Herschel's view on detached shells around evolved stars

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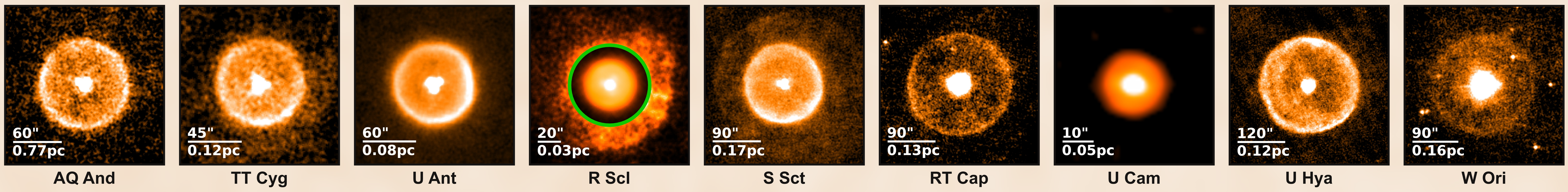
Introduction. While stars of intermediate mass ascend the AGB, they lose a large fraction of their mass through a slow wind. To improve the understanding of the formation of the circumstellar structures, we observed a representative sample of such carbon stars in the 70 and 160µm band in the course of the MESS Guaranteed Time Key Programme [Groenewegen 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.

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.

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



PACS imaging. For the mapping process SCANAMORPHOS [Roussell 2013] was used, which proved to handle the noise and drifts in the data best [Ottensamer 2011]. However, glitches in the pointing information still deteriorate the resolution of the final image. Additionally, for small objects like U Cam, deconvolution is crucial to gain as much spatial information as possible. Within the Herschel Imaging Legacy (HIL) project, funded by the Austrian FFG, we aim to enhance the PACS image reconstruction by improving on these key factors.

Modelling. The modelling of the circumstellar dust distribution was done using a modified and extended version of the radiative transfer code DUSTY [Ivezic 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 [Aringer 2009] were adopted. The appropriate stellar parameters are selected based on [Lambert 1986].
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 (VRIJHKL, IRAS). Where available, ISO SWS spectra [Sloan 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.

