The Sun: an introduction

Dr. Laurel Rachmeler, NASA/MSFC
UAH/MSFC Heliosphysics REU Program
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Our Sun

Super exciting right?

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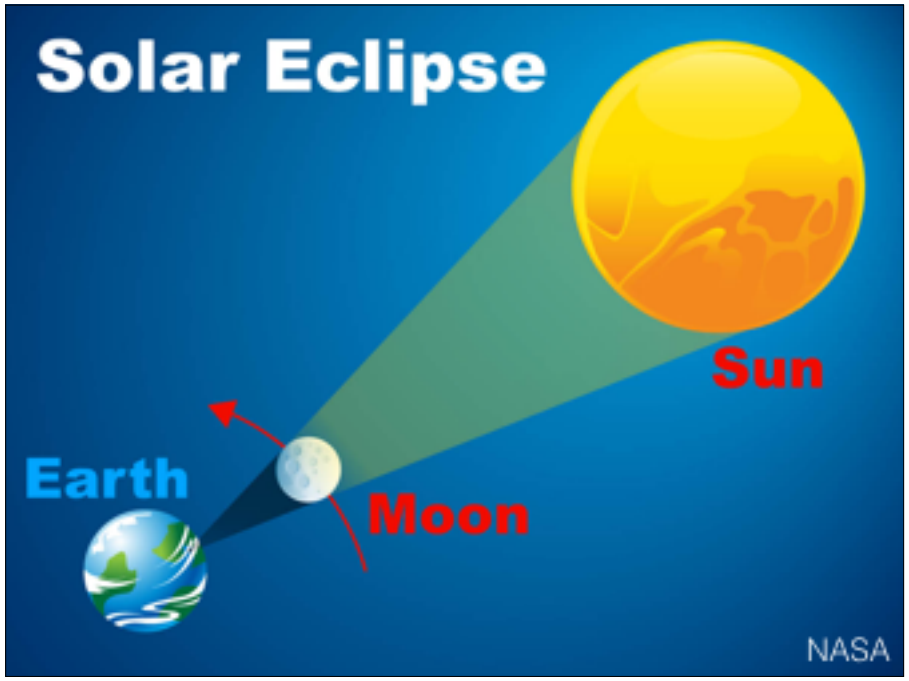
Sunset in Bangladesh, 2004

3



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Petroglyph ~1000 AD (source HAO)

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~1000 AD, De temporibus anni, Aelfric

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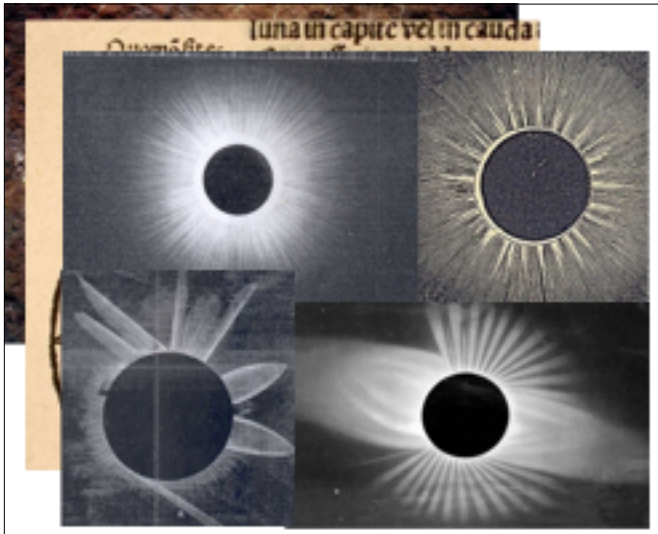

Drawings of eclipses in ~1800-1900

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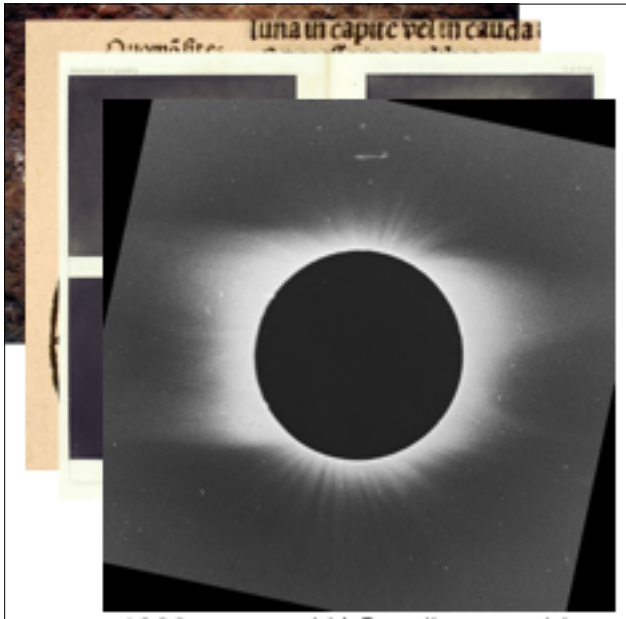

1889 source: HAO eclipse archive

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Activity

Get into groups of 2.

