Mid-Infrared Variability of Galaxies Surveyed for H_2O Megamaser Emission

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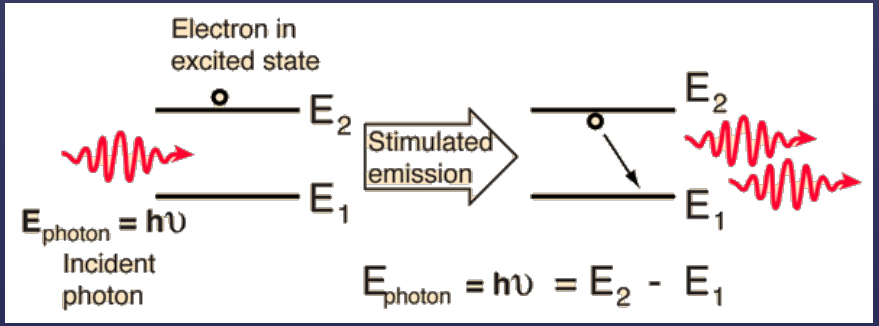
The Physics of Cosmic Masers

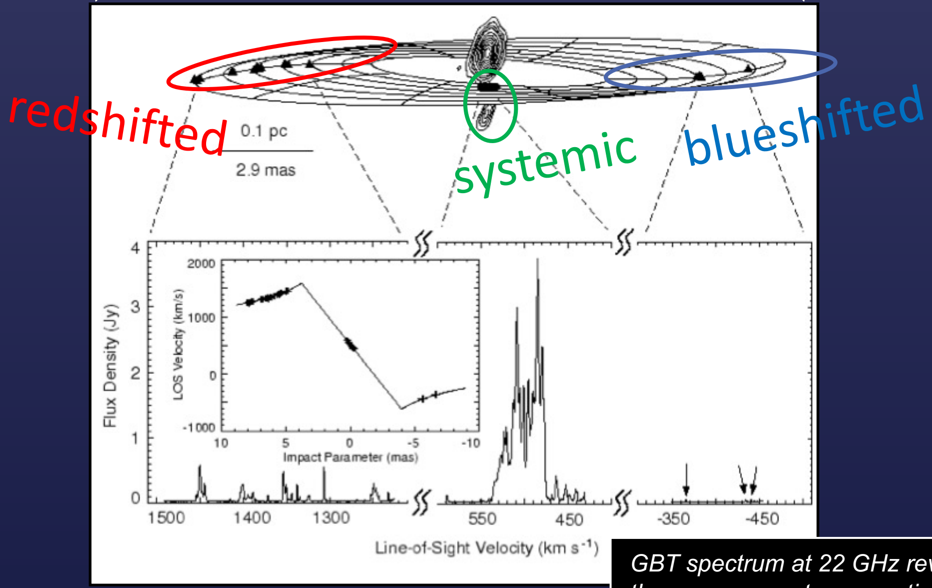
MASER: Microwave **A**mplification by **S**timulated **E**mission of **R**adiation

- Population inversion induced by energy source
  - e.g. proto-stars, shockwaves, blackholes
- Radiation amplified rather than absorbed by medium
- First found in spiral arms of our own galaxy



Water Megamaser Disks

- **Mega**maser = **10^6** > luminous than typical galactic masers
- Megamasers found in a *disk-like configuration*:
  - Measure direct geometric distances
    - Constrains H_0!!
      - Without standard candles or cosmological models
      - Better understand dark energy
  - Measure masses of SMBH

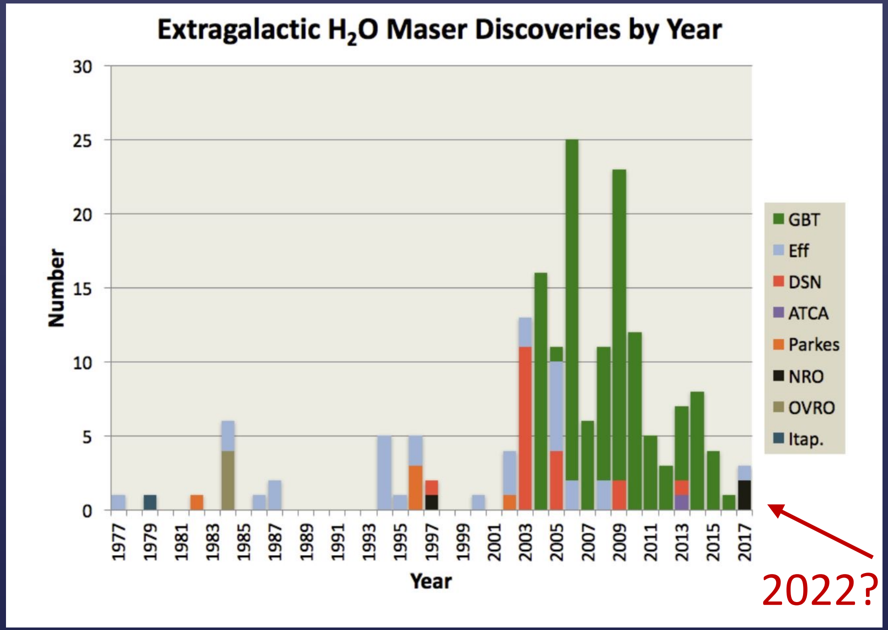


GBT spectrum at 22 GHz reveals three components suggesting disk-like configuration (Herrnstein et al. 1999)

