The Megamaser Cosmology Project
Survey Completion

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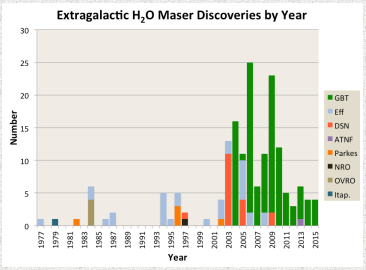
The Megamaser Cosmology Project (MCP) is an NRAO Key Science Project to measure the Hubble Constant by determining geometric distances to circumnuclear 22 GHz H_2O megamasers in galaxies well into the Hubble flow. In combination with the recent, exquisite observations of the Cosmic Microwave Background by WMAP and Planck, these measurements provide a direct test of the standard cosmological model and constrain the equation of state of dark energy. The MCP is a multi-year effort that includes a large survey of over 3000 AGNs to discover the rare disk megamasers, followed by spectral monitoring and VLBI to measure distances to the best candidates. The MCP has recently completed the survey component of the project. Final VLBI observations and analysis of data will continue for about two more years. Based on published distances to 4 galaxies so far, the MCP determines $H_0 = 67.6 \pm 4.0$ km s^{-1} Mpc^{-1}, which is consistent with the Planck prediction of H_0 in the context of the standard cosmological model. We expect to reach a precision better than 4% when all observations are completed.



To date there are 168 galaxies detected in the 22 GHz water maser line. Most have been detected with the GBT, including 76 by the MCP.

Here we show spectra of all the 22 GHz H_2O megamaser disks known, to date. Pesce at el. (2015) describe the criteria used to identify these maser disks. In general, these systems show the characteristic triple-peaked profiles indicative of an edge-on, sub-pc maser disk orbiting the central BH. The masers discovered by the MCP are indicated at the top right of each panel. All the spectra shown here were observed with the GBT except for the southern galaxy ESO 269-G012 (Greenhill et al. 2003) which used the DSN antenna at Tidbinbilla.

GBT Survey for H_2O Megamasers

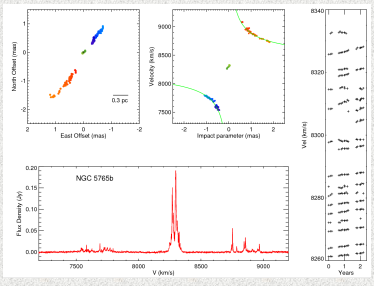
- The MCP survey aims to discover new megamasers in edge-on accretion disks appropriate for measuring M_{BH} and H_0. Our survey targets nearby (< 150 Mpc) narrow-line AGNs.
- Megamasers in AGN accretion disks have characteristic spectra with three distinct clusters of Doppler components. Masers near the systemic velocity come from the front side of the disk, while red- and blue-shifted masers arise from the edges of the disk, along the midline.
- Although detection rates are low (~ 3% overall, ~ 1% for disks), we are able to observe many candidate galaxies with the sensitive GBT.
- Survey candidates include Sy 2 and LINER galaxies identified by the SDSS, 2MRS, 6dF, and other optical surveys. We also target AGNs identified by Swift/BAT.
- The MCP observed ~3000 candidate galaxies and detected 76 new megamasers. Over half of the known disk masers were discovered as part of the MCP survey.

Progress in the Measurement of H_0

- Based on published distances to UGC 3789 (Reid et al. 2012), NGC 6264 (Kuo et al. 2012), NGC 6323 (Kuo et al. 2015) and NGC 5765b (Gao et al. 2015), the MCP determines:

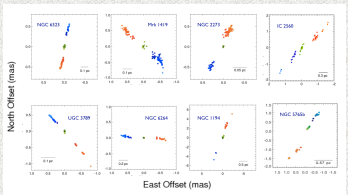
$$H_0 = 67.6 \pm 4.0 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

- We are improving this measurement by determining distances to five additional megamaser galaxies, including the spectacular maser in CGCG 074-064 discovered in March 2015.
- The distance measurement requires sensitive, precise VLBI maps combined with GBT monitoring of the spectral profile. We fit the data with a 3D warped disk model using an MCMC approach described in Reid et al. (2012).



The top left panel shows the maser map for NGC 5765b, which has a 9% distance determined by the megamaser method. Colors represent line-of-sight rotation velocities. The masers delineate an edge-on, circumnuclear disk. The P-V diagram in the top center panel shows that the masers trace a Keplerian rotation curve. The GBT spectrum in the bottom panel reveals the characteristic disk maser profile. The right panel shows the peak velocities of systemic masers over time, with the upward trends indicating the velocity drifts used to determine the centripetal accelerations of masers as they orbit the BH.

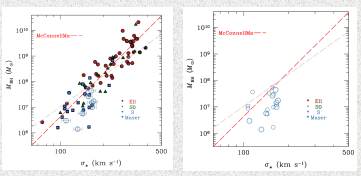
Gold Standard Masses of SMBHs



VLBI maps of eight of the megamasers measured by the MCP

- H_2O Megamasers trace gas rotation in the accretion disks of AGN directly in the "sphere of influence" of the SMBH.
- Megamasers provide the most precise masses of SMBH beyond the Milky Way.
- So far the MCP has measured 19 SMBH masses
- Megamasers are preferentially detected in Seyferts, which have relatively low-mass BHs (~ 10^7 M_{sun}).
- Low-mass systems measured with masers do not, in general, follow the M-σ relation defined by large ellipticals.

M-σ Relation *M-σ Relation (maser masses only)*



Greene et al. 2010, and Greene et al. in prep.