1999soho....8..633S

RELATIONSHIP BETWEEN LINE SHIFT AND INTENSITY INSIDE CORONAL HOLES

K. Stucki[1], **S.K. Solanki**[1,2], **I. Rüedi**[1], **U. Schühle**[2]
[1]Institute of Astronomy, ETH-Zentrum, CH-8092 Zurich, Switzerland
[2]Max-Planck-Institut für Aeronomie, Max-Planck-Str. 2, D-37191 Katlenburg-Lindau, Germany

ABSTRACT

We study the relationship between line shifts and intensities of chromospheric, transition region and coronal lines in polar coronal holes and in the normal quiet Sun.

Within coronal holes almost all the lines formed above 30′000 K exhibit a tendency towards blueshifts in brighter regions, i.e. in the network. This is in agreement with the conclusion reached by Hassler et al. (1999) that the fast solar wind emanates from the network.

In the normal quiet Sun, however, only lines formed above $3 \cdot 10^5$ K show such a trend, the cooler lines tend to be more redshifted in the network.

Key words: corona; transition region; solar wind; UV radiation.

1. INTRODUCTION

The difference in plasma conditions between coronal holes and quiet Sun regions, i.e, the source regions of the fast and slow solar wind, respectively, is of particular interest for coronal physics. It is known that polar coronal holes are the source of the fast solar wind and the primary example of coronal heating in regions with an excess of one magnetic polarity. But it is still not clear how this solar wind is accelerated to the high speeds observed near the Earth (Marsch, 1997).

The possibility given by SUMER (Wilhelm et al. 1995) of observing full EUV emission line profiles at high spatial resolution allows plasma properties to be determined in the chromosphere, transition region and lower corona.

Many authors have employed this capability of SUMER to study line shifts in the transition region and lower corona. A predominant redshift has been found in quiet Sun regions (Brynildsen et al. 1998, Chae et al. 1998, Brekke et al. 1997, Peter & Judge 1998, Teriaca et al. 1999). In view of understanding the differences between the slow and the fast solar wind we are interested in the differences that exist between their source regions, the quiet Sun regions and the coronal holes, respectively.

Hassler et al. (1999) found that a relationship exists between the outflow velocities seen in Ne VIII and the chromospheric magnetic network structure. Here we extend their work by analysing more spectral lines and quantifying the correlation between the velocity of the plasma at different temperatures and the intensity of network structures.

Our comparison is based on data taken close to the limb, but still on the solar disk. This differs from many other studies of coronal hole characteristics whose emphasis lies on off-limb data, or on disk center coronal hole data (Landi et al. 1999).

The present investigation is an extension of a previous study in which we used SUMER data to show that spectral lines with formation temperatures above 10^5 K exhibit a blueshift in coronal holes relative to quiet Sun regions (Stucki et al. 1999). This result confirms that the solar wind acceleration inside the polar coronal holes must already start deep in the solar atmosphere (see Figure 1).

2. OBSERVATIONS

The observations consist of 3 different data sets. The first set of observations (Joint Observing Programme JOP055), was obtained between the 10th and 17th of December 1996. This JOP was run 12 times. Each time, 14 different spectral frames were recorded with SUMER (1024 spectral × 360 spatial pixels), each exposed for 300 seconds. The slit position was located on the central meridian, where it crossed either the northern or the southern coronal hole. As the slit location was located very close to the pole, no rotation compensation was necessary. The 14 frames cover a large part of the spectrum between 730 and 1420 Å, including more than 70 identified spectral lines.

The second set (JOP55_TR), taken on the 6th of September 1997, is identical to the first set, but consists of only 4 series of 14 frames each.

