Cold molecular gas in H_2O megamaser disk galaxies

—— A JCMT pilot study

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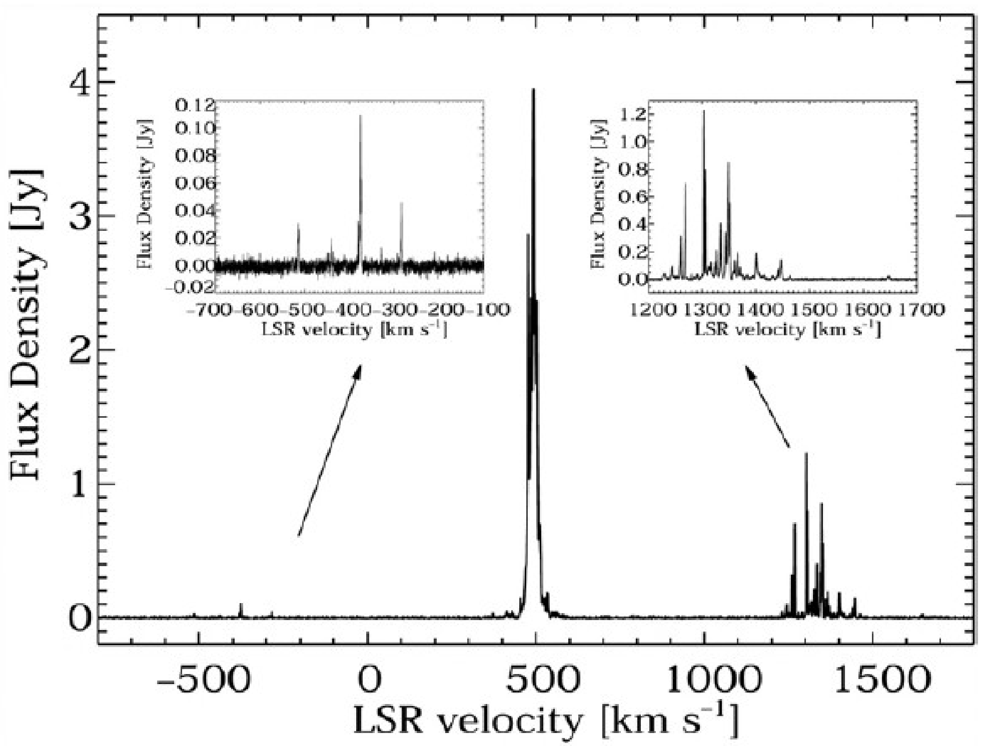
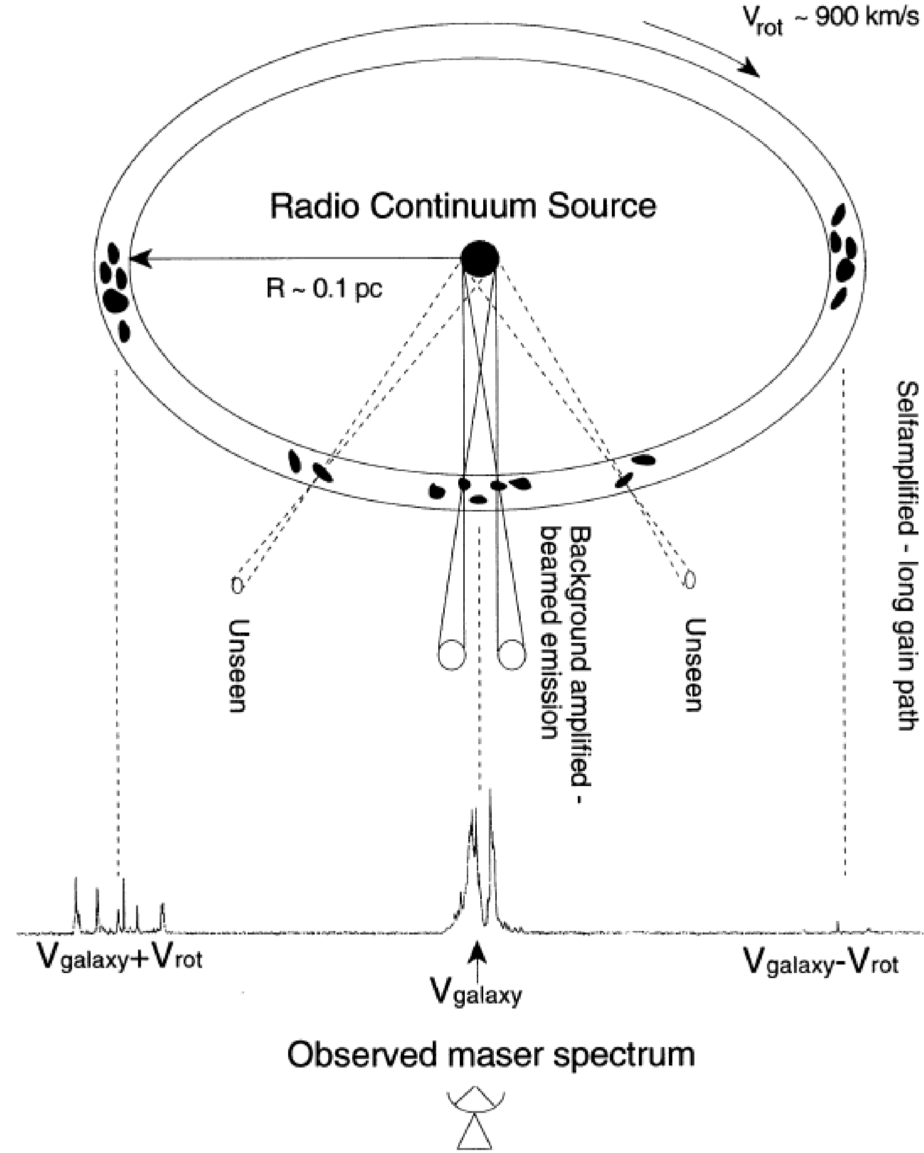
2017.2

