Chapter 10: Measuring the Stars

Notes and Sketches

10.1: The Solar Neighborhood

Stellar Parallax

- Apparent motion of an object against a background of more distance objects
- Farther objects, smaller parallax
- Relate distance to observed parallax: distance = 1/parallax
- Measure distance in parsec (1pc = 206265AU = 3.3 light years), measure parallax in arcsec

Our Nearest Neighbors

- Proxima Centauri = 1.3 pc = 4.3 ly (parallax = 0.77")
- Barnard's Star = 1.8 pc = 6.0 ly (parallax = 0.55")
- Closest stars have parallax less than 1 arc sec
- Need adaptive optics or space telescopes to really resolve parallax for more distant objects

Stellar Motion

- Apparent motion: Parallax results because Earth is moving, not because star is moving
- Radial velocity: Real motion of star towards or away from Earth (measure using Doppler shift)
- Transverse velocity: Real motion of star perpendicular to line of sight

Proper Motion

- Record apparent position of star, then return after a significant amount of time (years, not days) and observe again
- Change in apparent position can be broken into pieces: parallax and transverse velocity
- Once you take the parallax out, what remains is real: Proper motion

10.2: Luminosity and Apparent Brightness

- If it looks bright, maybe it really is bright
- Or maybe it's not really all that bright, it's just close
- Have to distinguish actual luminosity (how much energy the star generates) from apparent brightness

Another Inverse Square Law

- Farther = dimmer, closer = brighter
- The relationship is not linear
- Inverse square: double the distance, only one fourth the brightness
- Apparent brightness $\propto$ (luminosity/distance^2)
- To know how much energy a star really generates, you have to know both how bright it looks and how far away it is

The Magnitude Scale

- Origin in ancient Greece: brightest stars called first magnitude or first order, dimmer stars have second (or third, or fourth) order magnitude
- Smaller number indicates a brighter appearance, larger number indicates dimmer appearance
- Have to distinguish between the appearance and the actual energy!!

Apparent Magnitude

- How bright does a star appear as viewed from Earth?
- Scale is not linear!
- Smaller number is brighter, but magnitude 1 is not twice as bright as magnitude 2
- Scale is logarithmic, but not even log base 10
- Could we make this any harder? Yes! There are negative magnitudes as well!
- Every five magnitudes is a factor of 100 in brightness: Magnitude 1 is 100 times brighter than magnitude 6
- Brightest object observable: Sun = −26.8
- Dimmest object observable: magnitude ≈ +30 (HST limit)

NOTES AND SKETCHES

Absolute Magnitude

- Take the stars and line them all up at a distance of 10 pc from the Earth (this is an imaginary experiment)
- What appears brighter will actually be a more luminous star: this is an intrinsic property
- Now use pretty much the same brightness scale: smaller number = brighter, scale is logarithmic
- Typical to see side-by-side comparison of luminosity and absolute magnitude

10.3: Stellar Temperatures

Color and The Blackbody Curve

- We already know that color and temperature correlate (Stefan's Law, Wien's Law)
- Blackbody curves are very well behaved: easy to extrapolate
- This means you do not need a whole mess of measurements to figure out the shape of the curve
- B: Measure intensity using a blue filter (only allows narrow range of wavelengths)
- V: Measure intensity using a visible filter (narrow range of wavelengths in the green-yellow)
- These two measurements are enough to reconstruct an entire blackbody curve

Stellar Spectra

- The same composition can yield different spectra at different temperatures
- Hot stars mean more ionization, which shows up in the spectra
- Cooler stars allow formation of molecules, which shows up differently in the spectra
- Spectra give very accurate temperature profiles

Spectral Classification

- What do you do with thousands and thousands of stellar spectra, but no workable atomic theory?
- Pattern recognition: sort stars by line strengths, and hope someday it means something
- Historically, astronomers used letters A through P

Oh, Be A Fine Girl, Kiss Me

- If you think of a better mnemonic, please share it with the world
- This is what is left of the previous classifications: O B A F G K M
- Temperature decreases in order from O to M: type O are the hottest, type M are the coolest stars
- Subtypes: Give the letter a numeric appendage, and B0 is hotter than B1 is hotter than B2 $\cdots$ is hotter than B9

