Overview: The Sun

- Properties of the Sun
  - Sun’s outer layers
    - Photosphere
    - Chromosphere
    - Corona
  - Solar Activity
    - Sunspots & the sunspot cycle
    - Flares, prominences, CMEs, aurora
  - Sun’s Interior
    - The Sun as an energy source
    - Fusion in the Sun

Sun’s Properties

- Nearest star
- Distance ~ 1 AU
- Temperature ~ 5800 K
  - From peak intensity

Sun’s Properties

- Radius ~ 7 x 10^5 km
  - About 100x Earth’s radius
- Mass ~ 2 x 10^{30} kg
  - About 333,000x Earth’s mass

Composition of the Sun

Sun is gaseous
- Violent, bubbling up close
- Too hot to be solid or liquid
  - 73% Hydrogen
  - 25% Helium
  - 2% other stuff (near surface)

The outer layers

- Photosphere
- Chromosphere
- Corona

Photosphere: Visible Surface

- Innermost visible layer, only 400 km thick (0.06% of radius)
- Temperature: 6,000 K
- Defines “size” of the Sun
- Absorption lines
Photosphere isn’t actually smooth!

Features called granules are about 1000 km across

Convection causes granules

Convection (rising hot gas) takes energy to surface

Convection causes granules

• Convection: transfer of energy through currents
• Dark-colored areas => cooler gas
• Light-colored areas => hotter gas

Granules Up-Close: like boiling water

Chromosphere: UV light, higher temp.

Middle layer, temperature $10^4 - 10^5$ K

Chromosphere:

Hot hydrogen atoms form a red streak when viewed during a solar eclipse
Corona or “crown” of the Sun

- Very low density
  - 10 million to 10 billion times less dense than Earth’s atmosphere
- However, corona is extremely hot!
  - About 1 million K
  - Known from spectrum

Sunspots

- Dark spots on the photosphere
- Cooler than other parts of the Sun’s surface (4000K vs. 5800K)

Sunspots

- One of Galileo’s major observations
- More than 30 sketches from summer of 1612

Sunspot Number

- Number & locations change daily
- Can use observations to determine how fast the Sun spins on its axis

Sunspot number peaks about every 11 years: the sunspot cycle

Data goes back to the 1600’s

Sunspots often come in pairs

- One is positive, the other negative, like a magnet
- Connected by loops of bright gas
We think most solar activity is related to changing magnetic fields.

Solar activity is like “weather”
- Sunspots
- Solar Flares
- Solar Prominences
- Coronal Mass Ejections (CMEs)

- All are related to magnetic fields, vary on an 11-year cycle

Solar Prominences
- Erupt high above the Sun's surface
- Can be quite stable (hours-days)
- Usually form near sunspots!

Solar Flares
- Bursts of X-rays and charged particles
- 5-10 minutes
Coronal Mass Ejections
Rare bursts, more energetic than flares or prominences
Speeds up to 1,000 km/s
50,000 km above Sun’s surface

Solar Wind
- Not moving air, like on Earth
- Stream of charged particles from coronal holes
- 900,000 mph, reaches Earth in about 4 days

What is the Sun’s structure?
From inside out, the layers are:
- Core
- Radiation Zone
- Convection Zone
- Photosphere
- Chromosphere
- Corona

Solar Wind
Charged particles get trapped in Earth’s magnetic field and cause auroras

Core:
Energy generated by nuclear fusion
Inner 25%
~ 15 million K
Very dense!

Radiation Zone:
Energy transported upward by photons
10⁶-10⁷ K
Photons spend a long time here
Convection Zone:
Energy transported upward by rising hot gas
Outer 30%
$10^4$-$10^6$ K

How does the Sun shine?
- The Sun has its own energy source
  - Main difference between a star and a planet
  - Not well understood until 1940's
- Need to explain lifetime & luminosity

Luminosity of the Sun
- Energy output: $3.9 \times 10^{24}$ Joules/sec
- A 100-Watt light bulb emits 100 Joules per second

If we could completely cover the Earth in 100-Watt light bulbs, how many light-bulb-covered Earths do you think we would need to equal the Sun's output?

Lifetime of the Sun
- Need a vast, constant source of energy
- Sun is at least 4.6 billion years old (from fossils)
- Most ideas could not sustain the energy rate needed