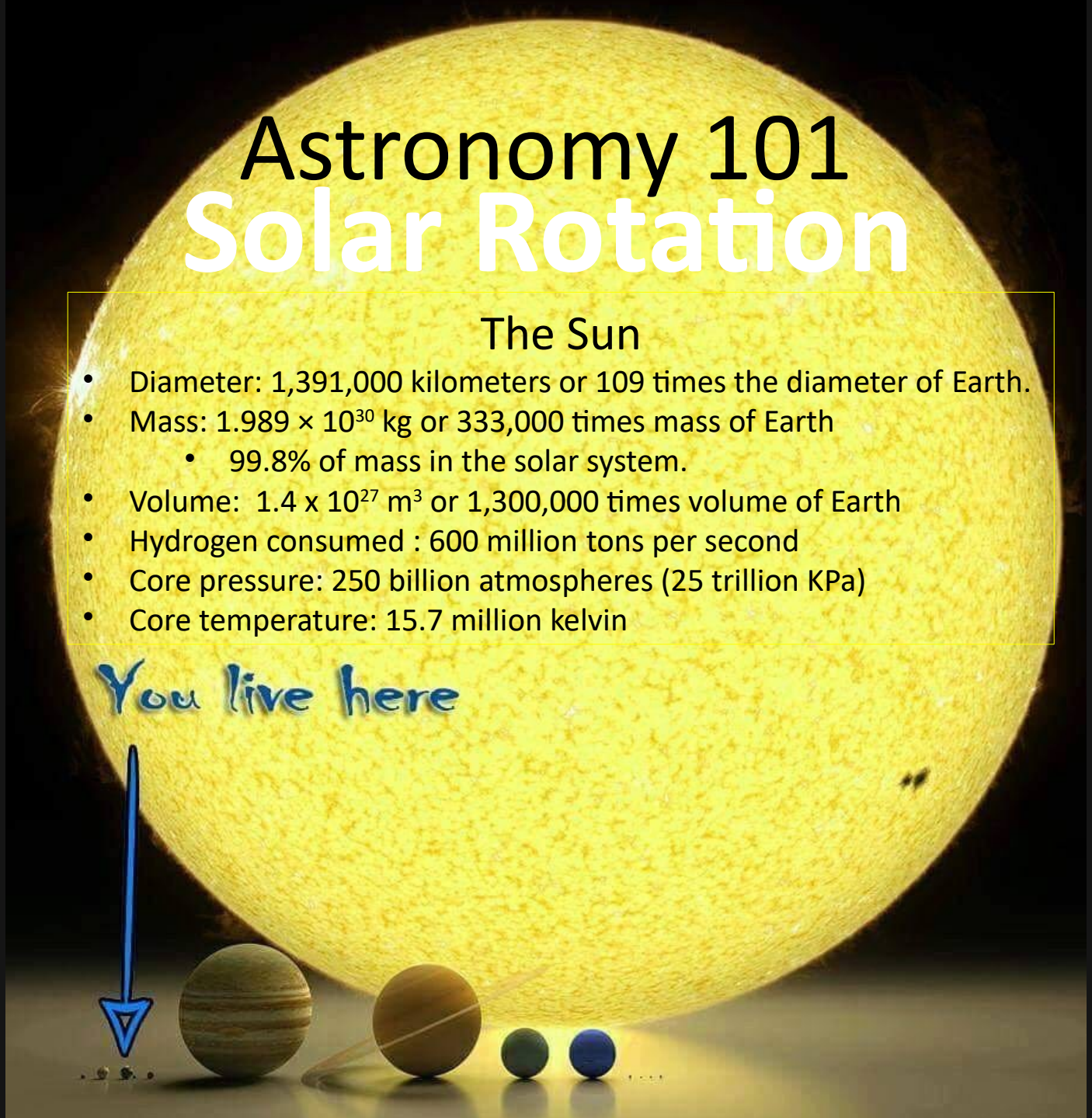
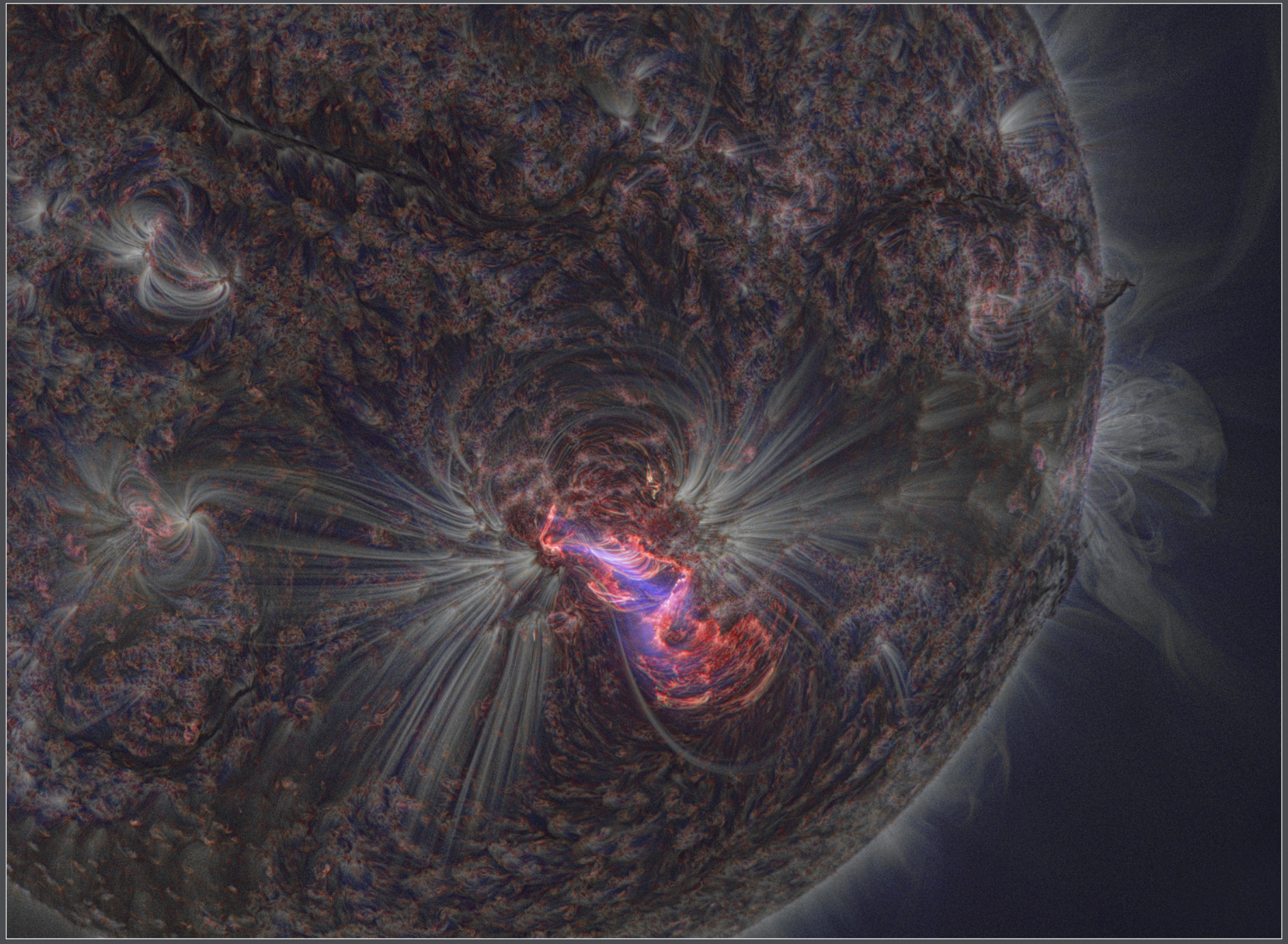
Astronomy 101
Solar Rotation

The Sun

- Diameter: 1,391,000 kilometers or 109 times the diameter of Earth.
- Mass: 1.989×10^{30} kg or 333,000 times mass of Earth
  - 99.8% of mass in the solar system.
- Volume: 1.4×10^{27} m^3 or 1,300,000 times volume of Earth
- Hydrogen consumed : 600 million tons per second
- Core pressure: 250 billion atmospheres (25 trillion KPa)
- Core temperature: 15.7 million kelvin



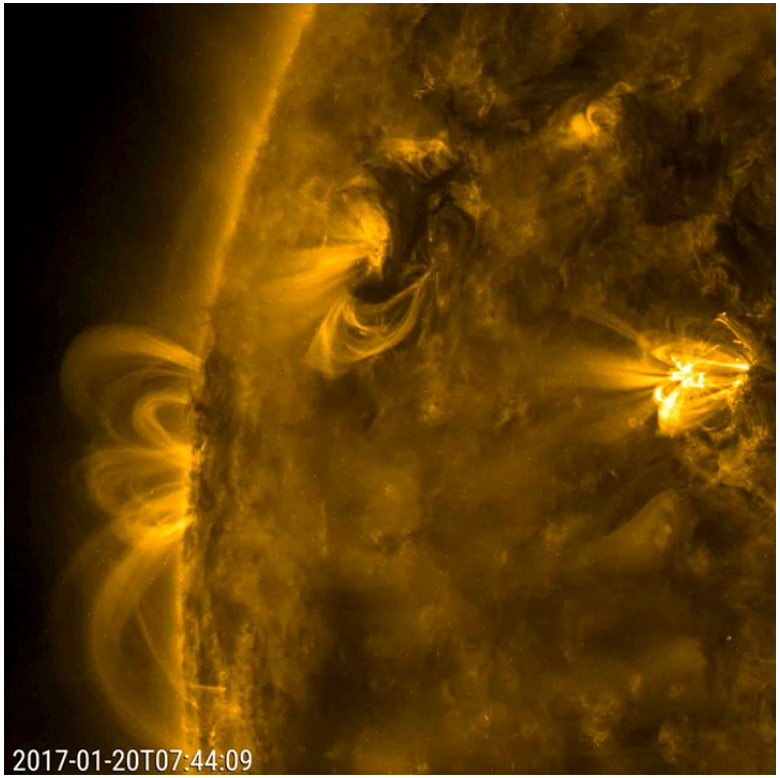
Forecasters inside the Space Weather Forecast Office of NOAA's Space Weather Prediction Center (SWPC) in Boulder, Colorado

