Double Stars

Robert W. Argyle
Institute of Astronomy, University of Cambridge

Introduction

The observation of visual double stars is one subject in which the use of small telescopes, which I take to mean about 30 inches or less, has been of great importance—almost all of the work done in the subject since the early 19th century has been accomplished by instruments in this aperture class. Even the space-borne mission Hipparcos had a primary mirror only 11.4 inches in aperture. A century ago, binary stars with separations around 0.1 arc second could be measured with apertures of about 36 inches by the best observers. This limit can only be exceeded today by the use of techniques such as speckle interferometry as well as distributed arrays such as CHARA at Mount Wilson.

Brief History

Telescopic double star astronomy probably began on January 7, 1617, when Benedetto Castelli, a student and later colleague of Galileo, turned a telescope to zeta UMa in the Plough and found that Mizar, the brighter of the naked-eye double system of Mizar and Alcor, was itself a double star. The observation was confirmed by the great man himself about a week later and he gave the distance as 15 arc seconds. According to Leos Ondra, who brought this little known fact to prominence on his webpage, Castelli is reported to have said "It's one of the beautiful things in the sky and I don't believe that in our pursuit one could desire better." Over the next ten years Castelli and Galileo observed a few more bright and wide doubles but interest in double stars as something other than celestial curiosities did not begin to emerge until the late 18th century when the Moravian astronomer and Jesuit priest Christian Mayer of Mannheim compiled the first catalogue of double stars which contained 80 pairs (Schlimmer 2006).

In 1767, the English theoretician John Michell suggested, using a statistical argument, that stars which appear close in the sky are actually physically connected, thus implying that Newton's laws held for objects beyond the solar system. It was left to William Herschel to confirm the reality of orbital motion in 1803, when it was clear from measurements of double stars which he made with his telescopes and micrometers that the relative movement of one star against the other with time was not a straight line but a curve.

In 1824, F. G. W. Struve began his systematic search for new double stars with the 9.6-inch Fraunhofer refractor in Dorpat, now Tartu, in Estonia. Struve cataloged more than 3,000 objects and his contribution was enhanced by the fact that he re-observed many of these stars on more than one occasion, thus laying down a valuable series of early epoch observations for later generations of researchers. At the same time the Frenchman Savary was able to take the observations of xi UMa and from the apparent orbit calculated the elements of the true orbit, which in turn allowed the calculation of the mass sum and orbital size, provided the parallax of the system is known.

The exploits of Struve in the Northern Hemisphere and John Herschel in the South, who cataloged even more double stars from Feldhausen in South Africa, encouraged many others to turn to the observation of double stars. This led to a boom in the manufacture of relatively large (and expensive) refractors. In the UK, first the Cooke family, then the Grubbs in Ireland were making refractors for those wealthy individuals who were able to pay someone else to do the observing for them. In the USA the firms of Clark and Brashear performed the same function for college observatories and between about 1850 to about 1880 double star observation was probably reaching a peak of activity in the amateur community. In 1860 S. W. Burnham began his career with a 6-inch Clark refractor which, although relatively modest in aperture, had a far-reaching effect on double star astronomy as a whole. Burnham was possessed of remarkable eyesight and could discover companions to stars that others could barely see in much larger telescopes. Burnham reignited the desire for discovery which had essentially come to a stop after Herschel and Struve.

Burnham benefited from collaboration with the great Italian amateur astronomer Ercole Dembowski. The son of an aristocratic Polish General—he was officially Baron Dembowski—he made a very large number of measures (21,318 according to the WDS) with apertures no greater than 7.5-inches and yet his discoveries number less than 3 dozen. His painstaking attitude to observing meant that his measures were regarded with great confidence by other observers and he supplied the first measurements of many of Burnham's early discoveries, in addition to re-observing virtually all of the 3,134 stars in Struve's Dorpat catalog, thus earning the gratitude of modern day orbit computers.

