Solar and Stellar Activity: Similarities and Differences
ASP Conference Series, Vol. 158, 1999
C.J. Butler and J.G. Doyle, eds.

Can Chromospheric Activity Mimic a Polar Spot?

J.H.M.J. Bruls & M. Schüssler

Kiepenheuer-Institut für Sonnenphysik, Schöneckstr. 6, D–79104 Freiburg, Germany

S.K. Solanki

Institut für Astronomie, ETH–Zentrum, CH–8092 Zürich, Switzerland

Abstract. Doppler imaging studies indicate that most rapidly rotating cool stars seem to have high-latitude (polar) spots. It has been proposed, however, that the flat-bottomed cores of spectral lines that are interpreted as due to polar spots, might also be caused by chromospheric activity. A thorough NLTE radiative transfer analysis of 14 of the most-used Doppler-imaging lines shows that chromospheric activity can produce filling in of the profiles of the strongest lines only, and that flat-bottomed lines occur only if the activity is concentrated towards the poles. In the observations, however, also the weaker lines have flat-bottomed cores, so that it is unlikely that polar spots are an artifact due to misinterpretation of the spectral signature of chromospheric activity. On the other hand, we cannot exclude that chromospheric activity provides part of the filling in of the cores of some stronger lines.

1. Introduction

Many of the stars accessible to Doppler imaging, necessarily rapidly rotating and thus with high activity levels, have line profiles with a flat-bottomed core. This filling in of the line profile is nearly time-independent and it is generally attributed to large, stable and long-lived starspots at high latitudes: polar spots. In addition to the imaging results, the presence of spectral lines that are formed at lower than photospheric temperatures indicates the presence of extended cool spots on such stars. A theoretical explanation why those spots can be encountered at high latitudes has also been given (Schüssler & Solanki 1992, Schüssler et al. 1996). Nevertheless, polar spots have been a source of controversy, and in particular it has been speculated (e.g., Byrne 1992) that the filling in of the spectral line cores — the most direct evidence for polar spots — could also be due to chromospheric activity. Since the high rotation rate may influence the star's atmosphere, it is conceivable that lines that are considered photospheric in non-active cool stars show cores filled-in by chromospheric emission in more active stars (Basri et al. 1989).

From a radiative transfer point of view, one of the most compelling arguments against chromospheric activity being the cause of the flat-bottomed line profiles lies in the fact that they occur almost independently of the line strength.

