Announcements

- **Midterm 1** grades are on D2L
  - Average 76%
  - Answers are posted on D2L (Content -> Handouts)
  - Scantrons here if you want them
  - Remember that lowest midterm grade is dropped
- **Quiz 5** due on Monday, **Problem Set 5** for practice
- Today we start **Chapter 9**, The Sun

More Extra Credit

- **Extra credit opportunity 2: write a short summary of an astronomy story in the news**
  - must use at least 3 different sources
  - explain what it is, how it was done, why it's important
  - sources must be cited
  - ***must be in your own words – no copying and pasting from websites***
  - Due by **Friday March 14, email or paper copy**
  - +1% on grade
  - info on D2L

Astronomy 103

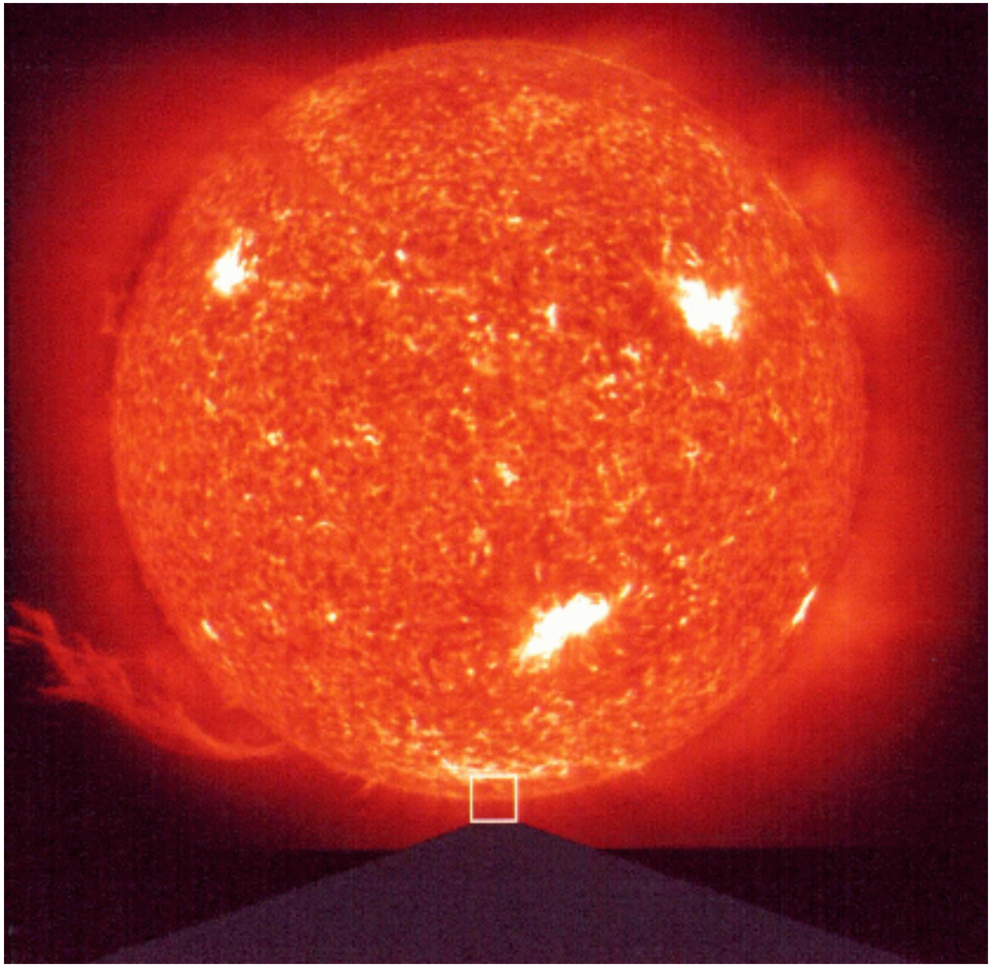
The Sun: Part I

Please read Chapter 9

Movie of the Sun from NASA's Solar Dynamics Observatory showing a solar flare that occurred on July 19, 2012. The flare was followed by a **coronal mass ejection** and a phenomenon known as **coronal rain**. The video shows extreme UV radiation with wavelength 30.4 nm, which traces very hot material at a temperature of about 50,000 K. Each second in the video corresponds to six minutes of real time.

see movie at https://www.youtube.com/watch?v=3Ghaf2du-XM

The Sun



The Sun is a star – the closest and most important star to us.

General Features

- Radius about 700,000 km, 100 times radius of Earth
- Composition: 3/4 hydrogen, about 1/4 helium by mass (90% of the atoms are hydrogen)
- Density: Roughly the density of water (1.4 times the density of water: 1.4 g/cm^3 or 1400 kg/m^3)
- Temperature very high at center (over 15 million K), dropping to 6,000 K near surface

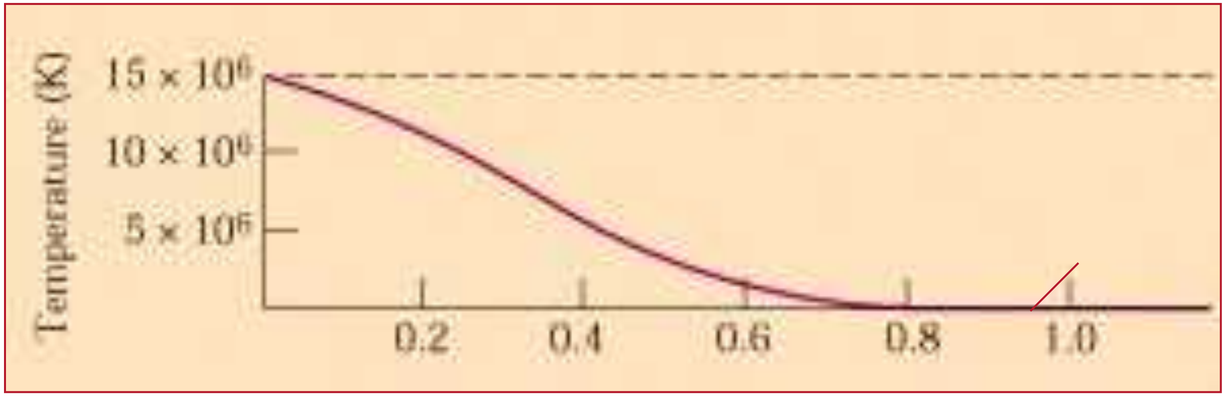


TABLE 9.1 Some Solar Properties

Radius	696,000 km
Mass	1.99×10^{30} kg
Average density	1410 kg/m^3
Rotation period	25.1 days (equator); 30.8 days (60° latitude) 36 days (poles) 26.9 days (interior)
Surface temperature	5780 K
Luminosity	3.86×10^{26} W

The radius of the Sun is more that 100 times the radius of the Earth, and the mass of the Sun is more than 300,000 times the mass of the Earth.

We know A LOT about the Sun - perhaps more than we know about the center of the earth.

$$\odot$$

This is the symbol for the Sun.

The mass of the Sun is written $M_\odot$ or solar mass. The masses of other stars are commonly given in terms of the Sun's mass. This will be important when we discuss other stars later in the course.

$$M_\odot = 2 \times 10^{30} \mathrm{kg}$$

Similarly, the radius of the Sun is $R_\odot = 700,000 \text{ km}$

Energy from the Sun

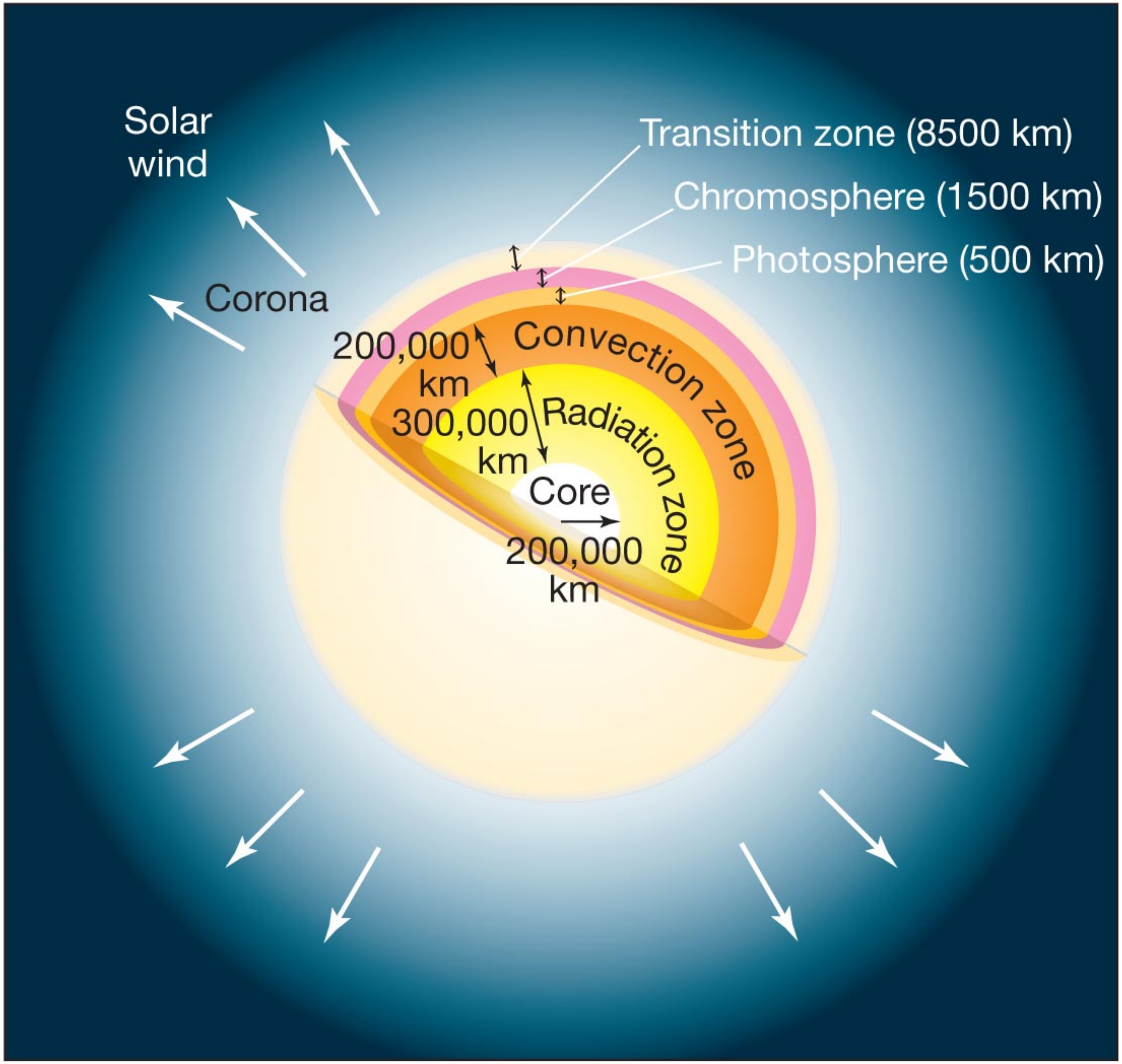
The amount of energy per second hitting each square meter of the Earth from the Sun is 1400 watts. This is called the **solar constant**. If you covered your ceiling with hundred-watt light bulbs, with 14 bulbs in in each square meter of ceiling, the room would be as bright as daylight.

- **The luminosity of the Sun is 4×10^{26} watts**

Total average power use by the entire world: About 10^{13} watts

A **watt** is a unit of **power**: energy per some unit of time.

Structure of the Sun



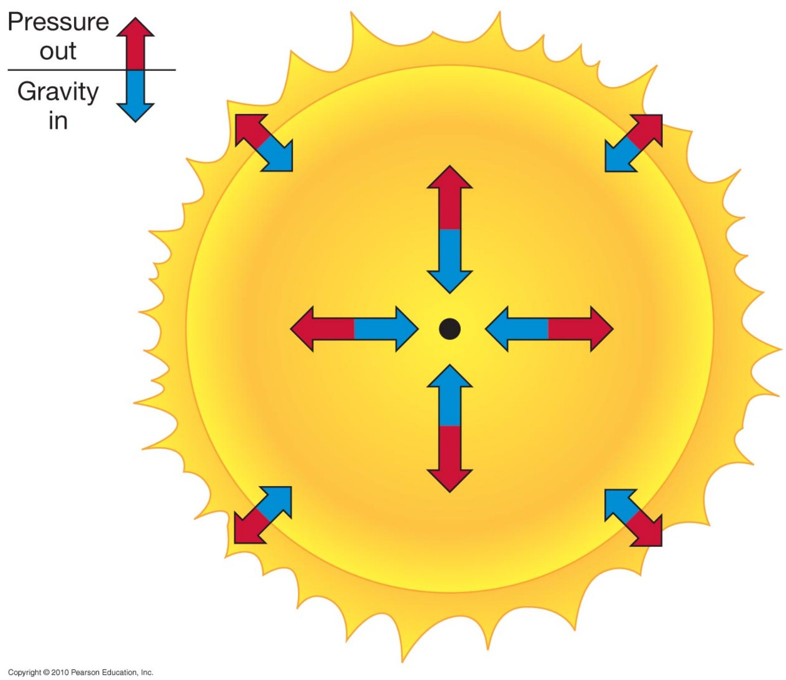
The Solar Interior

(core, radiation zone, and convection zone)

We cannot see inside the Sun. We use models and simulations to tell us what's going on inside it.

