Model ST-i

CCD Camera

Operating Manual

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Hot pixels are simply the pixels where the dark current is higher than the average and thus they show up as white specs against the salt and pepper background. Again, this is completely normal for CCD images.

The second effect you'll notice is a brightening on the left of the image, as if something bright was just outside the field of view. This is called the ***readout glow*** and is caused by the electronics in the CCD, in particular by a very small but ever present glow emanating from the on-chip amplifier that conditions the weak signals in the CCD so that they may be digitized.

The ***readout*** (or digitization) of images from CCDs is a sequential process whereby every pixel is digitized one-after-another until the whole image has been digitized. The readout starts at pixel (1,1) in the top-left corner and proceeds to pixel (648 x 486) in the lower-right hand corner. As each pixel in a row is readout the pixels to the right of it within the same row are shifted to the left one position in preparation for the next pixel's readout. The next pixel is then readout and the process repeated until every pixel in the first row has been digitized.

At this point the whole CCD is shifted up one row and digitization starts with the left-most pixel of the second row. The ***readout glow*** on the left of the images is a buildup of light from a glow from the preamplifier structures in the upper-left hand corner of the CCD while rows are queuing up for readout.

The final effect you'll notice is the salt-and-pepper look of the background. What you're seeing here is the ultimate noise floor of the CCD whereby adjacent pixels have slightly different values due to noise in the CCD and readout electronics. The noise in dark frames that have zero exposure time is referred to as the ***read noise*** of the camera.

Fortunately for us there are very simple image processing techniques we can use to eliminate the effects of ***dark current*** and ***readout glow***.

Let's open another image. Close the first image by clicking the **X** in the upper-right corner then use the ***Open*** command in the ***File*** menu again but, this time double-click on ***Image 2***. Note in the ***Image Parameters*** dialog that this image had an ***Exposure Time*** of 10 seconds. Click in the dialog to close it.

Now this image has a whole lot more hot pixels! That's because this exposure was 10 times as long and the pixels built up 10 times the dark current. It's hard to even see the background through all the hot pixels.

About this time you're probably asking yourself "How can I ever take images with all these hot pixels?" The answer is simple. Because the build up of dark current is a repeatable effect you can remove the effects of dark current by taking two images, one with the shutter open (***light frame***) and another of equal exposure with the shutter closed (***dark frame***). You then ***subtract*** the dark frame from the light frame, and because the ***hot pixels*** and the ***readout glow*** repeat from one image to another they are removed by the subtraction.

Let's see how this works. Close ***Image 2*** and Open ***Image 3***, which is a 10-second ***light frame*** where you can get a hint of the object but the hot

and decrease. Click the ones adjacent to the ***Range*** setting and you'll see the image ***contrast*** increase and decrease. Here's a summary of how this works:

*Increasing the **Back** decreases the image **brightness** and vice-versa.*
*Increasing the **Range** decreases the image **contrast** and vice-versa.*

Set the ***Back*** to 8,000 and the ***Range*** to 20,000 by typing in the fields (without the comma) and then hit the ***Apply*** button to get us back to where we started. When you manually enter values in the ***Back*** and ***Range*** you must hit ***Apply*** to see the effect.

Let's learn a little more about the controls in the ***Contrast*** dialog. Click the ***Invert*** checkbox and notice that the image now looks like a negative. For images of faint objects, viewing the image as a negative by clicking ***Invert*** can reveal faint structure.

Unclick ***Invert*** and then click ***Sharpen*** on and off several times while looking at the fine detail in the image. With the ***Sharpen*** checked it's almost as if the focus improves. That's the effect of Sharpen. It works great on well-exposed images but tends to increase the noise in faint areas.

The last thing to try in the ***Contrast*** dialog is the ***Mag*** popup. It's set to ***1:1*** but selecting ***2:1*** or ***4:1*** zooms in on the image, enlarging the image display. Selecting ***1:2*** or ***1:4*** zooms out on the image. Try the ***1:2*** and ***2:1*** settings. You may wonder if all these changes to the ***Contrast*** dialog are destructive to the image data. They are not.

