A Video Spectra-Spectroheliograph (VS²HG) at the
San Fernando Observatory

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ABSTRACT

The vacuum spectroheliograph has been adapted to a scanning spectrometer; i.e., a
spectra-spectroheliograph, in which one obtains a scan of a solar region with complete
spectral information at each image point. Two beams of opposite polarization are allowed
to fall on a panoramic detector. These video data are then recorded on a 3/4 inch video
cassette recorder for later digitization and analysis. Scanning by the spectroheliograph
requires approximately one minute per image; three different analyzers are used. Raw
video images of recent observations will be presented. Trials of hardware to carry out the
automated processing of the video data are being conducted.

I. Introduction

For some years, we have obtained magnetograms of solar active regions using the “Leighton”
method of photographic subtraction of two simultaneous photographic spectroheliograms
taken in opposite senses of circular polarization (Leighton, 1963; Mayfield, 1971). This
process is similar to the “Babcock” technique for obtaining a magnetic signal by converting
the change in wavelength due to the Zeeman effect into a change in intensity. This
process has been updated by digitizing the original photographic spectroheliograms (Vorpahl,
1977). The digitized images are then cross-correlated and subtracted with conversion
to magnetic flux density, using the slope of a digitized line profile observed with the same
optics.

There are inherent defects in these techniques. Changes in the line profile occur in
magnetic regions, thus changing the calibration which depends on the slope of the line
wings. Further, the standard “Babcock” technique saturates in sunspots due to the complete
separation of the Zeeman components and, in the case of photographic spectroheliograms, the sunspot umbra is badly underexposed. Many investigators have recognized
that a more robust technique is needed in order to make accurate measurements of magnetic
field strength without the usual assumptions of standard magnetographs. The problems
cited can be overcome by recording the entire line profile using photoelectric detectors.

At the San Fernando Observatory, we have adopted an approach based on the Spectra-
Spectroheliograph (SSHG) described by Title et. al. (1975, 1976). In our approach, we have
substituted a video camera and a U-matic video cassette recorder for the film camera. We
have also obtained some film SSHG's, but their analysis is quite laborious and the dynamic
range of the film is limited. The result, in either case, is a series of images, each consisting
of a spectral line profile with spatial information preserved along the slit; these images are
then taken at a series of slit positions on the solar disk.

An alternate method of data collection is used by other groups and proposed for some
future magnetographs. In this technique, complete spectral and spatial information of
an active region is obtained by tuning a narrow band filter through a spectral line. The
line profile at each image point is then reconstructed in post-processing. We believe this
technique is superior for space or balloon observations where seeing is absent, but the
SSHG approach has the advantage that all spectral information at a given point on the
solar image is obtained with the same seeing, minimizing any mixing of spatial information
into the spectral domain.

Analysis of these data, combined with the other instruments at SFO, will help deter-
mine the role of magnetic fields and their evolution in solar irradiance fluctuations.

II. Equipment Description

The telescope and spectroheliograph used at SFO have been described in some detail in
Mayfield et. al. (1969) and Richter et. al. (1985). We use an echelle grating that gives
a dispersion of about 2 mm/Å at the 6302.5 Å line. The spectrum is masked and passed
through a 15° Wollaston prism provided by Karl Lambrecht. The spectrum is focused
directly onto a CCD in a Cohu camera that produces standard RS-170 composite video.
This signal is recorded by a JVC Model 600CR videocassette recorder with a signal-to-noise
ratio of 49 dB in its black and white mode.

The camera is oriented such that each video scan line crosses the two oppositely
analyzed spectra of the same point on the entrance slit and the solar image. The spec-
throheliograph slit is then mechanically scanned across the image at a rate such that one
slit width is moved in $N$ TV frames, where $N$ is 8 at present. This procedure allows the
co-adding of $N$ frames in order to reduce noise. With this setup, the typical scan rate using
a 32 μm slit is 5" per second of time. At the 28 cm telescope's focal plane, the spatial
sampling interval along the slit (set by the CCD pixel size) is about 1" and the spectral
scanning interval is about 16 mÅ (set by the entrance slit width).

We anticipate that processing of the video data can be carried out using a personal
computer equipped with a video digitization board, an array processor, and an RS-422
serial controller for the VCR. Initial work will begin with simple models for line formation.
Later, as our data handling capabilities improve, we will move towards more sophis-
ticated models as indicated by experience and comparison of our results with those of other groups.

Initially, continuum images from the VSSHG will be compared with diode array and
photographic images. Subsequently, work will will continue, fitting simple models of line
formation to the data to determine magnetic field strength and relative velocity and in-
tensity.
III. Description of Observations

The observations are taken in groups of three sequences. The first two scans of a region are taken with opposite settings of a quarter-wave plate, and the third sequence with the plate removed. Each sequence takes about one minute of time for a moderate active region.