The Need to Find More

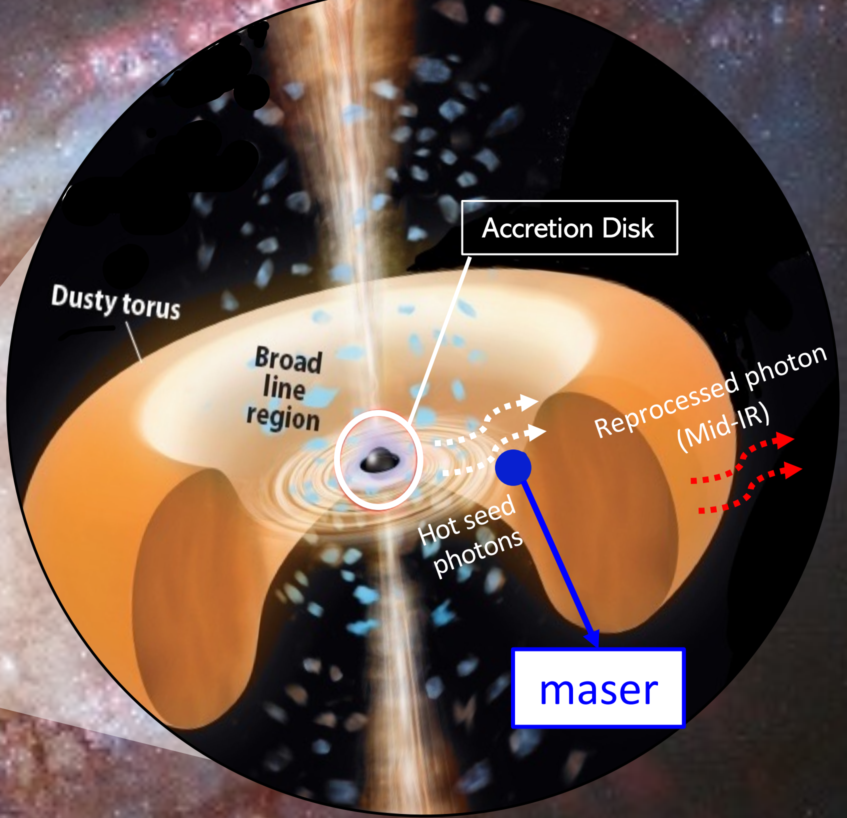
The search for H_2O maser disks:

- ~3% surveyed galaxies hold masers
    - ~60% of maser galaxies show megamaser luminosities
    - ~20% maser hosting galaxies in disk-like configuration
- Need better selection of potential maser disk candidates!!



Water Megamaser Crib

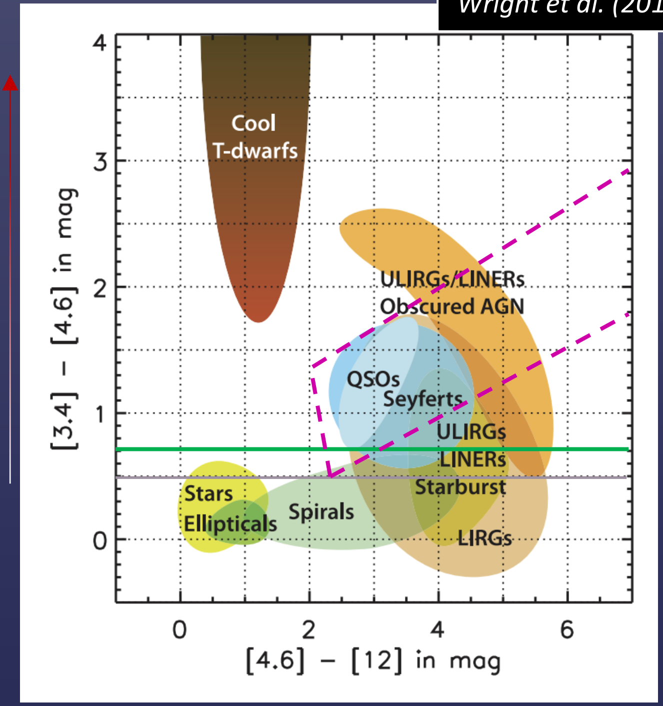
- Active Galactic Nuclei (AGN)?
- Maser activity may be associated with accretion disk emission
  - Accretion disk supplies seed photons for maser emission
  - Dust in inner edge of torus provides masing conditions (e.g. temperature, number density)



