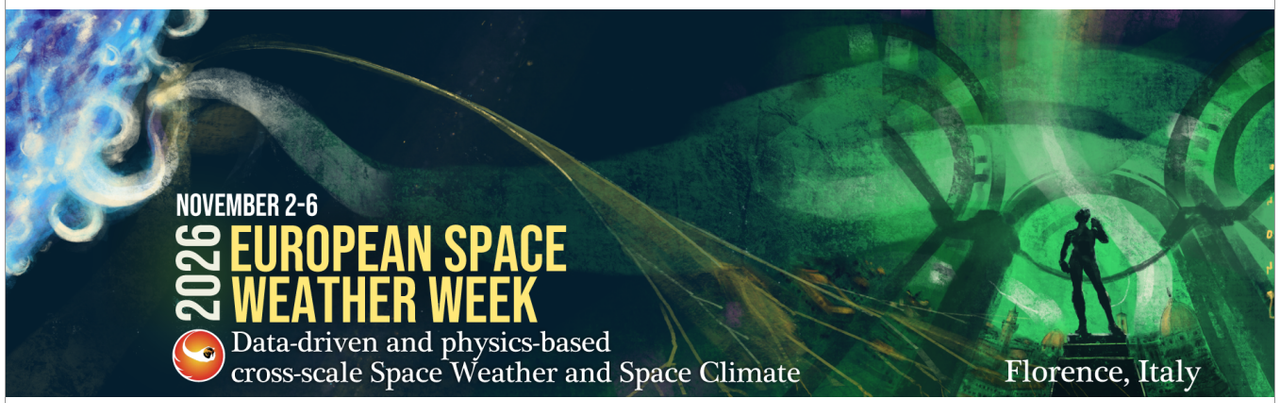
Space Weather Training Course

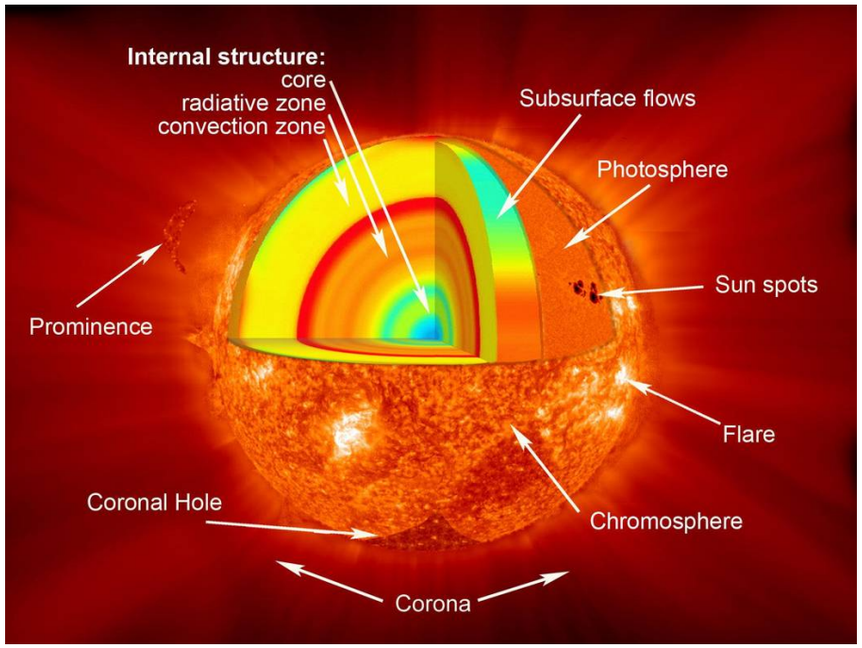


Collaboration of

e-SWAN

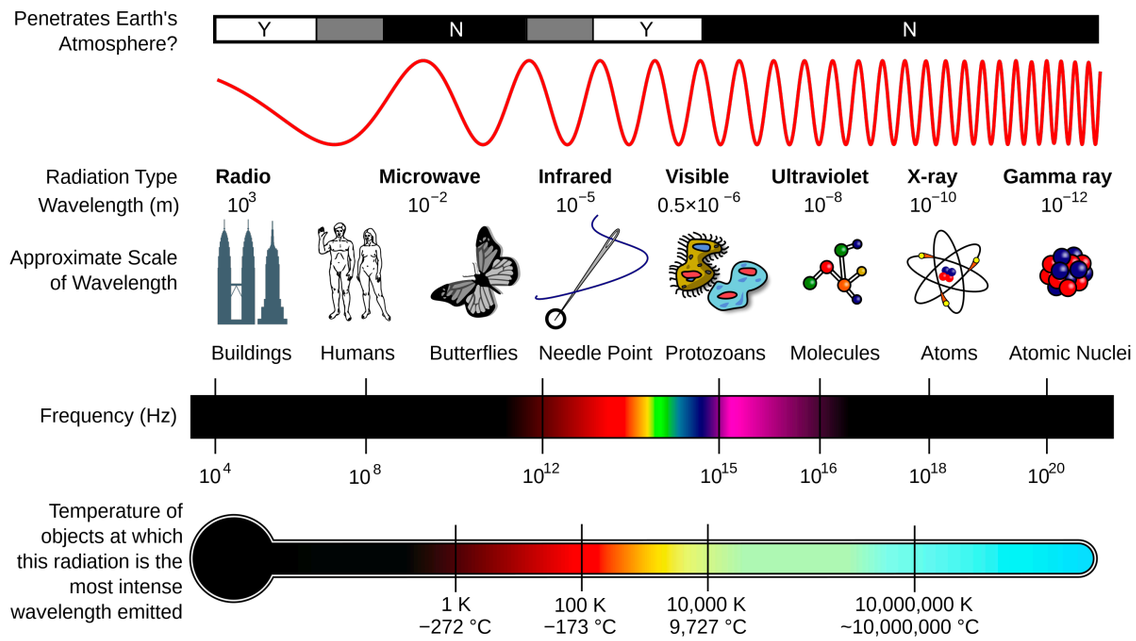
SWEC
Space Weather Education Centre

COMMUNITY COORDINATED MODELING CENTER



LAYERS OF THE SOLAR ATMOSPHERE

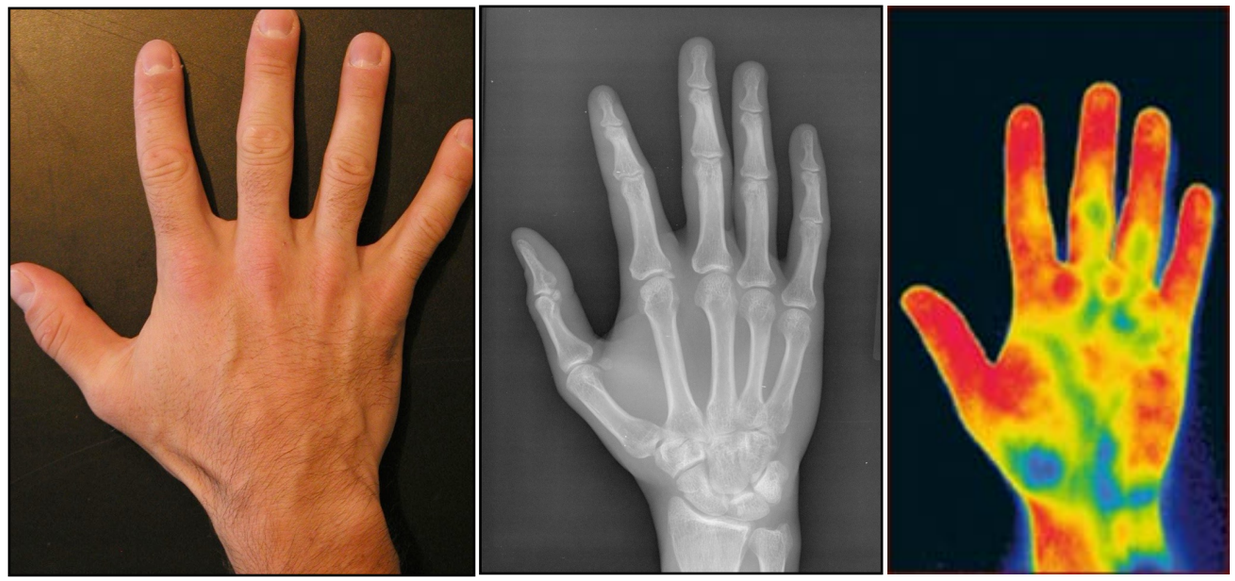
ELECTROMAGNETIC SPECTRUM



The electromagnetic spectrum ranges from radio waves to gamma rays.
As we move to higher temperatures, the wavelengths get shorter.
We can only use longer wavelengths such as radio and visible light to observe the Sun from ground, (E)UV wavelengths are absorbed by the atmosphere. We need satellites to observe in EUV.
Once the space age began, we were given a completely new view of the Sun.

H-alpha 656.28 nm - red - 9000 °K
C II K 3933.7Å - 393.37 nm - blue
Visible light: 780 - 380 nm / 7800- 3800 Angstrom / rainbow
UV: 380 - 10 nm / 3800 - 100 Angstrom
EUV: 100 - 10 nm / 1000 - 100 Angstrom

