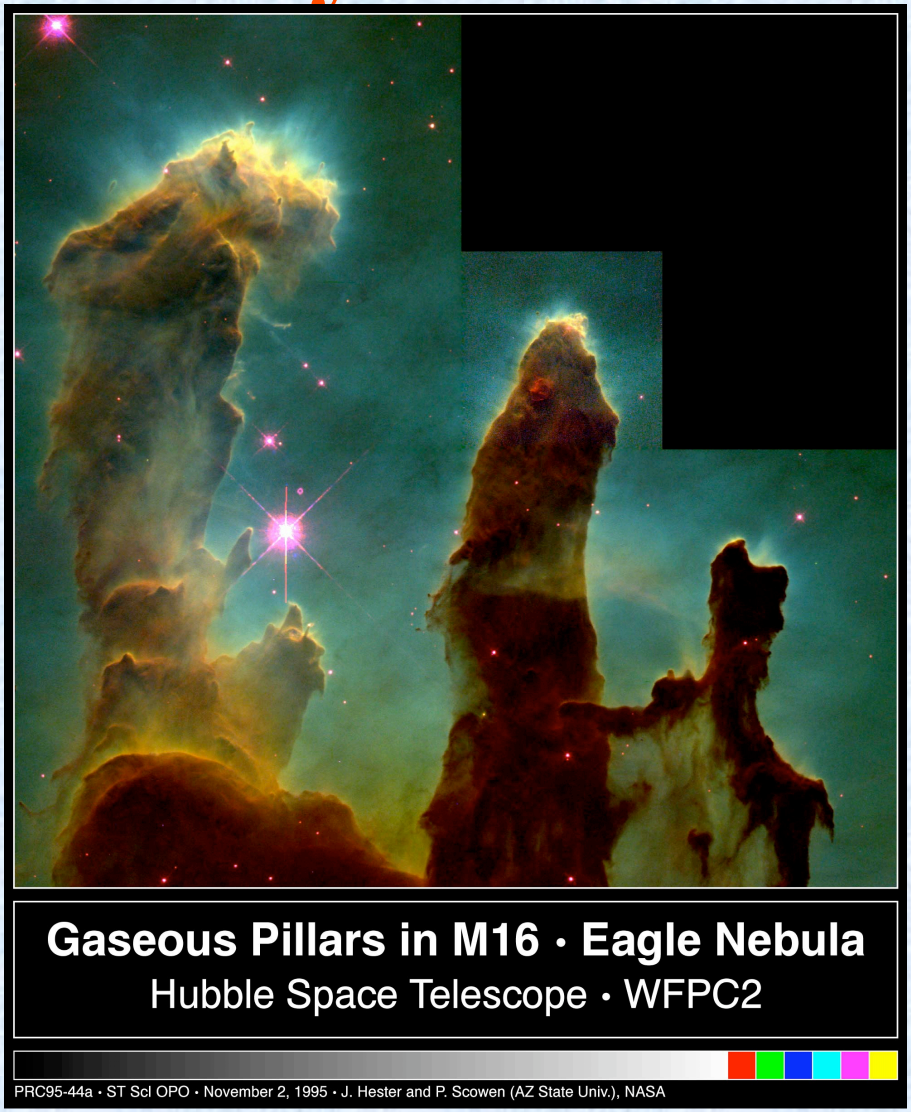
Astronomy 1 – Winter 2011



Lecture 19; February 23 2011

Previously on Astro-1

- **Asteroids**
- **Comets**
- **Meteors**

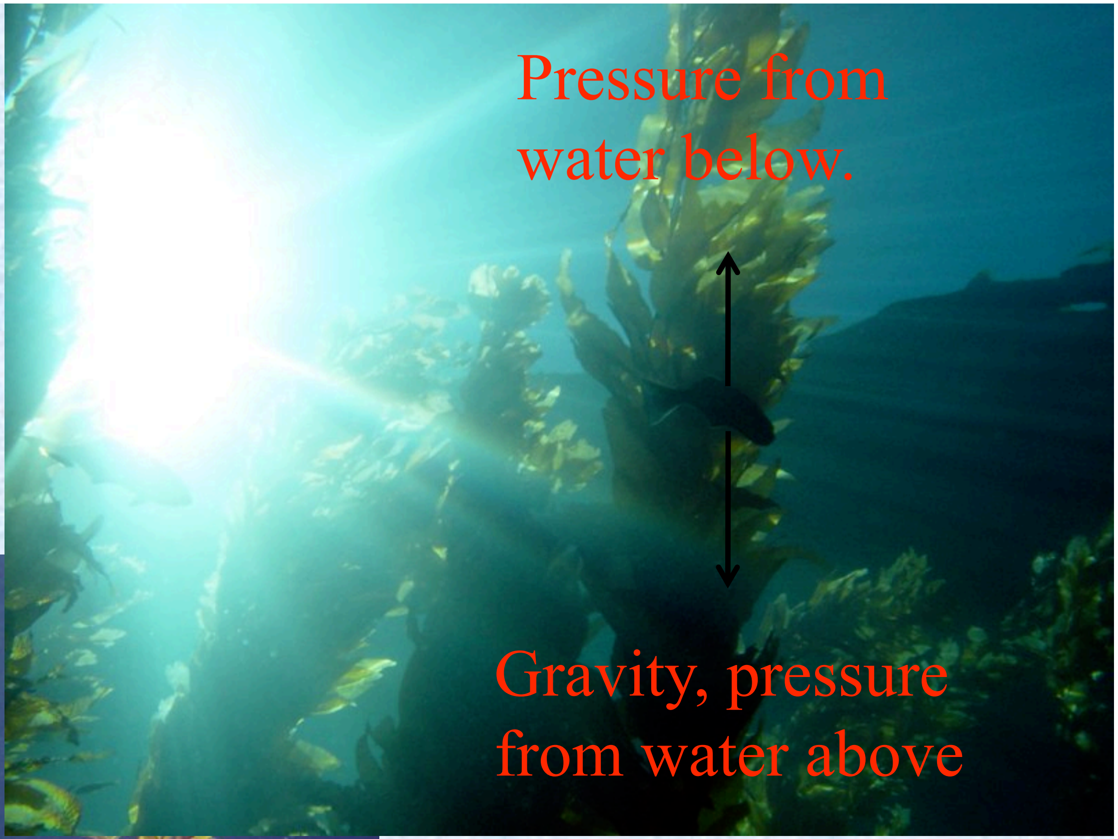
Homework – Due 03/02/11

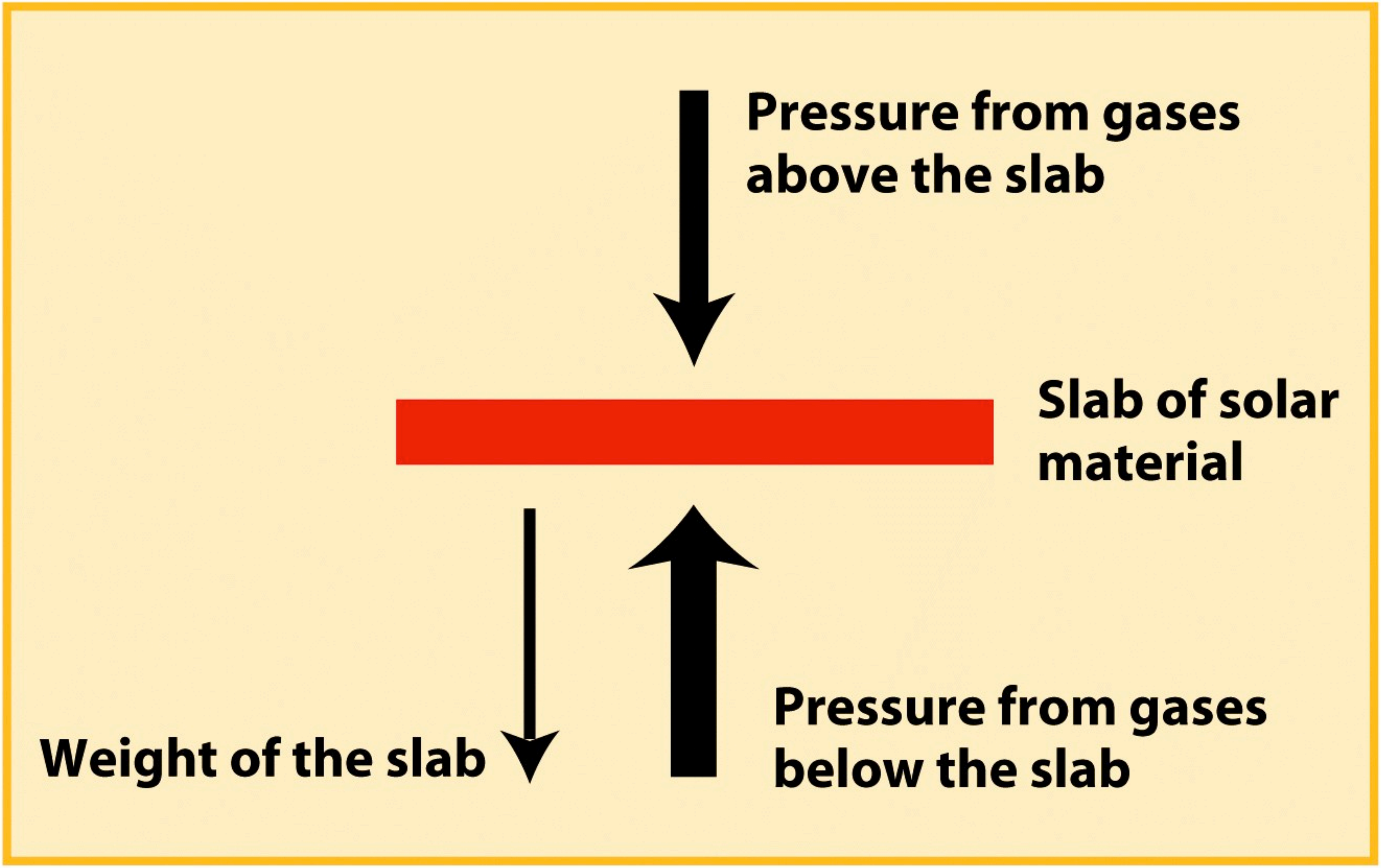
- On your own: answer all the review questions in chapters 16 17 and 18
- To TAs: answer questions 16.31 16.32 17.36 17.66 18.35 18.37

Today on Astro-1

- The Sun
  - Internal structure
  - Energy source
  - Neutrinos and the solar neutrino problem
  - Sunspots and the sun cycle

Why doesn’t the Sun shrink under the force of gravity? Earth doesn't shrink because it's a solid, with the size set by the physical sizes of the atoms. But what keeps the atmosphere up?


