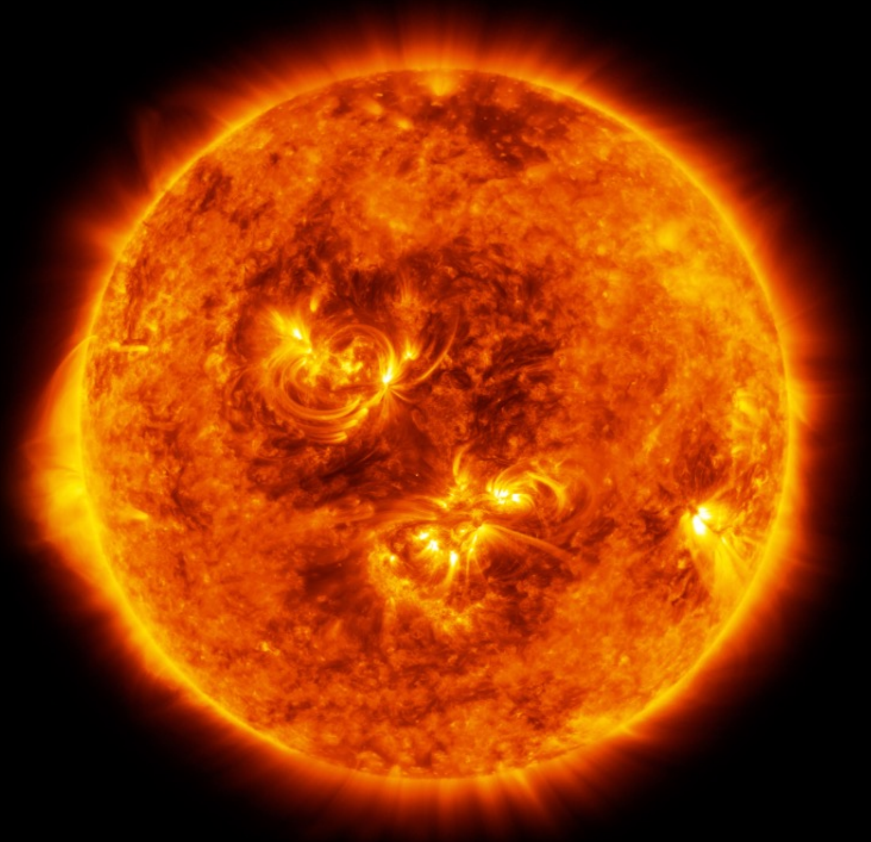
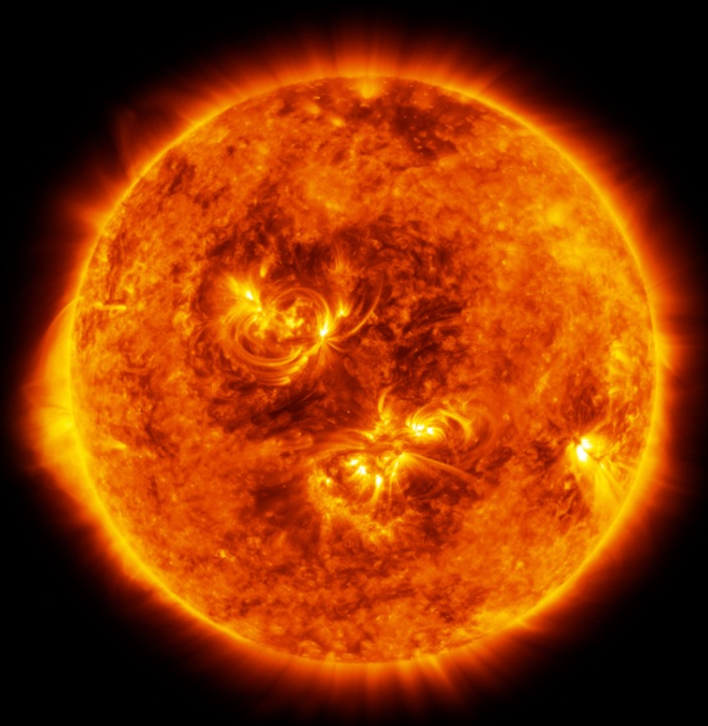
Astronomy 100
Chapter 8
The Sun



Vera Gluscevic

The Sun in numbers

- Radius = ~110 Earth radii (696,000 km)
- Mass = ~300,000 times mass of Earth (2×10^{30} kg)
- Luminosity = ~4×10^{26} watts
- Composition: 70% Hydrogen, 28% Helium, 2% heavier elements.
- Temperature:
    - Surface: 5,800 K
    - Core: ~15 million K
    - Corona: 1,000,000 K



Plan for this lesson:

Sun has layers.

Sun shines.

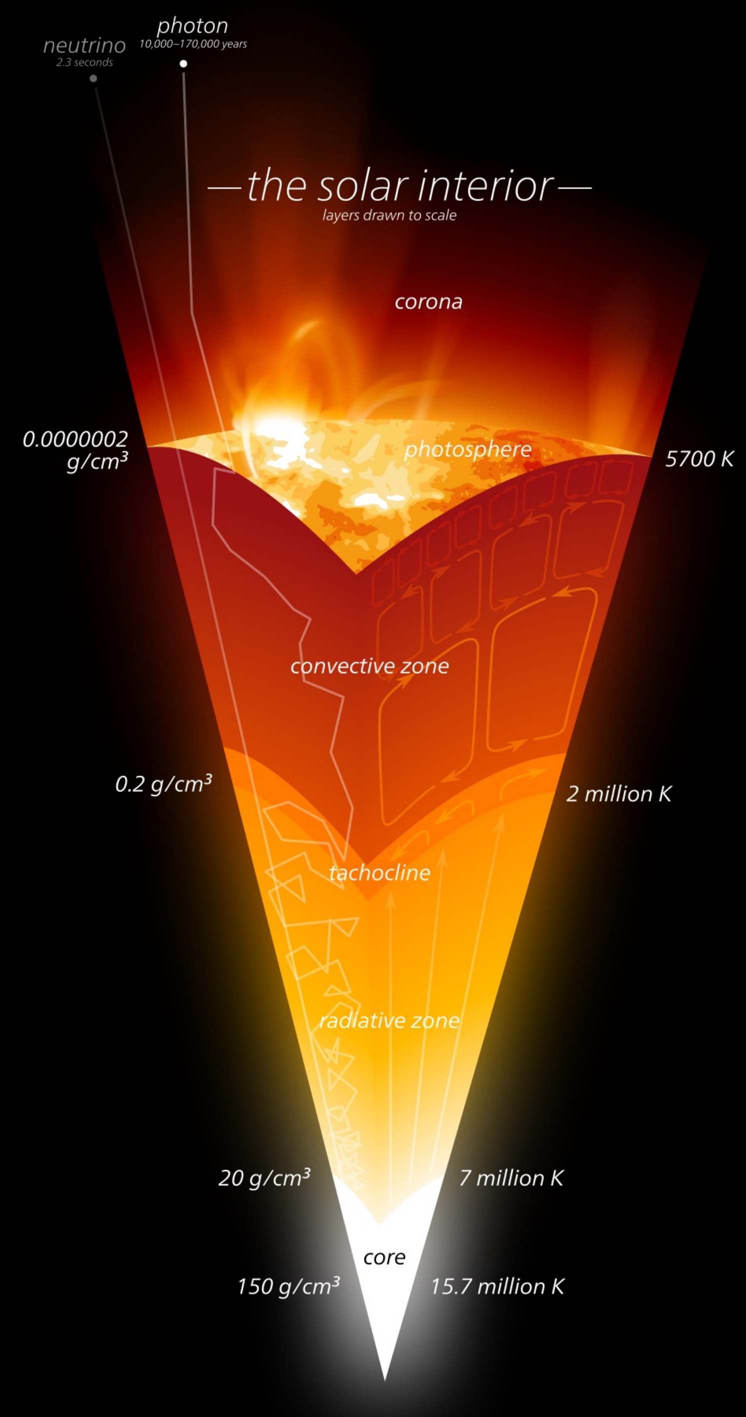
Sun is stable.

Sun is active.

Sun has layers.