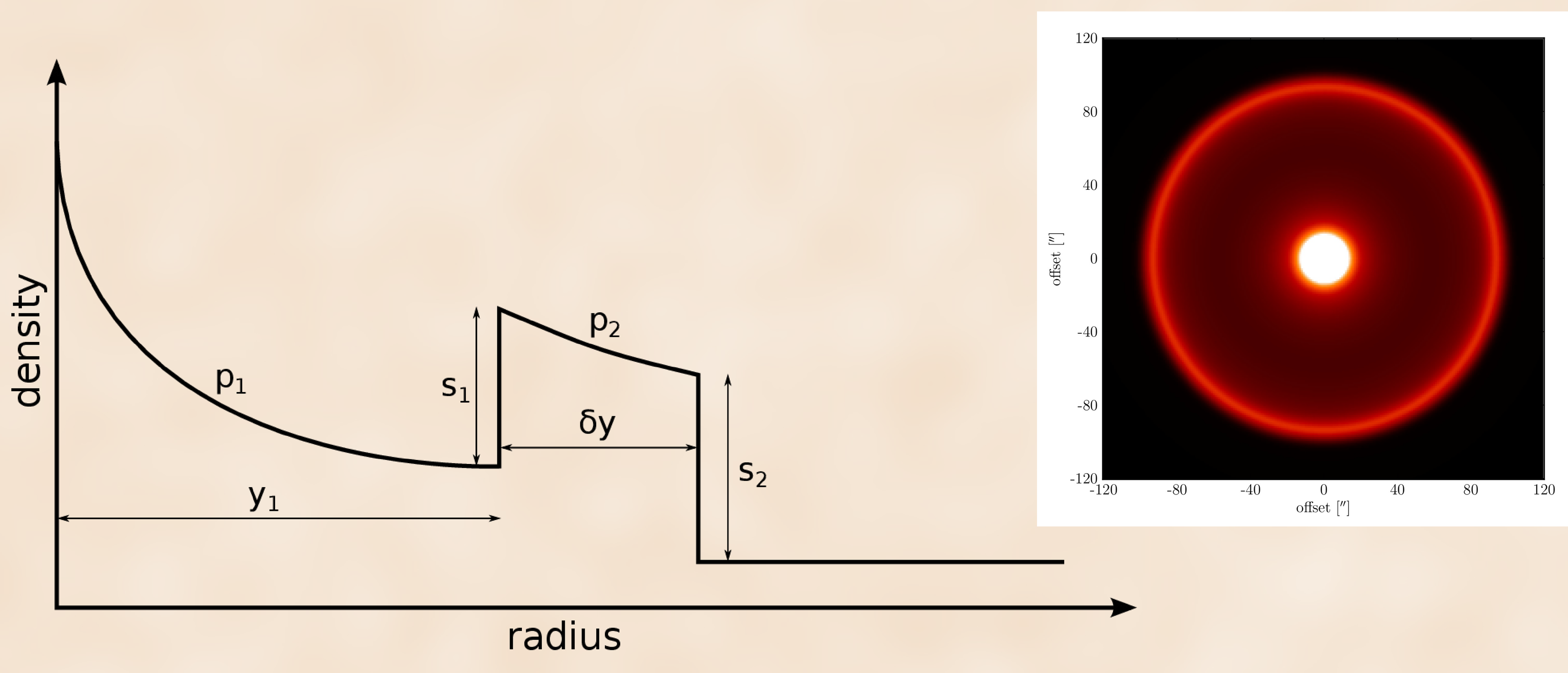


Figure 1. Scheme of the MoD radial density model and a 2D representation of the brightness distribution of a typical model shell at 70µm.

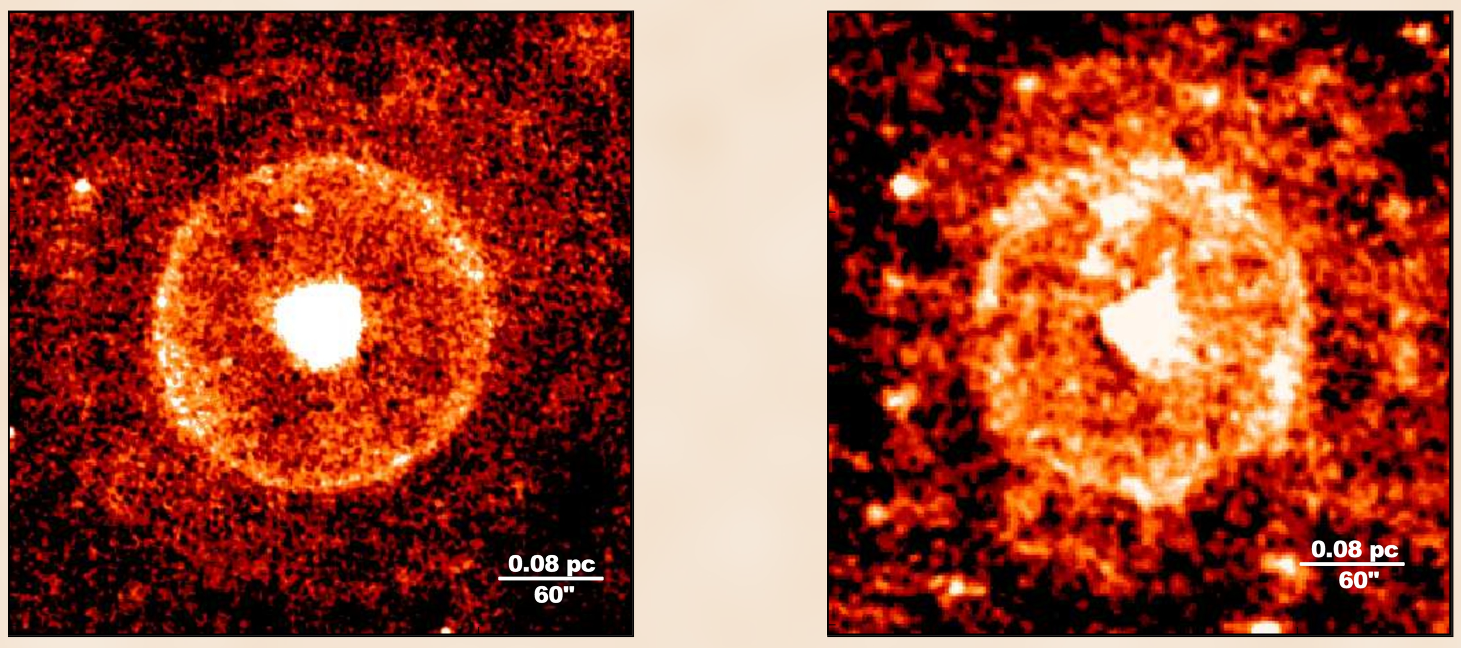


Figure 2. 70µm (left) and 160µm (right) PACS scanmaps of RT Cap. Note the almost complementary brightness distributions in the two bands in some parts of the inner ring.

