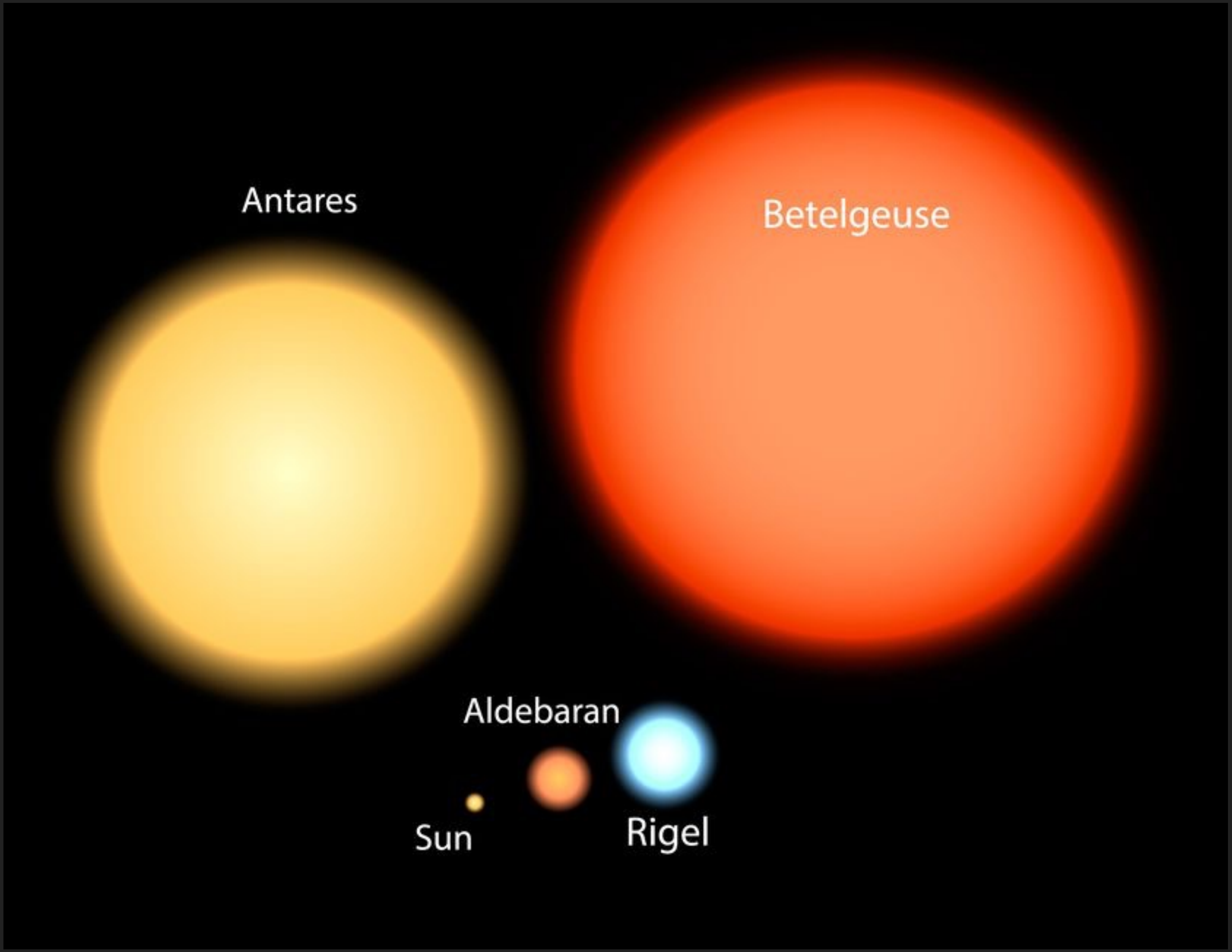
THE SUN

ASTROPHYSICS

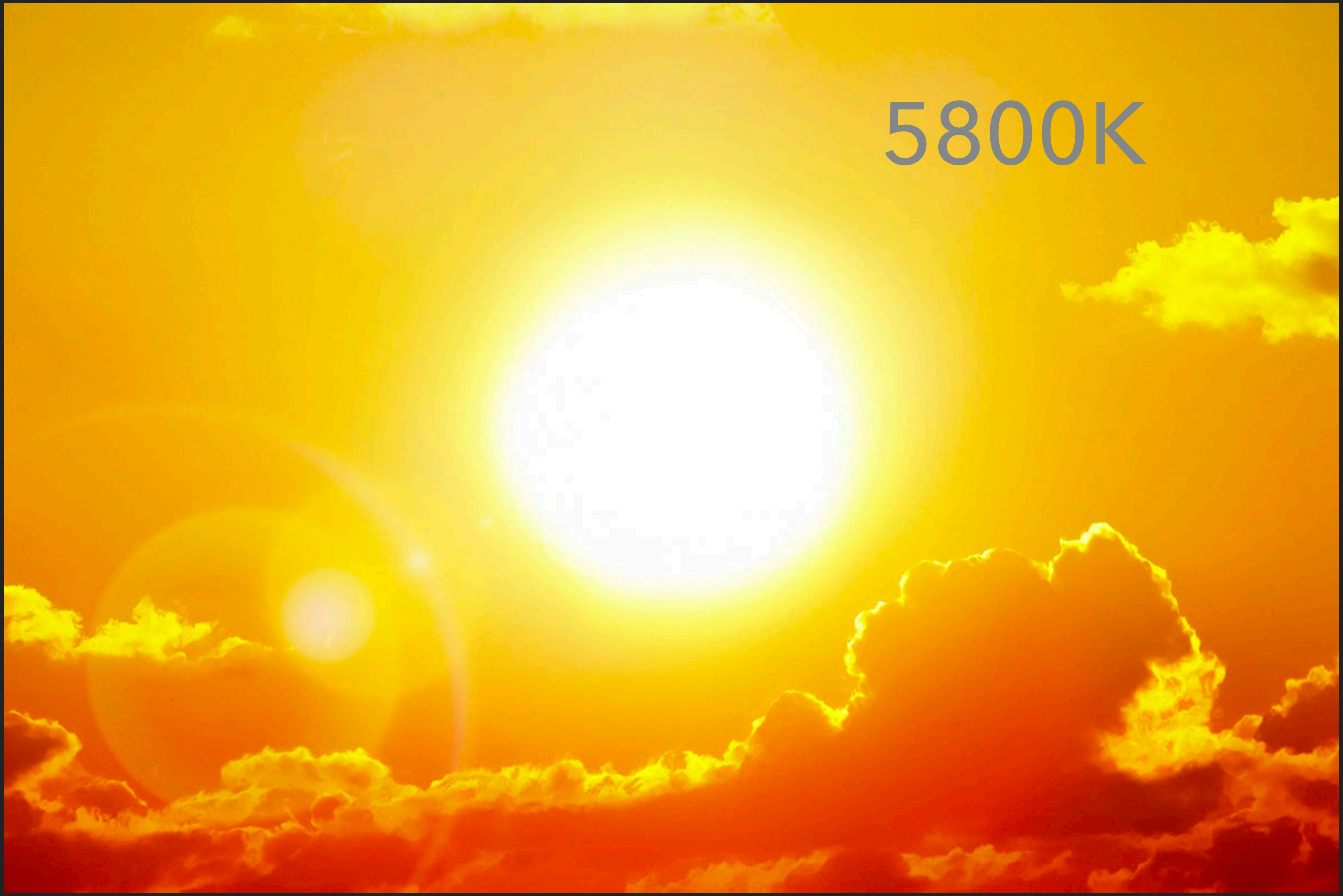
Dr H.T.Sener

WHY IS SUN IMPORTANT?

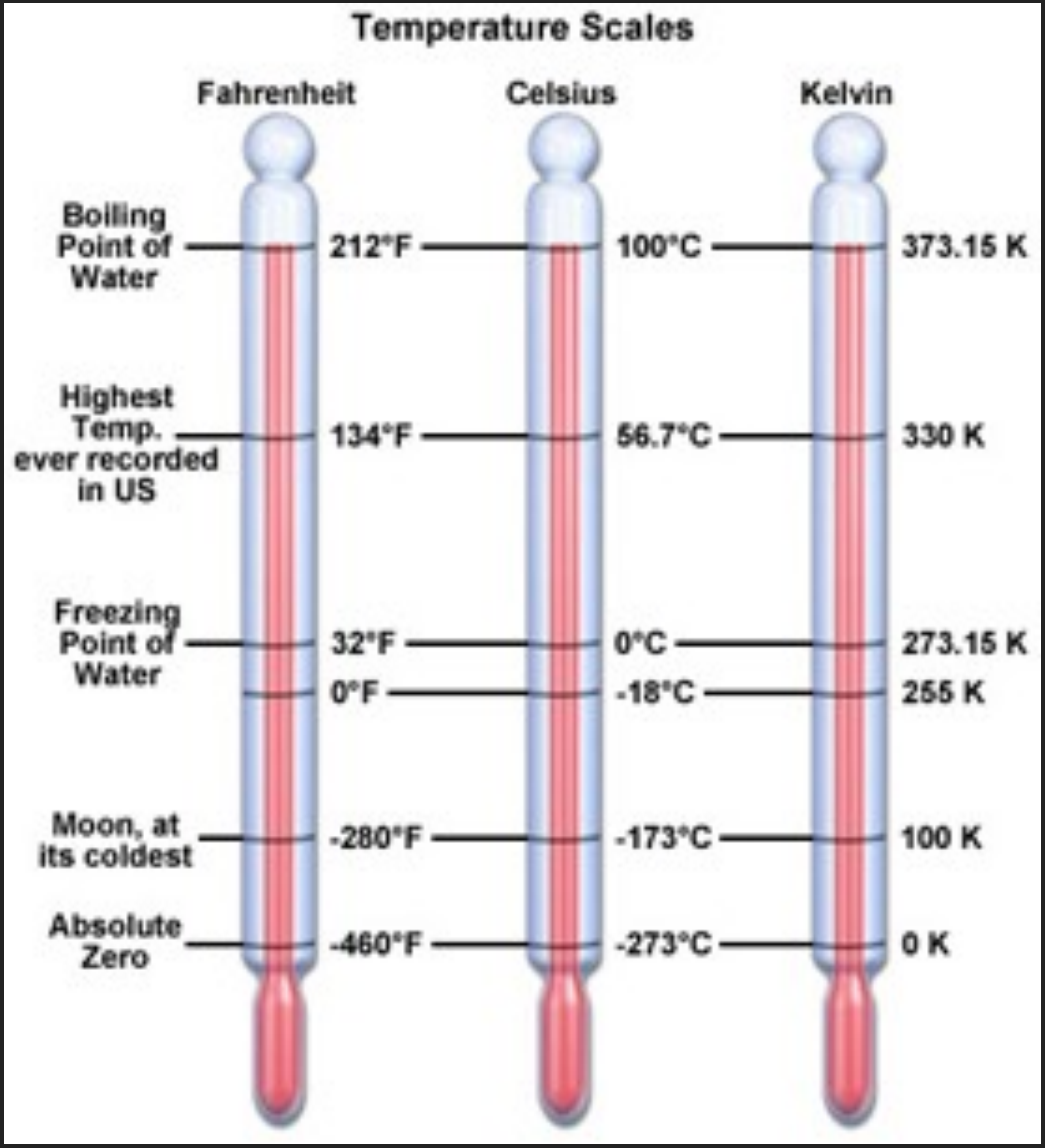


PHYSICAL PROPERTIES OF THE SUN

- How hot is the Sun?

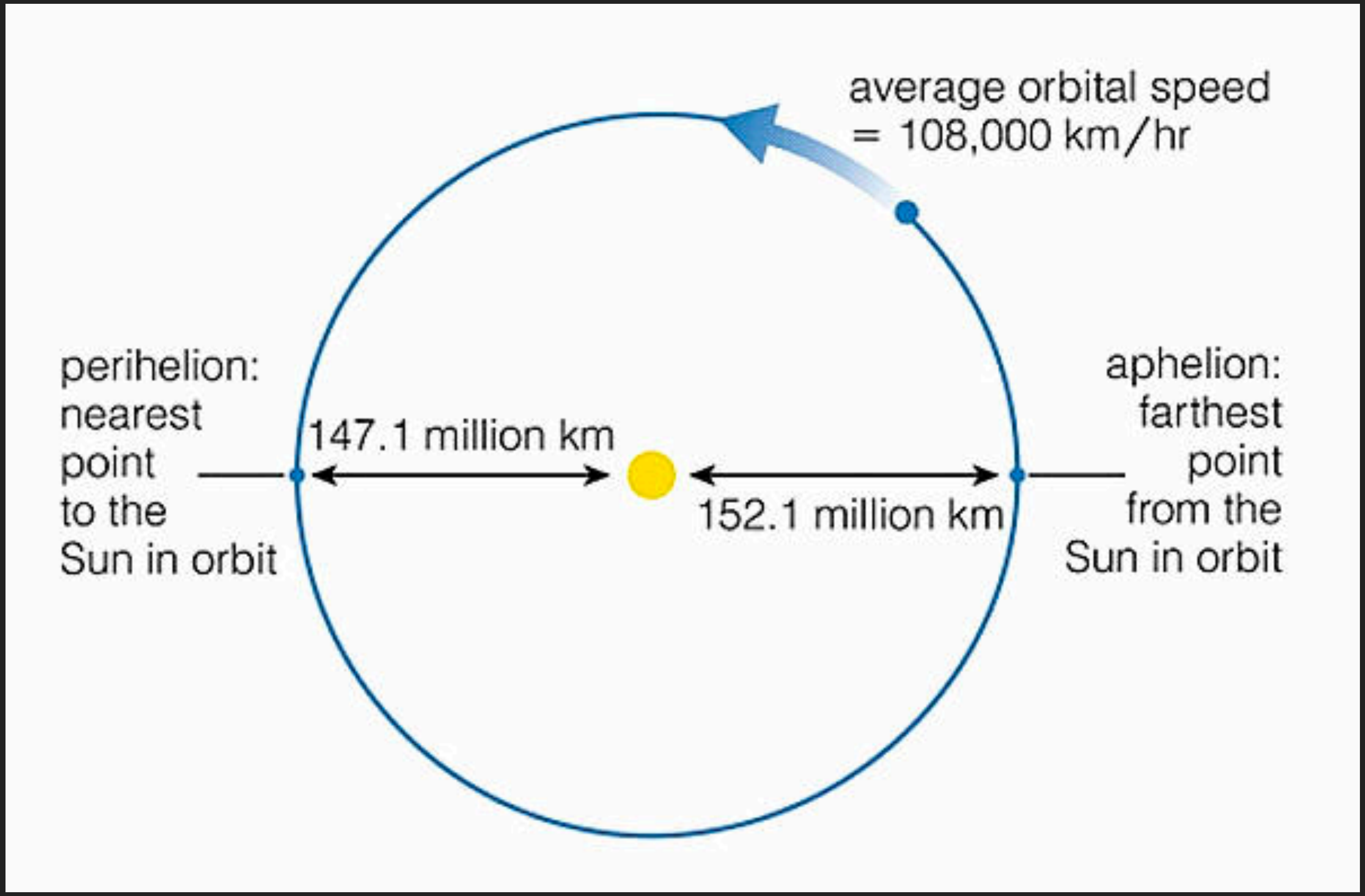


WHY KELVIN?



Temperature Scales
Fahrenheit
Celsius
Kelvin
Boiling Point of Water
212°F
100°C
373.15 K
Highest Temp. ever recorded in US
134°F
56.7°C
330 K
Freezing Point of Water
32°F
0°C
273.15 K
0°F
-18°C
255 K
Moon, at its coldest
-280°F
-173°C
100 K
Absolute Zero
-460°F
-273°C
0 K

HOW FAR IS THE SUN?

