Multipolar planetary nebulae: Not as geometrically diversified as thought
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Abstract: We present a general three-dimensional model of multipolar planetary nebulae (PNe). By rotating to different viewing angles and adjusting the angles between the multiple lobes, we demonstrate that the model is able to reproduce HST H-alpha images of 20 multipolar young PNe. Though this model only considers the geometrical projection effects, it significantly unifies the selected PNe and can be considered as a first-order fundamental model of the “multipolar” morphological class. This kind of model reduces complexity and is essential to pursuing of the shaping mechanism.

Keywords: planetary nebulae, multipolar

Introduction
Planetary nebulae (PNe) are believed to have formed from intermediate-mass stars (with 0.4–8 solar masses) when they leave the main sequence. Traditionally their shapes were described as bipolar, elliptical and round, but as the telescope power improves, more multipolar PNe have been discovered, and more known bipolar PNe have been or are ready to be re-classified as multipolar, e.g. NGC 6072 (Kwok et al. 2010) and NGC 6853 (Kwok et al. 2008). While the formation mechanisms of bipolar PNe remain unclear, in order to explain the presence of multiple outflow axes one has to introduce additional hypotheses such as precession motions. It is still under debate whether the multiple lobes are formed simultaneously or episodically (Sahai 2002).

Before starting to establish the theories, the first step should be to know the real three-dimensional (3D) structure, rather than only the projected two-dimensional (2D) images. Based on the 3D model, one can estimate the kinematic timescale in each outflow. Instead of making a single model for each nebula, it will be more effective to build a unified 3D model to reproduce the observed 2D images of individual objects by changing only a few parameters. Similarities and differences can then be more easily seen from the varying parameters.

The Model
We used an interactive graphical software SHAPE (Steffen 2011) to construct the 3D model. Basically, the model consists of three pairs of identical lobes (Fig. 1). At the moment, we are concerned about the projection effect on the lobes in different orientations, so we fix other parameters such as the sizes, and change only the inclination angle $i$ and position angle (PA) of each pair. Therefore there are six
independent parameters. From these six parameters, the separation angle $\theta$ between any two pairs of lobes can be calculated. The lobes are hollow inside with evenly distributed density within the "walls" of the lobes.

Figure 1. The 3D model in SHAPE.

Results

Some special combinations of the six angles make the projected images not easily interpreted as multipolar structures: when two or more pairs of lobes are aligned along similar projected directions, or if one pair is viewed nearly pole-on or slightly tilted in the equatorial direction which may be wrongly interpreted as a torus (Fig. 2). Moreover, the apparent shape varies with the sensitivity (Fig. 3).

To compare the modeled images with real observed ones, we obtained H-alpha images of 20 objects from the Hubble Space Telescope archive. Due to the limited space, only 5 of them are shown in Fig. 4.

Why We Use 3 Pairs?

The number 3 is also commonly found in literatures (NGC 7027 by Nakashima et al. 2010; and NGC 6644 by Hsia et al. 2010). It is possible that there are more than three pairs (e.g. IRAS 19024+0044 by Sahai et al. 2005), but adding more pairs means adding more parameters; at this stage we hope to keep the number of parameters down. The less obvious lobes can be treated as higher ordered structures.

References

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