Finding AGN via Variability

- Variability = total power output of galaxy centers, varies on timescale of hours-years
  - Postmark of AGN activity
- Mid-IR variability
  - Dust reprocesses radiation into mid-IR
  - Reveals indirectly variability of putative AGN
  - Peers through cosmic obscuration
- Identifying variability could further connect maser emission and AGN activity

Wright et al. (2010)



Proposed WISE AGN selection techniques:

1. **W1-W2 > 0.8 (green) (Stern et al. (2012)**
2. W1-W2 > 0.5 (grey) – more relaxed AGN criterion (Stern et al. (2012)
3. Mateos et al. (2011) (dashed magenta) – least contamination

Data Selection

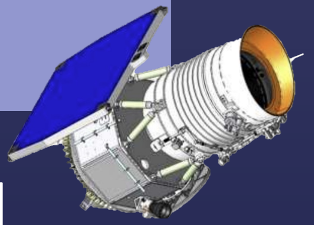
Galaxies Surveyed

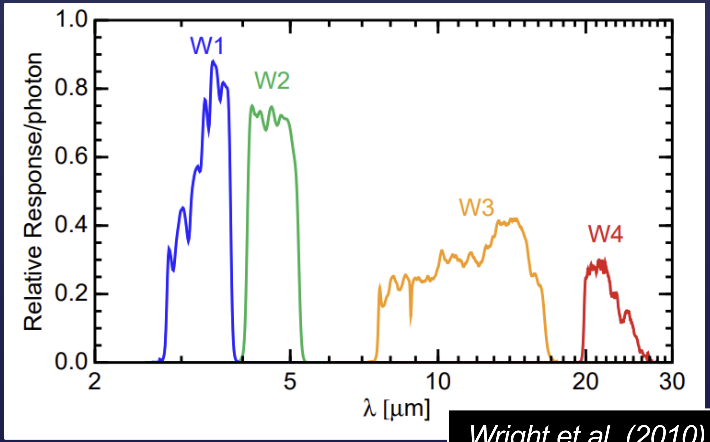
- Megamaser Cosmology Project (MCP)
  - International collaboration surveying for 22GHz emission in galaxy centers using GBT, VLA, VLBA, and Effelsberg telescopes (radio)
  - Maser & nonmaser samples

Class	MCP Count
Masers	180
Megamasers	116
Disks	34
Unique Nonmasers	4002

Mid-Infrared Counterparts

- **W**ide-field **I**nfrared **S**urvey **E**xplorer (WISE)
- Measured brightness (magnitudes W1, W2, W3, W4) of objects at 3.4 , 4.6, 12 & 22 µm
- AllWISE Multiepoch + NeoWISE archival data = 8.4 years of photometry





