H_0: NGC 4258 and the Megamaser Cosmology Project

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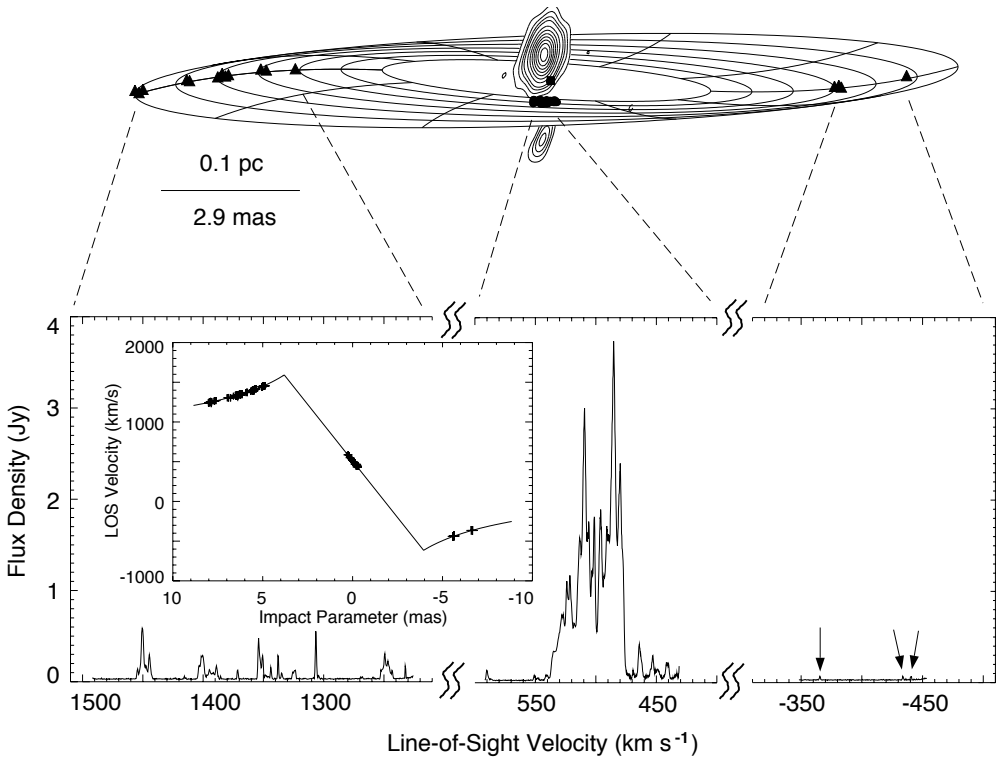
1. Estimating distance from H_2O masers in AGN accretion disks
2. NGC 4258 nearby (7.6 Mpc); used to calibrate Cepheids
3. More distant AGN in “Hubble flow” provide independent H_0 estimates

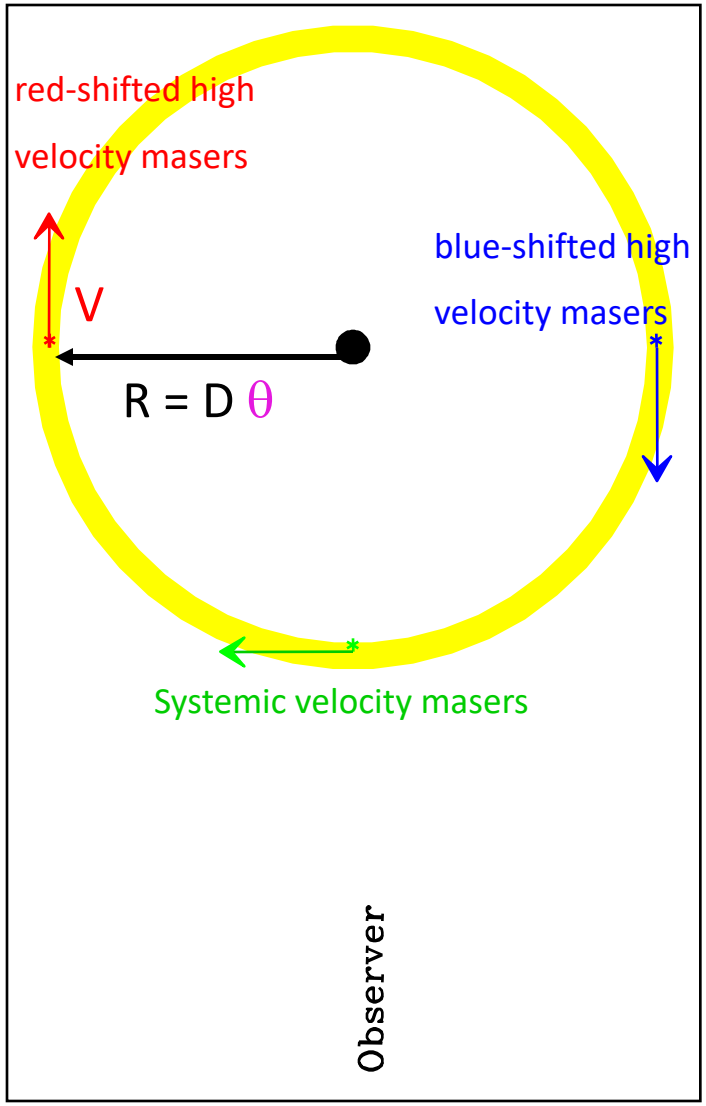
NGC 4258



- Seyfert 2 galaxy
- H_2O masers in accretion disk
- Radius = 0.25 pc
- Nearly edge-on; slightly warped
- Rotation speed = 1000 km/s
- Orbital period = 1000 years
- $M = 4 \times 10^7 M_{sun}$
- Geometric model ➔ D
- Calibrate Cepheid PL relation

