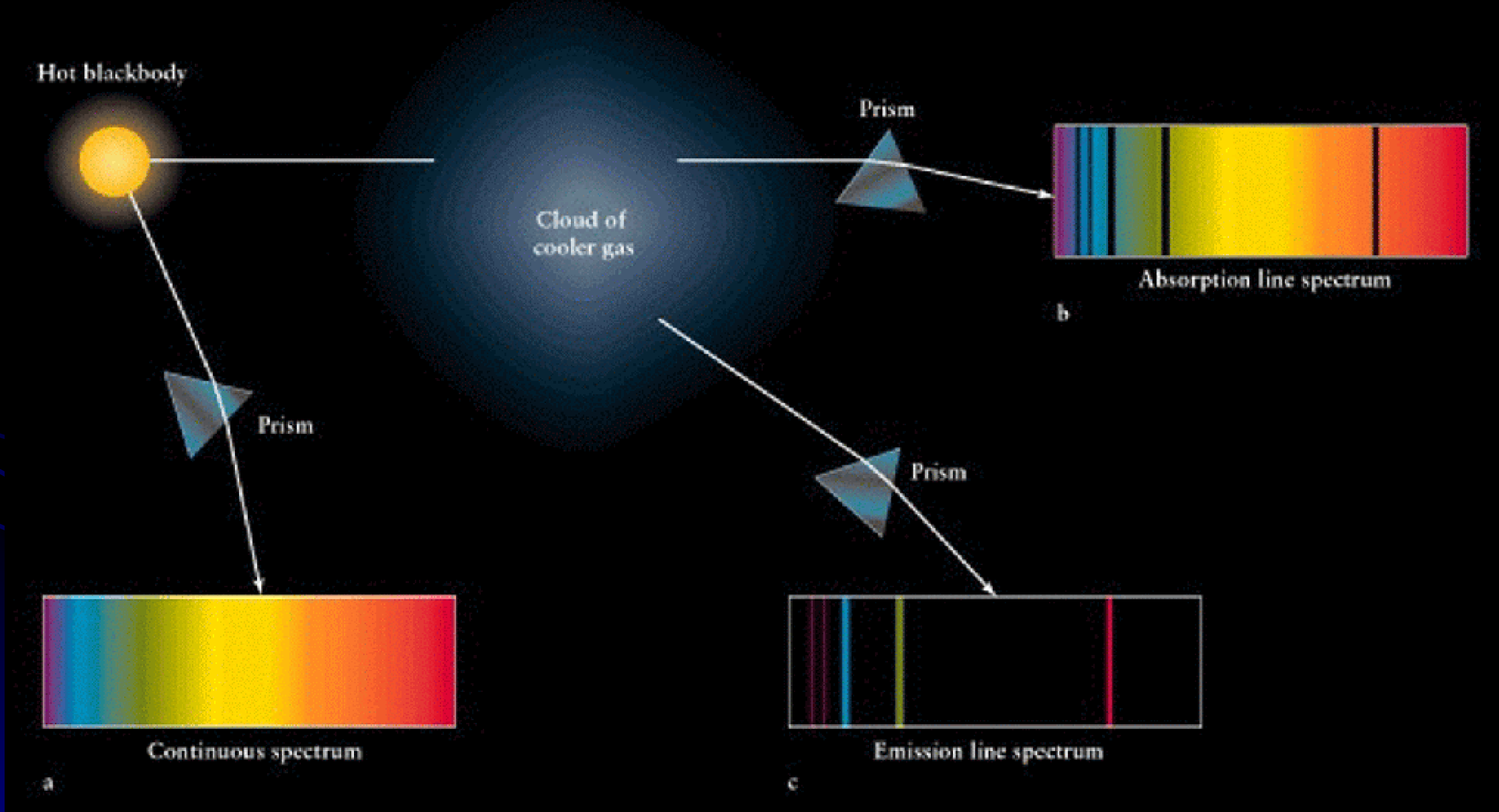
Radiation

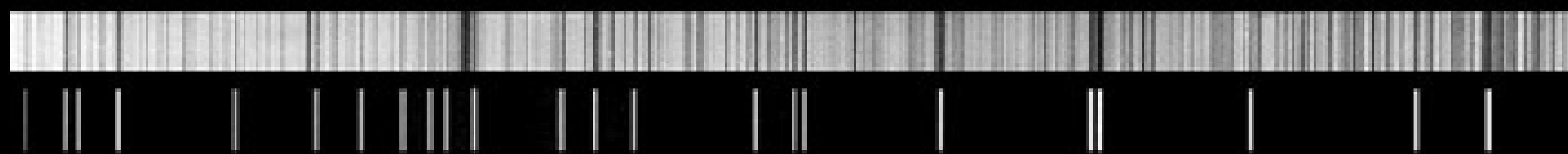
Kirchoff's Laws

- Light emitted by a blackbody, a hot opaque body, or hot dense gas produces a continuous spectrum
- A hot transparent gas produces an emission line spectrum