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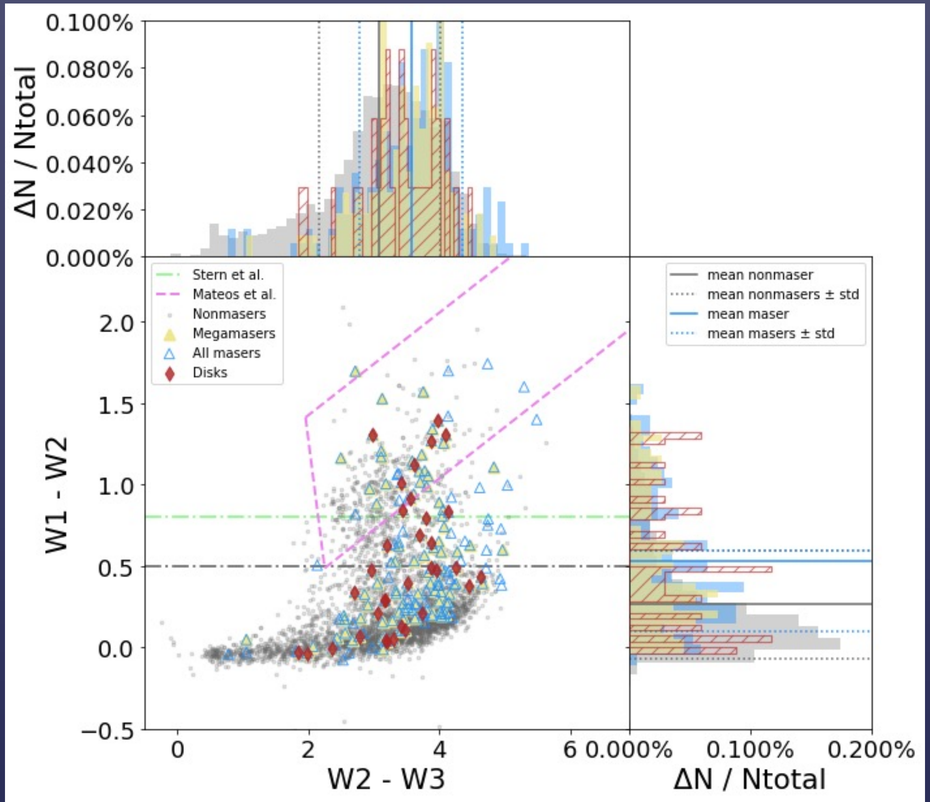
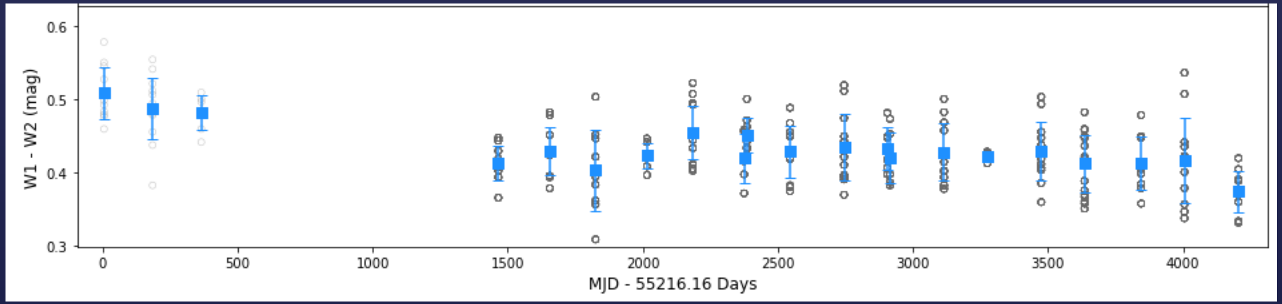
Data Properties

- WISE counterparts of all the MCP
  - 6" search radii for matches in the IPAC/IRSA Extragalactic database, and retained only WISE detections with SNR ≥ 5
- AllWISE Multi-Epoch + NeoWISE
  - 3” crossmatch NeoWISE
  - **~7-8 years of data**
- Bin observations into 10 day epochs
  - We rejected individual observations outside 3σ





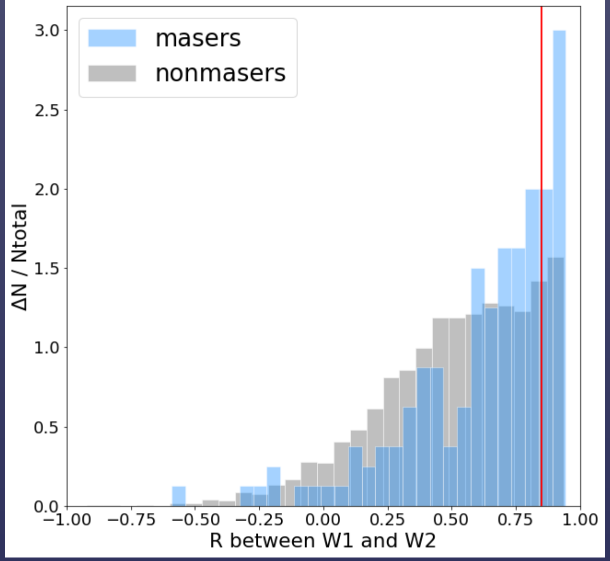
Measuring variability

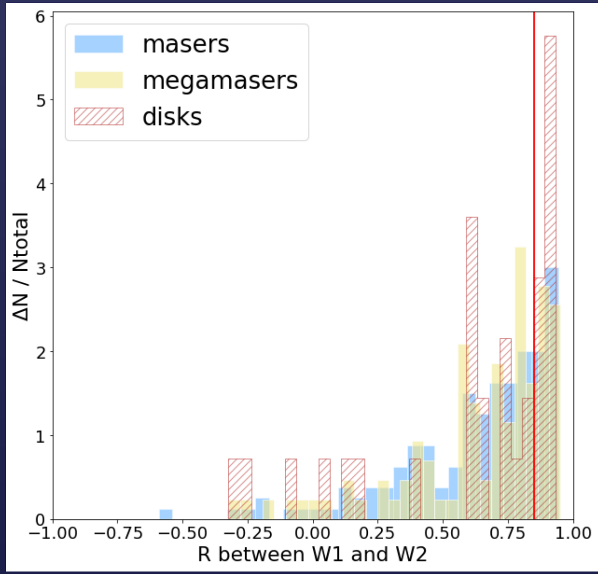
$$r = \frac{C_{m_1,m_2}}{\sigma_{m_1}\sigma_{m_2}}$$

$$C_{m1,m2} = \frac{1}{N-1}\sum_{i}^{N}(m_{1,i} - \langle m_1\rangle) \times (m_{2,i} - \langle m_2\rangle)$$

