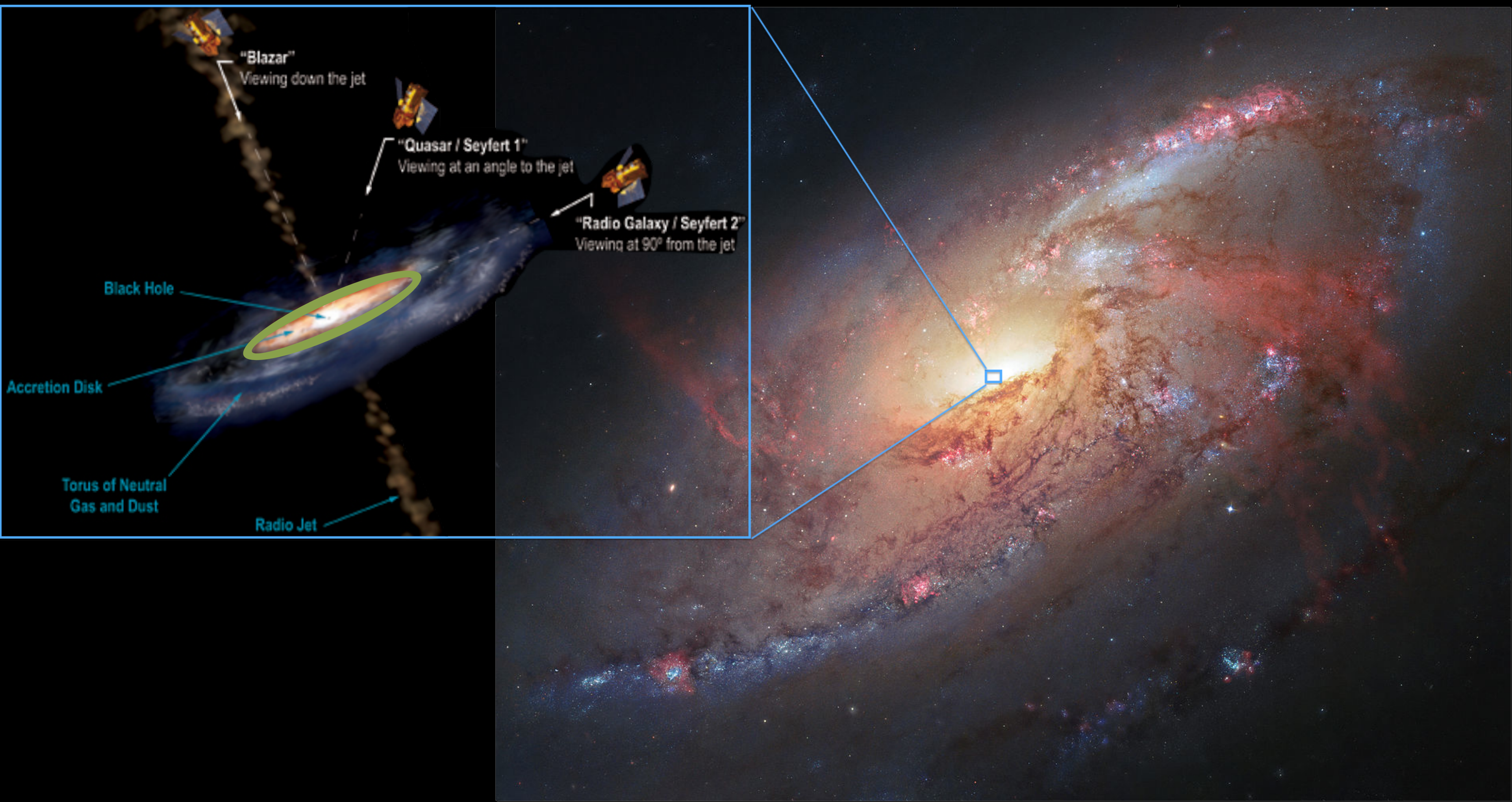
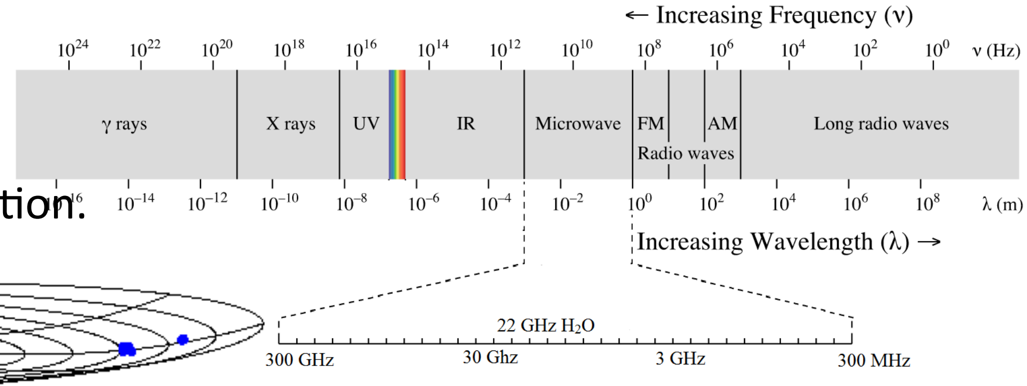
Probing the Connection Between Water Maser and X-ray Emission in Galaxy Centers

