Mid-Infrared Variability of Galaxies Surveyed for Water Megamaser Emissions

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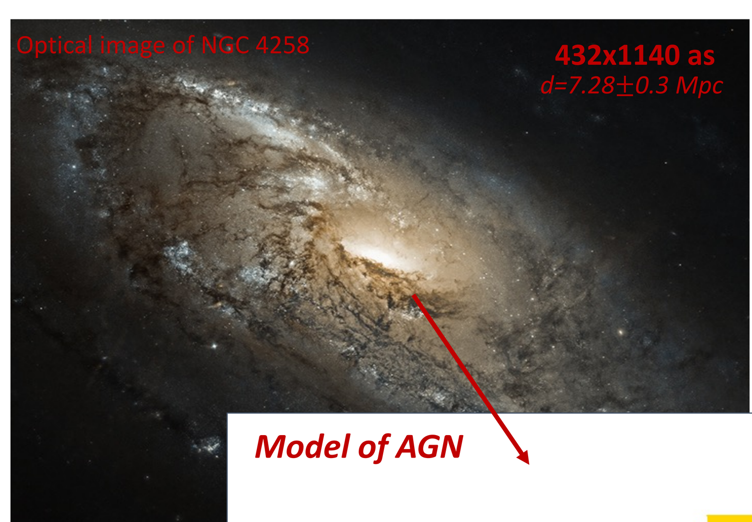
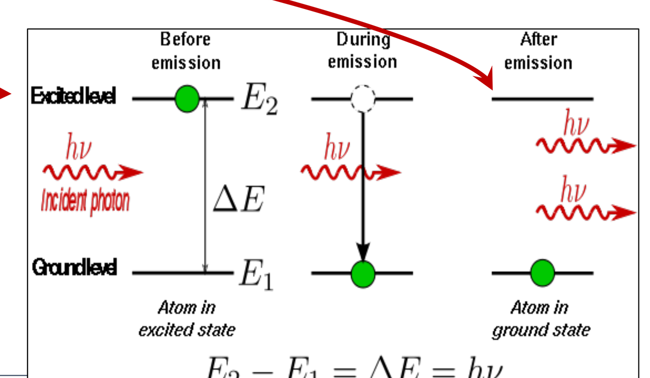
Abstract

Microwave Amplification by Stimulated Emission of Radiation (maser) from water molecules in galaxy centers prove to be one of the most important tools for accurate measurements of supermassive black holes and for geometric distance measurements to extragalactic astrophysical sources and therefore are crucial for providing constraints on our understanding of how the universe formed and evolves. Unfortunately, luminous water masers are notably rare, greatly hastening the need to find more. To be more efficient, future searches for water masers require a closer look at the conditions in which these emissions originate. Currently, there is tentative evidence to suggest that the maser pumping mechanism is associated with the accretion of matter onto supermassive black holes in galactic centers, otherwise known as active galactic nuclei (AGN). Thus, we investigate herein a way of identifying AGNs in maser galaxy hosts via mid-infrared variability. Mid-infrared flux fluctuations have the advantage of being less sensitive to cosmological obscuration, but still reveal variations in the putative AGN, as the circumnuclear dust reprocesses its radiation. With this in mind, we employ here measurements from the Megamaser Cosmological Project (MCP), which offers the most complete list of galaxies surveyed for water maser emissions, as well as multi-epoch mid-infrared data from *Wide-field Infrared Survey Explorer* (WISE), and present preliminary results of our analysis of variability in maser and non-maser galaxies.

