Astroart 7.0 SP6

User's Manual

Astroart 7.0, 1998-2021 MSB Software

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1 Welcome

Astroart 7.0 is a fast and complete software for image analysis, processing and camera control. Astroart also contains a star atlas for astrometry, photometry and minor planets research.

1.1 System Requirements

Astroart requires the following minimum hardware and software configuration:

- A computer 100% PC compatible with at least a Pentium™ 800 Mhz CPU.
- At least 512 MB of RAM. If you work with images bigger than 1024 x 1024 pixels, 1 GB or more is preferable.
- 400 MB of free hard disk space.
- 1024 x 720 graphic card with true color.
- Windows 10, 8.1, 8, 7, Vista, XP. 32/64 bit.

1.2 Installation

1. Insert the CD-ROM in the CD drive.
2. Open the folder "Install Astroart 7" and double-click SETUP.EXE.
3. During the installation it's possible to choose a destination directory for Astroart (default is C:\Program Files\MSB\Astroart7\).
4. In the first execution of Astroart the program will ask the user name and the serial number which is printed on the cover of this manual.
5. To change the language click the menu File / Language and restart Astroart.
6. To command your camera with Astroart it may be needed to download the latest version of the plugins, at the web site: www.msb-astroart.com . Follow the instruction in chapter 5 "Camera Control".

1.3 Technical Assistance

M.S.B. Software
Via Goetz 93, Classe
48124 Ravenna RA - ITALY
FAX/TEL: +39-0544-527265. Mobile +39-339-2739548
MAIL: info@msbsoftware.it

http://www.msb-astroart.com
http://www.msbsoftware.it/astroart

2 Introduction

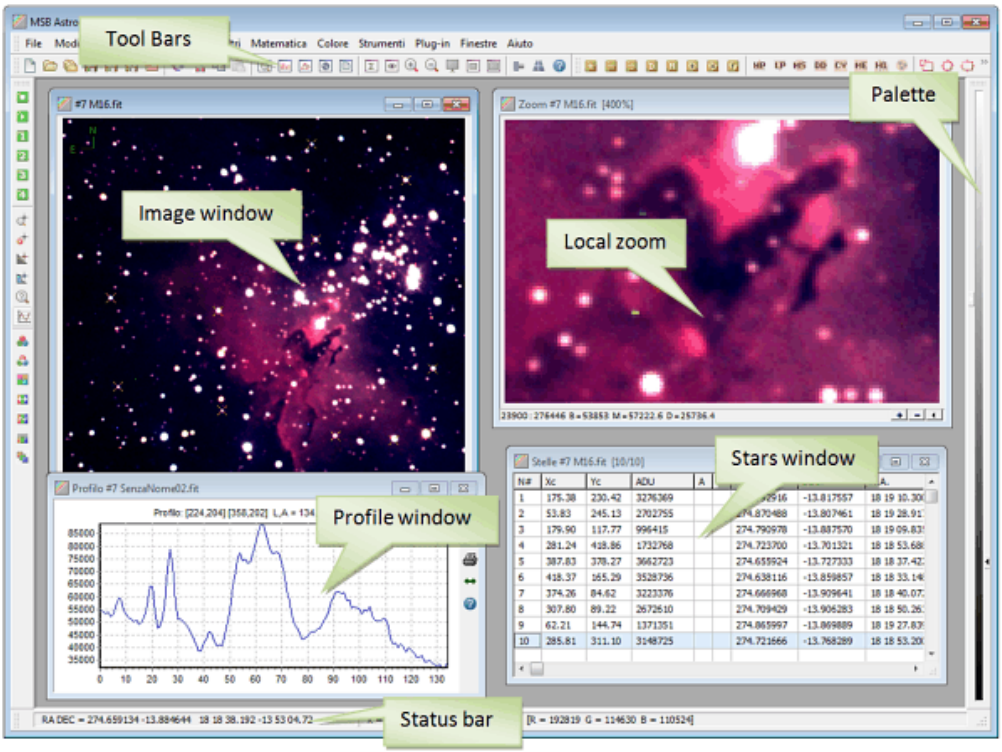
In this chapter, you will find the description of the GUI (Graphic User Interface) adopted by Astroart, how it operates and how all windows are related to each other.

2.1 The Astroart Desktop

The basic components of the Astroart desktop are the ***Tools bar*** at the top, the ***Status bar*** at the bottom, and a ***Palette bar*** on the right. The brightness of the desktop can be changed from the Preferences.

The Toolbars

They contain several buttons for quick access to common command. They can be docked everywhere on any side of the Astroart desktop. The size of the icons can be set in the Preferences.



The Status bar

Displays information about the active image: the X and Y coordinates of the pixel under the mouse pointer and the ADU value of that pixel (*Luminance* and *RGB values* for a color image).

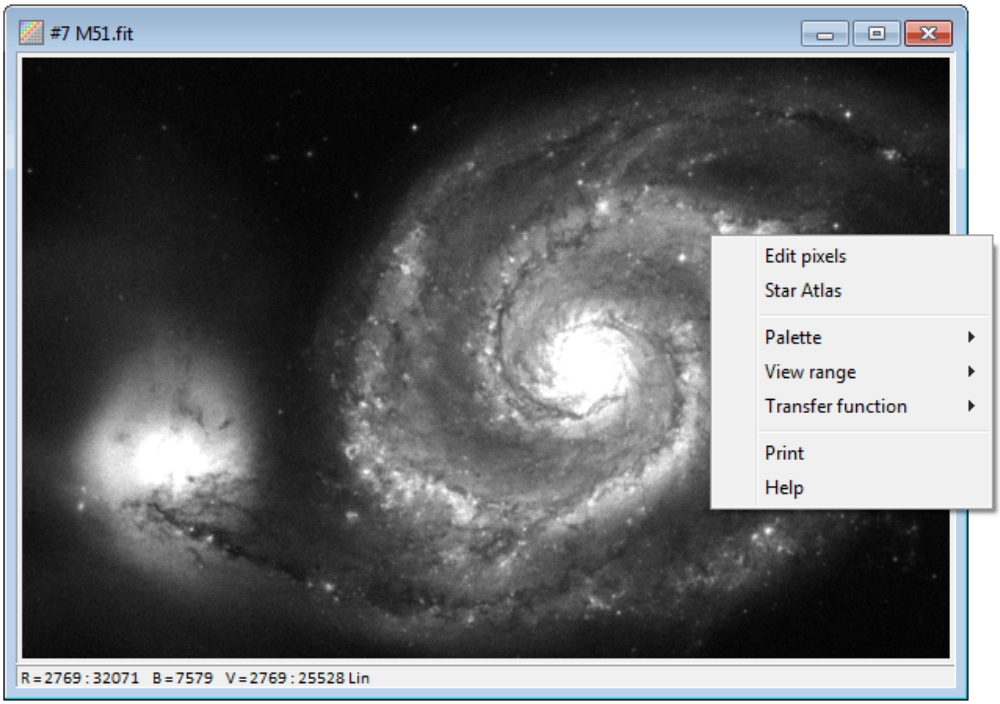
The Palette bar

Shows the gray levels (or the false color palette) used to display the image. Double click to open a custom palette from disk. Two small cursors represent the minimum and maximum visualization thresholds.

2.2 The Image Window

Image Windows are used to display images. When an image is shown on the screen, its pixel values (ADU) are converted in realtime to a shade of gray or to a color palette.

On the title bar of every *Image Window* you will find a number (it's a counter) and the name of the file. The counter is useful because you can open the same image multiple times.



Status bar

On the bottom of the *Image Window* there's another status bar, with the following data: (you may increase the size of the text with the option "Big fonts" in Preferences).

- **R** is the ADU range of the image (i.e. 2769:32071) this means that the darkest pixel has a value of 2769 ADU and the brightest a value of 32071 ADU, these units are proportional to the light captured by the CCD if it is working on the linear range of its response curve.
- **B** is the calculated sky background value.

- **V** are the visualization thresholds: the first number is the minimum threshold, the second is the maximum threshold (see below for the definition); the last is the transfer function used to map ADU values of the image to the gray levels of the PC monitor, in this example it's a linear function (labeled Lin).

Visualization

Every image is displayed according two visualization thresholds:

- **Minimum threshold**: every pixel below this value will be displayed black.
- **Maximum threshold**: every pixel above this value will be displayed white.

All other pixels with values between the two thresholds will be displayed as shades of gray (or shades of colors) according to the current transfer function and palette.

The fastest way to change the visualization is rotating the mouse wheel. It' also possible to drag the cursors on the palette bar (use the right mouse button for precise movements). Keep pressed CTRL for finer movements. To modify the visualization with the keyboard press [PAG_UP] and [PAG_DOWN]. For an automatic visualization click the status bar of the image.

Context menu

Click the right mouse button over the image to display the context menu: here you will find some quick commands: Edit pixels, Palette, View Range, Transfer Function.

Keyboard shortcuts

[+] (Numeric keypad). Zooms in the image.

[-] (Numeric keypad). Zooms out the image.

[*] (Numeric keypad). Adapts the window frame to the image.

[Arrows]. Moves the view when the image is zoomed. Press SHIFT for fast movements.

[PAG_UP] , **[PAG_DOWN]**. Changes the visualization (white threshold). Press CTRL for finer control.

[SHIFT + PAG_UP / DOWN]. Changes the visualization (black threshold). Press CTRL for finer control.

Mouse commands

Right click + drag. Pans the image if it's zoomed.

Wheel rotation. Changes the visualization (white threshold). Press Ctrl for finer control.

Wheel rotation + [Shift]. Changes the visualization (black threshold). Press Ctrl for finer control.

Wheel click + rotation. Changes the visualization (black threshold). Press Ctrl for

finer control.

Wheel click + drag. Zooms the image.

Right click. Displays the context menu.

Left click. Selects a point. If clicked over a star selects the star.

[Ctrl] + left click. As above with inverted logic.

Left click + drag. If some points are selected, deletes them otherwise it selects a rectangle or a line.

[Shift] + left click. Restores deleted points or copies them from another image.

Side by side comparison

[Ctrl] + Right click + drag. Pans both images. They must have the same size and should be aligned.

[Ctrl] + Wheel click + drag. Zooms both images.

[Ctrl] + [Shift] + Right click + drag. Pans both images when they have different size or when they are not aligned.

3 Tutorials

The following Tutorials are useful to make practice with the commands of Astroart.

3.1 Noise reduction

In these example you will learn the use of some Astroart commands to improve the quality of two images.

Example 1

Before to start, let's take a look at the *visualization* of an image.

1. Open the image M65_CAL.FIT from the folder IMAGES.
2. Press [PAGE_DOWN] three times, then [PAGE_UP] three times. Repeat this procedure again, looking at the image and at the cursors on the palette bar.
3. As you can see you are modifying the visualization, but you are not changing the image data. This is the difference between scientific software and painting software, the visualization stretch does not change the image content.
4. Now press [SHIFT] + [PAGE_DOWN] three times. This time you are modifying the brightness of the sky background, indeed you are moving the black cursor on the palette bar.
5. If your mouse has the wheel try to rotate it, it will move the white cursor. To move the black cursor click the wheel while rotating it.

Example 2

1. Open the image MOON.FIT. Press [PAGE_DOWN] on the keyboard to highlight the left part of the picture.
2. Click on menu *View* > *Local Zoom*. Move the zoom window if it overlaps with the main view. Move the cursor on the lower left side of the image and note with the zoom window some noise (pixels brighter than usual).
3. Click the right mouse button over the noisy area and select *Lock Zoom and 3D* from the *Context menu*.
4. Click on menu *Filters* > *Median* > *Median 3x3*, select Strength = 5%. Note the improved image quality; press [F9] key Undo / Redo many times to appreciate the difference between before and after.
5. Once you have eliminated the noise it is possible to enhance the definition with *High-Pass* or *Unsharp mask* filters.

Example 3

1. Click on menu *File* > *Open* to display the Open dialog window. In the combo box "File Type" select SBIG then select the file HORSE-SB.ST6 from the folder IMAGES of the Astroart CDROM.
2. Press [PAG_DOWN] to lower the visualization threshold and enhance the nebulosity.
3. Try to apply the filter *Hot Pixels* and *DDP*.

Example 4

1. Open the image N6824.fit and click *Filters* > *Remove gradient* with the option Adaptive Subtract to remove the vignetting.
2. Select (left click) the two end points of the satellite streak and click *Filters* > *Cosmetic* > *Remove line* to delete it.
3. Select a point in the middle of the saturated star and click *Filters* > *Cosmetic* > *Remove blooming* to fix the star. If some pixels are not corrected right click over the star and fix them with the menu command *Edit pixels*.

3.2 Dark frame and Flat field

1. Open the image M3_RAW.FIT from the folder IMAGES of the Astroart CDROM and note the noise caused by the dark current and the black spots caused by dust particles on the focal plane. Open M3_DARK.FIT and M3_FLAT.FIT: with these images we will correct the above defects.
2. Select the image M3_RAW.FIT (an image is Selected when his title bar is highlighted) and click on menu Arithmetic > Subtract and select the image M3_DARK.FIT in the dialog box. Modify the Visualization thresholds to better display the image corrected for dark frame (use the cursors on the right side of Astroart desktop or click on the status bar of the image).
3. Now it is possible to correct the image for the flat field. But before it is necessary

to correct the flat field for the dark frame too: select M3_FLAT.FIT and subtract from it the M3_DARK.FIT as you did before with the raw image.

4. Select M3_RAW.FIT and click on menu Arithmetic > Divide and select M3_FLAT.FIT in the "Select image" dialog box.

Automatic processing

Clean the Astroart desktop with menu File > Close All. Do not save the changes.

1. Click on menu Tools > Preprocessing. Drag & drop the file M3_RAW.FIT in the "Images" box, the M3_FLAT.FIT in the "Flat field" box and the file M3_DARK.FIT in the "Dark frame" box and in the "F. Dark frame" boxes; you could add in the same Dark boxes the file M3_DARK2.FIT: in this case there will be calculated a Master Dark Frame composed by the averaged values between the two dark frames. (During your own preprocessing session try to add at least 8 or 9 dark frames to reduce the noise fluctuations between the frames).

2. Click OK to start the automatic Preprocessing.

3.3 Searching for asteroids

Usually you can search faint asteroids blinking two images taken in different times.

1. Open the images ASTER_A1.FIT and ASTER_A2.FIT

2. Click on menu View | Blink to blink the two images.

3. Can you see the asteroid? It is just below a bright star near the center of the frame. Try to adjust the alignment between the two images clicking the Align button or the red arrows. Change the blinking frequency moving the slider.

4. Repeat the search with another asteroid using the images ASTER_B1.FIT and ASTER_B2.FIT.

3.4 FFT

In this tutorial we will study the Fourier Transform and the frequency domain, to correct images affected by periodic noise.

1. Open the image M81.FIT and click on menu Arithmetic > Image->FFT to create the FFT of the image. Press PAG-UP 3-4 times to darken the FFT.

2. Bring the mouse pointer to the approximate coordinates (140,50) and click the right mouse button, then EDIT PIXELS on the context menu.

3. Edit the pixel at coordinates (140,50) and write 10000. Click OK.

4. Now execute the command FFT -> IMAGE.

The result of this procedure is a new M81 image where a periodic noise affects the picture. Now, the way to correct such image is clear: at first perform the FFT transform, look for isolated and bright pixels, delete them, and perform the inverse transform at the end.

1. Open the image M51NOISE.FIT and perform the FFT.
2. Move the visualization threshold until you see two bright pixels at coordinates (140,46) and (140,47). Use the command EDIT PIXELS and set them to zero. Click OK.
3. Perform the inverse transform. Arithmetic > FFT->Image

The periodic noise is now perfectly corrected. Sometimes it's not easy to see the noise pixels (frequencies) and another step is required: after opening the image execute the command Scale > Transfer Function. Try with the M51NOISE.FIT image.

3.5 Aligning and summing images

To obtain a good Signal/Noise ratio it is often necessary to sum or average many images. Sometimes there is a misalignment from a frame to an other, due to a bad telescope motion, so all images should be shifted to fit exactly the other.

1. Open the images ALIGN1.FIT and ALIGN2.FIT, we will try to align and sum them.
2. Select ALIGN1.FIT and click on menu Arithmetic > Add image.
3. The image ALIGN2.FIT is summed on the ALIGN1.FIT but, as you can see, it is not exactly aligned with it (rotate the mouse wheel to fix the visualization). Press [F9] to undo.
4. To align the images we have to select a reference. In this case we'll use "Star pattern - translation only". Click on menu Image > Align and click OK.
5. The images are now exactly aligned and can be summed. After the sum click on the status bar of the result image to adjust the visualization thresholds.

The align method "Star pattern" is the recommended one. It will analyze the image and chose for you the best stars for the automatic alignment.

Automatic procedure

In this further example we will try to align and sum automatically a series of 4 images of the planetary nebula M57. These images are already preprocessed with dark frames but summing them we want to increase the overall signal to noise ratio.

1. Click on menu Tools > PreProcessing and *drag & drop* in the "Images" box the 4 images of the planetary nebula (if other images are present in the boxes click the Reset button).
2. Select "Sum" in the Images section ("Average" is possible too). Select the folder "Options" then disable the item "Confirm all images" and enable "Auto alignment", click OK.
3. Click OK again in the Preprocessing window: The result image, the sum of the selected 4 images, will be automatically built. Rotate the mouse wheel to adjust the visualization.

Close all images. Open in Astroart all four M57 images into the Astroart desktop, then try the command "Align all".

Planets

Aligning and adding planets is even simpler, since you don't need to select any reference.

1. Open the Preprocessing window and click on the Reset button. Select SBIG file format and Drag & Drop into the Images box all the Saturn images available.
2. Click on Automatic Alignment and select "planet" as aligning method. Click OK and wait for the final image. Remember to keep not selected the option "confirm each image".
3. Now that a good image has been built it's possible to apply the Unsharp Mask filter to improve its sharpness.
4. Just for fun, repeat the preprocessing without enabling the Automatic Alignment to verify that the planet is located at different coordinates in every frame.

3.6 Manual aligning

1. We will align a set of 4 images of the comet Hartley; the comet is quite faint and passes near a bright star, so an automatic aligning will be probably a difficult task.
2. Click on menu Tools | PreProcessing and drag & drop in the "Images" box the files from HARTL_01.FIT to HARTL_04.FIT. Select "Manual alignment" and press OK.
3. The first image will be opened. Select a centroid aperture of 15 pixels.
4. Try to find the nucleus of the comet, click on it with the mouse then use the arrows button to center the pointer over the nucleus of the comet. The square cursor can also be moved with the keyboard, using the arrow keys, to confirm press [ENTER].
5. Repeat the last step for the other images to correct the relative shifting of the comet. At the end of the process you will find a resultant image with a better signal to noise ratio.

3.7 Image processing on comets

To obtain a good and "clean" image of comet Hyakutake we will automatically average 21 frames. Then we will apply the "Larson-Sekanina" filter to enhance the jets and the shells around the false nucleus of the comet.

1. Click on menu Tools | PreProcessing and drag & drop over the "Images" box the frames from HYAK_001.FIT to HYAK_021.FIT (use multiple selection to select them all at once). Select the "Option" folder, disable "Confirm each image" and enable "Average" of images.

2. Select "Auto alignment" then "One star" method. Inside all of the 21 frames the false nucleus of the comet is the brightest stellar-like object: therefore, we can choose as a reference point the brightest pixel of the image, set for example X,Y = 100,100 and R = 400.

3. Press OK and wait for the resulting averaged image.

4. Select the pixel corresponding at the false nucleus of the comet (the brightest pixel is X=190 Y=160) and click on menu Filter | Larson-Sekanina .

5. In the Larson-Sekanina dialog box set Delta R=3 pixel and Alpha=10 degrees and click OK. The comet's dust shells and a bright jet (toward the lower right corner of the image) will be clearly visible.

3.8 Mosaic

A limitation of some CCD cameras is the little field of view caused by the small sensitive areas. Nevertheless it is possible to join many images of adjacent areas and compose them into a wide field image.

1. Open the images Mosa_1.fit and Mosa_2.fit

2. Select the same star (or point) on both images and click Image/Mosaic.

3. Enable the real time preview and move the brightness slider to match the two parts. You may want to disable the faded border for a better inspection.

4. Enable the faded border, increase it if you like, and OK.

5. Close Mosa_1 and Mosa_2.

6. Open Mosa_3 and repeat the procedure.

7. Close Mosa_3 and the Mosa1+2 partial mosaic.

8. Open Mosa_4 and repeat the procedure.

Doing so we obtain the mosaic, exactly balanced.

3.9 Astrometry and photometry

With the astrometric calibration we will establish a "link" between each point (x,y) of the image and the corresponding celestial coordinates (R.A. and DEC.).

The photometric calibration will allow us to derive a function which converts the brightness of a star from ADU to magnitudes. To do all this we need some "reference" stars with known R.A., DEC., and magnitude.

Manual procedure

1. Open M57_SUM.FIT.

2. Move the cursor of the mouse on a bright star. When the cursor becomes a little circle click on it with the left button: the star will be selected.

3. Repeat the last step for other 3-4 bright stars.

4. Open the Stars Window: Menu view > Stars
5. Click on menu Tools > Star Atlas, (the default field displayed by the Atlas will be exactly the field of the planetary nebula M57). Resize the Atlas window until it become about the same size of the image.
6. Click the first star in the Stars window (#1 or the first row), and a light blue cross will highlight the correspondent star of the image. Click with the left mouse button the same star on the Star Atlas and its data (RA, DEC. e MAG.) will be copied to the list of the Stars window.
7. Repeat the last step for all other stars.
8. Click on menu Tools > Astrometry then "OK".
9. Click on menu Tools > Photometry then "OK".

The image is now calibrated: for every new object added to the Star List, RA, DEC and MAG. will be calculated.

Automatic procedure

1. Close the M57 image and reopen it.
2. Click the button "Reference stars, automatic" in the Star Atlas.

That's all. Astroart finds for you the best stars in the atlas and the image and matches them via pattern recognition. Now you can click on menu Tools > Astrometry again. If the nebula was recognized as a star, repeat the procedure decreasing the FWHM max parameter to 5.0.

Semi-automatic procedure

1. Close the M57 image and reopen it.
2. Select some stars over the image.
3. Click the button "Reference stars, manual" in the Star Atlas.
4. A cross will indicate the first star you selected. Now click the star on the star atlas.
5. Repeat the last step for the other stars.

3.10 Deconvolution

Deconvolution is an iterative process which corrects a constant defect over the image, as bad focus or star trails. Theoretically there will be a total correction only in total absence of noise.

1. Open the image DECONV.FIT
2. Select a small rectangle around a non-saturated star: for example: x1,y1 = 126,26 x2,y2 = 140,37.
3. Click on menu Filters > Deconvolution > Maximum entropy, then click on "Get PSF" and then on OK.

4. Set 30 iterations and click OK to see the result.

Let's now simulate a guiding error. Open an image containing stars and click on menu Filters > Convolution then set the following matrix:

```
1 0 0 0 0
0 0 0 0 0
0 0 0 0 0        ( The central pixel must be zero )
0 0 0 0 0
0 0 0 0 1
```

Note that image obtained is similar to those obtained when the telescope is hit during the exposure. Click on menu Filters > Maximum entropy, with the same matrix to correct the defect.

Set 40 iterations and click OK.

Close the image and repeat with another image and the following kernel.

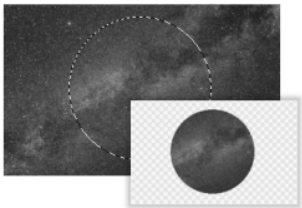
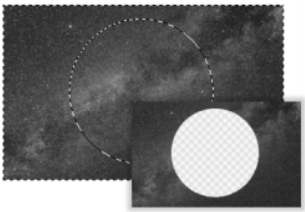
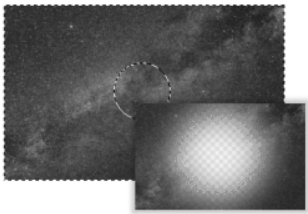
```
0 0 0 0 1
0 0 0 2 0
0 0 3 0 0
0 2 0 0 0
1 0 0 0 0
```

3.11 Masks

Masks are useful in image processing to process only a part of the image. For example, to highlight an object without modifying the surrounding stars, you could select a mask around the object then use the command "Histogram stretch" or "Color curves". For a nice result remember to smooth the mask before applying the filter.

In this example we'll use a mask to filter only the edges of an image.

1. Open the image Coma.jpg
2. Look at the corners of the image, we want to correct stars here without correcting the stars in the center of the image.
3. Zoom out to see the whole image, open the Mask Window, select the Ellipse tool and draw a circle with a diameter of 90% of the height of the image. While drawing you may press CTRL to force a circular shape.
4. Invert the mask clicking the button "Invert", then smooth (100) the mask:

Now we can apply the filter to compress stars: click Tools / "Find stars", write 5000 then OK. click Filters / Cosmetic / Compress Stars, enable the Adaptive option and click OK.

Close the mask window, press CTRL+D to delete the mask, zoom in to a corner of the image. Now if you press F9 (undo/redo) several times you can see the difference with the original image. Notice that stars in the middle are not changed.

3.12 Camera control

Astroart contains a "Camera Simulator" which let you make practice with common tasks like imaging, focusing and guiding.

1. Click on menu Plug-in > Camera control.
2. Select "Simulator" and click "Setup".
3. Click the Start button to acquire an image.
4. With the mouse, draw a rectangle around a star, select the Focus/Guide page and click on Focus.
5. Close the Focus window, then click the Guide button.

3.13 Scripts

A script is a list of commands which are executed in sequence to perform camera and telescope control.

1. Click on menu Plug-in > Camera control.
2. Click on the "Script" button to display the Script panel.
3. Click on button "Menu", select the first demo script then execute it.
4. Repeat the last step for the other demo scripts.

4 Reference

4.1 File Menu

The following commands perform the basic input-output actions.

4.1.1 New

This command creates a new blank image (all pixels values = 0 ADU), useful for tests. A dialog box will ask you the *X* and *Y* size in pixel. The maximum size is 24000 pixels.

For images bigger than 20 megapixels we suggest to use the LAA version of Astroart, or the 64 bit version.

4.1.2 Open

This command opens one or more images from disk. A preview of the image and the FITS header is available in real time.

Multiple files can be opened at a time using the standard features of Windows: [Shift] to select a range of files, [Ctrl] to select multiple individual files. For multiple selections with the mouse, draw a rectangle around the icons. Files can also be opened via *drag and drop* into the Astroart desktop, dragging from the Windows desktop or from programs like Total Commander.

DSLR images can be opened with or without automatic demosaic (debayer) see Preferences.

4.1.3 Save 16/32 bit

Saves the active image into a 8 / 16 / 32 bit file accordingly with the dynamic of the image. If the image is colored then three samples will be saved for every pixel. Annotations will be saved as comments into the FITS header.

FITS (32 / 16 / 8 bit)

If all pixels of the image are within the range 0 to 255 ADU and they are integer, Astroart will save the file as an **8 bit FITS.**

If all pixels of the image are within the range 0 to 65535 ADU they and are integer, Astroart will save the file as a **16 bit FITS.**

If just one pixel has a value outside the range 0 to 65535 ADU or it is expressed as a floating point value, Astroart will save the file as a **32 bit FITS** (integer or floating point).

PNG-FITS (16 / 8 bit)

Saves a *PNG* file maintaining the FITS header information. The FITS header will be saved into a "Text Chuck" of the PNG file.

If all pixel values of the image are within the range 0 to 255 and are integer, Astroart will save the file as a **8 bit PNG file** otherwise it will save the image as a **16 bit PNG file.**

TIFF (16 / 8 bit)

A widely used graphic format. Very useful to pass data to older programs.

ASCII (32 bit)

It's an one-column plain text file: the first rows are the dimensions x and y of the image in pixels, the third is blank, the following are the ADU value of the pixels and read line by line.

RAW (32 bit)

An array of 32 bit numbers without any header (not to be confused with the various RAW format from DSLR cameras).

4.1.4 Save view

Saves the active image as it appears on the screen. This means that the data saved is only a *view* of the image, not the real pixel data. Use this command to export the image to other graphic programs or to publish your image on the web. Annotations will be saved as pixels over the image.

The image can be saved at 8 bits per channel (256 levels), or 16 bits per channel (65536 levels). The file formats available are: PNG, TIFF, JPEG and BMP. To pass the image to other software you may also *copy and paste.*

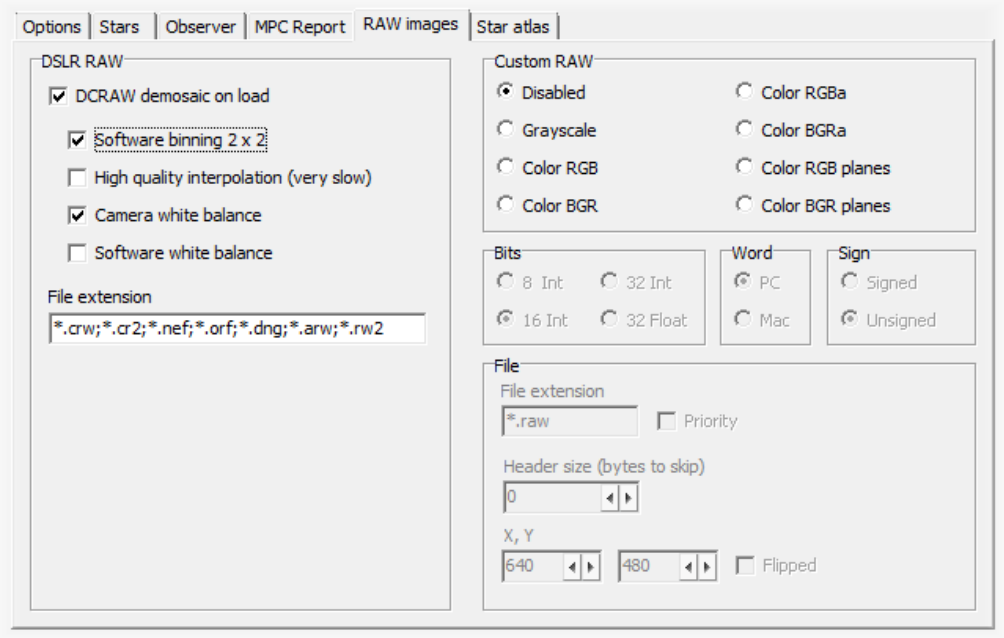
4.1.5 Close

Closes the active image. If you made any change in the image or in the FITS header then a dialog window will ask you to save or skip the changes.

- **Close all**. Closes all images, asking for confirmation only one time.
- **Close all and save**. A dialog window will permit to save each image before closing it.

4.1.6 Configure RAW

This command opens the *Raw Images* section of the *Preferences Window*. Here it's possible to configure two kinds of RAW files: DSLR RAW and Custom RAW.



DSLR means Digital Single-Lens Reflex, which are the best digital cameras available today. By default they save their images as JPEG, but RAW images are better, because they have an higher dynamic and they are not lossy-compressed. RAW files are also required for dark frame and flat field correction.

- **DCRAW demosaic on load**. If enabled, the image will be automatically converted to color using the DCRAW library. Remember that a DSLR RAW image is actually a grayscale image where the color information is encoded as a Bayer pattern. If you enable this option (not recommended) you won't be able to correct the dark frame and the hot pixels. Instead, disabling the option you will be able to correct the defects and you will demosaic later with the command Demosaic.
- **Software binning 2x2**. Works only if *DCRAW demosaic on load* is enabled The image will be reduced in size (50%) since four pixels will be summed into one, increasing the dynamic. This is an interesting option since has three important advantages: 1) On most image you don't lose any information since multi-megapixels images are often heavily oversampled (e.g. blurred) so a 2x2 binning does not worsen the resolution. 2) Hot pixels remain single pixels, so they still can be corrected. 3) The image consumes less memory when processed.
- **High quality interpolation**. On crisp images this improves the quality between transitions of colors, but for astronomical images, which are often oversampled, it may not worth the time.
- **Camera white balance**. The white balance is corrected using fixed coefficients which depend on the camera model.
- **Software white balance**. The white balance is corrected using a software

algorithm.

DCRAW DSLR in Astroart is implemented as a special plug-in that is updated every 8-12 months. Check for updates at: www.msb-astroart.com/plug_en.htm.

4.1.7 Optimize JPEG

This command allows to evaluate the quality of a compressed JPEG before saving it.

Move the slider until you are satisfied with the compromise between quality and size of the image.

4.1.8 Print

This command prints the current image.

1. Input a name in the *title* text box (default is the path and name of the current image).
2. Select an orientation (portrait or landscape).
3. Select a scale (from 5% to 100%). At 100% the image will fit the whole page.

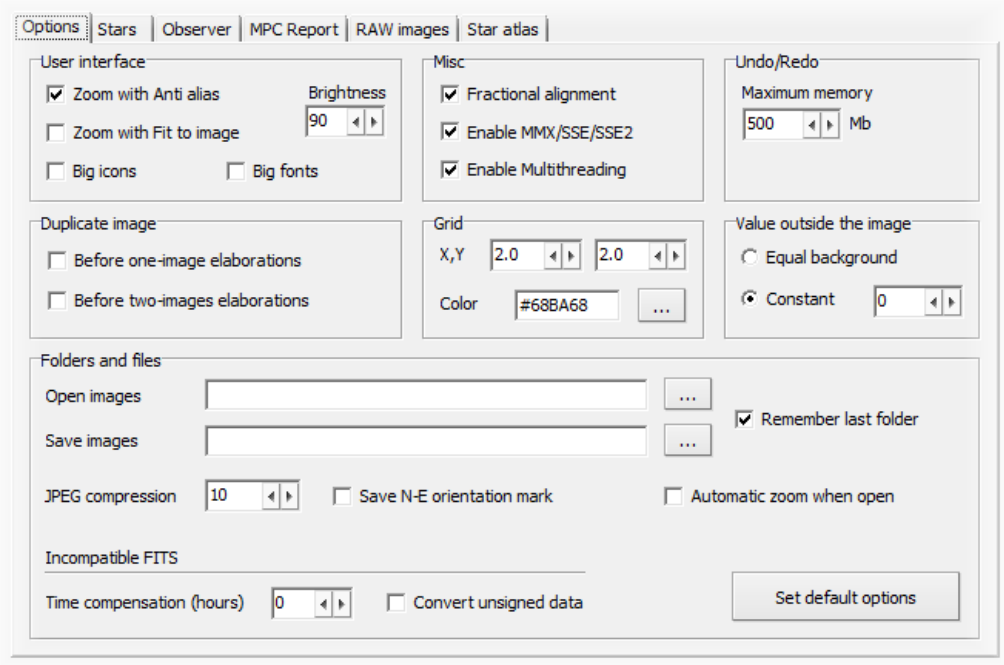
4.1.9 Language

This command changes the language of Astroart. Full support is available for English, French, German, Italian and Spanish. Please check the Astroart web site for upgrades.

4.1.10 Preferences

The *Preferences Window* is composed of six pages: Options, Stars, Observer, MPC Report, Raw Images and Star atlas.

Options



Zoom. Set "Anti alias" to enable the high quality drawing of the image when it's displayed zoomed out (drawing may be slower). Set "Zoom with Fit to image" to resize automatically the Image Window during zoom. See also: menu *Window* / *Fit To Image*.

Big icons and fonts. Sets the size of icons in the main Astroart window and the size of text in the status bar of the Image window, Local zoom and 3D window.

Fractional alignment. Enables sub-pixel shifting during alignment (recommended).

Enable MMX/SSE/SSE2. If enabled, Astroart will use the SSE CPU instructions to process 4 pixels at a time.

Enable Multithreading. If enabled, Astroart will use all cores of your CPU to process images.

Undo/Redo max. memory. Sets the maximum memory in megabytes for the undo buffers, when multiple images are processed at the same time. The depth of the undo buffer is always one, but there can be many buffers when working on different images.

Duplicate Image. Select these options (not recommended) to force the creation of a new image as a result of every operation.

Value Outside the Image. Some elaborations needs to estimate the value outside the boundaries of the image: here you can specify the Outside constant.

Grid. Select the number of sections for the Grid. Fractional values are accepted, for

example it's possible to enter the field of view in arcminutes (example: 15.8 x 10.3) so that every sector will be exactly one arcminute.

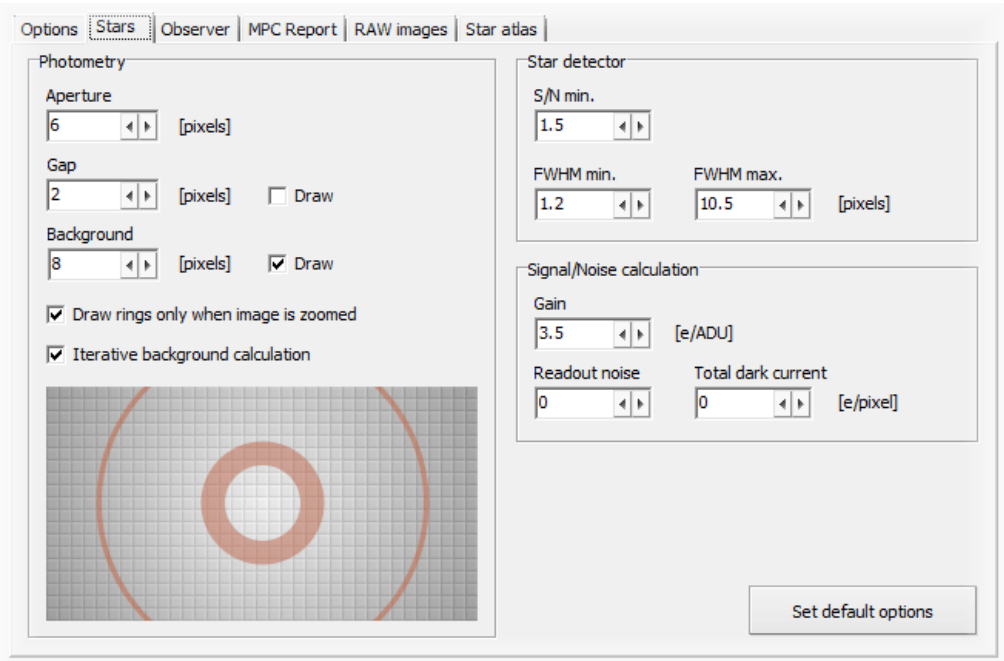
Open Images and **Save Images**. Select here the default folders for opening and saving images, or select the option to remember the last used folder.

JPEG Compression. Sets the quality of images saved as JPEG. Default = 10, a higher value produces better compression and lower quality. You may also select to embed the North-East astrometric marker.

FITS time compensation. (not recommended). If your FITS files have a wrong Universal Time, you may correct them here adding a time offset in hours.

FITS convert unsigned data. (not recommended). 16 bit FITS images with negative pixels and BZERO = 0 will be considered unsigned. Enable it only to import old images from incompatible software. When this option is enabled you won't be able to open valid FITS files with negative pixels.

Stars



Photometry. Select the size (in pixels) to calculate the magnitude and position of stars.

- **Aperture**. The diameter (in pixel) of the circle that should contains the star. Be careful that in previous versions of Astroart this value was a radius, now it's a diameter.
- **Gap**. The width (in pixel) of the annulus that is ignored while calculating the sky

background.

- **Background**. The width (in pixel) of the annulus used to calculate the sky background.

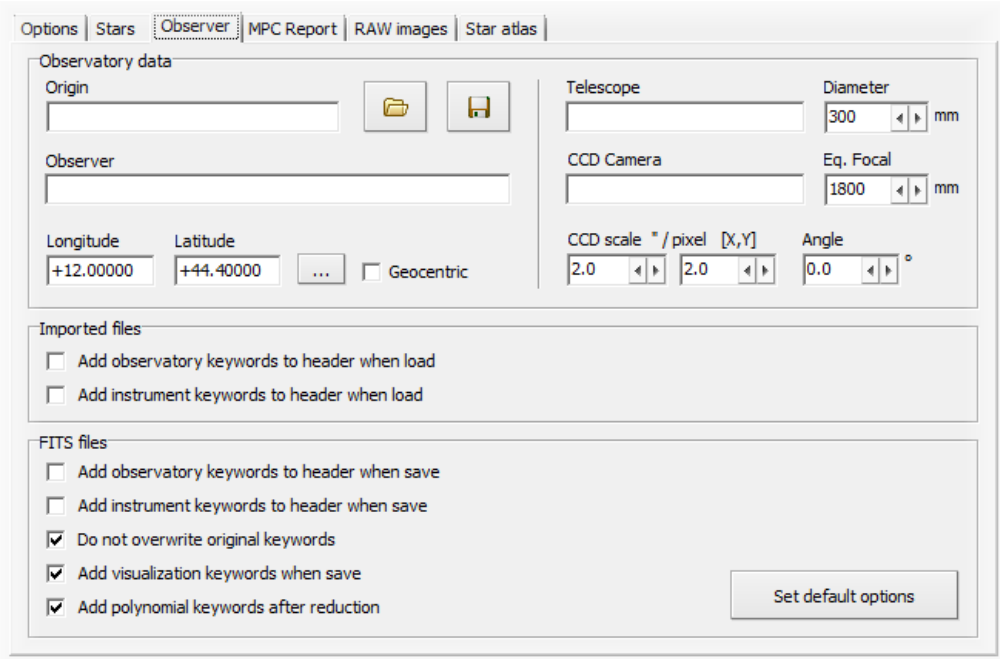
Draw ring when image is zoomed. By default the three rings above are drawn on the image only when the the image is zoomed 200% or more. You may disable this option to have them always drawn.

Iterative background calculation. If enabled (recommended) the background is calculated with an iterative algorithm which removes the stars and all bad pixels from the annulus. If not enabled, the background is calculated as a simple median of the pixels.

Star detector. Choose the minimum and maximum FWHM (in pixels) and Signal to Noise ratio to detect the stars of the image. See also: Find stars.

Signal to noise ratio. These values are used in the Stars window to calculate the S/N for every star.

Observer



Observatory and **Instruments** data. The most important data to be set is the longitude and latitude of the observatory (decimal or sexagesimal coordinates, e.g. +44 12 59, which is used for parallax calculation of minor planets) and the CCD scale / Angle which is used in Preprocessing for the option "Follow minor planet" (these values can be found with the Statistics Window on a astrometrically calibrated image).

All the other data (Origin, Observer, Diameter, Focal, etc.) are just the FITS keywords which will be written to every image if you enable one of the options below:

Imported files. (not recommended) These options work only when you open a non-FITS image in Astroart. They add *Observatory* or *Instruments* keywords to your imported files.

FITS files. These options act on the FITS header when you save your images.

The options "*Add observatory keywords to header when save*" and "*Add instruments keywords to header when save*" can be used to update a set of your images which do not contain the observatory and instrument keywords. By the way they are not recommended, since your risk to add the keywords to images which were not taken by you.

The option *Add visualization keyword on save*, writes to the FITS header the following keywords. When Astroart opens an image, these keywords are used to display the image.

- AVISUMIN. The minimum threshold visualization value.
- AVISUMAX. The maximum threshold visualization value.
- AVISUTYP. The type of the transfer function.

The option "*Add polynomial keywords after reduction*" (recommended) writes the astrometric (WCS) and photometric keywords when a calibrated image is saved. See Astrometry.

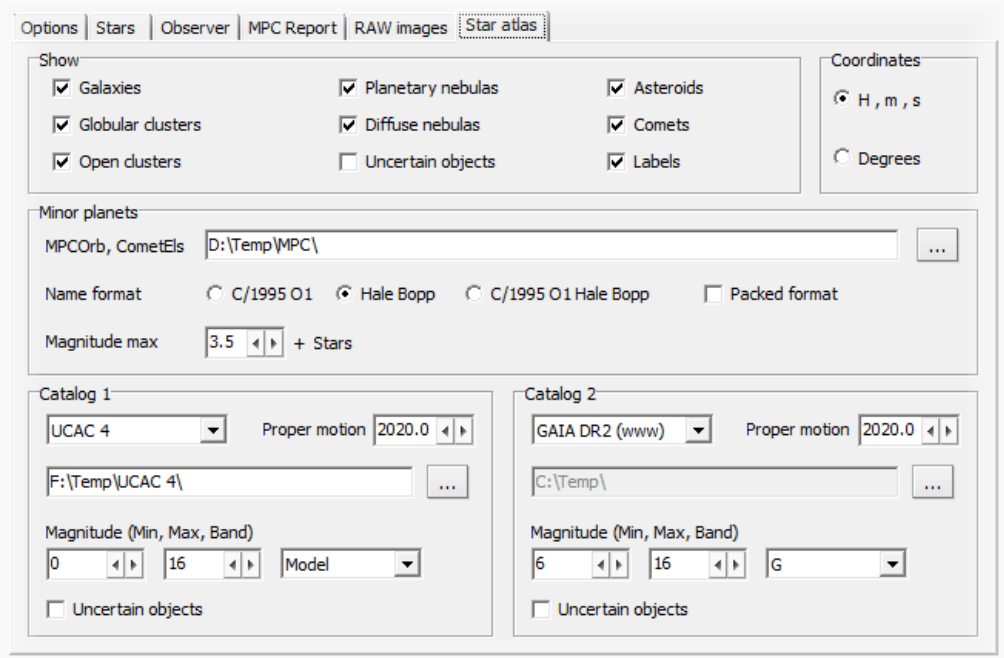
MPC report

This page contains of a text box to be edited following the rules of the Minor Planet Center, see also the MPC_Submission_Information_Page. They refer to the MPC 80-columns format, which is still accepted despite the introduction of the new ADES format.

RAW Images

See the Menu *File* / *Configure RAW* for details.

Star Atlas



Show. Select here which objects are to be shown in the atlas.

Coordinates. Choose between coordinates in the decimal or sexagesimal format (hours, minutes and seconds for Right Ascension and degrees, minutes and seconds for Declination).

MPCOrb.dat, CometEls.txt. To display comets and asteroids you need to download these files almost every month. Write here the folder where they are saved. These files are downloadable at the MPC site: www.minorplanetcenter.net/iau/MPCORB.html, click "MPCORB.DAT" and "Comets".

Minor planets magnitude max. The maximum magnitude is related to the stars currently shown. If you are displaying stars up to 8.0 mag, then "+3.5" will let you see asteroids and comets up to mag 11.5. However, you can display more objects clicking the button "More objects" in the Star atlas.

Catalog 1 and **Catalog 2**. Astroart supports two star catalogs at a time. Write here the folders where they are placed. You may also write the year for the proper motion of stars. The USNO-B and GAIA DR2 are available only as internet download. Astroart will query in background the stars of the required region from the Vizier web server. For fast downloads it's better to limit the magnitude to 15-18.

