MG II FLUX AND PROFILE VARIABILITY OF HYBRID-CHROMOSPHERE STARS

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ABSTRACT

Results from an investigation of the variability seen in the Mg II emission line fluxes and wind absorption components of a number of hybrid-chromosphere stars are presented. Real Mg II flux variability is shown with most of the variation being long-term. This variability appears to be due to global changes in the Mg II surface activity. Major changes in the wind absorption component were not seen.

Keywords: Stellar chromospheres; Stellar winds; Hybrid-chromosphere stars

1. INTRODUCTION

Hybrid-chromosphere stars are luminous cool stars that possess an unusual set of atmospheric characteristics. Their ultraviolet spectra show both transition region (TR) plasma ($T_e = 10^5$K), as evidenced by C IV, Si IV and N V emission lines and a substantial stellar wind, as evidenced by high velocity (100-200 km/s) blue-shifted absorption in the Mg II h and k lines (Refs. 7, 11). Hybrid stars have been found in two particular regions of the HR diagram, namely among early G-type supergiants and early K-type bright giants. Brown (Ref. 3) showed that TR emission is common among early K bright giants but that only about half these stars have obvious high velocity wind absorption, however it is possible that at least a few of the other stars have winds with even higher velocities. Brown, Reimers and Linsky (Ref. 4) showed that the TR plasma is at rest velocity and not within the high velocity wind. This implies that either the TR and wind are physically separate (Ref. 10) or that the hotter plasma lies at the turbulent base of the wind (Refs. 2, 8).

Drake, Brown and Linsky (Ref. 6) studied the Mg II absorption components of hybrid stars. Two absorption features are seen; Drake et al. (Ref. 6) concluded that the high velocity components are formed in the stellar wind while the narrow low velocity components are primarily due to the interstellar (IS) medium. O'Brien and Lambert (Ref. 11) showed that the He I 10830 A lines of hybrid stars behave unusually with strong variations from emission to absorption and outflow to inflow; unfortunately the formation of this line is poorly understood. Brosius, Mullan and Stencel (Ref. 2) studied the variability of the integrated Mg II line fluxes of hybrid stars. They found changes in the line flux that they interpreted in terms of rotational modulation. Oznovich and Gibson (Ref. 12) cast some doubt on the findings of Brosius et al. (Ref. 12) but did find emission line flux variability from SWP spectra of the hybrid stars α Aqr, γ Aql and σ Oph.

2. OBSERVATIONAL DATA

During the 8th IUE year (program LGHJL) we monitored the Mg II emission lines of 7 hybrid stars at roughly monthly intervals to test the claims of Brosius et al. (Ref. 2) and to produce an enhanced dataset with which to investigate the atmospheric variability of hybrid stars. In addition to our own data, we have analyzed all the available long-wavelength images for these stars that have appropriate exposure times. Images with short (usually 5-30 minutes) exposure times were used to measure the Mg II emission line fluxes, while deeper exposures were used to search for variability in the wind absorption components. The fluxes of both the h and k lines were measured and for each line the total flux and the flux redward of the IS absorption were measured to see if variability was due to changes in total line flux or merely changes in the wind absorption. Table 1 shows the number of spectra available for each type of measurement, while Table 2 presents the 1 σ standard deviations, expressed as percentages, found for each of the measured quantities. This analysis was all performed at the Colorado IUE Regional Data Analysis Facility using the ICUR

Table 1. Number of IUE Spectra Used

Star		Spectral Type	Fluxes h	Fluxes k	Wind h	Wind k	Spectra Used
α	Aqr	G2Ib	9	10	14	14	21
α	TrA	K4II	12	18	20	18	35
β	Aqr	G0Ib	15	16	15	12	24
δ	TrA	G2II	5	11	7	7	13
γ	Aql	K3II	5	13	11	8	18
ι	Aur	K3II	2	10	9	7	11
θ	Her	K3II	7	14	9	6	15

