The WISE View on Water Maser Galaxies

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Abstract

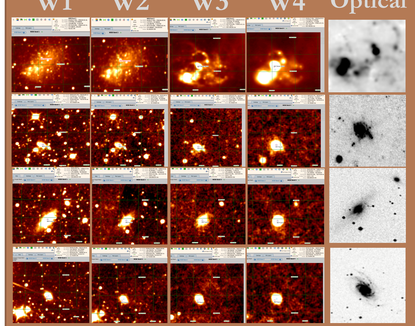
Extensive searches for water vapor mega-masers in active galactic nuclei (AGN) have resulted in ~120 detections out of ~3500 galaxies surveyed. In about 21% of the detections, the masers originate in the sub-pc circumnuclear disks. An investigation of the relationship between the mid-infrared properties and the water maser emission in galaxy centers is essential for both refinement of future maser surveys and for constraining the dominant ionization mechanism most likely associated with the maser activity. We present here the results of a careful cross reference of all galaxies surveyed to date in 22 GHz, offered by the Megamaser Cosmology Project (MCP), with the Wide field Infrared Survey Explorer (WISE) All-Sky Release data, which reveals an impressive overlap of 98% for both maser and non-maser galaxies. We find that, while the WISE classification of AGNs based on their redder W1-W2>0.8 colors produces a potential maser detection rate of ~20%, the cut recovers significantly less than half (27%) of all the disk detections to date. We also find that the W3 band (12 microns) appears to offer significant sensitivity to the maser detection for W3<7, as well as for maser disks, with a 13% overall maser detection rate, that includes 62% of all disks detections. These findings suggest that there is a strong connection between the 22 GHz detection and the W3 emission, implying a close physical association of the masing conditions with the strength of the PAH feature (11.3 microns) as well as to the warm continuum in AGNs.

Data: Finding Mid-IR Properties of Masers

The Megamaser Cosmology Project (MCP) is the most complete database of masers surveyed in 22GHz. The MCP aims to more accurately find the Hubble Flow constant by measuring precise distances to circumnuclear water masers and the masses of the central supermassive black holes (SMBH) in these water mega-maser disk galaxies. To date, >3500 sources have been surveyed, with 151 masers detected (e.g., Reid et al. 2009, 2013; Braatz et al. 2010, Kuo et al. 2013).

The Wide-Field Infrared Survey Explorer (WISE) satellite provides high resolution and all sky coverage in 4 bands: W1 at 3.4 μm, W2 at 4.6 μm, W3 at 12 μm, and W4 at 22 μm (Wright et al. 2010). Because the circumnuclear dust in AGNs is hot (i.e., at temperatures reaching its sublimation limit, 1500K; e.g., Simpson 2005), its emission is enhanced and much redder than the stellar light with a typical Rayleigh-Jeans tail in the 3-10 micron range, producing a distinctive mid-IR emission. WISE excels thus at selecting type 1 and type 2 AGNs compared to hard X Ray surveys with a 78% completeness and 95% reliability (e.g., Stern et al. 2012; Mateos et al. 2012).

The Cross-Matching process: We tested 4 cone search radii (6", 6.5", 10", and 12") and visually examined all border-line cases in all 4 filters; the final matching results used in this analysis are based on a 10"search radius. A careful cross match between the WISE All-Sky Release Data and the MCP sources reveals 98% mid-IR coverage of all galaxies surveyed in water maser emission.



