

An $H\alpha$ survey of infrared bow shocks around OB-type stars

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ABSTRACT

Context. Bow shocks around massive stars are commonly identified in mid-IR surveys, where emission from heated dust traces the interaction between stellar winds and the surrounding interstellar medium (ISM). In contrast, systematic optical investigations of these structures remain scarce, with only a few possible detections reported so far.

Aims. We investigated whether bow shocks identified in mid-IR observations around OB stars also produce detectable emission in the $H\alpha$ recombination line, confirmed prior detections, compared the morphology of bow shocks detected in $H\alpha$ and mid-IR wavelengths, and assessed the role of stellar radiation pressure in contributing to the support of these structures.

Methods. We performed a targeted $H\alpha$ imaging survey of 78 IR bow-shock candidates compiled from several literature catalogues. Observations were obtained with multiple ground-based facilities and complemented with archival mid-IR images from the *Spitzer* Space Telescope and the Wide-field Infrared Survey Explorer. For the detected bow structures, geometrical parameters such as spatial extent, width, and stand-off distance were measured, and the bows were classified using the parameters of their central stars, the measured stand-off distances, and the adopted plausible ISM conditions.

Results. Clear arc-shaped $H\alpha$ nebulae are detected in 15 objects, with one additional bow shock discovered serendipitously in a wide-field image. A further 35 objects exhibit diffuse $H\alpha$ emission associated with complex background structures, while 28 show no detectable $H\alpha$ emission. The $H\alpha$ and IR morphologies generally trace the same large-scale structures, although most of the IR arcs lie slightly closer to the star and appear broader than their optical counterparts. We find that several systems are consistent with radiation-supported bow shocks, bow waves, or dust waves, while others remain compatible with classical wind-supported bow shocks.

Conclusions. This survey demonstrates that a fraction of IR bow-shock candidates around OB stars also exhibit detectable ionised gas structures in $H\alpha$, and that both stellar wind momentum and radiation pressure can contribute to shaping these structures. No correlation is found between the detection of an $H\alpha$ bow shock and the stellar parameters, and the overlap in objects observed in $H\alpha$ and in the radio regime was too small for firm conclusions other than that stars with no $H\alpha$ emission also show no radio emission. Future spectroscopic observations will be required to determine the physical conditions and kinematics of the ionised gas and to further constrain the nature of these bow-shock systems.

Key words. methods: observational – circumstellar matter – stars: early-type – stars: massive – stars: winds, outflows

1. Introduction

Massive stars significantly influence the interstellar medium (ISM) through their winds, radiation fields, and ultimately through their explosions as supernovae. Thereby, they inject substantial amounts of energy and momentum throughout their evolution and enrich the surrounding gas with chemically processed material. The interaction with the ISM can lead to the formation of characteristic gas and dust structures such as H II regions, shells, and bow shocks. Bow shocks around massive stars arise when a supersonic relative motion develops between the stellar wind and the surrounding ISM. Supersonic motions can have different origins. In the runaway star scenario, the star itself moves with a high velocity, generating wind–ISM interaction fronts aligned with their direction of motion. Such high-velocity stars may have been ejected from multiple systems or young stellar clusters through dynamical interactions,

or by the disruption of binary systems, for example during a supernova explosion (Poveda et al. 1967; Blaauw 1961; Pflamm-Altenburg & Kroupa 2010; Fujii & Portegies Zwart 2011). On the other hand, non-runaway OB stars with bow shocks exist as well. In this so-called ‘weather vane’ scenario introduced by Povich et al. (2008), the bow-shock morphology is shaped by large-scale external flows, such as expanding H II regions, whose impinging momentum flux determines the shock orientation and structure.

Early analytical descriptions of wind–ISM interactions established the ram-pressure balance framework and the resulting bow-shock geometry (Baranov et al. 1971; Wilkin 1996, 2000). More recently, multi-dimensional simulations have examined bow-shock evolution under increasingly realistic conditions, including radiative heating and cooling, photoionisation, and evolving wind properties (Meyer et al. 2014; Meyer et al. 2016; Mohamed et al. 2012; Acreman et al. 2016; Mackey et al. 2016; Green et al. 2019), while magnetohydrodynamic (MHD) studies have further explored the role of magnetised stellar winds and

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ambient interstellar fields in shaping the shock structure (Meyer et al. 2017, 2021; Green et al. 2022; Mackey et al. 2021, 2025; del Valle et al. 2025).

An alternative interpretation attributes the observed arcs around massive stars to radiation-pressure-driven bow waves, where stellar photons transfer sufficient momentum to decelerate and deflect the dust grains (van Buren & McCray 1988). This mechanism has been investigated in detail in the context of late O-type stars with weak winds embedded in dusty photoevaporation flows within H II regions, where radiation pressure can dominate the dust dynamics and support arc-shaped structures distinct from classical wind-supported bow shocks (WBSs; Ochsendorf et al. 2014a,b; Ochsendorf & Tielens 2015). Building on this picture, Henney & Arthur (2019a,b,c) established a unified theoretical and observational framework for stellar bow shells around luminous stars. In their first paper, Henney & Arthur (2019a) developed a semi-analytic model in the strong gas–grain coupling limit, balancing the ram pressure of the ambient stream against stellar wind and radiation pressure. This framework yields three regimes defined by the optical depth of the shocked shell and the dominant internal support: WBSs, radiation-supported bow waves (RBWs), and radiation-supported bow shocks (RBSs). Radiation pressure becomes significant in dense environments with a high shell optical depth, for weak-wind stars with low wind momentum, and at low relative velocities between the star and the surrounding ISM. Henney & Arthur (2019b) investigated the breakdown of the strong gas–grain coupling limit and showed that radiation pressure can decouple dust from the gas upstream of the hydrodynamic bow shock. This process introduces a fourth regime, in which a distinct dust wave (DW) forms exterior to the gas shell. Their study also examined the influence of different magnetic field orientations on the structure and existence of these DWs. The third paper in the series introduced a novel diagnostic method that uses mid-IR data to distinguish between wind- and radiation-supported bow structures and to refine stellar wind mass-loss estimates (Henney & Arthur 2019c). Applying this method to a sample of observed bow structures, they identified four strong and three marginal RBW candidates but found no strong evidence of decoupled DWs. They further suggested that stellar wind mass-loss rates derived from the dust emissivities of IR bow shocks, following the method of Kobulnicky et al. (2018), should be revised downwards by approximately a factor of 2.

From an observational point of view, the first bow shocks around massive stars were identified based on emission in optical nebular lines (Gull & Sofia 1979) and pronounced structures detected on IR images from the Infrared Astronomical Satellite (IRAS) mission by van Buren & McCray (1988) and van Buren et al. (1995). These early surveys culminated in the catalogue of 21 candidate bow shocks and four bubbles compiled by Noriega-Crespo et al. (1997). Wide-field mid-IR surveys subsequently expanded the Galactic census of stellar bow shocks, with the Extensive stellar BOw Shock Survey (E-BOSS) catalogue compiled from Wide-field Infrared Survey Explorer (WISE) and Midcourse Space Experiment (MSX) data by Peri et al. (2012, 2015) and a systematic visual inspection of WISE and *Spitzer* Space Telescope images that yielded over 600 additional candidates (Kobulnicky et al. 2016, 2017). More recently, the combination of mid-IR imaging with *Gaia* Data Release 3 (DR3) astrometry has led to the identification of new runaway massive stars and associated bow-shock structures (Carretero-Castrillo et al. 2023, 2025). Radio studies have examined IR-selected bow shocks to identify thermal and non-thermal counterparts and to trace the shocked gas (Benaglia et al. 2010, 2021;

Moutzouri et al. 2022, 2025; Van den Eijnden et al. 2022; van den Eijnden et al. 2022, 2024), and X-ray investigations have searched for high-energy emission associated with particle acceleration in these systems (López-Santiago et al. 2012; Terada et al. 2012; Toalá et al. 2016; De Becker et al. 2017; Binder et al. 2019). While extensive work has been carried out at IR, radio, and X-ray wavelengths, optical investigations of massive-star bow shocks remain sparse, with the only dedicated H α survey conducted by Brown & Bomans (2005) and detailed spectroscopy largely restricted to isolated cases such as the red supergiant IRC–10414 (Gvaramadze et al. 2014). This lack of systematic H α studies motivated the targeted survey presented in this work.

The paper is structured as follows. Section 2 describes the target selection criteria adopted for this survey. Section 3 presents the H α observations obtained with various ground-based facilities, together with the archival mid-IR imaging from *Spitzer* and WISE (bands 2–4) used for comparison. The derived bow-shock parameters and the proposed morphological classification scheme are presented in Sect. 4. In Sect. 5, the results are discussed in the context of previous H α , IR, and radio surveys, and Sect. 6 summarises our conclusions and outlines prospects for future work.

2. Target selection

Bow shocks around runaway stars are efficiently identified in the IR because dust swept into the shocked layer is heated by stellar radiation and gas compression, resulting in strong emission at 12–24 μm . We therefore prioritised targets with established mid-IR arcs and assembled our sample from four literature sources.

The first IR catalogue of bow-shock nebulae around early-type stars was compiled by van Buren & McCray (1988), who conducted a visual survey of arcuate or bubble-like structures using the 60 μm all-sky survey of IRAS. Their search identified 15 objects with arc-like (or ring-like) morphologies, listed in their Table 1. From this sample, we selected the 13 objects classified as OB or Wolf–Rayet stars, excluding the fourth and fifth entries whose spectral types are unknown. We assigned the designations BS01–BS15 according to the order in which the objects appear in their table, omitting BS04 and BS05. One additional target, BS03: HD 192163, was not included in our observational sample. This object is a Wolf–Rayet star for which the H α morphology seen in the *Isaac Newton* Telescope Photometric H α Survey (IPHAS; Drew et al. 2005) indicates that the emission structure is not associated with a bow-shock nebula. In total, 12 targets from this catalogue were observed.

In a subsequent study, van Buren et al. (1995) extended their earlier work by compiling a catalogue of 188 OB-type runaway stars drawn from the surveys of Garmany et al. (1982), Cruz-González et al. (1974), and Stone (1979). Using IRAS data, they constructed 60 μm excess maps with the 100 μm images as a reference, and identified 58 candidate bow shocks, of which 25 exhibit well-resolved arc-like structures. From this sample, Brown & Bomans (2005) searched for H α counterparts to 37 O-type candidates using data from the two H α all-sky surveys Southern H-Alpha Sky Survey Atlas (SHASSA; Gaustad et al. 2001) and Virginia Tech Spectral-Line Survey (VTSS; Dennison et al. 1998). Their methodology relied on the analysis of radial surface-brightness profiles as a more robust alternative to visual inspection, and on the geometry of the arc-like emission to constrain ambient ISM properties. Eight bow-shock detections were reported in their Table 1. We selected these eight objects

for deeper and (where appropriate) higher-resolution follow-up observations and refer to them hereafter with the prefix ‘BB’.

The E-BOSS catalogue was compiled in two stages, namely the initial release (Peri et al. 2012) and the extended release (Peri et al. 2015). The first catalogue was drawn from two sources: (i) 56 OB stars previously listed as bow-shock candidates by Noriega-Crespo et al. (1997) and (ii) 244 O–B2 runaway stars extracted from Tetzlaff et al. (2010); 17 objects were present in both groups. The extended catalogue expanded the sample by adding 234 B3–B5 stars also selected from Tetzlaff et al. (2010), 42 runaways identified in the Galactic O Star Catalog Maíz-Apellániz et al. (2004), and 10 further runaway stars from Hoogerwerf et al. (2001), together with 45 objects previously reported in the literature or discovered by the authors. In both releases, a bow shock was defined as a comma- or arc-shaped structure located upstream of the stellar motion and brightest in the 12–24 μm bands. A total of 28 bow-shock candidates were identified in the first release, and 45 additional candidates in the second, as listed in Peri et al. (2015, Table 8). In the present work, we selected the first 28 candidates listed in that table, retaining the same identifiers (EB01–EB28). Four objects from this subset (EB03, EB07, EB09 and EB28) were not observed during our dedicated observing runs, but available IPHAS images were used to complete the sample. The authors noted that their inspection of SHASSA and VTSS $H\alpha$ maps did not yield any convincing evidence of bow-shock morphology.

Finally, the largest catalogue to date, comprising 709 IR bow shocks, was compiled by Kobulnicky et al. (2016) through a systematic examination of Galactic-plane images obtained with the 24 μm channel of the Multiband Imaging Photometer for *Spitzer* (MIPS) and WISE band 4, searching for symmetric mid-IR arc-like nebulae. Of the 709 identified candidates, 660 are new detections. From this catalogue, we selected a total of 39 candidates, with a primary focus on evolved massive stars according to their classification in SIMBAD¹. The remaining targets were selected based on a manual inspection of the IR morphologies, with preference given to objects displaying well-defined and isolated arc-like structures that were suitable for follow-up $H\alpha$ imaging observations. Additional practical considerations included target visibility from the observing sites and the angular size relative to the available telescope fields of view. We denote each selected candidate with the prefix ‘K’, followed by its catalogue index number.

After merging the above lists and removing duplicates, our study comprises 78 unique targets listed in Table A.1. These were observed in our imaging survey.

3. Observations and data reduction

3.1. $H\alpha$ imaging

Imaging observations were carried out over a period of four years beginning in 2020, with four objects observed in early 2026, using a combination of northern and southern facilities with different fields of view to adequately cover the spatial extent of the nebulae identified in the IR surveys. The campaign made use of the Danish 1.54 m telescope at La Silla (DK154) and the robotic T17 and T31 telescopes of the iTelescope network located at Siding Spring Observatory in Australia to observe southern targets, and of the Perek 2 m telescope and the Small Binocular Telescope (SBT) at Ondřejov Observatory for

northern targets. Depending on the angular extent of each nebula, either the smaller- or larger-field facility was used.

The DK154 is equipped with a 2048×2048 charge-coupled device (CCD) camera that delivers a pixel scale of $0''.396$ per pixel and covers a square field of view of $13'7 \times 13'7$. Observations were obtained through the European Southern Observatory (ESO) $H\alpha$ filter No. 693, which has a central wavelength of 656.23 nm and a bandpass of 6.21 nm.

The T31 telescope employs a 3056×3056 pixel CCD with a sampling of $1''.1$ per pixel and a field of view of $55'.9$ by $55'.9$. The T17 telescope uses a 4788×3194 CCD that provides a pixel scale of $0''.531$ per pixel and a field of $42'.4 \times 28'.3$. Both telescopes are equipped with an Astrodon $H\alpha$ narrowband filter with a central wavelength of 656.3 nm and a full width at half maximum (FWHM) of 5 nm.

Two CCD systems were used on the Perek 2 m telescope during the time span of the programme. The older CCD camera delivered a sampling of $0''.404$ per pixel and a field measuring $7'.31$ by $4'.94$. The newer Perek CCD operates with a 1056×1027 detector that provides a pixel scale of $0''.385$ per pixel and a square field of view of $6'.3 \times 6'.3$. Both instruments were used with a narrow-band $H\alpha$ filter of 3 nm bandwidth.

The SBT is equipped with a 4096×4096 CCD detector. This instrument offers a very wide field of view of $3'.5 \times 3'.5$ and a sampling of $3''.14$ per pixel, making it well suited for detecting large-scale nebular structures (Štrobl et al. 2019). The $H\alpha$ filter has a bandwidth of 3 nm.

We adopted a baseline exposure time of 900 s with our main survey facility, DK154, under typical seeing conditions ($1''$ – $2''$). If no discernable structure was detected, the object was classified as a non-detection. Otherwise, the exposure time was increased to achieve a higher signal-to-noise ratio (S/N). For the supplementary facilities, we applied the same strategy. Considering the different sizes of the telescope collecting areas, the different pixel sizes, and the different seeing conditions, we estimated that the 900 s exposure with the DK154 translates to ~ 3600 s with the T31 and to ~ 900 s with the SBT (due to the usually very bad seeing conditions under which the telescope was available for our purposes). Therefore, the sensitivity was very similar across these facilities. For each of them, the faintest detection, when scaled to the baseline exposure times, corresponds to a surface brightness value of ~ 10 Rayleigh (see Sect. 4.2), which we consider as the limiting value for our survey. Due to its very small field of view, the Perek telescope was not an ideal facility for our survey and was used only occasionally for a few small bow-shock nebulae in the northern sky. The same sensitivity would have been reached with a ~ 600 s exposure. However, we used 3600 s as baseline for (non-)detection, which is four times deeper than with the other facilities.

In all cases, the total exposure time for each target was divided into a series of shorter individual integrations. This approach prevents any excessive saturation of bright stars in the field and mitigates guiding instabilities that are commonly encountered during long single exposures. The full observational log is presented in Table B.1, which lists for each target the host star, equatorial coordinates, observation date, telescope used, total exposure time, number of combined frames, measured seeing, and the V band magnitude of the source.

The data reduction was carried out using standard procedures within the Image Reduction and Analysis Facility (IRAF)²

¹ We note that many objects in that catalogue lack a classification in SIMBAD (<https://simbad.u-strasbg.fr/simbad/>).

² IRAF was written at the National Optical Astronomy Observatory, which was operated by the Association of Universities for Research in Astronomy (AURA) under cooperative agreement with the National Science Foundation.

