Astronomy 150: Killer Skies
Lecture 18, March 1

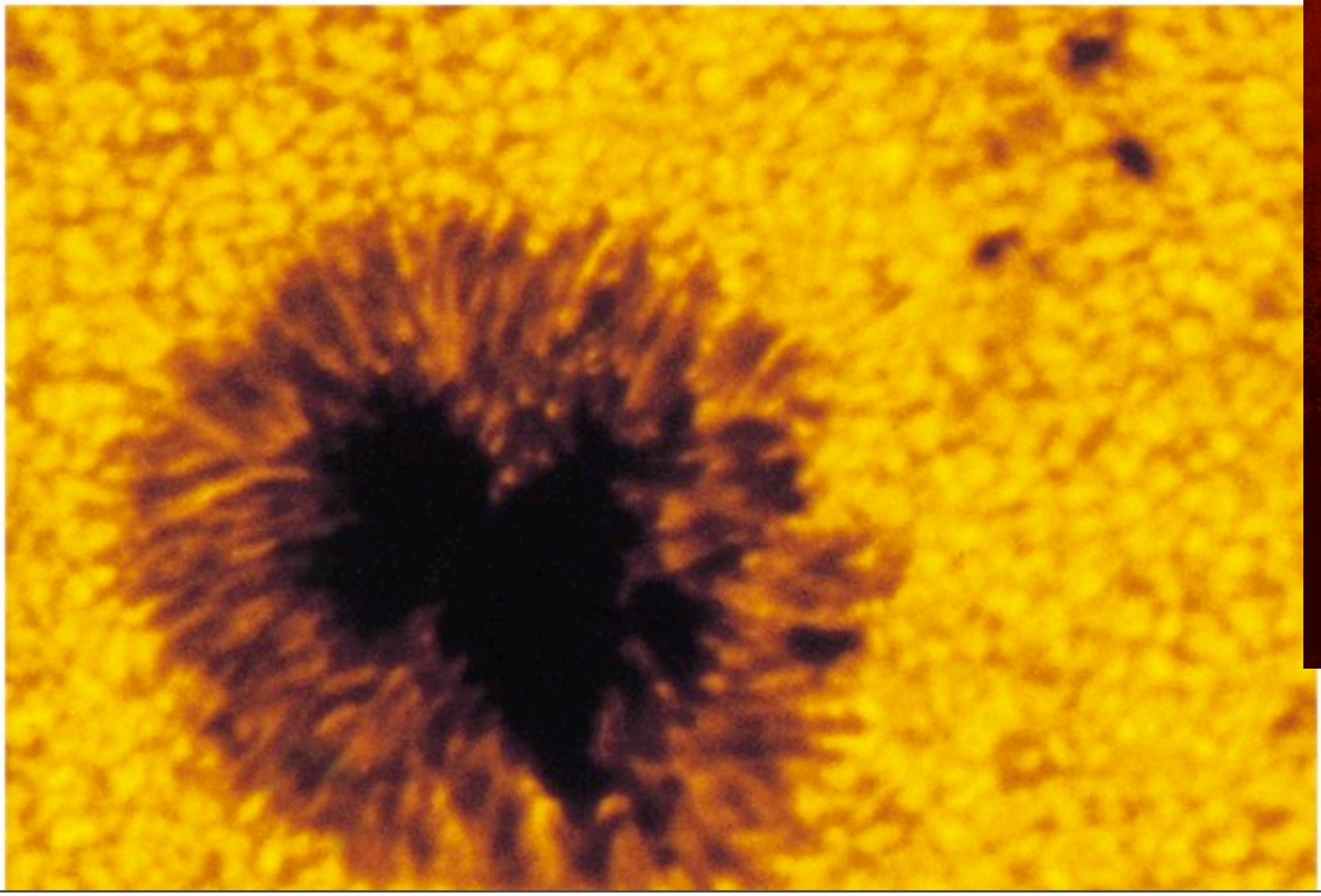
Assignments:

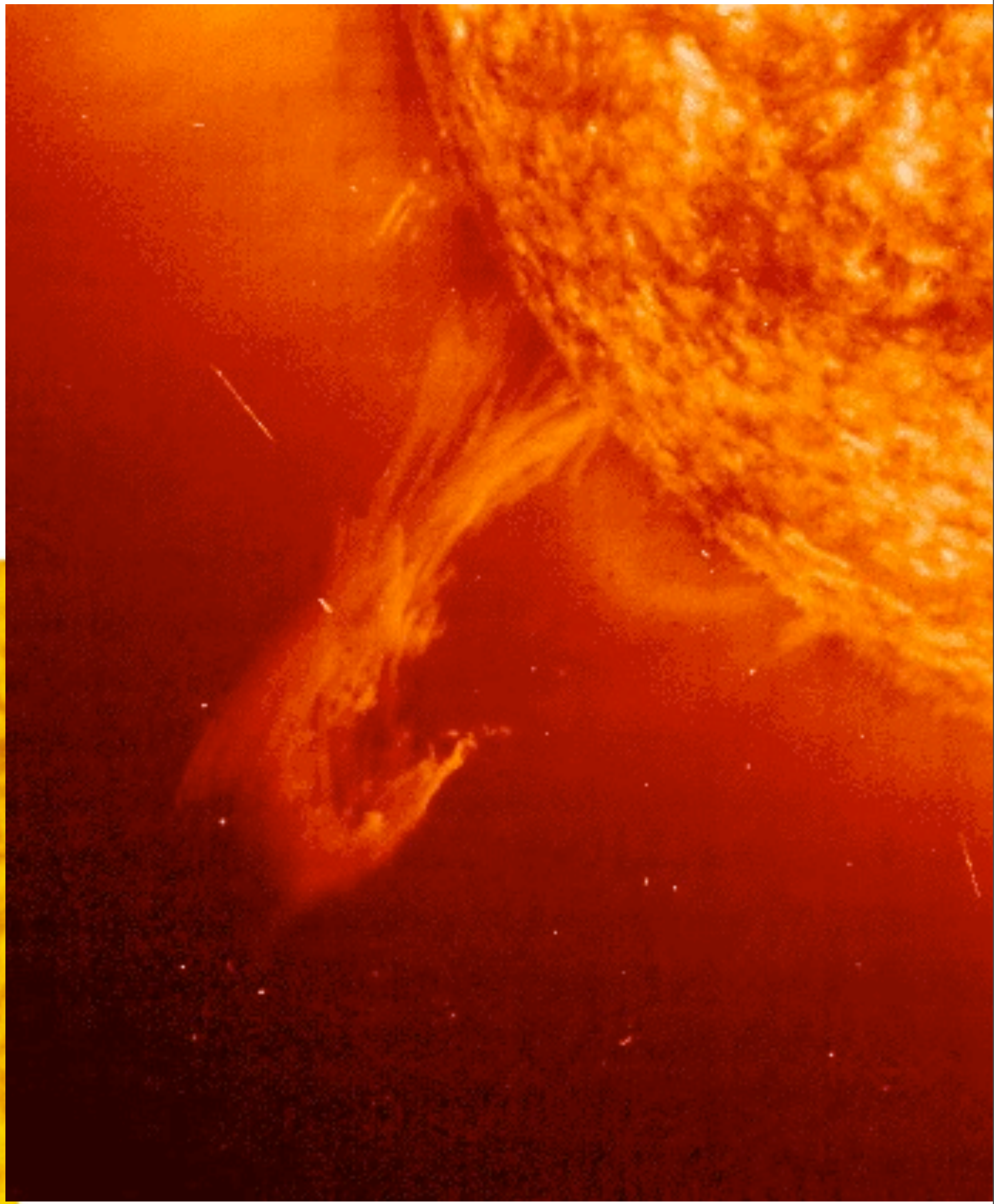
- HW6 due next Friday at start of class
- HW5 and Computer Lab 1 due
- Night Observing continues next week
- Computer Lab 1 due next Friday

Guest Lecturer: Prof. Athol Kemball

Last time: the Future Sun: The Final Fate

Today: Solar Storms





I Know You're Thinking

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Is there anyway that the Sun can kill us today?

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Is there anyway that the Sun can kill us today?

Yes!

Top 10 Ways Astronomy Can Kill you or your Descendents

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1. **Impacts!**

   Splat.. Boom… Watch out for space rocks!

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2. **Solar Evolution.**

   Hydrogen burning to Red Giant to White Dwarf.

Top 10 Ways Astronomy Can Kill you or your Descendents

1. Impacts!

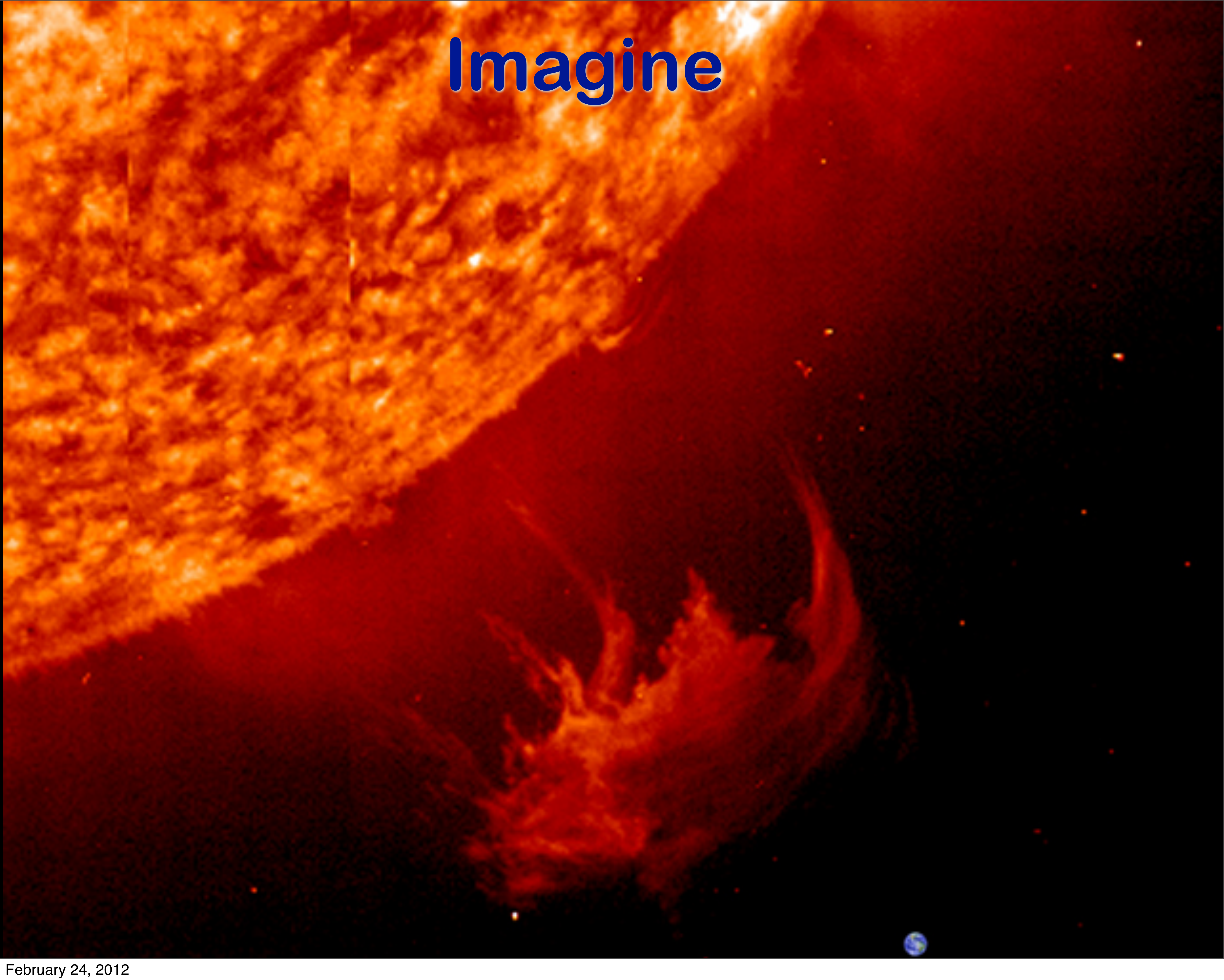
   Splat.. Boom… Watch out for space rocks!

2. Solar Evolution.

   Hydrogen burning to Red Giant to White Dwarf.

3. Solar Storms: Coronal Mass Ejections

   The Sun gets angry..


Imagine

Imagine

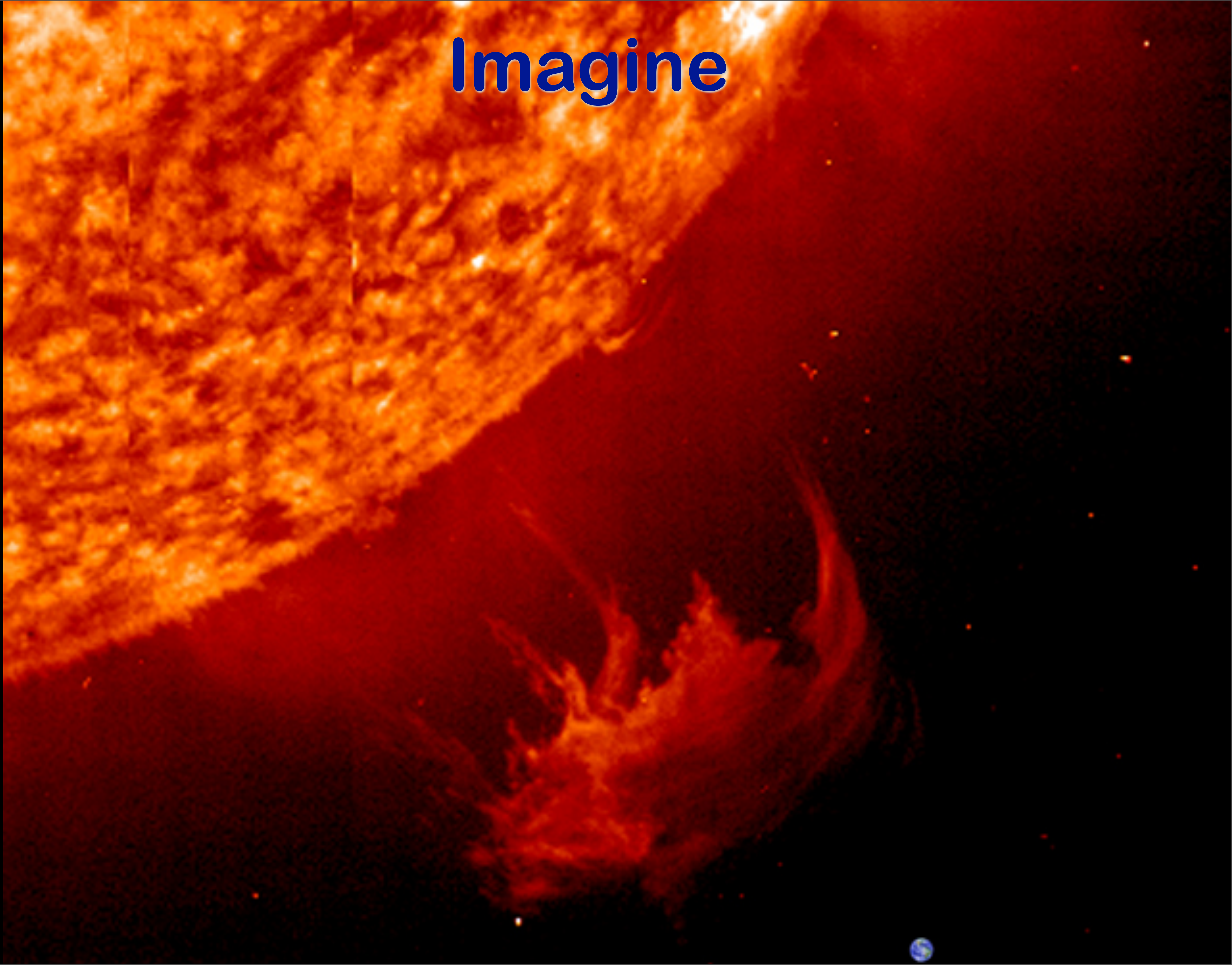
It's winter. It's cold.

The Sun is unusually active, and you hear NASA is worried about something called Space Weather.

A huge batch of new sunspots on the Sun's equator are seen..

A huge coronal mass ejection from the Sun comes screaming toward the Earth.

Imagine



Imagine

All of our satellites are knocked out.

Airplanes are left without communication

Electrical transmission lines overload and melt, causing wildfires.

Half the planet is without power.

Thousands die the first night…

Then, more sunspots…

And you can't remember what Brian mentioned about CMEs….

Top 10 Ways Astronomy Can Kill you or your Descendents

2. Coronal Mass Ejections, CMEs !

The Sun is a star!

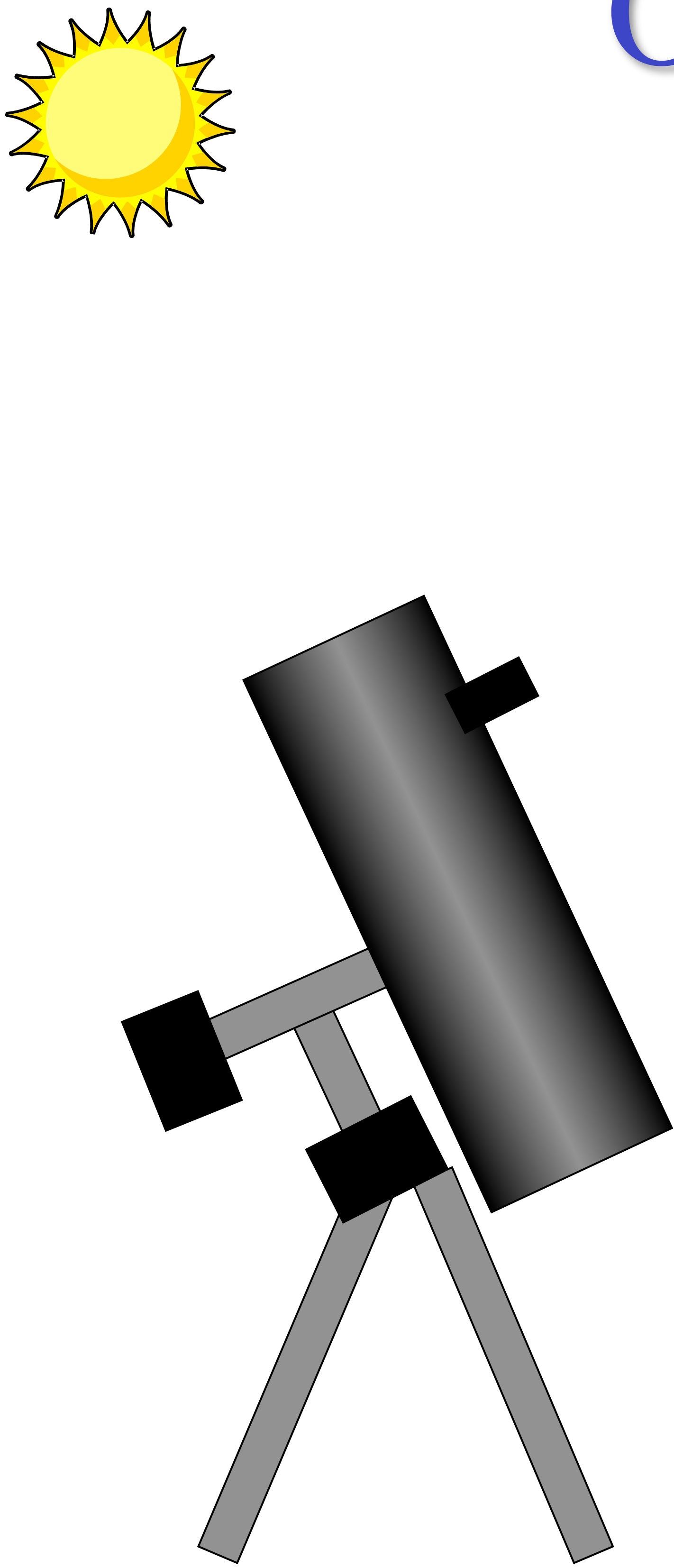
The Sun seems the same every day, but it isn't. It changes.

