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Late B-type stars and their candidate companions resolved with *Chandra*⋆

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Abstract. We present the first results from a series of *Chandra* observations carried out with the aim to examine the origin of X-ray emission in main-sequence late B-type stars. X-ray detections of late-B and early A-type stars have remained a mystery as none of the two major theories for stellar X-ray emission applies in this spectral range: while O- and early B-type stars drive strong winds that are subject to instabilities, late-type stars produce X-rays as a result of magnetic dynamo action. Since any dynamo works only in the presence of a convective zone, early-type stars are not magnetically active. We use high spatial resolution X-ray observations to enlighten the prevalent speculation that previously unknown late-type or low-mass companion stars are the sites of the X-ray emission, instead of the B-type primaries. Here we present the results for HD 1685, HD 113703, HD 123445, HD 133880, and HD 169978. Adaptive optics observations have recently revealed at least one faint object near each of these B-type stars (at separation of 1−6″). Four of the new infrared objects show infrared colors and magnitudes typical for low-mass pre-main sequence stars, and are likely true companions to the ∼10–50 Myr old B-type stars. These multiple systems are now resolved for the first time in X-ray light. We uncover that four of the new companions are X-ray emitters, and the fifth one is likely to be a weak X-ray source below the detection limit. Three of the B-type primaries are X-ray dark down to the detection limit of $L_x \sim 10^{28}$ erg/s. But we *do* detect X-ray emission from the position of HD 1685 A and HD 169978 A. The latter one indeed is a spectroscopic binary. The characteristics of all X-ray sources are compatible with those of typical young late-type stars: hard X-ray spectrum ($kT > 0.5$ keV) and high X-ray luminosity ($\log L_x \sim 29...30$ erg/s). Spectroscopic observations in the infrared will solve the question whether the one remaining X-ray detected B-star in our sample, HD 1685 A, also has an even closer companion or whether this is an intrinsic X-ray emitter.

Key words. X-rays: stars – stars: early-type, late-type, coronae, activity

1. Introduction

X-ray observations performed by the *Einstein* and *ROSAT* missions have revealed that X-rays are emitted by stars throughout the Hertzsprung-Russell diagram (e.g. Vaiana et al. 1981; Schmitt et al. 1995; Neuhäuser et al. 1995; Hünsch et al. 1999). For stars on the main-sequence (MS) two mechanisms are known to be responsible for the observed emission.

In hot stars the X-rays are produced by instabilities arising in the strong radiatively driven stellar winds (Lucy & White 1980). O-type stars are characterized by a scaling between X-ray and bolometric luminosity of $L_X/L_{bol} \approx 10^{-7}$ (e.g. Berghöfer et al. 1997). This empirical relation can be reproduced by models for optically thick winds that take account of X-ray attenuation (Owocki & Cohen 1999). However, the observed correlation breaks down near spectral types B2, where the L_X/L_{bol} ratio falls by more than one order of magnitude, and stars cooler than B4 require wind filling factors larger than unity, i.e. their X-ray emission can not be reconciled with any wind model (Cohen et al. 1997).

In late-type stars a solar-like magnetic dynamo driven by rotation and convection is thought to produce the observed (X-ray) activity (Parker 1955, 1993; Rüdiger & Brandenburg 1995). Interior models based on mixing-length theory place the transition from radiative to convective envelope near $T_{eff} \sim$ 8300 K (e.g. Christensen-Dalsgaard 2000). However, the minimum depth of a convective envelope able to support magnetic activity is not well established. Based on X-ray observations the onset of significant coronal emission is placed somewhere between spectral type A7 and F4 (Schmitt et al. 1985; Schmitt 1997). Spectroscopic observations in the ultraviolet (UV) seem to indicate that chromospheres exist in most early-F type stars (Simon & Landsman 1991; Simon et al. 1994). Furthermore, a survey in the far-UV among A-type stars with *FUSE* has revealed that chromospheric line fluxes are similar in strength to

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the Sun for stars with effective temperature ≤8200 K (corresponding to spectral type ∼A4 on the MS), while above this temperature activity drops abruptly (Simon et al. 2002).

Stars with spectral types late B and early A do not drive strong enough winds nor do they possess convective zones necessary to sustain a magnetic dynamo. Consequently no X-ray emission is expected. Nevertheless, the X-ray detection of these stars has been reported in several works (e.g. Caillault & Zoonematkermani 1989; Micela et al. 1990; Grillo et al. 1992; Schmitt et al. 1993; Berghöfer & Schmitt 1994; Caillault et al. 1994; Stauffer et al. 1994; Simon et al. 1995; Berghöfer et al. 1996; Panzera et al. 1999; Huélamo et al. 2000; Stelzer & Neuhäuser 2001; Daniel et al. 2002; Briggs & Pye 2003). Lacking another explanation, the X-ray emission of these stars is commonly attributed to unresolved late-type companions. Because a large fraction of the X-ray detected late B-type stars belong to rather young ($\sim 10^{7...8}$ yrs) stellar groups (e.g., Sco OB2, Carina-Vela, Tucanae), most of the predicted unresolved late-type stars may be young stars still contracting to the MS or just arrived on the zero-age MS, if bound to the primaries. This idea has been supported by (i) the high X-ray luminosities of the late B-type stars, comparable to those of pre-MS stars (Berghöfer et al. 1997) and (ii) the spectral distribution of their X-ray emission which is similar to those of young late-type stars, i.e., they are hard X-ray emitters (Huélamo et al. 2000).

In order to check the hypothesis of unresolved companions to late B-type stars Berghöfer & Schmitt (1994) carried out *ROSAT* High Resolution Imager (HRI) X-ray observations of visual binaries with separations >10″, i.e. those clearly resolvable by the HRI. In these observations only in 1 out of 8 cases the X-ray emission could be ascribed to the known visual late-type companion. On the other hand, *ROSAT* HRI studies of visual binary systems comprised of early-type stars and post-T Tauri stars (also known as Lindroos systems), has shown that both the late B-type primaries and their late-type companions emit X-rays at similar levels (Schmitt et al. 1993; Huélamo et al. 2000). The similarity of the X-ray properties of the Lindroos primaries and secondaries supports the hypothesis that the X-ray emission from the late B-type stars in fact originates from closer pre-MS late-type companions unresolvable by the *ROSAT* HRI.

In view of the large number of X-ray detected late B- and early A-type stars and the inconclusive results of the existent observations, the problem clearly needs further attention. Clarification of this issue can be obtained by carrying out high spatial resolution X-ray observations to precisely locate the X-ray source. The exceptional spatial resolution of *Chandra* allows to push closer and closer in: systems as close as ∼1″ can now be studied. At the distance of 100–200 pc where many of the X-ray emitting B- and A-type stars are located, this corresponds to <200 AU separation. This is much smaller than the maximum separation of visual binaries in the solar neighborhood (see Close et al. 1990; Duquennoy & Mayor 1991), and thus the systems are not unlikely to be bound.

We have started a series of *Chandra* observations pointing at selected multiple stars with a B-type primary. Here we report on the first results. Five X-ray emitting late B-type stars with recently identified faint objects at separations between ∼1–6″ were targeted with the Advanced CCD Imaging Spectrometer. This instrument, in addition to unsurpassed spatial resolution, provides spectral capabilities useful to constrain the nature of the X-ray emitter.

In Sect. 2 we explain the selection of the sample observed with *Chandra*. In Sect. 3 we describe the observations and the data analysis. All detected X-ray sources related with components from the B-star sample are presented in Sect. 4. The X-ray spectra and luminosities are discussed in Sects. 5 and 6. We examine the nature of the companions (Sect. 7), and discuss the X-ray characteristics of wide (>10″) companions in the Lindroos systems among our targets (Sect. 8). The results are discussed in Sect. 9.

