AstroImageJ User Guide

Introduction

AstroImageJ (AIJ) is simply [ImageJ](#) (IJ) with some customizations to the base code and a packaged set of astronomy specific plugins. The plugins are based on the [Astronomy Plugins](#) package written by Frederic V. Hessman et al. of [Inst. f. Astrophysik](#), Georg-August-Universität Göttingen. The AstroImageJ customizations are by Karen Collins (karen.collins --- at --- insightbb.com) and John Kielkopf of the University of Louisville. The application is open source, and the source code is embedded within the ij.jar file and the Astronomy_.jar file. To report bugs or suggest new features, please email Karen Collins at the address indicated above.

Installation

Java must be installed on a computer before running AstroImageJ. Java can be downloaded from:

http://www.java.com/en/download/manual.jsp

AstroImageJ can be downloaded from:

http://www.astro.louisville.edu/software/imagej/astronomy/index.html

Linux Installation

Download AstroImageJ for Linux from:

http://www.astro.louisville.edu/software/astroimagej/index.html

and extract "AstroIJ_x.x.x.tar.gz" to the desired ImageJ folder. A script file is available that shows how to set up AIJ for easy start-up under Linux. For Linux installation, refer to the readme file at the AstroImageJ website. For more information on running generic ImageJ with Linux, go to:

http://rsbweb.nih.gov/ij/docs/install/linux.html.

Windows Installation

Download AstroImageJ for Windows from:

http://www.astro.louisville.edu/software/astroimagej/index.html

and extract "AstroIJ_x.x.x.zip" to the desired ImageJ folder (ex: C:\Program Files (x86)\ ). An ImageJ.exe program is available in the upper most directory and can be used to start AstroImageJ. If preferred, one can set up a file type to be automatically opened by ImageJ.exe when double clicked by referencing that file type to the ImageJ.exe program. For more information on running generic ImageJ with Windows, go to:

http://rsbweb.nih.gov/ij/docs/install/windows.html.

Mac OS X Installation

Download AstroImageJ for Mac OS X from:

http://www.astro.louisville.edu/software/astroimagej/index.html

and click on "AstroIJ_Mac_x.x.x.zip" to extract the ImageJ folder. Move this folder to the Applications folder, open it, and copy either *ImageJ* or *ImageJ64* to the dock. *ImageJ* runs in 32-bit mode using Java 1.5 (Java 1.4 on OS X 10.3) and *ImageJ64* runs in 64-bit mode using Java 1.6. *ImageJ64* is not limited to 1800MB of memory but it requires a 64-bit Intel Mac running Mac OS X 10.5 or later. The "AstroIJ_Mac_x.x.x.zip" file can be deleted. For more information on running generic ImageJ with Mac OS X, go to:

http://rsbweb.nih.gov/ij/docs/install/osx.html.

Using AstroImageJ

AstroImageJ Control Window

When AstroImageJ is opened, you will see the main ImageJ control window shown in Figure 1 with seven AIJ-specific icons on the right side of the toolbar starting at the button shown depressed below. The toolbar can be used the same as for generic IJ, but for most operations with AIJ, you will want the "star-field" icon depressed as shown below (The icon is called "Astronomy Tool" in the menubar). This mode is referred to as astro-mode in this document. AIJ defaults to this mode at startup.

NOTE: although the right-hand portion of the toolbar can be customized as with generic IJ, it is recommended to leave the default AIJ icons installed as shown below when using the AIJ version.

Figure 1. ImageJ Toolbar with AstroImageJ tools to the right
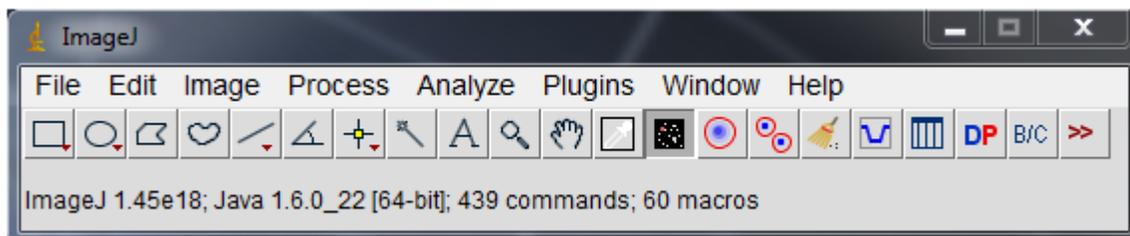
AstroImageJ Image Display Interface

When a FITS image (or any other native IJ image type) is opened, the image will be displayed in a window as shown Figure 2. The menubar, the data fields and buttons at the top, and the histogram and associated data fields at the bottom are specific to AIJ. The custom AIJ display can be disabled by deselecting the checkbox under the Preferences menu labeled "Use astro-window when images are opened". Then close and reopen the image to use the standard IJ image display with no controls or menus. To reenter the AIJ style image display, make sure that the star field icon is depressed, and then click on the image. To re-enable AIJ style image display for all opened images, check the Preferences menu "Use astro-window when images are opened" checkbox.

Figure 2. AstroImageJ Image Display Interface
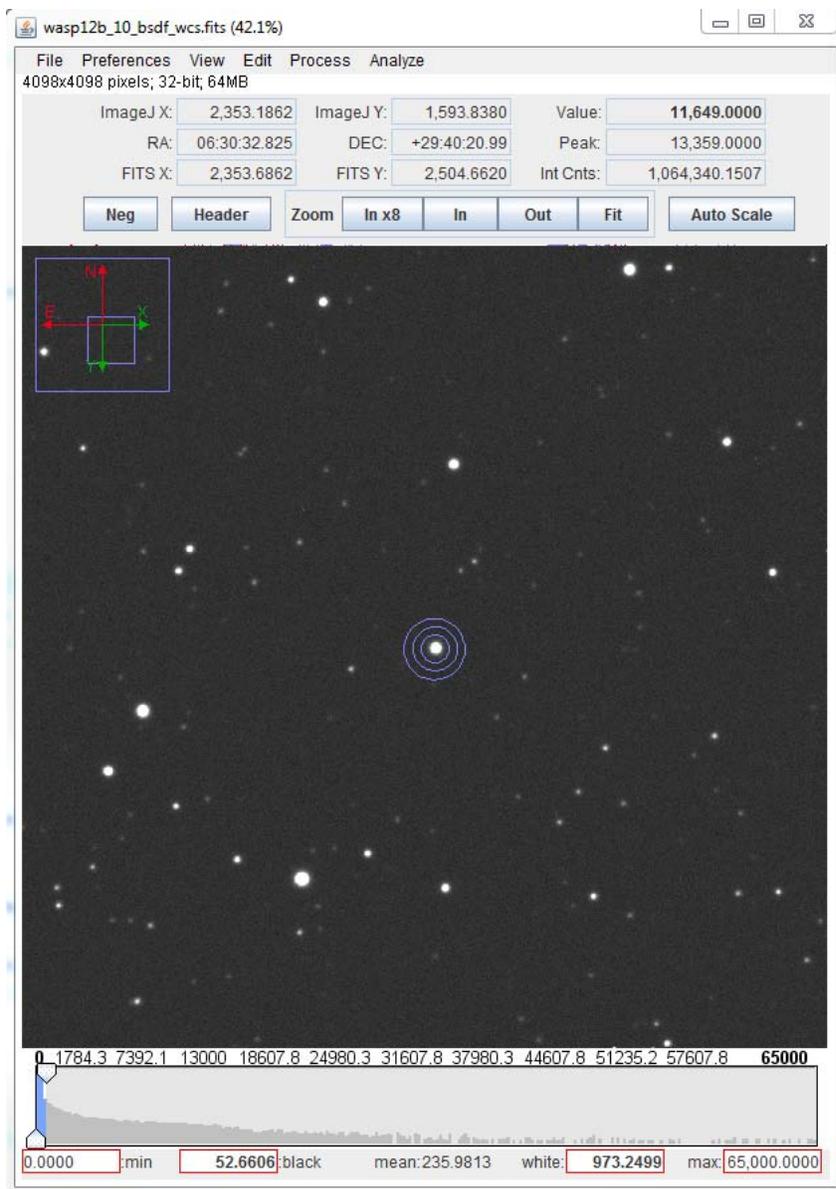
Important Notes Regarding AIJ vs. IJ User Interface

