Our Dynamic Sun

Dr. Laurel Rachmeler

2019 REU Program
28 May 2019

National Aeronautics and Space Administration

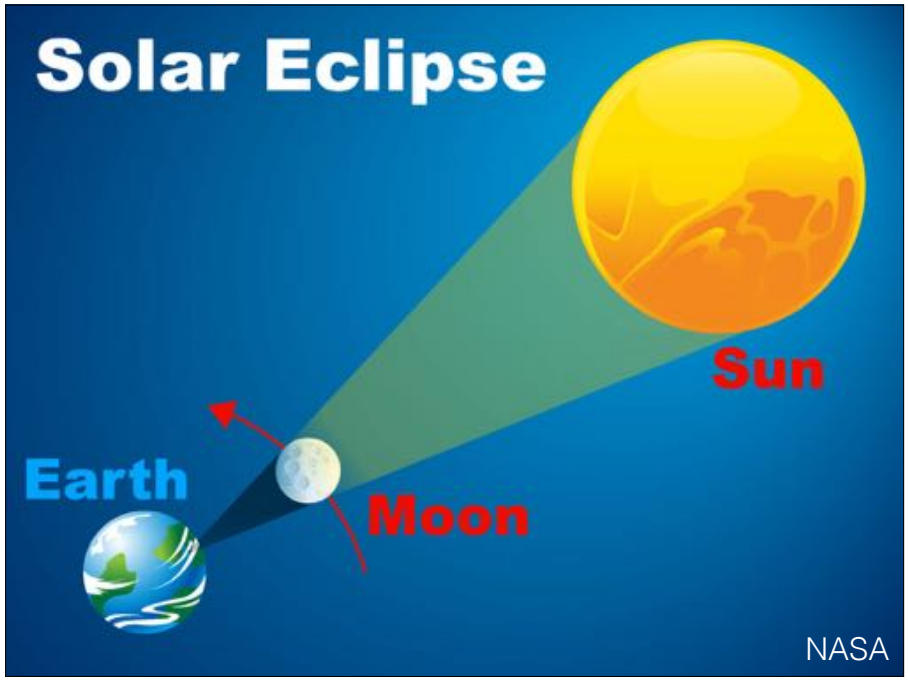
NASA

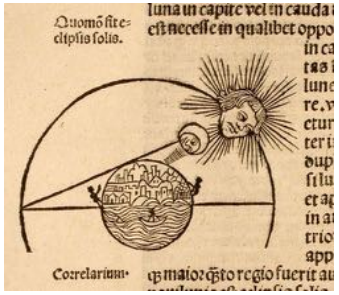
MARSHALL
SPACE FLIGHT CENTER

Our Sun

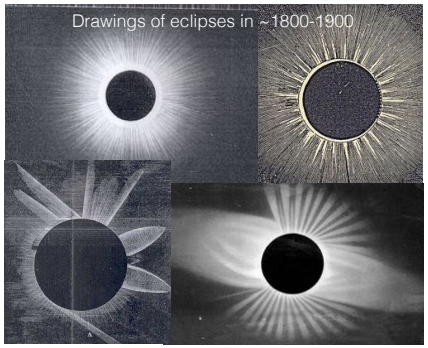
Super exciting right?

Sunset in Bangladesh, 2004





~1000 AD, De temporibus anni, Aelfric



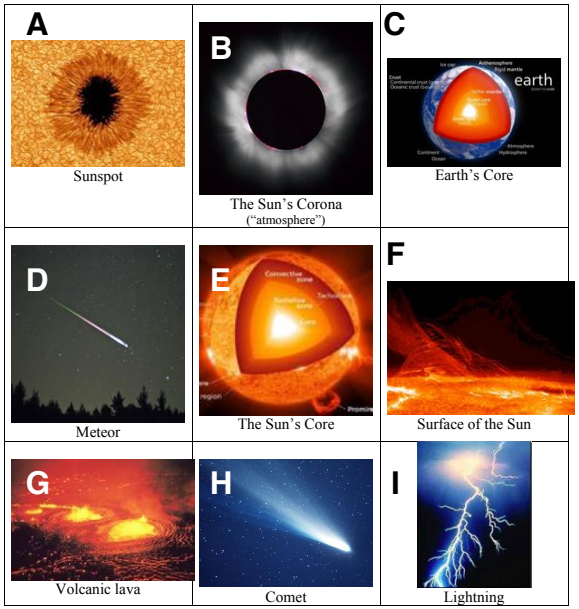
2008 eclipse, ApJ, 10.1088/0004-637X/719/2/1362

Activity

Get in a group (~2-4 people) with your nearest neighbors

Record your answers.

