# Announcements

- Homework #5 due today
- Review on Monday 3:30 – 4:15pm in RH103
- Test #2 next Tuesday, Oct 11

# Review for Test #2 Oct 11

Topics:

- The Solar System and its Formation
- The Earth and our Moon
- The Terrestrial Planets
- The Jovian Planets
- Moons, Rings, Pluto, Comets, Asteroids, Dust, etc.
- The Sun

Methods

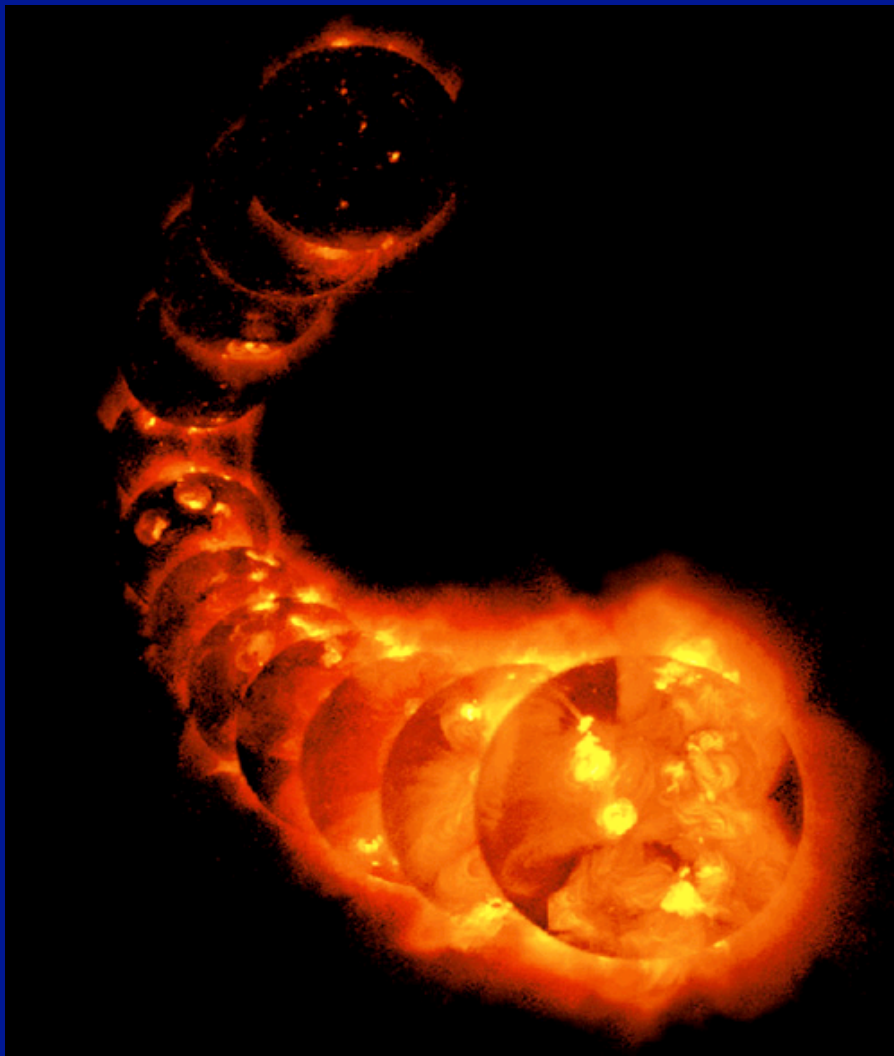
- Conceptual Review and Practice Problems Chapters 5 – 8 and 10
- Review lectures (on-line) and know answers to clicker questions
- Try practice quizzes on-line
- Come talk to me in office hours (Monday 9-11am)

•Bring:

- Two Number 2 pencils
- Simple calculator (no electronic notes)

Reminder: There are NO make-up tests for this class

# The Sun



The Sun in X-rays over several years

The Sun is a star: a shining ball of gas powered by nuclear fusion.

Mass of Sun $= 2 \times 10^{33}$ g $= 330{,}000\ M_{Earth}$
$= 1\ M_{Sun}$

Radius of Sun $= 7 \times 10^{5}$ km $= 109\ R_{Earth}$
$= 1\ R_{Sun}$

Luminosity of Sun $= 4 \times 10^{33}$ erg/s $= 1\ L_{Sun}$

(amount of energy put out each second in form of radiation, $= 10^{25}$ 40 W light bulbs)

We receive 1400 W/m$^2$

DEMO: Switch on the SUN!

Temperature at surface = 5800 K => yellow (Wien's Law)

Temperature at center = 15,000,000 K

Average density = 1.4 g/cm$^3$

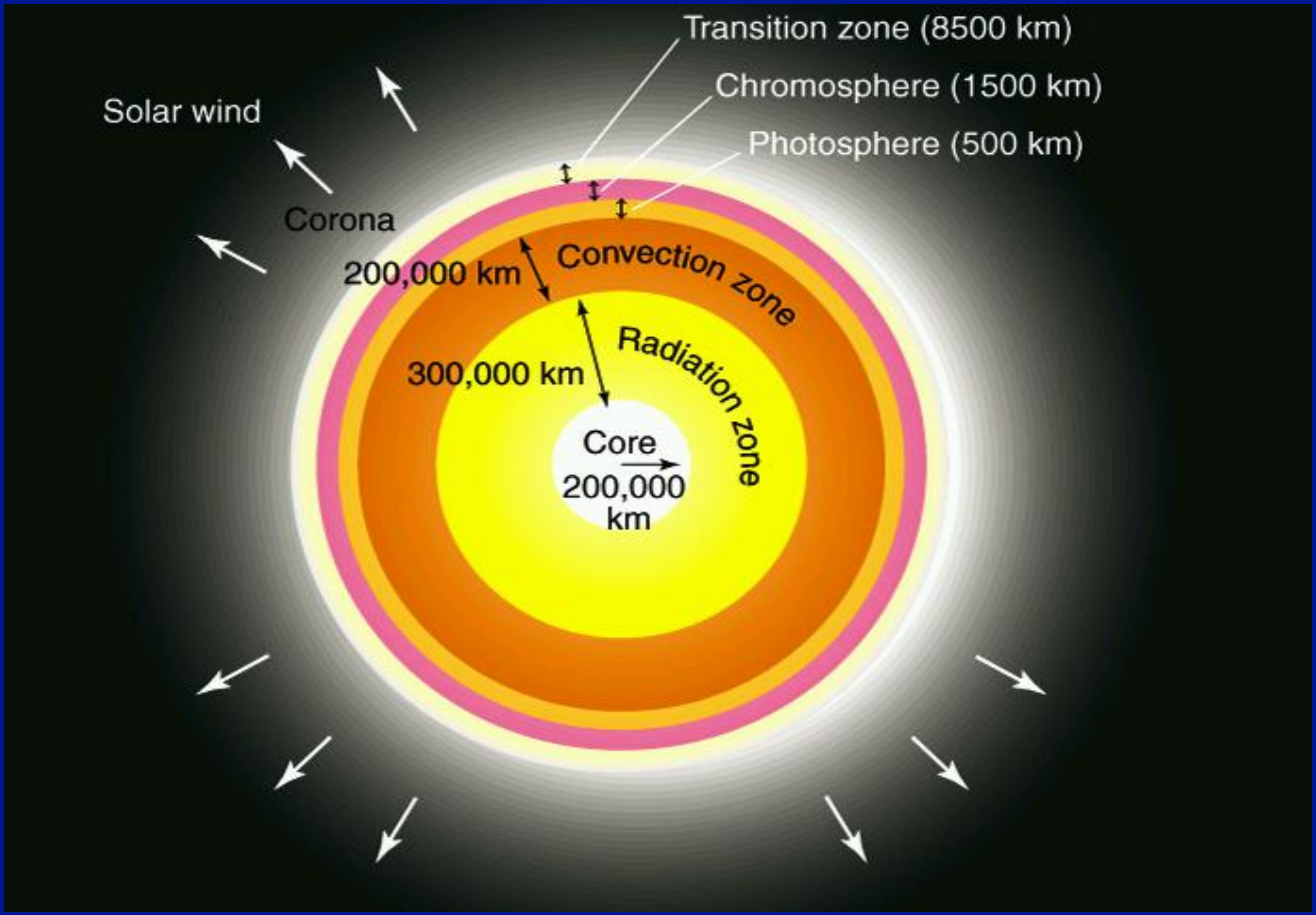
Density at center = 160 g/cm$^3$

Composition: 71% of mass is H
27% He
1% Oxygen
1% everything else

Rotation period = 27 days at equator
31 days at poles

Sun during solar eclipse Jan 2011

# The Interior Structure of the Sun
(not to scale)

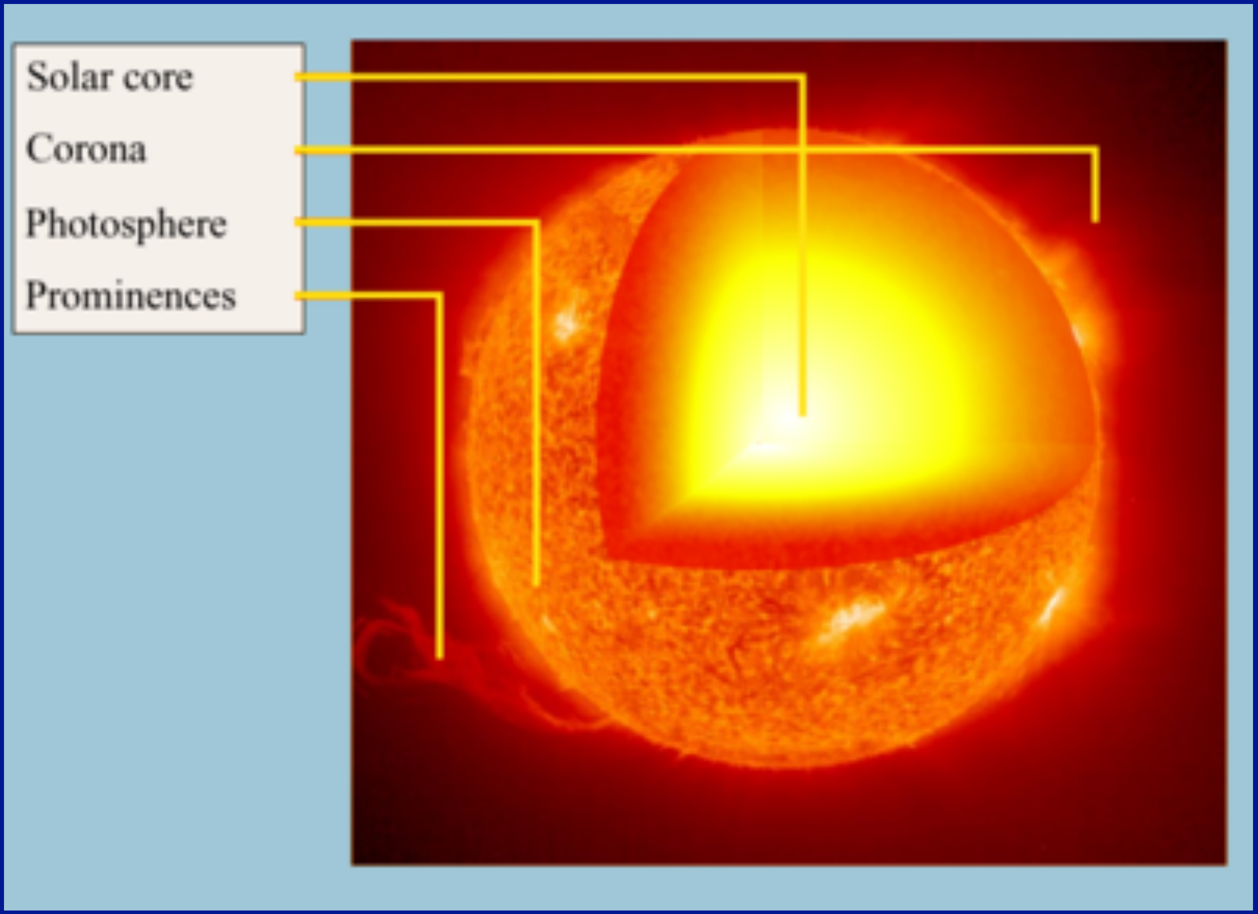



Let's focus on the core, where the Sun's energy is generated.