*Changes to the settings in the Contrast dialog only affect the way the image is displayed. They **do not modify** the actual pixel values.*

In Summary

- Clicking ***Auto*** is a good place to start with most images.
- ***Back*** controls image ***brightness*** and ***Range*** controls ***contrast.***
- Clicking ***Invert*** can help reveal faint detail in images.
- Clicking ***Smooth*** can reduce the noise in underexposed images.
- Clicking ***Sharpen*** reveals additional detail in well-exposed images.

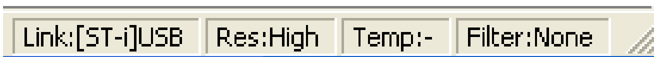
Establishing a Link

It's time to actually connect up to your camera and take some images. If you haven't installed the drivers already go back to **Section 2** and do so now.

If you've taken a break from the tutorial and the camera isn't powered up and attached to the computer do so now by connecting the USB cable between the camera and the computer. At this point the green ***LED*** on the back of the camera should be on.

Use the ***Graphics/Comm Setup*** command in the ***Misc*** menu to make sure ***USB*** is selected for the ***Interface***. Click ***OK*** to set/confirm that and then use the ***Establish COM Link*** command in the ***Camera*** menu.

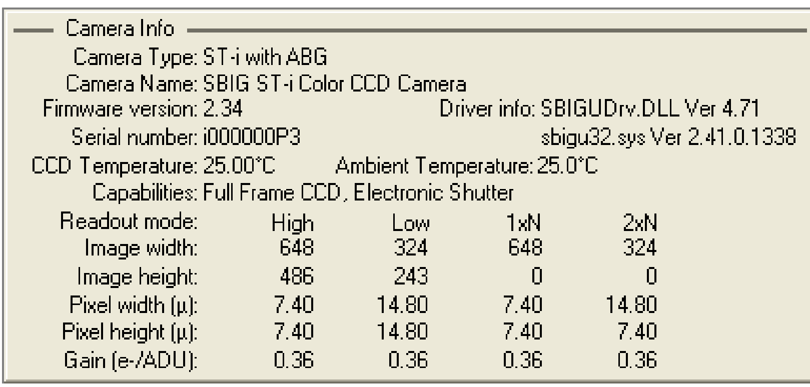
CCDOps will try to connect to your camera, which can take several seconds to complete. If successful you'll hear the shutter emit a series of clicking sounds as it finds home and you'll see updated information in the ***Link Status*** fields show in the lower-right corner of the CCDOps window as shown here:



This shows the link has been established to your camera. It should say ST-i in the status bar as shown above.

Camera Info

After establishing a link to the ST-i use the ***Information*** command in the ***Camera*** menu and you'll see a dialog box similar to the one below:



The ***Camera Information*** command shows you the capabilities of your camera. There are a few key items here that you should be aware of should you ever need technical support:

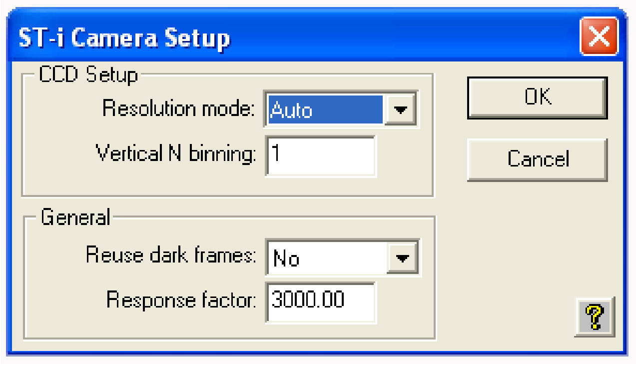
Firmware Version/Driver Info – Over time we revise the camera firmware and drivers to add new capabilities and fix software bugs. The ST-i actually has its firmware downloaded to it every time it connects to the PC after a power-up sequence, which makes it very easy for us to update the ST-i in the field. To make sure you have the latest firmware periodically run the ***Driver Checker,*** which checks our servers for later drivers and updates your system accordingly.

