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(NASA-CR-180603) IUE OBSERVATIONS OF Mg2 EMISSION FROM MIRAS Semiannual Report (Colorado Univ.) 6 p Avail: NTIS HC A02/MF A01 CSCL 03A
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This is the semi-annual report for NASA grant NAG5-350, *IUE Observations of MgII Emission from Miras.* During the past year, we have obtained 61 well exposed low dispersion LWP observations of the brightest normal M-type Mira variables around their pulsation cycles. Miras are large amplitude pulsators which occupy the tip of the asymptotic giant branch. They form a continuous sequence with the luminous but heavily obscured OH-IR sources. Progenitors for Miras are isolated stars with masses from 1 $M_\odot$ for the shortest period Miras to 6-8 $M_\odot$ for the OH-IR sources with periods of $\approx$ 1000 days. Mass loss during the Mira stage is almost certainly the mechanism which terminates red giant evolution for stars in this mass range, and this mass loss therefore probably determines both the typical masses of white dwarfs and the observed limiting luminosity of the asymptotic giant branch (Willson 1981; Willson and Bowen 1984, 1985). Observed mass loss rates for these stars are high enough to strip away the stellar envelopes in a few times 10^5 years, equal to the lifetime for these stars computed from their space density. These mass loss rates exceed those for non-Mira red giants of similar M, L, and R by at least an order of magnitude (Willson 1981).

By observing Mg II throughout the cycle, the intent is to determine the shock luminosity and duration, and the density in the upper atmospheres of Miras. These data also provide a mechanism for probing the radiative cooling in post-shock regions of the atmosphere as a function of time. This analysis is expected to yield useful information on the density structure of these highly extended atmospheres and ultimately on the mass loss process. Theoretical modeling calculations indicate that pulsation is the underlying cause of the enhanced mass loss, with radiation pressure on grains an important auxilliary mechanism for stars with $P > 300^d$. Models of the atmospheric structure of the pulsating Miras show that the mass loss rate during this key evolutionary phase depends strongly on the pulsation amplitude, i.e. the net input of the kinetic energy into the atmosphere. However the shock amplitude W_v is not very sensitive to this parameter. Instead as the amplitude is increased, the shocks form deeper in the atmosphere, and the density throughout the atmosphere increases, so that the power radiated by the shock increases. The best measure of the driving amplitude is thus the amount of radiation from the material behind the shock. The most obvious emission from this cooling post- shock material is in the Hydrogen Balmer and the ultraviolet Mg II lines. The Mg II h and k lines are better indicators of the shock behavior and the atmospheric structure than the Balmer lines for two reasons. First, the Balmer lines are badly mutilated by overlying absorption most of the time when they are present. Second, the Balmer lines require a shock amplitude > 20 km s^{-1} while the shock in Miras are expected to persist after their amplitudes are too small to excite the Balmer lines. Thus visible Balmer emission cannot be used to follow the shock into the upper atmosphere, into the region from which the wind originates; Mg II emission lines can.

For the second year of this two year program, we have been granted 6 shifts for the purpose of obtaining the necessary phase coverage as stated in our original proposal. The second year of observations are required in order to determine any cycle-to-cycle variations, which would affect the interpretation; and to fill in any missing phases.

A summary of the data acquired for IUE programs SRHLW and MGIEB under grant NAG5-350, is presented in Table 1.

Table 1 - Data Summary

L_2 PUP (Period 140 days; m_V range 3.4-6.2)

LWP	EXP (min)	JD 2440000+	FES-mag	MgII Flux ergs cm^{-2} s^{-1}
6091	30	6216	4.2	2.00×10^{-12}
6473	15	6271	4.2	1.00×10^{-13}
7435	35	6432	3.3	1.00×10^{-13}
7465	20	6438	3.2	1.00×10^{-13}
7681	45	6481	3.6	2.50×10^{-12}
7808	12	6507	4.2	2.00×10^{-12}
7970	15	6528	4.1	5.30×10^{-13}
8152	15	6557	3.5	1.00×10^{-13}
8350	15	6589	3.1	1.30×10^{-12}
8540	5	6616	3.8	4.00×10^{-12}
8868	3	6654	4.4	1.20×10^{-12}
9064	10	6686	3.5	7.10×10^{-13}
9389	15	6727	3.2	1.50×10^{-12}

R Hor (Period 402 days; m_V range 6.0-13.0)

LWP	EXP (min)	JD 2440000+	FES-mag	MgII Flux ergs cm^{-2} s^{-1}
7452	10	6435	8.0	3.20×10^{-12}
7469	15	6439	8.2	2.80×10^{-12}
7680	15	6480	8.9	1.70×10^{-12}
8153	20	6557	8.4	4.70×10^{-13}
8351	15	6589	8.0	2.50×10^{-13}
8539	30	6616	7.2	8.00×10^{-14}
8869	30	6654	5.3	1.00×10^{-13}
9040	30	6681	4.9	7.00×10^{-14}
9390	20	6727	5.3	3.50×10^{-13}

R Leo (Period 313 days; m_V range 5.9-10.1)

LWP	EXP (min)	JD 2440000+	FES-mag	MgII Flux ergs cm^{-2} s^{-1}
6095	45	6216	7.2	3.00×10^{-12}
7204	33	6399	4.4	1.20×10^{-13}
7467	20	6439	5.1	1.70×10^{-12}
8015	1	6533	7.4	2.50×10^{-11}
8151	1	6557	7.5	1.70×10^{-11}
8347	2	6589	6.8	1.00×10^{-11}
9395	55	6727	4.7	5.00×10^{-14}

S Car (Period 149 days; m_V range 6.9-11.0)

