The Sun—March 4

- Your grade at midterm has been e-mailed to you.
- Average is 2.9.
- Clicker answers for Wed., 2 March were lost when computer crashed.

Grade at midterm

- Average is 2.9.
- Weighting
  - Clicker 19%
  - Homework 6% (1hwk= 2 classes)
  - Test 37.5% each
- 38% is done; 62% (Test 3, Final, remaining clicker & homework) remains
- Your true grade at midterm may be slightly higher.
  - Last problem on test 2 not graded
  - Excused absences, some homework corrections, some paper clicker questions not entered

<table>
<thead>
<tr>
<th>Your score</th>
<th>Class median / Total</th>
<th>Calculation for median student</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>28</td>
<td>27.0*0.375 = 26</td>
</tr>
<tr>
<td>Test 2</td>
<td>23</td>
<td>20/31*0.375 = 24.2</td>
</tr>
<tr>
<td>Clicker</td>
<td>88</td>
<td>87/105*0.19 = 15.7</td>
</tr>
<tr>
<td>Homework 1</td>
<td>100</td>
<td>75/100*0.06 = 4.5</td>
</tr>
<tr>
<td>Homework 2</td>
<td>100</td>
<td>100/100*0.375 = 37.5</td>
</tr>
<tr>
<td>Homework 3</td>
<td>92</td>
<td>100/100*0.2 = 20</td>
</tr>
<tr>
<td>Total</td>
<td>95</td>
<td>77/100*0.2 = 3.5</td>
</tr>
</tbody>
</table>

Parts of the Sun

- Core
- Radiation zone
- Convection zone
- Photosphere
- Chromosphere
- Corona
- Wind

Energy transfer

- Possibilities are:
  - Radiation
    - photons (light) travel a short distance.
    - absorbed by atoms.
    - re-emitted.
    - random walk.
  - Convection
    - hot bubbles rise.
    - cooler bubbles fall.
    - occurs when pressure changes very little with temperature.
  - Conduction
    - Not important in Sun

[Fig. 10.7]
**Photosphere**
- Deepest layer from which light directly escapes into space.
- Low density and pressure \(10^{-4}, 0.1 \times \text{Earth's surface values}\)
- But hot (5800° K)

**Granules (in photosphere)**
- Tops of convection currents.

**Chromosphere**
- Transparent gas layer, reaches 2000-3000 km above photosphere.
  - T ~5,000-10,000° K
  - Photosphere = point where we can no longer see through chromosphere.

**Corona**
- T > 1,000,000° K
  - Very low density: \(10^{-10}\) bar.
  - Heated by magnetic energy.
  - Several x diameter of photosphere.

**Magnetic Field**
- Electrons move in tight spiral around magnetic field lines.

**Sunspots**
- Cooler areas
  - as much as 1500° less than photosphere.
- This makes them look darker.
  - But they actually are still very bright.
  - Glowing at 4300° K instead of 5800°
Sunspots
- occur where magnetic field lines leave, re-enter photosphere.
  - Spots come in pairs.
    - leading = 1 magnetic polarity
    - trailing = opposite polarity
  - polarity reverses between N, S hemispheres.
- Magnetic field prevents hotter gas (granules) from entering these regions

Interior of the sun
- Use physics to construct models
- Energy is generated by nuclear fusion, which depends on temperature and composition.
- Energy move from center, where fusion occurs, to outside, where it radiates into space.
- Gas pressure holds the mass of the parts above.

Solar oscillations with GONG
- 2D mapping of velocity of gas on Sun’s surface
  - Seismic wave patterns
    - Caused by sudden collapses of large volumes of gas on surface.
  - Wave pattern shows interior structure
    - similar to analysis of Earth’s, Moon’s interior structures.
- Results
  - Convection zone down to 30% of Sun’s radius.
  - Differential rotation throughout convection zone.
  - Helium abundance same as at surface, except in energy generation zone.

Model: Where is energy produced?
- Where is energy produced? Within central 10% (of radius)
Model: What is temperature of center?

- 16 MK (million degrees Kelvin)

Model: What is temperature of center?

- 16 MK (million degrees Kelvin)

Model: What is composition of sun?

- Q: Why is there more helium than hydrogen in the center?
  a. The heavier helium sunk to the center
  b. Helium was made there

Model: Density of sun

- In center, sun is 160 times denser than water, 8 times denser than gold.