

The Sun (Chapter 16)

[Remember, we're skipping 16.5 on "The Active Sun." But I think it would be foolish not to at least look through it to see how complex our star really is, and the sun-Earth connections.]

We can only observe light coming from the "surface" of the sun, called the **photosphere**—this is *not* a solid surface, like on the earth, but just the layer of the sun at which the density is low enough to allow the photons to escape.

From this we learn the sun's size (about 100 earths), mass (300,000 earths), and luminosity (how much energy per second is emitted, its brightness, like the wattage of a light bulb— 10^{26} Watts for the sun!), and its spectrum (from which we can get the abundances of elements (see sec. 16.4), as well as the amazing surface activity (which we won't cover for the exam—see 16.5).

We'll see later that the sun is more or less an average star.

How do we learn about the interior of the sun?
Three techniques:

1. Theoretical modeling—e.g. hydrostatic equilibrium (pressure balances gravity), energy conservation through each layer... This gives the values of temperature, pressure, density, luminosity as a function of radius, from the center to the photosphere. This is the only way to get detailed predictions about the sun's (and other stars') interiors, *and* how the sun has and will evolve in time.

The huge temperatures at the center obtained in these models is why we think that the source of the sun's energy is nuclear fusion by the proton-proton cycle (discussed below and in class) in the core.

These models are why we think the structure of the sun consists of (from center to surface):

Core (can only see by neutrinos—see below)—temperature about 10 million degrees! Understand why, and the implications.

Radiation zone—energy transport by huge number of absorptions and scatterings and reemissions.

Convection zone—can see the upper part of this layer as granulation.

Photosphere—where the density becomes low enough for photons to escape the sun. Interior to the photosphere the sun is *opaque* to its own photons.

This structure is discussed in sec. 16.3.

2. Helioseismology—Vibrations visible at the surface give information about how waves propagate through the stellar interior, and so info about the density and rotation, especially the upper layers. Textbook has good discussion, so read there and see Fig. 16.7. Type into google or wiki and see what happens.

3. Solar Neutrinos (sec. 16.6)—neutrinos are the products of nuclear reactions in the solar core. But unlike photons (light), neutrinos essentially don't interact with matter (except certain materials) and so pass directly through the whole sun.

Most of these pass right through the earth too, but if we can collect a few of them using some kind of "neutrino telescope", we would have a way of "seeing" directly into the center of the sun!

1960s-1990s: Ray Davis' Homestead Mine neutrino experiment: number observed much smaller than predicted ⇒ **solar neutrino problem**. But experiment is outrageously difficult, so many thought problem was with experiment.

Subsequent more recent experiments (SAGE, GALLEX, SuperKamiokande) confirmed Homestead result ⇒ something wrong!

The neutrinos are generated in the first step of the proton-proton cycle that generates the sun's energy. The missing neutrinos suggest that the nuclear reactions are not occurring. Maybe the sun has temporarily "turned off" by some instability! It would take 10 million years to us to find out using light. Or maybe we don't understand something at some other fundamental level.

One way out: maybe neutrinos *do* have mass (unlike photons), in which case they can spontaneously transform into other types of neutrinos, along their path from the earth to the sun, which would not be detected by the experiments. These possible transformations among neutrinos are called "neutrino oscillations." They were thought to be implausible for many years, but:

1998: Kamioka group reports evidence of neutrino oscillations.

2001: Ontario Sudbury Neutrino Observatory confirms, at just the level to explain the "missing" solar neutrinos.

So after over 40 years, the mystery is solved, and theoretical models for the solar interior are confirmed. *The culprit was that the neutrino has a (tiny) mass, which allows it to convert into another neutrino form on the way to the Earth.* In addition, this is our first indication of the intimate connection between knowledge of particle physics and astronomy.

[Later we'll see how the Kamioka neutrino experiment surprisingly detected the predicted neutrinos from a supernova explosion in 1987. Unfortunately the facility collapsed on the researchers shortly thereafter.]