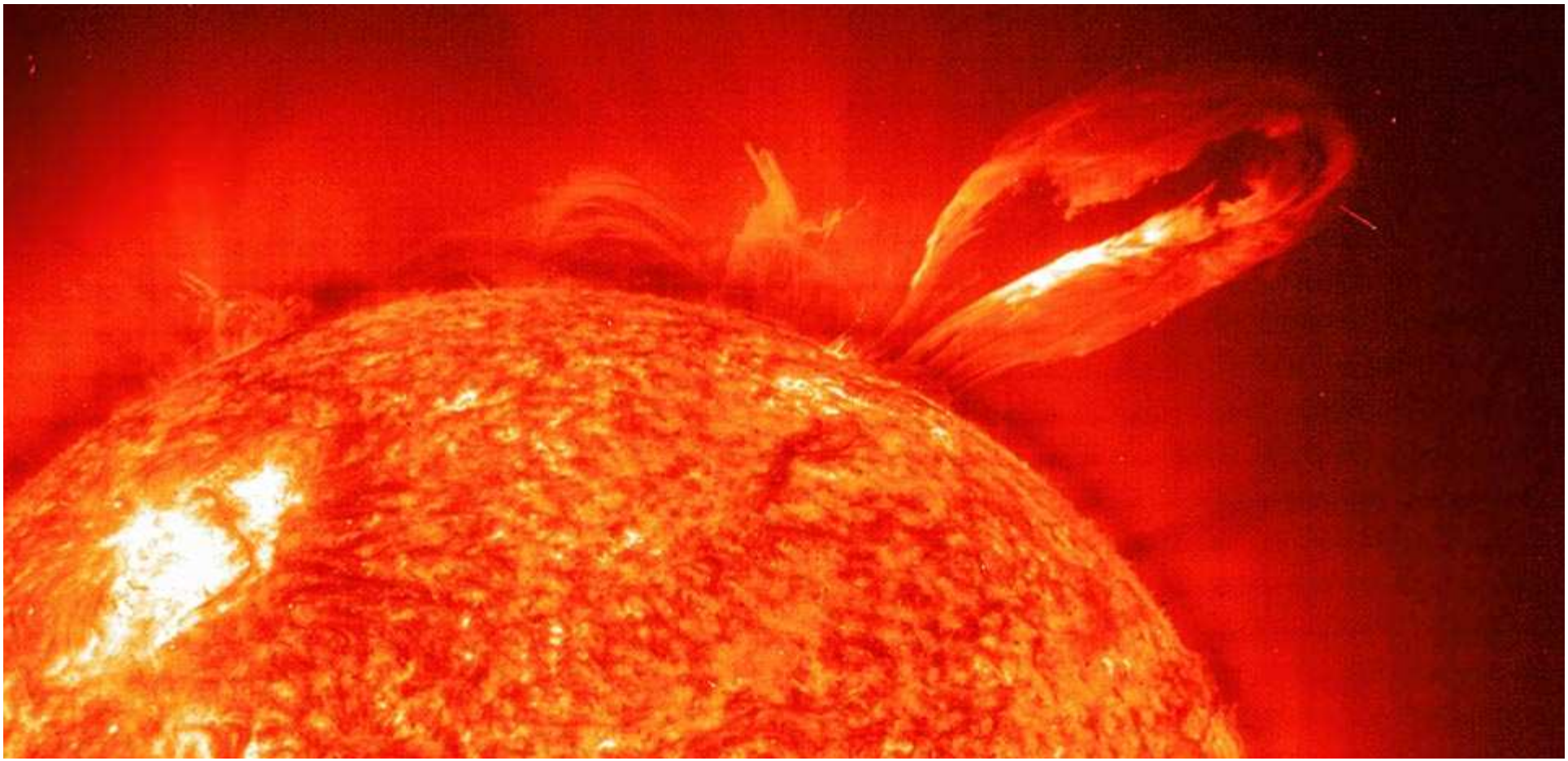


“The glorious lamp of heaven, the sun.”

Robert Herrick

What We Will Learn Today

- How does the Sun shine?
- What do we know about the Sun?
- What are the layers of the Sun?
- What is solar activity?

How Does the Sun Shine?

- Review
  - Gravitational collapse of solar nebula heated the core
  - Hydrogen fusion ignited the Sun
    - $E = mc^2$
- Details of energy production
  - M (4 ^{1}H) = 6.690 x 10^{-27} kg
  - M (1 ^{4}He) = 6.643 x 10^{-27} kg
  - Mass converted into Energy = 0.047 x 10^{-27} kg
  - Efficiency = 0.047/6.690 = 0.7%
  - Energy = 0.047 x 10^{-27} kg x c^2 = 4.23 x 10^{-12} J
- Sun's shining power
  - L = 3.8 x 10^{26} J/s or Watts (W)

