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The 43 GHz SiO Maser in the Circumstellar Envelope of AGB star R Cassiopeia

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Abstract

We present multi-epoch total intensity images of 43 GHz, v=1, J=1-0 SiO maser emission toward the Mira variable R Cas. These data were taken as part of a more extensive programme of observations of other stars. In total we have 23 epochs of data for R Cas. Data were recorded at each VLBA antenna in dual-circular polarization in two 4 MHz windows, each digitally sampled at the full Nyquist rate of 8 Mbps in 1-bit quantization at approximate monthly sampling over an optical pulsation phase range of ϕ = 0.158 to ϕ = 1.78. These maps show a ring-like distribution of the maser features in the shell which is assumed to be centered on the star at a distance of 1.9→2.3 times the radius of star (R_*) from the star's centre. It is clear from this image that the maser emission is significantly extended around the star. At some epochs a faint outer arc can be seen at 2.2 R_*. The intensity of the emission waxes and wanes during the stellar phase. Some maser features are seen infalling as well as out flowing. We are attempting to reconstruct the 3-D velocity field and comparing the result with models of Gray et. al. 2009.

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1. **Asymptotic Giant Branch Stars (AGB)**

The AGB is the last evolutionary stage of low- and intermediate-mass which is nuclear powered. This phase of evolution is characterized by nuclear burning of hydrogen and helium in thin shells on top of the electron degenerate core of carbon and oxygen, or for the most massive super-AGB stars a core of oxygen, neon and magnesium. These stars are very large, very cool (2000-3000 K) and have abundant, molecular, dusty winds (mass-loss rate $10^{-7} – 10^{-5}$ $M_\odot$ yr^{-1}) [Herwig 2005].

2. R Cassiopeiae

R Cassiopeiae is an oxygen-rich AGB star, it is classified as a M-type Mira-variable and its brightness varies from magnitude +4.7 to +13.5 with a period of 430 days and its mass is about 1.2 $M_\odot$. Vlemmings et. al. (2003) performed VLBI astrometry and obtained the distance of 176 pc and the measured the proper motion of the star (μ= 17.10 ± 1.75mas) and (μ= 80.52 ± 2.35mas).

3. Observations

The data on R Cas were taken as part of a more extensive programme of observations of other stars. In total we have 23 epochs of data for R Cas. Data were recorded at each VLBA antenna in dual-circular polarization in two 4 MHz windows, each digitally sampled at the full Nyquist rate of 8 Mbps in 1-bit quantization. The lower spectral window was centred at a fixed frequency corresponding to the υ=1, J=1-0 SiO transition, at an assumed rest frequency of 43.12207 GHz and a systemic velocity V_{LSR} = +27 km s^{-1}. R Cas was observed for three 45- minutes periods evenly spread over the 8 hour duration of the run. Adjacent to each R Cas observation 5 minutes was spent observing the continuum calibrator 0359+509 at the same frequency as R Cas. The data were correlated at the VLBA correlator in Socorro, NM. The correlator accumulation interval was set to 2.88 seconds. All polarization correlation products (RR, RL, LR, LL) were formed. This configuration produced auto- and cross-power spectra in each 4 MHz baseband with a nominal velocity spacing of ~0.2 km s^{-1}.

4. Results

Figure (1) shows the flux density in (Jansky) of SiO maser emission toward R Cas for the antenna Kitt Peak for the left hand of polarization and the VLBA shortest baseline. As it clear from the figure, the VLBA shortest baselines detected about ~ 27 percent of the single dish SiO flux. Kitt Peak was used as a reference antenna because of its stability in both pointing and receiver gain. Figure (2) shows the superimposed image of the SiO maser emission in the vibrational state υ=1 and rotational state J=1→0 with Local Standard of Rest velocity V_{LSR}= 27 km s^{-1} for 23 epochs. This map shows that the SiO emission is predominantly situated in a rarely completed ring at a distance 1.6-2 R_*. It is clear from this image that the maser emission is significantly extended. The ring-like appearance is thought to arise from a spherical shell, wherein strong radial acceleration or deceleration causes tangential beaming. The remnant of an outer, presumably older shell is seen on the East.

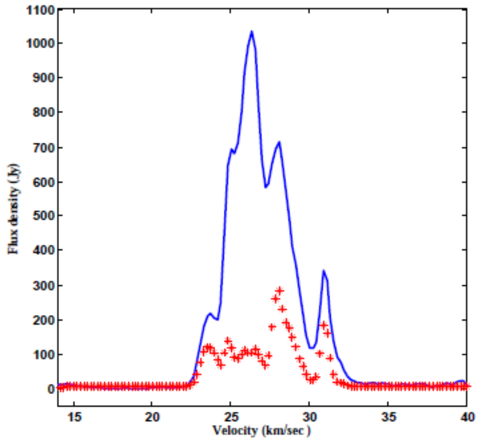


Fig (1) The flux density for antenna KP (solid line) (peaks ~1034Jy) and shortest baseline (LA-PT)(stars) (peaks at ~284Jy).

