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Brightness temperatures of galactic masers observed in the RadioAstron project

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Abstract. We present estimates of brightness temperature for 5 galactic masers in star-forming regions detected at space baselines. Very compact features with angular sizes of ~23-60 μas were detected in these regions with corresponding linear sizes of ~4-10×10^6 km. Brightness temperatures range from 10^{14} up to 10^{16} K.

Keywords. masers, techniques: high angular resolution

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1. Maser observations in the RadioAstron project

Galactic masers have been observed in the RadioAstron (RA) project during 6 year of operation since the launch in July 2011 (Kardashev *et al.* 2015). The satellite is equipped with receivers allowing observations of strong maser lines at 22235, 1665 and 1667 MHz. The space interferometer provides a record angular resolution up to 7 μas at 22 GHz. So, we can put tight limits on the sizes of very compact maser spots, estimate their brightness temperatures and, thus, obtain important parameters for maser models.

The sensitivity of the RA together with the 100-m Effelsberg radio telescope at 22 GHz is ~10 Jy (at 6σ) with a coherent integration time ~600 sec and typical line width ~0.4 km/s. Observations carried out for H_2O masers on the RA indicate in the most cases only a small contribution from ultra-compact components to the total flux of the separate spatial-kinematic features. Thus, the W3 IRS 5, observed on a baseline of 2.5 Earth Diameter (ED), showed a visibility function amplitude of only 1% of the total flux density (Sobolev *et al.* 2017).

Such super-compact H_2O features were successfully detected in 7 galactic star-forming regions regions and in 2 extragalactic masers in NGC4258 and NGC3079. Current statistics of RA observations can be found in (Sobolev *et al.* 2017). In the present work we consider 5 galactic H_2O masers and obtain upper limits on the angular size of the most compact components and lower limits on the brightness temperature. We used the data processed on the ASC software correlator for the RA mission (Likhachev *et al.* 2017).

2. Brightness temperatures from the interferometric visibilities

Normally, brightness temperature T_b can be obtained from imaging with a long period of observations and many telescopes involved. But there are a lot of short observations (~1 hour) in the early RA maser survey with a few baseline sets, about 3 to 6. In this case it is possible to estimate brightness temperature of a source using some assumptions.

Table 1. Brightness temperature for compact H_2O masers observed in the RA project.

Source	RA (J2000) hh mm ss.ss	DEC (J2000) ° ′ ″	Baseline, ED	Resolution, μas	$T_{\rm b,min}$, K	T_b, K
Orion KL	05 35 14.13	−05 22 36.48	3.3	66	1.2×10^{15}	6×10^{15}
Cepheus A	22 56 17.97	62 01 48.75	3.4	64	1.2×10^{14}	3×10^{14}
W3 OH	02 27 04.84	61 52 24.61	3.8	58	2.1×10^{14}	7×10^{14}
W3 IRS5	02 25 40.71	62 05 52.52	5.4	40	1.5×10^{15}	8×10^{15}
W49 N	19 10 13.41	09 06 12.80	9.6	23	4.5×10^{14}	3×10^{15}

Thus, without a priory information about brightness distribution, we may use a circular Gaussian and estimate T_b and size of a source as proposed in (Lobanov 2015):

$$T_{\rm b} = \frac{\pi}{2k} \frac{B^2 V_0}{\ln(V_0/V_q)} [K], \tag{2.1}$$

where V_q is the visibility amplitude, V_0 is the space-zero visibility, B is the baseline length, $q = B/\lambda$. It was shown in (Lobanov 2015) that T_b is at its lowest when $V_0/V_q = e$. This provides the minimal brightness temperature given the baseline length and correlated flux obtained from data processing using PIMA package (Petrov *et al.* 2011):

$$T_{\rm b,min} \approx 3.09\,(B[\rm km])^2\,(V_q[\rm mJy])\,[K]. \tag{2.2}$$

3. Results and conclusions

Results of our calculations of T_b and $T_{\rm b,min}$ according to Eqs. 2.1 and 2.2 are given in Table 1. Columns contain from left to right: (1) source name, (2) RA and DEC coordinates (J2000), (3) baseline in units of Earth diameters (ED), (4) corresponding resolution in μas (this value can be considered as an upper limit of angular size of the compact feature), (5) $T_{\rm b,min}$ (the lower limit of T_b) and (6) T_b.

Main conclusions. In star-forming regions very compact maser features with angular sizes of 23-60 μas were observed, which correspond to $\sim$4-10$\times10^6$ km. The best linear resolution was obtained for the H_2O maser in Orion – 4 million km. The best angular resolution for Galactic masers is 23 μas for W49 N (the distance is $\sim$11 kpc). Brightness temperatures for the most compact maser features range from 10^{14} to a few of 10^{15}.

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