ST-i Spectrograph

With ST-i Spectro Software

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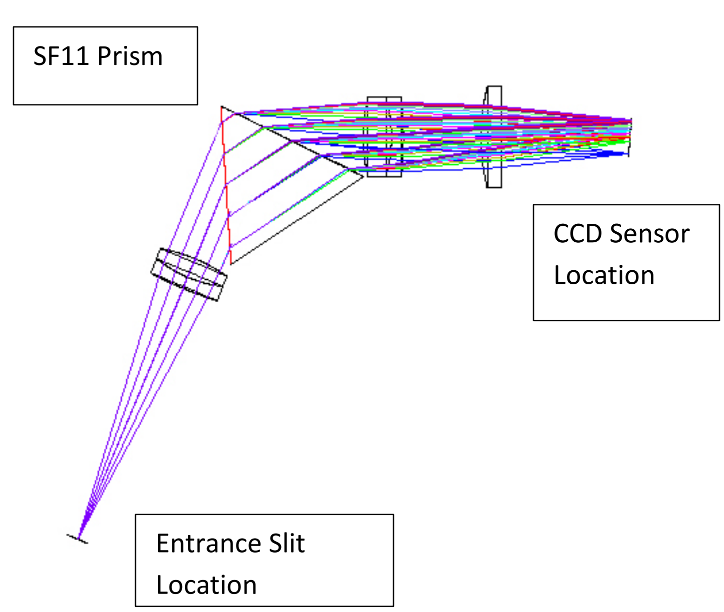
Introduction

SBIG's new ST-i spectrograph was designed specifically for our ST-i camera. This unit is intended to enable an amateur to characterize his/her skies, flat field sources, filter passbands, and other light sources. Its main purpose is to allow an amateur to measure his sky spectrum, and optimize his flat field sources to better match his conditions. The reason why this is important can be found in an article by Alan Holmes titled Flat Fields – The Ugly Truth found at the SBIG web site: http://www.sbig.com/about-us/blog/flat-fields-the-ugly-truth/

This unit also provides a good way for an amateur to compare his light pollution situation to users at other sites. The cold reality of the world is that good paying jobs are associated with cities and light pollution, and light pollution is fact of life for most of us!

The optical design of the spectrograph is shown in Figure One. A prism is used as the dispersing element instead of a grating. The reasons for this are two-fold. Most important, the optical efficiency is high across the spectrum, roughly twice that of a grating on average. This is valuable since the night sky is not that bright. Secondly, the spectral range without confusion from multi-order light is from 430 to 1000 nm (4300 to 10000 Angstroms), encompassing the full sensitivity range of SBIG CCD products. The skyglow in the near infrared (700 to 1000 nm) is significant to the CCD camera, even though it is invisible to your eye. This near infrared response is important in detecting faint stars and distant galaxies, but also is not well baffled by many commercial telescope optical systems, so it needs to be understood.

Figure One: ST-I Spectrograph Optical Design

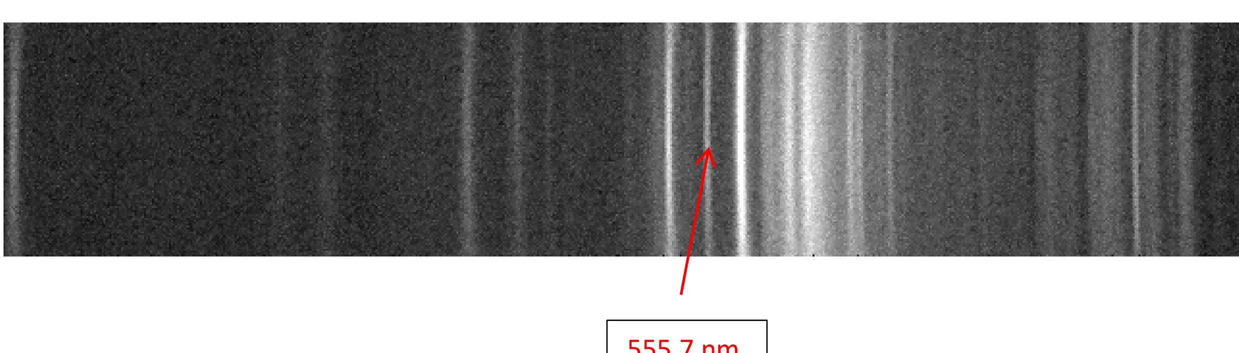


The design is simple: light enters the spectrograph through a 25 micron entrance slit and is collimated by an achromatic lens. It then passes through the Schott SF11 glass prism, where blue light is bent through a greater angle than red wavelengths. A second achromat focuses the light onto the CCD, with an additional plano-convex lens to shorten the focal length and increase the photographic speed of the system to F/3.66. The speed is important when trying to capture the sky background. The plane of the CCD is actually tilted a little bit relative to the angle of incidence of the light, as shown, to reduce the contribution of chromatic aberration to the optical blur. The spectrum of a neon gas discharge tube captured with this system is shown in Figure Two. Note that the spectral lines are straight, top to bottom, even though the slit is seen to be curved when inspected visually. The slit curvature was added to correct the natural tendency of the off axis rays from the slit being bent by a slightly lesser amount by the prism than on-axis rays. Curving the slit straightens out the lines, enabling greater vertical binning of the CCD for faint targets. In these figures, blue wavelengths are on the left, and red on the right.

