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Phase Dependent Spectroscopy of Mira Variables

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Abstract:

Spectroscopic measurements of Mira variable stars, as a function of phase, probe the stellar atmospheres and underlying pulsation mechanisms. Modeling the atmospheres is difficult due to the hydrodynamic nature of the gas as deduced from the large light variations and velocity measurements of various spectral lines. Many questions still need to be resolved concerning the atmospheres of these stars. Are the depths of formation of the molecular species such as TiO, VO, and ZrO produced in an extended region above the layers where Balmer line emission occurs or below this *shocked* region? What is the explanation for the Balmer–line *increment*, where the strongest Balmer line at phase zero is Hδ and not Hα? Furthermore, why is the Hϵ line virtually absent in the spectra of Miras when the other Balmer lines are strong?

We present results from a new program of low resolution (1.08 Å/pixel) spectroscopy of Mira variables from about 6000 Å to 8750 Å. The spectra are taken in a region which includes Hα, TiO, VO, ZrO, and the Ca II infrared (IR) triplet. Spectra of a dozen Mira variables observed at more than one phase are presented. We investigate the final question listed above by noting variations in the Ca II IR triplet in relationship with Hα variations as a function of phase. These preliminary observations suggest that Hϵ's observational characteristics result from an interaction of Hϵ photons with the Ca II H line.

1. Introduction

We began a new program of low-resolution spectroscopy of Mira variables as a function of phase to probe stellar atmospheres and underlying pulsation mechanisms. We are investigating three characteristics of Mira variables: the location of formation of molecular species (TiO, VO, ZrO); the nature of Balmer-line increment (Merrill 1940; Gillet 1988; Bowen 1988); and the possibility of an anticorrelation between the strength of the Hϵ line and Ca II 8662 Å absorption line. The Hϵ line is relatively weak when the other Balmer lines are strong. We predict that the Hϵ photons are being scattered by the Ca II H line out to the Ca II 8662 Å line, causing the Ca II 8662 Å line to be filled in with respect to the other two Ca II IR triplet lines.

2. Observations

Low-resolution (2.8 Å) spectra with 1.08 Å/pix from about 6000 Å to 8750 Å were taken of nine Mira variables. The spectra include the Hα, TiO, VO, ZrO, and the Ca II IR triplet features. Observations were made using the Southeastern Association for Research in Astronomy (SARA) 0.9-m telescope, and the Appalachian State University Dark Sky Observatory 0.45-m telescope; October 1996–January 1997. Table 1 lists the Mira variables observed. Table 2 is the log of observations.

Table 1. Coordinates and Ephemerides of the Variable Stars.

Star	RA (2000)	Dec (2000)	Sp. Type	V_{max}	V_{min}	Period (d)	Epoch 2430000+
o Cet	02 19 20.7	-02 58 23	M7 IIIe	2.00	10.10	331.65	8457
R Tri	02 37 02.2	34 15 51	M4 IIIe	5.50	12.60	266.40	8001
U Ori	05 55 49.2	20 10 31	M8 III	5.30	12.60	372.45	5953
R Gem	07 07 21.3	22 42 13	S	6.00	14.00	369.63	8124
R Leo	09 47 33.4	11 25 46	M8 IIIe	4.40	11.30	312.57	7339
V CVn	13 19 27.9	45 31 38	M6 IIIa	6.80	8.80	191.88	4930
R CVn	13 48 57.1	39 32 34	M6 IIIe	7.30	12.90	327.97	8971
V Boo	14 29 45.2	38 51 41	M6e	7.00	11.30	258.22	8095
χ Cyg	19 50 33.9	32 54 53	S	3.30	14.20	406.80	8037

