THE CHANDRA LETG AND XMM-NEWTON SPECTRA OF HR 1099

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Abstract

The X-ray luminous RS CVn binary system HR 1099 has been observed on several occasions in the early phases of Chandra and XMM-Newton. A very hot (up to 40 MK) dominant coronal plasma has been identified from the high-resolution spectroscopic data; cooler plasma is seen down to about 3 MK. We recently obtained 100 ksec in Chandra’s Guest Observer Program to study the corona of HR 1099 with the High-Resolution Camera (HRC-S) and the Low Energy Transmission Grating (LETG) across the complete temperature range above 1 MK. The data provide an unprecedented view of spectral lines and continua at high resolution between 1 and 175 Å. We present our investigations on the Chandra LETGS observation of HR 1099 into the context of the latest results obtained with XMM-Newton.

Key words: Missions: Chandra, XMM-Newton – stars: HR 1099 = V711 Tau – stars: coronae

1. Introduction

HR 1099 (=V711 Tau; d=28.97 pc, K1 IV+G5 V-IV) is one of the brightest binary systems of the RS CVn class. The active K subgiant mainly contributes to the chromospheric and coronal emissions (e.g., Ayres et al. 2001). While in the solar corona, a First Ionization Potential (FIP) effect is observed (low-FIP elements enhanced by factors of 4-6 relative to high-FIP elements), an inverse FIP effect in the corona of HR 1099 has been found (Brinkman et al. 2001). Other active stars also show such an IFIP effect (Güdel et al. 2001a, Güdel et al. 2001b, Drake et al. 2001, Huenemoerder et al. 2001), while it is not present in the intermediately active Capella (Audard et al. 2001a). It is unclear whether there is an enrichment or a depletion of the coronal material compared to the photospheric material in RS CVn systems, because of the high levels of activity and the short rotation periods. Estimates for HR 1099 range from [Fe/H] = −0.6 to 0. Hence the IFIP effect may only reflect the photospheric composition. However, in an analysis of solar analogs with known photospheric abundances (close to solar), Güdel et al. (2002) (see also Audard & Güdel 2002 in these proceedings) find an evolution from an IFIP to a normal FIP effect with decreasing activity, suggesting that the transition is real.

2. Analysis

The Chandra X-ray Observatory observed HR1099 between January 10–12, 2001 for 95 ksec (obsID1879) with the High-Resolution Camera (HRC-S) and the Low Energy Transmission Grating (LETG). Its LETGS spectrum displays bright emission lines from H-like and He-like transitions of various elements (C, N, O, Ne, Mg, Si, S, Ar, Ca), and a rich forest of lines from Fe L-shell and 2s-2p lines. A few bright L-shell lines from Si and Ne can be identified as well. Figure 1 shows the LETGS spectrum from 1.5 to 175Å together with identification labels from major lines. The X-ray light curve (sum of both grating orders) is also given in Fig. 1. The measured flux decreases with time, which could suggest that the observation has been performed during the decay of a flare. We have used the updated MEKAL code available in the SFXE fitting program (Kaastra, Meve, & Nieuwenhuijzen 1996) to fit the average LETGS spectrum (after co-adding the positive and negative orders). We have performed a multitemperature fit to obtain coronal abundances and then used a Chebyshev polynomial approach to derive the emission measure (EM) distribution. The latter is dominated by hot plasma (∼ 20–40 MK; Fig. 2). Coronal abundances (normalized to O) relative to the solar photospheric abundances (Anders & Grevesse 1989 except for Fe, Grevesse & Sauval 1999) as a function of the First Ionization Potential are shown in Figure 2. An enhanced Ne abundance is found, similarly to results shown by Brinkman et al. (2001), Audard et al. (2001b) and Drake et al. (2001). Note that the abundances differ from those obtained from the XMM-Newton RGS data (see Audard & Güdel 2002 in these proceedings), although the same systematic trend can be found. Most probably, the discrepancy originates from the use of a different plasma emission code in the analysis of the RGS data (APEC code). An upper limit of ne ≤ 10^{12} cm^{-3} has been derived from density-sensitive line ratios of Fe XXII (Fig. 2), while the O VII line ratio (sensitive to cool plasma ∼ 2 MK) gives ne = 2 − 5 × 10^{10} cm^{-3}.

The XMM-Newton RGS spectrum of HR 1099 is shown with other RS CVn spectra (UX Ari, λ And, Capella; Fig. 3). The Chandra and XMM-Newton spectra of HR 1099
show a dominance of a hot plasma indicating a high level of activity in this binary system. As found by Brinkman et al. (2001), low-FIP elements tend to be underabundant relative to high-FIP elements. It is probably related to the correlation between the activity level of a coronal source and its FIP bias (Güdel et al. 2002; see also Audard & Güdel 2002).

3. Conclusions

HR 1099 is a hot RS CVn binary that shows a high Ne/Fe ratio. Relative to solar photospheric abundances, the abundance pattern of HR 1099 (normalized to O) is similar to other active RS CVn binaries, although less active stars (λ And, Capella) show no inverse FIP effect. This pattern in active binaries fits well into the long-term evolution from IFIP to FIP found in solar analogs (Güdel et al. 2002; see also Audard & Güdel 2002).

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Figure 1. LETGS spectrum of HR 1099 together with major identified emission lines (at the exception of the Fe IX and Fe X lines, in violet, that have been marked to emphasize their absence in the spectrum as an evidence of the absence of a significant cool component, \( T \approx 1-2 \) MK, in the corona of HR 1099). Data are in red, and a best-fit model (cf. Fig. 3) is in green.
Figure 2. X-ray light curve of the LETGS observation of HR 1099. The sum of the positive and negative grating orders is shown. The light curve suggests that the observation was possibly performed during the decay phase of a flare.

Figure 3. Emission measure distribution of HR 1099 observed by Chandra LETGS. Abundances from a multi-temperature fit have been used. Note that a modified MEKAL plasma emission code available in SPEX has been used.

Figure 4. Coronal abundances of HR 1099 (normalized to oxygen) relative to solar photospheric abundances (Anders & Grevesse 1989, except Fe, Grevesse & Sauval 1999) as a function of FIP. Note that the abundances have been derived using a recent update of the MEKAL code in SPEX. Similarly to Brinkman et al. (2001), a high Ne/Fe abundance is found, suggesting the presence of an inverse FIP effect.

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Figure 5. Density upper limit from Fe XXII lines. The dotted blue line represents the measured line ratio, while the dashed blue lines are 1σ confidence ranges. The continuous red curve is a theoretical curve based on models derived by Brickhouse et al. (1995). The black dash-dotted line gives the upper limit to the measured density. Note that the O vii line ratio (sensitive to plasma ≈ 2 MK) gives $n_e = 2 - 5 \times 10^{10} \text{ cm}^{-3}$. 
Figure 6. XMM-Newton RGS spectra of HR 1099 with compared other RS CVn binaries (see Audard & G"udel 2002 in these proceedings). Note the difference in flux ratios between Ne IX (log$T_m \approx 6.6$; arrow) and Fe XVII (log$T_m \approx 6.73$; arrow), especially in UX Ari and Capella, suggesting that their coronae differ in their elemental composition.