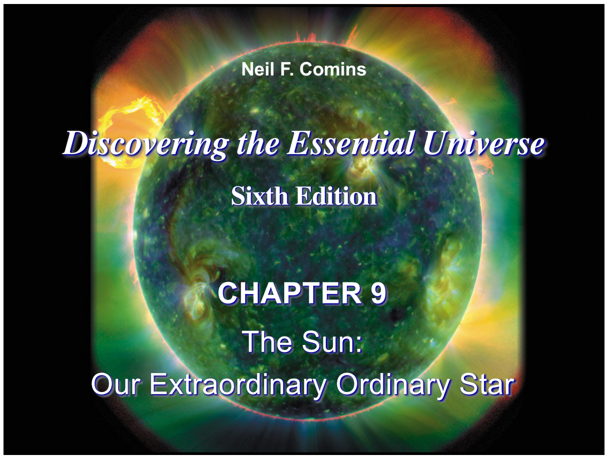


1

2

In this chapter you will discover…

- that the Sun has two layers of atmosphere above the layer that we normally see
- how magnetic fields churn up the Sun's outer layers
- that the Sun generates energy in its core
- that some particles created in the Sun's core pass straight through it and through you

3

table 18-1 Sun Data

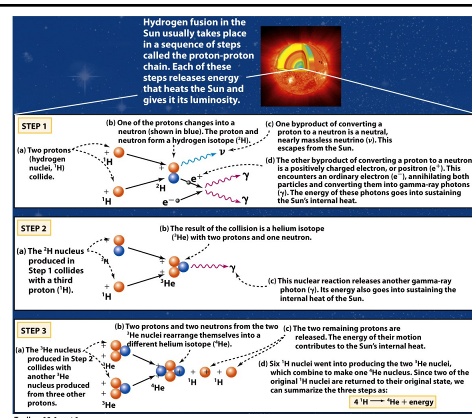
Distance from the Earth:	Mean: 1 AU = 149,598,000 km
	Maximum: 152,000,000 km
	Minimum: 147,000,000 km
Light travel time to the Earth:	8.32 min
Mean angular diameter:	32 arcmin
Radius:	696,000 km = 109 Earth radii
Mass:	1.9891×10^{30} kg = 3.33×10^{5} Earth masses
Composition (by mass):	74% hydrogen, 25% helium,
	1% other elements
Composition (by number of atoms):	92.1% hydrogen, 7.8% helium,
	0.1% other elements
Mean density:	1410 kg/m^3
Mean temperatures:	Surface: 5800 K; Center: 1.55×10^{7} K
Luminosity:	3.86×10^{26} W
Distance from center of Galaxy:	8000 pc = 26,000 ly
Orbital period around center of Galaxy:	220 million years
Orbital speed around center of Galaxy:	220 km/s

4

The Sun's energy is generated by thermonuclear reactions in its core

- The energy released in a nuclear reaction corresponds to a slight reduction of mass according to Einstein's equation $E = mc^2$
- Thermonuclear fusion occurs only at very high temperatures; for example, hydrogen fusion occurs only at temperatures in excess of about 10^7 K
- In the Sun, fusion occurs only in the dense, hot core

5



Toolbox 10-1 part 1
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6

Fusion reaction in Sun

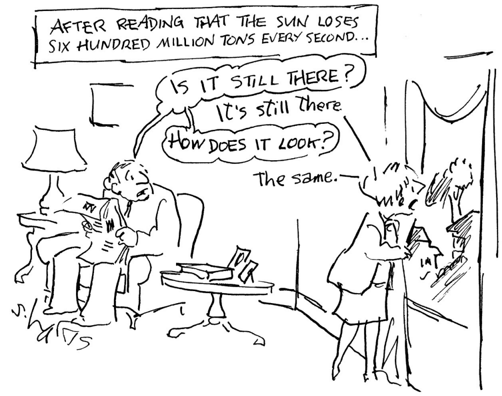
p+p ➔ $d+e^{+}+\nu$
d+p ➔ $^{3}He + \gamma$
$^{3}He+^{3}He$ ➔ $^{4}He+2p$

4p ➔ ^{4}He + 2ν's + γ's

m(4p) = 6.693×10^{-27} kg
m(^{4}He)= 6.645×10^{-27} kg

0.048×10^{-27} kg ~0.7% of mass converted into energy
$E=mc^2$
$E=0.048 \times 10^{-27} \times (3.0\times10^{8})^2$ J
$E = 4.3 \times 10^{-12}$ J

7



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8

…wait a minute..

