Nebulosity Version 4.0

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1. Acknowledgements

The author would like to extend his heartfelt thanks to several individuals who have helped in the creation of *Nebulosity*. In particular, I would like to thank Michael Garvin, Chuck Kimball, Sean Prange, and Dave Schmenck for all their perennial help. Several individuals worked very hard in translating *Nebulosity* into other languages and I am very grateful for the help of Ramon Barber (Spanish), Christoph Bosshard (German), Denis Bram (French), Michele Palama (Italian), Rudolphe Pineau (French), and Ferry Zijp-Herzberg (Dutch).

I would also like to acknowledge the fine wxWidgets cross-platform GUI library used extensively here. Without it, I would not have written Nebulosity. I would like to acknowledge use of the FreeImage, LibRAW, and CFITSIO libraries for image input and output. In addition, note that the noise reduction software GREYCstoration and the automatic alignment software ANTS, are included as binary applications bundled with and called from Nebulosity. Finally, the synthetic flat tool is written with Scientific Python (SciPy) with help from Emanuelle LaFace.

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3. Introduction

Welcome to *Nebulosity 4! Nebulosity* began in 2005 with the goal of providing a means of easily and efficiently capturing images of DSO objects using your CCD camera. It has grown considerably since then, but has remained true to those goals. It is designed to be a powerful, but simple to use capture and processing application for your CCD or DSLR camera. Its goal is to suit people ranging from the novice imager who wants to create his or her first images and the advanced imager who wants a convenient, flexible capture application for use in the field. As such, an emphasis has been placed on easy access to commonly-used camera controls, as nobody wants to navigate through many menus in order to simply capture a series of images. There is a lot of power under the hood, but what's presented on the surface should be easy to use. If you are new, be sure to check out the quick guide to your first night.

An emphasis has also been placed on compatibility with other applications. For many imagers, the tools provided here will be well-suited to produce images that are ready to be touched up in a graphics editing package (e.g., *Adobe Photoshop*). The tools provided are the tools most of us want and need to make great images. For more advanced imagers who already use more sophisticated astronomical image manipulation software, *Nebulosity* might serve as a suitable capture application and provide a set of key processing tools. *Nebulosity* supports a wide range of output formats, including various FITS formats and other 16-bit per color formats, so that your images can be easily imported into whatever software you use.

What *Nebulosity* is not designed to do is to be an all-inclusive, general-purpose, observatory control and image capture / analysis package. There are several of these on the market already and all are fine packages. All are very large, place more substantial demands on your computer, and, by virtue of being large and all-inclusive, do not typically present a simple, clean, interface for basic image capture control. The author of *Nebulosity* routinely stands in cold, dark fields with a laptop and a camera taking pictures. Under these situations, when gloves must be removed to operate the computer, simple, dedicated user interfaces are exceptionally welcome.

That said, the author is also a stickler for power and accuracy (he's a research scientist by day). You get quite a few "serious" tools in *Nebulosity*. The ones you get are purpose-built - tools that you will want for processing raw DSO images into beautiful pictures.

One more thing - I'm also a stickler for "fair use" in licensing. Your *Nebulosity 4* license is not tied to one machine or even one operating system. Feel free to use it on a laptop for image capture and a desktop for processing. Feel free also to upgrade to any new release in the v4 series. All upgrades within this (4.0.1, 4.2.1, 4.5, etc.) are free.

4. What’s New in 4.0?

If you’re a *Nebulosity* v3 user who’s migrating to v4, there are a number of new features to be aware of. First, if you bought v3.0 and never upgraded through v3.1, 3.2, and 3.3, you missed out on a number of new features (remember, all upgrades within a major version – v1, v2, v3, v4, etc. are free!). You missed out on:

- Native support for a number of new cameras for both Windows and Macs
- Enhancements to the scripting tool (focuser commands, TEC commands, etc.)
- Screen overlays to aid in composition
- New language translations
- Control for external focusers
- Enhanced GUI during Align and Combine (lets you pick a “master frame”, censor frames, etc).

In v4, we’ve got more new goodies (some of which were in v3 pre-releases)

- New percentile-based stacking modes to reject noise, planes, hot pixels, etc.
- New synthetic flat tool to remove gradients and vignetting
- Ability to link to FocusMax v4 for auto-focusing (Windows)
- Ability to use Nebulosity as it were an ASCOM Camera, so other programs can script and control Nebulosity’s captures.
- Can now name filters for both on-camera and external filter wheels and have multiple saved sets. Can even have “short names” used in filenames.
- Can use these filter names, series index number, and capture time in any combination you like when capturing a series (Preferences).
- Complete rewrite of the dialogs / GUI to work well with variable system font sizes and Retina / High DPI screens
- Simplified camera TEC / filter control into a single control
- Optionally have the image capture routines run in a separate “thread” so that USB or camera issues won’t lock up Nebulosity
- Support for Atik cameras greatly enhanced with the One’s filter wheel supported on both Mac and Windows and with most all Atik cameras now supported on the Mac (thanks Nick!).
- For Mac users, I can no longer say 10.6 is fully-supported. Too many libraries Nebulosity depends on just can’t run on 10.6 anymore. 10.7 is the new official minimum version.
- For Windows users, 32-bit versions of the OS (e.g., XP) are still supported but this has been now called “deprecated” meaning it is slated to go away down the road. You’re fine for now, though.

5. Features

- Cross-platform support
    - Mac OS X 10.7+ (Intel only, 10.6 may still work)
    - Windows 7, and 8 (Intel x86 only, XP may still work)
    - Same license code works on both platforms and all functionality is available across platforms (Note, not all cameras are supported on all platforms for image capture.)
- Simple, but powerful interface
    - All basic controls are present on the main screen. No need to navigate through lots of menus during an imaging session. *Nebulosity* was designed to be easily operated in the field by someone who actually operates it in an actual field.
    - Interface can be customized to show, arrange, or hide tools to suit your needs.
    - Ability to have multiple instances of *Nebulosity* running for processing different images or controlling different cameras.
    - Support for multiple languages (currently, English, Dutch, French, German, Italian, and Spanish)
    - By default, all displays are auto-scaled. Any scaling (including inverted) of the data onto the display possible using easy sliders.
    - Histogram gives a quick view of how much of the valid data range is being used during each capture.
    - Pixel statistics / area statistics pop-up window for real-time readout
    - Zoom button lets you rescale the displayed image quickly.
    - Image pan mode (shift key)
    - Unlimited undo/redo (0, 3, or unlimited levels of undo).
    - Small clock to show local time, UTC, GMST, local sidereal, Polaris RA, or current CCD temperature
- Capture control
    - All basic capture parameters present on main screen. Duration of exposure, number of exposures per captured series, delay between captures, name of series, camera gain and camera offset all in one simple panel.
    - 1x1 - 4x4 binning (depending on camera) and fast-readout modes supported
    - Quick *Preview* button captures one frame with current settings and displays it on the screen without saving. Helps in focus, composition, and tuning of capture parameters.

- *Frame and Focus* mode: Loops a quick, binned image to assist in rapid initial focus and framing (crosshairs can be enabled or disabled via Preferences).
- *Fine Focus* mode with HDR focus metric: Loops a very quick image around a selected star in full resolution and provides running statistics (and linegraphs of the history of the statistics) to assist in fine-tuning focus.
- Support for using LiveView during Frame and Focus and/or Fine Focus on Canon DSLRs supporting LiveView.
- Capture one-shot color in RAW CCD format or reconstruct color on the fly – your choice.
- Capture status able to be shown in large red display for easy viewing when away from computer.
- Link to PHD Guiding to enable pausing guiding during main image download and to dither location of images.
- Link to FocusMax v4
- Focus information available to other programs (see Preferences, Save Fine Focus info and CaptureSingle script command).
- Control of both on-board and external filter wheels both in the main user-interface (Tools) and automated via scripts

- Multiple file formats supported
    - Read virtually any FITS file to process images from virtually any camera (RGB color, black and white, compressed or uncompressed, any bit depth)
    - Load and process data from FITS, PNG, PPM/PNM/PGM, TIFF, BMP, JPEG and just about any DSLR “RAW” format.
    - Captured data saved in FITS as 16-bits (0-65,535) per color channel, 32-bit floating point, or in 15-bits (0-32767) per color channel.
    - One-shot color data captures may be saved in RAW CCD format or as reconstructed full-color images in an RGB FITS format (Maxim / AstroArt style or ImagesPlus style) or 3 separate FITS files (the latter only for capture and subsequent use in other programs).
    - Captured data saved in either lossless compressed FITS according to the FITS standard or uncompressed FITS
    - These same save formats available for any loaded image, making *Nebulosity* serve to convert between many FITS formats (just select your output format using the settings on the Preferences menu).
    - Save current displayed image in BMP or JPG format (24-bit color) *as displayed*
    - Save current image in 16 bit/color (48-bit color) uncompressed TIFF, compressed TIFF, or PNG (compressed) format

    - Load 8/24 bit PNG, TIFF, JPG, and BMP (scaled to 16/48-bit) or 16/48-bit PNG and TIFF.
    - Batch convert from FITS to 16/48-bit PNG or compressed TIFF
    - Batch convert from DSLR RAW and standard image formats (PNG, TIFF, JPG, and BMP) to FITS
- Extensive camera support (some cross-platform, some Windows-only)
    - Apogee Alta
    - Atik legacy (16/429/285) and modern (3xx, 4xx, 4000, 11000, etc)
    - ASCOM 5 and ASCOM 6 compliant cameras
    - Canon DIGIC II and higher DSLRs
    - CCD Labs
    - FLI
    - Fishcamp
    - Meade
    - Moriavian
    - Opticstar
    - Orion (original native - others via ASCOM)
    - QSI
    - QHY
    - SAC
    - "SC" (Steve Chambers) style long-exposure modified webcams / Atik 1&2 - all via the either a parallel port or via the ShoeString LXUSB adapter for all-USB (no parallel port) long-exposure imaging.
    - SBIG
    - Starlight Xpress
    - Simulated camera (Windows and OS X)
    - **Virtually any camera's images can be processed in *Nebulosity*.**
- Internal calculations
    - All data stored internally in 32-bit floating point *per color channel*. For B&W or RAW images, this equates to 32-bits and for color images, this equates to 96-bits in all math routines. You will never have overflow (saturation) or overflow or quantization issues as a result.
    - Critical math routines computed in double-precision (64-bit per channel) floating point.
    - Routines are optimized for high-speed operation and most will make full use

of however many processing cores you have on your machine.

- Image alignment, stacking and pre-processing
    - Dark / flat / and bias frame pre-processing tool to let you pre-process multiple sets of B&W, RAW one-shot color, or color images.
    - Create and apply *Bad Pixel Maps* as an alternative way of removing hot pixels.
    - Align a series of images using simple translation (for equatorially mounted telescopes) or using sub-pixel level accuracy and translation + rotation and (optional) scaling (equatorial or alt-az telescopes)
    - *Drizzle* alignment and resolution enhancement for either equatorial (translation only) or alt-az (translation + rotation).
    - *Colors in Motion*: Simultaneous over-sampling alignment and Debayer of one-shot color images to significantly decrease color error and increase resolution. For one-shot color imagers, this improves resolution and reduces color error.
    - Average a series of images without alignment (e.g., for combining darks, flats, bias frames, etc.)
    - Standard-deviation based stacking (aka "sigma clip") of aligned frames to reduce noise in final stack.
    - Percentile-based stacking (including median) to help remove outliers (e.g., hot pixel trails, airplane trails, etc.)
    - Adaptive scaling of combined data (stacks) to use full 16-bit range (gives you the best features of adding and averaging frames).
    - Demosaicing, color cameras, and color synthesis
    - De-mosaic a RAW one-shot color image using an array of very high quality debayer routines (VNG, PPG, AHD, Bilinear, and color-binning). Both interactive and batch-mode supported. Pixels become square in the process if native pixels were not square.
    - White balance on Canon DSLR settings for both stock and extended-IR cameras
    - Square pixels for images from B&W cameras.
    - *LRGB color synthesis* (RGB, traditional LRGB, and color-ratio LRGB)
    - *Line filter reconstruction for one-shot cameras*. Optimized reconstruction of RAW images taken using line filters. General mode plus modes optimized for H-alpha and O-III/H-beta on CMYG arrays.
    - Convert color-format images to monochrome or monochrome into color
- A host of easy to use interactive image manipulation tools
    - Versatile *Levels / Power Stretch* tool lets you apply not only simple linear

stretching of your images, but non-linear stretches as well. Pre- and post-stretch histograms interactively displayed.

- *Curves* tool to let you customize just how you'll stretch the image
- *Digital Development Processing* (DDP). A technique to make CCD images look more like film images by using a hyperbolic scaling of the data. Here, the basic technique is enhanced to allow easy darkening of the background at the same time.
- *Star Tightening*. A technique to sharpen stars using an edge-detection algorithm (does not leave the artifacts found in some other techniques).
- *Unsharp Mask* tool for image sharpening (Traditional and Laplacian image sharpening also available).
- *Color balance adjust* (offset and scaling) with real-time 3-color histograms for easy, accurate balancing. (Automatic color balancing available as well.)
- *Hue, saturation, and luminance* adjustment
- *Synthetic Flat Fielder* to remove gradients in the image
- *Gaussian blurring* tool
- *Vertical smoothing / deinterlacing*
- *Adaptive median noise reduction*
- Access to *GREYCstoration noise reduction*
- On any of these, use simple sliders or double-click on the value to set the numbers directly.

- Geometric and mathematical image processing
  - *Pixel math* tool to allow scaling / shifting the image intensities.
  - 2x2 binning of images: addition, averaging, adaptive, and low-noise 2x2 for one-shot color sensors.
  - Rotation / mirror imaging of images
  - Resampling / resizing of images using a choice of 6 algorithms: Box, Bilinear, B-Spline, Bicubic (Mitchell & Netravali), Catmull-Rom spline, & Lanczos sinc
  - Crop tool (interactive or direct specification)
- General tools
  - Processing history continually logged in the *History* tool
  - *Notes* tool for those bits you just don't want to forget
  - *Blink* tool to compare images (in Preview / Rename tool).
  - Grade a series of images to determine the sharpest / best of the set
  - Versitile *Image Preview / Rename* tool to quickly sift through large sets of

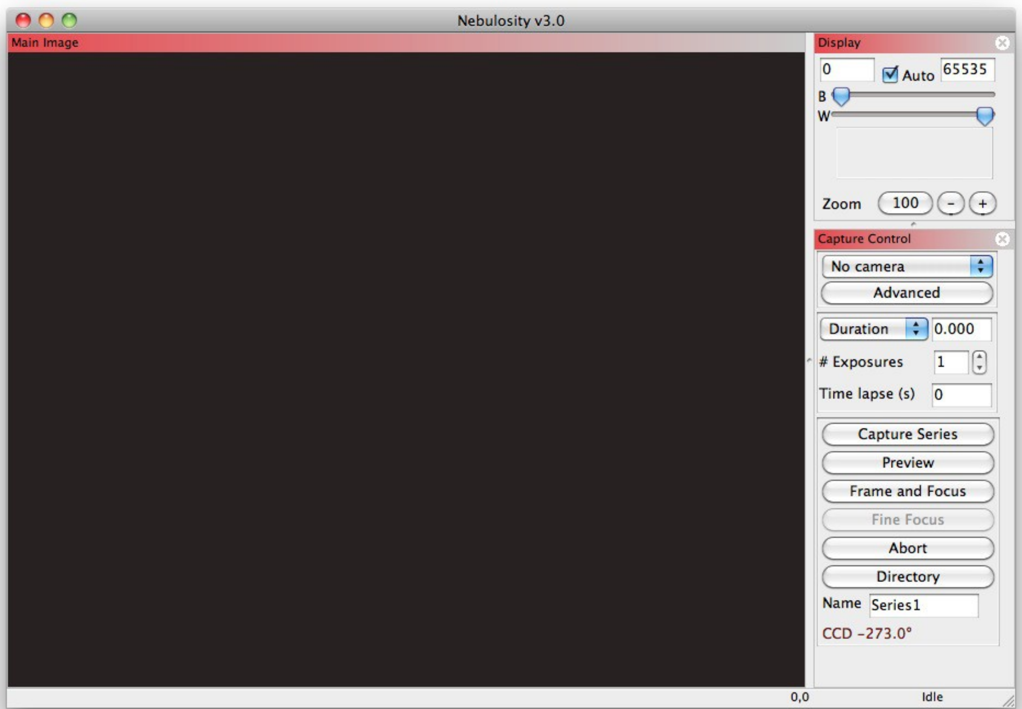
images.

- *Image normalization* and *Histogram matching* to balance intensity across images.
- Measure Distance tool lets you measure the distance (CCD pixels, arc-seconds, or arc-minutes) among up to 3 points.
- DSS Preview tool to let you use Digitized Sky Survey images to see what you can expect to get on your chip.
- Focuser and filter wheel control

- Scripting and Automation
    - Can write / run scripts to automate captures (interactive and unattended) using a simple tool anyone can work with.
    - Scripts can be dynamically created and sent to Nebulosity either via the clipboard or via TCP/IP sockets allowing other programs even to control Nebulosity.
    - On Windows, Nebulosity can be controlled as if it were an ASCOM camera (regardless of what camera is actually attached).
    - Image manipulation and processing can be scripted by copying elements from the History to the Macro tool

6. Main Screen

When you open *Nebulosity*, you are presented with a screen that looks like this (Windows version is similar):



It has 4 main sections:

1. Image Window (Large black area)
2. Display Panel (Top portion on the right)
3. Capture Panel (Middle right)
4. Status Bar (Bottom)

6.1. Image Window

> Tip: Want to slide around in an image quickly? Try holding down the shift key and dragging around in the image to do an accelerated "pan" through the image.

The image window is where your images will be displayed. It starts off at a default size (optimized for 1024x768 displays), but is easily resized by simply resizing or maximizing *Nebulosity* itself. If an image is too big to fit into the window, the scrollbars will allow you to navigate around the image. Alternatively, the Zoom button, located in the Display panel, will resize the image to help make it fit your screen.

6.2. Display Panel

Here, you have several controls that affect how the image is displayed in the Image Window. Keep in mind that your data are often in 16-bit (or 48-bit aka 16-bit/color) format. That means that you can have 65,536 shades of grey in the image. But, your monitor can most likely only display about 256 shades of grey (24-bit color). Thus, the data need to be scaled to display well on your screen. That's the purpose of the first three controls here.

Keep in mind that these tools only affect the way the image is displayed. They do not affect the actual data. If you save the image, adjust the sliders or zoom control and save it again under a new name, you'll have two identical copies of the same data. (There is one exception to this rule. The Save BMP As Displayed uses the values in the sliders to help get your data from 48-bits into 24-bits)

These are the **B** and **W** sliders, and the **Auto scale** checkbox. The B and W sliders set the level in your data to assign to black and white respectively. Slide the B slider to the right and your image gets darker. You've told *Nebulosity* that a higher image intensity equals black, meaning more of your data should be dark. Slide it to the left and the image gets brighter. Likewise, slide the W slider left and the image gets brighter as more of your data should be white. Put them closer and you have a higher contrast image. Put them further apart and you have a lower contrast image. Flip sides (white below black) and you'll invert the image. If you don't want to mess with any of this or if the image gets way out of whack, select **Auto scale** (it's set by default). The Auto scale checkbox tries to set the B and W sliders automatically by using data from the **Histogram.**

If you want to manually set specific values for B and W, you can enter them in the fields provided (that also read out the current values of the sliders). To make the changes take effect, press Enter inside the edit box.

Tip: Don’t like the auto-stretch? Ctrl-click on the box and select a different stretch algorithm.

Below the sliders is a **Histogram** display. When you first start *Nebulosity* it is black, but if you load an image or capture an image (use the Camera Simulator if you don't have one) you'll see a red display in this window. This box intentionally lines up with the sliders, for the left of the box corresponds to intensities near zero in your image and the right corresponds to intensities near the maximum (65,535 for 16-bits) in your image. So, if you see a small area of red on the left side of the histogram and you're not seeing anything on the screen, it means that you have a faint signal in the image. Slide the W slider to the left to come near that small area of red and you'll see your faint image.

The Histogram is a very powerful tool in image capturing, for it tells you a lot about your image. Are all of the data far to the left? If so, your entire image is faint and you should increase your exposure or gain if possible (see below). Do you see a nice curve that trials off to the right just before you get to the edge of the Histogram? If so, you've got a nice exposure and are making the most of your data. Do you see that instead of trailing off smoothly near the right edge, the curve ends abruptly at the right edge? If so, you're saturating a lot of the pixels in your image and should likely use a shorter exposure or less gain. Are you cutting of hard on the left edge? If so, use more gain, more offset, or a greater exposure duration.

You can use Ctrl + and Ctrl - (or Cmd + and Cmd - to zoom in and out.

Finally, the panel has the **Zoom** button (marked "100%" by default). Repeated clicks on the Zoom button will cycle through several zoom modes (20%, 25%, 33%, 50%, 100%, 200%, & 400%) to get a better view of your image. Next to this, you'll see + and - buttons that let you zoom in and out respectively. Note again, this only affects how you see your image, it does not change the underlying image itself.

For a more detailed inspection of your image, try activating the **Pixel Stats** pop-up window (under the *Image* menu).

6.3. Capture Panel

Too many cameras listed there to sort through each time? In the Edit menu, you'll find an option to De-select cameras and remove them from the list. Don't worry - you can always add them back in later.

The main Capture Panel has several sub-sections. At the top, we have an area that controls connection to the camera and advanced settings for the camera. Below this, we have an area that lets you control details of the exposure and below this we have a number of buttons that let you take various kinds of exposures.

6.3.1. Camera Section

The Camera section contains a pull-down to select your camera model. When you pull down your camera model, *Nebulosity* attempts to connect to the camera. Success of failure will be noted in the left-hand panel of the Status Bar.

If you're new to CCD imaging and don't have a camera yet or want to explore some of *Nebulosity* without attaching your camera, a **Camera Simulator** is provided as one of the camera choices. The camera is always aimed at the same patch of sky (that happens to have 20 stars of different brightness) but the mount isn't perfect, so you'll notice the stars move a bit from image to image. The camera has noise, and responds to all the controls in the **Exposure Panel**, letting you get a feel for what to expect and how to use the program.

Here, you will also find an **Advanced** tab. *Nebulosity* picks default values of a number of camera options that are optimal for most DSO imaging. However, if you want to select any of these yourself, you can do so in the dialog box that appears when you click this button.

6.3.2. Exposure Section

Here, you have controls for all basic exposure options.

- **Duration**: How long per image (in seconds) should the exposure be? Note, fractions like 1.5 allowed.
- **Gain (optional)**: Some cameras let you adjust the gain and offset of the A/D

converter. This entry controls how much CCD amplifier gain should be used during A/D conversion. (Think of gain as a volume knob for the signal coming off the CCD). Numbers range from 0-63.

- **Offset (optional)**: What offset should be added to the signal during A/D conversion? (The offset adds signal into every pixel to help you keep the pixels from having zero values anywhere). Numbers range from 0-255. (See Automatic Offset on p. 16)
- **# Exposures**: How many images do you want to take?
- **Time lapse**: How much time (seconds) should be inserted between each image?

Most of these are fairly self-explanatory, but Gain and Offset deserve a bit of attention. They get this in the Section [Taking Good Images](). For now, you can leave them at their default values.

Want to set your CCD's TEC status? The Advanced button and an entry in Preferences let you do this (as does any camera-specific tool). Want to know the current temperature? In Preferences, select CCD Temperature under "Clock / TEC display"

The **Duration** and **Time Lapse** entries allow you to specify the exposure duration in seconds, but fractions are allowed. So, if you want an exposure of a half a second, simply enter "0.5". Remember that a millisecond is a thousandth of a second (0.001). In addition to allowing you to enter the time directly, the **Duration** control lets you pull down any of a number of common times. The word "Duration" is actually a button. Click and hold on it and a list of common times will appear that you can quickly select without having to type numbers in while in the dark.

6.3.3. Capture Section

The default directory is located in your system-wide "Documents" folder in a sub-folder called "Nebulosity". If you use the default directory and it doesn't exist, Nebulosity will attempt to create it. If you forget to set the directory you actually want to use and capture a night's worth of data, this is where it is. If you use a different directory and pull down Save Preferences from the Preferences menu, the current directory will be saved as the default.

In this panel, you'll find the **Preview** button. This button takes a single image at whatever duration, gain, and offset you've specified and shows it on the screen. It does not save the image. This lets you fine-tune the composition of your image and hone in on correct focus of your telescope. It also lets you determine the optimal duration, gain, and offset. (Use the handy **Frame and Focus** button for rough focus and composition).

The Abort button works in a number of places - during capturing, frame/focus, fine focus, alignment, etc. On several cameras aborting can take several seconds to clear and reset the camera.

There are three controls used in capturing a **Series.** A text entry box near the bottom lets you set the default **Name** for the series and a button lets you select the **Directory** the data will be saved in. Finally, at the top of the panel is the **Capture Series** button. This starts the sequence acquisition process. For example, if you've setup for 10 exposures of 20 seconds to be stored in My

Documents\Nebulosity\August_20_2014 and called M51, *Nebulosity* will loop and take all 10 exposures. The first will be called M51_1.fit, the second M51_2.fit, etc. At the end of the capture, you'll hear the Windows *Ta-Da!* sound play. (To abort a sequence, press the **Abort** button).

Three things to note concerning series captures:

- If you provide a name that already exists (e.g., you hit Capture Series again without changing the name), *Nebulosity* will create a new name to use in saving the series. Here, it would be M51-1_1.fit, M51-1_2.fit, etc. Hit it again and you'll get M51-2_1.fit, etc.
- If you need to abort a series during the capture, press the Abort button in the Camera panel (or click the mouse inside the Image Window and press the ESCAPE key.)
- The format the files are saved in is based on your choice in the *Preferences* menu.
- You can configure what bits of info to include here. Want the date-stamp, filter name or light/dark/bias indication? Head on to the Preferences.

Finally, you will also see three buttons: **Frame and Focus**, **Fine Focus**, and **Abort.** Frame and Focus is a useful tool for composition of images and for obtaining rough focus. Press this button and the camera will enter its most-sensitive, fastest mode and continually loop exposures. This gives something of a "live video" display, showing you an image as quickly as possible (it may still take several seconds to update, depending on the camera). Adjust your focus, move your telescope, etc. until you have a reasonable image and then press **Abort** to cancel the automatic looping.

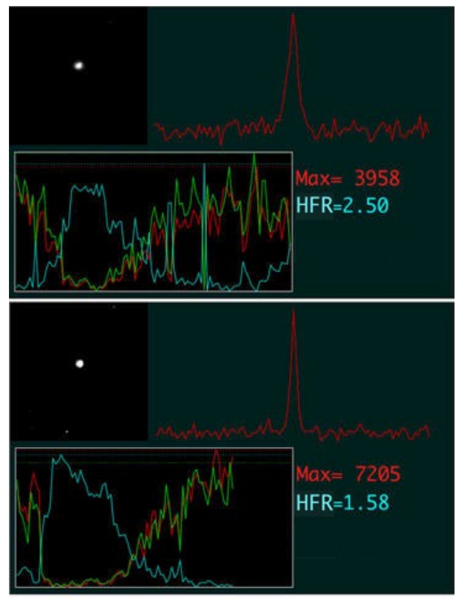
During Frame and Focus and Fine Focus, you can adjust a number of parameters on the fly. You can alter the exposure duration, gain and offset and you can also turn on and off Auto-Ranging and adjust your sliders. The effect of each won't be seen until the next image appears, though. You can also pause the looping by hitting Ctrl-Space. Hitting this again will restart the process.

Once you have a basic focus and framing of your shot, you'll likely now want to use the **Fine Focus** button to fine-tune your focus (not available on all cameras). When you click on this button, you're asked to click on a star. This can be either from the last Preview or from the last exposure in the Frame and Focus routine. When you do so, the image will now continually display the area centered on that star in full resolution. Use this to fine-tune your focus.

Focus can be achieved visually by looking for the sharpest image while adjusting your telescope's focus or by using the focus aids provided. Three additional aids are given to help you reach focus. The first of these is also a visual aid. To the right of the star you will see a profile of the star. When in sharpest focus, this profile will be at its narrowest and tallest.

The other two use calculated metrics to try to determine how good the focus is. The first uses the fact that when the star is in focus more light is hitting the center-most pixel leading to a brighter value in that pixel. Therefore, the maximum value recorded in the area should reach its peak when the image is in focus. The “Max” reading and the red line in the graph in the lower left show the current value and history of this value.

