Cosmic Masers: Proper Motion toward the Next-Generation Large Projects
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IC 485 : A candidate for a new disk-maser galaxy

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Abstract. Fundamental physical quantities of the nuclear regions of the Active Galactic Nuclei can be obtained using megamaser studies. In particular, disk-masers associated with accretion disks around the supermassive black holes are used, through high angular resolution measurements, to trace the disk geometry, to estimate the BH mass and to measure accurate distances to their host galaxies. In this contribution, we present the first results in continuum and spectral-line mode of a high-sensitivity, multi-epoch VLBI study of the nuclear region of the megamaser LINER galaxy IC 485.

Keywords. masers, technique:high angular resolution, galaxy:active, galaxy:individual (IC 485)

1. Introduction

Galaxies with intense activity in their nuclear regions are defined Active Galactic Nuclei (AGNs). They are classified according to the Unified Model by Urry & Padovani (1995) and according to their radio activity. In the framework of megamaser studies, the most relevant are the "radio-quiet" AGNs: Seyfert 2 and LINERs (e.g. Lal *et al.* (2011), Marquez *et al.* (2017)) where most of the known megamasers are observed. Three AGN components are associated with the activity of H_2O maser emission: disk, jets and outflows (e.g. Tarchi (2012)). In particular, disk masers are associated with the nuclear accretion disk and they permit to trace disk geometry, to measure the rotation velocity and the mass of the supermassive black hole (SMBH) (e.g. Gao *et al.* (2017), Pesce *et al.* (2020)) to estimate distances to the parent galaxies and cosmological measurement of H_0, (e.g. Reid *et al.* (2013), Braatz *et al.* (2013)). These studies are possible thanks to the high angular resolution of the Very Long Baselines Interferometry (VLBI) technique which also may allow to discern the observational signatures of a new peculiar typology of maser: "inclined maser disk" where the maser detection is possible thanks the gravitational lensing (Darling 2017).

Table 1. Observational details of the six epochs analyzed. [a]The rms has been calculated with the task IMEAN. [b]The noise in the cube map, indicated in boldface, is calculated in a range of 500 channels where there is not maser emission.

Project name	Epoch	Band	Array	# IF	Band-width	Numb. Channels	Integr. time (h)	rms[a] ($\frac{\text{mJy}}{\text{beam}}$)
BT142_A2	2018.11	L	VLBA	4	64 MHz	128	2.5	0.029
BT142_A1	2018.16	K	VLBA	1	64 MHz	4096	2.5	**3.02**[b] ; 0.064
ET038_A	2018.39	C	EVN	8	16 MHz	32	1.4	0.028
ET038_B	2018.40	L	EVN	8	16 MHz	32	2.3	0.018
BT142_A2	2018.59	L	VLBA	4	16 MHz	128	2.5	0.05
BT145_A1	2018.83	K	VLBA	2	16 MHz	4096	3.5	**5.87** ; 0.066

2. Outline of the project and target details

The present study is part of an ongoing Ph.D. project focused on a detailed study of H_2O (and OH) megamasers at VLBI scale in radio quiet AGN galaxies (Seyfert and/or LINERs). This will permit i) to increase the physical and geometric information of the maser phenomenon; ii) to expand the number of cases analyzed and thus collect evidence for (or against) the Unified Model. Indeed, the galaxy IC 485 is one of the targets included in the sample of this project. IC 485, with systemic velocity $V_{sys}^{hel,opt,} = 8338\,\mathrm{km\,s^{-1}}$, has been optically classified as a Sa spiral galaxy located at the distance of 122.0 ± 8.5 Mpc, assuming $H_0 = 70\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ (Kamali *et al.* 2017). The spectroscopic classification of the galaxy is unclear yet. The galaxy is presented as a LINER and is included in the sample of "inclined maser disk" candidate reported by Darling (2017). On the other hand, a classification as a Seyfert 2 was proposed by Kamali *et al.* (2017). Darling in his Very Large Array (VLA) observations reports a broad multi-component maser with a peak of 78 ± 2 mJy with a high luminosity ($L_{\mathrm{iso}} = 868 \pm 46\, L_{\odot}$). Unresolved and faint radio continuum emission was observed with the VLA at 1.4 GHz in the NVSS (Condon *et al.* 2002) and FIRST. Detections at 20 GHz and at 33 GHz although with a low significance or as tentative were also reported by Darling (2017) and Kamali *et al.* (2017), respectively.