The third set consists of series of 12 different spectral frames (each 512 × 360 pixels; exposure time: 150 s) taken during the SOHO roll manoeuver on the 20th of March 1997. Series of frames were obtained every

Proceedings 8th SOHO Workshop 'Plasma Dynamics and Diagnostics in the Solar Transition Region and Corona', Paris, France, 22-25 June 1999, (ESA SP-446, October 1999)

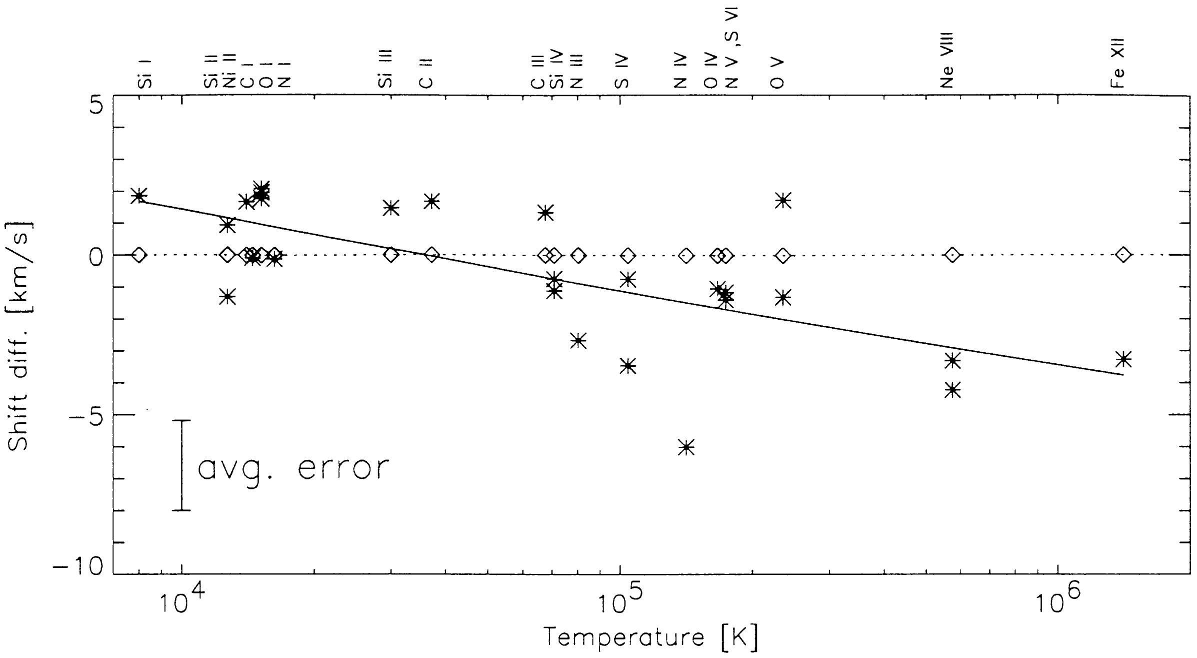

Figure 1. Wavelength shift difference in velocity units vs. formation temperature. The "shift difference" represents the difference between the shifts observed on the meridian and the ones observed at other locations at the same heliospheric angle θ ($\mu = \cos\theta$). Since the wavelength scale is not absolute we equalized the shifts between meridian and equator outside the hole.
Diamonds: *large μ sector (identically zero due to shift equalization);* **Stars**: *small μ sector (i.e. shift of coronal hole profile relative to non-hole profiles). The solid curve shows a linear least-squares fit to the small μ sector points.*

30 degrees along the disk, with emphasis on the equator. During the roll manoeuvre the slit was always oriented radially instead of being parallel to the N-S axis.

The data were reduced in the standard manner prior to the analysis: A flat-field correction was applied using the flat-field image taken closest to the date of the observation and the geometrical distortion introduced by the detector was reduced using the procedure supplied by the SUMER consortium.

The spectral ranges covered by the JOP55 and roll observations do not exactly coincide. 10 spectral regions that are common to all data sets and contain interesting spectral lines covering a wide range of formation temperatures were selected for further analysis.

A list of all the spectral lines retained for our analysis is given in Table 1. The formation temperatures of the corresponding ions have been taken from Arnaud & Rothenflug (1985).

The lines cover a wide range of formation temperatures. To facilitate data interpretation, lines with known blends have been avoided when possible, or a multi-Gaussian fitting routine was employed to separate the contributions of the individual blends.