The second metric calculated is the “Half Flux Radius” or HFR. This is a metric devised by Larry Weber and used in his popular [Focus Max] plug-in for several packages. This is an excellent metric and is quite possibly the most robust metric we have. In it, the best star in the small region is first found and its center is found. The total star flux is then found and the radius of a circle around the star’s center that would contain half the total flux is calculated. This is the HFR.



In the lower left the history of values for both the Max and the HFR are plotted. The most recent 100 samples are plotted so you can watch how the focus quality changes as you adjust you telescope's focus knob. This graph will auto-scale itself if the range is too large or too small for the display. Finally, also shown on here are the best values achieved during this Fine Focus run for both measures (horizontal dotted lines).

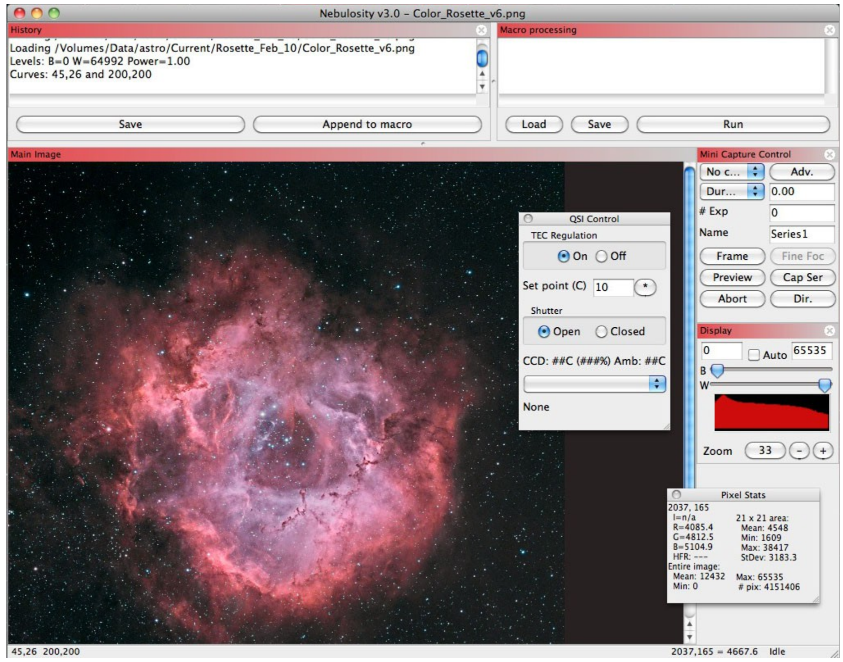
6.4. Status Bar

At the very bottom of the screen is the **Status Bar**. *Nebulosity* gives you a lot of information down there. The Status Bar is divided into 4 panels. The right-most panel always tells you what *Nebulosity* is doing. It may read "Idle" (it's not doing anything), "Capturing", "Processing", etc. Next to that, is a panel that shows you the X and Y location of your cursor and the intensity of the image at that pixel (see the Pixel Stats pop-up window under the Image menu to provide more detail).

The left two panels are used for information and instructions concerning what *Nebulosity* is doing. Load an image and you'll see its dimensions and the name come up here. Start an image alignment process and you'll get instructions and progress here. Start an image capture and you'll also see your progress down here, along with what file was just saved. When in doubt about what's going on, check the Status Bar.

6.5. Customization of the Interface

Nebulosity gives you the ability to customize the user interface to suit your needs. The Display and Capture panels that come up by default can be closed or “torn off” by simply dragging them off of the main window. Many components can be re-arranged and additional components can be added. These other components are available in the View menu. For example, here, we have replaced the normal Capture Panel with a more compact version, the Mini Capture Panel. We’ve also put the Notes tool above the main image area and have a specialized control for the QSI cameras there as well. Not everything needs to be “docked” to the main *Nebulosity* window. For example, the dialog that controls the link to *PHD Guiding* is seen here floating above the main *Nebulosity* window.



6.5.1. Notes and History

Ever wish you could jot down some information about the series you’re capturing? Something like “scope dewed up somewhere in the middle of the red frames” or “forgot the right spacer for the reducer on these” or even just to record the more mundane settings about the night’s progress? The Notes tool gives you handy place to do this. Your text is saved as plain text so any program can read it.

Also, ever wish you could remember just what settings you used as you processed an image for some step 12 steps ago? Open the History tool from the View menu and you’ll see a running log of exactly what you did.

6.5.2. Camera-specific Dialogs

The main interface of *Nebulosity* lets you control the basic features of all cameras with the same interface, but some cameras have more features. For example, you may have a filter wheel attached to the camera (also controllable via scripts) or the camera may let you control the shutter (to make it easier to take dark frames). You’ll find camera-specific control dialogs here in the View menu as well.

6.5.3. External Filter Wheel

If you’ve got an ASCOM-compliant filter wheel (Windows) or a Starlight Xpress filter wheel (Mac OS X), *Nebulosity* can connect to it and control it in the same way it controls filter wheels built into QSI, SBIG, or QHY cameras (see above). This control will let you select the desired filter. Keep in mind, you can also script your captures, telling *Nebulosity* to change filters as needed.

6.5.4. Pixel Stats

The Pixel Stats window will let you see the image intensity under the mouse pointer (like you also see in the Status Bar), but it will also show you a lot more. For color images, it splits this into the separate the R, G, and B values. For all images, it also shows local statistics and statistics on the whole image. Mouse over a star and it'll tell you the HFR value for that star.

6.5.5. Link to PHD Guiding

PHD Guiding is the popular freeware guiding package by Stark Labs. With it, guiding can be as simple as "Push Here Dummy." With the PHD Guiding dialog, you can establish a link to *PHD Guiding* so that the two packages can talk to each other. This gives you two powerful features. First, it lets you pause guiding during the download of your main image. Some cameras are sensitive to interruptions on the USB bus and if the guide camera shares the USB bus, the image quality can be degraded. The "Pause during download" option will let you enable this feature.

The second feature is to enable "dithering" of the image's location across frames. Between frames, *Nebulosity* can send a signal to *PHD* to tell it to move the "lock position" (the position of the crosshairs in *PHD*) by a small, random amount. Once *PHD* has moved the star and re-established stable guiding in the new location, a signal is sent to *Nebulosity* to let it know it can continue with the next frame in the series.

To do this, you must:

- Have *PHD* 1.8.6 or later running and tell it to "Enable Server" in the Tools menu (*PHD* will remember if you last left the server on and restart it the next time you start *PHD*). If Windows asks you whether it's OK to do this, tell it yes.
- In Nebulosity's PHD Guiding dialog, click on the "Connect" button (Note: Shift-click on the connect button and you can use a different TCP/IP port).
- In the dialog, tell it how much "dither" to send. The dither sent will be a random number of pixels in X and Y, scaled by the level you pull down here. In the lowest level, the random numbers will vary from -0.5 to 0.5 pixels and in the highest they will vary from -1.5 to 1.5 pixels *in the guide frame*. Since people typically guide at shorter focal lengths than they image at, this will usually have a much larger effect in your main images.
- It may be worth changing the "Settle threshold". This specifies how far off the star can be from the lock position before *PHD* sends the message that it has gotten the star back on target and it is OK to resume your series capture.

6.5.6. Macro Tool

If you've ever wanted to replay the processing you did on one image and apply it to another image, the Macro Tool is for you. This kind of thing is very handy for processing mosaics and can be useful if you want to re-create a state of an image (so long as you have the output of the History tool). To use the Macro Tool, simply copy and paste items from the History dialog into the Macro Tool window (or select them - a triple-click works well here - and hit the History Tool's "Append to Macro" button). When you've got the steps you want in the order you want, hit Run and Nebulosity will process the image accordingly.

You can, if you like, create the Macro Tool entries from scratch. Use previous entries in the History tool to see what the commands are supposed to look like.

7. Your First Night – A Brief Guide

There is a lot to learn in astrophotography and this manual goes into a lot of detail that can be overwhelming at first. Video tutorials are on the website to help, but if you're getting started, here is what you should read and understand prior to taking your first images:

- What is the Display Panel? What is the histogram for and what do the B and W sliders do?
    - The big thing here is to realize that what you see on the screen isn't actually what your sensor recorded. The histogram shows you how many of your pixels are dark (left side) and how many are bright (right side). How we map the darker and lighter pixel values to your screen's brightness is controlled by the B and W sliders. This is because your camera captures so much wider a range than you can see and because your cool DSO bits are all packed into small differences in the dark (left) side of the histogram while your stars dominate the right.
    - The "auto" checkbox there tries to come up with a way to see both, but play around with the sliders to see what you actually have.
- How do I connect to my camera?
    - If all your camera drivers are installed (Windows) and it's supported, just select it from the Camera pull-down.
- How do I get it composed and focused?
    - The first thing is to dial in a 1s or so exposure and hit Frame and Focus. It'll start looping 1s exposures and your job is now to get it close to focus. If you see nothing at all, odds are you're just well out of focus. Really bright stars will help get this rough focus as even when they're far out of focus, they have enough light to still see them. Slowly adjust your focus knob between frames to get it close.
    - Once you're on, get a rough composition of your shot using Frame and Focus.
    - Then, hit Abort (to stop looping) and click on Fine Focus. At that point, pick the star you want to focus on and, still using the 1s exposures, use the tool there to hone in on perfect focus.
- How do I take a series of images?
    - Ideally, you've got a guiding package like PHD that you've setup, calibrated, and gotten going by now. If not, you'll quite possibly be limited to 30s or so exposures. Wider-field shots can run longer and better mounts can run longer.
    - Dial in an exposure duration you're going to want to use – 30s, 1m, whatever it may be.

    - Hit Preview and take a single exposure to see just what you're getting. It may-well look dark. So, uncheck the "auto" stretch box, slide the B to 0, and slide the W slider way left. Start to see your galaxy / nebula now?
    - Give it a name you'll remember (something better than "Series1"
    - Once you like your setup, dial in some number of exposures (20 or more) and hit Capture Series. Nebulosity will take all your images.
- How many images should I take and just what the heck are lights, flats, darks and biases?
    - After you're done with your main images (Lights), you'll want to take some number of Dark frames (same duration, same camera temperature but the shutter closed or lenscap on).
    - Before you move or remove your camera, you may want to take Flat frames. These are easier to do in the morning unless you have a "flat box" or "flat panel" that glows. For your first night out though, feel free to skip the Flats if you can't do them. You can correct vignetting later using the Synthetic Flat Tool.

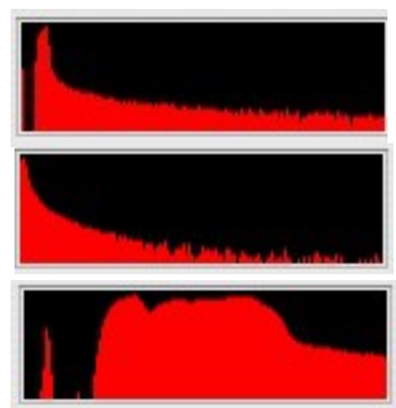
In addition to the sections above, there are a good number of video tutorials on the website to help get you going and to explain what the various tools are.

8. Capturing Images

Most of what you need to know to capture images was covered in the previous section on the Exposure section of the Capture Panel. There are a few topics worth considering on their own, however.

8.1. Lights, Darks, Flats, and Biases

You've probably heard these terms by now but just what is a flat or a bias and what are they used for? The lights are easy – they're just the shots you took of your DSO. The other three though are images of things you took inadvertently when imaging your DSO. They're used to correct the Lights and remove these inadvertent artifacts.



Lights: Let's start with the *Lights* – those are easy – they're just the shots you took of your DSO. Hopefully, you're shooting frames that are 1m or longer and you got at least 20 or so of them (if not a lot more!). When taking them though, pay attention to the histogram window. The first one is good and the other two have issues. See how on this first one here there's a nice gap on the left side? That means your background has some glow or offset and that's a good thing. You don't want the histogram banging into the left the way it is on the second one (or if you do, verify that pixel values aren't ever coming in as 0 – 0 is evil – increase your Offset if your camera has one). You also don't want your histogram banging hard into the right side like this third one here. A bit is fine – it just means the cores of your stars are saturated. But if it bangs into it hard like the third histogram, you'll want to dial the exposure (or Gain / ISO) down as a lot of your image is being saturated (aka over-exposed).

Darks: When you open the shutter and start letting in photons from the DSO, that's great. However, you're also getting photons building up from heat (whether the shutter is open or not). Each pixel may get the same average amount, but some are very sensitive to this (hot pixels) and even without that, the buildup is a somewhat random process. Taking a number of dark frames lets you estimate how much this added into your image. For starters, take 10-20 frames with the shutter closed (or scope lenscap on) of the same exact duration as the Lights and at the same temperature as the Lights.

Flats: Odds are your frame isn't perfectly evenly illuminated. You've probably got some vignetting making the middle brighter than the corners. You may also have dust spots making donuts on your image. In both of these cases, the odds that a photon that's heading towards your sensor actually makes it to the sensor varies as a function of where on the sensor it's heading as something may be blocking it (please don't enter into particle-wave duality here!). If we can image this, though, we can pull it out of your lights. For starters, take 10-20 frames by evenly illuminating the field. Some do this by putting a glowing "flat panel" on the front of the scope, others aim at a wall, and others aim at the early morning sky the next morning (perhaps putting a t-shirt over the scope). Whatever you do, make it even and then expose for a very short duration so that the histogram shows all of your values are well off the left and right side. Leave at least a quarter or so of the histogram blank on each side, ideally with it roughly centered (see first histogram above). If you're going to err on one side, have the peak more on the left than the right, but just make sure you're not banging into the left edge of the box. If you've got a color camera, it may look like the second one shown here with 3 separate distributions (you're getting ones for red, green, and blue pixels). That's fine. Just make sure there's a reasonable gap between the darkest of the first bump and the left side of the histogram window and the brightest of the last bump and the right side of the histogram window. Use your exposure duration or the brightness of the light source to shift this around. If changing exposure duration isn't moving it, you're saturating your sensor and need to cut things down a lot.

Biases: Every pixel has a bias – an offset – that gets added into each image. It's almost the same for every pixel, but not exactly the same. That offset is also in your light. Bias frames are very short (e.g., 0.001s) exposures with no light hitting the sensor. Think of them as zero-second darks. If you're going to use these (they're optional), again take at least 10-20 of them. They're optional, though, because your Darks already have the bias current in them. Remember, bias gets added no matter what into your image. Never use simple Darks and Biases at the same time when using Dark Subtraction or you'll end up subtracting this offset twice. Biases can be very effective at cleaning up your flats (which also have the Bias signal in them). But, odds are you can just smooth your flats a bit during pre-processing. It's up to you.

If you notice, for each of these, I said to take 10-20 frames for starters. Why? Each image is an estimate of the true value of the artifact (or of the DSO + artifact). It's a sample that was influenced by both the true value (what it should be) and random noise. There are several sources of noise but the nice thing is the noise bits are fairly random. Some times they go up and some times they go down. Some times it's a head and some times it's a tail. Sample it enough times and average the samples and you end up closer to the truth as the noise cancels.

8.2. Monochrome vs. Color Cameras

Monochrome cameras have CCD pixels that have no filter placed in front of them. Light simply hits the CCD array and the intensity gets recorded and saved. The CCD and *Nebulosity* don't care in the slightest whether you have no filter in place, an IR filter in place, a red filter, an Ha filter, or any combination thereof. To the camera and to *Nebulosity*, it's all black and white data that comes straight off of the CCD as every pixel operates just as every other pixel.

One-shot color cameras are a different story altogether. One-shot color cameras have tiny color filters placed over each CCD pixel. Typically, red, green, and blue filters are used (although other options for filter sets exist). For example, if one looked at a small 4x4 pixel patch of the CCD, one might see the arrangement shown on the right. Each pixel on the chip codes for only one color. So, if you have 1 million pixels, you have 500,000 green, 250,000 red and 250,000 blue pixels (CCD makers over-emphasize the green since our eyes are most sensitive to green). This is why you may hear people say that one-shot color imagers have less resolution than monochrome imagers.

To some degree, this is true. Yet, when you look at a digital photograph from a digital camera, you don't see this array of colors and you don't see a low-resolution shot. Digital cameras use this same kind of one-shot color CCD but produce crisp, full-color images with as many pixels in the output (each pixel having values for red, green, and blue) as they have pixels on the chip.

Whether the way this works is black magic or math is up for you to judge, but there are very good techniques for turning images from this "Bayer" matrix into a full-resolution, full-color image. This conversion is called "De-Bayering" or "De-Mosaicing" the raw CCD image. Depending upon the sophistication of the technique, the end result can be as poor as having resolution of one fourth the pixel count or as good as having nearly as good resolution as the full pixel count. In general, the "luminance" or "brightness" resolution is almost as good as a monochrome CCD, while the color resolution (the ability to rapidly change between red, green, and blue) is not as good, with techniques differing in just how much is lost. Fortunately, while intensity in both daylight and astronomical images can change very suddenly in an image (as we go from a black background to a star), the hue (or color) changes much more gradually. Thus, we can "get away" with having less color resolution than we have intensity resolution.

G	B	G	B
R	G	R	G
G	B	G	B
R	G	R	G

It is for this very reason that even when using monochrome CCDs, imagers often shoot a luminance channel at full resolution and color channels at lower resolutions (by "binning" their CCDs to increase the signal to noise ratio but decrease the resolution). Thus, low color resolution but high intensity resolution is often chosen by monochrome CCD imagers, narrowing the potential difference between the quality of the output between the two CCD types.

8.3. One-shot color cameras: Should I capture RAW or RGB?

Nebulosity lets you capture and save images from one-shot color cameras either in the RAW format from the CCD (where pixels still follow the Bayer pattern or whatever pattern is on your CCD) or in full-color RGB format. Here, by “RAW”, we don’t mean CR2, NEF, CRW or any other of the formats used in DSLRs. By “RAW”, we simply mean the pure, raw, unprocessed, unadulterated image data from the sensor of a one-shot color camera. All DSLRs are one-shot color cameras and all use the Bayer matrix described above. The data from this matrix, as noted above, is monochrome (grayscale) data. Before converting this into color, it is “RAW”. (This RAW data could hypothetically be stored in CR2, NEF, etc. format or it could be stored in FITS, PNG, TIFF, or any other format - it’s still the same data from the sensor.)

You have a choice in Nebulosity whether to keep the data in this pure RAW format on capture or whether you want to convert it to color. Many people instinctively want to convert it to color (since their camera is a color camera). This is an option and if you select this in your Preferences (Capture, Acquisition mode), *Nebulosity* first captures this raw data from the CCD and then applies a de-mosaic function to convert it into a full-color image. This full-color image is then saved and the raw data are lost.

On-the-fly conversion to RGB is perhaps the simplest and most intuitive format for the user. You ask for a full-color image and you get it. Many fine images are created this way, but it does have a few drawbacks. First, each image is 3x as large as a RAW image, taking up 3x as much space on your hard disk. Second, on-the-fly de-mosaic takes some amount of time for each image. Thus, if your capture machine is a lower-end machine, you may want to capture in RAW and convert to RGB later.

Finally, RAW capture has one more advantage. Dark frame, bias frame, and light frame pre-processing is somewhat more accurate at fixing images in RAW mode than in RGB mode. In addition, if you capture in RAW format you can use the powerful Bad Pixel Map tool, which must be used prior to the de-mosaic process (see Bad Pixel Mapping). **For these reasons, it is better to capture your one-shot color data in RAW format and convert it later.**

If you do choose to save the data in RAW format and not convert on the fly, you will pre-process your images in B&W / RAW mode and de-mosaic all of the pre-processed images prior to stacking (otherwise, you'll put red pixels atop green pixels, etc. and lose all hope of making a final color image).

8.4. File formats

Nebulosity can read just about any valid FITS image file out there (it makes extensive use of NASA's FITS library) and can write images in a range of useful FITS formats. The format it will write in is set by your choices in the Preferences menu. This is true not only for captures but for any time you pull down "Save" from the File menu (thus letting *Nebulosity* act as a FITS format converter).

For color images, you have several options. RGB FITS is the default. Here, a single file holds the red, green, and blue data after the image has been converted into a full-color image (de-mosaic). Unfortunately, there are two ways in which other programs have chosen to implement RGB data in FITS files. The differences are esoteric to most (and concern using 3 HDU's vs. using 3 axes) until one realizes that programs using one standard don't generally like files written by the other standard. So, *Nebulosity* will not only read both formats just fine, but it'll write either of them. They're labeled *RGB FITS: ImagesPlus* and *RGB FITS: Maxim / AstroArt*.

In addition to this, *Nebulosity* will write three separate FITS files for a full-color image if you so desire. One will have the red data, one the green, and one the blue. This is a far more cumbersome way of dealing with the data and unless you have a very good reason to do this, odds are you shouldn't do this.

Right click on a .fit file in Windows and select "Open With" and "Choose Program". Browse to Nebulosity (c:\Program Files (x86)\Nebulosity4\Nebulosity4.exe) and select "Always use the selected program". Or, on a Mac, right-click on it and pull down Get Info. Under Open With, select Nebulosity and then click the Change All button. Now, double-clicking on .fit file will automatically start Nebulosity and load the image.

Nebulosity can save in a compressed FITS format to save space. The compression algorithm used is native to FITS and is a lossless one. You're doing no harm to your data by using it. If you don't wish to use compression (e.g., you wish to use a program that doesn't support it), simply uncheck this in the Preferences menu. (Note: Maxim DL uses a "compressed FITS" format that is proprietary and not the standard FITS compression. Nothing outside of Maxim DL can read this format and Maxim doesn't seem to always like FITS' native compressed format.)

If space is not a concern and you want to absolutely maximize the quality of the saved data, you can choose to save the data in 32-bit floating point format. This is the native format used internally. Data files will be twice as large and, in truth, will likely show little more than the default of saving in 16-bit integers.

Finally, you can choose to rescale your data to 15-bits rather than the full 16-bits possible. Thus, your data will be scaled into the range of 0-32767 rather than 0-65535. This is anoption to support several programs.

Suggested settings if you plan to use other applications as well

AstroArt	16-bit, RGB FITS Maxim/AstroArt, uncompressed
ImagesPlus	16-bit, RGB FITS ImagesPlus, compressed
Iris	15-bit, 3-separate files, uncompressed or PNG/TIFF.
Maxim DL	16-bit, RGB FITS Maxim/AstroArt, no compression
Photoshop	File, Save 16-bit/color TIFF or PNG
PixInsight	File, Save 16-bit/color TIFF or use 16-bit RGB FITS Maxim uncompressed

FITS is used as a standard not only because it is so common in the astronomical community, but also because it allows for arbitrary information to be stored along with the image. So, *Nebulosity* stores information such as the time the image was captured, what camera was used, what exposure duration, gain and offset were used, etc. along with the image.

That said, many graphics programs do not support reading of FITS images. Here, you have two options. First, you can save an image *as displayed* (i.e., taking into account the B and W slider positions) in 24-bit BMP or JPEG format. If you do this, try to do most of your processing beforehand as this format will allow for only 8-bits of information for each color channel. Subtle gradations will be lost when you do this (but remember, your monitor will only display 8-bits per color anyway).

Second, you can save in 16-bit/color (aka 48-bit color) TIFF or PNG format. Both compressed (LZW) and uncompressed TIFF formats are supported (PNG format is always compressed). These options all provide ways of saving your data without any loss or degradation for use in other programs. *These also are excellent ways to get color images into programs like Iris v5.*

Finally, you can load both 8-bit/color (24-bit) and 16-bit/color (48-bit) images from a number of formats. 8-bit JPEG, BMP, TIFF, PNG, and TGA files can be loaded and will be automatically stretched to 16-bits/color. 16-bit TIFF and PNG can be loaded as well.

8.5. Camera Gain and Offset

While many cameras have their gain and offset set by the manufacturer, some let you adjust these parameters. For cameras that do, *Nebulosity* will include these fields in the Capture panel. My advice is to set it once and forget it. To understand why, we can first go over just what gain and offset do. If you want a good bit more on the details of what these are, skip ahead to the section on this in Taking Good Images.

8.5.1. How should I set my gain and offset to set it and forget it?

The best value for your camera may not be the best value for other cameras. In particular, different makers set things up differently. For example, on a Meade DSI III that I recently tested, running the gain full-out at 100% let it just hit full well at 65,535 ADU. Running below 100% and it hit full-well at 40,000 or 30,000, or 10,000 ADU. There's no point in running this camera at anything less than 100% gain. On a CCD Labs Q8-HR I have, even at gains of 0 and 1 (on its 0-63 scale), the camera would hit 65535 on bright objects (like the ceiling above my desk). There's no point in running this camera at gains higher than 0 or 1.

Why is there no point? The camera only holds 25k e-. If a gain of 0 or 1 gets me to 0.38 e-/ADU (so that those 25k e- become 65535), running at 0.1 e-/ADU will only serve to limit my dynamic range. Each single electron already comes out to more than 2 ADU.

So, to determine the gain and offset to use:

1. Take a bias frame and look for the minimum value in it. Is it at least, say 100 and less than a thousand or a few thousand? If so, your offset is fine. If it's too low, boost the offset. If it's high, drop it. Repeat until you have a bias frame with an offset in, roughly 100 - 1000. Don't worry about precision here as it won't matter at all in the end. You now know your offset. Set it and forget it. Never change it.
2. Aim the camera at something bright or just put it on your desk with no lens or lenscap on and take a picture of say 1s (the idea here is to ensure you're saturating the CCD so the wells will be full). Look at the max value in the image. Is it well below 65k? If so, boost the gain. Is it at 65k? If so drop the gain. Now, if you're on a real target (daylight ones are great for this) you can look at the histogram and see the bunching up at the top end as the camera is hitting full-well. Having that bunch-up roughly at 65,535 plus or minus a bit is where you want to be. If you pull up just shy, you'll get the "most out of your chip" but you'll also have non-linearity up there. You've got more of a chance of having odd color casts on saturated areas, for example, as a result. If you let that just clip off, you've lost a touch but what you've lost is very non-linear data anyway (all this assumes, BTW, an ABG chip which all of these cams in question are). Record that gain and set it and forget it. Never change it.

By doing this simple, daytime, two-step process you've set things up perfectly. You'll be sure to never hit the evil of zero and you'll be making your chip's dynamic range fit best into the 16-bits of your ADC. Again, all the cameras in question have full-well capacities below 65,535 so you are sure to have enough ADUs to fit every electron you record into its own intensity value.

8.6. Getting good focus

We've already covered the basics of the fine-focus tool. Click on Fine Focus and then, on a Preview image or on the result of your Frame and Focus, click on a star and it'll start looping frames of just that star. Adjust the focuser until it's nice and sharp and until the HFR (half flux radius) is at the lowest or the maximum intensity is at the highest, using the graph there to show you if your current value is really the best you've gotten. At that point, you're set.

But what if you can't see anything at all? Odds are you're *way* out of focus. Find a very bright star or planet in an eyepiece and try again using Frame and Focus and even a 1s or so exposure, slowly adjusting the knob until you start to see a blob or blobs and then your stars. Then, run the Fine Focus routine.

This process is only semi-automated as you can see and there are auto-focus routines out there. The *de facto* standard is Focus Max and as of Nebulosity 4, you can integrate Focus Max with Nebulosity for full auto-focus.

8.7. Lining up shots across nights or meridian flips

Many of us end up taking shots across several nights, be it just to collect more data or to collect data using several filters. Even more of us stay on the target across the meridian flip in which our GEM mounts must rotate around, flipping the image in the process. In both cases, odds are very high that you won't be in exactly the same spot you had been in the sky. If we image in a somewhat different spot, combining the data from the two will lead to a much smaller area in which you've got a full set of data (only where all the frames overlap).

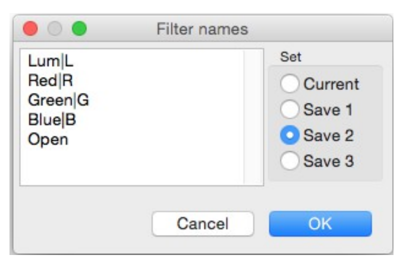
Fortunately, there's a very easy solution to the problem. The View, Overlay, Grid can help but there's a more accurate method that uses the markers you can lay down using the right mouse button. Here's how it works:

1. Load an image from the first night
3. Resize it / bin it according to your camera's highest bin mode (or 2x2 if you're using that for Frame and Focus). If it's 2x2, Image Bin will do it. If 4x4, you can run Image Bin twice. If 3x3, Image, Resize Image and use 0.333 as a scale factor. (To save you from having to do this, on the first night, after Frame and Focus, just save the image).
4. If it's a meridian flip you're fixing, rotate the image 180 degrees
5. Save this resulting image for posterity
6. Now, find some nice, prominent features like bright stars and right-click on them. You can do this for up to 3 stars and you'll get little circles with crosshairs on them. If they're not perfectly on the star, don't stress – just note which way they're off by a touch.
7. Enter Frame and Focus and now move your mount until the stars are under the markers you just laid down. Frame and Focus is streaming binned images and you laid the markers down on the binned image from the first night. When the markers are on the stars, you're in the same spot you were last time!

