




Jorge Ramirez
Instructor of Mathematics, Physics & Astronomy

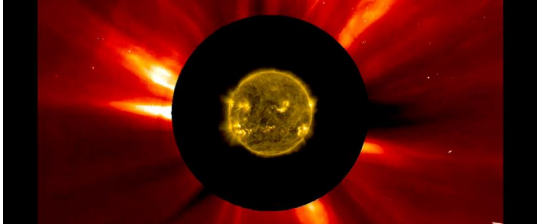
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ASTRONOMY

Chapter 15 THE SUN: A GARDEN-VARIETY STAR
PowerPoint Image Slideshow





15.1 THE STRUCTURE AND COMPOSITION OF THE SUN




► **Our Star.** The Sun—our local star—is quite average in many ways. However, that does not stop it from being a fascinating object to study. From solar flares and coronal mass ejections, like the one seen coming from the Sun in the top right of this image, the Sun is a highly dynamic body at the center of our solar system. This image combines two separate satellite pictures of the Sun—the inner one from the Solar Dynamics Observatory and the outer one from the Solar and Heliospheric Observatory. (credit: modification of work by ESA/NASA)

The Sun



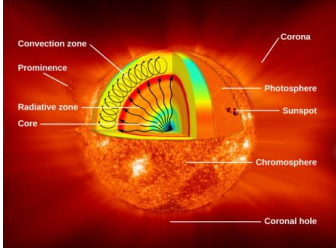
- Mass: 2×10^{30} kg
- (over 300,000 Earth masses)
- Luminosity: 3.8×10^{26} W
- Radius: 6.9×10^8 m
- 109 Earths across
- Surface Temperature: 5800 K
- Core Temperature 15×10^6 K
- 27 million degrees Fahrenheit

Figure 15.3



► **Cecilia Payne-Gaposchkin (1900–1979).** Her 1925 doctoral thesis laid the foundations for understanding the composition of the Sun and the stars. Yet, being a woman, she was not given a formal appointment at Harvard, where she worked, until 1938 and was not appointed a professor until 1956. (credit: Smithsonian Institution)

The Layers of the Sun



► **Parts of the Sun.** This illustration shows the different parts of the Sun, from the hot core where the energy is generated through regions where energy is transported outward, first by radiation, then by convection, and then out through the solar atmosphere. The parts of the atmosphere are also labeled the photosphere, chromosphere, and corona. Some typical features in the atmosphere are shown, such as coronal holes and prominences.

The Sun's Structure

- ▶ **Core**
Energy generated by nuclear fusion
15 million K
- ▶ **Radiation zone**
Energy transported upward by photons
- ▶ **Convection zone**
Energy transported upward by rising hot gas
- ▶ **Photosphere (surface)**
Visible surface of the Sun, inner layer of solar atmosphere. 6000 K
- ▶ **Chromosphere**
Middle layer of solar atmosphere
 10^4 – 10^5 K
- ▶ **Corona**
Outermost layer of solar atmosphere
1 million K
- ▶ **Solar Winds**
A flow of charged particles

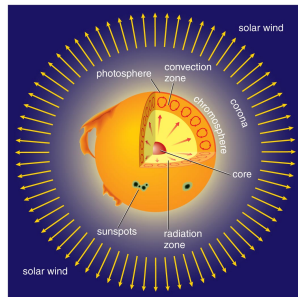
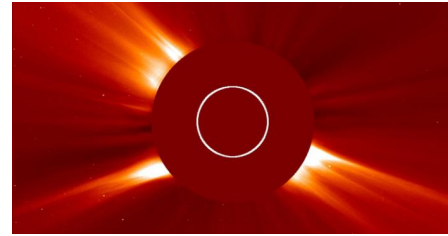
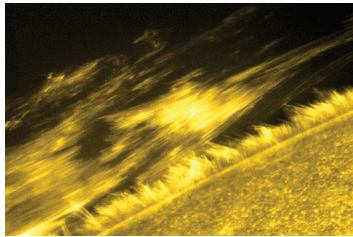


