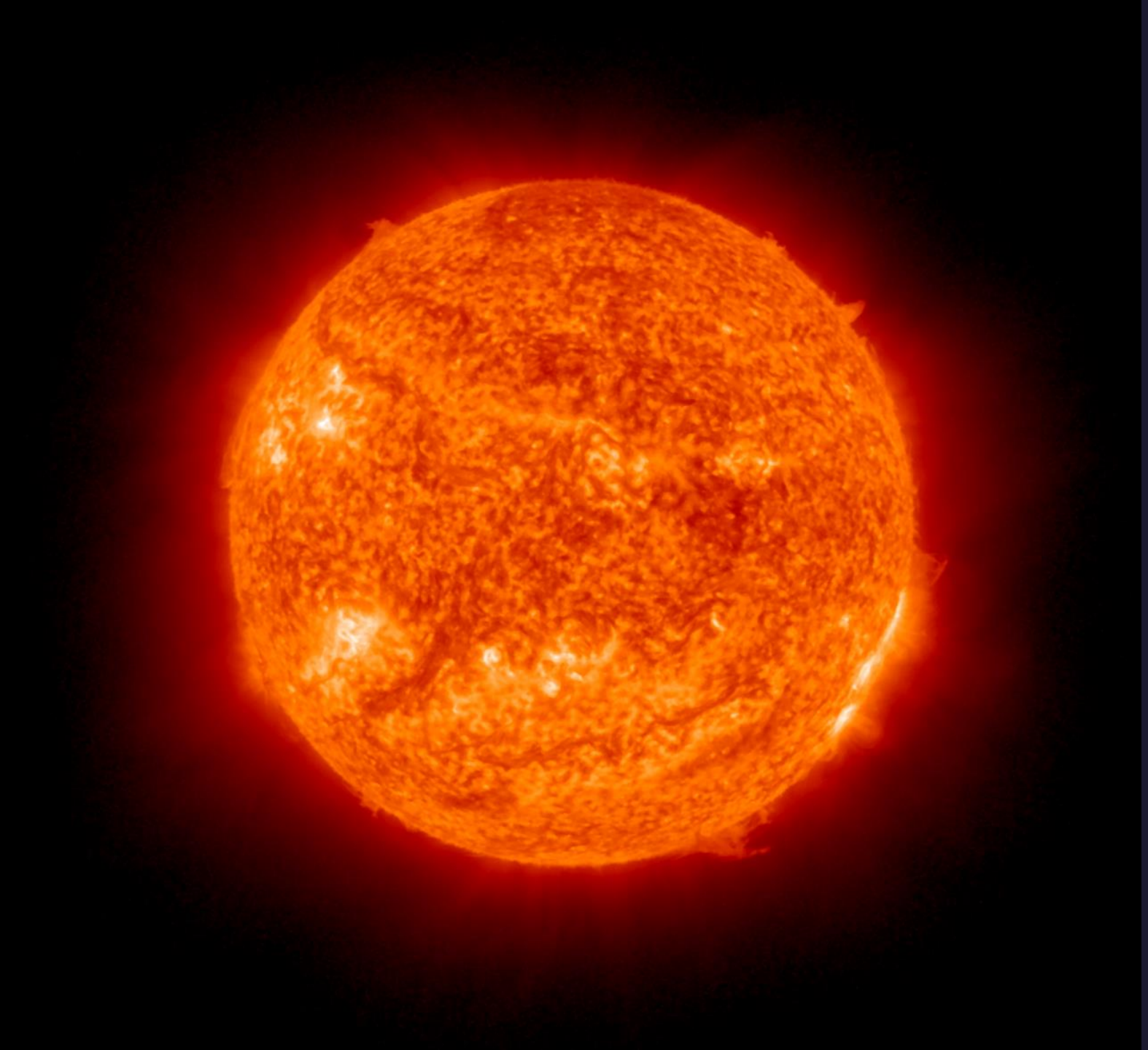


Solar Cycles and Sun Spots

Gary Heard

What We'll Cover

Sunspots and Coronal Holes

Solar Cycle from 1to 24

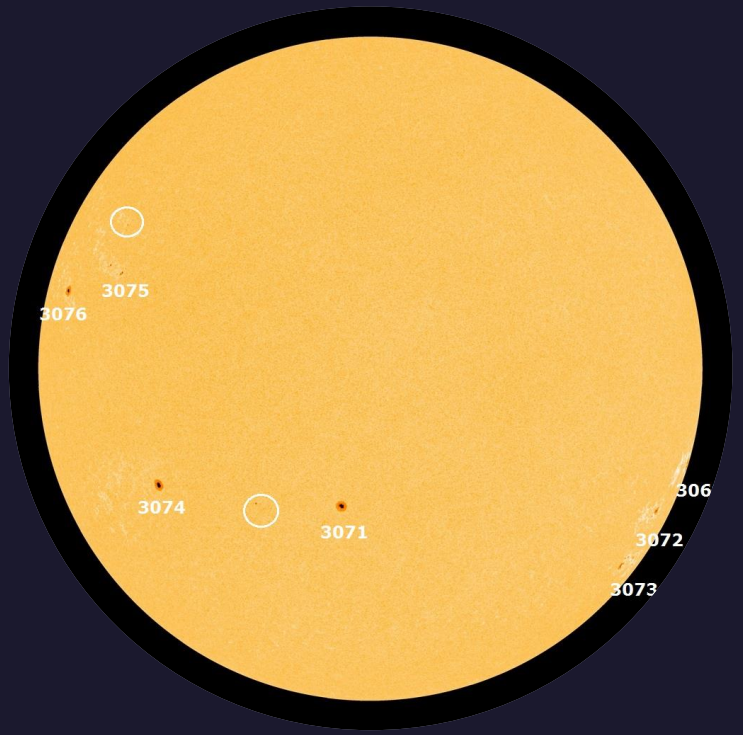
Supercycles

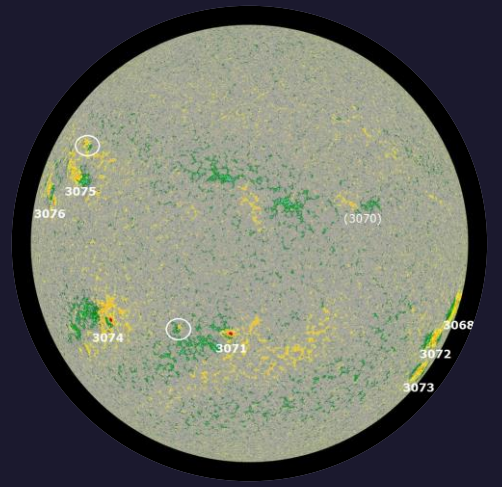
Coronal Mass Ejections (CME)

