MORPHOLOGICAL PROPERTIES OF PPNS: MID-IR AND HST IMAGING SURVEYS

Toshiya Ueta and Margaret Meixner

University of Illinois at Urbana-Champaign
ueta@astro.uiuc.edu, meixner@astro.uiuc.edu

Abstract
We will review our mid-infrared and HST imaging surveys of the circumstellar dust shells of proto-planetary nebulae. While optical imaging indirectly probes the dust distribution via dust-scattered starlight, mid-IR imaging directly maps the distribution of warm dust grains. Both imaging surveys revealed preferentially axisymmetric nature of PPN dust shells, suggesting that axisymmetry in planetary nebulae sets in by the end of the asymptotic giant branch phase, most likely by axisymmetric superwind mass loss. Moreover, both surveys yielded two morphological classes which have one-to-one correspondence between the two surveys, indicating that the optical depth of circumstellar dust shells plays an equally important role as the inclination angle in determining the morphology of the PPN shells.

1. INTRODUCTION

While circumstellar dust shells (CDSs) of asymptotic giant branch (AGB) stars display high spherical symmetry (e.g. Habing & Blommaert 1993), planetary nebulae (PNs) are renowned for their spectacular axisymmetry (e.g. Zuckerman & Aller 1986). To understand when and how such a drastic morphological conversion takes place, the proto-planetary nebula (PPN) phase, a brief transitionary phase between the AGB and PN phases (e.g. Kwok 1993) has been extensively investigated. In fact, PPNs are the most ideal space laboratories for such studies: AGB mass loss histories are imprinted on the PPN shells in the most pristine form because the PPN central stars are not hot enough to generate disturbing fast winds and/or ionizing UV photons as PN central stars.

Therefore, by conducting imaging surveys on a large number of PPN CDSs, we can pinpoint the epoch of morphological transformation and obtain insights about yet unknown mechanisms for the AGB mass loss. To achieve our goals, we employed mid-infrared (IR) and optical wave-
length ranges, both of which have strengths and weaknesses that would complement one another. Diffraction-limited mid-IR images give marginal resolution (1") but allow one to directly probe dust mass distribution through thermal dust emission. On the other hand, optical images are of high resolution (0.1"), while they only allow an indirect mass probing through dust-scattered starlight escaping from the dust shells.

2. MID-IR IMAGING SURVEY

The aim of the mid-IR survey is to map out distribution of warm dust grains at the inner edge of the PPN CDSs. So far we have observed about 70 PPN candidates with 8 to 25 micron filters. We have been using IRTF and UKIRT (∼ 1" resolution with ∼ 3m apertures) and MMT (sub-arcsecond resolution with 6.5m aperture). Out of 72 objects, we have only resolved 22 object due to marginal resolution. However, 16 of these 22 showed clear elongation, and moreover, elongations were morphologically characterized into two groups: toroidal and core/elliptical types (Meixner et al. 1999).

![Figure 1](image)

*Figure 1* Two types of mid-IR morphologies: toroidal (left) and core/elliptical (right) PPNs. Indicated are object names, instruments, wavelengths, and sizes. The size of the emission core with respect to the entire nebula is the main difference.

The toroidal PPN morphology is characterized by a large emission core which shows some evidence of a dust torus. The resolved peaks in the emission core are interpreted as limb-brightened edges of an optically thin dust torus. i.e., the inner structure is revealed through optically thin dust shells. The morphology of the core/elliptical PPNs is characterized by a relatively compact emission core which is surrounded by a larger
emission plateau. This type of PPNs seem to keep their inner structure hidden beneath optically thick dust shells.

3. **HST IMAGING SURVEY**

The goal of the optical imaging survey was to detect faint circumstellar nebulosities caused by dust-scattered starlight. We observed 27 PPN candidates using HST/WFPC2 during cycle 6 with typical resolution of 0''1. 21 out of 27 objects showed nebulosities, and all of which showed two kinds of axisymmetry (Ueta et al. 2000): the first group being star-obvious low-level elongated nebulae (SOLE) and the second group being dust-prominent longitudinally extended nebulae (DUPLEX).

![SOLE PPNs and DUPLEX PPNs](image)

*Figure 2: Two types of optical morphologies: SOLE (left) and DUPLEX (right) PPNs. Indicated are object names, WFPC2 filters, and sizes. The main difference is the visibility of the central star due to dust obscuration, which manifests itself in the nebula shapes.*

SOLE PPNs have very faint and smooth, elliptically elongated nebulosities with the central stars prominently visible at the very center of the nebulae. The morphology of DUPLEX PPNs is characterized by their bipolar nebulosities. Depending on the inclination angle of the object, you may or may not see the central star but you will always recognize some evidence for a dust lane between lobes.

