Search for systemic mass loss in Algols with bow shocks
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ABSTRACT

Aims. Various studies indicate that interacting binary stars of Algol type evolve non-conservatively. However, direct detections of systemic mass loss in Algols have been scarce so far. We study the systemic mass loss in Algols by looking for the presence of infrared excesses originating from the thermal emission of dust grains, which is linked to the presence of a stellar wind.

Methods. In contrast to previous studies, we make use of the fact that stellar and interstellar material is piled up at the edge of the atmosphere where the stellar wind interacts with the interstellar medium. We analyse WISE W3 12\,µm and WISE W4 22\,µm data of Algol-type binary Be and B[e] stars and the properties of their bow shocks. From the stand-off distance of the bow shock we are able to determine the mass-loss rate of the binary system.

Results. Although the velocities of the stars with respect to the interstellar medium are quite low, we find bow shocks present in two systems, namely π Aqr, and ϕ Per, a third system, CX Dra, shows a more irregular circumstellar environment morphology which might somehow be related to systemic mass loss. The properties of the two bow shocks point to mass-loss rates and wind velocities typical of single B stars, which do not support an enhanced systemic mass loss.

Key words. Binaries: close – Circumstellar matter – Infrared: stars – Stars: winds, outflows

1. Introduction

The group of Algols host stars with many different observed properties, like W Ser stars, β Lyre stars, binary B[e] and Be stars, and symbiotic Algols, which all have in common the paradox that the donor star is more evolved but less massive than the accretor. This is achieved by mass transfer when at a certain point the mass ratio reverses. Non-conservative evolution in Algol-type binary systems has been known for 60 years (Crawford 1955). For example Chaubey (1979), Samad (1993), and van Rensbergen et al. (2011) noted that Algol models must lose a significant fraction of their mass to reproduce observed properties. One of the most efficient scenarios that removes mass from the system is via a hotspot on the surface of the gainer\textsuperscript{1}. However, no direct detection of systemic mass loss during the mass transfer process in close binaries has been reported for Algols so far.

In this work, we focus on Be and B[e] stars for which bina-

\textsuperscript{1} for an extensive explanation of the hotspot mechanism, see van Rensbergen et al. (2011) and Deschamps et al. (2013, 2015).

We take advantage of the fact that some of these stars are not at rest, but move with a certain speed with respect to their surrounding medium. Assuming that mass is expelled supersonically from the binary system, it is decelerated by the oncoming interstellar medium (ISM) and forms a bow shock (Baranov et al. 1971; Weaver et al. 1977). Bow shocks have been observed at all kinds of wavelengths around many stellar types, covering runaway O stars to AGB stars (e.g. van Buren & McCray 1988; Cox et al. 2012). In the mid-IR, these shocks are visible through thermal dust emission, when the shock front heats up dust grains at the interface between the stellar wind and the ISM (Ueta et al. 2006). A bow shock detection around an Algol is therefore direct evidence of stellar material around the binary system. In this case, the distance of the system to the apex of the bow shock can be used to derive the systemic mass-loss rate if the wind velocity, stellar velocity, and ISM density are known (Baranov et al. 1971).

This research note is a complementary study to the work done by Deschamps et al. (2015) hereafter D15, but with emphasis on the observational aspects of the systemic mass loss. Based on radiative transfer calculations, Deschamps et al. (2015) predicted the IR colour excesses expected in the case of systemic mass loss. In addition to the WISE detections of extended material around CZ Vel and SX Aur presented in D15, we discuss the properties of the circumstellar emission of three other objects, namely CX Dra, π Aqr, and ϕ Per.

2. WISE observations

In D15, we performed a systematic search for extended IR emission around Algols (collected from the catalogues of Brancewicz & Dworak 1980 and Budding et al. 2004) and Algol-related Be
**Fig. 1.** Upper panel: WISE W4 image of CX Dra at 22 \( \mu \)m. The continuous black arrow gives the uncorrected proper motion from the reprocessed Hipparcos catalogue (van Leeuwen 2007), while the dashed arrow points to the direction of the space motion corrected from the solar motion (Cokurošoğ et al. 2011). The values of the motion are given in Tab. 1. The values of the colour bar are given in Jy pix\(^{-1}\). Lower panel: Integrated intensity cut through a wedge covering position angles (P.A.): 45°–135°.