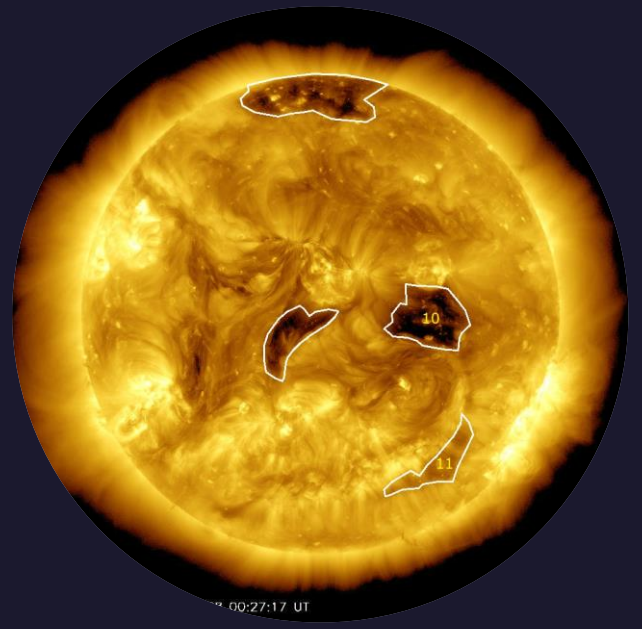
Solar Storms

Past Events

Solar cycle 25 predictions

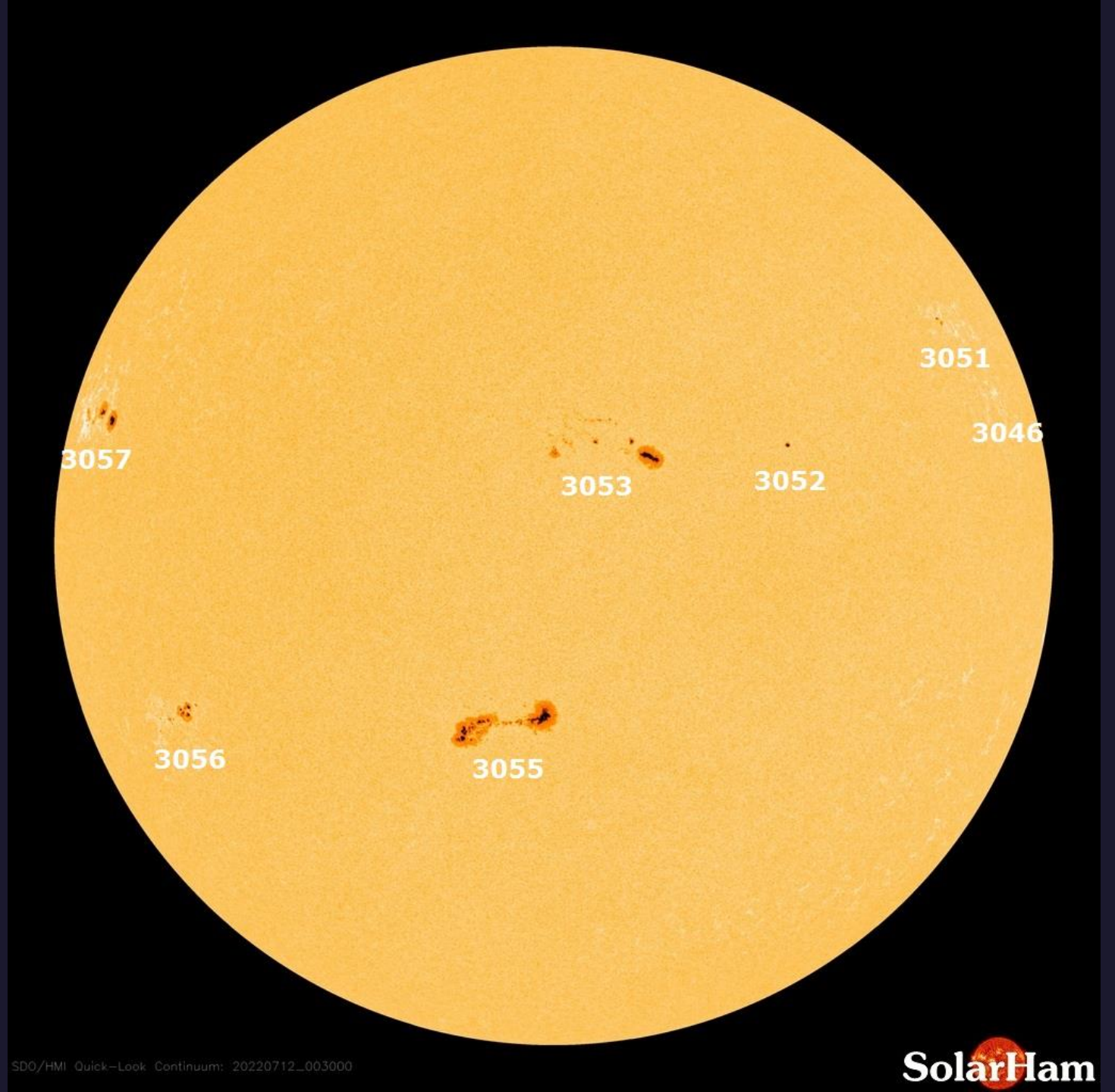






SunSpots

- Image from 12th July 2022
- Seven distinct groups of sunspots
- Biggest Group is 3055
  - What are they ?
  - How do we count them?
    - The Wolf Number
  - Why do they form?
  - What effects can they have on Earth?

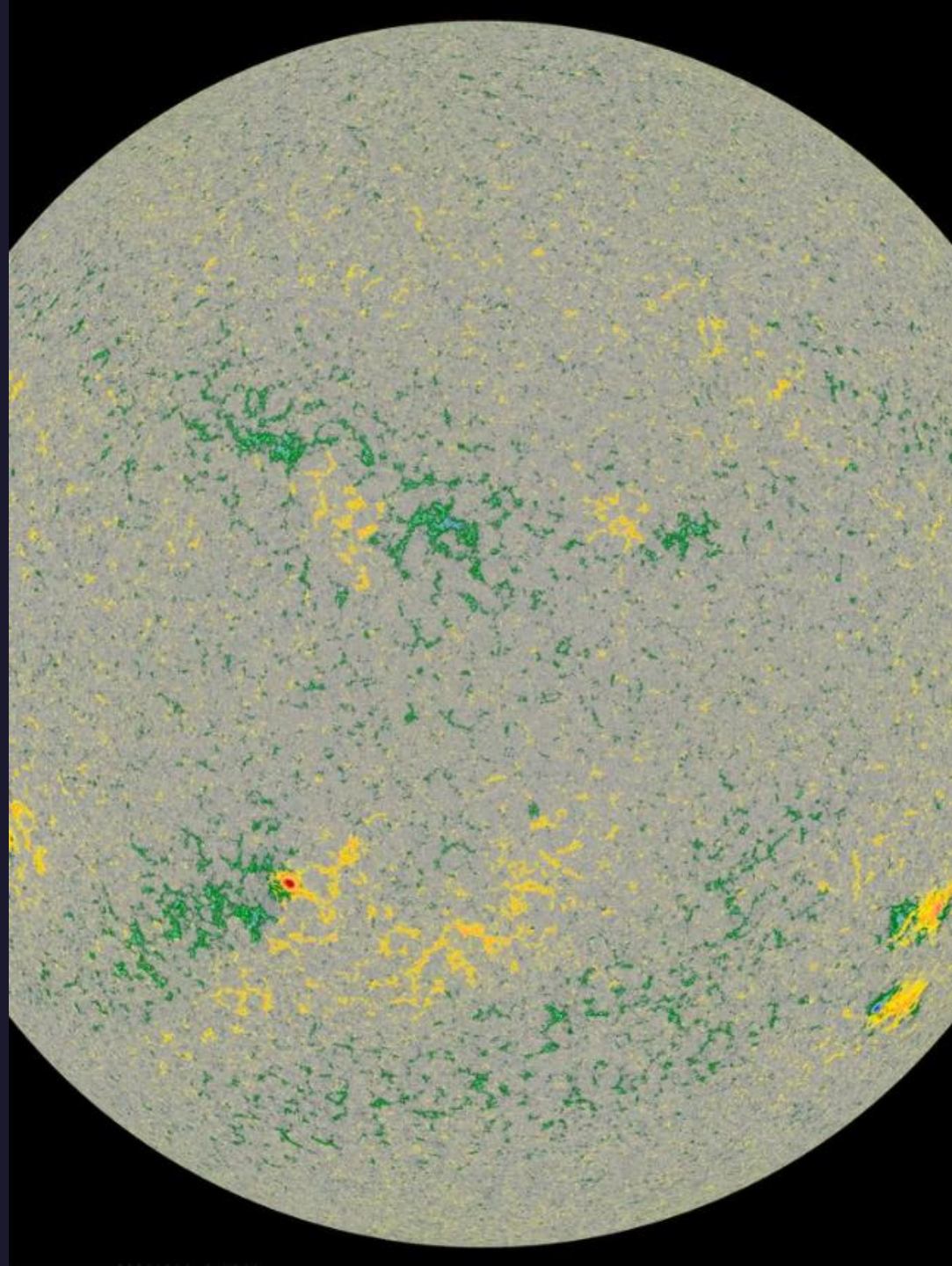


Sunspot 101

What are they?

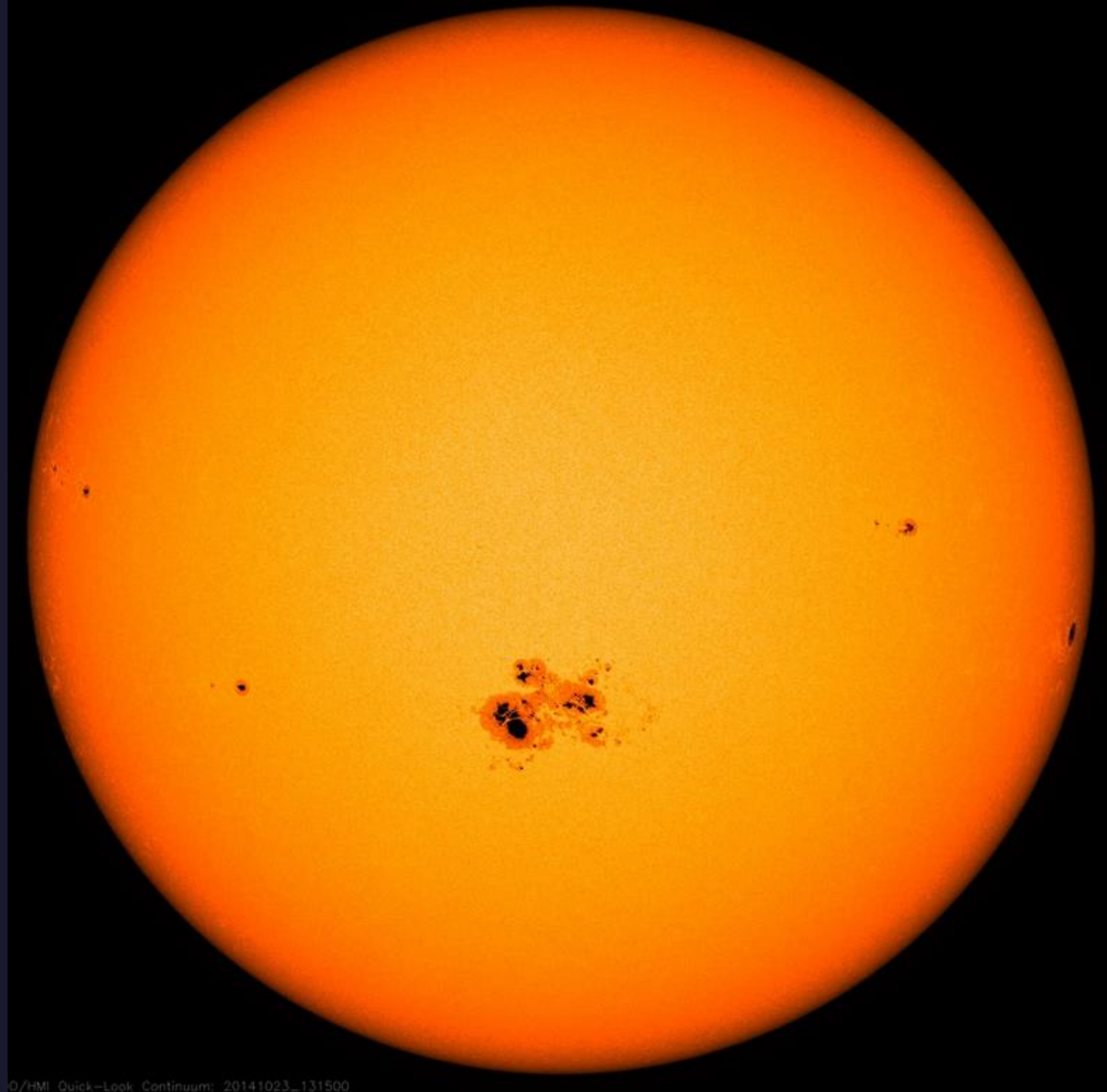
- Magnetic anomalies on the surface of the sun that appear darker than the main disc.
- They appear darker as the intense magnetic fields inhibit convection.
- Usually both magnetic poles (North and South) are present in a sunspot group.
- The picture to the right shows variations across the sun

- Sunspots are first mentioned in the "I Ching" the Chinese "Book of Changes" around 800BCE.
- First European mention was by Theophrastus around 200BCE
- First British mention was December 1128 by a monk, John of Worcester



