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On the correlation between line width and line depth of the solar HeI 1083 nm line

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Abstract. Seven sets of spectra in the region of the HeI 1083 nm absorption line of the active region NOAA 7558 + 7562 near the west limb, obtained at Norikura Solar Observatory, National Astronomical Observatory, Japan have been analysed to determine the line parameters at each of the 255 x 100 pixels covering the active region. The observed range in the linewidth is similar to that seen earlier for the quiet sun, while the observed line depth is enhanced by almost an order of magnitude. This can be reconciled by considering the helium absorption to occur in unresolved chromospheric inhomogenieties with an enhanced filling factor accounting for the enhanced absorption in active regions. The line broadening can be explained in terms of a range in finite optical thickness of the elements. In this case, one would expect broader profiles to be associated with greater helium absorption, and a scatter plot of line width versus line depth indeed shows a weak positive correlation.

Key words : Sun - atmosphere - HeI 1083 nm line

1. Introduction

The HeI line at 1083 nm is the strongest HeI line seen on the solar disc in ground based observations. The helium atom has two electrons. These two electrons can have their spins either parallel or anti-parallel. Pauli's exclusion principle prevents the electrons having parallel spins in the ground state. To have parallel spins, one of the electrons must go to the next higher energy state. The resulting state is the 2^3S state, and is about 20 eV above the ground state. For collisional excitation to the 2^3S state, the plasma temperature required is about 200000 K. However, the observed linewidth of the 1083 nm line indicates a thermal broadening of only 8000 K and locates the formation of the line in the chromosphere (Hirayama, 1971). A plausible way of exciting the HeI atom is through a photo-ionisation recombination process (Goldberg, 1939; Zirin, 1989).The high energy photons required for this process are presumably produced by heating of the transition region owing to conduction of heat along the magnetic field lines of coronal loops (Venkatakrishnan, et al. 1996). Thus the HeI line serves to connect chromospheric conditions with coronal processes, a fact that was realised empirically from the correlation of HeI absorption with X-ray emission (Harvey et al. 1975; Harvey & Sheeley 1977).

Venkatakrishnan et al. (1992) found a correlation between line width and equivalent width of the HeI line from a set of spectra obtained on a quiet region of the sun during 1985 and 1986, which were years of low solar activity. This correlation was interpreted as a correlation between chromospheric dynamics and coronal heating (Venkatakrishnan 1993).

A natural question then is the behaviour of the HeI 1083 nm line in active regions. This problem was addressed by Suematsu et al. (1994) and Kitai & Tohmura (1995, personal communication), who did find a weak correlation but did not provide any explanation. In this paper, we will also address this question using several sets of spectra of the active region NOAA 7558 + 7562 near the west limb, obtained at Norikura Solar Observatory, National Astronomical Observatory, Japan and try to provide a physical explanation for our results.

2. Observations

The spectra were obtained using a CCD camera with the Tektronix TK512B chip. The spectra were flatfielded and bias subtracted. The line parameters like line depth, equivalent width, line width, and line shift were obtained using the procedure described in Suematsu et al. (1994).

3. Results

Figure 1 shows a scatter plot of linewidth versus line depth for one out of the 7 sets of spectra taken sequentially in time. Each set of spectra comprise one spatial scan of the region, to provide, if required, one spectroheliogram of the region. The abscissae are the deviations of linewedth from the mean value, normalised to the standard deviation. The ordinates are likewise, the deviations of the line depth from the mean value, again normalised to the standard deviation. A weak correlation is seen between the line depth and the line width and a similar correlation was seen in the other 6 sets (not shown here). This is further quantified in Table 1 which shows the mean, standard deviation and the slope of a linear regression curve of line depth vs. line width, for all the 7 sets of spectra. Although these sets were taken at different times, there is no evidence for a significant change in the statistical behaviour.