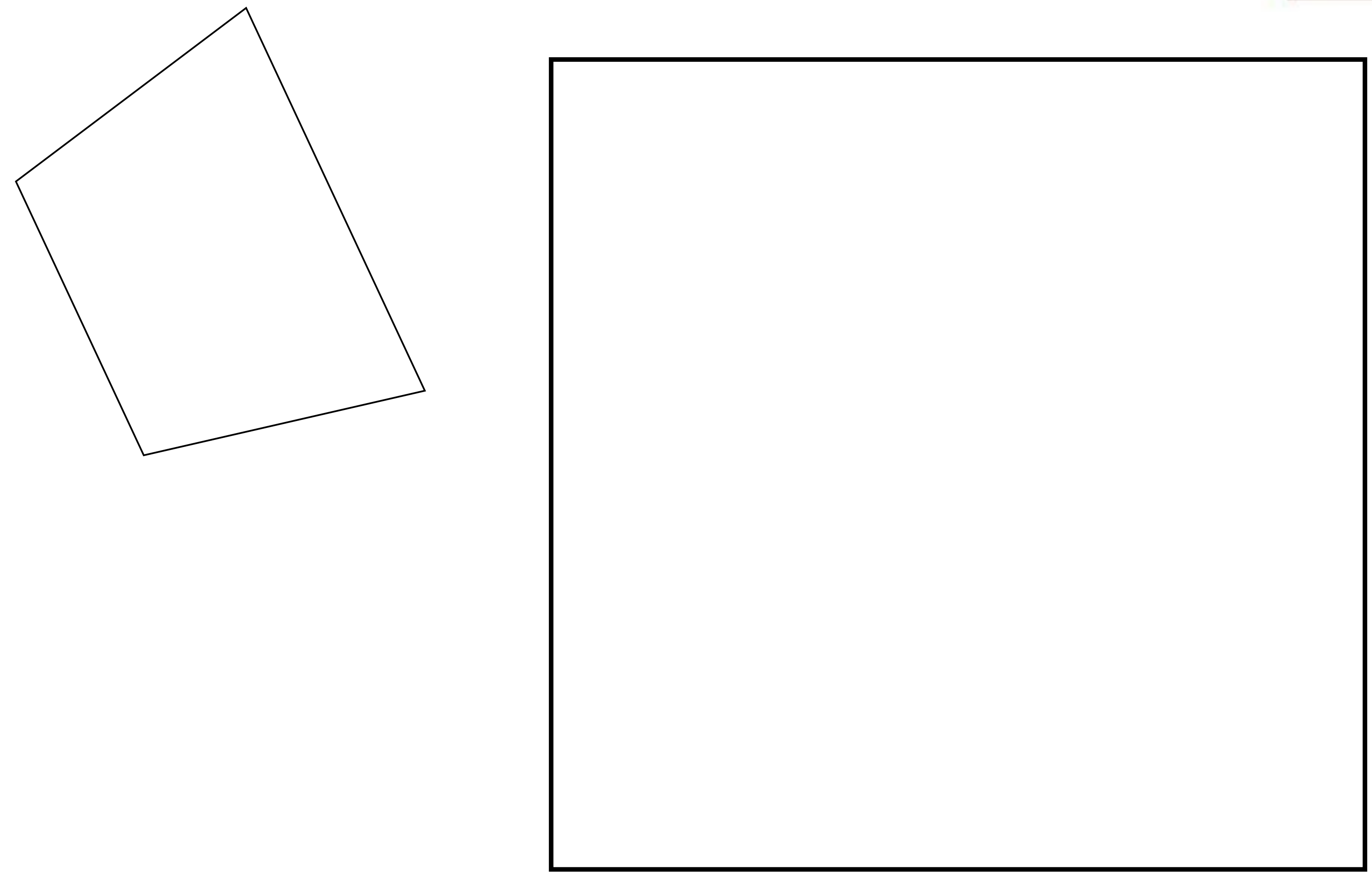
The Sun is a huge vast mighty furiously seething cauldron of mass and energy!

The Sun can get mean!

I mean rock impacts may never happen, and Solar Evolution is so far away, but CMEs can kill today.

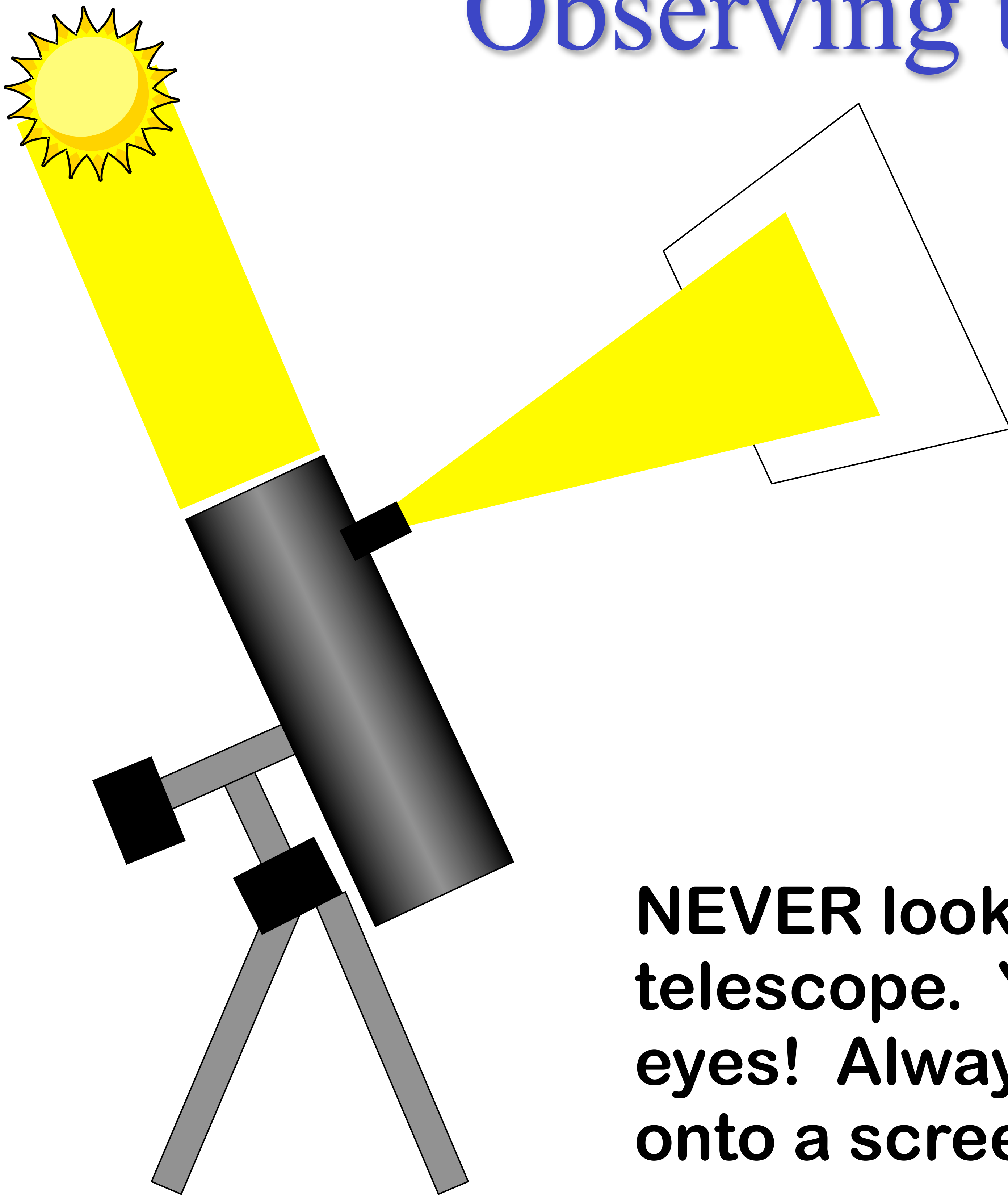
Observing the Sun

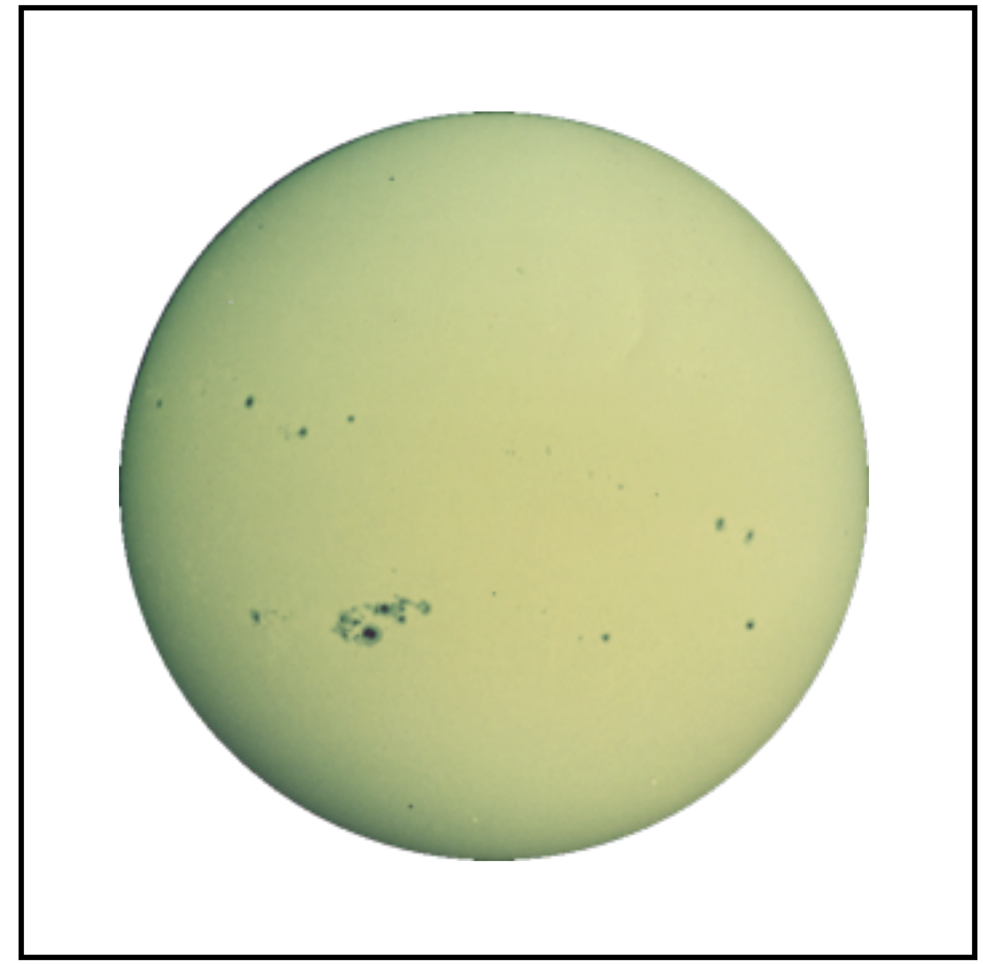




NEVER look at the Sun through a telescope. You will damage your eyes! Always project the Sun's image onto a screen.

Observing the Sun





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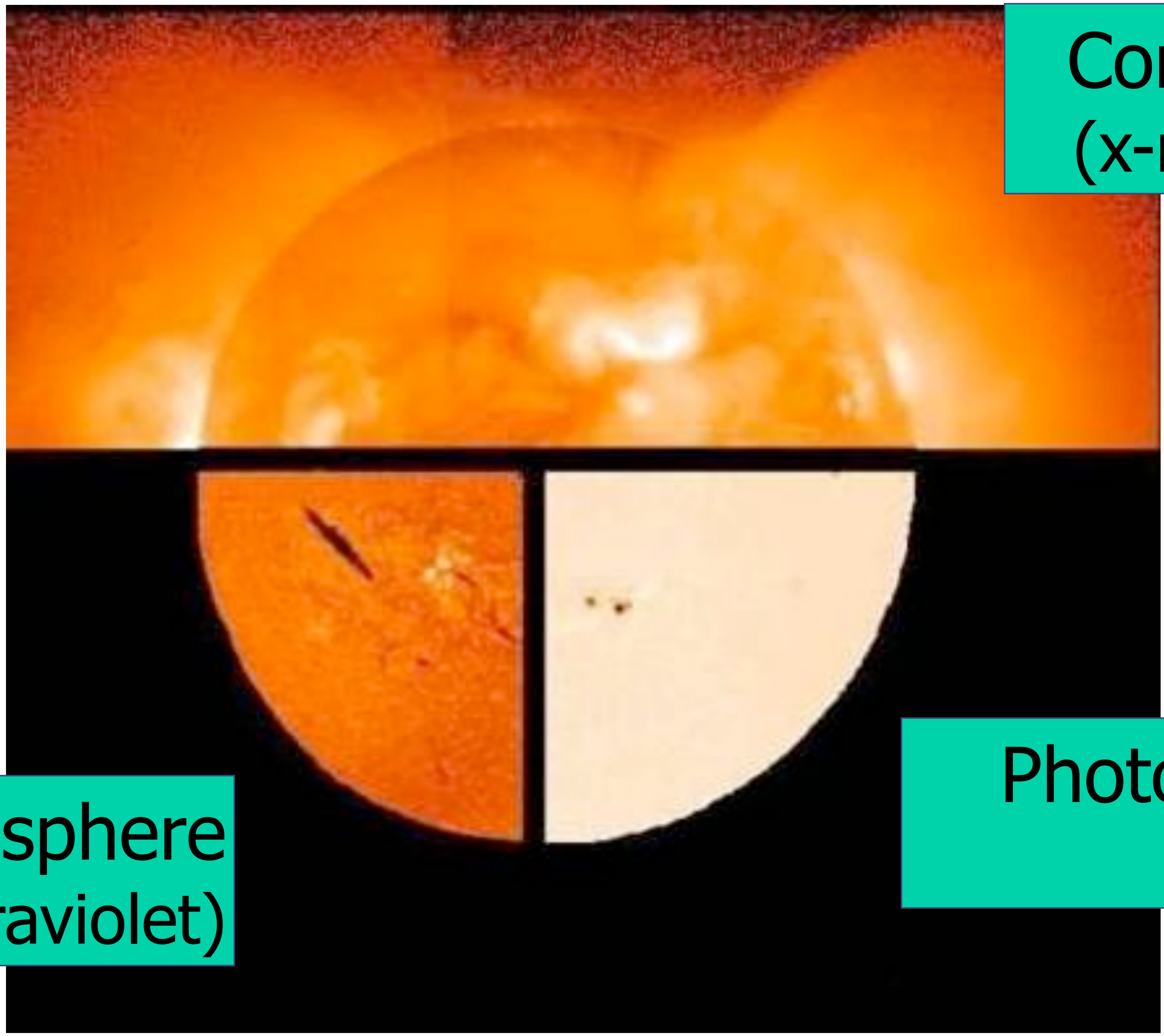
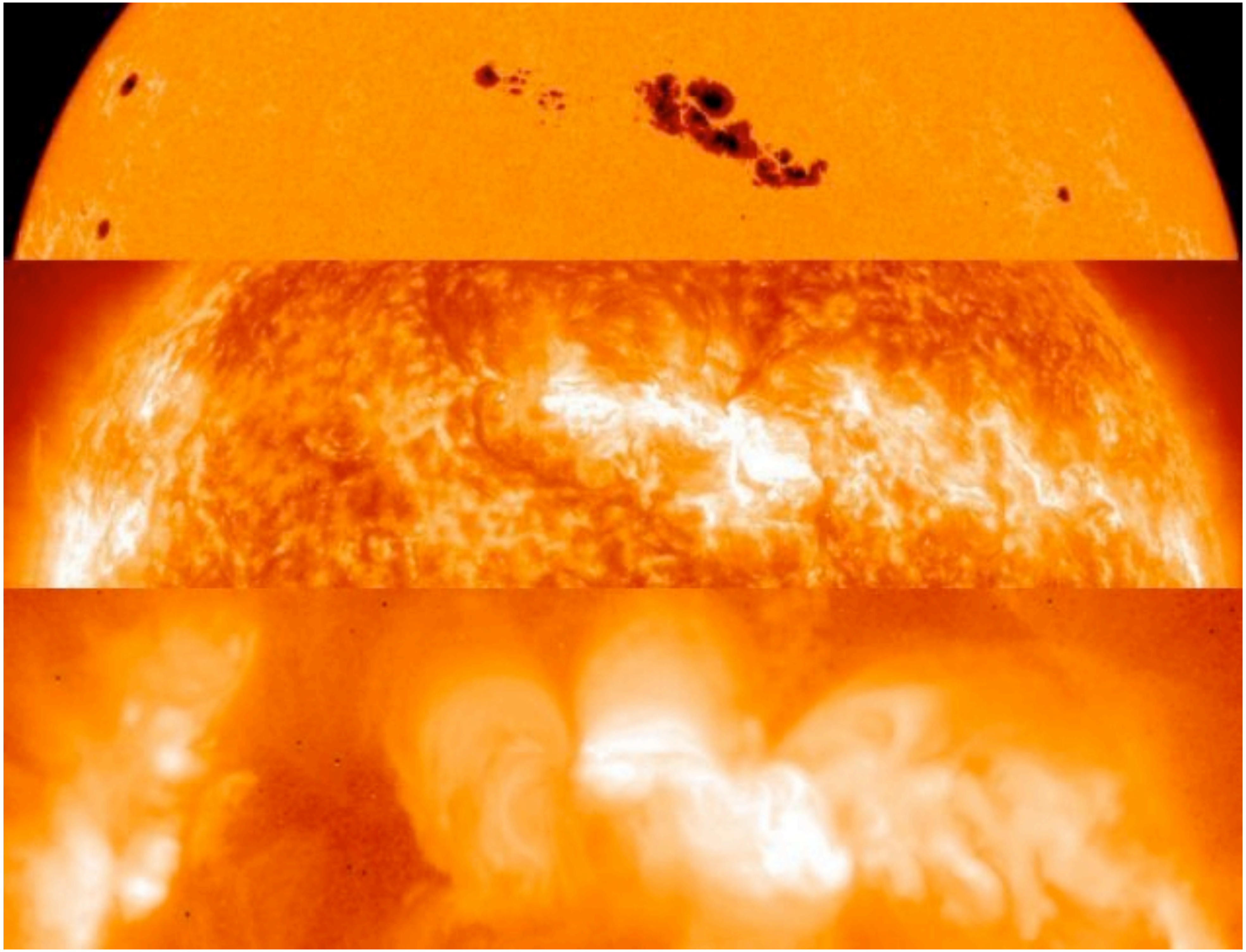
The Outer Layers of the Sun



The Various Layers



Photosphere
(optical)

Chromosphere
(ultraviolet)

Corona
(x-rays)

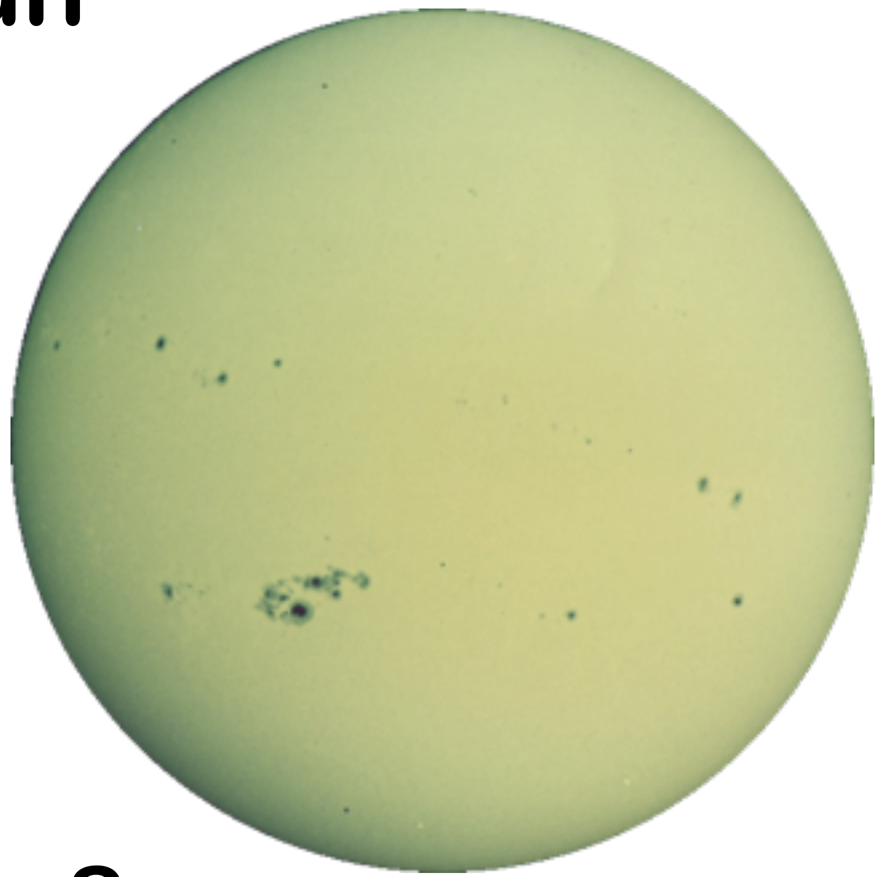
http://antwrp.gsfc.nasa.gov/apod/ap010419.html