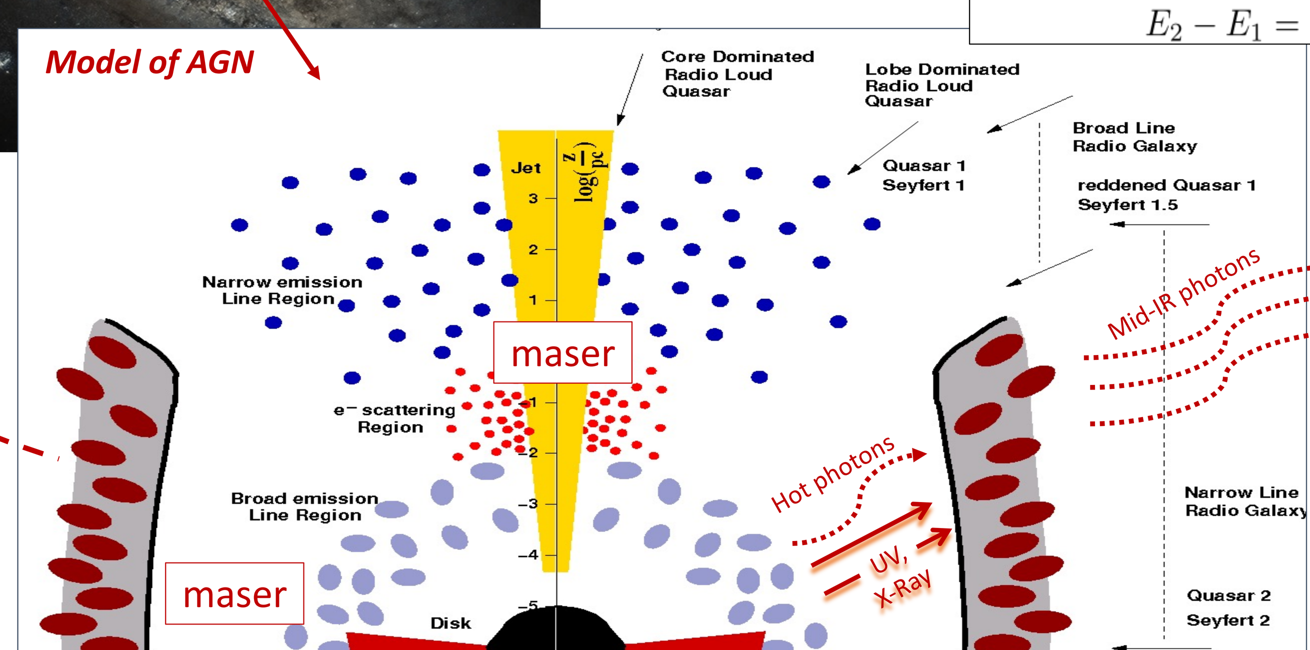
Physics of Maser Emission

MASER – ***M****icrowave* **A**mplification by **S**timulated **E**mission of **R**adiation





Model of stimulated atom emitting a photon



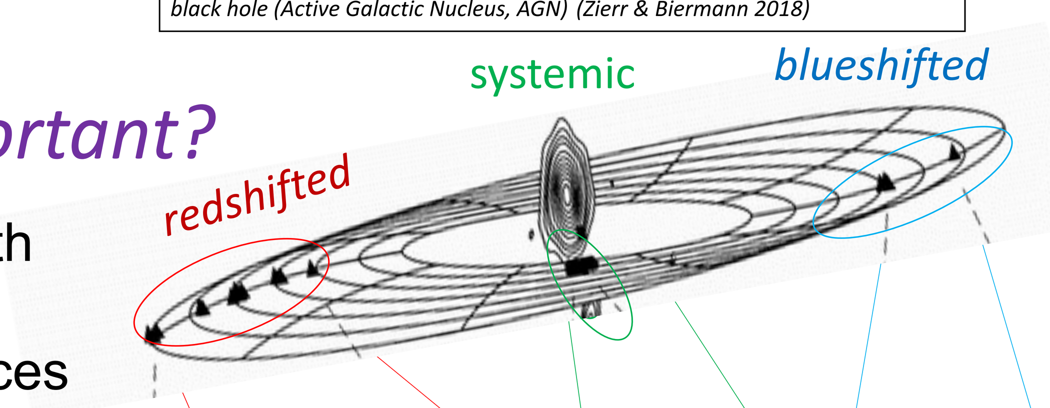
Model of components in nucleus of galaxy with actively accreting supermassive black hole (Active Galactic Nucleus, AGN) (Zierr & Biermann 2018)

