MULTIWAVELENGTH STUDY OF X-RAY EMITTING A- AND B-STARS
TESTING THE COMPANION HYPOTHESIS

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\textbf{Abstract}

No mechanism is known that produces X-rays in late B-type and early A-type stars. Nevertheless their detection has been reported from virtually all X-ray satellites, and has remained a mystery to date. We use a multi-wavelength approach to test the most widespread hypothesis that the X-rays are generated by late-type magnetically active companions. Our high spatial resolution observations of A/B-type stars in the IR using adaptive optics uncover hypothetical companion stars at arcsecond separations from the primary. The same targets are then followed-up in X-rays with \textit{Chandra}. \textit{Chandra}'s unprecedented spatial resolution allows to check whether the new infrared sources are responsible for the X-ray emission previously ascribed to the A/B-type star. Finally, those A/B-type stars that are still detected with \textit{Chandra} are studied with IR spectroscopy, where we search for temperature sensitive features indicating the existence of even closer cool companions. Even with this multi-fold strategy we are likely to miss the closest of the possible companions, but a study of the X-ray properties can provide further information on the nature of the emitters.

Key words: X-rays: stars, Stars: intermediate-mass, late-type, activity

\section{Introduction}

For stars on the main-sequence two mechanisms are known to generate X-ray emission: In O- and early B-type stars the X-rays are produced by instabilities arising in the strong radiatively driven stellar winds \cite{Owocki1999,Lucy1980}, and in late-type stars a solar-like magnetic dynamo is thought to produce the observed X-ray activity \cite{Ruediger1995,Parker1955,Parker1933}. No X-ray emission is expected from stars whose spectral types are late B and early A, because they do not drive strong enough winds nor do they possess convective zones necessary to sustain a magnetic dynamo. Therefore, their X-ray detection which has repeatedly been reported throughout the literature \cite{Grillo1992,Schmitt1993,Simon1995,Berghofer1996,Panzera1999,Huelamo2000,Daniel2002} has remained a mystery to date.

Lacking any theoretical model for X-ray production intrinsic to intermediate-mass stars, the observed emission is commonly attributed to unresolved late-type companions. In order to check this hypothesis Berghöfer & Schmitt (1994) carried out \textit{ROSAT} High Resolution Imager (HRI) X-ray observations of visual binaries composed of late-B type stars and known visual companions at 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 late-type companion. On the other hand, a \textit{ROSAT} HRI study 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 \cite{Schmitt1993,Huelamo2000}. 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 late-type companions unresolved by the \textit{ROSAT} HRI. Since 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., ScoOB2, Carina-Vela, Tucanae), most of the predicted unresolved late-type stars may be young stars still contracting to the main-sequence (MS) or just arrived on the zero-age MS, if bound to the primaries.

Thanks to an observationally established but theoretically poorly understood enhancement of magnetic activity at young stellar ages, late-type pre-MS stars ($=T$ Tauri stars) are ubiquitous X-ray sources. The picture is less clear for their higher-mass counterparts, the HAeBe stars. When starting their evolution fully convective they may drive magnetic activity by the same process as T Tauri stars, or by magnetic interaction between the star and an accretion disk (as proposed by Montmerle et al. 2004 for proto-stars). Tout & Pringle (1995) argue that intermediate-mass protostars may be able to maintain dynamo action also throughout the first part (several percent) of their radiative phase. On the other hand, close visual companions to HAeBe stars have been presented by Li et al. (1994) \cite{Pirzkal1997} and Leinert et al. (1997) \cite{Leinert1997}. Monte Carlo simulations by Pirzkal et al. (1997) have suggested that almost all HAeBe stars have companions within a completeness limit of $0.4''<\text{sep}<8''$ and $K<10.5$. The X-ray emission from HAeBe stars has been investigated systematically by Damian et al. (1994) \cite{Damiani1994} based on \textit{EINSTEIN}
observations and by Zinnecker & Preibisch (1994) using ROSAT. About 30% and 50% of the observed HAEBe stars were detected, respectively. According to Zinnecker & Preibisch (1994) the most plausible origin of these detections are their winds. On the other hand, X-ray flares have been detected on a small number of HAEBe stars (Hamaguchi et al. 2000, Giardino et al. 2004), and have been taken as evidence for magnetic activity. EINSTEIN and ROSAT observations did not resolve the HAEBe stars from the companions identified in the publications cited above.

