Displaying New Measurements on WDS Orbit Plots

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Abstract: Students who observe and measure a visual double star often want to see how their measurement compares with the historical record and with the orbit (if one has been determined). This paper describes how PowerPoint's graphical tools can display a newly-measured data point on the orbit plot from USNO's 6th Orbit Catalog, and how a simple spreadsheet can transform measurements expressed as (ρ,θ) into a Cartesian plot of the sky positions (E, N). This information is presented as a resource for future students.

Introduction

Observing and measuring visual double stars is a fruitful project for student research (Genet, et al 2012). It provides the students with a genuine research experience, it requires only a few hours of telescope time, and it provides the double-star community with a new source of measurements (separation and position angle) of neglected pairs.

Students frequently want to see how their measurement "fits in" with the historical record, and they are particularly interested in comparing their measurements to the published orbit of the pair they have measured.

This paper describes two tools that have been used by students under my guidance, that seem to meet their needs: (1) a graphical method of displaying their new measurements on the orbit plot from the 6th Orbit Catalog, and (2) a spreadsheet method to display the new measurement alongside the historical measurements for a pair whose orbit has not yet been determined.

Displaying a New Measurement on the Orbit Plot

If the pair under study has an orbit in the 6th Orbit Catalog, students would like to display their new measurement on the orbit plot, at a level of accuracy that is appropriate for an illustration in their report, such as Figure 1.

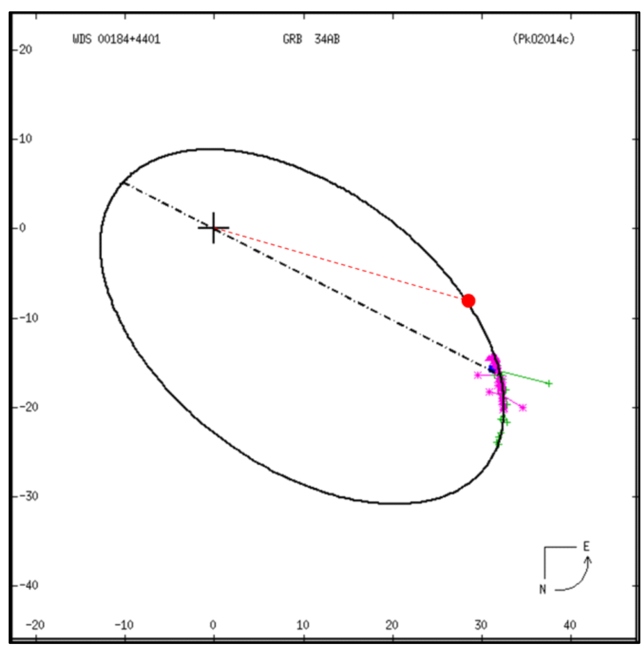


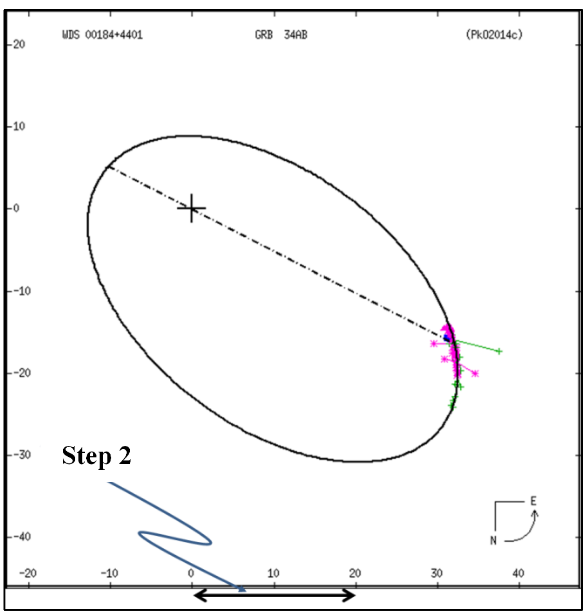
Figure 1. Example of an illustration that shows how a newly-measured position "fits in" to the orbit of a visual double star. The red dot is the student-measured position (ρ, θ).