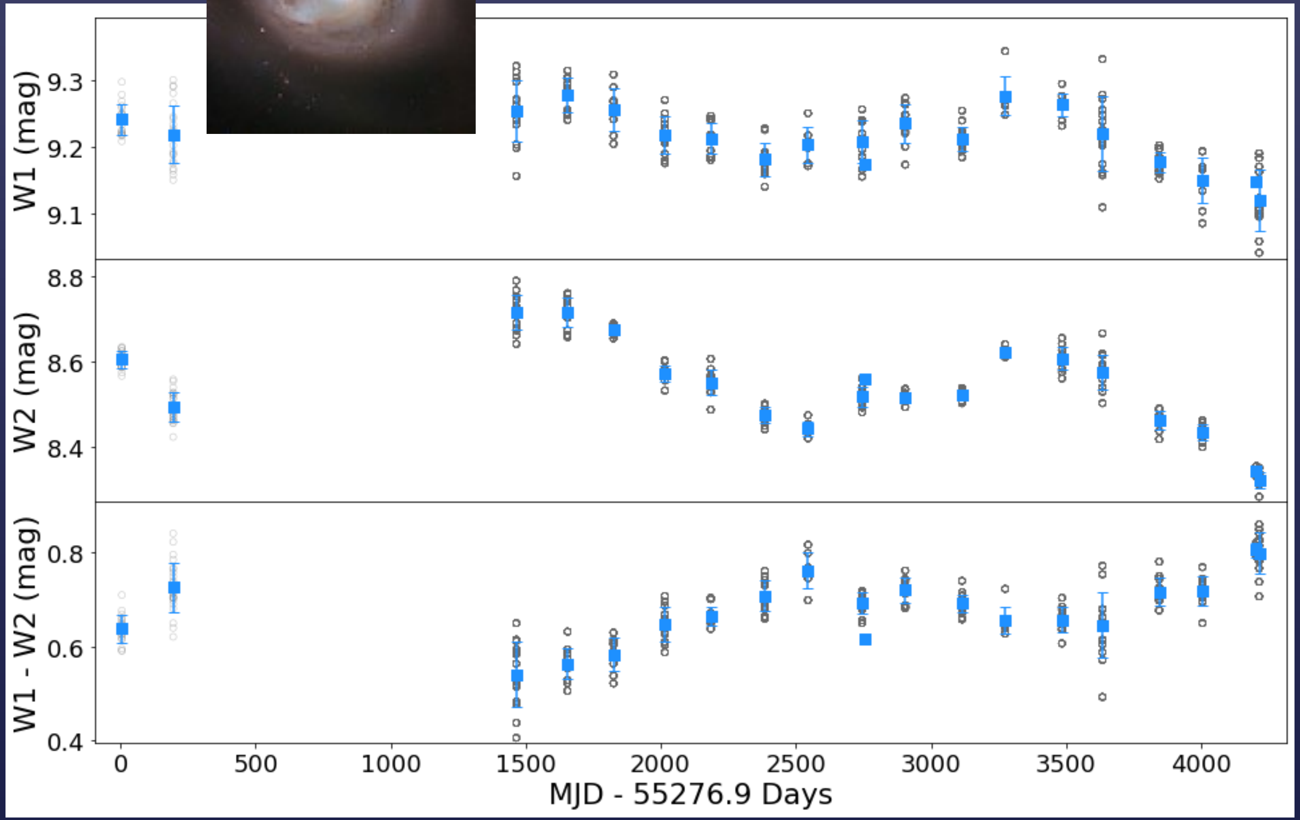
$$\sigma_m^2 = \frac{1}{N-1}\sum_{i}^{N}(m_i - \langle m\rangle)^2$$

