

# User's Guide to PS3 Speckle Interferometry Reduction Program

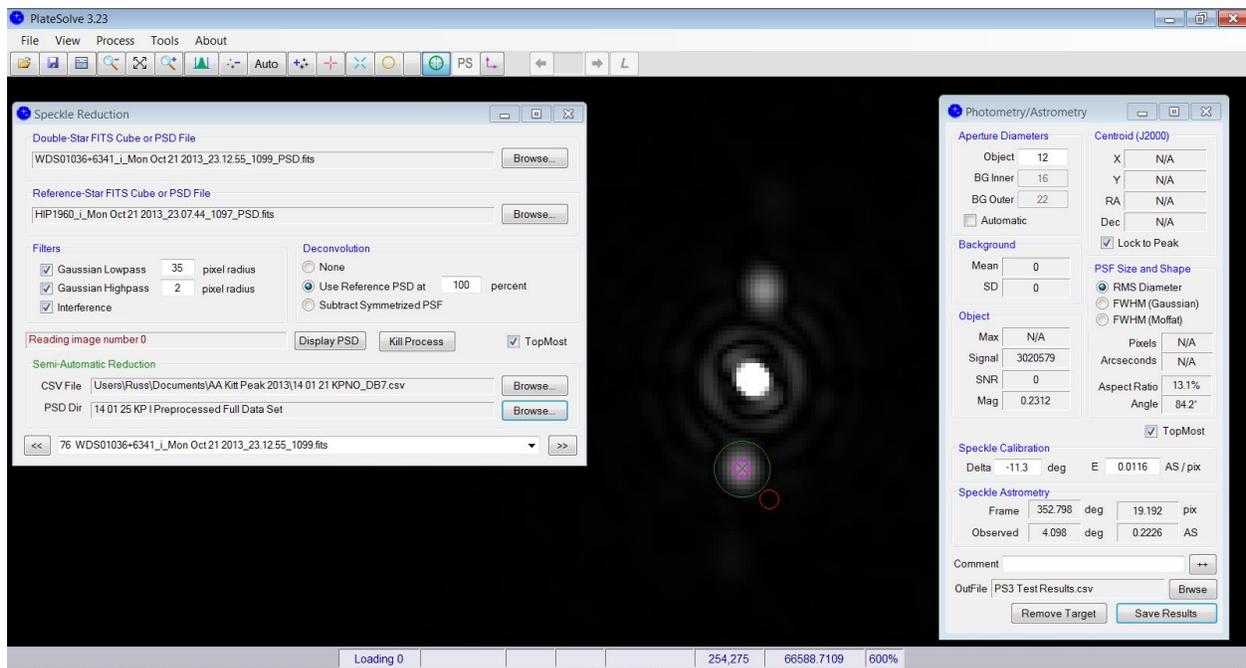
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**Abstract** The PS3 Speckle Interferometry Reduction Program, which runs on Windows PCs, reduces FITS cubes of close double star images taken at high speed. Single comparison star image cubes can optionally be used for deconvolution to help remove unwanted atmospheric and optical distortions. Data cubes can be automatically preprocessed to speed up the reduction process. Preprocessing can reduce the data volume by a factor of 1000, facilitating Internet transfers. Gaussian high- and low-pass filters can be employed to improve the signal-to-noise ratios. The Program can be run in either a manual or semi-automatic mode. Results are placed on a spreadsheet, and autocorrelograms are placed in a file.

## Introduction

PlateSolve 3 (PS3) is a general purpose program developed for stellar astrometry by one of us (Rowe). Given an image with a sufficient number of stars—but without any information as to plate scale, camera angle, RA, or Dec—PS3, using a patented process, quickly determines the plate scale, camera angle, and the RA and Dec of the image center. The main screen is shown in Figure 1.



**Figure 1.** The two major GUIs for PS3 speckle reduction are *Speckle Reduction* (left) and *Photometry/Astrometry* (right). In between the two is a typical double star image.

Besides this unique plate solving capability, PS3 also has many other capabilities such as viewing FITS headers, subtracting darks and flat fielding, aligning and combining images, lucky imaging analysis, and the double star speckle interferometry reduction process described in this paper.

This description of speckle reduction covers: *Preprocessing* of the data, which greatly speeds up the reduction process; *Speckle Reduction*, which sets the reduction parameters and modes and selects the input; *CSV Input File*, which, with PS3 running in a semi-automatic reduction mode, reads a CSV file with the list of object values used in subsequent double star reduction, facilitating much faster reduction of large data sets; *Photometry/Astrometry Tool*, which readies a reduction for final output (including insertion of comments); and the output file, *OutFile*, which records the results (including an image of the final reduction).