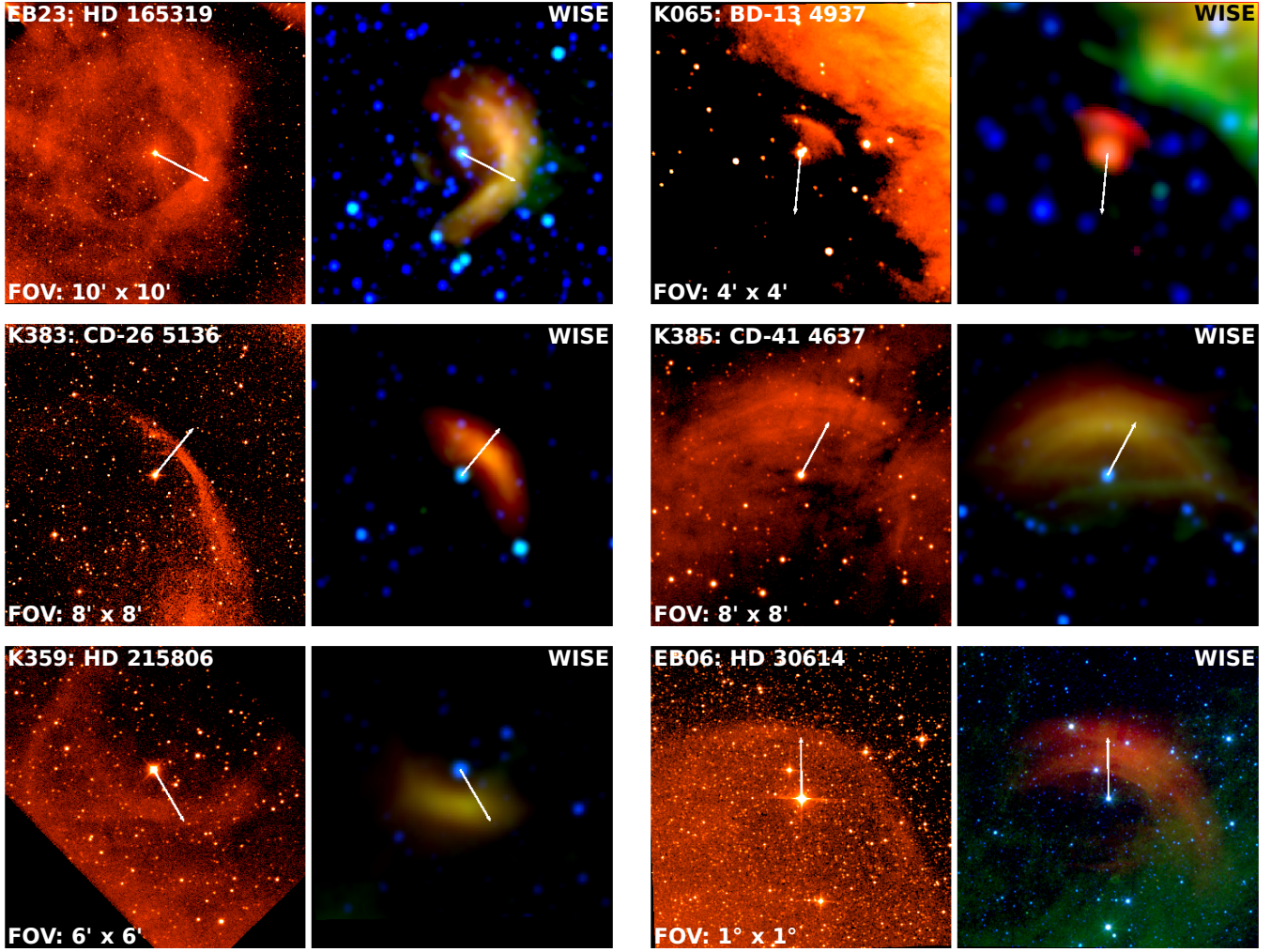


Fig. 1. Examples of $H\alpha$ bow shocks detected with DK154, as well as with Perek (K359) and SBT (EB06). The proper-motion vector (not to scale) corresponds to 20% of the image field of view. *Left:* $H\alpha$ image obtained from our survey. *Right:* Three-colour mid-IR image of the corresponding nebula, constructed from archival data: WISE W2 (4.6 μm ; blue); WISE W3 (12 μm ; green); and WISE W4 (22 μm ; red). Images are in equatorial coordinates with north up and east to the left. The remaining detections are shown in Fig. C.1.

(Tody 1986, 1993). This included subtraction of the bias level and division by normalised flat fields to correct for pixel-to-pixel sensitivity variations. Individual exposures were then aligned and median-combined to remove cosmic rays and to increase the resulting S/N. Astrometry was performed on all images.

The primary goal of the present survey was the detection and morphological characterisation of extended bow-shock nebulae. The observations were carried out using relatively narrow $H\alpha$ filters compared to those employed in large photometric surveys such as IPHAS (9.5 nm). No continuum observations were obtained, and the $H\alpha$ images are therefore not continuum-subtracted. Possible continuum contribution could become problematic if a bow-shock source is located within a H II region that itself has strong $H\alpha$ emission. Furthermore, emission at the wavelength of $H\alpha$ might originate from reflection of starlight from a dust structure, mimicking $H\alpha$ emission. While H II regions are easily recognised and bow shocks within them should still be detectable, distinguishing between real $H\alpha$ emission and a reflection nebula is more challenging using our data alone. As a qualitative assessment of the latter, we inspected Digitized Sky Survey 2 (DSS2) blue images for all detected nebulae.

3.2. Archival infrared survey data

Mid-IR images were retrieved from the archives of *Spitzer* (Werner et al. 2004) and WISE (Wright et al. 2010) through the NASA Infrared Science Archive (IRSA)^{3,4}. From *Spitzer*, we used data obtained with the Infrared Array Camera (IRAC; Fazio et al. 2004) in the 3.6, 4.5, 5.8, and 8.0 μm bands, which provide angular resolutions of 1.66, 1.72, 1.88, and 1.98 arcsec, respectively. Additional images at 24 μm were taken from MIPS (Rieke et al. 2004), which has a beam size of 6.0 arcsec. Complementary data were obtained from the WISE survey in the 3.4, 4.6, 12, and 22 μm bands, with angular resolutions of 6.1, 6.4, 6.5, and 12.0 arcsec, respectively.

4. Results

From the 78 objects included in Table A.1, we identify 15 bow-shock detections (Figs. 1 and C.1), 28 non-detections

³ <https://irsa.ipac.caltech.edu/applications/Spitzer/SHA>

⁴ <https://irsa.ipac.caltech.edu/applications/wise>

Table 1. Bow-shock parameters measured from the H α and IR images.

ID	H α							WISE/ <i>Spitzer</i>						
	R_0 ($''$)	(pc)	w ($''$)	(pc)	l ($''$)	(pc)	e	R_0 ($''$)	(pc)	w ($''$)	(pc)	l ($''$)	(pc)	e
EB06	790.30	6.48	272.43	2.23	3017.20	24.73	0.75	624.35	5.12	587.82	4.82	3228.88	26.46	0.73
EB12	126.38	1.04	35.78	0.29	383.79	3.15	0.42	65.52	0.54	100.28	0.82	473.18	3.15	0.42
EB15	15.92	0.39	8.95	0.22	56.08	1.36	0.64	14.66	0.36	10.34	0.25	60.35	1.46	0.56
EB21	290.567	0.19	172.07	0.11	1488.50	0.97	0.83	295.88	0.19	129.47	0.08	1290.76	0.84	0.82
EB23	108.24	0.77	47.14	0.33	389.38	2.76	0.21	93.22	0.66	50.91	0.36	448.18	3.18	0.57
BB1	605.58	7.08	288.11	3.37	2214.76	25.89	0.65	354.11	4.14	256.32	3.00	1836.83	21.47	0.77
BB4	807.83	3.59	329.87	1.47	1467.33	6.53	0.28	582.58	2.59	373.07	1.66	1865.75	8.30	0.55
BB5	71.86	0.90	35.20	0.44	418.63	5.23	0.82	46.97	0.59	40.10	0.50	385.98	4.82	0.76
BS11	728.78	1.36	185.54	0.35	1472.10	2.76	0.34	600.75	1.12	327.51	0.61	1868.42	3.50	0.30
K065	24.83	0.22	8.25	0.07	64.00	0.56	0.60	25.73	0.23	12.67	0.11	91.06	0.80	0.67
K359	48.50	0.62	27.25	0.35	278.04	3.56	0.81	44.19	0.57	38.89	0.50	216.60	2.77	0.62
K383	49.61	1.51	17.91	0.54	253.27	7.70	0.87	52.21	1.59	36.94	1.12	219.66	6.68	0.68
K385	122.50	1.40	55.85	0.64	381.28	4.35	0.69	83.83	0.96	80.30	0.92	418.72	4.78	0.65
K386	58.77	0.57	19.71	0.19	251.39	2.46	0.81	55.02	0.54	22.30	0.22	301.96	2.95	0.89
K692	50.46	0.44	30.14	0.26	185.51	1.61	0.69	34.51	0.30	43.14	0.36	243.39	2.12	0.37
N1	127.81	1.34	50.69	0.53	386.34	4.05	0.50	129.50	1.36	54.20	0.57	378.92	3.97	0.26

Notes. For each target, the table lists the stand-off distance, width, length, and eccentricity of the fitted annulus in H α and WISE 22 μ m or *Spitzer* 24 μ m images. The uncertainties quoted for R_0 correspond to one pixel for the respective H α and IR images. The pixel scales of the instruments are given in Sect. 3. To estimate the uncertainty associated with the fitting procedure, the measurements were repeated multiple times for each nebula. The relative uncertainty, quantified as $100 \times \sigma/\mu$, where σ is the standard deviation and μ is the mean of the repeated measurements, was found to be ~ 2 –15% for w , ~ 1 –7% for l , and ~ 1 –30% for e in the H α images, and ~ 3 –14% for w , ~ 1 –7% for l , and ~ 1 –47% for e in the IR images.

(not shown), and 35 sources (Figs. D.1–D.4) whose classification remains uncertain, mostly because they lie within bright and complex H II regions where extended emission masks the underlying structure. Hereafter, these objects are referred to as diffuse-emission objects. In addition, we report one previously unrecognised detection, designated N1, which appears in the wide-field SBT frame obtained for BB1: HD 17505. The arc-like structure of the nebula in H α matches with that seen in the W4 band image. The spectral type of the central star is O9.5 V, as reported by Garmany & Stencel (1992).

4.1. Bow-shock parameters

For each of the 16 detections, we measured the geometrical parameters of the arc-shaped nebula, namely its spatial extent (l), width (w), and stand-off distance (R_0), using both the H α and mid-IR images. The measurements are performed by visually fitting each nebula with an elliptical annulus (Fig. 2). The inner and outer ellipses of the annulus were constrained to have the same eccentricity (e). Their common orientation is chosen such that either the major or the minor axis approximately coincides with the apparent symmetry axis of the bow shock. In this framework, l corresponds to the partial circumference of the outer ellipse that traces the arc, with the endpoints defined by the extent of the detectable shell emission. These endpoints are not necessarily symmetric with respect to the major or minor axis of the ellipse. The width is determined from the thickness of the annulus along the symmetry axis. The stand-off distance is measured as the separation between the star and the brightest pixel of the nebula in the W4 band or MIPS 24 μ m band images, and in the H α images, with the brightest pixel constrained to lie within $\pm 10^\circ$ of the symmetry axis of the bow shock. The resulting values are listed in Table 1.

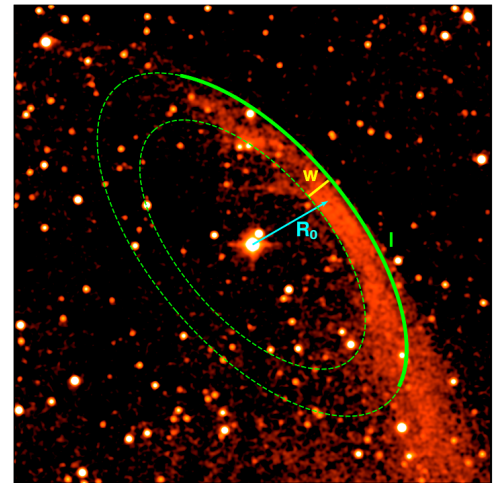


Fig. 2. Illustration of the measurements of the bow-shock parameters for the example of K383: CD-26 5136.

Although the H α and mid-IR morphologies generally trace the same overall structure, comparison of the inner boundaries along the symmetry axis indicates that the IR arcs are frequently located slightly closer to the central star. Furthermore, the H α arcs appear systematically thinner than their mid-IR counterparts (left panel of Fig. 3). To assess whether these differences arise from resolution effects, the H α images were convolved to the FWHM of the WISE band-4 (12 $''$) and MIPS 24 μ m (6 $''$) images. The measured arc widths in the H α images increase after convolution in all cases, with the effect becoming substantially more pronounced when the images are matched to the lower angular resolution of the WISE data (see Fig. 4). In several cases, the convolved H α widths become more consistent with the IR measurements, although noticeable discrepancies remain for some

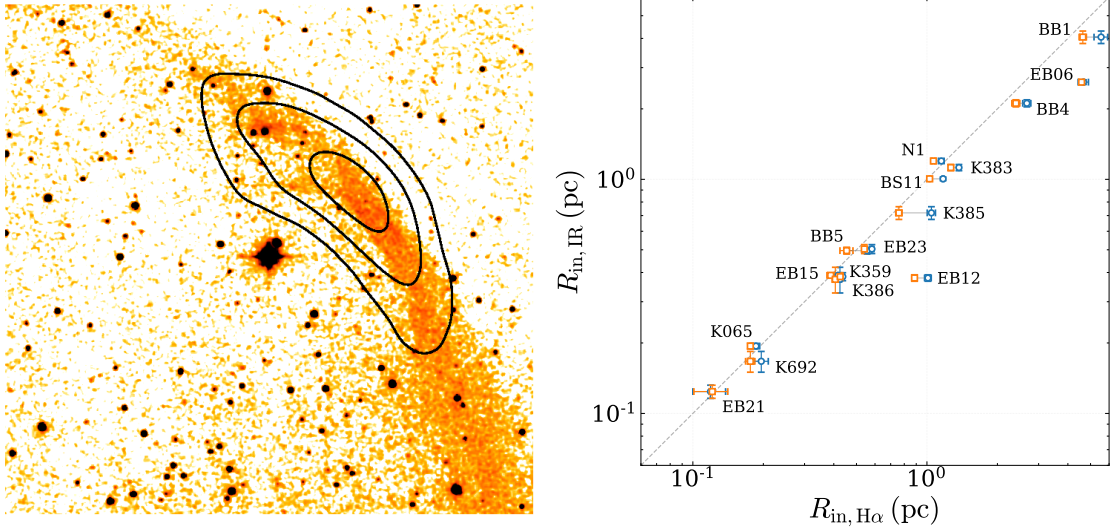


Fig. 3. *Left:* $H\alpha$ image of K383 with WISE W4 contours overlaid. The contours correspond to 30%, 50%, and 70% of the arc peak emission above the local background and illustrate that the IR arc lies slightly closer to the central star than the optical one. *Right:* comparison of the distances between the central star and the inner arc boundary measured along the symmetry axis in $H\alpha$ and IR emission. Blue circles denote measurements from the original $H\alpha$ images, and orange squares correspond to $H\alpha$ images convolved to the IR resolution. The dashed line indicates the one-to-one relation.

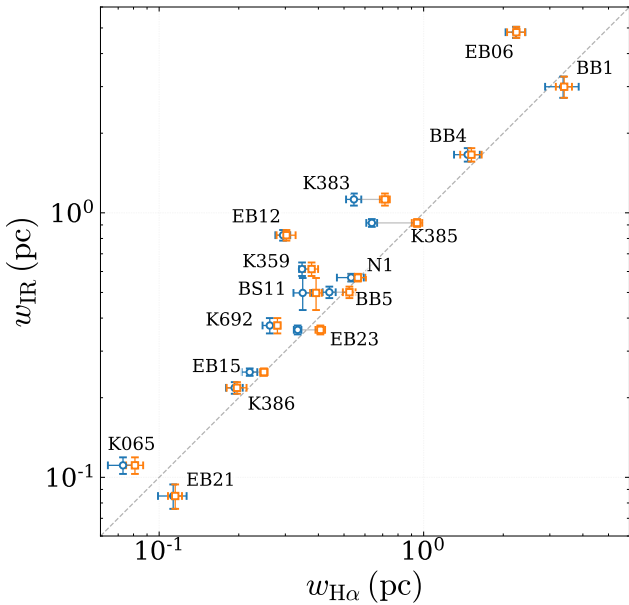


Fig. 4. Comparison of the bow-shock widths measured in $H\alpha$ and IR emission for the detected nebulae. Blue circles denote measurements from the original $H\alpha$ images, and orange squares show the corresponding point spread function-matched measurements. The dashed line indicates the one-to-one relation.

targets. Similarly, the measured distances from the central star to the inner boundary of the arc structures are smaller on the convolved $H\alpha$ images (right panel of Fig. 3). Nevertheless, a systematic difference in the measured offsets remains for a significant number of objects, suggesting that angular resolution alone cannot fully account for the observed trends.

4.2. $H\alpha$ surface brightness and emission measure

For the ten detections that lie within the SHASSA survey coverage, we estimated the $H\alpha$ surface brightness by flux-calibrating

the observed images against the corresponding SHASSA data. The calibration was obtained by matching the image resolution and spatial sampling to the SHASSA grid, comparing the fluxes measured over identical sky areas, and deriving a linear conversion factor between image counts (Analog-to-Digital Unit; ADU) and surface brightness (Rayleighs). A detailed description of the procedure is provided in Appendix E.