Herrnstein, Moran, Greenhill et al (1999)

AGN Maser Angular-Diameter Distance



$A = V^2 / R$

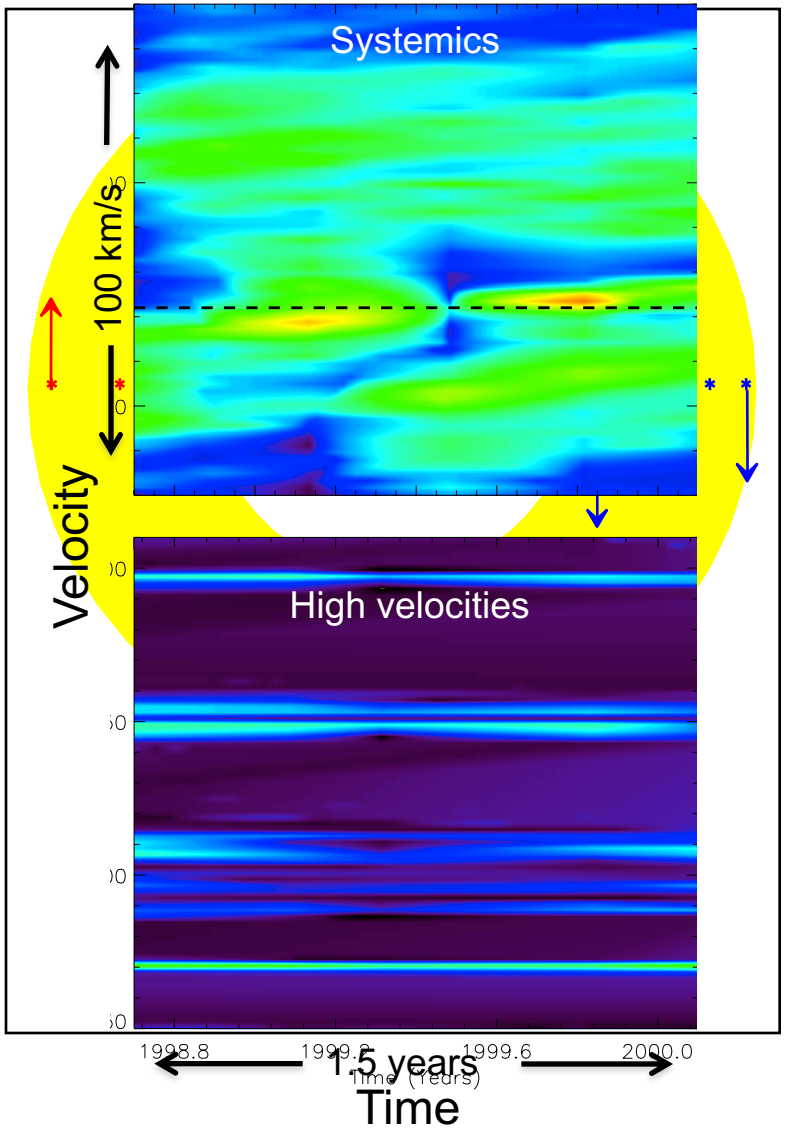
$R = D\,\theta$

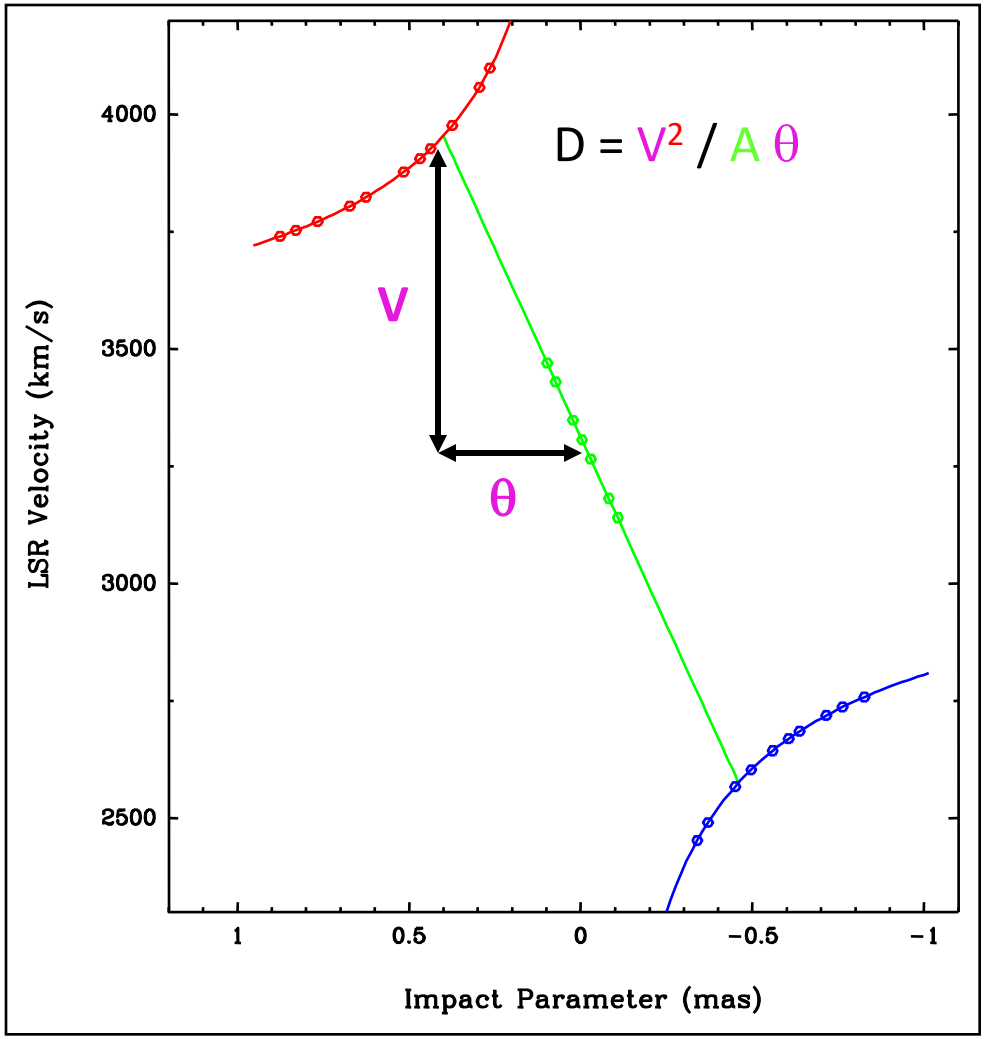
$\therefore \quad D = V^2 / A\,\theta$

High Velocity Maser Map

Velocity drift of systemic masers over time

Maser Distance Measurements (2)



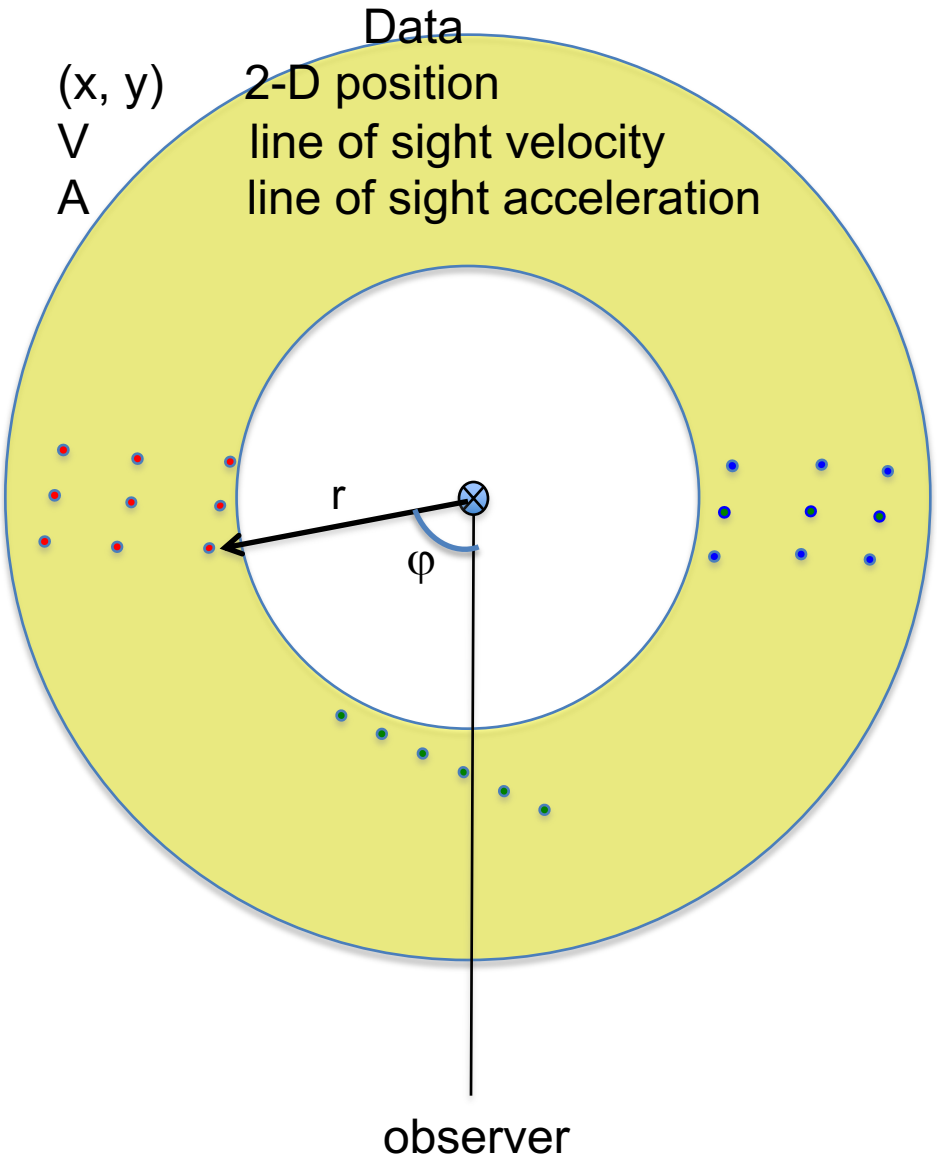


NGC 4258

Miyoshi+1995: $D = 6.4 \pm 0.9$ Mpc

Hernstein+1999: $D = 7.2 \pm 0.3 \pm 0.4$ Mpc

Model Fitting



Global Parameters

D = distance (or H_0)
M = central mass
V_{opt} = recessional velocity
X_0 = central X-position
Y_0 = central Y-position
i = disk inclination
di/dr = inclination warp
PA = disk position angle
dPA/dr = position angle warp
V_{cor} = vel correction to H-flow

ecc = orbital eccentricity
ω = argument of pericenter
dω/dr = pericenter twisting