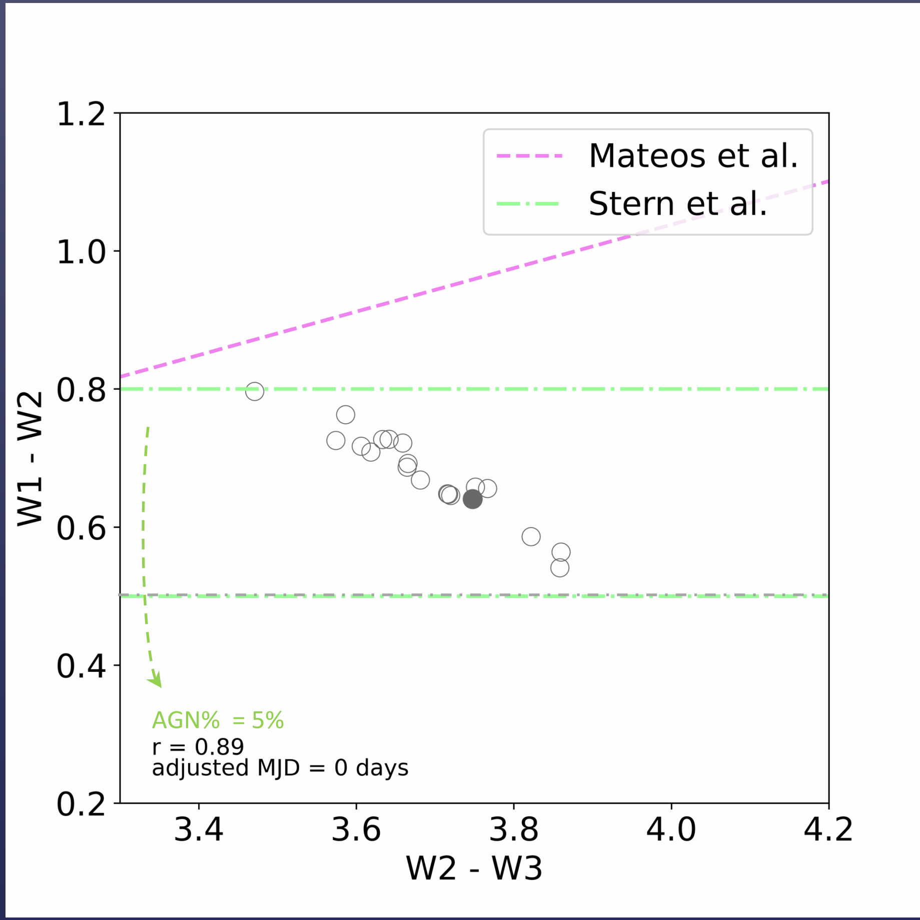
- r = Pearson's correlation coefficient
- C = measure of covariance
  - Covariance = how two variables vary together
- σ_1, σ_2 = variability amplitudes
- m_i = magnitude of the source during epoch i
- $\langle m_i \rangle$ = mean magnitude of the source in the given band.