### Preprocess FITS Cubes Folder

Preprocessing allows an entire folder of raw FITS data cubes to be preprocessed automatically. For each image in the original FITS cube, the modulus squared of the Fourier transform is computed. This is called the power spectrum. The average of all the power spectra is computed and then saved as the preprocessed FITS image. These preprocessed data cubes are megabytes instead of gigabytes in size, greatly reducing the overall file size. For example, the raw FITS data cubes data file from a run on a 2.1-meter telescope at Kitt Peak National Observatory in October 2013 was 1.4 terabytes. After preprocessing, it was a manageable 1.2 gigabytes, allowing downloading via the Internet. Not only does preprocessing produce manageable file sizes, but after preprocessing, the computer time required for each reduction is just seconds instead of minutes.

To preprocess a file of raw FITS data cubes, go to *Tools* and select *Process FITS Cube(s)*. Click *Select FITS Cubes*, navigate to the appropriate folder, and, using the multifile selection feature of Windows, select the file to be preprocessed. Under Target Folder, check Save Images in New Folder and click Browse to select the destination folder. Finally, click Process and the FITS cubes will be preprocessed. This can take many hours, but it only needs to be done once and it runs unattended. *Cancel* can be used at any time to stop the preprocessing. It is important to allow the suffix *\_PSD* to be added to the file name to differentiate the preprocessed FITS cubes from the “raw” FITS cubes. This suffix is required when using the semi-automated features of PS3.

On a Windows-7 machine with a 2 GHz processor, it takes approximately 2 minutes to preprocess a FITS cube with 1000 512x512 images. For a long, multi-night run, there can be upwards of 1000 data cubes, so preprocessing can take more than 24 hours.

### Speckle Reduction (Used to set the reduction parameters and modes)

Once the FITS cubes have been preprocessed (although the preprocessing step can be skipped, we do not recommend it), go to *Tools* and select *Speckle Reduction*. Figure 2 shows the overall GUI.

For a run on a specific telescope, the *Filters* can often be set once (perhaps after some experimentation) and then left alone for the reduction of an entire run. Proper setting of the two Gaussian filters should optimize the detection and measurement of the double. The *Gaussian Lowpass*, *Gaussian Highpass*, and *Interference* filters are each described below.

#### *Gaussian Lowpass Filter*

A telescope’s optical system is a spatial low pass filter where the low pass cutoff frequency (in pixels) is a function of the wavelength, the f/ratio of the telescope, and the size of the pixels. Recall that the Airy disk radius, R, is given by

$$R = 1.22 * \text{Lambda} * F/D$$

where Lambda is the wavelength and F/D is the focal ratio of optical system. In pixels, this is given by

$$R(\text{pixels}) = 1.22 * \text{Lambda} * (F/D) / h$$

where h is the pixel dimension.

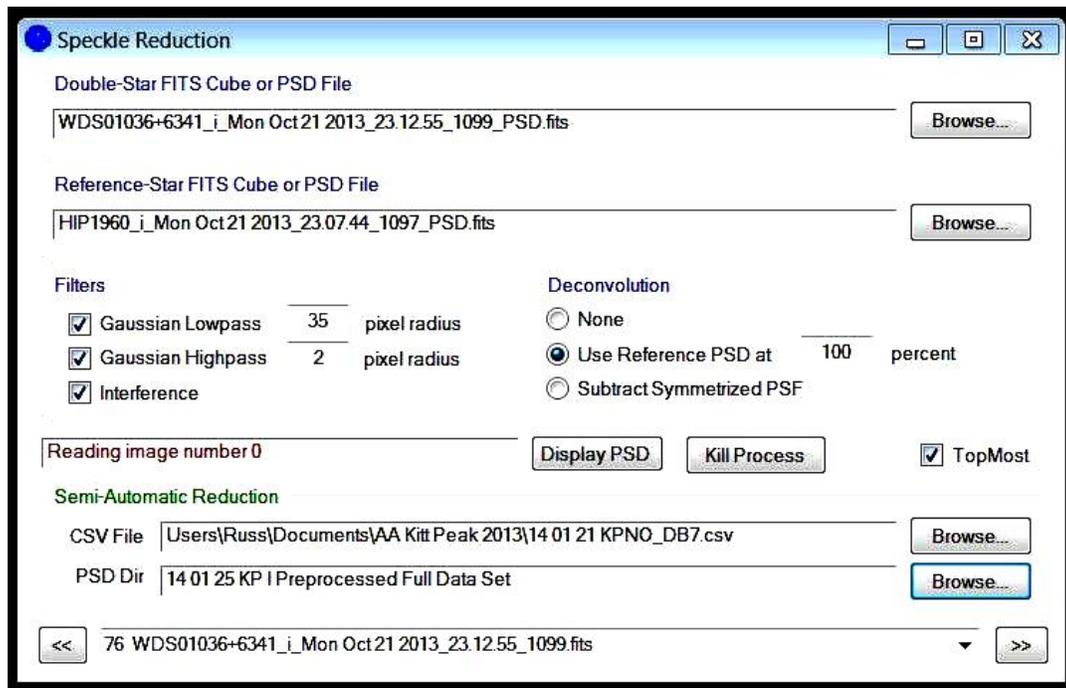


Figure 2. The *Speckle Reduction* GUI.