- A cool transparent gas in front of a blackbody produces an absorption spectrum

Visually Kirchoff's Laws



Kirchoff's Laws



- Top: solar spectrum
- Bottom: iron emission line spectrum

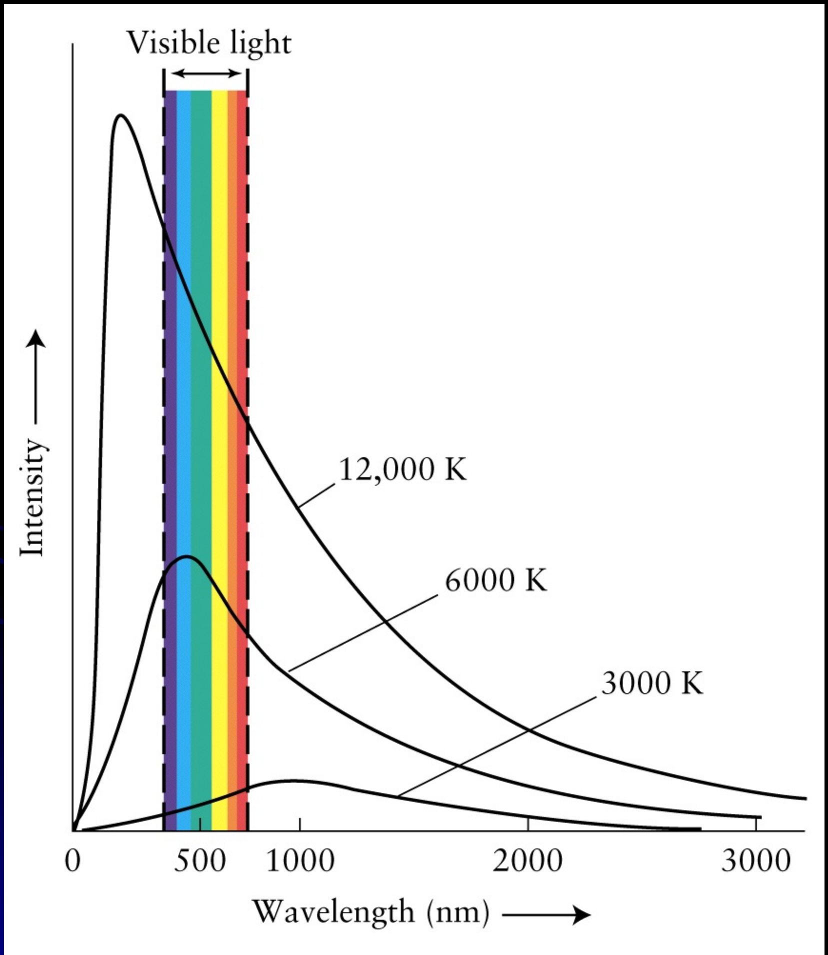
What can you conclude about the Sun's chemical composition from this comparison?