Record your answers.

10

Order from coolest to hottest

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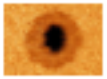
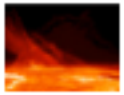
Answer

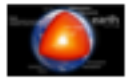

H Comet
-450°F to 200°F


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

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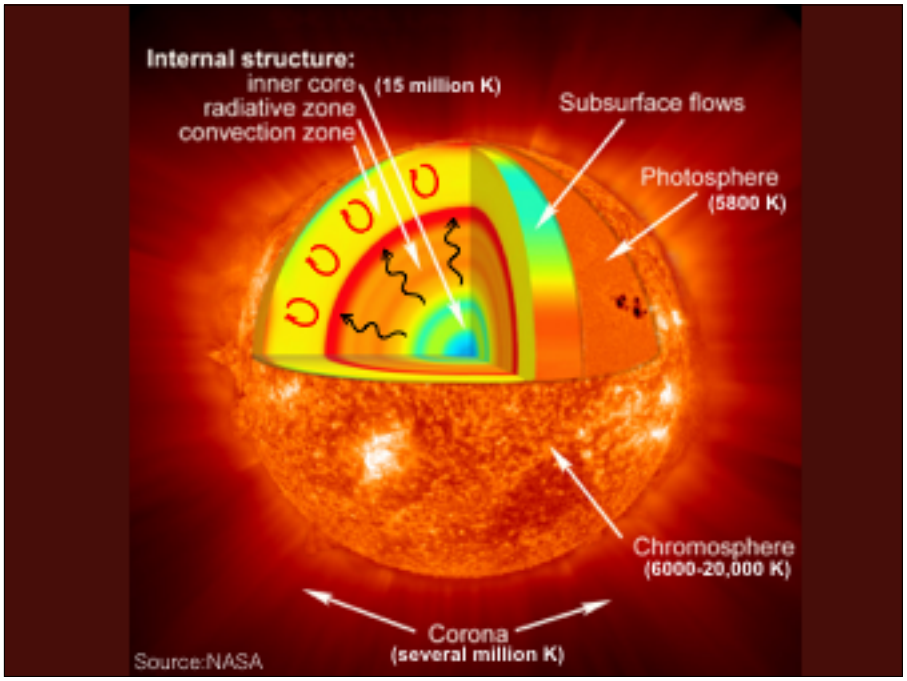
Internal structure:
inner core
radiative zone
convection zone
(15 million K)
Subsurface flows
Photosphere
(5800 K)
Chromosphere
(6000-20,000 K)
Corona
(several million K)
Source:NASA

