First AMBER/VLTI Science

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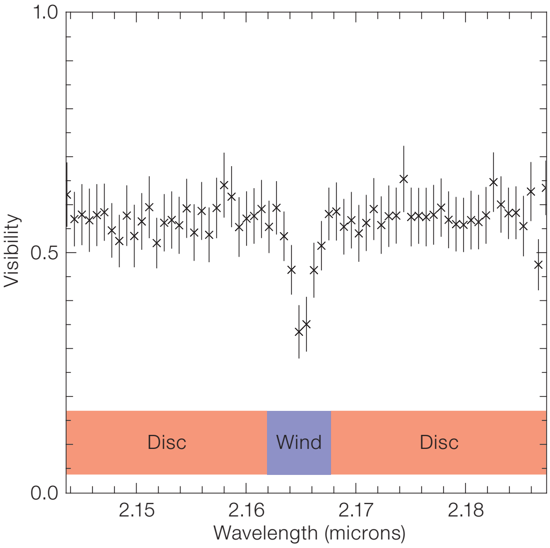
The AMBER instrument installed at the Very Large Telescope (VLT) combines the beams from three telescopes to produce spectrally dispersed interference fringes with milli-arcsecond angular scales in the near infrared. Three years after installation, first scientific observations have been carried out mostly during the Science Demonstration Time and the Guaranteed Time. The first science has mainly focused on the environment of various types of stars. Because AMBER has dramatically increased the number of measures per baseline, this instrument brings strong constraints on morphology and models.

AMBER is one of the two science instruments of the Very Large Telescope Interferometer (VLTI) described in Petrov et al. (2007). AMBER is an interferometric beam combiner for the VLTI working in the near-infrared *J*-, *H*-, and *K*-bands and able to simultaneously mix three beams coming from three identical telescopes. AMBER interferograms are spectrally dispersed with a resolution of about 35, 1 500, or 12 000. Therefore the instrument can measure visibilities and a closure phase in a few hundred different spectral channels. The spectral coverage, the spectral resolution, and the better sensitivity compared to small-aperture interferometers give access to many new astrophysical fields that we describe in this paper.

Discs and winds in young stars

The young stellar object MWC 297 is an embedded Herbig Be star exhibiting strong hydrogen emission lines and a strong near-infrared continuum excess. MWC 297 was observed with AMBER during its first commissioning run (Malbet et al. 2007). MWC 297 has been spatially resolved in the continuum as well as in the Brγ emission line where the visibility decreases to a lower value (see Figure 1). The interpretation of this result is that the gas emitting the Brγ emission line is located in a region larger than the disc from which the dust continuum emission arises. A picture emerges in which MWC 297 is surrounded by an equatorial, optically thick disc, that is possibly still accreting, and by an outflowing wind located just above it. AMBER's unique capability to measure spectral visibilities allowed Malbet et al. (2007), for the first time, to compare the apparent geometry of a wind with the disc structure in a young stellar system.

A lower-mass, less active system, the Herbig Ae system HD104237, was also observed with AMBER (Tatulli et al. 2007). The central emission line star is surrounded by a circumstellar disc that causes the infrared excess emission and that drives a jet. The visibility of this object measured by AMBER does not vary between the continuum and the Brγ line region, even though the line is strongly detected in the spectrum. This result demonstrates that the line and continuum emission have similar size scales. Assuming that the *K*-band continuum excess originates in a puffed-up inner rim of the circumstellar disc, Tatulli et al. (2007) conclude that this emission most likely arises from a compact disc wind very close to the inner rim location.