The Sun's interior

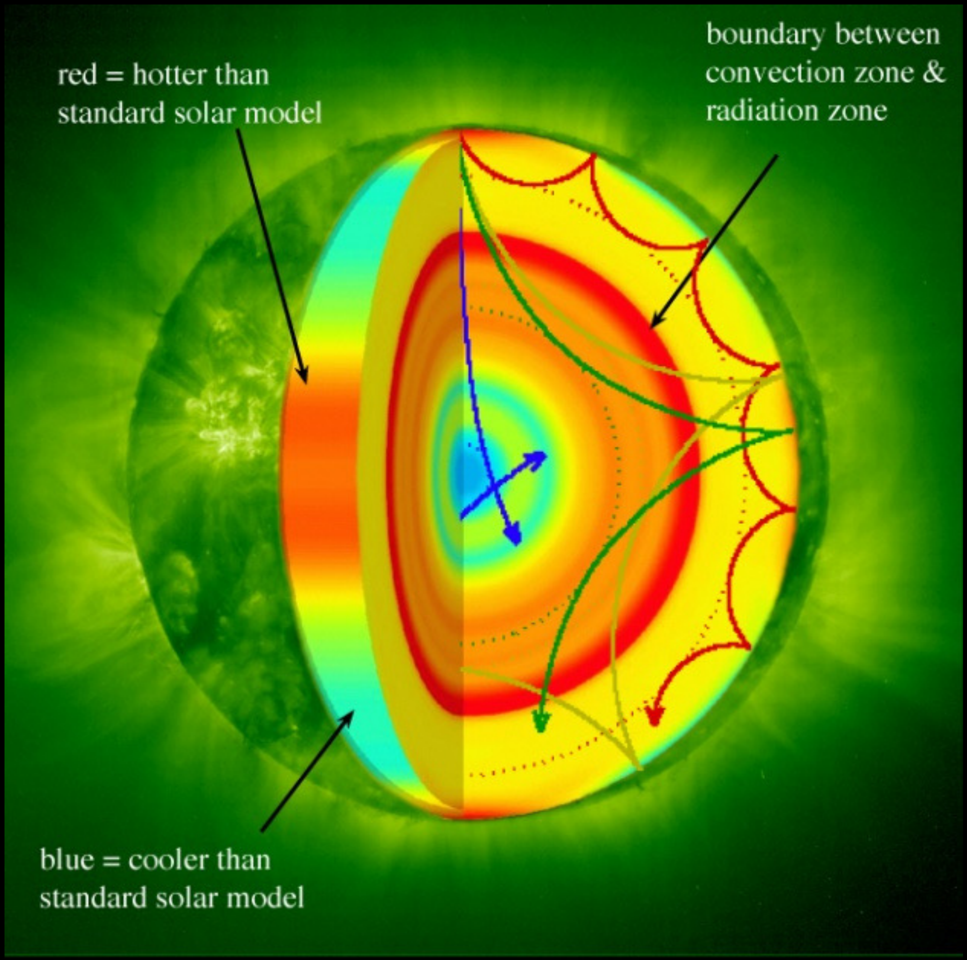
- From inside out, the main layers of the Sun's interior are:
  - core
  - radiative zone
  - convective zone
  - photosphere (first layer of its atmosphere).
- Nuclear fusion occurs in the dense, hot core.
- Newly formed photons diffuse outward through the **radiative zone**.
- In the **convective zone**, heat rises to the surface by convection.



How do we know about the Sun's Interior?

How do we know about the Sun's Interior?

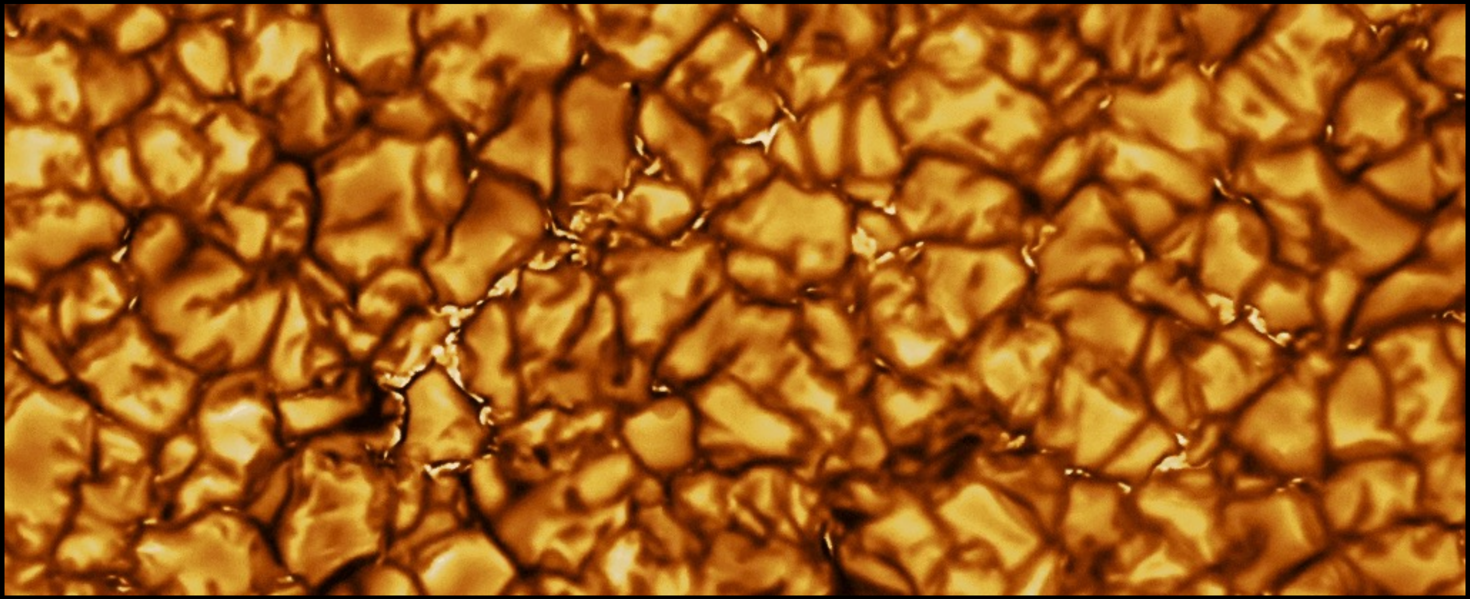
Helioseismology – tracking sound waves through the Sun.



Helioseismology

The Sun's visible "surface"

"Granulated" **photosphere** is the surface of the Sun. That's the deepest layer we see (below it, the Sun is opaque, but it isn't solid!).



NSO/NSF/AURA

The Sun's atmosphere

- **Chromosphere:** layer above photosphere.
- **Corona**: tenuous, hot, and visible only during solar eclipses.
- Sun's atmosphere is "carried away" by **solar wind**, extension of the corona.

Sun shines.

How does the Sun shine?

- Is it a large lump of burning coal?

  No… Sun would only last several thousand years and would have cooled considerably in the last hundred years.

- Does it use gravitational contraction?

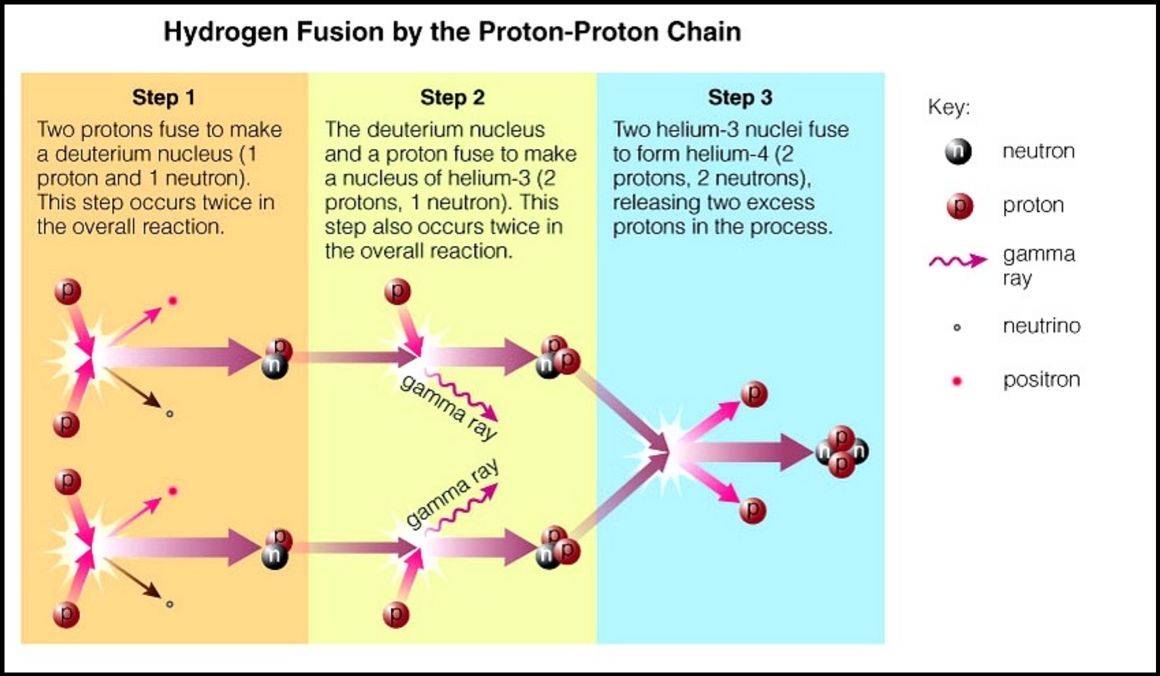
  No… Sun would only last 25 million years. The solar system is approx. 4.6 billion years old.