Table 2. Observation Log

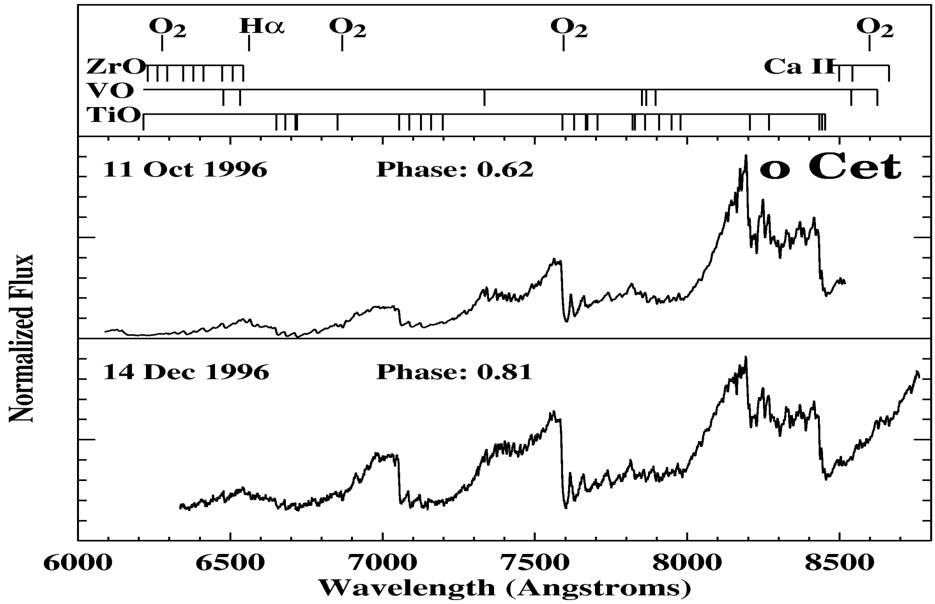
Star	Observation Date	Observation JD 2455000+	Visible Phase	V	Integration Time (sec)	Telescope
o Cet	11 Oct 1996	367.5	0.62	9.4	600	SARA 0.9-m
	14 Dec 1996	431.5	0.81	5.9	600	DSO 0.45-m
R Tri	11 Oct 1996	367.5	0.28	9.9	600	SARA 0.9-m
U Ori	2 Mar 1996	144.5	0.32	12.6	600	SARA 0.9-m
	11 Oct 1996	367.5	0.94	6.4	600	DSO 0.45-m
	14 Dec 1996	431.5	0.12	6.7	600	DSO 0.45-m
	26 Jan 1997	474.5	0.24	7.9	1200	DSO 0.45-m
R Gem	11 Oct 1996	367.5	0.96	6.2	600	SARA 0.9-m
R Leo	17 May 1996	220.5	0.35	7.0	1200	SARA 0.9-m
	14 Dec 1996	431.5	0.02	4.5	300	DSO 0.45-m
	26 Jan 1997	474.5	0.16	5.3	300	DSO 0.45-m
V CVn	1 Mar 1996	143.5	0.18	7.6	600	SARA 0.9-m
	17 May 1996	220.5	0.60	8.6	1200	DSO 0.45-m
R CVn	1 Mar 1996	143.5	0.00	7.3	600	SARA 0.9-m
	17 May 1996	220.5	0.23	9.6	1200	SARA 0.9-m
	26 Jan 1997	474.5	0.00	7.3	600	DSO 0.45-m
V Boo	1 Mar 1996	143.5	0.76	9.0	600	SARA 0.9-m
	17 May 1996	220.5	0.05	7.1	3600	SARA 0.9-m
χ Cyg	17 May 1996	220.5	0.78	8.9	1200	SARA 0.9-m
	11 Oct 1996	367.5	0.14	6.9	240	SARA 0.9-m

3. Results

Figure 1 shows the spectra of seven Mira variables taken at more than one phase.

The Ca II IR triplet is detected only in the spectra of *o* Cet, U Ori, R CVn, R Leo, and χ Cyg. Weak Hα emission is detected in the spectrum of R Leo at phase 0.2, and R CVn at phase 0.00. TiO and VO are observed in all spectra.

Figure 2 shows the spectra of R Tri and R Gem, each taken at only one phase. These two stars show strong Hα emission. Their spectra are included here for comparison with the other seven Mira variables.



