Proceedings of 12th Cambridge Workshop on Cool Stars, Stellar Systems, & The Sun, 2003 University of Colorado.

MUSICOS 1998: Observations of Rotational Modulation and Flares on the RS CVn Binary HR1099

D. García-Alvarez[1], B.H. Foing[2], D. Montes[3], J. Oliveira[2,4], J.G. Doyle[1], and MUSICOS 98 collaboration

Abstract.

We present simultaneous and continuous observations of Hα, Hβ, Na I D_1, D_2, He I D_3 and Ca II H & K lines of the chromospherically active binary HR 1099. We have observed HR 1099 for more than 3 weeks almost continuously and monitored two flares. An increase in Hα and Ca II H & K, Hβ and He I D_3 and a strong filling-in of the Na I D_1, D_2 during the flares are observed. We have found that the flares took place at the same phase (0.85) of the binary orbit, and both of them seems to occur near the limb.

1. Introduction

HR 1099 is a triple system and consists of a close double-lined spectroscopic pair with a spotted and rapidly rotating K1IV primary and a comparably inactive and slowly rotating G5V secondary in a $2\overset{d}{.}8$ orbit. The terciary is a fainter K3V star $6''$ away. The system HR 1099 is one of the few RS CVn systems, along with UX Ari, II Peg, and DM UMa, that shows Hα consistently in emission. Its tidally induced rapid rotation, combined with the deepened convection zone of a post main sequence envelope, is responsible for the very high chromospheric activity for its spectral class. The primary (K1IV) shows very strong and variable CaII H & K and Hα emission that is indicative of high chromospheric activity. A comparison of the close binary with evolutionary models suggests that mass transfer from the K primary onto the G secondary may begin within 10^7 years (Fekel 1983).

Following previous MUSICOS campaigns on HR 1099 (Foing et al. 1994) the main goals of this campaign were to monitor for flares and to observe chromospheric lines in order to diagnose the energetics and velocity dynamics. Also photospheric Doppler Imaging and the study of chromospheric activity variations were planned.

[1]Armagh Observatory

[2]ESA Space Science Department, ESTEC

[3]Departamento de Astrofísica, Universidad Complutense de Madrid

[4]Centro de Astrofisica da Universidade do Porto

2. Observations

The spectroscopic observations have been obtained during the MUSICOS 1998 campaign (Nov-Dec), using both Echelle and Long Slit Spectrographs. The sites and instruments involved in the campaign and some of their most important characteristics are shown in Table 1. The spectra have been extracted using the standard reduction procedures in the IRAF package. The wavelength calibration was obtained by taking spectra of a Th-Ar lamp. The spectra have been normalized by a low-order polynomial fit to the observed continuum. Finally, for the spectra affected by water lines, a telluric correction have been made.

Table 1.

Site	Telescope	Spectrograph	Number Nights	Resolving Power
ESO, Chile	0.9 m	HEROS	11	20 000
INT, La Palma	2.5 m	ESA-MUSICOS	9	35 000
KPNO, USA	0.9 m	Echelle	10	65 000
LNA, Brazil	1.6 m	Coudé	6	60 000
Mt.Stromlo, Australia	1.9 m	Echelle	5	35 000
OHP, France	1.9 m	Elodie	8	43 000
OHP, France	1.5 m	Aurelie	6	22 000
SAAO, South Africa	1.9 m	Giraffe	3	36 500
Xinglong, China	2.2 m	Echelle	10	35 000

3. Results

Phase coverage, line coverage, wavelength coverage and sites involved in the MUSICOS 1998 campaign are shown in Fig 1. From the sites involved in the campaign we can conclude that HR 1099 was observed almost continuously during the campaign, approximately 3 weeks.

Sample spectral of HR 1099 showing the chromospheric lines, namely, Hα, Hβ, Na I D_1, D_2, He I D_3, at different phases are presented in Fig 2 (top panel). During the campaign two flares were observed, one at JD 2451145.513 (28-11-98) and a second flare at JD 2451151.066 (03-12-98). This second flare shows an increase in the Hα emission line, He I D_3 line turns into emission during the flare and it also shows a strong filling-in of the Na I D_1, D_2 line (see bottom Fig 2).

