Imaging the closest environment of unclassified and supergiant B[e] stars

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Our method: interferometric imaging and multi-λ model-fitting

Interferometric imaging:

We use several image-reconstruction software for this project: MIRA, BSMEM and BBM, which have similar performances for optical interferometry, as compared in Millour et al. (2009, A&A, 507, 317). We made tests on simulated data to show that, in the current situation (3 telescopes with AMBER), the main limitation is the UV coverage rather than the errors on the measurements. For the next generation(s) of VLTI instruments, this limitation will still hold as the number of closure phases will not be large enough to perform accurate image reconstruction.

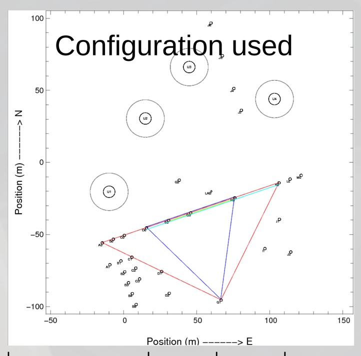
Multi-λ model-fitting:

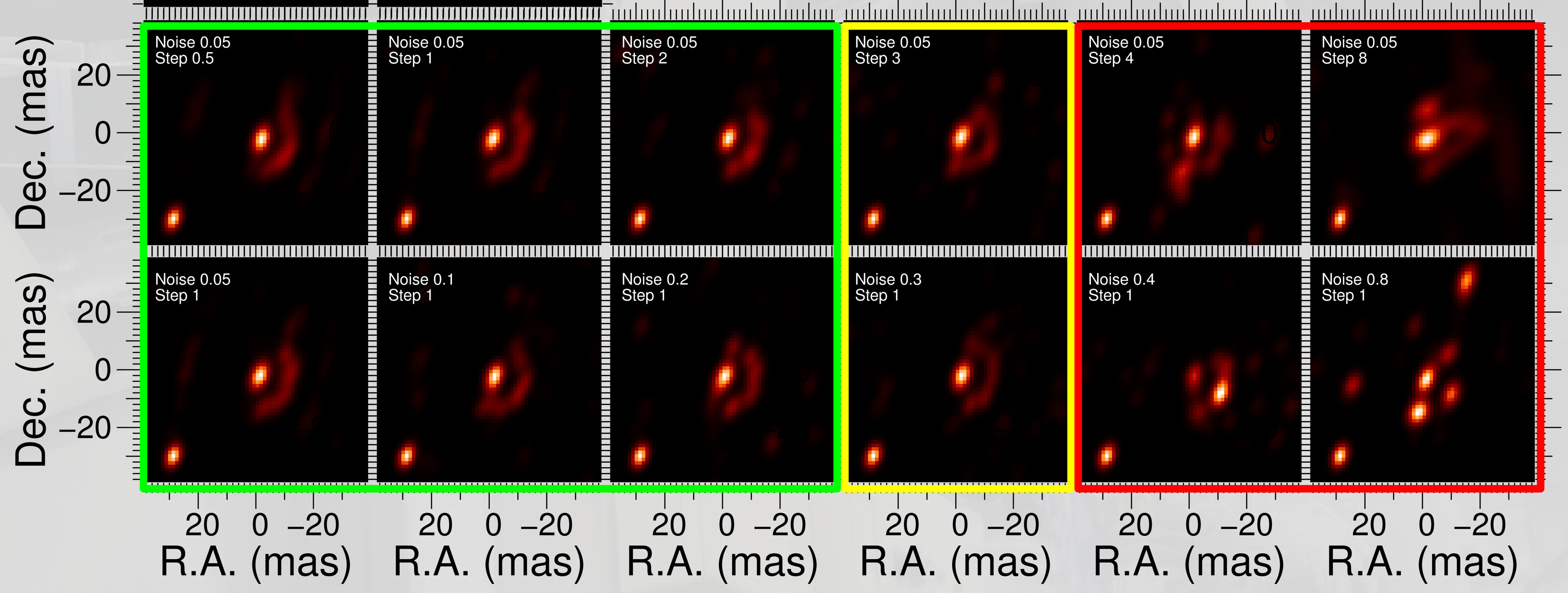
Inspired from the work of the JMMC (LITpro), we created a model-fitting environment called "fitOmatic", which natively uses multi-λ parameter. Changes compared to LITpro are:
- global optimization using a combination of a gradient-descent algorithm and a simulated annealing algorithm. Genetic algorithms will also be tested in the future,
- implementation of the differential phases, which enables us to fit them globally together with other observables (V^2 and closure phases)
- a modular software structure, largely inspired from LITpro

This allows one for example to directly fit both spectra of a binary system (e.g. Parameters vectors with 10 elements), while keeping their astrometry independent of wavelength.

