Pre-Processing images in Nebulosity

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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. 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 in the online manual for each tool), but it should help put all the pieces together.

The basic steps are as follows:

1. Prepare any sets of darks, flats or bias frames for use by stacking them
2. Take care of hot pixels (dark subtraction or Bad Pixel Mapping), bias signals, and/or vignetting (flats)
3. (optional) Normalize the images
4. 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)
5. (optional) Grading and Removing Frames
6. Stack the images (Align and Combine)
7. Crop the image to clean it up
8. (color only) Run the Adjust Color Offset tool to remove skyglow hue
9. Stretch the image (Levels, DDP, etc)

The last three steps (crop, color offset, and stretch) are covered in more detail in the Post-Processing How-To document.

Step 1. Preparing the darks, flats, and biases

If you've taken darks, flats, and/or bias frames for this imaging session, you'll need to put them together to form "master" darks, flats, and/or bias frames. If you've not got a new set of these, simply skip to the next step as there's nothing to do here. Assuming you do have some, what we need to do is take the set of them (e.g. 20 bias frames) and combine them so that you can use them to remove artifacts in your light 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.

When stacking these, we *don't want the frames to move*. That is, since there isn't a star whose motion we want to track, we don't want to align these images. We just want them stacked on top of each other as-is. To do this:

1. Pull down Processing, Align and Combine
2. Select "None" for the Alignment method and keep it set to "Save stack" and "Average / Default"
3. Click OK and then select all of your dark frames (or bias frames, or flat frames)
4. When all are stacked, give the resulting combined dark frame a name like "master_dark" or "master_dark_1m" (1m being a code for 1 minute - something to let you know what kind of master dark this is)
5. Repeat for any other types you have (flats and/or biases)

Ugly Details

At this point, you've got nice stacks of each and the stacks can be ready to use. If you want the absolute cleanest pre-processing and, it's worth considering the following issue. *Nebulosity*'s pre-processing just does the basic math for you. It subtracts the dark and bias from the image and divides this by the flat. It does not do anything to the bias, dark, and flat you pass in during Pre-processing. It just uses them.

So what's the problem? The problem is that that dark frame has the bias error in it already. The flat frame has the bias error and some amount of thermal noise in it (which will lead to hot pixels). So, if you use all of these as-is, you're going to do things like subtract out the bias error twice, which will actually inject the reverse of the bias error (still noise) back into your image. Oops.

The solution is to pre-process your pre-processing frames. You can, for example, apply the bias frame as the only pre-processing step for pre-processing your "master dark" and "master flat" frames. You can also have a dark frame taken at about the same exposure durtation as your flats and apply this to the flats. Before fully going down this route, consider the following recommendations:

Recommendations

- If you are using normal dark subtraction and not Bad Pixel Mapping to address the hot pixels, your darks already have the bias error in them. Do not collect extra bias frames and do not use any bias frames during pre-processing. Just use the darks and both the dark current and the bias error will be removed.
- If using flats, it is worth knowing that *Nebulosity* passes a mild smoothing filter over your flat in any case (a 2x2 mean filter). This will help remove hot pixels in the flat if your exposure duration was long enough to put them in there and will also remove some of the bias error. You may still remove the bias from this if you like, or simply pass something like the 3x3 median filter over your flat to smooth it out prior to applying this to your light frames.

- If using Bad Pixel Mapping, consider using bias frames as well. There is no need to clean up your dark frame (i.e. remove it's bias error) as with BPM, only the very hot pixels are touched. The bias error in your dark frame is ignored completely. If your camera has a strong bias error, grab a stack of bias frames once (shortest exposure possible) and grab and stack a bunch of these (you only need to do this once). Call it a "master bias" or "uber-master-bias" or whatever you like and apply this during pre-processing (below).

Step 2. Taking care of hot pixels, bias signals, and/or vignetting

At this point, you should have "master" darks, flats, and/or bias frames. If you don't and you're processing without these, skip this step. Keep in mind, you can use as many of these as you want (or don't want). You can use darks but nothing else, flats and biases but not darks, etc. It's up to you and what type of pre-processing images you actually have. If you've got a stack of darks to use, you have a choice to make.

Dark subtraction or Bad Pixel Mapping?

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" (Processing, 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 best), 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 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.

Applying Bad Pixel Mapping

To apply BPM to your light frames:

1. Create a Bad Pixel Map if you don't already have one. Processing, Bad Pixels, Make Bad Pixel Map. Select a dark frame or stack and start off by just hitting OK to use the default threshold.
2. Pull down Processing, Remove Bad Pixels, selecting the one for the kind of image you have. If you have a one-shot color camera that is still in the RAW sensor format and looks like a greyscale image and not color (another reason to capture in RAW and not color...), select RAW color. If it's a mono CCD, select B&W. If it's already a color image, you can't use Bad Pixel Mapping.
3. A dialog will appear asking you for your Bad Pixel Map. Select it.
4. Another dialog will appear asking you for the light frames. Select all of them (shift-click is handy here).
5. You will end up with a set of light frames that have had the bad pixels removed. They will be called "bad_OriginalName.fit" where OriginalName is whatever it used to be called.

Applying Darks, Flats and Biases

Here, you get to apply traditional dark subtraction, flats, and biases in any combination you wish. To do this:

1. Pull down Processing, Pre-Process Color images or Pre-Process BW/RAW images. Color images are already full-color. BW/RAW images were either taken on a monochrome camera (BW) or taken on a one-shot color camera but have not yet been converted into full-color via the Demosaic process.
2. A dialog will appear that will let you select your various pre-processing control frames (darks, flats, and/or biases). Select whichever you have by pressing the button and telling Nebulosity which file to use here.
3. If you are using dark subtraction and you doubt your exposure and/or temperature control was perfect, select the "Autoscale dark" option.
4. Click OK and you will be asked to select the light frames you wish to pre-process.
5. When all is done, you will have a set of files called "pproc_OriginalName.fit".

Step 3. 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. To normalize a set of images, simply:

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

Step 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*.

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 Processing, 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).
2. Select your frames

In the end, you'll have a set of images named "recon_OriginalImage.fit"

Step 5. 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.

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 Processing, 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.

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.

Step 6. 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 Processing, Align and Combine Images
2. 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.
3. Select your light frames
4. 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.
5. 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.
6. 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) 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. 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 alignment method (and one of the Std. Dev. thresholds in the Stacking Function). Make sure you have Normalized your images at some point.

Note: These last three steps are covered briefly here, but in more detail in the Post-Processing How-to.

Step 7. 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.

Step 8. Remove the Skyglow Color: Adjust Offset tool

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. Save this with a new name.

Step 9. 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 two main tools for stretching in *Nebulosity*. The first is the Levels / Power Stretch and the second is Digital Development Processing (DDP).

The goal in both 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 it's 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

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 slider), a white point (middle slider) and a midpoint or "power" (bottom slider). With several passes over the data you can do the same thing that a "Curves" tool will do for you. 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.

Digital Development Processing

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.