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## B[E] STARS AT THE HIGHEST ANGULAR RESOLUTION: THE CASE OF HD87643

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**Abstract.** New results on the B[e] star HD87643 are presented here. They were obtained with a wide range of different instruments, from wide-field imaging with the WFI camera, high resolution spectroscopy with the FEROS instrument, high angular resolution imaging with the adaptive optics camera NACO, to the highest angular resolution available with AMBER on the VLTI. We report the detection of a companion to HD87643 with AMBER, subsequently confirmed in the NACO data. Implications of that discovery to some of the previously difficult-to-understand data-sets are then presented.

### 1 Introduction

B[e] stars (or “stars with the B[e] phenomenon”) have little similarities with the classical Be stars. They do show permitted emission lines from Hydrogen and metallic elements, and they have an infrared excess. However, they also exhibit forbidden emission lines, and their infrared excess is due to hot dust ( $T \approx 1300 - 1500\text{K}$ ) instead of heated plasma. Another difference is that the evolutionary status of B[e] stars is unclear. Some of them show characteristics typical of evolved objects (e.g. supergiant B[e] stars or SgB[e]), while others show characteristics of young stellar objects (Herbig B[e] stars are an example). Hence, “stars with the B[e] phenomenon” do not form a homogeneous class of objects. They have sometimes a poorly known distance, making their evolutionary status highly controversial. As a consequence, many B[e] stars are “classified” as “unclassified B[e] stars” (or UnclB[e]). One example is the star HD87643, located in the direction of the Carina arm, which has been classified as SgB[e] due to its putative distance  $\geq 1$  kpc, and which, at the same time, shows variability typical of a young stellar object. It shows one of the most extreme infrared excess of all B[e] stars and, hence, needs to be further investigated. We have observed this star with a variety of techniques to try to fix its properties and evolutionary status. These techniques range from high-resolution spectroscopy to high angular resolution imaging. We present here the high angular resolution discovery images of a companion to HD87643, as well as a larger scale image of arcs in its surrounding nebula, that might be related to the binary star. These results were presented in details in Millour et al. (2009). We will also present a tentative new interpretation of previously published spectro-astrometric measurements (from Baines et al. 2006, that failed to detect the binary), having in mind, now, that HD87643 is indeed a binary system.