# Core of the Sun

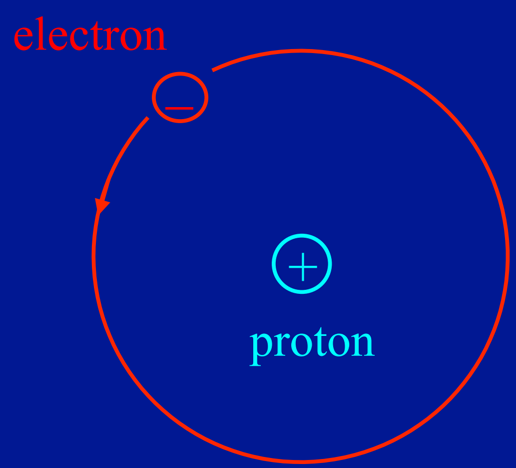
Temperature : 15 million K ($1.5 \times 10^7$ K)

Density: 160 gm/cm$^3$, 160 times that of water, 10 times the density of lead



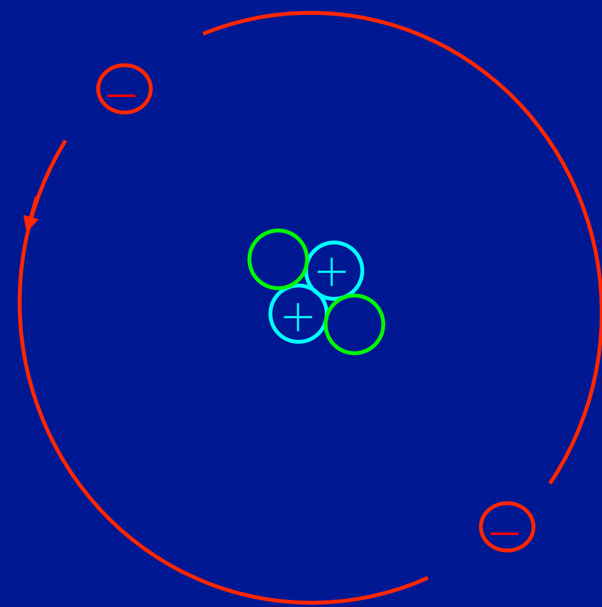
# Review of Atoms and Nuclei

Hydrogen atom:




The proton is the nucleus

Helium atom:



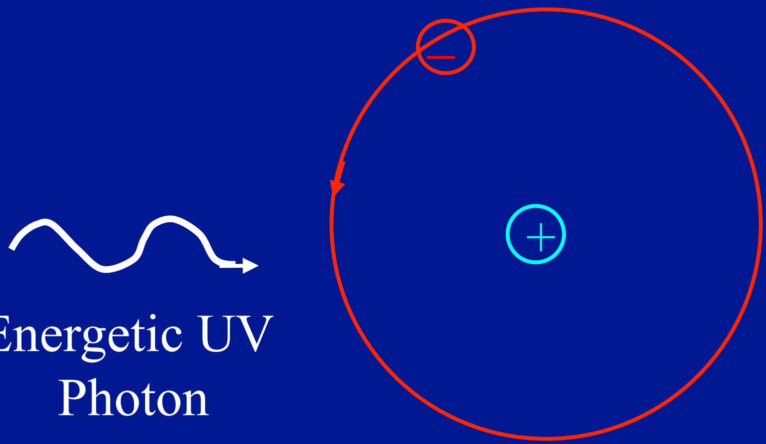
The nucleus is 2 protons +
2 neutrons

What binds the nuclear particles? The “strong” nuclear force.

Number of protons uniquely identifies element. Isotopes differ in number of neutrons.

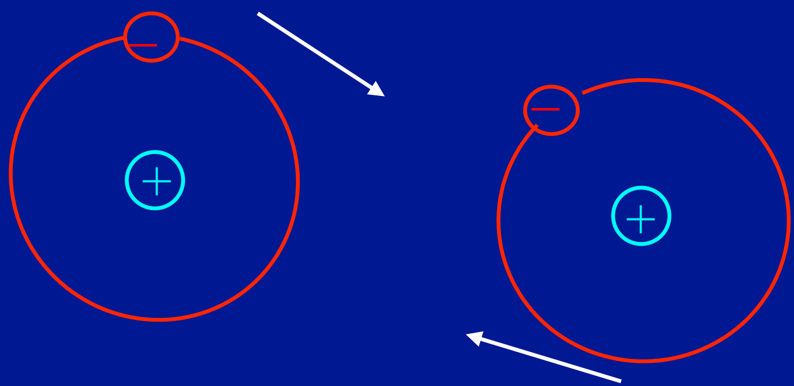
# Review of Ionization

## Radiative ionization of H



Energetic UV
Photon

## "Collisional Ionization" of H



# Clicker Question:

In overall composition the Sun is most like what planet?

A: Mercury

B: Venus

C: Earth

D: Jupiter

# Clicker Question:

What is an ion?

A:  an atom (or molecule) with a net charge.

B:  Another name for a proton

C:  An anti-electron

D:  A charged neutron

# Clicker Question:

What happens when 4 H atoms (protons) are combined into a single He atom?

A: Energy is absorbed, cooling the sun

B:  Energy is released, heating the sun

C:  No energy is produced, only neutrinos

D:  The sun becomes more negatively charged

# What Powers the Sun

Nuclear Fusion: An event where nuclei of two atoms join together.

Need high temperatures.

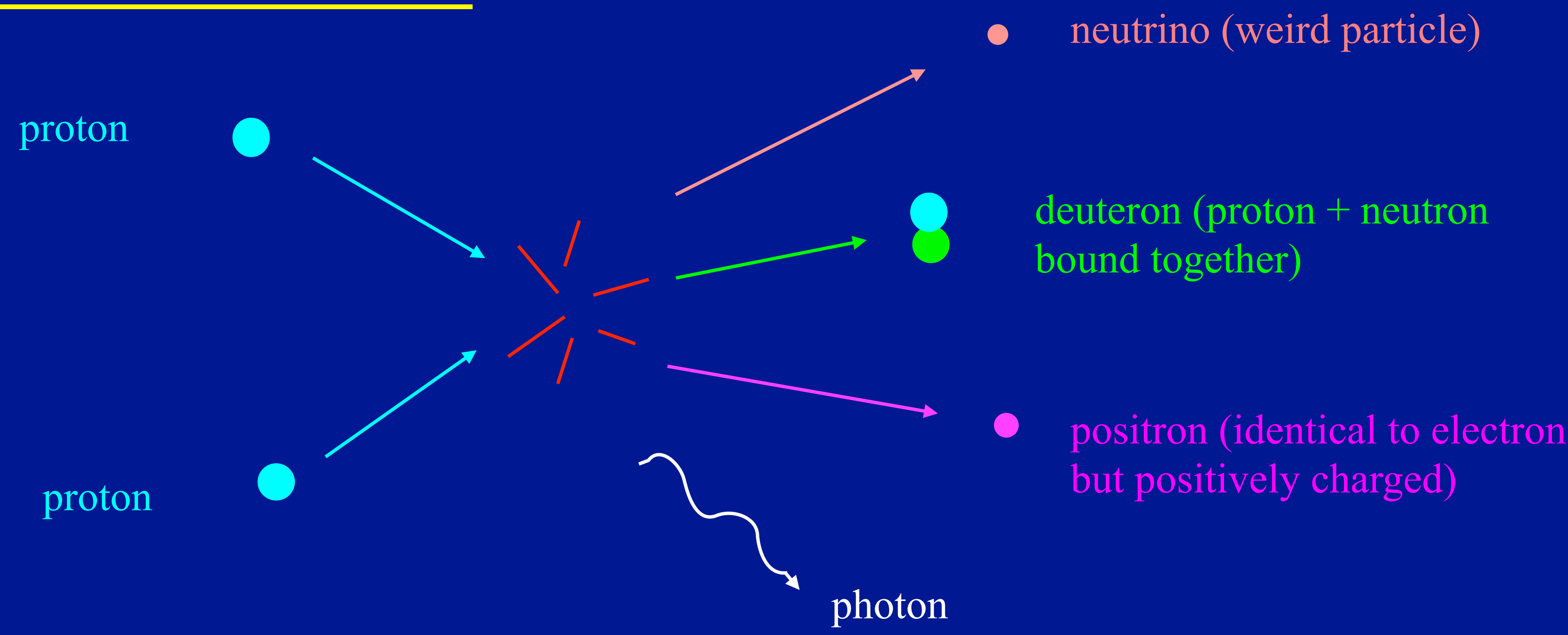
Energy is produced.

nuc. 1 + nuc. 2 $\rightarrow$ nuc. 3 + energy (radiation)

Mass of nuc. 3 is slightly less than mass of (nuc. 1 + nuc. 2). The lost mass is converted to energy. Why? Einstein's conservation of mass and energy, $E = mc^2$. Sum of mass and energy always conserved in reactions. Fusion reactions power stars.

Chain of nuclear reactions called "proton-proton chain" or p-p chain occurs in Sun's core, and powers the Sun.

# In the Sun's Core...




**1)** proton + proton → $\underbrace{\text{proton+neutron}}$ + neutrino + positron

(deuteron) (heavy hydrogen)

\+ energy (photon)

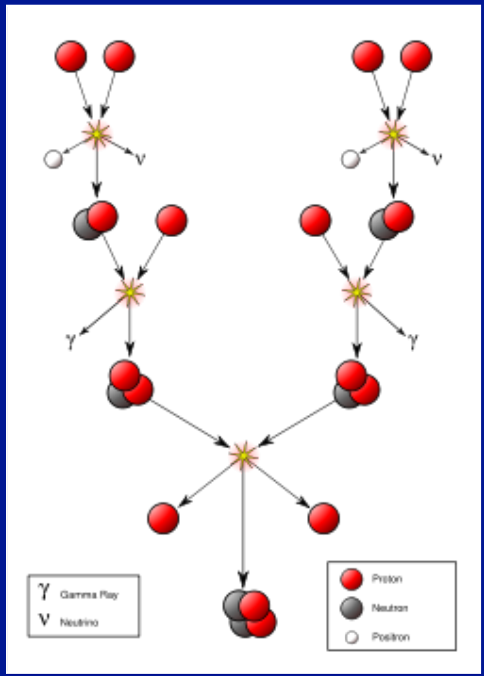
2) deuteron + proton $\rightarrow$ $^3$He + energy

He nucleus, only 1 neutron

3) $^3$He + $^3$He $\rightarrow$ $^4$He + proton + proton + energy

Net result:

4 protons $\rightarrow$ $^4$He + 2 neutrinos + energy




Mass of end products is less than mass of 4 protons by 0.7%. Mass converted to energy.

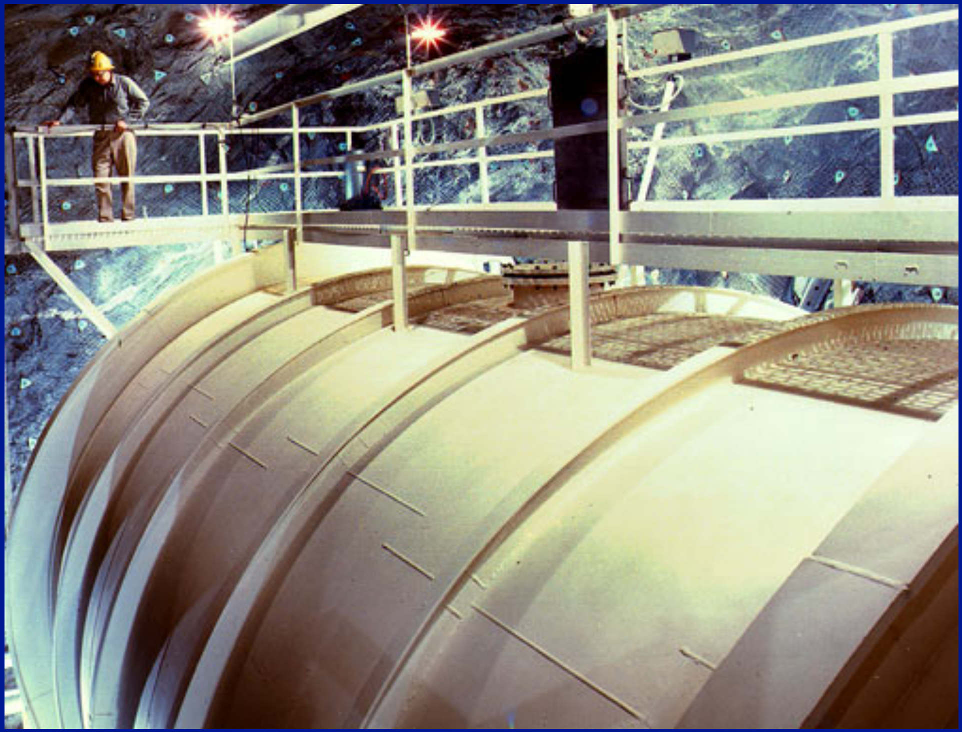
600 millions of tons per second fused. Takes <u>billions</u> of years to convert p's to $^4$He in Sun's core. Process sets <u>lifetime</u> of stars.