Figure Two: Spectrum of Neon Discharge Tube

Figure Three illustrates the sky background from the author's back yard, which has about 5th magnitude skies. To capture this, the spectrograph is simply pointed straight up. As a result, background starlight is also included in this spectrum and is visible as the semi-uniform continuum baseline. The resolution around the natural airglow line at 557.7 nm (marked) is adequate to separate it from the pervasive mercury line at 540.6 nm, and the sodium line at 568.8 nm (both from streetlights).

Figure Three: Airglow from my Backyard (Magnitude 5 Skies)



A program for a PC is included with the spectrograph that allows the user to control the ST-i and acquire spectra, to create a wavelength calibration for the spectrograph, output text files of the data for processing with Excel or another program, and re-bin the data into a format with uniform sized wavelength bins for simpler comparison with grating data or from other sources. The intent is to make this functionality easy to use, and to provide a window into the interesting spectral properties of light sources around us. Figure Four illustrates a screen shot from that program. A graph of the spectrum is shown, as well as a graph of the spectrum binned into spectral intervals of equal width to correct for the non-linearity of the prism design.

Appendix A describes how to use this spectrograph for hyperspectral imaging. Our software support for this interesting new capability for the amateur is a bit simplistic at present, but we think it will intrigue many users and enable the development of some new techniques. An example is posted in Figure 5 to illustrate the power of this technique.

Appendix B graphs the nominal calibration data for the spectrograph, as well as the dispersion in terms of Angstroms per pixel across the CCD. As you can see, the dispersion is much lower in the near infrared.

We hope this simple-to-use spectrograph will become an essential part of the amateur astronomer's toolkit. It enables the amateur to visualize the spectrum of the light around him, and to easily measure the transmission of filters, the reflectivity of diffuse surfaces, and even atmospheric transmission with a bit more time and setup. This technique will be described in a future paper.