Example:

Simulation of AMBER observations of a dusty disc inner-rim around a star with different noise levels and different UV sampling steps.





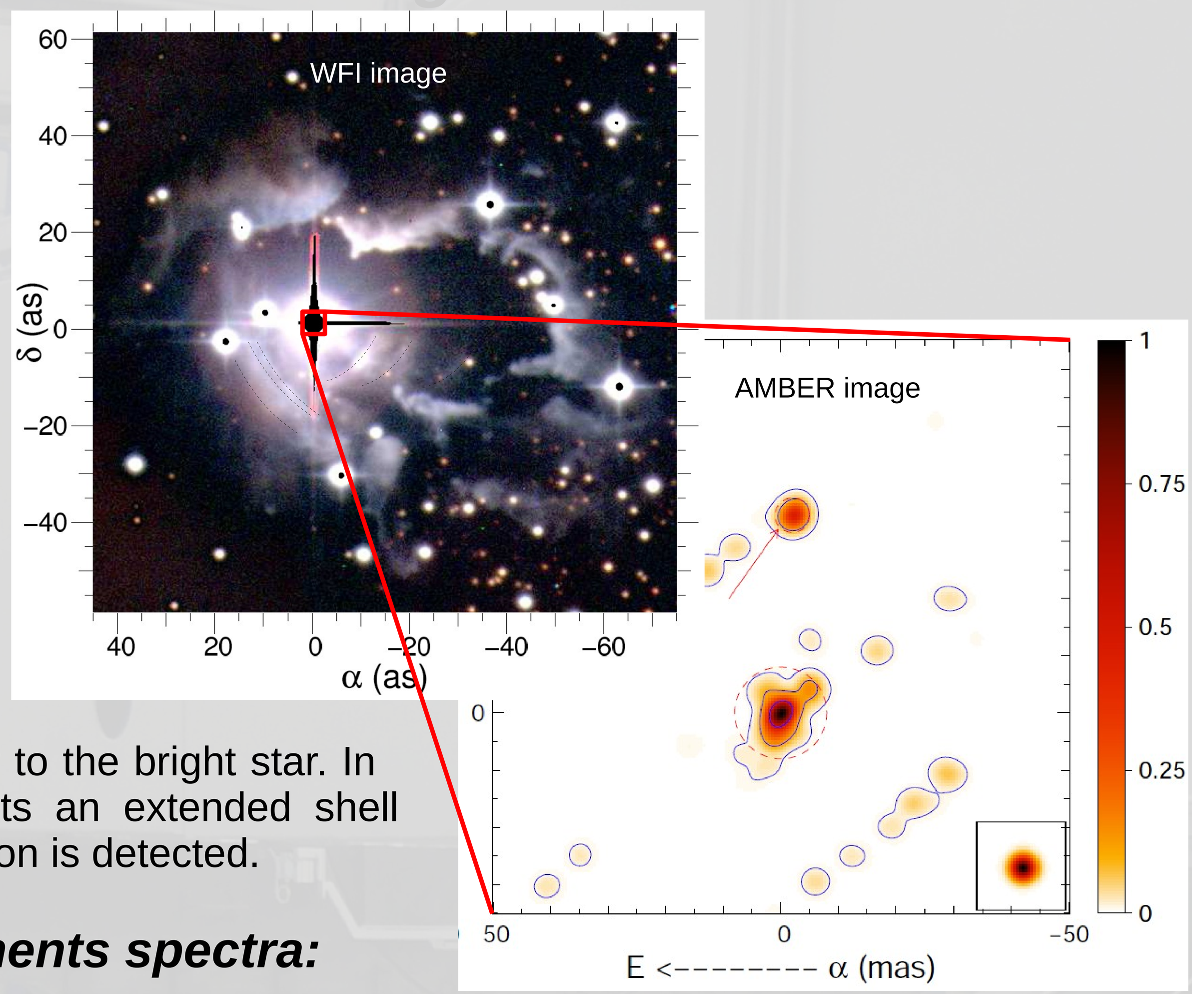
A companion and a disc imaged around HD87643

