Astr 2310 Tues. Feb. 28, 2017
Today's Topics

- **Chapter 13: Properties of Stars: Distances and Magnitudes**
  - **Distances to Stars**
    - **Trigonometric Parallax**
    - **Other Geometrical Techniques**
  - **Stellar Magnitude Scale**
    - **Apparent Magnitudes**
    - **Absolute Magnitudes and Distance Modulus**
    - **Magnitude Systems and Colors**
    - **Stellar Spectra and Spectral Classification**
    - **Extinction Corrections**
    - **Bolometric Magnitudes and Luminosities**

Chapter 13 & 14 Homework

Chapter 13: #2, 3, 5, 6, 8 (Due Thurs. March. 3)

Chapter 14: #1, 3, 5, 6, 7

Properties of Stars

- **Recall that in order to determine the Sun's physical properties we need to know it's distance. The same is true for stars.**
- **The distances of nearby stars can be determined via trigonometric parallax.**
- **Determining the distances of more distant stars is harder.**

How to get distances to stars: Parallax

The angular diameter here is "π" – the "parallax" in arcsec.

The linear diameter is 1 AU.

π(radians) = 1AU/d

But since 1 rad = 206265 arcsec,

and d = 206265/π in Aus then:

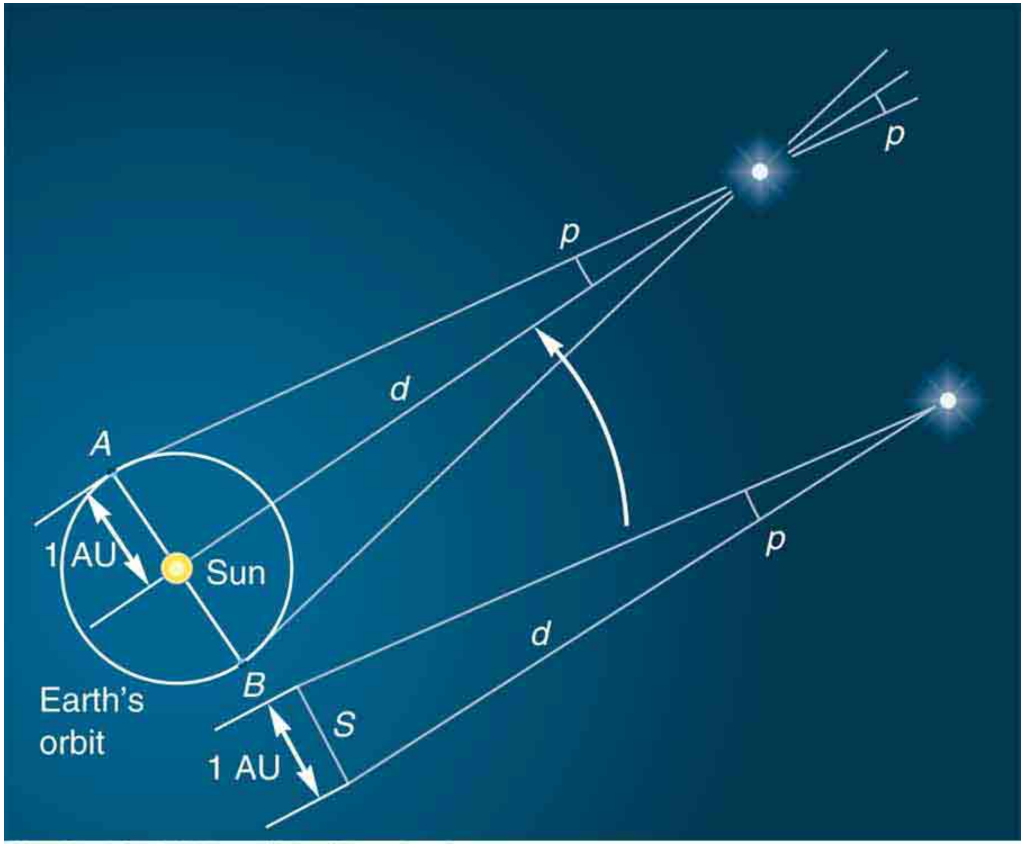
d = 1/π in units of "parsecs"

Thus:

1 parsec or 1pc = 206265 AU

or:

1 pc = 3.26 light years



From the text, Horizons by Seeds

Other Methods for Estimating Distance

- **Accurate parallaxes are limited to distances of about 100 pc.**
  - **Secular Parallax:**
    - **Motion of the Sun through space (20 km/sec, 4.1 AU/year) creates an apparent drift in the positions of stars over time (secular).**
    - **This is a statistical measure since the stars have random motions as well and so we must average to remove them.**
    - **Example: the average parallax of a large set of stars of a given spectral class can be used to infer an average distance and hence an average luminosity.**
- **Moving Clusters:**
  - **Since stars of a nearby star cluster are all at the same distance the Sun's motion through space creates an apparent "convergence point" for the cluster stars. Solving the geometry results in an average distance for the cluster**

Astronomy's Magnitude Scale - I

- Recall that the original magnitude scale was developed by Hipparcos.
  - The brightest stars are class 1, the faintest visible stars are class 6; the eye is logarithmic.
  - Modern quantitative measurements indicate this is roughly a factor of 100 in brightness (flux).
  - Response of the eye is known to be logarithmic
  - Thus we define a logarithmic intensity scale:

$F_n/F_m = 100^{(m-n)/5}$ thus:

$\log(F_n/F_m) = [(m-n)/5] \times 2$ so:

$m_m - m_n = -2.5 \log(F_m/F_n)$ note that larger mags. are fainter

  - Since magnitudes are a relative scale we define a zero point:
    - m(Vega) = 0.04 (originally 0.0 but a small mistake was made)

