Dual Axisymmetry in Proto-Planetary Nebula Reflection Nebulosities: Results from an HST Snapshot Survey of PPN Candidates

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Abstract. We summarize results of our HST imaging survey of proto-planetary nebula (PPN) candidates, in which we discovered two types of axisymmetric reflection nebulosities. The Star-Obvious Low-level-Elongated (SOLE) nebulae show a bright central star embedded in a smooth, faint extended nebulosity, whereas the DUst-Prominent Longitudinally-EXtended (DUPLEX) nebulae have remarkable bipolar structure with a completely or partially obscured central star. The intrinsic axisymmetry of the PPN reflection nebulosities demonstrates that the axisymmetry often found in planetary nebulae predates the PPN phase. We suggest that the major cause for the apparent dual morphology is the optical depth difference in the circumstellar dust shell rather than the inclination angle effect.

1. Introduction

Axisymmetry often seen in planetary nebulae (PNe) must arise before photoionization starts illuminating the fascinating structure of the nebulae. High resolution optical imaging of PPN reflection nebulosities can serve as an indirect probe for the innermost structure of the PPN dust shell, which is formed during the superwind mass loss phase at the end of the asymptotic giant branch (AGB) evolution. This conference contribution summarizes the results from our HST survey, which covered the largest number of PPN candidates to date including the ones associated with bright central stars (Ueta, Meixner, & Bobrowsky 2000). Our goal was to investigate if there exists any coherent trend that will bridge gaps in the circumstellar morphologies between the AGB and PN phases.

2. HST Snapshot Survey of PPN Candidates

Our HST snapshot survey of PPN candidates found that 78% (21 of 27) of the reflection nebulosities were resolved and all of the resolved nebulae were elongated (ellipticity = 0.44). This ubiquitous axisymmetry suggests that PPNe are intrinsically axisymmetric. Hence, given the spherical nature of the AGB
wind shell, the PN axisymmetry is likely to originate during the superwind phase. Moreover, there are clearly two types of reflection nebulosities which we classified as Star-Obvious Low-level-Elongated (SOLE) nebulae, showing smooth, low surface brightness elongations with extremely bright central stars, and Dust-Prominent Longitudinally-Extended (DUPLEX) nebulae, having bipolar lobes straddling dust lanes with totally or partially obscured central stars.

Figure 1. SOLE (left four frames) and DUPLEX (right four frames) types of PPN reflection nebulae. IRAS ID and filters are shown in each frame. N (E) is up (left) with tickmarks showing relative offsets in arcsec. “+ decon” indicates a deconvolved image.

3. SOLE vs. DUPLEX: Physically Distinct Nebulosities

We attribute the major source for the dual morphology to the optical depth in the superwind shell, which varies depending on the degree of equatorial density enhancement. The following evidence suggests that the inclination angle effect alone may not be good enough to interpret what we see in the data.

3.1. Mid-Infrared Morphology

A recent mid-infrared (mid-IR) survey of PPN candidates (Meixner et al. 1999) has revealed a corresponding dual morphology in the PPN dust emission regions. SOLE type optical nebulae corresponds to toroidal type mid-IR dust emission nebulae, in which we see two dust emission peaks that are interpreted as a limb-brightened dust torus. On the other hand, DUPLEX type nebulae is related to core/elliptical type dust emission nebulae, in which we see a very compact, unresolved core with a broad plateau (Fig.2). Characteristics of both optical and mid-IR images suggest that SOLE-Toroidal type nebulae are of optically thin dust shells and that DUPLEX-Core/Elliptical type nebulae are of optically
thick dust shells. We also schematically describe how the optical depth in the superwind influences the shape of the two types of reflection nebulosities in Fig.2.

Figure 2. Optical/mid-IR overlay images (left) and a schematic (right) of two PPN types. Both optical and mid-IR PPN morphologies appear to depend on the optical depth of the superwind shell.

More importantly, mid-IR images show that there are SOLE nebulae that are oriented rather edge-on (e.g. IRAS 07134+1005 in Fig.2, IRAS 17436+5003 in Fig.4), and therefore, elliptical reflection nebulae (SOLE) are not necessarily bipolar nebulae (DUPLEX) seen pole-on.

3.2. Spectral Energy Distributions and Two-Color Diagrams

SOLE and DUPLEX nebulae are also distinct in the shapes of spectral energy distribution (SED; Fig.3, left). Optically thin SOLE nebulae let the stellar emission pass while converting some to thermal dust emission, yielding comparable stellar and dust peaks. Optically thick DUPLEX nebulae absorb all stellar photons except for some scattered ones, yielding a large dust emission peak with an optical plateau.

The duality is also seen in both an IRAS/near-IR and a near-IR color diagrams, confirming the optical thickness interpretation. IRAS/near-IR diagram (Fig.3, right) shows three clusters of PPNe according to the visibility of the central stars (total, partial, and none obscuration). Near-IR diagram (not shown) shows a linear distribution of PPNe according to the degree of reddening (the redder, the more dust).

Figure 3. The optical depth difference in SOLE and DUPLEX nebulae manifests itself as the SED shapes (left) and color diagram (right).
3.3. Two-Dimensional Radiation Transfer Calculations

Preliminary results from full 2-D radiation transfer simulations of PPN dust shells generally agree with optical/mid-IR data. The optically thin superwind shell model yielded a resolved dust peak in the mid-IR and a diffuse reflection nebula without a dust lane in the optical, while the optically thick superwind shell model yielded a compact dust emission core with a broad emission plateau in the mid-IR and a bipolar nebula divided by a dust lane in the optical (Meixner, Ueta, & Bobrowsky 2000; also see the contribution by Meixner in this issue).

4. Discussions

The distinctness between SOLE and DUPLEX nebulae seems to originate from the varying optical depths in the superwind shells, and it is evidenced by the correlation between optical and mid-IR morphologies, characteristic SED shapes, color diagrams, and 2-D radiation transfer calculations. The inclination angle effect alone may not be good enough to interpret all SOLE nebulae being pole-on bipolar nebulae because we have found as many SOLE nebulae as DUPLEX nebulae, there are some SOLE PPNe that are rather edge-on, and SOLE nebulae do not show the imbalance of surface brightness, which is a signature of inclined orientation in DUPLEX nebulae, although the inclination angle effect still remains as a source of confusion.

Neither age nor chemical composition seems to be related to the morphological bifurcation, and the origin of equatorial density enhancement in the superwind remains unknown. However, there is a suggestion that DUPLEX PPNe may have evolved from higher mass AGB progenitors because of the Galactic distribution of PPNe: DUPLEX nebulae, having a mean height of 220pc with a range of $|z| < 520pc$, are more confined to the Galactic plane than SOLE nebulae, which have a mean height of 470pc with a range of $|z| < 2100pc$.

References

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