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Is the Outflow from RT Vir Bipolar or Rotating?

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Abstract. We present high angular resolution observations of H_2O maser proper motions in the circumstellar envelope of the semi-regular variable RT Vir. These MERLIN observations, at 12-mas angular resolution, were used to map H_2O maser emission at $\sim$2 week intervals over 10 weeks in 1996, during which period the brightness distribution changed markedly. The emission covers a region > 100 mas in radius on the sky. It is faintest along an NNE-SSW axis. The average cloud size is 10 mas (1.4 au), and the inferred density contrast between the clouds and the ambient medium is 30:1. The proper motions of 18 maser clouds were measured with $> 2\sigma$ significance; 11 were identified at all epochs. At the Hipparcos distance of 140 pc these yielded an average expansion velocity of 12 km/s. The motions show strong radial expansion and the limit on any rotational component is < 0.2 km/s. Hence up to 14 au from the star the envelope has negligible rotation.

1. Introduction

Mass-loss from long period variable red giants on the AGB phase replenishes the ISM with nucleosynthesis products such as C,N,O and Si in the form of molecules, as both gas and dust. It is by this process that efficient radiative molecules and chemical surface catalysts are placed in the ISM. These products make for more efficient future star formation and hence greatly affects future evolution of the galactic ISM and stellar populations.

A typical AGB star of 1 $M_\odot$ radially pulsates with a period of 300 days. The star loses mass at a rate of $10^{-6}\,M_\odot\,yr^{-1}$ for about 10^5 years. At the end

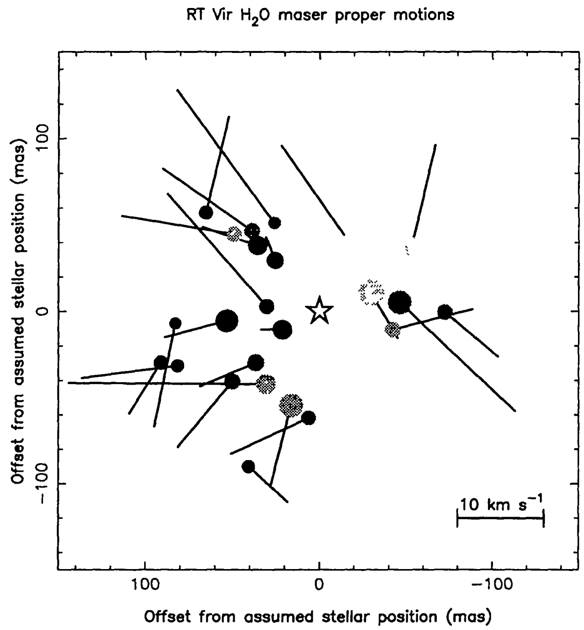

Figure 1. The H_2O maser proper motions at 6 epochs observed towards the semi-regular variable AGB star RT Vir over 10 weeks between April and June 1996. The proper motions are represented by heavy lines and are 10x their actual length. The maser features are represented by shaded circles; the darker, the more red-shifted they are.

of the mass loss the star will have lost up to 90% of its original mass. It will become a white dwarf star surrounded by a nebulae with both an ionised and molecular phase. The nebulae is often bipolar in both these phases.

Is there a link between the mass-loss on the AGB and the bipolar circumstellar structures observed in the nebulae? If the AGB mass-loss were asymmetric (latitude dependent), then when the white dwarf is exposed the spherical hot ionising radiation field/wind will plough into an asymmetric circumstellar density distribution. This will produce a bipolar outflow.

The semi-regular variable star RT Vir has a mass of 1.5$\odot$ and mass-loss rate of $3 \times 10^{-6}\,M_\odot\,yr^{-1}$. The Hipparcos distance is 140 pc. Yates and Cohen (1994) used MERLIN1 data (50-mas angular resolution) to show the 22-GHz H_2O maser emission was aligned E-W, with the blue-shifted emission offset to the W and the red-shifted emission offset to the East. The total velocity extent of the emission was 24 km s^{-1}, suggesting an expansion velocity of 12 km s^{-1} in the H_2O maser zone which had radial extent of 50-mas. Yates and Cohen suggested RT Vir was a strong candidate for a bipolar or rotating outflow.

CO(3-2) emission (Stanek et al. 1995) is elongated NNE-SSW, and the peak at blue-shifted frequencies is slightly N of its position at red-shifted frequencies. Some OH 18-cm mainline maser emission (between 100 and 300 mas from the star) is also aligned NNE-SSW, with the northern emission more blue-shifted than the southern.

In this paper we describe how 6-epoch 22-GHz MERLIN2 observations at milliarcsec resolution were used to measure the proper motions of circumstellar H_2O masers and hence determine velocity structure and density structure on scales of 2 mas (0.3 AU). These data show evidence of asymmetrical mass-loss from the semi-regular variable star RT Vir and rule out stellar rotation as the cause of the asymmetry.

