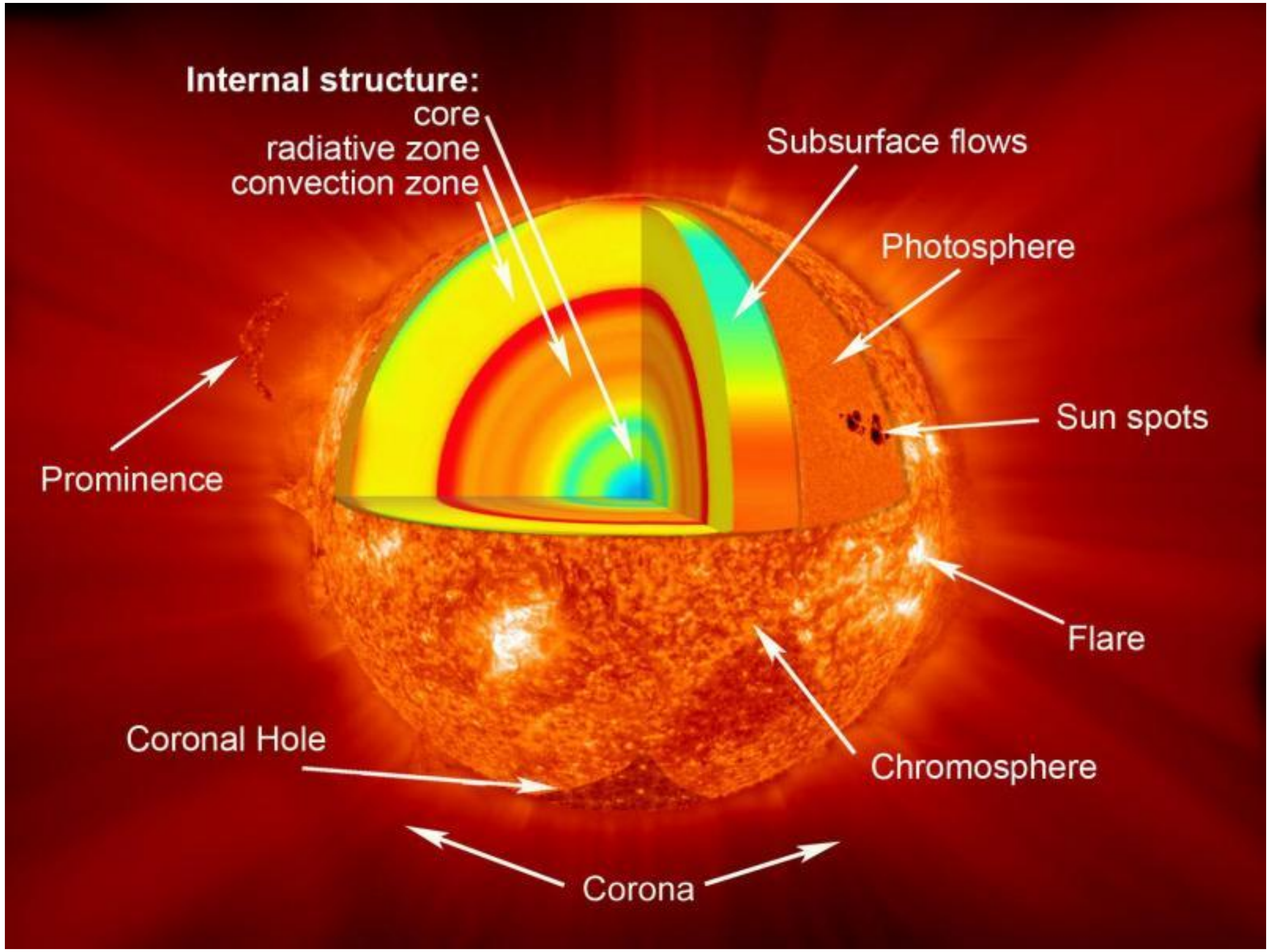
The Sun and Solar Observing

George Buckberry

Solar Structure and Basic Data



The Sun is the star at the center of the Solar System. It is a massive, hot ball of plasma, 91% hydrogen, inflated and heated by energy produced by nuclear fusion reactions at its core.

- The sun is about 93 million miles from Earth
- **Temperatures:** **Surface:** 5,772 K - **Core:** 15 million degrees C
- **Equator circumference:** 4,379,000km
- **Radius:** 696,340 km
- **Mass:** 1.989 × 10^30 kg - It contains 99.86% of the mass of the entire solar system and could contain roughly 1.3 million Earths.
- **Gravity:** 274 m/s²
- **Age:** 4.603 billion years
- **Star type:** Yellow dwarf
- **Spectral type:** G2V
- **Average orbital speed around the Milky Way:** 720,000km/h (200km/s)
- **Average time taken to rotate on axis:** 27 Earth days and approximate axial tilt relative to Earth of 7.5 degrees
- **Number of planets:** 8

The Earth is so small compared to the Sun

- The current best estimate for the mass of Earth is $M_{\oplus}$ = 5.9722×10^{24} kg, with a relative uncertainty of 10^{-4}. It is equivalent to an average density of 5515 kg/m^3.
- Roughly 1.3 million Earths could be contained in the Sun's Mass.
- Solar Prominences, Flares and Spots could easily engulf the Earth (see the details of the Sun imaged in Hydrogen-alpha).

Sun’s Life Cycle

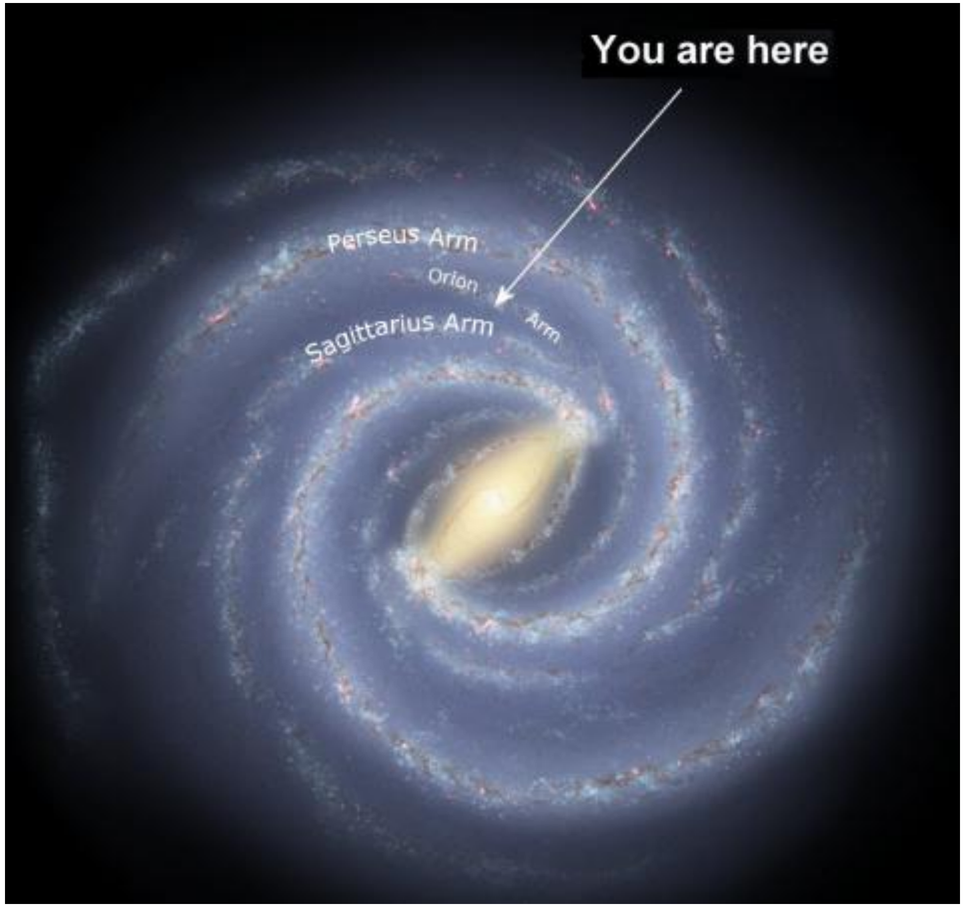
- The Sun is currently a yellow dwarf. Like all stars, it began as a contracting nebula - effectively a cloud of dust and gas.
- As each particle has its own tiny gravitational pull, the dust and gas began to coalesce into a protostar. As this mass is pulled together and collapses in on itself it generates heat. If it becomes big enough it will eventually get sufficiently hot to fuse hydrogen into helium. This was how the Sun formed.
- The celestial object then enters its main sequence stage, during which the outward pressure of nuclear fusion is balanced by the inward pressure of the stars own gravity. The Sun is currently in this stable phase.

What will happen to the Sun?