- It uses **nuclear fusion**!

The sun converts hydrogen to helium at a rate of **4 million tons per second.**

Nuclear fusion in the Sun

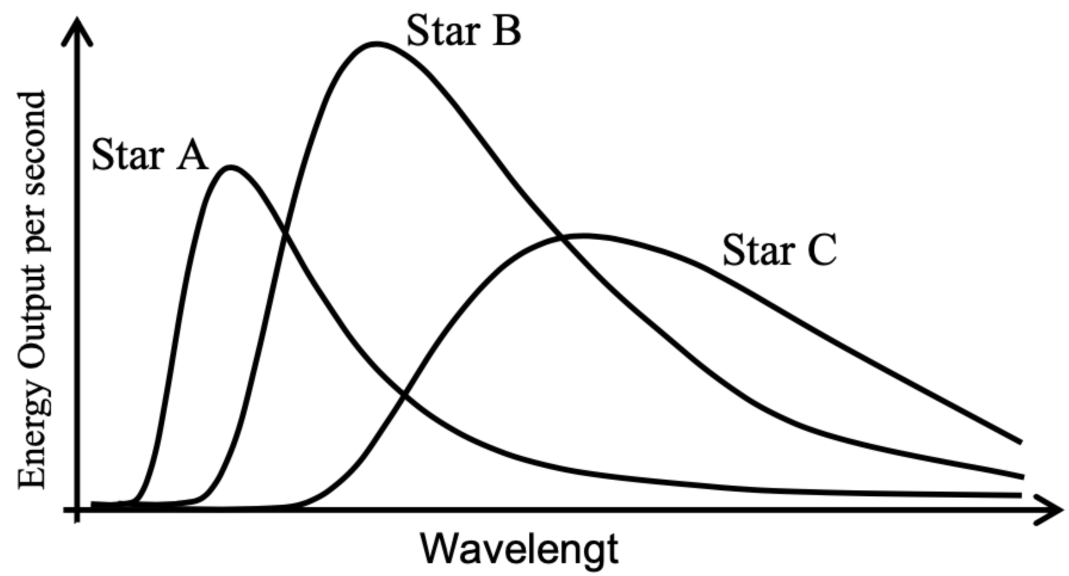
- All of the gas in the Sun is **ionized plasma**, which means that hydrogen atoms are broken into their nuclei (protons) and electrons.
- **Proton-proton chain:** protons collide (~10^{38} times each second) and fuse to form heavier nuclei, helium-4. This leads to buildup of helium-4 in the Sun's core.



Midterm 2: key correction!

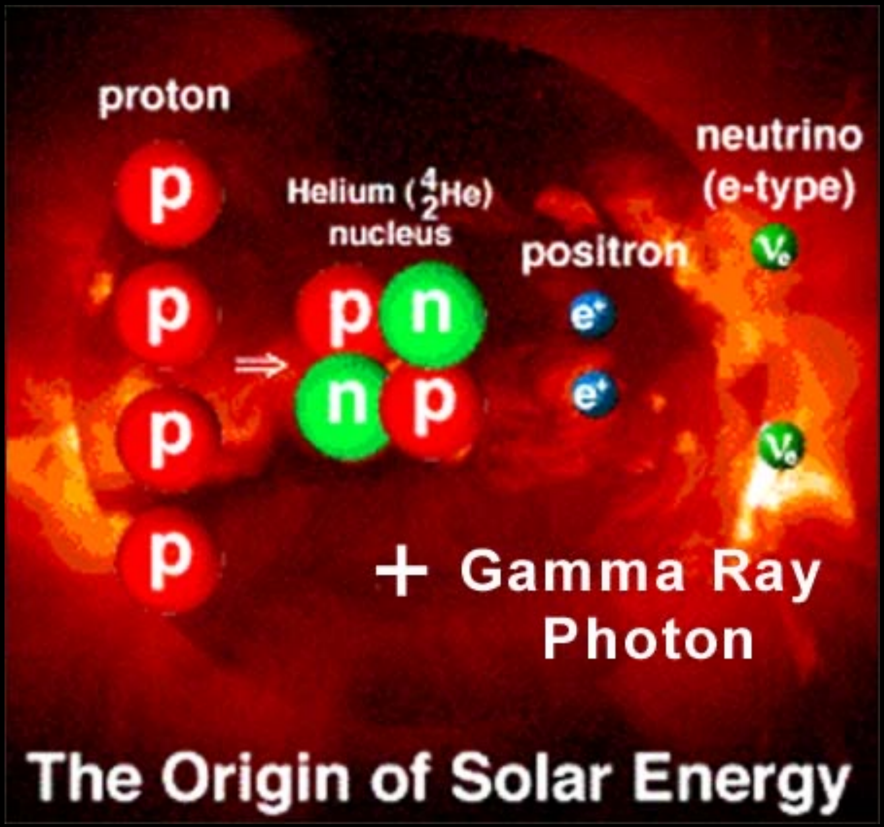
40. The graph at right shows the blackbody spectra for three different stars. Which of the stars is at the highest temperature?

    a. Star A
    b. Star B
    c. Star C



Nuclear fusion in the Sun

- 4 protons combine to produce 1 helium nucleus (2 protons, 2 neutrons).
- Helium nucleus is slightly less massive than four free protons.
- That difference in mass is converted into energy, in the form of neutrinos and gamma ray photons, **4 million tons each second.**



question for you

When a photon is produced in the Sun's core, it takes about **a million years** until it reaches the surface. Why?

A. Because it takes a zig-zag path, colliding with the electrons and nuclei on the way.
B. Because it takes a million years for light to travel the distance of one solar radius, moving at 300,000 km/sec.
C. Because the photon experiences gravitational redshift and slows down, trying to escape solar gravity.
D. Because the Sun created time delay effect, making it seem like the time is much longer than it really is.

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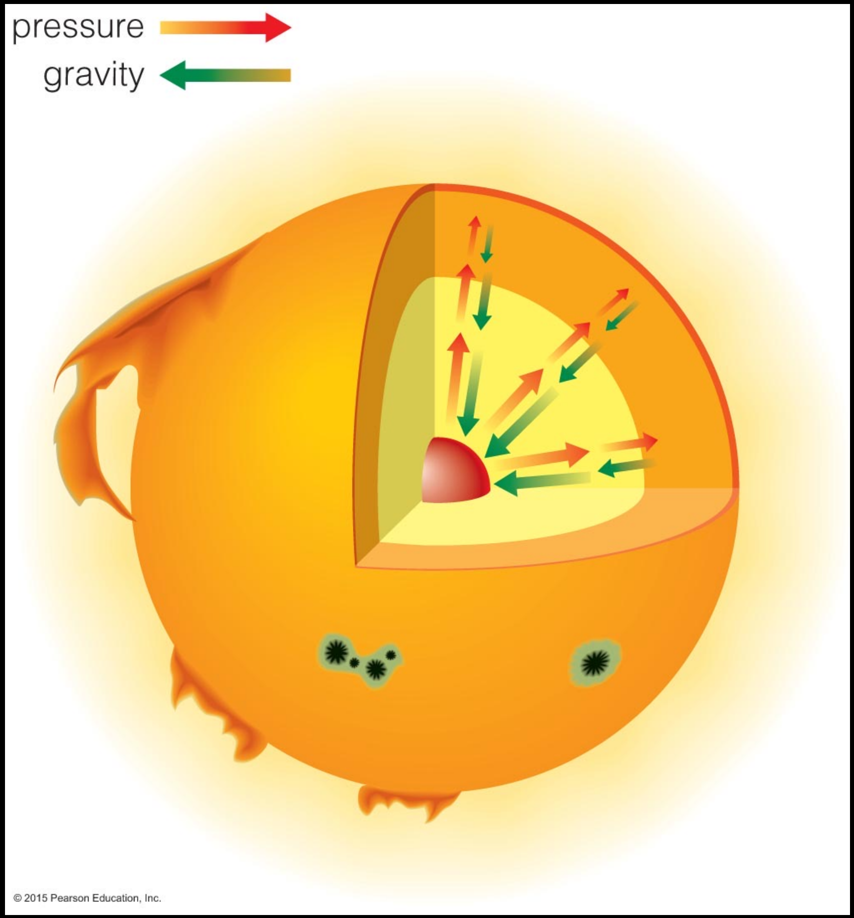
Sun is stable.

Hydrostatic equilibrium

- Sun is **not** changing its size.