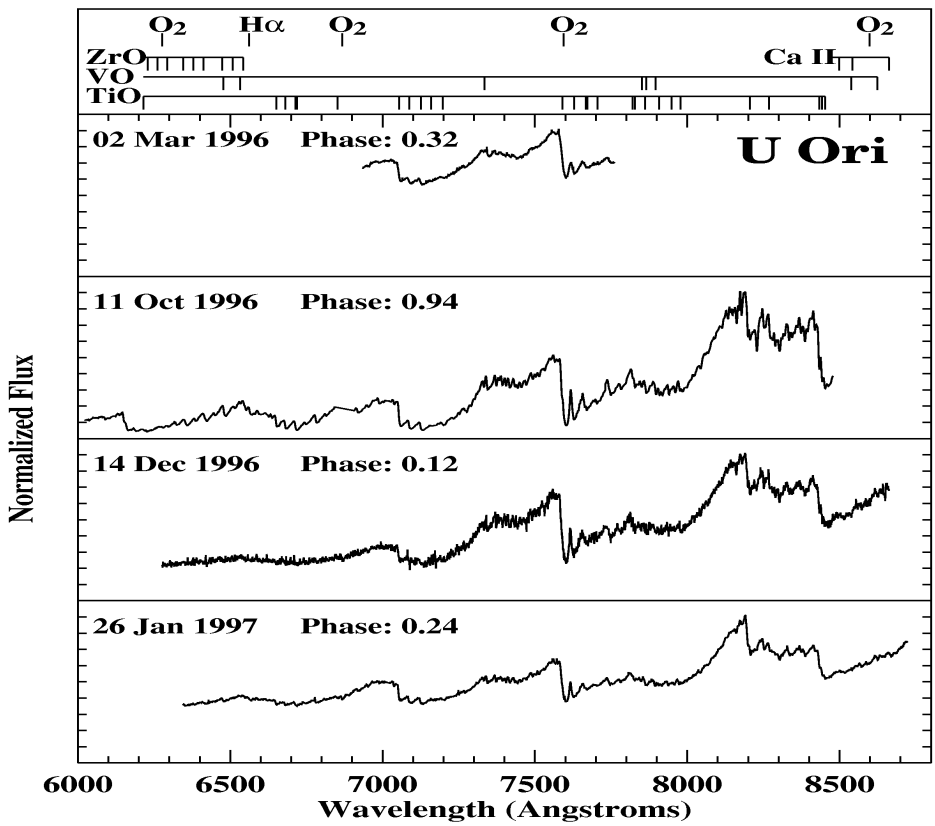


Figure 1. Spectra of seven Mira variables taken at more than one phase. The name of the star, date, and phase, are given on each spectrum. The flux is normalized to one. Above each set of spectra are markers for the major spectral features, and terrestial oxygen. Hα is weak, or not seen in most of the spectra.