8.8. Filter wheels and the Extra Camera Control panel

Many of us run with filter wheels either built into the CCD camera or as external units. Nebulosity lets you control these wheels (and script them) and, as of v4, you can name the filters too and use these names in your captures. It'll also stick the name in the FILTER header in FITS files.

8.8.1. Naming your filters



In both the Extra Camera Control and the External Filter Wheel tool there is a pull-down that lets you select your filter. Just to the right of that is a small button ("*"). Pressing this pulls up the filter name tool that lets you rename your filters.

Starting on the right, in the "Set" section, we have selections for "Current" and for three save spots. As you toggle among these, you change what is shown in the left portion. In the sample here, I'm viewing the second save set and I have setup an LRGB array of 4 filters. If I were to hit OK here, this filter set would be selected and become current. So, if

I entered the dialog again, the initial display and “Current” tab would show this set. Thus, if you’ve entered some filter names at any point in Save tab, they will get saved for later use and whatever is shown when you press OK becomes the new current, active set. Simple!

In this example, you’ll see that there are 5 names for my 5 filters and that 4 of them have a vertical bar | there separating portions of the name (“Lum|L”). First off, if you specify too few names, Nebulosity will fill in names for the missing filters. If I didn’t call the last one “Open” and only listed 4 names, the last one would become “Filter 5”. This is so that the pull-down to select your filter has something for each position on your wheel.

The vertical bar there is something different though. If you specify a name with X|Y, anything to the left of the | becomes what is shown in the dialog where you select your filter and anything to the right of the | becomes what is listed in the filename if you’ve set your Preferences up to append the filter name to the filename. So here, my filter selection dialog would list Lum, Red, Green, Blue, and Open and my filenames would include L, R, G, B, and Open.

9. Overview of Image Processing

You've taken your images and are now comfortably inside. Now what? How do you get all those raw frames to look like a nice pretty stack? Just what the heck is Bad Pixel Mapping? Should I try Drizzle?

The rest of the manual provides answers to many individual questions and documents each of the tools in more detail. The goal of this section is to let you see how all of these fit together and to give you the necessary information to choose a path through the initial processing of your data. This alone won't give you a full understanding of how each tool works (see the individual section for each tool), but it should help put all the pieces together. In addition to the coverage here, there are several tutorials and walk-throughs available on the web.

The basic steps are as follows:

1. Decide on how you'll deal with hot pixels (BPM vs. Dark subtraction)
8. Prepare and apply any sets of darks, flats or bias frames to remove hot pixels, vignetting, etc.
9. Convert RAW images into color via Demosaic (if one-shot CCD used and captured in RAW, which you really should do) and square-up your pixels (if needed)
10. (optional) Normalize the images
11. (optional) Grading and Removing Frames
12. Stack the images (Align and Combine)
13. Crop the image to clean it up
14. (color only) Remove skyglow hue
15. Stretch the image (Levels, DDP, etc)

9.1. Deciding on Bad Pixel Mapping vs. Dark Subtraction

Both of these techniques are designed to deal with the thermal noise inherent in your images and the resulting "hot pixels" that show up in the same spot on the image in each frame. Dark subtraction is the traditional way of doing this. It works by simply subtracting the value for each pixel in your "master dark" from the value of that pixel in each light frame. If your light frames and dark frames were taken with the same exposure duration and at the same temperature, dark subtraction will remove the hot pixels (and "luke-warm" pixels as well - any thermal noise, not just the brightest). This can work very well *if you control the temperature, exposure duration, and take a lot of dark frames*. If you don't do these, you can end up with "holes" in the image (black spots where the hot pixel used to be), incomplete hot pixel removal, and you can inject noise into your light frames (see above).

Bad Pixel Mapping works differently. You first create a "Bad Pixel Map" (Batch, Bad Pixels, Make Bad Pixel Map) using a dark frame or stack of dark frames. A slider appears to let you set a threshold (feel free to use the default). Values in the dark frame that are above the threshold say "this pixel is bad". Bad pixels, and only bad pixels are fixed in your light frames by using surrounding good pixels to help fill in what this pixel should have been. For many cameras (in my experience, the cooled cameras with Sony sensors work wonderfully), this is an exceptionally powerful technique as the hot pixels are removed effectively with no noise being injected. It's also very flexible as you can use the same "master dark" from night to night and from exposure duration to exposure duration just by adjusting the slider and making new maps as needed.

Note: If you use Bad Pixel Mapping you will typically not use Dark Subtraction and vice versa. One or the other but no need for both. If you use Bad Pixel Mapping you can still use flats and bias frames and it doesn't matter whether you apply BPM before or after your other pre-processing. BPM just locally fixes the bad pixels and doesn't touch any non-bad pixels. In fact, using both flats and bias frames is a good thing.

If you're using Dark Subtraction, keep in mind that your dark frames already have the bias current in them. You will not typically use both darks and biases as a result. If you do, you'll end up removing the bias twice (which injects the inverse of the bias back in). So, don't do that.

Now, it is possible to use Dark Subtraction first and to then follow this with a round of Bad Pixel Mapping. It's not common but it can have a use. For example, if you routinely end up with "holes" where you have over-subtracted the hot pixels or they were improperly fixed, you can run Bad Pixel Mapping to fill in values here rather than use the ones that the subtraction came up with.

When using flats, it can be a good idea to let Nebulosity smooth the flats a bit for you. At the very least, if using a one-shot color camera, use the 2x2 mean or CFA scaling option in the pre-process tool. I often use a 7 pixel blur. This reduces the noise in the flats and makes for smoother images.

9.2. Applying the darks, flats, and biases

Odds are you've taken some number of darks, flats, and/or bias frames (control frames) in addition to your lights. What the heck do you do with them? Your goal is to combine these control frames as needed (to reduce the noise in them) and use them to fix the problems in your lights. Your lights will have not only the signal from your DSO in them, but they will have dark current and bias current and will probably not be perfectly evenly illuminated. Pre-processing is the step that applies these control frames to your lights.

Before we apply them, though, we typically want to stack (or combine) multiple control frames. Having more than one dark, flat, and/or bias frame is a good thing as each individual frame has both the artifact you want to remove from your lights and random noise. Stack a bunch of these together and the random noise goes away leaving you with a clean image of the artifact you want to remove. Use just one and you remove the artifact and whatever random noise that one frame had. *Since it's random noise won't be the same as the random noise in your image, using just one dark, flat, or bias will actually inject noise into your light frame and make it noisier.* This is why people take a good number (20-100) of each of these.

In *Nebulosity*, you can stack them all first (to make “master” control frames) or you can stack these on the fly while correcting your lights. This all happens in the **Pre-process image sets** tool.

This tool allows you to pre-process 1-5 sets of lights using 0-3 sets of darks, 0-2 sets of bias frames, and 0-5 sets of flats. If you pass in more than one control frame (flat, dark, or bias), it will stack it on the fly for you. If you want to apply a bias frame or a dark frame to your flats, it can do that too. Got data from a mono camera with 5 filters each with its own flat and with a few different exposure durations (and therefore a few different darks)? No problem.

Using the tool is covered in more detail in the Multiple-Set Pre-Processing section, but can be quickly summarized as follows:

1. Pull down Batch, Pre-process image sets
16. Click on the buttons to define your “control sets”. For example, click on “Dark 1” to select one or more dark frames that you can now refer to as “Dark 1”.
17. (optional) If you want to do things to your flats on the fly, tell it which bias and dark to apply (both are entirely optional) and whether you want to blur the flats at all. If you’re using a one-shot color camera, you will at least want to use the 2x2 mean here to remove the Bayer matrix. Blurring the flats will help reduce the noise (grain) in them.
18. Click on the buttons to define your sets of light frames (“Light 1” through “Light 5”). You can have 1-5 sets of lights that you work on at once.
19. Select which biases, darks, and flats get applied to each of the sets of lights.
20. If this all made no sense, see the Multiple-Set Pre-Processing section where it is laid out in more detail.

9.3. Using Bad Pixel Mapping

Let’s say you chose not to use traditional dark subtraction to take care of those hot pixels and instead want to use bad pixel mapping. You still will probably apply flats and/or biases (bias frames are good to use if you’re using BPM). To apply BPM to your light frames:

1. Create a Bad Pixel Map if you don't already have one. Batch, Make Bad Pixel Map. Select a dark frame or stack and start off by just hitting OK to use the default threshold. If for some reason you don’t like that threshold, adjust the slider to let you remove more or fewer pixels.

21. During pre-processing, click one of the Dark buttons and load the Bad Pixel Map you created in step 1.
22. For that entry, go to where it says “Dark Subtract” and pull down one of the BPM options. If you’re using a mono camera, use “BPM Mono”. If it’s a one-shot color camera but you’ve not demosaic’ed yet, use “BPM Color”. If you’ve converted to color already, go back and read why I suggest you use RAW and don’t convert to color yet.

9.4. Converting RAW images to Color and/or Pixel Squaring (aka Reconstruction)

The last step before stacking your images is to convert them to color (if they are from a one-shot color camera and you captured in RAW) and square them up as needed. Some cameras have pixels that are not square and this will lead to oval rather than round stars. The process of demosaic'ing (color reconstruction) and/or pixel squaring is called *Reconstruction* in *Nebulosity* and the details of this can be found in the section on Reconstruction: Demosaic’ing and Pixel Squaring.

Note, you can tell if your images need to be squared up by pulling down Image, Image Info. Near the bottom you will see the pixel size and either a (0) or (1). If it is (1), the pixels are square. Of course, the pixel dimensions will be the same in this case too.

To reconstruct all of your light frames, simply:

1. Pull down Batch, Batch Demosaic + Square (if images are from a one-shot color camera) or Batch Square (if images are from a monochrome camera or you just feel like squaring up a color cam's but keeping the image as monochrome for some reason).
23. Select your frames
24. Ideally, *Nebulosity* will start loading and reconstructing the frames. If it pops up a dialog asking for things like offsets, it means it did not recognize what camera captured the image (or you have “manually override color reconstruction” checked in the Preferences). If this happens, consult the Reconstruction: Demosaic’ing and Pixel Squaring section.
25. In the end, you'll have a set of images named "recon_OriginalImage.fit"

9.5. Normalize Images (optional)

All things being equal, your 50 frames of M101 should all have the same intensity. They were taken on the same night one right after the other and all had the same exposure duration. So, they should be equally bright, right? Yes, but there's that nagging "all things being equal" we supposed and, well, all things aren't always equal. For example if you start with M101 high in the sky and image for a few hours it starts picking up more skyglow as the session goes on, brightening the image up. That thin cloud that passed over did a number on a frame that still looks good and sharp, but isn't the same overall intensity as the others, etc. All things are not always equal.

If you're doing the Average/Default method of stacking, you need not worry about this issue unless the changes are really quite severe. If you're using standard-deviation based stacking, Drizzle, or Colors in Motion, it is a good idea to *normalize* your images before stacking. What this will do is to get all of the frames to have roughly the same brightness by removing differences in the background brightness and scaling across frames.

There are two methods you can use to normalize images. The first (and original), performs a purely linear stretch to put the black and white points in roughly the same place. To normalize a set of images, simply:

1. Pull down Batch, Normalize images
26. Select the light frames you want to normalize
27. In the end, you'll have a set of images named "norm_OriginalName.fit"

The second, more advanced tool, attempts to equate the histograms of two or more images. This is a more complex stretching procedure that can account for more kinds of changes across images. To use this *Match Histogram* tool, simply:

1. Pull down Batch, Match Histograms
28. Select a reference frame and press OK. This will serve as the template image that others will be matched to.
29. Select the set of frames you wish to normalize
30. In the end, you'll have a set of images named "histm_OriginalName.fit"

9.6. Grading and Removing Frames (optional)

Sometimes bad things happen. The tracking goes awry, a breeze blows, you trip over the mount, etc. This is a good time to find those "bad" frames and pretend they never happened. There are two tools to help you here, covered briefly here and in more depth in Previewing and Grading Images.

9.6.1. Grade Image Quality

This will look at a set of frames and attempt to automatically grade them as to how sharp they are relative to each other. The idea here being that you'll not use the least sharp frames. Pull down Batch, Grade Image Quality and point it to your light frames. It will rename them (or copy them with a new name) denoting how sharp each frame is.

9.6.2. Image Preview

This will let you easily go through your images one by one to examine them, (optionally) rename them, and/or (optionally) delete them. File, Preview Files. If you've not tried this, try it. It's quick, easy, and immensely useful.

9.7. Stacking: Align and Combine

It's now time to Align and Combine (stack) your light frames. Here, there are a large number of options as to how to proceed. We'll start with the basic version first and then detail the other paths you can take.

1. Pull down Batch, Align and Combine Images
31. If you're not on an alt-az mount, hit OK, keeping the defaults of saving the stack, using Translation, and Average / Default stacking. If you're on an alt-az mount, you'll need to include rotation, so change the Alignment Method to Translation + Rotation.
32. Select your light frames
33. Find a star in your image that's not ultra faint and not big and bloated. Move your mouse over it to make sure that the core of the star isn't all 65535 (the max possible value). Click on that star and *Nebulosity* will advance to the next image. If your mount's tracking is at all decent, the same star on the next frame should be circled. If the circle is on the right star (don't worry about centering), just hit Ctrl-click (or Command-Click on the Mac) to tell Nebuolsity "yes, that's the right star and I want to use this frame". If it missed the star, just click on it (don't worry about being precise). If the frame is a bad one and you'd like to skip it and not include it, hit Shift-click.
34. If you're doing Translation + Rotation (or Drizzle), you'll need to find a second star and run through each frame again. Try to pick one that's not very close to the first star.
35. When you're done (the Status Bar will show you your progress), *Nebuolsity* will align and combine all the images and pop up a dialog asking you for a filename to save the resulting stack in.

There you have it! Basic stacking. There are some more advanced options you can try:

- Translation + Rotation (+ Scale): The normal Translation alignment will only shift images by whole pixels and does not account for any rotation across frames. Running these will shift the images by fractional pixels (interpolating them as needed), rotate them as needed and, if selected, scale them as needed to co-register the images.
- Drizzle: Drizzle is a powerful technique that will align, combine, and increase the resolution of your images during stacking. It is suitable for alt-az mounts as rotation is included in the alignment. You will therefore need to select two stars during alignment. Make sure you have Normalized your images at some point first.
- Colors in Motion: This tool is only available for images from one-shot color cameras that have not been converted into color yet. It will align the images and convert them into color at the same time. It is a translation-only based alignment.
- Standard Deviation (SD) or Percentile-based stacking: Instead of taking the average value for each pixel (across images), take the average but toss out "outliers" or values that are atypical. Thus, if a hot pixel "crosses over" a pixel in the aligned image (the hot pixel didn't move but the frame did when the stars were

aligned), this bright hot pixel will be an atypical sample and will be tossed out before averaging. ***This is very helpful if you find you have things like hot-pixel trails in your stacked image.*** To use this technique, you must first do your alignment, saving each frame first and then pass these aligned frames ("align_OriginalName.fit") into Align and Combine again, selecting "None (fixed)" as the alignemnt method (and one of the Std. Dev. thresholds in the Stacking Function). Make sure you have Normalized your images at some point.

9.8. Crop off the edges

After stacking, odds are you've got a dark border around your image as *Nebulosity* tried to make an output image big enough to hold everything from every frame (an exception here is in rotation where you will have bits cut off at times). Odds are you don't want this bit and it'll just make the histograms look funky when you're stretching. Use the mouse to define a rectangle that has the good part of the image and pull down Image, Crop. Save this with a new name.

> If you don't select a region to crop and pull down Image, Crop a dialog will appear asking you exactly how many pixels you want to remove from each side.

9.9. Remove the Skyglow Color

If you're shooting in color (one shot or having combined frames), odds are the background sky is not a nice neutral gray, but rather something rather unpleasant (green, pink, and orange are common). This comes from the color of your skyglow. Fortunately, it's easy to remove. Simply pull down Image, Adjust Color Offset (unless you've got a reason, accept the default values) or pull down Image, Auto Color Balance. Save this with a new name.

> Ever want to enter in a value for a slider manually? Click on the slider and you can often manually enter the value you want!

9.10. Stretching

Now, the fun begins as it's time to see what you really have in that shot. Sitting atop that skyglow should be the faint galaxy or nebula you were shooting and stretching is how we bring this out. There are three main tools for stretching in *Nebulosity*. The first is the Levels / Power Stretch, the second is Digital Development Processing (DDP), and the third is Curves. For each of these, more detail is provide in the section on Image Adjustment.

The goal in each of these is to pull your image's intensity profile (histogram) and stretch it so that very low contrast differences are made more apparent. Thus, you are pulling your faint galaxy arms away from the skyglow and doing things like sending the skyglow down to a nice dark background. When doing this:

- Keep your eye on the histogram. The histogram is your friend.
- Until the very last steps of stretching, don't let the left edge of the histogram get cut off and don't bang too much (e.g. the core of your galaxy) into the right edge of the histogram. Once they hit the edges (0 and 65535), you'll never resolve details in there again.

- Turn off auto-scaling (or let *Nebulosity* do this for you) so that what you're seeing on the screen is the full 16-bit data in all its glory. This will help you use the full range of intensities your image can take. Remember, the B and W sliders are just there to make the image prettier on the screen (they do a stretch for display but don't really affect the underlying image). So, have them at full left and full right and then start to stretch. (If you're in auto-scale when you enter Levels, it will turn it off and set these at the extremes for you).
- Don't try to do everything in one pass. Make several passes over the image to slowly pull it into the condition you want it.
- Save often

9.10.1. Levels / Power Stretch

The Levels tool in *Nebuolsity* does the same math to your image as tools like PhotoShop's Levels tool. You're setting a black point (top sider), a white point (middle slider) and a midpoint or "power" (bottom slider). This is much like a “Curves” tool but with a fixed basic shape to the curve (see Levels / Power Stretch). With several passes over the data you can build up a complex “Curves” transformation to your data. In general, for the first few passes, have the "power" slider be less than one (try values like 0.6) as this will help accentuate the low-contrast details and pull them out. Start getting the details to pull apart from the background before you work too hard on pushing the background to being dark. You can always darken the background later.

9.10.2. Digital Development Processing

DDP is a tool that applies a special transformation designed to make linear CCDs behave more like film. If you use DDP, do it first or without using the Levels tool much beforehand as the math behind it expects you to have not altered the linear response of your CCD's image. I find that DDP works best if the skyglow is not too bright to begin with. Feel free to use the Levels tool and adjust the black-point (first) slider to bring the histogram nearer to the left edge before running DDP. Just don't start adjusting the Power (aka midpoint, aka 3rd slider) in the Levels tool before using DDP.

9.10.3. Curves

The Curves tool gives you a lot more flexibility than you would get with either DDP or Levels and can be used both for initial stretching and for fine-tuning the results of something like DDP. Feel free to use all of the tools and to mix the tools as you see fit.

To use the Curves tool, simply grab one of the two blue dots and move it around. These two “control points” help you draw out the curve which is always shown in the dialog. By having these two points and the two endpoints, you can draw a wide range of very useful curves without getting into trouble by making a very odd transformation of your image. As with Levels, you can do a lot more in several iterations than you can in just one. As you re-use the tool, you’re effectively building up a more and more complex curve.

10. Image Pre-Processing: The Details

10.1. Pre-processing: Theory

Our CCD images have a number of artifacts in them. Typical artifacts include hot pixels (bright dots that appear in the same place on the image and that get worse with increased exposure duration or temperature), vignetting (un-even illumination of the field), dust spots (large blobs or donuts that appear superimposed on the image, looking a bit like a watermark), and noise (a static-like or grainy appearance to the image).

We can fix these by taking and applying a series of control frames that have the various defects but not our image and using them to remove the defects. When thinking about this, it is useful to consider the following:

$$
\begin{aligned}
&LightImage = TargetImage \times NonFlatness + DarkCurrent + BiasCurrent \\
&DarkImage = DarkCurrent + BiasCurrent \\
&BiasImage = BiasCurrent \\
&FlatImage = NonFlatness + BiasCurrent + DarkCurrent\_flat
\end{aligned}
$$

Our goal here then is to apply the following formula to our image:

$$NewImage = \frac{RawImage - DarkImage - BiasImage}{FlatImage - DarkImage\_flat - BiasImage}$$

Note, the dark current in a flat image (DarkCurrent_flat) is typically far, far less than in your light frame or dark frames since the exposure durations are typically a lot less for your flats and can typically be ignored.

Both **Dark Frames** and **Bias Frames** are taken with no light hitting the camera. Dark frames are to be taken under the same circumstances as your **Light Frames** (e.g., the RawImage pictures of your DSO). Use the same duration of exposure and try to have the CCD at the same temperature (e.g., if you use the TEC in your DSO shots, use it in the Dark frames. Often, these are taken in the same imaging session or a collection of "master" dark frames for various imaging situations is compiled. Always take a number of dark frames (somewhere between 10 and the number of exposures used in your light frames) and combine them (average or median) to create a suitable dark frame to be used during pre-processing.

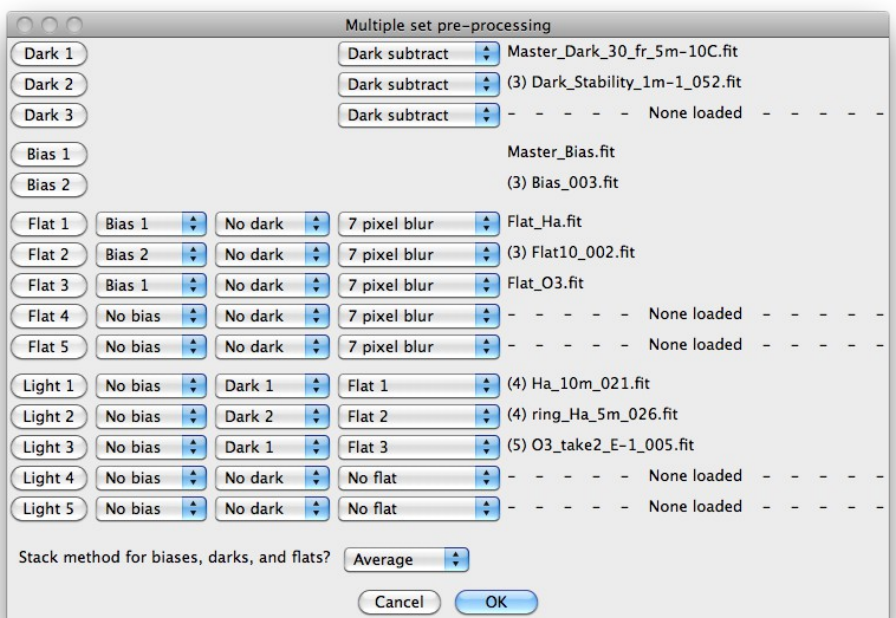
Bias frames can be taken at any time simply by covering the telescope or putting a lenscap on the camera and taking a series of short exposures (e.g., 10 ms). Take a good number of these some day when you're bored and combine them (average or median) to create a master bias frame.

In contrast to Bias and Dark frames, **Flat Frames** are taken with light hitting the camera, but with the light coming from an even field of illumination (e.g., aiming your telescope at a white wall, defocused at the sky at dusk bouncing the scope around, putting a diffuser over your telescope, etc). The exposure duration of Flat frames does not matter *per se*, but should be long enough to ensure no pixels are at or near zero and no pixels are near saturation (*Nebulosity* will automatically scale the intensity of the image to have a mean of 1.0, so don't worry how bright it is overall). Again, take several of these and combine them.

Nebulosity's Pre-process routine will subtract any Dark frame provided from each image, subtract any Bias frame provided from each image, and divide the result by the flat Frame. You may notice that this is leaving off part of the equation, as the denominator does not include the part about subtracting the Dark frame or Bias frame from the flat frame. This is because the Flat frame is typically taken at a different duration (usually much shorter) than the Light frames, meaning a different Dark frame is needed to remove the hot pixels from the Flat frame. What this means is that for best results, you should pre-process your Flat frame by treating it like a Light frame and applying a suitable Dark frame or Bias frame. The easiest way to do this is to tell *Nebulosity* to apply the bias frame to your flats as well (or to smooth the flats).

10.2. Image Set Pre-processing Tool

Some users will take a single set of lights, darks, and flats for a target. Others, monochrome imagers in particular, will end up with multiple sets of lights, darks, flats, etc. The Batch, Pre-process Image Sets tool lets either kind of user easily pre-process images.



When you first fire it up, it may not seem as if it's going to be easy as the dialog may seem a bit daunting. What's shown on the right here is a sample we'll walk through. It's really actually quite straightforward, though.

There are a few things to keep in mind:

Define your control frames (darks, biases, and flats) first. Here, you're saying "these are the frames I'm going to want to use to fix some lights."

You can select individual images or multiple images. *Nebulosity* will stack the frames on the fly if you select multiple. For the flats and lights, you can choose to apply the control frames - the bias, dark, (and, for the light frames, flats). When you're doing this, you're telling *Nebulosity*, which control set to apply.

Let's walk through this example. First, I pressed the **Dark 1** button and when the dialog appeared, I selected an existing master dark frame (in this case it is called "Master_Dark_30_fr_5m-10C.fit"). This is now *Dark 1*. I then pressed the **Dark 2** button and grabbed three frames (these are actually from another camera with a different sensor size even). Remember, you can select multiple images in those dialogs by shift-clicking, control-clicking (or on the Mac, Command-clicking) the way you can in other applications. Here, we're telling *Nebulosity* to stack those three dark frames and call that *Dark 2*. Note how next to the name of one of these dark frames ("Dark_Stability_1m-1_052.fit") you see the number three in parentheses. This is telling you that there are three frames you selected here that will be stacked on the fly.

I did a similar thing to select an individual bias (*Bias 1*) and to stack several raw bias frames (*Bias 2*). Again, these are actually from two different cameras (though they needn't be, of course).

I selected several sets of flats here as well. For *Flat 1*, I've got pre-stacked flats from the first camera when the H-alpha filter was on it. For *Flat 3*, it's the same camera with the O-III filter on it. For *Flat 2*, it's the other camera and I selected several flats here to stack on the fly. For the flats, though, we want to do some pre-processing to clean them up. First, the flats don't have much dark current but they do have bias current. So, I told *Nebulosity* to apply the appropriate bias frames to these flats. The first camera's bias frame was "Master_Bias.fit" and this was defined as *Bias 1*. For both *Flat 1* and *Flat 3*, we'll apply this bias frame. The second camera's bias frame was *Bias 2* (the stack-on-the-fly bias frame of three individual images, including one called "Bias_003.fit".) So, *Bias 2* is selected for *Flat 2* and *Bias 1* is selected for *Flat 1* and *Flat 3*. In addition, there will still be some noise here that I may want to reduce before applying the flats to my lights. So, *7 pixel blur* is selected here by default (the default value is set in the Preferences dialog). You've got several options here to choose from. If you're using a one-shot color camera, though, you'll want to do something here to at least remove the Bayer matrix (any of them should remove this).

Now, we move onto the lights. Here, I selected some H-apha and O-III data from the first camera and put them into *Light 1* and *Light 3*. It's important to note here that I could have put them in any set of lights. I could have done *Light 1* and *Light 2* or even started at the back and done *Light 4* and *Light 5*. Which set you put them in doesn't matter. ***You don't need to match up those numbers with your flats, biases, or darks. Where you do the matching is in those pull-downs.*** So, for these two sets ("(4) Ha_10m_021.fit" and "(5) O3_take2_E-1_005.fit"), we're going to apply the same dark frame - *Dark 1*. We'll apply different flats, though, as there were different dust bunnies on my two filters. So, the flat with the H-alpha filter (*Flat 1*) gets applied to the light with the H-alpha filter (*Light 1*). Same deal for the flat with the O-III filter (*Flat 3*) and the light with it (*Light 3*). For the lights from the second camera, *Light 2*, we're going to apply its dark (*Dark 2*), and it's flat (*Flat 2*). Of course, since the bias current is contained in the dark frame, we're not going to apply any bias frames here (that would double-subtract out the bias and inject the bias back in).

Once you're all set, press **OK** and go away for awhile. Note that if you have the History window open (View menu), you'll get a full blow-by-blow of exactly what is going on.