Serial Number – If you ever need to know this, here it is. It's on the label on the back of the camera as well.

Readout Mode Table – This shows the various readout modes the ST-i supports. The ***High***-resolution mode offers the full 648 x 486 resolution with 7.4 micron square pixels. The ST-i also supports ***binning*** whereby groups of pixels are combined to form a single larger pixel. This reduces the resolution but increases the sensitivity as larger pixels capture more light. The ***Low***-resolution modes utilize 2x2 binning as you can see by the ***Image Height/Width*** and ***Pixel Size*** entries.

Finally, review the information presented, then close the dialog by clicking in it.

Camera Setup
Use the ***Setup*** command in the ***Camera*** menu to see the ***ST-i Camera Setup*** dialog shown below.



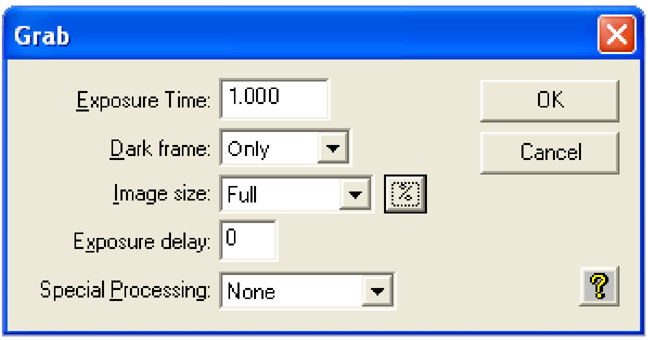
The key items in this dialog are described individually below.

Resolution mode – This popup controls the readout mode discussed in the ***Camera Information*** section above. You can select the ***High*** or ***Low*** resolutions modes directly but we recommend you start with the ***Auto*** resolution mode. In ***Auto*** mode the camera uses the high-resolution mode everywhere except in the ***Full Frame Focus*** mode (discussed below) where it uses the low-resolution mode to speed up the image throughput.

Reuse dark frames – This is a handy feature and you should set it to ***Yes***. What that means is that when you're taking images where you want to ***subtract dark frames*** the software will reuse a previously captured ***dark frame*** if it's the same exposure time and at the same CCD temperature.

You can read about the other items in the ***Help*** but for now just leave them set the way they are. Click ***OK*** to register your changes.

Grab Command
Let's take a ***dark frame*** with your new camera. If you haven't done so already, screw in the nosepiece and put the rubber cap on it. While the shutter was designed to block light from the telescope for ***dark frames***, it can't block flooding room light from leaking around the edges of the shutter blade. That's why you should cover it under bright light illumination. Now, use the ***Grab*** command in the ***Camera*** menu and set the dialog as shown below:



Here we're asking for a 1 second dark frame of the full CCD. Click the ***OK*** button and in a few seconds you'll see an image that looks a lot like the ***Image 1*** from the tutorial. Hot pixels, readout glow and salt-and-pepper noise, they're all there. Congratulations: You've just taken your first dark frame! That wasn't so hard was it?

Let's experiment with the settings in the Grab dialog. Try changing the ***Exposure Time*** to 10 seconds and grabbing another image but this time watch the LED on the back of the camera. It blinks while the camera is exposing the image. That's a handy thing to remember when you're in the observatory. *Don't bump the telescope when the LED is blinking*.

Anyway, the new image should look just like ***Image 2***. Try setting the ***Exposure Time*** back to 1.0 and the ***Dark frame*** to ***Also***. What happens here is the camera takes a ***dark frame*** first, and then takes a ***light frame***, ***subtracting*** the ***dark frame*** from it. The result should be uniform noise without ***hot pixels*** and without ***readout glow***.

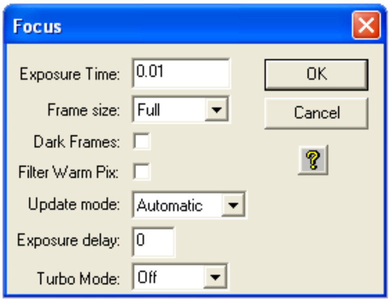
Had we had the camera on the telescope we would have seen the object but because we had the nosepiece covered we took a ***dark subtracted image*** of the dark. If you take enough of these, and stare at them long enough you'll see all kinds of patterns in the random noise, including even pictures of Elvis!