Pressure from water below.
Gravity, pressure from water above



Material inside the sun is in hydrostatic equilibrium, so forces balance

Figure 16-2a
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Why doesn’t the Sun shrink under the force of gravity? Earth doesn't shrink because it's a solid, with the size set by the physical sizes of the atoms. But what keeps the atmosphere up?

Pressure! Gas can exert an upward force which balances gravity. Pressure depends on number of atoms in a given volume and temperature.

The sun is about 300,000 times as massive as the Earth, so pressure needed to prevent it from collapsing is huge. But the average density is low, so the temperature must be high!

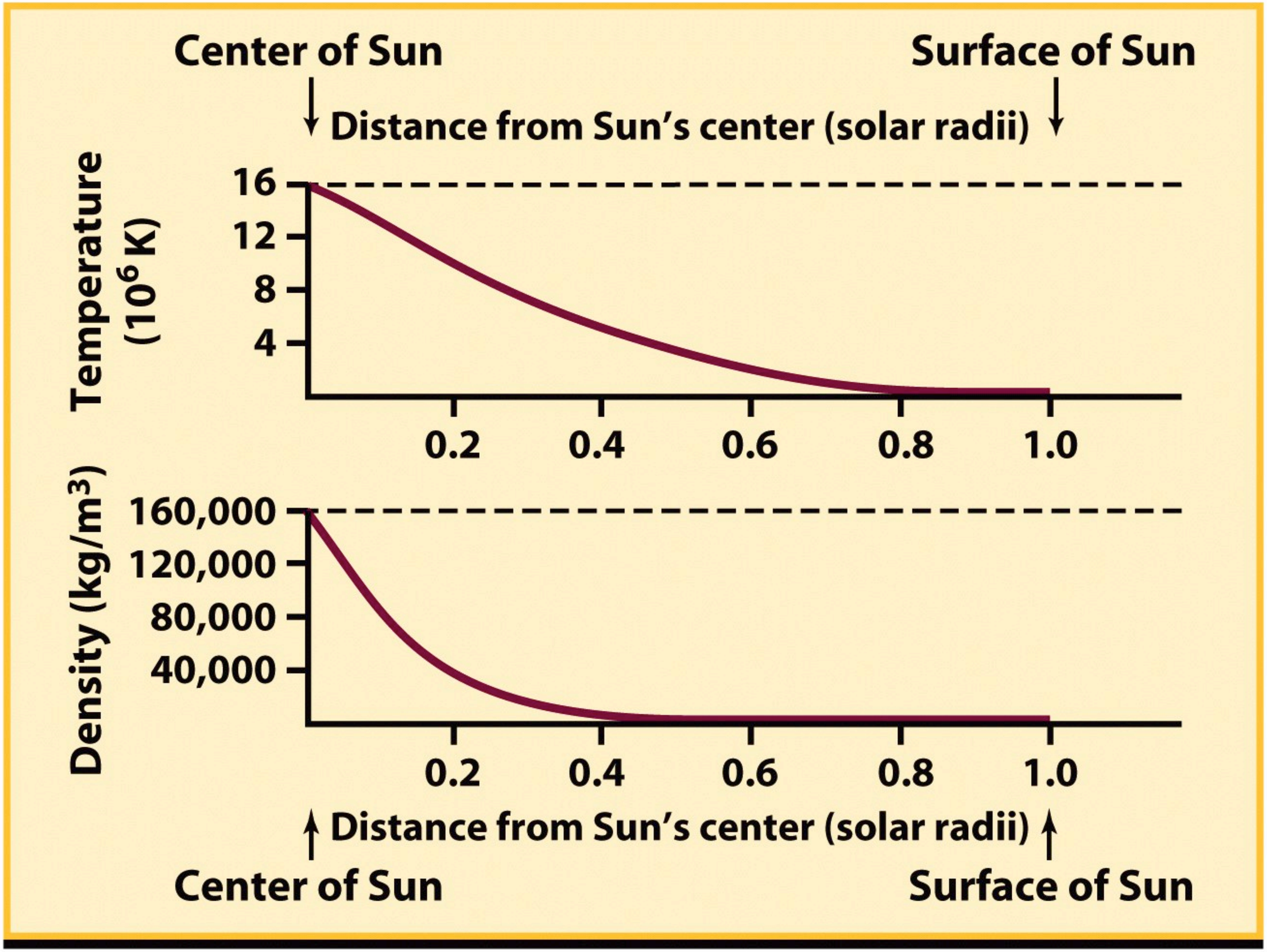

Figure 16-3 part 2
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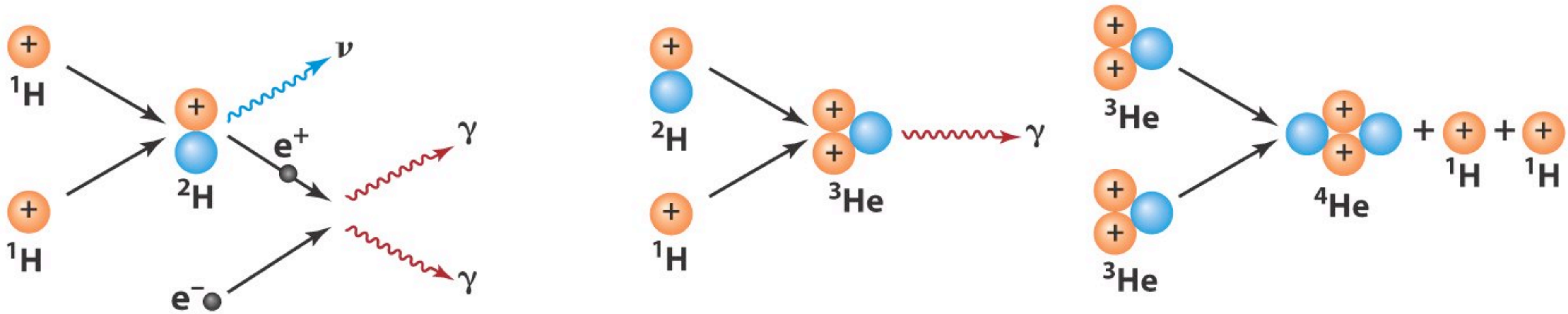
So what keeps the sun hot over billions of years without using up all the fuel? Great mystery of the 19^{th} century.

Chemical burning? Coal? Problem: would only last 3000 years.

Contraction? Only enough energy for 30 million years. (But this is how stars begin!)

Answer: Nuclear fusion. 4 Hydrogen atoms make one Helium atom.

The Sun's energy is produced by hydrogen fusion: 4 hydrogen nuclei → 1 helium nucleus + energy



(a) Step 1:

- Two protons (hydrogen nuclei, ^1H) collide.
- One of the protons changes into a neutron (shown in blue), a neutral, nearly massless neutrino (ν), and a positively charged electron, or positron (e^+).
- The proton and neutron form a hydrogen isotope (^2H).
- The positron encounters an ordinary electron (e^-), annihilating both particles and converting them into gamma-ray photons (γ).

(b) Step 2:

- The ^2H nucleus from the first step collides with a third proton.
- A helium isotope (^3He) is formed and another gamma-ray photon is released.

