Spectral Energy Distributions of H_2O Megamaser Disks

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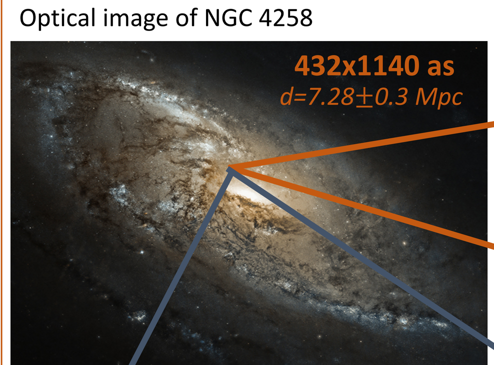
Abstract

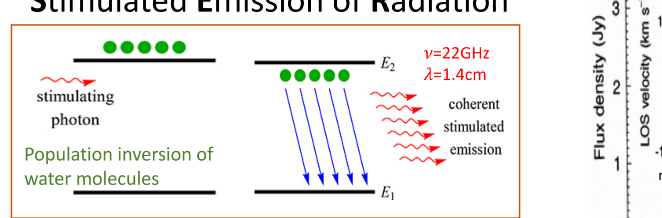
Within the compact central region of ~3% of galaxies, there is evidence for luminous light emission at 22 GHz originating in Microwaves Amplified by Stimulated Emission of Radiation (masers) from water molecules. More than 60% of these detections reveal intensities that are millions of times greater than that of the very first masers discovered in the star-forming spiral arms of our own Milky Way galaxy, and are therefore called megamasers. A fraction of these megamasers are found in a disk-like configuration, offering thus unprecedented tools for **accurate measurements of:** (1) direct distances to their host galaxies, independent of assumptions about the geometry of the universe, as well as (2) the masses of the central black hole masses that lurk in the centers of these systems, which are usually millions to billions of times heavier than our own Sun. Unfortunately, there are only a handful of these megamaser disks that we have been able to investigate in great detail. In an attempt to significantly increase the detection rate of these holy grails of astronomy, we are conducting a study of the physical properties of their host galaxies, with the hope of identifying galaxy traits connected to the megamaser disk phenomenon. In this work, we present our techniques for public data collection of the total flux emitted across the electromagnetic spectrum (i.e., building spectral energy distributions; SEDs) of the host galaxies of all known megamaser disks, with the goal of quantifying the degree to which various energetic components (e.g., black hole accretion, star formation, dust obscuration and reprocessing) contribute to the total galaxy light. Through SED comparisons of host galaxies that do not host maser emission, along with SED fits of template models from various main emission mechanisms, our SED plots will be used to best diagnose the relations between the 22 GHz emission and that from nuclear accretion, stellar light, or the reprocessing by surrounding dust. **This method will allow more efficient identification of the types of galaxies that are most likely to host megamaser disks in order to increase their detection rate.**