The Photosphere

Apparent “surface” of the Sun

- Ionized atoms make the gas highly opaque

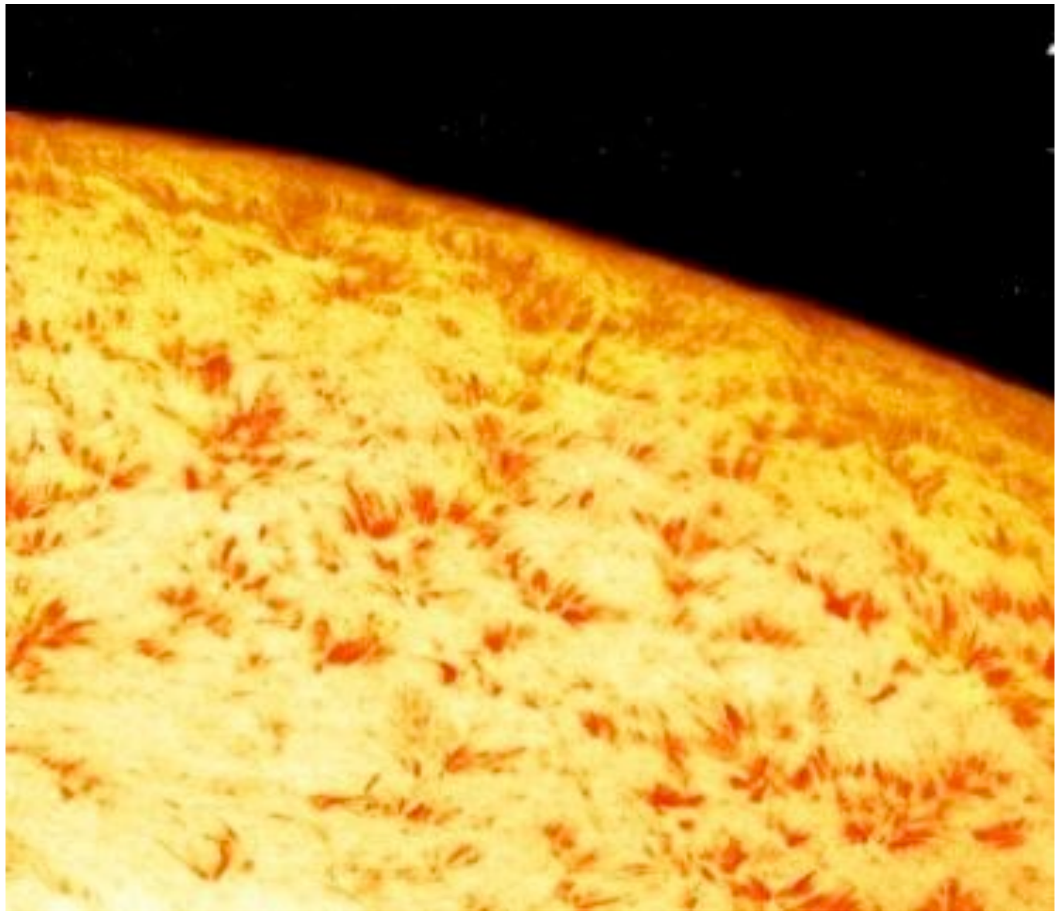
Most of the Sun’s light we see comes from the photosphere



Temperature, about 5800 K

- Hotter as you go deeper into the Sun

The Chromosphere



- Very sparse layer of gas above the photosphere
- Hot – Over 10,000 K
- Produces very little radiation – too sparse
- Only seen during eclipse or with special instruments
- Helium was first discovered in the chromosphere
- Heated by magnetic and acoustic energy

The Corona

- Sun's outer atmosphere
- Visible only by blocking light from photosphere
- Heated by magnetic and acoustic energy
- Temperatures about 2 million K
- Hot enough to produce X-rays!

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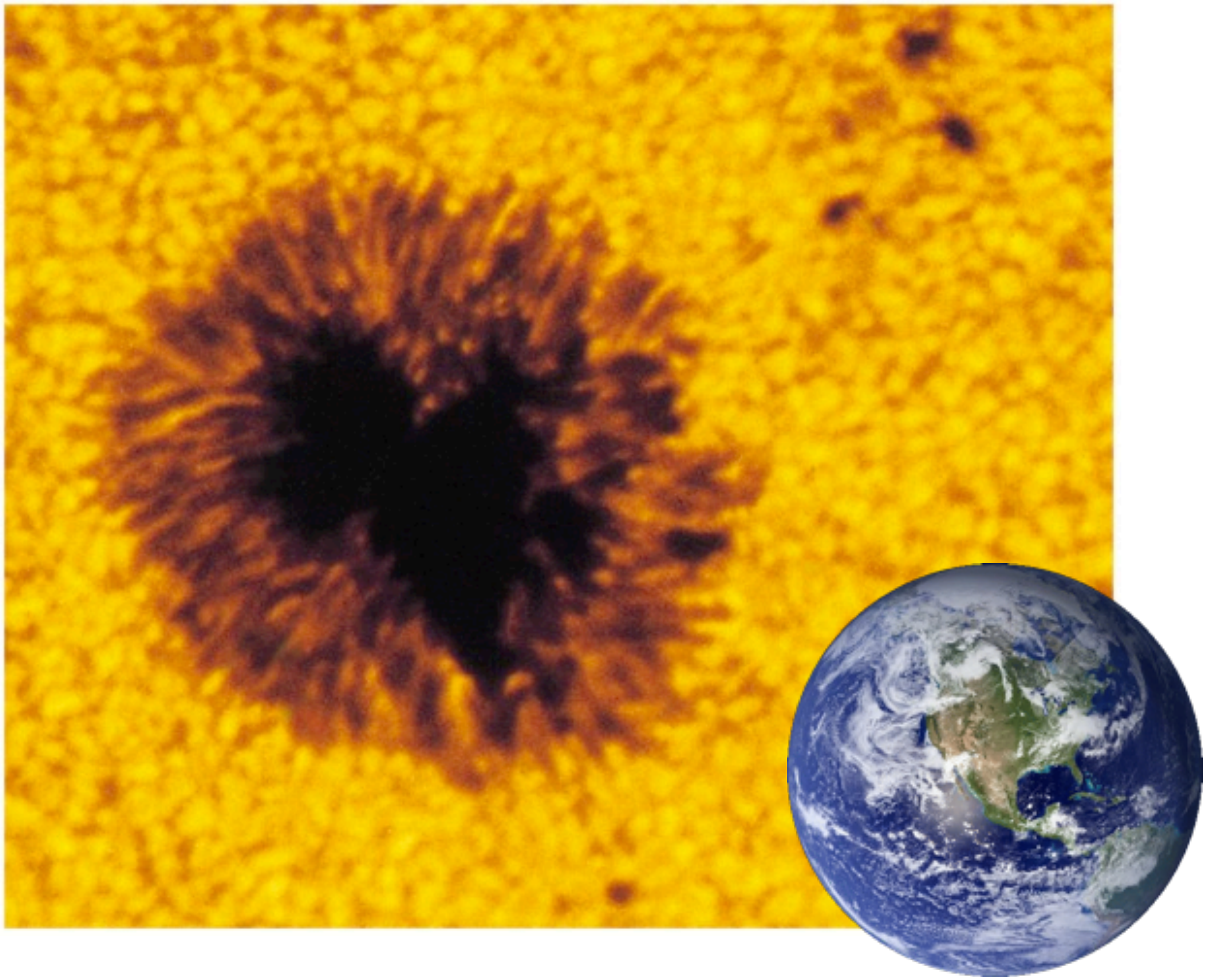
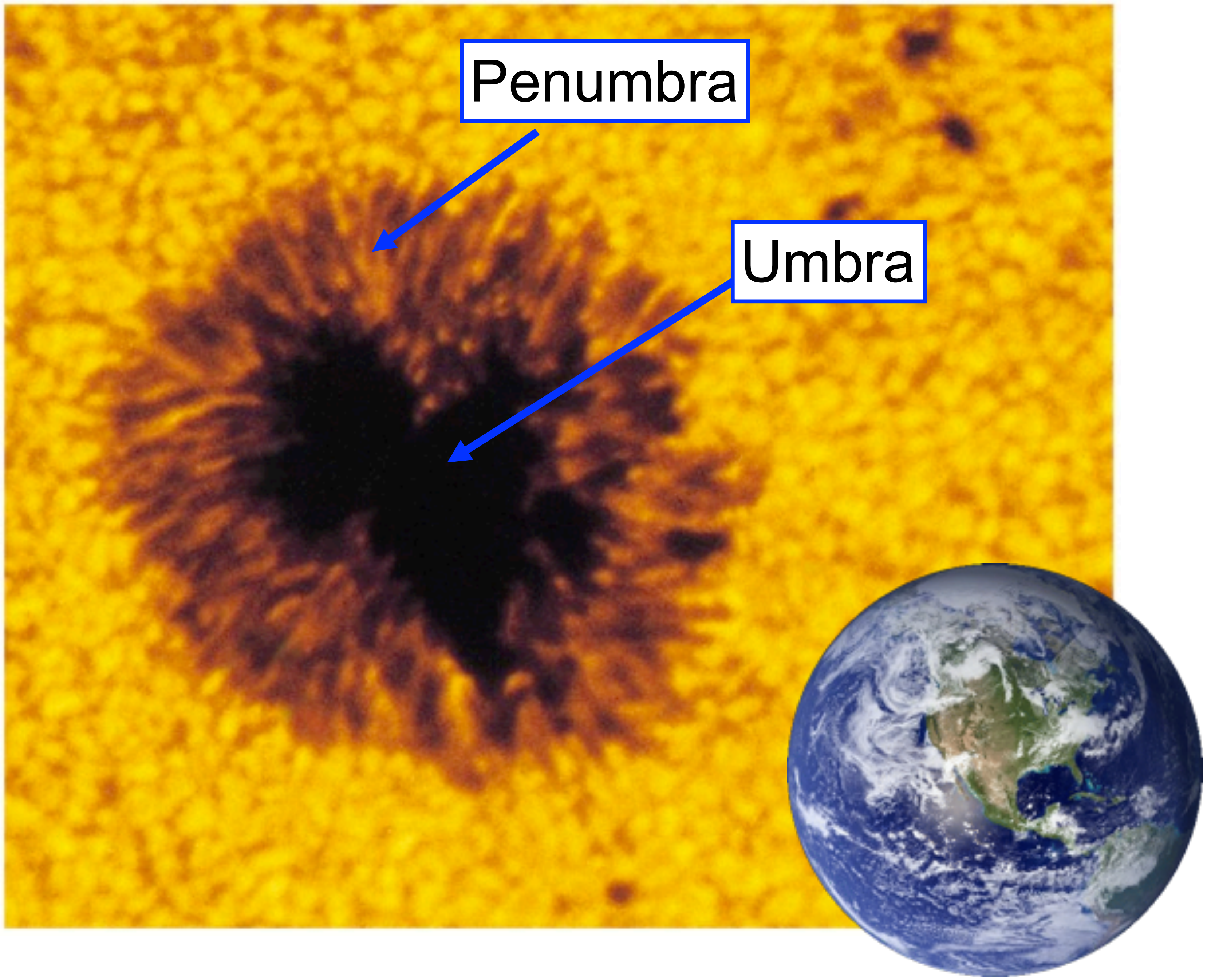
Why are Sunspots Dark?



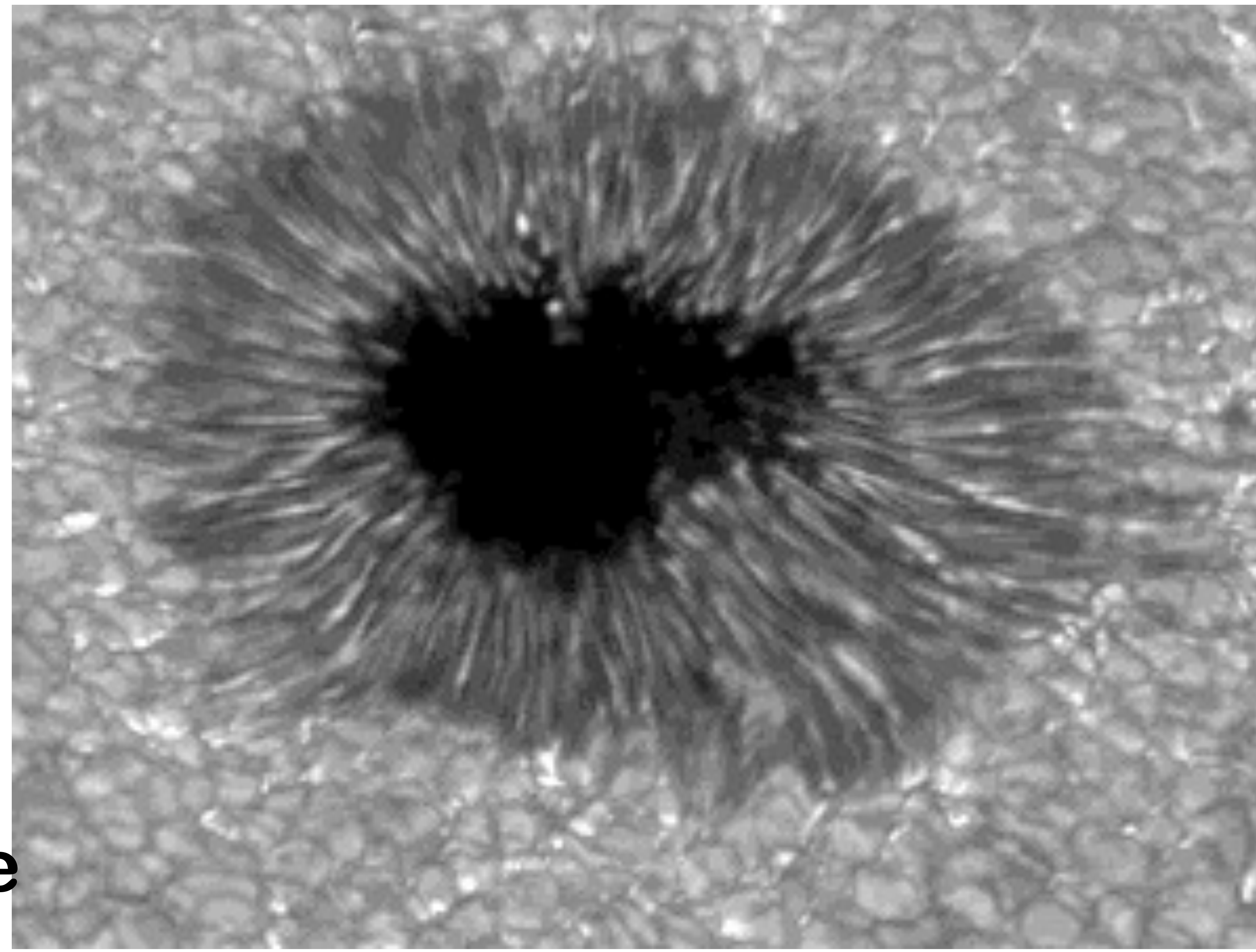
Why are Sunspots Dark?

- "Dark" spots on the Sun.
- Slightly cooler than their surroundings: 4000 K vs. 5800 K
- Brightness of thermal glow (blackbody radiation) depends strongly on temperature, so they appear dimmer.
- But still very hot, very bright!



Sunspots

- Usually last a few days to few weeks, sometimes months.
- Sunspots change over time
  - Grow, shrink, merge, rotate



http://antwrp.gsfc.nasa.gov/apod/ap000223.html

Sunspot Motion

Sunspots' motion reveals the Sun's rotation!

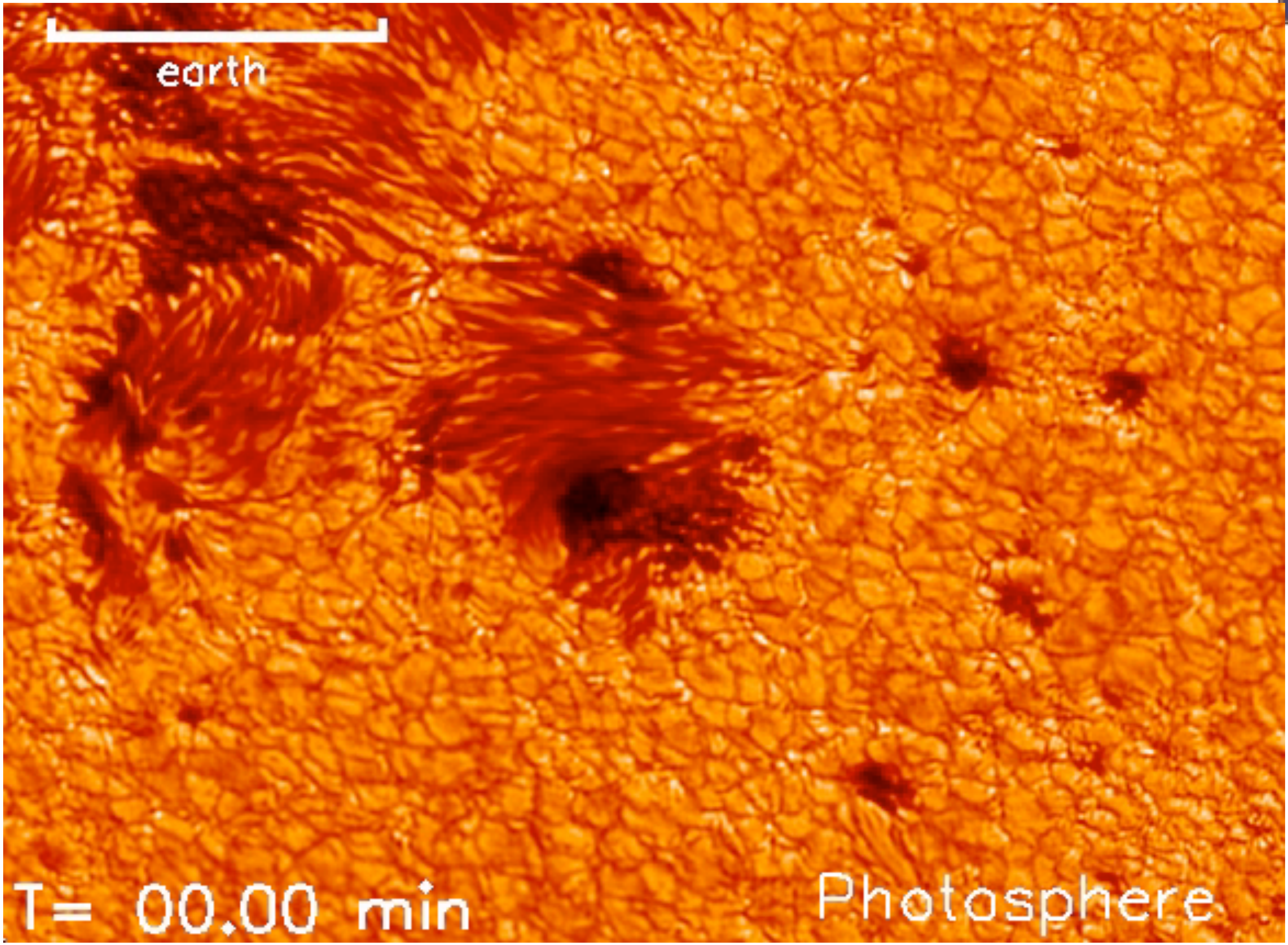
The Sun spins about once every 25 days at the equator

