22 GHz water maser search in 37 nearby galaxies

Four new water megamasers in Seyfert 2 and OH maser/absorber galaxies

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ABSTRACT

Aims. We report four new 22 GHz H\textsubscript{2}O water masers found in a Green Bank Telescope search toward 37 nearby objects. Our goal was to find new maser galaxies, active galactic nucleus (AGN) disk masers, and objects where hydroxyl and water maser species coexist.

Methods. We observed 37 sources within 250 Mpc that were selected by high X-ray luminosity (L\textsubscript{X} > 10\textsuperscript{40} W) and high absorbing column density (N\textsubscript{H} ≥ 10\textsuperscript{22} cm\textsuperscript{-2}). Sources included dual or triple AGN and interacting systems. We also searched objects detected in hydroxyl (OH). A catalog of 4038 known H\textsubscript{2}O (non)detections was assembled to avoid unnecessary reobservations. The final selection consisted of 16 new sources, 13 nondetections to follow up with a factor 10 higher sensitivity, 10 OH masers and 1 deep OH absorber, of which 37 were observed.

Results. Water megamasers were detected towards the Sy 2 galaxy 2MFGC 13581, towards the 6 GHz OH absorber NGC 4261 and towards the two 1.6 GHz OH maser sources IRAS 17526+3253 and IRAS 20550+1656. We set upper limits on 33 nondetections. The detection rate was 25% in OH galaxies and 11% overall. The mean sensitivity was 4 mJy over 24.4 kHz (0.31 km s\textsuperscript{-1}) or between 0.1 L\textsubscript{⊙} and 1.0 L\textsubscript{⊙} rms for the distances covered by the source sample. Combined with other searches, a total of 95 objects have now been searched for both OH and H\textsubscript{2}O masers.

Conclusions. The maser features in 2MFGC 13581 are typical of a sub-parsec accretion disk, whereas NGC 4261 likely has jet masers in a maser torus. The NGC 4261 galaxy (3C 270; dusty torus, twin jet) and its masers appear similar to NGC 1052, where continuum seed emission by a twin jet supports masers in the torus. Imaging with very long baseline interferometry is required to determine the masing regions in NGC 4261 and 2MFGC 13581. IRAS 17526+3253 has narrow 350 L\textsubscript{⊙} systemic masers, and the tentative 5σ detection in IRAS 20550+1656 (II Zw 96) strongly resembles massive star formation kilomaser in NGC 2146. The latter two detections increase the number of known “dual-species” objects containing both OH and H\textsubscript{2}O masers. Further, we found the overall dual-species detection rate (8 in 95) to be of the order of the joint probability of both species independently occurring in the same object (1% lower bound). However, this needs to be verified by a more detailed analysis that accounts for the individual selection criteria of the 95 searched objects. Lastly, we see a lack of H\textsubscript{2}O kilomasers in OH megamaser objects, which was previously noted. This may be due to sensitivity bias rather than for astrophysical reasons.

Key words. masers – surveys

1. Introduction

Water masers (H\textsubscript{2}O; 22.23508 GHz, 6\textsubscript{16} → 5\textsubscript{15}) and hydroxyl masers (OH; 1665 MHz and 1667 MHz) in the megamaser class have luminosities that far exceed their Galactic counterparts. They are best known as probes into some extreme environments, such as merging galaxies, nuclear starbursts in molecular tori at 100 pc scales in the case of OH, active galactic nucleus (AGN) accretion disks at sub-pc scales, outflows, and the vicinity of jets in the case of H\textsubscript{2}O. Water disk masers are of particular interest and are found between an outer circumnuclear region of molecular gas that is too cold for maser excitation and an inner atomic gas region that is too hot (>8000 K) for the molecular gas phase. The kinematics and very long baseline interferometry (VLBI) angular positions of disk or torus masers allow a well-constrained estimate of the central binding mass as in Mrk 273 (Klöckner & Baan 2004), with more accurate mass estimates made with H\textsubscript{2}O megamaser observations (Kuo et al. 2011). Additionally, H\textsubscript{2}O disk masers as in UGC 3789 allow a direct measurement of angular diameter distance and the Hubble constant (Reid et al. 2013).

To date, over 4030 galaxies have been searched for H\textsubscript{2}O masers, resulting in about 150 detections that include about 20 disk maser galaxies (see, e.g., Nakai et al. 1995; Braatz et al. 1997; Henkel et al. 2005; Kondratko et al. 2006; Braatz & Gugliucci 2008; Bennett et al. 2009); and the project web sites Water Maser Cosmology Project (WMCP)\textsuperscript{1} and Megamaser Cosmology Project (MCP)\textsuperscript{2}. In comparison, about 500 galaxies have been searched for OH masers, 120 were detected (at up to z = 0.265), and about 10 exhibit OH in absorption (see, e.g., Klöckner 2004; Impellizzeri 2008).