Physics of Masers

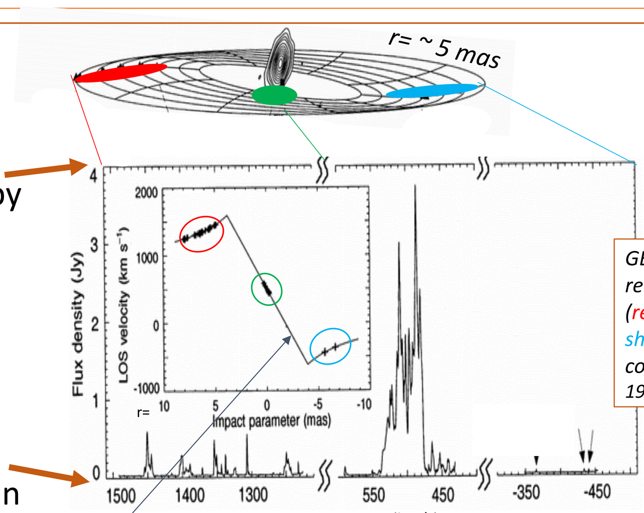
Optical image of NGC 4258



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



Megamasers – 10^6 times greater than typical galactic masers

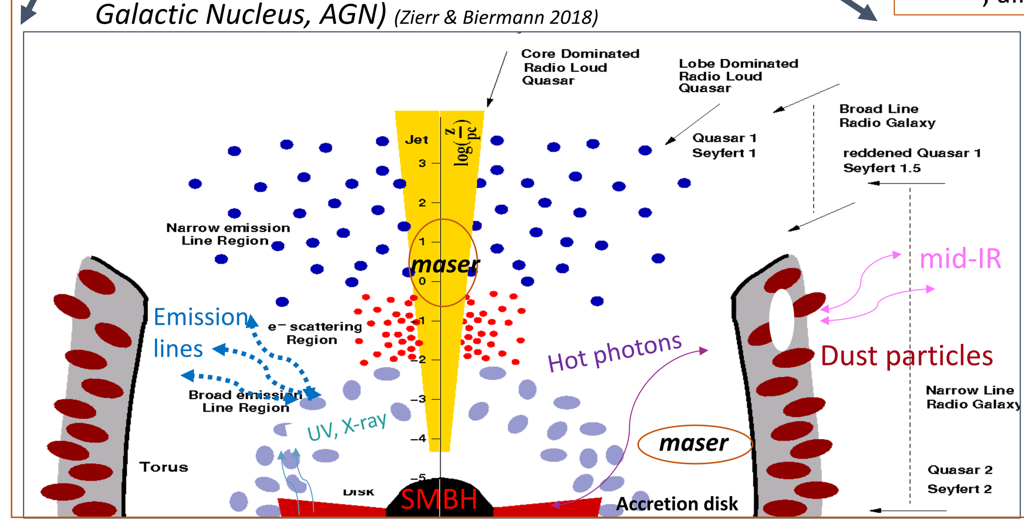


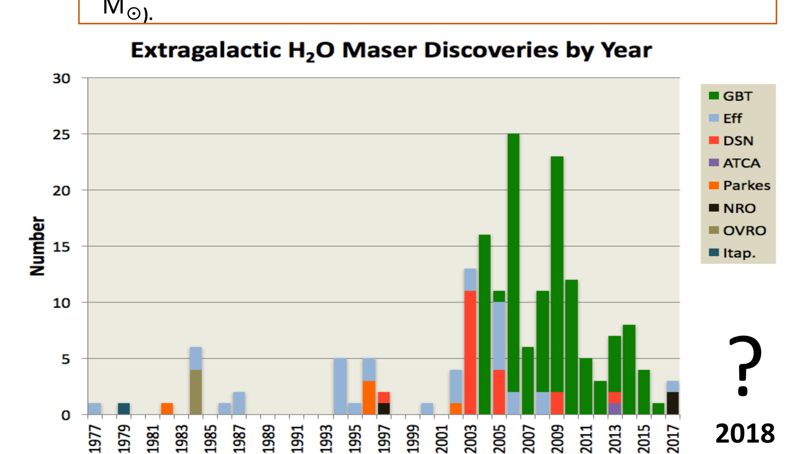
GBT spectrum at 22 GHz reveals three components (redshifted + systemic + blue shifted) suggesting disk-like configuration (Herrnstein et al. 1999).

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

1. **Measure direct distances**
   - Independent constraint to the Hubble Constant (age of the universe)
   - Constrain the geometry of the universe
   - Better understand dark energy
2. **Measure mass of supermassive black holes** (M_{SMBH}=~10^7 $M_\odot$).

