Announcements

- HW#6 due this Sunday, 11:45pm

- Finish chapter 11 for next week.

- Extra credit on magazine article, due Tuesday! 1.5% of total grade. See course website for details. MUST BE AN ASTRONOMY ARTICLE, 2 Pages Type-Written!!!

- Friday/Sat not an option for you? Email me and we can try to setup a weekday evening show.
**Classroom Etiquette**

**Productive:** Listening, pondering, questioning, hand-raising, being respectful of your classmates, waiting for the end of class to depart.

**Unproductive:** Talking, texting, sleeping, web browsing, disturbing classmates, departing early and noisily.
Andromeda
Galaxy
The Sun! One of billions of stars on our Galaxy, but ours. Average mass and size.

Not powered by fire (burn out in 10,000 yrs) or contraction (25 million years)... currently 5 billion years old!

Powered by nuclear fusion: hydrogen is smashed together into Helium at 10 million degrees in the core! The hotter it is, the faster fusion happens!

Not Fission, like in nuclear power plants
In our nuclear reactors, we gather the rare element Uranium-235.

Burns by a chain reaction.

Not encountered (much) in the sun or stars.
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Burns by a chain reaction.

Not encountered (much) in the sun or stars.
Last Time

Sun is locked in a battle between gravity (contraction) and the heat of fusion (pressure) which we call “Hydrostatic Equilibrium.” They balance each other like a thermostat.

Sun started shining due to gravitational contraction: converting potential energy (gas at great distances) into thermal energy (heat in a compact star).
Incandescent Plasma

Sun is not really an “incandescent gas”. They Might Be Giants actually corrected this 1950's folk remake in a (much less catchy) later tune.

Why? The sun is so hot everywhere, that it’s atoms are stripped of all electrons: this creates another phase of matter (solid, liquid, gas,... PLASMA!).
Regions

- Reacting core, hot radiation zone, “boiling oatmeal” convection zone, and the photosphere (what we see as the yellow ball).

- Atmosphere heated by surface activity: the chromosphere and corona.

- Sun-spots: Cooler regions on the surface which appear darker: the size of the Earth! 11 year cycle of sunspot activity. First used to measure the rotation period of the Sun (25 days!)
Magnetic Fields are very twisted and strong, reversing direction every 11 years.

Because the sun rotates faster at the equator than higher latitudes, the magnetic fields get twisted and erupt as prominences, with sunspots at their base.

Drive the solar wind, solar Flares, and (the biggest of all), coronal mass ejections that threaten satellites/ astronauts/communications.
Spicules on the sun: APOD 11/02/08
Imagine a pipe as wide as a state and as long as half the Earth. Now imagine that this pipe is filled with hot gas moving 50,000 kilometers per hour. Further imagine that this pipe is not made of metal but a transparent magnetic field. You are envisioning just one of thousands of young spicules on the active Sun.
Surveying the Stars

Thursday, October 28, 2010
Stars, Briefly

- There are billions of stars in the galaxy.

- Stars differ in mass (from 10% of the sun’s mass, to 150x the sun’s mass).

- ...and radius (from the size of earth to the size of Jupiter’s orbit!).

- ...and color (from deep red, to blue).

- ... but otherwise, stars are almost entirely alike each other!!!
Analyzing Starlight

- Starlight is only information we have
- Take picture
- Measure brightness
- Determine color
- Measure position
- Take spectrum
- Measure spectral lines
Stellar Positions

- **Stars move (slowly):** *Proper Motion* (sideways motion)
- **Determined by measuring position**
Stellar Positions

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  (sideways motion)
- Determined by measuring position
Brightness of Stars

- **Luminosity**: amount of energy emitted per second (Watts).

- Not the same as how much we observe!

- **We observe a star’s apparent brightness**

- Depends on luminosity & distance and other dimming effects, like dust in the way.
Apparent Brightness

The further the object, the fainter it appears.
**Inverse Square Law**

- **Apparent brightness falls as** $1/d^2$.