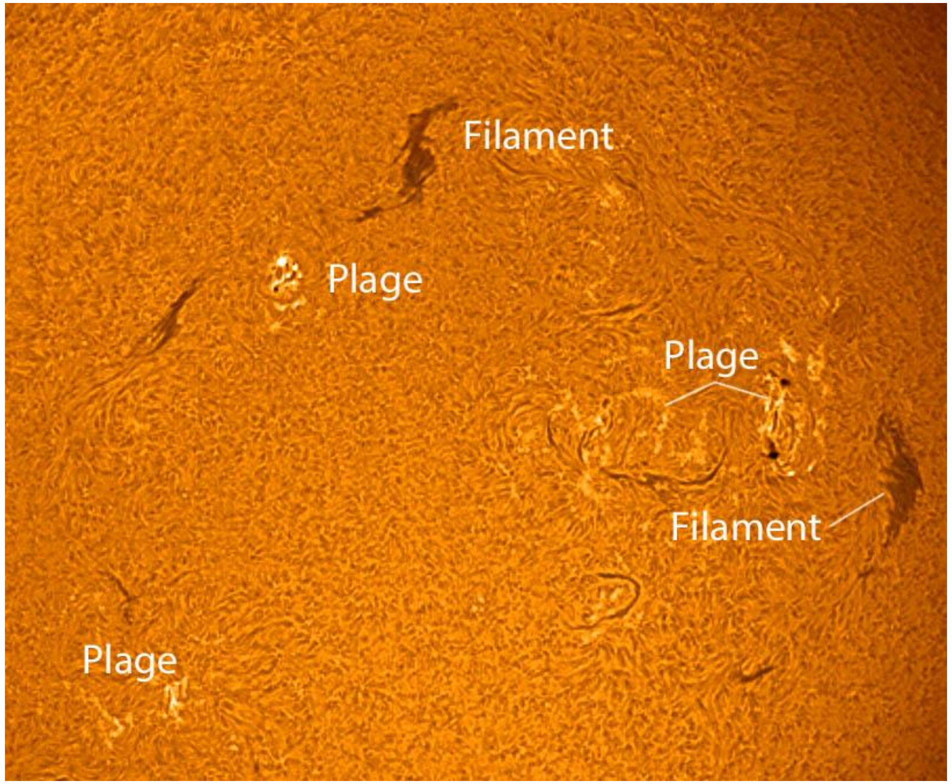
- When all of the hydrogen in its core is burned up, it exits the main sequence stage.
- As a relatively small star, the outer layers of the Sun will collapse in on themselves, creating temperatures hot enough to fuse helium into carbon. At this point the pressure will cause the star to rapidly expand outward to form a red giant.
- For the Sun, this is expected to occur in about five billion years. It is likely to engulf Mercury and Venus - and potentially even the Earth.
- It will eventually shrink to become a planetary nebula with a white dwarf at its core.

Where is the Sun in the Milky Way?

- There are an estimated 100 billion galaxies in the known universe. The Sun and its eight planets, including Earth, reside in one known as the Milky Way. Our galaxy is around one quintillion kilometres across, or 100,000 light years.
- The Sun is in a spiral arm of the Milky Way called the Orion Spur. This branches off from the galaxy's Sagittarius arm. The Sun and our solar system are orbiting around the centre of the Milky Way at a speed of 720,000 kilometres per hour. It takes 230 million years to make one complete orbit.



Filaments and Plages

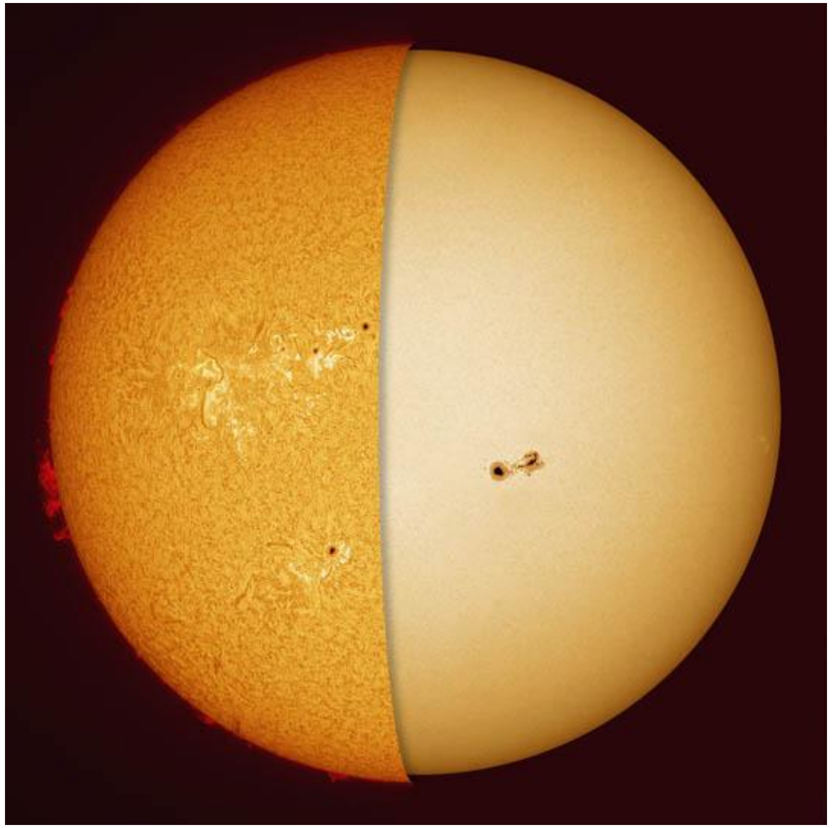


- Prominences can last for many days, which means they get carried across the face of the Sun as it rotates. Seen against the bright solar disk, they're called filaments and look like bushy eyebrows and sinuous snakes with small, dark anchor points that remind me of caterpillar "feet". If you're lucky, a bright prominence will extend well into the disk as a dark filament, and you'll get to see how they're one and the same. The unique placement also reveals the prominence/filament as a grand three-dimensional arch, a sight guaranteed to ping your awe meter. Filaments can stretch halfway or more across the Sun.
- Moving further into the disk, you'll suddenly realize where all that 1970s shag carpeting disappeared to. It's all over the chromosphere! What you're seeing is combination of spicules — which appear dark against the disk — and bundles of fibrils, hot plasma confined in magnetic tubes, that give the Sun a dark, mottled and swirly appearance.
- Running like tendrils of glitter between and the dark mottles are tiny, moderately bright points of light called filigree. Filigree define the chromospheric network, a web-like network that outlines the Sun's supergranules, giant convective cells that transfer energy from deep beneath the photosphere up to the surface. Filigree concentrate along their edges.
- Much more obvious when looking at the H-alpha Sun for the first time are the bright, patchy plages (PLAH-jez) that mark the sites of active regions or sunspot groups. Don't be surprised if you see plage where no spot group is visible in white light. These are emerging flux regions (EFRs) where a magnetic flux tube is just breaching the surface on its way to producing a bipolar sunspot group.
- As for sunspots, their dark cores or umbrae look similar to what you see in white light, but the penumbrae branch out into impressive whirls of fibrils and spicules.

Flares and Plages

- It's sometimes easy to confuse bright plage with a weak flare. Close inspection of large, complex plages often reveals tiny, brighter kernels of light that fluctuate in brightness.
- These are likely **Ellerman bombs** (named for an early 20th century astronomer who studied them) or tiny **microflares** that come and go within 5 minutes.
- Flares are unmistakable and involve a sudden brightening within a sunspot group often as multiple ribbons that resemble flows of white-hot lava. They can last from a few minutes to hours and change in both intensity and area in real time right before your eyes. Raw star power.

Solar images in H-alpha and White Light



Composite image showing the Sun in white light (right) and in H-alpha. In the red of hydrogen light, we peer into the solar chromosphere, the layer directly above the photosphere.

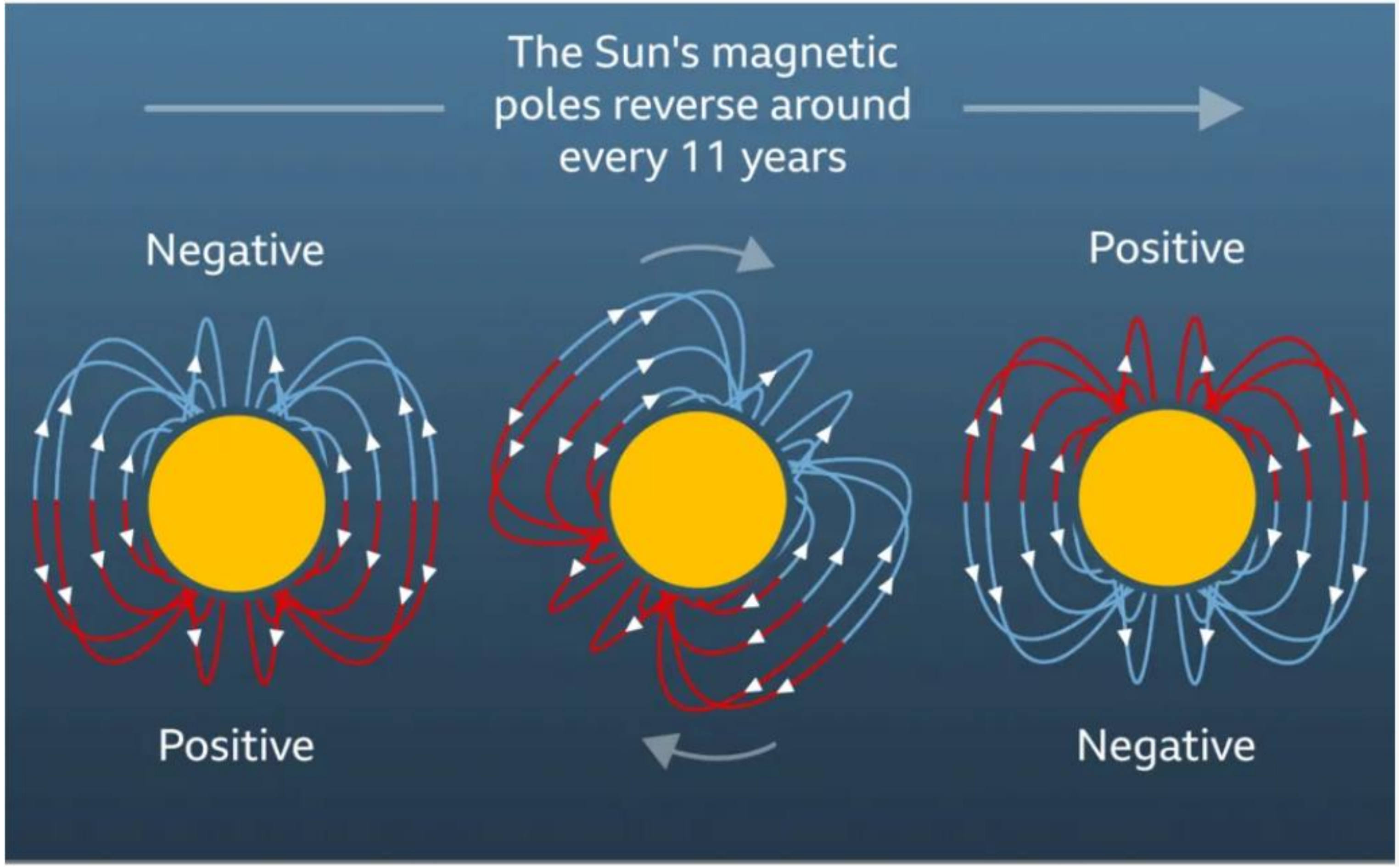
- White light filters provide a simple and inexpensive way to get to know the Sun; they allow us to see day-to-day and week-to-week changes in photospheric activity.
- Viewed in **H-alpha** (Hα) a narrow slice of the spectrum centered in the ruby-red H-alpha line, the Sun throbs with activity.
- Prominences, spicules, fibrils, Ellerman bombs, flares and more seethe and boil before your eyes. Unlike the more sedate white light view, H-alpha pulls back the curtain to expose the beast for what it is: a ferocious, unpredictable ball of incandescent hydrogen gas. Ribbons of gas can grow to a fiery brightness — brighter than anything else on the Sun. I watched with a mix of awe and fear.
- H-alpha light is emitted by hydrogen atoms, by far the most common element in the Sun, when electrons within those atoms absorb energy and **rise to a higher energy level** or orbit. When they cascade back to their original orbits, they release that energy as crimson light with a wavelength of 6562.8Å (656 nm).