Figure Four: ST-I Spectroscopy Program

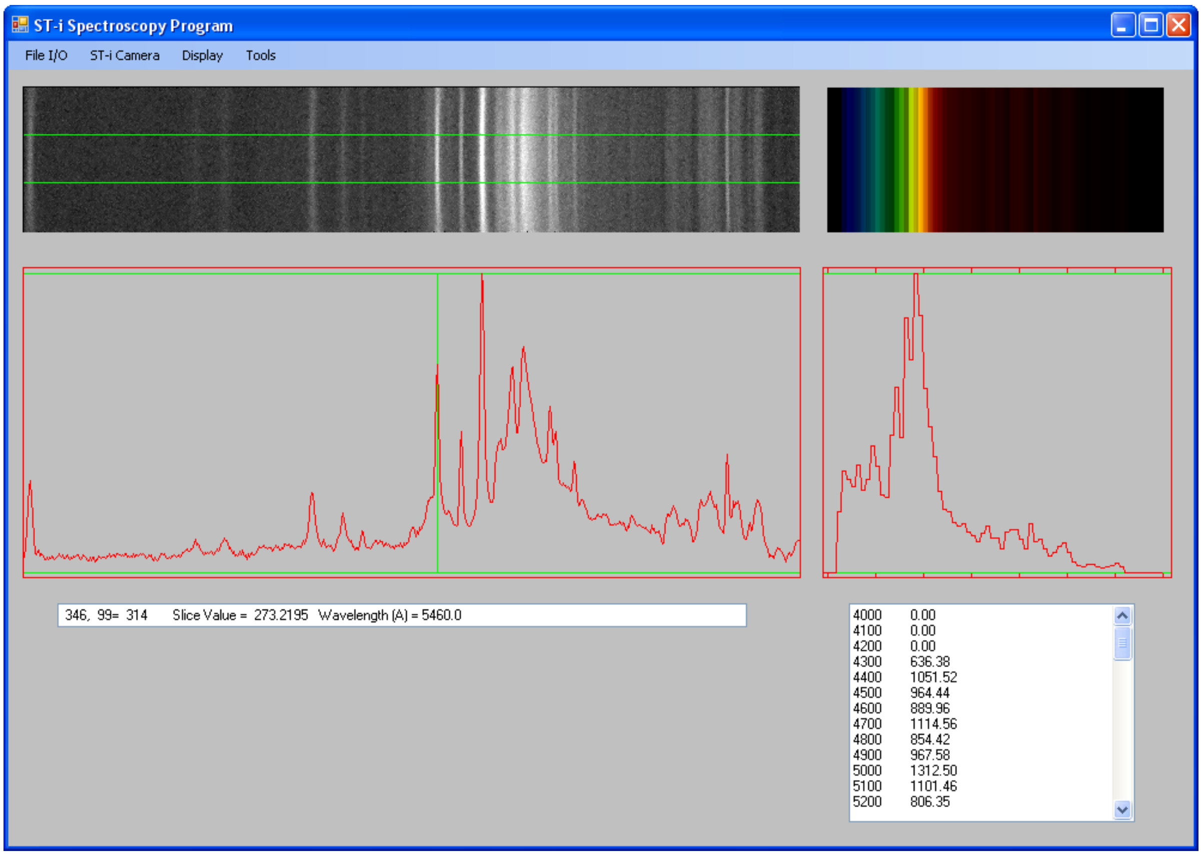
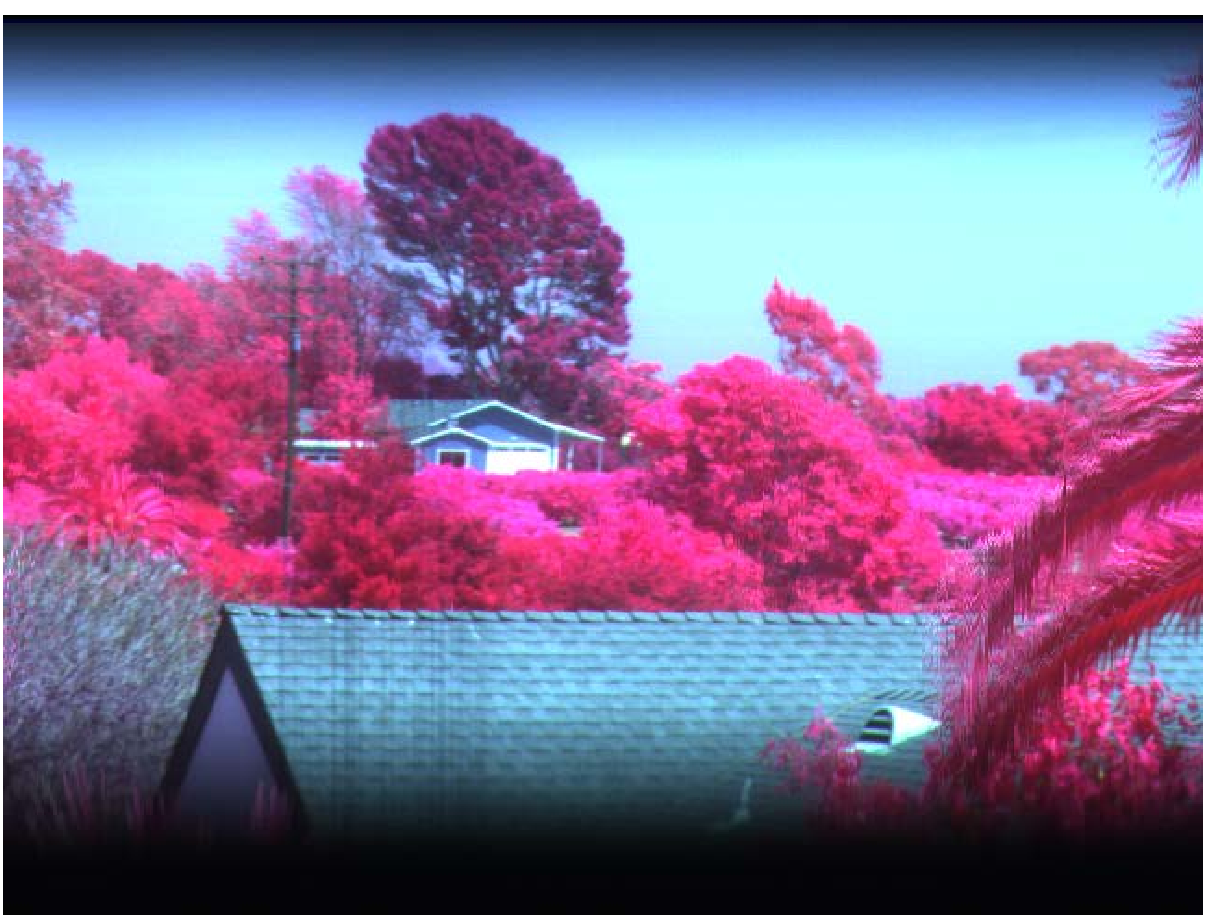


