Abstract. Past imaging observations of a post-AGB star, HD 161796, have probed different parts of its circumstellar shell which correspond to different epochs of the star’s AGB mass loss history. While the overall structure of the shell can be described by an axisymmetric model consisting of three layers of characteristic structure, the mass distribution in the shell appears to rotate its axis of symmetry in a continuous manner. It is thus interesting to observe the halo region of the shell using far-IR to sub-mm wavelengths and increase the “time resolution” during this critical epoch of the star’s mass loss history.

1. The Object

HD 161796 (IRAS 17436+5003) is a low metallicity oxygen-rich post-AGB star of F3Ib located at high Galactic latitude (e.g., Hrivnak et al. 1989). Due to the star’s relative proximity (≈ 1 kpc), its circumstellar shell has been relatively well studied at various wavelengths in order to understand its mass loss history.

2. The Outer Shell

The circumstellar shell around HD 161796 was marginally resolved by IRAS at 100 µm, and the IRAS map seems to show a spherically symmetric shell. Using ISO linear scan observations across the shell at 90 and 160 µm, Speck et al. (2001) have recently shown that the shell is indeed extended out to about 400″. Even though the ISO scan was done only in one direction, it seems reasonable that this cold (≈ 20 K) dust shell possesses generally spherically symmetric structure. This parsec-sized, nearly spherical cold dust shell corresponds to the part of the circumstellar shell that was created by an ancient AGB mass loss roughly 2 × 10⁵ years ago (Fig. 1 left).

3. The Inner Shell

While the outer shell represent the old AGB mass loss history, the inner shell is a manifestation of the most recent mass loss history that may provide clues for the latest structure formation in the circumstellar shell. By directly probing the distribution of warm (≈ 100 – 200 K) dust grains, Skinner et al. (1994) have revealed a two-peaked structure in the emission core in their deconvolved 12 µm image. Most recently, Gledhill et al. (2003) have taken N and Q band images
of the object using Gemini-N and resolved the two-peaked structure in the mid-IR emission core (Fig. 1, right). The two-peaked mid-IR structure is typically interpreted as limb-brightened edges of a dust torus (or an equatorially enhanced dust distribution) embedded in the innermost region of the circumstellar shell.

The dust shell structure can also be investigated indirectly through dust-scattered star light in the optical and near-IR. As part of their HST imaging survey of PPNs, Ueta et al. (2000) have detected an elliptically elongated shell surrounding the mid-IR core (Fig. 1, middle). These non-spherically symmetric structure of the shell seem to have developed during the last $\sim 500$ years before the mass loss was terminated nearly 300 years ago (Meixner et al. 2002).

4. The Overall Shell Structure

These images of the shell at various wavelengths probe different parts of the shell, and hence, can be thought of as “time slices” that would help to reconstruct the entire AGB mass loss history of the star. Based on the shell structure we see at different epochs, the overall shell structure seems to be explained by a “layered shell” model, in which the shell consists of three layers that represent different epochs of mass loss (Fig. 2 left).

The outermost layer of cold dust corresponds to the part of the shell created by the earliest AGB mass loss, in which the wind was spherically symmetric. The innermost layer of warm dust, on the other hand, corresponds to the part of the shell generated by equatorially enhanced (or axisymmetric/toroidal) mass loss at the end of the AGB phase. In addition, the mid-layer seen in the dust-scattered star light corresponds to one particular epoch during which the shell geometry transforms from spherical to axisymmetric (toroidal) symmetry.

2.5-dimensional dust radiative transfer calculations have been performed to test this layered shell model (Meixner et al. 2002; Ueta et al. 2003). The best-fit model has successfully reproduced the spectral energy distribution from UV to
far-IR and characteristic morphologies at various wavelengths from the optical through mid-IR (Fig. 2 right).

5. The “Twist” in the Shell

Although the overall shell structure can be understood by the layered shell model consisting of three distinct structures, the model is not enough to explain the detailed structure of the shell, especially the apparent deviation from axisymmetry. If we define the axis of the shell based on the toroidal structure in the mid-IR core, the axis would have the position angle of roughly 30°. However, the elliptical structure of the dust-scattered reflection nebulosity would delineate the axis of symmetry oriented at roughly 0° position angle. By comparing these two “time slices” (i.e., mid-IR and optical images representing different epochs of mass loss), this apparent “shift” of the shell orientation seems to occur rather abruptly.

However, recent mid-IR observations have captured dust emission of the innermost core and of the low emission halo regions in a single image. So, the axis of symmetry now appears to shift continuously in the counter-clockwise direction over the course of the star’s mass loss history (Gledhill et al. 2003; Fig. 3 left). Interestingly, if one follows the density distribution further away from the central star probing even colder parts of the shell through CO gas in the mm-wavelengths, the twisting of the shell seems to be continuing for quite some time (roughly 1000 years; Fong et al. 2003; Fig. 3 right).

6. Summary

As we have seen, imaging of the circumstellar shells at various wavelengths is equivalent to taking “snapshots” of the mass distribution at various epochs of the mass loss history. This method has been quite effective to observationally establish the geometrical transition of the circumstellar shells. Recent imaging of HD 161796 at the mid-IR has probed the outer shell of cold dust and has suggested that the axis of symmetry rotates continuously while the shell morphology assumes more equatorially enhanced structure.
Therefore, it is very interesting to increase the “time resolution” of the early to intermediate phases of the mass loss history represented by rather cold (around 20–100 K) part of the dust shells (corresponding to the mass loss epochs on the order of $10^3$ years ago). With far-IR to sub-mm telescopes/missions such as SIRTF, SOFIA, ASTRO-F, VLTI, Herschel, and SMA, we will have a plenty of opportunity to observe these critical regions of the circumstellar shells at higher resolution and with higher sensitivities. We can then follow the early phases of the mass loss history and address how spherically symmetric circumstellar shells develop the equatorially-enhanced structure. This line of research may also provide clues to explain how elliptical and bipolar PPNs assume their respective structure by comparing their early mass loss history.

References

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Figure 3. “Twist” of the shell axis in HD 161796. [Left] The mid-IR torus (white contours) does not exactly align with the optical reflection nebulosity (gray scale), which is aligned with the mid-IR halo (black contours). [Right] CO gas distribution seems to indicate continuous “twisting” of the shell structure at far radii (contours).