As an example, take the pixel dimension to be 10 microns, the wavelength to be 0.8 microns, and the focal ratio to be 50. The Airy disk radius will be approximately 5 pixels. The Fourier transform of the Airy disk will have most of its energy within a spatial frequency,  $f_c$ , given by:

$$f_c = N/(2 \cdot R)$$

where  $N$  is the size of the image and  $R$  is the radius of the Airy disk, all values being in pixels.

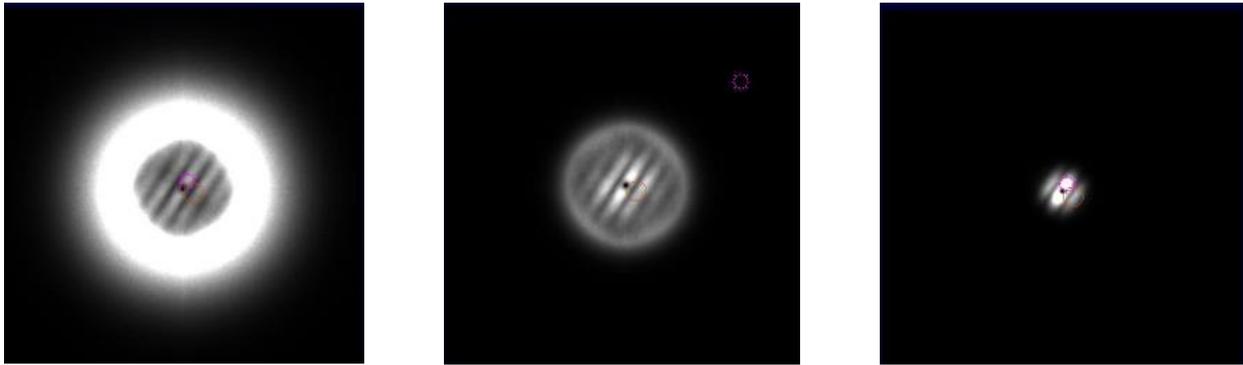
In the spatial frequency domain, there is very little signal higher than this frequency. However, beyond this frequency there is considerable noise from the electronics, from the sky background, and from photon shot noise from the object. Therefore, to improve the signal-to-noise ratio and to reduce unwanted interference from the electronics, it is wise to apply a low pass filter with a cutoff proportional to this spatial frequency. Thus, the cutoff frequency,  $f_c$  (pixel radius), should be approximately:

$$f_c = (h \cdot N) / (2.44 \cdot \text{Lambda} \cdot F/D)$$

Taking an example from the second speckle interferometry run at Pinto Valley Observatory (PVO II),  $\text{Lambda} = 0.8$  microns,  $h = 10$  microns,  $F/D = 50$ ,  $N = 256$ , yields  $f_c = 26$  pixels. In practice, it is a good idea to make the low pass filter somewhat wider than this so that most of the signal information is allowed through the filter.

This only provides a good starting point. In fact, the auto-correlation has noise and signal statistics that are more complicated than the above simplified argument would suggest. For PVO II, experimentation suggested that an  $f_c$  of about 50 pixel radius worked best, although the solutions were not overly sensitive to this setting. For the Kitt Peak run mentioned above, experimentation suggested a setting of about 35 pixels worked best.

Clicking *Display PSD* will toggle from the normal autocorrelogram solution image to the *PSD* (Power Spectral Density) fringe pattern display. If, as shown in Figure 3, the *Gaussian Lowpass* is set too wide, noise beyond the telescope cutoff will be seen, suggesting that the setting should be reduced to a smaller *pixel radius*. On the other hand, if there is no signal at all beyond the telescope cutoff, then the filter is set too narrow and should be widened.



**Figure 3.** On the left, the *Gaussian Lowpass* filter was set too wide (70 pixels), allowing high frequency noise to be included. On the right, it was set too narrow, cutting off useful information. In the middle it was set just slightly larger than the spatial cutoff frequency imposed by the telescope's aperture.

### *Gaussian Highpass Filter*

The Power spectral density (PSD) is the Fourier transform of the image. The purpose of the Gaussian Highpass Filter is to remove, as much as possible with a simple filter, the broad tail of the point spread function (PSF) that is due to seeing and optics. This filter removes the lowest-frequency information in the image and is typically set between a 2 to 5 pixel radius. It is set empirically to give the best auto-correlation.