The concept is straightforward: draw a line whose length represents the measured separation (ρ), at the scale of the orbit diagram, and rotate the line to align it with the measured position angle (θ). The presentation software MS PowerPoint contains graphics capability that can do this. The procedure – and the relevant commands – for doing this in PowerPoint 2010 are described in the following.

- Step 1: From the WDS 6th orbit catalog, display the orbit plot (in your browser). COPY and PASTE it into PowerPoint.

Scale it larger/smaller to make it nearly fill the PowerPoint frame. Use the setting FORMAT – SIZE - "lock aspect ratio" to maintain the same scale in x- and y-axes. The exact size of the image is not important.

- Step 2: Use the command INSERT-SHAPES to draw a horizontal line that spans an appropriate distance along the x-axis. (In the example below, the line was drawn to span 20 arc-sec, according to the scale on the orbit plot)



Use the FORMAT command to set the height of the line to zero (i.e. a perfectly horizontal line). The FORMAT block will then display the length of the line, to ±0.01 inch.

Read the length of the line (in inches) and calculate the scale factor of the image.

In the example shown, the reference line as drawn was 1.77 inches long. So, in this example, the scale factor is 1.77 inches per 20 arc-sec.

- Step 3: Use the command INSERT-SHAPES to draw a vertical line (hence aligned with North).

Use the FORMAT command to set the width of the line to zero (i.e. a perfectly vertical line). Set its length ("height") to match your separation measurement:

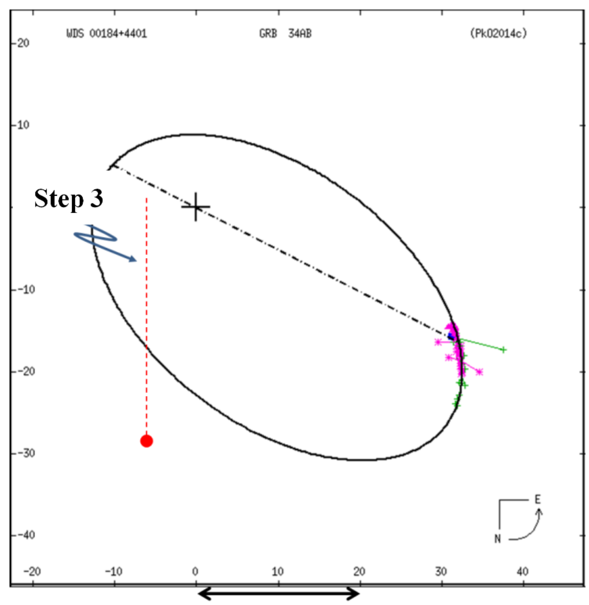
For example: suppose your measured separation was ρ= 29.75 arc sec,

Convert this to inches at the drawing's scale:

29.75 arc-sec *1.77/20 (inches/arc-sec) = 2.63 inches.

Note, at this point, it isn't necessary that the line be sitting on the location of the primary star ... just get it vertical and make it the correct length. An example is shown below.

Optionally, you can use the FORMAT – SHAPE OUTLINE command to set the color of the line, and FORMAT – SHAPE OUTLINE – ARROWS to put a symbol at the south end (e.g. the large "dot" shown in the example). You can also use FORMAT – SHAPE OUTLINE – DASHES to select the type of dashed line, and FORMAT – SHAPE OUTLINE – WEIGHT to set the desired thickness of the line.



- Step 4: Rotate the line by selecting it (click on it), and using the Drawing tool FORMAT – ROTATE – MORE ROTATION OPTIONS. This will open a window that allows you to enter a rotation angle.

Beware of the sign convention for rotation. On the USNO orbit plots, position angle increases in the counter-clockwise direction ("North toward East"). In PowerPoint, counter-clockwise rotation is *negative*.

For example: If your measured position angle was θ = 74 degrees, then in PowerPoint you select the line and set the rotation angle to -74 degrees (i.e. a *negative* angle).

The result for this example is illustrated below.

