CN Evershed Flows and Abundance

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1. Introduction

The famous line of Fe I at 15648 Å is perhaps the best line to use to measure magnetic fields on the Sun with the Zeeman effect, since the inherent sensitivity of the line is large ($g = 3$). However it is sometimes difficult to measure the Evershed flow in sunspots using atomic lines. A spectral line formed by the molecule CN is located just blueward of the iron line and has recently been used to measure the Evershed flow in sunspot penumbra. The molecular line reveals very rapid flow speeds, speeds measured to be over twice the speeds found with atomic spectral lines.

Another interesting fact about this CN line is that the line disappears in the coldest regions of sunspot umbra. It is likely that the carbon atoms in the coldest parts of the sunspots get used up in the formation of the CO molecule because the CO has a rapid formation speed below a certain critical temperature. By measuring the continuum intensity seen in the sunspot at the position where the CN line vanishes, we can estimate this critical "turn-over" temperature.

The CN line at 15646 Å is not the best CN line to use, but since it is in close proximity to the 15648 Å Fe I line, it is a convenient line to use to examine Evershed flows. It is weak and shows large shifts, so averaging many wavelengths will be required to make a velocity map.

The analysis steps below are described for the **07jul03 reduced01** data set on the CDROM. The wavelength of the CN line will change in other data sets and other days, but the following steps can be used as a guide for analyzing those days.

2. Process

First open the frame **AR375_bigspot.o.i.067**. Make a spectral plot near row number 124. The CN line is the noisy dip (about 7 pixels wide) at about pixel 202. (You can see that unfortunately some of this line is blended with the nearby Fe line at 15644 Å.) This frame is on the disk-center side of the sunspot.

Now open the frame **AR375_bigspot.o.i.107**; this frame is from the limbward side of the sunspot. Notice that the CN line has shifted its wavelength position to about pixel 198. Since the wavelength dispersion is about 0.05 Å per pixel, a 6 pixel shift from one side of the spot to the other implies a velocity difference of 5.7 km/sec across the sunspot (check this calculation for yourself, $v = \frac{c\delta\lambda}{\lambda}$). So even though the sunspot is not right at the limb on **07jul2003**, the CN line shows a very large Evershed flow.

2.1. Map the Evershed Flow

(Here we assume that line center is pixel 200.)

Produce a map of the Evershed flow in this line. First, add several frames in the red and in the blue wings of this line. Because the line shift is so large, you will have to make several intermediate summations. For instance, using image arithmetic, add spectroheliograph (SHG) files 196 and 197, and store the sum into **cnblue1**. (You can save this image into a file on your desktop, or just use the pull down menu on Image Arithmetic to access it later). Sum files 198 and 199 into **cnblue2** and save. Then use image arithmetic to add **cnblue1** and **cnblue2** together and save this image to **cnblue** file on your desktop.

Do the same thing for files 201, 202, 203 and 204 and create a **cnred** image. Then subtract the **cnblue** image from the **cnred** image to create a flow map.

2.2. Map the CN Abundance

Add the **cnred** and **cnblue** images and store to an intermediate file. Add to this the file from the line center (at 200), and store into **cn**. The **cn** is now a summation of 9 individual files.

Create a continuum image by summing at least four files where there are no absorption lines present in the spectrum (e.g. files 98, 99, 100, and 101; or 181, 182, 184 and 185; or use your own set of images). Take the difference $(\mathrm{cn} - 2.25 * \mathrm{contin})$ and save this as the "cn_abundance" image. (The factor of 2.25 originates because these images are summations of different numbers of files). Does part of the umbra appear bright, implying very little CN absorption?

We can now compute the temperature on the solar surface by using the **contin** file. Take the ratio of the average brightness away from the sunspot divided by the brightness of the sunspot umbra that corresponds with the bright umbral region in the image created in the paragraph above (the region with low CN absorption): $R = \frac{I_{\rm quiet}}{I_{\rm umbra}}$.

We assume that the quiet Sun continuum temperature at this wavelength is 6640 K. We can then use the black body radiation formula (eq. 1) to compute the temperature:

$$B(\lambda) = \frac{2h \cdot c^2/\lambda^5}{e^{(h\cdot c)/(\lambda \cdot k_B \cdot T)} - 1} \Rightarrow \quad (1)$$

$$T = \frac{(h \cdot c)/(k_B \cdot \lambda)}{\ln\left(\frac{e^{(h\cdot c)/(k_B \cdot \lambda \cdot (6640{\rm K}))} - 1}{R} + 1\right)} \quad (2)$$

The variables' values are:

- $h = 6.626 \cdot 10^{-34} \frac{\rm kg \cdot m^2}{\rm s}$
- $c = 2.998 \cdot 10^8 \frac{\rm m}{\rm s}$
- $k_B = 1.381 \cdot 10^{-23} \frac{\rm J}{\rm K}$
- $\lambda = 15646 \text{Å} = 1.5646 \times 10^{-6} m$

Find the temperature in the part of the umbra where the CN line is weak using eq. 2.

3. Further Questions

1. Generally it is assumed that Evershed flow is mostly horizontal in the sunspot penumbra. Find the position of the sunspot on the solar disk for 7 July 2003. If we observe a 5.7 km/sec velocity gradient across the sunspot at this disk position, what is the true velocity gradient across the sunspot if the flow is locally horizontal?

2. If the dopplergram intensity is plotted as a function of azimuthal angle around the sunspot, what does it show?

3. How does the blend from the blue Fe I line corrupt the results?

4. What velocities are seen in other sunspot data from other days?

REFERENCES

Penn et al., 2003, Sol. Phys., v213, p55

Penn et al., 2003, ApJ, v590, L119

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