ASTR 400/700: Stellar Astrophysics

Stephen Kane
Exams and homework

• The mid-terms and final exams are closed book and held in class. I will provide an equation sheet.

• Mid-term will cover everything up to and including Lecture 13 (the Sun). Final will cover everything!

• Graduate students will present a ~20 minute seminar on a stellar astrophysics related topic during last week of class. Proposed topic must be submitted by the mid-term exam. PDFs of presentations must be submitted to me (via email) by December 3.
Upcoming schedule

- Sep 24: Spectrographs and instrumentation
- Sep 29 / Oct 1: Solar atmosphere/interior
- Oct 6: Solar luminosity – climate change
- Oct 8: Mid-term
- Stellar atmospheres/interiors
Flowchart of Key Stellar Parameters

- Parallax \((p)\)
  \[d = \frac{1}{p}\]
  Distance \((d)\)
  \[L = 4\pi d^2 b\]
  Luminosity \((L)\)
  \[L = 4\pi R^2 \sigma T^4\]
  Radius \((R)\)

- Apparent brightness \((b)\)

- Spectrum
  - Spectral type
  - Surface temperature \((T)\)
  - Chemical composition
The story so far

- Distances
- Radial velocity
- Proper motion & tangential velocity
- Flux – distance – luminosity
- Apparent magnitudes
- Absolute magnitudes
- Spectral types
- Ionization vs temperature
- Diameters of stars
- Masses of stars
- Spectroscopic binaries
- Mass-luminosity relationship

The Hertzsprung-Russell diagram can visualize all of these things
The spectral class of a star is directly related to its surface temperature.

- O stars are the hottest
- M stars are the coolest
Russell’s 1914 Nature article describing his color-magnitude diagram
Stefan-Boltzmann Law:

\[
L = 4\pi R^2 \sigma T^4
\]

\[
R = \frac{1}{T^2} \sqrt{\frac{L}{4\pi \sigma}}
\]

If star A and star B have the same surface temperature, but star A is 100 times more luminous than the other, then how do the radii of stars A and B compare?
Spectroscopic Parallax

Recall:

\[ dist(pc) = \frac{1}{\text{parallax (arc sec)}} \]

\[ dist(pc) = 10^{(m-M+5)/5} \]

Uncertainty of +/- 1 magnitude leads to the distance being uncertain by a factor of \(10^{1/5} = 1.6\).
Stellar mass is one of the most fundamental parameters. More massive stars have stronger gravitational pressure, more fusion rxn’s, higher temperatures, greater luminosity.

Appendix G (textbook) lists stellar masses and radii as a function of spectral type.

With the stellar mass and radius, you can calculate density, but first guess!

- the density of rocky material (earth) is about 5 g cm$^{-3}$
- the density of water is 1 g cm$^{-3}$

What do you think the density of stars might be?

Do you think high mass (main sequence) stars will have higher or lower density than the lower mass stars?
Average density of stars:

The Sun (G2V):
\[ \bar{\rho} = \frac{M_{\text{sun}}}{\frac{4}{3} \pi R_{\text{sun}}^3} = 1.4 \text{ g cm}^{-3} \]

Sirius (A1V):
\[ \bar{\rho} = \frac{M_{\text{Sirius}}}{\frac{4}{3} \pi R_{\text{Sirius}}^3} = 0.76 \text{ g cm}^{-3} \]

Betelgeuse (M2I):
\[ \bar{\rho} = \frac{M_{\text{Bet}}}{\frac{4}{3} \pi R_{\text{Bet}}^3} = 10^{-11} \text{ g cm}^{-3} \]

Betelgeuse has an average density that is 100,000 times less dense than the air we breathe!
By carefully examining a star’s spectral lines, astronomers can determine whether that star is a main-sequence star, giant, supergiant, or white dwarf.

(a) A supergiant star has a low-density, low-pressure atmosphere: its spectrum has narrow absorption lines.

(b) A main-sequence star has a denser, higher-pressure atmosphere: its spectrum has broad absorption lines.
The Brightest Stars

Of the 20 brightest, only 6 are within 10 pc of the Sun. The vast majority of nearby stars, those less luminous than the Sun, do not send enough light across interstellar distances to be seen without optical aid.
The Nearest Stars

Only 3 of the 43 nearest stars (other than the Sun) are among the 20 brightest stars: Sirius, Alpha Centauri, and Procyon. The nearby stars also tend to have large proper motions. Also interesting is that 13 of the 44 stars are really binary- or multiple-star systems. Total of 59 stars within 5 pc.
The Nearest Stars

The most important datum is that **most nearby stars are intrinsically faint**.

Only 10 of the 50 nearest stars are visible to the unaided eye.

Only 3 are as intrinsically luminous as the Sun.

43 have luminosities less than 0.01 solar.

If the stars in our immediate stellar neighborhood are representative of the stellar population in general, we must conclude that the most numerous stars are those of low luminosity. In this sample, only about 1 star in 20 is as luminous as the Sun. (90% are main sequence; 10% are white dwarfs)
Brown Dwarfs

- A brown dwarf is not a star, nor a planet, but is in between.
- Classified as L, T, or Y (cooler than M stars).
- Glow in the infrared due to internal heat from gravitational contraction.
- Over 1,000 have been found since the mid-1990s.