Testing Star Formation as a Predictor of Maser Hosting

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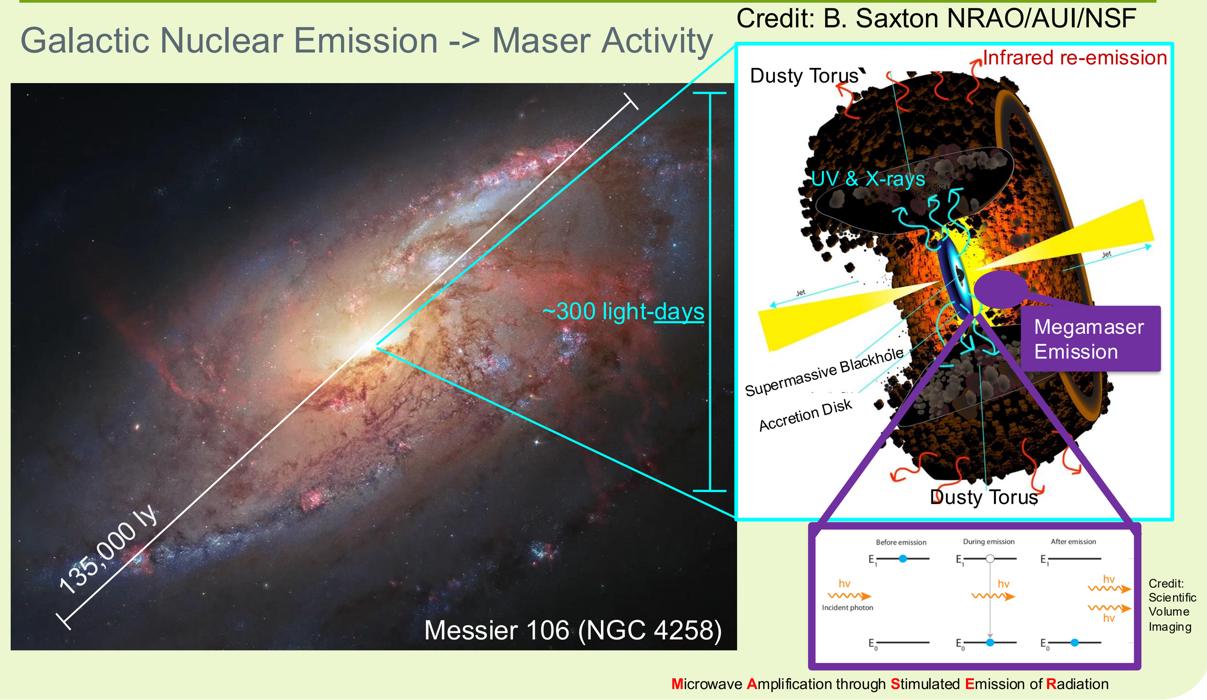
Anatomy of an Active Galactic Nucleus

Galactic Nuclear Emission -> Maser Activity

Credit: B. Saxton NRAO/AUI/NSF

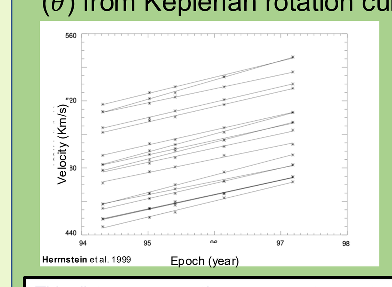


Microwave Amplification through Stimulated Emission of Radiation

Why do Megamaser Disks Matter?