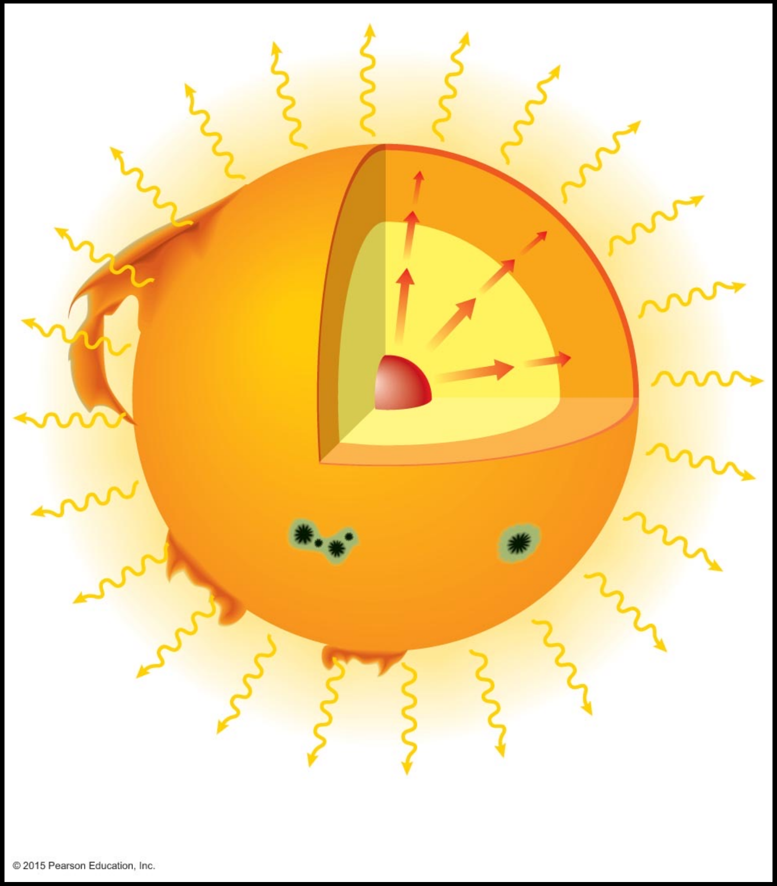
=> The inward push of gravity is balanced by the pressure of hot plasma and radiation pushing outward.



Energy balance

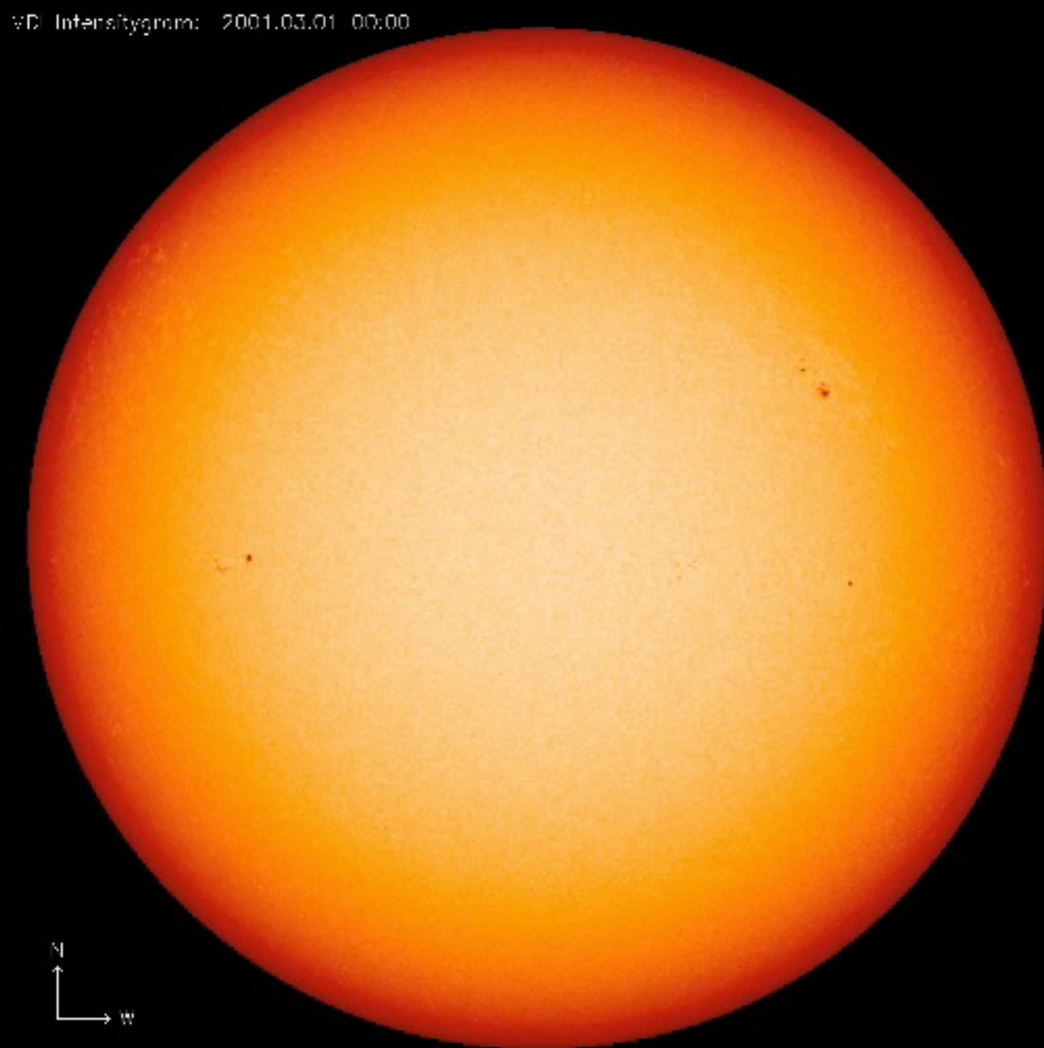
- Energy is released by nuclear fusion inside the Sun’s core.
- Energy is radiated away from the Sun’s surface.

=> The rate of fusion in the core must match the rate at which the Sun can radiate this energy away.

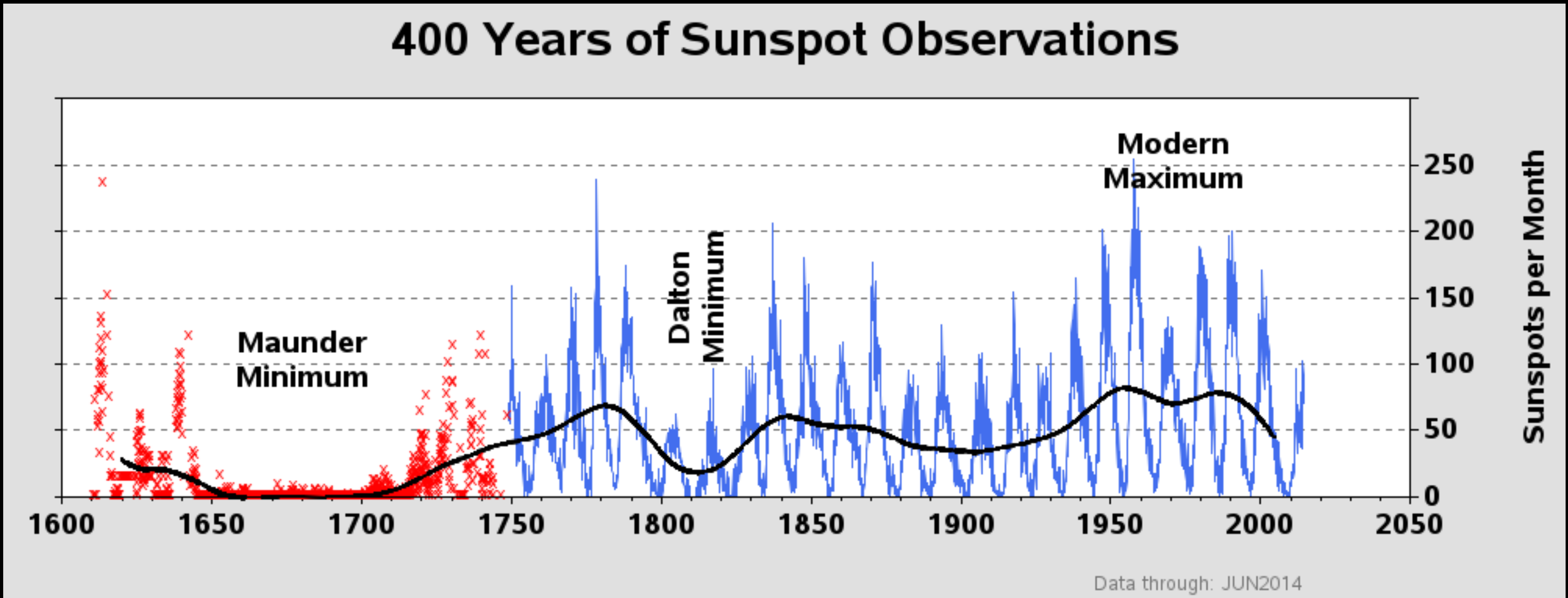


Sun is active.