and B[e] systems (Harmanec 2001), using archive data from the Wide-field Infrared Survey Explorer (WISE\(^2\)). WISE is an all-sky survey, which mapped the sky in four bands at 3.4, 4.6, 12, and 22 \( \mu \)m with angular resolutions of 6′′/1, 6′′/4, 6′′/5, and 12′′/0, respectively (Wright et al. 2010). Based on the list of 70 objects (Algols and Algol-like Be stars with a WISE-source counterpart) provided by D15\(^3\), we found that three systems, CX Dra, \( \pi \) Aqr, and \( \varphi \) Per, have unambiguous circumstellar emission and therefore deserve a specific analysis (in addition to CZ Vel and SX Aur, already discussed in D15).

All three objects are in the list of binary Be stars compiled by Harmanec (2001). They exhibit peculiarities that flag them as Algol candidates, or at least as systems with on-going mass transfer. With its sdO companion, \( \varphi \) Per has obviously undergone a severe mass transfer, the primary and more luminous B2[e] component being the most massive but the least evolved. In CX Dra, mass transfer in the binary has been inferred from the varia-

\(^2\) The IRSA:WISE archive can be found at http://irsa.ipac.caltech.edu/applications/wise/

\(^3\) The list of objects can be found in Appendix A

**Fig. 2.** Upper panel: WISE W3 images of CX Dra at 12 \( \mu \)m. Lower panel: Integrated intensity cuts through a wedge covering P.A.: 30°–65° (black line) where emission is visible and P.A.: 210°–245° (red line) without extended emission. We had to choose smaller wedges to avoid the flux being dominated by the diffraction spikes of the PSF.

The extended emission around the stars was detected in Band 3 (W3) at 12 \( \mu \)m (CX Dra, \( \pi \) Aqr, \( \varphi \) Per) and Band 4 (W4) at 22 \( \mu \)m (CX Dra, \( \pi \) Aqr, \( \varphi \) Per). For the two objects with circumstellar emission (CSE) detected in both bands, WISE W4 offers greater details, most likely because the thermal emission of the shock-heated dust grains peaks at longer wavelengths (Draine 1981). In the following, the CSM morphology of the three objects is described. Figures 1 and 2 depict the WISE images of CX Dra, \( \pi \) Aqr, and \( \varphi \) Per, while Tab. 1 provides their stellar properties.

### 2.1. CX Dra

CX Dra (HIP 92133) is a 6.696 d period Algol B2.5Ve+F5III system at a distance of 396 pc (van Leeuwen 2007); one of **
the components rotates rapidly. Although it is not eclipsing, Berdyugin & Pirola (2002) estimate the mass of the two components to be 3.9 $M_\odot$ and 0.9 $M_\odot$ at $i = 70^\circ$. The authors, however, correctly note that these masses are too small to match the spectral types of the two stars.

The circumstellar environment of the star is shown in Figs. 1 and 2. The emission in the WISE W4 22 $\mu$m band is concentrated to the east of the star and is traceable to a distance of about 120 $\prime\prime$ (47,500 au at 396 pc). The morphology of the circumstellar material is somewhat puzzling because several aspects are not in favour of an ISM interaction. First, the direction of the proper motion is S-E, but the shape of the emission is not symmetric and is more concentrated N-E of the star. Second, the emission is not detached from the star and the flux seems to decrease with distance, which is not expected for a bow shock where the brightest region is at the position of the shock front.

Furthermore, the circumstellar material of CX Dra on the WISE image describes an arc emerging east of the star and curved towards the north. Similar arcs are found to be part of an Archimedean spiral which is caused by a semi-detached companion interacting with the wind of a primary (e.g. Mastrodemos & Morris 1999; Mayer et al. 2011; Maercker et al. 2012). The spacing of the spiral arms is thereby defined by the wind velocity of the mass losing star and the orbital period of the companion. However, assuming a wind velocity of 1000 km s$^{-1}$ for the B2.5Ve star and an orbital period of 6.696 d for the F5III companion, the resulting spiral spacing is 3.87 au, which is several orders of magnitude smaller than what is seen on the WISE image. For comparison, the pixel size of the image is 1$^\prime\prime$375, which is 545 au at 396 pc. This implies that a spiral formed by the B2.5Ve+F5III system would show 140 windings per WISE W4 pixel. The observed arc is therefore not related to this shaping mechanism.