Maser spot$_i$ parameters

r_i = disk radius
φ_i = disk azimuth

NGC 4258

Miyoshi+1995: D = 6.4 ± 0.9 Mpc

Hernstein+1999: D = 7.2 ± 0.3 ± 0.4 Mpc

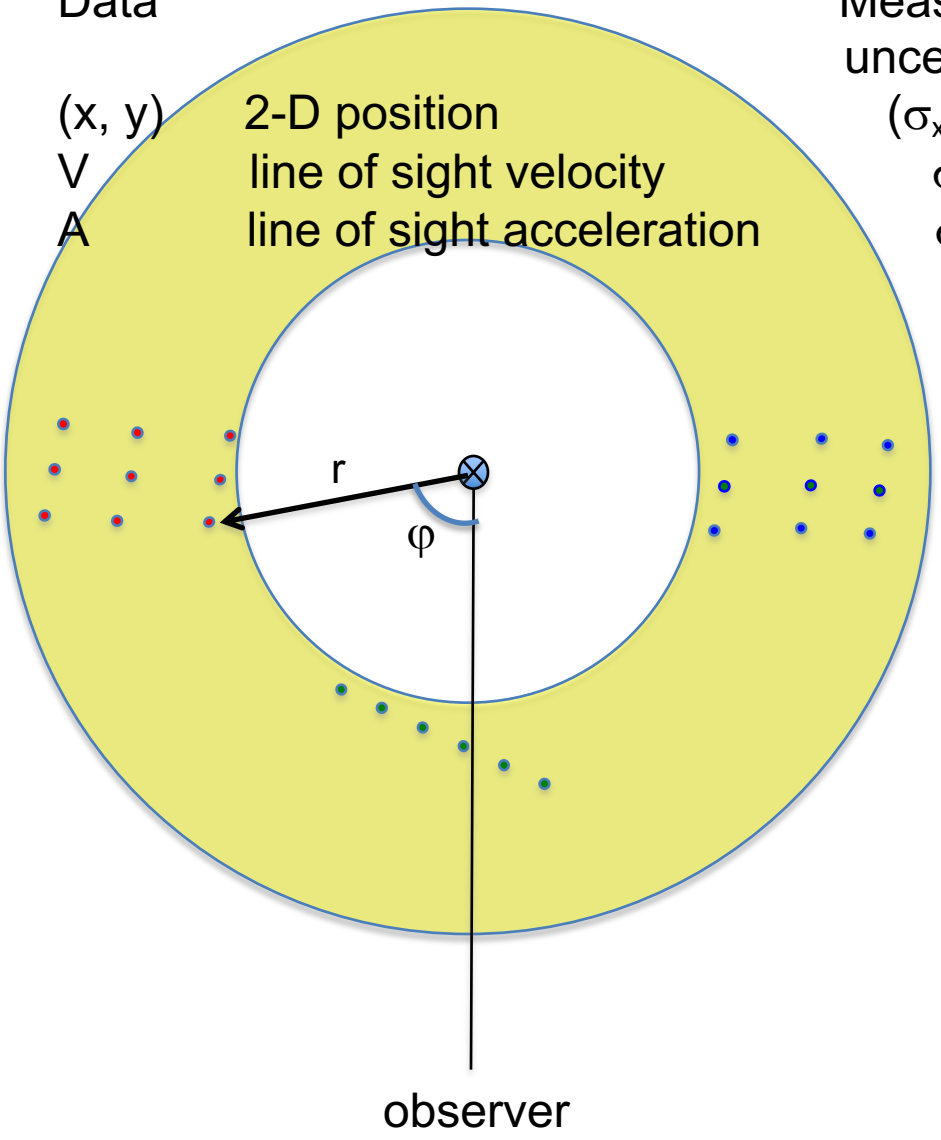
Humphreys+2013: D = 7.60 ± 0.17 ± 0.15 Mpc (ecc = 0.006 ± 0.001)

Riess+2016: D = 7.54 ± 0.17 ± 0.10 Mpc → H_0 = 72.2 ± 2.4 Mpc

Model Fitting

Data

(x, y) 2-D position
V line of sight velocity
A line of sight acceleration



Measurement uncertainties
(σ_x, σ_y)
σ_V
σ_A

Error "floors"
(e_x, e_y)
e_V
e_A

Previously:
- Added in quadrature to measured uncertainties
- User adjustable; treated as a contribution to systematic uncertainty

This talk:
- Incorporated as model parameters, adjusted in MCMC trials automatically
- Adopt loose priors…"let the data speak"
- Marginalize over them

Dom Pesce (postdoc at CfA) written an independent fitting code (Hamiltonian MCMC) and we get the same results.