4.2 Edit Menu

These commands allow to change some properties of images and macros.

4.2.1 Undo

This command cancels or restores the last elaboration. Press [F9] multiple times to switch with the keyboard, you may use this trick to compare the result of a filter with the original image.

4.2.2 Copy and Paste

Copy

Copies the active image to the *Clipboard*. If a rectangle or a mask is selected in the image, then only this region will be copied. You may paste this image into Astroart or into other graphic applications.

Paste

Pastes an image from the Clipboard as a new image, or inside the current image. Three options are available:

- **As new image**. A new image will be created from the image stored in the Clipboard.
- **Into selection**. The clipboard image will be copied inside the selected rectangle or mask.
- **Into image**. The clipboard image will be copied inside the current image, at the X,Y selected coordinates, using a given opacity. It's also possible to Add or Subtract the pixel values (ADU). Hint: If the clipboard image has a black background (zero ADU), then the Add option makes it equivalent to an alpha channel, so you may add a logo to the image. Logos can also be added as Annotations.

Empty Clipboard

Deletes the image stored in the Clipboard, to free the memory used.

4.2.3 Select

Selecting points and rectangles is a fundamental step to perform many elaborations with Astroart. Points and Rectangles are usually selected with the mouse, however with these commands you can select them with the keyboard.

- Select point . [CTRL+P] Set the X and Y coordinates of the point that you want to select.
- Select rectangle. [CTRL+R] Set the X and Y coordinates of two points that defines a rectangular region.

Astroart will keep in memory the coordinates of the most recent selections, so that they can be retrieved by the commands which need them.

4.2.4 Select point

An image can have one more selected points, a cross marks their position.

To select a point simply click with the left button. To select a point over a star press [CTRL] while clicking. You may also select a point in the *Edit Pixel* window pressing [SPACE], or launching the command *Edit / Select*.

To delete a point click on it. To delete all points draw a rectangle. To restore all points or copy them from another image, left click keeping [SHIFT] pressed.

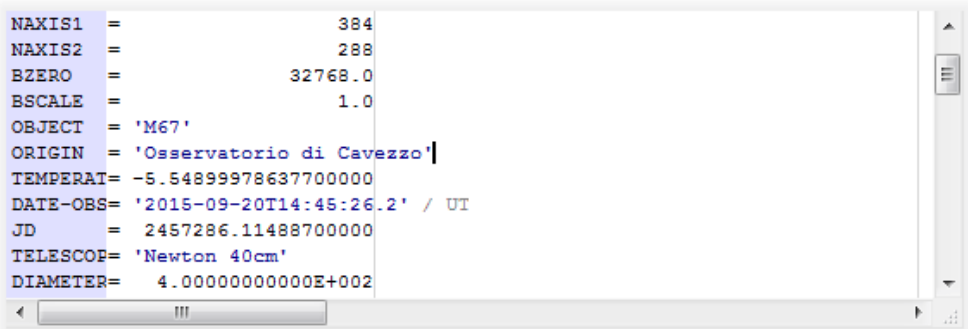
4.2.5 Select rectangle

To select a rectangle press the left mouse button and draw a rectangle, or use the command *Edit / Select*. To enlarge or shrink the rectangle press CTRL + NUMPAD PLUS or MINUS. To select a rectangle in the middle of the image press CTRL + NUMPAD5.

Once the rectangle is selected you may move it pressing CTRL + arrow keys, or CTRL + left mouse. The selected rectangle is not a mask for filters. Use masks for this purpose.

4.2.6 FITS Header

This command opens a window for reading or modifying the FITS header of the image.



Click the right mouse button to open a *context menu* with the following items:

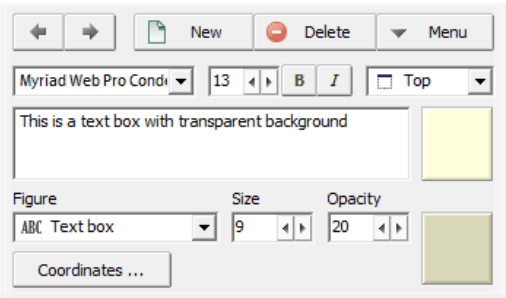
- **Undo**. Cancels all modifications.
- **Protect header**. If selected (by default) it does not allow any modifications of the *essential keywords*.
- **Insert from file**. Inserts a text file into the header at the position of the cursor.
- **Export to file**. Saves the header as a text file.

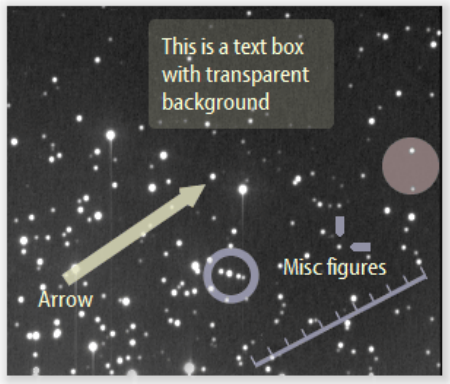
All the changes will be stored in memory when you close the window.

4.2.7 Annotations

Annotations are figures and labels placed over the image.

Click "New" to create a new annotation. Write a text in the edit box, then select the shape of the figure (select "None" if you want only a text). You may change the color of text and figure clicking the square buttons. Click the arrow buttons to change the selected annotation.





When an annotation is selected, it can be moved and resized using the mouse, and all its parameters can be changed in real time. To move with the keyboard press CTRL and arrow keys.

Annotations are saved as comments in the FITS Header, so the pixels below them are never lost. Annotations are kept in a separated layer, so they don't influence any filtering, analysis or visualization function of Astroart.

A special annotation is the Logo, which is an image that can be placed everywhere over the image. Logo images must be placed in the folder Public Documents\Astroart\Logos, the recommended format is PNG with alpha layer. On Windows 8 and 10 the path is: C:\Users\Public\Documents etc.

Copy/Paste

These commands are useful to copy an annotation to another image, or to duplicate it over the same image. You may duplicate an annotation also clicking the "New" button.

Copy All

Copies all annotations to another image.

Hide Annotations

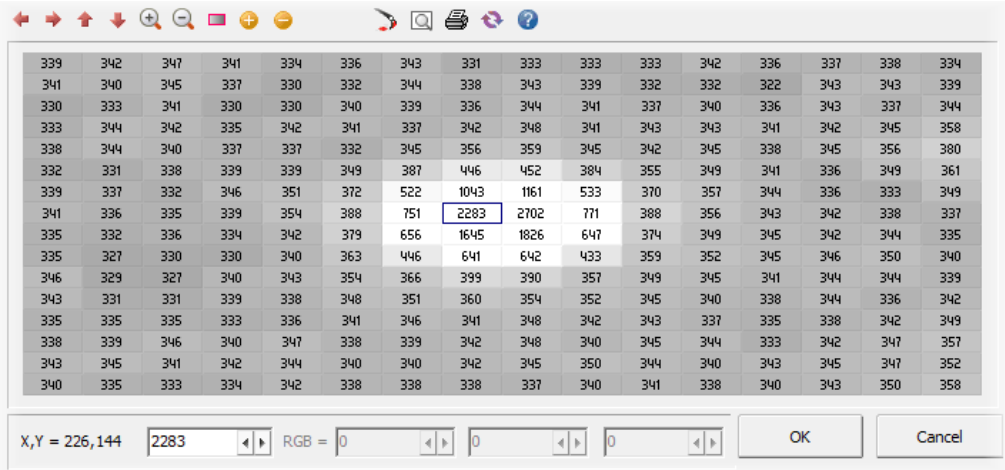
This command hides all annotations on all images. A button is also available on the left toolbar. Hotkey: CTRL+SHIFT+A.

Coordinates

These fields are useful to set with absolute precision the position and the size of the annotation.

4.2.8 Pixels

Use this command to analyze or modify the pixels of the image.



The window has two working modes: **Analyze+Edit** and **Paint**. We suggest to open a sample image and try all the following operations.

Analyzing and Editing with the keyboard

Arrow keys: moves the cursor.

Shift+arrows: moves the zone.

+ -: zooms in and out.

0..9: starts editing the current cell.

C, V: copies and pastes. S: selects a point over the image.

Analyzing and Editing with the mouse

Left click: selects the current cell.

Double left click: selects and enters edit mode.

Right click+drag: moves the zone.

Rotate wheel: changes visualization.

Wheel click+drag: zooms in and out.

Painting with the mouse

Left click: starts painting.

Right click: picks the color from the grid.

Right click+drag: moves the zone.

Painting mode is enabled after clicking the brush button. The window changes and new options become visible. Set a value used for painting (to pick a value with the mouse right-click over a cell) and an optional noise. You may also change the brush shape and its size.

4.2.9 Data Format

Astroart supports both floating point and integer images. Use this command to switch between these formats.

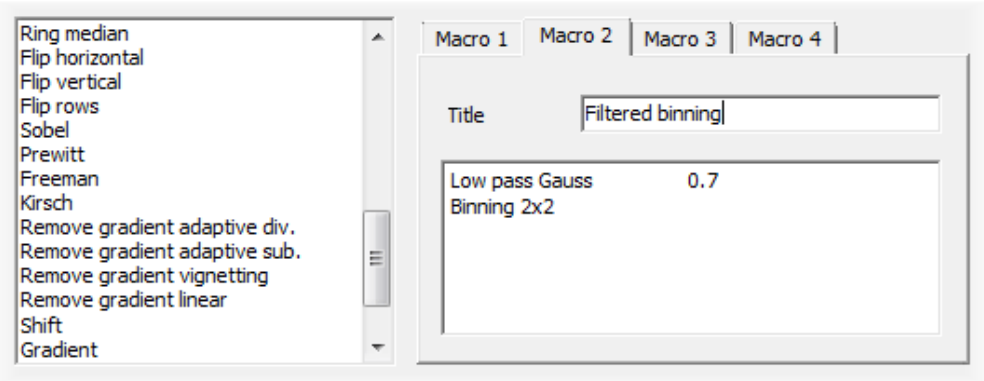
Although 16 bit images created by astronomic cameras have a sufficient dynamic, it could be convenient to manage them as floating point to avoid quantization. For example, imagine a division by two and then a multiplication by two, where the pixel value is 1035.

```
INTEGER:  1035/2 = 517    ->  517*2 = 1034
FLOAT:    1035/2 = 517.5  ->  517.5*2 = 1035
```

Working with integers causes a quantization error of 1, in this case it is not a great error, but in other cases (8 bit images for example) it may become a source of noise. For this reason, all temporary processing in Astroart is always performed in floating point.

4.2.10 Define Macro

A Macro is a list of commands which are executed in sequence.



1. Drag and drop or double click a command to add it to the list.
2. A dialog box will ask you the parameters of the command. If you click *Cancel* then the command will be added without parameters, they will be asked every time the macro executes.
3. In the *Title* text box, write a name for the macro: it will appear in the *Edit menu*.

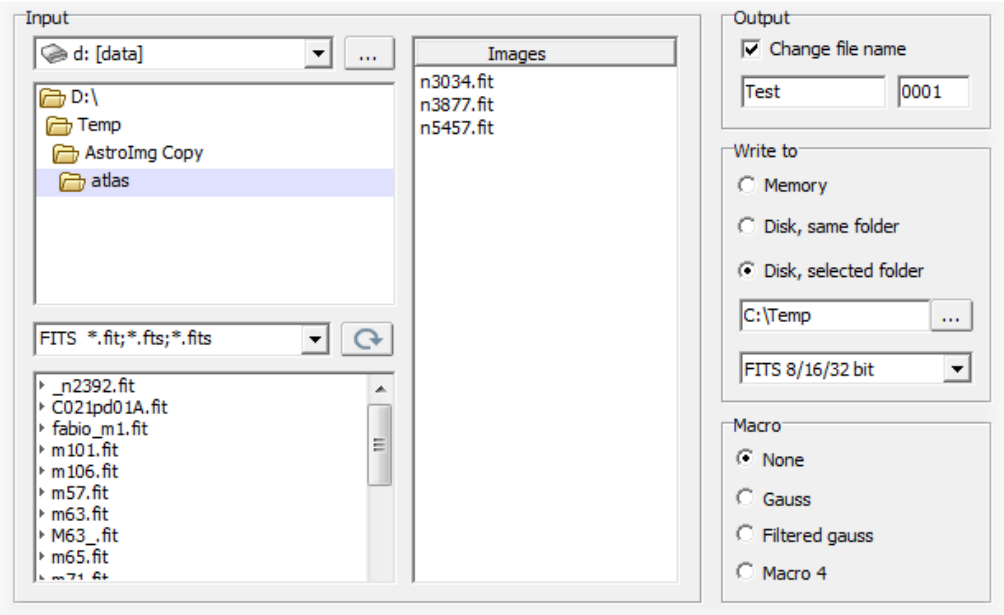
To remove one command in the list click it with the right mouse button. If you

execute a macro that require two images (see Arithmetic menu), then the second image must be present in memory, otherwise a dialog box will ask if you want to abort the macro or perform it with another image.

Use the Apply macro command to apply a macro on a series of images.

4.2.11 Apply Macro

This command executes a macro on a group of images.



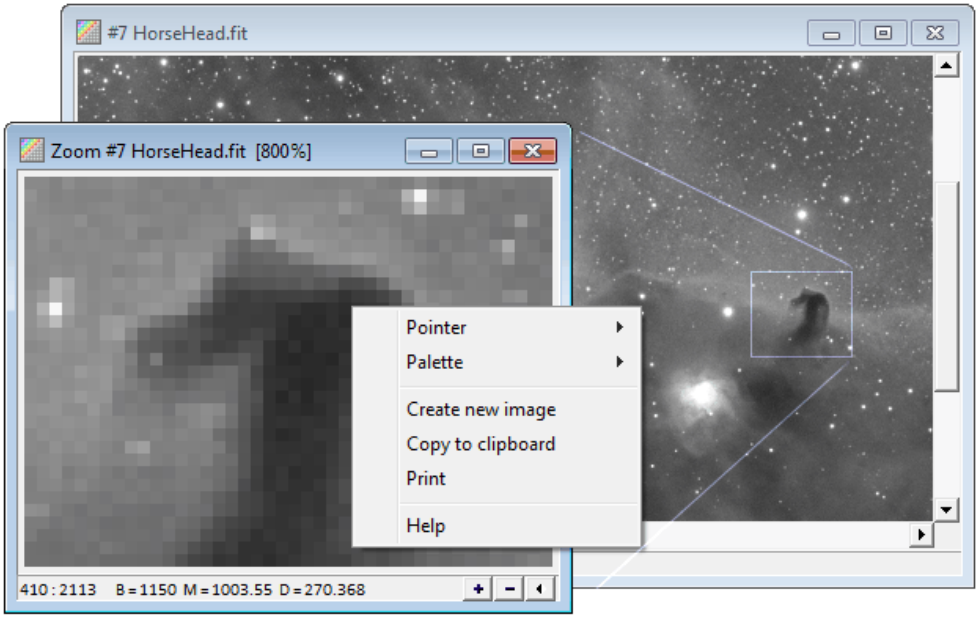
1. Drag and drop the files you intend to process into the *Images* box. To select all files of the same kind (same filter for example) double click on a filename. To select all files press SPACE or double click with the right mouse button o drag and drop an entire folder from the *Input* panel.
2. Select a name for the output files (Astroart will automatically add a counter to that name) and choose if you want to keep them in memory or write them to disk.
3. In the *Macro* panel, select the macro to be applied, or select "None" if you just need to rename of convert a group of images.

4.3 View Menu

These commands are related to the visualization of the image.

4.3.1 Local Zoom

This command displays an interactive window to analyze or to perform aperture photometry over the image.



Move the mouse pointer over the image window to select the region to be zoomed (you can disable that selecting *Lock 3D / zoom* from the Image Context Menu). The zoomed region can also be moved by:

1. Pressing the arrow keys on the keyboard, hold down [SHIFT] to move it faster.

2. Clicking the left mouse button on the zoomed region and dragging it.

Click the **[+]** and **[-]** buttons to increase or decrease the zoom factor (default 2X). The last button enables the auto-contrast, which is useful on low contrast parts of the image. In the status bar it's also calculated:

- The minimum and maximum pixel value in the window.
- **B**. The local background value.
- **M**. The local averaged value.
- **D**. The local standard deviation .

Context Menu

Pointer. Selects the shape of the pointer, with *Circle* and *Annulus* you can perform the aperture photometry.

Palette. Displays the image in false colors.

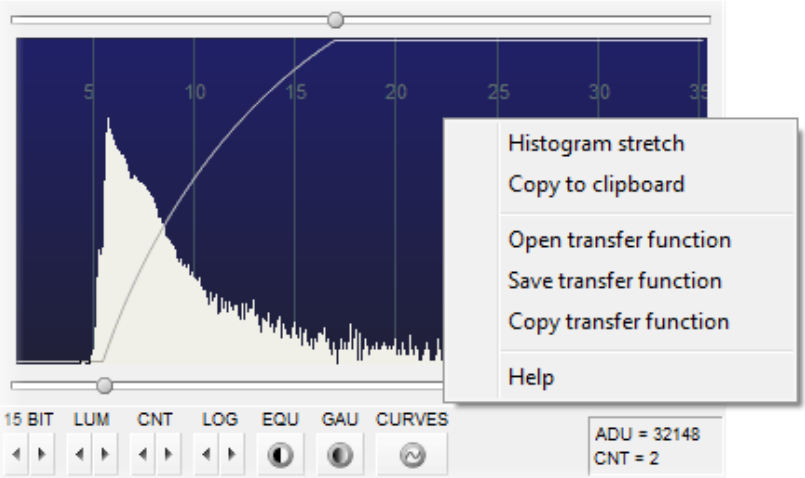
Create new image. Creates a new image from the zoomed area.

Copy to clipboard. Copies the zoomed area to the Clipboard.

4.3.2 Histogram

This window is used to change the visualization of the image and to inspect the *image histogram*.

The histogram of a digital image is a graph that shows the distribution of pixel values. On the X-axis we have the pixel values, on the Y-axis we have the "count" of pixels for each value.



The upper cursor in the histogram window corresponds to the *maximum visualization threshold*, it controls the pixels which appear white. The lower cursor corresponds to the pixels which appear black. Pixel in-between are displayed as shades of gray according to the current transfer function.

- **BITS** (15,14, etc.). These buttons change the scale of the X-axis.
- **LUM**. Changes the visualization brightness.
- **CNT**. Changes the contrast.
- **LOG (LIN, EXP)**. Changes the transfer function (or LUT, Look Up Table) which is the narrow line on the histogram graph.
- **EQU**. Histogram equalization: a non-linear transfer function which forces the final picture to have all level of grays represented equally. It is used to show the faintest parts of diffuse objects. The contrast is very high.
- **GAU**. Gaussian equalization: It is useful to highlight structures in nebulosity (and galaxies) while maintaining the natural appearance of an astronomical picture.
- **CURVES**. Sets a custom curve for visualization. It's possible to set up to 4 control points.

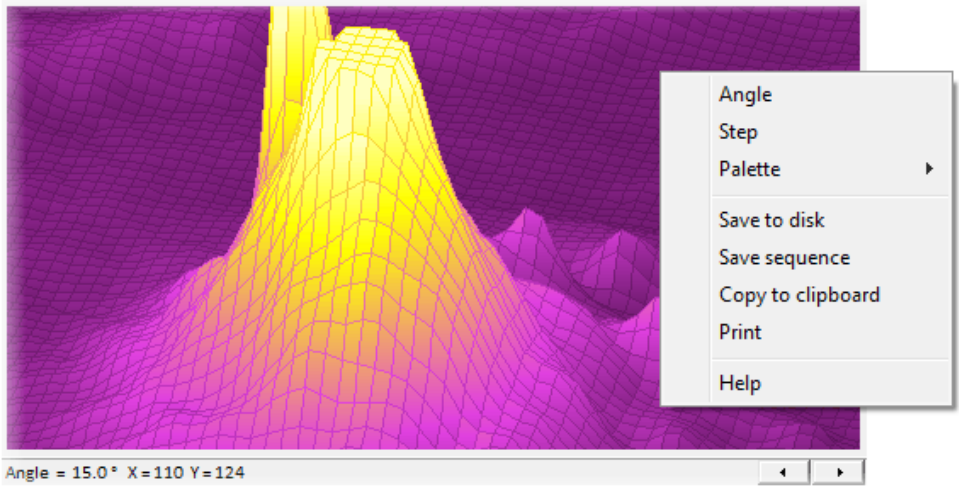
- **VAL**. Shows the ADU value at the position of the mouse pointer. In the CNT field you can see the number of pixel with this particular ADU value.

Left click and *drag left-right* to move the histogram. Left click and *drag up-down* to change the scale.

Right click to display the context menu. The command *Histogram stretch* (not recommended) modifies the image according the current visualization. You may obtain the same result using the command *Filter* / *Histogram stretch*. The histogram data can be saved as a list of values/counts into a text file. The transfer function can be saved for future use or copied to another image.

4.3.3 3D

This window displays in 3D a region of the image.



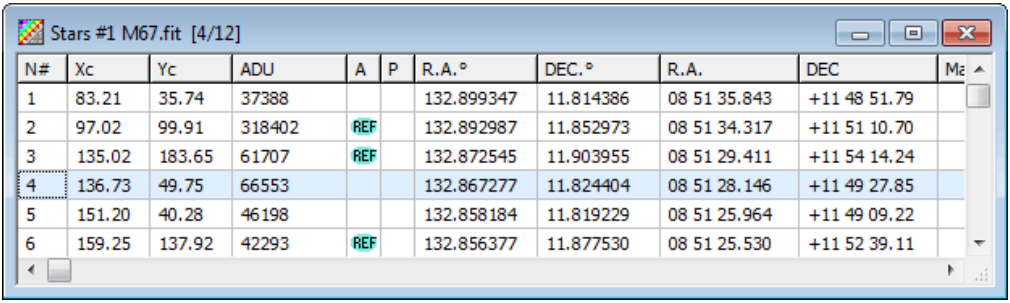
Move the mouse pointer over the image to explore it in 3D. To disable this select *Lock 3D/Zoom* from the *Image context menu*.

It's possible to rotate the graph with the keys [PAG_UP] and [PAG_DOWN]. Press [SHIFT] to rotate the image faster. Press the [Arrow keys] to move the region. To rotate and pan using the mouse, click and drag. Right click to display the *context menu*:

- **Angle, Step**. Sets the visualization angle and its step during movements.
- **Palette**. Changes the graph colors.
- **Save**. Saves the 3D graph as a BMP image. "Save sequence" saves a 360 degrees animation, the number of frames will be 360 divided by current Step.
- **Copy to clipboard**. Copies the graph into the clipboard.

4.3.4 Stars

Displays a table which contains information about the selected stellar objects of the image.



Stars #1 M67.fit [4/12]

N#	Xc	Yc	ADU	A	P	R.A.°	DEC.°	R.A.	DEC	Ma
1	83.21	35.74	37388			132.899347	11.814386	08 51 35.843	+11 48 51.79	
2	97.02	99.91	318402	REF		132.892987	11.852973	08 51 34.317	+11 51 10.70	
3	135.02	183.65	61707	REF		132.872545	11.903955	08 51 29.411	+11 54 14.24	
4	136.73	49.75	66553			132.867277	11.824404	08 51 28.146	+11 49 27.85	
5	151.20	40.28	46198			132.858184	11.819229	08 51 25.964	+11 49 09.22	
6	159.25	137.92	42293	REF		132.856377	11.877530	08 51 25.530	+11 52 39.11	

It's possible to sort the list clicking the buttons at the top of the table. Fields displayed are:

Field	Description
N#	A progressive number for the star.
Xc	The X coordinate of the star centroid (pixels).
Yc	The Y coordinate of the star centroid (pixels).
Adu	The sum of the pixels of the star, corrected from background.
A	"REF" states that the star is an astrometric reference, click it to change.
P	"REF" states that the star is a photometric reference, click it to change.
RA°	Right ascension of the star in decimal degrees.
DEC°	Declination of the star in decimal degrees.
RA	Right ascension of the star in hours, minutes and decimal seconds.
DEC	Declination of the star in degrees, minutes and decimal seconds.
Mag	Instrumental magnitude.
O-C Pos	The difference between the observed and the calculated position of the star.
O-C Mag	The difference between the observed and the calculated magnitude of the star.
FWHM x	Full width at half maximum of the star along the x axis (in pixels).
FWHM y	Full width at half maximum of the star along the y axis (in pixels).
S/N	Signal to noise ratio of the star.
A-G-B	Aperture, Gap, Background dimensions in pixels, which were used to measure the star. See the photometry settings in Preferences.

To collect stars from the image, left click when the mouse cursor is above a star and become a circle. This means that a star is recognized and can be collected. If the star is not recognized then it's possible to force the acquisition pressing the [CTRL] key and the left mouse button. Stars can also be collected from the Local Zoom Window pressing [ENTER]. Use the command Find stars to automatically collect the stars of the image.

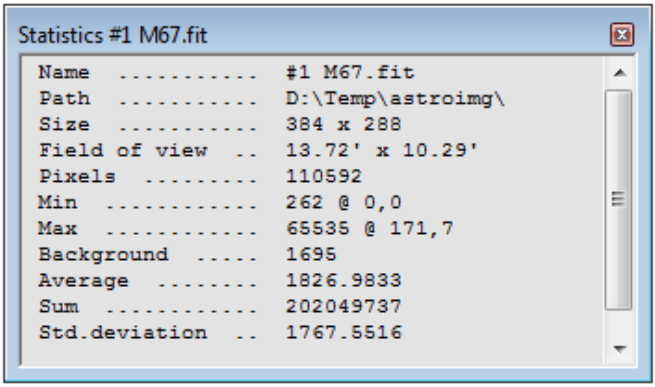
When some stars have been collected, move the mouse cursor over the image: when the pointer is over a recognized star, the relative row in the Star Window will be highlighted. Instead, if you click on a row of the list the corresponding star in the image will be marked with a blue cross.

Right click to display the *Context menu*.

- **Edit**. Allows to modify RA, DEC and MAG of a star. This procedure also makes the star a *reference* for further astrometric or photometric reduction.
- **Delete**. Deletes one or more stars from the list.
- **Reset**. Deletes RA,DEC and others calculated fields from the star.
- **MPC report**. Sends the current stellar object to the MPC Report.
- **Mark stars**. If enabled, stars will be marked on the image with a small sign.
- **Separation**. Calculates the separation and the position angle between two objects. If the list contains more than two objects, use CTRL+click to select the second object.
- **Open, Save**. Opens or saves to disk all stars as a text file. This file may be edited with a text editor.
- **Copy**. Copies the stars from another image of the same field (ADU and centroids will be recalculated). This command is useful to select the same stars on different images.

4.3.5 Statistics

This command calculates several statistical data about the image, or about a selected region of the image.



Name and **Path**. The name of the file and its path in the file system.

Size. Rows and columns of the image or boundaries of the selected area.

Field of view. This is a very important information to calibrate the plate solving engine of the Find Coordinate window. In the example above the horizontal field of view is 13.7 arcminutes. If possible, the rotation angle relative to the equatorial grid will be shown as well. All this data is only shown after the image has been calibrated. See: Tools/Astrometry.

Pixels. Number of points of the image or points of the selected area.

Minimum and **Maximum**. Minimum and maximum values and their coordinates.

Background. A calculated value for the sky level.

Sum and **Average**. The sum of the pixels values, and the sum divided by number of pixels.

Standard deviation. Gaussian standard deviation. If the region contains no stars this is a measure of noise.

4.3.6 Profile

Use this command to plot an intensity profile (in ADU) along the X or the Y axis or between two points.

X or Y profile

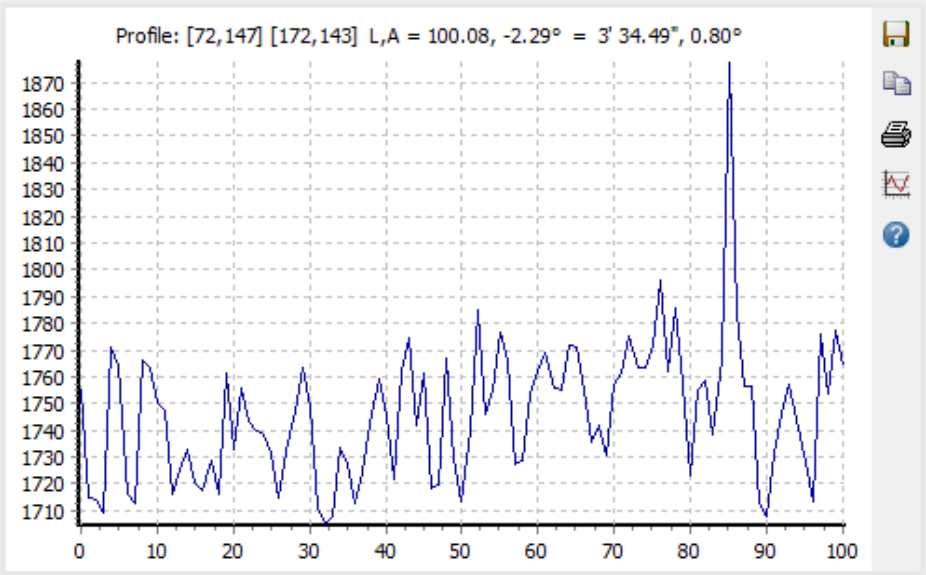
Select a point of the image. Click menu *View* / *Profile* / *X or Y*.

Free profile

Click the *Profile Mode* button in the left toolbar and draw a line over the image (click on the first point, keep pressed the mouse button and release it over the second point), or select two points then click menu *View* / *Profile* / *Free*.

Realtime profile

Once the graph is displayed, click the button "Change profile". Move the first or the second point and the profile will change in realtime.



The title of *Profile Window* shows the coordinates of the starting and ending point, the inclination and their separation (in pixel units) where L = length and A = Angle. If the image is astrometrically calibrated then the separation is also shown in arcseconds and the angle is shown as *position angle*. To measure the separation and the position angle between two stellar objects it's better to use the command Separation from the Stars Window.

It is possible to zoom in the graph drawing a rectangle from top-left to bottom-right. To zoom out, draw a rectangle in the opposite direction. The graph itself can be moved with the mouse keeping pressed the right button.

On the right side of the window there are some buttons. From the top:

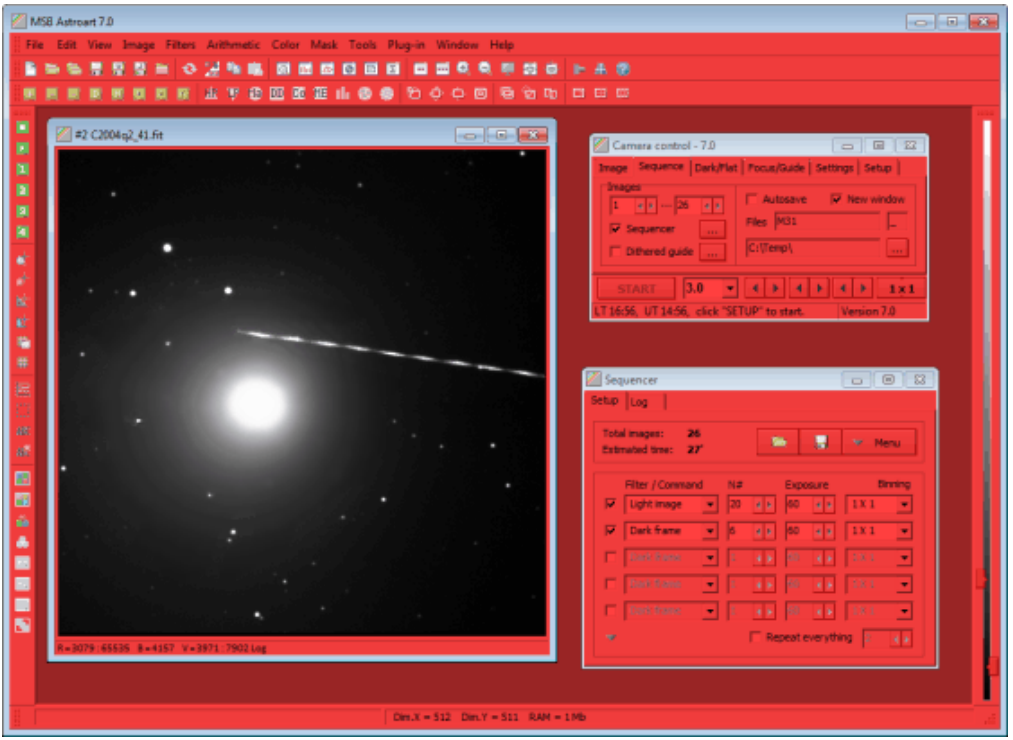
1. Saves the graph as a TXT or BMP file.
2. Copies the graph to the Clipboard.
3. Prints the graph.
4. Changes the profile, for realtime analysis.

4.3.7 Grid

This command displays a grid over all images. This is useful when centering the field during an image session, or to measure distances. The number of sectors and the color can be set in the Preferences. The *hotkey* is CTRL+ENTER.

4.3.8 Night Visualization

This command sets the Windows' system colors as shades of red. This is useful to don't disturb your eyes during an observing session.



4.3.9 Zoom

This command changes the visualization of the current image. Select the desired zoom factor from the main menu or click the lens buttons on the toolbar ( ).

Hints

Use the keys [+] and [-] on the numeric keypad to zoom in and out the image. To zoom with the mouse: click the wheel, move the mouse up or down, then release the wheel.

4.3.10 Palette

A *palette* is the set of colors used to display the image, use this command to change them.

Gray. Shades of gray, this is the default palette. Key: [F11].

Negative. Inverted shades of gray, often used for comparisons and printing. [F12].

Saw tooth. Cyclic shades of gray, useful to reveal faint details or isophotes.

Rainbow, **Flame**, **Jazz**. These are color palettes that give more visual information than shades of gray.

Open palette. Opens a custom palette from disk. It is also possible to open a palette double-clicking the palette bar on the right side of the Astroart desktop.

Palettes can be easily created with a text editor, example:

```
Astroart Palette File
4
0   10  0   0
100 255 100 0
200 40  120 255
255 255 150
```

Where the first row is a text description, the second row shows how many entries the file contains and the rest is palette data.

Each row of data shows: *Palette index*, *Red value*, *Green value*, *Blue value*. [0..255]. Spaces are ignored, missing indexes are interpolated. Index 0 and 255 can be omitted (default = [black,white]).

4.3.11 View Range

Changes the visualization of the active image. See also Transfer function.

To change quickly the visualization move the black and white cursors on the right side of the Astroart desktop or turn the mouse wheel (click the wheel button while turning the wheel to move the black cursor).

Every image is displayed according two visualization thresholds:

1. **Minimum (black) threshold**. Every pixel below this value will be displayed black.
2. **Maximum (white) threshold**. Every pixel above this value will be displayed white.

All the other values between the two thresholds will be displayed as shades of gray according the current Transfer function. See also: Palette.

Options

Auto. [F4] Astroart finds for you the best threshold values.

Min -> Max. [F3] The black threshold is set at the minimum pixel value of the image. The white threshold is set at the maximum pixel value.

CCD range. [SHIFT]+[F3] The black threshold will be set to zero, white threshold to the maximum value of the CCD image (usually 65536 or 255).

User Defined. You will be asked to input the minimum and maximum thresholds.

Hints

Click the status bar of the image window. Astroart will sets for you the best threshold values.

Press [PAG_UP] and [PAG_DOWN] to quickly modify the white threshold with the keyboard. Press [SHIFT] + [PAG UP/DOWN] to modify the black threshold.

4.3.12 Transfer Function

Use this command to change the visualization of the of the image. See also: View range.

A Transfer Function (also called lookup table or LUT) is a transformation used to visualize a scientific image. In Astroart the transfer function doesn't modify the pixel values, it affects only the visualization on the monitor. This is a big difference from classical image processing programs.

Linear. A straight line between the black and the white levels, to map equal changes in pixel values into equal changes in display levels.

Auto. Astroart finds for you the best transfer function for the active image. It is the default transfer function when an image is loaded from disk.

Logarithmic. A logarithmic curve (convex or positively skewed) between the black and the white levels. The contrast is highest at low levels and gradually decreases toward the high levels. It is often used for astronomical images to enhance faint details near the sky background.

Exponential. A concave curve between the black and the white levels. This transfer function accentuates contrast in the high levels at expense of the low levels.

Equalized. Sets the spacing between levels proportional to the height of the histogram. This gives the highest contrast to the levels containing the most pixels.

Gauss Equalized. Similar to equalized, but more “natural” and aesthetically pleasing. It is indicated to highlight structures in galaxies and nebulas.

4.3.13 Equalize Visualization

This command displays all images on the desktop with the same visualization thresholds and transfer function. This can be very useful to compare a group of images of the same subject.

4.3.14 Blink

This command compares two or three images by showing them cyclically. Blinking is used to search minor planets or supernovas.

Blinking two images

1. Open two images of the same subject.
2. Click *Blink 2* to display the blink window.
3. Change the blinking frequency moving the scroll bar. If needed, click the auto align button to align the images or the arrows buttons to manually align them. The check button keeps the final alignment when the blink is stopped. Use the button to switch the visualization from positive to negative.
4. While the blink is active, press "+" or "-" on the numeric keypad to zoom, or press the arrow keys to move. Rotate the mouse wheel to change the visualization. Click the "Save" button to create an animation.

Blinking three images

1. Open three images of the same subject.
2. Select the first image of the set, then click *Blink 3*.
3. Select the second image and click ok. Repeat for the third image to start the blinker.
4. Change the blinking frequency moving the scroll bar. If needed, click the auto align button to align the three images. If the auto align fails you will need to align the set using the command *Image* / *Align all*.

4.4 Image Menu

These commands perform common elaborations on the active image.

4.4.1 Duplicate

This command duplicates the active image. The keyboard shortcut is [F2]

This command is useful when you need a copy before modifying an image. Duplicates can be created automatically before all elaborations, see the paragraph: Preferences.

4.4.2 Flip

Flips the active image along the vertical or horizontal axis (or both). This is useful if the image comes from an optical system with an odd number of reflections.

Horizontal. The image is flipped along a vertical axis. [Shift] + [F5]

Vertical. The image is flipped along a horizontal axis. [Shift] + [F6]

Both. The image is flipped along both axes, this is equivalent to a rotation of 180°.

4.4.3 Rotate

Rotates the active image.

90 , **180** , **270** and **Angle**. Creates a new image rotated of a given angle.

Center and Angle. Rotates the image and preserve the image size: (you will lose something at the corners). Set the X and Y coordinates of the center of rotation as well as the angle. The default center of rotation is the Selected point.

4.4.4 Resize

This command creates a new resized image of the current one.

Interpolation

Bilinear. Linear interpolation, it's fast and preserves all scientific content of the image.

Gauss. Better for publication if you enlarge the image, keeps the scientific content.

Bicubic. Bicubic interpolation, sharper if you enlarge the image, but non-linear.

None. No interpolation, the enlarged pixels will appear as small squares.

Scale and Size

The size of the new image can be entered as absolute values (x,y) or relative percentage (%). It's also possible to select from common CCD cameras with rectangular pixels.

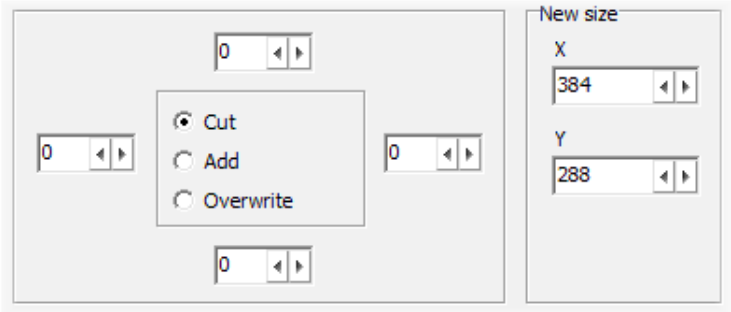
4.4.5 Crop

This command creates a new image from a selected rectangle or a mask in the current image.

If a point is selected over the image, then the size of the region can be entered as width and height.

4.4.6 Border

Adds, cuts or overwrites the borders of the active image. This is useful when an image has a blank border or after image stacking.



Select the task to perform: **Add**, **Cut** or **Overwrite**, then fill the text boxes with the number of lines to modify. With the options *Add* or *Cut* a new image will be created. With *Overwrite* you must set a new value for the border.

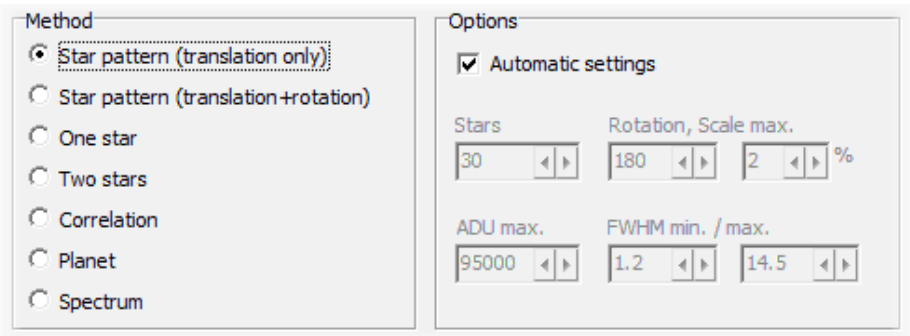
4.4.7 Align

This command aligns two images using some reference points.

The command **Align all** aligns all images opened in the Astroart desktop.

Methods

Star pattern (translation/rotation). Astroart analyzes the stars on both images to calculate the shift, rotation and scale between them. This is the recommended option. If the rotation is caused by meridian flips, so it's approx 180 degrees, disable the option "Automatic settings" and set 180 as maximum rotation.

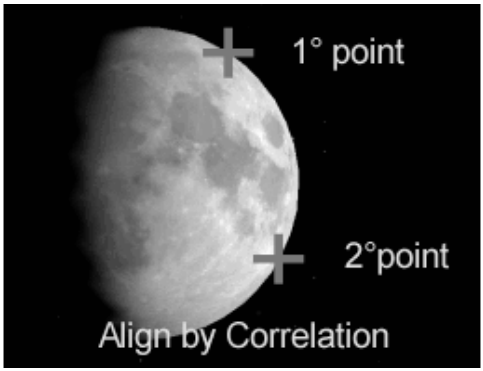


One star. You need to select a star before executing the Align command. The Radius must be larger than the maximum shift expected between the images.

Two stars. It works like the *One star* option but with two stars selected (they must be as far as possible from each other). This option shift and rotates, so it's able to align images taken with an altazimuthal mount.

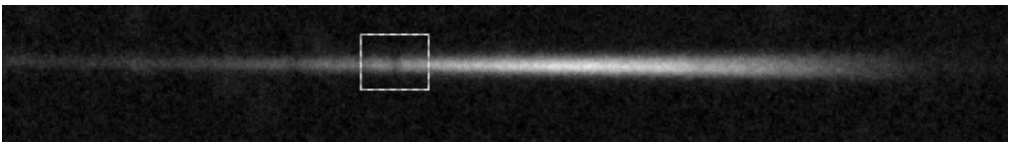
Correlation. Can align any kind of images, usually it’s used for the moon. Select two points over two edges of the image, if possible the directions of the two edges

(the tangent) should be orthogonal.



Planet. This option does not need any point to be selected over the image, but it works only on planet images.

Spectrum. You need to select a rectangle around an absorption line, as explained in the next figure:



Notes

About the methods "one star" and "two stars": the stars can be selected inside the image that will be shifted or inside the image that is used as reference.

If you are aligning a set of big images (more than 5000 pixels wide) and you get the error "cannot align with these references" it's possible that stars are not recognized because of their big size. To correct the problem increase the *FWHM max* parameter in the Preferences to 15 or more.

To align and sum a group of images use Preprocessing.

4.4.8 Shift

Shifts the current image by Delta X along the X axis and by Delta Y along the Y axis.

If a fractional Delta X or Delta Y is entered then Astroart calculates a linear interpolation. The region of the image that remains uncovered after the translation is padded with the Outside constant.

4.4.9 Rectangular To Polar

Transforms an image defined in rectangular coordinates (X = horizontal axis, Y = vertical axis) into an image defined in polar coordinates (R = radius, A = azimuth angle).

1. Select the X and Y origin for the center of the polar system: (usually this is the nucleus of a comet or a galaxy), the default value is the Selected point.
2. Select the maximum radius in pixel on which the calculation will be performed, starting from the X and Y origin.
3. Select a scale, in pixels per degrees. Default is 1 pixel/degree, this means that the new image will be 360 pixels wide.

4.4.10 Polar To Rectangular

Transforms an image defined in polar coordinates (R = radius, A = azimuth angle) into an image defined in rectangular coordinates (X = horizontal axis, Y = vertical axis).

The origin of polar coordinates is the bottom row. The distance of every pixel from this row (simply its Y coordinate) is the radius.

Set the maximum radius for the result image. The size of this image will be 2R x 2R. If R is less than the Y size of the original image you will lose some information at the corners.

4.4.11 Coregister

This command aligns two images which are shifted, rotated and scaled. If the images contain stars and their field of view is not too different, then the command aligns automatically. If not, use the manual procedure.

Manual procedure

1. Select three points or three stars on the first image.
2. Select the same three references, in the same order, over the second image.
3. Click menu *Image* / *Coregister*

Example

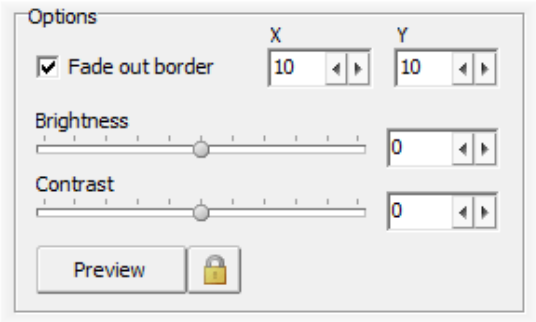
Suppose that there are 2 images, A and B on the Astroart desktop:

If image A is active when *Coregister* is clicked then a new image C is created, and it is a rotated/rescaled version of image A, but can be blinked with image B.

If B is active then the new image C is a rotated/rescaled version of B, and can be blinked with image A.

4.4.12 Mosaic

This command combines two adjacent images to create a bigger one.



1. Select a reference point on the first image (the brighter pixel of a star, a lunar crater, etc.)
2. Select the same point on the second image.
3. Click menu *Image* > *Mosaic*. Now you may select the width and the height of the faded border between the images and change in real time the brightness and contrast of the two parts.

