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The Coronal Metallicity of the RS CVn Binary HR 1099

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Abstract:
We have derived the abundance of iron relative to hydrogen in the corona of the active RS CVn binary HR 1099 (V711 Tau) using *EUVE* spectroscopic observations and additional X-ray constraints provided by *ASCA* observations. We have compared the results with simple two temperature optically thin plasma model fits to an *ASCA* spectrum of this star. Results from the two methods are in reasonable agreement. Existing photospheric studies also yield a similar Fe abundance of [Fe/H]~ -0.4, suggesting at face value an absence of any coronal abundance anomaly in HR 1099 involving Fe. However, as with nearly all of the RS CVn's, existing photospheric abundances are perhaps questionable and demand further scrutiny.

1. Summary

We have determined the coronal metallicity of the very active RS CVn binary HR 1099 (V711 Tau) using two methods:

1. Comparing the Fe line to continuum ratio in a high quality *EUVE* spectrum co-added from different observations to yield an aggregated exposure of 230,000 s;

2. Plasma model fits to ASCA pulse height distributions. The results indicate an iron abundance in the corona of HR 1099 of [Fe/H]$= -0.4 \pm 0.2$.

The highest temperature of significant coronal emission measure in active RS CVn stars such as HR 1099 exceeds the formation temperature of the hottest bright spectral line formed in the bandpass of the *EUVE* spectrometer (Fe XXIV 192 Å). Thus, in order to constrain this higher temperature plasma emission measure distribution and continuum flux contribution in the EUV bandpass, additional contraints from X-ray observations are required. We used the *ASCA* spectrum to place constraints on the hot tail of the EM distribution ($\log T > 7.3$) by fitting the continuum to determine the hottest significant plasma temperature. This technique can be extended to low S/N spectra by comparing the *EUVE* Deep Survey count rate to the predicted count rate based on the *EUVE* EM distribution calculated for different values of metallicity.

2. Analysis and Results

The analysis and results are described in the following figures and their captions.

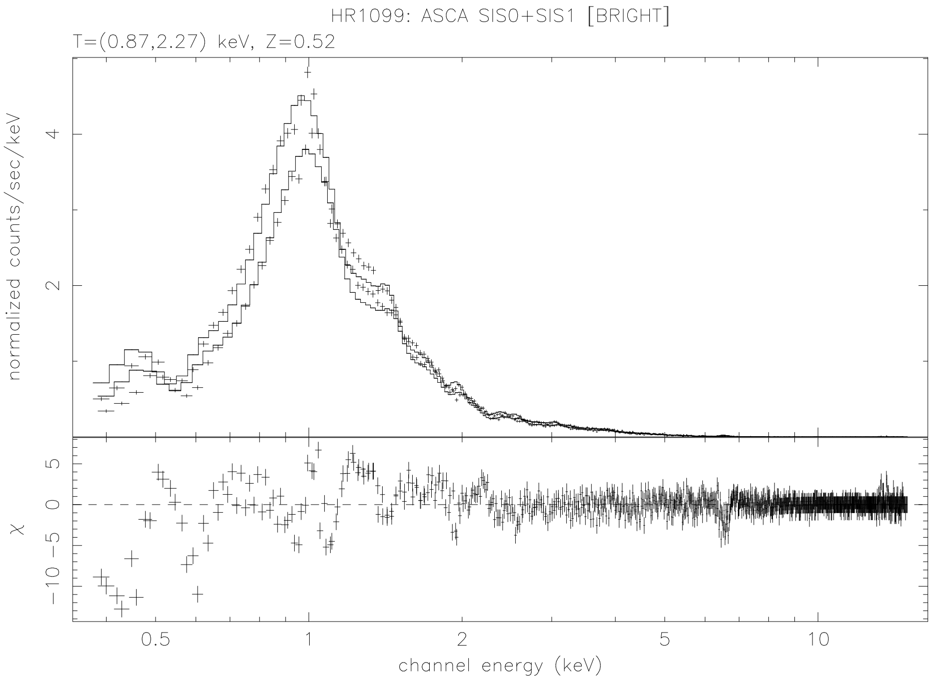


Figure 1. The $2T$-fit to the ASCA spectrum (MEKAL) with variable global metallicity. Care is needed not to arrive at unrealistic results. The fits are unstable to free parameters such as the intervening interstellar medium neutral hydrogen column density N_H, and to an additional gaussian component added to either mimic additional spurious or actual missing lines in the plasma radiative loss model. The $2T$ fit parameters derived here (reduced $\chi^2 = 2.4$) with $N_{\rm H}$ fixed at 1.35×10^{18} are $Z = 0.52 \pm 0.02$ or [Fe/H]= -0.3; $T1 = 0.87$ keV, Norm= 1.3; $T2 = 2.27$ keV, Norm= 6.2.