### 2 A companion star detected with the highest angular resolution.

#### 2.1 AMBER + NACO: detection of a companion star

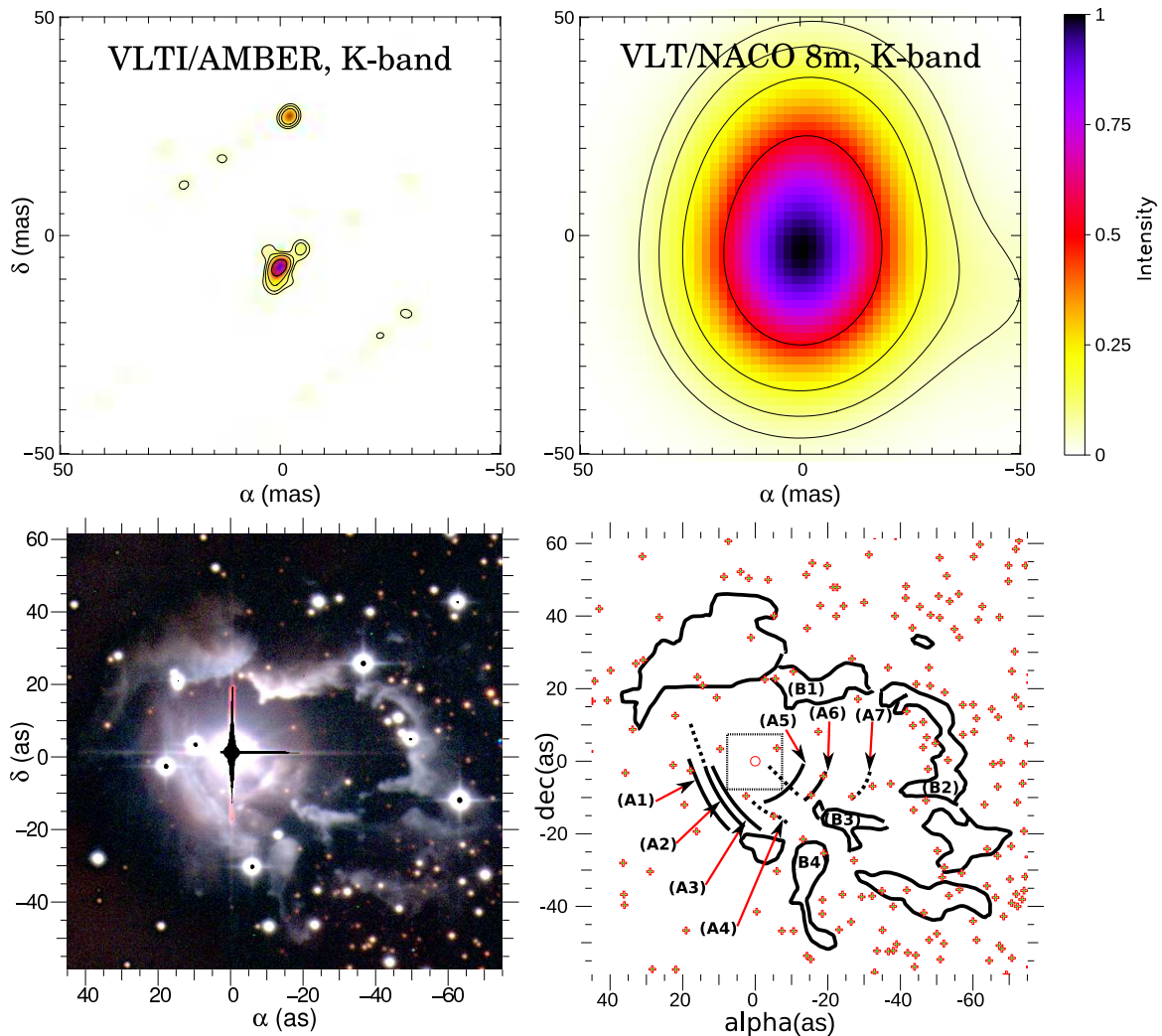
We observed HD87643 using AMBER (Petrov et al. 2007), the near-infrared instrument of the VLTI in 2006 and in 2008. The AMBER data-sets were recorded in the K-band in medium spectral resolution ( $R = 1500$ ) in 2006 and at low spectral resolution ( $R = 35$ ) in 2008. We were able to perform an image reconstruction analysis with various image reconstruction software: MIRA, BSMEM, and BBM. All gave the same result, i.e. the clear separation of the source into two components and the partial resolution of the southern component (see Fig. 1, top-left). A subsequent test using a home-made model-fitting tool gave basically the same result. This probably means that a companion star has been detected around HD87643 with AMBER.

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To check this discovery, we got additional observing time with the adaptive optics camera NACO (Rousset et al. 2003) of the VLT. We found that the L-band images did not show any elongation, as the angular resolution of NACO at that wavelength does not allow the partial resolution of the binary. On the contrary, the K-band de-convolved image was barely elongated in the same direction as the binary star detected with AMBER (see Fig. 1, top-right). Therefore, the NACO observation fully supports the AMBER observation, which detected a companion star for HD87643.



**Fig. 1. Top:** High angular resolution images of HD87643: Left: AMBER image giving a typical resolution of 2 mas; Right: De-convolved NACO image with a resolution of  $\approx 50$  mas. **Bottom:** The reflection nebula around HD87643: Left: WFI image (composite of R, V and B filter); Right: Sketch presenting the main structures. Saturated regions are masked by black zones. The sketch shows HD87643 as a red circle and other stars as red crosses. The nebular contours are drawn as black lines, and the prominent features are labelled (A1) to (A7) for arc-like structures and (B1) to (B4) for knots. Faint or uncertain structures are marked as dotted lines.

## 2.2 MIDI+AMBER: characterizing the system

In addition, we observed HD87643 in 2006 in low spectral resolution ( $R = 30$ ) using MIDI (Leinert et al. 2004), the mid-infrared instrument of the VLTI. Since MIDI only provides visibilities and differential phases, it is virtually impossible to recover an image from its data. Thanks to the same model-fitting software as described before, we could indeed fit the MIDI data-sets with a binary star model, whereas previous attempts using a 2D radiative-transfer dusty disk model completely failed to do so.