In the top panel of Fig 3 we show the equivalent width as a function of Julian date and as a function of phase for several chromospheric lines. From these results we observed that, although both flares shown an increase in Hα emission, the second flare produced a bigger increase. We have also observed that the first flare shows filling-in of Hβ but for the second flare this line turns into emission. Another remarkable feature is that the Na I D_1, D_2 lines have a strong filling-in during the second flare. Note that both flares took place at around the same phase (0.85), but ∼6 days apart. Note also that we have detected rotational modulation of the He I D_3 line that could be attributed to the pumping of the HeI line by coronal X-rays from active regions.

In the middle panel of Fig 3 we plot the radial velocity curves of the binary system HR 1099, calculated using photospheric lines. We have also plotted the radial velocity for the two monitored flares, calculated using Hα. As a result, we notice that during both flares, the radial velocity is slightly displaced (15-20 km s^{-1}) compared to the center of gravity of the primary. This result could be due to the fact that both flares had taken place near the limb.

The bottom panel of Fig 3 shows the $EW_{H\alpha}/EW_{H\beta}$ ratio as a function of Julian date and as a function of phase. During quiescent we obtained values around 1 for the $EW_{H\alpha}/EW_{H\beta}$ ratio, while during the first flare we obtained values slightly bigger than in the quiescent (2-3). During the second flare the ratio even reach values of 8.

4. Conclusions

We have observed the binary system HR 1099 continuously for more than seven orbits in the optical spectral range (at high spectral resolution over a wide wavelength domain) and we have also monitored two flares, one of which lasted more than one day.

Flares spectroscopic variations were measured in Hα, with Hβ and He I D_3 turning into emission and a strong filling-in of the NaI Doublet.

We have detected a rotational modulation of the He I D_3 line outside flares, that may indicate non axi-symmetry in the distribution of coronae active regions.

We shall compare these results with Doppler Imaging based on the photospheric lines, to study the connection between spots, chromospheric emission and flares.

Acknowledgments. We wish to thanks those that have contributed to the MUSICOS 1998 campaign. Research at Armagh Observatory is grant-aided by the Department of Culture, Arts and Leisure for Northern Ireland. DGA wished to thank the Space Science Department at ESTEC the finacial support. DM is supported by the Spanish DGESIC under grant PB97-0259.

