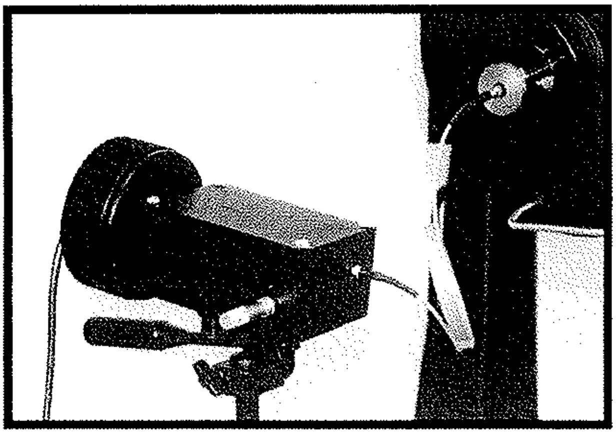
Professional Astronomical Spectroscopy
for
Colleges and Advanced Amateurs



The
ν-VIEW II
Fiber Optic Spectrometer

Turn your existing high quality astronomical imaging CCD camera into a professional quality fiber optic spectrograph, and enter the world of Astronomical Spectroscopy !

Our ν-VIEW fiber optic spectrometer mates to your CCD camera head and connects to your telescope's eyepiece tube via a custom designed fiber optic bundle cable. ν-VIEW acts as an adapter between your telescope and camera, turning the entire system into a high quality astronomical spectroscopy system.

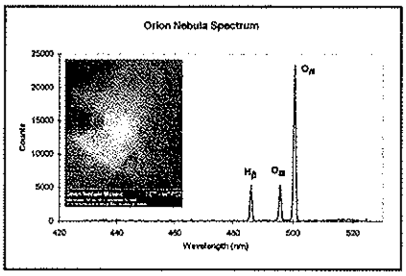
Our fiber optic coupled design has many advantages over other techniques which incorporate the light dispersing element on the telescope or in the eyepiece light path tube. These advantages include:

- Ease of use.
- No weight or bulky equipment on your telescope.
- Easy calibration of spectra for wavelength positioning and spectral efficiency.
- No degradation of resolution when taking spectra of extended objects (i.e. nebulae, planets and comets).

You've taken great astronomical images with your CCD camera. Why not study the objects you photograph ?

ν-VIEW is a powerful tool for original scientific research, as well as for educational use. With ν-VIEW, you can study nebulae, stellar temperatures, star classification, comet composition, planetary atmospheres, stellar atmospheres, novae, binary, variable, and peculiar stars.

Take a look at this high resolution spectrum of the Orion Nebula taken with ν-VIEW mated to a CCD camera with a KAF-0400 chip and a 10 inch telescope:



Here's what the ν-VIEW astronomical fiber optic spectroscopy package includes:

- Anodized aluminum spectrometer housing with f/2 optics, 1200 gr/mm plane grating (other gratings available), micrometer wavelength adjustment, SMA fiber optic cable attachment, 1¼ inch bore for mating to a CCD camera head.
- One meter long fiber optic bundle cable.
- 1¼ inch fiber optic bundle/telescope eyepiece tube coupler.
- Dial indicator to aid CCD head focusing.
- C code to convert CCD camera FITS spectral image files into text data files.
- Quick read instruction pamphlet.

This package is currently priced at:

$2365.00

The specifications for ν-VIEW are:

	ν-VIEW
Telescope Coupling	Fiber optic bundle with 30 fibers, each 50 μm in diameter
CCD Camera Compatibility	1¼ inch diameter bore for your 1¼ inch CCD camera head to eyepiece tube adapter
Grating	1200 groove/mm plane (others available)
Resolution	< 8 angstroms FWHM with 1200 groove/mm grating
Spectral Range	Adjustable over range of 385 nm to 900 nm with micrometer
Dispersion	14nm/mm @ H_β
Spectral Field of View	95 nm range on chip in one exposure (with CCD camera with a KAF-0400 chip)
Sensitivity	8 th magnitude stellar spectra in 20 minutes with a S/N of 10:1 (with 10 inch telescope and CCD camera with KAF-0400 chip)
Size	approx 3 x 4 x 6 inches
Weight	approx 5 lbs

