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Exploring the radio continuum in megamaser galaxies with the EVN

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The origin of the nuclear radio continuum emission in radio quiet AGN, differently from their radio loud counterpart, may be due to multiple physical mechanisms. Moreover, although they constitute the great majority of the AGN population, studying their radio emission is challenging due to their intrinsic weakness. Being preferentially found in radio quiet objects (e. g. Seyfert or LINER galaxies), water megamasers offer a powerful complementary way to shed light on the origin of the radio continuum emission in these AGN. In fact, beside accretion disks, H_2O masers may also trace nuclear ejecta in the form of jets or winds providing estimates of the shock speeds and densities of the outflowing material, and improving our understanding of its interaction with the ISM. Here, we present multi frequency VLBI radio continuum observations of two Seyfert galaxies hosting luminous water maser emission presently under thorough investigation by our group: IRAS 15480-0344 and IC 485.

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1. Introduction

H_2O masers associated with AGN (the "megamasers") constitute a unique way to directly map the molecular gas at (sub-)parsec distance from SMBH and, hence, to study the physical properties, the structure, and the kinematics of the gas surrounding the central engine. These are key ingredients to build detailed models of AGN and investigate AGN feedback processes. Water megamasers may form directly in the nuclear accretion disk, where they can be used to trace the disk geometry and to estimate the rotation velocity and the enclosed nuclear mass (e. g., [1]). In addition, H_2O masers may also trace nuclear outflows in the form of jets or winds. Jet-maser observations can provide estimates of the shock speeds and densities of radio jets, improving our understanding of the jet-ISM interaction (e. g. [2]). Water maser observations in Circinus ([3]) and NGC 3079 ([4]), instead, seem to have resolved individual outflowing torus clouds at <1 pc from the nuclear engine. Comparison of these "outflow-masers" with their disk counterpart offer a promising means to probe the structure and motion of outflowing torus clouds (e. g., [5]; [6]).

To date, more than 3000 galaxies have been searched for water maser emission and detections have been obtained in about 180 of them [7]. With few exceptions, most of the known maser hosts are radio-quiet AGN classified as Seyfert 2 (Sy 2) or Low-ionization nuclear emission-line regions (LINERs), in the local Universe ($z < 0.05$). Hence, water megamasers also offer a powerful way to shed light on the origin of the radio continuum emission in radio-quiet AGN. In addition to synchrotron emission from relativistic (or sub-relativistic) particles in low-power jets, the radio continuum emission in radio-quiet AGN might be produced by accretion disk winds and/or coronae, as well as by nuclear star formation (for a review see [8]). Disentangling the radio emitting processes acting in the nuclei of radio-quiet AGN is difficult because they are intrinsically weaker and more complex than their radio-loud counterpart. Beside the study of the radio morphology, the spectral index and the power of the continuum emission, high angular resolution observations of H_2O masers may pinpoint regions of strong interaction of low-power jets and/or nuclear outflows with the interstellar medium in the nuclei of radio-quiet objects, thus contributing to our understanding of the radio emission mechanisms at work in this class of AGN. Here, we present, as a test case, multi frequency VLBI radio continuum observations of two Seyfert galaxies hosting luminous water maser emission presently under thorough investigation by our group: IRAS 15480-0344 (hereafter IRAS 15480) and IC 485.

2. IRAS 15480

IRAS 15480 is a lenticular (S0) galaxy located at a distance of 130 Mpc that harbors a Seyfert 2 nucleus ([9]). A luminous H_2O maser was detected in IRAS 15480 reaching a total single dish isotropic luminosity of 200 $L_\odot$ ([10]). In order to shed light on the origin of the maser (outflow or disk), we observed the radio continuum emission in IRAS 15480 with the European VLBI network (EVN), at 1.7 and 5.0 GHz. The EVN maps show two bright sources (labeled SW and NE, Fig.1) in the nuclear region of IRAS 15480 which we interpret as jet knots tracing regions where the radio plasma impacts dense molecular clouds (for details see [11]). The narrow maser feature is approximately at the center of the imaginary line connecting the two continuum sources, likely pinpointing the core, and might be associated with the accretion disk or a nuclear outflow. The location of the broad maser feature, instead, coincides with source NE, suggesting that the maser emission might be produced by a jet cloud interaction as it was proposed for e. g. Mrk 348 ([2]).

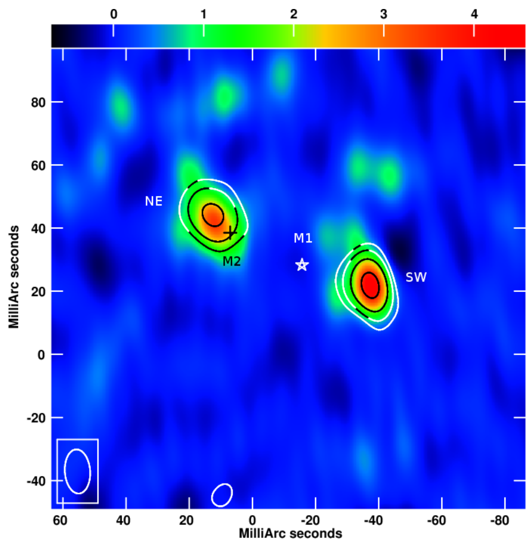

Figure 1: Radio continuum emission in the nucleus of IRAS 15480 ([11]). The color scale represents emission at L band ranging from 0.7 to 4.6 mJy, while the overlaid contours delineate the C band emission convolved with the L band beam (contour levels are -1, 1, 2, 4, 8, 16, 32, 64 $\times$ 0.45 mJy/beam.

