Appendix A

Revision of Astronomical Quantities

A1. Astronomical Units

At a research and academic level in astronomy, large distances are expressed in parsecs (pc), while at a popular level they tend to be given in light years (ly).

$$1 \text{ pc} = 3.0857 \times 10^{16} \text{ m} = 3.2616 \text{ ly}$$

Distances on the scale of galaxies are often expressed in kiloparsecs (kpc), with $1 \text{ kpc} \equiv 1000 \text{ pc}$. Distances between galaxies and on the cosmological scale are usually expressed in megaparsecs (Mpc), with $1 \text{ Mpc} \equiv 10^6 \text{ pc}$.

Distances on the scale of the Solar System are measured in terms of the semi-major axis of the Earth's orbit, the astronomical unit (AU), with $1 \text{ AU} = 1.4960 \times 10^{11}$ m.

Masses are often measured in terms of the mass of the Sun, the solar mass $M_\odot$, with

$$1 \, M_\odot = 1.989 \times 10^{30} \text{ kg}$$

Luminosities, defined as the total power output of radiation (in the form of visible light, infrared, ultraviolet etc.), are often expressed in terms of the luminosity of the Sun, the solar luminosity $L_\odot$, with

$$1 \, L_\odot = 3.826 \times 10^{26} \text{ W}$$

Angular separations on the sky are measured in degrees (deg or °), minutes of arc (arcmin or $'$) and seconds of arc (arcsec or $''$). The abbreviations arcmin and arcsec are used in preference to min and sec to distinguish them from the minutes and seconds of time that are used when expressing coordinates of right ascension on the sky.

Wavelengths of light are sometimes expressed in Ångström units (Å), with $1 \text{ Å} \equiv 10^{-10}$ m, in preference to the nanometre (nm, with $1 \text{ nm} \equiv 10^{-9} \text{ m} \equiv 10 \text{ Å}$). Wavelengths of infrared radiation are often expressed in micrometres (μm), with $1 \, \mu\text{m} \equiv 10^{-6}$ m. The micrometre is often called the *micron.*

Time is often expressed in years, with $1 \text{ yr} = 3.1557 \times 10^7$ s.

Long time spans are often measured in Gigayears, with $1 \text{ Gyr} \equiv 10^9 \text{ yr} = 3.1557 \times 10^{16}$ s.

In all other instances, S.I. units should be used. Unfortunately, some older systems, such as cgs units, still persist in research articles and textbooks.

A2. Astronomical Magnitudes

The brightnesses of astronomical objects in the optical, near infrared and near ultraviolet regions of the spectrum are expressed on a logarithmic scale called magnitudes. A magnitude is the brightness integrated over a some range of wavelength, and consequently any particular magnitude applies to a certain region of the spectrum. This region of the spectrum is conventionally selected by passing the light through a coloured filter and that region of the spectrum is called the filter's waveband, passband or the photometric band.

Commonly used wavebands are the U band in the near ultraviolet (around 360 nm wavelength), the B band in the blue (around 440 nm), the V band in the green/yellow (around 550 nm), the R band in the red (around 640 nm) and the I band in the near infrared (around

790 nm). It is always necessary to specify which waveband is being used when magnitudes are quoted (and precisely which definition of passband is being used).

The *apparent magnitude* m_F of an object in some waveband F is related to the flux of radiation F_F in that band at the top of the Earth's atmosphere by

$$m_F \; = \; C_F \; - \; 2.5\,\log_{10}(F_F)\ ,$$

where C_F is a calibration constant for that band. The constant 2.5 has been chosen to maintain consistency with historical definitions of magnitudes. A fundamental consequence of this definition is that brighter objects *have smaller magnitudes*. For example, a magnitude 16.3 star is *brighter* than a magnitude 19.7 star.

Therefore two objects that have fluxes F_1 and F_2 in some band will have apparent magnitudes m_1 and m_2 in that band that are related by

$$m_1 - m_2 \; = \; -\,2.5\,\log_{10}\left(\frac{F_1}{F_2}\right) \quad \text{and equivalently,} \quad \frac{F_1}{F_2} \; = \; 10^{-\frac{2}{5}(m_1 - m_2)} \quad .$$

The *absolute magnitude* is the magnitude that an object would have if it were observed at a distance of precisely 10 pc. The absolute magnitude therefore measures the luminosity, or total power output, in the photometric band. Absolute magnitudes are denoted by a capital M with a subscript indicating the photometric band, such as M_V for the V-band absolute magnitude.

The apparent magnitude m_F and the absolute magnitude M_F of some object through some filter F are related by

$$m_F \; - \; M_F \; = \; 5\log_{10}(D/\mathrm{pc}) \; - \; 5 \; + \; A_F\ ,$$

where D is the distance (here expressed in parsecs) and A_F is the loss of light due to extinction by intervening material (usually interstellar dust). This equation has to be modified for distant galaxies, for which cosmological effects are important, by using,

$$m_F \; - \; M_F \; = \; 5\log_{10}(D_L/\mathrm{pc}) \; - \; 5 \; + \; A_F \; + \; k_F\ ,$$

where D_L is the luminosity distance (again expressed here in parsecs), and k_F is known as the k-correction (it expresses the effect of redshift on the passband).

Apparent magnitudes are often denoted simply by the name of the waveband, rather than by a letter m followed by a subscript indicating the band. For example, V as well as m_V denotes the V-band apparent magnitude, and B as well as m_B denotes the B-band apparent magnitude.

The difference between magnitudes in different wavebands is known as a colour index. The colour index is an excellent measure of the colour of an object. For example, the $(B-V)$ colour index measures the relative brightness of an object in the blue and yellow parts of the spectrum.

The calibration constants C_F for different photometric bands are usually defined so that a star of spectral type A0 V (a relatively hot main sequence star) has zero colour indices. So the bright star Vega, which happens to be of type A0 V, has $(B-V) = 0.00$ and $(V-R) = 0.00$.

As an example of the use of magnitudes, if a star is observed to have a B-band apparent magnitude of $B = 17.85$ mag and a V-band apparent magnitude of $V = 17.05$ mag, its $(B-V)$ colour index will be $(B-V) = 17.85 - 17.05 = 0.80$ mag. If it lies at a distance of $D = 2000$ pc and there is negligible interstellar extinction between us and the star (i.e. $A_B = A_V = 0.00$), the absolute magnitudes will be $M_B = B - 5\log_{10}(D/\mathrm{pc}) \; + \; 5 \; - \; A_B \; =$ $+6.34$ mag and $M_V = V - 5\log_{10}(D/\mathrm{pc}) \; + \; 5 \; - \; A_V \; = \; +5.54$ mag.