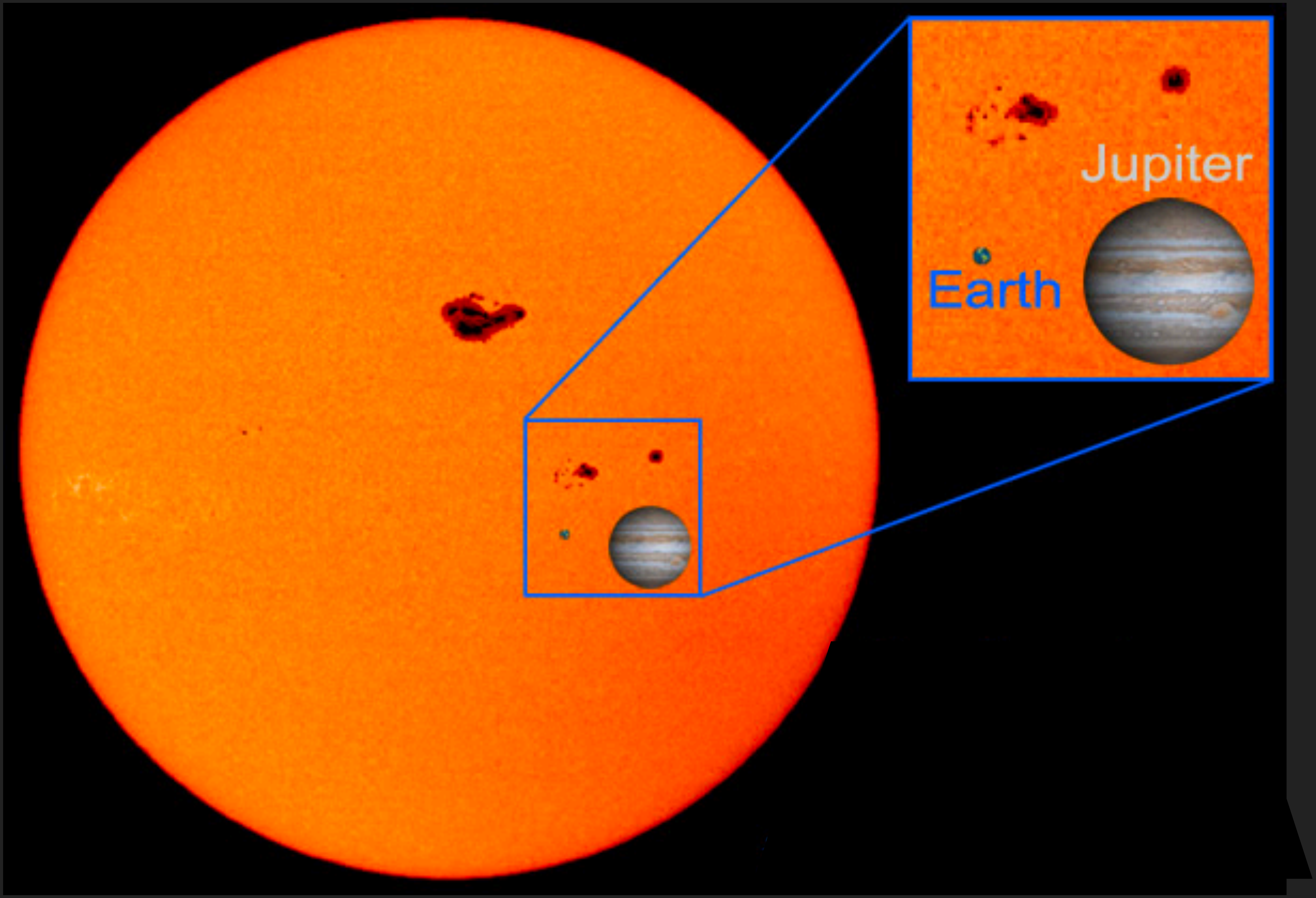


- 1 AU = 149,500,00 km

ASTRONOMICAL UNIT

How was the Earth-Sun distance originally calculated?

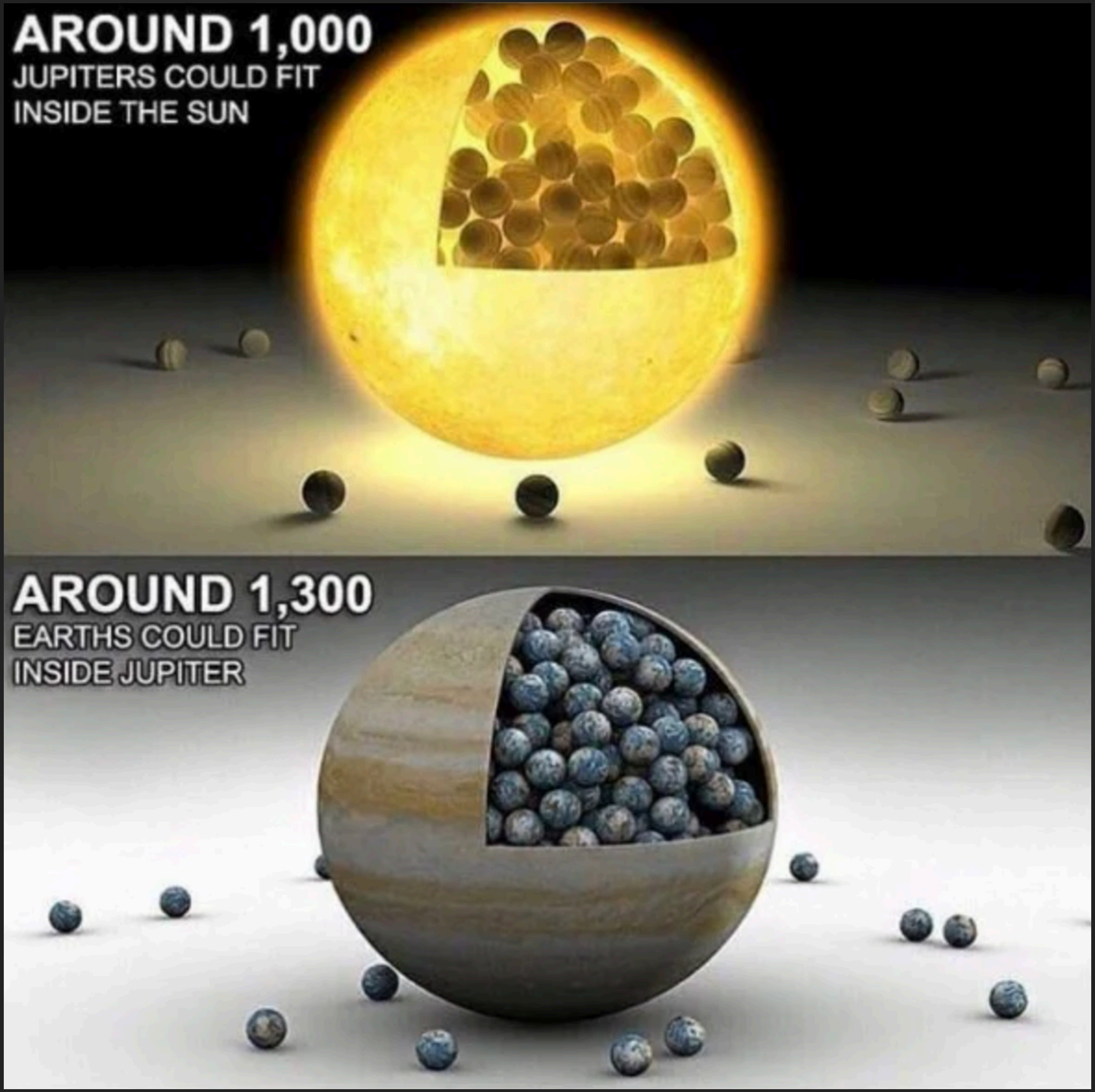
SIZE OF THE SUN



Credit: Original artwork by Randy Russell. Sun image courtesy SOHO/ESA/NASA. Jupiter image courtesy NASA/JPL/University of Arizona.

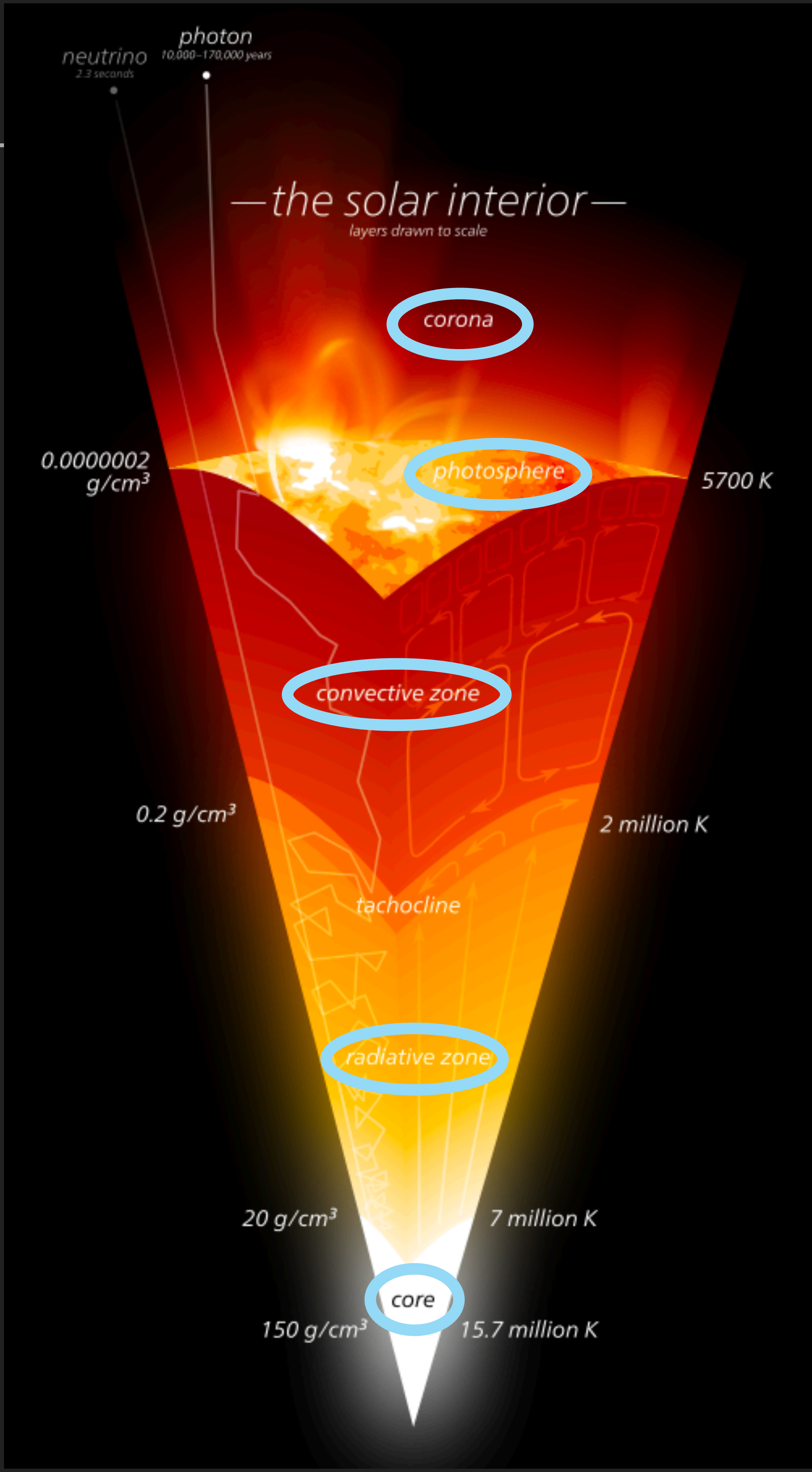
SIZE OF THE SUN

- Diameter of the Earth:
  - ~ 13.000km
- Diameter of the Jupiter:
  - ~143.000 km
- Diameter of the Sun:
  - ~1.400.000 km

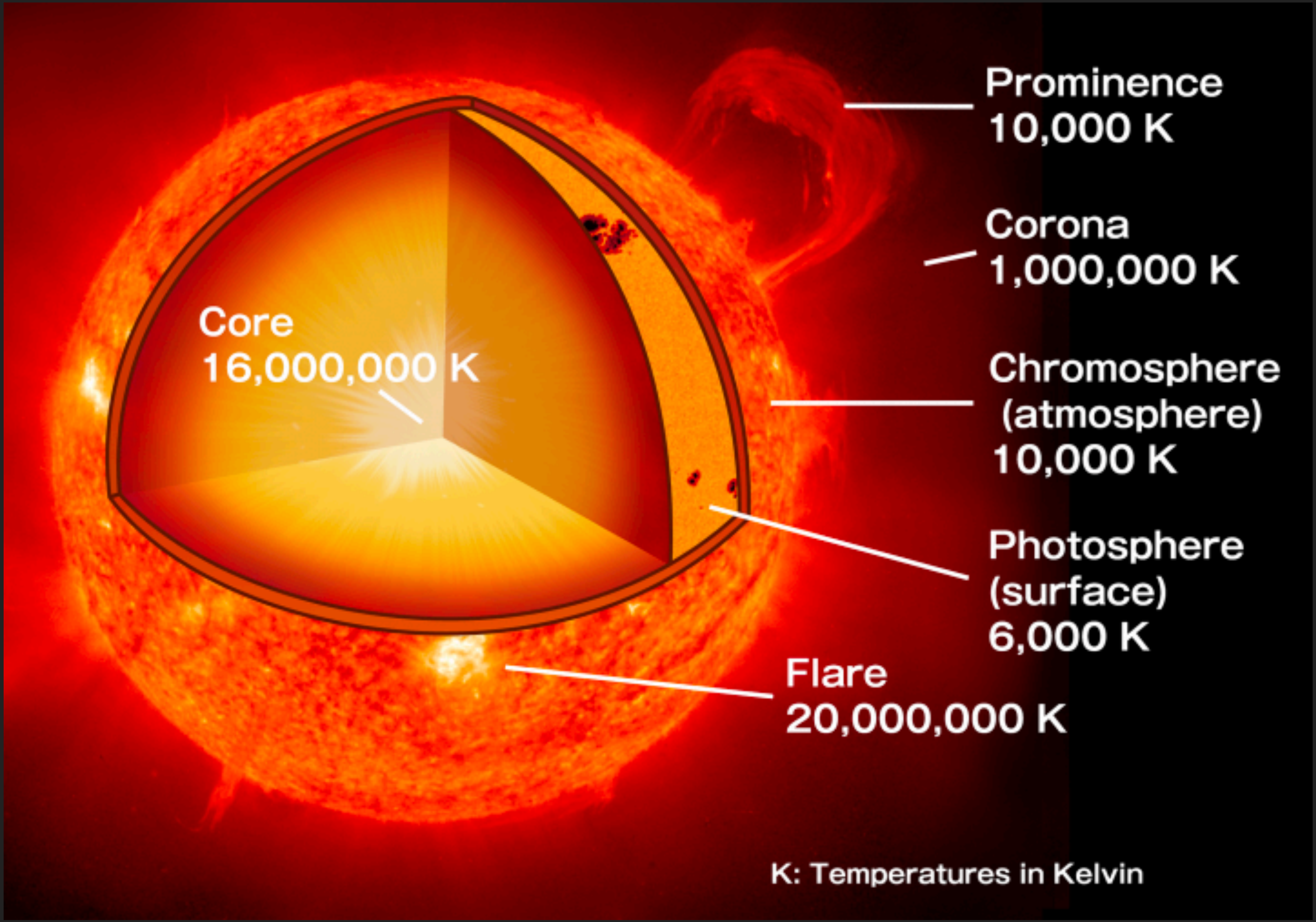


LAYERS OF THE SUN

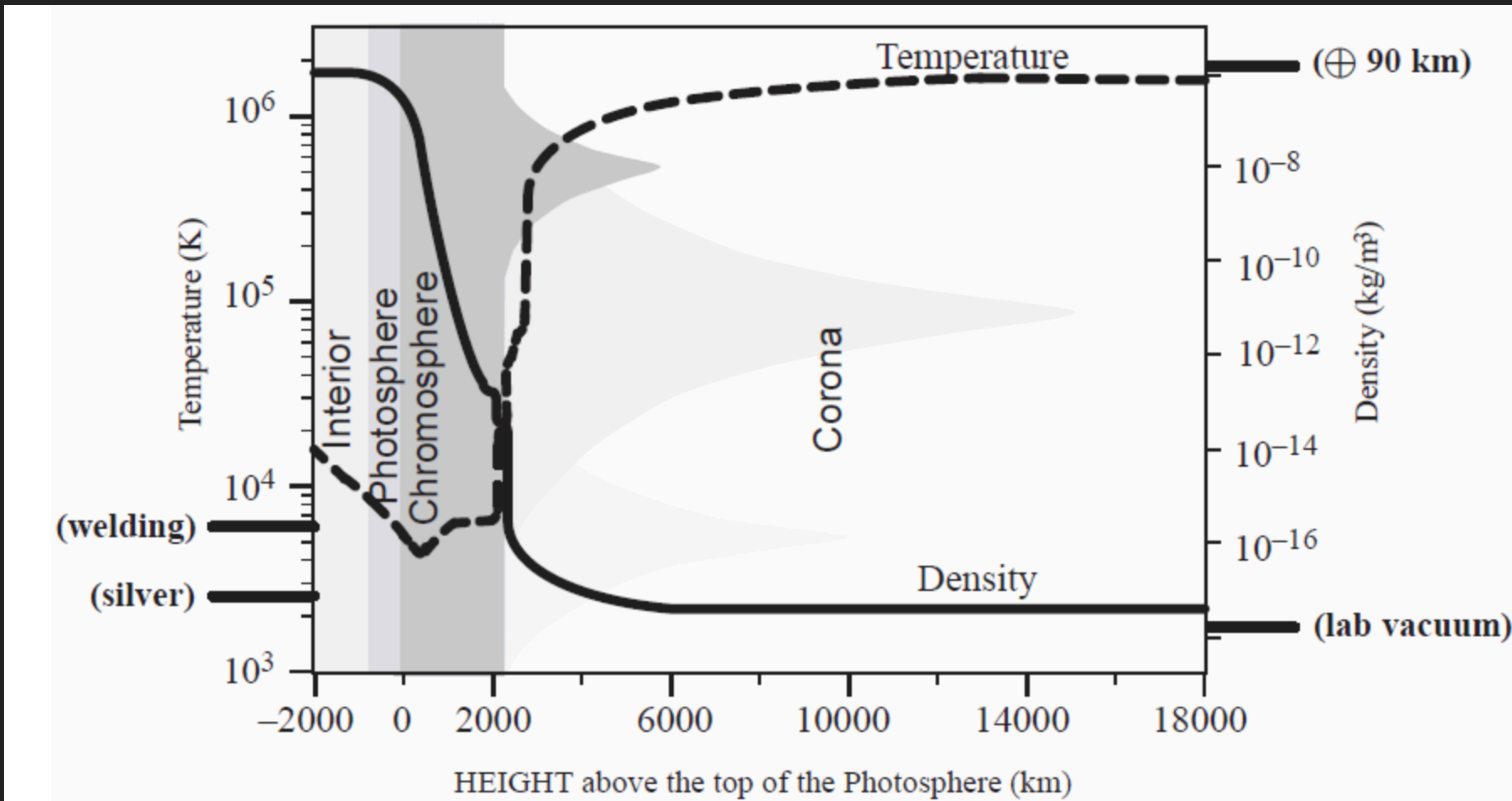
- Core:
    - the hottest part of the Sun.
    - ~ 20% of the size of the solar interior
    - Energy is generated by thermonuclear reactions
    - ~15 million K
- Radiative zone:
    - starts at about 25% of the distance to the solar surface and extends up to about 70% of the way to the surface
    - Energy move slowly outwards, takes more than 170.000 years to radiate through this layer. the high density of matter in this region means a photon cannot travel too far without encountering a particle, causing it to change direction and lose some energy.
- Convective zone:
    - the outermost layer of the solar interior.
    - ~200,000 kilometers deep
    - transports energy through giant convection cells, similar to a pot of boiling oatmeal. The plasma at the bottom of the convective zone is extremely hot, and it bubbles to the surface where it loses its heat to space. Once the plasma cools, it sinks back to the bottom of the convective zone.



