UNDERSTANDING SUPERMASSIVE BLACK HOLE ACCRETION THROUGH H_2O MEGA-MASER STATISTICS

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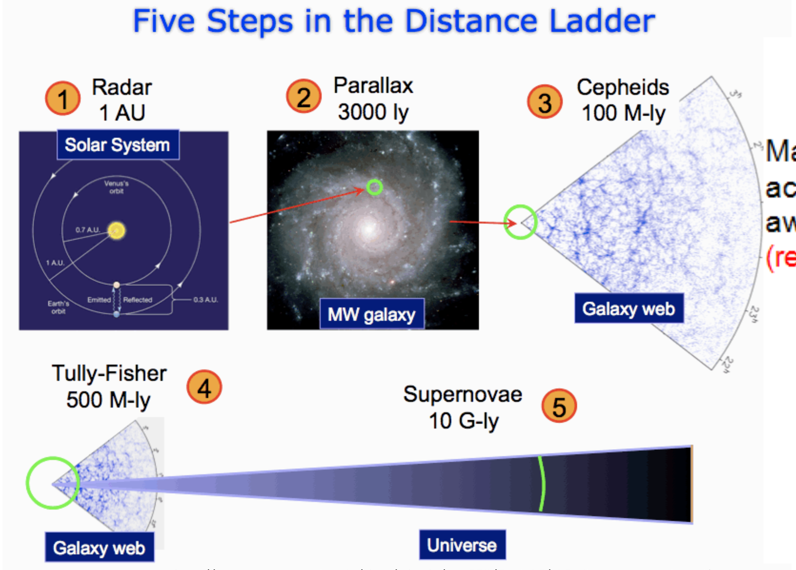
Abstract

Mega-maser disks currently provide the most accurate and direct method for calculating distances to galaxies and weighing super massive black holes (SMBHs). Moreover, direct radio mapping of water mega-maser disks provide probably the most direct view of the accretion process onto SMBHs. It is of great importance to deeply understand how the maser-emission and the masing conditions relate to nebular activity in galaxy centers, which can be characterized by optical spectroscopy. For the first time, a large enough sample of galaxies surveyed for mega-maser emission is available and allows for statistically significant comparisons of properties of galaxies with maser detections and non-detections. We present here the results of the first comprehensive multi-parameter analysis of photometric and spectroscopic measurements of galaxies with and without maser emission. We found that the maser activity is related to a narrow range in a suite of physical characteristics that pertain to both accretion strength and efficiency as well as nuclear star formation. We interpret these results in the frame of current models of galactic evolution processes in which the mega-maser disk detection can be related to a certain brief phase in the active galactic nucleus lifetime. This analysis is particularly important in light of future maser surveys as we are able to provide new sophisticated yet feasible criteria for targeting these systems with a projected two-fold increase in the detection rate.

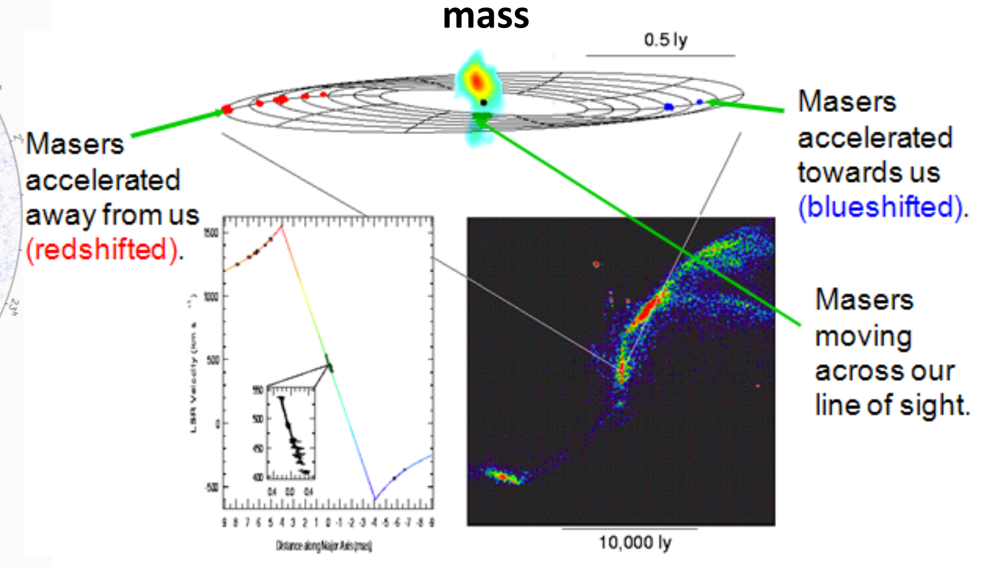
Mega-Masers: The Holy Grail of Astronomy