Sources that mase in both molecules are extremely rare. This may be expected since extragalactic OH and H\textsubscript{2}O maser species have a quite different pumping mechanism. While OH is radiatively pumped in regions of enhanced density by AGN or star-formation photons reprocessed via ≥45 K dust to 35/53 μm infrared (IR), gas phase H\textsubscript{2}O is collisionally pumped at ≥400 K. Nevertheless, five objects that mase in both species are known: OH and H\textsubscript{2}O kilomaser (OH KM, H\textsubscript{2}O KM; L\textsubscript{OH}, L\textsubscript{H2O} < 10 L\textsubscript{⊙}) coexist in the starbursts NGC 253 (Frayer et al. 1998; Henkel et al. 2004) and M 82 (Baudry & Brouillet 1996; Argo et al. 2007), an OH KM and an H\textsubscript{2}O megamaser.

\textsuperscript{1} https://www.cfa.harvard.edu/~lincoln/demo/HoME/
\textsuperscript{2} https://safe.nrao.edu/wiki/bin/view/Main/MegamaserCosmologyProject
(OH MM, H$_2$O MM; $L_{\text{OH}}$, $L_{\text{H}_2\text{O}} > 10 L_\odot$) are found in the Sy 2 NGC 1068 (Gallimore et al. 1996) and radio-quiet Sy 2 AGN NGC 3079 (Baan & Irwin 1995), whereas Arp 299 is the only OH MM and H$_2$O MM object (Tarchi et al. 2007). No source with an OH MM and an H$_2$O object has yet been found. This is likely because H$_2$O KM tend to occur in nearby objects, whereas OH MM are found up to high redshifts, where H$_2$O KM emission falls below sensitivity limits (see Tarchi et al. 2011).

There is no clear general link between OH and H$_2$O maser species in such “dual-species” objects. However, OH maser emission (and OH seen in absorption) may point towards sources that contain denser molecular regions and a generally larger reservoir of H$_2$O; OH is formed from the evaporation and dissociation of grain-bound H$_2$O (Lo 2005; Hollenbach et al. 2009). A larger H$_2$O abundance may favor an H$_2$O maser detection. Furthermore, both H$_2$O KM, OH KM and OH MM have a similar association with, among others, star-forming regions and nuclear regions with bursts of intense star formation (Lo 2005). We consider that in an H$_2$O maser search earlier OH detections could be one of the selection criteria that might increase the detection rate.

The search presented here attempts to identify new water maser galaxies, new dual maser species objects, and in particular any H$_2$O KM in an OH MM galaxy, as well as new AGN disk maser galaxies suitable for constraining the Hubble constant.

### 2. Source sample

We considered only sources within 250 Mpc (<16 000 km s$^{-1}$). We first assembled a database of initially over 8000 known water maser detections and nondetections published in the literature, including WMCP and MCP project web site catalogs of published and unpublished maser search results. We then used an automated NASA/IPAC Extragalactic Database (NED) lookup of source coordinates and name aliases to merge duplicates. This produced a final catalog of 4038 unique objects already observed for H$_2$O.

Next we identified 126 galaxies in the catalog with a low sensitivity H$_2$O nondetection (40 mJy to 200 mJy rms) that could be reobserved with a factor 10 higher sensitivity. To identify new sources not yet observed at 22 GHz, we reviewed recent X-ray and AGN data and literature, including recent extragalactic hydroxyl searches (e.g., Klockner 2004; Impellizzeri 2008). We chose objects with 2–10 keV X-ray data, high X-ray luminosities ($L_X > 10^{40}$ W), and large absorbing column densities ($N_{HI} > 10^{22}$ cm$^{-2}$), as found in over 90% of water maser galaxies (e.g., Kondratko et al. 2006; Zhang et al. 2006; Greenhill et al. 2008). We also chose objects with a nucleus classified as NLS1, Sy 1.5 to Sy 2.0, LINER, or HII region. Some of the sources are also Infrared Astronomical Satellite (IRAS) survey objects with OH masers or OH seen in absorption.

The final selection of 40 nearby galaxies, mergers, binary AGN and triple AGN systems is shown in Table 2. It consists of 17 previous nondetections at ≥40 mJy rms, 10 objects with OH seen in emission at 1.6 GHz (3 being previous H$_2$O nondetections), 1 source with strong OH absorption at 6 GHz (a previous H$_2$O nondetection), and 16 other sources not yet observed for 22 GHz water masers. Out of this sample, the OH maser galaxy ESO 320-G030 had the highest IRAS 100 µm flux density (46 Jy).