The surface brightness of each bow shock was measured in circular apertures placed along the nebular apex. Aperture radii ranging from $5''$ to $40''$ were adopted depending on the angular extent of the nebula and the resolution of the observations to ensure that each aperture fits entirely within the emission region while containing enough pixels for robust statistics. Within each aperture, the mean signal was computed after interquartile-range (IQR) clipping to suppress contamination from stars, cosmic rays, and other outlying pixels. The local background, including diffuse H II region emission where present, was estimated from nearby sky apertures and subtracted from the nebular measurement. For targets embedded in diffuse H II region emission (marked in Table 2), the reported values represent the excess $H\alpha$ surface brightness attributable to the bow shock alone.

The resulting background-subtracted $H\alpha$ surface brightness values are listed in Table 2. Assuming Case-B recombination and an electron temperature of $T_e = 10^4$ K, the corresponding emission measures were derived using $EM \approx 2.75 I_{H\alpha}$, where EM is in pc cm^{-6} and $I_{H\alpha}$ is the $H\alpha$ surface brightness in Rayleighs (e.g. Osterbrock & Ferland 2006; Haffner et al. 1999). The quoted uncertainties include contributions from the scatter among the nebular and background apertures and from the SHASSA-based flux calibration.

The emission measure can be used to make order-of-magnitude estimates of the density of the ambient ISM and the radio free-free emission, for example at 6 GHz. Assuming a strong shock, the post-shock electron density is $n_e \approx 4 n_{\text{ISM}}$, where n_{ISM} is the number density of the ambient ISM⁵. The

⁵ We caution the reader that the compression factor could be less than 4 for weak shocks, and significantly larger for radiative shocks close to the isothermal limit (see e.g. Draine & McKee 1993).

Table 2. H α surface brightness of our detections that are within the SHASSA survey coverage, and the corresponding emission measures, ambient densities, and lower limits of expected thermal free-free surface brightness at 6 GHz.

ID	$I_{\text{H}\alpha}$ (Rayleighs)	EM (pc cm $^{-6}$)	n_{ISM} (cm $^{-3}$)	$I_{6\text{GHz}}$ (kJy sr $^{-1}$)
EB12	142 $\pm$ 65	391 $\pm$ 179	$\sim$ 9	$\sim$ 33
EB15*	4975 $\pm$ 655	13 681 $\pm$ 1801	$\sim$ 62	$\sim$ 1152
EB21	44 $\pm$ 9	121 $\pm$ 25	$\sim$ 8	$\sim$ 10
EB23	171 $\pm$ 6	470 $\pm$ 17	$\sim$ 9	$\sim$ 39
BB4	12 $\pm$ 6	33 $\pm$ 17	$\sim$ 1	$\sim$ 3
BB5*	2775 $\pm$ 404	7631 $\pm$ 1111	$\sim$ 33	$\sim$ 643
K065	425 $\pm$ 113	1167 $\pm$ 311	$\sim$ 32	$\sim$ 98
K383	49 $\pm$ 9	135 $\pm$ 25	$\sim$ 4	$\sim$ 31
K385	95 $\pm$ 14	261 $\pm$ 39	$\sim$ 5	$\sim$ 22
K692*	230 $\pm$ 46	632 $\pm$ 127	$\sim$ 12	$\sim$ 53

Notes. *Excess emission above the local H II region background.

emission measure is $EM = n_e^2 l_{\text{eff}}$, where l_{eff} is the line-of-sight path length through the emitting shell. Near the apex, l_{eff} is assumed to be of the same order as the projected H α width w (Table 1). Taking $l_{\text{eff}} \sim w$ yields the simple relation

$$n_{\text{ISM}} = \frac{1}{4} \sqrt{\frac{EM}{w}}. \quad (1)$$

These values are listed in the fourth column of Table 2.

From the same emission measure, the free-free optical depth follows as (Mezger & Henderson 1967; Draine 2011)

$$\tau_\nu = 3.28 \times 10^{-7} \left(\frac{T_e}{10^4} \right)^{-1.35} \left(\frac{\nu}{\text{GHz}} \right)^{-2.1} EM. \quad (2)$$

For the optically thin case ($\tau_\nu \ll 1$), the Rayleigh–Jeans approximation,

$$I_\nu = \frac{2k\nu^2 T_e \tau_\nu}{c^2}, \quad (3)$$

yields the combined expression (Dickinson et al. 2003)

$$I_\nu [\text{Jy sr}^{-1}] \approx 11.1 \left(\frac{T_e}{10^4} \right)^{0.52} \nu_{\text{GHz}}^{-0.1} I_{\text{H}\alpha} [\text{Rayleigh}], \quad (4)$$

which evaluates to $I_\nu \approx 9.3 I_{\text{H}\alpha}$ at $\nu = 6$ GHz for $T_e = 10^4$ K. The resulting radio free-free intensity is given in the last column of Table 2. These values should be considered as lower limits, because the surface brightness values are not extinction corrected.

4.3. Morphological classification

Following the theoretical framework of Henney & Arthur (2019a), the interaction of a luminous star with the surrounding medium gives rise to distinct physical scenarios. These scenarios are governed by the stellar luminosity, the wind momentum, and the optical depth of the shocked shell (see their Fig. 1). When stellar radiation effects are negligible ($\tau \ll \eta_w$, where τ is the optical depth of the shocked shell in the ultraviolet and η_w is the wind-momentum efficiency), the stellar wind momentum dominates and a classical WBS is formed that is controlled

by pure (magneto)hydrodynamic interactions. With increasing optical depth of the bow shock, the stellar radiation pressure progressively contributes to the total internal pressure because the radiation is being trapped. As soon as the shocked layer becomes opaque to the stellar radiation field, the stellar radiation pressure dominates the internal pressure and balances the ISM ram pressure. This optically thick limit ($\tau > 1$) defines the RBS regime. For intermediate optical depths, two possibilities exist depending on the strength of the grain-gas coupling. If the coupling is strong, the ISM plasma is decelerated as a whole in response to the radiative force, producing a RBW. If the coupling is sufficiently weak, the radiative force acts primarily on the dust, allowing the grains to decouple from the gas and producing a DW scenario. In ionised gas, this coupling is maintained mainly by Coulomb drag, and the decoupling occurs at the rip point, where the radiation force exceeds the maximum drag force that the gas can exert. This condition is expressed by the local radiation parameter $\Xi = P_{\text{rad}}/P_{\text{gas}}$, with decoupling occurring when Ξ exceeds the critical value of $\sim 10^3$ (Henney & Arthur 2019b). For an outer DW to form, the rip-point radius must lie outside the wind bow-shock radius; otherwise the dust and gas enter the shocked shell still coupled, where the higher gas pressure further inhibits decoupling.

To estimate the stand-off distance (R_0) in the different interaction regimes, Henney & Arthur (2019a, see their Sect. 2) introduced the fiducial stand-off distance (R_1) in the optically thick, radiation-only limit, together with the corresponding fiducial optical depth τ_1 of the shocked shell as

$$R_1 = \left(\frac{L}{4\pi c \rho v^2} \right)^{1/2} \quad \text{and} \quad \tau_1 = \rho \kappa R_1, \quad (5)$$

where L is the bolometric luminosity of the star, ρ and v are the ambient ISM mass density and the relative stream velocity, c is the speed of light, and κ is the total opacity (gas plus dust) per unit mass. The ambient interstellar mass density (ρ) can be written as $\rho = n_{\text{ISM}} \bar{m}$, where $\bar{m}$ is the mean particle mass. Assuming solar abundances, we adopt $\bar{m} \approx 1.3 m_p \approx 2.17 \times 10^{-24}$ g. The combined dust–gas opacity is taken to be $\kappa = 600 \text{ cm}^2 \text{ g}^{-1}$, corresponding to an effective cross-section of $\sim 10^{-21} \text{ cm}^2$ per hydrogen nucleon, in line with typical interstellar dust properties (Bertoldi & Draine 1996). The contribution of stellar wind momentum to the support of the bow shock is quantified by the wind-momentum efficiency, defined as

$$\eta_w = \frac{\dot{M} v_\infty}{L/c}, \quad (6)$$

where $\dot{M}$ is the stellar mass-loss rate and v_∞ is the terminal velocity of the stellar wind. The stand-off distance is then written as

$$R_0 = x R_1, \quad (7)$$

where x satisfies

$$x^2 - (1 - e^{-2\tau_1 x}) - \eta_w = 0, \quad (8)$$

which applies across the full range from optically thin to optically thick shells. Equation (8) can be solved numerically, and x can be approximated by $x \approx (1 + \eta_w)^{1/2}$ corresponding to the RBS regime, $x \approx 2\tau_1$ for the RBW and DW regimes, and $x \approx \eta_w^{1/2}$ for the WBS regime.

We aim to classify our sample according to this theoretical framework for all objects with stellar and wind parameters available in the literature⁶. However, these calculations require estimates of the ambient ISM density for each target.

The ISM is not homogeneous, and measured values for local densities are rare. Therefore, we adopt plausible ranges for the ambient ISM density based on the local H α emission characteristics. When no discernible H α background is present, we assume $n_{\text{ISM}} \sim 0.1\text{--}5\text{ cm}^{-3}$, characteristic of diffuse phases such as the warm neutral medium and warm ionised medium (Draine 2011, Table 1.3). Such densities are also compatible with values inferred from H α observations of runaway-star bow shocks (Brown & Bomans 2005) and with median ambient densities of a few cm^{-3} derived in IR surveys (Peri et al. 2012; Kobulnicky et al. 2018; Carretero-Castrillo et al. 2025). Conversely, in regions with structured H α emission we adopt $n_{\text{ISM}} \sim 1\text{--}100\text{ cm}^{-3}$, corresponding to diffuse H II gas and the cold neutral medium (Draine 2011, Table 1.3), consistent with densities inferred for prominent IR bow shocks and shock-compressed gas layers (Kobulnicky et al. 2018; Moutzouri et al. 2025). These adopted ranges are supported by order-of-magnitude density estimates derived from the emission measure and projected H α width (Table 2). The derived n_{ISM} values separate into two distinct groups. Isolated objects (e.g. K383, K385, and EB21) yield $4\text{--}8\text{ cm}^{-3}$, consistent, within the geometric uncertainties, with the warm ionised medium, whereas targets embedded in bright H II regions (EB15, K065, EB12, EB23, and K692) give $9\text{--}62\text{ cm}^{-3}$, consistent with the typical H II-region range of $1\text{--}100\text{ cm}^{-3}$. With these ranges for the ISM densities, we compute the expected stand-off distances for the different interaction regimes and compare them to stand-off distances measured from the mid-IR images. Since the inclination of the bow-shock axis is generally unknown, the observed stand-off distance represents a lower limit to the true value, as projection effects reduce the apparent separation except in the edge-on configuration (Tarango-Yong & Henney 2018). In cases where the measured stand-off distance does not fall within any of the predicted ranges, we adopt the nearest higher theoretical value (i.e. the smallest value exceeding the observed R_0) to assign the corresponding regime. The results are presented in Table F.1.

5. Discussion

This work constitutes the first targeted H α survey of IR bow-shock nebulae, motivated by the detections reported by Brown & Bomans (2005). Previous searches have relied primarily on all-sky or wide-field surveys such as SHASSA and VTSS, which are constrained by low spatial resolution and short exposure times. The present survey was designed to overcome these limitations. Within the sample of 78 targets, we obtain clear detections of bow shocks in H α for approximately 19% of the objects. A further 45% of the targets are located within regions of complex or diffuse H α emission, where the presence of structures related to bow shocks cannot be unambiguously assessed. The remaining 36% show no detectable emission associated with the IR bow-shock candidates. For these non-detections, we note that deeper observations may still reveal faint or extended structures.

In the following, we compare our results with those of previous studies conducted in H α and at other wavelengths, and

we start with the eight objects, for which Brown & Bomans (2005) reported H α detections. We identify clear bow-shock structures in H α associated with four of their objects (see Fig. 1), namely BB1: HD 17505, BB4: HD 57061, BB5: HD 92206, and EB21: HD 149757 ($=\zeta$ Oph). In particular, Brown & Bomans (2005) previously classified the nebula around BB5 as small, noting the presence of a bright surrounding H II region. Our higher-resolution H α image resolves an arc-like emission structure embedded within this bright H II region, whose morphology closely matches the emission observed in the MIPS 24 μm band, supporting its interpretation as a bow-shock feature. Two additional targets, EB13: HD 48099 and BB8: HD 158186, are located within regions of complex background emission, which hampers the unambiguous identification of bow-shock-related H α emission. Finally, in two cases, BB2: HD 24431 and BB6: HD 135240, arc-like structures are visible in H α images, but the objects lack a corresponding mid-IR counterpart. Instead, they were detected on 60 μm images from the IRAS mission, indicating that these objects are associated with cooler ambient dust. It is also worth mentioning that Peri et al. (2012) searched for bow-shock emission in H α using data from the same surveys (SHASSA and VTSS) as Brown & Bomans (2005). For the 28 targets with mid-IR bow-shock detections reported in their first E-BOSS release, they did not identify any convincing bow-shock candidates. In contrast, our H α survey reveals four clear detections associated with EB06: HD 30614, EB15: HD 64315, EB23: HD 165319, and the already mentioned object EB21. The bow shock in H α connected to the object EB23 was also found by Gvaramadze & Bomans (2008) based on images from the SuperCOSMOS H-alpha Survey (Parker et al. 2005). The morphology shown in their Fig. 4 is in good agreement with our observations.

Although the H α and mid-IR morphologies generally trace the same overall structure, we observe the IR arcs to be located in many cases closer to the central star as mentioned in Sect. 4.1 (Fig. 3). This offset likely reflects differences in dust–gas coupling, with small grains tightly coupled to the gas and therefore closely following the ionised material traced by H α . Larger grains, by contrast, possess greater momentum and are more resistant to drag forces, resulting in longer deceleration timescales and dust distributions that progressively deviate from the gas morphology, producing spatial offsets between IR and H α emission (van Marle et al. 2011). We also observe that the widths of the IR structures are generally broader than their H α counterparts (see Fig. 4). Although the lower spatial resolution and coarser point spread functions of the mid-IR images lead to an apparent broader width of the nebulae compared to our higher resolution H α images, this effect can only partially account for the diverging widths of the structures. Therefore, we explore the emission mechanisms of both ionised gas and dust. The surface brightness of recombination lines such as H α scales with the emission measure, $\text{EM} \propto n_e^2$, and is therefore highly sensitive to gas compression in shocked regions (Osterbrock & Ferland 2006). In contrast, mid-IR dust emission depends primarily on the dust column density and grain temperature, with the latter determined from the balance between heating of the dust particles by the stellar radiation and cooling by their thermal emission (Draine 2011; Katushkina et al. 2018). Consequently, dust emission traces a broader region around the bow shock, producing wider and more diffuse IR arcs, while the H α emission peaks at the densest post-shock regions and appears correspondingly thinner, as seen in our survey.

Bow-shock nebulae have also been investigated at radio wavelengths, providing a complementary diagnostic of particle acceleration and non-thermal emission. The first detection of

⁶ We caution that this approach considers a homogeneous distribution of the ambient dust with a fixed dust-to-gas ratio. A different mixing value or fragmented dusty bow-shock structures may alter the optical depth in the ultraviolet and hence the theoretical predictions.

synchrotron radiation from a stellar bow shock was reported for EB27: BD +43 3654 by Benaglia et al. (2010, 2021). In our H α survey, this source is embedded within bright emission from an H II region, which hampers a clear optical identification of the bow shock. In the second E-BOSS release, Peri et al. (2015) reported radio features spatially coincident with IR arcs for EB03: HD 15629, EB15: HD 64315, and EB23: HD 165319. Of these, EB03 is affected by strong background H α emission, whereas EB15 and EB23 are clearly detected in H α , reinforcing their interpretation as bow-shock nebulae. The study by Van den Eijnden et al. (2022) included 19 of our targets selected from the E-BOSS catalogue. Of these, two were the sources with previously detected radio emission (EB15 and EB23) for which the authors confirmed the emission related to the IR bow shocks. They also found radio emission towards EB07: HD 34078; they concluded that it originates from an unrelated background source, and our H α images show that the target is embedded in bright background emission. The remaining 16 objects were not detected in the radio images used by Van den Eijnden et al. (2022). These are the objects EB21 (for which we clearly detect an H α bow), EB12: HD 47432 (which displays a faint H α arc; see Fig. 1), EB09 and EB11 (which both display diffuse H α emission; see Figs. D.2–D.4), and EB04, EB08, EB13, EB14, EB16, EB17, EB18, EB19, EB20, EB22, EB24, and EB25 (which also have no H α emission). Moutzouri et al. (2025) conducted a deeper follow-up radio survey. Their survey covered 24 northern bow-shock nebulae, of which we have nine objects in common. Of these, K072 and EB27 (detected in earlier surveys) were reported to be radio bow-shock detections, EB23, K159, K359 were marginal detections, and EB01, EB09, EB12, and EB21 were not detected. For K072: G 018.2660–00.2988, our H α images (Fig. D.1) show that the brightest emission is spatially offset from the IR bow shock and is instead associated with a larger nebular structure, also known as the IR dust bubble N22 (Ji et al. 2012). Closer inspection of the multi-wavelength images suggests that the radio emission better aligns with our H α emission rather than with the dust bow. This calls the radio bow-shock interpretation into question as was also noted by Moutzouri et al. (2025). Of the marginal radio detections, EB23 (as mentioned above) and K359: HD 215806 are clearly detected in H α , whereas K159: G 031.6770+00.1775 remains undetected and likely requires deeper observations, although Moutzouri et al. (2025) interpret their radio signal as just diffuse free-free emission from the H II region. Among the radio non-detections, EB01: HD 2083 is also undetected in H α and is likely a DW candidate whereas EB09: HD 37032 is dominated by strong background emission. As mentioned above, the arc seen in H α around EB12 is rather faint and longer radio exposures might be needed to detect the structure. The last object from this survey with no radio detection is EB21 (= ζ Oph), which has already been investigated by Van den Eijnden et al. (2022). The non-detection is surprising given that we see a clear bow structure in H α (Fig. 1) and simulations predict significant thermal radio emission at 6 GHz (Green et al. 2022). However, as mentioned by Moutzouri et al. (2025), the predictions of a radio flux of 35 kJy sr $^{-1}$ by Green et al. (2022) were about twice as high as their 3 σ upper limit measurement. Our estimate is with ~ 10 kJy sr $^{-1}$ (Table 2) even lower and in agreement with the non-detection. Information about all radio (non-) detections is included in Table F.1.