See also the Tutorial #8.

4.4.13 Fill

Fills a region with a constant value plus a gaussian noise. Before executing this command, define a rectangle or a mask over the image.

- **Inside**. Fills inside the selected rectangular region.
- **Outside**: Fills outside the selected region.

4.4.14 Isophotes

Transforms the active image into a graph of isophote curves.

Min and **Max**. The minimum and maximum values allowed to draw the isophotes.

Step. The interval between each curve (in ADU).

Monochrome. Draws the isophotes with a single ADU. If not selected, every isophote is drawn with the ADU that they represent.

Area. This command measures how many pixels are contained between Min and Max and their sum. This is useful for photometry of diffuse objects.

To better visualize the structure of the isophotes, try a logarithmic scaling before applying this command to the image.

4.4.15 Repair

This command replaces a column (row) with the average of adjacent columns (rows). This is useful if your camera has a damaged column or row.

4.4.16 Binning

Binning X and Y

Compresses an image file along the X-axis (rows) or the Y-axis, useful for spectroscopy. Select a rectangular area over the image of the spectrum to limit the filter to that area.

X Average. Each pixel will be replaced by the average of its row.

Y Average. Each pixel will be replaced by the average of its column.

X Median. Each pixel will be replaced by the median of its row.

Y Median. Each pixel will be replaced by the median of its column.

Binning Pixel

A new image will be created where four or nine pixels will be joined, reducing the image size but keeping the scientific content of the image. This command increases the dynamic of an image and it's very useful to resize a 8 bit image (JPEG, BMP, etc).

4.4.17 Normalize Background

This command acts between two images and sets the background value of the active image equal to the background value of the other, multiplying it by a coefficient.

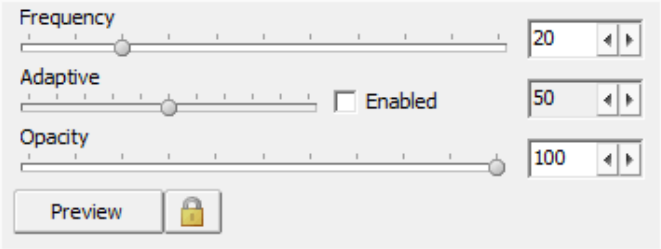
4.5 Filters Menu

These commands perform various filters on the image. To create a new image as a result of every filter see Preferences. See also: Image Processing.

4.5.1 High Pass and Low Pass

The **high-pass** filter emphasizes the details of the image by enhancing its high frequencies, however it may emphasize noise.

The **low-pass** filter smoothes the image by attenuating the high frequencies, however it may reduce the image sharpness.



Frequency. Controls the strength of the filter. Click the “lock” button to enable the real time preview.

High Pass Adaptive. When enabled, the image sharpening is applied only on important details of the image, skipping for example the sky background. Noise is therefore reduced, and quality improves. This option is not linear, so it cannot be used before astrometry or photometry.

Low Pass Adaptive. This powerful option reduces the noise of an image without blurring the details and without losing sharpness. Try this filter before or after a High-Pass to reduce noise. This option is non-linear. See also: Denoise.

Opacity. This is a further option to calibrate the strength of the filter. The result of the filter will be averaged with the original image.

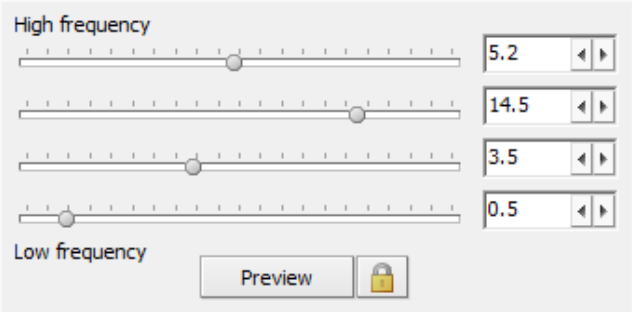
4.5.2 Gauss

This command performs a Gaussian convolution. The Gaussian curve is often found in nature, for example profiles of stars spread by atmospheric turbulence are very similar to a Gaussian curves.

Set a value for the *Sigma* parameter: a large value will give a heavier blurring effect. The option *Opacity* controls the strength of the filter, it can be used to obtain a “flou” effect.

4.5.3 Multiscale High pass

This filter is used to enhance details in planetary and moon images. It may be used also on the subject of a deep sky image, after having masked the subject (to avoid applying the filter to stars).



At first enable the realtime preview, then move the sliders to achieve the best compromise between definition and noise. Usually the first two values ("high frequency") are the most critical ones. Sometimes a deconvolution with a gaussian kernel is useful before applying this filter.

4.5.4 Unsharp Mask

Unsharp masking is a special high-pass filter excellent for planetary images. At first the program makes a gaussian blurred copy of the image then this copy is subtracted, enhancing all details of the image.

The formula is: `I'(x,y) = I(x,y) + c * (I(x,y) - Gauss[I(x,y)])`

Where `I(x,y)` represents the original image and `c` is a multiplicative coefficient.

The value `I(x,y) - Gauss[I(x,y)]` may become negative, it is truncated to zero if *adaptive* is enabled. This may reduce dark halos.

4.5.5 DDP

The DDP (Digital Development Process) gives to CCD images an aspect similar to film pictures. It's very useful on nebulas and galaxies. On grayscale images this may be the first filter to be applied after Preprocessing.

Procedure

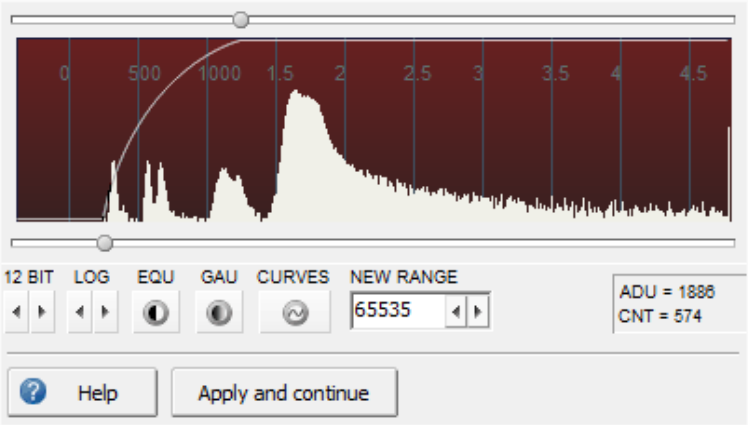
1. Enable the *real time preview* ("Lock" button) to apply the filter with default settings.
2. Set "High pass" options to zero, and move the "Threshold" slider to control the strength of the filter.

3. If the image is too dark or looks saturated, it could be a visualization issue, so modify the visualization moving the cursors on the palette bar, on the right side of the Astroart desktop.
4. If needed, enable the "High pass" options to increase the definition.
5. If you feel that the image can be stretched further, repeat the filter.

This filter is not linear, and the result images cannot be used for astrometry and photometry.

4.5.6 Histogram stretch

This filter improves the contrast of an image.

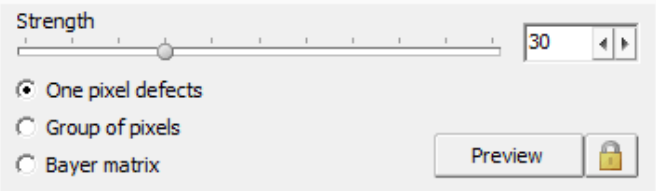


At first select a transfer function by clicking the Log, Equ, Gauss or Curves buttons. Select a new range for the result image (default is 0..65535, e.g. 16 bits) then click "*Apply and continue*". If needed, continue the procedure with another stretch.

To zoom the histogram, press the left mouse button on the graph and drag up/down , or click the "BIT" button.This filter works with masks, but the realtime preview will be on the whole image.

4.5.7 Hot pixels

This filter finds and deletes "hot pixels", which are bright isolated points over the image caused by defects of the CCD or cosmic rays. This filter can also be applied on RAW images with Bayer pattern (DSLR images).



One pixel defect. This is the default option which corrects very well isolated pixels, without modifying anything else in the image.

Group of pixels. This is a much stronger filter which can also correct “cold pixels” and groups of bright pixels.

Bayer matrix. This is the option to correct raw images with color information stored as Bayer matrix. Such raw image come from DSLR and color CCDs. Don’t use the other two methods since they may interfere with the color information, which is encoded as dithering.

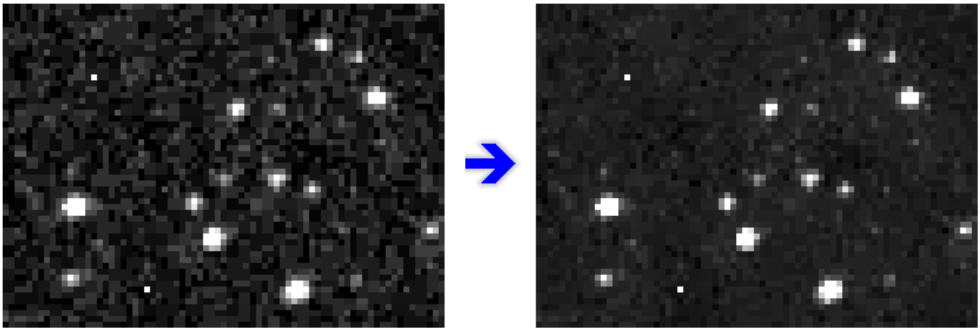
To correct the hot pixels during Preprocessing:

- On color CCDs enable the option "Hot pixel" inside the window Demosaic.
- On grayscale CCDs add a filter *Hot Pixels* in the Preprocessing "Extra" options.

See also: Defect Map.

4.5.8 Denoise

This filter reduces the noise without blurring the details.



Procedure. Enable the real time preview, set the kernel to 1X (fast but low quality) and move the Sigma slider until you have achieved the desired effect. Then set the kernel to 2X or 5X and click OK. As shown in the image above, hot pixels are not corrected.

4.5.9 Defect map

This command corrects all bad pixels of an image using a map as reference. This map is a special image where all pixels are zero except the ones which represent the defects.

To create a defect map you may elaborate a dark frame, deleting all pixels which are below a certain value. The best command to achieve this is the command Clamp Minimum.

Example: Clamp Minimum 2000, 0 (All pixels below 2000 will be set to zero).

The Defect Map command will analyze the map before to proceed. If the map is not

a true defect map (e.g. most pixels are not zero) then it will automatically create a map considering the 0.5% brightest isolated pixels of the image. For this reason it's possible to use directly a dark frame as a Defect Map. Obviously, this option is slower and less precise.

4.5.10 Median

The median of a list of numbers is that value that after sorting the array is placed in the middle. Selecting this value from a matrix around a pixel is an excellent way to reject impulse noise without losing resolution. This kind of noise is usually caused by cosmic rays or hot pixels.

3 x 3 Matrix

This is the most used size to reduce noise. A dialog box will ask you the strength of the filter. If you select 100% then the filter always replaces the pixel, but the better results are usually obtained with strength = 2-5% where only the brightest and isolated pixel are replaced. This filter is very useful to remove the hot pixels of the image without blurring it.

N x N Matrix

Uses a NxN matrix for a stronger median filter. When N is bigger than 7, stars disappear from the image and you can isolate the background nebulosity.

Ring median

Uses a ring around every pixel to calculate the median. It's very useful to remove the stars from an image. (for example to obtain a synthetic flat field).

4.5.11 Average

The average filter is a particular case of low pass filter. It replaces every pixel with the average value of a matrix around it, producing a strong blurring of the image.

4.5.12 Scaled dark frame

This command corrects the thermal noise of an image by subtracting an optimized thermal frame that was taken at a different temperature or different integration time.

Remember that: Thermal frame = Dark frame – Bias frame

So, for precise results, the bias must be subtracted from the dark frame and from the raw image before executing this command. If the bias was not already subtracted, follow this procedure:

1. Select the image and subtract the bias frame from it (menu Arithmetic / Subtract), or subtract a constant value (the average value of the bias frame) with the command Add offset.
2. Select the dark frame and subtract the same bias frame from it, just like in the previous step. You have obtained the Thermal frame.

3. Select again the image and execute the command *Scaled dark frame*. When the "Select window" appears, just select the thermal frame created at step 2.

4.5.13 Remove gradient

This filter corrects variations in sky background, using different methods:

Adaptive. This is the most effective method, it analyzes the image and choose the best way to correct it. The option "Low pass" is useful to prevent halos around big objects in the image. If there are no big objects you may decrease the value to 20-30 for finer corrections. If the image has a black or damaged border, remove it before to proceed.

Adaptive Divide should be used only on photometrically corrected images (the dark frame was corrected). In all other cases (processed images, JPEG pictures, etc.) *Adaptive Subtract* works better although it may require a white balance correction after the filter.

Linear. Corrects a sky background with a linear gradient.

Vignetting. Corrects vignetting. The vignetting must be centered in the image.

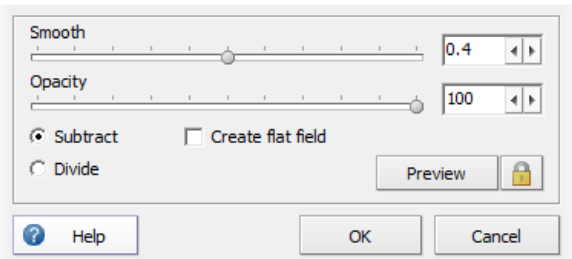
Linear+Vignetting. Corrects both variations at once, and corrects vignetting when it's not centered in the image.

For example, using the N6824.fit demo image, verify that:

Adaptive: Corrects well. *Vignetting*: Does not correct since it's not centered. *Linear+Vignetting*: Corrects well. *Linear*: Does not correct but at least it centers the vignetting.

"Points" method

In this method the control points are selected by the user. Before launching the filter select 10-40 points on the image, starting on the border of the image, always clicking on zones with no stars. If you delete some points you can recover them with SHIFT+left click. With SHIFT+click it's also possible to copy points to another image.



Enable the realtime preview (the Lock button) and move the Smooth slider to find visually the best correction. If you feel that the filter is over-correcting the image, decrease the Opacity value. If some zones are not corrected well, you may add

further points there (press Preview to update). The option "Create flat field" will show and create the synthetic flat field that is used by the filter.

4.5.14 Erosion & Dilation

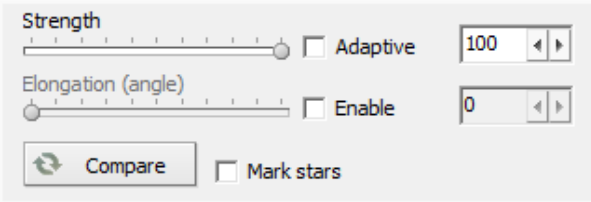
Erosion filter is useful to reduce the width of stars, to simulate a sharper image. It may be useful after a resize (for example 200%) to produce a cosmetic improvement of the image.

Dilation is rarely used, it has no applications in astronomy. It can be useful to enlarge a mask image.

4.5.15 Cosmetic filters

These filters correct some typical defects of astronomical pictures.

Compress stars. Reduces the diameter of stars and/or corrects elongated stars caused by bad tracking.



Before executing the command you must select all stars using the command *Tools / Find stars*. If the option "Adaptive" is enabled then the correction is stronger on wide stars and lighter on small stars.

Enable the “Elongation” option to correct bad tracking, then move the bar to find out the correct angle.

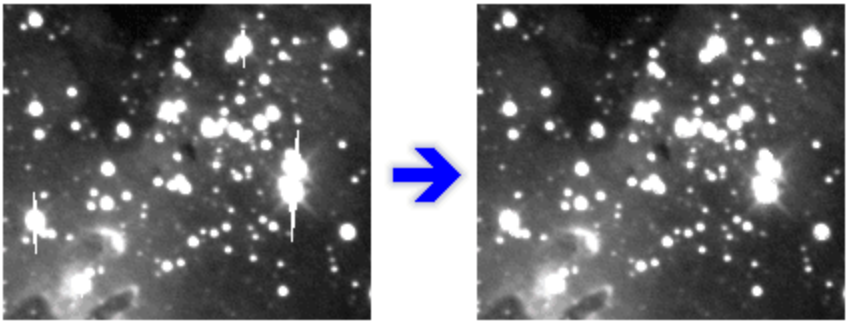
Remove stars. This filter removes all selected stars, it’s useful for photometry of comets.

Remove lines. This filter remove satellites and airplanes tracks. To select the line just select two points at its edges. This filter is smart and adaptive so it will not delete stars and other details below the line. Sometimes it’s required to apply to it two times.

Deinterlace. Removes the “venetian blind effect”, e.g. horizontal stripes caused by interlaced CCDs.

4.5.16 Deblooming

The deblooming filter deletes bright stripes around saturated stars.



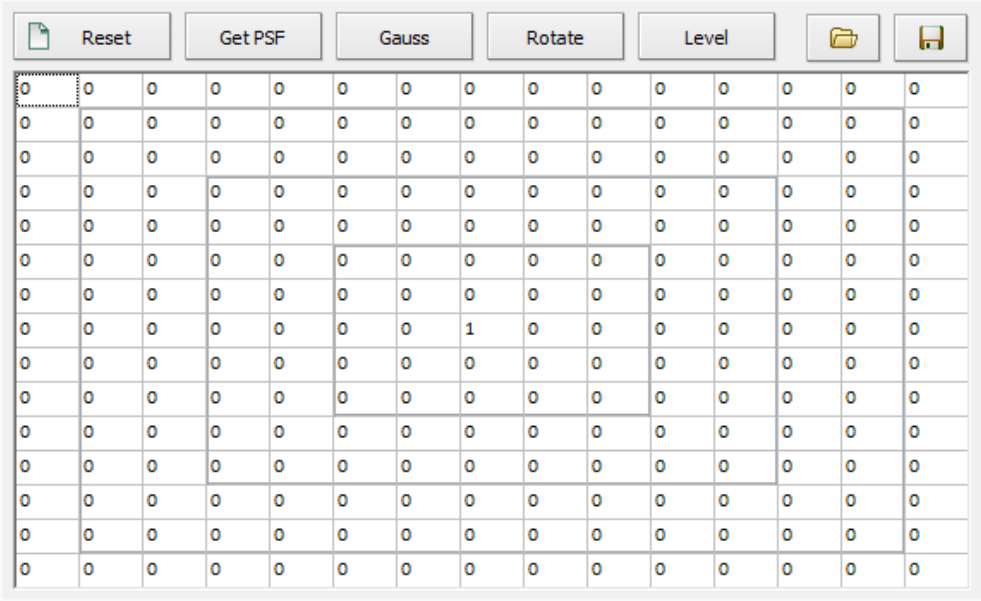
It's very important to select a correct value for the saturation level. Usually this value is 65535 for 16 bit cameras but if the dark frame was subtracted then the real value is surely lower. Sometimes a value lower than half dynamic gives a better result (example: 30000 ADU for 16 bit cameras).

Remove blooming. This is the most powerful filter, but you must click and select by hand the stars you want to correct.

Reduce blooming. This filter is soft but it works automatically on all stars. If your blooming is quite severe you may apply it two times. This filter is also an option (*Extra Filter*) of Preprocessing, because if you need to align and add a group of images it's better to apply the filter on every single image.

4.5.17 Convolution

Spatial convolution is an operation that modifies all pixel values according to the adjacent pixels. This command let you build your own convolution filters and save them to disk.



- **Get PSF**. If a rectangle is selected around a star then a kernel is calculated from it.
- **Gauss**. Makes a Gaussian kernel of a given sigma.
- **Rotate**. Rotates the matrix by 180°.
- **Level**. All pixels with intensity higher than *level* will not be processed, this is useful to process only the sky background of the image.
- **Open**. Loads a convolution matrix from disk.
- **Save**. Saves the matrix to disk, as a text file.

4.5.18 Deconvolution

This command performs the *Richardson-Lucy*, *Van Cittert* or *Maximum Entropy* restoration of an image. They are iterative algorithms that can correct almost any blurring defects over the whole image.

Procedure

The most important thing to know is the kernel that has generated the blurring effect. If you don't know it you can simply obtain one from a non-saturated star.

1. Select a rectangle around a star.
2. Click *Filters / Deconvolution* and select one of the four filters listed below.
3. Click "Get PSF", the matrix will be filled with numeric values.
4. If needed, click "Level" to don't apply the deconvolution on the sky background.

5. Select the number of iterations.

Maximum Entropy

This is the most powerful restoring algorithm.

Select Cut sky background to ignore the background during the process and obtain sharper images. The value used as background is the Low visualization threshold so be sure to have the image visualized with a dark sky. Don't use option to restore common images like film photos or astronomical images with variable background.

During the iterations some logarithms are calculated, so this filter is not linear and the restored image cannot be used to perform photometry.

Richardson-Lucy

This is a linear algorithm that keeps the photometric characteristics of the image, but provides worse images. It was used to correct the blurred images of the Hubble Space Telescope.

Van Cittert

A linear filter sometimes useful on planets, but it can be used only with guassian kernels.

Wiener

A linear deconvolution which is not iterative. Usually it produces only a partial restoration but is very fast.

Tips and tricks

To correct a bad focus blurring, instead of getting the PSF from a star, try to synthesize a Gauss kernel clicking the "Gauss" button in the window *Deconvolution*.

To correct a bad tracking (elongated stars) try to build a kernel as a Row of ones like the following examples:

```
0 0 0 0     0 0 0 0     0 0 0 0
0 1 1 0     0 0 1 0     0 1 0 0
0 0 0 0     0 0 1 0     0 0 1 0
0 0 0 0     0 0 0 0     0 0 0 0
```

These kernels correct a bad tracking, three pixels wide, with direction of 45° and 22° (There is a tolerance of 15 degrees for a good result). Use always Maximum Entropy.

```
0 0 0 0 0     0 0 0 0 0
0 0 0 1 0     0 0 0 1 0
```

```
0 0 2 0 0     0 1 4 1 0
0 1 0 0 0     0 1 0 0 0
0 0 0 0 0     0 0 0 0 0
```

If the central value is brighter the result image will have less artefacts. To correct both bad focus and bad tracking apply deconvolution two times, one for tracking (with row of ones) and one for focus (with Gauss PSF).

How to obtain better images

To reduce ringing around stars, the background value of the image must be set to near zero before deconvolution. So, use the command Add constant to remove it. For example if the background is 1700 ADU, do a "Add offset" of -1700.

If the deconvolution result is too “sharp” and crispy apply a light Low Pass filter or decrease the iterations.

With Maximum Entropy, 10-20 iterations are usually sufficient, 50 may be too many. Try this procedure: get the PSF from the star then quit deconvolution (the PSF kernel will be retained in memory). Apply a light low pass filter to the image, then apply deconvolution using the same PSF kernel.

4.5.19 Contour

These are morphological filters used to detect contours.

Sobel

It can reveal fine structures in galaxy arms. It calculates two convolution matrices, along the X and Y axes:

```
-1 -2 -1      -1  0  1
0  0  0      -2  0  2
1  2  1      -1  0  1
```

This double convolution is used to process image. After this filter it may be necessary to adjust the View range of the image, for example clicking the status bar of the active image.

Prewitt

Like Sobel, it can reveal fine structures in galaxy arms. It calculates two convolution matrices, along the X and Y axes:

```
-1 -1 -1      -1  0  1
0  0  0      -1  0  1
1  1  1      -1  0  1
```

This double convolution is merged and used to process the image.

Freeman

It is also called a circular gradient filter, it performs eight different convolutions

around each pixel to detect the direction of the contour.

Kirsch

Similar to Freeman, it performs eight convolutions to detect the direction of the contour.

4.5.20 Gradient

Applies the *gradient* operator, which gives an “emboss effect” to the image. The result is given by the formula:

```
I'(x,y)  =  I(x,y) - I(x-dx,y-dy)
```

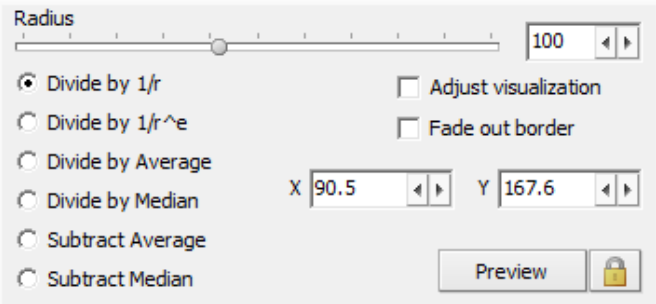
The result image will be displayed with a linear transfer function.

4.5.21 Comet

This command is used to analyze and enhance comet images.

Procedure

Before launching the filter select a point (or a "star") on the nucleus of the comet. The coordinates of the centroid will be shown in the "X" and "Y" boxes. Enable the realtime preview (the "lock" button).



Radius. Select the radius in pixels for the zone to be processed. You may enable the option "Fade out border" for a smooth transition with the non-processed zone.

Algorithm. Change the algorithm and find visually the best one for your purpose. You may enable the option "Adjust visualization" to adapt in realtime the visualization to the new algorithm. In any case you can change the visualization and the zoom with the usual methods of the Image Window.

Coordinates. Try to change the X and Y centroid. Sometimes a small change can reveal a hidden detail.

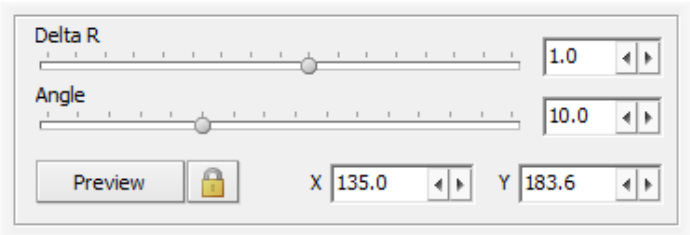
4.5.22 Larson-Sekanina

This command computes the radial and the rotational gradient of an image. It is used to enhance the faintest details of bright objects, which exhibits symmetry of

revolution (elliptical galaxies and comas of comets). This filter is very powerful to reveal inner details inside the coma of bright comets (like jets and shells). Other information is available in the chapter: *Image Processing* / *The Larson-Sekanina filter*.

Procedure

At first *select* the brighter pixel of the coma: this is probably the nearest pixel to the false nucleus of the comet: a little red cross will appear on the selected pixel. Now click menu *Filters* / *Larson-Sekanina*.



Delta R. Computes the radial gradient. This value is intended in pixels and depends on the resolution of the image (values from 1 to 5 are suggested). This parameter is very important to detect the radial brightness variations, like shells or fountains.

Angle. Computes the rotational gradient, centered in the selected pixel, using a rotation of *Angle* degrees (values from 1 to 20 degrees are suggested). This parameter is used to reveal faint straight jets departing from the nucleus of the comet. Be careful when interpreting the results obtained with this parameter: a too large Alpha can produce false details, on the other hand, a small angle could not be sufficient for the faintest structures.

Coordinates. Once the realtime preview is enabled, try to change the X and Y centroid: this could reveal an hidden detail.

4.6 Arithmetic Menu

These commands perform various operations between two images ("A" and "B" operands). The formula is:

A = f (A, B)

If only one image is opened inside Astroart, then the second operand is simply the image itself. If three or more images are opened then a dialog window let you choose the second operand.

You can force Astroart to create a new image as a result of every operation. See Preferences.

4.6.1 Add Image

Add an image to the active image.

This command is used to sum aligned images and increase the signal to noise ratio. After the sum the result image may appear bright, in this case regulate the visualization thresholds.

4.6.2 Subtract

Subtract an image from the active image.

It is commonly used to subtract a dark frame from an image, or to analyze the difference between images containing variable stars, asteroids etc.

4.6.3 Divide

Divides the active image **A(x,y)** from another image **B(x,y)** following the formula (for every pixel):

```
A(x,y) = A(x,y) / B(x,y) * c
```

where **c** is the average value of image **B**. This command should be used to apply a flat field to the current image, to correct vignetting, dust, etc.

4.6.4 Multiply

Multiplies the active image **A(x,y)** by another image **B(x,y)** following the formula (for every pixel):

```
A(x,y) = A(x,y) * B(x,y) / c
```

where **c** is the average value of image **B**. This command It is rarely used, it is involved during certain image restoration algorithms.

4.6.5 Min

Calculates the *minimum* of two images.

In the result image every pixel will be replaced by the minimum value of the two corresponding pixels in both images.

4.6.6 Max

Calculates the *maximum* of two images.

In the result image every pixel will be replaced by the maximum value of the two corresponding pixels in both images.

4.6.7 Distance

Calculates the "distance" between two images, which is defined as:

```
DIST [A,B] = ABS [A(x,y) - B(x,y)]
```

This command is useful to find the difference between two images.

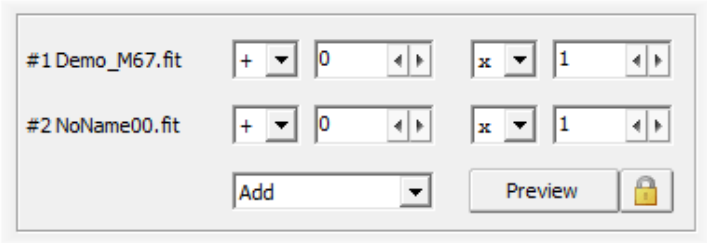
4.6.8 Average

Calculates the weighted average of two images.

Inside the dialog window move the slider to change in realtime the weight (in percent) for each image.

4.6.9 Merge

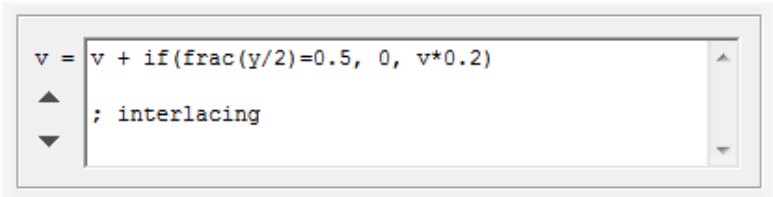
This command combines two images.



Both image can be processed with two constants, then the final combine can be performed by one of the following functions: **Add**, **Subtract**, **Multiply**, **Divide**, **Minimum**, **Maximum**, **Distance**, **Average**. Every processing step is calculated in floating point.

4.6.10 Formula

This powerful command applies a formula to every pixel of the image. Click the arrow buttons to experiment with some demo formulas.



For example: to add 20 to every pixel, simply write:

v = **`v + 20`**

All standard math functions are supported: sin(), cos(), tan(), exp(), ln(), log10(), log2(), sqr(), abs(), rnd(), sgn(), fix(), int(), round(), frac(), asin(), acos(), atan(), atan2 (,), sinh(), cosh(), tanh(), asinh(), acosh(), atanh(), clamp().

The **`if()`** function takes three parameters: a condition and two possible results. Example: **`if(x > y, 7, 4)`** returns **`7`** if x is greater than y.

To set a different formula for every color plane, use the colon separator. Example:

`v : v : v*2` doubles the value of the blue channel (red : green : blue).

Formulas can contain variables. Some of them depend on the position of the pixel.

x. The current x coordinate of the pixel.

y. The current y coordinate of the pixel.

r. Radius, the current distance from the center of the image.

a. Angle, the current angle from the center of the image.

v. The current pixel value.

v(,) The pixel at a given coordinates.

pi. 3.1415926535...

xc yc. The coordinates x and y from the center of the image.

dimx dimy. The size of the image.

vmin vmax vbkg. Minimum, maximum and background value of the image.

vismin vismax. Minimum and maximum visualization thresholds.

4.6.11 Add constant

This command adds a constant to every pixel of the image. To subtract a constant, set a negative value.

Formula: `A(x,y) = A(x,y) + c`

If some pixels become negative or higher than 65535, then the dynamic will exceed the 16 bit numeric format and the FITS file will take double space on disk.

4.6.12 Pedestal

This is an obsolete command that like Add constant adds a constant to every pixel of the image.

However if some pixels become negative or bigger than 65535 then their value will be wrapped around 65536. This makes this command reversible. Example:

`A(x,y) = 5 , B(x,y) = 7  A(x,y) - B(x,y) = 65534`.

4.6.13 Multiply and Divide

Multiplies or divides every pixel of the image by a constant.

- **Divide**. `A'(x,y) = A(x,y) / c`
- **Multiply**. `A'(x,y) = A(x,y) * c`

4.6.14 Clamp

This command limits the minimum and maximum value of the image.

- **Minimum**. Sets all pixels lower than "Value" to the "New value".
- **Maximum**. Sets all pixels higher than "Value" to the "New value".

4.6.15 Scale

Changes the value of each pixel of the active image according to a given transfer function.

Scaling (often logarithmic) was widely used in the past as a tool for better visualization, now it should NOT be used for this purpose because it is possible to obtain the same result in real time working with the histogram, without changing the pixel values. Scaling makes an image scientifically useless.

Options

Linear. `I'(x,y) = c * I(x,y)` The maximum value of A'(x,y) will be the normalization factor.

Logarithmic. `I'(x,y) = c * Log(I(x,y))` where c is a given coefficient.

Exponential. `I'(x,y) = c * Exp(I(x,y))` where c is a given coefficient.

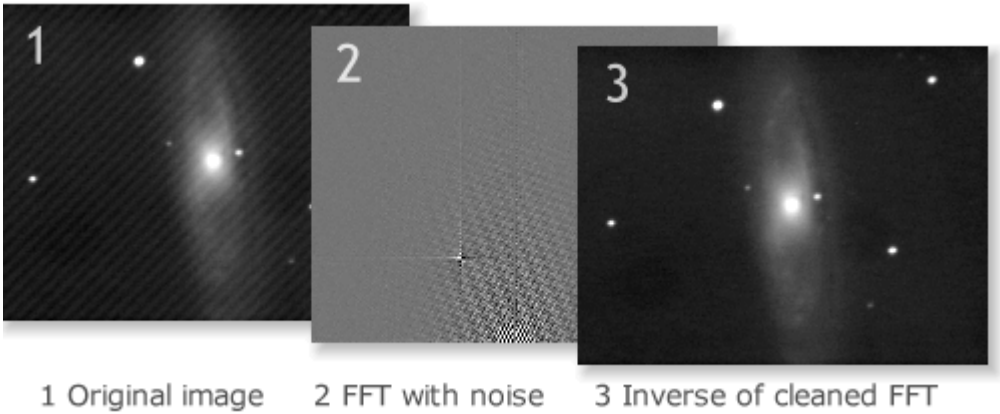
Transfer function. `I'(x,y) = f (I(x,y))` where f is the current visual transfer function.

4.6.16 Image -> FFT

Calculates the Fourier Transform of an image.

The Fourier transform is a representation of the image in the frequency domain. The low frequencies are displayed in the bottom part of the image. Every frequency is expressed as a complex number in the form X , iY. See: Tutorial #4.

An image may have a periodic noise, such as stripes, introduced during the digitization process. In the frequency domain, this periodic pattern is transformed to a few pixels.



In the example above, the periodic noise in (1) becomes a few pixels in the FFT image (2). Once these pixels have been deleted with the Edit Pixels window, the inverse FFT transform creates an image where the noise has disappeared (3), while the overall features remain.

4.6.17 FFT -> Image

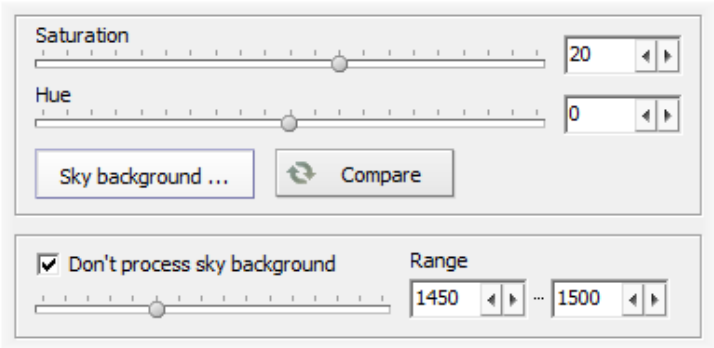
Calculates the Inverse Fourier Transform of an image. This command is required after a FFT to bring back the image to the spatial domain.

4.7 Color Menu

These commands are related to the color information of the image.

4.7.1 Saturation

Modifies in real time the saturation and the hue.



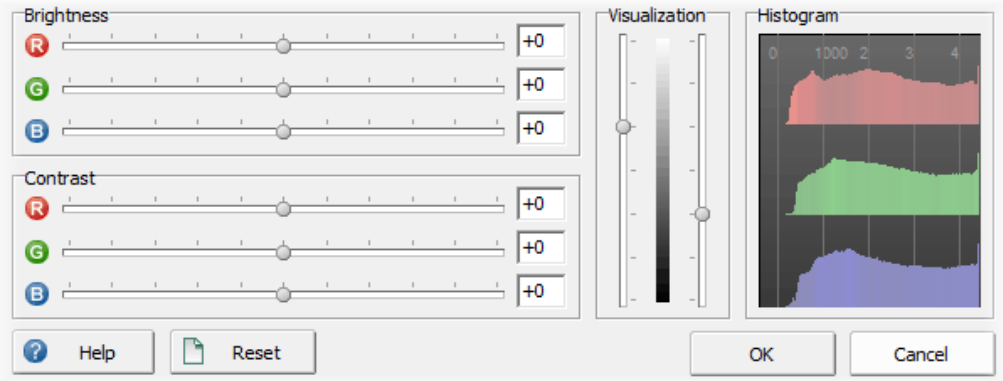
A saturation of zero will convert the image to gray tones, however the best method to obtain this result is the command Split Luminance.

When the option “Skip background” is enabled, the sky background of the image is not processed, to reduce the noise. Two numbers define a range for the sky

background: all values below V1 are not processed, all values above V2 are processed, all values between V1 and V2 are partially processed by linear interpolation.

4.7.2 Color balance

This command adjusts the colors of an image, with preview in real time.

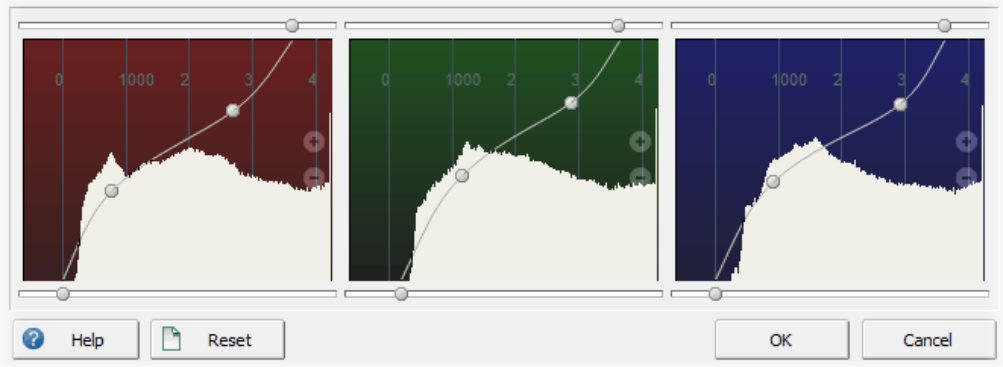


The upper sliders control the brightness of a channel (red, green, blue), adding or subtracting a constant to every pixel. The sliders control the contrast, multiplying a constant.

It's possible to move and zoom the histogram clicking the left mouse button and dragging. A good color balancing is usually achieved when the three histograms have the same shape and position.

4.7.3 Color curves

This command modifies in real time the color tones.

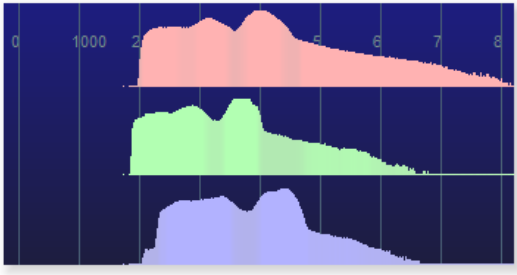


Click the buttons “+” and “-“ to change the number of control points. Left click and drag to zoom or move each histogram. The whole window can also be resized in real time.

4.7.4 White balance

White balance adjusts the colors the image to achieve a neutral color cast.

For classical 8 bit images and video cameras, only three parameters are required, the multiplicative coefficients for red, green and blue. For 16 bit images and DSLR RAW images, they don't suffice because a strong bias is usually present, so the black level is not zero and bias must be subtracted.



$$R' = (R - biasR) * balanceR + bias$$

$$G' = (G - biasG) * balanceG + bias$$

$$B' = (B - biasB) * balanceB + bias$$

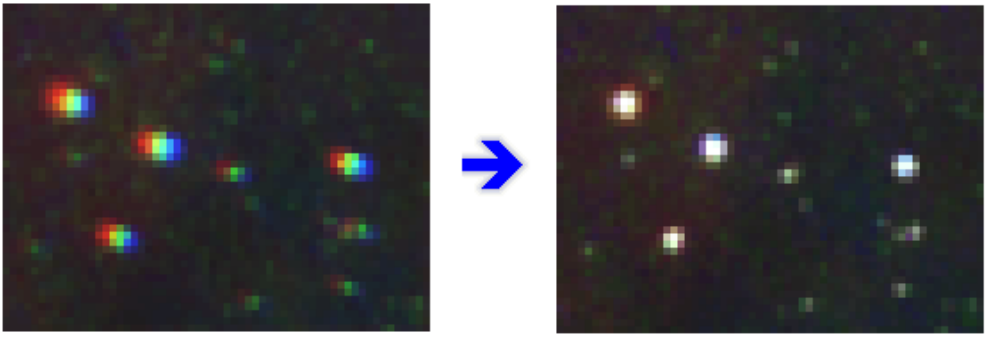
In the image above, the dynamic range is approx 7000 ADU, but the black level (the bias) is approx 2000 ADU and it's also slightly different for every color plane. For this reason it's required to set other three coefficients, the bias levels for red, green and blue.

Inside the White Balance window, these six coefficients can be set by the user, or calculated by Astroart using several algorithms. Try the algorithms on a daytime image with real time preview:

- **Average**. This is the classical "gray world" algorithm, which gives good results in most cases.
- **Adaptive**. It can be useful if an image contains a wide object with a very saturated color.
- **Histogram**. The coefficients are calculated via histogram equalization. It's used rarely.
- **White point**. The white balance is calculated analyzing the brightest parts of the image.

4.7.5 Reduce color fringes

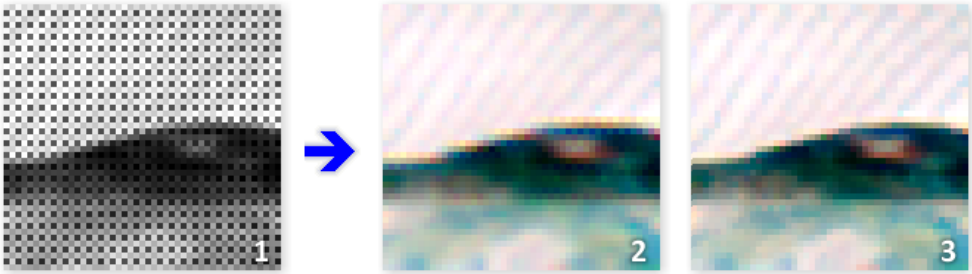
This filter attenuates the orange/blue color fringes which are caused by: imperfect trichromy, DSLR demosaic, lenses.



At first execute the filter with Cell = 3. If the correction is not sufficient, increase the cell size.

4.7.6 RGB demosaic

This command creates a color image from a RAW image with Bayer pattern (DSLR cameras and RGB CCD cameras).



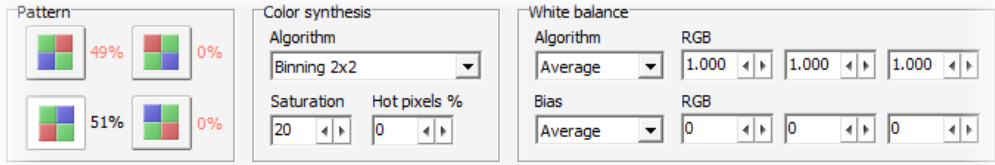
1) Original RAW image. 2) Demosaic with *1x1 Bilinear*, where some residual dithering and color fringes are still visible. 3) Demosaic with *1x1 Four gradients* where some color fringes are still a bit visible (they can be corrected enabling the option "Reduce color fringes").

Please note that on astronomy images these defects are less visible, since the original image is probably oversampled. So the Bilinear algorithm may be the best choice, because it's the only one that preserve the scientific content of the image. The other algorithms are not linear, so astrometry and photometry will not be possible on the result image.

To demosaic a DSLR image (.cr2, .nef, etc.) the image must be opened as true RAW, so don't enable the automatic demosaic in Configure RAW.

Pattern

Select here the correct pattern for you camera. Astroart suggest the most probable one.



Algorithm

Binning 2x2. Four pixels will be summed into one, increasing the dynamic. This is an interesting option since it has four important advantages: 1) On most images you don't lose any information since multi-megapixels images are often heavily oversampled. 2) Hot pixels remain single pixels, so they still can be corrected later. 3) The image consumes less memory when processed. 4) It's linear, so you can perform astrometry and photometry.

Bilinear 1x1. This is the standard algorithm if you are working with a camera with less than 15 megapixels so that Binning 2x2 is less appealing. The color image will have some residual dithering, but it will be possible to perform astrometry and photometry.

Two and Four gradients 1x1. These are non-linear algorithms which will not cause any residual dithering. Four gradients is more powerful (but slower) and it's able to correct partially the color fringes. Please note that the preview is performed always in binning 2x2.

Channels. These options let you extract a single color channel. It's a useful option for photometry. You may obtain the same result also setting "Binning 2x2", "None" for white balance and zero saturation.

Saturation. Select here the extra saturation to be applied to the result image. 20-40 is recommended.

Hot pixels. The strength of the Hot pixels filter applied during the demosaic. (It will not be used during the preview).

White balance

See the documentation about White balance. You may also choose "User defined" and set your own R,G,B coefficients.

Post processing

Select here which filters are to be executed automatically after the demosaic.

4.7.7 CMY demosaic

This commands creates a color image from a RAW image made with a CMYG (cyan, magenta, yellow, green) CCD camera.

XY Offset. In the *Image panel* you will see the pattern of the current image. In the other panel you must obtain the same pattern, changing the X and Y offsets.

1x1. This is the default option, select if for: Meade DSI, DSI II, Starlight-Xpress

M7C, M5C hires.

1x1 filtered. Similar to the previous option, but it provides stronger saturation. This option can also synthesize Starlight-Xpress images taken with the vertical low pass filter.

2x2. Images taken with vertical binning (example: M5C 500x290 pixels).