Models start from the idea of **hydrostatic equilibrium**:

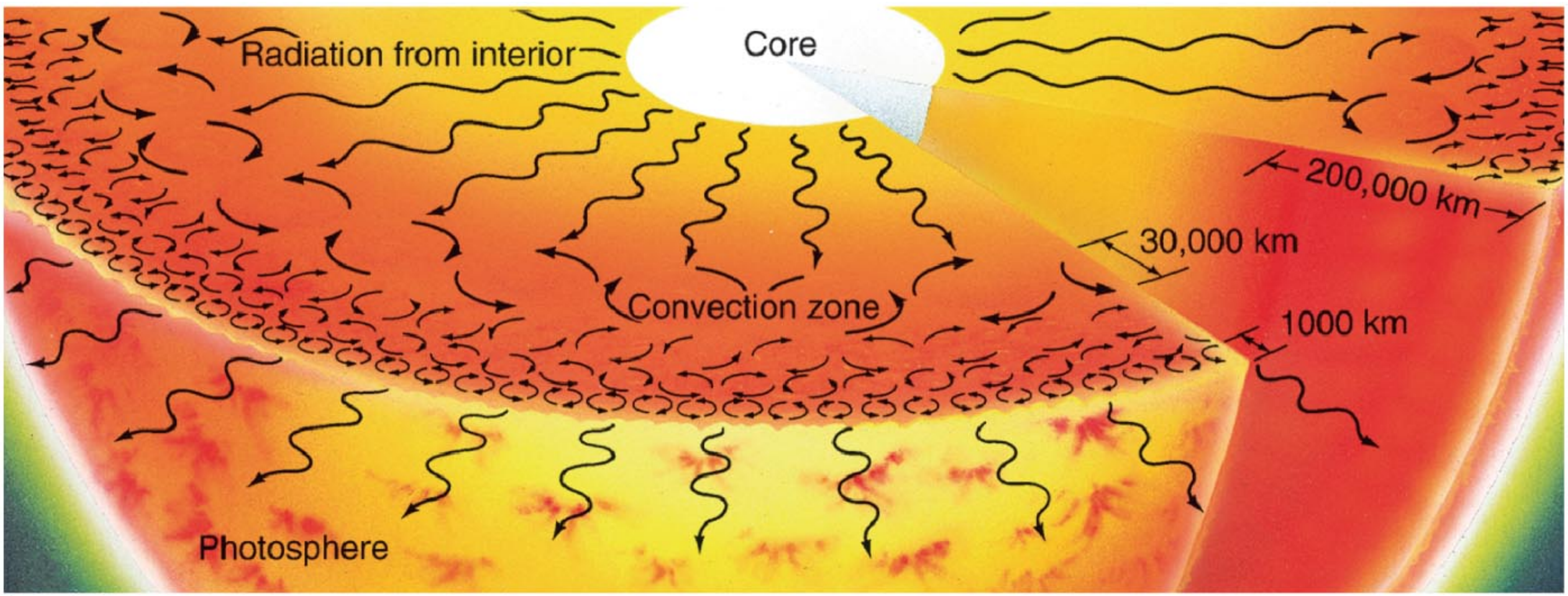
The pressure of gas exactly balances the gravitational pull of gravity.



Because the Sun is very massive, very high temperatures and pressures are needed to balance gravity.

How does Energy get out of the Sun? Radiation and Convection

The radiation zone is relatively transparent; the cooler convection zone is opaque.



What is radiation?

All objects give off and absorb electromagnetic radiation.

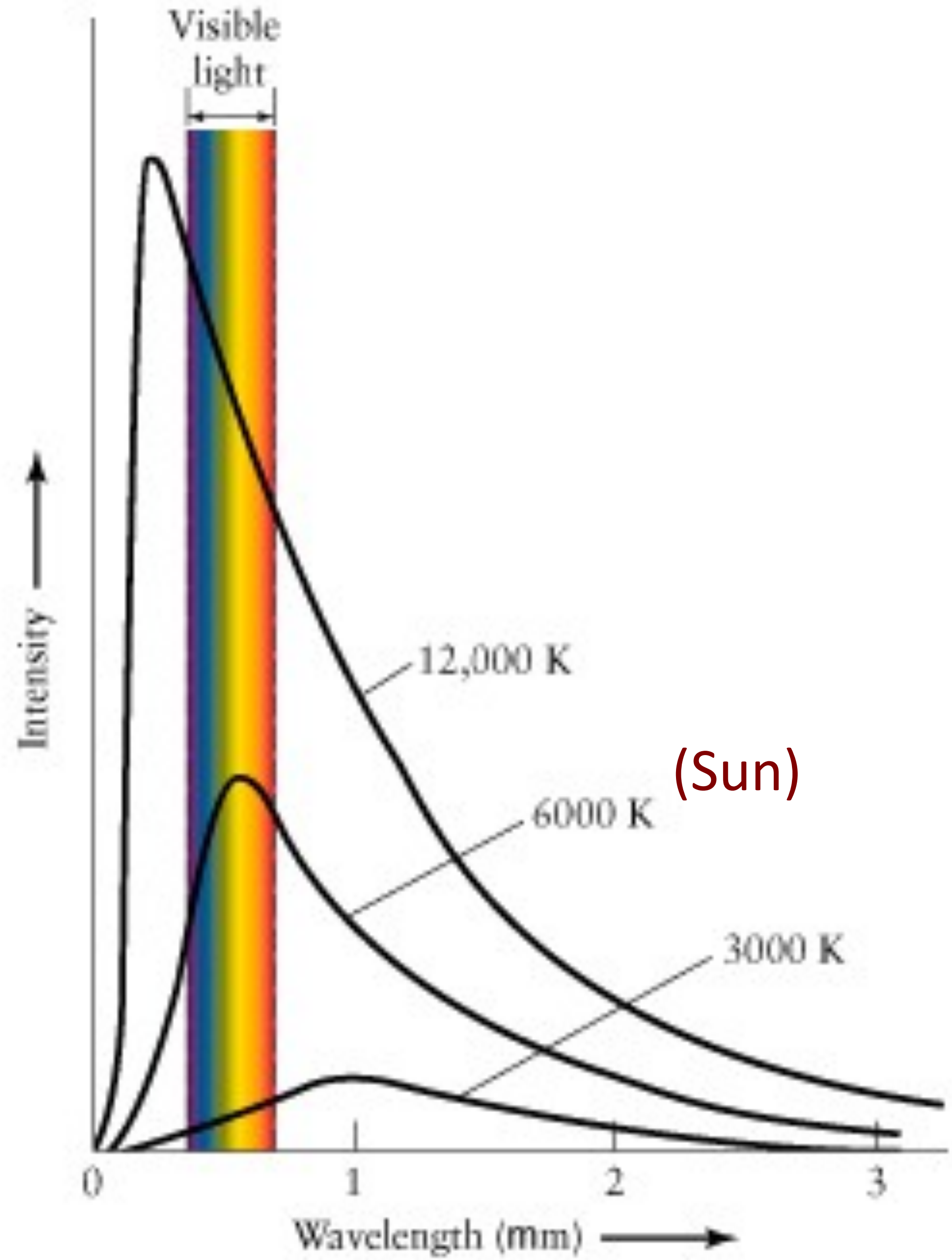
But hotter objects gives off more than cooler objects.

Remember this?

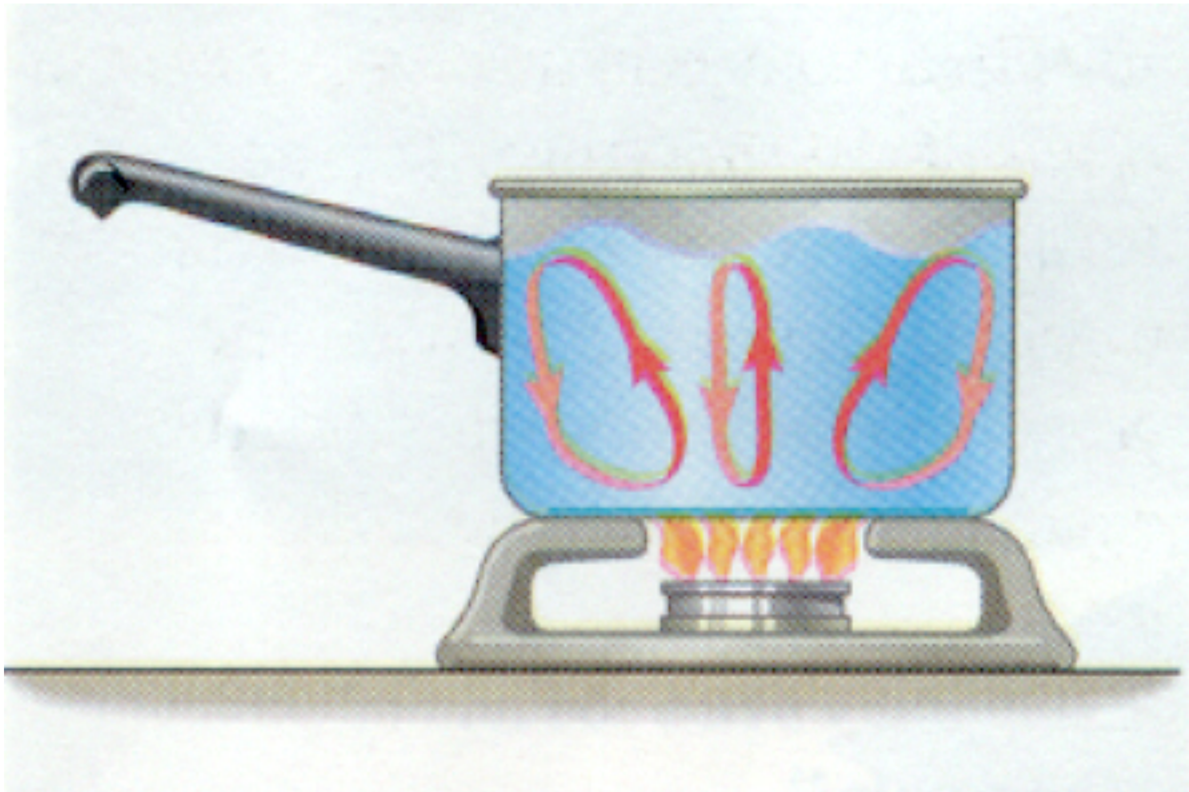
The peak intensity of light emitted by a star (or other hot object) depends on the temperature.

Hotter objects give off more and absorb less so they cool down.

Cooler objects give off less and absorb more so they get hotter.



What is convection?

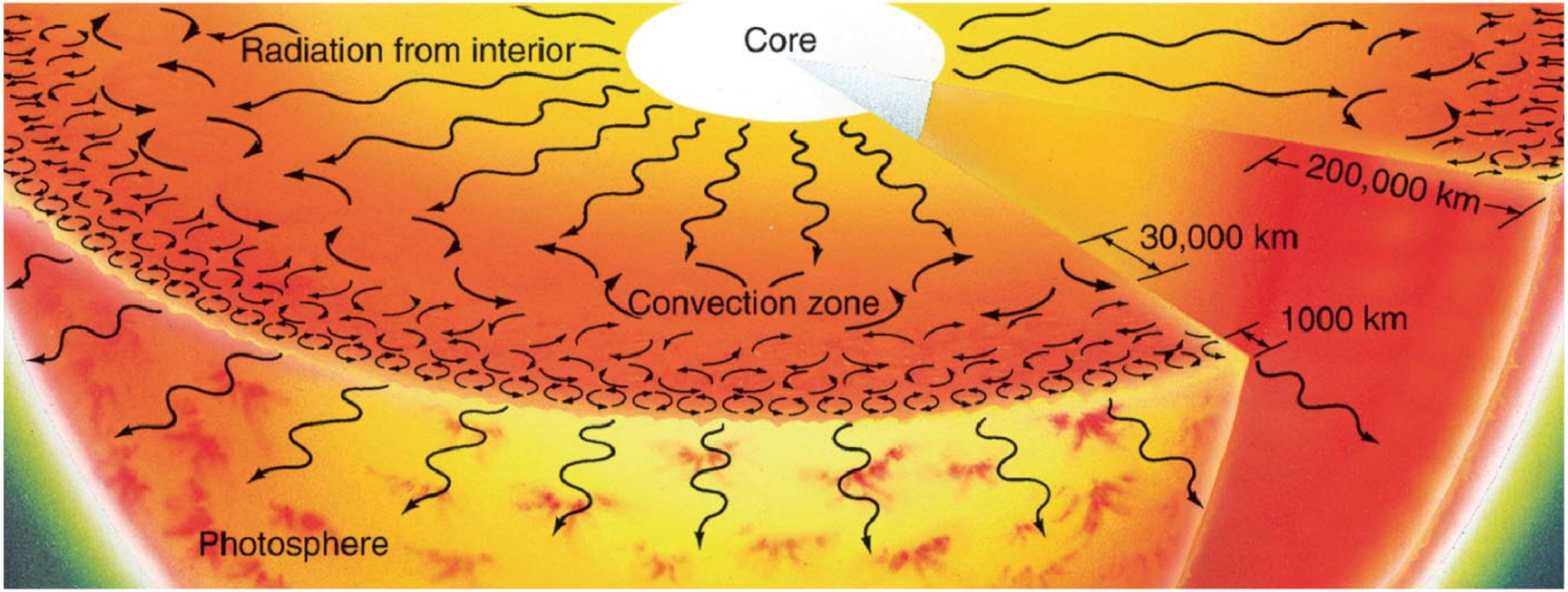


Convection transfers heat by moving stuff around. Hot stuff rises, cool stuff sinks.

Convection in the earth's atmosphere

The sun transports energy by radiation in certain parts and convection in others.

This is due to the different transparency of hydrogen and helium as a function of temperature.



The Solar Atmosphere

(photosphere, chromosphere, corona)

The Sun is mostly hydrogen; about 10% of its atoms are helium and there is a much smaller amount of heavier elements.

