

# Sun-Earth System Overview

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(thanks to Dr. Frank Eparvier for  
making most of the slides)

# Why do We on Earth Care about the Sun?

The Sun directly or indirectly provides nearly all of the energy to the Earth system.

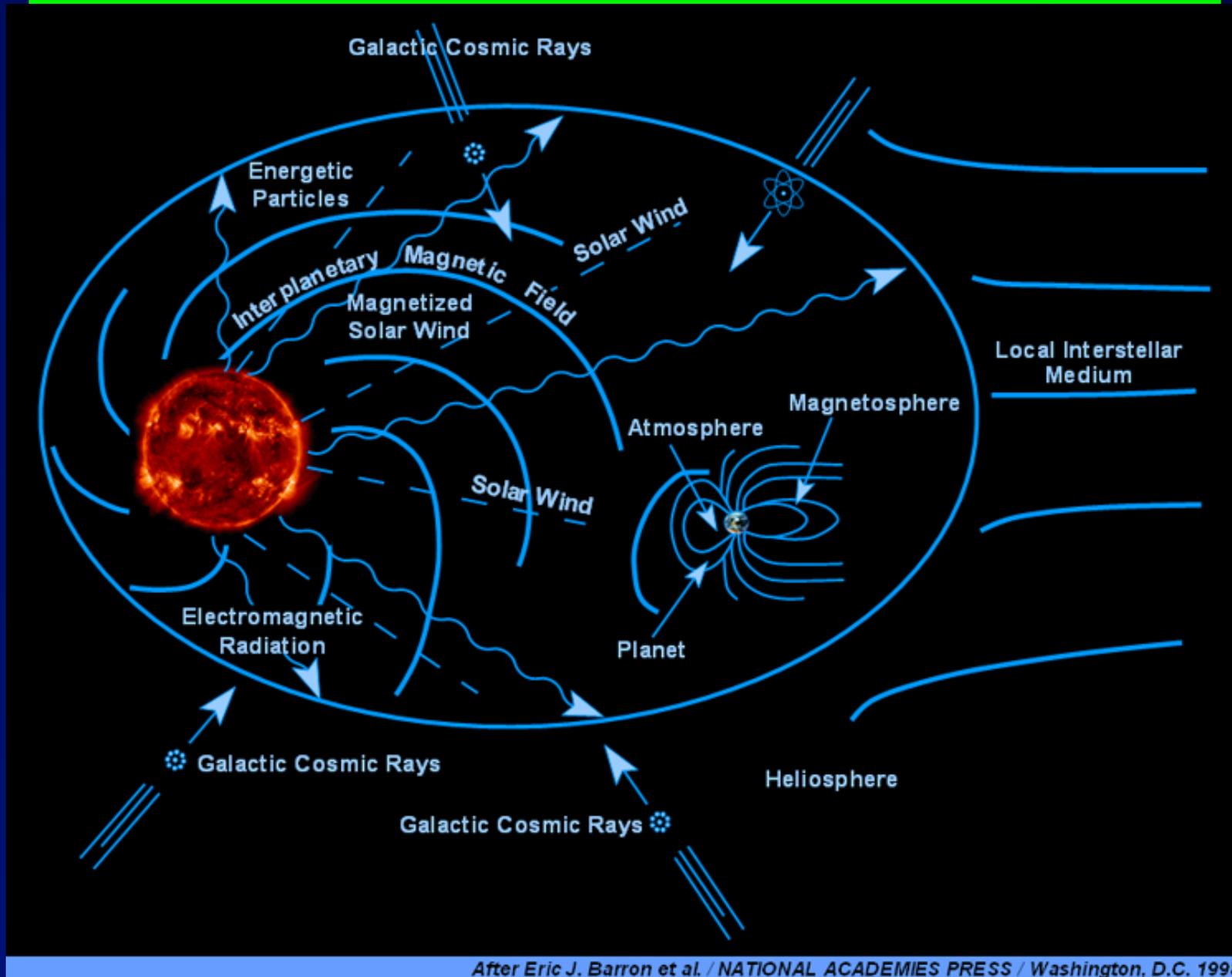
Photons (light of all wavelengths)

Plasmas (charged particles and magnetic fields)

Variability in the solar output drives variability in the Earth system.

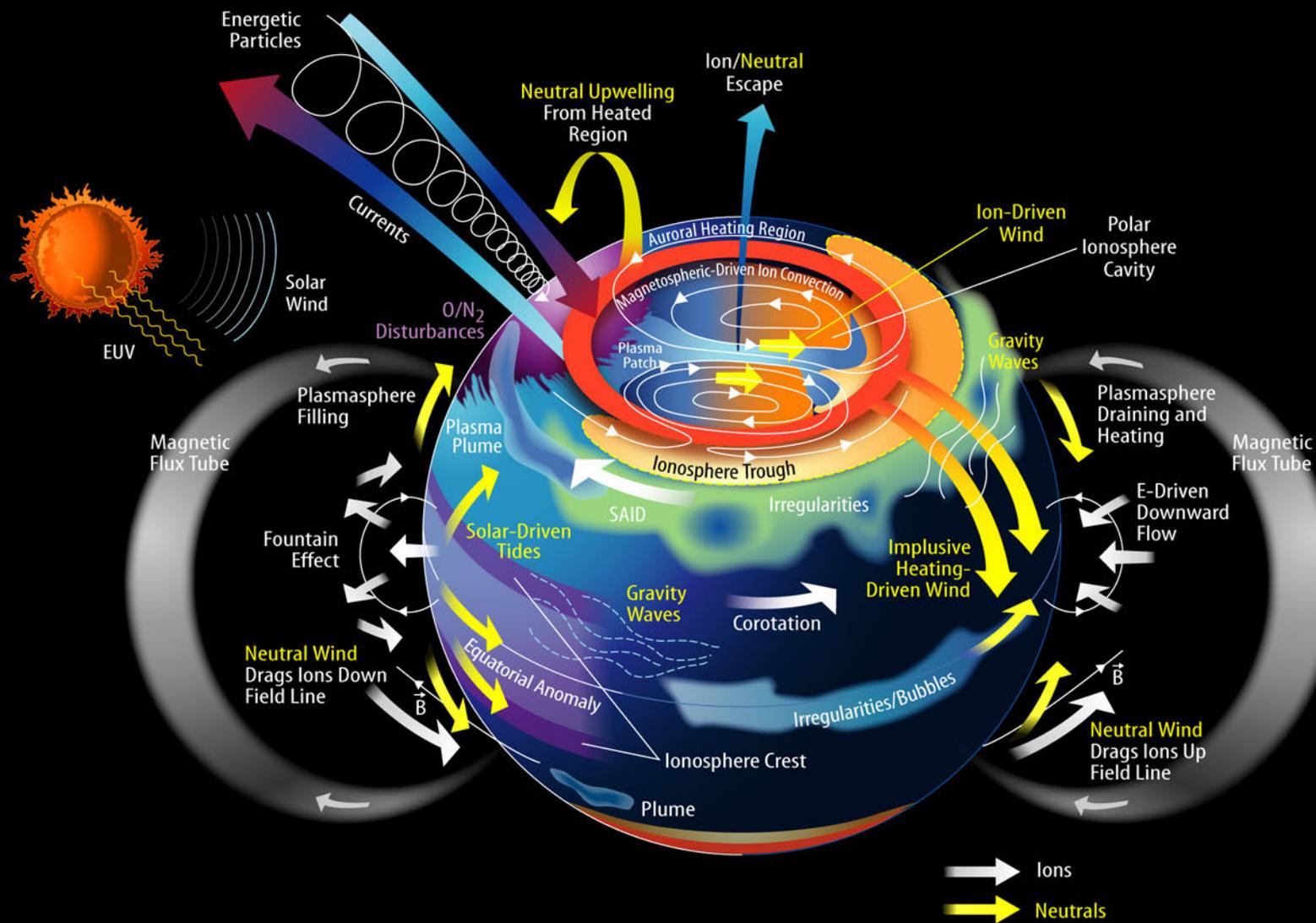
How the Earth system reacts to solar variability depends on the complicated, interconnected mechanisms involved in the Sun-Earth system.