The ONLY direct distance measurements



http://www.astro.virginia.edu/class/whittle/astr553/Topic16/t16_distance_overview.gif

The MOST accurate measurement of black hole mass



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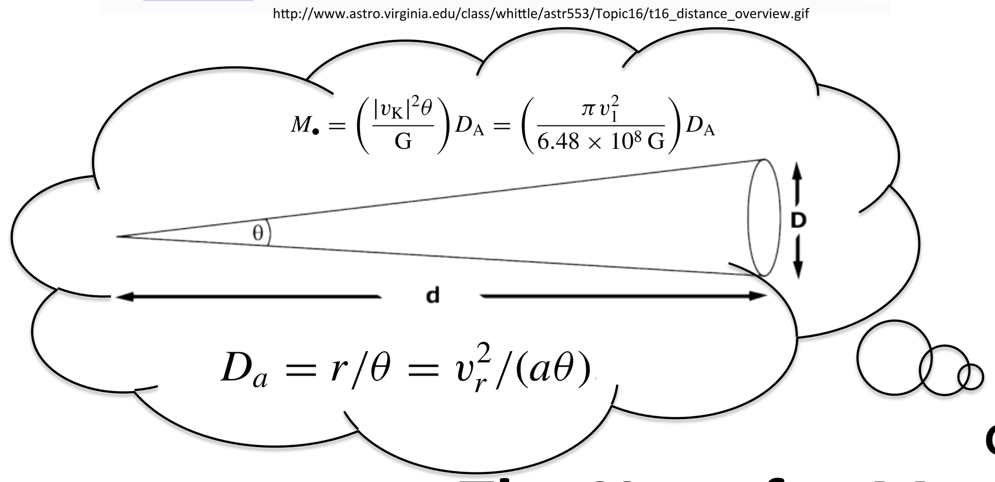
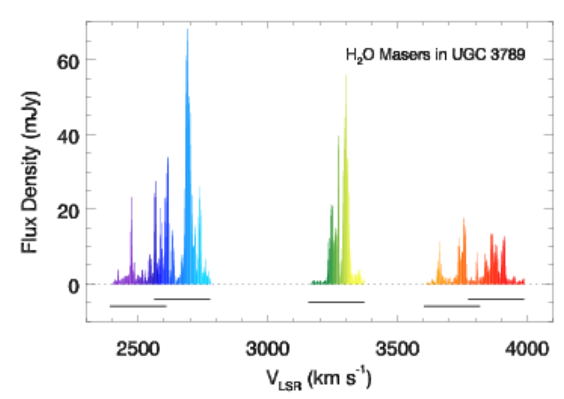
The Very Long Baseline Interferometry discovery of a Keplerian disk surrounding the SMBH in NGC-4258 (e.g., Braatz et al. 2010, Miyoshi et al. 1995).