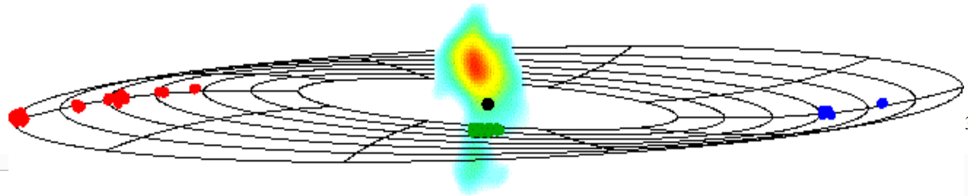
Drew Nutter

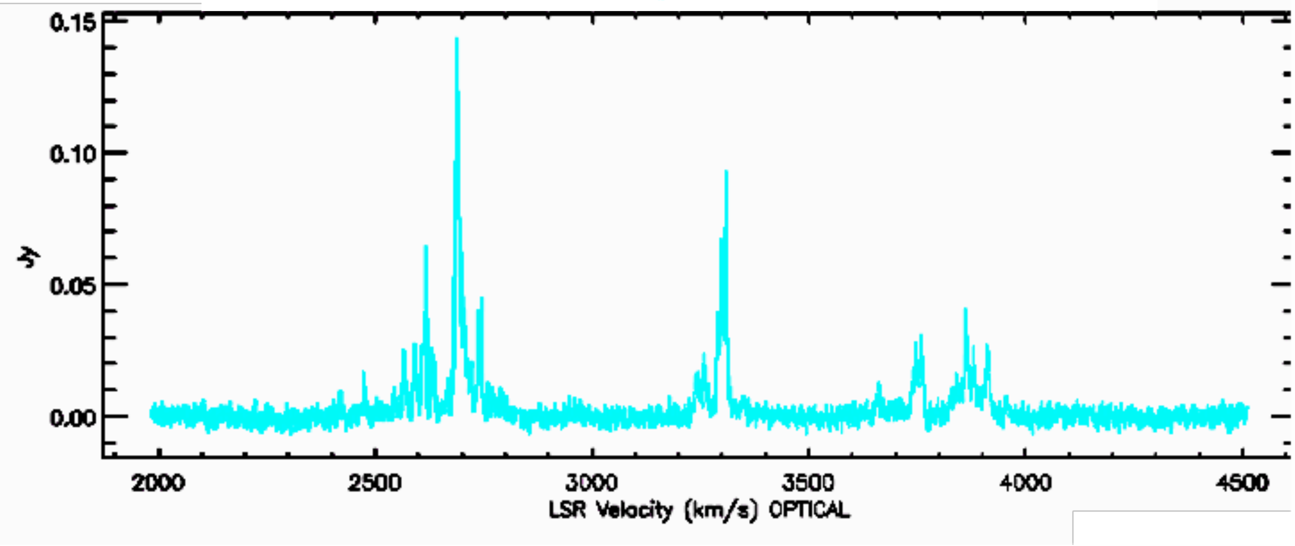


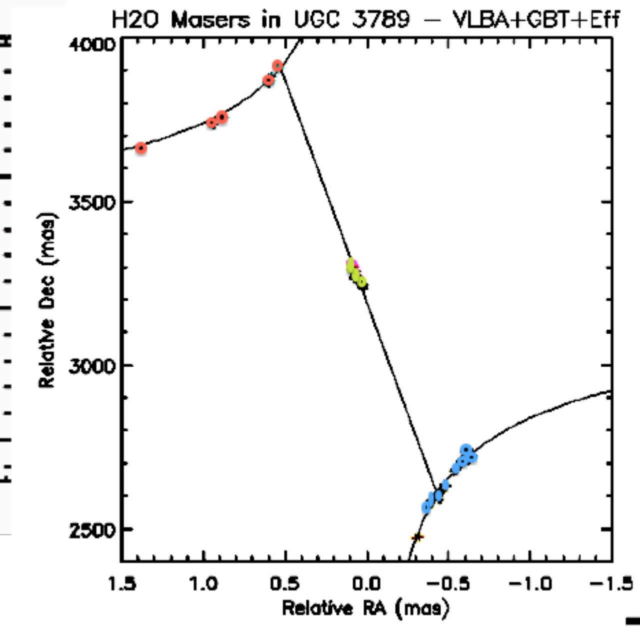
Megamasers

- Identified by 22 GHz microwave emission.
- 4% of galaxies have megamaser emission.
- Only 20% of those 4% are in disk configuration.









Cosmology

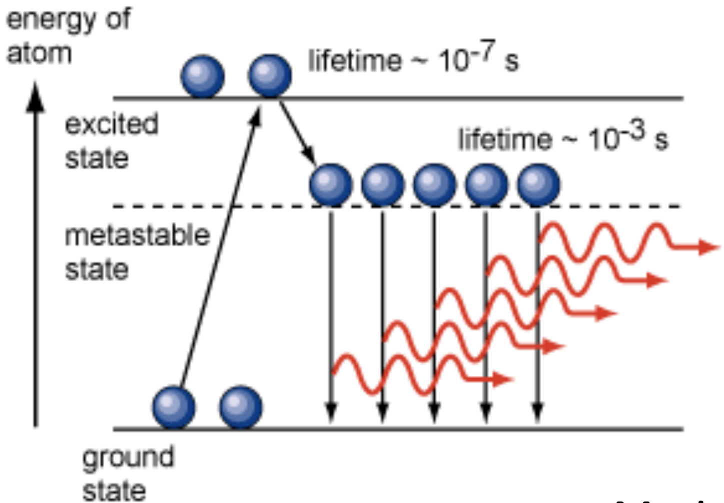
- Directly calculate extragalactic distances.
- Hubble Constant

