TITLE: Multipolar Bubbles, Point-Symmetry and Jets in Dying Stars

AUTHORS: Raghvendra Sahai (JPL) and Mark Morris (UCLA)

ABSTRACT

The imaging of young planetary and proto-planetary nebulae (PNe and PPNe) with unprecedented high angular resolution and dynamic range using the Hubble Space Telescope (HST), has led to the realisation that almost all of these objects are highly aspherical, with complex multipolar morphologies. The complexity, organization and symmetry of the morphological structures has brought about radical changes in our understanding of the mass-loss processes during late stellar evolution. We have therefore proposed a model for PN formation in which the primary agent for shaping PNe are high-speed collimated outflows or jets which operate during the late AGB and/or early post-AGB evolutionary phase. Episodic changes in their orientation (or the operation of multiple outflows which operate quasi-simultaneously with different orientations) may explain the widespread presence of multipolar structures and/or point-symmetric morphologies in these obejcts. In addition to the morphological data, spectroscopic observations with high angular resolution which can probe the kinematics of the circumstellar material are needed in order to test the above hypothesis (as well as competing ones) for shaping PN, and understand the physical properties (outflow speed, opening angle, mass flux history) of the jets. We are therefore carrying out a program including radio interferometric observations (with VLA, VLBA) of OH and H2O masers and optical long-slit spectroscopy with the HST/STIS instrument.

In this paper, we briefly describe the results from imaging surveys of young PNe and PPNe with HST, and then present new results from detailed kinematic studies of several prominent objects which support our hypothesis for shaping PNe. For example, STIS observations of V Hydrae, a carbon-rich AGB star, show extended forbidden-line emission from a very young (about 2 yrs) high-speed (190-260 km/s) outflow which most likely consists of more than one kinematic component with differing orientations. In the PPN He3-1475, STIS data show two very young (kinematic ages ~ few x 10 yr), high-velocity (speeds of about 2300 and 150-1300 km/s) outflows; the faster of these is collimated close to the central star, along an axis that is misaligned with the bipolar nebula at the center. In CRL618, a PPN currently evolving into a PN (and showing several highly-collimated lobes clustered along the optical axis of the nebula in HST images), our ground-based long-slit spectroscopy shows that the different lobes have roughly similar kinematical ages. We also describe a new effort to infer the properties of the fast outflows by modelling the observed spatio-kinematic structure of specific objects using numerical simulations of the hydrodynamic interaction of fast collimated outflows with slow spherical circumstellar winds.