- **Inversely with the square of the distance.**

- **Example:** Move 3 times further from the sun, and it’s $1/9$th as bright.
Measuring Brightness: History

- **Photometry** - the measure of brightness

- **Hipparchus (150 B.C.) made a catalog of 1000 stars, including position & brightness.**
  - Brightest stars were first magnitude (1.0)
  - Faintest stars were sixth magnitude (6.0)
  - Estimated by eye (logarithmic response)
  - Important: Lower Magnitude = Brighter!
Modern Magnitude System

- Refined scale of Hipparchus
- 5 magnitude difference = brightness factor of 100
  - 6th mag. star is 100x fainter than 1st mag. star
  - 1 magnitude difference is 2.5 times brighter/fainter
... but how bright are stars really?

We can only measure the apparent brightness of stars. If we knew their distance, we could find their luminosity.

We can measure the distance to stars with parallax (our old friend).
A tale of Two Magnitudes

Apparent vs. Absolute magnitude

Moving the sun further away would make it appear fainter... but it’s still the sun, producing the same power of $10^{26}$ Watts.

Apparent = “How bright it appears”, Absolute = “How bright it really is”
Parallax

Every January, we see this:

Every July, we see this:

Not to scale!
Parallax and Distances

Parallax: angle by which object shifts when viewed from different places

Triangulation: calculating distance from parallax angle
Parallax

Using the apparent shift a star makes on the sky from two opposite positions in the Earth’s orbit, we can determine its distance.

The more the star jumps, the larger the parallax angle, and the closer it is to the Sun.

The less the star jumps, the smaller the parallax angle, and the farther it is from the Sun.
Parallaxes

Parallaxes of the stars are all smaller than 0.1 arcseconds (a quarter at 5 km).

First measured in 1838 by Bessell (remember the greeks...).

Parsec: the distance of a star that has a parallax angle of 1 arcsecond ("PARallax SECond")

1 parsec = 3.26 light-years.
How intrinsically bright are the stars?

Combining our distances and apparent brightness, we find the stars have luminosities that range from $10^{-4} \, L_{\text{sun}}$ to $10^{+6} \, L_{\text{sun}}$ (one ten-thousandth to 1 million times the sun!!!).

$L_{\text{sun}} = 3.8 \times 10^{26}$ Watts
How hot are the stars?

When we say temperature, we really mean the surface temperature.

There are two ways to determine a star’s temperature, 1) its color, and 2) its absorption line spectrum.
“Color” Temperature

Hotter objects emit more light at all wavelengths

Hotter objects emit more of their light at shorter wavelengths (Wien 1893)
Thought Question:

Which star is hotter?
- The blue star
- The red star
Thought Question:

Which star is hotter?

The Blue Star

The Red Star
Stellar Spectra

Cool atmosphere in front of star

Schematic Stellar Spectra

Energy

Wavelength

OR
The Solar Spectrum
Sun’s Spectrum vs. Thermal Radiator

of single temperature $T = 5777$ K

![Graph showing the spectrum of the Sun compared to a thermal radiator of the same temperature. The graph is labeled with UV, Visible, and Infrared regions, and shows the observed intensity (Watts/m^2/nm) versus wavelength (nm).]
Star Colors

Measure brightness at different wavelengths

- $U =$ ultraviolet magnitude
- $B =$ blue magnitude
- $V =$ visual (yellow) magnitude

Color = magnitude difference

- $(B-V)$ or $(U-B)$

Gives stellar temperature (recall blackbody)
Spectra of Other Stars

H  H  H  H  H  H

Sun

Na
Fraunhofer measured solar spectrum

Spectra of other stars not the same

Hydrogen (and other) lines: Sometimes strong, Sometimes weak, not always present

Why? Because stars have different temperatures
Classification of Stars

Classified by absorption lines in their spectra

Annie Jump Cannon at Harvard (1863-1941)

Classified large numbers of stars (over 400,000!)

HD catalog (still used today)

From hottest to coolest stars:

O, B, A, F, G, K, M

Traditional: Oh Be A Fine Guy/Girl Kiss Me!
Alternate: Oh, Brother, Astronomers Frequently Give Killer Midterms!
The spectral type of a star can tell us its temperature very precisely.
Remembering Spectral Types

(hottest) O B A F G K M [L T] (coolest)

- Oh Be A Fine Girl/Guy, Kiss Me

- Only Boys Accepting Feminism Get Kissed Meaningfully

- Oh Be A Fine Girl/Guy, Kiss My Lips Tenderly
Aside

We recently added two new spectral types to this list. The “L”s and “T”s.