Megamaser disk system

Rest frequency: 22.23508 GHz



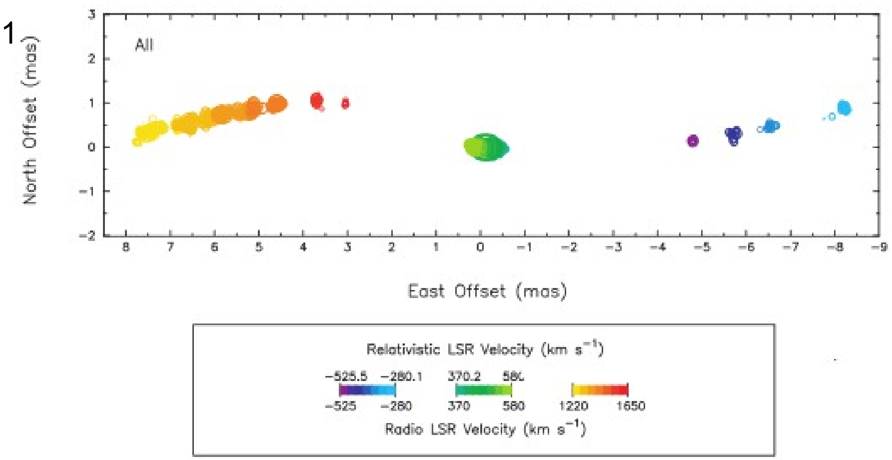
Moran et al. 2008

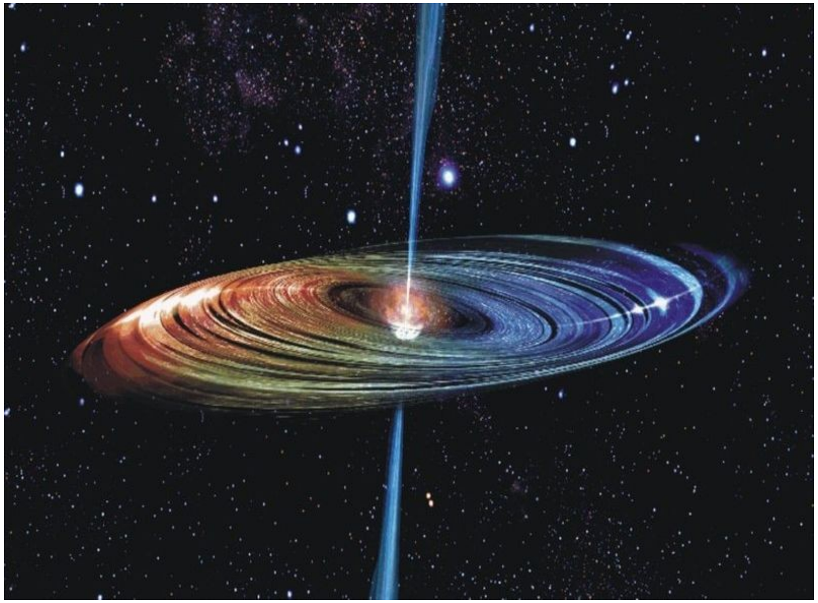


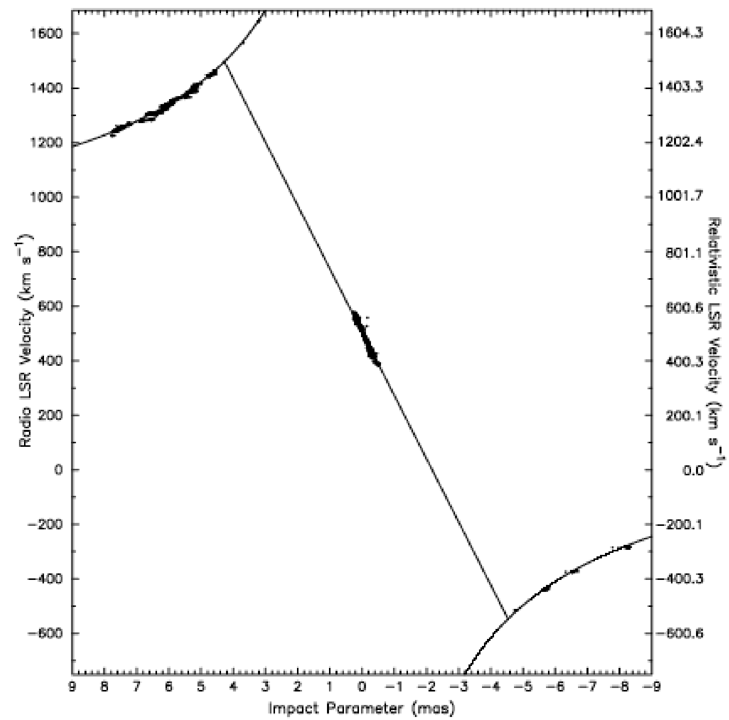
Greenhill et al. 1995

NGC 4258: archetypical maser disk

- Late-type Sy 2 galaxy, L_{bol}= 4x10^{41}ergs s^{-1}
- Disk size: 0.13 to 0.27 pc
- Distance: 7.60 ± 0.227 Mpc (3%)
- M_{BH}: 3.96 ± 0.119 x 10^{7} $M_{\odot}$