NGC 4258

Miyoshi+1995: D = 6.4 ± 0.9 Mpc

Hernstein+1999: D = 7.2 ± 0.3 ± 0.4 Mpc

Humphreys+2013: D = 7.60 ± 0.17 ± 0.15 Mpc

Riess+2016: D = 7.54 ± 0.17 ± 0.10 Mpc → H_0 = 72.2 ± 2.4 Mpc

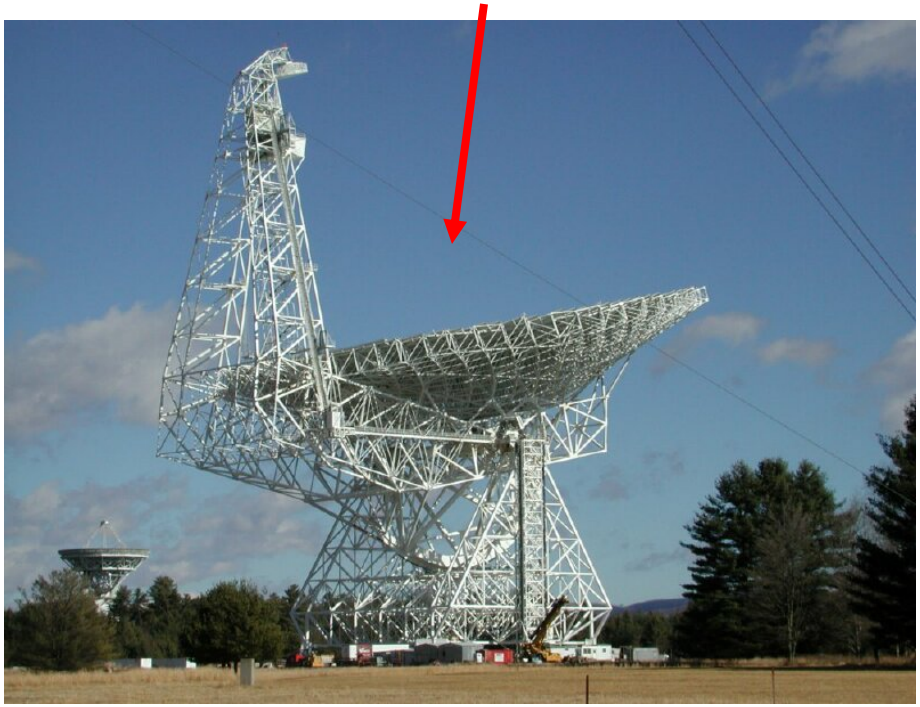
This talk: D = 7.57 ± 0.08 ± 0.08 Mpc → H_0 = 72.0 ± 1.9 Mpc

Maser Cosmology Project

Braatz, Condon, Gao, Henkel, Kuo, Lo, Pesce & Reid

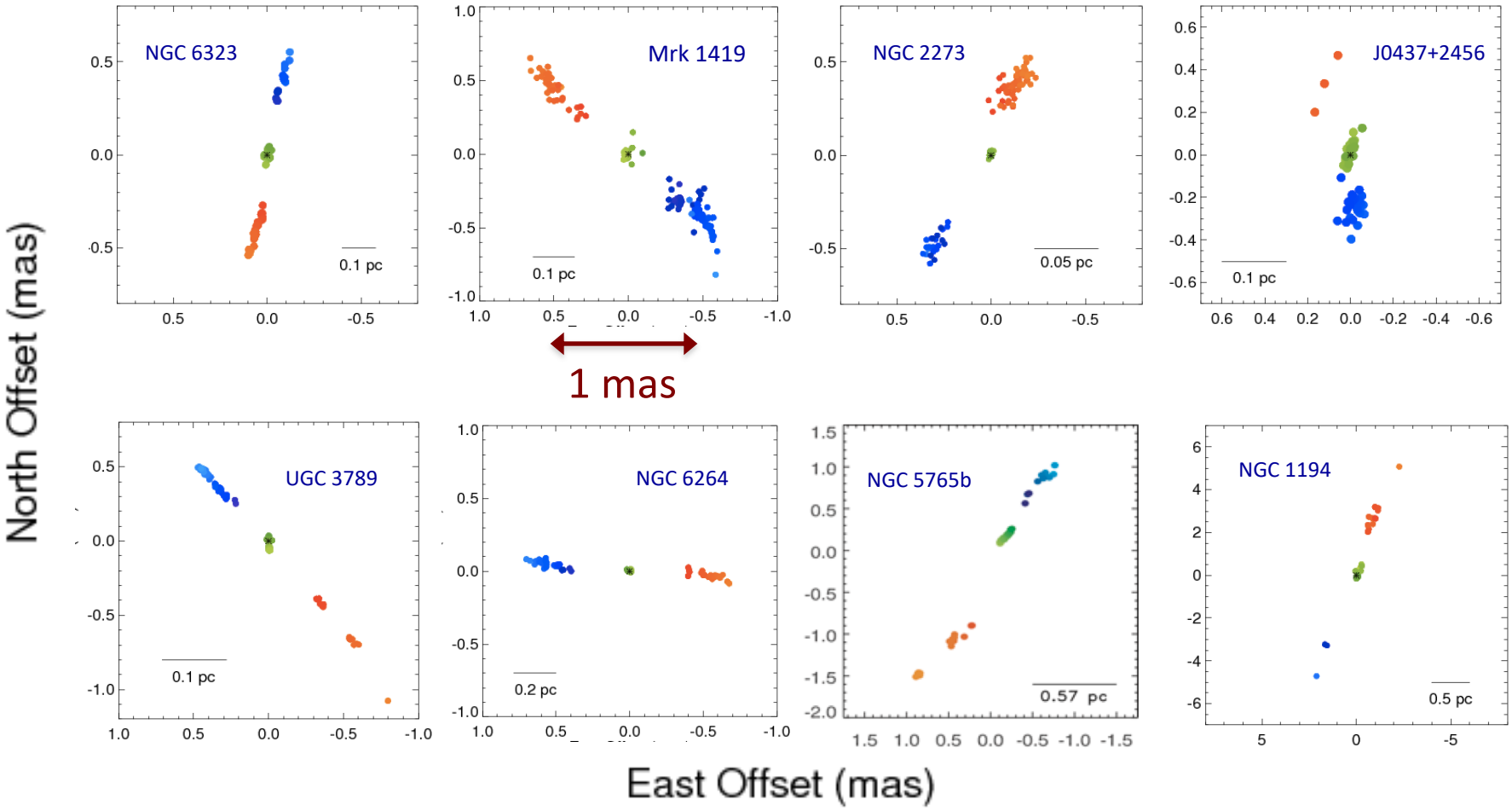
- Goal: H_o accurate to 3%
- How: Geometric Distances to H_2O masers in Hubble Flow

