A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

1

LA-UR-85-3983

RECEIVED BY OSTI DEC 06 1985

CONF-8510265--1



TITLE: COMPARISON OF THEORETICAL AND OBSERVED SODIUM $D_2$ LINE PROFILES FOR TWO LATE-TYPE DWARFS

LA-UR--85-3983

DE86 003678

AUTHOR(S): D. C. Boice

SUBMITTED TO: Proceedings of the Fourth Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun. Held on 16-18 October 1985 at the Santa Fe Hilton

## COMPARISON OF THEORETICAL AND OBSERVED SODIUM $D_2$ LINE PROFILES FOR TWO LATE-TYPE DWARFS

D. C. Boice
Los Alamos National Laboratory
Los Alamos, NM 87545

### INTRODUCTION

For many years the Ca II H and K lines and the Mg II h and k lines have been used as chromospheric diagnostics to compute semi-empirical model chromospheres for late-type stars. However, since Johnson (1964) showed that the Na I $D_1$ and $D_2$ lines are collision-controlled in the atmospheres of late-type stars, only a few researchers have studied the detailed NLTE formation of these lines. Here I summarize such a study for the two stars, EQ Vir (dK5e) and Gliese 616.2 (dM1.5e). A detailed discussion of this research can be found in Boice (1985).

High resolution observations of the D lines for these two stars have been obtained at the KPNO 4-meter Mayall telescope using the echelle spectrometer with a resolution of 0.158Å at $D_2$.

### MODEL SUMMARY

To solve the coupled equations of statistical equilibrium and radiative transfer for the neutral sodium atom the computational methods of Auer et al. (1972) have been used. Various assumptions are made in this approach which include the plane-parallel approximation, hydrostatic equilibrium, homogeneity of the atmosphere, Voigt profiles, and complete frequency redistribution (CRD) of scattered photons in the flux profile. The last assumption is justified by the success with which the $D_2$ line in the K2 giant Arcturus (Kelch, 1975) and in the Sun (Gehren, 1975) have been modeled using CRD. In the atmospheres of dwarfs with higher surface gravity it is reasonable to assume CRD, as the increased collision frequency would further destroy any coherency in the scattering process.

The model sodium atom consists of four bound states (3S, $3P_{1/2}$, $3P_{3/2}$, 3D) and a continuum. Following Athay and Canfield negligible splitting of the $^2D$ term. Collisional and radiative constants and other atomic parameters given by Schneeberger and Beebe (1976) have been adopted.

The transitions, $3S_{1/2}$ to $3P_{1/2}$ ($D_1$, 5895.9Å), $3S_{1/2}$ to $3P_{3/2}$ ($D_2$, 5890.0Å), and $3P_{3/2}$ to 3D (8194.8Å) are treated in detail. Photoionizations from the four bound levels are treated as fixed rates by specifying a radiation temperature $T_{rad}$ for each level.

Hartmann and Anderson (1977) have determined solar metal abundances for EQ Vir. In the absence of such a determination for GL616.2 and based on its galactic kinematics, a solar abundance has been adopted for this star also.

The photospheric temperature distributions from Mould (1976) are utilized, with $T_{eff}$ = 4250K and log g = 4.75 for EQ Vir and $T_{eff}$ = 3500K and log g = 4.75 for GL616.2. The chromospheric thermal and dynamic structure that Giampapa et al. (1982) adopted to model the Ca II K lines of these two stars are adjoined to the photospheres at the temperature minimum.

## RESULTS AND DISCUSSION

Numerous $D_2$ flux profiles have been computed to test the sensitivity of the calculations to the sodium abundance, the van der Waals interaction constant, and the $T_{rad}$ of the photoionizations. The $D_2$ line is sensitive to variations in $T_{rad}$ because this directly depopulates the 3S and 3P states by photoionization so that small changes affect the number of absorbers of this minority species. To assess the sensitivity of the line profile to this parameter, it is allowed to vary by 10%. Uncertainties of a factor of two are typically associated with abundance analyses. The effect of varying the abundance by 100% is investigated. The van der Waals interaction constant is the least well-determined atomic parameter and has been cited by Holweger (1971a, 1971b) as being in error by as much as a factor of 6. This parameter is allowed to vary by 50% in the calculations.

For EQ Vir the synthetic profiles were convolved with the instrumental and rotational ($v \sin i$ = 10 km/s) broadening functions. The result is a set of synthetic profiles which comfortably bracket the observations. The only discrepancy is the slightly darker wing of the observed profile due to blending with the

The synthetic profiles for GL616.2 are convolved with the instrumental broadening function and reasonable agreement is found throughout the flux profile except for within 0.25Å of the core. The synthetic profiles are not able to model the observed central reversal. Considering the variation of the line source function $S_\nu$ with depth, it is noticed that the coupling to the local temperature is weak. $S_\nu$ thermalizes deep in the photosphere but becomes less responsive to changes in the temperature before the temperature minimum is reached. At this point $S_\nu$ shows little response to the chromospheric temperature rise and the effects of scattering are already seen in the synthetic line.

## CONCLUSION

This study finds that the theoretical $D_2$ line profiles are in general agreement with observations when a reasonable assessment of the errors in the model parameters are considered. This leads to the conclusion that chromospheric models constructed using Ca II K line information are consistent with the observed sodium $D_2$ line for these two dwarfs. The central reversal in the observed $D_2$ line of GL616.2 is not accounted for in this study. This anomolous feature may be the result of emission from a circumstellar gas shell or may be evidence of another component in the stellar chromosphere.

I am grateful to acknowledge H. Beebe for useful discussions and R. Robinson and S. Worden for allowing me to assist them in obtaining the observations. This research was carried out while I was a graduate student at New Mexico State University.

## REFERENCES

Athay, R.G., and Canfield, R.C. 1969, Ap.J., 156, 695.
Auer, L.H., Heasley, J.N., and Milkey, R.W. 1972, K.P.N.O. Contrib. No. 555.
Boice, D.C. 1985, Ph.D. Thesis, New Mexico State University.
Gehren, T. 1975, Astr. Ap., 38, 289.
Giampapa, M.S., Worden, S.P., and Linsky, J.L. 1982, Ap.J., 258, 740.
Hartmann, L., and Anderson, C.M. 1977, Ap.J.(Lett.), 217, L67.
Holweger, H. 1971a, Astr. Ap., 10, 128.
__________ 1971b, Astr. Ap., 12, 319.
Johnson, H.R. 1964, in Proceeding of the Second Harvard-Smithsonian Conference, p. 333.
Kelch, W.L. 1975, Ap.J., 195, 679.