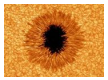
Order from coolest to hottest



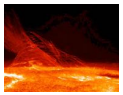
Answer

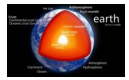
H  Comet
-450°F to 200°F

G  Lava
1450°F to 2000°F

A  Sunspot
6300°F

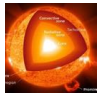
D  Meteor
10,000°F or 5800°K

F  Sun's surface
6000°K

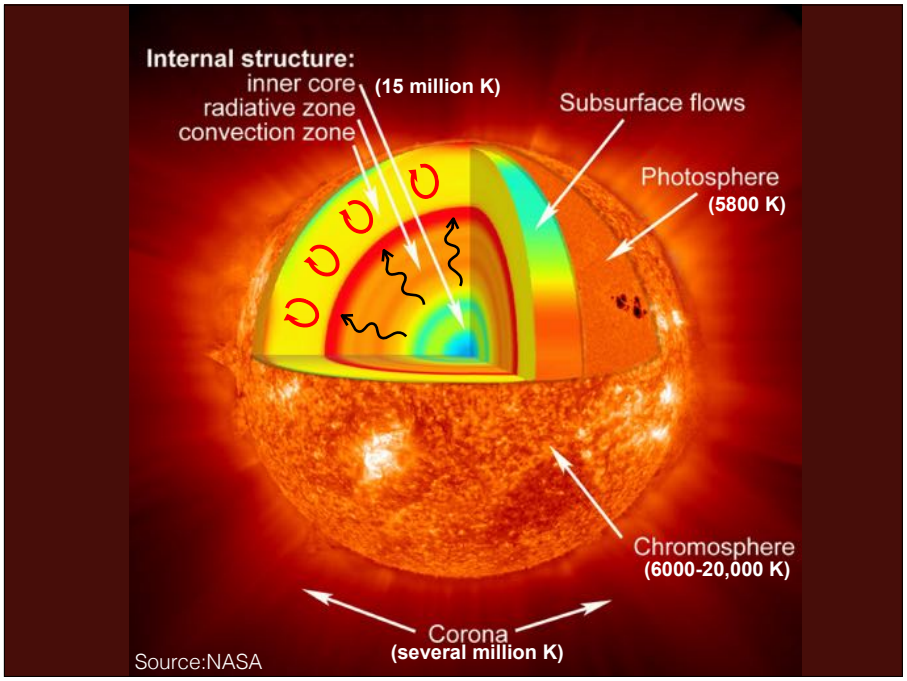
C  Earth's core
6200°K

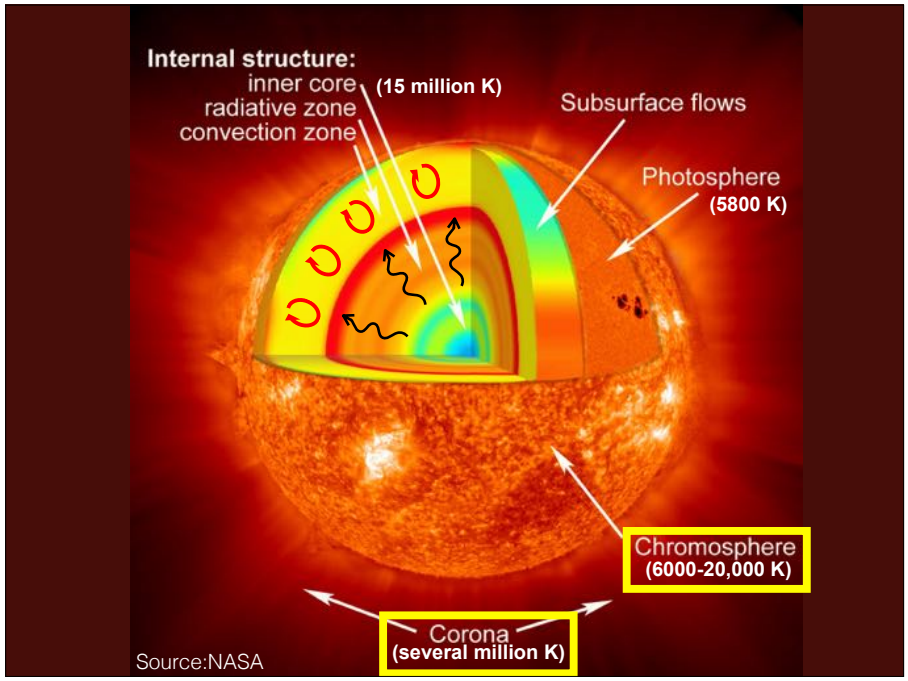
I  Lightning
30,000°K

B  Sun's corona
5 million °K

E  Sun's core
15 million °K

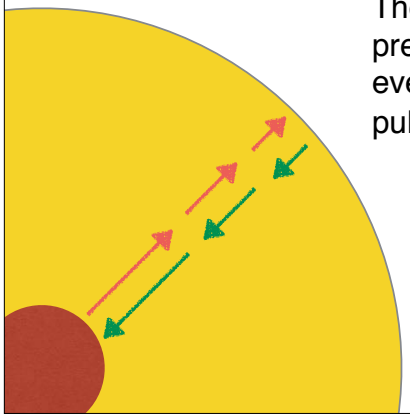
Source: http://solar-center.stanford.edu/activities/HowBig/How-Big-Far-Hot-Old.pdf





The Core

pressure →
gravity →

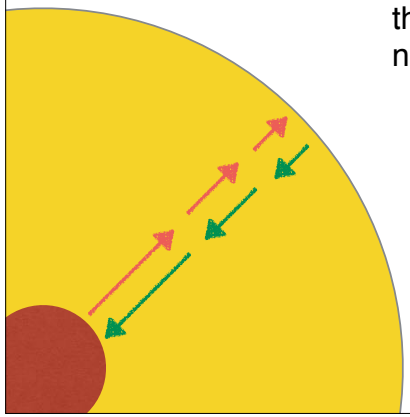


The outward push of pressure is balanced everywhere by the inward pull of gravity

Pressure, gravity, and density, are greatest at the core.