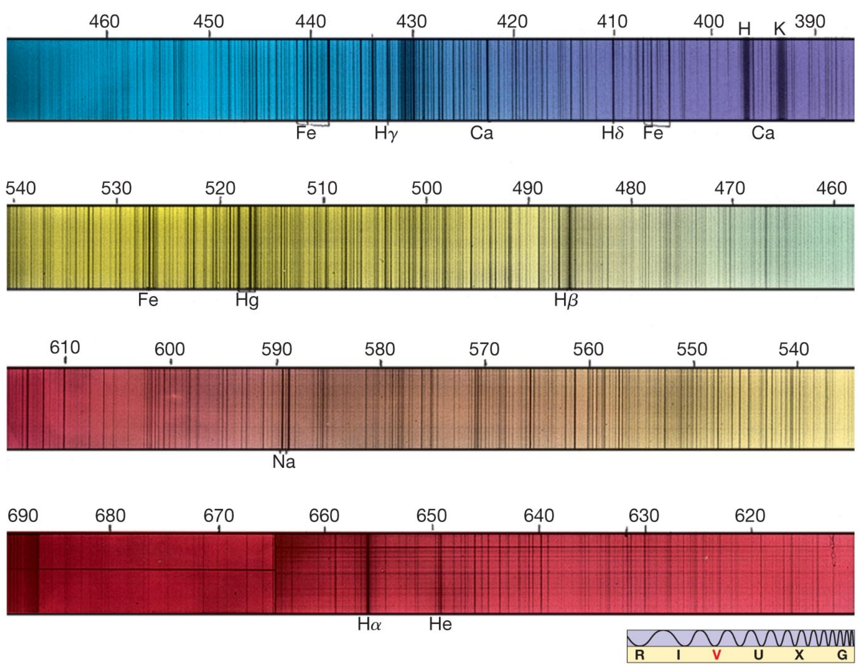
In nearly all of the Sun's interior, the temperature is too hot for electrons to stay attached to protons: The particles are moving fast enough that any collision with a bound electron will knock the electron off its atom. All the atoms are ionized: The Sun is a collection of free protons and electrons.

Near the surface of the Sun, the temperature is low enough for some of the protons and electrons to form atoms.

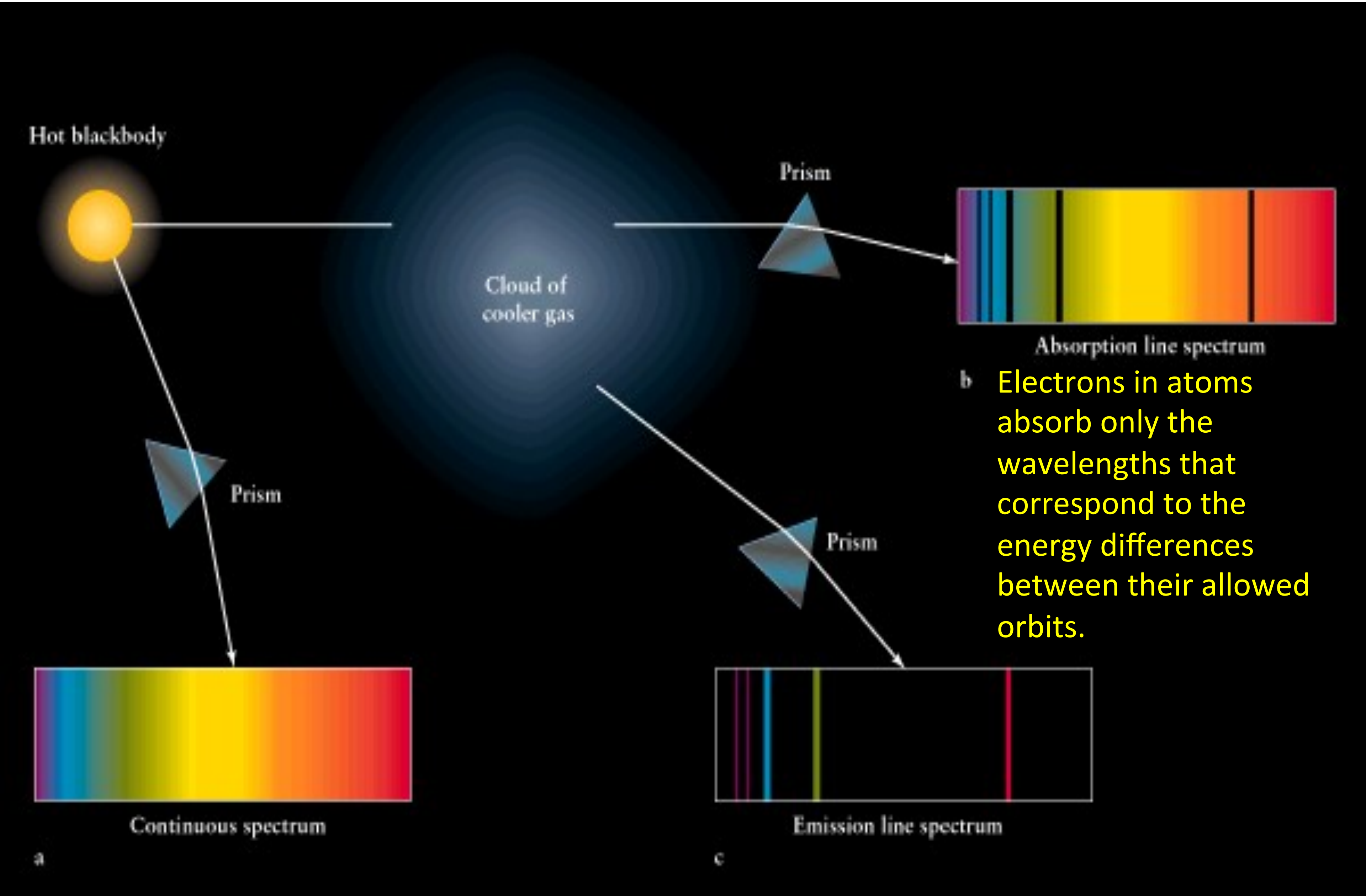
The Solar Atmosphere

(photosphere, chromosphere, corona)

When we look at the Sun, we see a continuous spectrum of light from the Sun's interior passing through a cooler outer atmosphere that has some atoms in it. As the light passes through these atoms, the light can excite their electrons, giving a set of dark absorption lines.



Remember this?



Electrons in atoms absorb only the wavelengths that correspond to the energy differences between their allowed orbits.

The Solar Atmosphere

(photosphere, chromosphere, corona)

Most light from the Sun leaves from the **photosphere**. This is what we see as the “surface” of the Sun, although it has no solid surface.

Its average wavelength (green) corresponds to the 6000 K temperature of the photosphere.