At the poles, it spins once every 30 days

Called differential rotation

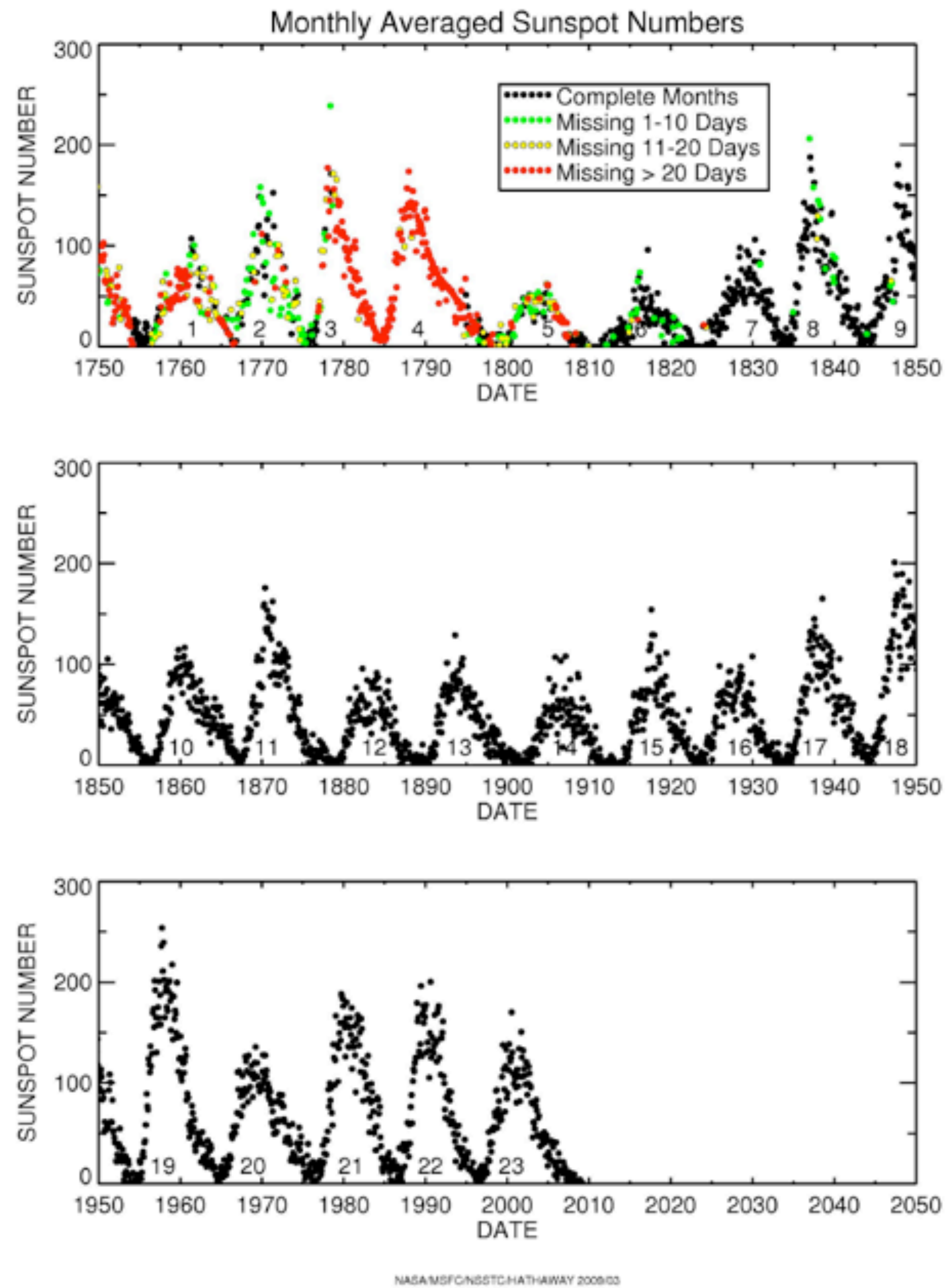
http://sohowww.nascom.nasa.gov/data/realtime/gif/

Sunspots

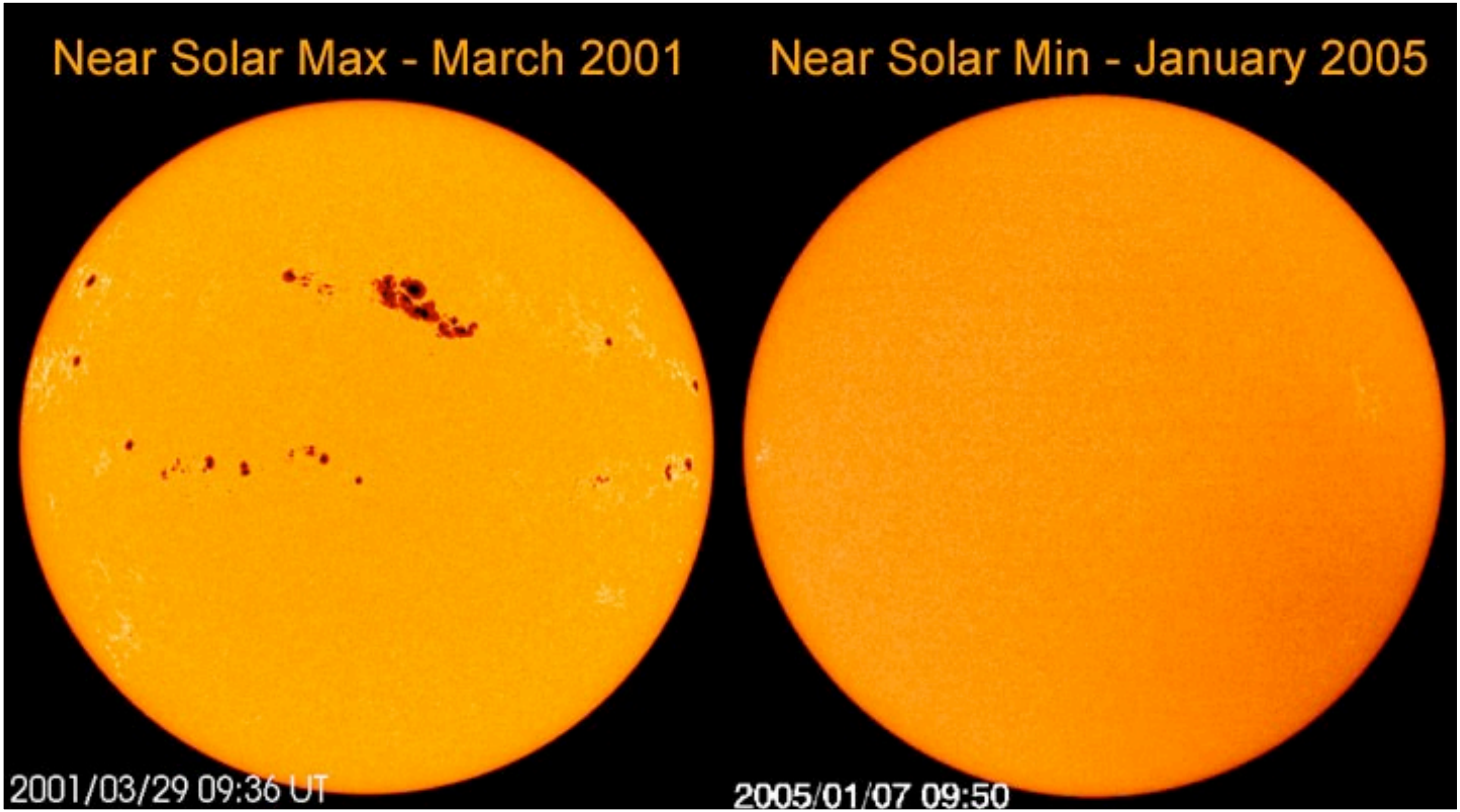


Sunspot Cycles

- Individual Sunspots appear randomly, typically last for weeks
- But over time, patterns emerge
- Start with most sunspots near 30°N/S,
- but over time, more are found near the Sun's equator
- More numerous every 11 years (solar maximum)
- 2008/2009 the least number of sunspots since 1950s
- Next maximum is May 2013 with expected below average count

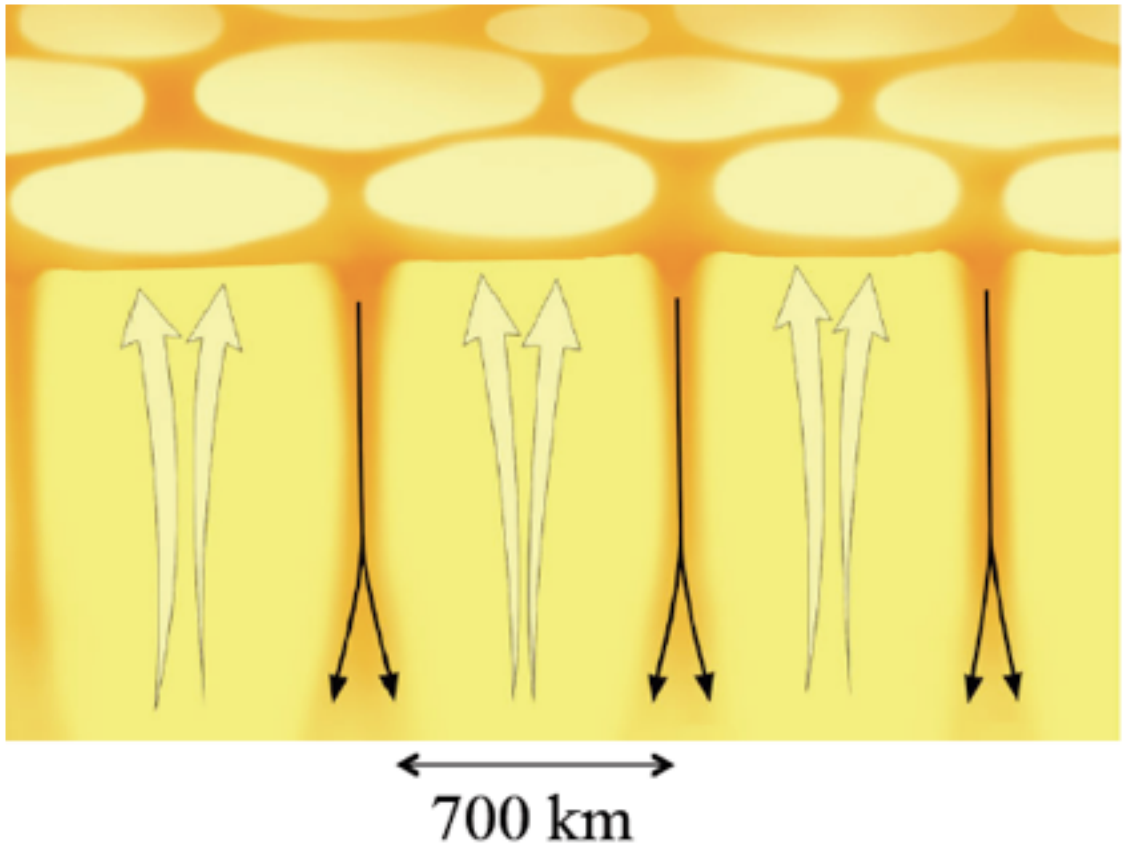


Sunspot Cycles

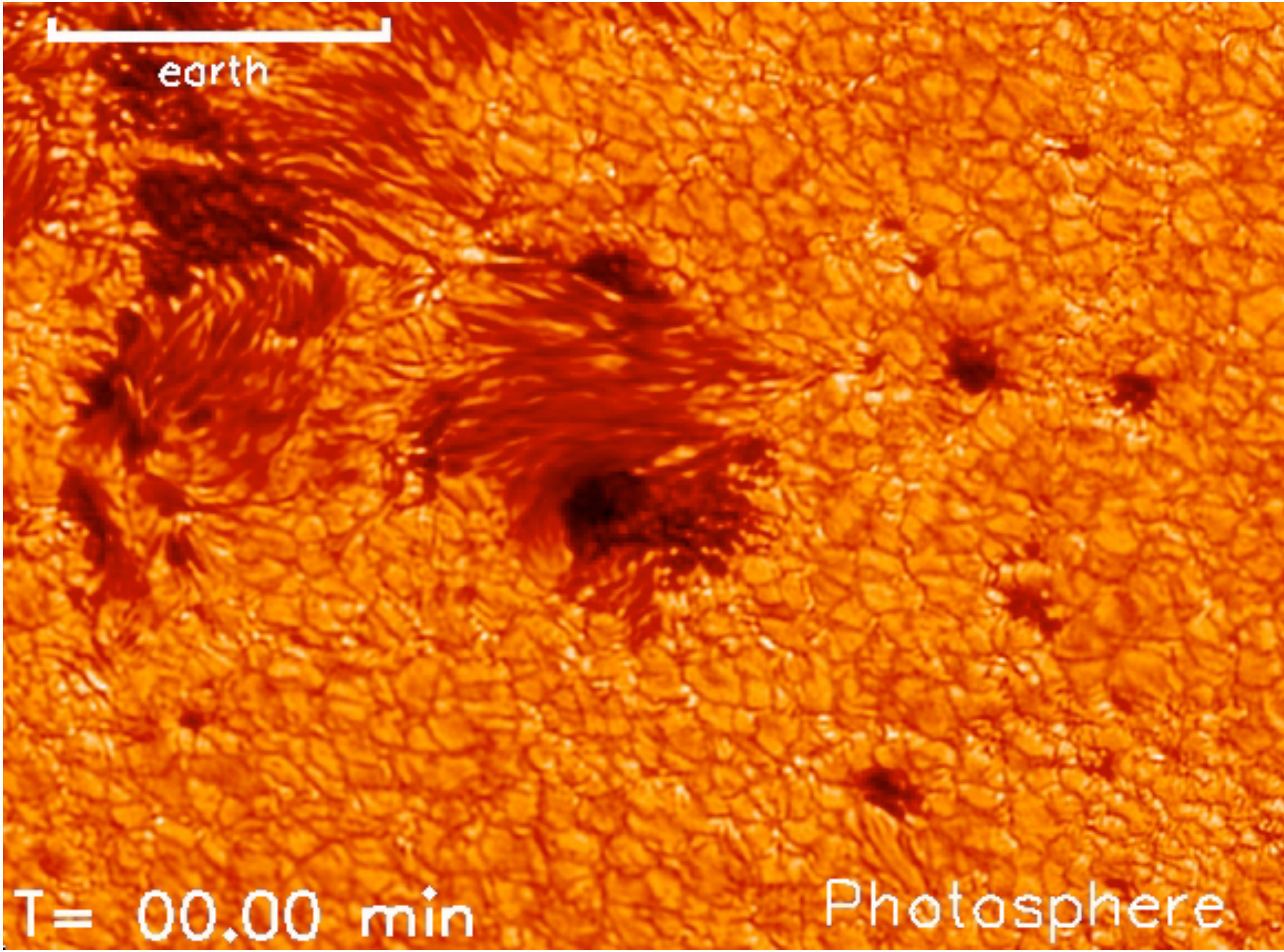


The Solar Surface: Boiling Soup

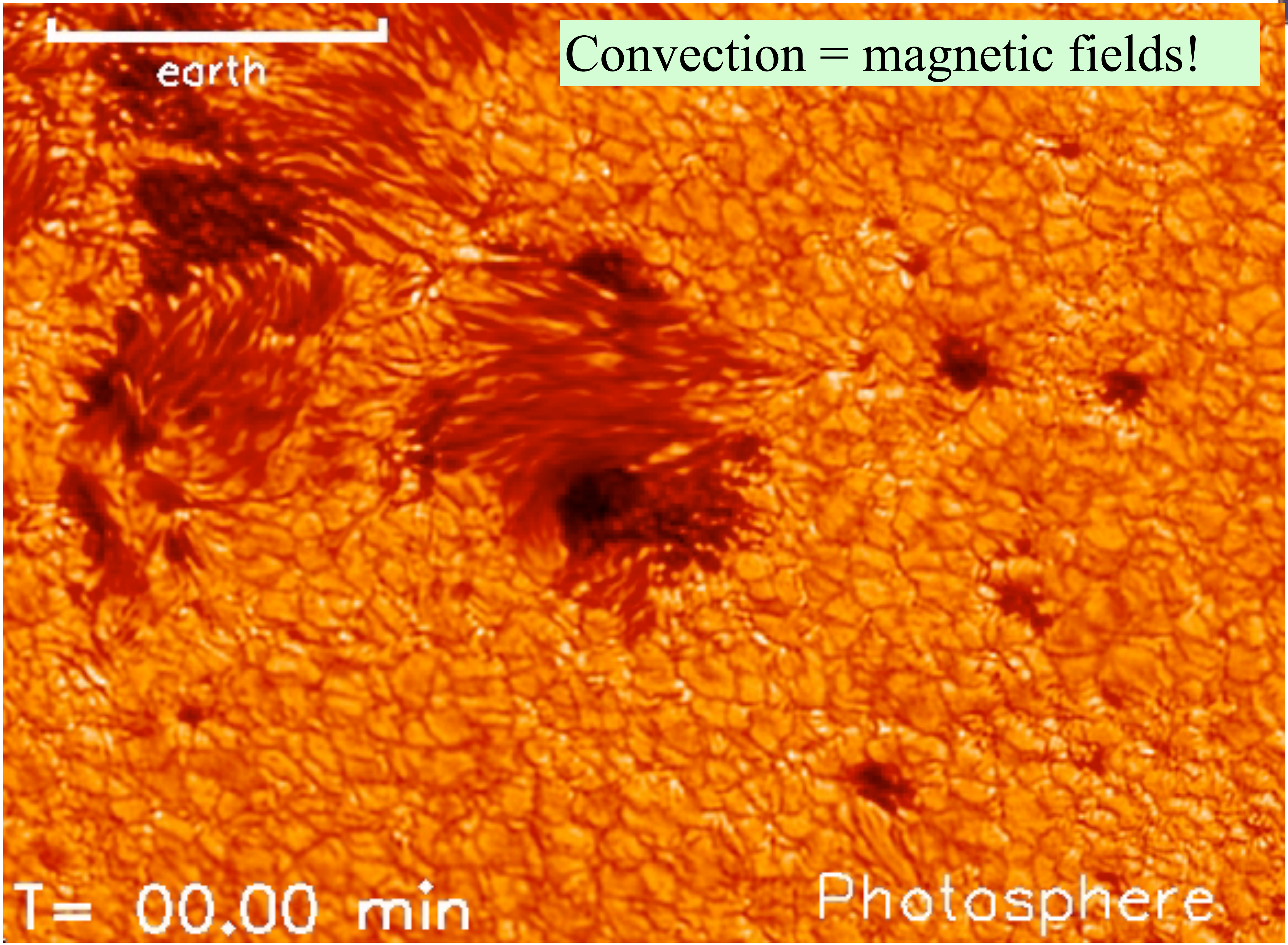
- The Solar surface is a cauldron of bubbling and noise.
- In the Sun's upper layers, hot gas rises to the surface, cools, and falls back into the Sun
- This **convection** is primary means of transporting energy to the surface.



