface air pressure of around 1000 hectopascals (hPa) the amount of water vapour in a column of air above the surface is finely balanced. With the temperature at 0 °C at the surface a column of saturated air above it in reality contains very little water, perhaps only a few mm of water available for rainfall, which is why many cold parts of the world are deserts. But at 18 to 22 °C a column of saturated air above the surface has enough water (perhaps 35-40 mm of precipitable water) to lead to severe flash flooding, which is why tropical and equatorial regions get so much rainfall. But on the Kelvin scale we have only gone from 273 degrees to 295 degrees. Such a small window shows the wonder of design. The water vapour is also largely responsible for the greenhouse effect, which helps to keep the Earth at the right temperature, while the heating effect of carbon dioxide is less.

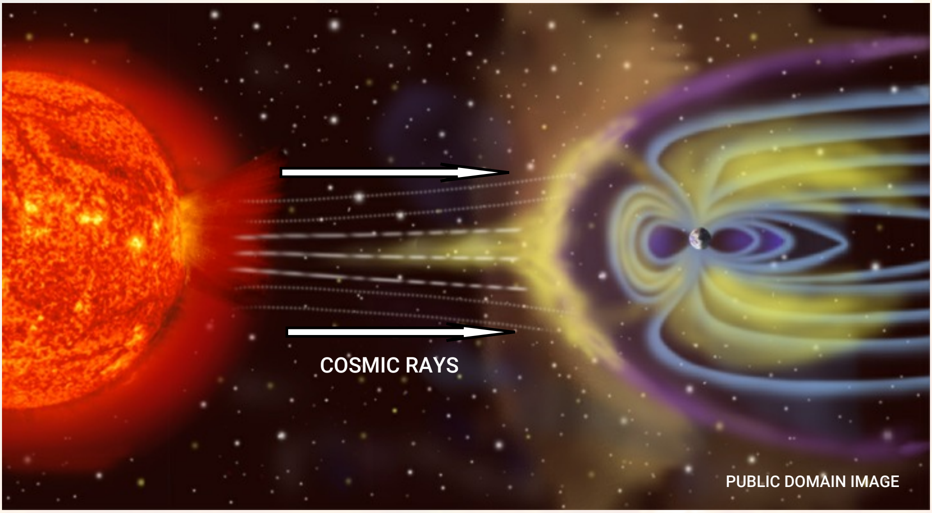
The composition of the air is also finely tuned for life with the right amount of oxygen and nitrogen (about 20% and 80% respectively). Oxygen is essential for respiration while nitrogen is a fairly inert gas that prevents the oxygen from supporting too much combustion! It is also the properties of oxygen and nitrogen atoms that allows the air to absorb the harmful X-ray and EUV rays in the upper air through complex chemical processes. (See the chart on P3).




SCHEMATIC SHOWING THE RELATIVE SIZES AND POSITIONS OF THE PLANETS AND THE SUN.
THE DISTANCES ARE NOT TO SCALE AND THE OUTER PLANETS ARE MUCH FURTHER AWAY THAN SHOWN.

## SUMMARY

The Sun is a very hostile place, and yet Earth is wonderfully protected from the harshness of space. The atmosphere is perfectly balanced for the sustaining of life and for its protection from harmful solar rays and particles. The atmosphere allows just the right amount of light and heat through that enables plants to grow, life to flourish, and humanity to observe the wonders of creation. It holds sufficient water so that rain can water the ground across many temperate regions, although tropical and polar regions suffer the extremes of weather where it is difficult to live due to hot and cold deserts. If the air were just a little thinner then far more cosmic radiation would reach the ground and the world would be a cold desert, as is the case with Mars. If the atmosphere were a little deeper and of a different composition then global temperatures and rainfall would be much higher, and the world would be a darker place with less light getting through. Venus suffers from a runaway greenhouse effect with acid rain. There are of course concerns about human abuse of the environment, and as Christians we do need to take seriously the need to look after the world God has given us.


THE EARTH'S MAGNETOSPHERE PROTECTING THE PLANET FROM COSMIC RAYS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