<u>Hydrostatic Equilibrium</u>: pressure from fusion reactions balances gravity. Sun is <u>stable</u>.

# Solar neutrino problem

In 1960s Ray Davis and John Bahcall measured the neutrino flux from the Sun and found it to be lower than expected (by 30-50%)

Confirmed in subsequent experiments
Theory of p-p fusion well understood
Solar interior well understood

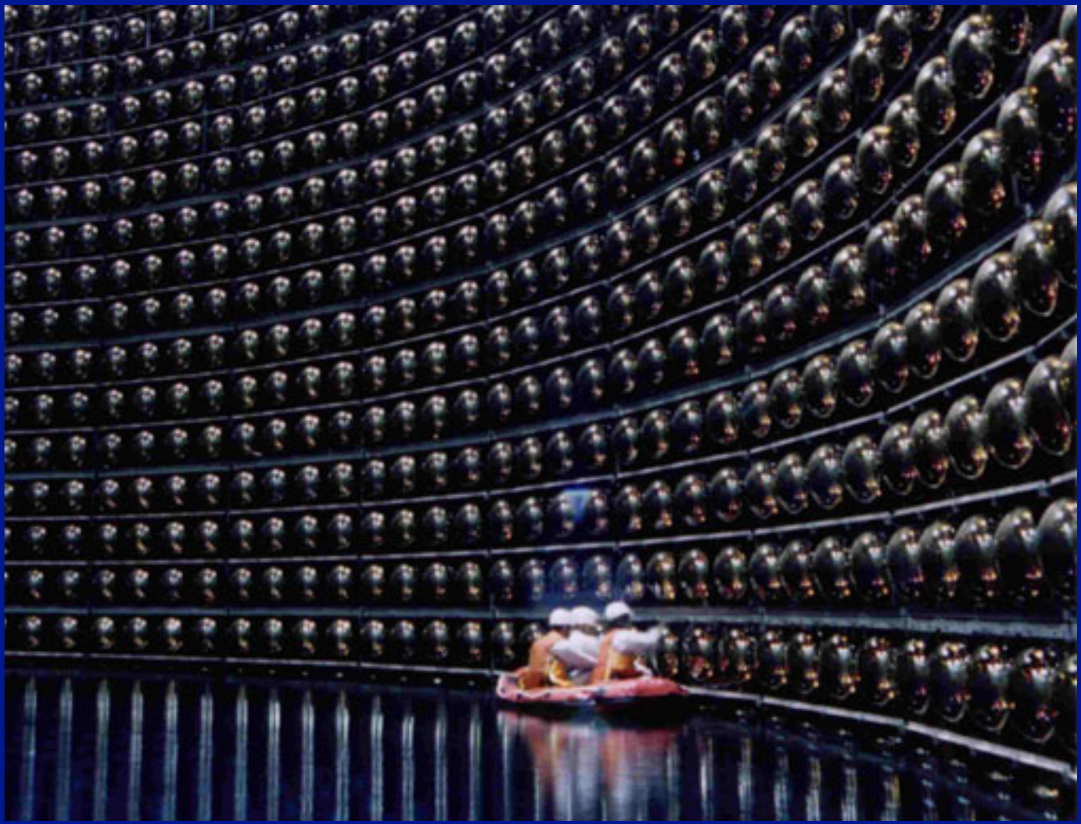


# Answer to the Solar neutrino problem

Theoriticians like Bruno Pontecorvo realized

- There was more than one type of neutrino
- Neutrinos could change from one type to another

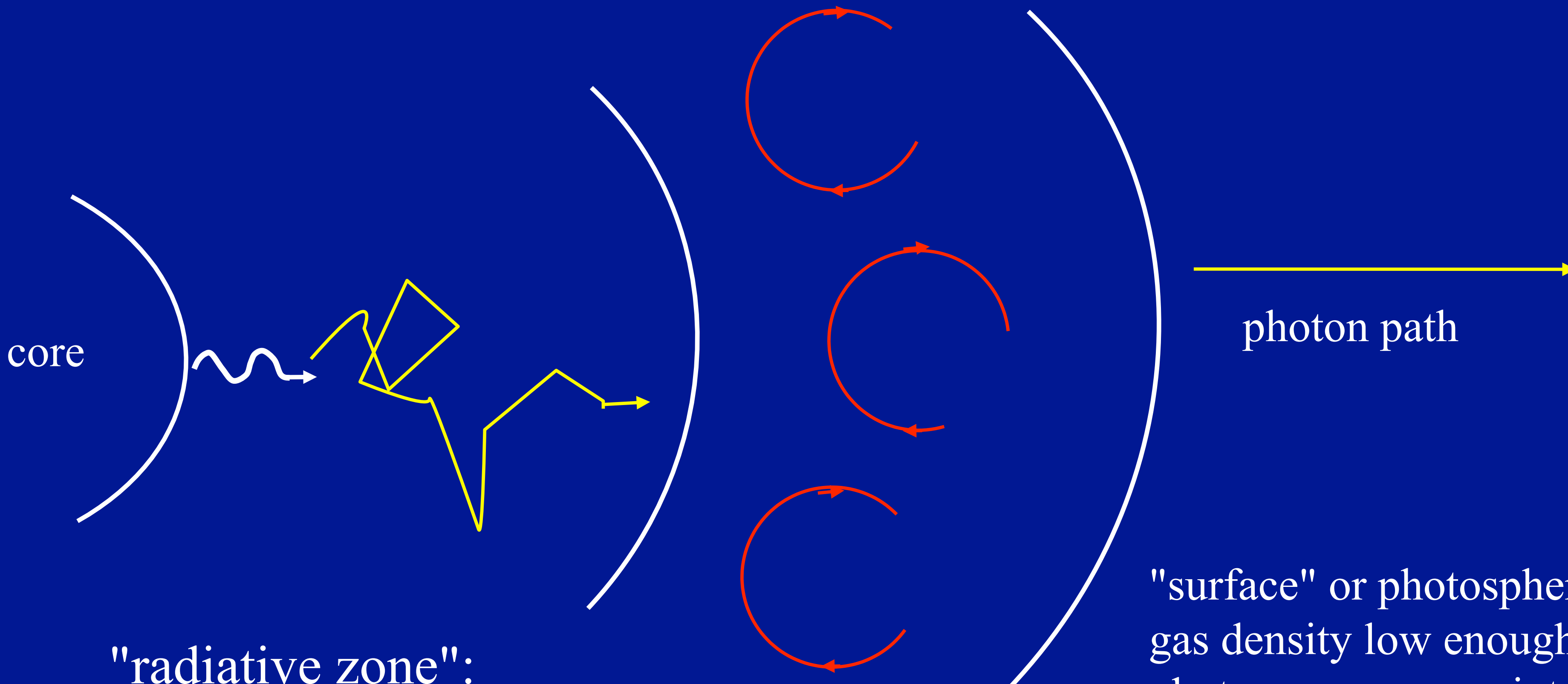
Confirmed by Super-Kamiokande experiment in Japan in 1998



50,000 gallon tank

Total number of neutrinos agrees with predictions

# How does energy get from core to surface?




"surface" or photosphere: gas density low enough so photons can escape into space.

"radiative zone":

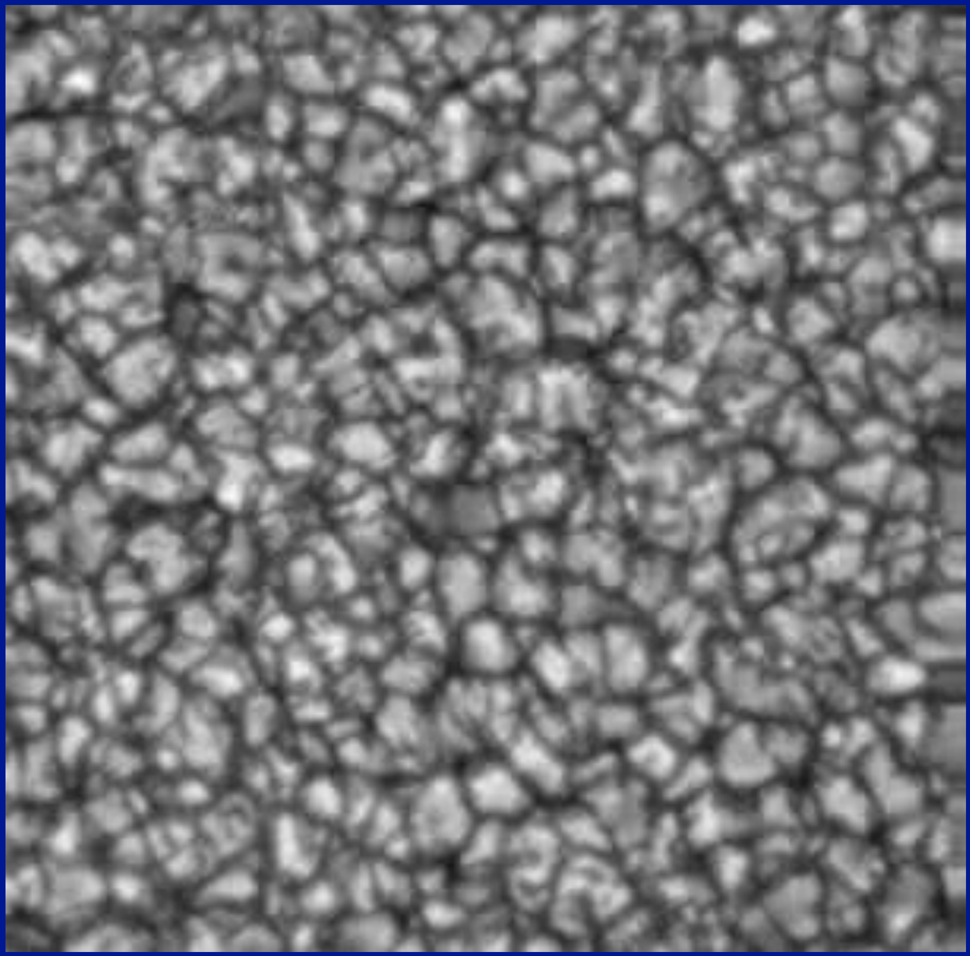
photons scatter off nuclei and electrons, slowly drift outwards: "diffusion".

"convection zone"

some electrons bound to nuclei
=> radiation can't get through
=> heats gas, hot gas rises,
cool gas falls

Can see rising and falling convection cells => granulation. Bright granules hotter and rising, dark ones cooler and falling. (Remember convection in Earth's atmosphere, interior and Jupiter).

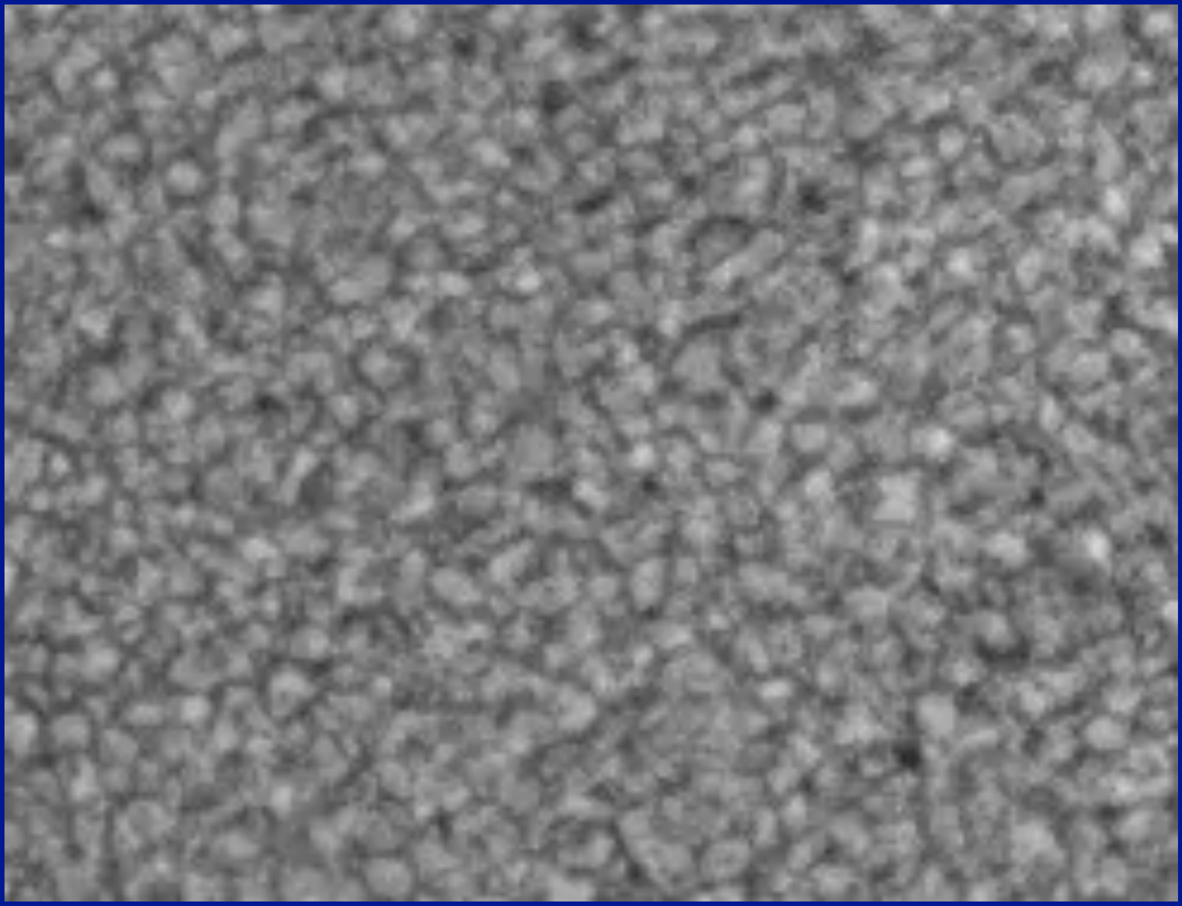
Granules about 1000 km across



Why are cooler granules dark? Stefan's Law: brightness $\alpha$ $T^4$

Can see rising and falling convection cells => granulation.  Bright granules hotter and rising, dark ones cooler and falling.  (Remember convection in Earth's atmosphere, interior and Jupiter).

