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The structure of the Proto-Planetary Nebula OH 231.8+4.2 as revealed by VLTI and MERLIN interferometric observations

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We present recent interferometric observations made with the VLTI/MIDI intrument and MERLIN towards OH 231.8+4.2 allowing us to investigate the circumstellar material morphology from very near to the central object to far out where the OH masers are found. The VLTI observations revealed that the shape of the central core is not the same at 8 and 13 μm, possibly due to emission from the dust being heated by the hot companion. The MERLIN observations in the 1667-MHz OH maser line revealed a well-organised magnetic field embedded in the outflow, possibly originating from the compact core suggested by the VLT/VLTI infrared observations. A correlation between the geometric structure and the magnetic field orientation is found. A tentative model of the overall geometric and magnetic structure of the circumstellar material surrounding OH 231.8+4.2 that takes into account all the dynamical and physical characteristics inferred from both the mid-infrared and OH maser results is presented.

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1. Introduction

Evolved stars during the AGB and especially the post-AGB phase develop markedly non-spherical circumstellar shells, evolving later into planetary nebulae. The physical mechanisms causing this runaway change in morphology from spherical to aspherical are still disputed: binarity, rotation and magnetic fields are being considered. OH 231.8+4.2 also known as the Rotten-Egg or the Calabash nebula, is located in the open cluster M46 at a distance of about 1.5 kpc. It is considered to be the prototype of bipolar proto-planetary nebulae. Yet, the central object is thought to be an intermediate-mass evolved AGB star with a progenitor mass of approximately 3 $M_\odot$ ([6]). Observations over a wide range of wavelengths have revealed its structure over size scales ranging from milliarcseconds to arcminutes. Infrared imaging revealed a highly complex nebula consisting of several substructures. In particular, the VLT/VLTI observations made with the NACO camera and MIDI interferometer ([8]) revealed the presence of a very compact dusty structure in its core (40-50 AU). Masers are a particularly powerful probe to explore both the geometrical structure of the circumstellar material and the dynamics, as they yield high angular and velocity resolution. SiO masers probe the innermost part of the circumstellar shell ([4], [12]) while H_2O masers probe intermediate regions ([9], [13]). OH masers found far away from the star can also probe the polarimetric properties at the maser location ([1], [5]). Both SiO and H_2O masers have been detected towards OH 231.8+4.2 over a total extent of 10 mas and 90 mas respectively ([3]). OH 231.8+4.2 is also a strong emitter in the OH ground state line at 1667 MHz. This strong maser emission, radiated by the circumstellar material around OH 231.8+4.2, has been mapped previously in 1988 with an angular resolution of 1 arcsec with the VLA ([14]). A torus/disk-like structure and the outflow material were detected covering a total extent of 10 arcsec.

This work presents the general geometric and magnetic structure of the circumstellar material surrounding OH 231.8+4.2 as inferred from mid-infrared VLTI/MIDI observations and high spectral resolution MERLIN observations taken in polarimetric mode at radio wavelength.

2. Observations

MERLIN phase-referenced observations of OH 231.8+4.2 in spectroscopic and full polarimetric mode in the OH ground state maser line at 1667 MHz were obtained in April 2005. In order to achieve high spectral resolution (i.e., 0.17 km s^{-1} degraded to 0.34 km s^{-1} in the final datasets to increase the signal to noise of each individual spectral channel map), two velocity settings were used, with the central (brightest) peak at V=+20 km s^{-1} incorporated in both settings and used to test the alignment of the data sets. The observations covered the full velocity range of the OH emission, from -20 to +80 km s^{-1}. The angular resolution is about 0.2 arcsec. The stellar velocity is taken to be V$\simeq$+35 km s^{-1}, that is, centered on the strongest central peak detected in ^{12}CO by [11] and corresponding roughly to the middle point of the OH maser velocity range.

The VLTI/MIDI interferometer operates like a classical Michelson interferometer to combine the mid-infrared light (N band, 7.5-13.5 μm). The observations of OH 231.8+4.2 have been performed in February and March 2007 in addition to the runs obtained in 2006 and reported by [8].