10.4: Stellar Sizes

Direct and Indirect Measurement

- Direct measurement of stellar radii is difficult: too far, too small
- A few very large stars are close enough to be measured directly
- Indirect measurement: Infer size based on luminosity and temperature
- Luminosity depends directly on both temperature (Stefan's law) and surface area (area $\propto$ radius^2)
- $R = (L_\odot)/T^2$, where R, L, and T are in solar units ($R_\odot = 1$, $L_\odot = 1$ and $T_\odot = 5800$K)

NOTES AND SKETCHES

Giants and Dwarfs

- Huge and cool: Aldebaran (4000K = cool, but $R = 40R_\odot$)
- Tiny and fiery: Sirius B (24,000K, and $R = 0.01R_\odot$)
- Dwarf: $R \le R_\odot$
- Giant: $10R_\odot < R < 100R_\odot$
- Supergiants: $R > 100R_\odot$

10.5: The Hertzsprung-Russell Diagram

H-R Diagram Axes

- Plot temperature on the x-axis
- Notice that T gets hotter as you move to the right!
- Plot luminosity on the y-axis
- Notice that units are stellar: $L_\odot = 1$

The Main Sequence

- When you start putting stars on the graph, a pattern emerges
- Most stars fall into a fairly narrow band on the graph: The main sequence
- This band is not perfectly linear
- There are plenty of exceptions to the rule, and they mean something

Constant Radius Diagonals

- Use relationship between luminosity, temperature and radius
- Diagonals = lines of constant radius run from top left to bottom right

The White Dwarf and Red Giant Regions

- On the main sequence: Blue giants and supergiants at top left (hot, luminous, large)
- On the main sequence: Red dwarfs at bottom right (cool, dim, small)
- White Dwarfs: Off the main sequence at bottom left (hot but dim)
- Red Giants: Off the main sequence (like a tree branch) on the top right of curve (very bright, but not very hot)

How Many of Each Type?

- You can see the brightest stars at much farther distances
- There are dimmer stars out there that cannot be mapped because they are too dim
- Recognize which types are over-represented because they are so bright, and which types are under-represented
- If our neighborhood is typical, 90% main sequence, 9% white dwarf, 1% red giant

10.6: Extending the Cosmic Distance Scale

Spectroscopic Parallax

- Actually has nothing to do with stellar parallax
- Work the distance problem backwards: Apparent brightness $\propto$ (luminosity/distance^2)
- Observe the apparent brightness, determine the luminosity by spectral type
- Solve for the distance, which means now you have another way to find distance without measuring apparent motion

Luminosity Class

- Start with O B A F G K M: Coarse temperature scale
- Add the number 0-9: Refine the temperature classification
- Add a luminosity class: Distinguish between main sequence stars (V) and non-main sequence stars (I through IV)
- How do you determine luminosity class? Line width gives you atmospheric density, density gives you distinction between giant, main sequence, and dwarf stars

10.7: Stellar Masses

Notes and Sketches

- We already know how to use orbits (Kepler and Newton) to figure out the mass of the sun (like we did for Jupiter)
- Same technique can be applied to other stars: if you have a planet orbiting a star, or two stars orbiting each other

Binary Stars

- It appears that most stars come in pairs
- Binary = two, but there may be multiple stars in a system

Types of Binaries

- Visual: Stars orbit each other, but they are far enough apart to be resolved individually
- Spectroscopic: Stars are too far/too close to be resolved independently; you know there is more than one because of the Doppler shift in the spectra
- Double-Line: Spectra from each star can be resolved separately
- Single Line: Cannot resolve separate spectra because one star is too faint; brighter spectrum reveals Doppler wobble
- Eclipsing: One star passes in front of the other; rare because the plane of the orbit has to edge-on as seen from Earth

Mass Determination

- Getting the period of orbit is not that hard
- It's the actual separation that's more difficult to determine
- Mass function: Sometimes the best you can do is determine a limit, or relationship; individual masses cannot be determined

Mass and Other Stellar Properties

- Once you start to mass some stars accurately, it gets easier to extrapolate
- Correlate temperatures, luminosities, radii to masses: Put everything together
- Stellar lifetime related to mass and luminosity: More mass to burn, longer life (but high luminosity means the star is burning fuel faster, so shortens lifespan)
- lifetime $\propto$ mass/luminosity