2. Sample selection

The sample of *Chandra* targets is based on near-infrared (IR) adaptive optics (AO) observations with ADONIS performed by Hubrig et al. (2001) and Huélamo et al. (2001). Both of these studies aimed at detecting new late-type companions to X-ray detected late B-type stars, in search for the origin of their X-ray emission.

Hubrig et al. (2001) carried out diffraction limited near-IR observations of 49 X-ray emitting late B-type stars extracted from the *ROSAT* study of Berghöfer et al. (1996). As a result they reported the discovery of new companions to 19 of their X-ray selected stars, with separations from the B-type primary between 0.2−14″.

In an analysis of X-ray emission from Lindroos binaries Huélamo et al. (2000) found that three of the X-ray detected B-type primaries show X-ray properties very different from those of the other early-type components in the Lindroos sample, suggestive of further unknown late-type companions. Subsequently Huélamo et al. (2001) performed AO observations on the B-type primaries in Lindroos systems and identified faint objects near one of them.

We selected a homogeneous subgroup of the Hubrig et al. (2001) and Huélamo et al. (2001) samples for observations with *Chandra*. The first group of objects consists of four systems: HD 1685, HD 123445, HD 133880, and HD 169978. We add an archived *Chandra* observation of the Lindroos system HD 113703 for which we also found a likely late-type companion with ADONIS (Huélamo et al., in prep.). The same faint IR object has been detected by Shatsky & Tokovinin (2002).

The selected group of stars fullfills the following selection criteria:

1. The stars have previously unknown visual companions revealed by AO observations.

2. The separations between the new companions and the late B-type star are larger than 1″, that is clearly resolvable by *Chandra*, but smaller than 6″. This means we studied the X-ray emission from sources that could not be resolved by previous instruments. Note that systems with separation >5″ should in principle be resolvable by the *ROSAT* HRI. However, the *ROSAT* HRI failed in resolving some of the Lindroos systems with separations between 5−10″ (Huélamo et al. 2000).

Table 1. Target list of *Chandra* observed B-star systems: optical parameters of primaries, separation and position angle of newly discovered component in the system, and information about the *Chandra* observations. Only the companions newly identified with AO observations are listed. Two of the stars are Lindroos systems, i.e. in addition they have previously known wider companions which are discussed in Sect. 8. HD 123445 has two faint companions discovered with ADONIS.

Designation	Position[1]		Dist[1]	SpT[2]	$\log L_{\rm bol,A}^{3}$	Sep[4]	PA[4]	ACIS observations[5]	
	α_{2000}	δ_{2000}	[pc]		[erg/s]	[″]	[°]	ObsID	Obs. date
HD 1685	00 20 39.0	−69 37 29.7	94	B9	35.42	2.28	211.4	2541	Sep. 23, 2002
HD 113703	13 06 16.7	−48 27 47.8	127	B5	36.26	1.551	268.2	0626	Jun. 10, 2000
HD 123445	14 08 51.9	−43 28 14.8	218	B9	35.84	5.56/5.38	65.0/64.0	2542	Jan. 06, 2002
HD 133880	15 08 12.1	−40 35 02.1	126	B8	35.76	1.222	109.2	2543	Apr. 04, 2002
HD 169978	18 31 22.4	−62 16 41.9	147	B7	36.29	3.085	168.7	2544	Jun. 21, 2002

[1] *Hipparcos* position and distance for the B-type star.
[2] spectral types adopted from Berghöfer et al. (1996) who originally extracted them from the Yale Bright Star Catalogue, (see Hoffleit & Warren 1991).
[3] Bolometric luminosities of the B-type star were derived from the V magnitude using the bolometric corrections by Schmidt-Kaler (1982).
[4] Separation and position angle from Hubrig et al. (2001), Shatsky & Tokovinin (2002), and Huélamo et al. (2001); separations have been measured in the ADONIS detector space.
[5] Obs-ID 0626 was performed with ACIS-S, all other observations with ACIS-I.

3. The primaries do not show signs of intrinsic binarity according to the *Hipparcos* data base and the $\Delta\mu$ database (Wielen et al. 2000). This way we minimize the chance that any X-ray emission discovered by *Chandra* at the position of the B-type star is due to a very close late-type companion not resolvable with both the AO IR images and *Chandra*. One of our targets is however a spectroscopic binary (Aerts et al. 1999).

To summarize, the sample we present in this paper is composed of five B-type stars with recently identified faint IR objects close-by. The *Hipparcos* position of our targets, their distance, spectral type, and bolometric luminosity are listed in Table 1. We give also the separation and position angle of the ADONIS companions. Two of the *Chandra* targets (HD 113703 and HD 123445) are Lindroos systems with an additional previously known late-type companion. The separations for these secondaries are large (>11″), and not of interest for the main aim of our *Chandra* study, isolating X-rays from the primary and the newly discovered ADONIS companions. But one of these Lindroos secondaries was not resolved in X-rays before, and therefore we discuss the X-ray properties of the late-type Lindroos stars in Sect. 8.

We point out that for the moment it remains unclear whether the newly discovered IR objects are physically bound to the B-type stars. Confirmation that they are true companions requires observations of their proper motion and/or spectra. The B-type stars in our sample are on the MS. A small doubt remains only for HD 169978, which has luminosity class III according to SIMBAD. But in Sect. 7 we show that this star is more likely to be on the MS. The contraction timescale of pre-MS stars to the MS is comparable to the mean lifetime of late B-type stars on the MS. Hence, if the IR sources are bound to the B-type star they must be young late-type stars in approach to the MS. In that case optical spectroscopy should reveal a Li I absorption feature at 6708 Å indicating their pre-MS nature. Lacking definite information about their status we will for simplicity continue calling the IR objects "companions", and the B-type stars "primaries". The issue is discussed in more detail in Sects. 7 and 8.

3. Observations and data analysis

All stars introduced in Sect. 2 were observed with *Chandra* using the Advanced CCD Imaging Spectrometer (ACIS) in imaging mode. The Obs-ID and date of all *Chandra* observations can be found in Table 1.

Except for HD 113703 ACIS-I was used as the prime instrument because of the optical brightness of the B-type stars ($V \sim 5...6$ mag), which is slightly below the limiting magnitude of ACIS-S. Two of the CCDs of the ACIS-S array were also turned on, but their data will not be discussed here. The somewhat lower sensitivity of ACIS-I with respect to ACIS-S did not restrict our observations, because the objects are bright X-ray sources. The net exposure time per target was between 2300 s and 2400 s.

The observation of HD 113703 was performed with the spectroscopic array of ACIS. Only the two central chips (S2 and S3) were turned on. The frame time had been reduced to 0.9 s. Generally this is useful in the case of X-ray bright targets to avoid pile-up. To enhance the observing efficiency despite the small frame time the 1/4 subarray of the chips were used. This observation was much longer than the other ones, ∼12 ksec. The different instrument setup and exposure time for HD 113703 stem from the fact that we added this observation from the archive to the projected sample.

