Mem. S.A.It. Vol. 81, 792

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Emerging flux as the source of downflows in the chromosphere

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Abstract. Downward flowing plasma is a common signature of Doppler diagnostics in spectral lines forming in the chromosphere. Examples of such are the foot points of arch filament systems associated with emerging flux and the inverse Evershed flow in and around the penumbrae of sunspots. This contribution puts forth the hypothesis that these downward flows, at least those occurring in and around active regions, trace their origin to the ubiquitous emergence of magnetic flux. In this scenario, the buoyantly rising, emerging flux carries mass upward from lower levels, then drains downward along magnetic lines of force to produce the observed downflow signatures in the chromosphere and below. The hypothesis is discussed and illustrated by chromospheric observations of sunspots and filaments.

Key words. Sun: chromosphere – Sun: filaments – Sun: prominences

1. Introduction

The advent of the Yohkoh space mission brought a new perspective to studies of the solar corona, in that it provided the first continuous movies of the entire solar disk in x-rays over long periods. One of the first and most notable results from that mission is that the corona, mainly seen as the plasma associated with fields arising from active regions, appeared to expand outward from the solar surface in a quasi-continuous manner (Uchida et al. 1992). The expansion is certainly related to the evolution of flux at the solar surface: as new flux emerges from the interior, the field lines rise rapidly upward into the highly-stratified atmosphere where they then fill the volume above that is occupied by much weaker fields. Evidently, the corona is bearing witness to a global-scale emergence of active region flux.

This presentation explores the possible relation between the ever-rising fields and the frequent occurrence of downflows in the active region chromosphere. Buoyant rise of fields from the interior into the atmosphere and corona will result in the upward advection of the mass frozen to those fields. The high conductivity of the solar atmosphere will constrain the plasma contained in the rising fields to move along the magnetic lines of force. Thus, the rising, dense plasma will tend to fall back along inclined field lines.

Perhaps the arch filament system (Bruzek 1967, 1969) is the solar phenomenon for which this mechanism of buoyant rise of mass-laden plasma followed by draining toward the magnetic foot points is most widely accepted. Through spectroscopy and imaging of

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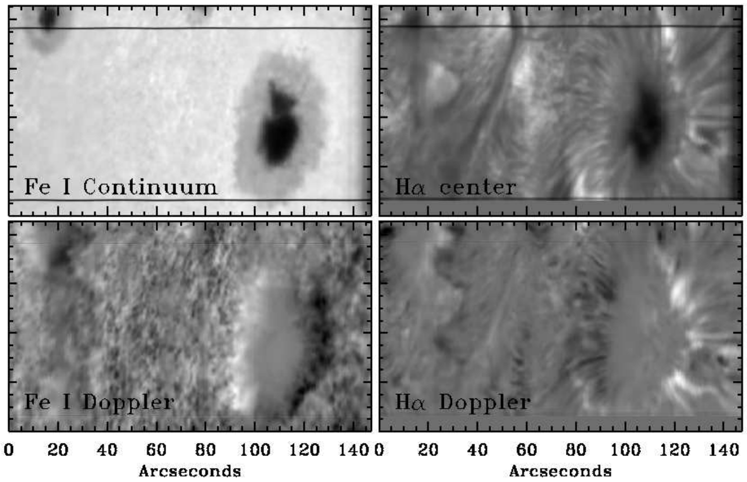

Fig. 1. Images are shown from spectro-polarimetric observations taken with the Advanced Stokes Polarimeter of NOAA AR 10397 near the east solar limb (9N, 54E) on 29 June 2003. The images at the top display the continuum intensity at 630 nm (left) and the intensity at the center of the Hα line (right). Lower images show the Doppler velocity taken as the wavelength shift of the intensity minima in the Fe I 630.15 nm line (left) and Hα (right). Solar north and west are up and to the right, respectively, and the east limb is close to the left edge of the images. Blue (red) shifted profiles are dark (light). These observations clearly show the chromospheric inverse Evershed flow surrounding the large sunspot at the right of the image.

the Hα line, that work identified moderate (~ 10 km s^{-1}) chromospheric upflows near the mid-points of the apparent loops, and high velocity downflows (~ 50 km s^{-1}) at their apparent foot points. A similar structure, but with correspondingly much slower velocities, has been identified with flux emerging into the photosphere (Lites et al. 1998). Here I raise the possibility that this process may be much more widespread in the solar chromosphere.

