The UV Spectrum of the Binary Star 88 Her:

Activity Cycles in the Circumstellar Envelope

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ABSTRACT

Since its discovery as a variable star, 88 Her has undergone three long-term photometric variation cycles with transitions between Be-shell and normal B phases.

From the spectroscopic study of fifteen high resolution spectra obtained by the IUE satellite between 1981 and 1992 we were able to set parameters such as optical depths and location of line forming regions. We also found that the periodic radial velocity variations of UV Fe II lines agree with the binary orbital period of 86.7 days (Harmanec et al, 1974) and that the line absorption depth variations have a cycle of about 1560 days.

Our aims are to relate the properties of the circumstellar envelope of 88 Her to the spectroscopic variability observed in Fe II and Mg II UV lines, and to understand the mechanisms which cause them, as well as the influence that binarity has on them.

Introduction

Be stars are main sequence or giant B type objects which exhibit or have ever exhibited hydrogen emission lines on their photospheric spectrum due to the presence of an extended envelope. When observed at high inclinations, Be stars often display a shell spectrum characterized by double-peak emission H profile with a deep central absorption component and ionized metal lines in absorption. They may show V/R spectroscopic variations in timescales of months or years, high rotation, IR excesses and linear polarization.

However, the group of Be stars is heterogeneous. It is composed by objects with many differences among them. Their envelopes may have different geometries, densities and kinematics, their photometric and spectroscopic long and short-term variations have not been properly explained, and it is not clear whether they are phenomena related to binarity or to the evolutionary state of the object.

In the present work, we seek to relate the properties of an extended envelope to long-term variabilities observed in Be stars in order to understand the mechanisms which cause them. Particularly, we use the information obtained from UV observations, which have proved to be very useful to quantify changes in extended envelopes (Smith 2001, Arias et al. 2004).

88 Her is a binary system and presents many of the typical characteristics observed in Be stars, this is why it results an excellent scenario to investigate which could be the causes of the observed variations as well as the influence that binarity has on them.

88 Her is a Be/Shell star classified as B6 IV-V by Divan et al. (1982) and has gone through three long-term optical photometric variations between 1963 and 1993 (Hirata, 1995). Measurements on line Doppler shifts proved the existence of a period of 86.7 days related to the orbital period (Harmanec et al., 1974).

Observations and Results

The IUE observations used for this work consist of 15 high dispersion UV spectra selected from the International Ultraviolet Explorer Newly Extrated Spectra (INES database, http://ines-laeff.esa.es/cgi-ines/iuedbsMy) (see Table 1). They are well distributed through the last long-term variation cycle and are evenly distributed over the binary orbital phase.

Table 1

IMAGE	J. D	DATE	IMAGE	J. D	DATE
LWR11278	2444826.16	09/08/1981	LWP07305	2446413.98	14/12/1985
LWR12530	2445008.92	08/02/1982	LWP08088	2446544.61	24/04/1986
LWR14265	2445238.87	26/09/1982	LWP09222	2446705.11	01/10/1986
LWR15124	2445361.88	27/01/1983	LWP11036	2446964.70	18/06/1987
LWR15992	2445475.75	21/05/1983	LWP12562	2447184.93	24/01/1988
LWR16229	2445510.47	24/06/1983	LWP17906	2448026.57	15/05/1990
LWP03408	2445842.78	22/05/1984	LWP23358	2448796.45	22/06/1992
LWP06213	2446230.53	14/06/1985			

We chose Fe II transitions belonging to multiplets UV1, UV2 and UV3, which present intensity variations (Granada et al. 2006). We determined radial velocities by fitting gaussian to the line profiles obtaining a period of 86.7 days for the velocity curve (Figure 1), which agrees with the orbital period determined by Harmanec et al. (1974). However, the Fe II line absorption depth variations seem to have a cycle of about 1560 days (*Figure 2*).

From multiplets UV1 and UV3 of Mg II, we also determined radial velocities assuming the observed line profiles are a blend of two gaussian profiles of Mg II, each one corresponding to a member of the binary system. In Figure 1 we also plot the behaviour of the obtained Mg II radial velocities, where we can evidence the presence of the secondary star.