Wide-field images:

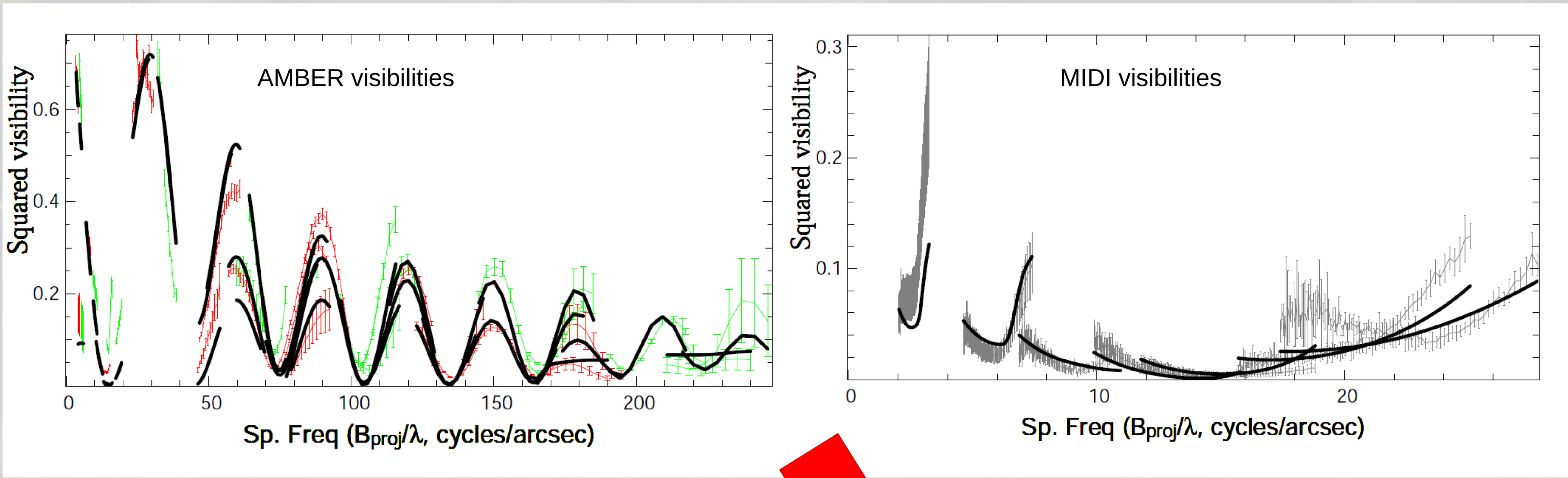
Many new details are seen in our wide field image of the nebula around HD87643:
- "blown up" structures in the large scale nebula, which could be the result of an eruption much like in LBVs,
- A series of arcs, unseen before, which could be the result of periodic ejections of matter.

Interferometric images:

Our interferometric images, made using the AMBER/VLTI instrument, show a companion star to the bright star. In addition, the primary star exhibits an extended shell (~4 mas), and background emission is detected.



Separation of the components spectra:



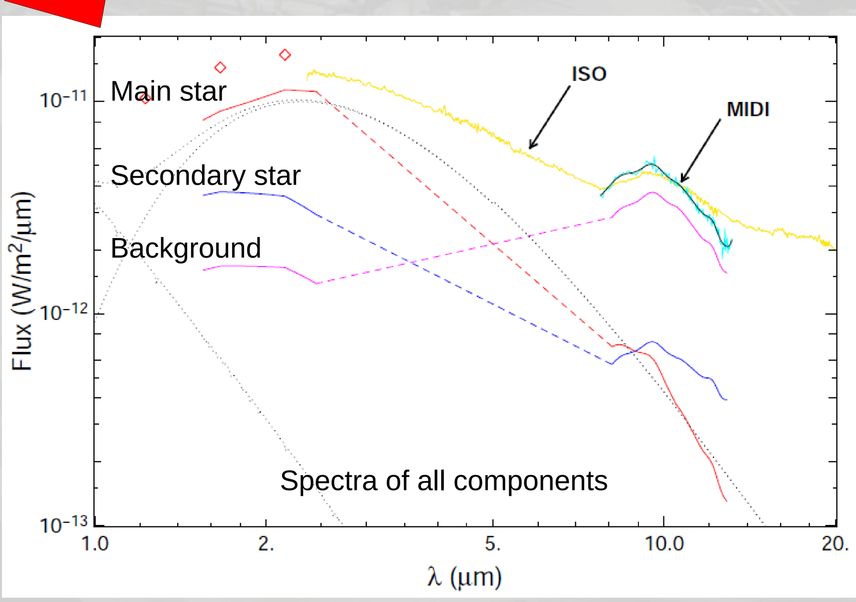
Using a model involving both stellar components plus a resolved background, we were able to separate individual spectra in H, K and N bands.