Sunspots



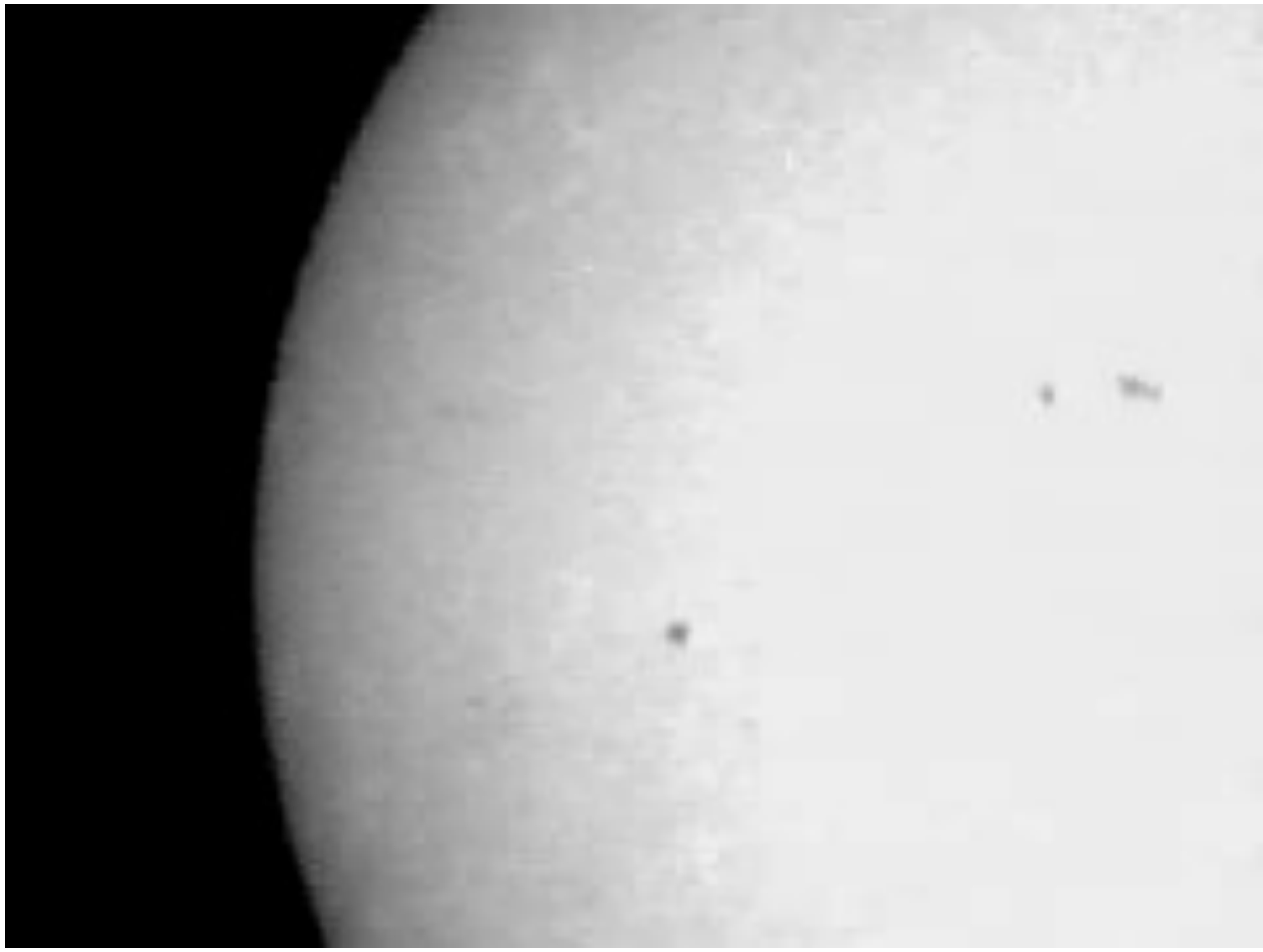
Sunspots



Convection = magnetic fields!

The Magnetic Cycle

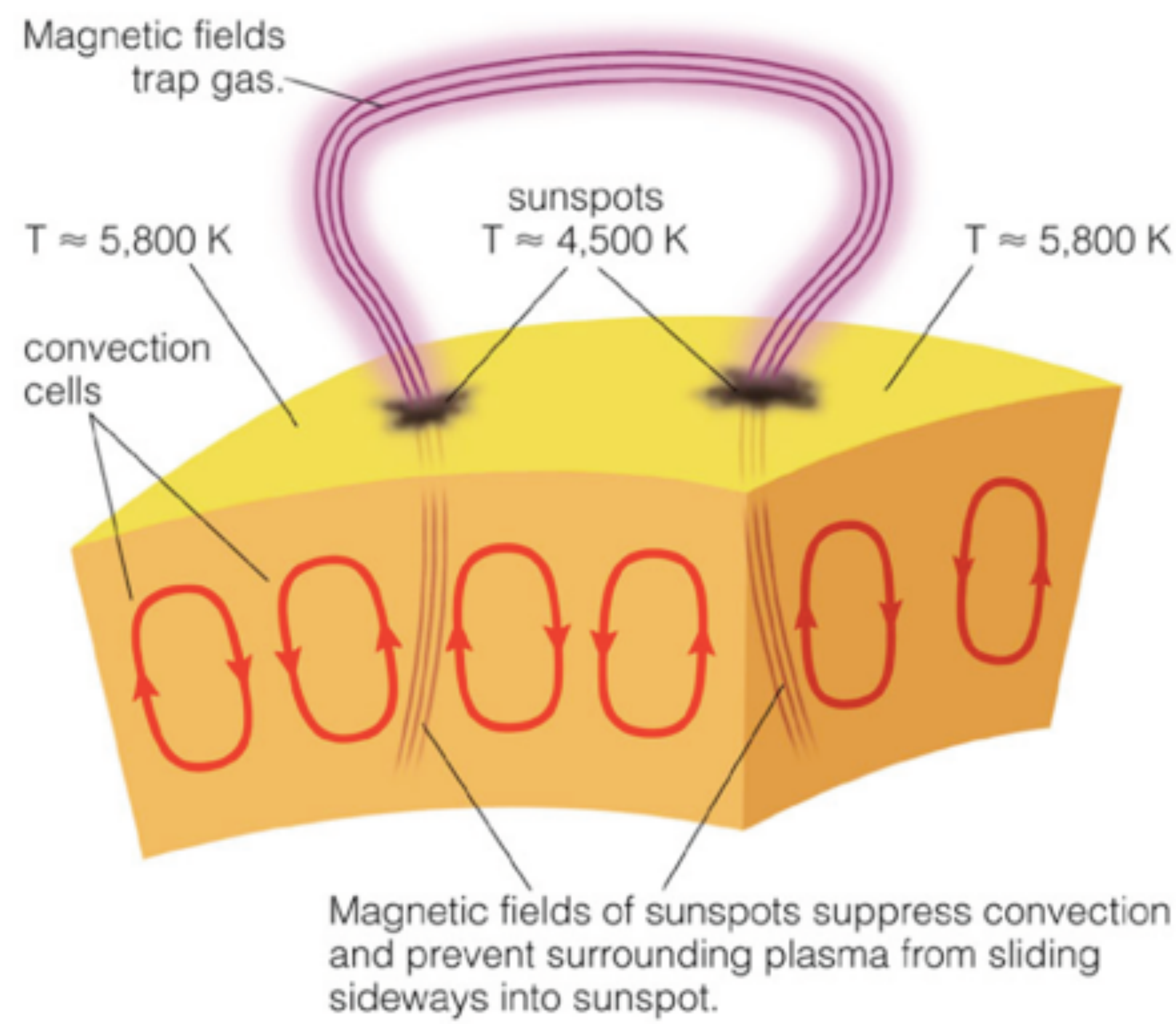
- Sun's magnetic field comes from its surface
- Convection and differential rotation twist and wrap magnetic field lines
- When field lines get too twisted, they pop through the surface
  - Makes sunspots!



What Causes Sunspots?

- Magnetic field "loops" popping through the photosphere
- come in pairs:

  north and south poles!
- Powerful magnetic activity shuts down convection
  - 5,000 times stronger than the Earth's field
- Gas cools off (4000 K)
- Appears darker than the rest of the photosphere



compare magnetogram with optical sunspot positions

http://sohowww.nascom.nasa.gov/data/realtime/realtime-update.html

Sunspots and the Outer Layers

Photosphere

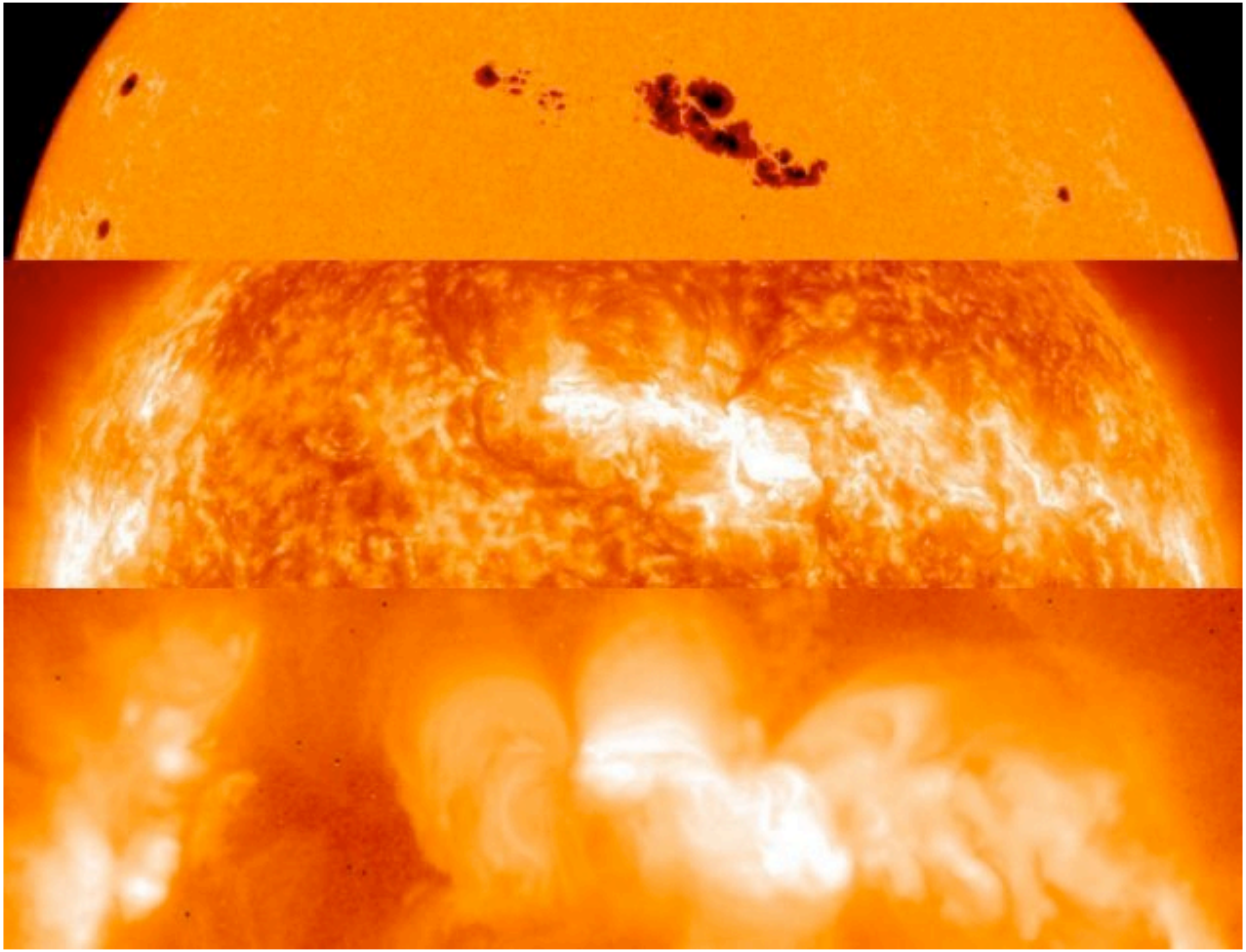
(optical)

Chromosphere

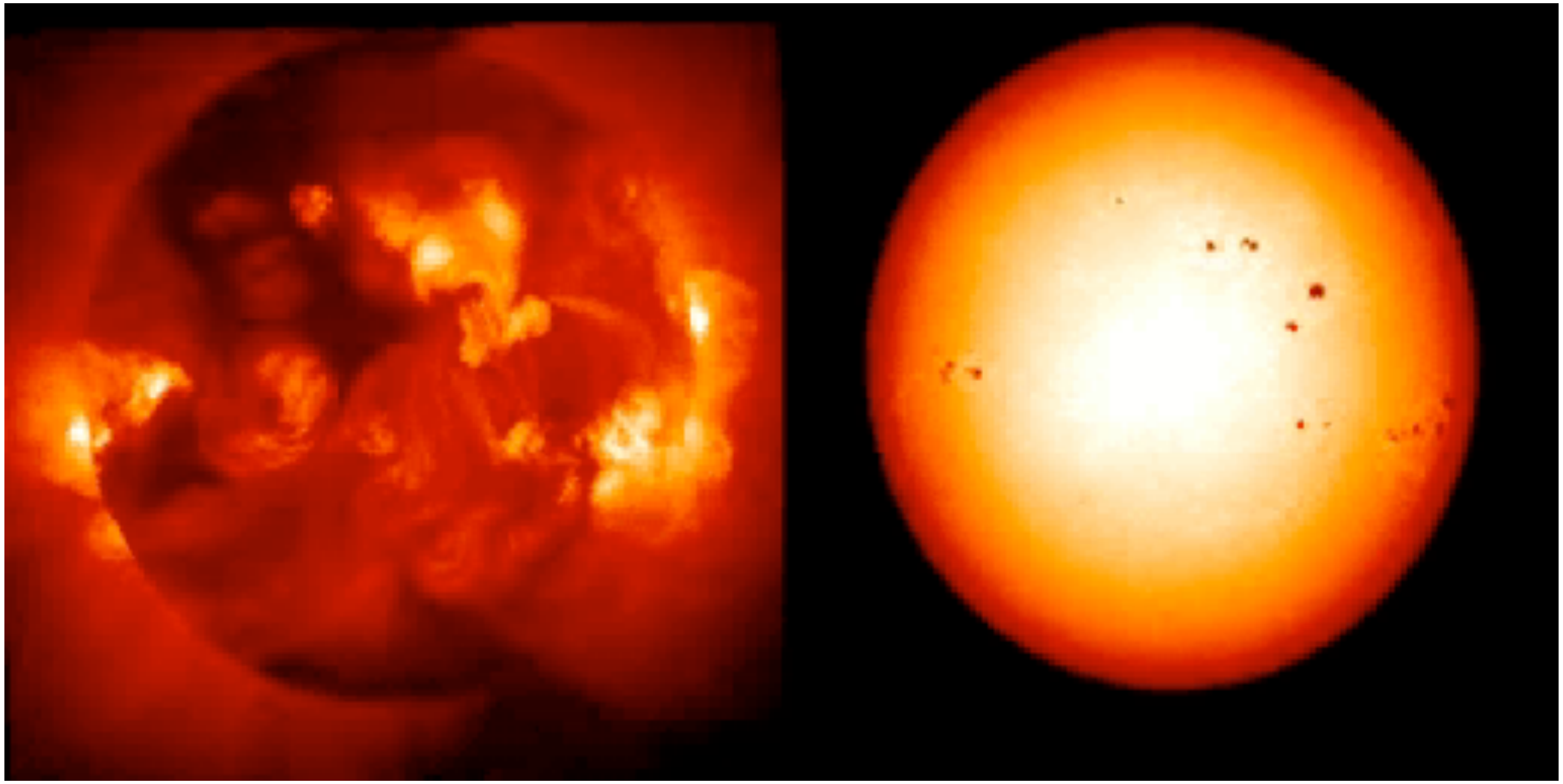
(ultraviolet)

Corona

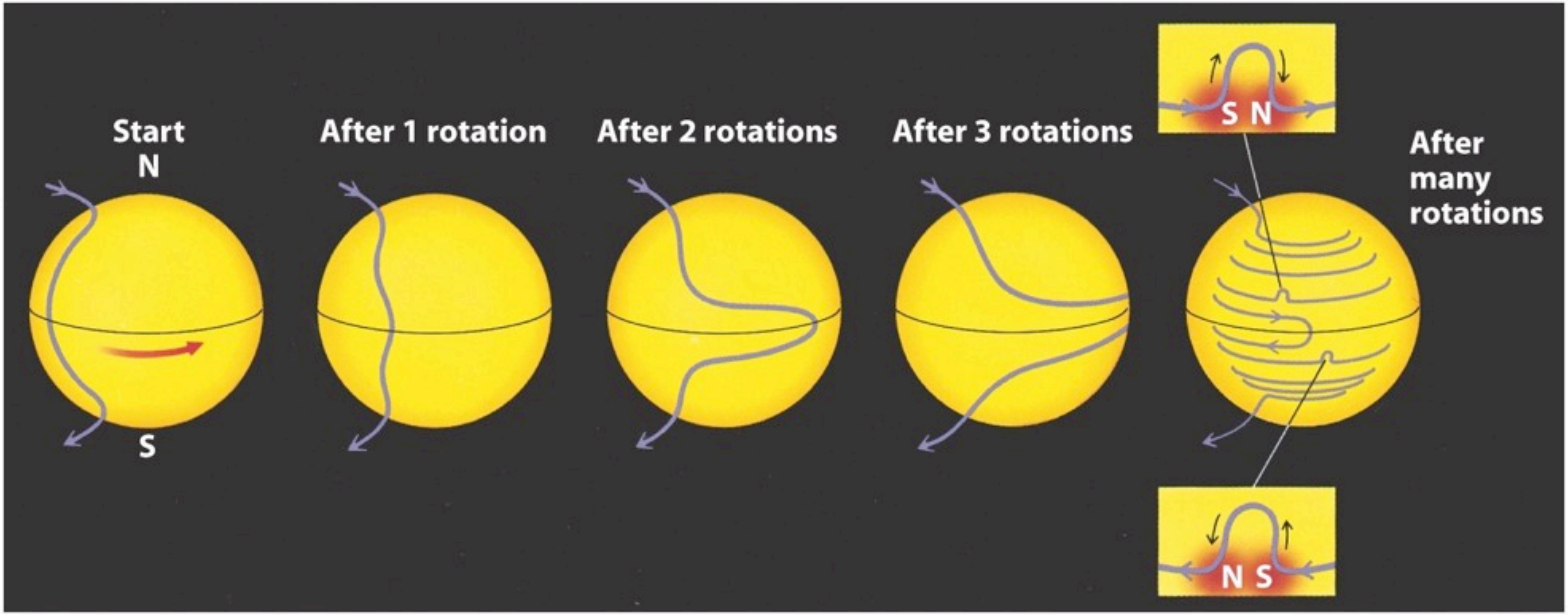
(x-rays)



