Class notes for 19 October

Reminders
- Problem Set 4 due today (11.1, 11.2, 11.3, 11.6, 11.8)
- Exercise 4 due Thursday
- Exercise 5 due Oct. 28
- Problem Set 5 due Nov. 4 (12.1, 12.2, 12.4, 12.15, 13.6, 13.10)

11.2 Solar Atmosphere

Big ideas - Understanding the physics of the Sun's upper layers
- Dominated by the convection zone, which protrudes into the base of the photosphere
- Convection zone result from high opacity due to H⁻ ion
- Convection produces granules, supergranules
- Effects of magnetic fields

Vocabulary
Photosphere
Granulation
Supergranulation
Chromosphere
Spicules
Transition region
Corona
K, F, E corona
Forbidden, allowed transitions
Metastable states
Coronal holes
Open, closed magnetic field lines
Solar wind
Plasma
Shock wave, shock front
Magnetohydrodynamics
Alfven wave

Factoids
- The Sun's sharp "edge" results from the rapid change of optical depth with distance (about 500 km).
- Photospheric temperature drops from 6500 K to about 5000 K.
- Granules are about 700 km in size, persist for about 5-10 minutes.
- Granule velocities are a few hundred km/sec.
- Only about 1 in $10^7$ H atoms forms an H⁻ ion.
- Spectral lines are formed in the same region as the continuum. The centers of spectral lines originate in higher layers (higher opacity at line center).
- The chromosphere is about $10^{-4}$ times fainter than the photosphere, but with temperatures up to 25,000 K (but lower density than the photosphere).
- Convection persists into the chromosphere (supergranules) but at larger physical scales (30,000 km).
- Spicules are filaments of gas that extend up from the chromosphere along magnetic field lines.
- The transition region marks the upper boundary of the chromosphere. Temperature rises steeply to more than $10^6$ K.
• Corona is above the transition region. Energy output 10^-6 times fainter than the photosphere. T=2x10^6 K
• The corona is a source of X-rays and radio waves.
• X-ray dark regions known as coronal holes are regions with open magnetic field lines, where the solar wind flows out into the solar system.
• The solar magnetic field is basically a dipole, with a strength of a few gauss near the surface.
• Regions of closed magnetic field lines trap ions.
• Presence of solar wind deduced from comet tails.
• Solar wind is primarily protons and electrons. The local mass density of the solar wind is about 7 protons cm^-3 and a velocity of about 500 km s^-1.
• Plasmas are good conductors of heat: the corona is close to isothermal.
• The corona is not in hydrostatic equilibrium. It is expanding into space.
• Energy is transported from the photosphere to the transition region by magnetohydrodynamic effects.

11.3 Solar Cycle

Big Ideas
The magnetic field does it all.

Vocabulary
Sunspots
Butterfly diagram
Umbra
Penumbra
Maunder minimum
Plage
Solar flare
Solar prominence
Magnetic dynamo

Factoids
• Sunspots are from a few thousand to 30,000 km in diameter, and may persist for a month or so.
• Sunspots remain at constant latitude on the Sun
• Succeeding sunspots tend to form closer to the equator (Butterfly diagram)
• The number of sunspots follows an 11 or 22 year cycle.
• Sunspots are regions of strong magnetic field that suppress convection (and hence the flow of heat upward).
• The Sun's luminosity seems to vary on long time scales (14C data)
• Plage - chromospheric regions with bright Hα emission near sunspots; plage forms before sunspots appear, and persists after the sunspots disappear.
• The Babcock model of the solar dynamo has the solar magnetic field oscillating between a dipole and a toroidal field due to differential rotation.
• Magnetic fields, tarspots and flares are also detected on other stars.