Double Star Section
– Astronomical Society of Southern Africa

DOUBLE STARS IN GENERAL

Most of us have observed double stars: they are some of the most favourite telescopic objects in astronomy today. Objects we proudly show visitors and friends who have never looked through a telescope before. Many are beautiful objects with lovely contrasting colours. Some are difficult targets for testing the acuity of your vision or the resolving power of your telescope. However, there's a lot more to double stars than this. They are fascinating objects of scientific study and measurement going back to the beginnings of observational astronomy.

A **double star** is a pair of stars that appear close to each other in the sky as seen from Earth when viewed through a telescope. This can happen either because the pair forms a binary system of stars in mutual orbit, gravitationally bound to each other, or because it is an *optical double*, a chance alignment of two stars in the sky that lie at different distances from Earth. Binary stars are important as knowledge of their motions allows direct calculation of the individual stars masses and other parameters. Without the mass of a star one cannot do astrophysics. Nearly everything about a star, its colour, its energy output, even its lifetime, is dependant upon its mass.

Since the beginning of the 1780s, both professional and amateur double star observers have measured the distances and angles between double stars to determine the relative motions of the pairs. If the relative motion of a pair determines a curved arc of an orbit, or if the relative motion is small compared to the common proper motion of both stars, it may be concluded that the pair is in mutual orbit as a binary star. Otherwise, the pair is optical. Multiple stars are also studied in this way, although the dynamics of multiple stellar systems are more complex than those of binary stars. Multiple star systems are systems where three or more stars move under their mutual gravitational attraction. In the vicinity of our sun 35 % of the stars are single whilst more than 50 % are physical doubles.

LOCATING DOUBLE STARS

One of the most time consuming exercise for any astronomer is locating double stars. Unfortunately there is no quick fix for many of us. If you are not fortunate to have digital setting circles or computerized GOTO telescopes your viewing time is substantially increased.

For those without, all I can say is practice. The more familiar you are with the sky and the constellations the easier your search becomes. Being familiar with your telescope or binoculars is also a great plus. If you are mentally able to divide your field of view according to the lens size the star charts are much easier to follow.

From experience I have found that it is more rewarding to do thorough planning of your intended nights viewing. Locate your targets from sky charts or Internet pages and keep to those preparations on the nights viewing. With this method you become familiar with selected areas.

OBSERVING DOUBLE STARS

Choose the brightest star in the constellation and then hop from one star to the other to find double stars. Spend the time determining the separation, magnitude and then lastly the colours. It takes a long time for your eyes to differentiate colours. Let's discuss resolution, colours of stars, position angle (PA) and separation in more detail.

Resolving Power

Seeing fine detail in the eyepiece is a matter of great importance for all aspects of visual astronomy and being able to see small rills on the Moon or knots of gas in Jupiter's clouds will depend on the resolving power of your telescope. But nowhere are resolving power more simply and directly shown, as a limiting factor, than in the observation of double and multiple star systems. The resolving power of your telescope is measured in arc seconds and you can find this number – if you are interested – by using either version of the formula that William Dawes developed in the 19th century. You will need to know the aperture of your telescope in either inches or millimetres.

Resolving power (in arc seconds):

- 4.56 / aperture in inches, or
- 116 / aperture in millimetres

Using these formulae quickly reveals why the phrase ‘aperture rules’ is heard so often during discussions of telescopes. A 70mm refractor can, going strictly by the numbers, resolve a pair of stars as closely spaced as 1.6 arc seconds, practically, almost impossible! But an 8 inch Newtonian reflector can – according to Dawes’ theory – resolve two stars as closely spaced as 0.5 arc seconds (also written as 0.5”). That’s a big difference, to be sure, but before the owners of smaller telescopes begin to worry, there’s more to this than just the numbers. The formulae for the Dawes Limit indicate only the potential, not the actual, resolving power. That 8 inch Newtonian does not, in fact, have a full 8 inches of aperture, since the secondary mirror blocks some of the incoming light. Owners of SCTs face a similar complication. And the diffraction spikes caused by the spider vanes holding that mirror beneath the eyepiece of a Newtonian reflector can sometimes make picking out a faint secondary star a bit of a challenge, especially on a night when the seeing is not very good. But over and above such concerns are the seeing conditions that prevail when you are out observing. Seeing conditions alone can limit how close your telescope can come to realizing its Dawes Limit. So, as useful as the number can be, it is not a perfect description of the resolving power of a telescope. An awareness of the Dawes Limit for your telescope will, however, aid you in planning an observing session, keeping you from wasting time trying to split double stars (or see lunar or planetary details) that are beyond your reach even under the best skies you will ever encounter. But try not to take it too literally!