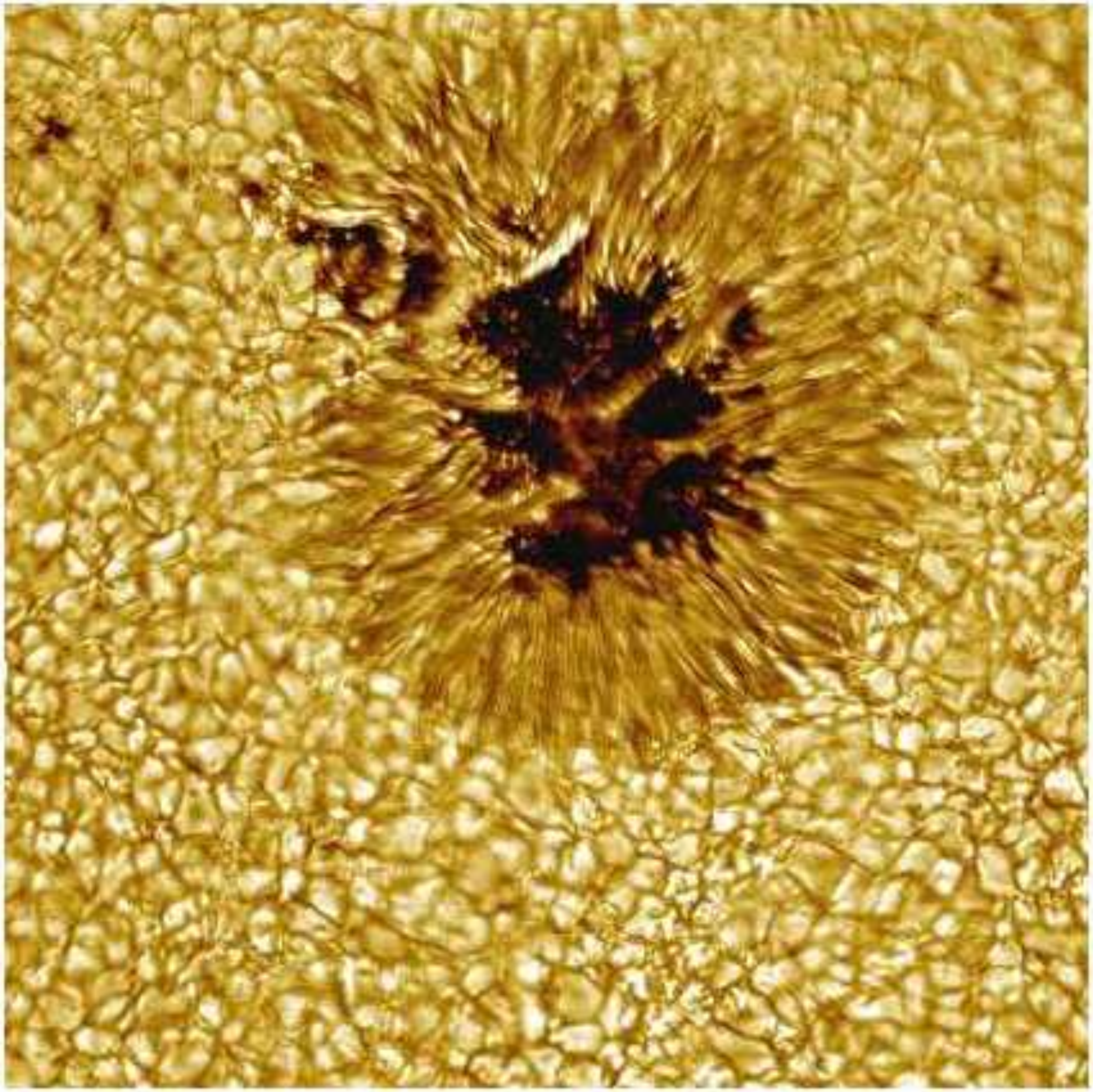
Photosphere with **sunspots**

Features of the Photosphere

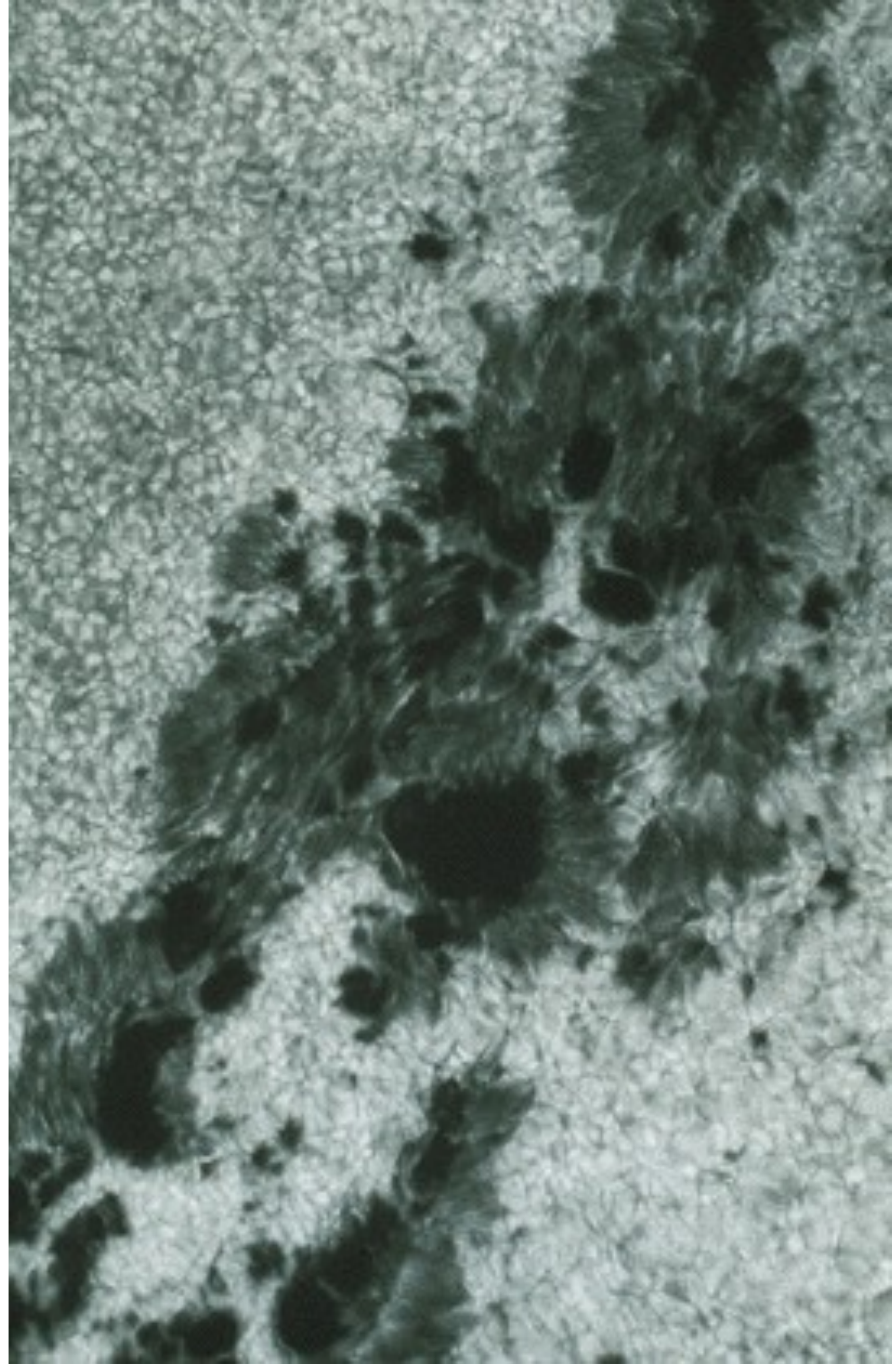
sunspots

&

granules



Close-up of a group of sunspots

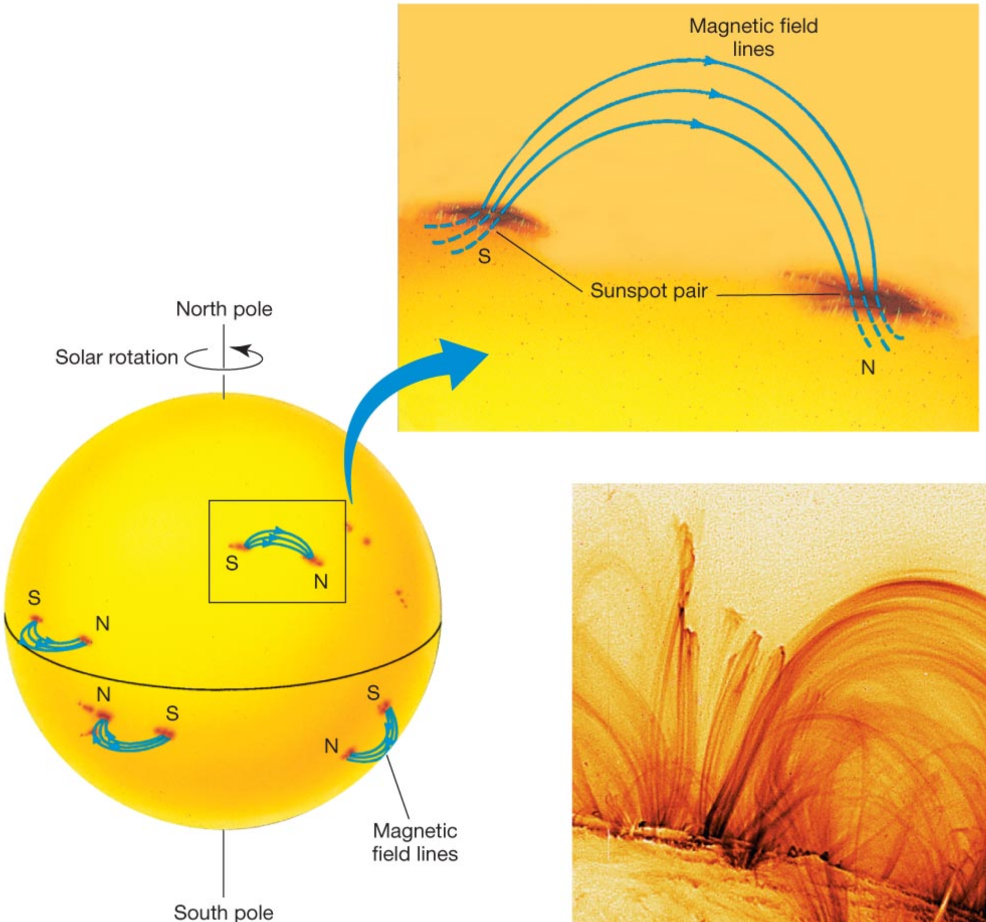


What are Sunspots?

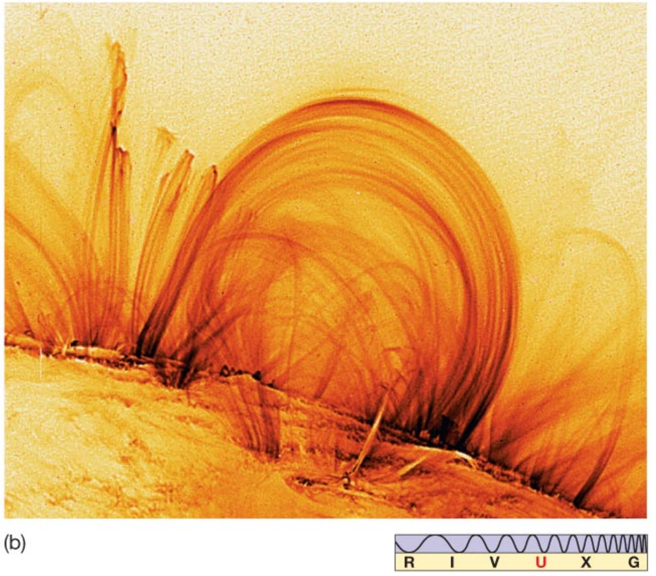
Sunspots come and go, typically in a few days.

Sunspot pairs are linked by magnetic field lines, which drain energy from the photosphere

They are dark because they are **cooler** than the surrounding photosphere



(a)



(b)

Looking closer at the photosphere

Convection on the photosphere is granulated, with areas of upwelling material surrounded by areas of sinking material.

These spots are called granules.

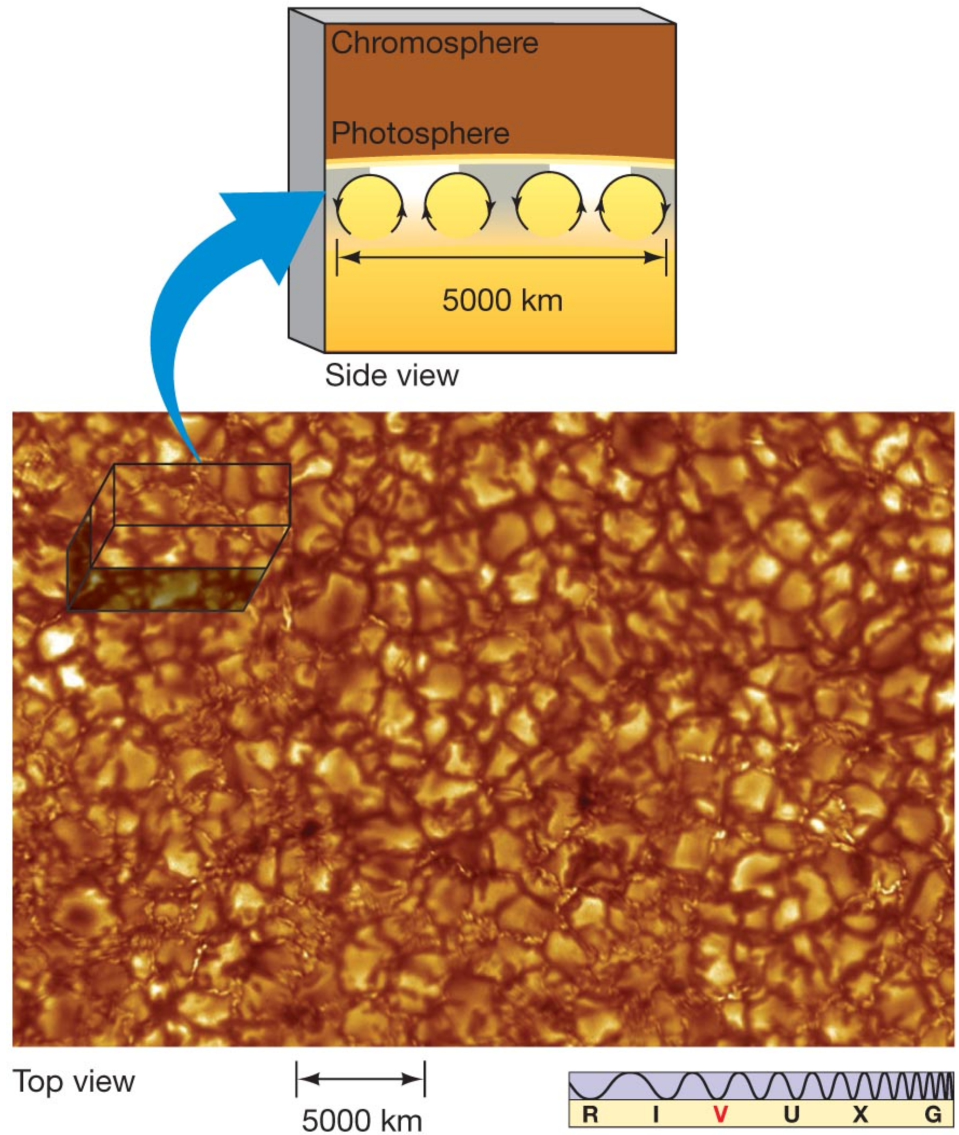
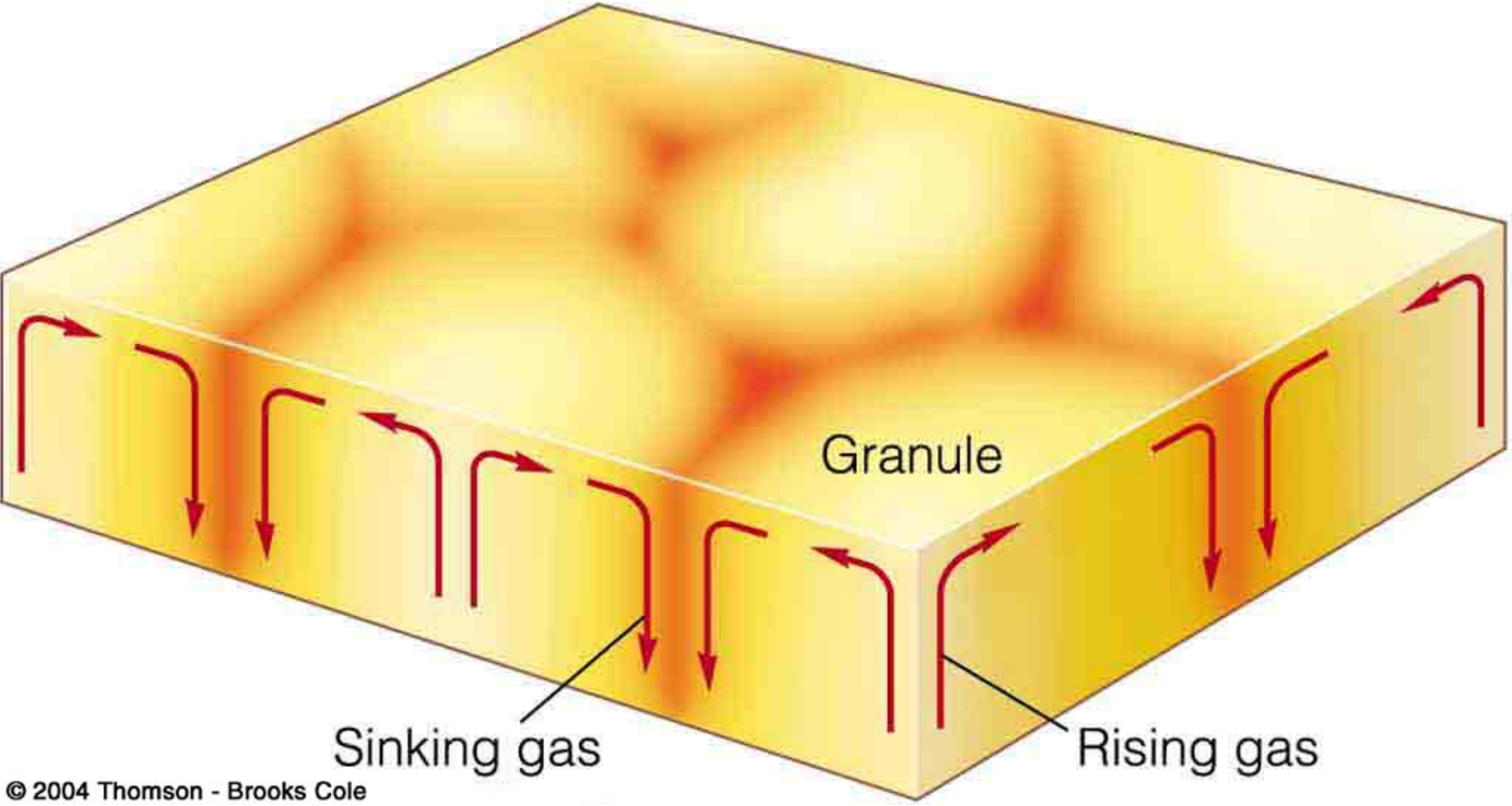


Diagram of a Granule



Summary: Features of the Photosphere

Heat from the interior moves by convection (hot hydrogen gas rising) to the photosphere

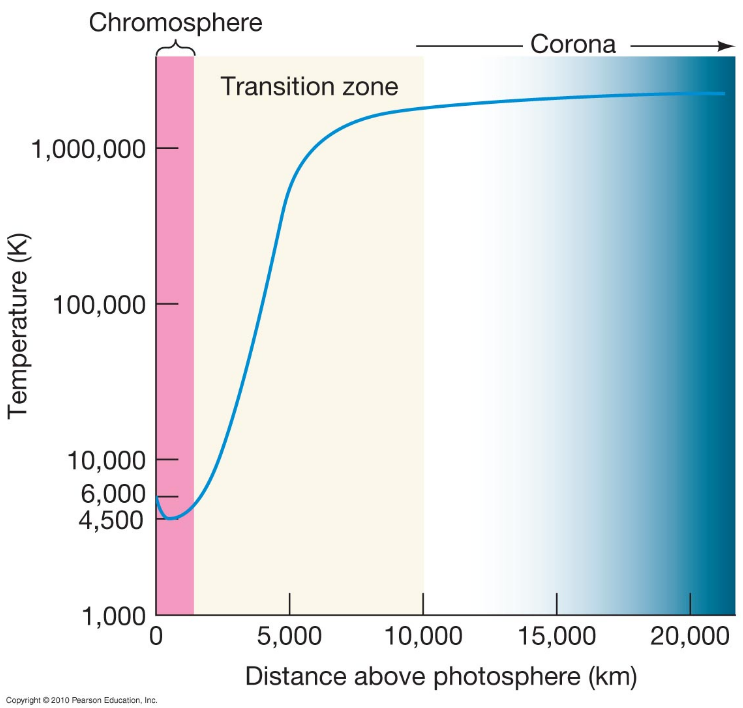
The tops of convection cells are called granules

Sunspots are the result of strong magnetic fields going in or out of the Sun's surface

