4 — Colors & Spectra [Revision : 1.3]

• Colors
  
  - Reminder: bolometric magnitude measures total flux
    \[ m = -2.5 \log_{10} F + C = -2.5 \log_{10} \int_0^\infty F_\lambda \, d\lambda + C \]
  
  - Also can use **photometric filter** to measure flux in specific passband:
    \[ m_X = -2.5 \log_{10} F_X + C_X = -2.5 \log_{10} \int_0^\infty S_X(\lambda) F_\lambda \, d\lambda + C_X \]
    
    (\( X \) represents passband label or name)
  
  - \( S_X(\lambda) \) is **sensitivity function** — fraction of light transmitted at wavelength \( \lambda \). Depends on filter, telescope optical, detector & atmosphere
  
  - Bolometric magnitude corresponds to complete transmission: \( S_{\text{bol}}(\lambda) = 1 \)
  
  - 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 \( m_{\text{bol}}, M \) as \( M_{\text{bol}} \)).
  
  - \( BC \) depends primarily on effective temperature \( T_{\text{eff}} \) 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 \( F_\lambda \)
    
    * Diffraction grating sends light into different directions depending on wavelength \( \lambda \)
    
    * 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

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

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