In the video playback, one can see the Zeeman pattern in a sunspot reverse when going between the two settings of the λ/4 plate. As seen in Figure 3, the Zeeman pattern is not always perfectly anti-symmetric, presumably due to velocity fields. The "light bridge" separating the two halves of the umbra of the sunspot in Figure 1 is also visible in Figure 2. Small Doppler shifts of the 6302.5Å line are also visible due to the granulation pattern of the quiet sun.

Figure 1. Photograph of one sunspot in the group for which data were obtained on 16 August 1988 with the 28 cm vacuum telescope. The photograph is from a CRT display of a 256-line image from a 256² Reticon diode array camera, uncorrected, hence the relatively poor quality. North is up and east is to the left.
The intensities of the two spectrum windows formed by the Wollaston prism are very nearly equal, showing that the linear polarization of the echelle grating is fairly small. This can be seen in both Figures 2 and 3. The polarization of the telescope and spectroheliograph have been measured and reported by Zeldin (1982).

Figure 2. CRT display of a single digitized spectrum. The slit was oriented in an east-west direction across the sunspot shown in Figure 1. The “light bridge” between the two halves of the umbra can be seen. The right and left spectra are obtained with opposite analysis for circular polarization.

Figure 3 is a plot of two spectra from an image also obtained on 16 August, though it is not from the image in Figure 2. The data in Figure 3 are a sum of eight successive video frames but are otherwise raw data; no dark or flat-field calibration has been applied. The shape of the continuum in both spectra is due to vignetting by the mask used to separate the two Zeeman components at the Wollaston prism; it is not in focus at its current location.
Figure 3. Intensity plot of two spectra with opposite circular polarization through a sunspot umbra and through quiet photosphere. These plots are from a sum of 8 successive video images (8/30 sec of data) created using a Matrox brand frame grabber in an IBM PC/AT computer. The solid line is quiet photosphere, and the dashed line is sunspot umbra. Red is to the right.

We have measured the separation of the magnetic ($\sigma$) components of the 6302.5Å line in Figure 2. The positions of the telluric lines are the same on the two spectra to within one pixel. On the left spectrum, the magnetic component is at a wavelength of 6302.34Å, and on the right spectrum, it is at 6302.62Å (one pixel is $8.59 \times 10^{-3}$ Å). This gives a Zeeman splitting of 0.14Å, or a magnetic field of approximately 2900 Gauss.
IV. Future Plans and Conclusions
Our firm near-term plans are to improve both the instrument and our data analysis capability. We are designing optics to reduce the image scale by a factor of two, trading some loss of spectral resolution for better spatial coverage. These optics will also place the aperture mask at a system image plane.

One problem with the data is the presence of image motion along the entrance slit, caused by both seeing and telescope wind shake. We are presently designing an image motion compensator to remove the large scale image motion. It may also be possible to remove some image motion after the fact by shifting the spectra so as to line up streaks in the granulation pattern of successive frames.

We have an RS-422 board installed in a PC for control of the VCR, and have ordered a video rate image processing board. This will allow unattended real-time summation of successive video images from various parts of a data videotape. Simple analysis will be followed by inversions of the Stokes profiles themselves.

If we can obtain the resources, we can make many improvements in the basic instrument. A video time-base corrector could be used to index our data tapes. The improved random-access and freeze-frame capability of writable analog video disks would greatly improve our data handling ability. Finally, a personal computer equipped with a fast array processor and frame-grabbing board might allow real-time line profile fits while observing, mitigating the need to store large amounts of analog video data.

We have shown that the idea of the $VS^2HG$ is sound and that the basic instrument works. The location and program of the San Fernando Observatory will allow us to devote large amounts of telescope time to this instrument in the future, allowing study of both short and long term magnetic field evolution.

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REFERENCES
Discussion

A. Bhatnagar: Wollaston prisms are known to be very bad regarding image quality of o- and e-beams. There will be considerable degradation in image quality of the two images. Perhaps you could try to use polarizing beam splitters in the spectrograph.

S. Walton: We may try this at a later date when cost and time constraints allow us to run two cameras simultaneously.

C. Keller: How do you want to remove the effects of different dispersion in the two polarization states?

S. Walton: We deliberately chose to observe \( \lambda 6302.5 \) because of the telluric lines on either side. These will give us both absolute wavelength and dispersion for each spectrum.

J.O. Stenflo: Your polarization analysis is placed very late in the optical system. Could you comment on the instrumental polarization of the instrument?

S. Walton: This has been investigated in detail by one of our master’s thesis students. My short answer is, the intensity of the two beams in continuum differs by about 10%.