SOLAR ATMOSPHERE

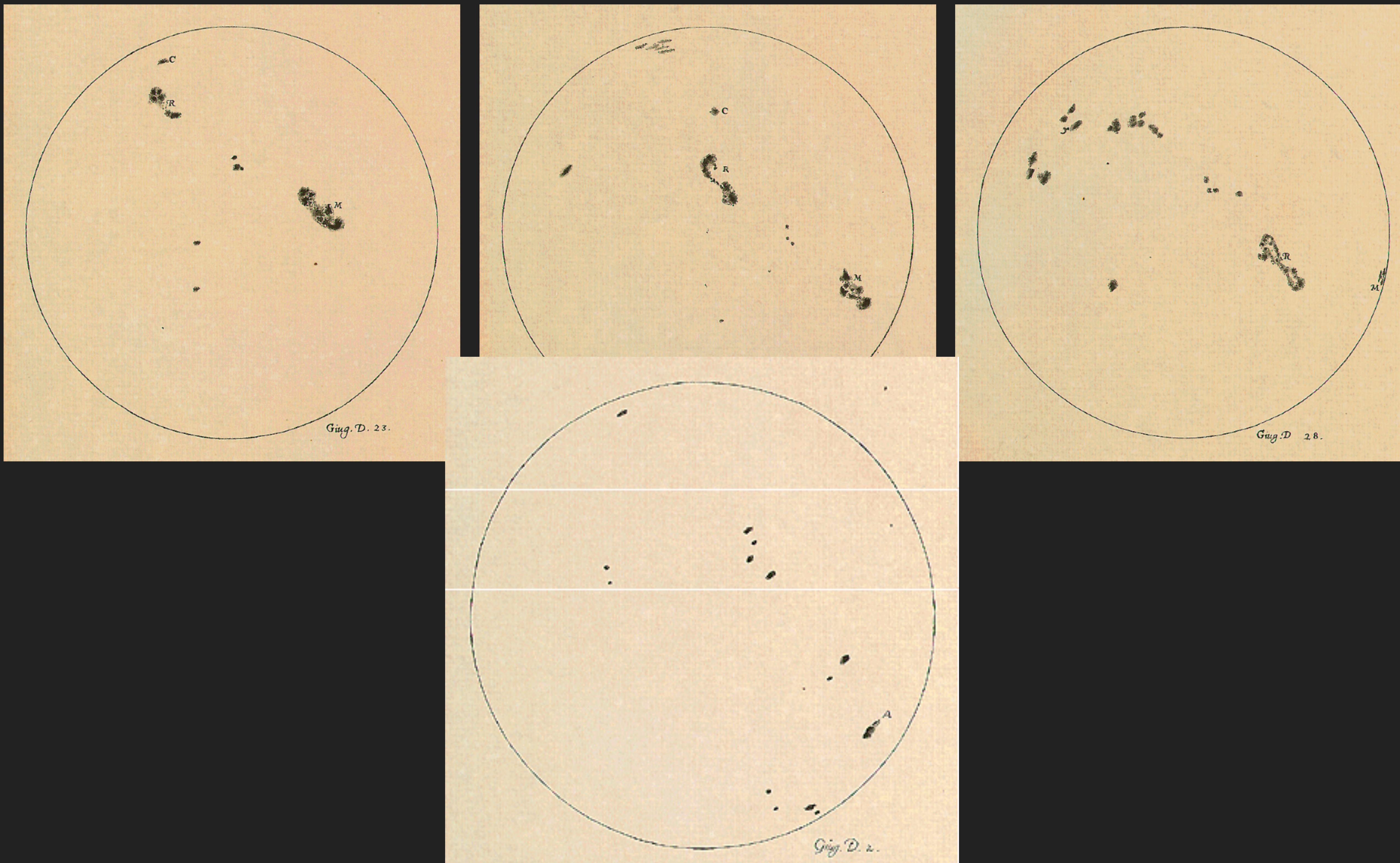


TEMPERATURE CHANGE



SUNSPOTS

SUNSPOTS - GALILEO



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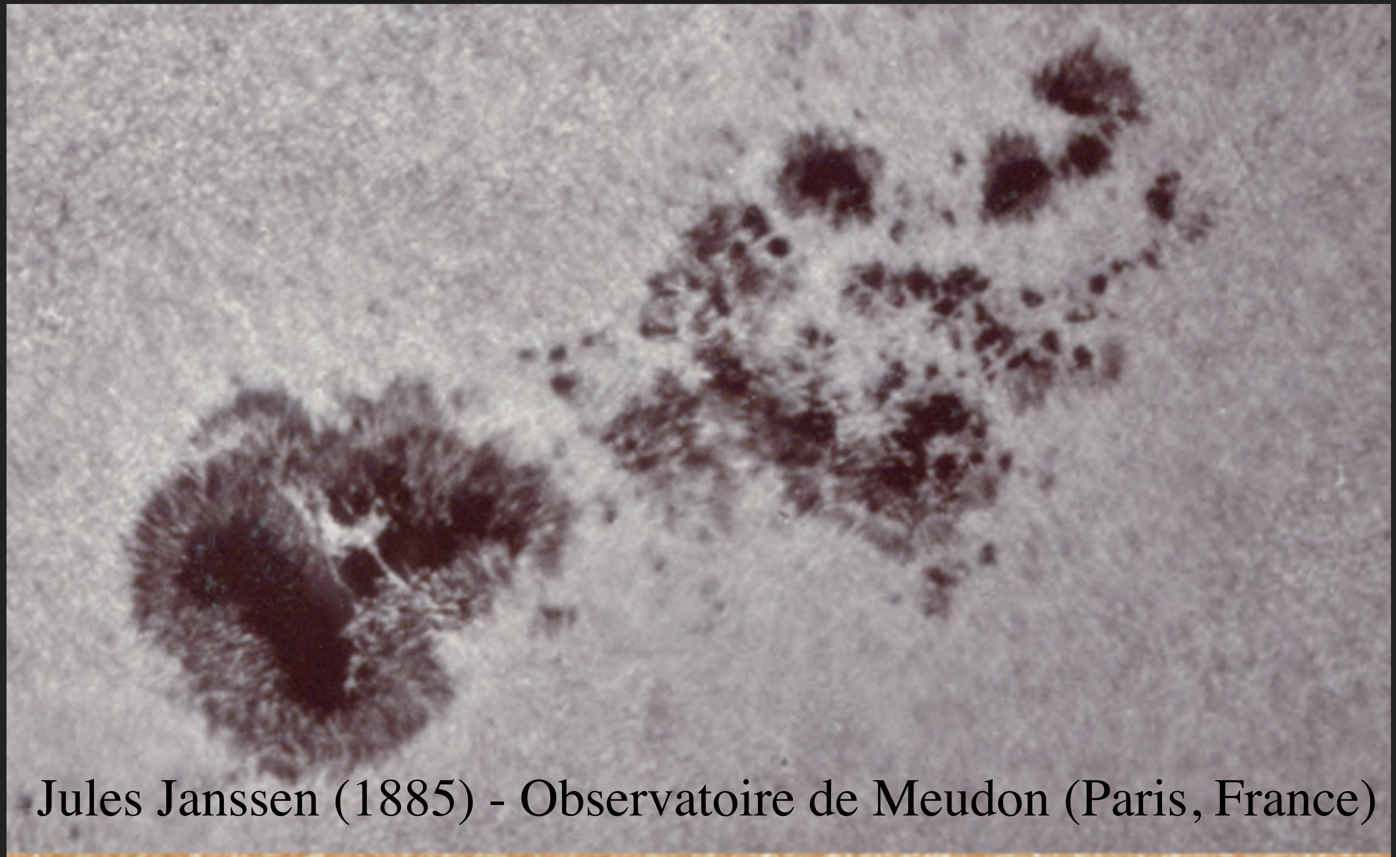
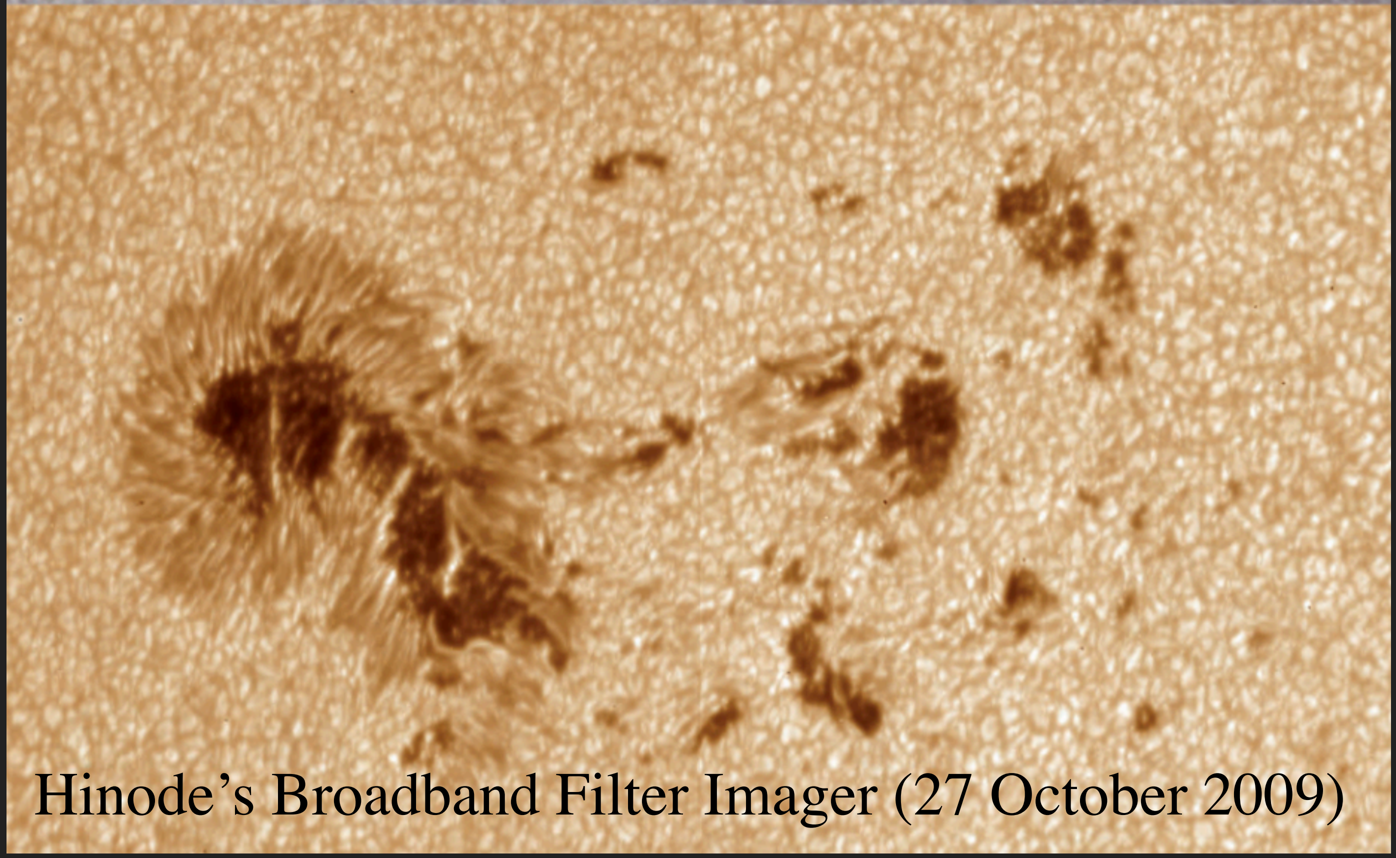
SUNSPOTS

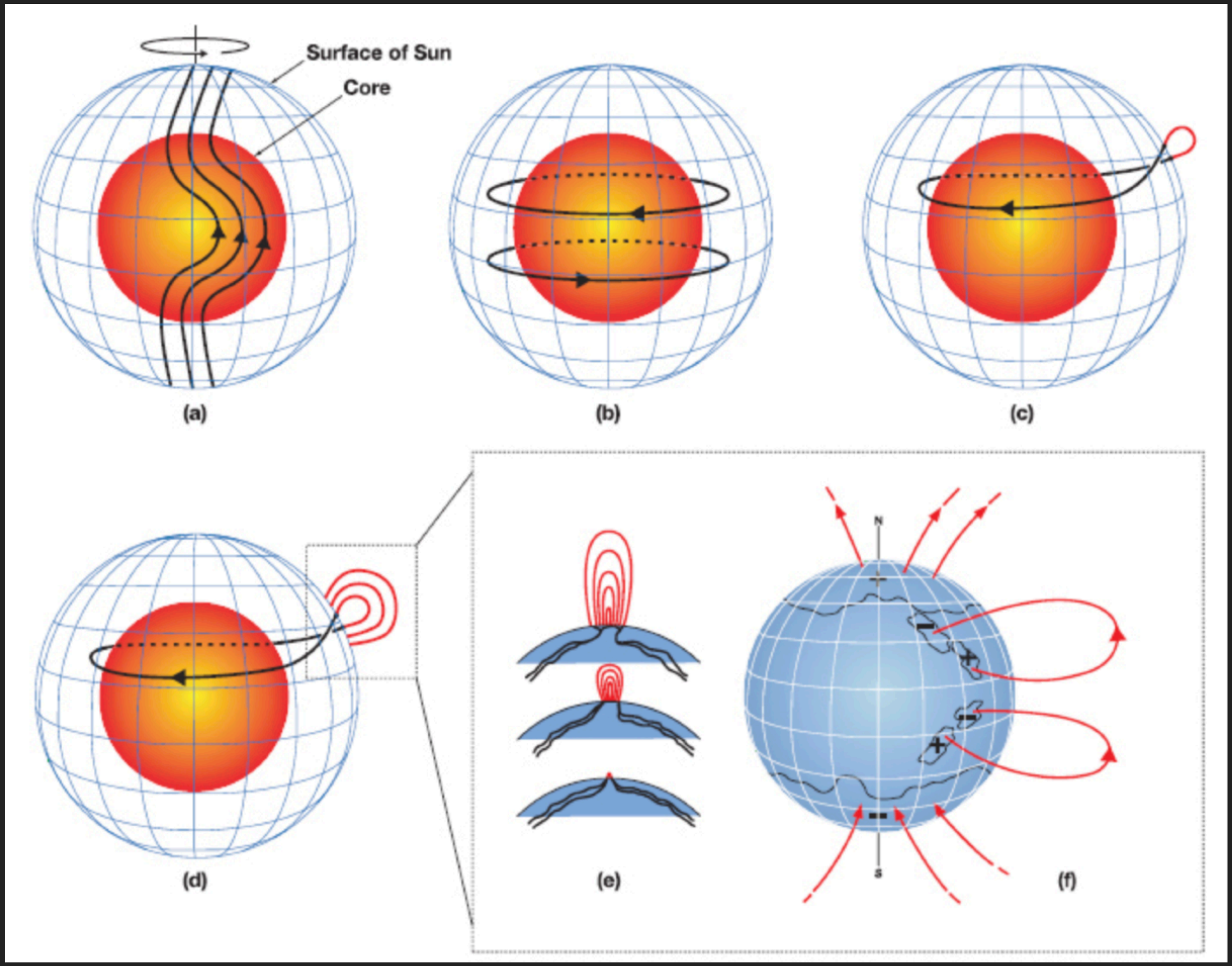

Jules Janssen (1885) - Observatoire de Meudon (Paris, France)


Hinode's Broadband Filter Imager (27 October 2009)

- Sunspots, pores of the active region, the granulation pattern of the solar surface
- The photograph recorded a very large field of view, and parts of it appear blurred because of the effects of atmospheric turbulence.
- The image quality is homogeneous over the entire field of view because the measurements are not affected by the Earth atmosphere.