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

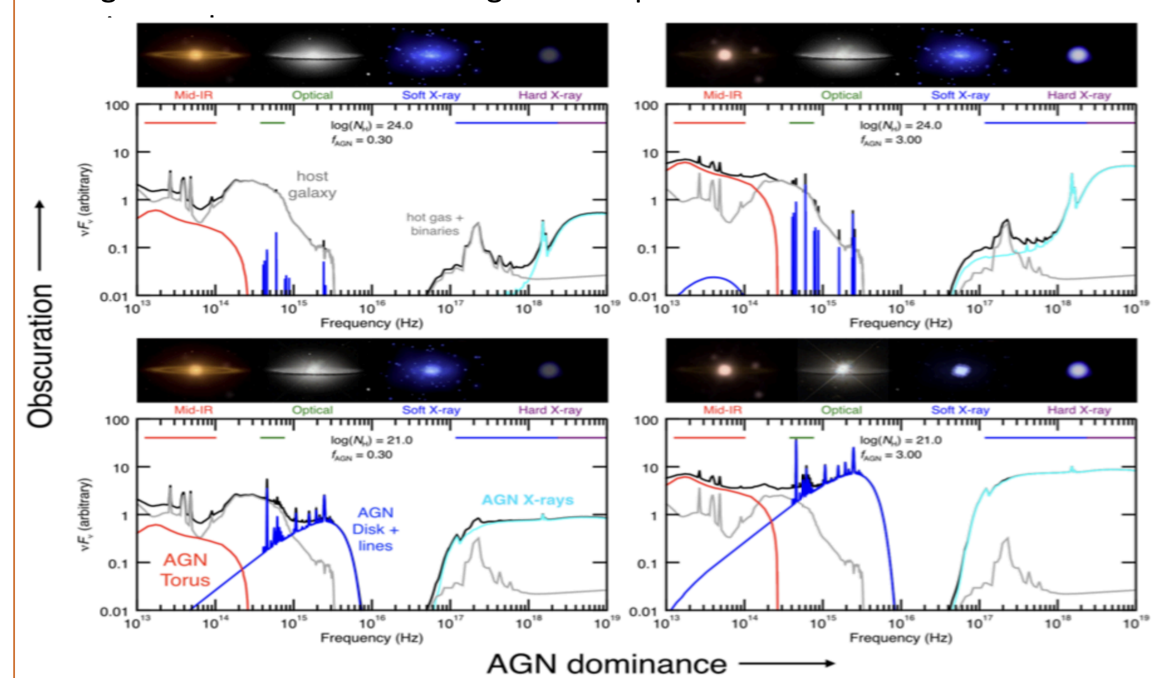




Spectral Energy Distributions (SED)

SED plots show the energy (νF_ν) emitted as a function of frequency(ν)

➢ Fitting multi-frequency observations, i.e. SEDs, attempt to identity the degree to which various energetic components contribute to the total flux of



Four panels exemplifying the dependence of the IR to X-ray SED shape on the varying nuclear obscuration and luminosity of the AGN, as well as the host galaxy stellar light contribution (from *Hickox & Alexander 2018)*.

Components and their emission

- ➢ Accretion disk produces X-ray emission
- ➢ Gas heated by hot photons from the accretion disk (power law + emission lines)
- ➢ Stellar emission from host galaxies peaks in near-IR + contributions from X-ray binaries in soft X-ray
- ➢ Hot dust within the torus emits in the mid-IR range
- ➢ Dust heated in star formation regions of host galaxy emits in far-IR
- ➢ Synchrotron emission, related to the accretion disk and/or radio jets, emits in radio

Importance of SEDs

While the connection between water megamasers and AGNs is not yet well understood, SEDs provide the tools to better understand the relative dominance of the light produced in the host galaxies of maser disks. In particular, by quantifying the light distribution over a large wavelength range, we should be able to address the following questions:

- ➢ **Are megamaser disks always associated with black hole accretion?**
- ➢ **What mechanisms of the nucleus influence this maser activity?**
- ➢ **Does maser activity require the torus?**
- ➢ **What is an accurate megamaser disk detection rate?**