A useful way to set the filter is to look at the PSD, which can be done by toggling Display PSD to bring up the fringe pattern. As shown in Figure 4, set the pixel radius to remove the bright spot in the zero-order PSD fringe pattern without hurting the rest of the fringe pattern. The Gaussian high pass is usually not needed when single star reference deconvolution is used.



**Figure 4.** On the left, the *Gaussian Highpass* filter was set too wide, not only cutting out the bright central peak, but also much of the fringe pattern. On the right the filter was set too narrow, allowing the bright central peak to shine through. The center is set correctly.

### *Interference Filter*

In certain situations we have encountered significant interference, possibly due to the interaction of the camera with the main 120V AC power source at remote locations. Much of the unwanted interference was found to lie along the lines  $fx = 0$  and  $fy = 0$  in the spatial frequency domain. If the Interference filter is checked, the values along the  $fx = 0$  and  $fy = 0$  axes in Fourier space are replaced by the average values of their neighboring pixels. This filter is quite specific to the type of interference produced by the camera.

### *Deconvolution*

There are three *Deconvolution* options: None, Use Reference PSD, and Subtract Symmetrized PSF. Each is discussed below.

None Although not recommended, speckle interferometry reduction can be accomplished without the use of single reference stars for deconvolution. For this option, simply select *None* under *Deconvolution*. It can be quite helpful to apply a Gaussian high pass filter when not using deconvolution.

Use Reference PSD The use of deconvolution reference stars is highly recommended. Not only will it sharpen the double star image, it will also remove much of the telescope's optical aberrations, including the effect of the central obstruction. In addition, if the reference star was taken close in time and located near the double star, deconvolution will remove much of the atmospheric dispersion and broad tail due to the effects of seeing. Deconvolution will help in almost all instances. If the reference star is a poor match for the double star, there are cases where a false detection can occur for doubles with dim, close companions.

Deconvolution is based on the following mathematical properties: (1) the recorded image of a very short exposure is the convolution of the "perfect" image of the object with the PSF of the telescope plus the instantaneous atmosphere, and (2) the convolution operation can be implemented by taking the inverse Fourier transform of the product of the Fourier transforms of the "perfect" image and the point spread function (PSF) of the telescope plus instantaneous atmosphere. Symbolically:

$$F(I) = F(O) * F(T)$$

where  $F()$  denotes the Fourier transform,  $I$  is the actual image recorded,  $O$  is the "perfect" image of the object, and  $T$  is the PSF of the telescope plus instantaneous atmosphere. Speckle interferometry is based on averaging a large number of very short exposures which "freeze" the atmospheric seeing, allowing us to take the average of the above equation in transform space. If we let  $\langle I \rangle$ ,  $\langle O \rangle$ , and  $\langle T \rangle$  denote the averages of the Fourier transforms of  $I$ ,  $O$ , and  $T$ , as defined above, then we can calculate an approximation for the Fourier transform of the object's power spectral density (PSD) as:

$$\langle O \rangle = \langle I \rangle / \langle T \rangle.$$

Taking the inverse Fourier transform of  $\langle O \rangle$  yields an approximation to the object's autocorrelation, with the telescope and atmosphere removed. This process is called deconvolution.

To perform this operation, we need an estimate of  $\langle T \rangle$ , the autocorrelation of the telescope plus atmosphere. A convenient way to find this estimate is to obtain a speckle cube of a nearby single star. The most effective deconvolution will be based on single star speckle observations that are very near the object from the point of view of the atmospheric conditions and telescope pointing. We feel that it is good practice to observe a single reference star that is as near as possible to the double star in both time and space. The reference star must, of course, be bright enough to show excellent SNR after speckle preprocessing.

To use a reference star for deconvolution, check *Use Reference PSD* and set it to 100 percent. The percentage option was included so one can experiment with the strength of the deconvolution when using non-ideal reference PSDs.

Subtract Symmetrized PSF This option was developed for close, dim double stars without good reference stars. A symmetrized PSF is made from the image and is subtracted from it, yielding only the non-symmetrical part. This can highlight an otherwise difficult-to-detect companion. This technique should be used with caution, since non-rotationally symmetric telescope aberrations can mimic a close, dim double.

#### *Display PSD*

Toggling *Display PSD* will move back and forth between the autocorrelogram solution and the power spectral density fringe pattern.

#### *Kill Process*

Kill Process simply stops the FITS cube speckle preprocessing.