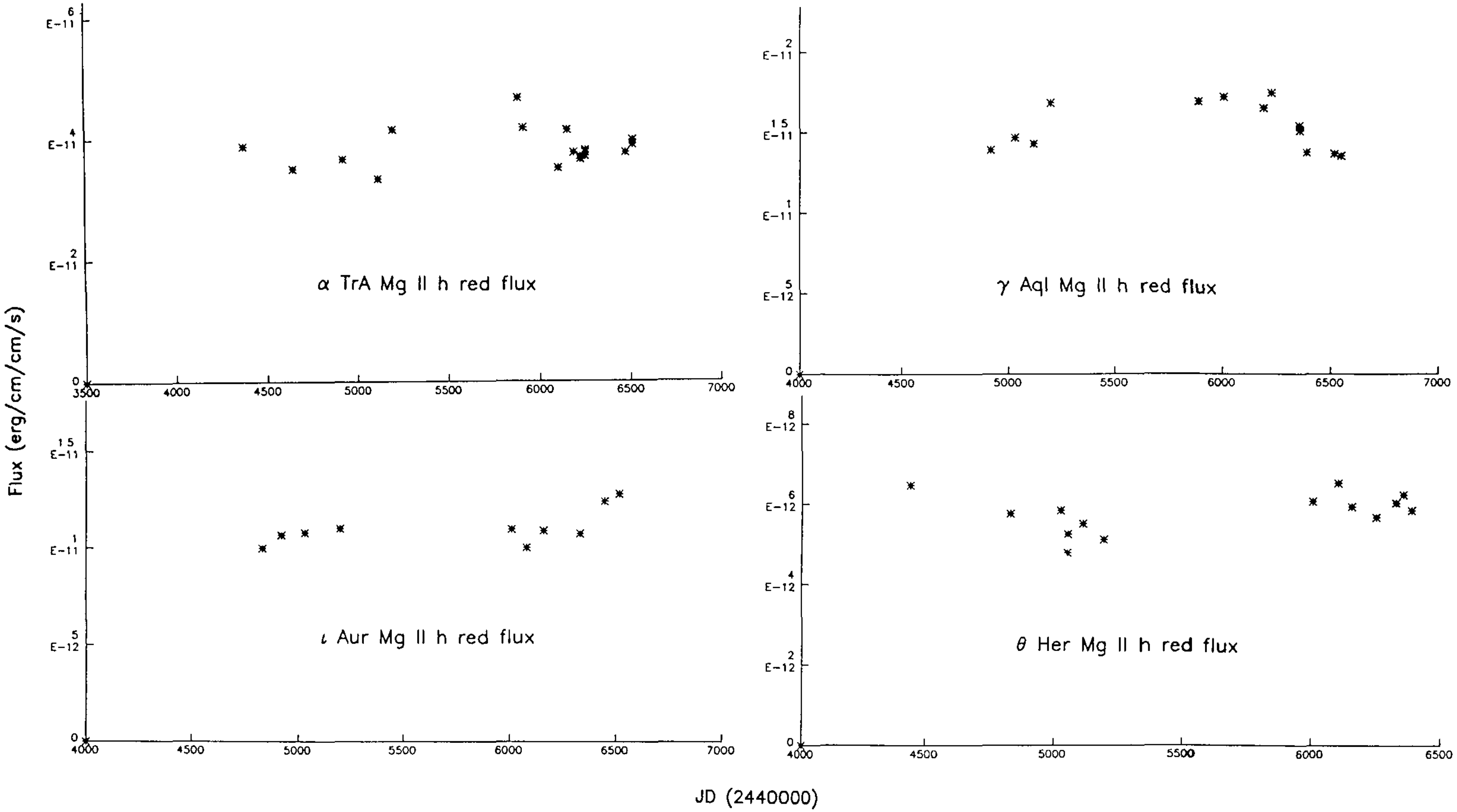

Figure 1. The temporal behavior of the Mg II h emission line flux measured redward of the IS absorption for four K bright giant hybrid-chromosphere stars. Note that many of the values obtained close in time (e.g. the latter parts of the coverage of α Tra and γ Agl) agree very well. Ranges of ±10% are shown for each star. When contrasted with the measurement error of 5% this implies real variability for all four stars. Note that for at least 1700 days the flux for ι Aur was essentially constant. The variability of γ Aql may be similar to behavior expected from stellar activity cycles.

