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VERA Astrometric Observations of 43-GHz SiO Masers towards R Leonis Minoris

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Oxygen-rich Asymptotic Giant Branch (AGB) stars are intense emitters of SiO maser lines at 43 GHz (J=1→0, v=1 and 2). The masers appear at a distance of a few stellar radii occupying a more or less circular structure. The relative position of the spots of both the v=1 and v=2 SiO transitions is an important result in order to elucidate the nature of the pumping mechanism, and hence a unique interpretation of the observations in terms of physical underlying conditions. VLBI observations of the SiO maser emission has been a unique tool to sample the innermost layers of the circumstellar envelopes in AGB stars, despite the difficulties to achieve astrometrically aligned v=1 and v=2 SiO maser maps. We present such maps, at multiple epochs, towards R LMi, and discuss the analysis.

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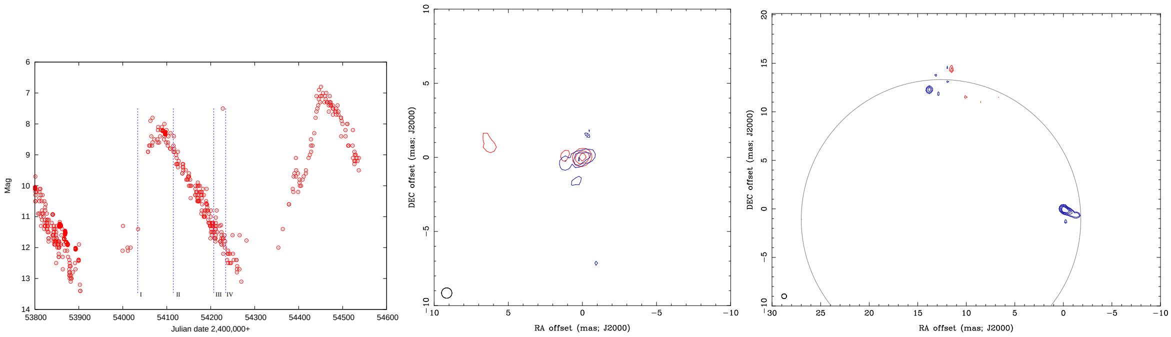

Figure 1: *Left:* Optical light curve (from AAVSO) and epochs of our VERA observations. *Center:* Astrometrically aligned maps of $v = 1$ (red) and $v = 2$ (blue) J=1-0 SiO emission towards R LMi at epoch II. Contours are 3, 6, and 10 Jy/beam. *Right:* Epoch IV, as for epoch II, also with superimposed circle for visual comparison with maps in Figure 2.

1. Observations

We carried out a series of dual-beam VERA observations at 5 epochs of the SiO maser emission (v=1 & v=2 J=1→0), at 43 GHz, towards R LMi, between 2006 October and 2007 May (Fig.1). During the observations, two 16-MHz channels were allocated to observations of the two SiO maser transitions with one beam (beam A); and fourteen 16-MHz channels were devoted to simultaneous observations of a nearby continuum reference source on the other beam (beam B), evenly distributed over the $\sim$ 300 MHz frequency gap between the two maser transitions. Every hour, a $\sim$ 5 minutes scan on a bright continuum fringe finder calibrator source, 4C39.25, was included.

2. Data Analysis

The weak emission of the continuum reference calibrator prevented a "conventional" phase referencing analysis with VERA data. Instead, we have followed a different analysis strategy, with AIPS, that allows measurements of the alignment between multiple transitions simultaneously observed, even in cases when the reference source is not detected: we used the interpolated group delays for the 14 IFs scans on the primary calibrator, $\sim$ 6 degrees away, to remove any instrumental long-term phase difference between the 2 IFs scans on R LMi, separated by $\sim$ 300 MHz, in order to preserve the relative coordinates between the v=1 and v=2 masers. Other related analyses are Yi et al. (2005), and Boboltz and Wittkowski (2005). The scarcity of calibrator scans ($\sim$ hourly) required us to take great care with the interpolation of the phase from the group delay solutions and data handling outside of AIPS was required in order to ensure the phase connection across the 300-MHz spanned bandwidth. For full details on the data analysis refer to Rioja et al. (2008). Then, we applied spectral-line calibration and imaging techniques on a compact and bright reference maser spot in the v=2 data set, to track the short-term atmospheric fluctuations, and obtain a map of the feature. The antenna-based phase and rate solutions from the reference channel in the v=2 IF were used to calibrate all other $v = 2$ spectral channels (the usual case) and also all v=1 channels in the other IF without separate v=1 reference channel calibration.