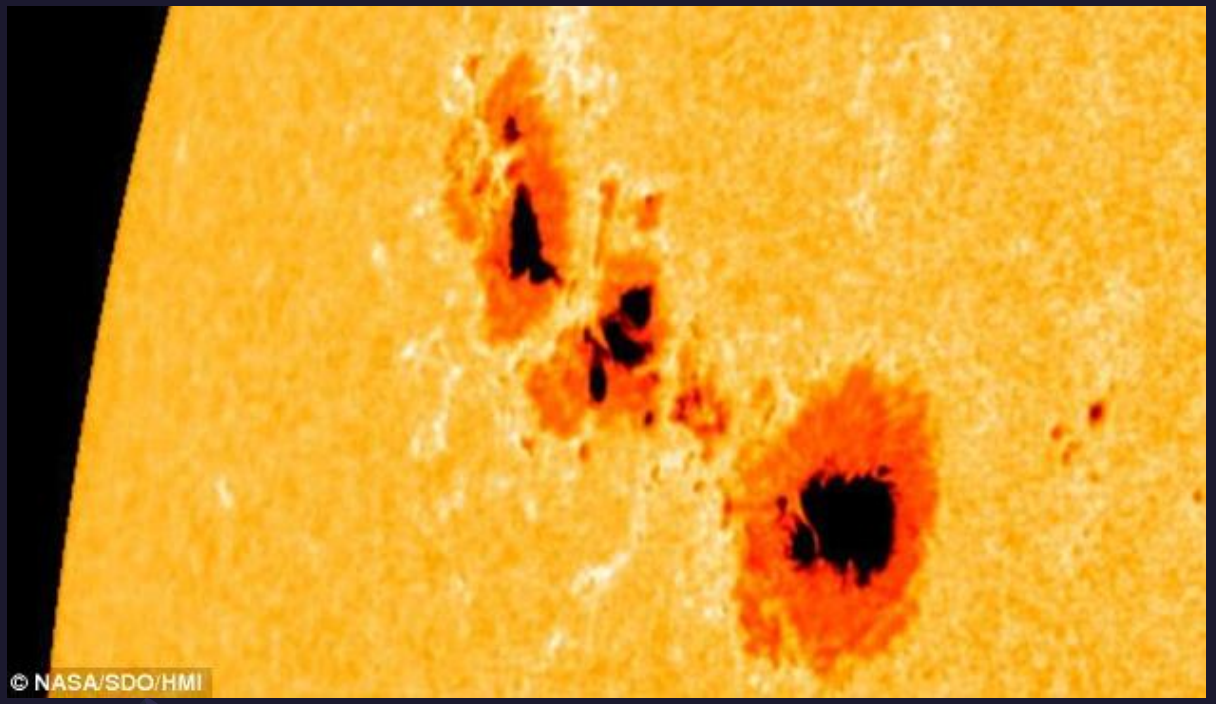
September 2011

- Largest group of Cycle 24
  - will come back to cycles.
- Note the Umbra, very dark regions of intense magnetic activity.
- Surrounding the Umbra is the Penumbra, These areas still have strong magnetic fields, but less intense than the Umbra.
- One contiguous Penumbra may have several Umbrae

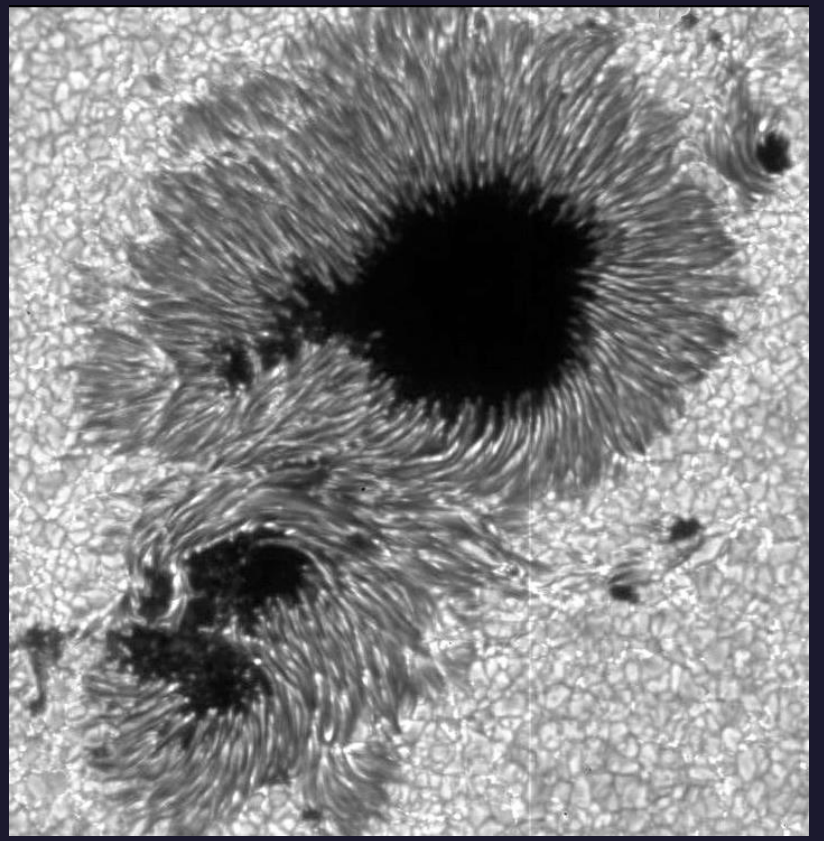


3055 in Greater Detail

Visible Light



Ultra Violet



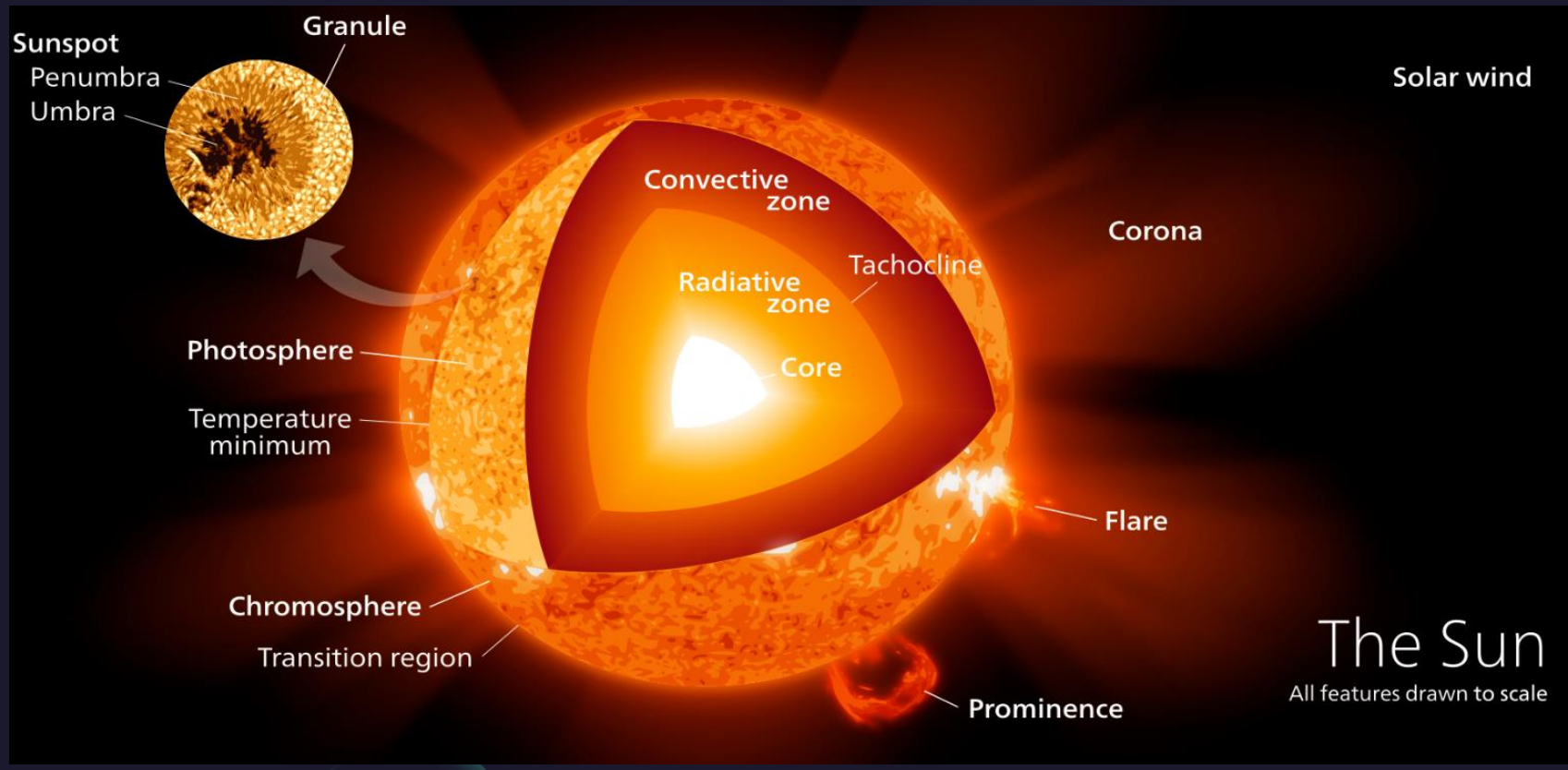
Extra Granularity of Ultra Violet Image

How do Sunspots Form?

Some of the reasons are still unknown but:-

The sun is a giant ball of plasma, ionised gas.

- Ionisation produces Magnetic Fields in the convection zone.
- These Fields create Flux Tubes that project through the Photosphere.
- They suppress convection and are about 2,000C cooler



By Kelvinsong - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=23371669

How do we count them?