Astronomy's Magnitude Scale - II

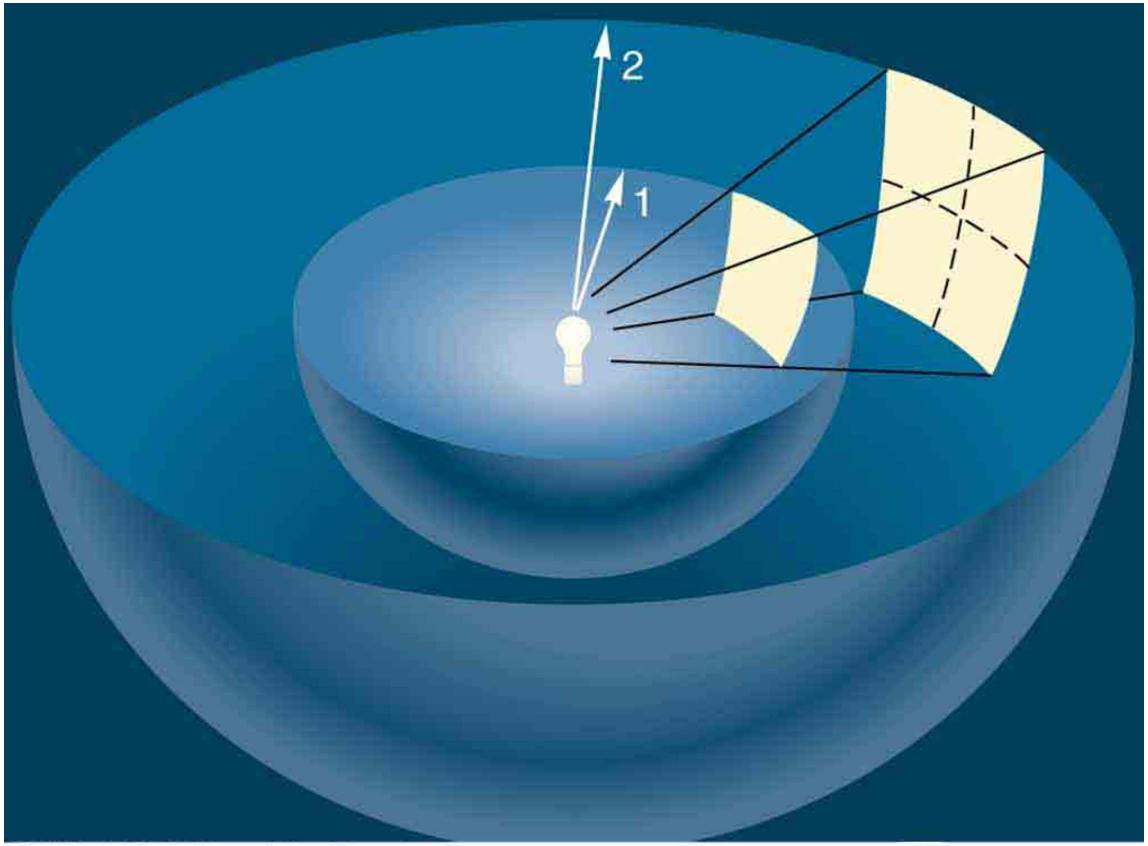
<u>Inverse Square Law:</u> **Flux falls of as 1/distance^2**

Double distance – flux drops by 4

Triple distance – flux drops by 9

Thus we can compute the effect of distance on the magnitude scale.

Define the Absolute magnitude as the apparent magnitude that a star would have at a fiducial 10 pc distance. This allows us to compare the luminosities of stars.



Absolute Magnitudes: Correcting for Distance

- To correct intensity or flux for distance, use Inverse Square Law

$$\frac{F_{\text{distance A}}}{F_{\text{distance B}}} = \frac{L/(4\pi r_A^{\ 2})}{L/(4\pi r_B^{\ 2})} = \left(\frac{r_B}{r_A}\right)^2$$

- Up to now we have used "apparent magnitudes" m_v
- Define absolute magnitude M_v as magnitude star would have if it were at a distance of 10 pc.

$$m_A - m_B = 2.5\log(I_B / I_A) \qquad \text{A = true distance d, B = 10 pc}$$

$$m - M = m_d - m_{10\,\text{pc}} = 2.5\log\left(\frac{I_{10\,\text{pc}}}{I_{\text{distance d}}}\right) = 2.5\log\left(\frac{d}{10\text{ pc}}\right)^2 = -5 + 5\log\left(\frac{d}{1\text{ pc}}\right)$$

$$m - M = -5 + 5\log\left(\frac{d}{1\text{ pc}}\right) \qquad d = 10^{(m-M+5)/5}$$

- This gives us a way to correct Magnitude for distance, or find distance if we know absolute magnitude. Note: the book writes m_v and M_v: The "V" stands for "Visual" -- Later we'll consider magnitudes in other colors like "B=Blue" "U=Ultraviolet"

What is the Absolute Magnitude of the Sun?

- We can determine the absolute magnitude of any star given its apparent magnitude and its distance (parallax). For historical reasons we adopt 10 pc as a fiducial distance:

  $m - M = 2.5 \log[(d/10)^2]$ or:

  $m - M = 5.0 \log(d) - 5.0$ where d is in parsecs

- What about the Sun?
  - Since 1pc = 206265 AU:

    $m_V - M_V = 5.0 \log (1/206265) - 5$ thus:

    $-26.75 - M_V = 5.0 \times (-5.314) - 5$ or:

    $M_V(\text{Sun}) = 4.82$ barely visible to the eye at 10 pc.

Magnitudes at Other Wavelengths

- Early photography allowed astronomers to measure the apparent brightness of stars at only blue and visual wavebands.
- With an electronic detector we can define magnitudes at several wavelengths using filters. The standard set is known as the Johnson/Kron-Cousins system.
- Quantitatively this corresponds to integrating the spectral energy distribution (SED) of an astronomical object multiplied by a filter band-pass:

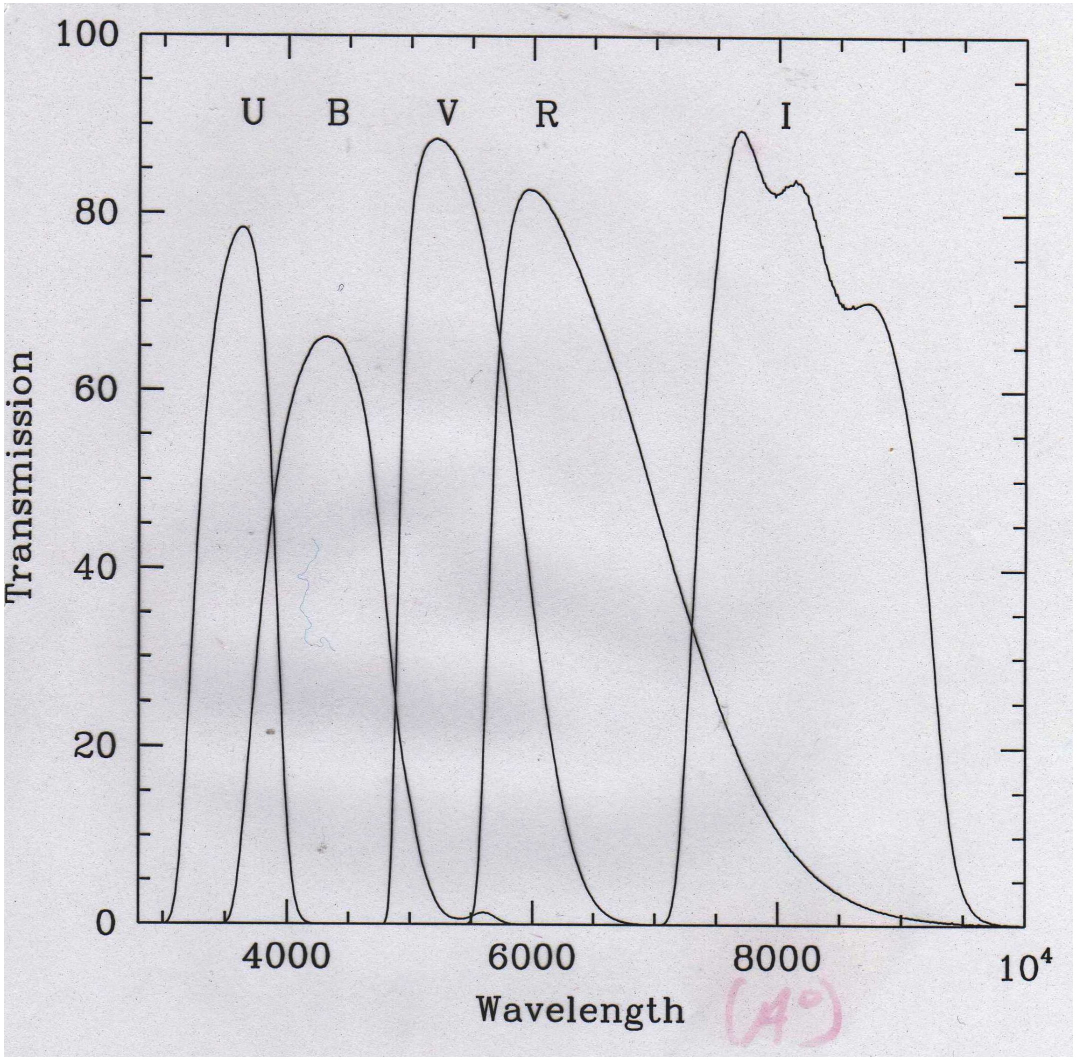
$$m_\lambda = -2.5\log\left\{\int_0^\infty F_\lambda S_\lambda d\lambda \Big/ \int_0^\infty F_\lambda d\lambda\right\} + C_\lambda$$

Johnson/Kron-Cousins Filters

Small set of colored filters are used to span the optical and near-infrared wavelengths.

Trade-off between resolution and small number of filters.

Several filter systems exists. Some, like Johnson, are designed to be broadly applicable and others, like Stromgren, are designed to measure specific stellar spectral features.



Astronomical Colors

- **Astronomers define color as the difference in magnitudes measured in two different band-passes.**
- **For example the B-V color:**

  $$B - V = m_B - m_V$$

Note that blue objects have negative colors and red objects have positive colors.

We can compute colors for Blackbodies:

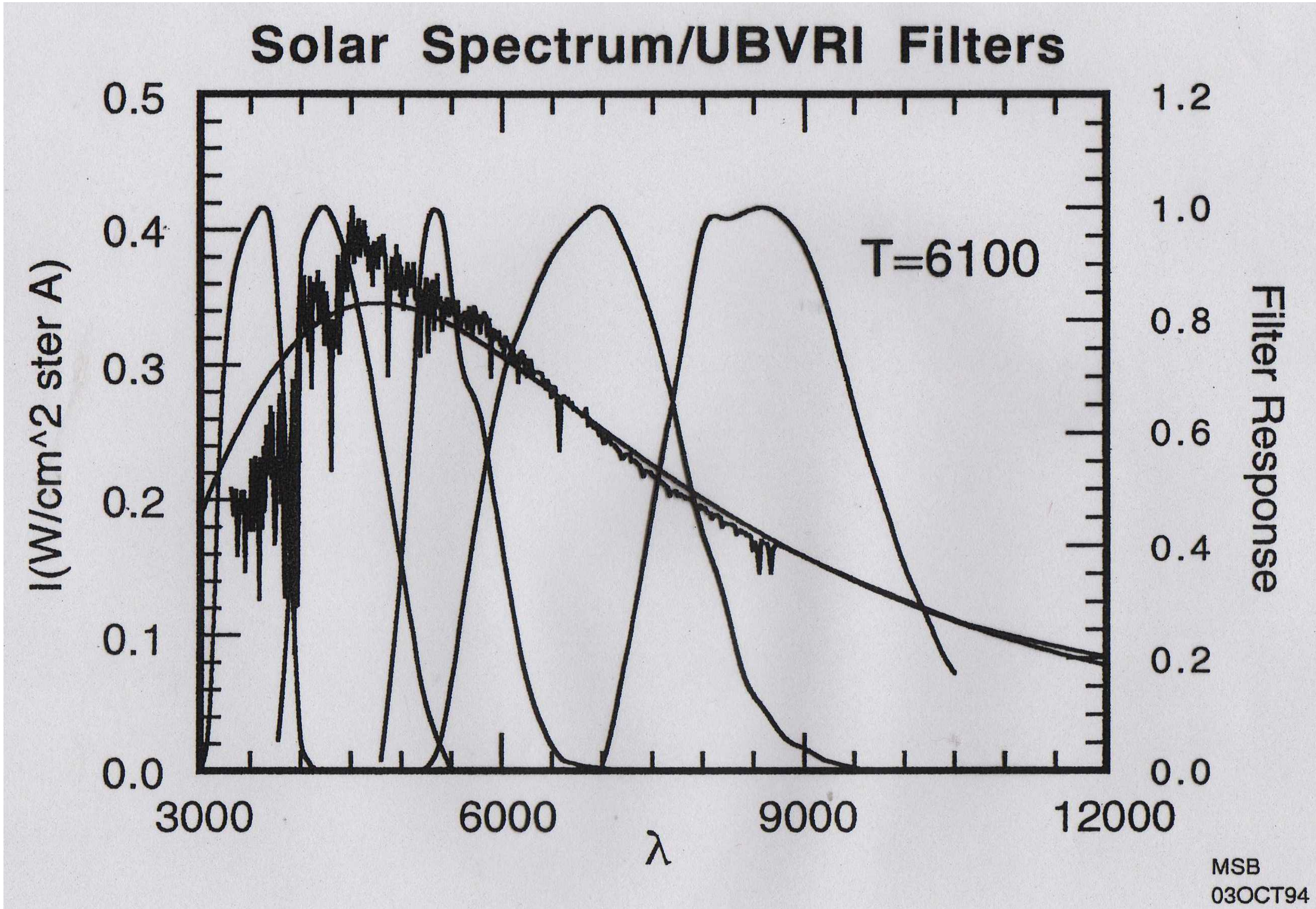
$$B - V = -0.71 + 7090/T$$

But stars are not really blackbodies so for stars similar to the Sun:

$$B - V = -0.86 + 8540/T$$

So we can use astronomical colors as a substitute for temperature.

Example using Solar Spectrum

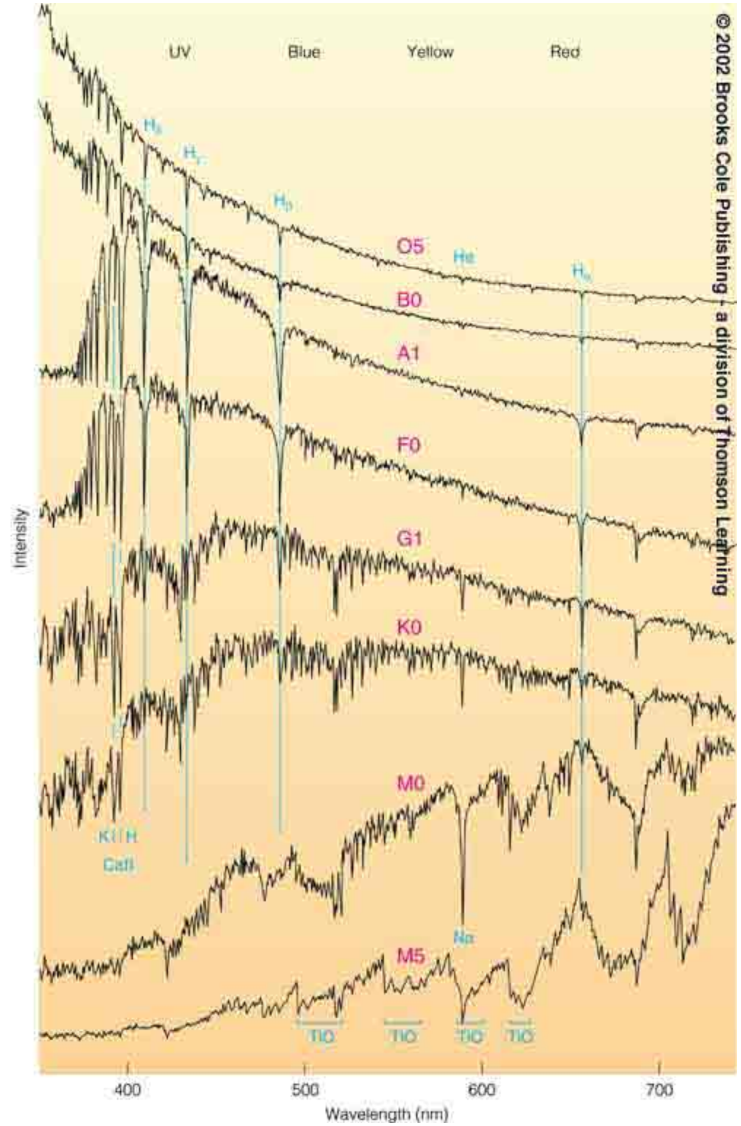


Classification of Stellar Spectra

- **O B A F G K M scheme**
  - **Originally in order of H strength – A,B,etc**
    Above order is for decreasing temperature
  - **Standard mnemonic: Oh, Be A Fine Girl (Guy), Kiss Me**
  - **Use numbers for finer divisions: A0, A1, ... A9, F0, F1, ... F9, G0, G1, ...**

Table 6-1 Spectral Classes

Spectral Class	Approximate Temperature (K)	Hydrogen Balmer Lines	Other Spectral Features
O	40,000	Weak	Ionized helium
B	20,000	Medium	Neutral helium
A	10,000	Strong	Ionized calcium weak
F	7500	Medium	Ionized calcium weak
G	5500	Weak	Ionized calcium medium
K	4500	Very weak	Ionized calcium strong
M	3000	Very weak	Titanium oxide strong



From our text: Horizons, by Seeds

Composition of Stars

- Atomic Physics (Quantum mechanics + Boltzman Equation)
- Regular pattern:
  - More of the simplest atoms: H, then He, ...
  - Subtle patterns later – related to nuclear fusion in stars

Table 6-2 The Most Abundant Elements in the Sun

Element	Percentage by Number of Atoms	Percentage by Mass
Hydrogen	91.0	70.9
Helium	8.9	27.4
Carbon	0.03	0.3
Nitrogen	0.008	0.1
Oxygen	0.07	0.8
Neon	0.01	0.2
Magnesium	0.003	0.06
Silicon	0.003	0.07
Sulfur	0.002	0.04
Iron	0.003	0.1