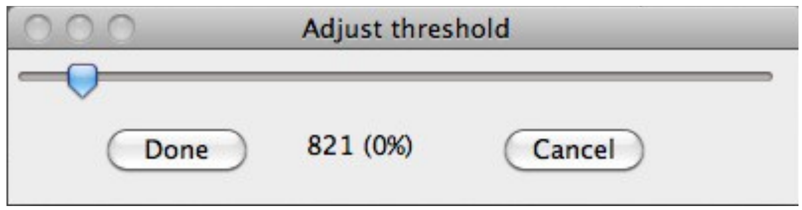
10.3. Bad Pixel Mapping

Removal of hot pixels using the typical (or automatically-scaled) dark frame subtraction technique does have one real drawback. Your dark frame contains not only information about the hot pixels, but it contains other kinds of noise as well. Stretch the dark frame and you'll see the same kind of "readout noise" you see in a bias frame along with other noise components. If you average many of these frames (some suggest twice as many dark frames as light frames), much of this noise will disappear, but it may take a lot of dark frames to have it go away. Therefore, while dark frame subtraction will remove hot pixels, *it can actually add noise into your image!*

An alternative method for removing hot pixels is called *Bad Pixel Mapping*. In this technique, you first identify those pixels on your CCD that are prone to problems – your hot pixels. Once you've identified those pixels, only those pixels in your light frames are touched. We don't really know what the value in that pixel should be, but the software can make an educated guess and fill in for the bad value. This can work very well as the images below show. First is a zoomed-in frame from a one-shot camera that was de-mosaiced without any correction. Next is the same area when the bad pixel map was applied prior to the de-mosaic process.

Using Bad Pixel Maps is quite easy but does require that you are either using a black and white camera or, if using a one-shot color camera, that you capture in RAW mode (Bad Pixel Mapping must be performed prior to converting the image into full-color). The first step is to generate the map. For this, you need a dark frame or an average of several dark frames.

Ideally, this will be a combination of several frames taken at the longest exposure duration you expect to use. Pull down *Make bad pixel map* from the Batch menu and load the dark frame when prompted. A slider will now appear and the display will show you your hot pixels. *Nebulosity* attempts to come up with a reasonable position of the slider for you. Here, we have the default setting and display for creating the Bad Pixel Map using a sample dark frame.



At this point, you can adjust the slider and you'll see the number of bad pixels identified change (here, showing 821 bad pixels). What you're seeing is actually the dark frame after some brightening and stretching. Currently flagged bad pixels are the black dots that are on the mostly gray background. The white dots shown here are hot pixels that haven't been marked as bad in this example. Move the threshold slider to the left and more pixels get marked as bad and more black dots thus appear. Move it to the right and fewer black dots appear (more white dots should appear). What you are doing is moving a threshold - saying that anything above this intensity is a bad pixel (shows up as black) and anything below it is a good pixel. When you like your map, click on Done and you will be prompted for a name to give this Bad Pixel Map. Give it a meaningful name, as you may well want to create several maps. If you used a 5-minute dark frame, you could use that dark frame to make several maps - one for ~5-minute exposures, one for ~1-minute exposures, and one for ~20-second exposures for example by using different values of the threshold (letting fewer hot pixels show for the shorter exposure maps). There is no "exact right value" here. You're simply telling *Nebulosity* which pixels not to trust.

Once you have your map, you can now process your light frames. In the Pre-process image tool change the entry that reads “Dark subtract” by default to the BPM option corresponding to the kind of images you have (images from a one-shot color camera in RAW format prior to the de-mosaic process OR images from a black and white camera). It'll prompt you for the map to apply and then for the set of light frames you want to process (shift-click or ctrl-click to select multiple frames).

When done, you can *Batch De-mosaic* the images if they were from a one-shot color camera and then go on to Alignment and Stacking.

11. Reconstruction: Demosaic-ing and Pixel Squaring

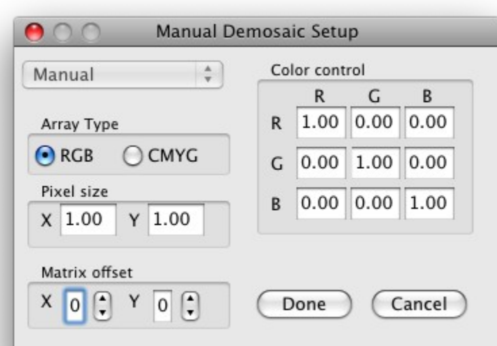
If you capture in RAW format from a one-shot color imager, you will at some point need to "Debayer" or "Demosaic" your images. (If you capture doing color on the fly, this happens immediately after image capture automatically). This converts the RAW image from the camera into a full-color frame (see One-shot color: RAW vs. RGB). This can be done either before or after pre-processing (although results will be best if you do it after pre-processing - see Pre-Processing. In addition, whether you use a color or monochrome imager, you will often need to convert the camera's native pixel dimensions into square pixels prior to stacking your images as many cameras have pixels that are natively not square.

Nebulosity provides tools to do this on both an individual image (on the Image menu) and in a batch mode for a series of images (on the Batch menu). If Nebulosity is able to determine the needed information about the image and where it came from, this will happen automatically. If not (or if you have "Manually override color reconstruction" selected in the Preferences), a dialog will appear and prompt you to enter in several parameters about your camera so that the processing can go on accurately.

In this dialog, you must first tell *Nebulosity* if the sensor uses RGB color filters or CMYG. Virtually all of the cameras in use by amateur astrophotographers are RGB cameras. Next, consider the offsets. What this is doing is telling *Nebulosity* what color the first pixel is (by saying how much of an offset - how many steps right and/or down - there is in your image's color coded array) versus what *Nebulosity* expects. Unfortunately, there is really no way of knowing ahead of time what is correct here. For RGB arrays, your choices are 0-1 for X and Y and for CMYG they're 0-1 for X and 0-3 for Y. Try various settings until you get something that looks even (not striped) and is close.

If your array uses pixels that aren't the same size, enter in their size in the **Pixel size** section (if they're square, don't worry about it and just keep the default values of 1).

If the resulting image is close, but not quite right, you can either adjust the color with the various tools in the **Image menu**, or you can use the **Color control** portion of the dialog. Here, the original (input) color value is given in the columns and the output color value is given in the rows. By default, the diagonal has 1.0 and the other values are 0, saying all of the red goes to red, green to green, etc. If you put a 0.5 in so that the first row had values of 1.0, 0.5, and 0.0 this would mean that 50% of the current green value for a pixel would be added into the red.



Typically, this level of control can be skipped, but if you're working with an odd filter setup or you're working with CMYG arrays, this can be quite helpful. For example, if you're using a

Sony CMYG chip and *Nebulosity* does not recognize the sensor, once the offsets are in place, values of 1.06, 0.29, -0.41 in the first row, -0.4, 1.06, and 0.54 in the second row, and 0.50, -0.4, and 1.11 in the last row will give a reasonable color rendition by compensating for the chip's imperfect color filters.

It is important to note that *Nebulosity* will automatically square the pixels during the debayer process for one-shot color images. Any color image is assumed to therefore have square pixels.

It is also important to note that if you use a Canon DSLR, ideal color balance in *Nebulosity* will be accomplished if you select the appropriate setting under "DSLR White Balance / IR Filter" in the Preferences dialog.

12. Previewing and Grading Images

Let's face it. Some images just don't look good. Some of your shots may look great and some may look horrible. Maybe the tracking failed, maybe dew started to form, maybe you hit the scope or the wind blew. Who knows what, but some shots just aren't as good as others.

When stacking images you have the chance to skip any frame you don't like but this can be a bit too subjective at times. *Nebulosity* provides two ways to do this beforehand.

The first is to use the Preview Files command in the File menu. You can use this to load up a set of images and rename or delete ones you do not wish to use (you can also use this to blink between images). The second is a way to automatically grade each image in your set **relative to each other image in the set** to let you pick the best frames. In the **Batch** menu, you'll find an entry for **Grade Image Quality**. Select it and you'll be asked to choose the frames you want to grade.

Earlier versions of *Nebulosity* used an image-grading algorithm that graded the relative quality of images. That is, which images were the sharpest and which were the least sharp based on an assessment of what the edges looked like in the image. This has now been replaced with an algorithm that grades the *absolute quality* of the images.

For each image that is graded, a set of stars is identified and the same half flux radius (HFR) used during Fine Focus is calculated for these stars. The average HFR (times 100) is used as the filename post-grading. So, if you see an image called Q382_M51.fit after grading, the average half flux radius was 3.82 in that image.

13. LRGB Color Synthesis

Nebulosity allows you to synthesize a color image from separate frames. For example, users of monochrome cameras must take a set of images through red, green, and blue filters to create a color image. Users might also want to combine a full-color image from a one-shot color camera with a "luminance" frame taken from a monochrome camera, or to combine images taken through separate line filters. *Nebulosity* provides a tool for this.

To use the tool, you must first align all your images and save each frame (rather than the whole stack) using the Align and Combine tool. Co-register the images using any version of the Translation (+Rotation +(Scale)) tool you wish. You can do this on all the raw frames at once or you can do this on the stacks you've made for each color type (i.e., your processed red data, your processed green data, etc.)

Located in the Batch menu, the LRGB Color Synthesis tool can then be activated. Select your mode (RGB, Traditional LRGB, and Color Ratio LRGB) and frames. If you have a full-color file, you can load all 3 color planes at once using the "RGB frame" button. This will overwrite any red, green, or blue data you have already loaded. (You can load these first and then replace any color plane by loading another file into that color plane directly.) If you know ahead of time you wish to scale the color channels relative to each other, you can do so using the sliders.

13.1. RGB Mode

In RGB mode, 3 color channels are used and directly create a color image. It is the simplest mode.

13.2. LRGB: Traditional HSI Mode

This implements the traditional LRGB technique. The red, green, and blue frames are used to calculate a hue and saturation value at each pixel. The luminance (or intensity) value is replaced by the value provided by the luminance frame. The resulting HSI (or HSL) data are converted back into RGB in the output image. This is the traditional method, but can lead to a loss of saturation.

13.3. LRGB: Color Ratio Mode

This technique gives an alternative method of luminance layering that avoids the loss of color saturation by the traditional method. The RGB data are used to create R:L, G:L, and B:L ratios (L derived from RGB). The L component is then replaced by the value in the luminance frame and the image converted back to RGB.

14. Image Normalization and Histogram Matching

Ideally, all frames taken under the same circumstances of the same target should all have the same intensity. Often, this is not the case as changes in light level, cloud cover, etc. can change the intensity from frame to frame. Further, if changes are made in the capture settings (e.g., different exposure durations), you're certainly going to have differences in overall image intensity across frames.

If you're doing the Average/Default method of stacking, you need not worry about this issue unless the changes are really quite severe. If you're using standard-deviation based stacking, Drizzle, or Colors in Motion, it is a good idea to *normalize* your images before stacking. What this will do is to get all of the frames to have roughly the same brightness by removing differences in the background brightness and scaling across frames.

There are two methods to normalize the images in *Nebulosity.*

1) The *Normalize* entry in the Batch menu will go through all selected frames and attempt to put them all in a common intensity range by taking care of offset and scaling differences across frames. After normalization, all frames should have their minimum at ~100 and their maximum at ~65535. Do this *before* you do any alignment of the frames (it can be done before or after pre-processing, but you don't want the black borders surrounding the image that can come in during alignment to throw off the normalization process.)

2) The *Match Histogram* entry in the Batch menu will ask you for a reference image and attempt to match the histograms for a set of target images to this reference image. It's performing a more advanced stretch than you'd get in *Normalize* and can thereby be more effective. Note, if you're using a one-shot color camera, do your demosaic before you try to use *Match Histograms.*

15. Stacking Images

Stacking multiple exposures is a fantastic thing to do for your images. If you can stack your images, you don't need to hold perfect tracking as long (making life easier) and you reduce any noise in your image that is not consistent from exposure to exposure (much of the noise is not). Thus, a stack of images will look less grainy (less noisy) than any one individual image. This lets you stretch and process the image more to bring out fainter details. All in all, stacking is a very good thing.

In *Nebulosity*, stacking can be done with or without alignment. For light frames (where stars are apt to move between each frame), you will want to align the images either prior to stacking or during stacking (see below). For things like dark frames, bias frames, and flat frames, you will not want to align the frames first.

15.1. Overview of Traditional Star-based Alignment

Few of us have perfect mounts that track or guide so well that there is no drift whatsoever across images. (In fact, it turns out to be better to have a bit of drift between images, as your image isn't always aligned with whatever consistent noise is in your camera, but this is a rather long topic not worth going into at the moment.) The net result of this is that if we were to stack a series of images atop each other as they came off the camera, we would end up with a blurred or streaky looking image. Each star was not in the same place in each image (the whole field of stars moved between images), so the result is quite poor.

In *Nebulosity*, this process is called "Align and Combine" and there are various options available to you (see below). In each, you are asked to find a star (or sometimes two) that is the same in each image. You will be asked to left-click on this common star (it is best to use a somewhat isolated and non-saturated star) in each image. Don't worry about being perfect in your clicking. *Nebulosity* will always search around the area where you clicked to find the star's centroid (i.e., it will refine your click automatically). In addition after the first image, *Nebulosity* will attempt to find the same star in each image for you and place a circle around that star.

If you wish to keep *Nebulosity*'s location, simply Ctrl-click (Command-click on the Mac) anywhere in the image (if it gets it wrong, just click on the correct star). If you know you want to keep all of the images and your tracking was good enough that *Nebulosity* can find the star from frame to frame, an Alt-click will pretend you did a Ctrl-click on each frame and accept all frames. Finally, if you want to skip an image (e.g., if it was blurred), simply Shift-Click anywhere in the image and it will not be used in the stacking process.

Nebulosity provides several ways to align a series of images prior to or during stacking to take out this overall movement in the image. In the simplest method (Translation), *Nebulosity* will take out shifts between your images (a.k.a. *translations*) and average the aligned data. You do this by picking a common star in each image, and *Nebulosity* takes care of the rest, shifting each frame (by whole pixels, without "resampling"). This works very well for equatorially-mounted telescopes (including fork-mounted scopes on a wedge). This does not work for Alt-Az mounted scopes. This style of mount makes stars not only move left/right and up/down but the entire field rotates as well.

A more complex technique, Colors in Motion, is also used for stacks that have shifts between images. Unlike the other techniques provided, Colors in Motion simultaneously aligns RAW images, stacks them, and reconstructs color information from one-shot color cameras. It cannot be used on RGB data or on black and white data.

To align and combine images using alt-az mounted scopes (or equatorially- mounted scopes), *Nebulosity* provides three other techniques. The first is similar to the above but allows for rotation and sub-pixel alignment. It is called Translation + Rotation. Related to this is Translation + Rotation + Scaling in which frames are allowed to be resized to align atop each other. To let *Nebulosity* know about the possible rotation, you must pick two stars in each image. Each image will be shifted and rotated to align them all prior to averaging the data.

The final technique that works on both equatorial and alt-az mounted scopes is called Drizzle (Align and Combine: Drizzle). Drizzle can not only combine images from alt-az (or equatorial) scopes, but it also enhances the resolution very well. To do this, you will again have to pick two stars in each image, and *Nebulosity* will do the rest.

15.2. Combination methods

In all of these, you have the option of using either strict averaging or adaptive stacking. In several (the Translation [+Rotation] [+Scaling]) you also have the option of saving each individual file post-alignment rather than saving the stack. This can be very useful, for example, in preparing frames taken through different filters for (L)RGB color synthesis or for using the Standard Deviation method of stacking.

15.2.1. Averaging vs. Adding vs. Adaptive Stacking

During any of the Align and Combine methods, *Nebulosity* can mathematically stack images in one of two ways. By default, an Adaptive Stacking technique is used (see Preferences menu). Some people worry a great deal about whether to add (sum) or average their frames during the stacking process. Each technique has its ups and downs. If you have 3 images in which the same pixel reads 100, 100, and 101, summing gives you 301, whereas averaging gives you 100. Internally, in *Nebulosity*, the average would be 100.33333 (as it should be), but when saved, it would become 100 as the images are saved in "integers" (aka whole numbers, not "floats" which let you have fractional bits as well). This makes one think that adding is best, but another example shows the problem there.

Let's now say that a bright pixel reads 32000, 32010, and 32100 in our three images. The sum is 96110 here where the average is 32036.666. When saved, this would become 65535 if summing were used and 32037 if averaging were used. Let's have another pixel - even brighter - reading 64000, 64010, and 64100 in the image. Once saved, the sum would make this 65535 and the average would make it 64037. Here, we see the problem with simple summing. You can saturate the image pretty easily, especially if you start with 16-bit images. Here, one pixel should be twice as bright as the other and yet it ends up equally bright (65535) if adding is used, since this is the highest possible value.

Nebulosity uses an Adaptive Stacking technique that avoids the weaknesses of both. It can be viewed as always being somewhere in between adding and averaging your data. The output (the stack) will always have a maximum value of ~65535 so that you are always using the full range of your data. This is enabled by default and for most uses will be optimal. (Note, it is not used when the Fixed Combine is selected as this tool is often used for dark frames). Unless you have a real reason to, you should leave this on (see Preferences menu). If you turn it off, *Nebulosity* will compute a straight average when stacking.

15.2.2. Standard Deviation Based Stacking (Sigma-clip)

If you were to take a perfect image of a target, each pixel would have its "ideal" or "true" value - how much intensity there is from that part of the target. The trouble is, each time we sample the target (take an image of the target), we record both that true value and some noise.

Averaging helps to get rid of this noise. It should tell us the central tendency and therefore estimate the truth. The more samples we have, the better the estimate is. But, if some samples are really abnormal ("outliers"), the average can get thrown off. For example if a hot pixel drifts into a patch of background sky, the average value will go up considerably and the hot pixel will show up in the stack, often as a small line or jagged trail (technically, of course, the stars and sky moved, not the hot pixel).

> Note: Another term used for this method is "sigma clipping" or "sigma clipped stacking". Sigma is the Greek symbol typically used to refer to the standard deviation.

Standard Deviation (SD) based stacking gives us a way to identify these outliers and eliminate them prior to computing the average. To do this, we calculate not only the mean (average) of each pixel's value in the dataset but also a second statistic that describes how much variability there is around that mean. We calculate the standard deviation (the square root of the variance) and use this to filter out "bad" samples.

If we assume the data are "normal", about 70% of all samples will lie within one standard deviation of the mean (that is, 70% are less than one standard deviation above or one standard deviation below the average). About 95% like within 2 SD of the mean.

During SD stacking each (aligned) pixel, has the mean and standard deviation calculated across all of the images in the stack. If your SD threshold is at 1.5, any samples of that pixel that have an intensity beyond 1.5 SD from the mean are removed and a new average, excluding these samples, is calculated. This is why hot pixels are often eliminated using SD stacking - those hot pixel values are very abnormal and lie far away from the mean.

With the filter set at 1.75, it takes a more extreme or "outlying" intensity value to be counted as "bad" than at 1.5. At 2.0, it takes even more abnormal a value to be excluded. Thus, more samples go into the final image using a higher threshold (and more noise as well). Typically, filtering values at 1.5 or 1.75 will yield the best results.

To use Standard Deviation stacking, you must first Normalize your frames. Then, you must align your images using any of the Translation (+Rotation (+Scaling)) routines. Do this to all of your images and save each file rather than saving the average stack. Then, select "None" for alignment method and the various SD stacking choices will appear. Try 1.75 or 1.5 initially before using any more extreme values.

Note, that this requires a lot more memory than the more traditional techniques. If you've not got much memory and you've got very large images, expect this to take awhile.

15.2.3. Percentile Based Stacking (%tile)

A related concept that's also used to remove oddball or outlying values is percentile based stacking. It works in a somewhat different manner than standard-deviation based stacking but is equally as powerful. Here, the notion is that for any given number of frames (samples of what the value at that part of the sky should be), you've got typical values and atypical values. The atypical ones can be extra-bright or extra-dim and we might hone in on the good / typical ones by simply discarding the brightest and dimmest values.

This is the basis for percentile based stacking but the "brightest" and "dimmest" aren't just the individual brightest and dimmest frames, but the brightest / dimmest percent of the frames. If you have 10 frames and choose the 10-90%tile option, the brightest and dimmest values are discarded and what you get is the average of the remaining 8 frames. If you have 100 frames and you choose this, you discard the brightest and dimmest 10 frames, leaving you with 80 to take an average of. Do the 30-70%tile on that same set and you drop the 30 brightest and 30 dimmest, leaving you with the average of the middle-most 40 frames.

Note, a special case of this is the 50%tile option. This is the median or middle-most value across all the samples. In statistics, this is an unbiased estimator (and nicely rejects outliers) but is also a noisy one. Experiment a bit with the options here and see what works well for you, but start with say 20-80%tile and go from there.

A very special, somewhat experimental case is the <20%tile option. This will only allow the darkest 20% of the images to pass through. The idea here is that if you're shooting a comet, it should help remove the stars and just leave the comet once you'

15.3. Align and Combine Options

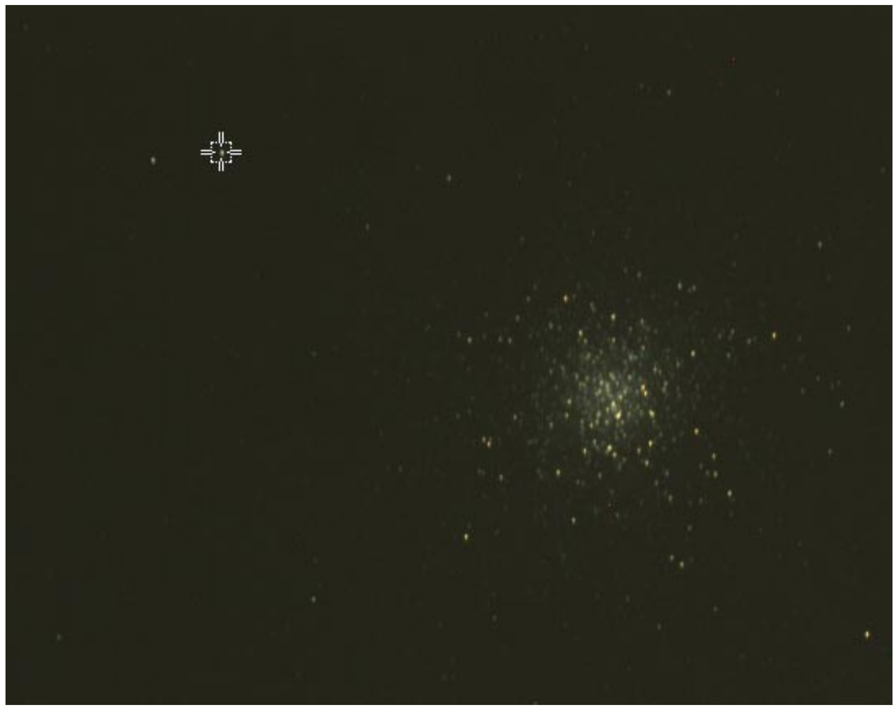
When aligning images to get them ready to stack, you've got a few options. Your choice comes down to asking yourself things like whether you need to account for rotation (e.g., your polar alignment isn't great or the camera rotated between images). Let's go through the various options here.

15.3.1. Align and Combine Fixed

Positive nothing moved or want to see just how much it did move? Fixed may be your choice here. Running this will stack things without any alignment at all. At the very least, it's useful (mandatory) for stacking any control frames like darks, flats, and biases.

15.3.2. Align and Combine Translation

This is the most straightforward method of stacking. Each image is shifted up, down, left, and/or right by whole pixels prior to align it with all the other images prior to combining.



Once your images have been pre-processed, select **Align and Combine: Translation** from the Batch menu. You will then be presented with a dialog asking you what frames you wish to align. Select all of your pre-processed frames, even if you think a few you may not want to keep and press OK.

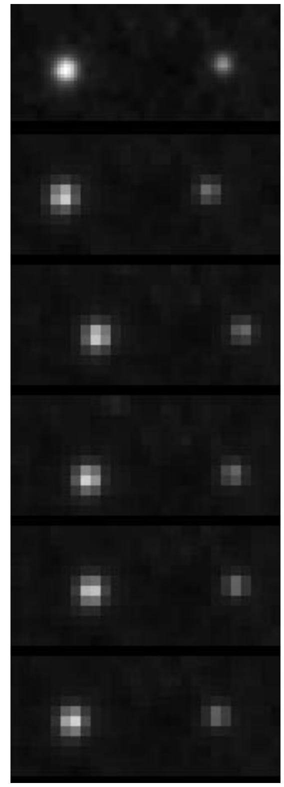
At this point, you'll notice the cursor has changed to a cross-hair (see below). You may also notice all of the menu items have gone grey, as you are now in alignment mode. The status bar shows your progress, telling you how many frames you've selected to align and how many you've done so far. Feel free to adjust the display levels or zoom factor here to get a good view.

If you want to abort the whole process, simply press the Abort button.

Your goal now is to identify the same star in each image. Pick a star that is fairly isolated and that is not saturated. Big, bloated stars need not apply nor should ultra-faint ones near the level of the background. Opening up the Pixel Stats window can help in selecting a suitable star. Put the cursor over this star (and remember which one it is) and click the left mouse button. In so doing, you're saying "The star is here" to *Nebulosity*.

In truth, you're actually saying, "The star is about here." None of us can click perfectly all the time and doing so would be a very time consuming process as we would obsess over whether it the click should be here or one pixel over. So, *Nebulosity* never assumes you got it 100% on target. Instead, it looks in a small area (+/- 5 pixels) to see if there's a better candidate for the center of that star. That is, it refines your click. So, get close, but don't obsess over being perfect. *Nebulosity* assumes you're not perfect and will try to fix it anyway. After the first image, you will notice a circle appear around a star - hopefully, the same star you've been using in prior images. To keep the current location (i.e. to say "yea, you got the right star, there Nebulosity), Ctrl-Click (Command-Click on the Mac).

If there is an image you don't want to include in the stack (e.g., a plane flew through your DSO, the mount mistracked, you moved the scope to re-center the target during imaging, the wind blew, a cop shined a spotlight at your scope - all of which have happened to me), just Shift-Left-Click anywhere in the image. That frame will be ignored.



Once you've selected the same star in each image (at least for each image you plan to use), *Nebulosity* then goes about aligning the images and combining them into one composite image. Depending on how many images you're aligning and how big they are, this could take some time. *Nebulosity* shows you its progress in the Status Bar. After all images have been combined, *Nebulosity* prompts you for a name to save the composite image as. Give it a name and press OK and you're done. The image now displayed on the screen is this composite image.

15.3.3. Align and Combine: Translation + Rotation (+ Scaling)

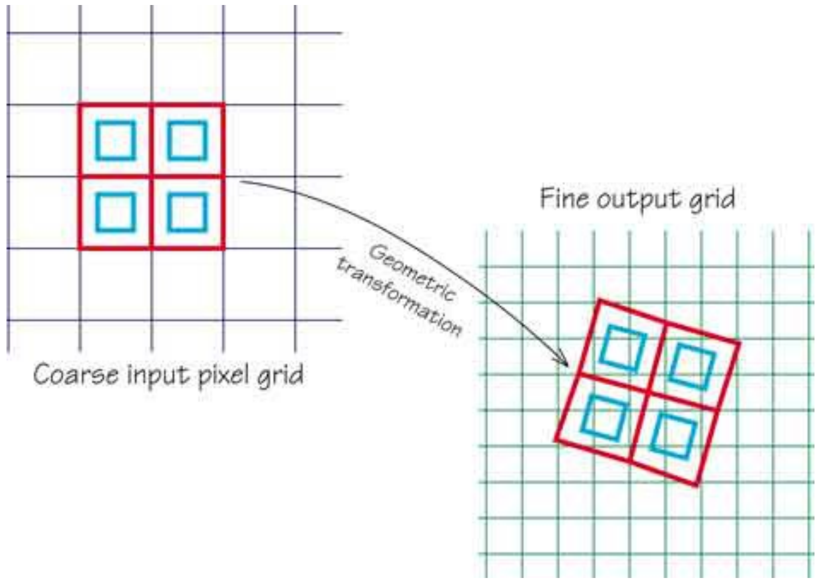
Using this method, images are shifted (translation), rotated, and optionally scaled by sub-pixel amounts in order to optimally align images prior to combining them. The process is very similar to that used in Align and Combine: Translation. The only difference in what you do is to pick two stars in each image.