In the colour–colour diagram shown in Fig. 13 of D15 that depicts the WISE W4/W1 against 2MASS $J/K_s$ flux ratios, CX Dra is located only slightly above the black-body curve ($F_1/F_K = 1.678$, $F_{W1}/F_{W4} = 0.047$). Many other objects fall into this region of the diagram and no peculiarity can be drawn from it. Still, there is no doubt that extended emission is present in the WISE W4 image.

In the shorter WISE W3 band at 12 $\mu$m (see Fig. 2), CX Dra also shows extended emission east of the star but in much less detail than in the W4 image. The detection of emission in W3 and W4, however, allows us to estimate the temperature of the dust emission around CX Dra. We performed aperture photometry on a circle of radius 15$''$ in both bands. The region we chose is centred at a distance of 56$''$ from the star at PA = 48$'$ and falls between the diffraction spikes of the PSF which dominates the W3 image. The resulting fluxes are $F_{\nu,12} = 0.207$ Jy and $F_{\nu,22} = 1.650$ Jy at 12 $\mu$m and 22 $\mu$m, respectively. Adopting...
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2.2. \(\pi\) Aqr

Pi Aquarii (HIP 110672) is a 84.1 d period binary located 240 pc

from the sun (van Leeuwen 2007). The system comprises a

rapidly rotating B1Ve star at the origin of the Be phenomenon

and an A-F type companion. Bjorkman et al. (2002) estimate

the mass of the components to be \(M_1 \sin^3 i = 12.4 M_\odot\) and

\(M_2 \sin^3 i = 2.0 M_\odot\) with an orbital inclination \(i = (50–75)^\circ\).

The stellar wind is one of the fastest among the Be stars with

a terminal velocity of 1450 km s\(^{-1}\); the mass-loss rate is one of

the highest with \(M = 2.61 \times 10^{-9} M_\odot\) yr\(^{-1}\) estimated from the

Si\(\text{iv}\) profile (Snow 1981). We note that the Si\(\text{iv}\) lines likely form

inside the Roche lobe of the gainer star and might therefore not

trace the systemic mass-loss rate.

The WISE W4 image of \(\pi\) Aqr is depicted in Fig. 3. The emission shows a morphology that is typical for a wind-ISM

interaction with a bow shock in the direction of the space motion. The bow shock cone is quite symmetric on the northern and

southern half, extending to about 220" (52 800 au at 240 pc) in

those directions. In the direction of motion, the material can be

traced to about 150" (36 000 au) from the binary system. The emission peak, however, is closer to the system at about 52"

(12 480 au).

In WISE W3 at 12 \(\mu\)m (see Fig. 4), the CSE is concentrated

to the east of the star at the same position where the bow shock

in W4 is visible, but not as extended in the north-south direction.

The lower panel of Fig. 4 shows cuts through regions with and

without extended emission.

In the same manner as for CX Dra, we also performed aperture

photometry (\(r = 15''\)) for \(\pi\) Aqr in both bands at a region centred at a distance of 61" from the star at PA = 46°. The resulting

fluxes are \(F_{12} = 0.481\) Jy and \(F_{22} = 4.411\) Jy at 12 \(\mu\)m and

22 \(\mu\)m, respectively. Adopting the same absorption coefficients of astronomical silicates as for CX Dra, the 12 \(\mu\)m and 22 \(\mu\)m

fluxes correspond to a temperature of 120 K.

Since no other archival observations are available for

CX Dra, we cannot conclude on the shaping mechanism of its circumstellar material. We note, however, that the star might be

a possible candidate for showing systemic mass loss in its circumstellar environment, but further observations are needed.

2.3. \(\varphi\) Per

Phi Persei (HIP 8068) is a long period Algol B2[e]+sdO system

\(P_{eq} = 127\) d at a distance of 220 pc (van Leeuwen 2007). The system is likely at the end of its mass-transfer phase (Gies et al.

1998) and the material transferred from the donor star has largely

spun up the gainer star (primary) to the rotation rate now ob-

served. Based on double-line spectroscopic orbital elements, the masses of the components have been estimated to be 9.3±0.3 \(M_\odot\)

for the Be[e] primary and 1.14±0.04 \(M_\odot\) for the sdO secondary

(donor star). A hotspot region detected on the edge of the disc

produces strong Fe\(\text{iv}\) lines. The envelope of the companion has

mostly been stripped off by the Roche-lobe overflow (RLOF) event and the secondary, now a hot sdO star, is only visible in the

UV.