Granules about 1000 km across



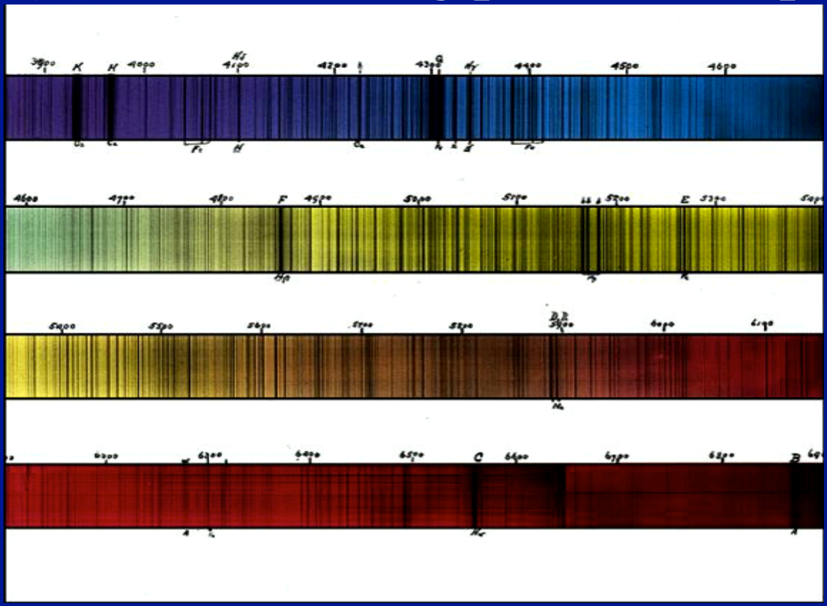
Why are cooler granules dark?  Stefan's Law:  brightness $\alpha$ $T^4$

# The (Visible) Solar Spectrum

Spectrum of the Sun shows:

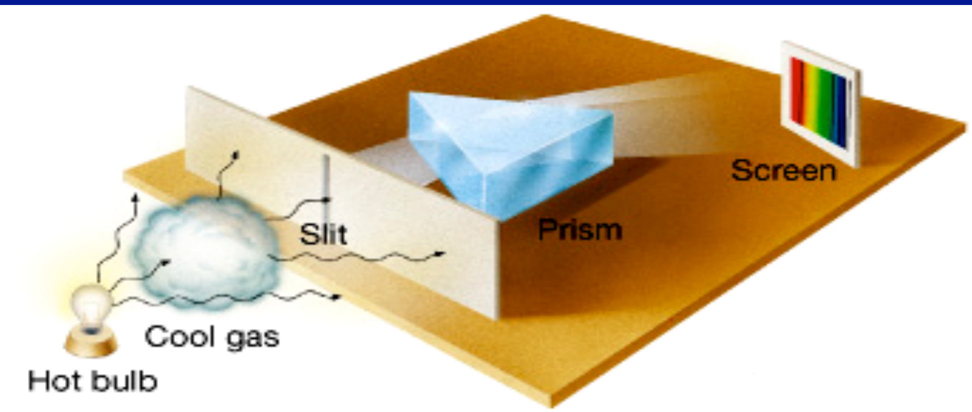
1) The Black-body radiation

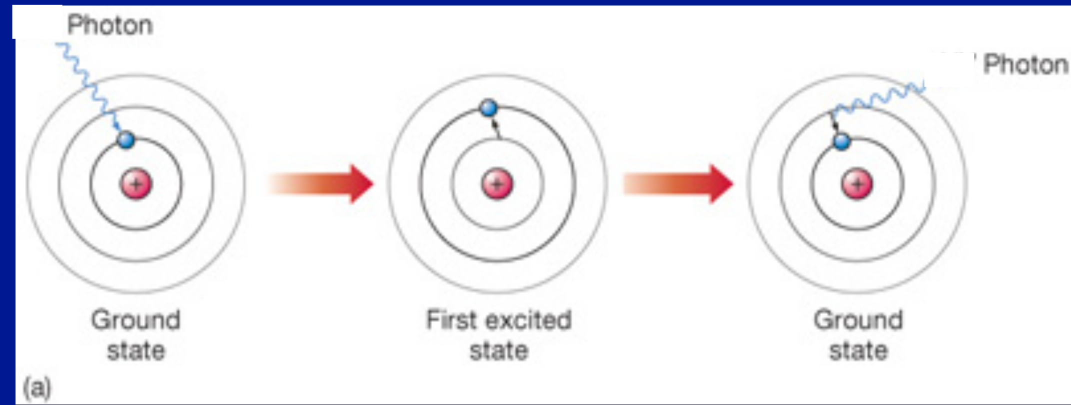
2) Absorption lines (atoms absorbing photons at specific wavelengths).



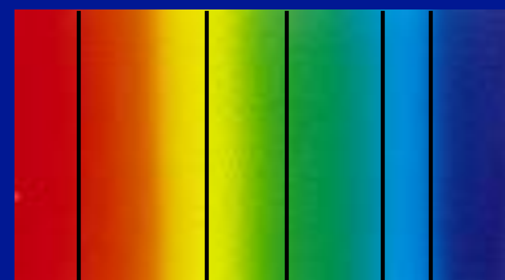
10,000's of lines from 67 elements, in various excited or ionized states.

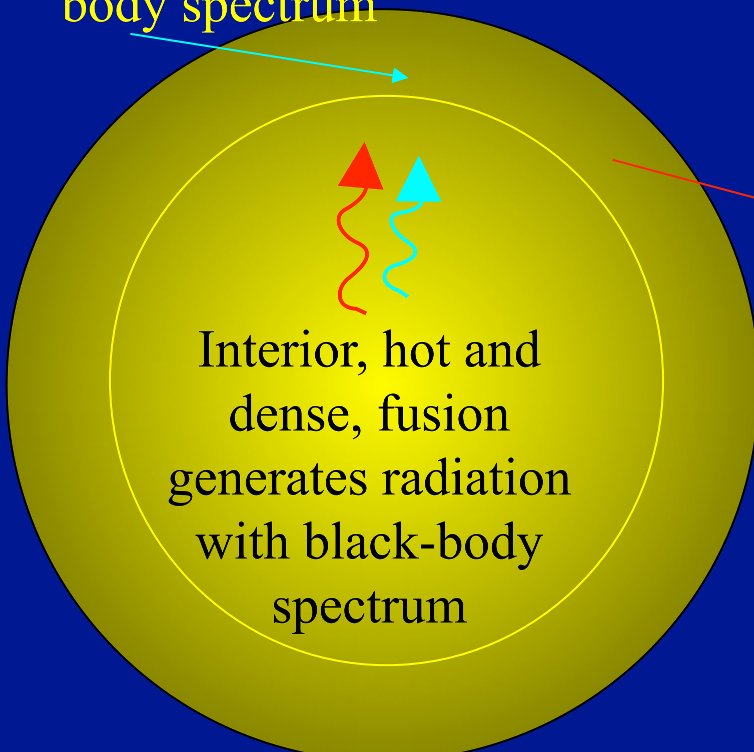
Again, this radiation comes from photosphere, the visible surface of the Sun. Elements weren't made in Sun, but in previous stellar generations



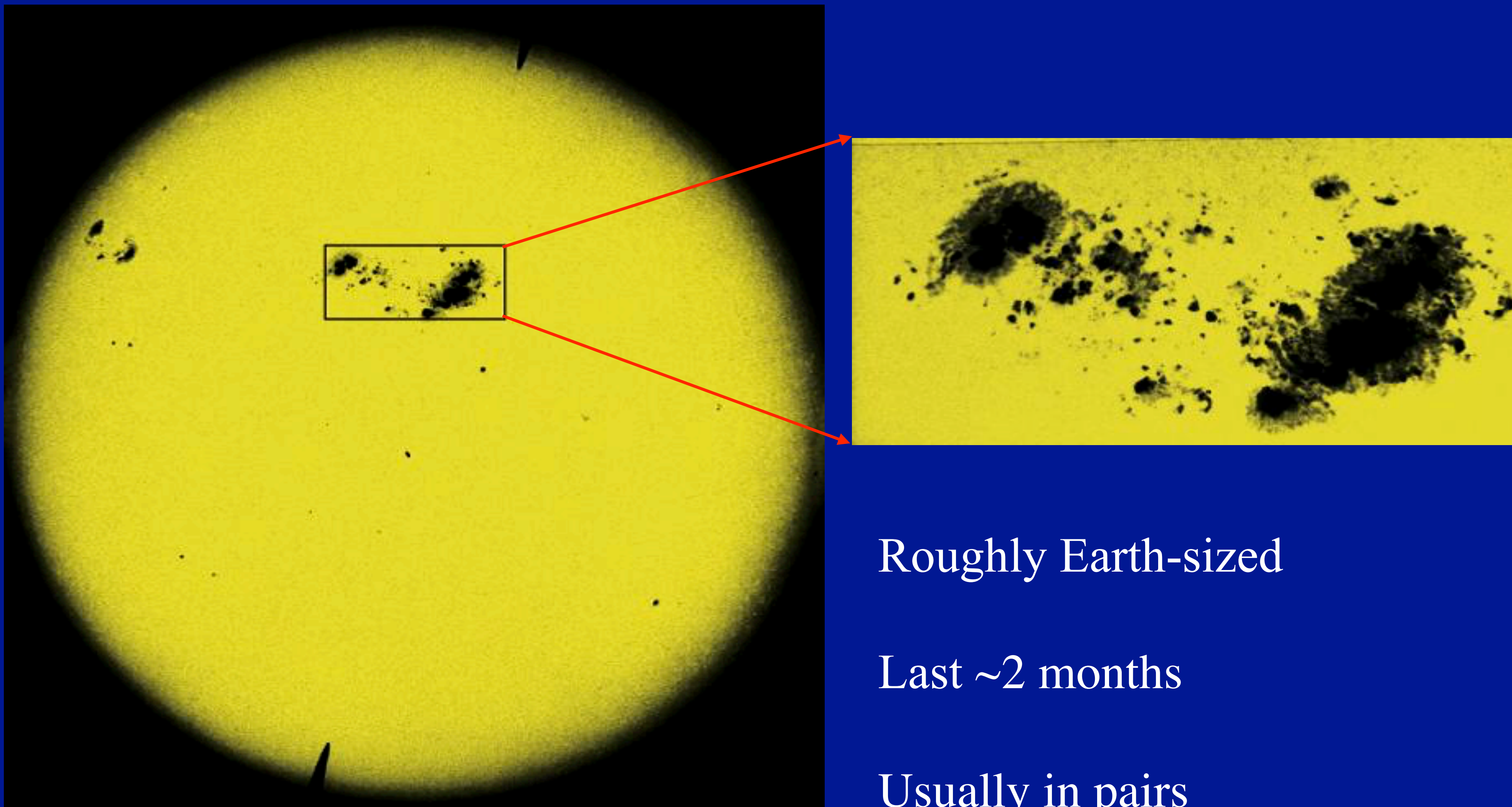

'Atmosphere', atoms and ions absorb specific wavelengths of the black-body spectrum