ELECTROMAGNETIC SPECTRUM

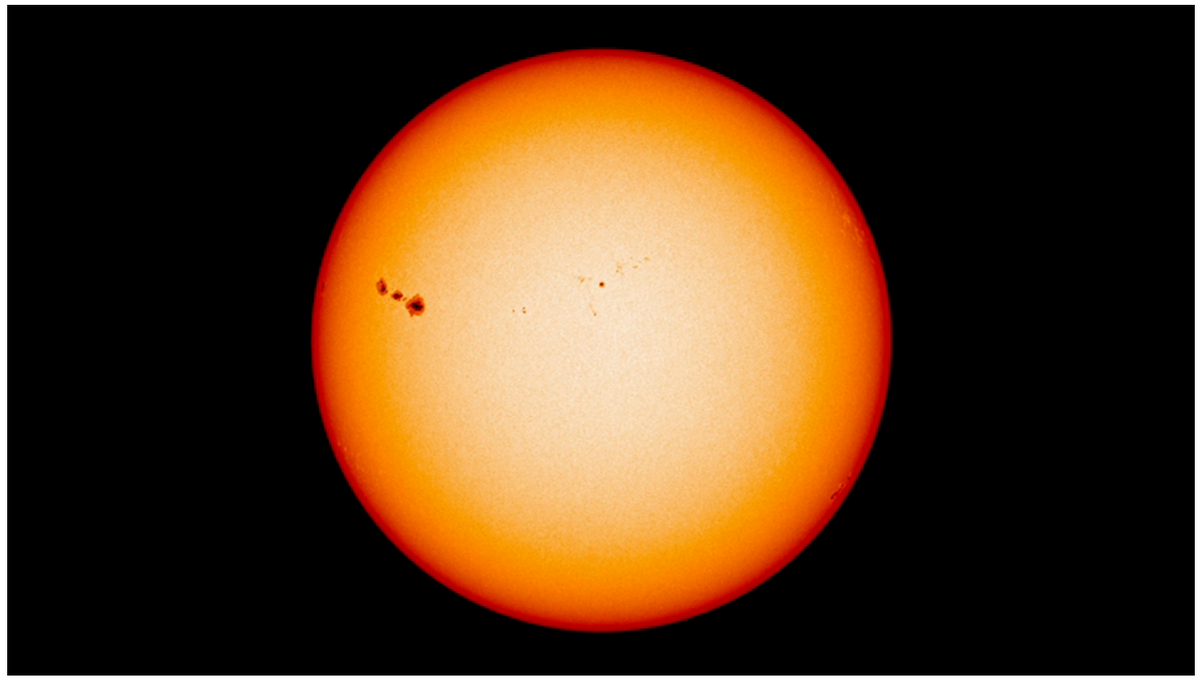


To study a **distant** object, **we can not take in-situ measurements**, but we can take pictures (**remote sensing**).
Similarly, a doctor can use an x-ray camera to image your bones. In fact, an x-ray picture shows the shadow of your bones which are not transparant for x-rays. The softer parts of your hand are partly transparant for x-rays, and are thus less visible in the image.

These pictures can show doctors parts of your body that they can't normally see.
Each wavelength gives complementary information.

Right image: temperature measured using infrared waves, red=cold and blue=warm in this color scale.

ELECTROMAGNETIC SPECTRUM



SDO/AIA

The Sun has a hidden region that became only visible at the start of the space age. From the moment we could inspect the Sun in other wavelengths, the Sun showed its dynamic, explosive and magnetic personality.

Indeed, we use many tricks to observe the Sun and its activity. One of them is to look at the Sun using different parts of the light spectrum, thus in different wavelengths. From Earth, with the naked eye, we see the surface of the Sun in white light like this.

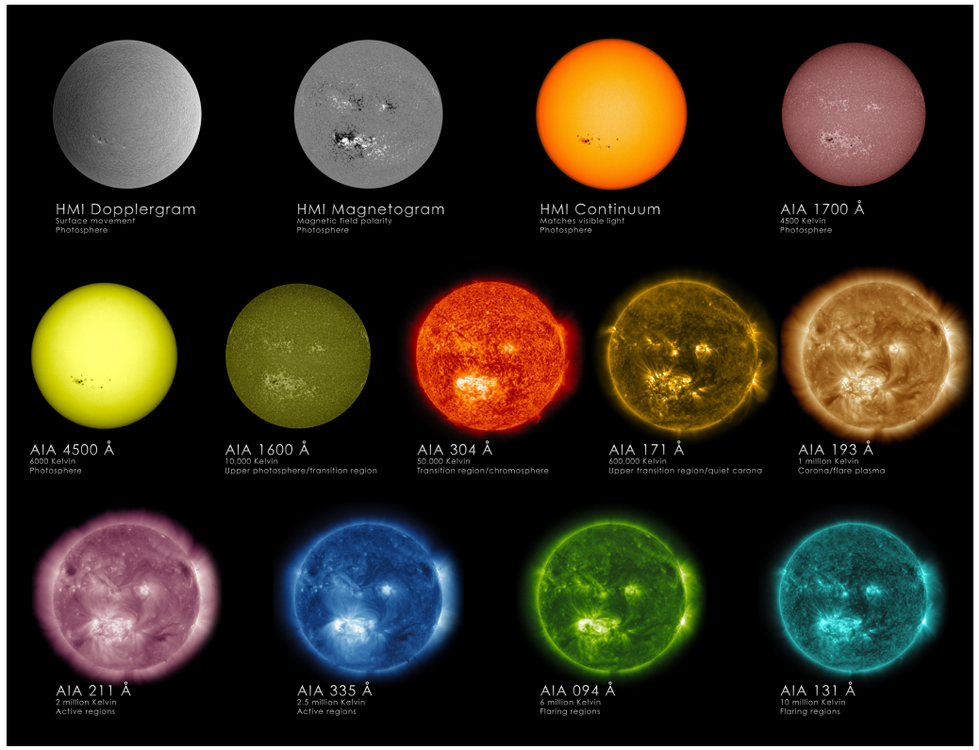
However, when the movie starts, you can see how looking at the Sun in other wavelengths (from space) reveals very different structures and complexity. For this we mainly use extreme ultraviolet wavelengths because we are studying the hot outer region of the Sun, the corona. We see active regions, these are the bright patches, that show up in EUV wavelengths where the sunspots were first seen in white light. We also see the effects of the sun's magnetic field in the many loops above these sunspots. Each wavelength shows us different aspects and different layers of the solar atmosphere and by combining them, we try to build a complete picture of the solar activity.