Their temperatures range from 2500 K down to 700 K.

These types generally contain the very lowest mass stars and “brown dwarfs”. Brown dwarfs have so little mass, they cannot even start nuclear fusion.
OBAFGKM Mid-Term #3 Extra Credit

- Make up your own mnemonic for the stellar types: OBAFGKM.
- Complete ONLINE on MasteringAstronomy by Tuesday, Nov. 9th (date of exam 3)
- Worth 2 free points on your mid-term!
- Especially good ones will be highlighted in class.
A bit more detail...

Each spectral type is further divided by into smaller types.

For example, B1, B2, B3.

The higher the number, the cooler the star.

The Sun is a G2 star.
What We Learn from Spectra

- Stellar Temperature
- Which lines are present and their strength

![Diagram showing spectral lines and their strengths across different stellar temperatures.]
Stellar Spectra, in detail

![Graph showing Stellar Spectra with Hot Star and Cool Star]

Logarithmic brightness vs. Angstroms
How hot are the stars?

We find that the temperatures of stars (at their surface) range from 2500 K up to > 50,000 K.

The Sun’s temperature is 5800 K.
What We Learn from Spectra

- **Abundances of elements**
  - From strength of absorption lines

- **Velocity along our line of sight**
  - From Doppler shift
  - Velocity toward (**blueshift**) or away (**redshift**) from us

- **Stellar Size**
  - Indirectly from atmospheric pressure
    - Low pressure: lines are narrow: **giant & supergiant stars**
    - High pressure: lines are wide: **normal stars**

- **Luminosity Class**: I, II, ..., V
  - I = narrow lines = supergiant = large radius
  - V = broad lines = normal star = small radius
What We Learn from Spectra

- **Rotation**

  - From line shape/width
  - Indirectly due to Doppler shift
What about how they live?

- Stars live for millions or billions of years.
- Since we cannot watch them be born, grow up, and die, we have to resort to other means.

Take a census of as many stars as possible, collect information on:

- Luminosity (how bright?),
- Temperature (how hot)
- Mass (how much matter?)
- Radius (how big?)
- Distance (how far?)
Results for Luminosities

- **Luminous stars are very rare!**

- **More low luminosity stars than high**

- **Most stars less luminous than sun**
Mass of the stars

Determining the mass of stars is difficult.

We can use Newton’s version of Kepler’s Laws to determine the masses of binary stars.

\[ P^2 = \frac{4\pi^2}{G(M_1 + M_2)} a^3 \]
Although most stars seem to be alone, most stars are in binary or multiple star systems.
Binary Stars

$M_1/M_2 = 3.6; e = 0.0$

$M_1/M_2 = 3.6; e = 0.4$
**How massive are the stars?**

By studying special binary stars called eclipsing binary systems, we have determined the masses of stars range from $0.08 \, M_{\text{Sun}}$ up to $150 \, M_{\text{Sun}}$.

The mass of the Sun is $M_{\text{Sun}} = 3.0 \times 10^{30} \, \text{kg}$.
Properties of the Stars

- **Luminosities range from** $10^{-4}$ to $10^{+6}$ $L_{\text{sun}}$

- **Temperatures range from** 2500 K to 50,000 K

- **Masses range from** 0.08 to 150 $M_{\text{sun}}$
... BUT THE MOST IMPORTANT PROPERTY OF A STAR...

... IS PERSONALITY.
... BUT THE MOST IMPORTANT PROPERTY OF A STAR...

.... IS MASS
Gravitational Equilibrium

- The more pressure at the core, the higher the rate of nuclear fusion.

- The higher the rate of nuclear fusion, the brighter and hotter (bluer) the star.

- A star 10 times the mass of the Sun fuses its hydrogen at a rate 10,000 times faster than the Sun!
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Reminders

- HW 6 due Sunday

- Go to the Planetarium (Fri/Sat)!

- Extra-Credit on Magazine article due by Tuesday

- Finish Chapter 11