Argon et al. 2007; Humphreys et al. 2013

The Megamaser Cosmology Project (MCP)

P.I. Jim A. Braatz (NRAO)

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The Megamaser Cosmology Project (MCP)

Project Description

- MCP Overview

Results

- MCP Publications
- VLBI Results
- Detected Megamasers
- Survey Results

Internal Resources

- Group Resources

Project Overview

The Megamaser Cosmology Project (MCP) is an NRAO Key Science Project to measure the Hubble Constant, H0, by determining geometric distances to circumnuclear 22 GHz H2O megamasers in galaxies well into the Hubble flow. In combination with the recent, exquisite observations of the Cosmic Microwave Background (CMB) 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 has so far determined H0 = 67.6 ± 4.0 km/s/Mpc from published observations of UGC 3789 (Reid et al. 2013), NGC 6264 (Kuo et al. 2013), NGC 6323 (Kuo et al. 2015) and NGC 5765b (Gao et al. 2015). Work on other galaxies in progress, and we expect to achieve a 4% or better measurement of H0 when the project is completed in 2017. Our measurement so far is consistent with the Planck prediction of H0 in the context of the standard cosmological model (H0 = 67.8 ± 0.9 km/s/Mpc; Ade et al. 2015) and mildly in tension with recent measurements based on standard candles (H0 = 74 ± 2.5 km/s/Mpc).

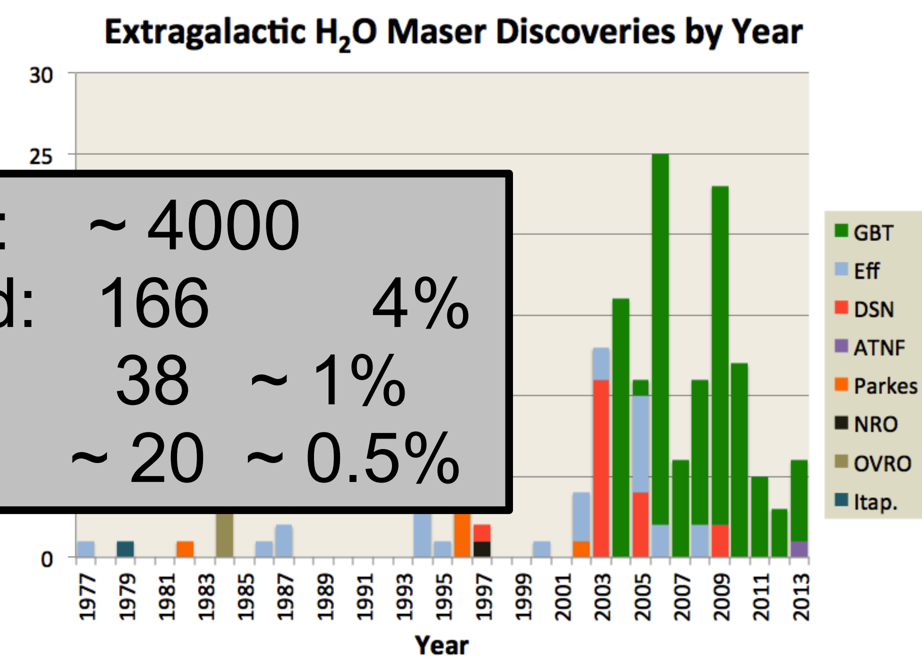
Main Results of MCP to Date

- We have so far measured H0 = 67.6 +/- 4.0 km/s/Mpc based on maser distances to UGC 3789 (Reid et al. 2013), NGC 6264 (Kuo et al. 2013), NGC 6323Kuo et al. 2015, and NGC 5765b Gao et al. 2016.
- We have mapped maser disks in 19 galaxies and measured "gold standard" masses for their supermassive black holes, e.g. (Kuo et al. 2011).

Current Survey Status

Mainly limited by sensitivity, so need large collecting area.

Main target sample: Seyfert 2 & LINER
(Braatz et al. 1996;1997)



Recent work done mainly b

Total searched: ~ 4000
Maser detected: 166 4%
Disk detected: 38 ~ 1%
Clean Disk: ~ 20 ~ 0.5%

Northern Hemisphere:

the Megamaser Cosmolog
with the GBT

Southern Hemisphere:
Tidbinbilla DSN (e.g. Greenhill et al. 2006; 2008)

Typical Exposure time:

10mins@ GBT, with dual beam receiver
10mJy with 24.5kHz spec resolution

Redshift range	0 — 0.01	0.01 — 0.02	0.02 — 0.03	0.03 — 0.04	0 .04 — 0.05
Searched	399	676	974	906	304
Maser detected	38	36	26	30	5
Disk detected	9	11	7	5	1
Maser detection rate (%)	9.5	5.3	2.7	3.3	1.6
Disk detection rate (%)	2.2	1.6	0.7	0.5	0.3

Table 1. Mega-maser survey status in Sy2 galaxies from The Megamaser Cosmology Project (MCP), data comes from their online catalog of GBT survey results on its web site.