# The Sun Side of the Sun-Earth System



After Eric J. Barron et al. / NATIONAL ACADEMIES PRESS / Washington, D.C. 1998

# The Earth Side of the Sun-Earth System



## Statistics of the Sun

Radius = 696,000 km  $\approx$  109  $R_{\text{Earth}}$

Volume  $\approx$  1,300,000  $V_{\text{Earth}}$

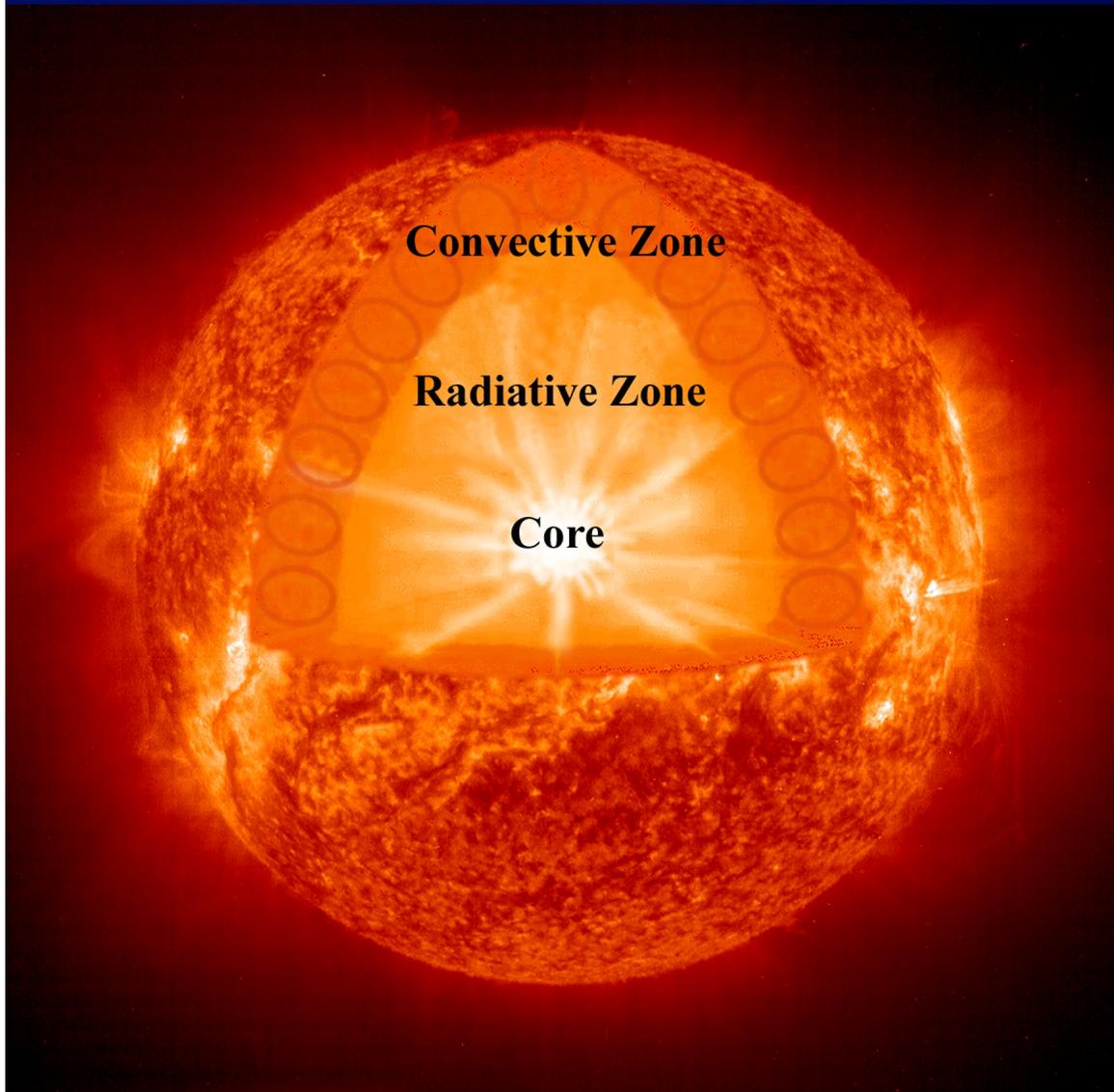
Mass =  $1.99 \times 10^{30}$  kg  $\approx$  333,000  $M_{\text{Earth}}$

Composition:

<b>Element</b>	<b>by Number</b>	<b>by Mass</b>
Hydrogen	92.1%	75%
Helium	7.8%	25%
Heavier Elements	<0.1%	<0.1%

Much of this is in the form of ionized atoms = **plasma**

# Energy Flow and Layers of the Sun



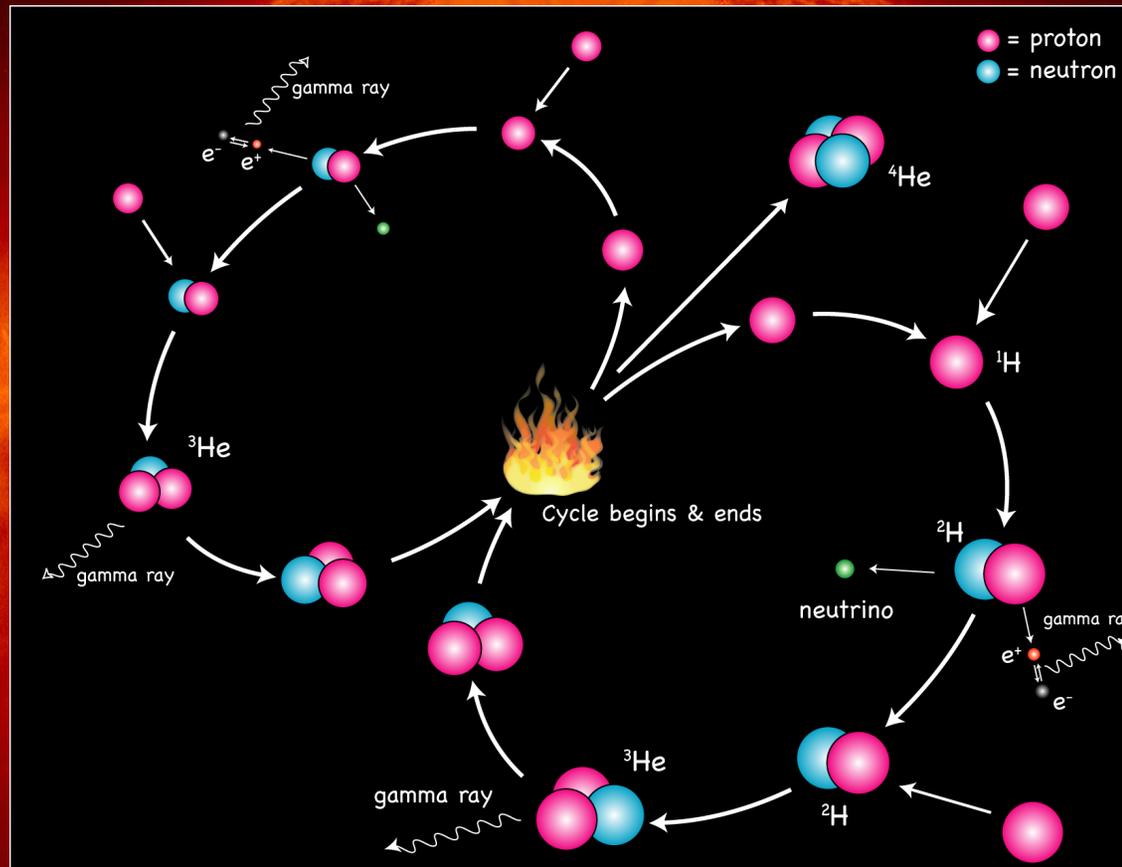
## Interior of Sun:

