The 3-D Kinematics of Water Masers around the Semiregular Variable RT Virginis

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(This paper appears in the Astrophysical Journal Vol. 590, 2003 June 10 issue.)

Abstracts

We report multi-epoch VLBA observations towards water masers around RT Virginis (RT Vir). The 3-D kimenatics of 61 water masers describes a circumstellar envelope expanding roughly spherically with a velocity of ~8 km/s, implying that the bipolarity of the envelope is obscured as increasing the mass-loss rate. Systematic radial-velocity drifts of masers were found with amplitudes of around 1 km/s/yr. From one maser feature, a quadratic position shift with time was discoverd with an acceleration rate of 36 km/s/yr, implying a passage of a shock wave driven by the stellar pulsation. We estimated a distance to RT Vir of ~220 pc on the basis of the statistical parallax and the model-fitting methods.

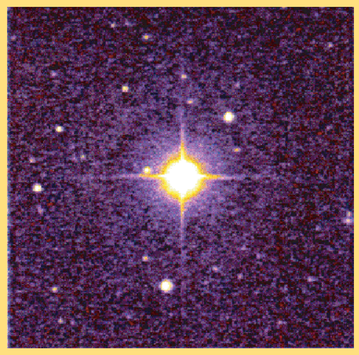

Figure 1:
Image of RT Vir taken by the Digitized Sky Survey

1. RT Virginis (RT Vir)

Visible magnitude: ~ 8.7 mag,
semiregular variable (M8III, SRb).
P~ 155 days (Etoka et al. 2001)
or ~365 days (Imai & Takeuti 1998).
Very bright water maser source.
Radial-velocity drifts were detected
(Imai et al. 1997)

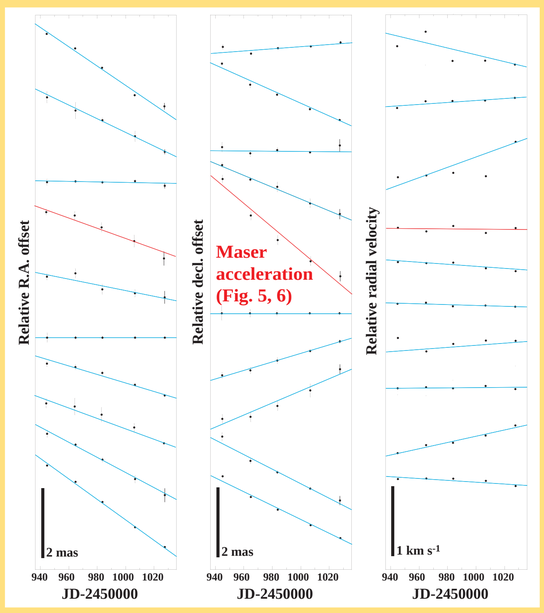

Figure 2:
Proper motions and the Doppler velocity drifts of maser features. Cyan lines show fit lines assuming constant velocity motions in proper-motions and constant acceleration motions in radial-velocity drifts, respectively.

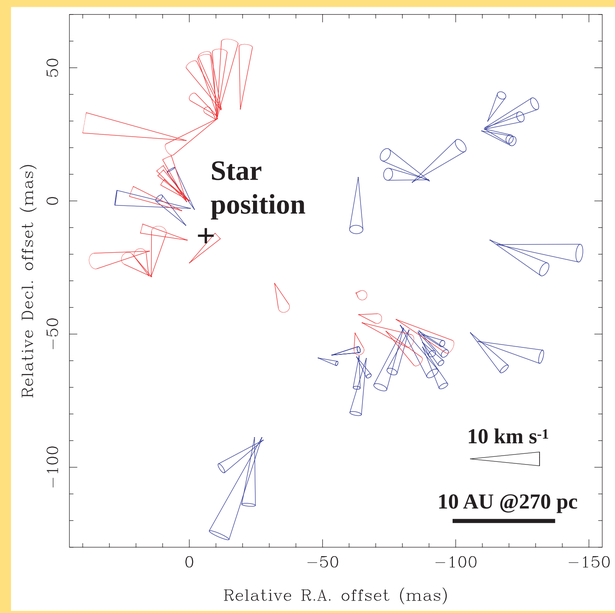

Figure 3:
3-D velocity vectors of water maser features (cones). Red and blue cones indicate receding and approaching features, respectively.

2. VLBA observations of the RT Vir water masers

1) 5 epochs in 1998 May-August, with a separation of 3 weeks between epochs.
2) Velocity resolution of 0.056 km/s.
3) Synthesized beam of 0.4 mas and 1.0 mas in R.A. and decl. directions.
4) Detection limit of 100 mJy/beam at 5-sigma level (without bright emission).
5) Proper motions of water maser features:
61/36 motions (detected at 2~5/3~5 epochs)(see Figure 2).

3. The 3-D kinematics of the circumstellar envelope

1) A radial-velocity gradient in the E-W direction unchanged for 15 years (Bowers et al. 1993), due to weak bipolarity of flow, not to rotation (see Figure 3).
2) The distribution extension of the masers was consistent with that expected from the anti-correlation between the extension and the light-curve (Imai & Takeuti 1998).
3) Some maser features exhibit infall towards the star (see Figure 3).
4) The expanding flow is roughly spherically symmetric (see Figure 3).
A ratio of velocity dispersion of 2.5:1.7:1 among three vetical axes, obtained from diagonalization of a velocity variance-covariance matrix (Bloemhof 2000).

