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Chromospheric Dynamics and the FIP Flip

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Abstract. This paper consists of two parts. The first, resembling many other SOHO contributions in this volume, reports on a recent campaign in which SUMER was employed simultaneously with groundbased telescopes. The campaign is described but results are not yet in hand.

The second part differs by proposing SUMER measurements and analysis to be contributed by *you*. It calls attention to the FIP effect, a puzzling outer-atmosphere element segregation that may have to do with quiet-sun chromospheric dynamics. SUMER data, including yours, may provide pertinent diagnostics.

1. Dynamics of the quiet chromosphere and SUMER campaign

Over the past years, studies of quiet-sun chromospheric dynamics have largely concentrated on the behavior of the Ca II H & K lines (see Rutten 1995 for a review). These strong lines portray a vivid distinction between chromospheric network (NW) and internetwork (IN) regions (Lites et al. 1993). The NW is delineated by fairly stable patches of bright emission that show modulation with 5–15 min periodicities. It is not clear whether the modulation comes from waves or simply from erratic foot-point motions. There is no evidence for faster wave motions. The IN areas show much more dynamic action, with three-minute oscillations (periods 100–300 sec) occurring everywhere and sometimes brightly peaking at K_{2V} and H_{2V}. Carlsson & Stein (1994) have identified the formation of these H_{2V} and K_{2V} "grains". They betray shock interference between upward propagating, steepening acoustic waves and backfalling matter from previous shock passages.

The frontiers in quiet-sun dynamics lie higher up and deeper down, and in the connection between these regimes. For the NW patches, the persistent downdrafts observed in the UV (Section 5.3 of Mariska 1992), the Hα mottle flows (Tsiropoula et al. 1994), the shocks occurring in the Freiburg flux sheet simulations (Steiner et al. 1996) and the long-neglected spicules (Beckers 1968) should be tied together. For the IN areas the roles of localized pistons that drive the three-minute oscillations (or even the five-minute ones, see Rimmele