You can read about the other items in the ***Grab*** dialog by clicking the ***Help button***, but in general the ***Grab*** command is used to ***take a single image*** and optionally do an ***automatic dark subtraction***.

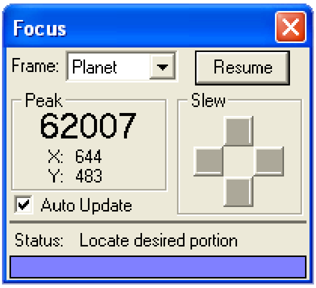
Note: Dark subtracted images have an offset of 100 ADU added to them to ensure values near zero are not clipped.

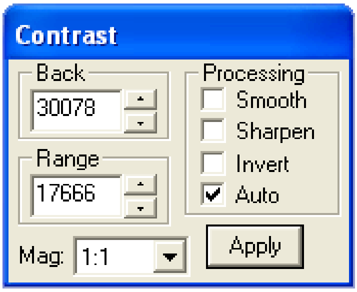
Focus Command

Using the **Grab** command to focus your telescope would drive you crazy, taking a single image at a time, tweaking the telescope, etc. Instead we use the **Focus** command, which is like **Grab** but it takes image after image automatically. Use the ***Focus*** command in the ***Camera*** menu and set it up in the ***Focus Setup*** dialog as shown below:



Click ***OK*** and the camera will go into ***Focus*** mode. You'll see image after image appear in a single window at a rate of several frames each second. The images will vary slightly from image to image, mostly in the random background noise, but in general they'll all look a lot like ***Image 1***. You'll also notice that a new ***Focus Mode*** dialog appeared.





Here's a brief description of the key items in the ***Focus Setup*** and ***Focus Mode*** dialogs.

Exposure Time – You'll be able to see most objects in a 1 second exposure. Use shorter exposures (down to 0.001 seconds) for faster rep rates when focusing on bright stars or longer exposures when trying to center dim objects. The first time you focus it helps to use an exposure of about 3 seconds so that you can see even out of focus stars. As the stars are brought to sharper focus you can reduce the exposure time.

Frame Size – ***Planet*** mode allows you to select a portion of the CCD's field of view (***FOV***) for faster rep rates due to smaller downloads. It's great for focusing the telescope on a star. The other three ***Full*** settings all show the full FOV of the CCD but are slower than ***Planet*** mode because there's more data to download.

Full-High uses high-resolution mode to show you all 648 x 486 pixels. ***Full-Low*** uses low resolution (2x2 binning) which is faster and more sensitive since there are fewer pixels to download and the pixels are larger. Finally ***Full*** works in conjunction with ***Planet*** mode and the ***Camera Setup*** such that when the camera is set to ***Auto*** resolution mode ***Full*** uses the low-resolution mode for faster downloads then switches to high-resolution for ***Planet*** mode.

Dark Frames – For most objects you won't need to take dark frames in Focus mode to frame and focus the object because the exposures tend to be short and the build up of dark current minimal. On some dim objects though, checking this item, which uses ***dark subtracted*** images for ***Focus*** mode, can help to pull the object out of the noise. The update rate is slightly slower when using dark frames so only use this when you need to.

Filter Warm Pix – Checking this box will cause the software to automatically filter out warm (bright) pixels. This will produce a smoother background. with less "salt-and-pepper" appearance.

Update Mode – Sometimes you want to tweak the focus, look at an image, tweak it again, etc. Setting this to ***Manual*** causes the Focus mode to pause between images until the **Space Bar** is hit or you click the **Pause/Resume** button.

Exposure delay – This will put a delay of x seconds between exposures

Turbo Mode – This is used with slower cameras to stop the shutter from moving in order to speed up focusing. It is not needed with the ST-i camera.

Peak – This shows the position and brightness of the brightest pixel in the Focus mode image. We'll use this later to get the best focus by maximizing the ***Peak*** on a ***star***.