We separated the spectra of all components of the system, composed of a binary system, whose southern component is partly resolved in the H and K bands, plus an extended envelope, clearly detected both in MIDI and L-band NACO data. We found that, while the extended envelope contains most of the silicate (warm dust) emission at  $10\mu\text{m}$ , the southern component can be well-described by a black-body emission at 1300 K. The temperature (1300 K) and size (6 AU at 1.5 kpc) of this southern component is compatible with the inner-rim emission of a circumstellar disk around a hot (B-type) star. On the other hand, the northern component keeps its secrets by exhibiting an unresolved shape with a variety of dust temperatures (from 1300 K to 300 K). It could be, for example, a T-Tauri star still deeply embedded in its dust cocoon.

### 3 Wide-field imaging: binarity at work?

We also retrieved and reduced unpublished data of HD87643 from the WFI camera in 2001. The image is shown in the bottom of Fig. 1, together with a sketch of all the features detected. In comparison with previous works (van den Bergh 1972; Surdej et al. 1981; Surdej & Swings 1983), the image presented here has a larger dynamic range.

It appears that the nebula around HD87643 is made of three components: filamentary structures, composing the main nebula in the north-west quadrant (thick black line in the sketch); apparently blown-up structures appearing as “knots” (labelled (B1) to (B4)), connected to the previous filaments; and finally, arc-like structures (labelled (A1) to (A7)), grouped in two sets south-east and south-west of the star, respectively.

The nebular filamentary structures can be explained by a past outburst that took place  $\approx 355$  yrs ago, given an expansion velocity of  $\approx 1000 \text{ km s}^{-1}$  and a distance of 1.5 kpc. The knots seen in our image would correspond to denser interstellar clouds or clumps that would offer more resistance to the nebular ejecta.

The arc-like structures appear regularly spaced in our image. At the same adopted distance, they would correspond to regular ejections every  $\approx 14$  yrs to  $\approx 50$  yrs, depending on the arc. These broken structures suggest short, localised ejection that might coincide with short periastron passages of the previously detected companion, triggering violent mass-transfer between the components.

