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High Temperature Structure in Cool Binary Stars

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Strong high temperature emission lines in the EUVE spectra of binary stars containing cool components [Alpha Aur (*Capella*), 44i Boo, Lambda And, and VY Ari] provide the basis to define reliably the differential emission measure of hot plasma. The emission measure distributions for the short-period ($P \leq 13$ d) binary systems show a high temperature enhancement over a relatively narrow temperature region similar to that originally found in *Capella* (Dupree *et al.* 1993). The emission measure distributions of rapidly rotating single stars 31 Com and AB Dor also contain a local enhancement of the emission measure although at different temperatures and width from *Capella*, suggesting that the enhancement in these objects may be characteristic of rapid rotation of a stellar corona. This feature might be identified with a (polar) active region, although its density and absolute size are unknown; in the binaries *Capella* and VY Ari, the feature is narrow and it may arise from an interaction region between the components.

1. Introduction

The emission measure defined by the well-exposed EUV spectra of the binary system *Capella* (G8 III + G0 III) surprisingly revealed a *narrow* high temperature "bump" (Dupree *et al.* 1993) occurring at $T = 6.3 \times 10^6$ K. The feature is continuously present irrespective of the orbital phase of the system (Dupree *et al.* 1994; 1995), and may arise from a continuously visible hot region on one component, or from an interacting region between the stars. The distribution of the high temperature emission measure in the *Capella* system differs from the broad emission measure distribution found in a solar active region (see Brickhouse *et al.* 1995). We investigate whether this feature is characteristic of binary systems and whether rotation controls its presence.

2. Spectra and the Emission Measure Distribution

EUVE spectra from our Guest Observer program and from the EUVE Science Data Archives were obtained for 4 binary systems (VY Ari, *Capella*, 44i Boo, λ And) and two rapidly rotating single stars (AB Dor and 31 Com). EUV spectra were extracted from the images and calibrated in a uniform manner. The reduced spectra are shown in Fig. 1. In spite of the varying physical characteristics of the stars, there are similarities among the spectra. The resonance line of He II ($\lambda 304$) dominates the MW spectra; strong resonance lines of iron dominate the SW spectra. However, the relative strengths of the lines differ among these objects, and so require detailed evaluation of the emission measure. It is the strength of the Fe XVIII and Fe XIX transitions relative to Fe XX, XXIII that controls the presence of the locally enhanced emission measure (the "bump") in *Capella*.

Signal to noise ratios were evaluated at the EUVE spectral resolution, and only the strongest features ($S/N \approx 9 - 15$) were selected to determine the emission measure. Correction of the observed fluxes for interstellar absorption was made with N_H from Table 1. The H/He abundance ratio was set to 11.6 (Kimble *et al.* 1993) and helium was assumed to be neutral. Assumption of higher values for N_H would strengthen the