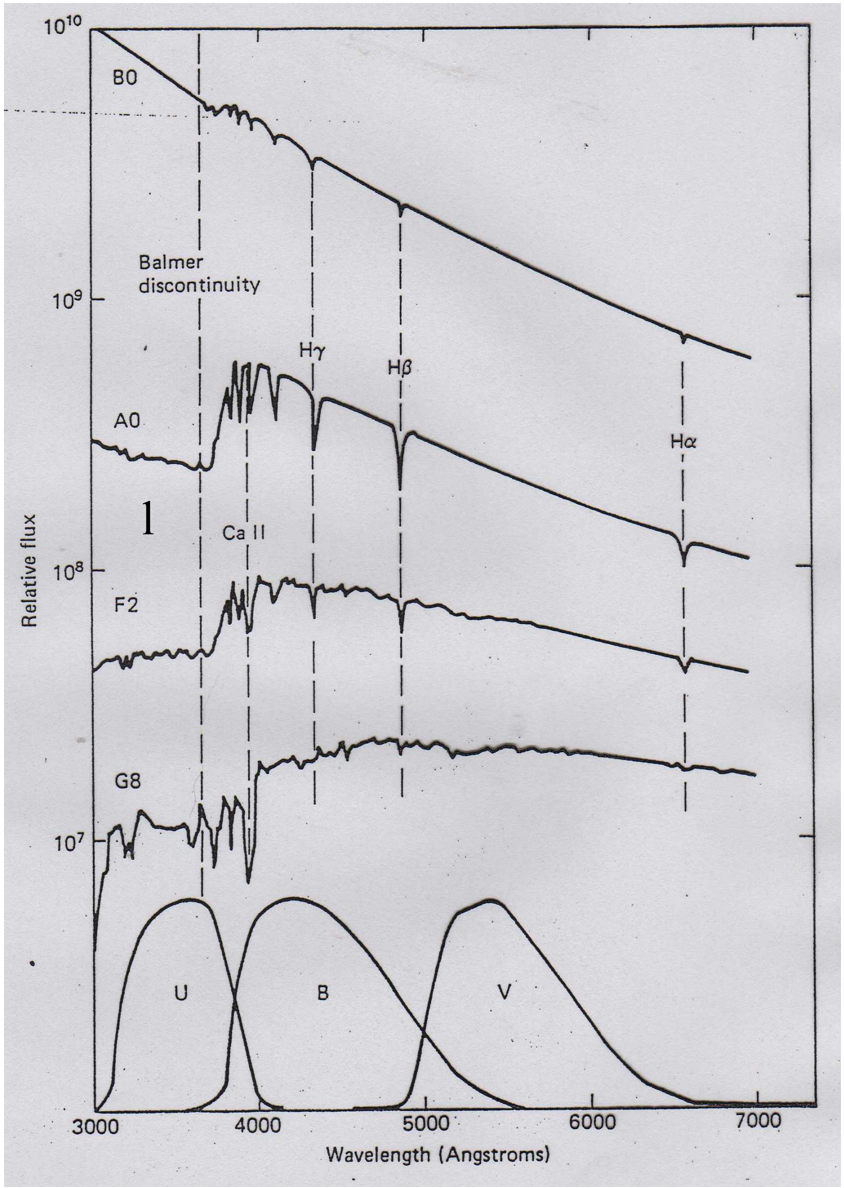
Stars of Different Temperature

Hotter stars are bluer, cooler stars are redder.

The temperature can be measured using only a small number of broad filters.

The original Johnson system included the U, B, and V filters. Kron and Cousins extended these to redder colors detectable with CCDs.

Note that the B-V color is a good tracer whereas U-B is not.

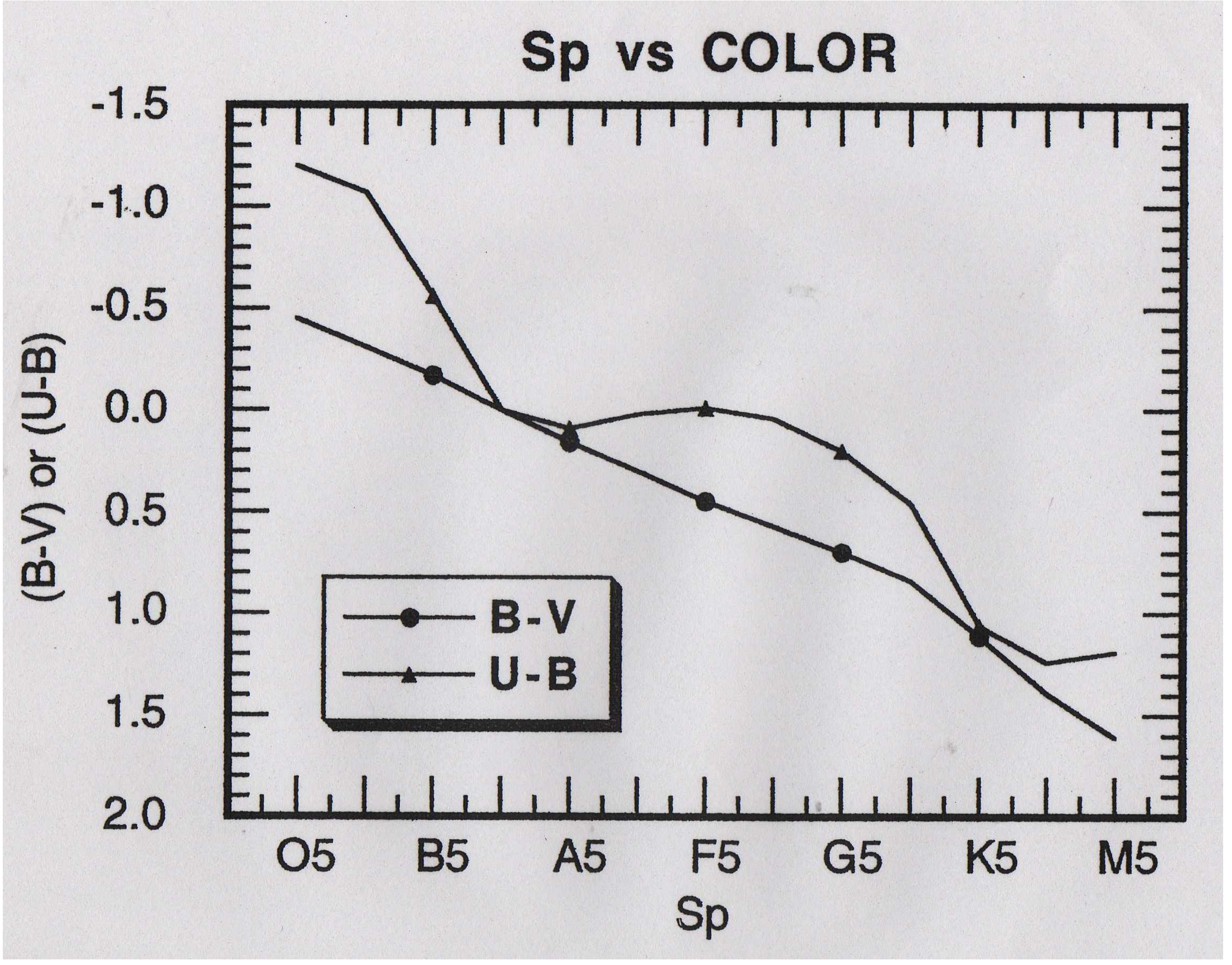


Color vs. Spectral Type

The colors and spectral types have been measured for hundreds of nearby stars.