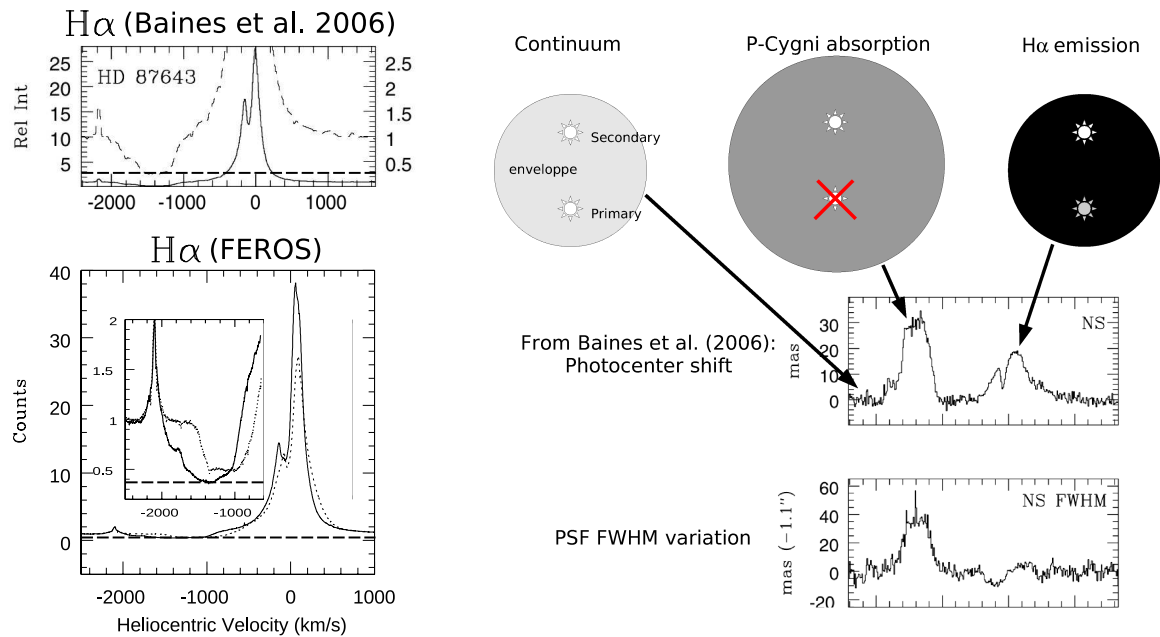
### 4 Comparison with previous works

Previous observations of HD87643 did not detect the companion star. Spectro-polarimetric (Oudmaijer et al. 1998) and spectro-astrometric observations (Baines et al. 2006) had the highest spatial resolution at that time. Both techniques provided evidence for a significant north-south asymmetry of the system, but the complexity of the signal prevented a direct interpretation, and especially the detection of the binary star.

The  $\text{H}\alpha$  P-Cygni profiles of HD87643 (between  $-1000$  and  $-2000 \text{ km s}^{-1}$ ) show a flat-bottomed shape, seen in both of the Baines et al. (2006) and Oudmaijer et al. (1998) spectra, as well as in spectra we acquired with the FEROS instrument in 1999 and 2000 (see Fig. 2). It could mean that in that spectral region, *one* source of continuum is strongly absorbed, while other emission sources are not. This (variable) absorption represents 50% to 60% of the continuum.

The spectro-astrometric results from Baines et al. (2006) can be summarized as follows. The photo-centre of the  $\text{H}\alpha$  emission and of the P Cygni absorption is shifted toward the north compared to the continuum photo-center. The PSF FWHM is increased by 40 mas both in the EW and NS directions in the P Cygni absorption, but not in other parts of the  $\text{H}\alpha$  line. This FWHM increase is larger than our inferred binary separation (34.5 mas). This implies that the remaining continuum originates from an extended component, unaffected by the P Cygni absorption. This component contributes *at most* (i.e. considering a fully saturated P Cygni absorption) 40-50% of the total visible continuum. We can tentatively attribute most of this contribution to the scattered light from the circumbinary envelope, detected by MIDI and NACO in the mid-infrared.

The photo-centre shifts may be understood as follows. The P-Cygni absorption hides the southern component; hence, a northern photo-centre shift is observed. Both stars emit  $\text{H}\alpha$ , but the northern star emits more; so again, a northern photo-centre shift in the  $\text{H}\alpha$  emission is observed. In the P-Cygni absorption, the large envelope surrounding the system appears larger as a consequence of, e.g., increase of optical depth, leading to the PSF FWHM increase. Therefore, in this frame, the spectro-astrometric observations of Baines et al. (2006) strongly support a multiple-component origin for the  $\text{H}\alpha$  emission. This also suggests that the northern companion is also a hot source able to ionize circumstellar hydrogen.



**Fig. 2. Left:** H $\alpha$  line as seen by Baines et al. (2006, top) and FEROS (1999, solid line and 2000, dotted line). Dashed lines indicate the flat-bottomed shape of the P Cygni absorption. **Right:** A tentative new interpretation of the Baines et al. (2006) spectro-astrometric measurements: Both stars emit H $\alpha$ , while only one is absorbed in the P Cygni absorption. Note the change in flux-balance of the two components between the continuum and both H $\alpha$  emission and P Cygni absorption.

## 5 Discussion and conclusion

We presented high angular resolution AMBER and NACO images as well as a high dynamic range WFI image of HD87643. AMBER and NACO images undoubtedly reveal a binary companion to the main star, while the WFI one suggests a high-eccentricity orbit for the binary. Separating the spectra of the different components in the system using the AMBER and MIDI data, it was possible to infer that the main source is likely a hot star encircled by a 6 AU hot dust envelope, that the secondary is embedded in a compact cocoon of dust, and that a circumbinary envelope holds most of the dust silicate emission in the system. Finally, we propose a new interpretation of literature spectro-astrometric data, in which both stellar components emit H $\alpha$ .

The global view of the system has been completely changed by our discovery of a companion to HD87643. The system might resemble in fact the following: a hot star encircled by a dusty disk, whose inner rim is seen in the AMBER image (a Herbig star?), a T Tauri companion star, and a dusty circumbinary envelope. All this suggests a much younger evolutionary status of HD87643 and, hence, a much closer distance than previously thought. A monitoring campaign of the binary throughout its orbit would enable us to set accurately and definitively the distance of the system and, hence, its evolutionary status.

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