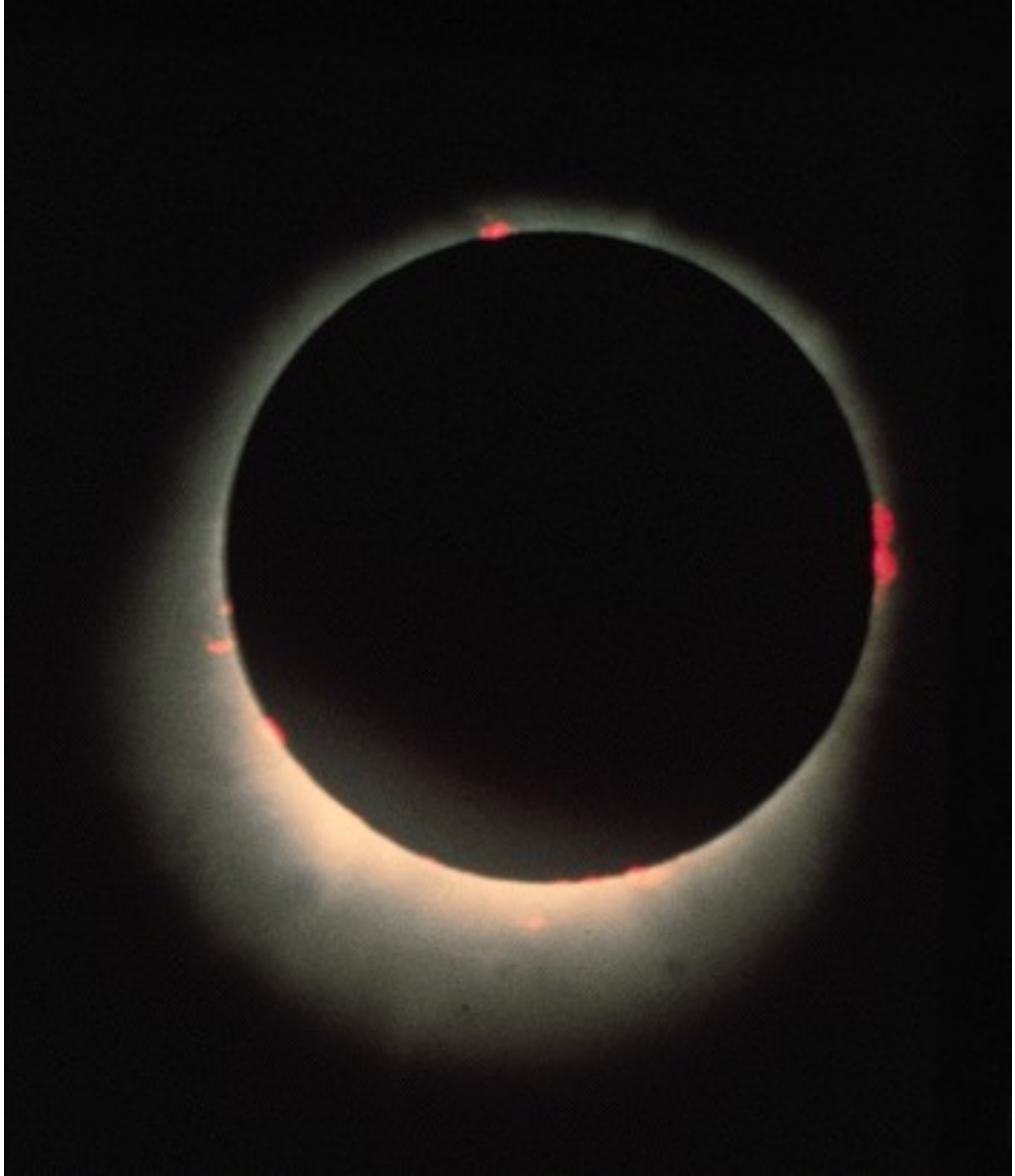
The magnetic field drains energy from the surrounding photosphere, cooling it; because the cooler gas is darker, it is seen as a dark spot.

The temperature of the photosphere is about 6,000 K.

But outside the photosphere, the temperature (surprisingly) increases, reaching 3 million K in the Corona.

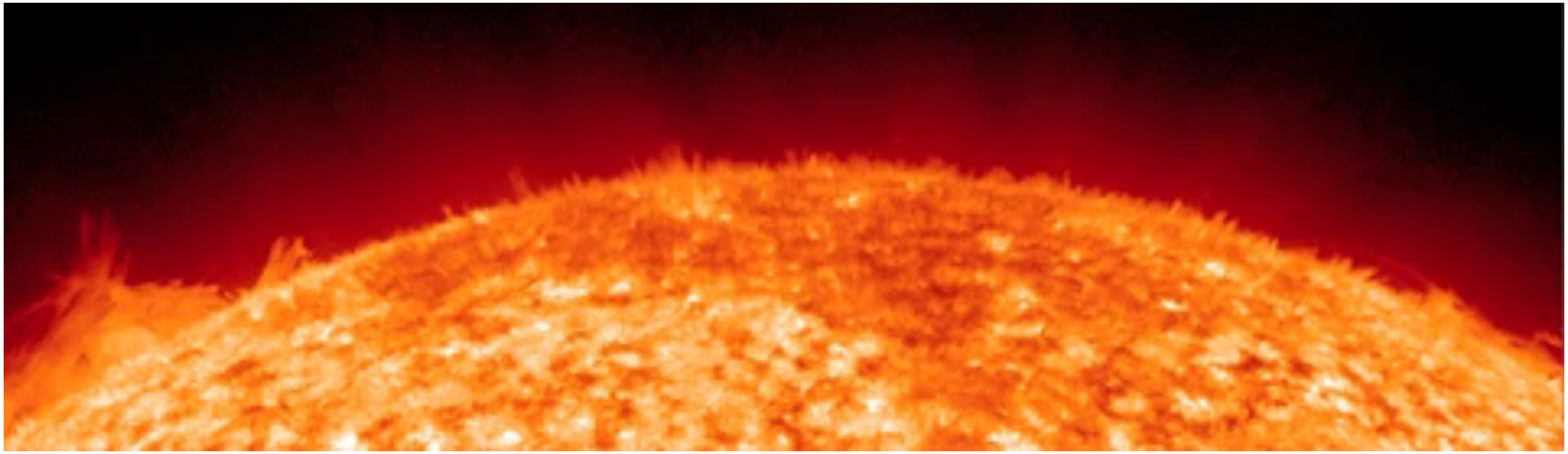


Chromosphere



Detail of Chromosphere

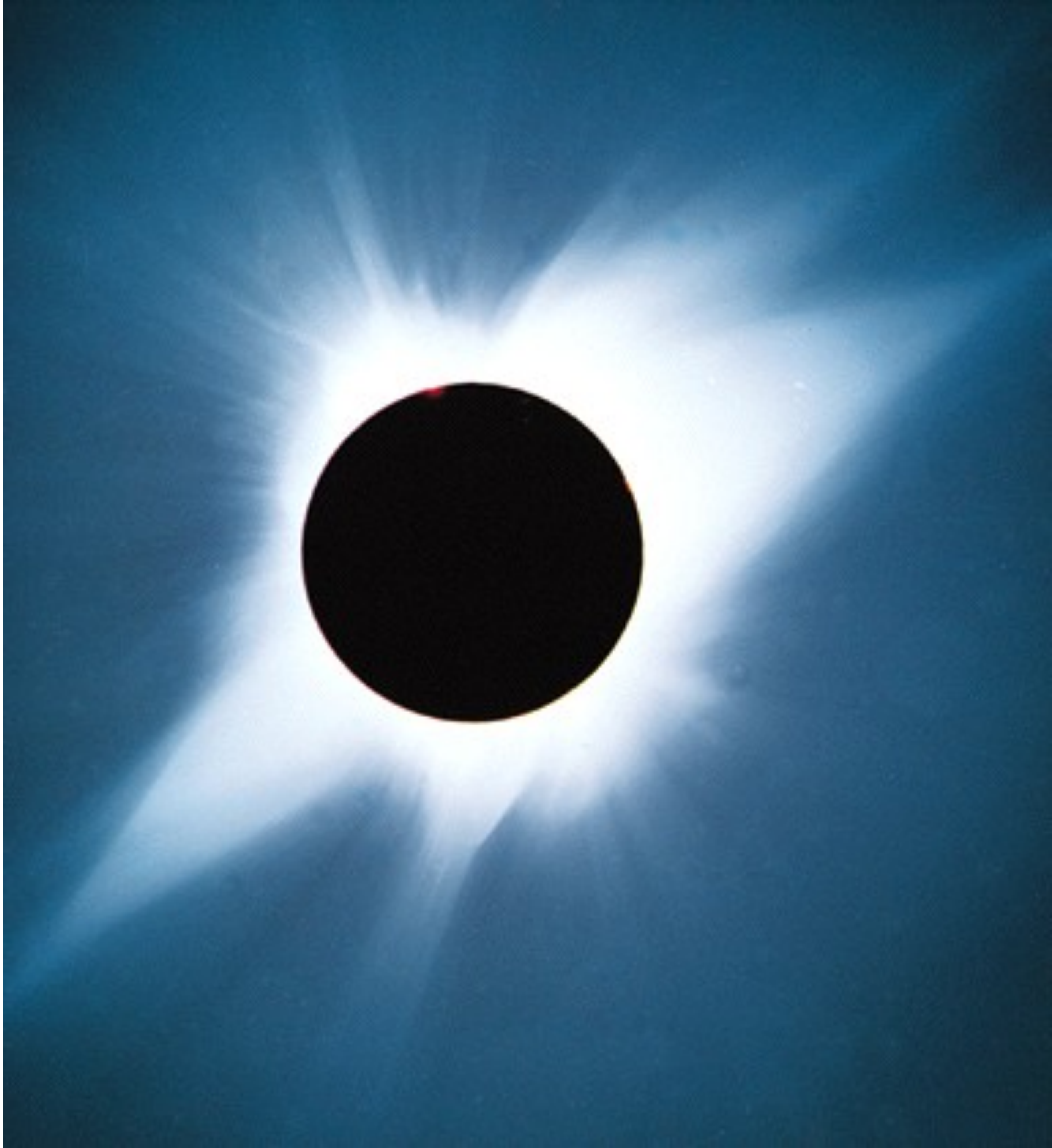
Hot spicules (jets of hot matter) point from chromosphere to corona



Corona

T = 3,000,000 K

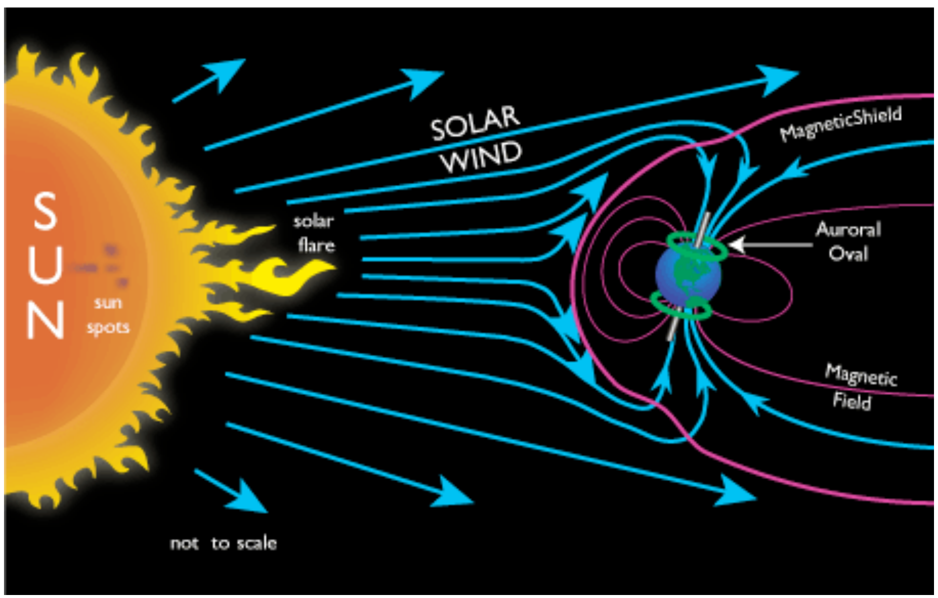
No one is quite sure why it is this hot, but it might be because of magnetic heating.



Solar wind

Finally, particles that escape the Sun form what is known as the solar wind.

Gas is so hot in the corona that particles move fast enough to escape. The Sun is slowly losing mass (it is evaporating). But don't worry, over the last 4.6 billion years only 0.1% of its mass has disappeared.