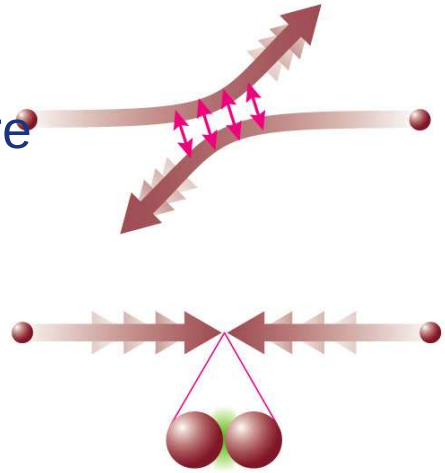


Fig 14.6

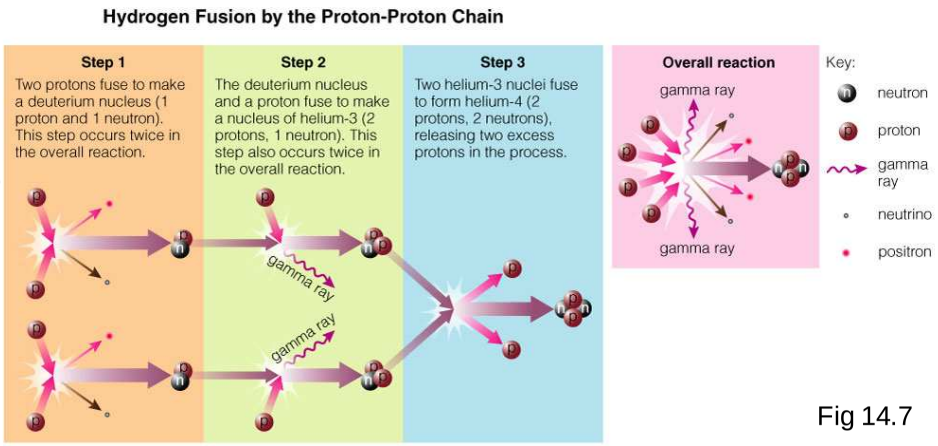


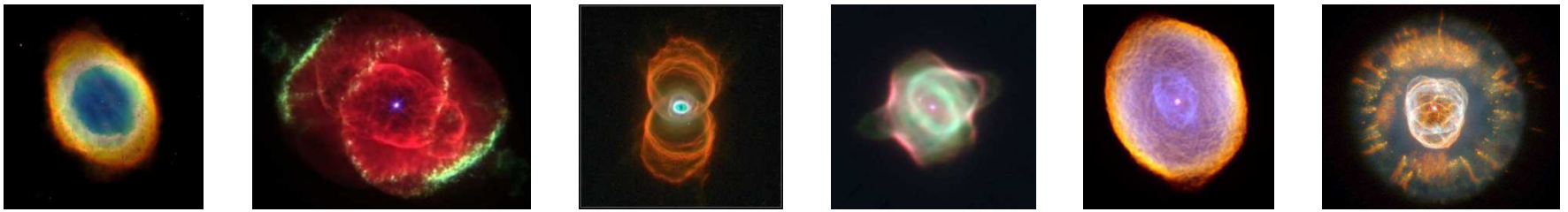
Fig 14.7

The Sun consumes 600 million tons (6 x 10^{11} kg) of Hydrogen *per second*

How Long Can the Sun Shine?

- Mass of the Sun = 2×10^{30} kg
- Rate of Hydrogen use = 6×10^{11} kg / s
- Fuel exhaustion time $\approx 3.3 \times 10^{18}$ s

  $\approx 10^{11}$ y
- That's 100 billion years!
- The Sun will spend ~ 10 billion years in the MS
- It has used only ~ 5% of its fuel so far!
- It will only use 10% of its fuel in its lifetime
  - The bulk is ejected into the beautiful planetary nebula