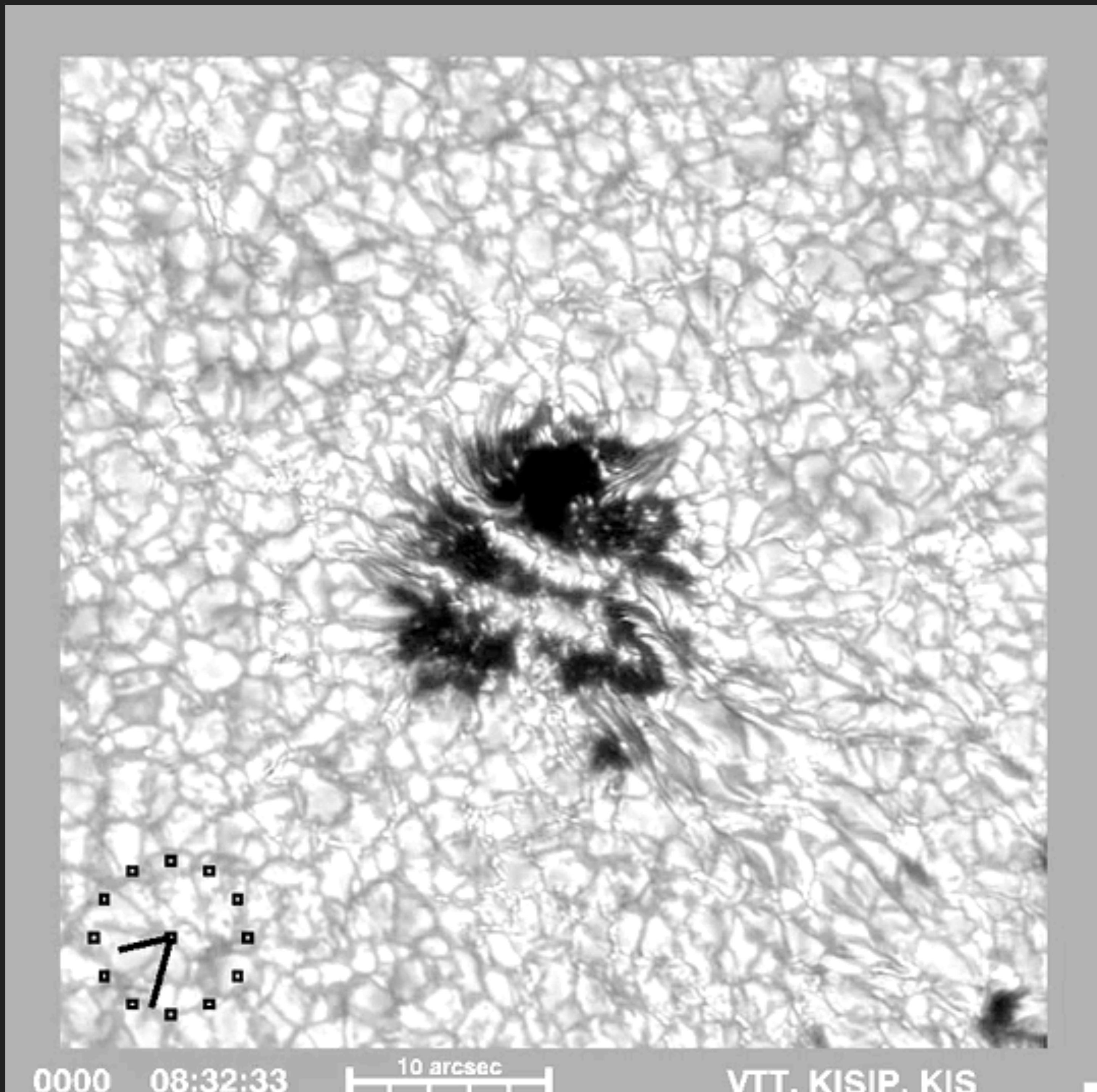
SUNSPOTS

- Sunspots do not appear suddenly at once. They are the result of small concentrations of magnetic field that pop up on the solar surface from the deeper layers of the Sun.
- These small concentrations result from a large magnetic rope; reached to the surface via convection during its rise.



https://iopscience.iop.org/article/10.1088/1367-2630/9/8/297

SUNSPOTS

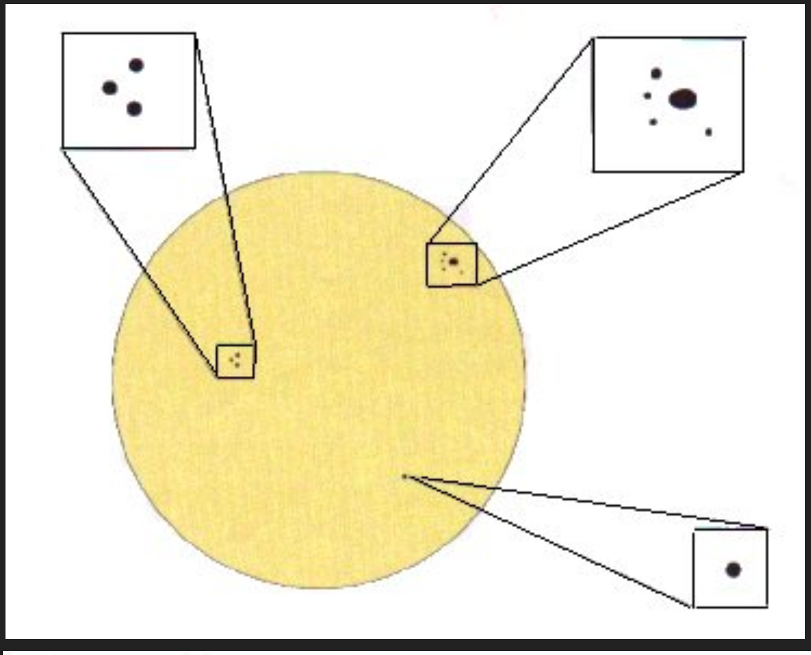


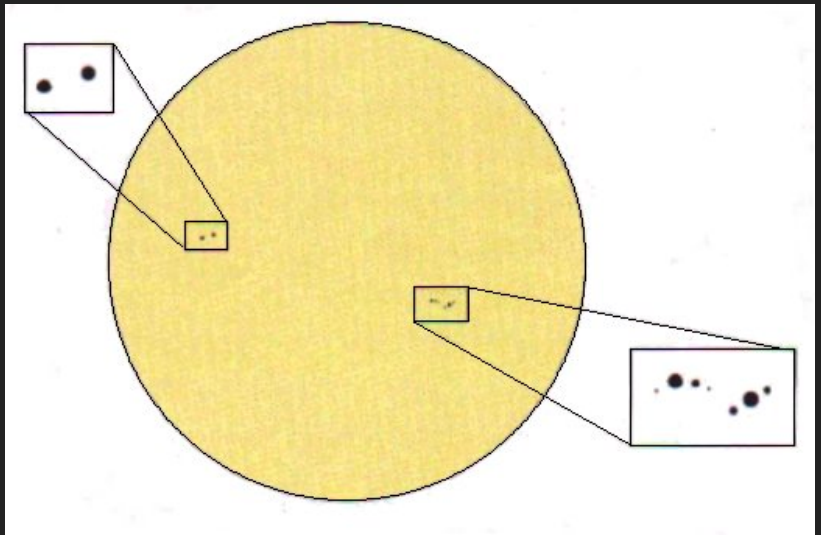
the Vacuum Tower Telescope (Tenerife, Spain) on the 4th of July 2009

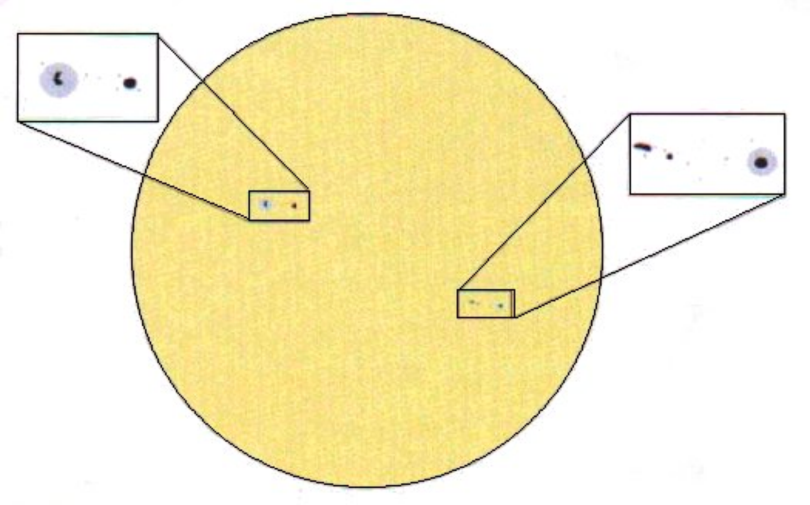
- The penumbra embraces the umbra in about 5 hours, so it is a relatively fast process.
- Sunspots can steadily live for days to weeks. When sunspots decay, they will first loose their penumbra to become again pores (or "naked" sunspots) and will get disrupted by the surrounding granulation into smaller pores until they eventually disappear as small magnetic concentrations or plages.

SUNSPOTS – ZURICH CLASSIFICATION

- "A" Type: One or more tiny spots that do not demonstrate bi-polarity or exhibit penumbra.
- "B" Type: Two or more tiny spots that demonstrate bi-polarity but do not exhibit penumbra.
- "C" Type: Two or more spots that demonstrate bi-polarity and either the lead spot or trailing spot has a penumbra.

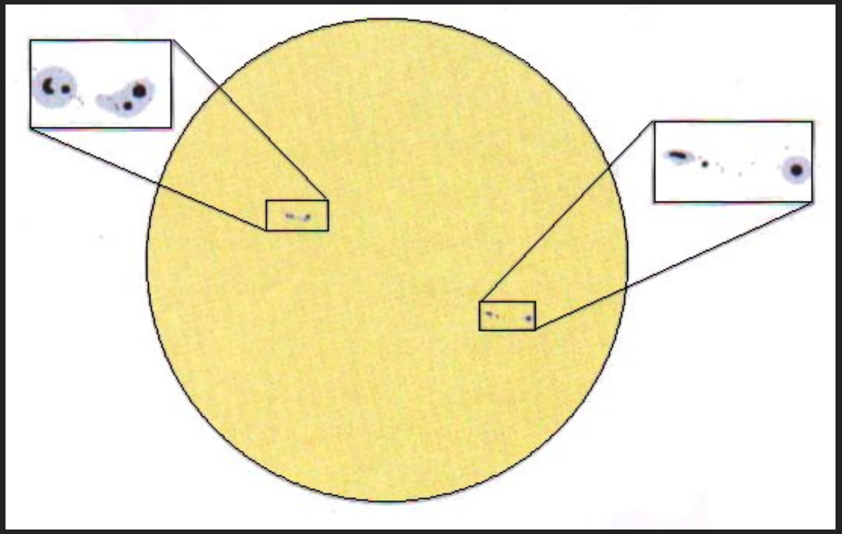




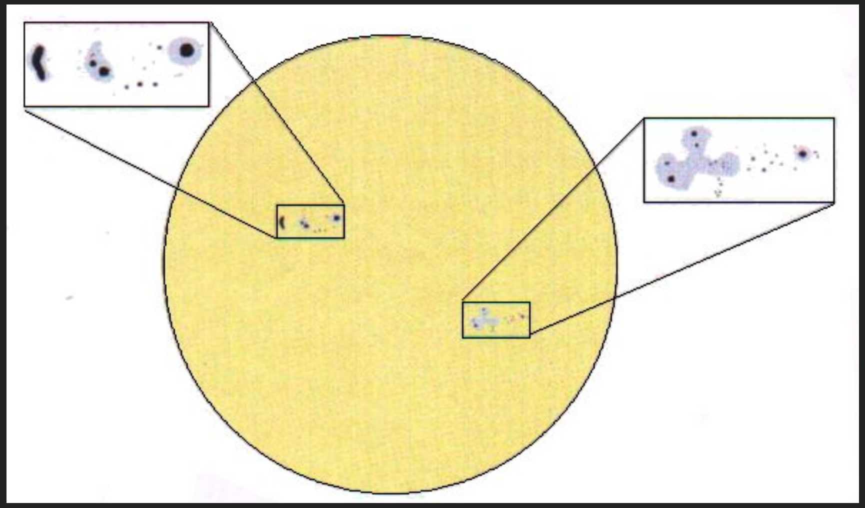


SUNSPOTS - ZURICH CLASSIFICATION

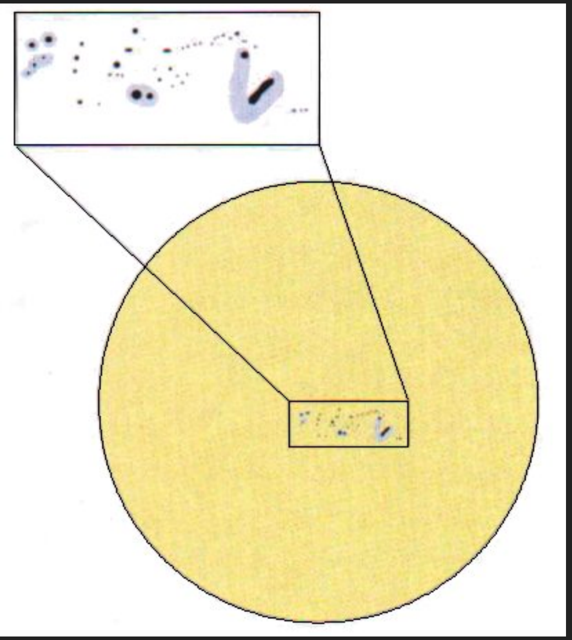
- "D" Type: Two or more spots that demonstrate bi-polarity and the lead spot and trailing spots display a penumbra. The "D" Type will occupy 10 degrees or less of Solar longitude.



- "E" Type: This group type is similar to the "D" type but spreads between 10 and 15 degrees of Solar longitude.

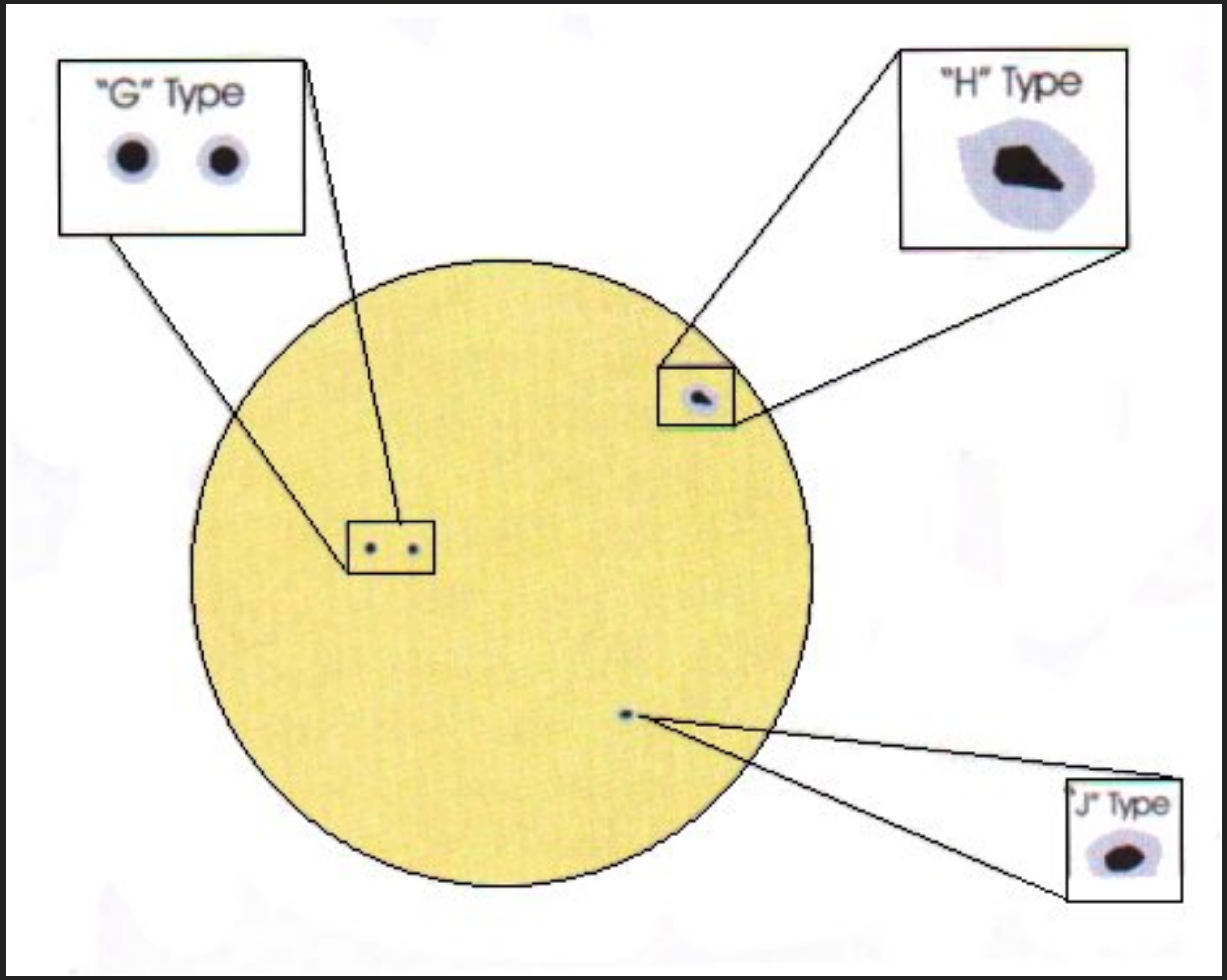


- "F" Type: Largest and most extensive of groups, similar to "E" type but will cover in excess of 15 degrees of Solar longitude.