At Lick Observatory, W. J. Hussey and R. G. Aitken started to make systematic sweeps for double stars with the 36-inch refractor. They discovered thousands of new difficult binaries, and with the completion of the systematic northern surveys, the time came to cover the sky from the south. Hussey was the driving force behind the purchase of a 27-inch refractor (later called the Lamont-Hussey telescope) to be based at Bloemfontein in South Africa. Another similar instrument, a Grubb refractor of 26.5 inches, was erected in Johannesburg as part of the Union Observatory and started operations in 1925. This was used by R. T. A. Innes, W. H. van den Bos, and W. S. Finsen, and remained in regular operation until 1971. It is still in working condition and the writer spent three weeks in Johannesburg in 2008 making micrometric measurements. The Lamont-Hussey telescope, used so thoroughly by Rossiter and co-workers, was given a new lease on life by the University of Michigan after Rossiter retired, but closed for good in 1974.

It is worth noting that some of the greatest contributors to double star measurement during the last century were either amateurs, such as Baize, or used relatively small apertures, such as Rabe. Baize made many of his observations in Paris using the 12-inch refractor, and his efforts put him 10th on the all time list of visual observers as compiled by Brian Mason at USNO. Baize made 24,268 measures divided into 7,814 means while Rabe mostly employed a 10.5-inch Fraunhofer/Merz refractor from 1835 at the University of Munich. His total of 37,644 measures and 6,442 means puts him in 4th place.

The Hipparcos satellite, launched from South America in 1988, eventually produced, after a few trials and tribulations, an astrometric (and photometric) catalog of unparalleled accuracy. One of the consequences was the not unexpected appearance of many new double stars, a lot of which are difficult to resolve from the ground because the components are close or unequally bright. The WDS contains 3,382 HDS pairs and 14,247 TDS/TDT (Tycho) pairs, all found by Hipparcos during its mission, but many of these require further measurement either for confirmation or to check for orbital motion because of the limited lifetime of the satellite.

The Present

Regular measurement of double stars by professional astronomers is preferably carried out using speckle interferometry, long base-line optical interferometry, or lucky imaging. Visual measurement of double stars remains as useful today as it was in the early days of the science because of the long time scales involved. In fact it could be argued that it is more important as the number of known systems is much larger than Struve's day (>100,000 systems as opposed to 3,000) and with only the closest being given attention, this suggests that a large proportion of the binaries in the catalog are under-observed. This is certainly true of southern binaries and stars in the HDS and TDS catalogs, already mentioned. There are a number of regular programs of measurement of `wide' binaries, say from 0.5 arc seconds upwards, by professional observatories—notably at Washington and Merate (Mason et al 2008; Scardia et al 2008). These programs tend to concentrate on slow moving pairs brighter than about 9th magnitude, but observers such as Andreas Alzner (Alzner 2004) have shown that with a 35-cm telescope it is possible both to reach separations of about 0.3 arc second and to resolve a number of Hipparcos double stars from the ground. A very promising technique which has been ably demonstrated by Rainer Anton is lucky imaging (Anton 2009). Apart from the obvious application to binary stars, the technique has been used on the 200-inch to produce better resolution than the HST (Mackay 2008).

Instrumentation

A telescope, if it is to be used for close visual binary stars, should preferably be on a solid equatorial mounting with a good drive. The reasons for this are that double stars tend to require rather high powers, and measurement of double star parameters is much easier with an equatorial mount since it overcomes the problem of field rotation, and a good drive is essential if a micrometer or a CCD camera is to be used.

Filar and double image micrometers are commercially available. The writer uses the RETEL instrument (e-mail: damian@retelmd.co.uk for further details). This is a compact instrument which uses two fixed orthogonal wires plus a third movable wire under the control of an engineering micrometer screw. The range of travel is about 13 mm, which means that with a telescope of 9 meters effective focal length, pairs with separations up to about 140 seconds of arc can be measured. The lower limit is essentially the resolving limit of the telescope—around 0.55 arc seconds in the case for fully resolved disks. The man-made wires are 12 microns in diameter which for the 8-inch Cooke converts to about 0.9 arc seconds. Using an x3 Barlow reduces the apparent size of the wires to about 0.3 arc second which is well matched to the resolving power of the telescope. Red field illumination is by an LED in the body of the micrometer and is not the best solution.