Table 1. Analysed spectral lines with the formation temperature of the corresponding ion.

Line	Wavelength [Å]	Temperature [K]
O V	629.70	$2.35 \cdot 10^5$
S IV	661.44	$1.04 \cdot 10^5$
S IV	753.76	$1.04 \cdot 10^5$
O V	758.67	$2.35 \cdot 10^5$
N III	764.36	$8.04 \cdot 10^4$
N IV	765.15	$1.42 \cdot 10^5$
Ne VIII	770.41	$5.75 \cdot 10^5$
Ne VIII	780.32	$5.75 \cdot 10^5$
S VI	933.39	$1.74 \cdot 10^5$
C III	1175.71	$6.76 \cdot 10^4$
Si II	1197.39	$1.27 \cdot 10^4$
Si III	1206.51	$3.00 \cdot 10^4$
Fe XII	1242.01	$1.41 \cdot 10^6$
N V	1242.80	$1.74 \cdot 10^5$
Si I	1258.80	$8.00 \cdot 10^3$
O I	1302.17	$1.51 \cdot 10^4$
O I	1304.86	$1.51 \cdot 10^4$
O I	1306.03	$1.51 \cdot 10^4$
Si II	1309.28	$1.27 \cdot 10^4$
C I	1315.92	$1.44 \cdot 10^4$
Ni II	1317.22	$1.40 \cdot 10^4$
N I	1319.00	$1.62 \cdot 10^4$
C II	1334.50	$3.72 \cdot 10^4$
Si IV	1393.75	$7.08 \cdot 10^4$
O IV	1401.16	$1.66 \cdot 10^5$
Si IV	1402.80	$7.08 \cdot 10^4$

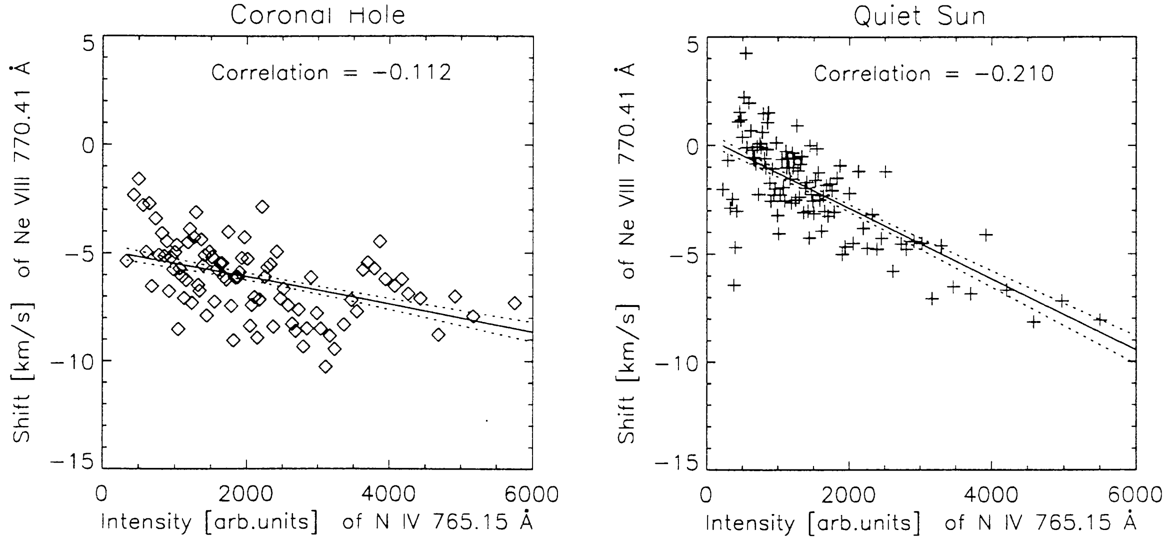

Figure 2. Wavelength shifts of Ne VIII 770.41 Å versus Intensity of N IV at 765.15 Å. **Left plot, diamonds***: Coronal hole.* **Right plot, crosses***: Quiet Sun. The solid lines represent linear fits of the binned data and the dotted line the error-bars. The correlation coefficients, however, refer to the unbinned data.*