The Colours of Stars

One of the most noteworthy features of double stars is the range of colours they often display. (This is actually true of stars in general, of course.) The members of a double (or multiple) star system do not always share the same hue, which makes these colours stand out all the more. The colour of a star can provide an indication of its temperature, with stars that are blue or white being much hotter that stars of a reddish hue. Our own yellow star, the Sun is on the cool side of this continuum. The colours you see will not always be a completely reliable indicator of a star’s temperature, however. For one thing, the brightness of the primary star can alter the way you see the colour of its companion and sometimes lead your eye to see shades of green, mauve, or other exotic colours that are not really present. This effect is known as 'dazzle tint.' The colour seen also depends very much on your *perception* of colour. Different observers often report very different colours, and the same observer may not see the same colours on different occasions when the conditions change dramatically. What you see in terms of colour is always worth recording, but there is no reason to be concerned if what you see does not quite match what is listed in books such as *Burnham's Celestial Handbook*. The magnification used, the observing conditions, and your own eyesight can greatly affect colour perception. *Always record exactly what colours you see, no matter what the references you use lead you to expect.*

Position Angle and Separation

Two other aspects of double star observation involve how far apart the components appear to be (separation) and what angle a line drawn between them forms relative to north in your field of view (position angle).

The **separation** of double stars is most often given in arc seconds. This measure of separation ranges from stars that are Very Close (between 0.5" and 2") and stars that are so far apart they are called 'Open' (30" apart or more). The list for the ASSA Double Star observing project will include both very close and wide open doubles. The reason for this wide range is that we cannot, of course, predict the sort of telescope you will be using, and we want it to be accessible – as well as a bit challenging – to as wide a variety of observer/instrument combinations as possible.

Position angle describes the location of the companion star (or stars) relative to the primary. It is measured in degrees from north in the field of view around through east, south, and west for a full 360°. Here is where knowing how to determine cardinal directions in the field of view is essential. Determine East by where stars drift out of your view, then determine South by nudging the scope toward Sigma Octanis; the centre of the side at which new stars appear is South. Mark South and East on your sketch and you will easily be able to mark the points for North and West.

North = 360° (or 0° if you prefer)
East = 90°
South = 180°
West = 270°

With the information provided above you should be able to sketch double stars accurately in terms of their position angles. The position angles of the stars we will use are provided in the list, so you will not need to determine these numbers. But for the sketch to count the double star under observation must be drawn in the correct relation to the direction marks you place around the sketch. You can use the position angles and the cardinal directions you include in the sketch to verify that the sketch is correct.

The doubles posted on the ASSA website are relatively easy to find and your observations are meant to be fun and challenging. We cannot do any science with the observations unless a micrometer is used to measure the double stars. I encourage all who not only observe double stars but also who measure double stars to send their information through to me, with possible photos or sketches for use in scientific research. Credit will be given to the respective observer for such submissions!

TYPES OF DOUBLE STARS

Binary stars are classified into four types according to the way in which they are observed:

- visually - by observation;
- spectroscopically - by periodic changes in spectral lines;
- photometrically - by changes in brightness caused by an eclipse; or astrometrically - by measuring a deviation in a star's position caused by an unseen companion.

Any binary star can belong to several of these classes; for example, several spectroscopic binaries are also eclipsing binaries.

Visual binaries

A *visual binary* star is a binary star for which the angular separation between the two components is great enough to permit them to be observed as a double star in a telescope. The resolving power of the telescope is an important factor in the detection of visual binaries, and as telescopes become larger and more powerful an increasing number of visual binaries will be detected. The brightness of the two stars is also an important factor, as brighter stars are harder to separate due to their glare than dimmer ones are.

The brighter star of a visual binary is the *primary* star, and the dimmer is considered the *secondary.* In some publications (especially older ones), a faint secondary is called the *comes* (plural *comites*; English: *companion*.) If the stars are the same brightness, the discoverer designation for the primary is customarily accepted.