- **Distance without the need of distance ladders**

  -Get velocity (v) and angular radius (θ) from Keplerian rotation curve



$$\frac{dv}{dt} = a_c$$

$$r = \frac{v^2}{a_c}$$

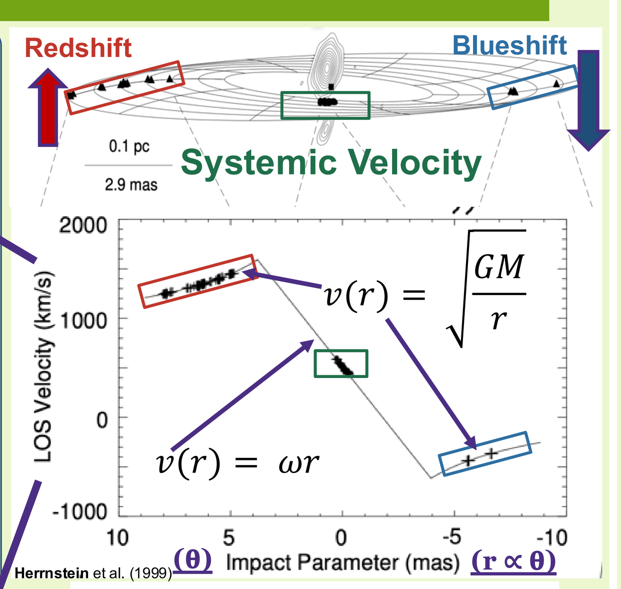
This distance calculation allows us to constrain the value of the Hubble constant (H_0), a value that represents the rate at which space-time expands. Constraining it will help us understand the space-time fabric of the universe.

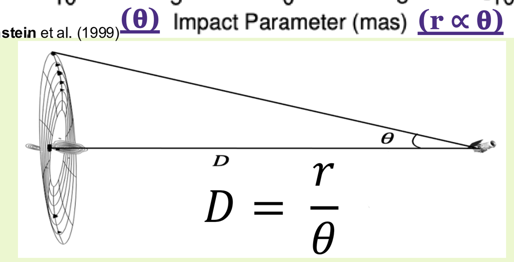
- **Calculating the mass of SMBH's**

  -Solve for BH mass using rotational velocity

$$v(r) = \sqrt{\frac{GM}{r}}$$

$$M = \frac{rv^2}{G}$$





Problem:

Maser emission is extremely rare, only occurring in 3-5% of galaxies, and only a small fraction of those objects are megamaser disks. There is insufficient information and/or investigation into how the megamaser emission associates with the central galactic dominant emission and its physical characteristics.

Solution:

We need to better understand how megamaser emission is produced and in which kinds of host galaxies. Here, we explore how star formation, stellar mass, and dust attenuation compare in galaxies with and without maser emission.

Data: Galaxy Samples & Features

(Megamaser Cosmology Project) The GALEX-SDSS-WISE Legacy Catalog

Crossmatch

MCP Survey → GSWLC

Braatz, J.A. et al. (2004) Salim et al. 2016

Object Count	MCP	GSWLC	SFR (UV)	SFR (Mid-IR)	Attenuation
Non-Masers	4766	2046	1844	1369	1844
All Masers	180	40	38	30	38
Megamasers	131	32	24	18	30
Disk-Masers	34	6	6	5	6

- *SFR* = Star Formation Rate, measures the mass of gas and dust converted into stars per year. ($M_\odot$/yr)
- M_* = Stellar mass, measures how many masses of our sun are contained in a galaxy.
- $A_{V,B,UV}$ = Dust attenuation in Visible (550 nm), Blue, (470 nm), UV (300 nm), measures the dimming of an object by brightness magnitude.

All masers include every detected water maser; megamasers are the subset with extremely high luminosity (>10 $L_\odot$, associated with AGN); disk-masers are the even rarer subset of megamasers, where maser spots trace a rotating disk around the black hole (Lo 2005).