The double-image micrometer manufactured by Meca-Precis in France dispenses with the probe of wires and field illumination (for more details e-mail: mecaprecis36@wanadoo.fr). By virtue of its bi-refringent Lyot prism, each star image in the eyepiece is doubled due to the splitting of the light into ordinary and extraordinary rays. Double stars therefore produce four images. The prism is mounted on the optical axis and can be both tilted toward and away from the observer and also rotated. The tilt of the prism increases the separations between the ordinary and extraordinary rays and this is used to measure the separation of the pair. There are a number of patterns which can be used to measure double stars this way—either arranging the images all in a line with each image equally distant from the next—or in squares and so on (Alzner 2004). For a comparison of the RETEL and Meca-Precis micrometers, see Alzner (2001).

Another possibility is the van Slyke micrometer, (see http.observatory.org/bfm.htm) which, although it is called a bifilar micrometer, appears to operate on a system of etched reticules in which the grid lines are 10 micron in diameter.

Another very popular instrument is the graticule or graticle eyepiece, particularly as manufactured by Meade or Celestron. These have been applied mostly to wide pairs for proper motion investigation and the coarseness of the graticules makes then unsuitable for closer, binary pairs.

In recent years with the availability of small pixel chips, there are exciting possibilities for observers with small telescopes to make significant contributions. For binary stars, at least, a large field is not necessary and indeed the smaller the field the better, as this allows the chip to be read out more quickly, and requires less disk space. Video cameras can also be used and are especially useful as they can be read out at high frame speeds. Readout speeds of 100 Hz or more begin to approach the frequency with which the atmosphere fluctuates and so it becomes possible to `freeze' the atmospheric turbulence. With this information, the technique of lucky imaging can be applied and this is explained more fully by Rainer Anton in a chapter in the coming book, *Lightweight Alt-Az Telescope Developments* (Anton 2010).

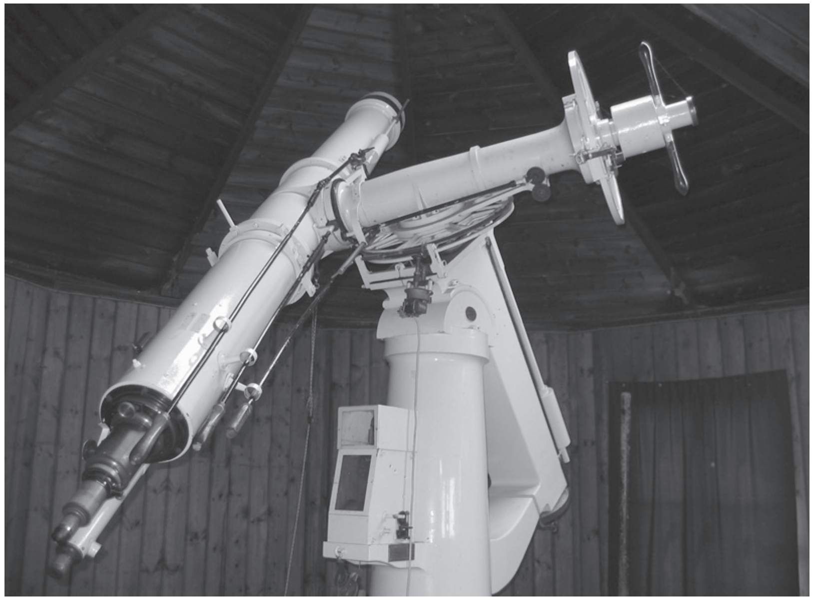

Figure 1: 8-inch Cooke refractor used by the author for double star measurements.

