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

The *FUSE* Cool Star Survey

T. B. Ake[1], A. K. Dupree[2], J. L. Linsky[3], & the *FUSE* Cool Star Team

Abstract. As part of the PI-team program, the *FUSE* cool star group has surveyed eight coronal, non-coronal, and hybrid stars using the LWRS ($30'' \times 30''$) aperture, providing full wavelength coverage in the *FUSE* bandpass. Additional stars are being observed with the MDRS ($4'' \times 20''$) slit for the team D/H program, primarily to obtain intrinsic Lyman β profiles. We provide here an overview of the observations to date, with examples of the types of studies currently in progress.

1. Introduction

The *FUSE* cool star team is performing a quick survey of a wide variety of late-type stars as part of the PI-team program. This survey includes some of the best prototypical examples of coronal, non-coronal, and hybrid stars. The *FUSE* passband covers lines formed from the chromosphere to coronal regions (10^7 K) in these objects. The primary survey uses the LWRS ($30'' \times 30''$) aperture, allowing full wavelength coverage and absolute fluxes to be determined. Additional objects are being observed with the MDRS ($4'' \times 20''$) aperture for the D/H program. These yield high S/N data on Lyman β, but the throughput at other wavelengths is variable due to channel misalignments during the exposures.

Table 1 lists the targets in the two programs. Initial results for Capella can be found in Young et al. (2001). In addition, initial early release observations were made of the rapidly rotating, pre-main sequence star, AB Doradus (Ake et al. 2000).

Table 1. *FUSE* Cool Star Observations

Cool Star Survey (LWRS)				D/H Targets (MDRS)	
Object	Sp. Type	Object	Sp. Type	Object	Sp. Type
α Car	F0 II	β Cet	K0 III	α Cen	G2 V + K1 V
α Aqr	G2 Ib	β Gem	K0 IIIb	ϵ Eri	K1 V
β Dra	G2 Iab	AU Mic	M0 Ve	α Aur	G8 III + G1 III
31 Com	G0 III	α Ori	M2 Iab	α Tau	K5 III

[1]Dept. of Physics & Astronomy, Johns Hopkins University, Computer Sciences Corporation

[2]Harvard-Smithsonian Center for Astrophysics

[3]JILA, University of Colorado, and NIST

2. Line Spectra

Except for the most luminous, coolest objects, all stars have strong emission lines of O VI $\lambda\lambda$1032,1037 and C III λ977, λ1176, and weaker lines of C II, N II, N III, S IV, Si III, and Si IV. Figure 1 shows the spectra of dwarf stars, scaled to bring out the weaker features, and Figure 2, the giants and supergiants. He II, Ne VI, Fe XVIII, and perhaps Fe XIX can be found in the most active dwarfs. The luminous stars show large differences in line ratios and line profiles, reflecting their evolutionary status. The X-ray bright giant, β Cet, shows intense coronal lines as in the active dwarfs and has a spectrum very similar to the long period RS CVn-type binary Capella (Young et al. 2001). The "pre-hybrid" star, β Dra, exhibits some characteristics of the coronal stars, but not the highest temperature lines seen in β Cet. Alpha Aqr, a prototypical hybrid star, is decidedly less active in the *FUSE* passband. The spectrum of the coolest object shown, α Tau, still shows O VI and C III, but is dominated by fluorescent lines of Cr II and Fe II. The coolest luminous object in the survey, the M2 supergiant α Ori, is devoid of all emission except for Fe II fluorescent lines.

3. Line Profiles

Figure 3 shows the O VI λ1032 region in detail for AU Mic and AB Dor. The quiescent line profiles have broad wings and can be represented by two Gaussians, a narrow component of 50–100 km s^{-1}, and a broad one of 150–300 km s^{-1}. The broad component typically contains about 50% of the flux of the line. In AU Mic, the broad feature is redshifted by 15–25 km s^{-1} with respect to the narrow component; in AB Dor, the wings are symmetric about the narrow core. The spectrum of AB Dor is a 10-minute integration during a flare seen on 1999 October 22 (Ake et al. 2000) and shows additional sharp emission components on the O VI peak as well as a redshifted feature extending to +600 km s^{-1}. Although we find no flares in the time-tagged data for AU Mic, the redshift of the broad component coupled with a high density as determined from the C III λ1176/λ977 ratio, may mean the observation occurred during a long term flare.

The C III λ977 line in β Dra and α Aqr has a conspicuous difference in shape (Fig. 4.) The apparent weakening of the short wavelength side of both profiles is indicative of line formation in a differentially expanding atmosphere. The additional absorption in α Aqr suggests that the wind acceleration at the 60,000 K level is larger than in β Dra. These profiles are evidence that the hybrid phenomenon is characterized by substantial outflow that is not as well-developed in the coronal stars.