Sun's Regulated Fusion

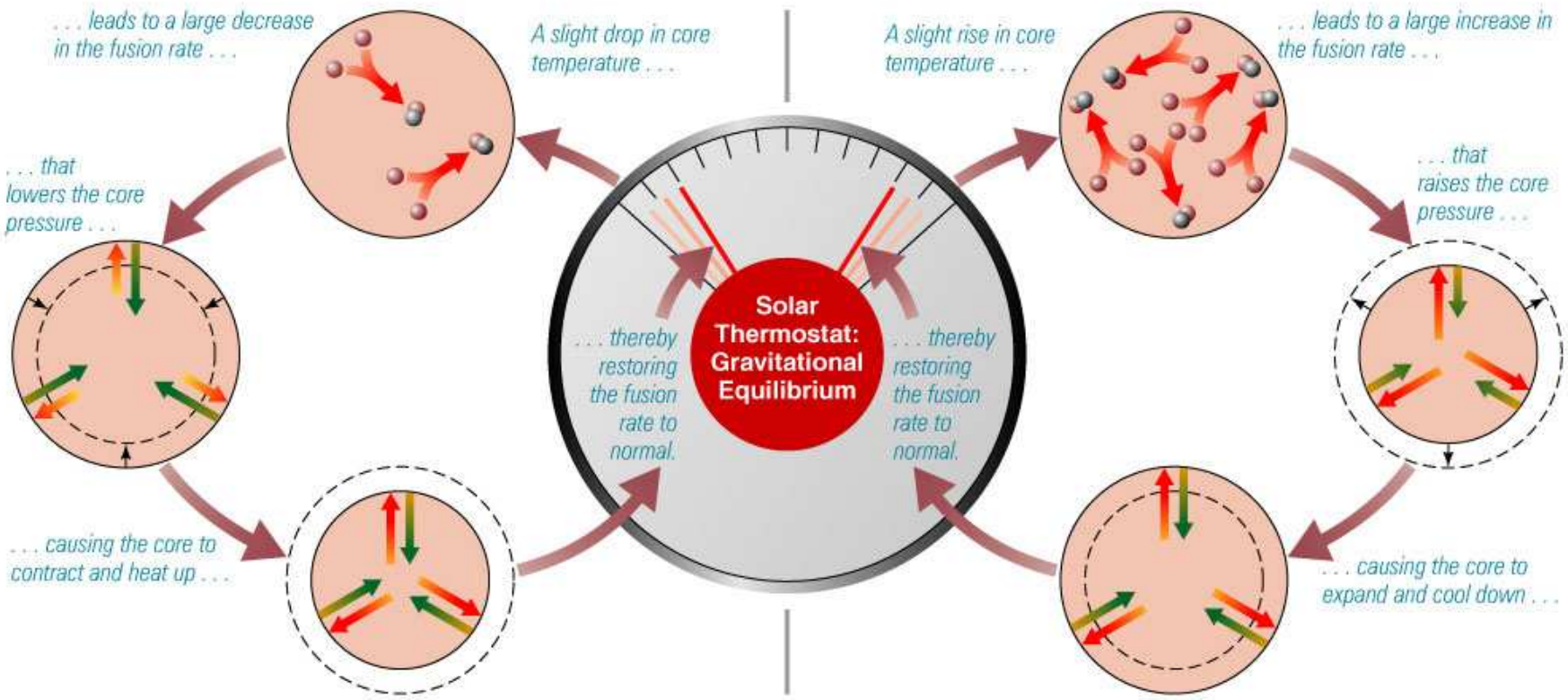


Fig 14.8

Light's Journey Through the Sun

- "Random walk"
  - Photon moves in a straight line until it interacts with an electron
  - In the dense core, it travels only a millimeter or so before the next interaction
  - Each interaction redirects the photon in a random direction
- The photon can take hundreds of thousands of years to exit the Sun!

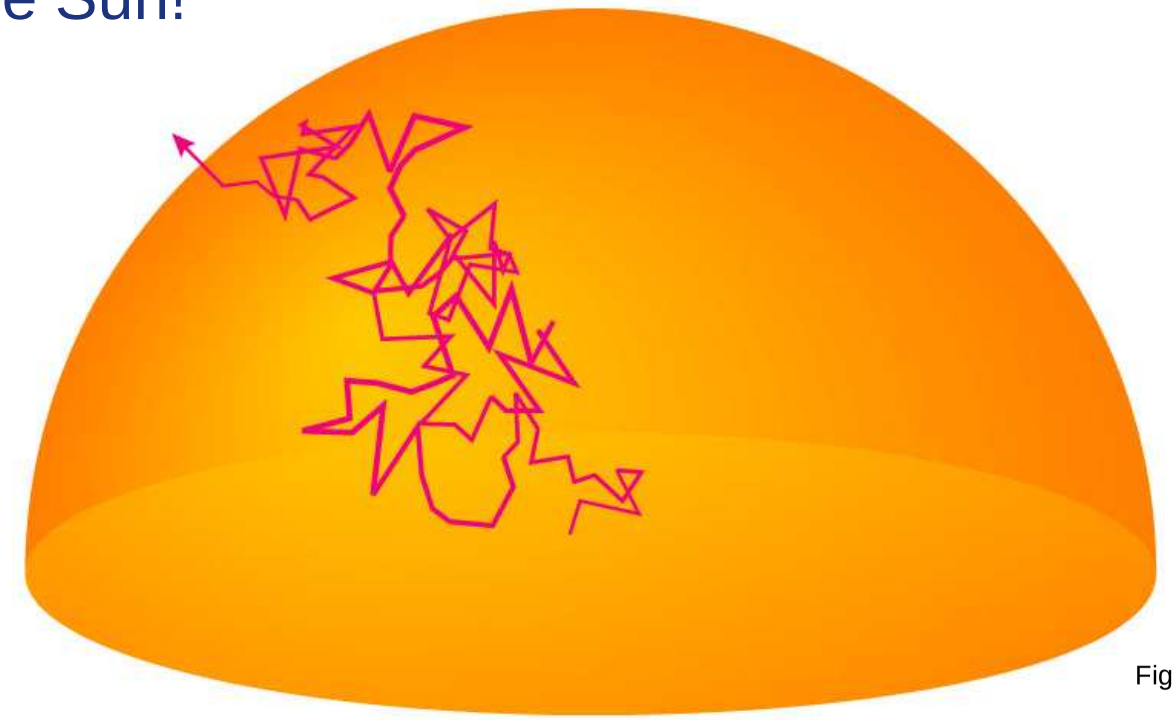


Fig 14.9

Through The Multiple Layers

- Random walk through the radiation zone
- Temperature drops in convection zone, enough to cause absorption
- Surface bubbles due to convection
  - Hot gas rises
  - Cool gas sinks