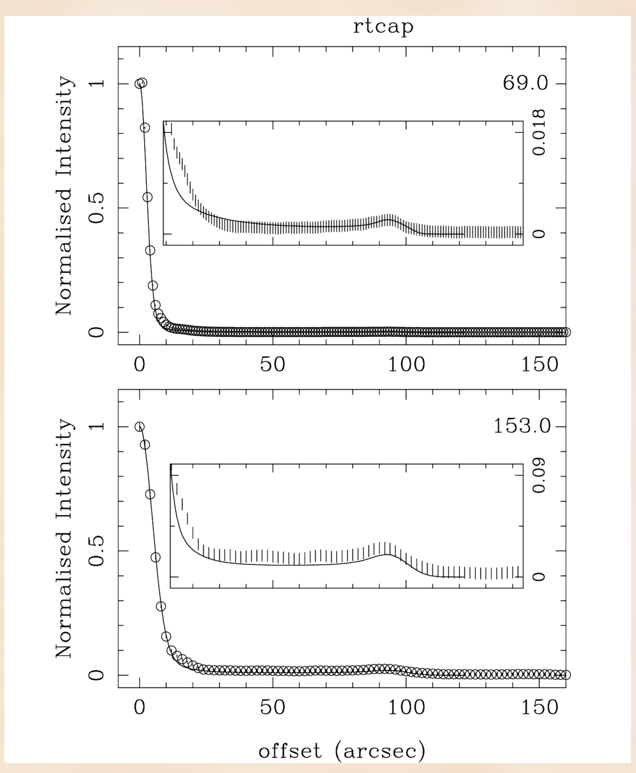


Figure 3. Best model fit (solid line) to the azimuthally averaged radial brightness distribution (circles) in the 70µm (top) and 160µm (bottom) band. The insets give a vertically magnified view.

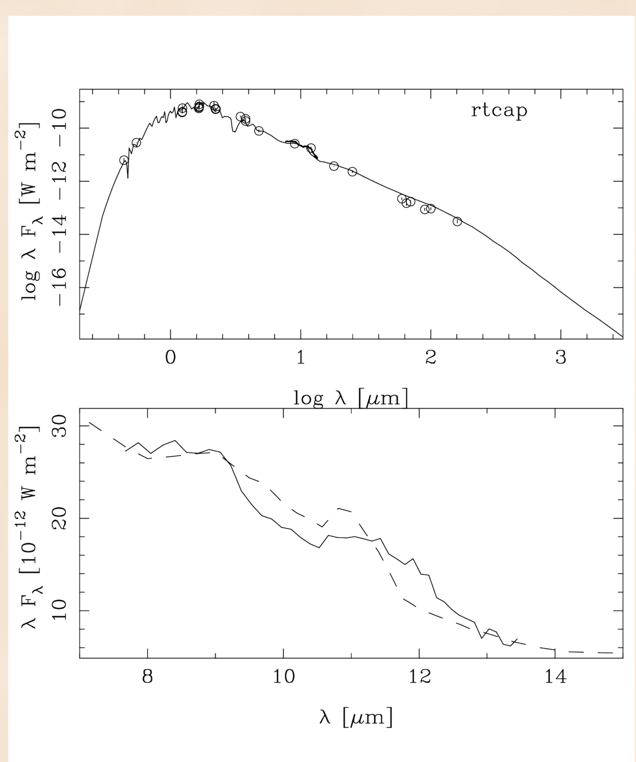


Figure 4. Top: Model SED (solid line) compared to photometric data (VRIJHKL, IRAS, PACS) and IRAS LRS (bold line). Bottom: Magnified view around the SiC feature – model (dashed) compared to LRS.