Detailed investigations of possible physical parameters of the bow shocks in H α are so far rare. In this respect, it is worth mentioning that the environment of EB21 was studied by Gvaramadze et al. (2012), who characterised the physical

conditions of the H II region surrounding the object as an almost circular photoionised bubble with a diameter of approximately 10 $^\circ$, corresponding to ~ 9.6 pc at a distance of 112 pc and derived the gas density to be ~ 3 cm $^{-3}$ and an emission measure of 90 cm $^{-6}$ pc. Green et al. (2022), based on their MHD simulations, predicted that the bow shock must have a sufficiently high emission measure to be detectable above the background, and explicitly called for new narrow-band H α observations. In their models, the contact discontinuity was found to be located at 0.11–0.13 pc and the forward shock at 0.22–0.26 pc, with the peak H α emission expected at the contact discontinuity. Our H α images resolve a bow shock around ζ Oph (Fig. 1) at a stand-off distance of 0.17 pc and a width of ~ 0.1 pc, in close agreement with their models.

The mass-loss rates adopted in Table F.1 use the Vink et al. (2001) prescription, which overpredicts $\dot{M}$ for late O- and B-type dwarfs by up to two orders of magnitude (e.g. Puls et al. 2008). For ζ Oph (EB21), the UV-derived rate is $\dot{M} \approx 1.6 \times 10^{-9} M_\odot \text{ yr}^{-1}$ (Marcolino et al. 2009), roughly 100 times lower than our adopted value, while the rate from its H II region and bow-shock radii is ~ 10 times lower (Gvaramadze et al. 2012). Using the Marcolino et al. (2009) mass-loss rate for EB21, the expected WBS stand-off distance drops from 4.10–0.48 pc to 0.33–0.05 pc, in much better agreement with the observed 0.19 pc, though the classification remains WBS. More generally, lowering $\dot{M}$ reduces η_w (Eq. (6)) and the WBS stand-off distance ($R_0 \propto \eta_w^{1/2}$), while the RBS and DW stand-off distances are not affected significantly. The values of predicted WBS stand-off distances in Table F.1 should then be considered only as upper limits. Hence, a lower mass-loss rate increases the role of radiation pressure in supporting the shell, which can shift borderline objects into the radiation-supported regime.

Another bow-shock object that was studied numerically is λ Cep = HD 210839 (BS07). The object has been observed in H α as part of the IPHAS survey (Drew et al. 2005) and a faint arc was detected and interpreted by Scherer et al. (2015) as a bow shock. Using 3D MHD simulations and the parameters of the H α arc, Scherer et al. (2020) modelled the astrosphere of λ Cephei and found the resulting structure to be approximately axially symmetric and with a distance of the bow shock of 1.1 pc. They also interpret the H α emission to be related to regions where the shocked ISM density is highest. Despite multiple extensive exposures of the structure, we did not detect any significant H α signal aligned with the IR bow structure (Fig. D.3) but mainly diffuse background emission⁷.

Three bow-shock candidates were reported in the study of runaway stars from the young star cluster NGC 6611 (Gvaramadze & Bomans 2008). One of them was associated with the object EB23. These authors proposed that the objects might have been ejected from the cluster based on the morphology of the detected structures and proper motion arguments.

From a sample of 23 targets comprising 20 objects from Kobulnicky et al. (2018) and three additional sources θ^1 Ori D, LP Ori, and σ Ori, Henney & Arthur (2019c) identified four strong and three marginal candidates for RBWs. While our survey does not include any of the objects classified as DWs or bow waves in their study, our H α analysis identifies three candidates:

⁷ A faint arc structure is visible in H α and on the WISE image to the south-east of the object, in agreement with what was reported by Scherer et al. (2015), but based on the full IR structure, we think its interpretation as bow shock is questionable.

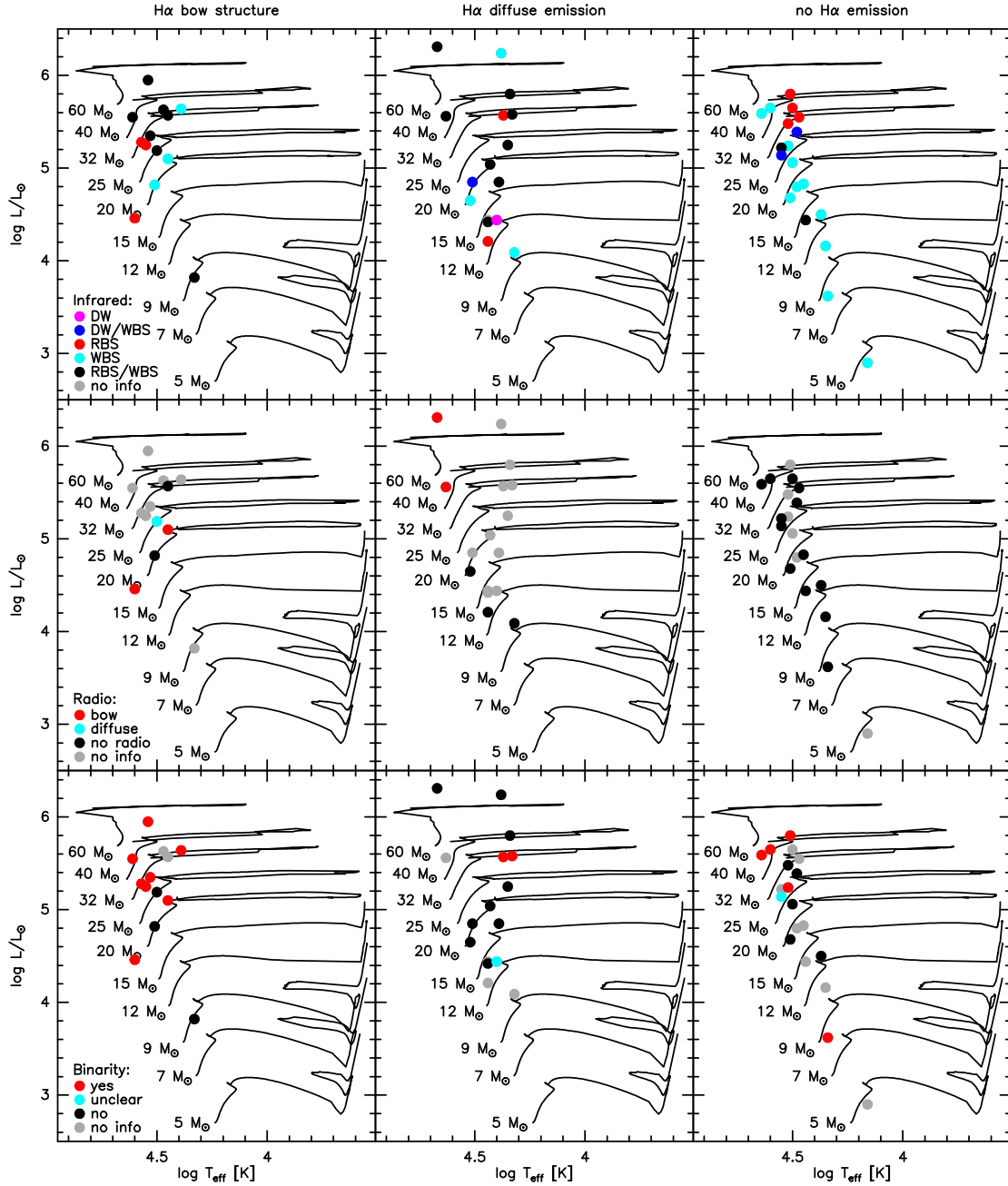


Fig. 5. Comparison of the H α detections – bows (*left column*), diffuse emission (*middle column*), and no emission (*right column*) – with the IR classification (*top row*), the presence of radio emission (*middle row*), and the information on companions (*bottom row*). The shown evolutionary tracks are for rotating stars with solar metallicity taken from [Ekström et al. \(2012\)](#).

EB01, EB24, and K150. EB01 and EB24 are strong DW candidates, as no H α emission associated with the IR arcs is detected, although deeper H α observations may still reveal faint structures. The classification of K150 remains uncertain due to its location within bright background H α emission. While we classify it as a DW, an RBW classification is also possible. The targets common to both studies, EB21, K067, and EB27, are classified as WBSs by [Henney & Arthur \(2019c\)](#), a conclusion that is also supported by our calculations. Of these, EB21 shows an associated arc like structure in H α , whereas K067 and EB27 are dominated by background emission. Notably, the DW candidates identified in our work span a wide range of stand off distances from 0.04 to 1.35 pc, in contrast to the small stand off distances

below 0.1 pc reported by [Henney & Arthur \(2019c\)](#). These candidates are further characterised by low stellar velocities relative to the ISM below 30 km s⁻¹ and weak mass loss rates of 4 to $8.7 \times 10^{-8} M_{\odot} \text{yr}^{-1}$.

In Fig. 5, we plot the sample stars with information on both effective temperature and luminosity (Table F.1) along with stellar evolutionary tracks of rotating stars with solar metallicity from [Ekström et al. \(2012\)](#). To search for possible correlations with other properties of the objects, we coloured them according to the assigned IR class of bow shocks, the information on radio emission, and binarity. The information on the radio (non-) detections as described above and on binarity (from [Patten et al. 2025](#) and from SIMBAD) is included in Table F.1.

Only 13 of our objects with H α bow structures have reported stellar parameters. With the exception of K065 and the binary star EB15, H α bow structures are seen around stars more massive than 20 M $_{\odot}$. The two exceptions are both embedded in dense H II regions. K065 lies in the Eagle Nebula (M16) associated with the young cluster NGC 6611 (Hillenbrand et al. 1993; Guarcello et al. 2007), whereas EB15 resides in the H II region S311 within the NGC 2467 complex and acts as one of its dominant ionising sources (Yadav et al. 2016; Lorenzo et al. 2017). For both targets, the proper-motion vectors deviate significantly from the symmetry axis of the bow-shock nebulae, suggesting a weather-vane scenario. Four objects appear to be evolved, of which two are binaries. The binary fraction in this sample is generally high (~58%). So far, only five objects have been observed at radio wavelengths, with two clear detections of bow structures.

From the objects with diffuse H α emission, 16 were found to have stellar parameters. Half of this sample are evolved stars, of which two are in binaries and only one of them was observed in the radio regime with a clear bow structure detected. A second target with a radio bow structure seems to be on the main sequence. The majority of objects in this sample are presumably single stars.

A large portion (19) of objects with known stellar parameters was not detected in our H α survey. While 13 objects of this sample have been observed at radio wavelengths, none was detected. This is the most clear correlation that we observe. The sample is composed mostly of main-sequence stars spreading in mass from 5–40 M $_{\odot}$, and the majority of them has a classical WBS detected in the IR. Three of the four evolved objects have RBSs, and with initial masses in the range 30 to 40 M $_{\odot}$, it is surprising that these objects have no detectable H α counterparts. The binary fraction in this H α featureless sample is about 26% in total, but increases to 45% when excluding objects with unknown status.

Finally, we would like to briefly address the question of whether the arc-like structures detected by the narrow-band H α filter might have been mistakenly interpreted as bow shocks, even though they could also be reflection nebulae. From our comparison of all bow-structure objects with the DSS2 blue images, no arc-like counterpart is visible for EB06, EB12, BB4, BS11, K359, K383, K385, and K386. In addition, we found that two objects, EB15 and BB5 are embedded within extended H II regions and show widespread blue emission, but no distinct arc-shaped feature corresponding to the H α morphology. Therefore, we consider these as real detections of bow-shock nebulae with H α emission. For the remaining objects, the situation is less clear. For EB21, the nebular region is saturated by stellar emission in the DSS2 image, preventing a meaningful assessment, whereas arc-like structures are visible for K065, K692, BB1, N1, and EB23. Whether these are due to reflection nebulae or maybe contribution from intense [O III] emission from the nebula as in the case of ζ Oph (Gull & Sofia 1979) cannot be finally distinguished. These objects clearly require follow-up observations to either confirm or discard their classification as H α -emitting bow shocks.

6. Conclusions

We have presented the first targeted H α imaging survey of IR-selected bow shocks around massive OB-type stars. Our sample comprises 78 objects selected from several extensive IR bow-shock catalogues. We identify clear arc-shaped nebulae in H α for 15 of these objects, and we additionally report one previously unrecognised bow-shock detection found serendipitously

in a wide-field frame. A further 35 objects show diffuse H α emission associated with complex background structures, while 28 objects remain undetected in H α . Most of the systems in our sample are associated with runaway stars, although a few objects may instead reflect environmental shaping consistent with the weather-vane scenario, in which large-scale flows in the surrounding ISM determine the orientation of the bow structure.

For the detected systems, we derived geometrical parameters of the bow-shock nebulae from both H α and mid-IR images. The large-scale morphologies traced by the ionised gas and dust are generally consistent, although some systematic differences are observed. In particular, the IR arcs tend to lie slightly closer to the central star and appear broader than the corresponding H α structures. These differences likely reflect the distinct physical processes governing dust and ionised gas emission in the shocked region.

Using available stellar and wind parameters from the literature, we explored the relative roles of stellar wind momentum and radiation pressure in supporting the bow-shock structures. By comparing the observed stand-off distances with theoretical predictions for plausible ranges of ambient ISM density, several objects appear consistent with RBWs or DW scenarios, while others remain compatible with classical WBSs.

No clear correlation is found between H α detections and the stellar physical parameters or binarity, although the binary fraction is relatively high. Objects undetected in H α are also generally undetected at radio wavelengths.

The primary aim of this survey was to establish the presence of ionised bow structures associated with IR bow-shock candidates. Future follow-up optical spectroscopy will be required to determine the physical conditions of the ionised gas, including density, temperature, and kinematics, and to compare these properties with theoretical models and numerical simulations. It would also be instructive to collect information about possible radio counterparts of the objects for which our survey detected H α bow structures. To facilitate radio observations, we have provided (where possible) measurements of surface brightness values in H α , emission measures, and estimates for expected thermal radio emission at 6 GHz.

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Appendix A: Target selection

Table A.1 presents the objects studied in our survey, as described in Sect. 2. The columns list the target identifiers, spectral type, proper motions, and distances to the central star.

Table A.1: Target selection.

