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PROBING THE OBSCURING MEDIUM AROUND ACTIVE NUCLEI USING MASERS: THE CASE OF 3C 403

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Abstract. We report the first detection of a water megamaser in a radio-loud galaxy, 3C 403, and present a follow-up study using the VLA. 3C 403 has been observed as a part of a small sample of FR II galaxies with evidence of nuclear obscuration. The isotropic luminosity of the maser is $\sim$1200 $L_{\odot}$. With a recessional velocity of $cz \sim 17680$ km s^{-1} it is the most distant water maser so far reported. The line arises from the densest ($>10^8$ cm^{-3}) interstellar gas component ever observed in a radio-loud galaxy. Two spectral features are identified, likely bracketing the systemic velocity of the galaxy. Our interferometric data clearly indicate that these arise from a location within 0.1″ ($\approx$110 pc) from the active galactic nucleus. We conclude that the maser spots are most likely associated with the tangentially seen parts of a nuclear accretion disk, while an association with dense warm gas interacting with the radio jets cannot yet be ruled out entirely.

Keywords: 3C 403, active galaxies, masers

1. Introduction

So far, water megamasers have been detected in radio-quiet active galactic nuclei (AGN; for a definition of radio-quiet AGN, see e.g. Kellermann et al., 1989), mostly in Seyfert 2 and LINER galaxies. Under the assumption that all megamasers are associated with molecular material orbiting around the central engine (e.g. Miyoshi et al., 1995) or interacting with the nuclear jet(s) of the host galaxy (e.g. Claussen et al., 1998) and that their amplification is unsaturated (i.e. the maser intensity grows linearly with the background radio continuum), one should expect a much higher detection rate in radio-loud AGN than is actually observed. This fact should be especially true for the radio-loud AGN classified as narrow-lined FR IIs for which the AGN unification scheme (e.g. Urry and Padovani, 1995) requires the presence of geometrically and optically thick obscuring structure.

Samples of radio galaxies belonging to the broad-lined and narrow-lined FR II class have been recently observed with the Effelsberg telescope (Tarchi et al., in

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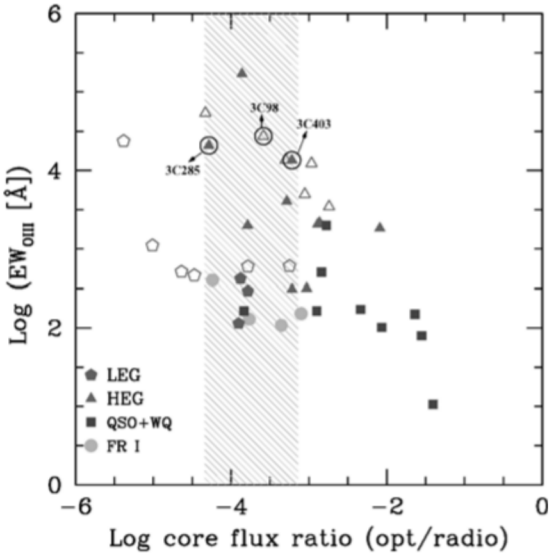

Figure 1. Equivalent width of the [OIII] emission line, measured with respect to the central compact core emission, is plotted versus the ratio between the optical central compact core to radio core flux (for details, see also Chiaberge et al., 2002). LEG: low excitation galaxy; HEG: high excitation galaxy. The targets of our sample with their respective names are those within circles.

preparation; Lara et al., private communication). As in the case of FR Is (Henkel et al., 1998), no maser detections have been obtained.

2. Sample Selection

Our sample comprises all nearby ($z < 0.1$) 3 FR IIs spectrally classified as high excitation galaxies (HEGs, Jackson and Rawlings, 1997) with nuclear equivalent widths of the [OIII]λ5007 emission line EW([OIII]) $>10^4$ Å (Figure 1). A high value for the nuclear EW([OIII]) in HEGs has been interpreted as a hint for the obscuration of the central ionizing continuum source (Chiaberge et al., 2002). In these sources the nuclear ionizing continuum would be obscured to our line-of-sight and only a small fraction of the emission is seen through scattered light. Therefore, our selection criteria provide us with a sample of galaxies with both high radio flux densities and nuclear obscuration of the central ionizing source.