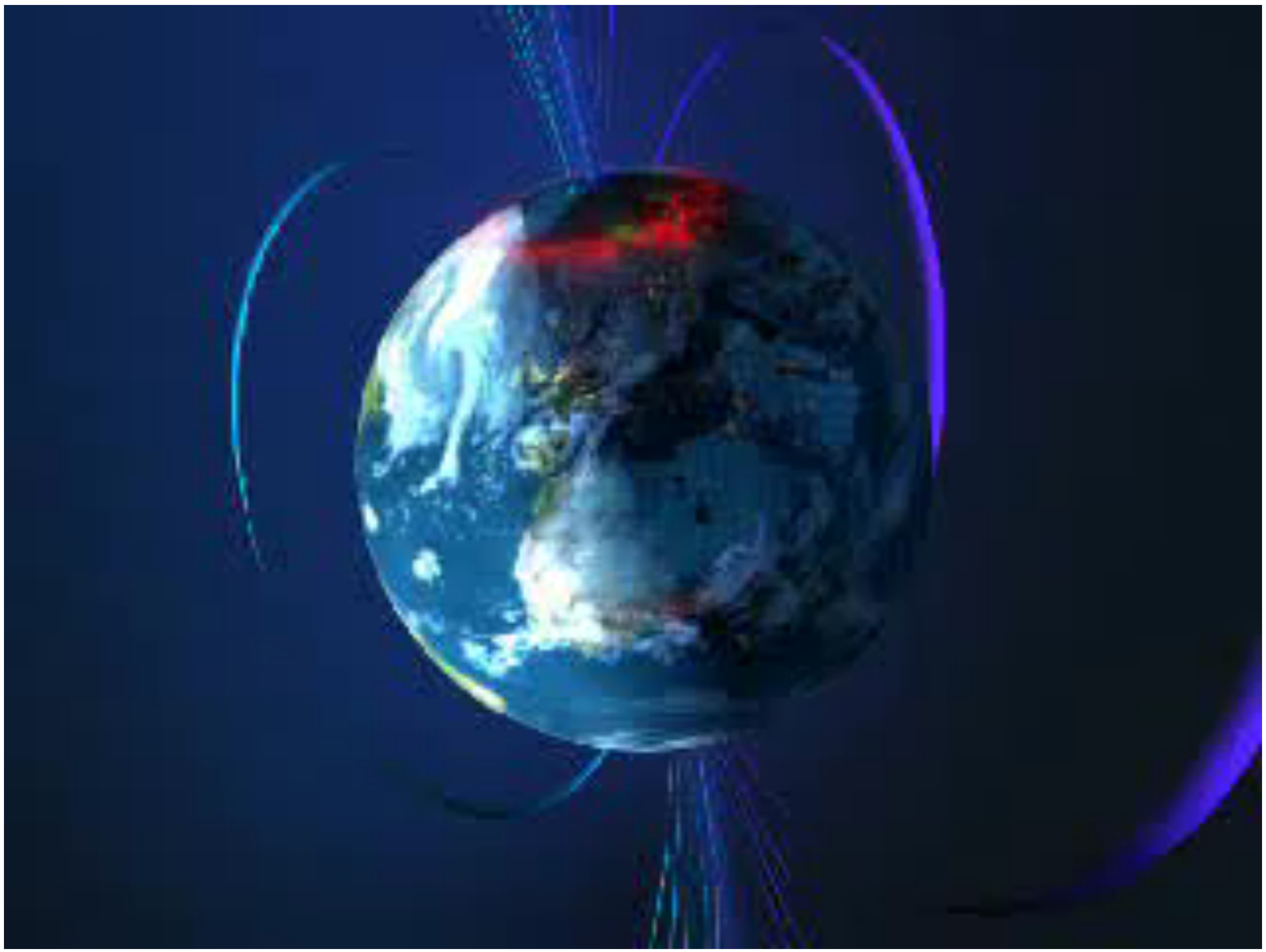


Solar wind

A manifestation of the solar wind is the Aurora Borealis or Northern Lights. It is a result of the interaction between the solar wind and the earth's magnetic field.

Solar wind

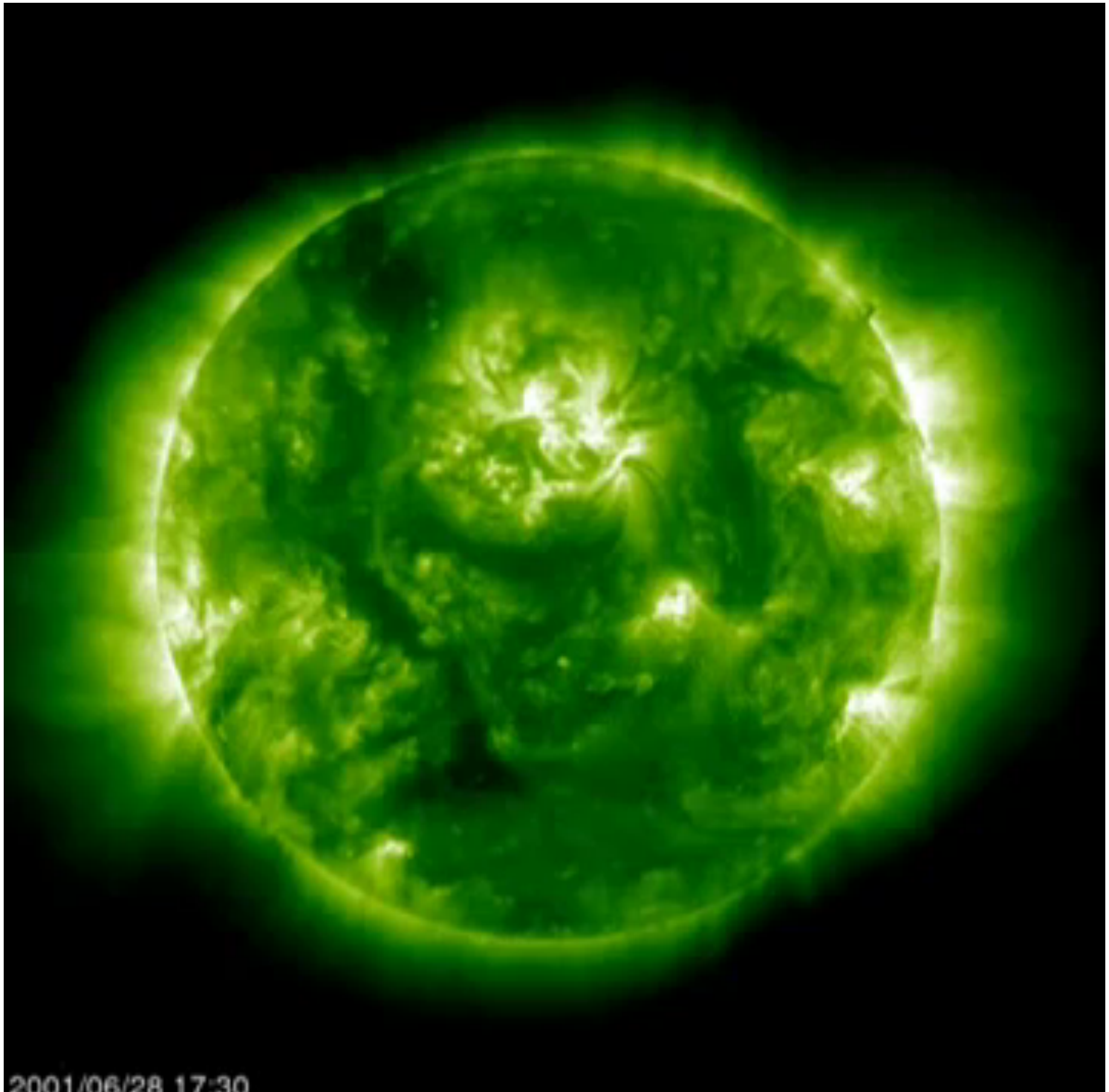
The solar wind blows Earth's magnetic field backward and drives high energy electrons to the magnetic poles. These electrons cause air molecules to glow.



Rotation of the Sun

Observing sunspots can tell you that the sun rotates.

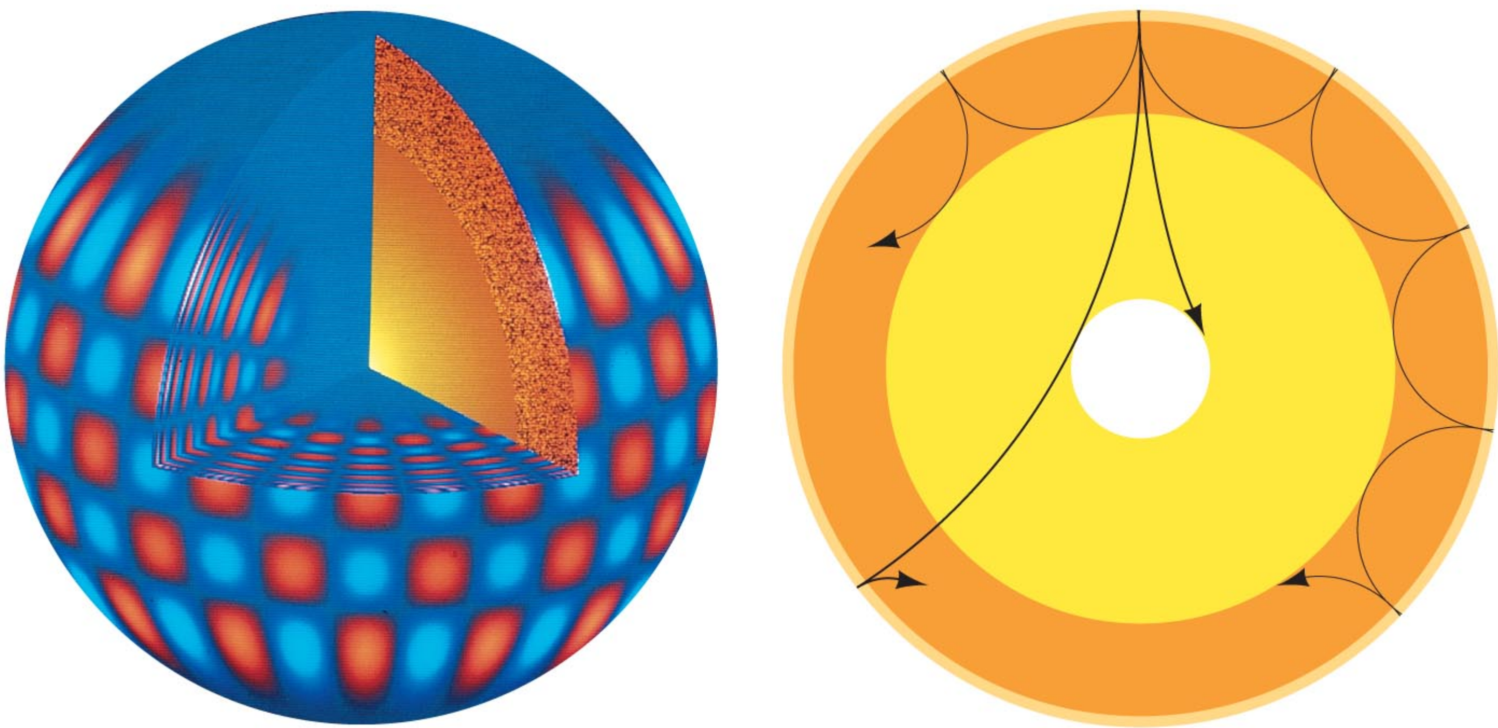
Rotation of the Sun



From SOHO in the X-rays

SOHO: Solar and Heliospheric Observatory, stationed between Earth and the Sun

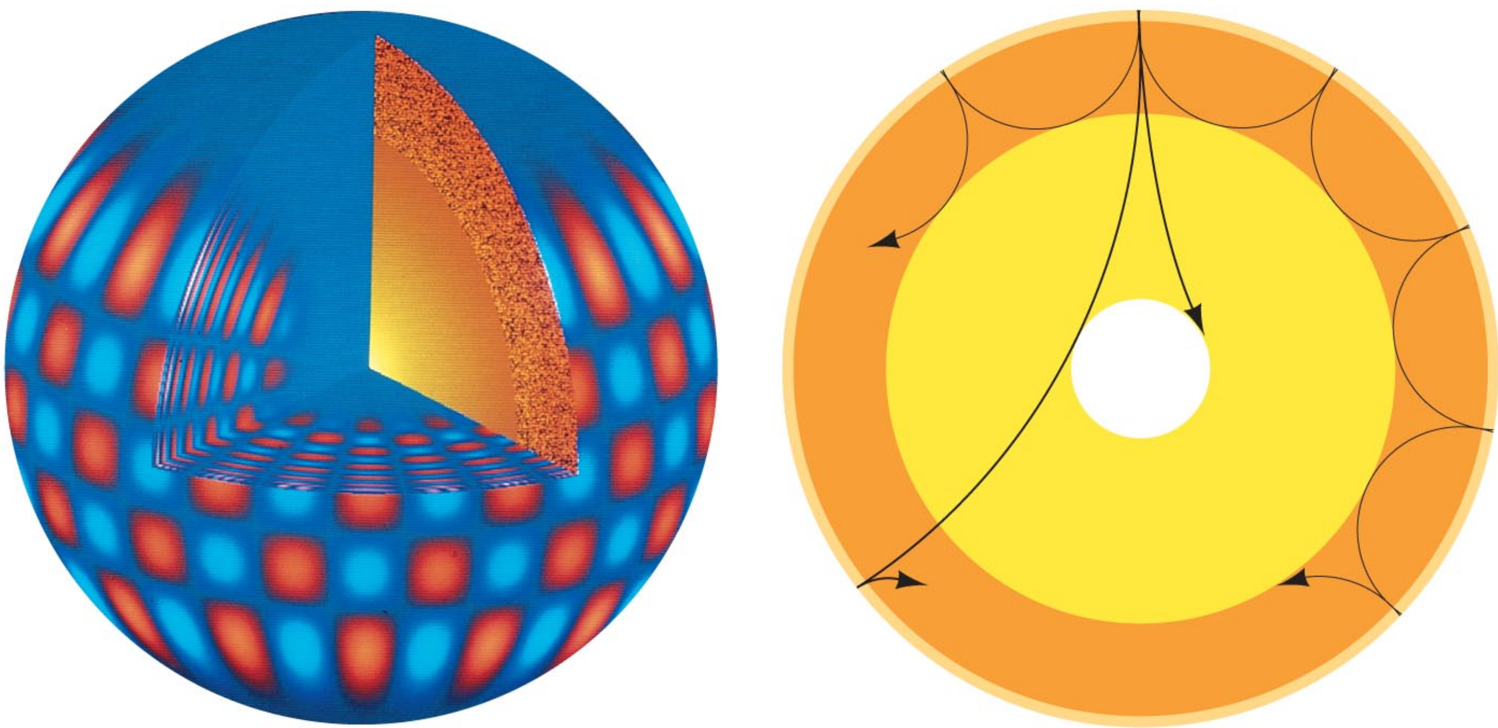
The entire Sun oscillates, and we can see the oscillations as waves on its surface. These oscillations are pressure waves ("sound") that reflect off the photosphere and travel through the Sun's interior. Studying the pattern of the waves on the surface tells us about the interior structure of the Sun.



