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Circumbinary discs around post-AGB binaries as a result of binary interactions: an infrared interferometric view

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Abstract. Post-Asymptotic Giant Branch (post-AGB) binary systems are binary interaction products. These stars have recently undergone a strong, but not well understood, binary interaction phase, leading to the formation of stable, compact circumbinary discs. These circumbinary discs are found to show many similar properties to protoplanetary discs around young stars. Here, we focus on one such system, namely IRAS 08544-4431 and resolve the inner regions of the complex circumstellar environment using multi-wavelength infrared interferometric techniques. The visibility data of PIONIER (H-band), GRAVITY (K-band), and MATISSE (L and N band) are analysed together using two families of geometric models, giving a good fit to all data.

Keywords. stars: AGB and post-AGB, binaries, circumstellar material, individual: (IRAS08544-4431), techniques: interferometric, high angular resolution

1. Introduction

Circumstellar discs are not only observed around young stellar objects (YSOs) but they are also present around various types of evolved stars. In this study, we focus on circumbinary discs around evolved low to intermediate mass ($0.8 - 8$ $M_{\odot}$) binary systems. The presence of circumbinary discs around post-Asymptotic Giant Branch (post-AGB) binaries has been well established (De Ruyter *et al.* 2006; van Aarle *et al.* 2011; Van Winckel 2003, 2017). Photometric observations of such targets show an infrared excess in the spectral energy distributions (SEDs), the shape of which provides observational evidence of the presence of a stable circumbinary disc in the system. Fig. 1 shows an example of a SED of one of the post-AGB binary systems in the Galaxy.

Post-AGB binaries are believed to have undergone strong binary interaction during their evolution. These systems can, therefore, be considered as prime targets to study the outcome of binary interaction. While the presence of these discs is observationally well established, their formation process is not well understood yet (see e.g. the reviews by Van Winckel 2017 and De Marco & Izzard 2017). Moreover, the dynamical evolution of the central binary is poorly understood as the observed orbital properties of the total sample do not match the predicted ones. Many post-AGB binaries have periods and eccentricities unaccounted for in binary synthesis models (e.g. Oomen *et al.* 2018). Moreover, we do not yet identify these post-AGB systems as the progeny of AGB binary systems that have been found with e.g. the ALMA large program ATOMIUM (Decin *et al.* 2020). In this contribution we focus on the structure of the circumbinary discs as part of our longer-term goals to constrain the formation and evolution of these binary systems.

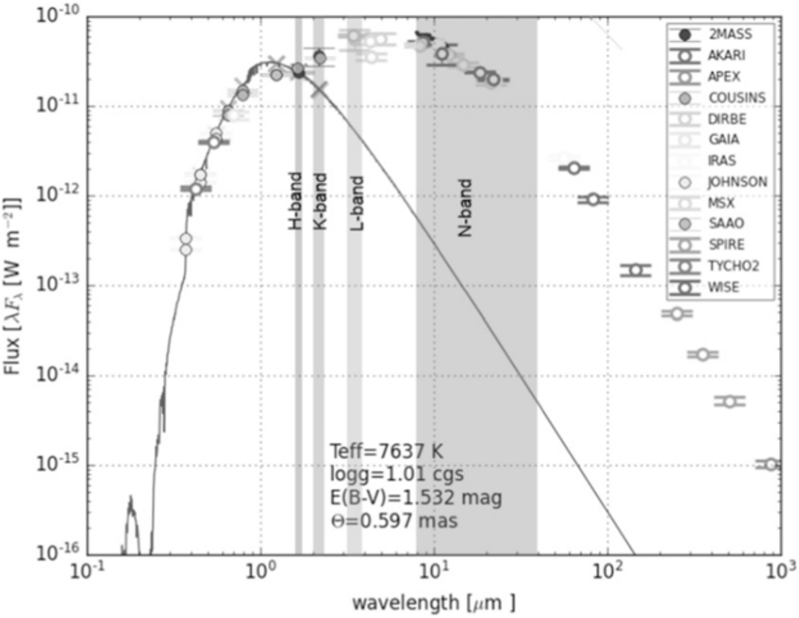

Figure 1. SED of the post-AGB binary system IRAS 08544-4431, showing the reddened photosphere of the star (full line) and the photometric data from several missions as well as the wavelength bands of interest for this study. Figure adapted from Oomen *et al.* (2018).

The circumbinary discs around these evolved binary systems show many similarities with protoplanetary discs around YSOs, despite their very different formation scenarios. Similarities include the stability and longevity (Bujarrabal *et al.* 2013a, 2015, 2017, 2018), disc mass (a few times $10^{-3} M_{\odot}$; e.g. Sahai *et al.* 2011; Hillen *et al.* 2014, 2015), and evidence for dust growth (e.g. Gielen *et al.* 2011). We use these discs as laboratories to study the disc structure and evolution at a very different stellar evolutionary phase than what YSOs provide. This includes the study of the formation of macrostructures, eventually leading to planet formation. Here we report the results of an observing campaign using all current VLTI instruments, to reveal the structure of the very inner disc regions of one post-AGB binary system, IRAS 08544-4431.