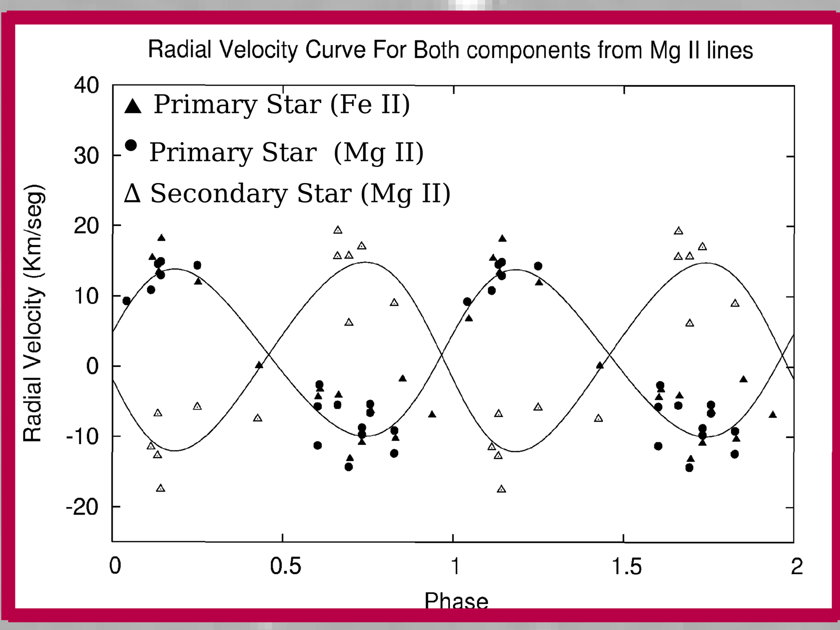


Figura 1

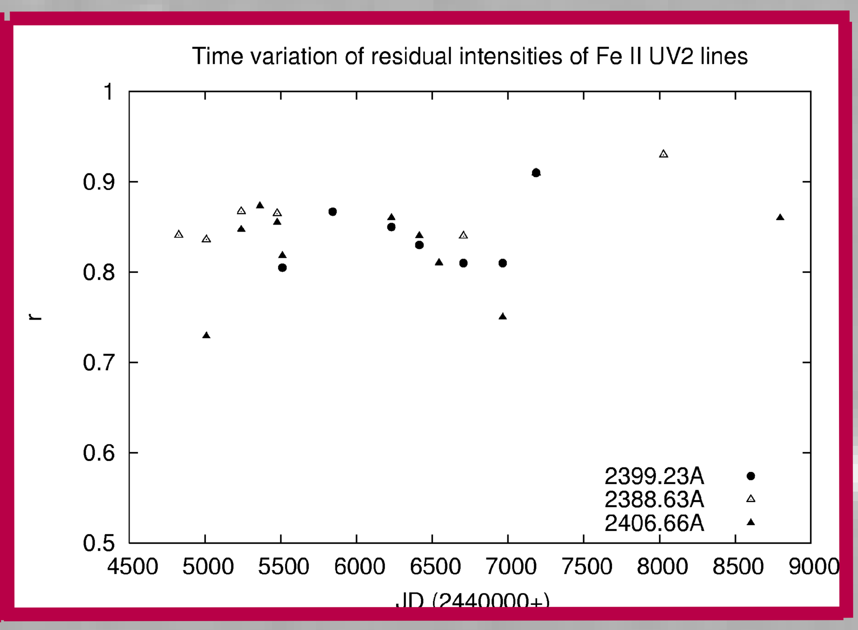


Figura 2

Orbital Elements of the Binary System

The fit of the radial velocity curve was performed as if each star was a single-line binary. In addition, another fit was made considering the system as a double line binary. Since both methods lead to similar results, we focus in the second method in which the data for both components were analyzed together.

The orbital elements obtained are tabulated in Table 2 which indicate that we are observing a non eclipsing binary system.

Assuming the mass of the Be component, corresponding to its spectral type B6IV, to be 5.4M⊙ we roughly estimated the mass of the secondary star, the inclination of the orbit, i_o, as well as the semimajor axes of the baricentric orbits, by means of the mass function equation for a double-line binary. The results are tabulated in Table 3. Even though the masses of both components are similar, the secondary seems to be a subluminous type star.

Model fitting by Frémat et al. (2005) yields that the projected rotation velocity of 88 Her is 310 km s^{-1} with an inclination of the rotation axis 72.9°. On comparing this angle with the value of i_o (Table 2) we conclude that it is probable that the equatorial plane of the primary star does not coincide with the orbital plane of the system.