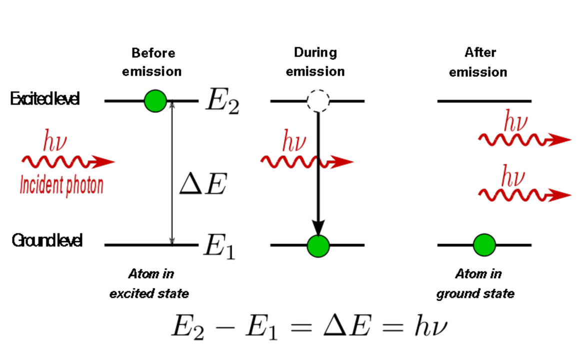


Simple Geometry



https://safe.nrao.edu/wiki/pub/Main/MegamaserCosmologyProject/MCPlogo_short.jpg

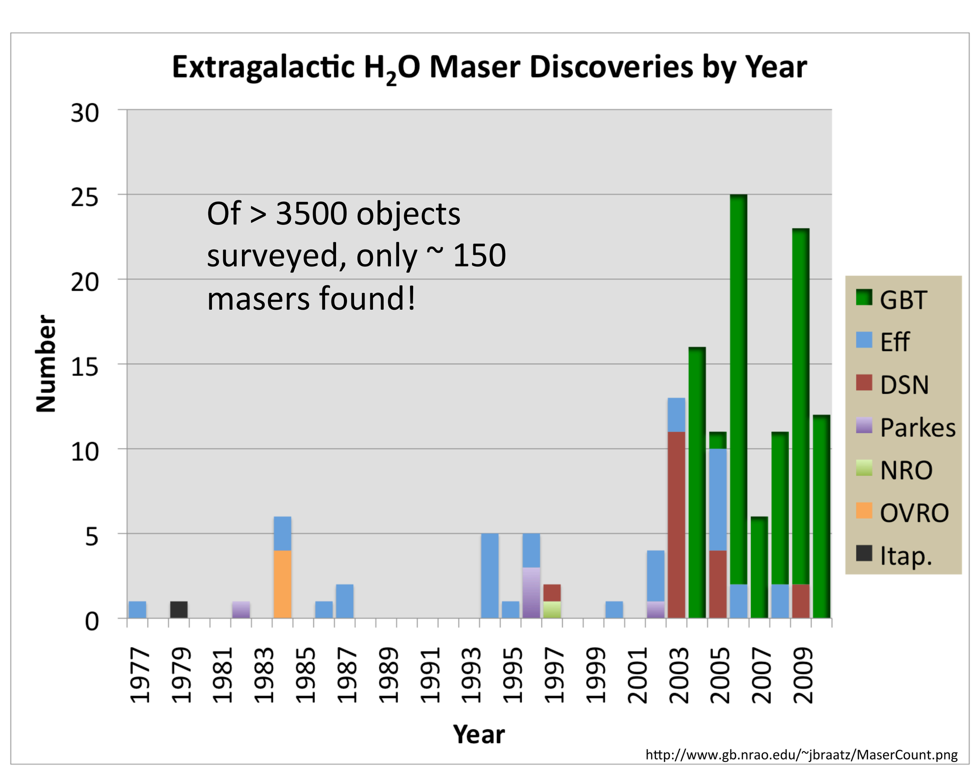
The Hunt for Masers



http://upload.wikimedia.org/wikipedia/commons/0/09/Stimulated_Emission.svg

MASER stands for Microwave Amplification by Stimulated Emission of Radiation. Think of a maser as an amplifier: it is analogous to an electric guitar amplifier except for microwave light waves instead of sound waves (Left). To find masers we "listen," not with our ears, but a radio telescope scanning at a frequency of 22 GHz (Right). The graph below shows maser detections per year.