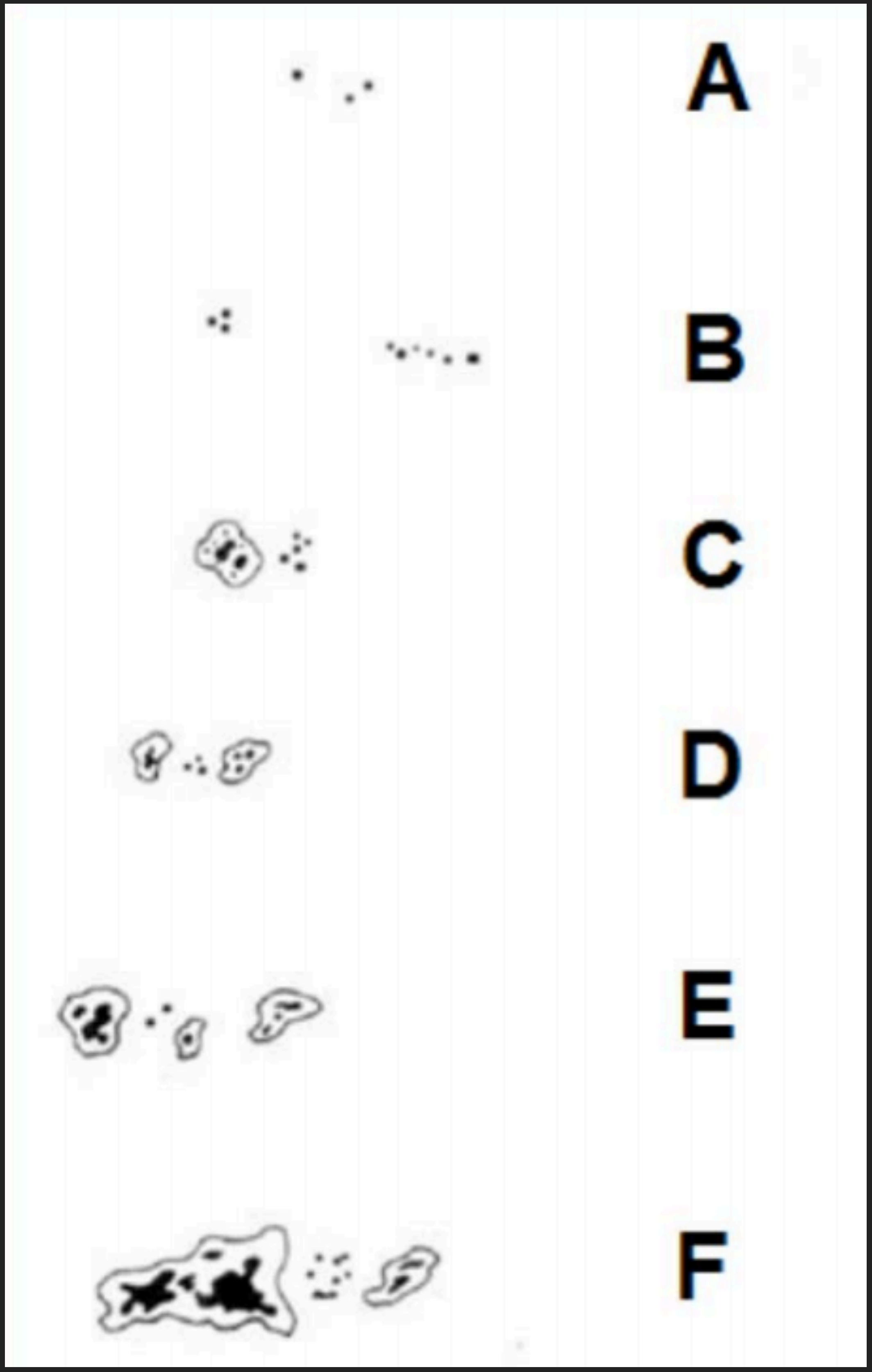


SUNSPOTS – ZURICH CLASSIFICATION

- "G" Type: The decayed remnant of "D", "E", and "F" groups. Demonstrates a bi-polar group with penumbras.
- "H" Type: The decayed remnant of "C", "D", "E", and "F" groups. A single spot group with penumbra. Must be larger than two and one-half degrees in diameter. The "H" type occasionally is accompanied by a few small spots.
- "J" Type: The same as the "H" type but has a diameter less than 2½ degrees.

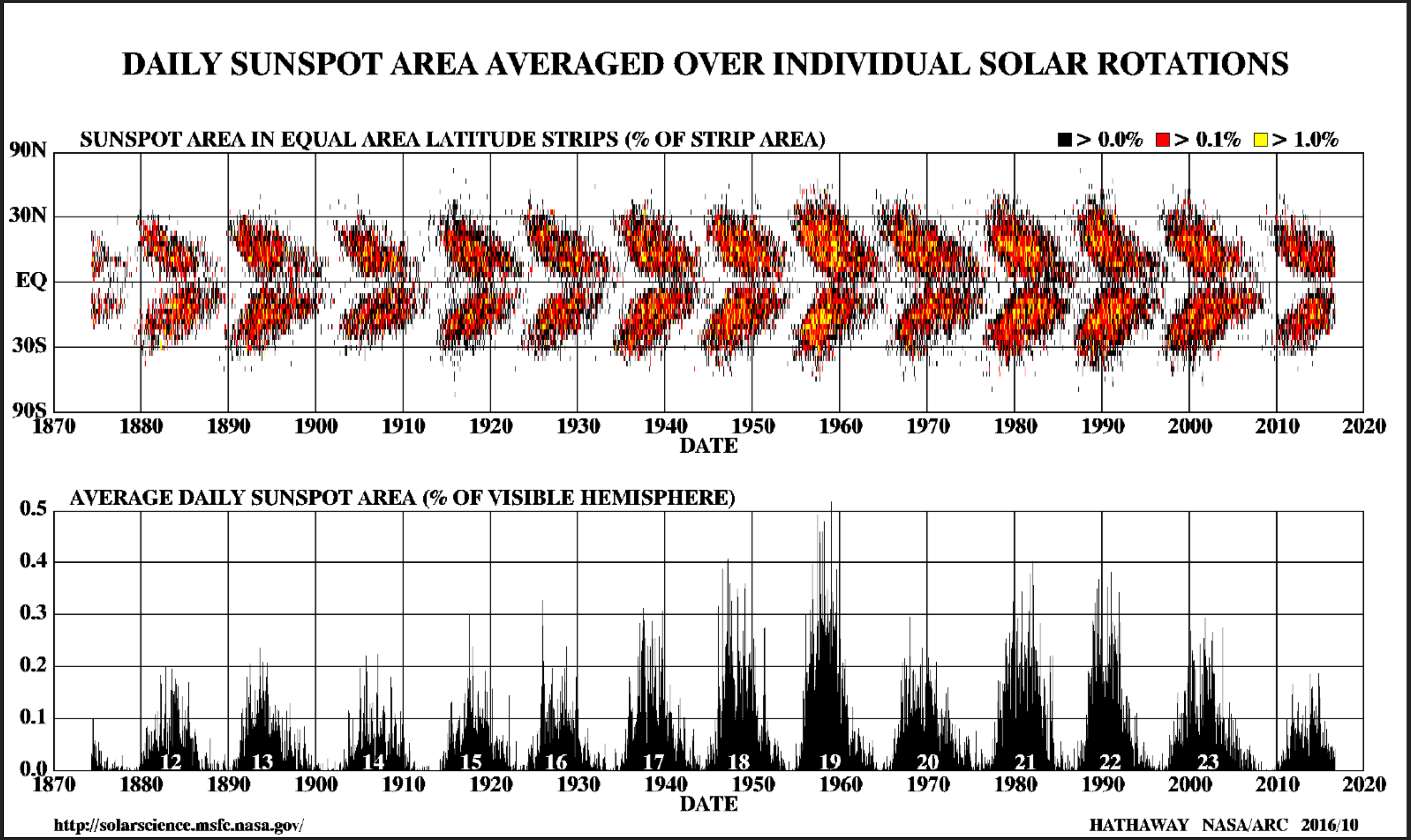


SUNSPOTS - ZURICH CLASSIFICATION



P. Clay Sherrod & Thomas L. Koed, "A Complete Manual of Amateur Astronomy," [Prentice-Hall, 1981]

BUTTERFLY DIAGRAM

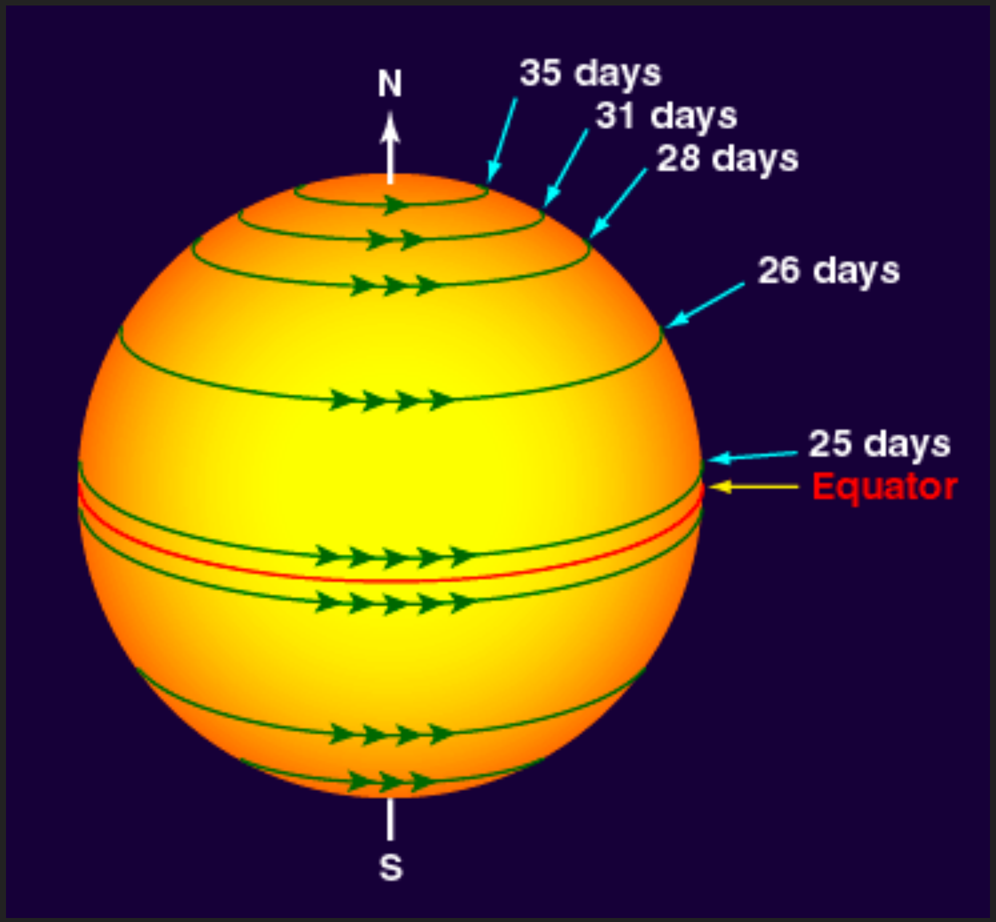


- Annie Russel Maunder in 1922 charted the latitude drift of spots during each solar cycle. Her chart is sometimes called the butterfly diagram because of the winglike shapes assumed by the graph. Each solar cycle begins with small spots appearing in middle latitudes of the Sun. Succeeding spots appear progressively closer to the Sun's equator as the cycle reaches its maximum level of activity and declines.

Why are there two wings?

ROTATION OF THE SUN

- Sidereal Period: At the equator, the **solar** rotation **period** is 24.47 days.
- Synodic Period: the time for a fixed feature of the Sun to rotate to the same apparent position as viewed from Earth - 26.24 days
    - The synodic period is longer because the Sun must rotate for a sidereal period plus an extra amount due to the orbital motion of the Earth around the Sun.
- Carrington Period: This chosen period corresponds to a rotation at a latitude of 26°, consistent with a typical latitude of sunspots and solar activity (27.275 days).

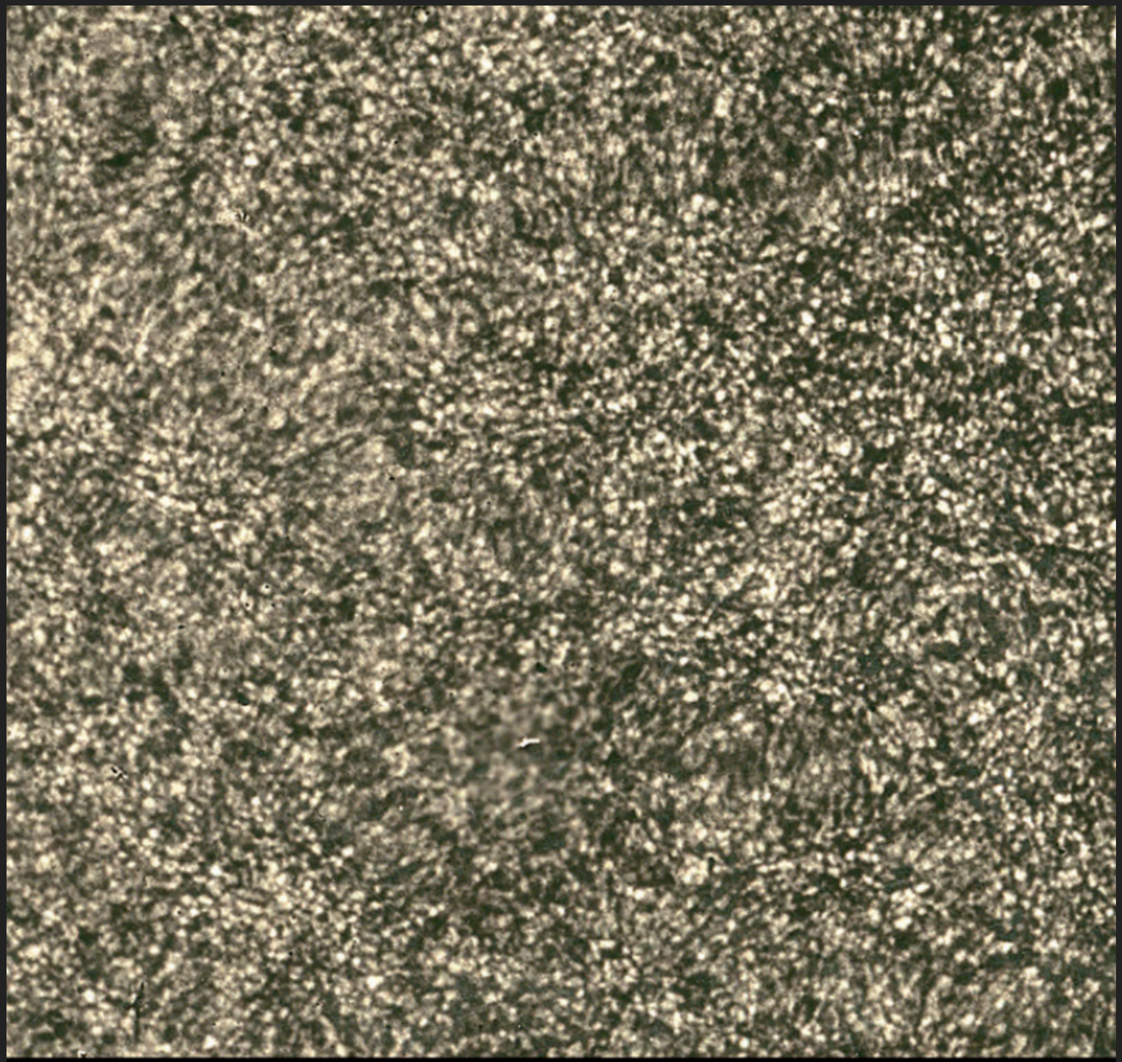


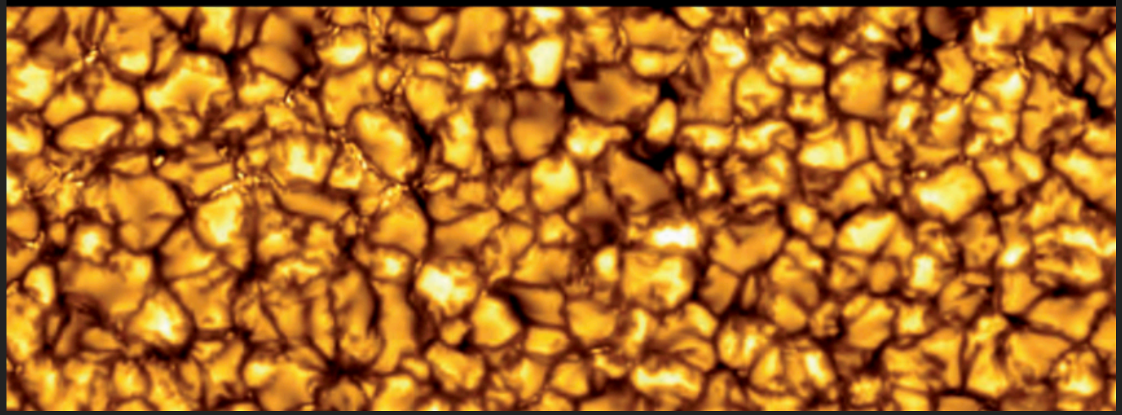
- Solar rotation varies with latitude. The Sun is not a solid body, but is composed of a gaseous plasma. Different latitudes rotate at different periods.