Figure 15.7



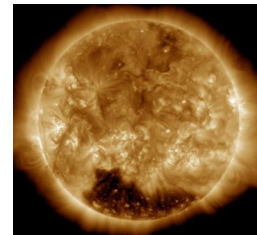
- ▶ **Coronagraph.** This image of the Sun was taken March 2, 2016. The larger dark circle in the center is the disk that blocks the Sun's glare, allowing us to see the corona. The smaller inner circle is where the Sun would be if it were visible in this image. (credit: modification of work by NASA/SOHO)

Figure 15.9



- ▶ **Portion of the Transition Region.** This image shows a giant ribbon of relatively cool gas threading through the lower portion of the hot corona. This ribbon (the technical term is filament) is made up of many individual threads. Time-lapse movies of this filament showed that it gradually heated as it moved through the corona. Scientists study events like this in order to try to understand what heats the chromosphere and corona to high temperatures. The "whiskers" at the edge of the Sun are spicules, jets of gas that shoot material up from the Sun's surface and disappear after only a few minutes. This single image gives a hint of just how complicated it is to construct a model of all the different structures and heating mechanisms in the solar atmosphere.

Figure 15.11

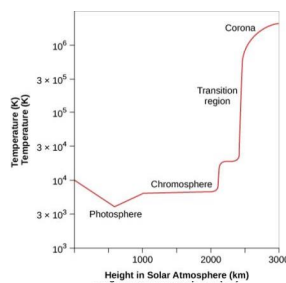


- ▶ **Coronal Hole.** The dark area visible near the Sun's south pole on this Solar Dynamics Observer spacecraft image is a coronal hole. (credit: modification of work by NASA/SDO)

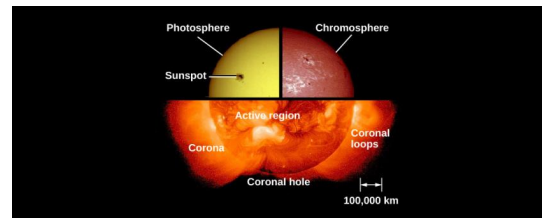


Figure 15.8

- ▶ **Temperatures in the Solar Atmosphere.** On this graph, temperature is shown increasing upward, and height above the photosphere is shown increasing to the right. Note the very rapid increase in temperature over a very short distance in the transition region between the chromosphere and the corona.

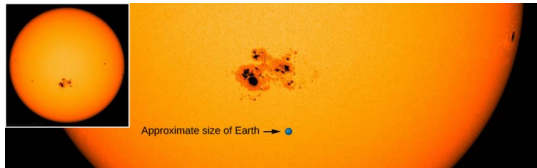


The Atmosphere



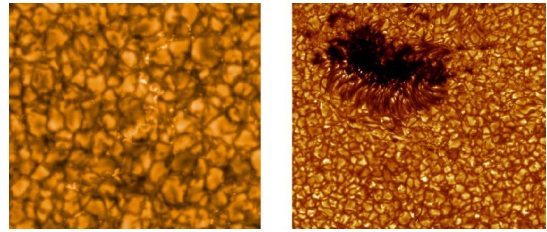
- ▶ **The Sun's Atmosphere.** Composite image showing the three components of the solar atmosphere: the photosphere or surface of the Sun taken in ordinary light; the chromosphere, imaged in the light of the strong red spectral line of hydrogen (H-alpha); and the corona as seen with X-rays. (credit: modification of work by NASA)

Figure 15.5



► **Solar Photosphere plus Sunspots.** This photograph shows the photosphere—the visible surface of the Sun. Also shown is an enlarged image of a group of sunspots; the size of Earth is shown for comparison. Sunspots appear darker because they are cooler than their surroundings. The typical temperature at the center of a large sunspot is about 3800 K, whereas the photosphere has a temperature of about 5800 K. (credit: modification of work by NASA/SDO)

Figure 15.6



► **Granulation Pattern.** The surface markings of the convection cells create a granulation pattern on this dramatic image (left) taken from the Japanese Hinode spacecraft. You can see the same pattern when you heat up miso soup. The right image shows an irregular-shaped sunspot and granules on the Sun's surface, seen with the Swedish Solar Telescope on August 22, 2003. (credit left: modification of work by Hinode JAXA/NASA/PPARC; credit right: ISPiST/Oddbjorn Engvold, Jun Elin Wiik, Luc Roupe van der Voort)

Bright spots appear on Sun's surface where hot gas is rising. . . . then the gas sinks after it has cooled off.

