THE IMPORTANCE OF RADIATIVE TRANSFER IN STELLAR PULSATION MODELS

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Abstract. With the advent of new astrophysical opacities it seems appropriate to discuss the need for a full radiative transfer (RT) theory instead of the usual equilibrium diffusion theory used in most nonlinear pulsation codes. Early studies on the importance of RT in the calculation of light curves for Cepheid models showed little effect over diffusion theory. The new opacities though may help to explain the "bump" mass discrepancy problem. For RR Lyrae models the use of RT theory causes some effects both in the color differences (U-B) as well as in the light curves. New opacities help to explain the period ratios for double mode RR Lyrae and beat Cepheids. A new area of research is in the modeling of stars with high luminosity to mass ratios that show tendencies for doubling and transitions to chaos, such as W Virginis and RV Tauri stars. For these stars it has been shown that RT is necessary in calculating their light curves and that the understanding of the shock dynamics depends on the transfer of lines in the pulsating RT dependent atmospheres (Fokin 1991).

1. Introduction

Considerations of the effect of RT as opposed to equilibrium diffusion theory on the light curves of pulsating stars has been studied since the early 60s. The early nonlinear pulsation models used the simpler approximation of equilibrium diffusion to calculate light curves. Because color bands were being used extensively (for example, U, V, B) in observing pulsating stars and the evidence of shocks from line spectra were being observed in RR Lyrae and W Virginis stars, it seemed appropriate to consider multigroup RT in our nonlinear stellar pulsation models. At this time (1965), the computers were also becoming more capable of handling these larger sets of equations with finer zoning and multigroup opacity tables necessary for RT calculations.

2. Radiative Transfer Models of Cepheids RR Lyrae and W Virginis Stars

While Castor and Christy were doing RT in RR Lyrae models, we concentrated initially on Cepheids and the importance of RT in the calculation of their light curves. We increased the normal zoning (usually around 60 zones, also used by Christy) to 72 zones and retained 7–11 zones in the optically thin region. The results confirmed our expectation that the effects would be small. Only small variations in the light curve around the region where the shock transits the atmosphere (near the so called pseudo-viscosity dip) occurred. The static structure would then be used with a snapshot analysis at

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a finer frequency grouping to obtain the colors. All these frequency grouped opacities were formed by using Rosseland means from the Cox-Stewart opacity tables.

For our RR Lyrae studies we concentrated on developing improved colors and the proper estimate of the mean color relation. The importance of RT on the light curve was only studied in one case (for a model of SW Andromadae)(Davis 1976). In this study there were indications that RT was important, not only from the effect on the excess U-B, but also on the limiting effect on the magnitude of the variation of M_{bol}. Following this work, Simon and Aikawa (1986) used models from Hill and Castor and showed that improved Fourier coefficients of $\phi 21$ and $\phi 31$ could be obtained from an RT model as compared with the usual diffusion or a convection model. There is a need in RR Lyrae modeling to do a more careful RT calculation with extended atmospheres and detailed zoning. In this regard, a recent paper (Ishida and Takeuti 1992) on zoning improvements to better understand the physics in Cepheid atmospheres should be consulted.

Finally we are convinced that RT is necessary in calculating the light curves for the high luminosity to mass stars such as W Virginis and RV Tauri. Our paper on a W Virginis model (Davis 1972) attest to this fact as well as the recent work of Fokin (1991).

3. The New Opacity Tables

With the advent of new astrophysical opacities (Iglesias et al. 1987, Daeppen 1991), it seems prudent to consider improved ways of handling these opacities in our RT coupled hydrodynamic codes. We should consider new methods to include these results such as "transmission means" (Freeman 1965) or possibly "multiband" methods (Cullen and Pomraning 1980) for further calculations.

4. Conclusions

There is the possibility that time-dependent convection will be added to our models in the near future. There is still a need for an improved radiative transfer coupled hydrodynamic code using the new opacities, and with a dynamic zoning algorithm to resolve the time-dependent structure of the atmospheres of these pulsating stars.

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