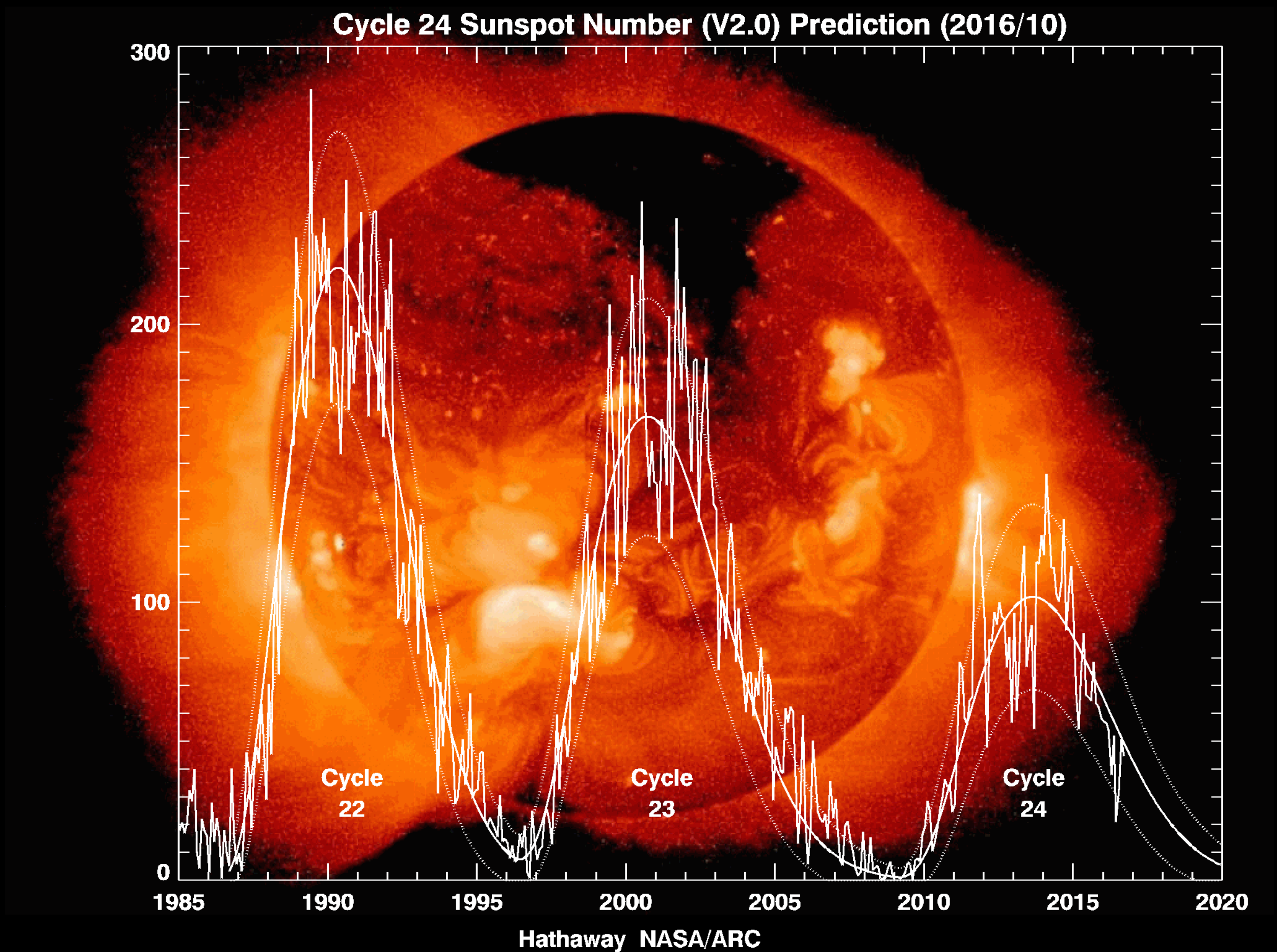
Sunspots



The sunspot cycle repeats every 11 years (more sports occur when Sun is near the peak of activity).

