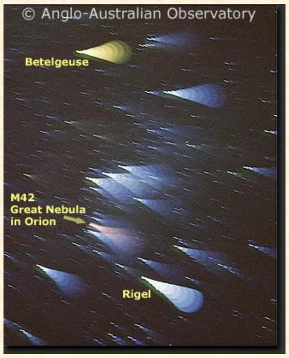
Lec #9: 12 SEP 11 Magnitudes and Brightness; Color and Temperature

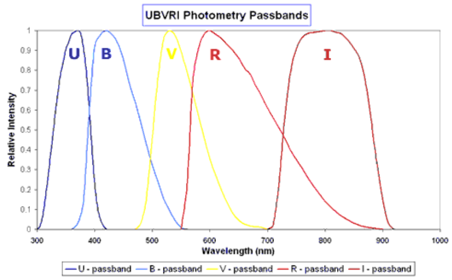
- LAST WEEK: Catalogs, Astrometry, Photometry
  - Apparent Brightness and Luminosity
  - The Magnitude Scale
- TODAY: Color & Temperature
  - Color & Color Indices
  - Introduction to Spectroscopy
  - Effective Temperature
  - Wien's law; Stephan's law
- Wednesday: Spectral Classification
  - Planck Distribution (Blackbody Radiation)
  - Classifying Stars by their low-resolution spectra

5. Color



- With our eyes, we can tell that stars have a range of colors.
- Colors are more prominent in a telescope, but only because the light is brighter.
- Qualitatively, color tells us very little. How can we quantify it?

- What affects color between star and us?
  - independent of distance, except for ...
    - interstellar reddening (ignore for now)
    - atmospheric extinction
    - atmospheric refraction and scattering
    - color response of optics
    - color response of detector (or our eye)
- Most detectors have broad (but not linear) color response. Need to define a wavelength (or range of wavelengths) corresponding to each color AND calibrate response of sky, telescope, and detector.



- Johnson UBV (365/68; 440/98; 550/89)
- Kron UBVRI
- Bessell UBVRI
- Infrared Colors (JHKLM)

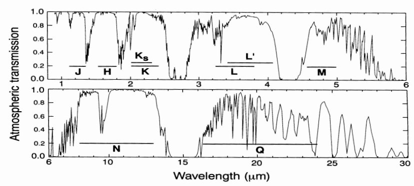
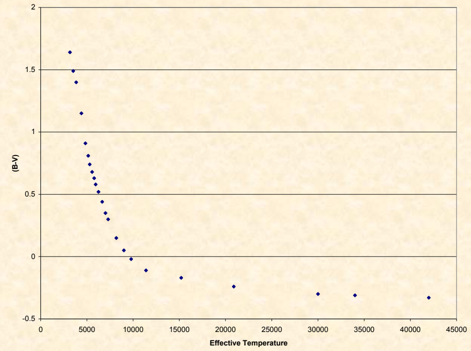


Figure 7.1. Atmospheric transmission from 0.9 to 30 μm under conditions appropriate for Mauna Kea, Hawaii. Altitude = 4.2 km, zenith angle = 30° (air mass = 1.15), precipitable water vapor overhead = 1 mm. $\lambda/\Delta\lambda$ = 300 for 1–6 μm and 150 for 6–30 μm. Spectra are calculated by Lord [1]. The infrared filter band passes are shown as horizontal lines; see Table 7.5 for definitions. Note that the filter transmission is modified by the atmospheric absorption. For the atmospheric transmission at Kitt Peak, see [2]. For ESO, see [3]. See also [4].

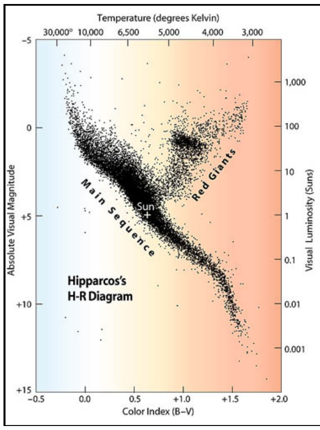
Color Index

- Magnitude difference between different bands; e.g. (B-V), (U-B), (R-I)
  - must have common "zero point", so
  - Vega: U=0, B=0, V=0, R=0, I=0
  - magnitude runs backward, and "bluer" color is always on the left, so a smaller color index -> bluer color
  - What is (U-B) for Vega? (B-V)?
- As we'll go into in great detail soon, color is related to the surface temperature of stars.
  - hotter stars -> bluer
  - warning: visual perception only works over a very limited temperature/color range



Data from “Astrophysical Quantities” 4E (Allen)

Notice that B-V is single-valued (but not linear) function of Temp.

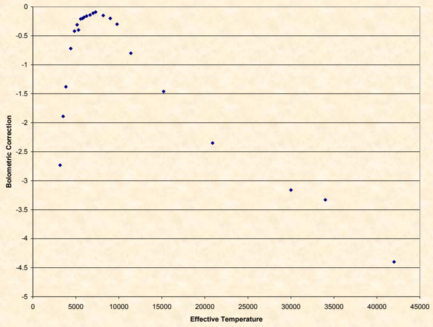


- Color is a proxy for Temperature. Absolute Magnitude measure of Luminosity.
- So we can now construct an HR Diagram from our “catalog”.
- Note that x-axis is continuous and linear (on a logarithmic scale), unlike Spectral Type HR diagram
- For a cluster (all stars same distance), we can even use apparent magnitude.