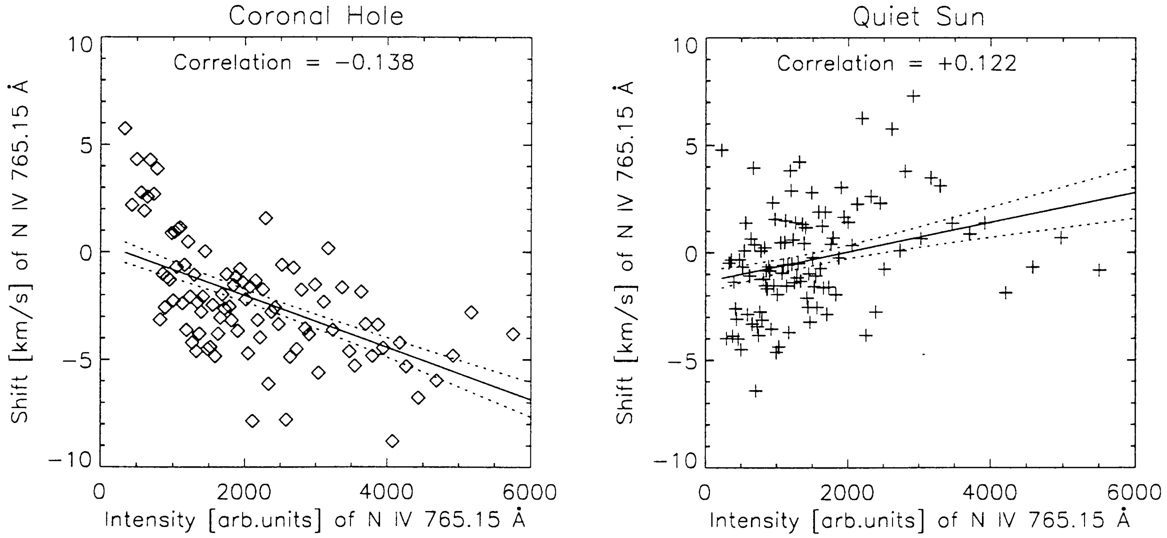

Figure 3. Wavelength shift versus Intensity for N IV 765.15 Å. The data were binned over 20 pixels, i.e. each symbol represents the average line shift of 20 pixels of neighbouring intensity. **Left plot, diamonds***: Coronal hole.* **Right plot, crosses***: Quiet Sun. The solid lines represent linear fits to the binned data and the dotted line the error-bars. The correlation coefficients, however, refer to the unbinned data.*

3. RESULTS

We calculated the intensity, shift and width parameters of the selected lines at each spatial pixel using Gaussian fitting. Here we study the possible relation between line shift and intensity.

The data cover approximately the outer third of the solar disk, corresponding to $\mu \lesssim 0.67$. Only the data with $\mu \gtrsim 0.1$ are analysed. The coronal holes were identified using concurrent EIT images (Delaboudinière et al. 1995). Their farthest extention was $\mu \approx 0.57$ in some of our images.

Figure 2 shows the shift of Ne VIII 770.41 Å, which is formed at temperatures above $5 \cdot 10^5$ K, versus intensity in the same spatial pixel, but of N IV 765.15 Å, a spectral line formed in the transition region at lower