### 3. Observations

To uncover kilomasers among the source sample a 4 mJy rms target sensitivity over 24.4 kHz (about 0.31 km s$^{-1}$) was chosen, equivalent to between 0.1 $L_\odot$ rms and 1.0 $L_\odot$ rms in isotropic luminosity. Observations were carried out in four runs during February and March 2013 under project AGBT13A-172 using the National Radio Astronomy Observatory (NRAO) Robert C. Byrd Green Bank Telescope (GBT). Sessions were scheduled in late winter under good 22 GHz weather conditions. The UTC date and time and zenith opacity $\tau_0$ are listed in Table 1. Excellent weather conditions (zenith $\tau_0 = 0.033$ to 0.047) and low $T_{sys}$ (35 K to 75 K) allowed us to observe most of the 40 sources in 16 h. We spent between 12 and 20 min on each source and the remainder on calibration.

We used the GBT spectrometer backend and GBT K-band focal plane array (KTPA) receiver, and selected two KFPAs elements near the cryo cooler with the lowest $T_{sys}$ (<25 K over 75% of the band). Beams were 33′ full width at half maximum (FWHM) with an aperture efficiency $\eta_ap$ of 0.66 at 21 GHz and had a 94.9′ beam separation. Observations were in dual-circular polarization and had a 30 s dual-beam nod cycle. Both 200 MHz frequency windows of each polarization (i.e. four windows in total) were centered on the systemic velocity. The 8192 spectrometer channels were 24.4 kHz wide and covered $V_{sys} = 1250$ km s$^{-1}$.

Pointing and focusing were corrected using strong standard calibrators (>0.8 Jy). The GBT dynamic corrections compensated for gravitational and thermal surface deformations and remained stable. The full setup was occasionally verified using brief pointings at megamaser galaxies NGC 1068, NGC 3079, and NGC 5793. Pointing and focusing were repeated every 1.5 to 2 h and after sunrise, with only small adjustments (<2.5′′ and <8 mm). Wind speeds were low with little to no cloud cover. Zenith opacity measurements $\tau_0$ at 21 GHz were supplied by nearby weather stations and remained stable during the observing runs.

### 4. Data reduction

A conservative estimate of the flux scale accuracy is ≤15%. All sources were observed in total power mode with $T_{cal}$ noise injection to determine $T_{sys}$. Although $T_{cal}$ has a nominal accuracy of 1%, slow temporal drifts typically degrade it to 10–15%. The initial aperture efficiency $\eta_{ap0}$ calculated by the GBTIDL toolbox was corrected for elevation via the GBT 22.236 GHz notes. Start time, duration in hours, and $\tau_0$ zenith opacity at 21 GHz of the four $K$-band observing runs in project GBT13A-172.

<table>
<thead>
<tr>
<th>Epoch</th>
<th>Start time (UT)</th>
<th>Hours</th>
<th>$\tau_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2013-02-21 20:30</td>
<td>3:15</td>
<td>0.036–0.037</td>
</tr>
<tr>
<td>2</td>
<td>2013-03-02 03:45</td>
<td>3:45</td>
<td>0.047</td>
</tr>
<tr>
<td>3</td>
<td>2013-03-02 07:30</td>
<td>1:30</td>
<td>0.043</td>
</tr>
<tr>
<td>4</td>
<td>2013-03-02 09:00</td>
<td>1:30</td>
<td>0.041</td>
</tr>
<tr>
<td>1</td>
<td>2013-03-03 18:30</td>
<td>2:15</td>
<td>0.036</td>
</tr>
<tr>
<td>2</td>
<td>2013-03-03 20:45</td>
<td>1:15</td>
<td>0.033</td>
</tr>
<tr>
<td>3</td>
<td>2013-03-09 11:15</td>
<td>2:15</td>
<td>0.036–0.035</td>
</tr>
</tbody>
</table>

Notes. Start time, duration in hours, and $\tau_0$ zenith opacity at 21 GHz of the four $K$-band observing runs in project GBT13A-172.

The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.
Table 2. Sample source of the 22 GHz H$_2$O maser search.