4. Discussion and conclusions

The interesting feature of the correlation is the fact that the range of linewidth values is the same as that for the quiet region results of Venkatakrishnan et al (1992).We must allow for a factor of 1.67 while comparing the present results with the quiet region results because we use the width of the gaussian while the earlier results reported the FWHM. If the

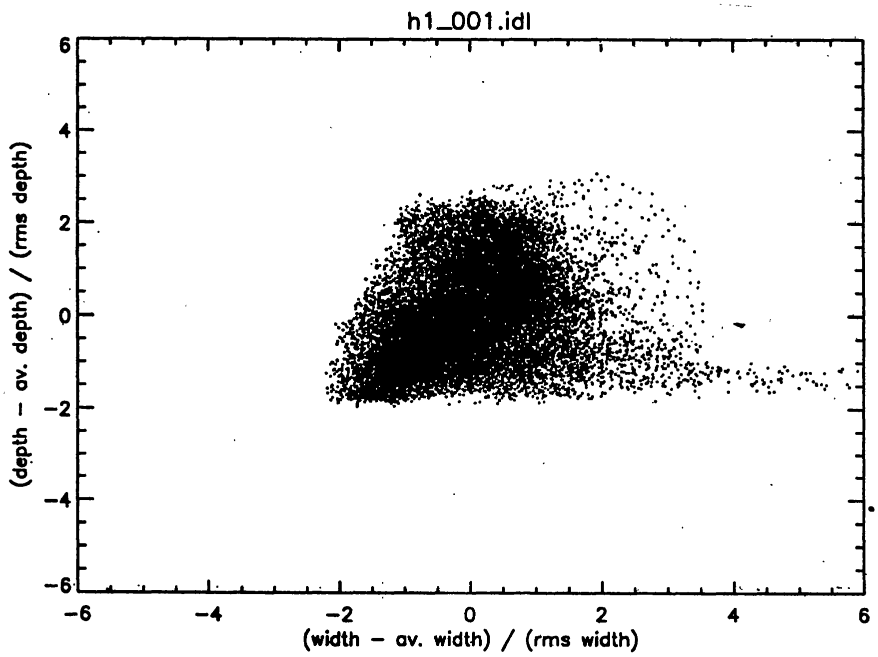

Fig. 1. Scatter plot of deviation of linewidth from mean linewidth (in units of the standard deviation), versus the deviation of the central depth from its mean value (in units of the standard deviation of line depth) is shown for one of the seven sets of spectra obtained at Norikura on 1993 August 12. Measurement error in line depth is typically 2.6 percent (compared to 40 percent spread seen in plot), while the error in linewidth is 3 percent (compared to observed spread of 17 percent).

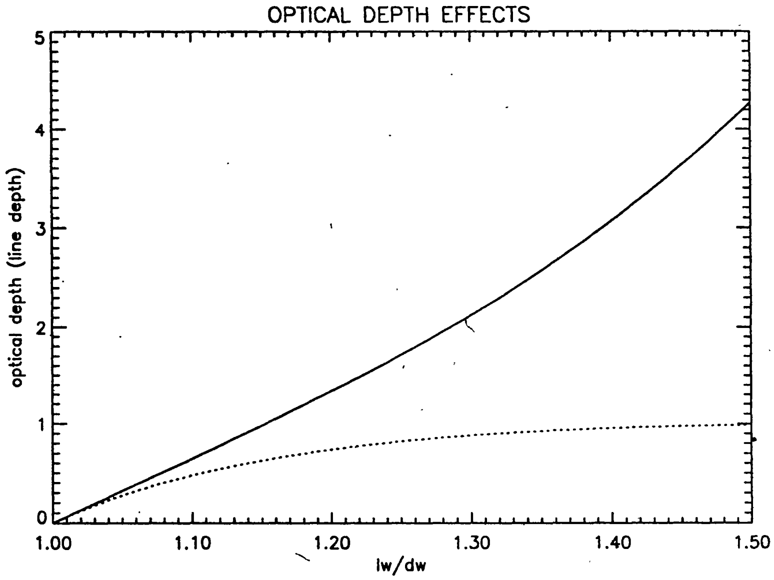

Fig.2. The optical depth (full line) and central line depth (dotted line) is plotted for different values of the ratio of linewidth to the Doppler width. Here, the linewidth is taken as that deviation from the line centre wavelength, which yields 1/e times the central line intensity.

linewidth characterises the flux of kinetic energy, as suggested by Venkatakrishnan (1993), then it is surprising that the same range of kinetic energy flux can produce an order of magnitude increase in HeI absorption in active regions as compared with the quiet region results.