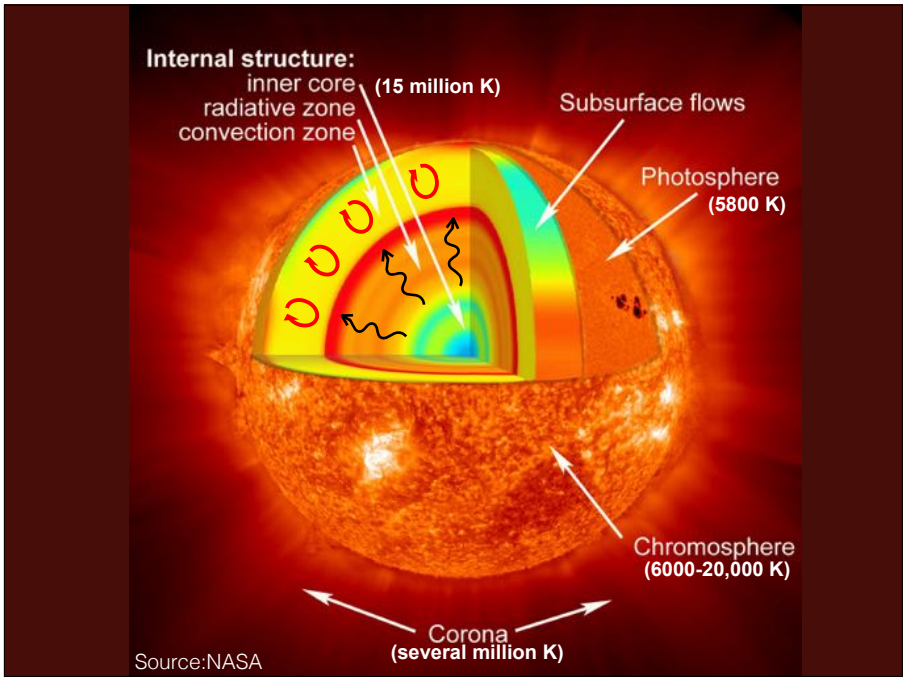
The Core

pressure →
gravity →



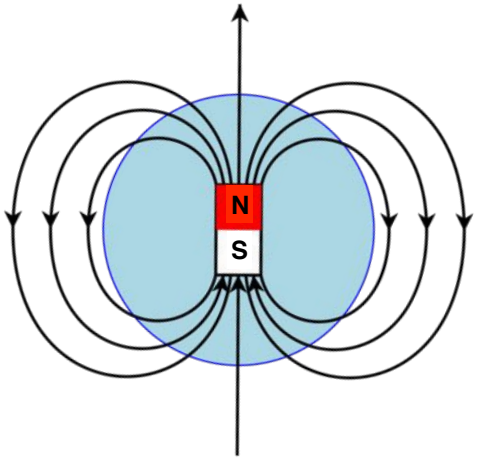
High densities at the core enable nuclear ***fusion***.

Hydrogen is combined into Helium, releasing energy ($E=mc^2$) as light and heat.

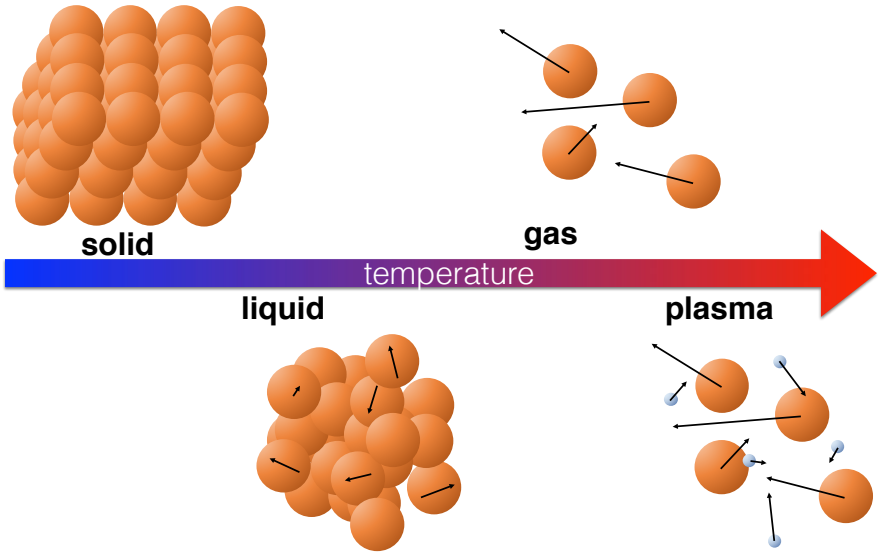


Magnetic field

The Sun, like the Earth, has a global magnetic field.

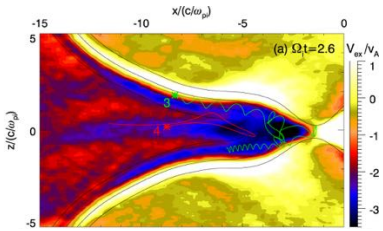


Phases of Matter

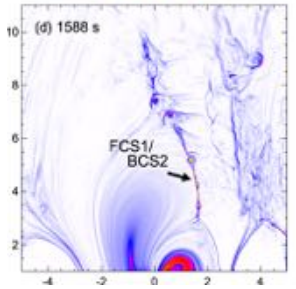


Motion of Plasma

- Microscopic level
  - Individual particles follow Maxwell's equations
  - Particle-in-cell (PIC) simulations of many particles.
- Macroscopic level
  - Plasma acts as a fluid that reacts to the magnetic field
  - Magneto-hydro-dynamics (MHD)



Lu et al. 2016
doi:10.1088/1367-2630/18/1/013051



Lynch et al. 2016
doi:10.3847/0004-637X/826/1/43

Frozen-in-flux

- Induction equation (Ampere's law, Faraday's law, Ohm's law):

$$\frac{\partial \mathbf{B}}{\partial t} = \underbrace{\nabla \times (\mathbf{v} \times \mathbf{B})}_{I.1} + \underbrace{\eta \nabla^2 \mathbf{B}}_{I.2}$$