SIVO SCIENTIFIC CO.
1400 Manhattan Avenue
Union City, New Jersey 07087

(201) 583-0279
www.sivo.com
jmsivo@sivo.com

The
Fundamental Equations of Spectroscopy
Governing the Operation of the ν-VIEW and ν-VIEW II
Fiber Optic Spectrometers *

(version 1.0)

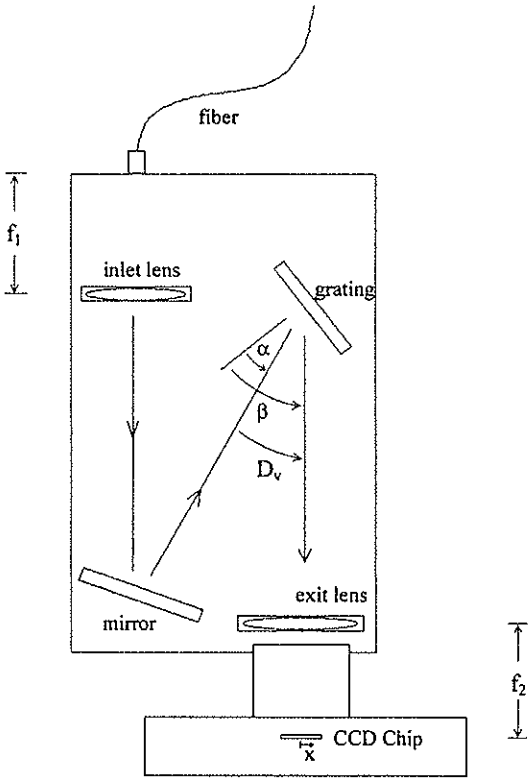
Dec 1998

SIVO SCIENTIFIC COMPANY

---

* The equations contained herein are for edification purposes only. Educators are free to photocopy and distribute these pages to their students. However, no liability shall be assumed for their accuracy, and users are encouraged to notify Sivo Scientific of any errors. Fiber optic cable theory, sample calculated performance tables, and references will be included in future updates.

Nomenclature



f_1 = focal length of inlet collimating lens in millimeters (mm).

f_2 = focal length of exit lens in millimeters (mm).

λ = wavelength of light in nanometers (nm).

α = angle of incidence of collimated light beam upon grating, measured counterclockwise from grating normal.

β = angle of diffraction measured counterclockwise from grating normal to a position x on spectral image plane (or CCD chip).

n = groove density of grating measured in number of groves per mm of grating width (gr/mm).

N = total number of groves on a grating.

W_g = width of fully illuminated grating, measured in millimeters (mm).

R = ultimate theoretical grating resolution using the Rayleigh criterion.

D_V = deviation angle or the angle between α and β calculated as $\beta - \alpha$.

$D_{V(x=0)}$ = deviation angle corresponding to the center of the detector at x =0. For ν-VIEW, this is approximately 30 degrees.

x = lateral position on spectral image plane (CCD chip) measured from center of image plane, in units of millimeters (mm).

FWHM = Full Width at Half Maximum, or system bandpass, or spectrometer system's spectral wavelength resolution, measured in nanometers (nm).

w = width of entrance slit, measured in millimeters (mm).

w' = width of image of entrance slit at the spectral image plane (CCD detector), measured in millimeters (mm).

h = height of entrance slit, measured in millimeters (mm).

h' = height of image of entrance slit at the spectral image plane (CCD detector), measured in millimeters (mm).

k = integer diffraction order (standard grating for ν-VIEW is mounted to operate at k = 1).

Δx_p = width of a pixel on CCD detector, measured in millimeters (mm).

dx = differential lateral x increment at image plane, measured in millimeters (mm).

$d\lambda$ = differential wavelength increment, measured in nanometers (nm)

Grating Equation

$$\sin(\alpha) + \sin(\beta) = 10^{-6}\ k\,n\lambda$$

or

$$10^{-6} k\,n\,\lambda = 2\sin\left[\frac{\beta+\alpha}{2}\right]\cos\left[\frac{\beta-\alpha}{2}\right]$$

This equation is the most fundamental grating equation from which all the following equations can be derived. The grating equation, itself, can be derived by examining the phase difference between adjacent incoming and outgoing wave fronts of particular wavelength striking a ruled grating. When the phase difference between incoming and outgoing adjacent wave fronts is equal to an integer number of wavelengths, constructive interference occurs, and a bright emission line is seen. **k** is that integer, and can take on negative or positive values. **k** = 0 corresponds to the undiffracted image, just like a plane mirror. Standard ν-VIEW gratings are mounted to operate in first order, **k**=1.

