The large scale environment of Betelgeuse from radio observations

Thibaut Le Bertre[1], Lynn D. Matthews[2] & Eric Gérard[1]

[1]CNRS & Paris Observatory, France

[2]MIT Haystack Observatory, USA

Outline: We present HI data obtained with the Nançay Radiotelescope and with the Very Large Array (VLA) on the red supergiant α Ori (Betelgeuse). The high spectral resolution allows us to identify three components emitting in narrow spectral lines (FWHM ~ 3 km/s).

By selecting different ranges of baselines from the VLA data, it is possible to obtain images revealing different structures in the environment of α Ori. The confusion arising from the emission by the interstellar medium on the same line of sight can also be identified and thus be mitigated by filtering short spacings.

The HI data reveal a quasi-stationary detached shell of neutral atomic hydrogen ~4 arcmin in diameter (~0.24 pc at 200 pc), and also atomic hydrogen emission associated with the 6 arcmin radius far-infrared arc discovered by IRAS.

Context: Red supergiants are massive stars in a short evolutionary stage preceding a supernova explosion. They have an extended atmosphere and lose matter at a high rate. They contribute to the enrichment of the interstellar medium (ISM), directly through mass loss, and indirectly as progenitors of supernovae or Wolf-Rayet stars. However, they are rare and many processes acting in these objects are not well understood.

α Ori is the closest red supergiant (d ~ 200 pc). As such it is a privileged target for detailed studies of this class of objects. The stellar surface is now resolved with interferometric techniques at near-infrared wavelengths (Φ ~ 45 mas, or 9 au, Hautbois et al. 2009, A&A, 508, 923, above right). The ejected material has been imaged at mid-infrared wavelengths (Kervella et al. 2011, A&A, 531, A117, right). These images revealed a complex structure of the circumstellar envelope that extends from a few au to a few 10^3 au. Further away the stellar wind is seen to interact with the surrounding medium (IRAS, Noriega-Crespo et al. 1997, AJ, 114, 837, below).

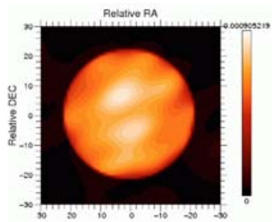


Image at 1.64 µm of the photosphere. The field is 0.06 arcsec by 0.06 arcsec.

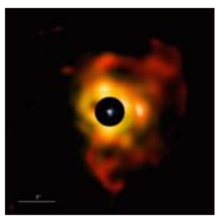
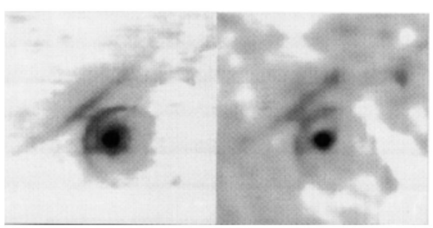
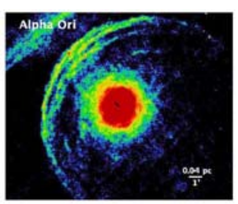


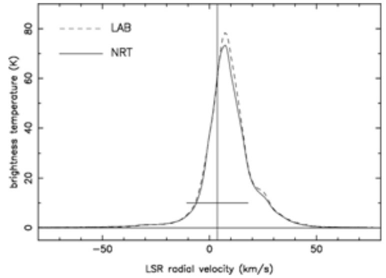
Image at 10 µm of the inner circumstellar shell. The field is ~6 arcsec by 6 arcsec.



IRAS images at 60 and 100 µm. The field is ~1°x1°. Note the far-IR arc of ~6 arcmin radius northeast, in the direction of the star's space motion.

The far-infrared arc discovered by IRAS has been resolved in several thin shells by Herschel (Cox et al. 2012, A&A, 537, A35, right). This structure has been interpreted as a bow shock resulting from the interaction of the stellar wind with the surrounding ISM. It has also been detected in the FUV by GALEX (Le Bertre et al. 2012, MNRAS, in press, arXiv:1203.0255).





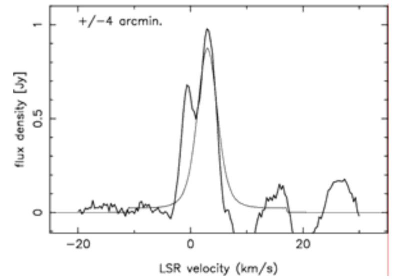
Frequency-switched spectrum obtained at the NRT in the direction of α Ori compared to the spectrum from the Leiden-Argentine-Bonn (LAB) atlas (Kalberla et al., 2005, A&A, 440, 775). Both spectra are dominated by ISM emission along the line of sight.

The far environment of Betelgeuse can give clues on the past history of mass loss, and on the injection of stellar matter in the ISM. Radio observations in the HI line at 21 cm may give unique information on the kinematics in this region.

