Cosmic Masers: Proper Motion toward the Next-Generation Large Projects
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Fine structure and refractive scattering of the H_2O maser in star-forming region W49N

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Abstract. We used the unprecedented resolution of ∼25 μas of the VLBI array formed with the RadioAstron satellite to study the structures of H_2O maser spots in the star forming region W49N. We found that anisotropic diffractive scattering of the ISM dominates the images of the maser spot, but does not completely blur them. The refractive scattering floor is about 0.001 in visibility at a baseline of 8 Gλ.

Keywords. Water masers, interstellar scattering, space VLBI

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1. Observations of the W49N region with RadioAstron

W49N is a well-known massive star-forming region located in the Perseus arm in the Galactic direction $(l,\ b) = (43.16^\circ,\ 0.01^\circ)$ at a distance 11.1±0.8 kpc from the Sun, 1.9 pc above the galactic plane (Zhang et al. 2013). W49N hosts the most luminous H_2O maser in the Galaxy, and the maser spots are distributed over ∼ 2" across the sky. In this work we have focused on one particular cluster of masers having a diameter of about 10 mas (110 AU) in the range of velocities of −73.2 to −45.7 km/s located at the extreme western edge of the W49N complex, where the brightest masers were found. A summary of observations is given in Table 1.

2. Structure of compact maser features

The individual H_2O maser spots in the velocity range studied have an average size of 240×150 μas at a position angle (PA) of about 100 degrees. Note that observations of OH masers at 1665 MHz from a separate star-formation site (offset by 0.13 pc) associated with W49N show that they have sizes of about 40×20 mas at a PA of about 107 degrees (Deshpande et al. 2013). Comparison of these parameters, especially the close correspondence of the position angles, suggest that both species of maser spots are substantially blurred by diffractive interstellar scattering, which scales as the frequency ratio squared. The OH maser spot image parameters, scaled to 22.2 GHz by a factor of 180, are 220×110 μas. The substantially larger value of the H_2O spot image minor axis compared to relevant values for OH spot images suggests a model wherein the OH maser spots are completely dominated by scattering, whereas the H_2O masers are only partially dominated by scattering and have intrinsic sizes of roughly 100 μas. We determined that the

Table 1. Observing sessions with RadioAstron.

Obs. code	Epoch	Time, hours	Baselines Mλ	Antennas	Spectral resolution	Velocity range, km/s
rags15a	03.07.2015	11	25 – 5000	RA, Ef, Ys, Nt, Tr, Sh, Hh	0.12 km/s (7.8 kHz	−98, +117
rags11ay	22.05.2015	1	25 – 450 7800 – 8100	RA, Gb, Ef, Mc, Tr	over 16 MHz)	−190, +25

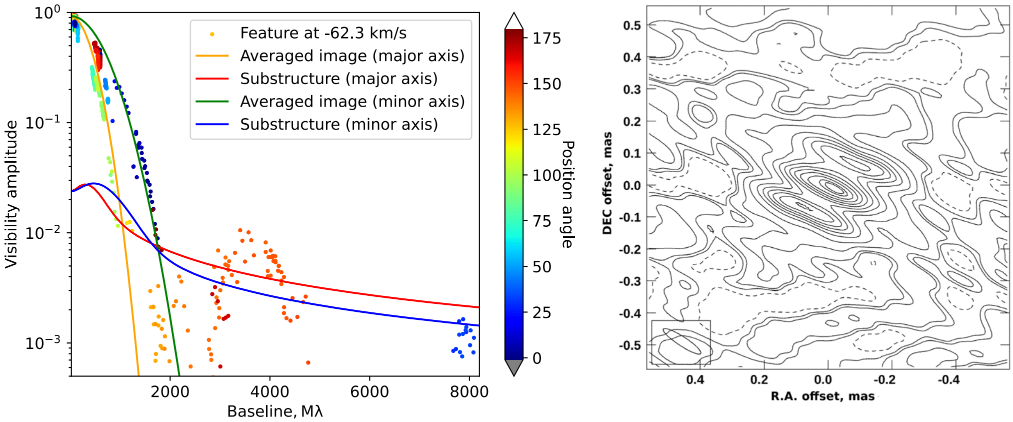

Figure 1. Left panel. *Dots*: relative visibility amplitude vs. baseline length for the brightest maser spot at $V_{LSR} = -62.3$ km/s. *Lines*: theoretical visibility curves for diffractive image and refractive noise. **Right panel**. Image of the spot at −62.3 km/s obtained with RadioAstron. The peak brightness is 2100 Jy/beam and the contours are plotted at −1, 1, 2, 5, 10, 20, 30, 40, 50, 60, 70, 80, 95, and 95% of the peak brightness.

sizes of several H_2O spots increase with velocity away from the line center, in accordance with theories of partially saturated masers. This also supports the idea that the H_2O maser structure is not completely masked by the scattering.

3. Refractive scattering of an H_2O maser emission

We determined that the relative fringe visibilities are between 0.001 and 0.01 in the projected baseline range of 1500 to 8000 Mλ (left panel of Figure 1), and this phenomenon can be attributed to refractive scattering. W49N is the first H_2O maser where refractive scattering is detected.

The magnitude of the refractive floor with respect to the magnitude of diffractive scattering is consistent with the H_2O masers being slightly resolved. Visibility curves for diffractive image and refractive noise predicted by theory (Johnson & Gwinn 2015) are also presented in the left panel of Figure 1. The refractive curves are calculated for a point source. In the case of a finite source size, the refractive floor will be lowered.

It is important that the refractive visibility curve at long space baselines changes for different spectral features, because we are viewing through different parts of the screen.

The image of the brightest maser spot at −62.3 km/s obtained with RadioAstron is presented in the right panel of Figure 1. The structure in the image shows the speckles produced by refractive scattering.

References

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