PRESSURE SHIFTS OF METAL LINES IN COOL WHITE DWARFS

Gordon L. Hammond
Astronomy Program, Department of Mathematics
University of South Florida, Tampa, FL 33620

Abstract

Model atmosphere techniques and an experimentally confirmed theory of collision broadening of CaII H and K by helium have been combined to show that the difference in velocity shifts for the two lines is a sensitive diagnostic for the H/He abundance ratio in cool, metallic line white dwarfs.

I. Introduction

Greenstein (1972) discussed the role of pressure shifts in his analysis of the radial velocity of the DZ8 van Maanen 2. He measured a discrepancy of 29 km/s in velocity of the two fine structure components, H and K, of CaII. Now that high resolution spectra of DZ stars are becoming available (see, for example, Wagner, Sion, Liebert and Starrfield 1988; Liebert, Wehrse and Green 1987), and the theoretical approach to neutral collision broadening has recently improved beyond the classical treatments of van der Waals and Lennard-Jones interaction potentials, a more precise study of pressure shifts in these high density atmospheres seems warranted.

The goals of this work are to provide corrections to observed radial velocities for more accurate gravitational redshift determinations, and to determine if the fine structure shift behavior might provide evidence of the H/He ratios. This evidence can be crucial in studies of accretion hypotheses (e.g., Aannestad and Sion 1985; Zeidler, Weidemann and Koester 1986).

II. Collision Broadening and Shifts

Laboratory measurements of both broadening and shifts of CaII H and K by helium under white dwarf atmospheric conditions were made by Hammond (1975). Those damping constants were used in a white dwarf model atmosphere program (Hammond 1974), but the experimental shifts were small and the temperature range was too small for accurate determination of the temperature dependences.

A recent theoretical study of the perturbation of both H and K lines of CaII by helium collisions was made by Monteiro, Cooper, Dickinson and Lewis (1986) using model potential methods. That work predicts broadening and shift parameters under impact approximation conditions, and the temperature dependence of these quantities.

346

The excellent agreement between experiment and theory for the damping constants has already been described (Hammond 1987). The agreement for shifts is shown in Figure 1, where least squares fits to both theory plus experiment (a), and to theory alone (b), are shown. Aside from some numerical noise in
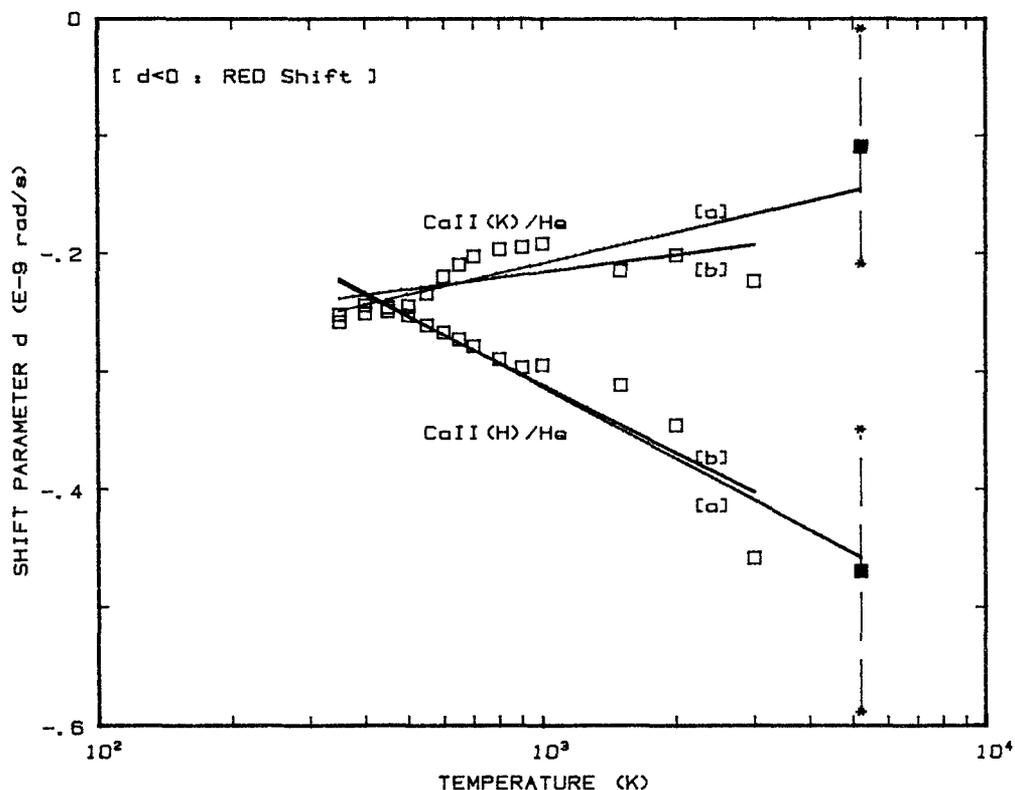