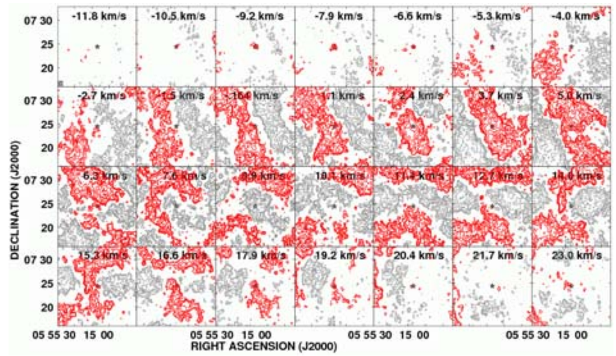
However the spectra at 21 cm in the direction of α Ori are dominated by the emission of interstellar matter on the same line of sight (left). The horizontal bar represents the velocity extent of the CO emission from the α Ori stellar wind (Huggins 1987, ApJ, 313, 400), corresponding to a stellar radial velocity, $V_* = 3.7$ kms^{-1} (vertical line), and a wind expansion velocity, $V_{exp} = 14.3$ kms^{-1}.

On the other hand, position-switched observations obtained with the Nançay Radiotelescope (NRT) have revealed an HI source of diameter ~4 arcmin, centered on α Ori. The line profile is narrow (FWHM~3 kms^{-1}) and centered on the stellar radial velocity (right).

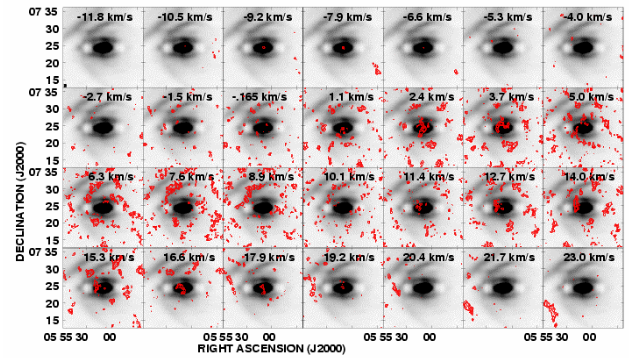
Observations have been obtained with the Very Large Array (VLA) in the C configuration (0.08 to 3.2 km baselines; Bowers & Knapp 1987, ApJ, 315, 305) and in the D configuration (0.035 to 1.0 km baselines; Le Bertre et al. 2012, MNRAS, in press, arXiv:1203.0255).



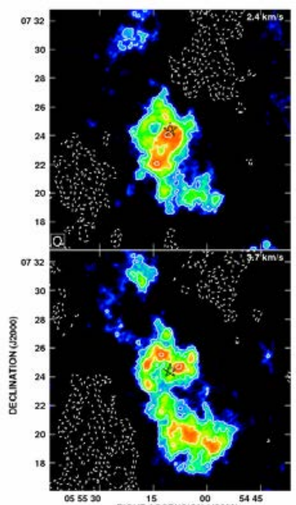
Position-switched spectrum obtained at the NRT (+/- 4 arcmin) in the east-west direction.



VLA channel maps, all baselines. The positive contours are in red, and the negative ones in grey. The synthesized beam has a size of ~35 arcsec.



VLA channel maps, restricted to baselines > 0.4 kλ (0.084 km). The negative contours have been suppressed. The background image is extracted from the IRAS survey at 60 µm. Note the association of HI emission with 60 µm emission in the four channels from 6.3 kms^{-1} to 10.1 kms^{-1}.



Channel maps at 2.4 kms^{-1} (top) and at 3.7 kms^{-1} (bottom). The star symbol marks the position of α Ori. These two channel maps are restricted to baselines > 0.2 k λ (0.042 km).

The data from the VLA C and D configurations have been combined. The resulting channel maps are presented (above left). The large-scale Galactic emission is poorly spatially sampled, resulting in patterns of strong positive and negative mottling across a number of channel maps. Despite this contamination, two emission features coincident with α Ori can be seen from -9.2 to -6.6 kms^{-1} and from 17.9 to 19.2 kms^{-1}. These features correspond to the extreme velocities expected from the wind of α Ori.

Furthermore, in the 2.4 and 3.7 kms^{-1} channel maps, there is a source of ~4 arcmin (0.24 pc at a distance of 200 pc) that is better seen when the data are restricted to baselines larger than 0.2 k λ (left), thanks to the filtering of the extended interstellar emission. The line profile and the size correspond to the source detected by the NRT. Emission peaks delineate a ring around α Ori. A tail in the direction opposite to the star's space motion is also visible. This structure is similar to the quasi-stationary detached shells observed around a number of Asymptotic Giant Branch stars (e.g. Libert et al. 2007, MNRAS, 380, 1161; Matthews et al. 2008, ApJ, 684, 603).

In order to facilitate the identification of small-scale features, we have also produced channel maps by restricting the baselines to those larger than 0.4 kλ (above right). These maps reveal a clear association of the HI emission in the four channels from 6.3 to 10.1 kms^{-1} with the far-IR arc discovered by IRAS. These velocities match the peak of interstellar emission. It is thus likely that the arc discovered in the far-IR is related to the compression of the interstellar medium surrounding α Ori by its stellar wind.

On the other hand, in the 2.4 and 3.7 kms^{-1} channel maps, only the peaks of emission remain. Selecting large baselines is very efficient in reducing the confusion, by cancelling the extended interstellar emission. This allows us to discover new features hidden by the confusion. However, it also removes part of the genuine emission from the source !

Summary: A quasi-stationary detached circumstellar shell of ~4 arcmin in diameter (~0.24 pc) has been detected in HI emission around α Ori.

The far-IR arc discovered by IRAS has also been detected in HI, but in a velocity range different from the detached shell.

Multi-configuration VLA data have allowed us to uncover circumstellar HI structures on a variety of spatial scales and to disentangle emission associated with α Ori from the ISM.

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