On the other hand, the line broadening could well be due to finite optical thickness. For example, the line profiles presented by Harvey and Livingston (1994) - for a variety of solar features ranging from a plage to a network element - show a variation in the strength of the 1082.92 nm component of the triplet relative to the main component. The relative strength of these components is supposed to be in the range of .125 for small optical depths and progressively become larger for larger optical depths (de Jager, 1964). The profiles in Harvey and Livingston (1994) do show values as large as .5 for the ratio. All the features also showed a broader profile wherever the optical depth was larger. Furthermore de Jager, Namba and Neven (1966) found the linewidth and the relative strength of the triplet components to increase from the centre of the solar disk towards the limb. This trend could also be construed as support for the premise that the line broadening is caused by finite optical thickness, although one must also bear in mind that Mohler and Golberg (1956) found no evidence for finite optical thickness.

It is only in the case of an optically thin line that the line width equals the Doppler width. Following Zirin's (1966) arguments for the increase of observed line width with the optical depth, for a given value of the kinematic Doppler width (equation 5.22 of Zirin, 1966), one can calculate the ratio of the linewidth to the Doppler width as a function of the optical depth (figure 2). The full line in this figure shows the optical depth as a function of the ratio of line width to Doppler width. The dashed line is the central line depth for the optical depths corresponding to the ratio of widths given by the abscissae. We have limited the range of these abscissae between 1 and 1.5, this being the range implied from table 1. One might then make a plausible assumption that observed range in the linewidth is in most part contributed by a range of optical depths, while the Doppler width tends to remain unchanged. It must be remarked that this statement can be confirmed only if one also knew the value of the ratio of the strengths of the two component of the triplet. We could not measure the strength of the weaker component in our data due to the presence of a faint interference fringe at the location of the weaker component in most of the spectra.

Table 1.

Mean line depth	Rms line depth	Mean line width (Å)	Rms line width (Å)	Slope of scatter
0.1057	0.0410	0.4321	0.0689	0.1626
0.1055	0.0412	0.4326	0.0699	0.1493
0.1053	0.0413	0.4320	0.0697	0.1558
0.1055	0.0407	0.4317	0.0687	0.1554
0.1049	0.0412	0.4329	0.0708	0.1463
0.1037	0.0412	0.4323	0.0680	0.1731
0.1036	0.0395	0.4344	0.0698	0.1518

An order of magnitude increase in the line depth can be understood if we assume HeI absorption to take place in unresolved chromospheric inhomogeneities. An order of magnitude increase in the filling factor of such inhomogenieties in active regions can account for the larger absorption. A given distribution of filling factors will then produce a progressively increasing value of mean linedepth for increasing optical depth. The observed correlation of line depth with line width can thus be interpreted as the increase of linedepth with optical depth. Since figure 2 shows that the line depth variation is not large beyond an optical depth of unity, the weak dependence of observed line depth on line width follows naturally. We are always making the assumption here, that the observed range in linewidth can be purely accounted for by optical depth variation. The immediate implication of the above interpretation is that one can no longer use the observed line width directly as a measure of the kinematic activity at that location.

Finally, the strongest observed linedepth is clearly too small for optically deep lines. Thus, we must invoke suitably small filling factors to account for this anomaly. Here, we will not be concerned with the abnormally large optical depths inferred for very shallow lines by de Jager, Namba and Neven (1966) since these were later shown to be due to a spectral feature at 1082.96 nm (Giovanelli and Hall, 1970). In general, though, the HeI excitation must be taking place on very small scales (smaller than the arcsecond size of the pixel). It follows that the exciting EUV photons must be generated from such tiny regions. We are now therefore poised for very interesting findings on the nature of HeI excitation, based on the fine structure of the HeI Line profile.

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