HOST GALAXIES AND NUCLEAR STRUCTURE OF AGN WITH H_2O MEGAMASERS AS SEEN WITH HST

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to appear in: "QSO hosts and Their Environments", Granada, January 2001, Ed. I. Márquez Pérez et al., Kluwer Academic Press

Abstract We present results of an HST survey in Hα and continuum filters of a sample of H_2O megamaser galaxies compiled by Braatz et al., all of which contain AGN. These observations allow us to study the AGN/host-galaxy connection, e.g. study the relation between the parsec scale masing disk/torus, bipolar outflows, and large scale properties of the galaxies such as dust lanes, signs for interaction, and galaxy types. A number of galaxies indeed show large-scale bi-polar Hα structures which, however, are more reminiscent of outflows then excitation cones. Most megamaser galaxies are found in spiral galaxies. Only one galaxy in the original sample is known to be an elliptical and one galaxy imaged by us shows clear signs of interactions. In all cases we see evidence for obscuration of the nucleus (e.g. dust-lanes) in our color maps and the disk galaxies are preferentially edge on. This suggests that the nuclear masing disk has some relation to the large scale properties of the galaxy and the dust distribution.

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1. INTRODUCTION

After the discovery of extragalactic water vapor masers in star-forming regions (Churchwell et al. 1977) a search started for other possible extragalactic H_2O masers. In the late seventies and early eighties, this work lead to to the discovery of five so-called megamasers in the nuclei of NGC 4945, the Circinus galaxy, NGC 1068, NGC 4258, and NGC 3079 which are 10^6 times more powerful than the commonly observed galactic masers. Only much later, after an intense search of a distance limited galaxy sample, Braatz, Wilson, & Henkel (1994, 1996) were able to increase the number of known megamasers by a factor of three, thus making for the first time a statistical analysis of this rare phenomenon possible.

It is obvious that the H_2O megamaser phenomenon must have something to do with nuclear activity as all such megamaser sources are either in Seyfert or Liner galaxies and the emission is always concentrated at the nucleus. Interestingly, Seyferts of type 1 are absent from this group. The standard interpretation for the difference between Sy 1 and Sy 2 is that a torus surrounds the nucleus which obscures the central engine (black hole and accretion disk) for large inclination angles.

It therefore appears reasonable to infer that the masers trace molecular material associated with this torus or an accretion disk that feeds the nucleus. This, and the small number of H_2O megamasers known, suggests that the maser emission occurs for certain, very restricted, viewing angles, perhaps where the line of sight is along the plane of the molecular disk or torus.

This notion was recently confirmed in great detail by VLBI observations of the megamaser in NGC 4258 (Miyoshi et al. 1995; Greenhill et al. 1995). The positions and velocities of the central, the red- and the blue-shifted H_2O maser lines show that the masing region is in a thin disk structure, rotating on Keplerian orbits around a central mass of $3.6 \cdot 10^7 M_\odot$ at a distance of 0.13 pc from the nucleus. This observations proved for the first time the existence of a small scale molecular disk surrounding an active nucleus. Recently, VLBI maps have been obtained for even more maser sources: while NGC 4945 (Greenhill, Moran, & Herrnstein 1997) and NGC 3079 (Trotter et al. 1998) also show a structure interpreted as a disk, the masers in NGC1068 show weak emission from a region presumably shocked by the nuclear jet at a projected galactocentric distance of $\sim$30 pc from the nucleus (Gallimore et al. 2001) in addition to the masers in the disk (Greenhill et al. 1996).

Although plausible scenarios for the megamaser phenomenon exist (e.g., Neufeld & Maloney 1995) it is by no means clear how the obscuring torus and the masing disk are related. The masing disk may be the innermost part of a molecular accretion disk adjacent to the torus or just be the thin, central plane of the torus in which the column density is high enough for strong amplification. Alternatively, it might also be dynamically independent from "the torus" with a strong misalignment between their axes. In the most simple-minded picture, however, one would hope to find that masing disk, obscuring torus and the extended molecular cloud distribution form one coherent accretion structure feeding the central engine.

We have therefore investigated a sample of megamaser host galaxies with the Hubble-Space-Telescope (HST) to look for large scale evidence of the molecular material, some of which we describe in the following.