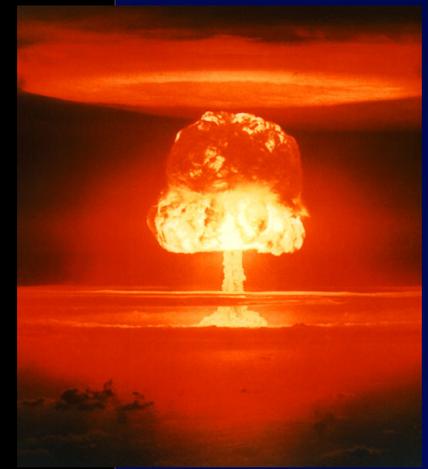
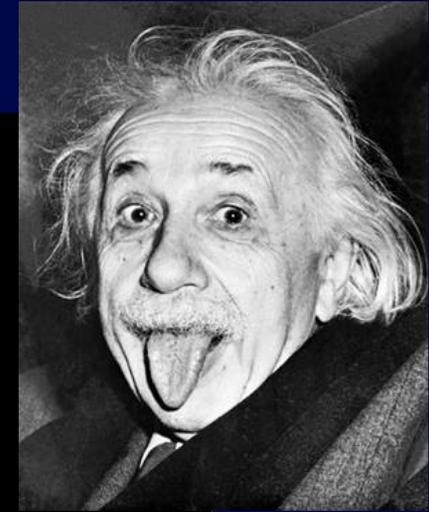
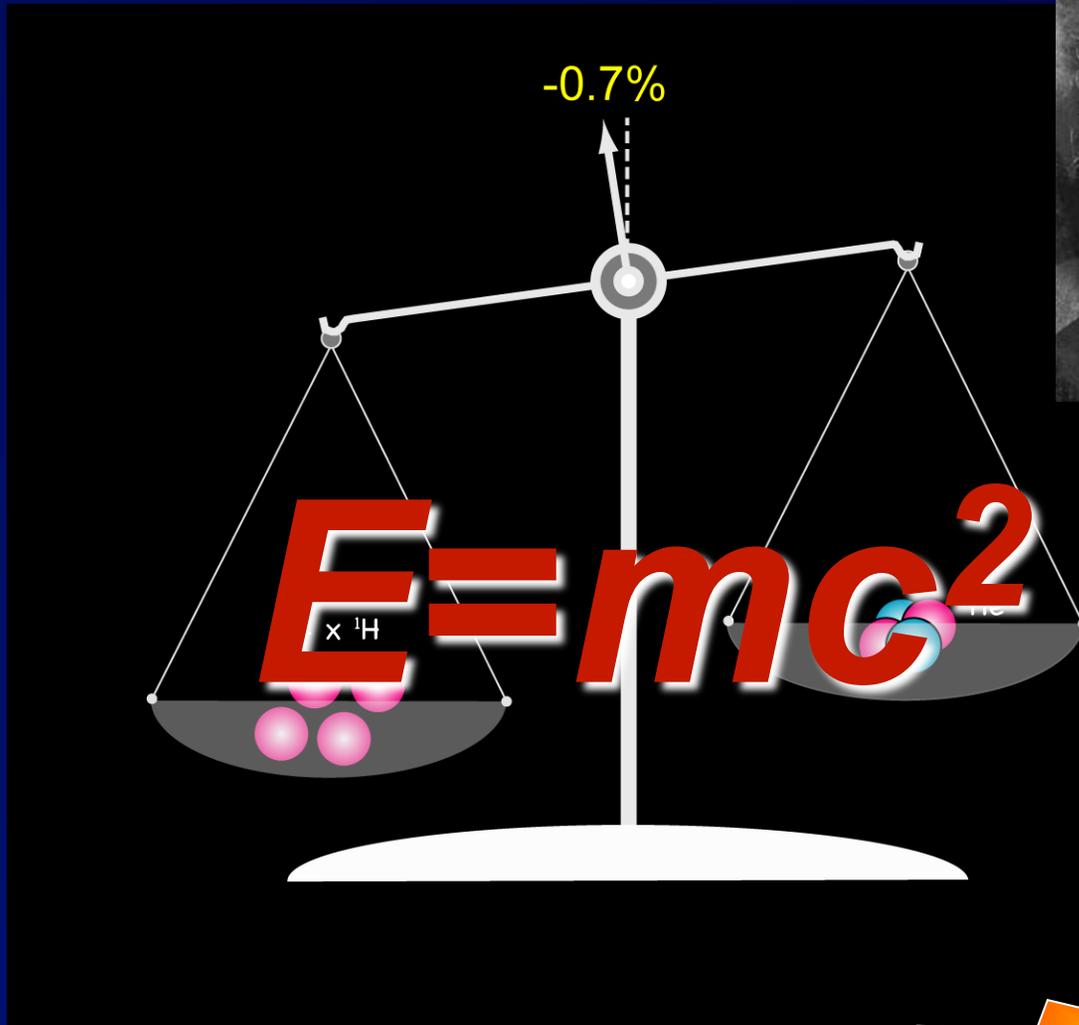
**Core:** Where fusion occurs, ~15 million K

**Radiative Zone:** Energy carried outward slowly (~200,000 yrs) by photons through a very thick region of H & He, T~5 million K

**Convective Zone:** Energy carried outward via convection (hot plasma rises, reaches surface, radiatively cools, then sinks again), T~1 million K

# Hydrogen Fusion in the Sun "The Proton-Proton Chain"





$600 \times 10^9 \text{ kg H} \longrightarrow 596 \times 10^9 \text{ kg He}$

$4 \times 10^9 \text{ kg to Energy}$

# Energy Output of the Sun

Measure all photonic energy coming from the Sun at all wavelengths

Total Solar Irradiance = 1361 Watt/m<sup>2</sup> at 1 AU



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# Energy Flow and Layers of the Sun (2)

## Atmosphere of Sun:

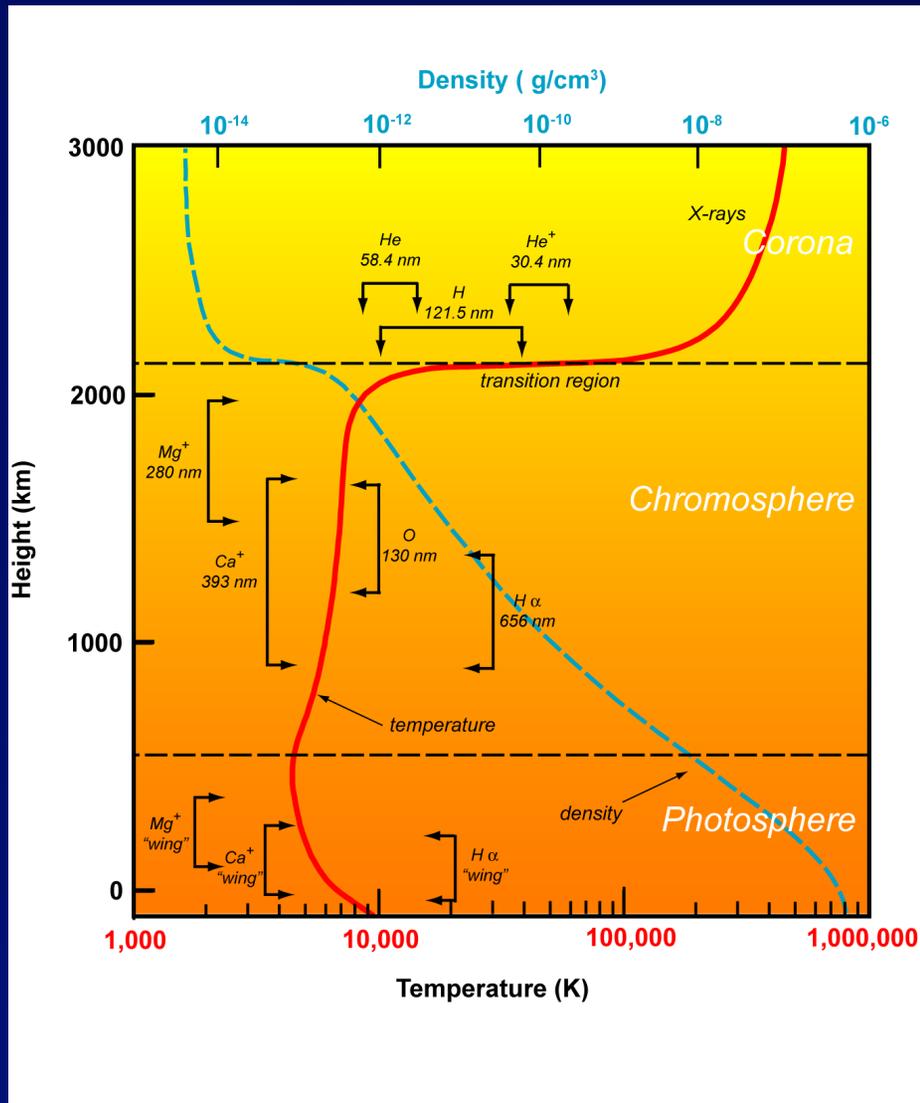
**Photosphere:** visible “surface” of Sun, point where gases go from being optically thick (opaque) to optically thin (transparent),  $T \sim 5700$  K

**Chromosphere:** “bottom” layer of atmosphere, visible as pink layer of hydrogen during total solar eclipses,  $T \sim 10,000$  K

**Transition Region:** narrow ( $\sim 100$ - $1000$  km) layer between chromosphere and corona where temperatures rise rapidly  $T \sim 10,000$  K - 1 million K

