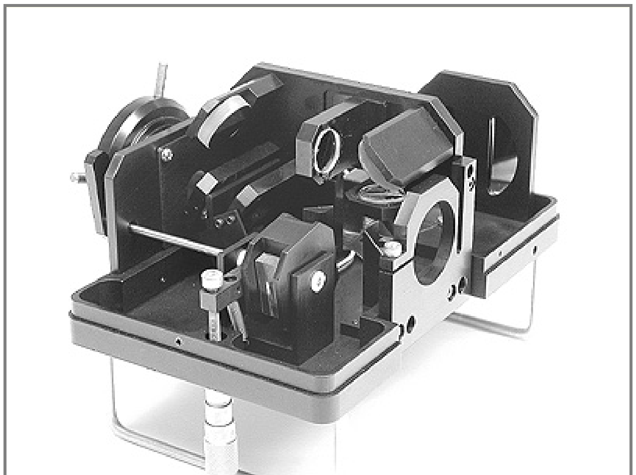
Model SGS Dual CCD Self-Guiding Spectrograph



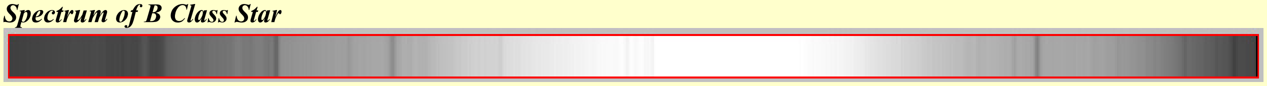
Model SGS Self-Guiding Spectrograph

The Self-Guiding Spectrograph is designed to be used with the ST-7XE/XME camera. For convenience, it can also be used with any dual sensor ST/7/8/9/10/2000 camera, but there is no advantage in bandwidth when using the larger format cameras. The spectrometer and camera body are coupled and mounted as a unit onto the telescope. The system is quite handy for collecting spectra since both the object of interest and the spectrometer entrance slit are simultaneously imaged onto the tracking CCD, allowing the object to be viewed and accurately placed onto the slit. The slit is backlit by an LED during the setup so it clearly shows on the tracking CCD. Once the object is maneuvered onto the slit, self guiding will then hold the object on the slit. The object that is to be analyzed is viewed on the tracking CCD, simultaneously with the slit. The slit is backlit by an LED during setup to render it clearly visible on the tracking CCD. The object is manually maneuvered onto the slit using the telescope controls, and is held there using SELF GUIDING during a long exposure. The spectra is recorded by the imaging CCD, oriented long-ways so the spectra falls across 763 pixels, with a height of about 16 pixels for stellar sources. Two gratings and two slits are available for maximum versatility. The standard grating, 150 rulings per mm, gives a dispersion of 4.3 angstroms per pixel, and allows the user to capture the entire interesting range from the calcium H and K lines to H-Alpha with a single exposure. Depending on the slit size, the resolution will be 10 or 38 angstroms per pixel. An interchangeable high resolution grating can also be used that gives 1.07 angstrom per pixel dispersion, with a resolution of about 2.4 angstroms when used with the narrow slit. The spectral range is smaller, being only about 75 angstroms. This resolution is adequate to detect the Doppler shift due to the earth's motion around the sun when carefully calibrated, and detect spectroscopic binaries.

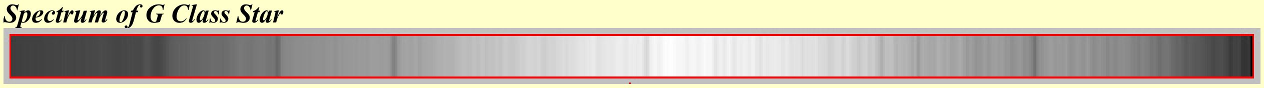
Overview of SBIG's Self-Guided Spectrograph Capabilities	
Measure Stellar Spectra: ***- Determine spectral class*** ***- Measure radial velocities***	Figures 2, 3, 9, 10
Measure Emission Nebula: ***- Determine spectral lines*** ***- Measure relative line strengths***	Figures 4, 5
Measure Galactic Objects: ***- Measure radial velocity (red shift) of brighter galaxies*** ***- Distinguish quasars from other objects***	Figures 6, 7, 8

Identify Stellar Spectral Class

Spectrum of B Class Star



Spectrum of G Class Star



Spectrum of M Class Star

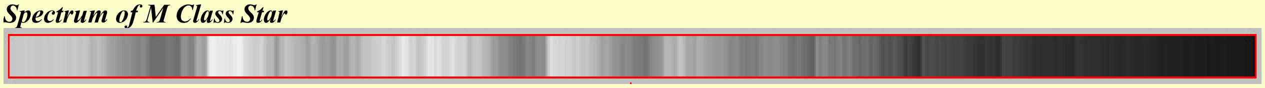


Figure 2
Sample Stellar Spectra

Measure Stellar Radial Velocities

<table>
<tr><th colspan="3">Stellar Radial Velocity of Selected Stars
Measured to +/- 6 km/sec with 8" SCT</th></tr>
<tr><td>Star</td><td>km/sec*</td><td rowspan="10">If you face the celestial equator, straight south at sunset, you are looking BEHIND the earth in orbit (the wind is against your back)!</td></tr>
<tr><td>ATAU1</td><td>88</td></tr>
<tr><td>ATAU2</td><td>88</td></tr>
<tr><td>ATAU3</td><td>95</td></tr>
<tr><td>AORI1</td><td>54</td></tr>
<tr><td>AORI2</td><td>51</td></tr>
<tr><td>AORI3</td><td>56</td></tr>
<tr><td>GLEO1</td><td>-15</td></tr>
<tr><td>GLEO2</td><td>-30</td></tr>
<tr><td>GLEO3</td><td>-14</td></tr>
<tr><td colspan="2">* Uncorrected for earth's orbital velocity</td><td></td></tr>
</table>