Once you have gone through and picked the first star (which *Nebulosity* uses to gauge the translation), you will go back through all images and be asked to pick a second star (used to gauge rotation). As before, feel free to keep the current best guess of the star's location (Ctrl-Left-Click or Command-Left-Click on the Mac), to skip any image you don't like by Shift-Left-Clicking or to abort by hitting the Abort button.

15.3.4. Drizzle alignment (Translation & Rotation + Resolution enhancement)

Drizzle is a technique developed by Andy Fruchter (Space Telescope Science Institute) and Richard Hook (Space Telescope European Coordinating Facility) to make the most of images from the Hubble Deep Field's WFPC2 camera. Their insight stemmed from the idea that images from the Hubble were *undersampled*. The optics were able to resolve a lot more detail than the size of the CCD pixels would allow. So, a star that hit the dead center of a pixel would have some spread over adjacent pixels but would still look blocky. Small motions of the star on the CCD could keep it on the same pixels, but the relative brightness of the pixels would alter slightly based on exactly where the star was centered.

That effect can be seen here. On the top is a well-sampled shot taken from the Digitized Sky Survey and below are several undersampled versions in which the stars moved a bit prior to being sampled (on a simulated camera). Drizzle uses this information to not only align images, but also to create a higher resolution stack than you find in any individual image.



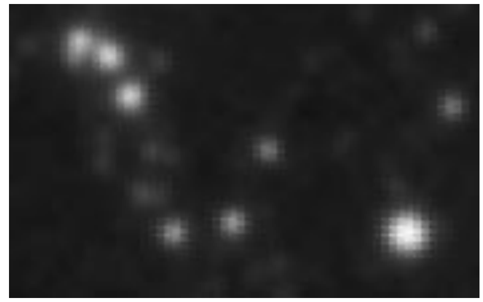
Here is a diagram from Andy Fruchter's page on Drizzle showing the technique. Each pixel in the original image is first reduced (from the red pixel size to the blue pixel size - this is the "pixfrac" or "pixel reduction factor" term). The pixels are then translated and rotated so that they will all be in the same position in the output image. You'll notice two things about the output image. First, the pixels in the output image are smaller than the original pixels. This is the "up-sample factor" - how much higher the output resolution is than the input resolution.

Second, these pixels will usually not line up perfectly with a pixel in the output image. Key to Drizzle is the fact that these "drops" (the blue pixels) fall onto the output pixels to the degree that they overlap. The value dropped by a blue pixel will fall a lot on one output pixel, a little on another, less still on a third, etc. Think of the output grid as having little wells (or spots on an ice-cube tray) for each output pixel and the water drop landing on a spot that hits multiple wells. As multiple images rain pixels down onto the output image, the output pixels fill up to the degree that input pixels line up with the output pixels.

That's the theory behind Drizzle. How does it work in *Nebulosity*? Images must be black and white or full-color (but not RAW) and pre-processed. There should also be some movement between images (e.g., if *Fixed combine of images* would make a blurry average). You'll also want to have a minimum of 8-10 images to work with as well and you should most likely have Normalized your images prior to stacking.

Drizzle requires two stars to be found in each image. First, find one star (left-clicking as in Align and Combine: Translation) in all the images (shift-left-click to skip an image, ctrl/command-left-click to keep the current guess). This first one will serve to let *Nebulosity* know how much translation is in each image. After you have selected the same star in each image, *Nebulosity* will loop back and ask you to find a second star in each image. A red target will appear over the first star to let you know what you picked the first time. Don't pick a star that's too close to the first one, as the second star lets *Nebulosity* know how much rotation is present. The further away it is, the more "leverage" you have.

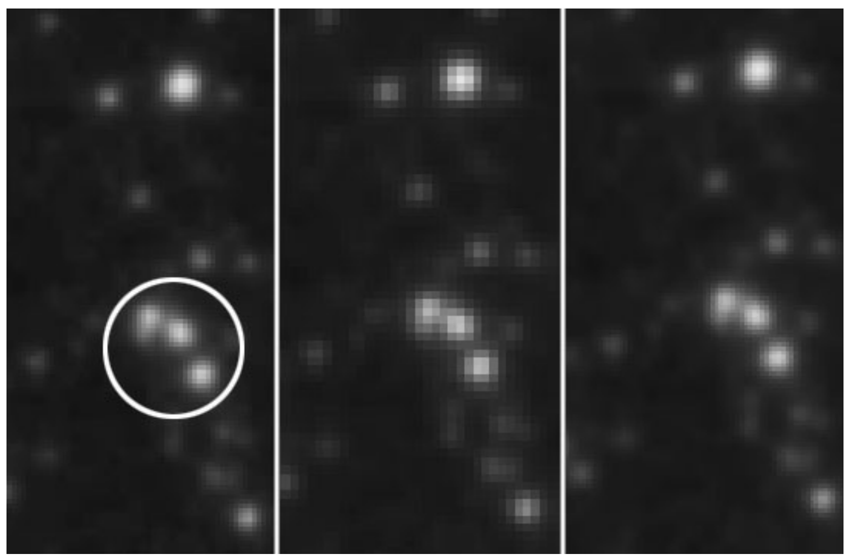
Once the stars are picked, you'll be presented with a dialog asking you for a few parameters to give to Drizzle. It asks for the "Pixel Reduction" factor (how much smaller the pixels become before being transformed to the output grid) and the "Up-sample" factor (how much bigger the output image is than the input images). Typical pixel reduction factors range from 0.5-0.8 (0.6 is the default) and typical up-sample factors range from 1.2-2.5 (1.5 is the default). If you try to use very small pixel drops (e.g. a pixel reduction factor of 0.2) or very large up-sampling factors (e.g., 3.0), you risk leaving "holes" in the output image where no pixels dropped from an input image to the output image or other artifacts (right).



Finally, you'll be asked for an "Atomizer" value (default value of 2). This parameter lets you trade off speed and accuracy of the Drizzle process. Think of it as how fine a "mist" is being made out of each "drop". 1 is the fastest but is a bit less accurate and should not be used if you have a small number of images. 3 is the slowest but most accurate. 2 represents a good trade-off (and will rarely look any different than 3).

Be warned - Drizzle is computationally intensive. Be prepared to find something else to do for a while after you've picked your stars.

Here is a shot of a small portion of a test image used to evaluate Drizzle. On the left, we have a single raw frame taken from the DSS again. This frame was shifted randomly and undersampled to create a stack of frames that where then aligned with either translation (middle) or Drizzle (right). For display here, each image is shown at the same scale. Note the separation of close stars recovered by Drizzle and its overall increase in resolution.



15.3.5. Colors in Motion (Simultaneous translation align + Color reconstruction)

Colors In Motion (CIM) is a tool developed for *Nebulosity* that combines the process of color reconstruction from one-shot color images, the alignment process, and the stacking process in one step. This is done not as a convenience to the user but to potentially achieve a more accurate and higher resolution final image by doing these steps at the same time.

To use CIM you must have captured data in RAW format and *you need to have a sizable* *number of frames*. In addition, you should most likely have Normalized your images prior to stacking. Ten frames is the absolute minimum and it wants as many as possible (30-50 frames would be reasonable starting points). Data should be pre-processed first but not de-mosaic'ed. Finally, your tracking should not be perfect. Good or excellent is fine, but perfect is not. If you can make a sharp image by stacking your frames without any alignment, don't bother trying CIM. If such a stack makes a blurry image, you're in great shape for CIM.

Using CIM is much like using the normal alignment process. You will be asked to locate the same star in each of the images you wish to align (Ctrl-click after the first image to keep the star Nebulosity chose - Command-click on the Mac). Here too, you can skip any individual image by simply Shift-Left-Clicking anywhere in the image. After picking a common star in each, you are then prompted for a "CIM Threshold" (if you have at least 10 images). This threshold marks the dividing line between "Full CIM" and "Partial CIM" (Partial CIM blends a standard debayer version of the image with the CIM version of the image). 10 is a reasonable value (lower numbers will force more pixels to be Full CIM and higher numbers will force more pixels to be Partial CIM).

CIM is computationally intensive, so be prepared to wait awhile once you've told it where the common star is in each image. When it's done, you'll be asked for a file to save the results in.

15.3.6. Automatic Alignment (non-stellar)

Finally, we have a fully automatic image registration option. It can work well for star fields, but one of its main goals was to be able to align images that don't have clear reference points (stars) and this is where it works best. The tool is found in the Batch menu and when started, the dialog shown here appears (the "Save stack" and "Diffeomorphic" options are currently not available). The first thing to do is to press the Select Master button and select a reference frame. If you hit OK, it will proceed with the defaults and ask you for a set of target frames to align. Note, this is not a fast process by any means. You may want to keep the History window open (View menu) to follow its progress. In the end, you will have a set of images called "aa_OriginalName.fit" (or instead of "aa_", whatever you specified in the Prefix field).

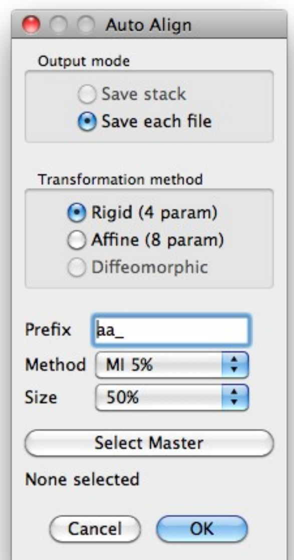
If you decide to experiment with the parameters, here is what they mean:

Transformation Method

How should we stretch and squish the image to make it line up with the reference? "Rigid" won't distort the image at all (translation + rotation only) and affine will (translation, rotation, scale and shear).

Method

This controls how we are determining how well the images overlap. You have a pull-down with a number of options. By default, we have "MI 5%". Here, MI=Mutual Information and MSE=Mean squared error. These are different "how much error is there" metrics. For MI, you've got a few sampling rates (what percent of pixels or # of pixels to work on). 5% seems to work well here and is a lot faster than if you go up to higher rates. For MSE, there are two options: Full (use the whole frame) and Stars (focus on things that look like stars).



Size

The amount of motion between frames can be accurately estimated without looking at the whole frame or without looking at it at full resolution. By default, *Nebulosity* downsamples the image to half size and runs on that to save time. You can run at full-size or at 25% size as well or focus on just the central 512 pixels.

16. Image Adjustment

While *Nebulosity* is not designed to be an advanced image processing application like PhotoShop or the GIMP, it does supply a number of purpose-built and very useful tools for adjusting your images (usually the result of stacking). These tools are located under the Image menu.

For any of these, if you decide you don't like the results, simply press ***Cancel*** or use the ***Undo*** command in the Image menu (or Ctrl-Z). By default you have 3 steps of Undo available, but with a quick trip to the Preferences menu, you can have unlimited Undos and Redos.

16.1. Demosaic'ing and Pixel squaring

The tools in this section are primarily aimed at one-shot color cameras. They let you convert the image into color (from a RAW Bayer-matrix grayscale image) or keep it as monochrome, but reconstruct it in ways optimized for various filters.

16.1.1. Demosaic Image

If you captured a one-shot color image in RAW format and wish to see it in full-color, use this tool. It will reconstruct the raw image and turn it into a full-color image for viewing or saving. The algorithm used for this (there are several available) is set in your Preferences. There is also a **Batch** version of this tool that will allow you to demosaic a series of files. (Note, this should be done if you capture in RAW format *after* pre-processing but *before* alignment).

It is also important to note that if you use a Canon DSLR, ideal color balance in *Nebulosity* will be accomplished if you select the appropriate setting under "DSLR White Balance / IR Filter" in the Preferences dialog.

16.1.2. Square B&W

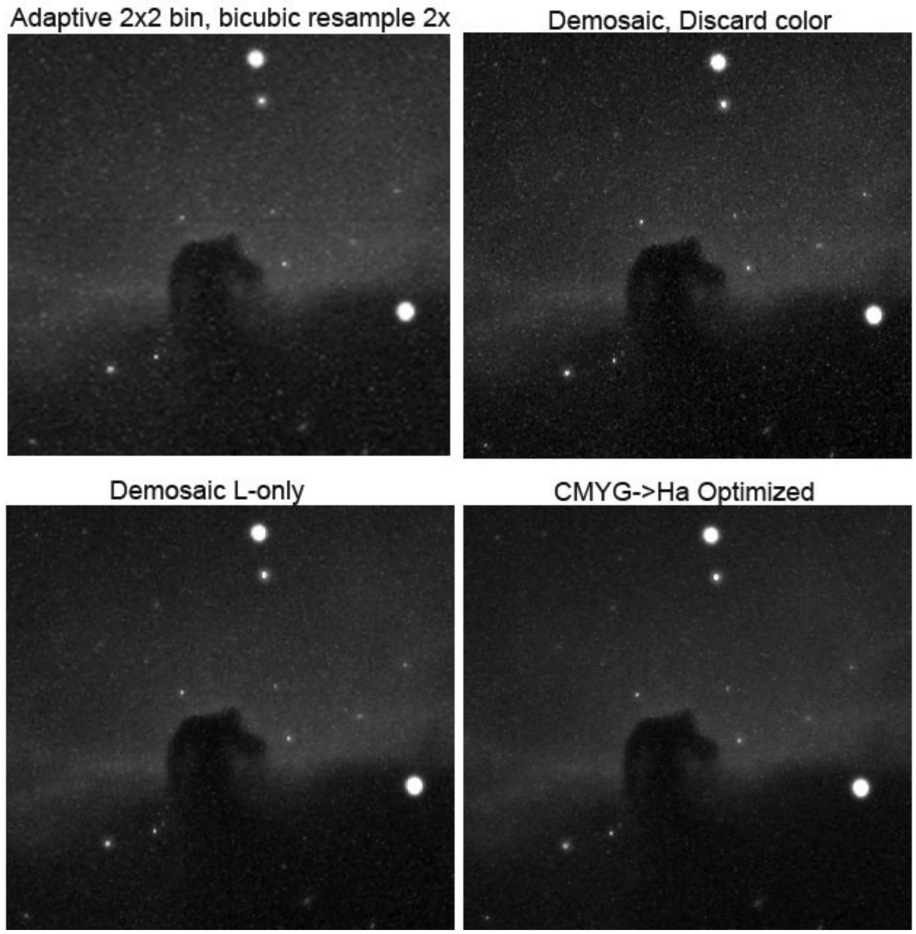
If your sensor's pixels are not square (i.e., they are a different height and width), you'll probably want to square them after pre-processing. For one-shot color cameras this happens during the demosaic process. For black and white sensors, this happens here. As with the demosaic process, you have tools to do this on the current image and on a batch of images.

16.1.3. Reconstructing Images from One-shot Color Cameras and Line Filters

In a previous section (see Monochrome vs. Color?) a typical color filter array was shown for a one-shot color camera that uses red, green, and blue filters. If we place a "line filter" in front of such a camera, what happens? For example, suppose we placed an H-alpha filter in front of this array? Such filters pass light in a very narrow range, centered on 656nm of "Hydrogen alpha". Emission nebulae emit light specifically at this wavelength (and several others), so passing this light and block all else can lead to an excellent way to image nebulae amid light pollution and can lead to stunning images of these nebulae.

When multiple lines are imaged separately (e.g. one frame of Ha, one of O-III, etc) they can be combined into beautiful "false color" images.

Typically, such imaging has been reserved for monochrome cameras. The reason can be seen in that Bayer array. Photons that pass through the Ha filter are well into the red area of the spectrum. As such, only the red pixels will get any light. The green and blue pixels will be dark. Thus, we have only 25% of our pixels doing anything and the others are merely contributing noise. So, when reconstructing RAW data, one could take the RAW data and use the Low Noise 2x2 Bin or Adaptive 2x2 Bin tools. This would create an image half the size but would remove all evidence of the Bayer pattern. The one valid red pixel would be averaged with the three invalid pixels in a local 2x2 area and the result would be dominated by the red signal. One could also use the normal debayer routine and simply use the Discard Color tool. This is a common approach, but one that may not be optimal (see image below).



While we cannot escape the loss of resolution entirely, there are ways of improving how images are reconstructed on one-shot color cameras when line filters are used. For example, when CMYG color arrays are used instead of RGB arrays, more pixels respond to Ha light (as is shown by this shot with an Ha filter of the Horsehead nebula, courtesy of Michael Garvin). Knowing this, and knowing how the pixels respond to this light can let us optimize this reconstruction.

Nebulosity gives you several tools to do the reconstruction in addition to using the binning tools or the Discard Color tool. One is a "Generic" method that will do a good job on any line filter with any camera but is not optimized for any specific combination. A second is a reconstruction optimized for "nebula" filters and O-III filters that leak light in the Ha and beyond regions (e.g., Televue, Meade, and Lumicon filters). This is also a rather generic reconstruction that will work well with a wide range of setups. Finally, for CMYG arrays, there are optimized reconstructions for Ha and pure O-III filters (e.g., Astronomik, Orion, and Custom Scientific) that do not leak light in Ha or higher wavelengths. A comparison of these techniques on the data from the Horsehead nebula taken on an Orion StarShoot's CMYG array is shown below.

In addition, this menu has options for pulling out each of the color channels directly for one-shot cameras with RGB sensors. Since the green pixels are twice as common as the red and blue, you have options to grab either of the green fields or to average this into a single green. Note, with these options, the image will be half the original's size.

16.2. Geometric manipulations

The tools in this section let you change the size of the image and its orientation.

16.2.1. Crop

Usually, after stacking a series of images, you end up with a dark border in your stacked frame. This is because *Nebulosity* had to move all the images around to get them to line up and some needed to be moved further than others. To get rid of these borders (or just to recompose your image), you can crop the image. One way to do so is to simply drag a selection using the left mouse. Start in one corner and hold the mouse button down to create a selection box and let go when the box is the desired size. Once happy with the box, pull down *Crop* from the *Image* menu and you'll have cropped in on just that area. A second way to do so is to pull down *Crop* from the *Image* menu and enter the number of pixels to crop off directly

16.2.2. Mirror / Rotate

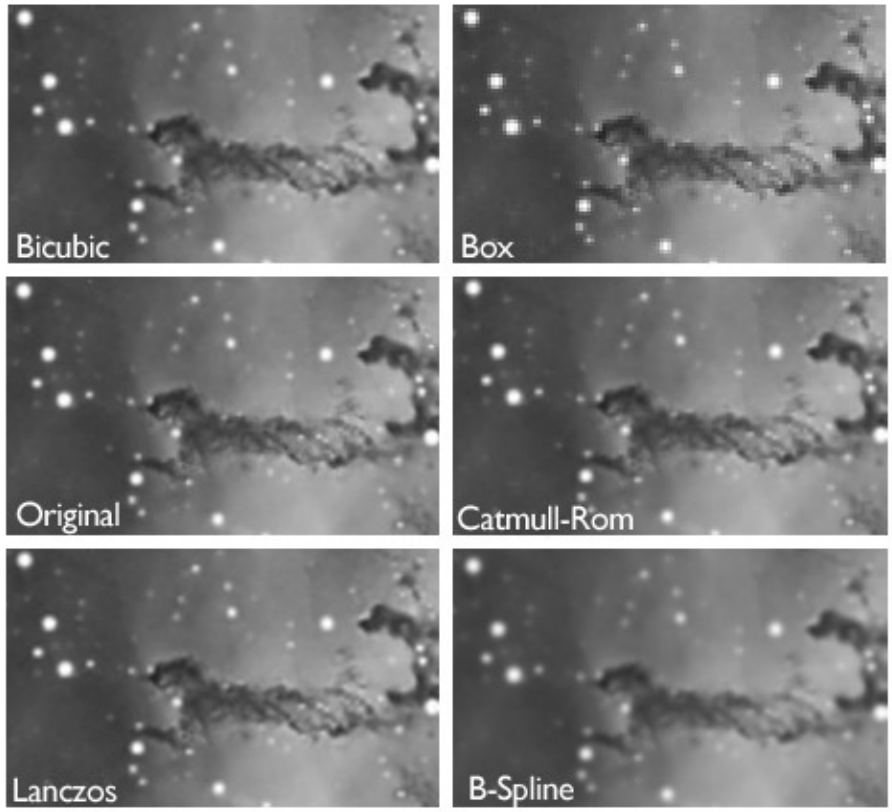
Need to rotate or mirror that image to get it to line up with something else (e.g., reality)? You can rotate 90 degrees clockwise or counter-clockwise, 180 degrees, or flip your image up/down or left/right. Note, there are batch versions of these tools as well.

16.2.3. Binning

Images from some cameras are quite large and it can be useful to cut their size down (e.g., to post to the Web). *Nebulosity* lets you bin images 2x2, thus cutting the image size in half. An added benefit of binning is that by combining data from 4 pixels into one, noise is reduced (much in the same way it is with stacking). Finally, one additional use of binning 2x2 is to remove all color information from a RAW frame off a one-shot color camera. This turns the one-shot color camera into something a lot closer to a monochrome camera.

Nebulosity gives you 3 ways to bin your image. You can sum all 4 pixels (which will brighten the image considerably), average all 4 pixels (which will keep the same brightness) or perform an adaptive bin. The adaptive bin will combine the data in a way between the summation and averaging, optimizing the combination so that the full 0-65535 range is used.

16.2.4. Resize



Want your image to be rescaled (aka "resized", aka "resampled")? The Resize tool in the Image menu can make your image larger or smaller using a number of different resampling algorithms. Simply enter in the scaling factor (e.g. "2" to double the size of the image, "0.5" to make it half as big) and choose an algorithm.

Here, we have an image that was first reduced to half its size by binning and then restored to full size with the different algorithms available. "Box" is fast but ugly when increasing the size of the image. "Bilinear" is fast but will smooth the image a bit more than some of the others. "B-Spline" will lead to the smoothest output. "Lanczos sinc" can lead to the sharpest output but is more prone to ringing than "Catmull-Rom" or "Bicubic". The Catmull-Rom usually outperforms the standard Bicubic.

16.3. Stretching and Intensity scaling

The tools in this section let you adjust the look of your image by stretching the contrast and by performing other transformations to the intensity of the image.

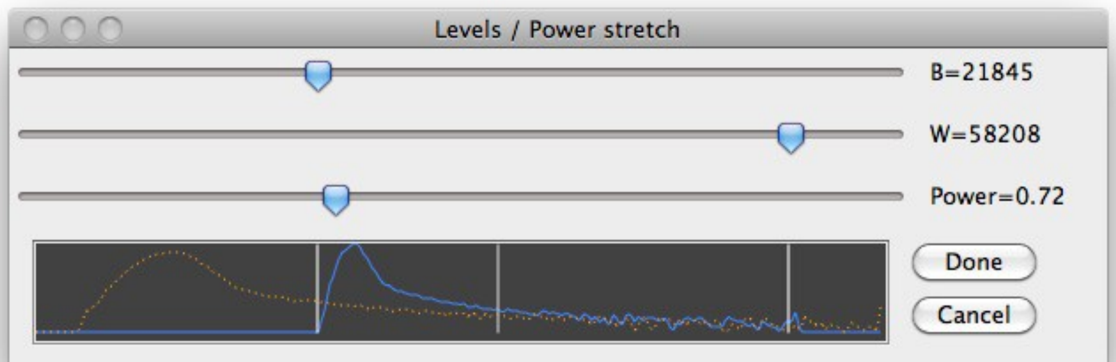
16.3.1. Levels / Power Stretch

> If you want even more control over the values in these tools, double-click on the readout (Mac/Win) or on the slider (Mac) and you can specify values directly.

The Levels / Power Stretch tool is a very versatile and useful tool. Once you have combined a number of images, you'll likely notice that your sky is still bright and the DSO is quite possibly still dim. Overall, the combined shot looks little like the wonderful shots you see posted on the Internet, even by others with the same camera. The problem is that even though you've combined many images, your skyglow and DSO are still at the same basic levels they were at initially. Combining images does not make the result any brighter than the original. What it does, though, is to make the result *cleaner* than the original. So, if your skyglow had been at 10,000 ± 2,000 it may now be at 10,000 ± 100. If the faint bits of your DSO were at 11,000 ± 2,000, they may now be at 11,000 ± 100. If we were to set the black level of the image (just with the slider) up to 10,000 the sky would go quite black and your DSO would remain.

The **Levels / Power Stretch** tool lets you do this and quite a lot more. When run, it presents you with three sliders and a window showing your image histogram (see above). One slider sets the black level and another sets the white level. The third sets the "power" (or middle slider in a "levels" tool - If you've used the Levels tool in Adobe PhotoShop© the only difference is that it reports 1/power). Leaving the power at 1.0 performs a "linear stretch" of the data. Setting

The histogram shown here is based on the luminance values of the image. This may lead to clipping of the data if you have not already balanced the color channels. Balance reasonably before stretching and/or keep an eye on the histogram shown in the main window (which is computed based on all color values).



the power below 1.0 will tend to brighten the fainter bits of the image. Setting it above 1.0 will tend to darken the fainter bits and brighten the already brighter bits. This is applying a specific kind of curve to your image (see below) by computing for each pixel:

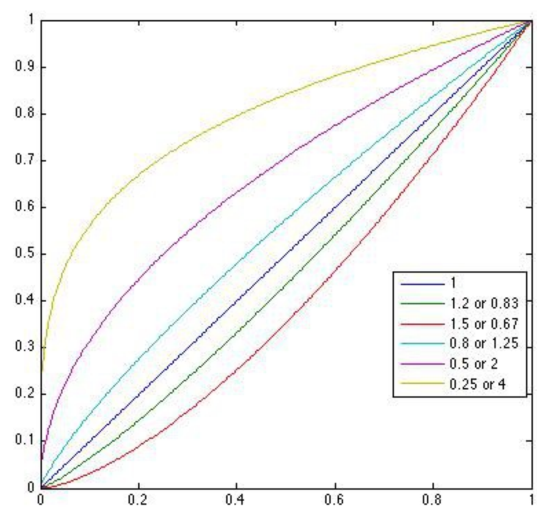
$$NewValue = OrigValue^{power}$$

At the same time, it is stretching the data so that the output ranges between the values set by the black and the white level sliders. You can see its effect in the histogram window. Here, the initial histogram is shown in blue and the output, or resulting histogram is shown as a dashed orange line. In the example shown here, you can clearly see the histogram being stretched to pull out interesting bits in the data while also resetting the black point.

To assist in using it this way, the black-point, midtone, and white-point lines are superimposed on the histogram. These lines show where in the original histogram (blue line) the black (left line), midtone (middle line) and white (right line) points lie. You will note that as you move the power slider, the midtone's position relative to the white and black points will move, but that it often won't be placed directly under the slider. This is entirely normal. If you wish to think in terms of setting the midtone level of the image, adjust the power slider until the middle line (slightly darker than the other two) is at the desired place in the histogram.

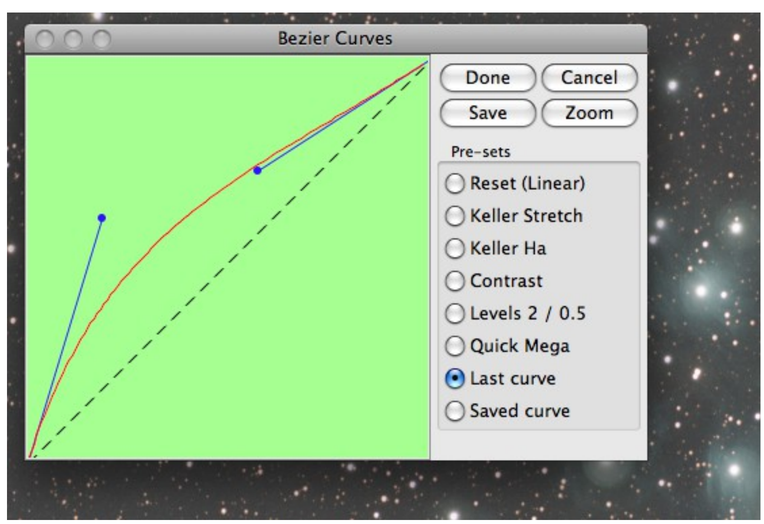
There are a few things to note. First, if Auto-Scale is turned on prior to entering the Levels tool, it will be turned off and the B and W sliders set at their full extent. This is to show you how much of the full data range you are using and to encourage you to stretch the image to use that full range. (If not in Auto-Scale mode, the sliders are not moved). Second, the Levels tool can be quite computationally taxing on your computer, especially if you are working with very large images. To make the adjustments more responsive, try defining a region of interest (ROI) with the mouse (just as when cropping) before entering Levels. You will preview the adjustments on this region only. When you hit OK, the same adjustment will be done to the whole image.

