HW1: Filters & Photometry

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Problem 1: Effective Wavelengths of Filters

Approach.

- Read each filter file.
- Infer wavelength units from scale (treat as μm or nm when appropriate) and convert to Å.
- Clean non-finite/negative rows, sort by wavelength, normalize transmission to unit peak.
- Compute $\lambda_{\rm eff}$ with logarithmic weighting.

Key formula. (Throughput $s(\lambda)$; log-weighted mean)

$$\lambda_{\rm eff} = \exp\left(\frac{\int s(\lambda)\, \ln\lambda \, d\ln\lambda}{\int s(\lambda)\, d\ln\lambda} \right), \qquad d\ln\lambda \equiv \frac{d\lambda}{\lambda}.$$

Output.

- **CSV:** `Problem1/effectivewavelengths.csv` (filter, file, $\lambda_{\rm eff}$ in Å and μm, detected units/format).

Problem 2: Vega→AB Corrections

Approach.

- Reuse the Problem 1 filter parser (units→Å, clean, sort).
- Load Vega, convert to (ν, f_ν) if needed.
- Interpolate f_ν onto each filter's ν-grid; compute $\langle f_\nu \rangle$ (log-ν weighting), then $m_{\rm AB}$(Vega).
- Merge Vega→AB offsets with the Problem 1 table by band stem (e.g., `V_Maiz`→V).

Key formulas.

$$\nu = \frac{c}{\lambda}, \qquad f_\nu = f_\lambda \, \frac{\lambda^2}{c} \quad \big(c = 2.997\,924\,58\text{e}10\,\mathrm{cm\,s^{-1}},\ \lambda \text{ in cm}\big),$$

$$\langle f_\nu \rangle = \frac{\int S(\nu)\, f_\nu(\nu)\, d\ln\nu}{\int S(\nu)\, d\ln\nu}, \qquad m_{\rm AB}(\text{Vega}) = -2.5\log_{10}\big(\langle f_\nu \rangle\big) - 48.60.$$

Output.

- **CSV:** `Problem2/EffectiveWavelengths_VegaABMag.csv` (adds $m_{\rm AB}$(Vega) per filter).

Problem 3: AB Absolute Magnitudes (U,B,V) & Colors

Approach.

- With Pickles (1998) templates, compute $m_{\rm AB}$ in U, B, V via photon-counting weights; form $U-B$ and $B-V$.
- Filters normalized to unit peak; also produce a quick $U/B/V$ sanity plot.
- Absolute magnitudes assume spectra are absolute SEDs at 10 pc; otherwise, colors remain robust.

Key formulas.

$$f_\nu(\lambda) = f_\lambda(\lambda)\,\frac{\lambda^2}{c}, \qquad \langle f_\nu \rangle = \frac{\int f_\nu(\lambda)\,S(\lambda)\,\lambda\,d\ln\lambda}{\int S(\lambda)\,\lambda\,d\ln\lambda},$$

$$m_{\rm AB,X} = -2.5\log_{10}\left(\frac{\langle f_\nu\rangle}{f_{\nu,0}}\right), \quad f_{\nu,0} = 3.631\text{e}{-20}\,\text{erg}\,\text{s}^{-1}\,\text{cm}^{-2}\,\text{Hz}^{-1},$$

$$(U-B) = m_{\rm AB,U} - m_{\rm AB,B}, \qquad (B-V) = m_{\rm AB,B} - m_{\rm AB,V}.$$

(If a spectrum is at distance $d_{\rm pc}$, rescale flux by $(d_{\rm pc}/10)^2$ before evaluating $m_{\rm AB}$.)

Outputs.

- **Tables:** `templates/pickles_stars/Table_with_AB_UBV.dat` (tab) and `Problem3/Table_with_AB_UBV.csv` (CSV) with $M_U, M_B, M_V, U-B, B-V$.
- **Figure:** `Problem3/filters_UBV.png` (normalized $U/B/V$ passbands).

Problem 4: H–R Diagrams (Pickles 1998) + Sun

Approach.

- Load `templates/pickles_stars/Table_with_AB_UBV.dat`; coerce Teff, M_V, $B-V$ to numeric; compute $\log_{10} T_{\rm eff}$.
- Normalize luminosity classes to I, II, III, IV, V, D.
- Panel A: M_V vs. $\log_{10} T_{\rm eff}$ (invert y: bright at top; invert x: hot on left); add spectral-type ticks (O→M).
- Panel B: M_V vs. $B-V$ (invert y: bright at top).
- Style points by luminosity class; overplot the Sun (G5 V if present, else fallback $T_\odot = 5772$ K, $M_{V,\odot} = 4.83$, $B-V \approx 0.65$).

Key formulas.

$$\log_{10} T_{\rm eff} = \log_{10}\big(\text{Teff}/\text{K}\big), \qquad (B-V) = m_B - m_V \quad \text{(AB)}.$$

$$M_V = \begin{cases} m_V, & \text{if spectra are absolute at 10 pc,} \\ m_V - 5\log_{10}\big(d/10\,\text{pc}\big), & \text{otherwise.} \end{cases}$$

Output.

- **Figures:** `Problem4/HR1_Mv_vs_logTeff.png`, `Problem4/HR2_Mv_vs_BminusV.png`.

Problem 5: Color–Color ($U-B$ vs. $B-V$) + Blackbody Locus

Approach.

