On the Dynamic Nature of the Prolate Chromosphere

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Abstract. The upper edge of the solar chromosphere looks not like a perfect circle in some spectral lines. It is prolate in the South-North direction at the epoch of minimum solar activity and nearly spherically symmetrical at the maximum phase. We attribute the effect to the dynamical nature of the upper chromosphere, which consists of a large number of small cool jets (jetlets) ascending into the corona. A proposed simple geometric model can explain the effect of the prolateness of the solar chromosphere. Due to the dynamic nature of the solar atmosphere above the 2 Mm level, the magnetic field is considered to play a very important role in the density distribution with the height, guiding the mass flows along the field lines. The difference of the magnetic field topology in the polar and the equatorial regions leads to different heights of the chromospheric limb. We could not resolve a source region of an individual jetlet, however similar but larger structures are visible in EUV coronal lines. We present an example of the jet formation obtained by TRACE in the 171 Å channel. Field aligned motion arises above the null point created in the corona by the emerging magnetic bipole. The scale of bipole is large enough to recognize the saddle structure around the 3D null point in the TRACE images. We believe that similar but smaller processes could happen very often at smaller scale in the chromosphere near emerging magnetic ephemeral regions forming numerous jetlets of the upper chromosphere.

1. Introduction

Many past observations showed that at the epoch of solar minimum the extension of the chromosphere near the poles is systematically higher than at the equator (Secchi 1877; Fracastoro 1948) and modern precise measurements (Fig. 1) confirmed and substantiated these early suggestions (Johannesson & Zirin 2000; Auchere et al. 1998; Vilinga & Koutchmy 2005). The amount of prolateness depends on the amount of plasma that emits at the observed light. In the transition region (TR) resonance line of He\textsc{II} at 304 Å, the effect seems more prominent than in a chromospheric cool Balmer line like H\textsc{α} of H\textsc{I} (\textasciitilde 8000 K), because additional structures appear at TR temperatures higher up, especially over coronal holes (CH).

The upper part of the chromosphere is far from the static state. It consists of numerous thin jet-like structures filling magnetic flux tubes. High resolution images of the solar limb in H\textsc{α} shows a “forest” of spike-like features. The highest of them are more straight and tilted to the vertical within the angle of 20-30°. In the lower part one can see a number of arches. We assume that the dynamical part of the solar atmosphere, being a mixture of moving up and down
jets of chromospheric matter and coronal plasma between them, is responsible for the solar prolateness. Due to the dynamic nature of this layer, the magnetic field plays a very important role in the density distribution with respect to the height, guiding the mass flows along the field lines.

Network magnetic elements in polar regions are predominantly of the same polarity. In the quiet solar equatorial regions, they are of mixed polarity (Varsik et al. 1999; Belenko 2001). For ballistic jet motion (which is not exact for a large part of spicules but can be assumed as a first approximation), the maximal height of a spicule would be the same for all trajectories along the curved field lines if a line reaches this height. In the polar region all jets are able to ascend up to a gravitationally limited height. The mean density distribution in the upper polar chromosphere is determined by i) the scale height in an individual spicule and ii) the distribution of the number of spicules versus the height. In the equatorial region some jets will be forced to come down after they reach the apex of a relatively low arch. When considering the average over time heights reached by spicules, this factor will reduce the mean chromosphere density at a given height proportionally to the fall of the magnetic flux of one polarity:

$$\rho(z) = \rho_0 \left( \frac{\Phi(z)}{\Phi_0} \right) \exp \left( -\frac{z}{h} \right),$$

(1)
where \( h \) is the effective scale height which is considerably larger than the 0.2 Mm hydrostatic scale height (Filippov & Koutchmy 2000).

2. A Small Jet in the Corona

Many jets are associated with emerging small flux regions that manifest themselves also as brightenings in chromospheric and coronal spectral lines. Such a new patch of parasitic polarity within a large-scale unipolar area, inevitably leads to the appearance of a new null point (X-point) in the chromosphere or corona (Filippov 1999). It is not trivial task to find real null points in the solar magnetic field. One can measure the magnetic field only on the photosphere level and only the line-of-sight component can be measured with satisfactory sensitivity and spatial resolution. These data are used to calculate the field above the photosphere by solving the boundary problem under current-free or force-free approximation. However, chromospheric and coronal plasmas filling the magnetic tubes visualise the magnetic field and one can find the specific saddle structures corresponding to the singular points.