3. Observations and data reduction

IC 485 was observed with the Very Long Baseline Array (VLBA†) and with the European VLBI Network (EVN‡) in six epochs during 2018. In order to measure absolute position and to correct phase variation, we observed in phase-referencing mode using J0802 + 2509 at 1.77° from the target. The configuration at K-band was chosen in order to cover the main broad maser emission line with a velocity resolution of $0.2\,\mathrm{km\,s^{-1}}$ and to leave enough line-free channels for continuum subtraction and to produce a K-band continuum image. We reduced and analyzed the data utilizing the NRAO Astronomical Image Processing System (AIPS§) with standard procedure of calibration and the spectra were analyzed with the software CLASS¶. Details of the observations are reported in Table 1.

4. Results and discussion

At the L- and C- band, no continuum source was detected above the 5σ noise level (the rms are reported in Table 1). At K-band, 9 unresolved continuum sources were detected with a SNR$\geq 5\sigma$ (Fig. 1, upper pannel). The results suggested that the diffuse and continuum emission reported in Darling (2017) with VLA was resolved-out by

† The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

‡ The European VLBI Network is a joint facility of independent European, African, Asian, and North American radio astronomy institutes.

§ www.aips.nrao.edu/

¶ www.iram.fr/IRAMFR/GILDAS

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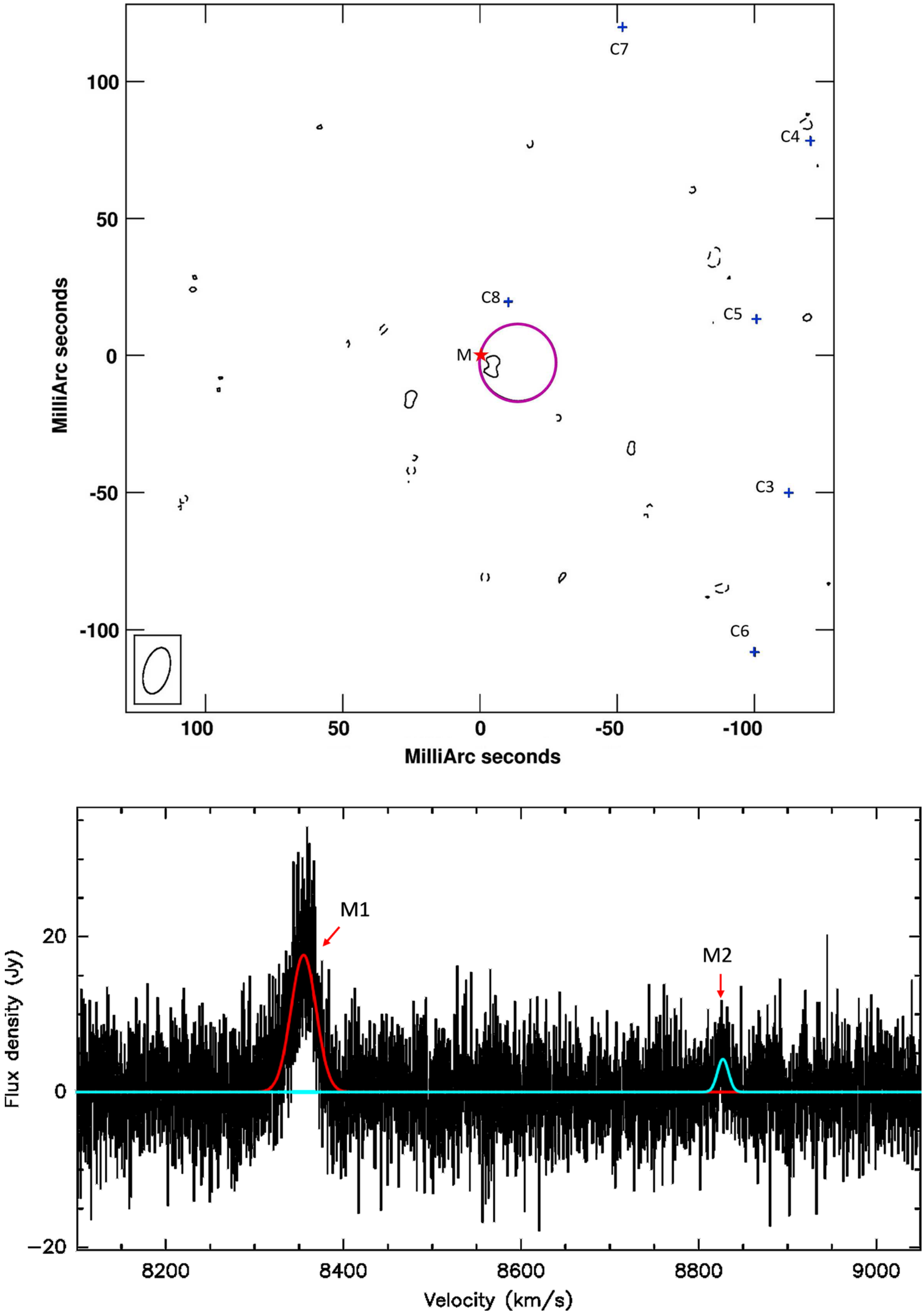