Supermassive Black Hole

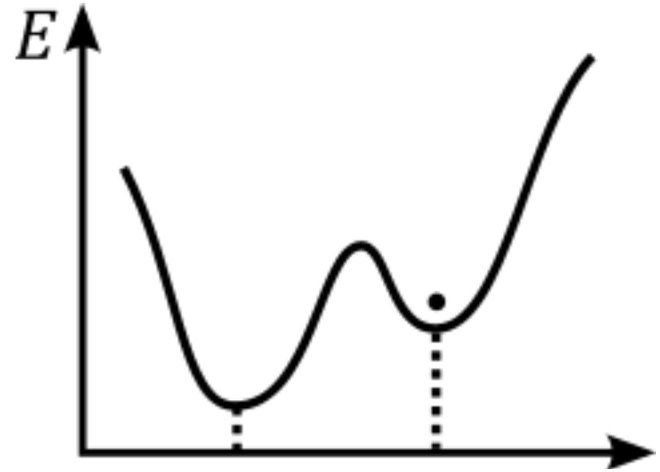
- Most accurate measurement for mass

MASER

Microwave Amplification by Stimulated Emission of Radiation

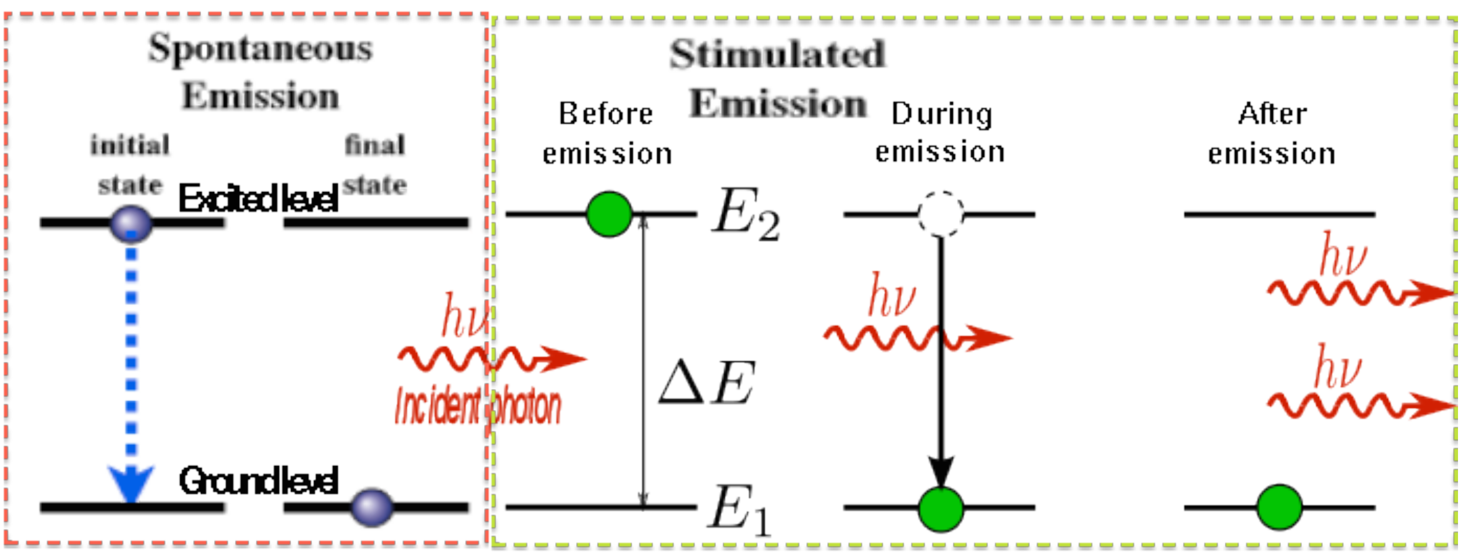


Masing process

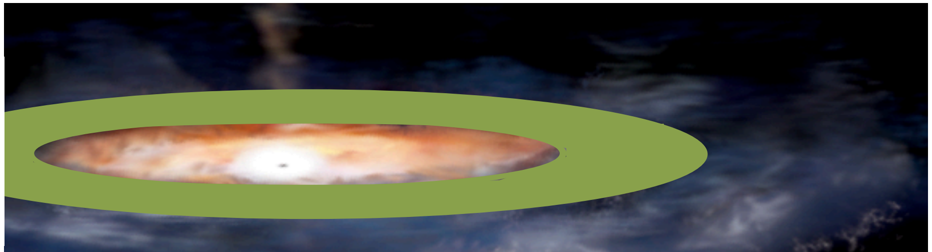


Metastability

1. Population inversion to a metastable excited state
2. H_2O molecule de-excites: radiate 22 GHz photon
3. Photon stimulates de-excitation 22 GHz emission from other molecule



