We can determine **temperature, power emitted (luminosity), distance, lifetimes, ages** and **metal abundances** of stars by measuring their flux in two different wavelengths (e.g. Blue and “Visible”; Blue and IR, Red and IR, UV and Red etc...).
HR Diagram is a plot of brightness or flux from one band against the “color” of the star(s). Color is the ratio of fluxes in two wavelengths (B-V, V-R, etc). How your data falls on this plot will determine stellar age, lifetime, etc.
HR diagrams

Hyades Cluster
Underlying physics model of main sequence (MS) stars
Physics: Why this works

Stars are blackbodies; light is emitted in a distinct pattern of radiation for a given temperature.

\[ B_\nu(T) = \frac{2\hbar\nu^3}{c^2} \frac{1}{e^{\hbar\nu/kT} - 1} \]
White lines are filter bandpasses. Different amounts of flux are emitted in each band for a given temperature.

Flux is the amount of radiation we receive at Earth ($\sim$Luminosity/distance$^2$).
Mass and Temperature

• What determines MS stellar surface temperature?
  ➔ Mass

• Each layer in star is in balance between gravity pressing down and pressure generated from core.

• More massive stars need more pressure generated to support star which comes from hot photons generated by nuclear reactions in core (fusion of hydrogen into helium)

• Result – big stars have hotter surface temperature and emit more photons.

• Other than these physics equations, how do we know that hotter stars are more massive?
Luminosity and Mass Relationship

Masses are measured from MS binary stars and Kepler’s 3\textsuperscript{rd} law \((M_1+M_2)\sim a^3/p^2\)
Implications of Luminosity and Mass Relationship

Lifetime of star is simply:

\[ \text{Lifetime} = \text{fuel/power output} \]

\[ \text{Lifetime} \sim \frac{\text{M}}{\text{L}} \]

In solar units this is:

\[ \frac{\text{M}}{\text{L}} \times 10^{10} \text{ years} \]

more massive stars are first to “die”
Stellar Clusters as Laboratories

• Stars are “born” from a collapsed molecular cloud of gas. Several stars are created at once, not one at a time.

• Stars still gravitationally bound to their “siblings” are part of a cluster

• Clusters are ideal to study:
  – Stars are the same age
  – Same initial chemical composition
  – same distance to Earth
Age of Clusters

• Bigger MS stars die* first. Knowing lifetimes of stars we can determine age of a cluster.

• Dead stars expand and redden in color (surface temperature cools)

*die means stars fuse most of their core hydrogen into helium. Star evolves to next stage
From luminosity we find mass and lifetime.
Lab 2: Measuring Flux

- “Count” the number of photons of star in a small aperture on image.
- Subtract the background sky
- = brightness or flux of star.
Flux is converted to **magnitudes**

- **Apparent magnitude:**
  \[ m = -2.5 \log_{10}(F) + \text{const.} \]

- Can be written as \( m \), \( m_{\text{filter}} \) (e.g. \( m_B \)) or filter abbreviation (e.g. B, V or R)

- **Absolute magnitude:** Flux measured at 10pc away from object (\( F = \frac{L}{d^2} \))
  \[ M = -2.5 \log_{10}(L) + 5 + \text{const.} \]

- Can be written as \( M_{\text{filter}} \) (e.g. \( M_B \)) or filter abbreviation (e.g. B, V or R)
<table>
<thead>
<tr>
<th>Object</th>
<th>Apparent Magnitude (V)</th>
<th>Absolute Magnitude (V)</th>
<th>B-V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>-27</td>
<td>4.8</td>
<td>0.6</td>
</tr>
<tr>
<td>Moon</td>
<td>-12.5</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Venus</td>
<td>-5</td>
<td>-</td>
<td>-</td>
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<td>1.42</td>
<td>0</td>
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<td>VY Canis Majoris</td>
<td>8</td>
<td>-9.4</td>
<td>2.24</td>
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<tr>
<td>Rigel</td>
<td>0.12</td>
<td>-6.69</td>
<td>-0.13</td>
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<tr>
<td>Naked Eye limit</td>
<td>6.5</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Andromeda Galaxy</td>
<td>3.44</td>
<td>-21.5</td>
<td>0.91</td>
</tr>
<tr>
<td>Most distant galaxy found</td>
<td>29 (in red filter)</td>
<td>??</td>
<td>??</td>
</tr>
</tbody>
</table>
Lab 2: Signal to Noise

• Read discussion in lab, based on poisson statistics. Uncertainty $\sim N^{1/2}$ where $N$ is the number of photons

• Conceptually, sky subtracted flux must be larger than the spread in noise of the background signal
Finding Distance

Sun: B-V=0.6
B-V is independent of distance. $M_V = +4.8$

Flux that we measure from Earth is apparent magnitude →

"Distance modulus" $m-M=-5\log(d) -5$
Finding Age

Compare the apparent magnitude of the most massive star to a sun-like star in the cluster:

Both stars are at the same distance, so you can directly compare their luminosities.