The WISE W4 22 \(\mu\)m emission of \(\varphi\) Per is shown in Fig. 5.

The CSM is elliptically shaped with the major axis approximately

in the N-S direction. The extent of the emission to the south is about 290" (63 800 au at 220 pc), while the frame is cut

off in the north 250" from the star. East of the star at \(\approx 100''\)

(22 000 au), a brightened bar is visible with the same N-S orienta-

tion as the whole elliptical emission and a length of about 240''

(52 800 au). The bar is bent towards the star at the same position angle as the direction of the space motion, which indicates that this

is the interface where the ISM interacts with the stellar material.

These bendings are visible in hydrodynamic simulations of bow shocks where the shocked stellar and ambient material cool
efficiently (see Fig. 15 in Comeron & Kaper 1998). A beautiful

example of a bent bow shock is found around the AGB star

X Per (Jorissen et al. 2011). In contrast to the other two objects, \(\varphi\) Per does not show extended emission in WISE W3.

3. Bow shock properties and systemic mass loss

For a star that moves with respect to its surrounding medium, the stellar motion adds an asymmetry to the wind velocity profile,
since different parts of the wind face the ISM with different relative velocities. If the motion is supersonic, a bow shock arises at

the interface where the ram pressure of the ISM and the stellar wind balance. The standoff distance, i.e. the distance of the star
to the apex of the shock front, is given by

$$R_0 = \sqrt{\frac{M v_w}{4 \pi \rho v_w^2}}, \quad \text{(1)}$$

where $v_w$ is the terminal wind velocity, $v_*$ the stellar velocity with respect to the ISM, $M$ the mass-loss rate, and $\rho_0$ the density of the surrounding medium (Baranov et al. 1971). The density can be expressed in number density of hydrogen atoms ($n_H = 1.6727 \times 10^{27}$ kg), which follows roughly

$$n_H = 2.0 e^{-\frac{z}{10}}, \quad \text{(2)}$$

where $z$ is the galactic height (Mihalas & Binney 1981) and $n_H$ is given in atoms per cm$^3$. Wilkin (1996) demonstrated that the shape of the bow shock only depends on the stand-off distance, while Cox et al. (2012) showed that this assumption remains valid for viewing angles up to 70°. Above this value, the bow shock cone becomes broader. Therefore, we were able to use Eq. (1) to estimate the mass-loss rate from the binary system by measuring the stand-off distance. Generally, the ISM density and stellar velocity can be determined following Eq. (2) and Johnson & Soderblom (1987). While the error of the space motion is negligible, the ISM density value is only an estimate since the star could move through a dense cloud, which is not considered by Eq. (2). The respective values of these quantities for the three objects are given in Tab. 1. To obtain the space motion ($v_{LSR}$) with respect to the local standard of rest, we corrected the heliocentric motions from the solar motion vector $(U, V, W)_\odot = (8.50 \pm 0.29, 13.38 \pm 0.43, 6.49 \pm 0.26)$ km s$^{-1}$ (Coskunolu et al. 2011). However, since the proper motions are quite small (a few mas yr$^{-1}$), the correction for the solar motion has a large impact, especially on the P.A. of the motion. Interestingly, the P.A. of the corrected LSR motion is a worse match to the bow-shock orientation than the P.A. of the uncorrected motion (see Figs. 1, 3, and 5). Using $(U, V, W)_\odot = (10.00 \pm 0.36, 5.25 \pm 0.62, 7.17 \pm 0.38)$ km s$^{-1}$ determined from the Hipparcos data by Dehnen & Binney (1995) leads to $v_{LSR}$ velocities which are slightly closer to the better matching heliocentric values. A similar discrepancy between bow-shock orientation and LSR motion (and less so with heliocentric motion) is found by Peri et al. (2012, 2013) for a large number of O- and B-type stars with bow shocks, as collected in the WISE E-BOSS survey. For this reason, we overplotted both the heliocentric and LSR motions on the WISE images in Figs. 1, 3, and 5.