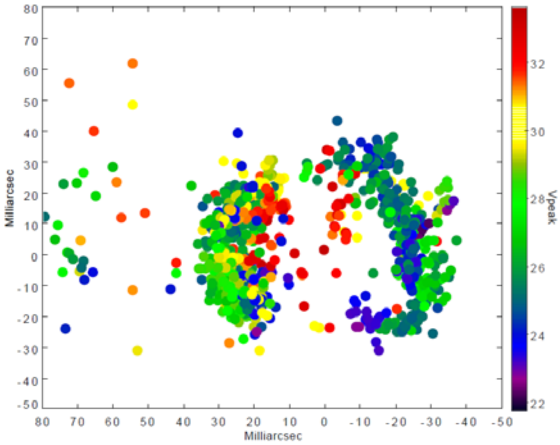
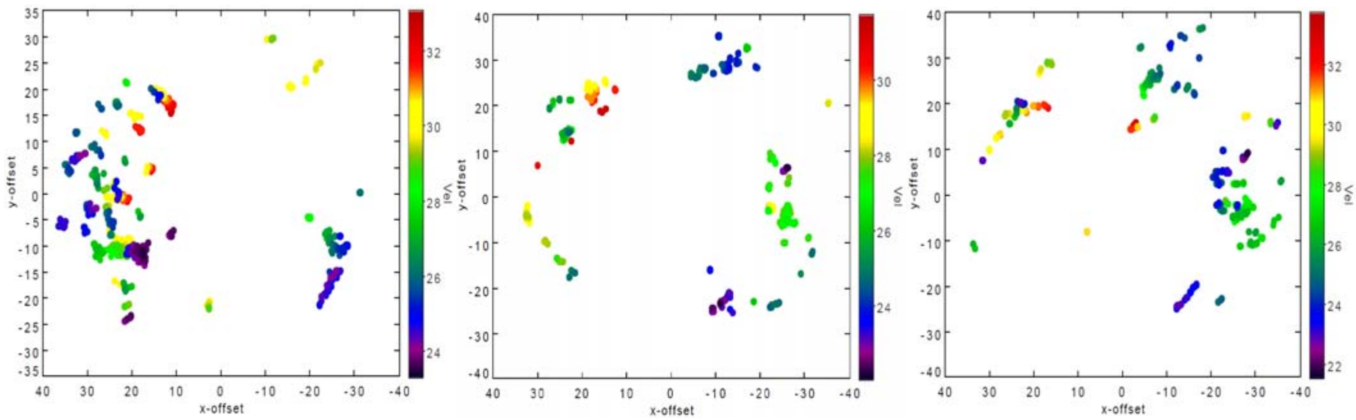


Fig (2) The superimposed image of the SiO maser emission for 23 epochs

Figure (3) illustrates how the shell is dominated by an Eastern arc during the first stellar period and by a Western arc during the second period. Figure (4) shows that expansion is the dominant overall kinematic behavior of the inner shell radius between the optical phase of $\phi \sim 0.158$ and $\phi \sim 1.3$. The projected shell starts shrinking beyond the optical phase $\phi \sim 1.3$ while a new inner shell boundary forms interior to the previously expanding shell.



Fig(3) The left-right change at different epochs

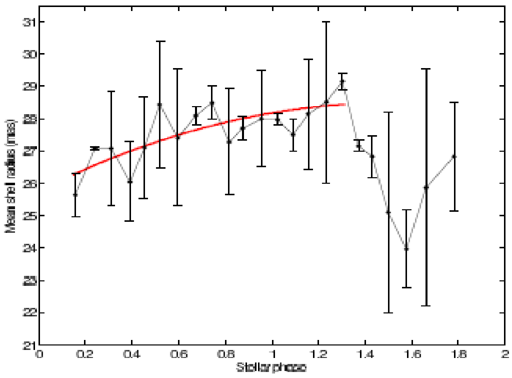


Fig (4) The change of the ring radius with the phase

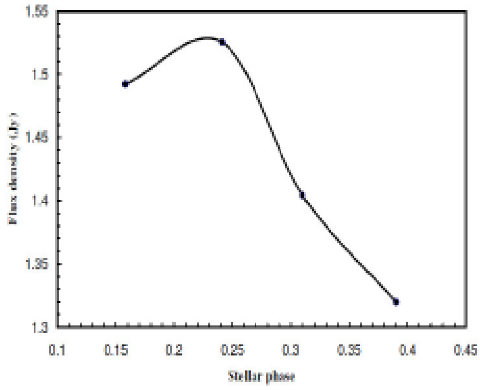


Fig (5) The change of the peak flux density with the stellar phase

5. Discussion

The change in E-W asymmetry from phase to phase could be due to bulk rotation of a spherical shell wherein one hemisphere is more favorable for masing, away from us in the E and towards us in the W, about an N-S axis. This would require an equatorial velocity of 10-20 km s^{-1} which is about twice the observed line of sight velocities, but this could be due to turbulence and selective maser amplification in our direction. However, it is hard to conceive a physical mechanism for spherical solid-body rotation, although a flared disc might be possible. We will model the proper motions in more detail to test this hypothesis. Alternatively, the star may eject mass into arcs, as has been seen in IRC+10216. The sporadic emission appearing near the centre could be due to infall or to the emergence of a new shell. The morphology of the SiO masers in R Cas is described as a partial ring structure. We will compare the structure of the maser with the model by Gray et. al. 2009. This model predicts that the diameter of the maser ring should be about twice the size of the stellar photosphere. The optical stellar diameter of R Cas is 25.3 ± 3.3 mas at ϕ= 0.93 (Weigelt et. al. 2000). We found that the SiO maser shell mean angular diameter, averaged over 23 epochs, is ~54 mas which is double the photospheric diameter within the uncertainties, showing that the model consistent with our data. This model also predicts that the ring size increases from stellar phase 0.1 to 0.25 and then decreases. Figure (4) shows that, during the first cycle, the radius continues increasing past phase 0.25. However, in the second cycle, the radius decreases sharply at the predicted phase. The model predicts that the maser weakens between phases 0.25 and 0.4. Figure (5) shows that the flux density decreases over the same range which suggests good consistency between our observations and the model.

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