Options

High Pass. Optimized high pass filter for the luminance of the image.

Deinterlace. Removes the “venetian blind effect”, e.g. horizontal stripes caused by interlaced download.

Hot pixels. Applies the *Hot pixels filter* during the synthesis.

Low pass. Reduces noise in the colors but slightly blurs the image.

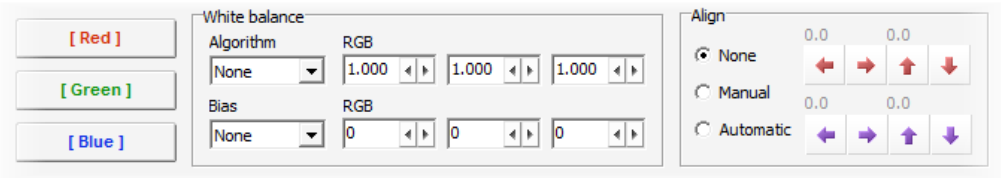
Color curves. Opens the *Color Curves* window after the synthesis.

Color balance. Opens the *Color Balance* window after the synthesis.

Anti-Alias. Reduces the false colors caused by sharp edges, but also reduces the saturation of the colors.

4.7.8 Trichromy

Tri-color imaging is an easy task with Astroart. Once you have taken three images of the same object with the red, green and blue filter, (or cyan, magenta and yellow), follow this procedure to create a color image:



1. Click the "Red" button and select your red image. Repeat for "Green" and "Blue".
2. If you need to align the images click the "Automatic" button, or click the "Manual" button to align with the arrow buttons. Another solution is to use the menu command "*Image / Align all*" before launching the trichromy. To zoom, click the image then use a keyboard or mouse command as described in the Image Window.
3. Select a white balance algorithm (see: Color / White balance) or select "User Defined" to enter your own coefficients. To emulate the result of Astroart 5, select Algorithm = None and Bias = RGB.
4. If needed, select a post-processing filter to be applied automatically after the trichromy.

4.7.9 LRGB combine

This command changes the luminance of a color image using the one of another grayscale image.

In color imaging the luminance is the most important parameter and gives details to the final image. The single frames R, G and B give only color information, this means that noise or blurring in the R,G,B frames can be corrected replacing the luminance with a high quality grayscale image.

Procedure

1. The LRGB combine can be considered the last step before publishing. So, at first process the Luminance image applying the filters needed and visualize it with a pleasing transfer function.
2. Perform a standard trichromy with the R,G,B images to obtain a color image. If needed, improve this image using the filters Denoise, Low Pass adaptive, Hot pixels, etc. and visualize it with a pleasing transfer function.
3. Align the color image to the luminance image, using the command Align or Coregister.
4. Select the color image, click "LRGB Combine" and select the luminance image. The color image will be modified with the new luminance.

4.7.10 Split (RGB, CMY, Channel)

This command separates a color image into one or three gray tones images which represents a primary color of the original image.

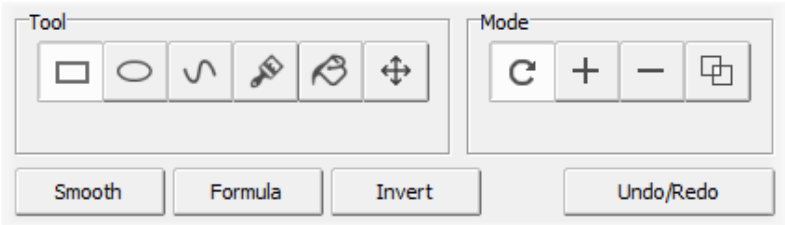
4.8 Mask Menu

Masks are used to analyze a part of the image (see: Statistics) or to apply a filter only on that part. Masks can be created using a Formula (for example: all pixels below a constant) or using the mouse, just like in graphic programs.

Once a mask is created, you may smooth its boundaries ("feather mask"), invert it, or copy it to other images.

4.8.1 Create

These tools create a mask using the mouse. To create a mask using a math function click "Formula".



Tools

- **Rectangle**. Click and drag to draw a rectangle over the image. Press CTRL to force a Square.
- **Ellipse**. Click and drag to draw an ellipse over the image. Press CTRL to force a Circle.
- **Path**. Click to start the path, then left-click to add other segments. To finish, right click or double-click the left button.
- **Brush**. Select the shape of the brush, its size, then click and drag to draw a mask over the image.
- **Fill**. Select the tolerance then click to select the mask by "flood fill". For example, if the pixel under the mouse pointer has an ADU value of 850 and the tolerance is 20, all connected pixels between 830 and 870 will be selected.
- **Move**. Moves the current mask, using the mouse. Click the arrow buttons for precise one-pixel movements.

Mode

- **Replace**. When a new mask is selected the current one is deleted. This is the default mode.
- **Add**. A new mask extends the previous one. This can be useful to select several parts of the image.
- **Subtract**. The new mask is subtracted from the current one. This is useful to create holes in the mask.
- **Intersect**. The new mask and the current one are intersected, the resulting mask contains all pixels of the new mask that also belong to the old mask.

Click the button "Smooth" to soften the mask edges.

4.8.2 Undo/Redo

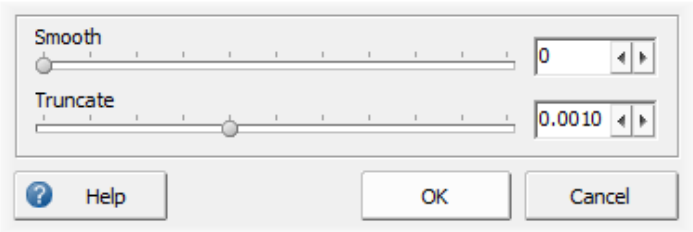
This command restores the previous mask. It's not related with the Undo of image processing, so that you can switch the latest two masks and the latest two image processing steps independently.

4.8.3 Invert

This command inverts the mask, e.g. the parts of the image which are not selected now become the ones selected.

4.8.4 Smooth

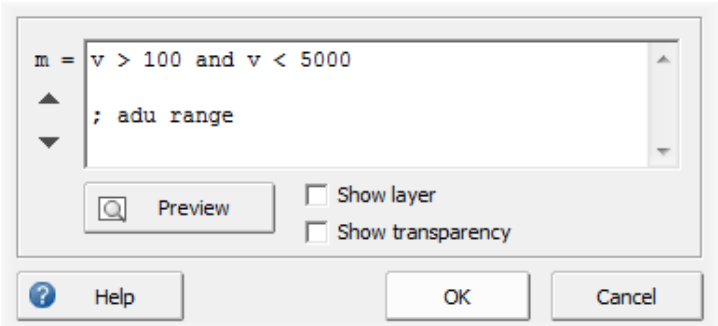
This command smoothes the edges of a mask ("feather mask"). It's strongly recommended before applying a cosmetic filter. If needed it can be applied several times on the same mask.



The Truncate parameter is useful to delete mask values close to zero. The default value is 0.001, but if you are working with 8 bit images you may increase it to 0.04 (e.g. 1/255).

4.8.5 Formula

This command creates a mask using a formula. For example, " **`v > 100 and v < 5000`** " will create a mask over those pixels with an ADU value between 100 and 5000.



The variable "v" is the ADU value of the pixel. The variable "m" is the mask value (from 0 to 1, where 1 means full mask). For more information about the other variables and the functions available, see Arithmetic / Formula.

4.8.6 Open/Save/Copy

These commands save or open the mask layer as a grayscale PNG image. It also possible to Copy and Paste the mask into the Clipboard.

4.8.7 Mask<>Image

Mask to image

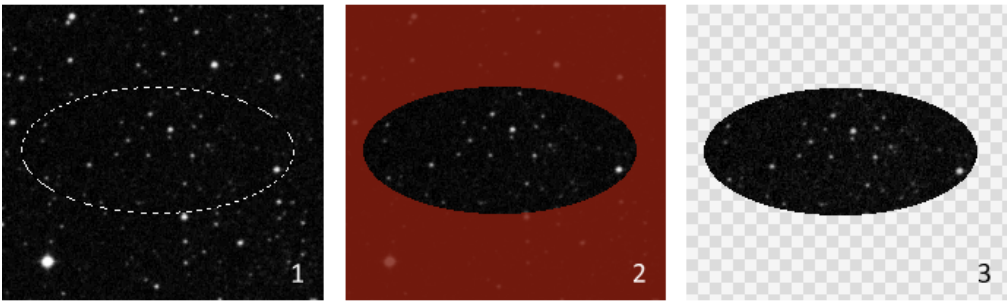
The mask is transformed into a grayscale image with 16 bit dynamic. You may then apply a filter over the image, then transform the image back to the mask.

Image to mask

This command create a mask from a grayscale image with 8 or 16 bit dynamic.

4.8.8 Show

Controls how the mask is displayed on screen.



1) **Show selection**. Displays the "marching ants" border around the current mask.

2) **Show layer**. Displays the part of the image which is masked as shades of red.

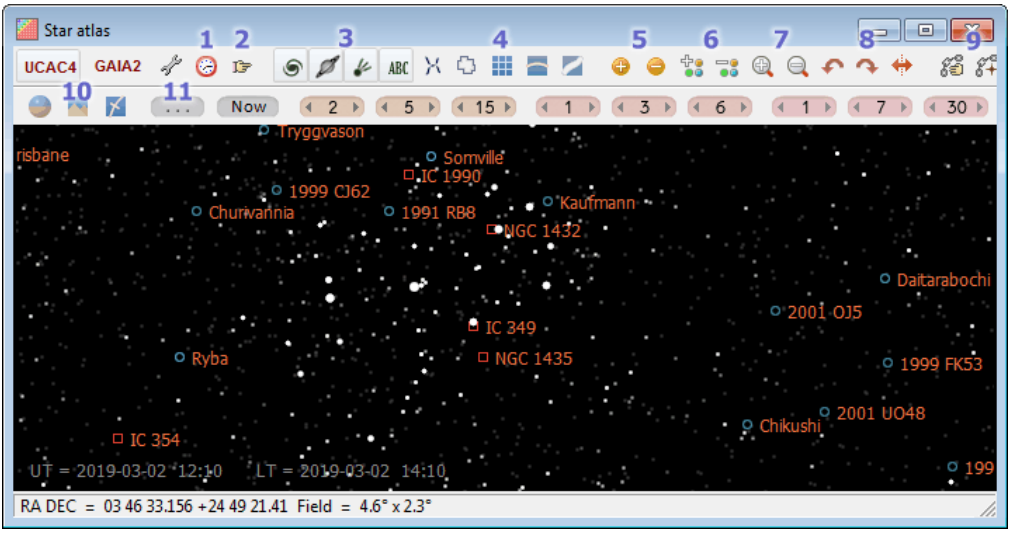
3) **Show transparency**. Displays the part of the image which is masked as a grid, just like in graphic programs.

4.9 Tools Menu

4.9.1 Star Atlas

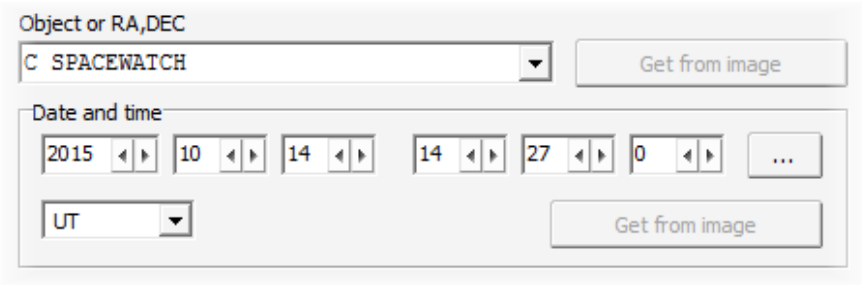
The Star Atlas is a used to display the position of stars, minor planets and deep sky objects and to perform the astrometric calibration. Left click to get information about an object with the Visibility window. Right click for the context menu, which has commands for centering the map and to connect with the Aladin web site.

The star atlas can use two star catalogs at a time, to configure them see: Preferences



1) **Time**. Click here to display the second panel where you can move the time or work in altazimuth mode.

2) **Find**. Opens the *Find window* to search for a minor planet or deepsky object.



Click the button "Get from image" to read the object coordinates from the FITS header of the current image. Some names (e.g. HALLEY, SPACEWATCH, TEMPEL) exist both as asteroids and comets, to force a comet write "C TEMPEL" or "COMET TEMPEL"). You may also write the name as "1P" or "C/1995 O1" or "CJ95O010". The *Find window* also allows to change the current time and to get it from the current image.

3) **Show**. Click these buttons to display deepsky objects, planets, minor planets and labels. Remember that minor planets require an updated MPCORB file, see: Preferences.

4) **Lines**. These buttons show constellations, equatorial grid, ecliptic and milky way.

5) **Brightness**. Changes the brightness of the stars.

6) **Objects**. Increases or decreases the number of objects displayed.

7) **Zooms** the chart.

8) **Rotates** or **Flips** the chart.

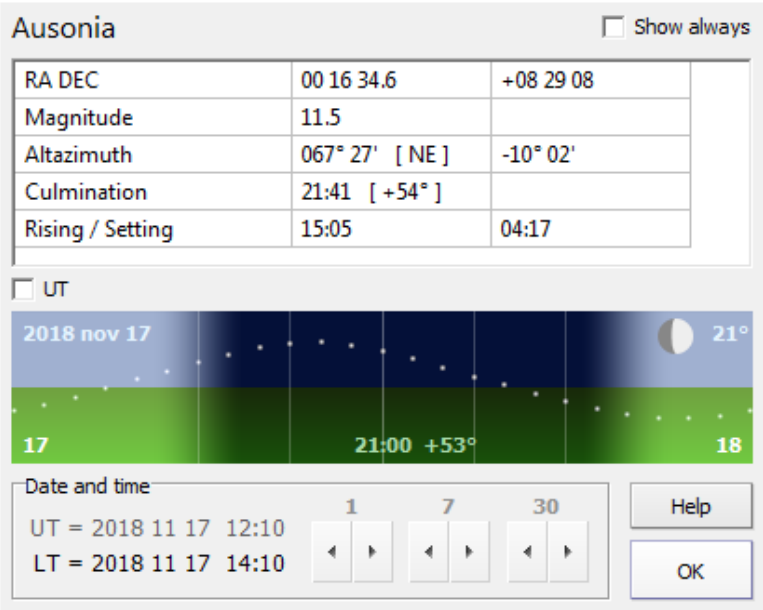
9) **Astrometry**. Manual and automatic reference stars. See astrometry.

10) **Altazimuth**. These buttons set the map in altazimuth mode with horizon and meridian.

11) **Time**. These buttons set the time or move by a given interval.

4.9.2 Star atlas (visibility)

This window shows the visibility of the selected object (left click on object to show).



Click the "1", "7", "30" buttons to change the date. The graph also shows the moon phase and the distance of the moon from the object, in degrees. If you enable the option "Show always" then the object will be always shown in the star atlas, regardless the zoom level.

4.9.3 Preprocessing

Preprocessing is the first elaboration that is performed when a group of images of the same subject are taken from an astronomic camera. It consists in three main steps:

1. Calibrating with dark frames and flat fields.

2. Aligning the images using some references.

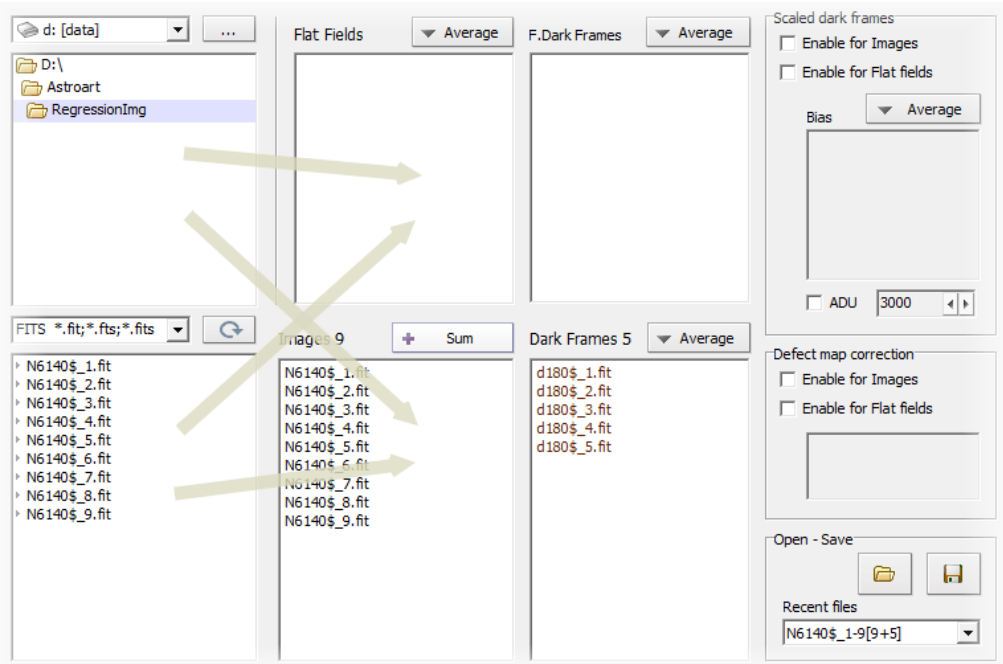
3. Combining i.e. adding or averaging all images to improve the quality.

Preprocessing on multi-megapixels images may require a lot of RAM. On Windows 64 bit you may use the appropriate version of Astroart.

Files

Select here the files to be used. There are four boxes where you can put your files (Images, Dark frames, Flat fields, Dark frames of Flat field).

To select all files of the same kind (for example M63-001-R, M63-002-R, M63-003-R, etc) just double click on a filename. To put some files in a certain box *drag & drop* from the file list or the folder list. You may also *drag & drop* from the folders of Windows or other file managers like Total Commander.



To select multiple files at once press [SHIFT] or [CTRL] then left click, or click the right mouse button. To select all files press SPACE, or drag the folder, or double click with the right mouse button. To delete one or more files from the destination boxes right click or press [DEL].

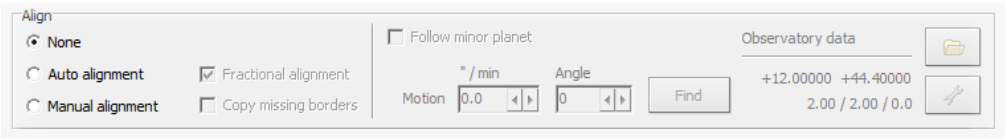
Add, **Average**, **Sigma** or **Median.** Select how to build the final image. Add and average are best methods in terms of S/N ratio. Add should be preferred on 8 bits images. Sigma is the best method to reject hot pixels if you don't correct the dark frame, but it requires more memory and it's not recommended for astrometry and photometry. Median is rarely used.

Scaled dark frame. See the menu command Filter / Scaled dark frame. As bias, you may use one or more bias images or just a constant value (ADU).

Defect map correction. See the menu command Filter / Defect map. Put here the defect map image.

About bias frames. Bias frames are never needed if you correct the dark frame (because the bias is included in the dark frame), however if your camera has a very low thermal current and you want to use bias frames as dark frames then place them in the "dark frames" box.

Alignment

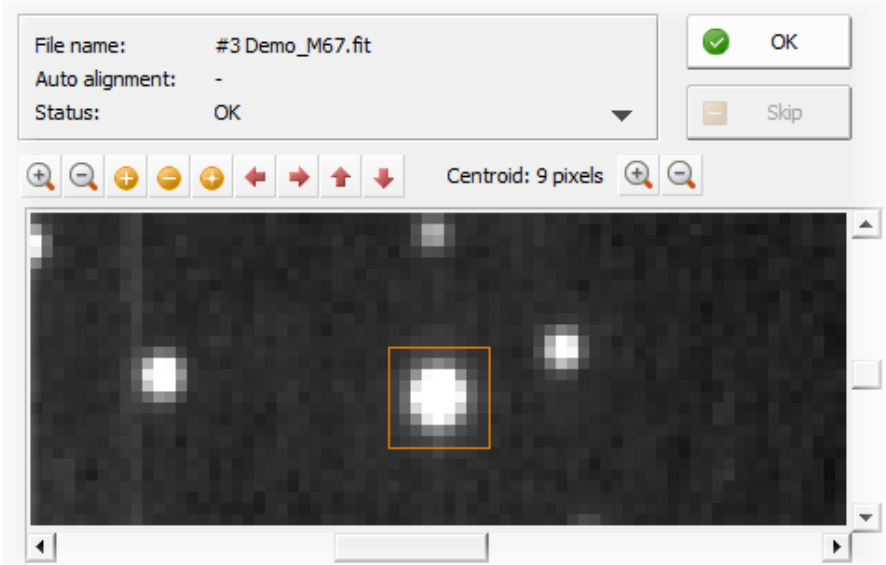


Auto alignment. Enables the automatic alignment. (see Align for more details). If the alignment method needs some reference points (e.g. *Correlation*) it's better to open the first image of the sequence and select with the mouse the reference. Its coordinates will be kept in memory and you will have simply to confirm them. Remember that to align a sequence of DSLR RAW images, the option "Demosaic" is mandatory (unless the automatic "Demosaic on load" is enabled in the Preferences, which is not recommended).

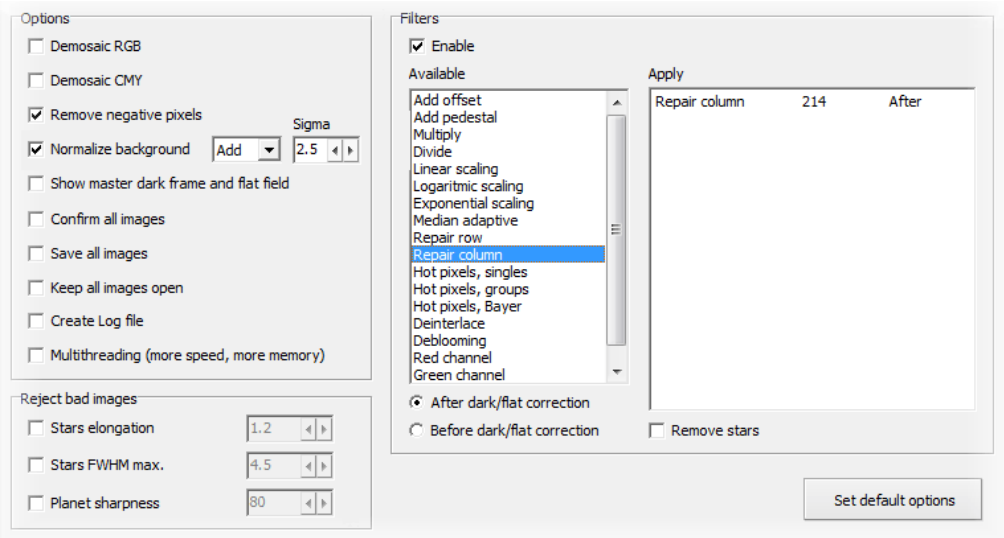
Follow minor planet. If enabled, an extra offset is added to the auto alignment, to track a minor planet. The required parameters are the motion of the minor planet (which can be calculated clicking "Find" if you have an updated MPCORB file) and the scale and the orientation of the CCD, which is an option of the observatory. This option is also required for astrometry or photometry of a moving object.

Copy missing borders. If enabled, the borders of the image which are lost by the alignment will be copied from other images. This attenuates dark borders in the final image. This option works only if there is no rotation between the images.

Manual alignment. Select this option if you want to align all images by hand. Every image will be opened and zoomed, and using the mouse or the keyboard, you will be able to track a reference object. You may enable the option "Multithreading" so that while you align the current image Astroart prepares the following one.



Options



Demosaic. This option is required to align and add raw images from color cameras. Every image will be demosaiced before being aligned (e.g. shifted), since it's not possible to shift a raw image with a Bayer matrix on it. To find the correct parameters for your camera, you should perform at least one manual Color / Demosaic on a sample image: the realtime preview will reveal the best parameters.

Normalize background. The Sigma and Median algorithms work best if the sky background is constant in the set. This option is used when your images have a

different background value, which can happen with light pollution or clouds. The "Add" method adds a constant to the images, this is recommended for correcting light pollution or clouds. The "Multiply" method multiplies all images with a constant, this is recommended to stack images with a different exposure time or for creating a master flat field. The "Scale" method both adds and multiplies, so it equalizes the dynamic of the images.

Confirm all images. Select this option if you want to follow the preprocessing step by step and discard some images from the final result. For maximum speed, use the keyboard during the selection: press ESC to discard or ENTER to accept.

Save all images. Every temporary image will be saved with a "_P" postfix. The folder can be set in the following section.

Keep all images open. (Not recommended) every temporary image will be kept opened in the Astroart desktop. Requires much memory.

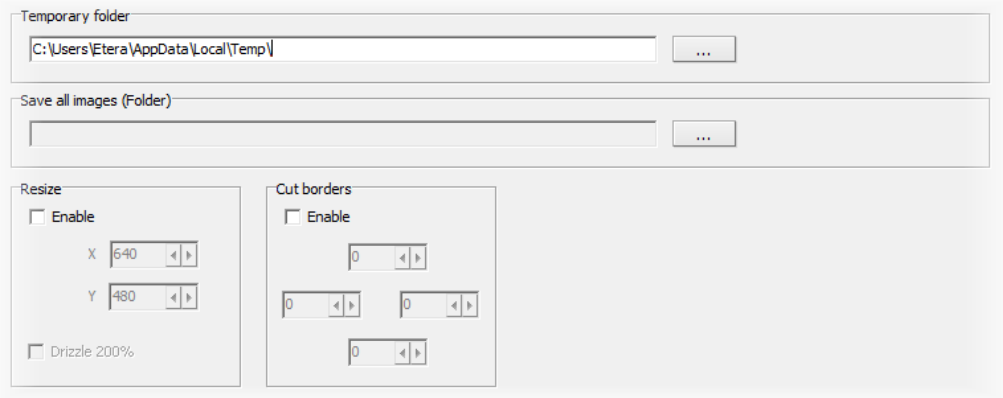
Multithreading (assembly line). While an image is processed, Astroart opens the next image and starts processing it. This doubles the memory requirement.

Reject bad images. Enable this option to discard bad images from the final result.

- Stars elongation. Discards images with bad tracking. The value means the ratio between the long and the short axis of the stars. Example: 1.2 means that all images with stars 20% bigger along an axis will be discarded.
- Stars FWHM max. Discards images with bad focus, where stars have a radius bigger than the selected value.
- Planet sharpness. For planetary and moon images only. 85% means that every 100 images 85 will be kept and 15 discarded. If the seeing was very bad, then 50% or less should be used.

Filters. Here you can get some filters from the “Available” box and *drag & drop* them into the “Apply” list. Select also if they are to be performed before or after the flat/dark correction. For example, if you don't correct the dark frame then the Hot pixels filter is recommended.

Extra



Temporary folder. The folder used to store temporary data when the memory available is low.

Resize. Resizes all images after the dark/flat calibration, but before aligning and combining them.

Drizzle 200%. Doubles the size of all images to increase the resolution IF THE IMAGES ARE UNDERSAMPLED. You can easily recognize an astronomical undersampled image: its stars are 1 - 2 pixels wide, they look like hot pixels. For a good result the images must not be aligned and a minimum of 20 images is required.

With modern multi-megapixels cameras it's almost impossible to get an undersampled image, so drizzle is often not useful.

Cut borders. It's used to cut lateral rows or columns from imperfect CCDs.

See also Tutorial #5, Tutorial #6, Tutorial #7.

4.9.4 Text Editor

This command executes a fast text editor inside Astroart. Right click to display the context menu to save or print your document.

4.9.5 MPC Report

This command open a special Text editor to write a "80-columns" MPC report. This format is still valid, despite the release of the new "ADES" format.

Usage

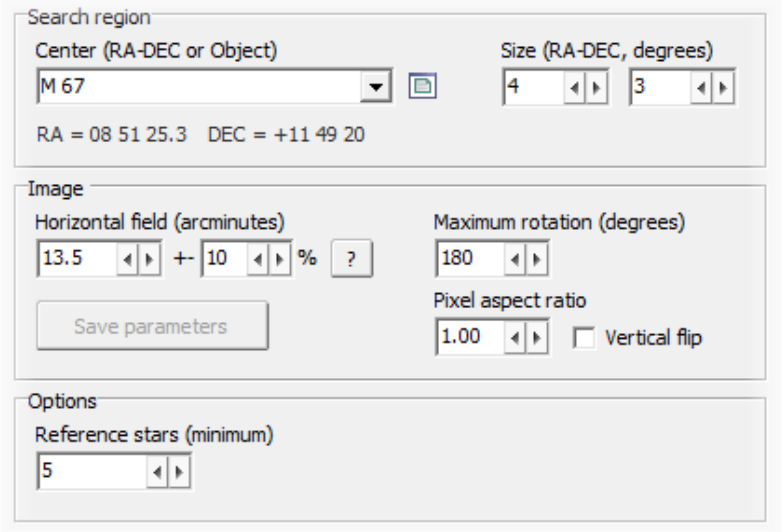
1. If needed, setup the MPC header in the Preferences window.
2. Click *Tools / MPC Report*.
3. After the astrometric calibration, for every object in the image or in the Stars window right click to display the *context menu* and select *MPC Report*.
4. Check the values in the *MPC Dialog Window* and click OK: a new record will be

added to the MPC report.

The report must be written following the rules of the Minor Planet Center, see http://cfa-www.harvard.edu/iau/ for details.

4.9.6 Find Coordinates

This command ("plate solving") automatically finds the center plate (RA and DEC coordinates of the center of the image). This command can be called by scripts to automatically center the telescope after a long GOTO. See: Scripts.



Search region. In the first section you need to set the approximate coordinate of the field (or the name of the object, e.g. NGC 4565), and the size of the search rectangle. The default is 4x3 degrees or 2x2 degrees if the function is used by scripts. Note that an unnecessary large region increases the chance of false positives if you use only 4 stars as reference.

Image. The second section is the most important. You need to set the horizontal field of view of the image, in arcminutes. For example, the default value is 13.5 +10% which means that every image from 12 to 15 arcminutes will be recognized.

The first time you use the Astroart plate solve write an estimated field of view and a tolerance of 20-50%. Then if plate solve succeeds, open the Statistics window to discover the exact value of the field of view and copy it in the Horizontal field, then decrease the error tolerance to +- 2%. This will speed up the following searches and will prevent false matches.

The last field is the maximum rotation of the camera relative to the equatorial axes. The default value is +-180 which means that all rotation will be recognized. If you mount your camera straight with the equatorial coordinates you may decrease this value to 20-30 degrees, this will speed up the search and most important it will

help to avoid false matches.

If the image is flipped remember to enable the option "vertical flip" otherwise the procedure will fail. If your camera has rectangular pixels, set the pixel aspect ratio (width / height). For example, the MX9 camera has pixels of 11.6 x 11.2 microns, so the aspect ratio is 1.04.

Reference stars. The number of stars to be matched for a valid result. The recommended value is "5" stars. 4 stars can be used in sky areas with few stars (example: high galactic latitude) but the error tolerance must be set to 5% or less (or the maximum rotation to 10° or less) otherwise false positives may be found.

Example

Using the M67 demo image, set “M 67” as center, “13.5” as field, “20%” as error tolerance and “180” as angle. Click "Find". The field is recognized in 3-4 seconds and the image will be astrometrically calibrated.

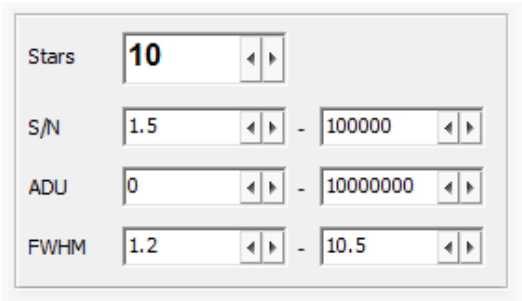
- Verify that the search is faster if your decrease the error tolerance (field and rotation) since the algorithm can discard easily more patterns.
- Find out the exact horizontal field of our camera/telescope with the command *View / Statistics*.
- Try a full sky search: set "0 0 0 +0 0 0" as zone, 360 x 180 rectangle, 13.5 +- 5%, 20 degrees rotation. After 2-3 minutes, when the progress bar arrives at 15%, the field will be found and you will be able to stop the procedure clicking "Cancel". The calibration will be kept.

Immediate

The menu command "Find coordinates immediate" performs the same operation, without displaying the dialog window.

4.9.7 Find stars

This command searches for stars. The data will be available in the Stars window.



Select the maximum number of stars. Remember that you can change the all numeric values rotating the mouse wheel and you may press CTRL for faster changes.

S/N Ratio. Signal to noise ratio, it's a measure of the intensity of the star. A minimum good value is 5, you may decrease it to 3 - 4 to recognize very faint stars, or increase it to recognize only good stars (with a S/N above 20).

ADU. Select the minimum and the maximum ADU of stars you need to select. If you need to select stars within a tight interval, increase the "Stars" number, since the filter is applied after the stars have been selected.

FWHM. "Full Width at Half Maximum" is a measure of the diameter of a star (in pixels). The standard minimum value is 1.2, you may increase it to find only larger stars. If you are working on big images it's possible that stars are not recognized because they are bigger than the FWHM maximum. To correct the problem increase the *FWHM max* value to 15 or more.

These parameters can be also set in the Preferences.

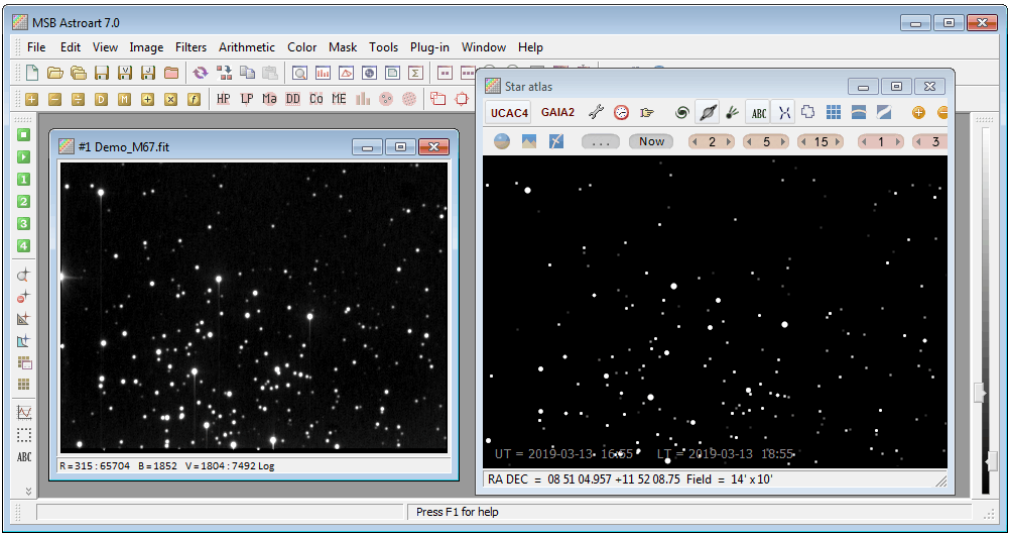
4.9.8 Delete Stars

This command deletes all stars selected on the image. A star can also be deleted clicking on it with the left mouse button.

4.9.9 Astrometry

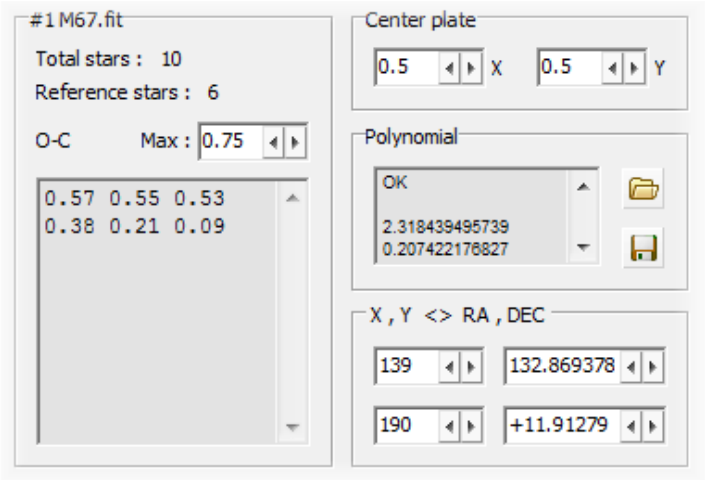
The astrometric calibration is a process that establishes a link between each point of the image (x,y) and the corresponding celestial coordinates (R.A., DEC). To perform the calibration we need some *reference stars* with known coordinates. Astroart will get them automatically from the Star Atlas.

A quick calibration can also be done with the Find Coordinates command, but the precision will be 0.4 - 0.7 arcseconds, while this command allows a precision of 0.1 - 0.4 arcseconds.



Procedure

1. Before to start take a look at Tutorial #9.
2. Click on the menu *Tools* / *Star Atlas* . Resize the atlas window until it becomes about the same size of the image and place it on a free area of the desktop.
3. (Optional) If you wish to choose by hand the stars to be used as reference, select them on the image. Otherwise they will be selected automatically in the next step.
4. For a full automatic procedure, click on "Reference stars, automatic" button on the star atlas. Otherwise you may assign the stars by hand clicking on the "Reference stars, manual" button. In this case each star will be indicated by a cross on the image and you will have to click the same star in the atlas.
5. Click on the menu *Tools* / *Astrometry*.
6. For a quick check of the calibration, take a look at the *O-C pos*: this is the residual error for every reference, it should be below 1 arc-second, if not you may exclude some stars decreasing in realtime the *Max O-C* value (here it's 0.75 arcseconds).



The image is now calibrated: for every new object added to the list of the Stars window, Right Ascension, and Declination will be calculated. A orientation mark will appear at the upper-left of the image. Also, when you move the mouse pointer over the image the coordinates are displayed in the status bar.

If you save the image and reload it, the image is still calibrated thanks to the WCS keywords which are saved in the FITS header. If you click again the *Star Atlas Button* on the *Main toolbar* the atlas will display immediately the star field of the active image.

Astrometry of moving objects

To perform astrometry on a sum of a sequence with a moving object, follow this procedure: At first perform astrometry on the first image, then save it with the same name. In Preprocessing align the images with the additional option "Follow minor planets". That's all: the sum image will be correctly calibrated.

Notes

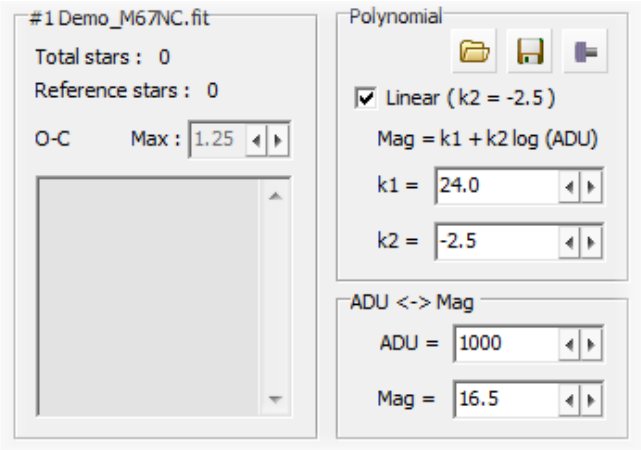
The result of all calculations is a two-dimensional polynomial that maps X,Y coordinates into a temporary space, and then to RA and DEC coordinates by further trigonometric transformations. This polynomial can also be saved to disk then reopened into another image to copy the calibration.

To view the direction of the sun, press CTRL+SHIFT+N, the setting will be remembered.

If you open an image with WCS keywords, this data will be used automatically for all astrometric measures. Astroart uses the same algorithms (least squares, etc.) used by most professional astrometric software under UNIX™.

4.9.10 Photometry

Use this command to perform the photometric calibration. With the term photometric calibration we intend a process that establishes a relationship between the ADU values of the pixels and the astronomic magnitude. The classic realtime *aperture photometry* can be performed instead with the *Zoom window*.



Method 1 - Instrumental magnitude

1. Inside the "Polynomial" section click the "Instrumental magnitude" button.
2. Set your own k1 and k2 and Click OK. In case of linear response k2 must be set to -2.5.
3. That's all, the image is now calibrated using instrumental magnitudes.

Method 2 - Reference stars

The following methods require that you prepare some reference stars with a known magnitude before launching the command Photometry. This procedure can be manual or automatic.

In the manual procedure right click over a reference star (after it has been selected, left-clicking on it) and from the context menu select "Edit star": write the magnitude of this reference star and enable the option "Reference stars". (The "Edit star" command is available also from the Stars Window).

The automatic procedure is performed with the Star Atlas, the magnitude of reference stars can be copied automatically from the Atlas with the same procedure used for Astrometry.

Single reference star. Select on the image the reference star, the variable star and (optional) the check star. Assign the magnitude of the reference star as written in the previous paragraphs, click "Tools/Photometry" and "OK" to finish.

Many reference stars. This will perform the "Ensemble photometry". Select on the image several reference stars and the variable star. Assign the magnitude of the reference stars as written in the previous paragraphs. Click "Tools/Photometry" and select the interpolation method: "Linear" is usually better for less than 5 reference stars, if your camera has a good linear response. Otherwise the non-linear interpolation can be used. Look at the O-C box: if one reference star has a bad "Observed-Calculated" value then you may exclude it from the process changing the "O-C max" value. Click "OK" to finish.

The image is now calibrated: for every new object added to the Stars Window the magnitude will be calculated (so the variable star could be added after the image has been calibrated). The magnitude is also calculated for the aperture photometry in the Zoom window. To display the rings used for calculating the flux of the star, zoom the image 200% or enable the option "Show rings.." in the Preferences.

Polynomial. The result of all calculations is a polynomial that maps the ADU value to the magnitude of a star. This polynomial is saved into the FITS Header if the corresponding option is selected in Preferences. This polynomial can also be saved to disk then reopened into another image to copy the calibration. DO NOT ADD, MULTIPLY, SCALE an image with photometric data, the polynomial cannot change in realtime.

These derived magnitudes are only as good as the catalog values. They are, however, instrumental magnitudes which must be corrected with the atmospheric extinction and the color-dependent terms if you desire to compare them with a standard photometric system. Higher accuracy demands at least some calibration to a standard photometric system using appropriate filters. A complete discussion of proper photometric techniques is beyond the scope of this manual. A good introduction is the book: A.A. Henden, R.H. Kaitchuck – Astronomical Photometry - Published by Willmann-Bell, Inc.

B-V range. If you use the UCAC4 catalog and many reference stars, then two new fields will appear to exclude all the reference stars outside the specified range.

See also: Tutorial #9.

4.9.11 Delete calibration

This command deletes the astrometric and photometric calibration of an image.

4.9.12 Batch photometry

This command calculates the photometry (as ADU) of an object on multiple images. The result is a text file which can be passed to custom software (or an Excel sheet) for further analysis. It's also possible to generate a graph as instrumental, differential or standard magnitude.

Procedure

1. Open the first image of the sequence into Astroart.
2. Select some stars over the image. The first one is the object to be measured, the other stars are the *reference stars*. If you select more than one reference stars then Astroart will use the *differential ensemble photometry* as explained in chapter 4.2 of the AAVSO CCD Observing Manual: www.aavso.org/ccd-observing-manual.
3. Click menu *Tools* / *Batch photometry*. Select (drag and drop) all images to be measured, the dark frame, flat fields and how to auto-align the sequence. (See Preprocessing).
4. At the end of the process a text file will be created. ADU of stars are corrected from local background. The aperture (Signal-Gap-Background) is the default one in the Preferences. Click the right mouse button for the context menu.

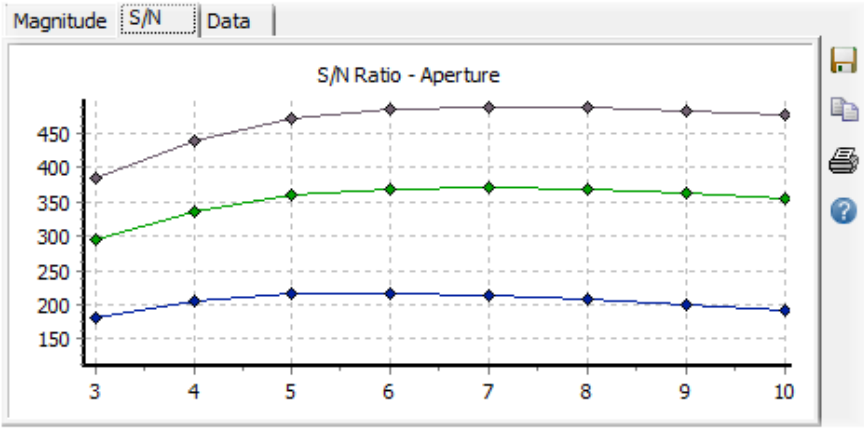
To create a quick graph in instrumental or differential magnitude right-click over the text editor and select "Photometry plot" from the context menu. It's possible to click over the points of the graph to get information about magnitude and time of every measure.

Photometry of moving objects

To perform photometry on a moving object, remember to set the option "Follow minor planet" as explained in Preprocessing.

4.9.13 Growth curve

Displays a special graph used in photometry. Before using this command select one or more stars on the image.



On the X-axis there's the aperture in pixel used to measure the star (see Aperture photometry), on the Y-axis the signal to noise ratio or the instrumental magnitude.

In the figure above, for three stars, it can be seen that the best S/N is achieved with an aperture of 6-7 (it slightly depends on the star).

4.9.14 Aperture photometry

Aperture photometry in realtime is available through two special "pointers" of the Local zoom window.

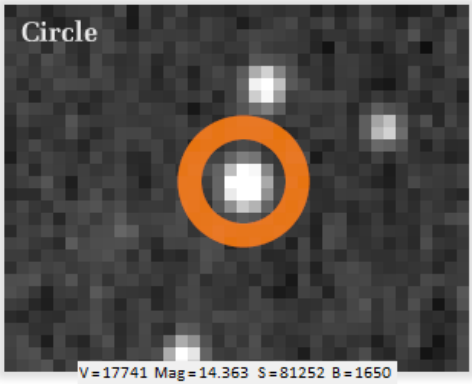
Circle

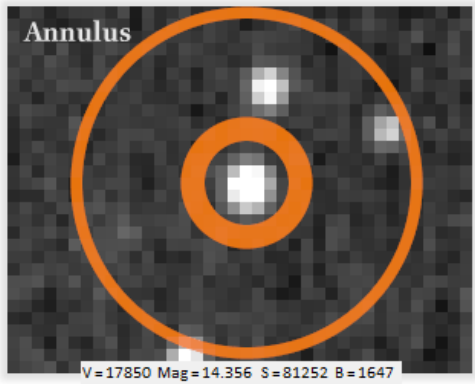
The pointer is a circle with a diameter of N pixels. The sum of all internal pixels "S" will be shown in the status bar.