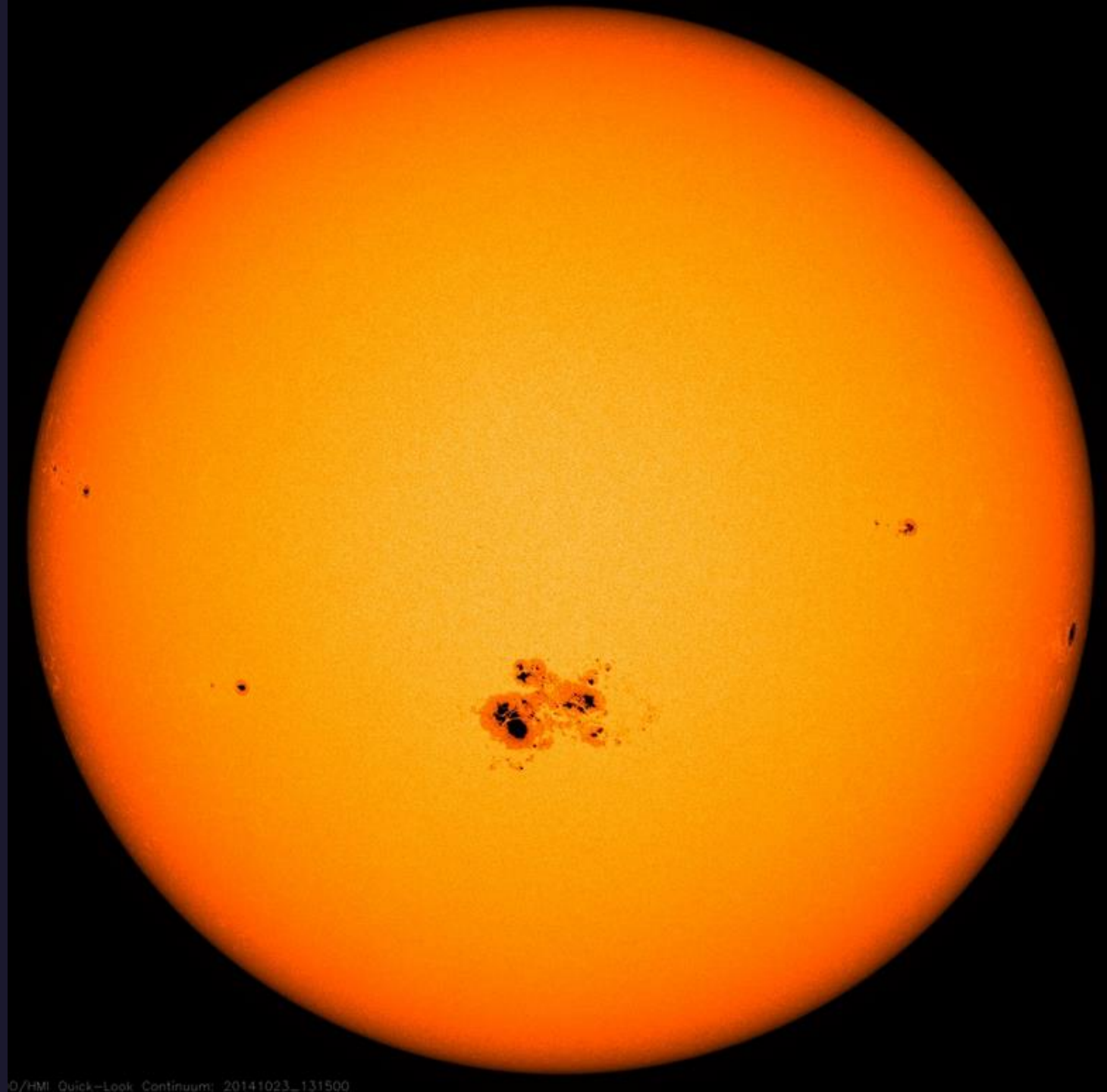
Traditionally, "The Wolf Number"

Also known as

- International sunspot number,
- Relative sunspot number,

or

- Zürich number



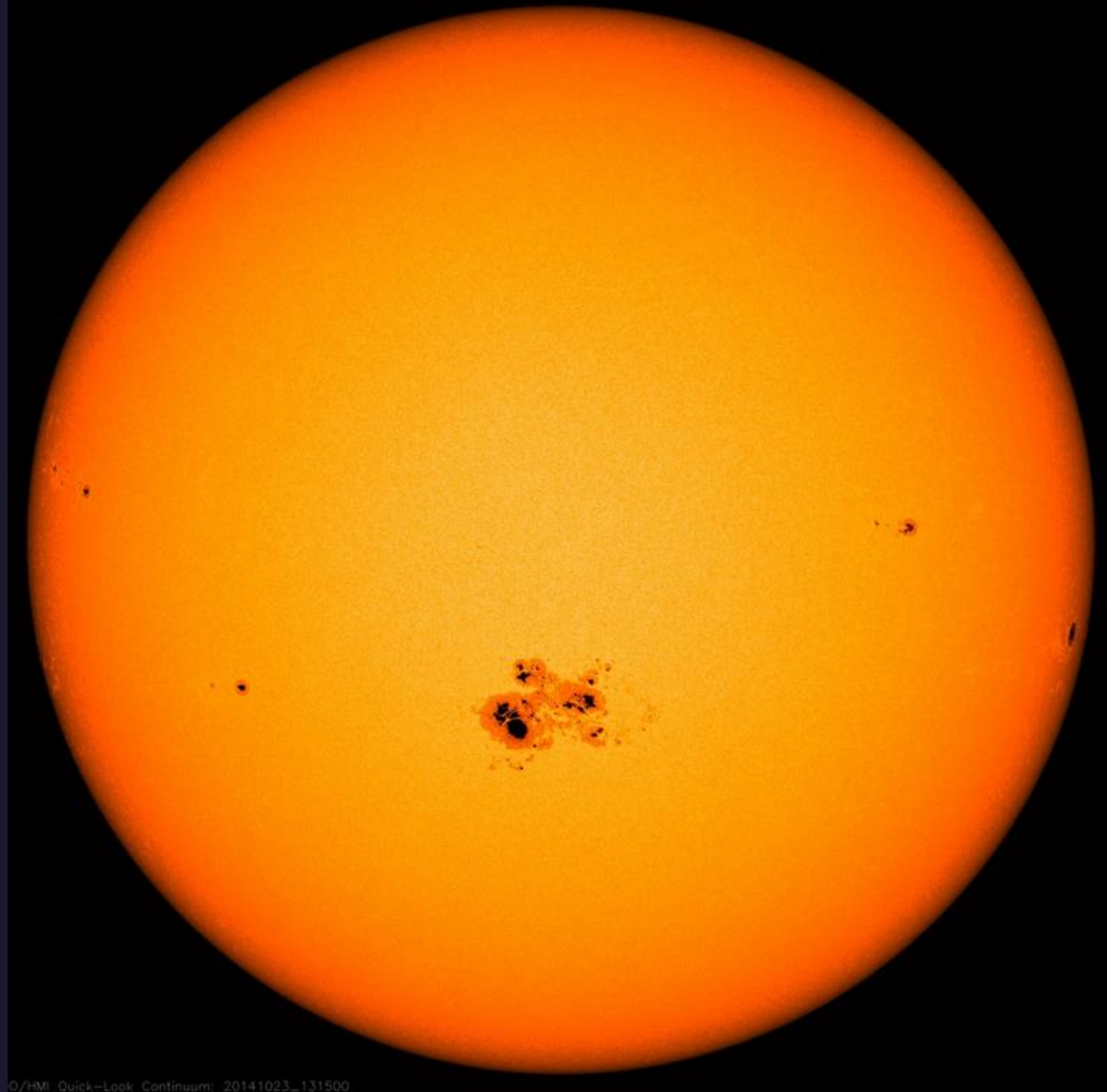
The Wolf Number

First formulated by Rudolf Wolf.

Counts Groups as well as Spots.

Can give numbers over 100 as it multiplies groups by 10!

Has a "Fudge Factor" to deal with poor observation conditions so may not always be accurate.

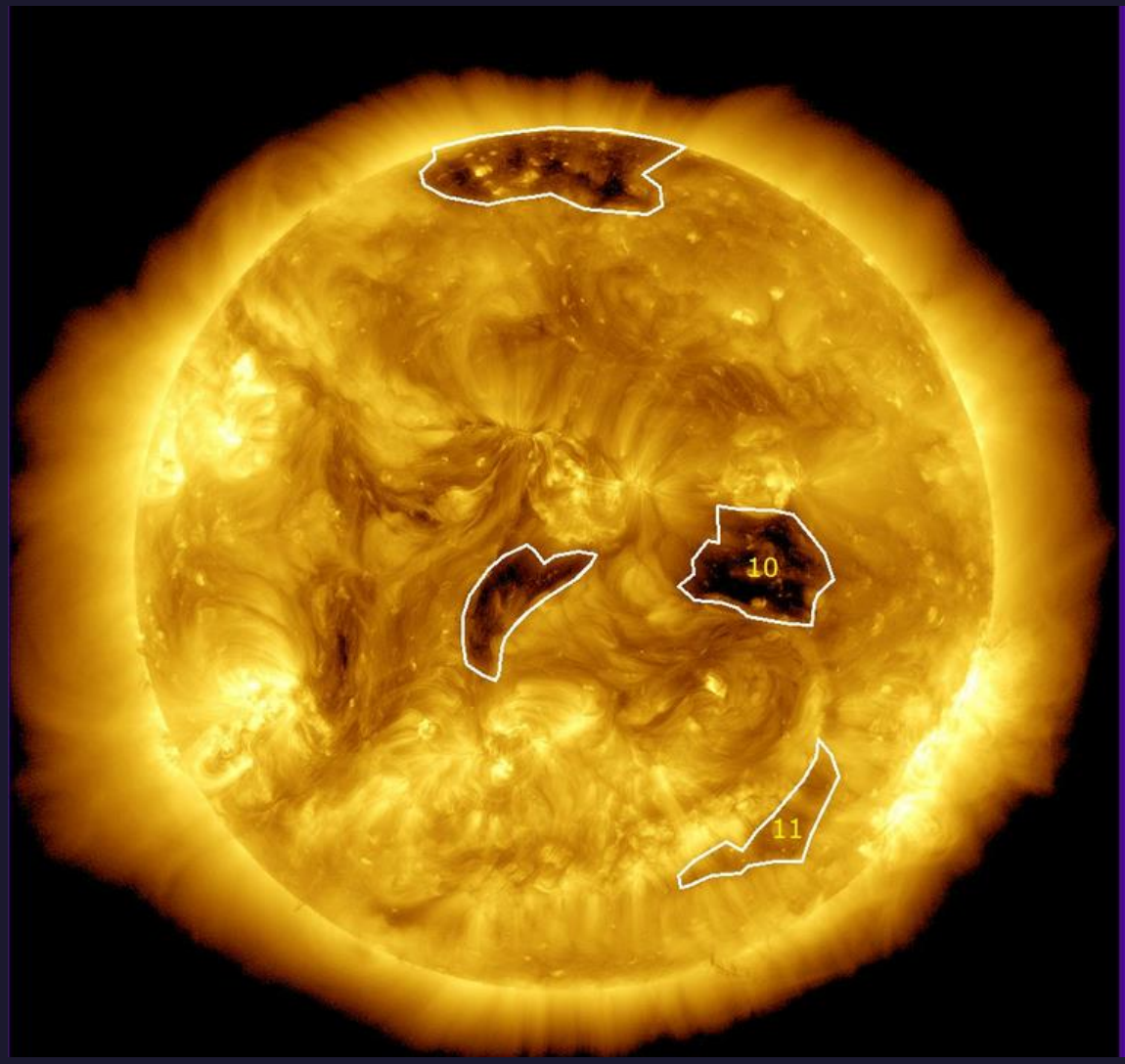


Coronal Holes 101

- The Corona surrounds the sun.
- It is extremely hot, over 1,000,000C
  - The surface of the sun is about 5,500C
  - How is it possible to be so much hotter?
    - This equation

$$k = 20\left(\frac{2}{\pi}\right)^{3/2} \frac{(k_B T)^{5/2} k_B}{m_e^{1/2} e^4 \ln \Lambda} \approx 1.8\ 10^{-10}\ \frac{T^{5/2}}{\ln \Lambda}\ Wm^{-1}K^{-1}$$

    - Not everything is simple.
  - It has a single magnetic polarity (unlike sunspots).
  - Has weaknesses which allow high speed Solar particles to flow through.
  - During Solar Minima are the main cause of Aurora.

