ANNOUNCEMENTS

Midterm I on Tue, Sept. 29
it will cover class material up to today (included)

Quiz #2 today, end of class

5. What's inside the Sun?
From the Center Outwards

- Core: Hydrogen fusing into helium, releasing energy in the form of gamma rays, neutrinos, and positrons
- Core temp = 15 million K, hot & dense from the gravitational weight of all that mass

Radiation Zone

- Gamma ray photons leave the core and move into an area known as the Radiation Zone
  - Neutrinos? They leave right away, no interaction
  - Positrons? Quickly find electrons in the core to annihilate with.
- Photons only travel about 1 mm before being redirected in another direction
  
  T=10 million K.

Meanderings of outbound photons

Our gamma-ray photons “random walk” outwards (getting redirected with every step), gradually cooling

Takes hundreds of thousands to a million years to get out!!
**Convection Zone**

- Eventually, gas is cool enough (2 million K at the boundary) and becomes turbulent
  - No longer just redirects photons, now absorbs them
- **Convection**: hotter regions rise, cooler regions sink
- Energy continues to work its way out - nearly 1 million years to get out

**Photosphere**

- At the top of the convection zone, the densities are now low enough that our photons can zoom away.
  - Now downgraded all the way to visible energies
- Photosphere is the “visible surface” of the Sun
- **T = only 5800 K**
- Photons free - seen at Earth 8 min later
- Blackbody spectrum (T= 5800 K) + absorption from cooler gasses just on top

**Granulation: turbulent convection**

- **Granulation Movie**
  - Typical granulations last only 8 - 15 minutes
  - Movie covers 35 min

**Granulation**

- Size: ~ 1 Mm across (that’s a Megameter!)

**Appearance of the photosphere**

*Taken by G. Scharmer & G. Simon at the Swedish Solar Telescope*
The Sun suddenly stops fusing hydrogen and loses its energy source. Which of the following is true?

A. The core will start to collapse.
B. The core will become cooler.
C. Both A & B
D. The Sun will appear fainter to us after 8 minutes.
E. The Sun will not change in brightness, but we will see the granulation stop (after 8 minutes).

In the core, what is the main wavelength of photons present?

A. Radio waves
B. Gamma Rays
C. Visible
D. Infrared
E. X-rays
At the photosphere, what is the main wavelength of photons present?

A. Radio waves  
B. Gamma Rays  
C. Visible  
D. Infrared  
E. X-rays  

The SUN

So Far...

How far is the Sun?
What is the Sun made of?
How does the Sun produce its energy? (and how do we know?)
Why is the Sun stable?
What is the structure of the Sun?

How do we know about the interior or the Sun?

Helioseismology: Millions of sound waves available to probe solar interior

Some waves bounce just below the surface
Others almost make it to the center
All excited by turbulent granulation visible in photosphere
One of millions of modes, each with a different tone!

Sunspots Caused By Magnetic Fields

- Magnetic fields entrain gas in huge bubbling loops
- Cooler areas at “liftoff” cause dark sunspots

But What Causes the Magnetic Field Lines to Stick Out Like That?

- **Differential Rotation**
  - The Sun rotates differently at different latitudes.
  - The Sun winds itself up
This Solar “Wind Up” Leads To The Sunspot Cycle

During the Sunspot Cycle Sunspots Form At Different Latitudes

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Complex Interplay of Convection, Magnetism and Differential Rotation.

What is believed to be the main cause of the sunspot cycle?

A. Temperature changes between the equator and poles of the Sun
B. Twisting of magnetic fields lines in the Sun due to a rotation rate varying with latitude.
C. Variability in the Sun’s brightness every 11 years
D. Interaction between the Sun and the orbits of the innermost planets
E. A variation of the fusion rate occurring in the core of the Sun.
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If we see the sunspot edge-on, it’s called a PROMINENCE.

When Prominences Go Bad

- Occasionally the magnetic field lines in a prominence “snap”
  - Energy & Light is released
    - Flares
    - Charged particles are spewed out into space
  - Coronal Mass Ejections
Coronal MASS Ejections Blast Out Charged Particles

• PROTONS!
  – Can:
    • Damage satellites
    • Harm astronauts
    • Induce currents on Earth and destroy electric transformers on the ground
    • Cause swelling in the Earth’s atmosphere

Protons interacting with the Earth’s magnetic field produce aurora

Chromosphere

• Temperature goes back UP!
• $T \approx 6,000-10,000 \text{ K}$
• Very thin density

• Heated by energy twisting and spilling around magnetic field lines

Outside the chromosphere, the temperature spikes up again!
**Corona**

- $T \approx 1,000,000 \text{ K}$
- Extremely thin density
- X-rays
- More magnetic heating

*Corona becomes clearer in visible light without glare from the rest of the Sun*

**Solar Eclipse: Sun’s light blocked by the Moon**

**Solar Wind**

- At the top of the corona, gas is hot enough (and far enough) to escape the gravity of the Sun
- In effect, the corona is “evaporating”
  - But replenished from below
- Solar wind carries about a million tons of solar matter per second!!
  - Yet the sun has only lost 0.1 percent of its mass!
QUIZ #2

1) NASA has given you money to build two telescopes: an X-ray and a radio one; one which can be 1m size and the other 10m, And one which can go in space while the other stays on Earth.

a) Which of the two would you put in space? [2.5pt]

b) Which one would you make to be 10m in size? [2.5pt]

Explain and motivate your answers for full credit.

2) We know the composition of the Sun and its source of energy.

a) What are the tools astromers have used to learn the composition of the Sun? [2.5pt]

b) How do we know that chemical burning does not power the luminosity of the Sun? [2.5pt]

Explain and motivate your answers for full credit.