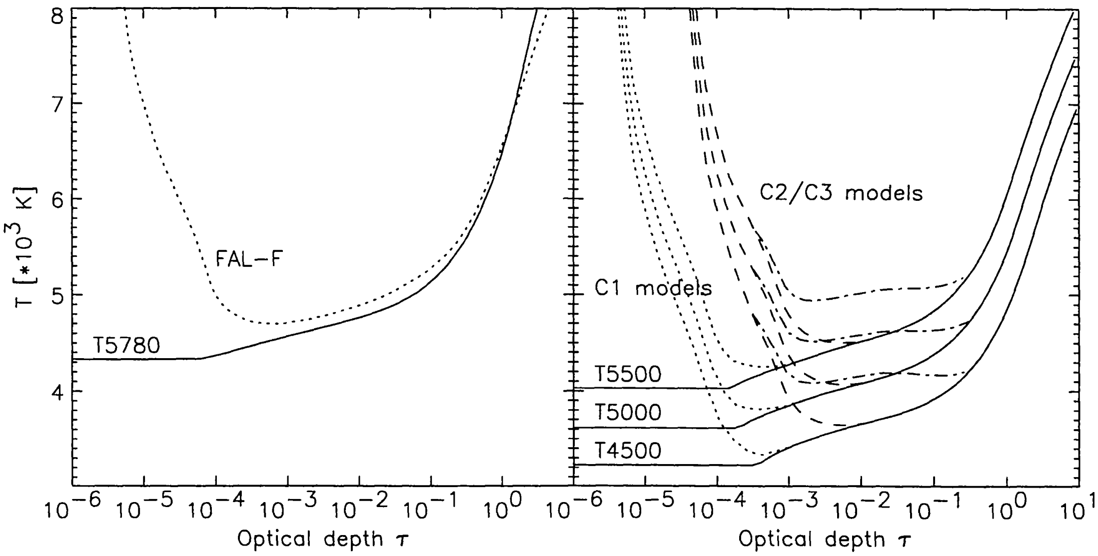


Figure 1. Temperature, T, as a function of optical depth τ at 5000 Å. Left: the solar models used to derive the temperature correction, ΔT, to represent chromospheric activity. Right: stellar models. Solid curves: inactive stellar atmosphere models with effective temperatures of 4500, 5000 and 5500 K; dotted curves: models with standard chromospheric activity (C1); dashed curves: models with increased chromospheric activity (C2); dot-dashed curves: C2 models with enhanced photospheric temperatures (C3).

This means that whatever is causing the filling-in of the line cores, it must be something that works over a significant height range in the atmosphere, not just in the chromosphere. We investigate the sensitivity of the profiles of 14 widely-used Ca I and Fe I Doppler imaging lines to chromospheric activity; the spread of line strengths is such that the formation heights of these lines cover a sufficiently large range in the atmosphere. A detailed account of this analysis has been given in Bruls et al. (1998); here we present the main results.

2. Chromospheric Activity Models

We use three atmospheric models of inactive stars with $\log(g) = 3.8$ and effective temperatures of 4500, 5000 and 5500 K, and the quiet Sun model T5780 (Figure 1), with a line blanketed radiative equilibrium model similar to those described by Edvardsson et al. (1993). An outward extension (isothermal layer in hydrostatic equilibrium) was appended to these models to allow some of the stronger lines to become optically thin.

Stellar activity is modelled by adding a schematic temperature rise $\Delta T(\tau)$ to an inactive stellar model and recomputing the hydrostatic equilibrium. Apart from a small offset to match the mid- and upper photospheric temperatures, the basic chromospheric temperature enhancement, ΔT^{C1}, is obtained by subtract-