Take your shot and try setting the power to 0.3 - 0.8 and then sliding the white and black levels. You should notice that the faint bits of your DSO start to appear and become a lot more prominent. Quite often, optimal results are obtained by using this tool multiple times. Each time, make only moderate adjustments to the image and don't worry about getting your background very dark the first time or so through. Gradually hone in on your desired image. Don't worry about the fact that you're doing this multiple times and that it might cause problems with the image range or values. Remember, *Nebulosity* does everything in 32-bit floating-point numbers (96-bits per pixel total) internally. Adjust and re-adjust as you see fit.



16.3.2. Curves

The Curves tool dialog has two main areas. In the lower-right are some sample / default curves you can try or use as a starting point. The “Keller” Curves come from Warren Keller, author of the IP4AP tutorials. The main part of the dialog is on the left. There are two control points (blue dots) that you can move to draw the curve. Grab one and move it and you will see the red line (the curve you are making) move and the screen will update to show the effect of the

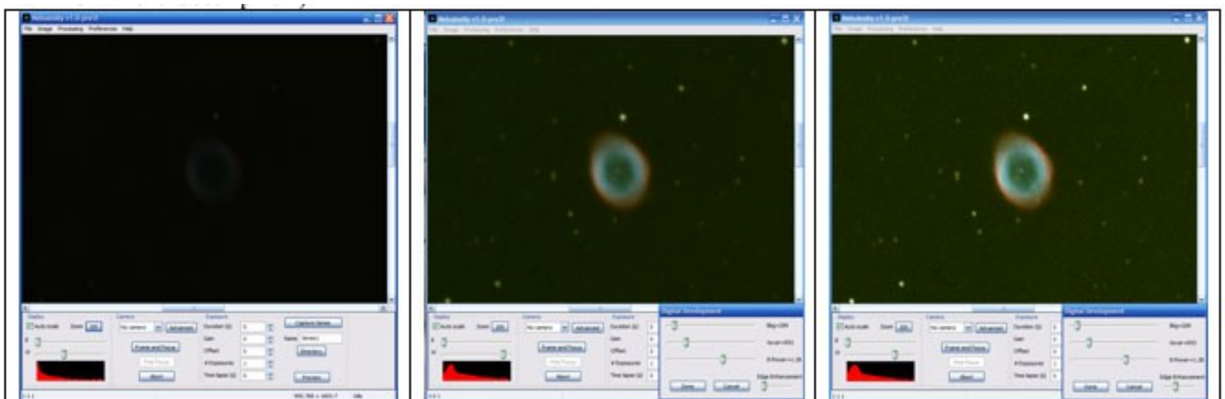


curve. These two points and the end points let *Nebulosity* build a sensible curve (using a Bezier). While more points will give more flexibility, they also can get you into more trouble. With two points many curves can be drawn and with a second pass through, the combined effect of both curves gives almost infinite control.

Note, in the Pre-set section, there are entries for the last curve you used and for a saved-curve (created with the "Save" button). These let you come back and re-trace out the curve used in the past. Note also that the Status bar and the History dialog will record the positions of both control points so that you could re-create a curve another time.

16.3.3. Digital Development Processing (DDP)

Digital Development Processing (DDP) is a technique developed by K. Okano to make CCD images look more like film images. Like the Power Stretch tool, it helps bring out faint detail in the image and helps suppress skyglow. Okano's technique passes a hyperbolic function to the data to make the linear CCD response much more like the S-shaped "gamma" response of film.



Unprocessed | DDP, No edge enhancement | DDP with Edge enhancement

When you select Digital Development, four sliders are presented. Default parameters for each are pre-selected.

The first slider, labeled *Bkg* sets a level for the background in the output image (Okano's *b* parameter). The second slider, labeled *Xover* sets the cross-over point (where the transformation shifts from a linear to a curved one - Okano's *a* parameter). The third slider, labeled *B-power* provides a method for darkening the background during the DDP process (not in Okano's description but may be set to 0 for a pure DDP processing). Finally, the fourth slider, labeled *Edge Enhancement* controls the amount of sharpening done during the DDP process (part of Okano's description).

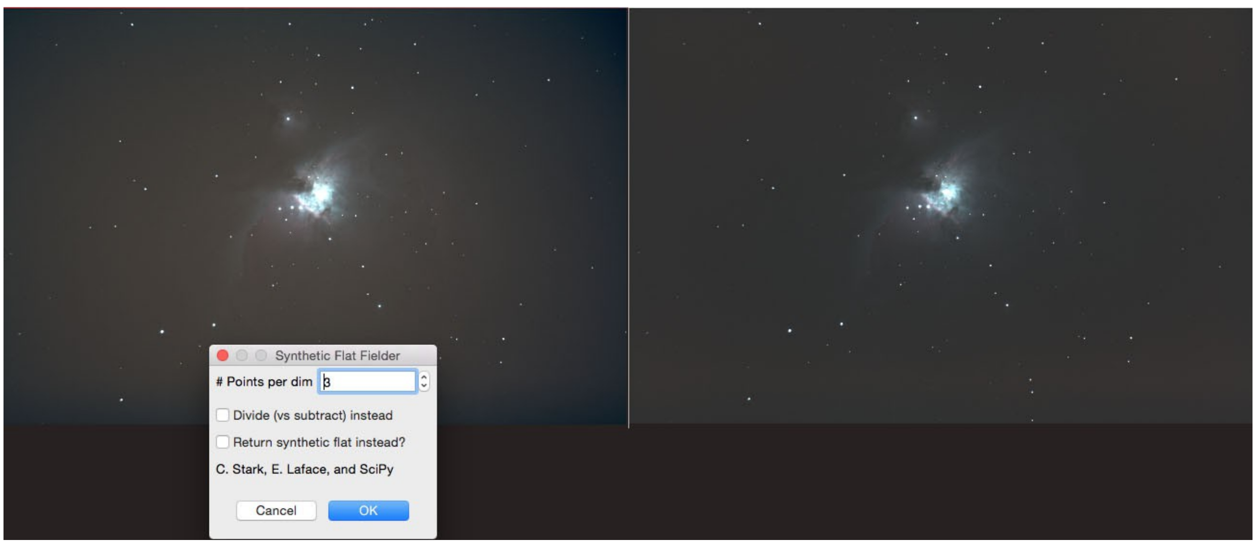
16.3.4. Zero Min

If the lowest pixel value in your image is at 20,000 (resulting from a bright sky), why would you want to let the rest of your data only use the remaining 44,535 possible values when you save? You could have a lot more "room" for a range of intensities if you shifted the whole image intensity down by 20,000. This tool will do that automatically for you, by making subtracting the current minimum value from each pixel.

16.3.5. Scale Intensity / Pixel Math

You may find times at which you wish to re-scale the brightness of an image in a very controlled way. For example, if you use the Adaptive Stacking (see Preferences) technique and have stacks taken with two different exposure durations, you might want to rescale the intensity of one before combining them. Or, you might simply want to brighten or darken the image, shift its intensity up or down, etc. The Scale Intensity tool lets you do a number of things under the general heading of "Pixel Math". You can multiply or divide each pixel by a constant and you can add or subtract a constant from each pixel. You can also transform the image by taking the log, square root, or arcsine of each pixel's value. (Using these, the image is normalized in the process). You can also invert the image.

16.4. Synthetic Flat



Ever forget to take your flat frames? Or, ever notice that your field isn't evenly illuminated after you've stretched the image even though you took flats? Ever see gradients of skyglow color and wondered how you could get it to not be pink on one side and green on the other? If the answer is yes to any of these and your image looks something like the one on the left here, fire up the Synthetic Flat tool!

When you have your image loaded and fire up this tool, it first pops up a dialog asking you to setup a few parameters. To begin with, simply accept the defaults, but what these do is:

- # points per dim: How many extra sample points (beyond 1) along the X and Y dimensions are going to initially be placed? The default of 3 here lays down a 4x4 grid of points, for example
- Divide vs. subtract: When removing the generated flat, should it subtract this (default) or should it divide the image (as is typically done in pre-processing)? Things like the brightness of the stars in the fixed area will differ depending on

which you choose. If it's really from solid vignetting, choose to divide instead.

- Return synthetic flat: If you want to see just what flat Nebulosity created (rather than fixing the image), check this.

After you click OK, a tool fires up (it may take a second) that shows you another view of your shot along with a set of red squares on it. If you need to brighten or darken the image, just use the up/down arrows so you can see your DSO and your vignetting. The idea here is to select samples of the sky that are free of major stars, free of your DSO, and free of any black borders (which you should really crop off before using the tool).

Clicking on a point removes it and clicking in a blank area adds a new one. What the tool will do once you hit Enter is to try to fit a 2D "surface" to the intensity profile found at the control points. It tries to reject stars and noise in and around the control points and fit a smooth surface based on Bezier splines. Where you place the points and how many you use will affect the results and this will involve a bit of trial and error.

If the resulting image has odd, new non-uniformities, odds are you're using too many points. If, for example, you have just a simple linear wash from one side or corner to another, you should only use 4 points in total (set the initial # to 1 extra in each direction) in the corners. Other simple gradients can use these 4 and one more somewhere in the middle of the image.

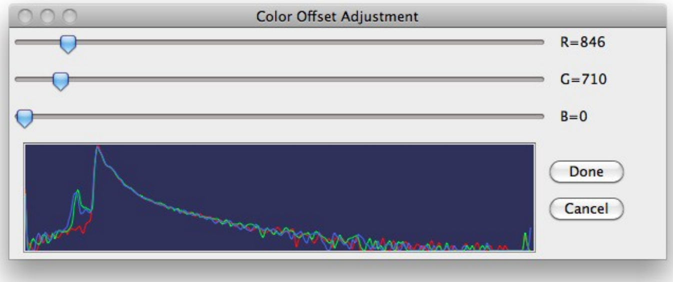
If the tool fails to run properly, it means it could not properly fit the 2D surface based on your points and your image. If there are black borders, remove them beforehand with a crop and try moving your control points inside a bit. Or, try to not stretch the image quite so much before going into the flat tool and make absolutely sure that the image doesn't have a pure-black (zero) background).

16.5. Color adjustment

Even if you go to great lengths to get your color balance "right" ahead of time, your shots will almost always have color issues when you start to process them. Some of this comes from camera issues, some from refractive effects in the atmosphere, and some from your skyglow's color. Tools in this section let you get the color just right.

16.5.1. Adjust Color Offset

When taking images in color, it is often the case that the background has a slight color hue rather than being a neutral grey. This can be the result of a color "bias" in the image -



the minimum value in each color channel not being the same (skyglow will give you this). This can be fixed by subtracting a constant number from one or two of the color channels. The Adjust Color Offset tool lets you do this. A dialog box will appear with sliders for red, green, and blue. *Nebulosity* will attempt to determine reasonable values for the sliders when the dialog opens. The values you enter here will be subtracted from the specified color channel(s). For example, sliding the Red slider to 1100 will not affect the green and blue data but will make every red value 1100 less than it was previously. A 3-color histogram is shown below the sliders to help in getting the offset just right. Aim to have the left edge of the histograms similar for all three colors. Pressing Cancel will revert back to the original image.

16.5.2. Adjust Color Scaling

In color imaging, it is often the case also that your color channels are not balanced in their scaling either. This is particularly true in using separate color filters in a black and white camera (if one does not perfectly adjust exposure duration to compensate for the varying transmission of color filters and for the CCD's varying sensitivity to different colors) but can occur in a one-shot color camera as well. The Adjust Color Scaling tool lets you rescale the intensity of individual color channels much like the Scale Intensity tool lets you rescale the intensity of the entire image. Setting the Green slider to 1.05 would, for example, multiply the intensity of each pixel's green component by 1.05. A 3-color histogram is shown below the sliders to help in getting the offset just right. Aim to get the histograms similar in size to color balance the image. Pressing Cancel will revert back to the original image.

16.5.3. Auto Color Balance

Rather than running the color offset and scaling tools (above) separately, you can have *Nebulosity* automatically stretch and scale the channels to fix global color casts (it does this by the same histogram matching routine used to normalize images' histograms to a reference image).

16.5.4. Hue / Saturation

While the color of your image can be adjusted by scaling each color channel separately you can often have better control over it when making "by eye" adjustments using the Hue, Saturation, and Luminance tool. Hue gives you control over the overall color shade, saturation gives you control over how rich the colors appear, and luminance gives you control over how bright the image is.

16.5.5. Discard Color and Convert to Color

At times, one may want to take a color image and strip it of all color information. This can be useful, for example, if you want to make a luminance (L) channel for image processing outside of *Nebulosity* or for using during pre-processing of monochrome images. The Discard Color tool does just this, converting your color image into a monochrome image (the average RGB value is used). The Convert to Color does the converse. It takes a mono image and makes it into an RGB image (with every pixel having R=G=B).

16.5.6. LRGB Color Synthesis Tool

This tool lets you combine separate L (optional), R, G, and B frames into a color image. It is described in detail here.

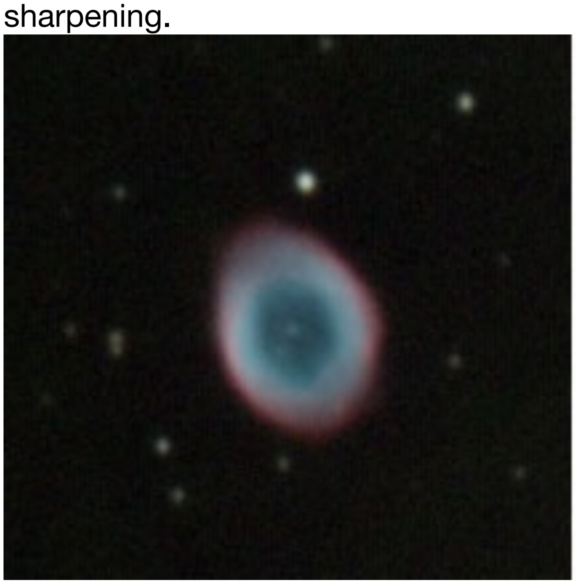
16.6. Sharpening, Blurring, and Noise Reduction

After processing our images, its usually necessary to perform some kind of sharpening on them to bring out the details and make it crisper. At times, it's also useful to blur your image (to reduce noise or remove artifacts). Tools in this section assist with these manipulations.

16.6.1. Sharpening and Tighten Star Edges

Often, lack of precise focus or seeing will end up making your images slightly blurry. There are numerous techniques astro-imagers have used to fix this. *Nebulosity* provides several tools for sharpening the image.

One very popular tool is an *Unsharp mask*. This algorithm actually makes a blurred version of your image and subtracts this blur to make a sharper image. When you pull down Sharpen Image, Unsharp Mask a dialog appears with two sliders. The "Amt" slider is asking how much sharpening should be applied (the amount of sharpening). The "r" slider is asking the amount of blur in the image - specifically, the radius of the Gaussian blur that is in theory in the image. Thus, this controls the size of details you're working on sharpening.



Nebulosity also provides a tool that takes a different approach to the problem. The Tighten Star Edges tool first examines your image and performs an edge detection analysis using a modified version of the Sobel Edge Detector (modified to work better with our round stars than the traditional Sobel). These edges are then subtracted from your image to yield tighter stars and enhanced edges. Note, this is not the same kind of edge enhancement done during DDP processing.

This is a shot of M57 as acquired (left) and after the Tighten Star Edge tool using the default parameters. Using the slider that appears when you run this tool (located in the Image menu), you can adjust the degree of edge enhancement applied.

16.6.2. Gaussian Blur

Nebulosity lets you apply a Gaussian blur to your image. This is another nice way of reducing noise. For example, prior to applying a flat frame to your image it can be useful to blur the flat first to reduce noise in the image. Small amounts of blur can also be used after over-sharpening.

16.6.3. 3x3 Pixel Median

One final way of smoothing the image is to apply a median filter to it. In this case, a sliding window of 3x3 pixels is passed over the image and the median value is put in place of the center pixel in that window. Thus, each pixel becomes the median of it and its neighbors (the median being the middle-most number if their intensity values were sorted).

16.6.4. Vertical Smoothing (deinterlace)

Some CCD sensors are “interlaced” while others (and CMOS sensors) are “progressive” scan devices. Interlaced sensors read every other line in one pass and then come back to read the skipped line in a second pass (e.g., 1, 3, 5, 7 … 2, 4, 6, 8, …) while progressive sensors read the image out in order in a single pass (e.g., 1, 2, 3, 4, 5, …). Since it takes time to read out the image (or half the image) interlaced sensors can be prone to a “Venetian Blind Effect” that makes the image appear to have fine horizontal lines. In truth, there are no lines on the image but one set of lines (e.g., the even lines) got a little bit longer exposure than the other set of lines (e.g., the odd lines). Most cameras that use interlaced sensors have some means by which they try to reduce or eliminate this effect, but at times it still comes through in the image. You can remove it with the Vertical Smoothing tool. When started, a dialog will appear with a slider that controls how much smoothing is applied. Adjust it until the artifact is gone. Don’t overdo it as this is smoothing your image.

16.6.5. Noise Reduction

Noise is in all of our images and nowhere is it more apparent than in the background sky or the faint bits of the DSO. Here, the real signal we care about is so close to the thermal noise, the read noise, and the skyglow’s shot noise that after stretching things can look downright ugly. One solution is to not stretch so much. Another is to stretch but then try to reduce this noise. *Nebulosity* has two tools to do this: Adaptive Median Noise Reduction and GREYCstoration Noise Reduction.

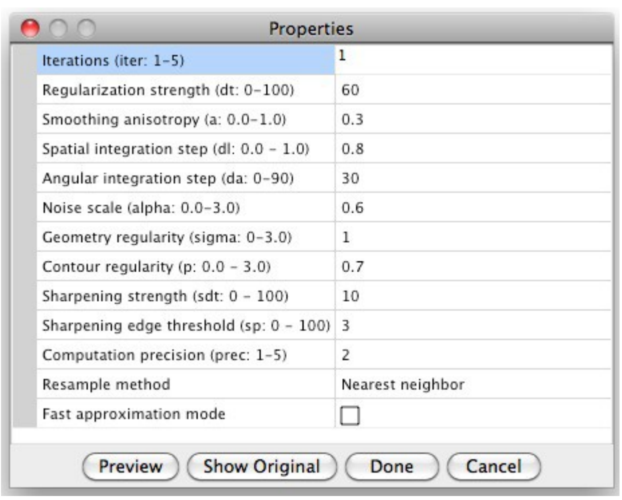
16.6.5.1. Adaptive Median Noise Reduction

The Adaptive Median Noise Reduction scheme works off of the premise that the noise you want to reduce is all in the darker areas. A dialog appears with a slider when you start the tool that asks for a threshold. Raising the threshold will have more of your image subjected to the filter and lowering it will have less. What this is doing is blending your original image with a median-filtered based image with the shift from one to the other based on your slider position.

16.6.5.2. GREYCstoration Noise Reduction

The GREYC Noise Reduction tool was authored by GREYC Labs and is an incredibly powerful tool. One of its main components is a noise reduction tool that removes local variations in intensity while respecting sharp boundaries in the image (e.g., our nice high contrast stars, transitions from sky to dust lanes, etc.) What is included here in *Nebulosity* is their command-line tool and an interface to this tool. You don't need to use the command line tool at all as the integration with it is designed to be as seamless as possible and to make it look as if it is one of *Nebulosity's* own tools.

GREYCstoration has a large number of parameters you can set and the dialog that appears when you start it is more like the dialog you see in many other programs. An array of parameters with arcane names appears and you may have no idea just where to go from there. At the very least, the defaults entered here should be a reasonable starting point (and differ from GREYCstoration's own defaults). That said, odds are you will be trying a lot of different parameters as you hone in on what will do the best noise reduction in your image without loosing vital details.



In this before and after example, there is clearly an improvement noise-wise. The background is a lot smoother and overall the image is still quite sharp. It's not perfect, though, and still could benefit from some tuning of the parameters. There are a few things that will help you do this:

- Before you enter GREYCstoration, select a box around something that has stars, background, and your main object. You will be able to preview things on just this region, which will make for much faster refreshes of the screen to see the effect.
- On entering GREYCstoration or after a change in parameters, hit the Preview button to see the effect. You can hit the Show Original button to revert the display back to the original image to see what was gained and what was lost. You can change parameters as much as you like hitting Preview between each iteration. Preview always goes back to the original data. Hitting Done will apply this to the whole image (and can take a long time – watch the title bar).

- Read the GREYCstoration documentation with examples.
- The “Fast approximation” and nearest neighbor resample methods do speed things up but don’t produce the best output.

17. Other Tools

The File and Edit menus have several other tools that are worth noting:

17.1. Launch New Instance

Ever want to work on two images at once? Or, ever want to control two cameras at once? Simply pull down Launch new instance from the File menu and you'll have another copy of *Nebulosity* running. Launch as many as you like!

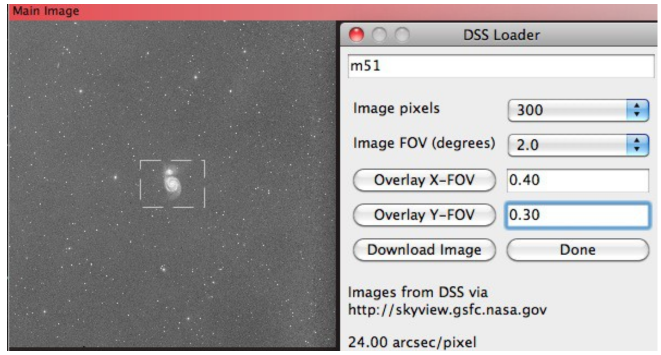
17.2. Change Language

English not your cup of tea? (Sorry, I couldn't resist.) Pull down Change language from the File menu and you can transform Nebulosity's menus and dialogs into several other languages following a restart of Nebulosity. Please note, I do not speak any of these other languages, so no help can be offered if you send me e-mails in German, Dutch, Italian, French, etc.

17.3. Image Info and FITS Header

Want to know when you took an image? How about what the CCD temperature was when you captured the frame? If the image is open, Image Info in the Edit menu will tell you these sorts of things and more. For any FITS image, you can get this information (and all information in the FITS header) by using the FITS Header tool in the File menu.

17.4. DSS Loader



Ever wonder what a target will look like on your camera with your telescope before heading out to image? Of course you have! The DSS Loader tool lets you see what kind of framing you'll have using real images from the Digitized Sky Survey. Start by entering the name of a target (or coordinate position) in the top field. Then select a desired Field of View (FOV). Don't worry about being precise here yet, just pick something bigger than your rig will show. At this point, you can hit Download Image and it'll query the DSS (via Skyview) for an image and put it onscreen (it may take a bit to download the image). Now, feel free to enter in values in the X-FOV and Y-FOV field corresponding to what your scope + camera will show and you'll see selected on the image your exact FOV. Don't know your current FOV? Click the X-FOV or Y-FOV buttons and a calculator will appear to figure this out for you. Note, the region is actually selected so if you like, you can now crop this out.

17.5. Measure Distance

Knowing how far apart several stars are can be quite useful. You can use it to calculate the effects of focal reducers (measuring the distance between stars in prime-focus and reduced images) or to say, "Hey is this pair of stars on my image really that pair of stars in the atlas?" The Measure Distance tool lets you do this.

First, select up to 3 stars in your image by simply right-clicking on them in the image. The first will get a red circle around it, the second a green, and the third a blue. If you make an error, either Shift-R-Click to erase all points or keep selecting stars (you'll cycle back to red after blue). Next, pull down *Measure Distance* from the *Image* menu. You'll be asked for the resolution of the image in arc-seconds per pixel. (If you don't know, simply use 1.0 as a value and all values will be in CCD pixels or see use the calculator built into the DSS Loader tool or the formula shown in *Your Telescope*). A window will then appear showing you the distance from red to green and, if three points were selected, green to blue and red to blue.

17.6. Check / Update License

If, for some reason, you need to update your license code or see what your license code is, this entry in the Edit menu will let you do so.

18. Supported Cameras

Nebulosity supports a wide range of cameras on both Windows and OS X. It's always best to check the website for the current list as it's often updated. They are:

- Atik
- Canon DIGIC II, III, and 4 and 5 DSLRs (not including the mirrorless ones I'm afraid a the Canon EDSDK doesn't support them) See below for more details.
- Fishcamp Starfish
- Meade DSI, DSI Pro, DSI II, DSI II Pro, DSI III, and DSI III Pro.
- QSI 500 and 600 series
- QHY8 / 9 / 10 / 12
- SBIG (See below for more details)
- Starlight Xpress SXV / SXVF / SXVR USB cameras (See below for more details)

In addition, on Windows, the following cameras are supported

- Apogee Alta
- CCD Labs Q285M / QHY2Pro
- FLI
- Moravian G2/G3 (v3 firmware or higher)
- QHY (others than just the Mac supported ones)
- Opticstar DS-335, DS-336C, DS-145, DS-142, and PL-130
- Orion StarShoot Deep-Space Color Imager (Other Starshoot cameras supported via ASCOM)
- SAC10
- SAC7 / SC1 long-exposure modified webcams / Atik 1 and Atik 2 cameras. See below for more details
- Any camera with an ASCOM v5/v6 driver (See below for more details)

18.1. SBIG

Almost all SBIG cameras are supported by using SBIG's Universal Driver (some very old ones are not supported by this driver and therefore not supported in *Nebulosity*). This must be installed first (see SBIG's website if you have not already used SBIG's software on your computer). On Windows and OS X, USB and Ethernet versions are supported. On Windows, but not OS X, parallel port models are supported. Note, however, that if you SBIG is a dual-chip model, the guide chip will not be available to any other program when the camera is in use in *Nebulosity*.

18.2. Starlight Xpress

While older USB-1 based Starlight Xpress cameras are not supported, all USB-2 based cameras (i.e., the "SXV" and later cameras) are supported.

The "Fast" mode available on the M (and MX) cameras is enganged whenever "High Speed mode" is selected in the Advanced Panel. On these cameras, short exposures are done via the "Interlaced" mode and longer exposures (generally ~1s or longer) are done via the "Progressive" mode.

If you have an older parallel-port camera, you can convert it to an SXVF version via Starlight Xpress' USB2 converter box. *Nebulosity* will detect and use cameras that have this device attached.

18.3. Canon DIGIC II, III, 4, 5, … DSLRs

The Canon DIGIC II, III, and 4-based DLSRs are supported in *Nebulosity* on both the Windows and Mac OS X platforms via Canon's EDSDK (software development kit). Note, older DIGIC I-based cameras (D30/60, 1D, 10D, and 300D) are not supported by their EDSDK and therefore not supported in *Nebulosity*. Also note that Canon does not support all of their cameras under Windows 7 and is phasing out support of older cameras by the EDSDK (notably the DIGIC II based cameras like the Rebel 350) on all platforms.

The supported DSLRs act much as any one-shot color astronomical camera would in *Nebulosity*. This can cause confusion for people when they first try to capture images. Images will come up looking monochrome, the interface on the camera always says "busy", they get FITS files rather than CR2 files, and their white balance settings don't seem to have any effect. What the...?

Some of these things can be changed in the Preferences, but some cannot. What you can't change is setup this way for a reason, however. It will say "busy" as *Nebulosity* has locked the camera and is preventing you from doing things like changing the shutter speed or the ISO value. When you want to change these, you change them in the Nebulosity interface (exposure time and gain / ISO) so *Nebulosity* knows these values. Likewise, it will ignore your white balance settings (as skyglow will throw the color balance off anyway - see below). It also won't let you select JPEG or RAW directly, but it will do so as needed based on what you're doing. When you hit Preview or Capture Series, it will take a RAW frame. When you hit Frame and Focus and Fine Focus, it will shift into a JPEG mode for high speed (but lower quality) readouts - just the kind of thing you want when trying to compose or focus.

18.3.1. Color images and FITS/CR2

Just like any one-shot color camera, you can opt to acquire images in pure RAW (Bayer-matrix images that have not been converted to color yet), or in RGB via the Preferences. Here, you can choose whether you wish to optimize speed (high-quality JPEG images are downloaded from the camera) or quality (the RAW image is downloaded, the Bayer matrix extracted, and *Nebulosity's* Demosiac routines are applied). RAW Bayer-matrix images are the best choice when the highest quality is desired as they allow you to pre-process the images *before* conversion into color, and the color conversion (Demosaicing) is done using *Nebulosity's* best routines.

One thing to note here is ***what we mean by the term "RAW"***. Some people feel that "RAW" means "CR2" or "NEF" or "CRW" format. These formats are just containers for image data. FITS is another container for image data as is TIFF or PNG or JPEG. All of these except JPEG can save the full 16-bit, pure data off the sensor with no loss whatsoever. "RAW" is just that - the raw sensor data. It has nothing to do with the container format per se.