6. Bolometric Brightness

- Total (“bolometric”) brightness is the integrated flux over all wavelengths. That should include from 0 to infinity (gamma ray to radio). How in the world can we know this unless we measure the complete spectrum using telescopes in space, radio telescopes, etc? We can’t, but most of the light from most stars is visual/IR. How do we combine UBVRIJHKLM?
- Define a “bolometric magnitude” (both apparent and absolute) for all stars:

“Bolometric Correction” = $M_{bol} - M_V$



Data from “Astrophysical Quantities” 4E (Allen)

Notice that BC defined to be negative, maxing out close to 0 for Vega.

Measuring Fundamental Parameters

- ✓ Unique Identification
- ✓ Position “on” the sky
- ✓ Distance (from parallax)
- ✓ Proper Motion --> (transverse velocity)
- ✓ Radial Velocity --> (space velocity)
- ✓ Apparent Brightness; Apparent Magnitude
- ✓ Luminosity; Absolute Magnitude
- ✓ Color

8. Temperature
9. Rotational Velocity
10. Mass
11. Radius

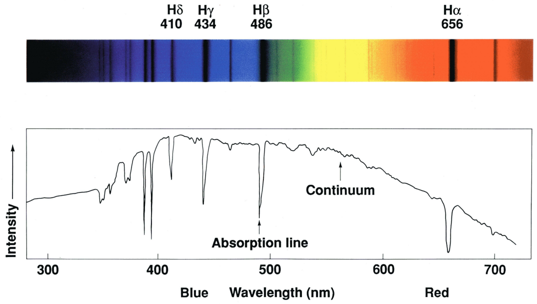
Stellar Spectra (Intensity v. Wavelength)

- Color has something to do with “temperature”
- To go further, we need to break “color” up into a spectrum of colors: intensity v. wavelength
- This introduces not just an additional constraint, but a whole new *dimension* of observational *constraints*
- How do we do that?
  - ✓selective absorption (e.g. narrow-band filters)
  - refraction (transmission)
  - diffraction (transmission and reflection)
  - calorimeter

Wavelength in horizontal direction

What does vertical direction represent?

What does *height* of black lines represent? *width*?



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8. "Surface" Temperature

- We've used it for a few plots. What is it?
  - what is temperature a measure of?
  - how do we determine it?
    - from color index
    - from fit to full continuous spectrum
    - from spectral lines
  - are all these temperatures the same?
  - what does it represent in the stellar atmosphere?
  - how/why do different temperatures produce different continuous spectra?

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1. What do we know?

- Solid or dense materials emit electromagnetic radiation characterized by their temperature above absolute zero.
- They emit at ALL wavelengths.
- The distribution of intensity v. wavelength always has a similar *functional form*, but...
  - The peak and amplitude of the distribution are functions of Temperature

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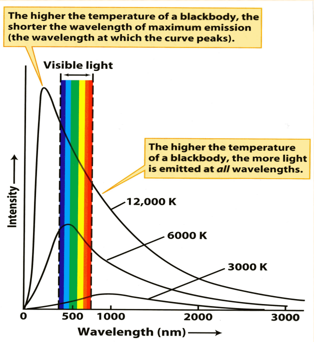
Wien's Law: Inverse *linear* relation between Temperature and *Peak* Wavelength



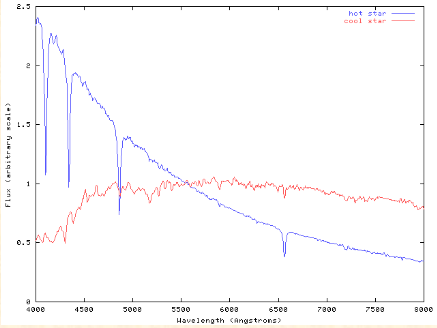
The higher the temperature of a blackbody, the shorter the wavelength of maximum emission (the wavelength at which the curve peaks).

The higher the temperature of a blackbody, the more light is emitted at *all* wavelengths.

Explore for yourself:

1. applet on our website
2. download "Spectrum Explorer" for your computer (or use it in 104)

- Can't remember the constant of proportionality? Remember the solar values instead!
  (5000 Å)*(5800 K) = Wien's constant
- A higher temperature object emits more light at EVERY wavelength than a lower temperature object (of the same size)
  - warning: what is wrong with the following figure...



Caution: Can a 10,000 K star be fainter than a 5,000 K star at 400 nm? at 800 nm?

Of course it can! Size does matter!

- Stephan's Law: The bolometric surface flux is directly proportional to the fourth power of temperature
  - Surface Flux: $F = \sigma T^4$
  - Luminosity: $L = (\text{Surface Area})\ \sigma T_{eff}^4$

    $= 4\pi R^2\ \sigma\ T^4$

    $\sigma = 5.67\text{E-}5$ (cgs) E-8 (mks)

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2. The Planckian Brightness Distribution

- The functional form of intensity v. wavelength exactly matches an analytic expression...

$B_\lambda(T) = 2hc^2/\ \lambda^5\ [e^{hc/\lambda KT} - 1]^{-1}$ erg/s cm^{-2} Å^{-1} sr^{-1}

or...

$B_\nu(T) = 2h\nu^3/c^2\ \ [e^{h\nu/KT} - 1]^{-1}$ erg/s cm^{-2} Hz^{-1} sr^{-1}

- We'll worry more about the angular distribution later. For now, the observed flux is

$f = \pi B$ erg/s cm^{-2} Å^{-1}