If you cannot afford one or do not possess a telescope or the associated equipment, is there an instrument near you which is not being used? Over the years I have heard from colleagues in the USA pointing out that the local college observatory has a restored Clark or Brashear refractor which is used occasionally for public viewing. Telescopes like this were built to be used for observing, not as museum exhibits. I use an 8-inch Cooke refractor from 1864 which was built for the Reverend W. R. Dawes. After Dawes' death it passed through other hands, particularly those of W. H. Maw who used it for extensive double star measurement. It fell into disuse for a time but since being set up on its present site at Cambridge in 1929, it has been regularly used, particularly by the University Astronomical Society and for the last 18 years by me for double star measurement. Examples of series of measures on two binary stars are given in Figures 2 & 3.

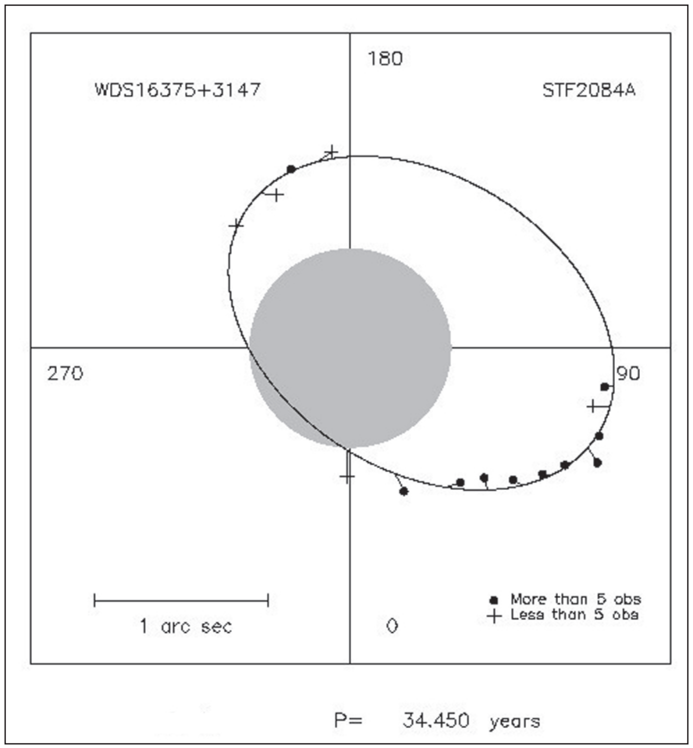

Figure 2: The apparent orbit of zeta Herculis (P=34.45 years) observed at Cambridge. The first point (at PA 80 degs) is from 1990, the last from 2008.

The telescope (Figure 1, previous page) has barely changed since Dawes' day—the original clockwork drive has been replaced by an electric motor—but the lens remains as good as it was when it was made and on the best nights produces outstandingly crisp images of double stars. In Spring 2005 the well-known binary gamma Virginis was seen elongated as it passed through periastron at a distance of 0.37 arc second.

What to measure

The main product of binary star measurements is stellar masses. Relative astrometry, i.e. the measurement of position angle and separation with time, allows the apparent ellipse to be drawn. The elements of the true orbit can be derived from this and in turn the total mass of the system, if the parallax is