The data analysis was carried out using the CIAO software package[1] version 2.3 in combination with the calibration

[1] CIAO is made available by the CXC and can be downloaded from `http://cxc.harvard.edu/ciao/download-ciao-reg.html`

database (CALDB) version 2.18. We started our analysis with the level 1 events file provided by the pipeline processing at the *Chandra* X-ray Center (CXC). Observation 0626 was processed at the CXC with CALDB version 2.3, and since it involves the S3 chip of ACIS we had to apply a new gain map and updates on the geometry (focal length, ACIS pixel size and chip positions). All other observations discussed here have been processed with CALDB version 2.9 or later where these modifications were performed automatically. In the process of converting the level 1 events file to a level 2 events file for each of the observations we performed the following steps: we filtered the events file for event grades (retaining the standard *ASCA* grades 0, 2, 3, 4, and 6), and applied the standard good time interval (GTI) file. Events flagged as cosmic ray afterglow were retained after inspection of the images revealed that a substantial number of source photons erroneously carry this flag. We removed the pixel randomization which is automatically applied by the CXC pipeline. Pixel randomization deteriorates the spatial resolution. Since the positional accuracy is particularly important to our observations we also checked the astrometry for any known systematic aspect offsets using CIAO software. In three cases (Obs-ID 0626, Obs-ID 2542, and Obs-ID 2543) we found that a small aspect correction is needed. We took care of this by modifying the respective header keywords in the events level 2 file.

3.1. Source detection and identification

Source detection was carried out with the *wavdetect* algorithm (Freeman et al. 2002). This algorithm correlates the data with a mexican hat function to search for deviations from the background. The *wavdetect* mechanism is well suited for separating closely spaced point sources. We used wavelet scales between 1 and 8 in steps of $\sqrt{2}$. The source detection was performed on an unbinned image, to achieve the best-possible spatial resolution. For the ACIS-I observations we used images with size of 2048×2048 pixels centered on the *Hipparcos* position of the primary. For the ACIS-S observation we examined only the S3 chip, i.e. the image size was 1024×1024 pixels. The threshold for the significance of the detection was set to 2×10^{-7}. For this value the detection of one spurious source is expected in a 2048×2048 pixel wide image. Although our targets are always located in the center of the ACIS field we analysed the full image. This way other X-ray sources can be used to cross-check the positional accuracy.

With the threshold given above we detected between 10 and 16 sources per field. In all cases at least one X-ray source is detected near our target, and these sources are always among the brightest in the respective *Chandra* field. For each of the exposures we measured the offset between the X-ray detections and the B-type star and the offset between the X-ray detections and the newly discovered AO companions listed in Table 1. Then for each of the X-ray sources corresponding to any one of the components of our targets photons were extracted from the 3σ source ellipse provided by *wavdetect*. For the X-ray undetected components in our sample we computed upper limits following the prescription for Poisson-distributed counting data given by Kraft et al. (1991).

To check the accuracy of the satellite's aspect solution we cross-correlated all detected X-ray sources with optical catalogues (*Guide Star Catalogue* [GSC] and *US Naval Observatory Catalogue* [USNO A2.0]) using an error radius of 2″. The pointing accuracy is expected to be better than this value. Most of the X-ray sources do not have a known optical counterpart within this search radius. Since many of them are very faint (<10 counts) this may indicate that they are spurious detections or could be as yet unknown extragalactic objects. Although we chose the detection significance threshold such that only one spurious source is expected per image previous observations have shown that the actual number of them is larger; see e.g. Daniel et al. (2002). Despite this fact each of the fields contains at least two X-ray sources with optical counterpart. Inspection of the offsets between optical and X-ray position for these sources shows no systematic effect, and we conclude that no aspect correction is required (besides the correction described in the previous section).

4. X-ray detections

Figure 1 shows the central portion of the ACIS images around our targets. We overplot the source extraction area computed with *wavdetect* (dark ellipses), as well as the *Hipparcos* position of the primary and the IR position of the companions (grey circles). Only in one case (HD 1685) two X-ray sources are detected, i.e. both B-type star and IR object are bright X-ray emitters. In four of the five targets an X-ray source can be associated with the new ADONIS object.

HD 169978 is the only case in the sample studied here where there is clearly no X-ray source at the position of the nearby companion. However, we find a total of 6 counts at the position of this object versus <1 count on average in a source-free region of the same area. This suggests that HD 169978 B is an X-ray source below the detection limit. In Sect. 6 we estimate an upper limit to the X-ray luminosity of this object.

The field of HD 169978 contains one X-ray source which has similar brightness to HD 169978 A. This X-ray source is identified with HD 170046, an A8/9 IV type star according to SIMBAD, already detected with the *ROSAT* HRI. The offset between the X-ray and the optical position in the Chandra image is 1.4″. A translational position error of this order is not ruled out. However, in view of the high precision of the X-ray coordinates in the other *Chandra* fields examined here we consider this an unlikely possibility. The optical position is NW of the X-ray source, i.e. it points opposite to the position angle of the AO companion of HD 169978 A. Therefore, if the offset between HD 170046 and the adjacent X-ray source was an error in the aspect solution of *Chandra* the X-ray source near HD 169978 would remain unexplained, as it would then coincide neither with the primary nor the secondary of this system. We speculate that HD 170046 may be another candidate for an X-ray emitting A-type star with a possible late-type companion separated by ∼1.5″. Recall, however, that late A-type stars may possess shallow convection zones, and thus the X-ray emission could also be intrinsic to HD 170046. In terms of hardness ratio