The B-V color correlates strongly with the spectral type and is thus an accurate, continuous measure of a star's temperature.

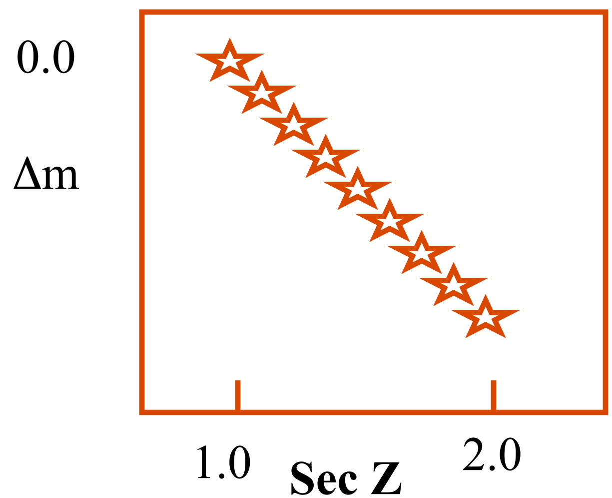
Colors can be measured for many more and for fainter stars than spectroscopy.



Extinction of Starlight - I

- **Scattering and dust in the Earth's atmosphere cause an extinction of starlight.**
  - **Light gets fainter as it is scattered or absorbed.**
  - **Atmosphere scatters more in the blue so the star is also reddened as is it observed further from Zenith [Airmass = sec(Z)]**
  - **By measuring stars of known magnitude (standards) as a function of zenith angle the extinction slope can be measured via least-squares fit to the standards.**
  - **Reddening can also be measured.**
- **Astronomers use this technique to calibrate the effects of the Earth's atmosphere on their measurements and correct for it**

Air Mass = 1/cos (Z) = sec (Z)



Extinction of Starlight - II

- **As light passes through the atmosphere a small amount is scattered. The longer the path length the more the extinction. Recall the corresponding solution to the transfer equation:**

$F(\lambda) = F_0(\lambda)\, e^{-\tau(\lambda)}$

The optical depth (τ) depends upon the properties of the atmosphere and how much we look through (path length or air mass):

$\tau(\lambda) = \tau_0(\lambda) \sec(Z)$

- **Thus in terms of magnitudes we have:**

$$\begin{aligned} m(\lambda) - m_0(\lambda) &= -2.5 \log[F(\lambda)/F0(\lambda)] \\ &= -2.5 \log\{\exp[-\tau(\lambda)]\} \\ &= 2.5 \log(e)\, \tau(\lambda) \\ &= 1.086\, \tau_0(\lambda) \sec(Z) \end{aligned}$$

or:

$$m_0(\lambda) = m(\lambda) - k_0(\lambda) \sec(Z)$$

extinction is linear effect in mags.

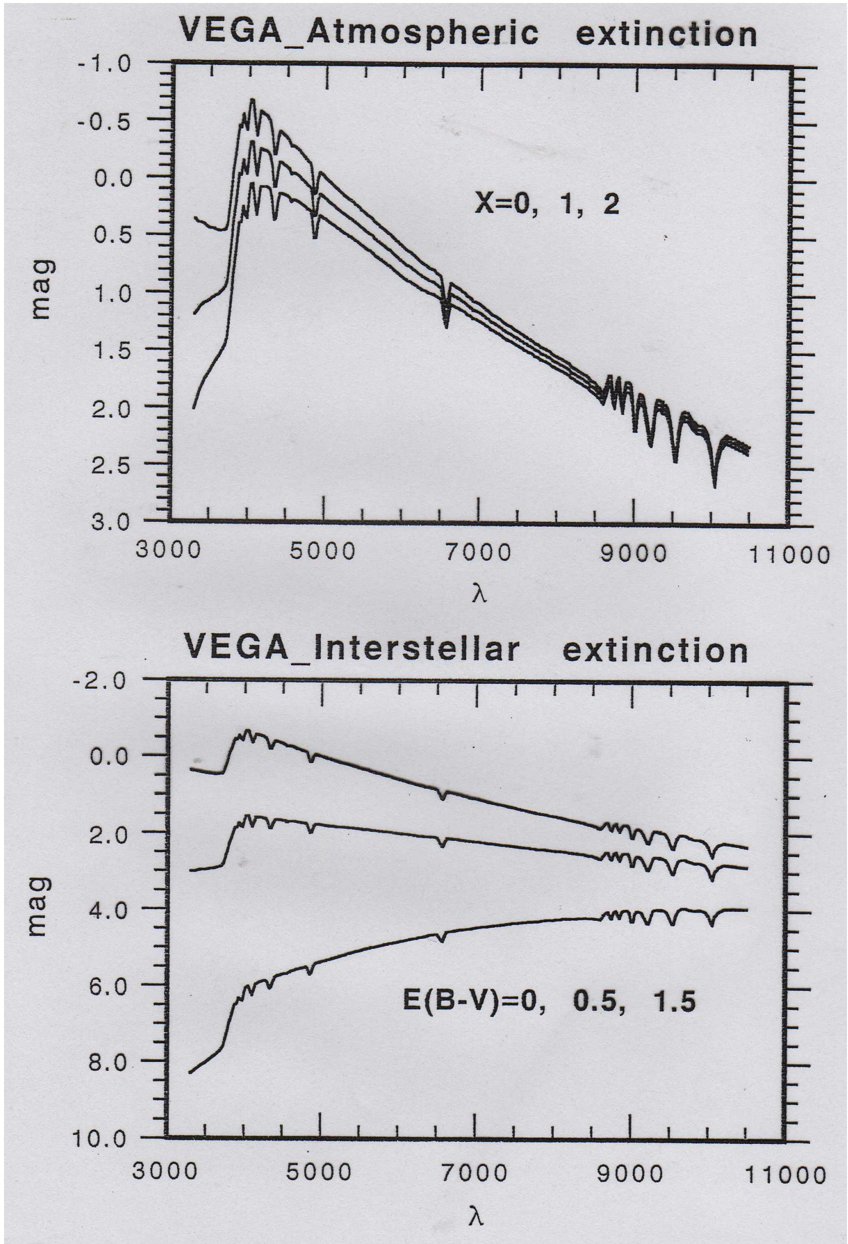
Reddening and Extinction

As star is viewed through increasing amounts of atmosphere, i.e., closer to setting, the star gets redder.