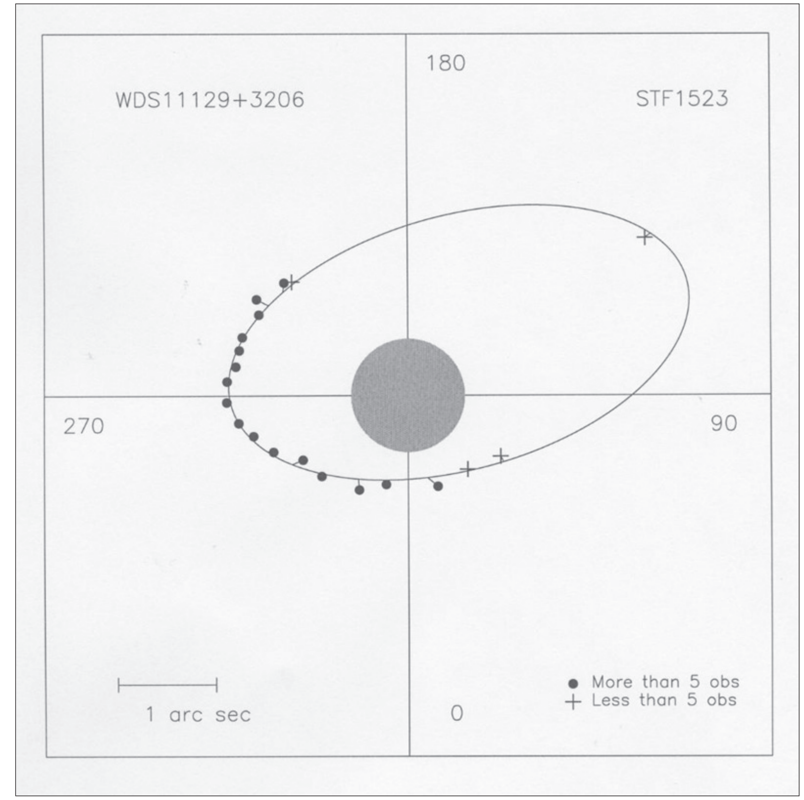

Figure 3: Xi UMa has a period of about 60 years. The solitary point was taken in 1970 and the remaining ones cover the period 1990 to 2008 inclusive (companion moving anticlockwise).

known. In order to get the individual masses, you measure each component with respect to the stellar background and then obtain not one but two apparent ellipses; the ratio of the size of the ellipses being inversely proportional to the ratio of the individual masses. Alternatively, making radial velocity measurements of the two stars can give an independent measurement for the sum of the masses, and in combination with the visual orbit each mass can then be derived. Both these techniques require professional instrumentation. Of course, it may be possible to make a good estimate of the stellar masses from other factors – magnitudes, colors, spectral type, and so on, but on the whole the amateur observer must content himself with the fact that his observations will lead to the mass sum.

Measuring the relative positions of optical double stars leads to proper motions and it is clear that if done properly this can match or even exceed the precision from the Hipparcos mission, which was constrained by collecting data for only three and a half years. Double star observers can call on up to 200 years of archival data to plot the motion of one star with respect to the other. Note that you still need an independent proper motion for one or the other star to determine the motions of both components. David Arnold deals with the subject of proper motion determination in double stars elsewhere in this book (Chapter 11).

Orbit calculation

Orbit calculation is certainly something that can be done by anyone with the proper training but it is not just an application of a number of equations. The data used to define the apparent orbit can be many and varied, from measures made with small telescopes and filar micrometers to those made with large telescopes and speckle interferometers, and even ground-based arrays. To use all this data properly it is necessary to appreciate that the law of areas applies and any fitted ellipse must satisfy this criterion. It is not enough to fit an ellipse through a series of points by eye. Also to be considered is the relative precision which each technique brings and to consider how each point may be weighted. The main problem is that orbits are attempted which are too premature. It is preferable that at least 180 degrees of motion have been observed and that this includes one end of the apparent ellipse, preferably the one including periastron. My own preference is for observation–7,200 measures to date.

Practicing double star astronomers publish new orbital elements in the Circular of Commission 26 (Double and Multiple Stars) of the International Astronomical Union. Past circulars can be found on the Internet.