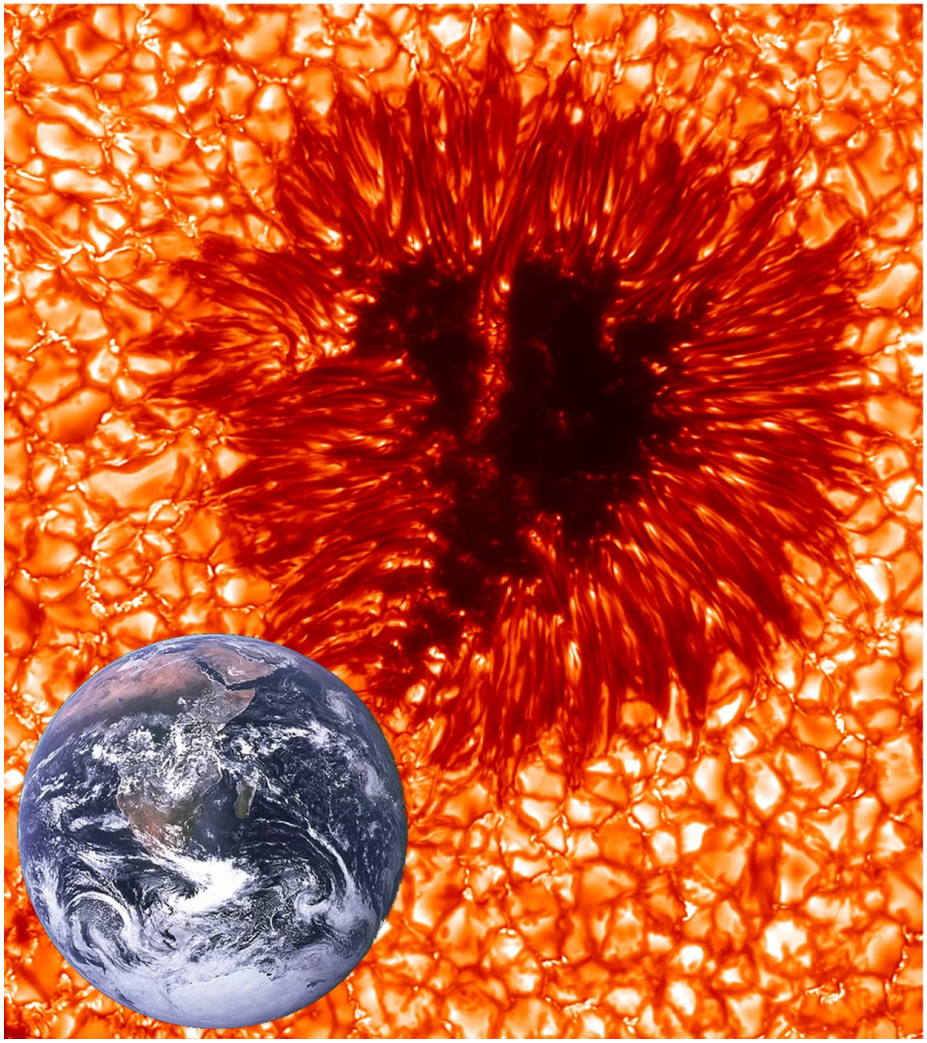


X 3.1 flare in sunspot 2192, 24. 10. 2014, 21:42 UT

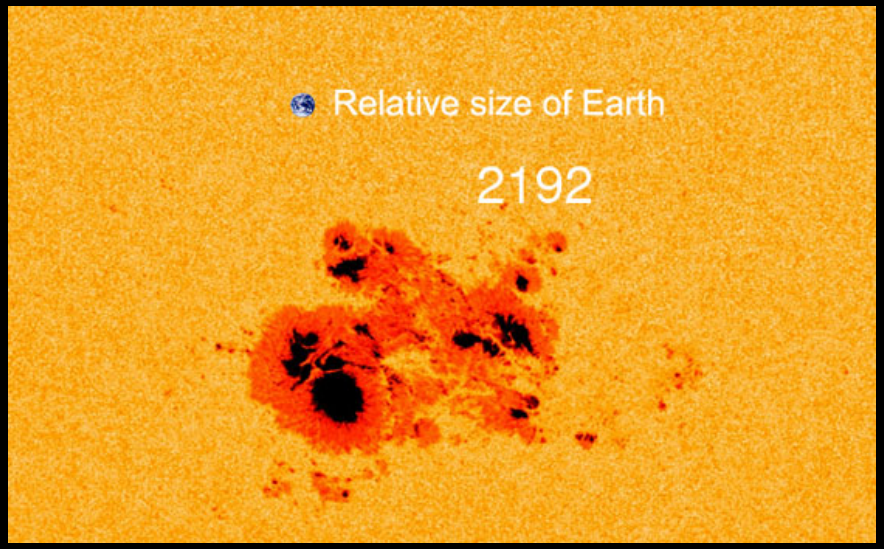
SDO AIA 193, 171, 304, NAFE processing Miloslav Druckmüller