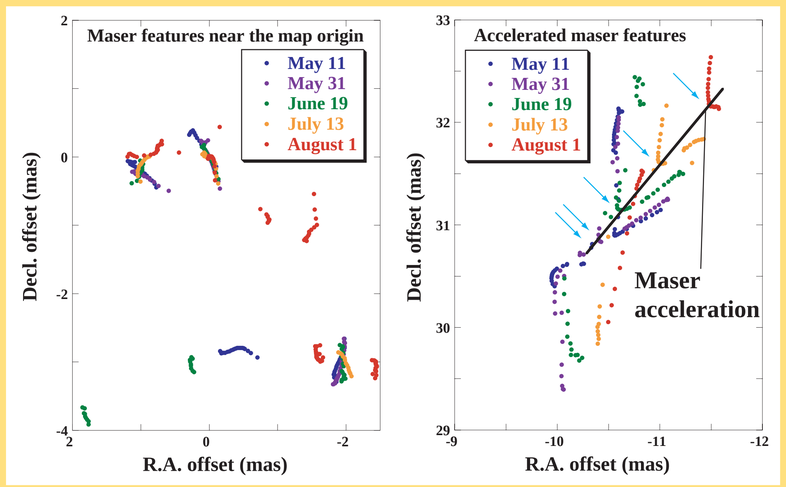

Figure 4:
Spatial structures of some maser features and their time variation. Each dot shows a velocity component (maser spot). The position-reference feature is spatially fixed at the map origin to make measurements of maser proper motions.

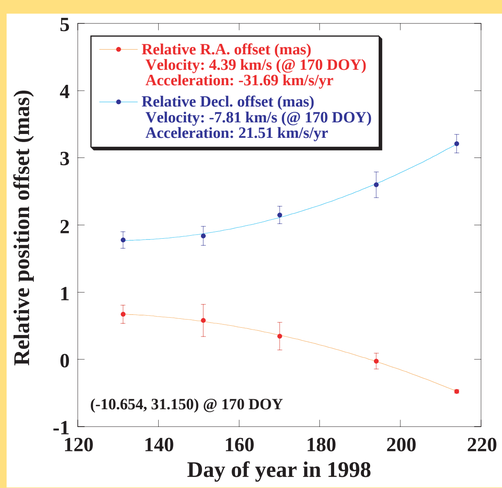

Figure 5:
Proper motion of the maser feature (at the brightness peak) exhibiting the acceleration and a fit to a constant acceleration motion.

4. Apparent acceleration motions of water masers

1) Radial-velocity drifts seen in individual maser features with rates of < 2 km/s/yr (see Figure 2, c.f. Imai et al. 1997).
2) Deviations from constant-velocity motions. They are not due to time variation in the spatial structure of a position-reference maser feature (see Figures 4 and 5).
3) From one maser feature, a quadratic position drift (a constant acceleration motion) was discovered with an amplitude of 33 km/s/yr (see Figures 4 & 5).
This implies a passage of a shock wave (e.g. Hoefner et al. 1995 and figure 6).

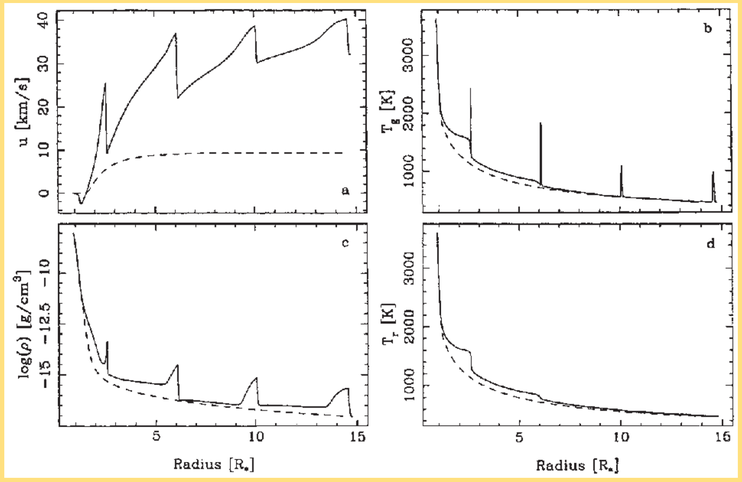

Figure 6:
Models of stellar pulsation induced by dust shells (expansion velocity, gas density, gas temperature, and radiation temperature). The models were based on a C-rich star. (Hofner et al. 1995). Solid lines: Oxygen rich envelope. Break lines: Carbon rich envelope.

5. Discussion

1) Clear bipolarity in R Crt with a low mass-loss rate (Ishitsuka et al. 2001) V.S. spherical symmetry in RT Vir.
>>> increasing a mass-loss rate obsures the bipolarity?
>>> variation of bipolarity with the light curve?
(A larger distribution and clearer bipolarity were found after the light muximum, Imai & Tekeuti 1998.)
2) By beaming effect of maser along a velocity-coherent path, a maser acceleration (in space and time) may be observed more easily on the sky plane rather than in a radial-velocity drift.
3) Statistical parallaces (sigma_Vx-sigma_Vz and sigma_Vy-sigma_Vz) give distances to RT Vir, D= 270+/-40 pc and D= 210+/-30 pc for all (including infall) and only expansion proper moions, respectively.
4) The model fitting give D = 85+/-12 pc and D= 240+/-30 pc for all and only expansion proper moions, respectively.
>>> Distance to RT Vir ~220 pc.

References

1) Bowers, P. F. et al. 1993, AJ 105, 284
2) Bloemhof, E. E. 2000, ApJ 533, 893
3) Etoka S. et al. 2001, A&Ap 378, 522
4) Hoefner, S. et al. 1995, A&A 297, 815
5) Imai, H., Takeuti, M. 1998, in: Pulsating stars: Recent Developments in Theory an Observation, p.123
6) Imai, H. et al. 1997, A&A 319, L1
7) Ishitsuka, J.K. et al. 2001, PASJ 53, 1231