Figure Five: Hyper-Spectral Image



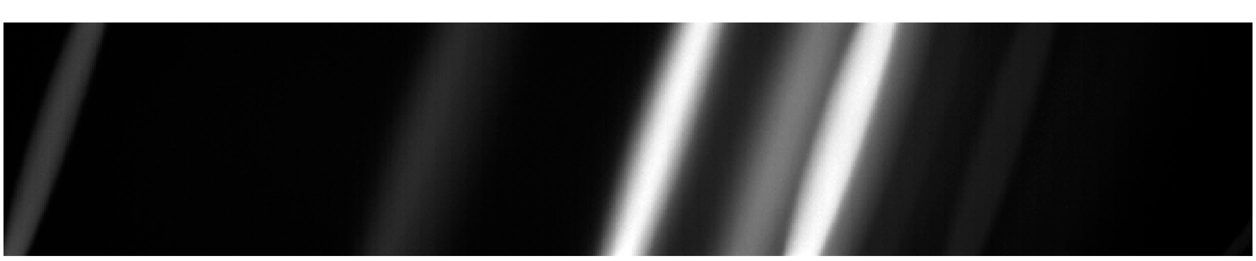
Section 1: Setting up the ST-i Spectrograph

This section assumes you are familiar with use of the ST-i with CCDOPS. To begin, insert the ST-i into the spectrometer block as shown in Figure Six. Note that the USB connector is to the right of the ST-4 style tracking connector in the middle of the camera. It is important to get this orientation right.

Figure Six: Correct Rotation Orientation of ST-i in the Spectrograph

Next, under fluorescent light illumination or even subdued daylight, point the combined ST-i and spectrograph at a white surface. In CCDOPS, establish a link to the camera, select a resolution of 1xN under CAMERA-SETUP, with a vertical binning of 4, and then start focus mode with about a 0.1 second exposure. You will get a blurry pattern with tilted, badly out-of-focus spectral lines as shown in Figure Seven.

Figure Seven: Initial Out-Of-Focus Rotated Pattern – Fluorescent Lit Room

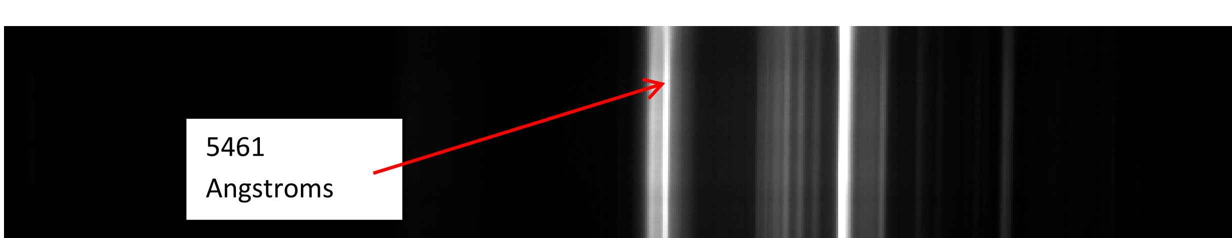


Make sure the small setscrews that secure the ST-i in the spectrometer body are loose, and using your thumb and forefinger, pull the ST-i out a few mm until the sloping lines in the image become sharp. At the same time (and this isn't very easy), rotate the ST-i to make the lines vertical. It is easier to see a slight error if you hit PAUSE to halt the focus process, and resize the image window to put one edge near a line. Hit RESUME to continue. The ST-i may rotate a little bit when you tighten down the setscrews, so this can a little time to get perfect. Do not over-tighten the setscrews. This can dent the ST-i and impede future small adjustments. When this is done the spectrum is probably not centered perfectly on the ST-i CCD, so one next needs to translate the nosepiece slightly to achieve perfect centering. One technique is to grab an image and display it on the screen at the same size and position as for focus mode. Use the SBIG crosshairs mode to place the cursor on the desired pixel. Then, stick a Post-It note on the screen with one corner marking the pixel location to which you will try to move a spectral feature. An easy line to see and recognize is 5461 Angstroms (for fluorescent lights). You should move this line to image column 349 (+/- 2 pixels). Another one is the atmospheric oxygen absorption feature at 7650 Angstroms. It is easily recognized as a dark band. Move this to pixel 558. When translating the nosepiece the lines may twist away from vertical you might have to repeat these steps until it is set. Once it is set, you don't need to touch it again.