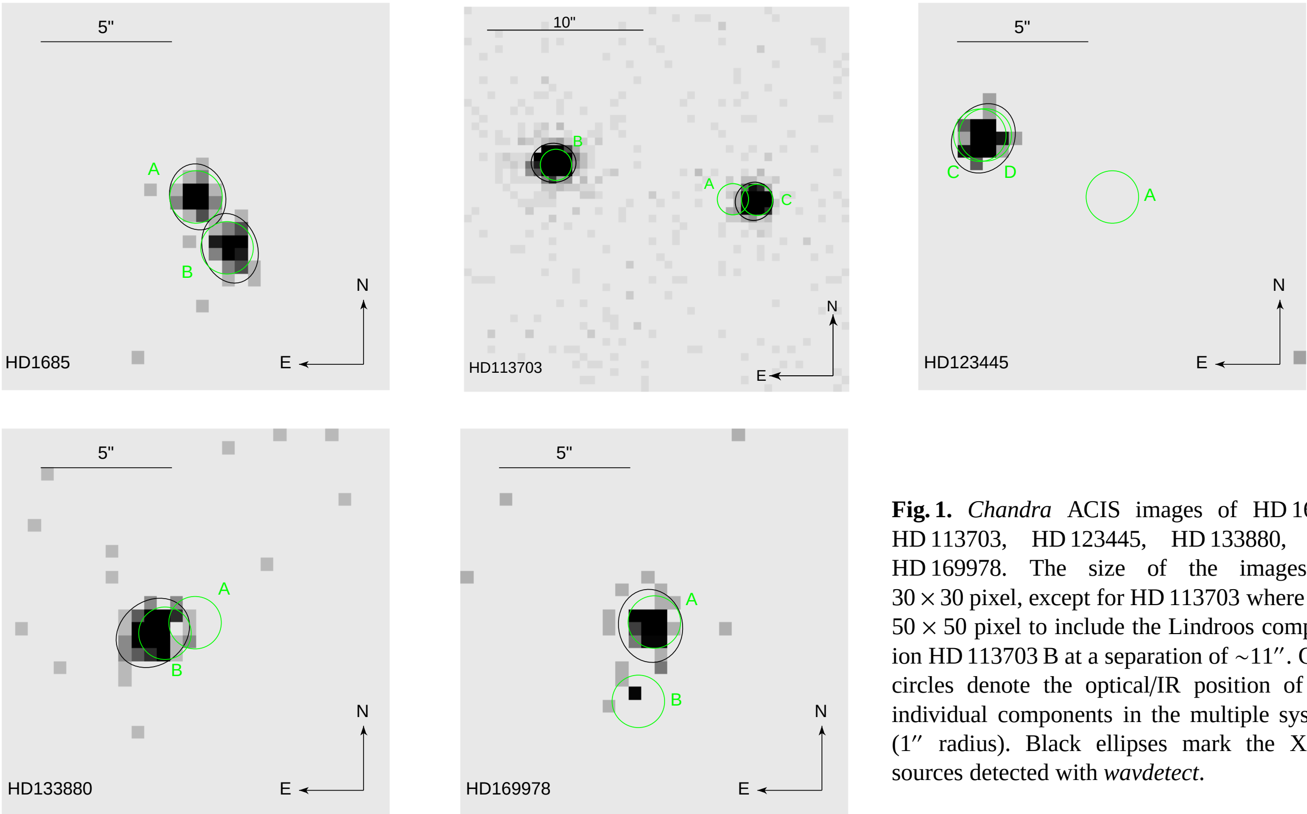

Fig. 1. *Chandra* ACIS images of HD 1685, HD 113703, HD 123445, HD 133880, and HD 169978. The size of the images is 30 × 30 pixel, except for HD 113703 where it is 50 × 50 pixel to include the Lindroos companion HD 113703 B at a separation of ∼11″. Grey circles denote the optical/IR position of the individual components in the multiple system (1″ radius). Black ellipses mark the X-ray sources detected with *wavdetect*.

HD 170046 resembles the other sources discussed in this paper, $HR = 0.21 \pm 0.15$ for $S = 0.5...1.0$ keV and $H = 1.0{-}8.0$ keV.

For HD 113703 we show a somewhat larger image to include the detection of the wide Lindroos companion HD113703 B. Adopting the *Hipparcos* position for HD 113703 B (position angle, PA, of 73°, separation of 11.2″) the distance between this star and the X-ray source is quite large (1.2″). We have examined our optical images of this star taken in February 2001 by one of us (NH), and find HD 113703 B at a position angle of 79° and separation of 11.5″ from the B-type star. Comparing the position of HD 113703 B in our optical images with the position of the X-ray source we find that the displacement is only 0.2″. Therefore, we suppose that the PA cited in the *Hipparcos* data base is erroneous.

In Table 2 we list the X-ray parameters for the X-ray sources shown in Fig. 1. We give HD number (Col. 1), X-ray position (Cols. 2 and 3), separation to B-type star and new companion (Cols. 4 and 5), significance of detection (Col. 6), exposure time (Col. 7). The total number of counts (Col. 8) and the X-ray luminosity (Col 10) refer to the 0.5–8 keV passband. L_x was derived by integrating the ACIS spectrum (see Sects. 5 and 6). It was assumed that the systems are physically bound, and all components are located at the distance of the B-star given in Table 1. This may not be true in all cases (see Sect. 7). Col. 9 is the hardness ratio defined as $HR = (H - S)/(H + S)$, where H and S are the number of counts in a hard band (1–8 keV) and soft band (0.5–1 keV), respectively. The last column is the X-ray temperature of a isothermal model fit to the ACIS spectrum (see Sect. 5 for details).

5. Spectral analysis

The high sensitivity of ACIS jointly with the improved spectral resolution as compared to the *ROSAT* PSPC allows for the first time to examine the characteristics of these stars by means of a direct spectral analysis. Except for Obs-ID 0626 the number of counts collected per X-ray source are rather small due to the low exposure time, but sufficient for a basic description of the temperature of the emitting plasma.

For each of the X-ray sources listed in Table 2 we extracted a spectrum, the corresponding detector response matrix that maps pulse heights into energy space, and an auxiliary response file which contains information about the effective area and detector efficiency across the chip as a function of energy. We binned each spectrum to a minimum of 10 counts per bin. As the background of ACIS is very low (measured to be <1 count in the source extraction area) it can be neglected. Spectral modelling was performed in the XSPEC environment, version 11.2.0.

Version 2.3 of the CIAO tools is the first one that implements a correction for the charge transfer inefficiency (CTI). CTI affects the spectrum of astrophysical sources by introducing an apparent gain shift and degrading the energy resolution. Currently the CTI correction is not included in the pipeline processing performed at the *Chandra* X-ray Center (CXC). Therefore, to apply this correction to the data the level 1 events file has to be reprocessed by the user and converted to a level 2 events file. After taking account of the CTI correction we encountered serious problems in the spectral fitting process. None

Table 2. Positions and X-ray parameters of X-ray sources associated with late-B type stars or their IR companions at separations between 1−6″.

HD	$\alpha_{x,2000}$	$\delta_{x,2000}$	Sep X-A [″]	Sep X-B [″]	Sign.	Expo [s]	ACIS counts*	HR	$\log L_x$* [erg/s]	kT [K]
Obs-ID 2541, Seq. No 200149										
1685 X-ray 1	00 20 38.99	−69 37 29.70	0.07	2.25	21.5	2338	44.0 ± 6.6	−0.09 ± 0.21	29.1	0.53
1685 X-ray 2	00 20 38.75	−69 37 31.66	2.35	0.11	33.8	2338	71.0 ± 8.4	0.07 ± 0.17	29.4	1.06
Obs-ID 0626, Seq. No 200051										
113703 X-ray	13 06 16.57	−48 27 47.97	1.37	0.21	299.5	12184	1327.0 ± 36.4	−0.35 ± 0.04	29.8	0.76
Obs-ID 2542, Seq. No 200150										
123445 X-ray	14 08 52.35	−43 28 12.57	5.39	0.15†	33.3	2237	65.0 ± 8.1	0.05 ± 0.18	29.8	0.87
Obs-ID 2543, Seq. No 200151										
133880 X-ray	15 08 12.24	−40 35 02.49	1.66	0.46	88.6	2461	218.0 ± 14.8	0.17 ± 0.09	30.0	1.05
Obs-ID 2544, Seq. No 200152										
169978 X-ray	18 31 22.42	−62 16 42.01	0.20	2.92	57.1	2420	125.0 ± 11.2	0.12 ± 0.13	29.9	0.83

* In the 0.5–8 keV passband; L_x refers to the distance given in Table 1.

† This is the distance to IR-companion "D". The distance to IR-companion "C" is 0.17″.

of the fits converged to an acceptable solution. Therefore, we decided to work on the uncorrected spectrum, until more reliable tools allow to consider the CTI effect. In any case, due to the low number of counts in our spectra this effect should not exceed the statistical uncertainties.

First we approximated each spectrum with a one-temperature (1-T) thermal model (MEKAL) including a photo-absorption term comprising the atomic cross-section by Morrison & McCammon (1983). For three of the systems the optical extinction is known (see Lindroos 1986), and N_H can be estimated using the relation by Paresce (1984) to be $\leq 2 \times 10^{20}$ cm^{-2}. The other two are likely to have similarly low values of absorption because of their proximity which provides low interstellar column density, and because at their age of ≤100 Myrs no substantial amount of circumstellar material is present. As the spectral fits showed a tendency to converge towards much higher values for N_H we imposed the constraint that the column density may not exceed 8×10^{20} cm^{-2}. The temperatures derived from the 1-T fits with solar abundances are presented in Table 2. In Fig. 2 we overlay the data by this model.

