SPA613M: Introduction to Celestial Observational Techniques

Lecture 3

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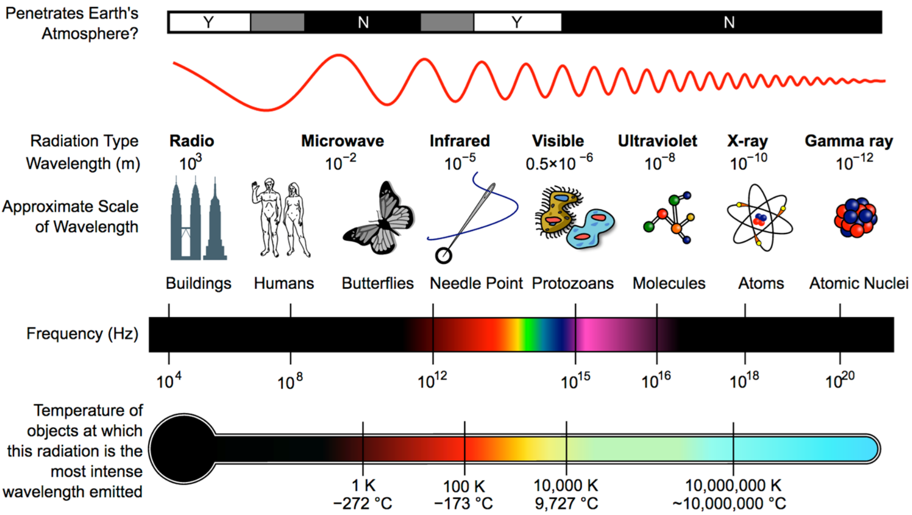
Summary

- Equatorial coordinate system.
- Positions of stars using RA and Dec.
- Epoch.
- Julian Date.
- Galactic and Ecliptic coordinates (homework).
- Electromagnetic Spectrum

Electromagnetic Spectrum



Blackbody Radiation

- Planck's law describes the spectral density of electromagnetic radiation emitted by a black body in thermal equilibrium at a given temperature T, when there is no net flow of matter or energy between the body and its environment.
- To a very rough, but quite useful, approximation, stars shine with the spectrum of a black body.
- The energy density of blackbody radiation, per frequency interval,

$$u_\nu = \frac{8\pi\nu^2}{c^3}\frac{h\nu}{e^{h\nu/kT}-1} \tag{1}$$

where, ν is the frequency, c is the speed of light, h is Planck's constant, k is Boltzmann's constant, and T is the temperature in degrees Kelvin.

Intensity

To obtain this so-called intensity, we take the derivative with respect to solid angle of the energy density and multiply by c.

$$I_\nu = c\frac{du_\nu}{d\Omega} \tag{2}$$

where $d\Omega$ is the solid angle. Blackbody radiation is isotropic (i.e., the same in all directions), and hence the energy density per unit solid angle is,

$$\frac{du_\nu}{d\Omega} = \frac{u_\nu}{4\pi}, \tag{3}$$

since the solid angle of a full sphere is 4π steradians.

Intensity of blackbody radiation

$$I_\nu = \frac{c}{4\pi} u_\nu = \frac{2h\nu^3}{c^2} \frac{1}{e^{h\nu/kT} - 1} = B_\nu \tag{4}$$

In cgs, one can see the units now are $erg\ s^{-1} cm^{-2} Hz^{-1} steradian^{-1}$.

- You can notice product of units, $s^{-1} Hz^{-1}$, cancel out.
- But they have different physical origins: one is the time interval over which we are measuring the amount of energy that flows through a unit area.
- The other is the photon frequency interval over which we bin the spectral distribution.
- The intensity I_ν of a blackbody is often designated B_ν.

Luminosity and Flux

The total amount of Power (energy/s) emitted by a star is called Luminosity (L), is the flux integrated over area of the the star.