A similar effect occurs as we look at distant stars due to the dust in interstellar space.

Note that the relative strength of adjacent spectral features is unchanged by extinction but the colors will be affected.

So, if the intrinsic colors of a given stellar spectral type are known then the measured colors can give the "color excess" (see below).



Color-Color Plots

Two color plots allow the temperature and spectral types of stars to be estimated.

The positions of the stars in a color-color plot are independent of distant.

However, the location of stars in the color-color plot do depend on extinction due to the reddening of starlight.

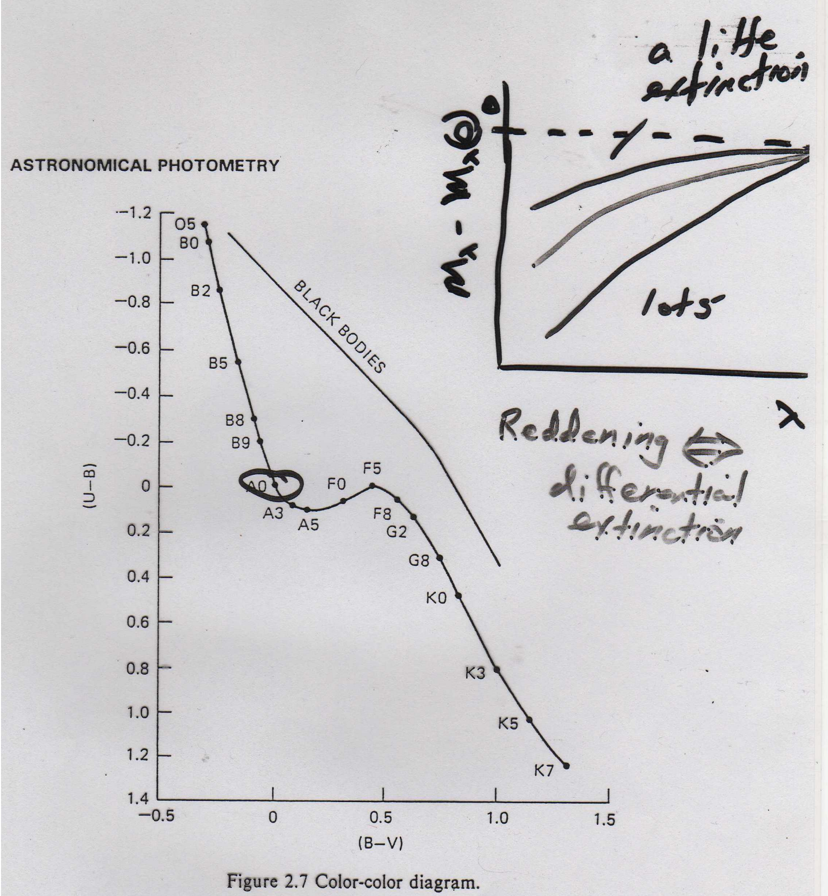


Figure 2.7 Color-color diagram.

Note that color-color diagrams are independent of distance. (but not extinction!)

Color-Color Plot of the Brightest Stars

The nearest stars are distributed along the locus of zero extinction.

More distant stars show increasing amounts of reddening as they are viewed through more and more dust.

Thus, the color excess or reddening of a star can be measured and can be used to estimate the amount of extinction (A):

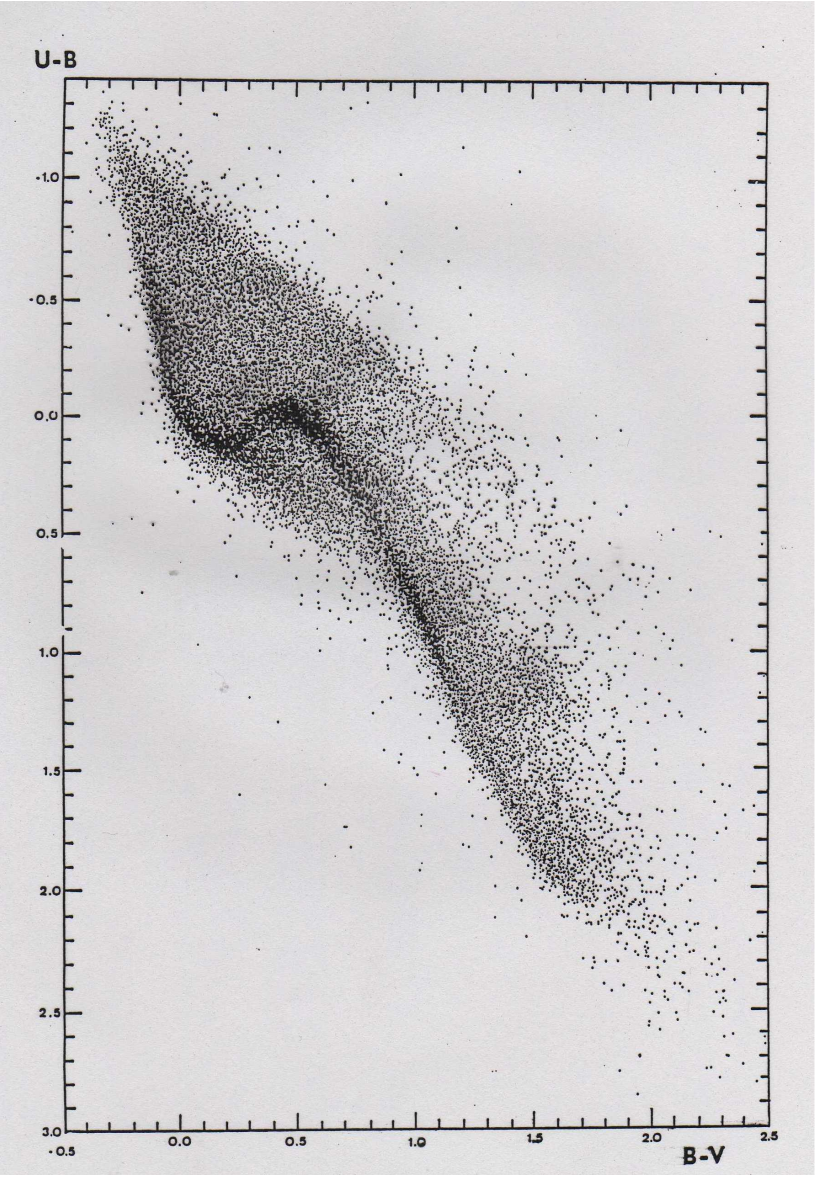
$m_B - M_B = 5 \log(d) - 5 + A_B$
$m_V - M_V = 5 \log(d) - 5 + A_V$