The background value, to be subtracted from every pixel, can be chosen pressing the [B] key when the circle is above a sky background (or by clicking the item *Background* in the context menu). If a background B value is selected, then a new value "V" will be displayed in the status bar and it is computed as (S - B*npixels). If the image is photometrically calibrated, then the value will also be shown as instrumental magnitude.

Annulus

It works just like *Circle*, but the background (which is always subtracted) is calculated automatically inside the annulus.





Press the arrow keys to move the pointer, [ENTER] to collect a star in the Stars list, [C] to center the star. You may set the default values for the circles in the Preferences.

4.10 Window Menu

4.10.1 Cascade, Tile, Arrange Icons

Cascade

Layers all windows so that all title bars are visible.

Tile

Divides the screen into smaller windows of equal size.

Arrange Icons

Regroups the icons of the minimized windows in the lower left corner of the Astroart desktop.

Minimize All

Minimizes all the windows to the lower left corner of the Astroart desktop.

4.10.2 Full Screen

Displays the image at full screen over a black background.

It's possible to move and zoom the image with the same commands of the *Image Window*. Example: press [PAG_UP] and [PAG_DOWN] to modify the visualization. Press [+] and [-] to zoom and the [ARROWS] to move the zoomed area. As usual it's possible to pan with the mouse clicking the right button and to zoom clicking the wheel (without rotating it) moving the mouse up-down.

4.10.3 Fit To Image

This command resizes the window frame to the size of the image. The shortcut is " * " on the numeric keypad.

4.10.4 Fit to Window

This command zooms the image so that it fits the window.

5 Camera control

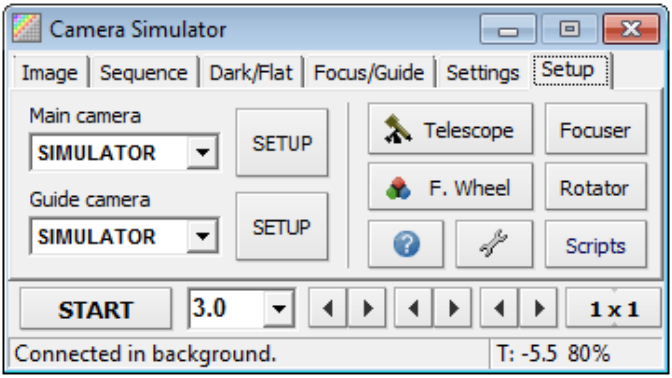
Camera control in Astroart is implemented as a "plug-in", this solution allow us to support new cameras very quickly. This documentation refers to the Camera Panel 7.0. For compatibility with older cameras it's still available the old Camera Panel 6.0 which nowadays is obsolete.

5.1 Installation

To install a plug-in, unzip it into the Astroart installation folder (usually: C :\ Program Files x86 \ Astroart). The documentation is included in the same zip archive.

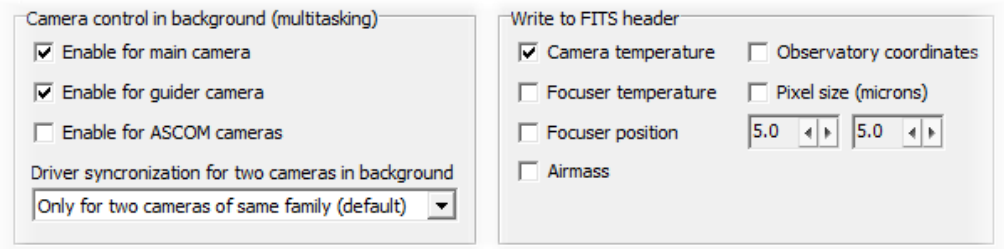
5.2 Setup page

The first option to be selected is the camera model, then click on "Setup". Nowadays most cameras are ASCOM compatible. If the camera is not in the list, then download its plugin in the "Camera control" page of the Astroart web site. To make indoor tests, use the Simulator.



To command an auxiliary camera click the second Setup button. Later, it will be possible to connect both cameras and other equipment with a single click, press CTRL + left click on the first Setup button.

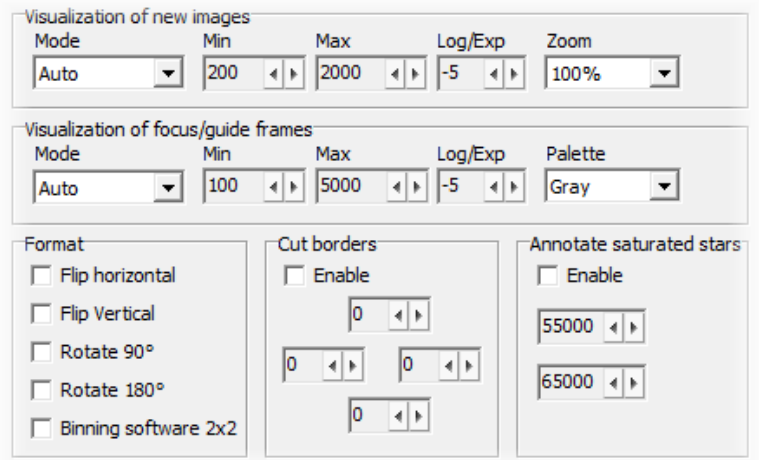
Click the *wrench* button to open the Options Window:



Camera control in background. Enables multithreading for image download, focus and autoguide, so that images from the camera are downloaded in background. If you see that the Focus window or the Autoguide window get blocked during download and "stutter" then enable the option. On (modern) ASCOM cameras the option is no longer needed since internally they work in background in any case. On some old cameras the option cannot be used at all.

The options "Driver synchronization" are used when you are controlling two cameras of the *same manufacturer*. Synchronization reduces performance in one rare case: when you are focusing with the primary camera and autoguiding with the secondary camera at the same time.

Write to FITS header. Select here which keys are to be written in the FITS header. If you select the airmass or the observatory coordinates, remember to configure them in the Preferences.



Visualization (automatic and custom). The view mode for every new image. The option “Auto (soft)” provides a natural look, “Auto (hard)” is useful for asteroid and supernova search. If ”Auto” is not selected then it’s possible to set the minimum and maximum visualization threshold and the transfer function.

Flip, **Rotate**, **Binning**, **Cut borders**. These options modify every image downloaded from the camera. "Binning software 2x2" is useful if the hardware binning of the camera is limited, or to increases the dynamic by two bits (since 4 pixels are

summed). For example: a 16 bit camera becomes a 18 bit one.

Annotate saturated stars. All stars with a peak value higher than the first value will be marked with a yellow circle (red circle if higher than the second value). This is useful for photometry, to ensure linear response. For example, for a 16 bit camera you may set 50000 and 60000. This command is also available for any opened image, just press CTRL+SHIFT+S.

Alerts. Options to play a sound on important events, for example the lost of the guide star. It's also possible to use a personalized WAV file.

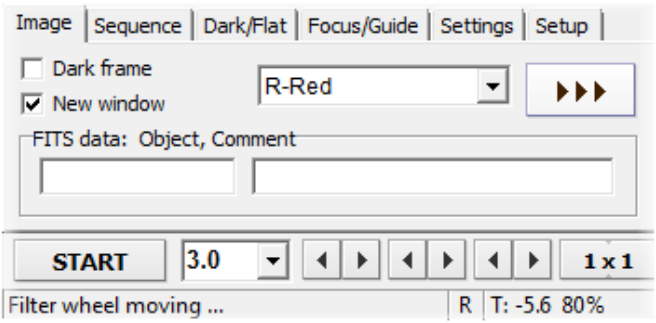
Shutter delay. A time in milliseconds which is added to the exposure start time in the FITS header, to compensate for the time spent by the camera to open the shutter and flush the CCD. It's useful when you need a precision of 0.1 seconds.

UT and LT. Universal time and local time, as read from Windows. You may compare them with a scientific watch.

Synchronize two sessions. This option permits to synchronize three cameras: two Astroart sessions which are taking sequences, plus an autoguide system in dithered mode. Select "Master" in a session and "Slave" in the other. The session which is guiding (or which is controlling the external autoguide software) must be the Master one. Then start the sequence in both session (the order is not important), every session will wait until the other one is ready.

5.3 Image page

To start a new exposure select the *Image Page*, write an exposure time in seconds (example: "0.002" for two milliseconds) or click then arrow buttons, then click the " Start" button. The binning factor can be increased and decreased clicking the "1x1" button.



Dark frame. Select this option to close the shutter during the exposition, if your camera has a built-in shutter.

New window. Every new image is usually displayed in a new window. If this option is disabled then every new image will overwrite the previous one, if they have the same size. This is useful when doing sequences or test images.

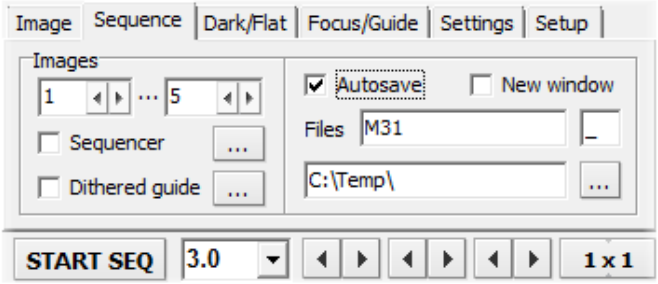
Filter wheel. Select the filter name and click the arrow button to move the wheel to

the desired position. The filters can be moved also from the Filter Wheel Window.

FITS Data. Here you may write the object name and a comment for the FITS header of the image. All other FITS data like date, time, temperature (if supported by the driver) are added automatically.

5.4 Sequence page

To improve the Signal-To-Noise ratio it is often necessary to take a set of images and sum them. In Astroart it's available a *simple sequencer* and a *full sequencer*.



Autosave. If selected, every image will be saved with the filename specified in the edit box plus an ordinal number, into the chosen directory. In the example above the filenames will be: M31_001.fit, M31_002.fit, etc. You may also modify the *separator* (underscore in the example). If you add a "t" to the separator then the exposure time will be added to the filename, for example with "-t" and an exposure of 60 seconds, the filenames will be: M31-60s-001.fit, M31-60s-002.fit, etc.

New window. Not recommended. Usually it's not selected, so that all images are displayed into the same window, to save memory.

Dithered guide. This option can be useful during a sequence autoguided exposures. Between each exposure the telescope will be move randomly by a given amount. This means that every image will not be aligned with the following one, but the signal to noise ratio will improve because different pixels will be used to collect the same data.

Simple sequencer

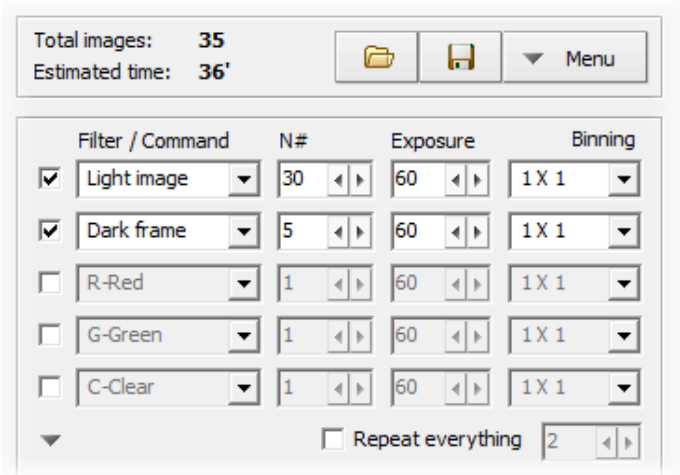
This is used when you don't need to move the filter wheel or take dark frames and images at the same time. Just write the number of exposures to be acquired, from 1 to 9999. It's also possible to set the initial index of the sequence. To take a sequence of dark frames just enable the option in the Image page. Press the button "Start Seq" to start.

To stop a sequence click the button "Stop" once, and wait a few seconds

Full sequencer

This is used for complex sequences, or simple sequences which are reused, thanks to its ability to save and reopen settings. Click the button near "Sequencer" to

activate.



Every row is composed by *Command*, *Number of images*, *Exposure time*, *Binning* and (optional) *Focuser position*. Click the arrow button to display more rows.

In the example, 35 images will be taken (index 1..35) if you need to skip some images, then modify this initial and final index in the main sequence panel.

Click the option "Repeat everything" to repeat the sequence several times. In the example above this could be used to take dark frames in the middle of the sequence, instead of taking them only at the end of the session.

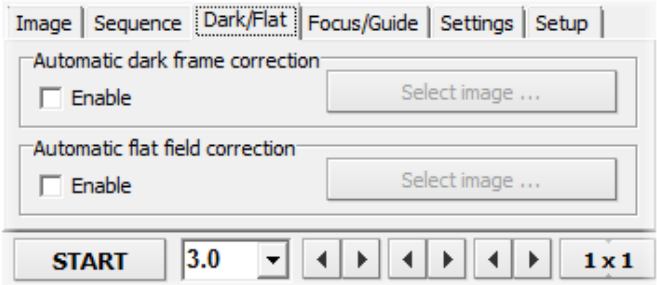
Once the focuser section is displayed, you may write an absolute position to be reached before taking a group of images, or write the special code "99999" to launch the full-frame autofocus. Click the button "Menu" to display more commands:

Filenames preview. This will display the exact list of files which will be generated, for example: M31_001R, M31_002R, M31_003R, etc. this is very useful to check the result of the sequence. Once the images have been created, remember that in Preprocessing you can double click on a single file to select all files of the same kind (filter, dark frame, etc).

Create similar script. Creates a script which is able take the same sequence. This is useful to customize a sequence with other commands.

5.5 Dark/Flat page

This page enables the automatic correction of dark frames and flat fields during the acquisition of images. This function is **not recommended**, since you will not be able to analyze the original raw images. It can be useful for live demonstrations.



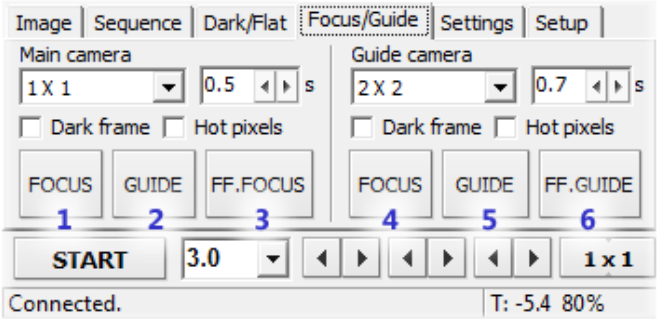
Dark frame correction. Select this option to disable or enable the dark frame subtraction for every new image. If you change the binning factor the correction will be disabled.

Flat field correction. Select this option to disable or enable the flat field correction for every new image.

For best results remember to take at least 5-10 dark frames and average them to reduce the random noise.

5.6 Focus/Guide page

This page contains several buttons to focus or guide, three for the main camera (left section) and three for the guider camera (right section).



For the subframe focus and guide (1, 2, 4, 5) at first download a full image: for the main camera just click the "Start" button. For the guide camera click the "FOCUS" or the "GUIDE" button. Then select a rectangle around a bright star and click again the focus or the guide button.

For the full-frame commands (3, 6) see the chapter Autofocus and Autoguide.

Exposure. The exposure time for every frame. It's always possible to change it in realtime.

Binning. The binning factor of every exposure.

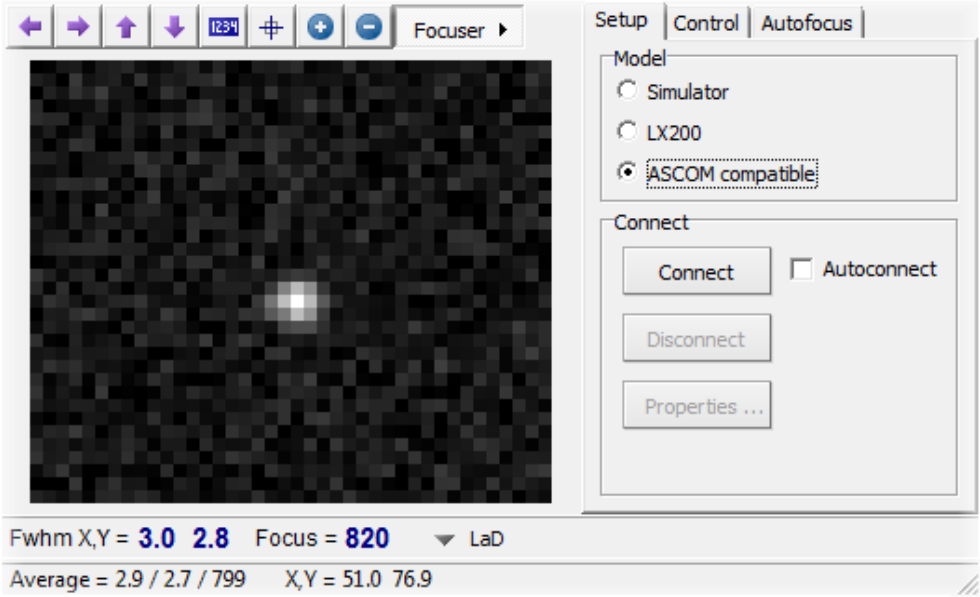
Correct Dark frame. If selected, a dark frame is acquired at the beginning of the focus session: (if the camera has not a shutter you should cover the scope before

starting) Astroart will keep in memory the first frame as a dark frame and every subsequent image will be automatically corrected.

Hot pixels. Enables the automatic correction of hot pixels for every frame.

Focus window (subframe)

This window acts as "live view" and can be used to focus or center the field. To select a subframe centered exactly in the image, see: Select rectangle.



FwhmX, FwhmY. "Full Width at Half Maximum" is a measure of the size of the star (in pixel) along the X and the Y axis.

Focus. A precise sharpness indicator. The higher the value (from 0 to 1000), the better the focus. 5 algorithms are available to calculate the focus for more information see the paragraph about Autofocus.

Average (FwhmX / Fwhmy / Focus). The averaged values from the last few exposures.

X, Y. The absolute coordinates of the star, inside the full image. This can be used to center exactly the field between two nights.

At the top of the Focus Window you can find some buttons: The four **arrow** buttons move the focus subframe across the CCD area. The **cross** button displays a reference cross. The **[+]** and **[-]** buttons increase or decrease the exposure time. The **[1234]** button displays the calculated focus and its average with a big font, then click the "loudspeaker" icon to have them spoken by the computer.

For a smoother operation of the *Focus Window* you may want to enable "Camera control in background" in the Options, if the camera driver supports this mode.

Autofocus

See the paragraph Focuser inside "Other devices".

Autoguide

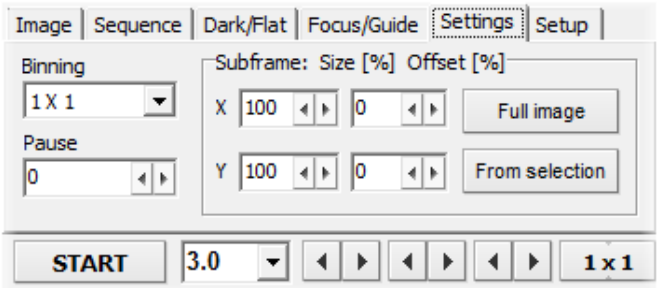
See the paragraph Autoguide inside "Telescope control".

Camera control

5.7 Settings page

Binning. If 1x1 is selected then the CCD works at full resolution (example: 768x512 for a KAF400). If 2x2 is selected then four pixels will be grouped into one and the resolution is halved (example: 384x256 for a KAF 400). The advantage of binning is a faster download and better signal to noise ratio. 3x3 and 4x4 are useful to find or center an object.

Pause. Before each exposure there will be a pause of N seconds.



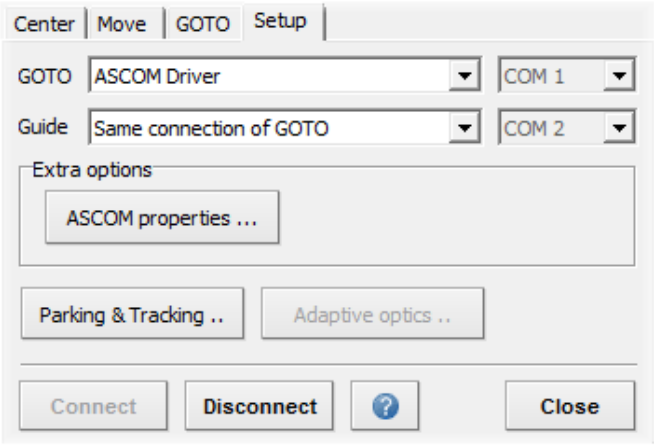
Sub-frame. This is a useful feature for planetary imaging at high resolution. To speed-up the download and save space on disk it is possible to acquire only a part of the CCD array. To use this feature, download a full frame, select a rectangle on it, then click the "*Select from...*" button. The frame boundaries will be written into the four edit boxes as percentage.

6 Telescope control

To configure and control the telescope select the Setup Page and click the "Telescope" button.

6.1 Setup Page

This page is used to connect the telescope. Select here the protocol used to command the telescope ("Goto"), and the secondary connection (if available) used to send guide pulses ("Guide"). If you have a guider camera with integrated relays and a ST4 cable to the mount, the Guide protocol is usually "Camera 2 relays".



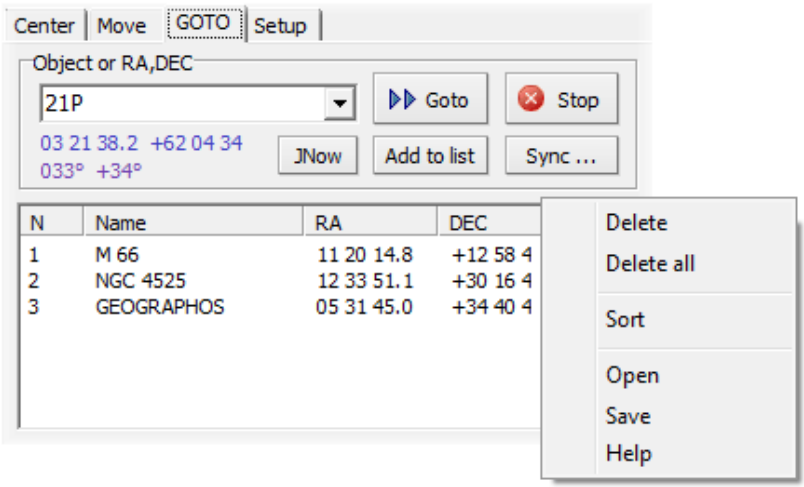
Options

Parking and Tracking. Commands to park and unpark the telescope and to turn off and on the sideral tracking. Turning off the tracking can be useful to take flat fields directly on the sky.

Active Optics. These options are shown when an AO is connected. See: Active Optics.

6.2 Goto Page

This page is used to move the telescope to a given object and to manage lists of objects.



Object or RA,DEC. Write here the name of a object (for example: M42, see also: Star Atlas) or some RA/DEC coordinates (example: 18 34.3 +34 56) then click on the

GOTO button to slew the telescope to that object. The "**JNow**" option is used to convert the coordinates from J2000 to the current epoch. If the observatory coordinates are set then the altazimuth coordinates will be shown as well, be sure that the time of the PC is correct.

Sync button. Synchronizes the position of the telescope, three options are available: 1) The object written in the "Object" box above. 2) The coordinates of the last GOTO. 3) The current image if it's calibrated (plate solved).

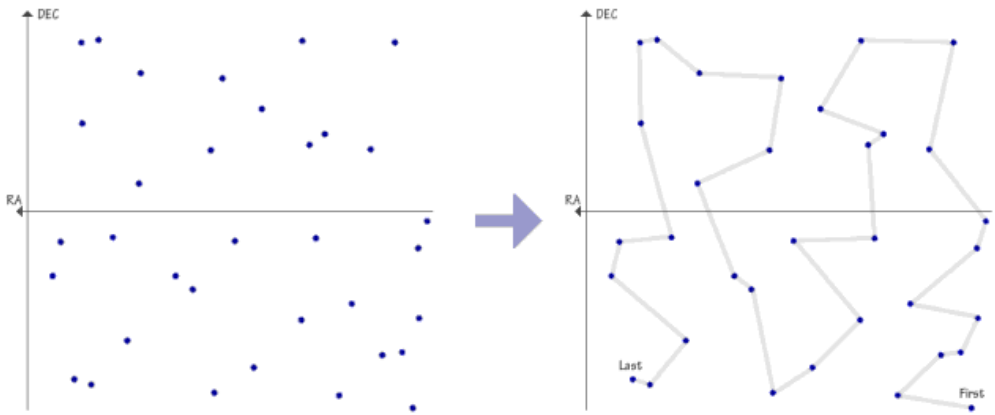
Add to list. Adds the current object to the list. When adding a custom object you may specify a name, for example: "MyObject" 23.5 +12.3

Object list. Right click to open the context menu. When opening a text file every row must contain: *Name*, *RA*, *DEC*. The format of the coordinates is free, but the declination must contain the sign. Example:

```
"NGC4567" 12 34.8 +78 45
"M 67" 12 34 56 +78 23.8
"PK456+789" 12 12.2 + 34 34 34
"UGC 3456", 12, 14, 16, +34, 54, 34     // Comments this way.
"UGC 4567", 12.23445, -23.23456
```

This format is also valid for the "Add to list" button. In this example the last two rows are CSV [comma separated values] which can be exported and imported by Microsoft Excel.

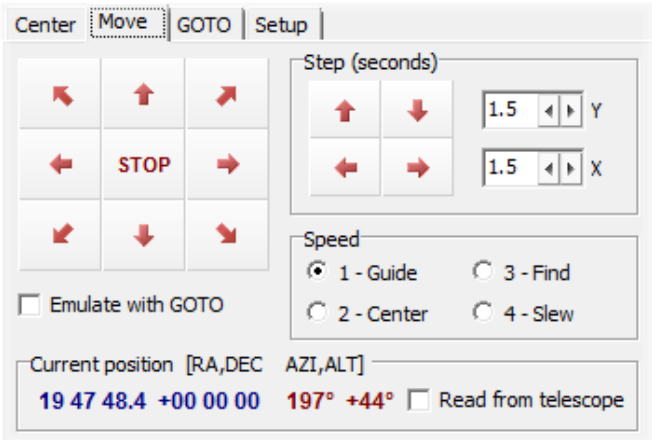
Other commands in the menu allow to delete rows and to sort the list:



The object list is sorted using a compromise between a shortest path algorithm and a increasing RA algorithm.

6.3 Move Page

This is a virtual keypad to move the telescope, useful to center an object. Please note that some ASCOM drivers do not support this function, in this case you may try the option "Emulate with GOTO".



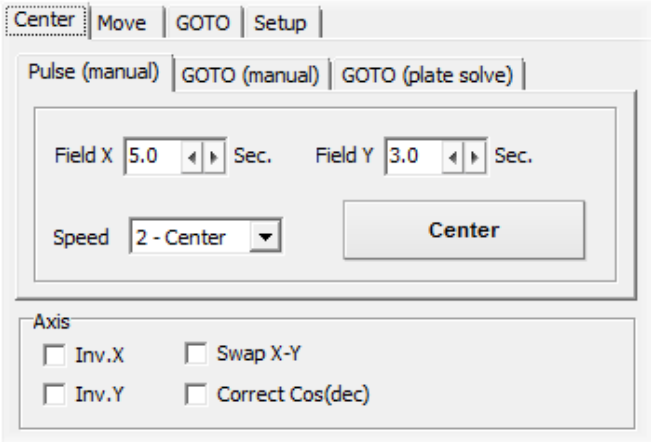
Emulate with GOTO. Select this option if your scope cannot be controlled for simple North, South, East, West commands, but it supports the GOTO protocol and the STOP-GOTO command. The speed depends on the telescope, usually 1 - 2 degrees per second.

Speed. The telescope speed, this option is not supported by some telescopes. Remember to select “Guide” before autoguiding.

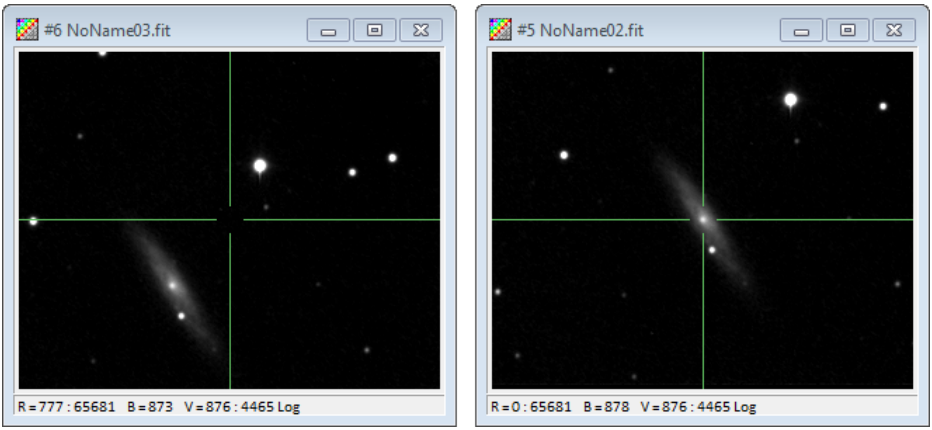
Current position. Displays the current equatorial coordinates as read from the telescope. For the altazimuth coordinates you have the option to have them calculated or read from the telescope.

6.4 Center Page

This function centers the object in the field of view of the CCD. You may automatically obtain the same result using the “Find coordinate” (plate solving) script available in the next chapter.



Three methods are available to center the object. The first two methods are manual, you will need to select a point over the object then click the [Center] button. The third method is automatic:



- **Pulse (manual)**. The telescope will be moved using the pulse commands (North, South, East, West) at the given speed. The field of view of the CCD image must be known in seconds (time), this parameter is simply the time necessary for the telescope to move along a full field. The field along the X axis can vary slightly with the declination, to correct this measure the field X at the equator and enable the option *Cos(declination*).
- **Goto (manual)**. The telescope will be moved with a GOTO command (Goto (ra+dx,dec+dy)). The field of view of the image must be known in arcminutes. The field X varies with the declination and it's possible to enable the option *Cos (declination)*.
- **Goto (automatic)**. The telescope will be moved with a GOTO command, after having calibrated the image via plate solving. Be sure that the plate parameters in

the Find Coordinates window are correctly set.

6.5 Autoguide introduction

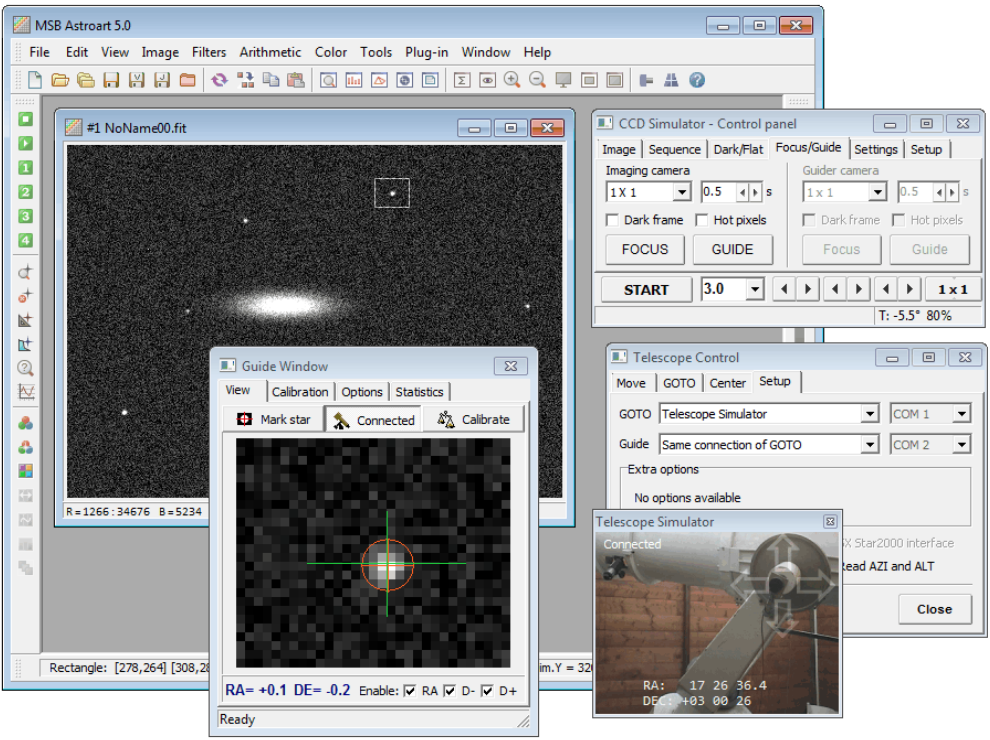
If you follow a star with your telescope at high magnification, you will notice that the position of the star changes. This movement is caused by three reasons:

- A poor polar alignment which causes a slow drift in declination.
- The periodic error in the mount's tracking, this error results from gears that are slightly out of round. Some mounts have a built-in periodic error corrector called **PEC**.
- The random errors due to many causes as dirt, dents and variations in the gears.

These problems do not permit to take long exposures with the camera. Actually if the mount is sufficiently precise to allow correct exposures of 1 minute, the autoguide is usually not needed, it's more productive to take a Sequence and to stack the images later.

Autoguide tutorial

To quickly understand how the camera and telescope work together during an autoguide session, try this step by step tutorial.



1. Inside the Setup page of the camera control panel, select "SIMULATOR" as main camera and click "SETUP" to connect it.
2. Click on "Telescope ..", select "Telescope Simulator" as protocol, and click "Connect".
3. Close the main Telescope Window, but don't close the Simulator window.
4. Click "START" to start an exposure of 3 seconds.
5. Draw a small rectangle around a bright star and click "Guide" in the Focus/Guide page.
6. Click "Mark star" inside the Guide Window. The telescope simulator will now guide on the reference star and the pulses will be shown with red arrows.
7. Try to pause the autoguide: you may disconnect the telescope, clicking the button "Connect Telescope" or deselect the options "RA", "D-", "D+". Verify that the star slowly drifts away.

Let's repeat the procedure using the *Guider Simulator* (the secondary camera). During the guide, we will start a long exposure with the Camera simulator and verify that both virtual cameras work at the same time.

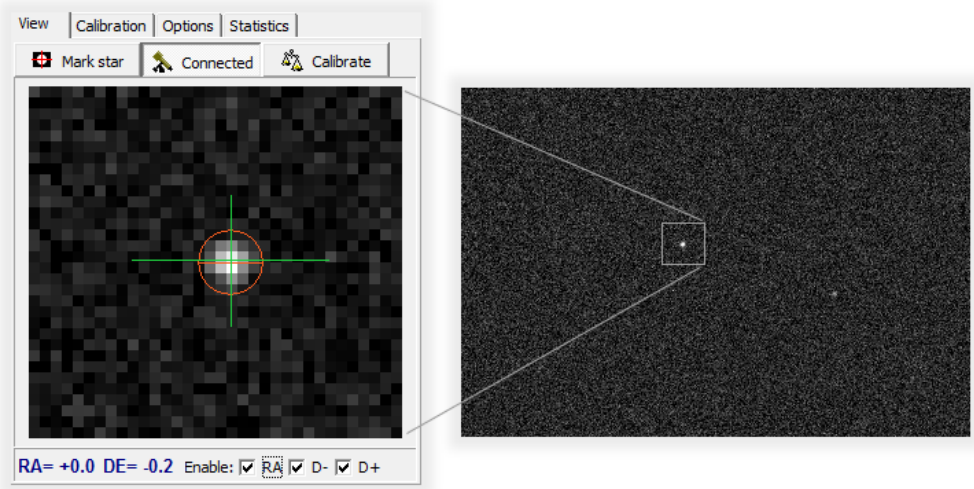
1. Close the Guide Window.
2. Go to the Setup page (Guider camera) to connect the Guider Simulator.
3. Click "Guide" (second camera) in the Focus/Guide page to take a full exposure with the guider camera.
4. Select a rectangle around a star and repeat the procedure above from point (6). During the guide, start a long exposure with the main camera.

6.6 Autoguide

Autoguide means to use a secondary camera to correct the tracking of the telescope as explained in the previous paragraph. Four methods are possible with Astroart (the dithering commands are supported for all).

Method 1 - Two cameras using subframe mode

1. Go to the Focus/Guide page and select an exposure time. A typical time is between 0.1 and 4 seconds. Usually you will need to change the binning from 1x1 to 2x2 or more, since you should aim for stars with a diameter of 2 - 4 pixels, which are the best compromise between S/N and precision.
2. Click the "Guide" button to download a full frame from the guider camera, then draw a rectangle around the best star. Click again the Guide button to open the Guide Window.



3. The star will appear in the Guide Window. Click on the "Mark Star" button: a green cross will mark the initial position of the guide star, while a red marker will follow the star while it shifts from the original position.
4. If needed, click on the "Connect telescope" button to activate the telescope and to start sending pulses. If needed, enable all the options "RA" , "D+" , "D-".

Method 2 - Two cameras using full-frame mode

This is a new mode released with Astroart 7 SP4. The most important feature is the autoguide on multiple stars, with automatic exposure time. See the next chapter for more details.

Method 3 - PHD Guiding

The only option to configure in Astroart, if needed, is the dithering in the Sequence page. Inside PHD it's recommended to set "Spiral mode" for dithering. A complete communication is also possible via scripts.

Method 4 - Two Astroart sessions

This is useful only for autoguiding for a long time (several hours) on the same subject. The second session could be minimized and "forgotten". If you like, you may connect the guide camera as "primary camera" in the second session of Astroart.

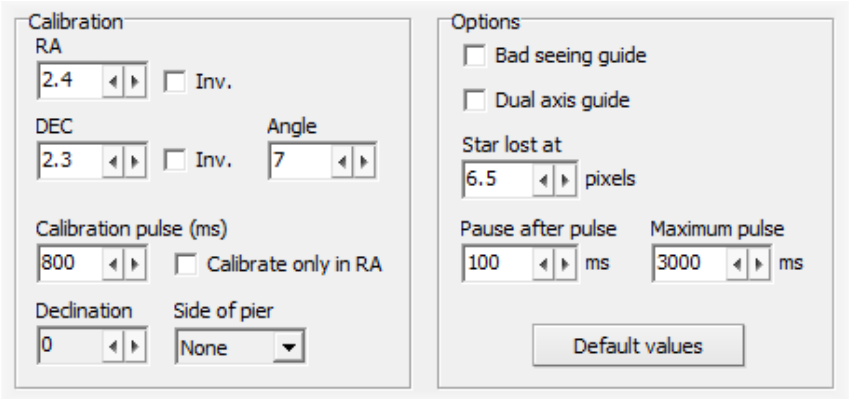
Calibration

A guide system requires at least three parameters: apparent speed in RA, apparent speed in DEC and rotation angle. The speed (measured in pixels per second) is "apparent" since it depends on the size of the pixels and the binning factor. To measure the speed and the angle, it's usually available an automatic procedure called "calibration". In Astroart just click the button "Calibrate".

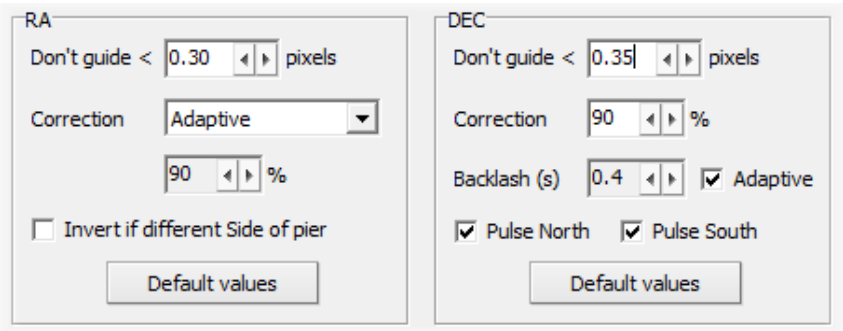
The apparent speed should be not too slow nor too fast, the best range is between 2 and 5 pixels per second. If the speed is too slow, then the guide pulses will be too long and this will decrease the frame rate so the "efficiency" of the exposure time. If the speed is too fast then the guide pulses will be too short (milliseconds) and they will not be precise.

The apparent telescope speed and angle could be measured also by hand: move the telescope with the keypad for one second and measure how many pixels the image moves. The *angle* is the rotation of the camera relative to the equatorial axes.

In the figure below, the Calibration box is filled automatically during the calibration procedure. If needed it's possible to set the length of the calibration pulses and the option to calibrate only in RA.



To completely define a guiding system another value is needed: the distance (in pixels) from the reference position where the star is free to move without corrections (sometimes called "minimum movement"). This "*Don't guide zone*" for RA and Dec, is shown in the next figure. This value is needed to prevent unwanted corrections caused by the seeing. 0.30 pixels is a good compromise between precision and rejection of noise. Values lower than 0.30 should be used only on a short focal length.



Reusing the calibration

Usually it's possible to reuse the calibration for a long time. Two issues may prevent this: the "side of pier" of german mounts and the "Cos(dec)" factor. To solve the first problem you may use the option "*Invert if different Side of pier*". This option must be enabled before launching the Calibration so that the original "side of pier" is saved in the Calibration box. It's supported only on ASCOM mounts.

The "Cos(dec)" effect slows down the apparent speed in RA at high declination. To address this problem there are two schools of though, both supported by Astroart:

1. Do a calibration at Dec 0, then multiply all pulses by 1/Cos(dec) to compensate the problem. This seems natural but it's not without risks: increasing the pulses will slow down the frame rate, and if the seeing become worse there's the risk to oscillate on long pulses. In Astroart the calibration can be done at any Dec, the original value will be saved in the Calibration box.
2. Do a calibration at Dec 0, then ignore the problem. At high declination the guide will be less aggressive, for example at Dec 60 every pulse will correct half of the error. BUT: at high declination the telescope tracking is much more precise by itself, all defects are attenuated, so the result image may have the same quality of one guided at low declination.

These options are available in the "Correction" field inside the RA box. Astroart uses by default an in-between method ("Adaptive") which detects in realtime if the RA guide is too lazy or too aggressive and then adjusts it.

Options

Correction. Sometimes called "aggressivity", it's the percentage of the correction that it's actually sent to the mount. Usually 90% is a good value. This value is linked with the "Don't guide zone", in some cases it's possible to decrease the zone and then decrease the correction so that pulses sent on random seeing don't cause oscillations.

DEC backlash. Backlash may be a problem when the declination motor changes its direction. By default Astroart compensate automatically the DEC backlash unless you set a specific time compensation in seconds. In this case be careful! Backlash corrections should be always under-compensated, an over compensation will cause an overshoot. In RA backlash is never a problem.

Pulse North and South. If needed it's possible to disable one of the pulses, for example if you know in advance the direction of the declination drift. This will prevent all problems caused by backlash.

Calibration pulse. The duration of the pulses during the calibration. The default value of 800 ms is usually good, by the way it's recommended to increase to 1200 ms or more it if the guide scope has a very short focal length and to decrease it to 500 ms for some active optics models.

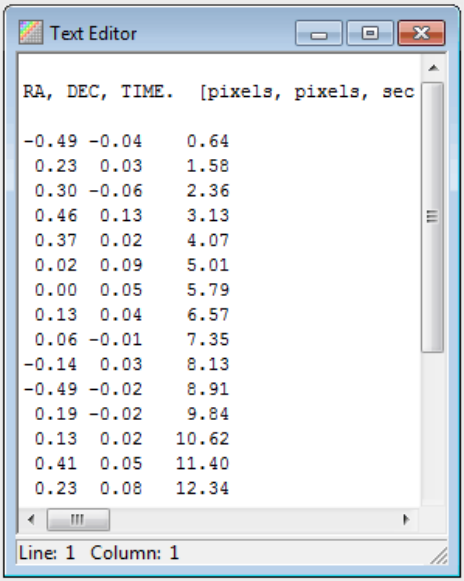
Bad seeing guide. A special mode for extreme conditions (bad seeing, wind), it’s not recommended for normal guide.

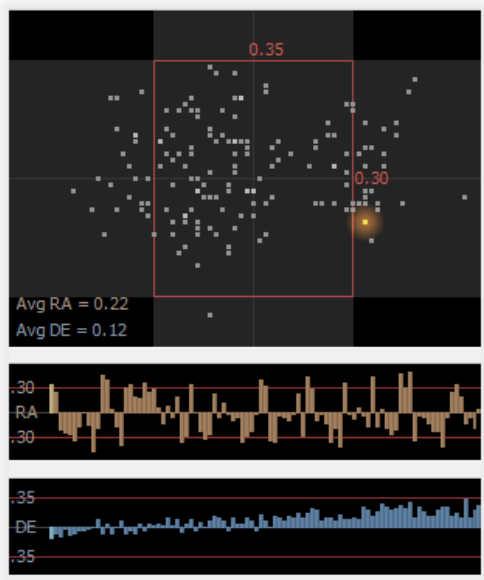
Dual axis guide. If enabled, Astroart drives the telescope with two axes at a time. For equatorial mounts this option is usually not required because the DEC axis changes very slow depending the precision of the polar alignment, while fast DEC movements (wind, bad seeing) should be ignored.

Star lost at. This value is just for safety: if the stars drifts away so far, then the guide will be paused and the problem will be notified.

Guide on slit for spectroscopy. This option is used to force the reference position to a given X and Y coordinates, to allow spectroscopy during autoguide. The reference position can be changed in real time clicking on the 8 sectors near the border of the image. Press SHIFT+click to move by 0.5 pixels and SHIFT+CTRL+click to move by 0.1 pixels. For more information see the PDF tutorial available at the Astroart forum (search for: Guiding a star on spectroscope slit).

The Guide Window can be used as a recorder to measure the dX and dY errors of the mount (left image). These values can the be copied and pasted into a text file.





The image on the right shows the statistics of an actual autoguide for a "Don't guide zone" of 0.30 x 0.35 pixels. Click the right mouse button for the context menu. Rotate the mouse wheel to zoom in and out the graphs. The linear graphs can be panned left-right clicking the left mouse button.

