The high-resolution X-ray spectrum of Castor A and Castor B from a simultaneous *XMM-Newton* and *Chandra* observation

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We present a simultaneous *Chandra* and *XMM-Newton* observation of the Castor sextett, focusing on Castor A and Castor B. Our study represents the first unambiguous X-ray detection of all three visual components in the Castor sextett making use of the unprecedented spatial resolution of *Chandra*. Of the present day X-ray instruments only *Chandra* can isolate the X-ray lightcurves and spectra of Castor A and B (angular separation $\sim 4''$). We compare the *Chandra* observation with *XMM-Newton* data obtained simultaneously. Albeit not able to resolve Castor A and Castor B from each other, the higher sensitivity of *XMM-Newton* allows for a quantitative analysis of their combined high-resolution spectrum. We use He-like line triplets to examine the temperature and the density in the corona of Castor AB, and find $n_{\rm e} = (0.5...1)\,10^{10}\,{\rm cm^{-3}}$ (for oxygen) and $n_{\rm e} = 2\,10^{12}\,{\rm cm^{-3}}$ (for neon). The latter one is likely to be too high due to contamination of the Ne IX triplet with iron lines. Our comparison with the conditions of the coronal plasma of other stars shows that Castor AB behave like typical late-type coronal X-ray emitters supporting the common notion that the late-type secondaries within each spectroscopic binary are the sites of X-ray production.

1. The Castor System

Castor is a sextett system composed of three visual stars each of which is by itself a spectroscopic binary. Castor C consists of two late-type stars, and is separated from Castor AB by $\sim 74''$. Castor A and Castor B are both composed of a A-type primary and a late-type companion. The separation between Castor A and Castor B is $\sim 4''$. This is smaller than the resolving power of previous X-ray instruments, at the limit for *XMM-Newton*, and clearly separable only with *Chandra*.

Due to its small distance (16 pc) the Castor system is a rewarding object for X-ray observations, and it has been targeted by virtually all X-ray observatories so far [5,1,7,2,8]. Investigating X-ray emission from Castor A and Castor B is particularly interesting because their A-type primaries are not expected to emit X-rays: they possess neither strong stellar winds that generate hot shocks nor convective zones indispensable for sustaining magnetic activity. Nevertheless, with increasing spatial resolution of the X-ray instruments there was growing evidence that both Castor A and Castor B are X-ray sources. Recalling the theoretical considerations outlined above it is most likely that the X-rays are generated by the late-type secondaries. In a recent *XMM-Newton* observation [2] marginally resolved the two stars. We make use of a simultaneous *XMM-Newton* and *Chandra* observation to examine the high-resolution X-ray spectrum of Castor A and B.

2. X-ray Observations

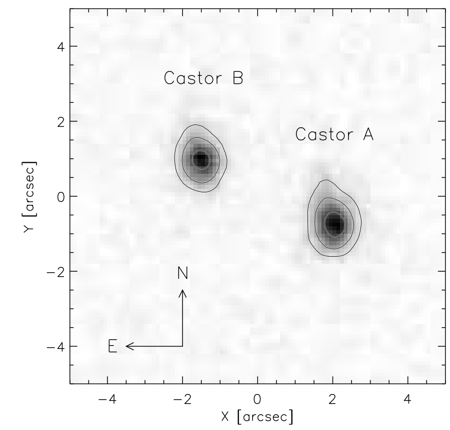

Figure 1. *Chandra* zeroth order LETGS image of Castor A and B.