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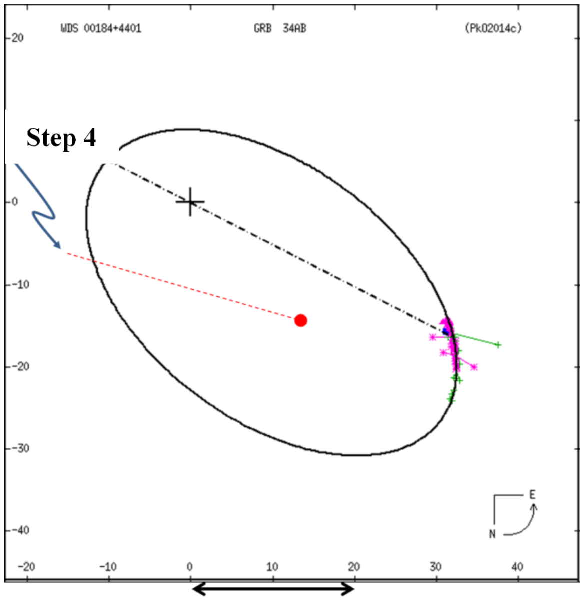


When PowerPoint rotates the line, it uses the midpoint of the line as the center of rotation. As a result, both ends of the line move and it may appear as if the line has translated. This is not a problem: the next step is to translate the line into the correct position.

- Step 5: Translate the line so that one end sits on the position of the primary star (the "+" on the orbit diagram). In PowerPoint, click-hold on the line and drag it up/down and left/right so that one end sits on the location of the primary star. The other end will then mark the position that represents your new measurement of ρ, θ, as was illustrated in Figure 1.

You can then put this diagram into your report. In PowerPoint, use SELECT ALL, then right-click to COPY; and in your Word processor right-click and use PASTE OPTIONS to paste the diagram as a PICTURE.

Plotting Historical Data

An e-mail request to USNO will return all of the historical measurements of a double-star of interest (including all components, if there are more than two). The data is provided as a plain text file that contains (among other parameters) the date, measured position angle, and measured separation for each historical measurement of the pair. It is instructive for students to visualize the apparent motion of the pair as it would be seen in the plane of the sky, and to insert their own measurement to see how it "fits" with the historical data. This is a simple exercise with a spreadsheet, and it

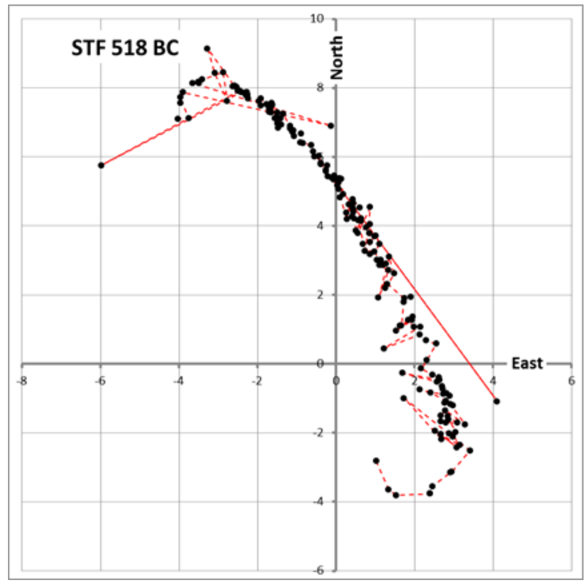
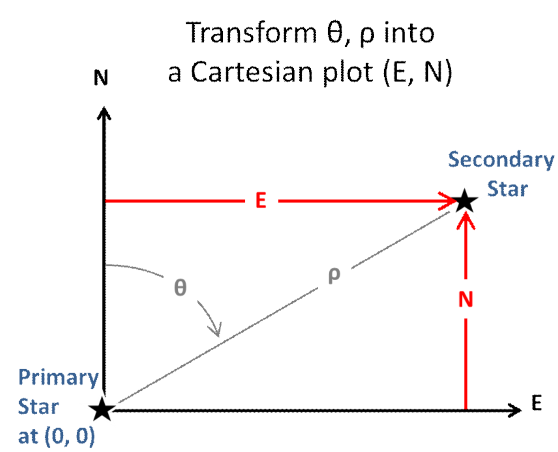


Figure 2: Example of a plot of historical measurements (ρ,θ) converted into a Cartesian-coordinate display of the trajectory of the secondary star as it would be seen relative to the primary, in the plane of the sky.

is a practical application of the lessons they had in their math classes, about Cartesian coordinates and trigonometry functions. Figure 2 shows an example of the goal of this exercise.

