The Chromospheric Prolateness and its Variations

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Abstract. The chromospheric prolateness (also called ovalisation) of the extended dynamical chromosphere was established from measurements performed above 2Mm heights during the years of solar minimum, using the Hα, Ca II K and HeII 304 line emissions from both groundbased and spacebased observations. Coronal X-EUV emissions usually penetrate deep enough into the chromosphere to completely mask this effect on transition region lines and produce the so-called coronal hole effect. However, cool lines like Hα and Ca II lines, do not show this CH effect. Coronal lines and HeI (D3; 1083 nm) do show coronal holes but no prolateness effect. We briefly review different methods which can potentially be used to measure the prolateness. Further we note the similarity of the geometric behaviour of the prolateness and its variation along the solar cycle compared to the behaviour of the fast solar wind. It suggests the same origin related to the emergence of the small scale network and internetwork magnetic field towards the corona. A simple geometric model was proposed to explain the effect of the prolateness of the solar chromosphere by considering that the specific dynamical part of the solar atmosphere above the 2 Mm level, being a mixture of up and down moving jets of chromospheric matter with the coronal plasma between them, is responsible for the solar prolateness. We however note that polar regions are showing different types of activity in the low corona, including prominence eruptions seen in Hα and jets seen in SXR and EUV. Some kind of dissipation of the newly emerged magnetic field is needed. More systematic measurements should be done to build a more complete, possibly 3D, picture to explain this lifting effect of a large part of the chromosphere.

1. Introduction

It is known that the solar white-light limb looks like a perfect circle when the obvious photospheric structures of the solar activity, sunspots and faculae, are ignored. Precise measurements of the photospheric solar radius in polar and equatorial directions showed a very small difference of order of 10 milli-arcsec (e.g. Rozelot & Rosch 1996), making the Sun oblate. This is roughly the value anticipated from the “flattening” effect due to the bulk rotation of the Sun. This is not the effect we discuss here where the case of the extended solar chromosphere is considered. From historic visual and later, photographic Hα observations, it was evident that the polar chromosphere looks more extended than the low latitude chromosphere at solar minimum of activity (Secchi 1877; Roberts 1945; Fracastoro 1948). However, at groundbased, effects due to the Earth atmosphere should be considered, see further and Figure 1.

Johannesson & Zirin (1996) using photometric data more recently measured the extension of the chromosphere at Hα center to reach typically 4.3-4.4 Mm
Figure 1. Distortion due to the Earth atmospheric differential refraction effect computed for both a sea level site and a mountain site of 2800 m altitude like the Sac Peak Observatory. (adapted from an unpublished report by E. Di Folco)

at the equator and just below 6 Mm at the solar poles, with a true local scatter of 0.5 Mm. This is in agreement with the values reported in the literature, see e.g. the Dunn’s (1965) thesis, although the definition of this extension however is still a matter of debate, see also Suematsu (1998) and Dara, Koutchmy, & Suematsu, (1998). Auchere et al. 1998 performed a more statistical comparative analysis of the shape of the corona and, also, of the chromosphere, using He II 304 observations. They also describe strictly simultaneous Hα ground-based observations and space-based observations with SOHO EIT, see also Georgakilas, Koutchmy, & Alissandrakis (1999). The solar chromosphere was found to be prolate to an extent of 3°.0 ± 0".1 over a solar diameter in Hα full line and up to ∼ 12" for He II emission, without removing effects due to the weaker radial gradients known to exist above coronal holes (CH), see Huber et al. (1974) who were the first to describe this CH effect. A similar result was independently obtained for the EIT data by Zhang, White, & Kundu (1998). At the time of solar minimum the limb seen in EIT coronal images is also higher at the poles than at the equator by 1.3 ± 0.65 Mm, but this effect is mainly due to the presence of polar coronal holes. The transition region (TR) outer limb seen in He II images is significantly higher than the limb measured in “absorption” on coronal images, see Auchère et al. (1998). The height difference is 3.1 ± 1.2 Mm at the equator and 6.6 ± 1.2 Mm at the poles, see further. After considering effects due to the polar coronal holes, the prolateness has been confirmed using new measurements obtained from an observing run at the SP/VTT on August
These results were first discussed in Filippov & Koutchmy (2000).

Figure 2. Typical HeII 304 filtergram taken near the sunspot minimum to show the relative prolateness effect superposed to the effect produced by the polar coronal holes (from G. Artzner). Note that the radial positions of the inflection points are very sensitive to the presence of a limb feature like a macro-spicule.

