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THE CHROMOSPHERE/SHOCK DILEMMA OF NON-MIRA, LATE-TYPE VARIABLE STARS

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The Chromosphere/Shock Dilemma of Non–Mira, Late–Type Variable Stars

L. A. Willson

Summary: This NASA grant covered the ISU portion of a collaborative program involving D. G. Luttermoser (ARC/ETSU), L. A. Willson and G. H. Bowen (both at ISU). The project concerned a detailed investigation of the atmospheric structure of non–Mira, asymptotic giant branch stars through NLTE radiative transfer modeling applied to hydrodynamic models. Synthetic spectra resulting from these calculations were compared with IUE observations of these stars to test the validity of the models. The ISU effort focussed on the development of the hydrodynamical models; these were combined with radiative transfer by collaborator Luttermoser who then also assumed primary responsibility for preparation of he papers presenting the results. We report here on the ISU portion of the effort but in the context of the broader project.

1 Summary of Findings

We proposed to investigate the similarity and differences between the atmospheric structure of Mira–type variable and semiregular–variable red giant stars through an analysis of previously obtained IUE data and NLTE radiative transfer calculations of hydrodynamic models representative of these stars. Miras are observed to have global shock waves that propagate outward through the outer atmosphere as the star pulsates, whereas semiregular variables have generally been modeled with a *classical* hydrostatic chromosphere in order to reproduce the UV emission lines seen in the spectra of these stars. The question asked in our proposal was: *Are global shock waves also present in the semiregular variables, making them dynamically similar to the Mira variables?*

Hydrodynamical models were computed for two representative semi-regular variables: **g Her** (M6 III) and **R Lyr** (M5 III). Comparison was made with a model and observations for a Mira, **R Leo** (M8 IIIe). These were chosen to facilitate comparison with previous work, as there were already hydrodynamic models for R Leo and static, chromospheric models for g Her and R Lyr.

Data available for comparison with the final results, obtained by Luttermoser in his part of the collaborative project, included IUE spectra obtained from the NSSDC (listed in Table 1) and ground–based spectra of these stars (obtained by Luttermoser with the McMath–Pierce telescope on Kitt Peak). These data were used to investigate the fluorescence processes that occur in these stars through high–dispersion (0.2 Å) spectroscopy in the 3900–4500 Å region.

Before hydrodynamical models could be constructed, inconsistencies among the physical parameters (*i.e.*, mass, radius, luminosity, effective temperature, and pulsational period) obtained from standard sources needed to be resolved. Since many of the input parameters are very uncertain (mass, radius, etc.), making modification to these parameters is valid, as long as the new values are consistent with the uncertainties of the published values. We reviewed the original papers containing the published parameters to check for this consistency. Table 2 shows our resulting input parameters for the hydrodynamic models. These final input parameters are consistent with Newton's law of gravity; the blackbody luminosity, radius, effective temperature relation; stellar pulsational theory for fundamental and first–overtone pulsators; the distance, angular diameter, radius relation; and V–K color, magnitude, and luminosity relations for cool stars.

In parallel with the observational work and data reduction by Luttermoser, detailed hydrodynamical models were calculated at ISU. NLTE radiative transfer calculations for both the hydrodynamic models and the hydrostatic models were then completed by Luttermoser. Figure 1 shows the C II] (UV0.01) intersystem multiplet for one of the hydrodynamic models and Figure 2 for one the hy-

Table 1: **IUE HI–DISP Spectra Obtained from the NSSDC**

Image Number	Star	Exposure Time	Date
LWP 06575	g Her	15 min	4 Aug 1985
LWP 06576	g Her	360 min	4 Aug 1985
LWP 09596	R Lyr	385 min	28 Nov 1986
LWP 11020	R Lyr	20 min	15 Jun 1987
LWP 13442	g Her	40 min	16 Jun 1988
LWP 13443	g Her	880 min	16 Jun 1988
LWP 19097	R Lyr	20 min	31 Oct 1990
LWP 19098	R Lyr	100 min	31 Oct 1990
LWP 25278	R Lyr	20 min	6 Apr 1993
LWP 25279	R Lyr	60 min	6 Apr 1993

Table 2: **Physical Parameters of the Sample Stars**

Parameter	R Lyr (M5 III)	g Her (M6 III)
Mass ($M_\odot$)	2.7	4.2
Radius ($R_\odot$)	170	435
Luminosity ($L_\odot$)	3700	19,000
Period (days)	53.0	89.0
Temperature (K)	3445	3250
Angular Diameter (mas)	15.9	23.7
Log g (cm/s^2)	0.4	-0.2
Distance (parsec)	98	250
M(V)	-1.0	-2.0
B-V	1.56	1.56
V-K	6.03	7.01
V(mag)	3.93	5.01
K(mag)	-2.10	-2.00