Sunspots and the Outer Layers

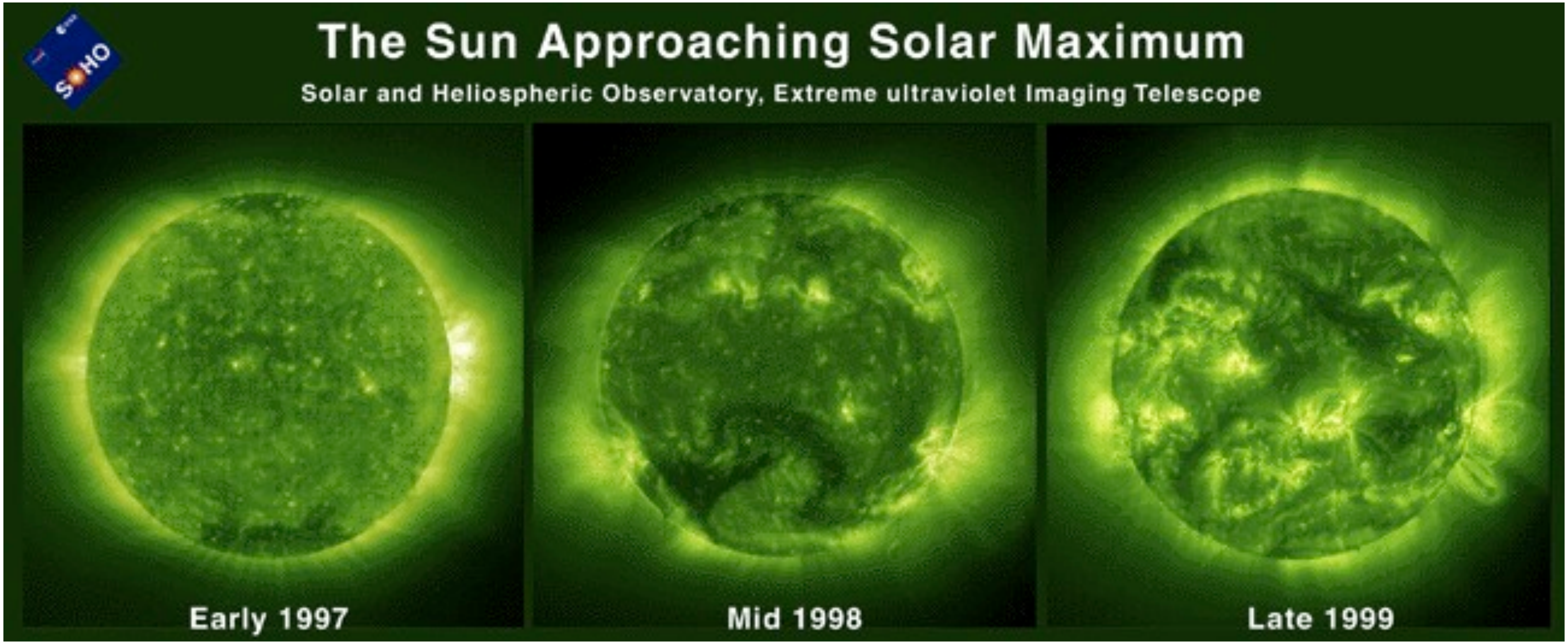


The Magnetic Cycle= Solar Cycle

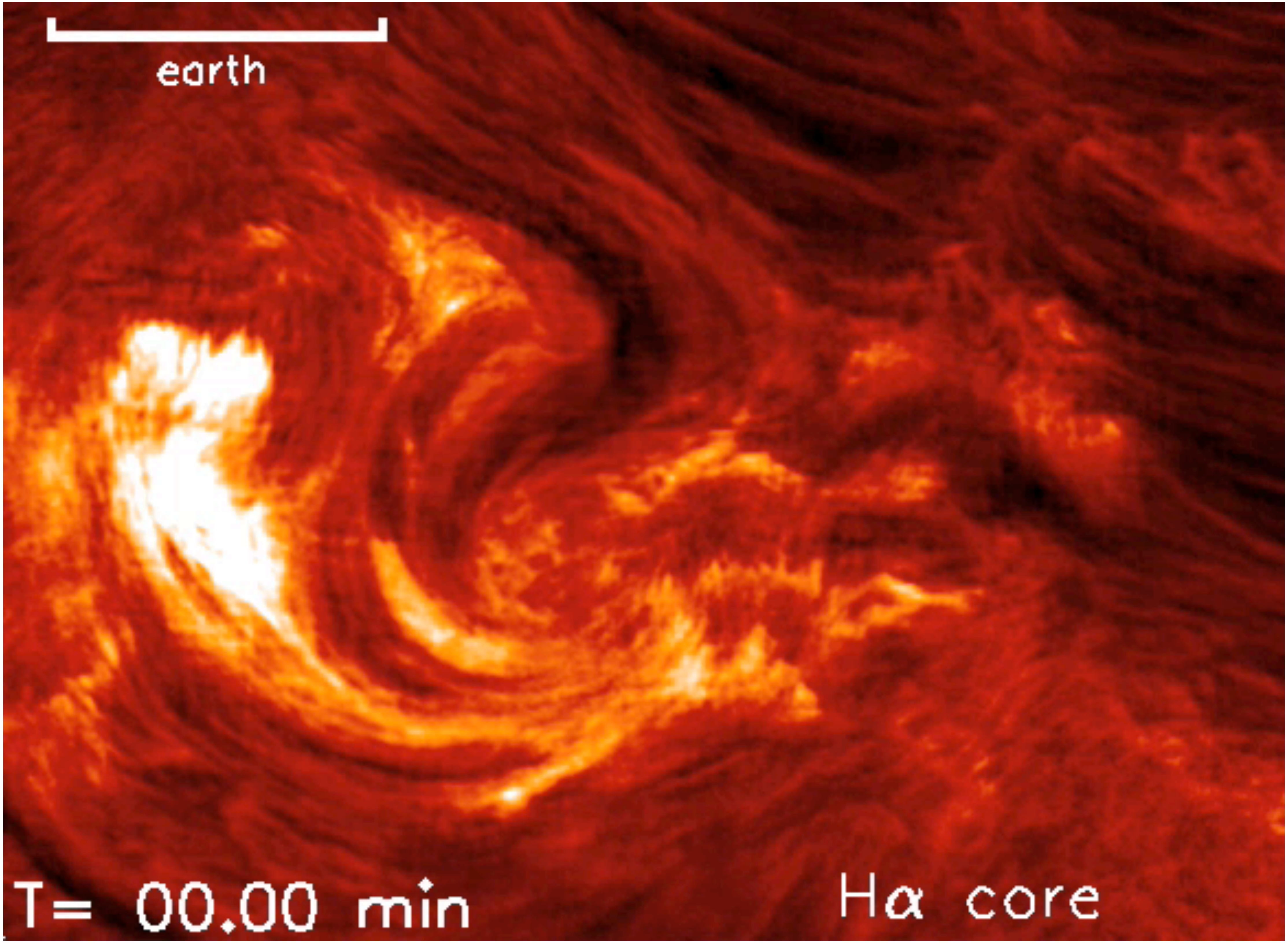


- Every 11 years, the field breaks apart and reorders itself
  - North and south magnetic poles flip!

Magnetic Activity on the Sun

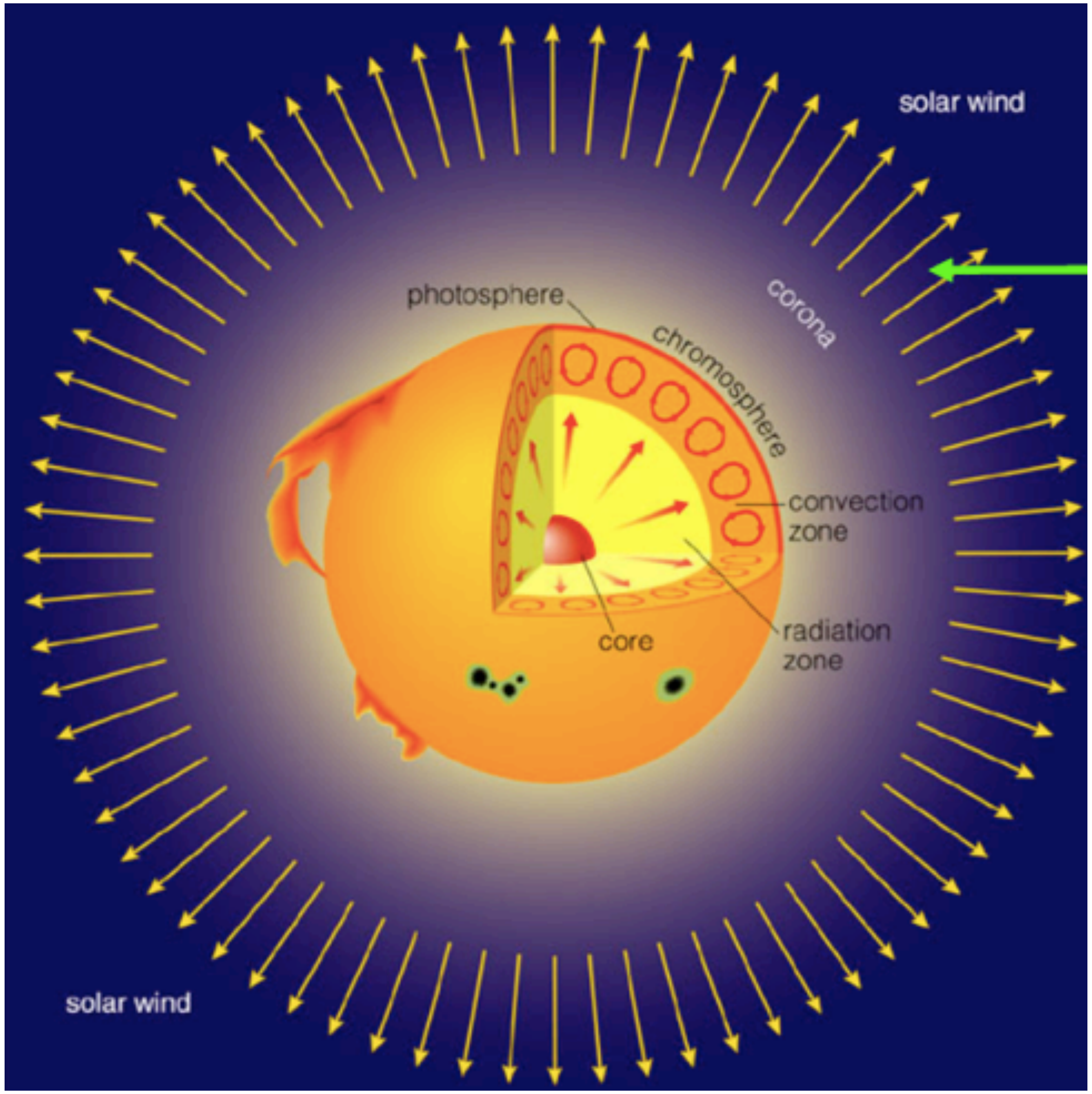


Sunspot and Magnetic Fields

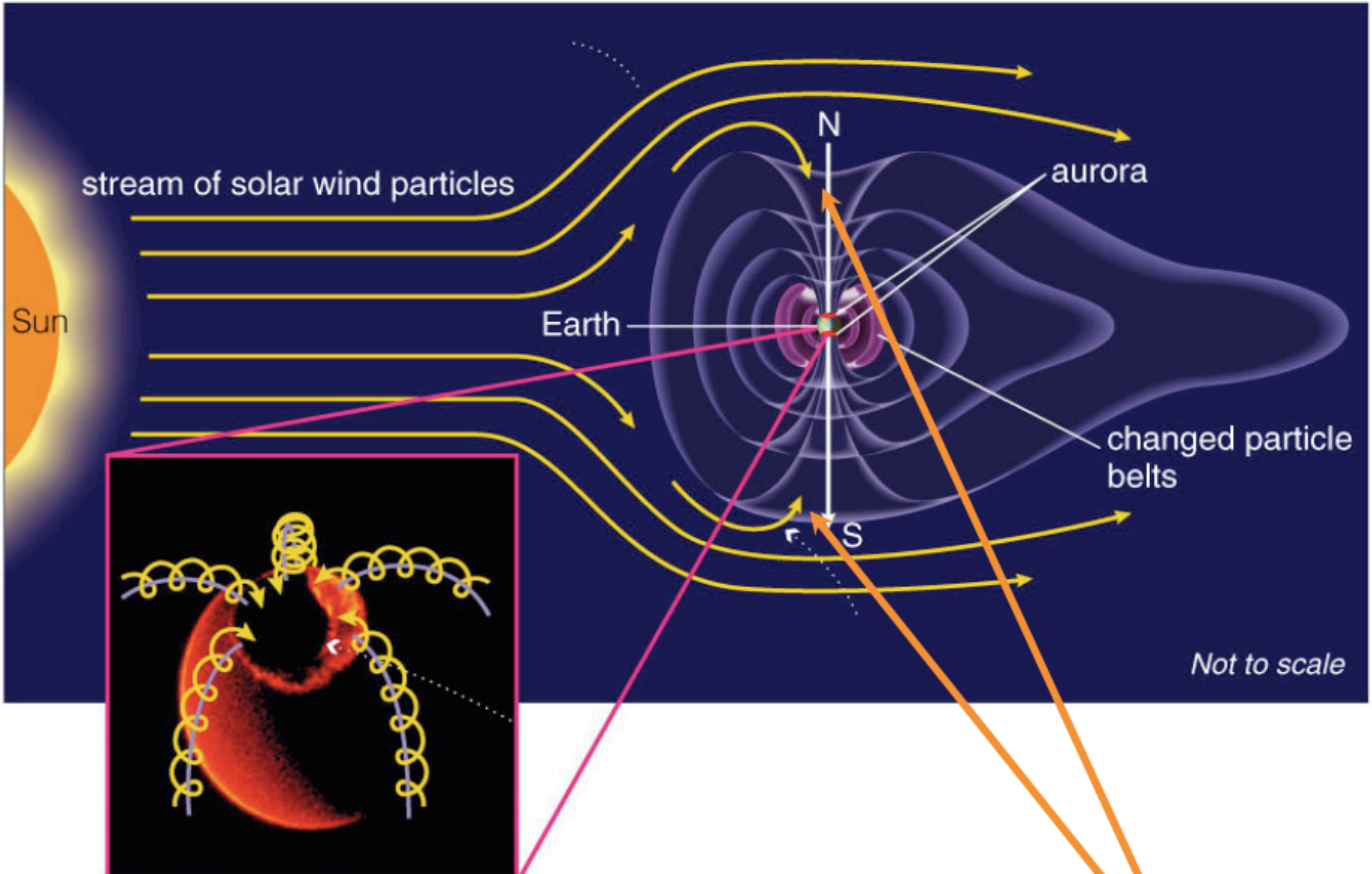


Solar Wind

- Some of the gas in the Sun's corona is moving fast enough to escape the Sun's gravity
- Accelerated by the Sun's magnetic field
- Flows out into the solar system
- Made of charged particles



http://sohowww.nascom.nasa.gov/data/LATEST/current_c2.gif



Most solar wind particles are deflected by Earth's magnetic field, but some enter at the poles

Auroras (Northern/Southern Lights)

http://www.youtube.com/watch?v=icugqEEOgkg

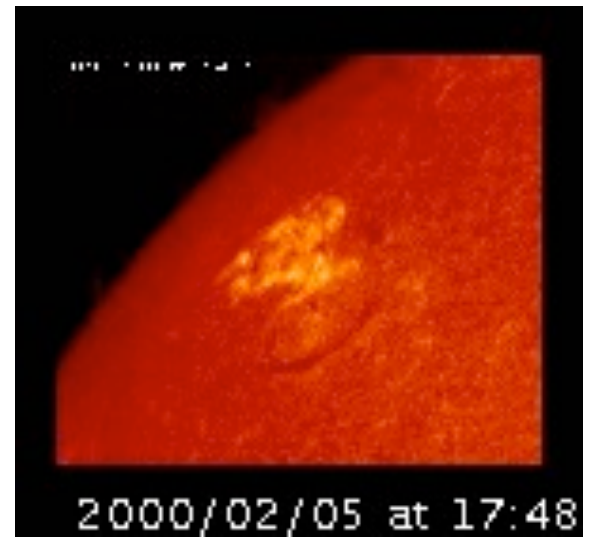
Energetic particles from the solar wind cause *auroras*

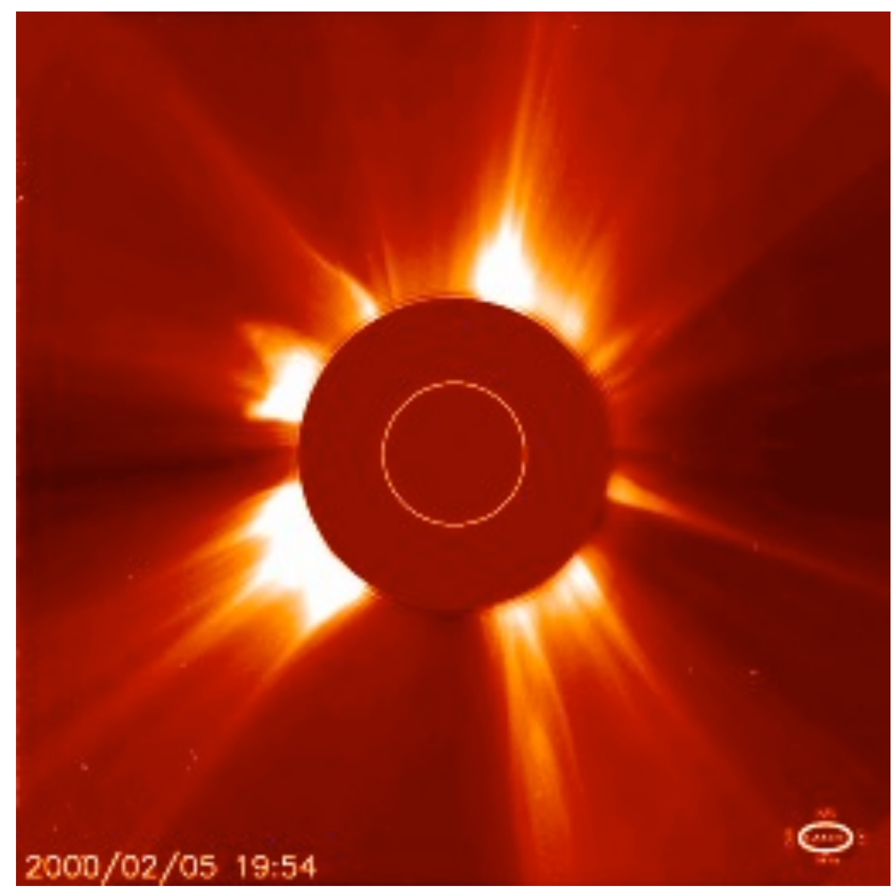
Prominences

- Ropes of gas trapped in magnetic loops
- Almost always associated with sunspots
- Gas can reach temperatures of 50,000 K!