Measure Emission Nebula

The spectra of M57 below was obtained using the low resolution grating and the narrow slit:

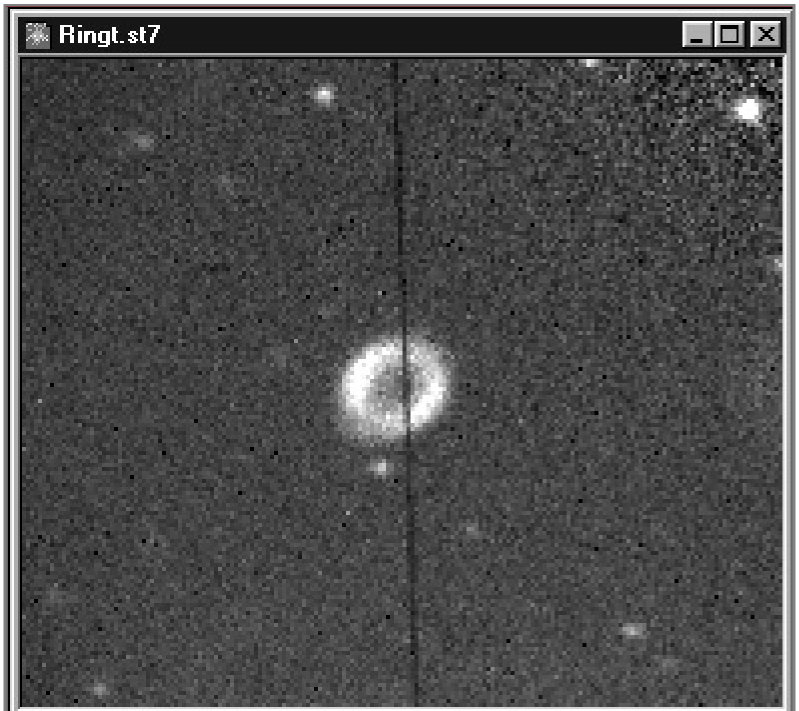


Figure 4

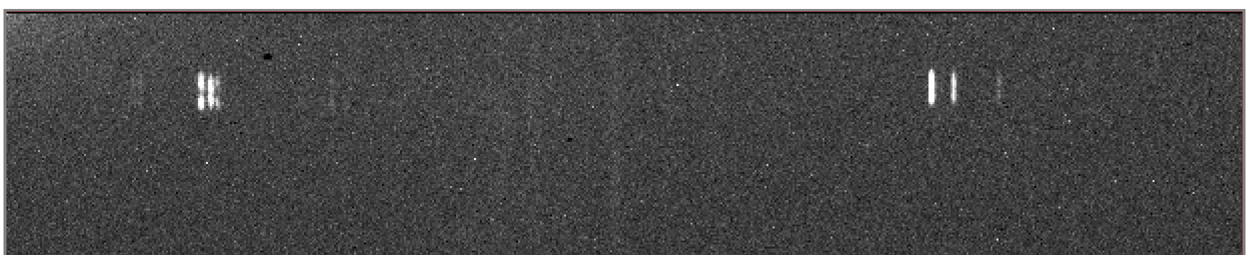


Figure 5

The top image (Figure 4) is a screen shot showing the view of the tracking CCD displaying the slit and the object (M57) simultaneously. The lower image (Figure 5) is a screen shot showing the view of the imaging CCD with emission lines from M57.

Measure Galactic Objects and Distinguish Quasars

The self-guiding feature of the ST-7/8 camera makes taking long exposures relatively painless and helps to keep the object centered on the slit for extended periods of time. This technique is necessary if one attempts to measure the red shifts of galaxies of emission lines of quasars. The samples below of M104 show the red shift of the galaxy relative to the star Mu UMA:

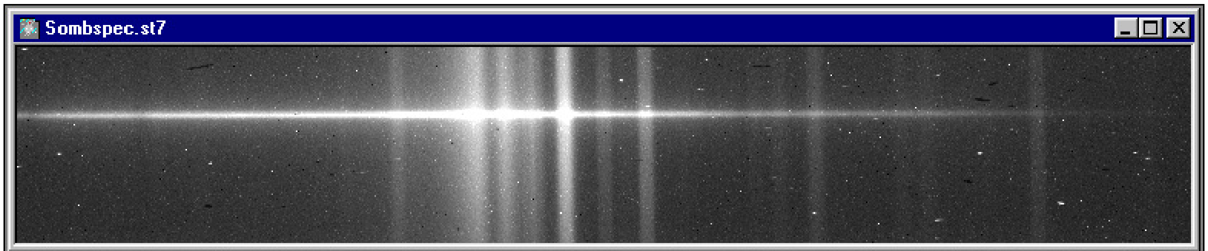


Figure 6
Screen shot of spectrum obtained of M104, The Sombrero Galaxy
(The many small white spots are cosmic ray hits)