Maser disk generation

Requirements for pumping H_20 maser:

Central heating (e.g. X-ray) · Molecular gas · Cold Dust · Amplification path length · Coherent Velocity Field

Requirements for detecting H_20 maser:

Narrow Beaming angle (e.g. for systemic masers)

Current Sample Selection Criteria:

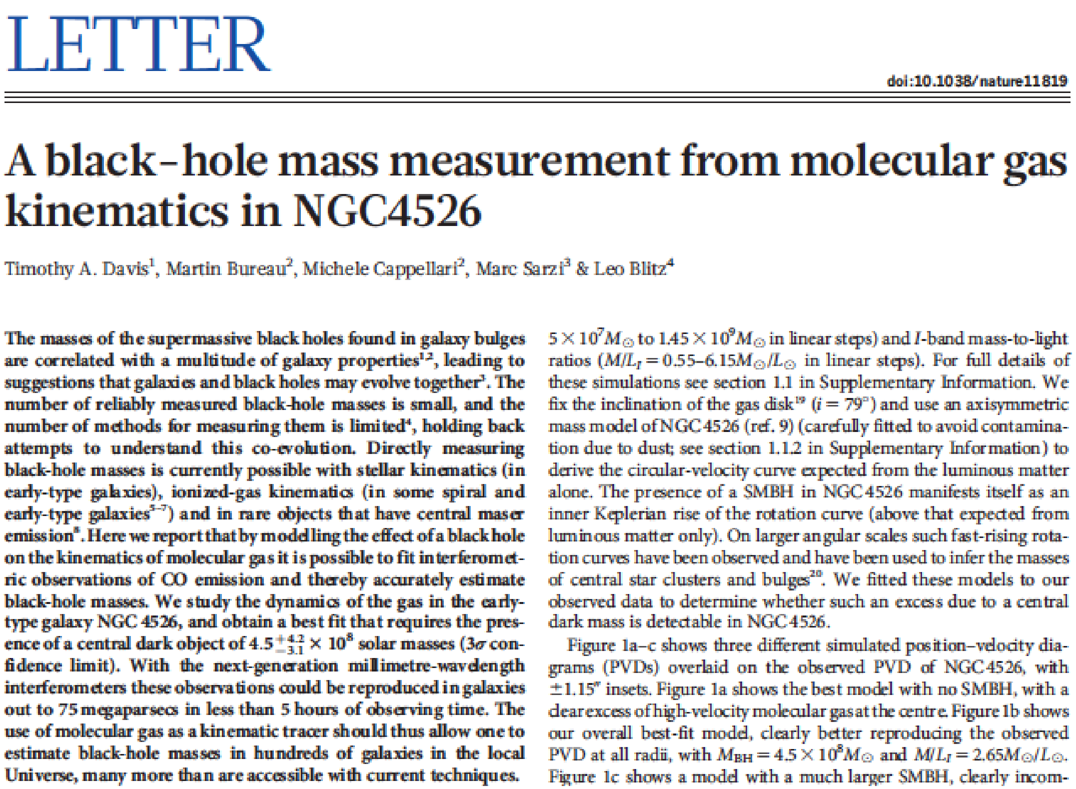
Seyfert 2 / LINER with $M_B < -19.5$, $V_{re} < 15000$ km s^{-1}

- In general, dust provides an effective cooling mechanism to absorb H_20 IR transition lines, so as to maintain the population inversion.

- For the 22 GHz line:
  - $T_d < 100K$ dust radiation is negligible
  - $T_d = 300K$ ~10% emitted compared to $T_d = 100K$

Yates et al. 1997

Calibrating CO-based M_{BH}


LETTER

doi:10.1038/nature11819

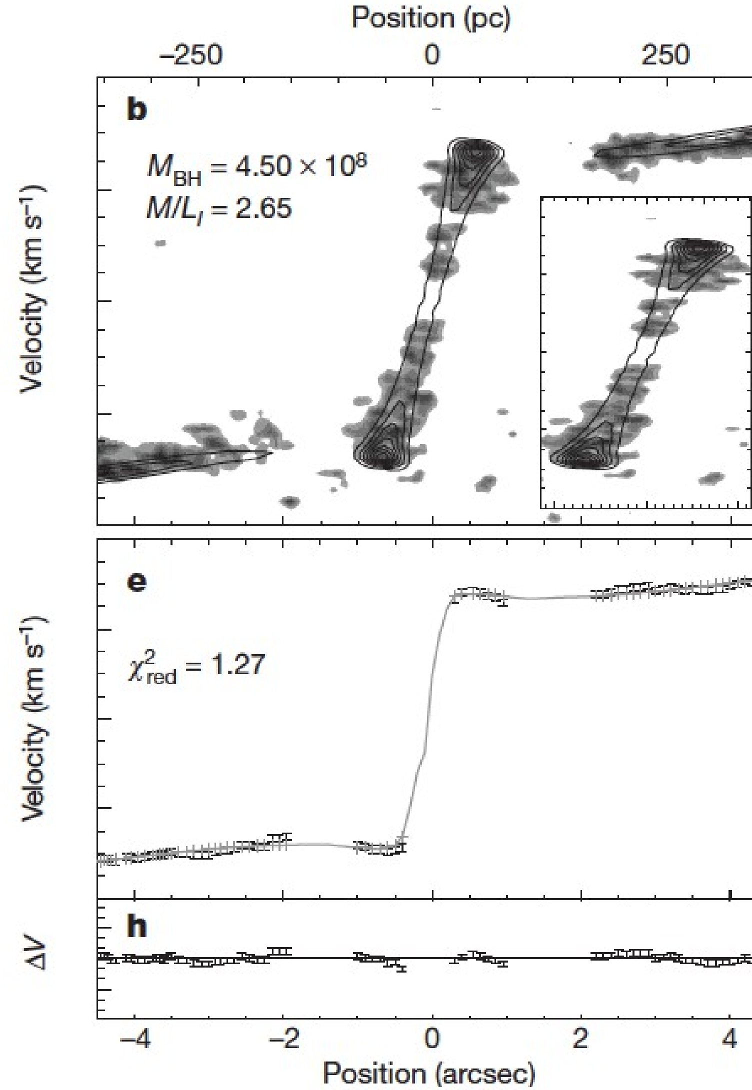
A black-hole mass measurement from molecular gas kinematics in NGC4526