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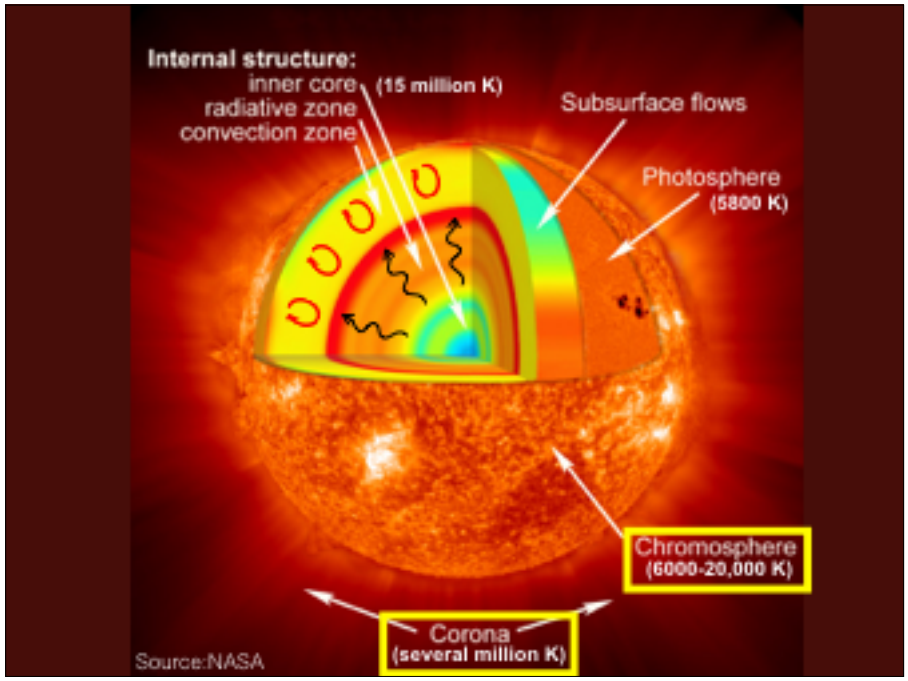
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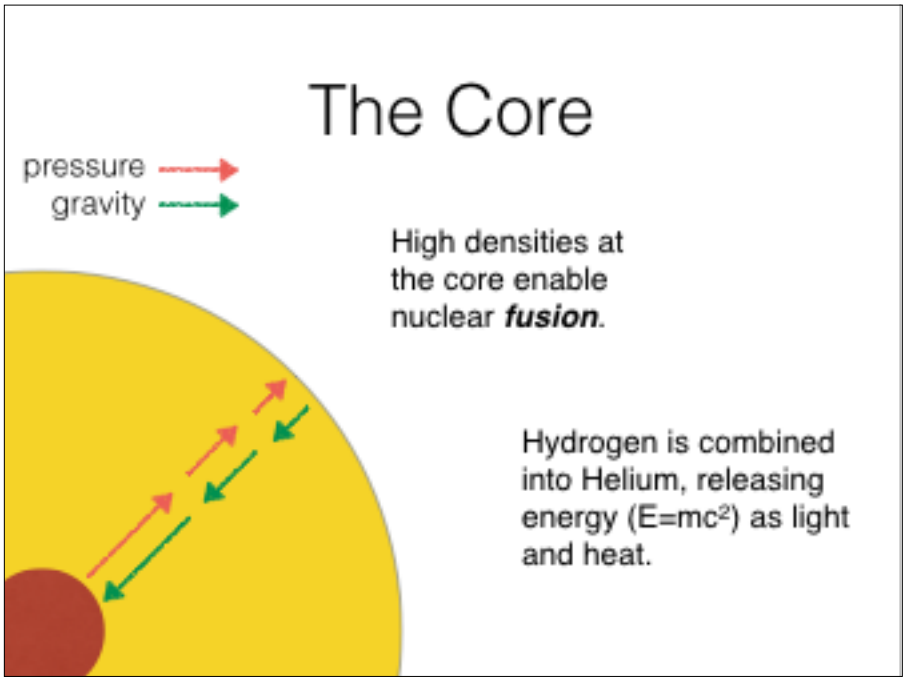
The Core
pressure
gravity
High densities at the core enable nuclear fusion.
Hydrogen is combined into Helium, releasing energy (E=mc²) as light and heat.

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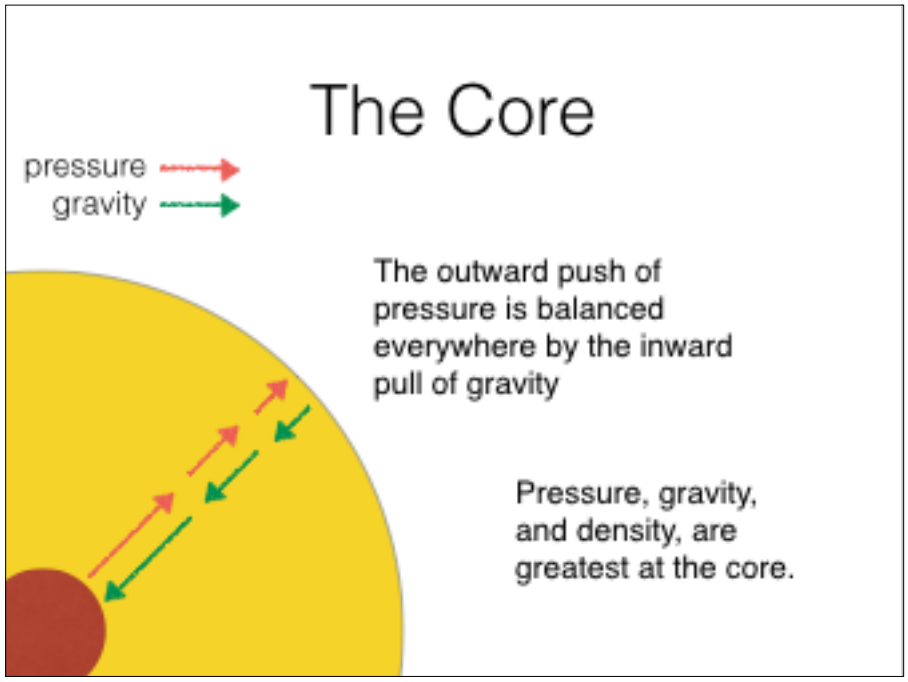
The Core
pressure
gravity
The outward push of pressure is balanced everywhere by the inward pull of gravity
Pressure, gravity, and density, are greatest at the core.