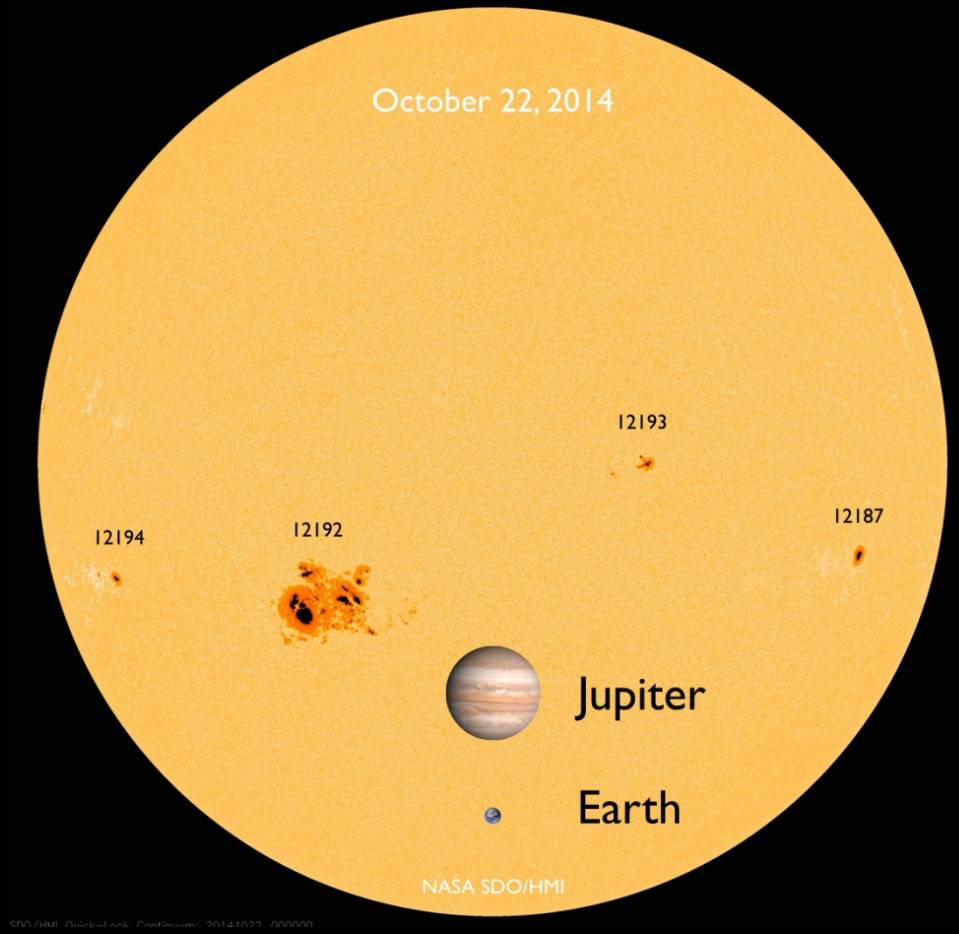
Solar Activity





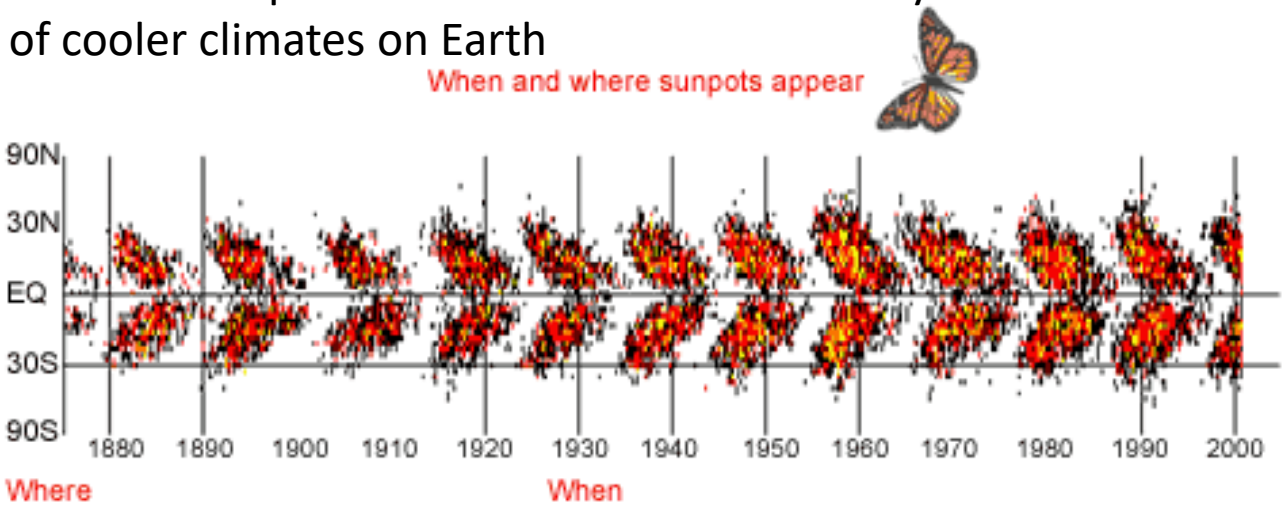
Sun Spot Size Comparison





Sun Spots

- First written record of sunspots was made by Chinese astronomers around 800 B.C.
- Astronomers in 17th century observed sunspots
  - Some thought they were shadows of undiscovered planets crossing the Sun or were dark clouds in the Sun's atmosphere.
- In 1843 the rise and fall of yearly sunspot cycle was discoverd
- Around 1852 astronomers noted the period of the sunspot cycle was identical to the period of geomagnetic activity at Earth
- Higher levels of sunspots and associated solar activity has coincided in the past (at least partially) with a period of warmer climates on Earth
- Lower levels of sunspots and associated solar activity has coincidesd with a period of cooler climates on Earth



Lab Exercise 3
Solar Rotation

LEARNING OBJECTIVES

- Structure of the Sun/Stars
- Solar activity and sunspots
- Solar rotation from sunspot observations
- Estimation of the size of a sunspot

Question: Is the Sun stationary or rotating?

Knowledge:

- The Earth, Moon and other solar system objects are rotating
- Sunspots are observed to move across the face of the Sun

Hypothesis: The Sun is rotating.

Prediction: All sunspots appear to move at constant speed equal to rotation speed of the sun

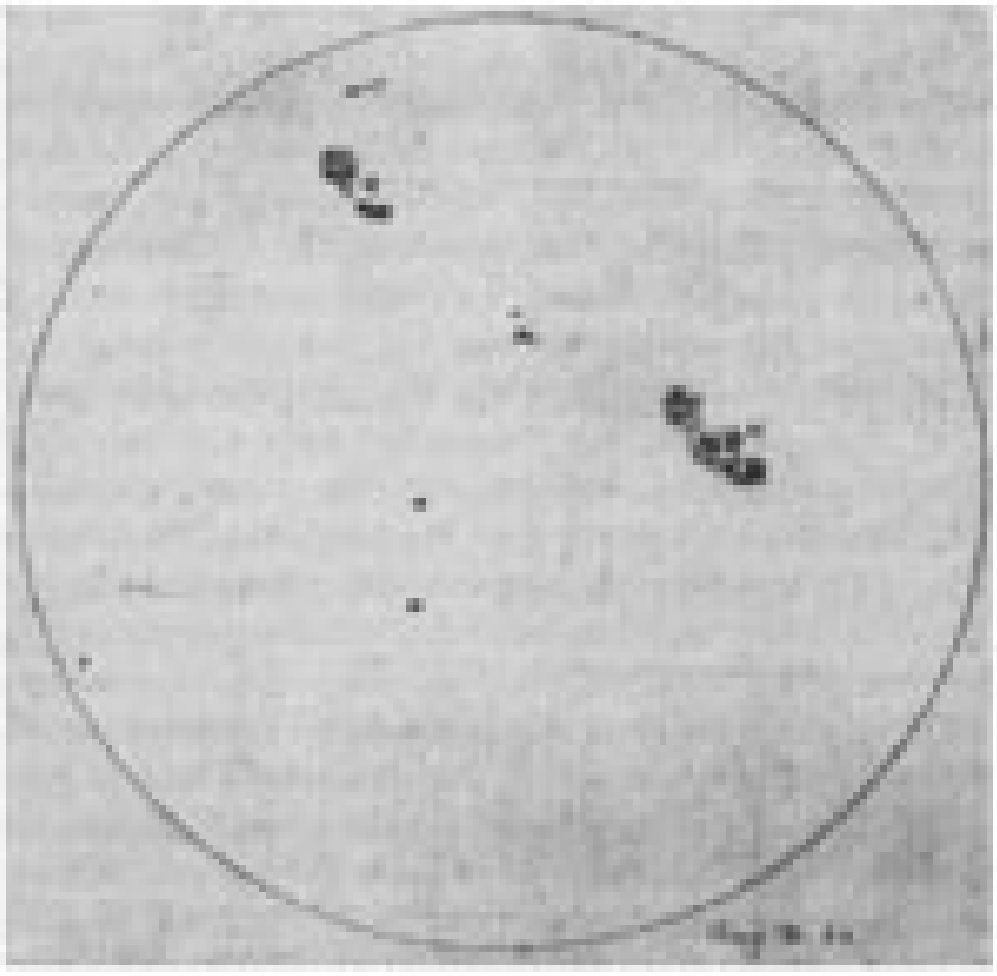
Assumption: Sunspots are on the Sun's surface and fixed to it

Solar activity and sunspots

Dark spots on the sun have been observed and reported in ancient observations from China / India / Europe

Theories:

- Shadows from planets?
- Clouds in the Sun's atmosphere?
- Birds?
- Imperfections in Earth's atmosphere?
- Dark spots on the sun?



Galileo drew these sunspots on June 23, 1612. There is a very clear demarcation between the umbra and penumbra.

The Sun

Core: 15 million K.

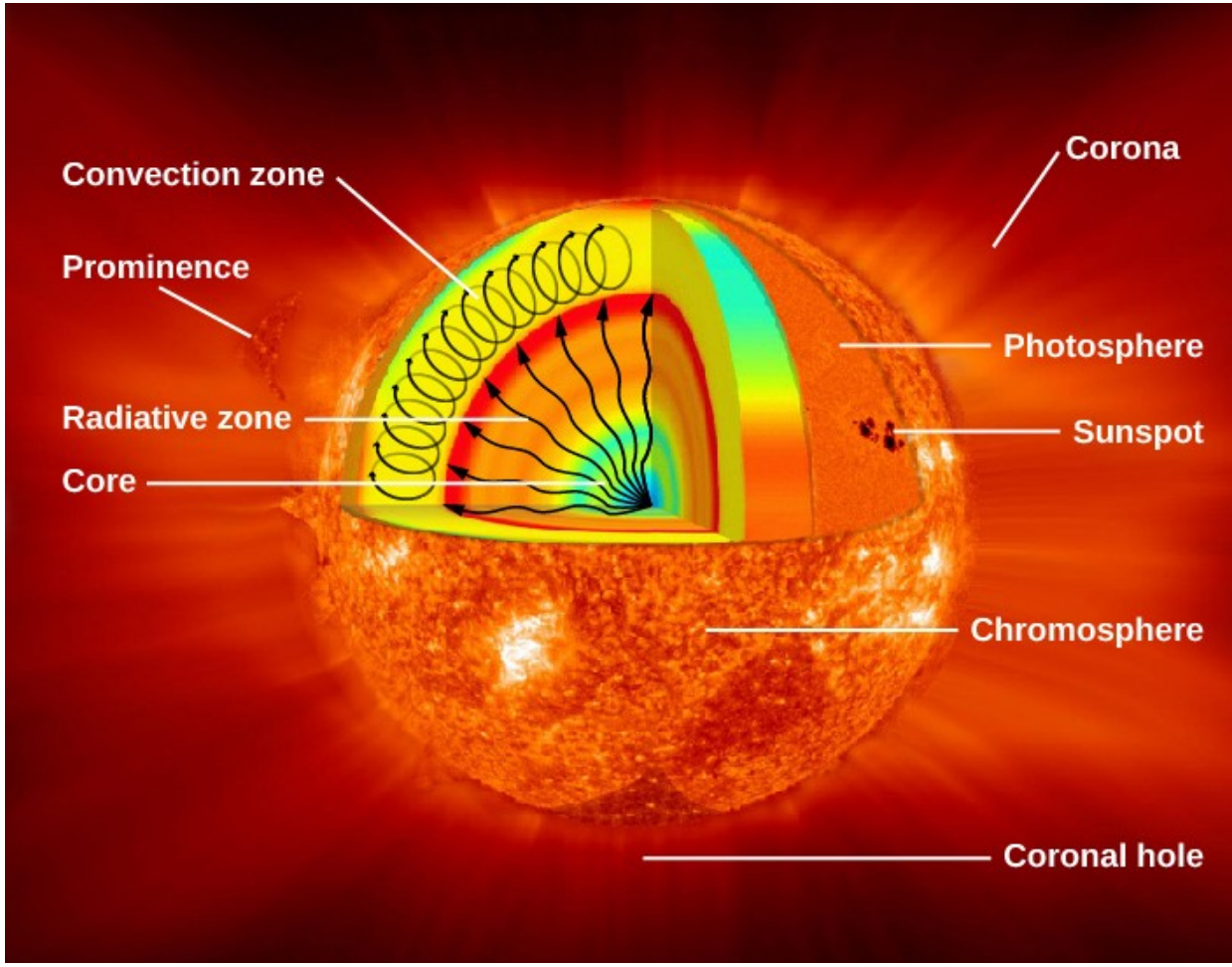
Radiative Zone: 7 to 2 million K.

Convection Zone: 2 million K to 5800K .