### Table 1. Stellar properties

| Spec. type | CX Dra | π Aqr | ϕ Per |
|------------|-------|-------|-------|
| $M_1$ [M$_\odot$] | 3.9 | 14.0 ± 1.0 | 9.3 ± 0.3 |
| $M_2$ [M$_\odot$] | 0.9 | 2.3 | 1.1 ± 0.3 |
| $P_{orb}$ [d] | 6.696 | 84.1 | 127 |
| $D$ [pc] | 396 ± 35 | 240 ± 15 | 220 ± 9 |
| $z$ [pc] | 149 | 169 | 43 |
| $n_H$ [cm$^{-3}$] | 0.45 | 0.37 | 1.30 |
| RV [km/s] | $-2.1 \pm 2.3$ | $-4.9 \pm 0.1$ | $-4.0 \pm 2.1$ |
| $v_*$ [km/s] | 107.6 ± 1.2 | 82.3 ± 0.6 | 119.7 ± 0.2 |
| $i$ [°] | $-5.7 \pm 63.1$ | $-13.5 \pm 1.2$ | $-7.7 \pm 20.3$ |
| $v_{LSR}$ [km/s] | 25.5 ± 2.1 | 13.5 ± 1.0 | 13.1 ± 1.7 |
| $P_{A-LSR}$ [°] | 125.7 ± 1.0 | 31.5 ± 0.5 | 109.4 ± 0.6 |
| $\alpha_{LSR}$ [°] | 32.4 ± 11.4 | 6.6 ± 3.7 | $-4.4 \pm 90$ |

References. (1) Berdyugin & Pirola (2002); (2) Zharikov et al. (2002); (3) Linnell et al. (1988); (4) Bjorkman et al. (2002); (5) Hummel & Stell (2001).
tion between the mass-loss rate and the wind velocity may help us to evaluate the likelihood of systemic mass loss triggered by the hotspot scenario. In these calculations, we used the ISM densities \( \rho_0 = n_\text{H} \times m_\text{H} \) and space velocities \( v_\text{LSR} \) listed in Table I with stand-off distances of \( R_0 = 36,000 \text{ au} \) for \( \pi \text{ Aqr} \) and \( R_0 = 22,000 \text{ au} \) for \( \varphi \text{ Per} \), as measured on the WISE images. Fig. 6 depicts the relationship between mass-loss rate and wind velocity for \( \pi \text{ Aqr} \). The colours show the differences in the calculated \( R_0 \) to the observed value of 36,000 au.

For an expected wind velocity between 700 and 1500 km s\(^{-1}\), only a small range of mass-loss rates from \( 4 \times 10^{-10} M_\odot \text{ yr}^{-1} \) to \( 4 \times 10^{-9} M_\odot \text{ yr}^{-1} \) can match the observed stand-off distance (±5000 au) of the bow shock around \( \pi \text{ Aqr} \). This range of mass-loss rates is well below the systemic mass-loss rate inferred from the hotspot scenario (of the order of \( 10^{-5} M_\odot \text{ yr}^{-1} \)). Such a high mass-loss rate in combination with a wind velocity of \( \approx 1000 \text{ km s}^{-1} \) would cause a stand-off distance that is a factor of 100 larger than observed. To bring the wind velocity in line with the proposed \( M \) from the hotspot scenario and with the observed \( R_0 \), it has to decrease almost to 0. In other words, it is highly unlikely that a systemic mass loss of the order of \( 10^{-5} M_\odot \text{ yr}^{-1} \) is currently present in \( \pi \text{ Aqr} \). If systemic mass loss is ongoing, it does not exceed \( 10^{-4} M_\odot \text{ yr}^{-1} \). We emphasise, however, that the mass-loss rate of \( \pi \text{ Aqr} \) inferred from the bow-shock properties fits well the value observed for the Be star (\( 2.61 \times 10^{-9} M_\odot \text{ yr}^{-1} \), Snow 1981). We obtain similar results for \( \varphi \text{ Per} \): \( M = 2 \times 10^{-10} - 6 \times 10^{-9} M_\odot \text{ yr}^{-1} \) for \( v_w = 700–1500 \text{ km s}^{-1} \) for a measured \( R_0 \) of 22,000 ± 5000 au.

The Be star wind as the origin of the bow shock is further demonstrated by the fact that the bow shocks discovered in the present study are restricted to early-type B stars (Figs. 7, 8). Our sample also includes a O9.7Ibe star, RY Sct, which shows a high WISE W4/W1 flux ratio. However, RY Sct is much farther away than the three B stars discussed in the present paper since it has a parallax not significantly different from zero (van Leeuwen 2007); hence, if present, the extended emission would be hardly detectable. Given that the \( V \) magnitude of RY Sct (O9.7Ibe) amounts to 9.1, compared to \( V = 4.6 \) for \( \pi \text{ Aqr} \) (B1Ve), RY Sct is located at least a factor of 10 farther away than \( \pi \text{ Aqr} \). All other parameters being equal, the bow shock of RY Sct would thus only extend up to 15′′ from the star, and would not be resolved by WISE. This conclusion is supported by Fig. 8, which reveals that the Be stars with a detected bow shock are the nearest and the warmest in the sample.

