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Understanding facular granules and lanes

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Abstract. Recent high resolution observations by Lites et al. (2004) show details of facular granules at $0.12''$, including dark facular lanes. For an interpretation of these data a basic facular model is constructed, consisting of a magnetic flux sheet embedded in a plane parallel atmosphere. While the maximum contrast originates from the "hot wall" of the flux-sheet depression, the model explains the wide brightening limbward of the facular magnetic field as due to a radiative transfer effect caused by the reduced opacity of the rarefied flux-sheet atmosphere. This model produces a dark, narrow lane centerward of the facular granule even in the absence of granular flow as a consequence of the cool deep layers of the magnetic flux sheet. These results carry over to a self-consistent simulation of a flux concentration in dynamic interaction with convective motion, where the dark lane deepens and broadens.

Results from a basic model and from numerical simulations

We construct a basic facular model consisting of a magnetic flux sheet embedded in a plane parallel atmosphere. The atmosphere within the flux sheet is similar to the external one but shifted in the downward direction to result in a "Wilson depression" of 140 km. The upper layers are in thermal equilibrium, $T_i = T_e$, while in deep layers, the tube interior is cooler than the external atmosphere at equal geometrical height.

The steep increase in brightness at the disk-center side of the facula (dashed curve in Fig. 1b, left) is due to the "hot wall" of the flux-sheet depression (Spruit, 1976). It extends into a wide, limbward gently fading brightening due to the reduced opacity of the rarefied flux-sheet atmosphere. For a conceivable explanation we note that from a location at the solar surface and sideways of the flux sheet the sky is more transparent in the direction of the flux sheet compared to an equal altitude direction away from it, leading to enhanced radiation escape in this direction. The resulting asymmetric shape of the contrast curve is also a characteristic of the profiles shown by Lites et al. (2004). Thus, a single flux sheet/tube influences the radiative escape in a cross-sectional area that is much wider than the magnetic field concentration proper.

On the disk-center side of the magnetic flux sheet a narrow, dark facular lane with $C < 1$ may occur as can be seen in Fig. 1b, right. It arises from the low temperature gradient of the flux-sheet atmosphere in the height range of $\tau_c = 1$ and its downshift relative to the external atmosphere in combination with an inclined line of sight. Hence, one could say that the lane is an expression of the "cool bottom" of the magnetic flux sheet. Note that this lane occurs without even taking convective flow into account and without an energetically self-consistent treatment that must lead to a lower surface temperature in the surroundings of the flux concentration (the dark ring of Spruit, 1977) as a consequence of the extra cooling.

Results of the basic hydrostatic model carry over to a fully self-consistent model of a magnetic flux sheet in dynamic interaction with nonstationary convective motion. In this case the facular lane becomes broader and darker. The radiation in the flux-sheet

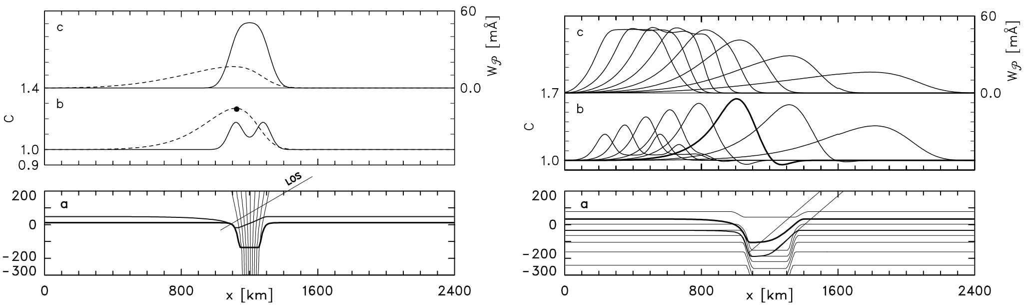

Figure 1. Left: a) Magnetic flux sheet with optical surfaces of $\tau_c = 1$ for vertical lines of sight (LOS) and LOS under zenith angle $\cos(\theta) = \mu = 0.5$. **b)** Corresponding continuum contrasts, $C(x) = I_c(x)/I_{c\,0}$. All values of the dashed curve left of the black dot are from LOS left of the one indicated in panel a). **c)** Corresponding equivalent widths of the total polarization of Fe I 630.25 nm. **Right: a)** Isothermal contours and two surfaces of optical depth $\tau_c = 1$ and $\tau_c = 5$, both computed for LOS under a zenith angle of $\theta = 50°$. **b)** Continuum contrast, for LOS with $\theta = 0° \ldots\ 70°$. For the prominent profile belonging to $\theta = 50°$, the region where $C < 1$ is bounded by the two LOS indicated in panel a). **c)** Equivalent width of the total polarization of Fe I 630.25 nm.

surroundings is strongly anisotropic with preferential photon escape towards the flux sheet and a partially compensating deficit away from it (along centerward directed lines of sight), causing the extra width of the dark lane.

Going from center to limb, the increasing obscuration of the "hot wall" by the disk-center "edge" of the flux-sheet depression is compensated for by the increasing width of the limbward brightening. Therefore, the apparent (measured in the plane of the sky) size of faculae perpendicular to the solar limb stays fairly constant over a wide distance towards the limb as observed by Auffret & Muller (1991) and different from what would be expected of "hot wall" obscuration alone or of foreshortening effects.

References

Auffret, H. & Muller, R. 1991, *ApJ* **246**, 264–279

Lites, B. W. Scharmer, G. B., Berger, T. E., & Title, A. M. 2004 *Sol. Phys* **221**, 65–84

Spruit, H. C. 1976, *Sol.Phys.* **50**, 269-295

Spruit, H. C. 1977, *Sol.Phys.* **55**, 3-34

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