v. 3, May 2024

Astro 103/104 lab Name: ____________ Date: ___/__/20__ Sec. __

Advanced Image Processing

This is laboratory introduces students to techniques that they need to use in the image reduction and processing part of their semester project. A word of caution: in a real-life project the skills learned here must be used intelligently (change what needs to be changed), and it should not be followed blindly and without thinking.

Steps (1-a) through (2-c) of this lab needs Windows personal computers with CCDOPS installed (free software), and Step (2-b) needs CCDSSOFT; (3-a) though (4b) can be done on either Windows or Mac and requires Adobe Photoshop.

It is necessary that students attempting this lab *have done and remember* the introductory Image Reduction Laboratory. If considerable time has passed since doing the introductory lab, additional review will be required.

Exercise 1: Preparation.

It is necessary to re-read, the day ***before*** lab time, Sections 1, 2 and 5 of the booklet entitled “Image taking with a CCD camera”.

Your work will be complex enough, so you will need to organize your work neatly on the computer. Please **follow the steps and conventions** below to avoid confusion. Be especially adamant in using the folder locations and names as suggested; otherwise it will be impossible to locate your work (and you may receive no credit at all). Disorganized work invariably leads to confusion and as a consequence you will be unable to finish this lab in the available two hours.

On the computers in the lab, you must be running Windows. If the computer is running as a Mac, restart it while holding down the *Option* key until you are given a choice to start it up as Windows. Log in as *Student*. (After finishing, restart the computer in Mac!)

The materials for the lab are in the *AstroLabs/Advanced Image Reduction Lab* folder on the desktop. However, make sure you do not make any changes there! Instead, open *TemporaryStudentWork* and make a new folder inside it with your *last* names (call it something like *DoeAndDoe*), and copy the *01Originals, 07Emergency, Darks* and *Flats* folders into it by CTRL-dragging. You’ll be working on this copy, which makes sure that you do not destroy the originals.

The first several steps in image reduction and processing[1], called Steps (1) here, are fairly standard, essential the same for any type of astronomical imaging. These steps are done on all images taken with the *same* filter (red, green, blue, or any other); these images are all combined into one image. This way, the result is *one image* with each filter (i.e. each color). These steps are best done with software specialized for astronomical image reduction, such as CCDOPS and CCDSSOFT. These and the further steps are, in this order:

(1-a) Dark subtraction
(1-b) Flat fielding
(1-c) Removal of blooming streaks
(1-d) Hot and cold pixel removal
(1-e) Median filtering
(1-f) Assessing the quality of each image and dropping the bad ones

(2-a) Aligning multiple images
(2-b) Combining images with the same filter
(2-c) Removing image gradient
(2-d) Sharpening

(3-a) Converting to Photoshop and cutting the background
(3-b) Color composition
(3-c) Balancing the colors
(3-d) Contrast adjustment

(4-a) Resizing, cropping and converting to .png format
(4-b) Submission of work.

Exercise 1: Single image reduction

Perform steps (1-a) through (1-f) on each image separately. You should already know how to do these steps; however here are a few pointers to speed up this process.

Start CCDOPS on the computer by clicking its icon on the taskbar. Recall that whenever you want to open a file in CCDOPS, drag the file icon(s) onto the CCDOPS panel and *never double-click on the file icon!*

Open each dark frame and fill in the table to make it easy to select which one(s) to use.

Name	Exposure time	Temperature

[1] Image processing is the name of the whole procedure. Image reduction is the standard, scientific procedure contained in steps (1a-f) and (2a-d).

(1a) Make a copy of your *01Originals* folder by control-dragging and dropping its icon; rename the copy *02DarkSubtracted*. Dark subtract each image in it, and re-save each resulting image.

(1b) Next, open each frame in the *Flats* folder. Some of the flat frames are damaged, over-exposed (use the crosshair: pixel readings over 40,000 is too much) or under-exposed (pixel readings under 10,000 is too little in a flat frame). Which ones will you use?