Therefore, we have many instruments in space to observe the solar atmosphere.

Credits: This movie was made combining different observations from the Atmospheric Imaging Assembly (AIA) telescope on board the Solar Dynamics Observatory (SDO).
https://youtu.be/g08XKIz2SD0

MANY DIFFERENT FACES

SDO/AIA & HMI



The Sun has many different faces. Here you see images taken of the Sun in different wavelengths at approximately the same time by the Atmospheric Imaging Assembly (AIA) and the Helioseismic and Magnetic Imager (HMI) on-board the Solar Dynamics Observatory (SDO). Each wavelength reveals a different aspect of the solar activity, e.g. bright regions called active regions or dark spots called sunspots.

At the top you see a magnetogram, which shows you the strength of the solar magnetic field. You immediately see that the field is very strong at the location of the sunspot seen in the photospheric image just to the left of the magnetogram.

So both sunspots and active regions are different features indicating the same area of strong magnetic field.

Another example: flaring in active region 1158
https://www.youtube.com/watch?v=u6PSejWooNM

From the sun's surface on out, the wavelengths SDO observes, measured in angstroms, are:

4500: Showing the sun's surface or photosphere.

1700 (roos/paars): Shows surface of the sun, as well as a layer of the sun's atmosphere called the chromosphere, which lies just above the photosphere and is where the temperature begins rising.

1600: Shows a mixture between the upper photosphere and what's called the transition region, a region between the chromosphere and the upper most layer of the sun's atmosphere called the corona. The transition region is where the temperature rapidly rises.

304: This light is emitted from the chromosphere and transition region.

171: This wavelength shows the sun's atmosphere, or corona, when it's quiet. It also shows giant magnetic arcs known as coronal loops.

193: Shows a slightly hotter region of the corona, and also the much hotter material of a solar flare.

211: This wavelength shows hotter, magnetically active regions in the sun's corona.

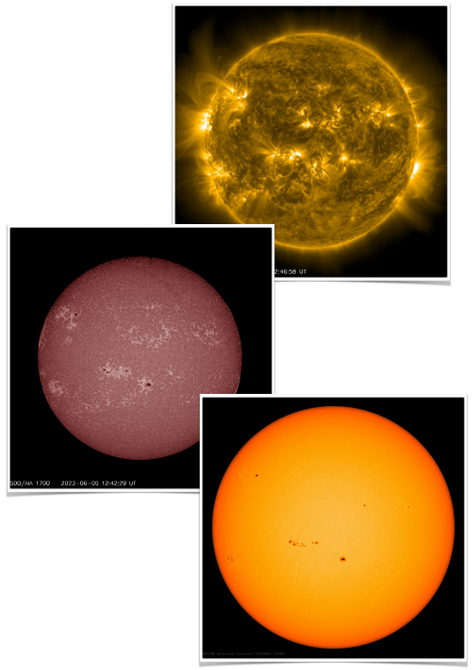
335: This wavelength also shows hotter, magnetically active regions in the corona.

94 (groen): This highlights regions of the corona during a solar flare.

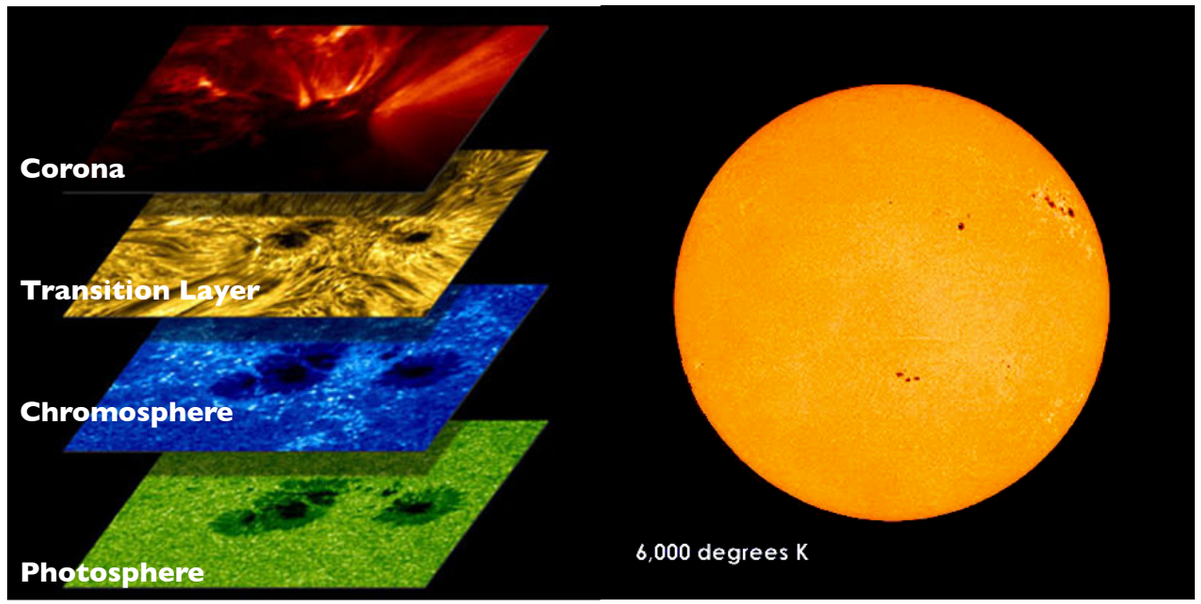
131: The hottest material in a flare.