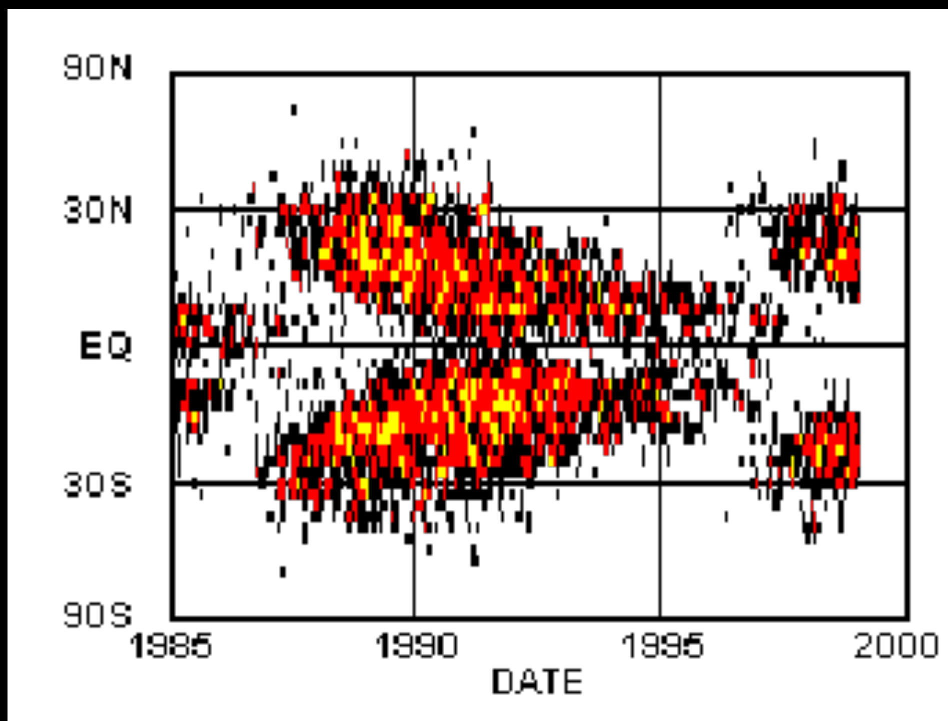


The sunspot cycle

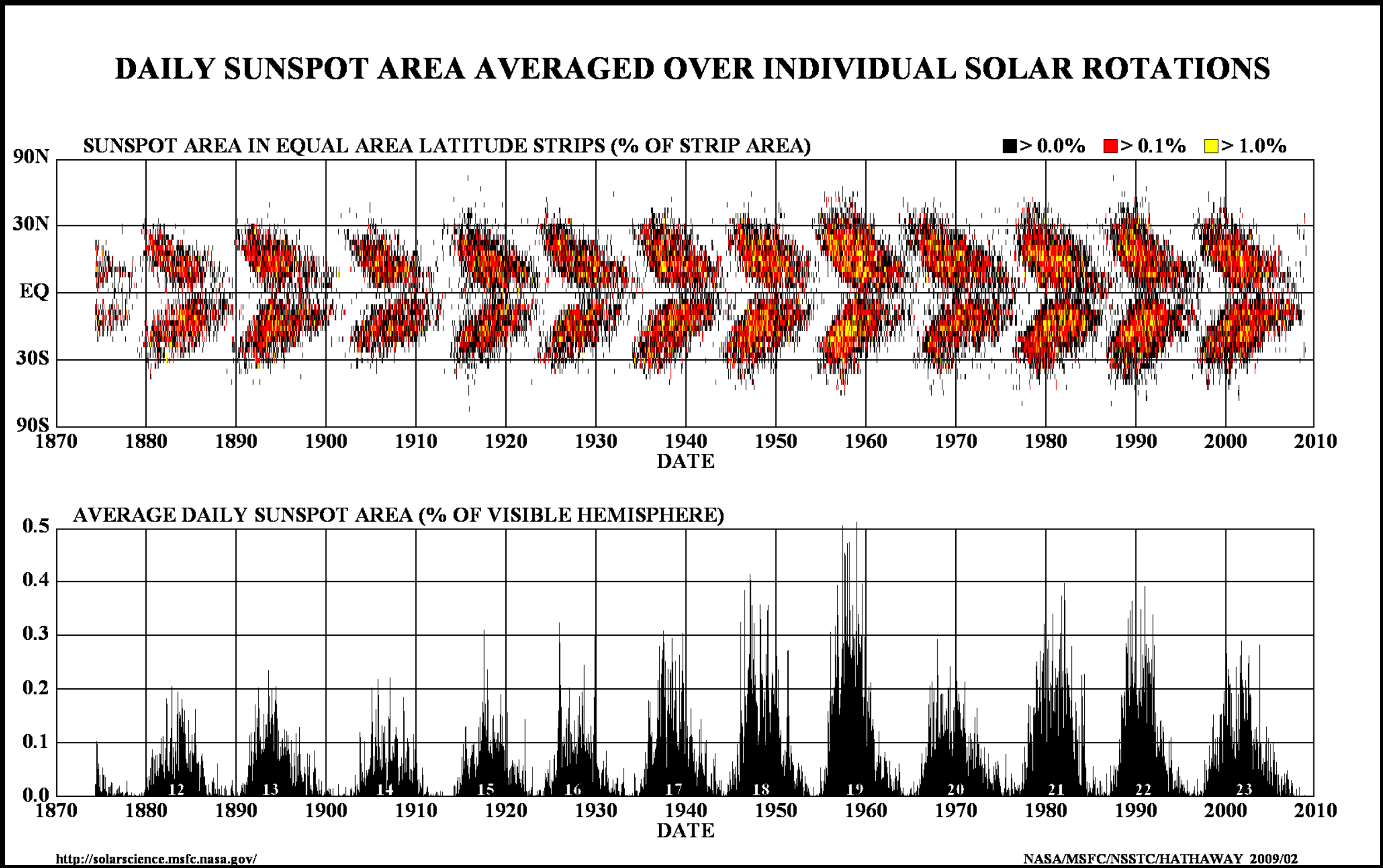


The "butterfly" diagram

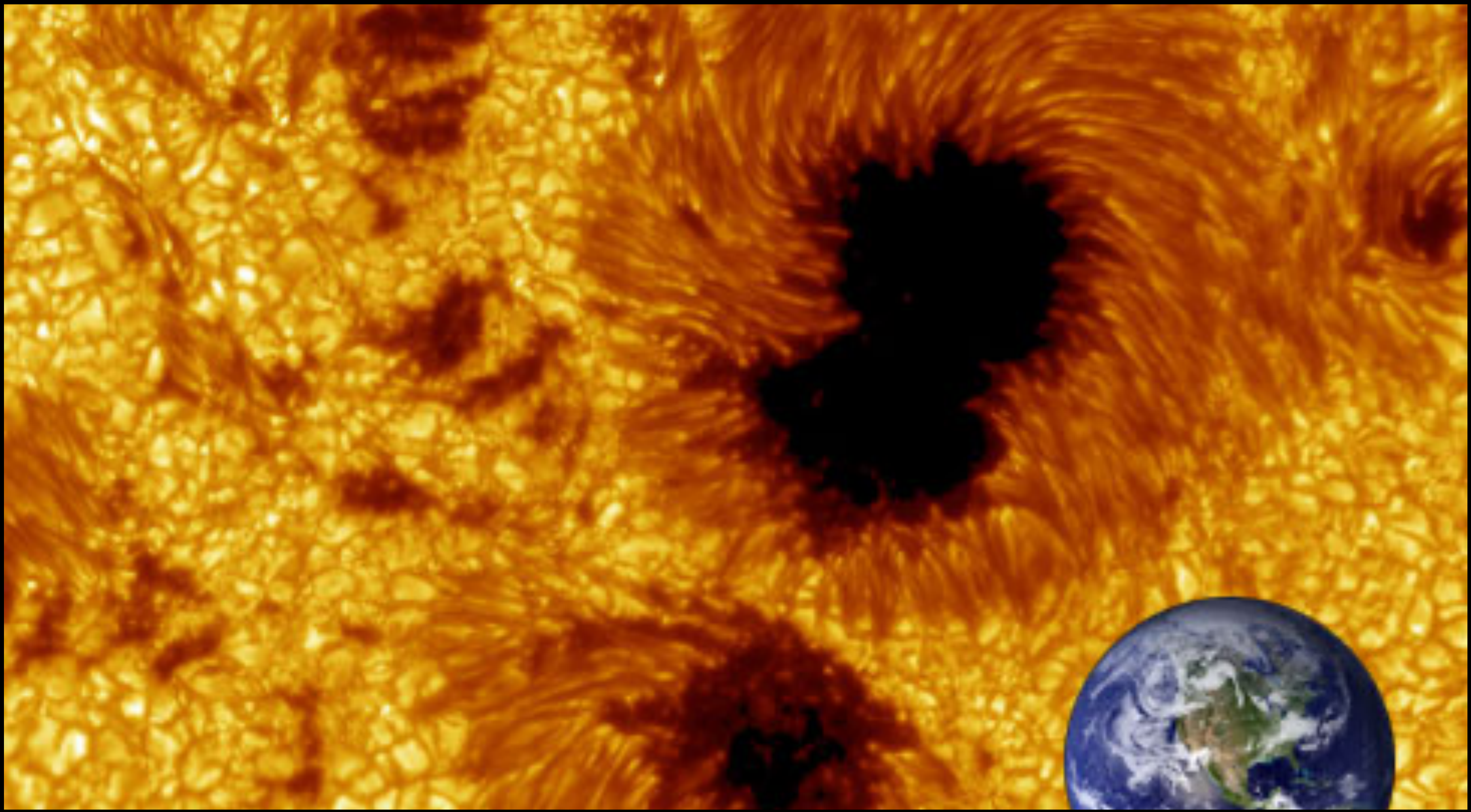
At the beginning of sunspot cycle, sunspots appear between 20 and 30 degrees N and S latitude, then migrate towards the equator and diminish later in the cycle.



The sunspot cycle



What are sunspots?