<table>
<thead>
<tr>
<th>Source</th>
<th>Epoch</th>
<th>Position</th>
<th>$\nu_{\text{sys}}$</th>
<th>$\sigma_{S_{22}}$</th>
<th>$S_{22}$</th>
<th>$S_{16}$</th>
<th>$N_{16}$</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRAS 01416-0719</td>
<td>3</td>
<td>00:18:35.9 – 07:02:56.0</td>
<td>5396</td>
<td>2.9</td>
<td>&lt;8.7</td>
<td>&lt;2.06</td>
<td>Sy2+HII</td>
<td></td>
</tr>
<tr>
<td>ESO 350-IG038</td>
<td>3</td>
<td>00:36:52.7 – 33:33:17.0</td>
<td>6175</td>
<td>4.6</td>
<td>&lt;13.8</td>
<td>&lt;4.48</td>
<td>pair, LIRG, HII/ SB</td>
<td></td>
</tr>
<tr>
<td>IRAS 15244-0056a</td>
<td>3</td>
<td>00:51:51.8 – 30:40:00.0</td>
<td>15529</td>
<td>5.3</td>
<td>&lt;15.9</td>
<td>&lt;3.86</td>
<td>SB, ULRG</td>
<td></td>
</tr>
<tr>
<td>NGC 0315a</td>
<td>3</td>
<td>00:57:48.9 – 30:21:09.0</td>
<td>4942</td>
<td>3.0</td>
<td>&lt;9.0</td>
<td>&lt;1.54</td>
<td>LINER(?) jett</td>
<td></td>
</tr>
<tr>
<td>NGC 0526A</td>
<td>1</td>
<td>01:23:54.4 – 35:03:56.0</td>
<td>5725</td>
<td>4.3</td>
<td>&lt;12.9</td>
<td>&lt;3.62</td>
<td>5.0 × 10$^{22}$</td>
<td>LINER(?)</td>
</tr>
<tr>
<td>IRAS 01416+1651</td>
<td>1</td>
<td>01:44:30.5 – 17:06:05.0</td>
<td>8225</td>
<td>2.9</td>
<td>&lt;8.7</td>
<td>&lt;2.15</td>
<td>Sy2, LIRG</td>
<td></td>
</tr>
<tr>
<td>NGC 0833</td>
<td>3</td>
<td>02:29:09.8 – 10:50:38.9</td>
<td>3864</td>
<td>2.9</td>
<td>&lt;8.7</td>
<td>&lt;1.05</td>
<td>2.7 × 10$^{23}$</td>
<td>Sy2, LINER</td>
</tr>
<tr>
<td>NGC 0925a</td>
<td>3</td>
<td>02:27:16.9 + 33:34:45.0</td>
<td>553</td>
<td>2.7</td>
<td>&lt;8.1</td>
<td>&lt;0.03</td>
<td>LLAGN</td>
<td></td>
</tr>
<tr>
<td>IC 1583a</td>
<td>3</td>
<td>02:09:08.4 – 31:17:22.0</td>
<td>6070</td>
<td>3.5</td>
<td>&lt;10.5</td>
<td>&lt;3.41</td>
<td>Sy2, LINER(?)</td>
<td></td>
</tr>
<tr>
<td>IRAS 02580-1136</td>
<td>1</td>
<td>03:00:30.6 – 11:24:57.0</td>
<td>8962</td>
<td>3.5</td>
<td>&lt;10.5</td>
<td>&lt;8.37</td>
<td>5.6 × 10$^{23}$</td>
<td></td>
</tr>
<tr>
<td>NGC 1156b</td>
<td>1</td>
<td>03:01:42.4 + 35:12:21.0</td>
<td>4945</td>
<td>2.7</td>
<td>&lt;8.1</td>
<td>&lt;1.70</td>
<td>Sy2+HII, merger</td>
<td></td>
</tr>
<tr>
<td>NGC 1275b</td>
<td>3</td>
<td>03:19:48.1 + 41:30:42.0</td>
<td>5264</td>
<td>26.4</td>
<td>&lt;79.2</td>
<td>&lt;17.3</td>
<td>1.5 × 10$^{22}$</td>
<td></td>
</tr>
<tr>
<td>IRAS 04040-1623a</td>
<td>1</td>
<td>04:04:40.6 – 16:30:36.4</td>
<td>8463</td>
<td>3.1</td>
<td>&lt;9.3</td>
<td>&lt;6.37</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes. Epochs refer to observing dates (see Table 1). The three sources without epochs were not observed. Optical heliocentric recession velocities ($\nu_{\text{sys}}$) are adopted from literature (Risaliti et al. 1999; González-Martín et al. 2009; Noguchi et al. 2010; Tan et al. 2012; Vasudevan et al. 2013). The last column shows the object classification adopted from NED and literature. Remarks: (a) Source has a previous published or unpublished H$_2$O non-detection (20 mJy to 200 mJy rms), with references on the WMCP or MCP project pages. (b) The velocity coverage on NGC 1275 was 3000 to 14000 km s$^{-1}$ (800 MHz), to include the infalling object at +3000 km s$^{-1}$. (c) NGC 4261 exhibits HI in absorption at 1.4 GHz and OH in deep absorption at 6 GHz but has not been searched for OH at 1.6 GHz (van Langevelde et al. 2000; Impellizzeri 2008). (d) Sensitivity on IRAS 20550+1656 was 5.8 mJy without smoothing and 1.5 mJy rms after 16-channel Gaussian smoothing.

gain-elevation curve of April 8, 2008, which is based on the current Zernike model (FEM plus 2005/Winter2) for the GBT adaptive surface. The correction curve is $\eta_{\text{tap}} = \eta_{\text{tap}}(0.910 + 0.00434 \times ZD – 5.22 \times 10^{-5} \times ZD^2)$, where $ZD = 90^\circ$ – elevation is the angle off zenith.