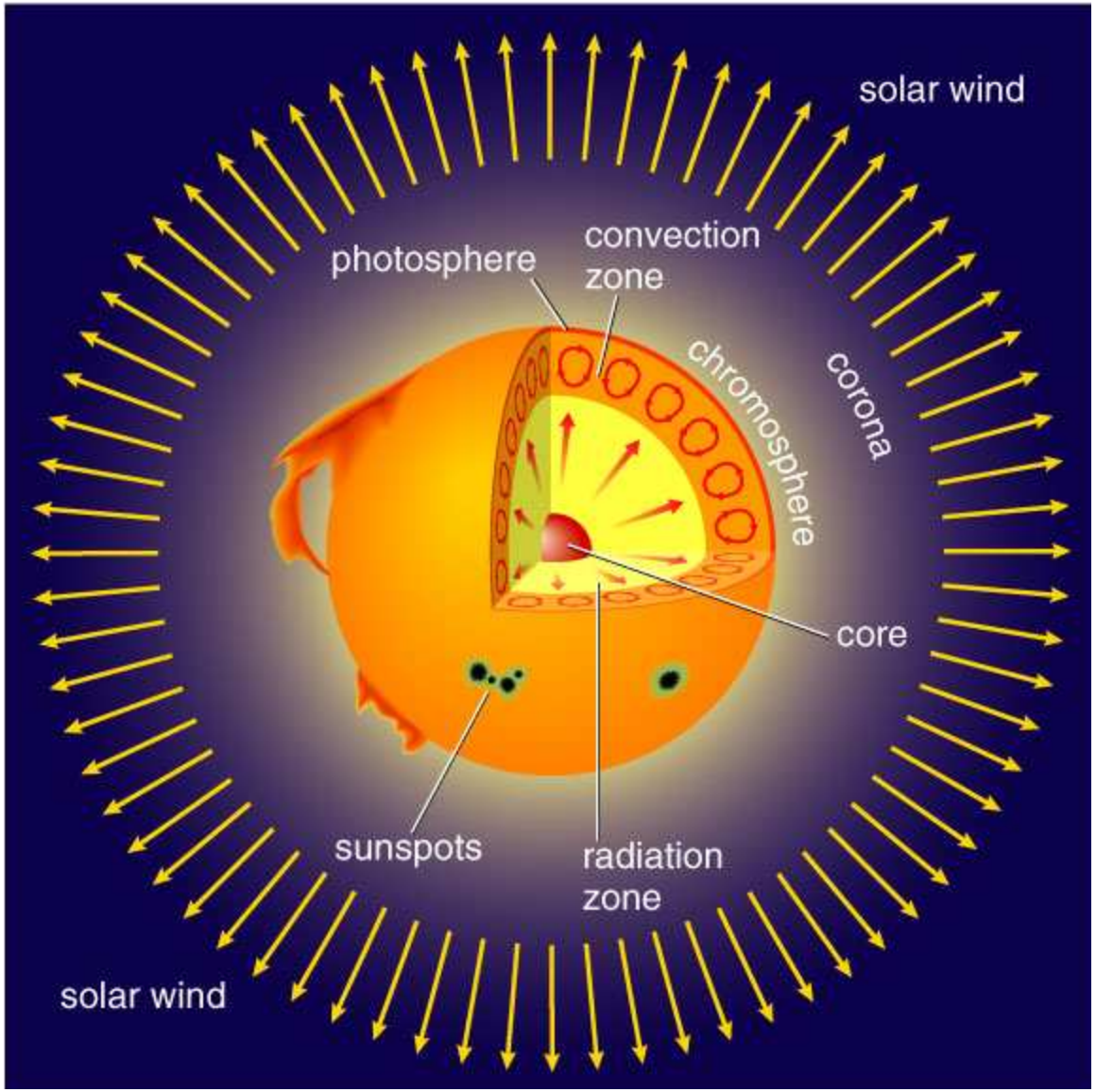


Fig 14.3

Learning About the Interior

- Mathematical Models
  - Prediction of radius, surface temperature and other observables are very good
- Helioseismology
  - Measure vibrations on the surface via Doppler shifts and correlate to structure of the interior
- Solar neutrinos
  - Trillions pass through your body every second!
  - Rarely interact with matter
  - Produced as a byproduct of fusion
  - Solving the solar neutrino “problem” was a major victory

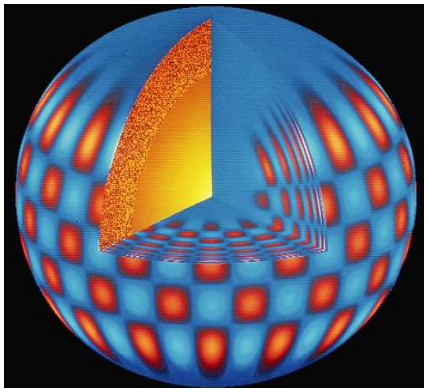


Fig 14.11

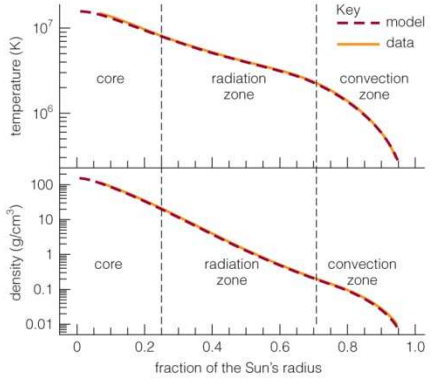
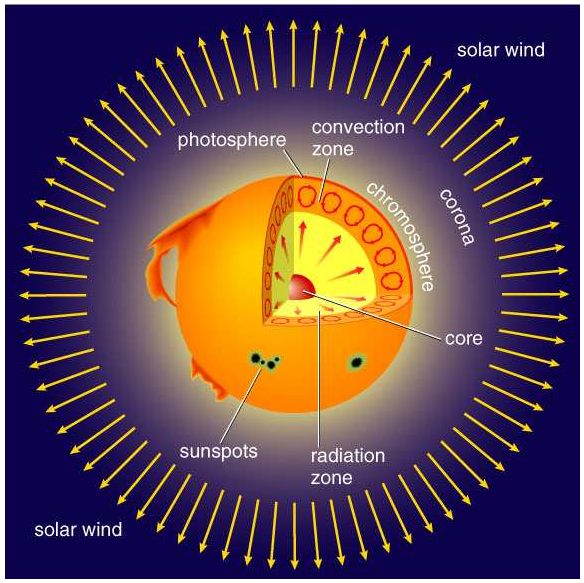