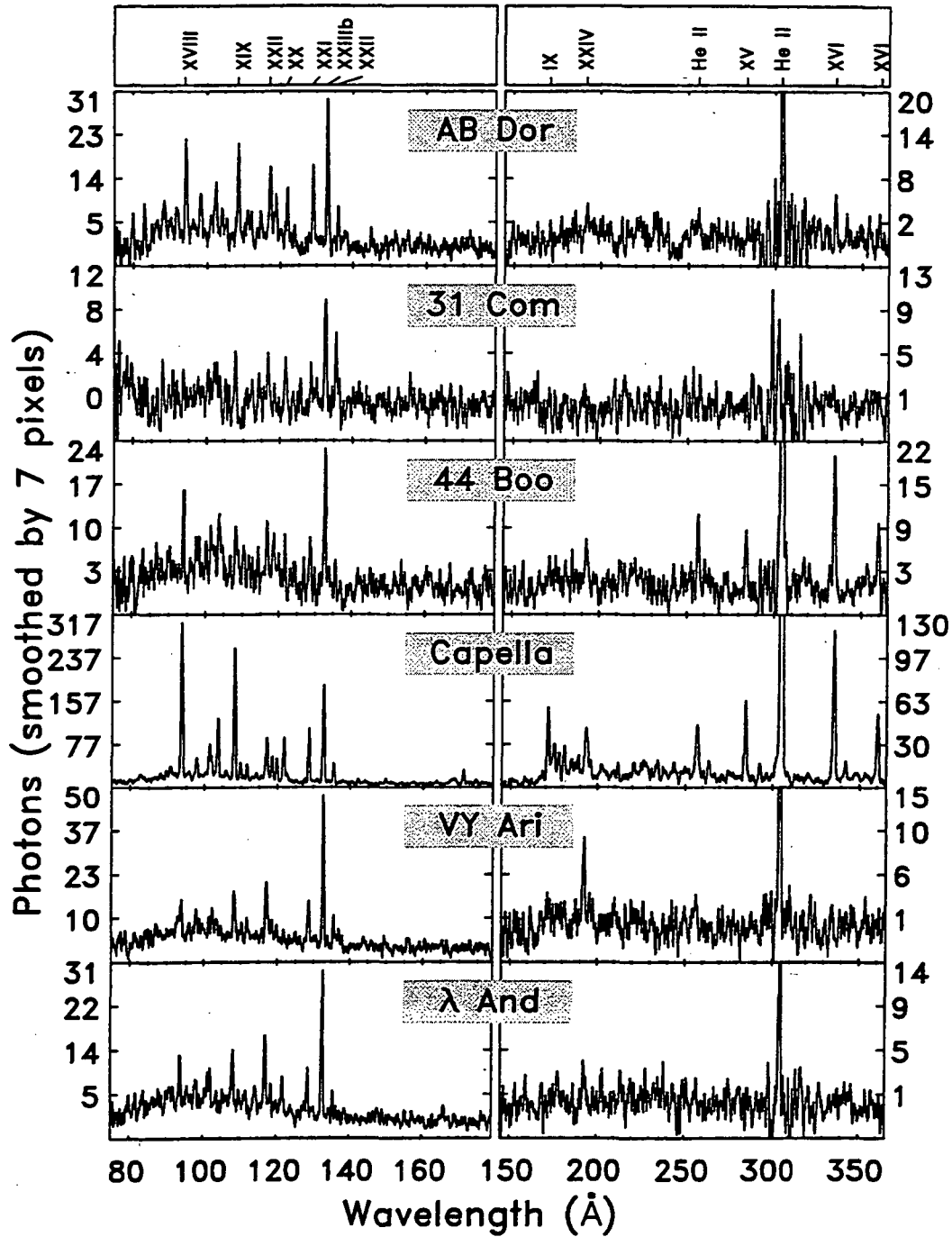


FIGURE 1. EUVE spectra in the SW (*left panel*) and MW (*right panel*) band for the rapidly rotating single stars AB Dor and 31 Com and the binaries 44 Boo, *Capella*, VY Ari, and λ And. Species of Fe are marked by ionization stage. Fe XXIII (λ132.8) is blended with Fe XX.

HD	Star	Sp. Type/Lum.	P_{orbital} (days)	$P_{\text{phtm.}}$ (days)	N_H (cm^{-2})	SW Exp (s)
17433	VY Ari†	K3-4V-IV	13.208	16.64	1.0×10^{18}	168557
34029	α Aur‡	G0 III/G8 III	104.0	8/80	1.8×10^{18}	281571
36705	AB Dor¶	K1 IIIp	...	0.514	1.0×10^{18}	166460
111812	31 Com	G0 III	< 6	...	1.0×10^{18}	84503
133640	44 ι Boo††	G0 V	0.268	...	1.0×10^{18}	104145
222107	λ And†	G8IV-III	20.52	53.95	4.0×10^{18}	105701

TABLE 1. PARAMETERS OF TARGET STARS

† RS CVn-type binary.

‡ RS CVn-type binary; EUVE spectra of *Capella* taken at several phases were averaged together.

¶ Rapidly rotating single star.

|| 31 Com is a rapidly rotating single star thought to be a Hertzsprung Gap giant. The "orbital" period was evaluated from the $v \sin i$ value of 77 km s^{-1} , assuming a radius of $9R_{\odot}$.

†† W UMa-type contact binary.

Fe XVI emission ($\lambda 336$) relative to the Fe XV emission ($\lambda 284$) were observed, but leave the fluxes in the short wavelength region ($\lambda 85$ – $\lambda 170$) essentially unchanged.