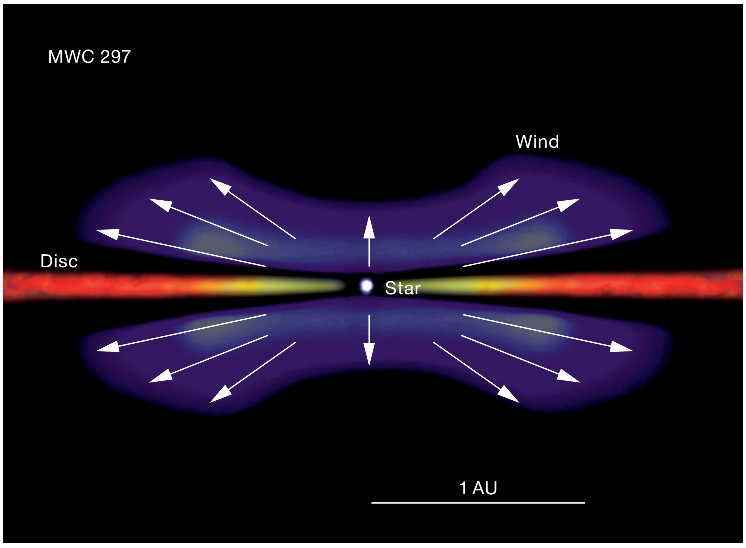
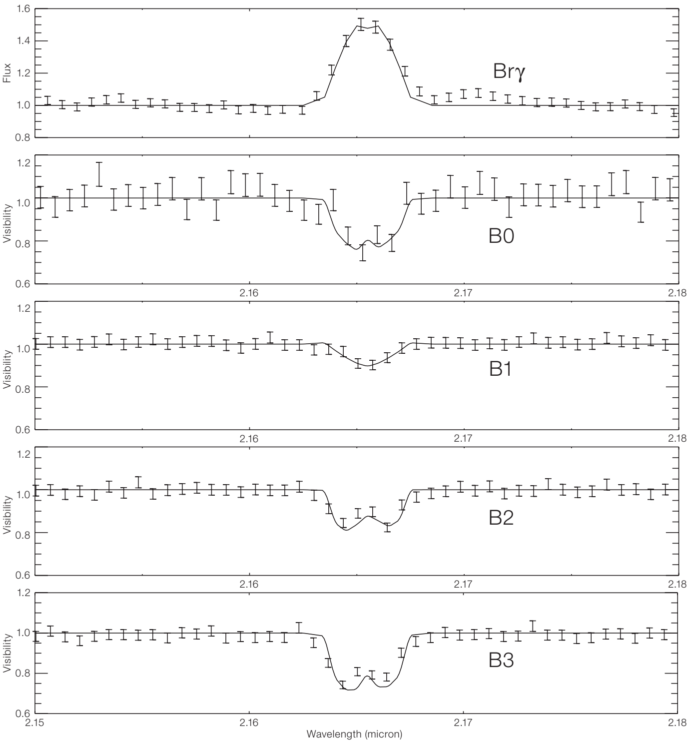
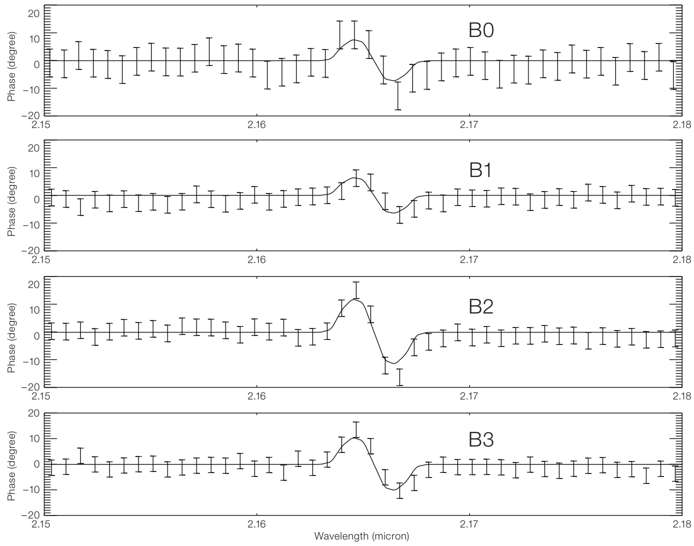


Figure 1: Left: Spectral dependence of the visibility as measured with AMBER for MWC297 around the Brγ line. **Right:** Edge-on view of the model including an equatorial optically thick disc (in red/yellow) and an outflowing wind (in blue). The wind geometry has been computed to both fit the visibility drop in the Brγ line and reproduce the object spectrum. The apparent size of the wind is larger than the apparent size of the disc. From Malbet et al. (2007).