The Solar Cycle

- The Solar Cycle is over an 11 year period and the "solar maximum" – occurs at a point during this cycle when its activity is strongest.
- That happens when the Sun’s magnetic poles flip - a process that creates sunspots that fire out material, generating space weather.
- This solar cycle is the 25th since humans started systematically observing sunspots in 1755.
- The intensity of a cycle is estimated by the number of these sunspots.
- But that doesn't actually tell us how strong the storms will be when they reach Earth.

Solar Flipping

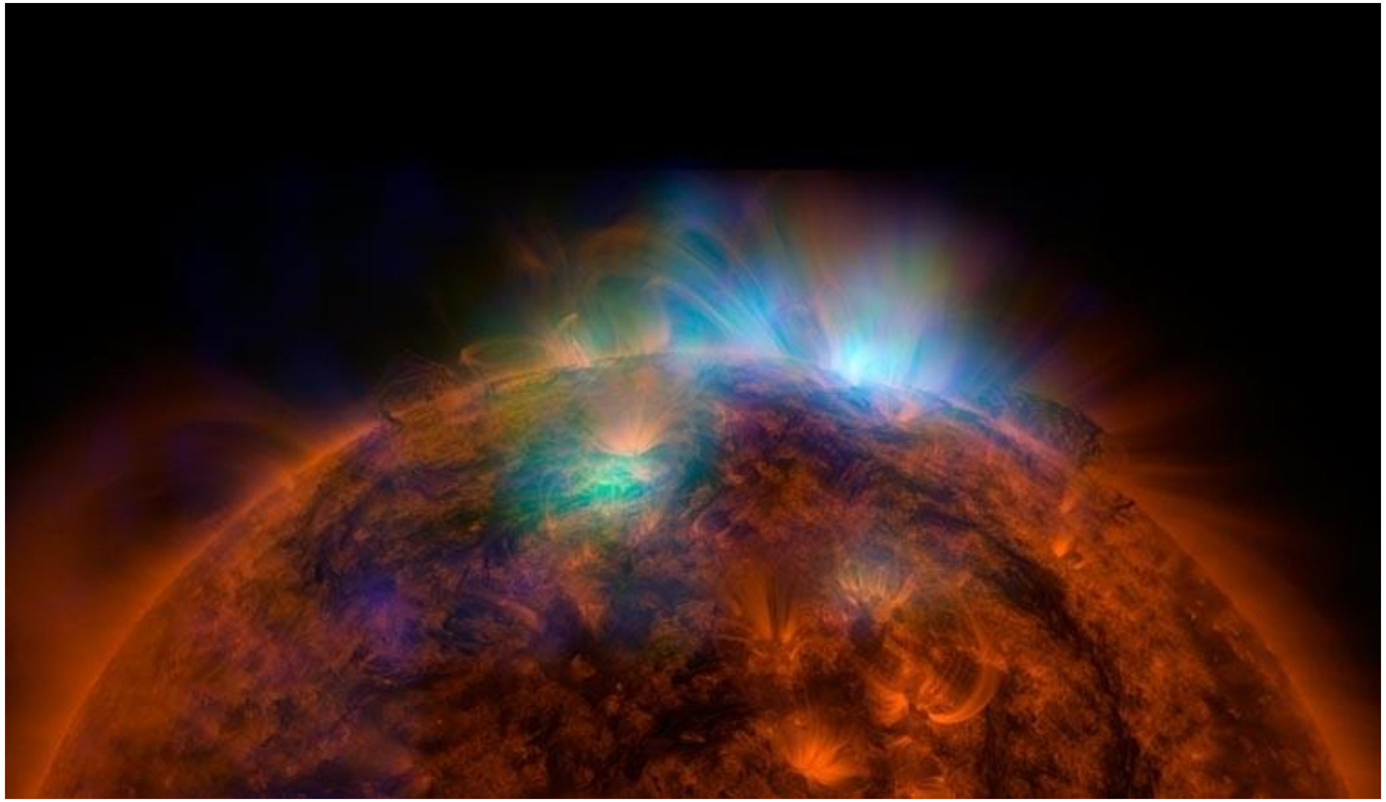
- Every 11 or so years, the sun undergoes an epic transformation: its magnetic poles reverse.
- The sun's poles **last reversed in 2013** so the next flip is due to happen in 2024/5 around when it reaches the Solar Maximum but a Google search said it was completed in 2023/4.



Coronal Mass Ejections (CMEs)

- A **coronal mass ejection** (**CME**) is a significant ejection of magnetic field and accompanying plasma mass from the Sun's corona into the heliosphere. CMEs are often associated with solar flares and other forms of solar activity
- They can eject billions of tons of coronal material and carry an embedded magnetic field (frozen in flux) that is stronger than the background solar wind interplanetary magnetic field (IMF) strength.
- CMEs travel outward from the Sun at speeds ranging from slower than 250 kilometers per second (km/s) to as fast as near 3000 km/s. The fastest Earth-directed CMEs can reach our planet in as little as 15-18 hours. Slower CMEs can take several days to arrive. They expand in size as they propagate away from the Sun and larger CMEs can reach a size comprising nearly a quarter of the space between Earth and the Sun by the time it reaches our planet.
- The more explosive CMEs generally begin when highly twisted magnetic field structures (flux ropes) contained in the Sun's lower corona become too stressed and realign into a less tense configuration – a process called magnetic reconnection. This can result in the sudden release of electromagnetic energy in the form of a solar flare; which typically accompanies the explosive acceleration of plasma away from the Sun – the CME.
- If a CME enters interplanetary space, it is referred to as an **interplanetary coronal mass ejection** (**ICME**). ICMEs are capable of reaching and colliding with Earth's magnetosphere, where they can cause geomagnetic storms, aurorae, and in rare cases damage to electrical power grids.

