PHY2003 ASTROPHYSICS I

Lecture 1. Basic Measurements and scales

Numbers in Astronomy

Astrophysics deals with physics on the largest scales, and hence physical properties of objects will involve large values.

Distance: For planetary systems, the natural unit of distance is the average distance between the Sun and Earth, 1.496×10^{11}m, the Astronomical Unit or au.

Distances outside the Solar System are measured in Parsecs (pc), where 1 pc $\equiv 206,265$ au $\equiv 3.086 \times 10^{16}$m. The *2nd* nearest star to Earth is 1.295 pc distant.

Mass: Masses of planets are given in kg, or in terms of the mass of the Earth ($1M_{Earth} = 5.974 \times 10^{24}$kg) or Jupiter ($1M_J \equiv 1.898 \times 10^{27}$kg).

Masses of stars are measured in terms of Solar masses, where $1M_\odot = 1.989 \times 10^{30}$kg. Many other stellar parameters (*i.e.* temperature, radius) are often quoted relative to the Sun.

Energy: A natural unit of luminosity is the total energy emitted by the Sun. The Solar luminosity is $L_{Sun} = 3.83 \times 10^{26}$ J/sec.

The amount of energy received by telescopes can be very small. We can easily detect a single photon of light per second, where
$E_\gamma = \frac{hc}{\lambda} \simeq \frac{6.6\times10^{-34}\times3\times10^{8}}{5.5\times10^{-7}} \simeq 4 \times 10^{-17}$J

Velocity: Velocities are normally quoted in km/sec. For example, the orbital velocity of the Earth is given by equating the gravitational and centripetal forces:

$$\frac{GM_{Sun}M_E}{r^2} = \frac{M_E v_E^2}{r}$$

$$v_E = \sqrt{\frac{GM_{Sun}}{r}} = 29.8\,\mathrm{km/sec}$$

The orbital velocity of the Sun about the centre of the galaxy is 220 km/sec.

In extreme environments (*i.e.* near compact objects) velocities may become relativistic. In these situations velocities are quoted as a fraction of the speed of light c.

Astrophysical Measurements

Only in the Solar System is it possible to take samples directly from astrophysical objects.

Objects outside the Solar System can only be studied remotely using three techniques:

(a)Astrometry is the science of precisely measuring the angular position of objects on the sky , either relative to one another or using a fixed co-ordinate system. Astrometry can easily be performed to an accuracy of ten thousandths of a degree. To measure small angles we split degrees into *arcminutes* and *arcseconds*.

1 degree $= 60$ arcminutes, 1 arc minute $= 60$ arcseconds.

Over time we can measure changes in position, which gives an apparent sky-plane velocity in (say) degrees/century. If we know the distance d to the object , we can convert that to a true space velocity perpendicular to our line of sight

(b) Photometry is the science of precise measurement of the amount of radiation (number of photons) reaching the Earth. This gives the magnitude of an object.

So photometry gives the apparent brightness of a body at a certain wavelength, and the absolute (intrinsic) brightness if we know the distance d.

$f =$ flux at Earth (photons/sec/unit area)

$L =$ total luminosity of object (photons/sec)

$$f = \frac{L}{4\pi d^2}$$

The flux-luminosity relationship is probably the most used in all of astrophysics - if we can measure the flux of radiation at the Earth and assume the source emits isotropically, we can calculate its energy release if we know the distance.

(c) Spectroscopy is the science of measuring the relative amounts of light as a function of wavelength, thereby producing a spectrum of the object.

When plotting spectra using fluxes, the amount of radiation as a function of wavelength is plotted. The spectral flux units would be J/s/m^2/m in SI units, but may be reported as something like photons/sec/m^2/nm or J/sec/m^2/angstrom.

If the spectrum is like a black-body, we can obviously estimate the temperature from measuring the wavelength of peak emission.

Atoms can either absorb or emit photons. Therefore in astrophysical objects we can observe both absorption line and emission line objects.

Spectroscopy allows measurement of the composition of an object through measurement of wavelengths and strengths of lines.

Spectroscopy can also easily reveal the velocity of an object v relative to the observer through the *Doppler shift* of its lines.

$$\frac{\lambda' - \lambda_0}{\lambda_0} = \frac{d\lambda}{\lambda_0} = \frac{v}{c}$$

So if we obtain a spectrum, at the very least we can measure the relative velocity of an object and estimate what it is made of.

Example: What spectral accuracy is required at optical wavelengths to accurately measure velocities of ≥ 1 km/sec?