An HST Archival Survey of Departures From Axisymmetry

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Summary. It is well known that outflows from planetary and proto-planetary nebulae often exhibit axial symmetry. What is not so well understood are the departures from axial symmetry, which need to be investigated if we are to have a complete understanding of how planetary nebulae form and evolve. By measuring the departures from axisymmetry for targets in the HST archive, we hope to learn something about how the departures are related to, and caused by, the physical and dynamical conditions of the nebulae and central stars. Here we present some examples of different types of departures from axisymmetry. Out of 112 PNe examined, we find that approximately two thirds of them exhibit some type of deviation from axisymmetry. Of these, 11% have an off-center central star, 10% have a nebula with an asymmetrical brightness structure, 43% are asymmetric in the shape of the lobes, and 26% have complex structures or multiple types of departures from axisymmetry that do not fit neatly into one of the previous categories.

Key words: PN Morphology

1 Introduction

The axisymmetric morphologies of planetary nebulae (PNe) are well known. These morphologies have been classified and correlated by Balick (1987, 2007), Corradi & Schwarz (1995), Manchado et al. (1996, 2000), Sahai et al. (2007), Schwarz, Corradi, & Stanghellini (1993), Shaw et al. (2001), and Stanghellini (2000). Less well-studied are the deviations from axisymmetry. Soker & Hadar (2002) considered several types of departures from axisymmetry, although they were limited mainly to departures in the equatorial plane. These types of departures from axisymmetry included (1) a central star not at the center, (2) one side of the nebula brighter than the other, (3) unequal size or shape of the two sides, (4) a bent symmetry axis, and (5) departures in the outer regions, e.g., outer arcs.

Causes of departures from axisymmetry can be external (e.g., interactions with the interstellar medium) or internal (e.g., a binary companion). The binary companion explanation is currently popular, however that is not sufficient to explain the departures in all cases. Approximately 50% of all PNe in Soker and Hadar's sample have a large-scale departure, despite only a 25-30% incidence of binary companions. In the present work, 58% were found to have a departure from axisymmetry. It will be interesting to explore what can be learned about PNe from the departures from axisymmetry. This will be especially useful if the departures can be generalized to other types of objects.

2 Examples of Departures

One PN that shows a displacement of the central star is IC 418 (Fig. 1).

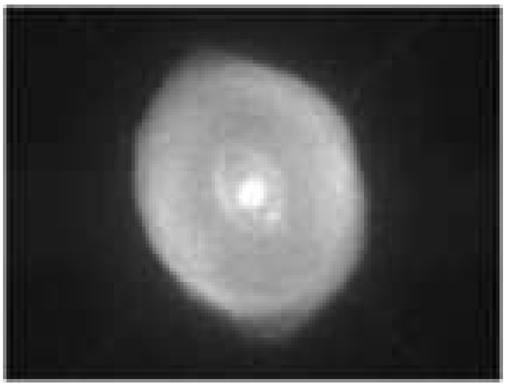

Fig. 1. IC 418 shows a displacement of the central star.

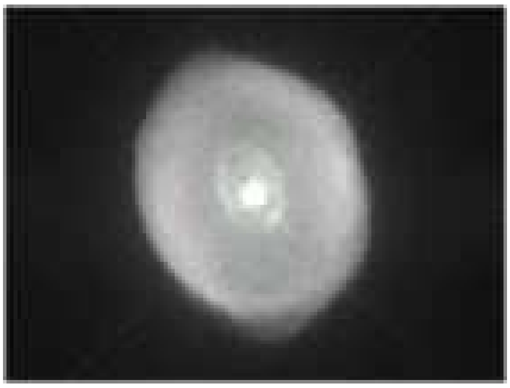

Fig. 2. IC 418 with an ellipse fit to the inner ring.

An ellipse can be fit to the inner ring (Fig. 2), and in this case, the displacement is $\Delta R/R = 5\%$.

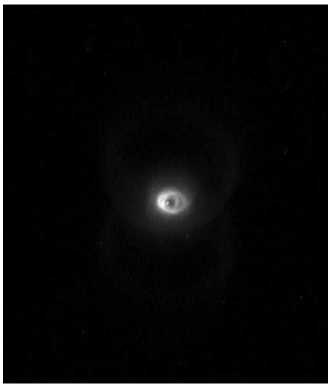

Fig. 3. MyCn 18 also shows a displaced central star.

Another PN with a displaced central star is MyCn 18 (Fig. 3).

An ellipse fit to MyCn 18 (Fig. 4) shows a central star with a displacement of $\Delta R/R = 23\%$.

Fig. 4. An ellipse fit to MyCn 18.

