Multipolar Structures in Planetary Nebulae

Raghvendra Sahai, JPL/Caltech

One of the most exciting challenges facing theories of post-main sequence evolution today is to understand how Asymptotic Giant Branch (AGB) stars transform themselves into aspherical planetary nebulae (PNe). PNe form from intermediate mass stars (1-8 Msun) after a phase of intense mass-loss on the AGB, when the central star temperature exceeds 30,000K, and stellar UV ionises the ejected gas. PNe show bright rims and well defined shell-like structures, and a dazzling variety of morphologies, which include complicated axisymmetric and point-symmetric. In contrast, the extended circumstellar envelopes (CSEs) of most AGB stars appear largely spherically symmetric. There is no consensus yet on the physical mechanism(s) responsible for producing the dramatic transition in the geometry of the ejected matter. However, there is increasing observational evidence that fast collimated outflows, operating during the late-AGB or proto-planetary phases, play a crucial role in this transition. The most succesful model for shaping PNe - the ''generalised interacting-stellar-winds'' model, in which a fast (>1000 km/s) spherical stellar wind interacts with an equatorially-dense AGB CSE to produce an axisymmetric PN - no longer appears adequate.

This paper reviews recent results from the imaging of protoplanetary and very young planetary nebula obtained with the Hubble Space Telescope. All objects imaged so far show highly aspherical morphology, with a majority characterised by multipolar bubbles distributed roughly point-symmetrically around the central star. The complexity, organization and symmetry of the above structures have led us to propose that 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. The presence of multipolar morphologies requires episodic changes in the axis of a bipolar outflow or the operation of multiple collimated outflows with different orientations. We briefly summarize current theoretical hypotheses which may lead to a better understanding of the nature and origin of these outflows. We conclude with describing the discovery of a very highly-collimated, extended jet in a planetary nebula - its amazing morphological similarity to a low-mass YSO is the strongest evidence yet for a commom physical mechanism for collimated outflows in protostars and evolved stars.