IC10. Kilo-maser
Angular separation =9.8"

Mrk 1089. Mega-maser, but not a disk.
Angular separation =3.1"

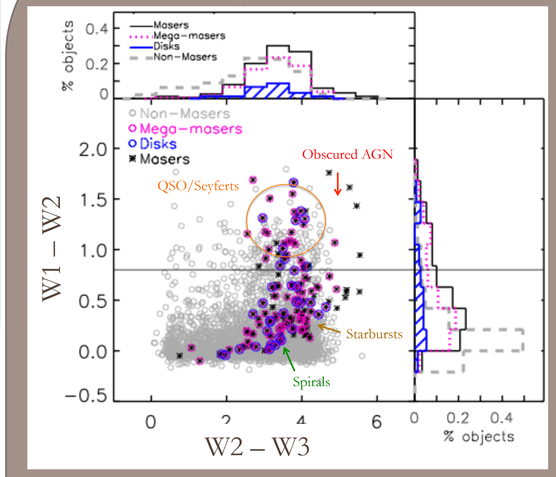
NGC 1194. Mega-maser disk. Angular separation =0.13"

NGC 2989. Not a WISE detection in the 10" search radius, but included in analysis based on visual inspection.

	Maser Detections	Non-Masers
MCP Sources	151	3339
WISE Detections	150	3287
Cross-match Results	98.7%	98.4%

The inclusion of the W3 band offers crucial sensitivity to PAH (11.3 m) emission in nearby galaxies as well as to warm continuum in nearby AGNs. A key feature of the WISE color-color diagrams is the reliable separation from star-forming systems of the AGNs where accretion dominates the bolometric luminosity output, and when the AGN is highly obscured (i.e., redder colors, [3.4] - [4.6] > 0:8; Assef et al. 2012, Yan et al. 2012); systems with dominant stellar emission are expected to peak at 1.6m, and thus have bluer [3.4] - [4.6] colors. Therefore, WISE could be used to identify previously undetected obscured, narrow-lined AGNs that are expected to host maser disks.

Masers & Non-Masers in WISE Color-Color Diagram



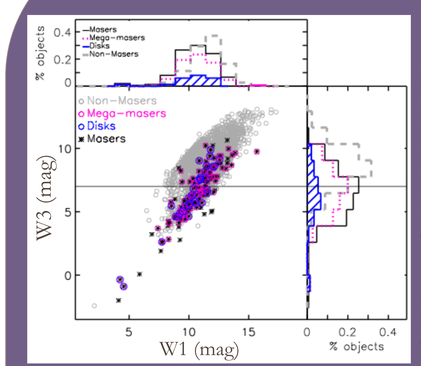
WISE color-color diagram for the masers (black symbols) and non-maser galaxies (grey circles). The mega-masers are marked with additional magenta circles, and the disk mega-masers feature an additional black circle. The location of various classes of objects is from Wright et al. (2010).

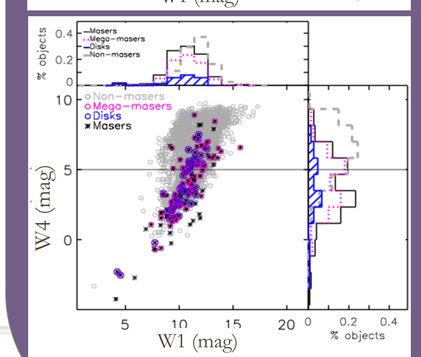
The maser detection rate among the WISE detected galaxies with W1-W2>0.8 is 20%, at least a factor of 4 increase relative to current surveys.

Probably the most apparent and surprising result is that of all maser disks, 67% are in the blue (W1-W2< 0.8) region, suggesting that either:
1) the mega-maser disks are not necessarily associated with the AGN activity, or
2) the SMBH accretion associated with the maser disk is heavily buried in hosts of other type(s) of dominant emission.

	Non-Masers	Masers	Mega-masers	Disks
AGN (W1-W2>0.8)	167	41	30	9
Detection Rate		**20%**	28% of mega-masers	26% of all disks
Non AGN	3120	109	78	25

W3 and W4 can Constrain Future Maser Detection





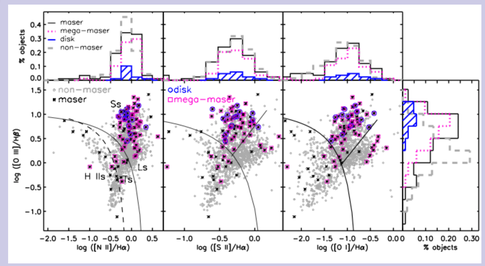
Maser and non-maser galaxies appear to separate well in terms of their W3 and W4 bands. Here are the scatter plots of these magnitudes as a function of the W1 magnitude, with different symbols for non-masers, masers, and the subgroups of mega-masers and the mega-maser disks, together with the corresponding histogram distributions.