2. OBSERVING STRATEGY

Solving the puzzle of X-ray emission from intermediate-mass stars calls for a complex observational approach involving imaging and spectroscopic observations in different wavelength bands. Our strategy to test the companion hypothesis is as follows: (i) search for cool companions to A- and B-type stars with high-resolution imaging observations in the IR using the adaptive optics (AO) technique, (ii) follow-up X-ray observations with similarly high spatial resolution to pinpoint the X-ray emitter in the newly identified systems, (iii) IR spectroscopy for those intermediate-mass stars that are X-ray detected even after being resolved from any (sub-)arcsecond visual companions to search for even closer companions.

Throughout this article, we will for simplicity call any faint IR object near the intermediate-mass stars of interest ’companions’. It should be kept in mind, however, that the objects newly discovered in AO imaging have not been confirmed yet to be physically bound to the ’primaries’. True late-type companions to MS B-type stars are expected to be young, because of the different evolutionary time-scales of early- and late-type stars. Optical spectroscopy should reveal a LiI absorption feature at 6708 Å in physical companions proving their pre-MS nature. But no observations have been carried out yet to that effect.

Work on the three sub-projects introduced above has started in parallel. Here we report on the first results of

- AO imaging of early-A type stars in the northern hemisphere at the Telescopio Nazionale Galilei (TNG) on La Palma;
- Chandra X-ray observations of late-B type stars for which the recent AO studies of Hubrig et al. (2001) and Huéamo et al. (2001) have identified AO companions;
- IR spectroscopy of X-ray emitting late-B type stars at the Thüringer Landessternwarte Tautenburg.

3. RESULTS

3.1. IR IMAGING WITH ADAPTIVE OPTICS

Previous AO searches for faint companions to (X-ray emitting) intermediate-mass MS stars have been carried out in the southern hemisphere (see Hubrig et al. 2001, Huéamo et al. 2001 and Shatsky & Tokovinin 2002). These studies have provided a wealth of new candidate companions, but have been restricted to the higher-mass end of the ‘X-ray forbidden’ range of spectral types. Since the final aim is to prove/disprove the existence of the theoretically predicted gap in X-ray emission along the spectral type sequence, and to understand its point of onset, we must sample the whole critical range of spectral types. Therefore we have engaged in AO observations of A-type stars. The sample was selected from the Catalogue of Optically Bright Main-Sequence Stars detected during the ROSAT All-Sky Survey (Hünsch et al. 1998). We have chosen stars with spectral types ranging between A0 and A5 and without indications of binarity according to the Hipparcos and Wielen Catalogues (Turon et al. 1993, Wielen et al. 2000). With this latter criterion we minimize the probability that spectroscopic binaries are included in our sample. In contrast to previous studies our targets are located in the northern sky.

So far we have obtained H- and K-band images of 23 early-A type stars using the small field of the Near Infrared Camera Spectrometer (NICS) at the TNG. Combined with the AO system the field-of-view is 0.7′×0.7′. As a first result we show in Fig. 1 the reduced frame for HR 7826, an A3 V star with no reports on binarity in the literature. Dark patches result from the subtraction of the science frames effected to eliminate the contribution of the sky background. The white (black) objects that – together with the main negative (positive) – delineate a square-shaped region are ghosts. Potential companion stars are to be found among the remaining bright point-like features. Indeed, several of them have already known 2MASS counterparts, marked with white circles and numbers for identification with the 2MASS image aside. The large circle overlapped on the image denotes a separation of 10″ from the B-type star. On the right hand side in the same figure we show the corresponding 2MASS image. Obviously, in 2MASS no faint sources can be detected within the critical region of ~ 10″ around the bright B-star due to the poor spatial resolution of this survey.

A thorough analysis of this TNG image and those of the other targets will produce a substantial list of new companion candidates. These new objects shall then be considered in follow-up Chandra observations and optical spectroscopy.

3.2. HIGH SPATIAL RESOLUTION X-RAY FOLLOW-UP

Chandra is the first and so far only X-ray satellite providing spatial resolution comparable with AO observations. In addition it provides spectral capabilities that give information about the properties of the X-ray emitting plasma, such as temperature and luminosity, which can be used to constrain the nature of the target.
Figure 1. K-band images of HR 7826. left - TNG/NICS+AdOpt, 0.7′ × 0.7′; the black features are negatives resulting from the subtraction of two science frames, as well as the three white features forming a square with the main negative; the faint white objects are real, and those of them labeled with numbers can be identified on the 2MASS image to the right, right - 2MASS, 1′ × 1′; the area of the TNG image is marked by the slightly tilted squared frame; dark crosses are artifacts, arrows with numbers are 2MASS sources.