Table 2

Orbital Elements of the 88 Herculis System

P=86.7days	e=0.1±0.09
T_1=2445218.47JD	ω=283°±62°
T_2=2445175.75JD	$\sin(i_o)$=0.242±0.12
T_0=2445178.75JD±15JD	γ=-14.6km/s±0.8km/s
K_1=11.89km/s±1.29km/s	K_2=13.46km/s±1.41km/s

Table 3

$M_1\sin^3 i$=0.077	$M_2\sin^3 i$=0.068
M_1=5.4M⊙	M_2=4.77M⊙
$a_1\sin(i)$=20.27±2.80	
$a_2\sin(i)$=22.95±3.08	
a_1~83.73R⊙	a_2~94.79R⊙

Line-forming regions

There is no evidence of a strong flow of material through the atmosphere of 88 Her. Then, we can describe its envelope by a quasihydrostatic model (Cidale & Ringuelet, 1989), which enables us to determine properties of the line forming regions, such as their location and opacity. This model has already proved to be appropriate to make a statistical analysis of envelopes of Be stars (Moujtahid et al. 1998, Arias 2004) and to interpret the spectrophotometric behaviour of long-term variations in V923 Aql (Arias et al. 2004).

In the present work we determine distances from the center of the star to regions of line formation (R_e/R_*), in order to follow the time evolution of their characteristic parameters and analyse the mechanisms which could be taking place in the envelope.

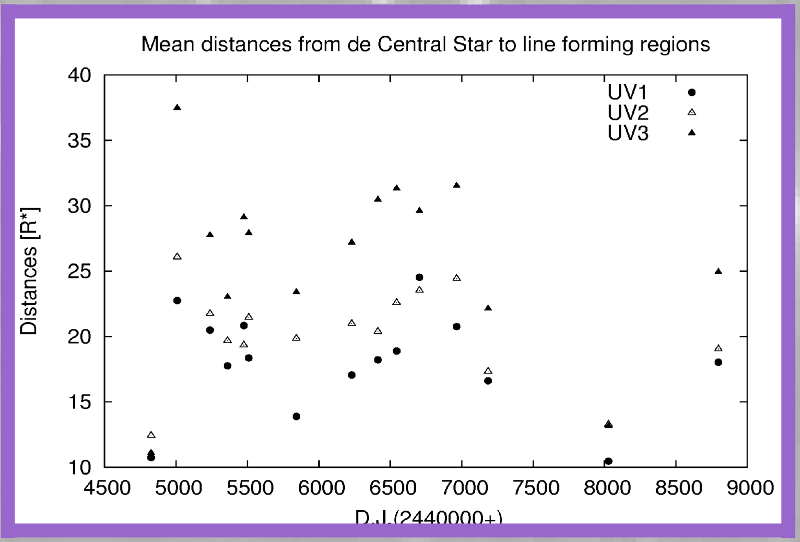
The line radiative flux as a function of the optical depth, , emerging from the system star-plus-circumstellar envelope is obtained by solving the equation of radiative transfer (Cidale & Ringuelet, 1989).

$$\frac{F_l}{F_*} = e^{-\tau} + \alpha[1 - 2E_3(2\tau)]. \quad \text{for } \tau < 1$$

$$\frac{F_l}{F_*} = e^{-\tau} - 2\alpha H(\tau). \quad \text{for } \tau > 1$$

where

$$\alpha = \left(\frac{R_e}{R_*}\right)^2 \frac{S_l \phi}{I^*_\nu}$$



The parameter   can be determined from observations and permits us to infer physical conditions such as τ and R_e/R_*. We have considered a two level-atom with continuum, assuming a line source function, S_l, for collision-dominated lines.

We determine the parameters   and   by minimizing the sum of the square of the differences between the function obtained in equation (1) and the observed line absorption depths. We find that Fe II lines are optically thick and that the parameter   oscilates between 0,04 and 0,25. Therefore we derive the location of the line-forming regions as a function of time (Figure 3).

Conclusions

We have shown in Figure 1 that radial velocity variations obtained from Fe II and Mg II lines fit the binary period of 86,7 days. The Mg II lines allowed us for the first time to evidence the radial velocity variations of secondary star. For future works we suggest performing high resolution observations (R > 40000) to confirm the double-line binarity.

The absorption depths of Fe II lines have a variation cycle of about 1560 days. The most intense shell phase starts two years before the UV continuum reaches a minimum intensity (Smith, 2001) and ends up two years later. At the same time, the observed intrinsic visual polarization percentage increases (Arsenijević et al., 1994).

In figure 3, we can see that during the shell-phase the line forming regions are closer to the star. Polarimetric observations suggest that these regions may be highly non spherical. When the star turns back to a normal B phase the regions are more distant and less non spherical.

As a plausible mechanism to explain the variability observed, we propose periodic mass ejections which slowly dilute as the material becomes further from the central star.