We selected a clear observation of a jet formation above an X-point in the corona (Fig. 2). The event was observed by the Transition Region and Coronal Explorer (TRACE) camera on 3 October 2001. The cadence of TRACE images was about 20s and all temporal changes within the saddle structure were clearly visible. A movie of the event can be found at the TRACE Web site in the collection of movies as the movie Nr. 50 from http://vestige.lmsal.com/TRACE/Public/Gallery/Images/TRACEpod.html.

The null point was created by an emerging nearly horizontal bipole and the ambient vertical magnetic field. The growth of the bipole leads to a reconnection of the field lines and to a specific plasma motion in the vicinity of the null point.
that results in a plasma flow along the spine line of the 3D null. During the growth of the emerging bipole, nearly vertical field lines of the unipolar region should be rearranged coming from the left side of the bipole to the right side. Frozen-in plasma motion is shown by dashed lines in a sketch of the 3D geometry of the magnetic field in the right-hand part of Fig. 2. Some field lines pass through the reconnection in the X-point while most of them are able simply to flow around the null point (fan reconnection), what is impossible to represent in a 2D geometry (Priest & Titov 1996). Difference image (Fig. 3) obtained by subtracting the image at 02:57:26 UT from the image at 03:04:10 UT shows the changes in the location of the coronal loops and the formation of new ones.

The frozen-in plasma motion will evolve in accordance with the expression

$$v_d = c \frac{E \times B}{B^2},$$

(2)

where

$$E = -\frac{1}{c} \frac{\partial A}{\partial t}$$

(3)

is the induction electric field, and $A$ is the vector potential of the magnetic field $B$. Transient inhomogeneities of the velocity field inevitably result in the formation of regions with plasma compression and rarefaction, in agreement with the equation of continuity

$$\frac{\partial \rho}{\partial t} + \text{div} \rho \mathbf{v} = 0.$$

(4)

Hyperbolic shape of field lines leads to plasma compression within two diametrically opposed quadrants, where flows converge, and rarefaction within two other quadrants, where flows diverge. The action of this geometrical factor is enhanced by the effect of acceleration of plasma approaching to null point, as $B$
is decreasing \((\text{div } \mathbf{v} > 0)\). Plasma that outflows from the null point decelerates \((\text{div } \mathbf{v} < 0)\). So, regions of enhanced density (and enhanced pressure) should appear right-and-above the center of the saddle structure in the TRACE images and left-and-down of it during the growth of the bipole. It is two bright features in the difference image that are located just in these two quadrants, namely, a small arch to the left of the saddle, both end of which are anchored in the photosphere, and to the right of it, a jet-like structure along the spine. Enhanced gas pressure initiates field aligned motion that forms the jet.

For a smaller scale emerging magnetic bipole we would not be able to see a saddle structure created by its interaction with the background magnetic field but would still observe the field-aligned jet-like motion. A lot of small jets could be created by very small magnetic elements that have been found everywhere on the solar surface. These small jets could be identified as spicules, dark mottles, macrospicules, surges. Their shapes and direction are defined by the geometry of the larger-scale ambient magnetic field and the orientation of the magnetic moment of emerging ephemeral magnetic regions. A host of jet-like structures (jetlets) forms the dynamic upper chromospheric shell that shows the prolateness at the epoch of low activity. Although it is still difficult to observe the null points and the small-scale saddle structures within the low chromosphere, we believe that the physics is the same as in the processes in the larger-scale saddle structures in the corona where plasma motion is visible more clearly. Hopefully, the new observations planned in space with Solar-B and SDO will permit to resolve this issue.

3. Conclusions

We analyzed a jet-like event observed by TRACE on 3 October 2001 above a structure that could be recognized as a saddle structure around a null (X-type) point. This null point was created by an emerging nearly horizontal bipole and the ambient vertical magnetic field. The growth of the bipole leads to a reconnection of the field lines and to a specific plasma motion in the vicinity of the null point that results in a plasma flow along the spine line of the 3D null. We believe that similar but smaller processes could happen very often at smaller scale in the heart of the chromosphere, near emerging magnetic ephemeral regions, producing numerous jet-like structures (jetlets) in the upper chromosphere such as spicules, dark mottles, giant spicules, macrospicules, spikes, and surges (see also Yamauchi et al. 2004). Assuming that this structure is “universal” and exists at very small scale, the geometry of the ambient magnetic field influences the jet trajectories and should determine the average density distribution in the upper chromosphere. At the epoch of low activity, the difference in the large-scale structure of the polar magnetic field and the one of the low latitude quite regions magnetic field results in a natural explanation of the prolateness of the chromospheric dynamic shell overlying the quasi-hydrostatic atmospheric layers.

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