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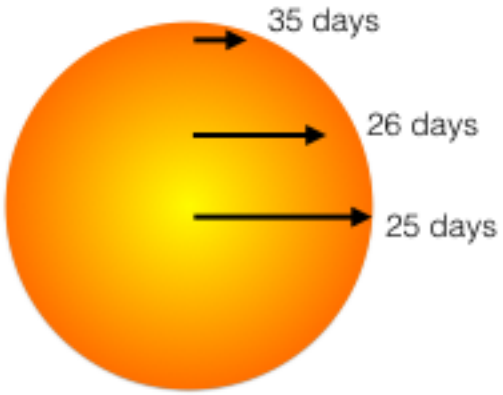
Solar Rotation

The equator spins faster than the poles: ***differential rotation***.



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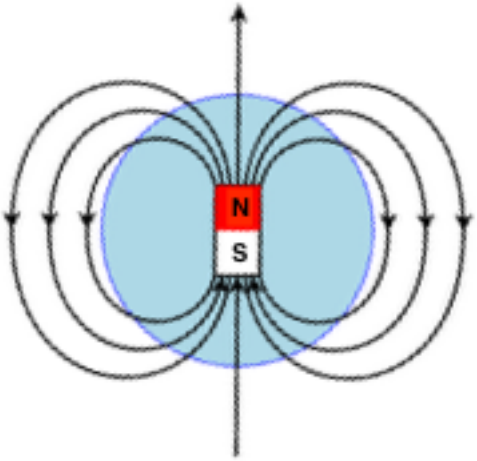
Magnetic field

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



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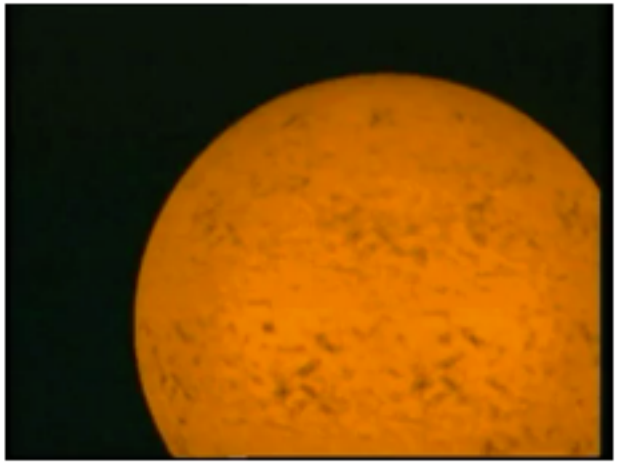

Solar Dynamo

Spinning plasma drags the magnetic field.

Source:SOHO (ESA/NASA)

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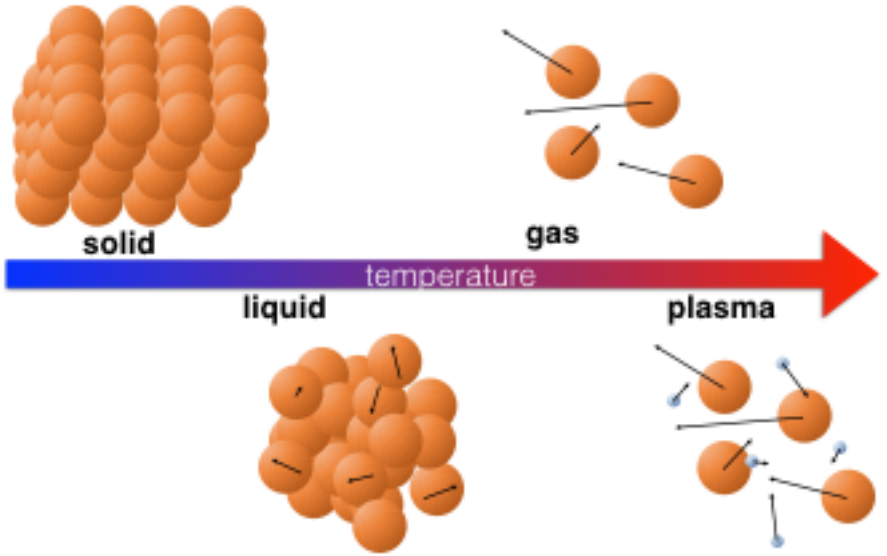
Phases of Matter



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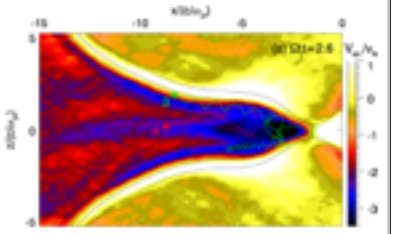
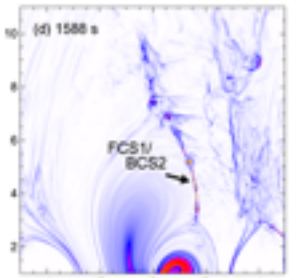
Motion of Plasma

- 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):