GRANULATION

- A projection of the solar disk
- The field of view is so large that parts of the image appear blurred by turbulence in the Earth's atmosphere.
- The observations were acquired using adaptive optics.
- In addition to granules and intergranular lanes, one can observe tiny bright points that represent small-scale magnetic fields on the solar surface.

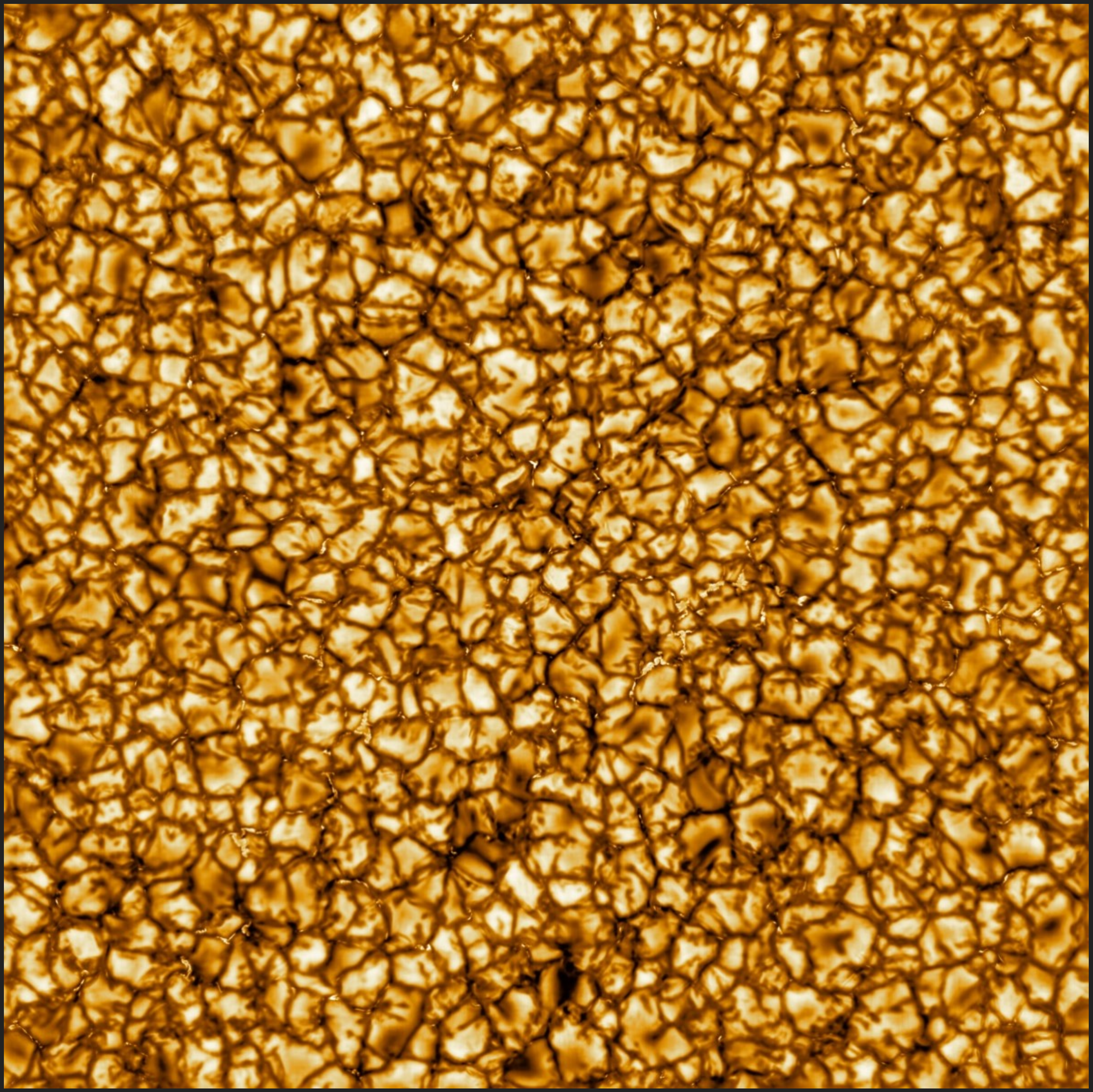
Jules Janssen (1890)-Observatoire de Meudon (France)





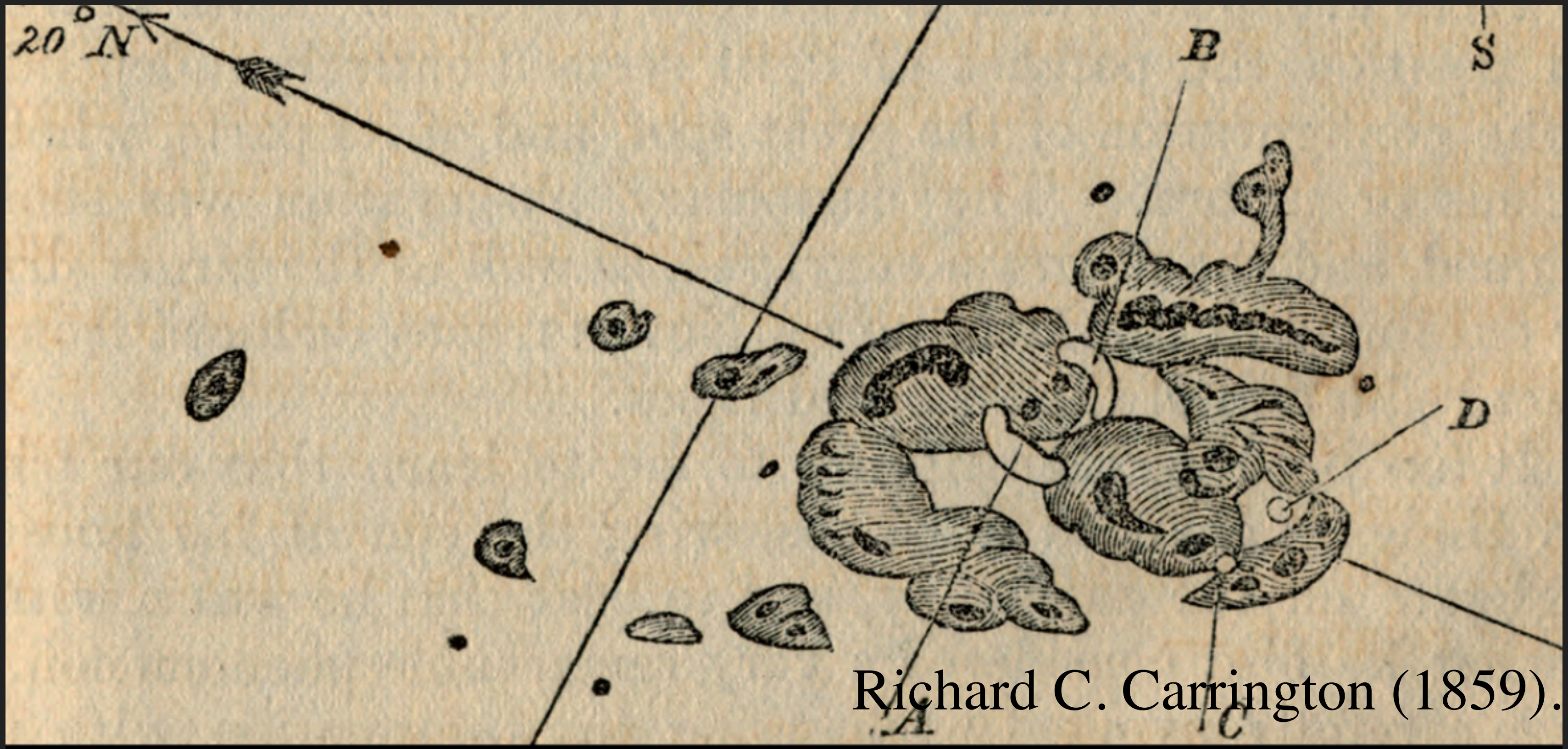
Swedish 1m Solar Telescope (2004)-1-m Solar Telescope on La Palma (Spain)

GRANULATION

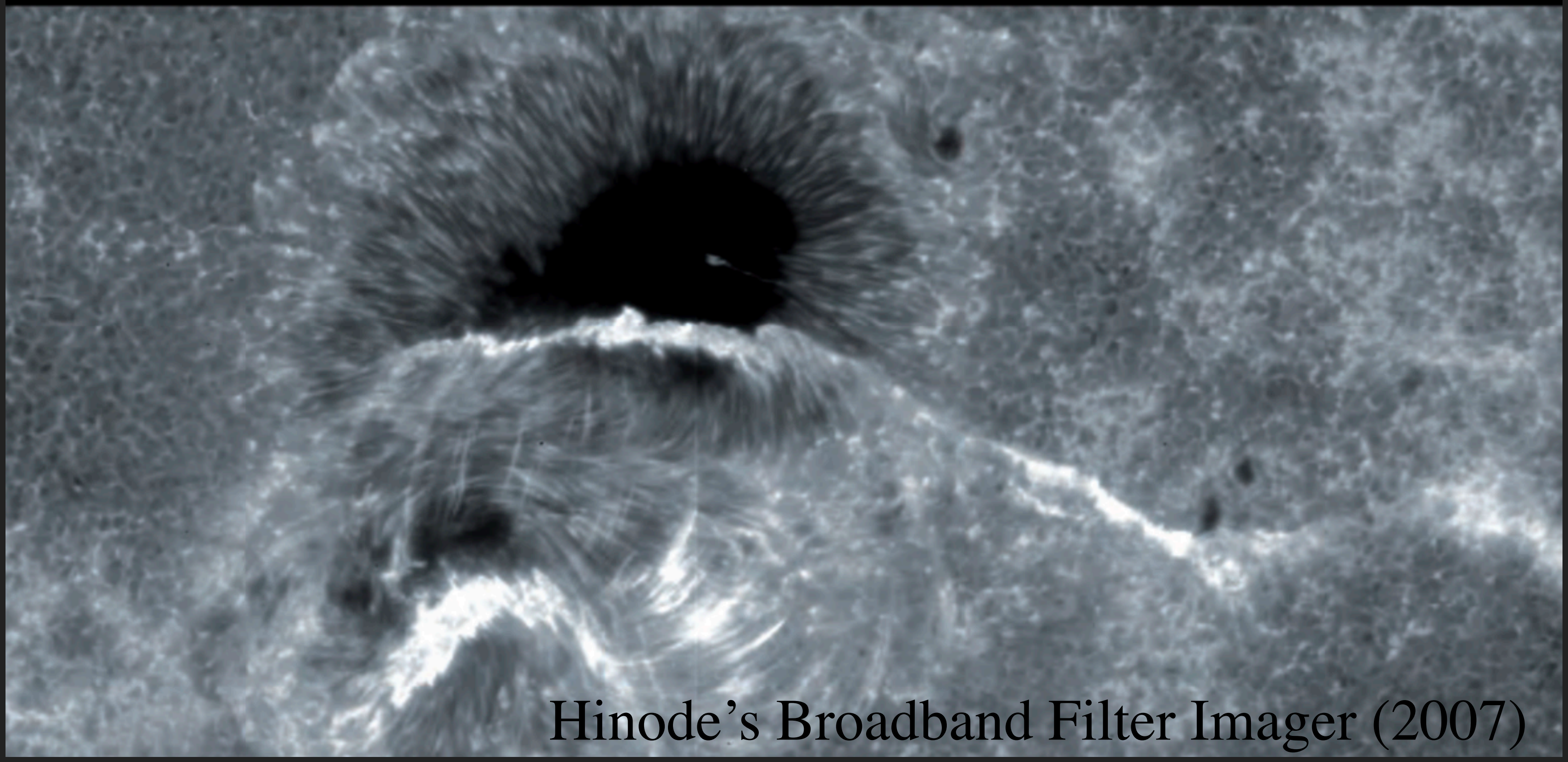


- The Daniel K. Inouye Solar Telescope is located on the Haleakala volcano on the island of Maui. A primary mirror that's 4 meters (about 13 feet) wide makes this the biggest solar telescope on Earth, and it will be able to resolve smaller details on the Sun than ever before.