Constant Deviation Monochromator

$$D_v = \beta - \alpha = \text{constant at a given x}$$

given by:

$$D_V = D_{V(x=0)} + \tan^{-1}\left(\frac{x}{f_2}\right)$$

Therefore, the grating equation becomes:

$$10^{-6} k\,n\,\lambda = 2\sin\left[\frac{\beta+\alpha}{2}\right]\cos\left[\frac{D_v}{2}\right]$$

Solving the grating equation for α and β:

$$\alpha = \sin^{-1}\left[\frac{10^{-6}\,k\,n\,\lambda}{2\cos\left(\frac{D_v}{2}\right)}\right] - \frac{D_v}{2}$$

$$\beta = D_v + \alpha$$

Technically, ν-VIEW operates as a constant deviation monochromator. Geometrically, the positions of the slit and the detector are fixed with respect to the grating. Therefore, corresponding to a particular lateral position **x** on the image plane of the detector, there is an associated deviation angle **D_V**. Turning the grating turret merely changes α and β, in such a way that the deviation angle, (**D_V** = β − α), is constant at a particular **x**.

ν-VIEW is designed so that corresponding to the center of the detector, **x**=0, the deviation angle is approximately 30 degrees.

As an example of using these equations, suppose you would like a particular wavelength λ to fall at a particular **x** position on your CCD detector.

First solve for the deviation angle at that **x** using the second equation at left.

Then solve for α and β using the last two equations. α is a measure of the angle of orientation of the grating to produce your desired result. It is geometrically related to the positioning of the grating turret's linear micrometer.

Dispersion

$$\left(\frac{d\lambda}{dx}\right)_{\text{detector}} = \frac{10^{6}\cos(\beta)\ f_2}{k\,n\,(f_2^{\,2} + x^2)}$$

The linear dispersion is a measure of the lateral variation of wavelength across the spectral image plane (at the CCD detector), in units of nanometers of wavelength per millimeter of lateral position increment (nm/mm). This equation can be derived by using the differential calculus on the previous equations. Notice that the dispersion itself changes across the image plane (explicitly **x** dependent, and implicitly **x** dependent through β) and this is why polynomial calibration curve fits are best when calibrating for lateral pixel position to wavelength correspondence. Notice that for small **x**, (i.e. a small CCD chip), the dispersion is approximately inversely proportional to the exit focal length, $\mathbf{f_2}$.

Much confusion is associated with the terminology of dispersion. High dispersion means that wavelengths are greatly spread. In this case, the dispersion is numerically a smaller number, as wavelength slowly varies across the width of the CCD chip. With high dispersion, a pixel subtends a smaller wavelength range, and the wavelength range one can fit on a chip is less. Confused ?

It is important to note, at this point, the role of groove density, **n**. A grating with a higher number of grooves per mm will spread light more (high dispersion), and hence, as given by the above equation, the dispersion is numerically a smaller number.

The dispersion equation can be used as a conversion factor to convert a lateral width on a detector to a corresponding wavelength range. The range of wavelengths subtended by a single pixel on the detector is given by the physical width of a pixel multiplied by the dispersion at that pixel. The total range of wavelengths imaged onto a CCD detector is approximately given by the dispersion at the center of the detector (x=0) multiplied by the physical width of the CCD chip.

Width of Image of Entrance Slit

$$\boxed{w' = w\frac{\cos(\alpha)}{\cos(\beta)}\frac{f_2}{f_1}}$$

The width of the image of a spectrometer's slit at the spectral image plane (at the CCD detector) differs from the actual slit width at the entrance to the spectrometer for two reasons. One is due to an optical magnification factor due to potentially different entrance and exit focal length lenses, $\mathbf{f_1}$ and $\mathbf{f_2}$ (for ν-VIEW, $\mathbf{f_1} = \mathbf{f_2} = 50$ mm). The other is due to the fact that a ruled grating is an anomorphic optic, and has a lateral magnifying effect on spectral lines. This lateral magnifying effect is wavelength dependent, as it depends on α and β.