By default, *Nebulosity* saves images from your DSLR in FITS format. It saves the raw sensor data in this container rather than in CR2, CRW, or whatever is the native format for your camera. But, fear not, it is storing the raw sensor data. It just doesn't store things like the focal length setting of the zoom lens (that's probably not hooked up to the camera since you're probably shooting through a telescope). (Aside - it's not like CR2 isn't odd in it's own right. It's a lossless JPEG-compressed bit-packed image stored inside a massive TIFF-like hierarchy.) If you want CR2 files, though, you do have an option to save them in addition to the FITS files. Preferences, DSLR Save location will let you choose Computer (FITS only), Computer FITS and CR2, and even to save them on the CF card.

18.3.2. White balance

One cannot read a setting on the camera that lets you know if the camera uses a stock IR filter or if it has been modified to have an extended-IR response (e.g. using a Baader IR filter or a Huetech filter). Color reconstruction must be done differently if an extended-IR filter is used, however. To ensure accurate color, make sure you have made the appropriate selection in the Preferences, Processing, DSLR White balance / IR filter section. If you're not sure which one is correct, try taking a normal daytime shot (a CR2 file shot of something outdoors with your DSLR lens is just fine) and try the various options until you find one that gives a good color balance. *Note, that if you see pink cores to saturated areas, try the Straight Color Scale option.* Keep in mind that skyglow, atmospheric refraction, etc. will always muck with your colors, so there is no need to get this spot-on. Every night will have a bit different color and every time you, like all other imagers, will need to work the color balance.

18.3.3. Long exposures / bulb triggers

Canon DSLRs can be classified into several generations based on the DIGIC processor used inside. With the advent of the DIGIC III and 4 DSLRs (circa 2007 and beyond), the cameras can take exposures of any length via a special "bulb" command. By default, *Nebulosity* will try to use these commands when you connect to a Canon DSLR ("DIGIC III onboard" in the Preferences - see below). The only downside to this arrangement is that you cannot use mirror lockup if you are using this method for long exposures.

Older, DIGIC II DLSRs (e.g., 350 XT) are limited to 30s exposures when the camera's internal timing is used. If you connect the USB cable to the camera and your computer and this is your only connection, you will be limited to 30 seconds of exposure. To achieve longer exposures, some form of "bulb adapter cable" is required . Various forms of this exist to drive the camera's "bulb" setting from USB, serial, or parallel ports on your computer. ***If you use one of these to allow you longer exposures you must also keep the USB data cable connected*** (i.e. you will have two cables connected).

In the Preferences menu, you will find options to let you choose your long-exposure cable setup. Nebulosity supports the following:

- ShoeString DSUSB or DSUSB2 USB adapter (PC and Mac)
- Serial port adapters (COM1-8) such as Hap Griffen's (PC and Mac)
- Parallel port adapters (Pin 2 or Pin 3 on ports 0x378, 0x278, and 0x3BC) such as Hap Griffen's (PC only)
- Onboard "blulb" timing for DIGIC III and 4 DSLRs (default)

Note: Not all USB->Serial adapters will work as we need direct control over several data pins on the serial port. Generally, those that require a driver disk will be more likely to work (tested with inexpensive Prolific-based adapters and Keyspan adapters).

Select your long-exposure adapter prior to connecting to the camera. Nebulosity attempts to connect to the long-exposure adapter when it connects to the camera itself.

18.3.4. Mirror lockup

The Canon cameras all support a mirror-lockup mode. When enabled, pressing the shutter button once lifts the mirror and pressing it a second time triggers the exposure. Enabling this mode involves entering your camera's Tools menu and finding the appropriate Custom Function (CFn) - usually either 12 or 7, selecting and enabling this prior to connecting to the camera in *Nebulosity*. *Nebulosity* has no way to set this mode itself, but it can detect if the camera is in mirror-lockup mode and, if so, will send the appropriate shutter pulse prior to the main exposure.

Unfortunately, if using the onboard "bulb" mode for DIGIC III or later DSLRs, you cannot use the mirror lockup mode. There is no way to trigger a lockup over the USB line. *Thus, for mirror-lockup mode to be used, you must have a long-exposure cable selected and attached.* Another consequence of this is that mirror-lockup cannot be used in USB-only mode.

18.3.5. Mode dials and lens settings

Nebulosity will attempt to read the current setting of your camera's mode dial and inform you if it is set improperly. For most cameras (those without a “B” setting on the mode dial), the proper setting is “M” on the mode dial and if you have a DSLR lens attached, it should be in the “MF” position. *Nebulosity* will program the camera and use the onboard timing for short (<30 s) exposures and use whatever long-exposure adapter (including the onboard DIGIC III/4) for longer exposures.

For cameras with a “B” setting on the mode dial (e.g., the 5D Mk II), things get a bit more complex. On these cameras, if you want >30 s exposures, you must set the camera to the “B” position on the mode dial. Unfortunately, we cannot program short exposures in this mode. We can manually time short exposures, but you will never get a precise 1/1000 s exposure this way. To get precise timing for short exposures, have the camera in the “M” mode. As with the other cameras, any attached lens should be set to “MF”.

Note also, that onboard noise reduction (automatic dark frame collection and extraction) should quite probably be turned off. What this does is to take a dark frame right after your light and do the dark subtraction on the fly. A nice feature of this is that it’s done with the camera at the same basic temperature for your light and your dark. The downside to this, though, is that it’s taking darks when your DSO is available in the sky. If you’re trying to maximize the amount of time you capture photons from that DSO (as is typical), you’re not helping by taking the darks at the same time. You’ll end up with half has much light frame data. Some people do use this mode (for the temperature advantage) but if you do use it, remember you’re getting half as much data from your DSO. If you can take your darks once the sun is up or the DSO has set, you’ll get much more data.

18.3.6. Troubleshooting Connections

There are several steps to take to ensure *Nebulosity* will connect to your camera.

- Ensure that the USB data cable is connected (in addition to any long-exposure "bulb" cable) and that the camera did not decide to shut itself off from inactivity (once connected, *Nebulosity* will keep it turned on)
- Ensure that your camera drivers (from the Canon CD) have been installed on your computer.
- Verify that the EOS utility is installed and that it connects to the camera and can be used to control the camera.
- Ensure that the camera is set to communicate (Menu, Tools, Communication) to the computer in "PC Connection" mode.

18.4. ASCOM Cameras

Nebulosity supports image capture through ASCOM v5/v6-compliant cameras under Windows. This means that any camera with an ASCOM camera driver can be used with *Nebulosity*, thus greatly expanding the number of cameras that can be used.

There are several things to know about ASCOM cameras, however.

- For your ASCOM-compliant camera to work, you must install both the ASCOM platform itself (www.ascom-standards.org) and the specific driver for your camera.
- When you attempt to connect to an ASCOM camera, an ASCOM dialog (the “Chooser”) will appear. This is not a Nebulosity dialog, but one of ASCOM’s. If your camera is not listed in there, your camera driver is not properly installed.

Consult your camera maker or the author of the driver for assistance. If the ASCOM “Chooser” does not appear, ASCOM itself is not properly installed.

- In *Nebulosity* v2, there were two styles of ASCOM connections corresponding to the two ways ASOCM v5 let you talk to the camera: “early” and “late” binding. The meaning of this is too arcane for users here and ASCOM dropped “early” binding. Here in Nebulosity 4 (and in v3), all binding is “late”.
- Not all of your camera’s features may be present. ASCOM’s camera driver specification may not include features unique to your camera.

18.5. SAC7 and Long Exposure Webcams

The SAC7 and other cameras based on long-exposure modifications to webcams according to the work of Steve Chambers (otherwise known as "SC-modified" webcams) are supported in *Nebulosity*. There are a few things to note, however.

First, these cameras can either be used directly when attached to a parallel port (you'll need to know the "port number") or via a USB port. Many modern computers lack a parallel port or only include one that is derived from an internal USB-Parallel adapter. Unfortunately, these adapters do not make the right signals for the cameras to operate. ShoeString Astronomy has devised an excellent solution with their "LXUSB" product. This plugs into a USB port and, when controlled by *Nebulosity*, will make signals that can be used to fully control these cameras. Thus, cameras like the SAC7 can now be used on machines that only have USB ports and that do not have a parallel port at all!

Second, these cameras typically have two modes - a "short exposure" mode and a "long exposure" mode. In short exposure mode, the camera's own controls adjust the exposure duration (typically 1/25th of a second or shorter) via a pop-up window. In long exposure mode, the program (such as *Nebulosity*) controls the exposure duration.

In *Nebulosity*, short exposure mode is selected by setting the exposure duration to 0. Anything greater than zero will put the camera into long exposure mode. In short exposure mode, the shutter speed is controlled via a pop-up window. Press the Advanced button in the Camera panel and you'll get a slightly different version of the Advanced dialog described above. You'll find *Setup* and *Format* buttons that let you configure the resolution, shutter speed, gain, frame rate, etc.

> Note: For the best images in both short and long exposure modes, always set the frame rate to a low setting such as 5 FPS. This minimizes the amount of compression your images undergo. Do this in the Advanced Dialog using the Setup and Format buttons

In addition to these buttons, the Advanced Dialog has one added section for these cameras. A "Read delay" can be entered. The default value should work on most systems but if you find you are dropping frames, try adjusting this value (5 ms increments will be good). System speed and specifics of your camera may dictate a slightly different value

(10ms - 30ms for a typical range).

18.6. Camera Advanced Panel

If you click on the Advanced button in the Camera panel, a dialog box will appear that lets you set various advanced controls on the camera. Some of the options may be grayed out or not even present. If so, this means either that the current camera does not support this feature or that some other feature is preventing it from being activated. Below is a description of the available options.

- *Amp off*: Checking this box will have the CCD camera's amplifier turned off during the exposure. This amplifier, when on causes "amp glow" - a brightening usually in one corner of the image. Rarely would you ever want to uncheck this box.
- *Double Read*: This option enables a feature designed to fix the "interlacing artifact" found on interline transfer CCDs like the SAC10 and Orion StarShoot. You'll notice each exposure takes twice as long but that you end up with a smoother image. This option is particularly useful for shorter exposures where the problem is worse (4 seconds of read time is a lot in comparison to a 2 second exposure but not much in comparison to a 5 minute exposure). If you're working with bright objects or short exposures, you'll want to use this or the VBE option.
- *High speed read*: If selected, the camera will read the image off the CCD more rapidly but at the expense of increasing the noise. This is enabled by default during Frame and Focus but is not to be used for DSO imaging. *Selecting both* High speed read *and* Double Read *is an excellent way to take good planetary or lunar shots.*
- *Bin mode*: Selecting this option will put the camera into a binned mode whereby pixels are combined during the CCD readout itself. This increases sensitivity at the cost of resolution and, at times, at the cost of color on one-shot color cameras. The available bin modes depend on your particular camera.
- *Enable TEC*: You can set the cooler on your camera to a certain temperature (if the camera supports this)
- *Close shutter*: If you want to take dark frames, setting this will keep the shutter on your camera closed (if your camera supports this).
- *Oversample*: If selected the camera will sample and convert the information from the CCD twice. The net result is a less noisy image, but one that takes a bit longer to read and process.
- *VBE balance color exp times: (SAC10 only)* This feature attempts to fix the same problem addressed by the Double Read option (the problem is sometimes called the Venetian Blind Effect), but to do so with a single exposure. It intelligently balances the intensity of the odd and even lines and can be quite useful for shorter exposures.

19. Taking Good Images

You didn't buy a camera to take dim, noisy, fuzzy images, yet chances are quite decent that's what you could get your first night out. How do those pros make such good images? This guide won't make you a pro, but it will at least get you started in the right direction. For help on any of these, consider joining the Stark Labs Yahoo Group. In addition, head on over and have a look at the series on Signal to Noise I did for Cloudy Nights.

19.1. Your Telescope

CCD cameras are not as forgiving as your eye and can be used to reveal any flaws you have in your telescope. It's time to make sure it's in good shape by checking:

- Is it well collimated?
- Can you rigidly mount the camera to it or is there play in the focuser or attachment?
- Have you got a good handle on dew prevention? (The author has more than once taken a long series of exposures only to realize he was shooting through a solid layer of due on the telescope objective.)
- Is it well-matched to the camera?

This last is, in and of itself, a rather lengthy topic with some disagreement as to what is the absolute best match, but a few things can be agreed on. The most critical aspect of this is to determine just how much sky each pixel covers using your telescope. That can be done with the following simple formula:

For maximum resolution, with perfect tracking (see below) and excellent seeing, a value of 1"/pixel is a good target (some pros go to slightly smaller values still). For more typical conditions with good seeing and good tracking, 1.5-2"/pixel is another fine target. Larger

$$\text{Arcseconds per pixel} = \frac{206.265 \times PixelSize}{FocalLength}$$

amounts of sky covered per pixel will let you cover more sky and will not stress your mount's guiding accuracy as much (see below), making values of 3-6"/pixel quite reasonable for many situations. In so doing, you are trading off extreme resolution for wider swaths of sky and less difficulty guiding.

From this formula, you can see that there are two ways to adjust the final resolution in your image. You can either adjust the pixel size of the camera or you can adjust the focal length of your telescope. Neither seem trivial at first glance and, while they can be adjusted, it is only to a limited degree. (Telescope focal length can be shorted with a focal reducer and lengthened with a Barlow. CCD pixel size can be effectively increased by binning.) Thus, determining what telescope to use for a given camera or vice versa is often best done before purchase.

19.2. Your Mount

A number of aspects about your mount will affect the quality of your images. Here, we'll talk about accurate polar alignment and about periodic error and guiding.

Note: To see how much your mount is moving between images, right-click on a star to lay down a "target" circle around it. This target will remain in the same place on the image across captures, and let you see how far that star has moved.

19.2.1. Polar Alignment

If you've got an equatorial mount, aiming at Polaris with the RA and DEC zeroed will get you somewhat close to polar alignment but not close enough for imaging. Using a polar alignment scope on your equatorial mount or using your GOTO mount's alignment procedure will get you closer. But, neither will get you spot-on enough for long-exposure work. To do that, you've got two main options:

1) Drift alignment. In this technique, you watch how stars drift through the field and adjust your mount accordingly. For a standard equatorial mount, this is your best bet. It takes a bit of practice, but, once you know what you're doing, it'll take about 30 minutes to get a decent drift alignment - decent enough for the kind of exposures you'll be able to do without guiding anyway. Others have done a good job describing the technique, including a site by Pete Kennett or one by Scott Tucker of Starizona.

2) Iterative alignment. If you have a GOTO scope, you owe it to yourself to learn how to do this. I can get a nice alignment that won't drift (well, periodic error of course, but no overall drift) for an hour worth of imaging in about 5-10 minutes of work. There are several sites on the web that go over the method (e.g., Michael Covington's), but the basic idea is very simple.

First, do a "one star" alignment - the kind in which the scope aims itself towards where Polaris should be (using the Kochab clock if that makes sense to you) and then asks you to adjust the mount physically to center Polaris. After centering Polaris, the scope slews over to a single star and asks you to use the keypad controls to center that other star. At this point, you're close and have done the standard "one star" alignment.

Now, tell the scope to GOTO Polaris. Adjust the mount physically to remove about half the error between where it ended up and where Polaris actually is (i.e., have it aim to the spot about halfway between the GOTO and Polaris). Now, do a GOTO back to your alignment star, center, and SYNC to that star. Repeat a few times until your GOTOs on Polaris end up without any error and you're good to go!

19.2.2. Periodic Error and Guiding

Now that your scope is polar aligned, the stars won't drift across the field *on average*.

You'll still notice that they will rock back and forth a bit - sometimes very slowly and sometimes in abrupt jumps. This is called *periodic error* and caused by minor imperfections in your mount's *worm gear* - a cylindrical gear that actually turns the telescope to counteract the earth's rotation. No worm gear is perfect, but some have bigger problems than others. If you don't choose to guide your telescope during imaging, these imperfections will limit how long you'll be able to expose each image. Exactly how long you can go will depend on the size of the periodic error and the amount of sky covered by each CCD pixel. Wide-angle shots with 10"/pixel are a lot more tolerant of periodic error than zoomed-in shots at 1"/pixel.

Some amateurs run shots unguided and end up stacking many 15-40s long exposures into one long image. With enough images, and with the right exposure settings (see below), this can be used to make very nice images.

But, what can you do to lengthen this time or to fix the problem entirely? Several mounts offer *Periodic Error Correction (PEC)*. On these mounts, you train the telescope to know what the error is like by following a single star and correcting the errors using the telescope's controller. The mount then learns these corrections and applies them automatically. This can reduce the error quite a bit.

A second technique, often used on its own or in conjunction with periodic error correction is guiding. Here, an image of a star is sent to either an eyepiece (*manual guiding*) or a second camera (*autoguiding*) while your main imaging camera collects pictures. Two approaches are taken. In one, an *Off-Axis Guider* is used to split some of the light away from the main camera and towards this eyepiece or second camera. A small prism is placed so that the light split off is light that would not have fallen on your main imaging camera anyway. In a second, another telescope (a *guide telescope*) is attached to the imaging telescope. In both, this second view of a star is used to determine when the telescope is drifting slightly off target and to correct this problem by sending very small movement commands to the mount.

Many packages are out there to help you autoguide your mount. A free one from Stark Labs, *PHD Guiding*, works well on a wide range of cameras and mounts and is designed to be "Push Here Dummy" simple. Its goal is to make it so that you have little excuse for not trying autoguiding.

19.3. Focus

Getting your camera sharply focused is critical to taking good pictures. The Frame and Focus routine will get you close, but will often not get you to as sharp a focus as you could get. For this, you'll want to make sure you're using the full Preview mode or the Fine Focus mode, making only small adjustments to your focus between each shot.

You can evaluate your focus by simple visual inspection or by calculating several statistics about a star. In particular, when a star is in focus, it will get more of its light on a central CCD pixel than when out of focus. The Fine Focus tool offers an excellent focus aid that will help you achieve critical focus.

In addition to these techniques, there are a few others you can try. One technique is to build or buy a Hartman Mask, a diffraction mask, or a Bahtinov Mask. They're not tough to build - many consist of cutouts in pieces of cardboard and one is assembled out of TinkerToys (no, really). All work by having you place something in front of the scope during focusing. When the star is nice and sharp, the artifacts induced by each disappear or form a particular pattern. The Bahtinov mask is an exceptionally easy to use version and is very effective.

A second technique to try is to use the fact that in focus stars get more of their light on the CCD than out of focus stars. When in focus, you'll be able to see stars in the Preview or even Frame and Focus that would disappear when out of focus. Adjust the exposure duration or gain until you can just barely see a star. Adjust the focus to see if you can make it brighter or if it disappears on either side of where you are right now (or, if you know you're a bit out, make the star disappear with the duration or gain and reappear with the focus knob).

19.4. Exposure settings

When taking images, there are a few simple rules to follow that will let you collect frames that can be used to make a nice final picture.

19.4.1. Rule #1: Use the Histogram to keep your background above the floor and bright bits below the ceiling.

First, you should always try to expose images so that the background sky is "off the floor" and the stars (or at least the cores of the DSOs) are "off the ceiling". What this means is that you don't want large parts of your image to have values of zero or of 65535 (the minimum and maximum possible values). Any time a pixel has either of these values, we've lost information. For example, let's say a star is at 65535 and one next to it is really twice as bright. Both get recorded at 65535 and the final image doesn't show a difference between the two. Once we've reached this maximum, we simply can't go any higher and so important details (such as the difference between these stars) are lost.

The same holds true on the dim end. Let's say a faint arm of a galaxy is just barely brighter than the skyglow around it (a very common situation). If your background sky is recorded as zero, quite possibly the faint bit of the galaxy is at zero as well. No matter how many images you stack, if they all have zero in them, you'll never be able to find that dim galaxy arm in your image.

How do you do this? The exposure duration is the most obvious method. Longer exposures will brighten the image (moving the histogram to the right). In addition, the increasing the gain and offset controls will also brighten the image. Both will add more noise into the image, but a little bit more noise is a lot better to have than ultra-black backgrounds. If you're running unguided images, you'll likely use higher values of gain and offset than those running guided.

19.4.2. Rule #2: Take lots of images

Every image you take has noise in it. So, adding images together adds noise into the image, right? Yes and no. If you compare a stack of 20 exposures of 30-second each to one exposure of 10 minutes, the single longer exposure will quite probably be a cleaner looking shot. But, if you compare one of the 30-second long images to the combination of all 20 exposures, the combination or "stack" of images will have a lot less noise in it than the single frame.

Why is this? Much of the noise in our images is *uncorrelated* or *white* noise. What this means is that each time we sample something (e.g., each time we take an image), we get some noise added into the image that has nothing to do with the amount of noise added in the last time we took the image. (Hot pixels and readout noise are examples of *correlated* noise and are addressed in dark frames and bias frames respectively).

When we combine multiple images, this uncorrelated noise starts to disappear. Four 30-second exposures will have half the noise of a single 30-second exposure (noise follows a 1/sqrt(N) function where N is the number of images you combine). One hundred such frames will have one tenth as much noise (and therefore 10x the SNR). Reducing the noise allows one to "stretch" the image to make a very fine distinction between dim portions of a DSO and the skyglow that is just the tiniest bit darker than the DSO (this will always be the case - its just a question of how small that difference is.)

19.4.3. Rule #3: Don't over-tax your mount

If your mount can only take exposures of 30-seconds before showing tracking errors on most exposures, don't try going any longer than 30-seconds until you can guide your mount (*PHD Guiding* from Stark Labs is free and tries to make this as painless as possible). Take Rule #1 and Rule #2 to heart and gather many noisier shots. Each one may look pretty bad and it may look like you'll never get a good image out of your efforts. Don't despair. I've had many nice shots come out of raw frames that look like noise with barely a hint of any DSO in there much less a nice smooth one.

19.4.4. What do gain and offset do?

After coming off the CCD and before hitting the actual analog-digital-converter (ADC) to turn the signal into a number, there is typically a small pre-amplifier (this may be inside the ADC chip itself). What this preamp does is allow you to boost the signal by some variable amount and to shift the signal up by some variable amount. The boosting is called gain and the shift is called offset.

So, let's say that you have pixels that would correspond to 0.1, 0.2, 1.1, and 1.0 ADU were the ADC able to deal with fractional numbers. Now, given that it's not, this would turn into 0, 0, 1, and 1 ADU. Two bad things have happened. First, the 0.1 and 0.2 have become the same number and the 1.1 and 1.0 have become the same number. We've distorted the truth and failed to accurately represent subtle changes in intensity. This failure is called quantization error. Second, the first two have become 0 and, as noted above, 0 is an evil black hole of information.

Well, what if we scaled these up by 10x before converting them into numbers (i.e., we introduce some gain)? We'd get 1, 2, 11, and 10. Hey, now we're getting somewhere! With gain alone, we've actually fixed both problems. In reality, the situation is often different and the ADC's threshold for moving from 0 to 1 might be high enough so that it takes a good number of electrons to move from 0 to 1. This is where injecting an offset (a DC voltage) into the signal comes in to make sure that all signals you could possibly have coming off the CCD turn into a number other than zero.

19.4.5. Gain's downside: Bit depth and dynamic range

From the above example, it would seem like we should all run with lots of gain. The more the better! Heck, it makes the picture brighter too! I often get questions about this with the assumption that gain is making the camera more sensitive. It's not. Gain does not make your camera more sensitive. It boosts the noise as well as the signal and does not help the signal to noise ratio (SNR) in and of itself. Gain trades off dynamic range and quantization error.

We saw above how it reduces quantization error. By boosting the signal we can have fractional differences become whole-number differences. What's this about dynamic range?

Let's come up with another example. Let's have one camera with a gain of 1. So, 1 e-/ADU. Let's have another run at 0.5 e-/ADU. Now, let's have a pixel with 1k e-, another with 10k e-, another at 30k e-, and another at 50k e-. In our 1 e-/ADU cam, we of course have intensities of 1000, 10000, 30000, and 50000. In our 0.5 e-/ADU cam, we have intensities of 2000, 20000, 60000, and 65535. What? Why not 100000? Well, our 16-bit camera has a fixed limit of 65535. Anything above that gets clipped off. So while the 1 e-/ADU camera can faithfully preserve this whole range, the 0.5 e-/ADU camera can't. Its dynamic range is limited now.

19.4.6. How do manufacturers determine gain and offset for cameras that don't allow the user to adjust them?

Let's pretend we're making a real-world camera now and put in some real numbers and see how these play out. Let's look at a Kodak KAI-2020 sensor, for example. The chip has a well-depth specified at 45k e-. So, if we want to stick 45,000 intensity values into a range of 0-65,535, one easy way to do it is to set the gain at 45,000 / 65535 or at 0.69 e-/ADU. Guess what the SBIG ST-2000 (which uses this chip) has the gain fixed at... 0.6 e-/ADU. How about the QSI 520ci? 0.8 e-/ADU. As 45k e- is a target value with actual chips varying a bit, the two makers have chosen to set things up a bit differently to deal with this variation (SBIG's will clip the top end off as it's going non-linear a bit more readily), but both are in the same range and both fix the value.

Why? There's no real point in letting users adjust this. Let's say we let users control the gain and they set it to 5 e-/ADU. Well, with 45k e- for a maximum electron count at 5 e-/ADU, we end up with a max of 9,000 ADU and we induce strong quantization error. 10, 11, 12, 13 and 14 e- would all become the same value of 2 ADU in the image, loosing the detail you so desperately want. What if the user set it the other way to 0.1 e-/ADU? Well, you'd turn those electron counts into 100, 110, 120, 130, and 140 ADU and wonder just what's the point of skipping 10 ADU per electron. You'd also make 6553 e- be the effective full-well capacity of the chip. So, 6535:1 would be the maximum dynamic range rather than 45000:1. Oops. That nice detail in the core of the galaxy will have been blown out and saturated. You could have kept it preserved and not lost a darn thing (since each electron counts for > 1 ADU) if you'd left the gain at ~0.7 e-/ADU.

What about offset? Well, it's easy enough to figure out the minimum value a chip is going to produce and add enough offset in the ADC process to keep it such that this is never going to hit 0.

20. Controlling Nebulosity from other software

There are a number of ways in which advanced users can take control of Nebulosity for remote automation. Here is a brief overview of the options available to you.

20.1. Scripting via files, the clipboard, or TCP/IP sockets

The scripting language lets you control Nebulosity's capture processes nicely and will suffice for many use cases. Script files can be passed in as parameters when starting Nebulosity to let you start the software, run some captures, and quit if you like. More often than not, though, you'll want to connect to Nebulosity and control it in a dynamic way. Here, the Listen and ListenPorts come into play. Once these are run (e.g., via a startup script), you can send commands to Nebulosity via the clipboard (start each command with "/NEB" so in the format of "/NEB CommandName Parameter") and it'll runt hat command. Or, you can connect to a TCP/IP port specified there and send ASCII text commands that way.

20.2. Using Nebulosity as an ASCOM Camera

As of version 4, Nebulosity can itself act as an ASCOM camera. If you're connected to a camera in Nebulosity (by a native driver or by an ASCOM driver) you can have other software connect to Nebulosity as if it were an ASCOM camera. So, anything that can talk to an ASCOM camera can talk to Nebulosity in the same way. To do this, you'll need to install the Nebulosity ASCOM Camera Driver and the ASCOM platform. For example, here is a small Visual Basic Script (VBS) to connect, report some information, and capture a small ROI from an image:

```
Option Explicit
Dim cam
Dim CamImArray
Dim image
Set cam = CreateObject("ASCOM.Nebulosity.Camera")
cam.Connected = True

On error resume next

'Get cam parameters
WScript.Echo "Connected to " & Cam.Name
WScript.Echo "Version=" & Cam.Description
WScript.Echo "Info=" & Cam.DriverInfo
WScript.Echo "Pixels = " & Cam.CameraXSize & " x " & Cam.CameraYSize
WScript.Echo "BinX, BinY = " & cam.BinX & ", " & cam.BinY
WScript.Echo "MaxBinX, MaxBinY = " & cam.MaxBinX & ", " & cam.MaxBinY
WScript.Echo "NumX, NumY = " & cam.NumX & ", " & cam.NumY
WScript.Echo "StartX, StartY = " & cam.StartX & ", " & cam.StartY
WScript.Echo "Camera state = " & cam.CameraState

'Set cam parameters
WScript.Echo "Keeping on Bin 1, setting the ROI "
cam.BinX=1
Cam.BinY=1
```

```
cam.StartX = 200
cam.StartY = 100
cam.NumX = 400
cam.NumY = 300
WScript.Echo "BinX, BinY = " & cam.BinX & ", " & cam.BinY
WScript.Echo "NumX, NumY = " & cam.NumX & ", " & cam.NumY
WScript.Echo "StartX, StartY = " & cam.StartX & ", " & cam.StartY

cam.StartExposure 1, True
Do
  WScript.Sleep 100
Loop While cam.ImageReady = False

'Image is now ready
CamImArray = cam.ImageArray

If Err.Number > 0 then
  WScript.Echo "Err.NUmber: " & Err.Number & " Desc: " & Err.Description & " Source = " & Err.Source
End If

Cam.Connected = False

WScript.Echo "All done"
WScript.Echo "Image is " & LBound(CamImArray,1) & "-" & UBound(CamImArray,1) & " x " &
LBound(CamImArray,2) & "-" & UBound(CamImArray,2)
```

If any are interested in using this sort of API to control cameras on the Mac, let me know as it can readily be implemented via TCP/IP instead of via COM and DDE (the internals of what's used in the Windows support).