LWP	EXP (min)	JD 2440000+	FES-mag	MgII Flux ergs cm^{-2} s^{-1}
6093	45	6216	6.8	2.20×10^{-12}
7437	15	6433	6.1	1.00×10^{-13}
7451	20	6435	6.1	3.50×10^{-13}
7807	30	6507	6.3	2.20×10^{-12}
8542	20	6616	5.8	5.00×10^{-13}
8871	5	6654	6.2	1.20×10^{-12}
9041	5	6681	7.4	1.90×10^{-12}
9392	15	6727	6.1	6.80×10^{-13}

R Car (Period 308 days; m_V range 4.6-9.5)

LWP	EXP	JD	FES-mag	MgII Flux
	(min)	2440000+		ergs cm^{-2} s^{-1}
6092	30	6216	5.8	2.40×10^{-13}
6478	45	6271	4.3	5.00×10^{-14}
7450	20	6435	7.7	1.50×10^{-12}
7466	20	6438	7.7	1.30×10^{-12}
7806	20	6507	5.8	5.00×10^{-14}
8352	7	6589	4.0	1.00×10^{-13}
8541	20	6616	4.5	8.80×10^{-13}
8870	15	6654	5.6	4.40×10^{-12}
9065	5	6686	6.4	1.00×10^{-11}
9391	8	6727	7.3	8.30×10^{-12}

R Cen (Period 560 days; m_V range 5.9-10.7)

LWP	EXP	JD	FES-mag	MgII Flux
	(min)	2440000+		ergs cm^{-2} s^{-1}
6477	30	6271	7.7	5.00×10^{-13}
7470	30	6440	6.0	2.50×10^{-13}
8154	25	6557	5.9	6.00×10^{-14}
8349	30	6589	5.5	1.00×10^{-13}
8543	30	6616	5.7	1.00×10^{-13}
8867	30	6654	6.3	3.20×10^{-13}
9042	15	6681	7.1	3.70×10^{-13}

R Hya (Period 405 days; m_V range 4.2-9.5)

LWP	EXP	JD	FES-mag	MgII Flux
	(min)	2440000+		ergs cm^{-2} s^{-1}
6094	30	6216	4.9	2.90×10^{-13}
6476	30	6271	4.4	3.10×10^{-13}
7472	3	6440	5.5	1.80×10^{-11}
7679	2	6480	6.3	1.20×10^{-11}
8348	5	6589	4.9	6.10×10^{-13}
8544	15	6616	4.6	5.80×10^{-13}
8866	30	6654	4.5	1.80×10^{-13}

T Cep (Period 387 days; m_V range 6.1-10.1)

LWP	EXP (min)	JD 2440000+	FES-mag	MgII Flux ergs cm^{-2} s^{-1}
6475	30	6271	6.8	6.00×10^{-12}
7202	10	6400	6.5	1.90×10^{-12}
7439	30	6432	5.8	8.10×10^{-13}
7678	30	6480	5.8	1.20×10^{-13}
7968	15	6528	4.8	1.00×10^{-14}
8346	20	6589	5.1	1.60×10^{-12}
8538	10	6616	5.7	3.90×10^{-12}
8865	10	6654	6.6	6.00×10^{-12}
9063	3	6686	7.1	5.20×10^{-12}
9394	4	6727	7.4	2.60×10^{-12}

The above observations, while still incomplete, are consistent with our expectation that the shock which gives rise to the Mg II emission survives for more than one cycle in the atmosphere. Thus the hydrogen lines appear near maximum and fade near minimum; the Mg II lines appear later, and persist to or beyond the next maximum. The observational difference between R Car (Mg II disappearing before the next maximum) and R Hya (Mg II at roughly constant strength over the last quarter cycle) is consistent with a difference in the time that effectively isothermal (strongly radiating) shocks are expected to be present in the atmospheres of stars with different gravities and/or pulsation amplitudes.

Both on theoretical grounds and from the data sample obtained so far, we are convinced that the monitoring of Mg II emission from Miras will yield important information on the atmospheric structure and thus ultimately on the mass loss processes operating in these stars. In this context, we have presented an initial analysis for the star R Leo (Brugel, Willson and Cadmus 1986) at the London IUE symposium.

In conjunction with our IUE program, monitoring of the Hydrogen Balmer and other visible line emission is being carried out at the Grant O. Gale observatory of Grinnell College, Iowa under the supervision of Dr. R. Cadmus. The automated 24" telescope at the Gale Obsevatory is equipped with a spectrum scanner designed and built for the purpose of monitoring emission line strengths in Miras and related red long period variables. Combining the UV and optical data will give us a measure of shock activity throughout the cycle for at least the more northern objects. This also allows precise phasing of Hydrogen and Mg II emission for those stars, which is important because Miras are notorious for cycle-to-cycle variability.

The primary scientific datum obtained from each IUE LWP spectrum is the net intensity of the Mg II emission. Trends in Mg II emission with phase, with period of the star, and with spectral type will be investigated and compared with atmospheric models. Mg II strengths predicted from models for the shock waves in Mira atmospheres will be compared with the observed line strengths, and these compared with the H line emission when it is present. Also, the duration of the Mg II emission provides a constraint on the atmospheric structure: higher driving amplitude leads to higher densities, which means the shock is observable for a larger fraction of the cycle.

George Bowen (1987) at Iowa State University has been calculating theoretical models for the development and decay of shock waves in Miras as a result of subatmospheric pulsation. In conjunction with this project the relative importance of various cooling processes in the post-shock portion of the atmosphere is being investigated. In addition to being incorporated in the models, this information will be available for comparison with UV and optical observations. The first comparisons of observations and theory will be presented at the Turin, Poland IAU Colloquium 103, *The Symbiotic Phenomenon* - objects to which Miras are closely related.

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