Figure 2. Images of HD 1685: Left - ADONIS ESO/3.6m, K-band discovery image of a faint IR object 2.3′′ south-west of the B-type primary; right - Chandra ACIS image showing that both objects are detected, ‘A’ is the primary, ‘B’ is the new IR object.

Within this project 9 late-B type stars on the MS were observed with Chandra’s Advanced CCD Imaging Spectrometer (ACIS). The targets have shown to be X-ray emitters in the ROSAT All-Sky Survey (= RASS; Berghöfer et al. 1996) and they have AO companions from the work of Hubrig et al. (2001) with separations ranging from ∼ 1 – 8″, i.e. the systems are well resolvable with Chandra. This sample is complemented by data of two stars extracted from the Chandra archive, that obey the same criteria: spectral type late-B, on the MS, X-ray sources according to the RASS, and close companions resolvable with Chandra. Some of the targets are Lindroos systems (Lindroos 1985), and have additional companions at wider separations. We searched for X-rays also at the position of these Lindroos secondaries.
In addition we scanned the Chandra archive for any observations of HAeBe stars, and found 15 of them. Some of these data have been published by Feigelson et al. (2003) and Giardino et al. (2004) others are serendipitous sources of pointings with a different scope. We point out that the HAeBe star sample diverges from the original selection criterion, in that many of them are not known to have close visual companions. But they are of interest to our study because the physical processes related with their X-ray emission may be different from those of the more evolved MS B/A-type stars. A comparison between X-ray properties of HAeBe and MS B/A-type stars should allow to test whether and where there is an age-related transition or shut-off in the dynamo action.

An example for the Chandra imaging observations is given in Fig. 2 which shows the ACIS exposure of HD 1685, together with the corresponding AO discovery image of the ‘companion’ at the 3.6 m telescope of ESO (Chile). Two X-ray sources are seen, that can be identified with the B-type primary and the AO companion, respectively.

To summarize, almost all of the new IR sources turn out to be X-ray emitters: only one of them is undetected with Chandra, but it is probably a faint source just below the detection sensitivity (see discussion in Stelzer et al. 2003 where the first 5 targets have been presented). However, this does not prove the companion hypothesis, as we have detected also 7 out of 11 B-type stars. One of them is known to be a spectroscopic binary, the other 6 B-type stars remain candidates for being intrinsic emitters until tested for closer companions with IR spectroscopy (see Sect. 3.3).

Previously known Lindroos companions at separations \( \geq 10'' \) are present in HD 113703, HD 129791, HD 32964 and HD 123445. The latter two are undetected, suggesting that they may not form bound systems with the ‘primary’. Indeed – consistent with our X-ray observations – the Lindroos companions of HD 32964 and HD 123445 have been labeled as likely optical pairs, while the Lindroos companions of HD 113703 and HD 129791 have been dubbed likely physical based on their optical photometry and spectroscopy (Eggen 1963, Pallavicini et al. 1992).

Among the HAeBe stars 12 out of 15 are detected with Chandra. Whether the higher detection fraction with respect to the MS B-type stars indicates a different emission mechanism or is the result of hidden companions remains unclear so far. If all X-rays from the position of intermediate-mass stars are assumed to be generated by late-type companion stars the higher detection rate of HAeBe stars could also be due to higher activity levels of their companions, because of their younger age with respect to the companions of MS stars.

Table I gives a summary of the sample of Chandra targets, including information on the components in the multiples and two flags estimating the companion status based on X-ray data and near-IR photometry. The upper part of the table lists MS stars, and the lower part HAeBe stars.