Possible problems

If the system does not guide well, watch the behaviour of the star, this will reveal where the problem is, since only 4 scenarios are possible:

- **Overcorrection**. The system is much faster than expected, so every correction brings the star beyond the center. This could be a software problem (calibration not precise) or hardware (guide speed too fast, the best setting is between 0.3 X - 0.7 X sideral). If you see long series of oscillations there could be an overcorrection problem or the "Don't guide zone" is too small for the seeing.
- **Undercorrection**. The guide is "lazy" and the star is brought to the center too slowly. This can also mean that the pulses are not reaching the telescope at all.
- **Wrong direction**. After a few pulses the star is brought away from the center. The direction of one of the axis must be inverted. Enable the option"Inv. X" or the option "Inv. Y".
- **Extreme speed**. The star disappears at the first pulse. Probably the telescope was not configured for guide speed, see the "Move" page of the Astroart Telescope Window, or check if some settings are required in the hardware or in the ASCOM driver.

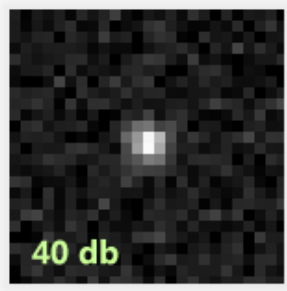
6.7 Autoguide full-frame

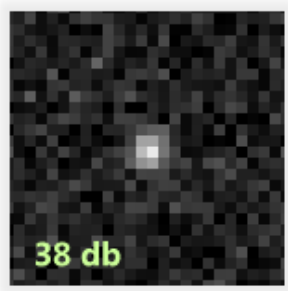
Astroart 7 SP4 contains a new full-frame autoguide, with the additional features:

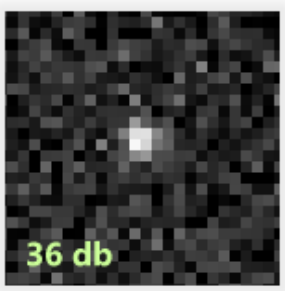
- Usage of all stars. If several "good" stars are present in the field, then those stars are used to autoguide, just like when stacking a sequence of images.
- Automatic exposure time. If the star is too faint, then the exposure time is increased to an optimal value. If the star is too bright then the exposure time is decreased.

What is a "good" autoguide star? The classic S/N Ratio was not optimal to define it, the reason is that in amateur astronomy the strongest source of noise is light pollution, which is not included in the formula of the classic S/N.

For this reason a new metric, based on PSNR was used. The noise is now measured directly on the image, so all contributions (light pollution, thermal current, readout noise) are evaluated at the same time. The PSNR is usually defined in decibel, e.g. 20 Log(Signal / Noise) here is an example for three stars:



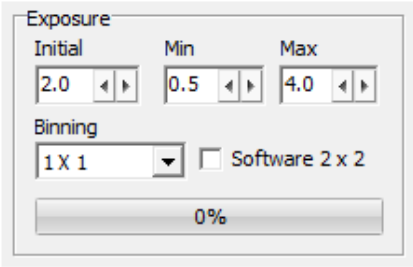


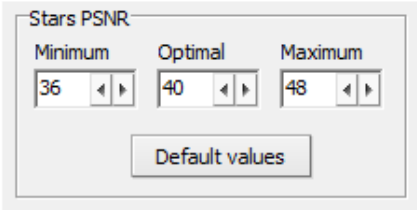


For more information about PSNR see this internet search: www.google.com/search?q=image+psnr

Automatic exposure time

The exposure time is controlled by three *Time values* and three *PSNR values:*



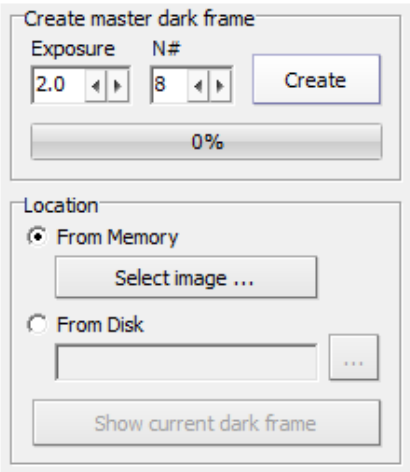


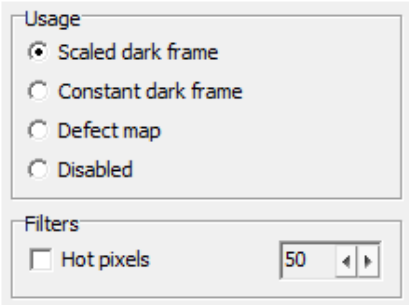
At first an exposure of **Initial** seconds is taken. If no stars have an **Optimal PSNR** then the exposure time is increased to achieve that optimal PSNR, obviously the increment is limited by the **Max** exposure time. Then another exposure is taken, if no star has at least the **Minimum PSNR**, then the procedure is declared failed and it's terminated.

For those rare cases where the star is too bright, so it's brighter than the **Maximum PSNR**, the exposure time is decreased to reach again the Maximum PSNR, but not less that the **Min** exposure time, this prevents blooming and gives a better frame rate to the autoguide.

Scaled dark frames

If the camera needs dark frames, the variable exposure time poses a problem, how to correct it? To solve, a new scaled dark frame algorithm was created and it's active by default. The first step of a good dark frame correction is the creation of a master dark frame, averaging several exposures:





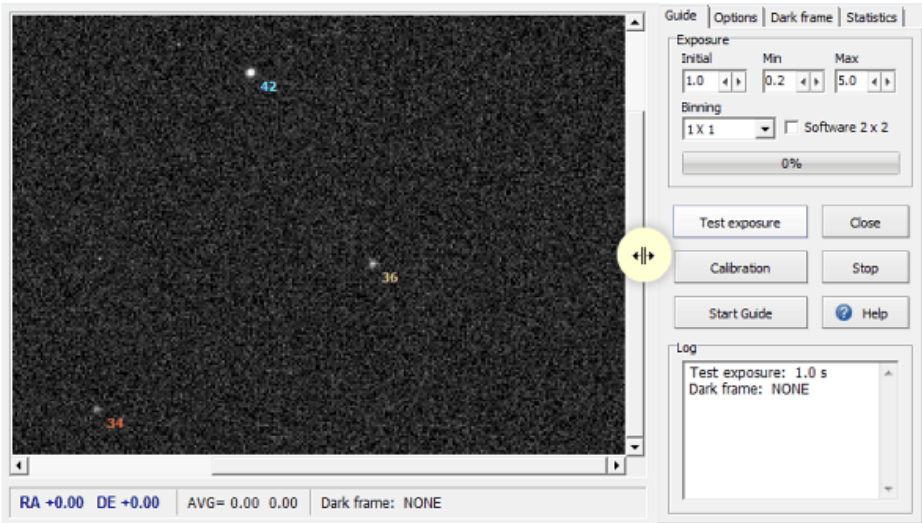
when the procedure is finished, it's possible to click the button "Show current dark

frame" to save it to disk for later use. If the noise is caused mainly by hot pixels, then the dark frame could be used as a defect map or completely replaced by the Hot pixel filter.

A last word about autoguide stars: for best results the stars should have a width of 2 - 5 pixels, not more. This is the best compromise between S/N and centroid precision. This means that on some cameras binning 2x2 or more should be used. If the camera does not support it, then enable the extra *software binning 2x2*.

Usage

At first connect the two cameras and the telescope, you may practice indoor with the camera, guider and telescope simulator. Then go to the Focus/Guide page and click the button "FF.Guide" to open the full frame autoguide window:



Click "Test exposure" to download a first image from the camera, the PSNR of detected stars will be shown. If needed increase the Binning factor to achieve stars of 2 - 5 pixels. If you need to calibrate press "Calibration". About all the parameters and the calibration see the chapter about autoguide.

To change the zoom of the image, right click for the context menu, or use the same mouse commands of the Image Window. To enlarge the Statistics, just place the mouse between the image and the panel and drag left-right.

Script commands

The new script functions for controlling the full-frame autoguide are:

Guider.FullFrameAutoguide() Guider.AutoguideStatus() Guider.Calibrate() Guider.CalibrationOK()

The command AutoguideStatus returns a string, which indicates the Status ("Guiding", "Calibrating", "Stopped", etc). To wait for settling just make a loop until

the status is "Guiding". The command "Calibrate" start the calibration, but does not return a result, use the command CalibrationOK() to verify.

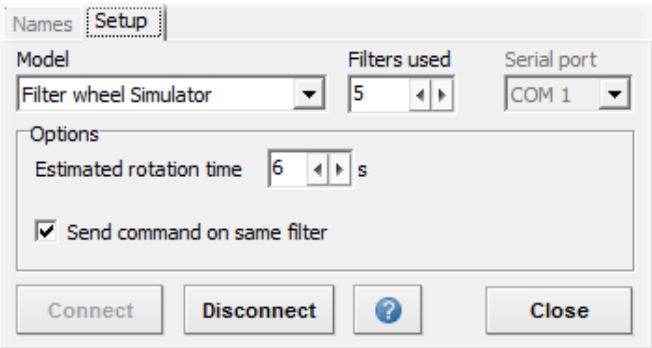
All the other commands for subframe autoguide (Guider.Close(), Guider.WaitStar(), etc.) remain valid also for the full-frame autoguide.

7 Other devices

To open the control panel for filter wheels, focusers and rotators use the buttons in the Setup Page of the camera control panel.

7.1 Filter wheel

To open this window click the button "F. Wheel" in the Setup Page of then Camera Control. Select the model, the number of filters used, and click on "Connect".



Model. Select the model, nowadays most wheels are ASCOM compatible. To make indoor tests use the Simulator.

Filters used. You may set how many filter are effectively used, or just set the total number of positions for your wheel.

Serial port. If your filter wheel is controlled via the serial port, select here which port you are using.

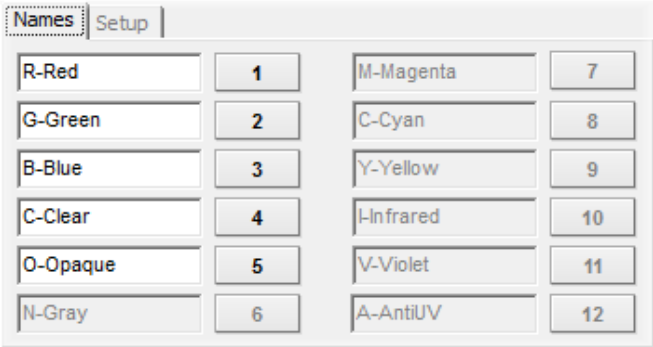
Estimated rotation time. This value is used for those wheels which have no feedback on their position: the value will be used as a pause for completing the rotation. For most ASCOM wheels it's not needed. However it has also another purpose: in the Sequencer, it's used to estimate the total time required to complete a sequence.

Send command on same filter. If enabled, Astroart sends the "go" command to the filter wheel also when the correct filter is in position yet.

Filter names

From this page you may set the filter names. The first letter identifies the filter in scripts, so it must be unique. For this reason you may use the syntax "Character -

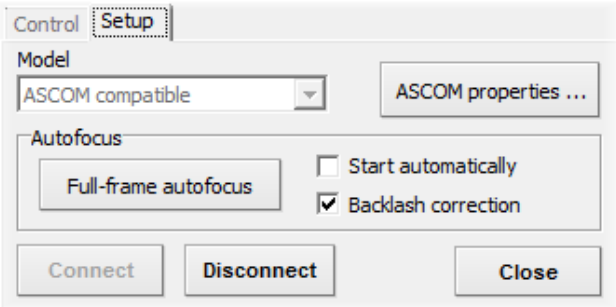
Name" as in the following figure, but it's not mandatory. Both "G-Green" and "Green" are acceptable.



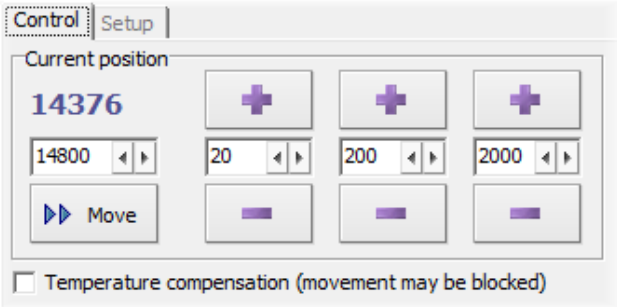
Buttons. Click a button to move the wheel to that position. The wheel can also be moved by the button in the Image page, by sequences and by scripts.

7.2 Focuser

To connect the focuser select "ASCOM" as model and click Connect. For indoor practice and to test your scripts you may connect the Simulator. The analogic focuser of the LX200 can be used for manual focus and it's available only in the Focus Window (subframe).



Software backlash correction. If enabled, the focuser always moves in the same direction (+) during the steps of autofocus. If your focuser has an integrated backlash correction (most focuser have) you may not enable this option, which slightly slows down the procedure.



In the "Control" page you may move the focuser to a given position. The option " **Temperature compensation**" enables that function if available in hardware, by the way on some focusers it blocks all movements and control.

Autofocus

This procedure finds automatically the best focus position. Two procedures are available: "subframe" where a single star is measured, and "full frame" where several stars are measured at a time. Both methods share some options:

Positions. The number of positions to find the best focus. Usually it's an odd number. For example, if you set "7" the program will search: three positions back, the current one, and three ahead.

Step. The step between positions, this value depends by the range of your focuser (some have a range 0..5000 up to 0..50000). Usually 1/500 of the range is a good starting value. The best value is the one which gives slightly defocused stars at the extreme positions.

Binning. The binning mode when taking focus images. If possible set a value which gives focused stars of 3-4 pixels, this will optimize the S/N ratio and the download time.

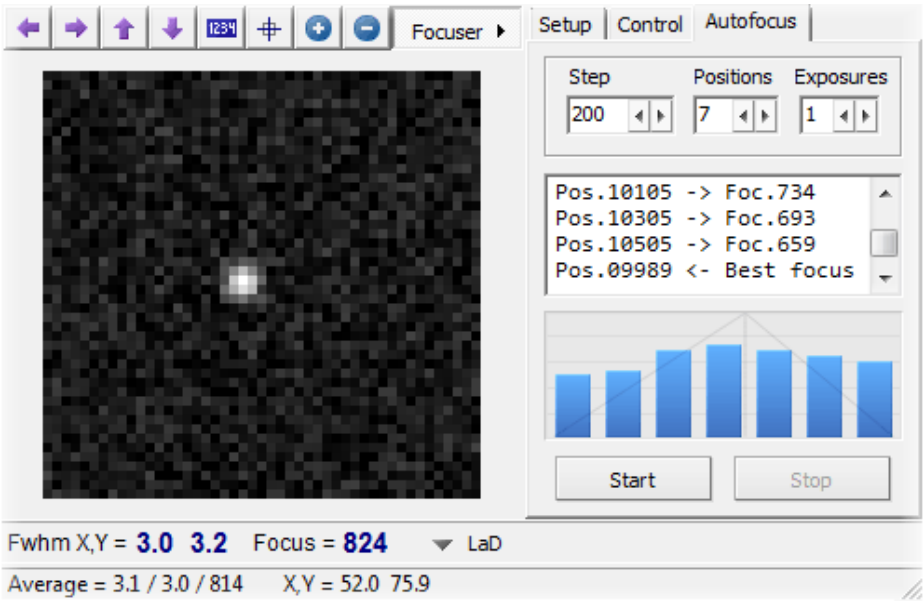
Method. The algorithm to estimate the focus from the star. If you know in advance that for a good focus you can get stars of 2-5 pixels (i.e. setting an higher binning) then the method "Small disc" is usually the best. For slightly bigger stars (5..8 pixels), use the method "Large disc". If you prefer a generic algorithm then it's also available the FWHM (full width half maximum) and the HFD (half flux diameter, see: Wikipedia). Since the best method depends on your instrumentation, a quick initial test with all methods is recommended. Every focus method produces a measure from 0 to 1000, which is relative, and cannot be used to compare methods.

The subframe focus window contains two extra methods to focus, one for the Bahtinov Mask on a bright star, see Wikipedia, and one for a spectrum reference line, where the width of the line is used to estimate focus.

Exposures. How many exposures per position. This is used only in the "subframe" procedure when the seeing is not good. If the seeing is good, choose a value from 1 to 3, if it's bad, 3 to 5.

Autofocus (subframe)

This procedure is available in the Focus Window. It's recommended only at the beginning of a session, when the focus is unknown and a bright star is used for focusing. The exposure time is usually quite short (0.05 - 2 seconds) and the star is chosen manually.

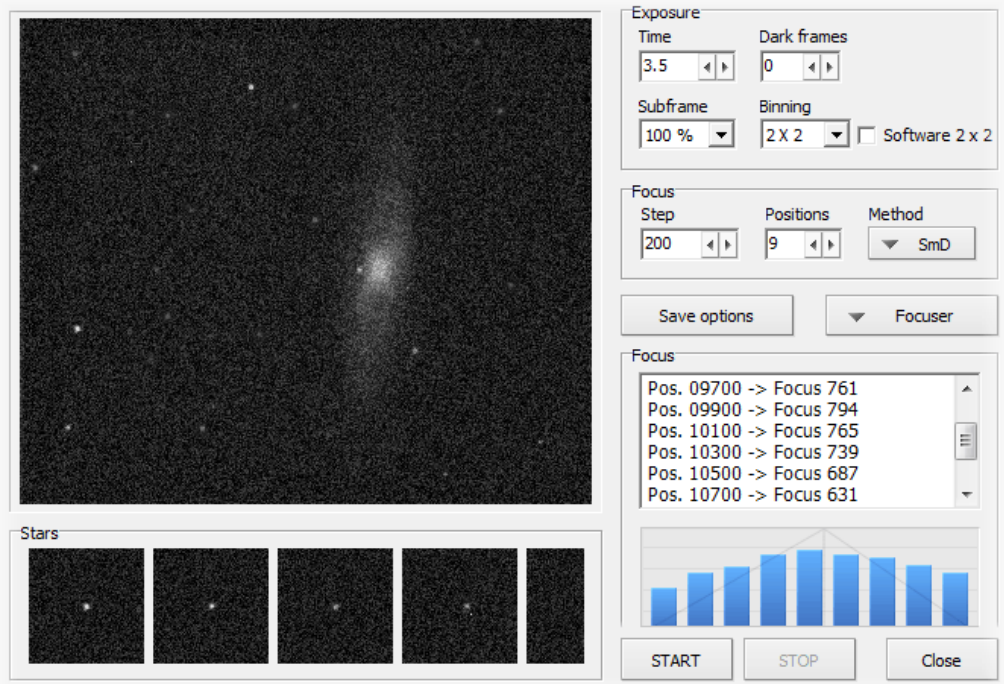


Click the arrow button near the "Focus" parameter to change the algorithm, then "Start" to launch the procedure. For every step the measure will be shown as text and graphics. At the end the focuser will be moved to the best position (calculated).

Autofocus (fullframe)

This is the procedure to be used when you are focusing on the same field of the object. The typical exposure time is usually higher, for example 2 - 8 seconds. To improve the S/N and the download time, it's recommended to work with a high binning, to obtain stars of 3 - 5 pixels if possible. If your camera is unable to do so, you may enable the further "software binning 2x2".

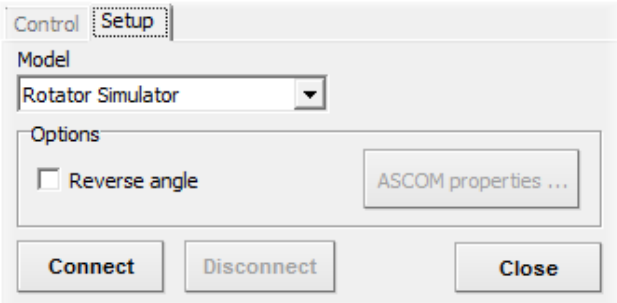
If you are using a extremely large CCD with *coma* at the borders, you may exclude the borders decreasing the "Subframe" value from 100% to 90-80%.



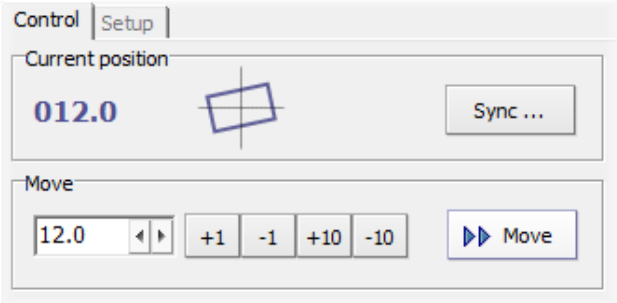
This autofocus procedure can be launched by Scripts with the command "Camera. FullframeAutofocus", and can be launched automatically by the Sequencer. If no stars are found during the procedure, the original focuser position will be restored.

7.3 Rotator

In the past these devices were called "derotators" and were used on altazimuthal mounts. Nowadays they are used on equatorial mounts to easily rotate the camera to a given position, this is the purpose of this command.



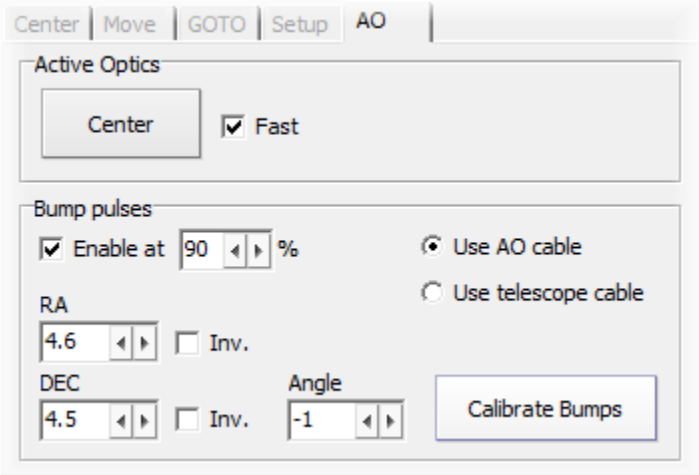
To connect the rotator, select the Model and click Connect.



In the "Control" page the current position of the rotator will be shown. Press "Sync" to set the angle (without moving the rotator) to a given reference, manual or calculated from a plate-solved image. To move the rotator, use the button in the section "Move". If the rotator moves in the wrong direction, enable the option "Reverse angle" in the Setup page.

7.4 Active Optics

Active optics are managed as "Guide devices" of the Telescope Window. Once selected, a new page will be shown with the following options:



Click the "Center" button to move the prism or the mirror of the AO to the middle position. Some models do support a faster mode.

Bump pulses

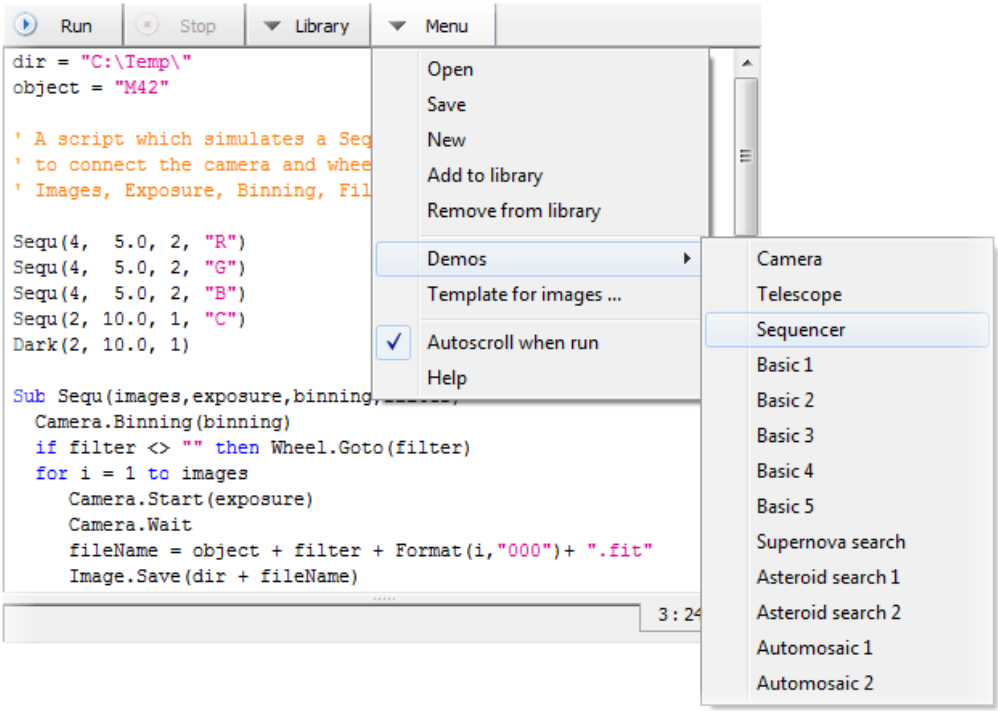
These are very small pulses that can be sent to the mount to avoid reaching the limits of the AO, which can happen in DEC if the polar alignment is not perfect, or in RA if the periodic error of the mount is too high. These pulses can be sent via a dedicated autoguide cable from the AO to the mount, or just using the main connection with the telescope (ASCOM, USB, serial port, etc.).

These pulses need to be calibrated, it's required to measure the apparent speed in RA and DEC and the rotation of the AO. The procedure ("Calibration") is described in the chapter about Autoguide.

8 Scripts

A script is a list of commands which are executed in sequence. Using scripts it's possible to perform complex tasks, like supernova and asteroid search.

The script language of Astroart is based on BASIC, see: en.wikipedia.org/wiki/Basic



Try this example after having connected the Camera Simulator:

```
Camera.Start(10)
Camera.Wait
Image.Save("C:\Temp\sample.fit")
```

The first command starts a 10 seconds exposure, the second command waits until the end of the exposure, the last command saves the image. To learn the script features, try indoor all the demos available in the Menu: all simulators will be connected automatically. Take a look also at the *Script* section of the Astroart Forum.

Library. Once you have written your scripts you may add them to the Library menu, so that they are accessible with a simple click.

Template for images. This command asks you to select a list of files, then creates a template for analyzing or processing them.

Undo. To undo the last changes to the script, right click on the editor for the context menu.

8.1 Script Types and Variables

Four types are supported: **numbers** , **strings** , **booleans** and **arrays**. A numeric variable contains a number, a string variable contains some text, a boolean is "true" or "false".

Numeric variables

They contain a number. The number is internally represented by a floating point value with double precision (64 bit, 15 digits). Example:

```
x = 10.5

y = x + 1
```

String variables

A string variable contains text. This text may be a single row or a multi-line text. The maximum size is 64 MByte. You may append the dollar sign ($) to the variable name to remember that it contains a string.

```
a = "Hello"

b = a + "World"
```

The variable **b** now contains the string "HelloWorld".

A single character of a string can be read using square brackets: referring to the previous example **a[1]** returns "H" and **a[2]** returns "e" and so on. If the index exceeds the length of the string then it restarts from the beginning, so **a[6]** returns "H".

A single row of a multi-line string can be read using curly brackets. Example, if **a** contains:

```
"This is a

text placed on

three rows"
```

Then **a{2}** returns "text placed on". The function **count(a)** returns how many lines are contained in a multi-line string (3 in our example).

Boolean variables

A boolean can have only two values: *true* and *false*.

b = false

b = 5 > 2 ; b now contains true, try now: "print b"

Booleans are type-compatible with numbers. Just like in most languages, zero means "false" and every non-zero means "true". The following instructions have the same meaning:

if b then print ... / ... **if b = true then print** ... / ... **if b = 1 then print** ...

Array variables

An array is a list of values, for example:

dim a = {1, 99, "Hello", 42} ... / ... **dim b(4)**

every element of the array can be accessed using brackets, for example: **print a (4)** . The index starts at 1, and ends at 4 in the previous example. The last index can be found with the standard function: **UBound(a)**. Arrays can be passed and returned from functions.

Reserved words

The following words are reserved and cannot be used as variables names (see the documentation available for VBScript, Visual Basic or any other BASIC compiler):

IF THEN ELSE OR AND NOT MOD REM FOR NEXT STEP EXIT BREAK CONTINUE WHILE GOTO GOSUB PRINT INPUT END SUB FUNCTION CLS DIM

Comments

To write a comment into a script use the symbol " **'** ", example:

' This is a comment

8.2 Script Functions

USER DEFINED FUNCTIONS

User defined functions (subroutines) can be defined everywhere within a script, using the keyword "Sub" or "Function":

```
sub PrintSum(a,b)
  print a+b
end sub
```

User subroutines can return one or two values, so actually they are "functions":

```
function mySum(a,b,c)
  return a+b+c
end function
print "the sum is: "; mySum(4,6,2)
```

another example:

```
sub PolToRect(r,a)
  return r*cos(a),r*sin(a)
end sub
x,y = PolToRect(10,pi/4)
```

The following example calculates ra and dec at south, for parking.

```
myLon = 12.5 : myLat = +45
ra,de = AltazToEquat(180,+5,myLon,myLat)
```

See also: Demo scripts

LIBRARY FUNCTIONS

Most of these function are standard in the Basic language, so it's possible to find more information with an internet search: <*function name*> BASIC, for example: "ucase basic". See also the demo scripts in the menu of the Script Window.

Numeric functions

PI() Sin(n) Cos(n) Tan(n) Exp(n) Ln(n) Log10(n) Log2(n) Sqr(n) Abs(n) Rnd([n]) Sgn(n) Fix(n) Int(n) Round(n[,n]) Frac(n) ASin(n) ACos(n) ATan(n) ATan2(n,n) Sinh(n) Cosh(n) Tanh(n) ASinh(n) ACosh(n) ATanh(n) DegToRad(n) RadToDeg(n) Modulo(n,n)

String functions

Len(s) Val(s) Asc(s) UCase(s) LCase(s) LTrim(s) RTrim(s) Chr(s) Str(n) Mid(s,n,n) Hex(n) Left(s,n) Right(s,n) LTab(s,n) RTab(s,n) Instr([n],s,s) InstrRev(s,s,[n]) Format(s,n) Crlf() OpenText(sfile) SaveText(s,sfile) AppendText(s,sfile) CopyText(s) PasteText()

Other functions

Pause(n) Speak(s) Beep() CreateDir() FindDirs(s,s) FindFiles(s,s) IsNumber(var) IsString(var) IsBoolean(var) IsArray(var)

Time and Coordinate functions

JD() Time() Date() UTDateTime([jd]) SideralTime(lon,[jd]) DateToJD(y,m,d) JDToDate(jd) LTBias() Culmination(ra,de,lon,lat,[jd]) EquatToAltaz(ra,de,lon,lat,[jd]) AltazToEquat(azi,alt,lon,lat,[jd]) PrecessionJ2000(ra,de) PrecessionJNow(ra,de) Precession(jdFrom,jdTo,ra,de) RA(n) DEC(n) DistanceFromMoon(ra,de) DistanceFromSun(ra,de) DistanceEquat(ra1,de1,ra2,de2) SunRaDec(jd) MoonRaDec(jd) ObjectCoordinates(name) ObjectMagnitude(name) Observatory.Longitude Observatory.Latitude

Camera functions

`Camera.Start(`time,[shutter]**`)`**

Starts an exposure of <time> seconds. Set <shutter> to zero to integrate a dark frame. Example: `Camera.Start(30,0)` takes a dark frame of 30 seconds.

`Camera.Wait`

Waits until the end of the exposure.

`Camera.Exposing`

Returns the boolean "true" if a exposure is in progress, otherwise "false".

`Camera.Binning(`mode**`)`** **`Guider.Binning(`**mode**`)`**

Sets the binning mode. <mode> is a index to the binning list in the Settings Page of the Camera Panel. Example: `Camera.Binning(2)`

`Camera.Subframe(w,h,x,y)`

Sets a subframe for future exposures. All number are expressed as percentage. The example sets a subframe of half size (50%) shifted by 25% so that it's centered on the CCD: `Camera.Subframe(50,50,25,25)`

`Camera.Connect(`[driver]**`)`** **`Guider.Connect(`**[driver]**`)`** **`Camera.Disconnect`**

Connects or disconnects the camera. Disconnecting the main camera disconnect also the guider. Example: `Camera.Connect()` `Camera.Connect("Simulator")`

`Camera.Connected` **`Guider.Connected`**

Checks the camera connection and returns *true* or *false*.

`Camera.SelectDarkFrame` **`Camera.EnableDarkFrame(`**enable**`)`**

Select the current image as dark frame and enables the correction for the following images.

`Camera.Stop` **`Guider.Stop`** **`Guider.Close`**

Stops the current exposure or an autoguide session (some cameras are not able to stop an exposure).

`Camera.GetTemperature` **`Guider.GetTemperature`**

Returns the current temperature of the CCD.

`Camera.SetTemperature(`t,[power]**`)`** **`Guider.SetTemperature(`**t,[power]**`)`**

Sets the temperature and starts cooling. It's also possible to set the power of the cooler (0..100%).

`Guider.SetExposureTime(`time**`)`**

Sets the exposure time used for autoguide (maximum 3 seconds).

`Camera` / **`Guider.StartAutoguide(...)`** () - (r) - (r,x,y) - (r,snrel) - (r,snrel, satmax,expo)

Starts an autoguided session. It's possible use some parameters to select the radius of the subframe and its coordinates, otherwise this command takes a sample image and selects

automatically the best star. It's possible to define a minimum relative S/N for that star, (default = 1.0), a maximum saturation value and the exposure time. Example: `g = Camera.StartAutoguide() : if g then` [.. star found and autoguide active]

`Camera` / `Guider.StopAutoguide()`

Stops an autoguide session.

`Camera.FullframeAutofocus(...)` (time) - (time,darks,count,step,binning)

Starts a full frame autofocus. Example: `Camera.FullframeAutofocus(5)` starts focusing with an exposure of 5 seconds, using the parameters saved previously in the autofocus window.

`Camera.Autofocus(...)` () - (r) - (r,x,y) - (r,snrel) - (r,snrel,satmax,expo)

Starts a subframe autofocus session. The parameters are the same of the function StartAutoguide().

`Guider.ShortExposure`

Starts a full frame short exposure with the guider camera.

`Guider.WaitStar`

Stops the script until the guide star is returned to the central position.

`Guider.LostStar`

Returns *true* if it's not possible to center the guide star.

`Guider.MoveReference(`[dx,dy]**`)`**

Changes the x and y coordinates of the reference star, to perform the "dithered guide". If dx and dy are not specified then the shift will be pseudo-random.

`Guider.FullFrameAutoguide`

Starts a full-frame autoguide sessions.

`Guider.AutoguideStatus`

Returns the full-frame autoguide status as a string ("Guiding", "Calibrating", "Stopped", etc). To wait for settling just make a loop until the status is "Guiding".

`Guider.Calibrate` `Guider.CalibrationOK`

Starts the full-frame calibration and blocks the script until done. Use the command CalibrationOK to check for the result.

`GuideLog.Text`

Returns the log file of the guide window as a string.

Telescope functions

`Telescope.Connect` `Telescope.Disconnect` `Telescope.Connected`

Connects or disconnect the telescope.

`Telescope.Ra` `Telescope.Dec` `Telescope.RaDec`

Returns the current coordinates of the telescope. Example: `ra,de = Telescope.RaDec`

Telescope.Goto(ra,dec**)**

Moves the telescope to the equatorial coordinates: ra (0..24), dec. (-90..+90). Example: `Telescope.Goto(23.4, 45.1)`

Telescope.Wait([ra,dec,delta]**)**

Waits until the telescope has completed a Goto. On some telescopes the base function `Telescope.Wait()` is not supported, so you may use the syntax: `Telescope.wait(ra, dec,delta)` which waits until the telescope is arrived at coordinates *ra,dec*, with a precision of *delta* degrees, for example 0.005 for a few arcseconds. Then in the script add a `Pause()` to wait a few seconds.

Telescope.Pulse(dir [,time]**)**

Moves the telescope for <time> seconds towards the <dir> direction ("N","S", "E","W"). If <time> is negative then the direction is inverted. If <time> is omitted, it moves until the Telescope.Stop command. Example: `Telescope.Pulse("N", 0.5)`

Telescope.SyncTo(ra,dec**)**

Sets the telescope internal coordinates.

Telescope.Stop

Stops the telescope.

Telescope.Speed(n**)**

Sets the speed for Pulse motion. (1=guide, 2=center, 3=find, 4=slew). It's not supported by all telescopes.

Telescope.Send(string**)** **Telescope.Receive**

Sends and receives a string to the telescope via the serial port. Example: `Telescope.Send("#Hc#") : R = Telescope.Receive`

Telescope.Park **Telescope.Unpark**

Parks/Unparks the telescope. They work only with GOTO or ASCOM protocol.

Telescope.StartTracking **Telescope.StopTracking** **Telescope.Tracking**

Starts/Stops/Reads the sideral tracking. They work only with GOTO and ASCOM protocol.

Telescope.AOCenter

Sets the Adaptive Optics mirror/prism to the central position.

Telescope.List.Open(file**)** **Telescope.List.Save(**file**)**

Opens or saves a text file which contains objects and coordinates. See the Telescope Goto window.

Telescope.List.Count

Returns how many objects are listed in the list.

Telescope.List.Ra(index**)** **.Dec(**index**)** **.Name(**index**)** **.Comment(**index**)**

Returns a field of the i-th object of the list.

Telescope.List.Sort

Sorts the list, using a compromise between a shortest path algorithm and a increasing RA algorithm.

Telescope.List.Delete(index**)** **Telescope.List.Clear**

Deletes objects from the list.

Filter wheel functions

Wheel.Connect **Wheel.Disconnect** **Wheel.Connected**

Connects or disconnects the filter wheel.

Wheel.Filters

Returns the number of filters of the filter wheel.

Wheel.Goto(n**)** **Wheel.Goto(**filter**)**

Moves the filter wheel to the given filter. Examples: `Wheel.Goto(4)` , `Wheel.Goto("R")`

Wheel.Wait

Wait until the movement is complete. On wheels which don't support this feature a time in seconds will be used. See the Filter wheel window.

Wheel.Position **Wheel.PositionName**

Return the number or the name of the current filter.

Focuser functions

Focuser.Connect **Focuser.Disconnect** **Focuser.Connected**
Focuser.ConnectASCOM

Connects or disconnects the focuser.

Focuser.Position

Returns the current position.

Focuser.GotoAbsolute(n**)**

Moves the focuser to a given position.

Focuser.GotoRelative(delta**)**

Moves the focuser up or down by a specified amount. Example: `Focuser.GotoRelative(-50)`

Focuser.Wait

Waits until the movement is complete.

Focuser.IsMoving

Returns *true* if the focuser is moving.

Focuser.Temperature

Returns the temperature, it could be used as ambient temperature.

Dome functions

`Dome.Connect` `Dome.Disconnect` `Dome.Connected`

These functions are intended for connection with the ASCOM *hubs*, for example "POTH" or "DeviceHub", where the movement of the dome is controlled by ASCOM. Your scripts will just open or close the window, or park the dome. Example:

Dome.Connect("ASCOM.DeviceHub.Dome") , Dome.Connect("POTH.Dome") , Dome.Connect("Simulator")

By the way, if your dome is fixed and you only need to open and close it, you can directly connect with its driver. To find out the name of this driver, the first time use the following code:

Dome.Connect("ASCOM.Chooser") : Print Dome.Name : Dome.Disconnect

`Dome.OpenShutter` `Dome.CloseShutter` `Dome.ShutterStatus`

Opens or closes the window. The Status is a number 0..5, for more information see the official ASCOM docs, do an internet search: "ASCOM Dome Class".

`Dome.Park` `Dome.AtPark` `Dome.FindHome` `Dome.AtHome`

Parks the dome or returns the current status.

`Dome.Slewing`

Returns *true* if the dome is moving. See the Demo scripts for a procedure which waits until the dome is no longer moving.

`Dome.GetSlaved` `Dome.SetSlaved(`true/false**`)`**

Reads of sets the "slaved" status of dome, usually you need to disable it before closing the dome.

PHD Guiding functions

`PHD.ConnectDevices` `PHD.DisconnectDevices`

Connects or disconnects the devices used by PHD Guiding.

`PHD.Pause` `PHD.Resume` `PHD.Stop`

Pauses, resumes or stop the guiding.

`PHD.Guide` `PHD.CalibrateAndGuide`

Starts guiding. It's possible to specify the three parameters for settling (pixels, time, timeout) as described in the PHD EventMonitoring interface: https://github.com/OpenPHDGuiding/phd2/wiki/EventMonitoring , for example: `PHD.Guide(1.5, 8, 50).`

`PHD.Dither(`pixels**`)`**

Request a shift of the reference position. Again it's possible specify the extra three parameters for settling (pixels, time, timeout).

`PHD.Status`

Returns a string which indicate the status, see "AppState" in the site above. For example:

"Guiding" , "Calibrating", etc. See the demo script.

Image functions

Image.Open(filename**)**

Opens an image from disk. Example: `Image.Open("C:\moon.tif")`

Image.Save(filename**)** **Image.SaveView(**filename**)**

Saves the current image. "SaveView" saves with a graphic format (jpg, bmp, etc.). Example: `Image.Save("C:\images\saturn.fit")`

Image.Close **Image.CloseLast** **Image.ClosePrevious**

"Close" closes the current active image. "CloseLast" instead closes the last opened image. "ClosePrevious" closes the previous opened image.

Image.Rename(name**)** **Image.Filename()**

Renames the current image or get the current name. Example: `Image.Rename ("jupiter.fit")`

Image.GetKey(key**)** **Image.GetKeyString(**key**)**

Reads values (both strings and numbers) from the FITS header. If the key is not found then zero or an empty string is returned.

Image.SetKey(key,value**)** **Image.DeleteKey(**key**)**

Writes values (both strings and numbers) into the FITS header. Examples: `Image.SetKey ("COMMENT", "Bad seeing")` `Image.SetKey ("JD", 2453709.22791)`

Image.FlipH **Image.FlipV** **Image.Resize(x,y)** **Image.Rotate(a)** **Image.Binning2x2**

These functions modify the current image. Example: `Image.Resize(320,240)`

Image.Crop(x1,y1,x2,y2**)**

Removes the outer parts of an image, keeping the subframe defined by the two points x1,y1 and x2,y2.

Image.Ra ([x,y]**)** **Image.Dec (**[x,y]**)** **Image.RaDec (**[x,y]**)** **Image.XY (**[ra,dec]**)**

Returns the coordinates of the center plate, if the image is astrometrically calibrated. It's also possible to convert the coordinate of a given point from x,y to ra,dec and vice versa. Example: `ra,de = Image.RaDec() , ra,de = Image.RaDec(440, 186)`

Image.EstimateRaDec

If the image is not astrometrically calibrated, returns the approximate coordinates as read from the telescope keywords in the FITS header. Otherwise, it returns the exact coordinates of the center plate.

Image.DistanceFrom(ra,de**)**

Returns the distance from the given coordinates to the center plate, in degrees.

Image.BlinkAlign

Temporary aligns the current image with the previous one and blinks them.

Image.Align

Aligns the current image with the previous one.

Image.FindCoordinates (ra,de,stars,[side],[fovarcmin]**)**

Finds the center plate via plate solving. It's possible to set the side of the search zone in degrees, default is 2°x2° and the field of view in arcminutes.

Image.MaxValue Image.MinValue Image.Width Image.Height Image.Rotation Image.Average Image.StandardDeviation Image.Background

Calculates some statistics on the current image.

Image.GetPixel(x,y**) Image.SetPixel(**x,y,v**) Image.Update**

Read and write single pixel over the image. After having written some pixels call the function "Update".

Image.Visualize([vMin, vMax, vExp]**) Image.Zoom(**percentage**) Image.CenterView(**x,y**)**

Updates the visualization of the image, you may set the black and white thresholds and the exponent of the transfer function (negative for logarithmic).

Image.Macro(n**)**

Launches one of the four *macros* defined in Astroart. Example: `Image.Macro(2)`

Image.Formula(s)

Applies a *formula* over the image. See the documentation about Formula, example: `Image.Formula("v+500")`

Image.AddConstant(n**) Image.MulConstant(**n**)**

Adds or multiplies the image with a given constant.

Image.FWHM

Calculates the average width and height of the stars of the image, to evaluate focus or good tracking: `wx,wy = Image.FWHM`

Image.Focus([method]**)**

Calculates the average focus of the stars of the image, from 0.0 to 1.0. It's possible to specify the algorithm (1 .. 4), see the Autofocus Window.

Image.JD

Gets the time of exposure. Example: `midJD = Image.JD + Image.GetKey("EXPTIME")/3600/24/2`

Points and Rectangles

Image.GetPoint Image.GetPointX Image.GetPointY

Returns the coordinate(s) of the selected point (or selected star, or rectangle) on the current image.

Image.Points.Get(i**)** **Points.GetX(**i**)** **Points.GetY(**i**)**

Returns the coordinate(s) of the i-th selected point over the image.

Image.Points.Count

Returns how many points are selected.

Image.Points.Add(x,y**)** **Image.Points.Clear**

Adds a points at coordinate x,y, or delete all points.

Image.Rectangle.X1 **.Y1** **.X2** **.Y2**

Returns the coordinates of the selected rectangle.

Stars

Image.Stars.Find(n**)**

Finds and select the N# brightest stars in the image. They will be also sorted with the brightest first.

Image.Stars.Count

Return how many stars are selected over the image.

Image.Stars.Ra(i**)** **.Dec(**i**)** **.ADU(**i**)** **.SN(**i**)** **.X(**i**)** **.Y(**i**)** **.Mag(**i**)** **.OCMag(**i**)** **.OCPos(**i**)** **.FwhmX(**i**)** **.FwhmY(**i**)** **.ARef(**i**)** **.PRef(**i**)**

Returns a field of the i-th star of the image. Example: `adu = Image.Stars.ADU(4)`

Image.Stars.Add(ra,de**)** **Image.Stars.Clear**

Adds to the list a star at ra,de coordinates in degrees or clears the list.

Image.Stars.Open(filename**)** **Image.Stars.Save(**filename**)**

Opens and saves the star list to disk.

SetStarAperture(signal, gap, background**)**

Configures the size of the circles used to collect stars, see Preferences.

SetCameraSN(gain, readout, current**)**

Configures the parameters to calculate the Signal/Noise of stars. see Preferences.

Mask

Image.Mask.Active

Returns true or false, depending if a mask is active.

Image.Mask.GetPixel(x,y**)**

Returns the value of the mask for a given pixel, from 0.0 to 1.0.

Image.Mask.X1 **.Y1** **.X2** **.Y2**

Returns the coordinates of a rectangle which contains the masked region.

Serial port functions

Serial.Connect(port, [baudRate]**)** **Serial.Disconnect()**

The serial port is used to send commands to custom hardware. By default the protocol is 9600 baud 8N1. Disconnection is automatic when a script terminates. Example: `Serial.Connect(1)`. After connection a pause of 1 second is recommended.