The position angle of the secondary with respect to the primary is measured, together with the angular distance between the two stars. The time of observation is also recorded. After a sufficient number of observations are recorded over a period of time, they are plotted in polar coordinates with the primary star at the origin, and the most probable ellipse is drawn through these points such that the Keplerian law of areas is satisfied. This ellipse is known as the *apparent ellipse*, and is the projection of the actual elliptical orbit of the secondary with respect to the primary on the plane of the sky. From this projected ellipse the complete elements of the orbit may be computed, with the semi-major axis being expressed in angular units unless the stellar parallax, and hence the distance, of the system is known.

Spectroscopic binaries

Sometimes, the only evidence of a binary star comes from the Doppler Effect on its emitted light. In these cases, the binary consists of a pair of stars where the spectral lines in the light emitted from each star shifts first toward the blue, then toward the red, as each moves first toward us, and then away from us, during its motion about their common center of mass, with the period of their common orbit.

In these systems, the separation between the stars is usually very small, and the orbital velocity very high. Unless the plane of the orbit happens to be perpendicular to the line of sight, the orbital velocities will have components in the line of sight and the observed radial velocity of the system will vary periodically. Since radial velocity can be measured with a spectrometer by observing the Doppler shift of the stars' spectral lines, the binaries detected in this manner are known as *spectroscopic binaries*. Most of these cannot be resolved as a visual binary, even with telescopes of the highest existing resolving power.

In some spectroscopic binaries, spectral lines from both stars are visible and the lines are alternately double and single. Such a system is known as a double-lined spectroscopic binary (often denoted "SB2"). In other systems, the spectrum of only one of the stars is seen and the lines in the spectrum shift periodically towards the blue, then towards red and back again. Such stars are known as single-lined spectroscopic binaries ("SB1").

The orbit of a spectroscopic binary is determined by making a long series of observations of the radial velocity of one or both components of the system. The observations are plotted against time, and from the resulting curve a period is determined. If the orbit is circular then the curve will be a sine curve. If the orbit is elliptical, the shape of the curve will depend on the eccentricity of the ellipse and the orientation of the major axis with reference to the line of sight.

It is impossible to determine individually the semi-major axis a and the inclination of the orbit plane i. However, the product of the semi-major axis and the sine of the inclination (i.e. $a \sin i$) may be determined directly in linear units (e.g. kilometers). If either a or i can be determined by other means, as in the case of eclipsing binaries, a complete solution for the orbit can be found.

Binary stars that are both visual and spectroscopic binaries are rare, and are a precious source of valuable information when found. Visual binary stars often have large true separations, with periods measured in decades to centuries; consequently, they usually have orbital speeds too small to be measured spectroscopically. Conversely, spectroscopic binary stars move fast in their orbits because they are close together, usually too close to be detected as visual binaries. Binaries that are both visual and spectroscopic thus must be relatively close to Earth.

Eclipsing binaries

An *eclipsing binary star* is a binary star in which the orbit plane of the two stars lies so nearly in the line of sight of the observer that the components undergo mutual eclipses. In the case where the binary is also a spectroscopic binary and the parallax of the system is known, the binary is quite valuable for stellar analysis. Algol is the best-known example of an eclipsing binary.

In the last decade, measurement of eclipsing binaries' fundamental parameters has become possible with 8 meter class telescopes. This makes it feasible to use them as standard candles. Recently, they have been used to give direct distance estimates to the LMC, SMC, Andromeda Galaxy and

Triangulum Galaxy. Eclipsing binaries offer a direct method to gauge the distance to galaxies to a new improved 5% level of accuracy.

Eclipsing binaries are variable stars, not because the light of the individual components vary but because of the eclipses. The light curve of an eclipsing binary is characterized by periods of practically constant light, with periodic drops in intensity. If one of the stars is larger than the other, one will be obscured by a total eclipse while the other will be obscured by an annular eclipse.
The period of the orbit of an eclipsing binary may be determined from a study of the light curve, and the relative sizes of the individual stars can be determined in terms of the radius of the orbit by observing how quickly the brightness changes as the disc of the near star slides over the disc of the distant star. If it is also a spectroscopic binary the orbital elements can also be determined, and the mass of the stars can be determined relatively easily, which means that the relative densities of the stars can be determined in this case.