Fig 14.12

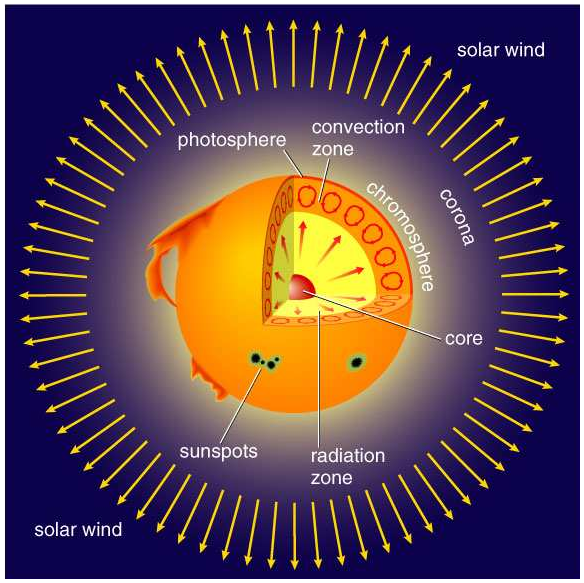
The Core

- 200,000 km radius
- Highest density (~ 160 g/cc)
- Highest temperature (15 million K)
- Where all the fusion occurs



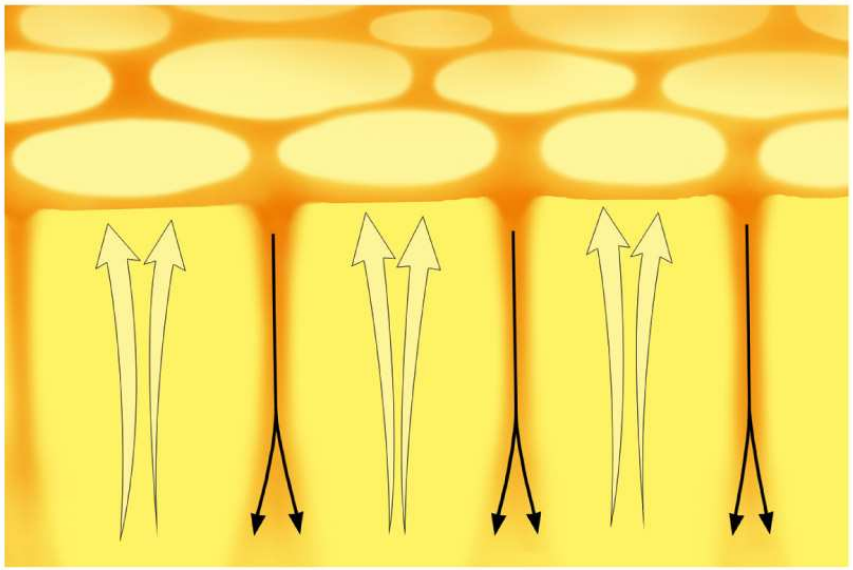
The Radiation Zone

- 300,000 km thick
- Temperature ~ 7 million K
- Light makes its way out via random walk
- Neutrinos stream through with little interaction



The Convection Zone

- 200,000 km thick
- Temperature drops to ~ 2 million K
- Convective cells bubble energy up



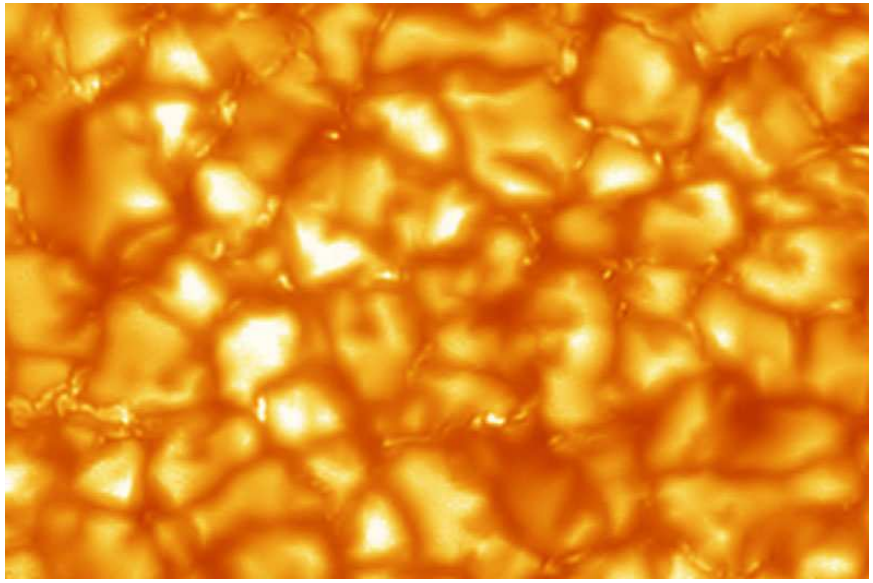


Fig 14.10

The Photosphere

- The “surface” of the Sun
  - 500 km thin
- Temperature = 5800 K
- See sun spots and granulation (convection cells)
- The Earth would fit inside a typical sunspot!