3. Observations and Data Reduction

Observations of the 6_{16}–5_{23} transition of H_2O (rest frequency: 22.235 GHz) were carried out with the 100-m telescope of the MPIfR at Effelsberg[1] in January and

March 2003. The beam width (HPBW) was 40″. Flux calibration was obtained by measuring W3(OH) (see Mauersberger et al., 1988). Gain variations of the telescope as a function of elevation were taken into account (Eq. (1) of Gallimore et al., 2001). The pointing accuracy was better than 10″.

The follow-up VLA[2] A-array observations of the detected maser in 3C 403 were performed in July 2003 with two IFs and a bandwith of 12.5 MHz each centered on one of the two maser features. Using 32 spectral channel a velocity resolution of $\sim$6 km s^{-1} was reached. The beam width (HPBM) was $\sim$0.1″ and the total on-source observation time was about $\sim$8 h.

All data were reduced using standard procedures belonging either to the GILDAS or the AIPS software packages.

4. Results

The maser spectra of 3C 403, taken in January with the Effelsberg telescope, are shown in Figure 2. The profile is composed of two main components

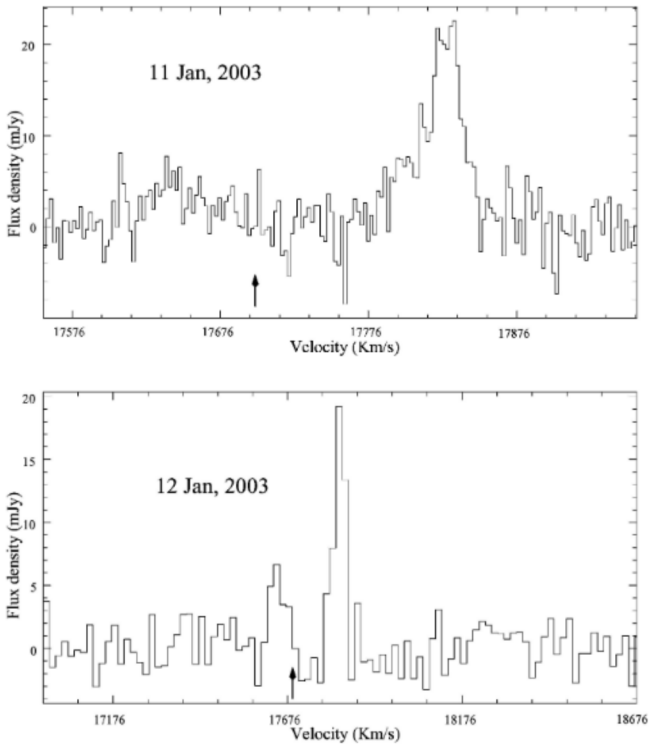

Figure 2. Maser lines in 3C 403. *Upper panel* spectral resolution of 78 kHz = 1.15 km s^{-1}. *Lower panel* spectral resolution of 1.25 MHz = 17.8 km s^{-1}. The arrow marks the nominal systemic velocity of the galaxy = 17688 km s^{-1}.

(asymmetrically) bracketing the nominal systemic velocity of the galaxy (cz = 17688 km s^{-1}, see next section): the stronger one has a velocity of $cz = 17827 \pm 1$ km s^{-1}, a width of 31 ± 2 km s^{-1}, and a flux density peak of 23 ± 3 mJy; the weaker one has a velocity of $cz = 17644 \pm 5$ km s^{-1}, a width of 53 ± 8 km s^{-1}, and a peak flux density of 4.0 ± 0.5 mJy. Using a distance of 235 Mpc (H_0 = 75 km s^{-1} Mpc^{-1}), the total isotropic luminosities are 950 ± 140 and 280 ± 55 $L_\odot$ for the main components, respectively. Hence, the maser in 3C 403 is the most distant and one of the most luminous water maser so far reported (the most luminous maser, with 6000 $L_\odot$, and, before this discovery also the most distant one, is in TXFS2226-184; Koekemoer et al., 1995).

The outcome of the VLA observations (Figure 3; right-hand side) confirms the presence of the two main maser features, and indicates that the maser emission is unresolved and arise from a location within 0.1″ (≈110 pc) from the active galactic nucleus. The strength of the weaker line is consistent with the single-dish result, while the stronger line is much weaker than that obtained with Effelsberg. Because of the unresolved nature of the emission it is unlikely that the loss of flux density in the feature is due to extended emission resolved-out because of the higher resolution. More probably, the cause is a flare-down of the component due to strong variability, a phenomenon already well known to exist in water masers.

