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VLBI observations of the water megamaser in the nucleus of the Compton-thick AGN IRAS 15480-0344

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As part of a search for water maser emission in a well defined sample of Compton-thick AGN, we detected a luminous H_2O maser in the mid-IR-bright Seyfert 2 galaxy IRAS 15480-0344. The maser spectrum shows two main features: a broad weak blueshifted (w.r.t. the systemic velocity of the galaxy) component and an extremely bright narrow line feature at the systemic velocity of the galaxy. VLBA observations have been obtained to image the line emission from the innermost regions of this galaxy. Here, I report the preliminary results from this experiment that has successfully detected the strongest maser component and part of the blueshifted emission. High angular resolution observations allowed us to pinpoint the location of the line emission with subparsec accuracy and revealed that the systemic and blueshifted features originate from spatially and physically distinct regions separated by $\sim$15 pc. Our results exclude that the entire emission may arise from an edge-on accretion disk, while tend in favour of a jet/outflow or composite (disk + jet/outflow) nature for the maser in IRAS 15480-0344. At present, an association of part of the emission with star formation activity cannot be ruled out.

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1. Introduction

The knowledge of the physical state, the structure, and the dynamics of the matter in the innermost regions of AGN is crucial not only to understand the physics of these objects (i. e. the connection between accretion onto supermassive black holes, SMBH, and the formation of jets and outflows) but also to shed light on the active role of AGN in galaxy formation and evolution, inferred from the strong correlations between SMBH and the properties of the stellar spheroid of galaxies [2]. The radio emission from luminous H_2O masers (the so called "megamasers") constitutes a fundamental instrument to study the geometry and kinematics of the molecular gas in the proximity of SMBH, particularly in the case of Compton thick AGN ($N_{\rm H} > 10^{24}$ cm^{-2}), where the radiation in the optical and ultraviolet bands is heavily absorbed by the large amount of gas and dust along the line of sight. VLBI and single-dish monitoring studies of disk-masers allow us to map accretion disks and to determine the enclosed dynamical masses [1]. Jet-masers observations, instead, can provide estimates of the shock speeds and densities of radio jets [4], while outflow-masers trace the geometry of nuclear winds at < 1pc from the nuclear engine [3].

Here we report the preliminary results of Very Long Baseline Array (VLBA) observations of a new water megamaser in the Seyfert 2 galaxy IRAS 15480-0344 (hereafter IRAS15480). This galaxy has been observed as part of a survey to search for 22 GHz maser emission in a new well defined sample of 36 Compton thick AGN, selected through a very efficient method based on the combination of mid-IR and X-ray data [6]. The single-dish spectrum, obtained with the Green Bank Telescope (GBT), shows two main features (Castangia et al. in prep.): a broad, blueshifted component with peak velocity and flux density of 8960 km s^{-1} and $\sim$10 mJy, and a stronger one ($S_{\rm peak}$ $\sim$50 mJy) at $V_{\rm HEL}$=9106 km s^{-1}, thus very close to the systemic velocity of the galaxy ($V_{\rm sys}$=9084 km s^{-1}).

2. VLBA observations, archival data, and imaging

IRAS15480 was observed with the Very Long Baseline Array (VLBA) on June 2 and 3, 2012, in two tracks of 5 hours each (project code BC207). The data were taken with two 16 MHz IFs in dual circular polarization. The two IFs were centered at the velocity of the two maser features ($V_{\rm HEL}$=8960 and 9106 km s^{-1}). Cross-correlation of the data was performed using the DiFX software correlator with 128 channels per IF and polarization, yielding a channel spacing of 125 kHz (corresponding to $\sim$1.7 km s^{-1} at 22 GHz). A second DiFX pass in "spectral zooming" mode provided a channel spacing of 15.6 kHz ($\sim$0.2 km s^{-1}) over a 2 MHz band centered on the velocity of the narrow maser component. We observed in phase-referencing mode, to correct phase variation caused by the atmosphere. We used J1555-0326 as a phase calibrator. We also observed the strong compact quasars J0927+3902 and J1800+3848 at intervals of 1hr and 20 minutes in each observing session, in order to correct instrumental single-band delays. Data reduction and analysis were carried out utilizing standard routines with the NRAO Astronomical Image Processing System (AIPS). We calibrated each track and spectral mode separately, with the exception of the final phase calibration of the data in "spectral zooming" mode, where we used the solution of the fringe fitting on the reference source calculated from the lower resolution dataset. Then, the calibrated data from the two tracks were combined for imaging. The data were Fourier-transformed using

Table 1: VLBA maps of IRAS15480.

Band	ν (GHz)	Channel width ($\mathrm{km\,s^{-1}}$)	Synthetized beam HPBW (mas)	P.A. ($^{\circ}$)	r.m.s (mJy/beam)
K	21.571	1.8	1.8×1.0	-10	2.2
	21.581	1.8	1.8×1.1	-7	2.1
	21.579	0.2	1.8×1.1	-7	5.1

natural weighting and deconvolved using the CLEAN algorithm. We mapped a field of 0.8×0.8 arcseconds^2 (corresponding to $\sim$480×480 pc^2) centered at the position of the optical nucleus of IRAS15480. We obtained three images from the line dataset, one for each of the two IFs in the standard mode and one for the "spectral zooming" mode. The details of the maps are reported in Table 1.