Spectra

- Spectroscopy is the study of spectral lines, and it's very useful in astronomy. Over 80% of all astrophysical information is contained in **spectra** not in images.
  - chemical composition (spectral lines)
  - distance (redshift)
  - velocity (Doppler effect)
  - temperature (shape and type of spectral lines)
  - density (ratios of spectral line intensities)

The Planck Function

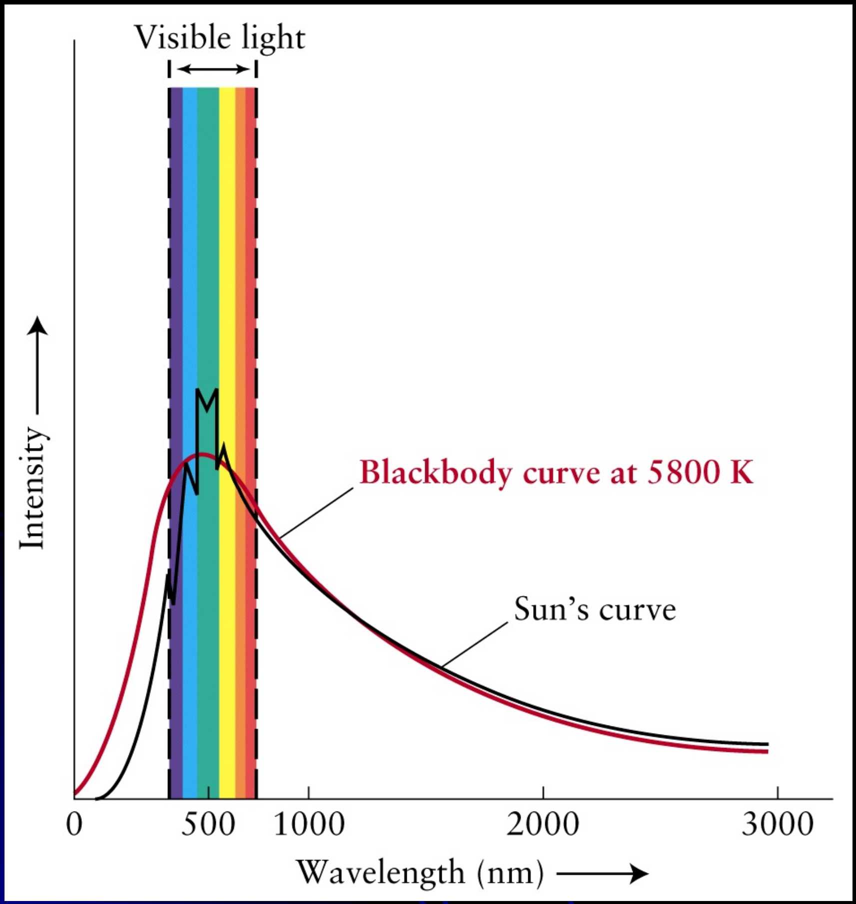
Blackbody Curves



The emitted energy distribution of a blackbody depends only on its temperature

$$B(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{(hc/\lambda kT)} - 1}$$