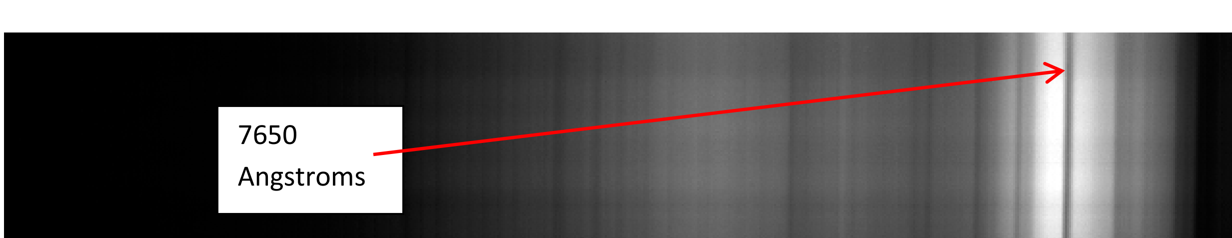
These alignment lines are identified in Figure Eight. Note that the fluorescent light spectrum may not look exactly like this since the bulbs have different color temperatures and phosphors in them. However, they all have the 5461 line.

Figure Eight: Alignment Lines

Fluorescent Lights



Daylight



Section 2: Using the ST-i Spectrograph

It is easy to use the ST-i spectrograph to capture the spectrum of any diffuse source. For night sky light pollution, for example, just mount the unit to a tripod and point the slit straight up. No optics are necessary since the sky fills the field of view. The acceptance angle of the spectrograph is F/4.3 (13.3 degree full width), so you need a clear view of the sky with a greater angular width than that. If you average 3 to 7 images with exposures of two to five minutes each you can get a pretty good measurement of the night sky. When capturing such images, always bin 4:1 vertically to improve the SNR and so the data can be accepted by the analysis program ST-i Spectro later. The program will read both FITS and SBIG format images, but only saves in SBIG format. CCDOPS can convert between the two, as well as can many other astronomical image processing programs.

Section 3: Installing and Using ST-i Spectro Software

The ST-i Spectro program can be used to plot the spectrum, and assign a wavelength to the values. It operation is described in this section.

To install the software, download the folder labeled ST-i Spectro Installer and put it in a directory on your PC. Next, open the folder and double-click SETUP.EXE. This should install the program. Find the new program in the program list (selected by clicking the START button in the lower left corner of your PC's screen), and select it to start the program. You can also right click it to create a shortcut on your desktop.

To become familiar with use of the program, start it up, and go to the installation folder and go to the FILE I/O menu, select LOAD SBIG IMAGE, and find the image file SkyGlow.SBIG in the installation directory. Select it. It will load and show on the screen. The image is shown at the top left. Below the image is a graph of the average counts between the two green crop bars lines in the image, minus the background crop region. The program assumes the image has been dark subtracted and has a "no light" pedestal level of 100, so it subtracts this from the image data in preparing the graph. If a background crop area is selected it will subtract the average of that region from the image data. The idea behind having a cropped region is that when a star is focused on the slit it produces a spectrum that is a streak only a few pixels tall.

By moving the cursor around on the image data, you will see a line move below it on the graph, as well as the pixel location and value displayed in the text box below the graph. The wavelength is also shown. Note that the wavelength value initially will be off, and requires a simple calibration step to improve it.

The graph to the right of the image graph shows the counts per 100 nm wide wavelength interval. With a prism system the wavelength is not a linear function of the pixel location, so some math has to be performed to “linearize” the data. This is done here, and is useful for estimating the total energy in a wavelength interval. Above it is a visual representation of the energy distribution, color coded according to the appearance of that wavelength to the eye.

Under display you will find a menu item labeled “ADJUST CONTRAST”. A new background and range value can be entered to change the display of the image on the screen. Under TOOLS you will find numerous items. The SHOW CROP DIALOG item allows you to set the cropped regions to optimize the data shown to the portion of the image desired. The calibration of the spectrograph can also be adjusted here. When the SHOW CROP DIALOG item is not shown, slide the cursor around on an image that shows mercury (fluorescent) emission lines. Find the pixel corresponding to the peak of the line, and write it down. Enter that value in the appropriate box that pops up when you select SHOW CROP DIALOG. It is unlikely you will need to adjust the scale factor for wavelength calibration. You can determine if there is a significant error by looking at an emission line near the edge of the spectrometer’s range. The mercury line at 4358 Angstroms is a convenient one to check. Note that the program does not centroid to find the exact wavelength of the center of the line, so errors of a few angstroms should not be cause for concern. The intent of this program is more focused on energy distributions rather than spectral line identification or shifts.

TOGGLE CROP LINES merely turns the green lines on and off. The SMALL SPECTRAL ROTATION allows you to rotate a near horizontal spectrum to be horizontal. This is not actually a rotation, but rather a vertical shift that varies across the array. It is not uncommon for the horizontal dispersion direction to be a few pixels off the perpendicular to the spectral lines. This is not a great cause for concern. The dispersion direction is set by the prism, while the orientation of the spectral line can be changed by slight rotations of the entrance slit. They are not necessarily square to each other because of the physics of the spectrograph. Spectral rotations up to +/-8 pixels can be used.