2. The Chromospheric Inverse Evershed Effect

The chromosphere above and surrounding sunspots exhibits a persistant Doppler motion indicating mass flow toward the center of the sunspot. This motion is known as the Chromospheric Inverse Evershed Effect (CIEE). As its name implies, the sense of the flow is opposite to that of the outward flowing photospheric Evershed effect. Though persistent, the CIEE is by no means steady. Doppler movies in Hα reveal that the flow is comprised of many individual small-scale threads that come and go on time scales of a few minutes or less. The photospheric Evershed effect is confined to the penumbra of sunspots, but the CIEE mainly exists in the regions just outside of the sunspot. Figure 1 illustrates both the photospheric Evershed effect and the CIEE as observed with the Advanced Stokes Polarimeter. The inverse Evershed flow is clearly seen in the Hα Doppler image at lower right of Fig. 1. It is apparent that the flow exists mainly in the moat region outside of the sunspot penumbra. The CIEE shows much coarser structure than its photospheric counterpart, and it follows the superpenumbral chromospheric fibril structures visible in the Hα image at the upper right of Fig. 1.

3. Active region filaments that terminate in sunspots

The commonly accepted paradigm for filaments/prominences (hereafter denoted as filaments) is that they are a quasi-static magnetic structure containing material at chromospheric temperatures suspended within and

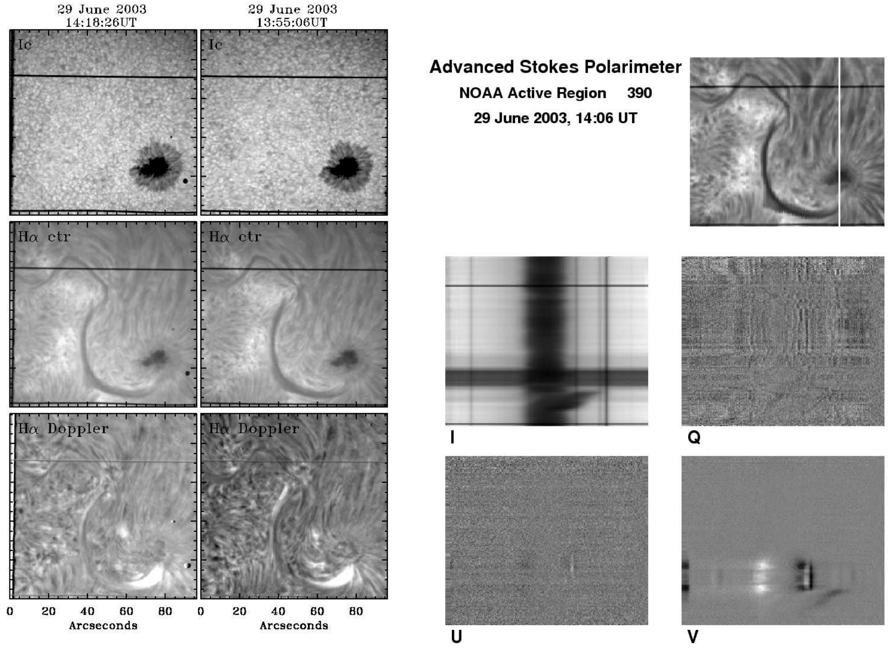

Fig. 2. Left: Images of continuum intensity (top) Hα line center (middle), and Hα Doppler signal (bottom) are shown for NOAA AR 10390 observed near the center of the disk (N16, W10) on 29 June 2003. Red (blue) shifts appear as bright (dark) in the Doppler images. The long filament terminates in the sunspot penumbra, and is accompanied by rapid downward motions that persist over the duration of these measurements. Right: Stokes spectra of the Hα line show the dramatic downward velocity associated with the end of the filament at the sunspot. The vertical white line in the upper right image indicates the position of the spectrograph slit corresponding to the Stokes spectra below.

