A More Efficient Search for the Holy Grail of Astronomy

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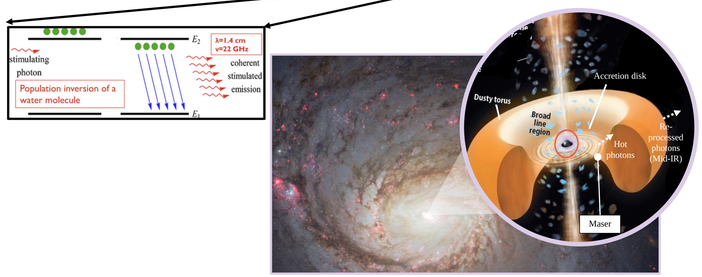
Introduction

Microwave Amplification by Stimulated Emission of Radiation (maser) from water molecules in galaxy centers are an important tool for measurements of supermassive black holes and distance measurements to far away objects and therefore are crucial for furthering our understanding of how the universe formed and evolves. Sadly, this phenomenon is notably rare, 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 evidence proposing a link between the maser pumping mechanism and the area around supermassive black holes in galactic centers, known as active galactic nuclei (AGN). Thus, we investigate a way of identifying AGNs in maser hosts via mid-infrared variability. Mid-IR flux fluctuations are less sensitive to obscuration, but still reveal variations around the AGN. With this in mind, we use measurements from the Megamaser Cosmological Project (MCP), which offers a complete list of galaxies surveyed for water maser emissions, as well as multi-epoch mid-IR data from Wide-field Infrared Survey Explorer (WISE), and present preliminary results of our analysis of variability in maser and non-maser host galaxies.

Physics of Megamasers

Microwave **A**mplification by **S**timulated **E**mission of **R**adiation

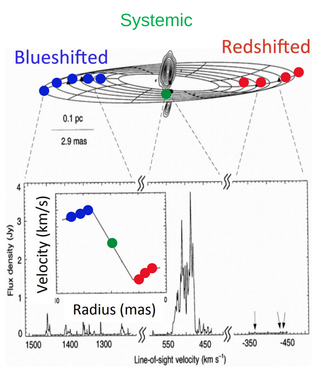


Why are Megamasers Important?

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) ∝ r-1/2 allows:

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



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

Searching with Mid-Infrared Variability

- 3 main ionization processes could account for masing activity
  - Only AGN capable of short time span variability in Mid-IR
- Variability in total power output of galaxy centers (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-IR 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-IR variability selection allows for new identification of AGN activity where other wavelength selection can miss them.
- Mid-IR variability studies have unique advantages as they are less sensitive to dust obscuration, which constitutes a large fraction of the nearby low-luminosity AGN population in general and is also believed to be strongly associated with the maser activity.
- Identifying variability could further connection between masers and AGN

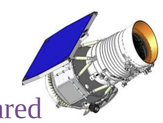
Proposed WISE AGN selection techniques:
1. W1-W2 > 0.8 (blue) (Stern et al. (2012))
2. W1-W2 > 0.5 (green) – more relaxed AGN criterion (Ashby et al. (2009))
3. Jarret et al. (2011) (dashed gray) – least contamination

Data

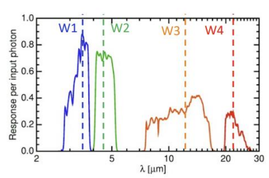
Megamaser Cosmology Project

- Largest catalog of galaxies surveyed for H2O maser emission in 22 GHz (>5000 galaxies; Braatz et al. 2018)
- ~3% of galaxies surveyed for masers host the emission
- ~80% of maser galaxies show megamaser luminosities
- ~20% of host galaxies are found in a disk-like configuration

Wide-field Infrared Survey Explorer (WISE)



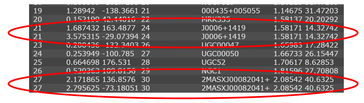
- A mid-infrared survey of the entire sky with bands centered at wavelengths of 3.4 μm, 4.6 μm, 12 μm, 22 μm



Data Sifting

SDSS Querying

- Learn SQL
- Removing duplicates



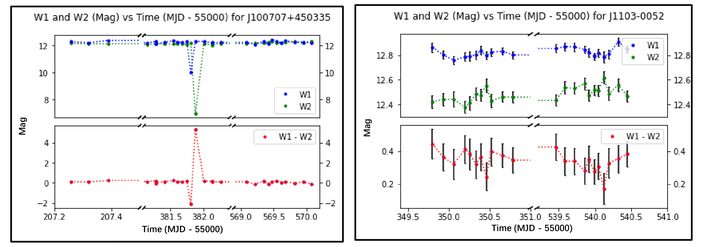
19	1.28942	-138.3661	21	000435+005055	1.14675 31.47203
20	0.153190	52.44822	22	[illegible]	1.58432 20.20292
21	1.687432	163.4877	24	J0006+1419	1.58171 14.32742
22	3.575315	-29.07394	24	J0006+1419	1.58171 14.32747
23	0.220525	133.3403	26	[illegible]	2.20933 17.49422
24	0.253949	-100.785	27	UGC00050	1.66733 26.15447
25	0.664698	176.531	28	UGC52	1.70617 8.62853
26	0.630523	122.0120	29	[illegible]	1.81506 77.70808
27	2.171865	136.8576	30	2MASX00082041+	2.08542 40.6325
27	2.795625	-73.18051	30	2MASX00082041+	2.08542 40.6325

Multi-epoch Crossmatch

- Find counterparts of MCP data in WISE catalogs (NASA/IPAC)
- Re-cross-match with Multi-epoch Photometry catalog
  - Multiple observations over time scales of hours to years

Results

Is there Mid-IR variability? **Yes!**

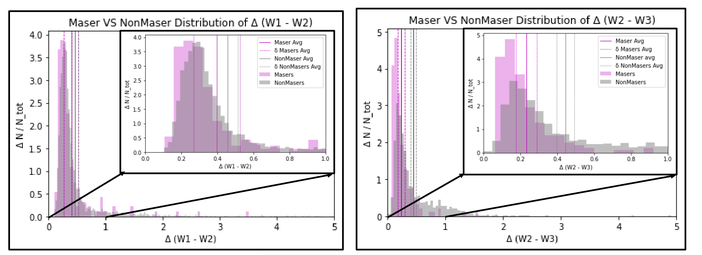


Examples of variability in individual bands (W1, W2) and the W1 – W2 color. Left shows J100707+450335, a galaxy without maser emission extremely variable in the Mid-IR. Right shows a less variable maser host.

Through preliminary analysis, we found that:

- Statistical comparison in the distribution of the change in the color of maser and nonmaser host galaxies
- Δ(W2-W3) greater for galaxies without maser emission
- Δ(W1-W2) shows similar trend, although less statistically significant

Indicating that maser host galaxies may be more "stable" in their color.



Comparison of the distribution of change in different bands (W1 – W2, W2 – W3) reveals reveal AGN activity not detected by conventional methods

Acknowledgements

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