RADIATIVE TRANSFER EFFECTS ON THE COLORS OF RR LYRAE STARS

C.G. Davis
University of California, Los Alamos National Lab.

ABSTRACT. The methods of Davis and Cox (1980), are applied to a series of models described by Bono and Stellingwerf(1994) to determine the colors of RR Lyrae stars. Convection is ignored and the radiation flow is treated by a complete variable Eddington, multi-frequency dependent radiative transfer approximation.

Key words: Stars: RR Lyr–type; radiation transfer

1. Introduction

The application of the method of variable Eddington multi-group radiative transfer to the problem of colors of pulsating stars was started in Art Cox's group (J-15) in 1965. We initially addressed the question for cepheids in lieu of the "bump" mass discrepancy problem (Davis, 1971). As determined, the effects of a multi-frequency dependent radiative transfer calculation(mfrt), on the light curves of Cepheids is small. (Keller and Mutchlecner, 1971). The "bump" mass discrepancy problem was resolved by new opacities that include more detailed line calculations (Moskalik, Buchler and Maron 1992). Believing that effects from the mfrt approximation are more important, as compared to the usual equilirbiun diffusion approximation, as we go to higher luminosity to mass pulsating stars, we decided to study a model of W. Virginis, first proposed by Christy (1966). The effects of mfrt, over Christy's diffusion model, was to cause a standstill in the light curve that more closely agreed with the observations, (Davis, 1972 and 1974). This model also showed alternations in the minimum and maximum of the velocity curve which is an indication of period doubling and then an extension towards chaos(Buchler and Kovacs 1987). The process is observed in RV Tauri stars (Tsesevich, 1975). In 1972, working with Art Cox, we decided to apply these techniques to the question of the appropriate color average for pulsating stars, The result was that the $\langle B\rangle - \langle V\rangle$ average is the most appropiate for cepheids (Cox and Davis, 1975) and RR Lyrae (Davis and Cox, 1980) stars. In this paper we discuss further application of our mfrt approximations to obtain colors for a series of models proposed by Bono and Stellingwerf (1994). As expected the effects on the luminosity's is to increase the flux over the diffusion flux and therefore result in an increase color temperature for these RR Lyrae models of from 2 to 300 K. This increase more closely agrees with the star's steady state temperature.

In section II we briefly describe the hydrodynamic models and in section III the mfrt results. A discussion of the resulting colors and conclusions is given in section IV.

2. Hydrodynamic models

To conserve computer time we run the initial phase of the models using a non-equilibrium diffusion form of the radiative transfer until near limiting amplitudes are obtained. The hydrodynamic models are standard with quadratic pseudo-viscosity (4) and a simple cutoff (0.001). The opacities are KingIA tables from Los Alamos. The models are initiated using an LNA code and 100 zones with 10 zones in the optically thin region of the atmosphere and initial fundamental driving amplitude of 10 Km/s at the surface. We studied most of the models included in BS. From the linear analysis of the

BS model 3.40 we found a fundamental period, $P_0 = 0.532$, compared to a $P_0 = 0.527$ from BS (table 3).

3. Multi-frequency radiative transfer (mfrt) results for selected models

Do to space limitations we limit our discussion here to a general results only, leaving the details to a paper to be presented elsewhere. The hydrodynamic models (secII) are restarted using a multi-frequency set of opacities. In this case we used 13 groups located over the expected Planck distribution and with attention to selected edges, the Balmer edge for instance. Runs continued with the Gray opacities, and for the set of model parameters; Luminosities ($\log(L/L_\odot) = 1.81, 1.72, 1.61, 1.51$) and effective temperatures ($6000K < T_{eff} < 7500K$) as defined in BS, for comparison to the multi-frequency runs. General conclusions on colors will be given in section IV. The morphology of our light curves, grey and mfrt, for a model at L=1.51 and $T_{eff} = 6800K$ agrees fairly well the result in BS (fig.16). The light curve has a sharp spike before light maximum. Bono defines this model as a possible double mode pulsator. One major difference in the comparison of our models to those in BS, is not only the effect of convection, but in the amplitude of the velocity excusion. Our limiting amplitudes are considerably lower and the effect is undoubtalby due to the treatment of pseudo-viscosity.

4. Colors and Conclusions

The $\langle B\rangle - \langle V\rangle$ colors as estimated in the manner described in DC are closer to the correct static Teff values using mfrt than for diffusion, i.e. approximately 300K closer. For a model at 7000 K and $\log(L/L_\odot) = 1.72$ we get $\langle B\rangle - \langle V\rangle = 0.22$ and a $T_{eff} = 6850K$. Bono, Caputo and Stellingwerf (1997) find a $\langle B\rangle - \langle V\rangle = 0.231$ in general agreement with ours (table 19). Our slope in luminosity ($\log(L/L_\odot)$) versus $\langle B\rangle - \langle V\rangle$, at $T_{eff} = 7000K$, is steeper than theirs which in their case is almost constant at 0.23. From these results it still appears necessary to calculate the mfrt atmosphere if one is interested in obtaining the correct colors. As far as locating the appropiate velocity in the atmopshere a line transfer calculation of the mfrt atmopshere versus phase may be the preferred proceedure at present. An adaptive mesh may not be that necessary an could infact, as an implicit scheme, smooth out observables such as "bumps" or "dips".

References

Bono G., Stellingwerf R. F.: 1994, *ApJ Suppl. Ser.*, **93**, 233. (BS)

Bono G., Caputo F., Stellingwerf R.F.: 1994, preprint to ApJ.

Buchler J.R., Kovacs G.: 1987, *ApJ*, **320**, L57

Christy R.F.: 1966, *ApJ*, **145**, 337

Cox A. N., Davis C.G.: 1975, "Theoretical Mean Colors of Pulsating Cepheids" *Memoire Societe, Royale de Liege*, **6**, Serie Tome VI.

Davis C.G.: 1971, *JQSRT*, **11**, 647.

Davis C.G.: 1972, *ApJ*, **172**, 419

Davis C.G.: 1974, *ApJ*, **187**, 175

Davis C.G., Cox A.N.: 1980, in *Current Problems in Stellar Pulsation Instabilities, ed. D. Fischel, et. al.* (NASA TM 80265), 293. (DC)

Keller C., Mutchlecner J. P.: 1971, *ApJ*, **167**, 127

Moskalik P., Buchler J. R., Maron A.: 1992, *ApJ*, **385**, 685.

Tsesevich V. P.: 1975, in *Pulsating Stars, ed B. V. Kukarin* (New York: J. Wiley), 112.