Timothy A. Davis[1], Martin Bureau[2], Michele Cappellari[2], Marc Sarzi[3] & Leo Blitz[4]

The masses of the supermassive black holes found in galaxy bulges are correlated with a multitude of galaxy properties[1,2], leading to suggestions that galaxies and black holes may evolve together[3]. The number of reliably measured black-hole masses is small, and the number of methods for measuring them is limited[4], holding back attempts to understand this co-evolution. Directly measuring black-hole masses is currently possible with stellar kinematics (in early-type galaxies), ionized-gas kinematics (in some spiral and early-type galaxies[5–7]) and in rare objects that have central maser emission[8]. Here we report that by modelling the effect of a black hole on the kinematics of molecular gas it is possible to fit interferometric observations of CO emission and thereby accurately estimate black-hole masses. We study the dynamics of the gas in the early-type galaxy NGC 4526, and obtain a best fit that requires the presence of a central dark object of $4.5^{+4.2}_{-3.1} \times 10^8$ solar masses (3σ confidence limit). With the next-generation millimetre-wavelength interferometers these observations could be reproduced in galaxies out to 75 megaparsecs in less than 5 hours of observing time. The use of molecular gas as a kinematic tracer should thus allow one to estimate black-hole masses in hundreds of galaxies in the local Universe, many more than are accessible with current techniques.

$5 \times 10^7 M_\odot$ to $1.45 \times 10^9 M_\odot$ in linear steps) and I-band mass-to-light ratios ($M/L_I = 0.55$–$6.15 M_\odot/L_\odot$ in linear steps). For full details of these simulations see section 1.1 in Supplementary Information. We fix the inclination of the gas disk[19] ($i = 79°$) and use an axisymmetric mass model of NGC 4526 (ref. 9) (carefully fitted to avoid contamination due to dust; see section 1.1.2 in Supplementary Information) to derive the circular-velocity curve expected from the luminous matter alone. The presence of a SMBH in NGC 4526 manifests itself as an inner Keplerian rise of the rotation curve (above that expected from luminous matter only). On larger angular scales such fast-rising rotation curves have been observed and have been used to infer the masses of central star clusters and bulges[20]. We fitted these models to our observed data to determine whether such an excess due to a central dark mass is detectable in NGC 4526.

Figure 1a–c shows three different simulated position–velocity diagrams (PVDs) overlaid on the observed PVD of NGC 4526, with ±1.15″ insets. Figure 1a shows the best model with no SMBH, with a clear excess of high-velocity molecular gas at the centre. Figure 1b shows our overall best-fit model, clearly better reproducing the observed PVD at all radii, with $M_{BH} = 4.5 \times 10^8 M_\odot$ and $M/L_I = 2.65 M_\odot/L_\odot$. Figure 1c shows a model with a much larger SMBH, clearly incom-



– Great potential for M_{BH} measurement

– Degeneracies between M_{BH}, M/L and $\sigma_{turb(r)}$

– Could be tested by disk maser systems

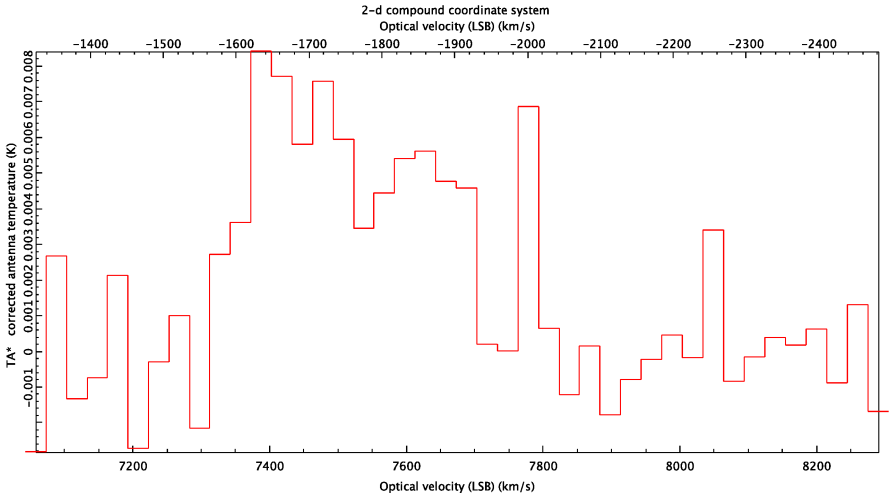
– ALMA cycle 4 project 2016.1.1553.S (B-graded)

Davis et al. 2013, Nature

The JCMT observations

- M16BP068
- 39 hours, 30 targets ,T_{int} ~ 40 min per target
- 50/50 maser/non-maser, 7 Mpc ~ 150 Mpc
- RxA for CO (J=2-1) , band 4 weather
- 92% completion by now
- CO detection rate:

  10/15 for both the maser and the control sample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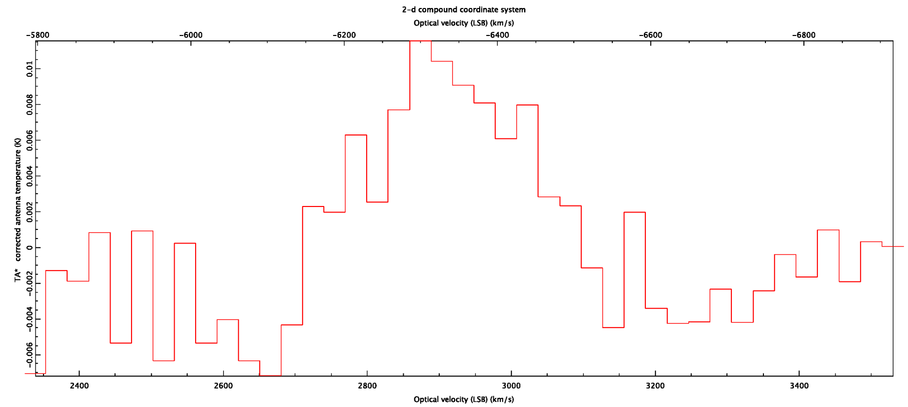
Optical velocity (LSB) (km/s)
TA* corrected antenna temperature (K)
Optical velocity (LSB) (km/s)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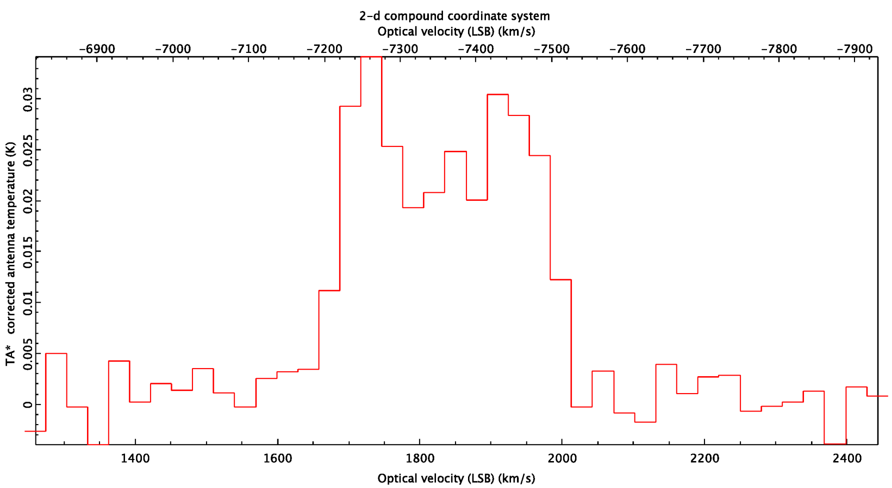
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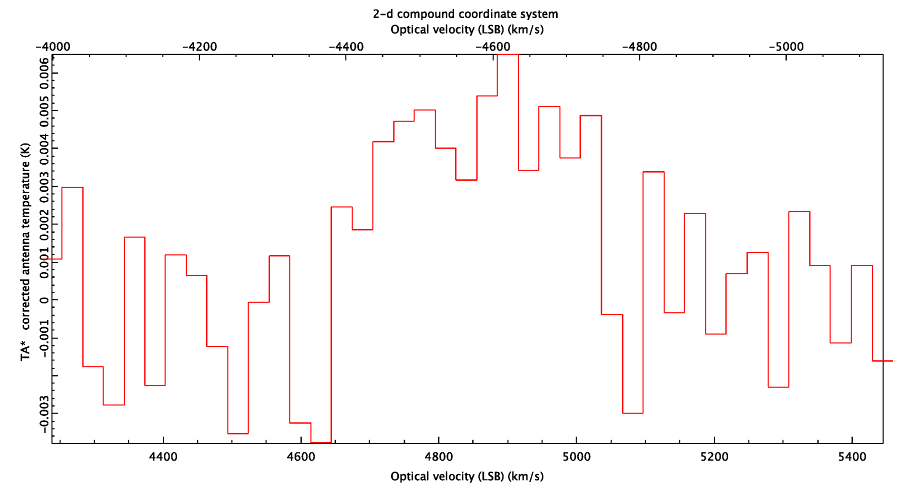
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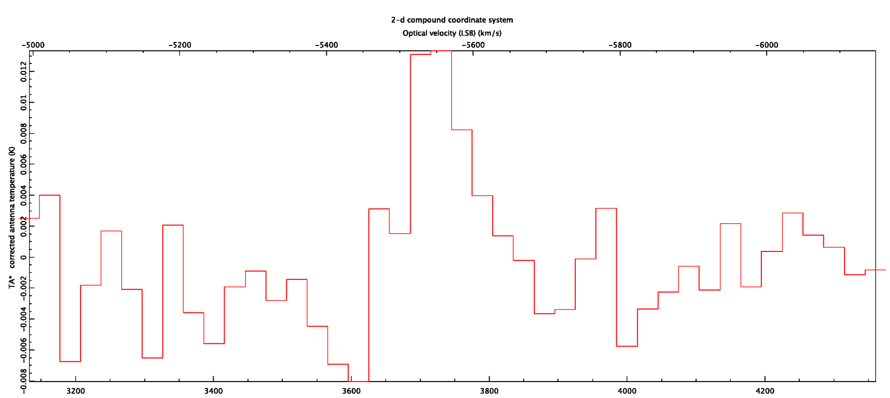
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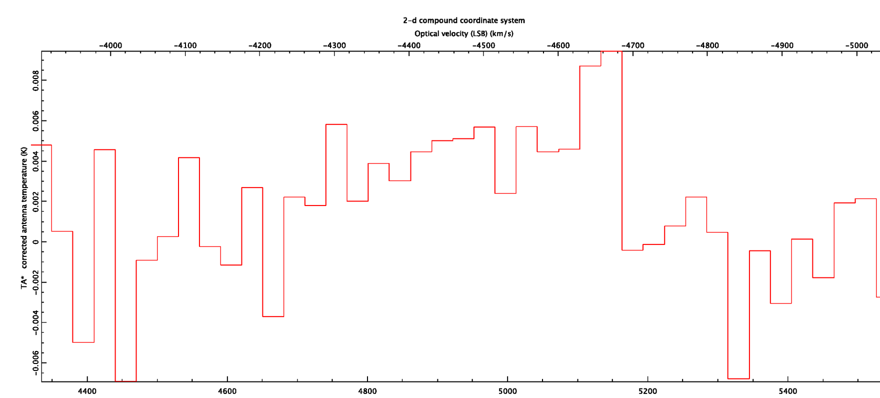
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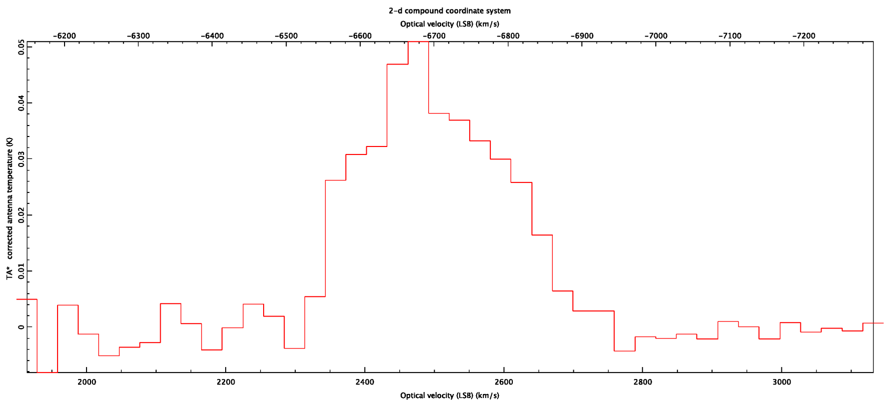