The emission measure distribution is determined iteratively, by fully integrating the line emissivities through a trial emission measure distribution, and comparing the predicted and observed line fluxes. There is no restriction on the "smoothness" of the emission measure distribution such as occurs with spectral fitting procedures; moreover the fit is not degraded by bins containing noise or weak signals. Only strong lines are considered in evaluating the emission measure. We require that these fluxes agree within acceptable uncertainties which in this case is better than a factor of two. Detailed current models for all iron ions (Brickhouse *et al.* 1995) were used. Results for λ And are taken from another publication (Hanson *et al.* 1995) where fluxes of ultraviolet lines measured with *IUE* were included so that the emission measure below 2×10^5 K is well-defined.

3. Conclusions

All of the target stars exhibit a range of high ion stages indicating a generally continuous distribution of temperature. The spectral resolution of EUVE demonstrates that two-temperature fits which rely on energy band measures do not represent these stellar atmospheres. For the weaker spectra, the strongest observable lines arise from high stages of ionization (Fe XVIII ... XXIII), the Fe XV ($\lambda 284$) and Fe XVI ($\lambda 336$ and $\lambda 361$) emission is not prominent, and the emission measure can only be reliably defined in a restricted temperature range.

Inspection of the emission measure distributions contained in Fig. 2 and 3 shows that the *Capella* "bump" is not unique. The binary systems (VY Ari, 44 ι Boo) clearly show the enhanced emission measure distribution similar to *Capella*. The appearance of the emission measure enhancement is most pronounced in binary systems with short orbital period (≤ 13 days) and/or high rotational velocity. The orbital period of *Capella* is 104 days, however the hot component of *Capella* is rotating rapidly with a period of ≈ 8 days (Fekel *et al.* 1986) so that the system may be classified as a rapid rotator for these purposes. The strong lines of Fe XVIII ($\lambda 93.9$) and Fe XIX ($\lambda 108.4$) demand the presence

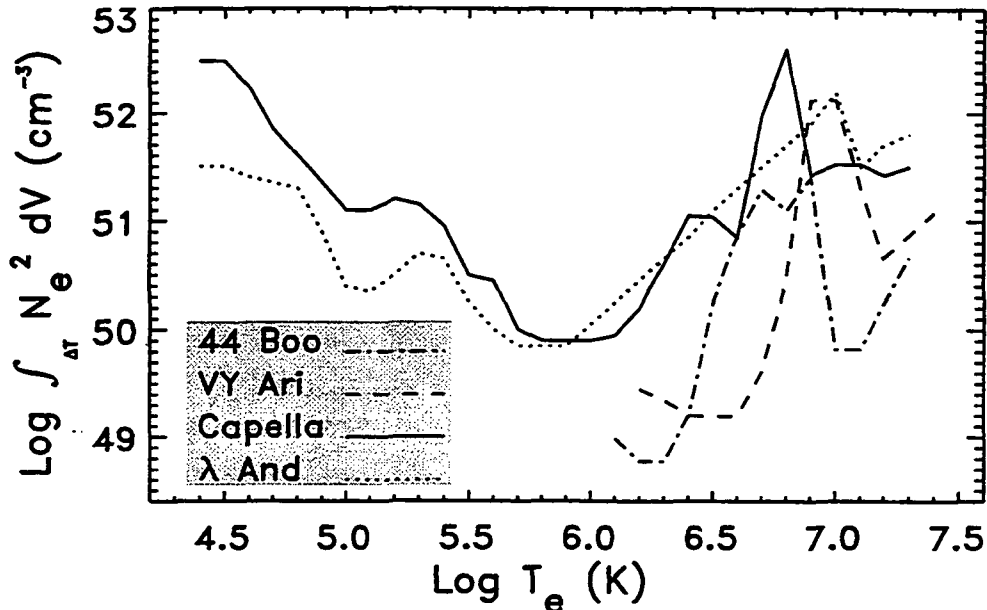


FIGURE 2. Emission measure distribution determined for 4 binary systems.