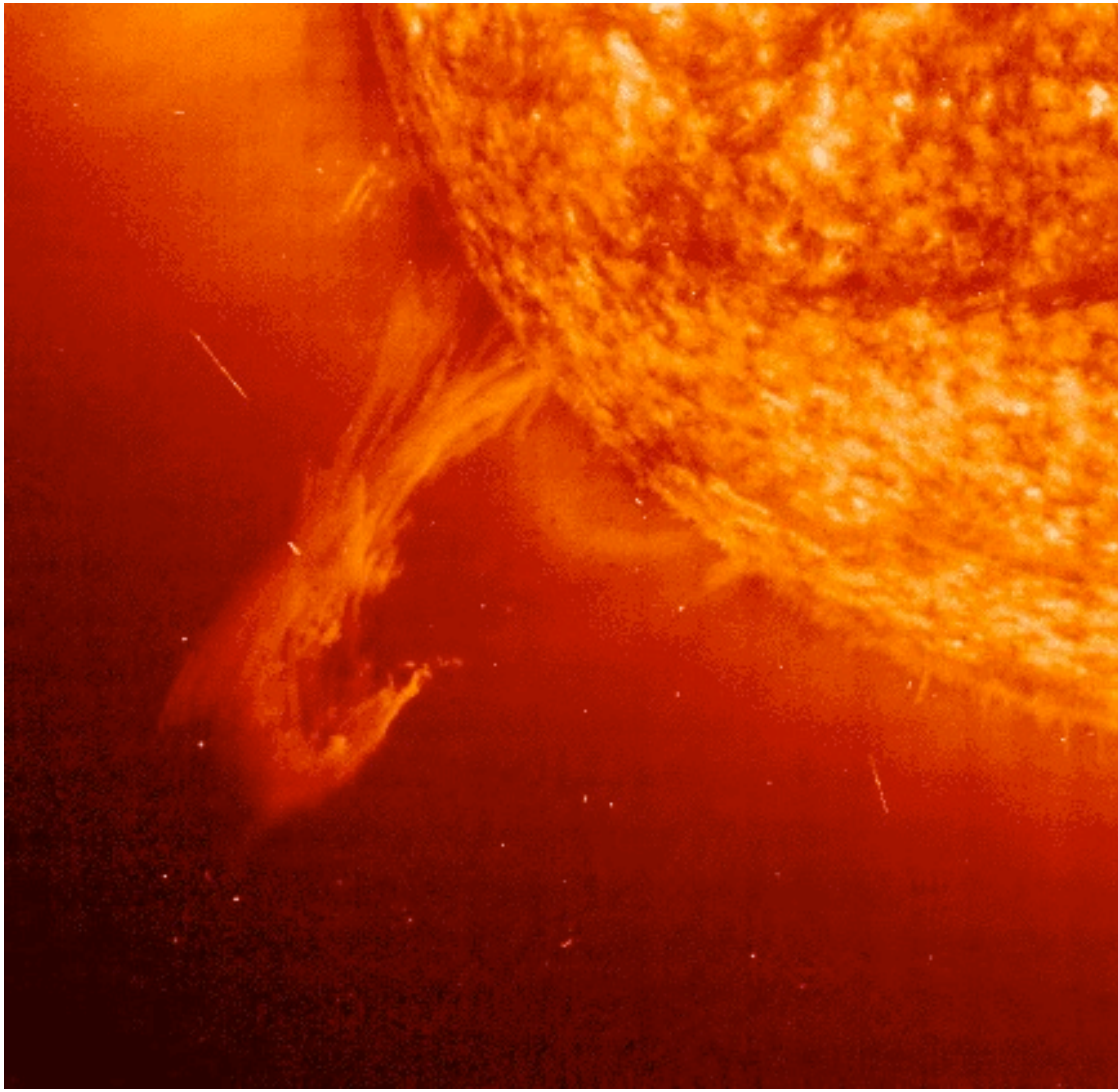
Solar Flares

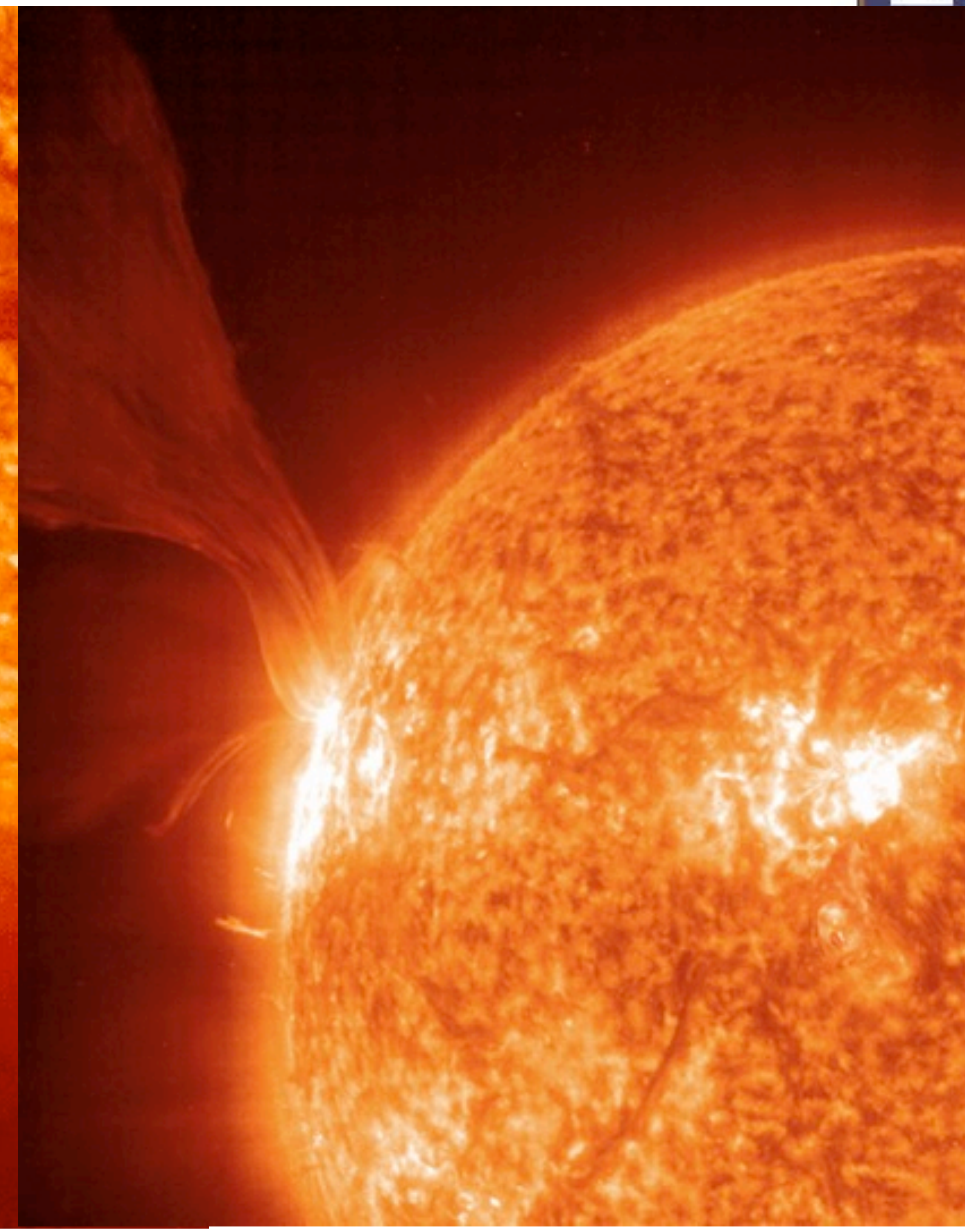
- Explosive releases of magnetic energy above sunspot groups
- Occur when magnetic loops get tangled
- A “short-circuit” of the magnetic field
- Think of it as cutting a coiled up spring.. It releases energy all at once.





Flares





Magnetic activity causes *solar flares that* send bursts of X-rays and charged particles into space from a sunspot group.

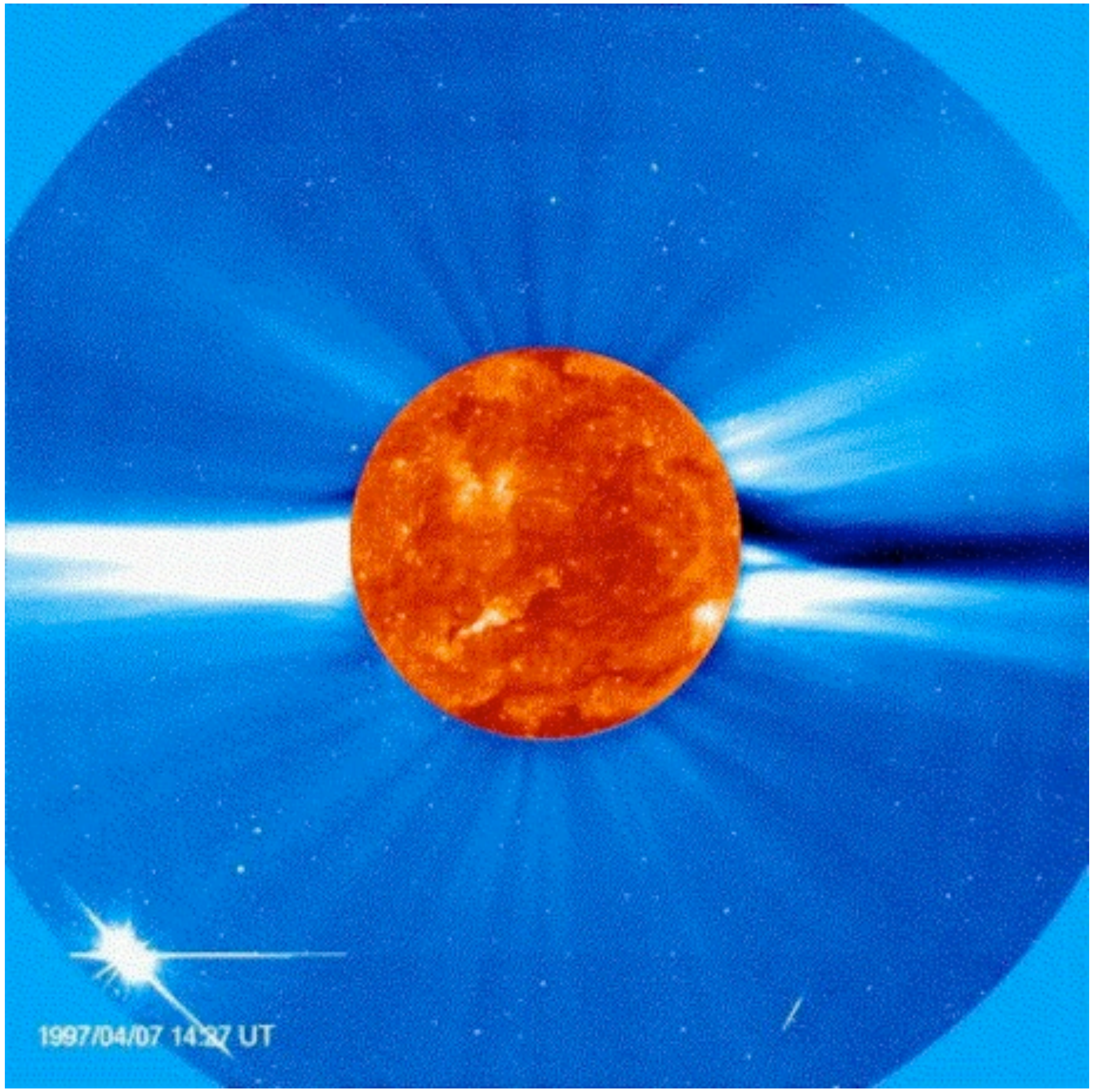
Coronal Mass Ejections

Huge bubbles of gas ejected from the Sun

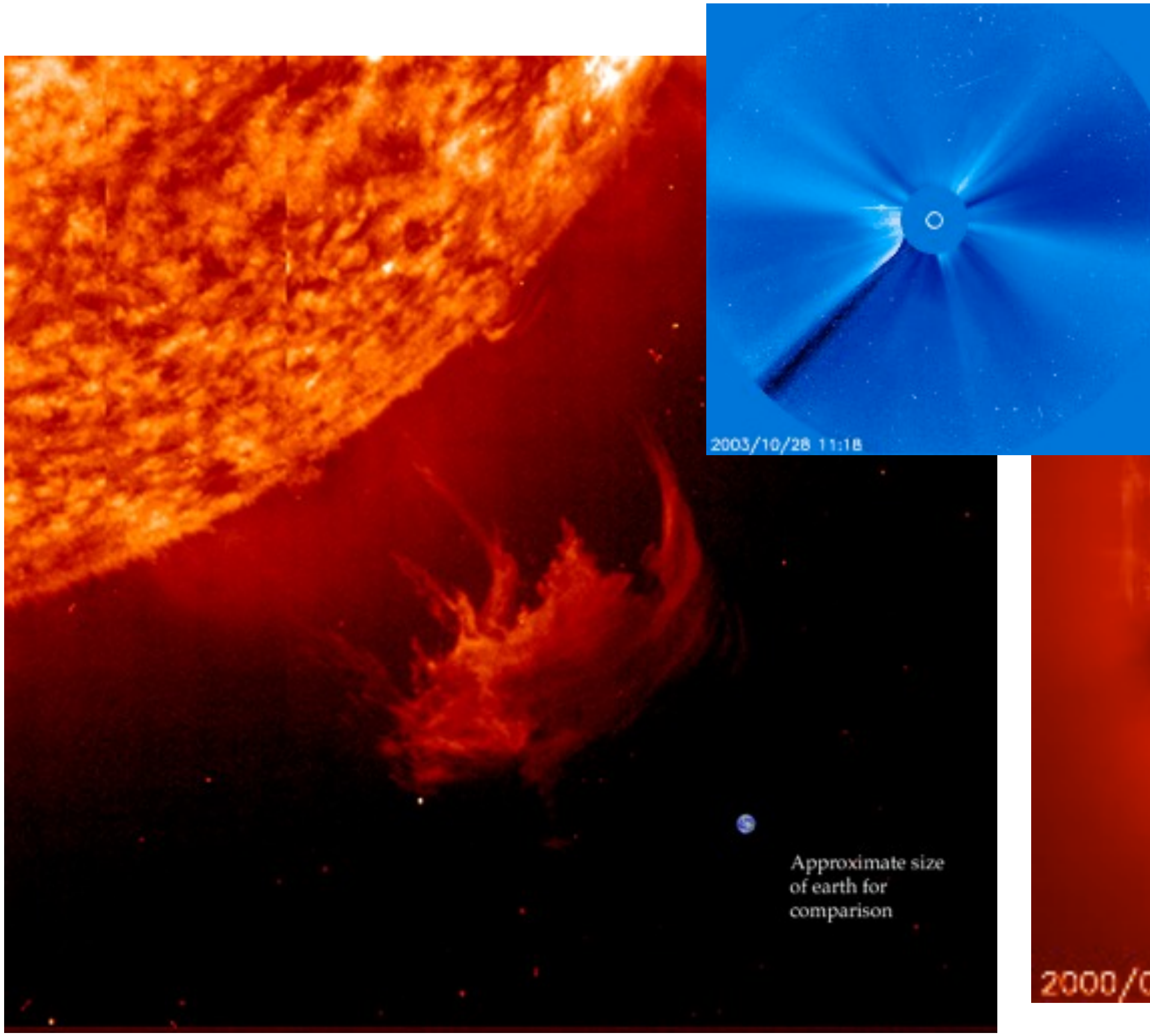
Often associated with flares and/or prominences

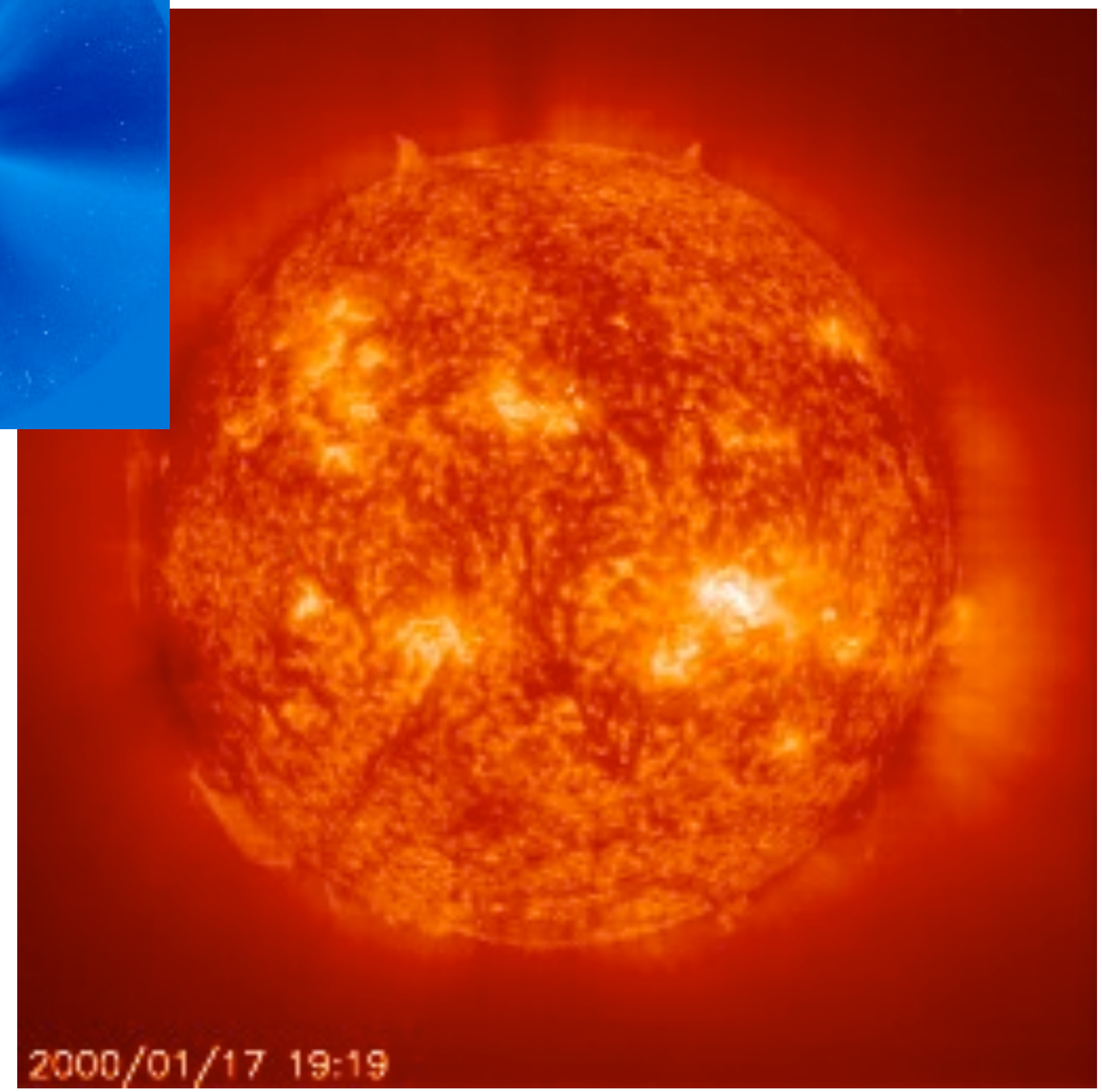
2 trillion tons of ionized gas hurled into the solar system

2-3 day at solar maximum
(1 per week normally)



