Shaping Proto-Planetary and Young Planetary Nebulae with Collimated Fast Winds
Chin-Fei Lee and Raghvendra Sahai Jet Propulsion Laboratory, MS 183-900, 4800 Oak Grove Drive, Pasadena, CA 91109 chinfei@eclipse.jpl.nasa.gov, sahai@eclipse.jpl.nasa.gov

abstract Using two-dimensional hydrodynamical simulations, we investigate the interaction of a collimated fast wind (CFW) interacting with a spherical asymptotic giant branch (AGB) wind as the mechanism for shaping proto-planetary nebulae and young planetary nebulae. In particular, we compare our simulations to the observations of an evolved PPN with multiple, highly collimated lobes, CRL 618. We characterize our model CFW by three parameters: opening angle, velocity and mass-loss rate, and explore the dependence of the properties of the shell on the first two. For given opening angle and velocity, the mass-loss rate is chosen to give a shell velocity of about 150 km s$^{-1}$ at the tip, similar to that seen in CRL 618. In our simulations, the shell dynamics is found to depend on the velocity of the fast wind: we obtain a momentum-driven shell for a 300 km s$^{-1}$ fast wind and a ballistic bow-shock driven shell for a 1000 km s$^{-1}$ fast wind. The shell driven by the collimated fast wind is highly collimated, even though the AGB wind is spherical. Time variations in the velocity of the fast wind produce a series of internal shock pairs interacting with the inner surface of the shell. Due to radial expansion, the density of the internal shocks decreases with distance.

Various emission diagnostics have been derived from our simulations. For a 300 km s$^{-1}$ fast wind, the optical emission arises from both the shocked AGB wind and shocked fast wind, showing one or two bright bow-like structures at the tip of the lobe. However, for a 1000 km s$^{-1}$ fast wind, since the shocked fast wind is much hotter, it emits mainly in X-ray emission; the optical emission forms only one bow-like structure at the tip associated with the shocked AGB wind. The position-velocity (PV) diagrams derived from our simulations all show a broad range of velocities at the tip. The detailed PV structure and velocity range at the tip depend on the shell dynamics and the relative contributions of the shocked fast wind and shocked AGB wind.

We make a detailed comparison of our simulations to the observations of the relatively isolated northwestern (W1) lobe of CRL 618. We find that a 300 km s$^{-1}$ collimated fast wind with an opening angle of 10° can readily produce a highly collimated lobe similar to the W1 lobe, including the bow-like emission structure at its tip. However, our models have difficulty producing the bright emission structures seen along the body of the lobe. The [SII] λ6716Å/λ6730Å ratios at the tip of the lobe in all of our simulations are similar to that observed at the tip of the W1 lobe. The optical line ratios indicate a temperature stratification in the tip, both for the simulations and observations, however, the temperatures at the tip of the lobe in our simulations are higher than observed. The position-velocity (PV) diagrams derived from our simulations are all qualitatively consistent with the current observations. The collimated fast wind in CRL 618 is unlikely to be steady and is not radiatively driven.