3. Conclusions

The coronal abundance derived here is similar to the photospheric iron abundance of [Fe/H]=-0.6 derived for the secondary star (which dominates the EUV and X-ray emission) by Randich, Giampapa & Pallavicini (1994). At face value, this suggests no coronal abundance anomaly is present. *However*, the iron abundances derived for the primary is solar, [Fe/H]=0.0! This Fe dichotomy is common to other RS CVn's, which in general also appear more metal poor than their ages and galactic locations might suggest. Either: i) The photospheric abundances are incorrect; or ii) The RS CVn's pose a major puzzle for stellar evolution theory.

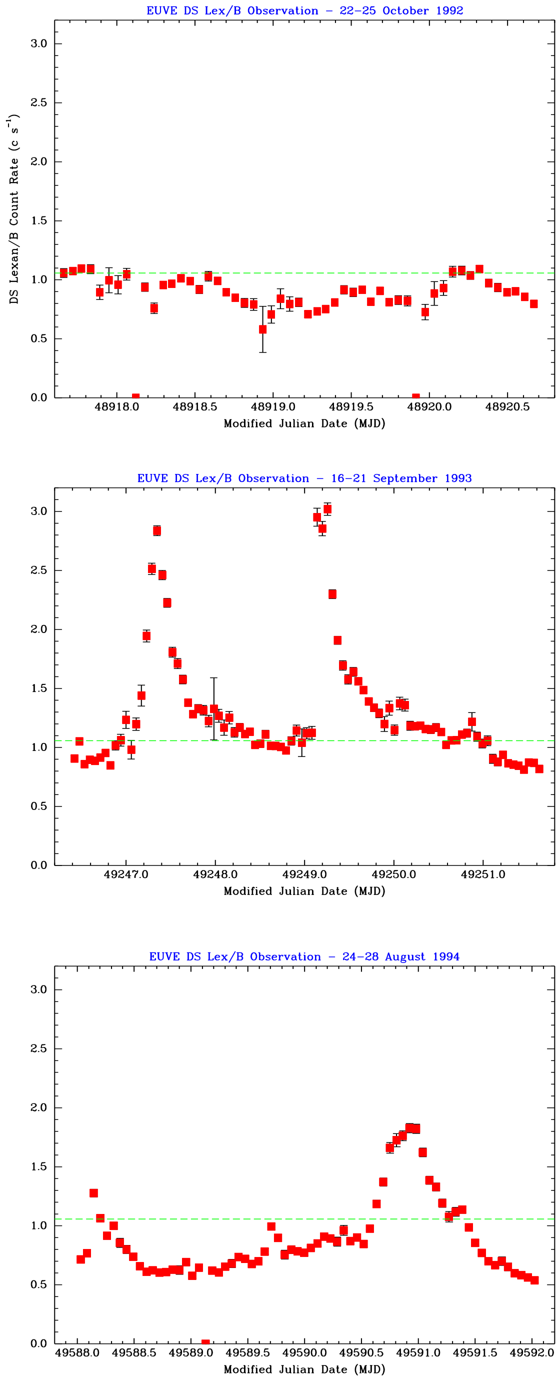


Figure 2. The DS light curve of HR 1099 for the three co-added observations corresponding to the spectra used in our analysis. Each time bin corresponds to one *EUVE* orbit, or about 5540 s of elapsed time, and to between ~ 500 and ~ 2000 s of exposure time. The average count rate is indicated by the green (dashed) line. Two or three flares occur, but the combined spectrum is not flare dominated.