Notice that the width of the image of the entrance slit can be made smaller by making the entrance slit physically narrower (i.e. using smaller diameter fibers), or by increasing the focal length of the entrance lens, $\mathbf{f_1}$ (possible with ν-VIEW II).

Height of Image of Entrance Slit

$$\boxed{h' = \frac{f_2}{f_1}h}$$

The height of the entrance slit is magnified or de-magnified by the ratio of the exit lens to inlet lens focal lengths. By increasing the inlet lens focal length, $\mathbf{f_1}$, one can compress the height of the slit (or vertical fiber column) onto fewer CCD camera pixel rows, and boost signal to noise ratio.

FWHM (or Instrument Bandpass)

$$\mathrm{FWHM} = \left(\frac{d\lambda}{dx}\right)_{\mathrm{detector}} \cdot \max\left(\Delta x_p, w'\right)$$

If $w' > \Delta x_p$:

$$\mathrm{FWHM} = \frac{10^6\, w\cos(\alpha)}{k n f_1}\cdot\frac{f_2^{\,2}}{f_2^{\,2} + x^2}$$

The **FWHM** is a measure of how well a spectrometer system can resolve adjacent emission lines. It is defined as the spectral width in nanometers of an emission line from a monochromatic light source at half the signal height on an intensity versus wavelength spectral plot. It is approximately given by the greater of the size of a pixel, $\mathbf{\Delta x_p}$, or the width of the image size of the entrance slit, **w'**, multiplied by the dispersion. The **FWHM** is a function of wavelength because of the α dependence. Notice that using a grating with a higher grove density, **n**, will increase system resolution by decreasing **FWHM**. Also, notice that for small **x** (small CCD chip), the second term in the above equation is approximately equal to 1 and hence the **FWHM** is approximately inversely proportional to the inlet focal length, f_1. It is this equation that motivates the ν-VIEW II design, where one can increase the inlet focal length to boost system resolution.

Ultimate Grating Resolution

$$\boxed{R = \frac{\lambda}{d\lambda} = k\,n\,W_g = k\,N}$$

This is the diffraction limited resolution of a grating when fully illuminated with a collimated light beam. However, a spectrometer's system resolution rarely approaches this quantity, as the system resolution is determined by the much larger **FWHM**. It is, however, the theoretical maximum limit of resolution of a given spectrometer design with a given grating size. It is analogous to the theoretical resolution of a telescope being based on the diameter of a telescope's main mirror or primary objective, but rarely can be achieved because of a variety of factors. In the case of the spectrometer, the factor limiting resolution is predominantly the finite entrance slit width, **w**.

A Sampling of Easy Targets for the Amateur Spectroscopist

Planetary targets are ideally suited for spectroscopy with a fiber-optic link and a small telescope, since the light signals are very high, but the objects are extended. The fiber link prevents degradation of resolution as seen in imaging spectroscopic techniques (e.g. using objective prisms or transmission gratings).

Light from the planets is primarily reflected sunlight, though some chemicals present in the planetary atmospheres can absorb light at certain wavelengths creating absorption features not seen in sunlight. For example, the spectrum of Jupiter (Figure 1) shows solar Fraunhofer lines from absorptions in the sun's atmosphere, but also absorptions due to methane in the planet's atmosphere.

Venus (Figure 2) has some weak absorptions due to CO_2 amidst a variety of Fraunhofer lines. Here we have to rely on greater dispersion to separate the features, but the light signal is so large from Venus, that high resolution studies with a small telescope are fairly simple.