On Sep 29/30, 2000 Castor was observed simultaneously with *XMM-Newton* and *Chandra* for a

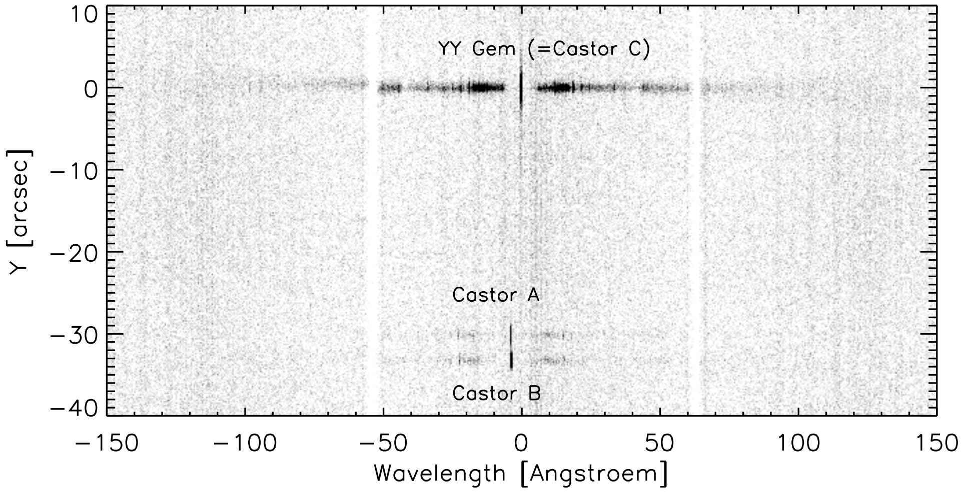

Figure 2. Raw LETGS spectrum of the Castor system.

duration of 55 ksec and 59 ksec, respectively. The prime target was Castor C, discussed by [8]. But the instrumental setup allows to examine the temporal and spectral characteristics of the other visual components in the Castor system as well.

Fig. 1 shows components A and B in the zeroth order image of the *Chandra* LETGS. Their separation on the LETGS image is 3.8″ and the position angle is 64.9°, in agreement with the expectation from the optical ephemeris ([3]). In Fig. 2 we present the raw image of the high-resolution X-ray spectra of Castor obtained by the *Chandra* LETGS where for the first time all three visual components of the sextett are isolated.

3. High-resolution X-ray Spectra

In Fig. 3 we display the extracted RGS and LETGS spectrum of Castor A and B. While the LETGS provides the spatial resolution to separate their spectra, the low signal-to-noise is clearly insufficient for a quantitative analysis. The RGS, on the other hand, does not resolve the two stars, but has much higher sensitivity. Since the appearance of the LETGS spectrum of Castor A and B is quite similar, we feel justified to consider the combined RGS spectrum as representative for both stars.

The most interesting lines in terms of plasma diagnostics are the triplets of He-like ions: resonance r, intercombination i, and forbidden f line. Their line ratios are sensitive to the electron temperature T_e and the electron density n_e. A zoom into the RGS spectrum in the region of the Ne IX and the O VII triplets is seen in Fig. 4. We used the CORA[1] line fitting application to model the individual lines by Lorentz profiles, and the background by a constant factor. The Ne IX triplet is known to be blended with a number of iron lines. We included additional Lorentzians to the right of the $f-$line in the fit because of the intensity enhancement at this position. Iron lines contaminating the r and the i line are impossible to separate from the triplet with the spectral resolution of the RGS, and a major source of uncertainty in the derived line fluxes.

We make use of the calculations for collision dominated coronal plasmas by [6]. The assumption of a collisional plasma is justified if the G-ratio ($G = (f + i)/r$) is ~ 1. Caution is needed in the case of Castor, because the A-type stars exhibit strong UV radiation fields, that may alter the population of the f and i levels. In order to take account of this effect we estimated the radiation temperature $T_{\rm rad}$ from the UV fluxes derived from archived *International Ultraviolet Explorer* (IUE) data and the stellar parameters of Castor A and B. In Table 1 we summarize the results. The two values for the density measured from the oxygen triplet arise from slight differences in the radiation field of Castor A and B. The high value for n_e of Ne IX is questionable because of likely

[1] CORA is provided by J.-U. Ness and available at http://www.hs.uni-hamburg.de/DE/Ins/Per/Ness/Cora/index.html