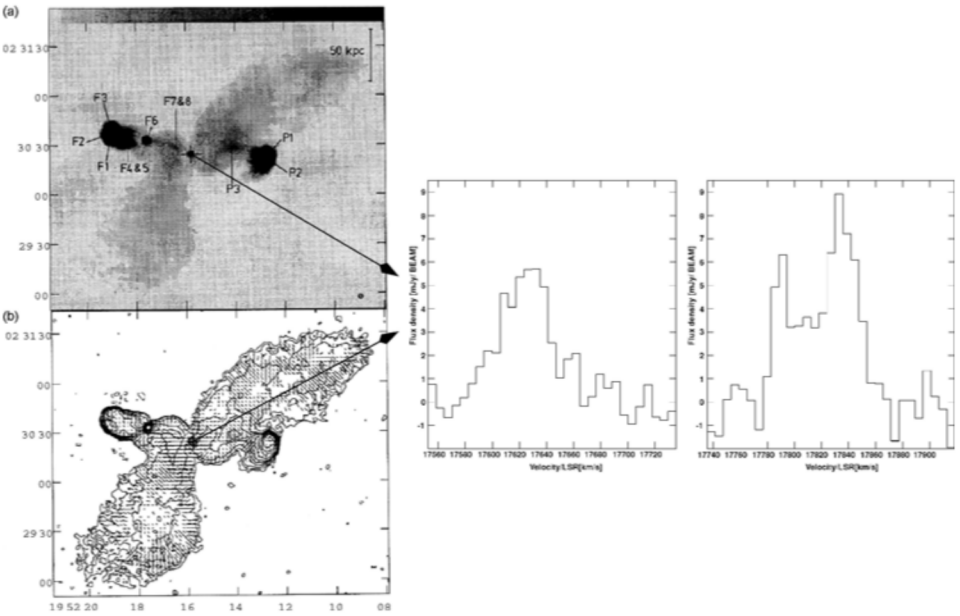

Figure 3. *Left-hand side* VLA 8.4 GHz maps in grey-scale (top) and contours (bottom) of 3C 403 at a resolution of ~2.5″ (FWHM). For details, see Black et al. (1992). *Right-hand side* the two main water maser features in 3C 403 observed with the VLA A-array. Both lines arise from a location within 0.1″ (≈110 pc) from the active galactic nucleus ($RA_{B1950} = 19^h\ 52^m\ 15.8^s$; $Dec_{B1950} = 02°30'24''$).

5. Discussion and Conclusions

The standard unified scheme of AGN requires an obscuring region, possibly containing molecular gas that surrounds the central engine and that effectively shields the inner few parsecs from view, if the radio axis lies close to the plane of the sky (Antonucci, 1993). In the innermost part, at radii up to some tenths of a parsec, this material is likely to form a rapidly rotating accretion disk around a central supermassive black hole. At larger distances (up to about 50–100 pc) the atomic and molecular gas is possibly distributed in a toroidal structure providing obscuration of the central regions to particular lines-of-sight.

Indeed, very few direct detections of molecular gas in radio-loud galaxies have been reported so far (H_2 in Cygnus A: Evans et al., 1999; CO in 3C 293: Wilman et al., 2000). The detection discussed here strongly favors the presence of molecular material near the central engines of at least some FR IIs. Past negative results in molecular line surveys may also be a consequence of observational sensitivity limits (such a possibility was also mentioned by Henkel et al., 1998). Furthermore, because of the high gas densities required for H_2O masers to operate ($>10^8$ cm^{-3}; e.g. Elitzur et al., 1989), our detection represents the densest interstellar gas component ever observed in a radio-loud galaxy (typical values for molecular gas densities range between $\sim 10^3$ and $\sim 10^5$ cm^{-3}; e.g. Wilman et al., 2000).

5.1. Accretion disk or jet interaction?

Because of the large uncertainty of the systemic velocity[3] (V_{sys}) of 3C 403, the following discussion and (preliminary) conclusions are based on the assumption that V_{sys} is placed (as indicated in Figure 2) between the two main H_2O maser components.

As mentioned in Section 1, interferometric studies of H_2O megamasers have shown that the emission is either associated with a nuclear accretion disk (for NGC 4258, see e.g. Miyoshi et al., 1995) or with the radio-jets interacting with dense molecular material near the center (for Mrk 348, see Peck et al., 2003).

The interferometric observation performed with the VLA in its A configuration confirms that also the megamaser in 3C 403 has a nuclear origin.