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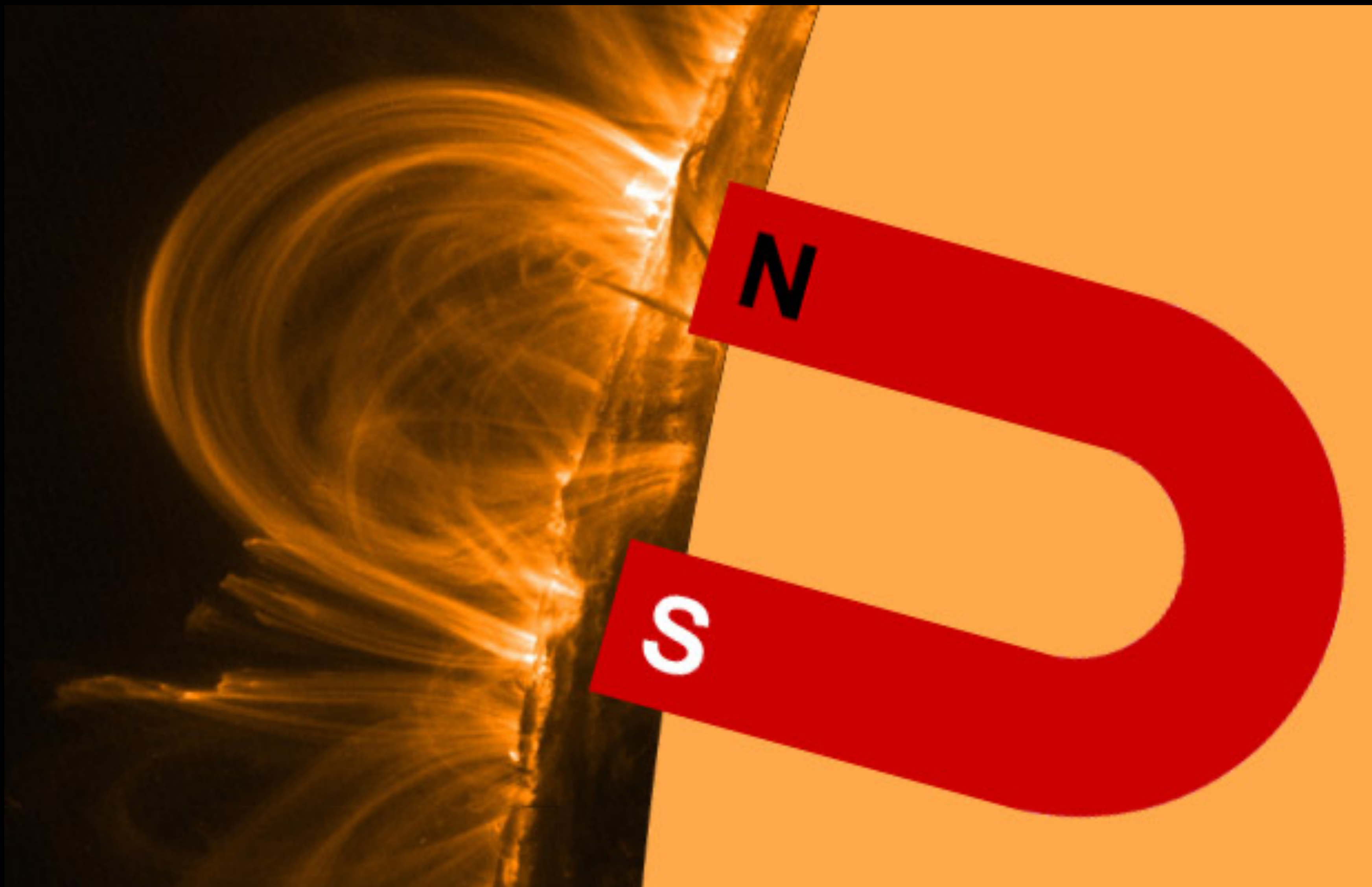
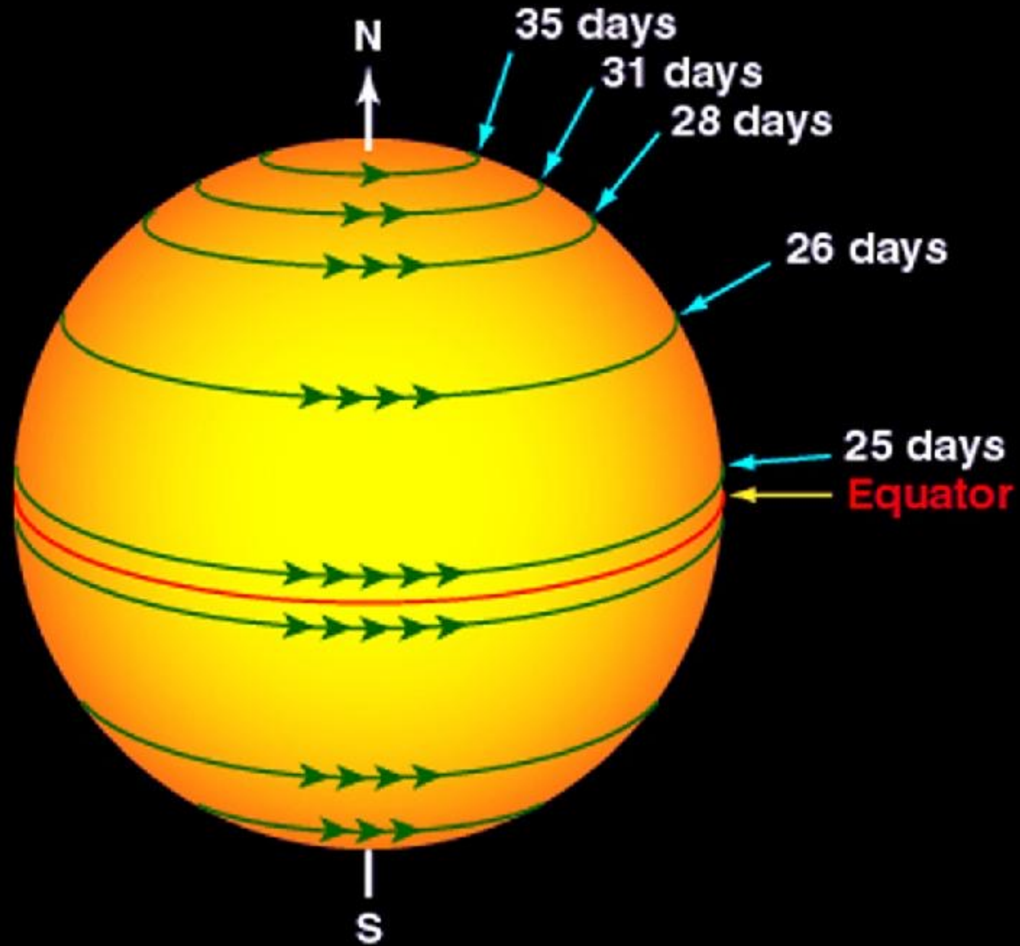
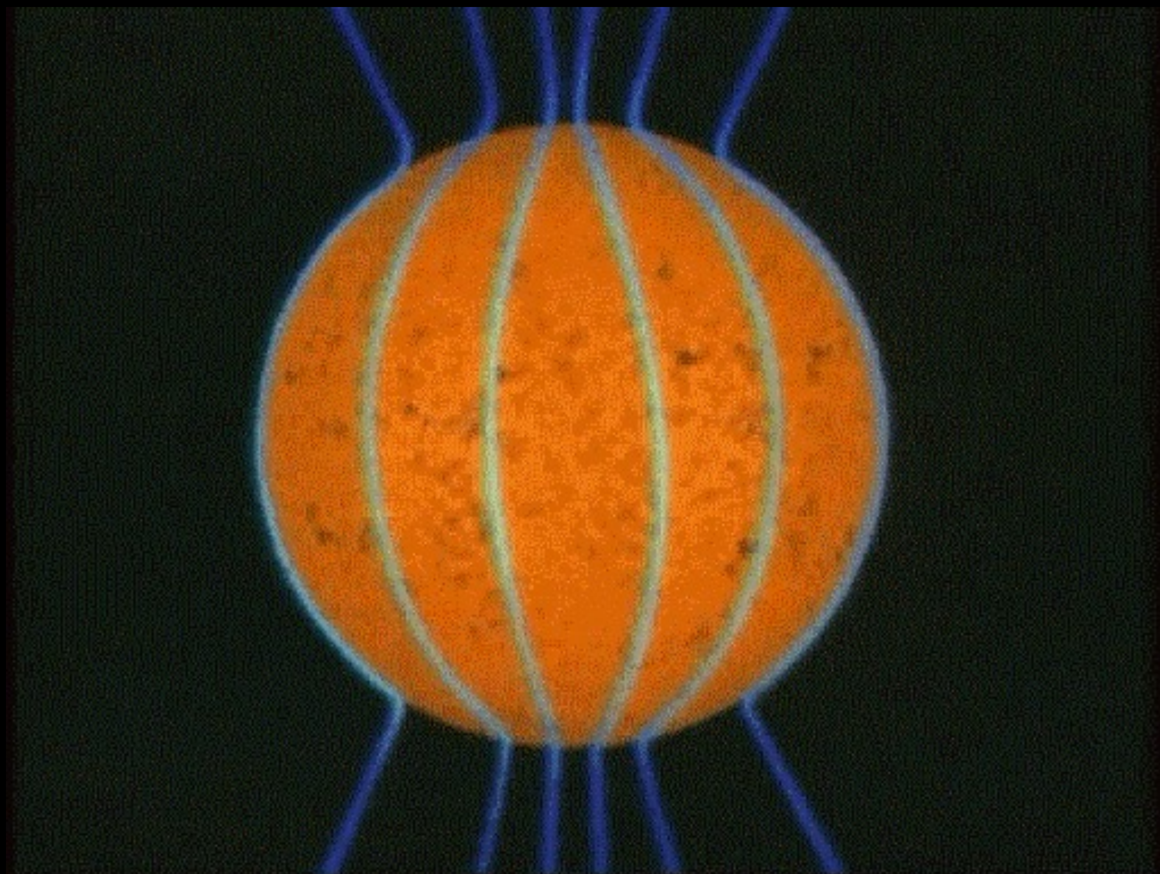


Sun's rotation

Rotation rate: about a month.
(25 days at equator to 35 days at poles)