2. OBSERVATIONS

The sample was selected from the list of 16 known megamasers known in 1996 and published by Braatz, Wilson, & Henkel (1996). We observed all galaxies that had not been previously observed with HST, which included: NGC449 (Mrk 1), NGC1386, NGC2639, NGC3079, IC2560, NGC4945, IRAS18333-6528, TXS 2226-184, and IC1481. Observations were made with WFPC2 to cover a red and a green continuum filter, as well as the Hα+[N II]$\lambda\lambda$6548,6583 emission lines. The filters used were F814W (red continuum), F547M (green continuum), F673N and the Linear-Ramp-Filters (LRF) for galaxies at higher redshifts. The pixel scales were either $0\farcs1$/pixel or $0\farcs0455$/pixel depending on whether LRF usage required imaging on the Wide Field or Planetary Camera. All observations were made within one orbit.

The images were processed through the standard Wide-Field and Planetary Camera 2 (WFPC2) pipeline data reduction at the Space Telescope Science Institute. Further data reduction was done in IRAF and included: cosmic ray rejection, flux calibration, and rotation to the cardinal orientation. The galaxy continuum near the Hα+[N II] line was determined by combining the red and green continuum images, scaled to the filter width of the narrow-band filter and weighted by the relative offset of their mean wavelengths from the redshifted Hα+[N II] emission. From the two broad-band images and the emission-line image, we constructed three-color (RGB) maps, where, for better contrast, the Hα+[N II] image was assigned the green channel, and the F814W and F547M filter images were assigned the red and blue channels respectively. Galaxy profile fits were made to the red continuum images. More details and first results for one galaxy (TXS 2226–184) are given in Falcke et al. (2000b).

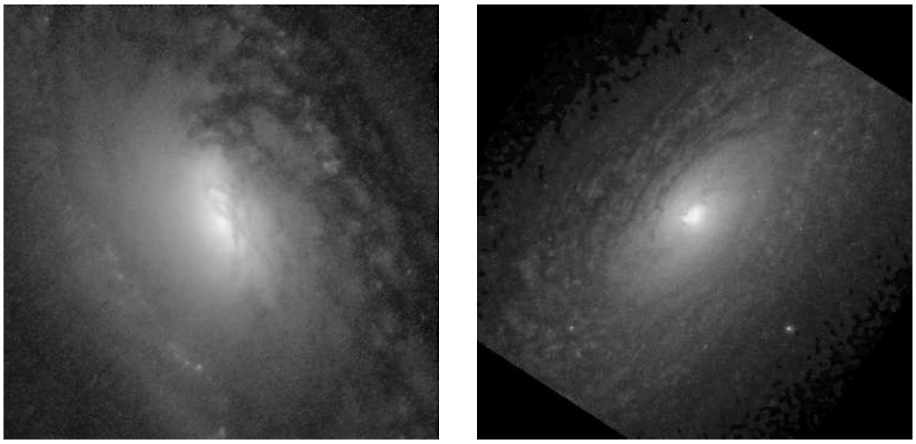

Figure 1 Gray-scale representation of three-color HST images of the megamaser galaxies NGC1386 (left) and NGC2639 (right). North is up and East to the left. The images are $18\farcs25$ and $32\farcs35$ on each side respectively.