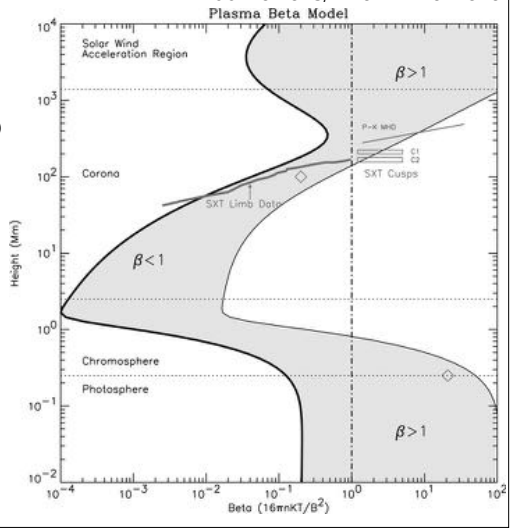
- Almost all astrophysical plasmas have very small *magnetic diffusivity,* η. (hotter plasmas have lower diffusivity)
- I.2 >>I.1
- The fluid motion is tied to or 'frozen into' the magnetic field. (figure 2.17 on p 89 of your book)

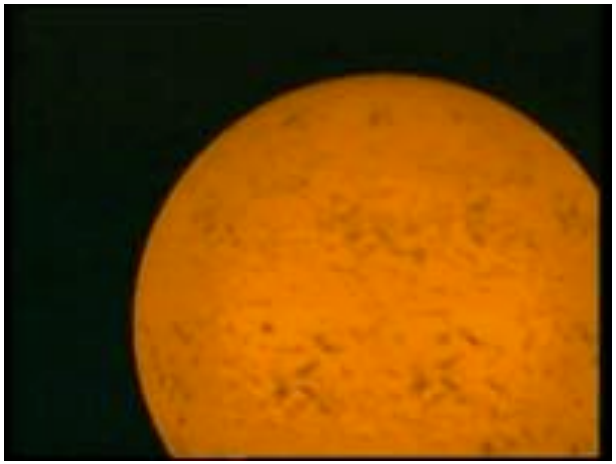
Plasma-β

$$\frac{\partial \mathbf{B}}{\partial t} = \underbrace{\nabla \times (\mathbf{v} \times \mathbf{B})}$$

- Plasma-β is the ratio of plasma pressure to magnetic pressure.
- In the photosphere the plasma moves the magnetic field.
- In the corona the magnetic field moves the plasma.

G.A. Gary 2001
doi:10.1023/A:1012722021820

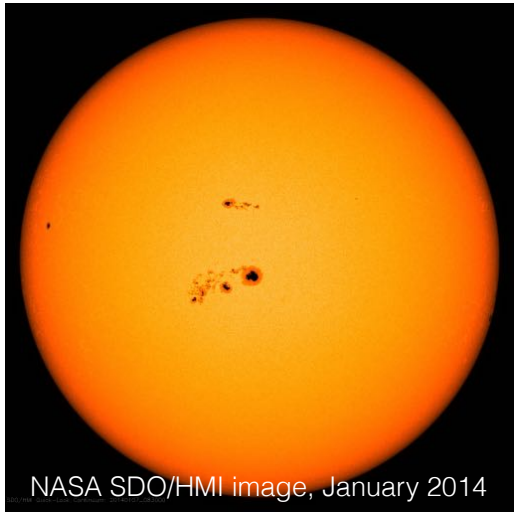




Solar Dynamo

Spinning plasma drags the magnetic field.

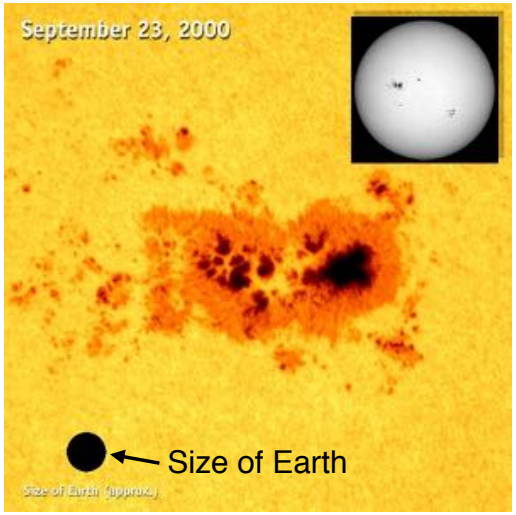
Source:SOHO (ESA/NASA)