Red	Green	Blue

Again, make a copy of your *02DarkSubtracted* folder by control-dragging and dropping its icon; rename the copy *03FlatFielded*. Flat field each image in it and re-save each resulting image.

(1c-1d-1e) Next, make a copy of *03FlatFielded* and rename it *04PixelsFixed*. Then, make some 'filtering' on each image. The necessary utilities are located under UTILITIES→FILTER UTILITIES. First, use the FIX BLOOMING STREAKS filter (this will affect only very bright stars and may not do an obvious change on each image; do it anyway), then use the KILL WARM PIXELS (strong) filter, then the REMOVE COLD PIXELS (medium) filter, and use the MEDIAN FILTER and save. Observe the change each time, pressing the AUTO button on the CONTRAST panel. Finally, check DISPLAY→ MODIFICATIONS that it shows the above operations in the right order and each operation only once; otherwise you have made a mistake.

Exercise 2: Combination of multiple images

There may be students who have not managed to prepare a good quality set of three images in their *04PixelsFixed* folder, or ran out of time. To make sure everyone has a shot at Exercise 3, we made a *05_Emergency* folder with the nine images already prepared. Compare your images in your *04PixelsFixed* folder to these. In case your images are bad, or you ran out of time, use the *05_Emergency* version instead. (This will result in loss of credit; but it is still better than not do the remaining exercises at all.)

(2-a) When you have more than one image taken with the same color filter, you must align the images, otherwise each star will 'become a double' when the images are combined. Unless the camera has been turned between taking the images, this alignment involves only shifting the images, and that can be most effectively done with CCDSOFT. Follow the procedure exactly, because an ineffective organization of your work will make our job extremely tedious.

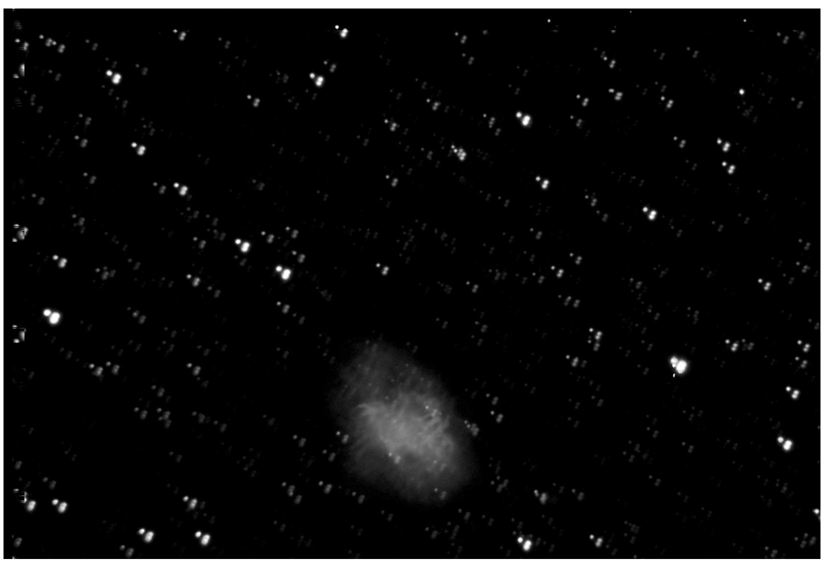


Figure 1:

Bad alignment results in multiple pictures of each star.

Make a copy of your *04PixelsFixed* folder by control-dragging and dropping its icon; rename the copy *06Aligned*. Start CCDSOFT by clicking on its icon in the taskbar; its panel opens. Now, open the *06Aligned* folder, select all the files in it, and drag-and-drop them onto the CCDSOFT panel. Select the align tool and mark the same star on each image by clicking on it. This star must be reasonably bright, but *should not be clipped* in its center (i.e. not too bright), otherwise the software will not find its centroid correctly. Once you have marked one star on each image, perform the alignment by IMAGE→ALIGN→ALIGN CENTROIDS. Now you have the images all aligned. The easy way to save them now is ALIGN→CLOSE ALL and answer *yes* to save each file.

Notice that, instead of the procedure here, you could have aligned the images in the *04PixelsFixed* folder directly, but saving them under a new name in a new folder would have been a very tedious job.