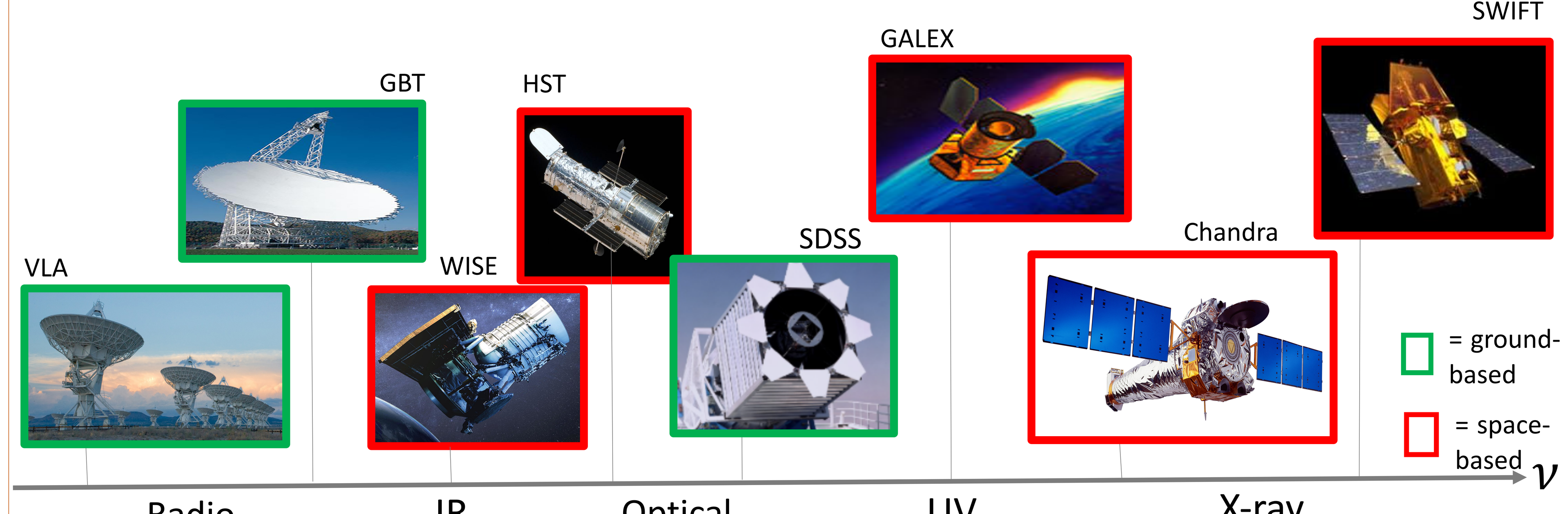
The Megamaser Disk Sample: The Megamaser Cosmology Project (MCP)

MCP provides the largest catalog of galaxies surveyed for water maser emission in 22 GHz with the primary goal of **measuring the Hubble constant (H_0) by determining geometric distances to H_2O megamaser disks well within the Hubble flow,** greater than 50 Mpc (Braatz, J., 2009)

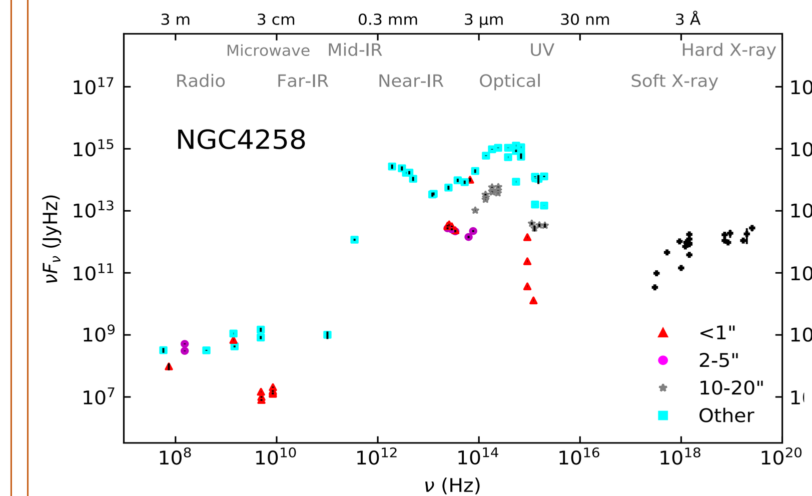
- ➢ 47 megamaser disks candidates to date; 15 confirmed (with Very Large Baseline Interferometry (VLBI) measurements of rotational velocity as a function of impact parameter that fit a Keplerian disk)
- ➢ Most updated list of megamaser disks, along with investigation of their optical and mid-IR properties, extracted from Kuo, Constantin, et. al (2018)

SED Data: NASA Extragalactic Database (NED)

- ➢ NED is a multiwavelength database of for extragalactic objects
- ➢ Combines data from large sky surveys and research publications
- ➢ Extracted the **frequency** (Hz), **flux** (Jy), **uncertainty for the flux measurement**, and the **aperture sizes** used for each observation