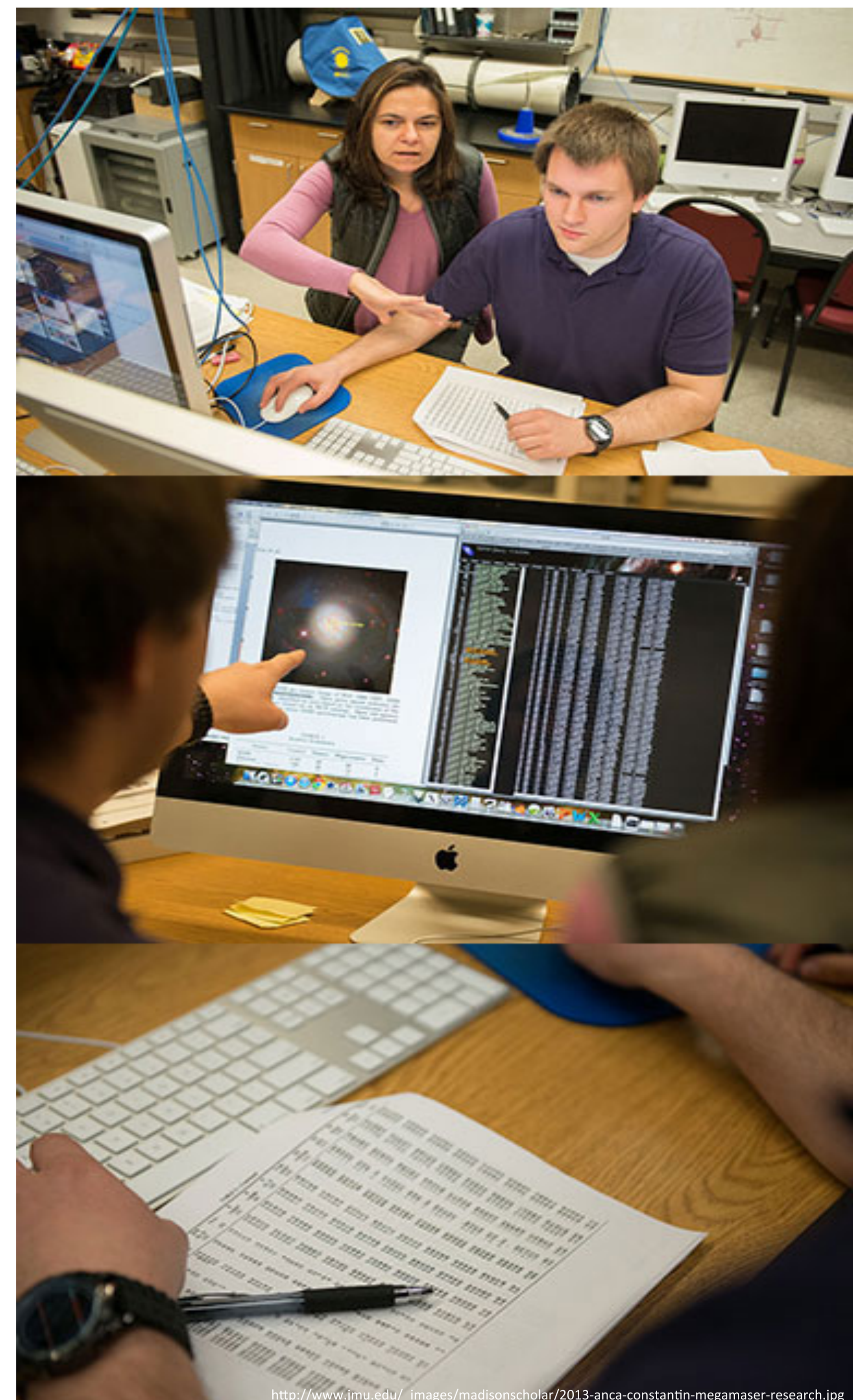
http://wcnews.ucsd.edu/graphics/images/2008/10-08GreenBankTelescopeBIG.jpg



http://www.gb.nrao.edu/~jbraatz/MaserCount.png

Motivation for Study

Mega-maser disks are sparse. The detection rate of maser emission in galactic nuclei is only ~4%. Out of ~3500 galaxies surveyed only ~150 galaxies were found to host maser emission (Reid et al. 2009). Only 20% of these appear to be mega-masers ($L_{H2O} > 10\ L_{sun}$) and occur in a disk like configuration. In an attempt to increase the efficiency in maser detection in future surveys, we characterize and compare the nuclear and host optical properties of galaxies with and without detected maser emission.



http://www.nrao.edu/...images/madisonscholar/2013-anca-constantin-megamaser-research.jpg