Finally, check the quality of your alignment with a traditional device called *blink comparator*, which is used to detect any moving or changing object in the pictures. To use it, select all the files in the *06Aligned* folder, then click RESEARCH→COMPARISON→BLINK COMPARATOR. If you have any misalignment, stars will be moving, otherwise they stay the same place (although their brightness may change). You'll also see one moving star. Using the time elapsed between when each image was taken (you can look up the times clicking CONTROL-I to get the info), what do you think this object may be, and why?

____

Close the images but do not save them at this time.

(2-b) The next job is to combine the images taken with the same color filter. The following comments are in order:

(i) These images are all in black-and-white, so combining images with different filters would be wrong: it would mean losing the color altogether.

(ii) The simplest way to combine the images would be to co-add them in CCDOPS. However, doing that would lead to clipping the bright stars. Think this over and explain why with an example of pixel numbers

(iii) The correct way to combine is to form the weighted average of the images, weighted by exposure time. If the exposure times are equal, the weighted average is equivalent to a simple average.

You will notice that all your images have exposure times of 300 *sec*, 600 *sec* or 900 *sec*. A good way to perform the weighted average is to do simple averaging, but include the images with 300 *sec* exposure once, the images with 600 *sec* exposure twice, and each image with 900 *sec* exposure three times. Make an empty folder, call it *06Combined*. Record the filenames and exposure times in the table:

Name	**Exposure time [sec]**	**To be used ___ times**	**Total # of images to average**
Crab_Blue			
M1_Blue1			
M1_Blue2			
Crab_Green			
M1_Green1			
M1_Green2			
Crab_Red			
M1_Red1			
M1_Red2			

Use CCDOPS's AVERAGE IMAGES utility to perform the averaging. Do not use any offsets. Note that when you have finished selecting all the files that are to be averaged, you'll need to hit CANCEL; this will *not* cancel the averaging but rather perform it. (You may want to show your images in *1:1 magnification* and with *Auto*-contrast.) Save the images in the *07Combined* folder as *M1_Blue.fit*, *M1_Green.fit*, and *M1_Red.fit*.

(2-c) A careful examination of these three images reveals a *gradient* in each of your three images; it is especially bad in the green image. A gradient is the result of an uneven illumination of the background sky by streetlights: this is why it is strongest in green. Open your three images and *enhance the contrast* in each by setting the RANGE parameter to, say, 50; adjust the BLACK point so that the background is grey (neither black nor white). Now the gradient is obvious in each image.

You'll find the REMOVE GRADIENT tool under UTILITIES→PIXEL UTILITIES. Before using it close your images (don't save), make a copy of your *07Combined* folder by control-dragging; rename the copy *08GradientRemoved*. Open the three files in it with CCDOPS, and start the REMOVE GRADIENT tool. You'll also need the crosshair. Select three points close to three corners of the image, making sure that each of these points is *pure background* not part of a nebula, nor a star. Use the crosshair to make sure of that. Now, perform the gradient removal, and check your work: set the RANGE parameter to about 50, and again adjust the black point. If you are not satisfied with the result, you can UNDO the operation, and select different points. You may need a few tries to get it right. When done, hit AUTO-contrast and save the three files.

(2-d) Seeing causes a certain amount of blur on each image. You can read off the seeing (in arc seconds) using CCDOPS's X-HAIR (crosshair) utility, to be found under DISPLAY. Open your images and click on some reasonably bright stars. You can precisely navigate the crosshair onto the center of the star using the left-right-up-down arrows on the keyboard. (It is important that your star's image is not clipped, nor too dim; for this reason, select stars whose central pixel reading, called VALUE on the X-HAIR panel, is within the 2000 to 40,000 range.) The you can read off the FWHM (full width at half maximum) size of the image of the star (called SEEING on the X-HAIR panel). Do this for several stars on each image, and write your estimated seeing in the following table:

Filename	.fit	.fit	.fit
Seeing	as	as	as

Notice that the seeing on these combined long exposure images is much worse than it would be on individual short exposures. This is due to the fact that the long-time component of seeing is much larger than seeing on short time scales.