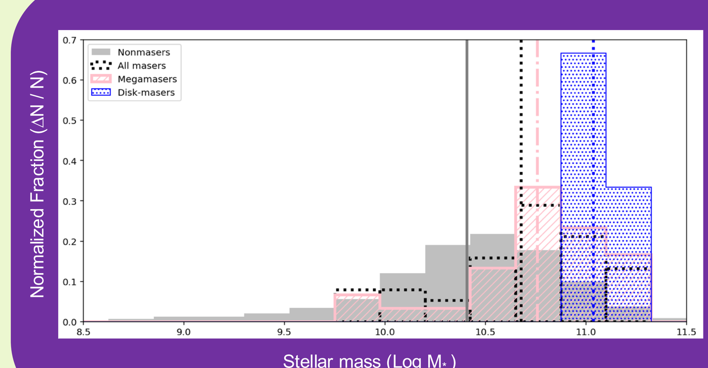
Abstract

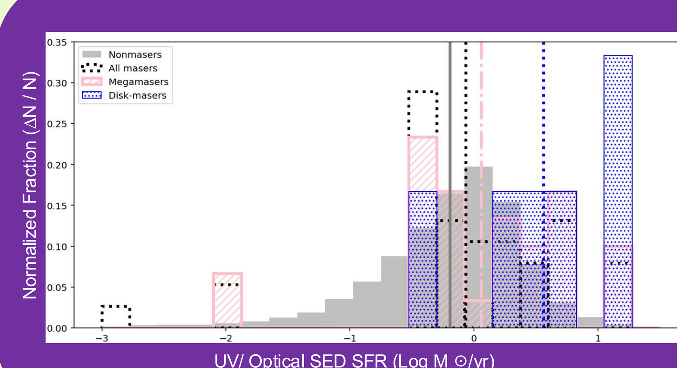
While megamaser disks are among the most valuable tools for accurate determinations for cosmic distances and masses of supermassive black holes in galaxy centers, they are exceptionally rare. In order to find more of these systems, we need to better understand their origin. Megamaser emission is basically a laser in microwave (22GHz) that is detected in centers of galaxies that is millions of times more intense than that associated with stellar emission processes. Previous studies have shown that the physical conditions required for megamasing—dense, radiatively pumped molecular gas shielded from disruptive radiation—are closely associated with cosmic dust, which both enables this shielding and reprocesses radiation from young stars and active nuclei. We investigate here how dust attenuation and star formation rates are measured and differ across the electromagnetic spectrum between galaxies that host maser emission and those that do not. We find tentative evidence for the fact that megamaser galaxies have a more dominant emission coming from accretion of matter onto the central supermassive black hole which, surprisingly, appears weaker in the masers with a disk-like morphology. We explore physical reasons for this finding and implications for building future efficient surveys for the coveted disk maser detection.

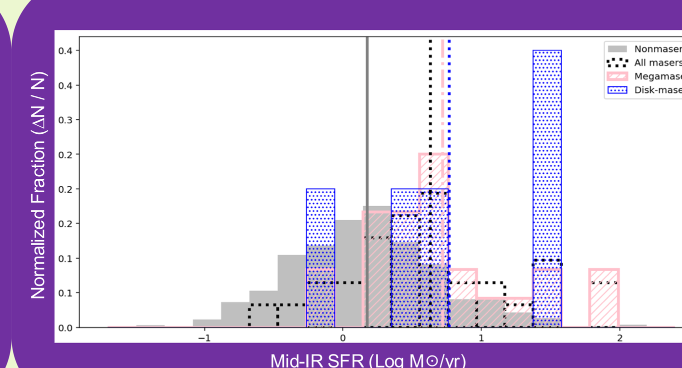
Our Study: A Comparative Analysis of Optical And UV Galactic Features

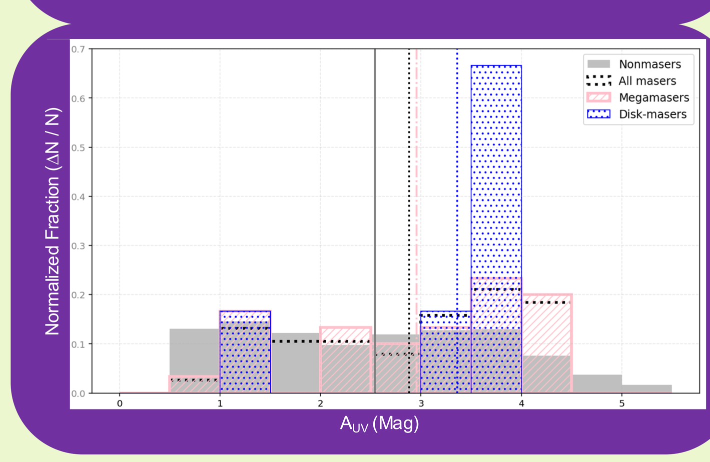
- Disk masers show the highest stellar mass, and the highest attenuation in all bands.
- SFR measured in IR is higher for all types of masers, however, not statistically significant.
- UV derived SFR's are lower than SFR's in IR for all types of masers, and the difference is more pronounced for the disk masers.