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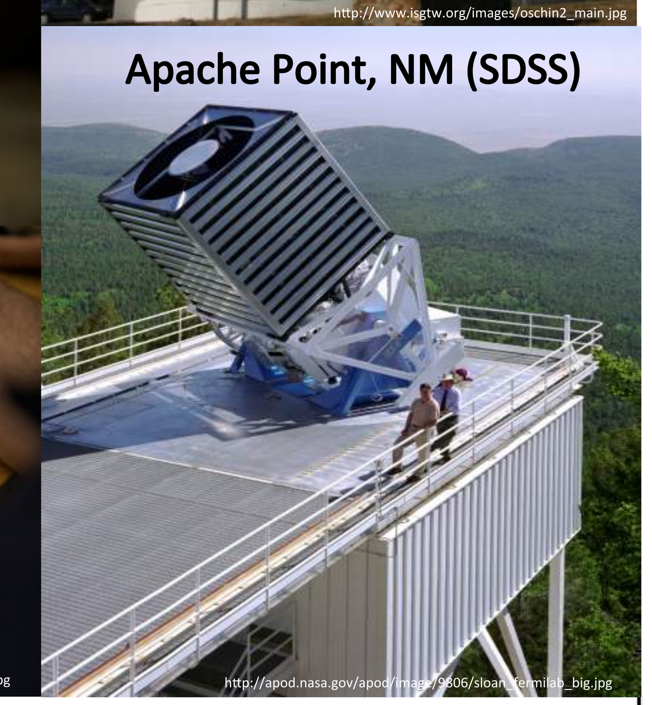


Optical Spectroscopic Data

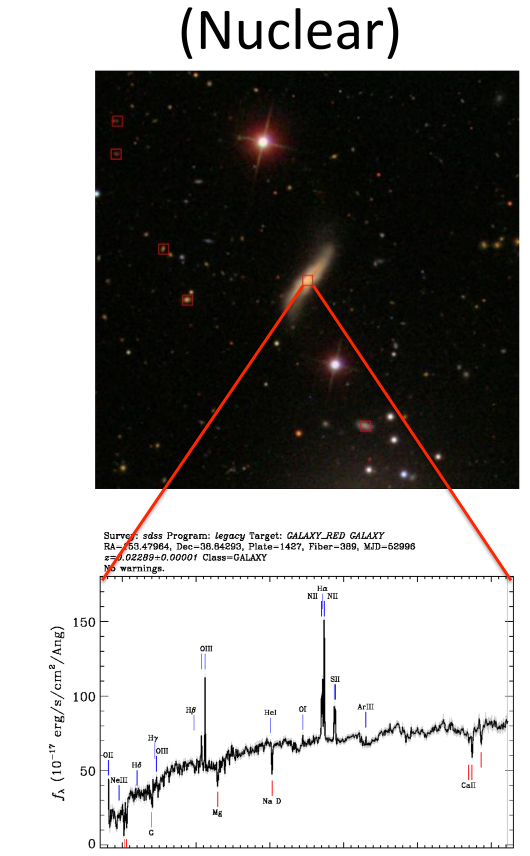
Source	Control	Masers	Mega-masers	Disks
SDSS	1181	46	34	9
Palomar	183	25	11	4
Palomar & SDSS[a]	25	7	2	1
Other	0	7	5	1
Total	1339	71	48	13

[a] Galaxies with both Palomar and SDSS spectra; in these cases, we adopt the Palomar spectra and measurements.

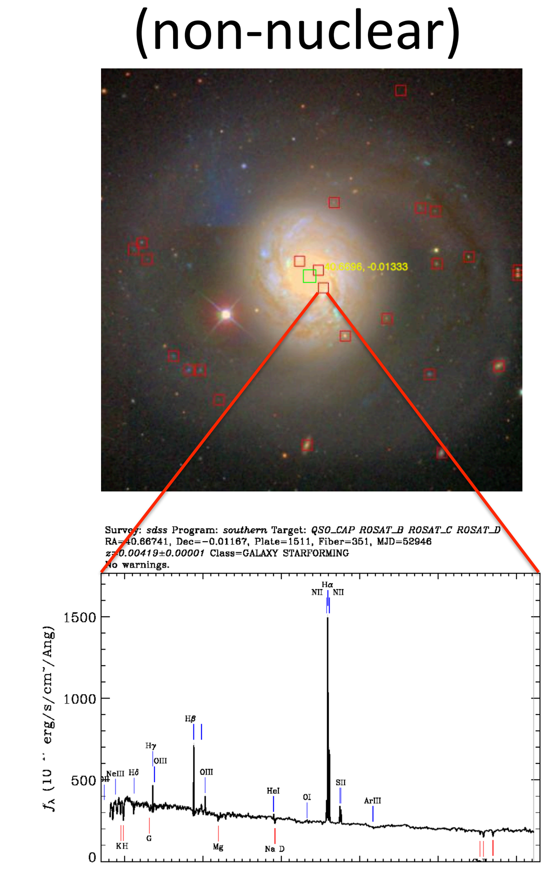
The results of cross matching the MCP maser and non-maser samples with large optical spectroscopic surveys (Palomar; Ho, Fillippenko & Sargent 1997, and SDSS DR7; Brinchmann et al. 2004) are listed in the table above. We performed visual inspection of every match in order to assure that all matches were indeed nuclear. We present below examples of good and bad matches.