There is a way to reduce this blur by a sophisticated computer algorithm (the Lucy-Richardson deconvolution method). There is a piece of software on the computers in the lab, called CCDSHARP that realizes this. However, deconvolution is only successful when there is only limited noise on the images, otherwise it creates nonexistent features and enhances sharp noise. For this reason, and also because learning to use CCDSHARP would take more time than one laboratory exercise permits, we do not pursue it at this time. However, you may consider sharpening when you are processing your project images later in the semester.

Exercise 3: Format conversion, color composition, and scaling

This part of the laboratory is where you learn the most important, and new, skills in image processing. Pay particularly careful attention to this part.

(3-a) Convert to Photoshop and cut the background. The .FIT file format is the standard that is used in professional astronomy. To produce pretty pictures for the public, for yourself, or for the media is not a scientifically well-defined process, but it is surely necessary. It is almost always done using Adobe's PHOTOSHOP; the color capabilities of CCDOPS and CCDSOFT are extremely limited. However, PHOTOSHOP cannot open .FIT files. ESA/ESO/NASA publish a piece of free software called FITS LIBERATOR which can convert files into .TIF format, which can in turn be converted to the native .PSD format by PHOTOSHOP. (Note that .FIT, .TIF, and .PSD are *lossless* formats, while .JPG is not, so the latter must not be used for quality pictures.) Now, FITS LIBERATOR is continuously being updated, so the version you have on the computers may not exactly match the version described here. The differences are, however, minor.

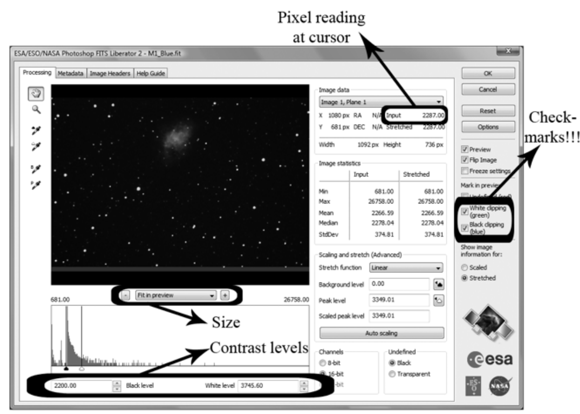
The first step is to launch FITS LIBERATOR. Then, drag one of your .FIT file's icon onto the LIBERATOR panel. You'll have to adjust the black point and the white point. Play around with changing the black and white points, both by dragging and be typing in numbers. Note that a high number for the black point turns a lot of pixels blue (these are the black-clipped pixels, *pixel value < black point*), and a low number for the white point turns a lot of pixels green (these are the white-clipped pixels, *pixel value > white point*). Please make sure that, on the Liberator panel, *White clipping (green)* and *Black clipping (blue)* are checked. Walk around with the cursor and observe the *pixel value* change. (With some versions of LIBERATOR it is called *input*.)

You need to find the black point value now. In practice, you want a value for it when only a few pixels of background noise are blue. (Of course, some of the faulty regions in the picture might be entirely black-clipped, that is not an error.) This leaves a very little background noise in the image, without cutting away the faint parts of the nebula – but removing much of the background haze, which is mainly due to streetlights, so it has to be removed. Setting the black point is a sensitive part of the operation, and you may not get it right for the first try – in that case you'll have to come back to this stage and do it again.

Next you'll find the white point. Drag the white point up to where only a very few stars' centers are clipped (i.e. green). Do not worry that the nebula may vanish from the screen: it is still there but can be made visible only through nonlinear scaling, which you'll achieve in PHOTOSHOP later.

Save your file (in .TIF format) in a new folder called *09FormatConversion.* Then, do the same operation with the remaining two files. Record the black and white points you used.