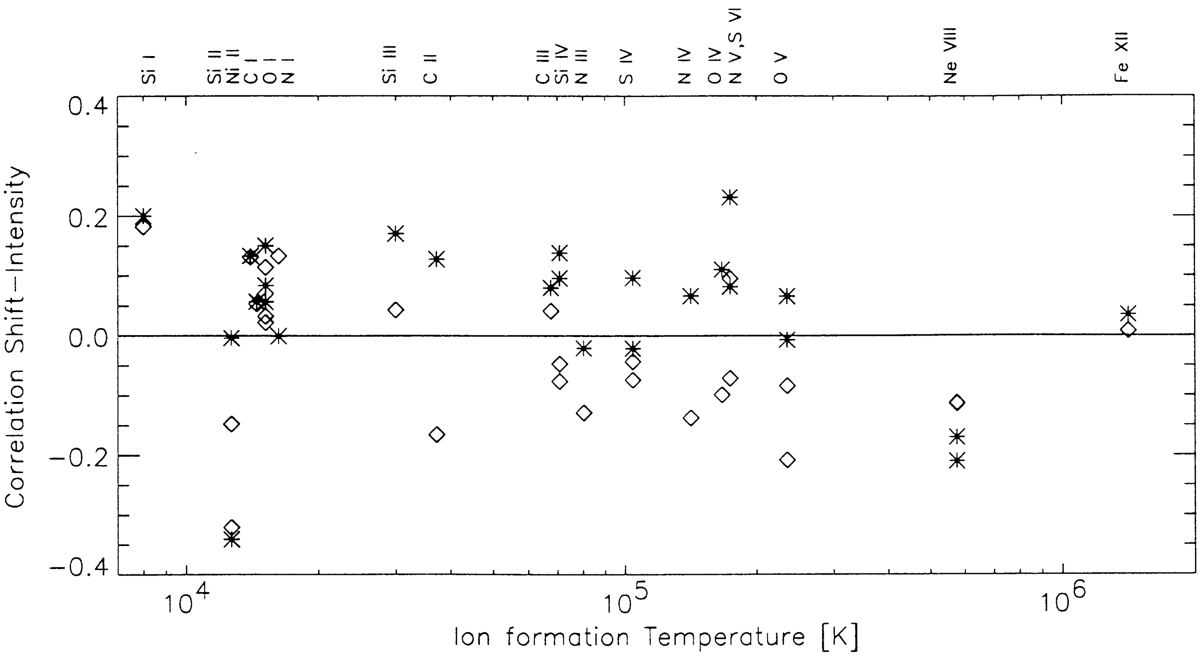

Figure 4. Correlation coefficient between wavelength shifts and intensities, versus the ion formation temperatures. **Diamonds**: *Coronal hole.* **Stars**: *Quiet Sun.*

temperature. The cooler line was chosen because it clearly shows the network, is strong, unblended, and is coregistered on the same SUMER image. Negative shifts signify blueshifts. Each plotted symbol corresponds to the binned values of 20 pixels of similar intensity. The solid lines represent linear fits to the binned data, while the correlation coefficients refer to the unbinned data. The binned data reveal a clearer trend. Since we did not use an absolute scale for the shifts, the line shifts at the meridian cannot be compared directly with those obtained at other locations on the disk. Hence only the meridian data (JOP055) have been plotted here. Note that quantities such as the correlation coefficient or the gradient of the least-squares fit are not affected by this uncertainty and can be compared between the data sets.

The Ne VIII line shows a trend towards larger blueshifts with increasing intensity of the cooler N IV line (Figure 2) in both the coronal hole and in the quiet Sun. In addition, this line is distinctly more blueshifted inside the coronal hole than in the quiet Sun (cf. Fig. 1). Both these results are in agreement with the findings of Hassler et al. (1999).

In Fig. 3 we plot line shift versus intensity for a transition region line, N IV at 765.15 Å. We observe stronger blueshifts with increasing intensities inside the coronal hole. The trend is reversed in the quiet Sun as expected for lines at this temperature which show large redshifts at disk center (Brynildsen et al. 1998, Brekke et al. 1997). Closer to the limb, however, Peter (1999) sees no correlation between the redshift and the intensity. The correlation we obtain between the two parameters is weak in both cases (at least for the unbinned data). Here also, we used only the meridian data.

To test whether the opposite behaviour exhibited by Ne VIII and N IV in the quiet Sun is real or is due to the peculiarity of one of the lines we have analysed also the remaining lines in Table 1.