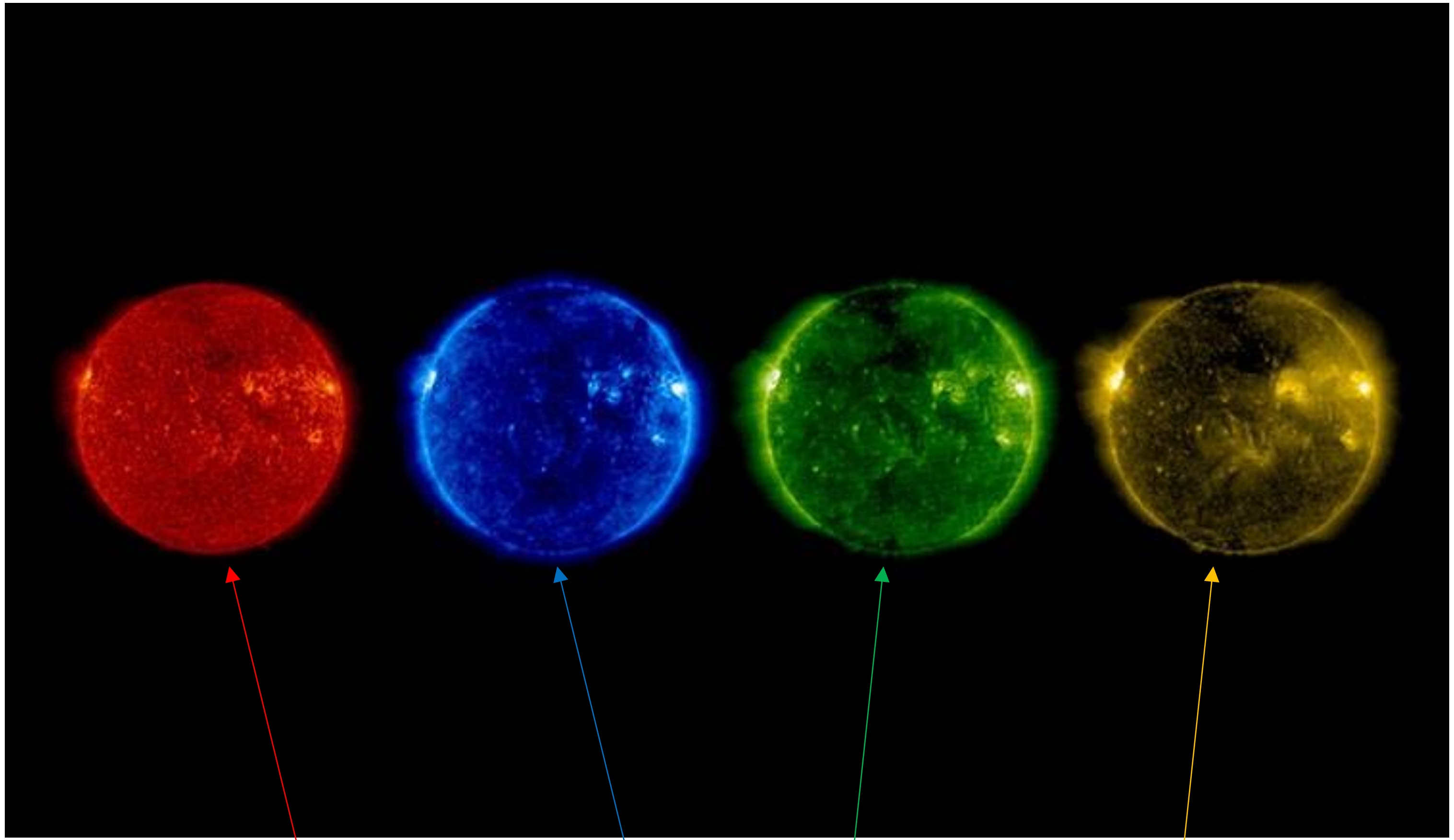
What are solar flares?



A solar flare as seen in high energy X-rays © NASA/JPL-Caltech/GSFC

- Solar flares are the largest explosive events in the entire solar system. They occur when the magnetic fields associated with the sunspots convert energy into heat and accelerating particles, ejecting it into space.
- They are characterised by a burst of photons - or light - at almost every wavelength. Scientists usually measure the ultraviolet rays, X-rays and gamma-rays coming from the solar flares.
- These typically show up as bright flashes on the surface of the Sun, and can last from just a couple of minutes to a few hours.

The Sun at different ultraviolet wavelengths



(l-r) the bright spots are **60 000–80 000ºC**, **1 million**, **1.5 million** and **2 million** degrees © SOHO/ESA/NASA

Latest findings from Aditya-L1 – Solar Observation

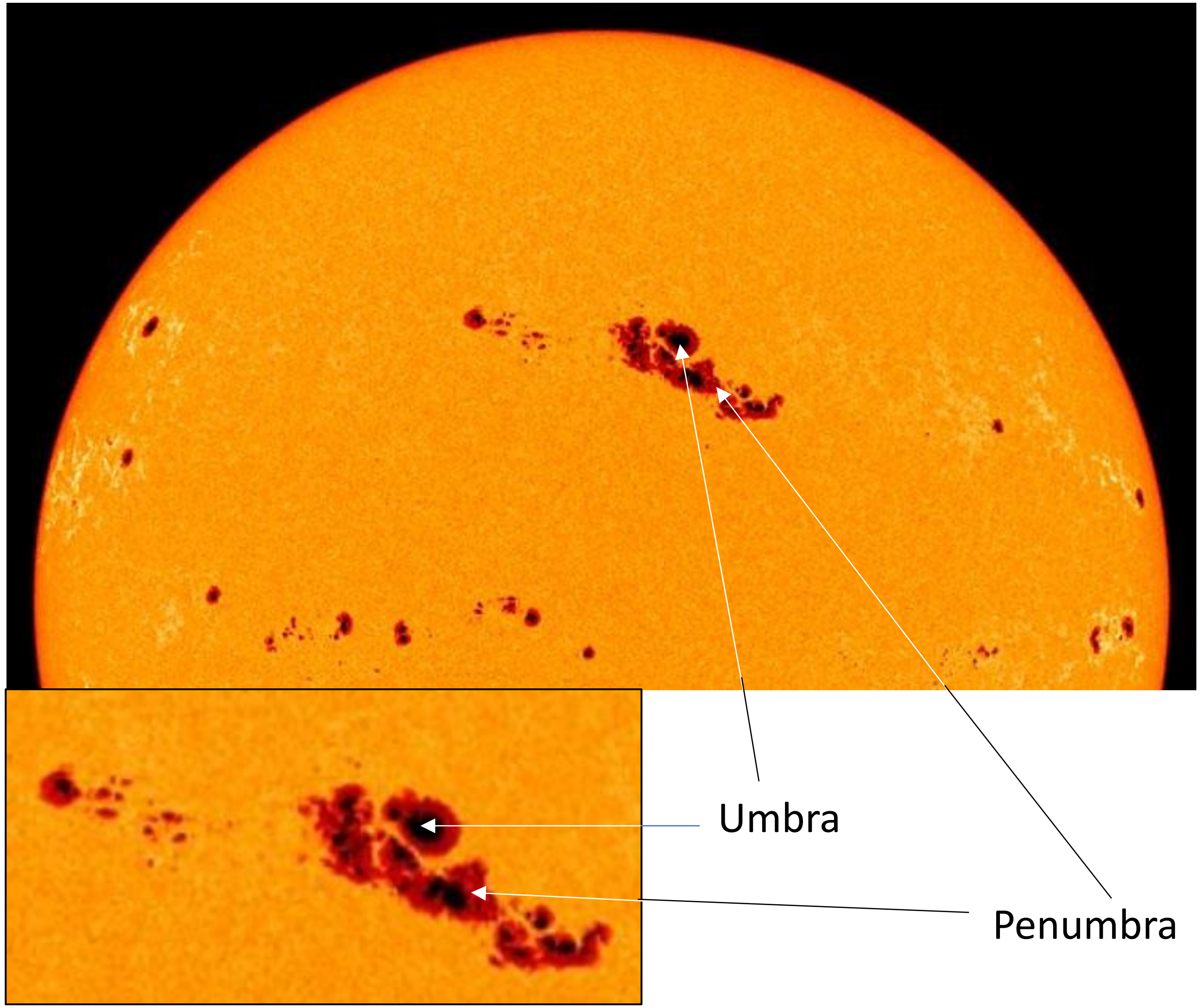
Geeta Pandey - BBC Correspondent, Reporting from Delhi on interview with Prof Ramesh *14/8/2026*

- One of the most enduring mysteries that has been puzzling scientists forever is how the Sun's outer atmosphere - the corona - is millions of degrees hotter than its surface. And how does the corona continue to remain so hot despite frequent eruptions during which it loses huge amounts of energy?
- Scientists put it down to two factors - one, the bubbling boiling motions on the Sun's surface that constantly generate waves which, as they travel outwards, carry energy to the corona - a bit like sea waves carrying foam and froth to the shore. 7% energy
- The second is the "tangled magnetic field lines" in the Sun's atmosphere that constantly snap and then reconnect. A CME occurs when these twisting, looping lines - which resemble braided hair - rupture, throwing out massive clouds of magnetised plasma and gas in space. 93% energy.
- The research team analysed a very energetic CME in 2024 and saw that in 10 hours after the CME, the tangled field lines were able to go back to their original place, they reconnected and corona's energy was reconfigured.

Studying the Sun in Different Wavelengths

- We can study the nearest star in either **white light** or choose among several narrow wavelengths, the most common of which are red hydrogen-alpha and violet calcium K-line light.
- White light filters reveal the glaring face of the Sun called the **photosphere**, home to granulation, a rice-grain texture of rising and sinking convective cells; **faculae**, bright patches of concentrated magnetic energy; and **sunspot groups** that come and go as the rotating Sun carries them in and out of view.

What are Sunspots?



