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High-Resolution Mapping of Mass Loss from Highly Evolved Carbon Stars

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Summary. Interferometric observations of a pair of carbon stars which are evolving toward the planetary nebula stage have revealed evidence of episodic, non-spherically symmetric mass loss, and may lead to a fuller understanding of shielding properties of the dust grains involved in these flows.

Mass loss by stellar winds from red giants is an important source of recycled material to the interstellar medium. The precise evolutionary tracks of the stars involved are poorly known (see the review by Iben and Renzini 1983), but this process and the subsequent formation of planetary nebulae apparently can allow stars of initial masses up to $\sim 5\ M_\odot$ to reach stable end states as white dwarfs. The material returned to the ISM is likely to be enriched to various degrees in CNO and other elements, depending on the previous history of the star. In order better to understand the physics of the mass loss process itself, Lee Mundy and I have mapped the molecular component of the mass outflow at high resolution with the Owens Valley Millimeter-Wave Interferometer in two well-known objects, CRL 2688 and CIT 6.

These carbon-rich objects are in a rapid mass loss phase, and are thought to be evolving from the asymptotic giant branch to planetary nebulae. We observed emission in 3 mm rotational lines of the molecules CS and CN. In the usual spherical models of mass outflow in these sources, one would expect to find CN distributed in a shell centered on the star; at the inner radius of the shell CN is formed from photodissociation of HCN, and is then dissociated itself at the outer radius. Therefore, by mapping the shell one can determine shielding properties of the grains in the flow. It is important to understand the grains better, because a large class of models – which has had limited success to date – explains the mass loss as being driven by radiation pressure on the dust near the stellar surface. The CS molecule, which traces the presence of rather dense gas ($\sim 10^5\ cm^{-3}$ and greater) was observed in addition to CN so that departures from the expected symmetry in the flow itself would not confuse the issue.

However, interesting structure is seen in the flows which may complicate the interpretation of the results in terms of the photodissociation picture. Both objects have been resolved by the CS observations. The source sizes are some 21″ by 12″ for CRL 2688, and about 20 percent larger for CIT 6. The largest extent of the objects would then be $\sim 3 \times 10^{17}$ cm and 8×10^{16} cm, respectively, if the very uncertain "standard" distances from the literature are assumed. More interestingly, the two sources show a similar structure, consisting of a resolved, bright core with irregular extended emission. This extended structure is broken up into a number of unresolved, dense clumps with no regular velocity pattern. The dynamical ages of the clumps are in the range 200 to 600 years for CIT 6, and 900 to 2100 years for CRL 2688. The mass loss from these stars is clearly asymmetric and also is apparently rather episodic. An example of the irregular asymmetries is shown in the single velocity channel (3 km s^{-1}) map of CRL 2688 below.

CRL 2688, the Egg Nebula, shows features of particular interest. In the CS maps there is a velocity gradient of 9 km s^{-1} across the core, aligned along the major axis of the reflection nebula seen optically. This reflection nebula (Ney *et al.* 1975; Yusef-Zadeh, Morris, and White 1984) has two symmetric halves cut by a dark lane which is presumed to obscure the star. The dense molecular disk that should be associated with this lane is definitely not seen in the CS data, contrary to expectations. The CN, on the other hand, is extended in the disk direction as one might expect if the denser outflow there shields the gas from interstellar UV to greater radii. An explanation of the CS observations as a chemical abundance effect is being sought.

The CN maps of single velocity channels are, like the CS maps, centrally peaked. This observation rules out a simple shell distribution for the molecule, as predicted by the simplest photodissociation models, but the emission regions tend to have sharp edges and central plateaus. Thus, models featuring a sharp outer CN cutoff by photodissociation, with a nonzero abundance of the molecule at the outflow source, seem promising. In other words, not all of the CN is a daughter molecule formed by photodissociation of HCN.

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