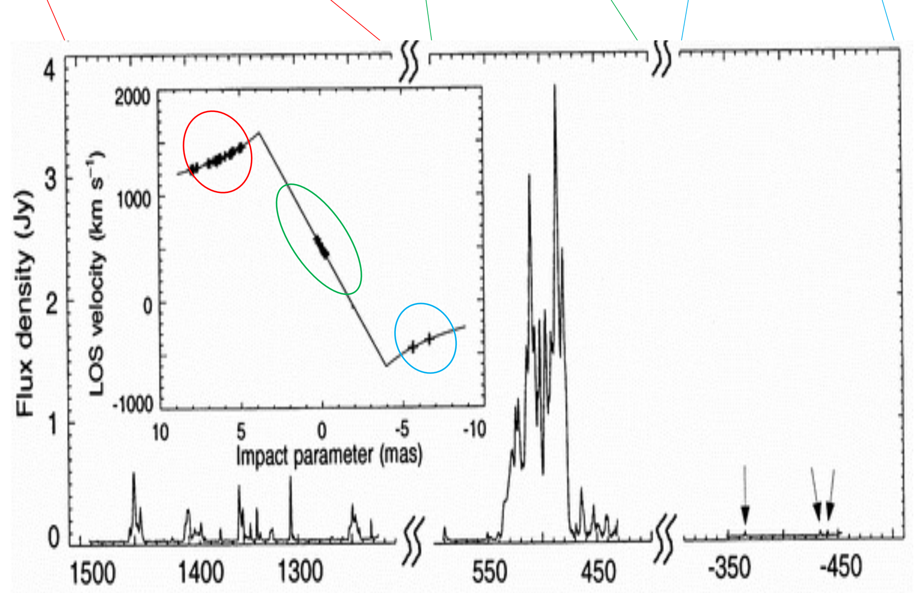
Why are megamasers important?

Megamasers – Cosmic masers with luminosity lines ~10^6 times more luminous than typical galactic sources

VLBI data cleanly fit by a Keplerian disk, $v(r) \propto r^{-1/2}$ allows:

I. Accurate measures of masses of supermassive black holes
II. Direct geometric distance measurements to extragalactic sources
  - Constrains H_0 (Hubble) constant (rate at which universe is expanding)
  - Better understand dark energy