In Fig. 4, the correlation coefficients between line shifts and intensities of all the spectral lines studied here are plotted versus the formation temperature. The chromospheric lines show a larger redshift in the network for both coronal hole and quiet Sun regions (except for the Si II 1309.28 Å line, which seems to be slyly blended by an Ni II line in its left wing, while the Si II 1197.39 Å line is too weak inside the coronal hole to give a reliable result). Most transition-region lines show the same trend in the quiet Sun but the opposite trend inside the coronal hole. Finally, lines formed above $3 \cdot 10^5$ K show a decreasing redshift with increasing intensity in both coronal holes and the quiet Sun (this includes the Ne VIII lines). For the Fe XII line, the one with the highest formation temperature in our sample, the shift is plotted versus the intensity of Si I 1258.79 Å(for the same reason as in the case of Ne VIII which is plotted against N IV at 765.15 Å). The result for the Fe XII line is marginal, due to its weakness and to blends.

The plotted coefficients have been calculated using all available data pixels, which means that although the coronal hole results include only meridian observations, the quiet Sun profiles are taken also at the other locations, in order to achieve better statistics.

4. SUMMARY

We have analysed the line shift as a function of the intensity of selected spectral lines observed by SUMER in coronal holes and in quiet Sun regions. In the polar coronal holes we find evidence for increasing blueshifts (relative to the quiet Sun) with increasing formation temperatures above 10^5 K, which may be the signature of the fast solar wind acceleration (see Stucki et al. 1999).

We confirm the results of Hassler et al. (1999) that the Ne VIII line at 770.41 Å shows increasing blueshift with increasing intensity of N IV at 765.15 Å in both quiet Sun regions and coronal holes. We find, however, that this result depends on the choice of spectral line. In particular, for lines formed below $3 \cdot 10^5$ K we need to distinguish between coronal holes and the normal quiet Sun. This suggests a difference in the acceleration mechanisms of the fast and slow solar wind.

ACKNOWLEDGMENTS

We would like to thank the SUMER team, as well as the SOHO command staff whose help was invaluable in obtaining these observations. SOHO is a mission of international cooperation between ESA and NASA. The SUMER project is financially supported by DLR, CNES, NASA, and the ESA PRODEX programme (Swiss contribution). This work was partly supported by the Swiss National Science Fundation, grant No. 21-45083.95, and by a grant from the ETH-Zurich which is greatly acknowledged.

REFERENCES

Arnaud M., Rothenflug R., 1985, Astronomy and Astrophysics 60, 425

Brekke P., Hassler D.M., Wilhelm K., 1997, Solar Physics 175, 349

Brynildsen N., Brekke P., Fredvik T., Haugan S.V.H, Kjelseth-Moe O., Maltby P., Harrison R.A., Wilhelm K., 1998, Solar Physics 181, 23

Chae J., Yun H.S., Poland A.I, 1998, Astrophysical Journal Suppl. Ser. 114, 151

Delaboudinière J.-P. et al., 1995, Solar Physics 162, 291

Hassler D.M., Dammasch I.E., Lemaire P., Brekke P., Curdt W., Mason H.E., Vial J.-C., Wilhelm K., 1999, Science 283, 810

Landi E., Mason H.E., Lemaire P., Landini M., 1999, Astronomy and Astrophysics, to be submitted

Marsch E., 1997, Lecture Notes in Physics, Space Solar Physics Proceedings, Orsay, p.107

Peter H., 1999, Astrophysical Journal 576, 490

Peter H., Judge P.G., 1999, Astrophysical Journal, submitted

Stucki K., Solanki S.K., Rüedi I., Stenflo J.O., Brković A., Schühle U., Wilhelm K., Huber M.C.E., 1999, Space Science Reviews, SOHO-7 Conference Proceedings, in press

Teriaca L., Banerjee D., Doyle J.G., Erdélyi R., 1999, ESA-SP, SOHO-8 Conference Proceedings

Wilhelm K., Curdt W., Marsch E., Schühle U., Lemaire P., Gabriel A., Vial J.-C., Grewing M., Huber M.C.E., Jordan S.D., Poland A.I., Thomas R.J., Kühne M., Timothy J.G., Hassler D.M., Siegmund O.H.W., 1995, Solar Physics 162, 189