LAYERS OF THE SUN

- Corona
  (visible during eclipse as atmosphere extending from the Sun into space)
- Chromosphere
  (visible during eclipse as red color on edge of Sun)
- Photosphere
  (visible sunspots, granulation)



LAYERS OF THE SUN



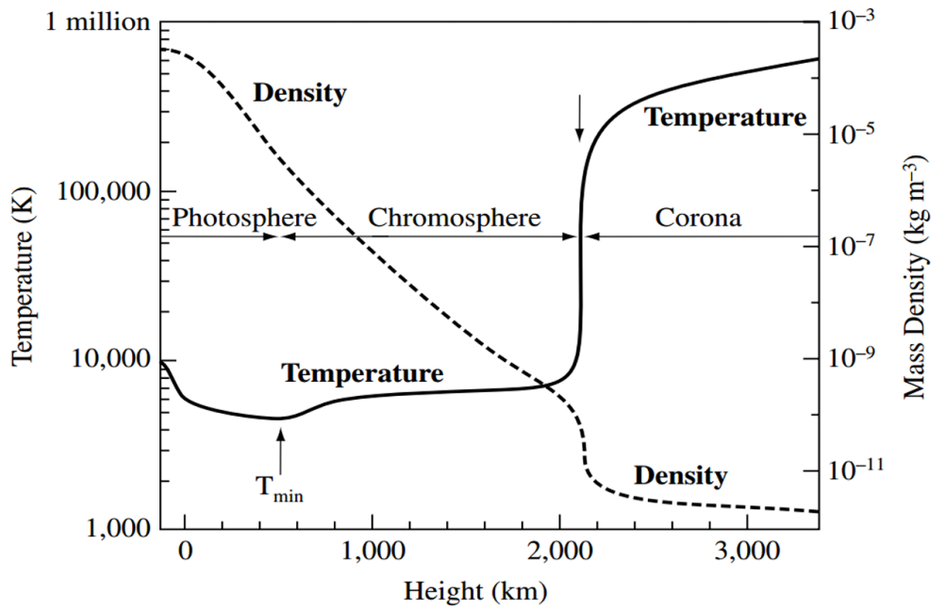
The solar atmosphere is formed by the most outer layers of the Sun from where the solar radiation can escape freely, in contrast to the un-transparant inner layers.
The solar atmosphere has 4 basic layers: photosphere - chromosphere - transition layer - corona.

Temperature increases as you go higher up to the outer layers, which is sort of strange. Normally you would think that the temperature decreases if you go further away from the heat source. Why is the corona so hot? This is a hot topic in solar research and still subject of debate.

The name photosphere comes from the greek work photon which means ‘light’. The photosphere radiates mostly in visible light, which we can see from ground.
In contrast, the corona radiates in (E)UV and X-rays, wavelengths which we can not see with our eyes. That’s why we see the Sun as a non-dynamic structure. The coronal loops and dynamic structures in the corona are invisible to us unless we observe them in the EUV using special filters translating the EUV into a picture which we can see.

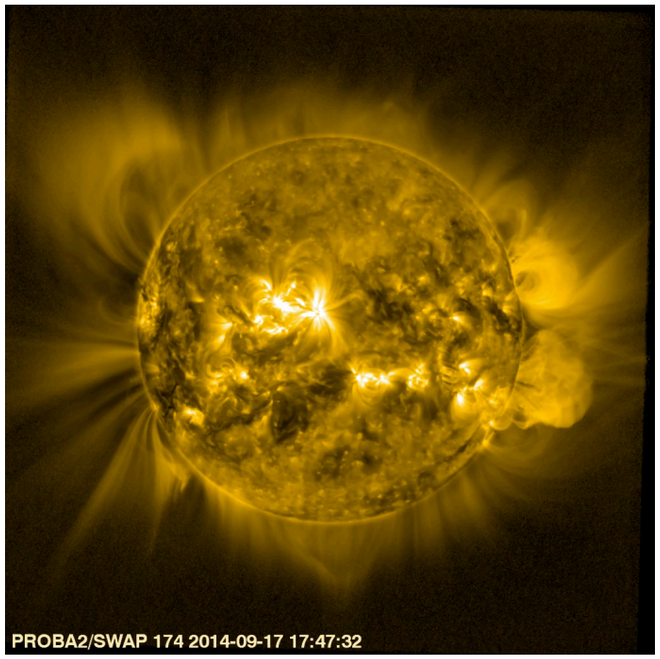
Corona (visible during eclipse as atmosphere extending from the Sun into space)
Chromosphere (visible during eclipse as red color on edge of Sun)
Photosphere (visible sunspots, granulation)

LAYERS OF THE SUN



But, although the corona is a million degrees Kelvin hot, satellites don't burn up. This is because the corona is not dense at all. Compare this with a sauna and a bath. You can sit in a sauna of 90°C but not take a bath of 90°C. The air is the sauna is less dense than the water in the bath, which is why you don't get burned in the sauna.