### Manual Speckle Reduction (Selecting data cubes)

There are two ways to manually select data for reduction. Each is described below:

- (1) If, under *Deconvolution*, *None* has been selected, a *Double-Star FITS Cube or PSD File* can be navigated to by clicking the *Browse* button at the top of the *Speckle Reduction* box. If a file, you will be asked to click on the desired FITS cube. The file name will appear in the window, and if it is a PSD (preprocessed), a solution will appear in seconds. Otherwise, it may take a couple of minutes for the raw data cube to be processed.
- (2) In addition to (1) above, if, under *Deconvolution*, *Use Reference PSD* has been selected, a *Double-Star FITS Cube or PSD File* can be navigated to by clicking the corresponding *Browse* button. If a file, you will be asked to click on the desired FITS cube. The file name will appear in the window. The solution image (autocorrelogram) will change as the single reference star is included in the solution. The improvement in the solution can be dramatic.

### Semiautomatic Speckle Reduction (Selecting an entire file)

Although the speckle interferometry tool in PlateSolve 3 can be operated entirely by way of user GUI inputs, there is a *Semi-Automatic Reduction* option for using a comma-delimited input file (*CSV File*) that speeds up the reduction process. The *CSV File* allows PS3 to automatically load each double star file as well as the corresponding single star file. With hundreds of targets and corresponding reference stars to process, looking up individual files can be tedious. An added benefit of this mode of reduction is that, based on information on the “expected” position angle and separation of the two stars (from last observed catalog values or calculated values) provided in the *CSV File*, PSD places a red circle at the “expected” solution location. This allows the 180° ambiguity inherent in autocorrelograms to be avoided. It also gives immediate visual feedback on how close the automated PS3 solution is to the “predicted” position. If the automated PS3 solution is not the best solution, one can intervene and pick a more appropriate solution.

### Image Navigation and Brightness

The main image displayed by PS3 can be manipulated for better viewing and interpretation of the target.

#### *Image Size*

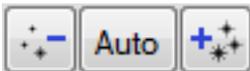


These three buttons are used to control the displayed image size. From left to right, they make the image smaller (zoom out), fit the image to the screen, and make the image larger (zoom in). One can also zoom in and zoom out by right clicking on the main screen and selecting from the various Zoom options.

#### *Image Position*

Right-click on the image and select Center to center it. The image can be dragged by left-clicking and holding down the mouse button.

#### *Image Brightness and Contrast*



These three buttons are used to control the brightness of the image. From left to right, they reduce the image brightness, autoscale the image brightness, and increase the image brightness.

## Photometry/Astrometry Tool

With an autocorrellogram now displayed (with either manual or semiautomatic inputs), click on the green “target” icon on the toolbar to bring up the *Photometry Tool* shown in Figure 5. Under *Centroid (J2000)*, click on *Lock to Peak* to activate centroid detection.

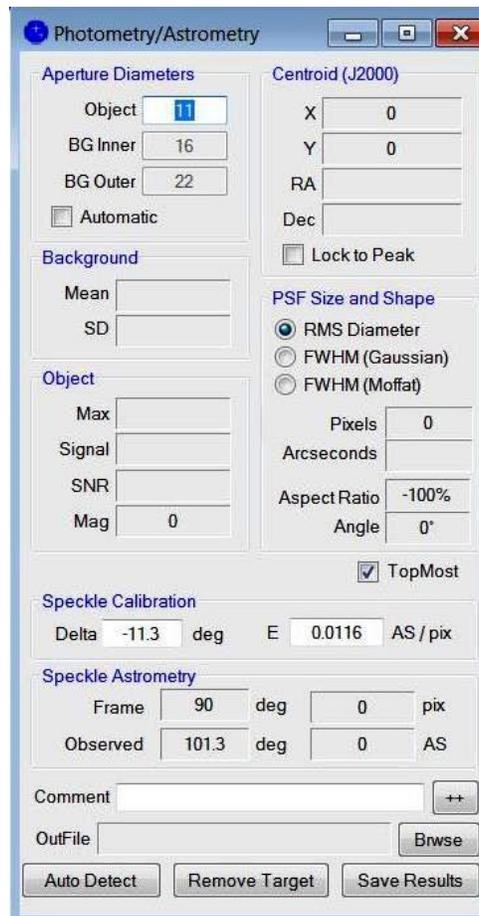


Figure 5. The Photometry/Astrometry GUI.

Under *Aperture Diameters*, set *Object* to a pixel radius that will fully encompass the image of the secondary star but not the primary star or any noise. For widely spaced doubles, setting the *Object* aperture diameter (in pixels) is straightforward. For very close doubles, however, setting the *Object* pixel diameter can be more difficult. It might be noted that in many cases the dark circle around the companion is the first null in the Airy function. Often the *Object* pixel diameter can be set so that the “green circle” falls in this first null.

Under *Speckle Calibration*, enter, if known, the values of the camera angle, *Delta*, (in degrees), and the plate scale, *E* (in arc seconds per pixel). These values, *Delta* and *E*, are used to transform the *Frame* separation and position angle, *ThetaF* and *RhoF* respectively, to *Observed* separation and position angle, *ThetaO* and *RhoO* respectively. If *Delta* and *E* are not known, as may be the case during initial calibration, the values of *ThetaO* and *RhoO* will not have any meaning.