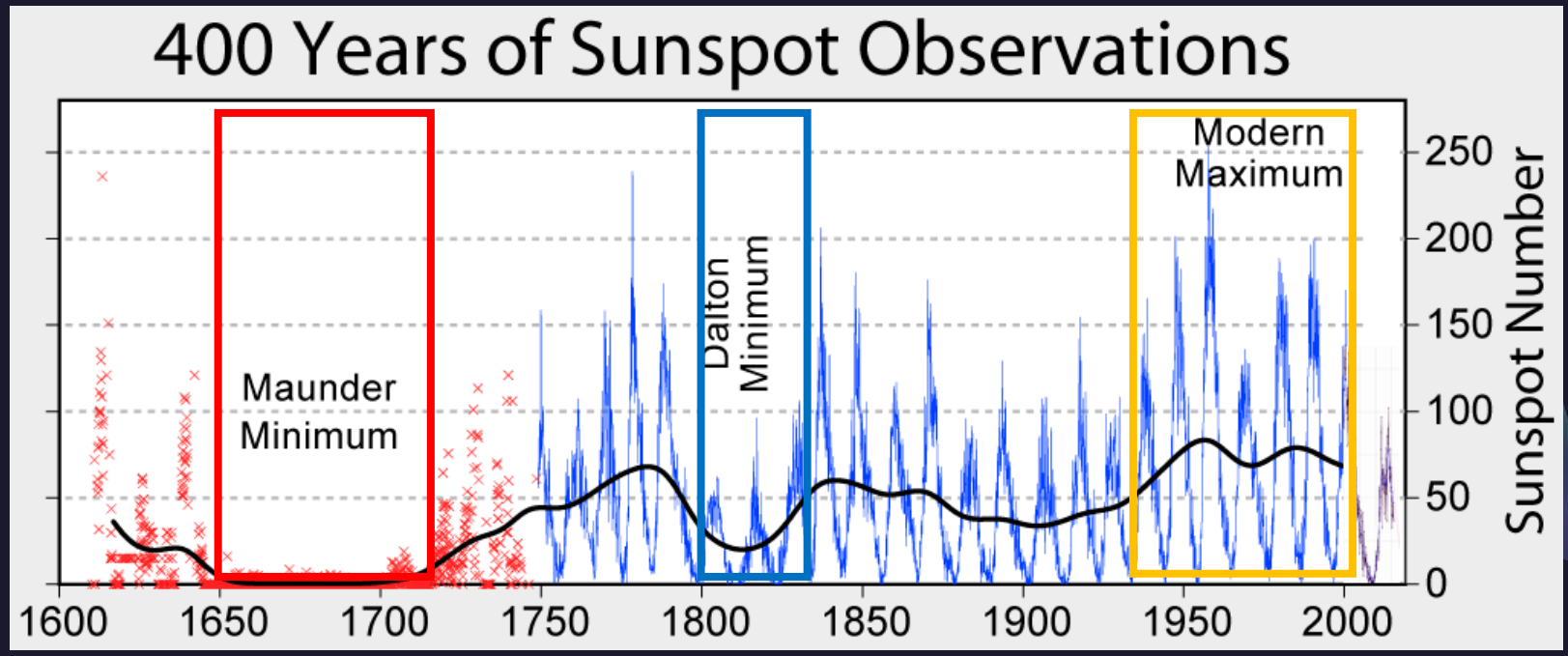


Solar Cycles

- Each Solar Cycle displays a rise and fall in the number of sunspots showing on the disc of the sun.
  - Solar Cycle 1 was deemed, by Rudolf Wolf, to have started in February 1755.
    - We are now in the early stages of Solar Cycle 25.
      - Started December 2019.
      - Expected end between 2029 and 2031.
  - Earlier cycles are not explicitly named.
- A complete cycle is two Solar Cycles and is known as a Hale Cycle.
  - Through a cycle, the Sun's Magnetic Field flips. So after a Hale cycle the Sun has returned to it's original magnetic orientation.
- Supercycles, groups of cycles that combine to have a duration longer than the Hale cycle have been observed.

Cycle 1-24

- Solar cycles only recorded for the Blue line.
- Pre "Cycle 1" Red observations will be looked at when we look at supercycles.



- Variations are apparent even in the last 270 years.
  - 1800-1850 was a 3 cycle event of very low sunspot numbers and is called the Dalton Minimum.
  - 1950-1999 was characterised by much higher sunspot numbers and is characterised as the Modern Maximum.
  - Maunder Minimum was pre Modern Cycle measurement, but is quite well documented, There were very low sunspot numbers throughout the Maunder

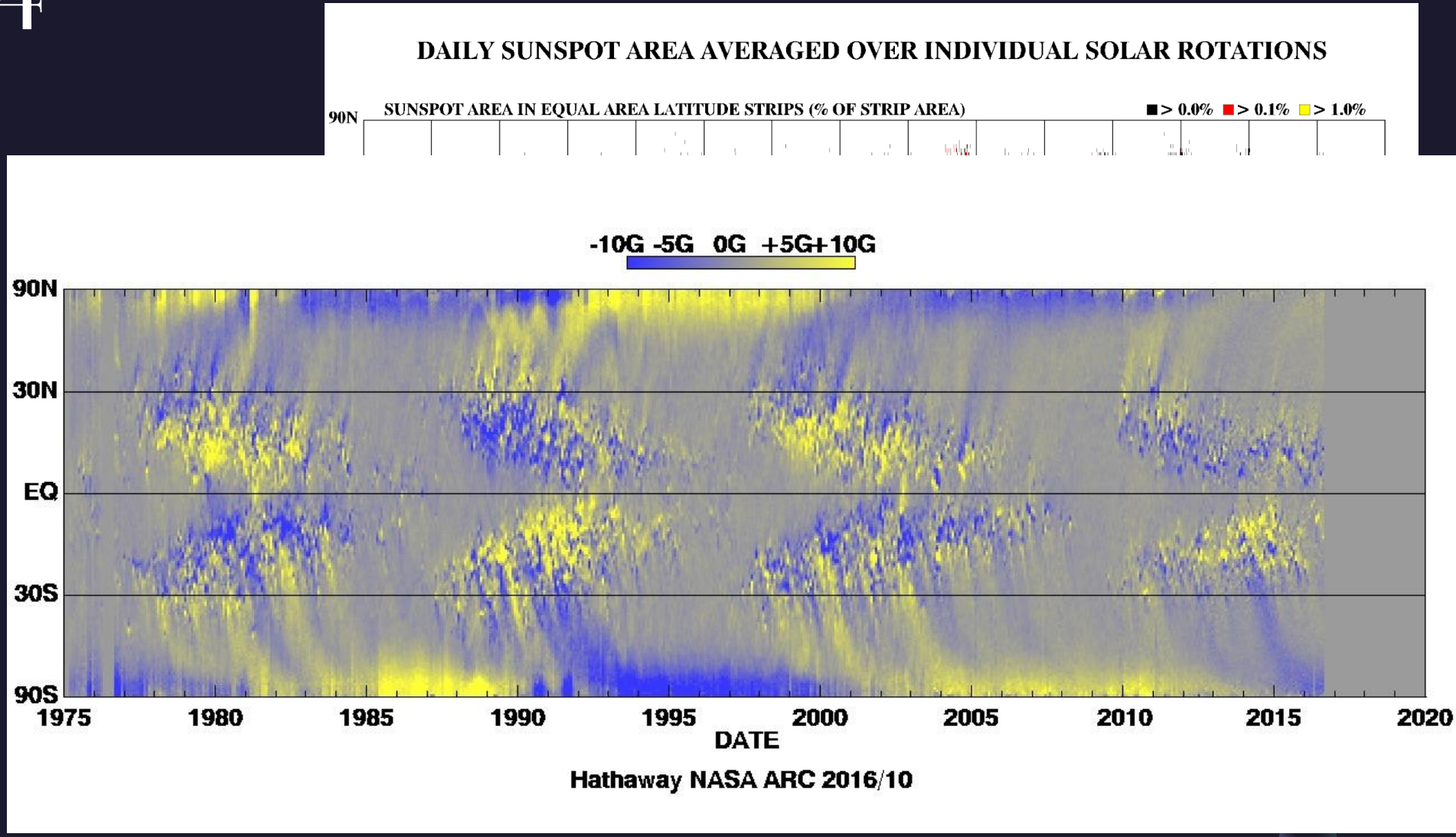
Cycles 1-24

The Butterfly diagram

- Shows how spots evolve between 30N and 30S.
- Show strength of cycles.

The rush to the Poles

- As the cycle progresses, spots and groups move much more quickly to the poles



Viewing the Sun

Solar Dynamics Observatory (SDO)

The SDO Gives us a near instantaneous view of the sun.
Visible Disk
Magnetogram.
3 Wavelength (Composite).