WHICH LAYER IS THIS?

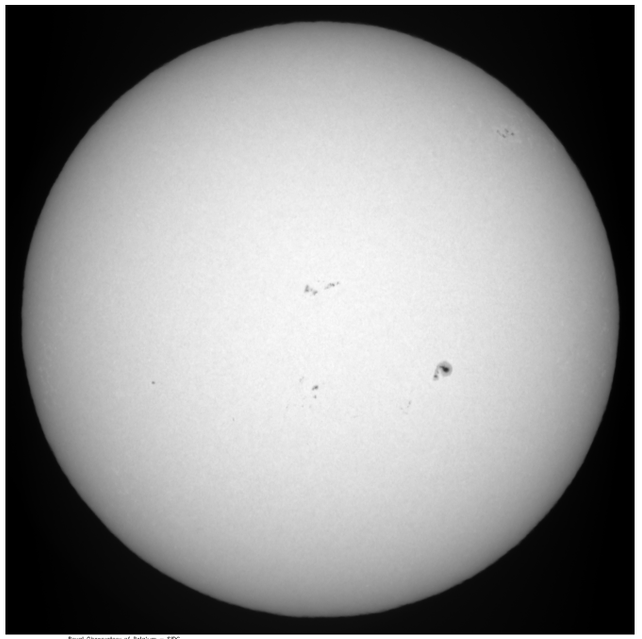




PROBA2/SWAP

Corona ~ 1 million degrees

WHICH LAYER IS THIS?

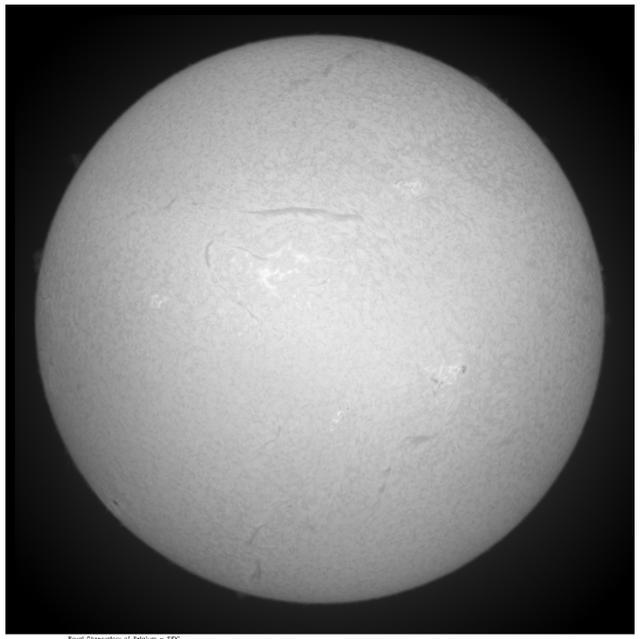




USET

Photosphere – sunspots – 6000 degrees

WHICH LAYER IS THIS?

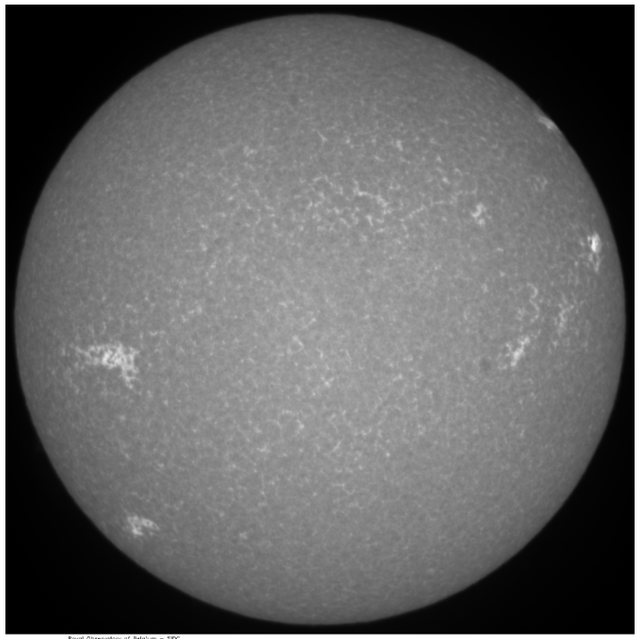




USET

H-alpha line - Red part of visible spectrum
chromosphere - filaments
Flares can be observed directly in this layer as bright structures

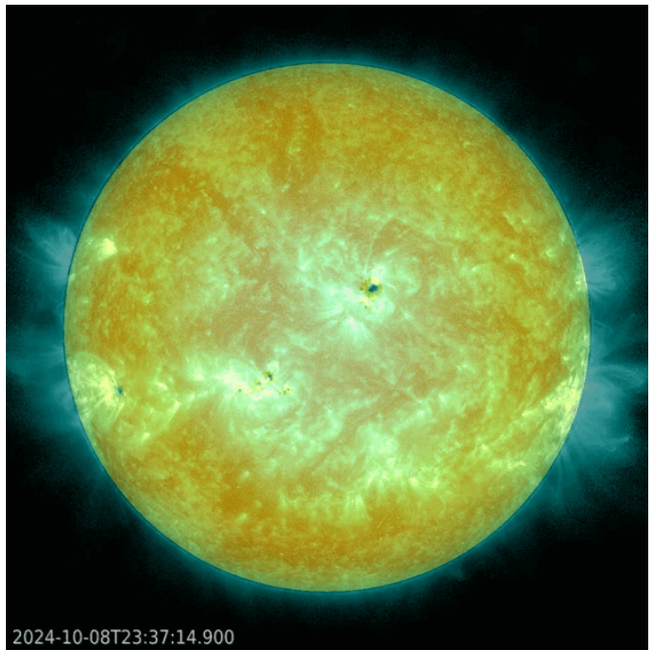
WHICH LAYER IS THIS?





