
Resolving the dusty discs around post-AGB binaries

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Summary. Although the presence of a circumbinary disc around binary post-AGB stars is now well established, its actual structure but also its formation, stability and evolution remain largely unknown. We therefore used the MIDI interferometer to observe the discs around a sample of 9 post-AGB binaries. These measurements show the very compact nature of the circumstellar environment and confirm the disc interpretation of their SED. In addition, a large diversity is observed in the radial distribution of the crystallinity over the N-band. While some objects show a homogeneous distribution of the crystallinity, for some objects the crystallinity is confined to the inner most regions. Whether this is a result of the formation process or due to annealing during the long storage time in the disc is not clear. Moreover, using the combination of AMBER and MIDI, we were able to constrain with extreme detail the dust geometry for one target. We modeled the circumstellar environment for this target using a passive disc in hydrostatic equilibrium and find that the dust around this evolved target is indeed locked in such a circumbinary disc in which the inner rim is largely puffed up.

Key words: stars: AGB and post-AGB, Stars: circumstellar matter, Techniques: interferometry

1 Introduction

One of the common observational characteristics of binary post-AGB stars is that they are surrounded by a stable dusty disc (see e.g. [8]). For these objects, the dust excess starts at dust sublimation temperature, irrespective of the effective temperature of the central star [3]. Using the equation of thermal equilibrium of blackbody dust grains, dust starting at sublimation temperature translates into a limit on the distance of these dust grains from the central star ($= d$):

$$1200 \text{ K} = T_{\text{dust}} = \left(\frac{R_*}{2d}\right)^{1/2} T_* \quad (1)$$

The effective temperature of the post-AGB objects are deduced from spectroscopy. The linear relationship between R_* and d shows that the angular size

of the hottest inner region is independent of the poorly known distance of the object given the photometric magnitudes detected. For a central star of 7500 K and a typical luminosity of $5000 L_{\odot}$, the dust sublimation radius is about 4 A.U..

Because the discs around binary post-AGB objects must be compact, interferometry is a necessary and ideal tool to study their spatial structure. Because for all objects, a large fraction of the total luminosity is emitted in the N-band, the MIDI interferometer – producing spectrally dispersed fringes in the N-band – is ideally suited, not only to resolve the compact discs, but also to obtain spatial information of the different dust components.

2 a MIDI interferometric survey in the N-band

To study the spatio-chemical nature of the dusty discs, we observed a sample of 9 objects with the MIDI instrument mounted on the VLTI. All selected objects are confirmed binaries with binary periods ranging from 288 to 1350 days (for a reference on the binarity see e.g. [8]).

In [1], a subsample of only two objects was studied, i.e. SX Cen and HD 52961. It was demonstrated that the circumstellar emission originates from a very compact region with the emission of SX Cen being unresolved even on a 45 m baseline. This implies an upper limit for the diameter of the dust emission of some 18 A.U.. Moreover, it was shown that for HD 52961, which was resolved, the dust is not homogeneously distributed in the disc. For this object, the inner regions of the disc are much more crystalline than the outer most regions. The other objects of the sample confirm the results obtained in [1] but also show diversity in their circumstellar environments.

All objects show a compact emission region with diameters ranging from 20 to about 60 A.U.. Because a dusty mass loss is not expected for the objects due to high temperature of the post-AGB star, this provides conclusive evidence for the existence of a stable reservoir around the binary. A Keplerian disc seems the most likely geometry. The disc-like nature of the circumstellar environment can be inferred from the asymmetric emission observed for some objects, with the most striking observation being IRAS 17038-4815 (see Fig. 1). This object was observed at three different projected angles (PA) for which a large difference in diameter of the emission region is observed. This clearly points to the occurrence of an inclined disc around this object.

While the circumstellar environment consists for all objects of highly processed silicate dust ([4]), large differences are observed in the spatial distribution of this processing. While two objects show an inhomogeneous distribution of the dust processing, with the crystallinity confined to the inner most regions, most objects do not show evidence for this. The distribution of the crystallinity can give important clues to the formation history of the disc. Two formation processes are proposed: the disc is formed through (1) capture of a “normal” AGB wind or through (2) non-conservative mass transfer in an interacting binary. In the first scenario, the dust enters the disc in the form of amorphous silicates (e.g. [7]), after which the inner most regions crystallize through heating above the glass temperature. In the interacting binary scenario, all grains were likely at high temperatures for a long period

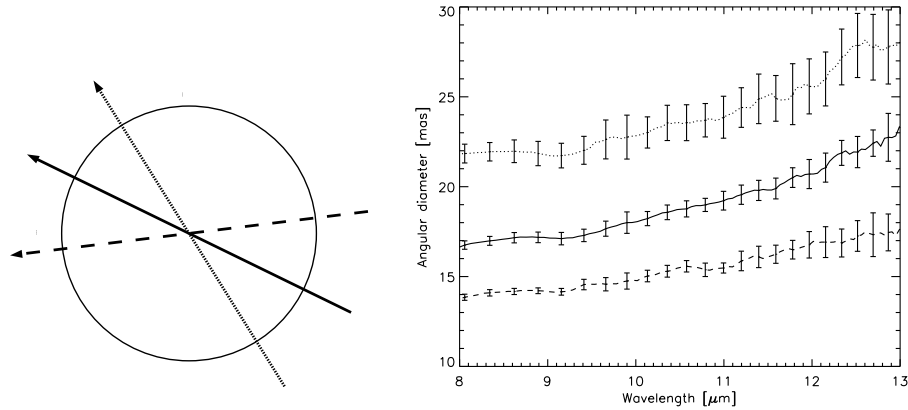


Fig. 1. The elongated emission region of IRAS 17038-4815. *Left:* A schematic diagram of the different angles under which the three measurements were performed. *Right:* The observed diameter of the N-band emission along the different angles.