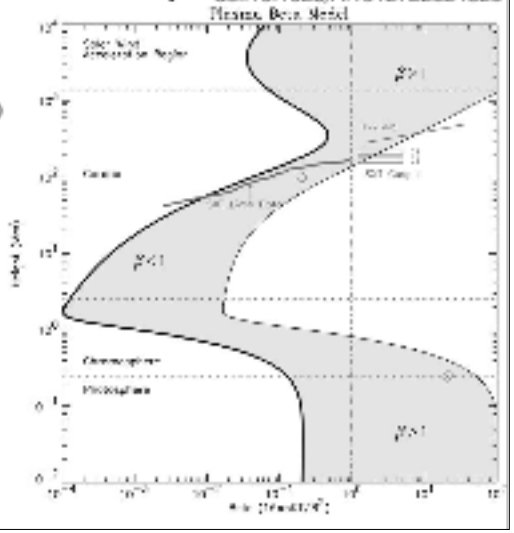
$$\frac{\partial \mathbf{B}}{\partial t} = \underbrace{\nabla \times (\mathbf{v} \times \mathbf{B})}_{I.1} + \underbrace{\eta \nabla^2 \mathbf{B}}_{I.2}$$

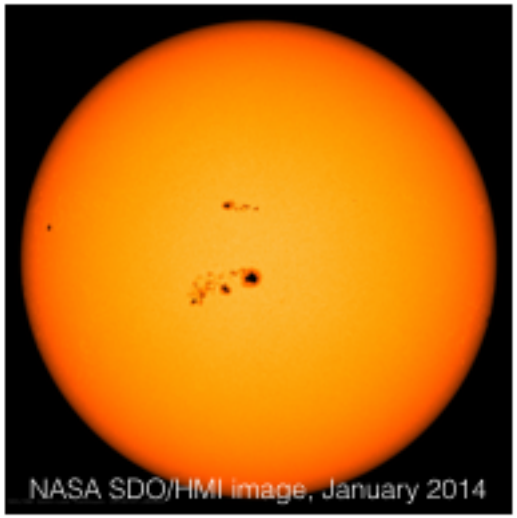
- Almost all astrophysical plasmas have very small *magnetic diffusivity*, η. (hotter plasmas have lower diffusivity)
- I.2 >>I.1
- The fluid motion is tied to or 'frozen into' the magnetic field.

Plasma-β

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

- 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.

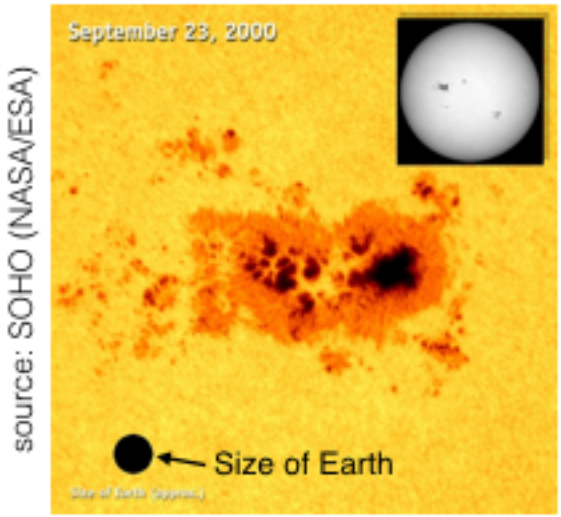




NASA SDO/HMI image, January 2014

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.

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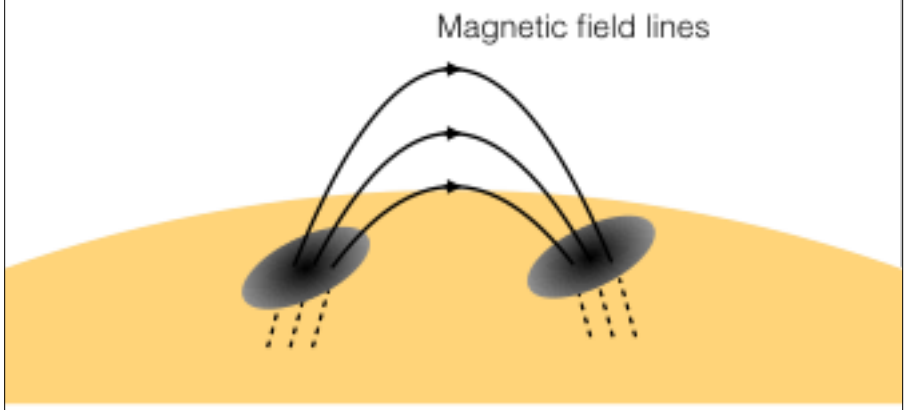

Sunspots

Strong magnetic field threads through sunspots.