Star

# Sunspots

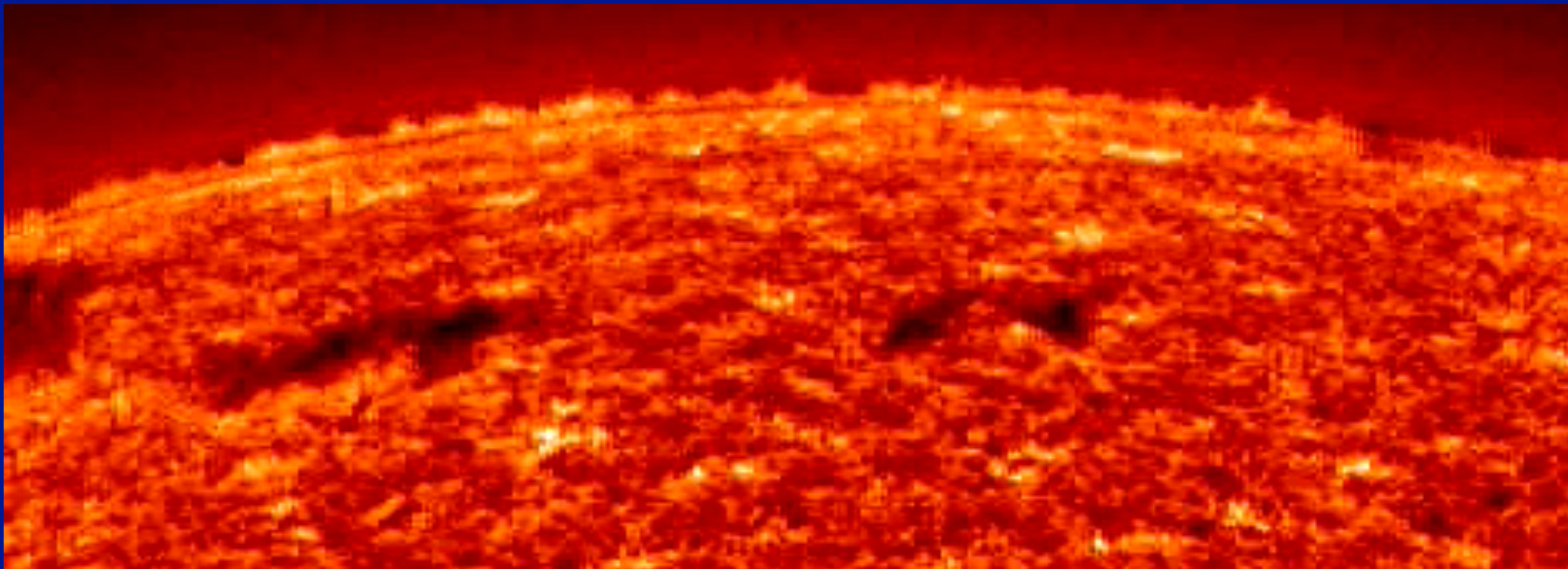


Roughly Earth-sized

Last ~2 months

Usually in pairs

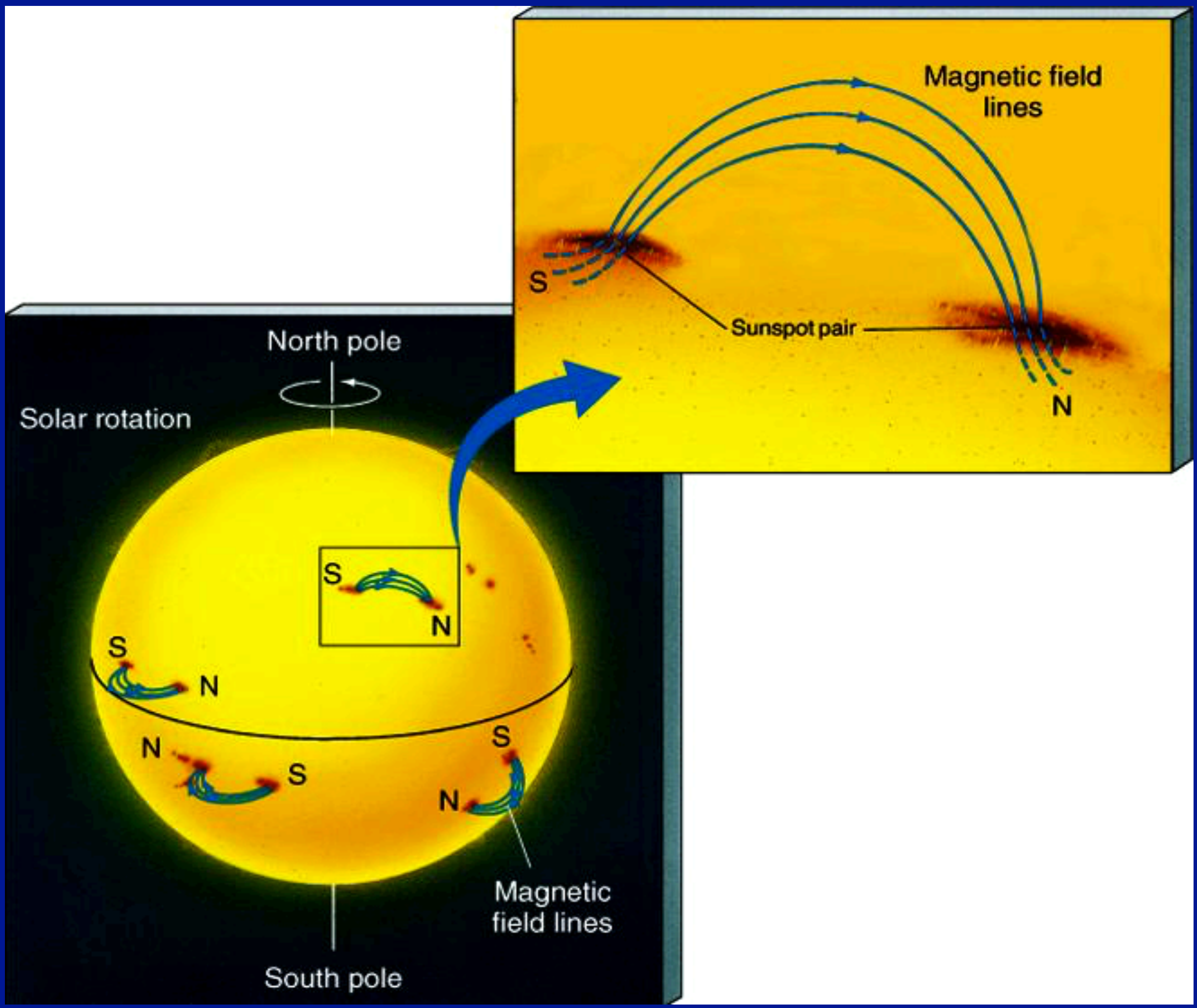
Follow solar rotation

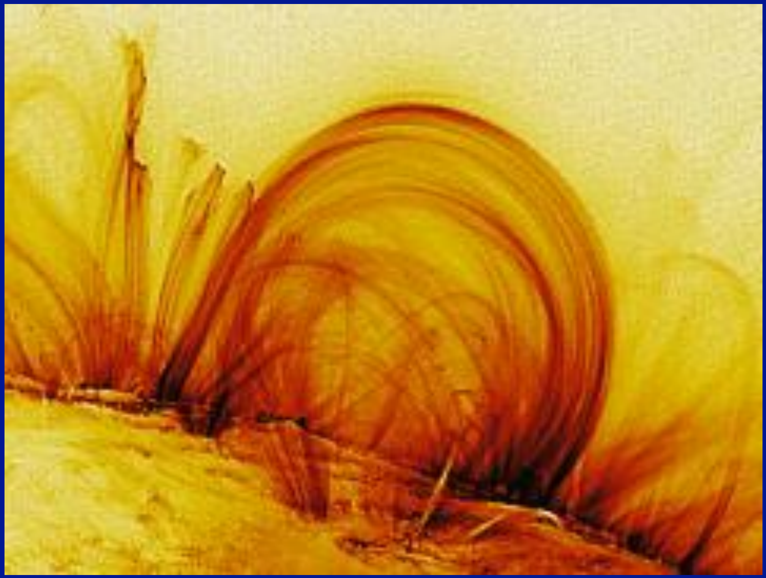


# Sunspots

They are darker because they are cooler (4500 K vs. 5800 K).

Related to loops of the Sun's magnetic field.

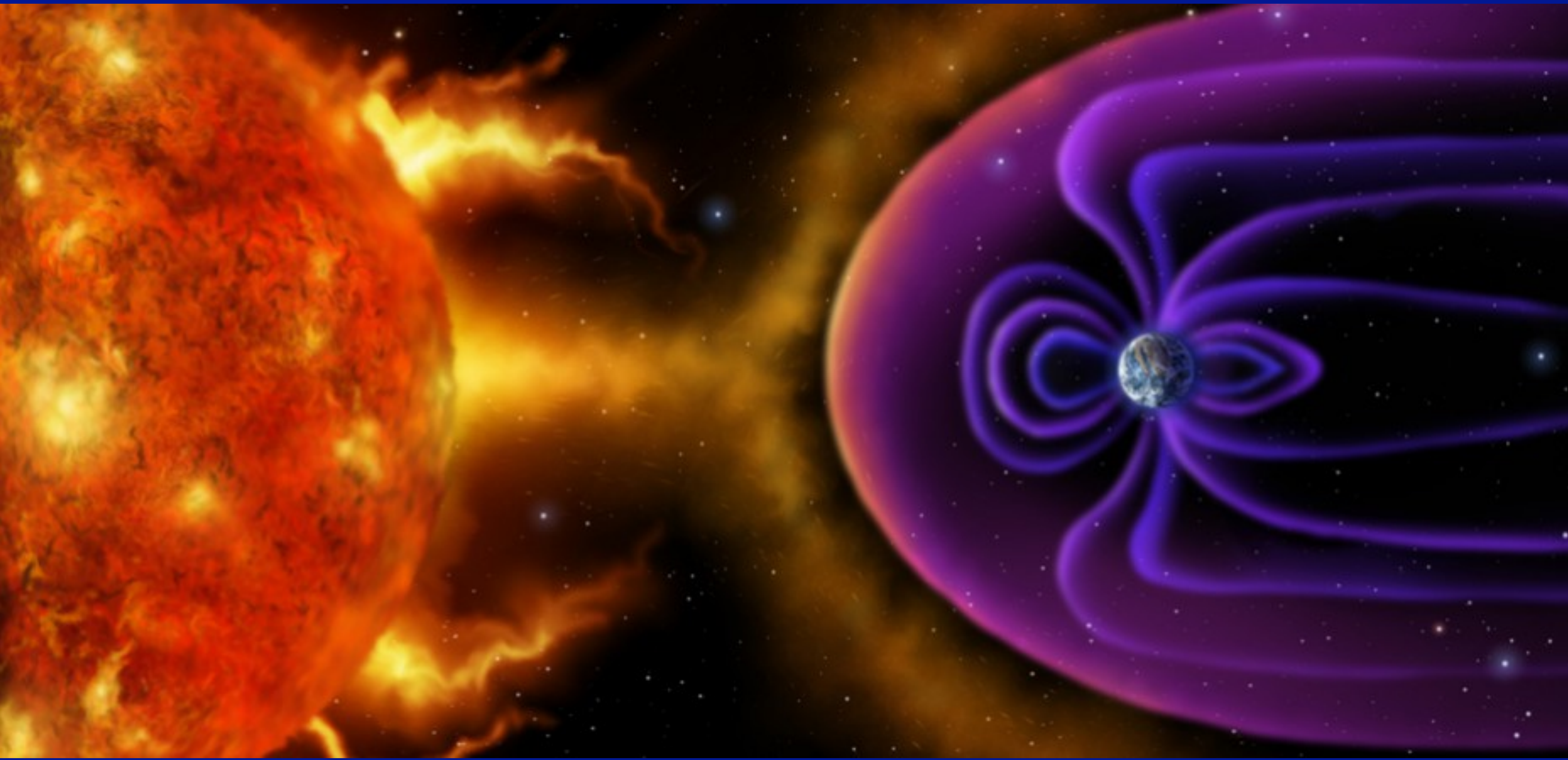


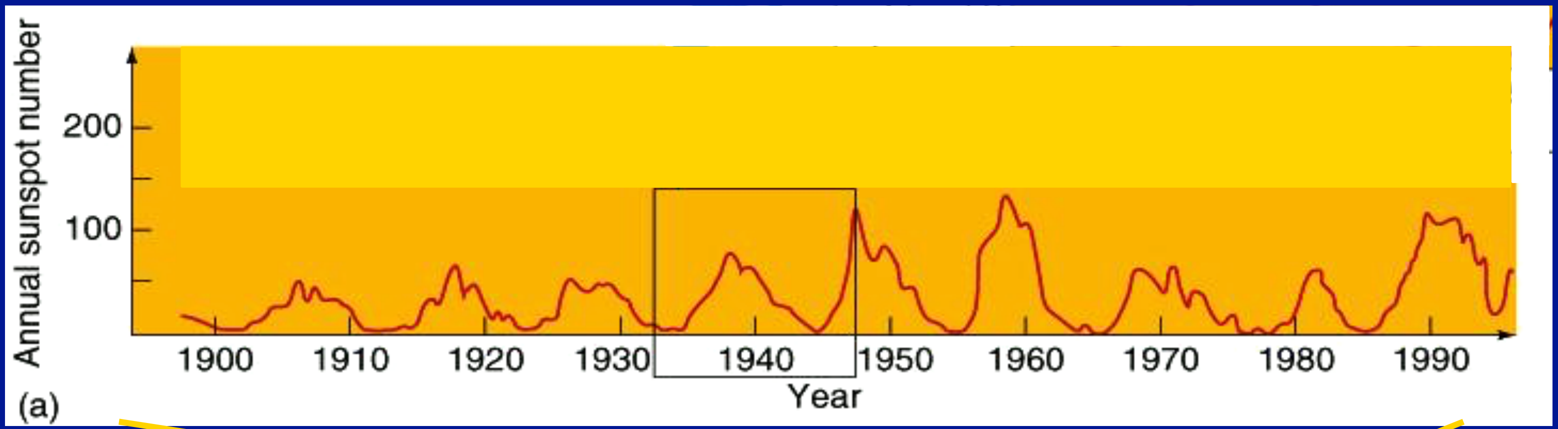
radiation from hot gas flowing along magnetic field loop at limb of Sun.