To arrive at a final *Observed* position angle, *ThetaO*, the camera angle, *Delta*, determined by calibration, is subtracted by PS3 from the frame camera angle, *ThetaF*. To arrive at a final *Observed* separation, *RhoO*, the frame separation in pixels, *RhoF*, is multiplied by PS3 by the plate scale constant, *E* (in arc seconds/pixel), that has been previously determined through a calibration process.

## Manual Solution

With the *Object* diameter set appropriately, center the green aperture over the appropriate one of the two secondary star images. It is good practice to check the “solidness” of the solution results by moving the cursor around a small amount near the center of the secondary. Do the *Observed* values of position angle and separation,  $\theta O$  and  $\rho O$ , change as the cursor is moved? If so, try increasing or decreasing the *Object* pixel diameter until a solid *Lock to Peak* is achieved in spite of small cursor position variations. If this is not possible, then the quality of the solution may be in question and should be noted in the *Comment* or written down if the *OutFile* is not being used.

With an appropriate *Aperture Diameter* set for the *Object*, and with the green circle centered on the secondary and a satisfactory *Lock to Peak* achieved, right click the mouse to display the drop-down menu shown in Figure 6. Select *Set Target Location* and a red circle with eight short radials will appear centered over the secondary. This completes the solution.

At this point the answers can simply be written down. However, it is usually more convenient to record them in the *OutFile*, along with an automatically-recorded image of the final solution. If recording is desired, *Browse* to and select the desired *OutFile* using the Multifile selection feature of Windows.

An optional *Comment* can be typed in. The comment can be of any size and can include commas, even though the *Comment* will be placed in a comma delimited file. For long comments, clicking ++ will bring up a larger *Add Comment* text entry box. A corner of this box can be dragged to increase its size. Multi-line comments are supported and will appear in the CSV file with the pipe symbol “|” as the delimiter between lines.

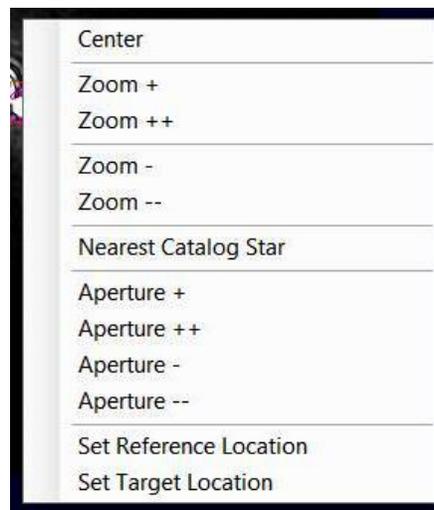


Figure 6. The drop-down menu that appears for the final solution.

## Automatic Solution

In its semi-automatic mode, PS3 provides an automatic solution that, under normal circumstances, will be correct. However, it may not be the best solution if the signal-to-noise ratio (S/N) is poor, the secondary is not the brightest object in the autocorrellogram (other than the central peak), or the separation is very small and Airy rings are prominent.

The first step in obtaining an automatic solution is detecting all the brightest peaks in the image. Typically there are several thousand. The centroid location of each peak is found by activating *Lock to Peak*. Typically, the centroid location (to a fraction of a pixel) will be different than the brightest pixel location. The centroid location is noted and a new *Lock to Peak* initiated. This is repeated twice more. If after four tries the *Lock to Peak* still results in a shifting centroid location (greater than two pixels), the solution is deemed unsatisfactory. Also, if the elongation of the secondary image is too great, the solution is considered unsatisfactory.

At this point, from all possible remaining solutions, PS3 simply selects the brightest one. As there typically will be two equally bright secondary solutions  $180^\circ$  apart, PSE simply selects the one closest to the predicted position (the red circle) as the final solution. PS3's automatic solution can be accepted simply by clicking *Save Results*. One can then increment to the next target by simply clicking >> in the bottom right corner of the *Speckle Reduction* box.

It is not unusual to have many correct automatic solutions in a row, especially if good single reference deconvolution stars have been carefully chosen and the observations are not pushed too close (or beyond) their limits. With a plethora of correct solutions, one simply presses >>, the automatic solution appears in a couple of seconds, one checks to see that the solution is correct, and, if so, presses *Save Results*. This can be accomplished in about 5 seconds, allowing a dozen targets to be processed per minute, as long as correct solutions continue unabated.