$L_{sun}=3.9 \times 10^{26}$ W
$E=mc^2$
Mass loss per second?
Mass conversion per second?

9

How much mass does the Sun really loose per second?

$L_{sun}=3.9 \times 10^{26}$ W

10

How much mass does the Sun really loose per second?

$L_{sun}=3.9 \times 10^{26}$ W

$dE_{sun}/dt = L_{sun}$

$dM_{sun}/dt = dE_{sun}/dt \times 1/c^2$

11

How much mass does the Sun really loose per second?

$L_{sun}=3.9 \times 10^{26}$ W

$dE_{sun}/dt = L_{sun}$

$dM_{sun}/dt = dE_{sun}/dt \times 1/c^2$

$= 3.9 \times 10^{26} \times 1/(3\times10^{8})^2$
$= 4.3 \times 10^{9}$ kg/s

The Sun converts 4.3 Mill tons of H per second into energy.

Since this is only 0.7% of the mass of H that is converted into energy every second, 100/0.7 times more mass is coverted into He per second.

The Sun converts 614 Mill tons of H per second into He.

12

Energy Transfer

Conduction

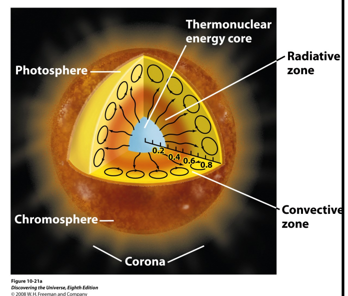
Convection

(Electromagnetic) Radiation

13

A theoretical model of the Sun shows how energy gets from its center to its surface

- Hydrogen fusion takes place in a core extending from the Sun's center to about 0.25 solar radius
- The core is surrounded by a radiative zone extending to about 0.71 solar radius
  - In this zone, energy travels outward through radiative diffusion
- The radiative zone is surrounded by a rather opaque convective zone of gas at relatively low temperature and pressure
  - In this zone, energy travels outward primarily through convection



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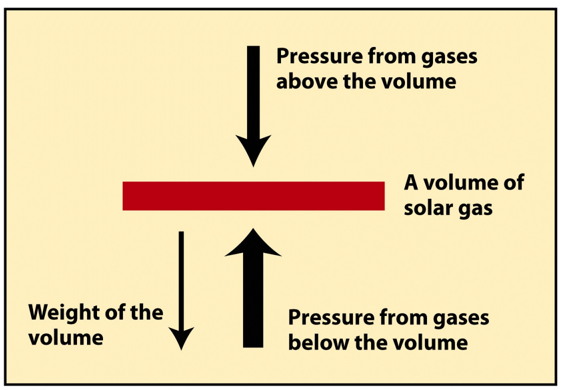

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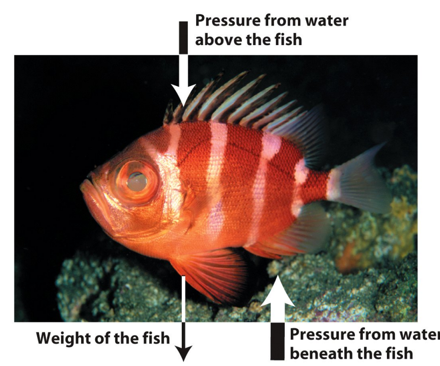
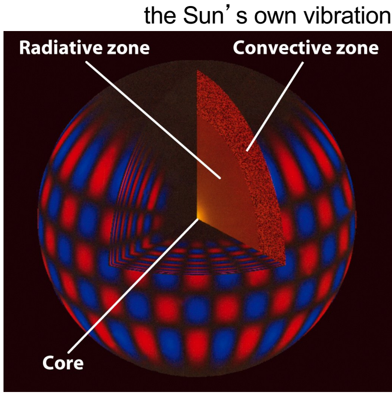