References

Fekel, F.C. 1983, ApJ, 268, 274

Foing, B.H. et al. 1994, A&A, 292, 543

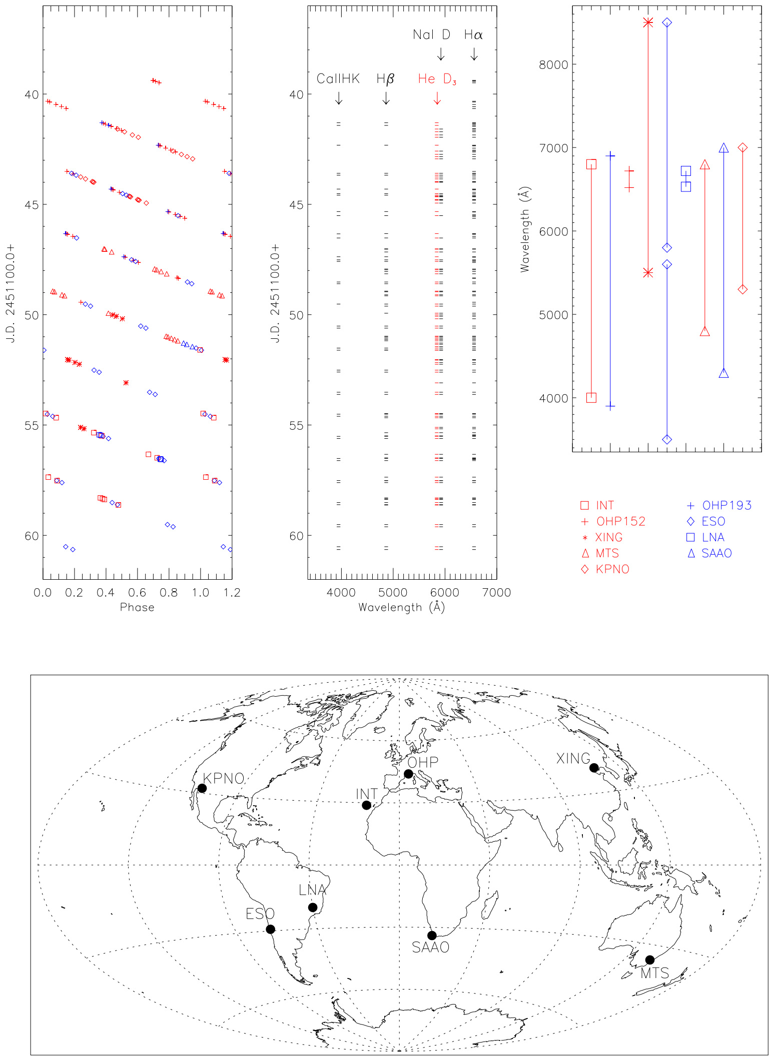

Figure 1. Top left: Phase coverage of the spectroscopic observations versus Julian date. Top middle: Line coverage of the observations of HR 1099 during the MUSICOS 98 campaign. Top right: Wavelength coverage of the instruments involved in the MUSICOS 98 campaign. Bottom: The sites involved in the MUSICOS 98 campaign: INT, OHP, XING (Xinglong), KPNO (Kitt Peak), MTS (Mt. Stromlo), LNA, ESO and SAAO.

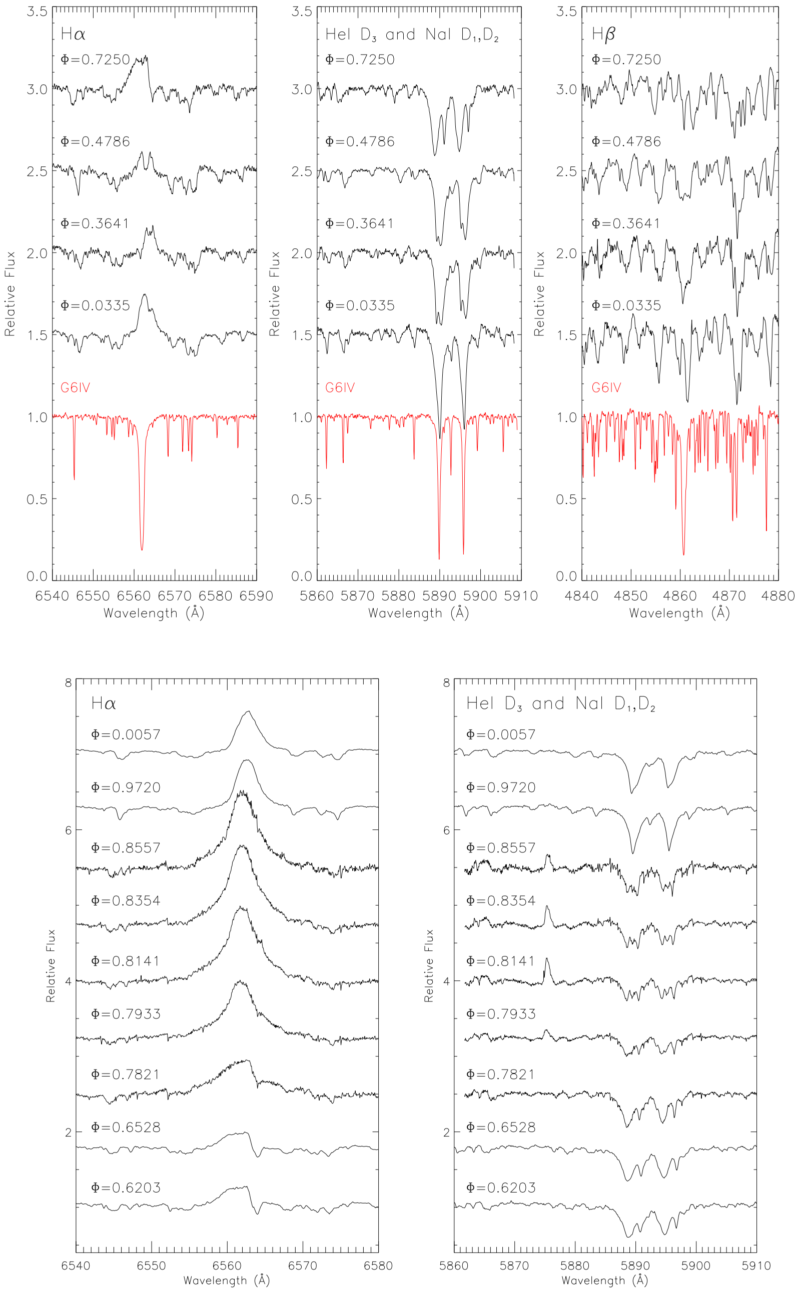

Figure 2. Top panels: Phase sequence of optical spectra observed during the MUSICOS 1998 campaign. A spectral standard type G6IV spectrum is shown for comparison. Bottom panels: The observed spectra for Hα (left panel) and He I D$_3$ and Na I D$_1$,D$_2$ (right panel) of the second monitored flare starting at JD 2451151.066 arranged in order of the orbital phase.