2. Observations

2.1. General

A problem occurs when precise measurements of the shape of the solar disk are analysed due to the distortion effects. Spectro-heliograms, for example, cannot be used because large instrumental distortions are introduced when constructing the whole image from slices, and non linear effects introduced during the scanning. Distortion is usually not reproducible. Even the accurately recon-
constructed whole disk images recently produced in space (SUMER/SoHO atlas) are not precise enough. Provided the instrumental distortion is minimised by using properly collimated systems, ground-based filtergrams can yet be used. Then, the Earth atmospheric distortion should be taken into account, especially for observations made with a not very high Sun. We computed the effect produced by the Earth atmosphere induced differential refraction effect, see Figure 1, in order to immediately show the influence on the apparent shape of the solar disk. This result can also be used to introduce corrections when measuring the ratio of diameters pole/equator but a more sophisticated algorithm has to be developed to analyse the whole limb profile. For this reason, it is much easier to measure just the thickness of a part of the chromosphere, around the poles and around the equator, because the correction for differential refraction is then negligible compared to the value due to the prolateness, see Table 1.

In space, there is no Earth atmospheric induced distortion effects. The chromospheric prolateness can then be measured on full disk filtergrams like those which are provided by the EIT experiment of SoHO, because they are free of significant instrumental distortion effect. Coronal EIT filtergrams are not suitable to precisely show the chromosphere, although some absorption effect seen near the limb could be attributed to the chromosphere. Indeed, the plasma filling the space between the corona and the chromosphere at transition region (TR) temperatures produces this absorption, see a discussion in Daw, DeLuca, & Golub (1995). Accordingly, the shape of the limb is dominated by effects at high TR temperature, including the effect of coronal holes, see Huber et al. (1974) and Auchere et al. (1998). Fortunately, HeII 304 resonance line emission filtergrams are available and permit a direct evaluation of the shape of the HeII chromosphere which includes the prolateness effect.

Figure 2 is an example of an EIT HeII filtergram processed by G. Artzner to show everywhere around the disk the relative positions of the chromospheric “limb” given by the position of the intensity inflection points at each radial direction used in the analysis, see Figure 2.

A more direct method to measure the prolateness is to use filtergrams obtained in low excitation emission lines free of CH effect. Unfortunately, there is no spaceborne experiment providing a full disk filtergram of lines at these low temperatures, even on the near future space missions.

2.2. Ground-based Observations

As mentioned before, the prolateness can be evaluated thanks to relative measurements of the thickness of the extended dynamical chromosphere, looking well above the 2.1 Mm heights given by the theoretical hydrostatic VAL model atmosphere (Vernazza, Avrett, & Loeser 1981) for the top of the chromosphere. We performed these measurements using different methods and found the “spectroscopic” method particularly useful. In this method, many spectra are taken along a strictly radial direction in the region of a low excitation lines, with optimum exposure times to get a good signal to noise ratio on emissions recorded outside the limb (in addition, to properly subtract the scattered light), without overexposing the disk parts seen in the neighboring continuum. In order to provide relevant results, it is necessary to average the spectra, both in space and in time. We used averaged spectra after processing typically 160 spectra taken
near each reference positions (2 polar positions around the North and the South poles, and 2 equator positions, around the positions of the East and of the West limbs) in typically 10 min of time for each position, see an example of spectra on Fig. 4. Measurements of the chromospheric thickness are taken with respect to the precise position of the photospheric limbs as measured using the continuum parts of spectra. The limb position is deduced from the position of the center of gravity position of the curves obtained after deriving in space the intensity variations of the extreme limbs curves, see Figure 3.

The position of the outer “limbs” of the chromosphere is evaluated using the position of the inflection point which is rather close to the position of half width intensities, see Figure 3, after subtracting the intensity of the nearby continuum from the intensity of the considered chromospheric emission in order to remove the scattered light.

In Table 1 we present the results coming from our solar minimum measurements, see also, Filippov & Koutchmy (2000).

<table>
<thead>
<tr>
<th>Element</th>
<th>Line</th>
<th>Height of the average limb at equator (Mm)</th>
<th>Height of the average limb at poles (Mm)</th>
<th>Prolateness over a solar radius (Mm)</th>
<th>Temp. of line formation (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>Hα</td>
<td>4.2 ± 0.35</td>
<td>5.3 ± 0.35</td>
<td>1.1 ± 0.35</td>
<td>8000</td>
</tr>
<tr>
<td>Ca II</td>
<td>K2</td>
<td>2.65 ± 0.1</td>
<td>2.85 ± 0.1</td>
<td>0.2 ± 0.1</td>
<td>6500</td>
</tr>
<tr>
<td>Ca II</td>
<td>K3</td>
<td>3.35 ± 0.15</td>
<td>3.8 ± 0.15</td>
<td>0.45 ± 0.15</td>
<td>6500</td>
</tr>
<tr>
<td>He II</td>
<td>30.4nm</td>
<td>5 ± 0.5</td>
<td>6.5 ± 5</td>
<td>1.5 ± 5</td>
<td>(50000)</td>
</tr>
<tr>
<td>He I</td>
<td>1083nm</td>
<td>1.9 ± 0.3</td>
<td>1.9 ± 0.3</td>
<td>0 ± 0.3</td>
<td>(8000)</td>
</tr>
<tr>
<td>D3</td>
<td></td>
<td>1.9 ± 0.3</td>
<td>1.9 ± 0.3</td>
<td>0 ± 0.3</td>
<td>(8000)</td>
</tr>
</tbody>
</table>

Measurements were later done during the solar maximum using both the filtergrams (with the Themis telescope at Tenerife) and the spectroscopic method (at NSO/Sacramento Peak with the HSG of the Dunn’s telescope). We could not measure any definite prolateness; sometimes the equatorial chromosphere appears even more extended than the polar one. In Figure 4 we show a mosaic of Hα average spectra to illustrate the absence of measurable prolateness effect, see Figure 5, comparing the chromospheric extensions of the Hα line emissions.

