Lecture 15

The Sun

Solar Atmosphere
Solar Activity

The Sun

- The energy source for the whole solar system
- Studied in much more detail than other stars
- What is easily measured:
  - Radius ($R_{\text{sun}}$): 696,000 km = 109 Earth radii
  - Mass ($M_{\text{sun}}$): 1.99x10^{30} kg = 330,000 Earth Masses
  - Luminosity ($L_{\text{sun}}$): 3.8x10^{26} J/sec = 3.8x10^{26} Watts!
- Deduce
  - Mean density: 1.4 g/cm³ (like water!)
  - Surface escape speed: 618 km/s (55 x Earth)
Solar Spectrum

- Continuous spectrum similar to blackbody which peaks at 520 nm (yellow)
  \Rightarrow \text{Surface Temp: 5800 K}
- Visible Absorption lines of Ca+, Fe+, H
  \Rightarrow \text{Surface Composition (by mass)}:
  - 71% H
  - 27% He
  - 2% Others (C,N,O,Fe, etc)

Solar Atmosphere

- Sun is only star whose surface we can study in detail.
  - The transparent outer layer of gas is the atmosphere. Working inside out,
- **Photosphere.** Where most of the visible light comes from. 300-400 km thick, density < 1/3000 Earth atmosphere.
  - continuous spectrum: temperature 5800 deg K
  - overlying absorption lines: temperature 4500-5500 deg K
  - High-resolution pictures show granulation: mottling of surface. These are "convective cells" about 1000 km across, lasting for about 5 minutes.
Outer Atmosphere

- **Chromosphere.** Hot (10,000-100,000 deg K) transparent gas above photosphere. ~2000 km thick. To see it:
  - *emission lines:* Seen at edge of sun against space, especially the red Balmer Alpha line ("Hα": H level 3- >2), making it pinkish (hence "chromo"sphere).
  - *filtergrams:* Take picture in light of absorption line opaque in chromosphere (eg Hα). Shows chromosphere is very patchy.

Corona, Solar Wind

- **Corona.** Very hot (millions of degrees) very thin gas out to several times solar radius.
  - *Seen in solar eclipse*
  - *emission lines* from highly ionized atoms (eg Fe XIV, or 13-times ionized iron)
- **Solar Wind.** Extending out from corona to beyond Pluto,
  - extremely thin ionized gas (few atoms/cm³), blowing out from Sun at 300-800 km/sec.
  - Most easily seen in comet ion tails being blown away from sum.
Solar Activity

- Source of heat and energy for chromosphere, corona, and wind is controversial, but may be
  - acoustic "noise" from convection in photosphere
  - and/or magnetic activity (weather):
- Sun's interior luminosity is very constant (varies less than 1%, luckily for us!). But Sun's weather is very active, and many phenomena are poorly understood:

Sunspots

- **Sunspots**. Lower temperature areas, appearing as dark spots in photosphere:
  - **Size**: Up to 10,000 km across (size of Earth).
  - **Duration**: Last a few months.
  - Allows measurement of rotation of upper part of sun: 25 days at equator, 35 days near poles.
  - Sunspots related to magnetic activity of sun: - average solar magnetic field about same as Earth, but in sunspot 1000x higher. - At solar temperatures, gas is partially ionized, responsive to magnetic field.
  - **Chromosphere filtergrams** show gas structures looking like iron filings around magnet.
Solar Activity Phenomena

- **Spicules**: spikes extending up to 10,000 km above sun, last 5-15 minutes
- **Flares**: Very energetic events above sunspots.
  - **Prominences**: arching structures 500,000 km, last hours
- **Coronal Mass Ejections**: Causes **auroras** on Earth and other planets.
- **Auroras**:
  - Uppermost atmosphere of planets ionized like solar atmosphere: "Ionosphere".
  - In an aurora, hot thin gas in streamers along magnetic field emits emission lines

**Cool Movies**: [http://sohowww.nascom.nasa.gov/](http://sohowww.nascom.nasa.gov/)
**Space Weather**: [http://www.sec.noaa.gov/today.html](http://www.sec.noaa.gov/today.html)

Solar Cycle

- **Solar Cycle**.
  - Number of sunspots, flares, and their arrangement on sun varies with an 11 and 22-year cycle.
  - We are currently approaching minimum
  - Historically, sometimes solar cycle goes away (e.g. 1645 -1715). It was very cold then, so many think solar storms effect Earth weather.
The Sun

Solar Photosphere
Approx. 23,000 km (about 14,400 miles)
Chromosphere

H-alpha Filtergram
Corona

Spicules
Prominences

Coronal Mass Ejection
Aurora