The last two items under the TOOLS menu allow you to save either the spectral data or the binned data (into 100 Angstrom increments) to a text file, along with the wavelength, for graphing using Microsoft Excel or some other spreadsheet program.

ST-i Spectro can also control an ST-i camera and provide real time spectral data. Under the ST-i Camera menu item, after you have attached a camera to your computer, select ESTABLISH LINK to connect to the ST-i. Then you can take a single exposure using TAKE EXPOSURE, or select CONTINUOUS UPDATE to continuously take new exposures and refresh the screen. Both choices automatically take dark frames at the start. You can click the red ABORT button that pops up in CONTINUOUS UPDATE mode to terminate the process, after which you can save an image or view the data. Note – if you are capturing skyglow spectra with long exposures you will be better off using AUTOGRAB in CCDOPS for acquisition since it will save multiple images.

Under the FILE I/O menu you will find commands to load an image in SBIG or FITS format, or save it in SBIG format. The EXIT command will not only close the program, but it will also shutdown any attached SBIG camera.

Section 4: Some Suggested Observations

As mentioned earlier, this device is superb for capturing the spectrum of the night sky. No other low cost device has the sensitivity to accomplish this observation. At the same time it is a good idea to measure the spectrum of the twilight sky. A lot of users use twilight flats as flat fields when doing CCD imaging, but spectrally they are a very poor match to the dark sky, as you will find. You can also measure any flat field sources you might have, at which point you will discover that they are not great either. White LEDs are very blue, and incandescent bulbs are very red. You can measure filter transmissions by pointing the unit at a white screen and collecting some data, and then holding a filter in front of the slit and repeating the exact exposure. You can then calculate a ratio of the two readings using Excel or some other program, and determine a transmission curve. And, as I mentioned previously, it is possible to measure your absolute atmospheric transmission with this device and a cardboard box and some white paint. I will describe this technique in an Application Note in the future. For those who are interested in trying it now please look up “Langley plots” on the internet. This technique can also produce an absolute radiometric calibration for your device since solar irradiance is known to a percent.

Appendix A: HyperSpectral Imaging

The ST-i Spectrometer can be used for hyperspectral imaging. This is a technique where an image can be taken of an object at many wavelengths simultaneously. It is useful in agriculture and mineral exploration where the spectrum of individual points can be examined for the signature of chlorophyll, drought stress, and other attributes. The technique was actually used in astronomy to determine that the "canals" and darkish patches on Mars were not caused by green plants. Green plants become very reflective at wavelengths longer than 700nm, a feature not present in the spectrum of the Martian regions. Anyway, it is possible to experiment with this technique with this spectrograph. If your optical system is a long focal length telescope, your targets are limited, with the moon being the obvious one. SBIG sells a C-mount lens attachment for the spectrograph, though, similar to that shown in Figure Nine. The way to collect a hyperspectral image is to mount the ST-i Spectrograph and C-mount lens on a rotary turntable and point it at the desired scene. One then collects 648 frames of data while the turntable rotates. If it rotates at the sky's sidereal rate (15 arcseconds per second) then you need to collect an image every 140/FL seconds, with FL being the focal length of your optics in mm. A pixel appears to be 10.34 microns wide at the slit, for this calculation. SBIG has HyperSpectral Analysis software that will then pick the same pixel from each image and reconstruct an image from the data set.

Figure Nine – C-Mount Lens Attachment for ST-I Spectrograph

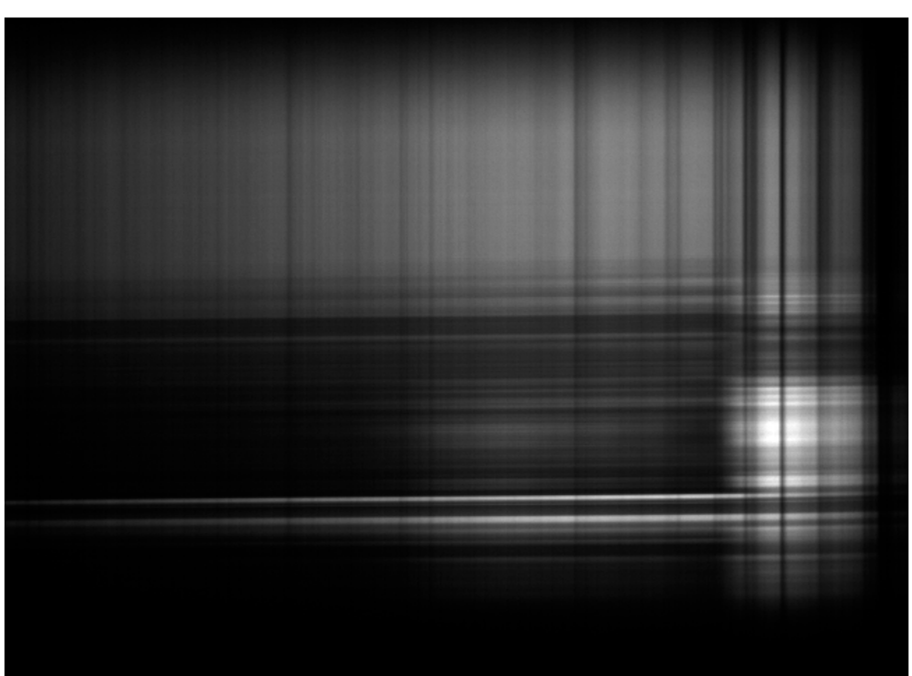
This brief explanation is an introduction. Below I will show a specific example. Figure Ten shows the ST-i Spectrograph and 35 mm C-mount lens mounted on an