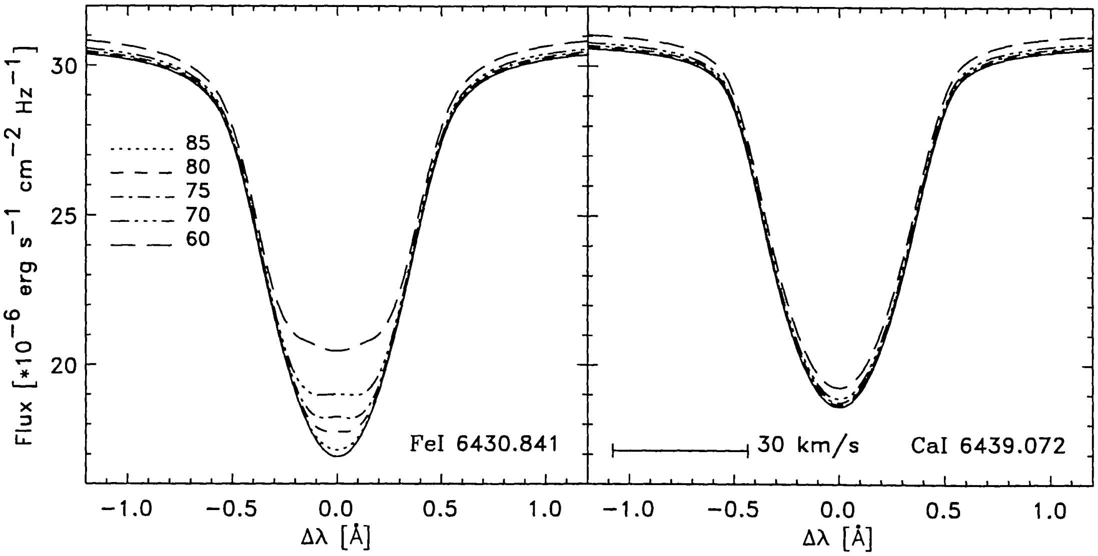


Figure 2. Rotationally-broadened line profiles of Fe I 6430 Å (left) and Ca I 6439 Å (right) for a star with $T_{\rm eff} = 4500$ K and a rotation rate of 30 km/s with T4500/C3 active regions of varying extent placed at the poles. The various curves are labelled with the latitude (in degrees) above which the T4500/C3 activity model is applied and below which the inactive T4500 model is present. The star's rotation axis is inclined by 45° w.r.t. the line of sight.

ing the temperature of the T5780 model from that of the FAL-F network model of Fontenla et al. (1991). As expected, the C1 models are similar to the very low ('basal') activity dwarf M star models of Mauas et al. (1997). The C2 models are obtained by shifting $\Delta T^{\rm C1}$ downward by one decade in optical depth, simulating a very early chromospheric temperature rise. The C3 models, finally, also have a photospheric temperature enhancement. $\Delta T^{\rm C3}$ was chosen such that $T(\tau)$ is almost constant throughout the photosphere; it is stronger than the photospheric temperature enhancement exhibited by FAL-F relative to T5780.

3. Computed Line Profiles

The line profiles emerging from the above model atmospheres (without rotation) can be summarized as follows. Only very few lines are sensitive to a chromospheric temperature rise. The two most prominent Doppler imaging lines, Fe I 6430 Å and Ca I 6439 Å, can actually be taken as representative of two groups of lines that sense the chromosphere to some extent. Fe I 6430 Å already notices a C1 type chromosphere, and its influence strongly increases with decreasing effective temperature; both the disk-center and the limb profiles are affected. Ca I 6439 Å, on the other hand, is only weakly sensitive. It requires the strong C2 chromospheric activity in combination with the T4500 model to induce noticeable line profile changes, and even then they occur mainly near the limb.

In the present case, we assume the chromospheric activity to be homogeneously distributed over the stellar surface, it requires an intensity enhancement near disk center (where the Doppler shift is negligible) and preferably in the line core to produce a rotationally-broadened disk-averaged profile with an enhanced core intensity. Only the Fe I 6430 Å line satisfies this requirement, but its line core does not have a flat bottom, because the strong limb emission also enhances the wings of the disk-averaged profile. The only way around this is to concentrate the chromospheric activity near the stellar poles, so that the rotation does not shift the line parts with largest emission into the wings of the disk-averaged profile. Due to projection effects, the influence on the line profile is more clearly visible if the rotation axis of the star is not perpendicular to the line of sight. The left panel of Figure 2 shows the line profiles of Fe I 6430 Å from the T4500 model with T4500/C3 activity within a certain area around the stellar poles. Indeed, the line core is filled-in and the remainder of the line profile is unmodified with respect to the inactive star's profile, but more importantly, for a certain size range of the polar active region, the core is virtually flat. The same results for activity type C2. The right panel of Figure 2 displays the corresponding profiles for the Ca I 6439 Å line. This line does not have a flat-bottomed core.

4. Conclusions

Figure 2 represents sort of a worst-case scenario — low effective temperature, extreme amounts of chromospheric activity concentrated towards the poles and a favorable inclination angle — and even then we find that we can produce flat-bottomed line cores only in a few lines.

Our analysis suggests that chromospheric activity cannot be the main cause of the flat-bottomed line cores that are observed on many active stars. We cannot exclude, however, that polar active regions, a magnetic phenomenon (as are starspots), contribute to the line core filling in stronger lines.