Subtracting:

$(B\text{-}V) = (B\text{-}V)_0 = A_B - A_V$

$E(B\text{-}V) = f(A_V)$

Determining $f(A_V)$ requires multi-wavelength photometry of stars of known intrinsic color.



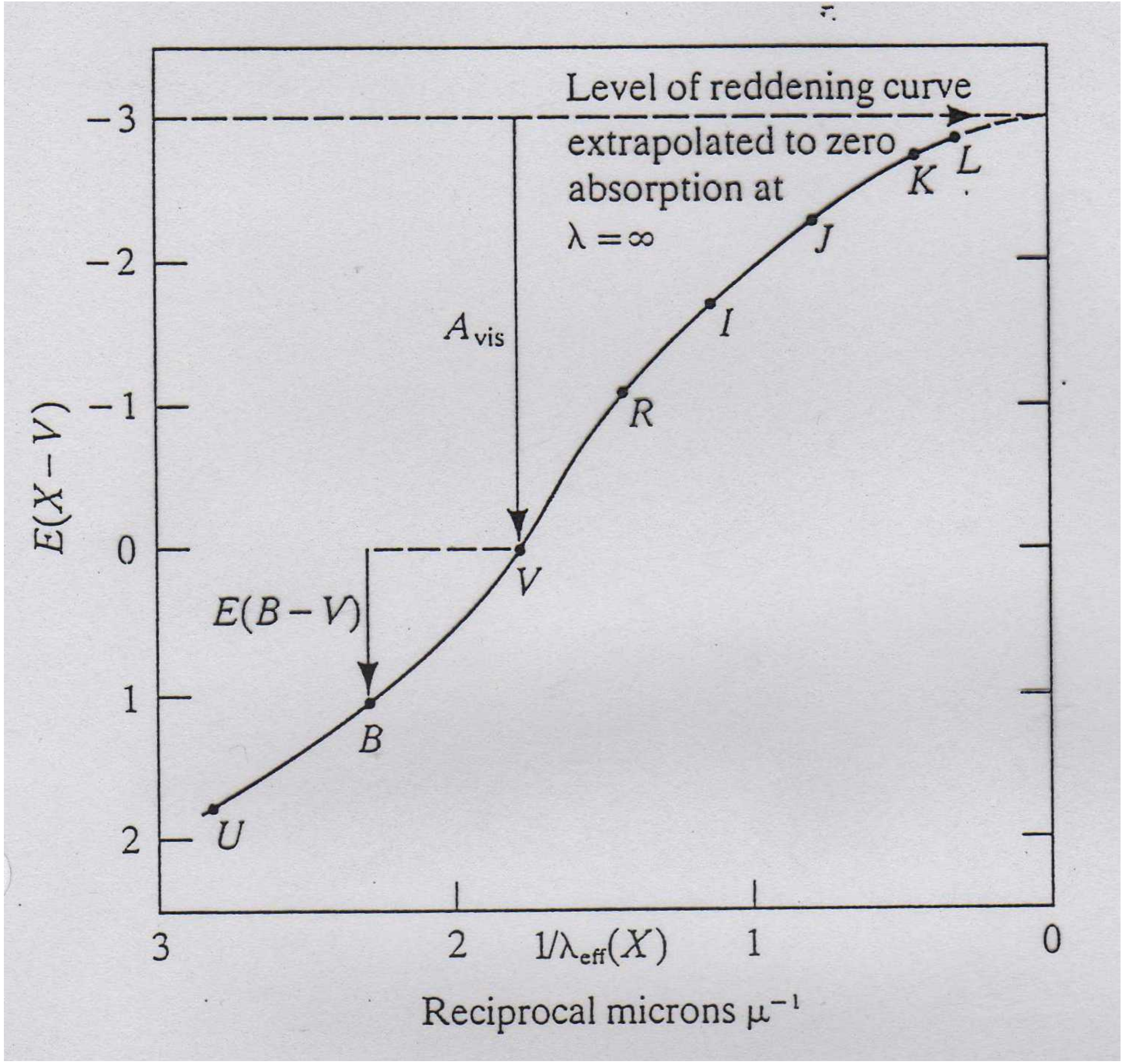
Interstellar Extinction Curve

The differential extinction can be fit with an extinction curve.

A given amount of extinction, e.g. at V, results in reddening that can be quantified as a color excess E(B-V). In this example:

$A_V = R_V \times E(B\text{-}V)$

The value of R can be inferred by extrapolating the curve to infinite wavelength since at this point the extinction should go to zero. For the V-band $R_V \sim 3.1$, for the B-band $R_B \sim 4.1$, etc.



Bolometric Magnitudes

- **The large temperature range of stars means that no single filter band samples the total luminosity so that blue stars and red stars can be easily compared.**

  - **Solution is to measure brightness of the full range of spectral classes from the UV to IR in order to derive their total apparent magnitude. When compared with the V-band the difference is known as the bolometric correction and is a function of stellar spectral type (see Table A4-3).**

  - **Recall that the Sun's integrated flux and distance are known. The flux can be measured over the V-band so we can compute the absolute V magnitude (M_V = 4.82).**

  - **The bolometric correction (BC) is defined such that:**

    $$M_V - M_{bol} = BC$$

  - **Thus the absolute bolometric magnitude of the Sun is 4.75**

Chapter 13 & 14 Homework

Chapter 13: #2, 3, 5, 6, 8 (Due Thurs. March. 3)

Chapter 14: #1, 3, 5, 6, 7

Reading This Week

Chapter 13: Properties of Stars