(c) Step 3:

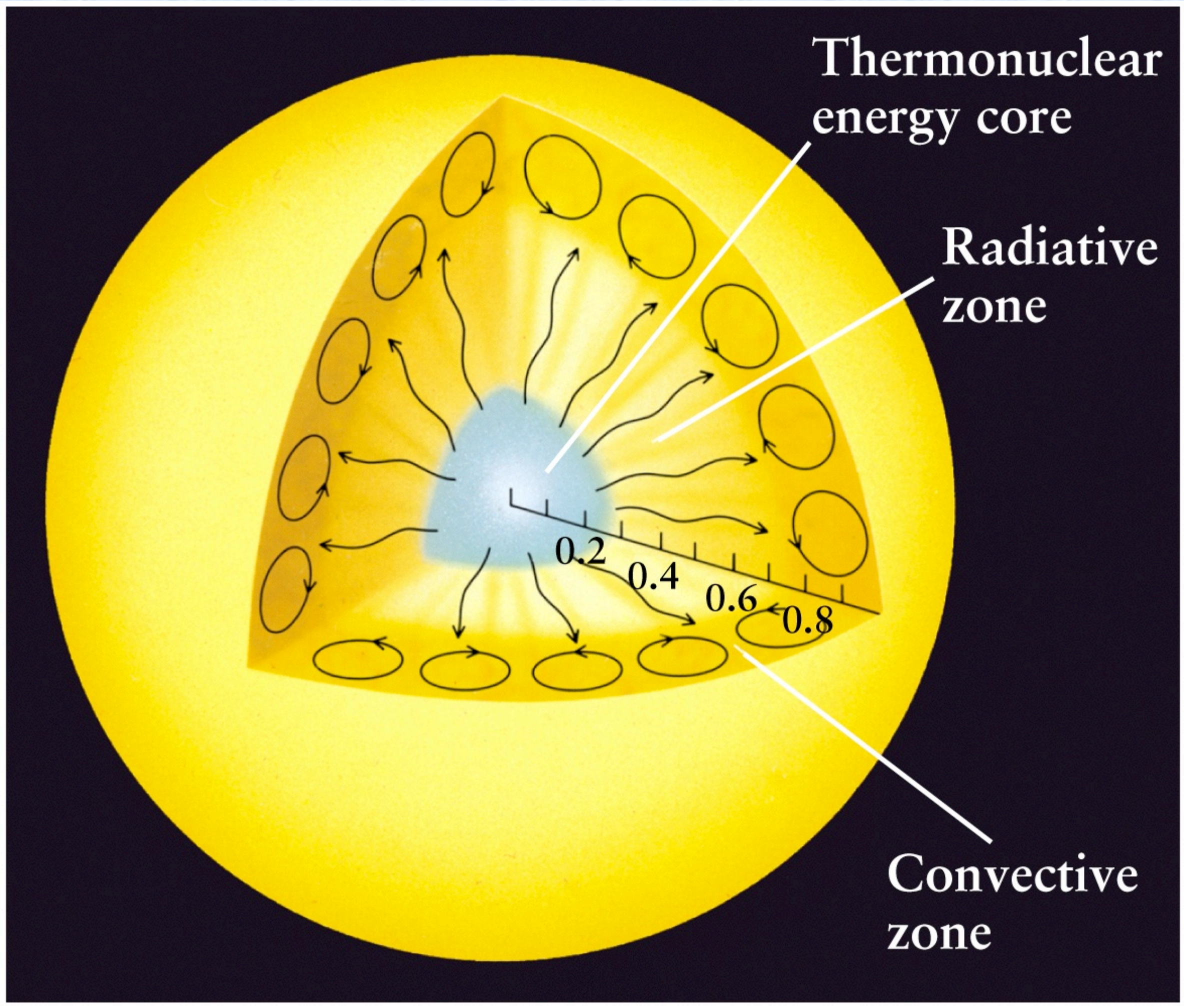
- Two ^3He nuclei collide.
- A different helium isotope with two protons and two neutrons (^4He) is formed and two protons are released.

$E=mc^2$ Very efficient: By converting 1 g Hydrogen (mass of a paper clip) to 0.99 g He you get enough to lift a 40,000 ton battleship 40 miles high!

The sun converts 600 million metric tons of hydrogen to helium each second!

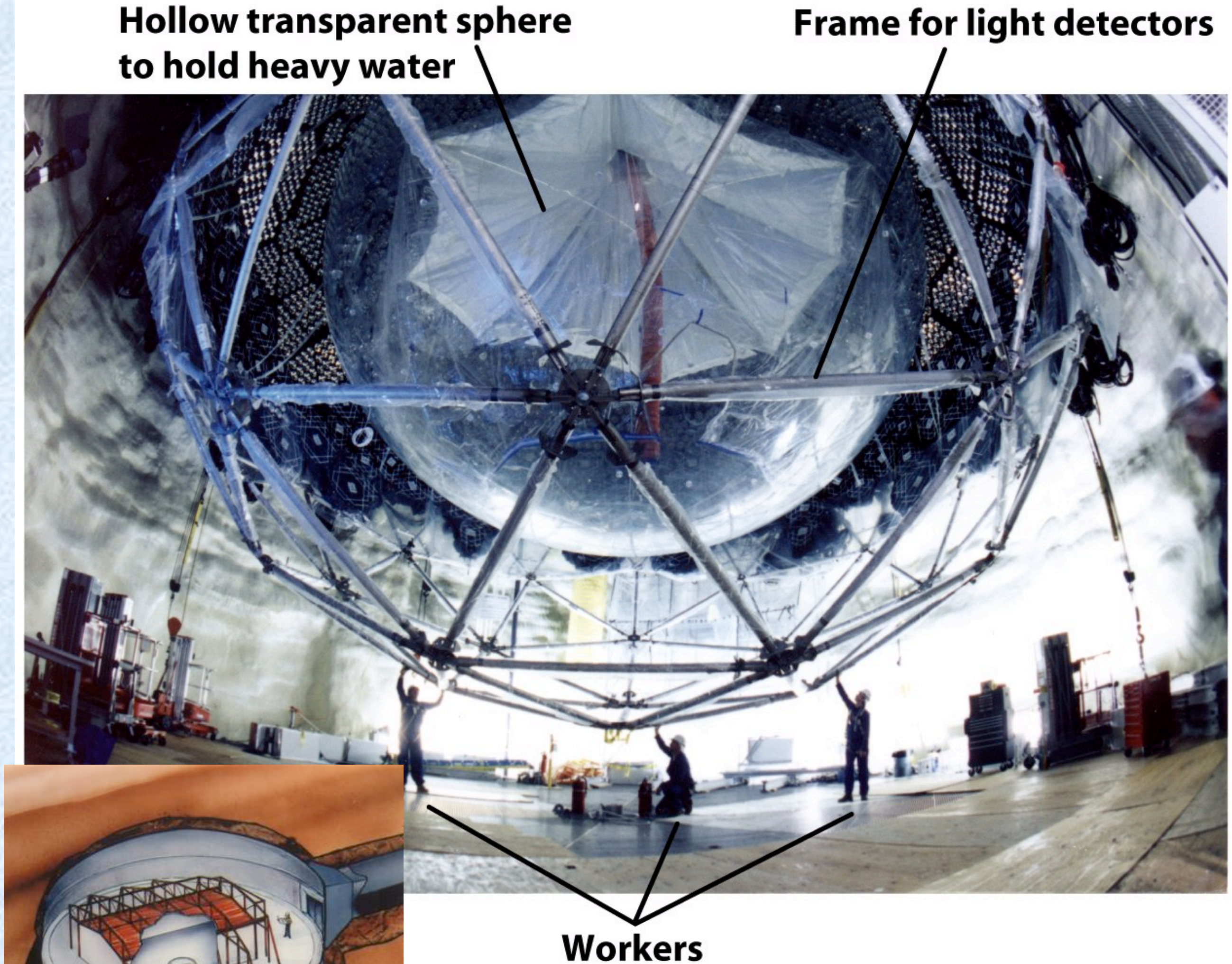
The H-bomb is nuclear fusion (note: different than nuclear weapons dropped on Japan at the end of WWII, which were *fission*-based).

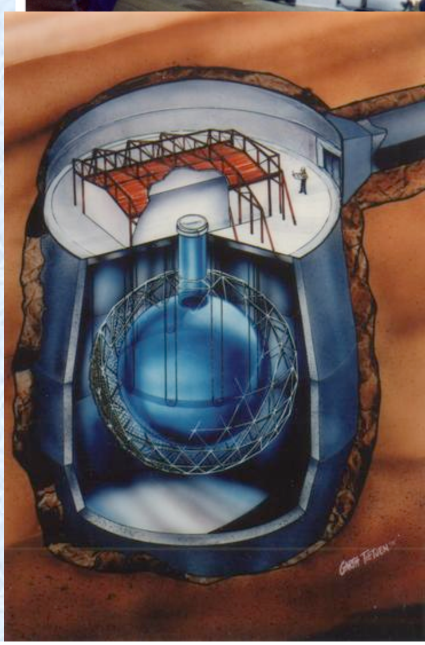
Thermonuclear reactions can only occur in the Sun's core — that's the only place where pressures and temperatures are high enough



It takes light about 200,000 years to get from the core to the surface (then 8 minutes to get to us)!

But neutrinos get out immediately (and get to Earth in 8 minutes).
And oscillates!
Superkamiokande





The Sudbury Neutrino Observatory Under Construction

The transparent acrylic sphere holds 1000 tons of heavy water. Any of the three types of solar neutrino produces a flash of light when it interacts with the heavy water. The flash is sensed by 9600 light detectors surrounding the tank. (The detectors were not all installed when this photograph was taken.)

Hydrogen fusion also takes place in all of the stars visible to the naked eye. (Fusion follows a different sequence of steps in the most massive stars, but the net result is the same.)