(a) (b)

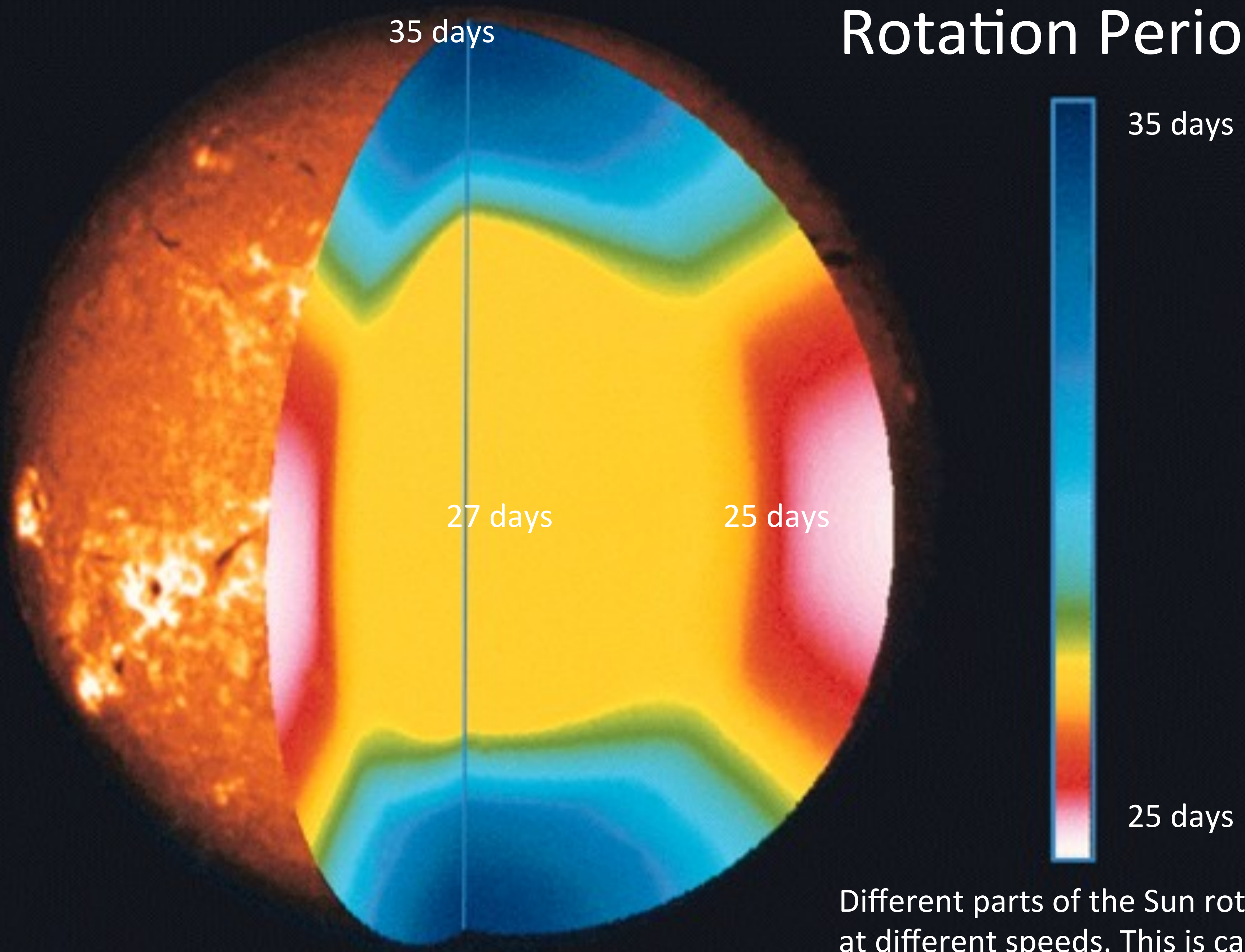
According to our models, the particular oscillations that are allowed depend on the rate of rotation in the Sun's interior.

In models of the Sun that reproduce the observed oscillations, the Sun's core rotates once every 27 days. So we know the Sun really well!!



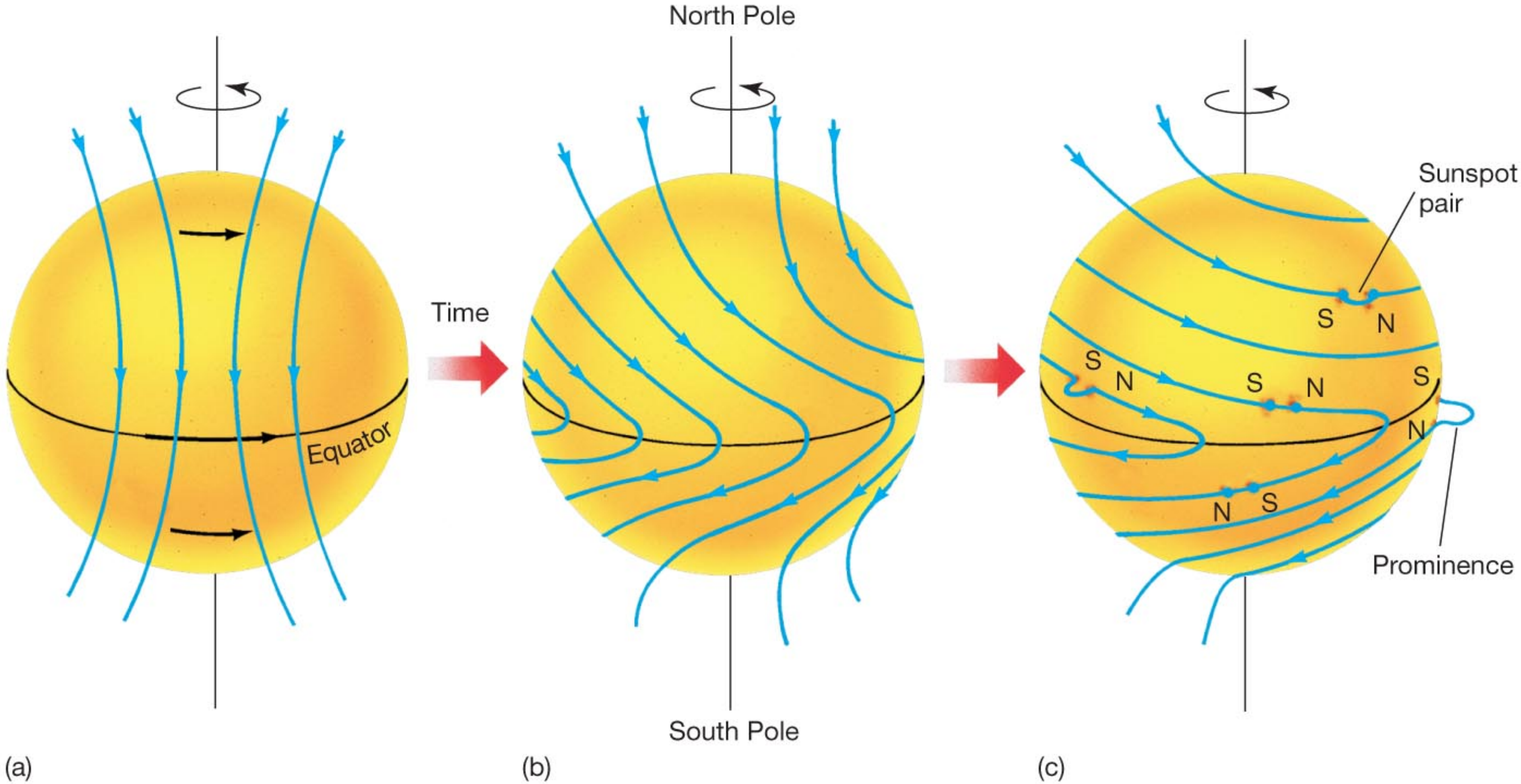
(a) (b)

Rotation Period



Different parts of the Sun rotate at different speeds. This is called **differential rotation**.

The rotation of the Sun drags magnetic field lines around with it, causing kinks in the field lines.