Noticeably this model is not adequate for most of the stars. Therefore, we refined our approach and allowed for variable abundances. This results in an acceptable solution for HD 1685 X-2 with $Z \sim 0.16\,Z_\odot$ ($\chi^2_{red} = 0.9$ for 3 d.o.f.s), and presents a slight improvement in χ^2-statistics for HD 133880 ($Z \sim 0.18\,Z_\odot$ and $\chi^2_{red} = 1.4$ for 17 d.o.f.s) and HD 169978 ($Z \sim 0.20\,Z_\odot$ and $\chi^2_{red} = 1.9$ for 8 d.o.f.s). However, in the latter two cases substantial residuals remain. The clearest improvement is found for HD 113703, where $Z \sim 0.15\,Z_\odot$ and $\chi^2_{red} = 1.4$ for 17 d.o.f.s. For HD 1685 X-1 and HD 123445 the poor quality of the spectrum does not justify the use of a more refined model.

To remove the remaining residuals in the spectrum of HD 113703 C, HD 133880 B, and HD 169978 A introducing a second temperature is in order. We find hotter components in the range 1.5–3.5 keV, and cooler components only slightly smaller than in the 1-T models. However, due to the low statistics at high energies the hotter temperatures are poorly constrained. Indeed, the parameter space of the 2-T model shows several local minima depending on the initial values of the temperatures. We mention in passing that the elevated emission near 6 Å in the spectrum of HD 169978 A is likely to be explained by enhanced silicon abundance. But the low number of counts prohibits the determination of the abundances of individual elements.

We stress that despite the short exposure times and the problems outlined above with the 2-T fits the derived parameters are not meaningless. In particular, the 1-T model does reproduce the temperature of the bulk of the emitting material, although the detailed temperature structure of the corona is inaccessible. Feigelson et al. (2002) have shown for similar models fitted to X-ray faint young stars in Orion that the typical uncertainties in kT for sources between 30 and 100 counts with ACIS are about 30...60%. Thus, our *Chandra* observations allow for the first time a quantitative assessment of the X-ray temperature of these stars. An earlier study of the X-ray emission from early-type stars by Berghöfer et al. (1996) based on *ROSAT* All-Sky Survey (RASS) observations used the *ROSAT* PSPC hardness ratio in comparison with a grid of model spectra generated for various column densities and X-ray temperatures to estimate the conditions in the emitting region. They concluded that most OB stars have a very soft X-ray spectrum, with a typical temperature $T_x < 0.5$ keV. This is in clear contrast to our *Chandra* observations: all our targets require temperatures in excess of 0.5 keV, and the three stars with the highest S/N among our targets even suggest a second spectral component with temperature above 1.5 keV.

The discrepancies between the *ROSAT* estimate and the *Chandra* spectra are graphically demonstrated in Fig. 2: the dotted lines are simulated ACIS spectra based on the spectral parameters listed by Berghöfer et al. (1996). Only HD 123445

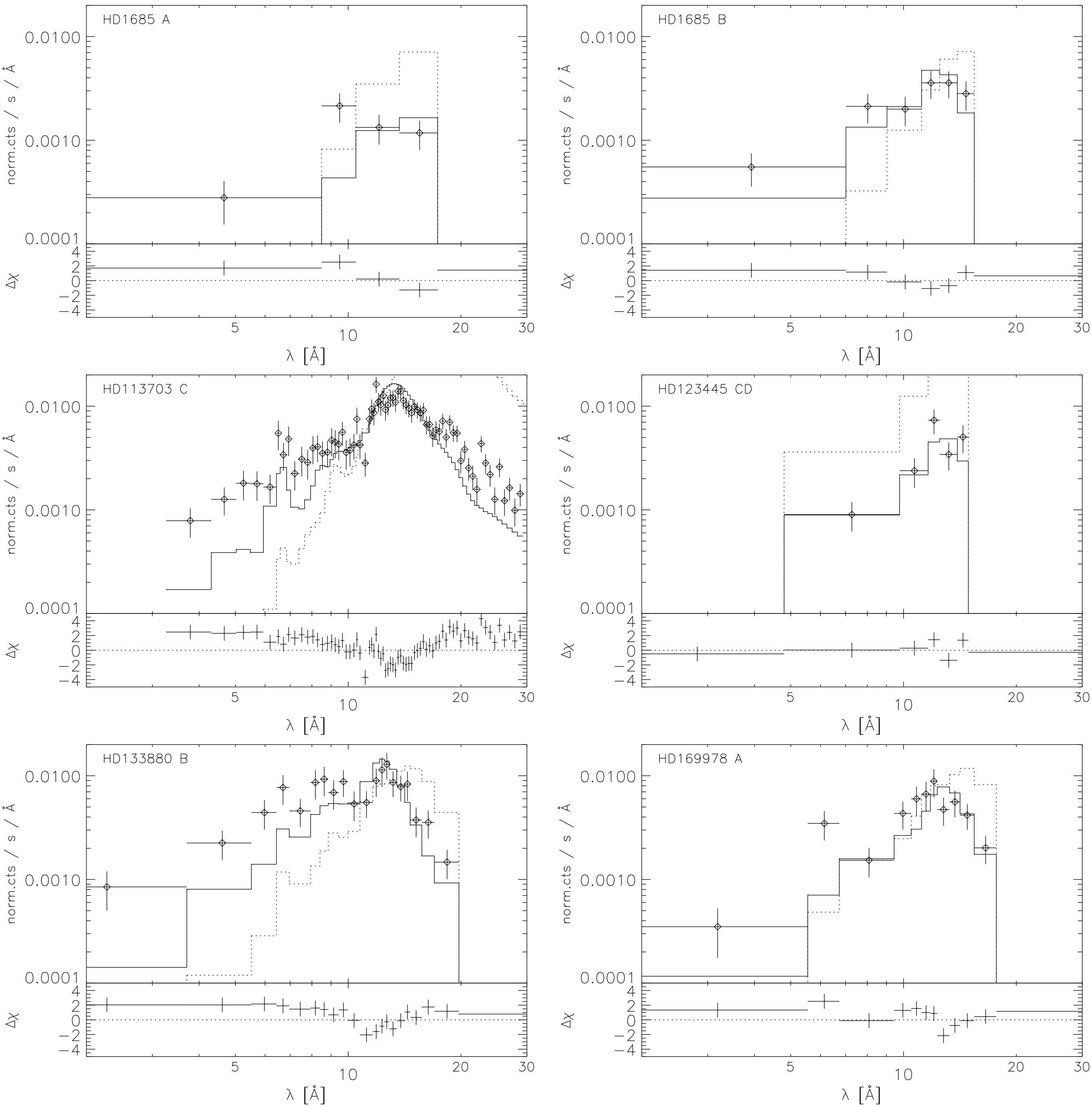

Fig. 2. ACIS spectra of X-ray sources identified with a component of the B-star systems. *solid lines* – best fit of 1-T model with solar abundances (see text in Sect. 5 and Table 2), *dotted lines* – simulated spectrum obtained for spectral parameters estimated from *ROSAT* observations (Berghöfer et al. 1996 and Huélamo et al. 2000).

was not detected in the RASS, and we use the parameters given by Huélamo et al. (2000) extracted from a *ROSAT* HRI observation. The simulations were performed with XSPEC for a 1-T model with $N_{\rm H}$ and kT fixed on the *ROSAT* values, and the normalization was varied until the X-ray luminosities given by Berghöfer et al. (1996) and Huélamo et al. (2000) were reproduced. We also took into account that Berghöfer et al. (1996) have used their own estimate of photometric distances, which are different from the ones in Table 1. Figure 2 shows clearly that *ROSAT* has misestimated both the brightness and spectral distribution of these sources, presumably due to the low S/N of the data which necessitated (wrong) model assumptions.

6. X-ray luminosities

The ACIS observations at hand facilitate the derivation of X-ray luminosities of the detected sources directly by integrating the spectrum. The results are listed in Table 2 for the

0.5–8 keV energy band. We add here some remarks on the individual objects and present upper limits for the undetected components.

