Magnitudes

Most of our discussion regarding magnitudes and the magnitude system is contained in the Sparke & Gallagher Ch 1.1 readings. Here are a few key points to keep in mind when dealing with magnitudes.

- Astronomical magnitudes are logarithmic measures of relative fluxes:

\[ m_1 - m_2 = -2.5 \log_{10}(F_1/F_2) \]

so if \( F_1/F_2 = 0.01 \) we express this difference as “5 mag”.

- The distance modulus is based on the ratio concept. If we compare the flux of a star at 10 pc distance, \( F(10) \) with the same star at 100 pc, we have \( F(10)/F(100) = 100 \), corresponding to a difference of 5 magnitudes. In this way we can (and will!) express distances in terms of magnitude differences. The distance modulus is a measure of the distance as the difference between an actual observed magnitude and the apparent magnitude for the same object if it were at a distance of 10 pc:

\[ (m - M)_0 = 5 \log_{10}(D \text{ pc}) - 5 \]

where the subscript 0 indicates we are dealing with the case of transparent space, where dimming due to interstellar extinction has been corrected for. Thus an object at 100 pc has a distance modulus of 5 mag, and at 1000 pc 10 mag, etc. Here the absolute magnitude is \( M_0 \); the apparent magnitude an object would have if it hypothetically could be observed at a distance of 10 pc. This is applied even to galaxies, which are much larger than 10 pc; we just pretend all of the light is concentrated in a small space and proceed.

- Magnitudes of stars are usually observed in filters which allow a limited range of light wavelengths (or, equivalently, frequencies) to be transmitted. As we showed in class, we can roughly approximate the response of a given filter system in terms of its effective wavelength \( \lambda_e(i) \) and a bandwidth \( \Delta \lambda(i) \) where the index \( i \) tells us which filter we are working with. The total flux observed from some object through this filter, \( F^*_i(i) \), then is

\[ F^*_i(i) \approx F^*(\lambda_e(i)) \times \Delta \lambda(i). \]

To put these fluxes on a magnitude scale we then need to make a comparison with some standard flux which defines the zero point; ZP of the system. If we adopt the ‘Vega system’
then our ZPs are related to the flux from an idealized version of the star Vega at the effective wavelength of each filter $i$ calculated with the spectrum of Vega-like stars. Since the flux of our ideal Vega is not constant with wavelength, each filter has a different $ZP(i)$! So this is an operationally simple system that, unfortunately, is physically a bit obscure. The alternative is the ‘AB’ system where we work in frequency units, $f_\nu$, and compare the fluxes at the effective frequency of each filter $i$ to that of the standard flux $f_\nu(0)$.

- Most astronomical magnitudes have historically been measured in the UBVRIJHK filters (see the Table 1.2 from Sparke & Gallagher handed out in class). The $ZP$ of the AB-magnitude system is then fixed so that $V=0$ for the same flux on both the Vega and AB systems, i.e. the $f_\nu(0)$ at the V-filter effective wavelength is the reference flux for all filters on the AB system. In practice one sets the $ZP$ with one filter in the AB system and then measures colors for other wavelengths for stars with known SEDs. AB system magnitudes are used, for example, with cameras on the Hubble Space Telescope and are standard for the ultraviolet, dating back to the Wisconsin experiment on the Orbiting Astronomical Observatory in the late 1960s.

- Magnitudes can also be used to give colors of astronomical sources. In this case we measure our two fluxes for the same object but at different wavelengths of light, which we denote $\lambda_1$ and $\lambda_2$. A color is then defined as the apparent (or absolute) magnitude difference between the two wavelengths,

$$color = m(\lambda_1) - m(\lambda_2).$$

The trick here is to remember the hidden ZPs! On the Vega system each magnitude is relative to fluxes in the spectrum of a moderately hot star. Thus a star like Vega should have $B-V=0$ on the Vega system; indeed all colors should be about 0 for stars with SEDs like Vega, A0 main sequence stars. See if you can convince yourself why this would be true. Objects with negative colors (short — long wavelength magnitudes) are bluer than the standard spectral energy distribution (SED) defining the Vega system, while those with positive colors are redder (e.g, Tables 1.3-1.5 in S & G). In the AB system zero color differences correspond to spectra having $f_\nu = constant$ and objects where $f_\nu$ increases to higher frequencies will have blue colors, and where it drops with frequency, red colors.

- Then someone may have decided that this system bordered on sensible and so another magnitude system was needed. These are bolometric magnitudes in which the absolute bolometric magnitude is proportional to $L_\lambda$ integrated over all wavelengths, or the total radiated luminosity, $L$, of the system. Bolometric magnitudes have their own special $ZP$. They come from the idea that absolute bolometric magnitudes will satisfy the equation $M_{bol} = M_V + BC$ where $BC$ is the “bolometric correction”, and $BC \approx 0$ for the Sun. This
was achieved by arbitrarily setting $M_{bol}(\odot) = 4.75$ which then defines the zero point of the system. Thus a star with $L=100 \, L_\odot$ has $M_{bol} = 4.75 - 5 = \sp{-0.25}$.

In summary, astronomical magnitudes are steeped (some would say ‘stuck’) in history. Until recently the ‘standard filters’ have been UBVRIJHK band passes discussed in Sparke & Gallagher, with magnitudes on a Vega system. Now we are seeing more magnitudes on the AB or other systems where the ZP is tied to a specific flux rather than standard star SEDs.

The next step could be to follow the approach used by astronomers at radio and infrared wavelengths, and quote fluxes in *physical units*. The usual choice for this case is the jansky, named after the discoverer of radio emission from space, Karl Jansky (a Madison, WI native, UW-Madison class of 1927-see historical reading note.). The jansky is defined as

$$1 \, Jy = 10^{-26} \, W \, m^2 \, Hz^{-1}.$$ 

The disadvantage of abandoning the flux ratio system on which magnitudes are based is that these depend at most on knowing the flux in one part of the spectrum; everything else is a flux ratio, easily measured at the telescope. On the other hand, measuring absolute fluxes across the spectra of astronomical sources is much more difficult, and so a purely flux-based measurement system would frequently have to be updated for both absolute fluxes and colors (flux ratios for a given object) as calibrations improve over time.