Umbral Spectra in the Ultraviolet via Molecular V-Stokes

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Abstract. Scattered light prevents the direct observation of umbral spectra at less than 4000Å. Many molecules reside only in cool umbrae and are absent in penumbrae and the photosphere. By measuring the polarization signal from the molecular Zeeman Effect one can discriminate against scattered light and deduce actual umbral conditions.

1. Introduction

Shortward of about 4000Å scattered light in the telescope and atmosphere, plus the falloff of intensity in the low temperature umbra compared to the surrounding photosphere, conspire to mask the actual umbral spectral radiation. Inspect the photographic umbral atlas of Harvey (1977) or the FTS umbral spectral atlas of Wallace et al. (2000) and note that umbral spectra become indistinguishable from that of the photosphere as we go into the violet. We expect this will be particularly true for the dark ‘voids’ (Livingston 1991) of large sunspots where the temperature can be as low as about 3030K, corresponding to that of an M5 V star. Figure 1, which is from Wallace et al. (2000) illustrates how molecular signals increase in a sunspot compared to the photosphere. The top spectrum is for the quiet Sun (photosphere) in the visible at 5608Å. The second represents a small, relatively warm umbra at this same wavelength. The third is the cold region in a void of a large umbra. One can see how the TiO lines, which are completely absent in the photosphere, greatly strengthen in this cold umbra. TiO lines are Zeeman sensitive (Berdyugina, et al. 2001) and confined to the umbra. Any molecular V-Stokes signal in an umbra represents pure umbral conditions uncontaminated by the photosphere and possibly even the penumbra. An important lesson from the Wallace et al. atlas is that there is no unique umbral spectrum. Every spot is different and positions within a spot likewise differ.

In this paper we give some preliminary attempts to record the V-Stokes in the UV. We have not yet had a large spot to work with, and neither have we tried to invert the V-Stokes to obtain I-Stokes. These efforts lie in the future.
Figure 1. Page from Wallace et al. (2000) showing how cold umbrae enhance molecular spectral lines
2. Observational Technique

For this work we employ the all reflective McMath-Pierce Telescope and its 13.5 meter spectrograph (Pierce 1964). The only refractive elements in the system are of quartz or calcite. Proceeding through the optical train we have the 2.39 arcsec/mm main image incident on a quartz piezo-electric modulator (50 kHz), followed by a calcite Nicol prism which serves as a linear polarizer. Together they analyze circular polarized light. This is followed by a quartz prism predisperser (set for the 8th order at 3531Å). A 1x1 mm Bowen-type image slicer feeds the spectrometer with an entrance slit whose effective size is 0.1 x 10 mm. At the camera focus of the Czerny-Turner spectrometer is a 0.3 mm exit slit and a quartz envelope photomultiplier tube. Output from this PMT is fed to a lockin phase sensitive amplifier and hence as input to the rapid-scan photometry system. The recorded signal, suitably integrated by multiple scans, represents the V-Stokes content of the spectrum. We can work down to 3100Å.

To tune the lockin or observe I-Stokes one places a circular polarizer in front of the Morvue. At present our CP is very wasteful of light, having a transmission of only a few percent at 3100Å. This loss is mostly due to the HN°PB polaroid component. Thus the I-Stokes signal is noisy compared to V-Stokes.

On a sunspot umbra the I-Stokes is noisy not only because of shot noise but also because of any image motion due to seeing. It is interesting that V-
Stokes is relatively immune to seeing effects since only the polarized component contributes, whereas I-Stokes becomes a mix of umbra and photospheric light, particularly in the visible.

3. Observational Results

Figure 2 illustrates how similar the umbra spectra is with the photosphere in I-Stokes. There are differences; these might even be traced to the penumbra, but we have not verified this. Figure 3 gives V-Stokes in the umbra. In this region we are unaware of any molecules and most of the features are undoubtedly atomic in origin. It simply illustrates that we have a good signal/noise at this wavelength. The paper by Berdyugina at this conference presents other results of V-Stokes in the visible.

4. Conclusions

We have presented a method for studying the spectra of sunspot umbrae in the UV. We have not had the opportunity to pursue this topic for a lack of large sunspots during our recent observing time. We plan to continue this work when the sun obliges.
During the conference someone asked about calibrations. This is important, of course, but requires circular polarizers of known efficiency. Such devices are expensive for the UV. Perhaps after we have demonstrated the value of UV umbral studies we can quantify our results with their use.

We thank Jack Harvey for providing the calcite plate that proved essential in the UV.

References

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