2. Multi-wavelength infrared interferometry

Infrared interferometric techniques are needed to spatially resolve the compact infrared emission of the very inner regions of the circumbinary disc. The current instruments on the VLTI, PIONIER, GRAVITY, and MATISSE, operating in the H, K, and L and N-bands, respectively, are perfectly suited for these observations. From Fig. 1 the corresponding wavelength ranges of these bands can be inferred. It shows that the SED of IRAS 08544-4431 is shifting from a star-dominated regime in the near-infrared (near-IR) to a disc-dominated regime in the mid-infrared (mid-IR). With interferometry in the near-IR, the structure of the optically thick disc inner rim is probed. Mid-IR interferometry, however, probes deeper into the disc, beyond the inner rim. We focused on modelling the visibility data, which is one of the interferometric observables. The visibility amplitude is the amplitude of the Fourier transform of the intensity or image on the sky.

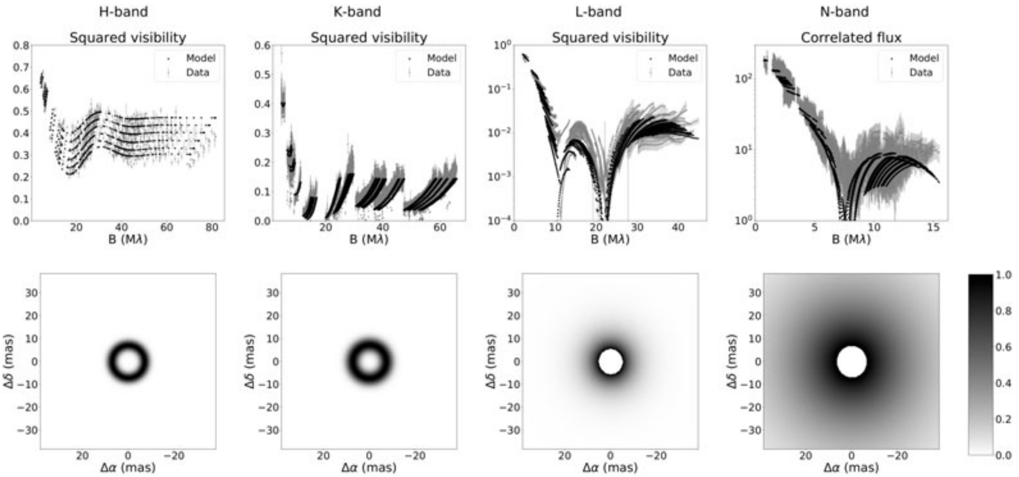

Figure 2. Top: Visibility data (grey dots) and the best-fitting geometric model (black diamonds) for the infrared interferometric bands. Bottom: images of the best-fitting geometric model of each band. Figure in gray-scale from Corporaal *et al.* (2021).

3. Results

We fitted geometric models to the visibility data of the different bands. Fig. 2 shows the visibility data overplotted with the best-fitting geometric model for the four bands and the corresponding model images. A family of geometric models was used to fit the data. Both a single temperature ring and a temperature gradient model were applied in our attempt to fit the data of each of the bands. From the χ^2 statistics, it was found that the near-IR bands were better fitted with a single temperature ring model while the mid-IR bands were better fitted with a temperature gradient model. The change of these best-fitting models from the near-IR to the mid-IR, in combination with information from the SED (Kluska *et al.* 2018), can be used to infer the structure of the inner rim of the disc. From the SED, it can be inferred that about one-third of the energy that is emitted by the post-AGB star, is captured by the circumbinary disc. To attain this amount of captured energy, a vertical extension somewhere in the disc is needed. From the difference in the best-fitting model between the near-IR and mid-IR, as well as from the amount of energy radiated by the disc in the H-band, we concluded that the vertical extension is at the inner rim. We propose that the inner rim is puffed-up and rounded, in a similar manner as protoplanetary discs around YSOs (Isella & Natta 2005).

4. Conclusions

Combining infrared interferometric instruments operating at different wavelengths, can give us an unprecedented, spatially-resolved view of the complex environment of the intriguing circumbinary discs around post-AGB binaries and of circumstellar discs in general. While in the near-IR we probe details of the inner rim of the disc, in the mid-IR we probe dust emission beyond the disc inner rim. By combining near-IR and mid-IR interferometric observations, we can conclude that the inner rim of the post-AGB binary system IRAS 08544-4431 is puffed-up and rounded. This work will be continued by modelling the disc with 3D radiative transfer models using MCMax3D (Min *et al.* 2009) with the goal of fitting both the photometric observations and the infrared interferometric observations of the four bands simultaneously.

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