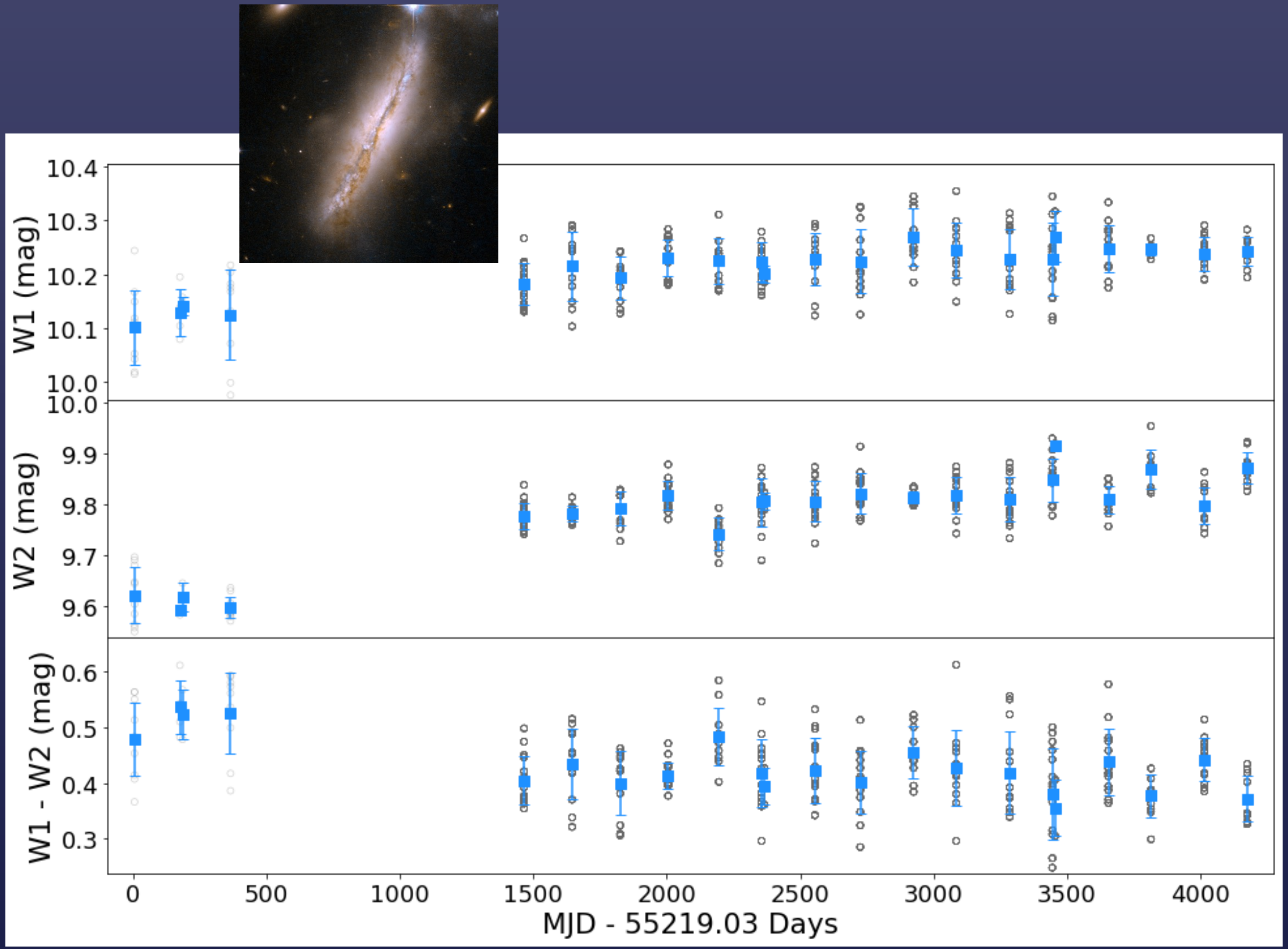


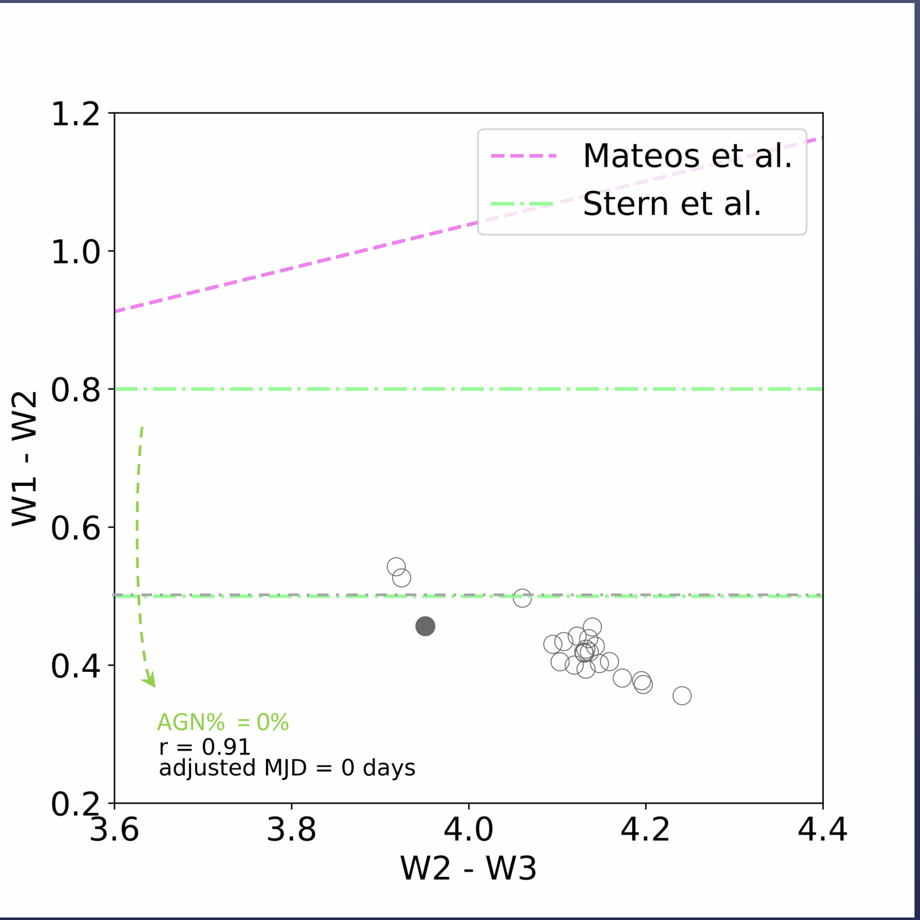
Disk Maser NGC 4388





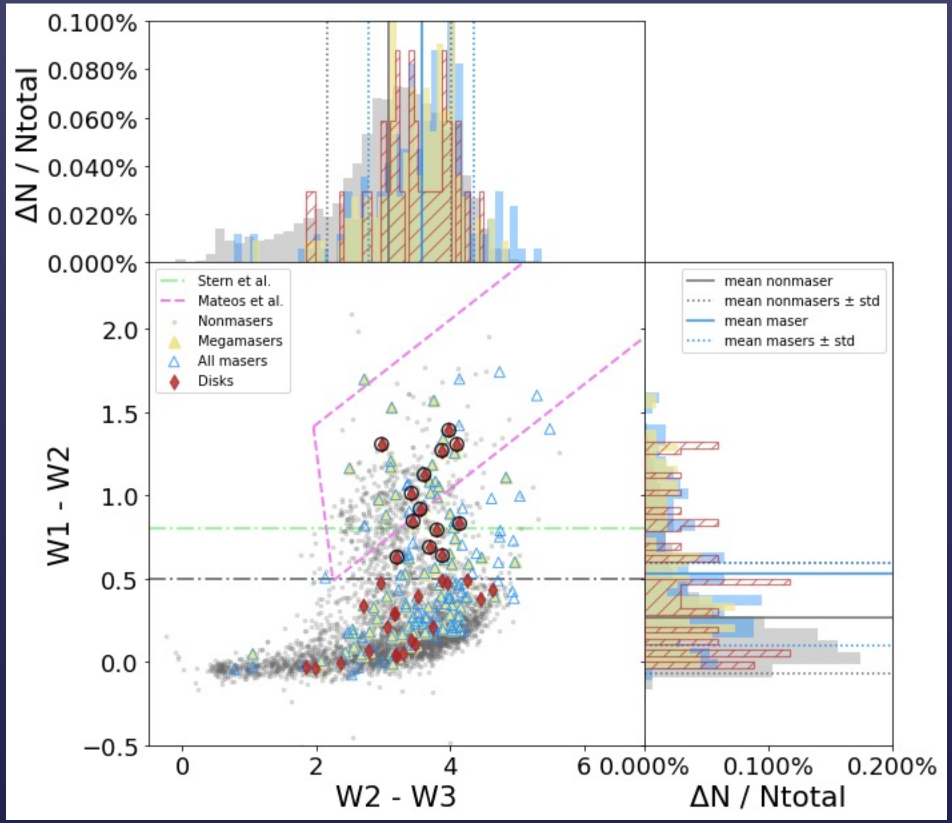
Disk Maser UGC 9618





Conclusions

- Masers more variable than nonmasers
- Masers are redder in W1 - W2 color
- Mid-IR variability reveals AGN-like behavior in masers
  - Where other methods missed them
- Single-epoch data not a good indicator of AGN status