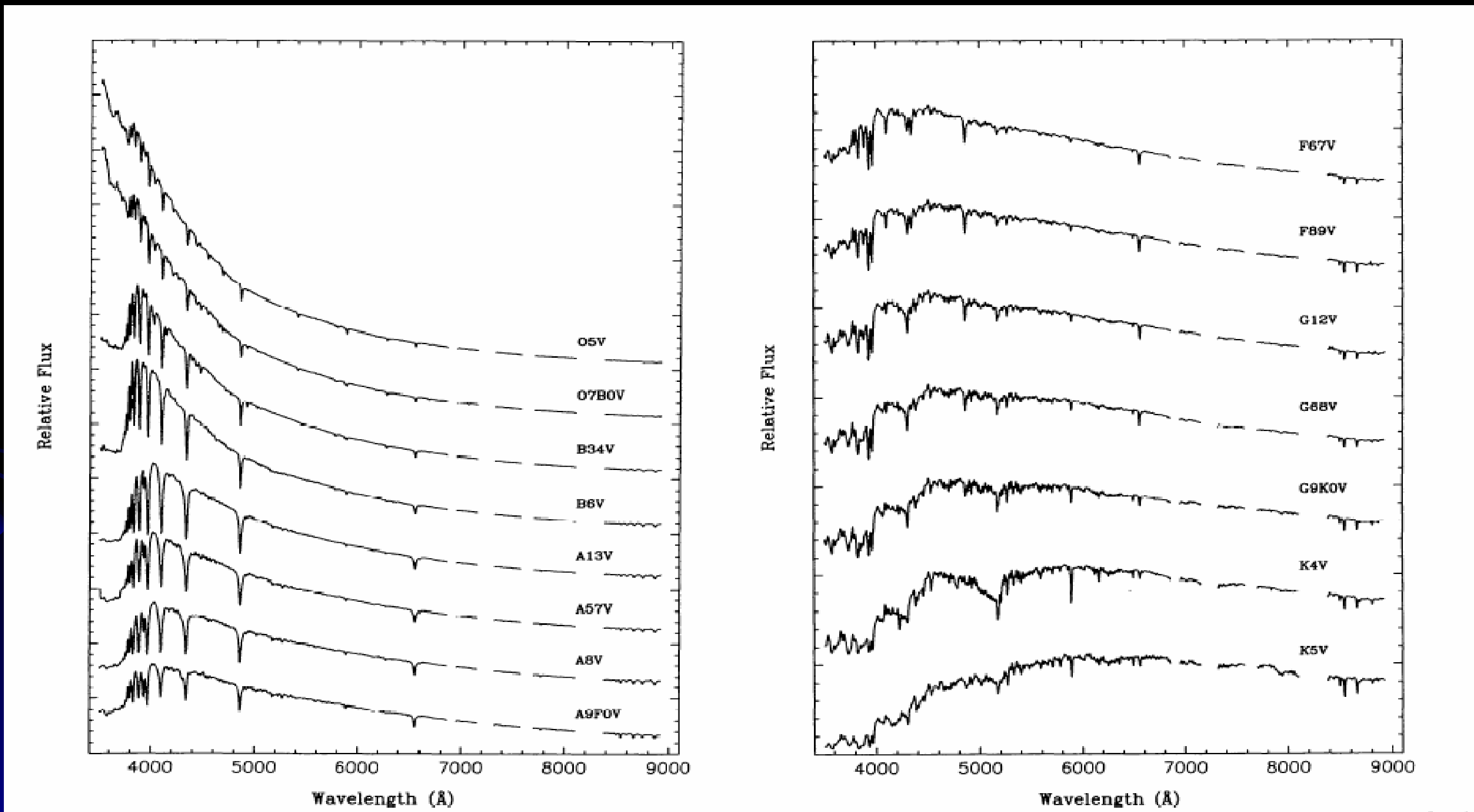
What is a Blackbody?



A perfect emitter and absorber of radiation; for example, black asphalt.

Stars are to a large part a good approximation to a blackbody.

Just to Convince You



From Silva and Cornell, 1992, ApJS 81, 865.

A Demonstration of the Properties of the Planck Function

Unfortunately the demo program accesses the hardware directly!

Interesting Results From the Planck Function!

- Wien's Law: $\lambda_{max} = 0.2898 / T$ (λ in cm)
  - Sun T = 5780 K ==> $\lambda_{max} = 5.01(10^{-5})$ cm = 5010 Å
- Stefan-Boltzman Law: $L = \sigma T^4$
  - Total Luminosity $L = 4\pi R^2 \sigma T^4$
  - $\sigma = 5.67(10^{-5})$ ergs s^{-1} cm^{-2} K^{-4}
  - Solar Luminosity = $3.862(10^{33})$ ergs s^{-1}
  - $R = 6.960(10^{10})$ cm
  - $L = 3.85(10^{33})$ ergs s^{-1}! ==> It works!