Only VLBI interferometric observations at milliarcsecond resolution (spatial scales of $\approx$1 parsec) will allow us to determine (or to provide an upper limit to) the extent of the emission and to pinpoint the exact location of the H_2O emitting region(s) in order to see if the maser is associated with an accretion disk or radio jets. Nevertheless, a qualitative discussion is possible on the basis of the single-dish spectra of Figure 2 and the new VLA observation.

Accretion disk: this scenario is particularly supported by the expected almost edge-on orientation of the nuclear obscuring layer (see Chiaberge et al., 2002). As in the case of the Seyfert galaxy NGC 4258 (e.g. Miyoshi et al., 1995), the spectrum should then show three distinct groups of features: one centered at the

systemic velocity of the galaxy (originating along the line of sight to the nucleus) and two groups symmetrically offset from the systemic velocity, arising from those parts of the disk that are viewed tangentially. If the latter are the two lines we are observing, the rotational velocity of the disk is $\sim$100 km s^{-1} (which is, we have to point out, very small when compared with that derived for NGC 4258). In 3C 403 the systemic lines seem instead to be missing. To explain this fact, partly following the hypothesis proposed by Henkel et al. (1998), we could argue that the circumnuclear disk is actually a *thin rotating ring* of the type modeled by Ponomarev et al. (1994; their Figure 2), where masing gives a double-peaked profile only.

Jet interaction: the handful of bright knots visible in the radio images shown in Figure 3 (left-hand side) hints at the presence of jets interacting in several regions with the interstellar medium. The profile of the spectrum does not contradict a 'jet-origin' of the detected maser emission in 3C 403. If we assume a symmetric molecular distribution, the two observed features could be interpreted as the red-shifted and blue-shifted counterparts of the maser line, arising from opposite jets close to the core.

Notes

1. The 100-m telescope at Effelsberg is operated by the Max-Planck-Institut für Radioastronomie (MPIfR) on behalf of the Max-Planck-Gesellschaft (MPG).
2. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.
3. Velocities derived from optical emission lines may be uncertain or biased by motions of the emitting gas (e.g. Morganti et al., 2001). From the rotation curve measured by Baum et al. (1990), we deduce that these uncertainties in 3C 403 are < 100 km s^{-1}.

References

Antonucci, R.: 1993, *ARA&A* **31**, 473.
Baum, S.A., Heckman, T. and van Breugel, W.: 1990, *ApJS* **74**, 389.
Black, A.R.S., Baum, S.A., Leahy, J.P., et al.: 1992, *MNRAS* **256**, 186.
Chiaberge, M., Capetti, A. and Celotti, A.: 2002, *A&A* **394**, 791.
Claussen, M.J., Diamond, P.J., Braatz, J.A., Wilson, A.S. and Henkel, C.: 1998, *ApJ* **500**, L129.
Elitzur, M., Hollenbach, D.J. and McKee, C.F.: 1989, *ApJ* **346**, 983.
Evans, A.S., Sanders, D.B., Surace, J.A. and Mazzarella, J.M.: 1999, *ApJ* **511**, 730.
Gallimore, J.F., Henkel, C., Baum, S.A., et al.: 2001, *ApJ* **556**, 694.
Henkel, C., Wang, Y.P., Falcke, H., Wilson, A.S. and Braatz, J.A.: 1998, *A&A* **335**, 463.
Jackson, N. and Rawlings, S.: 1997, *MNRAS* **286**, 241.
Kellermann, K.I., Sramek, R., Schmidt, M., Shaffer, D.B. and Green, R.: 1989, *AJ* **98**, 1195.
Koekemoer, A.M., Henkel, C., Greenhill, L.J., et al.: 1995, *Nature* **378**, 697.
Mauersberger, R., Wilson, T.L. and Henkel, C.: 1988, *A&A* **201**, 123.
Miyoshi, M., Moran, J., Herrnstein, J., et al.: 1995, *Nature* **373**, 127.

Morganti, R., Oosterloo, T.A., Tadhunter, C.N., et al.: 2001, *MNRAS* **323**, 331.
Peck, A.B., Henkel, C., Ulvestad, J.S., et al.: 2003, *ApJ* **590**, 149.
Ponomarev, V.O., Smith, H.A. and Strelnitski, V.S.: 1994, *ApJ* **424**, 976.
Urry, C.M. and Padovani, P.: 1995, *PASP* **107**, 803.
Wilman, R.J., Edge, A.C., Johnstone, R.M., Crawford, C.S. and Fabian, A.C.: 2000, *MNRAS* **318**, 1232.