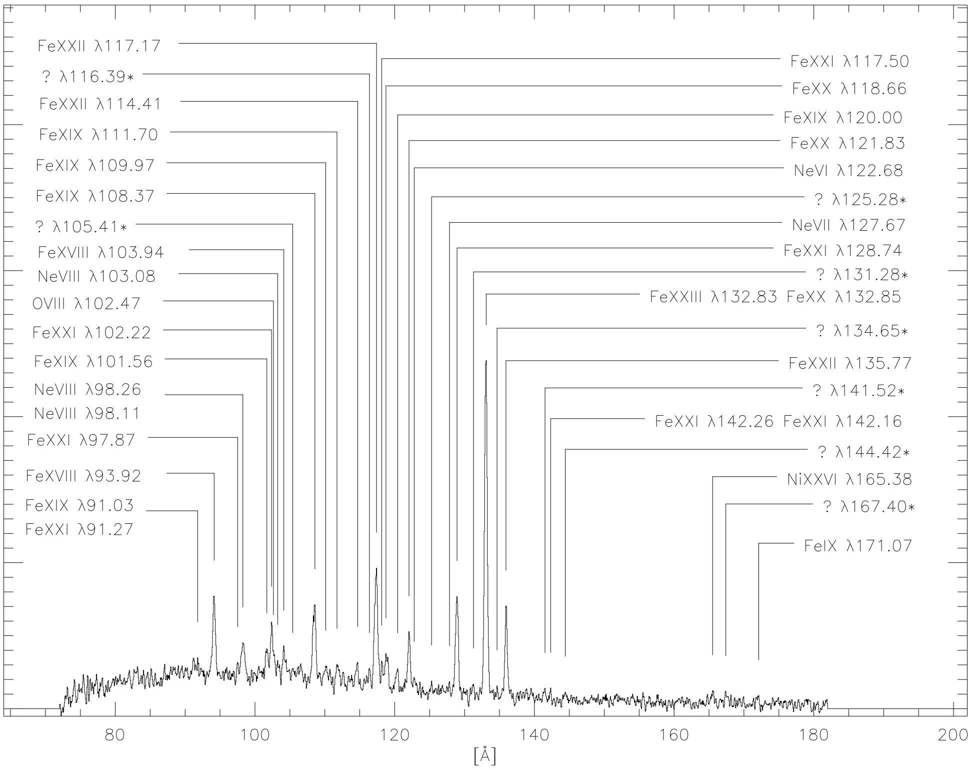


Figure 3. The *EUVE* spectrum with line identifications. We draw attention to the likely presence of of many weak transition region lines in the 80–140 Å range arising from $n = 2$–3 L-shell transitions in Ne, Mg and Si.