3. RESULTS

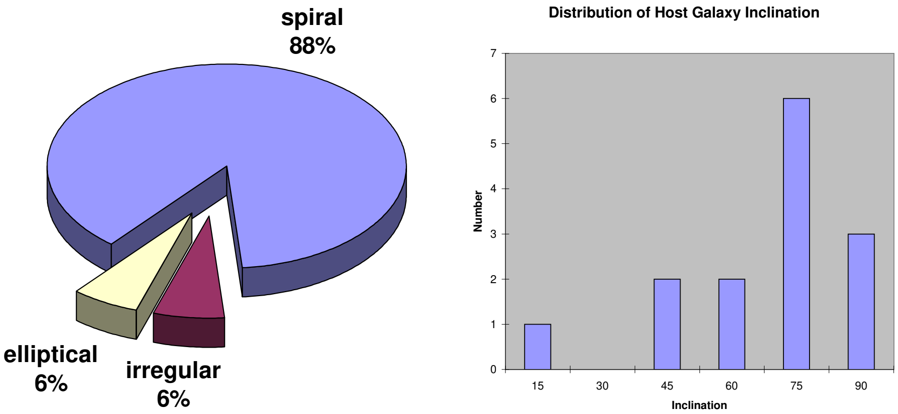

Figure 2 Left: The distribution of host galaxy types for all megamasers in the Braatz et al. (1996) sample determined from our HST observations and the literature. Right: Distribution of host galaxy inclination. The majority of megamaser galaxies are edge-on spirals.

The HST images contain a wealth of information. In many cases dust lanes and spiral arms are clearly visible and in basically all galaxies we resolve the narrow-line region (NLR). The most spectacular structures are the well-known Hα-bubble in NGC3079 (see also Cecil et al. 2001), a fan-shape region in NGC4945 (Marconi et al. 2000), and linear jet-like features in TXS 2226-184 (Falcke et al. 2000b) and NGC 1386 (Ferruit, Wilson, & Mulchaey 2000). In these cases the structure might be mainly related to an outflow rather than an excitation cone. The water vapor maser emission in these galaxies has been imaged with VLBI (either published or private communication: L. Greenhill and J. Braatz). In those four cases the presumed axis of the nuclear disk (even though the disk interpretation is not secure in all cases) seems to be perpendicular within less than 30° to the closest nuclear dust lane, as would be the case if the maser disks and the dust lanes tend to align. On the other hand the large scale radio or Hα axis is not always perpendicular to the disk axis (see, e.g., NGC3079, Trotter et al. 1998).

In all galaxies of our sample, we see clear evidence for the presence of large scale dust obscuration. In most, i.e. seven, cases we directly see relatively well-defined narrow dust-lanes passing through the nucleus; in the remaining two cases we see an elongated nucleus and reddening on one side of the inner galaxy.

The profile fitting of the continuum images yielded a significant preference for disk models over bulge-only/elliptical models. We also see clear signs of spiral arms in a number of the disk galaxies. Only for one galaxy, IC1481, do we obtain inconclusive results. The optical appearance is very irregular suggesting that this might be the site of an ongoing galaxy merger. One galaxy, TXS 2226-184, was re-classified as a spiral (see Falcke et al. 2000b – it was originally thought to be an elliptical). If we supplement our sample with literature data we find that only one out of 16 galaxies is an elliptical and one is irregular (see Fig. 2a) – the vast majority of megamaser host galaxies are indeed spirals.

From the observed ellipticity we can derive inclinations for the spiral galaxies in our sample. This shows that the majority of the galaxies are highly inclined with only a few face-on odd-balls (Fig. 2b).

4. CONCLUSIONS

Braatz, Wilson, & Henkel (1997) suggested that the nuclear properties of AGN with megamasers might be connected with their large scale structure. Our investigation seems to confirm this trend. Megamaser galaxies seem to be preferentially edge-on and in spiral galaxies. After TXS 2228-184 was reclassified there is only one elliptical galaxy left (NGC 1052), which, however, has masers along the jet (Claussen et al.

1998) and hence may be different from the majority of galaxies which have been interpreted in terms of masers from molecular disks[1].

The fact that we always see some obscuring material in the HST images directly on scales of several tens to hundreds of parsecs could indicate that the masing structure (the 'torus') on the milli-arcsecond (i.e., sub-pc) scale is related to large scale dust lanes and is thus not an isolated nuclear feature. Confirmation of this hypothesis may come from further VLBA-observations which could reveal the orientation and geometry of the nuclear disk in relation to the dust lanes seen with HST.

Acknowledgments

This work was supported by DFG grant 358/1-1 & 2, NASA grants NAG8-1027 and HST GO 7278, and NATO grant SA.5-2-05 (GRG 960086)318/96.

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[1]The same may be true for the recently discovered megamaser in Mrk 348 (Falcke et al. 2000a), the galactic disk of which is very much face-on. VLBA observations of this galaxy show the masers to be at the tip of an expanding jet (Peck et al., in preparation).