ID	Alt. ID	Star	Sp. T.	μ_{RA} (mas yr ⁻¹)	μ_{Dec} (mas yr ⁻¹)	d (kpc)	ID	Star	Sp. T.	μ_{RA} (mas yr ⁻¹)	μ_{Dec} (mas yr ⁻¹)	d (kpc)
EB01	K366	HD 2083	B0.2V	7.90	0.17	0.40 ± 0.01	K007	G 003.8417 -01.0440	B2-3V ¹	1.93	-1.87	1.22 ± 0.02
EB02	BS08	HD 2905	BC0.7I	3.13	-1.83	0.94 ± 0.14	K014	G 006.2977 -00.2012	-	-0.68	-1.94	3.03 ± 0.73
EB03	HD 15629	O4.5V	B0.4V	-0.67	-0.66	2.06 ± 0.08	K048	HD 166996	B2I	0.11	-1.76	1.83 ± 0.14
EB04	K373	HD 21856	B1V	-8.89	1.67	0.42 ± 0.01	K051	NGC 6618 258	O9.5V	0.34	-1.60	1.42 ± 0.04
EB05	BS10	HD 22928	B5III	29.04	-23.36	0.16 ± 0.01	K052	NGC 6618 326	O7:V	0.96	0.34	2.28 ± 1.30
EB06	BS09; K370	HD 30614	O9I	0.22	7.19	1.69 ± 0.38	K053	G 015.1032 -00.6489	B2V	0.12	-1.97	1.87 ± 0.24
EB07	K375	HD 34078	O9.5V	-4.75	43.54	0.39 ± 0.01	K063	BD -13 4934	B1V	0.37	-1.72	1.76 ± 0.06
EB08	K378	HD 36512	O9.7V	-0.70	-4.88	0.41 ± 0.02	K065	BD -13 4937	B1.5V	0.15	-1.55	1.81 ± 0.06
EB09	HD 37032	HD 37032	B0.5V	0.25	-2.46	2.35 ± 0.07	K067	NGC 6611 584	O9V	0.19	-1.48	1.86 ± 0.06
EB10	K374	HD 41161	O8V	-2.51	-1.28	1.49 ± 0.01	K072	G 018.2660 -00.2988	O6V-O5V	0.07	-1.47	4.14 ± 0.30
EB11	BS14	HD 42933	B1/2III	-3.75	8.09	0.46 ± 0.03	K101	G 023.1100 +00.5458	-	0.24	-2.29	2.27 ± 0.12
EB12	HD 47432	HD 47432	O9.7I	-0.06	-1.43	1.69 ± 0.01	K148	G 030.3745 +00.0252	-	-	-	-
EB13	BB3; K376	HD 48099	O5V + O9V	1.04	2.75	2.75 ± 0.04	K150	TYC 5118-279-1	B1V ¹	0.61	-5.80	0.61 ± 0.01
EB14	K381	HD 54662	O6.5V + O7.5V	-2.54	3.13	1.38 ± 0.01	K159	G 031.6770 +00.1775	-	-	-	-
EB15	HD 64315	HD 64315	O5.5V + O7V	-3.37	2.43	5.00 ± 0.80 ³	K262	G 049.4683 -00.2527	-	-	-	-
EB16	HD 110879	HD 110879	B2V + B3V	-37.43	-10.58	0.10 ± 0.01	K330	HD 229159	B1I ¹	-2.01	-5.80	1.71 ± 0.05
EB17	HD 130298	HD 130298	O6.5III	-6.49	-1.20	2.55 ± 0.10	K345	HD 199021	B0V	-1.06	-3.67	0.80 ± 0.01
EB18	K544	HD 136003	B1I	-7.73	-9.21	1.07 ± 0.03	K346	G 083.9246 -00.6778	B1III ¹	-2.74	-4.05	3.68 ± 0.20
EB19	HD 329905	HD 329905	O9I	-5.16	-2.97	4.66 ± 0.34	K347	BD +42 3914	Be	-1.38 ²	-3.86 ²	0.35 ± 0.12 ²
EB20	BS15; K679	HD 143275	B0.3IV	-10.21 ²	-35.41 ²	0.15 ± 0.02 ²	K351	LS III +55 26	B2I	-2.64	-2.17	9.33 ± 1.51
EB21	BB7; BS01	HD 149757	O9.2IV	10.46	24.74	0.13 ± 0.01	K359	HD 215806	B0V ¹	-2.49	-2.23	2.64 ± 0.09
EB22	K575	HD 150898	B0I	-5.58	-20.96	1.14 ± 0.01	K379	HD 51756	O9.7IV	-2.32 ²	2.11 ²	1.70 ± 1.00 ⁴
EB23	K054	HD 165319	O7V + ...	-2.41	-1.20	1.46 ± 0.01	K383	CD -26 5136	O6.5I	-3.69	4.52	6.27 ± 0.53
EB24	HD 175514	HD 175514	O7.5I	-0.69	0.50	1.46 ± 0.05	K385	CD -41 4637	O6I	-4.91	6.92	2.35 ± 0.07
EB25	HD 188001	HD 188001	O9.7I	-0.24	-10.12	1.93 ± 0.13	K386	HD 77581	B0.5I	-4.82	9.28	2.01 ± 0.06
EB26	K343	HD 195592	O9.7I	-2.50	1.06	1.78 ± 0.05	K388	HD 75860	B1.5I	-6.68	4.79	2.29 ± 0.22
EB27	K344	BD +43 3654	O4I	-2.59	0.73	1.72 ± 0.04	K389	HD 76031	B1I	-6.14	4.03	1.81 ± 0.08
EB28	HD 17505	BD+63 1964	B0I	-6.74	-0.72	2.51 ± 0.10	K391	HD 77207	B7I	-5.36	3.68	1.81 ± 0.05
BB1	HD 17505	HD 17505	O6.5III + O8V	-0.69	-0.81	2.41 ± 0.11	K399	G 284.0765 -00.4323	O6V	-5.41	3.06	8.03 ± 3.41
BB2	HD 24431	HD 24431	O9III + B1.5V	-1.77	-0.05	0.96 ± 0.05	K404	G 286.0498 -01.65836	-	-5.95	3.45	2.96 ± 0.10
BB4	BS13	HD 57061	O9II	-2.31 ²	5.02 ²	0.92 ± 0.47 ²	K489	G 311.1657 +00.0448	-	-3.47	-1.76	3.81 ± 0.37
BB5	HD 92206	HD 92206	O6.5V + O6.5V	-7.29	2.81	2.58 ± 0.14	K506	HD 126593	B1/2I	-5.26	-2.91	2.55 ± 0.15
BB6	HD 135240	HD 135240	O8V	-4.09	-3.76	0.68 ± 0.06	K509	G 315.3719 +00.6043	-	-4.99	-1.53	4.56 ± 0.70
BB8	HD 158186	HD 158186	O9.5V	1.76	-1.34	1.12 ± 0.07	K534	G 319.7182 -00.7290	-	-4.19	-2.73	2.68 ± 0.38
BS02	K154	HD 171491	B3IV	-2.69	-5.95	0.65 ± 0.02	K542	G 322.1986 +00.5183	-	-5.94	-4.66	2.93 ± 0.86
BS06	HD 203467	HD 203467	B3IV	5.47	5.92	0.40 ± 0.01	K634	HD 152756	B3/5I	-0.44	-2.88	1.60 ± 0.04
BS07	HD 210839	HD 210839	O6.5I	-7.02	-10.81	0.85 ± 0.06	K681	G 350.6032 +01.0332	B3I	-0.23	-2.12	1.88 ± 0.06
BS11	BD +09 879	BD +09 879	O8III + B0.5V	2.90	-3.18	0.39 ± 0.06	K692	G 353.4162 +00.4482	O7.5	1.49	-2.27	1.79 ± 0.06
BS12	HD 50896	HD 50896	WN4	-4.32	3.10	1.53 ± 0.09	K705	CD -29 13925	B0.5I	-1.12	-2.60	2.35 ± 0.10

Notes. Spectral types are adopted from the SIMBAD database unless otherwise indicated. Proper motions are taken from *Gaia* DR3, and distances are derived from *Gaia* DR3 parallaxes, except where alternative sources are specified.

References. (1) Patten et al. (2025) (2) van Leeuwen (2007) (3) Lorenzo et al. (2017) (4) Pápics et al. (2011).

Appendix B: Observation log

Table B.1 presents the complete observation log for all 78 targets in our survey. The columns list the target identifier, equatorial coordinates (J2000), observing date, telescope, total exposure time, number of individual frames, seeing, and V-band magnitude. Multiple entries for the same target correspond to observations obtained on different nights. For objects lacking a V-band magnitude in SIMBAD, the *Gaia* DR3 G-band magnitude is provided (where available) instead and marked with an asterisk.

Table B.1: Observation log.

Name	RA (J2000)	Dec (J2000)	Date	Telescope	Total T_{exp} (s)	No. of Frames	Seeing ('')	V (mag)
HD 2083	00:25:51.23	+71:48:25.65	2020-07-09	SBT	8460	47 × 180 s	6.97	6.91
HD 2905	00:32:59.99	+62:55:54.41	2020-02-08	SBT	5400	30 × 180 s	7.06	4.16
HD 17505	02:51:07.97	+60:25:03.87	2020-06-12	SBT	2340	13 × 180 s	7.54	7.07
HD 21856	03:32:40.01	+35:27:42.21	2020-07-12	SBT	3780	21 × 180 s	9.86	5.9
HD 22928	03:42:55.50	+47:47:15.17	2020-07-09	SBT	6120	34 × 180 s	7.63	3.01
HD 24431	03:55:38.42	+52:38:28.73	2020-03-16	SBT	4320	24 × 180 s	7.13	6.74
HD 30614	04:54:03.01	+66:20:33.63	2020-07-05	SBT	3240	18 × 180 s	6.88	4.29
			2020-07-06	SBT	3420	19 × 180 s	6.92	4.29
HD 36512	05:31:55.86	−07:18:05.53	2026-02-20/03-03	SBT	35460	197 × 180 s	8.20	4.63
BD+09 879	05:35:08.27	+09:56:02.96	2026-02-20/03-03	SBT	41400	230 × 180 s	8.18	3.66
HD 41161	06:05:52.45	+48:14:57.42	2020-11-30	SBT	7020	39 × 180 s	7.54	6.76
HD 42933	06:10:17.91	−54:58:07.11	2021-03-09	T31	3600	12 × 300 s	4.23	4.72
HD 47432	06:38:38.18	+01:36:48.67	2026-02-20/03-02	SBT	28080	156 × 180 s	8.91	6.31
HD 48099	06:41:59.23	+06:20:43.53	2026-01-20	SBT	9540	53 × 180 s	8.94	6.37
HD 50896	06:54:13.04	−23:55:42.02	2021-03-05	T31	3600	12 × 300 s	3.42	6.91
HD 51756	06:58:28.16	−03:01:25.40	2022-04-03	DK154	900	5 × 180 s	1.48	7.83*
HD 54662	07:09:20.24	−10:20:47.62	2021-03-09	T17	3600	12 × 300 s	1.91	6.21
HD 57061	07:18:42.48	−24:57:15.70	2021-04-06	T31	3600	12 × 300 s	3.81	4.4
HD 64315	07:52:20.28	−26:25:46.68	2020-12-12	DK154	3600	20 × 180 s	1.01	9.24
CD-26 5136	07:53:01.01	−27:06:57.70	2020-12-13	DK154	4500	25 × 180 s	0.95	9.67
HD 75860	08:50:53.24	−43:45:05.40	2022-04-02	DK154	3600	20 × 180 s	1.38	7.58
HD 76031	08:52:04.13	−44:00:35.00	2020-12-13	DK154	3600	20 × 180 s	0.85	9.5
CD-41 4637	08:55:27.66	−41:35:22.20	2020-03-22	DK154	2700	3 × 900 s	2.00	9.87
HD 77207	08:59:14.91	−48:49:49.20	2020-12-13	DK154	1260	7 × 180 s	0.73	9.91
HD 77581	09:02:06.86	−40:33:16.90	2021-03-14	DK154	3600	30 × 120 s	1.09	6.87
G 284.0765 −00.4323 ^a	10:22:23.08	−57:44:28.00	2020-02-23	DK154	900	1 × 900 s	0.81	16.54*
G 286.0498 −01.6583 ^b	10:30:23.28	−59:49:53.20	2020-03-22	DK154	900	1 × 900 s	2.49	12.44
HD 92206	10:37:22.24	−58:37:22.86	2020-12-12	DK154	3960	22 × 180 s	1.07	8.11*
HD 110879	12:46:16.80	−68:06:29.21	2021-03-14	DK154	915	61 × 15 s	0.97	3.98*
G 311.1657 +00.0448 ^c	14:01:45.74	−61:41:51.50	2020-03-22	DK154	900	1 × 900 s	2.79	13.44*
HD 126593	14:28:50.87	−60:32:25.10	2022-04-02	DK154	1800	5 × 180 s	1.33	8.65
			2022-04-03	DK154	1800	10 × 180 s	1.44	8.65
G 315.3719 +00.6043 ^d	14:32:50.57	−59:47:44.10	2020-03-22	DK154	900	1 × 900 s	2.01	12.73*
HD 130298	14:49:33.76	−56:25:38.47	2022-04-02	DK154	1800	10 × 180 s	1.26	9.83
G 319.7182 −00.7290 ^e	15:08:10.24	−59:04:12.60	2020-03-22	DK154	2700	3 × 900 s	1.80	13.43*
HD 135240	15:16:56.89	−60:32:25.10	2020-07-24	T31	3300	11 × 300 s	3.79	5.09
G 322.1986 +00.5183 ^f	15:19:16.98	−56:43:06.30	2020-03-22	DK154	900	1 × 900 s	1.85	13.31*
HD 136003	15:20:42.81	−56:07:57.44	2022-04-02	DK154	2760	23 × 120 s	1.23	6.79
HD 329905	15:47:54.90	−48:37:48.48	2022-04-03	DK154	2100	7 × 300 s	1.25	10.43
HD 143275	16:00:20.01	−22:37:18.14	2021-07-06	T31	1200	10 × 120 s	3.52	2.32
HD 149757	16:37:09.53	−10:34:01.52	2020-06-12	SBT	5580	31 × 180 s	9.12	2.56
HD 150898	16:47:19.65	−58:20:29.19	2022-04-02	DK154	2580	43 × 60 s	1.63	5.61
HD 152756	16:57:15.03	−43:43:15.80	2022-04-02	DK154	2640	44 × 60 s	1.48	9.41
G 350.6032 +01.0332 ^g	17:17:00.53	−36:13:36.15	2022-04-02	DK154	1800	6 × 300 s	1.58	14.89
G 353.4162 −00.4482 ^h	17:27:11.24	−34:14:35.09	2021-03-13	DK154	3300	11 × 300 s	1.24	10.79*
HD 158186	17:29:12.93	−31:32:03.42	2020-07-24	T31	2700	9 × 300 s	3.78	7.04
CD-29 13925	17:45:08.21	−29:56:45.30	2022-04-02	DK154	3600	12 × 300 s	1.54	10.69
G 003.8417 −01.0440 ⁱ	17:58:30.65	−26:09:49.12	2021-08-31	T31	3600	12 × 300 s	3.41	12.74*
G 006.2977 −00.2012 ^j	18:00:40.59	−23:36:50.70	2022-04-03	DK154	1800	6 × 300 s	1.45	16.75*
HD 165319	18:05:58.83	−14:11:52.99	2021-03-13	DK154	3600	12 × 300 s	1.25	8.04
HD 166996	18:13:49.35	−15:48:32.50	2022-04-03	DK154	1800	10 × 180 s	1.36	9.52
NGC 6611 584	18:18:23.65	−13:36:27.90	2021-03-14	DK154	2700	9 × 300 s	1.28	12.02
BD-13 4934	18:19:05.58	−13:54:50.60	2022-04-02	DK154	3600	12 × 300 s	1.28	10.78
BD-13 4937	18:19:20.04	−13:54:21.30	2022-04-02	DK154	3600	12 × 300 s	1.28	10.78
NGC 6618 258	18:20:22.75	−16:08:34.20	2022-04-03	DK154	1620	9 × 180 s	1.28	13.69
NGC 6618 326	18:20:25.91	−16:08:32.40	2022-04-03	DK154	1620	9 × 180 s	1.28	14.2
G 015.1032 −00.6489 ^k	18:20:26.71	−16:07:09.10	2022-04-03	DK154	1620	9 × 180 s	1.28	17.5
G 018.2660 −00.2988 ^l	18:25:18.13	−13:09:43.00	2021-03-13	DK154	2700	9 × 300 s	1.23	16.75*
G 023.1100 +00.5458 ^m	18:31:25.47	−08:28:49.17	2021-09-01	T31	3600	12 × 300 s	3.94	12.06*

Table B.1: continued.

Name	RA (J2000)	Dec (J2000)	Date	Telescope	Total T_{exp} (s)	No. of Frames	Seeing ($''$)	V (mag)
HD 171491	18:35:08.21	+00:02:34.71	2020-07-06	SBT	3600	20 $\times$ 180 s	8.18	7.99
G 030.3745 +00.0252 ^a	18:46:40.09	−02:15:51.90	2022-04-02	DK154	900	3 $\times$ 300 s	1.92	-
G 031.6770 +00.1775 ^o	18:48:31.03	−01:02:09.20	2022-04-02	DK154	900	3 $\times$ 300 s	1.69	-
TYC 5118-279-1	18:49:25.06	−02:21:09.70	2021-09-02	T31	3600	12 $\times$ 300 s	3.25	10.48
HD 175514	18:55:23.12	+09:20:48.08	2020-07-12	SBT	5400	30 $\times$ 180 s	7.37	8.64
G 049.4683 −00.2527 ^p	19:23:11.97	+14:33:15.70	2023-08-09	Perek	7200	24 $\times$ 300 s	1.76	-
HD 188001	19:52:21.76	+18:40:18.75	2020-06-12	SBT	5400	30 $\times$ 180 s	8.83	6.23
HD 229159	20:22:54.07	+39:12:29.40	2020-09-16	Perek	4260	142 $\times$ 30 s	1.69	8.62
HD 195592	20:30:34.96	+44:18:54.85	2020-06-11	SBT	6480	36 $\times$ 180 s	8.72	7.08
BD+43 3654	20:33:36.07	+43:59:07.36	2020-06-11	SBT	6480	36 $\times$ 180 s	10.49	10.06
G 083.9246 −00.6778 ^q	20:51:50.20	+43:19:29.80	2020-09-16	Perek	3600	12 $\times$ 300 s	1.05	12.53*
HD 199021	20:52:53.20	+42:36:27.80	2023-05-21	Perek	3780	126 $\times$ 30 s	1.19	8.49
BD+42 3914	20:56:24.08	+43:07:46.50	2023-05-21	Perek	1980	100 $\times$ 20 s	1.18	8.49
			2023-06-25	Perek	1700	85 $\times$ 20 s	1.18	8.49
HD 203467	21:19:22.22	+64:52:18.68	2020-07-04	SBT	7020	39 $\times$ 180 s	6.93	5.18
HD 210839	22:11:30.57	+59:24:52.14	2020-07-04	SBT	1080	6 $\times$ 180 s	7.67	5.05
			2020-07-05	SBT	9540	53 $\times$ 180 s	7.41	5.05
LS III +55 26	22:12:29.95	+55:32:05.40	2020-09-16	Perek	3720	31 $\times$ 120 s	1.79	11.42
HD 215806	22:46:40.45	+58:17:43.80	2020-09-06	Perek	3720	62 $\times$ 60 s	1.57	9.23

Notes. Some targets were observed on multiple nights. In these cases, we report the start and end dates of the observations. For objects for which no V-band magnitude is available in SIMBAD, the *Gaia* DR3 G-band magnitude is listed instead. These entries are indicated by an asterisk. The SIMBAD identifiers of the marked IR nebulae are as follows: (a) 2MASS J10222305-5744280, (b) 2MASS J10302331-5949542, (c) 2MASS J14014576-6141513, (d) 2MASS J14325057-5947441, (e) 2MASS J15081025-5904126, (f) 2MASS J15191694-5643060, (g) 2MASS J17170051-3613362, (h) 2MASS J17271123-3414349, (i) 2MASS J17583064-2609490, (j) 2MASS J18004059-2336505, (k) 2MASS J18202666-1607088, (l) 2MASS J18251808-1309427, (m) 2MASS J18312547-0828490, (n) [KCS2016] J184640.09-021551.9, (o) 2MASS J18483100-0102094, (p) [ABB2014] WISE G049.465-00.254, (q) 2MASS J20515020+4319298.