GBT finds masers

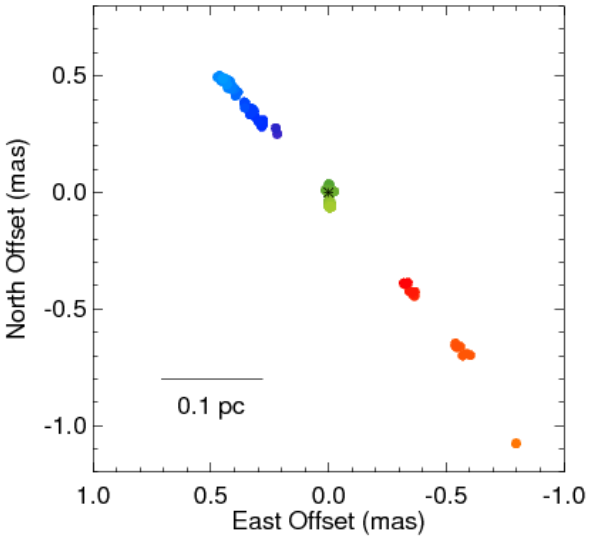


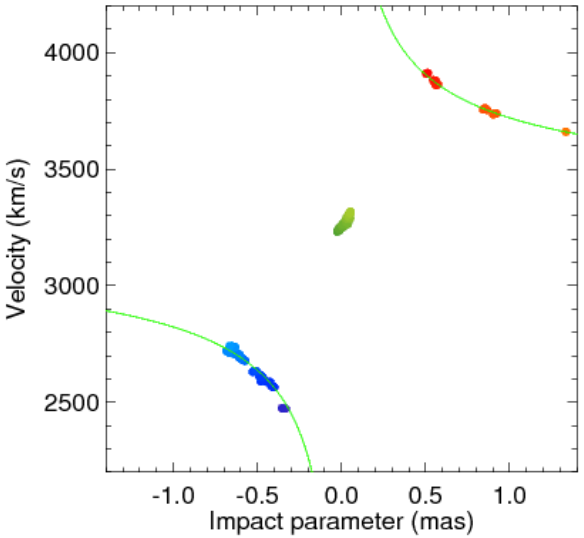
VLBA+GBT+Effelsberg maps them

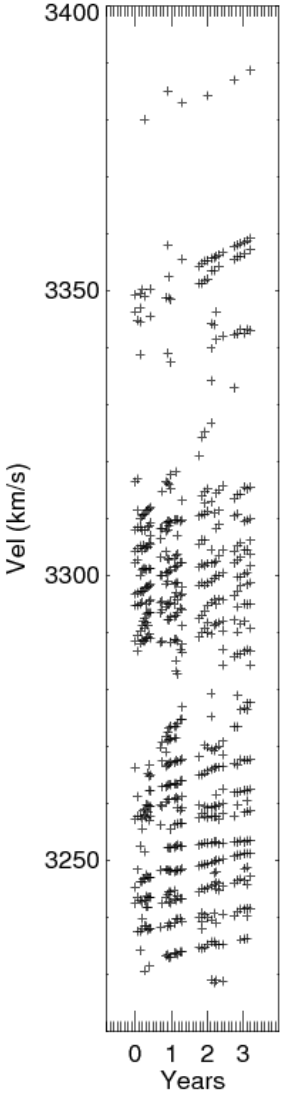
H_2O Megamaser Disks

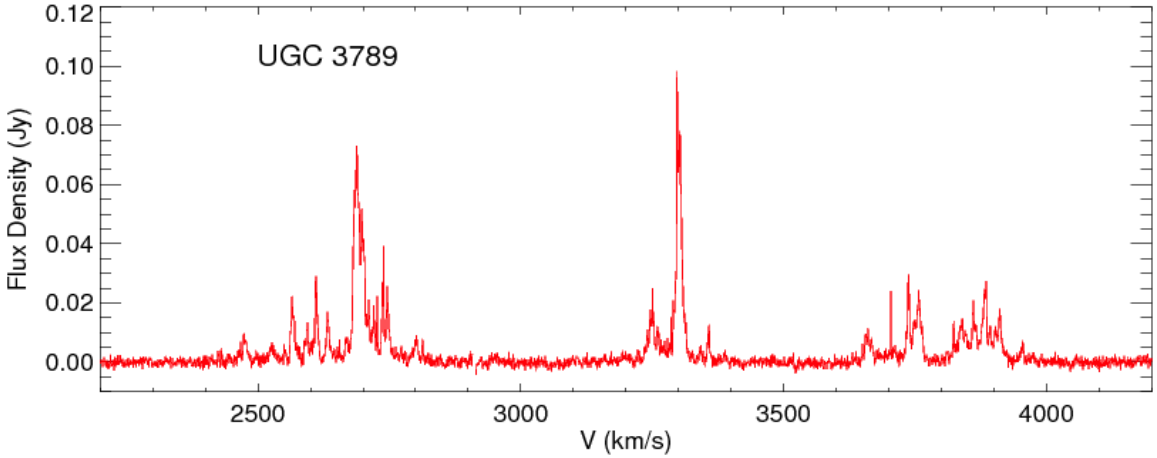