(Courtesy of Wally Pacholka)

Cosmic Connections 16b
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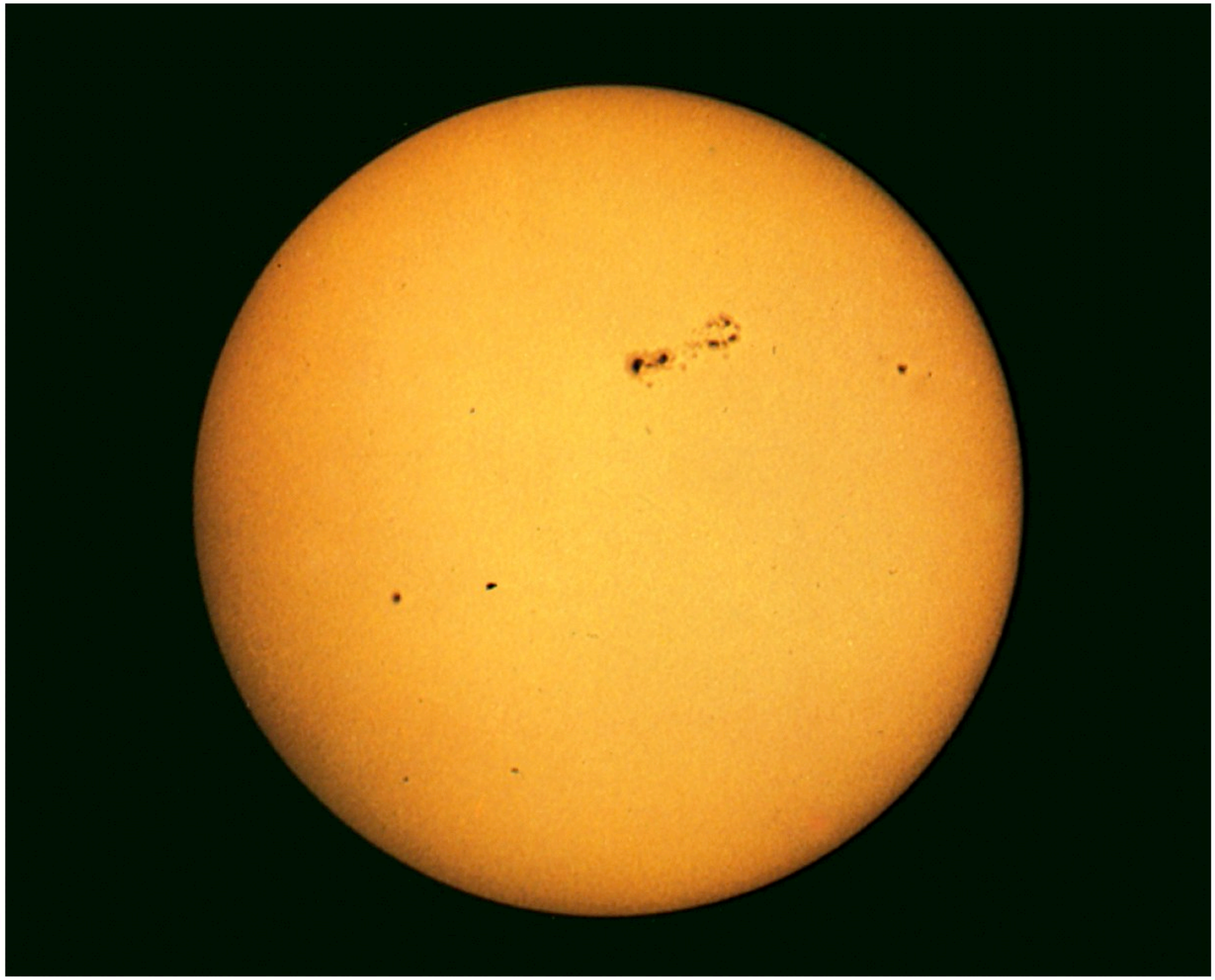
Question 19.1 (iclickers!)

- Hydrogen burning occurs only deep in the interior of the Sun (and other stars) because this is the only place where
    - A) There is sufficient hydrogen
    - B) The density is sufficiently low for the high temperature atoms to build up enough energy to collide and undergo fusion
    - C) The temperature is low enough and the density is high enough to allow Hydrogen atoms to collide with each other often enough for fusion to occur
    - D) The temperature and density are high enough to allow Hydrogen atoms to collide with each other and undergo fusion

The appearance of the sun: the photosphere



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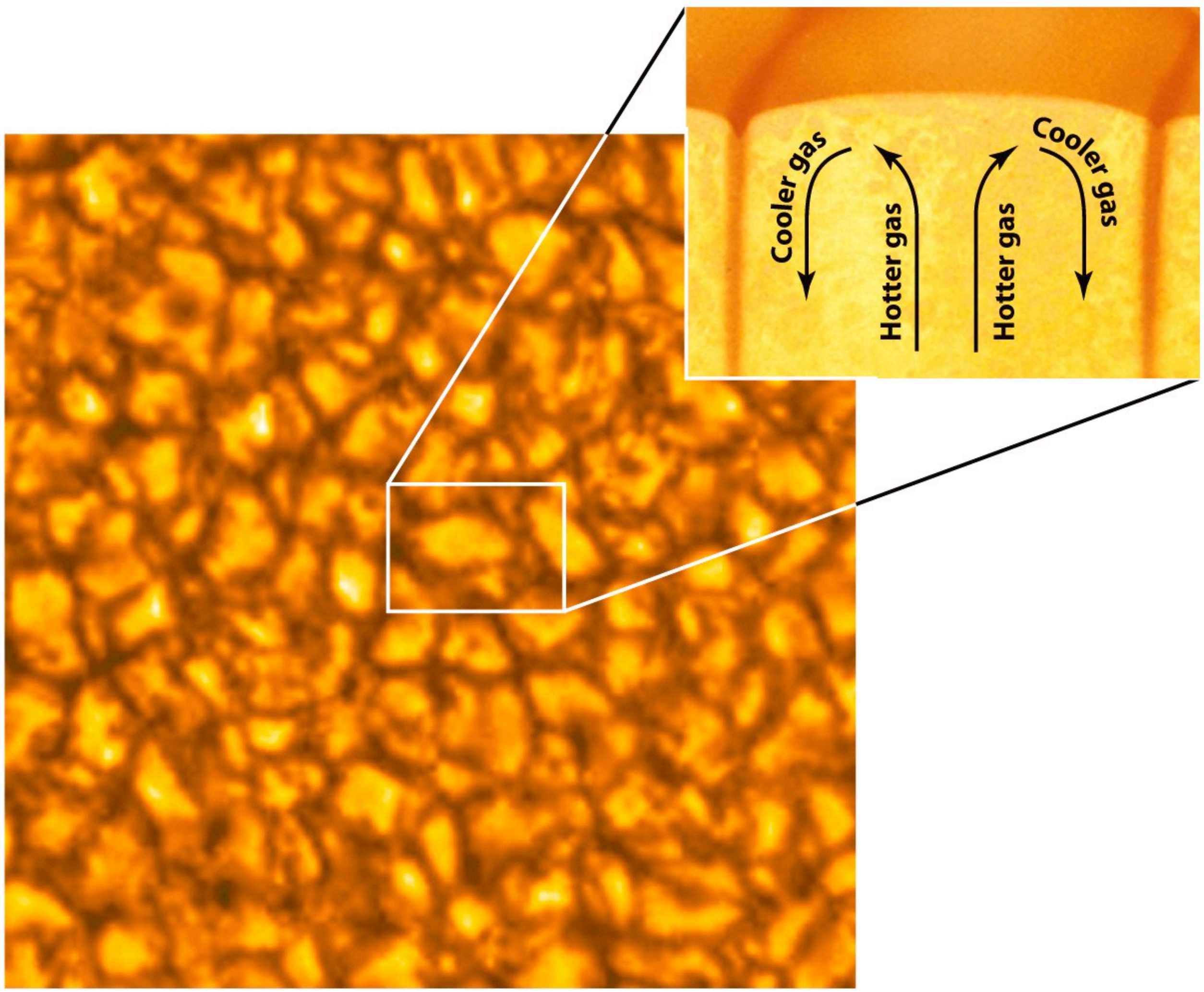