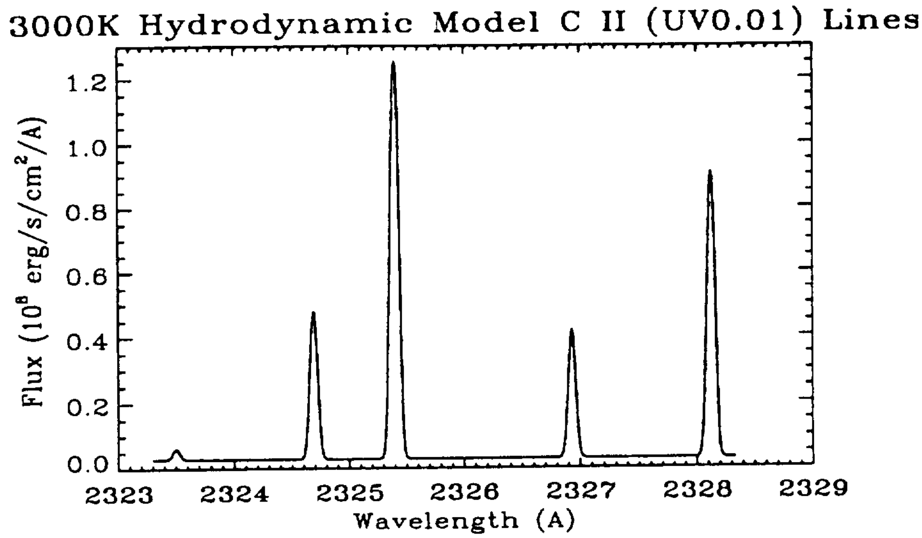

Figure 1: Synthetic spectrum of the C II] (UV0.01) multiplet for the 3000 K hydrodynamic model.

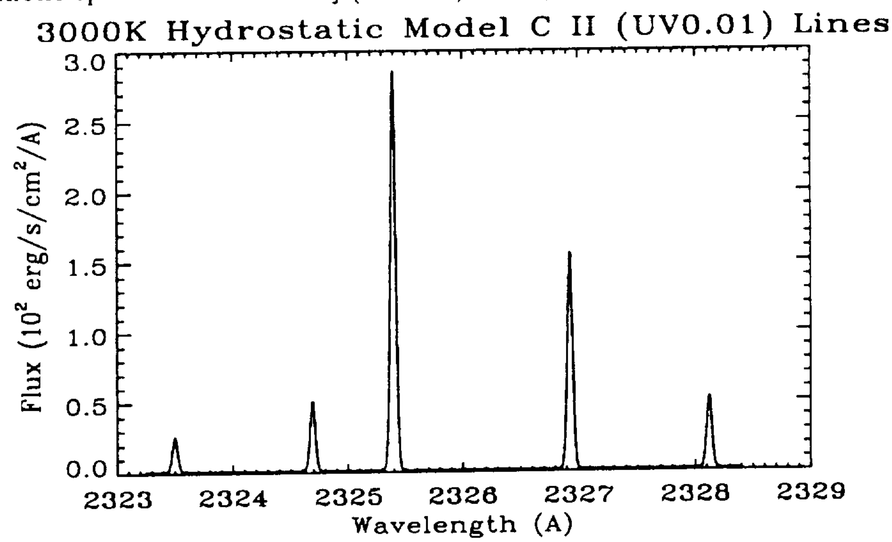

Figure 2: Synthetic spectrum of the C II] (UV0.01) multiplet for the 3000 K hydrostatic model.

drostatic chromospheric models. None of the hydrostatic models that we tried could produce the proper C II] line flux ratios (which are sensitive to electron density of the emitting gas) along with the observed Mg II h & k flux. However the hydrodynamic models, with their outward moving shocks, can produce the proper C II] line ratios in conjunction with realistic Mg II profiles for the semiregular variables.

In conclusion, the results of this work clearly indicate that the outer atmospheres of both Mira and semiregular variables are related in that both contain a *chromospheric-type* layer of enhanced temperature above the continuum formation depths <u>and</u> outward moving shocks (which produce this *chromosphere*). The only difference is the *temperature* reached in the shocks — a measure of the shock amplitude — the shocks in the semiregular variables had (T_{sh} < 8000 K) while in the Miras (T_{sh} > 8000 K), according to the best-fitting hydrodynamical models.

2 Papers and abstracts concerning this research:

The following papers reporting the results of this research are in various stages of preparation for publication, submitted, or in press. In addition, related papers have been published by Luttermoser concerning aspects of his part of the collaborative project; these are included in his final report on NAS5—32863.

- Luttermoser, D.G., Bowen, G.H., & Willson, L.A. 1997, *NLTE Synthetic Spectra for Hydrodynamic Models of AGB Stars. I. Hydrogen Spectra*, ApJ, (in preparation).
- Luttermoser, D.G., Bowen, G.H., Willson, L.A., & Brugel, E.W. 1997, *NLTE Synthetic Spectra for Hydrodynamic Models of AGB Stars. II. Ultraviolet Spectra*, ApJ, (in preparation).