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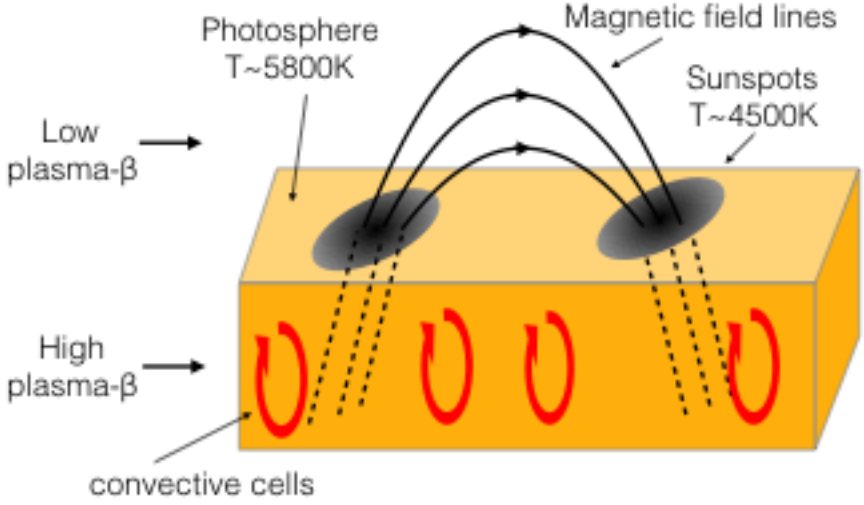

Sunspots

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

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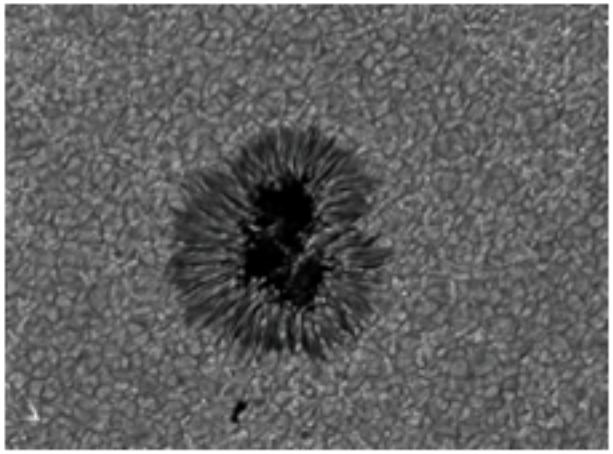
Sunspot



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

Dutch Open Telescope - 1 April 2001

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Above Sunspots: Active Regions

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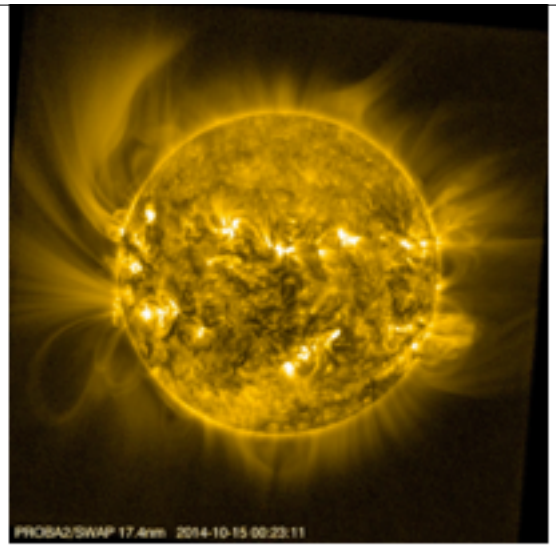

The dynamic corona

PROBA2/SWAP movie of 3 solar rotations

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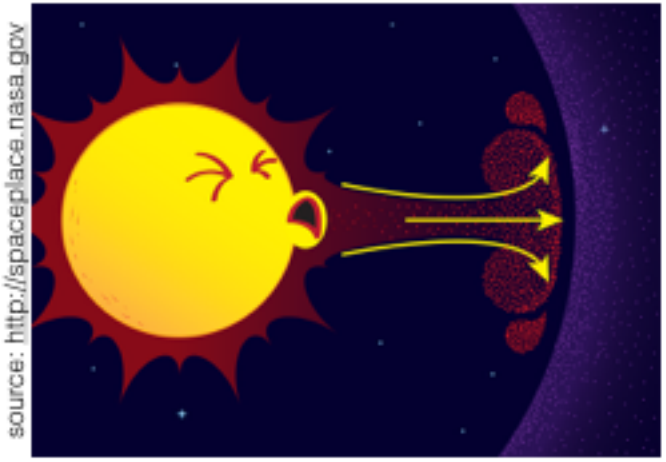
Heliosphere

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



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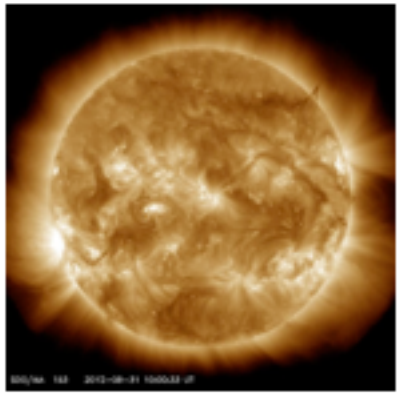
Eruptions