4. Fluorescent Emission

Alpha Tau and α Ori are strikingly different from other stars in the survey. Alpha Tau shows C III and O VI weakly, and in α Ori, the spectrum is devoid of any high temperature lines. Emission lines in the 1100–1150 Å region are clearly present. In α TrA (K2 II–III), Harper et al. (2001) have identified the lines in this region as Fe II fluorescent transitions pumped by H I Ly α. In Figure 4, we compare their model spectrum with the observations of α Tau and

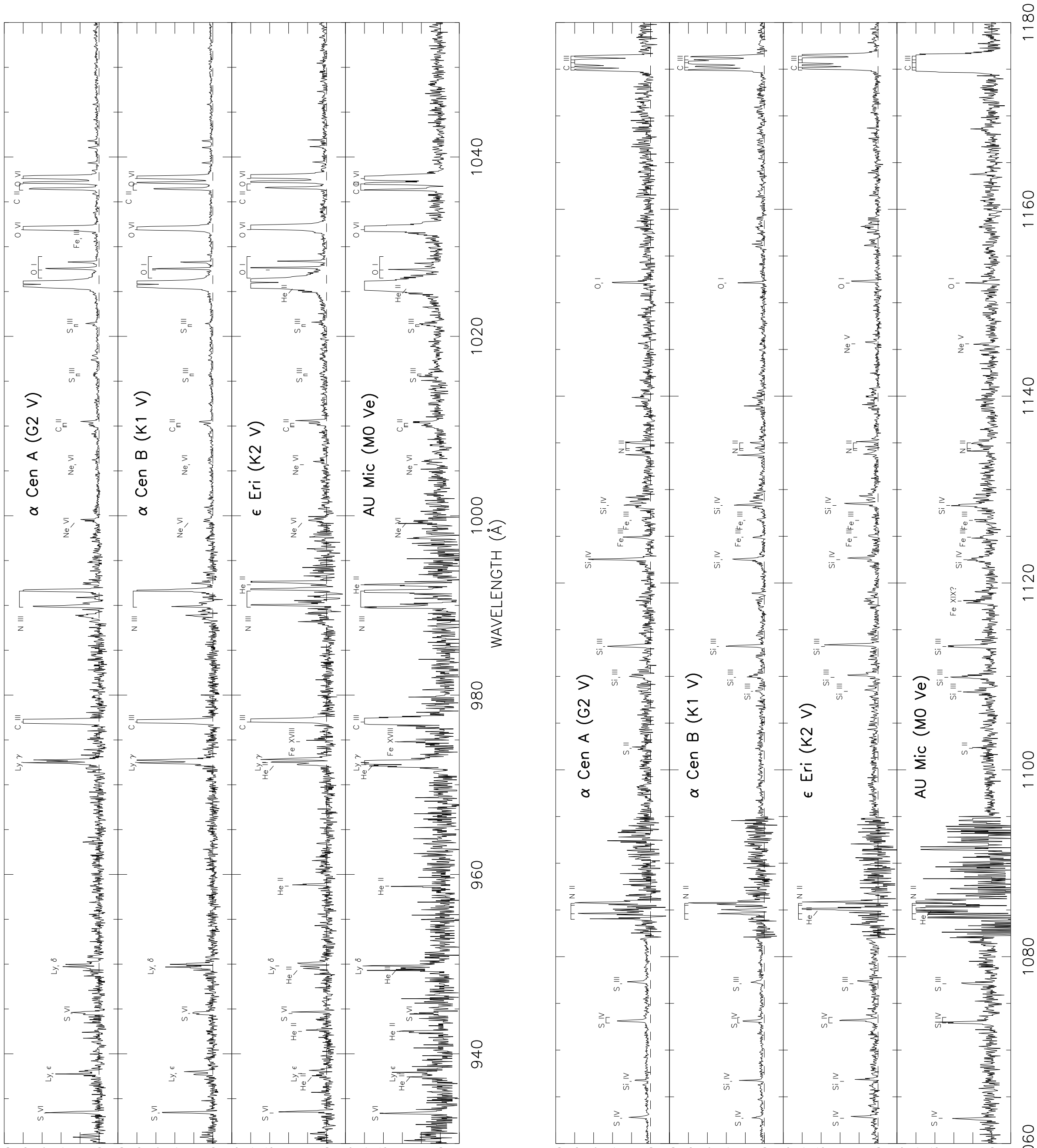

Figure 1. *FUSE* spectra of late-type dwarfs from the survey. Prominent emission lines are identified.