- Load `templates/pickles_stars/Table_with_AB_UBV.dat`; coerce Teff, $U-B$, $B-V$ to numeric and compute $\log_{10} T_{\mathrm{eff}}$.
- Read $U/B/V$ passbands (auto-detect units, convert to Å, clean, sort, normalize to unit peak).
- For each spectrum, compute m_{AB} in U, B, V via a photon-weighted band average of f_ν; form colors $U-B$ and $B-V$.
- Build a blackbody locus by evaluating $B_\lambda(T)$ on a dense λ-grid across many T, then computing $(U-B,\ B-V)$.
- Plot $(B-V,\ U-B)$ with points styled by luminosity class and colored by $\log_{10} T_{\mathrm{eff}}$; overlay the blackbody curve.

Key formulas.

$$f_\nu(\lambda) = f_\lambda(\lambda)\,\frac{\lambda^2}{c}, \qquad d\ln\lambda \equiv \frac{d\lambda}{\lambda}.$$

$$\langle f_\nu \rangle = \frac{\displaystyle\int f_\nu(\lambda)\,S(\lambda)\,\lambda\,d\ln\lambda}{\displaystyle\int S(\lambda)\,\lambda\,d\ln\lambda}, \qquad m_{\mathrm{AB,X}} = -2.5\log_{10}\left(\frac{\langle f_\nu\rangle}{f_{\nu,0}}\right).$$

$$(U-B) = m_U - m_B, \qquad (B-V) = m_B - m_V.$$

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5}\,\frac{1}{\exp\!\left(\frac{hc}{\lambda k_B T}\right) - 1}.$$

Output.

- **Figure:** `Problem5/ColorColor_UBvsBV_custom.png`.

Discussion (Problem 5). The $u-b$ vs. $b-v$ map shows the classic stellar track: hot, early-type stars (yellow) sit up/left and slide down/right toward cooler (purple) types. There's a sharp knee near $b-v \simeq 0$ (around A0) where the Balmer jump makes $u-b$ change quickly. Different luminosity classes follow similar paths but are offset vertically: lower gravity (giants/supergiants) tends to enhance the Balmer jump and other wavelength-dependent opacity, so at the same $b-v$ they appear redder in $u-b$ than dwarfs; white dwarfs cluster at the extreme blue end. The blackbody locus runs bluer in $u-b$ than real stars at cooler T_{eff} because real stellar atmospheres introduce extra, wavelength-dependent absorption in the near-UV/blue, which depresses the U-band more than B and shifts colors redward relative to a smooth blackbody. In general, the motion along the sequence mostly tracks T_{eff}, with the horizontal spread set mainly by intrinsic color/temperature (broadened by interstellar reddening) and the vertical spread reflecting surface gravity and overall composition.

Problem 6: Bolometric Corrections (U, V, K, AB system)

Approach.

- Load $U/V/K$ filter curves (auto-units→Å, clean, sort, normalize).
- Read Pickles spectra (λ, f_λ); clean, sort.
- For each star, compute $m_{\rm AB}$ in U, V, K using an energy–weighted band average in $\ln\lambda$.
- Compute the AB bolometric magnitude by integrating f_ν over $\ln\lambda$.
- Form $BC_X \equiv m_X - m_{\rm bol}$; plot BC_X vs. $\log_{10} T_{\rm eff}$ with class styling.

Key formulas.

$$f_\nu(\lambda) = f_\lambda(\lambda)\,\frac{\lambda^2}{c}, \qquad \langle f_\nu\rangle = \frac{\displaystyle\int f_\nu(\lambda)\,S(\lambda)\,d\ln\lambda}{\displaystyle\int S(\lambda)\,d\ln\lambda},$$

$$m_{\rm AB,X} = -2.5\log_{10}\big(\langle f_\nu\rangle\big) - 48.60, \qquad m_{\rm bol} = -2.5\log_{10}\left(\int f_\nu\,d\ln\lambda\right) - 48.60, \qquad BC_X \equiv m_X - m_{\rm bol}.$$

Outputs.

- **Table:** `Problem6/Table_with_BCs.dat` $(m_U, m_V, m_K, m_{\rm bol}, BC_U, BC_V, BC_K)$.
- **Figure:** `Problem6/BC_three_panel.png` (scatter by luminosity class; BC_U, BC_V, BC_K vs. $\log_{10} T_{\rm eff}$).

Discussion (Problem 6). We use $BC_X \equiv m_X - m_{\rm bol}$ in the AB system, so a **larger (more positive) BC** means the band is **fainter** than the bolometric magnitude and captures a smaller fraction of the total flux.

- **U band:** $BC_{\rm AB}(U)$ is small for hot stars and rises steeply toward cooler types.
- **V band:** $BC_{\rm AB}(V)$ shows a shallow U-shape with a minimum near solar-like $T_{\rm eff}$ ($\log_{10} T_{\rm eff} \approx 3.76$); it increases toward both hot and cool ends.
- **K band:** $BC_{\rm AB}(K)$ is largest for hot stars and declines toward zero (sometimes slightly negative) for cool stars, where the IR carries a larger share of the luminosity.
- **Class trends:** Class-to-class differences are modest compared to the temperature trend; gravity/composition introduce some scatter.

Problem 7: Distance Modulus — Naked–Eye Visibility of the Sun

Approach. Use the distance–modulus relation in the V band (no extinction): $m - M = 5\log_{10}(d/10\,{\rm pc})$.

Key formula.

$$d_{\rm pc} = 10 \times 10^{\frac{m_{\rm limit} - M_{V,\odot}}{5}}, \qquad d_{\rm ly} = 3.26156\,d_{\rm pc}.$$

Output. With $M_{V,\odot} = 4.83$ and $m_{\rm limit} = 6.0$,

$$d_{\rm pc} \approx 10 \times 10^{(6.0-4.83)/5} \approx 17.14 \text{ pc} \quad (\approx 55.90 \text{ ly}).$$