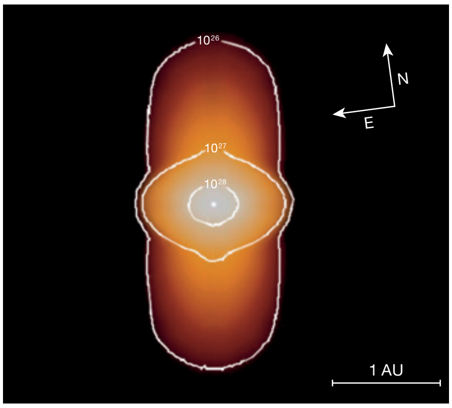


Figure 2: Relative visibility (left plot) and differential phases (right plot) of α Arae across the Brγ line profile for several VLTI baselines. The upper left subpanel is the Brγ line profile. The plain lines are the fits we obtain with the best model, whereas the VLTI/AMBER data are the points with error bars. **Bottom right figure:** intensity map in the continuum at 2.15 μm obtained with the best model parameters of α Arae.

These two results show that AMBER on the VLTI is going to be a major tool for understanding the very close environment of young stars and will disentangle the regions of emission of dust and gas, especially those coming from the disc and the wind.

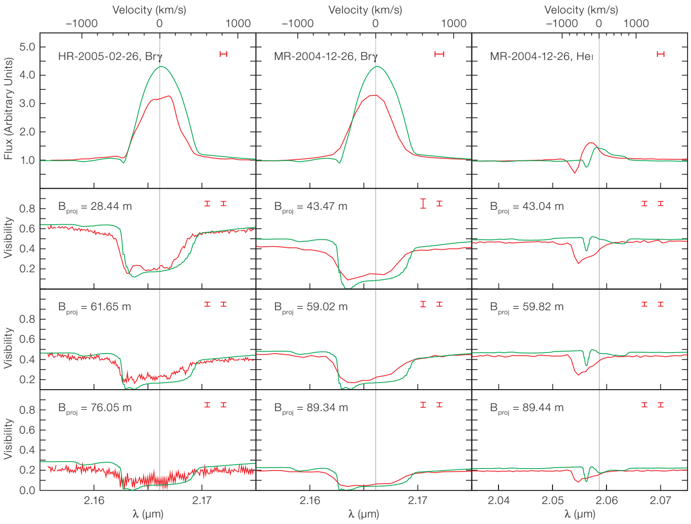
Rotating gas envelopes around hot active stars

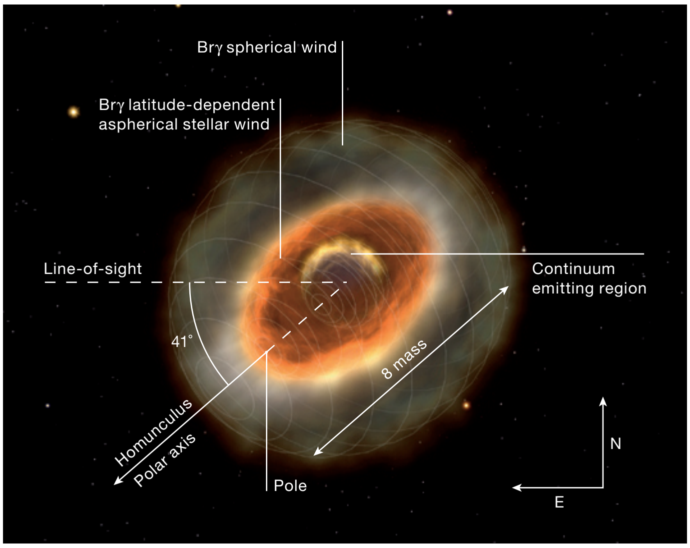
Several emission-line stars have been scrutinised by AMBER: two Be stars, α Arae, one of the closest Be stars (Meilland et al. 2007b) and κ Canis Majoris, one of the brightest ones (Meilland et al. 2007a), and one B[e] supergiant star, CPD-57°2874, which is one of the rare hot stars showing forbidden lines and IR emission from dust (Domiciano de Souza et al. 2007).