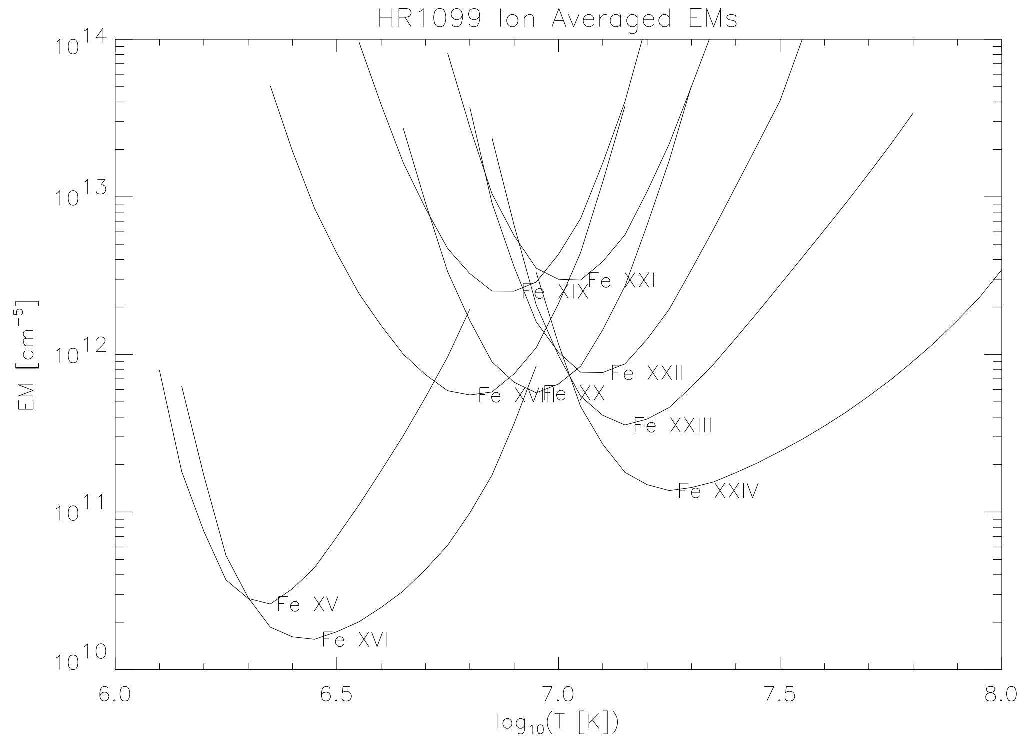


Figure 4. The EM distribution outlined by the various lines due to charge states of Fe ranging from Fe xxv– xxiv.

While, in comparison to the photospheric state-of-the-art, stellar coronal abundance estimates are currently slightly crude, especially those based on radiative loss model fits to low resolution X-ray pulse height spectra (e.g., Figure 1), in the case of the RS CVn's we are currently in a situation where the best possible coronal results are probably more reliable than existing photospheric measurements. However, it should be remembered that in the coronal case we are also often treating observations of both coronae of a binary system as that of a single star. In the event that the two stars are at different evolutionary phases, or even that abundance anomalies, in which coronal values differ from photospheric, are present in the RS CVn's, the coronal abundances might differ on the two components.

The manifold simplifications involved in the optically-thin, ionization and excitation equilibrium approach to the analysis of what are highly complex and dynamic coronae should also be born in mind. However, in cases where photospheric studies are presented with problems, such as large rotational broadening and composite spectra in the case of RS CVn and BY Dra binaries, and atmospheric modeling difficulties in the case of active M dwarfs, the coronal regime offers an alternative route to stellar abundances. Moreover, elements such as Ne and Ar that are inaccessible in late-type photospheres are observable in coronae.

In order to verify whether or not true coronal abundance anomalies are present on the RS CVn's, the photospheric abundances demand further atten-

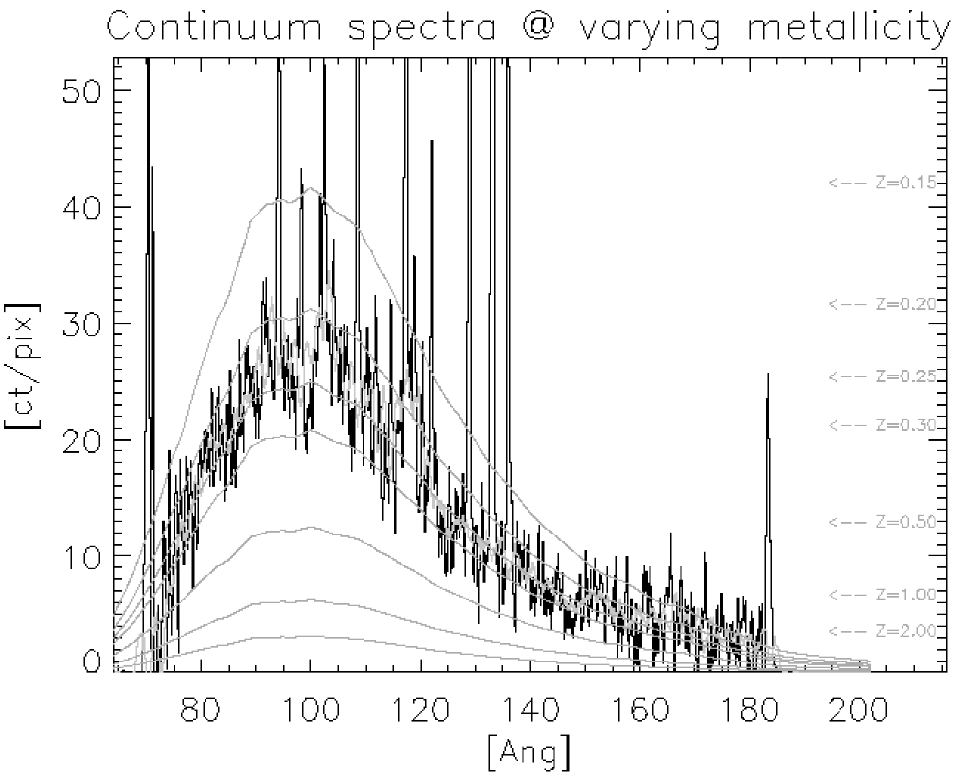
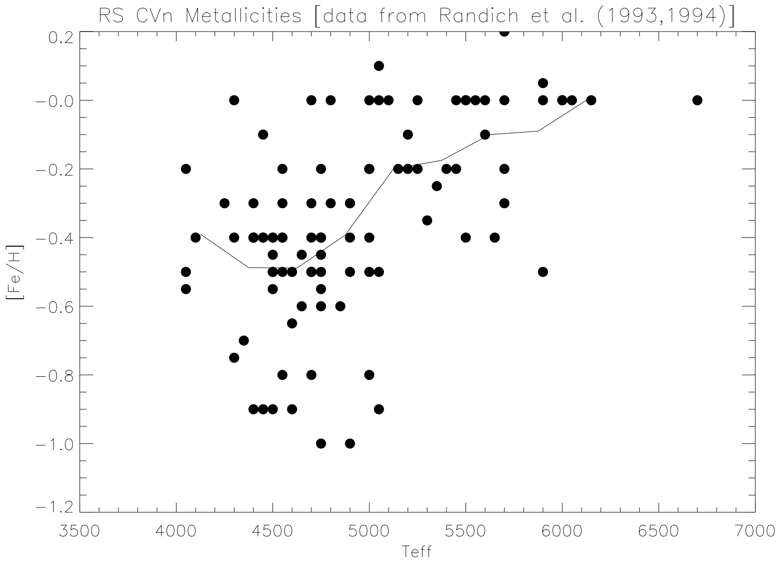