Appendix C: Detections

The remaining objects with bow-shock detections, supplementing Fig. 1. Information on individual targets is provided in Sect. 5.

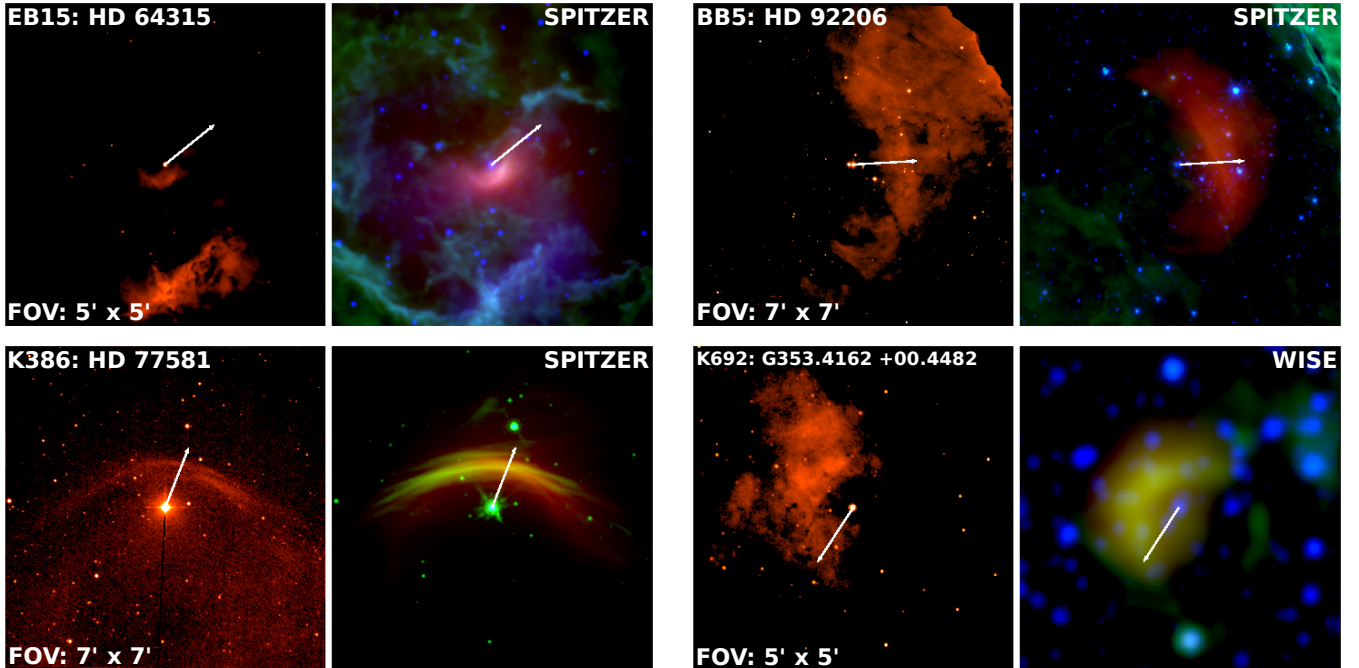


Fig. C.1: Detections of $H\alpha$ bow shocks with DK154. The proper-motion vector (not to scale) corresponds to 20% of the image field of view. *Left*: $H\alpha$ image obtained from our survey. *Right*: Three-colour mid-IR image of the corresponding nebula, constructed from archival data: WISE W2 (4.6 μm) or IRAC 4.5 μm (in blue); WISE W3 (12 μm) or IRAC 8 μm (in green); and WISE W4 (22 μm) or MIPS 24 μm (in red). Images are in equatorial coordinates with north up and east to the left.

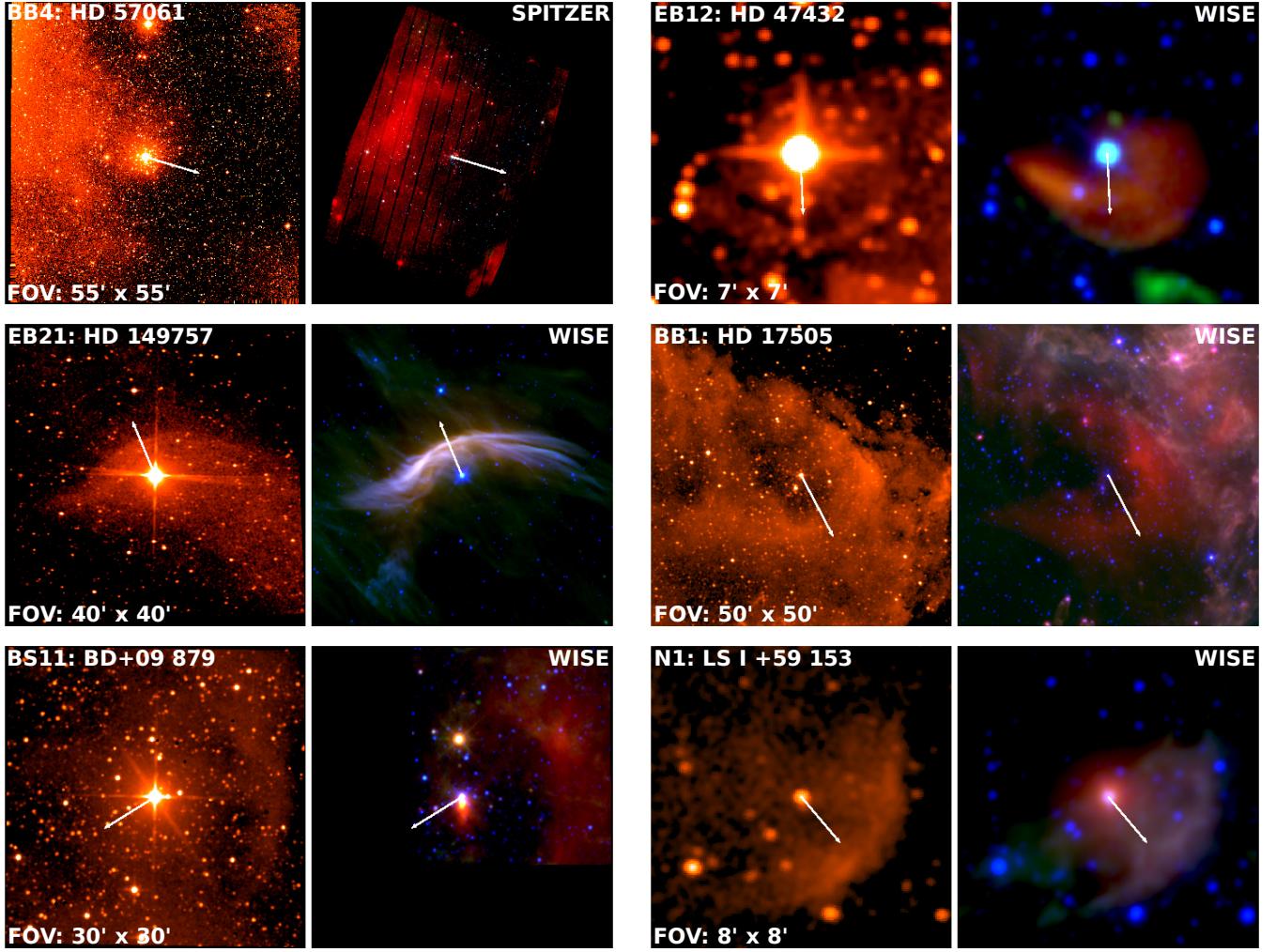


Fig. C.1: Continued. Images were taken with the SBT, except for BB4 (T31).

Appendix D: Objects with diffuse H α emission

Figures D.1–D.4 present the H α images of 35 sources classified as having diffuse background emission. These targets are located within bright and complex H II regions, which prevents the unambiguous identification of bow-shock-related H α structures. The image quality varies across the sample due to the range of telescopes and instrumental setups used (see Sect. 3). Below, we group the objects by instrument and provide brief notes on individual sources.

D.1. DK154 and Perek observations

DK154 and Perek provide high-resolution images with pixel scales of $\sim 0.4 \text{ px}^{-1}$ (Sect. 3) and seeing ranging from $\sim 0.7''$ to $\sim 1.9''$ (Table B.1), over fields of view smaller than $10' \times 10'$. These instruments resolve fine H α structures, as detailed below.

K051, K052, and K053. All three targets lie within a single $7' \times 7'$ DK154 frame covering the bright M17 (Omega Nebula) H II region. Structured diffuse H α emission is seen throughout the field, but no clear arc-like structure is discernible. The corresponding WISE band 3 and band 4 images are corrupted.

K063 and K067. Both targets lie in the M16 (Eagle Nebula) H II region. The bright, structured nebular emission prevents an unambiguous H α detection.

K072. The H α emission is dominated by the IR dust bubble N22. As noted in Sect. 5, the radio emission aligns better with the H α nebula than with the IR bow shock.

The remaining targets are not associated with any prominent H II region. Their DK154 and Perek images reveal detailed nebular emission on small scales, but no arc-shaped structure is discernible.

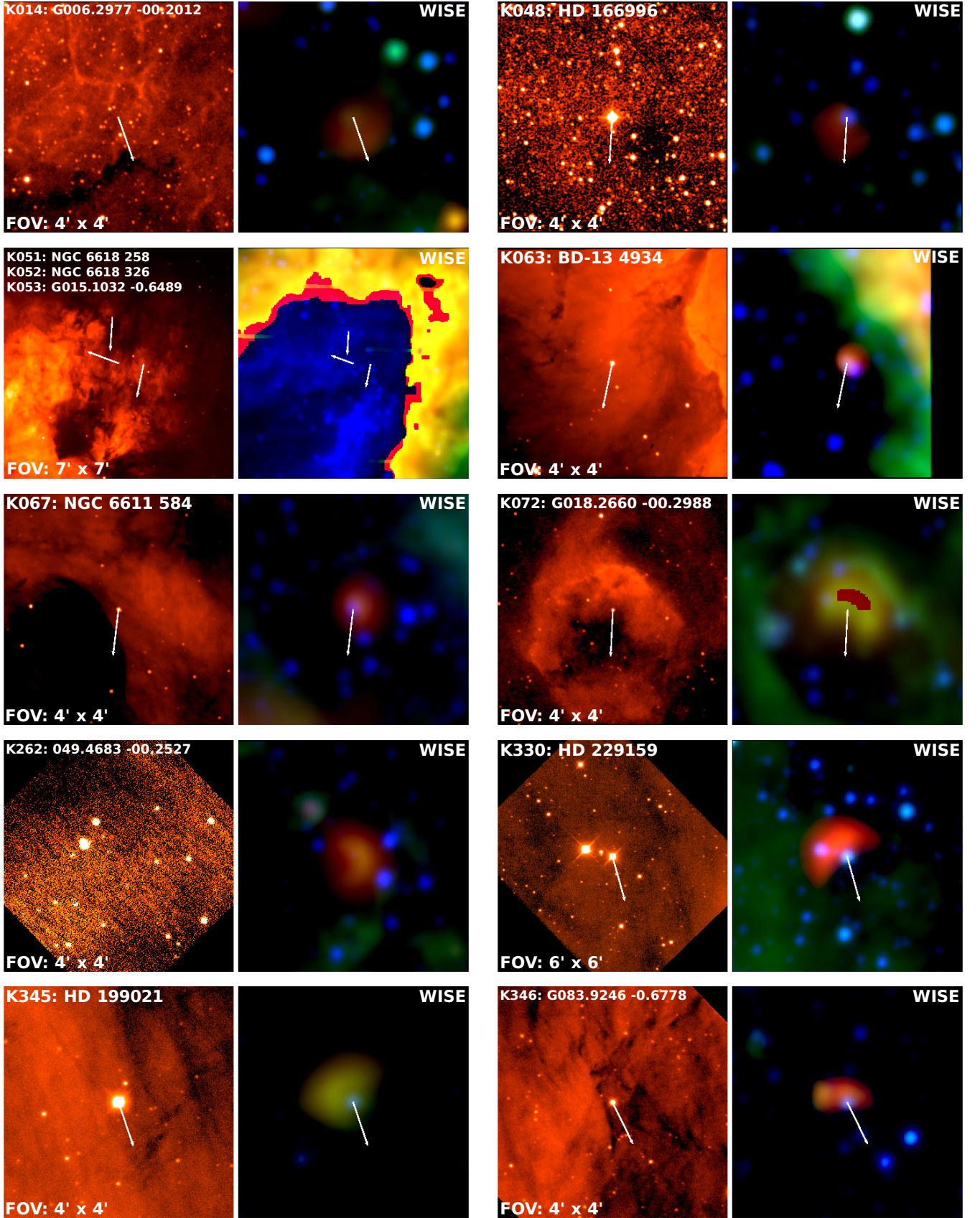


Fig. D.1: Objects with diffuse background H α emission, as observed with the DK154 and Perek telescopes. The colour scheme is identical to that in Fig. C.1. North is up, and east is to the left.

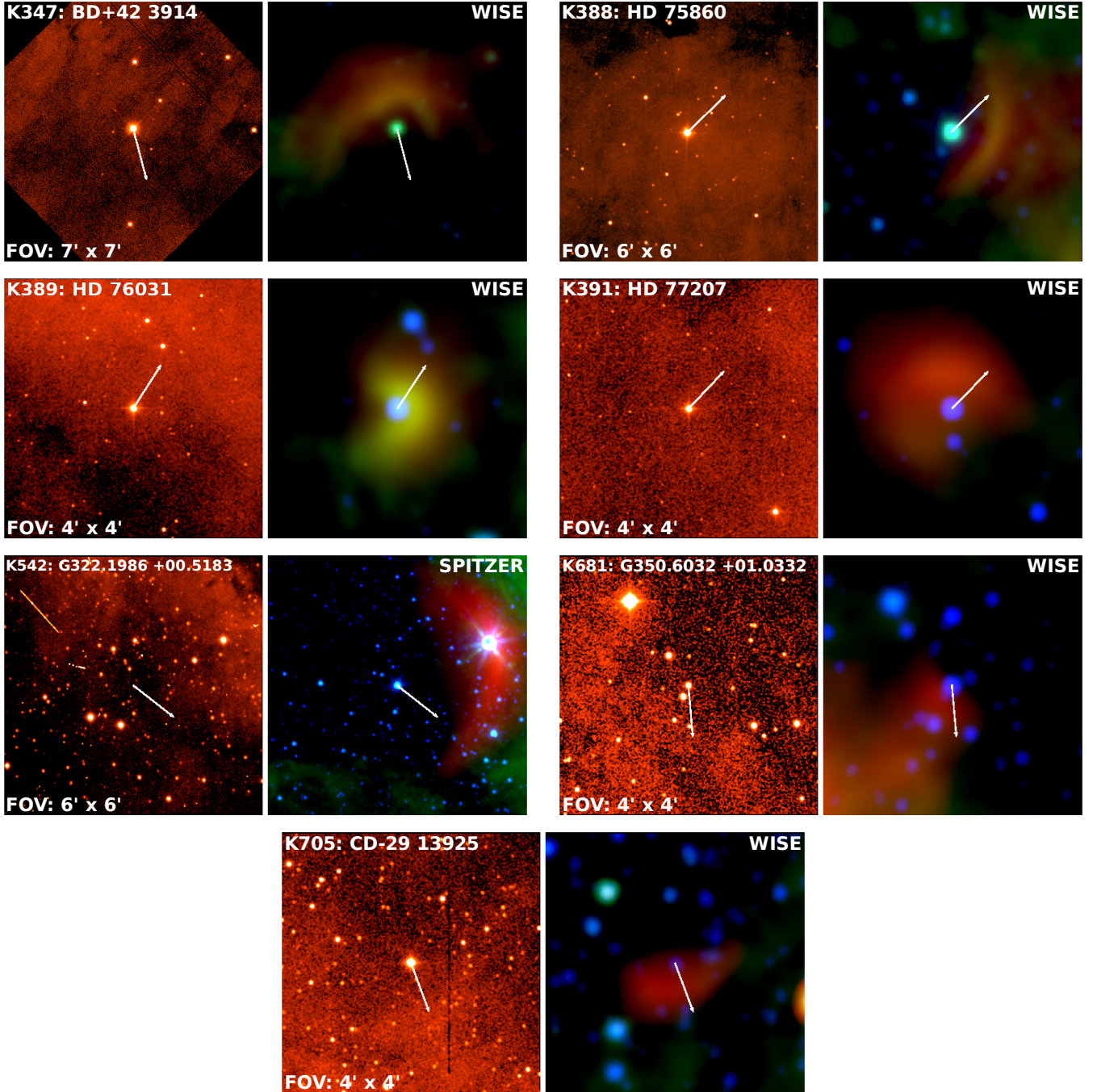


Fig. D.1: Continued.