3. Results

In the low resolution dataset (channel spacing $\sim$1.8 $\mathrm{km\,s^{-1}}$), we detected two maser features: one at V_{HEL}=9106 $\mathrm{km\,s^{-1}}$, identified with the narrow component in the single-dish spectrum, and the other at V_{HEL}=8994 $\mathrm{km\,s^{-1}}$, within the velocity range of the broad line emission observed with the GBT. Both features arise from single spatially unresolved spots and were detected in only one channel. The narrow component at the systemic velocity was detected also in the image obtained from the dataset in "spectral zooming" mode (channel spacing $\sim$0.2 $\mathrm{km\,s^{-1}}$). Here, the line profile is slightly resolved (Fig. 1; right panel) with a full width at half maximum linewidth of 0.45±0.06 $\mathrm{km\,s^{-1}}$ and a peak flux density of about 47 mJy. A 2-dimensional Gaussian fit to the maser emission in the velocity-integrated map (Fig. 1; left panel) yielded a centroid position α_{2000}=15$^{\mathrm{h}}$50$^{\mathrm{m}}$41$^{\mathrm{s}}$.49695 and δ_{2000}=$-$03°53$'$18$''$.0217, where the uncertainty is of 0.2 and 0.4 mas in right ascension and declination, respectively, and is dominated by the uncertainty in the position of the reference source, J1555-0326 (Sect. 2). The emission is spatially unresolved with dimensions smaller than 0.9×0.5 mas (0.5×0.3 pc). The weaker blueshifted feature has a peak flux density of $\sim$12 mJy and is located $\sim$25 mas ($\sim$15 pc) toward the northwest w.r.t the brighter maser spot. Both maser emission regions are coincident, within the error, with the position of the nuclear radio continuum source detected by the VLA at 8.4 GHz [5].

4. Discussion and concluding remarks

High angular resolution observations of the maser in IRAS15480 with the VLBA successfully detected the narrow component close to the systemic velocity of the galaxy. Line properties (velocity, linewidth, peak and integrated flux density) are consistent with those derived from the single-dish spectrum. On the contrary, only a weak narrow line has been detected in the frequency band centered on the velocity of the broad blueshifted component, suggesting that the latter is the result of the superposition of many weak features which are below the detection threshold of our VLBI experiment. The distance of $\sim$15 pc between the systemic and blueshifted emission features indicate that they arise from spatially and physically distinct regions. This rules out the hypothesis

PoS(EVN 2014)030

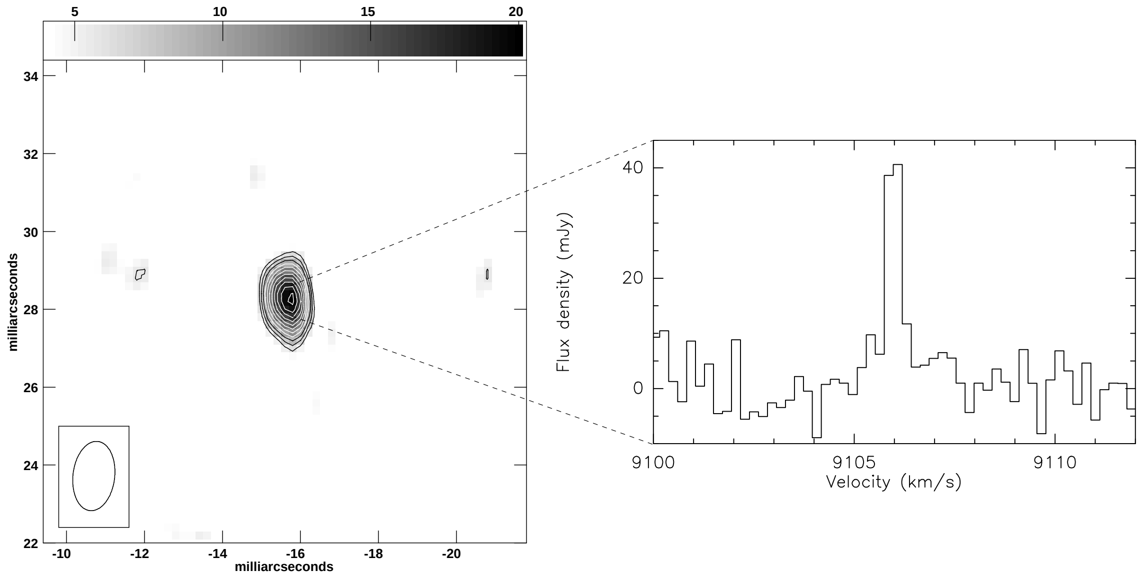

Figure 1: *Left panel:* Greyscale plus contour plot of the VLBA moment-0 map of the strongest maser feature in IRAS15480. Greyscale flux range is 4.2–20.0 Jy beam^{-1} per m s^{-1}. Contour levels are 4, 5, 6, 7, 9, 9, 10, 11, 12, 13, 14, 15 $\times$ 1.4 Jy beam^{-1} per m s^{-1}. Integration was performed over the velocity interval 9105.8–9106.0 km s^{-1}. *Right panel:* VLBA spectrum of the brightest maser spot. The channel spacing is 0.2 km s^{-1}.

that they might be part of the maser emission from an edge-on accretion disk. Indeed, the radii of masing disks measured so far are typically $<$1 pc [1]. Our results, instead, tend in favour of a jet/outflow or composite (disk + jet/outflow) origin for the maser emission in IRAS15480. In addition, an association with a particularly vigorous star formation activity in the proximity of the galactic nucleus, cannot be excluded. Although the maser spots are coincident with the nuclear radio continuum source detected at 8.4 GHz with the VLA, the coarse angular resolution of the continuum map prevented us from conclusively determine the nature of the maser emission. A detailed study of the nuclear environment of IRAS15480 with an angular resolution comparable with that of our VLBA spectral line observations, is indeed mandatory in order to associate the location of the line emission with that of other sources of activity in the innermost regions of the AGN. Approved European VLBI Network observations at L and C bands of IRAS15480 will be performed soon and these data will help shedding light on the hidden nucleus of this Seyfert galaxy.

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