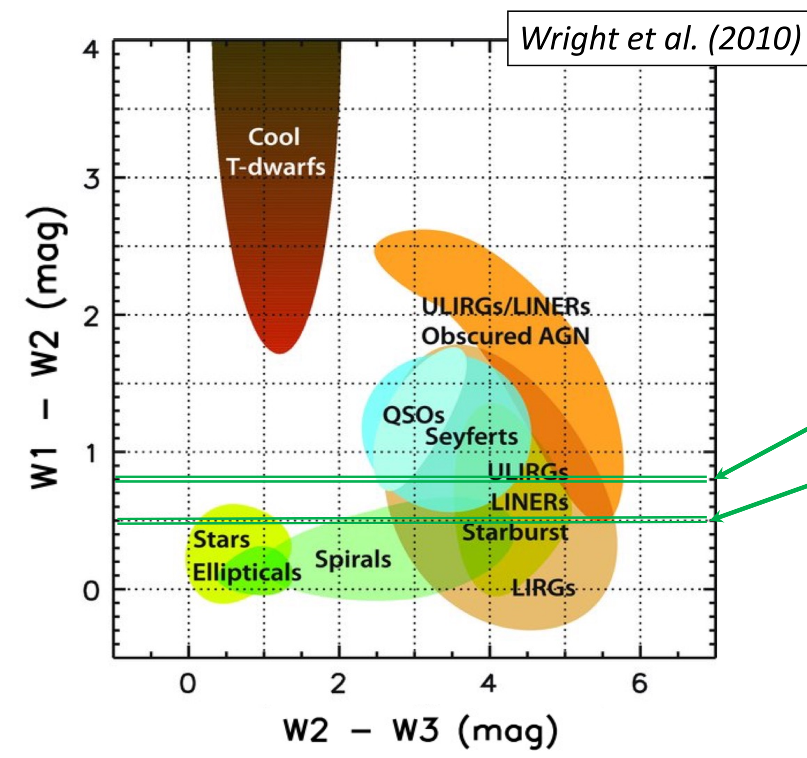


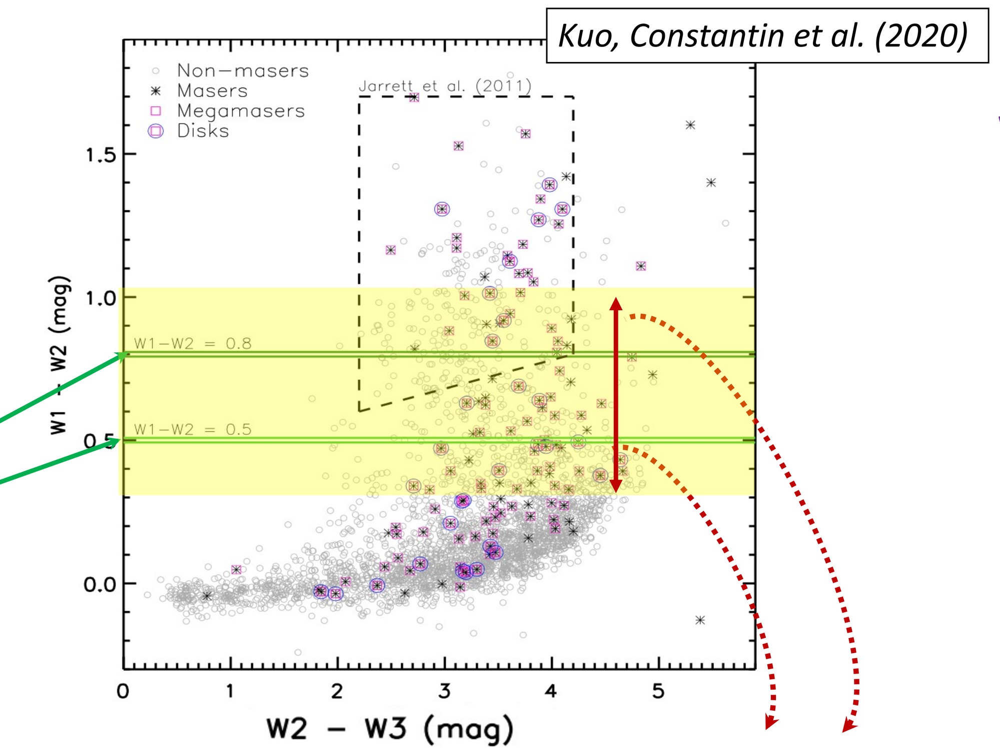


GBT spectrum at 22 GHz reveals three components (redshifted + systemic + blue shifted) suggesting disk-like configuration (Herrnstein et al. 1999).

Why Variability? Why in Mid-Infrared?

- Variability in the total power output of galaxy centers, with timescales of hours to years (e.g. Ulrich et al. 1997, Kozlowski et al. 2016), can be associated with instabilities in the accretion disk or surface temperature fluctuations.
  => Variability selection can reveal accreting SMBHs as power sources (e.g., Trump et al. 2015).
- Mid-Infrared variability selection of galaxies can reveal changes towards redder (higher) W1-W2 colors, i.e., moving them in the AGN wedge of the WISE color-color diagrams (e.g., Stern et al. 2005).
  => Mid-Infrared variability selection allows for new identification of AGN activity where other wavelength selection can miss them.
- Mid-Infrared variability studies have unique advantages: they are less sensitive to dust obscuration, which constitutes a large fraction of the nearby low-luminosity AGN population in general, and also believed to be strongly associated with the maser activity.