What to observe

Many of the visual binary systems to be found in the Washington Double Star catalog are of long period—greater than the human lifespan—so measurements of these pairs must be regarded as an ongoing project. In cases where the orbits are not particularly eccentric, the motion will be steady and slow and, even to the enthusiastic observer, not particularly exciting, but they are useful nevertheless. The USNO grades the quality of an orbit from 1 (definitive) to 5 (indeterminate). Most of the grade 1 orbits have periods of 100 years or less, so there are many bright long-period binaries where regular and accurate measurement at intervals of say 2 to 5 years would be welcome by observers of the future. Such pairs tend to be wider and therefore producing accurate measures is easier. Examples are mu Cyg, delta Cyg, mu Boo, mu Dra, and zeta Aqr. The latter system is now deviating from the

latest orbit and further observations will be important in defining the future motion—see Anton (2009).

Another reason to continue to observe the brighter systems is to look for signs of third components. These stars make themselves known by the gravitational tug they apply to the visible stars in the system. The classic case is zeta Cancri, whose 4th component was known 150 years ago but imaged only for the first time about 8 years ago. Other such systems are known—zeta Aquarii has a 25-year astrometric perturbation; in lambda Cygni, it is 11 years. Both the bright pairs 70 Ophiuchi and zeta Herculis have been suspected of harbouring third components but no firm evidence is available as yet. I have observed the zeta Cancri system every Spring since 1990 and after a few years it was apparent that the effect of the fourth star on the 6 arc second component in the visual triple was becoming visible in the measures. The CD system has a period close to 18 years, so I now have measures covering one complete orbital cycle of CD. In measuring C with respect to AB, I set the micrometer wire to the geometric centre of the image of AB since this is rather easier than trying to set on either A or B. Unfortunately, the orbital ephemeris works on the centers of mass and not light and this means that producing the predicted position of AB-C is not trivial. The figures on the next page show the results of my observations plotted against the theoretical curve of the motion of AB-C with the effect of D applied. The observations are close to the limit of what can be achieved with this set-up; the size of the observed oscillation during the 18 year period is 0.3 arc second which is the same as the apparent thickness of each micrometer wire. I am greatly indebted to Andreas Alzner for the ephemeris.

Those with 8 to 12-inch telescopes and CCD cameras can use them to image faint double stars, many of which are not yet in the catalogs. Imaging of brighter pairs may reveal previously hidden extra components. Coronagraphic imaging such as the enterprising work undertaken by James Daley (2007) can help in this regard.

For those lucky enough to have a large aperture, say 16 to 20 inches, it is perfectly feasible to measure binaries down to separations of about 0.3 arc second whether by micrometer or CCD camera

The southern hemisphere

It is certainly true that there are many interesting binaries in the southern sky which need regular attention. An excellent example of this is the bright pair beta Phe, discovered by R. P. Sellors in 1891. The pair was regularly observed through apastron when motion was relatively slow but as the motion speeded up from the 1970s onwards, there were few observations until some

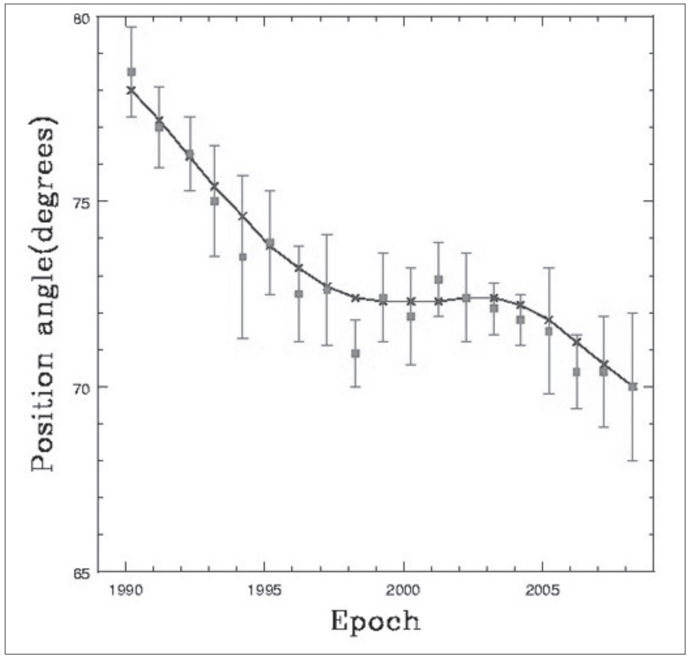

Figure 4: Observed and calculated position angles for zeta Cnc AB-C.