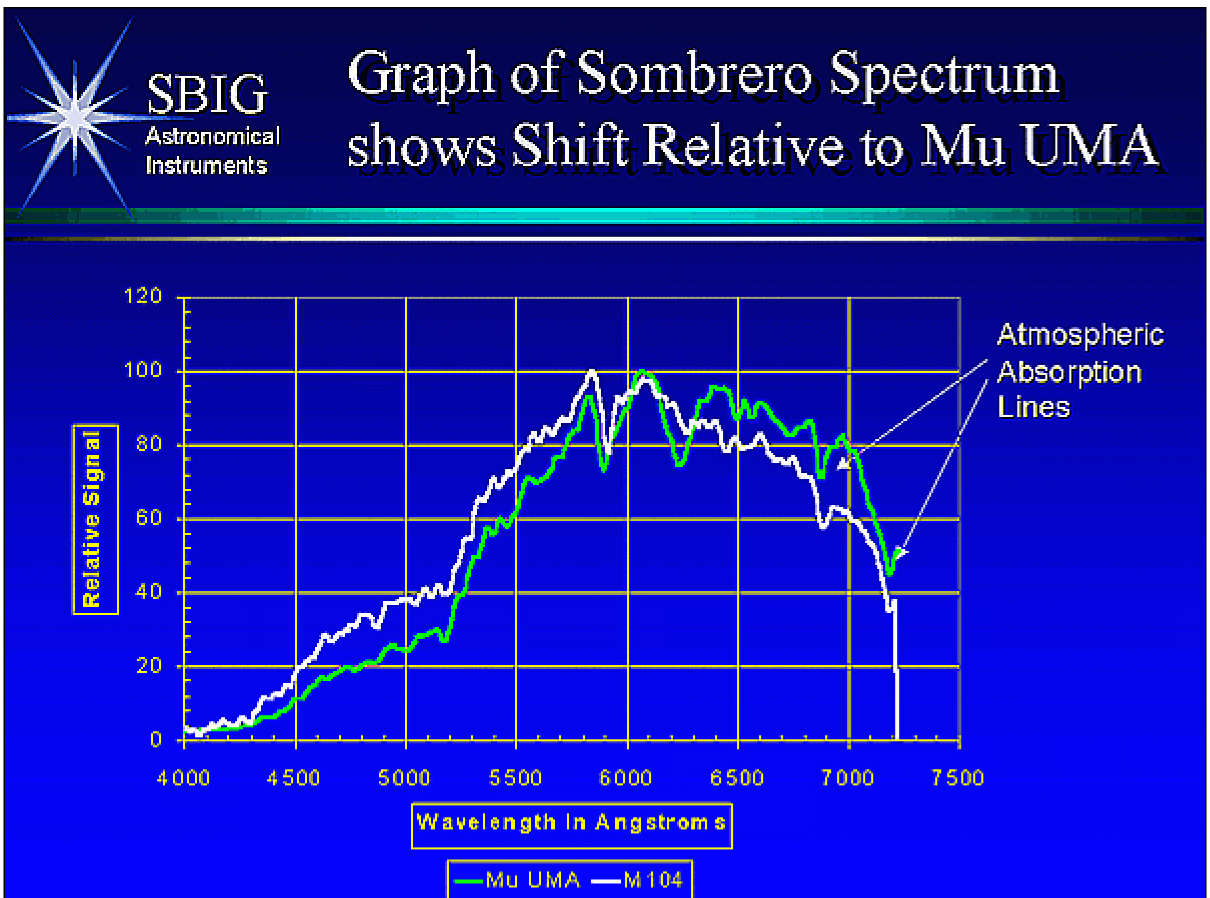


Figure 7
Graph showing the measured red shift of M104 relative to Mu UMA

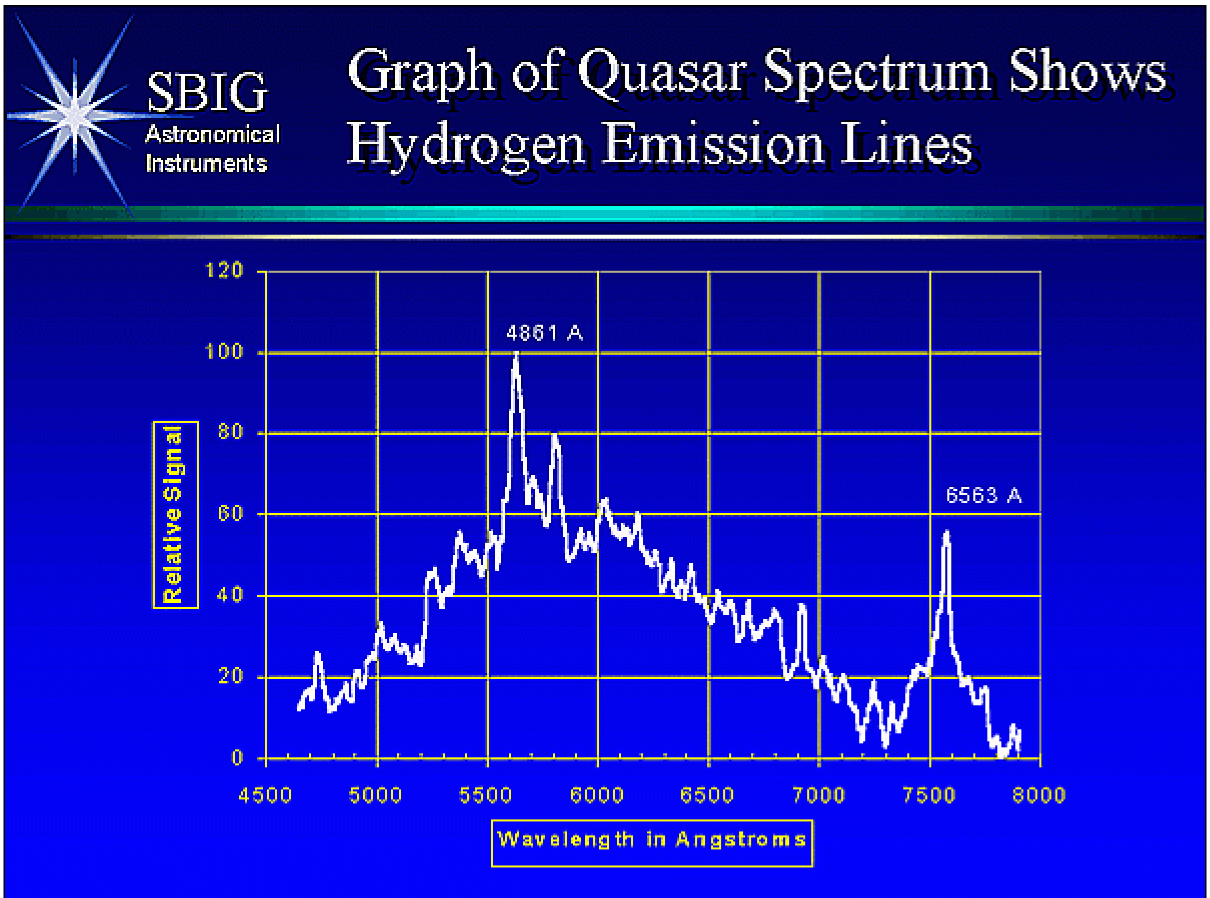


Figure 8
Graph of emission lines in Quasar 3C273 obtained using an 8" SCT

Obtain High Resolution Spectra

Using the high resolution grating and the narrow slit the spectrograph is capable of resolving narrowly separated lines. The sodium doublet lines in Figure 9 below are easily separated although they are only 6 angstroms