*WHY GALAXIES CARE ABOUT AGB STARS II:*
*SHINING EXAMPLES AND COMMON INHABITANTS*
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# Stable Discs around Galactic and LMC Post-AGB Binaries

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**Abstract.** The results of our study of a particular class of Galactic and extragalactic evolved stars, which are part of a binary system and surrounded by a stable dusty disc, are discussed. By combining spectroscopic, photometric and interferometric observations with detailed models describing dust properties and disc structure, we investigate the exact disc composition and structure.

## 1. Binary Post-AGB Stars

With the discovery of the first binary post-AGB stars, it became clear that these evolved stars have common observational characteristics such as a broad infrared (IR) excess. This observed broad IR excess points to the presence of both cool and hot (up to the sublimation temperature) dust around the star (De Ruyter et al. 2006). An outflow model is not adequate to explain the presence of such hot dust, since the near-infrared excess is expected to disappear within years after the cessation of the dusty mass loss. The dust must thus reside in a long-lived, stable reservoir close to the star. This led us to suspect that these objects are surrounded by a stable Keplerian disc.

The specific observational characteristics allowed for a systematic search for these objects and, so far, more than 70 Galactic objects have been discovered (De Ruyter et al. 2006). For these stars our group started an extensive multi-wavelength study, including high spectral resolution optical and infrared studies, submillimetre observations, and high spatial resolution interferometric studies.

The formation of the disc is still a badly-understood process, probably the result of non-conservative Roche lobe overflow during evolution in a binary system (Verhoelst, van Aarle, & Acke 2007). To detect this binary motion, we started an extensive radial velocity monitoring programme, which confirmed the binary hypothesis and gave a typical semi-major axis for the orbit of around 1 AU (Van Winckel et al. 2009). Given the effective temperature of the central star and its high luminosity, all the discs must be circumbinary, since the orbits all lie well within the sublimation radius of the dust. The mass functions calculated from the orbit indicate that the companion is likely a main-sequence star. So far we have orbital parameters for about 30 sources, with orbital periods ranging from 100 to 2000 days and high eccentricities, up to 0.6. This is surprising, since theory predicts efficient circularisation by tidal forces on very short time scales (Pols et al. 2003).

All orbits discovered so far are too small to have accommodated a full-grown AGB star. This implies that the system must have been subject to severe binary interaction while the evolved star was at giant dimensions.

### 1.1. The Circumbinary Disc

The presence of the circumbinary disc has an impact on several observational characteristics of the post-AGB star:

- The strong infrared excess, $L_{IR}/L_* > 40\%$ in most cases, shows that significant amounts of circumstellar material are present to reprocess the incoming stellar light. Surprisingly, a very low total reddening towards these stars is observed. This is clear evidence for a non-spherical circumstellar environment (CE).

- The binary disc sources are characterised by a depletion pattern in their photospheres (e.g. Van Winckel et al. 1998; Maas et al. 2005). Generally, a lack of carbon or *s*-process enhancement is found. These stars apparently did not undergo a third dredge-up process on the AGB, even though they have initial masses which would theoretically make them evolve to carbon stars. The abundance pattern is the result of gas-dust separation in the CE, followed by a reaccretion of the gas component, which is now poor in refractory elements. Waters, Trams, & Waelkens (1992) had already proposed that the most likely circumstance for this process to occur is when the dust is trapped in a disc.

- Recent interferometric studies confirm the very compact nature of the circumstellar material (Deroo et al. 2007a,b). All disc sizes are similar, with N-band sizes between 30 and 50 AU. Some objects show crystalline dust species close to the inner rim, others show strong processing throughout the disc.

- Kinematical information on several objects detected in CO shows typical Keplerian rotation velocities instead of outflows (e.g. Bujarrabal et al. 2007).

- Submillimetre measurements (De Ruyter et al. 2005, Gielen et al., in prep.) indicate the presence of large grains (> cm-size) in the CE. A disc is an ideal environment for grain growth, since it is a long-lived stable reservoir, with relatively high densities. These large grains have smaller dust-settling times, causing the disc to be inhomogeneous, consisting of small hot grains in the surface layer of the disc and a cool midplane of mainly large grains.

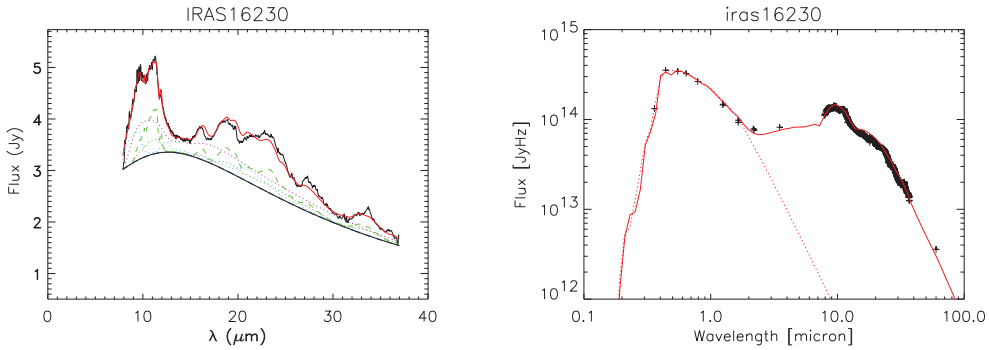



Figure 1. *Left*: The result from our full-spectrum fitting. The observed spectrum (black) is plotted together with the best model fit (red solid line) and the continuum (black solid line). *Right*: The result from our 2-D disc modelling. Observations are represented by crosses; the underlying Kurucz model is given by the dotted line. The full line represents the SED of the disc model.