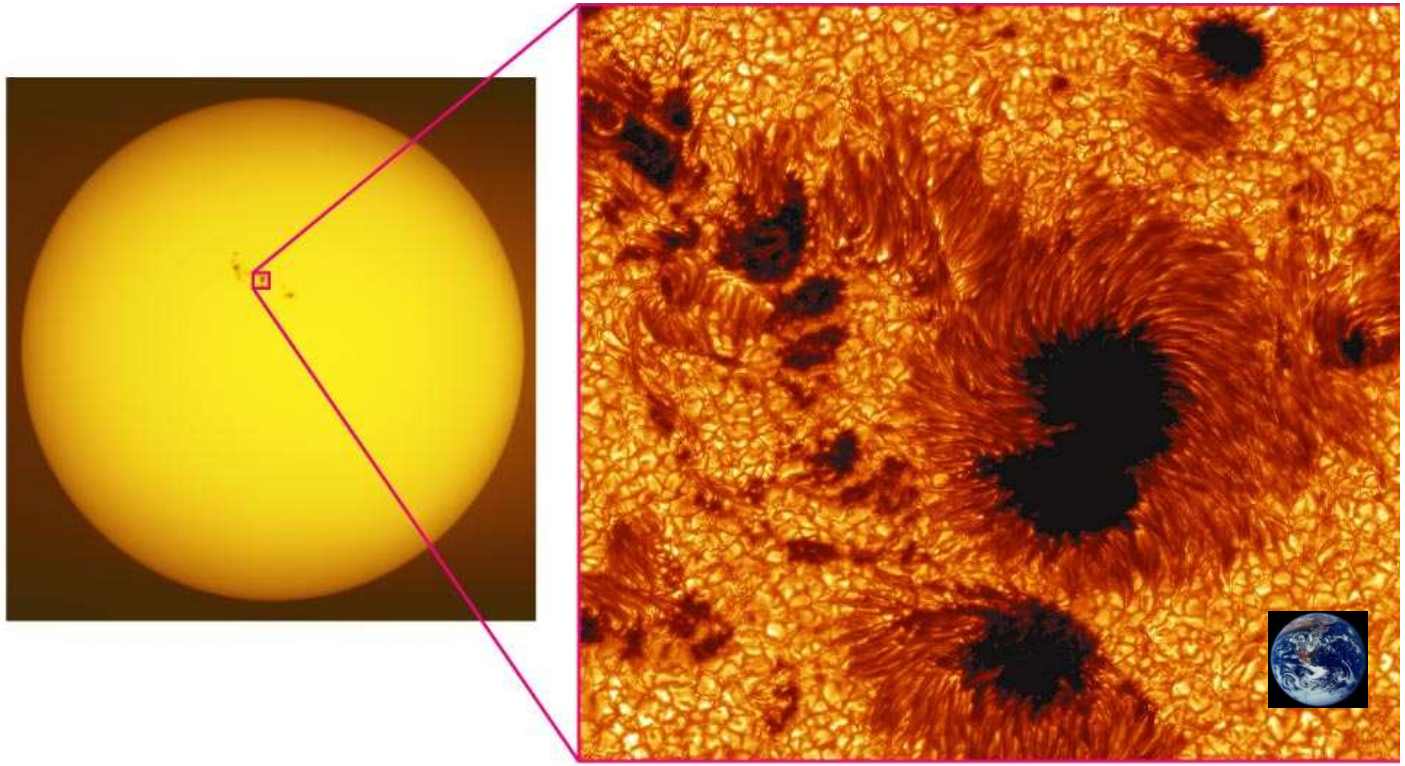
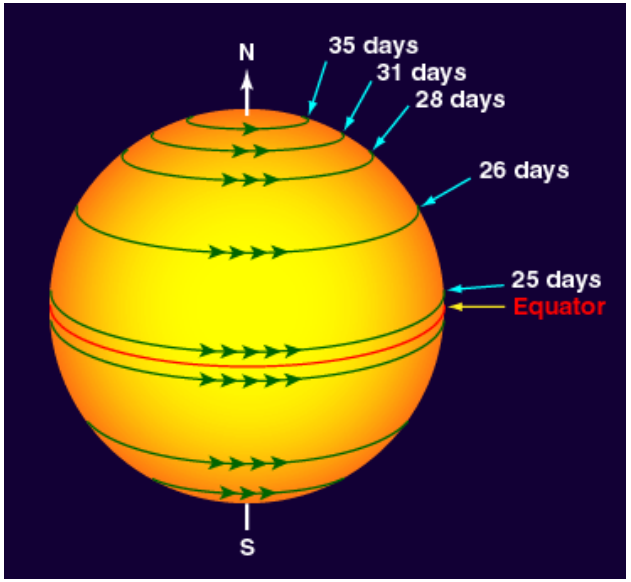
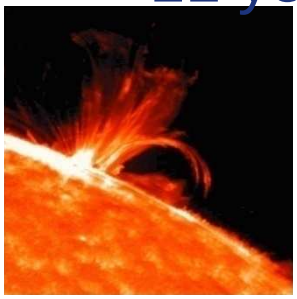


Fig 14.15

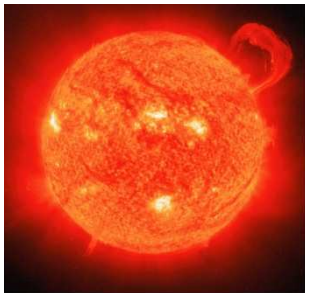
What Causes Sunspots?