Nod scans were processed in GBTIDL. The $\tau_0$ and $\eta_{\text{tap}}$ gain corrections were applied first. Next, subspectra affected by internal radio frequency interference (RFI) or spectrometer faults were flagged. To improve the signal-to-noise ratio, the blank sky reference subspectra (for subtracting the standing wave across the band) were smoothed with a short 4- to 32-channel boxcar function. Care was taken to avoid introducing artifacts. Third-order baselines were removed from individual subspectra. All subspectra and both polarizations were time averaged into a Stokes I spectrum, and a final third-order baseline fit was removed. Sensitivity was calculated over line-free channels without smoothing.

For each detection, Gaussian models $S(v) = a \times e^{-(v-\nu)^2/2\sigma^2}$ were fitted into the calibrated nonsmoothed spectra to estimate $\sigma^2$

\url{https://safe.nrao.edu/wiki/view/GB/Observing/GainPerformance}
line peak $a$ (Jy), center $\mu$ (km s$^{-1}$) and FWHM width $w$ (km s$^{-1}$). The integrated line profile $S_{\text{int}} = \int S(\nu) \, d\nu$ (Jy km s$^{-1}$) for a single Gaussian $S(\nu)$ equals $a \sigma_s \sqrt{2\pi}$. Noting that $\sigma_s = w/2.35482$ and using the luminosity distance $D_L$ and redshift $z$ of the source, the equivalent isotropic luminosity of

$$\frac{L_{\text{iso}}}{L_\odot} = 0.023 \times \frac{S_{\text{int}}}{\text{[Jy km s}^{-1}\text{]}} \times \frac{1}{1+z} \times \left(\frac{D_L}{\text{[Mpc]}}\right)^2$$

(1)

can be written for the fitted Gaussians in the form of the sum

$$\frac{L_{\text{iso}}}{L_\odot} = 0.023 \sqrt{2\pi} \frac{\sum a_i w_i}{2.35482} \times \frac{1}{1+z} \times \left(\frac{D_L}{\text{[Mpc]}}\right)^2$$

(2)

over all Gaussian components (see also Bennett et al. 2009). The factor 0.023 contains unit conversions and the water maser rest frequency (for 1.6 GHz OH masers the factor is 0.0017). Upper luminosity limits for water maser nondetections are given for single wide Gaussian H$_2$O line with 2.0 km s$^{-1}$ FWHM and a 3$sigma$ peak. The luminosities for detections are based on Eq. (1), with $S_{\text{int}}$ evaluated directly over the line regions of the spectrum using Simpson’s Rule. Spectra of the detections presented here were smoothed with a third-order, nine-point (2.79 km s$^{-1}$) Savitzky-Golay shape-preserving filter to reduce the noise floor by 70% while maintaining the shape and height of the maser features.

5. Results and discussion

Of the 40 sources listed in Table 2, 37 were observed for H$_2$O masers with a detection rate of 11%. Three sources have a strong maser detection, and one has a tentative detection. The spectra are shown in Fig. 1. Interestingly, three detections are in the set of 11 sources that are also detected in hydroxyl in emission or in deep absorption. No spectra were captured for three sources (NGC 3341, NGC 7130, and ESO 323-G077). The observed sources, sensitivities, isotropic luminosities (H$_2$O and OH), and absorbing column densities are given in Table 2. The luminosity distances, source redshifts, and recession velocities, $v_{\text{LSR}}$, were adopted from the NASA/IPAC Extragalactic Database (NED). Recession velocities use the optical definition and are in the kinematic local standard of rest (LSR).

Selection by X-ray data did not appear to enhance the H$_2$O maser detection rate. In our sample, 14 active galaxies have a published X-ray absorbing column density. Two of these yielded a H$_2$O MM detection. One source hosts a heavily obscured AGN ($N_H > 10^{25}$ cm$^{-2}$) and the other a Compton-thick AGN ($N_H \geq 10^{24}$ cm$^{-2}$). This is consistent with Castangia et al. (2013), who find 96% (45/47) of H$_2$O MM sources have $N_H > 10^{23}$ cm$^{-2}$. However, the same two sources were also selected by OH, resulting in a better detection rate given by the OH selection (3/11) than by the X-ray selection (2/14).