The primary star is enshrouded in a dust shell heated at the dust-sublimation temperature: we resolved the inner region of the HD87643 disc.

The secondary component is also enshrouded in dust, at temperatures ranging from 500 to 50K.

The resolved background holds most of the silicate emission, hence being likely composed of colder condensed dust.

As a conclusion, and since the distance to the system is still poorly constrained, HD87643 could be a YSO instead of an evolved object.



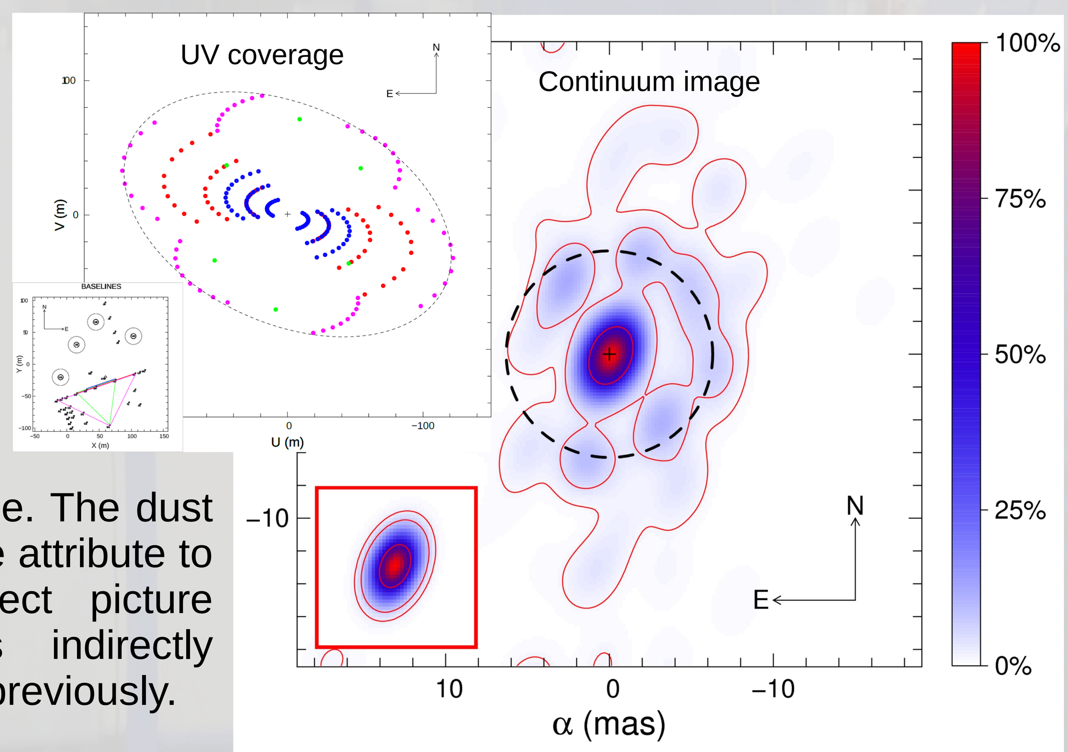
Millour et al. 2009, A&A, 507, 317

Rotation imaged in the disc of l Puppis

The continuum:

We clearly resolve the gas and the dust disc in the continuum, imaging for the first time the disc of an evolved star.

The image shows an outer ring corresponding to the inner rim where dust sublimation occurs, while we also resolve a central region where free-free emission from the gas takes place. The dust emission is asymmetric, which we attribute to an inclination effect. This direct picture strikingly confirms what was indirectly inferred from spectroscopic data previously.