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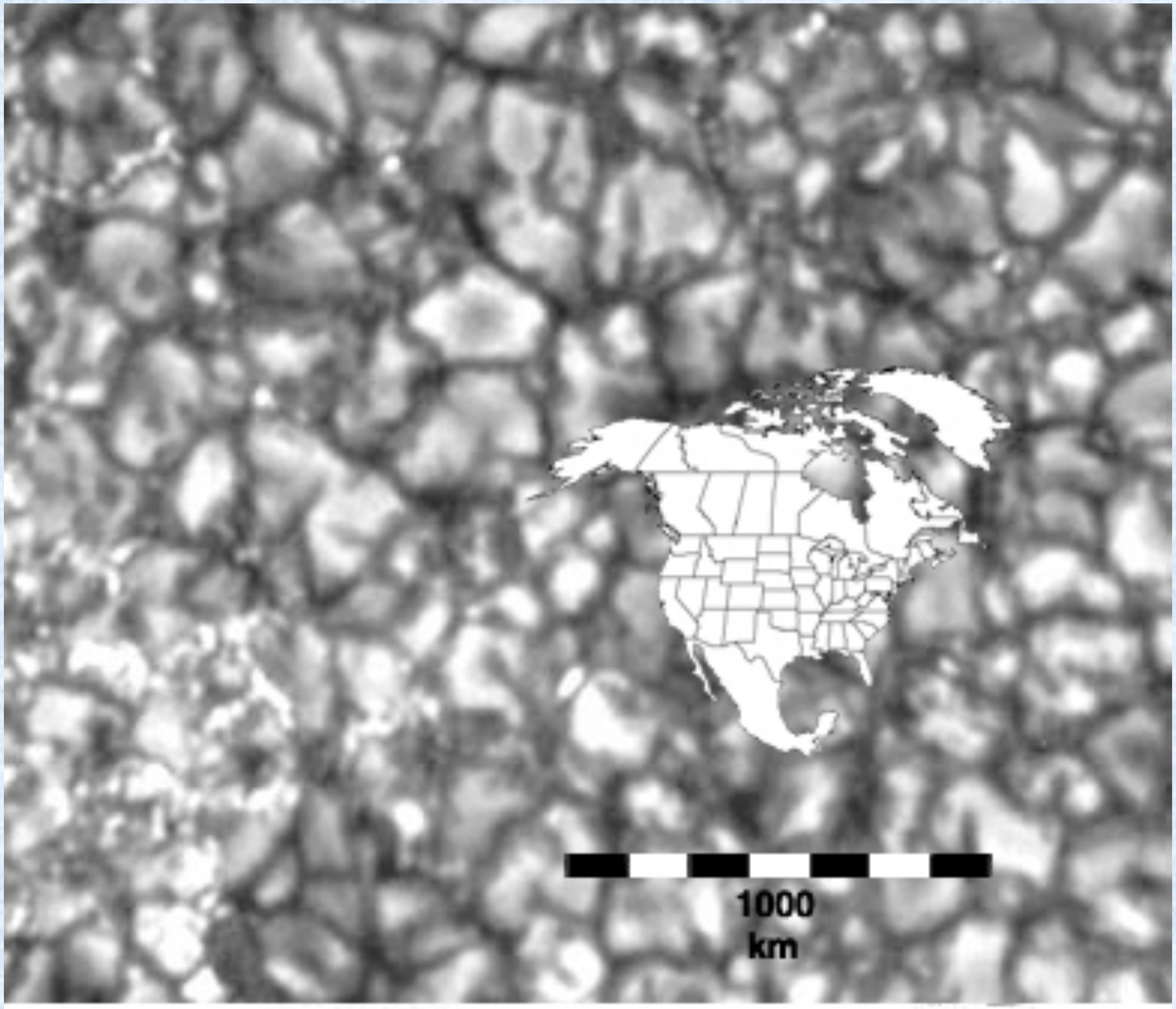
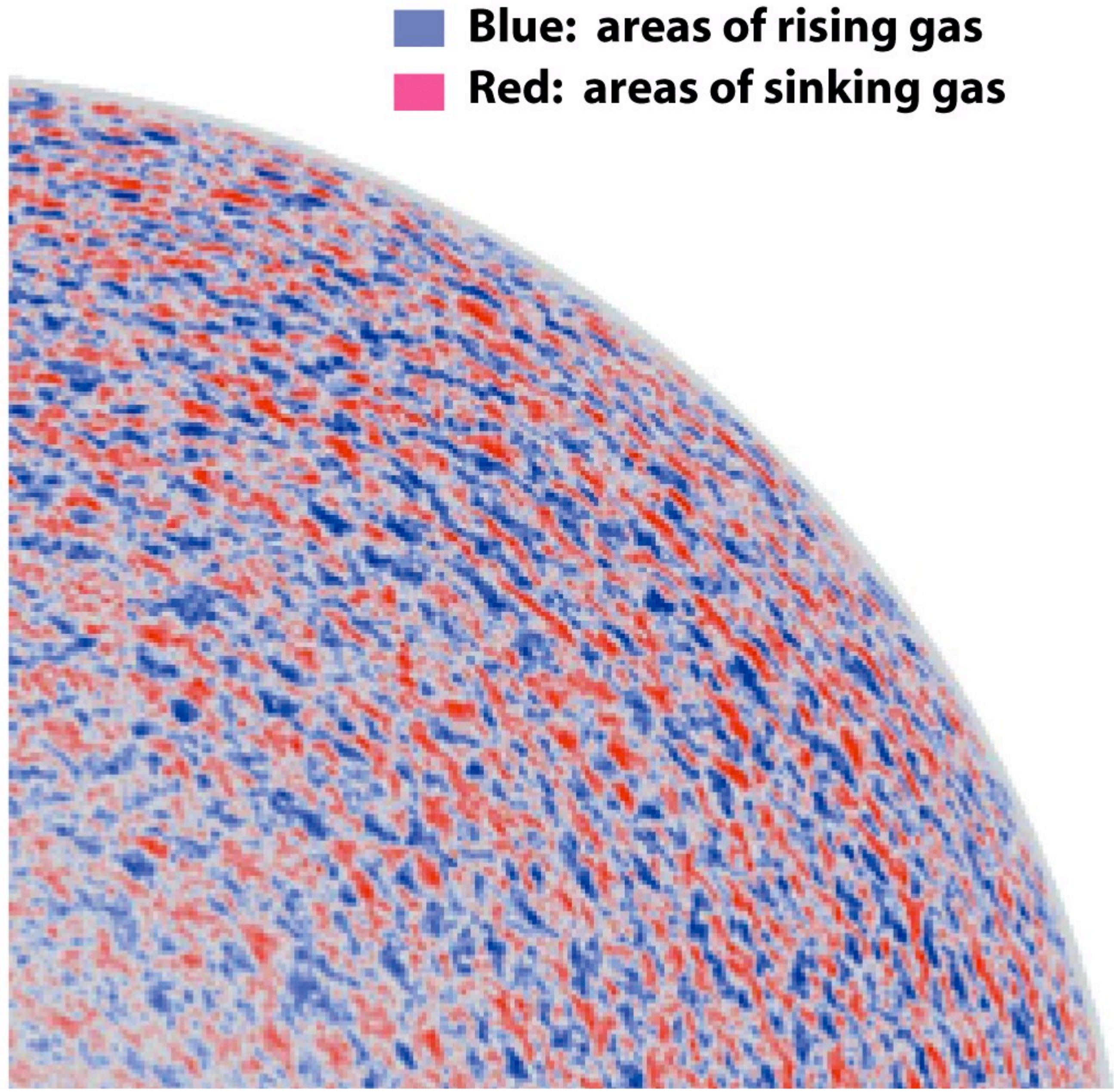
Granules are convection cells about 1000 km (600 mi) wide in the Sun's photosphere. Inset: Rising hot gas produces bright granules. Cooler gas sinks downward along the boundaries between granules; this gas glows less brightly, giving the boundaries their dark appearance. This convective motion transports heat from the Sun's interior outward to the solar atmosphere.

Scale of granules



Photospheric granulation, G. Scharmer
Swedish Vacuum Solar Telescope
10 July 1997



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Supergranules display relatively little contrast between their center and edges, so they are hard to observe in ordinary images. But they can be seen in a false-color Doppler image like this one. Light from gas that is approaching us (that is, rising) is shifted toward shorter wavelengths, while light from receding gas (that is, descending) is shifted toward longer wavelengths

