

SOME CONSTRAINTS ON CHROMOSPHERIC MODELLING FOR SOLAR-TYPE STARS WITH HIGH S:N SPECTRA

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ABSTRACT. High signal to noise spectra are required in chromospheric modelling because chromospheric emission lines are formed in a boundary layer under conditions of NLTE and in non-hydrostatic equilibrium, as well as in multiple magnetically-controlled streams, with horizontal structure on several scales, and vertical velocity fields. To obtain useable estimates of energy dissipation with height we have obtained sequences of spectra from F8 to K5 and for stars of different activity levels. These comprise Call H and K, the IR triplet, and MgII h and k obtained with the ESO CAT+CES or IUE. We outline the constraints such observations place on models and indicate theoretical and observational difficulties.

1. SEMI-EMPIRICAL MODELS

Solar physicists have produced semi-empirical model chromospheres (Vernazza et al., 1981) either from EUV continua, obtained using Skylab, or by modelling strong lines, Call H and K from the ground, or MgII h and k and Ly α from space (cf. OS08, Lemaire et al., 1981). The model of Vernazza et al (1981) is given in Fig. 1 showing heights of formation of features in a plane parallel, horizontally homogeneous model, with hydrostatic equilibrium and uniform microturbulence. Such models allow one to calculate net radiative losses in key lines: Ly α , H α , Call and MgII as functions of height, and show, grasso modo, which lines dominate the energy balance at each height.

2. INHOMOGENEITIES

Ca spectroheliograms, or EUV images, as in Fig. 2, show the inhomogeneity of the solar chromosphere on large scales for the plages or the network, and on small scales for the properties of elementary flux tubes. Multicomponent models are needed, of the quiet sun in the almost field-free supergranular cells, as well as of the network and of plages. There is growing evidence that inside flux tubes the temperature minimum is higher, and the chief cooling agent is H⁻, whereas outside flux tubes the temperature minimum is lower, and the chief coolant is CO, which dissociates much above 4000 K.

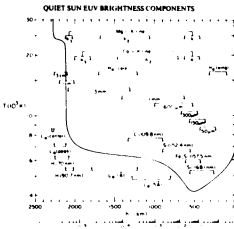


Fig1: Schematic one-stream model of temperature v. height in the chromosphere (Vernazza et al., 1981) indicating spectral features used to probe heights.

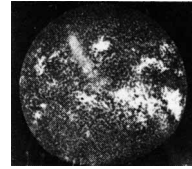


Fig. 2: EUV spectroheliogram, shown here to illustrate plages (white areas) network (light mottling) and cell (dark mottling) components, and the need for multi-stream models.

If such considerations are partially understood on the sun, it is correspondingly more difficult on stars without angular resolution. Among the resolved solar phenomena anticipated in other chromospheres are systematic downflows in the network, and time varying responses to shocks and oscillations which can introduce profile asymmetries. Network downflows have now been observed in MgII lines from dwarfs and giants (Vladilo et al., 1987).

3. OBSERVATIONS.

These have been of CaII H and K, and IR triplet lines at $\lambda/\Delta\lambda \sim 10^5$ with S:N >200 for bright solar-like quiescent and active dwarfs, using the ESO CAT+CES combination and MgII h and k with $\lambda/\Delta\lambda \sim 2 \times 10^4$ using IUE for some of these objects. For IUE a set of two-dimensionally extracted (Franco et al., 1984) absolutely calibrated spectra of stars strongly expected to be free of Local Interstellar Absorption were co-added to produce spectra of exceptionally high (for IUE) S:N, up to 100 in the continuum and 30 in the h1 and k1 minima. An example is shown in Fig. 3 for the quiescent G5 dwarf δ Pavonis. All spectra have been flux-calibrated, to compare with height-dependent predictions. In the case of the Ca H line, an extensive modelling programme has helped us to establish fluxes to $\pm 20\%$ in a heavily line-blanketed part of the spectrum.

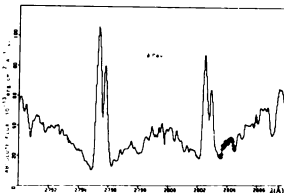


Fig. 3: MgII h and k emission from quiescent G5V star δ Pavonis. In this one of the highest S:N spectra from IUE yet published (S:N \approx 30 at h1 and k1, S:N \approx 100 in continuum) red-shifted h3 and k3 are clearly seen.

4. ACTIVE AND QUIET CHROMOSPHERES

With the aim of separating 'active' spectra from the spectra of the surrounding

cooler medium, we compare and subtract normalized spectra of quiescent stars from active stars of the same luminosity and spectral type. In Fig. 4 we show an example of such a comparison for H α and the Call triplet λ 8542 line for the active star ϵ Eri (K2V) compared with the quiescent object O₂ Eri (K1V). The differential spectra are indicators of the incremental emission of an "active" stream. Careful comparison with solar analogs will help yield an "atlas" set of ideal active and quiet profiles which can be modelled independently using monotonically varying models, and the classical tools of radiative line transfer.

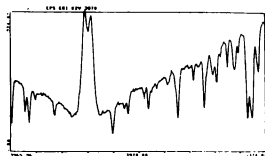


Fig. 4a: Call H emission from the chromosphere of the active dwarf ϵ Eri (using CAT+CES). Note strong emission and red-shifted h3 (downflow in network)

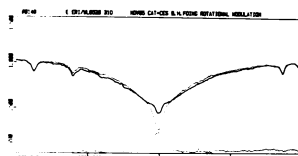


Fig 4b: Call IR triplet line at λ 8542 A for ϵ Eri (K2V) compared with same feature in quiescent star O Eri of similar spectral type (K1V). The different spectrum illustrates the net chromospheric flux from ϵ Eri.

5. VELOCITY FIELDS

The comparison of the MgII h and k profiles of the "quiescent" star δ Pav in Fig. 3, and the Call H profile of the active star ϵ Eri in Fig. 4 shows the common feature of red-shifted h3, k3 and H3. The presumption is that these features all sample downflow and hence all originate in the network. High S:N spectra, coupled with good absolute velocity calibration can supply true vertical velocity fields with reference to the photospheric rest frame and hence give dynamically valid model parameters (see Vladilo et al., 1987).

6. SYNTHESIS

Although we are still some way from chromospheric models which are anything other than schematic, high S:N, high resolution line spectra are beginning to show us when, and in what admixture, classical (NLTE, PRD) line transfer can be used to probe chromospheres and to what extent further refinements in these techniques are of no value when confronting real chromospheres because of boundary value constraints.

References

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