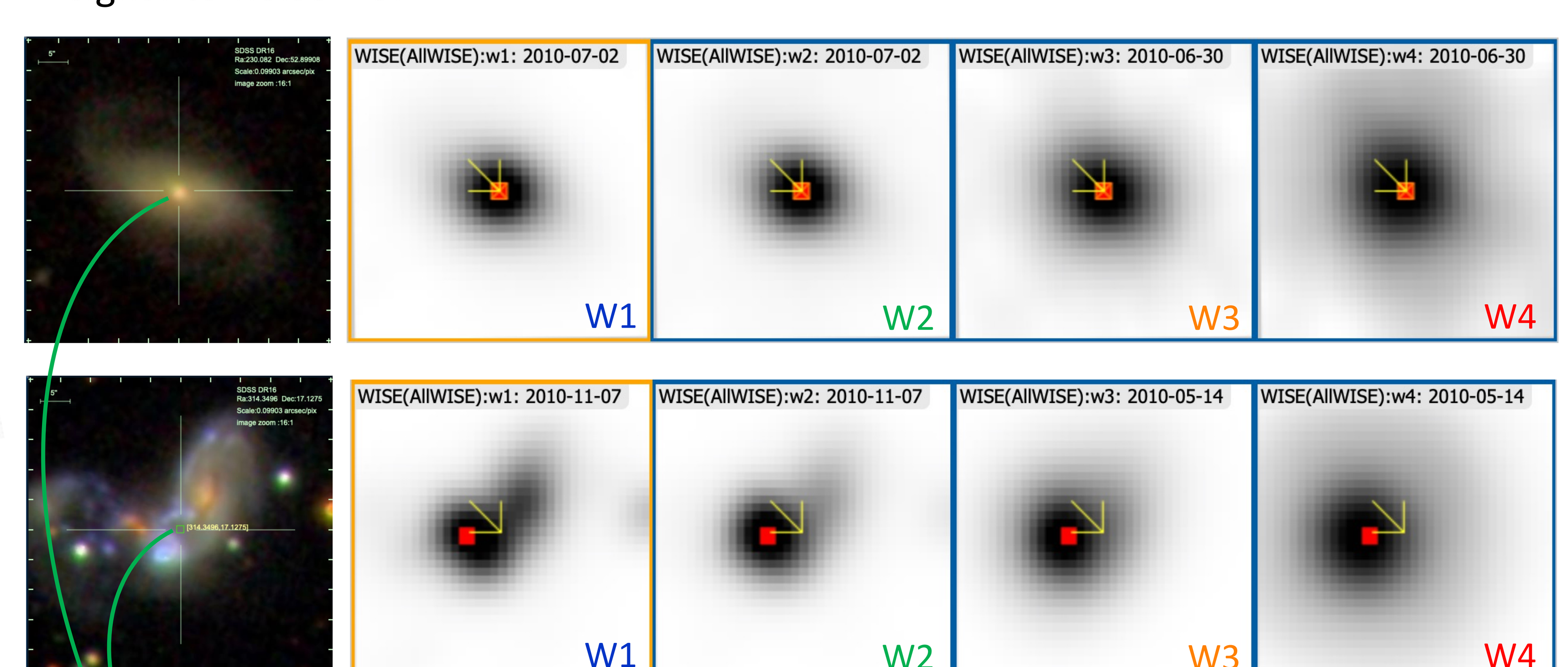




Changes in W1-W2 that would reveal AGN activity not detected by conventional methods

Cross-matching & Data Selection

- We identify the WISE detection counterparts of all the MCP sources, masers and non-masers alike, via 3" search radii for matches in the IPAC/IRSA Extragalactic database, and retained only WISE detections with signal-to-noise > 5.



MCP object coordinates represented as green square. Images provided by SDSS Navigate

Top left: Optical image of J1520+5253 Top right: WISE images of J1520+5253
Bottom left: Optical image of J2057+1707 Bottom right: WISE images of J2057+1707
All images are 50" across. MCP object coordinates represented by yellow arrow. Coordinates of AllWISE Mid-IR matches of MCP objects represented by red squares. J1520+5253 is 0.04" away from its WISE match. J2057+1707's match is offput by 2.84".

- For the best MCP-WISE matches, we then employ the WISE Multi-Epoch catalog to search and identify multiple observations over time scales of hours to years.

	Masers	Non-masers
MCP Sources	180	6,353
3" WISE Matches	160 (88.9%)	4,265 (68.9%)

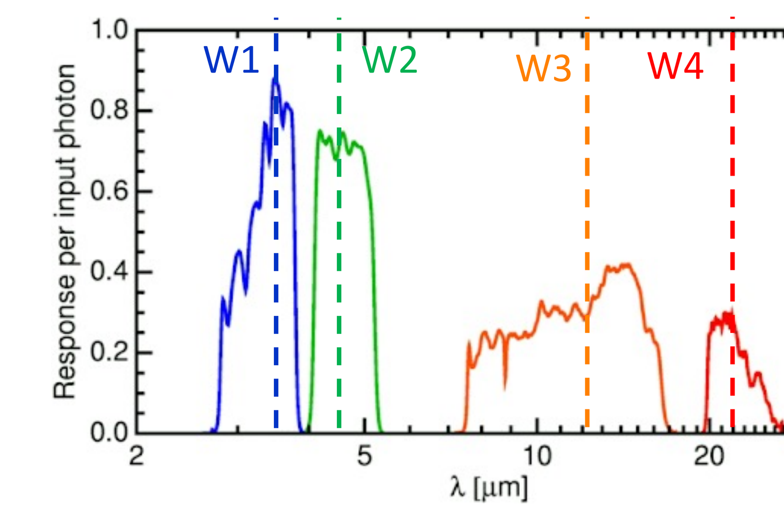
Data

Megamaser Cosmology Project (MCP)

- Largest catalog of galaxies surveyed for H_2O maser emission in 22 GHz (>5000 galaxies; Braatz et al. 2018)
- ~3% of all surveyed galaxies host maser emission
- ~80% of maser galaxies show megamaser luminosities
- ~20% of host galaxies emission are found in a disk-like configuration
- Need better selection of potential maser disk candidates, which in turn needs a better understanding of how the masing activity relates to the properties of their host galaxies in all wavelengths.