Figure 5. *Spot the continuum! Use your skill, judgement and subjective bias to estimate the coronal iron abundance of HR 1099. Answers on a postcard to ...* The EUV continuum calculated from the observed emission measure for different values of the Fe abundance. The "true" continuum, in my (JJD: subjective and biased) opinion, lies at about $Z = 0.4$ solar, or [Fe/H]$= -0.4$.

tion. Indeed, we note that one or two new photospheric abundance studies appear elsewhere in this volume. This is one direction we are pursuing in future work.



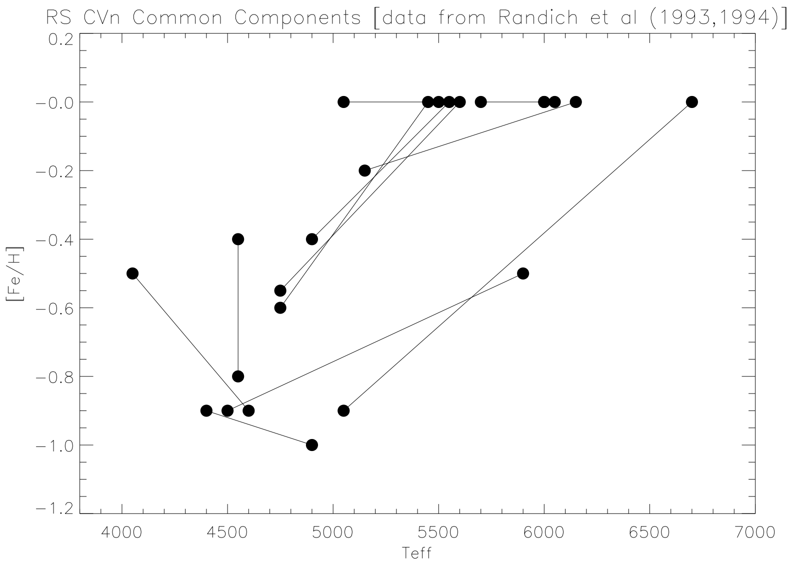


Figure 6. *(top panel):* The metal abundances for RS CVn's and active stars derived by Randich, Giampapa & Pallavicini (1994) and *(bottom panel):* the abundances in the RS CVn's for which estimates were made for both primary and secondary components (joined dots). The solid line in the upper panel illustrates the mean abundance vs temperature. In general this sample of active stars is too metal poor for thin disk stars; moreover, the wildly different Fe abundances in primary and secondary components cannot be understood within current stellar evolution theory if they were formed from the same protostellar material. As also discussed by Randich et al., the abundances could be affected by, e.g.: i) problems in deconvolving the composite spectra; ii) spots; ii) in-filling by the chromosphere.

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References

reference Randich, S., Giampapa, M.S., & Pallavicini, R., 1994, A&A, 283, 893