$$(\Delta\theta)^2 = (\Delta\alpha \cos\delta)^2 + (\Delta\delta)^2$$

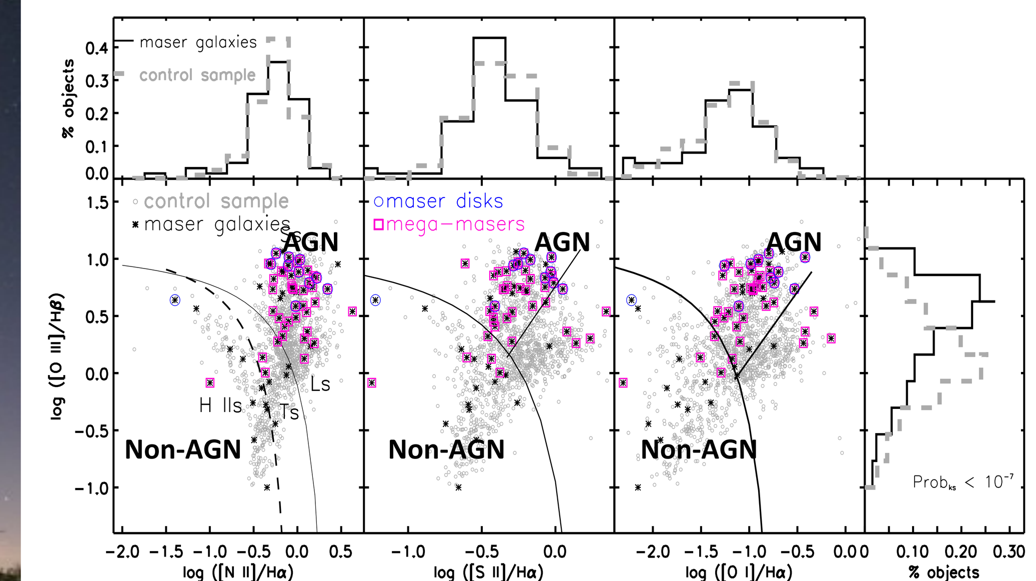
Good Match (Nuclear)



Bad Match (non-nuclear)



Data Analysis



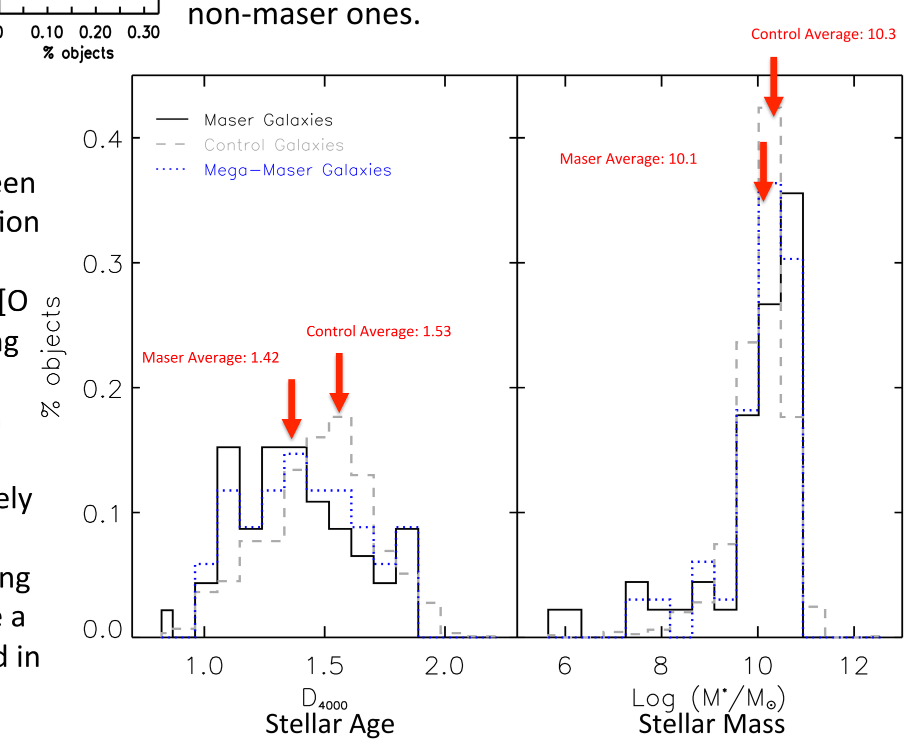
Line Diagnostic Diagram (Above)