This user guide assumes that an image is displayed in the AIJ interface shown in Figure 2 above and with the astro-mode icon selected on the ImageJ toolbar as shown in Figure 1 above. In the default mode, all images are opened in this state. If any of the IJ specific tools are selected (the icons to the left of the astro-mode icon), operation will revert to standard IJ operation. Clicking back on the astro-mode icon will revert to AIJ operation.

A three button mouse with a scroll wheel and separate middle mouse button, such as the Logitech Anywhere MX mouse, provides the most convenient and efficient AIJ operation.

Data Displayed Above the Image

AIJ displays several data fields above the image that contain information specific to the mouse location within the image. All of these values update as the mouse is moved. Two pixel coordinate systems are displayed in the interface. IJ's native origin (i.e. x,y = 0,0) is at the top left of the image with "x" increasing to the right and "y" increasing toward the bottom. IJ pixel coordinates are useful when using some of the built-in IJ features. The FITS standard origin is at the bottom left of the image with "x" increasing to the right and "y" increasing toward the top. Pixel coordinates based on the FITS standard are often needed by astronomers and are particularly important when working with images with World Coordinate System (WCS) headers. There is also an additional 0.5 pixel offset between the two coordinate systems. IJ designates the top left of a pixel as the (X.0, Y.0) location while FITS designates the center of a pixel as the (X.0, Y.0) location. AIJ displays pixel coordinates for both of these systems on the first and third lines of data above the image. The middle line displays RA and DEC when WCS headers are available from a FITS file. The top right box labeled "Value" indicates the pixel value under the mouse cursor. The "Peak" value indicates the highest pixel value within a circular aperture, while the "Int Cnts" value displays the sum of all the pixel values within the circular aperture. The "Int Cnts" box label changes to either "Length" or "Arclen" to report length in pixels or arclength in decimal or sexagesimal format when the mouse is being dragged with the middle mouse button depressed. Sexagesimal format can be selected/deselected in the Preferences menu. If WCS headers are available or if the pixel scale of the image has been set under the Preferences menu, arclength will be displayed. Otherwise, distance in pixels will be displayed. The length data can be written to a log window and saved if desired by selecting the corresponding option in the Preferences menu.

Contrast/Brightness Adjustment

Under the Preferences menu, select either auto brightness & contrast (based on the image's pixel value standard deviation), fixed brightness & contrast (keeps the same user defined levels from image to image), or full dynamic range (displays the full range of pixel values in the image). The selected option is saved and recalled when new images are opened or a new image is displayed in a stack. The "black" and "white" values indicated below the histogram can be directly entered in any mode, but if auto mode is selected, they will update when the image is updated or another image is opened. The "min" and "max" histogram values are normally automatically set to the min and max pixel values of the displayed image. However, the values can be directly entered and will not change from image to image if the Preferences menu item "Use fixed min and max histogram values" is enabled.

AIJ provides a number of ways to adjust the contrast and brightness of an image. The simplest way is to click the "Auto Scale" button above the image. If auto-scale does not provide the desired result, the

arrows in the histogram can be dragged left and right to adjust the image display. The currently displayed range of pixel values is shown in blue in the histogram. The blue region can be dragged with the mouse to adjust the brightness. The pixel value corresponding to black is indicated in the histogram "black" box, and the pixel value corresponding to white is indicated in the "white" box. These numbers can be directly modified by clicking on an existing number and typing a new value and pressing <Enter>. Alternatively, a right mouse drag in the image will control the image brightness/contrast similar to DS9. When right-click dragging, watch the histogram to see how the motion affects the settings. Moving up and down moves the range of values displayed up and down similar to dragging the blue region in the histogram. Moving right and left increases and decreases the width of the displayed range. Alternatively, pressing the shift key while rolling the mouse wheel adjusts the image brightness and pressing the control key while rolling the mouse adjust the contrast.

Panning

Left click and drag the mouse to pan the image.

Zooming

If using a mouse with a scroll wheel, the wheel can be used to zoom in and out of the image. Place the mouse cursor at the point in the image where the zooming should take place and roll the wheel. If a mouse wheel is not available, click in the image at the desired zoom point and use the zoom buttons above the image, or press "control" and left click to zoom in, or "control" and right click to zoom out. Press the "In x8" button above the image or double left click to zoom in "fast". Double right click to zoom out such that the image will fill the available area in the image display. Press "Fit" or triple right click to zoom out such that the full image is displayed on the screen (which may leave white space at top/ bottom or left/right of the image).

Measuring Length

A middle mouse button click and drag shows distance in arclength in the bottom right box at the top of the image when a pixel scale is set in the Preferences menu or WCS headers are available. Otherwise length is shown in pixels. Middle click on the image to remove the line that was drawn during the measurement. Two Preference menu options are available to enable image data to be written to a log file when the middle mouse button is clicked or dragged. The resulting log file can be saved if desired.

Single Aperture Photometry

AIJ offers a "live" photometer which follows the mouse pointer around in the image and provides a peak pixel count and an sky subtracted integrated count for a defined aperture. The photometer radius and inner and outer background radii can be set in the Edit menu after selecting aperture settings. Display of the photometer can be disabled by unchecking the Preferences menu item "Show photometer regions at mouse cursor". The photometer peak and integrated counts will be updated above the image even if the photometer annuli are not showing. The display state of the photometer annuli can be temporarily inverted by pressing the Shift key while rolling the mouse.