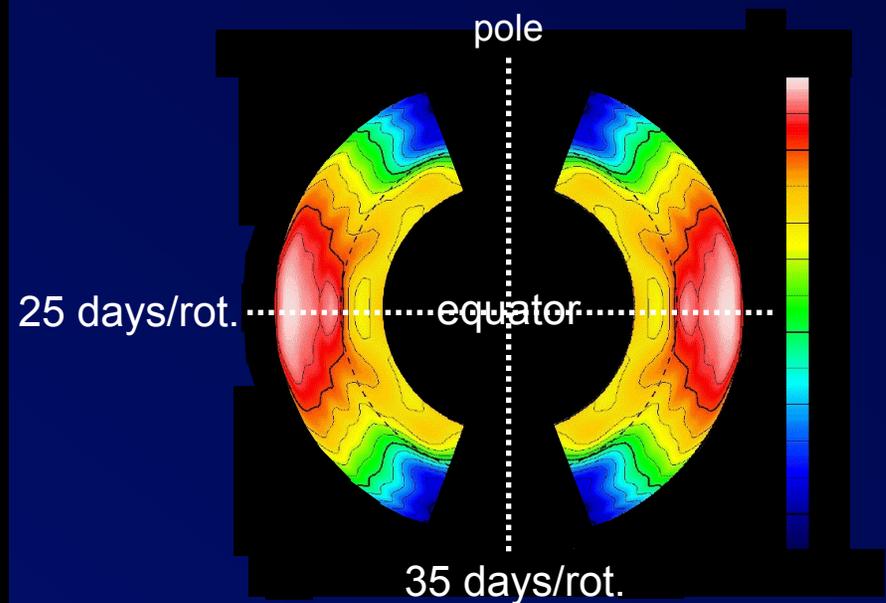
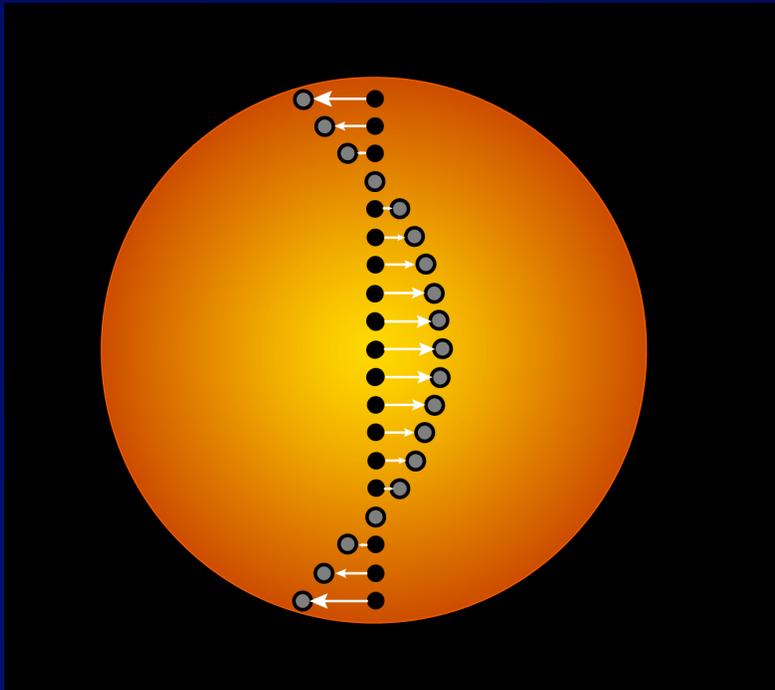
**Corona:** “top” of solar atmosphere heated to extremes by complex (and not fully understood) magnetic means,  $T \sim 2$  million K

**Solar Wind:** extension of corona into interplanetary space, mostly protons and electrons streaming out on Sun’s magnetic field at speeds of  $\sim 400$ - $1000$  km/s,  $T \sim 200,000$  K at 1 AU



# Differential Rotation of Sun

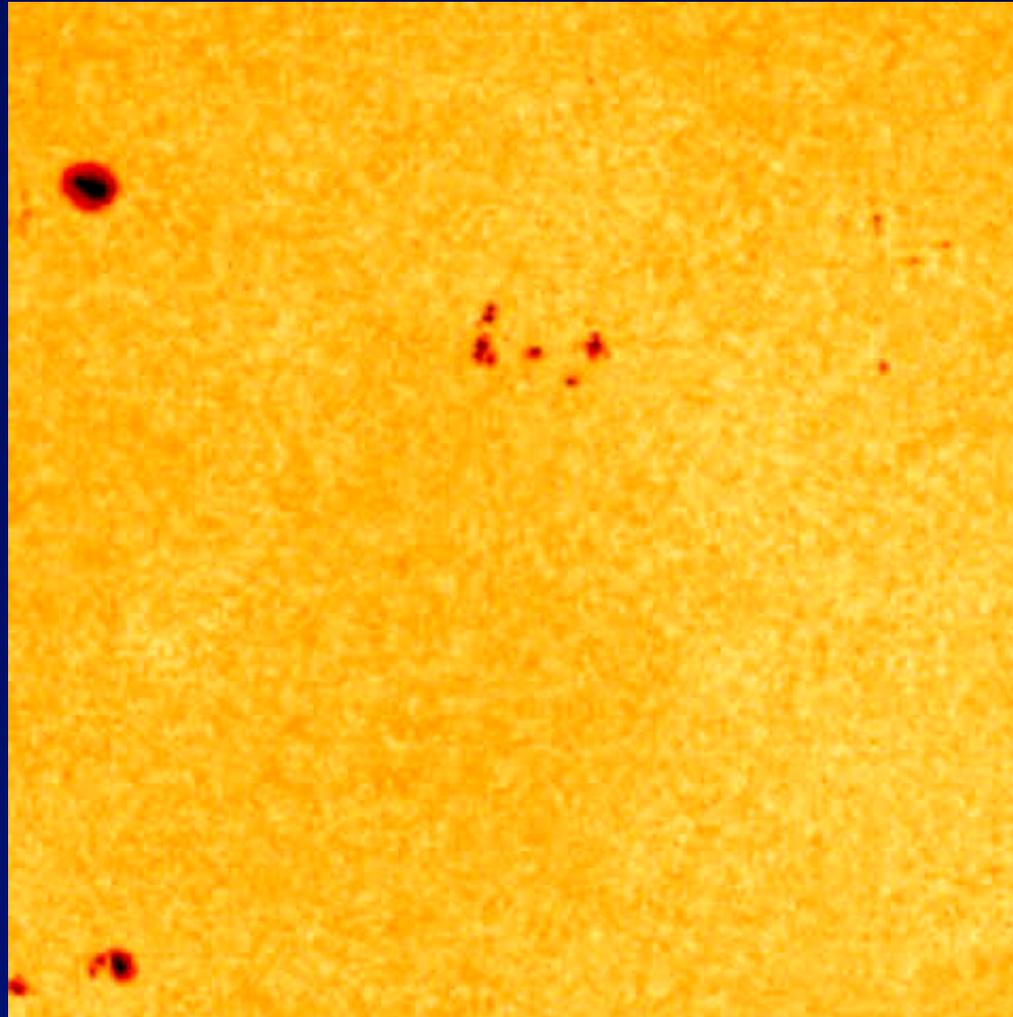
Core and Radiative Zone rotate rigidly.  
Outer layers of Sun rotate differentially.



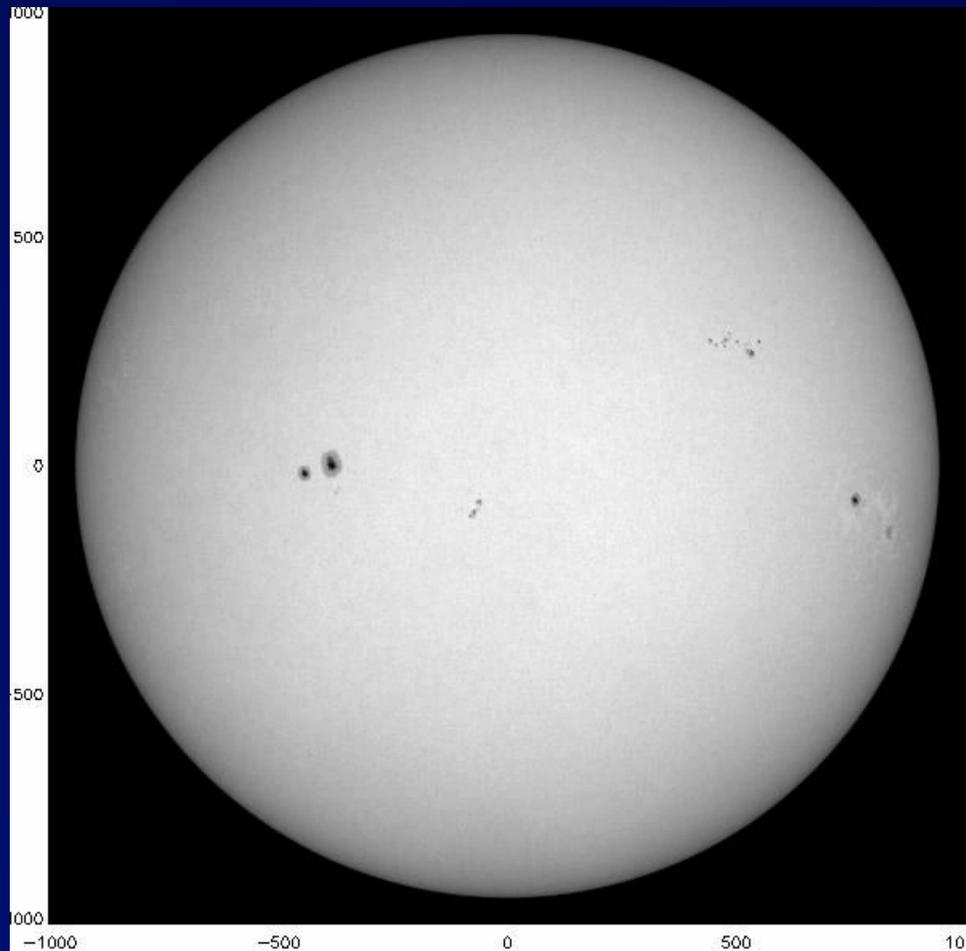
# Looking at the “Surface” of the Sun

Different wavelengths show us a different Sun.

Features that are dark at one wavelength are bright at other wavelengths.