apart. The magnesium lines in the three stars shown in Figure 10 are separated by only 5.4 angstroms.

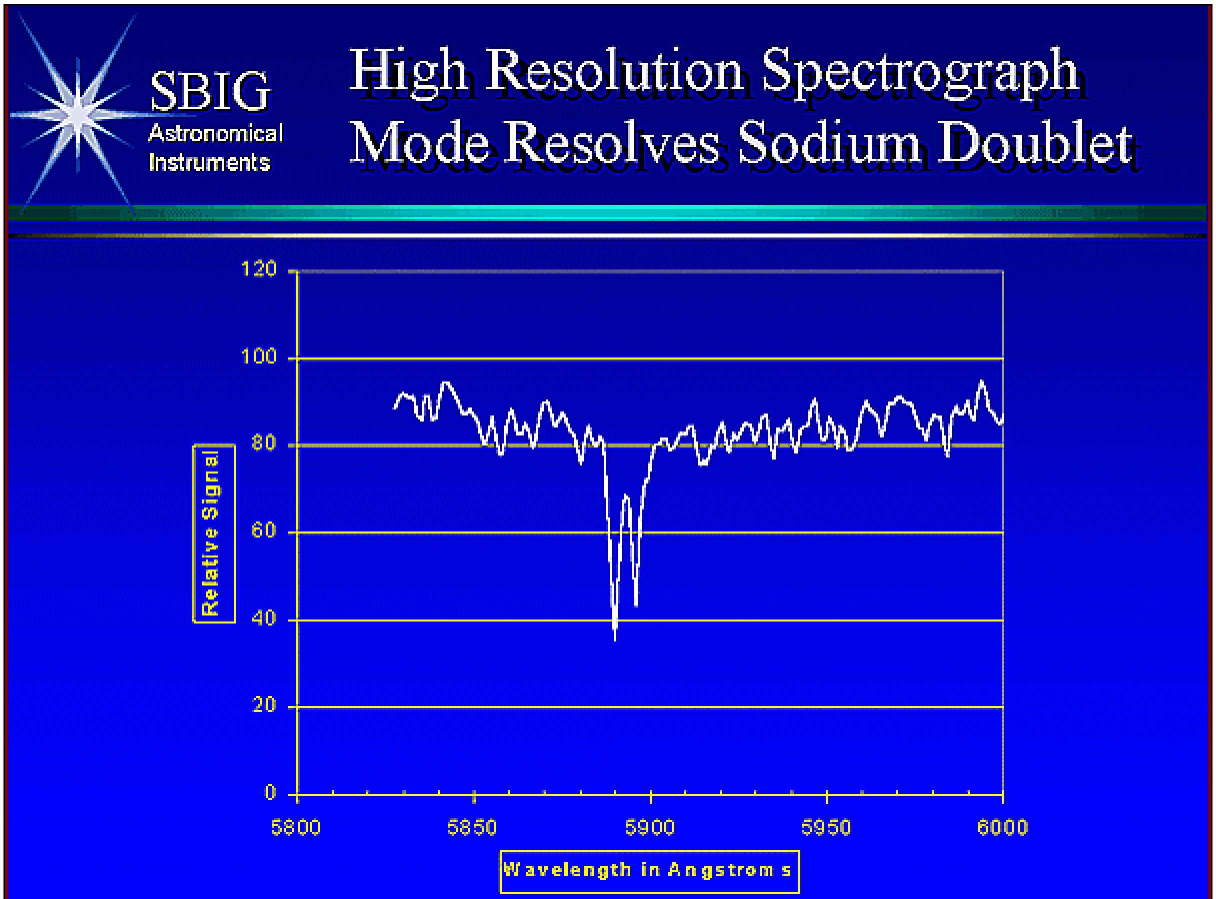


Figure 9

Acquisition and Analysis Software Included

The spectrograph is provided with a special version of CCDOPS for data acquisition and SBIG's Spectral Calibration Program for analysis. These programs make the spectrograph immediately useable as an analytical instrument without the need for the user to write or obtain third party software.