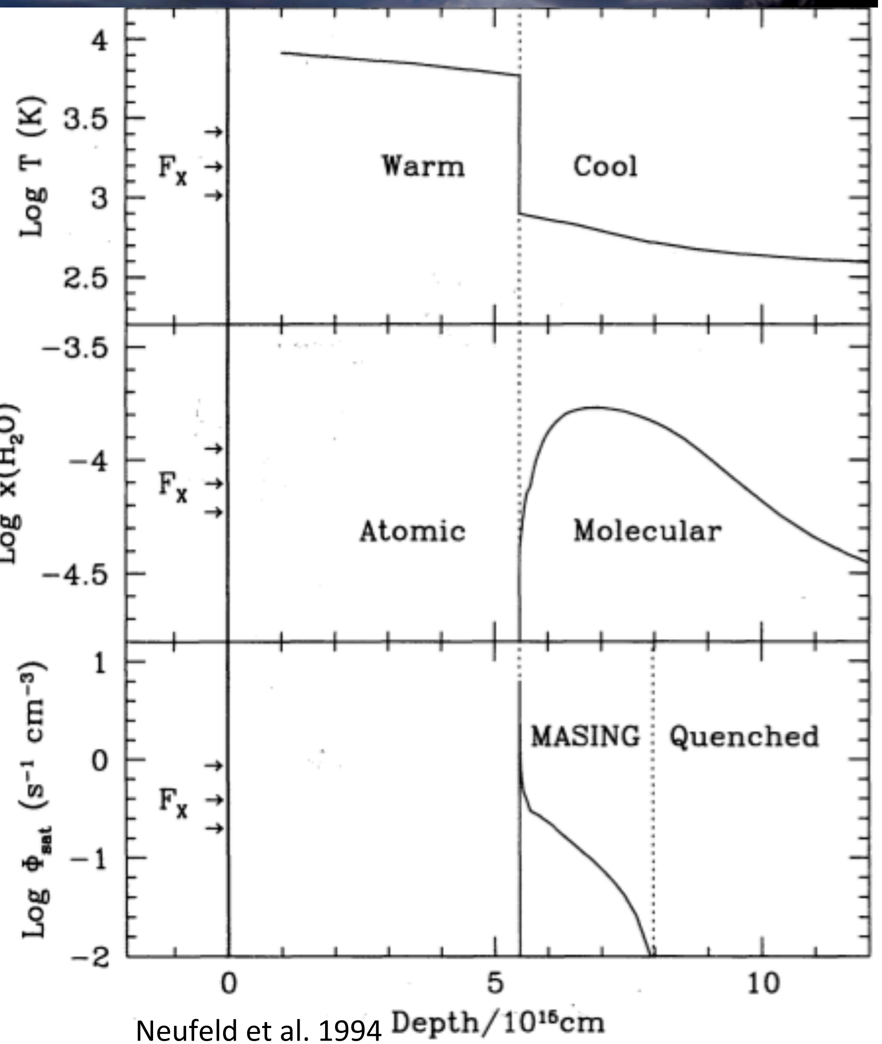
Masing Conditions in Megamasers



Temperature

H2O Abundance

Maser Emission



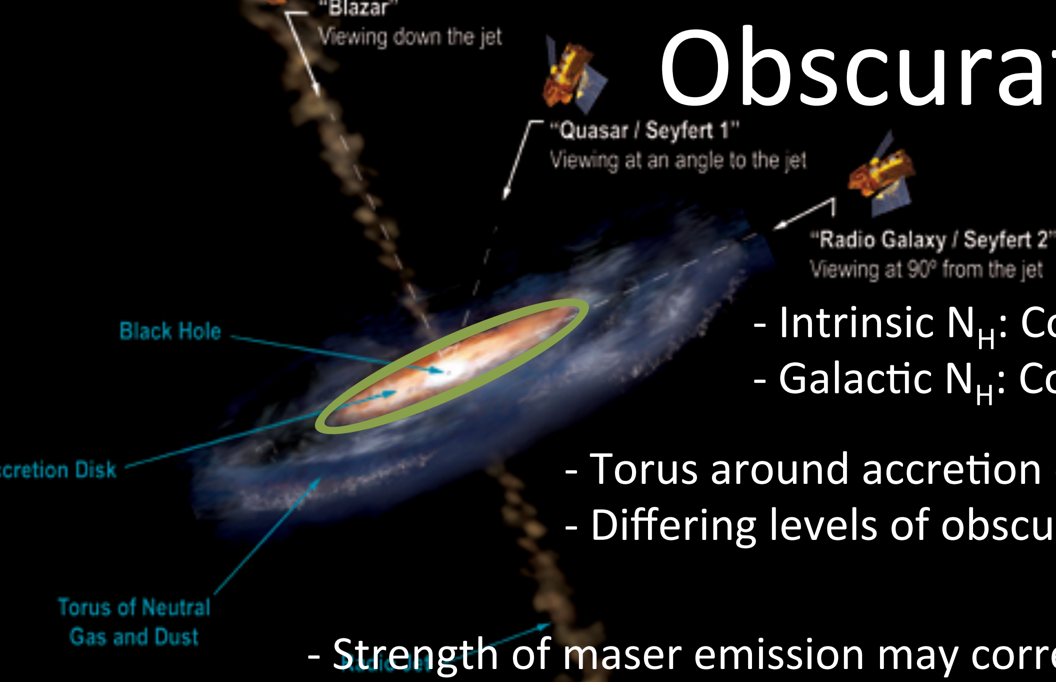
Neufeld et al. 1994

- Active Galactic Nucleus (AGN): Central supermassive black hole with active accretion.
- X-ray emission from accretion disk heats surrounding clouds of gas.
- This heat provides energy to create population inversion required for maser emission.