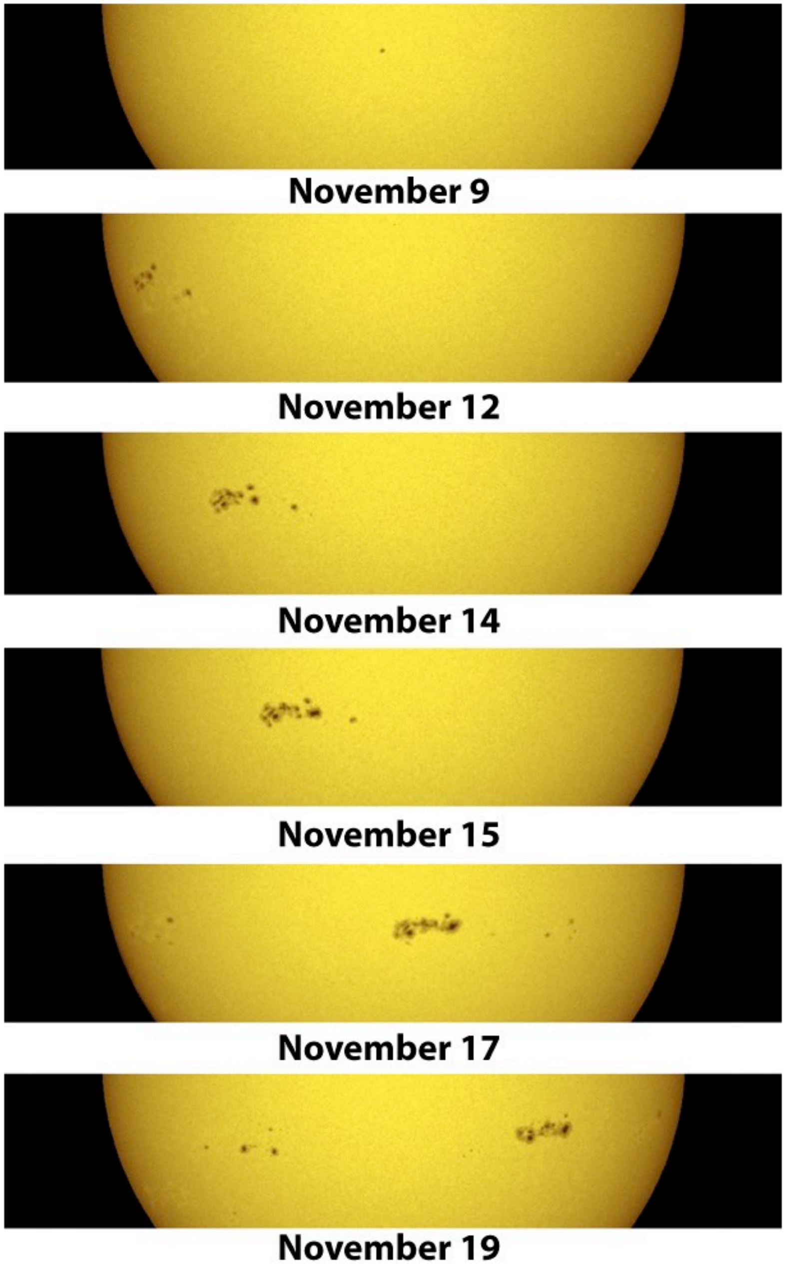

Figure 16-17
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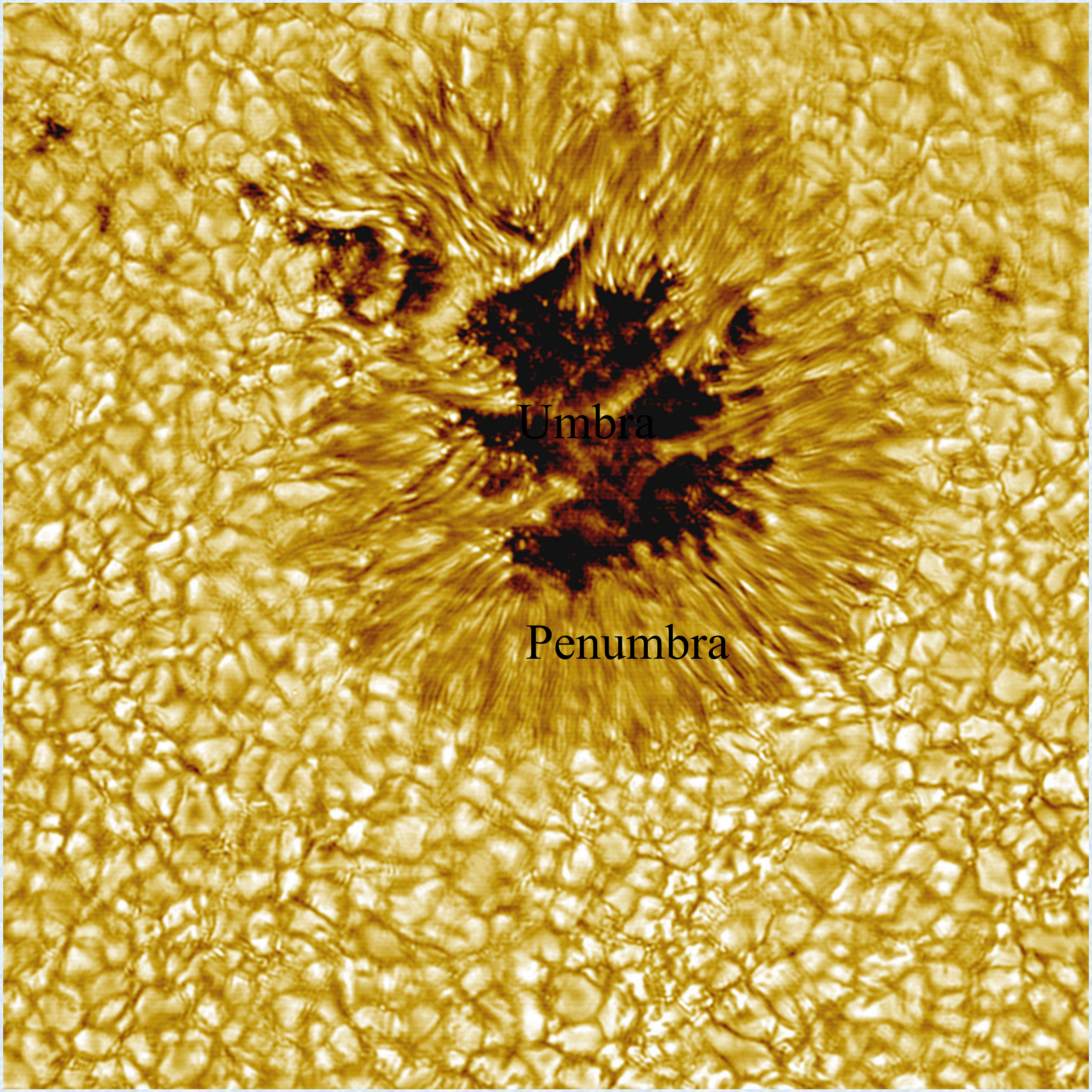
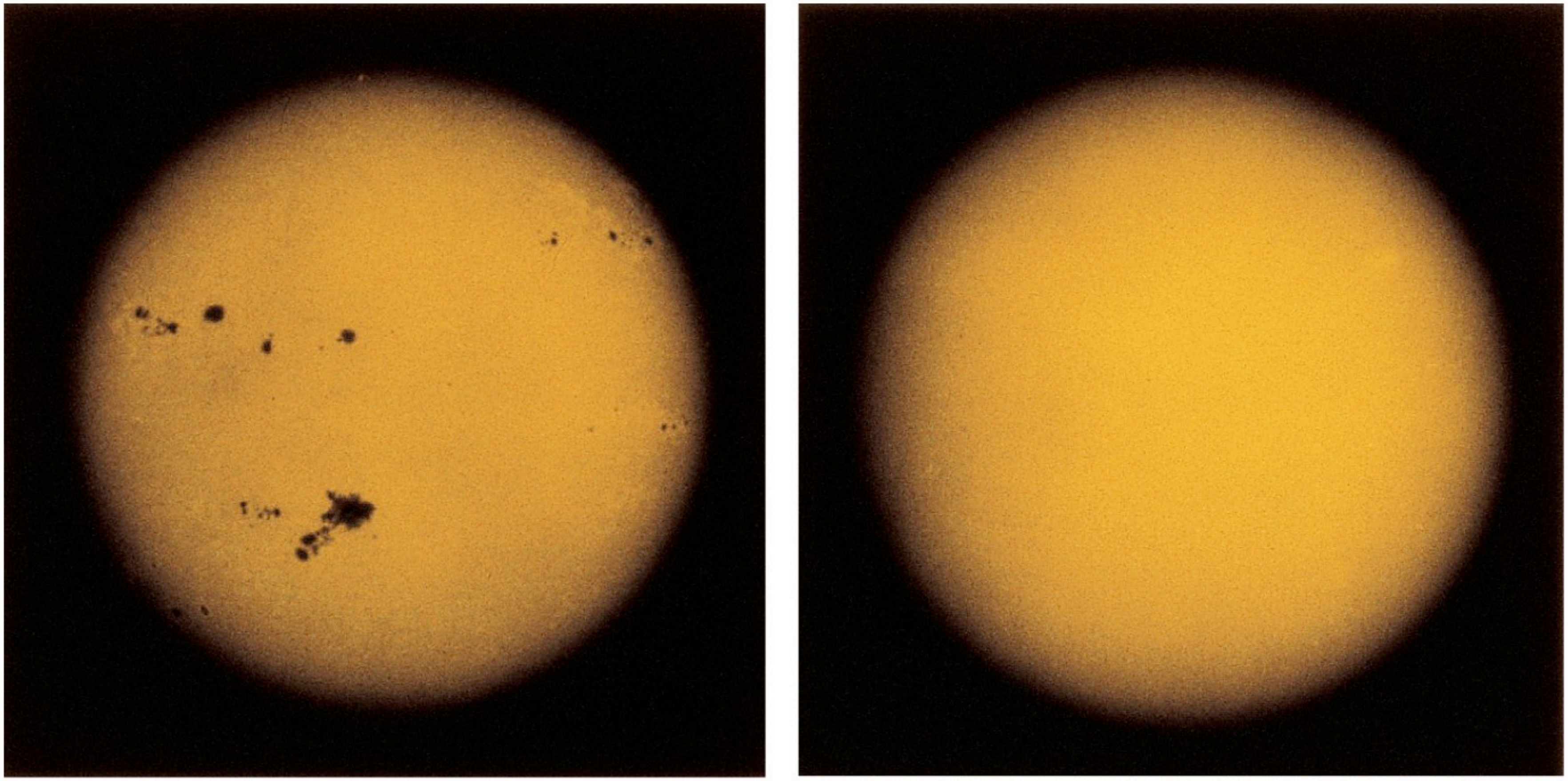
This series of photographs taken in 1999 shows the rotation of the Sun. By observing the same group of sunspots from one day to the next, Galileo found that the Sun rotates once in about four weeks. (The equatorial regions of the Sun actually rotate somewhat faster than the polar regions.) Notice how the sunspot group shown here changed its shape.