The case of RT Cap. RT Cap has been observed in CO radio line emission [Olofsson 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 arcminutes [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 a radial offset of 94" from the star, corresponding to 0.13 pc 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 94" we detect an additional even fainter structure further out. It is also roughly circularly shaped with a radius of ~155" (0.22 pc). For the central source, we adopt a COMARCS spectrum with a C/O ratio of 1.10 and T_{eff}=2500K. 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 39K of the detached shell. For the dust mass contained therein we compute $(1.0\pm0.2)\times10^{-5}\,M_\odot$. 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 0.01pc thick shell, corresponding to a dust mass-loss rate of $(2.3\pm0.8)\times10^{-8}\,M_\odot$/yr for the bulk material. For the dynamical age we estimate 8500 years.

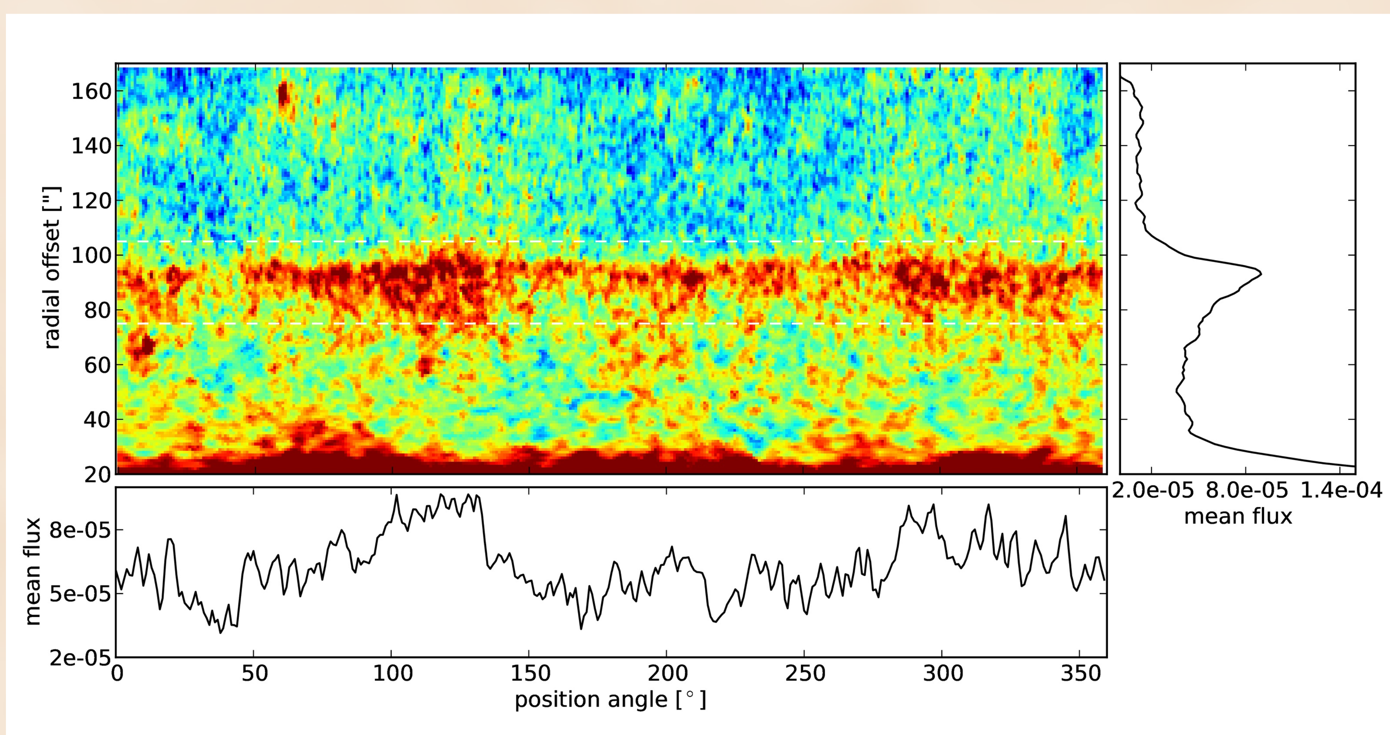


Figure 5. 70µm map of RT Cap in polar coordinates. The graphs to the right and at the bottom give the azimuthally and radially averaged profiles, respectively.

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 [Steffen 2000, Mattsson 2007] favour a density enhancing wind-wind interplay. In our sample, RT Cap and S Sct 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 2006], is also observed. While the case is clear for R Scl, where we see a detached bow structure outside the spherical shell, the extended structures of e.g. RT Cap and S Sct 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 eruption. 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].

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FWF Der Wissenschaftsfonds.

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