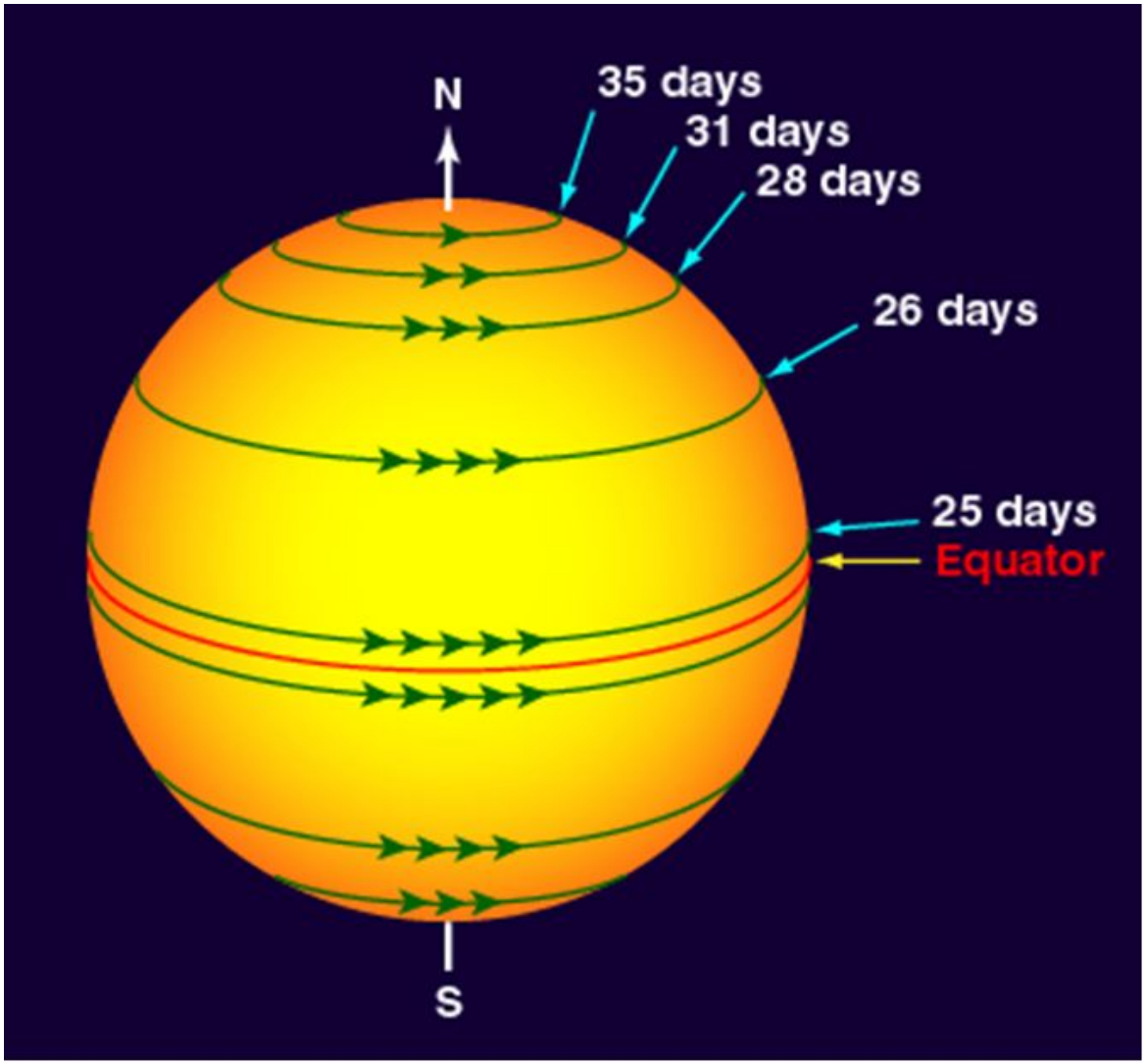
Photosphere: 5800K, although sunspots are about 3800K - that's why they are dark.

Chromosphere: 4300 up to 8300 K from inside edge to outside edge

Corona: about 1 million degrees



The Sun's Differential Rotation

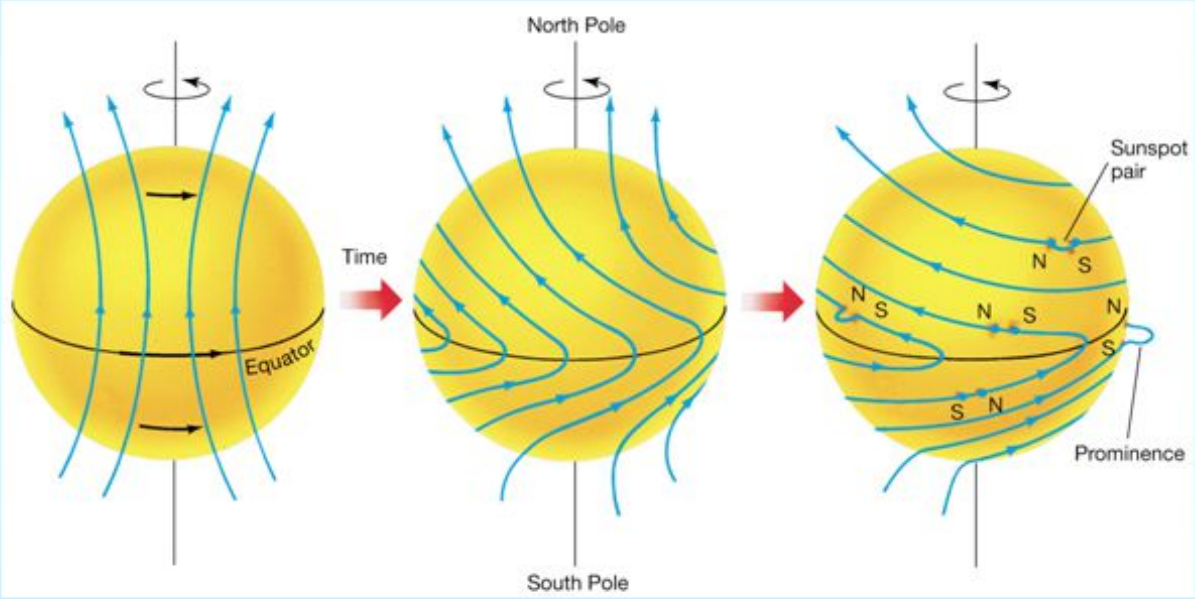


Sunspots reveal that the Sun has <u>differential rotation</u>:

The equatorial area rotates more rapidly than the polar areas.

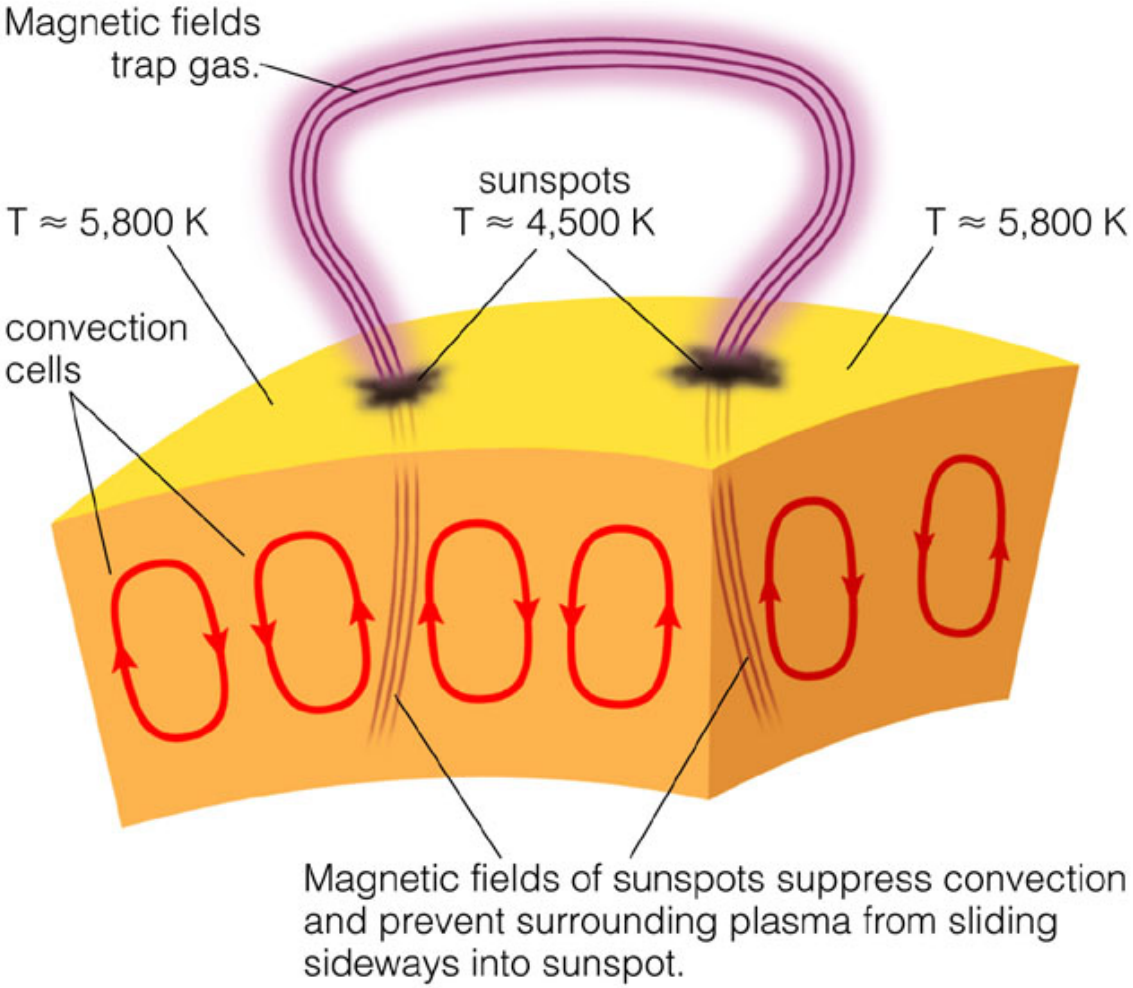
The Sun's Magnetic Field

Imagine the Sun as a bar magnet, with magnetic field lines cutting through it.