The combination of our VLBI radio continuum and maser observations unveil the presence of a compact radio jet and of strong interactions of the latter with the dense interstellar medium in the nucleus of a relatively radio quiet galaxy. This results highlight the potential of maser studies to shed light on the parsec scale environment around AGN and, possibly, on the role of low power jets on galaxy evolution.

3. IC 485

Located at a distance of 122 Mpc, IC 485 is a spiral galaxy spectroscopically classified as a Seyfert 2 ([12]), although an alternative classification as a LINER was reported in [13]. An H_2O megamaser of 900 $L_\odot$ was detected in this galaxy showing a triple-peak profile ([14]). The sensitive single-dish spectrum together with the accurate position of the maser spots determined through 22 GHz VLBI observations indicate that the maser emission might be produced (at least in part) in an edge-on accrection disk (Ladu et al. in prep.; Ladu's contribution, this volume).

Unresolved and faint radio continuum emission was detected at kpc-scales with the VLA at 1.4 GHz, within the NVSS ($S_{\rm peak}$=4.4 mJy; [15]) and FIRST ($S_{\rm peak}$=3.01 mJy) surveys. [13] detected a compact unresolved radio source in the nucleus of IC485 also at 20 GHz, with the VLA, although with a low significance ($S_{\rm peak} = 77 \pm 15\,\mu$Jy, $\sim 5\,\sigma$). In order to associate the maser position with other sources of activity in the nuclear region of the galaxy and to shed light on the origin of the maser, we observed the radio continuum emission of IC 485 with the EVN in May 2018, at 1.4 and 5.0 GHz, for a total of 4 and 2.5 hours, respectively. We reached rms noise levels of 18 and 28 μJy, at L- and C-band, respectively. Surprisingly, no continuum source was detected above the 5σ noise level neither at 1.4 nor at 5.0 GHz in a region of 100 mas (∼600 pc) radius from the maser position. A tentative source is visible in the L band map with a peak flux density of 68 μJy (3.8σ). This source coincides with the VLA source detected at 20 GHz by [13] and is very close to the main maser line (see Fig.2).

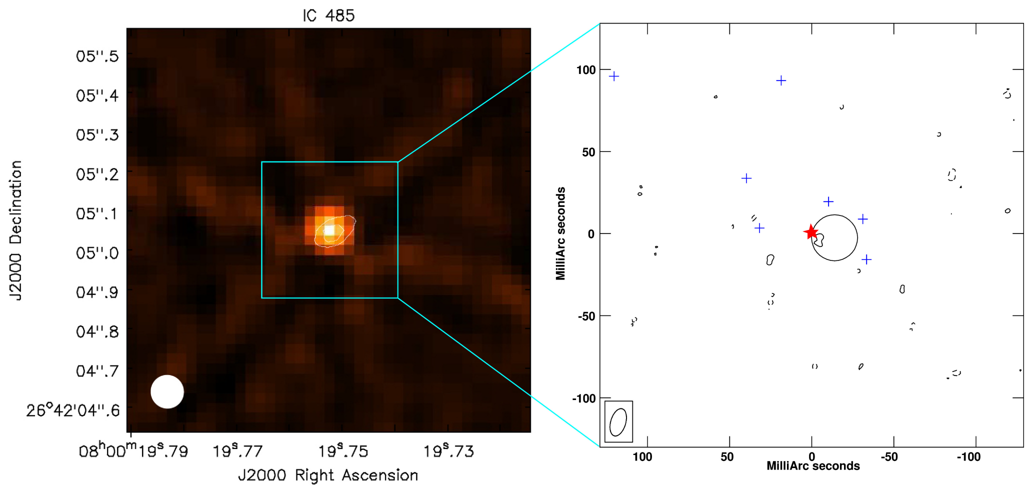

Figure 2: IC 485 integrated water maser (colour) and 20 GHz radio continuum (white contours) maps from [13] (left panel); L-band EVN radio continuum map of the nuclear region of IC485, contour levels are -3, 3, 4, 5 x 18 μJy/beam (right panel). The position of the main maser line is indicated by the red star, while the blue crosses pinpoint the tentative radio continuum sources detected at K-band (Ladu et al. in prep.). The black circle represents the position of the VLA continuum source detected by [13].

The non detection with the EVN, therefore, suggests that the kpc-scale radio emission observed with the VLA at lower angular resolution is mostly resolved out, indicating a diffuse morphology. The bulk of the radio emission in IC485 likely does not arise from a compact nuclear source, but is diffused over a region larger than 0.1 arcsec (60 pc), the largest detectable angular scale of EVN observations. This favours the hypothesis that the AGN in IC485 is either radio silent (i. e., radio emission is entirely produced by star formation) or the AGN emits in the radio band but its emission (which might be produced by a jet, a nuclear wind, or a corona) is faint and the radio emission is dominated by the star forming regions in the host galaxy.

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