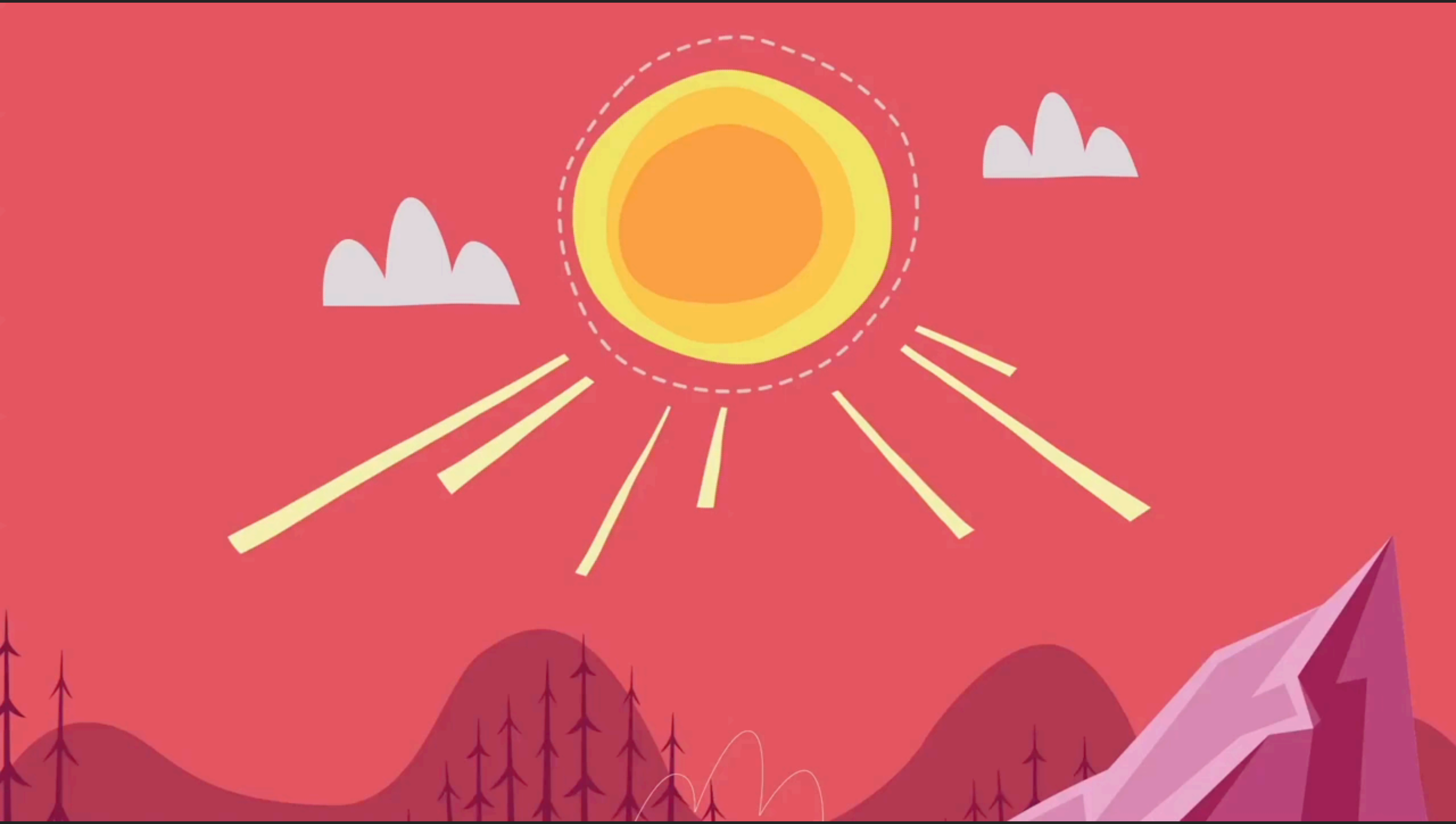
SOLAR FLARES



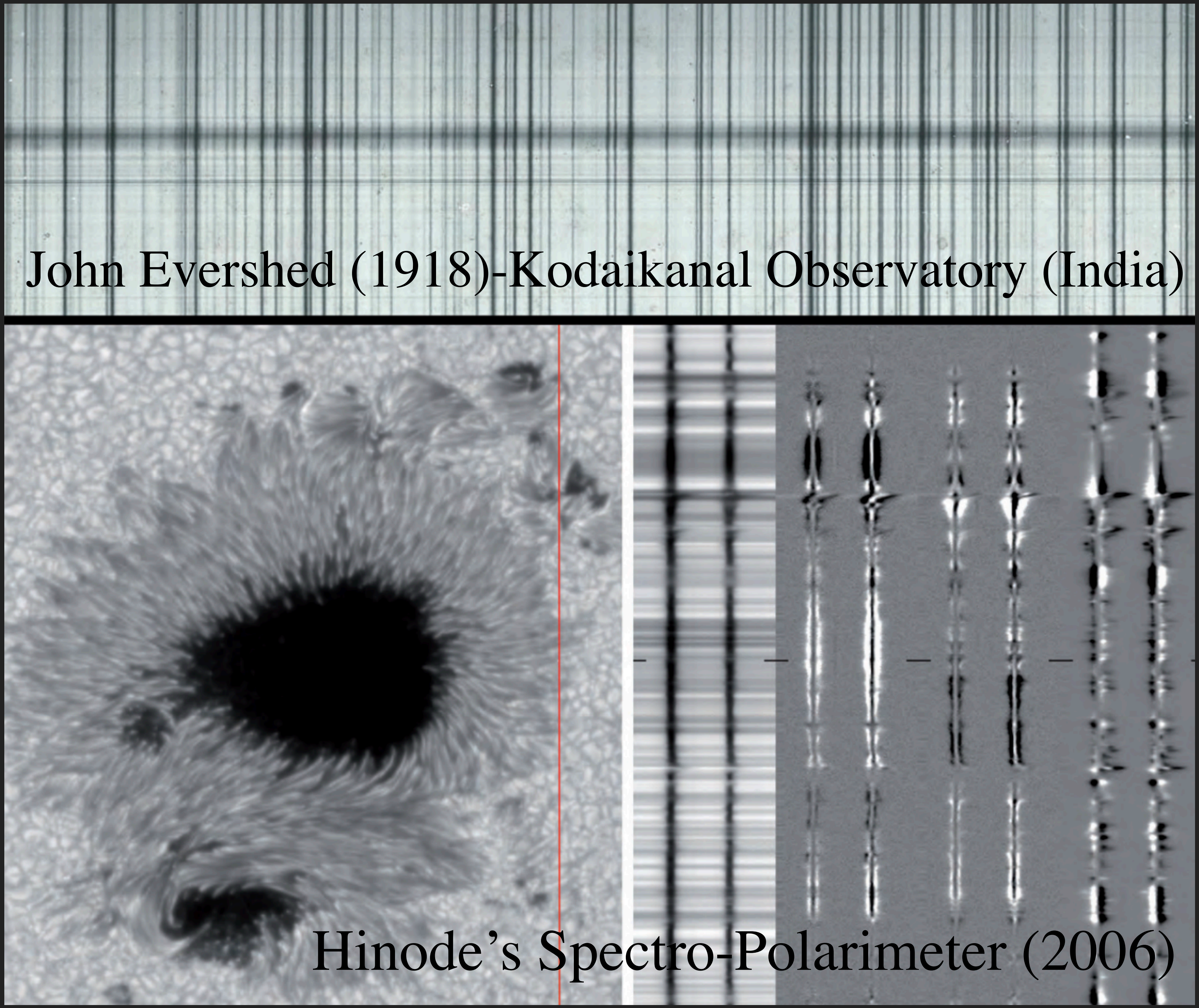
Richard C. Carrington (1859).


Hinode's Broadband Filter Imager (2007)

TEXT

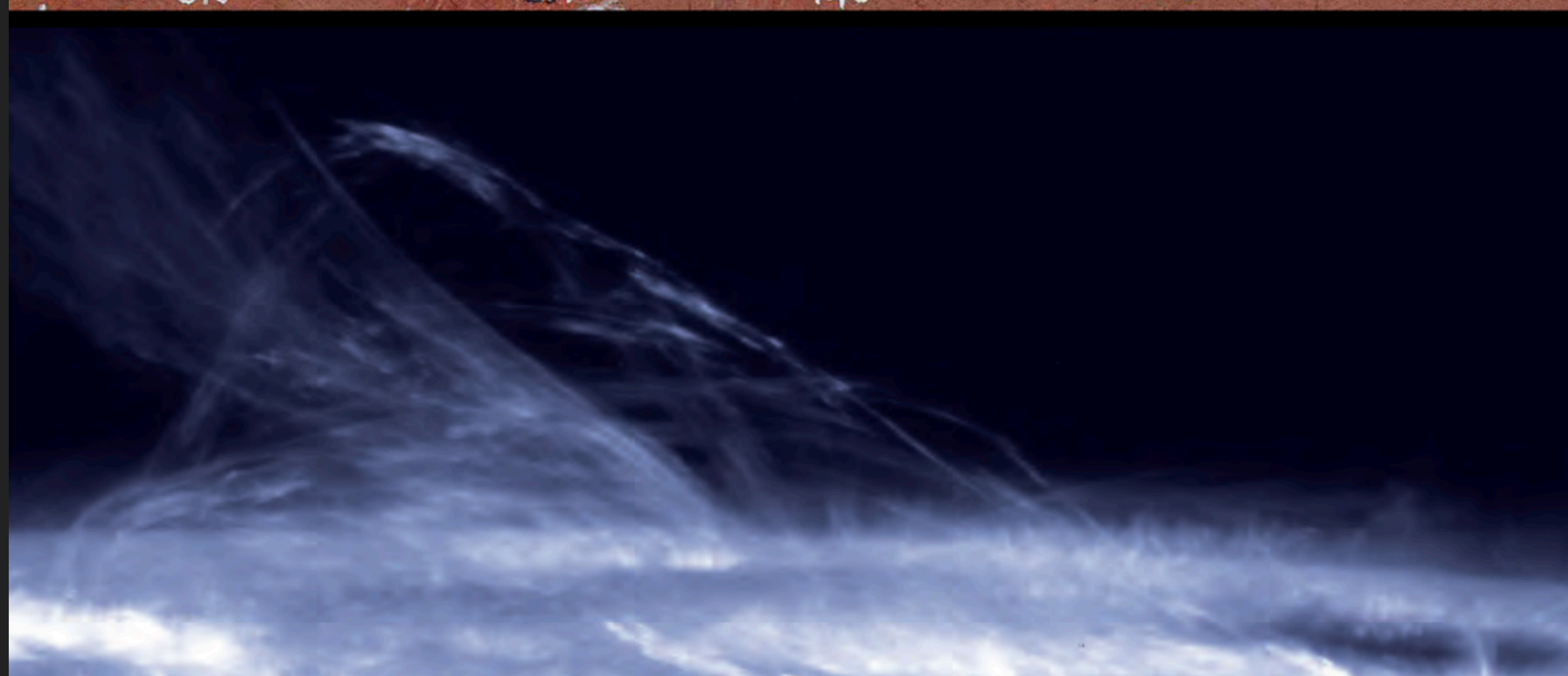


SOLAR SPECTROSCOPY



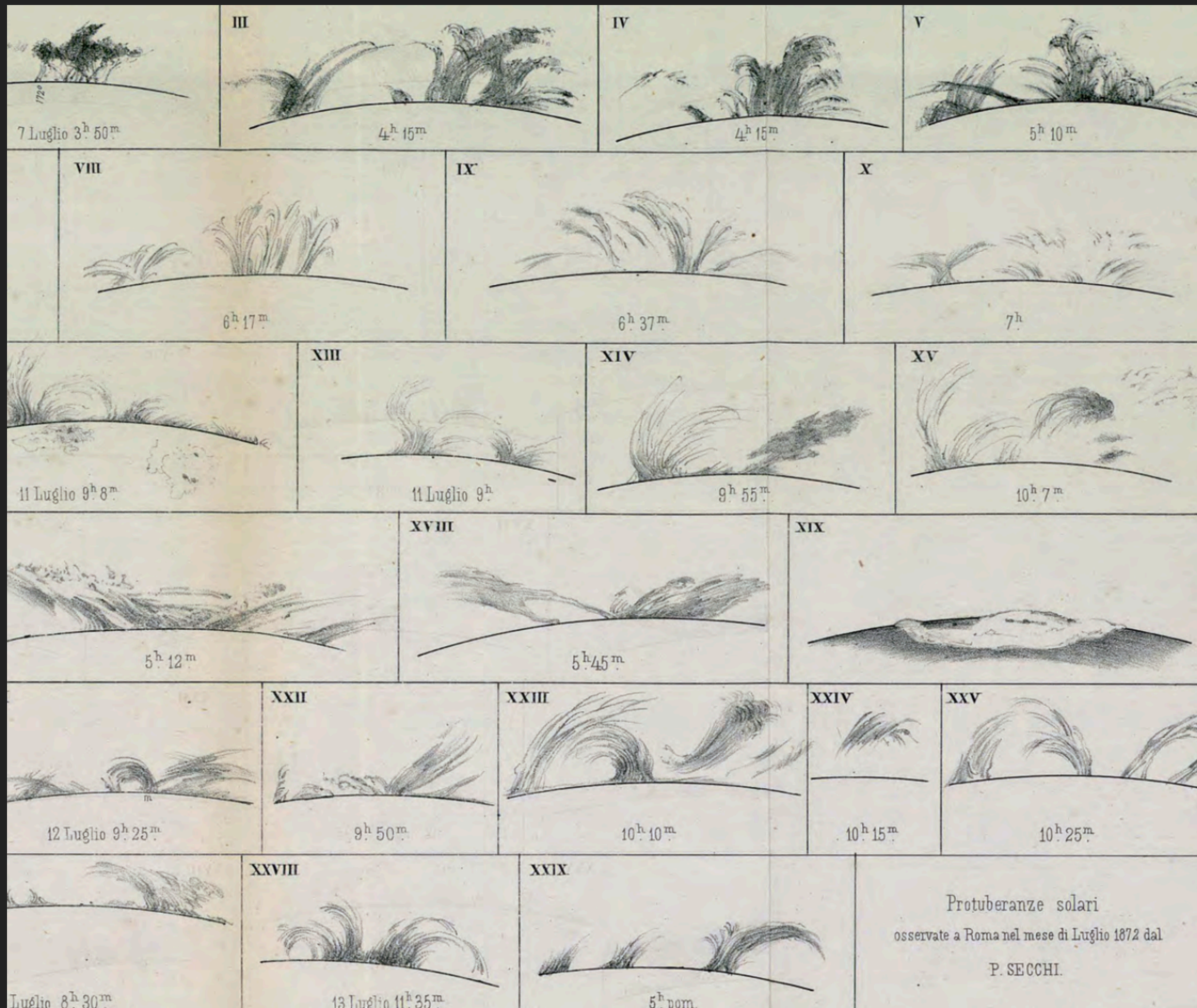
PROMINENCES

Lorenzo Respighi (1870) - Italy



Hinode’s Broadband Filter Imager (2007)

PROMINENCES



Father Angelo Secchi in July 1872

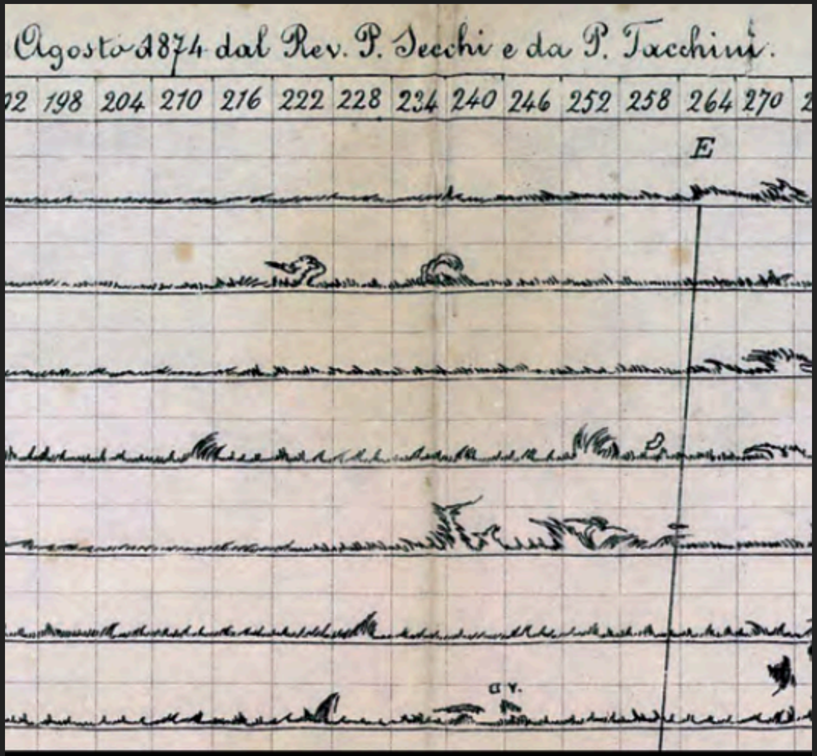
FLARES - PROMINENCES

- A typical solar flare may last from few minutes to few hours and can be observed as bright areas on the Sun.
- A prominence is anchored to the Sun's surface, unlike a flare, and is often characterized by a loop shape.
- A prominence is bound by the Sun's magnetic field and can last for months.

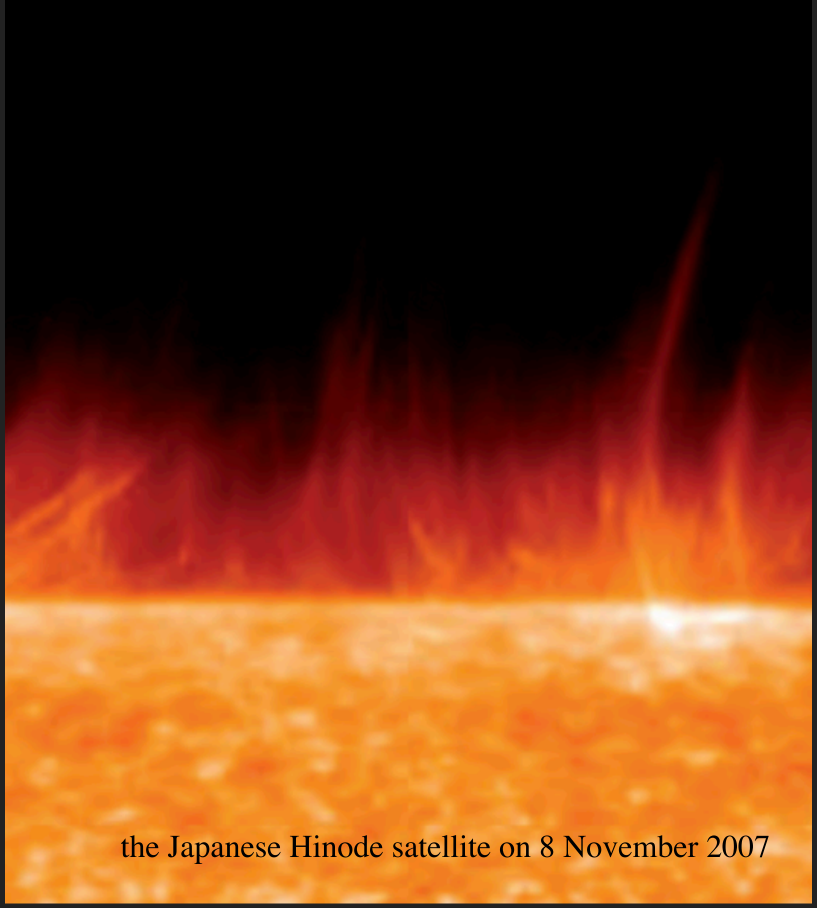
SPICULES

- Solar spicules were discovered by Angelo Secchi in the 19th century, observing the Sun by spectroscopic means. He called them “prateria ardente”, which means “burning field” in Italian. By that time, systematic observations of the solar limb were made daily in Rome, Palermo and Padova (Italy), recording incredible detail.

- High-resolution observations of spicules. The Broadband Filter Imager was used to study the rapid evolution of spicules at the solar limb in the Ca II H spectral line. Spicules are ubiquitous jets of plasma in the chromosphere, but their origin is not fully understood.