The *Chandra* observation of HD 1685 has shown that *ROSAT* had confused two X-ray sources of similar brightness, and that the X-ray luminosity of the ACIS source at the position of HD 1685 B is lower than thought before. Both the X-ray temperature and luminosity of HD 1685 A are similar to the detected late-type stars, and therefore point at the presence of another as yet undiscovered late-type companion.

For HD 113703 Berghöfer et al. (1996) provided a value for L_x which is too high by one order of magnitude. This difference can not be explained by the smaller energy range of the *ROSAT* PSPC. In principle it could be due to variability of the star, but a mis-estimate of the *ROSAT* luminosity resulting from the method used by Berghöfer et al. (1996) (see Sect. 5) seems more probable.

The possible nature of HD 123445 CD was discussed by Huélamo et al. (2001). A binary composed of two K-type stars was put forth as most likely because the *ROSAT* luminosity and hardness were not in agreement with them being foreground M-type stars or background giants. Huélamo et al. (2001) argued that if HD 123445 CD were indeed K-type stars their IR colors indicate a distance of ~140 pc (consistent with the mean distance of the Upper-Centaurus-Lupus (UCL) association; de Zeeuw et al. 1999). In this case they may not form a physical pair with HD 123445 A. Accordingly their X-ray luminosity would be lower than given in Table 2, namely $\log L_x = 29.4$ erg/s. Regardless on whether the distance is 218 or 140 pc the *ROSAT* estimate for L_x was far too high. As in the case of the estimates by Berghöfer et al. (1996) discussed above this is presumably a result of the assumptions on the spectral properties of the source made by Huélamo et al. (2000).

Hubrig et al. (2001) noticed that the *ROSAT* X-ray luminosity of HD 169978 is too high in terms of $\log(L_x/L_{bol})$ to be emitted from the companion, which is a very-low mass star ($M_B = 0.15\,M_\odot$). Our *Chandra* observation has assigned the X-ray source to the B-type star which is meanwhile known to be a spectroscopic binary. The X-ray luminosity of 8×10^{29} erg/s provided by ACIS at the position of HD 169978 A is consistent with the earlier *ROSAT* measurement.

To compute upper limits for the undetected components of our target systems we used the method described by Kraft et al. (1991). We count the photons in a circle of 1.25″ radius centered on the optical/IR position of the star. This photon extraction area is similar to the *wavdetect* source ellipses of the detected sources. For HD 133880 A and HD 113703 A these circles overlap with those of their nearby detected companions. Therefore, we use the number of photons collected in the semicircle pointing away from the companion, and extrapolate this value to the full extraction area. Not a single photon was collected at the position of HD 123445 A. We measure 6 counts at the IR position of HD 169978 B. We took account of the background fluctuations by estimating the background within a squared area of 1′ radius centered on the optical/IR position of the respective star, and scaling this mean background to the source extraction area. Using these numbers in connection with the values tabulated by Gehrels (1986) provides the number of upper limit counts. The conversion to X-ray flux and luminosity is performed with help of PIMMS[2] assuming a 10 MK hot thermal plasma and negligible absorption. We tabulate the resulting X-ray luminosities for the 0.5–8.0 keV band in Table 3.

Table 3. 95% confidence upper limits to the X-ray luminosity of undetected primaries and new IR objects; numbers are for the ACIS broad band (0.5–8 keV).

	113703 A	123445 A	133880 A	169978 B
$\log L_x$ [erg/s]	< 27.85	< 28.54	< 28.02	< 28.76

6.1. The L_x/L_{bol}–relation

The ratio between X-ray and bolometric luminosity, L_x/L_{bol}, is a crucial indicator for stellar activity. The most active late-type stars – generally coinciding with the most rapid rotators – are observed to display values near 10^{-3}. An unidentified mechanism seems to prevent the generation of X-rays above this limit. Several possible causes for the saturation phenomenon are discussed, such as stripping of the corona by centrifugal forces (Jardine & Unruh 1999) or complete filling of the stellar surface with active regions (Vilhu 1984). Less active late-type stars range between $L_x/L_{bol} = 10^{-4...-5}$. The spread is thought to be caused by the influences of various stellar parameters such as mass, rotation, and age on the level of X-ray emission. Hot stars, for which X-ray emission is thought to arise in a stellar wind, are clearly distinct from late-type stars with a typical value of $L_x/L_{bol} \approx 10^{-7}$.

Figure 3 displays the L_x/L_{bol} ratio for all components of the B-star systems observed with *Chandra*. The bolometric luminosities for the low-mass components (both the Lindroos secondaries and the new companions) are given in Tables 4 and 5 of Sect. 7 and Sect. 8, where we explain also how they were derived. For comparison, in Fig. 3 we show also the Lindroos systems observed with *ROSAT* (Huélamo et al. 2000).

In the sample investigated here all new IR objects display $\log(L_x/L_{bol})$ values near the saturation limit. For HD 169978 B only an upper limit is derived, and due to its small bolometric luminosity the $\log(L_x/L_{bol})$ ratio is still rather ill-constrained, although the sensitivity is improved by more than one order of magnitude with respect to previous X-ray measurements for this stellar system. For the three undetected B-type stars the upper limits to $\log(L_x/L_{bol})$ are below 10^{-7}. The two detected early-type stars show $\log(L_x/L_{bol}) \sim -6.5$, similar to that of most of the primaries of the Lindroos sample studied with *ROSAT*.

7. Evolutionary state of the system components

Next we examine whether the low-mass companions and the B-type primaries are physical rather than optical systems by comparing their evolutionary stage. If they form bound

[2] http://asc.harvard.edu/toolkjet/pimms.jsp

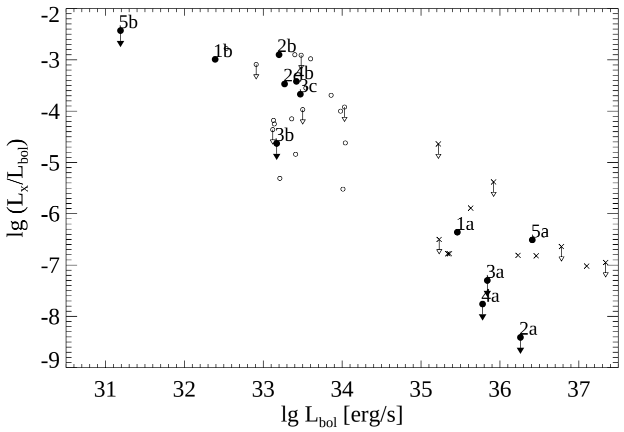

Fig. 3. Ratio between X-ray and bolometric luminosity $\log(L_x/L_{bol})$ versus bolometric luminosity. *Filled circles* – detections and upper limits derived in this paper; individual objects: [1] – HD 1685, [2] – HD 113703, [3] – HD 123445, [4] – HD 133880, [5] – HD 169978; for Lindroos systems [b] denotes the Lindroos secondary and [c] the new IR object, else [b] is the IR object. Note that if the "secondaries" were not bound to the B-type stars their distance would be different from the value given in Table 1, and our estimate of the luminosities would be wrong. *Open circles* – late-type stars in Lindroos systems observed with *ROSAT* (see Huélamo et al. 2000), *x-points* - early-type stars in Lindroos systems observed with *ROSAT* (see Huélamo et al. 2000).

systems, both the late B-type star and the IR object should have the same age.