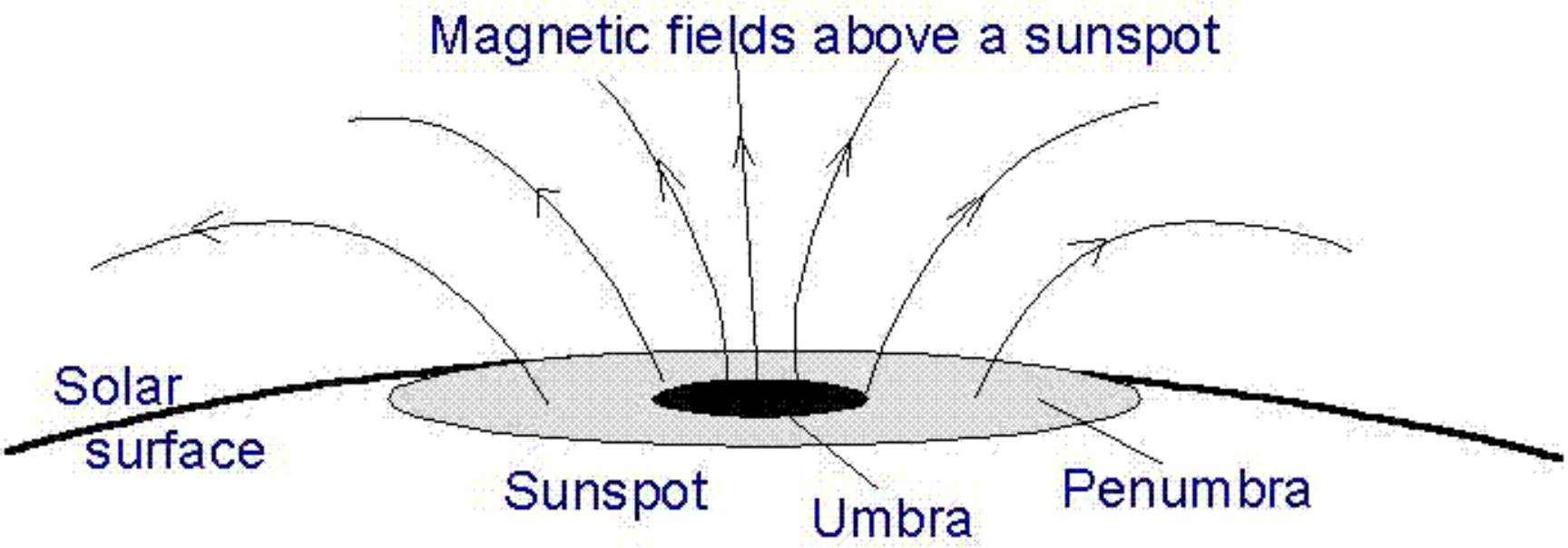


Because the equator is rotating faster than the poles, the magnetic field lines near the equator are pulled around the Sun faster, resulting in loops and kinks in the magnetic field.

Convection and Sunspots

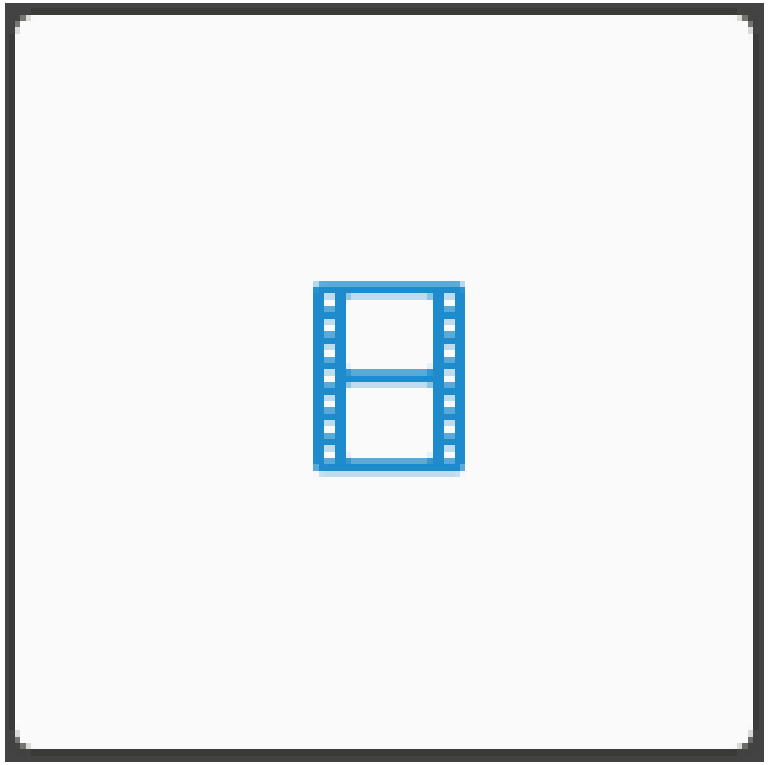


Sunspots

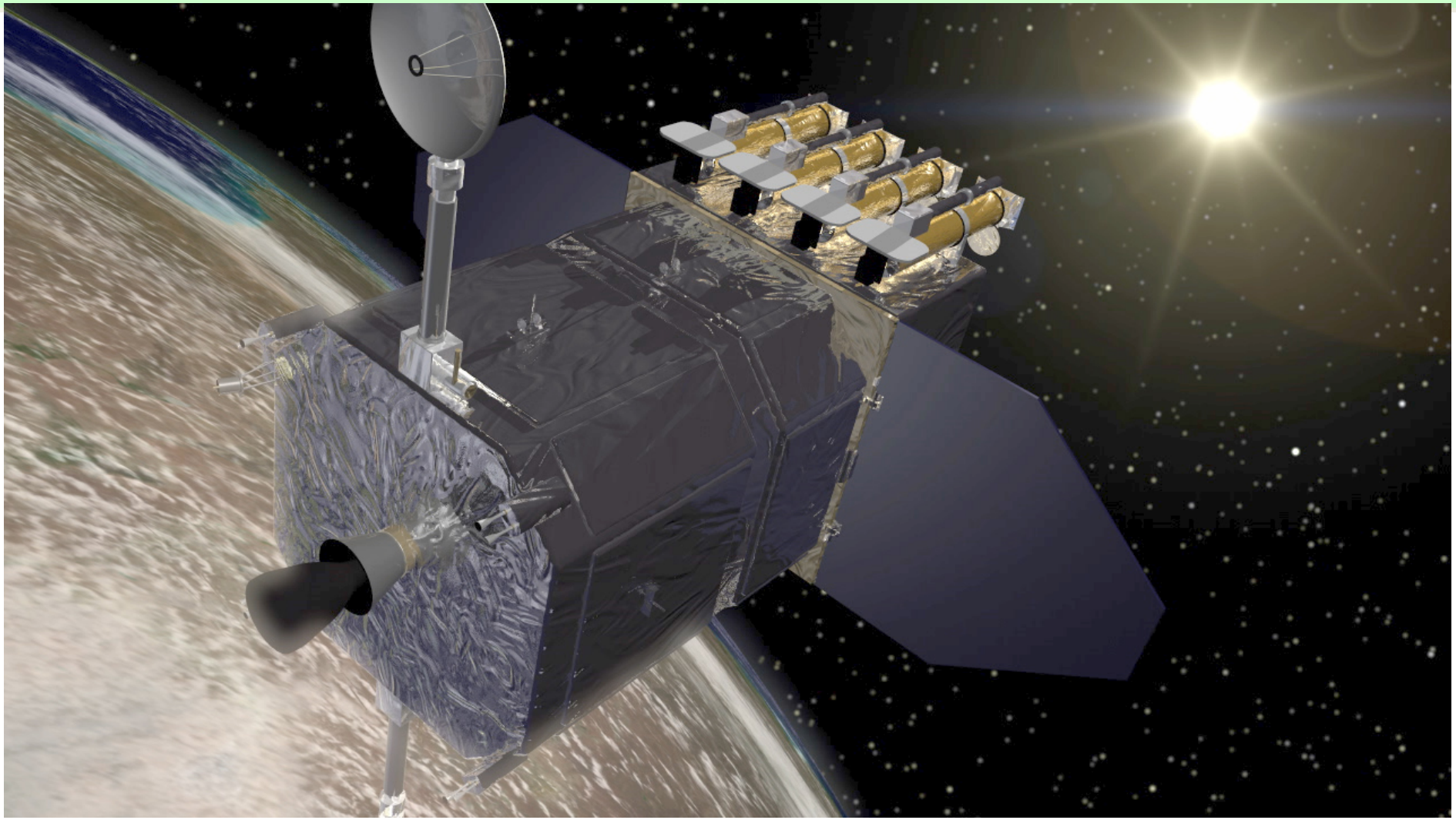

Magnetic fields above a sunspot
Solar surface
Sunspot
Umbra
Penumbra

Solar rotation from sunspot observations

Sample data
Observations from http://www.spaceweather.com/
for the period 8 – 20 April 2016