Spectral analysis provides X-ray luminosities and an estimate of the temperature in the emitting region. Since the exposure times were short – the major aim was the detection, not a detailed analysis – typically only \( \sim 20 - 100 \) source photons were collected. In cases of such poor statistics commonly hardness ratios are used to describe spectral properties of X-ray sources. Hardness ratios are defined as \( HR = (H - S)/(H + S) \), where \( H \) and \( S \) are the number of counts in a hard band and in a soft band, respectively. Here, \( HR_1 \) compares the 0.5 – 1 keV (S) and the 1 – 8 keV (H) band, and \( HR_2 \) the 1 – 2 keV (S) and the 2 – 8 keV (H) band. In Fig. 3 we display the observed hardness ratios super-imposed on a model grid representing a 1-T Raymond-Smith (Raymond & Smith 1977) spectrum subject to photo-absorption. The model grid was computed with PIMMS. The plotting symbols for the data have been scaled to the visual extinction. The most absorbed sources (some of the HAeBe stars) are found in the right part of the diagram, where the model indicates high column density. Thus, we conclude that the hard X-ray emission of these stars is not an intrinsic property, but an artifact produced by absorption of the soft component. This is supported by the fact that the weakly absorbed HAeBe stars and the MS stars and companions can not be distinguished in terms of their hardness ratios. The majority of the MS B-stars and their companions cluster at intermediate values of \( HR_1 \), just above the unabsorbed 1-T model. Their location outside the boundaries of the RS-model can probably be attributed to the fact that the iso-thermal model is an inadequate representation for their coronal temperature structure. No drastic differences in the hardness of primaries and companions are observed, suggesting that the X-rays are produced by the same mechanism.

Figure 3. Chandra ACIS hardness ratios for all stars discussed in this paper with \( \geq 10 \) counts in the broad band. The size of the plotting symbols is scaled to \( A_V \).
Fig. 4 displays the $L_x/L_{bol}$ ratio for all components of the A- and B-type stars observed so far with Chandra. The ratio between X-ray and bolometric luminosity is a crucial indicator for stellar activity. In general, the most active stars – often being the most rapid rotators – are observed to display values near $10^{-3}$. An unidentified mechanism seems to prevent the generation of X-rays beyond this limit. Less active late-type stars range between $L_x/L_{bol} = 10^{-4} \ldots 10^{-5}$. 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. O- and B-type 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 $L_x/L_{bol} \approx 10^{-7}$.

In the sample investigated here the IR companions display log $(L_x/L_{bol})$ values near the saturation limit. For all intermediate-mass MS stars of the sample which are not detected the upper limits we derive are lower than the canonical value of $10^{-7}$, making stellar winds an unlikely cause for their production. The detected B-type MS stars show intermediate values of log $(L_x/L_{bol})$ and need to be examined for the presence of further, as yet undiscovered companions. The HAeBe stars fill the gap in $L_{bol}$ between the intermediate-mass stars and their low-mass companions. In terms of log $(L_x/L_{bol})$ they also occupy an intermediate position with values of $-4 \ldots -6$, except for the two very luminous objects MWC 297 and HD 147889. However, we note that the bolometric luminosities of the HAeBe stars in some cases are highly uncertain, due to excess emission from remnant circumstellar material.

3.3. High S/N IR spectroscopy

The aim of this part of the project is to unveil signatures of late-type stars in the high S/N IR spectra of intermediate-mass stars. The IR range is preferred over the optical because of the lower flux ratio between early- and late-type stars, favoring the detection of the latter. While in a late B-type star the strongest (and only) features in the $H$- and $K$-band spectrum are the hydrogen lines, in the case of a late-type star the IR spectrum shows strong absorption lines from atomic species (CaI, MgI, SiI) and molecular.
lar bands (CO and OH). Therefore, this spectral range is suited to determine the spectral class of the target.

In a pilot study we observed HD 32964 at the 2.2-m-telescope on Calar Alto. HD 32964 is a complex system composed of the following objects:

- the primary, a spectroscopic binary of two stars with nearly equal mass of $\sim 2.4 \, M_\odot$;
- a Lindroos companion at 53″, spectral type K5 V;
- an AO companion at 1.6″.

The only X-ray source detected with Chandra is the AO companion. Near-IR photometry puts this object near the zero-age MS in the color-magnitude diagram, consistent with the relatively old age ($\sim 200$ Myr) derived for the primary by Hubrig et al. (2001). The non-detection of the Lindroos secondary provides support for the suggestion by Eggen (1963) that it is probably physically unrelated.

For the IR spectroscopy we used the Coudé Spectrograph with the MAGIC infrared camera at the f/12 camera of the spectrograph. The setup provides a 2-pixel-resolution of $\lambda/\Delta\lambda = 14000$. The wavelength region between 16820 – 16940 Å was chosen, because it contains the OH-features which are prominent in late-type stars.