AstroTrac mount for astrophotography with camera lens, turned so the motion is in the horizontal plane.

Figure Ten: AstroTrac Rotary Platform Turned Horizontal

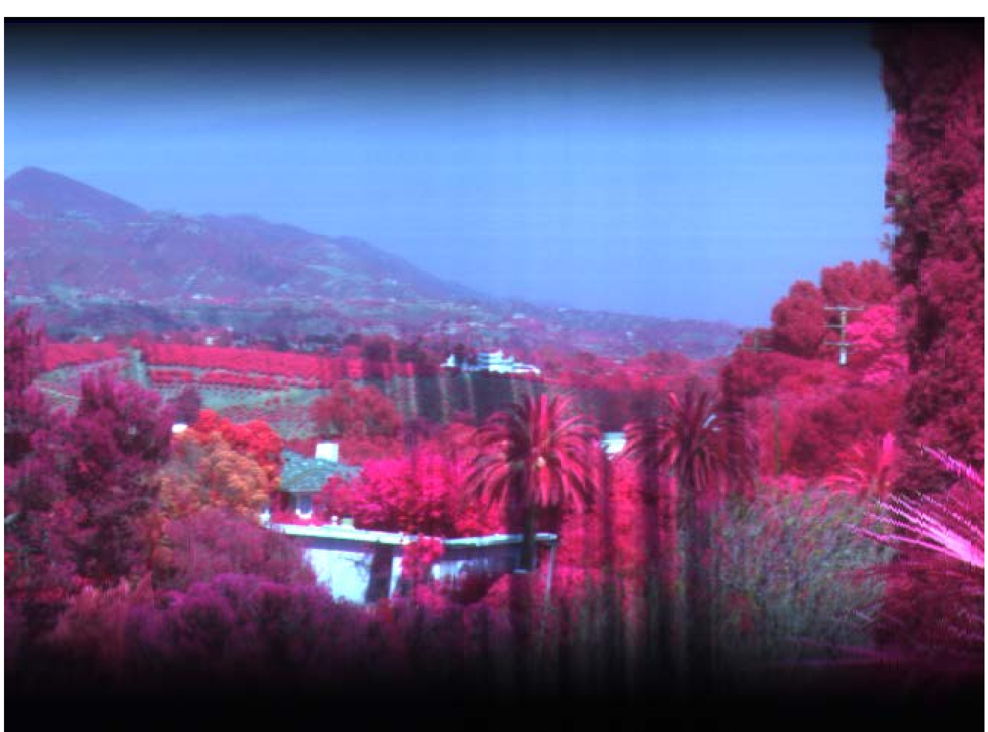
This platform is a bit slow for short focal length lenses, but it is what was available to the author at the time of testing. By sighting down the edge of the spectrometer block, the unit is lined up. Then, 650 samples are collected, one every four seconds, while the AstroTrac rotated. Each image looked similar to what is shown in Figure Eleven

Figure Eleven: Individual Frame with C-Mount lens Mounted



The broad glow at the top of the frame is blue sky near the horizon, and a few white surfaces causes the horizontal streaks 1/3rd of the way up from the bottom. The glow on the right around the oxygen is the bright chlorophyll feature mentioned earlier, from green plants. After installing the HyperSpectral Imaging Utilities Program, run it. First, load the first image of your sequence by selecting LOAD SBIG ST-i IMAGE under the file menu. The image will then load and display. Next, under the TOOLS menu, select the SET SMALL SPECTRAL ROTATION command and enter a value that you have determined to be correct for rotation the dispersion into perpendicularity with the lines. If you get this value wrong then your final images will appear to be shifted vertically with respect to each other. This parameter must be set each time you run the program – it is not remembered in this software version. Once this is set, select SET BANDS to enter new pixel values you wish to have binned together for each of the eight bands the program will reconstruct. These values will be saved in the directory with the images. After these two adjustments are made then go back to FILE I/O and select PROCESS FOLDER. The software will automatically go through all of the files and extract the band data, and construct the eight images. It will show an image building up every 50 pixels. In version 1.0 of the software the contrast is set to be whatever the first spectral image was displayed with. However, when the process finishes, you can look at several of the bands using the menu items under the DISPLAY menu. The intermediated image that builds up on the screen is band 5. To save the resulting images select SAVE HYPERSPECTRAL COMPONENTS under the FILE I/O menu. The files will be saved in the image directory where the spectral files were read. The resulting image from my session is shown below in Figure Twelve.