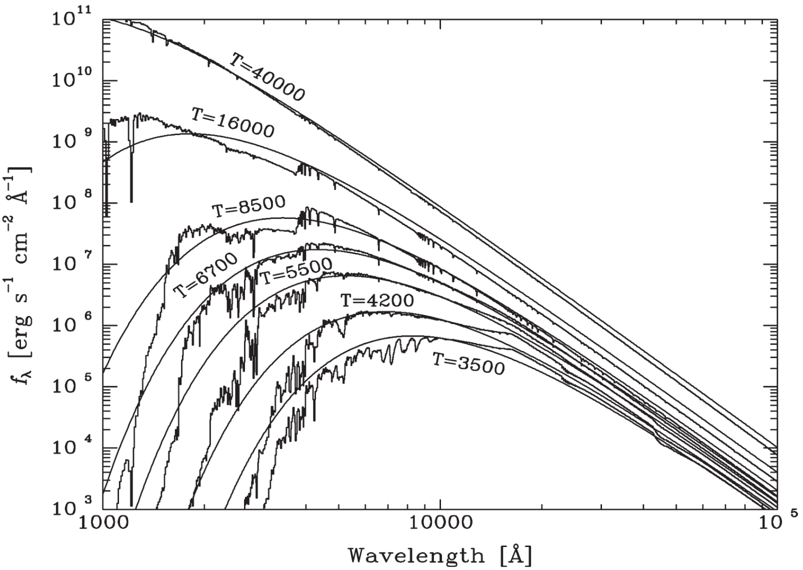
$$L = \int I_\nu d\nu d\Omega dA \tag{5}$$

$$L = 4\pi R_\star^2 \int I d\Omega = 4\pi R_\star^2 F \tag{6}$$

$$F = \frac{L}{4\pi R_\star^2} \tag{7}$$

- Flux (F): total energy per unit area per sec.
- Luminosity of the Sun = $L_o = 3.825 \times 10^{26}$ W (J/s –joule per sec –).

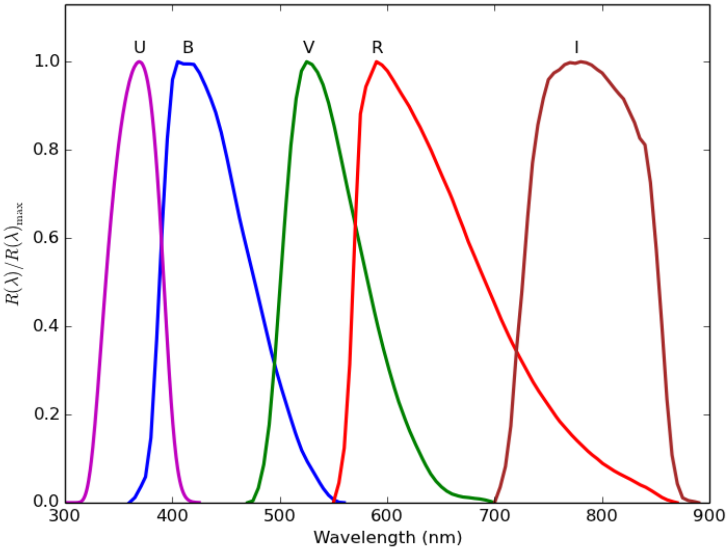
Blackbody Radiation of some Stars



Filter System

- In practice we never measure the bolometric magnitude directly because our detectors are only sensitive to light in a finite wavelength band.
- We can also get a good deal of information from knowing the color of the object.
- In order to compare observations made on different observatories with different detectors, astronomers have agreed on standard response functions.
- One of the first and still one of the most commonly used is the Johnson-Cousins UBVRI system.

Filter System



Filter System

Table 1.2. *Common broad band-passes in the visible (UBVRI), near-infrared (JHKLM), and mid-infrared (NQ). Chapter 10 discusses standard bands in greater detail*

Name	λ_c (μm)	Width (μm)	Rationale
U	0.365	0.068	Ultraviolet
B	0.44	0.098	Blue
V	0.55	0.089	Visual
R	0.70	0.22	Red
I	0.90	0.24	Infrared
J	1.25	0.38	
H	1.63	0.31	
K	2.2	0.48	
L	3.4	0.70	
M	5.0	1.123	
N	10.2	4.31	
Q	21.0	8	

Magnitude System

- Ancient Greeks (Hipparchus) were the first to use a “magnitude” system, listing stars that where the brightest as being of “first importance” or first magnitude, and the next brightest stars as being of second magnitude etc. The sensitivity of the eye is logarithmic.
- In 1856, Norman R. Pogson quantified this scale. He worked at the Madras Observatory.
- Pogson noted that the difference of 1 mag was equal to a brightness difference of 2.512, and $\Delta m = 5$ was a brightness difference of $=$ $2.512 \times 2.512 \times 2.512 \times 2.512 \times 2.512 = 2.512^5 = 100.$

Magnitude System

$$m = -2.5 \log_{10} F + C \tag{8}$$

- F is flux in a filter and constant C defines the zero point of the magnitude system through the equation $C = -2.5 \log_{10}(F_0)$, is the flux density from a $m = 0$ star.
- Assigning the star Vega to be $m \approx 0$ (for historical reasons). This makes Vega the standard against which all the other stars are measured.
- The problem with this system is that Vega is slightly variable, by about 0.03 magnitudes, and has an atypical infrared spectrum.
- In most practical systems, the constant C is specified by defining the values of m for some set of standard stars.
- Another unit called the janskys (Jy) is used extensively by radio astronomers. 1 Jy $= 10^{-26} Wm^{-2} Hz^{-1}$.

