On the diagnostic contents of Na I lines in M dwarfs

V. Andretta, P. B. Byrne and J. G. Doyle

Armagh Observatory, College Hill, Armagh BT61 9DG, N. Ireland

1. Introduction

The Na I resonance doublet at 5890-5896 Å (D lines) is a prominent feature of the visible spectrum of cool stars. In active M dwarfs it can show rather strong core emission reversals, a typical chromospheric signature. However, not much work has been done so far to understand the diagnostic potential of these lines and, in general, of the Na I spectrum in cool stars. It would be especially interesting to ascertain whether Na I lines can give information that complements those available from other better-known chromospheric lines, like the hydrogen Balmer series.

2. Calculations and Results

In our calculations we have utilised a modified version of MULTI, a code for non-LTE radiative transfer by Carlsson (1986). The sodium model atom is essentially that used by Caccin, Gomez and Severino (1993), with a few differences and the addition of a further stage of ionisation (Na⁺²). We considered the particular case of a star with $T_{\text{eff}} = 3700$ K, $\log g = 4.7$ and solar metallicity; the corresponding model photosphere is from Allard & Hauschildt (1995).

One potentially important problem, in cool stars, is the correct treatment of background opacities (mostly due to numerous atomic and molecular lines). We have added to the “standard” opacities calculated by MULTI, the line opacities kindly provided by Allard & Hauschildt (1995) together with their model photosphere. The effect of the additional opacity on the very broad wings of the D lines is remarkable: in practice the equivalent width is increased by almost a factor two. In fact, Tripicchio et al. (1995) show that the observed equivalent widths tend to be larger than theoretically expected (when line blanketing is not taken into account), and the later the spectral type, the larger the discrepancy.

To study the effect of chromospheric activity on Na I lines, we have superimposed to the base model photosphere several chromospheric structures, as illustrated in the upper-left panel of fig. 1. The effect on the D lines is clear; for the sake of comparison, the upper-right panel shows the response of Hα to the same chromospheric structure.

Given the often vigorous coronal activity of some M dwarfs, we have also explored the effect of an XUV coronal illumination on the ionisation equilibrium of sodium (the photoionisation cross-section of Na⁺ is at 262 Å). We adopted a spectral distribution typical of the quiet Sun (adapted from Tobiska 1991) multiplied by a factor $10^3$. For a stellar radius $R = 0.7 R_\odot$, such an illumination corresponds to an X-ray luminosity of about $1.5 \times 10^{29}$ ergs/s in the band 0.15–
4 KeV. The resulting line profiles are over-plotted in the lower panel of fig. 1 (thinner lines) and show that the effect is not negligible, at least for the most active M dwarfs.

Finally, a comparison of the formation depth of Hα lines with Na I D, shows that the cores of the latter probe the chromosphere at rather lower temperatures. Therefore we think that the Na I lines promise to be a good constraint for models of the lower chromosphere of active M dwarfs, effectively complementing the information given by Hα.

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References

Allard, F., and Hauschildt, P.H., 1995, private communication
Carlsson, M., 1986, Uppsala Observatory Internal Report n. 33