PULSATIONS OF Be STARS: TIME SERIES ANALYSIS OF He I λ4921

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1. Observations

We present the results of time series observations of He I λ4921 in the spectra of 10 Be stars. The spectra were obtained during multi-wavelength campaigns of IUE spectroscopy, optical photometry and polarimetry, and spectroscopy undertaken to study the connection (if any) between nonradial pulsation (NRP) and mass loss in Be stars. Power spectra have been calculated for the time series of intensity variations within the profiles. These were used to determine periodic variability and phase content to analyze the variations in the context of the NRP model. The observations were made at three observatories (Table 1). All the spectra record at least Hβ and He I λ4921 with a $S/N > 200$ per pixel and a resolution of ≈ 0.2 Å. We have concentrated the analysis on He I λ4921 as a probe of photospheric variability. This line is generally free of emission (unlike He I λ6678), but in some cases an Fe II λ4924 shell component appears in the red wing.

2. Analysis

The spectra were transformed to a uniform wavelength grid. The global mean spectrum was calculated for each star, and difference spectra were then formed by subtracting the global mean spectrum. At each wavelength point, the variation in the difference spectrum is analogous to a photometric light curve. A Fourier transform of the time series was performed at each wavelength point across the profile. The resulting power spectra were analyzed to search for any periodic content (Gies & Kullavanijaya 1988, ApJ, 326, 813). We followed the method of Gies & Kullavanijaya to estimate what $l = |m|$ modes would be associated with these periodicities in the NRP model. The complex phase was determined across the line profile at the signal frequency. The difference in phase between the red and blue edges of the line determines an upper limit for the order m. A lower limit for m was found by making a power weighted linear fit of the phase variation with wavelength near line center. Finally, we integrated the derived semi-amplitude of variation across the profile and formed the ratio, R, of this quantity to the line equivalent width. Our results appear in Table 1. We have verified that

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TABLE I
Time Series Analysis

Object	Telescope	Dates	P (d)	$-m$	R
o And	McD/2.7m	1987 Aug 2-5	1.48±0.33	0	0.056
			0.83±0.10	0	0.056
λ Eri	McD/2.7m	1987 Nov 3-5	0.71±0.12	2	0.173
ω Ori	McD/2.7m	1987 Nov 3-5	...	...	...
28 Cyg	KPNO/0.9mCF	1989 Sep 19-22	0.64±0.06	2	0.088
η Cen	CTIO/1.5m	1991 Mar 29-Apr 2	0.61±0.04	2	0.082
48 Lib	CTIO/1.5m	1991 Mar 29-Apr 2	...	...	...
ζ Tau	KPNO/0.9mCF	1991 Oct 6-11	0.80±0.06	2	0.066
ψ Per	KPNO/0.9mCF	1991 Oct 6-11	...	...	...
2 Vul	KPNO/0.9mCF	1992 Sep 11-16	1.27±0.15	2	0.086
KY And	KPNO/0.9mCF	1992 Sep 11-16	0.79±0.60	2	0.070

our method successfully recovers the modal identity of pulsations in model profiles formed with an NRP line synthesis code.

3. Conclusions

All of the detected signals correspond to a $m = -2$ mode with the sole exception of o And which has $m = 0$. In no star do we find evidence of higher order modes (however narrow blue-to-red moving features are generally observed, but we doubt that they have a photospheric origin). There is broad agreement between the periods determined by photometry and spectroscopy. The NRP phase of minimum light for two targets with excellent UV light curves, 28 Cyg and η Cen, occurs at phase 0.75. This is consistent with the NRP interpretation in which temperature fluctuations dominate the light curve. In this model, a hot, bright patch crosses the meridian at phase 0.25 (maximum light). There is a general correlation between the amplitude of the line profile variations (measured by R, the ratio of integrated pulsation amplitude to equivalent width) and the FUV flux variation. Finally the power distribution across the profile is generally flat or peaked in the line wings in accordance with our expectation that horizontal motions will dominate over vertical motions for g-mode pulsations. Taken together these characteristics strongly indicate that the periodic line variations result from NRP and not from spots on a rotating star.

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