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



NASA SDO/AIA movie

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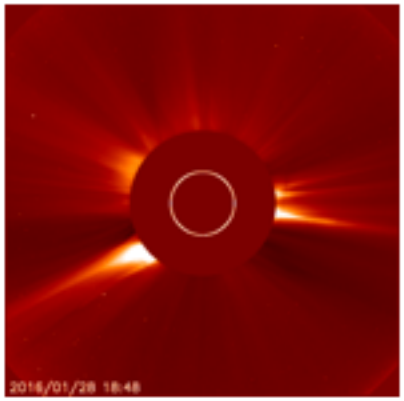

NASA LASCO C2 movie

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Quiz

How fast are these eruptions?

✊	✋	👍
5 m/s	5 km/s	500 km/s

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Quiz

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

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

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Eruption statistics

- How big? About as 1 cubic km^3 of water
- How fast? About 500 km/s (1100 mph)

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Eruption statistics

- How big? About as 1 cubic km^3 of water
- How fast? About 500 km/s (1100 mph)
- How much energy? About 20x the last year's global energy consumption.

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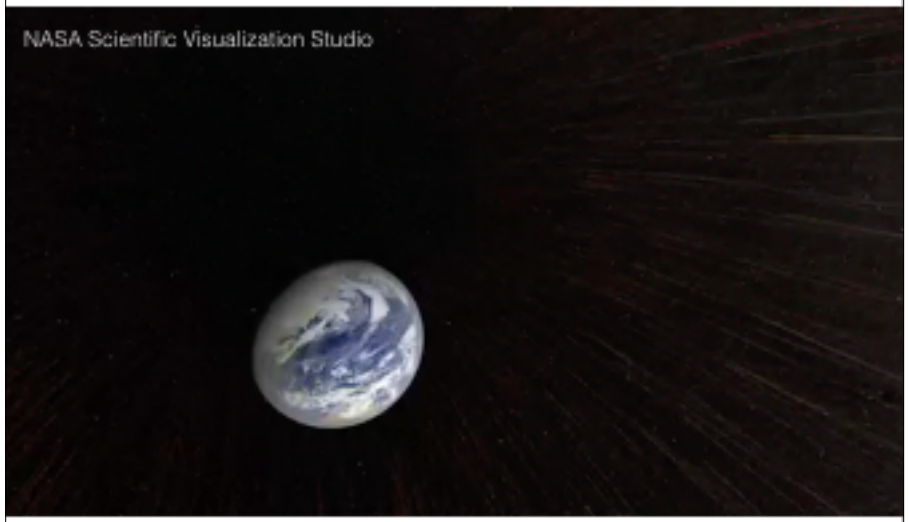
Eruptions in the heliosphere



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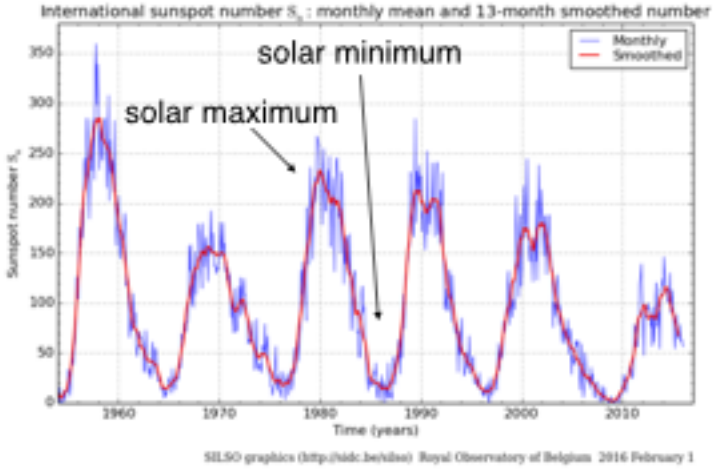
Activity cycle

There are times when the Sun is more active than others. It is linked to the solar dynamo. The activity cycle period is roughly 11 years.



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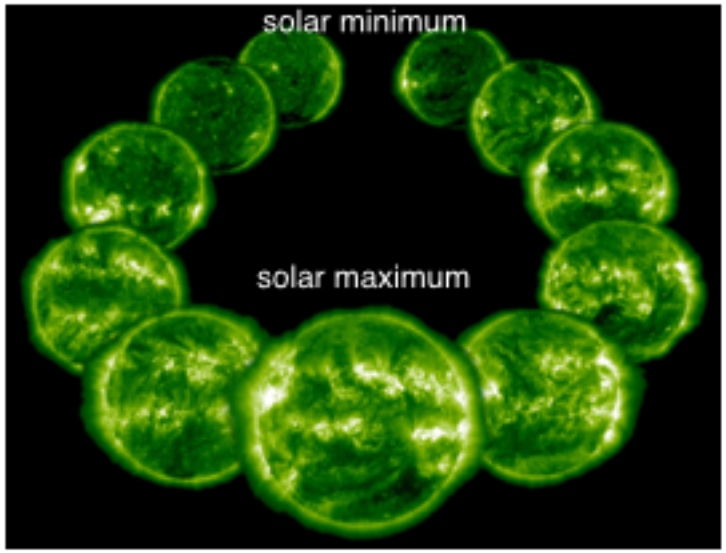
Activity cycle