Stellar Properties

- Mass
- Temperature
- Luminosity
- Composition

Spectral Types

- O Stars: Strong Helium Lines (35000K)
- B Stars: Moderate Hydrogen lines and no Helium lines (20000K) - Rigel
- A Stars: Strong Hydrogen lines (12000K) -Vega
- F Stars: Moderate Hydrogen lines with ionized metal lines (7500K) - Procyon
- G Stars: Weak Hydrogen lines with strong neutral metal lines (5500K) - The Sun
- K Stars: Very strong neutral metal with some molecules (4500K) - Arcturus
- M Stars: Strong molecular features (3500K) - Betelgeuse

Stellar Mass

A Difficult Proposition at Best

	Dwarfs	Giants	Supergiants
O Stars:	30	30	
B Stars:	10	10	
A Stars:	5	10	5-15
F Stars:	3	5	5-15
G Stars:	1	3	5-15
K Stars:	0.7	1.5	5-15
M Stars:	0.3	1	5-15

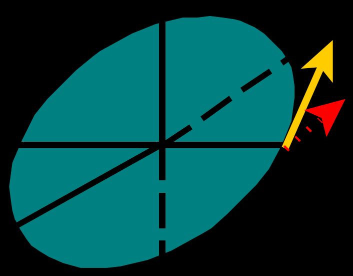
Determination of Stellar Mass

A Very Difficult Problem

- Mass of the Sun: From Kepler's 3rd Law
- Kepler's 3rd Law: $P^2 = ka^3$
  - P = Period of Planet
  - a = semimajor axis of planet
  - k = constant ($4\pi^2/GM_\odot$)
  - G = Gravitional Constant

Determination of Stellar Mass

- Eclipsing Binaries
  - It is NOT possible to directly determine the mass of a single star.
  - Our only available tool is Kepler's Third Law.
  - $P^2 = ka^3$
    - where P= Period of the system
    - $k = 4\pi^2/G(M_1 + M_2)$
    - a = Separation of the components
- Why Eclipsing Binaries?
  - Inclination of the Orbit!