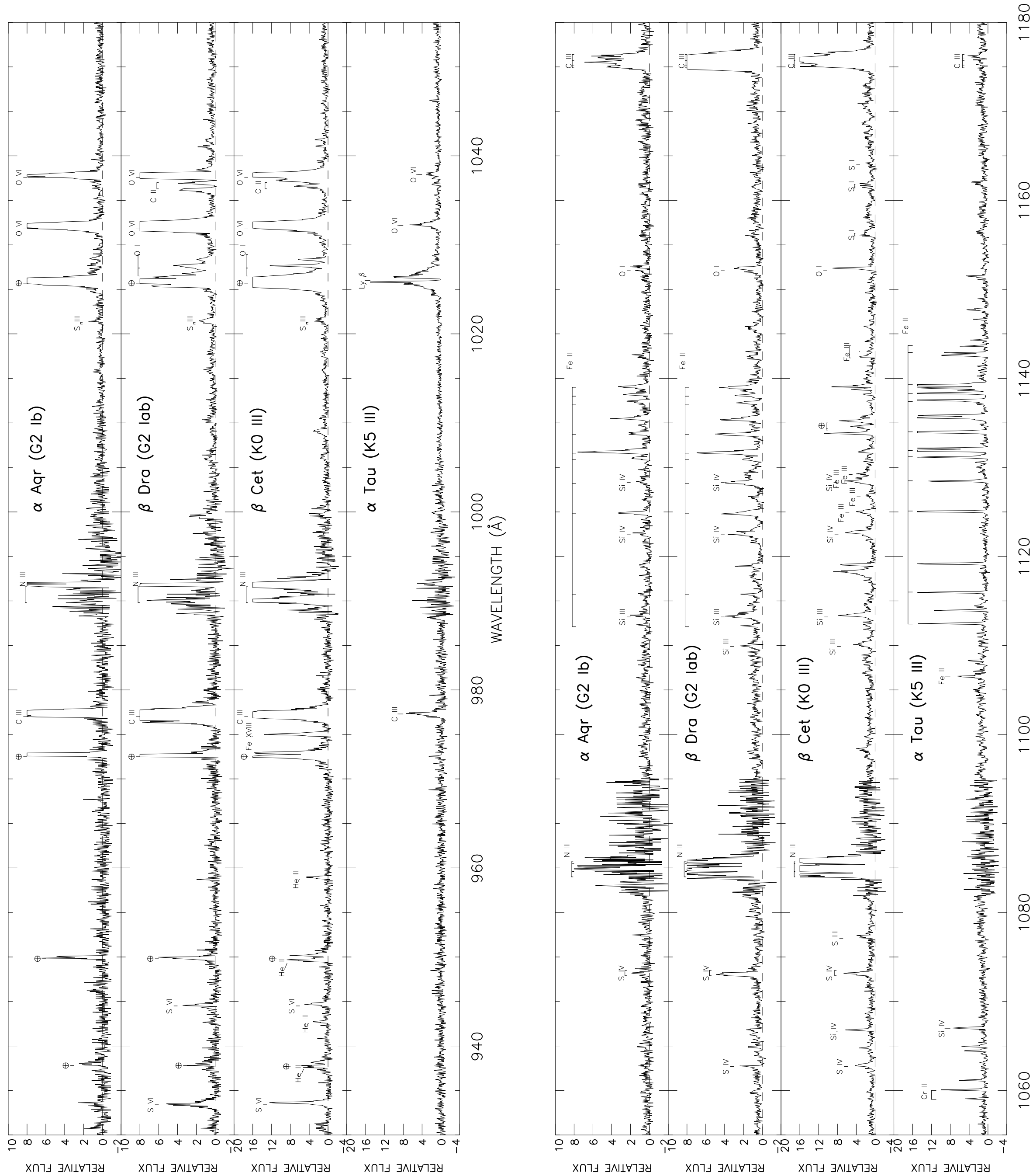

Figure 2. *FUSE* spectra of giants and supergiants from the survey. Prominent emission lines are identified.

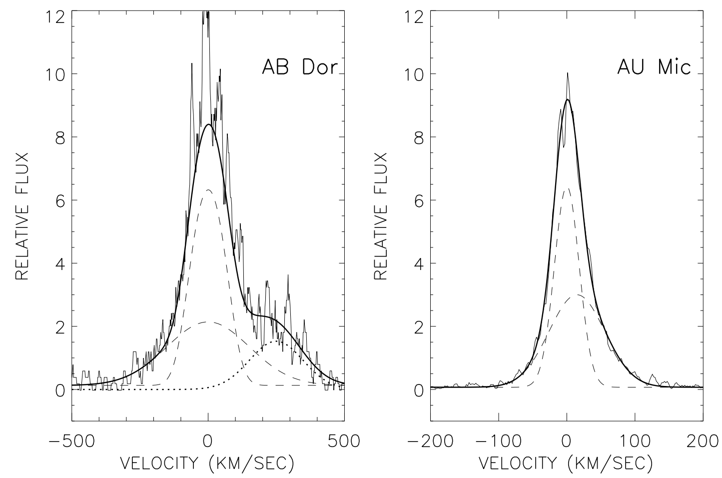

Figure 3. O VI λ1032 profiles of AB Dor and AU Mic, with corresponding dual Gaussian fits to the lines (*dashed lines*). Note the redshift of the broad component compared to the narrow core for AU Mic. The AB Dor spectrum is an integration during a large flare on 1999 Oct 22 and shows an additional component at +235 km s^{-1}.