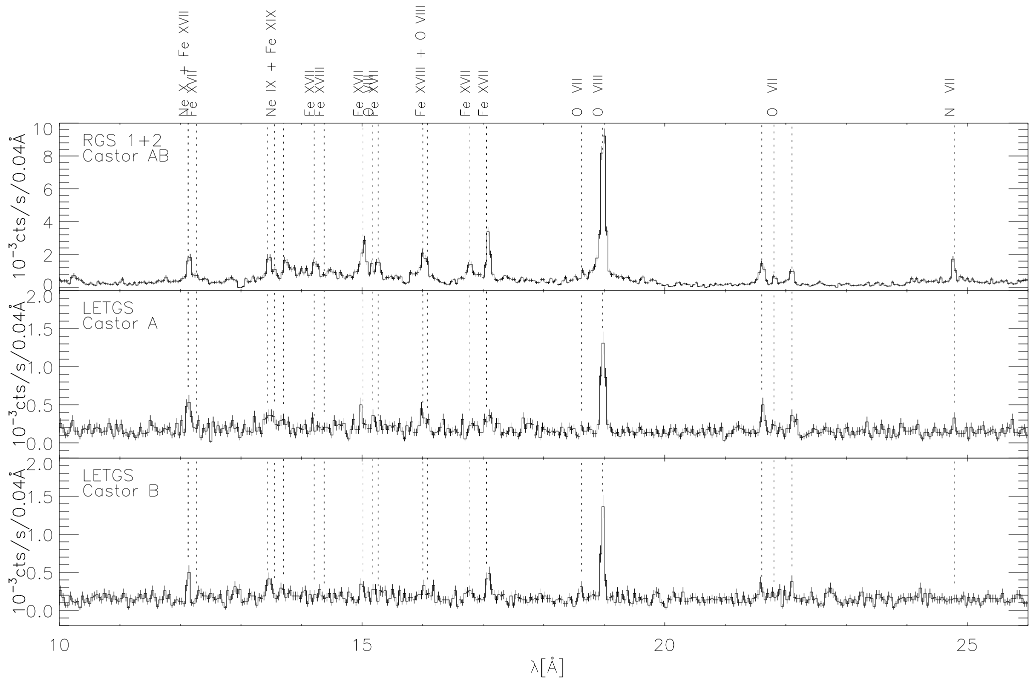

Figure 3. First order RGS count rate spectrum of Castor AB (top), and LETGS count rate spectra of Castor A and Castor B (middle and bottom; left and right side of the LETGS added). Outside the wavelength range on display the only line which is significantly detected above the background is from C VI (at 33.7 Å).