Shift click is a shortcut to access the full single aperture photometer which is also available on the IJ toolbar (the first icon to the right of the astro-mode icon). The single aperture photometer will provide full aperture photometry data which is displayed in a MeasurementsTable and can be saved or plotted. The

data values reported can be set in the Edit menu Aperture Settings selection or by double clicking on the single aperture tool on the IJ toolbar. Apertures displayed on the image can be removed by double middle clicking or by clicking the "broom" icon on the IJ toolbar.

FITS Header Access

The "Header" button above the image displays the fits header in a separate text window. The Edit menu "FITS Header" option will allow FITS header editing by hand, but currently will not save the new setting back to the image.

Using an Inverting Lookup Table

AIJ can display an image as a "negative" by selecting the "Neg" button above the image. AIJ uses an inverting lookup table to display the image rather than modifying the underlying image.

Regions of Interest

Several items in the Analyze menu require a region of interest (ROI) to be defined within an image before running that selection. The most commonly used ROI shapes are oval, rectangular, and line. ROIs can be drawn by clicking on the related icon on the IJ toolbar, however, astro-mode panning and other convenient mouse functions will be lost while the ROI is being drawn. If you use the IJ toolbar, remember to click on the astro-mode icon when you are finished to restore astro-mode functionality. Short cuts are available to draw these three common ROI shapes without leaving astro-mode. Press and hold <shift> while left dragging to draw an oval ROI. Press and hold <control> while left dragging to draw a rectangle ROI. Press and hold <alt> while left dragging to draw a line ROI. To move or edit an existing ROI, press and hold the <tab> key, then use the mouse to point at the ROI and drag it to the new location. To edit the shape of an ROI, hold the <tab> key and hover the mouse cursor over one of the ROI selection points until it changes to a finger shape, then click and drag to change the ROI shape. Currently, to modify some ROIs, it may be necessary to set the image orientation to "Invert None" and "0 degrees" under the View menu. It may be quicker to simply redraw the ROI using the shortcuts described above. This issue will be resolved in a future AIJ release. ROIs can be cleared by either using the View menu "Clear Overlay" selection or a middle mouse click will clear any ROIs.

Menus in the Image Display

Pull-down menus are provided at the top of the image display to allow direct access to many features commonly used by astronomers.

File menu: provides several options for opening and saving image, stack, and MeasurementTable files. The first image will need to be opened from either the OS or the IJ toolbar File menu. Subsequent images can be opened from the AIJ File menu, the OS, or the IJ toolbar File menu.

Preferences menu: provides several options for changing how an image is displayed. When an image is closed, its preference settings are saved to ImageJ memory. If multiple image windows are open and the preference settings in more than one window have changed, the settings of the last window closed are saved over any other previously saved settings. Preference settings are not saved to hard disk until AIJ closes, so if AIJ crashes or is terminated improperly (using something like "killall imagej" in Linux), the settings will not have been updated in the IJ_Prefs.txt file for use the next time ImageJ is started. Also, if

AIJ is closed from the IJ toolbar while an image is still open, any preference changes will not be saved when IJ closes. The best practice is to close all images before closing the IJ toolbar.

View menu: provides several options for setting the displayed orientation of an image and for enabling informational overlays. The "Clear Overlay" option clears any apertures or ROIs drawn on the image, but not the informational overlays.

Edit menu: provides options to edit various data associated with an image or stack. These options include editing of aperture settings, IJ measurement settings, FITS header entries, and stack configuration.

Process menu: provides various tools to modify the data within an image.

Analyze menu: provides several options to measure the data within an image and to plot and/or save those results.

Zoom Status and Image Orientation Indication

The zoom status and image orientation graphical information can be overlaid at the top left corner of the image as shown in Figure 2. The outer blue rectangle represents the size of the image and the inner blue rectangle represents the part of the image that is current displayed in the window. The red arrows indicate the north and south directions in the image. Currently, the orientation of these arrows must be set by the user under Preferences menu. The setting indicates the number of degrees the arrows are rotated in a counter clockwise direction from standard north = up, east = left position. Eventually, if WCS headers are available, the north and east arrow directions will be set automatically, but for now, all images require the manual setting. The green X and Y arrows indicate the orientation of the X-Y axes in the standard FITS coordinate frame. These arrows change direction according to the View menu invert and rotation settings. If an image is oriented as "Invert None" and "0 degrees", the Y-direction will be up and the X-direction will be to the right. The overall zoom indicator size can be set under the Preferences menu. The View menu provides three options to enable or disable each component individually.

Data Reduction Interface

Overview of Operation

To start a data reduction session, click the DP (Data Processor) icon on the IJ toolbar or use an image's Process menu "Data Reduction Facility" selection if an image is already open. Figure 3 below is an example setup that would process 148 WASP-12b images, first creating a master bias from files in the same directory as the science images, but that start with "bias_" and end with ".fits", similarly creating a master dark, but using a master flat that has previously been created and exists two directories up in a "cals" directory. Wildcards are allowed in filename specifications with "?" representing any single character, and "*" representing any number of characters. RA and DEC of the target and latitude and longitude of the observatory are required if calculations of altitude/airmass/HJD are desired. Check "Use" to calculate these values and check "Save" to add the values to the output file's FITS header. The processed files are placed in a subdirectory called "pipelineout" in this case and each file has the suffix "_bsdf" added (i.e. bias subtracted, scaled for non-linearity, dark subtracted, and flat-fielded).

A key field to set up is the polling interval at the bottom right. When set to "0", all matching files in the specified directory when the script is started will be reduced and then the process will stop. If set to any

other number, the "Primary Directory" will be polled at that interval (in seconds) for new incoming files after all of the initial files have been processed. This mode is useful for monitoring for the arrival of new images from a camera and provides for the capability of near real-time light curve plotting during an observing session.

When all fields are setup as desired, click the "Start" button to begin processing. Any specified master calibration files will be created first, followed by the science image processing. If STOP is pressed, processing will pause after the next image reduction has been completed. Press "Reset" to start over, or press "Continue" (the "Start" button will now be labeled "Continue") to finish processing without starting over.

Note: Most options and fields in the Data Processor interface have generous tooltips available to explain the feature's operation. Hover the mouse over a field to see its tooltip. To keep it displayed longer while reading lengthy tooltips, move the mouse back and forth slowly over the field after the tooltip has been displayed.