A fish floating in water is in hydrostatic equilibrium, so forces balance

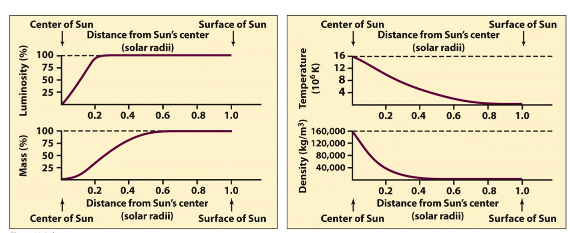
16

Astronomers probe the solar interior using the Sun's own vibrations



Helioseismology is the study of how the Sun vibrates. These vibrations have been used to infer pressures, densities, chemical compositions, and rotation rates within the Sun

17



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Element	Number of atoms (percent)	Percent of total mass
Hydrogen	91.2	71.0
Helium	8.7	27.1
Oxygen	0.078	0.97
Carbon	0.043	0.40
Nitrogen	0.0088	0.096
Silicon	0.0045	0.099
Magnesium	0.0038	0.076
Neon	0.0035	0.058
Iron	0.030	0.014
Sulfur	0.015	0.040

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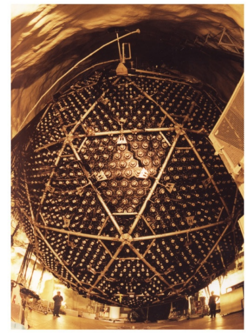
A Solar Neutrino Experiment



Located 2703 m (6800 ft) underground in the Creighton nickel mine in Sudbury, Canada, the Sudbury Neutrino Observatory is centered around a tank that contains 1000 tons of water. Occasionally, a neutrino entering the tank interacts with one or another of the particles.

Neutrinos emitted in thermonuclear reactions in the Sun's core have been detected, but in smaller numbers than originally expected.

Now we know that neutrinos have mass and show oscillations changing their type:

➔Now observations consistent with theory

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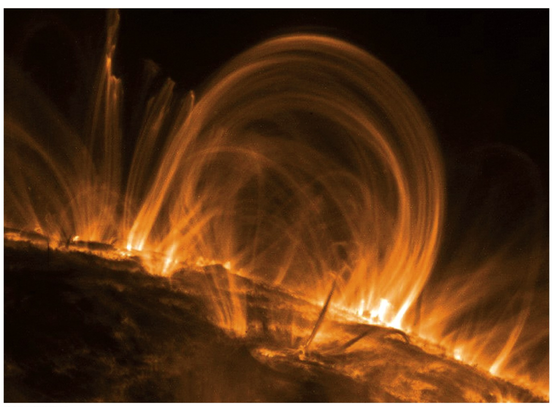

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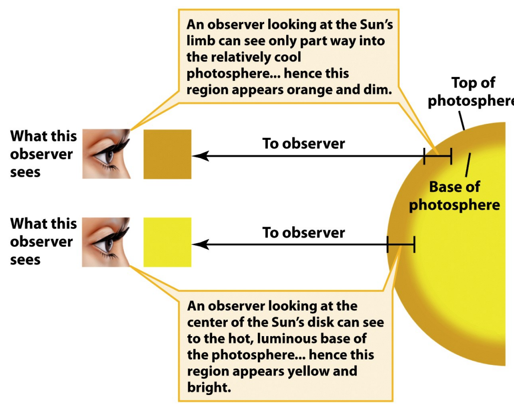

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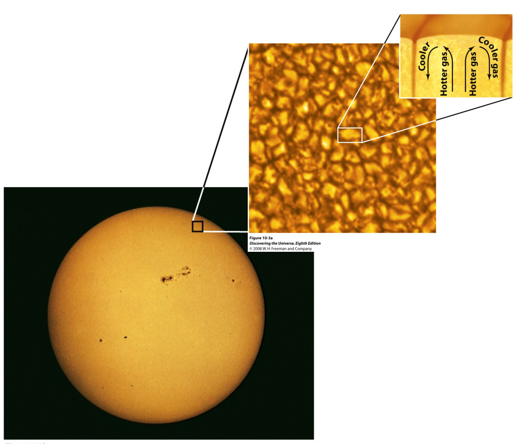