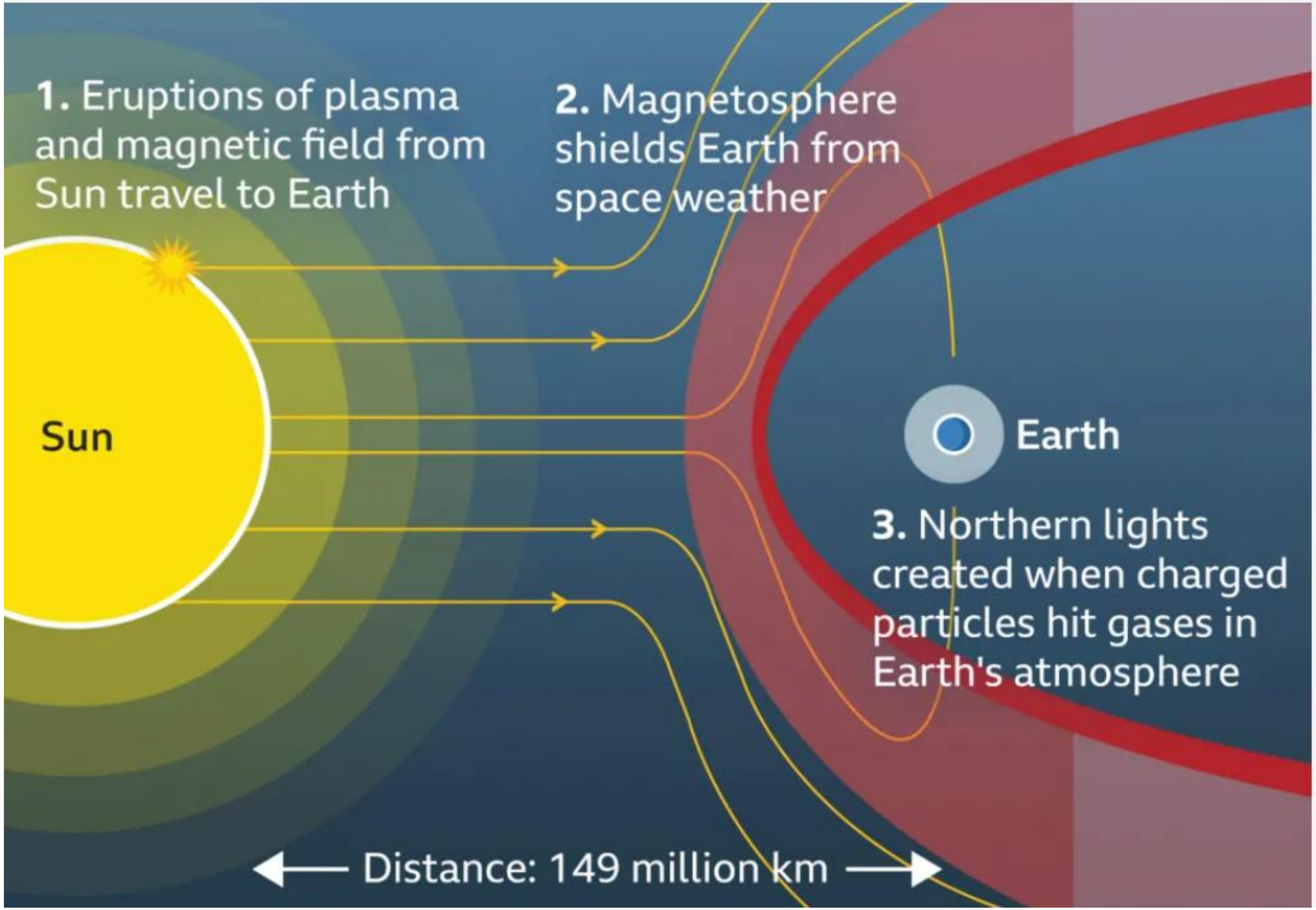
- Sunspots are cooler parts of the Sun's surface, and occur in the photosphere. The temporary splodges across the surface appear darker to us than the warmer plasma surrounding it.
- They are still incredibly hot — around 6,500 degrees Fahrenheit — and bright. That's just relatively cooler than the sun's typical 10,000-degree surface temperature.
- These cooler spots can be up to 50,000 kilometres across (*compare to Diameter of the Earth at 12,742 km*).
- They are thought to be caused by interactions with particularly strong regions of the underlying magnetic field, which slightly reduce the radiation coming up from the core, cooling the surface.

How are Sunspot Groups Classified?

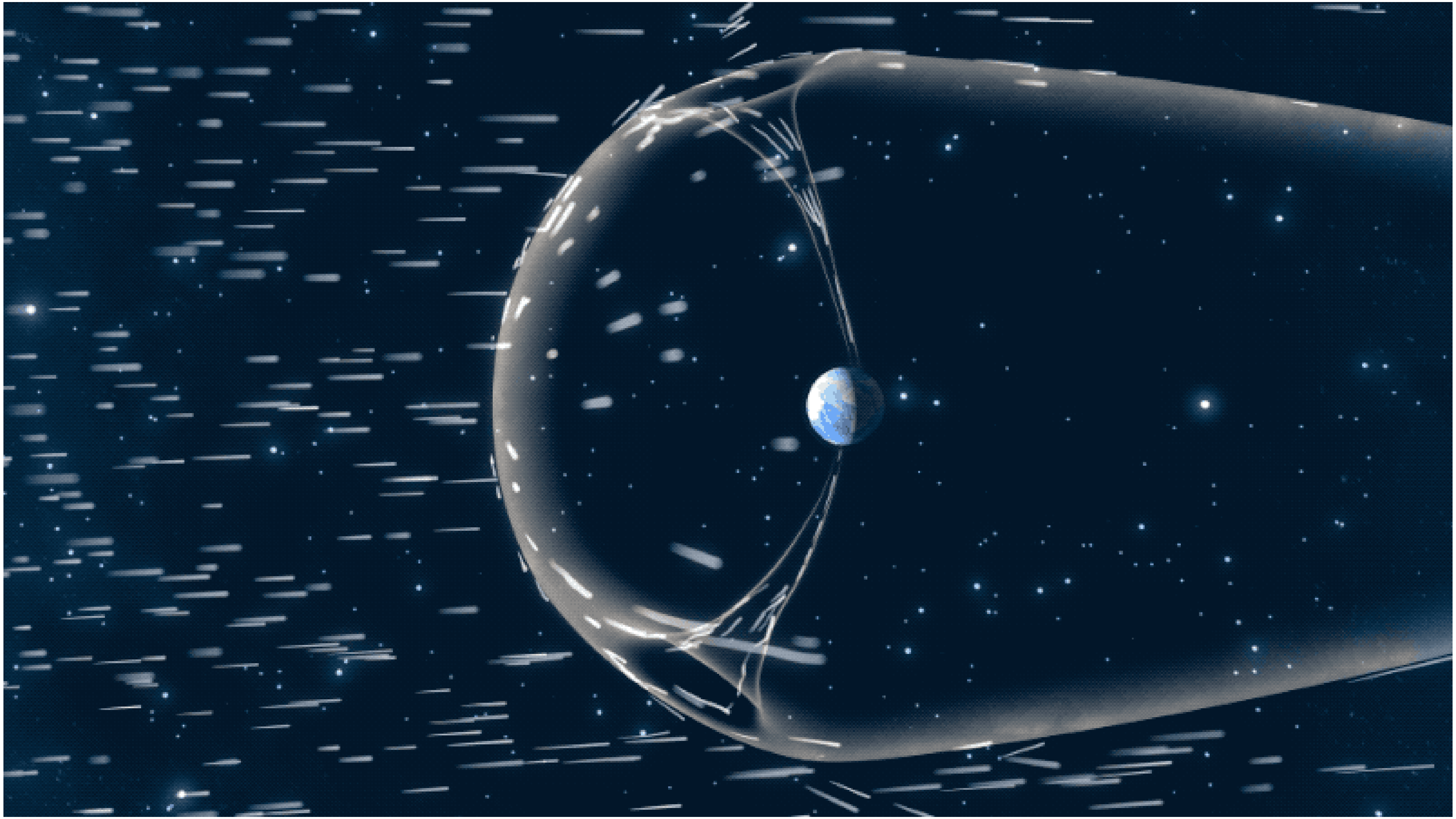
- Sunspot Group Classification
  - A: A small single unipolar sunspot or very small group of spots without penumbra.
  - B: Bipolar sunspot group with no penumbra.
  - C: An elongated bipolar sunspot group. One sunspot must have penumbra.
- A group of sunspots is known as an active region.
- Active regions are allocated numbers by the US government's National Oceanic and Atmospheric Administration (NOAA) in order of appearance.
- Sunspot Number
  - In solar-terrestrial terms, a daily index of sunspot activity (R), defined as R = k (10 g + s) where S = number of individual spots, g = number of sunspot groups, and k is an observatory factor.
  - Generally, sunspot reports from observatories calculate sunspot numbers whereby each sunspot group counts as 10, and every umbra within each spot group is individually considered as 1.

Interaction of Solar Wind with Earth’s Magneto-Sphere 1

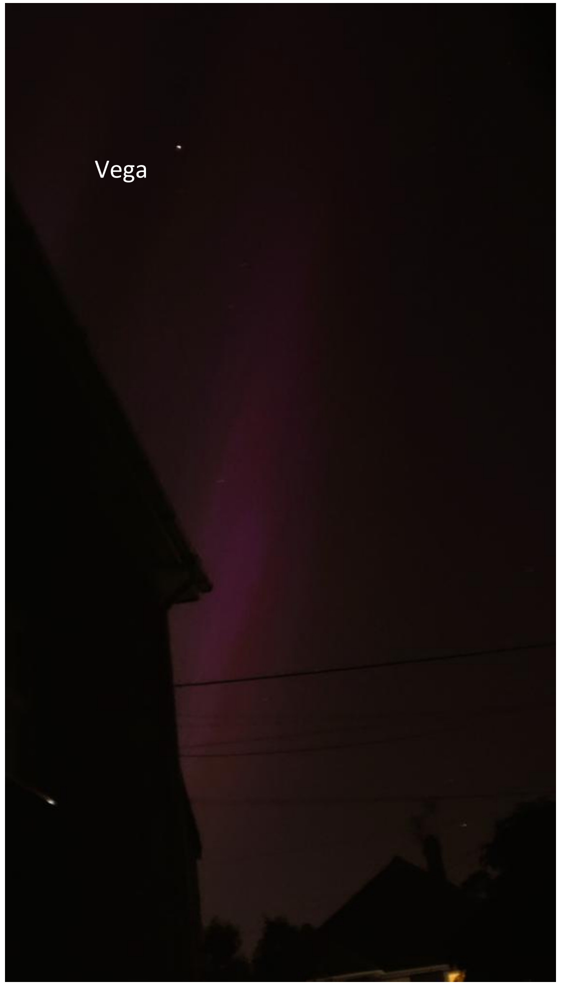
- Interaction causes the Aurora Borealis (North Pole) and Aurora Australis (South Pole), creating stunning light shows where visible.
- The Earth’s own magnetosphere protects the planet from the ravages of the Strong Solar storms.
- But the Sun’s strong Geomagnetic energy can interfere with electronic systems including Satellites, GPS and Power Grids and Mobile Networks.
- An example of this was the “Carrington Event” of 1859 which disrupted telegraph sysetms and even causing fires on Earth.