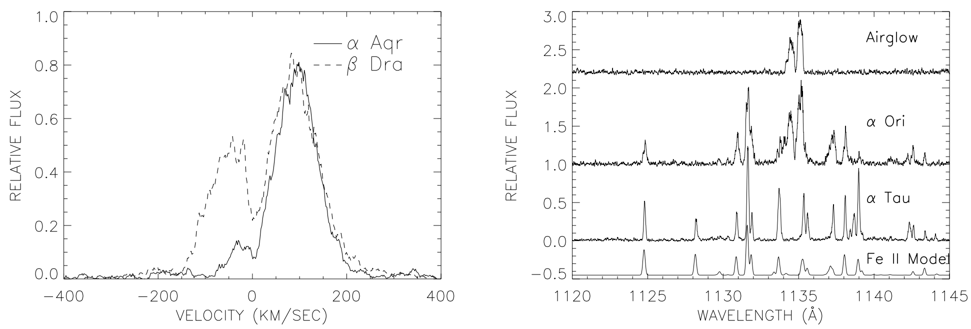

Figure 4. (*Left*) Comparison of C III λ977 emission in β Dra and α Aqr. Both profiles show a blue asymmetry indicative of an expanding atmosphere. α Aqr shows substantial absorption in the presence of a wind. The deep narrow absorption near line center likely results from interstellar C III. (*Right*) The spectrum of α Tau and α Ori compared to the Fe II fluorescence model by Harper et al. (2001) for the hybrid star α TrA. N II airglow lines are the strongest features in α Ori since the data were taken mainly during orbital day. While the α Tau spectrum is replicated by the model, only some features in α Ori are present.

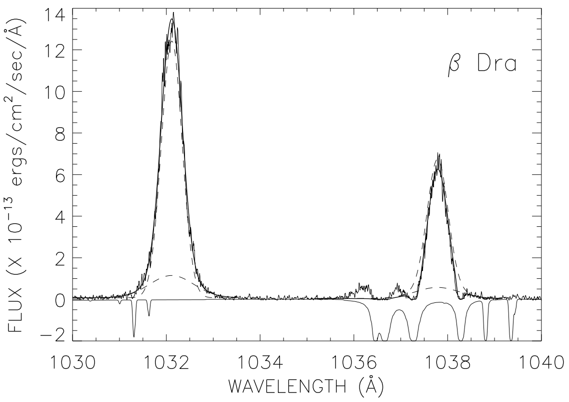

Figure 5. The O VI lines in β Dra, affected by overlying H_2 absorption. The $\lambda1032$ line can be fit by a two-component Gaussian (*dashed line*), but the $\lambda1037$ line cannot be matched by using the $\lambda1032$ profile reduced by the doublet ratio. The lower spectrum shows an H_2 spectrum with N(H_2)= 1×10^{19} cm^{-2}, $b = 5$ km s^{-1}, $T = 100$ K, and velocity shift of +35 km s^{-1}, which reproduces the $\lambda1037$ line when modeled by the $\lambda1032$ profile (*thick line*).

α Ori. The match is very good for α Tau, which, like α TrA, also shows Cr II fluorescence in the $\lambda1060$ region. The line coincidences and relative fluxes in α Ori are suggestive that Fe II fluorescence is the source of these features, although the details of the photoexcitation are different than in α TrA and α Tau.

5. H_2 Absorption

When working with emission-line objects with *FUSE* one must always be cognizant of the effects of interstellar absorption due to molecular hydrogen. Even for lightly reddened objects, line profiles and flux ratios can be subtly modified. Figure 5 shows the effects of H_2 on the $\lambda1037$ region of β Dra. The O VI $\lambda1037$ profile is narrower and reduced in intensity by the overlying absorption; C II 1036 and 1037 Å are affected even more.

Acknowledgments. This work is based on data obtained for the Guaranteed Time Team by the NASA-CNES-CSA FUSE mission operated by the Johns Hopkins University. Financial support to U. S. participants has been provided by NASA contract NAS5-32985.

References

Ake, T. B., et al. 2000, ApJ, 538, L87

Harper, G. M., et al. 2001, ApJ, 551, 486

Young, P. R., et al. 2001, ApJ, 555, L121