- 211nm (red)
- 193nm (green)
- 177nm (blue)

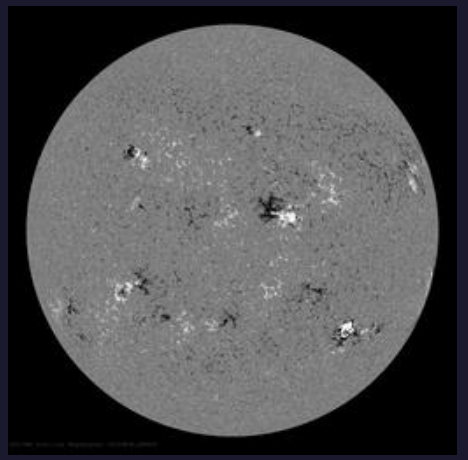
Coronal Holes.

Helps understand Space Weather

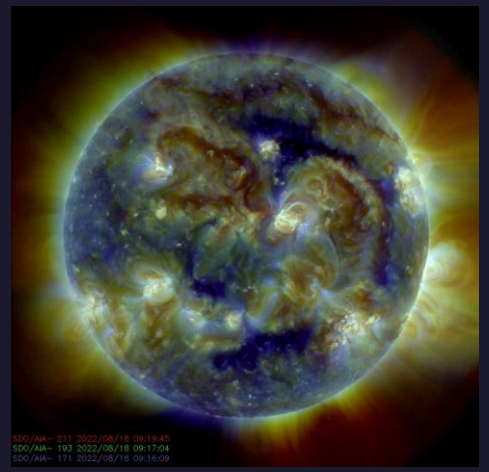
- Allows Prediction of Aurora.
- Helps protect Spacecraft and Astronauts.

Visible

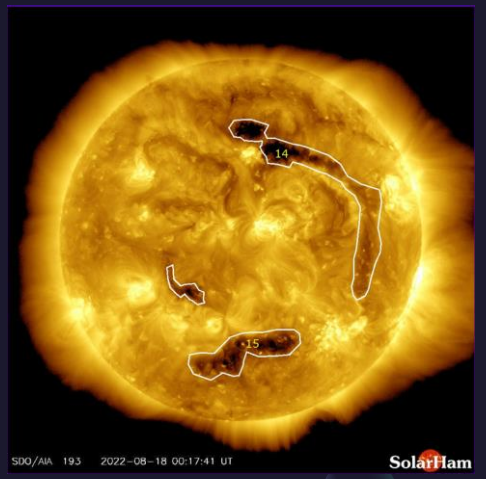
Magnetogram



3 Wavelength

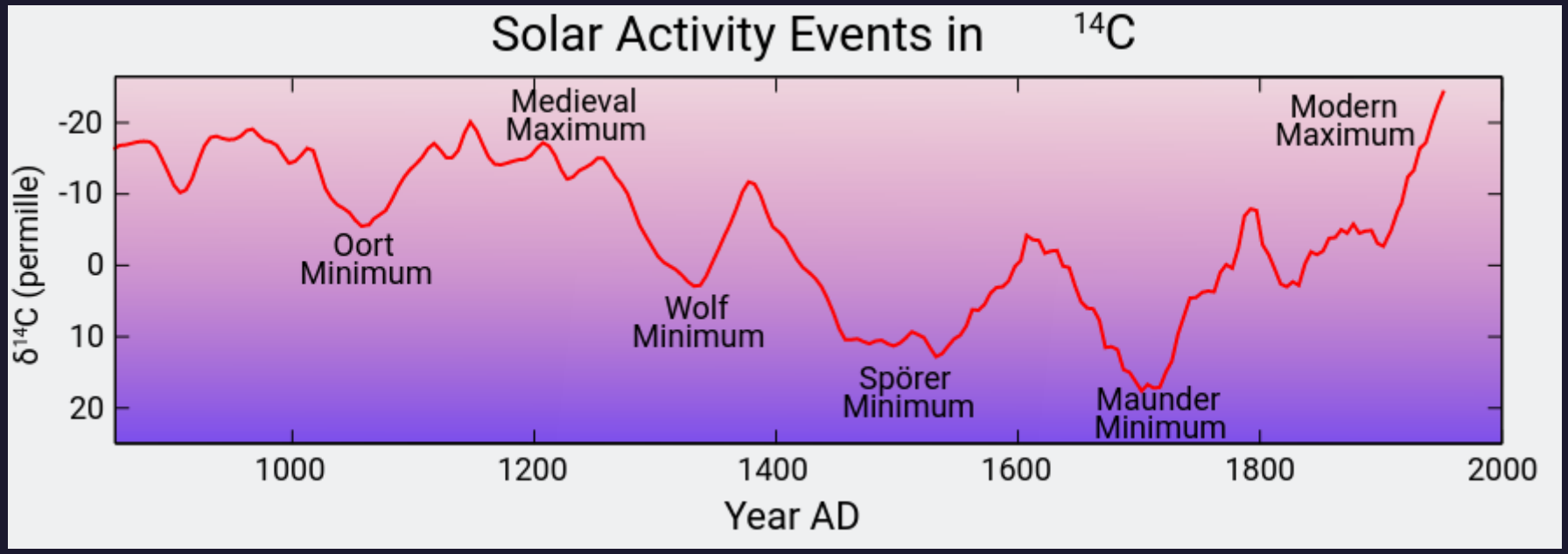


Coronal Holes



Data from https://sdo.gsfc.nasa.gov/data/
https://www.solarham.net

Supercycles



Carbon 14 is created in the upper Atmosphere.

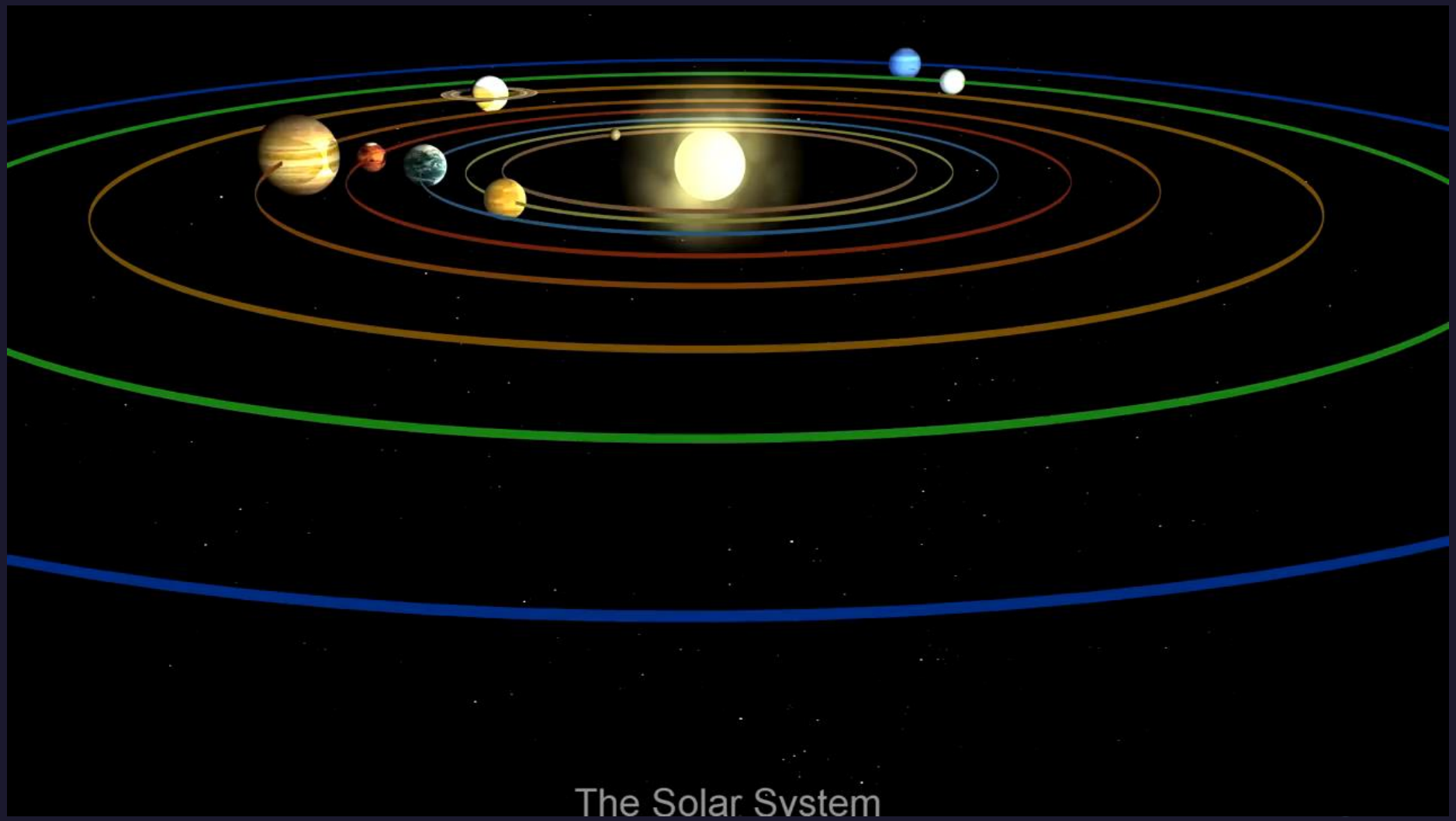
- Using ^{14}C as a Proxy we can use it to look at when earlier cycles occurred
- Limited by the radioactive decay of ^{14}C
- This and other techniques show the Minima as Cooling periods in the worlds Climate

Supercycles

What causes them?