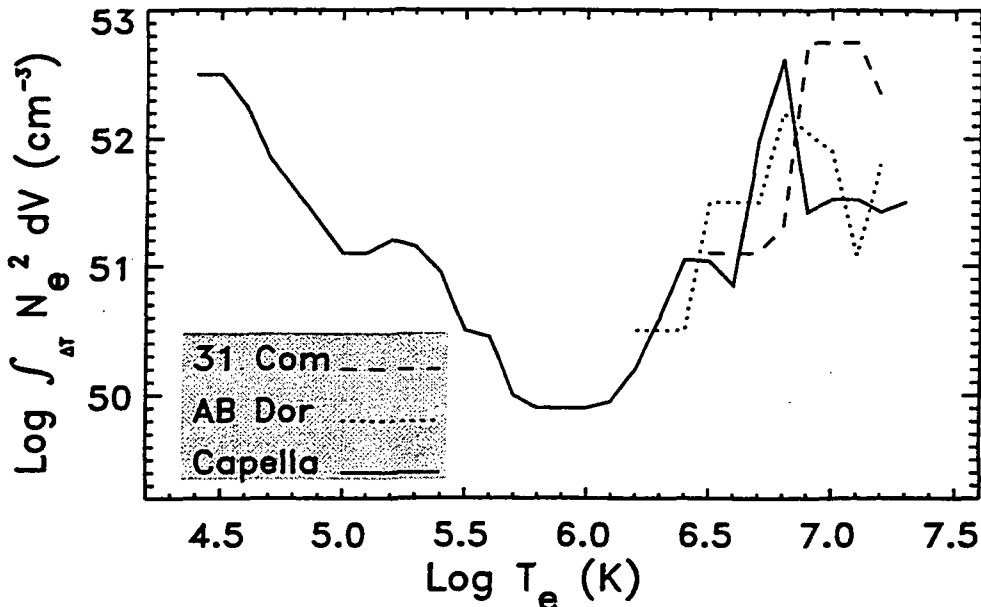


FIGURE 3. Emission measure distribution determined by the strongest lines for 2 rapidly rotating single stars (31 Com and AB Dor) and the binary system *Capella*.

of an increased emission measure in *Capella* for their production. That *44 Boo* would have a similar feature is apparent from inspection of its SW spectrum; the enhancement is broader in temperature than the *Capella* bump. The SW spectrum of *VY Ari* shows an exceptionally strong feature of Fe XX, XXIII ($\lambda 132.8$) relative to the Fe XVIII and XIX transitions; thus the local enhancement of the emission measure occurs at a temperature higher by 0.2 dex, namely $T(K) = 7.0$ dex. The long period system, λ And has a much

less well defined emission measure enhancement (Hanson *et al.* 1995). The slopes of the emission measures with temperature are consistent with models of magnetic loops or arcades.

Two single stars can address the question of whether the “bump” is unique to binaries. The rapidly rotating single giant 31 Com is of particular interest because it lies in the Hertzsprung gap (Wallerstein *et al.* 1994). Since the hot rapidly rotating secondary in the *Capella* system is believed (Pilachowski & Sowell 1992) to be passing through the Hertzsprung gap too, 31 Com might prove helpful in disentangling the composite EUV spectrum of *Capella*. The star 31 Com has a broad enhancement required by the dominant Fe XXII and Fe XXIII transitions, at a temperature higher (7.0 dex) than the *Capella* feature. Such a broad hot component is not found in the *Capella* emission measure. AB Dor, another rapidly-rotating single giant shows a broad enhancement, also different from *Capella*. Thus, rapidly rotating single stars have “bumps” but they appear different from those in *Capella* and VY Ari.

Rotation appears to be a significant physical parameter in producing an enhanced emission measure feature in cool star atmospheres. This feature is generally present in those systems with periods ≤ 13 days. However the temperature of the maximum and the width and strength of the enhancement differ from star to star. It is plausible to associate this feature with magnetic structures in a rapidly-rotating corona, in which case it could be dense and of small scale; however, in the binary systems *Capella* and VY Ari, a narrow enhancement (of unknown density) is found. It may be that such a feature results from interaction between the components. Binaries of longer period, represented by λ And and σ Gem (Hanson *et al.* 1995) do not show such well-defined enhancements in the emission measure, although they possess equally hot plasma. However longer EUV exposures are needed on many of these stars to detect weaker species and to define the atmospheric structure over a wider temperature range.

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