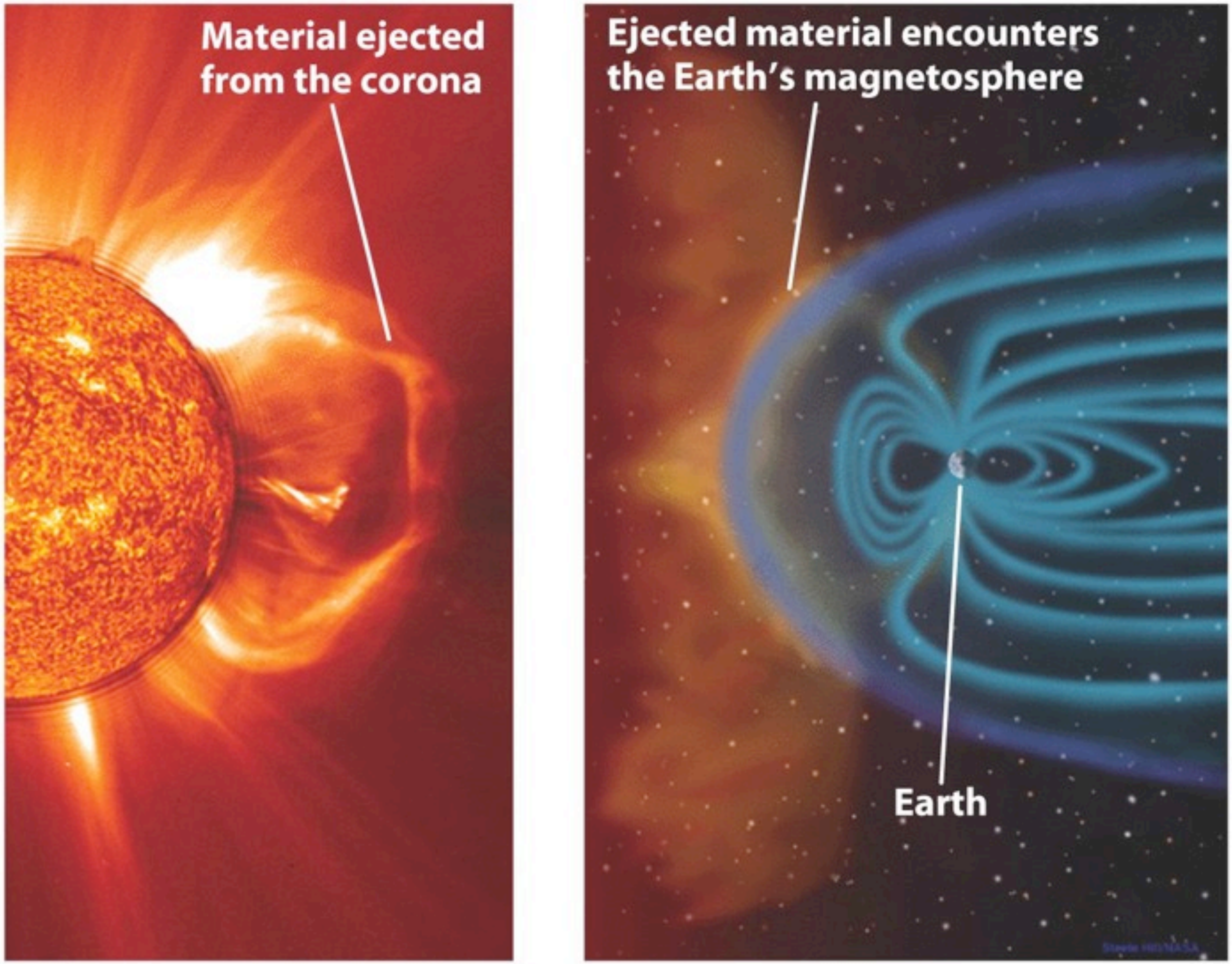
Coronal Mass Ejection: CME





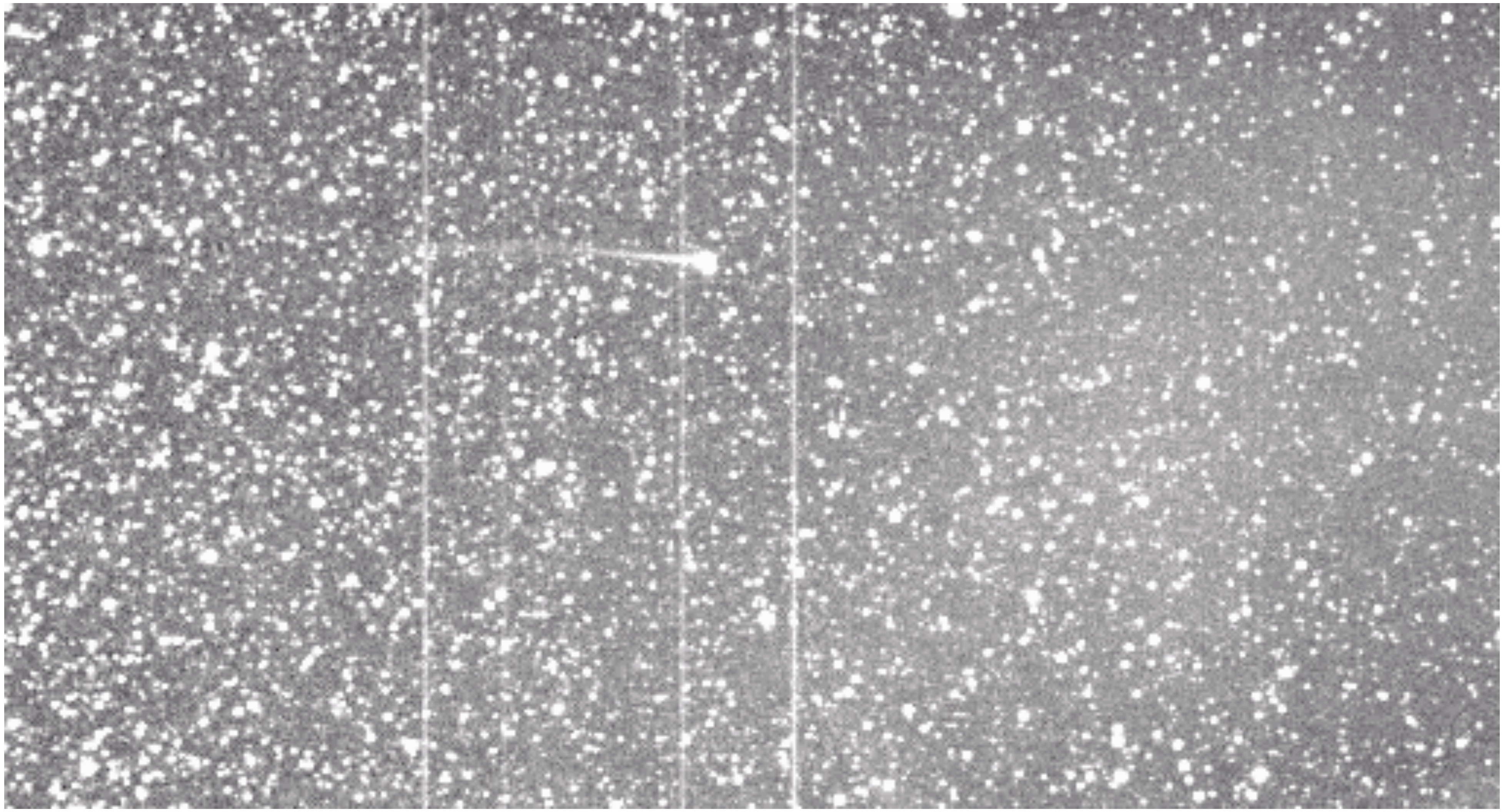
A coronal mass ejection is a much larger eruption (at once) than a solar flare. CMEs eject immense amounts of gas.

CMEs



(a) A coronal mass ejection (b) Two to four days later

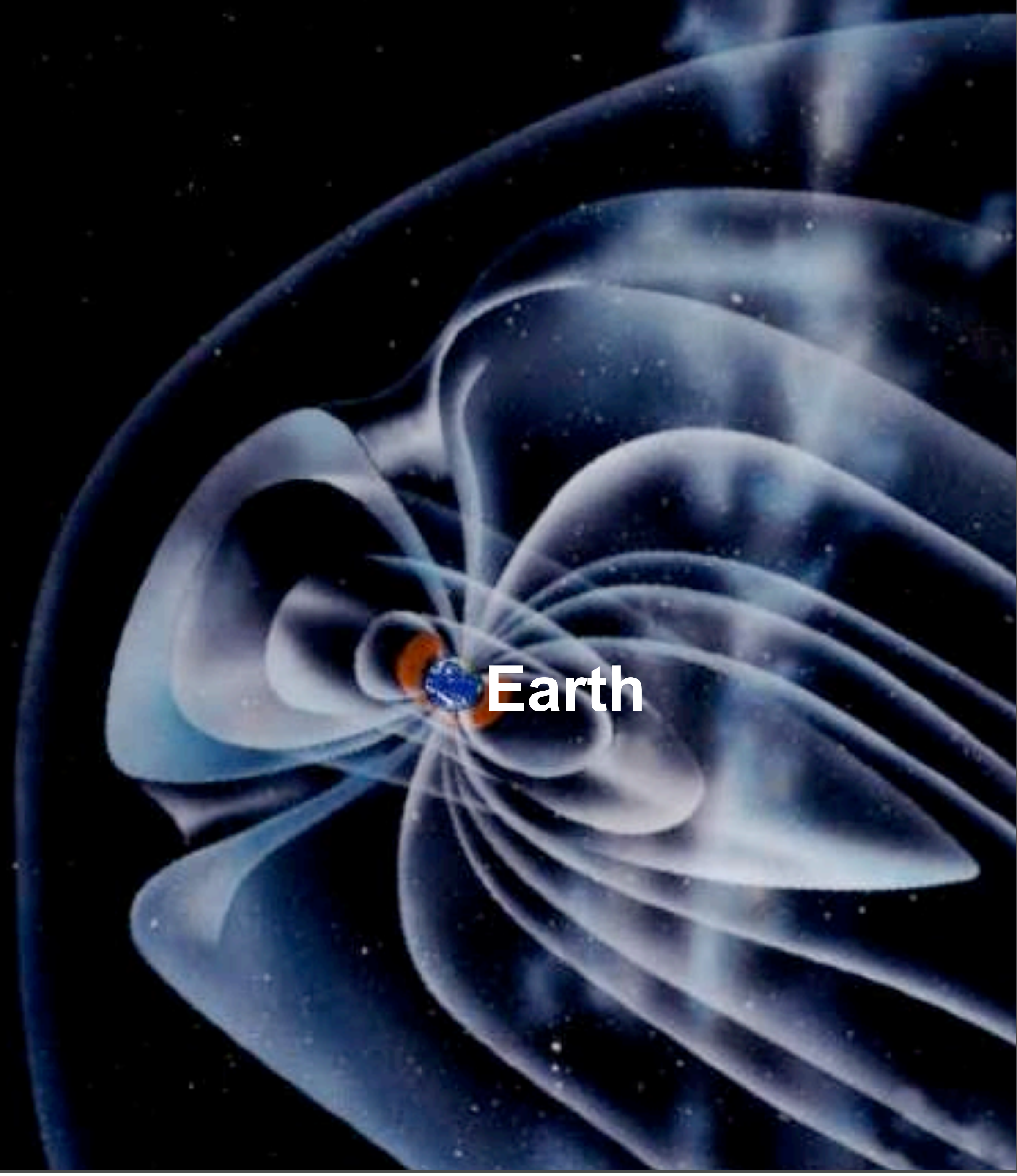
A CME Ripping Off Comet Encke's Tail



Space Weather:

What is it?

Space Weather refers to conditions in space that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health.



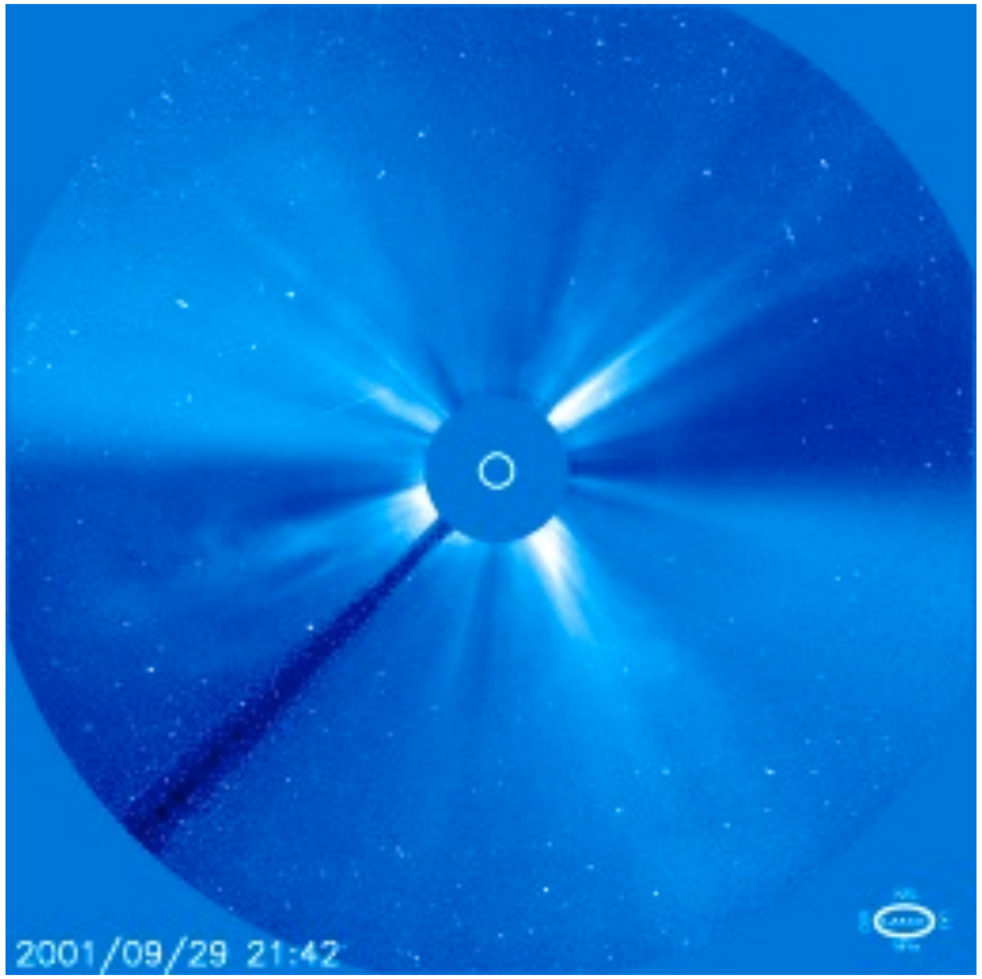
Sun:

- **Energy released in the form of photons, particles, and magnetic fields**

- **Sources of major disturbances:**
  - **Coronal Holes**
  - **Solar Flares**
  - **Coronal Mass Ejections**
  - **Solar Particle Events**

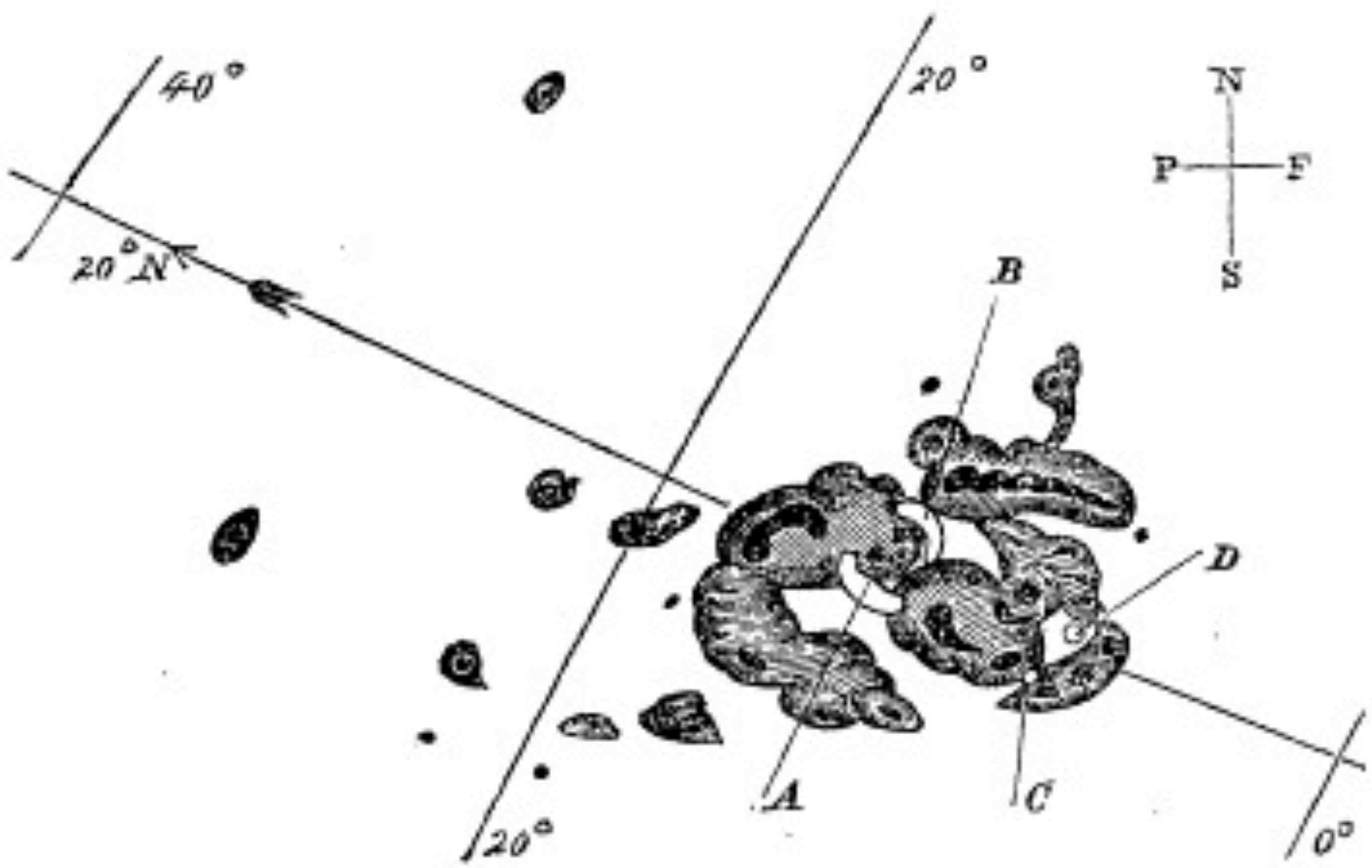
1859: The Perfect Space Storm

- Most CMEs don't hit the Earth.
- To hit, CME must be from the Sun's equator and in proper orbital phase.
- The bigger the more of an effect
- And, the magnetic field of the event can make a larger impact on the Earth.



Description of a Singular Appearance seen in the Sun on September 1, 1859. By R. C. Carrington, Esq.

While engaged in the forenoon of Thursday, Sept. 1, in taking my customary observation of the forms and positions of the solar spots, an appearance was witnessed which I believe to be exceedingly rare. The image of the sun's disk was, as usual with me, projected on to a plate of glass coated with distemper of a pale straw colour, and at a distance and under a power which presented a picture of about 11 inches diameter. I had secured diagrams of all the groups and detached spots, and was engaged at the time in counting from a chronometer and recording the contacts of the spots with the cross-wires used in the observation, when within the area of the great north group (the size of which had previously excited general remark), two patches of intensely bright and white light broke out, in the positions indicated in the appended diagram by the letters A and B, and of the forms of the spaces left white. My



first impression was that by some chance a ray of light had penetrated a hole in the screen attached to the object-glass, by

Monthly Notices of the Royal Astronomical Society, Volume 20, November 11, 1859

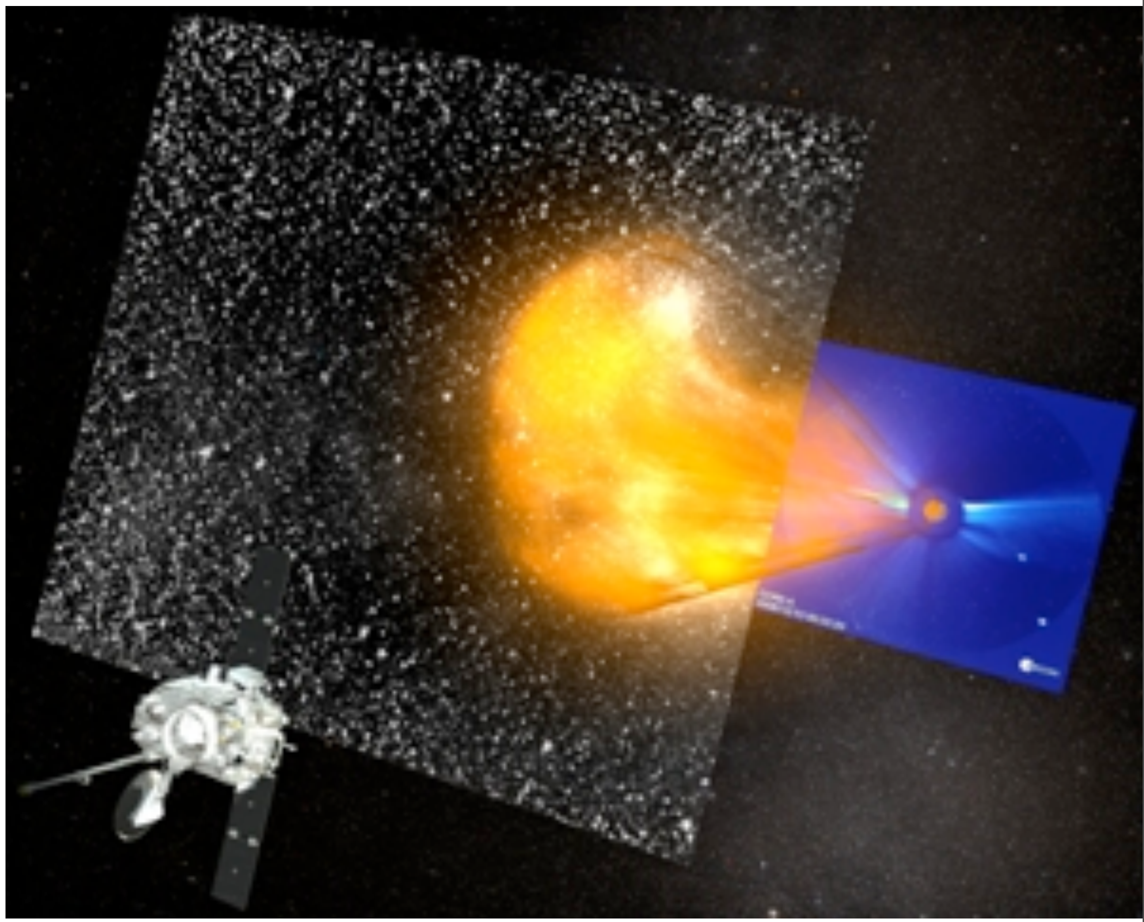
The great magnetic storm hit 18 hours later, traveling at 2300 km/s!

1859: The Perfect Space Storm

- Plasma blob ejected from the Sun right at the Earth.
- The blob had extremely high speeds
- The plasma blob's magnetic field were opposite from the Earth's field
- High technology at the time was telegraphs.
  - The charged particles overloaded the system
  - Melted wires, starting wildfires
  - Aurora were seen as far South as Rome and Hawaii

1958: Storm Hard

- Feb 1958 CME observed
- 28 hours later, one of the greatest magnetic storms
- Effects:
  - Toronto area plunged into temporary darkness
  - Western Union experienced serious interruptions on its nine North Atlantic telegraph cables
  - Overseas airlines communications problems



1989: Storm Hard

- March 13, 1989 – a CME knocked out a power transformer in Quebec
- Plunged 6 million customers into darkness!
- Affected power grids across North America