Hertzprung-Russell Diagram

- Hertzprung and Russell found a correlation between luminosity and spectral type (temperature)

![Diagram showing Hertzprung-Russell Diagram with luminosity on the y-axis and spectral type on the x-axis. The diagram illustrates a line connecting cool, dim stars to hot, bright stars, with the Sun situated on the main sequence.]
• Most stars (~90%) are on the main sequence
  – The greater the temperature, the more luminous the star
  – M type stars are the most common.
  – O type stars are the least common.
Sizes of Stars

• Size of star is related to the temperature and the luminosity by:

\[ \text{Luminosity} \propto \text{Temperature}^4 \times \text{Radius}^2 \]

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

– If you know the position on HR diagram you know the size of the star.
Supergiants

Giants

White Dwarfs

Main Sequence

Luminosity (Solar units)

hot
O B A F G K M cooler

hot, bright stars

100\(R_\odot\)

10\(R_\odot\)

1\(R_\odot\)

0.1\(R_\odot\)

0.01\(R_\odot\)

0.0001\(R_\odot\)

Sun

Cool, dim stars
Mira is _____ than Barnard’s star because it is ______.

A. hotter … larger
B. smaller … more luminous
C. more luminous … larger
D. more luminous … hotter
• **Supergiants** -- cool, bright, red, large stars
• **Giants** -- cool, bright red, less large stars
• **Main Sequence** -- spans range from hot, bright stars to cool, dim stars.
• **White dwarfs** -- hot, small, dim stars.

• These classifications will give clues to stages in the evolution of stars.
Stars come in many sizes!
Sizes of Objects in our Universe

Images from webisto.com/space
Sizes of Objects in our Universe
Sizes of Objects in our Universe

- Sun
- Jupiter
- Earth
- Pluto
Sizes of Objects in our Universe

Sun: Jupiter is about 1 pixel in size
Sirius
Pollux
Arcturus: Earth is invisible at this scale
Sizes of Objects in our Universe

Betelgeuse

Antares

Jupiter is invisible at this scale

Sun (1 pixel)

Sirius

Pollux

Arcturus

Rigel

Aldebaran
A star has a high luminosity (100 solar luminosities) and a surface temperature of 3500 K. What type of star is it?

A. A high mass–main sequence star
B. A low mass–main sequence star
C. A red giant
D. A white dwarf
Masses of Stars

• We cannot directly measure the mass of an isolated star.

• If something is orbiting the star, can use the general form of Kepler’s Third Law

\[(M_1 + M_2)P^2 = a^3\]

• Luckily, 2/3 of all stars are binary stars, two stars that orbit one another
A binary star consists of two identical stars orbiting each other. If the semimajor axis of the orbit is 4 AU and orbit period is 4 years, how massive is each star?

A. $4M_\odot$
B. $2M_\odot$
C. $1M_\odot$
D. $0.5M_\odot$
A binary star consists of two identical stars orbiting each other. If the semimajor axis of the orbit is 4 AU and orbit period is 4 years, how massive is each star?

A. \(4 M_\odot\)  \( (M_1 + M_2)P^2 = a^3 \)

B. \(2 M_\odot\)

\( (2M) = \frac{a^3}{P^2} \)

C. \(1 M_\odot\)

D. \(0.5 M_\odot\)

\[ M = \frac{a^3}{2P^2} = \frac{(4 \text{ AU})^3}{2(4 \text{ yr})^2} = 2 M_\odot \]
Mass-Luminosity Relation

- True ONLY for Main Sequence stars
- As the mass increases, the luminosity increases rapidly

Luminosity $\propto$ Mass$^3$
HR Diagram: Main sequence stars labeled by mass in units of solar masses.
H-R Diagram summary
Fig. 12-10b
p. 317

Interactive Figure
Apparent Brightness

- The brightness an object appears to have.
- The further away the object, the dimmer it looks

\[
\text{Apparent Brightness} = \frac{\text{Luminosity}}{4\pi d^2} \quad d = \text{distance}
\]
Main-Sequence Fitting (see p. 411)
(Spectroscopic Parallax)

• If luminosity and apparent brightness are known, distance can be determined.

\[ m - M = 5 \log d - 5 \]

• Difficult to accurately measure luminosity for one star
  – Use spectra to get spectral type and class

• Alternatively, we can use a cluster of stars

• Distance to the cluster can be determined by comparing the HR diagram of the cluster with a template HR diagram
Main-Sequence Fitting

Observations

Apparent Brightness (arbitrary units)

hot O B A F G K M cooler

Template

Luminosity (Solar units)

0.0001 0.01 1 100 10000

hot O B A F G K M cooler
Main-Sequence Fitting

Luminosity (Solar units) vs. Stellar Type

- Hot: O, B, A, F, G, K, M
- Cooler: Stars plotted on the graph

The graph shows the relationship between luminosity (on a logarithmic scale) and stellar type (O, B, A, F, G, K, M), illustrating the main-sequence fitting of stars.
The Distance Ladder

• See also Figure 16.17 on p. 416

• First rung: parallax

• Second rung: spectroscopic parallax, or “main-sequence fitting”

• Third rung: standard candles/inverse square law (Cepheids supernovae)

• Fourth rung: Hubble’s Law
The Distance Ladder (see p. 415)

We will be discussing the longer distance “rungs” of the ladder in subsequent lectures.

Figure 26.12, Freedman and Kaufmann, 7th ed. Universe, © 2005 W. H. Freeman & Company
The Distance Chain

Fig. 16.17 p.416