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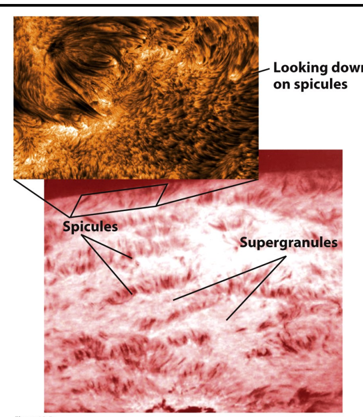

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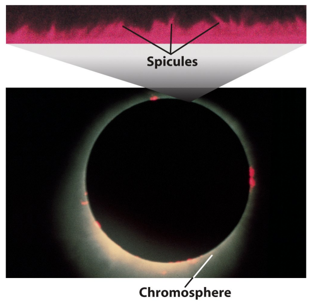
The chromosphere is characterized by spikes of rising gas

- Above the photosphere is a layer of less dense but higher temperature gases called the chromosphere
- Spicules extend upward from the photosphere into the chromosphere along the boundaries of supergranules



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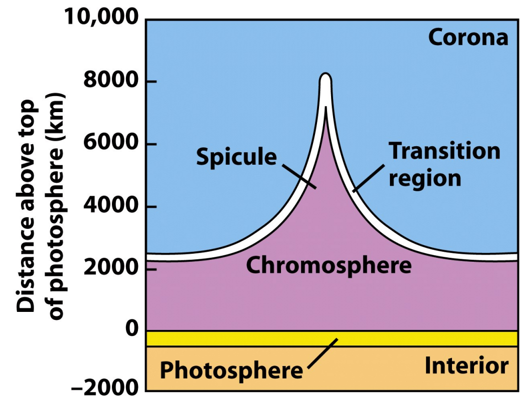

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Corona

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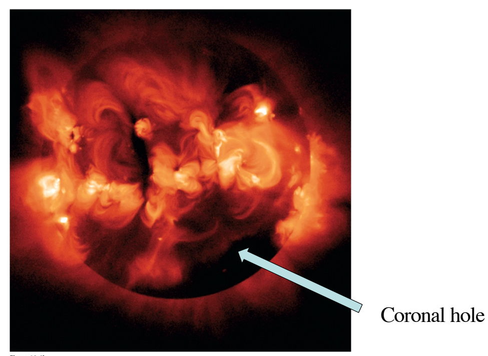
X-ray picture of the Sun



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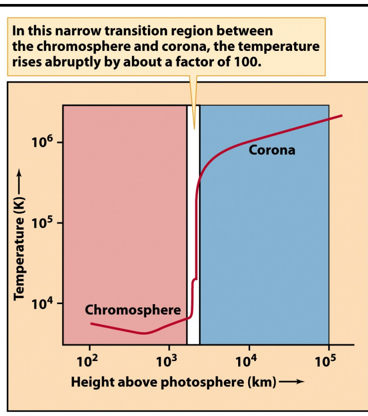

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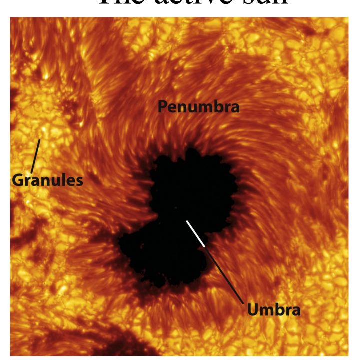
The active sun



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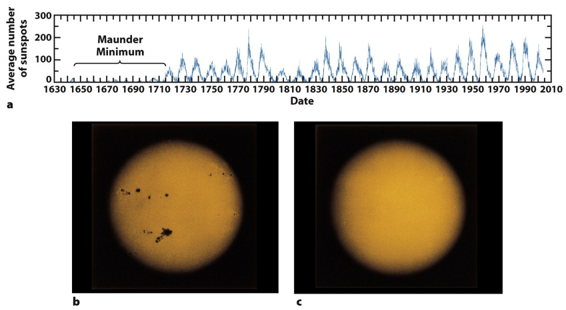

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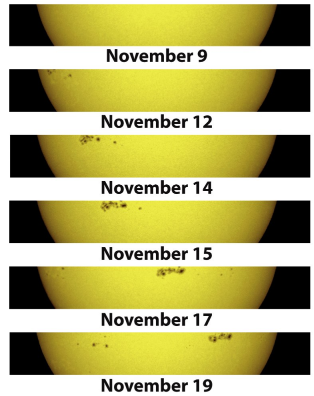

