Maser Mapping of Red Supergiants and the Onset of Bipolar Outflow

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Maser emission from SiO, H_2O and OH is found in oxygen–rich red giant circumstellar envelopes at successively larger distances from the star. H_2O emission at 22 GHz has been mapped with MERLIN (the Multi Element Radio Linked Interferometer, `http://www.jb.man.ac.uk/merlin/MERLIN.html`) with a beamsize of 8 mas. Typically the 22 GHz emitting region is seen to be a thick expanding shell 100 mas across. Small-scale clumpiness is revealed. The shell is resolved into discrete features of velocity extent 1 to 3 $\mathrm{km\,s^{-1}}$ and spatial extent 2 to 20 mas. Using this 3–D datacube, constraints are placed on the physical conditions such as kinetic temperature, density and local radiation field. These observations show that the size of the region increases with stellar mass-loss rate and that the mass outflow is undergoing acceleration. The outflow is gravitationally bound to the star at the inner radius of the H_2O masing region, but unbound at its outer radius (Chapman & Cohen 1986, *MNRAS*, 230, 415; Yates & Cohen 1994, *MNRAS*, 270, 529).

In NML Cyg (mass $\sim 50\,M_\odot$), proper motion has been detected in two isolated features outside the rest of the H_2O maser shell which are symmetric in position and velocity with respect to the stellar position (Richards, Yates & Cohen 1996, *MNRAS*, 282, 665). The increase in separation over 9 years corresponds to a transverse velocity of 19 ± 6 $\mathrm{km\,s^{-1}}$ at a distance of 2 kpc. This is consistent with the observed radial-velocity range of the 22 GHz emission. OH and dust observations show a similar axis of symmetry, and this may be a sign of the onset of bipolar outflow. Axisymmetric structures are often seen in supernova remnants, and also in the planetary nebulae which originate from $\sim 1\,M_\odot$ stars. Results are also given for other supergiant stars currently being observed.

Papers relating to this work will be available by ftp; those interested should write to amsr@jb.man.ac.uk for details.