Figure 3. Data Processor Interface
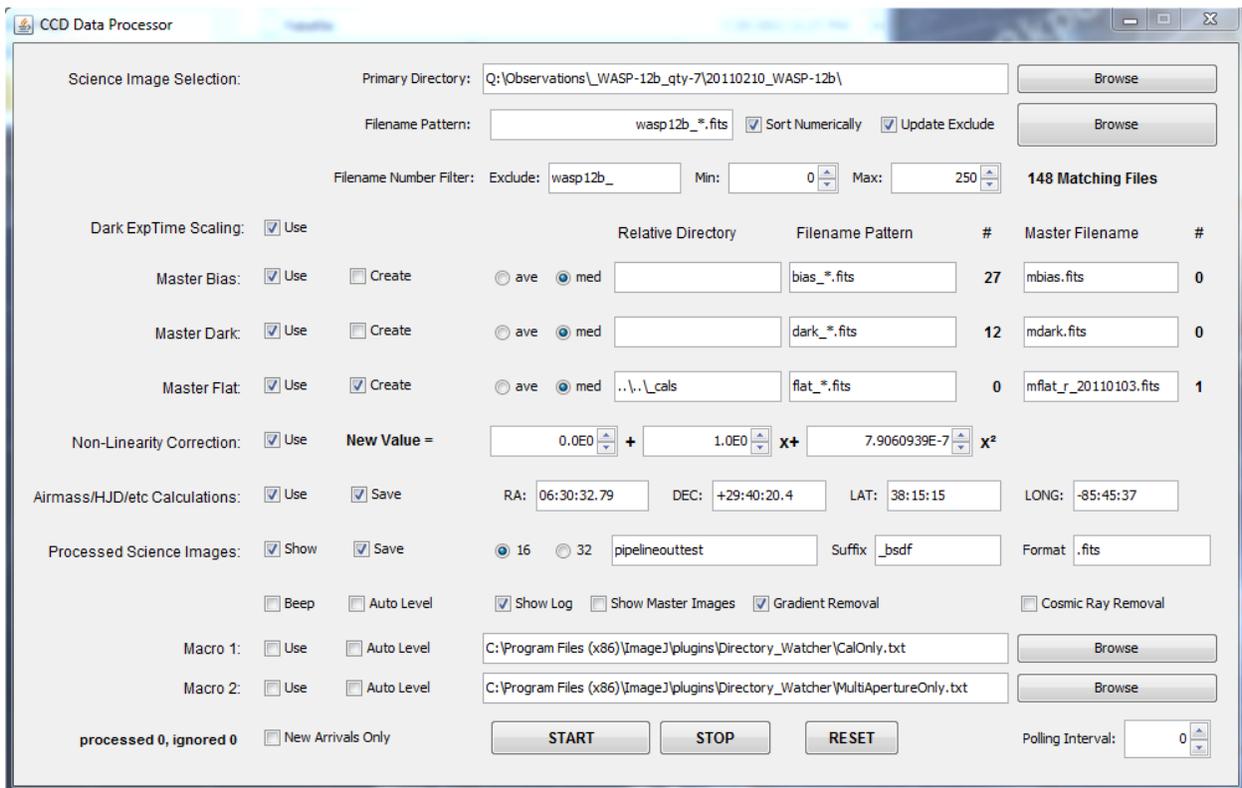
Data Reduction Algorithms

The data reduction algorithm in general executes the check boxes that are enabled starting from the top left and advancing toward the bottom right check box.

For master bias, dark, and flat usage, click "use" next to the corresponding label to use a pre-existing master calibration file that is defined by the "Relative Directory" and "Filename Pattern" to the right.

Click "use" and "create" to build a new calibration file using files in the specified "Relative Directory" that match the specified "Filename Pattern". The master file is created in the same relative directory with the filename specified in "Master Filename". Make sure that the proper number of files is displayed under the "#" symbol for each category before starting the run. Each calibration file can be created using either an average or a median of the individual images by selecting "ave" or "med", respectively.

Master Bias: when create is selected, the specified images will be average or median combined to create the master bias file specified. The use of a master bias is not required in general, but is required for exposure time scaling and non-linearity correction.

Master Dark: when create is selected, the specified images will be average or median combined to create the master dark file specified. If "use" master bias is selected, the resulting master dark image will be bias subtracted using the previously generated or specified master bias image. If "use" master bias is not selected, the master dark will not be bias subtracted. If "use" non-linearity correction is selected ("use" bias must also be selected), the bias subtracted dark is scaled using the three specified non-linearity coefficients.

Master Flat: when create is selected, the specified images will be processed and average or median combined to create the master flat file specified. If "use" master bias is selected, each individual flat is bias subtracted before combining. If "use" master dark is selected, each individual flat is dark subtracted before combining. If "use" is selected for both bias and dark, the flat is both bias and dark subtracted before combining. For "dark exposure timing scaling" to be applied when creating the master flat, "use" master bias and master dark must both be selected and either created or available, and "Dark ExpTime Scaling" must be selected. Selecting it without selecting "use" bias and "use" dark will result in no dark exposure time scaling. The full flat-field creation algorithm first bias subtracts each flat image (if selected), scales the pixel values by the non-linearity coefficients (if selected), dark subtracts the resulting image (if selected), removes any gradient from the image (if selected near the bottom), and normalizes the image to an average value of 1.0. After all specified flat images have been processed in this way, the resulting images are either average or median combined to create the master flat-field image.

Processed Images (Science Images): after any selected master calibration files have been created, each science image matching the "Primary Directory", "Filename Pattern", and "Filename Number Filter" settings defined at the top of the window are processed according to the "use" values selected. To "use" dark exposure time correction, it must be selected, and "use" must be selected for both master bias and master dark. The full science processing algorithm first bias subtracts each image (if selected), scales the pixel values by the non-linearity coefficients (if selected), dark subtracts the resulting image (if selected), and then divides by the master flat (if selected). If "Cosmic Ray Removal" is selected, outlier pixels in the image are replaced by the average of its four neighbors. Cosmic ray removal is not suggested for use with photometric data since it can clip steep peaks of stars. The selection of "gradient removal" does not apply to science images. If "Save" processed images is selected, the new file will be written to the specified relative directory with the specified suffix added in either 16-bit integer or 32-bit float format, as selected. The filename format can be any natively supported image file type (such as .fits, .tif, .jpg, .gif, .bmp, etc.).

"Show Log" displays a list of the steps completed in a log window. This data can be saved for reference if desired. "Show Master Images" shows the master calibration creation process as it progresses and displays the final master calibration files. However, this option uses more memory. The "Auto Level"

selections can be ignored since this function is now implemented as an option in the image display window.