### Reduction Autocorellogram

The reduction autocorellogram is the “picture worth a thousand words.” As shown in Figure 7, the primary star is always at the exact center. The secondary star is displayed as two fainter images exactly  $180^\circ$  apart. If semi-automatic reduction is employed, as it was for the double shown in the figure below, then a “predicted” position will be indicated with a **red** circle (in this case offset from the lower secondary at the 5 o'clock position). The large **green** circle around the lower secondary is the *Object Aperture*. It should encompass all or most of the secondary's image. Once satisfied with the solution, *Set Target Location* is clicked if manual, and the bright **pink** circle with the X and eight short radials will appear. If this is an automatic solution, the bright **pink** circle will automatically appear.

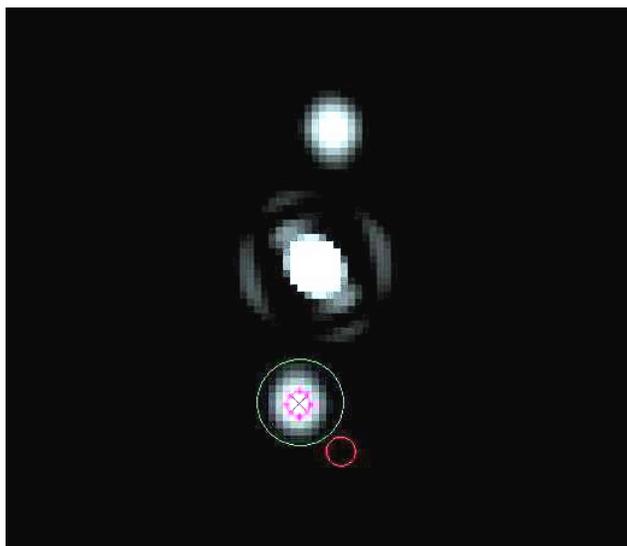


Figure 7. Autocorellogram of a typical “easy” solution.

If, in a semi-automatic mode, the automated solution (**pink** circle) is not in the center of the secondary star, then one can revert to a manual solution mode by clicking *Remove Target* in the bottom-center of the *Photometry/Astrometry* box. Conversely, if one is in a manual solution mode and desires an automatic solution, simply click *Auto Detect* in the lower left-hand corner of the *Photometry/Astrometry* box.

### OutFile Columns and Abbreviations

As shown in Table 1, the output file is coma delimited; one row per output. The top row provides column content abbreviations. These abbreviations are provided below, followed by a short description.

Num	Target	ThetaO	ThetaC	ThetaO-C	RhoO	RhoC	RhoO-C	ThetaF	RhoF	ApD	RelInt	DMag	Comm
24	00283+6344	111.831	91	20.831	0.3857	0.4	-0.0143	100.531	33.251	12	0.2216		
76	01036+6341	4.098	19	-14.902	0.2226	0.3	-0.0774	352.798	19.192	12	0.2312		
1	00022+2705	228.354	273	-44.646	0.166	0.8	-0.634	217.054	14.312	12	0.0571		Close one!
2	00024+1047	69.213	73	-3.787	0.2468	0.2	0.0468	57.913	21.273	12	0.0535		Prediction close.
3	00029+4715	294.729	295	-0.271	1.5947	1.6	-0.0053	283.429	137.47	12	0.155		Wide and easy. Prediction right on.
4	00046+4206	105.922	95	10.922	0.1304	0.1	0.0304	94.622	11.244	5	0.0486		Very close but good solution.
5	00055+3406	307.239	304	3.239	0.15	0.2	-0.05	295.939	12.933	5	0.0675		Also close. Prediction off a bit.
6	00073+0742	321.309	323	-1.691	0.3515	0.4	-0.0485	310.009	30.3	11	0.2919		Easy. 2nd & 3rd order images.
7	00085+3456	52.817	79	-26.183	0.1383	0.1	0.0383	41.517	11.922	5	0.1508		Close. Solution not stable.
13	00118+2825	67.367	69	-1.633	0.4474	0.5	-0.0526	56.067	38.571	11	0.1454		Easy. Prediction close.
14	00121+5337	317.605	313	4.605	0.3344	0.3	0.0344	306.305	28.827	11	0.1709		Very easy.
18	00174+0853	305.499	307	-1.501	0.1556	0.2	-0.0444	294.199	13.417	5	0.0411		Difficult. Not quite stable.
19	00174+0853	303.657	307	-3.343	0.1553	0.2	-0.0447	292.357	13.386	11	0.1254		Easy and stable.
20	00205+4531	96.724	102	-5.276	0.656	0.7	-0.044	85.424	56.553	11	0.0896		Verely easy. Clean!
21	00209+1059	118.746	117	1.746	0.7557	0.7	0.0557	107.446	65.145	11	0.1286		Very easy. Clean.
23	00251+4803	273.507	242	31.507	0.3186	0.3	0.0186	262.207	27.464	11	0.0335		Prediction off, but not too far.