Name	Black point	White point
M1_Blue.fit		
M1_Green.fit		
M1_Red.fit		

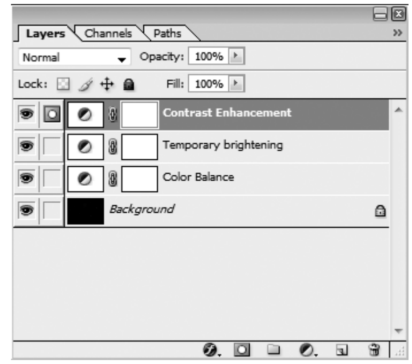


At this stage you can shut down LIBERATOR and start up PHOTOSHOP. Drag each of the three .TIF files in turn into the PHOTOSHOP panel, and save them (in the same *09FormatConversion* folder) in .PSD format.

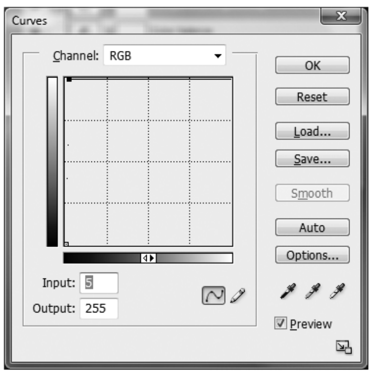
(3-b) Compose colors. Open all the three images in PHOTOSHOP.

Merge the channels to form an RGB colored image. Bring up the CHANNELS palette (use WINDOW→CHANNEL if needed) and click MERGE CHANNEL. (It is hidden behind the double arrow on the CHANNELS palette, see the picture.) Select RGB and match the filenames. When prompted, do not save the *.fits* files, but save (use SAVE AS) the resulting color image as *CrabYourNames01.psd* in Photoshop format in a new folder *10_Color*. Make sure you navigate to *your own folder and do not save into somebody else's area!*

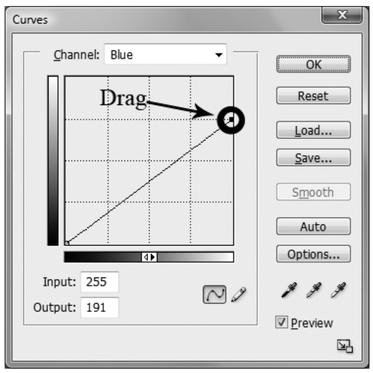
(3-c) Balance the colors. Make sure your image is 100% size. (The size is in the bottom left corner of the Photohsop window; click it to change.) Click F7 to show the LAYERS palette and insert three curves layer. Use LAYER→NEW ADJUSTMENT LAYER→CURVES for this, name them *Color balance*, *Temporary brightening*, *Contrast Enhancement*, in this order, but do not actually modify the curves as yet. The LAYERS palette should look like the picture indicates.



Select the *Temporary brightening* layer, and brighten up the image using LAYER→CHANGE LAYER CONTENT→CURVES; use an RGB curve as indicated on the picture. This enhances the dim pixels, but clips bright ones. You'll notice that color has not been fully balanced. It is impossible to predict, due to changes in atmospheric extinction, which color needs to be enhanced or suppressed. Next, select the *Color balance* layer, and change all the three of red, green, and blue curves as indicated. Doing so will allow you to suppress or enhance each color without causing additional clipping. Save your image, using FILE→SAVE AS, under the name *CrabYourNames02.psd.*



The curve to modify the*Temporary brightening* layer.



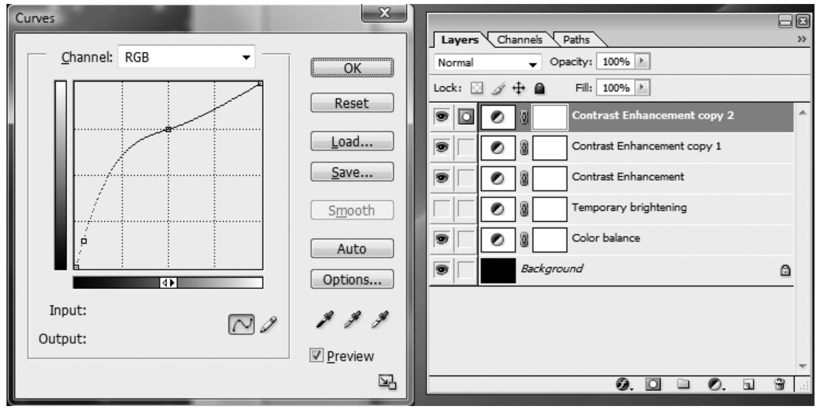
The curve to modify the *Color balance* layer.