Fig. 1-- Temperature dependence of the CaII H & K line shift parameters. The experimental points (filled squares) show the probable errors from nine measurements at an average temperature of 5200 K.

the theoretical points (open squares), there is good agreement in magnitude, temperature dependence, and shift direction. The fits for theoretical plus experimental points, (a), have been added to the model atmosphere code.

III. Model Atmosphere Program

The early form of the code was written by Bell (1970) for work on G and K giants. Hammond (1974) modified it to treat high gravity stars, paying close attention to obtaining flux constancy in the presence of strong convection. The program yields flux-constant, non-grey, LTE models, and calculates UBVRI and uvby colors and several MCSP colors (Greenstein 1984). The H and K line

347

profiles are calculated at 2 Å intervals from 3888 to 4012 Å. The line fluxes
are convolved with an instrumental slit function of 4 Å half-width. The wave-
length shifts are measured by fitting a trigonometric series expansion to the
line cores. The wavelength of the bisector of the core can thus be determined
to 0.05 Å (4 km/s). This technique simulates the Greenstein Grant machine
method used on photographic spectra, and is applicable to electronic spectra
where noise at the minima also reduces precision. The fitting function also
can fit the asymmetric profiles exhibited by the cool, helium rich models.

IV. Results and Discussion

      Inspection of Fig. 1 indicates the H line shifts much more than the K
line at temperatures greater then 1000 K, and the difference in shift,
V(H)-V(K), will then be a function of atmospheric pressure. That pressure, in
turn, will be a function of the H/He ratio due to the differing opacities of H⁻
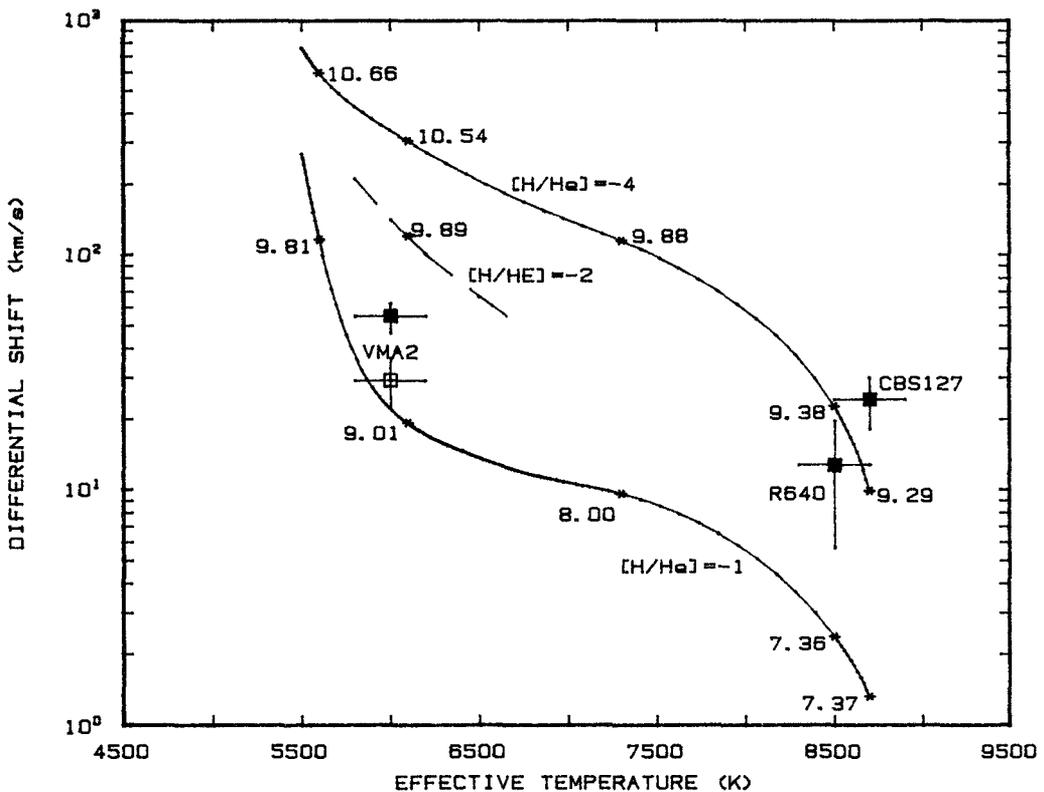and He⁻. It only remains to determine the magnitude of the differential shift.