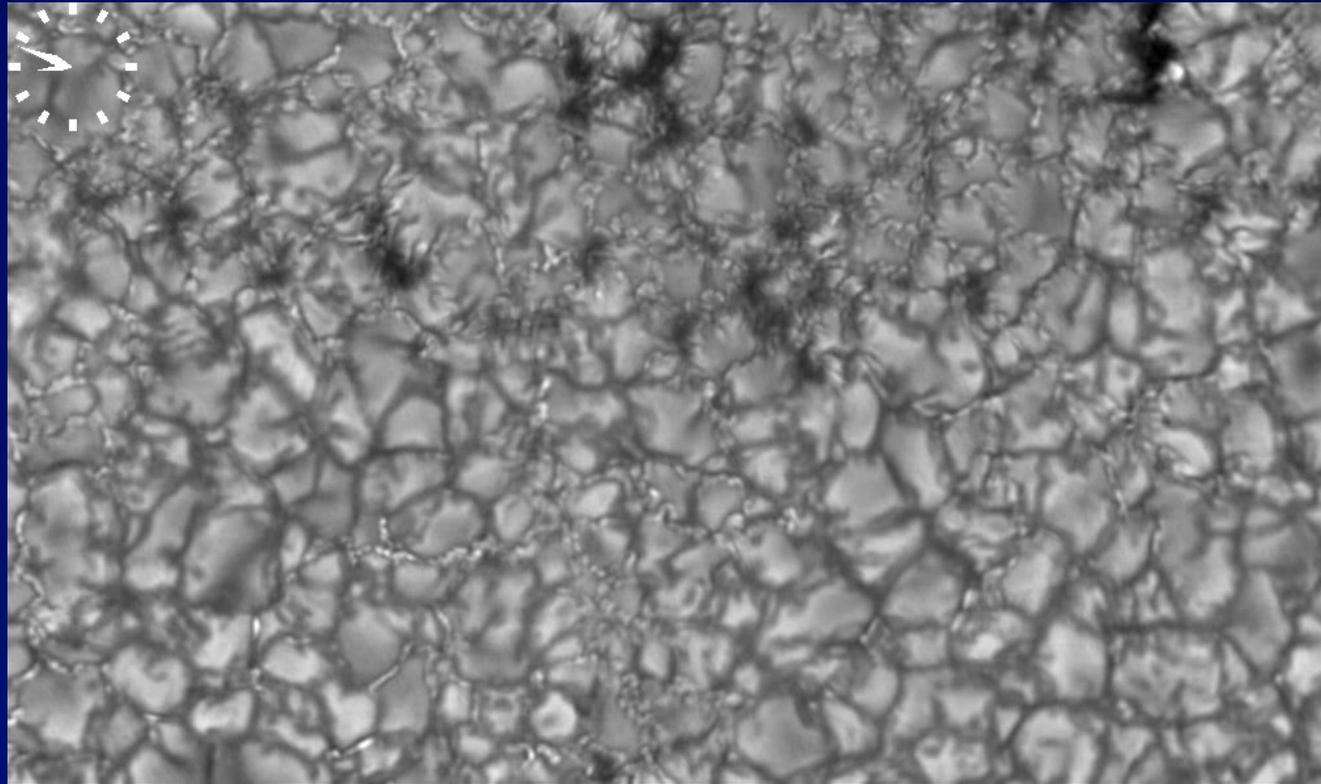


# Surface Features

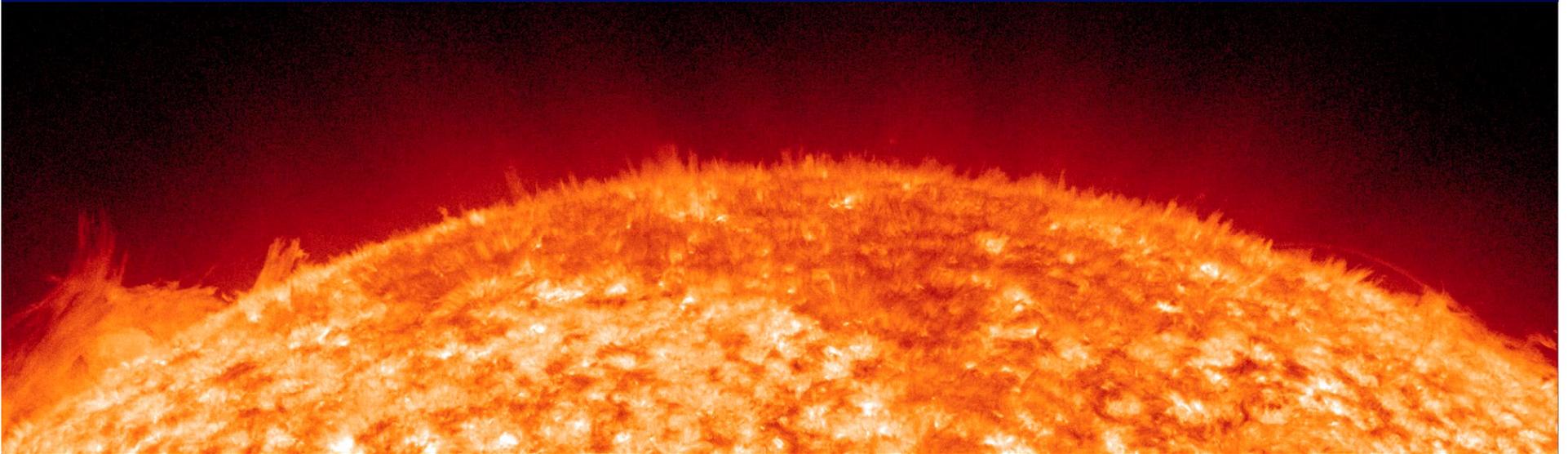


# Granules

**Granules:** Convection cells on photosphere, size ~ 1000 km (~ size of Texas)



# Spicules



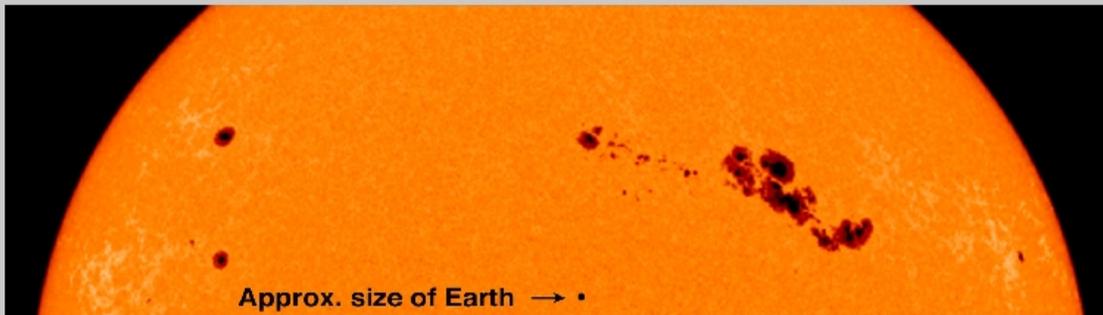
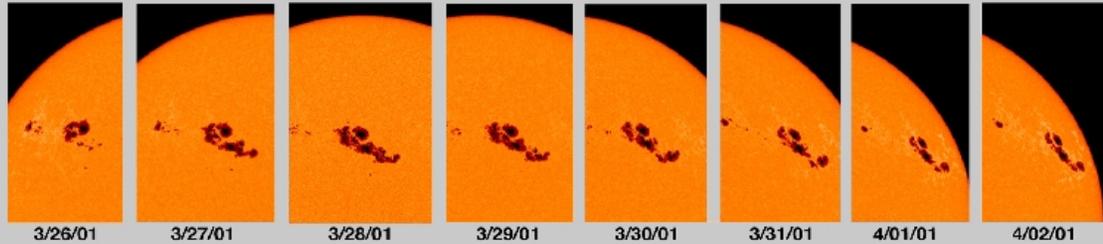
The Sun's surface is in constant motion.

...unlike your typical cat.