We determine qualitatively that source selection among sources bluer than w3 < 7 and w4 < 5 results in exquisitely high maser detection rates, with significantly large inclusion fractions for disk systems.

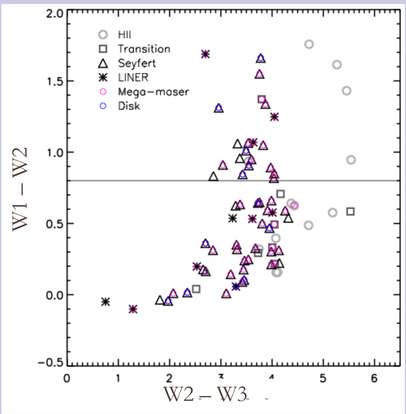
	W3<7	W3>7
Non-Masers	584	2703
Masers	92 (14% detection rate)	58
Mega-masers	62 (57% of mega-masers)	46
Disks	21 (62% of disks)	13

	W4<5	W4>5
Non-Masers	774	2513
Masers	100 (11% detection rate)	50
Mega-masers	67 (62% of mega-masers)	41
Disks	22 (65% of disks)	12

A More Complete View: Adding Optical Spectral Types to the WISE Colors



Optical emission-line galaxy classification diagram for the MCP sources with available high quality optical spectroscopy. The solid and dashed curves illustrate the empirical separation lines that define the classification criteria. Masers and non-masers are in black and grey respectively; again, the mega-masers are shown as magenta squares and the disk masers are marked by blue circles (See Christensen et al., poster 150.27 for details and discussion).



AGN (W1-W2>0.8)	Non-Masers	Masers	Mega-masers	Disks
HII	7	5	0	0
Transition	24	1	1	0
Seyfert	25	17 (21%)	14	5
LINER	27	3	3	0

Non-AGN (W1-W2<0.8)	Non-Masers	Masers	Mega-masers	Disks
HII	223	8	1	0
Transition	326	7	3	0
Seyfert	325	32 (40%)	27	6
LINER	388	7	5	1

The WISE color-color diagram showing the spectral types for the 80 masers with optical spectroscopy reveals once again that the red WISE systems the Seyferts constitute the bulk of the megamaser hosts. Nevertheless, **the blue (W1-W2 < 0.8) WISE Seyferts remain twice more prone to hosting mega-masers, and also more disks.** This suggests that the most efficient masing conditions are connected to more vigorous (recent) star formation episodes associated with galactic nuclear activity. The kilomaser activity is similarly represented among the red and blue WISE sources classified as H IIs.

Conclusions & Future Directions

The use of WISE colors can improve significantly the maser detection. By targeting AGN sources with W1-W2>0.8, the detection rate of masers can reach ~20%, which is more than a factor of 4 larger than what current searches achieve. A selection based on sources with W3 < 7 mag produces a potential maser detection rate of 14%, and recovers 62% of the mega-maser disks. With an additional condition for red WISE AGN-like signature, the maser detection rate jumps to 23%. Similarly, with W4 < 5 mag, the detection rate is ~11%, with ~65% rate of disk-like emission among them; the detection rate increases to 21% when the AGN criterium is added. Nevertheless, limiting results to only WISE AGN sources (i.e., W1-W2>0.8) would exclude over half the masers, mega-masers, and disks. This criterium only recovers about 26% of the mega-maser disks which are essential to a more accurate approximation of the Hubble flow constant and for obtaining the most accurate determinations of supermassive black hole masses. We will test these predictions for the significant increase in the maser detection rate with upcoming observations with the Green Bank Telescope.

References

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