The spectrum of HD 32964 is shown in Fig. on the top. Next to the OH-features we mark other lines seen in the solar spectrum (Livingston & Wallace 1991) and thus possibly visible in the spectrum of a K-type star. Comparison with the spectrum of Vega (middle panel of Fig. 5), similar in spectral type to the primary HD 32964 A, reveals major differences. The spectral shape of HD 32964 resembles much more that of a mid-K type star (see comparison spectrum on the bottom of Fig. 4). We must caution that with a slit width of $\sim 2″$ the AO companion probably contributes to this spectrum. Therefore, our data does not report the discovery of an additional spectroscopic companion, but contamination by the nearby visual companion. However, it demonstrates that the approach works in principle and outlines that the instrumental setup must be carefully chosen. A detailed discussion of this data set awaits further analysis. Observations of a subsample of southern late-B and A-type stars have been carried out with SofI at the NTT. The results will be presented elsewhere.

3.4. Nature of the Companions

X-ray detection can help to single out true companions from chance projections. Of the 15 companions to the 11 MS B-stars observed with Chandra 12 are detected. The 15 HAeBe stars have 9 companions in total of which 4 are detected with Chandra. One object from the HAeBe sample is a close binary composed of two intermediate-mass stars. The remaining 4 undetected ‘companions’ are probably unrelated objects. However, final classification requires confirmation of the companion status by means of spectroscopy or proper motion. To date this information is not available for any of the IR objects discovered with AO near the MS A- or B-type stars discussed in this article. In the meantime available near-IR photometry allows for a rough estimate of their evolutionary stage, comparing their position in the near-IR color-magnitude diagram to pre-MS models.

Fig. 4 shows the $M_K$ vs. $J-K$ diagram with model calculations by Baraffe et al. (1998) $Y = 0.275$, $[M/H] = 0$, $\alpha_{\text{ML}} = 1$. For the distances needed to compute the absolute K-band magnitude we assumed that all companions are bound to the primaries. Note that of the presumed low-mass companions 5 have been observed only in the K-band, such that they can not be placed in Fig. 4. For 4 ‘companions’ the near-IR colors are not compatible with them being on the pre-MS, and therefore these objects are likely physically unrelated to the A-/B-type or HAeBe star.

We tentatively assigned a companion status based on X-ray detection/non-detection and near-IR photometry. Corresponding flags are given in the last two columns of Table I.

4. Summary and Outlook

We have engaged in IR and X-ray observations of intermediate-mass stars in order to examine whether late-type
companion stars are the cause of their unexplained X-ray emission. Previous X-ray studies of known visual systems composed of B-type primary and late-type secondary have remained inconclusive. A major part of these systems were not resolvable with ROSAT. The exceptional spatial resolution of Chandra allows us now to study systems as close as $\sim 1^\prime$. This enables to access in the X-ray range many of the faint IR objects discovered near B-type stars in recent AO surveys. Combined Chandra and AO imaging yields a large sample of homogeneous observations on which the companion hypothesis can be tested. Our AO survey of A-type stars in the northern hemisphere increases substantially the list of companion candidates identified in similar surveys of B-type stars in the southern hemisphere. Chandra observations suggest that most of such new, faint IR objects are truly bound companions. The detection of $\sim 60\%$ of the B-type primaries with Chandra indicates the need to search for even closer, spectroscopic companions. Our pilot study has shown that it is possible to identify late-type stars in the IR spectrum of a B-type star. For X-ray emitting B-type stars with negative results in all searches for companions, as an ultimate step sensitive X-ray spectroscopy shall be used to examine the physical conditions in the hot plasma. A comparison of these spectra with similar data for known late-type coronal X-ray sources will constrain the production mechanism for X-rays in intermediate-mass stars.

The age dependence of dynamo action in intermediate-mass stars is studied by a comparison of X-ray properties of the primaries in our sample of MS stars to the X-ray properties of HAeBe stars. We find that the detection fraction with Chandra is even higher for the latter ones ($\sim 80\%$). This may be due to either of two reasons: (i) a shut-off of the magnetic dynamo at a critical as yet undefined point in the life of a B-/A-type star, or (ii) unidentified binary companions of HAeBe stars.