The second Be star with extended emission that we did not include in this study is the B2Vne star V696 Mon. The WISE W4 image is depicted in the upper panel of Fig. 9 and shows a peculiar morphology around the star. The extended emission reaches north of V696 Mon and seems to engulf the star BD-06°1393 located 148′′ from V696 Mon at PA = 8°. This association is probably not real, since the Tycho-1 parallaxes of the two stars are quite different. Although the space velocity of V696 Mon \( \mu_{\text{LSR}} = (15.8 \pm 6.2) \text{ km s}^{-1} \) is comparable to the three stars studied here and the IR emission seems to be aligned with the direction of the space motion, the upstream structure does not resemble a bow shock.

We also note that the surrounding ISM of V696 Mon is extremely rich (the star-forming region Monoceros R2 is 56′ away) as seen in the IRAS 100μm image (lower panel of Fig. 9), and it is difficult to conclude whether the WISE 22μm emission originates from CSM or ISM.

4. Conclusion

We studied a sample of 70 Algol and Algol-like Be systems with entries in the WISE catalogue with the aim of identifying those Algol systems surrounded by dust left over by systemic mass loss. In D15, the two objects, CZ Vel and SX Aur, were discussed, and here we find that three new objects, CX Dra, \( \pi \text{ Aqr} \), and \( \varphi \text{ Per} \), show circumstellar material in the WISE W4 band at 22μm; \( \pi \text{ Aqr} \) and CX Dra also show material in WISE W3 at 12μm. The two objects \( \pi \text{ Aqr} \) and \( \varphi \text{ Per} \) show clear evidence of an interaction of circumstellar material with the ISM. For these events, we used the distance of the star to the bow shock to derive the mass-loss rate of the matter that escapes from 4 We checked the Herschel Science Archive as well, but only 2 of the 70 targets had been observed by the Herschel Space Observatory, neither of which showed circumstellar emission.
70 targets, only a handful of stars appear to exhibit IR excesses. Systemic mass loss in Algols seem dark. Of the initial sample dropped.

... has already come to an end and the systemic mass-loss rate has

... is comparable to the mass-loss rate found for single B-type stars and much lower than the predicted systemic mass-loss rate from the hotspot scenario (see Figs. 13-14 of D15). It is conceivable that the simulations of D15 overestimate the amount of dust that survives the hotspot mechanism. For the two stars that show the presence of circumstellar material expressed by a bow shock (π Aqr and ϑ Per), neither shock appears to be tied to systemic mass loss.

In the case of CX Dra, we were not able to identify the shaping mechanism responsible for the asymmetric circumstellar emission. Both common triggers for asymmetries, ISM interaction forming a bow shock and binary interaction forming an Archimedean spiral, can be excluded for various reasons. We note therefore that this system is an interesting case for further observations since it may be a case where mass lost from the system is visible in the circumstellar environment.

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... the system. For both systems we estimate a mass-loss rate of

... with the uncorrected proper motion from the reprocessed Hipparcos catalogue (van Leeuwen 2007), while the dashed arrow points to the direction of the space motion corrected from the solar motion (Coşkunoğlu et al. 2011). The colour bar values are given in Jy pix^-1. Lower panel: IRAS 100 µm image of the surroundings of V696 Mon (marked as an X). The colour bar values are given in MJy sr^-1.

fig. 9. Upper panel: WISE W4 image of V696 Mon at 22 µm. The continuous black arrow gives the uncorrected proper motion from the reprocessed Hipparcos catalogue (van Leeuwen 2007), while the dashed arrow points to the direction of the space motion corrected from the solar motion (Coşkunoğlu et al. 2011). The colour bar values are given in Jy pix^-1. Lower panel: IRAS 100 µm image of the surroundings of V696 Mon (marked as an X). The colour bar values are given in MJy sr^-1.
### Appendix A: List of objects