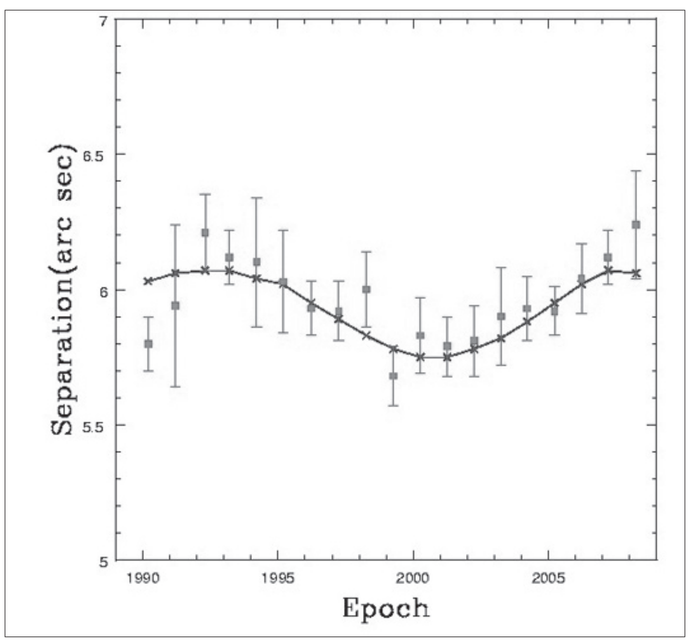

Figure 5: Observed and calculated separations for zeta Cnc AB-C.

speckle observations in the 1990s and even then the first orbit by Alzner did not appear until 2002 (Argyle et al 2002). Figure 6 (below) shows several interesting aspects. Although periastron was predicted by this orbit for 2003, no observations were made again until 2006 when the stars were too close for the 24-inch Lowell-Tololo telescope. The observation by Rainer Anton in 2008 has shown that the first orbit now needs to be revised. Another point worth noting is how the earlier measurements, while not particularly in good agreement, at least constrain the size of the apparent orbit and allow an ellipse to be fitted. Normally, measures of pairs around the 1 arc second mark do not result in errors in separation of 15% - 20%, but in the case of beta Phe the two stars are very bright (magnitudes 4.1 and 4.2). A similar case is that of the even brighter star delta Velorum (see Otero, 2006). That these bright systems are under-observed is entirely due to the paucity of observers in the southern hemisphere and it is clear that properly equipped amateur observers can fill this gap. Clearly the larger 50-cm aperture used by Anton is useful but the technique of lucky imaging means that the observer does not have to acquire the skill needed for micrometric measurement and the results are more effective.