The Sun is a ball of Gas

- The Gravitational Centre (GC) of the Solar system varies.
- The Gas Giants pull the GC away from the Solar centre disrupting magnetic currents in the solar core.
- This pull varies depending on where the planets are in relation to each other



Earthly Effects

Aurora

Solar Wind is deflected by the Magnetosphere towards the poles.
If the Solar Wind has a South facing magnetic effect (bz), it's attracted to the North Pole of the Earths field.
Enters the Upper Atmosphere with more energy to create an Aurora

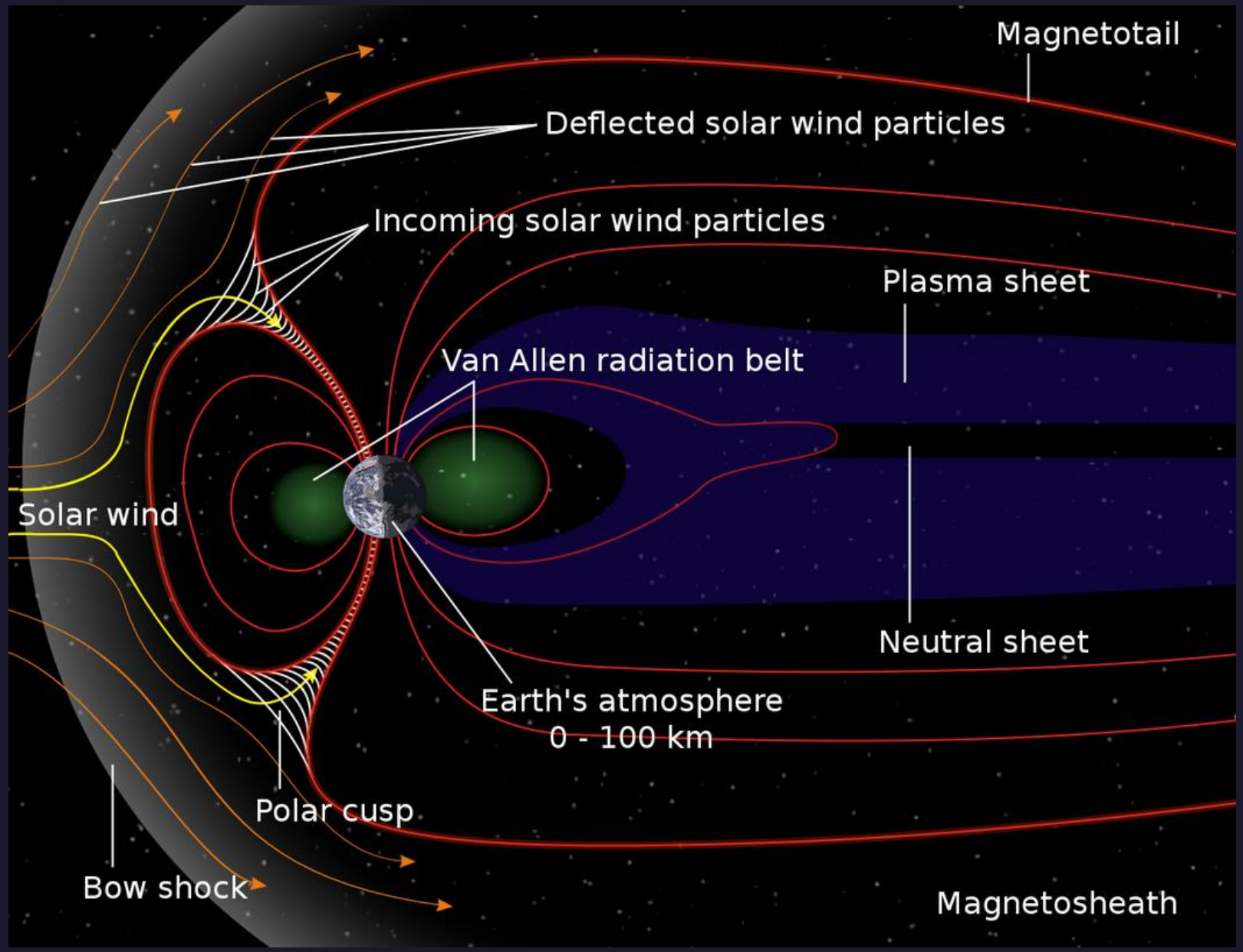
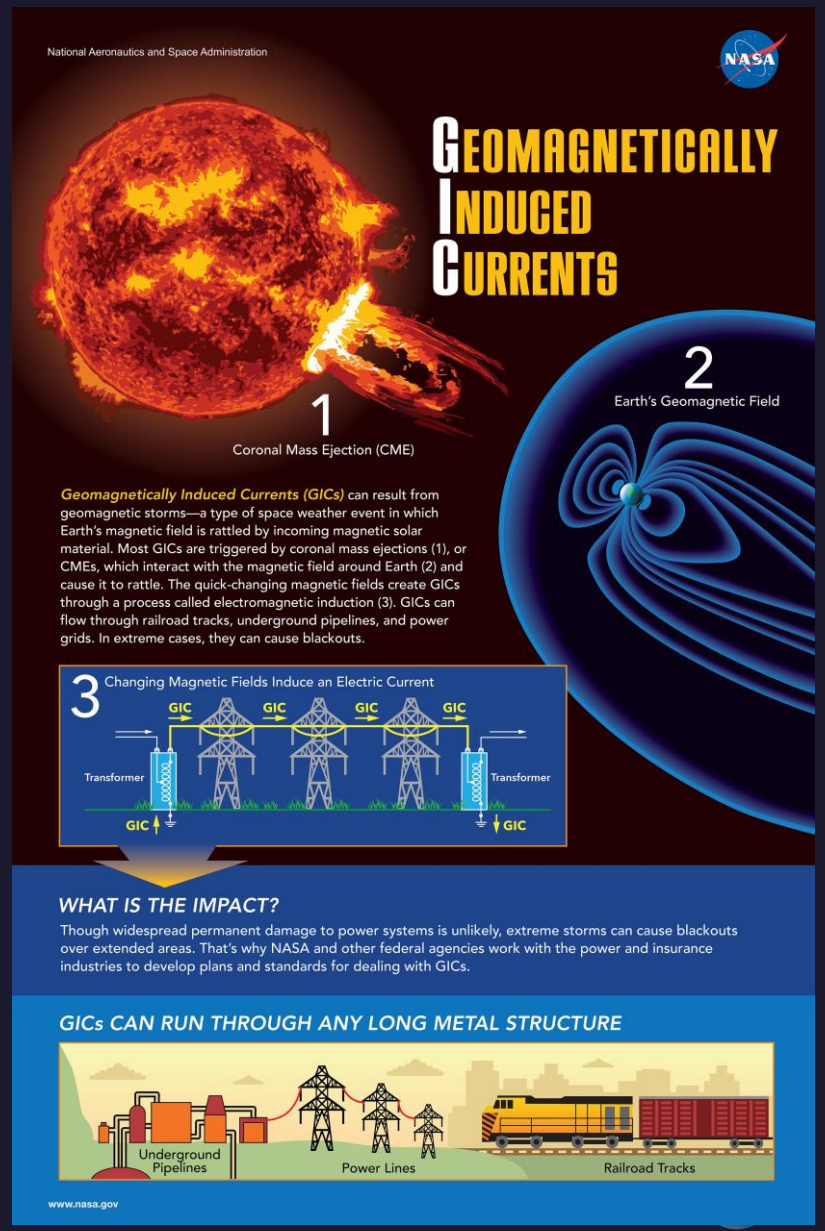


Diagram from Wikipedia

Earthly Effects

Geomagnetically Induced Currents

- The Earth has an electrical current flowing from Poles to Equator on the sunlit side and Equator to Poles on the dark side.
- Solar Storms can disrupt this current and can cause the "Earth" in an electric circuit to have a non zero voltage causing problems with many types of circuit.
- Transformers use Alternating Current and can be disrupted by a changing "Earth".
  - In the worst Cases, the Transformers can fail



Near Earth Effects

Satellites affected (approx. 4550) :-

- Near Earth Satellites can be affected by the expansion of the atmosphere caused by a Solar Storm.
  - Worst case can cause the satellite to fall out of orbit.
- Geostationary Satellites can be nudged out of position.
- Satellites are positioned to minimise potential problems with Solar Panels during Solar Storms.