**Table A.1.** Seventy Algols and Algol-like Be stars with a WISE source counterpart sorted by declination. Objects marked with an asterisk (*) show extended emission in W4, while the plus sign (+) marks objects with a WISE W4/W1 flux ratio which is above the black-body law (see Tab. 6 in D15). References: (1): Harmanec (2001); (2): Brancetic & Dworak (1998); (3): Budding et al. (2004).

| V* Name               | 2MASS       | HD/BD | Spec. type | Ref. |
|-----------------------|-------------|-------|------------|------|
| BP Mus                | J12503775-7146186 |      |            | 3    |
| DW Aps                | J17233003-6755448 | HD 156545 | B6III | 2,3  |
| EP TrA                | J14549261-6415574 | HD 140809 | A0   | 2,3  |
| AN Tuc               | J23302225-5825346 | HD 221184 | A5III | 2,3  |
| R Ara                | HD 149730 | B9IV | 1,2,3 |
| UZ Nor +              | J16282115-5319215 | B9 | 3    |
| Wd64 Cen              | J11363587-5312354 | HD 100987 | B8IV | 2,3  |
| RV Pic               | J04572970-5208458 | HD 32011 | A1V  | 2,3  |
| CZ Vel +              | J09104446-5042405 | B3   | 3    |
| KV Pup                | J07471912-4832121 | HD 63562 | A0IV | 2,3  |
| TT Hor               | J03270438-4552566 |      |        |      |
| DN Vel               | J09193768-4540477 | HD 80692 | A0III | 2,3  |
| YY Mic                | J20490707-3343543 | HD 198103 | A4III | 2,3  |
| DM Pup               | J08070409-2531522 | A2.5 | 3    |
| AA Pup               | J08013612-2443034 | HD 66226 | F3IV | 2,3  |
| YY Cma                | J07005186-1914315 | A2V  | 3    |
| AO Eri                | J03420003-1744475 | A2   | 2,3  |
| SS Lep +              | J06045913-1629039 | HD 41511 | A1V  | 1    |
| W Ser +                | J18095907-1513009 | HD 16626 | F5III | 1,2,3 |
| RY Set +              | J18253147-1241241 | HD 169515 | O9.7Ib | 1,2,3 |
| XY Pup               | HD 67862 | A3 | 1,2,3  |
| V644 Mon              | J06570938-1049281 | HD 51480 | Ape | 1    |
| AW Mon [BD]          | J10-2233 | A2 | 2,3  |
| RZ Scir            | J18263352-0912060 | HD 169753 | B3Bb | 1,2,3 |
| XZ Aql                | J20221335-0721034 | HD 193740 | A2   | 2,3  |
| V696 Mon +           | J06041349-0642321 | HD 41335 | B2Vne | 1    |
| AR Mon               | J07208485-0515357 | HD 57364 | K0II | 2,3  |
| AU Mon               | J06545471-0122328 | HD 50846 | B4IV | 1,2,3 |
| V699 Mon +           | J09471071-0102147 | G4IV | 3    |
| pi Aur +             | J22551662-0122389 | HD 212571 | B1Ve | 1    |
| AC Tau               | J04370635+0141311 | A8  | 2,3  |
| SS Cet               | HD 17513 | A2 | 2,3  |
| AX Mon               | J06302293+0552012 | HD 45910 | B2III | 1    |
| DN Ori                | J06082035+1013049 | HD 40632 | A2e  | 1,2,3 |
| FM Ori                | J05085439+1033341 | HD 241071 | A5  | 3    |
| V930 Oph             | J18414565+1202111 |      |        | 3    |
| BI Del                | J20273662+1420091 | G0 | 2,3  |
| AL Leo                | J09581290+1872282 | F5 | 2,3  |
| U Sge                 | J19184840-1936377 | HD 181182 | B7.5V | 1,2,3 |
| AL Gem                | J06573855+2053325 | HD 266913 | F6V  | 2,3  |
| RS Vul                | J19174000+2226284 | HD 180939 | B5V  | 2,3  |
| DH Her +              | J18473455+2205439 | HD 343047 | A5   | 2,3  |
| RW Tau               | J04055432+2807334 | HD 25487 | B8Ve | 1,2,3 |
| UCnB                 | J15181133-1338492 | HD 136175 | B6V | 1,2,3  |
| BC Aur                | J05461654+3250500 |      |        | 3    |
| RX Gem                | J06501154+3314207 | HD 49521 | A0  | 1,2,3  |