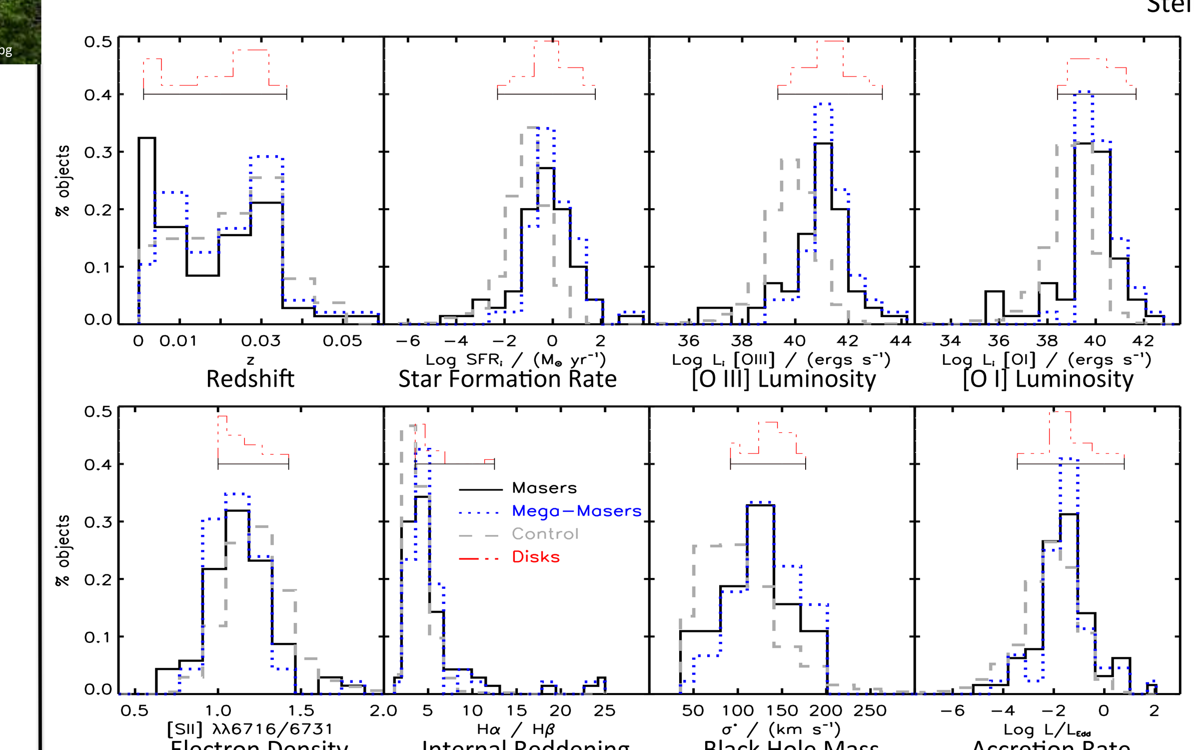
Line diagnostic diagrams are useful for distinguishing between star formation and SMBH accretion as the dominant ionization mechanisms in galactic nuclei. Star forming galaxies (H II's), where ionization is produced by hot young stars, have low [O III], [N II], [S II] and [O I] emission while Seyfert's show strong emissions in the same. There are also objects which show a mix of these two ionization types. Separation lines between types are semi-empirical fits from Kewley et al. (2006).

