Goddard High Resolution Spectrograph Observations of Variability in the RS CVn System V711 Tau (HR 1099)

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1. Introduction

Through examination of line profile asymmetries and their phase-dependent behavior at high-resolution and high S/N we can determine the spatial structure (i.e., size, location, temperature, magnetic field distribution) of atmospheric inhomogeneities on stars other than the Sun. Vogt & Penrod 1983 used this technique to map the photospheric spots on V711 Tau. Walter et al. (1987) and Neff et al. (1989) applied similar spectral imaging techniques to the Mg II lines from AR Lacertae to produce maps that show the location, sizes, and brightness of the plages. With IUE it has been possible to map the spatial structure only in the lower chromosphere of the uv brightest stars. With its ability to obtain very high-resolution and high-S/N spectra, the GHRS on HST offers an excellent opportunity to expand upon this previous work. In an effort to simultaneously probe several lines in addition to Mg II we observed the RS CVn V711 Tau (HR 1099, $P_{rot} = 2.^d8$, G5 IV + K1 IV) with the GHRS in the fall of 1993. In this paper we present results of detailed modeling of the the UV emission profiles and compare them to contemporaneous IUE observations.

Ultraviolet observations were obtained with HST's GHRS over a one week interval beginning 1993 September 14. Full details can be found in Dempsey et al. (1995; see also Wood et al. 1995). Spectra of the Mg II h- and k-lines, C IV, Si IV and the density sensitive C III] and Si III] lines at 1909Å and 1892Å respectively, were obtained with side 2 of the GHRS in ACCUM mode using the G160M, G200M, and Echelle-B gratings. *This represents the first attempt at spectral imaging using Mg II, SiIII] and C III].* Observations with IUE were obtained nearly continuously starting on 1993 September 16 and covering one complete rotation cycle of V711 Tau. Both SWP and LWP spectra were taken. Line fluxes and profile models for the emission lines were calculated using least-squares gaussian fits as described in Neff et al. (1989).

2. Profile fitting

Linsky et al. (1989) were able to model the IUE data assuming gaussian emission profiles for the K- and G-stars along with an unresolved interstellar absorption feature. Additional features required to fit the lines were interpreted as resulting from flares or active regions.

Of our four Mg II spectra, the data from phase 2.73 represent the greatest separation in velocity between the two components. Therefore, we used this phase to estimate the "true" characteristics of the emission from each star, which were then used in modelling the other phases. As a first model, we used only two gaussian emission components. While the line core could be reasonably well fit with this model, the line wings were poorly matched. Figure 1 shows that a single gaussian component for each star does not fit the observed profiles. Residuals from subtracting the best single component models are shown in Figure 2. Integrated fluxes in the residual wings are around 8-20% of the total Mg II k-line flux, the highest value corresponding to a probable flare (see below). In this single component model the mean K-star and G-star component fluxes are 23.1 $pm0.9x10^{-12}$ erg s^{-1} cm^{-2} and 4.9 $pm0.1x10^{-12}$ erg s^{-1} cm^{-2}, respectively. Replacing the gaussian profiles with a Voigt profile proved no better in matching the profile. Although these observations were taken prior to the installation of COSTAR, the broad wings cannot be due to the aberration of the point spread function. The Mg II lines are too broad for the PSF to matter in the large science aperture (LSA) spectra.

The model can be improved by combining a broad and narrow gaussian to fit the K star component. This approach was used by Wood et al. (1995), who interpret the broad component as arising from microflaring. While profile fits using a combined narrow and broad gaussian component can reproduce the observed profiles, we emphasize that this does not imply there are two distinct components. Clearly, from Fig. 2 the deviation from a single gaussian is mostly in the line wings. However, adding a broad component to match these *wings* introduces a significant contribution in line flux to the line *core*. Alternatively, one could fit the lines by using a single gaussian for the line core and two small gaussians on either side to fit the wings.

The Mg II profile at phase 1.97 is difficult to model because the emission components for both the G and K star lie at nearly the same velocity, making it difficult in separating the two stellar components. No acceptable fit using the above schema could be obtained unless either we added an additional component or unconstrained the position of the broad component. Adding components will always improve the fit, and an unconstrained multiple gaussian fit will naturally yield a broad component. Unless this additional component is constrained to have minimal flux, it will dominate the fit (cf. Wood et al.). Our procedure is to minimize the flux in this additional, broad component by first fitting and "freezing" the narrower line-core components. Therefore, we restricted ourselves to the 3 components. A marginally acceptable fit was achieved in this manner if the broad component is redshifted from the predicted orbital velocity by 5–12 km s^{-1}. This behavior is identical to that seen in the C IV lines at phase 1.95 (Dempsey et al. 1995). We conclude that a flare occurred around this phase.

In addition, fluxes and line widths from the LWP spectra were measured for the Mg II h- and k-lines. Two large flares are observed around phases 1.1 and 1.7, respectively. The flares are typical to that seen before (e.g., Linsky et al. 1989). Fluxes from the IUE data are shown in Figure 3 with those from the HST spectra. Unfortunately, phase overlap is poor.