- Differential rotation
- Twisting magnetic field lines
- Magnetic lines penetrate surface, ejecting material into space
  - Some falls back: prominences
  - Other are blown away: flares
- 11 year sunspot cycle observed





Flare: Fig 14.19



Prominence: Fig 14.18

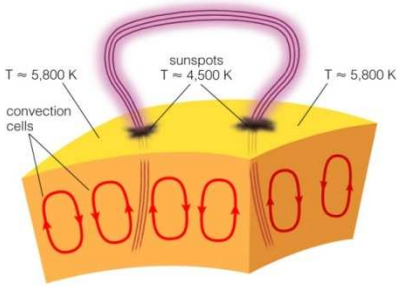
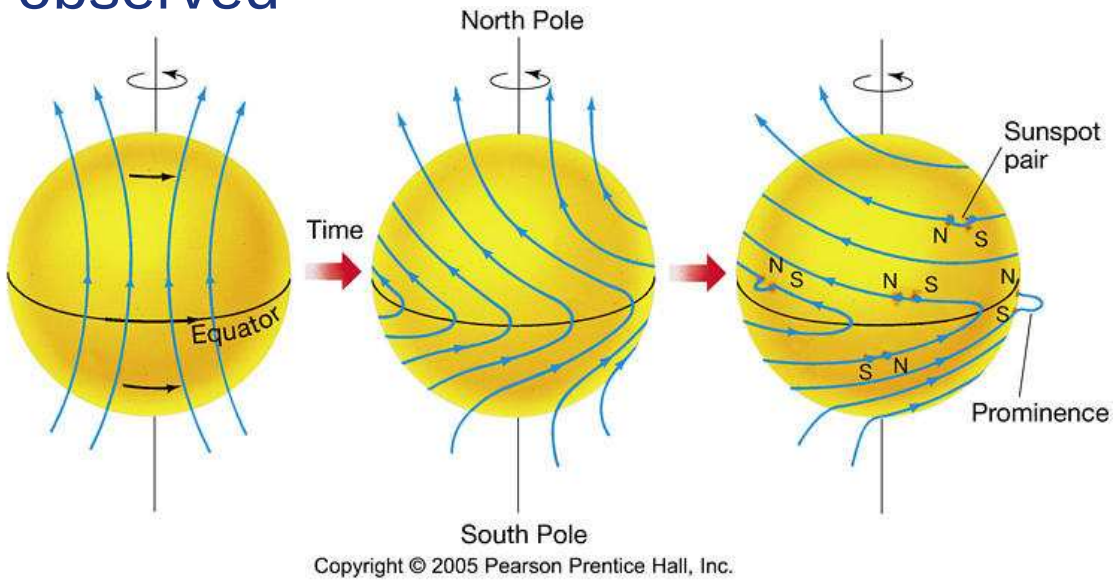
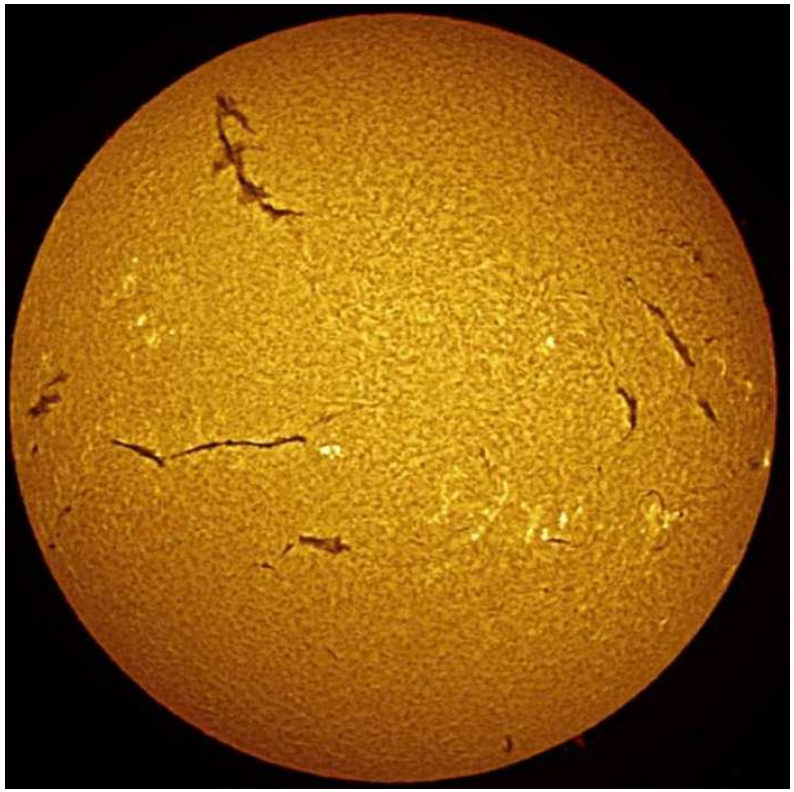


Fig 14.17



The Chromosphere

- About 4500 K
- Seen in Hydrogen-alpha filter
- Shows spiclues (jets of gas shooting out), and filaments (cooler areas)