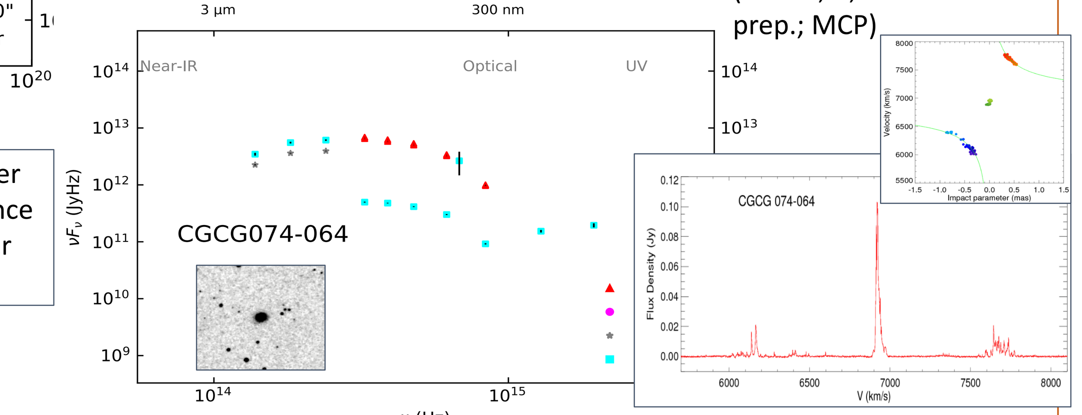


Results: SEDs for best studied megamaser disks

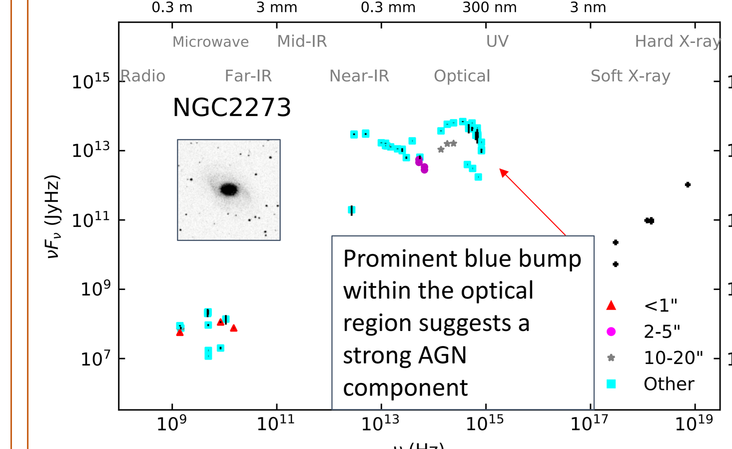


At a distance of 7 Mpc, NGC 4258 is the first megamaser disk detected. This is a Seyfert 2 galaxy (i.e., only detects narrow line emission) and shows a collection of fluxes ranging from radio to X-ray. The mass of the black hole, which is thought to be these systems' source of energy (i.e., gravitational energy from accretion disk and the black hole's spin), is 3.9x10^7 $M_\odot$ (Herrnstein, 1999).

(Braatz, J., et al. 2018 in prep.; MCP)

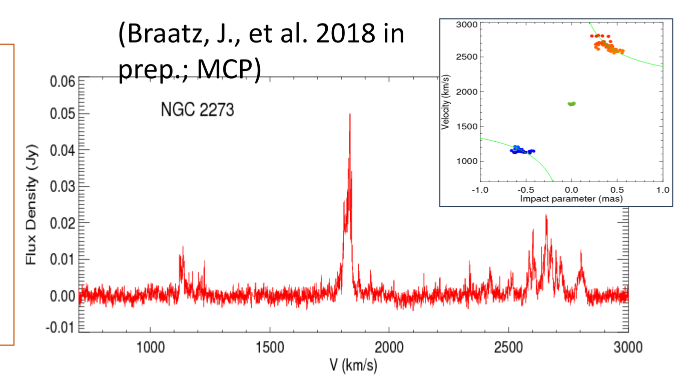


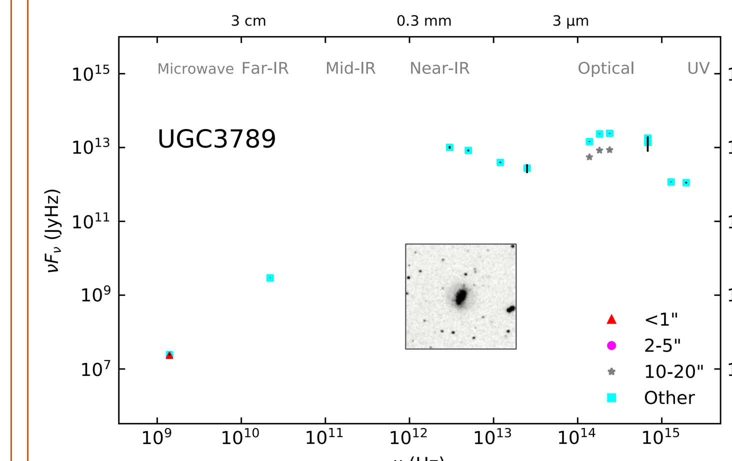
CGCG074-064 is the most recently discovered water megamaser disk to include VLBI results. At a distance of 83 Mpc, this galaxy has a black hole at it's center with a mass of 2.28x10^7 $M_\odot$ (Pesce 2018)