Pause/Resume – Click this button at any time to pause or resume the focus mode. This can be handy for going back and forth between the telescope and the computer or for studying the images.

You can read more about the other items in the ***Help*** but we now know enough for basic operation. Exit ***Focus Mode*** by closing the ***Focus Mode*** dialog or closing the image window.

3. At the Telescope

Connect the camera to the computer and start ***CCDOps***. Establish a link to the camera and run the ***Camera Setup*** command. At this point we're ready to hook up to the telescope.

Focusing the ST-i camera is much easier than most CCD cameras due to its faster frame rates. Nevertheless, it can be difficult the first time when the star images are likely to be well out of focus and difficult to detect. Use 3 second exposures the first time in order to detect even stars that are out of focus. As you get closer to focus you can reduce the time to increase the update rate and use just the brightest stars for final focusing. The backfocus distance (the distaqnce from the front of the camera tube to the CCD focal plane) is 0.53 inches.

To achieve fine focus, first center a bright star then insert the CCD head into the eyepiece tube, taking care to seat it, and then enter the CCDOps ***Focus Mode***. Do not initially try to focus on the moon or planet – they are harder. As we learned in the tutorial, the ***Focus Mode*** automatically displays successive images on the screen as well as the peak brightness value of the brightest object in the field of view. Using the telescope controls, center the star image in the CCD, and adjust the focus until the star image is a small as can be discerned. Next, shift the telescope to fainter stars so the CCD is not saturated. Further adjust the focus to maximize the displayed star brightness in counts and minimize the star diameter. This can be tedious. It helps considerably if a pointer or marker is affixed to the focus knob so you can rapidly return to the best focus once you've gone through it.

With the fast update rate of the ST-i camera, use the ***Full frame*** mode to focus, or screen update rate can be increased significantly by using ***Planet mode***. In Planet mode the Focus command takes a full image and then lets you position a variable sized rectangle around the star. On subsequent images the Planet mode only digitizes, downloads, and displays the small area you selected. The increase in frame rate is roughly proportional to the decrease in frame size, assuming you are using a short exposure.

The telescope focus is best achieved by maximizing the peak value of the star image. You should be careful to move to a dimmer star if the peak brightness causes saturation. The saturation levels of the various resolution modes are shown in Table 3.2 below. Another point you should also be aware of is that as you approach a good focus, the peak reading can vary by 30% or so. This is due to the fact that as the star image gets small, where an appreciable percentage of the light is confined to a single pixel, shifting the image a half a pixel reduces the peak brightness as the star's image is split between the two pixels. The Kodak CCD pixels are so small that this is not likely to be a problem.

dark. The shutter covers the CCD. Dark Frames are subtracted from normal exposures (light frames) to eliminate fixed pattern and dark current noise from the image. Dark Frames must be of the same integration time and temperature as the light frame being processed.

FITS Image File Format - The FITS image file format (which stands for Flexible Image Transport System) is a common format supported by professional astronomical image processing programs such as IRAF and PC Vista.

Flat Field - A Flat Field is a image with a uniform distribution of light entering the telescope. An image taken this way is called a flat field image and is used with CCDOPS to correct images for vignetting.

Focal Reducer - A Focal Reducer reduces the effective focal length of an optical system. It consists of a lens mounted in a cell and is usually placed in front of an eyepiece or camera. With the relatively small size of CCDs compared to film, focal reducers are often used in CCD imaging.

Full Well Capacity - Full Well Capacity refers to the maximum number of electrons a CCD pixel can hold. This number is usually directly proportional to the area of the pixel.

Histogram - The Histogram is a table of the number of pixels having a given intensity for each of the possible pixel locations of the image file.

Light Frame - The Light Frame is the image of an object before a Dark Frame has been subtracted.

Photometry - Photometry is the study of stellar magnitudes at a given wavelength or bandpass.

Pixel Size - The smallest resolution element of a CCD camera is the CCD pixel.