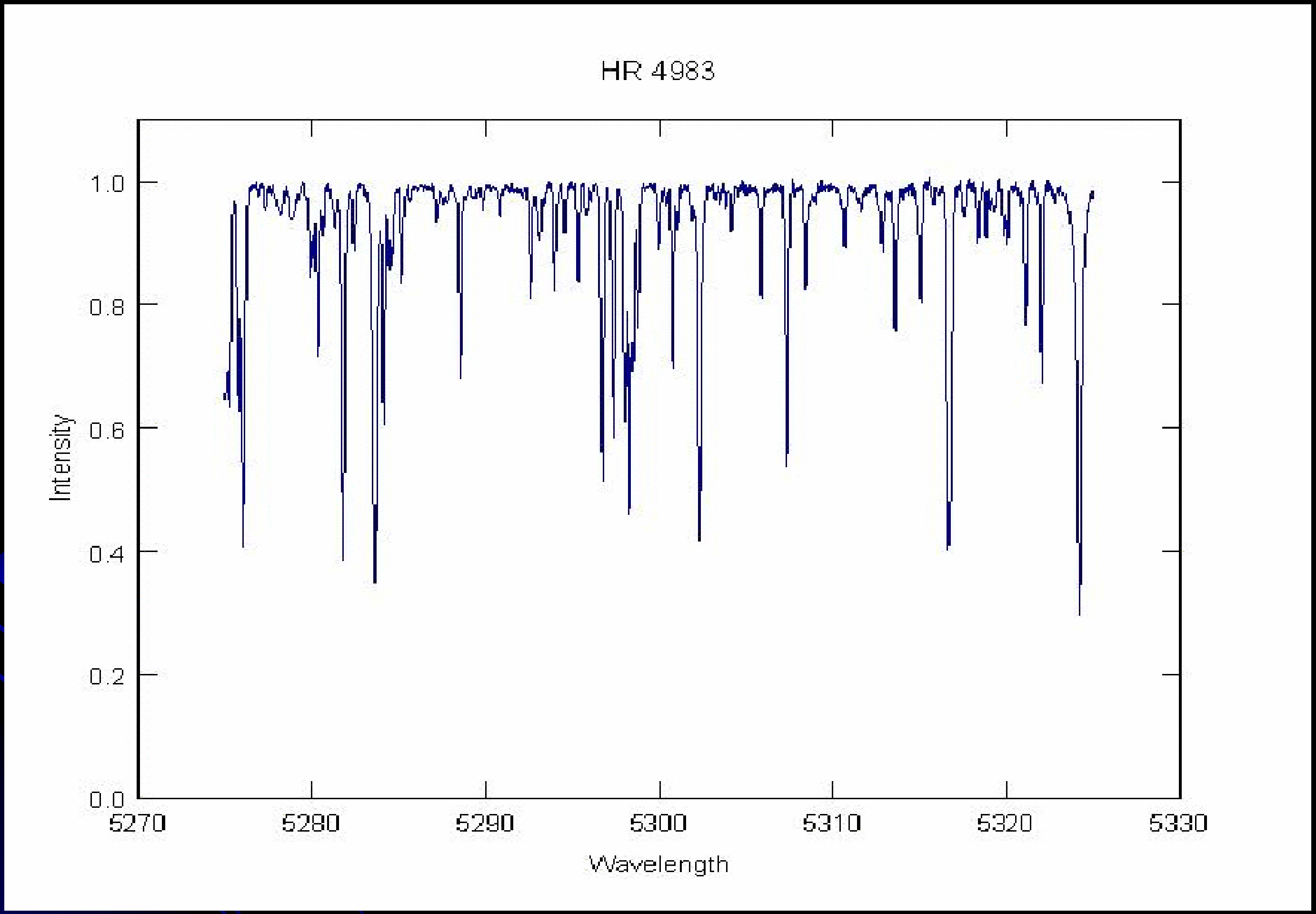


Composition

The Sun Is the Common Reference Point

	Number	Mass
Hydrogen	10^{12}	70%
Helium	10^{11}	28%
Lithium	$10^{1.00}$	
Carbon	$10^{8.55}$	
Nitrogen	$10^{7.99}$	
Oxygen	$10^{8.75}$	
Silicon	$10^{7.55}$	
Calcium	$10^{6.36}$	
Iron	$10^{7.50}$	
Barium	$10^{2.13}$	

A Stellar High Resolution Spectrum



The Definition of Magnitudes

Pogson's Ratio

- A difference of five (5) magnitudes is defined as an energy ratio of 100.
- Therefore: 1 magnitude = 100**0.2 = 2.512 difference in energy.
  - $2.512^5 = 100$
- If star 1 is 1 magnitude brighter than star 2 then:

$$l_1 / l_2 = 2.512$$

where l is the received energy (ergs, *photons*).