NGC 2273 is a Seyfert 2 galaxy at a distance of 26 Mpc with a warped maser disk at an inclination of 84°. The central black hole has a mass of 7.5x10^6 $M_\odot$ (Kuo, et al. 2010).

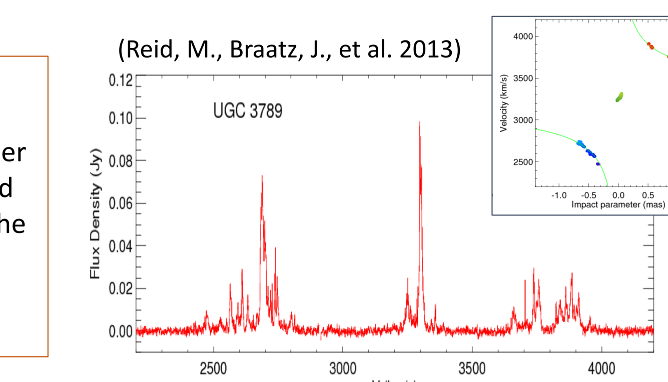
(Braatz, J., et al. 2018 in prep.; MCP)

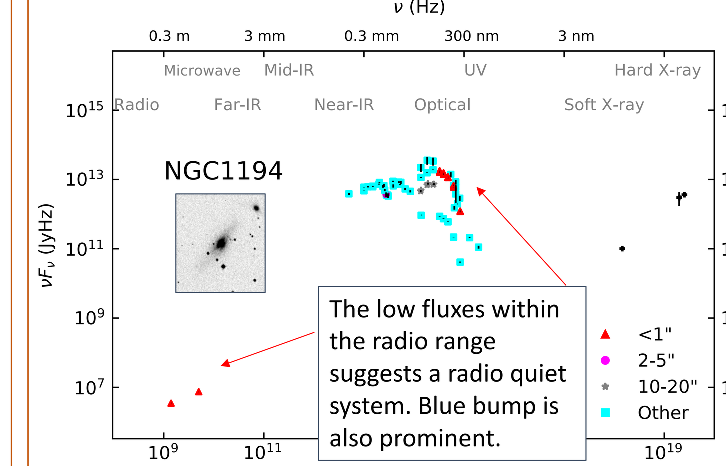




At a distance of 50 Mpc, UGC 3789 is a Seyfert 2 galaxy. The edge-on maser disk is most likely warped along the line of sight. The black hole has a mass of 1.04x10^7 $M_\odot$ (Kuo, et al. 2010).

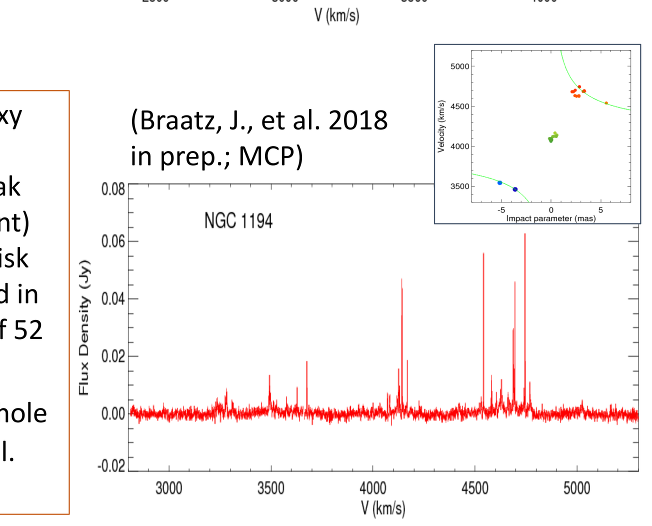
(Reid, M., Braatz, J., et al. 2013)