The concept should be familiar to high school students who have taken trigonometry, except that the angle θ is defined differently than the angle used in standard cylindrical coordinates.



The description of the position of the secondary star is transformed from ρ, θ (cylindrical coordinates) into E, N (Cartesian coordinates) using equations that should be familiar to high school students:

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$$\cos(\theta) = \frac{N}{\rho}$$

and

$$\sin(\theta) = \frac{E}{\rho}$$

so that the transformation is

$$E = \rho \sin\theta \qquad \text{in arc-seconds} \tag{1}$$

and

$$N = \rho \cos\theta \qquad \text{in arc-seconds} \tag{2}$$

Doing the transformation and plotting the trajectory of the secondary star is a simple spreadsheet exercise:

- Step 1: Prepare a spreadsheet workbook with three columns, for Date, Position angle, and Separation. Enter all historical observations, one observation per row, into this spreadsheet. Dates should follow the WDS format (decimal year). Position angle (θ) will be in degrees (measured from North toward the East) and Separation (ρ) will be in arc-seconds.
- Step 2: At the bottom of the table of observations (date, θ, ρ), insert the students' new measurement (date, theta, θ, ρ).
- Step 3: In two columns to the right, program the equations Eq. 1 and Eq. 2, to calculate the Cartesian coordinates E ("east") and N ("north). Copy these equations downward, so that each observation is transformed to E, N coordinates.

Beware that most spreadsheets (such as MS Excel) expect the angle in trig formulas to be expressed in radians (not degrees). Thus, the spreadsheet formulas will be sin($\theta\pi$ / 180) and cos($\theta\pi$ / 180), when the angle θ is expressed in degrees.

- Step 4: Create a graph that shows the measurements in Cartesian coordinates, to illustrate the trajectory of the secondary star relative to the primary, as it would appear in the sky. Select the two columns containing the calculated "E" and "N" coordinates, including all of the rows for all historical (and new) measurements. With the data array selected, use the command INSERT – SCATTER to create a scatter chart from this data.

This will yield a plot similar to Figure 2

This sort of display can highlight several features of the data. First, the graph is an intuitive visual display of the trajectory of the secondary star. In the example of Figure 2, a little imagination will suggest the shape of a probable elliptical orbit.

Second, the plot nicely displays the more-or-less random "scatter" in the observations, with individual points being arrayed near the probable orbit, but not lying cleanly on it. The inevitability of some random uncertainty in any scientific measurement is an important lesson for the students, and it can be seen in their own double star measurements.

Third, most plots will show some discordant data points – measurements that fall significantly "off" of their expected locations, given the overall trend of the majority of data points. In situations where there are only a few historical measurements, the student can be challenged to think about whether a discordant measure is "wrong", or if it is just a manifestation of normal measurement uncertainty; and of the difficulty of reaching a conclusion about an individual data point. This can lead to a discussion of when – if ever – it might be appropriate to "toss out" a data point.

Finally, it may be useful to format the data point that represents the students' measurement so that it is highlighted relative to the historical measurements. This gives the student a clear picture of how their measurement "fits in" to the historical record.

Limitations

The display methods presented here (Figure 1 and Figure 2) are intended only as tools for visualization of double-star motion. They are not appropriate for determining orbits, nor for quantitative assessment of the residuals between an orbit versus a new measurement. If a quantitative comparison of a new measurement to an orbit is needed, then the student must refer to the orbit ephemeris (USNO 6th Orbit Catalog) and use a rigorous calculation of the residual, such as that described in Smith et al 2016.

Acknowledgement

This research has made use of the Washington Double Star Catalog and Sixth Catalog of Orbits of Visual Binary Stars, both of which are maintained at the U.S. Naval Observatory.

References

Smith et al 2016: Nick Smith, Chris Foster, Blake Myers, Barbel Sepulveda, and Russell Genet, "Orbital Plotting of WDS 04545-0314 and WDS 04478+5318", JDSO Vol 12 No 1 (January 2016)

Genet et al 2012: Russell M. Genet, "Observing Double Stars", Proceedings of 31st SAS Symposium (May 2012)