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Fluorescent Clues for the Atmospheres of AGB Stars

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Abstract. Coincident IUE and McMath–Pierce telescope observations for the asymptotic giant branch (AGB) stars R Leo (M8 IIIe, M) and R Lyr (M5 III, SRb) were made to investigate the differences between the atmospheric structure of Mira-type and semiregular variables through the Fe I (42) lines at 4202 and 4308 Å. These lines are fluoresced by the Mg II lines near 2800 Å. Fe I (42) peak flux occurs at the same phase as the Mg II lines, which corresponds to a ∼0.3 phase lag behind the peak Balmer line flux. This phase lag results from the existence of a permanent chromosphere in the shocked Mira atmosphere. The Fe I (42) lines in the semiregular variable do not vary from changes in the Mg II flux, indicating the circumstellar shells of semiregulars are not as optically thick as Miras.

1. Introduction

Mira variables are pulsating red giants which vary in brightness by at least 2.5 magnitudes at visual wavelengths at a somewhat regular basis over a period from 150 to over 500 days. Their spectra show strong Balmer emission lines and strong Fe I lines at visual wavelengths and strong Mg II and Fe II at UV wavelengths. Meanwhile, light variations of semiregular variables are less regular and not as extreme in brightness variation. Spectra of R Leo and R Lyr in the blue on various dates were taken with the McMath–Pierce telescope. During this four year monitoring program, nearly coincident IUE observations were obtained for these stars. This is the first coordinated UV/visual survey of Mira variables.

2. Observations

The Fe I (42) emission lines at 4202 and 4308 Å in Miras are fluoresced by the Mg II *k* line via an Fe I (UV3) transition at 2795.0 Å. Fe I (42) reaches greatest flux near phase 0.30 before weakening. This phase is coincident with the peak flux of the Mg II lines. Meanwhile, Hγ reaches greatest flux near phase 0.0 (maximum visual brightness). Hγ weakens as the Fe I (42) lines strengthen.

Comparisons between the IUE spectra of the Mira star R Leo and the semiregular variable R Lyr show that the semiregular's Mg II lines are more symmetric than those of the Mira. R Lyr's lines show that the blue side of the *k* line is weaker than the red side, whereas this is not the case for the *h* line. This results from overlying absorption of Mn I (UV1) at 2794.8 Å and Fe I (UV3).

which gives rise to the Fe I (42) emission lines in Miras. The Mg II lines in the Mira are blueshifted with respect to the photospheric rest frame.

3. Results

Dynamic models representative of Miras (Bowen 1988), where dust opacity is negligible, present a chromosphere (or calorisphere) that exists throughout the entire pulsation cycle. NLTE radiative transfer calculations have shown that the emission portions of the Mg II lines form at τ(line–center) = $10^3 - 10^4$ (Luttermoser & Bowen 1992). Meanwhile dusty models do not display such a chromosphere. In the non–chromospheric models, these τ's are not encountered until the innermost shock is reached. Emission lines result with maximum fluxes occurring near phase 0 and at the same time as the peak Balmer line flux. In the chromospheric model, these τ's occur in the chromosphere, whereas the opacity in the Balmer lines is not high enough for these lines to form there — they still form in the innermost shock that lies between the photosphere and chromosphere. Also, this inner shock enhances the continuum under the Mg II lines, which produces Mg II absorption at this phase. However, once the innermost shock propagates out to the chromosphere, the H lines and the UV continuum reduce in strength and the chromosphere heats slightly, causing Mg II to go into emission. The models predict a phase lag of ~ 0.3 between the peak H flux and peak Mg II flux — just as is observed! The fact that the Fe I (42) flux variation matches the variations of the emergent flux of Mg II, indicates that the Fe I (42) emission arises from depths above the Mg II emitting regions.

Little if any variation is seen in the Fe I (42) absorption lines in R Lyr when a maximum change in the Mg II flux ($\sim$ 30%) occurs. Since there is sufficient flux in the Mg II lines to pump Fe I (42) in this star, the lack of Fe I (42) variation dictates that the optical (hence geometric) thickness of the circumstellar shell in R Lyr (and perhaps in all semiregulars) is much less than that of Mira stars. Based upon semiempirical, chromospheric modeling of semiregulars (Luttermoser *et al.* 1994), the chromospheric emission from SRs must arise in regimes where hydrodynamic and not hydrostatic processes exist. This suggests that the semiregular stars may be *weaker* versions of the Mira stars. If this is the case, pulsational shocks heat a chromosphere (just as they do in Miras), but the innermost shocks never achieve temperatures greater than 5000 K since Balmer emission lines are not seen in the SRb variables.

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