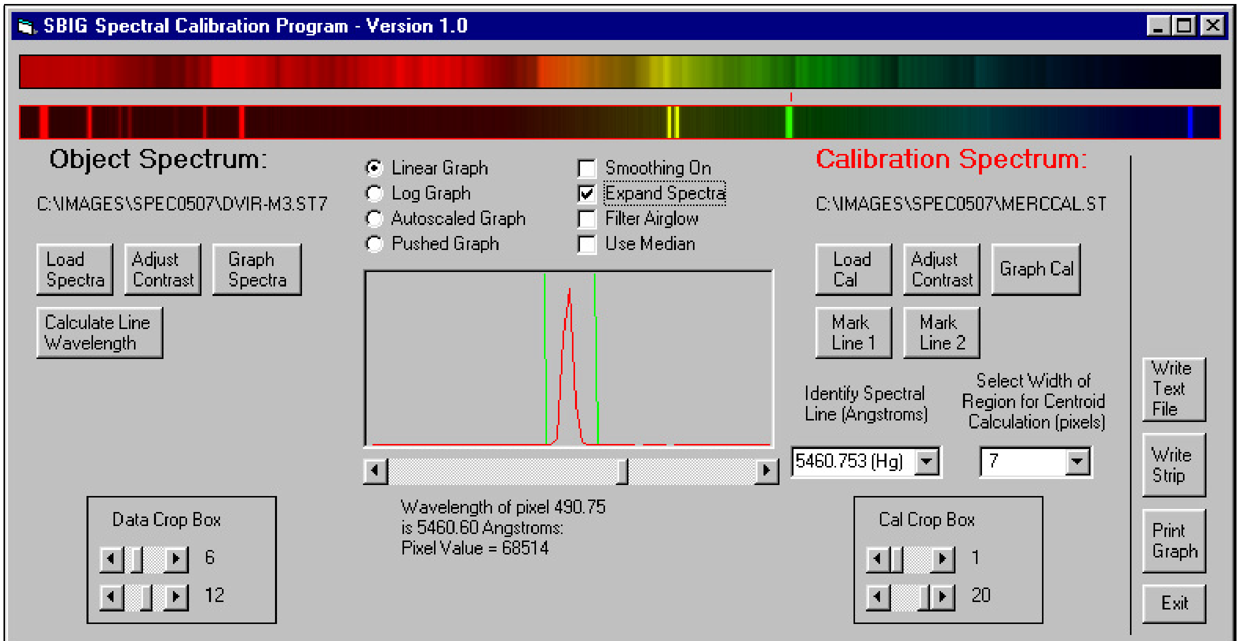


Figure 11
Screen shot of the Spectral Calibration Program supplied with the spectrograph