Below we discuss the four water maser detections.
5.1. 2MFGC 13581

A new H$_2$O disk MM is found in the optically edge-on galaxy 2MFGC 13581 ($v_{LSR} = 10309 \pm 42$ km s$^{-1}$ (Hopp et al. 2000), $D_L = 145$ Mpc, $z = 0.034$). It is the second-closest of six Seyfert candidates in the Hamburg/SAO survey for emission-line galaxies and is a probable Sy 2 (Hopp et al. 2000). Masers are detected in two high-velocity groups, which are symmetrically offset from the systemic velocity by about $\pm 390$ km s$^{-1}$. No systemic emission is detected, giving a 3$\sigma$ upper limit of 6.3 mJy. The red group peaks at 25 mJy and forms a forest of $\pm 3$ km s$^{-1}$ FWHM lines, similar to the blue group that peaks at 20 mJy. Each group can be approximated by a wide profile, with the blue one centered at 9940 km s$^{-1}$ and the red one at 10 724 km s$^{-1}$ (4.4 mJy peak, 114.4 km s$^{-1}$ FWHM). Their mean, 10 332 km s$^{-1}$, lies within 1$\sigma$ of the systemic recession velocity. The blue and red groups have luminosities of 120 $L_{\odot}$ and 170 $L_{\odot}$, respectively.

The symmetric spectrum suggests that emission most likely originates from a circumnuclear masering disk. The absence of systemic emission may be explained by a warp in the disk that shadows parts of the disk from X-ray emission by the central engine which is thought to support maser emission (Neufeld et al. 1994). The undetected systemic masers may also have a quite low flux density. Alternatively, they may be highly variable like the systemic (disk-)maser emission in Circinus and thus not always detected (Greenhill et al. 2003; McCallum et al. 2009).

We can estimate the radius of the masering disk annulus in 2MFGC 1358 if we assume Keplerian rotation, a black hole mass of $10^7 M_{\odot}$ typical of other disk maser galaxies (e.g., Kuo et al. 2011), and a fully edge-on disk. The observed orbital velocity of $\pm 390$ km s$^{-1}$ then translates into a 0.4 parsec (0.8 mas) average disk diameter. Unfortunately, given the low maser flux, prospects for a successful VLBI map and a determination of variability and the secular acceleration of possibly existing weak systemic maser components are poor.

5.2. IRAS 17526+3253

Water megamasers in this IR galaxy (UGC 11035; $v_{LSR} = 7818 \pm 9$ km s$^{-1}$ (de Vaucouleurs et al. 1991), $D_L = 108$ Mpc, $z = 0.026$ (NED), $L_{22} \approx 7 \times 10^{11} L_{\odot}$ estimated from IRAS fluxes using the method by Wouterloot & Walmsley 1986) have a relatively high peak flux of 60 mJy peak, 10.9 km s$^{-1}$ FWHM, and the red one at 10 724 km s$^{-1}$ (4.4 mJy peak, 114.4 km s$^{-1}$ FWHM). Their mean, 10 332 km s$^{-1}$, lies within 1$\sigma$ of the systemic recession velocity. The blue and red groups have luminosities of 120 $L_{\odot}$ and 170 $L_{\odot}$, respectively.

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5.3. NGC 4261

The WMCP project lists the giant elliptical galaxy NGC 4261 ($v_{LSR} = 2240 \pm 7$ km s$^{-1}$ (Trager et al. 2000), $D_L = 35.6$ Mpc, $z = 0.0075$) as a 109 mJy rms nondetection observed in 2002. We reached 3.1 mJy rms and detect broad emission that is fitted by a single Gaussian of 10.3 mJy, 154 km s$^{-1}$ FWHM centered on 2302 km s$^{-1}$. Peak emission is redshifted by about +60 km s$^{-1}$ relative to the systemic velocity and has a total isotropic luminosity of 50 $L_{\odot}$.

NGC 4261 is a LINER galaxy associated with the low-luminosity FR-I radio source 3C 270 that launches a highly symmetric kpc-scale twin jet. The galaxy is known for its 240 pc nuclear torus/disk found by the Hubble Space Telescope. The nucleus hosts a 4.9 $\times$ 10$^8 M_{\odot}$ SMBH and has an X-ray absorbing column density $N_H \approx 5 \times 10^{22}$ cm$^{-2}$ (Gliozzi et al. 2003). Recent hard X-ray data show a slightly higher obscuring column density of $16 \times 10^{20}$ $^{22}$ cm$^{-2}$ (González-Martín et al. 2009).

The VLBI shows neutral H$_1$ absorption against the counter-jet, with deepest absorption at 2260 km s$^{-1}$, redwards with respect to the systemic velocity. It has been modeled by atomic gas in a thin disk with an absorbing column density of $N_H \approx 10^{22}$ cm$^{-2}$ (van Langevelde et al. 2000). There is also deep OH absorption at 6 GHz against a 1.3 Jy continuum with a 400 km s$^{-1}$ FWHM around the systemic velocity (Impellizzeri 2008).