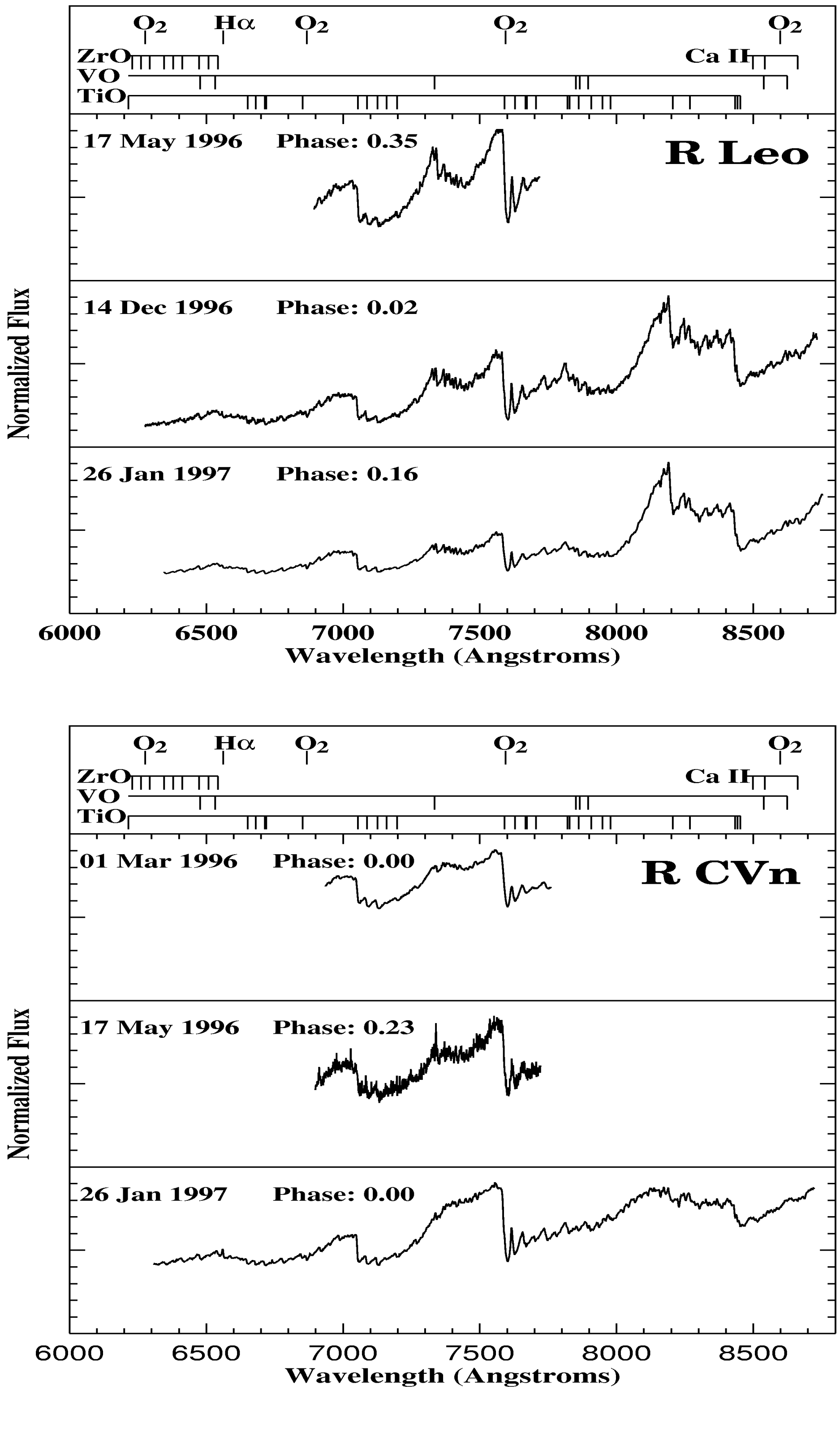


Figure 1. (continued)