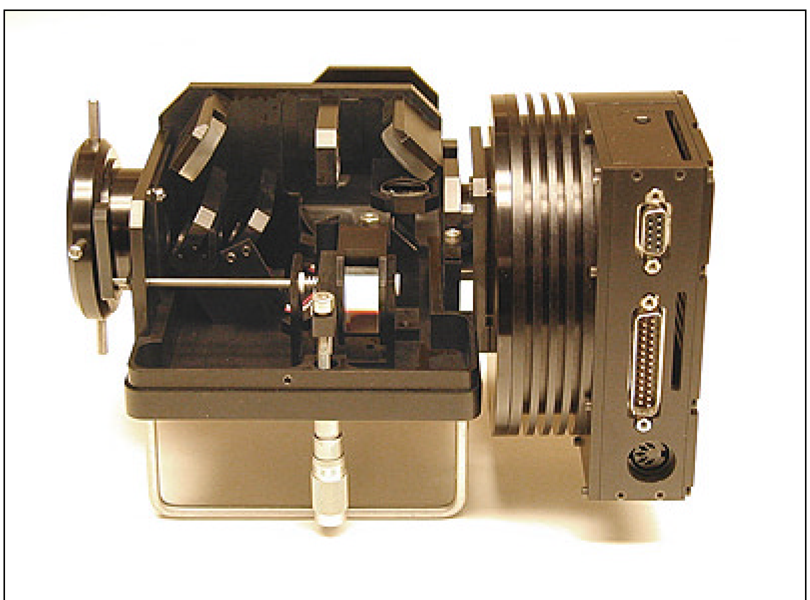


Figure 12 SBIG Spectrograph shown attached to an ST-7E

Optical Specifications

<table>
<tr><th colspan="2">Dispersion:</th></tr>
<tr><td colspan="2">Two gratings are available, on a carousel for rapid selection
- 150 lines per mm (4.3 Angstroms per pixel)
- 600 lines per mm (1.0 Angstroms per pixel)</td></tr>
<tr><td colspan="2">Slit Width
Interchangeable slits are included
18 microns wide (2 arcseconds at 80 inch focal length)
Best for stellar work
72 microns wide (8 arcseconds at 80 inch focal length)
Best for galaxies</td></tr>
<tr><td colspan="2">Acceptance cone angle: F/6.3 by F/10</td></tr>
<tr><td colspan="2">Resolution:</td></tr>
<tr><td>Narrow slit & 600 lines/mm</td><td>2.4 Angstroms</td></tr>
<tr><td>Narrow slit & 150 lines/mm</td><td>10 Angstroms</td></tr>
<tr><td>Wide slit & 600 lines/mm</td><td>10 Angstroms</td></tr>
<tr><td>Wide slit & 150 lines/mm</td><td>38 Angstroms</td></tr>
<tr><td colspan="2">Relative Sensitivity to Diffuse Sources:</td></tr>
<tr><td>Narrow slit & 600 lines/mm</td><td>1.0</td></tr>
<tr><td>Narrow slit & 150 lines/mm</td><td>4.0</td></tr>
<tr><td>Wide slit & 600 lines/mm</td><td>4.0</td></tr>
<tr><td>Wide slit & 150 lines/mm</td><td>16.0</td></tr>
</table>

Typical Specifications

General Specifications
Dispersion: 1.07 or 4.3 Angstroms per pixel
Resolution: emission line is recorded with 2.4, 10 or 38 Angstroms Full Width at Half Maximum
Spectral coverage per frame: about 750 Angstroms with the high resolution grating, or 3200 with the low resolution grating
Center Wavelength Selection: Calibrated Micrometer Adjustment
Wavelength Range: 3800 to 7500 Angstroms
Sensitivity: Signal to noise ratio of 10:1 for a 9th Mag star, 20 minute exposure using a non-ABG ST-7 and a 10 inch (25 cm) aperture in high resolution mode. An ABG ST-7 will reach magnitude 8. The low resolution mode will be 1.5 magnitudes more sensitive.
Entrance Slit: 18 micron (2.3 arcseconds wide with 63 inch focal length telescope) or 72 microns.
Dimensions: 3 x 4 x 7 inches (7.5 x 10 x 18 cm)
Weight: 3 pounds (with ST-7 head attached)
Uses: Stellar Classification Analysis of Nebular Lines Identification of spectroscopic binaries Measurement of Stellar proper motion to +/- 6 km/sec accuracy Measurement of Emission Nebula Proper Motions Spectra of Laboratory and field sources
Galactic Red Shifts: When used with the new Kodak "E" detectors red shifts of bright galaxies are possible with amateur sized telescopes.

Model DSS-7 Deep Space Spectrograph

SBIG's new Deep Space Spectrograph is a spectrograph optimized for the types of spectral observations that an amateur has always been interested in, from stellar classification to nebular analysis to galactic red shifts. It is a more general purpose instrument than our Self Guided Spectrograph (SGS), which is optimized for stellar work, and is much less expensive. It is optimized for the ST-7XME or the low cost ST-402ME, and will work well with ST-8/9/10/2000 cameras and ST-237s. It will not work with the STL series due to their deeper backfocus required by the built in filter wheel. This memo describes the DSS-7 in detail, and present examples of observations that can be made by the amateur.

Figure 1. Model DSS-7 Deep Space Spectrograph

Figure 2. DSS-7 attached to ST-7XME camera

Spectroscopy Fundamentals: a spectrograph is a device that can produce a graph of the intensity of light as a function of color, or wavelength. A spectrometer is a device that measures only one selectable color, and a monochromator is a device that transmits only one color. The DSS-7 spectrograph is designed to separate and focus wavelengths from 4000 to 8000 angstroms across the width of an ST-7 CCD. The human eye is sensitive from about 4500 (deep blue) to 7000 (deep red) angstroms, with its peak sensitivity at 5550 angstroms. The silicon CCDs used in SBIG cameras has a larger range of sensitivity than the eye. Most stars put out a continuum of wavelengths with a number of absorption lines superimposed on it. Most emission nebula like the Orion Nebula produce a spectrum this is composed of a few bright emission lines, such as H-alpha (a hydrogen line at 6563 angstroms), H-beta (a hydrogen line at 4861 angstroms), and O-III (a triply ionized oxygen line at 5007 angstroms). An angstrom is one ten billionth of a meter. You will also quite often see wavelengths written in nanometers, which is one billionth of a meter. 6563 angstroms (A) is 656.3 nanometers (nm). Galaxies have a spectrum that is an aggregate of many stars, and have a similar spectrum. Most galaxies only have a few obvious features – the cores tend to show a sodium absorption line due to the older stars there. Seyfert galaxies and other active galaxies show an excess of H-alpha, which is great since it makes a red shift much easier to determine. Quasars, nova and supernova in general exhibit strong 6563 emission. In the case of quasars it can be red shifted quite a bit, hundreds of angstroms, so it may actually appear at a different wavelength. For a nova, the line will only be shifted slightly since the star is in our own galaxy, but it may be greatly broadened. The individual hydrogen atoms are moving very fast due to the tremendous temperatures involved, producing Doppler broadening that smears out the line.

Stars can be classified spectrally into the well know OBAFGKM groups. The very hot stars have few features in their spectrum, perhaps only a few hydrogen lines. The spectrum of Vega shown later illustrates this. The cool stars tend to be old, with many metallic lines producing a very complex and structured spectrum. There are also several types of peculiar stars, which show strong emission lines or other structure. The DSS-7 can reveal these features.