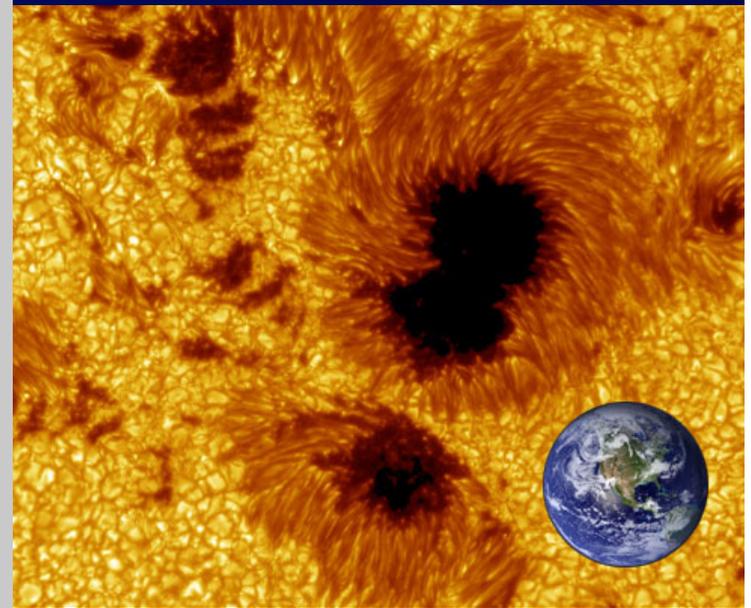


# Sunspots

**Sunspots:** Magnetically disturbed regions cooler than surrounding areas ( $\sim 4000 - 5000$  K) of photosphere ( $\therefore$  darker), usually come in pairs (N and S magnetic polarity), size  $\sim 1500-50,000$  km, can last for months

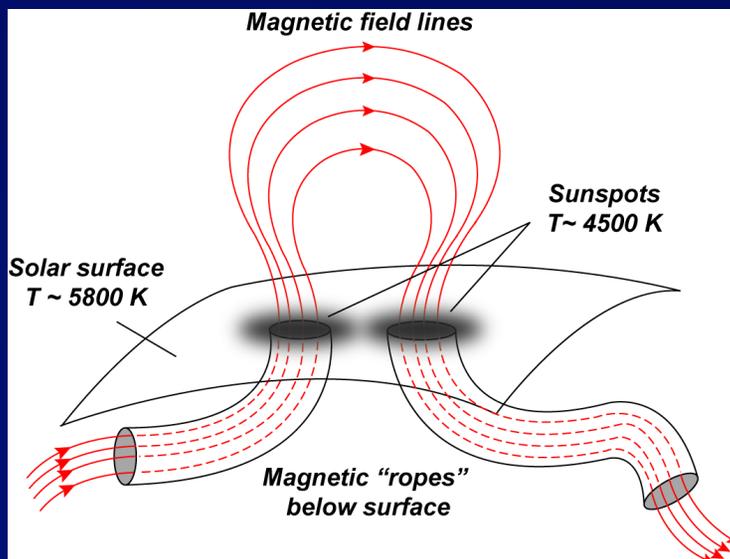
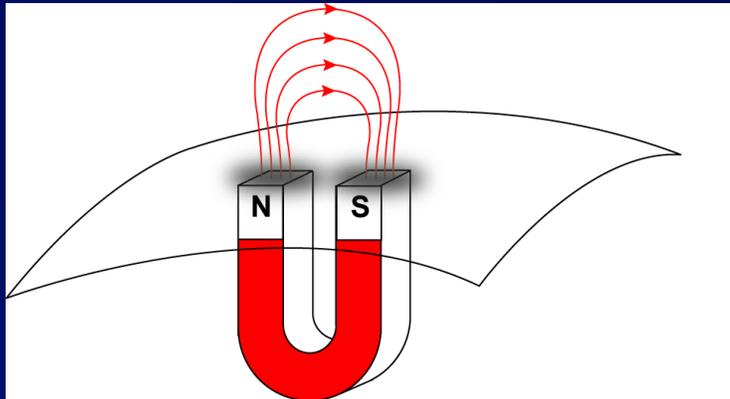


March 30, 2001



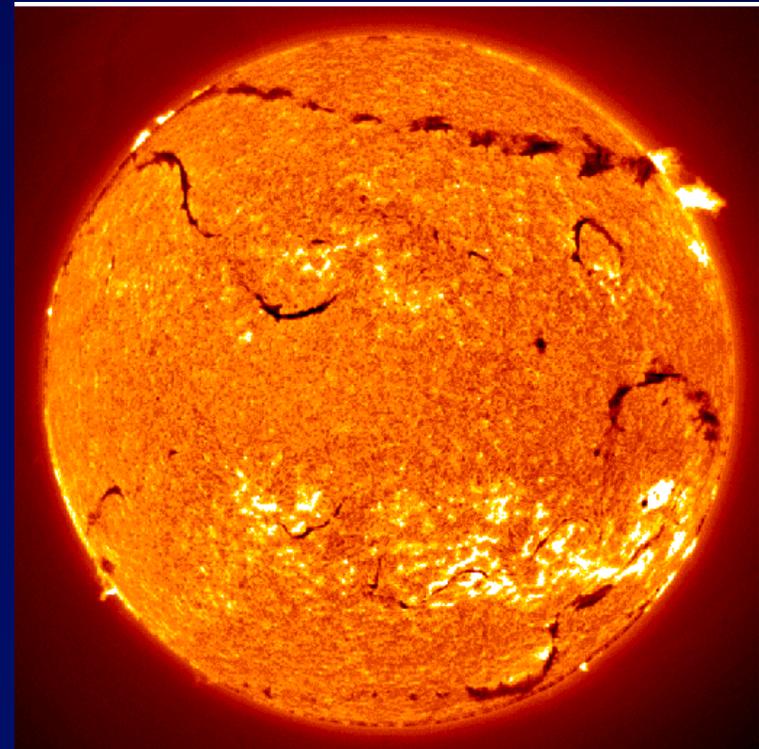
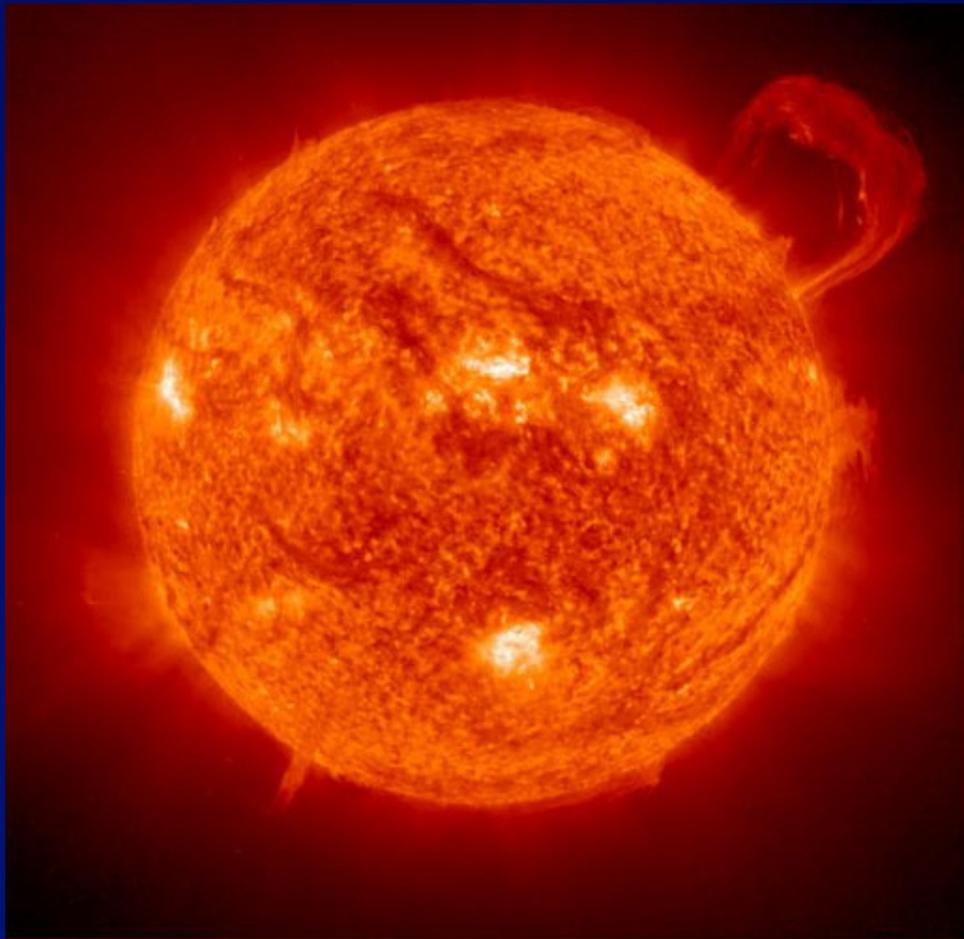
# The magnetic nature of sunspots

*Hale provided the first proof that sunspots are the seats of strong magnetic fields*