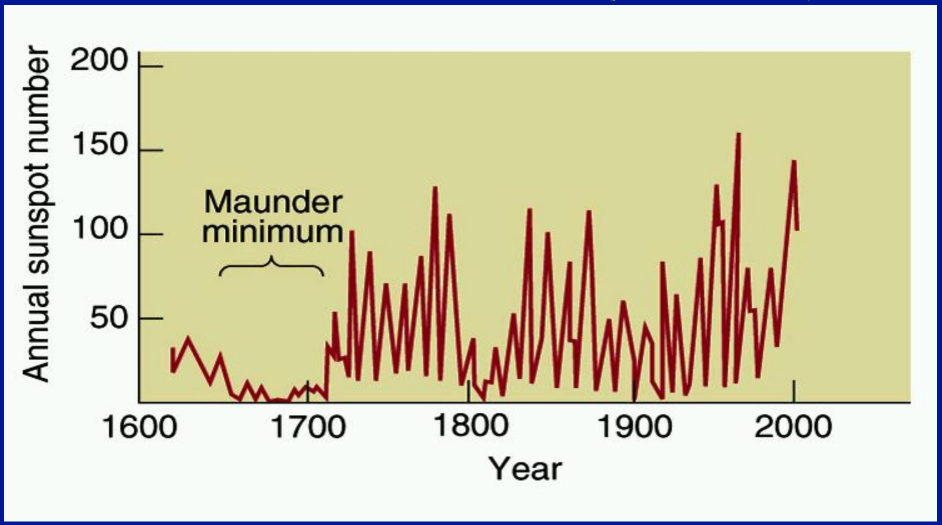
# Filament Ejection Movie

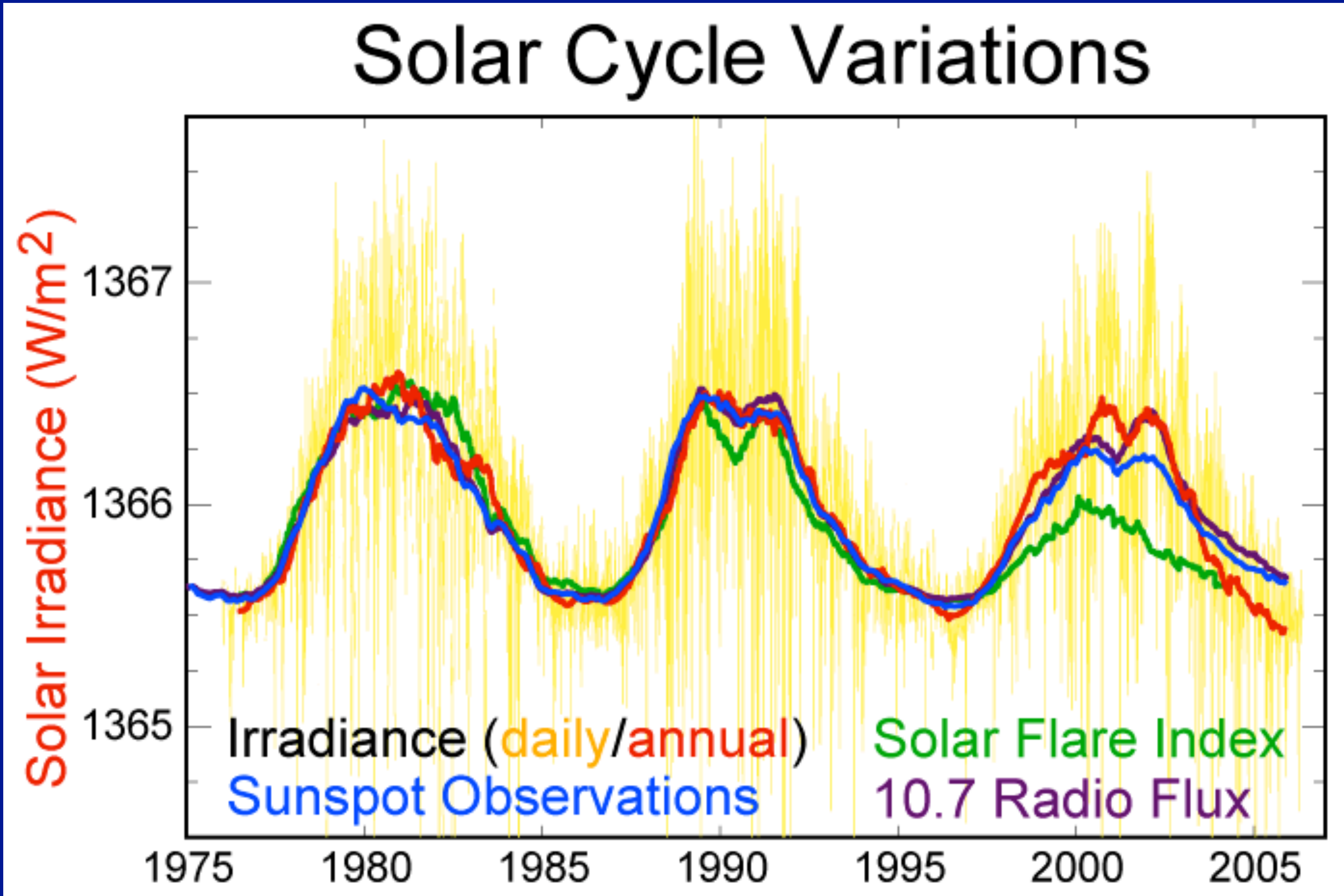
# Solar Storms!



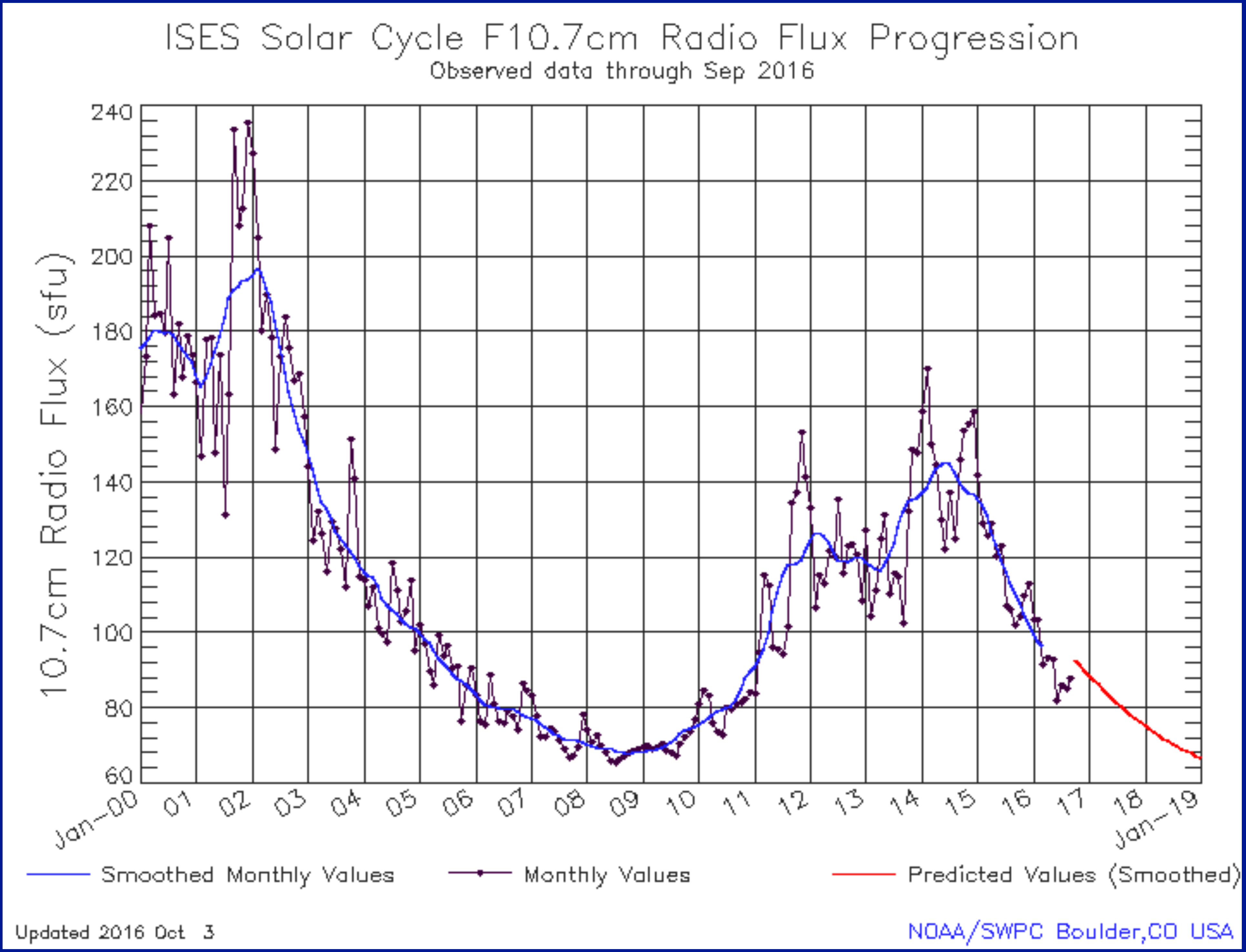
Sunspot numbers vary on a 11 year cycle.



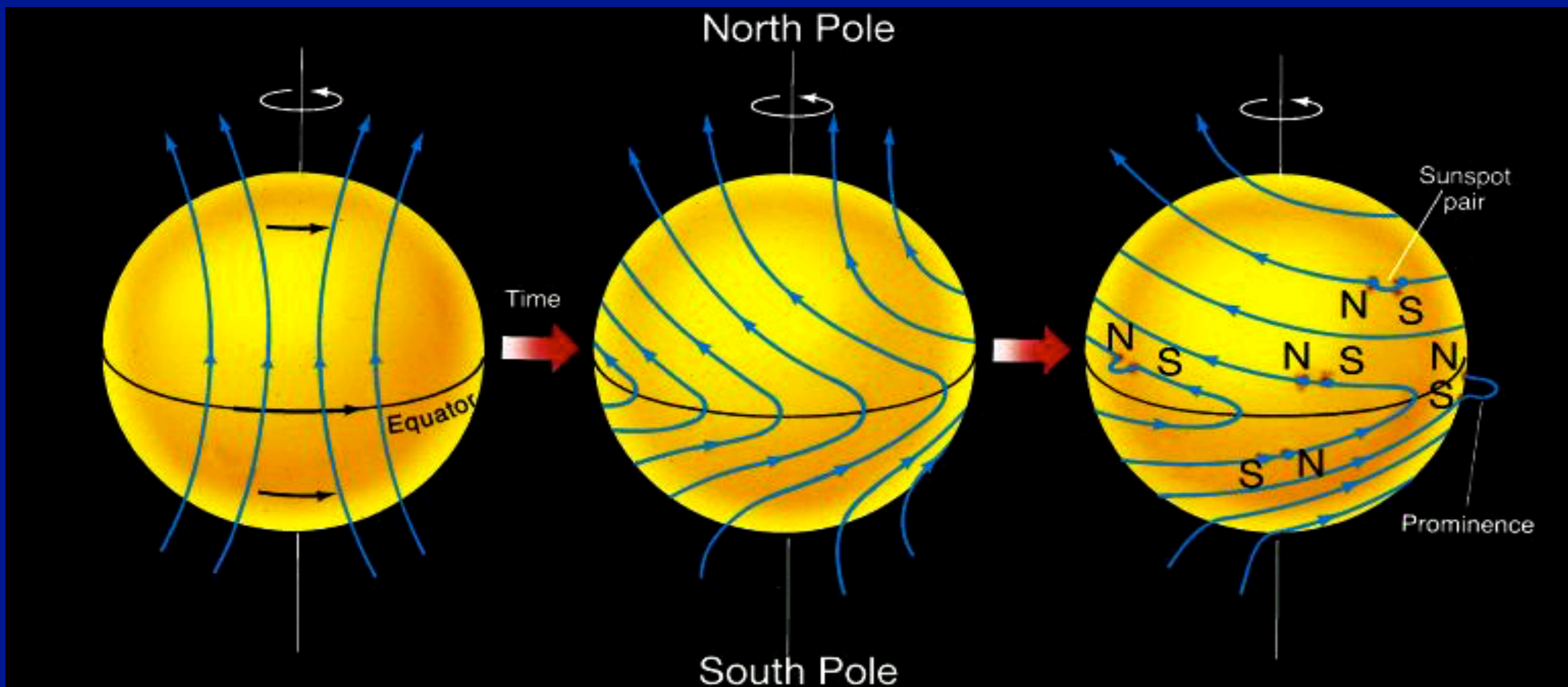



0.1% variation from maximum to minimum



ISES Solar Cycle F10.7cm Radio Flux Progression
Observed data through Sep 2016
10.7cm Radio Flux (sfu)
240
220
200
180
160
140
120
100
80
60
Jan-00
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
18
Jan-19
Smoothed Monthly Values
Monthly Values
Predicted Values (Smoothed)
Updated 2016 Oct 3
NOAA/SWPC Boulder,CO USA