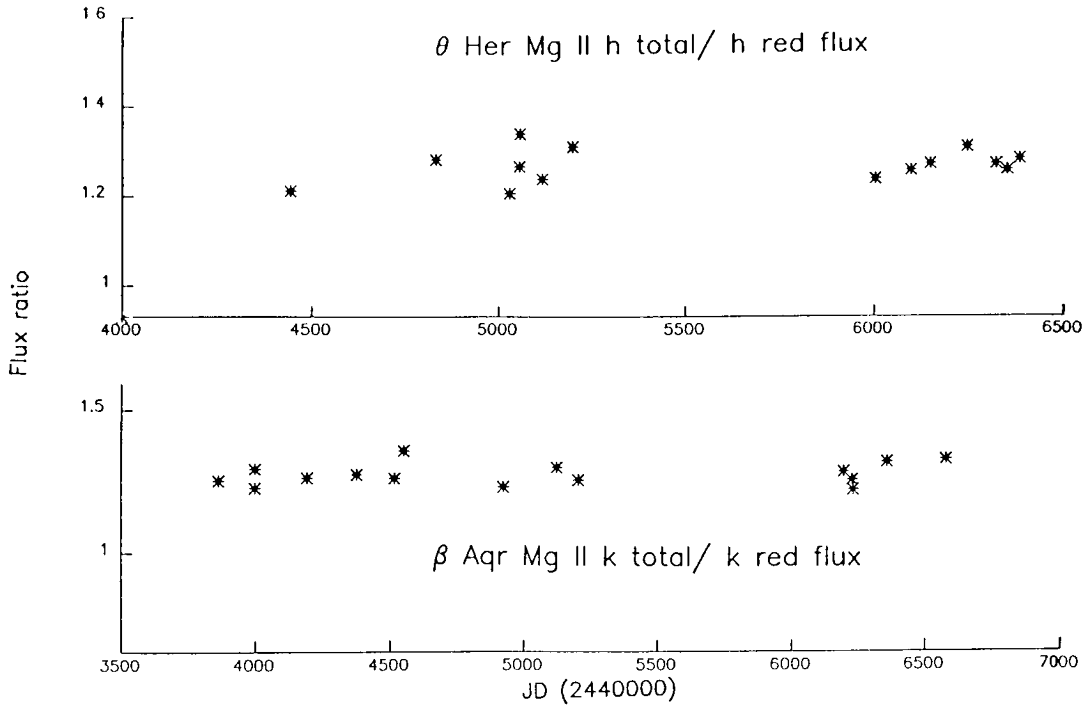

Figure 2. The ratio of the total Mg II emission line flux to the flux redward of the IS absorption for two hybrid-chromosphere stars. Note that the ratio of the fluxes stays almost constant, while the total line flux varies. This implies that true global changes in stellar activity are occurring rather than merely line profile changes.

Table 2. Percentage 1 σ variation

	Fluxes				Wind	
	k	k_{red}	h	h_{red}	k	h
α Aqr	8	8	7	7	3	6
α TrA	7	7	10	8	4	4
β Aqr	11	11	11	11	4	4
δ Tra	7	5	7	7	9	9
γ Aql	10	10	10	10	6	6
ι Aur	16	11	14	8	8	6
θ Her	6	6	7	9	7	5

program developed by Dr. Fred Walter. The measured emission line fluxes were corrected for long term changes in the sensitivity of the IUE cameras (Ref. 5) and for temperature effects (Ref. 9).

3. ACCURACY OF OUR TECHNIQUES

For the Mg II line fluxes we found that relative flux measurements are accurate to better than 5% and that fluxes from similar optimum spectra taken in the same shift agree to better than 3%. Considerable care must be taken in the study of Mg II flux variability and we find that it is best to: a) only compare the same line in the same order, rather than mixing measurements from both orders (for much of the previous data this introduces a 10% spread due to the incorrect ripple correction); b) use a fixed wavelength interval for a given line of each star (this interval can be shifted somewhat to allow for image displacement on the camera), as this is much easier to apply systematically than trying to estimate where each line ends on an individual spectrum; c) not use data acquired when the radiation background is above 2.7 volts as these always give systematically higher emission line fluxes, even when no obvious noise spots are evident, and; d) not use emission lines that are saturated or affected by obvious noise spots.

The cleanest results are found using either the total flux or only the flux redward of the interstellar line for the G supergiant hybrids but better results are found when using the flux redward of the IS line for the K bright giant hybrids. This occurs because the flux shortward of the IS line for the K stars is very weak and extending the wavelength coverage only increases the noise in the measurement. Of course if a deeper exposure is combined to define the weaker blue part of the line, then an accurate total flux can be derived. The IS absorption line velocities derived by Drake et al. (Ref. 6) and Brown (Ref. 3) were used to fix the velocity zero-point for the wind absorption measurements. This method provides relative velocity measurements that should be accurate to 3 km/s (1 standard deviation). The position of the high velocity edge of the wind absorptions were measured. In some cases this feature was not as easily seen as in most of the spectra and this may have introduced some error.

4. RESULTS

1. Real Mg II flux variability is present with even the more constant stars showing 3 σ variations in excess of the spread expected due to measurement errors. The temporal behavior for some of the stars is shown in Fig. 1. In general the spread in flux is between 20 and 30% of the mean, with most of the variation being long-term.

2. In our larger sample there is no evidence to suggest the presence of rotational modulation of the emission line flux as suggested by Brosius et al. (Ref. 2).

3. The flux variability appears to be due to global changes in the Mg II surface activity rather than merely due to line profile variations, (i.e. in particular the variability is not due to large changes in the flux absorbed by the stellar wind). This is illustrated in Fig. 2.

4. There is in fact very little evidence for major changes in the wind absorption components based on this sample. Previous deep exposures have shown large changes in the wind absorption of LTA (Refs. 4, 6, 8) but such changes are not discernible with the relatively weakly exposed spectra in our present study.

ACKNOWLEDGMENTS

We thank Carol Ambruster, Ken Carpenter, Stephen Drake and the staff of the Goddard IUE ground station for their assistance in acquiring these data. This work was supported by NASA grants NAG5-82 and NAG5-985 through the University of Colorado.

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