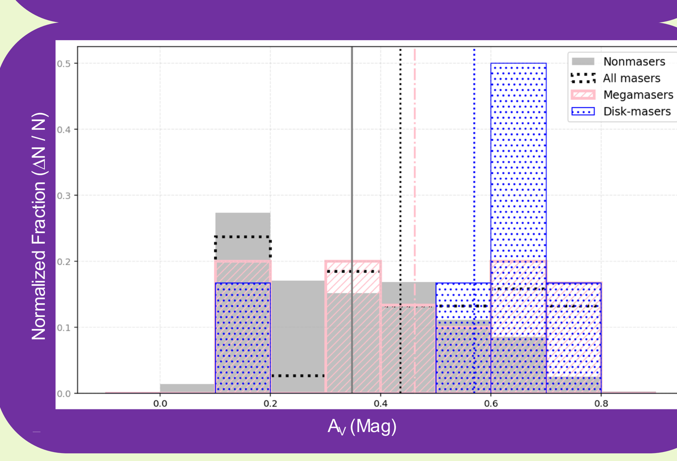
Avg Val (Stan. Dev.)	M^*	SFR UV	SFR IR	A_{UV}	A_B	A_V
Non-Masers	10.4 ± 0.5	-0.2 ± 0.6	0.2 ± 0.5	2.5 ± 1.2	0.5 ± 0.3	0.3 ± 0.2
All Masers	10.7 ± 0.4	0.0 ± 0.7	0.7 ± 0.6	3.0 ± 1.1	0.7 ± 0.3	0.5 ± 0.2
Megamasers	10.8 ± 0.4	0.1 ± 0.7	0.7 ± 0.5	3.0 ± 1.1	0.7 ± 0.3	0.5 ± 0.2
Disk-Masers	11 ± 0.1	0.6 ± 0.5	0.8 ± 0.6	3.3 ± 0.9	0.8 ± 0.3	0.6 ± 0.2