Interaction of Solar Wind with Earth’s Magneto-Sphere 2



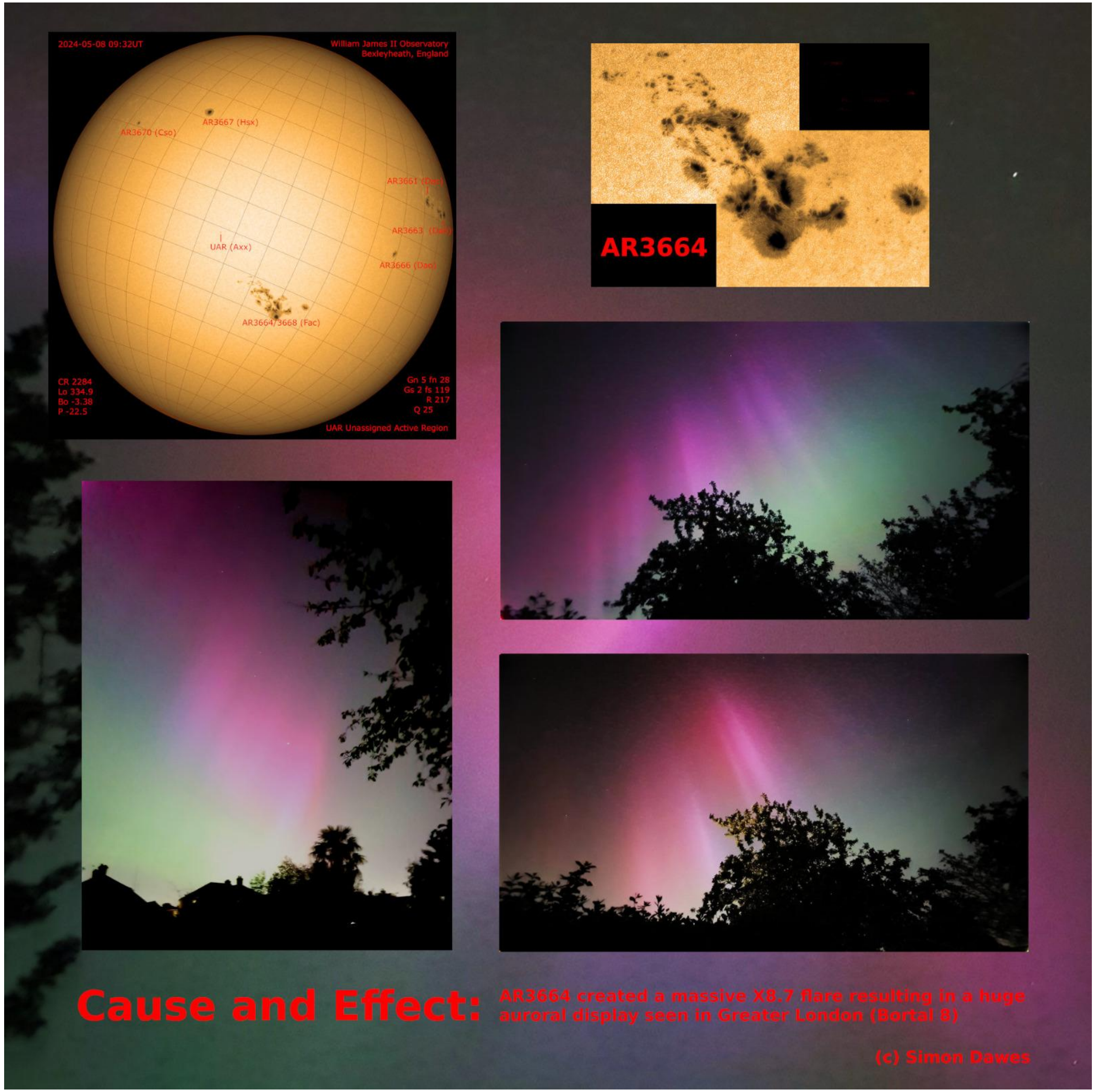
Auroral Images over Hextable 10th May 2024



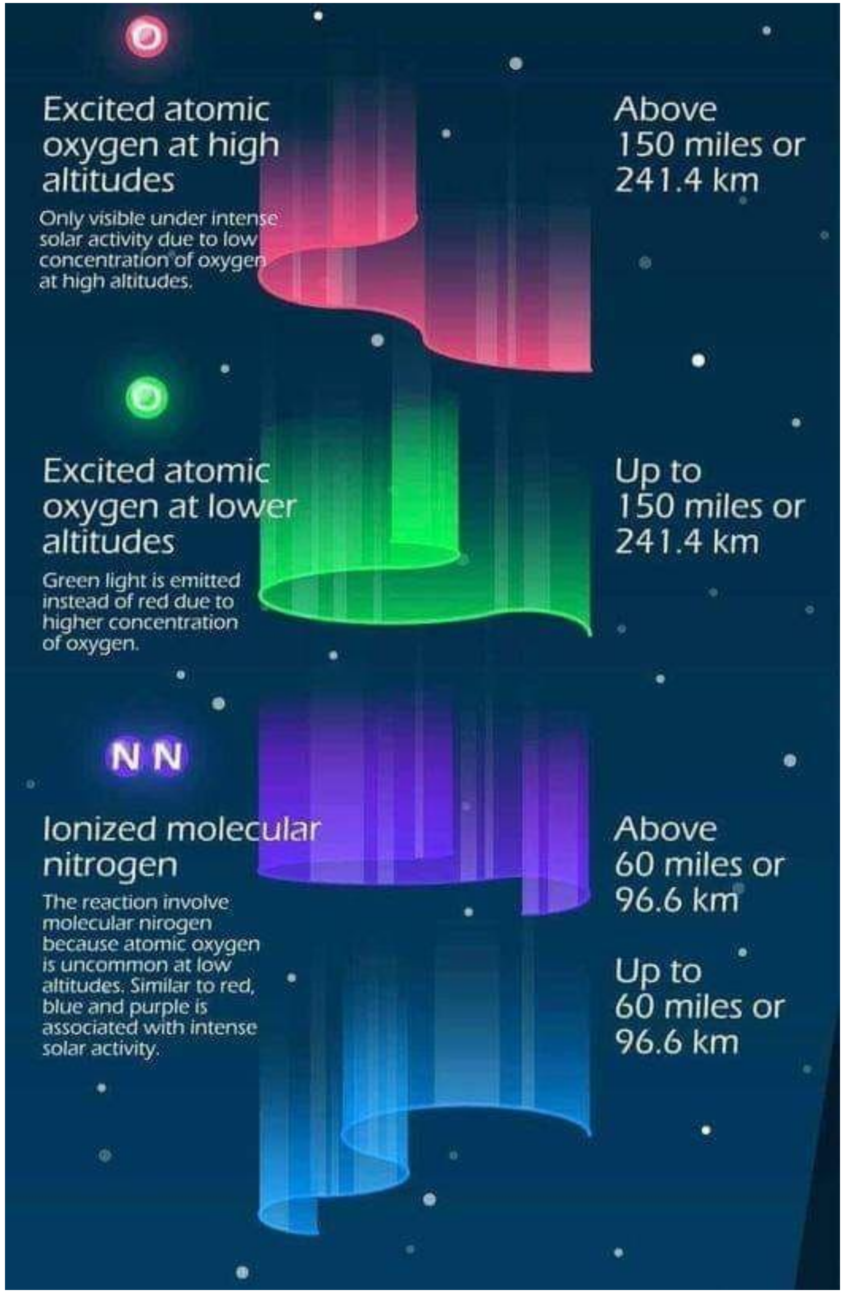
Cause & Effect

Courtesy Simon Dawes

- AR3664 created a massive X8.7 flare resulting in a huge auroral display seen in London (Bortle 8) on Friday 10th May 2024.
- The Auroral display was seen as far South as Bexhill-on-Sea and probably further South, reported to reach 23 degrees North or around the tropic of Cancer.
- It was the largest such far-reaching event seen for many years and gave a spectacular light show



Aurora Colours

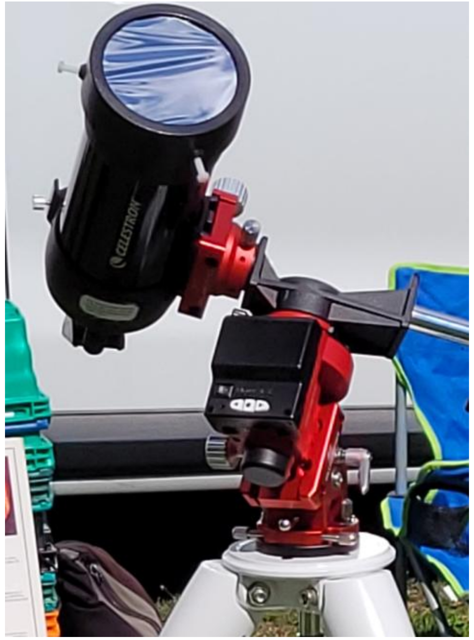


What is a Solar Eclipse?