D.2. T31 observations

The T31 telescope offers a pixel scale of $1''.1 \text{ px}^{-1}$ (Sect. 3) over a $55'.9 \times 55'.9$ field, with seeing typically $3'' - 5''$ (Table B.1). The coarser resolution limits the detection of compact structures compared to DK154 and Perek, but the wide field was used to observe extended emission from southern hemisphere targets. Details of individual objects are given below.

BB6. An arc-like $\text{H}\alpha$ structure is visible in the T31 image, but no corresponding mid-IR counterpart is detected; the bow shock was originally identified on IRAS $60 \mu\text{m}$ images (van Buren & McCray 1988), indicating cooler ambient dust.

BB8. Brown & Bomans (2005) reported arc-like $\text{H}\alpha$ emission on scales of $\sim 1^\circ \times 1^\circ$ using SHASSA data. The WISE W4 band reveals a compact IR arc within a $5' \times 5'$ field. Our deeper T31 image shows the object embedded in diffuse $\text{H}\alpha$ emission, but no arc-like structure corresponding to the IR arc is discernible.

BS12. A WN4 Wolf-Rayet star embedded within the wind-blown bubble S308 (Sh 2-308). The T31 image is dominated by diffuse $\text{H}\alpha$ emission from the bubble, and no compact arc-like structure is resolved.

EB11 and K101. No published follow-up exists. No distinct arc is resolved.

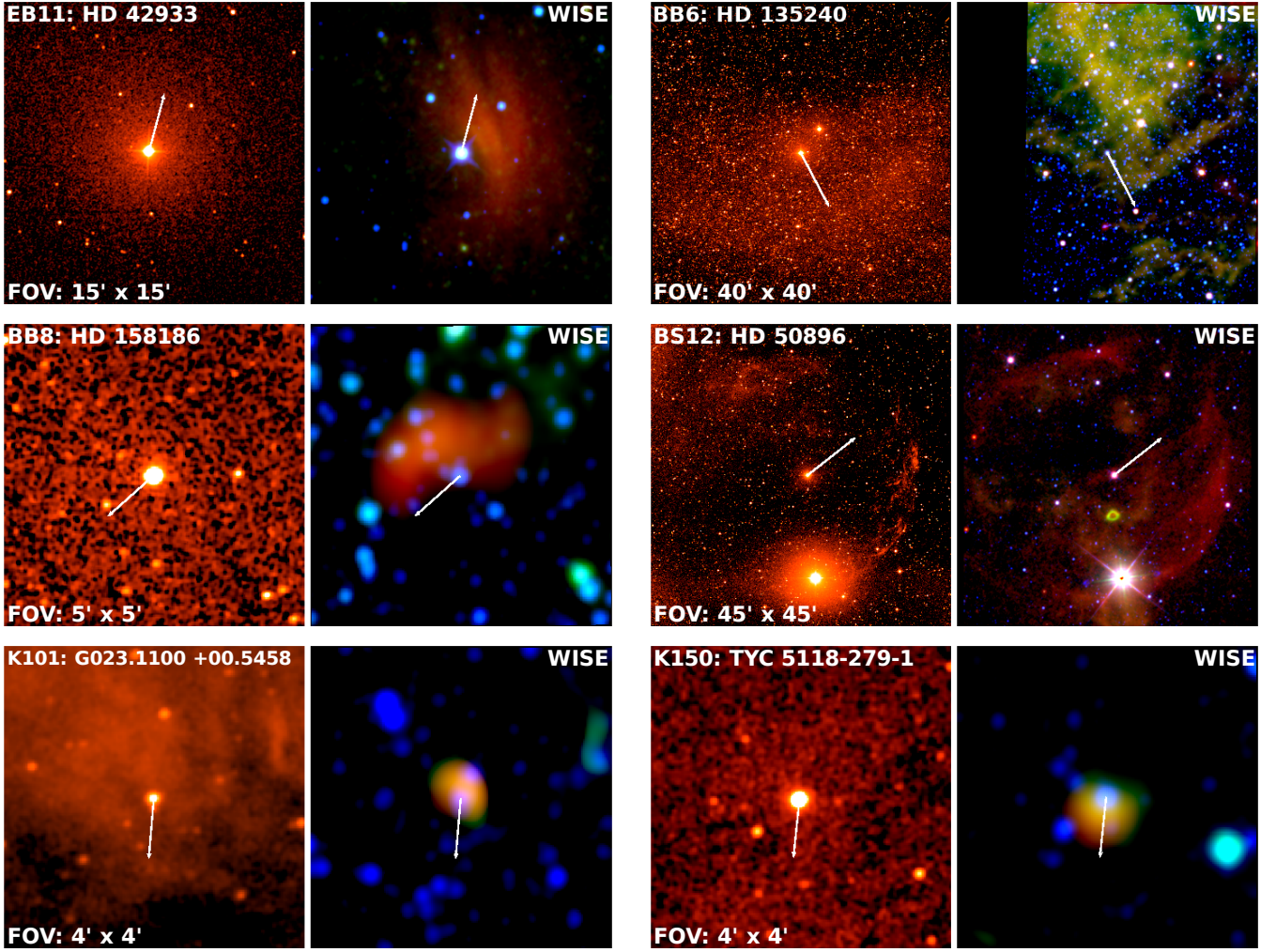


Fig. D.2: Same as Fig. D.1 but showing the observations with the T31 telescope.

K150. Embedded in bright diffuse $H\alpha$ emission. The object is a candidate DW or RBW (Table. F.1), but the surrounding background prevents an unambiguous classification.

D.3. SBT observations

The SBT provides a wide 3.5×3.5 field of view with a pixel scale of $3''.13 \text{ px}^{-1}$ (Sect. 3), making it well suited for mapping the full extent of large-scale nebulae. The SBT was primarily used to observe extended emission from northern hemisphere targets, as well as sources that could not be scheduled on DK154 or Perek due to observational and telescope constraints. The coarse angular resolution limits the detection of compact structures compared to the higher-resolution instruments, and the seeing is typically $\sim 6'' - 10''$ (Table B.1). Details of individual targets are given below.

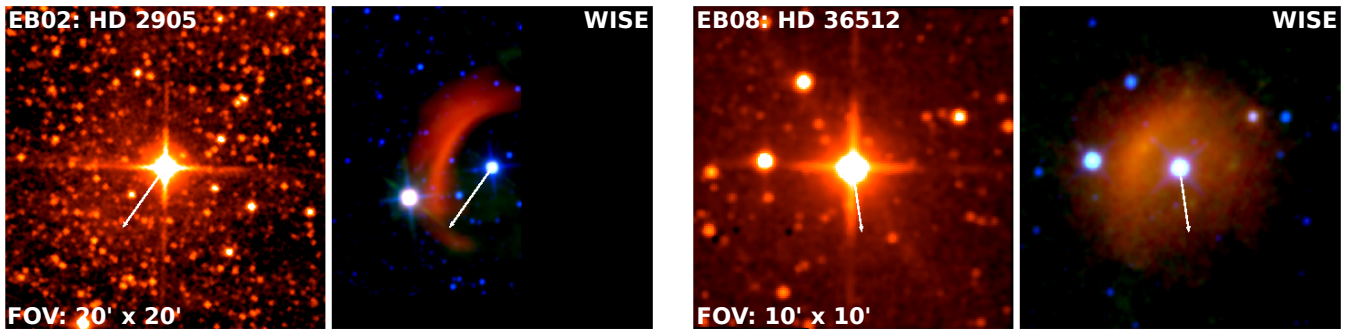


Fig. D.3: Same as Fig. D.1 but for the observations with the SBT telescope.

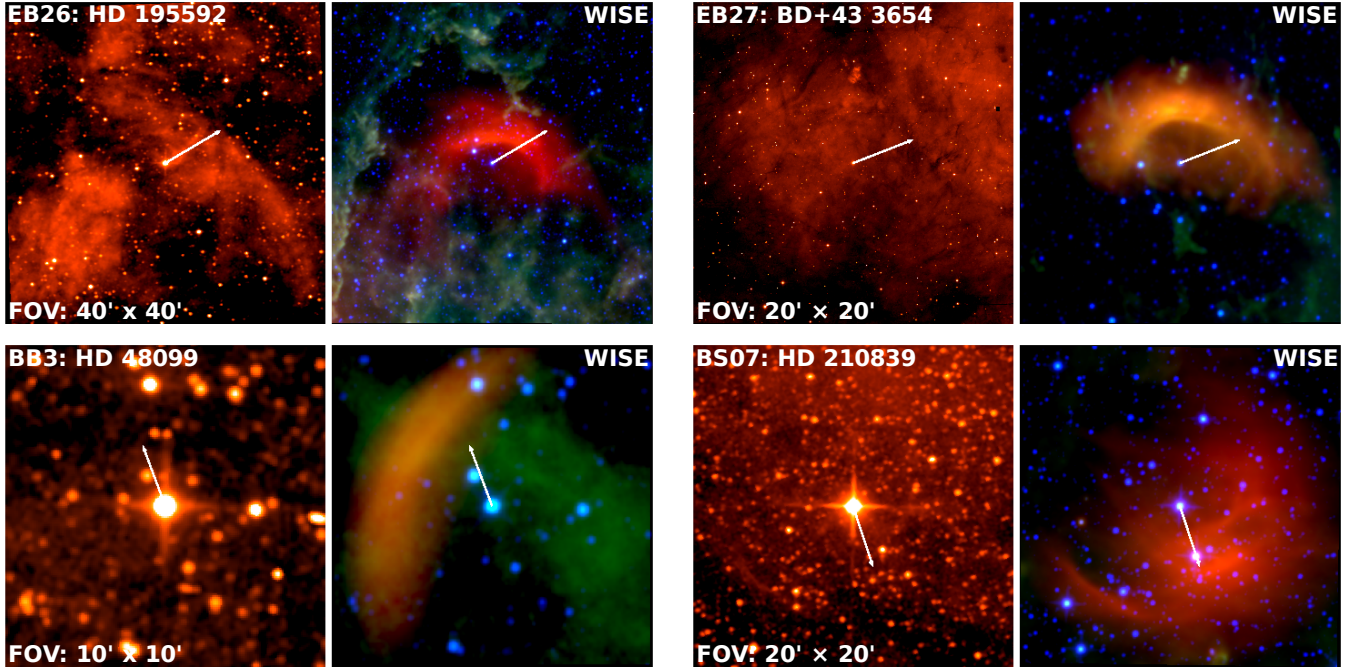


Fig. D.3: Continued.

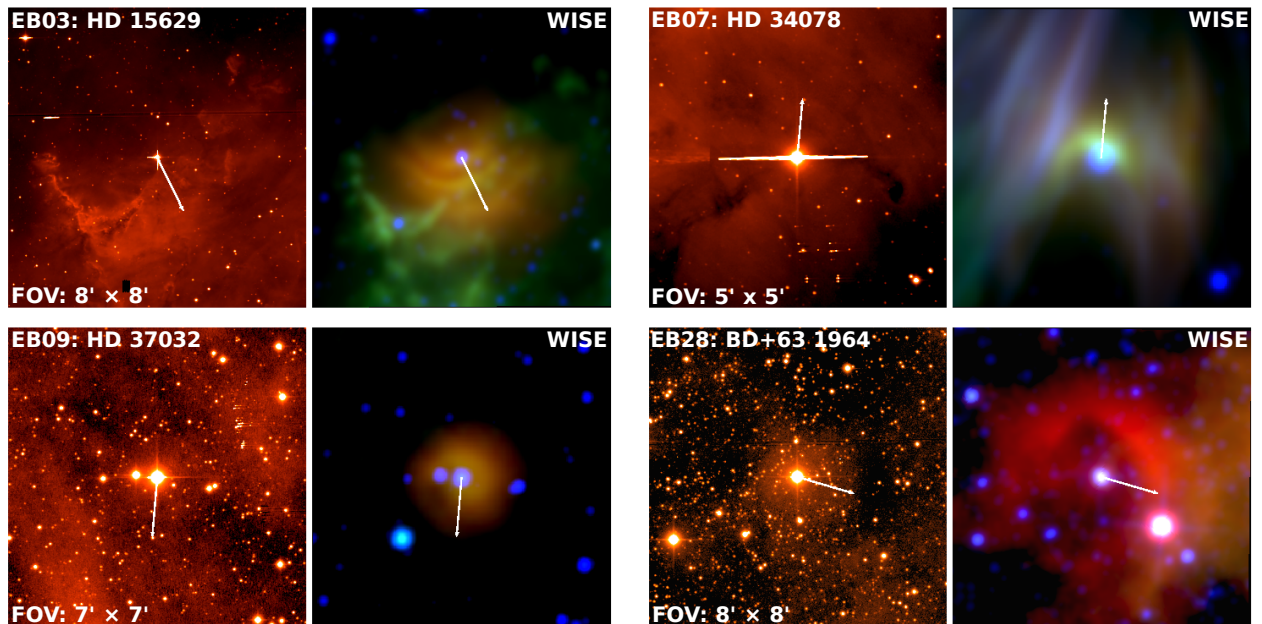
EB27. Known synchrotron bow shock that has been studied extensively at radio wavelengths (Sect. 5). Embedded in a bright H II region, the SBT image is dominated by the surrounding emission, preventing an unambiguous optical identification.

BS07. A faint H α arc was reported from IPHAS (Scherer et al. 2015), but despite our deep SBT exposures, no significant H α counterpart to the IR bow shock is detected.

The rest of the objects show diffuse H α emission in the SBT images with no distinct arc resolved.

D.4. IPHAS archival images

For EB03, EB07, EB09, and EB28, which could not be scheduled during our dedicated runs, we used archival H α images from the IPHAS survey to complete the sample. All four images show diffuse H α emission, and no distinct arc is discernible in any field. Deeper follow-up observations may be required to reveal faint bow-shock structures.

Fig. D.4: Same as Fig. D.1 except the H α images are taken from the IPHAS archive.

Appendix E: SHASSA-based flux calibration

This appendix provides a step-by-step account of the flux calibration procedure introduced in Sect. 4.2. We describe the cross-calibration of our science images against the absolutely calibrated SHASSA survey, the derivation of conversion factors from detector counts to $H\alpha$ surface brightness, and the estimation of the associated uncertainties.

The science images are recorded in detector counts (ADU), whereas SHASSA provides absolutely calibrated $H\alpha$ intensities in deci-Rayleighs. Prior to calibration, isolated artefacts in the science images were suppressed to prevent them from biasing the flux comparison. Extreme pixel values were identified using a robust dispersion estimate derived from the IQR,

$$\sigma_{\text{IQR}} = \frac{Q_3 - Q_1}{1.349}, \quad (\text{E.1})$$

where Q_1 and Q_3 denote the 25th and 75th percentiles of the pixel-value distribution. Pixels lying more than $10\sigma_{\text{IQR}}$ from the image median were replaced by clipped values, removing residual cosmic rays, hot pixels, and other non-physical outliers while preserving the diffuse nebular emission. Invalid pixels in the SHASSA maps, identified through the survey quality flags, were masked and excluded from all subsequent analysis.

The SHASSA survey has an effective angular resolution of $\sim 96''$ and a pixel size of $\sim 48''$, substantially coarser than the DK154 ($0.396'' \text{ pixel}^{-1}$), T31 ($1.1'' \text{ pixel}^{-1}$), and SBT ($3.13'' \text{ pixel}^{-1}$) observations. To enable a meaningful flux comparison, the science images were degraded to the SHASSA resolution. Since direct convolution at the native image scale would be computationally expensive, each science image was first re-binned to a pixel scale of $\sim 20''\text{--}25''$ using flux-conserving block summation. The corresponding re-binning factors were approximately 60 for DK154, 8 for T31, and 6 for SBT. The re-binned images were then convolved with a Gaussian kernel whose width was determined from

$$\sigma_{\text{kernel}} = \sqrt{\sigma_{\text{SHASSA}}^2 - \sigma_{\text{sci}}^2}, \quad (\text{E.2})$$

where $\sigma = \text{FWHM}/2.355$ and σ_{sci} denotes the native image quality of the science frame and FWHM is the full-width at half-maximum of the Gaussian.

The SHASSA image was re-projected onto the world coordinate system of the science image using bilinear interpolation and converted from deci-Rayleighs to Rayleighs. The two datasets were subsequently placed on the same coarse grid, with the re-projected SHASSA image re-binned using the same block size as the science image. This procedure ensured identical spatial sampling and enabled a direct pixel-by-pixel comparison of the two datasets over common sky areas.

A validity mask was then constructed to select reliable calibration pixels. Only pixels with finite positive values in both images were retained. Additional constraints were applied to exclude detector edges, vignetted regions, saturated pixels, and areas outside a circular region centred on the bow shock. The radius of this region was adjusted for each target to provide a representative sample of the local diffuse $H\alpha$ background while avoiding image artefacts.