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Table 1: Journal of observations with MIDI

		Projected	Baseline		Projected	Baseline	
Star	Date	Length	P.A.	Star	Date	Length	P.A.
		(m)	(deg)			(m)	(deg)
OH231 (OB1)	04/02/07	46.62	44.61	OH231 (OB1’)	02/03/06	61.70	112.0
OH231 (OB2)	04/02/07	44.60	47.80	OH231 (OB2’)	02/03/06	58.90	116.2
OH231 (OB3)	03/02/07	42.36	24.12	OH231 (OB3’)	02/03/06	52.80	123.8
OH231 (OB4)	03/02/07	46.23	40.64	OH231 (OB4’)	02/03/06	47.40	131.2

A typical MIDI observing sequence was used as described in [7]. Visibilities have been obtained at different projected lengths (47-62 metres), but similar position angles (112-131 degrees). The observing log is summarised in Table 1.

3. Results

Figure 1 presents the Stokes I spectrum for the 1667-MHz maser emission detected by MERLIN and for comparison, in the top-right corner, that of the VLA for the observations obtained in 1988 with this instrument (taken from [14], their Fig. 4). The comparison with the former observations obtained with the VLA clearly shows that mostly foreground (blueshifted) OH emission is detected by MERLIN: the redshifted counterpart detected by the VLA appears to be mainly made of more extended emission and is not picked up by the MERLIN interferometer, while the blueshifted emission consisting of more compact components is detected by both interferometers. The right hand-side corner of Fig. 1 presents a single-dish observation of the source taken with the Nançay Radio Telescope (NRT). The extended nature of the redshifted emission is confirmed by the single-dish observation. The blueshifted emission is most likely amplifying a continuum radiation located between the central object and the OH material, the nature of which has still to be identified.

Figure 2 presents the alignment of the velocity map of the OH maser emission with the infrared L’-band image obtained at the VLT by [8]. The right panel of Fig. 2 shows the detailed maser spot distribution on which the polarimetric information is superimposed. The OH maser emission is located to the south and east, within the darker lane seen in the L’-band image, and traces the waist of the trapezium, allowing for orientation and projection effects. The maser spot distribution clearly delineates a ring-like structure. The velocity field shows a clear gradient with the northern part of the ring-like structure being entirely dominated by the bluest components ($V_{LSR} \simeq [-0.3;+10]$ km s^{-1}) and the southern part by less blueshifted components (typically $V_{LSR} \simeq [+20;+30]$ km s^{-1}). The reddest emission is found to lie on the edge of the ring-like structure. The spatial distribution and the velocity field observed are inconsistent with an expanding torus but are consistent with each other if we are observing the blueshifted rim of a biconical outflow tilted toward us. The rim would therefore delineate the interface where the fast outflow caught up the much slower older AGB envelope.

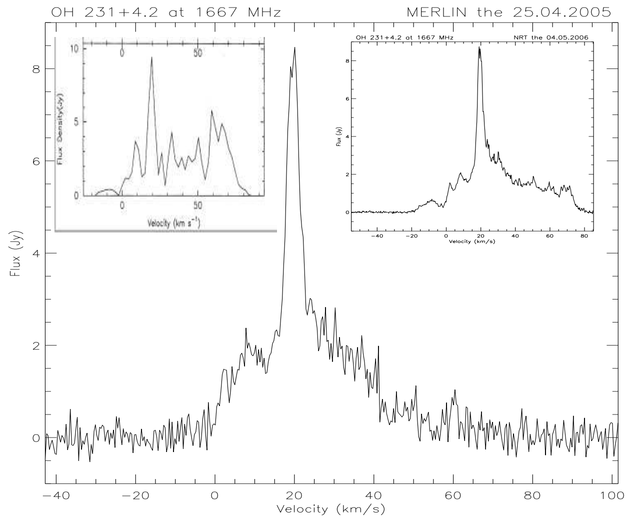

Figure 1: MERLIN Stokes I spectrum. Also shown for comparison purpose is the VLA spectrum from [14] in the left hand-side corner and the NRT spectrum in the right hand-side corner.

The former infrared observations by [8] revealed that the central region contains a bright, very compact, unresolved source. To see if this structure was a dusty disc similar to the ones observed at the heart of some planetary nebulae ([2]), observations of this bright central source were taken with the VLTI mid-infrared recombiner MIDI. The Gaussian fit to the MIDI visibilities provide a measurement of the size of the observed structure along the baseline direction. The right panel of Fig. 2 shows that the shape of the structure depends on the wavelength. At 8 μm, the dusty structure is 1.3 times more extended along the equator than along the poles of the nebula. At 13 μm, this structure has almost the same dimension in all directions. These visibilities shows that there is a flattened structure at 8 μm that could correspond to the inner rim of the dusty environment, embedded in a more spherical dusty halo.