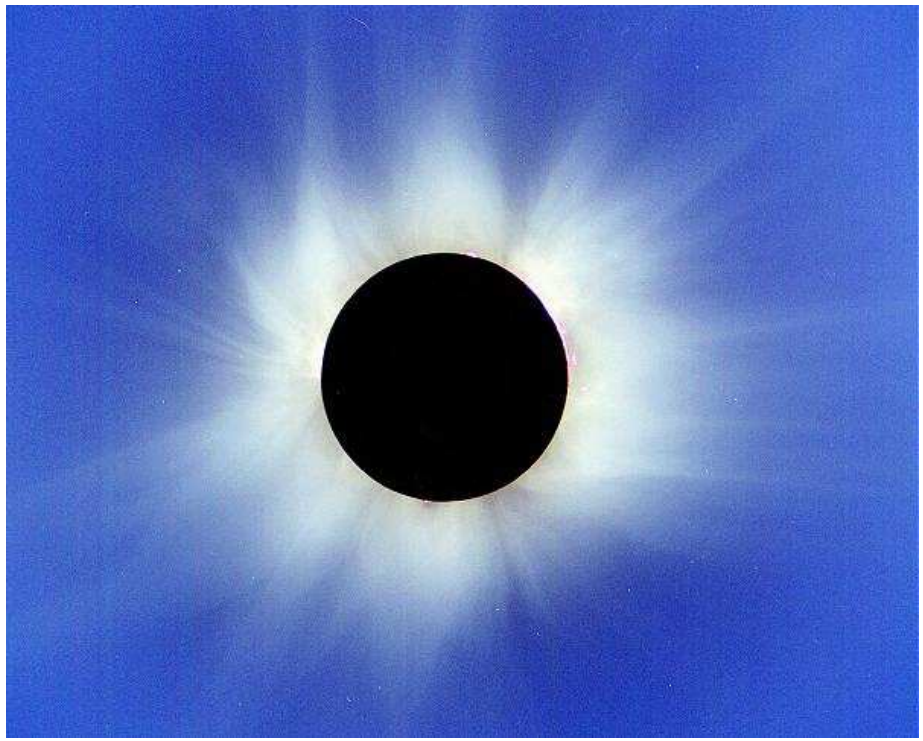


Sun, viewed through H-alpha filter

Spicules

The Corona

- Visible during a solar eclipse
- Outermost layer of the Sun
  - Extends 100,000s km beyond the surface
- Much higher temperature than other layers (millions of K)!



The Solar Wind

- Stream of particles blown away by the Sun
- Extends out to Jupiter and beyond
- Causes Aurora Borealis
  - Charged particles accelerated by Earth's magnetic field interact with atmosphere

Coronal Mass Ejection

- Very large flares blow a lot of mass into space
  - Occur a couple of times a week
  - If directed at Earth, can disrupt satellite communication, electrical grids
  - And they can blow off comet tails!

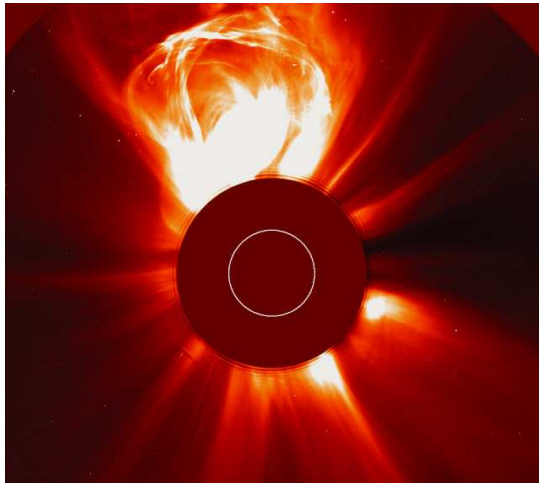
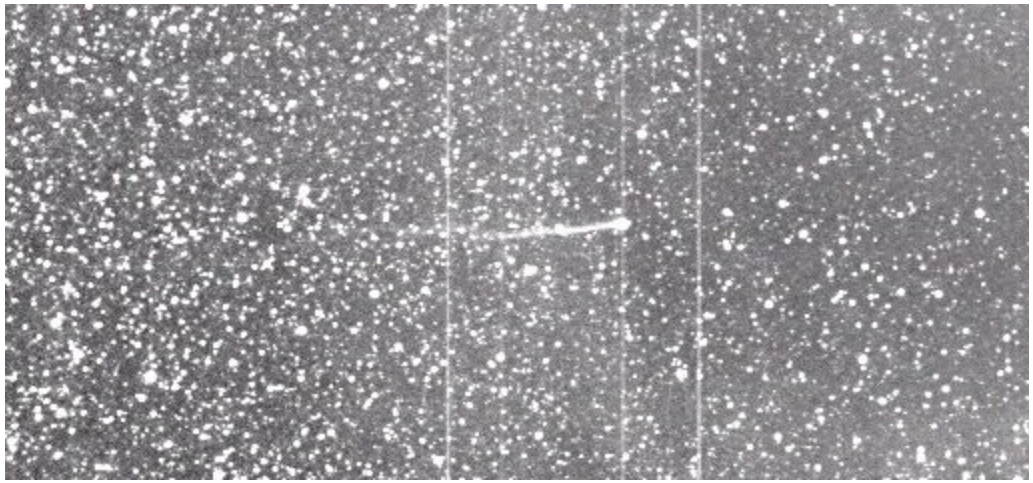


Fig 14.18



NASA movie

Basic Properties of the Sun

Table 14.1 Basic Properties of the Sun

Radius (R_{Sun})	696,000 km (about 109 times the radius of Earth)
Mass (M_{Sun})	2×10^{30} kg (about 300,000 times the mass of Earth)
Luminosity (L_{Sun})	3.8×10^{26} watts
Composition (by percentage of mass)	70% hydrogen, 28% helium, 2% heavier elements
Rotation rate	25 days (equator) to 30 days (poles)
Surface temperature	5,800 K (average); 4,000 K (sunspots)
Core temperature	15 million K

- Average density = 1.4 g/cc (¼ of Earth's)
- Gravity = 274 m/s^2 (28 times Earth's)