Our comparison reveals that maser emission is not exclusively associated with Seyfert type activity as previously believed. The maser detection rate is clearly non-zero for non-accreting sources. It is also apparent that maser galaxies tend to have a higher [O III]/Hβ flux ratios, a property that can be exploited in future survey target selection.

Comparison of Stellar Properties (Below)

Comparison of distributions of stellar age and stellar mass (measured via two parameters as described by Kauffmann et al. 2003) for maser galaxies, non-maser galaxies (control), and the mega-maser subset. This comparison uses only the SDSS spectroscopy (46 maser galaxies & ~1200 non-masers). While there is no apparent difference in the host stellar masses there seems to be a significant difference in age, in the sense that maser galaxies are younger than the non-maser ones.





Comparison of Nuclear Emission Properties (Left)

For masers, the subsets of mega-masers and ones showing disk like configuration, as well as for the non-maser (control) galaxies, we compare redshift, nuclear star formation rate (via Hα luminosity), [O I] and [O III] line luminosities (measures of ionization), electron density (via [SII] ratio), internal dust reddening (Balmer Decrement), black hole mass (via stellar velocity dispersion, σ*), and accretion rate (via the Eddington rate L/L_{edd}). We find that mega-maser galaxies and particularly those with disks exhibit a narrow "goldilocks" range of values in all of these parameters.

K-S Statistics for Maser/Non-maser Parameter Comparisons

Variable	Masers/Control	Maser/Megamasers	Control/Megamasers
z	0.72	0.91	0.91
Log(SFR)	0.0018	0.85	$< 1 \times 10^{-4}$
Log L[OIII]	$< 1 \times 10^{-4}$	1.00	$< 1 \times 10^{-4}$
Log L[OI]	0.00065	0.98	$< 1 \times 10^{-4}$
S[II] Ratio	0.091	0.91	0.00030
Hα/Hβ	0.52	0.43	$< 1 \times 10^{-4}$
σ^*	0.0026	0.73	$< 1 \times 10^{-4}$
L/L_{edd}	0.10	0.90	$< 1 \times 10^{-4}$

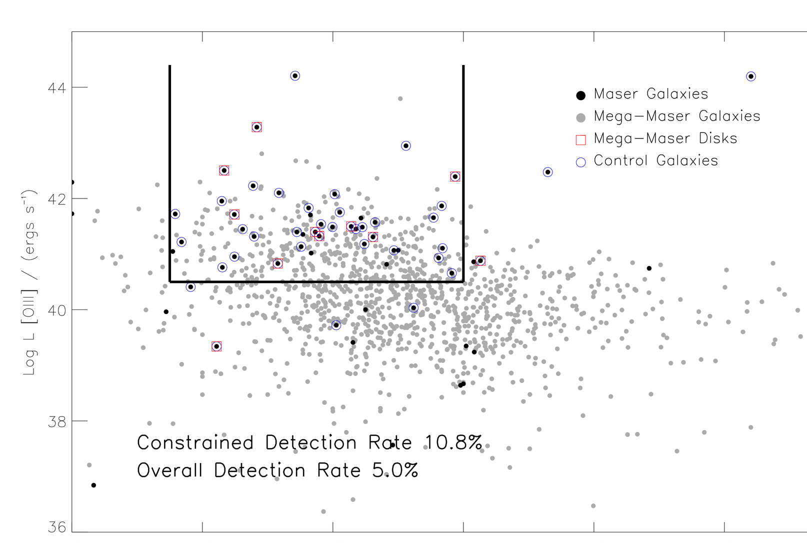
Kolmogorov-Smirnov Statistics (Left)

The K-S statistic is a method of quantifying the similarity of two distributions. If two distributions have a low K-S probability, it is less likely that they were drawn from the same parent distribution. K-S probabilities are consistently low for the control/mega-maser comparison, showing that they do not share the same parent population.

Constraining The Detection Rate (Right)

Here is an example of how a two parameter constraint can increase the mega-maser detection rate by at least a factor of two. If the survey for maser emission is conducted only for galaxies with a [S II] ratio between 1.0 and 1.4 as well as an [O III] luminosity greater than 10^{40} ergs/s (as shown in the distribution above), the detection rate jumps from 5% to 11%.

We are working on a Principle Component Analysis to determine the optimal range of nuclear and host properties for which the detection rate is maximized.



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