2.3. Spaceborne Observations

A first analysis of the SXR limb behaviour is due to Daw et al. (1995). More spaceborne observations of the shape of the limb from full disk images were done using the EIT/SoHO experiment, see Auchere et al. (1998). They mainly show the effect of polar CHs on the shape of the limbs computed using coronal line emissions. However, the limb positions and the limb intensities observed using the HeII 304 line do show the prolateness effect superposed to the rather large effect due to the polar CHs. We show on Figure 6 a synoptic view of both
Figure 3.  a and b - Intensity variations of the chromospheric and the photospheric (derivative) limbs used to evaluate the extension of the chromosphere at different positions for a 160 arcsec average along the limb. Curves corresponding to the HeI 1083 nm line center and to the CaII K line emissions in K3 (dotted lines) and in K2V and K2R are shown. Observations of 1998 to show the CH effect in 1083 and the prolateness effect in K CaII.

the limb positions and limb intensities measured in the HeII line by Frederic Auchère during the years 1996 to 2000 to show the disappearance of the CH effect presumably correlated with the disappearance of the prolateness effect. It is also illustrating that spaceborne observations are superior in quality compared
to ground-based data to show a continuous variation during years of a global solar effects.

3. Discussions and Conclusions

When the chromospheric prolateness, which is well apparent at solar minimum, was evaluated, the first impression was that it reflects the influence of the global dipolar field of the Sun. Indeed, Roberts (1945) already used deep Hα filtergrams to demonstrate that the distribution of spikes seen around the occulting disk of his coronagraph corresponds to what is expected from a magnetic dipole seeded well inside the Sun. Much later, these spikes were compared to macro-spicules which are seen using TR emission lines, see e.g. Koutchmy & Loucif (1991) and Yamauchi et al. (2004), where they appear related to CHs. Figure 7 shows a time sequence of deep Hα filtergrams taken by Georgakilas and one of the authors at NSO/SP, around the N-pole at the time of solar minimum (1996). Not only many spicules are shown to erupt permanently, but also a small prominence-like
eruption is well documented. This eruption appears to be recurrent, a property which has been noticed before watching polar spikes, see Koutchmy & Loucif (1991).

Figure 8 shows simultaneous observations taken above a polar region in Hα at ground-based and in HeII 304 line from space (EIT/SoHO). The time sequence illustrates the difference seen between the behaviour of the dynamical chromosphere observed simultaneously in a cool line (Hα) and in a TR line (HeII 304). Obvious spikes and macro-spicules can easily be identified without being possible to claim any definite correlation, a situation already described by Mariska (1992) when discussing the TR physics to demonstrate that 1D models are not adequate.

Now, SXR jets and jetlets are also observed in polar regions at sunspot minimum, see Koutchmy et al. (1998), telling us that fast and hot events are present, exactly what is needed to drive the fast solar wind. In addition, we note the similarity between the azimuthal distribution of the fast wind as recorded from Ulysses (see Figure 9) and the prolateness effect. An obvious similarity also exists regarding the solar cycle variations.

R. Woo and Sh. Habbal (see e.g., Woo et al. 2000) promoted for a long time the idea that it is important not to limit the source of the fast wind to the CHs areas, but to also involve the quiet Sun. The prolateness effect we measured seems to bring one more argument in favor of this view. To go further and understand the process of emergence of the small scale magnetic field generated...
in lower layers, the role of the global dipolar field and the production of small scale dynamical events, capable to heat the high corona, see e.g. Falconer et al. (2003) and finally lift a large part of the outer chromosphere, we clearly need more observations. At least the measurements of the prolateness effect is feasible and should be made more often to also look at a possible longitudinal effect and also get more variabilities to correlate with other parameters, including the position of CHs.

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Fracastoro, M. G. 1948, Pub. R. Oss. Arcetri 64, 44
Figure 8. Simultaneous images taken above the polar region in 1996 at groundbased in Hα and in space using the EIT/Soho experiment with the HeII 304 channel (Georgakilas & Koutchmy).

Secchi, S. J. 1877, in ‘Le Soleil’, Gauthier-Villars, p. 38
Figure 9. Distribution around the Sun of the speed of the wind measured on the Ulysses spacecraft.