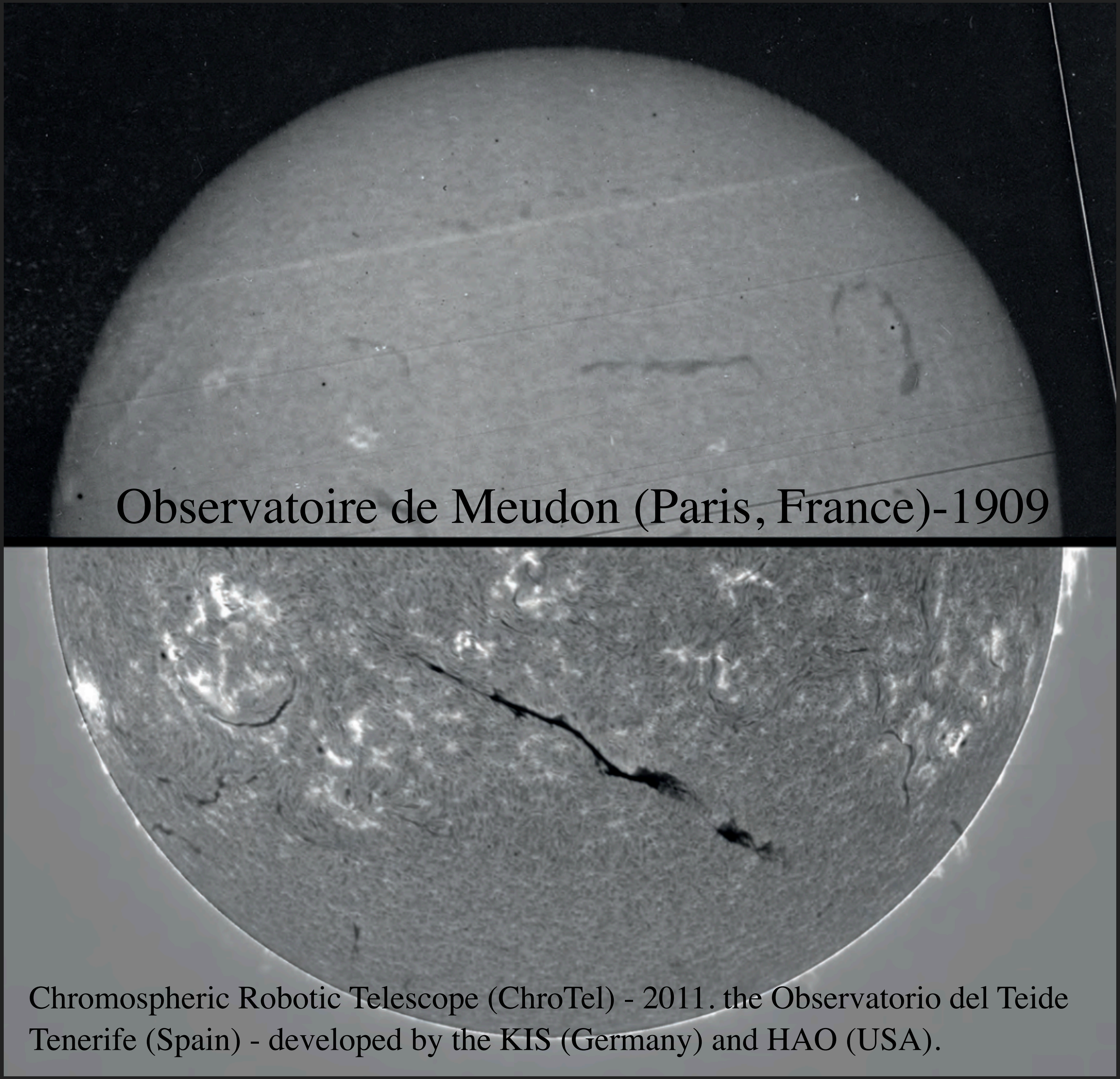


Angelo Secchi and Pietro Tacchini in 1874



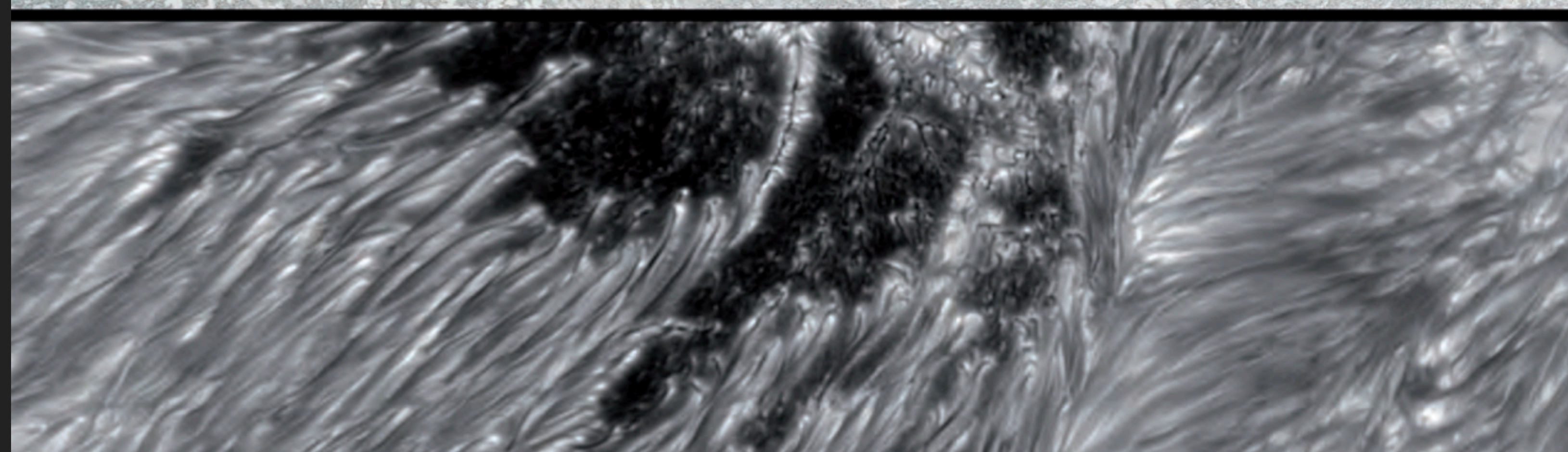
the Japanese Hinode satellite on 8 November 2007

FILAMENTS


Observatoire de Meudon (Paris, France)-1909
Chromospheric Robotic Telescope (ChroTel) - 2011. the Observatorio del Teide
Tenerife (Spain) - developed by the KIS (Germany) and HAO (USA).

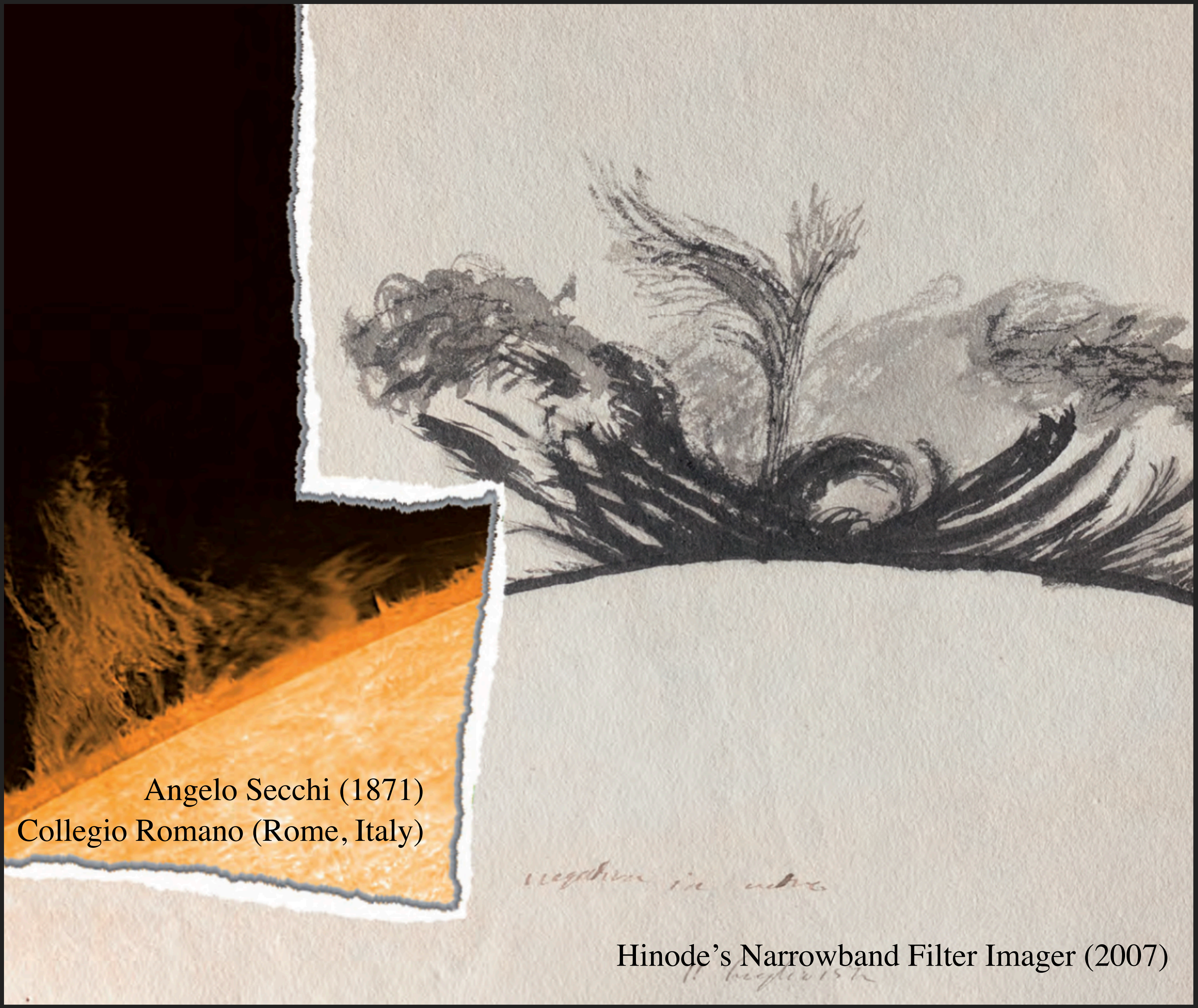
PENUMBRA

Samuel Langley (1873)-13-inch Fitz-Clark refractor
of the Allegheny Observatory (Pennsylvania, USA)

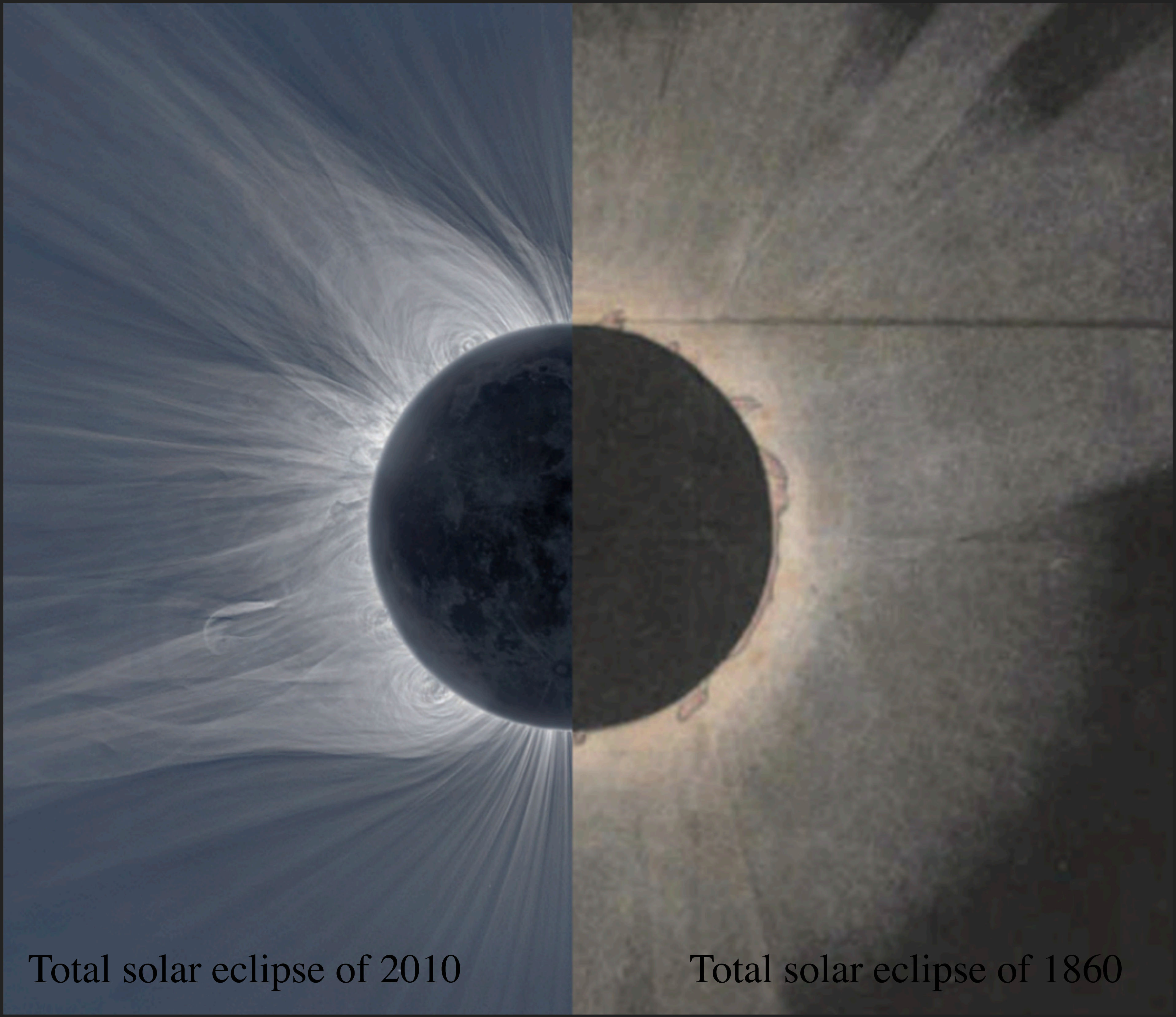


Goode Solar Telescope (2015)-1.6-m Goode Solar Telescope
at Big Bear Solar Observatory (California, USA)

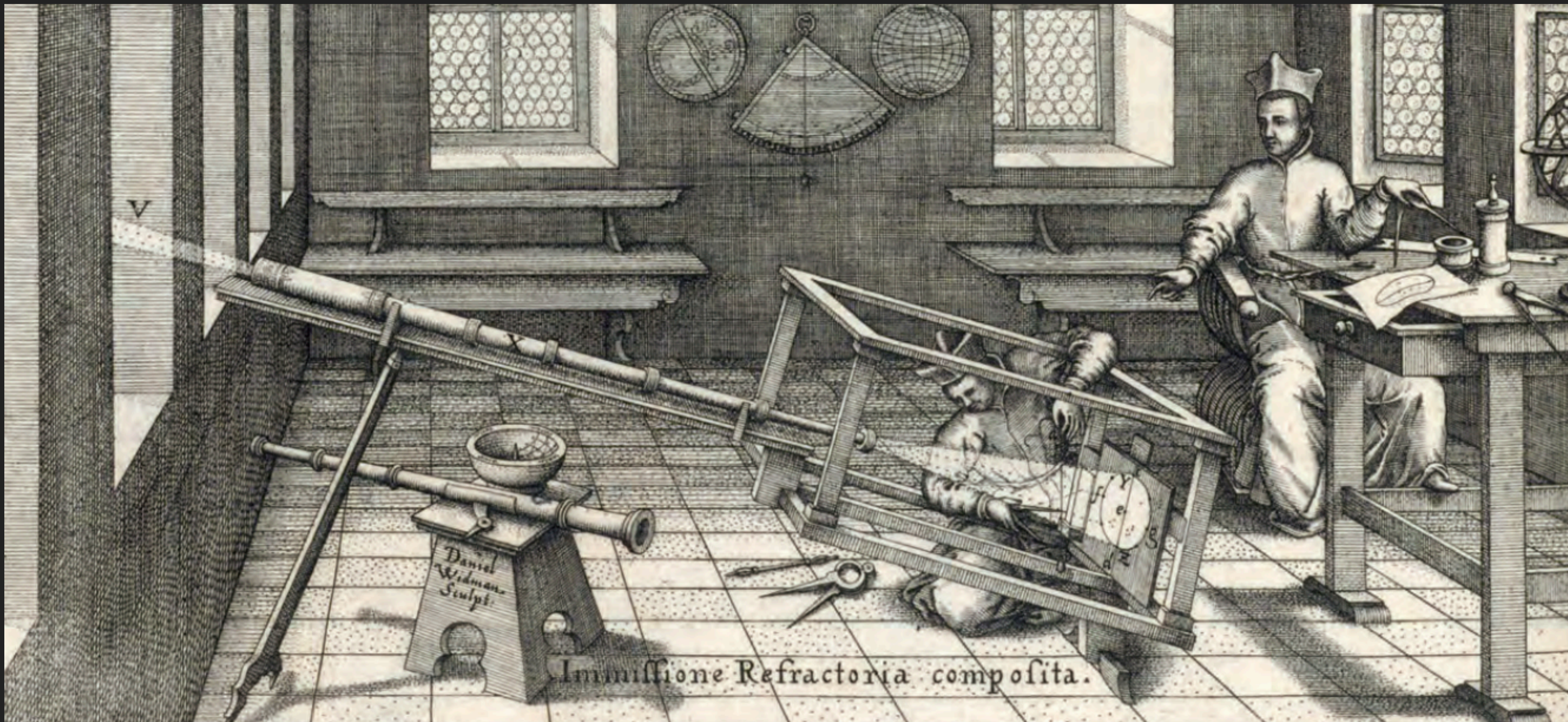
PROMINENCES



CORONA



SOLAR TELESCOPES



Christoph Scheiner's telescope (circa 1625)-Rome (Italy)　　The illustration is from the book "Rosa Ursina" by Scheiner

- The image of the Sun created by the instrument was projected on a screen, over which sunspots could be drawn accurately. Scheiner's telescope was a small refractor made up of lenses.

EUROPEAN SOLAR TELESCOPE

- With a primary mirror of 4 meters, it will be the largest telescope ever built in Europe. Construction will start towards the end of 2021. The EST design is optimized to study the magnetic and dynamic coupling of the solar atmosphere through multi-wavelength observations. EST will be equipped with state-of-the-art instrumentation, including spectropolarimeters based on integral field units.

RESOURCES

- ESTCalendar2020: http://www.est-east.eu/est/images/media/pdf/ESTCalendar/ESTCalendar2020_web.pdf
- http://www.est-east.eu/est/index.php?option=com_content&view=article&id=924lang=en&lang=en
- https://www.swpc.noaa.gov/products/aurora-30-minute-forecast
- https://www.aavso.org/zurich-classification-system-sunspot-groups