Astrometric binaries

Astronomers have discovered some stars that seemingly orbit around an empty space. *Astrometric binaries* are relatively nearby stars which can be seen to wobble around a point in space, with no visible companion. The same mathematics used for ordinary binaries can be applied to infer the mass of the missing companion. The companion could be very dim, so that it is currently undetectable or masked by the glare of its primary, or it could be an object that emits little or no electromagnetic radiation, for example a neutron star.

The visible star's position is carefully measured and detected to vary, due to the gravitational influence from its counterpart. The position of the star is repeatedly measured relative to more distant stars, and then checked for periodic shifts in position. Typically this type of measurement can only be performed on nearby stars, such as those within 10 parsecs. Nearby stars often have a relatively high proper motion, so astrometric binaries will appear to follow a sinusoidal path across the sky.

If the companion is sufficiently massive to cause an observable shift in position of the star, then its presence can be deduced. From precise astrometric measurements of the movement of the visible star over a

sufficiently long period of time, information about the mass of the companion and its orbital period can be determined. Even though the companion is not visible, the characteristics of the system can be determined from the observations using Kepler's laws.
This method of detecting binaries is also used to locate extrasolar planets orbiting a star. However, the requirements to perform this measurement are very exacting, due to the great difference in the mass ratio, and the typically long period of the planet's orbit. Detection of position shifts of a star is a very exacting science, and it is difficult to achieve the necessary precision. Space telescopes can avoid the blurring effect of the Earth's atmosphere, resulting in more precise resolution.

Binary Star Designations

The components of binary stars are denoted by the suffixes *A* and *B* appended to the system's designation, *A* denoting the primary star and *B* the secondary star. The suffix *AB* may be used to denote the pair (for example, the binary star α Centauri AB consists of the stars α Centauri A and α Centauri B.) Additional letters, such as *C*, *D*, etc., may be used for systems with more than two stars. In cases where the binary star has a Bayer designation and is widely separated, it is possible that the members of the pair will be designated with superscripts; an example is ζ Reticuli, whose components are ζ^1 Reticuli and ζ^2 Reticuli.
Double stars are also designated by an abbreviation giving the discoverer together with an index number. α Centauri, for example, was found to be double by Father Richaud in 1689, and so is designated *RHD 1*. These discoverer codes can be found in the Washington Double Star Catalog.

BINARY STAR EVOLUTION

Formation of Binary Star Systems

While it is not impossible that some binaries might be created through gravitational capture between two single stars, given the very low likelihood of such an event (three objects are actually required, as conservation of energy rules out a single gravitating body capturing another) and the high number of binaries, this cannot be the primary formation process. Also, the observation of binaries consisting of pre main sequence stars supports the theory that binaries are already formed during star formation. Fragmentation

of the molecular cloud during the formation of protostars is an acceptable explanation for the formation of a binary or multiple star system.
The outcome of the three body problem, where the three stars are of comparable mass, is that eventually one of the three stars will be ejected from the system and, assuming no significant further perturbations, the remaining two will form a stable binary system.

Use in astrophysics

Binaries provide the best method for astronomers to determine the mass of a distant star. The gravitational pull between them causes them to orbit around their common center of mass. From the orbital pattern of a visual binary, or the time variation of the spectrum of a spectroscopic binary, the mass of its stars can be determined. In this way, the relation between a star's appearance (temperature and radius) and its mass can be found, which allows for the determination of the mass of non-binaries.

Because a large proportion of stars exist in binary systems, binaries are particularly important to our understanding of the processes by which stars form. In particular, the period and masses of the binary tell us about the amount of angular momentum in the system. Because this is a conserved quantity in physics, binaries give us important clues about the conditions under which the stars were formed.

For more information or if you are interested in observing Double Stars, please contact the director of the ASSA Double Star Section, **Lucas Ferreira**, at doublestar@assa.saao.ac.za or Tel: 083 376 4910

Double Star References

- *The Night Sky Observer's Guide* (two volumes) George R. Kepple & Glen W Sanner (Willman-Bell)
- *Burnham's Celestial Handbook* (three volumes) Robert Burnham Jr. (Dover Publications)
- *Norton's Star Atlas and Reference Handbook 19th Edition* Ian Ridpath (Prentice-Hall)
- *A Visual Atlas of Double Stars* Mike Ropelewski (The Webb Society)
- *A Field Guide to Double Star Observing* Joe DalSanto (self published)
- *Double Stars* – Wikipedia, the free encyclopedia.