The AMBER instrument, when operating in the *K*-band, provides a gain in spatial resolution of a factor of five compared to previous VLTI/MIDI observations of α Arae. Moreover, high angular resolution is combined with medium spectral resolution which allows the kinematics of the gas envelope inner part to be studied and its rotation law to be estimated (see Figure 2). Meilland et al. (2007b) obtained, for the first time, direct evidence that the gas envelope is in Keplerian rotation, answering a question that has existed since the discovery of the first Be star, γ Cassiopae, by Father Secchi in 1866. The envelope around α Arae is compatible with dense equatorial matter confined in the central region, whereas a polar wind is outflowing along the rotational axis of the central star. Between these two regions the density must be low enough to reproduce the large visibility amplitudes obtained for two of the four VLTI baselines.

Using differential visibility amplitudes and phases across the Brγ line, Meilland et al. (2007a) detected an asymmetry in the circumstellar structure around κ Canis Majoris. However, this star is difficult to fit within the classical scenario for Be stars, i.e., fast rotating B star close to its breakup velocity surrounded by a Keplerian circumstellar gas envelope with a strong polar wind. We found that κ CMa does not seem to be a critical rotator, the rotation law within the envelope is not Keplerian, and the detected asymmetry seems to be hardly explained within the one-armed viscous disc framework.

The first high spatial and medium spectral observations of the circumstellar envelope of a B[e] supergiant, CPD-57°2874, were performed with the VLTI using both the AMBER and MIDI instruments. Thanks to these observations Domiciano de Souza et al. (2007) estimated the size and geometry of the circumstellar regions re-





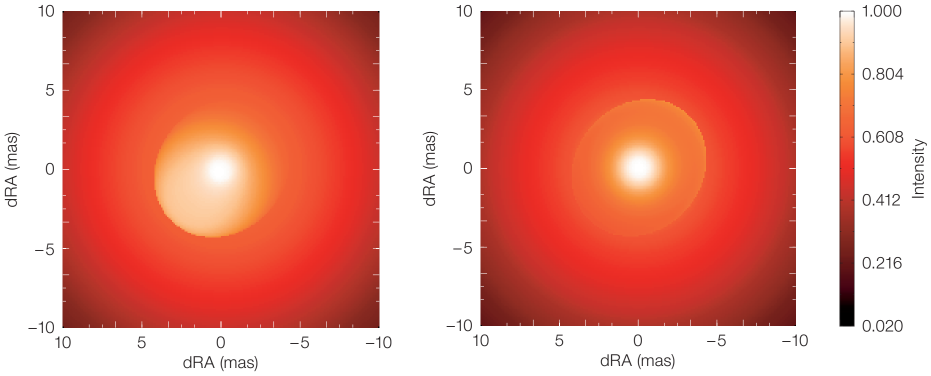


Figure 3: **Left panel:** ηCar's AMBER visibilities (red lines) compared to model predictions (green lines) in the spectral regions of the Brγ and HeI emission lines (from left to right: Brγ, high spectral resolution 12 000; Brγ, medium spectral resolution 1 500; and HeI, medium spectral resolution 1 500). The figure shows the spectra (upper row) and the wavelength dependence of the visibilities (lower three rows; three different projected baseline lengths). **Upper right panel:** Illustration of the components of the geometric model for an optically thick, latitude-dependent wind (for the weak aspherical wind component, we draw the lines of latitudes to illustrate the 3D-orientation of the ellipsoid). **Bottom right panels:** for two representative wavelengths, the total brightness distribution of the model including the aspherical wind component and the contributions from the two spherical constituents. From Weigelt et al. (2007).