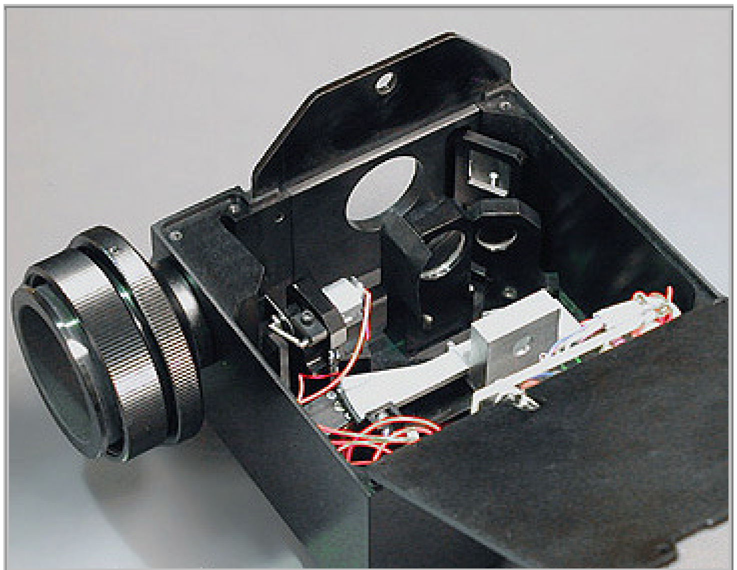


Figure 3. Inside view of the DSS-7 with SCT connector at left and exit aperture at top center of image

Optical Design: the optical design of the DSS-7 is illustrated in Figure One. Light enters the spectrograph through an entrance slit and is folded and then collimated (made parallel) by the collimation lens. The light then impinges upon a diffraction grating, which causes different colors to be reflected at different angles. You can see a similar effect in the light reflected from a CD or DVD. The light diffracted from the grating is then collected by a focusing lens, and imaged onto the CCD. Light of a discrete wavelength through the slit will be imaged into a vertical line. If the light does not fill the slit (such as is the case with a star) the discrete wavelength will produce a star like point on the CCD, with different wavelengths spread out along a line. This is illustrated by the next few figures.

The DSS-7 is designed to accept an F/10 cone of light, a value typical of popular commercial Schmidt-Cassegrain telescopes. In the imaging mode, it acts like a 2:1 focal reducer, increasing the field of view of the CCD. It also is effectively a 2:1 focal reducer in spectrograph mode, increasing the sensitivity to extended objects like nebulas or galaxies. It will accept the center portion of the cone of light from a faster telescope, but light is lost around the edges of the collimator lens.

The small DC motors in the DSS-7 are powered by a 9 volt battery. The motors are controlled by signals from the CCD camera's relay port through a phone jack connector. There is no provision for guiding. The length of exposure one can take will be limited by your telescope's ability to track unguided unless you have another camera set up to work as a guider. For stellar work, it is not easy to keep the star on the narrowest slit. For diffuse objects it is much easier since a little motion still usually leaves some nebulosity passing through the slit. Reasonable spectra of stars as faint as 9th magnitude can be achieved in 30 seconds with an eight inch (20 cm) aperture telescope. Putting the star in one of the wider slits helps, but will yield some blurring of the spectrum. The 100 and 200 micron slits are included mainly for diffuse object observations.

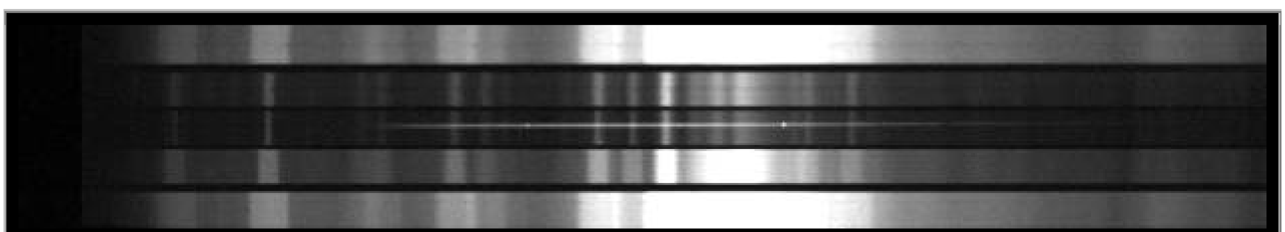


Figure 4. Spectra of P Cygni and Sky Glow: Bright Points are 4861 and 6563 Angstroms
This shows a spectrum collected while examining P Cygni, a peculiar star with permanent emission lines. The broadband radiation from the star produces a horizontal line, while the emission lines show up as bright points, and the airglow lines (some natural, some light pollution) show up as copies of the slit pattern. For this image the airglow lines have been exaggerated to illustrate them better – P Cygni is bright enough that exposures are short and airglow is not so prominent.

Comparison to Slitless Spectrographs: the inclusion of an entrance slit in this design allows the user to obtain good spectra of extended objects, a measurement that was impossible with low cost slitless spectrographs using transmission gratings. The other advantage of the slit is the sky background is both resolved spectrally and reduced considerably, improving the signal to noise ratio for faint objects. With slitless spectrographs, guiding errors blur the spectrum. For the DSS-7, guiding errors cause the object to move away from the slit and light is lost.

Analysis Software: SBIG has modified the SPECTRA software originally developed for the SGS to make is simple to use with the DSS-7. The software allows the user to easily perform a wavelength calibration on collected data, and save the result as a text file that can be read by Microsoft Excel. Software features include the ability to subtract the sky background from stellar data, and display modes that smooth or colorize the data to aid in visualization of the spectra in a traditional manner.