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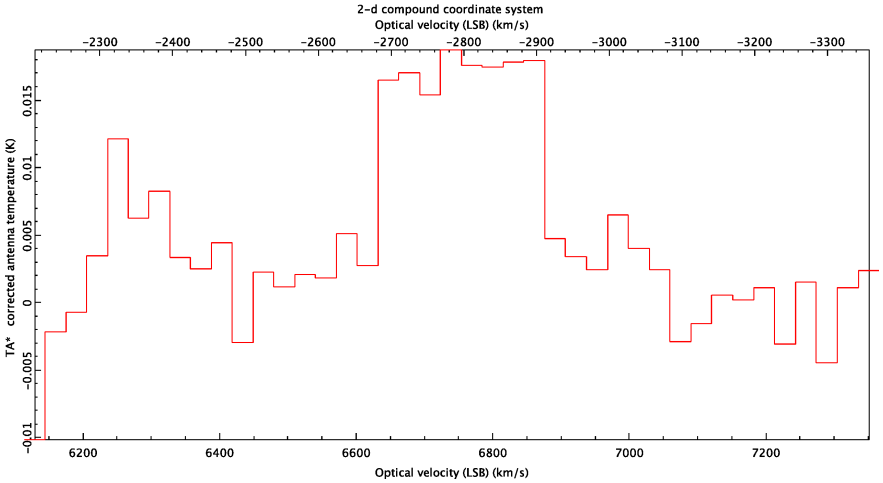

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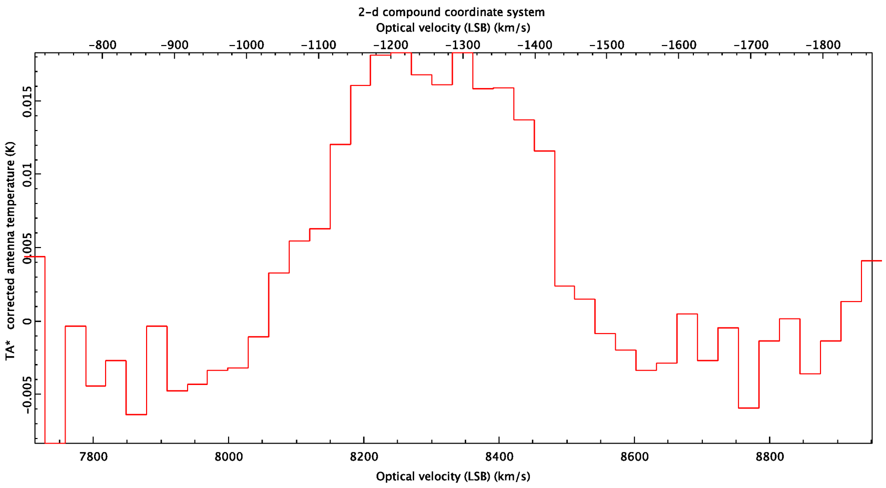