21. Menu Quick Reference

21.1. File Menu

- *Open File*: Loads any FITS (color or B&W, compressed or not, 8-64 bits, integers, floating points, you name it), PNG, TIFF, JPG, BMP, or DSLR RAW (CR2, CRW, NEF, etc.) file into memory and display. 8-bit/color files are automatically stretched to full range.
- *Preview Files*: Opens a dialog that lets you preview a set of files, deleting and renaming them as desired. Useful for filtering images and for quick looks at files.
- *DSS Loader*: Download an image from the Digitized Sky Survey and overlay an FOV indicator to help you plan your shots.
- *FITS Header Tool*: Lets you view the contents of the header of a FITS file.
- Save *current file (FITS)*: Saves the currently displayed image in FITS format using 16-bit integers (0-65,535). Compression set by *Preferences*, *Save as compressed FITS.*
- *Save BMP file as displayed*: Saves the currently displayed image in Windows BMP (bitmap) format. The values of the black and white sliders set the black and white levels in this, since BMP format is only 8-bits / color. How it looks is how it will save.
- *Save JPG file as displayed*: Like Save BMP, but in JPEG format. Any JPEG quality / compression (0-100) factor possible.
- *Save 16-bit/color TIFF*: Saves the current image in TIFF format (lossless compressed or uncompressed) at full 16-bit/color (aka 48-bit color) bit depth. This preserves all information in your image for use in graphics programs
- *Save 16-bit/color PNG*: Saves the current image in PNG format (always lossless compression) at full 16-bit/color (aka 48-bit color) bit depth. This preserves all information in your image for use in graphics programs
- *Save 16-bit/color PPM/PGM/PNM*: Saves the current image in the appropriate variant of these "portable pixel map" UNIX-based standard formats.
- *Save Color Components*: Saves the current color frame as three separate FITS files corresponding to the the red, green, and blue components of the image.
- *Launch new instance*: Launches a separate running copy of *Nebulosity* to let you work on another image or control another camera.
- *Change language*: Changes the language used in the user-interface. You must restart *Nebulosity* after this.
- *Exit*: Exit the program (on Macs, in the Nebulosity menu)

21.2. Edit Menu

- *Undo*: Undo the last change to your image. Undo will let you step back from any changes made by tools in the Image menu. By default, you can take 3 steps back. You can opt to disable Undo in the Preferences menu (to run a bit faster) or to have virtually unlimited undo capability.

- *Redo*: Think you liked it better with that processing you just undid? Redo.
- *Image Info*: Shows information about the current image including its size and the various capture parameters that either were stored in the FITS header or will be stored when the image is saved.
- *Measure Distance*: Measure the distance in CCD pixels, arc-seconds, and arc-minutes among up to 3 points in the image (right-click to set points first).
- *Edit / Create Script:* Open a window that allows you to create a capture script and load / edit an existing script.
- *Run Script*: Run a capture script, automating the image capture process
- *De-select cameras:* Camera pull-down getting a bit cumbersome? Use this to remove entries from the list (you can always add them back in later).
- *Check / Update License*: Verify your current license code and status and/or update your license code.
- *Preferences*: Set various preferences. See Preferences. (On Macs, in the Nebulosity menu)

21.3. Batch Menu (see also the Pre-Processing section)

- *Pre-process image sets*: Apply traditional dark frame or bad pixel maps, flat frame, and bias frame corrections to correct for typical CCD artifacts. Apply these corrections to a series of images.
- Make *Bad Pixel Map*: Create a map of the bad pixels on your CCD.
- *Batch Demosaic + Square RAW Color* and *Batch Square BW*: Batch versions of the tools found in the Image menu.
- *Grade Image Quality*: Grade a set of images to determine the sharpest (and fuzziest) of the set.
- *Normalize Intensities*: Normalize all images in a set to remove offset and scaling differences.
- *Match Histograms*: Equate a set of images' histograms to match that of a target image.
- *Align and Combine*: Align and (optionally) combine a series of images. A dialog will appear to let you control the method. Methods include: Fixed (no alignment), Translation ("one star", full-pixel shifts), Translation + Rotation (subpixel, including rotation such as with an alt-az mount), Translation + Rotation + Scaling (same, but including a scaling term), Drizzle, and Colors in Motion. For Fixed alignment, Standard Deviation based stacking is an option.
- *Automatic Alignment (non-stellar)*: Automatically align frames without picking

reference stars.

- *Batch Geometry*: Batch versions of rotation, binning, resampling and cropping.
- *Batch Conversion:* Tools to convert a set of images from FITS to various graphics formats or vice versa.
- *Batch One-shot Color with Line Filters:* Batch versions of the tools in the Image menu that extract portions of the color filter array.

21.4. Image Menu (see also the Image Adjustment section)

- *De-Mosaic RAW + Square*: Convert a single RAW CCD image currently displayed from a one-shot color camera into a full-color image. Faster and better quality modes available.
- *Square B&W pixels*: Squares pixels from black and white images.
- *One-shot color with line filters*: Tools for reconstructing a RAW image taken with line filters (e.g., Ha, Hb, OIII) from a one-shot color camera are provided along with a special Low Noise 2x2 bin optimized for these cameras.
- *Crop*: Resize the image by removing or trimming unwanted edges.
- *Mirror/Rotate Image*: Tools are provided for 90 and 180 degree rotation and for mirroring an image horizontally or vertically.
- *Resize Image*: Resample the image to change its size using any one of 6 different resampling algorithms (Box, Bilinear, B-Spline, Bicubic, Mitchell, Catmull-Rom)
- *Bin Image*: Shrink an image by binning (combining 2x2 patches of an image into individual pixels). Perform 2x2 binning using simple summation, simple averaging, or an adaptive algorithm. These reduce your image size by 2x.
- *Levels / Power Stretch*: Apply a user-controlled stretch routine to the current image. You can use this much in the same way a Levels tool is used to bring out details in the image.
- *Digital Development*: Apply a user-controlled stretch routine to the current image designed to make CCD images look more like film images. An excellent way to bring out faint detail in your images.
- *Curves*: Create a curve to transform the intensity of your image. Very powerful stretching tool.
- *Zero Min*: Add or subtract a constant from the current image so that its minimum will be zero.
- *Scale Intensity*: Pixel math to add, subtract, multiply, etc. each pixel.
- *Synthetic Flat Tool*: Remove background gradients
- *Adjust Color Background (Offset)*: Subtract user-specified values from the red, green, and blue color channels (e.g., from skyglow) to balance the color of the background in the image.
- *Adjust Color Scaling*: Apply a user-controlled scaling to the red, green, and blue

color channels separately to help balance the image.

- *Auto Color Balance*: Automatically balance the color (both offset and scaling) to remove a color-cast.
- *Adjust Hue / Saturation:* Tool to adjust the hue, saturation, and luminance of the image.
- *Discard Color*: Remove all color information from an image (extract the luminance data).
- *Convert to Color*: Change a monochrome image into a color-format image.
- *LRGB Color Synthesis*: Create a color image from separate files using RGB, traditional HSI-based LRGB, or Color Ratio based LRGB
- *Gaussian Blur Image*: Blur (smooth) your image by using a Gaussian kernel.
- *Sharpen Image*: Four tools are provided. Traditional and Laplacian sharpen tools based on 3x3 kernels are provided along with an *Unsharp mask* and the *Tighten Star Edge* tool. This applies an edge-detection routine (not a typical "sharpen" or "unsharp mask") to tighten stars and enhance edges in your image.
- *Vertical smoothing (deinterlace)*: Smooth the image vertically to remove effects from interlaced sensors.
- *Adaptive median noise reduction*: Blend a median-based denoised image with your original image to remove noise in the background
- *GREYCstoration noise reduction*: Use the powerful tool from GRYEC Labs to reduce noise while preserving details and important features in your image.

21.5. View Menu

Toggle the visibility of any of the following tools

- *Main image*: Your actual image. Why are you turning it off?
- *Display Control*: The B and W sliders and historam
- *Capture Control*: The capture control panel that lets you connect to the camera and control exposures
- *Notes*: A text box that lets you jot down notes and save them to a basic text file
- *History*: A text box that keeps track of your processing history (what you've done at each step to your image). You can save this for future use or reflection upon in your golden years.
- *Macro*: Image processing steps that were logged in the History window can be replayed to the same or a different image using this tool. Copy the items from the History window, put them in the order you like, and hit Run.
- *Extra Camera Control*: A small dialog that lets you control the TEC, filter wheel, shutter state, etc. for various cameras that have these built-in features.
- *Mini Capture*: A shrunken version of the main Capture Control panel. This small

version lets you keep more panels active while capturing images.

- *PHD Link*: Control the link to *PHD Guiding*
- *Ext. Filter Wheel*: Control an external ASCOM-compliant (Windows) or Starlight Xpress (Mac) filter wheel.
- *Pixel Stats*: Opens a pop-up window that shows the intensity (I), red (R), green (G), and blue (B) values under the current pixel, the min, mean, and max in a box 21x21 pixels big (+/- 10 pixels) around the current pixel, and the min, mean, and max of the entire image. If there is a star near the cursor, it will also report the HFR of the star (how wide it is) and any shift between the peak value of the star and the center based on the HFR. You can keep this dialog up as long as you like and continue to work in *Nebulosity*. As the mouse moves around or as new images are acquired, the window will update itself.
- *Reset View*: You GUI look like a tornado hit it? Use this to reset to the default layout.
- Reset Position: Where did that window get to (in particular when I added or removed another monitor)? Bring them back home…
- *About*: Display program and version information
- *Show Help*: Display this manual
- *Check web for updates*: Connect to the Stark Labs website and check for updates. If an update is available, the Release Notes will be shown and you will be given the opportunity to visit the Stark Labs website to download the new version.

22. Preferences

22.1. Capture

- *DSLR Long Exposure Adapter*: Modern cameras (>2007) should almost always use "DIGICI III+" here. Without a "bulb" adapter cable ("USB only, 30s max"), DIGIC II cameras will be limited to 30 second exposures. Here, select which long-exposure adapter you have. Please make this selection before connecting to the camera.
- *Mirror lockup delay (ms)*: Number of msec to wait after the mirror-lockup signal has been sent on DSLRs before starting the exposure.
- *DSLR Save location:* Should the images be downloaded to the computer, saved on the compact flash card, or both? Should CR2 files be saved locally as well as FITS?
- *DSLR LiveView use*: Should LiveView be used in Fine Focus, Frame and Focus, both, or never?
- *DSLR 16-bit scale*: DSLRs aren't 16 bit cameras but it's often nice to treat them as if they were and to turn the image into a 0-65535 range on capture as this is what Nebulosity expects. Checking this will pad the bits (to convert 14 bit ADCs to 16 bit) and can easily be your default unless you really want to know pure ADU values.
- *Atik 16IC ChipID*: The Atik 16IC is an outlier in the Atik support on the Mac and you need to know your individual camera's ID here to work with it. I have a small utility that lets you get this number
- *Acquisition mode*: When taking images with a one-shot color camera, what should be done about converting them to full-color?
  - *RAW CCD data*: Do no reconstruction and keep the data as RAW CCD data. When saved, one FITS file with the raw data from the CCD (effectively a black and white image that contains the color information) will be saved. This is the ideal and should be your default.
  - *RGB Optimize speed*: Do color reconstruction on the fly during image acquisition and try to go for the fastest good color reconstruction at the expense of a bit of quality.
  - *RGB Optimize quality*: Do color reconstruction on the fly during image acquisition and try to go for the highest quality color reconstruction at the expense of a bit of speed.
- *Capture alert sound:* Give an audible alert at the end of each image or the end or the entire series.
- *Use max binning in Frame & Focus*: Use the highest binning level or restrict to 2x2 binning for Frame and Focus.
- *Show crosshairs in Frame & Focus*: Enable or disable the crosshairs (disable is useful for a real-time video view).
- *Save Fine Focus info*: Enable this and during fine focusing, an image will be

created of the full fine focus info. The file is in the current save directory and has the name "Focus_#_#_#_#.bmp". The #'s are CurrentMax, Historical max of CurrentMax, CurrentHDR, Historical max of CurrentHDR. By doing it this way, all one needs to do is to scan the directory for a file that matches this pattern and look at that filename to get the info. Of course, there can be a short period of time in which no file exists (last one erased before new one written).

- *Enable Big Status Display during capture*: During series captures, the progress will be displayed in a pop-up dialog for easy viewing if you've left the computer unattended.
- *Use separate capture thread*: When talking to the camera, we have a choice here of whether Nebulosity's other processing should remain active or whether talking to the camera should be the one and only priority. The multi-tasking flavor there has the camera communications in a separate "thread" or process. The upside is that you won't lock up Nebulosity if there is an issue with the camera or communications. The downside is that it's possible for some cameras that this will induce artifacts. Prior to v4, all communication was non-threaded.
- *TEC / CCD Temperature set point:* For cameras that can regulate the cooling, this is the desired temperature (degrees Centigrade).

22.2. Output

- *Save as compressed FITS*: FITS files are saved in lossless compressed FITS format to save space with no loss of data integrity (default). Note, however, that some applications do not support this aspect of the FITS standard.
- *Save in 32-bit floating point*: FITS files are saved in the 32-bit floating point format used internally to ensure no possible loss of data resolution at a cost of files being twice as large
- *Scale to 15-bit (0-32767) at save*: FITS files are saved in data ranging from 0-32767 rather than 0-65,535 if this is selected. Some programs require this format.
- *Color file format*: When saving full-color data from a one-shot color CCD camera (e.g., the SAC-10), this preference controls how the color data are to be saved.
    - *RGB FITS - ImagesPlus*: One FITS file with red, green, and blue components of a reconstructed (de-mosaic'ed) full-color image stored inside in the style expected by ImagesPlus (separate "HDU" per color) (default).
    - *RGB FITS - Maxim / AstroArt*: One FITS file with red, green, and blue components of a reconstructed (de-mosaic'ed) full-color image stored inside in the style expected by Maxim DL and AstroArt (a "3-axis" or "3D" image with color along the third axis).
    - *3 FITS files*: Reconstruct the full color image and save the red, green, and blue data in three separate files. This should only be used if *Nebulosity* is not to be the primary pre-processing application and if the application to be used does not support RGB FITS (e.g., Iris). Seriously - don't use this unless you really, really know what you're doing and know you need this. I estimate

there is one person in the world that needs this as the default.

- *Series naming convention*: What other bits of information (other than your series name) should be included in the filename when you do a Capture Series?
    - *Include number*: Append the frame number (3-digit code, sequential).
    - *Include time*: Append a UTC date code (DDD_HHMMSS).
    - *Include internal filter* and *Include external filter*: Append the name of the filter
    - *Include light / dark / bias*: Try to determine (based on exposure duration and shutter state) if this is a light, dark, or bias and add that.

22.3. Processing

- *Undo / Redo settings*: You can opt for either no undo capability (to run faster and save hard disk space), 3 steps worth of undo (default), or virtually unlimited undo capacity.
- *Use adaptive stacking*: For the stacking techniques that you use on your light frames (Translation, Drizzle, Colors in Motion), the image will automatically have the intensity scaled to use the full range of the 16-bit file format used. Adding images and averaging images each have their strengths and weaknesses. The Adaptive stacking technique side-steps the weaknesses of each and lets you get the most out of your data. The only downside is that a stack of 30s images and a stack of 3m images would appear equally "bright" after stacking this way.
- *Flat processing*: What should be done to your flats when you apply them by default in the pre-processing dialog? You can choose to have nothing done or to have several filters applied. If you're using a one-shot color camera, you'll at least want to apply the 2x2 mean filter (this removes the Bayer matrix).
- *Demosaic (debayer) method:* What algorithm should be used for converting one-shot color images to color? VNG (Variable Number of Gradients by Ting Chen) is the default and an excellent choice. PPG (Patterned Pixel Grouping by Alain Desboilles) and AHD (Adaptive Homogeneity-Directed by Keigo Hirakawa, Thomas Parks, and Paul Lee) are also popular advanced debayers. Bilinear is quite fast if a bit soft. Color binning will reduce your image size by a factor of 2 but does no interpolation.
- *Manually override color reconstruction*: Typically, Nebulosity will attempt to determine what kind of camera a one-shot color file comes from and set the various demosaic options automatically. At times, you may wish to override this automatic behavior and specify offsets, array types, color mixing, etc. manually. Enabling this preference will bring the manual color reconstruction dialog up each time so that you can override any automatic behavior.
- *DSLR White Balance / IR filter*: Ideally, the pixels are white balanced prior to actually implementing the demosaic of a RAW image. For most cameras, this white balance is known *a priori*, but DSLRs can be stock or modified. Choose the setting

here that best corresponds to your camera setup. Note, that at times, if there are severely saturated areas, this may lead to a pink area in the saturated zones. If this occurs, the Straight Color Scale option can be used.

22.4. Colors

If you want to customize the interface's coloring, you've got a few options here. Have fun!

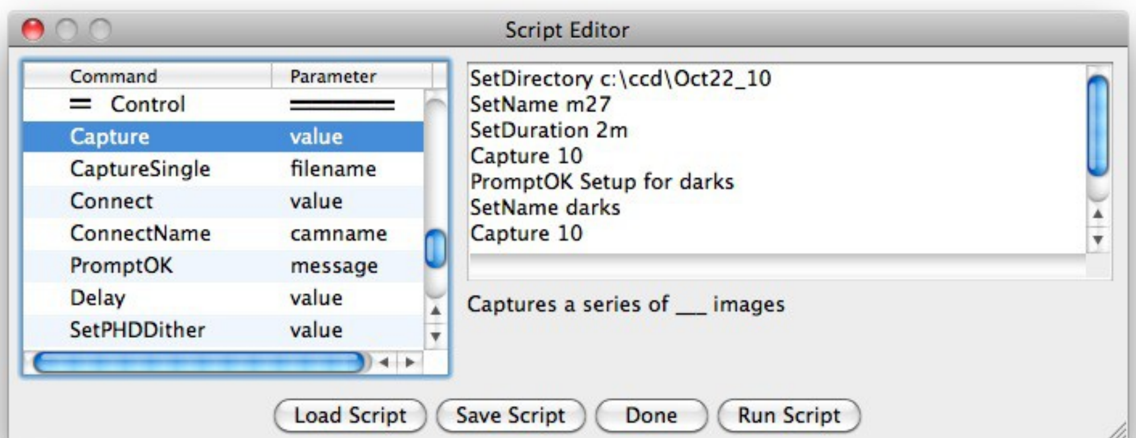
22.5. Misc

- *Display orientation*: Should *Nebulosity* flip or rotate the display?
- *Clock / TEC display*: In the control panel, *Nebulosity* can display a small clock that will show the current time in a range of time formats or show the CCD's current temperature. The time formats all use your computer's internal clock as the starting point and convert that into other times. Note that local sidereal time and Polaris RA depend on *Nebulosity* knowing your longitude.
    - *No clock:* Hide the clock
    - *Local time*: The current local time
    - *UT/GMT time*: The current Universal Time (or Greenwich Mean Time)
    - *GMT Sidereal*: GMST or Greenwich Mean Sidereal Time
    - *Local sidereal*: The current local sidereal time (useful in finding objects with setting circles)
    - *Polaris RA*: Polaris' current right ascension (useful in using polar alignment scopes)
    - *CCD Temperature*: Current temperature of the CCD in centigrade.
    - *Longitude*: Local sidereal and Polaris RA require knowing your current longitude. Enter it in decimal notation (e.g., -77.1 not H:M:S) with west (e.g., USA locations) being negative.

23. Scripts

Nebulosity provides you with the ability to automate your capture process by using scripts. Scripts are simple text files that list a series of commands for *Nebulosity* to perform in sequence. For example, the script shown here would set the output directory to be \ccd\Oct22_11 on your "C" drive (usually the letter associated with your hard drive). If the directory didn't exist, Nebulosity would attempt to create it. It would set the output file name to be "m27", the duration to be 2 minutes and then capture 10 images in a series (m27_1.fit, m27_2.fit, etc). It would then pause and alert the user to "Setup for darks" (i.e., place the lenscap over the telescope). After the user hits OK, it would then capture 10 dark frames (dark_1.fit, etc.)

Nebulosity's scripts can be created dynamically using the clipboard's operating system. If commands are placed on the clipboard and *Nebulosity* is in a special "Listen" mode, it will suspend reading commands from the script file and instead read them from the clipboard. In addition, with a “Listenport #” command, commands can be sent via TCP/IP sockets. This allows other programs to dynamically control *Nebulosity*'s actions. Full list of Commands



23.1. Script Editor

Commands act just as if you were to do them in the GUI. So, if you've already set something in the GUI or if it is the default, there is no need to enter it in the script.

You can write scripts in any text editor (save in "ASCII text" format) or in *Nebulosity*'s built-in editor. Simply pull-down Create / Edit Script from the Edit menu. Here, you can start typing commands, load an existing script, or, most simply, use the list of commands on the left. The left side of the dialog shows all the available script commands (the most common ones are grouped at the top of the list and repeated below in the appropriate sections). Find a command you want and double-click on it (or drag/drop it) and it’ll be added to the script on the right. Don’t know what you want? On the right, you’ll also see what each command does and what the parameter means. Here, for example, you see that the Capture command takes a number value that is the # of images in the sequence.

When done, you'll likely want to save your script (Save button) and then press Done.

When you're ready to execute the script, either press Run Script while the Script Editor is open or simply pull down Run Script from the Edit menu. *Nebulosity* will then first verify that it's a valid script. Then, it will go through line by line, executing each command until it reaches the end of the file. As it does so, the Status bar will keep you apprised of what *Nebulosity* is currently doing. Pressing the Abort button will cancel the script at any time.

Script files can contain extra spaces or blank lines if you want to make them look cleaner when writing them. Nebulosity will simply skip any extra spaces or lines it finds. In addition, if you start a line with the "#" symbol, the line will be ignored. This is a useful way to put comments in your scripts.

One thing of note - when you're specifying times, the units are seconds (in Nebulosity 1 and 2 times were all in milliseconds). You can use fractions if you like (e.g., 10.5 would be ten and a half seconds and 0.001 would be one millisecond). You can also put an "m" suffix on the number to indicate minutes. So, if you wanted a minute and a half (90 seconds) exposure you could use "90", "90.0", or "1.5m".

You can execute scripts at startup by passing the script name as a command-line argument. For example "nebulosity script.neb" will automatically execute script.neb

23.2. Full Command List

The following is the list of commands recognized by *Nebulosity*. They are presented here capitalized to help show you the meaning of the command, but *Nebulosity* ignores the case of all commands. So, "SetName" is the same as "setname" and "SeTNAme".

Each command must be placed on a separate line and each line must have a command and a parameter with at least one space between the command and the parameter. When the list shows the parameter to be N, it means a number should be provided as the parameter. When the list shows the parameter to be S, it means a string (aka text) should be provided as the parameter.

23.2.1. Capture Setup Commands

These commands mirror the controls present in the Control Panel and several of the settings available in the Preferences menu.

- **SetName** S - Sets the base filename to be S
- **SetDirectory** S - Sets the capture directory to be S
- **SetDuration** N - Sets the exposure duration to N seconds (fractions allowed - use "m" as a suffix to denote minutes)
- **SetTimelapse** N - Sets the time lapse to be N seconds (fractions allowed - use "m" as a suffix to denote minutes)
- **SetBinning N** – Sets the bin mode. 0:No binning, 1 or 2:2x2, 3:3x3, 4:4x4

- **SetShutter N –** Sets the shutter state. 0:Open (light frame), 1:Closed (dark frame)
- **SetFilter N –** Selects filter #N from your camera's filter wheel if connected (1-indexed)
- **SetExtFilter N –** Selects filter #N on the external filter wheel if connected (1-indexed)
- **SetTEC N** – Sets the camera TEC temperature set-point to N degrees
- **SetGain** N - Sets the camera gain to be N
- **SetOffset** N - Sets the camera offset to be N
- **SetColorFormat** N - Sets the color file format used when (and if) full-color images are written. 0: RGB FITS in ImagesPlus format. 1: RGB FITS in Maxim / AstroArt format. 2: 3 separate FITS files.
- **SetAcqMode** N - Sets the color acquisition mode. 0: RAW or BW images. 1: RGB Optimize speed. 2: RGB Optimize quality.

23.2.2. Control Commands

These commands control the capturing process itself and let you interact with the user.

- **Capture** N - Captures a series with N images according to the current settings.
- **CaptureSingle** S - This (e.g., "CaptureSingle foo") will capture a single frame and save it with the given name (e.g. "foo.fit") even if it already exists. The file will be in the current save directory. In addition, if the filename specified is "metric" (or "metric.fit"), it will run the whole-image HFR routine used in quality grading and the file will be "metric_###.fit". The ### is 100x the HFR. Note, since *Nebulosity* doesn't know when this file has been used and when you're done with it, it will only erase / write a new one if you run CaptureSingle again. If you quit *Nebulosity* though, this file will still linger in the directory.
- **Connect** N - Connect to camera N where N is where you would find the camera in the pull-down list in Nebulosity's main window (0=indexed). So, "No camera" (aka disconnect) is "Connect 0". Passing in -1 will connect to the last-used camera.
- **ConnectName** S - Connect to camera named S, where S is the name as-listed in the pull-down list in the main window. For example, "Connect Meade DSI"
- **PromptOK** S - Displays S on the screen and prompts the user to hit OK or Cancel. If OK is hit, the script continues. If Cancel is hit, the script is stopped.
- **Delay** N - Pause execution for N seconds (fractions allowed - use "m" as a suffix to denote minutes)
- **SetPHDDither** N - Sets the dither level in the link to PHD guiding (0=none, 1=0.1 pixels=small, ... 15=1.5 pixels=extreme)
- **FocGoto N** – Tell the focuser (if connected) to go to position N
- **FocMove N** – Tell the focuser (if connected) to move N units in (negative) or out

(positive).

- **SetBLevel** N and **SetWLevel** N - Sets the B and W slider levels to N. If N = -1, auto-scaling is turned on.
- **Listen** N - Enable (1) or disable (0) listening to commands from the clipboard. Each command on the clipboard must start with "/NEB". For example, "/NEB Listen 0" on the clipboard will return processing to the script file.
- **Listenport** N - Enable (port number) or disable (0) listening to commands via sockets. For example, you might have a script with one line saying: Listenport 4301 and when run, Nebulosity would begin waiting for a connection on port 4301.
    - Nebulosity first waits for the connection to be formed (if you wish to bail, the Capture Abort will break out) and after that, it enters into a loop. It will wait for any data to come in using "blocking sockets". There is a timeout of 1s per read though, giving you the ability to break out. Many commands can be sent at once and if there are commands still to be processed, Nebulosity will do them without waiting (currently, a 2kb buffer is used for each read). Thus, it's not like you can only do one command per second. You can only abort once a second.
    - To leave the mode and return control to Nebulosity itself either a) break the connection (Nebulosity will pop up a "connection lost" dialog) or b) send the command "Listenport 0".
    - During all this, a small dialog will pop up that will show what Nebulosity is getting over the port, the status of the connection, etc. -- all useful info for debugging. At the moment, said dialog is not functioning on the Mac but you will see things flash by on the status bar.
- **Exit** N - Wait N milliseconds and then exit the program

23.2.3. Advanced Camera Control Commands

These commands have the same function as the Advanced camera dialog box, allowing you to override the current settings shown in the dialog. If the camera is not capable of the command given in the script, the command is ignored.

- **SetAmpControl** N - 1: Amplifier control is enabled and the CCD amp is off during exposures. 0: Amplifier control is disabled and the CCD amp is on during exposures.
- **SetHighSpeed** N - 1: Enable high speed readout mode. 0: Disable high speed readout mode.
- **SetOversample** N - 1: Enable CCD oversampling. 0: Disable CCD oversampling.
- **SetDoubleRead** N - 1: Enable double-read mode. 0: Disable double-read mode