4. **COMBINED RESULTS**

Both surveys showed that PPN dust shells have a striking preference towards axisymmetry. This is consistent with previous studies on the axisymmetry in PPNs (e.g., Trammel et al. 1994; Hrivnak et al. 1999). It is, therefore, most likely that the epoch of morphological transfor-
formation should start before the end of the AGB phase. If we restrain ourselves from invoking any exotic mechanisms, a standard AGB evolution scenario (e.g., Iben 1995 for a review) suggests one event which might trigger the transformation, the superwind. The bulk of the PPN dust shell is considered to be ejected during this brief but violent phase of mass loss at the end of the AGB phase, and superwind may be violent enough to cause such a drastic morphological change.

Thus, we propose a zeroth-order model for the structure of the PPN dust shells, shown on the left. In this model, an axisymmetric superwind shell is embedded in an otherwise spherical AGB wind shell. Mid-IR thermal emission comes from the inner edge of the superwind shell, which manifests itself as a dust torus we have observed (Fig. 1), while optical bipolar lobes are evidently dust-scattered starlight escaping the dust torus through these bicone openings.

Now, how does this model explain the observed dual morphologies in these surveys? Interestingly, there is a one-to-one correspondence between two dual morphologies found in both surveys (Fig. 3): toroidal mid-IR shells are always associated with SOLE type optical nebula, and core/elliptical mid-IR shells are always associated with DUPLEX type optical nebulous.

While the extent of both mid-IR and optical nebulae is comparable in SOLE-Toroidal PPNs, in DUPLEX-Core/elliptical PPNs, optical nebulae can reach far beyond the mid-IR emitting regions, which roughly cover the core of the dust torus. The optical morphologies have been explained by the inclination angle effect, in which an intrinsically bipolar nebula can be viewed as a bipolar nebula near edge-on or an elliptically elongated nebula near pole-on depending on the the inclination angle of the object. This explanation fails to explain the mid-IR morphology of SOLE-Toroidal PPNs. Within the framework of the inclination angle interpretation, SOLE-Toroidal PPNs must be oriented nearly pole-on. However, their mid-IR morphology clearly indicates the presence of rather edge-on dust toroids and can not be satisfactorily explained by the inclination angle effect alone.

The two-layered PPN shell model we proposed can explain both mid-IR and optical morphologies if we consider the PPN dust shells that
can have a range of optical depth (Fig. 4). In this optical depth effect interpretation, the optical depth of the SOLE-Toroidal PPN dust shells are low enough that starlight can scatter into all directions making an elliptical looking nebulosities while mid-IR images showing two emission peaks. On the other hand, in DUPLEX-Core/elliptical PPNs,
the optical depth is very high and starlight can escape into only the bi-
cone openings of the dust shell making bipolar nebulosities while mid-IR
emission showing only one, compact emission core.

Although the overall morphology of PPN dust shells is still depen-
dent on the inclination angle of the shells, the results from our surveys
evidently demonstrated that the optical depth effect plays an equally
important role in defining the morphology of the PPN dust shells.

5. FUTURE PROSPECTS

As we have seen, well-resolved mid-IR images are very effective means
to directly probe the structure of dust distribution. With large aperture
telescopes coming online, we are now able to obtain sub-arcsecond reso-
lution mid-IR images, and detailed spatial information at the innermost
regions of PPN CDSs will permit refined understanding of the AGB
mass loss. Also, spatially detailed data will help constraining input ge-
ometrical parameters for radiative transfer calculations done in a fully
two-dimensional grid. These model calculations are important because
they allow us to quantify the axisymmetric nature of PPN CDSs by,
for example, the pole-to-equator density ratio. We will also be able to
constrain the inclination angle from such model calculations, clarifying
ambiguities between effects of the inclination angle and optical depth of
the PPN dust shells.

Acknowledgments

These surveys have been done in collaboration with W. F. Hoffmann, P. Hinz
(Steward Obs./Univ. of Arizona), A. Dayal (IPAC/JPL), J. L. Hora, G. Fazio (Har-
vard/CfA), L. K. Deutsch (Boston Univ.), B. J. Hrivnak (Valparaiso Univ.), C. J.
Skinner (deceased), and M. Bobrowsky (Challenger Center for Space Science Educa-
tion).

References

Habing, H. & Blommaert, J.A.D.L. 1993, in IAU symp. 155: Planetary
Nebulae, eds. R. Weinberger & A. Acker (Dordrecht: Kluwer), 243
Hrivnak et al. 1999, ApJ, 513, 421
Iben, I. Jr. 1995, Phys. Rev., 250, 2
Kwok, S. 1993, ARA&A, 31, 63
Meixner et al. 1999, ApJS, 122, 221
Trammel, S.R., Dinerstein, H.L., & Goodrich, R.W. 1994, AJ, 108, 984
Ueta, T., Meixner, M., & Bobrowsky, M. 2000, 528, 861
Zuckerman, B. & Aller, L.H. 1986, ApJ, 301, 772