Real Time Light Curve Plotting

The macro options near the bottom provide the capability to perform "real-time" data reduction and light curve plotting during an observing session. To use this feature, select "use" Macro 2 checkbox and then browse to the IJ plugins directory on your computer. Then navigate to the Directory_Watcher folder and select MultiApertureOnly.txt as the macro file. This macro runs Multi-Aperture (see Multi-Aperture section below for description) after each new image arrives and has been calibrated. After the first file has been calibrated, the Multi-Aperture setup window will be displayed, allowing any number of aperture locations to be selected in the image. After then final aperture has been selected, Multi-Aperture runs differential photometry on the image and creates a MeasurementsTable containing the results. Then the macro opens Multi-Plot and plots the light curve as set up in the Multi-Plot interface (see below for details). After the first image is completed, each subsequent image is processed automatically. Multi-Aperture uses the same relative aperture positions without intervention. Each aperture is repositioned at the centroid of the corresponding star in the new image, unless the image field moves by more than the aperture radius from one image to the next, in which case the process is halted. The plot is automatically updated after Multi-Aperture has completed photometric measurements and has updated the MeasurementsTable.

IMPORTANT: As long as the light curve plot is displayed, the Multi-Aperture settings dialog is bypassed and the previous aperture locations are used as reference. If new Multi-Aperture settings are desired, close the light curve plot window and the settings dialog will be display for the next image that is processed. Since a new set of Multi-Plot control windows will be opened when a new plot is generated, the old Multi-Plot control windows should be closed as well. All the settings will be saved and restored to the same state when the plot windows are opened. If you want to start the run over with new data for all images, close the MeasurementsTable window as well. Otherwise, new measurements will be appended to the old measurements.

<u>Single Aperture Photometry</u>

To perform single aperture photometry in astro-mode, hold the <shift> key and left-click near the object to be measured to place an aperture at its centroid. Alternatively, photometry mode can be entered by clicking on the IJ toolbar "Aperture Photometry Tool" icon to the right of the astro-mode icon. In photometry mode, left-click (without holding <shift>) near an object to be measured to place an aperture at its centroid. The photometric results will be written to a MeasurementsTable that will be created and displayed after creating the first aperture.

The parameters of the photometer and the data recorded in the MeasurementsTable can be set up by double clicking the single aperture icon on the IJ toolbar. If an image is open, the settings can be accessed under the Edit menu "Aperture Settings" selection. There are many options available but figures 4 and 5 below show an example of settings that should be a good starting point. Adjust the aperture sizes properly for the data being analyzed. Be sure to select "Show other configuration panel" to display the second set of options after the first set is closed.

Figures 4 and 5. Aperture Photometry Parameters
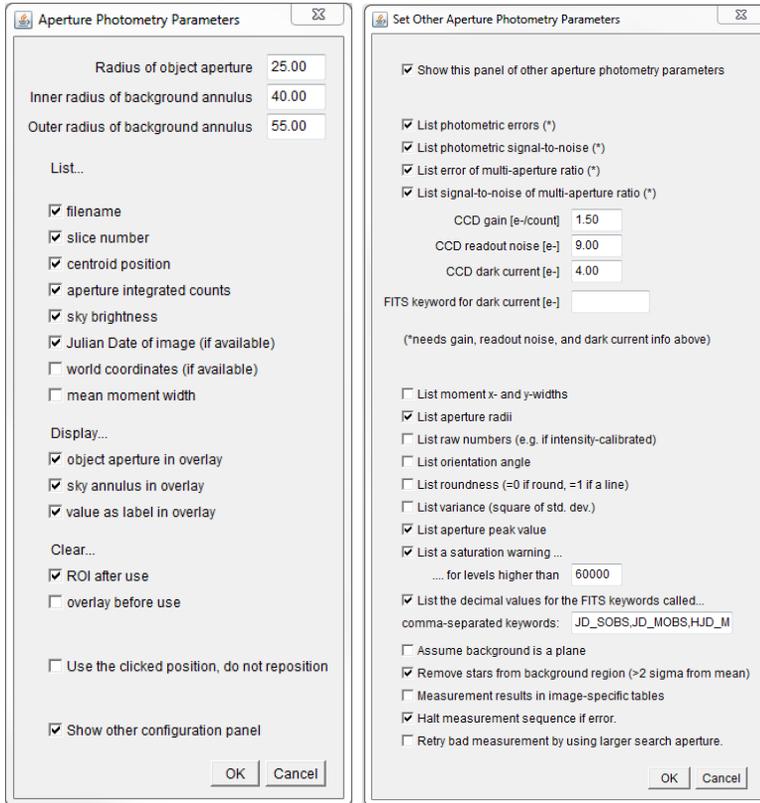
Multi-Aperture Photometry

Multi-aperture photometry provides the capability to run a series of photometric measurements on multiple objects within an image and to repeat those measurements for a sequence of images. Before starting Multi-Aperture photometry, an image stack needs to be opened. A stack is a sequence of images opened into a single AIJ or IJ image display window. To open a stack, if an image is already displayed, go to its File menu and select "Open sequence in new window". Otherwise, go to the IJ toolbar and select File/Import/Image Sequence. Using either method, select the directory containing the images to be opened. After pressing open, you will see the dialog shown in Figure 6 below.

Figure 6. Open File Sequence Options
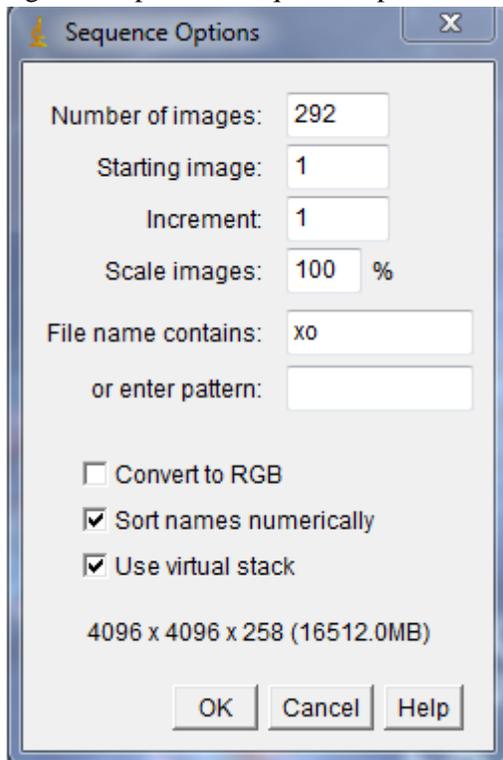
Define a file name pattern that is unique to the image set that is to be processed. In the case above, there are 292 images in the directory, but by entering "xo" in the "File name contains" field, the number of files to be opened has been reduced to 258 as can be seen at the bottom. An important checkbox here is the "Use Virtual Stack" field. If this is checked, AIJ loads only one image at a time into memory. If this is not checked, one needs to have enough memory in the computer, and allocated to IJ, to open a "stack" of images that totals the number of MB shown at the bottom (16512 MB in this case). After pressing OK, the image display will open (this may take some time if not using a virtual stack). Note the addition of the scroll bar below the bottom of the displayed image. The scroll bar allows the user to move through the stack to inspect each image individually. When moving the scroll bar, the display of a virtual stack updates more slowly than non-virtual stacks due to hard disk access time.