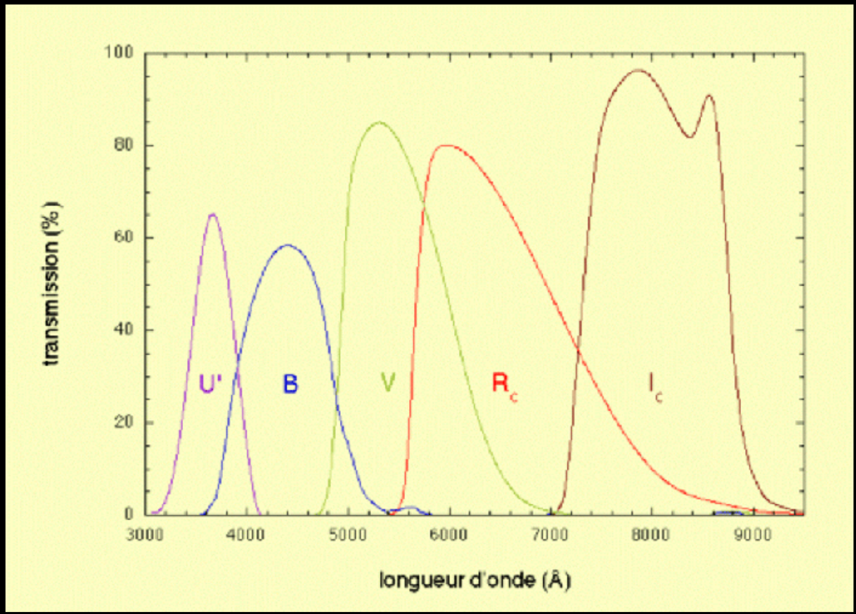
More on Magnitudes

- Or in general: If star 1 is of magnitude m1 and star 2 is of magnitude m2 (star 1 brighter than star 2): $$l_1 / l_2 = 2.512^{-(m_1 - m_2)}$$
  - The - sign is necessary as the brighter the star the numerically less the magnitude.
  - This means: m_1 = -2.5 log l_1 and m_2 = -2.5 log l_2!
- Now convert the equation to base 10:

$$l_1 / l_2 = (10^{0.4})^{-(m_1 - m_2)} = 10^{-0.4(m_1 - m_2)}$$

Band Passes

- A Band pass is the effective wavelength range that a filter (colored glass in the case of Johnson filters and interference filters for narrow band systems) transmits light.



Apparent and Absolute Magnitudes

- Apparent Magnitude:
  - Magnitude as observed on the Earth
  - Apparent magnitudes depend on wavelength.
  - Sirius has apparent magnitudes of
    - $m_V = -1.46$
    - $m_B = -1.46$
    - $m_U = -1.51$
- Absolute Magnitude
  - (Apparent) Magnitude a star would have if it were at a distance of 10 parsecs from the Sun
    - Makes it possible to directly compare intrinsic brightnesses of stars.
    - Just like apparent magnitudes absolute magnitudes are wavelength dependent.

Absolute Magnitudes

- Let l_d = energy observed from star at distance d
- Let l_{10} = energy observed from star at 10 pc

$$l_d / l_{10} = (1/d^2)/(1/10^2) = 10^2/d^2 = 10^{-0.4(m_d - m_{10})}$$

- Call m_d the apparent magnitude m and m_{10} the absolute magnitude M.
- d = distance in parsecs.

The Distance Modulus

$$100/d^2 = 10^{-0.4(m-M)}$$

$$\log(100/d^2) = -0.4(m-M)$$

$$2.5(\log(100) - 2\log(d)) = -(m-M)$$

$$5 - 5\log(d) = -(m-M)$$

$$5\log(d) - 5 = m - M$$

or

$$5(\log(d) - 1) = m - M$$

$$5(\log(d) - \log(10)) = m - M$$

$$5\log(d/10) = m - M$$

Distance Modulus II

- m - M is the distance modulus
  - 0 = 10 pc
  - 5 = 100 pc
  - Each 5 magnitude increase is a factor of 10 in distance: $10^2 = 100$ ==> 5 magnitudes!
- If there is interstellar absorption then
  - $5 \log (d/10) = m - M - A$
  - A = absorption in magnitudes.
  - m = apparent (observed) magnitude
  - $m = (m_o + A)$ where m_o is what the observed magnitude would be if there were no absorption.
- m, M, and A are all wavelength dependent.

Bolometric Magnitude

- Wavelength independent magnitude.
  - $L = 4R^2\sigma T^4$ and is the total (wavelength integrated) luminosity of a star.
  - $M_{bol} = -2.5 \log (L)$ [Absolute Bolometric Magnitude]
  - The observed bolometric magnitude is:

$$m_{bol} = -2.5\log(\int_0^\infty F_\lambda d\lambda)$$

  - Where F is the observed flux (energy).
- The bolometric correction is defined as
  - $M_{bol} = M_V + BC$ (Note that one could use other wavelengths (filters).

Solar Bolometric Magnitude

- First:

$$\frac{L}{L_u} = 10^{-0.4(m_{bol} - m_{bol}^{u})}$$

- What is the bolometric magnitude of the Sun?
  - m_v = -26.74 BC = -0.07
  - m_v - M_v = 5 log (d/10)
  - d = $(206265)^{-1}$ pc
  - Plug in the numbers: M_V = +4.83 and M_{bol} = +4.76
  - The solar luminosity = 3.82 (10^{33}) ergs s^{-1}