Umbra
Penumbra



Near sunspot maximum Near sunspot minimum

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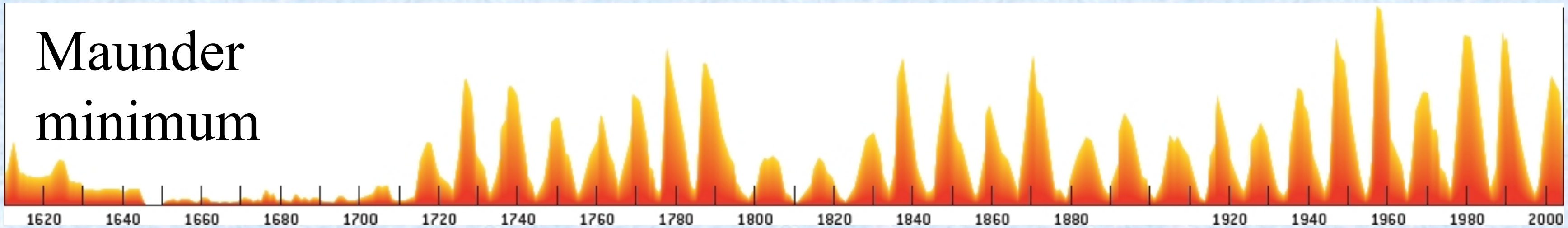
The Sun's 22-year cycle is NOT uniform

Number of sunspots versus year, 1610-present



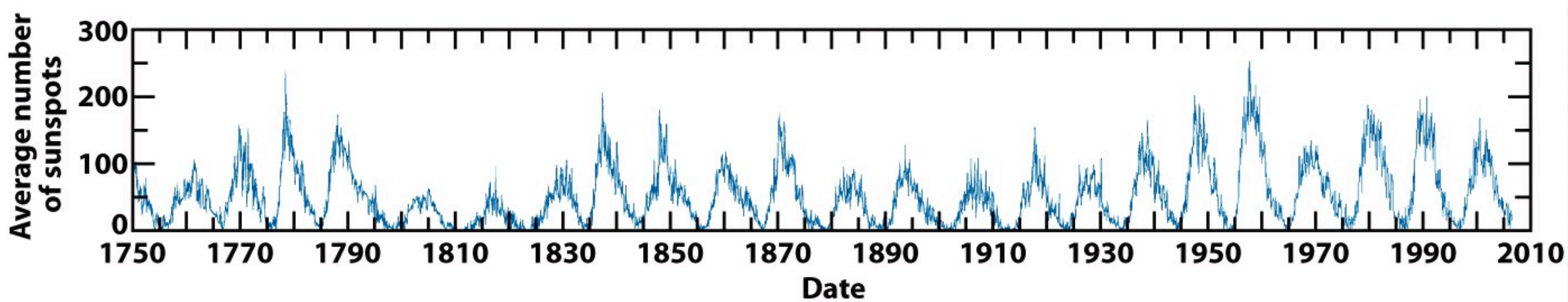


Figure 16-18a
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The number of sunspots on the Sun varies with a period of about 11 years. The most recent sunspot maximum occurred in 2000, next one will be in 2013 (predicted).

Question 19.2 (iclickers!)

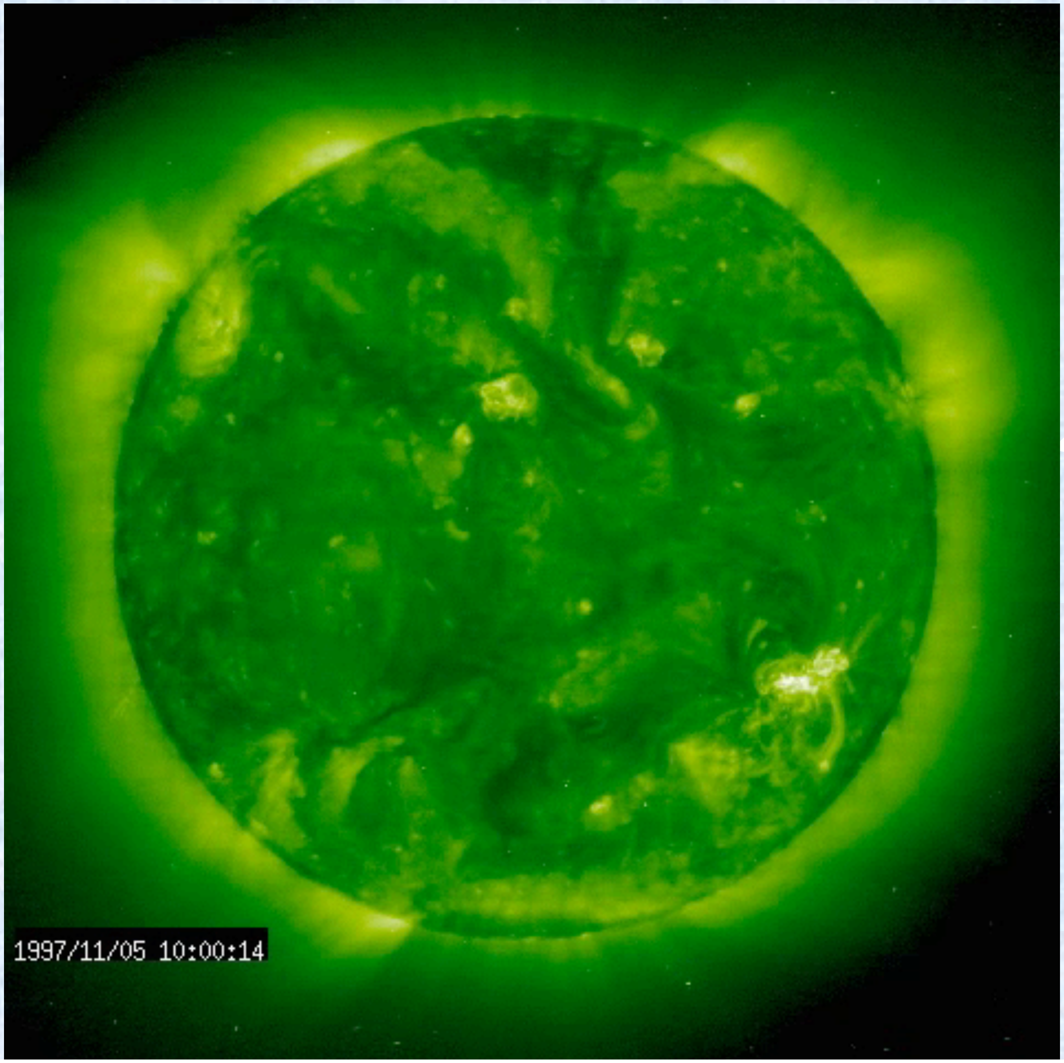
- Any massive object will collapse under its own gravity unless something stops it. In an ordinary star like the sun this collapse is prevented by
  - A) The rotation of the star
  - B) The star’s solid core
  - C) Gas pressure pushing outward
  - D) Turbolence and upwelling in the atmosphere of the star.

Question 19.3 (iclickers!)

- The average time taken for energy generated by thermonuclear fusion in the center of the Sun to reach the surface layers and escape is calculated to be
    - A) just a few seconds, because this energy travels at the speed of light
    - B) about 10 million years
    - C) about 1 year
    - D) about 200,000 years.

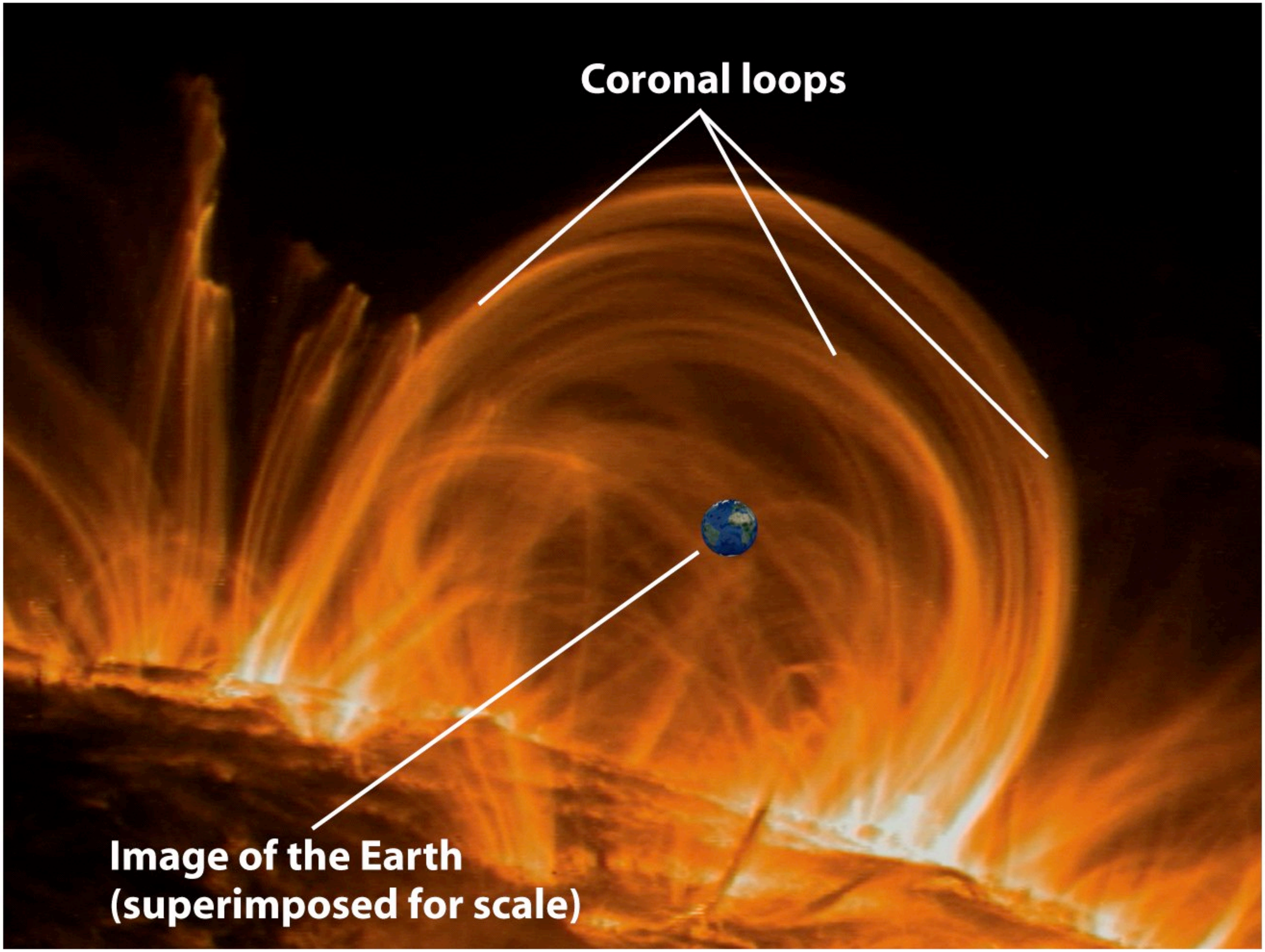

The surface (photo
sphere) of the Sun is
about 5800K, but the
corona above it is
about a million
degrees. How?