UGC 3789

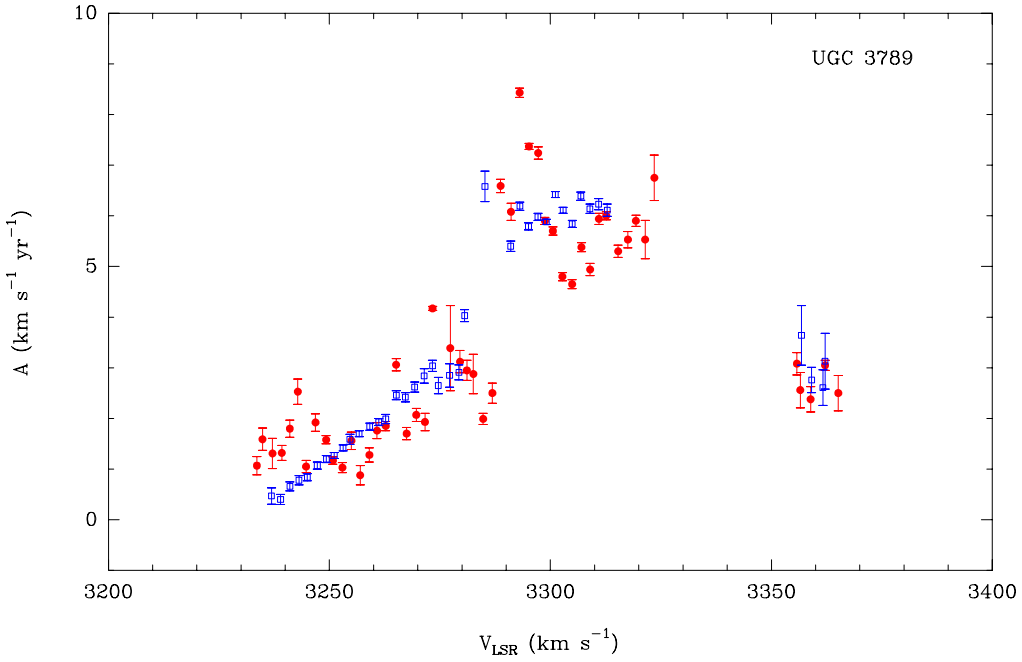

North Offset (mas)
East Offset (mas)
0.1 pc


Velocity (km/s)
Impact parameter (mas)

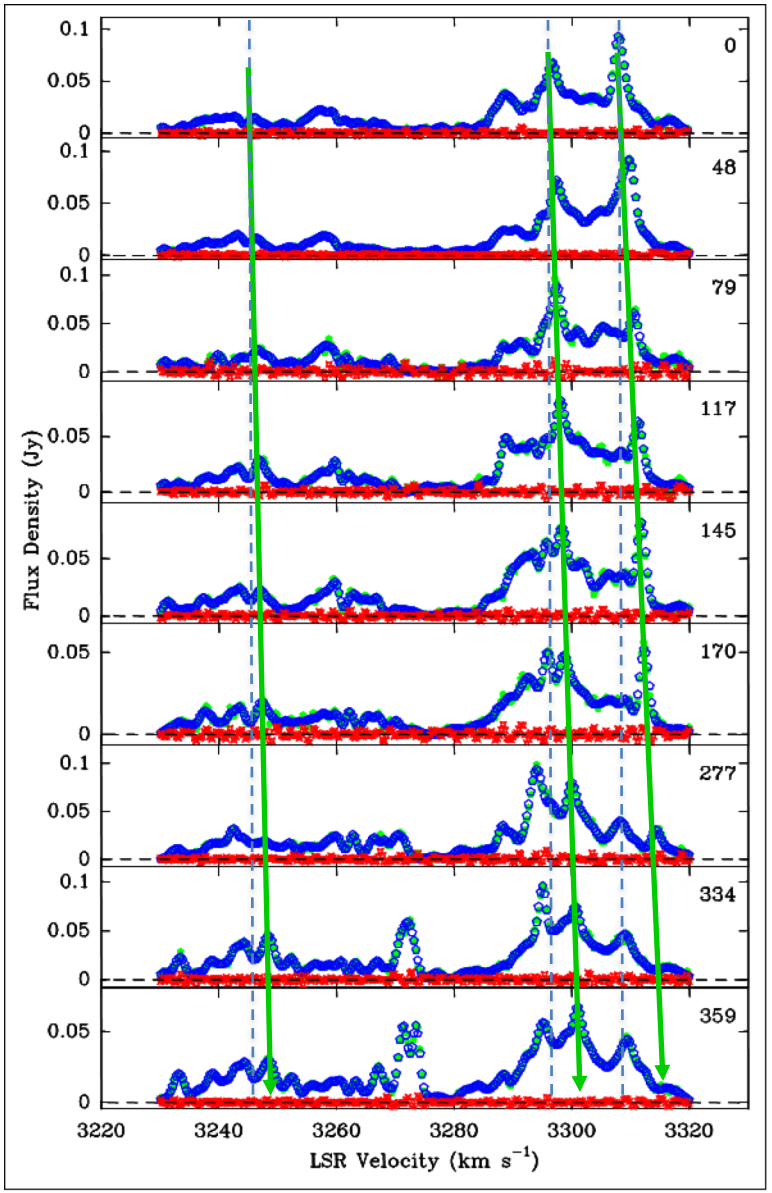

Vel (km/s)
Years


UGC 3789
Flux Density (Jy)
V (km/s)