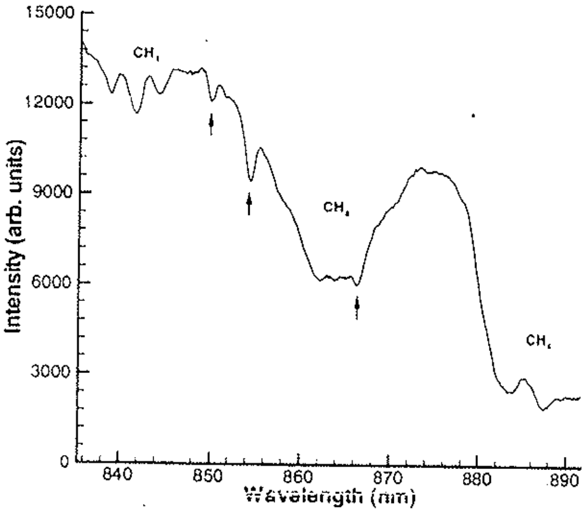


Figure 1: The spectrum of Jupiter in the near-infrared as obtained with the authors' fiber optic spectrometer mated to a Meade 216XT CCD camera, a 10 inch LX-200 telescope and a four minute exposure. Three separate broad bands of methane are observed in the vicinity of 844, 864, and 888 nm. The arrows denote solar Fraunhofer absorption lines.

Nebula spectra such as that of Orion (Figure 3) show emission lines due to elements present in the gas cloud. Here we see hydrogen and oxygen lines, though many other species can be observed in different regions of the spectrum. Though most nebulae are typically dim, the light is emitted only in discreet spectral lines, which allows many well-known nebulae to still yield high signal to noise ratio spectra.

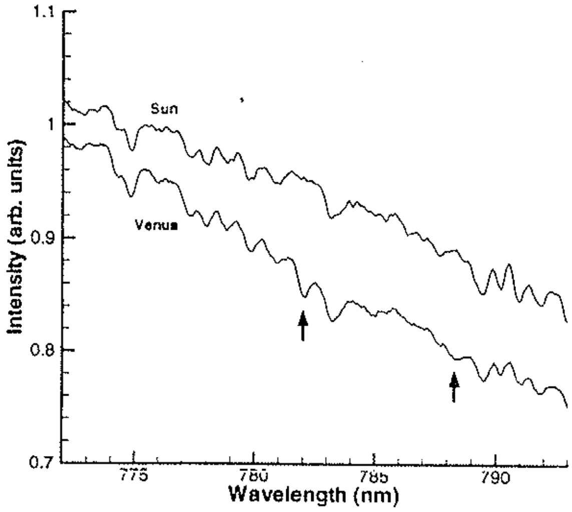


Figure 2: The moderate dispersion spectrum of Venus as compared to that of the sun. Absorption features common to both spectra are solar Fraunhofer lines. Arrowed features at 782 nm and 788 nm are absorptions due to carbon dioxide in the atmosphere of Venus.

Stellar classification out to at least 8th magnitude is easily possible with an 8" telescope, our spectrometer, and a typical CCD. Taking spectra gives the astronomer much more information than visual observation. For example, Deneb and Vega (Figure 4) appear similar in the eyepiece, but a quick 5 minute spectrum reveals some interesting differences, including slightly different surface temperatures and doppler-shifting from the atmosphere of Deneb.

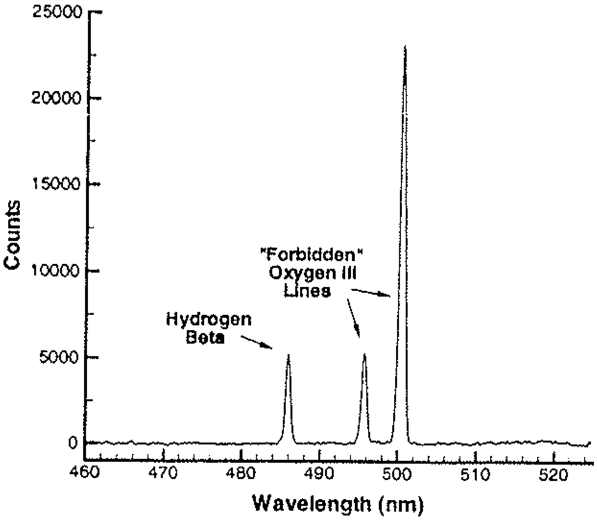


Figure 3: A spectrum of the Orion Nebula (M42) taken near the Trapezium. Fiber-coupling of the image to the spectrograph allows the emission lines to be clearly resolved and separated, even on extremely diffuse objects such as this.