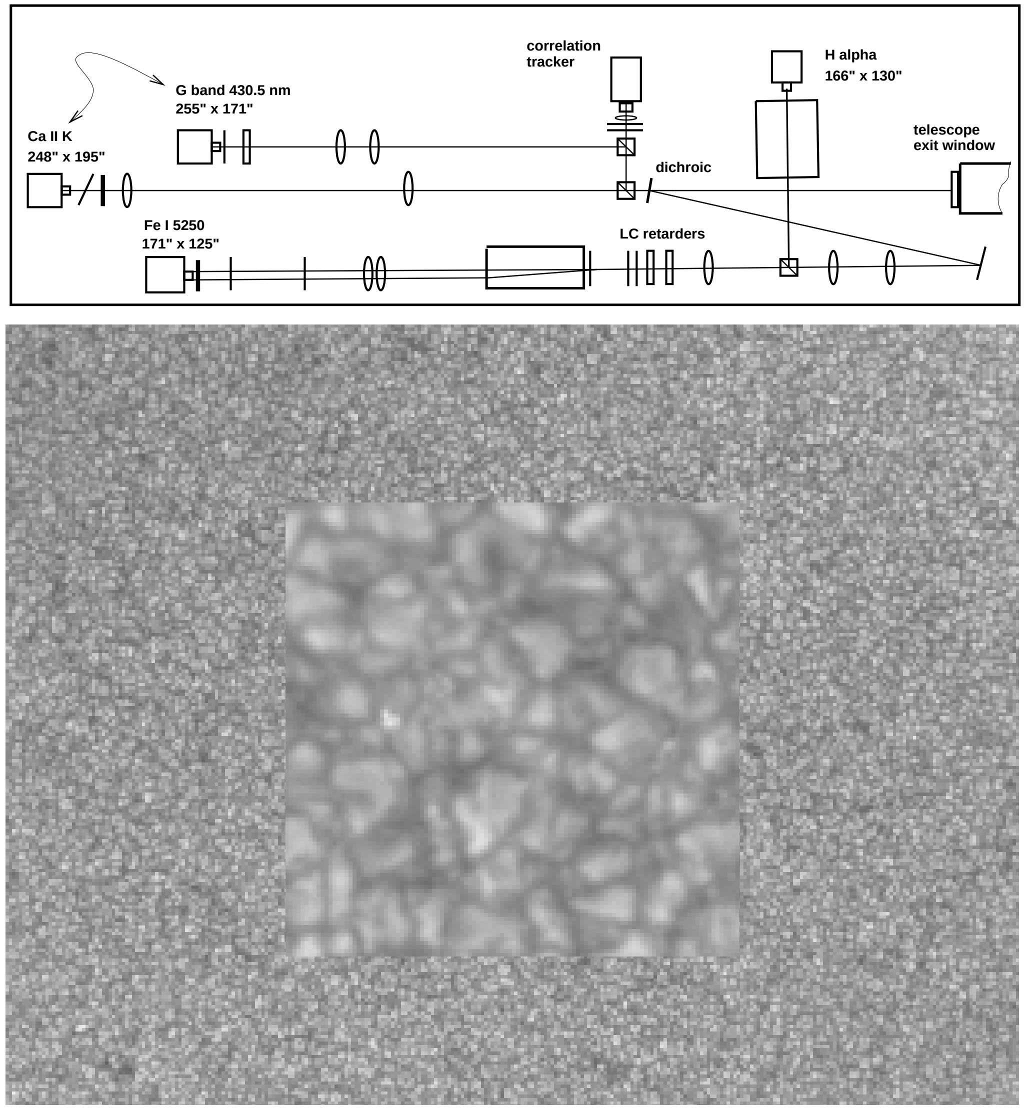

Figure 1. Top: SVST setup. The Ca II K camera (0.3 nm bandwidth) and the G-band camera (1 nm) ran synchronously, with the G-band camera selecting the best two frame pairs every 20 seconds for disk storage. The Hα and Fe I 525.0 nm cameras were used alternatively. The latter is part of a liquid crystal full-Stokes filtergraph that is being developed at the SVST but was not yet operational during the SUMER run. Bottom: G–band frame taken on Sep 9 UT 14:21:05. Demagnification by a factor two was used to cover the whole SUMER slit. Even so, Muller bright points and bright granule edges are visible over the full 255×171 arcsec field. The central part of the image is enlarged at the center of this print to illustrate its quality.

et al. 1995) and of the enigmatic internetwork fields (Keller et al. 1994, Lites et al. 1996) must be ascertained. Higher up, the IN regions contain C I jets and 160 nm bright points that are connected to the acoustic shock dynamics (Hoekzema et al. 1997). It is not clear at what height and how magnetism affects the shocks.

These issues are obvious motivation for SUMER data gathering. Bruce Lites (HAO) initiated and led a September campaign, first setting up the Advanced Stokes Polarimeter (ASP) at NSO/SP and than traveling to Goddard for SUMER spectrometry while Tom Berger (Lockheed) moved from La Palma to Sacramento Peak and Dan Kiselman (Stockholm), Luc Rouppe van der Voort (Utrecht) and I took over at the SVST. We tried to use SUMER, ASP and the SVST simultaneously and cospatially during 14:00–17:30 UT on September 1–10, running into the usual problems of pointing alignment and bad weather or bad seeing at ground level.

SUMER was used mostly at disk center with the slit set to follow rotation, selecting the $\lambda = 131$ and 103 nm wavelength regions. The ASP slit was set to scan around the (alleged) SUMER slit position. At the SVST, we obtained filtergrams with the setup shown in Fig. 1. The best day at la Palma was Sep 9, when the seeing was often good (Fig. 1). These data should permit correlation of granular behavior in the photosphere with the chromospheric dynamics seen in Ca II K and by SUMER.

2. The FIP flip and SUMER

The FIP effect is a well-established deviation of the coronal and solar wind abundances from the composition of the solar photosphere (see reviews by Meyer 1985, 1991, 1993). A similar deviation occurs in galactic cosmic rays and in solar energetic particles. In the slow-speed solar wind and the underlying closed-field regions of the corona, elements with First Ionization Potential (FIP) below 10 eV (Mg, Fe, Si) are overabundant with respect to high-FIP elements (N, O, Ar, Ne, He and possibly C) by about a factor four. Figure 2 displays this flip.

The segregation must obviously occur in circumstances where difference in FIP makes a difference, so well before the high-FIP atoms loose their outer electrons and are accelerated into the solar wind. Therefore, the outer-atmosphere low-FIP excess must be due to some neutral-ion separation process in the chromosphere where hydrogen and C, N and O are still predominantly neutral. In this regime, the charged low-FIP particles (which are predominantly once-ionized even throughout the photosphere) are presumably line-tied to magnetic fields while the high-FIP neutrals may flow or diffuse transversely across field lines. The segregation must be sensitive to the topology of the magnetic field since it is much smaller or absent in the fast wind streams that emanate from the open-field regions.