Remember: The sun spins faster at the equator than the poles

The Solar Magnetic Cycle

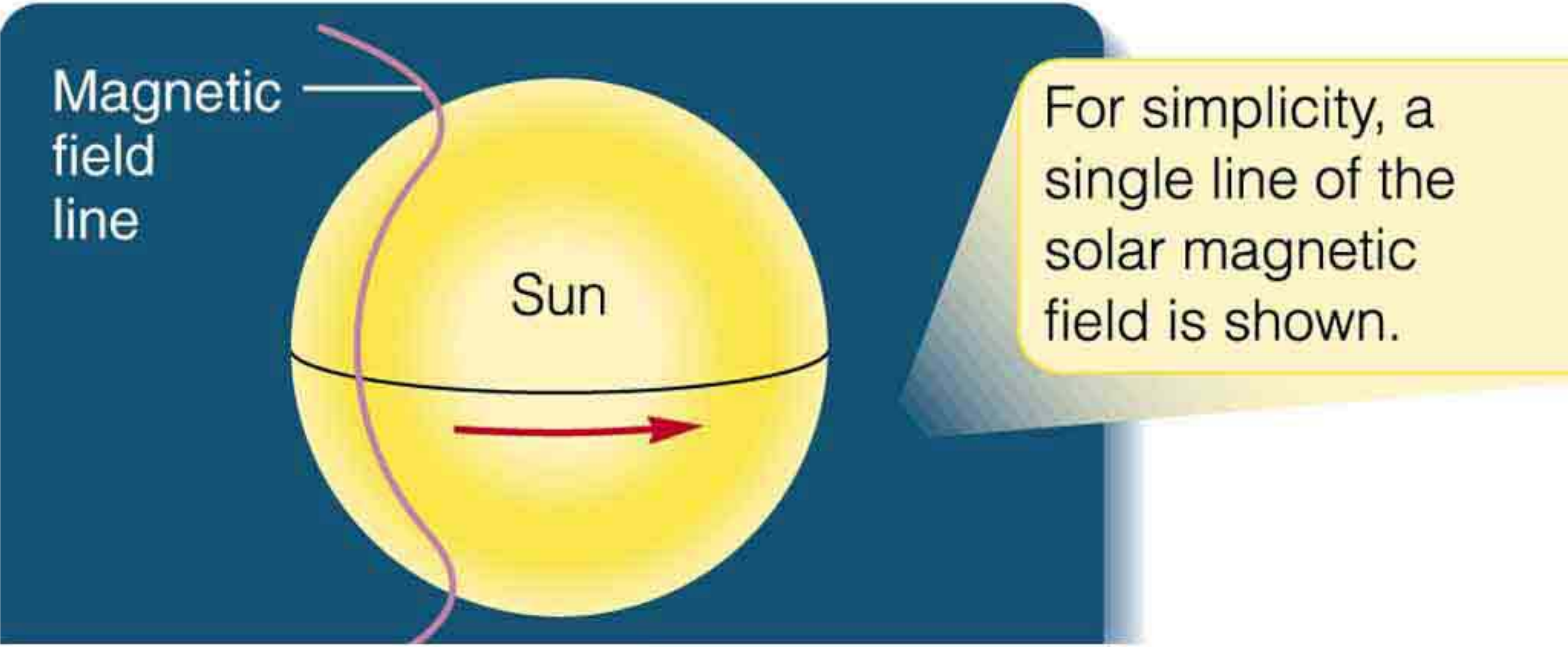


Fig. 7-14a, p. 122

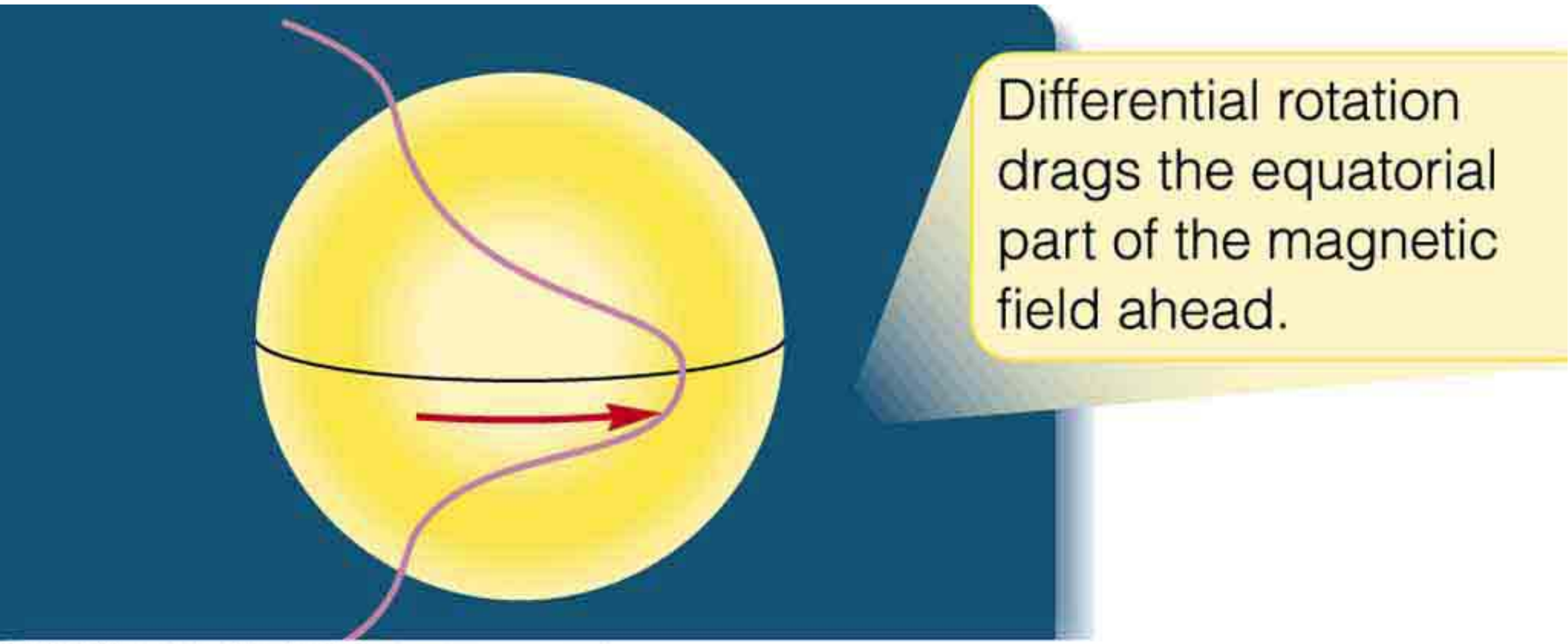


Fig. 7-14b, p. 122

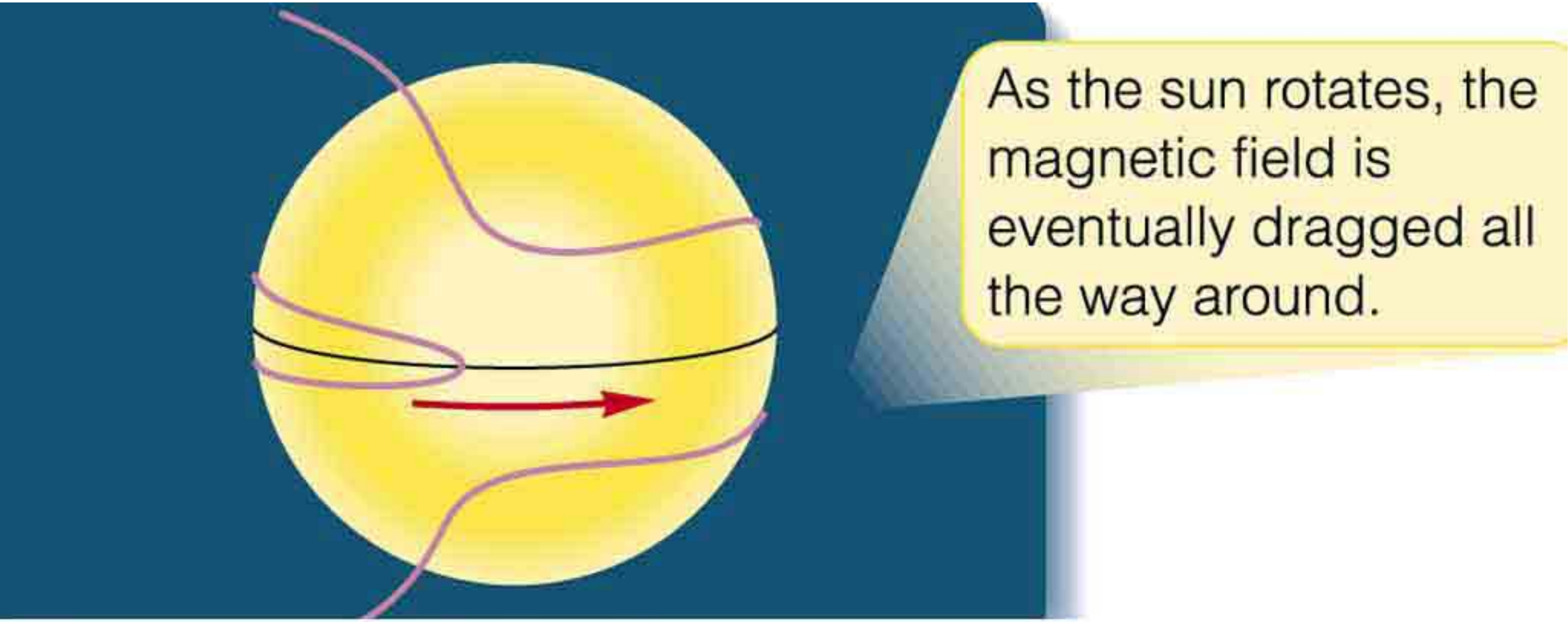


Fig. 7-14c, p. 122

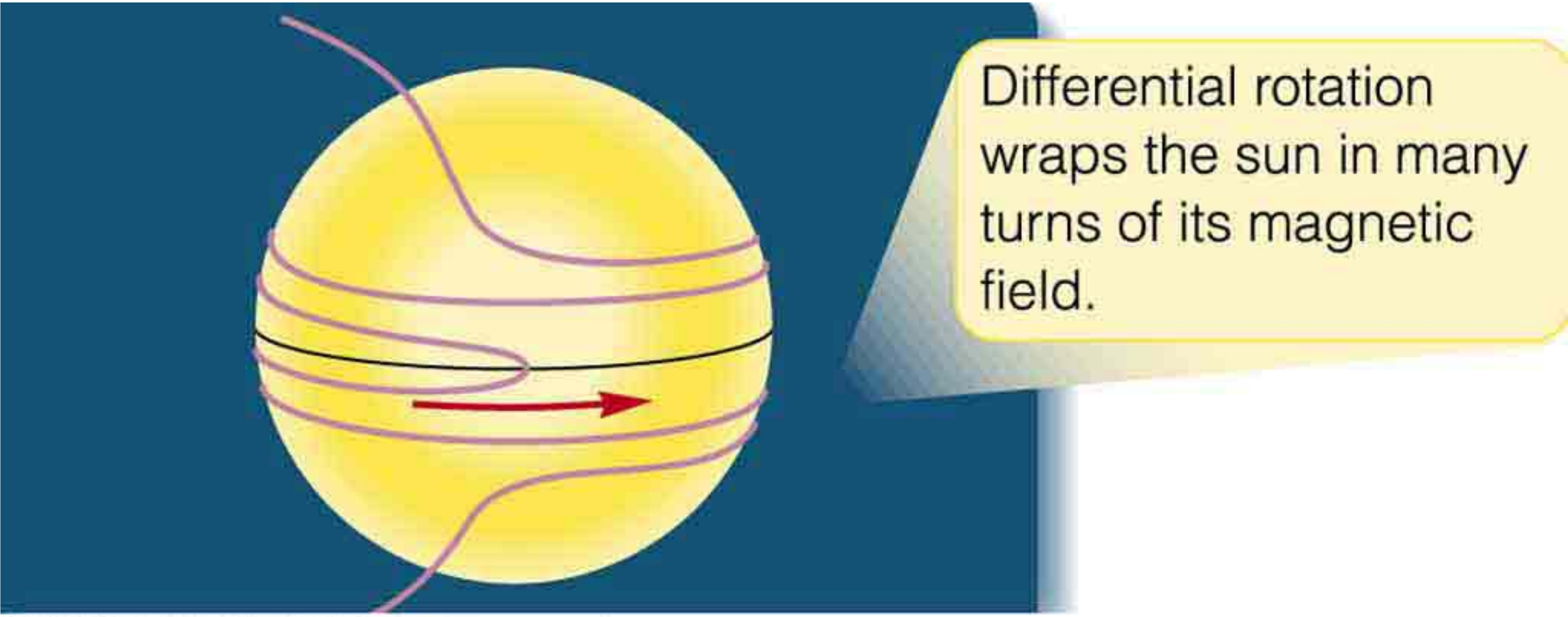


Fig. 7-14d, p. 122

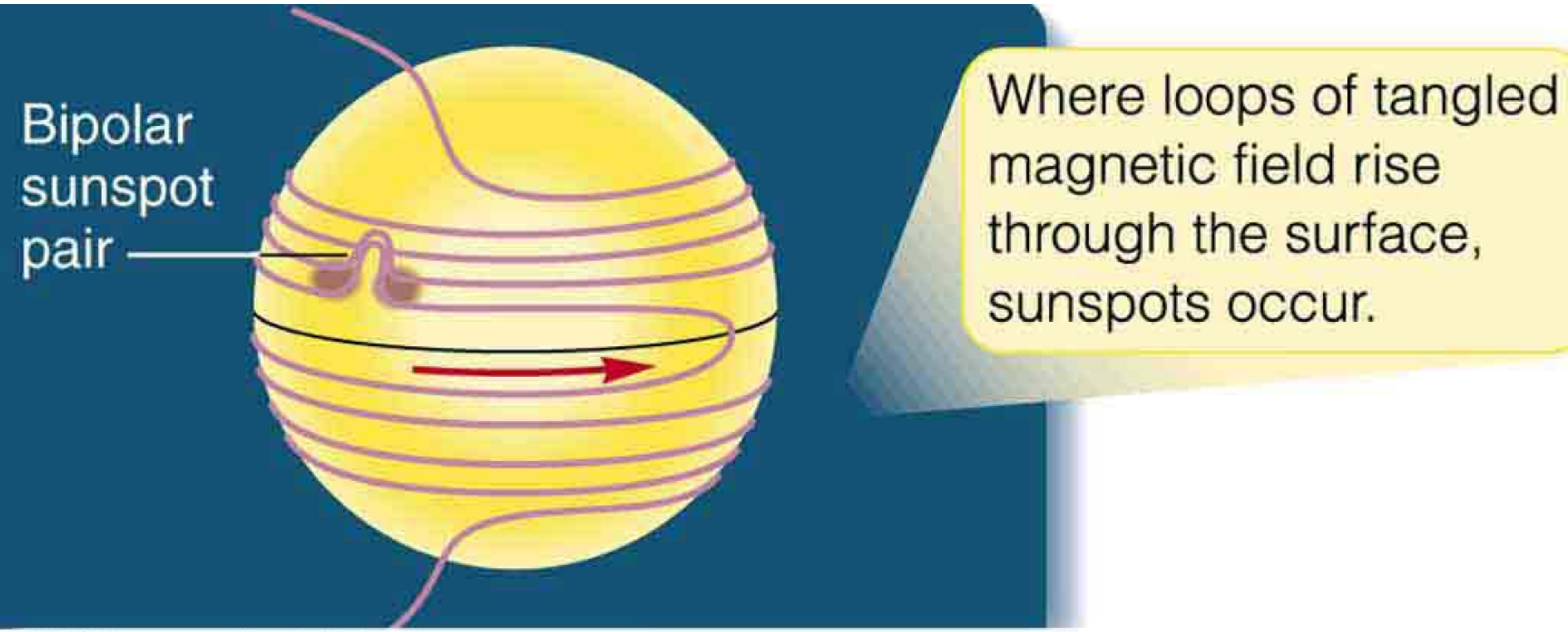
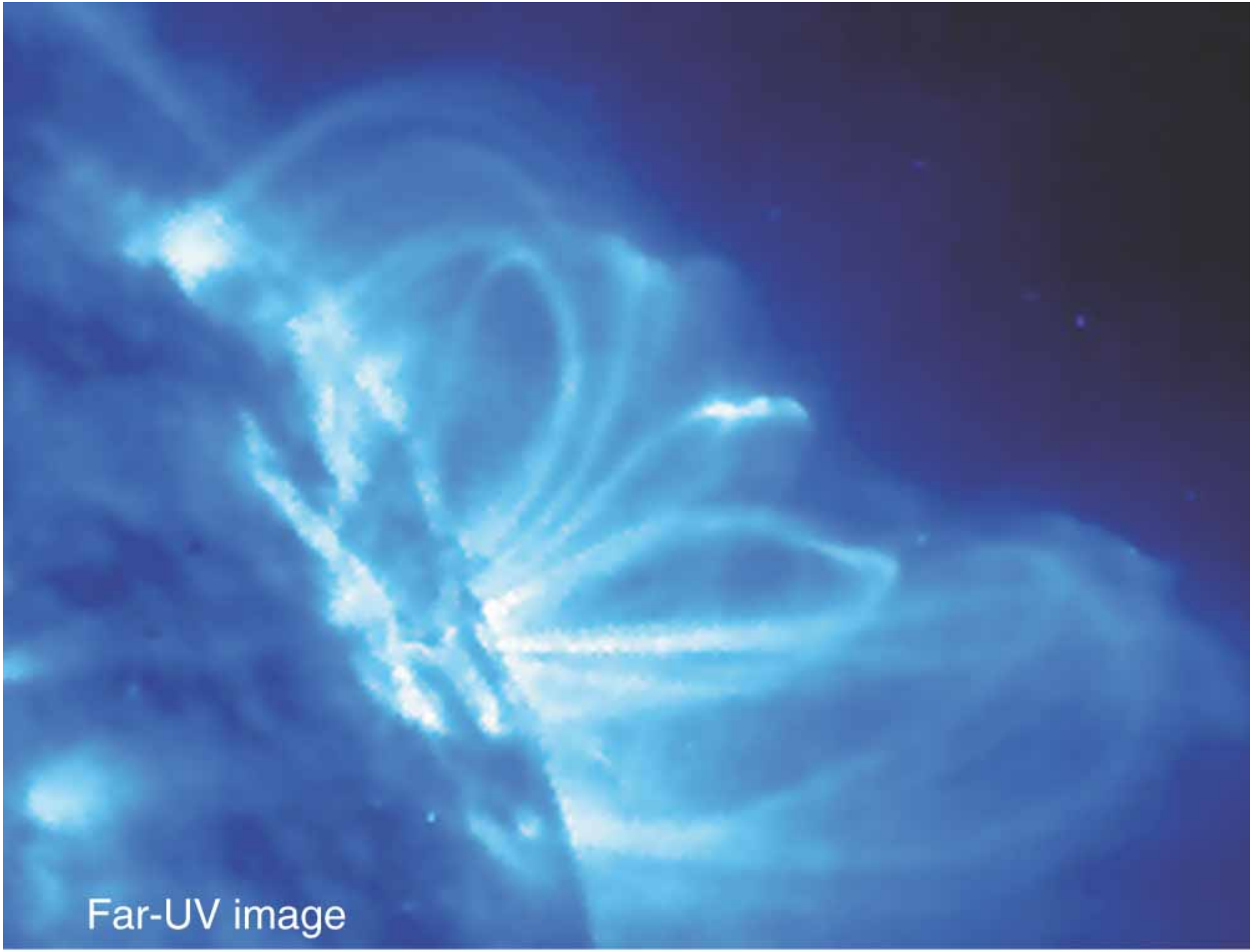


Fig. 7-14e, p. 122


Far-UV image