7 — Spectral Classification & the HRD [$Revision: 1.2$]

- Harvard System
  - Divide stars up into differing **spectral types**, according to strengths of different absorption lines
  - Originally alphabetical sequence
    - Devised by Pickering & Fleming
    - Based on strength of Balmer hydrogen lines
      - Balmer series formed by transition from $n = 2$ to $n = 3, 4, 5, \ldots$
      - Greek letters $n = 2 \rightarrow 3$ is Hα (or Balmer α), $n = 2 \rightarrow 4$ is Hβ, etc.
      - Useful because all located in visible part of spectrum
    - Strongest Balmer lines $\longrightarrow$ A-type, weakest $\longrightarrow$ Q-type
    - Completely empirical
  - Antonia Maury & then Annie Jump Cannon (also 'Harvard Computers') updated sequence
    - Eliminated some types
    - Reordered sequence (OBAFGKM — 'oh be a fine girl/guy, kiss me')
    - Introduced decimal subtypes (e.g., A0-A9)
    - Basis of the **Harvard System**
    - Led to **Henry Draper catalog** ('HD' numbers)
  - Cecilia Payne-Gaposchkin (another Computer) showed different spectra types due to different surface temperatures
    - Consequence of **ionization** (Saha equation); affects how many atoms are in lower stage of line transition
    - **Temperature calibration**: type $\longrightarrow$ effective temperature T_{eff}
    - Abundances of most stars are similar (and mostly hydrogen)
  - 'Roman numeral' notation for ionization stage: I = neutral, II = singly ionized, III = doubly ionized, etc
  - Jargon: all elements apart from H & He known as **metals**
  - Principal features of spectral types (see also O&C, table 8.1), from hot to cool:
    - **O-type** — Strongest He II lines
    - **B-type** — Strongest He I lines
    - **A-type** — Strongest Balmer lines
    - **F-type** — Weakening Balmer lines, strengthening Ca II & neutral metal lines
    - **G-type** — Weak Balmer lines, strengthening Ca II & neutral metal lines
    - **K-type** — Strongest Ca II & neutral metal lines
    - **M-type** — Molecular absorption bands, esp. TiO & VO
    - **L-type, T-type** — more recent, various molecules (CO, CH_4, H_2O)
- Hertzsprung-Russell diagram
  - Observe and classify many stars
  - Plot stars in diagram with Harvard spectral type on x-axis, absolute magnitude (from apparent magnitude & distance) on y-axis — **Hertzsprung-Russell diagram** (HRD)
  - Most important concept in stellar astrophysics!

- Find that most stars are **dwarfs**, lying on diagonal strip — the **main sequence**
- Some stars lie above main sequence — **giants** and **supergiants**
- Some stars lie below main sequence — **subdwarfs** and **white dwarfs**
- Use models to create theoretician's HRD
  * spectral type $\longrightarrow T_{\rm eff}$ (note: highest $T_{\rm eff}$ on left, lowest $T_{\rm eff}$ on right!)
  * absolute magnitude $\longrightarrow L$
  * plot $\log_{10} T_{\rm eff}$ against $\log_{10} L$
- Since

  $$L = 4\pi R^2 \sigma T_{\rm eff}^4,$$

  each point in HRD has unique radius

  $$R = \sqrt{\frac{L}{4\pi\sigma T_{\rm eff}^4}}$$

- Lines of constant R are diagonals intersecting main sequence (higher $T_{\rm eff}$ on main sequence $\leftrightarrow$ larger R)
- Supergiants and giants bigger/more luminous than dwarfs of same $T_{\rm eff}$ — hence the name

• Morgan-Keenan System

- Problem: to construct HRD, need to know distance to find absolute magnitude and/or lumunosity
- Morgan & Keenan found luminosity can be judged instead from **line widths**
- Full MK spectral type is Harvard type with **luminosity class** appended
- In order of decreasing luminosity: **Ia** — luminous supergiants; **Ib** — less-luminous supergiants; **II** — bright giants; **III** — giants; **IV** — subgiants; **V** — dwarfs; **VI** — subdwarfs
- Line widths depend on surface gravity

  $$g = \frac{GM}{R^2}$$

  because gravity affects how dense photosphere is, and thus how much **line broadening** occurs
- With MK classification, we know $T_{\rm eff}$ and L, and can determine distance — **spectroscopic parallax**

• Color-magnitude diagrams

- For cluster of many stars (1,000's more more), very laborious to find MK type of each one
- Use alternative form of HRD based on Johnson system photometry:
  * Measure B and V magnitudes (correct for reddening)
  * plot $B - V$ color on x-axis, V magnitude on y-axis
- All stars at same distance, so V differs from absolute magnitude M_V by fixed amount:

  $$V - M_v = 5 \log_{10} \frac{d}{10\,{\rm pc}}$$

  where d the same for all stars
- Calibrate main sequence from nearby stars: M_V as a function of $B - V$
- Use M_V calibration and V observations to find cluster distance
- Complication: part of main sequence missing for some clusters!
  * Consequence of hotter stars evolving faster
  * Turn-off is measure of cluster age