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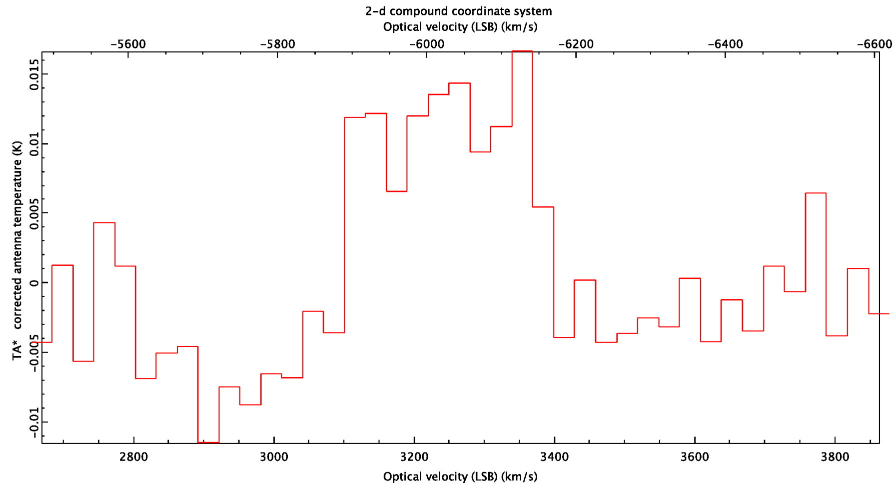

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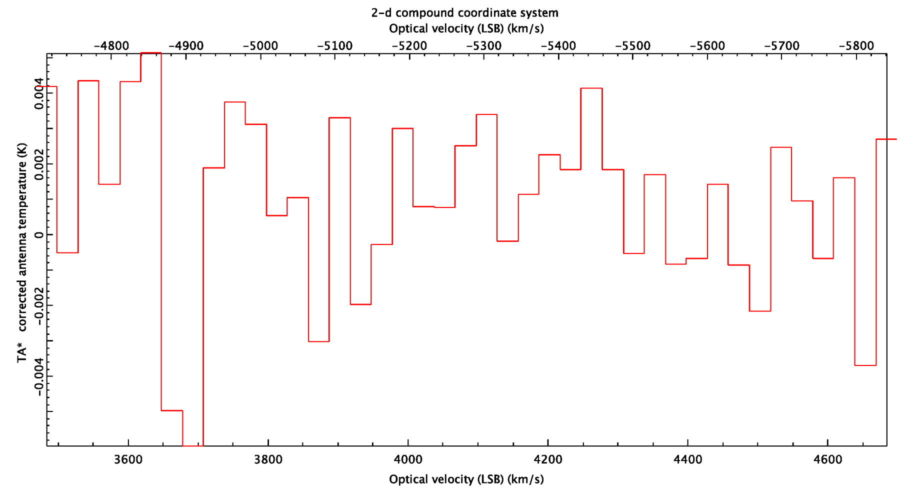
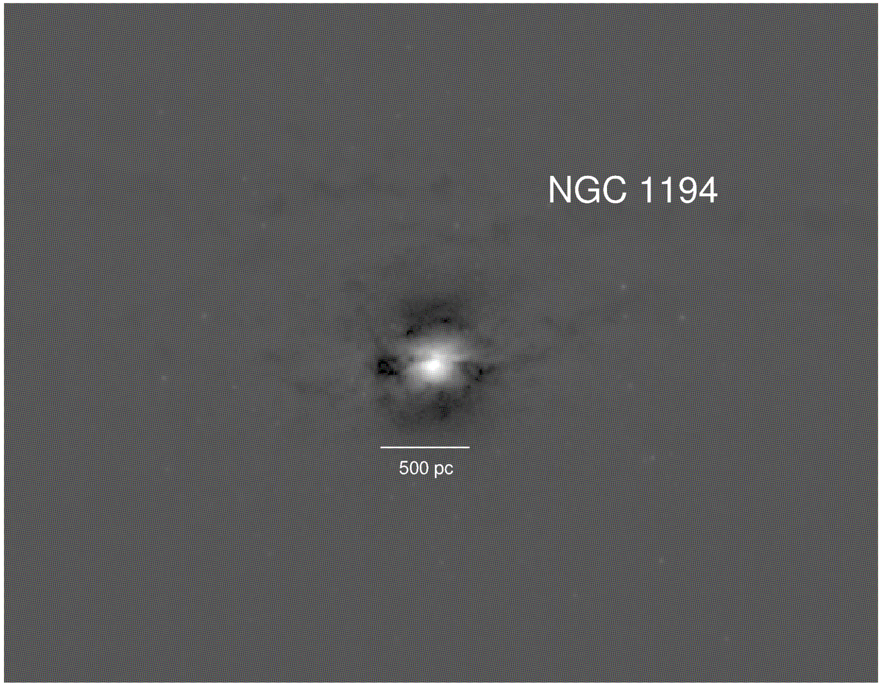
NGC1194: what's going on?

- 53.2 Mpc
- S0, Seyfert 2
- No detection from JCMT
- No detection from ALMA
- Dust lane at the GC
- CO intensity predicted based on FIR: 0.16 Jy





The “clean” disk sample (accessible by ALMA)

Name	BH mass ($10^7 M_\odot$)	Dist. (Mpc)	Velocity Dispersion (km s^{-1})	SOI (pc)	SOI (arcsec)
NGC 4388	0.84	19.0	107.2	3.15	0.034
IC 2560	0.35	44.5	141.3	0.75	0.003
NGC 1194	6.5	53.2	147.9	12.78	0.050
NGC 3393	3.10	56.2	147.9	6.10	0.022
J0437+2456	0.30	65.3	109.6	1.07	0.003
NGC 2960	1.16	72.2	166.0	1.81	0.005
NGC 5495	1.02	95.7	166.0	1.59	0.003
NGC 6323	0.94	106.0	158.5	1.61	0.003
ESO 558-G009	1.76	107.6	169.8	2.63	0.005
NGC 5765b	4.55	117.0	162.2	7.44	0.013
NGC 6264	2.91	139.4	158.5	4.98	0.007
UGC 6093	2.65	153.2	154.9	4.75	0.006