Special Brooks Observatory opportunity this week: **Comet Holmes**

An erupting comet, a unique object . . .

Monday through Thursday 8:00 to approx. 9:00 PM, or after class

Not required, no ticket needed, no report due

Session will stay open as late as interested people are present.

ASTR 1010 students free, public $2.00, children 12 and under $1.00
Quiz 5: October 31

- October 22: Venus (chapter 7), Jupiter, jovian planets, Galilean satellites of Jupiter (chapter 8)
- October 24: Titan and Saturn’s rings; meteorites, asteroids, comets (chapters 8 and 9)
- Today: The Sun (chapter 10)
Comments about Homework 5

5. An extrasolar planet is discovered that is made primarily of hydrogen and helium. It has approximately the same mass as Jupiter but is the same size as Neptune.

This statement is self-contradictory. Some possible answers:

• In order to be smaller than Jupiter, a hydrogen-helium planet would have to be more gravitationally compressed, so it would have to have a larger mass than Jupiter.

• A planet with that size and mass would be too dense to be made of hydrogen and helium.
The Sun: vital data

Angular diameter: direct measurement

Size (true diameter): must know distance from Earth at any given time

Mass: orbital speed of a planet & its distance from the Sun tell you its acceleration in its fall toward the Sun. Then Newton’s law of gravitation gives the Sun’s mass.
Sun’s density: close to 1 gram per c.c.

Luminosity: total rate of energy output, at all wavelengths, in all directions, 400 trillion trillion watts

Energy received at Earth: 1400 watts per square meter
Atmosphere: outer skin from which light reaches us (thickness exaggerated)

Interior: volume inside/underneath; light within does not get out
Composition of solar atmosphere: from analysis of spectrum

- Dark absorption lines are signatures of atoms in Sun’s atmosphere
- Each element has a characteristic set of wavelengths and can absorb or emit light at those wavelengths (only).
- Degree of blackness of each line is related to amount of each element present in gas producing spectrum. It’s also related to the temperature and density of the gas, so the analysis is complicated.
For example, here’s how we know the Sun is mostly hydrogen. Hydrogen atom (simplified):

- Innermost energy level or ground state
- 2nd energy level
- 3rd energy level

Absorbs UV

Absorbs Red
Before the atom can absorb red light, it first must absorb an ultraviolet (UV) photon.

But the Sun emits very little UV energy.

Most hydrogen atoms never get to absorb UV photons.

So a lot of hydrogen is needed to produce even the modest absorption found in visible light.

(If you observe the spectrum of the Sun in ultraviolet light, you find almost complete absorption by hydrogen.)
Findings on composition of atmosphere, counting by number of atoms

- 90% hydrogen
- 10% helium
- Much less than 1% all else together
The Sun’s outermost atmosphere

The corona is the pale, pearly-white halo that surrounds the Sun and is visible during total eclipses.

It is extremely hot, with temperatures over a million degrees Kelvin, but also extremely low in density.

Its outer fringes escape and travel away from the Sun at speeds over 600 mph — the solar wind.

Occasionally, larger streams of (mostly) protons and electrons escape from the Sun: coronal mass ejections.

Image shown is Slide 13 on linked page.
When these streams hit the Earth’s upper atmosphere, they energize atoms there and cause them to glow: the northern lights or aurora borealis. Usually, the northern lights occur at locations in a ring around the Earth’s magnetic poles.

(The image I used in class appears to be no longer available on the Web. This link points to a similar image.)
More about magnetic fields

Visualize as field lines or lines of force

Demonstrate with bar magnet and iron filings

Like tiny compass needles, the iron filings line up along the lines of force from the magnet. (See Fig. 10.14)

Where lines are closer together, the field is stronger.

Protons, electrons, ions cannot cross magnetic field lines and are constrained to follow them.

Earth’s magnetic field lines channel particles to auroral ovals.
Magnetic fields in the Sun

Very strong in sunspots

Traced out by gas in corona

Sunspot numbers vary in an 11-year cycle.

Every 11 years, the magnetic poles of the Sun flip over (magnetic south and north change places). So the Sun’s magnetic cycle is 22 years long.
Significance of Sun’s luminosity

Not only is this a lot of energy, but the Sun has been shining this way for a long time.

- Life on Earth for at least 2.5 billion years (evidence: fossil bacterial colonies with this radioisotope age) implies roughly constant solar luminosity during that time.

- Physical law: conservation of energy. Energy is never created out of nothing, but only converted from one form to another.

- Most types of stored energy conversion are not efficient enough.
Need to understand Sun’s interior to understand this.

These facts about the Sun imply two related questions. They were a major unsolved scientific problem until about 1920.

- How can the Sun be so stable for so long?
- From what stored form and by what process is the energy being converted that the Sun radiates to space?
Possible energy conversion processes

Gravitational contraction

- When an object falls from rest, energy is converted from a stored form, called gravitational potential energy, to energy of motion.

  ![Diagram showing energy conversion from potential to kinetic energy]

  - Held at rest: energy stored
  - In motion: energy released

- In gravitational contraction, this energy of motion is converted into heat and thermal radiation.
• Suppose the Sun were shrinking. Conversion of gravitational potential energy could account for the energy it loses into space.

Hypothetical! Sun does not actually shrink!

• But the Sun could shine for only about 40 million years.
Fusion of hydrogen nuclei (protons)

- We’ve already found that the Sun’s visible exterior is mostly made of hydrogen. Interior also.
- Ordinarily, protons repel each other because of equal electrical charge
- But if they approach each other at high speed, they collide
- Then, fusion is possible
• Result: a nucleus of deuterium with one of the protons having changed into a neutron

• With 2 more protons added, helium-4 forms as end product

![Diagram of a nucleus with protons and neutrons]

• Energy is released, mostly in the form of gamma rays (photons)

• They heat the Sun’s interior.
• Energy has been converted from a stored form to thermal energy—which makes the Sun hot—and electromagnetic radiation.

• Clue to the nature of the stored energy: the mass of the helium-4 nucleus is 99.3% of the mass of the original 4 protons.

• The stored form is the mass of the protons, of which 0.7% is converted to energy when helium-4 is made out of 4 protons.

• Remember Einstein’s equation $E = mc^2$, which says that mass is another form of energy.
This fusion process is called the \textit{proton-proton chain}.

Summarize:

\begin{itemize}
  \item Four protons $\rightarrow$ 1 helium-4 nucleus
  \item A small fraction of the mass of the protons is converted to electromagnetic radiation and heat; the rest goes into the helium-4.
\end{itemize}
How long the Sun’s fuel supply will last

- The total fuel supply is the Sun’s mass times 0.007
- The number of grams (mass) of fuel consumed per second, times $c^2$, equals the Sun’s luminosity
- The time needed to consume all the fuel is about 10 billion years.