H_2O Maser Requirements:
- Cool enough to form molecules
- Warm enough for population inversion.
- High abundance of H_2O

Non-masing zones:
-Inner area too hot: Atoms only.
-Outer area too cool: Quenched.
-Through radiative trapping, outer area insulates middle masing area

Obscuration



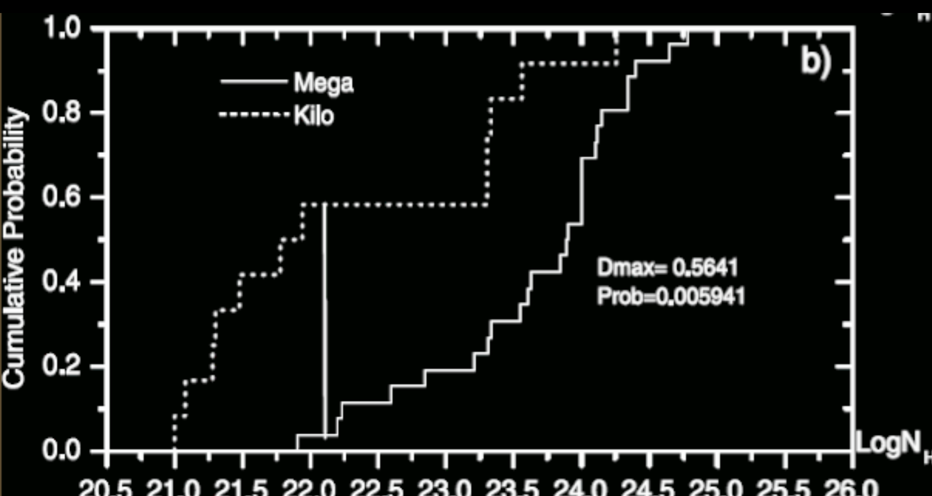
Column Density (N_H): Density of Hydrogen atoms along the line of sight.

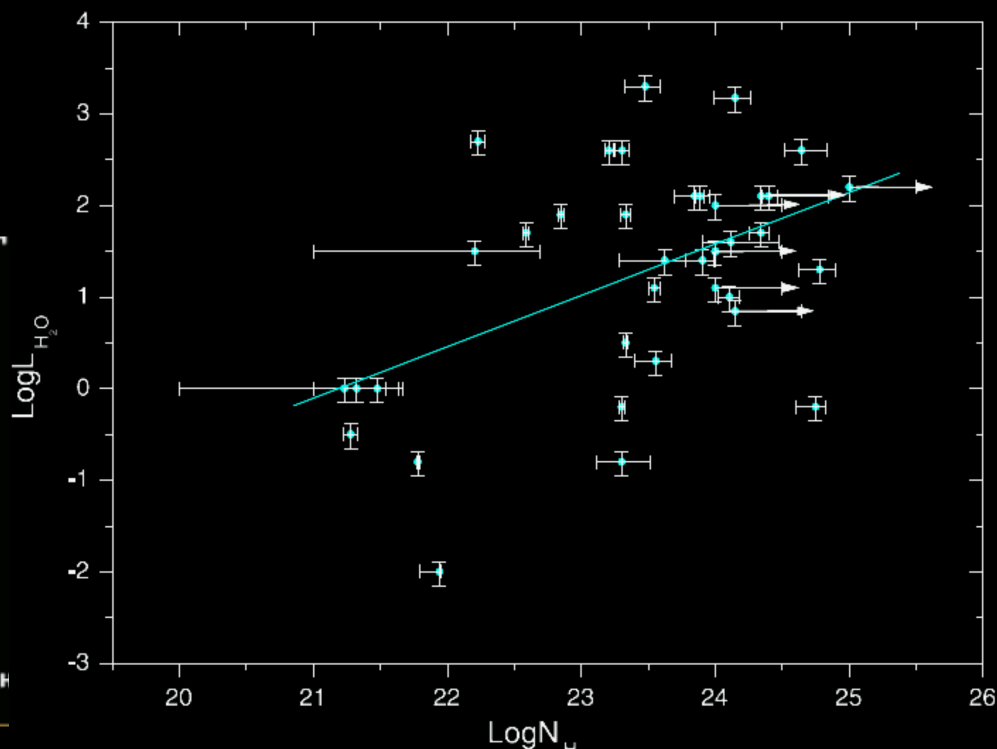
- Intrinsic N_H: Column density inherent to object viewed
- Galactic N_H: Column density within Milky Way

- Torus around accretion disk obscures X-ray emission (intrinsic N_H)
- Differing levels of obscuration depending upon angle viewed

- Strength of maser emission may correlate to column density.