Former observations of the OH maser emission in the ground-state line at 1667 MHz by [14] obtained with the VLA picked up both extended and compact emission coming from both the outflow and the “disk-like” structure. On the other hand, MERLIN “filtered out” the more extended redshifted counterpart. Left panel of Fig. 3 presents the maser spot distribution for the 1667 MHz maser emission detected by MERLIN towards OH 231.8+4.2. Also displayed is the polarisation information for those maser spots exhiting a linearly polarised intensity greater than 3 σ. The vectors superimposed on the maser spots are rotated vectors of polarisation so as to directly indicate the orientation of the magnetic field lines. Accounting for the projection effect, these vectors indicate magnetic field lines ’flaring out’ of the ring-like structure. The right panel of Fig. 3 presents a tentative model of the overall geometric and magnetic structure of the circumstellar material surrounding OH 231.8+4.2 as inferred from both the mid-infrared and OH maser results. A poloidal field in the outflow is consistent with the magnetic field observations of [10].

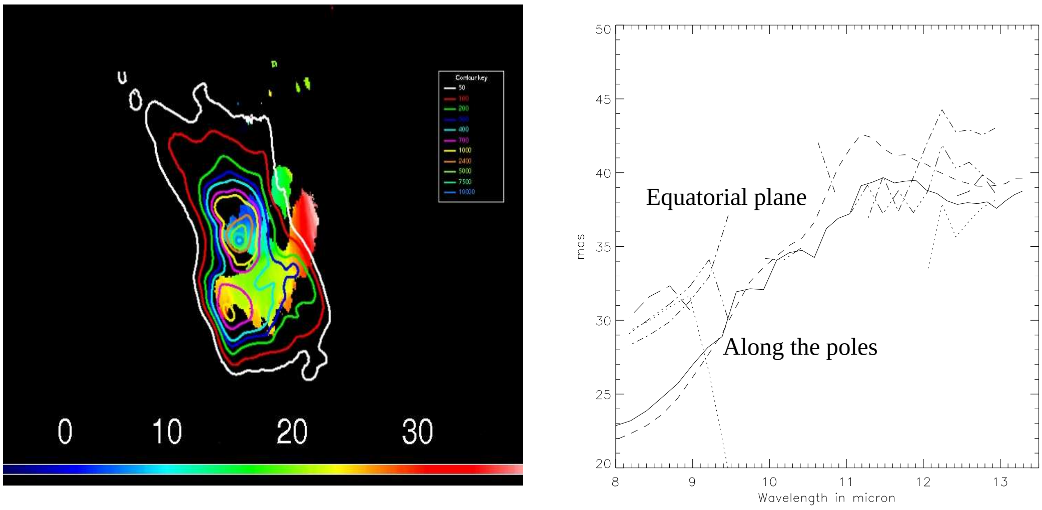

Figure 2: The left panel presents the alignment of the infrared L'-band image obtained at the VLT by [8] with the velocity map of the 1667-MHz maser emission superimposed. The right panel presents the Gaussian fit of the MIDI visibilities for different baselines.