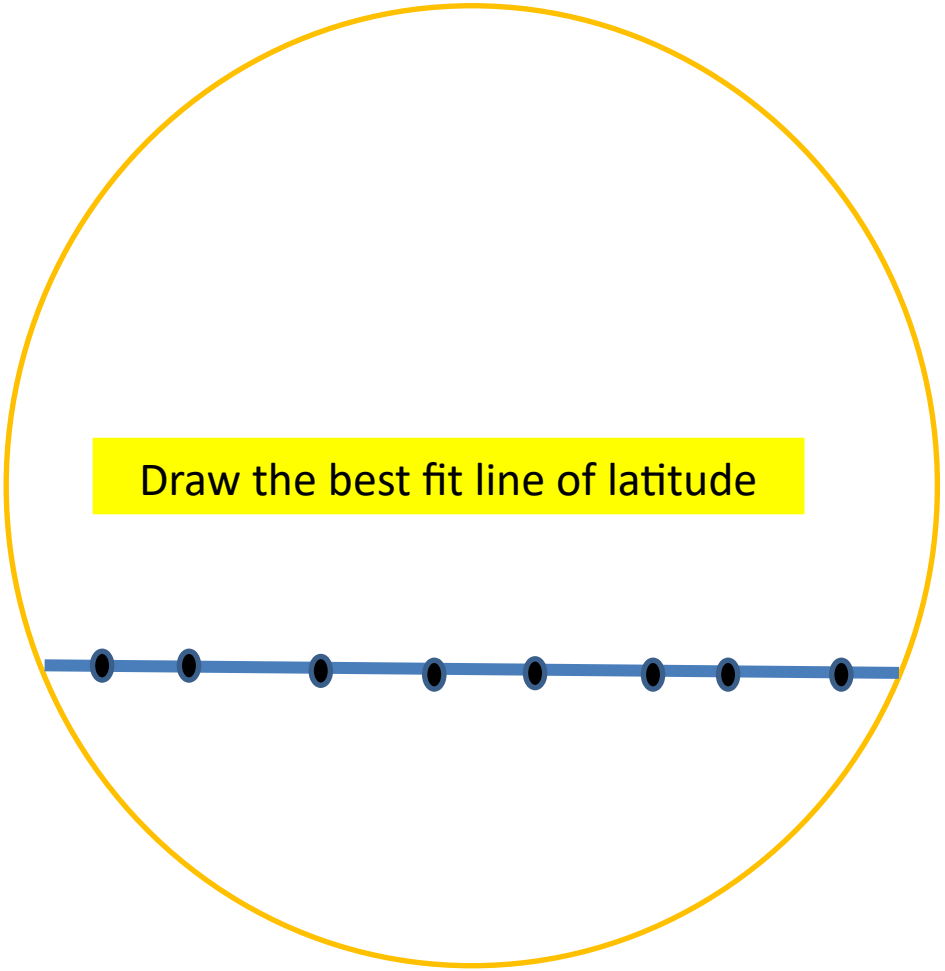
Solar Dynamics Observatory



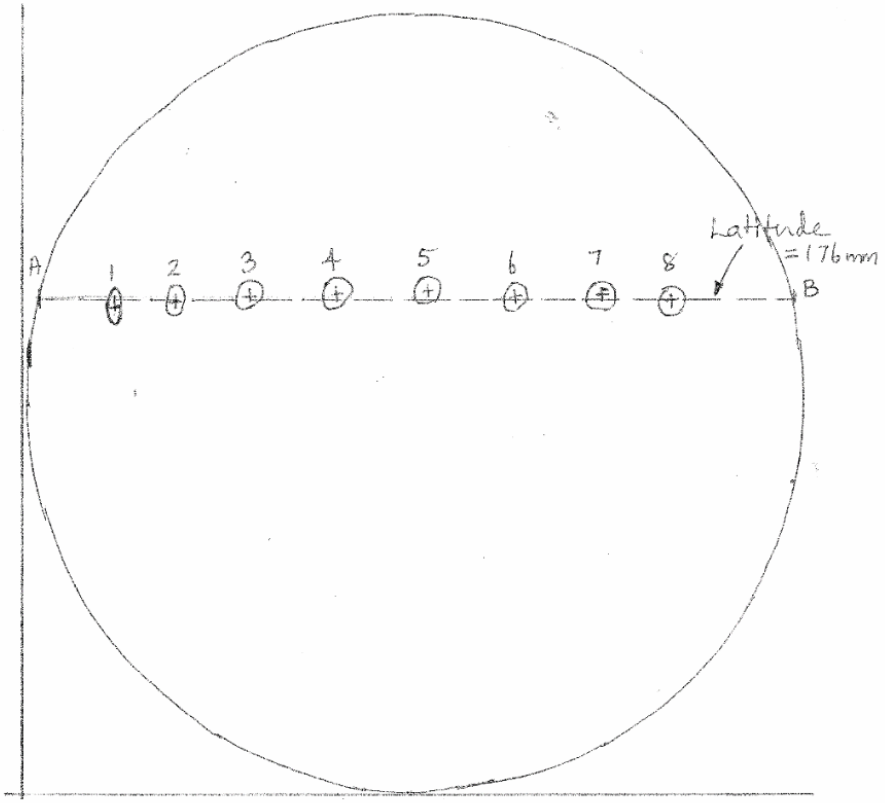
The SDO spacecraft was developed at NASA's Goddard Space Flight Center in Greenbelt, Maryland, and launched on February 11, 2010, from Cape Canaveral Air Force Station.
http://sdo.gsfc.nasa.gov/

Expt.#3: Solar Rotation

Trace and label points for one sunspot that can be seen in all eight images.


Draw the best fit line of latitude

Solar Rotation Calculation



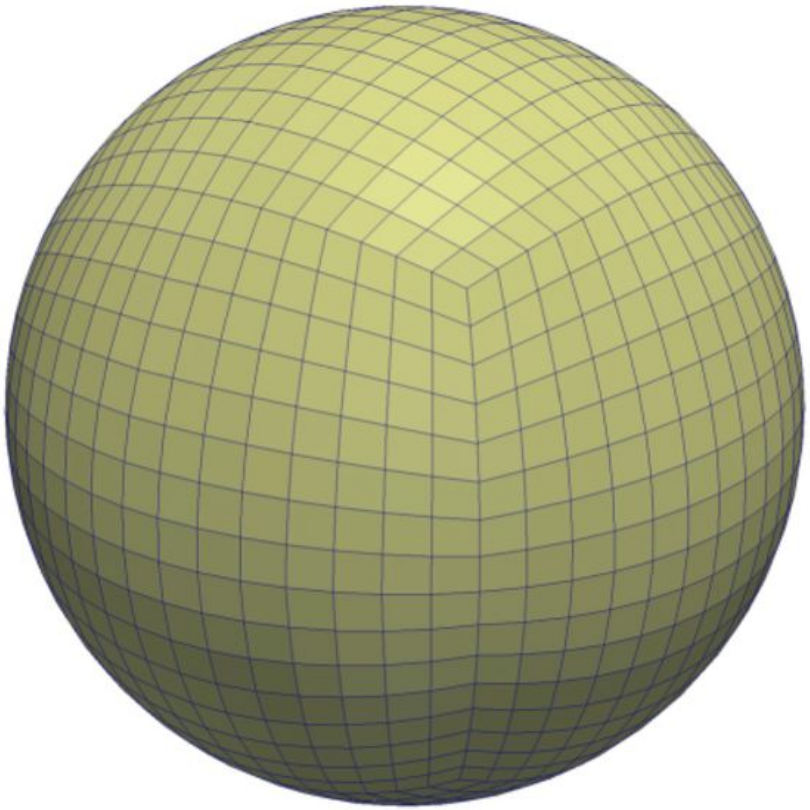
AB = 176 mm

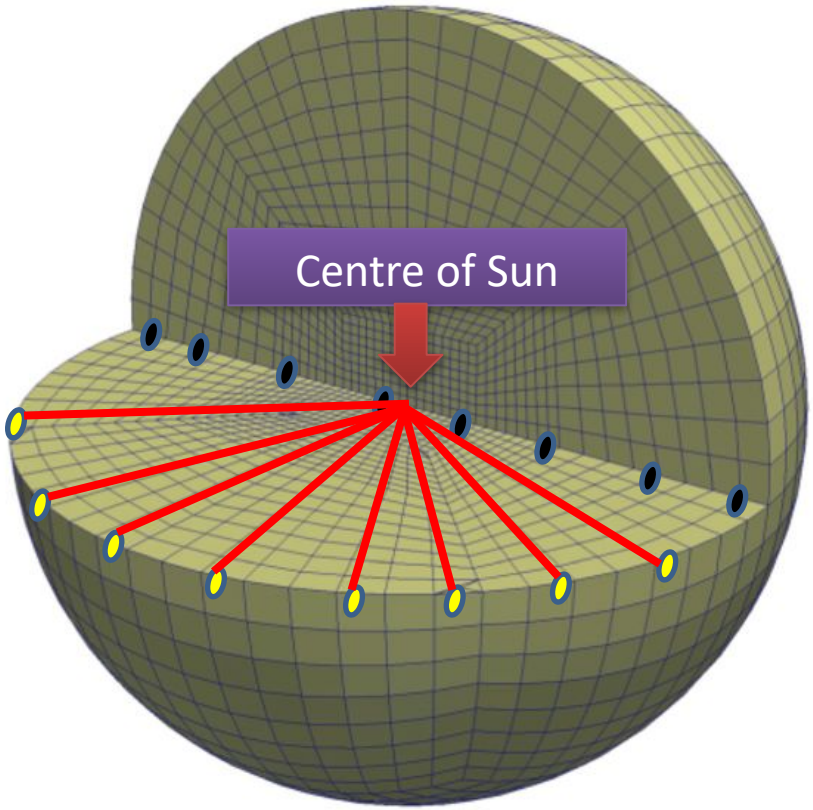
Radius = $\frac{AB}{2} = \frac{176}{2} = 88$ mm

Trace the locations of sunspot on tracing paper and draw latitude line.