Sunspots

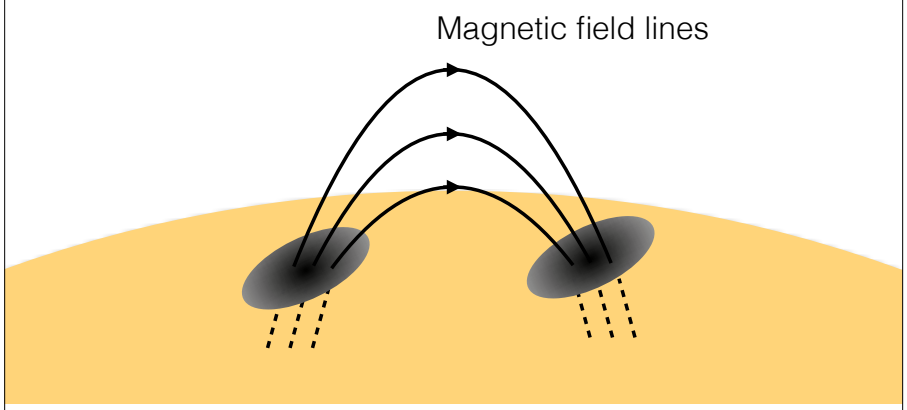
Sunspots form where concentrated magnetic field emerges through the photosphere.

source: SOHO (NASA/ESA)



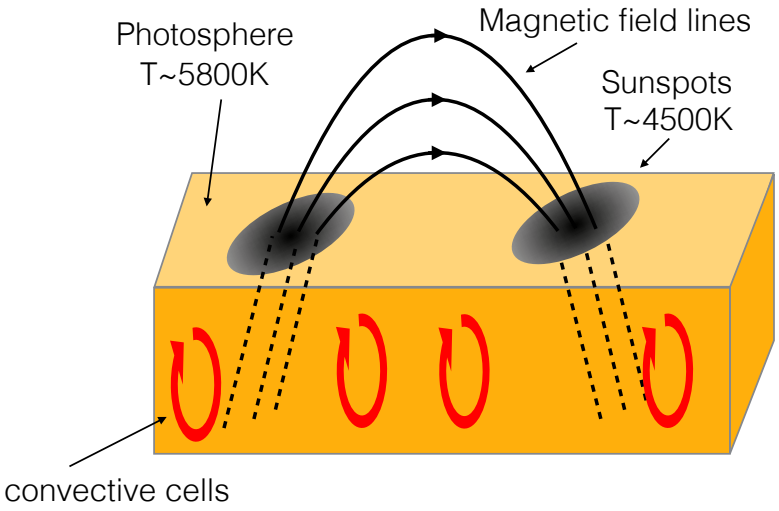
Sunspots

Smaller sunspots are about the size of the Earth.



Sunspots

Strong magnetic field threads through sunspots.

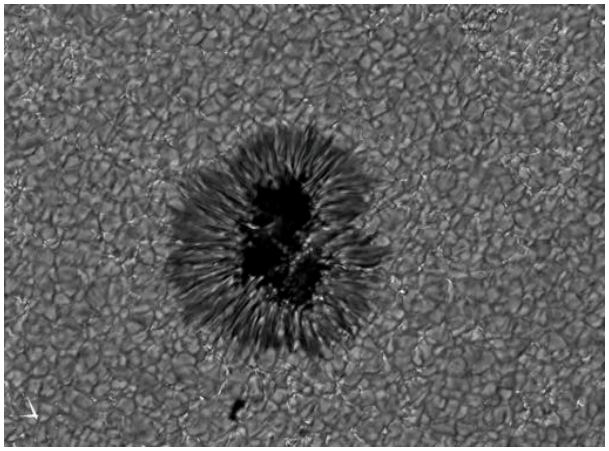


Sunspots

Strong vertical field inhibits convection, making sunspots cooler than the surrounding photosphere.