With the presence of a low-luminosity core, an optical dusty torus, molecular absorption, and a twin radio jet, NGC 4261 is remarkably similar to the twin jet LINER NGC 1052. The spectrum of NGC 1052 has a single, broad, and slightly redshifted luminous 150 mJy maser feature. The VLBI observations of NGC 1052 found water masers in two regions along the jet axis. Emission has been associated with continuum seed emission from jet blobs being amplified in an X-ray dissociation region located on the inner surface of a torus at a typical (for a J-type shock) temperature of 400 K (Sawada-Satoh et al. 2000). Given the evidence for abundant H$_1$ and OH molecules and a high X-ray absorbing $N_H$ column density towards NGC 4261, combined with the radio jet and the maser profile, a masing torus region with gas infalling at $+60$ km s$^{-1}$ seems plausible. Existing
observations found a single X-ray source and a high abundance species. The H$_2$O maser species, with 35 detected in H$_2$O only (x) and 18 in OH only (+). The circle diameters are proportional to the source redshift. The OH MM sources tend to have a higher redshift. Masers of both species may be found in up to 8 sources (solid squares; source names given), with the caveat that the OH KM in UGC 5101 and IRAS 17526+3253 reported by Martin et al. (1989) were not detected in later (or earlier) observations. The inset shows OH and H$_2$O luminosities or 3$\sigma$ upper limits against redshift for the 61 detected sources and for 34 sources undetected in either species. The H$_2$O and OH detection thresholds (solid and dashed lines) assume 1.0 mJy rms and a 2.0 km s$^{-1}$ FWHM.

VLBI datasets map only NGC 4261 continuum emission and do not cover the maser frequency range. A VLBI follow-up is required to determine a masering torus association.

5.4. IRAS 20550+1656

We tentatively find broad megamasers in the LIRG/ULIRG irregular galaxy IRAS 20550+1656 (II Zw 96; $v_{LSR} = 10 837 \pm 10$ km s$^{-1}$ (Giovanelli & Haynes 1993), $D_L = 148$ Mpc, $z = 0.036$). With Arp 299, IRAS 20550+1656 may be the second galaxy that hosts megamasers of both the OH and H$_2$O species. The sensitivity was 5.8 mJy per 0.3 km s$^{-1}$ channel and 1.5 mJy after 16-channel Gaussian smoothing. Two 9 mJy features are seen at $\pm 110$ km s$^{-1}$ around the recessional velocity. The combined isotropic luminosity of the blue 10 737 km s$^{-1}$ feature (9.0 mJy peak, 102.8 km s$^{-1}$ FWHM) and the red 10 957 km s$^{-1}$ feature (9.1 mJy peak, 96.4 km s$^{-1}$ FWHM) is relatively high with $600L_\odot$. Narrower features seem to be symmetrically distributed around the systemic velocity, such as two offset by $-380$ km s$^{-1}$ and $+420$ km s$^{-1}$. However, this but could also be explained as a particularly pronounced baseline ripple. The broad features are, however, persistent over different smoothing settings for the nod reference spectra, and different baseline fits prior to averaging all subspectra. The broad masers have a post-fit confidence of somewhat better than 5$\sigma$. The GBT integration time was 12 min, and additional time would be needed for a more robust detection, especially of the narrower features.

The object is an ongoing merger or close binary system with a peculiar rotation curve that is known to host an OH MM with 26 mJy peak and 83.2 $L_\odot$ luminosity (Andreasian 1992; Klöckner 2004). H$_2$I is seen in emission with a FWHM of about 200 km s$^{-1}$ (van Driel et al. 2001). XMM-Newton observations found a single X-ray source and a high abundance of alpha process elements suggestive of starburst activity, but they could not rule out an AGN or AGN-starburst composite. The X-ray core is either very faint or has an $N_{\text{H}_{\text{a}}} > 10^{24}$ cm$^{-2}$ (Inami et al. 2010; Mudd et al. 2012). Starburst activity would be consistent with earlier optical and IR spectroscopy (Goldader et al. 1997). The VLBI observations of the OH MM emission have placed it off-center in a merging system. The OH masers trace a 300 pc region around the second nucleus with a mass of $10^9 M_\odot$ that has some probability of being a heavily obscured AGN (Migenes et al. 2011). Spitzer observations found starburst activity similar to extranuclear starbursts in NGC 4038/9 and Arp 299. In the latter, three maser regions are associated with both nuclear regions of Arp 299 and an overlap region (Tarchi et al. 2011). The spectrum of the IRAS 20550+1656 water masers is also strongly reminiscent of that of NGC 2146 with its massive star formation kilomaser. The data are quite suggestive that IRAS 20550+1656 water masers can be related to starburst and star-formation activity. The maser flux is unfortunately rather low for a VLBI follow-up.