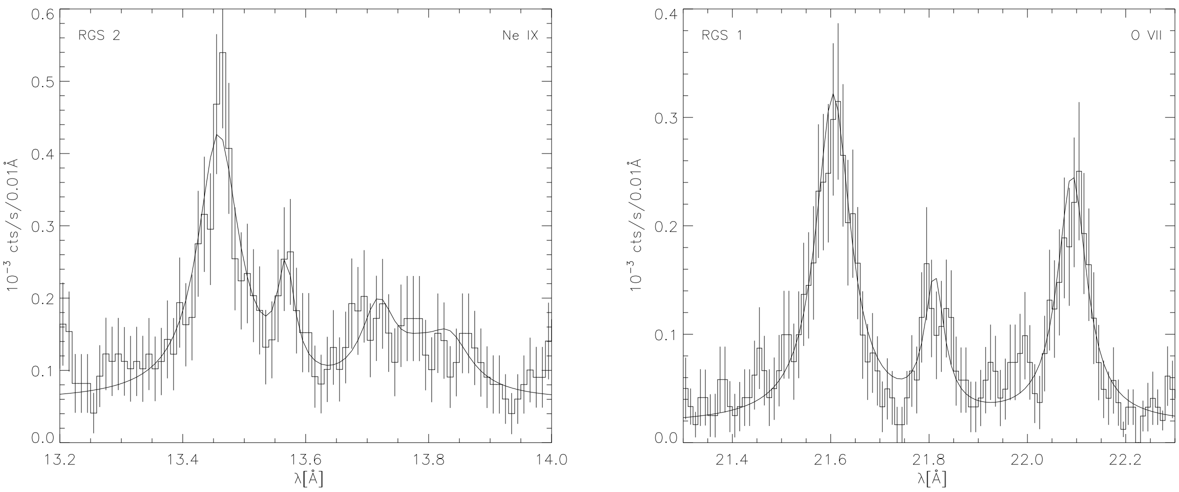

Figure 4. Triplet of helium-like neon and oxygen measured on Castor AB, unresolved with the RGS. The Ne IX triplet is known to be blended with a number of Fe lines, which can presently be disentangled only with the High Energy Grating (HEG) on *Chandra* (see workshop contribution by Ness et al.).

Table 1
IUE flux and radiation temperature of Castor A and B at the wavelength corresponding to the $f \longrightarrow i$ line transition, line ratios measured in the unresolved RGS spectrum of Castor AB: $G = (f+i)/r$, $R = f/i$, and electron temperature and density derived using the calculations for CIE by [6]. Where two numbers are given they are for A and B, respectively.

		O VII	Ne IX
$\lambda_{\rm fi}$	[Å]	1637	1270
$f^{*}_{\rm UV}$	$[10^{10}\,{\rm erg/s/cm^2/Å}]$	8 / 8.5	4.5 / 4.
$T_{\rm rad}$	[K]	9950 /9280	8730 / 8250
G		0.88 ± 0.11	0.43 ± 0.09
R		2.79 ± 0.63	1.55 ± 0.61
$T_{\rm e}$	[MK]	~ 2	~ 8
$n_{\rm e}$	$[10^{10}{\rm cm^{-3}}]$	0.5...1	200

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contributions of iron lines to the emission in the spectral range of the neon triplet.

4. Activity - Temperature Relation

Another temperature sensitive line ratio compares the strength of the $Ly\alpha$ line of an H-like ion to the resonance line of the He-like ion of the same element. The dependence between coronal temperature expressed in the $Ly\alpha/r$ ratio and activity level (represented by the X-ray surface flux) was recently investigated by [4] for a number of late-type stars. We add Castor AB to this sample. From the EPIC pn spectrum we derive $\lg L_{\rm x} = 28.96\,{\rm erg/s}$ in the $0.1-2.4\,{\rm keV}$ *ROSAT* band. When converting this number to the X-ray surface flux we assumed that the observed X-rays are distributed over the whole area of both late-type stars in the Castor A and B binaries. Fig. 5 shows that Castor AB fits well into the activity-temperature correlation for late-type stars and represents a moderate activity level.

5. Summary

In this paper Castor A and B are for the first time resolved using the *Chandra* LETGS. In the high-resolution spectrum of both stars neon, iron, and oxygen features are identified. The temperature and density derived from the combined *XMM-Newton* RGS spectrum of Castor AB, show

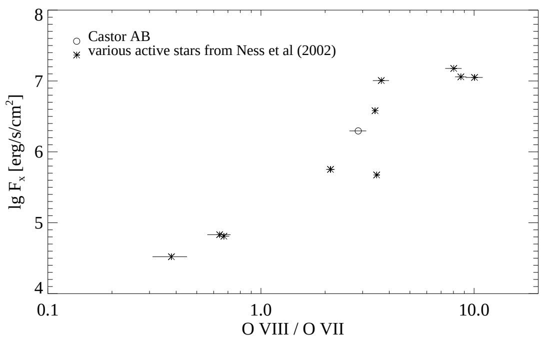

Figure 5. X-ray surface flux versus $Ly\alpha/r$ line ratio of oxygen as a measure for the coronal temperature. $F_{\rm x}$ relates to the ROSAT band $(0.1-2.4\,{\rm keV})$.

that they are typical coronal emitters, fitting well in the sequence of late-type stars with moderate activity level.

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