Extragalactic water masers in bright IRAS sources

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\textbf{Abstract.} We report the results of a search for 22 GHz water maser emission in IRAS-bright galaxies, using the 100-m Effelsberg telescope. In particular, we present the details of four new maser detections (IC 342, NGC 2146, NGC 3556, and Arp 299) and follow-up interferometric studies. A comparison between water maser detection rates derived in the present study and those in previous similar surveys is also presented.

1. Introduction

To date, there is evidence for a total of three distinct classes of extragalactic H$_2$O masers: i) H$_2$O megamasers (with isotropic luminosities $L_{\text{iso}} > 10 L_\odot$) associated with accretion disks in active galaxies (e.g. NGC 4258, Miyoshi et al. 1995) ii) H$_2$O megamasers resulting from an interaction between the nuclear radio jet and an encroaching molecular cloud (e.g. Mrk 348, Peck et al. 2001, 2003) iii) weaker H$_2$O masers, the ‘kilomasers’ (with $L_{\text{iso}} < 10 L_\odot$), often associated with prominent star forming regions in large scale galactic disks, and, thus far found in galaxies containing bright IRAS (Infrared Astronomical Satellite) point sources (e.g. NGC 2146, Tarchi et al. 2002b).

We have undertaken deep searches optimized to detect emission arising from the last class of sources. The sample (hereafter ‘FIR-maser’ sample) is comprised of all galaxies with declination $>-30^\circ$, known velocity, and IRAS point source flux densities of $S_{100\mu m}>50$ Jy (e.g. IRAS 1989). There is a total of 45 sources.

2. Observations

The target sources of the sample were measured in the 6$_{16} - 5_{23}$ line of H$_2$O (rest frequency: 22.23508 GHz) with the 100-m telescope of the MPIfR at Effelsberg on various occasions between April 2001 and September 2002. The full width at half power beamwidth was $\sim 40''$ and the pointing accuracy was always better than 10''. The autocorrelator backend was split into eight bands of width 40 or
80 MHz and 512 or 256 channels each. This yielded channel spacings of \( \sim 1 \) or \( \sim 4 \text{ km s}^{-1} \).

3. Results

Including the early part of our survey (Tarchi et al. 2002a, b), from the FIR–sample, we have detected three new kilomasers (IC 342, NGC 2146, and NGC 3556) and a new megamaser (Arp 299). Line profiles are shown in Fig. 1. Properties of the individual sources are discussed below.

3.1. Recent detections

**IC 342:** We have obtained the first definite detection of water maser emission in the nearby spiral galaxy IC 342 (at a distance \( D = 1.8 \text{ Mpc} \)). The maser
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arises from a location 10–15″ to the west of the centre of the galaxy\(^1\) and is associated with a powerful star forming region at a projected distance of \(\sim 100\) pc from the nucleus. Time variability (see Fig. 1a), if intrinsic, yields a maser size of \(\lesssim 1.5 \times 10^{16}\) cm\(^{-3}\) and a brightness temperature \(\gtrsim 10^9\) K.

**NGC 2146:** The one detected toward the starburst galaxy NGC 2146 (\(D = 14.5\) Mpc) is the most luminous and distant \(\text{H}_2\text{O}\) kilomaser detected so far (see Fig. 1b). Interferometric observations with the Very Large Array (VLA) show that a part of the emission originates from two prominent sites of star formation that are associated with compact radio continuum sources, likely ultra-compact \(\text{H}_\text{ii}\) regions.

**NGC 3556:** is a nearby spiral galaxy located at a distance of \(\sim 12\) Mpc. Its FIR luminosity, \(L_{\text{FIR}} \sim 10^{10}\) \(L_\odot\), is similar to that of the Milky Way. The detected \(\text{H}_2\text{O}\) maser line initially had a central velocity of \(\sim 738\) km s\(^{-1}\). With a peak flux of 20–40 mJy, the maser had an isotropic luminosity of \(\sim 1\) \(L_\odot\). More recently, the maser feature disappeared and another weaker component, at \(\sim \)708 km s\(^{-1}\), was detected in September 2002. The profiles are shown in Fig. 1c.

**Arp 299:** is a merging system composed of three main regions of activity: the nuclear regions of IC 694 in the east, NGC 3690 in the west, and the interface where IC 694 and NGC 3690 overlap, located approximately 10″ north of NGC 3690. In Arp 299, the water maser profile is extremely broad (\(\sim 200\) km s\(^{-1}\)), with a peak flux density of 30 mJy (Fig. 1d). Adopting a distance of 42 Mpc, the total isotropic luminosity is \(\sim 250\) \(L_\odot\), placing the object among the more luminous \(\text{H}_2\text{O}\) megamasers. The maser line is centered at a velocity of 3100 km s\(^{-1}\), i.e. very close to the systemic velocity of the entire complex of sources which constitute Arp 299.

4. **Discussion and Conclusions**

More than 700 active galaxies have been observed in water vapor maser surveys to date. In order to search for a large number of sources, these surveys were not very sensitive and had a low detection rate, between zero (e.g. Henkel et al. 1998) and a few percent (e.g. Henkel et al. 1984; Braatz, Wilson, & Henkel 1996, Greenhill et al. 2002).

We detected with IC 342, NGC 2146, NGC 3556 and Arp 299 four new \(\text{H}_2\text{O}\) masers. The new detections are a consequence of higher sensitivity (noise levels of \(\sim 10\) mJy for a 1 km s\(^{-1}\) channel), more stable continuum sampling over large bandwidths (i.e. improved baselines), and luck (in the case of the short-lived flare observed toward IC 342). Including all previously detected sources in the complete FIR-sample, we find a detection rate of 10/45 (or 22%).

The high rate of maser detections in our sample of galaxies strongly suggests that a relationship between FIR flux density and maser phenomena exists, consistent with the assessment by Henkel, Wouterloot, & Bally (1986). Fig. 2 shows the cumulative detection rate above a given 100\(\mu\)m IRAS Point Source Catalog flux for the parent galaxy. The detection rate strongly declines with

\(^{1}\)The position has been derived from an Effelsberg map we have produced taking advantage of the high line intensity and good weather conditions
Figure 2. Detection rate of the H$_2$O FIR-maser sample (see Sect. 1 for selection criteria) for all galaxies above a given IRAS Point Source Catalog $S _{100\mu m}$ flux density.

decreasing FIR flux. For fluxes $\sim 1000$ Jy, 100–300 Jy, and 50–100 Jy, we find detection rates of 2/2 (or 100%), 5/17 (or 29%), and 3/26 (or 12%). This indicates that an extension of the sample to lower fluxes would be worthwhile.

It appears that $S_{100\mu m}$ (and thus also the FIR luminosity, $L_{\text{FIR}}$) and H$_2$O peak fluxes are roughly proportional, as was already suggested by Henkel et al. (1986) on the basis of a smaller number of detected sources.

The possibility that a correlation between $L_{\text{IR}}$ and $L_{\text{H}_2\text{O}}$, similar to that found by Genzel & Downes (1979) for galactic star forming regions, exists is under investigation.

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