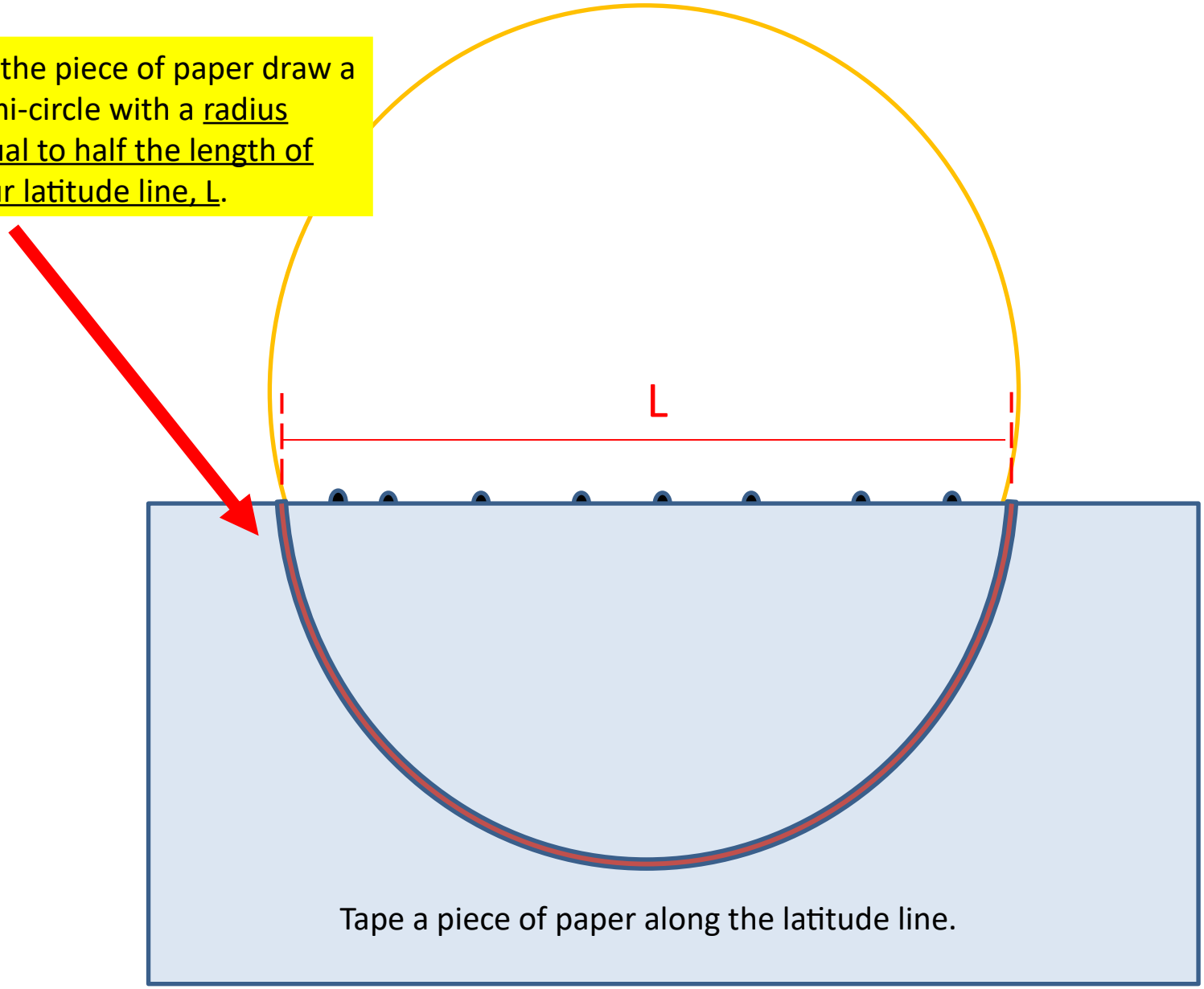
IMPORTANT: Also trace the outer edge of the Sun and the edge of the photo

Projecting the Sunspots

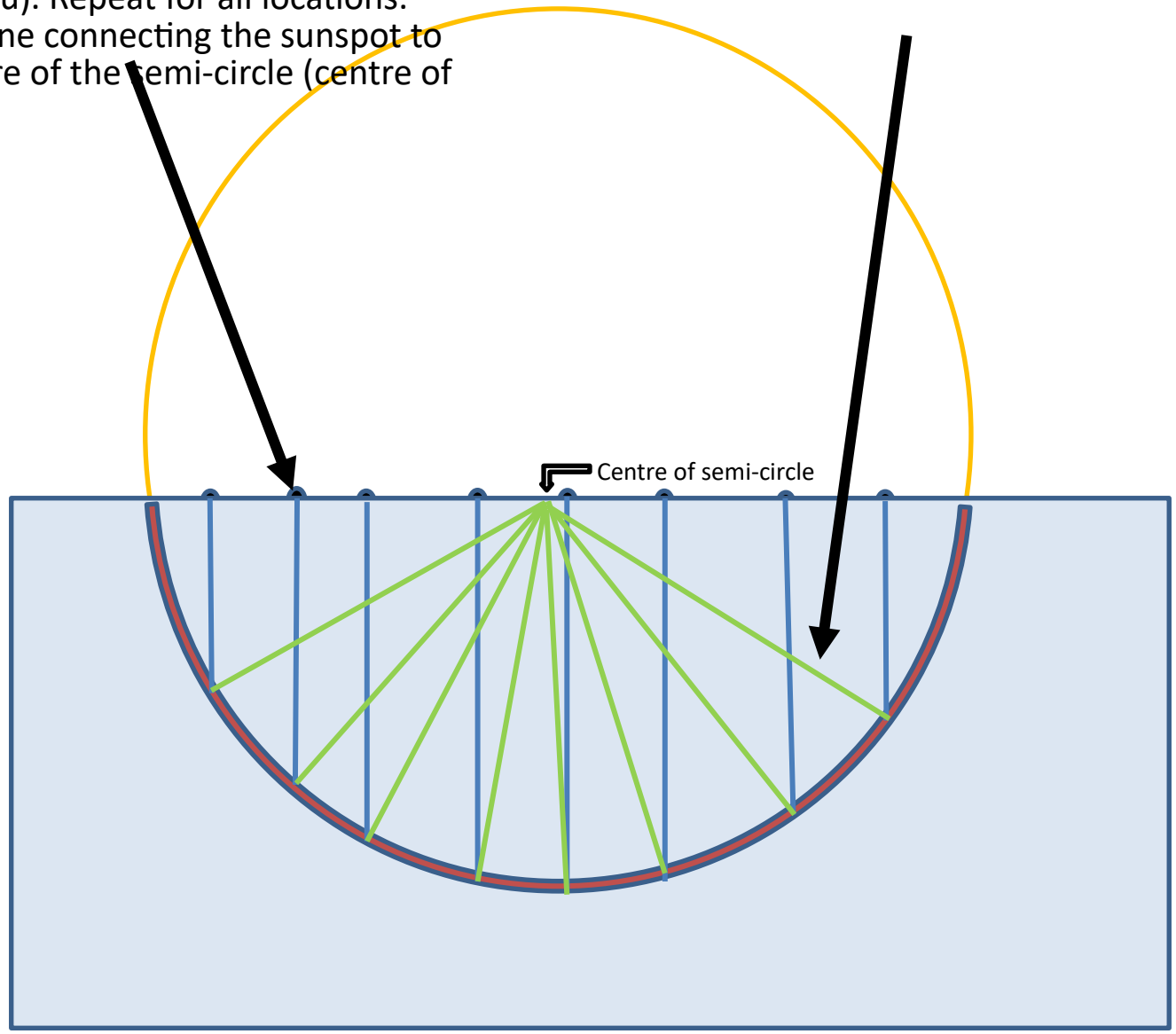




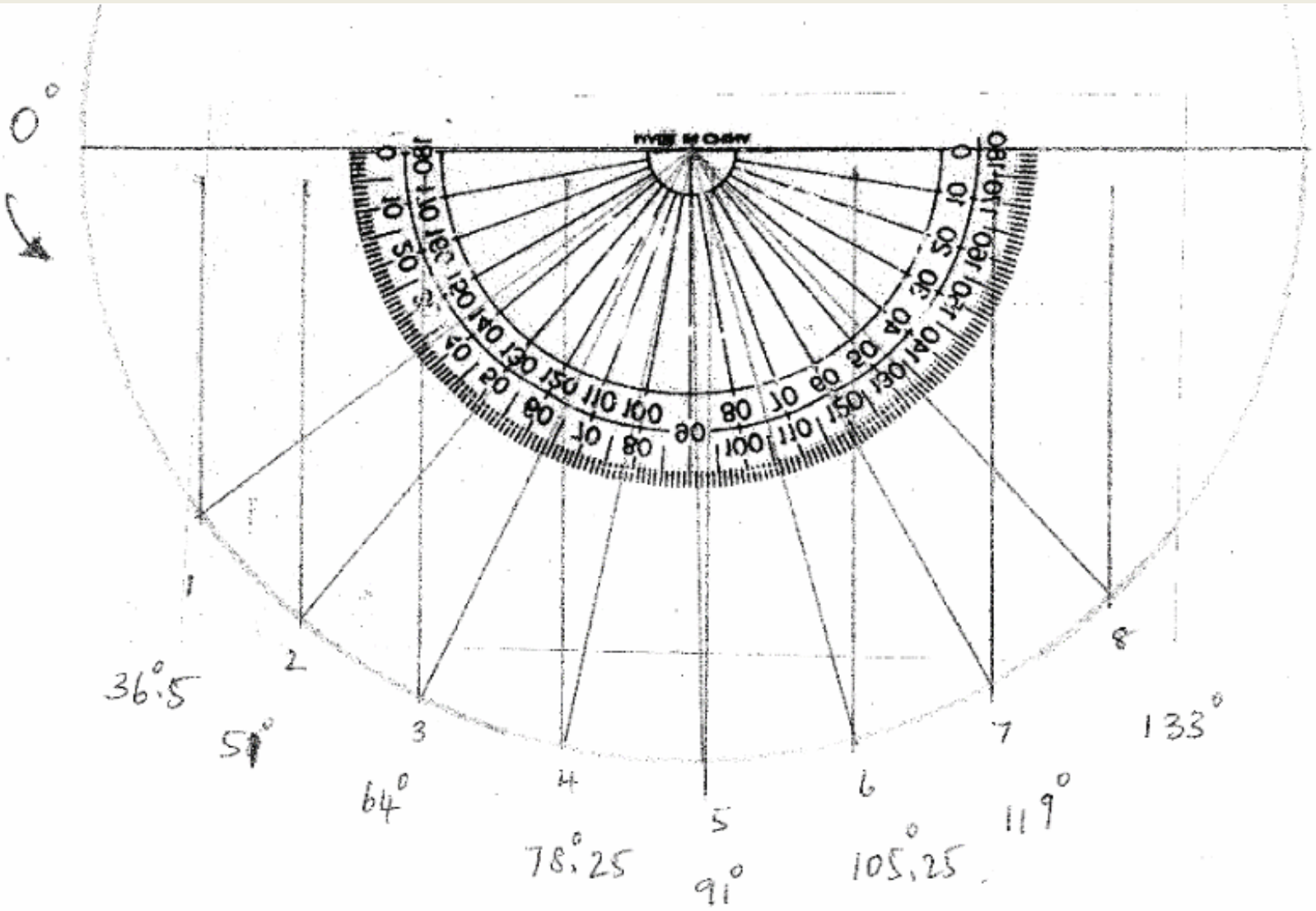
On the piece of paper draw a semi-circle with a <u>radius equal to half the length of your latitude line, L</u>.