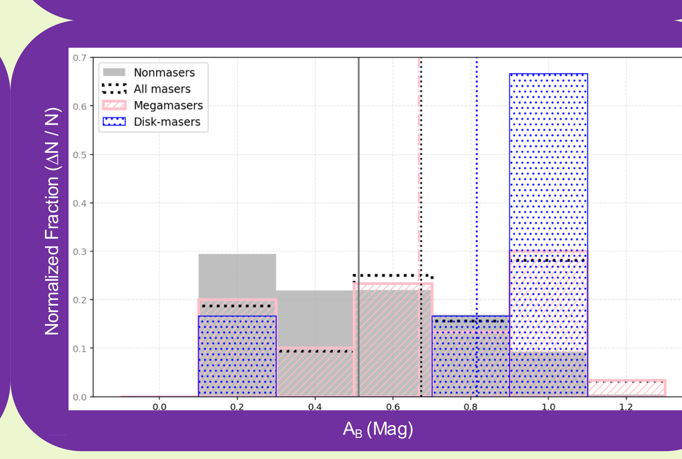






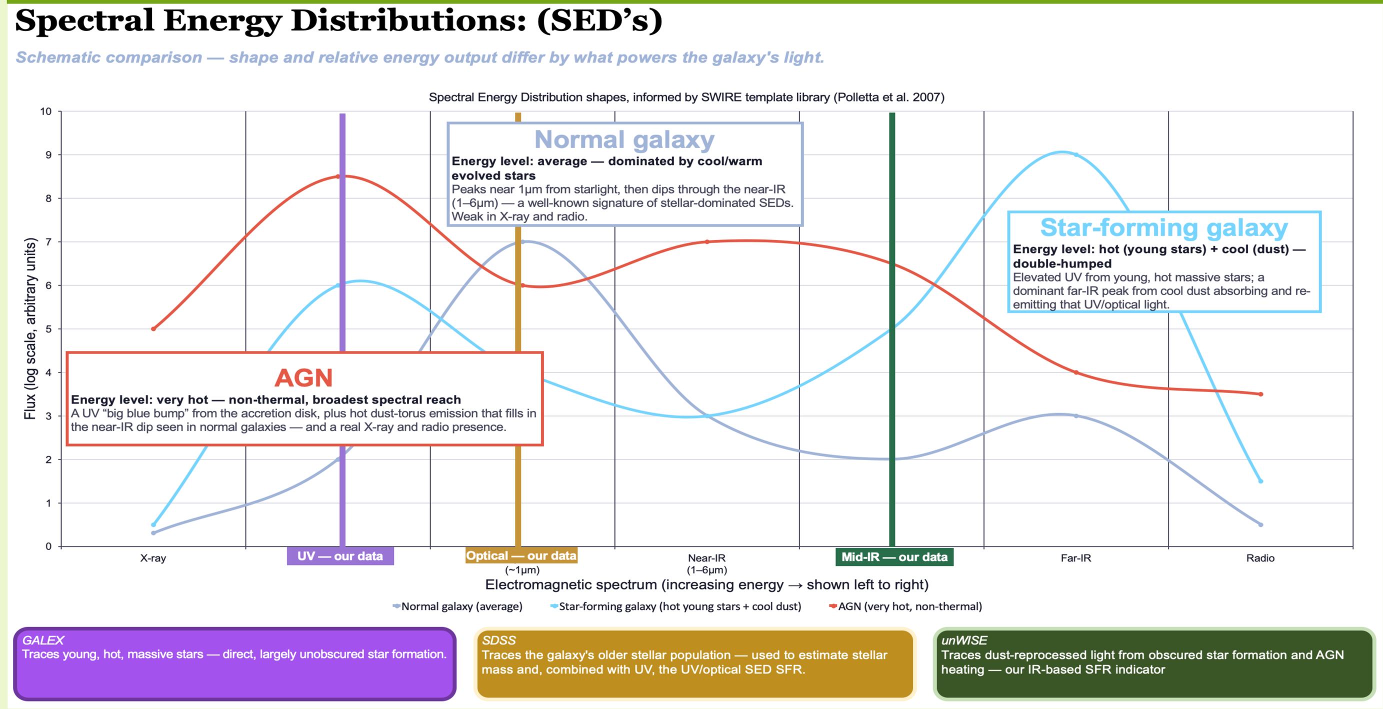






Disk Masers → Star formation or AGN?

Spectral Energy Distributions: (SED's)



Normal galaxies: UV and IR SFR should agree, close to 1:1 — minimal star formation and dust mean little UV gets absorbed and re-emitted, so both indicators track the same small signal.

Star-forming galaxies: UV and IR SFR should agree — dust doesn't erase the UV signal, it redistributes it into the far-IR, so a combined UV+IR estimate reconstructs the true SFR even in dusty starbursts.

AGN: UV and IR SFR should disagree — UV/optical SFR is inflated because the accretion disk's non-thermal "big blue bump" gets miscounted as star formation, while IR SFR is comparatively less affected. This mismatch is a contamination signature, not real star formation.

References

Braatz, J.A. et al. (2004), *Astrophys. J. Lett.*, 617, L29; **Greenhill**, L.J. et al. (1995), *Astron. Astrophys.*, 304, 21; **Herrnstein**, J.R. et al. (1999), *Nature*, 400, 539; **Lo**, K.Y. (2005), *Annu. Rev. Astron. Astrophys.*, 43, 625; **Miyoshi**, M. et al. (1995), *Nature*, 373, 127; **Moran**, J.M. et al. (1995), *Proc. Natl. Acad. Sci. USA*, 92, 11427; **Polletta**, M. et al. (2007), *Astrophys. J.*, 663, 81; **Salim** et al. (2016), *ApJS*, 227, 2; B. **Saxton** NRAO/AUI/NSF. AI tools (Claude) have been used for literature review, summarizing, coding, designing, and analyzing. All these contributions have been verified and incorporated into the analysis and presentation.

Masing Conditions / AGN, Star formation & dust

1. **A pump source**

   Accretion Disk — X-ray / UV — Pump Source — Dense gas cloud — Microwave (22 GHz) — Maser Emission

2. **Density below the critical density**

   Too dense: *Frequent collisions de-excite atoms before they can emit — the inversion is destroyed.*

   Proper density: *Atoms stay excited and spaced apart — ready to be stimulated by a passing photon.*

3. **A long, dense gain path**

   Short path → low luminosity: *few excited atoms*

   Long path (edge) → high luminosity: *many excited atoms along a longer gain path*

4. **Velocity coherence** Identical velocity vectors — every atom moves at the same speed

