Chapter 12. The Sun

Basic Properties of the Sun

- The Sun is the nearest star and the most important source of energy to us.

- The radius of the Sun is 109 times that of the Earth. The mass of the Sun is ∼1000 times that of Jupiter, although the average density of the Sun, 1.4 g/cm^3, is similar to that of Jupiter.

- The effective surface temperature of the Sun is 5,780 K. The blackbody emission peaks at 5,020 Å, the green part of the spectrum, but the combined radiation appears yellow to the eyes.

The Quiet Sun - solar phenomena that are always present

- The visible Sun consists of three layers: the photosphere, the chromosphere, and the corona. Light emitted from deeper than the photosphere is either absorbed or scattered.

- The photosphere is a few hundred km thick. It absorbs the energy from the solar interior and emits continuous radiation. The temperature and density in the photosphere decreases outward. The upper part of the photosphere, cooler and less dense, produces absorption lines in the spectrum (according to Kirchhoff's laws), and causes the *limb darkening* we see.

- The analysis of the solar absorption lines shows that the solar photosphere consists of 92% H and 8% He (by number of atoms). ∼2/3 of known elements have spectral lines detected in the solar spectrum; the others either do not have stable isotopes or have very low abundances.

- The photosphere is covered by millions of *granules*, bright cells about 700 km across (the size of Texas), separated by darker areas of similar widths. The granules are caused by convection. The Doppler-shifted spectra show that the granules are rising and the darker regions are falling.

- Convection in the photosphere create sound waves that shocks and heats the chromosphere above. The shocks produces the *spicules*, needles of rising gas, in the chromosphere.

- The chromosphere has high temperature and low density, hence produces emission-line spectrum. Thus, it can be imaged with filters centered on the Hα line or CaII H and K lines. The element He was first discovered in the spectrum of the chromosphere, hence its name "helios".

- The corona is the outermost layer of the solar atmosphere. Its temperature reaches a few million K. It can be observed in X-rays. The corona is most likely heated by the solar magnetic field.

The Active Sun - transient solar phenomena associated with magnetic activity

• Sunspots are cool, dark regions on the solar surface. They come in pairs with opposite magnetic directions. The number of sunspots on the solar surface changes with a 11-yr *sunspot cycle*. However, the magnetic direction of the leading sunspot alternates between cycles. The 11-yr sunspot cycle is actually a 22-yr *magnetic activity cycle*.

• The convection and differential rotation of the ionized gases in the interior of the Sun create a *solar dynamo* that generates the solar magnetic field.

• Sunspots and other solar activities, such as, prominences, flares, and filaments are all related to tangled magnetic field lines.

The Solar Interior

• For a solar luminosity of 3.85×10^{26} joules/s, the gravitational energy supply can last only 10^8 yr. The Solar System is 4.6×10^9 yr old. The Sun must have another source of energy.

• The mass of 4 H atoms is greater than the mass of 1 He atom. If 4 H atoms can be combined into 1 He atom, the mass difference can be converted into energy according to Einstein's famous equation $E = Mc^2$. This could be the source of energy in the Sun.

• The fusion of hydrogen into helium in the solar interior is described by the *proton-proton chain* (p-p chain). This thermonuclear fusion, or nuclear burning, requires a minimum temperature of 7 million K. In this reaction, 4 H atoms fuse into 1 He atom, releasing γ-rays and neutrinos.

• The solar interior cannot be observed directly. Its structure must be modeled theoretically using the principle of hydrostatic equilibrium. The center of the Sun reaches 15 million K. Thermonuclear fusion occurs within the inner 30% of the solar radius, the *solar core*.

• The solar core is surrounded by a *solar envelope*, which is radiative at bottom and convective on top. The convection causes the solar granulation and *solar oscillations*. The 5-min period oscillation is caused by resonant sound waves trapped by the solar surface.