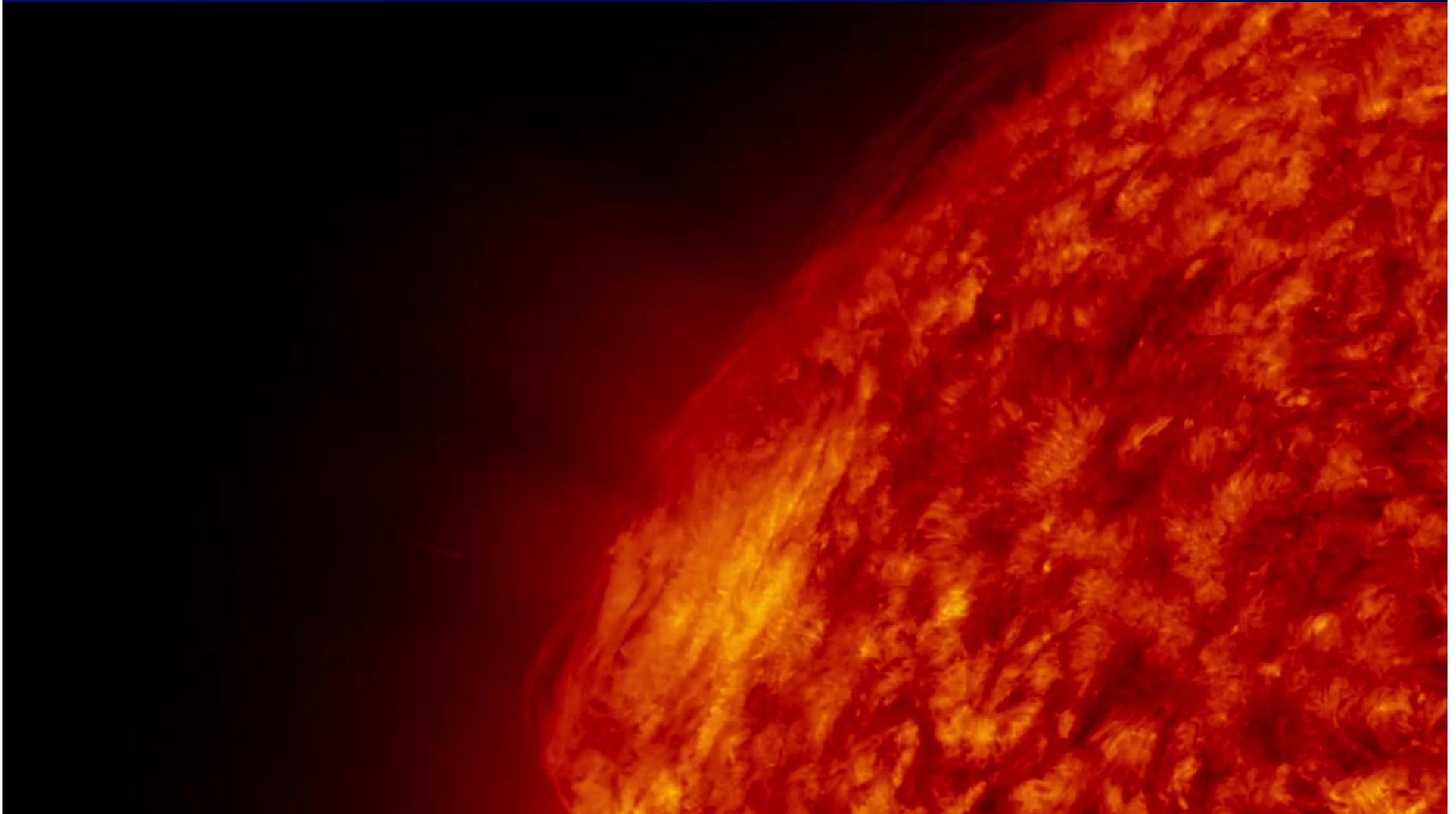


# Prominences

**Prominences & Filaments:** Long-lasting (hours or days) condensations of gases held above the surface by erupting sections of magnetic field