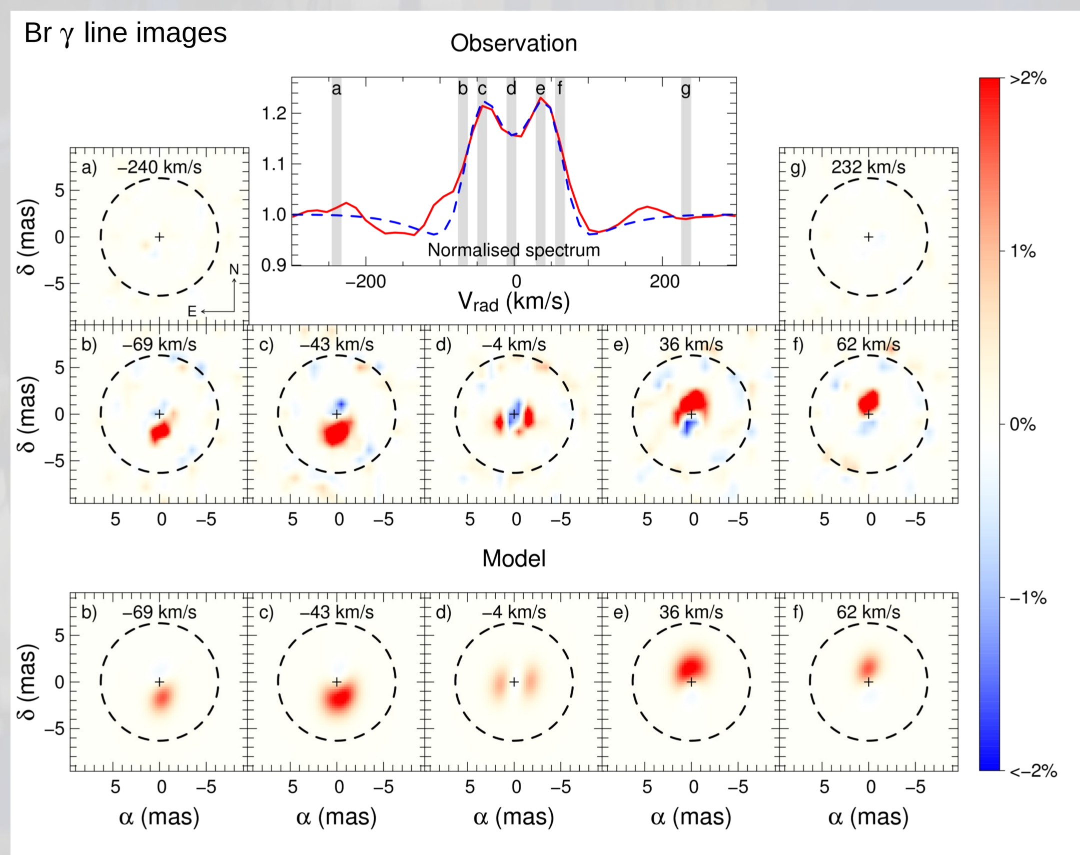


The Br γ line:

Our high-spectral resolution image cube in the Br γ line directly shows the motion of the gas in different velocity bins. The combination of a model of the dust, which gives the on-sky orientation and inclination of the disc, and of a model of the rotating gas, allows us to claim that we detected Keplerian rotation in that disc.

We can now clearly rule out expanding wind models for l Puppis. Instead, we have a Keplerian rotating disc, where expansion is negligible.

Such a disc, unexpected for massive stars, is common with young stellar objects like Herbig stars. In the case of l Puppis, the presence of a very close unseen companion, previously detected by radial velocities, might be the key to the formation of such a rotating disc.



Millour et al. 2010, submitted

Conclusion

We have now two characteristic examples demonstrating the power of optical/IR interferometry for the characterization of supergiant and unclassified B[e] stars:
- HD87643 is a binary system whose companion could be e.g. a T Tauri star. This could mean that the primary is an Herbig star
- l Puppis has a Keplerian-rotating disc, which is very hard to explain in such a low-temperature supergiant star, where radiation pressure is not sufficient to expell large amount of matter. The presence of a companion star rotating very close to the primary could be an explanation for such a disc.

Perspectives

A complete observing program is now ongoing using optical interferometry to further characterize B[e] stars. More results are coming in the next few years using a combination of AMBER and MIDI observations.

New generation VLTI instruments like MATISSE will open better imaging capabilities than AMBER and a multiplied efficiency giving more constraints on the models. Images of the dust discs around B[e] stars (including Herbig stars) in the mid-infrared will become feasible, which opens wide new opportunities, e.g. characterizing the discs of YSOs in the mid-infrared.

MATISSE