**Table 1.** The first 14 columns of output. The .csv file was saved as .xlsx and lightly formatted. *Differential Magnitude, DMag*, is being worked on.

*Num* — This is the object sequence number from the input CSV file directory, when used. If an input CSV file is not used, this entry will be blank.

*Target* — This is the target (double star) identification. Usually it is the Washington Double Star (WDS) catalog name, such as 09345+0723, but it can be some other identifier, such as GJ3579.

*ThetaC* — This is the last catalog or predicted (input) double star position angle (PA,  $\theta$ , and Theta are all abbreviations for position angles). This calculated (prediction) may be the last reported position angle, but could be an interpolated value from an orbit ephemeris, or even a maximum likelihood prediction. *ThetaC* is used by PS3 to place a small red circle on the autocorrelogram, where the secondary is expected.

*ThetaO* — The observed position angle. This only has meaning when the user provides the camera angle, *Delta*, from some calibration external to the reduction. If not available, the user can enter any number and ignore the results, or enter a camera angle of “0” and the output would be the “uncorrected” camera angle.

*ThetaO-C* — PS3 simply calculates this as *ThetaO* minus *ThetaC*. This is the difference between the observed position and the calculated (i.e. predicted or expected) position angle; the classic O-C.

*RhoC* — This is the last catalog or predicted (input) double star separation (Sep,  $\rho$ , and Rho are all abbreviations for separation). This calculated (predicted) separation may be the last reported separation, but could be an interpolated value from an orbit ephemeris, or even a maximum likelihood prediction. *RhoC* is also used by PS3 to place the small red circle on the autocorrelogram where the secondary is expected.

*RhoO* — The observed separation angle. This only has meaning when the user provides the plate scale (arc seconds per pixel), *E*, from some calibration external to the reduction. If not available, the user can enter any number and ignore the results, or enter a plate scale of “1” and the output will be the “uncorrected” frame pixel separation.

*RhoO-C* — PS3 simply calculates this as *RhoO* minus *RhoC*. This is the difference between the observed position and the calculated (i.e. predicted or expected) separation; the classic O-C.

*ThetaF* — Position Angle in the Frame. *ThetaF* is calculated by PS3, using simple trigonometry, from the centroid pixel locations.

*RhoF* — Separation in the Frame. *RhoF* is calculated, using simple trigonometry, by PS3 from the centroid pixel locations.

*ApD* — Aperture Diameter (radius in pixels).

*RelInt* — This is the total (integrated) intensity of the companion divided by the integrated intensity of the primary. This will be used to form an estimate of the differential magnitude of the double star.

*DMag* — This will be calculated in a future version of the program. At this time the entry is blank.

*Comm* — User comment added during reduction.  
*DSFN* — Double star (FITS cube) file name.  
*RSFN* — Reference star (FITS) cube file name.  
*AR* — Elongation Aspect Ratio (degrees).  
*AA* — Elongation Angle (degrees). The angle that corresponds to the elongation aspect ratio.  
*Delta* — Camera Angle (degrees). Camera orientation angle with respect to the sky.  
*E* — Plate scale (arc seconds/pixel).  
*GLP* — Lowpass Radius (pixels). Settings for Gaussian lowpass filter.  
*GLPen* — Lowpass used (True/False).  
*GHP* — Highpass Radius (pixels). Setting for Gaussian highpass filter.  
*GHPen* — Highpass used (True/False).  
*IFen* — Interference Filter used (True/False).  
*DCon Deconvolution* — Type: *None*=0, *Use Reference PSD*=1, *Subtract Symmetrized PSF*=2.  
*DConP* — Deconvolution percent, usually set at 100%.  
*LTPen* — Lock to Peak (True/False).  
*JPEGFN* — Filename of the solution image.  
*DaT* — Date and time output created.

### Optional Input File (CSV File)

The seven items, below, must appear in the input file, *CSV File*, in the order shown. They must be the first seven columns, although there may be any number of other columns to the right. All columns past seven are simply ignored by PS3. Please note that changing *Delta* and *E* in the *Photometry/Astrometry* box during semi-automatic reduction will not actually change their values as they are read from the input *CSV File*. The *Delta* and *E* values need to be changed in the file itself.

*TID* — Target ID. If the Target ID is a “D”, then PS3 will process this file, otherwise it will be ignored. This allows a master database to contain, for instance, single stars used for deconvolution, slit mask or drift calibrations, etc.

*DSFN* — Double star (FITS cube) file name.  
*RSFN* — Reference star (FITS) cube file name.  
*ThetaC* — Calculated (input) estimated, predicted, or last catalog reported double star position angle.  
*RhoC* — Calculated (input) estimated, predicted, or last catalog reported double star separation.  
*Delta* — Camera Angle (degrees). Camera orientation angle with respect to the sky.  
*E* — Plate scale (arc seconds / pixel).

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