7.1. Late B-type primaries

The primaries in the stellar systems under consideration have been compared to evolutionary models by Hubrig et al. (2001) and Gerbaldi et al. (2001), who found that their ages range from ~50...200 Myrs. On the other hand three of the targets are known to be members of different OB associations: HD 113703 A is believed to belong to the Lower Centaurus Crux subgroup of the ScoCen OB 2 association, while HD 123445 A and HD 133880 A are members of the UCL co-moving group (de Zeeuw et al. 1999). The Sco-Cen OB 2 subgroups have ages between 5–13 Myrs (de Geus et al. 1989), about one order of magnitude lower than the individual ages derived by Hubrig et al. (2001) and Gerbaldi et al. (2001) from model tracks. We suppose that this discrepancy arises from uncertainties in the stellar parameters that can be summarized as follows:

- For HD 133880 A, e.g., the $B - V$ color varies with an amplitude of ~0.1 mag, leading to a spectral type range of B3...B9 according to Kenyon & Hartmann (1995), and an uncertainty of at least ±2000 K in $T_{\rm eff}$ allowing for an age as small as ~10 Myrs.
- For HD 123445 A a major uncertainty stems from the distance. This star has a *Hipparcos* parallax of 218 ± 40 pc, while the distance to the UCL association is 140 pc (de Zeeuw et al. 1999). Thus $L_{\rm bol}$ is not constrained very well, and the age of HD 123445 A may be smaller than suggested by Gerbaldi et al. (2001).
- HD 169978 A is listed as a possible member of the Wolf 630 moving group (McDonald & Hearnshaw 1983). The age of the Wolf 630 cluster is ~5 Gyrs. Therefore, HD 169978 A could already have left the MS, consistent with its luminosity class (III) found in SIMBAD. However, the membership of HD 169978 A to Wolf 630 has not been established firmly. Rather its bolometric luminosity and effective temperature place it near the end of the MS, and taking the newly discovered spectroscopic companion into account should move its position further down in the HR diagram.

7.2. IR secondaries

In order to examine the evolutionary state of the ADONIS companions we compare their IR magnitudes and colors with models for low-mass pre-MS stars. We use the calculations by Baraffe et al. (1998) with helium abundance of $Y = 0.275$, $[M/H] = 0$, and mixing length parameter of one pressure scale height ($\alpha_{\rm ML} = 1$). Models with $[M/H] = -0.5$, $Y = 0.25$, and $\alpha_{\rm ML} = 1.9$ are also available, as well as models with $[M/H] = 0$ and $Y = 0.282$. The former one reproduces the present-day Sun but has been calculated only for a small range of masses.

In Fig. 4 we show the Baraffe model in the $M_{\rm K}$ versus $J-K$ diagram. To position the ADONIS objects on the tracks and isochrones we made use of published J and K magnitudes (see references in Table 4), and we assumed that all companions are bound to their primaries, i.e. their distances are those listed in Table 1. Estimates for mass, age, luminosity, and effective temperature for those companions that are compatible with the pre-MS evolutionary tracks are obtained by interpolating the tracks, and are given in Table 4. Next we discuss the individual objects:

- For the companion to HD 169978 only a K band image was taken, and we can not put it into the color–magnitude diagram (CMD). Therefore its evolutionary stage remains unclear;
- As pointed out by Hubrig et al. (2001) the companion of HD 1685 has near-IR colors inconsistent with pre-MS models, questioning that this object is physically bound to the B-type star;
- The error in the $J - K$ color of the companions to HD 123445 are large. Because of this and the large uncertainty of the distance of HD 123445 the mass and age of HD 123445 C and D are not well constrained. But if assumed to be at 218 pc both objects are most likely younger than 30 Myrs. Therefore we conclude that being a member of the young UCL association (age ~10 Myrs; de Geus et al. 1989) is favored for both new IR sources near HD 123445. While uncompatible with the age of 160 Myrs that Gerbaldi et al. (2001) derived for HD 123445 A, it seems quite possible that they are physically bound to the B-type star, if the actual age of the latter one is smaller as discussed above.
  In May 2001, i.e. about one year after the first ADONIS images were taken, the AO observations of HD 123445 CD were repeated. The aim of this effort was to measure relative movements between the components C and D to track

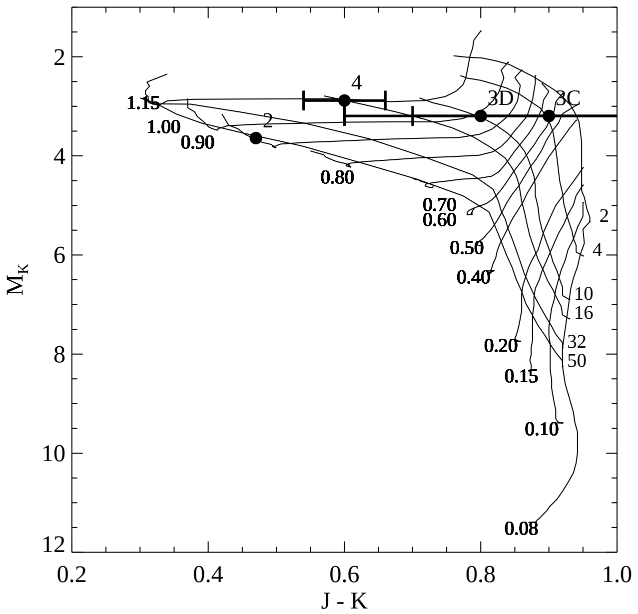

Fig. 4. Infrared color-magnitude diagram according to the evolutionary models by Baraffe et al. (1998) for $Y = 0.275$ and $\alpha_{\rm ML} = H_{\rm p}$. Filled circles indicate the positions of new companions: [2] – HD 113703, [3] – HD 123445 C and D, [4] – HD 133880. The IR magnitudes of the companion to HD 1685 do not allow to place it onto the tracks, and for the companion to HD 169978 no J-band image is available.

down their orbital motion, or their proper motion with respect to A. In the new IR images we measure nearly the same separation and position angle of C and D with respect to the primary as before (Huélamo et al., in prep.). The fact that both components have not moved contrasts with the previous suspicion that they may be unrelated foreground M-type stars. But we still can not exclude the possibility that the two objects are K-type stars at 140 pc. For this distance the errors in the IR photometry allow for HD 123445 C and D a somewhat older age, but are still compatible with them being on the pre-MS. So the conclusion that these stars are UCL members remains unchanged;

– For HD 113703 C the error in the IR color is negligible, and thus the mass and age are much better defined. Furthermore, the *Hipparcos* distance for HD 113703 is in agreement with the mean distance of the LCC association to which this star belongs according to de Zeeuw et al. (1999). We derive an age of 50 Myrs for HD 113703 C consistent with the age of the B-type star (48 Myrs according to Gerbaldi et al. 2001). This suggests that HD 113703 C is a true companion to HD 113703 A;
– According to Fig. 4 HD 133880 B is a 1.15 $M_\odot$ pre-MS star at ~16 Myrs, and therefore a likely member of the UCL for which de Zeeuw et al. (1999) give an age of 13 Myrs. As discussed above the B-type primary is a confirmed UCL member and probably younger than suspected by Hubrig et al. (2001) who derived an age of 150 Myrs for HD 133880 A. We conclude that HD 133880 B is most probably a true physical companion.

Table 4. Stellar parameters for *Chandra* observed IR sources near B-type stars. Mass, age, bolometric luminosity, and effective temperature are derived by comparison of published IR magnitudes and colors with evolutionary tracks from Baraffe et al. (1998). The references (Col. 2) refer to the JK magnitudes.