sponsible for the mid-IR emission (mostly coming from dust) and for the near-IR emission (probably resulting from a complex interplay among the radiation from the central star, the tail of hot-dust emission as well as free-free and free-bound radiation from the fast polar wind and the disc-wind interaction). By adopting elliptical Gaussian models with wavelength-dependent diameters, typical angular sizes of the major-axes derived are 3.4 mas (8.5 AU adopting a distance of 2.5 kpc) in the continuum at 2.2 µm, 5.2 mas (13 AU) in the Brγ emission line, and 15 mas (38 AU) in the continuum at 12 µm. These spectro-interferometric VLTI results provide direct evidence for a multi-component environment around B[e] supergiant stars supporting the non-spherical, gaseous, and dusty circumstellar envelope paradigm for these complex objects.

Mass loss from massive stars

One of the most luminous, most massive, and unstable Luminous Blue Variable stars, η Carinae, is suffering from an extremely high mass-loss rate. A variety of observations suggest that the central source of this object is a binary, even if it is still a matter of debate. η Car was observed with AMBER (Weigelt et al. 2007) at two different epochs using three Unit Telescopes and both medium and high spectral resolutions in the spectral regions around the HeI and Brγ emission lines.

The visibility measurements revealed and resolved the η Car's optically thick wind region (see left part of Figure 3). Comparing the AMBER continuum visibilities with recent NLTE radiative transfer models, a very good agreement is found. In both the Brγ and the HeI emission lines, non-zero differential phases and non-zero closure phases were measured, indicating a complex and asymmetric object structure. Weigelt et al. (2007) developed a model which shows that the asymmetries measured within the wings of the Brγ line with differential and closure phases are consistent with the geometry expected for an aspherical, latitude-dependent stellar wind (see right part of Figure 3).

Colliding wind binary in late stellar evolution

The Wolf-Rayet (WR) and O star binary system γ^2 Velorum was observed using AMBER in medium-resolution mode (Millour et al. 2007). Signals strongly varying through the broad Wolf-Rayet (WR) emission lines were observed and interpreted in the framework of a simple model that consists of two unresolved sources, whose flux ratio (close to one) is strongly wavelength dependent due to the strong emission of WR lines. Millour et al. (2007) demonstrated that the combination of differential visibility, differential phase and closure phase, as a function of the wavelength, allows both the angular separation of the binary components to be retrieved and their respective spectra to be extracted, leading to a direct measure of the distance of the system. It is found to be significantly larger than the Hipparcos-determined distance, placing the target in the Vela OB association. One of the by-products is a direct and model-independent measurement of the spectrum of the WR component, improving the modelling of this star. Furthermore, the signature of the circumstellar material is revealed in tens of spectral channels by a 5 to 10σ residual between the AMBER measurements and the binary model. These significant residuals allow speculations on the nature of the corresponding emission, probably associated with the wind-wind collision zone that contributes both to the emission lines and to the free-free continuum.