Magnitude System

The difference between relative flux and magnitude;

$$\Delta m = m_1 - m_2 = -2.5 \log_{10} \frac{F_1}{F_2} \tag{9}$$

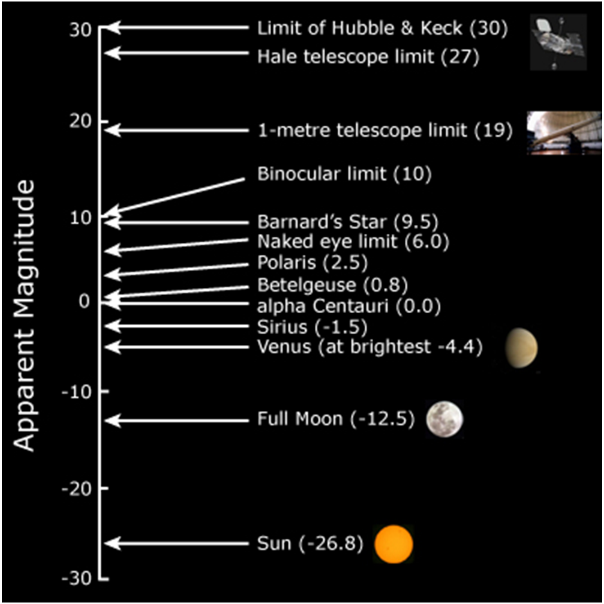
The difference in the magnitude of the two stars m_1 and m_2 is independent of the constant C.

Above equation can be rewritten as,

$$\frac{F_1}{F_2} = 10^{-0.4\Delta m} \tag{10}$$

Notation: the B band apparent magnitudes of a certain star could be written as $m_B = 5.67$ or as $B = 5.67$ and its visual band magnitude written as $m_V = V = 4.56$.

Apparent Magnitude



Absolute Magnitude

The absolute magnitude M is defined as the apparent magnitude a star would have if observed from a distance of 10 parsecs (pc).

$$m - M = 5 \log_{10} d - 5 \tag{11}$$

where M is the absolute magnitude and d is the actual distance to the source in parsecs.

- The above equation also called as "distance modulus".
- Absolute magnitude is directly related to the luminosity of the star.
- Example: Star C has an absolute magnitude of 0, and an apparent magnitude of 14. What is the distance to star C?

Bolometric Magnitude

- Based on total Luminosity including all wavelengths
- Sirius: lot of UV and visible and less IR.
- Betelgeuse (red giant – large star –): bright in IR, surface is relatively cool compared to Sirius. But emits more light compared to Sirius.
- Apparent magnitude (m_v) of Sirius is more.
- Bolometric magnitude (integrated) of Betelgeuse is more.
- Notation: To symbolize the absolute magnitude in a band-pass, use the band name as a subscript to the symbol M.
- Example: Suns absolute magnitude: $M_B = 5.48$, $M_V = 4.83$, $M_{bol} = 4.75$.

Color Indices

- If we were able to measure a stars monochromatic flux at all wavelengths we could determine its bolometric magnitude.
- Any filters can be used for color indices, but some of the most common are B - V and V - R.
- **Color index:** difference between the magnitudes in two different band passes, and gives the ratio of the fluxes in these two band passes. For example the $B - V$ color index is:

$$B - V = -2.5 \log_{10} \frac{F_B}{F_V} + C_{B-V} \tag{12}$$

A large $B - V$ color index implies that $B > V$ so the star is less blue (larger B magnitude) than one with a small $B - V$.

Bolometric Correction

- If the color indices of a star are known then in principle we should be able to approximate its bolometric magnitude.
- Astronomers have used a combination of stellar-spectra modeling and observations to derive a bolometric correction BC that is used to determine the bolometric magnitude of a star from its V magnitude,

$$BC = M_{bol} - V \tag{13}$$

The bolometric correction depends on the spectral and luminosity class of a star.