`Serial.Send(`string**`)`** **`Serial.Receive()`**

Sends and receive string data from the serial port. Example: `Serial.Send("#GH#") : Pause(0.1) : r = Serial.Receive()`

System functions

`System.Execute(`filename**`)`**

Starts an external program. Example: `System.Execute("C:\Windows\Notepad.exe myfile.txt")`

`System.Broadcast(`message, wparam, lparam**`)`**

Sends a *Windows Message* to all windows. This can be used to control other programs. It's equivalent to the following C++ code: h = RegisterWindowMessage(message) ; SendNotifyMessage(HWND_BROADCAST, h, wparam, lparam)

Output functions

`Print`

Prints a text on the "Script output" panel.

`Print` [expression [, expression] [; expression]]

Every expression must be separated by a semicolon or comma; if semicolon is used then a space is added between the writings. If comma is used then a TAB separator is added between the writings. Example: `Print "Some math" ; 3+7 ; 4*4*4 ; pi` will print three numbers with up to 10 significant figures.

`Output.Save(`filename**`)`** **`Output.Append(`**filename**`)`**

Saves the output panel to disk. Remember that it's possible to save strings to disk also with the functions: SaveText(s, filename) and AppendText(s, filename).

`Output.Copy`

Copies the output panel to the Clipboard.

`Output.Text`

Returns the output panel as a string.

`Output.SetLines(`n**`)`**

Sets the number of lines displayed.

`Message(`text**`)`** **`Warning(`**text**`)`**

They show a dialog window and wait until the user press "OK". Example: `Message("Ready to start")`.

Input functions

`Input`

Shows a dialog window where the user can enter data with the keyboard.

`Input` [<Question> ,] variable

Use this function to ask the user for input values. If the user doesn't press the "OK" button then zero or an empty string is returned, depending how the variable was initialized. Example:

```
Input "How old are you ?", y
Input "Your name ?", name
Print name ; "is"; y ; "years old"
```

InputButton

Shows a dialog window with up to 12 buttons where the user can click a choice. Example:

```
resp = InputButton("Park the telescope?", "Yes", "No",
"Later")
if resp = "Yes" then
  print "Now parking..."
else
  print "Let's continue..."
end if
```

A simple function for asynchronous input is: `KeyboardCTRL()` which returns true if the CTRL key is currently pressed and the script window is active.

8.3 Loop Instructions

Two loop instructions are supported: **For** and **While**. The following example prints the numbers from 1 to 10, "a" is the control variable:

```
For a = 1 to 10
  Print a
Next a
```

FOR - NEXT loops

For <variable> = <expression> **To** <expression> [**Step** <constant>]

```
...
...
```

Next <variable>

Examples:

```
For angle = 1+asin(0.4) to 1+asin(0.75) Step 0.1
  Print angle
Next angle

sum = 0
For y = 1 To 5
  For x = 1 To 10
    z = x*y : Print z : sum = sum+z
```

```
  Next x
Next y
Print sum
```

WHILE - ENDWHILE loops

This instruction evaluates a condition at the beginning of the loop. If the condition is false then the cycle stops and execution continues after the **EndWhile** instruction. Example:

```
a = 1
While a <= 10
  Print a
  a = a+1
End While
```

BREAK and CONTINUE instructions

The **Break** instruction is used to exit from For/Next and While/EndWhile loops. In this example the loop stops when "a" becomes greater than 5.

```
For a = 1 to 10
  Print a
  If a > 5 Then Break
Next a
```

The **Continue** instruction acts as a **Next** instruction. A new iteration starts immediately.

```
For a = 1 to 10
  Print a
  If a > 5 then continue
  Print "Test"
Next a
```

8.4 Conditional Instructions

The **IF - THEN** instructions evaluates a logical expression and determines the flow of the program based on the result of that expression. For example:

```
a > 5 AND exts = ".fits"
a >= 3 OR NOT (b <> 5 and b+3 = c)
```

Precedence of operators

(Higher precedence).

```
( )
<   >   <=   >=   <>   =
NOT
AND
OR
```

(Lower precedence).

Syntax

IF <logical expression> **THEN**

```
...
...
[ELSE]
...
...
END IF
```

Compact Syntax

IF <logical expression> **THEN** <instructions> **ELSE** <instructions>

"IF" instructions can be nested without limits. The "ELSE" part is optional. Example:

```
FOR a = 1 TO 10
  IF a < 6 THEN print "-" ELSE print "+"
NEXT a

FOR a = 1 TO 10
  IF a < 6 THEN
     print "-"
     IF a = 5 THEN print "Half work"
  ELSE
     print "+"
     IF a = 10 THEN print "The end"
  ENDIF
NEXT a
```

8.5 Demo scripts

Several demo scripts are available in the context menu of the Script Window. Here is a selection from that menu and from the Astroart Forum.

Simple Loop

```
for i = 1 to 8
  print i, SquareNum(i)
  if i = 4 then print "half work"
next i

function SquareNum(v)
  return v*v
end function
```

Arrays-lists ("dim" is optional)

```
dim a = {1, 99, "Hello", 42}
PrintList(a)
```

```
dim b(4)
b(1) = 1
b(2) = 99
b(3) = "GoodBye"
b(4) = 43
PrintList(b)

sub PrintList(arr)
  for i = 1 to UBound(arr)
    print arr(i)
  next i
end sub
```

Reading pixels inside a rectangle

```
x1 = Image.Rectangle.X1
y1 = Image.Rectangle.Y1
x2 = Image.Rectangle.X2
y2 = Image.Rectangle.Y2
if x1 = x2 then
   print "Please select a rectangle"
   end
end if
cnt = 0
sum = 0.0
for y = y1 to y2
for x = x1 to x2
   sum = sum + Image.GetPixel(x,y)
   cnt = cnt + 1
next x
next y
print "Average inside rectangle = " + Str(sum/cnt)
```

Reading pixels inside a mask

```
if not Image.Mask.Active then
   print "Please select a mask over the image"
   end
end if
x1 = Image.Mask.X1
y1 = Image.Mask.Y1
x2 = Image.Mask.X2
y2 = Image.Mask.Y2
```

```
cnt = 0
sum = 0.0
for y = y1 to y2
 for x = x1 to x2
   m = Image.Mask.GetPixel(x,y)
   if m < 0.5 then continue
   sum = sum + Image.GetPixel(x,y)
   cnt = cnt + 1
 next x
next y
print "Average of masked region = " + Str(sum/cnt)
```

Simple camera control

```
Camera.Binning(1)
Camera.Start(10)
Camera.Wait
Image.Rename("Hires.fit")

Camera.Binning(2)
Camera.Start(10)
Camera.Wait
Image.Rename("Lores.fit")
```

Simple telescope control

```
x = Telescope.RA
y = Telescope.DEC
Message("Position: " + RaToString(x) + DecToString(y))
Pause(1)
Message("Moving telescope 5°North 5°East")
Telescope.Goto(x+(5/15), y+5)
Telescope.Wait
Warning("Telescope arrived")
```

Simple 2x2 mosaic

```
ra = Telescope.RA
raStep = 12/60/15     ' 12 arcmin RA step
de = Telescope.DEC
deStep = 8/60         ' 8 arcmin DEC step

for n = 1 to 4
  if n = 2 then ra = ra + raStep
  if n = 3 then de = de + deStep
```

```
  if n = 4 then ra = ra - raStep
  Telescope.Goto(ra,de)
  Telescope.Wait
  Camera.Start(5)
  Camera.Wait
  Image.Rename("Part_" + Str(n))
next n
```

Configurable NxN mosaic

```
n = 3                  ' 9 images
exposure = 5.0
ra = Telescope.RA
raStep = 12/60/15      ' 12 arcmin RA step
de = Telescope.DEC
deStep = 8/60          ' 8 arcmin DEC step

for y = 1 to n
  for x = 1 to n
    Telescope.Goto(ra, de)
    Telescope.Wait
    Camera.Start(exposure)
    Camera.Wait
    Image.Rename("M_" + Str(y) + Str(x))
    ra = ra + raStep
  next x
  ra = ra - raStep*n
  de = de + deStep
next y
```

Configurable sequence

```
dir = "C:\Temp\"
object = "M42"
closePreviousImage = false
'   Images, Exposure, Binning, Filter
Sequ(4,  5.0, 2, "R")
Sequ(4,  5.0, 2, "G")
Sequ(4,  5.0, 2, "B")
Sequ(2, 10.0, 1, "C")

Sub Sequ(images,exposure,binning,filter)
  Camera.Binning(binning)
  if filter <> "" then
```

```
      Wheel.Goto(filter)
      Wheel.Wait
   end if
   for i = 1 to images
      Camera.Start(exposure)
      Camera.Wait
      fileName = object + filter + Format(i,"000")+ ".fit"
      Image.Save(dir + fileName)
      if closePreviousImage then Image.ClosePrevious
      closePreviousImage = true
      print dir + fileName
   next i
End Sub
```

Detecting daytime and nighttime

```
myLon = 12  ' positive if East
myLat = 44  ' North

al = SunAlt
if al < -15 then
   print al; "= nighttime"
else
   print al; "= daytime"
end if

sub SunAlt
  ra,de = SunRaDec(JD)
  az,al = EquatToAltaz(ra,de,myLon,myLat,JD)
  return al
end sub
```

Detecting star trails

```
shape = "OK"
wx,wy = Image.FWHM
if wx > wy * 1.3 then shape = "Elongated X"
if wy > wx * 1.3 then shape = "Elongated Y"
if wx = 0 then shape = "No stars found"
print shape ; ":" ; wx ; wy
```

Pausing and continuing (press the button "Run" to resume).

```
For i = 1 to 8
  Print i, i*i
```

```
  Pause(9999)
Next i
```

Waiting for PHD guide settling

```
while true
  if PHD.Status = "Guiding" then break
  Pause(2)
end while
```

or, to don't wait forever:

```
for i = 1 to 100
  if PHD.Status = "Guiding" then break
  Pause(2)
  if i = 100 then .....
next i
```

Waiting until the dome is not moving (max. 60 seconds)

```
Sub DomeWait
  for i = 1 to 60
    if not Dome.Slewing then break
    Pause(1)
  next i
End Sub
```

Imaging and stacking in realtime

```
expo = 3.0
for i = 1 to 10
   if i = 1 then
      Camera.Start(expo)
   else
      Camera.StartAndStack(expo)
   end if
   Camera.Wait
next i
```

8.6 Automatic research script

A script for automatic research may control the telescope, the camera and the filter wheel.

Telescope and camera script

Usually it consists of three tasks:

1. Open a list of objects (example: variable stars, galaxies, etc.)

2. Setup a loop.

3. For every cycle, move the telescope, select the filter, take an image and save it.

For step (1) two methods are possible:

A) The function "**Telescope.List.Open(**filename**)**" which loads a list of objects (see Telescope Goto page). Eventually inside the script it is possible to use the commands "**Telescope.List.Name(index)**", "**Telescope.List.Ra(index)**" and "**Telescope.List.Ra(index)**".

B) The function **OpenText(**filename**)** which loads any text file into a string variable. This multi-line string can be parsed using the functions "**Mid**", "**Val**", etc.

Example (the object list was already opened):

```
n = Telescope.List.Count
for i = 1 to n
  ra = Telescope.List.Ra(i)
  de = Telescope.List.Dec(i)
  name = Telescope.List.Name(i)
  print n; name, ra; de
  Telescope.Goto(ra,de)
  Telescope.Wait
  Pause(4)
  Camera.Start(120)
  Camera.Wait
  Image.Save("c:\images\2015\" + name + ".fit")
  Image.Close
next i
```

Autocenter script

The autocenter script centers the object after a GOTO, using the “Find coordinate” (plate solving) feature of Astroart 5. There are two versions of the script, the first one uses the “resync” command of the telescope:

```
' < Get ra,de from your object list>
' < nstars = 4, or 5 if you set an high error >
' <                  in Find coordinates parameters >
....
Image.FindCoordinates(ra,de,nstars)
dist = Image.DistanceFrom(ra,de)
if dist > 0.1 then
   print "Centering telescope..."
   Telescope.SyncTo(Image.RA,Image.DEC)
   Telescope.Goto(ra,de)
   Telescope.Wait
endif
```

The function “Image.FindCoordinates()” calibrates the image via plate solving. The result is “1” on success or “0” for failure. In the example above we don’t check the return value since the check is performed by the next instruction:

The function “Image.DistanceFrom()” calculates the distance in degrees between the center plate and the given coordinates. If the image is not calibrated, it returns “0”. As you can see, if the distance is higher than 0.1 degrees (6 arcminutes) the telescope is synced to the corrected coordinates and a small GOTO is executed to the object.

This script is safe since a failure in FindCoordinates() does not move the telescope to a wrong position. Depending your system you may reduce the maximum distance to 0.05 degrees (3 arcminutes). Before using this command it’s mandatory to calibrate the Find Coordinates parameters, as explained in the Reference chapter.

Another script is the following one: it doesn’t need a centering GOTO, nor a resync, but the first displaced image is not corrected so the maximum “dist” must be smaller.

```
raOff = 0
deOff = 0
...
' <start of cycle>
' <raObj,deObj = read from the object list>
 ra = raObj - raOff
 de = deObj - deOff
' <Telescope GOTO towards ra,de>
 Image.FindCoordinates(ra,de,nstars)
 dist = Image.DistanceFrom(ra,de)
 if dist > 0.05 then
    raOff = Image.RA - raObj
    deOff = Image.DEC - deObj
 endif
 ....
```

This script simply keeps track of the difference between the real coordinates (as measured by FindCoordinates) and the object coordinates. This difference is then stored in raOff and deOff to correct the next GOTO. This make since the error increases with time, so this script is useful on a list of many objects (e.g. supernova search).

Measuring the offset in RA and DEC can also be used to in the first example, if your telescope does not support the Resync() command then you may emulate it with the sequence:

```
....
if dist > 0.05 then
    raOff = Image.RA - raObj
```

```
    deOff = Image.DEC - deObj
    Telescope.Goto(raObj - raOff, deObj - deOff)
    Telescope.Wait
 endif
....
```

Blink and align script

The function “BlinkAlign()” automatically aligns two images and blinks them, to help you in comparing the images. This is useful for search of asteroids, supernovas and comets.

Example: open one image from a recent session, then execute the following script:

```
mydir = "D:\Astroimages\OldReferences\"
Image.Open(mydir + Image.Filename)
Image.BlinkAlign
Image.Close
Image.Close
```

Where mydir is a folder of old images of the same field. This reference image will be opened, compared to the new one, then both images will be closed. To compare another pair of images, open the next one from the recent folder and execute the script again. The whole procedure could be make fully automatic iterating through all images of the recent folder, here is a sample script:

```
new = "D:\Astroimages\NewImages\"
old = "D:\Astroimages\OldReferences\"
im = FindFiles(new,"*.fit")
n = Count(im)
for i = 1 to n
  Image.Open(new + im{i})
  Image.Open(old + im{i})
  Image.BlinkAlign
  Image.Close
  Image.Close
Next i
```

See all the demos (click the "menu" button) for more examples.

9 Image Processing

This chapter describes the main techniques of image processing and how they can be performed with Astroart.

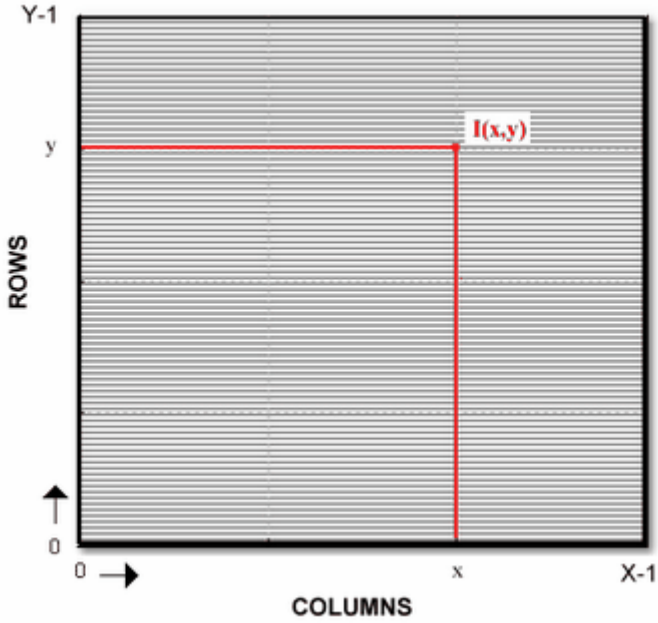
9.1 Introduction

A digital image is a rectangular array of pixels (picture elements).

The location of a pixel is expressed as (x,y), called "coordinates", while the pixel

value at that location is designated as I(x,y). In a image with X columns and Y rows the valid range for is 0 <= x <= X-1 and 0 <= y <= Y-1. In Astroart the origin (x=0, y=0) is on the lower left corner, just like in the FITS standard.

Pixel values can be expressed in different units of measurements: in images acquired with professional cameras these units are called ADUs (analog-to-digital units).



The pixel values of an image may be grayscale or color. A grayscale pixel can be represented by a number, a color pixel needs three numbers, one for every primary color (red, green, blue).

It is very common in astronomic cameras to acquire images with 16 bits of dynamic. This means that a grayscale image has a range from 0 (no light intensity, or full black) to 65535 (full light intensity, or full white), in integer steps. Each of these values need two bytes of storage, so an image with a width and height of 512 pixels will need 512x512x2 = 524288 bytes on disk.

9.2 Stretching filters

These filters modify the contrast and the brightness of some parts of the image, to highlight the subject. The most used filters are DDP and Histogram Stretch.

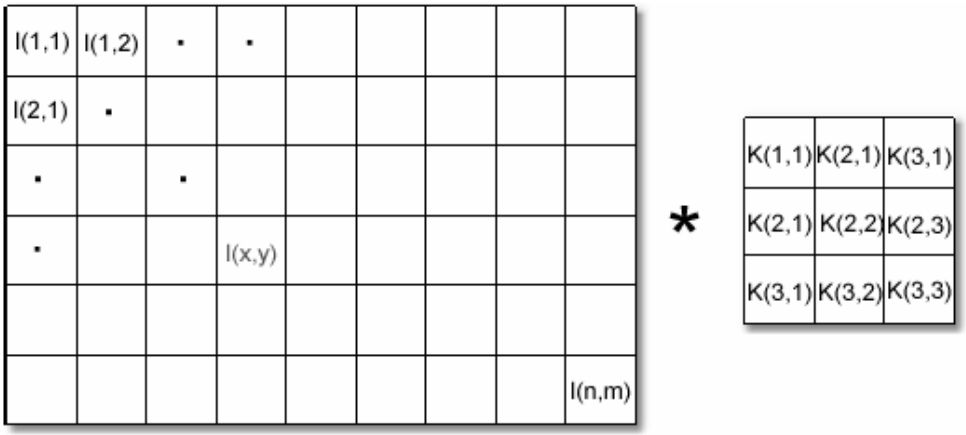
For grayscale images, these filters can be the first ones to be applied after Preprocessing.

If the image is used for science and shall not be modified, Astroart permits to simulate these filters with the Visualization.

9.3 Convolution filters

The base of many image processing filters is the *convolution product*. We know that a digital image is a matrix of numbers, the convolution product is a mathematical operator which multiplies of two matrixes. In our case it involves two matrixes of notably different dimensions: the image to be elaborated composed by thousand of elements (example: 512x512 = 262144 pixels) and a smaller matrix, designed to filter the image. This matrix is called *kernel* because it is the center of all changes that will affect the original image.

In the figure below the image is represented by the matrix **[I]** composed by n x m elements while the kernel is a square matrix **[K]** of 3x3 elements.



The convolution product consists of multiplying every pixel of the matrix **[I]** with

the matrix **[K]**, adding every product of the generic pixel I(x,y) with the pixel K(u,v) of the kernel. In our case 1 <= u <= 3 and 1 <= v <= 3.

100	100	100	100	100
100	100	100	100	100
100	100	150	100	100
100	100	100	100	100
100	100	100	100	100

*

0	-1	0
-1	5	-1
0	-1	0

=

100	100	100	100	100
100	100	50	100	100
100	50	350	50	100
100	100	50	100	100
100	100	100	100	100

In the preceding figure, all the pixels have an intensity of 100 ADUs except that central one which has 150. If we perform the convolution product on the central pixel we get (150•5) + (-1•100) + (-1•100) + (-1•100) + (-1•100). The pixels at the vertexes of the kernel don't appear in the formula because they are zero.

At the end of the multiplication the result is divided by the sum of the elements of the kernel. This last operation doesn't belong to the convolution product itself but it's required to maintain the dynamic range of the original image.

The example above corresponds to a faint star that collects all its brightness in a single pixel (150 ADU) and a sky background of constant intensity (100 ADU). How can we underline the presence of this star? We usually say that we have to increase its contrast, but in which way the contrast should be measured? We can start from:

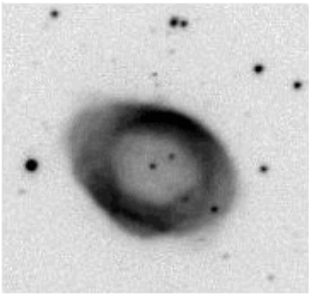
Contrast = I(x,y) / N

Where I(x,y) is the intensity of the pixel (ADU) and N the average intensity of the adjacent pixels. In this case the intensity of the central pixel is (150-100) ADU = 50 ADUs (obviously we have to subtract the background value) while the background is always 100 ADUs; from the definition we get a contrast equal to 0.5. If we apply the convolution product defined above, we get a new image where the average background becomes 75 ADUs and I becomes (350-75) ADU = 275 ADUs, bringing the contrast to 3.67, seven times greater than the original contrast.

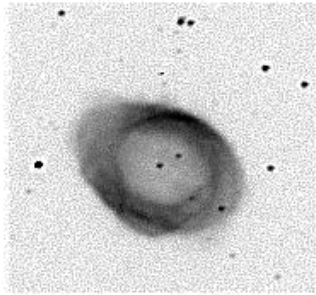
For sake of simplicity, a kernel of 3x3 has been used (nine elements). We can also consider greater kernels (5x5, 7x7 etc.), obviously a greater kernel is justifiable only if we want to consider more distant pixels from the central one. Astroart allows the creation of kernels up to 15x15 (225 elements).

9.4 High Pass filters

The main application of the convolution product is the creation of high pass and low pass filters. A high pass filter emphasizes the high spatial frequencies, (e.g. the details), therefore we will use it to increase the contrast. A high pass filter is always characterized by a kernel with negative values around the central pixel, as in the following example:



$$* \begin{bmatrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{bmatrix} =$$



In this image the high-pass filter was used to enhance the details of the famous planetary nebula M57. An accurate examination of the processed image underlines some side effects:

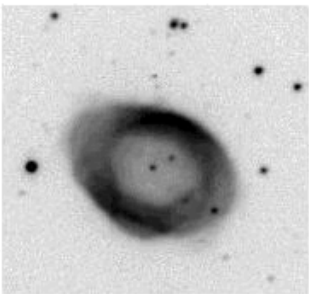
Noise increase. Especially in images with a low Signal-to-noise ratio, the application of high-pass filters inevitably increases the granularity of the image.

Ring effect. The effect of the filter on stellar objects is positive, increasing the contrast and therefore the visibility over the sky background, and negative, creating an artificial ring around them. The cause of this ring is well comprehensible if we observe a kernel of a high-pass filter: the negative values near the center create a sort of depression around the star, which somewhere degenerates into an ugly ring, darker than the overall sky background.

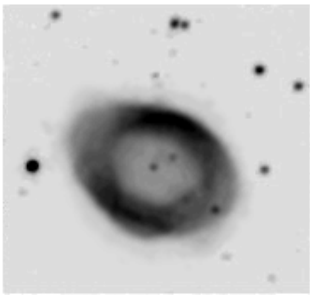
These side effects can be prevented using an adaptive (non linear) filter. For example: High Pass Adaptive and Deconvolution with a gauss kernel.

9.5 Low Pass filters

The low-pass filter truncates most high spatial frequencies. The result is a softening of the details of the image and a decrease of the granular noise.



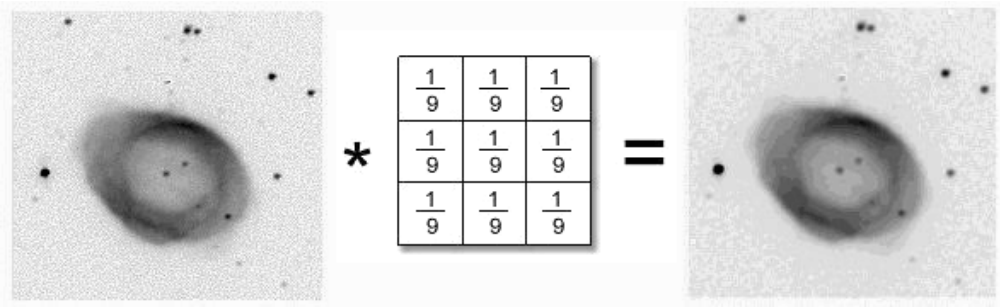
$$* \begin{bmatrix} 1 & 1 & 1 \\ 1 & 4 & 1 \\ 1 & 1 & 1 \end{bmatrix} =$$



The low pass filter made with simple convolution also blurs the image details, (unless the image was oversampled), so if there's no need to make photometry or astrometry, a non-linear filter is preferred, see below.

Average filters

These are a particular case of the low-pass filters. They replace every pixel of the image with the average of the adjacent pixels, including the central pixel. The larger the kernel is, the greater it is the "softening" effect of the filter on the image.



In figure we can see an example with the kernel 3x3. Using a kernel 5x5 or bigger the effect on the image will be very heavy and unnatural.

Median filters

The median filters eliminates all isolated pixels which have an extremely high contrast compared to their neighbors. They are therefore ideal to eliminate defects of the CCD, usually called "hot pixels" or "cold pixels".

The median filter is not a convolution filter but its operation is similar: a kernel flows on all the pixels of the image gathering them into a list. Considering the example in figure below, the kernel is 3x3 = 9 elements, these elements are then ordered from the lowest to highest: in this example we obtain the following 9 elements:

412, 420, 430, 432, 434, 435, 437, 440, 1120

The median value of this ordered list is represented by the value at the center of the list (434). Therefore the algorithm replaces the original value 1120 with the value 434.

The result of the filter is the elimination of isolated pixels without too much alteration in the original image. Nevertheless the median filter introduces a defect: due to its non linear characteristics, it may not preserve the photometric and

astrometric qualities of the original image.

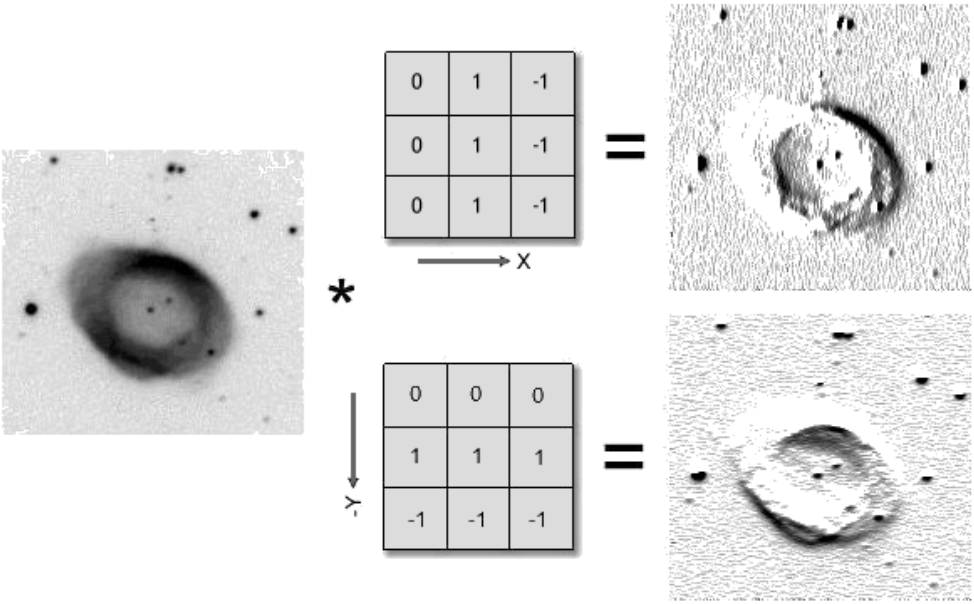
Non linear filters

The filters above may also modify some interesting parts of the image, so very often a non-linear (adaptive) if preferred. To remove hot pixels use the specific Hot pixels filter. To attenuate generic noise use Adaptive low pass or Denoise.

9.6 Gradient filters

Most image processing filters are *isotropic*, e.g. they are represented by a kernel which has identical characteristics in all directions.

Sometime it's useful to have some indications about how the brightness of an object changes with respect to one direction. For this purpose we use the so-called *gradient filters*: in fact they represent the calculation of the partial derivative of the image along a well determined direction, usually one of the two Cartesian axes.



Laplacian filter

The Laplacian is a particular gradient used to emphasize details with rapid variation of brightness. For this reason the Laplacian is ideal to highlight edges of objects and it was used for pattern recognition and military applications. Mathematically, the Laplacian is the second order two-dimensional derivative in every point of the image. In formula:

$$L(x,y) = \frac{\partial^2 I(x,y)}{\partial x^2} + \frac{\partial^2 I(x,y)}{\partial y^2}$$

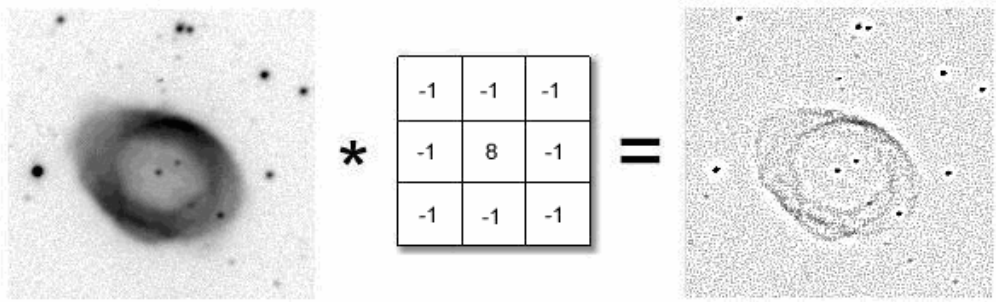
In image processing, the original picture I(x,y) is not a continuous function, but a discrete one, from which we approximately make the *second order derivative*. Three typical 3x3 kernels often used are:

0	-1	0
-1	4	-1
0	-1	0

-1	-1	-1
-1	8	-1
-1	-1	-1

1	-2	1
-2	4	-2
1	-2	1

For example, if we apply the second kernel to the image of M57:

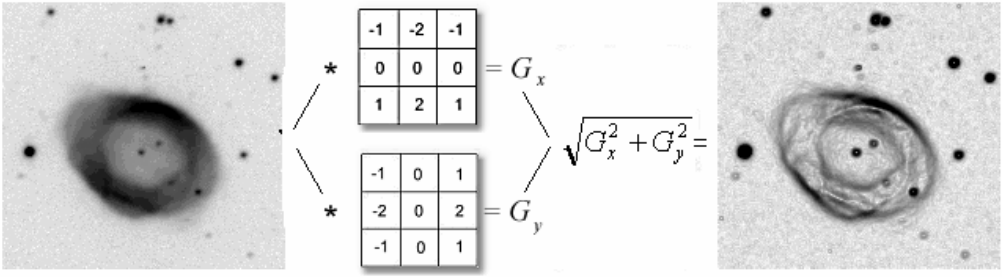


The sum of all elements of a Laplacian kernel is always zero: this implicates that the filter is not linear.

Contour detection

The filters of Prewitt, Sobel, Freeman and Kirsch, which take the name from their inventors, have all the same purpose: to detect with the maximum precision the natural contours hidden in a digital image. They were originally designed for artificial vision, but they can also be helpful in the morphological studies of astronomical objects.

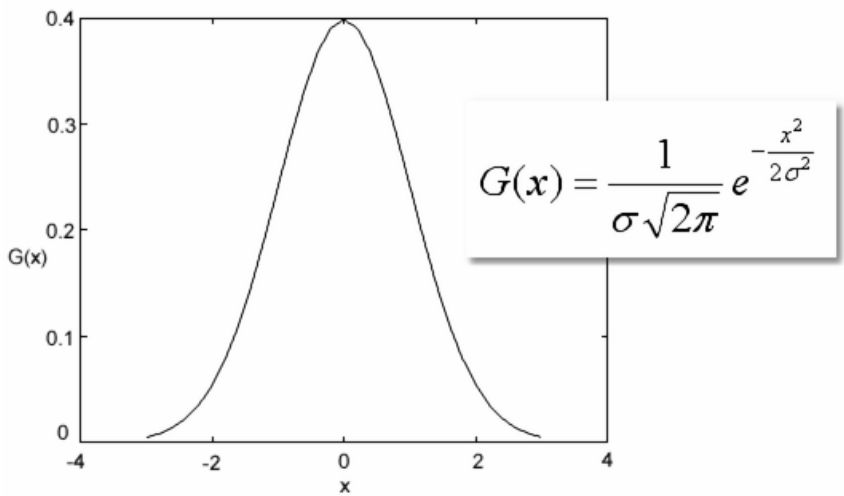
The Sobel's filter for instance uses two kernels 3x3 one for the horizontal axis (X) and one for the vertical axis (Y) that actually represents gradients along the respective axes, then the two gradients are combined together and applied on the image:



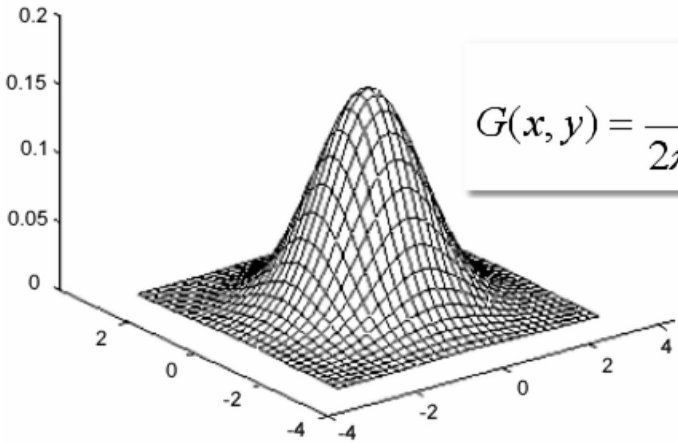
9.7 Gaussian filters

The gaussian filter is a special isotropic operator with some precise mathematical properties. The gaussian function is very common in nature and it is often used to describe statistic distributions.

In the 1-dimensional case the gaussian function G(x) is defined as:



In image processing however we have to deal with 2-dimensional functions, therefore the analogous gaussian function G(x,y) is defined as:

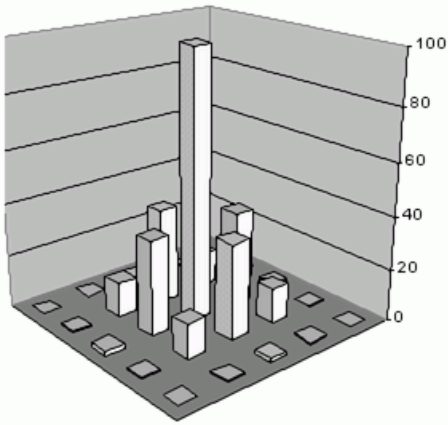


$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{(x^2+y^2)}{2\sigma^2}}$$

The parameter σ (sigma) is called standard deviation (*sdv*) and it gives the width of the Gauss's bell. The most important characteristic of the gaussian distribution is its similarity with Point Spread Functions (PSF) of stars blurred by turbulence and bad seeing.

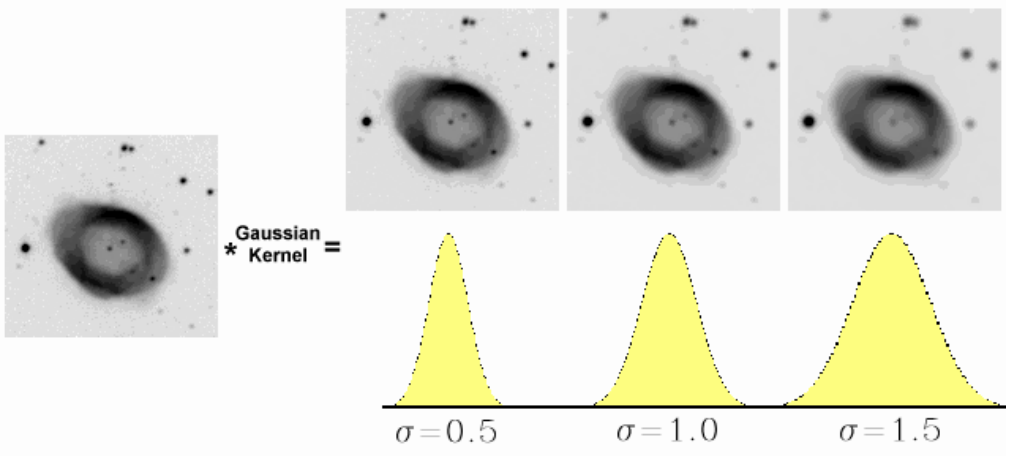
Since digital images are composed of pixels, the gaussian kernel will necessarily be discrete, as shown in the following figure:

0	0.6	1.7	0.6	0
0.6	13	36	13	0.6
1.7	36	100	36	1.7
0.6	13	36	13	0.6
0	0.6	1.7	0.6	0

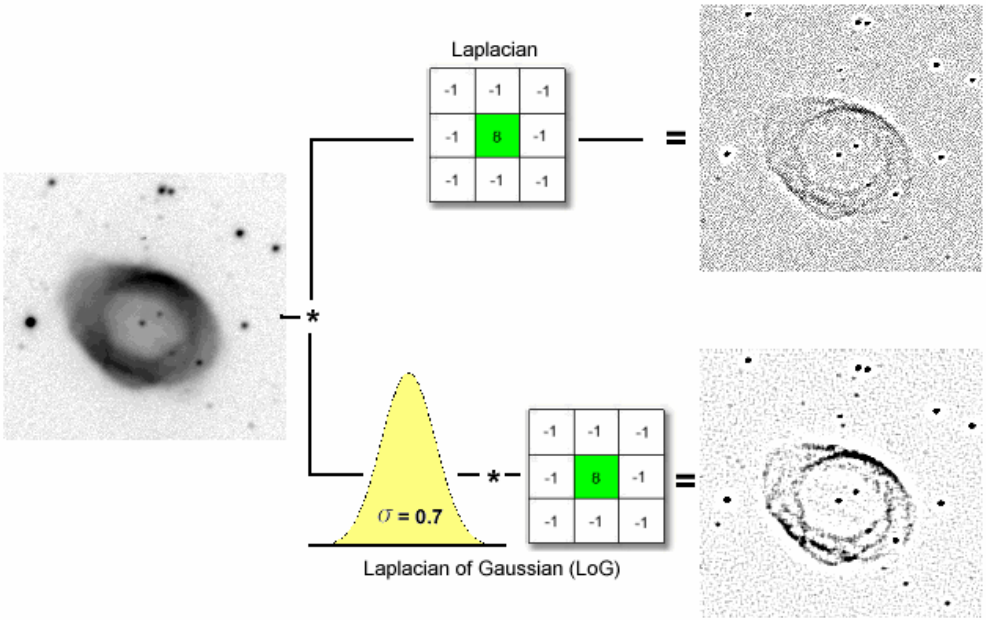


The effect of the filter is similar to the average filter, indeed it's a weighted average where the pixels closer to the center of the kernel have more weight in comparison to those on the border.

Usually the gaussian filter is used with sigma < 1 to reduce noise and with sigma > 1 to create particular "unsharp masks" for elaboration of planetary images.



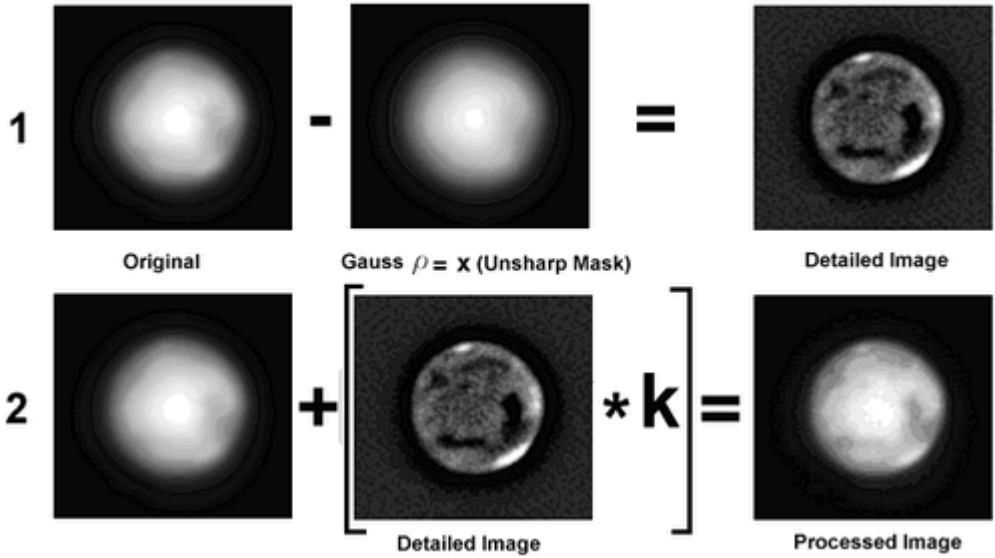
The noise reduction properties of the Gaussian filters can be used in combination with other filters which increase noise, as for instance the Laplacian filters. In fact, utilizing the associative properties of the convolution product, we can apply at first a Gaussian filter to reduce the effects of the noise and therefore the Laplacian filter to detect the points of rapid variation of brightness.



In this example the application of the gaussian filter before the laplacian filter reduces the noise of the final image and allows a sharp outline of the regions with big variation of brightness.

9.8 Unsharp Mask

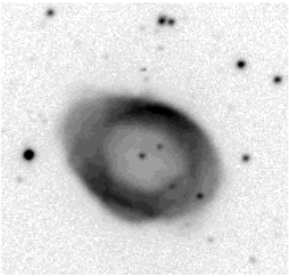
This powerful filter creates a blurred image from the original image, then subtract it from the original one. The result is a new image which contains the sharpest details present in the original one: in fact the mask that was subtracted contains the low spatial frequencies of the image that are therefore eliminated.



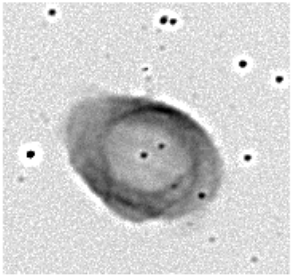
The steps of the algorithm are reproducible with the tools of Astroart, but it is more convenient to use the direct command in the Filter Menu, which allows to see the result with realtime preview. The filter is defined by two parameters:

- s (sigma), is the amount of blur of the mask image, mathematically expressed as the standard deviation of the gaussian filter which blurs the mask. Recommended values vary from 1.0 to 5.0 accordingly with the sharpness of the original image.
- A coefficient (in figure pointed out with k) that has the function to regulate the effectiveness of the filter: good results can generally be reached adopting values from 2.0 to 10.0

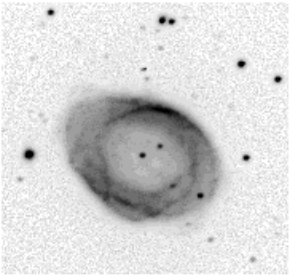
Astroart also contains the option *Adaptive* that prevents the appearance of dark halos around the brightest stars.



Unprocessed

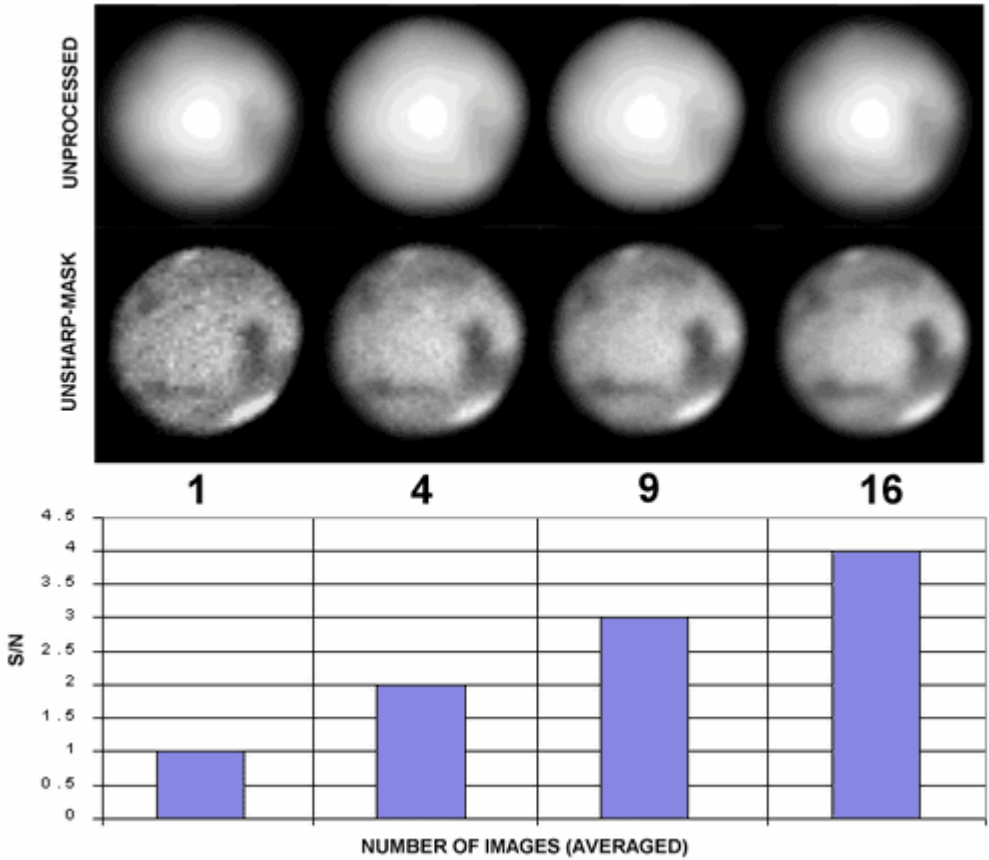


Unsharp Masking



Adaptive Unsharp Masking

The unsharp masking technique is really effective on planetary imaging, but it needs images with a great S/N ratio. This ratio, can be improved (under the same conditions and equipment) only combining (add or average) a series of images.