Planet Mode - Planet Mode is the most useful way to achieve focus. When you select Planet mode, a full frame is exposed, downloaded, and displayed on the computer monitor. A small window can be placed anywhere in the image area and the size of the window can be changed. Subsequent downloads will be of the area inside the box resulting in a much faster update rate.

Quantum Efficiency - Quantum Efficiency refers to the fractional number of electrons formed in the CCD pixel for a given number of photons. Quantum Efficiency is usually plotted as a function of wavelength.

Readout Noise - Readout noise is associated with errors generated by the actual interrogation and readout of each of the CCD pixels at the end of an exposure. This is the result of fixed pattern noise in the CCD, residual charge in the readout capacitors and to a small extent the noise from the A/D converter and preamplifier.

Resolution Mode - The resolution of a CCD camera is determined by pixel size. Pixel size can be increased by combining or binning more than one pixel and displaying it as one pixel. Doing so decreases the effective resolution but speeds up the download time of the image. Maximum resolution is determined by the size of the individual CCD pixel. The ST-i can run in High, Medium, Low and Auto resolution modes.

Response Factor - Response Factor is a multiplier used by CCDOps to calibrate CCDOps to a given telescope for photometric calculations.

Saturation - Saturation refers to the full well capacity of a CCD pixel as well as the maximum counts available in the A/D converter. The pixel is saturated when the number of electrons accumulated in the pixel reaches its full well capacity. The A/D is saturated when the input voltage exceeds the maximum.

Sky Background - The sky background illumination or brightness is the number of counts in the image in areas free of stars or nebulosity and is due to city lights and sky glow. High levels of sky background can increase the noise in images just like dark current. For some objects deep sky filters can be used to reduce the sky background level.

Seeing - Seeing refers to the steadiness and the clarity of the atmosphere during an observing session.

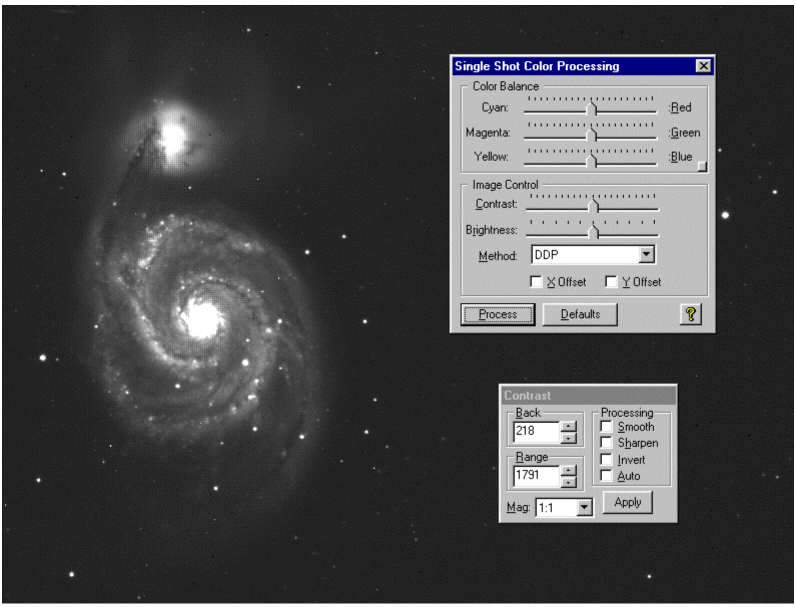
TE Cooler - The TE Cooler is a Thermal Electric cooling device used to cool the CCD down to operating temperature. The CCD is mounted to the TE Cooler which is mounted to a heat sink, usually the camera head housing (Note: TE cooling is not used on the ST-i camera).

TIFF Image File Format - The TIFF image file format (which stands for Tagged Interchange File Format) was developed jointly by Microsoft and Aldus Corporations to allow easy interchange of graphics images between programs in areas such as presentation and desktop publishing. CCDOps can save image files in this format but unless they're color images it can not read them.

Track and Accumulate - The Track and Accumulate function is a SBIG patented feature of CCDOps that allows the user to automatically

The image below is a screen captures of the single step process and the dialog box shows the settings in their default positions using DDP as the method:

Step 1: Capture the image and save the raw data - it will appear monochrome on the computer screen when first downloaded from the camera.