There are various FIP-effect scenarios in the literature that all assume line-tying of charged particles (with the exception of the implausible meteorite scenario of Lemaire 1990). For example, Vauclair & Meyer (1985) let neutral atoms diffuse downwards out of horizontal magnetic field, Ip & Axford (1991) and Vauclair (1996) propose that an upward sweeping horizontal fluxtube collects charged particles, while Von Steiger & Geiss (1989) and Marsch et al. (1995)

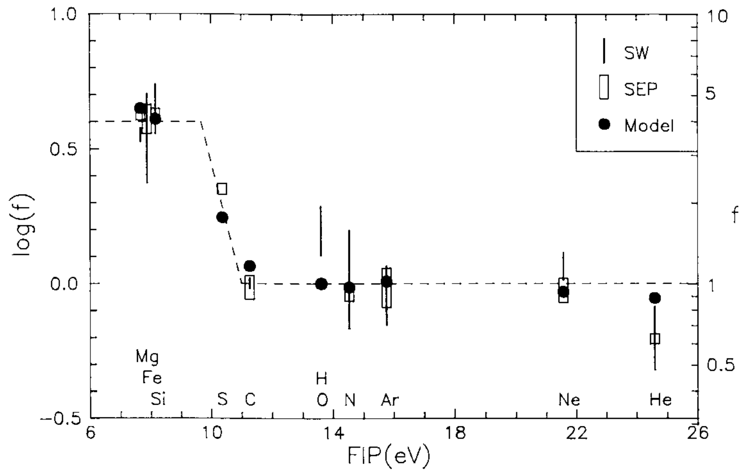

Figure 2. The FIP effect. The quantity f measures elemental abundance normalized by the photospheric value, on a relative scale with $\log f = 0$ assigned to oxygen. Bars (SW) are from in-situ slow solar wind sampling, rectangles (SEP) for solar energetic particles. The dots follow from a diffusion model. From Von Steiger & Geiss (1989).

use UV radiation from above to ionize the neutral low chromosphere at some characteristic depth, letting the remaining neutrals diffuse horizontally out of a narrow vertical fluxtube (first paper) or the ions differentially upward along a vertical field (second paper).

It seems to me that the IN shock dynamics represent a viable alternative since the shocks observed in Ca II H & K and in HRTS C I jets represent the largest-amplitude motions in the low quiet-sun chromosphere and are ubiquitously present all over the quiet sun. In closed field regions, the upward propagating shocks penetrate into a rather low-lying canopy. At the height where neutrals and ions may start to uncouple (as set by the collision frequency), such low-lying canopy fields may be strong enough to dampen the shocks and in particular, to inhibit the post-shock ballistic backfall which is the major dynamical phenomenon in the Carlsson–Stein simulation. Thus, the canopy field may act as a sieve through which high-FIP neutrals drop back down easier than low-FIP ions. The trapped ions may then preferentially take part in the mottle flows along the field towards the network locations, and eventually end up in the outer atmosphere when fibril loops expand and erupt.

How might SUMER diagnose such FIP segregation? I suspect that low-chromosphere Dopplershift signatures of the network and internetwork dynamics provide a clearer FIP diagnostic than line intensities. Interpretation of the latter tends to be questionable even for apparently optically thin conditions (Schrijver et al. 1994), whereas line formation in the hydrogen-neutral regime where the FIP fractionation takes place is optically thick and very complex for most if not all lines of interest. Thus, dynamical profile resolution and interpretation is required, rather than simple time-averaging of integrated line intensities. Averaging will be required to bring out low-FIP versus high-FIP dynamics differences, but such averaging must be done over resolved states of dynamic behavior. In SUMER setup terms, this means that a dynamically-oriented search for FIP fractionation imposes quite similar constraints as the various SUMER chromospheric dynamics programs. High time resolution and full spatial resolution are required to resolve the dynamical state of the chromosphere. Obviously, both low-FIP and high-FIP lines must be measured, preferably with difference in formation characteristics (height; thick/thin if feasible). On the other hand, a FIP search requires very large datasets, covering much space and much time to gain sufficient statistics in sampling the various dynamical processes. Finally, such a search should also enable differentiation between closed-field and open-field regions of the corona.

The message is that data from many programs will have to be combined in such a search. My request to you is to make sure that your line selection in any SUMER dynamics programs aims to include FIP difference.

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