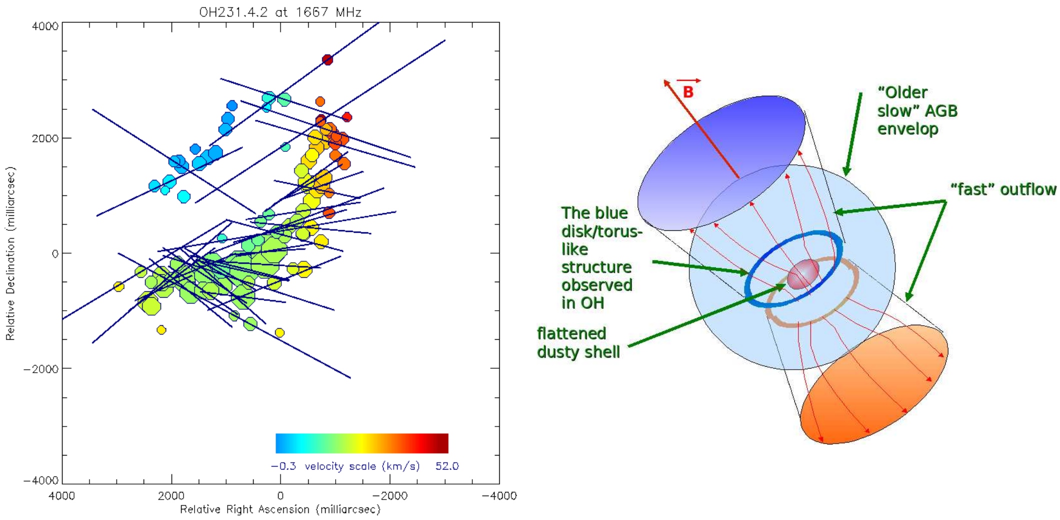

Figure 3: The left panel presents the maser spot distribution. The orientation of the magnetic field lines associated with each individual maser spot is also shown. The right panel presents a tentative model that accounts for the velocity distribution as well as magnetic field structure inferred from the 1667 MHz maser emission.

4. Conclusion

We presented new results based on interferometric observations obtained in mid-infrared at 8 and 13 μm with the VLTI/MIDI instrument and at radio wavelength in the OH ground-state maser line at 1667 MHz obtained with MERLIN. This allowed us to study the overall geometric and magnetic structures of the circumstellar material surrounding the proto-planetary nebulae OH 231.8+4.2. The VLTI observations showed the presence of a flattened dusty structure at the centre of the system elongated in the equatorial direction. This structure could correspond to the inner rim of the dusty environment, embedded in a more spherical dusty halo. While single dish observations obtained with the NRT in the 1667-MHz OH maser line shows the presence of redshifted emission, MERLIN only detected the blueshifted emission made of compact maser spots. The blueshifted emission is most likely amplifying a continuum radiation located between the central object and the OH material, the nature of which has still to be identified. The 1667 MHz emission detected by MERLIN delineates accurately a blueshifted ring-like structure. A clear gradient in the velocity field is seen along that ring. The ring-like structure is interpreted as the rim interfacing the old AGB wind and the outflow. Finally, the polarimetric structure inferred from the OH maser emission attests to a well-organised magnetic field “flaring out” in the outflow direction.

References

[1] Bains, I., Gledhill T.M., Yates, J.A., & Richards, A.M.S. 2003,MNRAS, 338, 287

[2] Chesneau, O., Lykou, F., Balick, B., Lagadec, E., Matsuura, M., Smith, N., Spang, A., Wolf, S. & Zijlstra, A.A. 2007, A&A 473L, 29

[3] Desmurs, J.-F., Alcolea, J., Bujarrabal, V., Sánchez Contreras, C. & Colomer, F. 2007, A&A, 468, 189

[4] Diamond, P.J. & Kemball, A.J. 2003, ApJ, 599, 1372

[5] Etoka, S., & Diamond, J.P. 2004, MNRAS, 348, 34

[6] Jura, M., & Morris, M. 1985, ApJ, 292, 487

[7] Leinert, C., et al. 2003, SPIE, 4838, 893

[8] Matsuura, M., Chesneau, O., Zijlstra, A. A., Jaffe, W., Waters, L. B. F. M., Yates, J. A., Lagadec, E., Gledhill, T., Etoka, S., & Richards, A. M. S. 2006, ApJ, 646L, 123

[9] Richards, A.M.S., Yates, J.A. & Cohen, R.J. 1999, MNRAS, 306, 954

[10] Sabin., L., Zijlstra, A.A., & Greaves, J.S. 2007, MNRAS, 376, 378

[11] Sánchez Contreras, C., Alcolea, J., Bujarrabal, V., & Neri, R. 1997 A&A, 327, 689

[12] Soria-Ruiz, R., Alcolea, J., Colomer, F., Bujarrabal, V. & Desmurs, J.-F. 2007, A&A, 468L, 1

[13] Vlemmings, V.H.T., van Langevelde H.J., & Diamond P.J. 2005, A&A, 434, 1029

[14] Zijlstra, A. A., Chapman, J. M., te Lintel Hekkert, P., Likkel, L., Comeron, F., Norris, R.P., Molster, F. J., & Cohen, R. J. 2001, MNRAS, 322, 280

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