The first row of pictures shows the average of 1, 4, 9 and 16 images of Mars. The

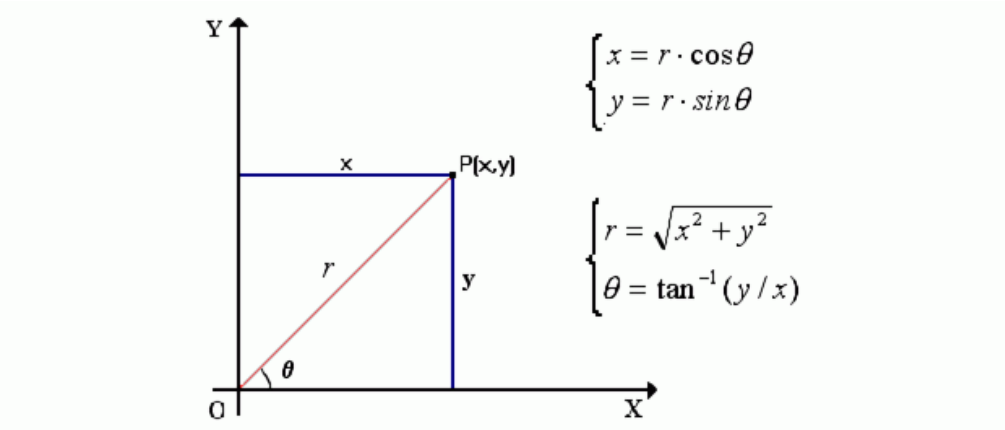
second row has the same images after the application of the unsharp masking. The quality clearly improves using many images; in fact the S/N ratio increases with the square root of the number of images (e.g. an average of 16 frames has a S/N ratio four times greater than a single one).

Remember that in image processing Average and Sum are almost the same thing, since the Average is the Sum divided by a constant, and a scale factor does not change an image.

9.9 Larson-Sekanina filter

This is one of the most used filter for the morphological study of comets. It was for the first time presented by Z. Sekanina and S. M. Larson in 1984 in an article of the Astronomical Journal. In those years there were only some basic techniques to detect the directional gradient of brightness (see the paragraph about gradient filters), these techniques were insufficient because they analyze a single direction of the brightness variations.

Steven M. Larson of the Lunar and Planetary Laboratory in Arizona and Zdenek Sekanina of the Jet Propulsion Laboratory in California conceived a new algorithm which allows the application of derivatives on any direction through a simple transformation of coordinates.



With respect to a Cartesian system of coordinates, a digital image can be represented with a bidimensional function I(x,y).

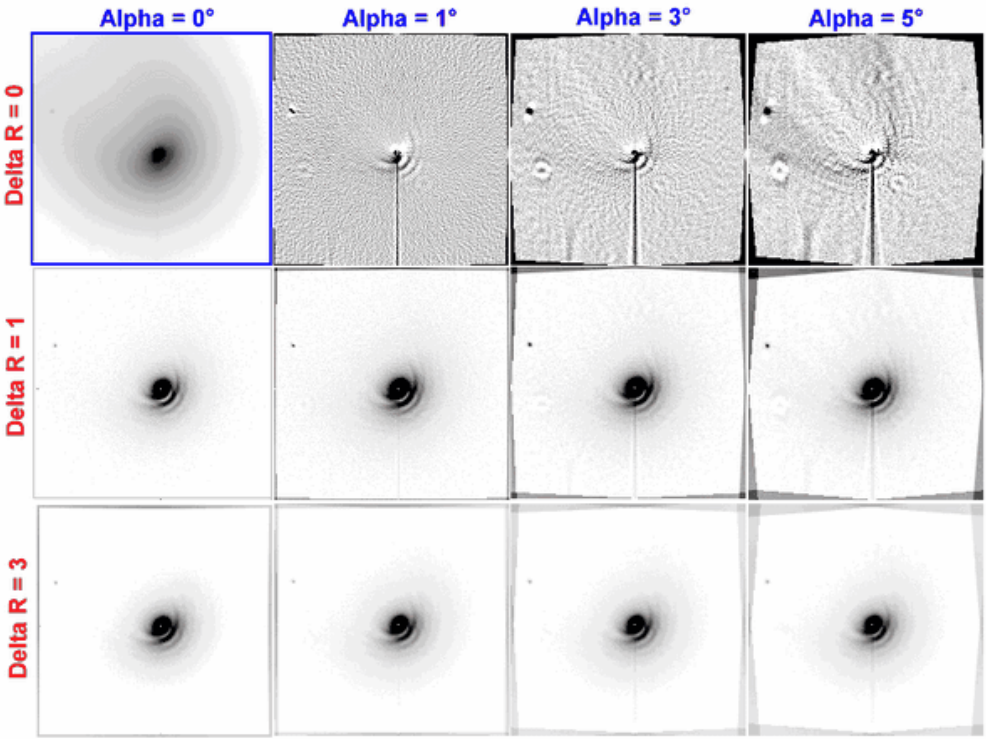
In a system with polar coordinates we can describe the same function as B(r,θ) where r is the distance from the origin and θ it is the angle between the point and the x axis. The origin of this new system of coordinates is no longer the pixel of coordinates (0,0) but a generic pixel of our choice that we will point out as (x0,y0), usually the nucleus of the comet.

The algorithm of Larson-Sekanina can be written as:

$$B'(r,\alpha;\Delta r,\Delta\alpha) = 2B(r,\alpha) - B(r-\Delta r,\alpha+\Delta\alpha) - B(r-\Delta r,\alpha-\Delta\alpha)$$

In the formula, from the original image B(r,θ), doubled for convenience, we subtract two images which are geometrically modified with a radial shift of -r and a rotational shift of +θ and -θ .

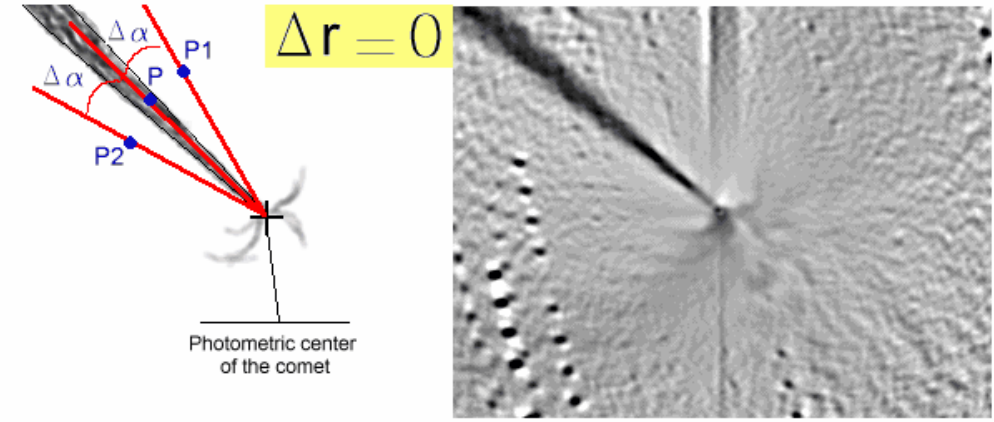
The result image will lose all the possible photometric information, but it will reveal the hidden variations of brightness inside the coma. It is interesting to outline that these elaborations appear very similar to the sketches drawn by the most experienced visual observers.



The amount of the shifts r and θ is empirically established with some tests and they greatly depend on the experience of the analyst. Sometimes it is also possible to reveal artifacts that don't correspond to any morphological characteristic of the comet.

- **Δr = 0**. The equation of the filter becomes:

$$B'(r,\alpha,\Delta\alpha) = 2B(r,\alpha) - B(r,\alpha+\Delta\alpha) - B(r,\alpha-\Delta\alpha)$$



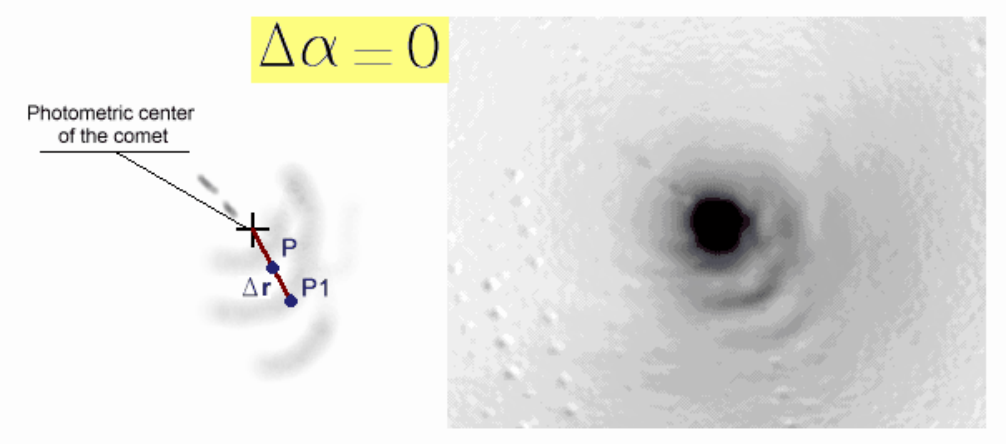
In the case of zero radial shifts, we increase the contrast of all those details that have an angular gradient of brightness with respect to the origin of our polar system of coordinates (the false nucleus). These enhanced details are generally jets erupting from the nucleus.

In the figure it's evident the principal jet that arise from the origin of the tail and crosses the whole quadrant to the up left corner of the image. This gradient, calculated in correspondence of the points P-P1 and P-P2, has enhanced the contrast of the main jet arising from the nucleus of the comet, while on the other side of the coma it allows to glimpse some weak fountain structures that would also be able to originate from points with elevated activity on the surface of the nucleus.

The same gradient has however pointed out a defect of the CCD: the two vertical lines in the superior and inferior part of the image are in fact due to a smearing effect caused by the high brightness of the object and lack of a fast shutter in the CCD camera.

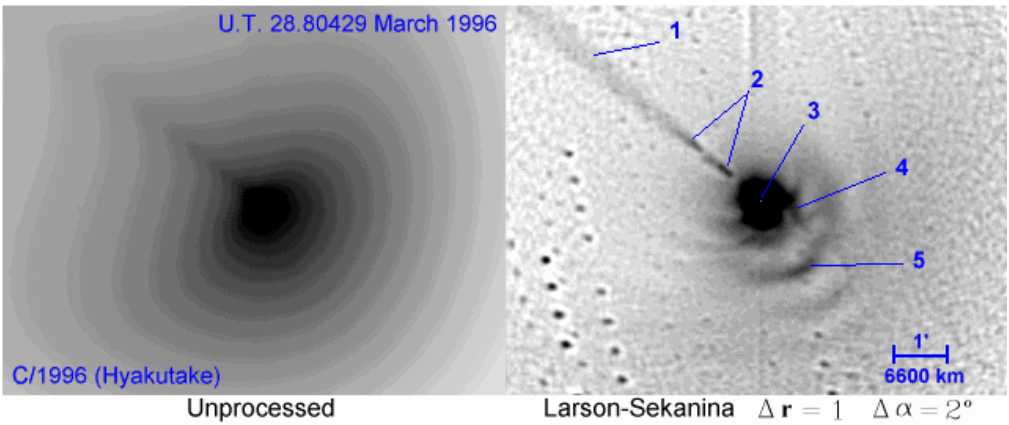
- $\Delta\alpha$ **= 0**: the equation of the filter becomes:

$$B'(r,\alpha;\Delta r) = 2\cdot[B(r,\alpha) - B(r-\Delta r,\alpha)]$$



In the case of zero rotational shifts, modifying the value of (Δr), we enhance the contrast of all those details with a radial gradient of brightness with respect to the false nucleus. The jets are no more visible, but we enhance halos, spiral structures and shells of dust and gas that compose the inner layers of the coma.

The following image illustrates the comet C/1996 B2 (Hyakutake) taken at the Observatory of Cavezzo on April 28 1996: it's the sum of 30 images of 10 seconds each.



1) jet; 2) material disconnection; 3) false nucleus; 4) fountains; 5) shells.

10 Image Calibration

An optimum condition for an amateur astronomer (and professional too) is to take a single shot of the astronomical subject. But life is not that easy!

All raw images returned by a CCD contain a number of instrumental effects which must be removed before the image can be used for scientific purposes. CMOS

sensors, like those used in many Webcams and DSLR cameras, may also have a fixed pattern noise.

These effects are usually corrected by taking various sorts of calibration frames in addition to the images of the astronomical objects. A raw CCD image consists of the following signals:

- IMAGE SIGNAL - The signal from the source, generated by the arrival of photons.
- THERMAL SIGNAL - A signal (dark current, thermal electrons) due to the thermal activity of the semiconductor. This is an unwanted signal, and must be reduced as much as is possible. The thermal signal is reduced by cooling of the CCD to low temperature.
- BIAS SIGNAL - Initial signal already on the CCD before the exposure is taken. This signal is due to biasing the CCD offset slightly above zero A/D counts (ADU).

Now we introduce a few special CCD images: they are the bias frame and the dark frame, from which we can also extract the thermal frame and finally the flat field. Using these images it's possible to perform a *preprocessing task* called image calibration (not to be confused with astrometric and photometric calibration).

10.1 Dark Frame

The dark frame is an exposure without exposing the CCD to any external light. Remembering that every image contains the bias signal, so we have:

DARK FRAME = BIAS FRAME + THERMAL FRAME

The dark current is the main component of the dark frame: the motion of atoms in the silicon lattice release some free electrons which are collected by the CCD capacitors. This effect increase greatly with temperature, for this reason most CCDs used in astronomy are cooled to very low temperatures.

To remove the dark frame from an image it's required to take an exposure of the same duration, keeping the shutter of the camera closed. The dark frames must be taken at the same temperature and duration of the light images. The thermal signal is generated by a current of electrons, it is a time dependent phenomenon, a long duration exposure will have more dark current than a short one.

Like every other CCD image, the dark frame has some casual noise associated with it. The more dark frames you combine, the less noise will be introduced into your image when subtracting the master dark frame.

Usually, if you subtract a single dark frame the overall noise of the image increase. You are obviously favorably impressed by the disappearing of hot and cold pixels, but actually you are adding noise to your image. To avoid this, always combine (average, median) some dark frames. For example, try to take two dark frames and subtract one from the other: what you get is a "salt & pepper" image. This is a representation of the noise that you will add to your images using a single dark frame.

In conclusion: it's recommended to get many dark frames and average or median them (see Preprocessing). Averaging frames reduces the random components by the square root of the number of frames averaged: although it takes more time, you will obtain much better images.

10.2 Flat Field

Another problem of CCD images is that the response to light may change slightly from pixel to pixel, due to variations in electrode size and shape, vignetting or just dirt and dust on the CCD window. If these variations are not corrected, they end up as errors in magnitudes of stars. The three main culprits are:

- Vignetting in the optics.
- Intrinsic and surface defects of the CCD.
- Shadows cast by dust.

Vignetting

A perfect optical system would lead every incoming light ray to its proper place on the focal plane and the entire focal plane would receive equal amounts of light. In the real world, some portions of the focal plane get more light than others. Usually, the central portions get a bit more than the outer edges.

Figure above: in this raw frame the typical aspect of a vignetted field with a brighter center area in the field of view.

Intrinsic and surface defects of the CCD

Sometimes, one region of the CCD is just more sensitive to light than others.

Thinned, back-illuminated chips are prone to showing artifacts due to the grinding, polishing and etching of their surfaces.

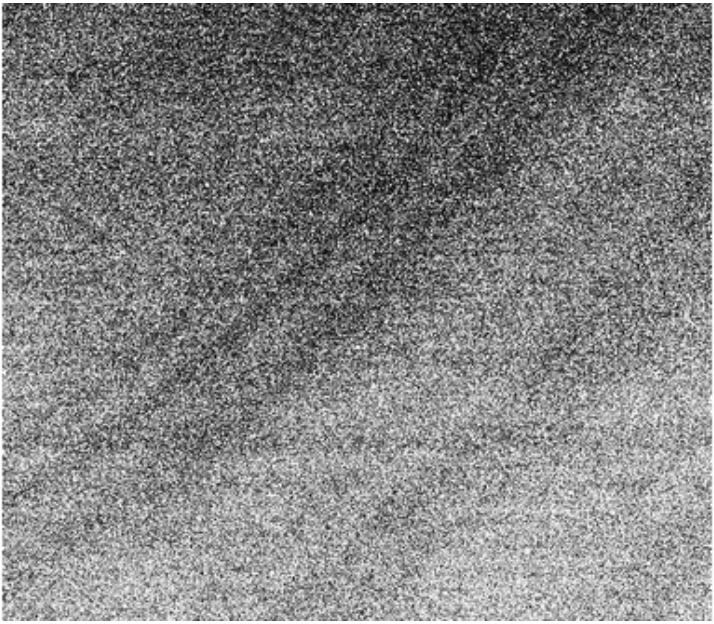


Figure above: in this highly stretched dark frame taken from a thinned back-illuminated chip is clearly visible a diagonal pattern caused by the grinding and polishing of the silicon layer.

Dust particles in the optical path

Dust gets everywhere. Any particles which stick to the optical surfaces, the lenses of a focal reducer or the optical window of the CCD will cast shadows on the focal plane. Diffraction turns these shadows into the so called "dust donuts".

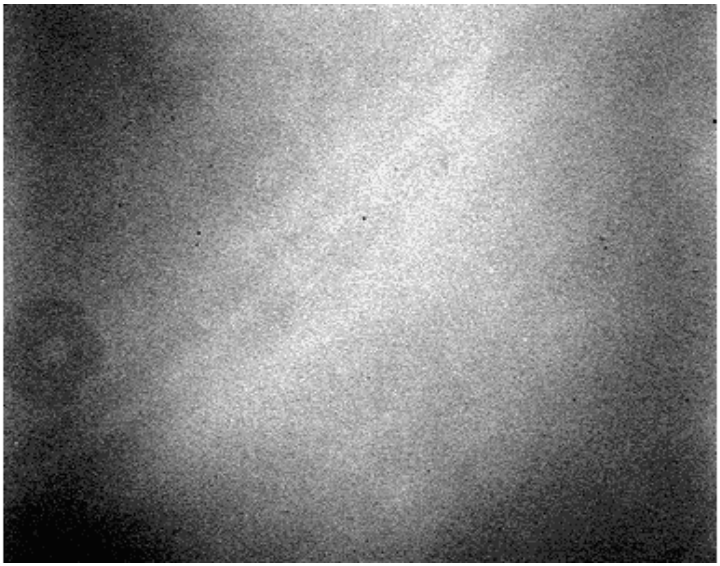


Figure above: some dust particles are visible in this flat field.

To correct these defect it's used a special image called "Flat field". This image must be corrected for dark frame then it used as a divisor for the light frame:

Corrected image = Image / Flat field

Some flat field methods

- **White screen**. Many professional astronomers take their flat fields using a white screen illuminated by lamps inside the dome. This will work well to flatten the image to about 1% and has the convenience of being able to be made in the afternoon, or when conditions are poor. The signal to noise of these flats are very good because the light levels are high. However, the screens often do not accurately match the illumination pattern of the night sky, nor the colors, but for small telescopes this method tends to provide better results than twilight flats which often have too many stars.
- **The sky + white plexiglass**. This combination produces results that are as flat as dome flats and eliminates the need to remove stars. At twilight, point your telescope at the zenith and place a 1/8-inch to 1/4-inch thick piece of white plexiglass over your telescope. You may need to integrate longer than a dome flat since the signal to noise may be lower.
- **The sky**. Accurate flat fields are very important when trying to detect the faintest portions of a nebula or the coma and tail of comets. To very accurately flatten the images, you need to use the sky as a flat field. You can take flats during the twilight, beginning just after sunset in your bluest (B) filters, and progressing toward redder (R) filters as the sky darkens. Be sure to have the telescope tracking on and to move the telescope significantly between each exposure so

that the stars can be removed later. Take a minimum of 3 flats for each of the filters you plan to observe with. Ideally, at least 5 good flats per filter are needed, each with a signal level approximately 2/3 the level of the linear range of your detector. These flat fields accurately represent the illumination pattern of the sky.

10.3 Thermal Frame

The thermal frame is an image of the dark current of the CCD (thermal signal) corrected from the bias level. It has not practical use, but it's an important theoretical concept.

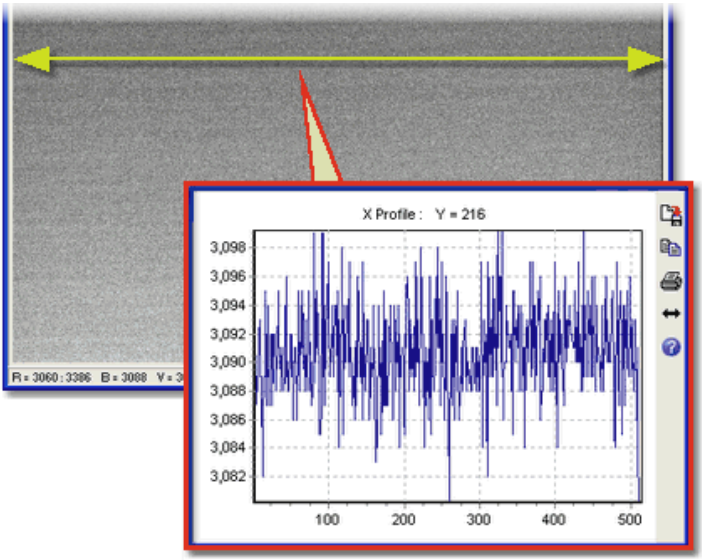
THERMAL FRAME = DARK FRAME - BIAS FRAME

The thermal frame can be obtained subtracting the bias frame from a dark frame. This signal is caused by the "dark current" of the CCD. It increases with temperature and exposure time.

10.4 Bias Frame

The bias frame is an image taken with an exposure of zero, with shutter closed. Usually it's not used in image processing, since the bias frame is always included in the dark frame, so when you subtract the dark frame your subtract the bias frame as well. The only use for bias frames is for scaled dark frames.

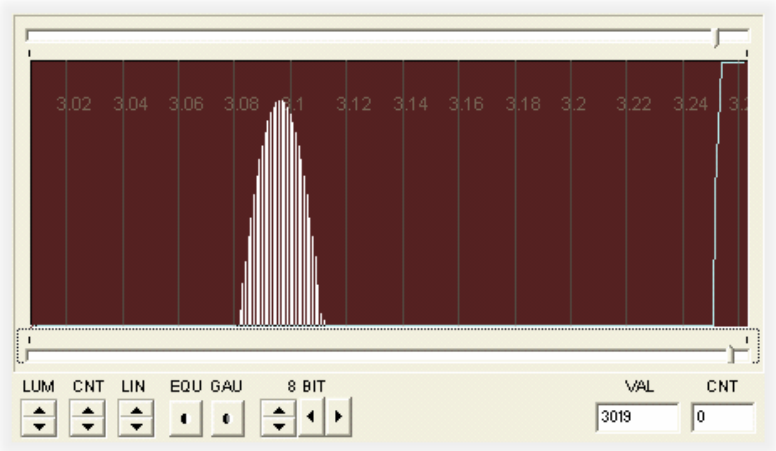
The bias is an additional voltage at the output port of the ADC (analog to digital converter). For this reason the bias is a signal which is added to the signal of every pixel of the CCD. This bias varies slightly with position on the chip, it can vary slowly with time and inevitably has noise associated with it.



In the figure above we can see a typical bias frame analysis. The profile window

shows that pixels along the profile line vary from about 3086 to 3096 ADU leading to an average value throughout all the line of about 3091 ADU, this is what we call the "offset" value.

The "pixel to pixel" variations are caused by random noise. The standard deviation, sometimes called "sigma" or "rms" (root mean square) of the bias signal is called system readout noise.



If we plot an histogram of the bias frame (figure above), we can find that the shape of the histogram is similar to a gaussian bell. The width (σ = sigma) of this distribution is related to the readout noise and the device gain by the following expression:

$$\sigma_R = N_R / G$$

where N_R is the total number of electrons per pixel resulting from the readout noise and G is the gain of the CCD (expressed in electrons/ADU).

But which role has the bias frames in our CCD image processing? Usually none, because when we subtract the dark frame, we are subtracting at the same time the bias frame and we do not need to deal with it any more.

A last note: professional CCD cameras cooled to cryogenic temperature may have a zero dark current, in this case it's possible to use the bias frame as a dark frame. If your camera has an extremely low dark current and/or the exposure was very short, then it could be possible to use the bias as dark frame. As usual, to minimize noise it's important to average some bias frames into a master bias frame.

10.5 Calibration

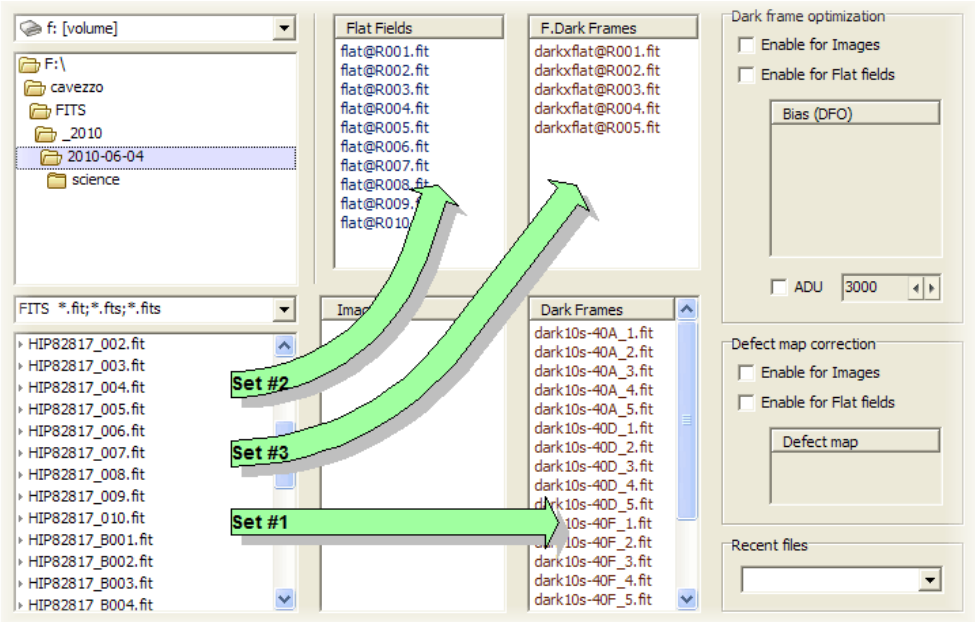
If you read a paper in astronomy journals, you'll often see the phrase "*we applied the standard reduction procedure to our images*." What does that mean? Let's suppose we have a raw CCD image, we have to:

1. **Subtract** a (master) dark frame. As written before this will correct the bias frame too.
2. **Divide** by a (master) flat field, (but the flat field must be corrected with its dark frame).

Every set should be composed of at least 5-10 image to decrease the noise.

- **SET #1**. Dark frames for the light image: be sure to take the set at the same temperature and exposure time of your light frames.
- **SET #2**. Flat fields, which are usually taken at a different exposure time and different temperature.
- **SET #3**. Dark frames for the flat fields. Since the flat fields were taken with a different exposure and temperature, you cannot reuse the dark frames of Set#1.

Using the Preprocessing Window, it's possible to *drag and drop* each set into its box.



11 FITS Overview

The native file format for Astroart images is FITS (Flexible Image Transport System), the standard used in the scientific community.

FITS data format was designed by NOST (NASA / Science Office of Standards and Technology) to provide a way to exchange astronomical data between installations whose internal formats and hardware differ. It is important to outline that FITS was designed to transport scientific data, it's not a simple graphical format like BMP,

TIFF, JPEG etc.

All FITS files are structured as records of 2880 byte and consist of three parts: the *header*, the *data* and the *tailer*.

- **The header.** The beginning of the file is a human-readable text of 36 rows and 80 columns, for a total of 2880 bytes. Most rows are composed of a keyword (left justified, 8-character) followed by a numeric or a string value. It's possible to add other records of 36 rows, until the header is terminated by the keyword "END".
- **The data.** The data (for our specific case the *image data*) is coded in binary format. FITS supports 8, 16, 32, 64 bits and floating point.
- **The tailer**. The tailer adds extra bytes (ASCII 0 characters) to pad the file to a standard length multiple of 2880 bytes. This is required by obsolete tape readers.

In FITS the first bytes of data describe the bottom pixels of an image. This feature was ignored by some Windows programmers, the result is that some Windows software now save and open all FITS files flipped up/down which are not compatible with the NASA's standard. Astroart is one of the few software which manages FITS correctly, letting you to pass your images to professional astronomers which use academic software under UNIX.

For more information about the FITS file format see official FITS web site: http://fits.gsfc.nasa.gov/

11.1 Standard mandatory keywords

Any FITS header must contain the keywords shown below in the order given:

- **SIMPLE**. This value can be T (true) or F (false) to indicate a "simple" FITS image. "Non-simple" images can be encoded as binary tables, also in compressed format.
- **BITPIX**. The number of bits (8, 16, 32, 64). Minus 32 means floating point.
- **NAXIS**. The number of axes (images have NAXIS = 2, or 3 for color FITS).
- **NAXISn**. The number of pixels along the n# axis. For an ordinary image NAXIS1 is the width and NAXIS2 is the height.
- **END**. This keyword has no associated value and ends the header.

11.2 Standard reserved keywords

These keywords are optional, but they are defined by the FITS standard.

- **DATE-OBS**. The date and time of the start of exposure, in UTC, in the form YYYY-MM-DDThh:mm:ss[.sss...]. Please note that the mid of exposure, which is used for all measures, is always a calculated field, as: DATE-OBS + EXPOSURE / 2.
- **EXPTIME** or **EXPOSURE**. The exposure time, used to calculated the mid of the exposure with the formula above.

- **JD** or **DATE--JD**. The Julian Date, in UTC.
- **ORIGIN**. The organization creating the FITS file.
- **TELESCOP**. The model of the telescope.
- **INSTRUME**. The model of the camera used to acquire the image.
- **OBSERVER**. The name of who acquired the image.
- **OBJECT**. The name of the observed object.
- **BZERO** and **BSCALE**. These keywords are used when the data values are not the true physical values. These coefficients allow to recover the physical values using the following equation. (If not used the default values for BZERO and BSCALE are 0.0 and 1.0).

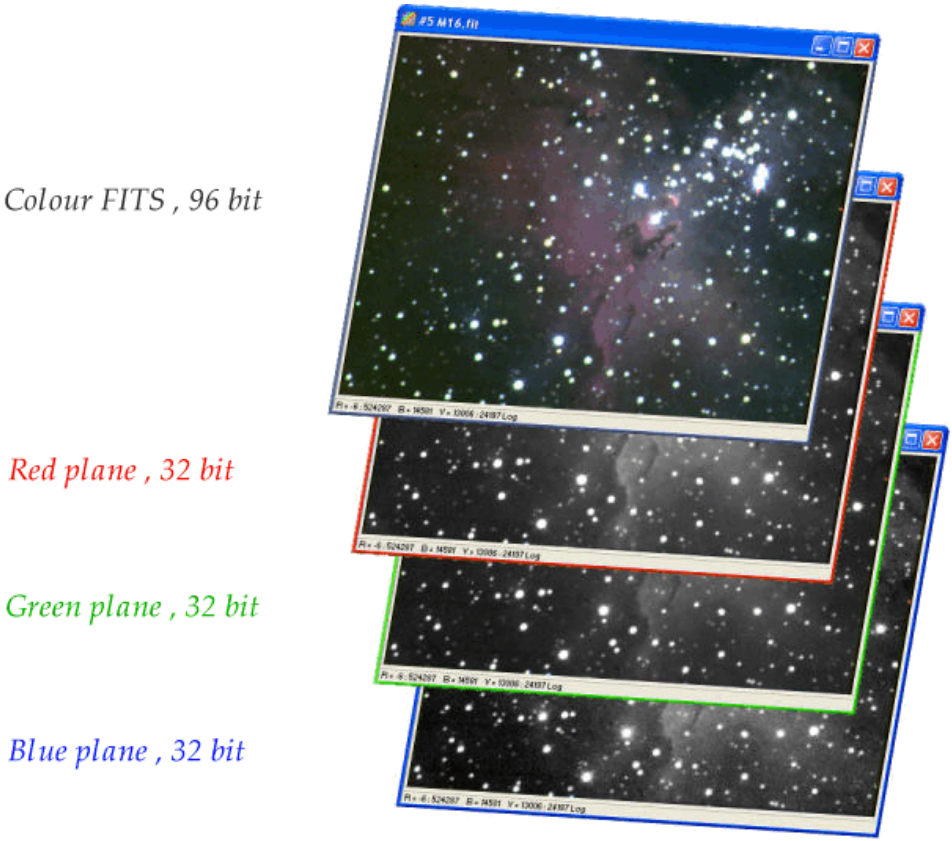
```
physical value = BZERO + BSCALE  x array value
```

- **BUNIT**. The unit of measure of the physical units, after the application of BSCALE and BZERO.
- **COMMENT**. This keyword has no associated value, columns 9-80 just contain ASCII text. Any number of COMMENT can appear in a header.
- **HISTORY**. This keyword has no associated value, columns 9-80 just contain ASCII text. It contains a history of the steps used to process the image.

11.3 Color FITS

A key feature of Astroart is the creation and management of FITS files with colors. Astroart uses the standard keywords **NAXIS=3** and **NAXIS3=3**, to store the three color channels in the same FITS file as a 3-D data cube (see the picture below).

Other programs which are able to read color FITS are: **SAOIMAGE DS9** (http://hea-www.harvard.edu/RD/ds9/) and **FV**, *The Interactive FITS File Editor* (http://heasarc.gsfc.nasa.gov/ftools/fv/).



Using color FITS, you can save in a single file the three RGB components. Each component can be as deep as 32 bit floating point data, giving you the unique power of a 96 bit color imaging.

11.4 WCS

The WCS (World Coordinate Systems) is a standard composed by FITS keywords which permits to share the astrometric calibration.

- **CTYPE1** and **CTYPE2** indicate the coordinate type and projection. The first four characters are **RA--** and **DEC-** in case of equatorial coordinates). The second four characters contain a four-character code for the projection type (**-TAN**).
- **CRPIX1** and **CRPIX2** are the pixel coordinates of the reference point to which the projection and the rotation refer.
- **CRVAL1** and **CRVAL2** give the center coordinate as right ascension and declination in decimal degrees.

There are three options for the scale and rotation:

- Historically, **CDELT1** and **CDELT2** have been used to indicate the plate scale in degrees per pixel and **CROTA2** has been used to indicate the rotation of the horizontal and vertical axes in decimal degrees.
- The FITS WCS standard uses a rotation matrix, **CD1_1**, **CD1_2**, **CD2_1**, and **CD2_2** to indicate both rotation and scale, allowing a more intuitive computation if the axes are skewed. This model has been used by HST and IRAF for several years.
- Another standard uses **PC001001**, **PC001002**, **PC002001**, and **PC002002** to represent the rotation matrix but retained **CDELT1** and **CDELT2** for the scale. It is also read by this software, but should not be used for new WCS's.

Astroart supports both the approximate standard based on keywords **CDELT** and **CROTA** and the more precise system based on keywords **CDx_y**.

12 Glossary

12.1 ADU

A.D.U. or "Analog to Digital Unit" is the unit of measurement of pixel values.

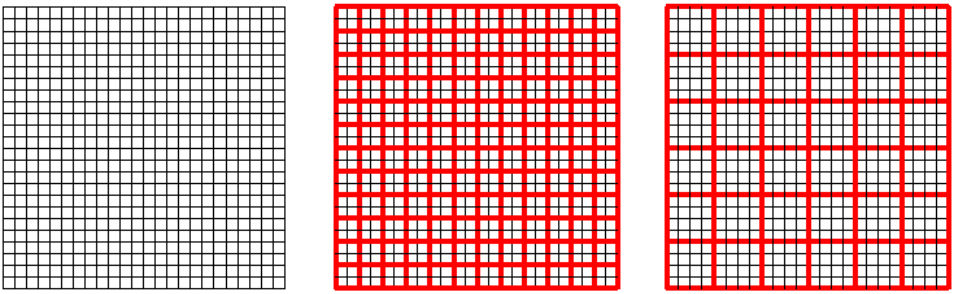
Electrons captured during the exposure are converted to ADU by the ADC chip (analog to digital converter). ADU represents the voltage of the pixel as read from the CCD compared to the maximum voltage of the ADC. This maximum value defines the dynamic range of the ADC (12 bit = 2^12th = 4096 values, 16 bit = 2^16th = 65536 values, etc.).

To read the ADU value of a pixel with Astroart just move the mouse pointer over that pixel and look the *Status bar* of the Astroart desktop. To modify a pixel's ADU see: *Edit Pixels*.

12.2 Binning

Binning means the union of two or more pixels.

A CCD chip is an array of light detecting regions called pixels (for picture elements). A CCD picture can be acquired joining some adjacent pixels and making them one effective superpixel. The figures below represent a detector of 144 pixels, the thick lines indicate the current binning mode.



Binning 1x1	Binning 2x2	Binning 4x4
Number of pixels: 576	Number of pixels: 144	Number of pixels: 36

The advantage of binning is the reduction in noise, so the Signal to Noise ratio increases.

Imagine a 2x2 array of pixels. Each pixel has signal and noise. If you add the values of the four pixels the new S/N doubles, because it becomes 4*Signal / sqrt (4*Noise). Noise adds as the square root because it is a random process.

The drawback of binning is the loss of resolution. Smaller pixels detect more portions of an object. However with sufficiently small pixels binning has not a large impact since it's generally the sky (seeing) that limits the resolution.

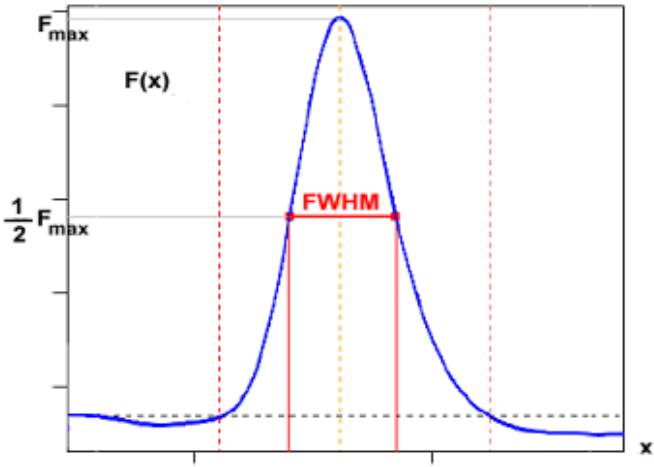
12.3 CCD

CCD chips consist of an array of light-sensitive capacitors. When light falls on the chip during the exposure, electrons released by the semiconductor are collected by these capacitors. The number of electrons is proportional to the amount of light.

At the end of the exposure the charge of each capacitor is measured, the resulting electric signal is converted by a component called ADC (analog-to-digital converter) into a number which is transmitted to the PC. This number is called "ADU", the value of the pixel.

12.4 FWHM

FWHM or *Full Width at Half Maximum* is a measure of star size. To calculate it from a profile of a star simply measure the distance between the two points where the signal is 50% of the peak value.



The FWHM can be measured in pixels or arcseconds. Inside the Stars window the FWHM is measured in pixels.

12.5 Gain

The gain of a CCD camera, or the system gain, express how many electrons are represented by one ADU. A gain of 2.0 electrons/ADU means that each ADU represents 2 electrons. This implies that the total well depth of a Kodak KAF-0400 CCD (85,000 electrons) could be represented by 85000 / 2.0 = 42500 counts.

As long as the total well depth of a sensor can be represented, a lower gain is better to minimize the noise and give better resolution. Gains which are unnecessarily high can result in more digitization noise, while gains which are too low will minimize noise at the expense of well depth. For example, a 16 bit CCD camera with a gain of 1.0 would allow only 65,536/1.0 = 65,536 electrons of the 85,000 to be digitized. System gains are designed as a balance between digitization counts, digitization noise, and total well depth.

12.6 LAA and 64 bit

The Setup always install three executables of Astroart: 32 bit, 32 bit LAA, and 64 bit (Astroart.exe, AstroartLAA.exe and Astroart64.exe). They are installed in the same folder and they share the same settings and data files. Depending your task, just use the best one for you.

Version	OS	Max memory	Use
32 bit	Windows 32 and 64	2 Gb	Image processing and camera control
32 bit LAA	Windows 64 only	4 Gb	Image processing and camera control
64 bit	Windows 64 only	Physical RAM	Image processing only

Astroart LAA is a special version of Astroart compatible with the Microsoft "LARGE ADDRESS AWARE" technology on Windows 64 bit. Astroart LAA can therefore use 4 Gb of RAM instead of 2 Gb. This version is kept separate because some very old camera and telescope drivers are not compatible with it.

Astroart 64 bit works only on Windows 64 bit, it's intended for image processing of large images (20+ megapixels), it does not contain camera and telescope control.

After the installation the 64 bit and the LAA version can be launched from the Start Menu of Windows. If you use them often, add a shortcut to the Desktop.

12.7 Point Spread Function

The Point Spread Function (PSF) is a function which defines how a point source would appear if imaged with the instrument.

Ideally a point source would produce a clear signal in just one pixel on the image but due to the optical effects this is not the case. Optical diffraction and atmospheric distortion are the factors causing light from point sources to be smeared into many pixels. This means that the PSF defines the resolution of the instrument.

12.8 Outside constant

This is a constant used when considering points "outside the image".

In the Preferences window it’s possible to set a value for it (example: zero) or to force to make it variable and equal to the sky background.This constant is used by the commands: Rotate, Shift, Align, other filters calculates a more precise value computed near every edge of the image.

12.9 Readout Noise

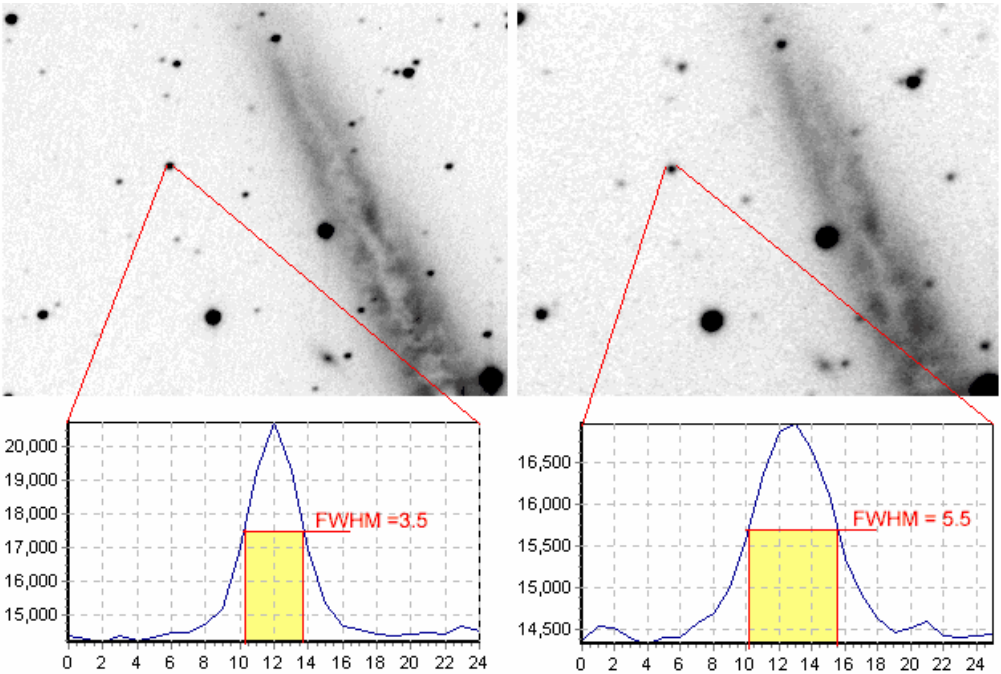
Each time the charge is dumped out of the CCD there is an uncertainty in the measure which is called readout noise and expressed in electrons (e-).

Readout noise is specified both for the CCD sensor and the total system. For example, a good noise figure for the Kodak KAF-0402E and KAF-1602E is 13e- typical, while a good number for the entire system is 15e- typical. Most applications are not limited by readout noise, since the noise caused by the sky background and dark current is much higher.

12.10 Seeing

Without an atmosphere, a small star would appear as a diffraction figure determined by the optical system, and would be inversely proportional in size to the diameter of the telescope. However when light enters the Earth's atmosphere, the different temperature layers and different wind speeds distort the light and the image of the star.

This distortion changes at a high rate, usually more than 100 times a second. In a typical astronomical image with an exposure of several seconds, the distortion blurs the star into a disc called the point spread function or "seeing disc". The diameter of the seeing disc is the *Full Width at Half Maximum* (FWHM) which is a common measure of the seeing conditions.



On the left, an image with a seeing of 2.9 arcseconds. On the right, the same image on a worse night, with a seeing of 4.6 arcseconds. Courtesy Cavezzo Observatory.

The FWHM of the seeing disc (or just Seeing) is usually measured in arcseconds, abbreviated with the symbol (''). A 1.0'' seeing is a good one for average astronomical sites. The seeing of an urban environment is usually much worse. At the best high-altitude mountaintop observatories the air is stable, since it's not in contact with the ground during the day, so sometimes the seeing is as good as 0.4''.

12.11 Signal to noise ratio

Signal-to-noise ratio (SNR) is the ratio between the signal and the noise of an image (or a part of it). The higher the SNR, the better the image. Noise in CCD images is caused by sky background, dark current, electronic sources and statistical randomness of the signal. For a correct measure of SNR of stars, you must set the camera parameters (gain, etc.) in the Preferences.

What is the noise with a ideal CCD camera (i.e. with zero noise) on a absolutely dark sky (again, zero noise)? The result is not zero, it's SquareRoot(N), where N is the number of photons collected.

This result is surprising, there is still some noise as predicted by the Poisson theory. This noise is caused by *randomness*. For example, with 100 photons the noise is 10, so measuring the star you may get 92, 104, 88, 107 and so on. To understand that, remember that photons are emitted with a random trajectory and a random emission rate.

So, even with with a perfect CCD under a black sky we still need a long exposure, to be able to collect thousand of samples. For example, with 50000 photons the noise is 223, so we may expect an error of about +- 223/50000 = 0.4 % which may be acceptable. The error itself follows a gaussian distribution, so there may be cases where the error is much higher than 0.4 %.

Please notice that the unit in this example is photons, while in CCD images the unit is ADU. If your camera produces 1 ADU every 4 photons then a star measured 25 ADU was sampled by 100 photons. The Poisson noise is 10 photons, so 2.5 ADU.