References

Basri G., Wilcots E. & Stout N., 1989, PASP, 101, 528

Bruls J. H. M. J., Solanki S. K. & Schüssler M., 1998, A&A, 336, 231

Byrne P. B., 1992, in P. B. Byrne & D. J. Mullan (eds.), Surface Inhomogeneities on Late-Type Stars, Springer-Verlag, p. 3

Edvardsson B., Andersen J. & Gustafsson B. et al., 1993, A&A, 275, 101

Fontenla J. M., Avrett E. H.& Loeser R., 1991, ApJ, 377, 712

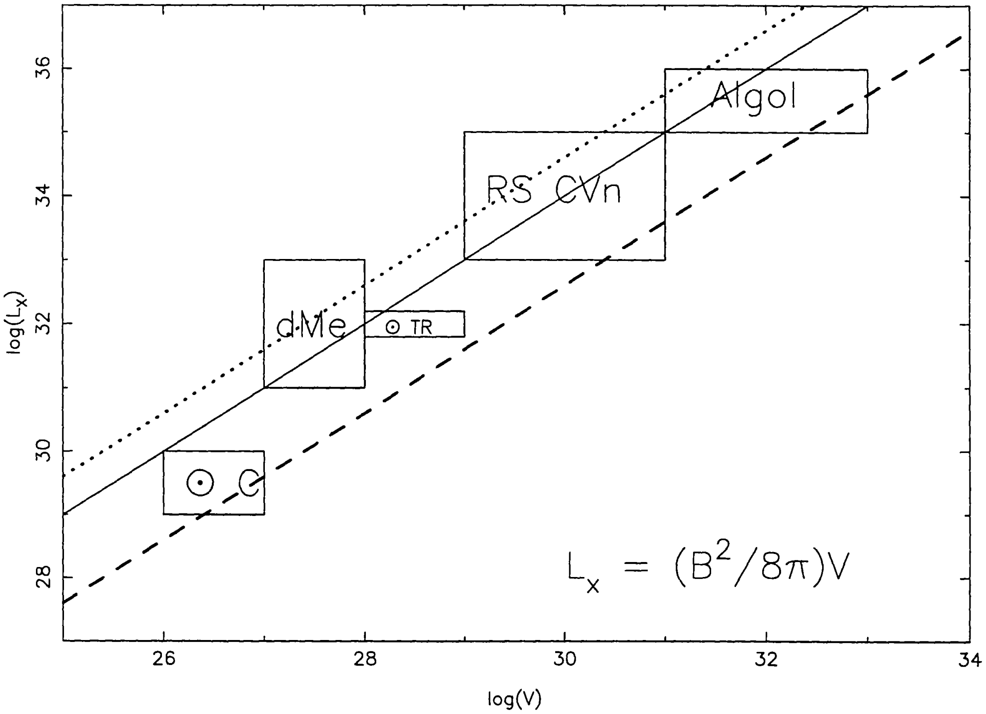
Mauas P. J. D., Falchi A., Pasquini L.& Pallavicini R., 1997, A&A, 236, 249

Schüssler M. & Solanki S. K., 1992, A&A, 264, L13

Schüssler M., Caligari P., Ferriz-Mas A., Solanki S. K. & Stix M., 1996, A&A, 314, 503

Part 4

PHYSICAL MANIFESTATIONS OF ACTIVITY: FLARES



Typical ranges of the X-ray losses and the flare volumes for dMe stars, RS CVn-systems and Algols as determined for *EXOSAT* observations. Also shown are the ranges for solar compact (C) and solar two-ribbon (TR) flares as observed during the solar maximum year in 1980. Older *EXOSAT* data are used to have a sample observed with a single instrument. The volumes have been obtained from the decay phase of stellar flares and have been measured for solar flares. The lines indicate the relation $L_X = (B^2/8\pi)V$ for values of the magnetic field at the flare site of 100 G (dashed), 500 G (solid) and 1000 G (dotted). The typical field strength is indicative at which height in the corona a flare occurs.