Stellar Phenomenology and Stellar Properties

- Stellar spectral classification
- Hertzsprung-Russel and color-magnitude diagrams
- Fundamental stellar properties, observables
- Stellar population properties
Spectral Classification: Temperature

infrared spectra

visible spectra
## Spectral Classification: Temperature

<table>
<thead>
<tr>
<th>Spectral Type</th>
<th>Atmospheric Temperature (K)</th>
<th>Hydrogen (Balmer) Features</th>
<th>Other Features</th>
<th>(M/M_\odot)</th>
<th>(R/R_\odot)</th>
<th>(L/L_\odot)</th>
<th>Main Sequence Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>&gt;33,000 K</td>
<td>weak</td>
<td>Ionized Helium (He(^+)) features sometimes in emission Strong UV continuum</td>
<td>20-60</td>
<td>9-15</td>
<td>90,000-800,000</td>
<td>10-1 Myr</td>
</tr>
<tr>
<td>B</td>
<td>10,500-30,000 K</td>
<td>medium</td>
<td>Neutral He absorption</td>
<td>3-18</td>
<td>3.0-8.4</td>
<td>95-52,000</td>
<td>400-11 Myr</td>
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<tr>
<td>A</td>
<td>7,500-10,000 K</td>
<td>strong</td>
<td>H features maximum at A0 Some features of heavy elements, e.g. Ca(^+)</td>
<td>2.0-3.0</td>
<td>1.7-2.7</td>
<td>8-55</td>
<td>3 Gyr - 440 Myr</td>
</tr>
<tr>
<td>F</td>
<td>6,000-7,200 K</td>
<td>medium</td>
<td>Weak Ca(^+)</td>
<td>1.1-1.6</td>
<td>1.2-1.6</td>
<td>2.0-6.5</td>
<td>7-3 Gy</td>
</tr>
<tr>
<td>G</td>
<td>5,500-6,000 K</td>
<td>weak</td>
<td>Ca(^+) H&amp;K, Na &quot;D&quot; Sun is G2V</td>
<td>0.9-1.05</td>
<td>0.85-1.1</td>
<td>0.66-1.5</td>
<td>15-8 Gy</td>
</tr>
<tr>
<td>K</td>
<td>4,000-5,250 K</td>
<td>v. weak</td>
<td>Ca(^+), Fe, Strong molecules, e.g. CH(_3), CN</td>
<td>0.6-0.8</td>
<td>0.65-0.80</td>
<td>0.10-0.42</td>
<td>17 Gy</td>
</tr>
<tr>
<td>M</td>
<td>2,600-3,850 K</td>
<td>v. weak</td>
<td>Molecules, e.g. TiO Very red continuum</td>
<td>0.08-0.5</td>
<td>0.17-0.63</td>
<td>0.001-0.08</td>
<td>56 Gy</td>
</tr>
<tr>
<td>L</td>
<td>1,400–2,500 K</td>
<td>none</td>
<td>Molecules: H(_2)O, hydrides reddest star-like objects</td>
<td>&lt;0.08</td>
<td>~ 0.1</td>
<td>10^{-5}–10^{-3}</td>
<td>&gt;100 Gyr</td>
</tr>
<tr>
<td>T</td>
<td>400–1,400 K</td>
<td>none</td>
<td>Molecules: H(_2)O, CH(_4)</td>
<td>&lt;0.08</td>
<td>~ 0.1</td>
<td>10^{-6}–10^{-5}</td>
<td>N/A</td>
</tr>
<tr>
<td>Y</td>
<td>&lt;400 K</td>
<td>none</td>
<td>Molecules: H(_2)O, CH(_4), NH(_3)</td>
<td>&lt;0.08</td>
<td>~ 0.1</td>
<td>&lt;10^{-6}</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Stellar Classification: Temperature

- Sun: ~5700 K
- M dwarf: ~3500 K
- L dwarf: ~2000 K
- T dwarf: ~1000 K
- Brown dwarfs
- Planets: Jupiter (160 K)

(G dwarf)
Spectral Classification: Luminosity

• luminosity, radius, surface gravity, and surface pressure are mutually related
  \[ L = 4\pi R^2 \sigma T_{\text{eff}}^4, \quad g = GM/R^2, \quad P = \rho gl \] (\( l \) is photon m.f.p.)