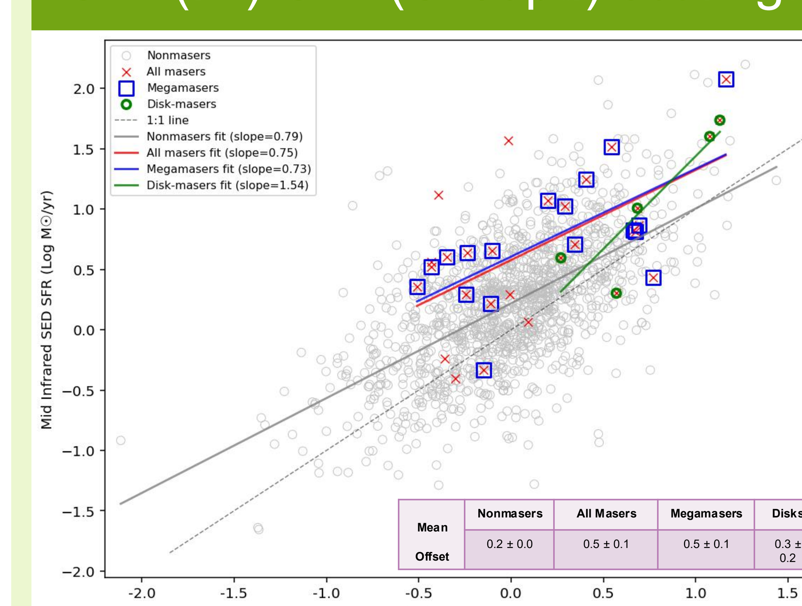
   This keeps photons resonant with each atom in turn, so the beam keeps amplifying instead of losing coherence.

Kolmogorov-Smirnov (KS) Test Statistic

KS Comparisons	Stellar Mass	SFR UV	SFR IR	AFUV	AB	AV
All Masers vs Nonmasers	0.34	0.2	0.39	0.18	0.21	0.23
Nonmasers vs Megamasers	0.43	0.28	0.5	0.24	0.27	0.27
Nonmasers vs Disk-masers	0.87	0.64	0.5	0.57	0.69	0.68
All Masers vs Megamasers	0.12	0.11	0.11	0.06	0.08	0.08
All Masers vs Disk-masers	0.68	0.46	0.24	0.41	0.52	0.49
Megamasers vs Disk-masers	0.63	0.37	0.23	0.37	0.43	0.43

- Each value is the KS statistic (D), the maximum distance between two cumulative distributions. D ranges from 0 (identical) to 1 (fully separated), so larger values mean bigger differences between distributions. The largest separations, i.e., distributions which do not share the same parent populations in all of these parameters are prevalent when non-masers are compared with disk masers.
- Disk masers also seem to show distinct distributions from those of the group of all masers and their subgroup of megamasers.

SFR(IR)-SFR(UV/opt.) scaling: Largest for Megamaser Disks



- The UV/optical-vs-Mid-IR SFR relationship is fundamentally different for disk-masers compared to nonmasers, and megamasers indicating disk-masers don't follow the same underlying SFR-SFR scaling as the rest of the sample.
- Disk-masers also show a near-zero mean UV-vs-IR SFR offset, while non-disk megamasers show a much larger negative offset — meaning their UV/optical SFR is close to their IR-based SFR, unlike other megamasers where UV/optical SFR is noticeably inflated.
- Given disk-masers' higher dust attenuation, this near-zero offset may reflect heavier obscuration of AGN-driven UV emission in these edge-on systems, suppressing the UV excess seen in non-disk megamasers.

Conclusions

We find that megamasers and disk-masers differ meaningfully in mean SFR offset, stellar mass, dust attenuation, and SFR-SFR scaling — pointing to a real, characteristic difference between the two populations that is not yet fully explained, with orientation and dust obscuration as one plausible physical driver.

Future Work

We plan to further explore the galactic physical properties distinguishing disk-masers from other megamasers — testing whether orientation and dust obscuration genuinely drive their reduced UV excess by comparing host-galaxy inclination angles, independent AGN indicators (e.g., X-ray or mid-IR diagnostics), and other structural or environmental properties between disk and non-disk megamasers. A larger disk-maser sample would also help confirm whether the observed differences in stellar mass, SFR, and SFR-SFR scaling are robust rather than driven by small-number statistics, moving from a described pattern toward an explained one. Nevertheless, the exact purpose is to find more of these megamaser disks.