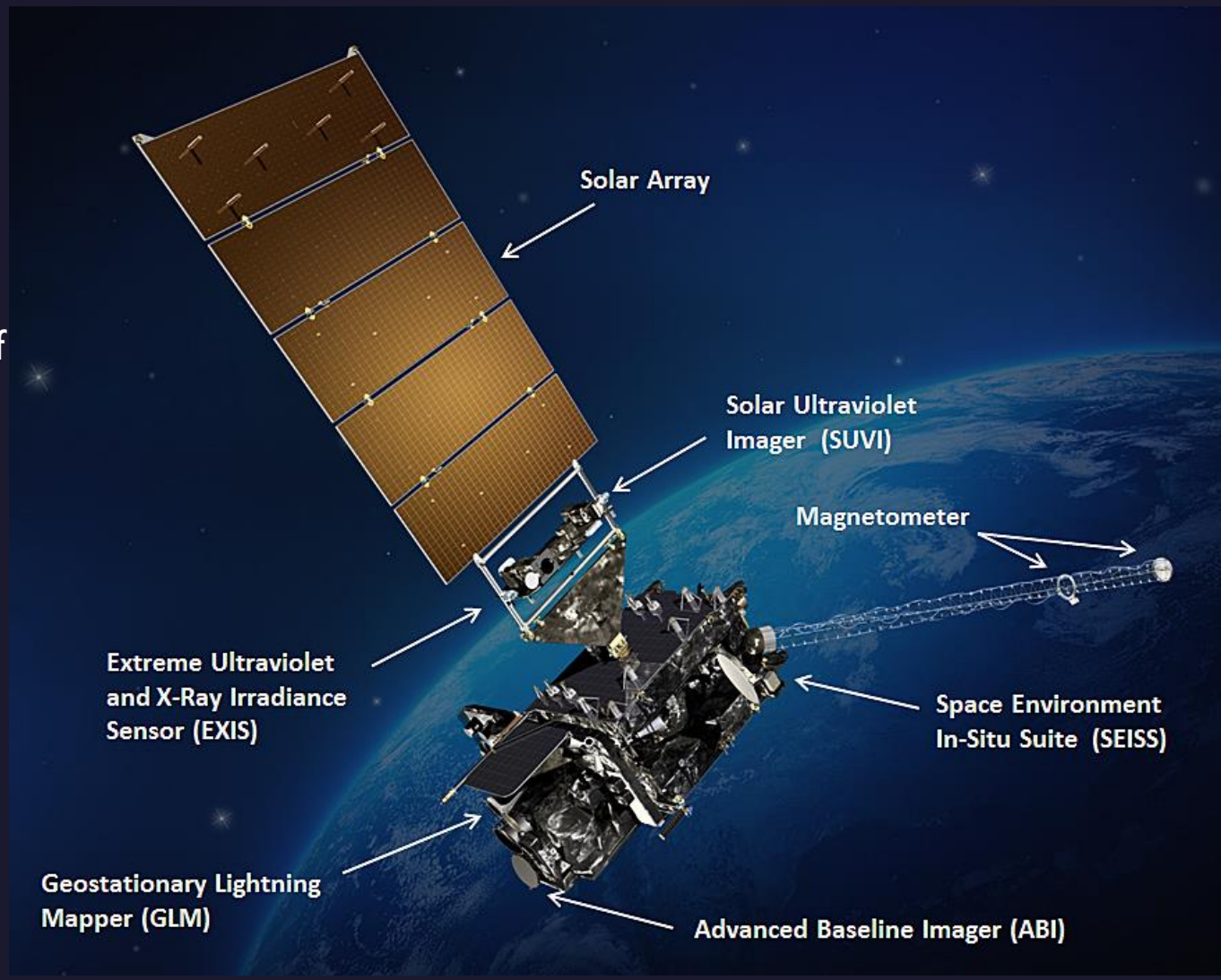


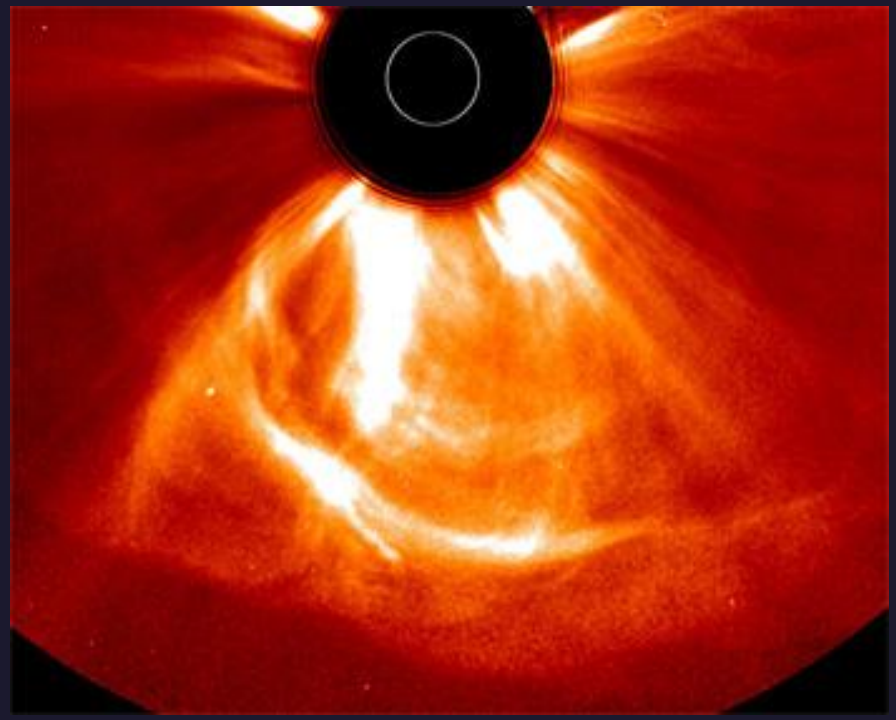
Image of GOES16 Weather Satellite operate by NASA And NOAA

Past Events

Carrington 1859

- Solar Cycle 10
  - 1st September 1859 a few months before Cycle to Maximum.
    - Solar Flare Spotted by Carrington and Hodgson.
  - 2-3 September Aurora seen as far South as the Caribbean just 18-20 degrees from the Equator.
- Now thought to be a massive Earth facing CME.

- Picture shows a CME from 2012, pictured by STEREO A, thought to be about the same strength but missed Earth by 1/3 solar rotation

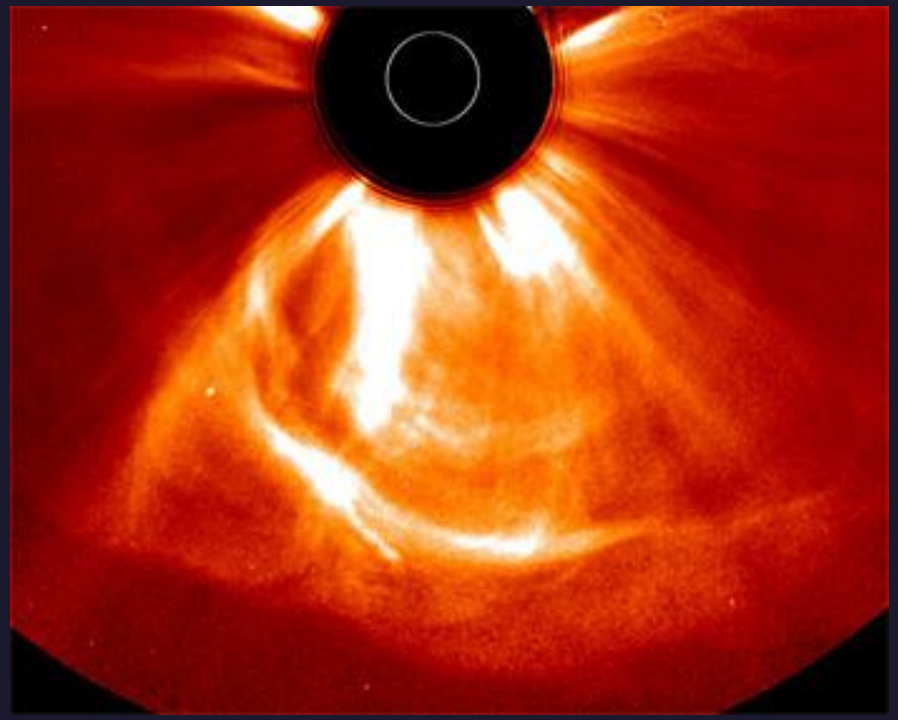


Past Events

Quebec 1989

- Solar Cycle 22
  - 06th March 1989 high activity cycle 22 period.
  - A X15 Class Solar Flare Caused a CME and associated Solar Storm.
- GOES Weather Satellites disrupted.

- Caused a 9 hour electrical Blackout in Quebec due to power surges due to Telluric currents

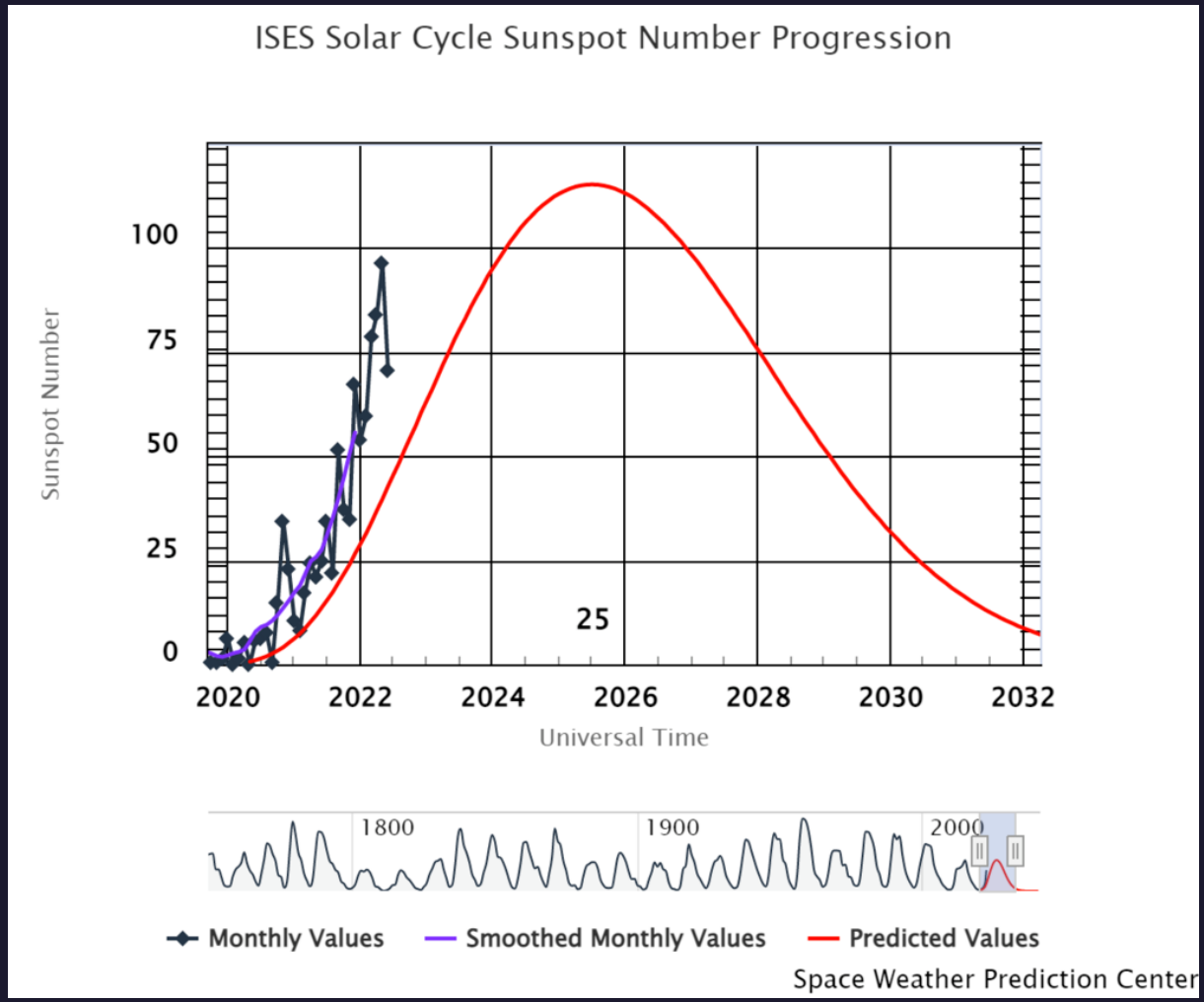


Cycle 25 Predictions

Original Forecast

- Predictions were varied from very weak to strong.
  - Originally Expected to be as weak or weaker than Cycle 24
    - Prediction based on Polar Magnetic strength at Solar Minimum
    - Currently somewhat stronger than anticipated.
  - Aurora watch in place for today 18-08-2022.

  - More than 30% stronger that Cycle 24.



And to Finish