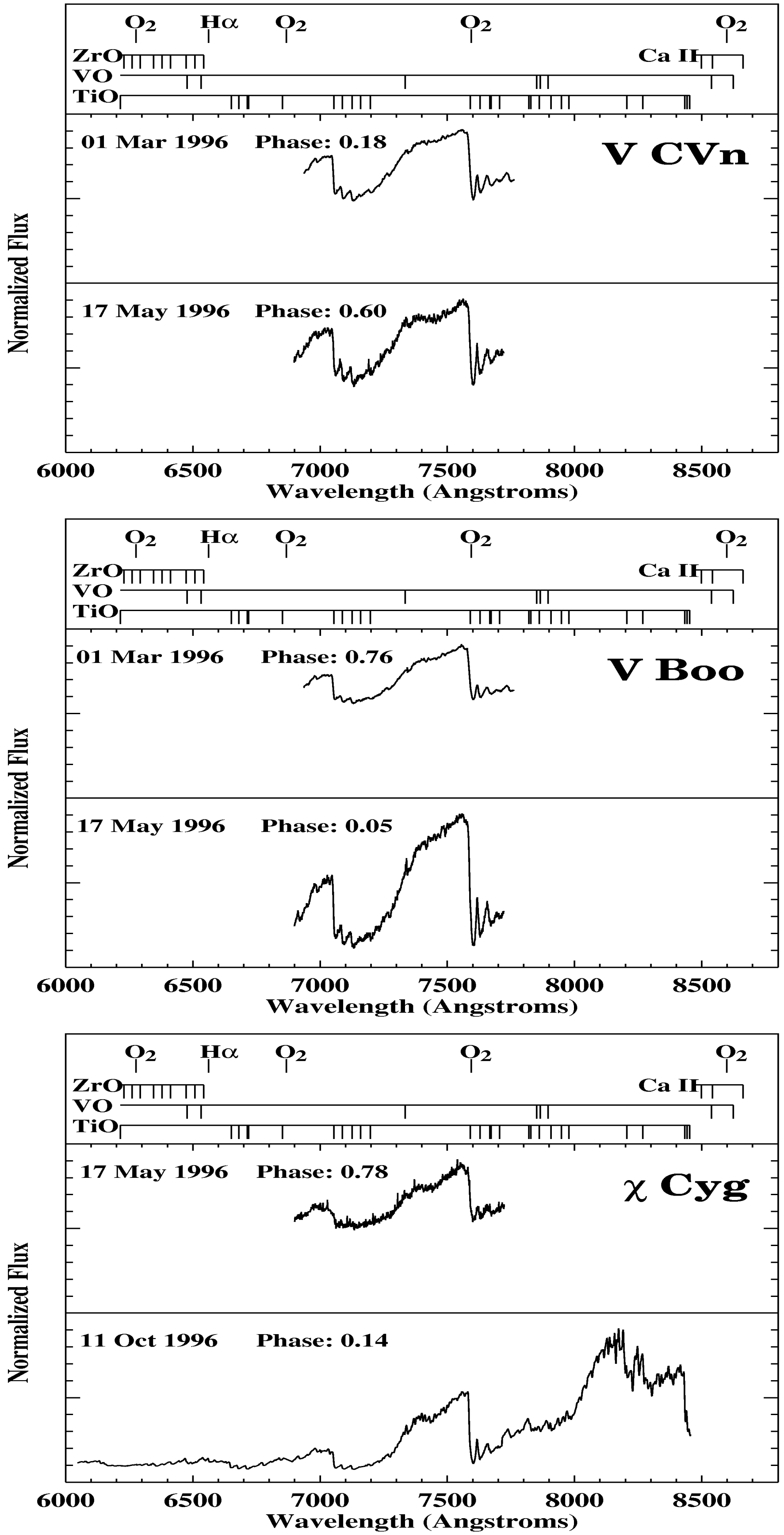
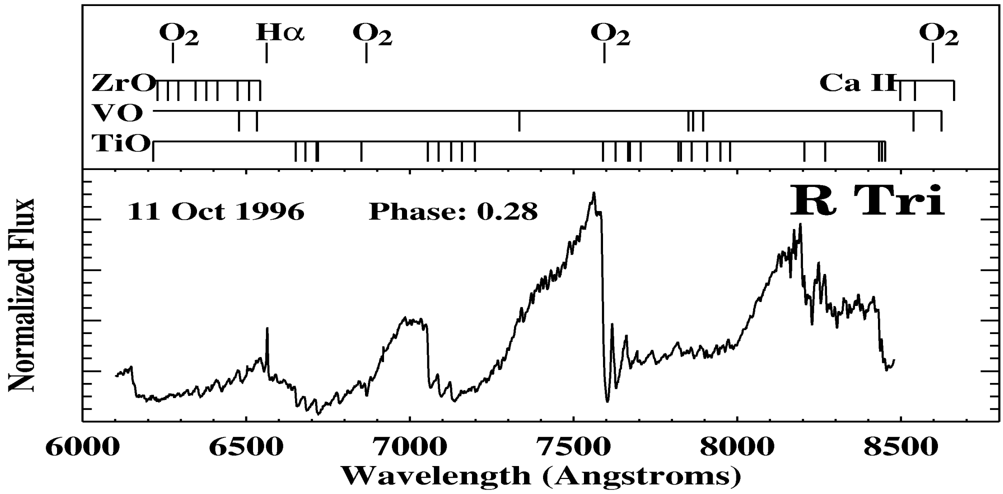


