INTRODUCTION. While stars of intermediate mass ascend the AGB, they lose a large fraction of their mass through a slow wind. To improve the understanding of the formation of the circumstellar structures, we observed a representative sample of such carbon stars in the 70 and 160µm band in the course of the MESS Guaranteed Time Key Programme [Groenewegen et al. 2011]. Thanks to the unprecedented spatial resolution of the PACS photometer the morphology of the cold dust component – in our sample overall spherically symmetric detached shells – is revealed.

The MESS sample of detached shells – a view at 70µm

We used 1D radiative transfer modelling in order to determine shell properties such as the dust mass, the corresponding mass-loss rate (MLR) and dust temperature and to estimate the involved timescales. Below we present the modelling approach and, as an example, show its application to the case of the carbon semiregular variable RT Cap, around which two previously unknown detached dust shells were detected for the first time Herschel.

MODELLING. The modelling of the circumstellar dust distribution was done using a modified and extended version of the radiative transfer code DUSTY [Ivezic et al. 1999], called MoD (More of DUSTY), presented in [Groenewegen 2012]. In a nutshell, it employs DUSTY in a minimisation routine in order to determine the model which fits the provided input data best. Both smooth, continuous as well as detached shells can be treated. The modelled envelope is realised by a piece-wise powerlaw density distribution (see Fig. 1). Moreover, MoD requires information about the radiation source and the dust properties. For the radiation source (i.e. the central star) COMARCS model atmospheres [Anting 2009] were adopted. The appropriate stellar parameters are selected based on [Lambert 1988]. Since the studied objects are carbon stars, a mixture of amorphous carbon [Rouleau 1991] and a small fraction of silicon carbide [Pitman 2008] was selected as the grain constituents. The optical properties of the dust were set by adopting a distribution of hollow spheres [Min 2003].

Observational constraints were photometry from the new PACS observations and archive data (VRIJHLK, IRAS). Where available, ISO SWIS spectra [Soan 2003] and IRAS LRS [Volk 1989] were included. Additionally, the new Herschel/PACS observations provide spatial information, which is incorporated by azimuthally averaged radial profiles at 70 and 160µm. This constrains the radial brightness distribution of the model in unprecedented accuracy.

The case of RT Cap. RT Cap has been observed in CO radio line emission [Olszewski 1988], however, no indications of a detached envelope were found. Examining 60 and 100µm IRAS data vaguely suggested extended dust emission and an envelope size on the scale of several arcmersions [Young 1993]. As is clearly visible now in both PACS bands, RT Cap is indeed surrounded by a remarkably thin, spherically symmetric detached shell of dust. The envelope brightness peaks at 9.4° from the star, corresponding to 0.13µm at the adopted distance of 290 pc. No offset in RA or DEC between star and shell centre is measurable within the accuracy of the PACS data. Fig 3 clearly shows that the dust is not distributed smoothly, but exhibits a rather patchy structure. Besides the shell at 9.4° we detect an additional even fainter structure further out. It is also roughly circularly shaped with a radius of ~115° (0.22 pc). For the central source, we adopt a COMARCS spectrum with a CO ratio of 1.10 and ~×250K. The dust is assumed to be an amorphous carbon mixture with 5% SiC abundance (see Fig.4). In the resulting model we obtain a dust temperature of 79K of the detached shell. For the dust mass contained therein we compute 1.0x10^-12 M_sol. We adopt an expansion velocity of 15km/s for the ejected matter. This yields a duration of enhanced mass-loss of 700–900 years for the 0.1pc thick shell, corresponding to a dust mass-loss rate of (2.3±0.6)×10^-10 M_sol/yr for the bulk material. For the dynamical age we estimate 8500 years.

Shell formation. A short period of enhanced mass-loss is the most probable primary cause of the shell formation, very likely tied to a thermal pulse. Additionally, other effects can be expected to influence the evolution of the structure. For example, a research of known detached shell objects by [Schöier 2005] found indications for younger material running into an older, slower wind. Correlations such as growing shell mass with increasing radius or a slowing down of expansion velocity are hints to such an interaction taking place. Also modelling attempts [Stephen 2000, Mattsson 2007] favour a density enhancing wind-wind interplay. In our sample, RT Cap and S Cct with their double shells are prime candidates for this scenario.

Additional influence by interaction of a stellar wind with the surrounding ISM, as discussed by [Wareing 2000], is also observed. While the case is clear for R Scii, where we see a detached bow structure outside the spherical shell, the extended structures of e.g. RT Cap and S Cct do not show strong indications of a possible wind-ISM interaction.

CONCLUSION. We have investigated the circumstellar dust structures around a sample of carbon stars. For example, we detect a prominent detached shell surrounding RT Cap plus previously unknown remains of an older mass ejection. By means of radiative transfer modelling we determined essential shell parameters such as dust mass and corresponding mass-loss rate. For the targets modelled so far, the derived MLRs confirm periods of enhanced mass-loss. We conclude that wind-wind interaction is the primary mechanism of shell formation and the interaction with the ISM is of minor importance – supported by the fact that spherically symmetric detached shell objects tend to have low space velocities [Cox 2012].

References.

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