Step 2: Click the "PROCESS" button to create the color image - this step can be repeated without reloading the original image data - the monochrome image will change to color.

If you don't like the color balance of the result, simply modify the color balance pointers by making <u>small</u> changes and click the "process" button again. For more in-depth color image processing, you can extract the RGB color channels and perform more traditional tri-color image processing techniques (see Processing Separate RGB Images, below).

Enhancements
Images of galaxies tend to have a lot of dynamic range and you may find it difficult to reveal the faint details in the arms without causing the core to saturate. Try selecting the DDP instead of RGB in the "Method" drop down box. Hit the Process button. DDP compresses the dynamic range of the image. This may not look natural on all images but don't be afraid to try it. An example is shown below.

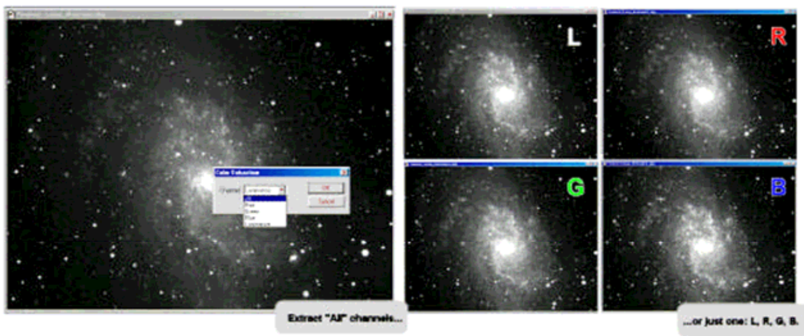
RGB Processed DDP Processed

The initial color processing doesn't have to be difficult or complicated. Once you have saved the original B&W image you can experiment over and over with different settings until you achieve the results you like. Of course, if you want more control over the image you may wish to process the R,G and B frames separately and combine them just as you would if the three frames were taken separately though RG and B filters as they are with monochrome cameras. See below for more about extracting, processing and combining RGB frames.

Easy Processing of Separate R,G and B Images

Monochrome cameras with filter wheels are used to make color images by shooting separate red, green and blue frames through color filters. Separate Red, Green and Blue frames may also be extracted from a Single Shot Color Camera image for more control during the processing stages. Advanced users may desire the additional control this gives them over the color processing steps. CCDOPS also offers you the option to extract individual color channels from the raw frame.

If you want to follow along with this example, a copy of the M33 raw image is available on the SBIG software CD-ROM in the Images folder.



To do this using CCDOPS select **<u>Utility</u>** --> **<u>Single Shot Color</u>** --> **<u>Extract Color Channel(s)</u>...** The Color Extraction dialog box will open and give you the option to extract any (or all) of the individual color channels (Red, Green, Blue) and a synthesized Luminance (greyscale) channel:

Once extracted, the R,G and B frames from a Single Shot Color Camera are treated the same as RGB frames shot with a monochrome camera and color filter wheel. The individual color channels are extracted at full resolution by interpolating the data from the neighboring pixels. Once the individual color channel images are saved to disk, you can combine them using any image processing software.

The RGB Combine dialog box will still remain open after the color image is displayed, allowing you to adjust the color balance of the final image. Each time you click on “Do It” the image will update and display your changes. Select File -> Save As to save the final color image as a TIFF file.

Processing separate RGB images to create a color image involves the following steps:

1. Co-aligning the images
2. Normalizing the Sky Background
3. Setting the White Balance.

CCDOps makes this relatively easy. Here's a step-by-step procedure for quick and easy RGB Processing:

1. Co-align the images - Open the Red, Green and Blue images and then open the Crosshairs.Visually identify a common star or feature in the images to serve as an alignment reference. Starting with the Red image, position the Crosshair on the reference position, using the peak pixel brightness on a star for example, then right-click the mouse. Select the Set RGB Red Position item to mark the reference position. Do the same in the Green and Blue images, selecting the Set RGB Green Position and Set RGB Blue Position respectively. This tells CCDOps how it will co-align the images