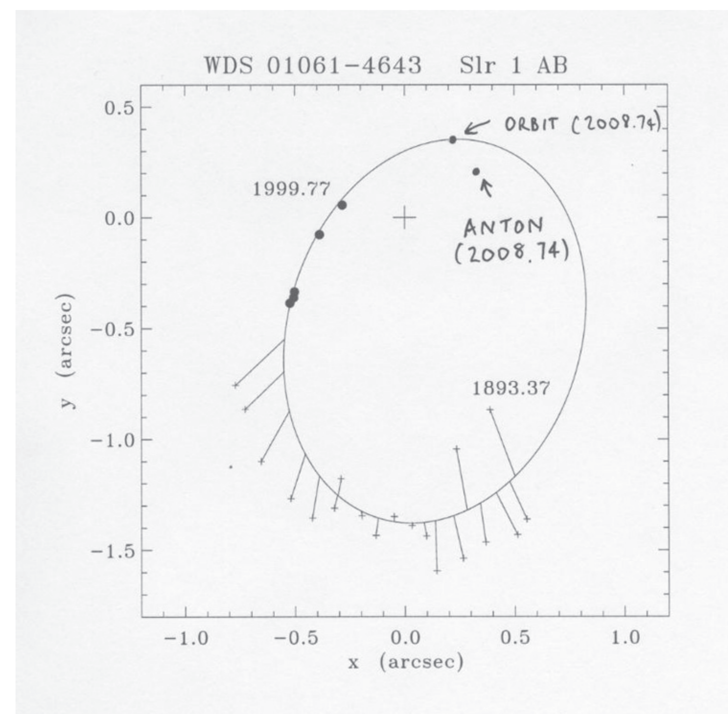

Figure 6: Observed positions and orbit for beta Phe.

Catalogues and Publications

Double star observers are fortunate in having a single central repository, the Washington Double Star Catalog known universally as the WDS for reference. In addition, it is maintained by Brian Mason, who is unfailingly cooperative in his dealings with observers, and who has constantly stressed the importance of contributions made by amateur observers. The days are long gone when the double star catalog was a twin volume set of close-packed type and available only in major observatories and a request for data would bring, a week or so later, a huge package from Charles Worley containing a thick stack of computer printout. Now thanks to Mason and colleagues, it is updated every night and is available to anyone with a modem (or on CD-ROM by application to USNO for anyone without). It takes no more than a few minutes to download the 13 MB file and its associated references and notes files. What is not available is the Observations Catalog, which contains some 750,000 single measurements, but requests for data can be submitted via the WDS website. Other useful catalogs are the Sixth Orbital catalog—again regularly updated—and, for the specialist, the Fourth Interferometric Catalog. For the optical pair enthusiast there is the Linear Elements Catalog. Full details can be found in the article by Mason (2005).

Equally useful on the WDS website are the files of neglected observations, which have been divided into three sections—north, equatorial, and south—and then into groups of difficulty. Many modern observers have been grateful to have these lists to work from and slowly re-observe the many long-neglected pairs that populate the WDS. This helps to concentrate minds on systems which have been under-observed. There are also the occasional errors in the catalog which surface from time to time and I know that the efforts to find solutions for these cases are appreciated by the WDS management, as is work carried out to find pairs whose input positions are either poor or the stars involved have high proper motions (see for instance the work on the Luyten common proper motion pairs carried out by Richard Jaworski (2005)).

Measures of double stars, provided the author thinks they are reliable, should be published and these days that means placed on-line at a dedicated website. For the amateur observer there are two main sites - *Journal of Double Star Observations* (www.jdso.org) and the Webb Society Double Star Section (www.webbdeepsky.com/dssc). Then, if the editors of these publications and the folks at USNO are happy, the measures will enter the Observations Catalog.

Organizations

The *Journal of Double Star Observations* is described elsewhere in this volume by Kent Clark (Chapter 12). The Webb Society group formed in 1968, but it was not until a decade later that measurements with grating micrometers were being tried. By 1990 or so, commercial filar micrometers were generally available and micrometer measurement became more widespread. Although these devices were (and still are) relatively expensive, they have proved to be reliable. The man-made micrometer wires installed in the RETEL micrometer have proved to be very long lasting—I have made approximately 75,000 individual settings of position angle and separation in 18 years. By the beginning of the present decade, CCD cameras and web-based astrometry were beginning to fill many of the pages of the Circulars. Early issues of the DSSC appeared at intervals of a few years, but recent editions are appearing annually, a testament to increased interest in the subject and to the extra observations being submitted. Other organizations also exist to serve the double star observer—there is a list on the WDS website.

Conclusion

The amateur still has a role to play in visual double star astronomy, especially from the southern hemisphere. It was Ejnar Hertsprung who said in 1961,"The debt to our ancestors for the observations they made to our benefit, we can pay only by doing the same for our ancestors."

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