2. Observations and Results

The 22-GHz H_2O maser emission towards RT Vir was observed at 6 epochs over 10 weeks from April to June 1996 by the UK MERLIN2. The beam size was 12 mas and the velocity resolution was 0.2 km s^{-1}. Typical rms sensitivity per channel was 30-mJy.

The MERLIN2 observations showed that the brightness distribution varied markedly over 10 weeks. The emission was spread over a region 140 mas (19 au) in radius. The average inner radius of emission was 33 mas, 4.6 au. The ability of MERLIN2 to detect structure on all spatial scales allowed us to measure the unbeamed sizes of the maser features. These turn out to be discrete dense clouds with a density contrast of 30:1 over the ambient medium, with sizes ranging from 2 to 16 mas. The typical cloud size is 10 mas.

These clouds were used as proper motion markers and be used to measure the velocity field in the inner 100 mas of the circumstellar envelope around RT Vir. 11 maser clouds were detected at all 6 epochs and a further 7 also had proper motions accurate to $> 2\sigma$. The proper motions and positions of the maser clouds are shown in Figure 1. The lines are a least-squares fit to the maser positions; however there is actually possibly some systematic curvature as well as scatter.

The average proper motion corresponds to an expansion velocity of 12 km s^{-1}, which agrees with that deduced from the maser spectrum. The proper motion velocities of the clouds are anticorrelated with their Doppler velocities, which is expected for an outflow. The proper motions show a strong radial expansion component and the expansion velocity is **not** dependent on position angle. However the brightest masers are found along a WNW-ESE axis. The tangential components are randomly directed and the extreme red- and blue-shifted maser clouds show detectable proper motions. The upper limit on the rotation velocity is 0.2 km s^{-1}, hence rotation is negligible 7-14 au from the star.

2.1. Discussion

Maser physics suggests that OH mainline emitting regions are 10-100$\times$ less dense than H_2O maser clouds. H_2O maser emission is weakest along an NNE-SSW axis, where OH mainline masers between 100 - 300 mas from the star are brightest. There is a latitude dependent density contrast, which is traced by the H_2O and OH maser emission. However the transition between H_2O and OH maser regions is not smooth nor well-defined. Weak masers of both species are detected at all position angles. The density contrast is most apparent over a small range of position angle. The Doppler velocity does depend upon sky position. This suggests an axi-symmetric circumstellar gas distribution. However the radial velocity of the masers does not depend on position angle and there is no preferred axis of expansion for the water masers. This is an odd result. The density distribution is latitude dependent, but the velocity structure is not. For Red

Supergiants, such as VY CMa, (Richards, Yates and Cohen 1998) both the velocity structure and density structure are latitude dependent.

This begs the question as to why low mass AGB stars have this seemingly contradictory difference between their velocity and density structure. The total velocity extents of OH emission, and of H_2O emision observed in 1996, are similar, and dense regions containing the brightest 22 GHz masers are certainly not expanding more slowly. Thus explanations involving braking to explain high-density regions cannot apply here. Whatever is causing the mass-loss asymmetry is not detectably affecting the expansion velocity. Both aspherical stars and magnetic channelling of the mass outflow would be expected to cause an asymmetry in the velocity structure. For RT Vir it appears that a dense cloud is accelerated by radiation pressure without impediment.

The answer could lie in the small position angle range over which the density contrast appears to take place. If semi-regular stars are new to the AGB of the H–R diagram, there may not have been enough time to set a density contrast which covers a large range in position angle. It has also been suggested that SRbs like RT Vir are nearing the end of the AGB (Szymczak & LeSqueren 1999) when the density contract begins to develope more strongly.

High angular resolution observations (10-mas) of the OH maser emission is required to investigate the kinematics of the OH outflow. If the density contrast is only affecting high latitudes then we would expect to see latitude dependence in the OH maser outflow.

3. Conclusions and Further Work

The H_2O maser emission from RT Vir shows a clumpy outflow, with a maximum expansion velocity of 12 km s^{-1} and a spatial extent of 280 mas. There is a clear density contrast showing latitude dependent mass-loss. The proper motion results rule out rotation as the cause of the density asymmetry in the outflow of the AGB star RT Vir. However there is no clear asymmetry in the velocity field. These data show the value of acquiring high angular resolution density and kinematic data in order to test models of AGB stellar mass-loss.

A programme is underway to monitor the OH and H_2O maser emission from a sample of 7 AGB stars and 4 red supergiants using the EVN and MERLIN to measure the circumstellar density distribution and the velocity field in the inner 20 au of these outflows. These observations should show if rotation or the magnetic field is the prevalent cause of asymmetric outflow, and if density and kinematics depends upon the position of the star in the IRAS colour-colour diagram.

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