6. Dual maser species

In the literature, there are five known sources (or six, if including uncertain OH masers in UGC 5101) that are known to host both OH and H$_2$O maser species. These dual-species objects typically have a complex morphology and the masers are located in unrelated regions. Our two detections in ten searched OH maser objects increase the number of known dual-species objects to eight.

Tarchi et al. (2011) report 57 sources searched for both 1.6 GHz OH and 22 GHz H$_2$O maser species. Six are detected in neither species, 45 in only one, and six in both species. Tarchi et al. also note a curious lack of H$_2$O kilomaser in OH megamaser objects. Adding our sources and
sources common to the 4038-entry H₂O database and recent OH searches (Staveley-Smith et al. 1992; Klöckner 2004; Impellizzeri 2008; Willett et al. 2011), we find a total of 95 sources searched for both transitions, 34 detected in neither, 35 detected in H₂O only, 18 in OH only, and about 8 detected in both species (if the two uncertain OH masers in UGC 5101 and IRAS 17526+3253 are included). This gives a total of 61 sources detected in at least one of the two maser species. Luminosities, 3σ limits, and redshifts of these 61 detected sources are presented in Fig. 2. Luminosities against source redshifts for all 95 sources are shown in the insert. The upper limits of the non-detections have a median of 0.04 L⊙ for OH and 0.4 L⊙ for H₂O. This demonstrates that a large fraction of H₂O kilomaser sources (L < 10 L⊙) may go undetected. The difference in the two medians is partly due to the frequency proportionality of the isotropic luminosity in Eq. (1). An at least factor 13 higher sensitivity is partly due to the frequency proportionality of the isotropic luminosity in Eq. (1). An at least factor 13 higher sensitivity would improve the search for dual species masers. The 8 masers in the insert show luminosities of 10 L⊙.

In the past decade, the most important OH maser detection rate of P(H₂O/1612 MHz OH) = 2% is higher than the average 4% rate achieved in H₂O maser searches. We could speculate that OH masers point towards systems with an overall larger molecular reservoir or a larger number of over-densities and shocked regions with favorable conditions for producing detectable luminous H₂O maser emission. The dual-species detections in a sample of 95 objects may be explained by a random coincidence of two regions with suitable maser conditions in a single system. However, a more detailed analysis that inspects actual source selection criteria of each of the 95 sources is necessary to determine if dual-species detections are indeed a random coincidence and if the seemingly enhanced detection rate of H₂O masers in extragalactic objects selected by the presence of OH masers is only a product of the small dataset.

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7. Conclusions and summary
We detected water megamasers in four galaxies: three in OH galaxies, and one in a Sy 2 galaxy with no previous OH search. The OH MM galaxy IRAS 12050+1656 has a tentative starburst-like H₂O MM detection, the presumed OH MM galaxy IRAS 17526+3253 has narrow 0.17 Jy systemic masers, and the 6 GHz OH absorption source NGC 4261 (2C 270) with a twin jet hosts a likely jet maser. Disk masers were found towards the probable Sy 2 AGN in 2MFGC 13581. The black hole mass is unknown, but assuming a mass of 10⁶ M☉ typical of AGN masers in galaxies, the massing disk may be around 0.4 pc in diameter. Masers in NGC 4261 are particularly interesting because the host galaxy and the maser profile are remarkably similar to the H₂O MM galaxy NGC 1052. AVLBI map of NGC 4261 may be able to locate regions of a molecular torus that are excited by a background jet continuum like in NGC 1052. The VLBI imaging of the disk maser galaxy 2MFGC 13581 might produce a precise MBH estimate, although the maser flux densities are very low for VLBI. A lack of systematic features in 2MFGC 13581 makes this source less interesting for measuring the angular diameter distance and the Hubble constant. We plan VLBI follow-ups on the more luminous detections in IRAS 17526+3253 and NGC 4261.

Our detection of water masers in two OH maser galaxies updates the current count of six dual-species objects to eight. The conditional H₂O detection rate in OH maser galaxies P(H₂O/OH) = 25% is higher than the average 4% rate achieved in H₂O maser searches. We could speculate that OH masers point towards systems with an overall larger molecular reservoir or a larger number of over-densities and shocked regions with favorable conditions for producing detectable luminous H₂O maser emission. The dual-species detections in a sample of 95 objects may be explained by a random coincidence of two regions with suitable maser conditions in a single system. However, a more detailed analysis that inspects actual source selection criteria of each of the 95 sources is necessary to determine if dual-species detections are indeed a random coincidence and if the seemingly enhanced detection rate of H₂O masers in extragalactic objects selected by the presence of OH masers is only a product of the small dataset.

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