• define “luminosity spectral class”
  
  V: dwarfs, \( \log g \sim 4.5 \) [cgs units]
  
  IV: subgiants, \( \log g \sim 3 \) (approximately as on Earth)
  
  III: giants, \( \log g \sim 1.5 \)
  
  II: (bright) giants, \( \log g \sim 0.5 \)
  
  I: supergiants, \( \log g \sim -0.5 \)

• Sun: G2 V star (\( T_{\text{eff}} = 5777K, \log g = 4.43 \))
Luminosity Effects at A0

(figure from D. Gray)
Hertzsprung-Russell (H-R) Diagram

- \( \log L \) vs. \( \log T_{\text{eff}} \)

- main sequence:
  - locus of most stars
  - bulk of stellar lifetimes
  - \( L \propto M^{3.8} \)
  - \( \tau_{\text{MS}} \approx 10^{10} \text{ yr } (M/M_{\odot})^{-2.8} \)
Color-Magnitude Diagram (CMD)

- proxy for the \((T_{\text{eff}}-L)\) Hertzsprung-Russell diagram
- e.g., \(B-V\) vs. \(M_V\), \(J-K\) vs. \(M_K\), etc.
Stellar Abundances

- derived from spectral lines
- compared to the Sun or to abundance of hydrogen (H) in star—or both
- a.k.a., “metallicity”
- “metal-poor” stars, a.k.a. “subdwarfs” are hotter than dwarfs of same luminosity

\[
[\text{Fe/H}] = \log \left( \frac{n(\text{Fe})}{n(H)} \right) - \log \left( \frac{n(\text{Fe})}{n(H)} \right)_{\text{Sun}}
\]
Stellar Populations

- Population I:
  - low galactic scale heights, rotate with galactic disk, similar composition to Sun

- Population II:
  - large scale heights, high space velocities, low mass: *old stars*
Star Clusters

- globular clusters (e.g., M80): Pop II stars, gravitationally bound, dense
- open clusters (e.g., Pleiades): Pop I stars, gravitationally bound, < 2 Gyr
- “O-B” associations: loose, not gravitationally bound, < 20 Myr
Stellar Phenomenology and Properties

- Stellar spectral classification
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- **Fundamental stellar properties, observables**
- Stellar population properties
Spectroscopic Binary

- **double-lined (SB2)**
  - spectra of both stars visible

- **single-lined (SB1)**
  - only spectrum of brighter star visible

(a)  
(b)  
(c)  
(d)
Radial Velocity vs. Time for Double-lined SB in a Circular Orbit

(a) Diagram showing the relative positions of the stars in orbit, with velocities $v_1$, $v_2$, and $v_{cm}$.

(b) Graph showing the radial velocity over time, with $v_1$, $v_2$, and $v_{cm}$ as functions of $t/P$. The graph ranges from $-40$ to $120$ km s$^{-1}$ on the y-axis and $0.0$ to $1.0$ on the x-axis.
Totally Eclipsing Binaries

$t_a$ – start of secondary ingress
$t_b$ – end of secondary ingress
$t_c$ – start of secondary egress
$t_d$ – end of secondary egress

Time
Luminosity-mass relation for binary stars with well-determined orbits

Data from Popper (1980; ARA&A 18, 115)
Radius-mass relation for binary stars with well-determined orbits

Compiled by Malkov (1993), based mostly on work over many decades by Popper.
Temperature-mass relation for binary stars with well-determined orbits

Compiled by Malkov (1993), based mostly on work over many decades by Popper.
Mass vs. $T_{\text{eff}}$

Effective temperature vs. dynamical mass for main sequence stars from Malkov (2007) and Hillenbrand & White (2004)

$\log(M/M_{\odot}) = a_0 + a_1 \times \log T_{\text{eff}}$

- $a_0 = -8.445396e1$
- $a_1 = +6.094505e1$
- $a_2 = -1.489638e1$
- $a_3 = +1.240992e0$

(3.523 < $\log T_{\text{eff}}$ < 4.613)
Taking the Stellar Temperature

- \((\text{Fe II} \ \lambda 5317 / \text{Fe I} \ \lambda 5328)\) line ratio decreases with decreasing \(T_{\text{eff}}\)
Energy Generation: p-p Chain
Initial Mass Function

- $\xi_L \equiv \frac{dN}{d \log M/M_{\text{Sun}}} \propto (M/M_{\text{Sun}})^{-\Gamma}$
- $\xi \equiv \frac{dN}{d (M/M_{\text{Sun}})} \propto (M/M_{\text{Sun}})^{-\alpha}$
- slope $\Gamma \equiv \alpha + 1$
• lower mass stars are more commonly single

Single Star Fraction

Lada (2006)