To perform multi-aperture photometry, click the icon with two apertures on the IJ toolbar (second icon to the right of the star-field icon). The dialog shown in Figure 7 will be displayed.

Figure 7. Multi-Aperture Setup Dialog
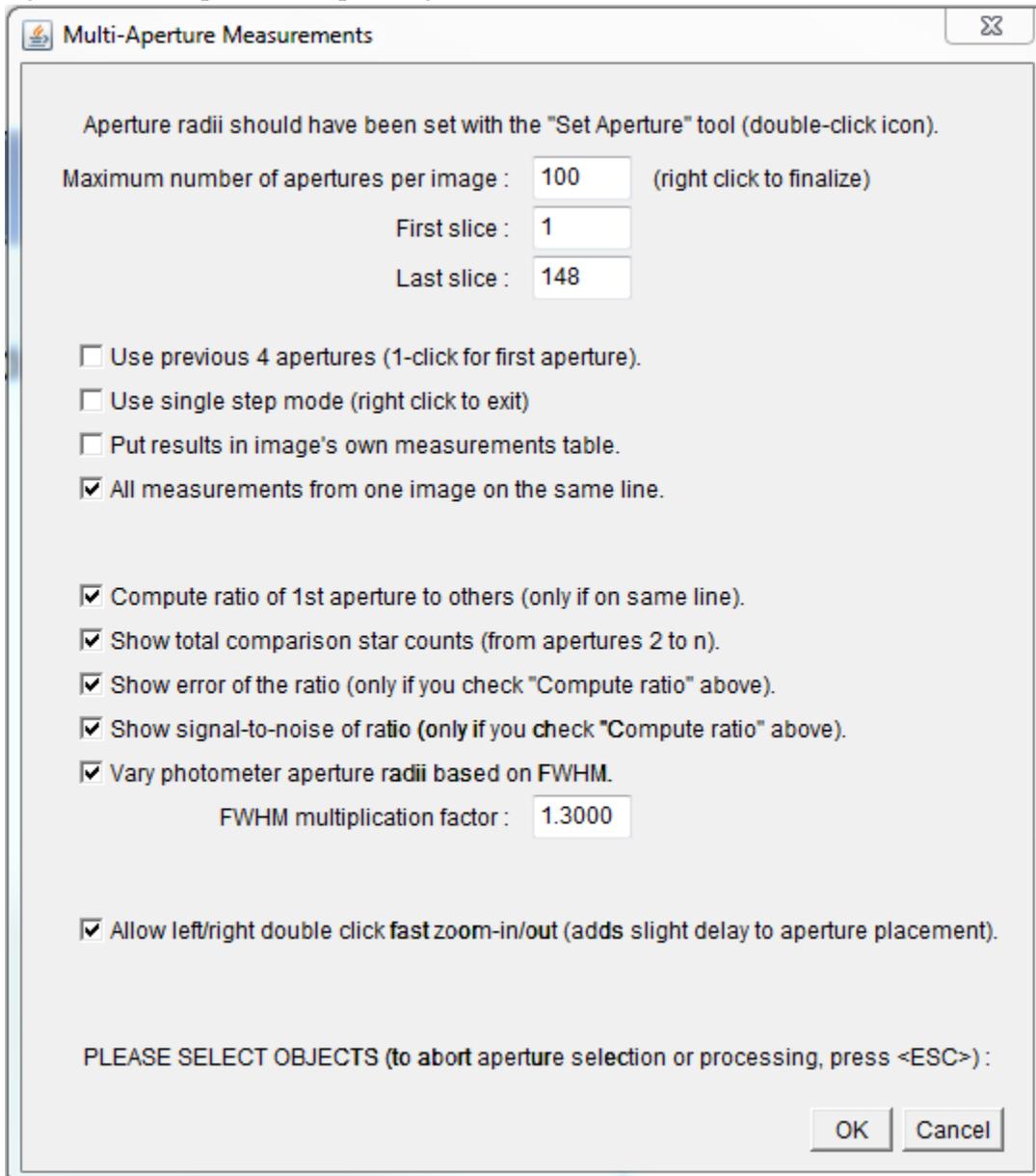
To process a full stack of images the first time, set up the options as shown above and make sure the "Maximum number of apertures per image" setting is higher than the number you will need. The aperture size must have been previously set using the image's Edit menu "Aperture Settings" selection or by a double click of the single aperture icon as described in the Single Aperture Photometry section. The "Vary photometer aperture radii based on FWHM" check box and the associated FWHM multiplier can be used rather than a fixed aperture size. In this mode, the aperture will vary based on an estimate of the FWHM of the target star. This option is particularly useful when seeing is changing dramatically throughout an observing sequence. As a starting point, use a multiplication factor of 1.3 x FWHM and adjust based on the data being processed.

After pressing OK, go to the image display, and click on or near the target star. An aperture will be drawn in green at the centroid of the star. Next click on the comparison stars one after another and more

apertures will be drawn in red. When an aperture has been placed at the last star of interest, right click to start processing. After the first image has been processed, a table will be displayed with a row that contains the photometric results. The next image in the sequence will then be displayed and the apertures will be re-centered based on the new centroids of the stars of interest. The centroid operation will fail if a star has moved by more than the aperture radius from image to the next. If the image shift is greater than the aperture radius, single step mode is available, which requires clicking only the target star in each image, to give a new offset reference. To use this mode after a centroid failure, check "Use previous apertures" and "Use single step mode" in the Multi-Aperture dialog. After clicking on the target star in the new image, new apertures will be drawn using the relative spacing from the previous image. After verifying that the apertures are centered properly, click on the image again to advance to the next image. Erroneous rows in a Measurements table can be deleted by selecting the row and using Edit/clear or right click/clear.

NOTE: The "Allow double click fast zoom in/out" option in the Multi-Aperture setting dialog enables the user to left double click on an image to zoom in by a factor of 8 at that point, and to right double click to zoom-out and fit the image to the window. Enabling the option can speed aperture placement, but it does introduce a slight delay in drawing a new aperture on the screen, and can take some practice to perform the right double click reliably. The double clicking option can be particularly confusing to a new user, and should be disabled until one gets familiar with the clicking combinations.

Once photometry on the full sequence is complete, a "Measurements" table will be displayed as shown in Figure 8 below. The data can be saved in tab delimited format by using the File/Save as ... command at the top of the data window.