Convection (rising hot gas) takes energy to the surface.

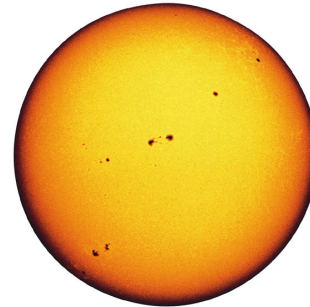
Hot gas is rising here. . . . and cooler gas is sinking here.

a This diagram shows convection beneath the Sun's surface: hot gas (yellow arrows) rises while cooler gas (black arrows) descends around it.

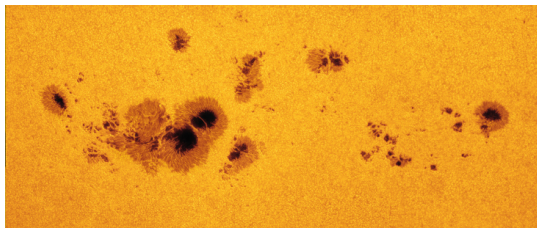
Bright blobs on photosphere where hot gas reaches the surface

b This photograph shows the mottled appearance of the Sun's photosphere. The bright spots correspond to the rising plumes of hot gas in the diagram in part a.

15.2 THE SOLAR CYCLE

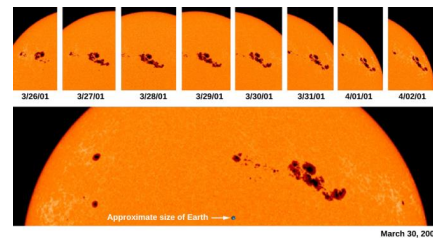


Sun Spots



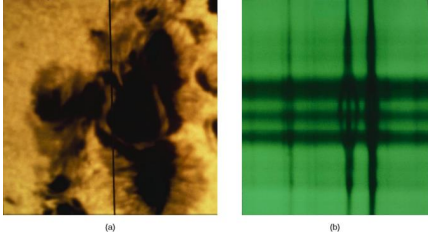
► **Sunspots.** This image of sunspots, cooler and thus darker regions on the Sun, was taken in July 2012. You can see the dark, central region of each sunspot (called the umbra) surrounded by a less dark region (the penumbra). The largest spot shown here is about 11 Earths wide. Although sunspots appear dark when seen next to the hotter gases of the photosphere, an average sunspot, cut out of the solar surface and left standing in the night sky, would be about as bright as the full moon. The mottled appearance of the Sun's surface is granulation. (credit: NASA Goddard Space Flight Center; Alan Friedman)

Figure 15.14



► **Sunspots Rotate Across Sun's Surface.** This sequence of photographs of the Sun's surface tracks the movement of sunspots across the visible hemisphere of the Sun. On March 30, 2001, this group of sunspots extended across an area about 13 times the diameter of Earth. This region produced many flares and coronal mass ejections. (credit: modification of work by SOHO/NASA/ESA)

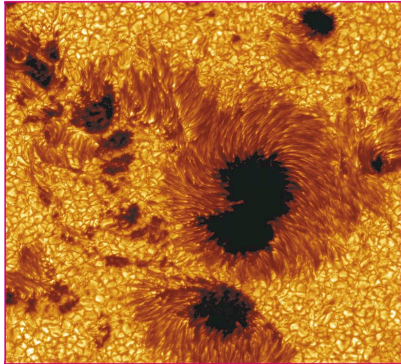
Magnetism



(a) (b)

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► **Zeeman Effect.** These photographs show how magnetic fields in sunspots are measured by means of the Zeeman effect. (left) The vertical black line indicates the position of the spectrograph slit through which light is passed to obtain the spectrum in (right). (credit: modification of work by NSO/AURA/NSF)



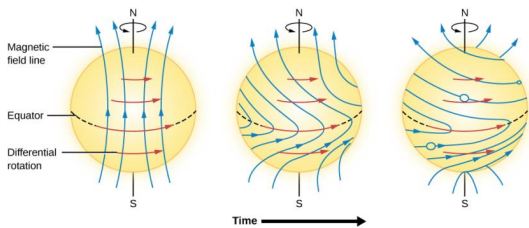
Sunspots...