of time, increasing the chance of a substantial crystallization. The large difference in the spatial distribution of the dust components in the sample could therefore be a result of a different formation history of the disc. This could be linked with the fact that indeed only the objects with the largest binary periods display an inhomogeneous dust distribution. The binary periods are, however, for all objects too small to accommodate a full grown AGB star. This would point more to the occurrence of an interacting binary scenario for all objects.

3 the dust geometry through the AMBER + MIDI combination

To determine most strongly the inner structure of the dusty environment, we probed the circumstellar disc around IRAS 08544-4431 using the AMBER and MIDI interferometer. In this manner, we got spatial information on the dusty environment in both the K and N-band, tracing two totally different temperature regimes. Moreover, the unique closure phase capabilities of the AMBER instrument allow us to detect directly the asymmetry in the dusty emission and that on milli-arcsecond scales. The object IRAS 08544-4431 was selected as an ideal case study because the binary nature of the object is well established (orbital period is 499 ± 3 days, [6]) and it is bright in both wavelength regions.

In [2], we developed, compliant with the energetics of the source, a self-consistent, passive disc model to understand the interferometric observations. The disc model contains a large inner hole, since dust cannot survive above sublimation temperature (~ 1500 K). The main consequence of this inner hole is the occurrence of a vertical boundary irradiated directly by the central post-AGB star. This results in a high temperature of this region and will cause the inner disc rim to be puffed up by gas pressure. In order to constrain the geometry self-consistently, we used a 2D

radiative transfer code developed in [5] to compute the temperature and vertical density structure of the disc.

As a first step, we determined a model which reproduces the broad band SED of IRAS 08544-4431 and constrained most parameters of the disc based on the unresolved characteristics of the sample. In [2], we show that this model, constrained solely on the basis of the spatially unresolved characteristics of the emission, reproduces the interferometry extremely well. Not only the wavelength dependent intensity distribution of our disc model (in K and N !) is fully compatible with the observations, even the strong K-band closure phase is reproduced with extreme precision.

The morphology of the dust emission reproducing the interferometry best is shown in Fig. 2. We find that the disc of IRAS 08544-4431 is seen under an inclination of 58_{-30}^{+5} deg and at an orientation of 186 ± 10 deg East of North. The SED, the non-zero closure phase and the visibilities show that the disc is circumbinary with a large puffed up inner rim (see Fig. 2).

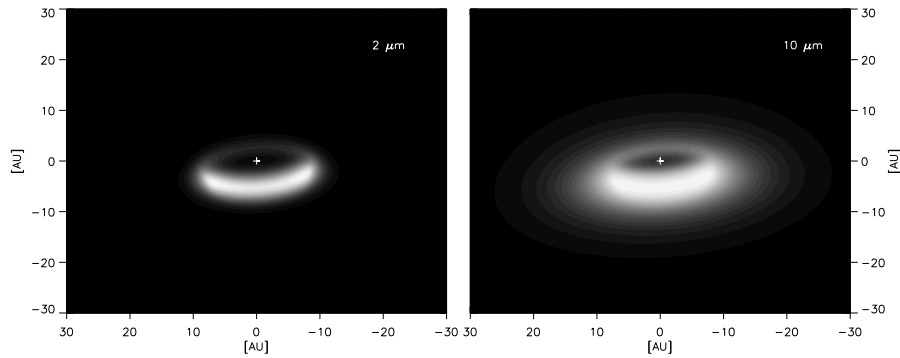


Fig. 2. The morphology of the circumstellar environment of IRAS 08544 in the K-band ($2 \mu\text{m}$, left panel) and the N-band ($10 \mu\text{m}$, right panel): North is up and East is to the left. The position angles of the baselines in the K-band are 43, 85 and 112 deg and in the N-band 49 and 58 deg. The images are contour plots using 25 equally spaced levels which are filled in greyscale. The position of the giant is indicated by the cross. The brightest region is the inner wall on the far side.

4 Conclusion:

The main conclusion of our observations is that they prove the very compact nature of the circumstellar environment for all objects. Moreover, from the combination of AMBER + MIDI, we could very stringently constrain the geometry of the dusty environment as that of a passive circumbinary disc with a large puffed up inner rim. Remark that the asymmetric nature of the circumstellar environment is found for various targets even in the N-band. A Keplerian disc is indeed the only plausible solution.

The observations also show the diversity of the sample, especially in the radial distribution of the crystalline dust. For some objects the crystallinity is confined to the inner most regions while for others it is more homogeneously distributed.

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