4 — Colors & Spectra [*Revision* : 1.3]

- Colors
  - Reminder: bolometric magnitude measures total flux

$$m = -2.5 \log_{10} F + C = -2.5 \log_{10} \int_0^\infty F_\lambda \, \mathrm{d}\lambda + C$$

  - Also can use **photometric filter** to measure flux in specific **passband**:

$$m_X = -2.5 \log_{10} F_X + C_X = -2.5 \log_{10} \int_0^\infty \mathcal{S}_X(\lambda) F_\lambda \, \mathrm{d}\lambda + C_X$$

    (X represents passband label or name)
  - $\mathcal{S}_X(\lambda)$ is **sensitivity function** — fraction of light transmitted at wavelength λ. Depends on filter, telescope optical, detector & atmosphere
  - Bolometric magnitude corresponds to complete transmission: $\mathcal{S}_{\mathrm{bol}}(\lambda) = 1$
  - Standardized collection of filters makes up **photometric system**
  - Most common system is **Johnson system**:
    * U-band (3650 Å ± 340 Å) — ultraviolet
    * B-band (4400 Å ± 490 Å) — blue
    * V-band (5500 Å ± 445 Å) — visual

    ...defined by 2 aluminum mirrors, 1p21 photomultiplier tube, filters & (for U-band) atmospheric transmission (see
  - m_U, m_B, m_V ('color magnitudes' or 'photometric indices') often written as U, B, V (similarly with other systems)
  - C_U, C_B, C_V originally chosen so that Vega & similar stars have (U, B, V) close to zero
  - Visual magnitude related to bolometric magnitude by *bolometric correction*:

$$BC = m - V = M - M_V$$

    (sometimes m written as m_{bol}, M as M_{bol}).
  - BC depends primarily on effective temperature T_{eff} of star (look it up in table)
  - **Photometric colors** are differences between magnitudes in passbands; e.g.,

$$U - B = -2.5 \log_{10} F_U - C_U + 2.5 \log_{10} F_V + C_V = -2.5 \log_{10} \frac{F_U}{F_B} + C_{UV}$$

  - Colors give approximate information about shape of star's spectrum; location on BB curve $\longrightarrow$ temperature
  - More negative colors $\longrightarrow$ bluer spectrum
  - Important: photometric indices affected by absorption in interstellar medium (**extinction**)
  - Extinction more pronounced in bluer passbands $\longrightarrow$ **interstellar reddening**
- Spectrum
  - Use a **spectrograph** to measure F_λ
    * Diffraction grating sends light into different directions depending on wavelength λ
    * Split light is recorded on photographic plate / photomultipliers / CCD

    * Spectrograph characterized by **resolving power** $\lambda/\Delta\lambda$ ($\Delta\lambda$ is smallest difference in wavelength measurable)
- General features of optical stellar spectra (see Fig. 9.5 of O&C):
    * Smoothly-varying **continuum**
    * Sharp **absorption lines**
    * Abrupt **absorption edges** (mainly, hot stars)
- Understand features in terms of **Kirchhoff's laws**:
    * Hot, dense gas produces featureless continuum (similar to BB)
    * Hot, diffuse gas produces bright emission lines
    * Cool(er) diffuse gas in front of continuum source produces dark absorption lines
- General picture of stellar surface: **atmosphere** with hot, dense gas lower down, overlaid by cooler, low-density gas
- Each spectral line formed by specific element in specific state of excitation, ionization (e.g., 'Hα' line at 6563 Å due to absorption by neutral hydrogen in $n = 2$ excited state)
- Use measurements of line strengths & shapes to determine atmosphere structure
- Also, use measurements of line wavelengths to determine **radial velocity** of star

$$\frac{\lambda_{\rm obs} - \lambda_{\rm rest}}{\lambda_{\rm rest}} = \frac{\Delta\lambda}{\lambda_{\rm rest}} = \frac{v_r}{c}$$

  (Doppler effect, assuming $v_r \ll c$). Especially useful for binary stars (next lecture)