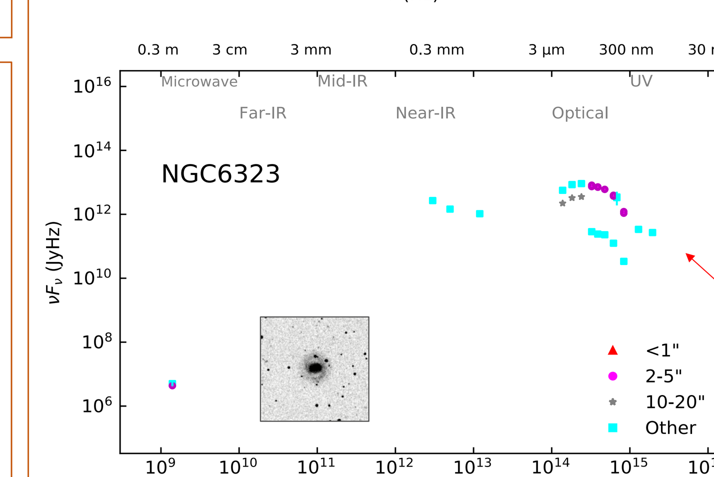




NGC 1194 is a Seyfert 1.9 galaxy (i.e., shows most features of a Seyfert 2, however, with a weak broad-line emission component) with the largest megamaser disk and black hole mass presented in this collection. At a distance of 52 Mpc, this maser disk has an inclination of 85° and a black hole mass of 6.5x10^7 $M_\odot$ (Kuo, et al. 2010).

(Braatz, J., et al. 2018 in prep.; MCP)

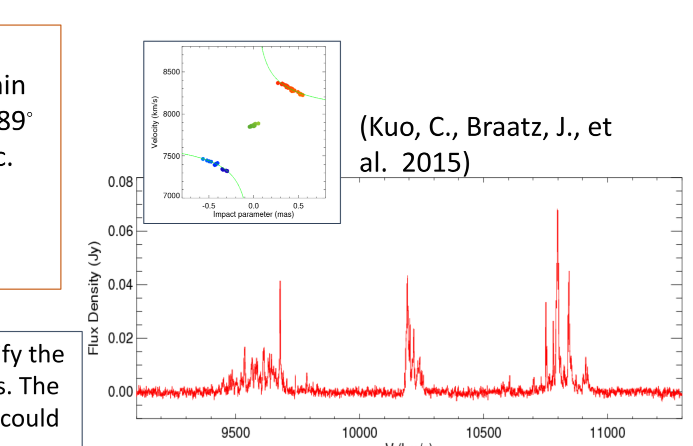




NGC 6323 is a Seyfert 2 galaxy with a warped, thin disk at an inclination of 89° and distance of 105 Mpc. The black hole mass is 9.4x10^6 $M_\odot$ (Kuo, et al. 2010).

More data is needed to quantify the contribution of the dusty torus. The lack of data in the X-ray range could indicate obscuration or weak accretion activity for this radio quiet system.

(Kuo, C., Braatz, J., et al. 2015)



Future Work

- ➢ Collect and include **mid-IR photometry** from Wide-field Infrared Survey Explorer (Wright et al. 2010) to the SED plots in order to investigate the link between maser activity and the reprocessing of the nuclear AGN radiation by the surrounding dust (e.g., Stern et al. 2012)
- ➢ Proceed with SED fitting **to quantify the contribution of AGN compared to stellar light and other energetic phenomena in these galaxies**

References. **Braatz, J.,** et al., 2009, ApJ, 695, 287; **Braatz**, et al., 2018, https://safe.nrao.edu/wiki/bin/view/Main/Megam aserCosmologyProject; **Dattoli, G.**, Doria, A., et al., 2017, IOP, 4, 1; **Herrnstein**, et al., 1999, A&A, 20, 165; **Hickox,** R. & Alexander, D., 2018, ARA&A, 56, 1; **Kuo, C.**, et al., 2010, ApJ, 727, 20; **Kuo, C.,** Constantin, A., et al., 2018, ApJ, 860, 169; **Pesce,** 2018, PhD Thesis, UVA; **Stern, D.,** et al., 2012, ApJ, 753, 30; **Wright E.,** et al., 2010, AJ, 140, 1868; **Zierr, C.** & Biermann, P., 2018, A&A, 69, 1

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