Are cooler than other parts of the Sun's surface (4000 K).

Are regions with strong magnetic fields.

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Figure 15.17



Magnetic field line

Equator

Differential rotation

N

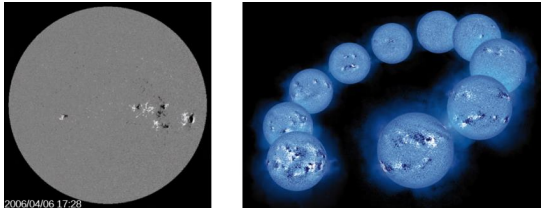
S

Time →

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► **Magnetic Field Lines Wind Up.** Because the Sun spins faster at the equator than near the poles, the magnetic fields in the Sun tend to wind up as shown, and after a while make loops. This is an idealized diagram; the real situation is much more complex.

Figure 15.16

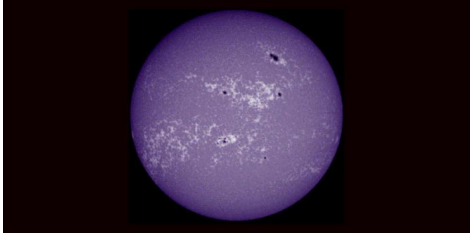


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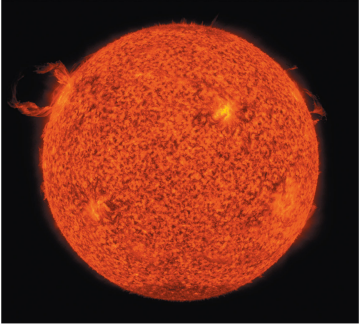
► **Magnetogram and Solar Cycle.** In the image on the left, called a magnetogram, we see the magnetic polarity of sunspots. The black areas are where the magnetism is pointing toward the Sun's core, whereas the white regions are where it is pointing away from the core, toward us. This dramatic sequence on the right shows the activity cycle of the Sun.

15.3 SOLAR ACTIVITY ABOVE THE PHOTOSHERE



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► **Plages on the Sun.** This image of the Sun was taken with a filter that transmits only the light of the spectral line produced by singly ionized calcium. The bright cloud-like regions are the plages. (credit: modification of work by NASA)



Magnetic activity also causes **solar prominences** that erupt high above the Sun's surface.

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Magnetic field lines represent the directions in which compass needles would point.

Lines closer together indicate a stronger magnetic field.

Charged particles follow spiraling paths along magnetic field lines.

Charged particles spiral along magnetic field lines.

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Magnetic fields trap gas.

sunspots $T \approx 4500\text{ K}$

convection cells $T \approx 5800\text{ K}$

Magnetic fields of sunspots suppress convection and prevent surrounding plasma from sliding sideways into the sunspot.

a Pairs of sunspots are connected by tightly wound magnetic field lines.

Loops of bright gas often connect sunspot pairs.

b This X-ray photo (from NASA's TRACE mission) shows hot gas trapped within looped magnetic field lines.

Figure 15.19

Approximate size of Earth $\rightarrow e$

(a) (b)

Prominences.

(a) This image of an eruptive prominence was taken in the light of singly ionized helium in the extreme ultraviolet part of the spectrum. The prominence is a particularly large one. An image of Earth is shown at the same scale for comparison.

(b) A prominence is a huge cloud of relatively cool (about 60,000 K in this case), fairly dense gas suspended in the much hotter corona. These pictures, taken in ultraviolet, are color coded so that white corresponds to the hottest temperatures and dark red to cooler ones.