isolated from the corona by the magnetic field. Although filaments do show a wide array of dynamic phenomena, notably revealed in great detail recently by high resolution Hinode observations (for example, Berger et al. 2008), much of the quiescent filament material must be subject to approximate hydrostatic equilibrium and will therefore obey the stratification of material at chromospheric temperatures with a scale height of a few hundred km. In this picture of filaments, each field line has a local minimum in height within the corona, and the cool filament material collects at this minimum with its stratification along field lines obeying the hydrostatic condition. Individual field lines, each having a local dip, may be stacked vertically. Quasi-static cool material could reside in the lowest few hundred km of each field line thereby allowing a prominence to have a vertical extent many times greater than the chromospheric scale height, as is commonly observed.

Now consider the case of an active region filament, one end of which terminates in a sunspot (see Fig. 2). The filament is quasi-static, as demonstrated by its unchanging structure over some 22 minutes spanned by the observations. Indeed, the filament had a similar appearance on the previous day, and has a concave-upward (dipped) field geometry in the photosphere under the upper portions of the filament (Lites 2005). The right end of the filament appears to terminate in the sunspot penumbra. It is extremely unlikely that the field structure above this simple, isolated sunspot could have a local minimum in height over, or just adjacent to, the outer penumbral boundary. The field lines traced by the filament therefore must follow the converging sunspot field structure and terminate in the sunspot itself.

The Hα images presented in Fig. 2 come from a slit-jaw imaging sequence of this region using the Universal Birefringent Filter at NSO/Sac Peak, in which the filter was tuned alternately to the continuum, red, blue, and line center wavelengths. The Hα Doppler images in the bottom two panels of Fig. 2 result from the simple Dopplergram processing: Doppler = (blue-red) / (blue+red). Thus, for Hα in absorption, redshifted material appears bright. These Dopplergrams show highly redshifted material in the segment of the filament leading down into the sunspot.

Accompanying these slit-jaw image sequences is a spectro-polarimetric map in the Hα line. The right side of Fig. 2 shows the Stokes profiles for one slit scan position (highlighted in the image at upper right). The Stokes I spectrum shows the large redshifted component. This downflow occurs in a rather strong magnetic field as evidenced by the strongly red shifted component visible in the Stokes V image.

4. Discussion

The flux emergence/draining scenario is a possible explanation for the CIEE, and also may be an explanation for the quasi-steady down flows at the sunspot end of the filament shown in Fig. 2. Under the assumption that the superpenumbral field itself is static, Maltby (1997) has postulated that siphon flows might explain the CIEE, but he also discusses the possibility of episodic upflows followed by downflows. The emergence/draining scenario avoids both the issue of establishing a pressure difference between the foot points of the superpenumbral fibrils needed to maintain the siphon flow, and the necessity of establishing counter-streaming flows. Further, it perhaps provides an alternate and simpler explanation to the reconnection scenario proposed by Katsukawa & Jurčák (2009) for the compact, isolated photospheric downflows they discovered in the penumbral photosphere. These downflows are associated with the more vertical component of the uncombed penumbra, so it remains to be established if those field lines have a connection with the superpenumbral filaments that harbor the CIEE.

The persistant nature of the flows at the sunspot end of the filament shown in Fig. 2, coupled with the fact that the sunspot magnetic field almost certainly does not posess dips at this location, strongly suggests that the sunspot end of the filament is maintained by a dynamic rather than static equilibrium. The mass needed to supply this flow continuously may arise from a siphon flow, but it could also be supplied by the continuous emergence of the filament system through the photosphere into the chromosphere and corona. The latter hypothesis is strengthened by the fact that this filament had erupted and then re-formed on the previous day (Lites 2005).

Acknowledgements. I thank the observers and staff of the Dunn Solar Telescope at the National Solar Observatory (NSO) for their assistance in performing the observations presented herein. The National Center for Atmospheric Research is sponsored by the National Science Foundation. NSO is operated by the Association of Universities for Research in Astronomy, Inc. (AURA), for the National Science Foundation.

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