Astronomy 113
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The Nature of Stars

8-2
Parallax

For "nearby" stars - measure distances with parallax

\[ d = \frac{1}{p} \text{ [arcsec]} \text{ [pc]} \]

- \( p \gtrsim 1 \) arcsec
- Using satellites, can measure to \( \text{d} \gtrsim 1,000 \text{pc} \)

8-3
Brightness

- Apparent Magnitude (log scale - the eye's response)
- Bright
- Faint
- 1 magnitude = 2.5 times real brightness (so 1 to 6 is 100 times difference: \( 2.5^5 = 100 \))
- Magnitudes can be negative too. So,
  - Sun = -25
  - Moon = -12
  - Sirius = 0

Faintest objects = +30 (with HST, for example)

8-4
Magnitudes

- Apparent magnitude (m) is not "real" brightness
- Apparent brightness decreases inversely with square of distance - the "inverse square law".
- Double distance — apparent brightness decreases \((1/2)^2 = 1/4\)
- Triple distance — \((1/3)^2 = 1/9\)

Need to be able to compare real brightness, so correct for distance

- Absolute magnitude (M) = apparent magnitude an object would have if it were at 10 pc
- Sun = +4.8 (range for stars: -10 to +17)
- Measure m and d, then: \( M = m - 5 \log(d/10) \)

8-5
Inverse-square Law

- Insert figure
8-6

**Luminosity**

- Absolute magnitude is related to Luminosity (the physical brightness of an object).
- Solar luminosity = $3.9 \times 10^{26}$ Watts
- Call this 1 L

Stars with:
- M = -10 have $10^{6}$ L
- M = +17 have $10^{3}$ L

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**Stellar Temperatures**

- Remember Wien’s law? ($\lambda_{\text{max}} = 1/T$; color related to surface temperature)
- Use a photometer to measure light intensity and filters to measure intensity at different bands:
  - U (UV), B (blue), V (visual)
  - That is, 3 apparent magnitudes which tell us where most energy in spectrum is (B-V = color index; if small, object is blue, if large, it is red)

8-8

**Spectral Types**

- A star’s surface temperature determined from color index or spectral line strengths.
- In the 1920s, Cecilia Payne classified stars based on spectral features visible (and ordered them by surface temperature).
- Spectral types:
  - O B A F G K M
  - Sun = G2
  - Further subdivided: B0 – B9
  - Hottest: HeII (singly ionized) SiIV (triply ionized)
  - Coolest: Molecules (TiO)

8-9

**Spectral Types**

- Spectral type figure

9-1

**The Hertzsprung-Russell Diagram**

- Supergiants
- Giants
- Sun
- Main Sequence
- White Dwarfs

Types of Stars
The Hertzsprung-Russell Diagram

- Pattern when color-index is plotted against absolute magnitude
- Also called "Color-Magnitude" diagram

Surface Temperature and Absolute Magnitude are Related!

- Main Sequence: 90% of stars in Solar neighborhood are on Main Sequence (called "dwarf" stars)
  - M-type stars most common
  - O-type stars rarest
  - Most M.S. stars are like the Sun

The Hertzsprung-Russell Diagram

- Insert figure

Giants

- From Stefan-Boltzmann Law: $E = T^4$
- Cool objects radiate less $E$ than hot (per unit surface area)
- So, for Giants to be so bright, they must be huge!

$T \sim 3,000 - 6,000K$

$R \sim 10 - 100x$ Solar Radius

Red Example: Arcturus

Supergiants

- Even bigger and brighter than Giants
- Example: Betelgeuse
- 1% of all stars in Solar neighborhood

9% of stars in Solar neighborhood are "white dwarfs" - more later

Binary Stars

- Two stars gravitationally bound
- Orbital motion of binaries shifts spectral lines (Doppler Shift)

Eclipsing Binaries

- We see stars along their orbital plane
- Causes effects in light curve:

Total eclipses allow us to measure radii of stars
Stellar Masses

How do you measure mass?

Newton’s adaptation of Kepler's Law:

$$M_1 + M_2 = \frac{a^3}{p^2}$$

(both measured in binaries)

Mass-Luminosity Relationship:

On the Main Sequence, the more massive a star, the more luminous

Contact Binaries

- Roche Lobe - Sphere of gravitational influence
  - “Detached” Binaries
  - “Semi-detached” Binaries
  - “Contact” Binaries

The Sun

- The nearest star - easiest to study - use as a model
  - The Atmosphere
    1. Photosphere - the visible layer (about 400km thick)
      - Low density (0.01% of our atmosphere at sealevel)
      - Perfect blackbody at 5800 K
      - Can’t see below
      - Features:
        - Granulation
        - Limb Darkening
    2. Chromosphere - layer of less dense gas above the photosphere (about 500km thick)
      - T ~ 4000 K
      - Features:
        - Spicules - spikes or jets of gas
    3. Corona - uppermost layer of atmosphere; extends to millions of km
      - Very low density
      - Can be seen during eclipses
      - T = 2 x 10^6 K
      - Heated by magnetic fields
      - So hot particles have high velocities and escape as solar wind (p & e): 1 million tons per second!!

The Sun
The Sun

The Atmosphere
- Sunspots - cooler regions on surface (where magnetic fields exit and enter Sun)
  - Follow an 11-year cycle
  - 10,000s km (Earth-sized)
  - Last days - month
  - Can determine Sun's rotation rate
    - Differential rotation: Equator rotates more rapidly than poles (25 day - 35 day)
    - Further proof Sun is gaseous
- Solar Flares - eruptions of charged particles and radiation

The Solar Interior

The Energy source - (18th cent. View - coal, etc)
- Thermonuclear Reactions
  - \( E = mc^2 \)
  - Fusion in core
    - Because \( P (3 \times 10^{11} \text{ atm}) \) and \( T (2 \times 10^7 \text{ K}) \) are so high, protons stick (H = 1p 1n & He = 2p 2n), so:
      \[
      4 \text{ H} \rightarrow \text{He} + \text{energy} + \text{neutrinos}
      \]
      For this reaction: \( E = 4 \times 10^{13} \text{ J} \) (enough to light a 10W lightbulb for \( 5 \times 10^{12} \) seconds!)
      But the Sun's luminosity is \( \sim 4 \times 10^{26} \text{ W/sec} \)!
      600 million metric tons/sec of Hydrogen is being converted into Helium!!

We use models to understand what's happening in the interior.

Fusion

In the sun, 300 million times of Hydrogen/sec - 170,000 yrs to consume mass of earth in 10 billion years...
Neutrinos

Nearly massless subatomic particles. Produced in huge quantities during fusion and supernovae.

- Important for cosmological reasons and understanding of nuclear fusion
- Billions of them pass through every square centimeter all the time - yes, even now!
- Weakly interacting: can pass through 1 light year of lead without interacting with a lead atom!! (Luckily for us)
- Can be detected

The Solar Interior

- Hydrostatic Equilibrium
  - Balance of force of gravity, which tries to squeeze Sun, and radiative pressure from fusion, which tries to blow apart Sun

- Radiative transport
  - Energy transported outward by photons
    - High P, High T create High E photons (γ-rays)
    - But High P keeps them in, leading to a Random Walk - photons collide, lose E, eventually fly free (after 10^6 yrs) from photosphere as visible photons

Interior of Sun

Transport of energy

Radiative (= photons) + Convection

"Random walk": γ-ray to visible (Infrared)