Now you are ready to balance the colors. Modify the *Color balance* layer again, and *drag up and down* the dots at the right end of the red, green, and blue curves. (We circled this dot on the picture of the blue channel.) Make sure the input is always at 255; the output will be changing. Your aim is to make the average star white with a hint of orange on the image. Note that the center of bright stars is always white, but this is not real: it is only the result of clipping. Make sure that the average *dim star* becomes white with a hint of orange color. When you are satisfied with the color of your stars, save the image as *CrabYourNames03.psd.*

(3-d) Adjust the contrast. In order to enhance the nebula we must enhance the dim pixels on the image. You have probably noticed already that it is impossible to enhance the contrast without clipping the middle of the bright stars. On your image right now, the nebula is bright, but the center of most stars has lost its true color and became pure white. This is an artifact of the curve on the *Temporary brightening* layer.

The problem is that on the *Temporary brightening* layer we used only linear scaling (a *straight* 'curve'). This was necessary; nonlinear scaling would have hopelessly confused the colors. Now, we can address this problem and add nonlinear scaling. It must be applied after colors have been balanced: the *Contrast Enhancement*, layer that does it must be above the *Color balance* layer.

So now, switch off the *Temporary brightening* layer (click on the 'eye' on the LAYERS palette). The image becomes very dark. Now modify the *Contrast Enhancement* layer, do not touch the individual color channels, work only on the RGB. Your mileage may vary, but in one trial we found the best result with a curve in the picture, but we have duplicated the curve layer twice. This procedure may involve some trial and error. Once you are satisfied, save the image as *CrabYourNames04.psd.*



Exercise 4: The final touches

By now you should have a decent-looking color image. However, it is not ready for publication yet. For one, look at the size of your image file; its size is _______ Mbytes. This is too big to send in an email or put on the internet. Look at your image carefully now. You see that the image is blurred, and stars blobs that are much larger than one or two pixels in size. It makes sense to resize the image, make it smaller. At the same time, the edges of the image are bad due to the alignment process. To see this, make the *Temporary brightening* layer visible again.

(4-a) Crop, resize and re-format.

To remedy both of these issues, use the CROP utility (click the  button on the toolbar). Type *800 px* and *500 px* into the width and height boxes – that will be the size of your resized and cropped image. Now, drag a rectangle across your picture, but be sure to leave out the bad edges. Try, as much as possible, to center the nebula so you get a pleasing picture. Click the checkmark to accept the crop, then make the *Temporary brightening* layer invisible. Save your file as *CrabYourNames05.psd.* Now, the file size became _______ Mbytes.

If you wish, you may use the CLONE STAMP utility () on the *Background* layer to doctor out minor smudges from the picture.

This file is in Photoshop format (.PSD), and most computers (and printers) cannot directly print it. The standard picture format on the internet, as well as the format for insertion into a Microsoft Word document, is 24-bit .PNG . (The primitive and lossy .JPG is used only when quality is not an issue.) You can convert your file into a .PNG file using FILE→SAVE FOR THE WEB. Be sure to select the PNG-24 format, and check that you are saving in your own folder.

(4-b) Submission of work. Your instructor will grade your work, not only by looking at your final images (both in .PSD and .PNG formats), but also at your intermediate files. These must be well-organized; the folder than bears your name should have, in addition to the copied Darks and Flats folders, a set of subfolders numbered 01 to 10 with the names as indicated in the above. Write the number of the computer here so the instructor can find your files:

Computer number: __. **Files located in folder**: _TemporaryStudentWork/___________________

Look at the solution file in the *AstroLab/Advanced Image Processing Lab* folder.

Make sure to restart the computers so they automatically return to Mac.