- Sometimes the Moon comes between the Sun and Earth. If all three are aligned, the Moon can block the Sun entirely, casting a shadow on Earth and causing a solar eclipse. This is because even though the Sun is 400 times larger than the Moon, the Moon is 400 times closer to Earth.
- Solar eclipses occur roughly every six months, but total solar eclipses, in which the Sun is completely obscured by the Moon, are much rarer. They tend to occur around every two years, although often in remote areas of the Earth. These total eclipses can last for as little as a few seconds, but never longer than seven minutes.

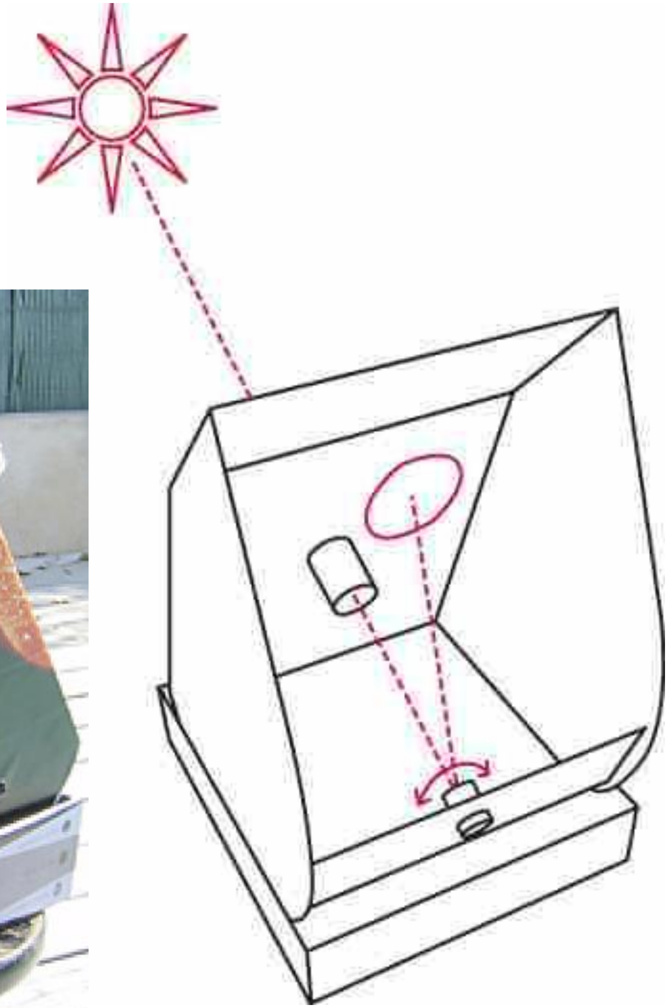
Different Techniques for Solar Observing

- Using a SolarScope
- Visual Observing using a traditional telescope with protective Solar Filter (see image to the right)
- Using a H-alpha Telescope
- Using a Smart electronic Telescope
- Satellite in Space



SolarScope Basic Function

- The SolarScope employs a light gathering tube that holds a primary lens that is focused onto a reflecting lens and the image of the Solar disc is displayed on the white inside of the rear back panel.



How do we study the Sun in Space?

- Due to its extreme temperatures studying the Sun with spacecrafts is incredibly difficult. We have to rely on observations using telescopes and cameras on Earth satellites.
- However, in 2020 the European Space Agency and NASA launched the **Solar Orbiter**, which will enter an elliptical orbit of the Sun allowing unprecedented observations.
- After taking three and a half years to reach the Sun, it will begin a seven-year mission to study the stars solar wind, magnetic fields, and plasma. It will orbit as close as 42 million kilometres from the Sun's surface, closer even than Mercury.
- Other solar observing satellites include: Deep Space Climate Observatory (DSCOVR); the NASA Solar and Heliospheric Observatory (SOHO) and NASA STEREO-A.

Partial Solar Eclipse 12th August 2026 Planning and Preparation

- Ensured Latest App Beta version and Firmware installed on mobile and Dwarf3.
- Run Tests and trial captures using all tools to be used on the day.
- On the day set up rig and took a stacked image of the Sun a little before the onset of the Partial Eclipse to ensure centring and tracking of the Sun.
- Facility to double tap the Sun in Wide to centre it makles the process quicker.
- Set the time-lapse Shooting as calculated

Output MP4 fps	Shooting Duration (M)	Shooting Duration (S)	Shooting Interval (S)	Images Captured	Time-Lapse Duration (S)
30	240	7200	15	480	16
30	240	7200	1	7200	240

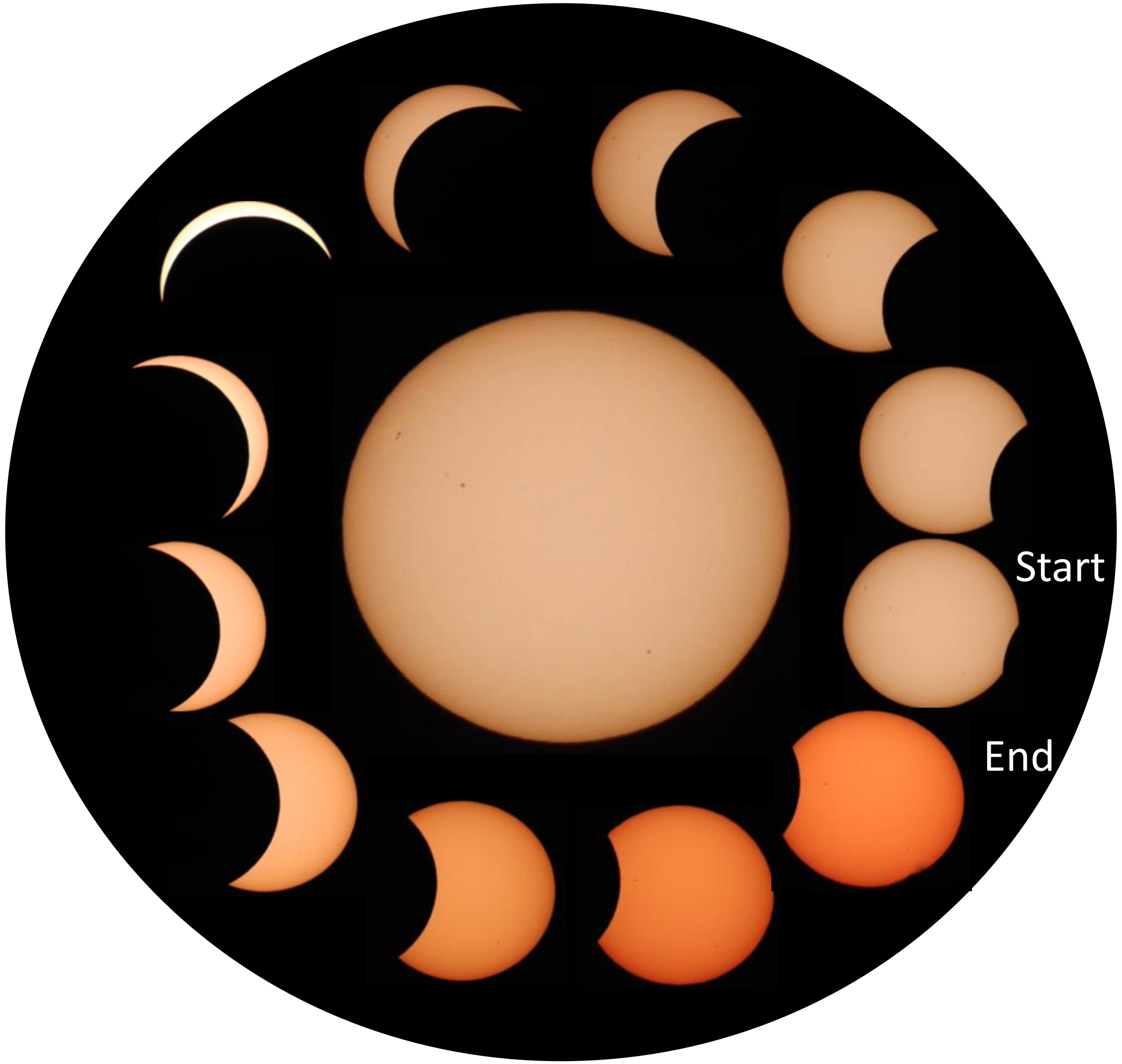
- Set Exposure = Auto; Filter = VIS; Gain = 0; AWB = Sunlight.
- Set the Shooting Duration (7200S for 2 hours) and Shooting Interval (George selected 15S and Tina selected 1S)
- Start the time-lapse a little before first contact of the Partial Eclipse.
- End the time-lapse a little after last contact of the Partial Eclipse or disappeared Sun.

Partial Eclipse Sequence from 12th August 2026

- Playback at Full Speed.
- Minor movements from Dwarf3 maintaining tracking of the Sun.
- Larger movements for same reason either side of peak Partial Eclipse

Partial Eclipse Sequence images from 12th August 2026

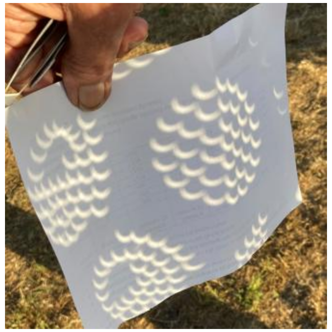
- Central image of the Sun taken when setting up to centralise and track it ready to start the time-lapse sequence capture.
- All other images taken as clippings at each pause in the playback to show this sequence.