http://www.staff.science.uu.nl/~rutte101/dot/albums/movies/album.html

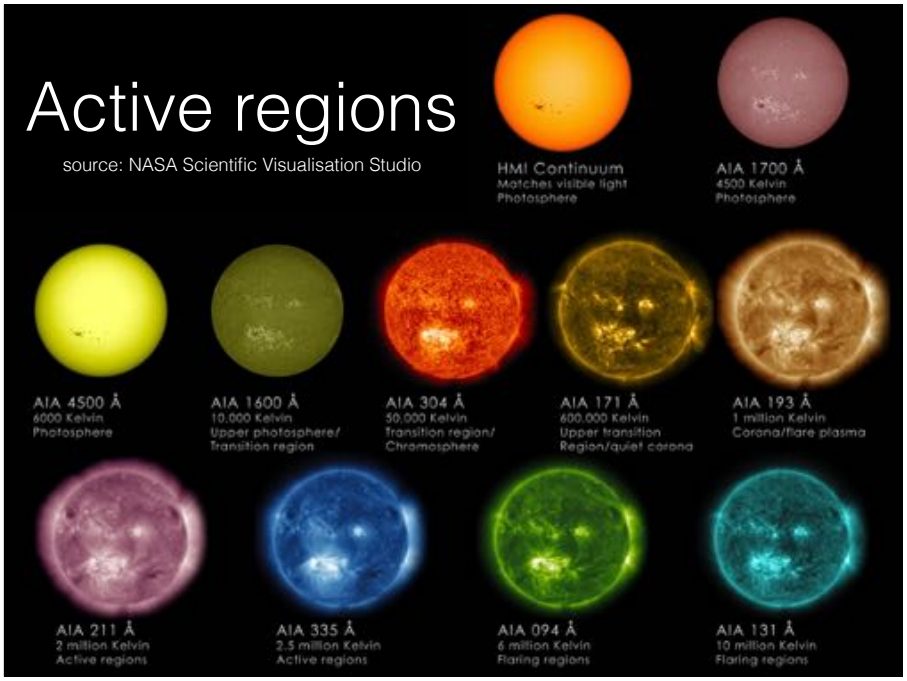
Sunspot



Dutch Open Telescope - 1 April 2001

Active regions

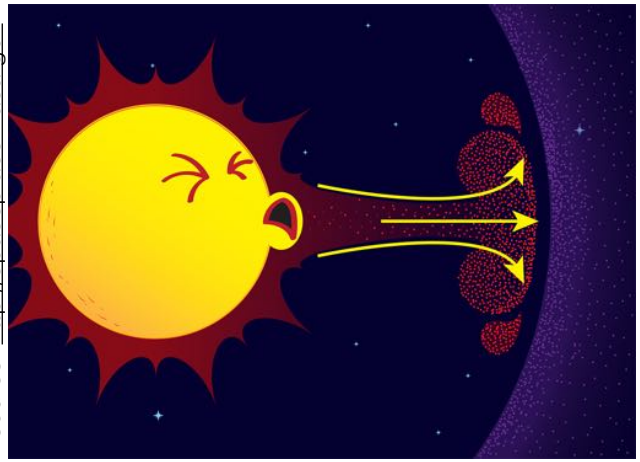
source: NASA Scientific Visualisation Studio

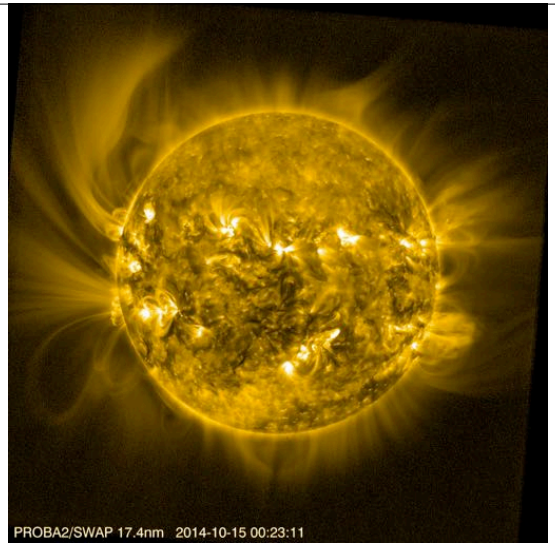


Heliosphere

The bubble-like volume surrounding solar system caused by the *solar wind*. Outside the heliosphere is *interstellar space*.

source: http://spaceplace.nasa.gov



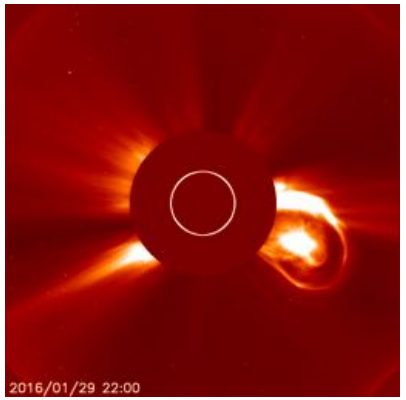


The dynamic corona

PROBA2/SWAP movie of 3 solar rotations

Eruptions

Major disturbances in the heliosphere are caused by massive explosions in the Sun's atmosphere: ***coronal mass ejections***.