Observations: We have used a prototype DSS-7 to measure a number of objects, which illustrate its capabilities. One result is shown below. Figure 5 illustrates the red shift of NGC 7603, a 14^{th} magnitude Seyfert galaxy in the Virgo cluster. The red shift of the H-alpha line at 6563 angstroms is obvious, and is about 190 angstroms, an easily measurable amount (35 pixels). This required three 15 minute exposures using a Celestron 8 guided by an STV. Some residual artifacts from subtraction of the light pollution lines remain between 5400 and 6000 angstroms. This galaxy is interesting since the relative brightness of the 6563 emission relative to the continuum has increased three-fold since the 1970's, a change an amateur can now track!

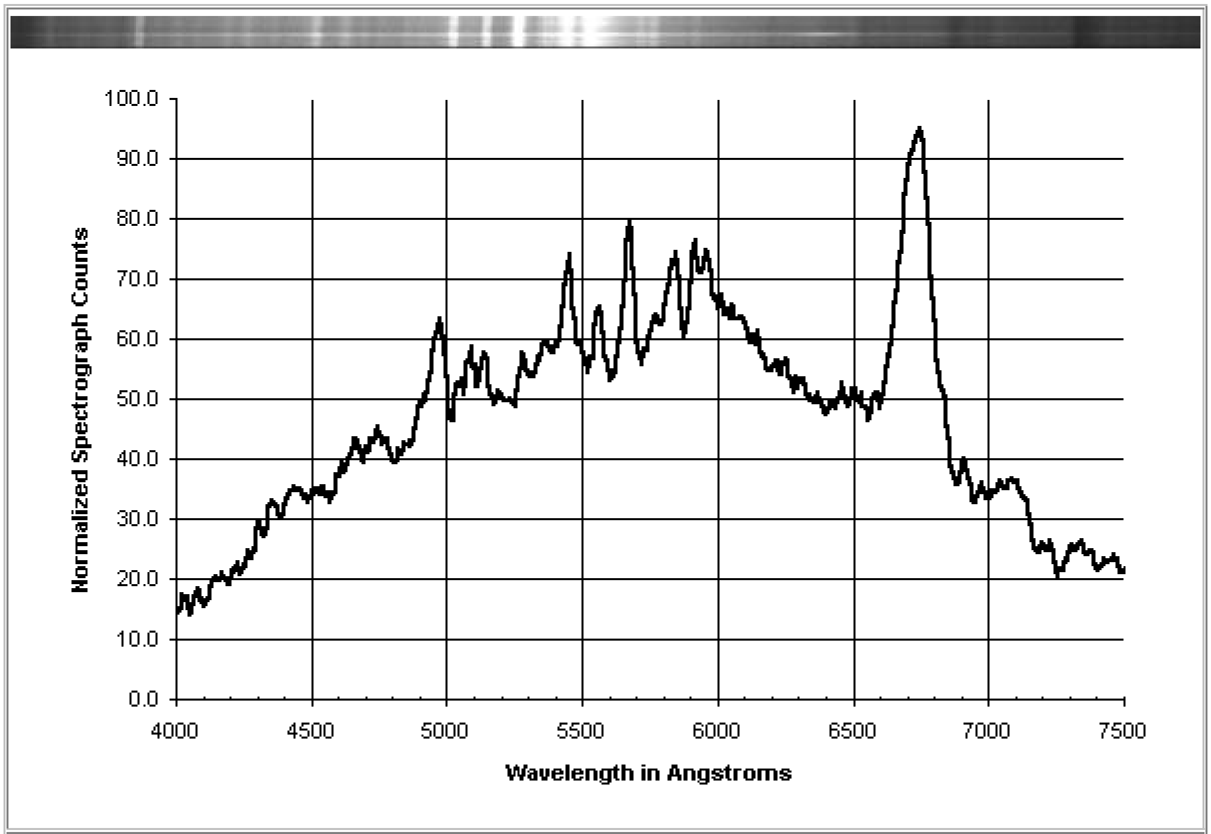


Figure 5. Galactic Red Shift of NGC7603

Specifications

Comparison of DSS-7 to SGS Self-Guided Spectrograph

	DSS-7	SGS
Input F/number	F/10	F/6.3 x F/10
Dispersion	5.4 Angstroms/pixel	High Res = 1.07 Angstroms/pixel Low Res = 9 Angstroms/pixel
Resolution with 9u pixels (ST-7XME or ST-402ME)	15 Angstroms	High Res = 2.4 Angstroms Low Res = 9 Angstroms
Spectral range (ST-7XME or ST-402ME)	4130 Angstroms	High Res = 820 Angstroms Low Res= 3290 Angstroms
Projected width of narrowest slit on CCD	25 microns	18 microns
Blur perpendicular to slit	~ 25 microns	~ 100 microns
Lower resolution slit choices	50, 100 and 200 mcirons	72 microns
Ideal for measuring	Extended Objects	Stars
Relative sensitivity for dim extended objects near H-alpha	5 - 10X	1X
Dimensions (excluding connectors)	2.2 x 4 x 4.3 in.	3 x 4 x 7 in
Weight (excluding camera)	1.5 lb.	1.5 lb.
Self-Guiding with ST-7XME or Other Dual CCD Camera	No	Yes
ST-402ME Compatible	Yes	No