2. Conclusions

Based on the high-resolution and high S/N Mg II spectra we can conclude:

• Very extended wings are present in the K-star Mg II emission profile. This component contains 8-20% of the Mg II line flux, although unconstrained fits can yield broad components containing up to 70% of the total Mg II flux. To help solve the riddles of the profile shapes (e.g., does the G star Mg II profile also possesses extended wings as does the K star) HST will need to

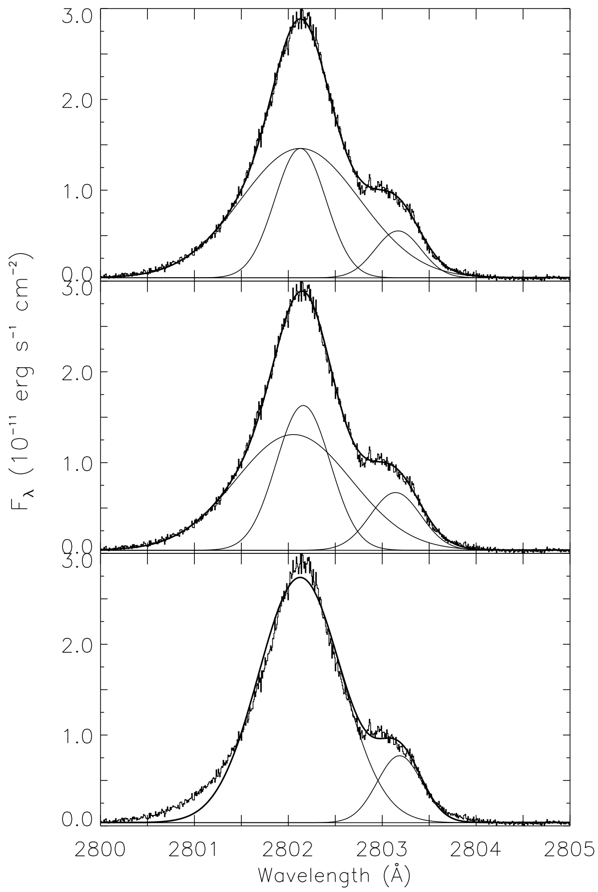

Figure 1: Evolution of gaussian fits to the Mg II h-line. In the bottom panel a single component is used for the K and G star, respectively. A third component was added in the middle panel. A broad gaussian near the K star velocity is favored. The top panel represents an optimum fit with the broad and narrow K-star gaussian being fixed to the same position.

observe some *single* stars for a baseline comparison.

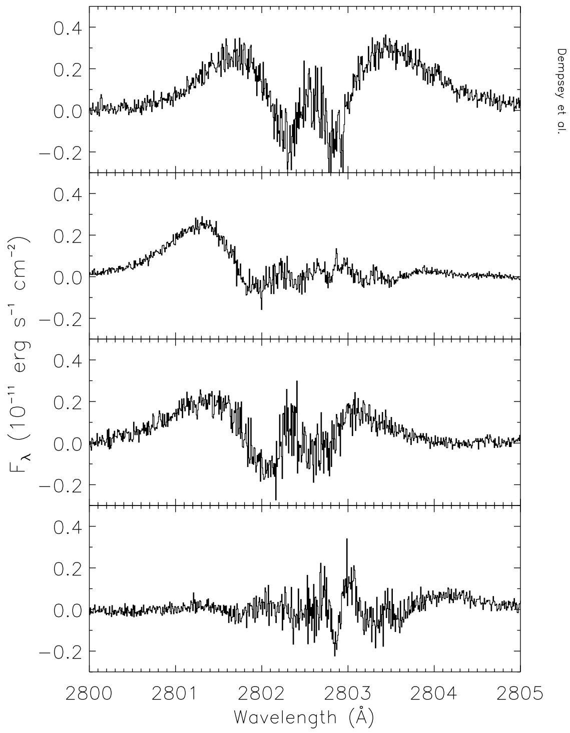

Figure 2: Residuals from subtracting the 2 gaussian fits (bottom panel in Fig. 1) at 4 phases for the k-line. In this model the G star was fixed to the velocity as expected from the orbit and its line width was fixed at its phase 2.73 value.

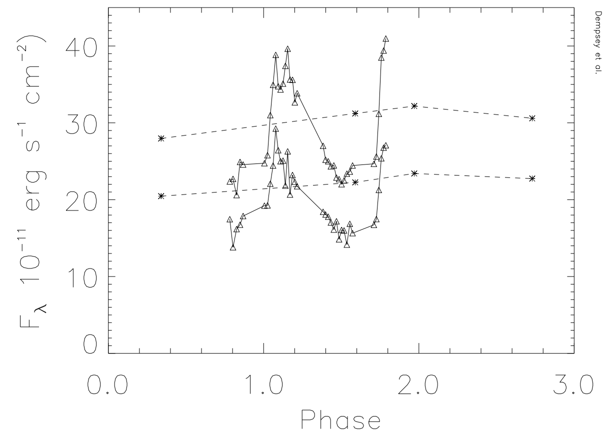

Figure 3: Mg II h- and k- fluxes. The diamonds and solid lines are the IUE data while the dashed line and asterisks indicate HST values. The upper line of each set corresponds to the k-line flux.

• The G star contributes approximately 14% to the total Mg II flux.

• The 3 component model is not adequate to the fit the Mg II profile at phase 1.95. This is likely due to a large flare.

• There appears to be a systematic difference in the line fluxes where values from HST are approximately 22-30% *brighter* than the IUE measurements. This is because the higher S/N HST data allow a better measurement of the flux in the very extended, broad wings. It appears that the majority of variability in the Mg II lines occurs in the narrow component.

In the spring of next year we will be able to expand upon these findings when HST observes a second RS CVn for 26 continuous HST orbits. This will allow nearly uninterrupted observation of a number of UV lines over one stellar rotation of the RS CVn.

Acknowledgements: RCD and JLL acknowledge the support of HST grants GO-4447.03-92A and S-56460-D.

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