The outburst of the recurrent nova RS Oph

The famous recurrent nova RS Ophiuci exploded on 12 February 2006, an event expected since the previous outburst that occurred only 21 years ago. The extension of the expanding milliarcsecond-scale emission was measured by AMBER only five days after the discovery using three telescopes and the medium spectral resolution in the *K*-band continuum, the Brγ 2.17 μm line and the He I 2.06 μm line (Chesneau et al. 2007). Unfortunately, the 200 km s^{-1} spectral resolution was unsufficient to get a deep insight into the kinematics of the outflowing material ejected at high velocities. The low visibilities in the lines, compared to their values in the nearby continuum, are consistent with extended line-forming regions, the He I emission being formed in the fastest ejecta, close to the shock front. Both the continuum and the line emissions are highly flattened, sharing apparently the same global geometry, at different scales (see Figure 4). In addition, two radial velocity fields were detected in the Brγ line: a *slow* (~ 1800 km s^{-1}) expanding ring-like structure and a *fast* (~ 3000 km s^{-1}) structure extended in the East-West direction, a direction that coincides with the jet-like structure seen in the radio domain. These results demonstrate the capabilities of the VLTI to study the geometry and the kinematics of the earliest stages of nearby, i.e. few kiloparsec distant, recurrent or classical nova explosions.

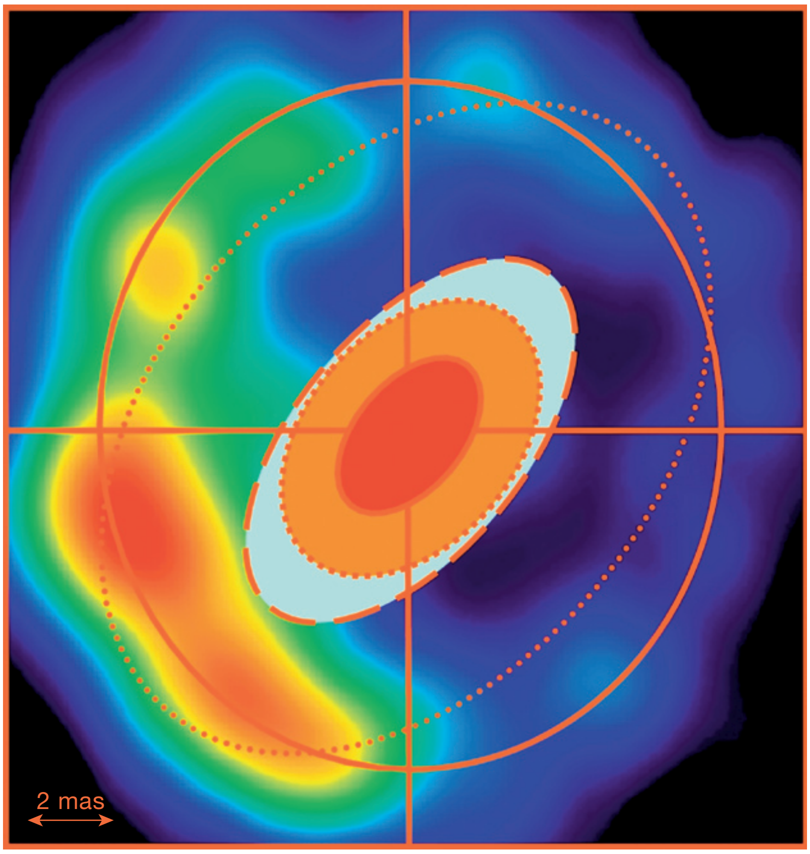


Figure 4: Sketch of the fitted elliptical extension in the near-IR for RS Oph nova at t = 5.5 d compared with the radio structure observed at t = 13.8 d (thick extended ring). The continuum ellipse is delimited by the solid line, the ellipse that corresponds to the core of Brγ by the dotted line and the one corresponding to the core of He I by the dashed line. The outer small dotted line delimits the Brγ ellipse scaled at t = 13.8 d. North is up, East left. From Chesneau et al. (2007).

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References

Chesneau O. et al. 2007, A&A 464, 119
Domiciano de Souza A. et al. 2007, A&A 464, 81
Malbet F. et al. 2007, A&A 464, 43
Meilland A. et al. 2007a, A&A 464, 73
Meilland A. et al. 2007b, A&A 464, 59
Millour S. et al. 2007, A&A 464, 107
Petrov R. et al. 2007, A&A 464, 1
Tatulli E. et al. 2007, A&A 464, 55
Weigelt G. et al. 2007, A&A 464, 87