Sun's magnetic field changes direction every 11 years. Maximum sunspot activity occurs about halfway between reversals.



# Clicker Question:

What is the source of energy in the sun?

A: fusion of protons into heavier nuclei

B: burning of coal and other hydrocarbons

C: the slow gravitational collapse of the sun

D: nuclear fission of heavy nuclei into lighter elements

# Clicker Question:

What is a positron?

A: A positively charged neutrino

B: Another name for a proton

C: An anti-electron

D: A charged neutron

# Clicker Question:

Besides being darker relative to other parts of the photosphere, sunspots are characterized by what quality?

A: They rotate faster than adjacent regions

B: They have stronger magnetic fields than adjacent regions

C: They have much greater density than adjacent regions

D: They have much higher temperature than adjacent regions

Above the photosphere, there is the chromosphere and...

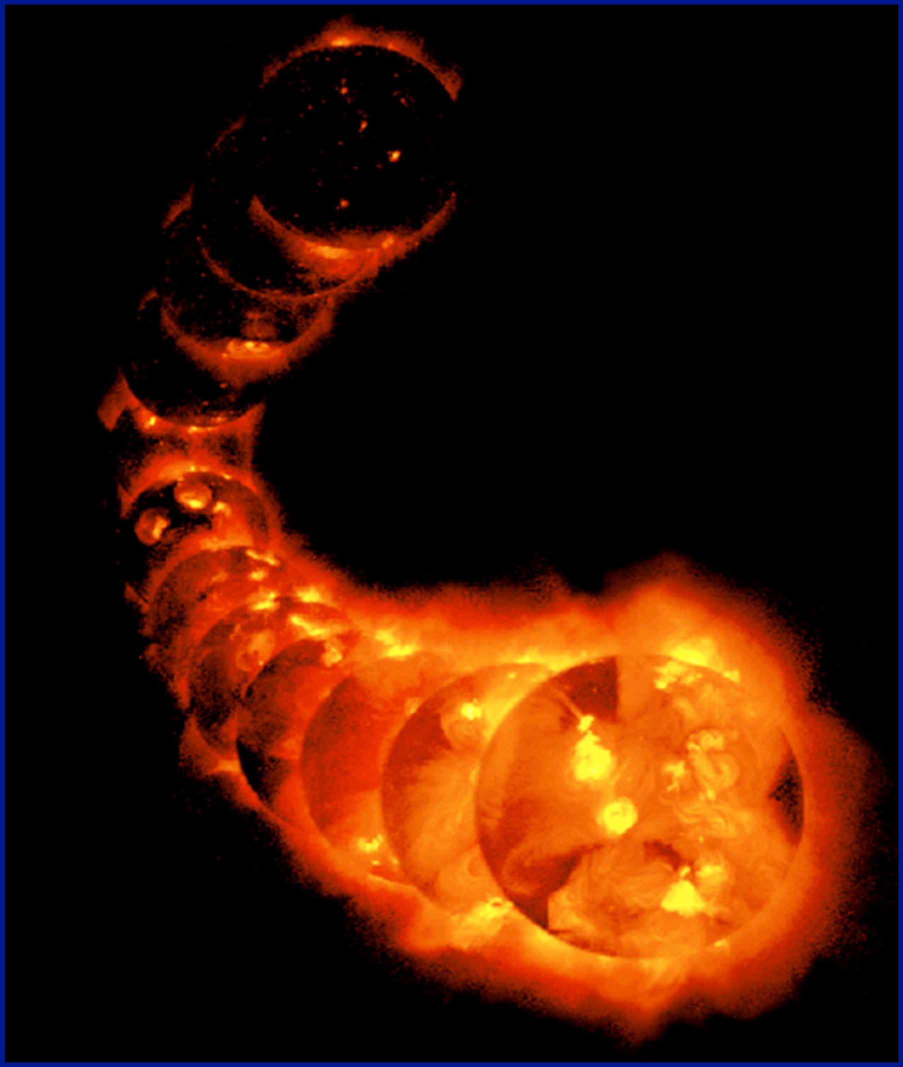
## The Corona

Best viewed during eclipses.

$T = 10^6$ K

Density = $10^{-15}$ g/cm$^3$ only!

We expect X-rays from gas at this temperature.



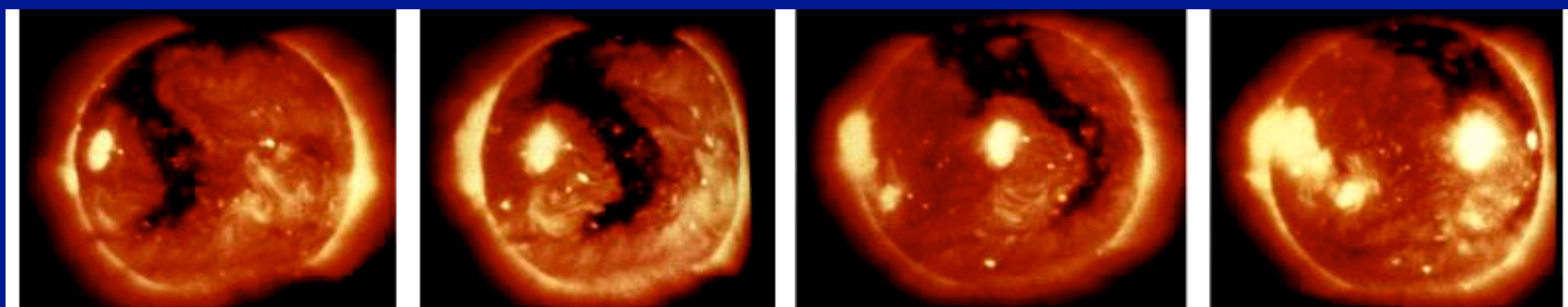
Yohkoh X-ray satellite

X-ray brightness varies over 11-year Solar Cycle: coronal activity and sunspot activity go together.

# The Solar Wind

At top of corona, typical gas speeds are close to escape speed => Sun losing gas in a solar wind.

Wind escapes from "coronal holes", seen in X-ray images.



Wind speed 500 km/sec (takes a few days to reach Earth).

$10^6$ tons/s lost.  But Sun has lost only 0.1% of its mass from solar wind.

# Space Weather

Today's forecast: solar wind velocity = 434 km/s

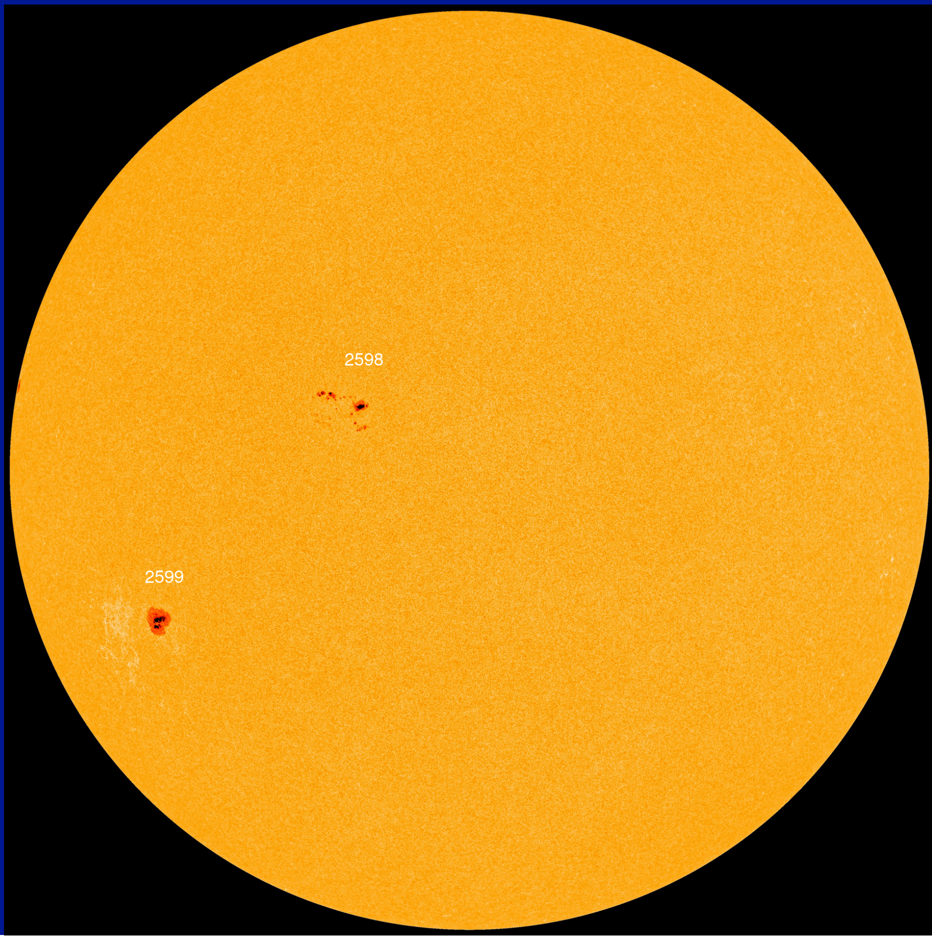
density = 4.3 protons/$cm^3$

Sunspot number: 38

days without a sunspot since: 0 day

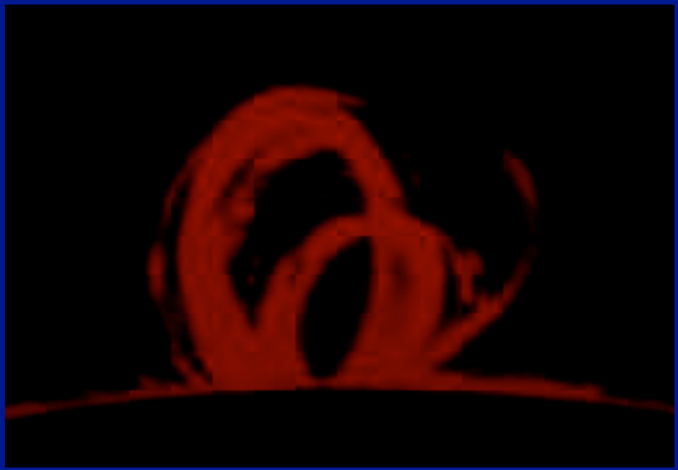
For update see www.spaceweather.com

List of recent and upcoming Near-miss encounters and space related news.