- Multi-epoch mid-IR data paints a more accurate picture of AGN-maser disk connection
- Some disk masers are in fact AGN even when classified as star-forming by mid-IR colors alone



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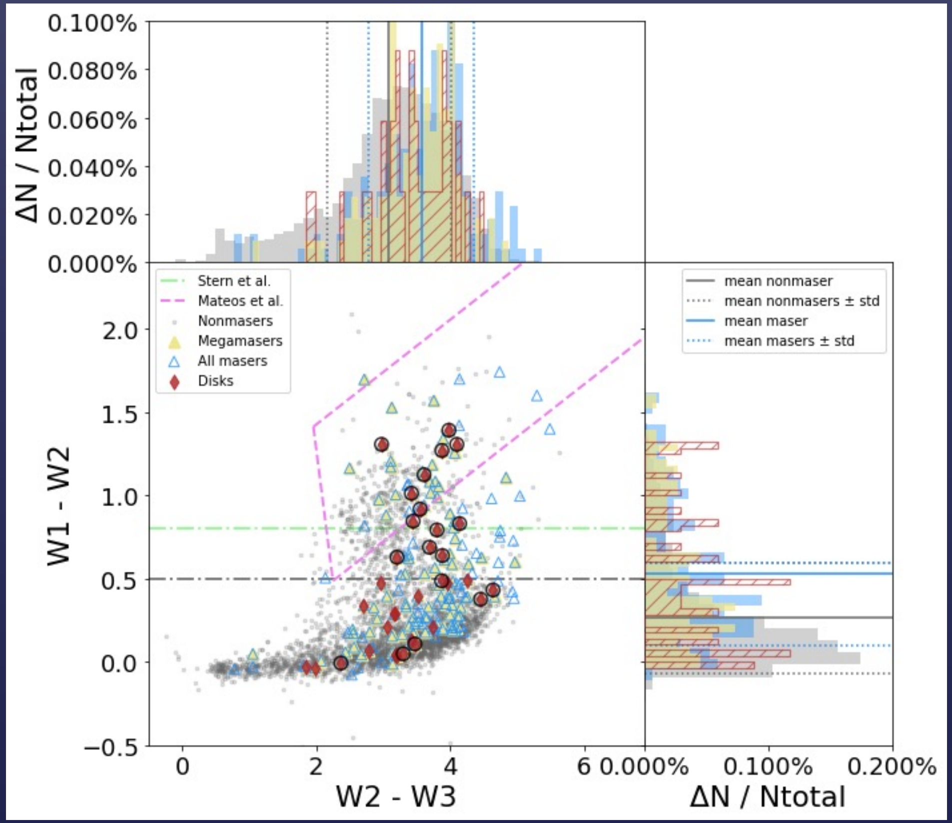

Future Directions

- Continue variability analysis
- Different areas of the electromagnetic spectrum
- Honors Thesis ☺

Acknowledgements

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