Draw a line perpendicular to the latitude line from the marked sun spot location to the semi-circle (surface of the sun facing you). Repeat for all locations.
Draw a line connecting the sunspot to the centre of the semi-circle (centre of the sun).



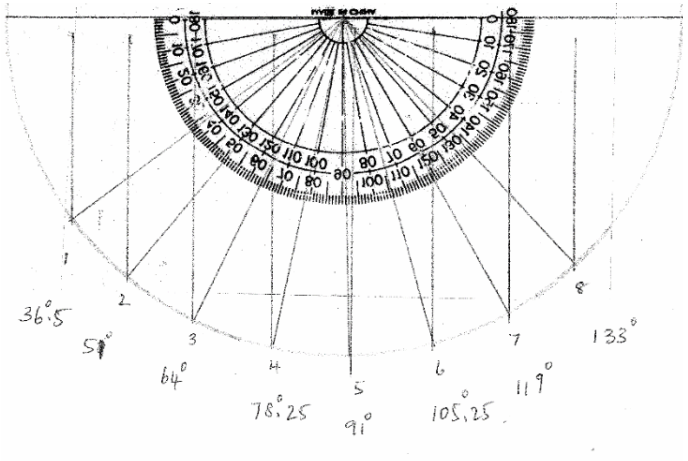
Solar Rotation Calculation: STEP 3



STEP 3: Measure the angles using a protractor

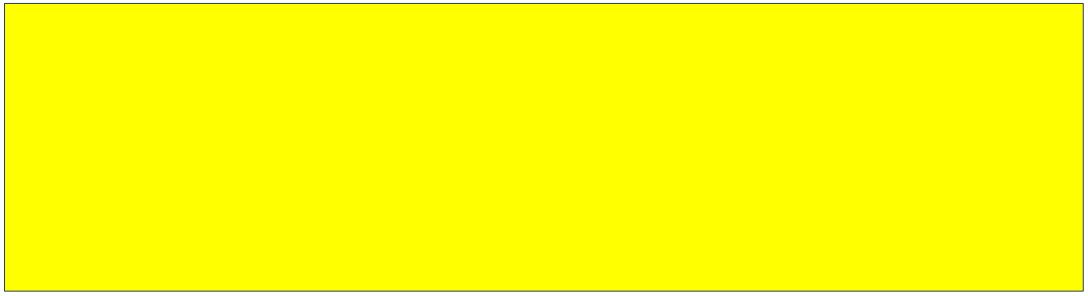
Solar Rotation Calculation

Sunspot Location	Angle (degrees)	Change in Angle () (degrees)	Period (days)
1	36.5		
2	51.0	14.5	
3	64.0	13.0	
4	78.3	14.3	
5	91.0	12.7	
6	105.3	14.3	
7	119.0	13.7	
8	133.0	14.0	



Solar Rotation Calculation

Sunspot Location	Angle (degrees)	Change in Angle () (degrees)	Period (days)
1	36.5		
2	51.0	14.5	24.8
3	64.0	13.0	27.7
4	78.3	14.3	25.3
5	91.0	12.7	28.2
6	105.3	14.3	25.3
7	119.0	13.7	26.2
8	133.0	14.0	25.7



Solar Rotation Calculation: STEP 4

Example:

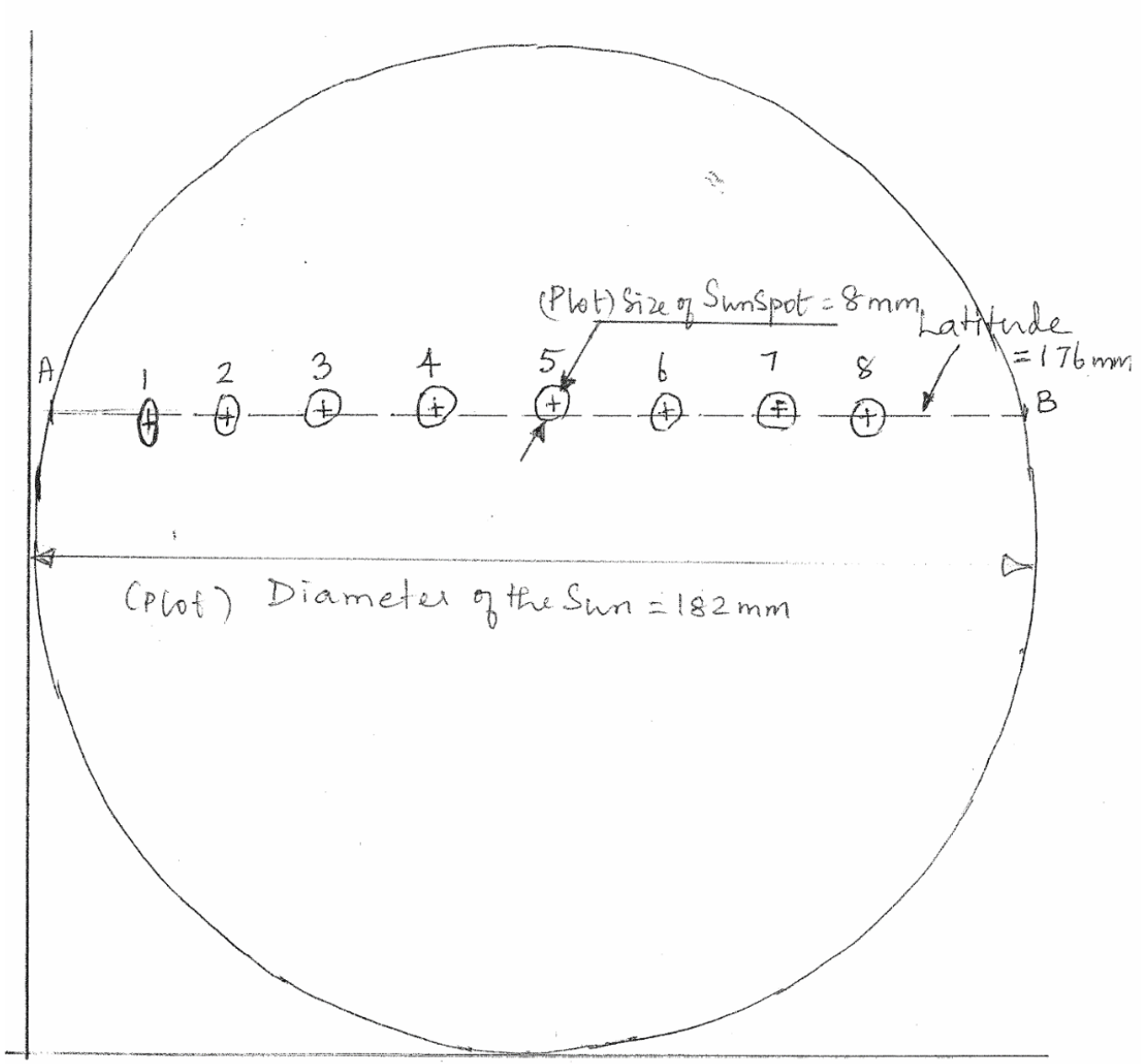
Period (days)	Sorted (days)		
24.8	24.8		
27.7	25.3		25.3
25.3	25.3		
28.2	25.7		25.7
25.3	26.2		
26.2	27.7		27.7
25.7	28.2		

(Median) Value =	25.7
Uncertainty (Error) = (27.7-25.3)/2 =	1.2

Median value = 25.7 days
Measurement error = 1.2 days

Mean = 26.2 days
Std dev = 1.3 days

Calculate Sunspot Size



Calculate Sunspot Size

$$\frac{\text{Actual diameter of the Sun}}{\text{Plotted diameter of the Sun}} = \frac{\text{Diameter of Earth}}{\text{Plotted diameter of sunspot}}$$

Example:

Actual diameter of the Sun = 1392500 km

Plotted diameter of the Sun = 182 mm

Plotted diameter of sunspot = 8.0 mm

Diameter of Earth = 12756 km

Size of sunspot ~ 5 x diameter of Earth!