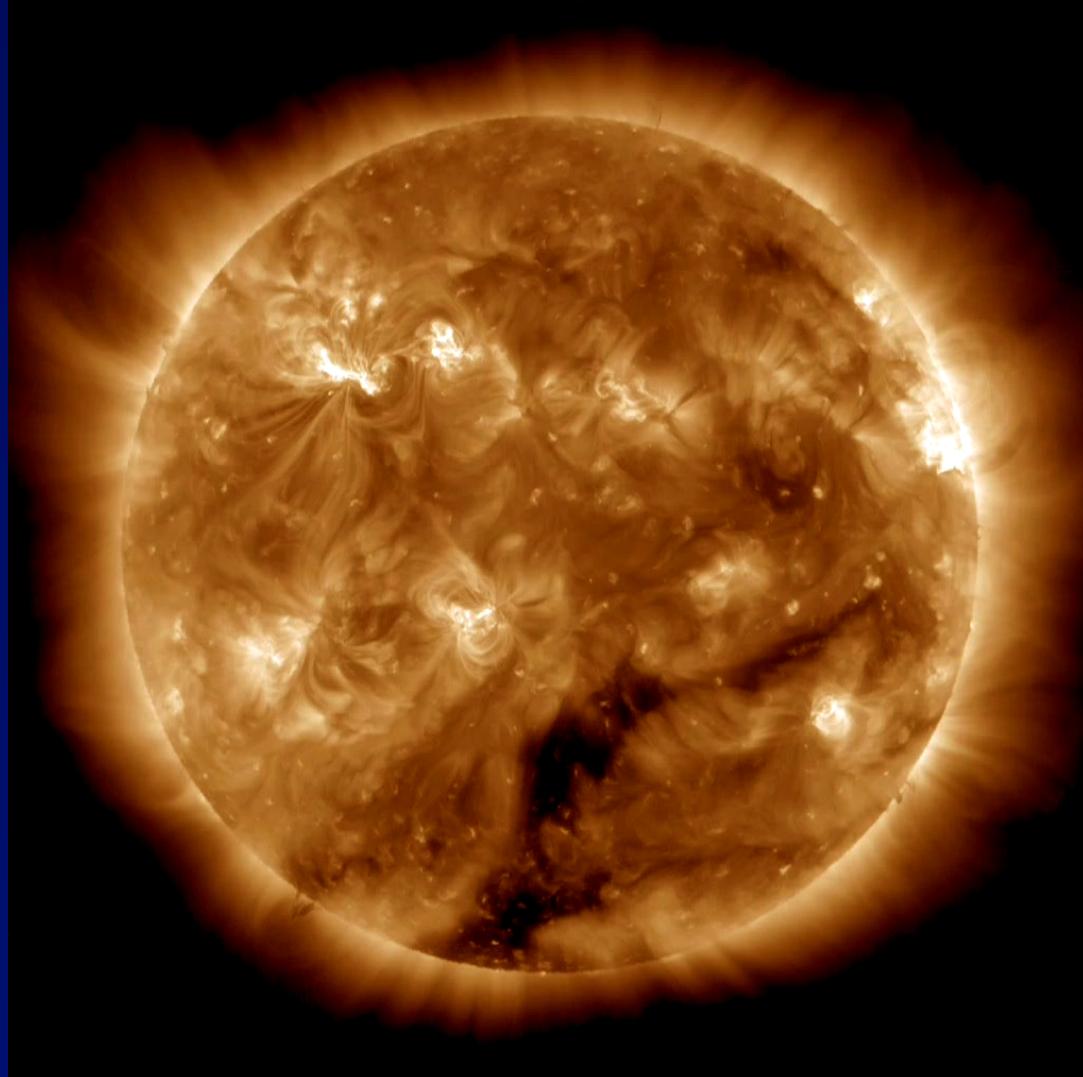


## Prominences (2)



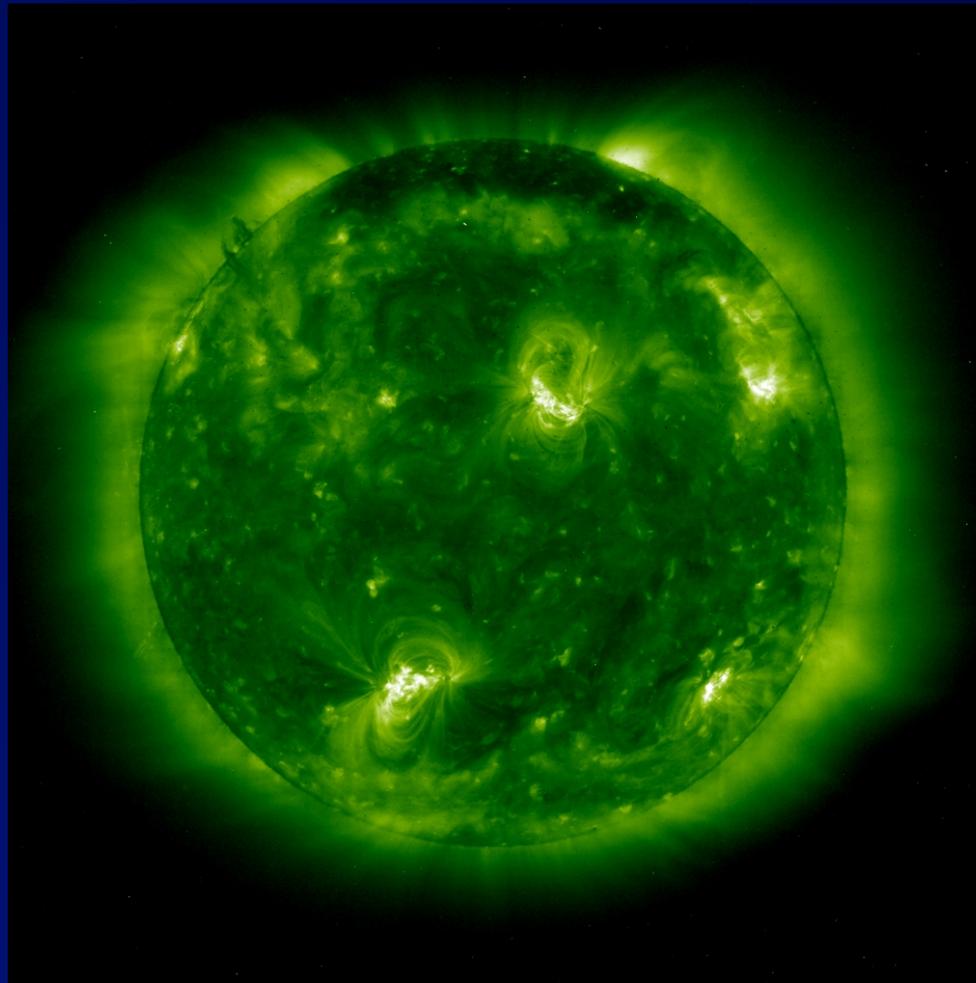
# Flares

**Flares:** short duration (minutes to hours) bursts of hot material out of surface, very bright at all wavelengths



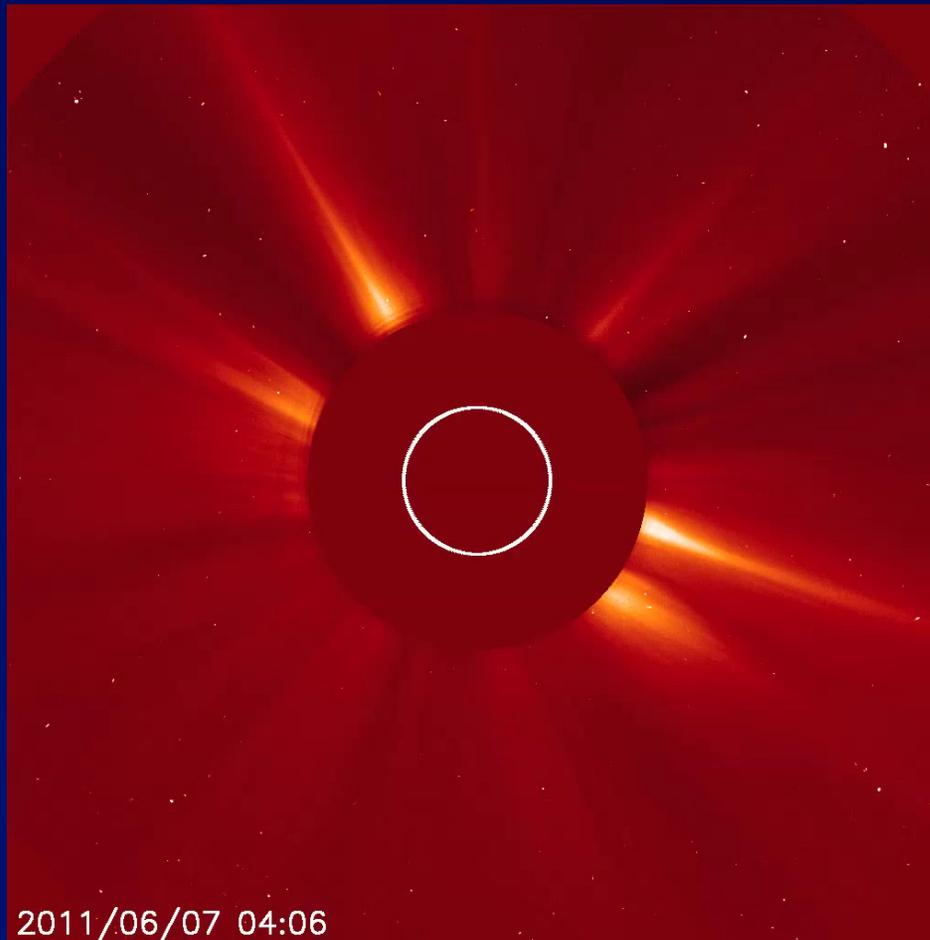
## Coronal Holes

**Coronal Holes:** areas of “open” magnetic field allowing plasma to stream out into solar wind



# Coronal Mass Ejections

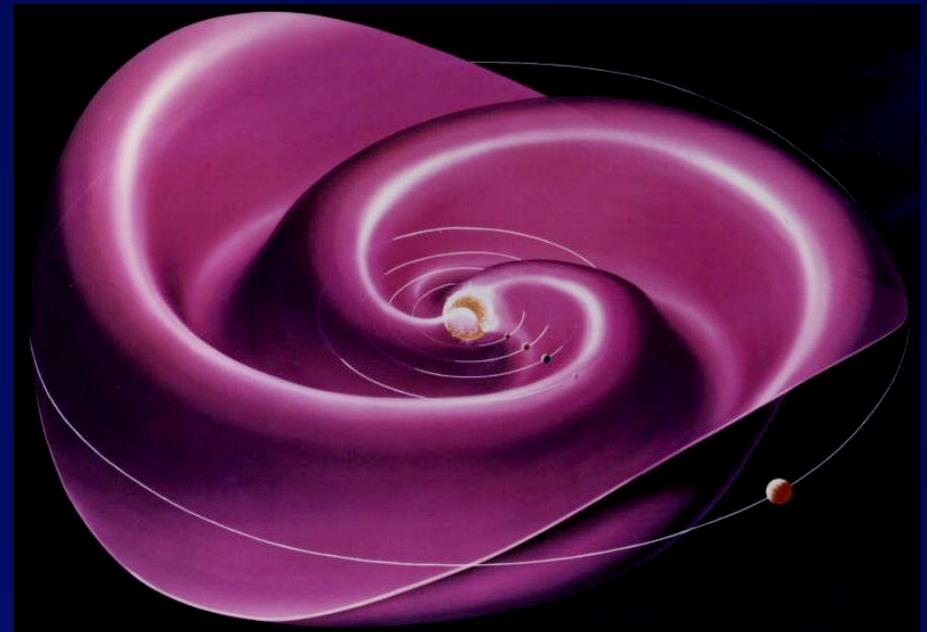
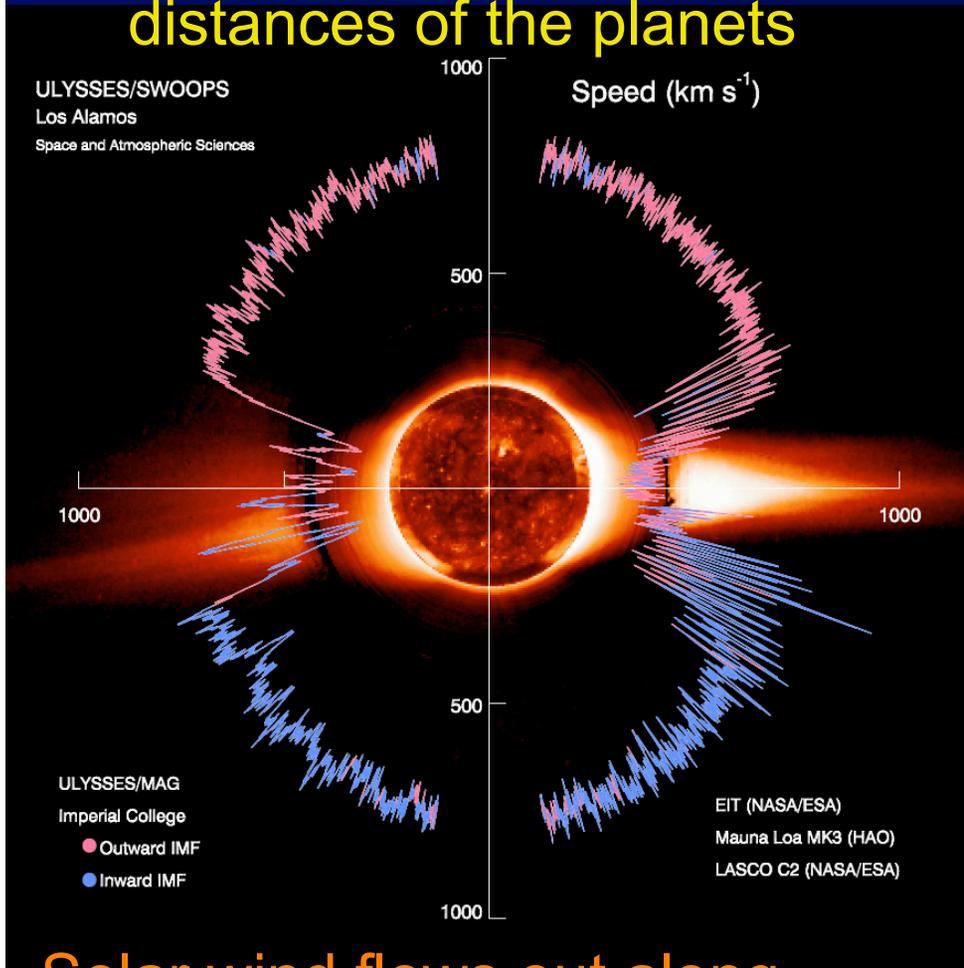
**CMEs:** large “blobs” of plasma (hot ionized gases enclosed in bubbles of magnetic field) that blow off the Sun and travel out through the solar system



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# Solar Wind and IMF

Solar Wind: Charged particles streaming out from Sun  
Interplanetary Magnetic Field (IMF): Solar magnetic field at distances of the planets



IMF is twisted into “ballerina skirt” shape by solar rotation.

Solar wind flows out along “open” magnetic field lines.

# Photon Output of the Sun