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Figure 15.20

Solar Flare. The bright white area seen on the right side of the Sun in this image from the Solar Dynamics Observer spacecraft is a solar flare that was observed on June 25, 2015. (credit: NASA/SDO)

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Coronal mass ejections send bursts of energetic charged particles out through the solar system.

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Magnetic activity causes **solar flares** that send bursts of X rays and charged particles into space.

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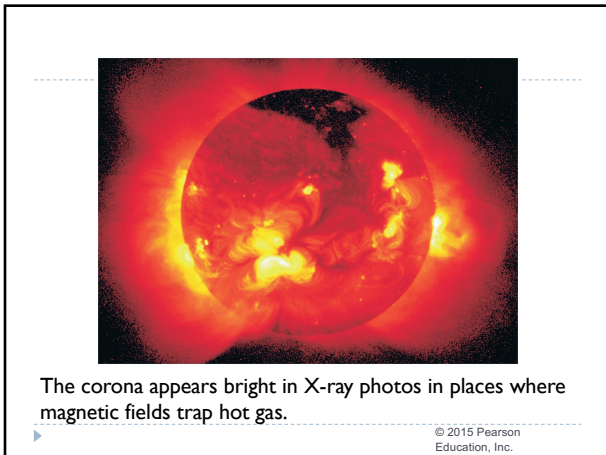


Figure 15.21

► **Flare and Coronal Mass Ejection.** This sequence of four images shows the evolution over time of a giant eruption on the Sun. (a) The event began at the location of a sunspot group, and (b) a flare is seen in far-ultraviolet light. (c) Fourteen hours later, a CME is seen blasting out into space. (d) Three hours later, this CME has expanded to form a giant cloud of particles escaping from the Sun and is beginning the journey out into the solar system. The white circle in (c) and (d) shows the diameter of the solar photosphere. The larger dark area shows where light from the Sun has been blocked out by a specially designed instrument to make it possible to see the faint emission from the corona.

Figure 15.23

► **Solar Active Region Observed at Different Heights in the Sun's Atmosphere.** These four images of a solar flare on October 22, 2012, show from the left: light from the Sun at a wavelength of 171 angstroms, which shows the structure of loops of solar material in the corona; ultraviolet at 304 angstroms, which shows light from the region of the Sun's atmosphere where flares originate; light at 335 angstroms, which highlights radiation from active regions in the corona; a magnetogram, which shows magnetically active regions on the Sun. Note how these different types of activity all occur above a sunspot region with a strong magnetic field. (credit: modification of work by NASA/SDO/Goddard)

Figure 15.22

► **Solar Cycle.** This dramatic sequence of images taken from the SOHO satellite over a period of 11 years shows how active regions change during the solar cycle. The images were taken in the ultraviolet region of the spectrum and show that active regions on the Sun increase and decrease during the cycle. Sunspots are located in the cooler photosphere, beneath the hot gases shown in this image, and vary in phase with the emission from these hot gases—more sunspots and more emission from hot gases occur together. (credit: modification of work by ESA/NASA/SOHO)

How does solar activity vary with time?

a This graph shows how the number of sunspots on the Sun changes with time. The vertical axis shows the percentage of the Sun's surface covered by sunspots. The cycle has a period of approximately 11 years.

b This graph shows how the latitudes at which sunspot groups appear tend to shift during a single sunspot cycle.

The number of sunspots rises and falls in 11-year cycles.

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15.4 SPACE WEATHER

Solar Storm Damage: Charged particles streaming from the Sun can disrupt electrical power grids and disable communications satellites.

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Figure 15.12



- ▶ **Aurora.** The colorful glow in the sky results from charged particles in a solar wind interacting with Earth's magnetic fields. The stunning display captured here occurred over Jokulsarlon Lake in Iceland in 2013. (credit: Moyan Brenn)

Links

- ▶ [Sun 3 min](#)
- ▶ [15.4 space weather 5 min](#)

Reading

- ▶ 15.1
 - ▶ 15.2
 - ▶ 15.3
 - ▶ 15.4 optional
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