Figure 1. (continued)



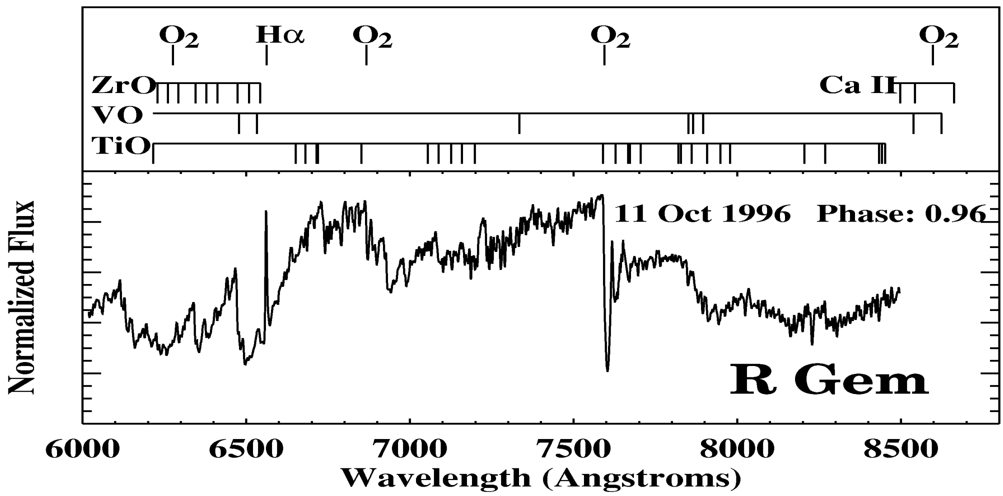


Figure 2. Spectra of R Tri and R Gem showing strong Hα emission.

4. Discussion

We test the idea that the apparent lack of Hϵ when the other Balmer lines are strong is due to scattering of Hϵ photons by the Ca II H line out to the Ca II 8662 Å feature. Using Hα as a proxy for Hϵ, we look for an anticorrelation of Hα with the strength of the Ca II absorption feature at 8662 Å. We define a relative line strength, F, between two points selected on either side of the absorption or emission feature. The relative line strength is calculated by

$$F = \frac{f_\ell - f_c}{f_c}.$$

where f_ℓ is integrated flux under a straight line connected between the two points, representing a pseudocontinum and f_c is the integrated flux across the profile of the absorption or emission feature