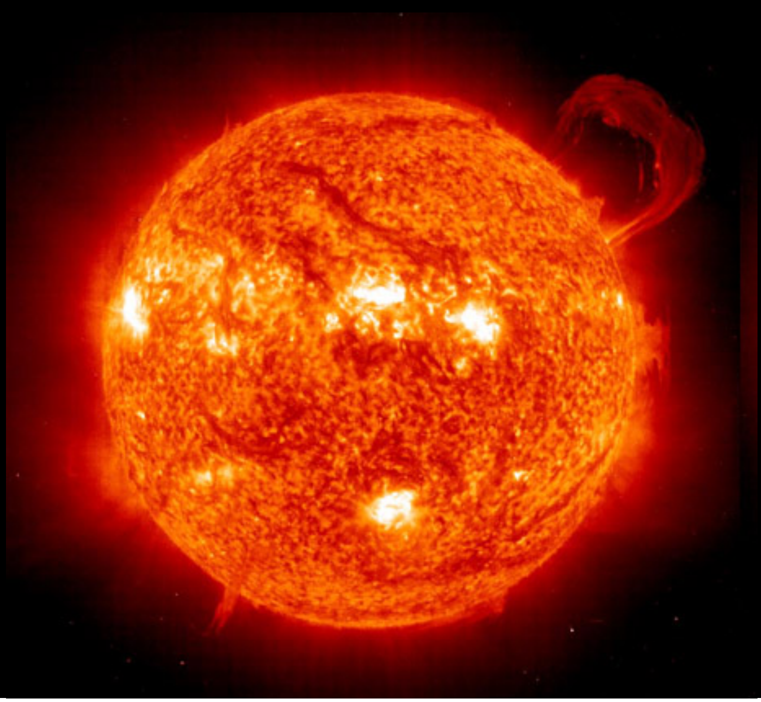
Magnetic activity of the Sun

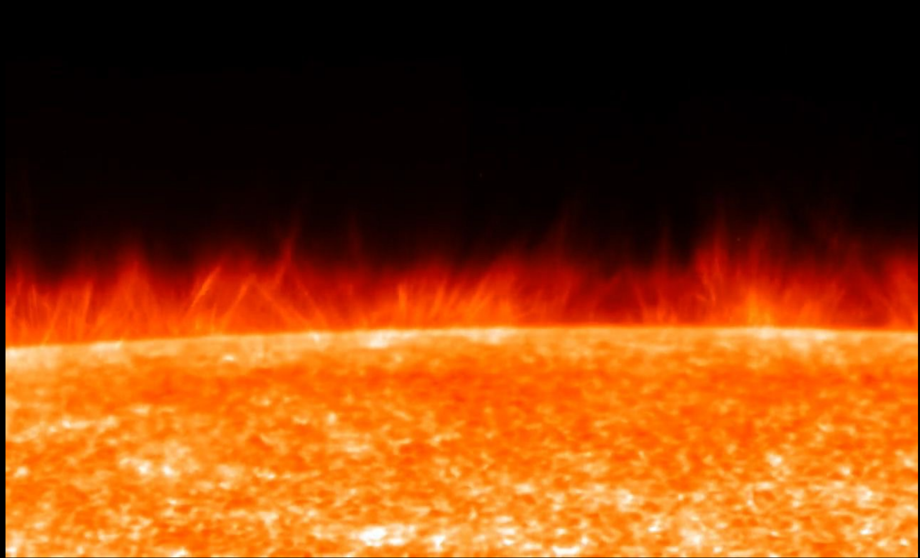


Magnetic activity of the Sun

Magnetic activity of the Sun

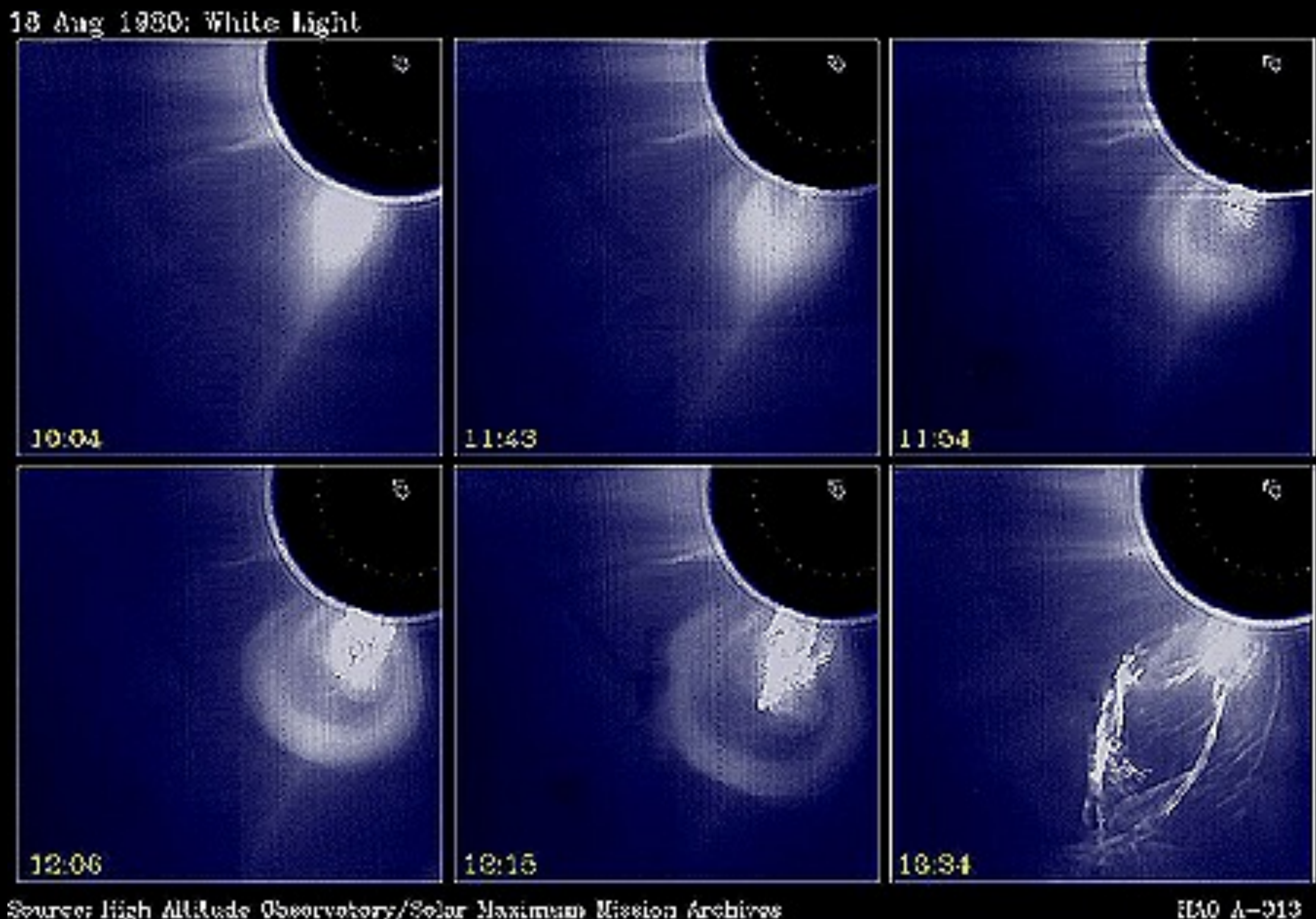
- **Prominence** = bright, dense, cool arched cloud of ionized gas in solar atmosphere. It can last or months and appears as a dark **filament** as it projects onto the photosphere.
- **Solar flare** = sudden and brief, explosive release of magnetic energy that heats and accelerates the gas in the solar atmosphere, releasing lots of x-rays and photons.
- **Spicules** = short-lived jets of plasma shooting from the surface, in high magnetic flux regions, lasting about 15min.





Solar flare

Solar flares lead to **coronal mass ejections**: large clouds of energetic magnetized plasma erupting from the corona into space, causing radio and magnetic disturbances on the earth.



3d view from NASA STEREO mission


The Aurora

CME and the Earth

Geomagnetic Storm

- Historical definition referred to a worldwide magnetic disturbance lasting anywhere from 6 to 24 hours.
- First, the x-rays from the flare site reach the earth, ionizing atmospheric particles. Short radio communications are disrupted for minutes to hours.
- Next, within several hours, solar energetic particles reach the earth and cause large-scale radio blackouts that last for days (polar cap absorption events).
- Finally, CME arrives as a “magnetic cloud,” causing auroras at lower latitudes and disrupting the Earth’s magnetic field.
- Solar proton events (energetic particles accelerated by the CME) do not reach ground level, but can be a problem if flying on an airplane over the poles, or if you’re an astronaut in space.
- Flares can cause power surges and damage to satellites.

What did we learn in Chapter 8?

- The Sun contains 99.9% of the mass of the solar system.
- The sun undergoes differential rotation, with the equatorial region rotating faster than the poles, for an average rotation period of 28 days.
- The Sun is 98% hydrogen and helium, with trace elements making up the rest.
- The core of the Sun is 15 million K, while its surface is 5800 K.
- The Sun generates its power through nuclear fusion of hydrogen into helium in its core.

What did we learn in Chapter 8?

- The sun is in hydrostatic equilibrium (gravity pushing in, hot gas pressure pushing out) and in energy balance (all the energy generated in the core must be radiated to space).
- The sun's interior: core, radiative zone, convective zone.
- The Sun's interior layers are identified using helioseismology.
- The solar neutrino problem referred to the seemingly low number of neutrinos detected from the Sun.
- The sun's atmosphere: photosphere, chromosphere, corona (corona is 1 million K)

What did we learn in Chapter 8?

- Space weather is the effect of solar flares and geomagnetic storms on Earth and satellites in Earth orbit.
- Sunspots are cooler (by about 1000 K) than the Sun's surface, and are locations where the Sun's magnetic field has twisted out.
- The sunspot cycle is the 11-year cycle during which the number of visible sunspots increases to a maximum (solar max) and decreases to a minimum (solar min).
- Solar flares launch coronal mass ejections (CMEs) toward the Earth. CMEs can cause radio blackouts, enhance the radiation in Earth orbit and on trans-polar flights, cause failure of power grids, errors in GPS navigation, and result in spectacular auroral displays.