NASA LASCO C2 movie

Quiz

How fast are these eruptions?

✊	✋	👍
5 m/s	5 km/s	500 km/s

Quiz

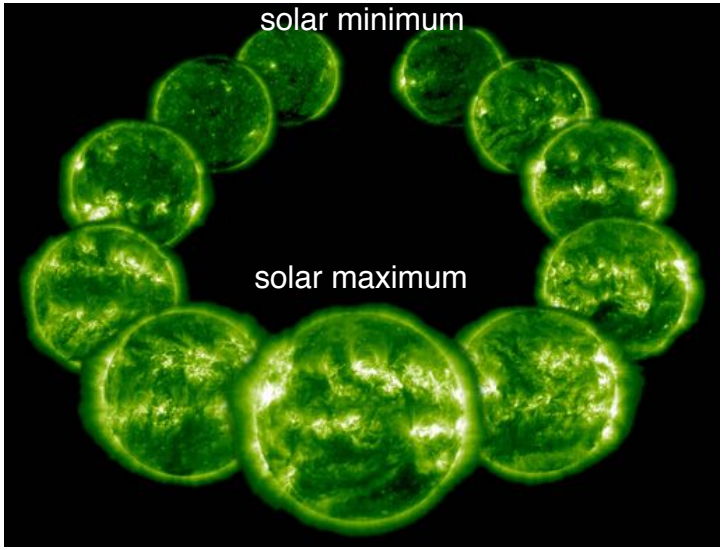
How massive are these eruptions?
(1 m^3 of water = 1000 kg = 1 metric ton)

✊	✋	👍
1 km^3 10^9 m^3	1000 km^3 10^{12} m^3	100,000 km^3 10^{15} m^3

Eruption statistics

- How massive? 1 cubic km^3 of water
- How fast? About 500 km/s (1.1 million mph)
- How much energy?

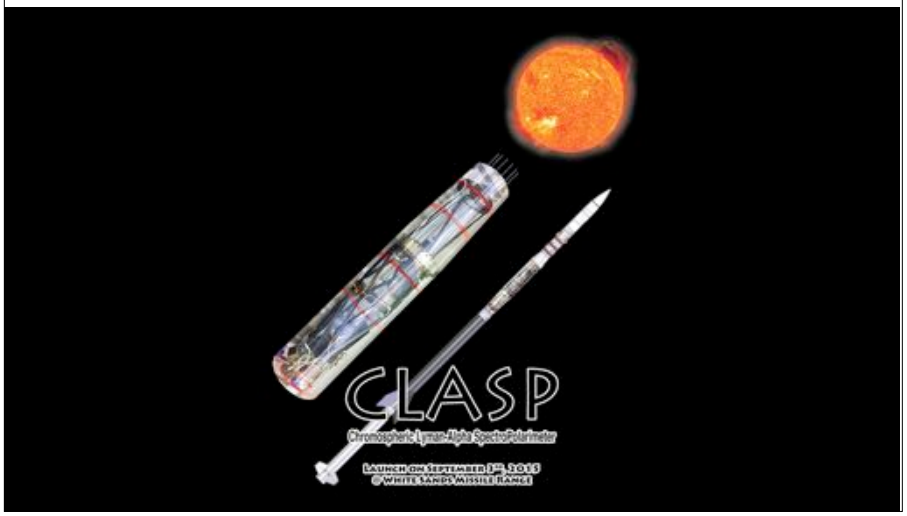
Activity cycle



Source: ESA & NASA/SOHO

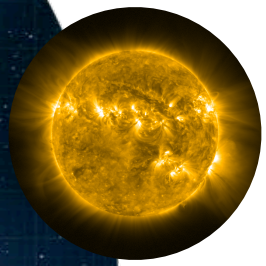
CLASP launch 3 September 2015, White Sands Missile Range

MSFC Sounding Rocket



LASP Sounding Rocket

Thank you!



laurel.rachmeler@nasa.gov

National Aeronautics and Space Administration

NASA

MARSHALL
SPACE FLIGHT CENTER