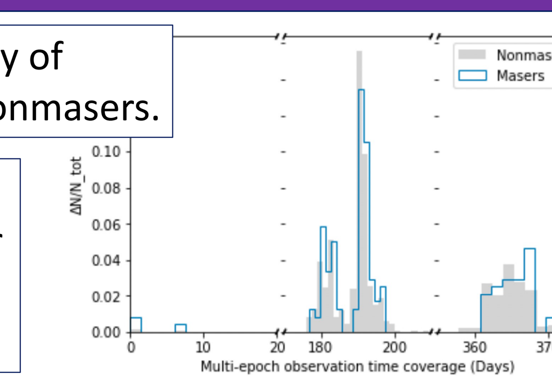
Wide-field Infrared Survey Explorer (WISE)

- A mid-infrared survey of the entire sky with bands centered at wavelengths of: 3.4 μm, 4.6 μm, 12 μm, 22 μm

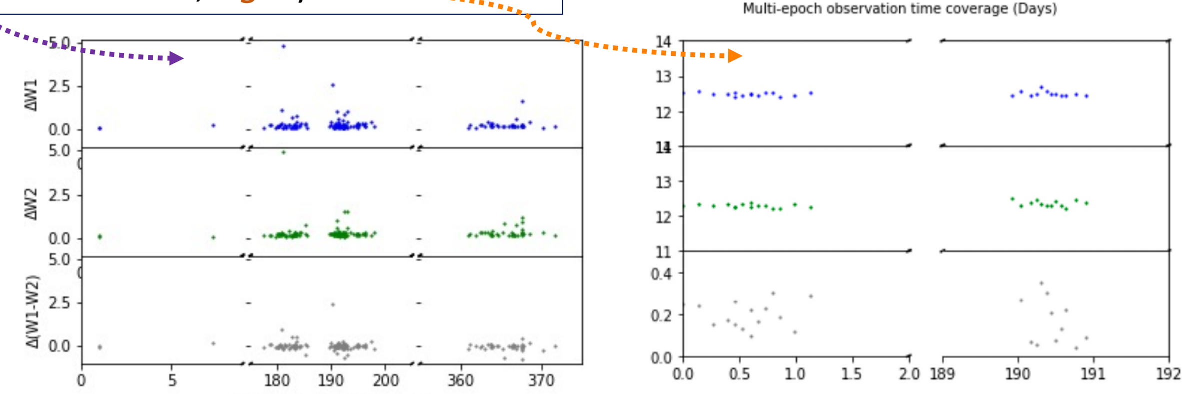


Results So Far

Histogram comparing frequency of observations for masers and nonmasers.



Range in flux variation in W1, W2, and the color W1 – W2, for the whole maser sample (*left*), and for one single maser galaxy (J1202+3519, *right*).



	W1 – W2	Δ(W1-W2) > .1	Δ(W1-W2) > .3	Δ(W1-W2) > .5
Masers	0.53±0.43	52 (33.13%)	11 (6.88%)	9 (5.63%)
Nonmasers	0.24±0.32	1613 (37.82%)	453 (10.62%)	259 (6.07%)

References

Braatz, J., et al., 2009, ApJ, 695, 287; **Braatz**, et al., 2018, https://safe.nrao.edu/wiki/bin/view/ Main/Megam aserCosmologyProject; **Herrnstein**, et al., 1999, A&A, 20, 165; **Kuo, C.**, Constantin, A., et al., 2018, ApJ, 860, 169; **Stern, D.**, et al., 2012, ApJ, 753, 30; **Trump** et al. 2015, ApJ, 811, 26; **Wright E.**, et al., 2010, AJ, 140, 1868; **Zierr, C.** & Biermann, P., 2018, A&A, 69, 1

Acknowledgements

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