The calibration factor C (Rayleigh ADU $^{-1}$) was obtained from a linear least-squares fit of the SHASSA surface brightnesses (y , in Rayleighs) against the corresponding science-image counts (x , in ADU). Because zero detector counts should correspond to zero physical flux, the fit was constrained to pass

through the origin, $y = Cx$, yielding

$$C = \frac{\sum x_i y_i}{\sum x_i^2}. \quad (\text{E.3})$$

An initial fit was performed using all valid pixels. Residuals about this relation were then examined and pixels deviating by more than 3σ were rejected. The fit was repeated on the clipped sample to obtain the final calibration factor. The formal least-squares uncertainty depends primarily on the number of fitted pixels and may underestimate the true error when the dominant scatter arises from real astrophysical differences between the SHASSA and science images. We therefore adopted a more conservative uncertainty based on the fractional RMS scatter of the residuals,

$$\sigma_C = C \frac{\sqrt{\frac{1}{N} \sum_{i=1}^N r_i^2}}{\langle y \rangle}, \quad (\text{E.4})$$

which captures the full pixel-to-pixel dispersion between the two datasets. The resulting calibration factors and their uncertainties are listed in Table E.1.

Table E.1: SHASSA-derived calibration factors converting detector counts (ADU) into $H\alpha$ surface brightness (Rayleighs).

ID	C (Rayleigh / ADU)	σ_C (%)
EB12	53.92 ± 24.23	44.9
EB15	0.41 ± 0.03	7.4
EB21	9.18 ± 1.91	20.8
EB23	0.29 ± 0.002	0.6
BB4	1.55 ± 0.80	51.7
BB5	0.86 ± 0.08	8.8
K065	0.36 ± 0.08	23.2
K383	0.34 ± 0.06	18.1
K385	0.25 ± 0.03	12.0
K692	0.25 ± 0.05	18.0

Notes. Relative uncertainties are estimated from the RMS scatter of the fit residuals.

For each bow-shock detection, the calibrated $H\alpha$ surface brightness was measured using circular aperture photometry. Aperture radii were chosen to fit entirely within the nebular emission and ranged from $5''$ to $40''$ depending on the angular size of the bow shock. For a given image, the aperture size was kept constant. Multiple apertures were placed visually across the bow-shock-emitting region to sample the nebula, and a number of apertures were placed in adjacent blank-sky regions or in the surrounding $H\text{II}$ emission to characterise the local background.

Within each aperture, the robust dispersion σ_{IQR} was computed from the IQR and pixel values exceeding $3\sigma_{\text{IQR}}$ from the aperture median were clipped to exclude stars, cosmic rays, and hot pixels. The mean of the clipped pixels was then taken as the aperture value. The net flux F_{net} was obtained by subtracting the mean sky level F_{sky} from the mean nebular level F_{apex} , and the corresponding measurement uncertainty was estimated from the standard deviation of the aperture values,

$$F_{\text{net}} = F_{\text{apex}} - F_{\text{sky}} \quad \text{and} \quad \sigma_{\text{net}}^2 = \sigma_{\text{meas}}^2 + \sigma_{\text{sky}}^2, \quad (\text{E.5})$$

where σ_{meas} is the scatter among the nebular apertures and σ_{sky} is the scatter among the sky apertures. The net flux was converted to Rayleighs using the calibration factor C from Table E.1, $\Sigma = C \times F_{\text{net}}$, and the total uncertainty was computed by combining the calibration and measurement errors in quadrature,

$$\sigma_{\Sigma}^2 = F_{\text{net}}^2 \cdot \sigma_C^2 + C^2 \cdot (\sigma_{\text{meas}}^2 + \sigma_{\text{sky}}^2). \quad (\text{E.6})$$

Appendix F: Morphological classification

Table F.1: Morphological and physical parameters of bow-shock nebulae.

ID	$\log T_{\text{eff}}$ (K)	$\log(\frac{L}{L_{\odot}})$	$M \times 10^3$ ($M_{\odot}$)	u_{∞} (km s^{-1})	u_b (km s^{-1})	v_r (km s^{-1})	v (km s^{-1})	Ref.	n_{ISM} (cm^{-3})	RBS (pc)	Expected R_0 DW (pc)	WBS (pc)	Obs. R_0 (pc)	Class	BS in radio	H α	Binary
EB01	4.48	5.39	3171	5.28	25.02	25.57	25.57	1, 14, 27	0.1 – 5	13.98 – 1.98	0.15	3.19 – 0.45	0.24	DW/WBS	no	no	no
EB02	4.38	6.24	1105	16.16	0.30	16.16	16.16	1, 12, 16	1 – 100	23.15 – 2.32	2.62	14.5 – 1.45	0.75	WBS	–	diff	no
EB03	4.63	5.56	2800	9.21	–68.00	68.62	68.62	7, 16	1 – 100	2.05 – 0.21	0.03	0.67 – 0.07	0.43	RBS/WBS	y	diff	–
EB04	4.37	4.50	500	17.82	28.10	33.27	33.27	2, 16	0.1 – 5	3.74 – 0.53	0.01	0.08 – 0.01	0.08	WBS	no	no	no
EB05	4.16	2.90	500	28.60	4.00	28.88	28.88	3, 15, 17	0.1 – 5	0.70 – 0.10	0.0004	0.12 – 0.02	0.071	WBS	–	no	–
EB06	4.47	5.63	50.00	57.74	10.00	58.60	58.60	5, 18	0.1 – 5	10.75 – 1.52	0.05	7.41 – 1.05	5.12	RBS/WBS	–	bow	–
EB07	4.52	4.65	1500	80.71	51.00	95.47	95.47	1, 13, 18	1 – 100	0.51 – 0.05	0.002	0.16 – 0.02	0.03	WBS	no	diff	no
EB08	4.51	4.68	1500	9.52	16.00	18.62	18.62	4, 13, 18	1 – 100	2.73 – 0.27	0.05	0.82 – 0.08	0.15	WBS	no	no	no
EB09	4.44	4.21	750	27.56	–15.00	31.38	31.38	3, 15, 16	1 – 100	0.86 – 0.09	0.006	0.16 – 0.02	0.26	WBS	–	diff	–
EB10	4.52	5.24	2070	19.98	–16.40	25.85	25.85	1, 12, 16	0.1 – 5	12.76 – 1.81	0.10	6.10 – 0.86	1.11	RBS	–	no	SB2
EB11	4.32	4.09	600	19.68	30.60	36.38	36.38	3, 15, 16	0.1 – 5	2.12 – 0.30	0.004	0.10 – 0.01	0.24	WBS	no	diff	–
EB12	4.45	5.57	1573	11.54	64.00	65.03	65.03	4, 12, 18	1 – 100	2.39 – 0.24	0.03	1.19 – 0.12	0.54	RBS/WBS	no	bow	–
EB13	4.64	5.59	2960	18.29	15.00	23.65	23.65	1, 12, 20	0.1 – 5	23.25 – 3.29	0.27	14.27 – 2.02	1.12	WBS	no	no	SB2
EB14	4.60	5.65	2456	26.39	42.80	50.28	50.28	1, 12, 28	0.1 – 5	10.93 – 1.55	0.07	5.70 – 0.81	1.49	WBS	no	no	yes
EB15	4.60	4.46	2875	98.44	50.4	110.59	110.59	6, 13	1 – 100	0.35 – 0.04	0.001	0.09 – 0.01	0.36	RBS	y	bow	yes
EB16	4.34	3.62	300	20.05	46.00	50.18	50.18	3, 15, 17	0.1 – 5	0.97 – 0.14	0.0008	0.14 – 0.02	0.024	WBS	no	no	yes
EB17	4.55	5.22	4.79	79.96	–36.54	87.91	87.91	8, 13	0.1 – 5	3.79 – 0.53	0.008	1.95 – 0.28	1.07	RBS/WBS	no	no	–
EB18	4.35	4.16	1.4	106.5	–4.00	60.97	60.97	3, 13, 15, 16	0.1 – 5	1.69 – 0.24	0.0015	0.98 – 0.14	0.14	WBS	no	no	–
EB19	4.47	5.55	2.50	1990	131.62	15.00	132.47	2, 16	0.1 – 5	3.26 – 0.46	0.008	0.83 – 0.12	1.18	RBS	no	no	–
EB20	4.45	4.83	1.40	1100	26.33	–7.00	27.24	2, 21, 22	0.1 – 5	7.03 – 0.99	0.04	2.24 – 0.32	0.24	WBS	no	no	–
EB21	4.51	4.82	1.49	1505	17.2	12.20	21.09	1, 12, 24	0.1 – 5	9.15 – 1.29	0.06	4.10 – 0.48	0.19	WBS	no	bow	no
EB22	4.44	4.44	0.90	1345	116.81	–53.30	128.40	3, 12, 15, 16	0.1 – 5	1.00 – 0.14	0.0007	0.42 – 0.06	0.14	RBS/WBS	no	no	–
EB23	4.45	5.10	2.22	1535	18.66	25.40	31.52	1, 12, 15, 16	0.1 – 5	8.35 – 1.18	0.05	2.88 – 0.41	0.66	WBS	y	bow	SB1
EB24	4.55	5.14	0.4	2295	–2.00	6.20	6.20	4, 13, 15, 17	0.1 – 5	42.56 – 6.02	1.41	7.59 – 1.07	1.34	DW/WBS	no	no	?
EB25	4.50	5.65	5.00	1980	92.84	19.00	94.76	2, 18	0.1 – 5	5.18 – 0.73	0.02	1.63 – 0.23	3.29	RBS	no	no	–
EB26	4.37	5.57	2.3	1735	23.53	–11.00	25.97	4, 13, 15, 18	1 – 100	5.41 – 0.54	0.22	1.22 – 0.12	1.6	RBS	–	diff	SB2
EB27	4.67	6.31	254.75	21.96	–53.00	57.37	57.37	1, 13, 23	1 – 100	8.58 – 0.86	0.24	6.60 – 0.66	1.69	RBS/WBS	y	diff	–
EB28	4.44	4.44	6.00	80.71	–125.3	149.04	149.04	3, 13, 15, 16	1 – 100	0.40 – 0.04	0.0005	0.31 – 0.03	1.06	–	–	diff	–
BB1	4.55	5.25	2500	12.20	–27.80	30.36	30.36	9	0.1 – 5	10.50 – 1.49	0.08	3.37 – 0.48	4.14	RBS	–	bow	yes
BS07	4.51	5.80	14.13	2100	52.00	–75.10	91.35	10, 16	1 – 100	2.13 – 0.21	0.03	0.93 – 0.09	1.10	RBS	–	no	yes
BS11	4.53	5.35	7.20	2125	7.87	30.10	31.11	4, 13, 16	1 – 100	3.89 – 0.39	0.09	1.95 – 0.20	1.12	RBS/WBS	–	bow	yes
K065	4.33	3.82	0.07	817	13.40	–	–	1, 14	1 – 100	1.42 – 0.14	0.02	0.27 – 0.03	0.23	RBS/WBS	–	bow	no
K067	4.51	4.85	0.76	1500	13.15	–	–	1, 13	1 – 100	4.61 – 0.46	0.16	1.26 – 0.13	0.067	DW	–	diff	?
K150	4.40	4.44	0.40	1267	16.97	–	–	1, 14	1 – 100	2.24 – 0.22	0.04	3.36 – 0.34	0.04	–	–	diff	–
K330	4.35	5.25	10.55	1065	49.84	–22.00	54.48	1, 13, 22	1 – 100	1.96 – 0.20	0.02	0.96 – 0.10	0.22	RBS/WBS	–	diff	no
K345	4.44	4.42	0.11	1821	14.52	–45.72	47.97	1, 14, 19	1 – 100	0.76 – 0.08	0.004	0.15 – 0.01	0.09	RBS/WBS	–	diff	no
K346	4.33	5.58	19.20	908	85.36	–	–	1, 14	1 – 100	1.77 – 0.18	0.02	0.76 – 0.08	0.19	RBS/WBS	–	diff	SB1
K351	4.52	5.48	11.76	790	151.43	–	–	1, 13	0.1 – 5	2.73 – 0.39	0.005	0.99 – 0.14	1.28	RBS	–	no	no
K359	4.50	5.19	3.15	2043	41.89	–50.30	65.46	1, 14, 25	1 – 100	1.46 – 0.15	0.014	0.60 – 0.06	0.57	RBS/WBS	diff	bow	no
K379	4.48	4.80	0.76	1505	25.29	25.00	35.56	11, 13, 21	0.1 – 5	5.15 – 0.73	0.02	1.48 – 0.21	0.43	WBS	–	no	–
K383	4.54	5.95	46.99	2180	173.68	57.80	183.05	1, 13, 26	0.1 – 5	4.51 – 0.64	0.01	2.72 – 0.38	1.59	RBS/WBS	–	bow	SB2
K385	4.61	5.55	19.14	2300	94.75	87.79	129.17	1, 13, 21	0.1 – 5	4.10 – 0.58	0.008	2.53 – 0.36	0.96	RBS/WBS	–	bow	SB2
K386	4.39	5.64	51.39	1105	100.0	–3.20	100.05	1, 12, 29	0.1 – 5	5.93 – 0.84	0.017	3.71 – 0.52	0.54	WBS	–	bow	EB
K388	4.34	5.80	75.00	750	88.86	16.80	90.43	1, 13, 16	1 – 100	2.33 – 0.23	0.03	1.29 – 0.13	0.67	RBS/WBS	–	diff	no
K389	4.39	4.85	2.97	1065	63.14	–	–	1, 13	1 – 100	1.03 – 0.10	0.007	0.44 – 0.04	0.14	RBS/WBS	–	diff	no
K634	4.50	5.06	3.07	590	22.20	–27.00	34.95	1, 13, 22	0.1 – 5	7.07 – 1.00	0.04	1.89 – 0.27	0.28	WBS	–	no	no
K692	4.57	5.28	1.40	22.95	23.11	29.23	37.26	1, 13, 19	1 – 100	0.98 – 0.10	0.007	0.27 – 0.03	0.30	RBS	–	bow	SB2
K705	4.43	5.04	1.22	1405	31.59	–	–	1, 13	1 – 100	2.40 – 0.24	0.04	0.64 – 0.06	0.32	RBS/WBS	–	diff	no

The results from the morphological classification procedure described in Sect. 4.3 are given in Table F.1, which lists the target identifiers taken from Table A.1 in Col. 1. Column 2 gives the effective temperatures. Values are adopted from Patten et al. (2025) where available; their spectral classifications agree in most cases with those obtained from SIMBAD within 1–2 subtypes. For the remaining objects, temperatures were estimated from the spectral types using theoretical temperature scales for O stars (Martins et al. 2005a), B supergiants (Markova & Puls 2008), and B main-sequence stars (Trundle et al. 2007). Column 3 lists stellar luminosities taken from the literature when available or derived from the spectral type using the tables from Martins et al. (2005a) and Hohle et al. (2010). Column 4 gives the stellar mass-loss rates derived using the prescription of Vink et al. (2001). Column 5 lists the terminal wind velocities taken from, or derived from the tabulations of Howarth et al. (1997) or Prinja et al. (1990) when available; otherwise they are estimated from the escape velocity following Vink et al. (2001). Column 6 gives the tangential velocities derived from the proper motions listed in Table A.1. Column 7 lists radial velocities adopted from the literature when available, and for binaries we use the systemic γ -velocity when available in the literature, while Col. 8 gives the resultant space velocities. Column 9 lists the reference numbers corresponding to the literature sources used; all references are provided in Table F.2, where references 1–11 correspond to stellar parameters, 12–15 to terminal velocities, and 16–29 to radial velocities. Column 10 lists the adopted ISM density range based on the local H α emission characteristics. Columns 11–13 give the stand-off distances estimated for RBSs, RBWs or DWs, and WBSs using the solutions of Eqs. (5)–(8). Column 14 lists the measured stand-off distances from WISE band 4 and *Spitzer* MIPS 24 μ m images. Column 15 provides the likely morphological classification. Column 16 indicates the detection of bow shocks in radio wavelengths (y — detection; no — non-detection; diff — diffuse emission from a background source). Column 17 describes the emission characteristics in the H α images from our survey (bow — arc-shaped nebula detected; diff — complex background H α emission; no — no emission detected). Column 18 lists the binary flags: SB1 — single-lined spectroscopic binary; SB2 — double-lined spectroscopic binary; EB — eclipsing binary; no — no indication (from Patten et al. 2025); yes — binary reported in SIMBAD.

Table F.2: Literature references corresponding to the sources used in Table F.1.

No.	Ref.	No.	Ref.
1	Patten et al. (2025)	16	Gontcharov (2006)
2	De Becker et al. (2017)	17	Kharchenko et al. (2007)
3	Hohle et al. (2010)	18	Holgado et al. (2018)
4	Martins et al. (2005a)	19	Gaia Collaboration (2023)
5	Crowther et al. (2006)	20	Mahy et al. (2010)
6	Lorenzo et al. (2017)	21	van Leeuwen (2007)
7	Martins et al. (2005b)	22	Duflot et al. (1995)
8	Mahy et al. (2022)	23	Kobulnicky & Chick (2022)
9	Raucq et al. (2018)	24	Zehe et al. (2018)
10	Bouret et al. (2012)	25	Abt (1963)
11	Pápics et al. (2011)	26	Williams et al. (2011)
12	Howarth et al. (1997)	27	Jönsson et al. (2020)
13	Prinja et al. (1990)	28	Mossoux et al. (2018)
14	Vink et al. (2001)	29	Pourbaix et al. (2004)
15	Peri et al. (2012)		

Notes. References 1–11 provide stellar parameters, 12–15 terminal wind velocities, and 16–29 radial velocities.