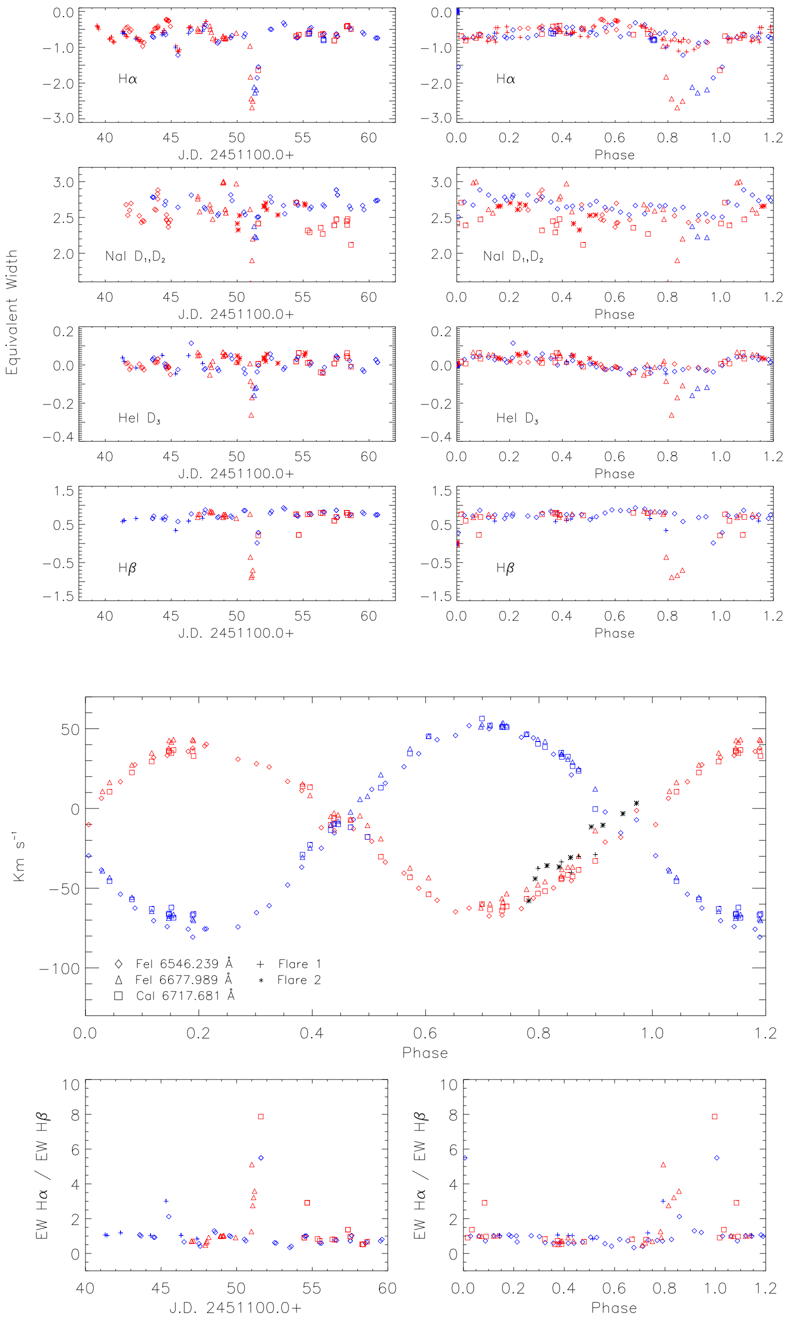

Figure 3. Top panels: The equivalent width as a function of Julian date and as a function of phase for Hα, Na I D_1,D_2 , He I D_3 and Hβ lines. Middle panel: The radial velocity curves of the binary systems HR 1099, calculated using photospheric lines. Red and blue symbols are used for the primary star and secondary star respectively. Bottom panels: The $EW_{H\alpha}/EW_{H\beta}$ ratio as a function of Julian date and as a function of phase. Symbols follow Fig.1.