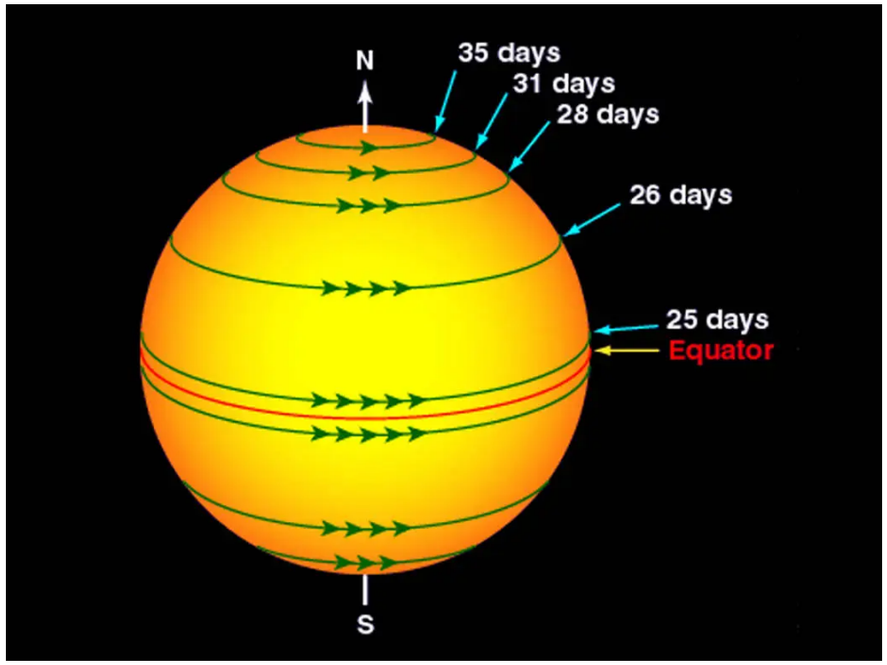
USET

CAII line - Blue part of visible spectrum (near UV light) - still chromosphere
no prominences visible so unobstructed view of the chromospheric network (large scale convection cells)
Bright regions are chromospheric plages



BASIC CONCEPTS

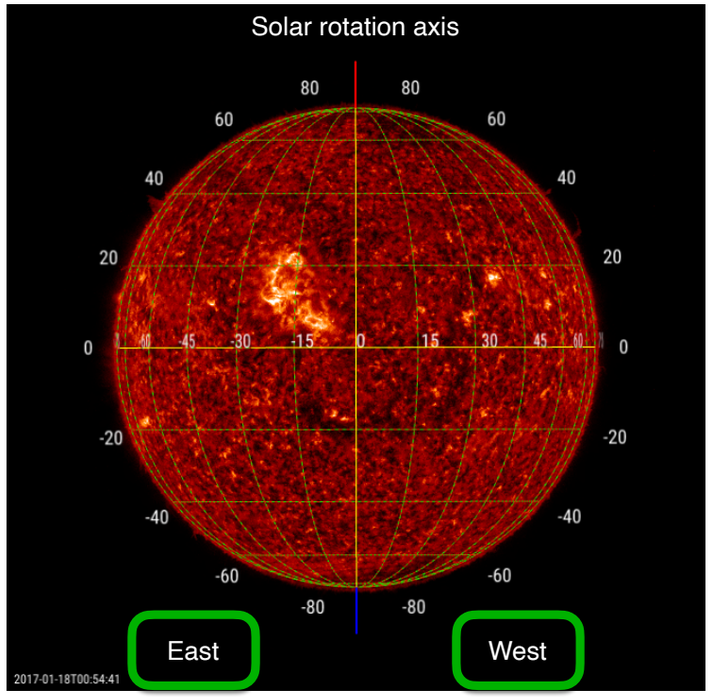
DIFFERENTIAL ROTATION



The Sun rotates from (solar) East to West, so left to right in approximately 27 days (at the equator, 35 days at poles). We can see (some types of) activity coming on the East limb and predict the effects of possible related space weather.

Image from: https://www.nasa.gov/image-article/solar-rotation-varies-by-latitude/
“The Sun rotates on its axis once in about 27 days. This rotation was first detected by observing the motion of sunspots. The Sun’s rotation axis is tilted by about 7.25 degrees from the axis of the Earth’s orbit so we see more of the Sun’s north pole in September of each year and more of its south pole in March.
Since the Sun is a ball of gas/plasma, it does not have to rotate rigidly like the solid planets and moons do. In fact, the Sun’s equatorial regions rotate faster (taking only about 24 days) than the polar regions (which rotate once in more than 30 days). The source of this “differential rotation” is an area of current research in solar astronomy.”