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Table 1. Intermediate-mass stars observed with Chandra and known companions or companion candidates at arcsecond separations (Lindross companions are labeled ‘L’; separation and position angle are given in columns 4 and 5). The last two columns provide flags for the companion status: ‘√’ - X-ray detection or near-IR photometry suggests late-type pre-MS star and consequently likely bound system, ‘?’ - no near-IR color available, ‘N.A.’ - primary, the flag is not applicable.

| Designation | SpT | Compon. | Sep  | P.A.  | Companionship |
|-------------|-----|---------|------|-------|---------------|
|             |     |         | ["] | [°]   | X-rays  NIR phot. |

Main-sequence B-type stars and companion candidates

| Designation | SpT | Compon. | Sep  | P.A.  | Companionship |
|-------------|-----|---------|------|-------|---------------|
| HD 1685     | B9  | A       | N.A. | N.A.  |               |
| HD 1685     | –   | B       | 2.28 | 211.4 | √             |
| HD 113703   | B5  | A       | N.A. | N.A.  |               |
| HD 113703   | –   | B       | 1.55 | 268.2 | √             |
| HD 113703   | K0  | L       | 11.5 | 79    | ?             |
| HD 123445   | B9  | A       | N.A. | N.A.  |               |
| HD 123445   | –   | B       | 5.56/5.38 | 65.0/64.0 | √     |
| HD 123445   | K2  | L       | 28.6 | 35    | –             |
| HD 133880   | B8  | A       | N.A. | N.A.  |               |
| HD 133880   | –   | B       | 1.22 | 109.2 | √             |
| HD 169978   | B7  | A       | N.A. | N.A.  |               |
| HD 169978   | –   | B       | 3.09 | 168.7 | –             |
| HD 32964    | B9.5| A       | N.A. | N.A.  |               |
| HD 32964    | –   | B       | 1.61 | 232.6 | √             |
| HD 32964    | K5  | L       | 52.8 | 10.0  | √             |
| HD 73952    | B8  | A       | N.A. | N.A.  |               |
| HD 73952    | –   | B       | 1.16 | 205.3 | √             |
| HD 110073   | B8  | A       | N.A. | N.A.  |               |
| HD 110073   | –   | B       | 1.19 | 75.0  | √             |
| HD 134837   | B8  | A       | N.A. | N.A.  |               |
| HD 134837   | –   | B       | 4.70 | 154.3 | √             |
| HD 134946   | B8  | A       | N.A. | N.A.  |               |
| HD 134946   | –   | B       | 8.21 | 45.3  | √             |
| HD 129791   | A0  | A       | N.A. | N.A.  |               |
| HD 129791   | –   | L       | 35.3 | 205.5 | √             |

HAeBe stars and companion candidates

| Designation | SpT | Compon. | Sep  | P.A.  | Companionship |
|-------------|-----|---------|------|-------|---------------|
|             |     |         | ["] | [°]   | X-rays  NIR phot. |

| Designation | SpT | Compon. | Sep  | P.A.  | Companionship |
|-------------|-----|---------|------|-------|---------------|
| HD 104237   | A   | A       | N.A. | N.A.  |               |
| HD 100546   | B9  | A       | N.A. | N.A.  |               |
| HD 100546   | –   | B       | 4.54 | 196.5 | –             |
| HD 100546   | –   | C       | 5.22 | 155.1 | –             |
| HD 100546   | –   | D       | 5.91 | 26.4  | –             |
| HD 100546   | –   | E       | 5.55 | 322.6 | –             |
| HD 141569   | B9  | A       | N.A. | N.A.  |               |
| HD 141569   | –   | B       | 7.57 | 311.5 | √             |
| HD 141569   | –   | C       | 8.93 | 310.0 | √             |
| HD 150193   | A1  | A       | N.A. | N.A.  |               |
| HD 150193   | –   | B       | 1.10 | 236   | √             |
| V892 Tau    | A6  | A       | N.A. | N.A.  |               |
| V892 Tau    | –   | B       | 4.10 | 23.4  | √             |
| HD 152404   | F5  | A       | N.A. | N.A.  |               |
| HIP 16243   | B8  | A       | N.A. | N.A.  |               |
| HD 147889   | B2III/IV| A       | N.A. | N.A.  |               |
| HD 97300    | B9  | A       | N.A. | N.A.  |               |
| V380 Ori    | B8+A1| A+B     | 0.15 | 204.2 | N.A.          |
| V590 Mon    | B8  | A       | N.A. | N.A.  |               |
| TY CrA      | B9  | A       | N.A. | N.A.  |               |
| R CrA       | A5II| A       | N.A. | N.A.  |               |
| HD 176386   | B9IV| A       | N.A. | N.A.  |               |
| MWC 297     | O9  | A       | N.A. | N.A.  |               |