Figure 8. Measurements Table

	Label	slice	X	Y	Source-Sky	Peak	Saturated	Sou
1	xo1b_3_bsdf.fits	1	2199.692051	2270.171399	1909362.958296	24328	0	231
2	xo1b_4_bsdf.fits	2	2198.893961	2269.185065	1919245.358842	26623	0	224
3	xo1b_5_bsdf.fits	3	2197.175387	2267.972628	1920315.553501	24773	0	217
4	xo1b_6_bsdf.fits	4	2200.627221	2266.786392	1923524.939505	27739	0	211
5	xo1b_7_bsdf.fits	5	2199.266815	2266.557166	1923615.705544	25226	0	206
6	xo1b_8_bsdf.fits	6	2198.551662	2268.091921	1917340.764596	30287	0	200
7	xo1b_9_bsdf.fits	7	2197.630486	2268.098625	1921881.683998	25237	0	197
8	xo1b_10_bsdf.fits	8	2200.045176	2268.924408	1920073.192201	26579	0	193
9	xo1b_11_bsdf.fits	9	2198.229886	2267.159481	1914614.819836	25435	0	190
10	xo1b_12_bsdf.fits	10	2199.725069	2268.999279	1910781.134917	24290	0	187
11	xo1b_13_bsdf.fits	11	2198.043583	2267.194001	1902778.862745	21244	0	184
12	xo1b_14_bsdf.fits	12	2200.769749	2268.384532	1909100.971589	17243	0	182
13	xo1b_15_bsdf.fits	13	2200.873746	2269.423613	1916378.279550	16528	0	180
14	xo1b_16_bsdf.fits	14	2199.153329	2267.778850	1912040.048933	18843	0	178
15	xo1b_17_bsdf.fits	15	2199.923294	2268.661805	1912807.950000	14781	0	177
16	xo1b_18_bsdf.fits	16	2197.274299	2267.823331	1912935.524418	17048	0	176
17	xo1b_19_bsdf.fits	17	2200.228295	2269.730418	1918603.190184	23147	0	175
18	xo1b_20_bsdf.fits	18	2198.115084	2269.133638	1910869.631498	19871	0	174
19	xo1b_21_bsdf.fits	19	2200.434514	2268.002715	1910138.517171	23982	0	173
20	xo1b_22_bsdf.fits	20	2199.410385	2267.789189	1915703.039176	19317	0	172
21	xo1b_23_bsdf.fits	21	2199.723548	2268.672055	1931308.141117	22590	0	172
22	xo1b_24_bsdf.fits	22	2197.283145	2267.267717	1931146.784621	20088	0	172
23	xo1b_25_bsdf.fits	23	2200.437677	2268.904202	1932366.786644	21647	0	171
24	xo1b_26_bsdf.fits	24	2199.376459	2267.945255	1941177.232558	20940	0	171

Light Curve Plotting

To plot a light curve and/or other data, make sure a MeasurementsTable is open in AIJ, and then open the main Multi-plotting window by either using an image display's Analyze menu "Multi-plot" selection or click on the light curve plotting icon on the IJ toolbar (4th icon to the right of the astro-mode icon). The main plot settings window will be displayed as shown in Figure 9 below.

Figure 9. Main Plot Settings Window
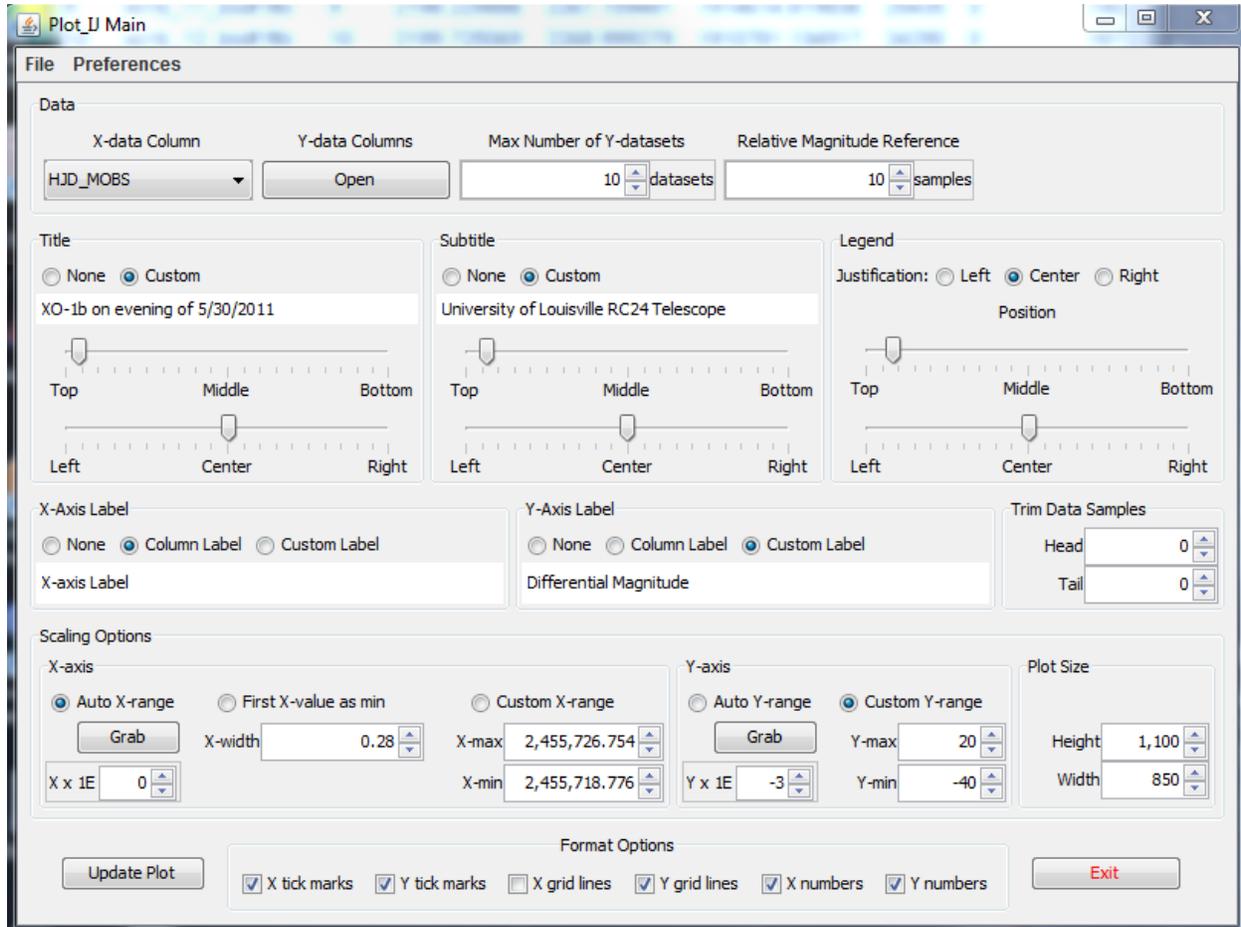
Most of the fields (or the labels above a column) on this and the following window have "tool tips" that pop up if the mouse is hovered over them which describe the use of the item. If a second plot settings window does not display automatically, press "OPEN" "Y-data Columns" near the top left of the main window and a second window will be displayed as shown in Figure 10 below.