Figure 1. *Top panel*: The L-band EVN radio continuum map of the nuclear region of IC 485. Contour levels are (−3, 3, 4, 5) × 18 μJy beam^{-1}. The blue crosses pinpoint the continuum sources detected at K-band. The red star indicate the position of the main maser feature. The purple circle represents the position of the VLA continuum source detected by Darling (2017). *Botton panel*: The spectrum of the main features observed with the VLBA in the epoch 2018.83.

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Table 2. Parameters of the maser features. The columns indicate the epoch of detection, the name of the maser features, right ascension, declination, the peak velocity and the isotropic luminosity.

Epoch (VLBA)	**Maser**	**RA** (α_{2000}) [$^{h}:^{m}:^{s}$]	**Dec** (δ_{2000}) [$^{\circ}:':''$]	**Peak velocity** [$\mathrm{km\,s^{-1}}$]	L_{iso} ($L_\odot$)
2018.16	M1	08:00:19.75253	26:42:05.0523	8353.6±0.1	524±56
2018.83	M1	08:00:19.75252	26:42:05.0525	8354.8±0.5	239±38
	M1B	08:00:19.75247	26:42:05.0520	8355±2	76±18
	M2	08:00:19.75252	26:42:05.0528	8827±1	24±16

VLBA and EVN interferometer. The AGN in IC 485 may be considered radio silent or that its contribution is faint in radio band. Another explanation is that the continuum radio emission is dominated by the star forming regions in the host galaxy. In the spectral line mode, we report maser emission from three features. Two features are observed close to systemic velocity: a main bright maser component, labeled M1; a weaker tentative feature, M1B; and a third feature, M2, is observed at a velocity shifted w.r.t. the systemic velocity (Fig. 1, botton pannel). The main maser feature M1 is observed on both epochs. The details of the features detected are reported in Table 2. The position and the linear distribution of the two components, M1 and M2, allow us to speculate a disk-maser nature with a radius of 0.2 pc. Assuming a Keplerian rotation, the black hole mass in the center of the nuclear region estimated is $M_{BH} \approx 10^7 M_\odot$. This value is consistent with the one expected for a SMBH in a Seyfert or a LINER galaxy (e.g. Kuo *et al.* (2010)). Our hypothesis is built on the high sensitivity observations reported in Pesce *et al.* (2015), where the three components (although the blue component was reported as tentative) associable with a disk-maser are observable in the spectrum of IC 485. Furthermore, a recent survey of the H_2O emission at 183 GHz in AGNs already known for the presence of 22 GHz maser-disk reveals how the sub-mm transition can similarly trace the same accretion disk as that at cm wavelength (Pesce *et al.* 2023). The detection of the two transitions of masers in these galaxies and in our target, IC 485, seem to support and encourage our hypothesis of disk-maser. Interestingly, the feature M1B is spatially distinct from M1 and detached by the disk, suggesting a distinct origin, possibly associated with a jet or an outflow maser. This may hint at a composite nature of the maser in IC 485, already known to be observed in other megamaser galaxies (e.g. Gallimore *et al.* 1996 for NCG1068).

5. Summary

Here, we report the main results of six-epochs VLBA and EVN multi-band observations of the nuclear region of the megamaser LINER galaxy IC 485. The outcome suggests that the maser traces an accretion disk associated with a relatively "radio-quiet" AGN. Therefore the scenario for the maser in IC 485 being a candidate for an "inclined maser" seems to be ruled out. Further measurements are presently ongoing aimed at confirming the disk nature and better constraining the nuclear components' parameters.

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