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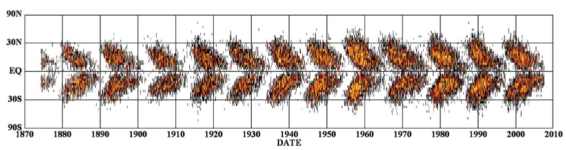

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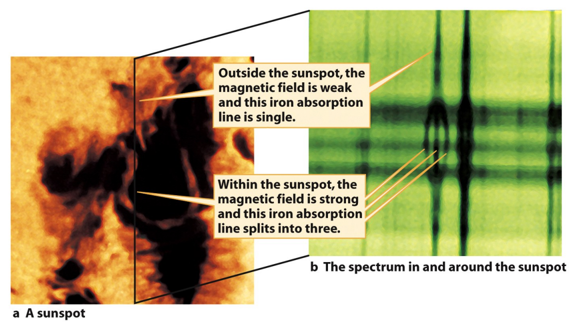

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Rotation of the solar interior

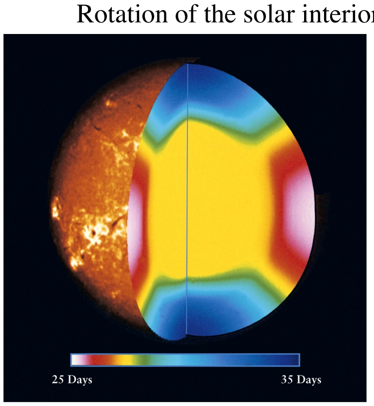

Figure 10-12b
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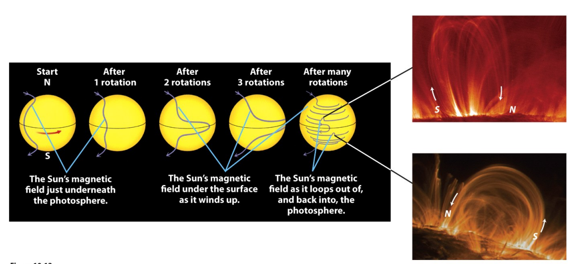

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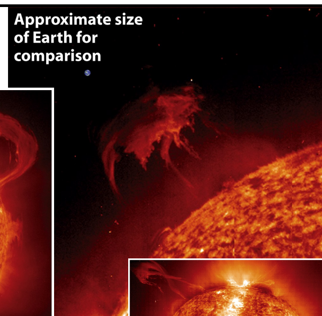
Prominences: arches of gas



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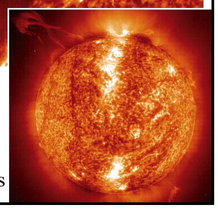
Flares: violent eruptive events



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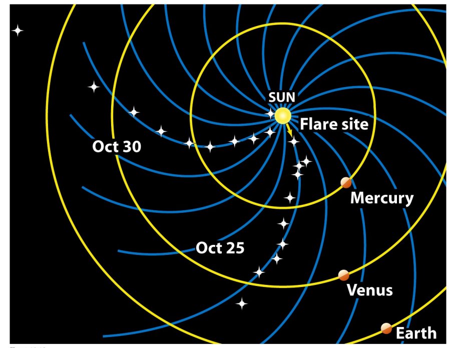
Tracing the interplanetary magnetic field



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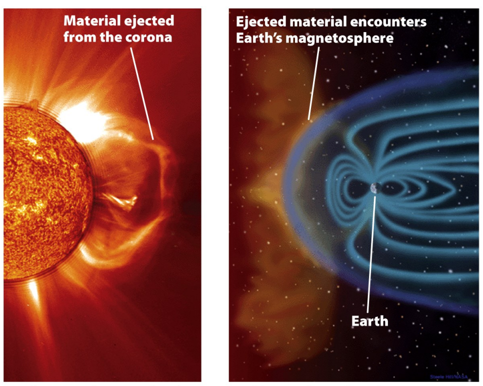

a A coronal mass ejection **b** Two to four days later

Figure 10-19
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