POSITIONING



Solar North Pole

Magnetic North Pole
Negative/Inward

Northern hemisphere

Solar Equator

Solar South Pole

Magnetic South Pole
Positive/Outward

Southern hemisphere

Eastern hemisphere

Central meridian

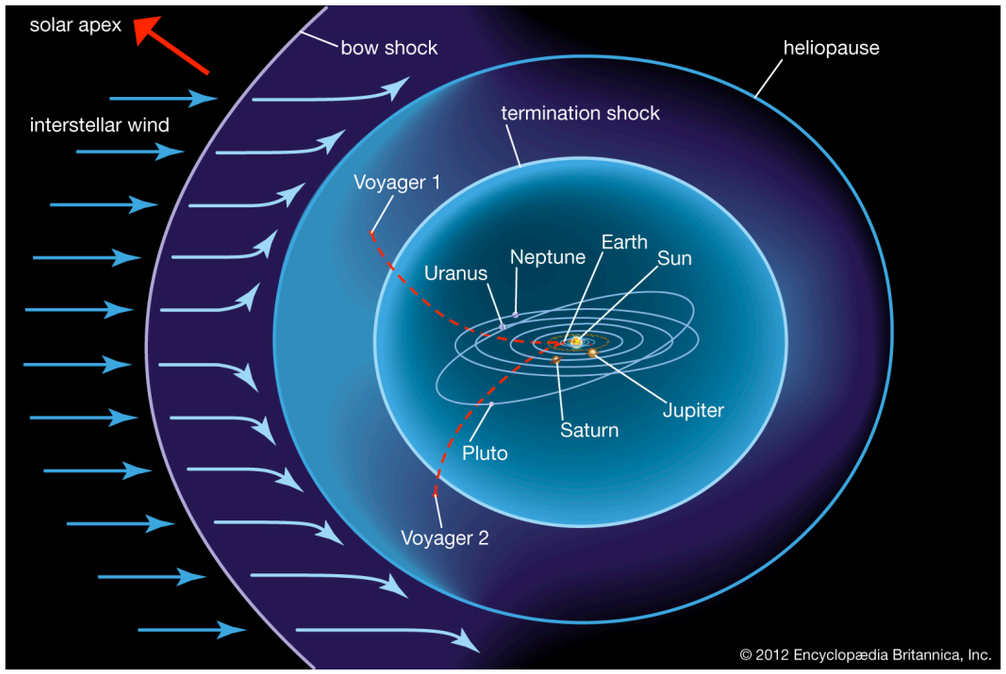
Western hemisphere

Before going into more detail of the space weather ingredients, we have to be able to ‘navigate’ on the sun.
Two important lines are the central meridian and the solar equator. With these, you determine positions on the solar surface (east/west and north/south, respectively).

Currently (early 2025), the solar north pole is the magnetic north pole, which means the magnetic field there is negative and inward directed. (See e.g. http://wso.stanford.edu/gifs/Polar.gif)
Every 11 years, there is a magnetic field reversal where the magnetic north pole becomes the magnetic south pole (and vice versa). This happens at the time of solar maximum. This leads to a full magnetic cycle of 22 years (return to original polarities).

During the previous solar cycle (SC 24), there was an unusually long reversal in the field in the northern solar hemisphere: this started as early as June 2012, was followed by a sustained period of near-zero field strength lasting until the end of 2014. Meanwhile, the southern solar hemisphere unambiguously reversed polarity in mid-2013 already.
(https://www.aanda.org/articles/aa/full_html/2018/10/aa32981-18/aa32981-18.html)

HELIOSPHERE



The heliosphere – influence of the solar wind extends far beyond the planets

The heliosphere is the region surrounding the Sun and the solar system that is filled with the solar magnetic field and the protons and electrons of the solar wind.

The solar wind flows outward through the solar system into the interstellar medium (ISM) and begins to feel the effects of the ISM at the termination shock, where the solar wind starts to lose speed. The region beyond the termination shock in which the solar wind slows is called the heliosheath. At the outward boundary of the heliosheath is the heliopause, where the outward pressure of the solar wind balances the pressure of the incoming ISM. The heliopause is usually considered to be the boundary of the solar system and is about **123 astronomical units** (AU; 1 astronomical unit = 150 million km) from the Sun. (By comparison, Neptune, the outermost planet, is 30 AU from the Sun.)
(https://www.britannica.com/science/heliosphere)

https://science.nasa.gov/mission/voyager/where-are-voyager-1-and-voyager-2-now/
On Wednesday, Nov. 18, 2026, at 2:16:07 a.m. PST, NASA's **Voyager 1** spacecraft will be 16.094 billion miles (25.902 billion kilometers) away from Earth — or, the distance light travels in 24 hours, also known as one **light-day**.

Voyager 1 will be the first human-made object to reach this distance from Earth, adding to a long list of historic firsts for the mission. Voyager 1 and its twin, Voyager 2, are the only spacecraft to ever operate outside the heliosphere, or the protective bubble of particles and magnetic fields generated by the Sun.