HD	Ref. JK mag	M [$M_\odot$]	t [Myrs]	$\log L_{\rm bol}$ [erg/s]	$T_{\rm eff}$ [K]
113703	(1)	0.9	50	33.27	5020
123445 C	(2)	0.6	4	33.10	3603
123445 D	(2)	1.0	10	33.23	4011
133880	(3)	1.15	16	33.42	4515

(1) - Shatsky & Tokovinin (2002), (2) - Huélamo et al. (2001), (3) - Hubrig et al. (2001).

8. Secondaries of Lindroos systems

As mentioned in the introduction two of the surveyed stars had previously known late-type companions discovered by Lindroos (1986) in a photometric study of visual binary stars, hereafter termed "Lindroos systems". HD 123445 AB was observed and resolved with the *ROSAT* HRI, but the late-type companion was not detected (Huélamo et al. 2000). As also shown by Huélamo et al. (2000) for HD 113703 the *ROSAT* HRI provided one elongated X-ray source, and left open whether this source corresponds to the primary or the secondary. The present *Chandra* study separates the Lindroos binaries of HD 113703 and HD 123445.

Only one of the late-type components in these systems is detected, HD 113703 B. We list its X-ray luminosity and the 95% confidence upper limit for HD 123445 B in Table 5 together with optical parameters of interest. The upper limit was calculated as described in Sect. 6. The bolometric luminosities were computed with the bolometric corrections of Schmidt-Kaler (1982). We assumed that both Lindroos secondaries are bound to the primaries, i.e. they are at the same distance as the B-type stars.

Both Lindroos systems of Table 5 had been included in the optical spectroscopic sample examined by Pallavicini et al. (1992). The aim of that study was to establish or refute the pre-MS nature of the presumed companions. Interestingly, only HD 113703 B was found to exhibit strong Lithium absorption (indicative of youth) as well as strong Ca II emission and filled-in Hα profile (both indicative of magnetic activity). HD 123445 B showed no sign for a Lithium feature and neither Ca II nor Hα activity, in agreement with its non-detection in X-rays.

Ages for the late-type stars in Lindroos systems have been computed by Gerbaldi et al. (2001), who have studied the position of these objects in the HR diagram using various sets of pre-MS models. We use the IR photometry for the Lindroos secondaries in the *Chandra* sample in conjunction with the Baraffe et al. (1998) IR CMD to check their evolutionary stage. For HD 123445 B Lindroos (1983) derive $J - K = 1.02 \pm 0.25$ mag. Its photometric errors do not exclude that it is a pre-MS star. But its age should be younger than ~10 Myrs. Gerbaldi et al. (2001) have derived a similar age (3...8 Myrs).

Table 5. Secondaries of Lindroos systems observed with *Chandra*. Column "Ref" refers to the separation and position angle.

HD	SpT	V [mag]	Sep [″]	PA [°]	Ref.	$\log L_{\rm bol}$ [erg/s]	$\log L_{\rm x}^{*}$ [erg/s]
113703	K0 Ve	11.5	11.5	79	(1)	33.20	30.3
123445	K2 V	13.0	28.6	35	(2)	33.17	<28.5

(1) - Huélamo et al., in prep., (2) - Turon et al. (1993).
* In the 0.5–8 keV band.

While Gerbaldi et al. (2001) have argued that this Lindroos system is probably not bound, we think that the distance and age of the B-type primary are not well enough constrained to rule out a physical connection. No near-IR photometry is available for HD 113703 B. However, this star is most probably bound to its primary, given that (i) they form a common radial velocity pair, (ii) it shows the Li I absorption line in its spectrum, (iii) its age is compatible with that of the primary (Gerbaldi et al. 2001), and (iv) it is a strong X-ray source.

9. Summary

In a sample of five late B-type stars with close but spatially resolved companion candidates discovered in AO observations *Chandra* observations have revealed all but one of the new IR objects as X-ray emitters, with $L_{\rm x}$ between 10^{29} and 10^{30} erg/s. The only one which is not detected is the companion of HD 169978. However, the ACIS image displays an enhanced count rate over the local background, and thus HD 169978 B may be a weaker X-ray source.

Two of the late B-type primaries, HD 1685 and HD 169978, are detected. This could be due to either (i) further (even closer) late-type companions not resolved in the AO observations or (ii) to intrinsic X-ray emission from the late B-type stars. As mentioned in Sect. 2 Aerts et al. (1999) found that HD 169978 is a single-lined spectroscopic binary. The X-ray luminosities of both HD 1685 A and HD 169978 A are comparable to those of the new IR objects, favoring low-mass companions as the site of the X-ray production. The upper limits for the undetected B-type stars range between $\log L_{\rm x,lim} \sim 27.8...28.5$ erg/s (dependent on the background emission level, exposure time, and distance of the target). Most of the observations were short, but HD 113703 A is not detected despite the exposure was deeper.

We examined whether the new IR objects are true companions to the B-type stars or just chance projections by placing them on the CMD and comparing them to evolutionary tracks. In three cases (HD 113703 C, HD 123445 CD, and HD 133880 B) the ages of the IR sources derived from the tracks are compatible with them being on the pre-MS, and since the primary B-type stars are known to be young these objects likely form bound systems. However, definite confirmation of their status requires spectral information that will prove or reject the youth of these companion candidates.

The X-ray luminosities we measured with *Chandra* for our targets tend to be smaller than the values given before based on *ROSAT* data. We believe that the *ROSAT* values are less reliable because they are just estimates based on hardness ratios, while our observations with ACIS represent the first X-ray spectra for these stars. In contrast to an earlier conjecture by Berghöfer et al. (1996) the spectra of this sample are not soft, but rather hard with most of the emission emanating at energies >0.5 keV. This is another indication for the youth of the objects because the strength and hardness of the X-ray emission is known to decrease rapidly with stellar age (e.g. Damiani & Micela 1995; Stelzer & Neuhäuser 2001).

In terms of $L_{\rm x}/L_{\rm bol}$ the late-type stars, i.e. the Lindroos secondaries and the new IR objects, are typical for young late-type stars: $\log{(L_{\rm x}/L_{\rm bol})} \sim -3... -4$ for all of the detections. Strong X-ray emission points at youth, and given the youth of the primaries may be interpreted as indication that the objects form truely physically bound systems. The upper limit for the Lindroos secondary to HD 123445 A places it at the lower end of the typical activity range, consistent with the lack of youth signatures in its optical spectrum. Note that the upper limit to $L_{\rm x}$ for this object is uncertain because it is possibly at a different distance than the one assumed. For the companion to HD 169978 a deeper observation is needed to obtain a useful constraint on its X-ray emission.

Our observations support the trend of the primaries to split in two groups in the $L_{\rm x}/L_{\rm bol}$-diagram. Such a bifurcation was recently pointed out by Daniel et al. (2002) for A...F-type Pleiades stars: apparent X-ray emitters on the one side, and on the other side X-ray quiet stars with upper limits by 1–2 orders of magnitudes lower than the $L_{\rm x}/L_{\rm bol}$ values of the detections. In view of the fact that one of our two detected B-type stars and a few of the Pleiades A...F-type stars are known to have a close companion unresolved even with *Chandra* it seems reasonable to think that in the active group the X-rays are actually produced by the late-type companions, which would move the objects up and to the left in Fig. 3. However, firm conclusions can only be drawn if it can be established that all of these stars have faint companions.

In our future work we will continue to track down the problem of X-ray emission from B-type stars by (a) pushing upper limits on $L_{\rm x}/L_{\rm bol}$ well below the present values with help of deeper X-ray observations, and (b) examining the multiplicity of the apparently X-ray active B-type stars through IR spectroscopy. Both techniques combined on a large sample are likely to show that with present-day X-ray and IR instrumentation it is possible to approach a solution to this longstanding mystery.

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