Fig. 2-- Differential shifts from the model grid and observational data.
Points (*) on the curves are labeled with log Pg at tau=0.10. The filled
squares are from data supplied by Sion (1988); the open square is from
Greenstein (1972).

The results from a grid of models with effective temperatures from 5600 K
to 8700 K and H/He abundance ratios from 10% to 0.01% are shown in Figure 2.
All models were calculated with log g = 8.0, and the metal abundances were
adjusted to yield equivalent widths of H plus K of about 35 Å, a value typical
of cool DZ stars.   The upper limit of 10% hydrogen was dictated by the lack of
data on the shifts of H and K by hydrogen collisions.   The grid models are
labeled with log Pg at tau = 0.10; the curves are empirical cubic spline fits.

There is a clear separation of the helium rich models from the hydrogen
contaminated models; the differential shift increases by about 1 dex for the
helium rich models at any effective temperature.   At differential shifts
greater than about 50 km/s, the core of the H line becomes noticeably red
asymmetric due to the high gas pressures and large shift parameters.   This is
also the regime where the impact approximation becomes invalid for the line
wings (helium number densities greater than 5.E+21/cc), and the regime where
departures from the ideal gas equation of state may become important. It
remains to be seen whether any real DZ stars exhibit such large differential
shifts and asymmetry.

The differential shift for vMa2 (open square, Greenstein 1972) and for
several DZ stars with high resolution electronic spectra (filled squares, Sion
1988) are shown in Fig. 2; the effective temperatures are from matching model
and observed colors and continuum fluxes. The agreement between the old photo-
graphic measurements and the new data for vMa2 is good and indicates a H/He
ratio between 1% and 10%, a result that agrees with a determination from
infrared colors (Hammond 1974).   The result for Ross 640, log(H/He) = -4,
agrees with the hydrogen abundance found by Liebert (1977) from very weak
Balmer lines.   Several other cool DZ stars with strong H and K lines have been
observed at high resolution by Sion (1988) and are now being analyzed in the
above fashion.   The present results show that the differential shift, coupled
with accurate effective temperatures, can reveal the H/He abundance ratio in
cool DZ stars within quite narrow limits.

References

Aannestad, P. A., and Sion, E. M. 1985, A. J.,90,1832.
Bell, R. A. 1970, M.N.R.A.S.,148,25.
Greenstein, J. L. 1972, Ap. J.,173,377.
Greenstein, J. L. 1984, Ap. J.,276,602.
Hammond, G. L. 1974, Ph.D. Dissertation, University Maryland, College Park, MD
Hammond, G. L. 1975, Ap. J.,196,291.
Hammond, G. L. 1987, Bull. AAS,19,755.
Liebert, J. 1977, Astr. Ap.,60,101.
Liebert, J., Wehrse, R., and Green, R. F. 1987, Astr. Ap.,175,173.
Monteiro, T., Cooper, I.,Dickinson, A., and Lewis, E. 1986, J. Phys. B,19,4087
Sion, E. M. 1988, private communication.
Wagner, R., Sion, E. M., Liebert, J., and Starrfield, S. 1988, Ap. J.,328,213.
Zeidler-K.T., E.-M., Weidemann, V., and Koester, D. 1986, Astr. Ap.,155,356.