Source: ESA & NASA/SOHO

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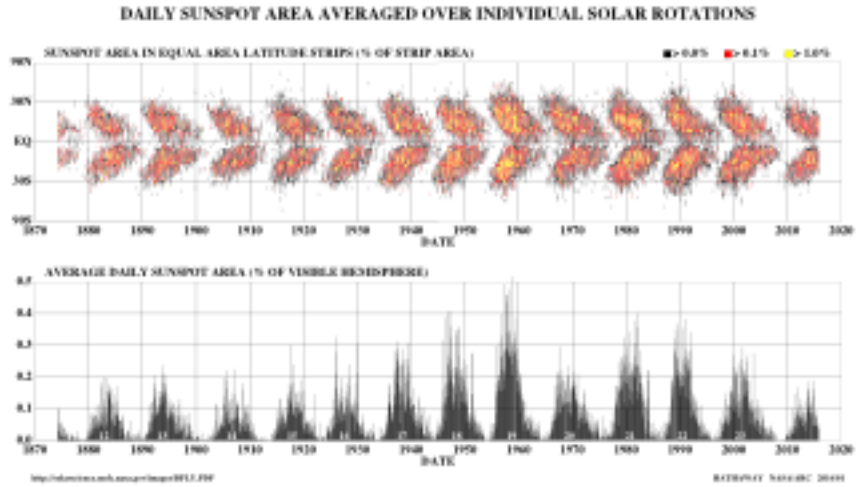
Butterfly diagram



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How do we know all of this?

- Solar data:
  - remote sensing: images, total brightness, spectra, polarimetry, helioseismology
  - in-situ plasma density, velocity, magnetic field information
- Computer modeling of the sun at all scales.

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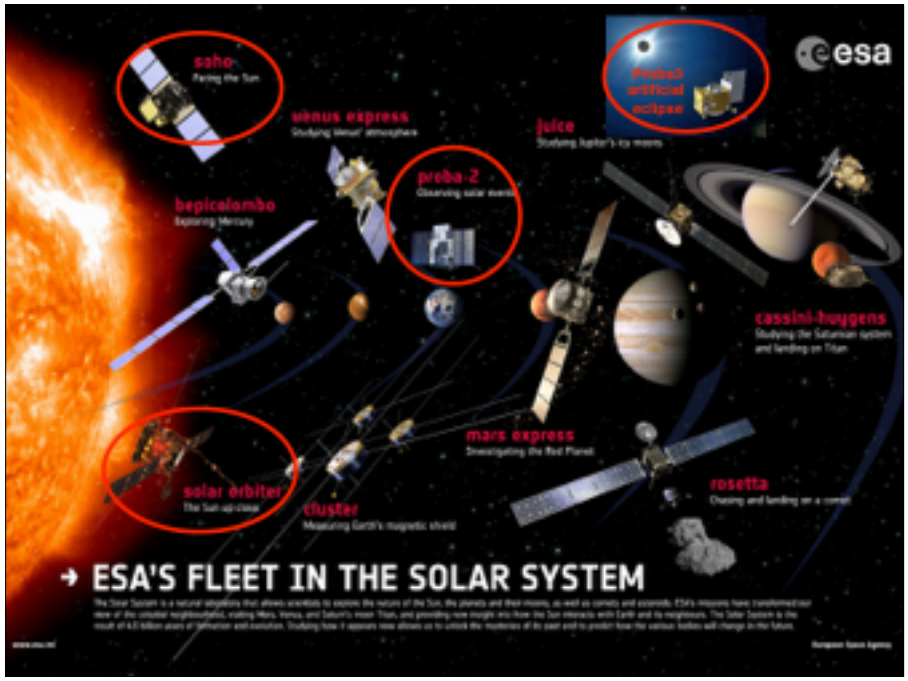

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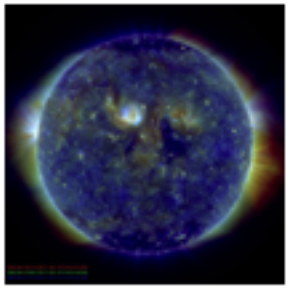
Contact:

laurel.rachmeler@nasa.gov

Office 2026

Current solar conditions:

https://sdo.gsfc.nasa.gov/data/



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