Figure 10. Y-datasets plot settings
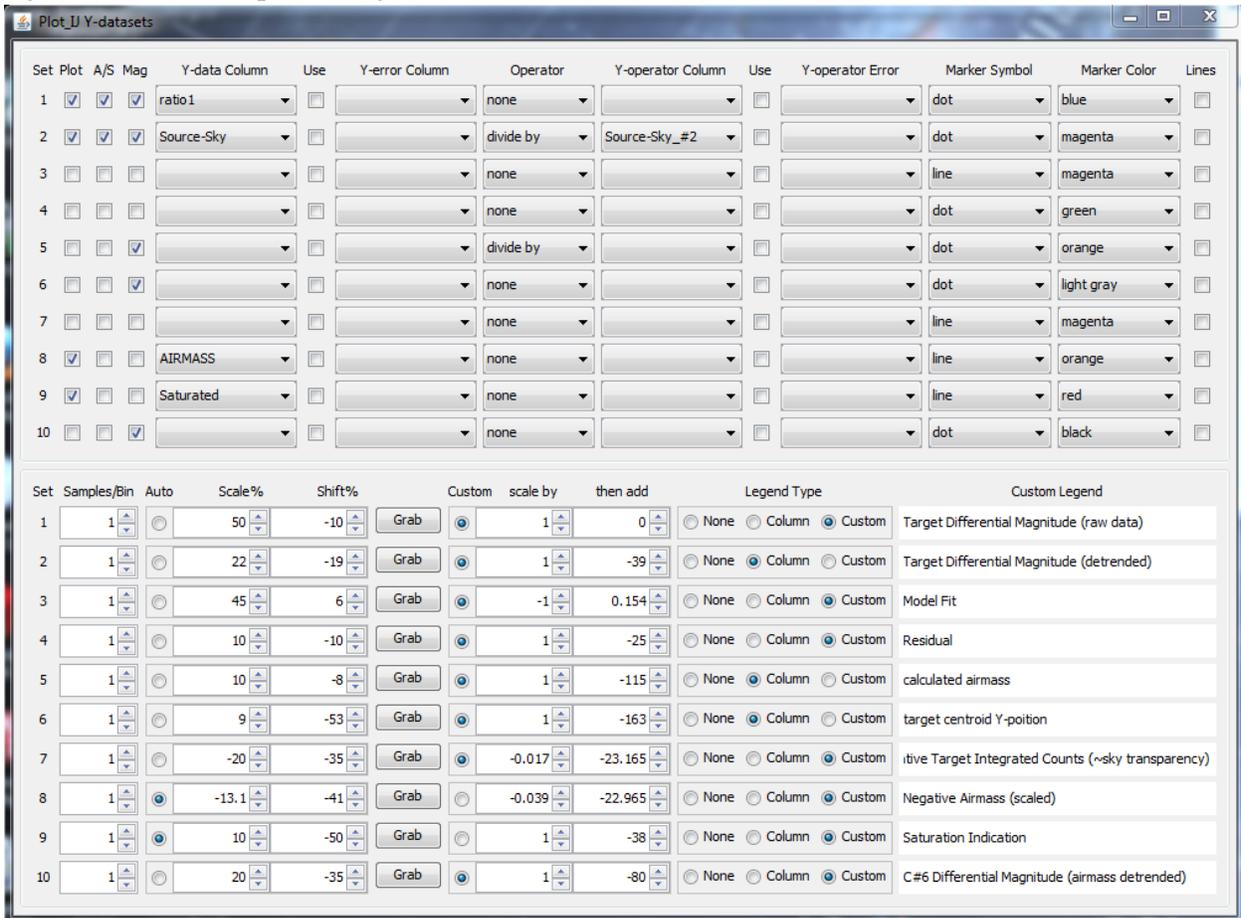
If a large screen (1920 x 1080 or larger) is available, the Plot_IJ_Main/Preferences/"use wide Y-data columns" option can be enabled to display all Y-data options for each plotted curve in one continuous row as shown in figure 11 below.

Figure 11. Wide Y-data options display mode
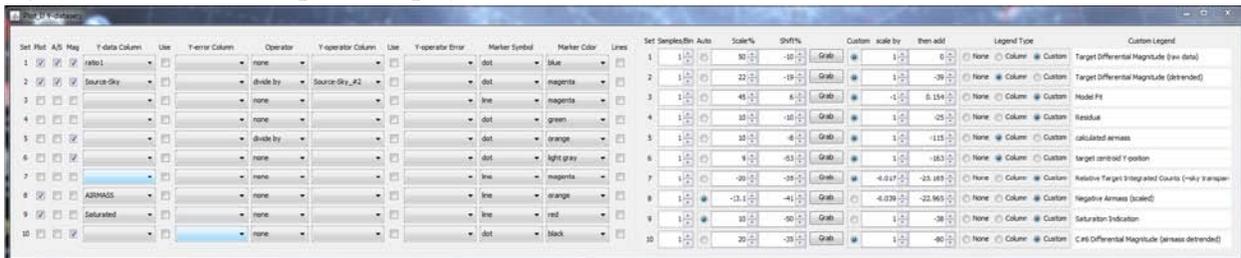
"Auto" and "Custom" are radio buttons that enable one of two plotting modes for each data set. "Auto" scales the data set to fit onto "Scale %" of the displayed image and shifts it to "Shift %" of the displayed image, whereas "Custom" sets an absolute scaling and shifting. However, in this mode the curve may not end up on the plot if it does not fall within the displayed Y-axis range.

The mathematical "Operator" feature allows calculations to be performed on one column of data using data from a second column, with the result being plotted. For example, as set up in dataset number two above, the target net integrated counts (Source-Sky) is divided by only the first comparison star's net

integrated counts (Source-Sky_#2), where as the first dataset (ratio1) is a column in the table that represents the target counts which have already been divided by the total of all the comparison star counts by the Multi-Aperture application. Since the data table contains only the ratio of the target to the combination of all the comparison stars (i.e. ratio1), the "Operator" feature can be used to easily check for the non-variability of comparison stars, etc.

To zoom in on the plot window, left click it. To zoom back out, right click it. It is easy to inadvertently zoom in on the plot when left clicking the window to bring it to the front. Plotting will be changed in a future release to change this behavior. For now, click on the edge or top of a plot window to select it without zooming in. On Linux systems, the plot zooming feature does not work properly at this time. The settings shown above result in the multi-curve plot shown in Figure 12.

Figure 12. Multi-Curve Plot Produced by AstroImageJ