### 1.2. Similar Sources in the LMC

Recently the SAGE (Surveying the Agents of Galaxy Evolution) *Spitzer* LMC survey (Meixner et al. 2006) observed the LMC, using all *Spitzer* IRAC/MIPS instruments. Thanks to this database, we found that the LMC post-AGB objects have infrared excesses similar to the Galactic sources. A search for post-AGB disc sources in this survey, based on their location in colour-colour diagrams, resulted in a list of about 650 disc candidates (van Aarle et al., in prep). From the follow-up SAGE–Spec programme we also have *Spitzer* IRS spectra for the LMC objects (Kemper et al. 2010).

Recent chemical studies of a few extragalactic post-AGB disc sources (Reyniers & Van Winckel 2007; Gielen et al. 2009), show that, as in the Galaxy, the disc candidates display a depletion pattern in their photospheres.

## 2. Disc Composition

To study the mineralogy of the disc, we use *Spitzer* mid-infrared spectra. So far, we have spectra for 33 Galactic and 24 extragalactic LMC sources. Using a full-spectral fit routine (see Figure 1), we determined the parameters, such as composition and temperature, of the dust responsible for the observed spectra (Gielen et al. 2008).

All sample stars show signatures of oxygen-rich dust species in their infrared spectra, more specifically amorphous and crystalline silicates. The magnesium-rich end members of crystalline silicates seem to prevail in the spectra, with strong emission due to forsterite, and to lesser extent enstatite. From our full spectral fitting we also find that the amorphous dust might be strongly Mg-rich. Detailed chemical studies of these stars (e.g. Maas et al. 2005; Gielen et al. 2009) have shown that the stellar photospheres are devoid of iron, with the iron instead being locked up in the dust of the disc. If no iron is detected in the observed dust species, this could imply that iron is stored in the form of metallic iron or iron oxide, which have no distinct observable dust signatures.

We find that the discs are the ideal environment for strong dust grain processing to occur, both in grain growth and crystallinity. For our sample stars, the mass fraction in crystalline grains ranges from 10 to 70%, which is much higher than observed in outflow sources. The observed peak-to-continuum ratio shows that, on average, grain sizes above 0.1 $\mu$m prevail. There thus seems to be a removal of the smallest grains in the disc surface layers. Several sources show strong crystalline emission features at longer wavelengths, coming from rather cool crystalline dust grains in the disc. Crystalline dust is typically formed close to the inner rim, where temperatures are high enough for crystallisation to occur. The presence of cool crystalline grains shows that either radial mixing must be very efficient or that the grains have a crystallinisation process which is already efficient at low temperatures.

A few sources show rather atypical spectral signatures, with emission features due to polycyclic aromatic hydrocarbons (PAHs), $CO_2$ gas lines, and/or fullerene $C_{60}$ emission lines (Gielen et al., in prep). The low $^{12}C/^{13}C$ ratio, derived from the gas lines, again indicates the lack of third dredge-up processes.

So far, no clear difference is found in the disc composition of the Galactic and extragalactic sources. Also, no correlation is found between the observed dust parameters and other characteristics, such as the central star or binary orbit.

## 3. Disc Geometry

To determine the structure of the discs, we performed 2-D disc modelling on the observed photometry and spectroscopy of the Galactic and LMC disc sources (see Fig. 1), using the MCMax radiative transfer code (Min et al. 2009). We found that a good fit is obtained with a passively-irradiated, self-shadowed disc with a puffed-up inner rim. The inner radius of the disc is found slightly below the dust sublimation radius, but the outer radius is unfortunately less well constrained. Typical values for the inner and outer radius are 2–20 AU and 100–500 AU, respectively. Dust masses range from $10^{-6}$ to $10^{-4} M_\odot$, with a surface density powerlaw $> -2$, using a gas-to-dust ratio of 100.

## 4. Conclusions

Our studies show that, both in our Galaxy and beyond, circumbinary discs around evolved stars are clearly present, and are a common by-product of binary evolution.

Both from our mineralogy study and from our disc modelling, we find that the chemical and physical properties of these discs around evolved binaries are very similar to those seen in protoplanetary discs around young stars – a remarkable conclusion, since these discs have very different formation histories. All discs are oxygen rich, and thus formed when the star was oxygen rich. In both disc types, dust processing is very effective: large grain sizes prevail and the crystallinity is very high. The observed correlation between the evolutionary phase and the disc parameters found for young stars is not yet observed in our limited sample of evolved binary stars.

Clearly, many open questions remain on the formation, structure and evolution of these circumbinary discs around evolved stars, and on the impact the disc has on the evolution of the central binary system. The interaction in the binary system is fundamental in trapping part of the dust in a stable circumbinary environment, and it determines the further evolution of the binary star and the disc.

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**Discussion**

*Meixner*: Some past papers by Jura and others show very narrow and faint CO lines suggesting very low gas to dust ratios. Do you have measurements of gas masses in these sources (I see you will go after some with Herschel) and what gas-to-dust-mass ratios do you find?

*Gielen*: Several problems arise when trying to measure gas ratios in these post-AGB disk systems. (i) the systems are located at great (unknown) distance (>>kpc) and the disks themselves are relatively small. This means they have very small angular scales on the sky (<<arcsecond, ~50-200 mas). This often gives a beam problem. (ii) the gas component of the disk is in most cases probably optically thick, this means you cannot accurately measure the gas content, resulting only in lower limits (see Bujarrabal et al. 2007). (iii) the disk in these systems must be gas rich: to get the observed $L_{IR}/L\star$ ratios the disk must absorb a lot of stellar light, and thus needs a large surface. You cannot have such a large disk surface without sufficient gas pressure. A gas poor disk will collapse due to gravity and will become too thin.