UGC 3789

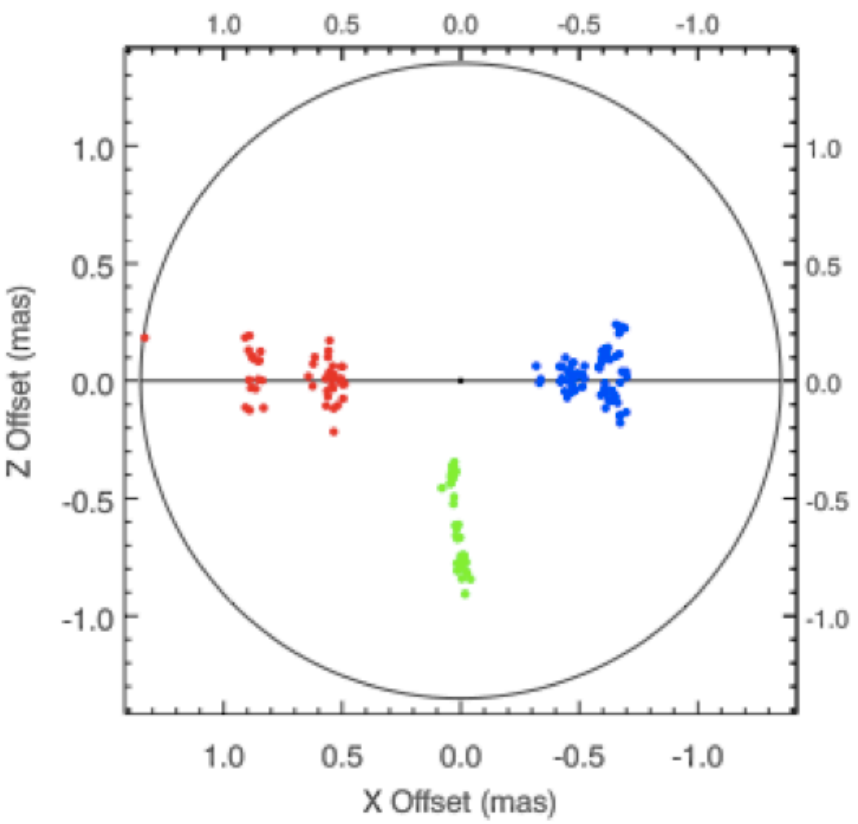


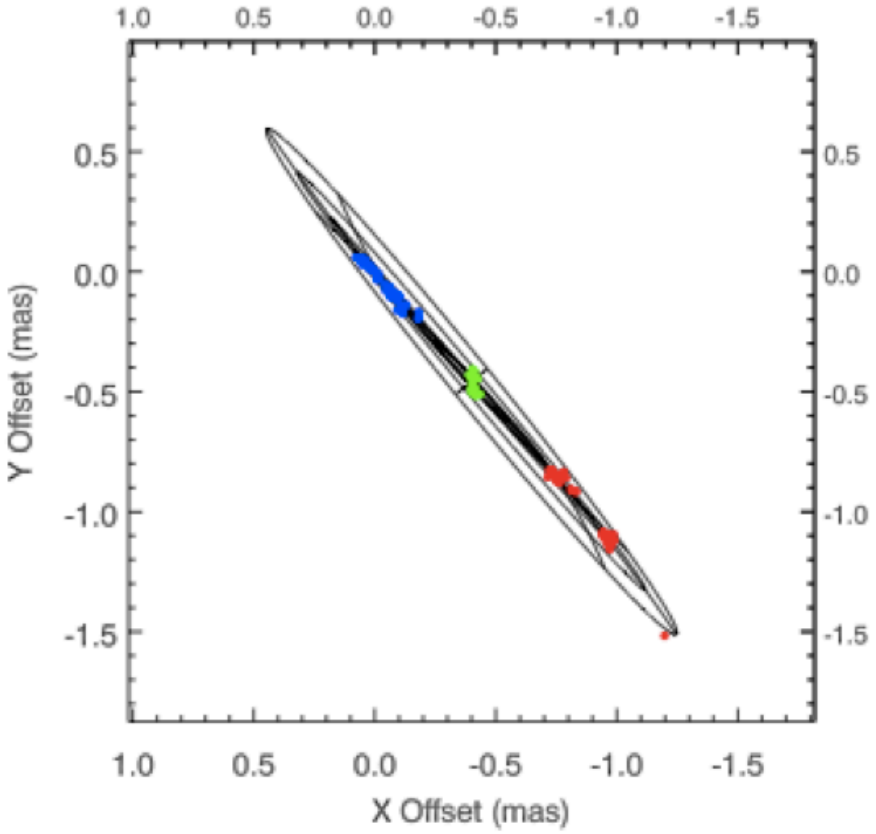
2 km/s/yr 5 km/s/yr 6 km/s/yr



UGC 3789

$H_0 = 66.2 \pm 6.3$ km/s/Mpc





$M_{BH} = 1.21 (\pm 0.09) \times 10^7 M_{sun}$; $V_{GC\text{-}frame} = 3470 \pm 1$ km/s; $D = 53.2 \pm 4.5$ Mpc

H_0: an MCP Status Report

Galaxy	Distance (Mpc)	H_0 (km/s/Mpc)
UGC 3789	53	66.2 ± 6.3
CGCG 074-064	85	83.2 ± 6.7
NGC 5765b	110	75.5 ± 4.5
NGC 6264	141	74.9 ±10.8
Combined		74.8 ± 3.1

(variance-weighted average with $\chi^2 = 3.45$ for 3 degrees of freedom)