Variations in the Sun's magnetic field drive the activity on and above the solar surface



Rearrangements of the magnetic field cause eruptions and flares

(an ultraviolet movie)



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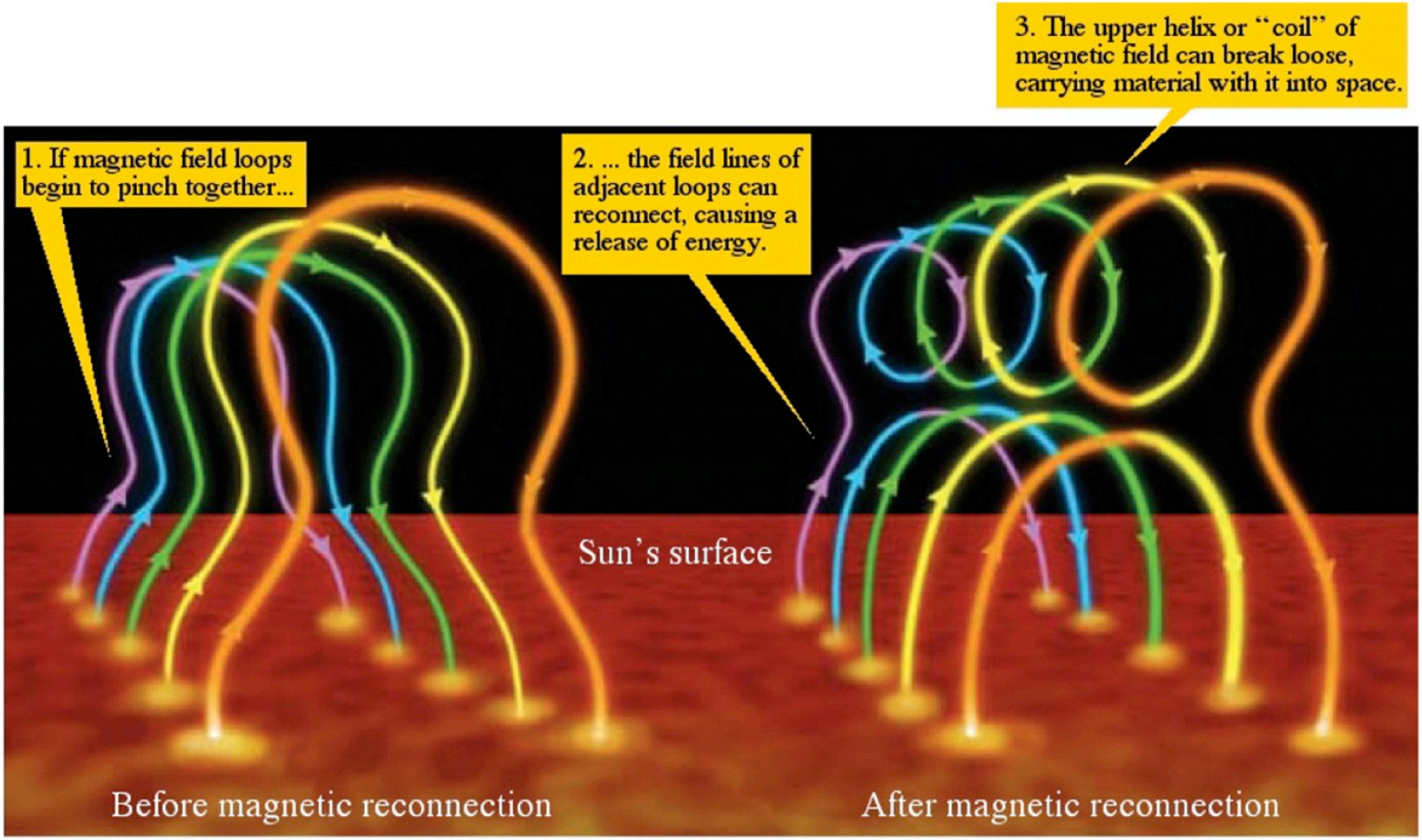

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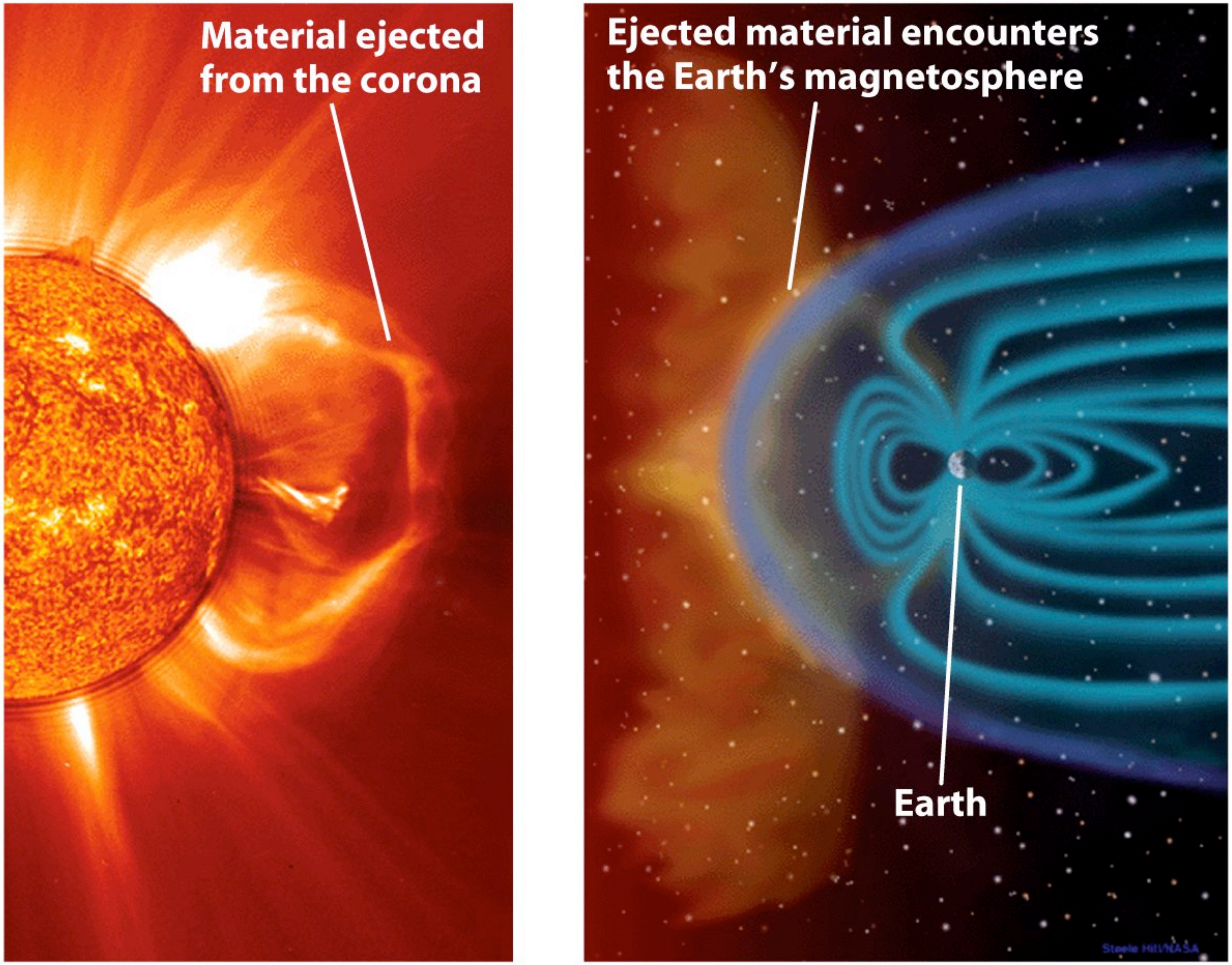

(a) A coronal mass ejection **(b) Two to four days later**

Figure 16-28
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Summary

- The Sun's energy is produced by hydrogen fusion ($E=mc^2$), occuring at 10^7 K in the nucleus of the sun.
- The standard model of the Sun
  - hydrogen fusion within 0.25 solar radius.
  - a radiative zone extending to about 0.71 solar radius
  - opaque convective zone
  - Photosphere (5800 K blackbody)
  - Chromosphere (hotter)
  - Corona (very hot; powered by magnetic fields)
- Neutrino's escape from the Sun's core and reveal neutrino oscillations

Summary

- **The Sun's cycle is 22 long:** Its magnetic field increases, decreases, and then increases again with the opposite polarity, creating a 11 year cycle in Sun spot activity
- The magnetic-dynamo model suggests that many features of the solar cycle are due to changes in the Sun's magnetic field. These changes are caused by convection and the Sun's differential rotation.
- A solar flare is a brief eruption of hot, ionized gases from a sunspot group. A coronal mass ejection is a much larger eruption that involves immense amounts of gas from the corona.

The End

See you on friday!