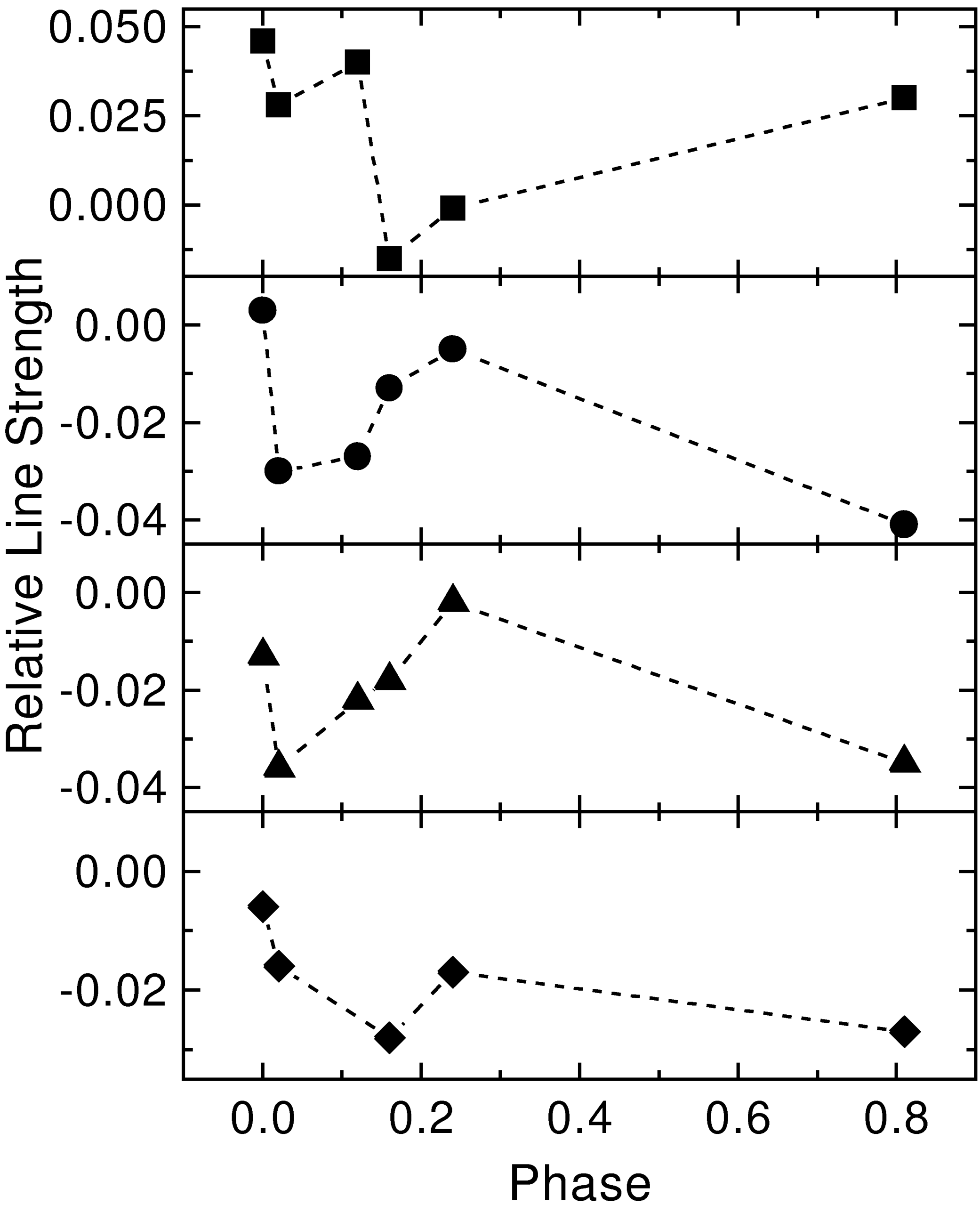


Figure 3. Relative line strengths of Hα (filled square, Ca II lines at 8498 Å (circle), 8542 Å (triangle), and 8662 Å (diamond), as a function of light variation phase. Variation in the Ca II lines at 8498 Å and 8542 Å mimic each other, whereas the Ca II line at 8662 Å does not follow the same trend.

Figure 3 shows the relative line strength F as a function of phase for stars in our sample. The strength of the Ca II features at 8498 Å and 8542 Å mimic each other. The strength of the Ca II feature at 8662 Å does not follow the same trend as the other two Ca II lines. The strength of the Hα emission feature appears to be anticorrelated with the absorption strength of the Ca II 8662 Å feature.

The amount of data is insufficient to make any definite conclusions about the interaction between Ca II H and Hϵ. However, this preliminary data suggests Hϵ is weak because the Hϵ photons scatter out to the near IR through the Ca II 8662 Å line via the Ca II H line.

5. Conclusion

The spectra of Mira variables at different phases suggest a possible anticorrelation between Hα emission and Ca II 8662 Å absorption. The apparent anticorrelation suggests a flourescence in the Ca II 8662 Å line with Hϵ serving as the pump through the Ca II H line. Results are preliminary — we are continuing the low-resolution spectroscopy program to fill in the gaps of our phase space diagram shown in Figure 3.

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References

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