A displaced central star is also evident in the Stingray Nebula (Fig. 5). In this case the displacement is $\Delta R/R =\sim 10\%$. The displacement of the central star can be understood from its orbital motion caused by the companion star. If the nebula formed during 10^4 yr, the mass of the companion star is 1 $M_\odot$, and the mass of the central star was also 1 $M_\odot$ before losing mass, then the orbital period is 7.3×10^4 years. The distance of the central star from the center of mass of the system is 1100 AU (1.6×10^{16} cm), and the orbital velocity is 0.5 km s^{-1}. During the formation of the nebula, the central star moved about 1/8 of a circle ($\sim 10^{16}$ cm) in its orbit, and its direction of motion changed by 45° (Bobrowsky et al. 1998).

Therefore, the last mass-loss episode occurred with an ejection in a different direction and at a different location relative to the first one. If the expansion velocity

Fig. 5. The Stingray Nebula contains a companion star and a displaced central star.

is 10 km s^{-1}, a deviation of 5% would be observed in the distance to the two sides of the equatorial plane. Differences between the two sides of the ring of gas can result if either the central star has been displaced from its original position or if the nebular morphology is not identical on the two sides. In the Stingray Nebula, there clearly were multiple episodes of mass loss. Other examples are found in Soker (1999) based on the work of Ciardullo et al. (1999).

Examples of a PNe containing unequal sizes and shapes of the two sides are He 2-166 (Fig. 6) and He 2-459 (Fig. 7).

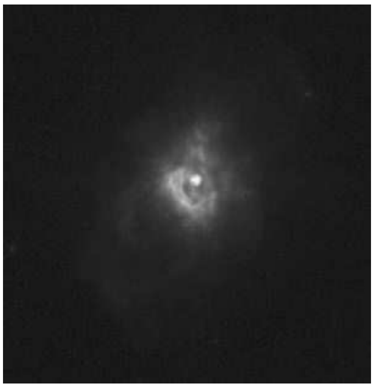

Fig. 6. He 2-166 has two sides with different morphologies.

Examples of bent PNe are He 2-180 (Fig. 8) and NGC 6886 (Fig. 9).

PNe with different lobe structures include J900 (Fig. 10) and PK 130 − 11°1 (Fig. 11).

It is not yet clear what the explanation is for the different structures. Akashi et al. (2007, APN4) suggested that there might be instabilities in the outer lobes when

Fig. 7. He 2-459 also has two sides with unequal sizes and shapes.

Fig. 8. He 2-180 appears bent.

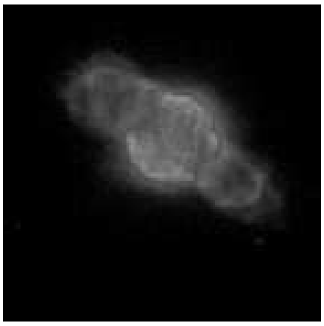

Fig. 9. NGC 6886 is also obviously bent.

a fast wind interacts with jets. Dennis et al. (2007, APN4) considered fragmentation of explosively launched clumps.

Fig. 10. J900 has different structures in its two lobes.

Fig. 11. PK $130 - 11°1$ is another example of a PN with different lobe structures.

3 SN 1987A vs. PNe

SN 1987A exhibits many of the same features as a PN such as the Hourglass nebula (see Fig. 12). Both objects include an inner ring and two large outer rings. In both objects there are departures from axisymmetry.

Figure 13 shows diagram of the geometry of the major structures (Podsiadlowski & Cumming 1994). The departure of axisymmetry is evident. Morris & Podsiadlowski (2007) developed a model of SN 1987A in which they were able to reproduce the overall geometry of the major structures – provided that an additional 2 km s^{-1} velocity component is included.

It is not clear where the additional 2 km s^{-1} velocity component would come from. Possible sources include a non-radial pulsational mode excited during an early spiral-in phase or perhaps orbital motion caused by a more distant low-mass third star in the system.

Fig. 12. SN 1987A, like MyCn 18, has multiple ring structures with departures from asymmetry.

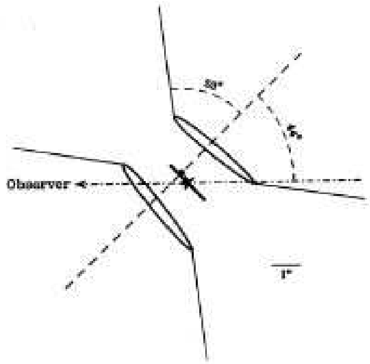

Fig. 13. Structure of SN 1987A

4 Conclusions

Departures from axisymmetry are both significant and measurable. One likely cause of the departures is orbital motion caused by a companion object. This can give expelled mass additional velocity in the direction of the orbital motion. In the future we hope to generalize the discussion to other types of objects.

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