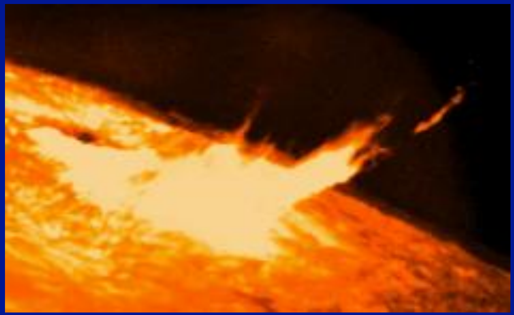


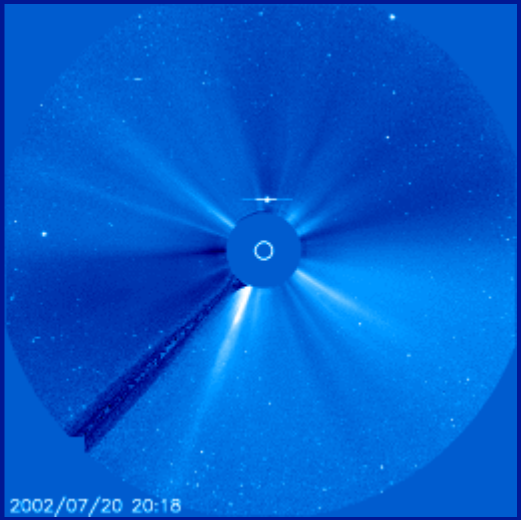
# Active Regions

Prominences: Loops of gas ejected from surface. Anchored in sunspot pairs. Last for hours to weeks.



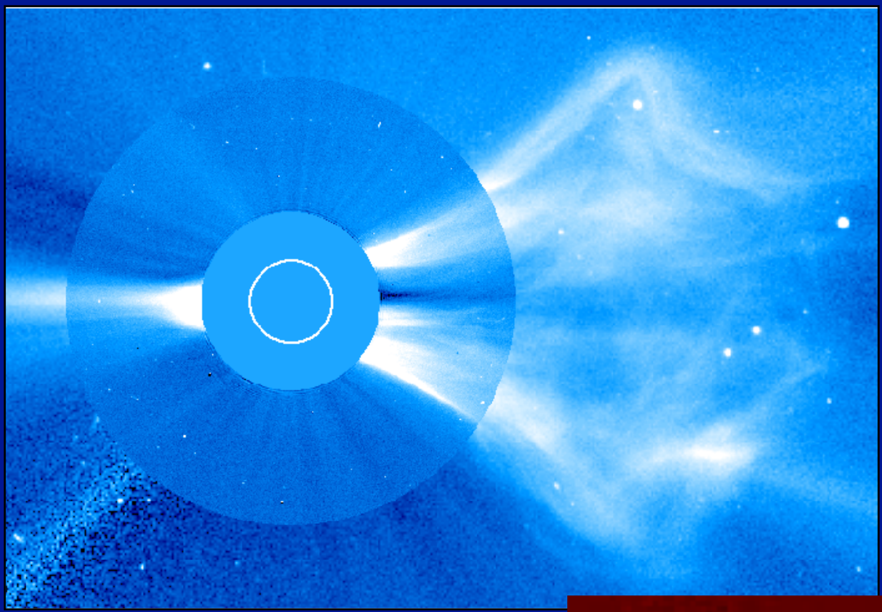
Flares: A more energetic eruption. Lasts for minutes. Less well understood.



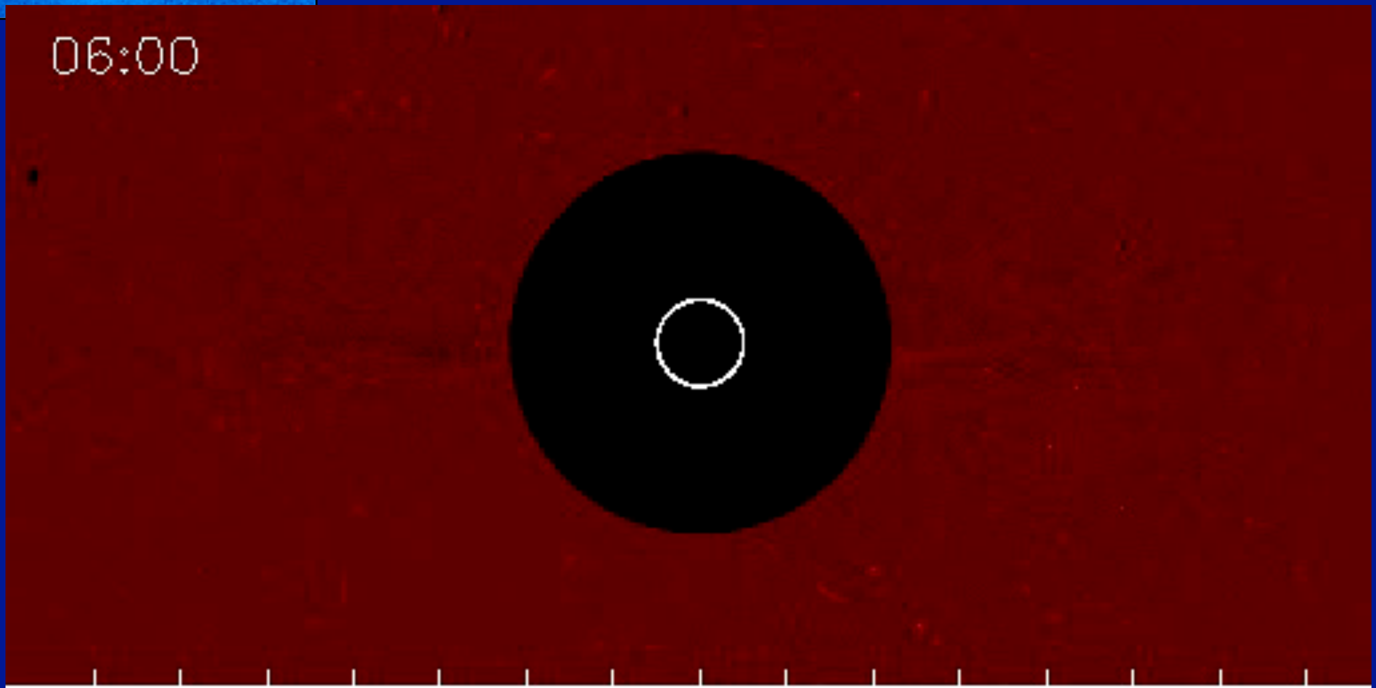



Prominences and flares occur most often at maximum of Solar Cycle.

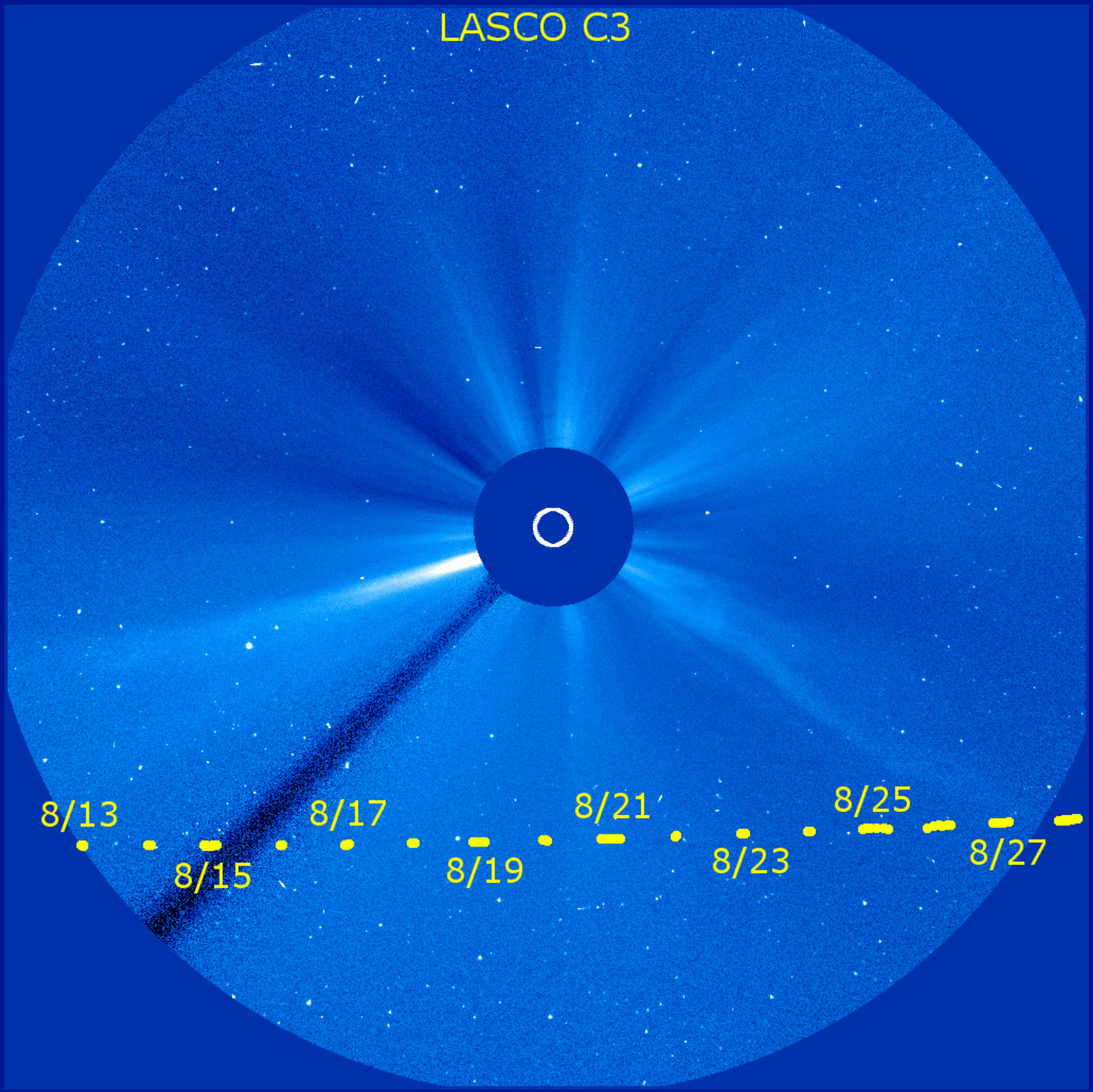
# Space weather and solar science



- Coronal Mass Ejections: solar science and ultimately predicting space weather



# Space weather and solar science




Coronal Mass Ejections:

Using a background pulsar to measure density and magnetic field of the sun and CME

# Solar Probe Plus in 2018

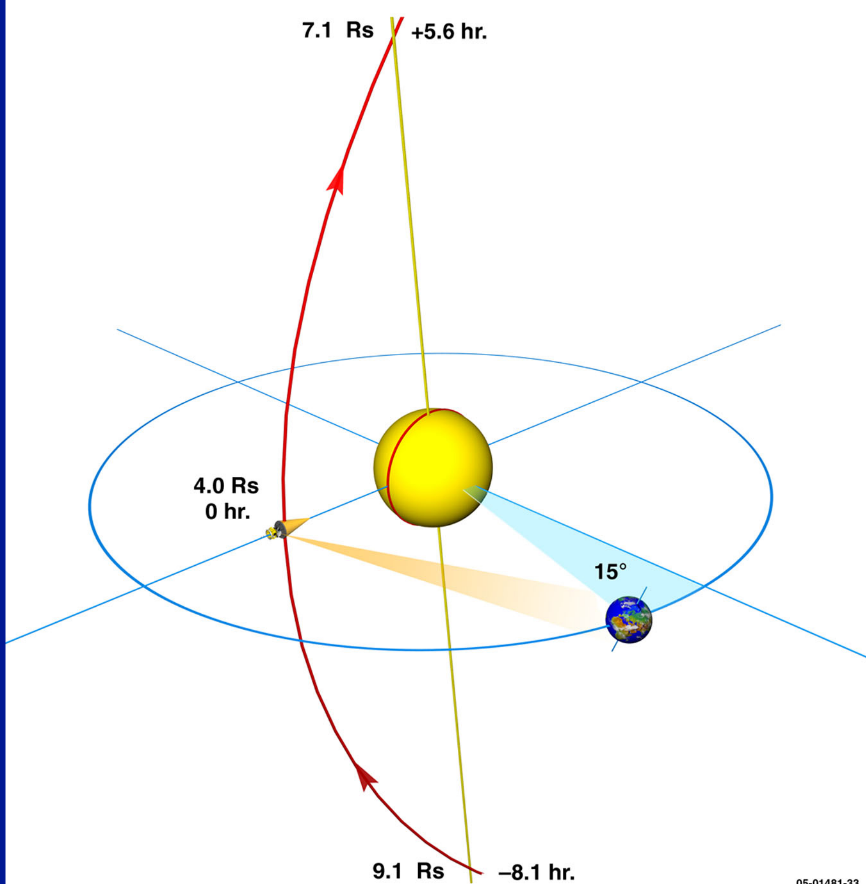



**Figure 4-3.** Geometry of the first solar encounter. Earth is positioned 15° off quadrature relative to the Sun–spacecraft line, allowing simultaneous observation from Earth of coronal features being sampled in situ by Solar Probe. The high-gain antenna points earthward, enabling real-time data transmission at a high data rate.