Figure Twelve: Looking Across a canyon toward Santa Barbara



This image illustrates a problem you might have if you have a slow turntable like I did. It took 40 minutes to collect this data and during that time the thin clouds near the sun shifted around, causing the slightly tilted dark bands in the foreground. The total time spent in data collection here was about 45 minutes. The ST-i can collect image data (for short exposures) at about 3 frames a second, so with a more optimal turntable the collection could be done in as little as 4 minutes and reduce the likelihood of this annoying problem.

One can also use CCDOPS to process the final data in interesting ways. It can create a color image by using the RGB Combine menu item under the UTILITY menu. It also is interesting to flat field one image with another, which yields an image that is a ratio of two bands.

Remember that curved entrance slit on the spectrometer? It causes the data to be sampled along an arc instead of with rectilinear coordinates. We intend to add a resampling routine in a later version to straighten these out (updates will be available for free from the SBIG web site), but note that it is present in both of the images in this instruction manual, so it does not prevent experimentation. Also, the dark band at the bottom of Figures Five and Twelve is due to the light from the lens used at F/16 not making it through the entire system. C-mount lenses will vary from one another. At F/5.6 the problem is reduced. It represents a vignetting effect that we also hope to provide a means to correct in a later update. Flat fielding the band images (using CCDOPS) with a band image of a uniform white scene like a white card or integrating sphere can correct the effect.

The fields that refer to red, green and blue colors on the program's startup screen, and their associated slider controls, are for a future version and should not be used yet in version 1.0.

The HyperSpectral program is a work in progress, so please alert us to any major bugs that are found. Also, if you find a particularly interesting result, please send us some images so we can see what you are doing. This is a new arena for amateur imaging, so many uses might exist of which we are not aware.

Appendix B: Calibration Data

Figure Thirteen: Nominal Wavelength as a function of Pixel Location

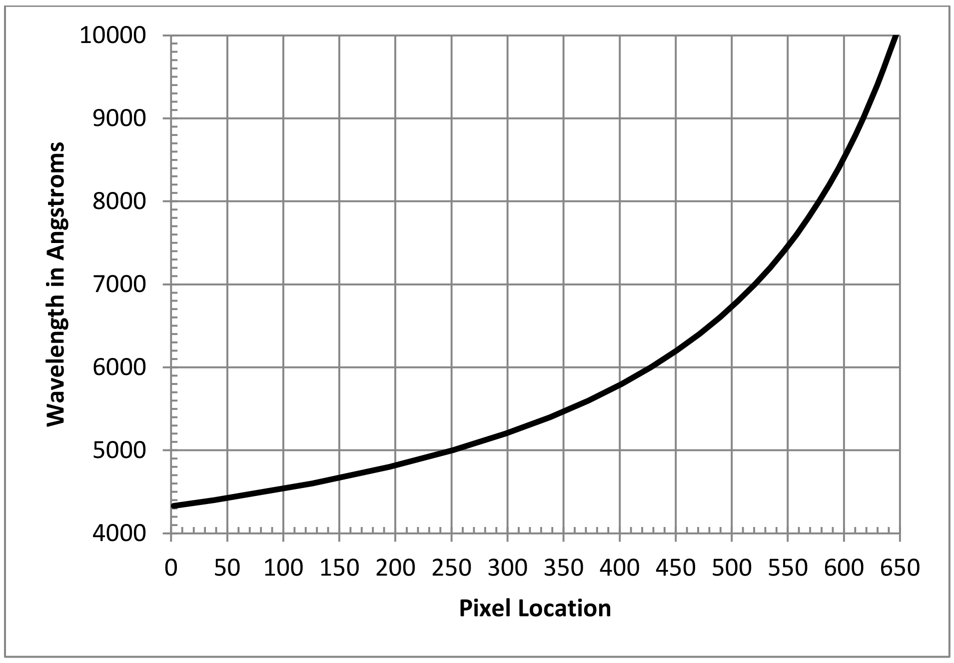


Figure Fourteen: Dispersion (Angstroms per Pixel) as a function of Wavelength