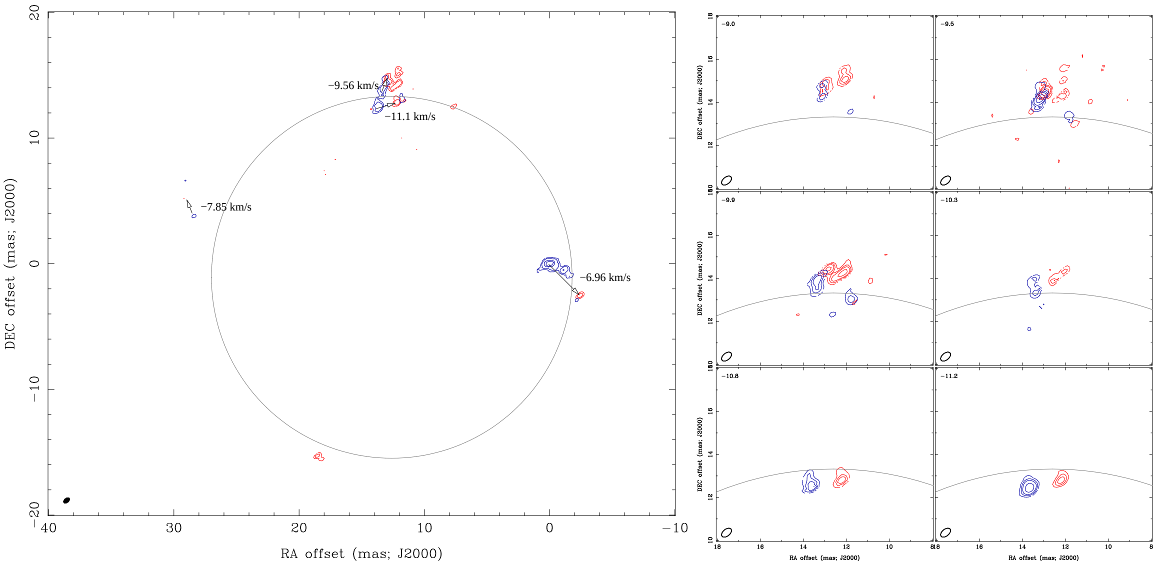

Figure 2: *Left:* Astrometric map of $v = 1$ (red) and $v = 2$ (blue) maser emission at epoch III. The circle serves for visual comparison of distribution of spots at epochs III and IV - not a fitted solution. Arrows show relative position between nearby spots of $v = 1$ and $v = 2$ with common velocities. Arrow's head side is our position error estimate. *Right:* Detail of Northern cluster in map at epoch III. Channels averaged to 4.4 km/s. None of the clusters overlap, except for one.

3. Results

The phase-referenced visibilities were Fourier transformed without further calibration to yield relative astrometrically aligned maps of the $v = 2$ and $v = 1$ maser emission at each epoch of observations - here shown in Figures 1 and 2. Our error analysis gives a conservative estimate of the relative $v = 1$ and $v = 2$ maser position in the maps, at all epochs, of 0.4 mas. An inspection of the maps show that the radius of the v=1 is greater than the $v = 2$ - as found by other authors. Both maser emission occupy roughly the same regions, but the respective spots are rarely coincident; we find only about 1/10 of the identified spots are coincident to within our error estimates. The offsets are of several *mas*, and clearly resolved by VERA. For a discussion on astrophysical results see Rioja et al. (2008). The data analysis route presented here does not suffer from the lack of reference sources, and we plan to apply it to other SiO maser sources to investigate further the $v = 1$ and $v = 2$ separation.

References

[1] D.A. Boboltz & M. Wittkowski, 2005, *Joint VLBA/VLTI Observations of the Mira Variable S Orionis 2005*, *ApJ* **618** (953)

[2] M.J. Rioja, R. Dodson, R. Kamohara, F. Colomer, V. Bujarrabal, & H. Kobayashi, 2008, *Relative astrometry of v=1,2 SiO masers towards R Leonis Minoris using VERA*, *PASJ* **60** (1031) [arXiv:0811.3820]

[3] J. Yi, R.S. Booth, J.E. Conway, & P.J. Diamond, 2005, *SiO masers in TX Cam. Simultaneous VLBA observations of two 43 GHz masers at four epochs*, *A&A* **432** (531)