Observation Tools Used on 12th August

A variety of telescopes were used on the day including:

- Smart telescopes such as Dwarf 3, Seestar S30 and S50
- Solar Scopes to view/capture in Hα, e.g. Lunt, Coronado, Solarmax, Acuter
- Refractors and Reflector telescopes – many personal and some from the Society (Anita & Tiny). All had Solar filters attached to the front.
- Cameras (some attached to scopes others held) and mobile phones.
- Eclipse Shades worn by many.
- Colander and Paper.



- Cereal boxes made up as Camera Obscura.
- Lots of Excitement, a great day!

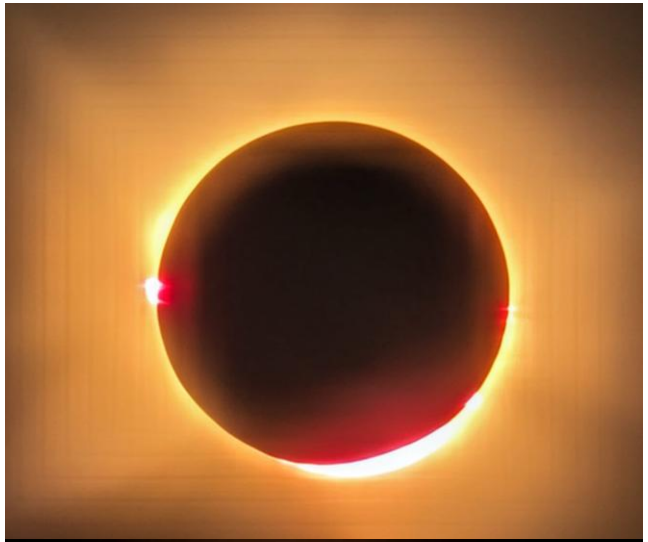
Observers and Visitors on the day

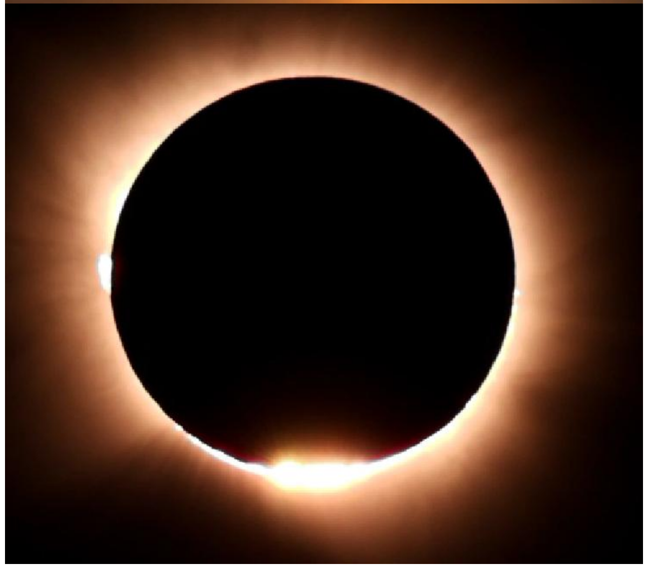
Gary estimated over 80

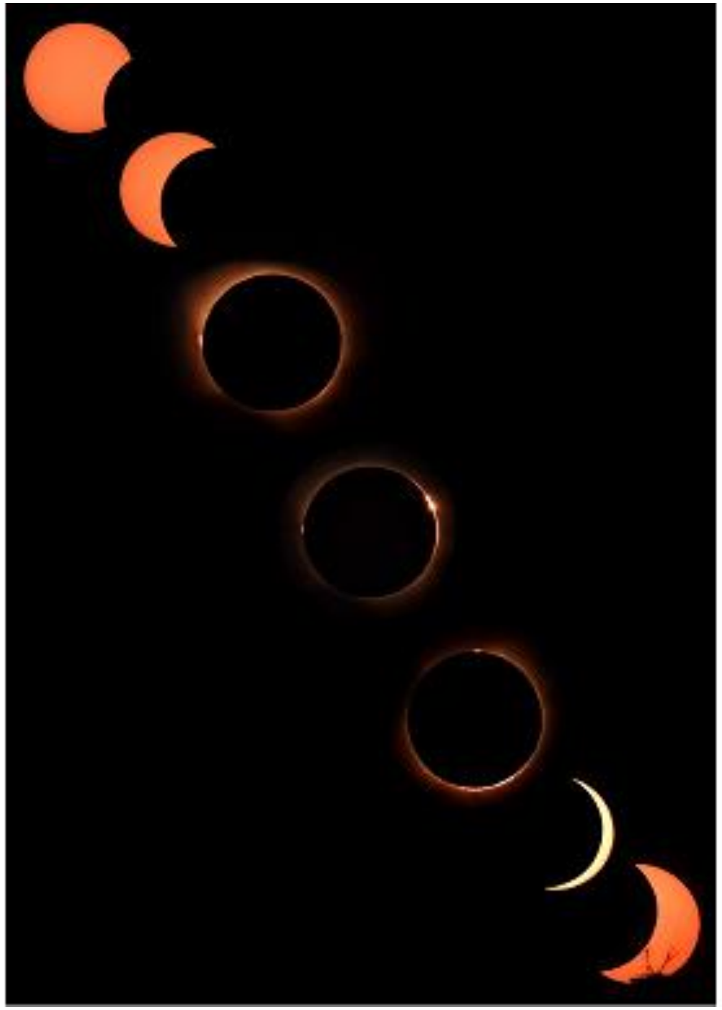
Some Total Eclipse Images Captured in Spain

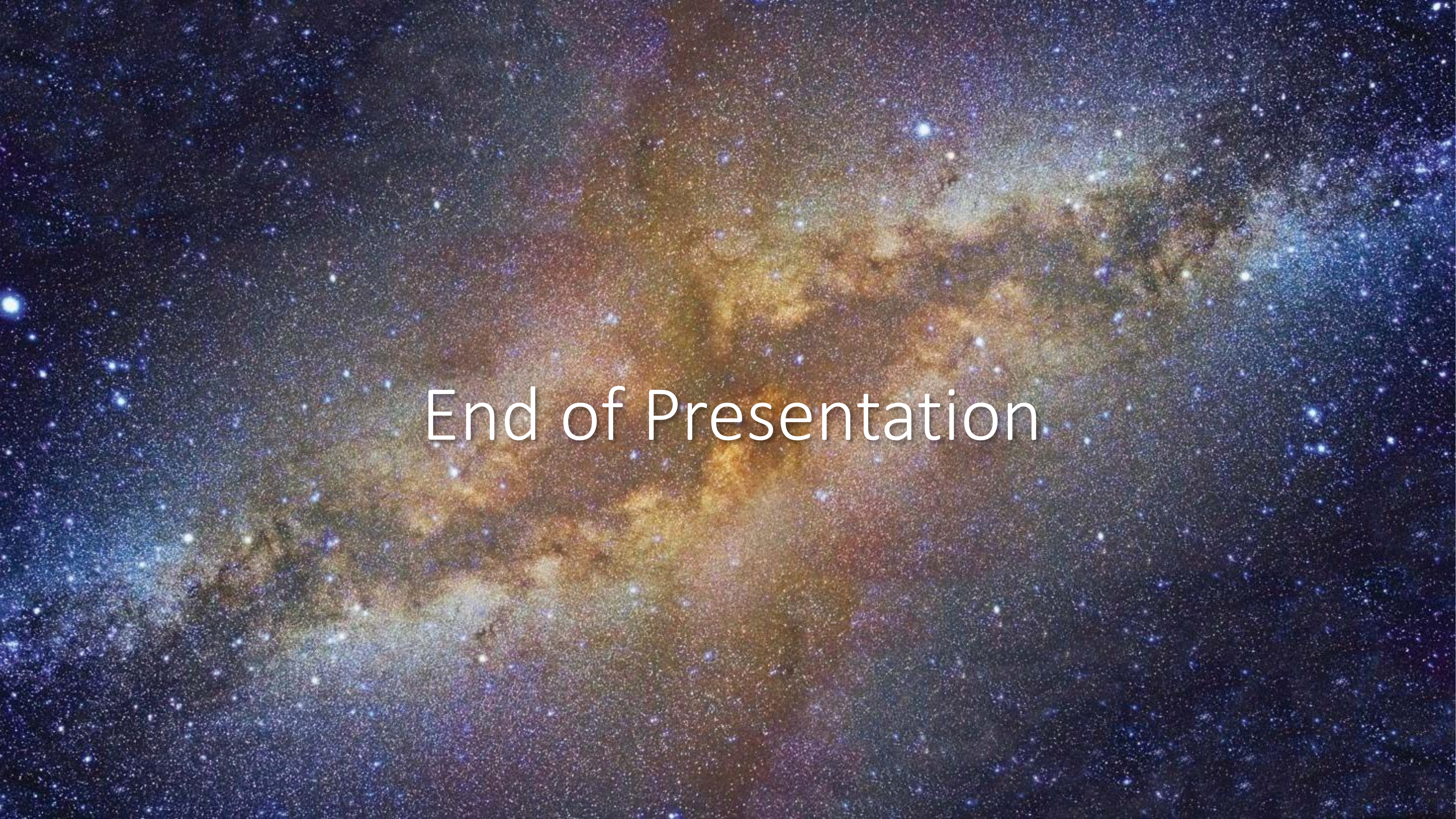
Examples of some posted on the CMHASD WhatsApp and sent by DwarfLabs

- Top left image is from a friend of Jo's.
- Bottom left is a still from John Archer's Video clip.
- Right image taken by asenav13 on a Dwarf mini in Zaragoza and sent by DwarfLabs.









End of Presentation