- Maser clouds may increase obscuration.
- Greater numbers are needed for more conclusive evidence.

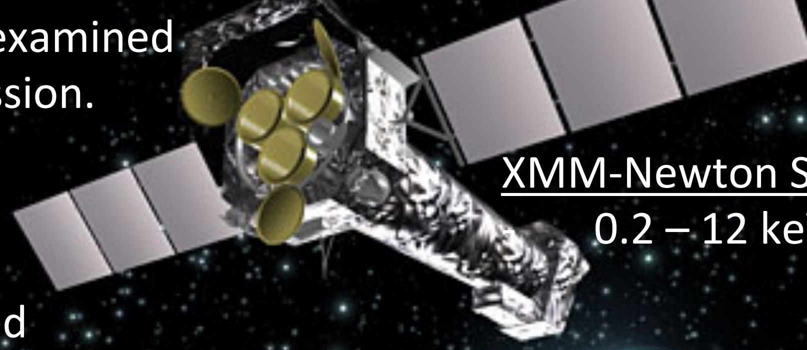




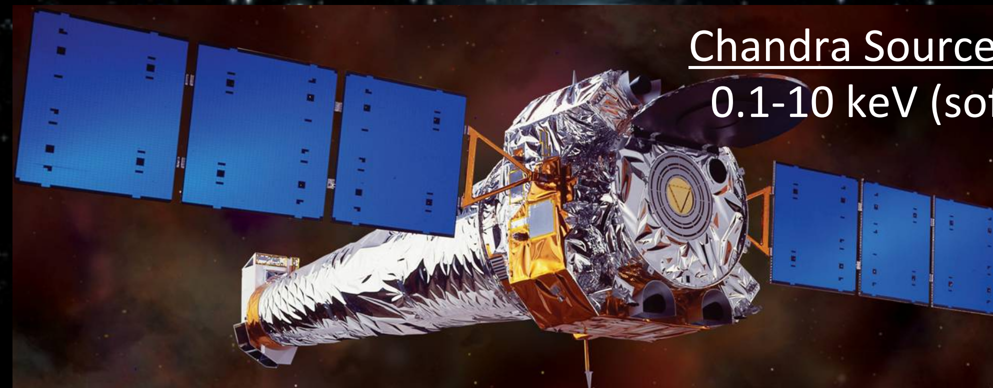
Catalogs

Previous Studies: 40 total galaxies examined with varying degrees of maser emission.

Megamaser Cosmology Project
- 151 total megamasers found (103 in X-ray catalogs)
- 3339 non-maser galaxies identified (650 in X-ray catalogs)



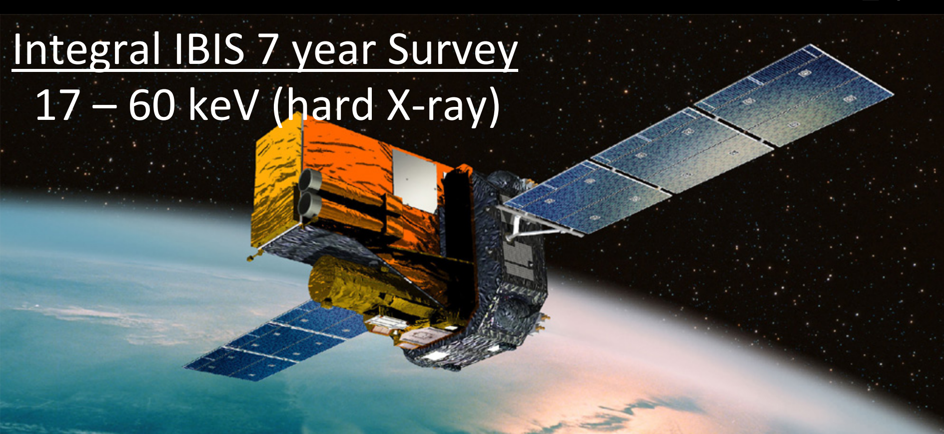
XMM-Newton Serendipitous Survey
0.2 – 12 keV (soft X-ray)



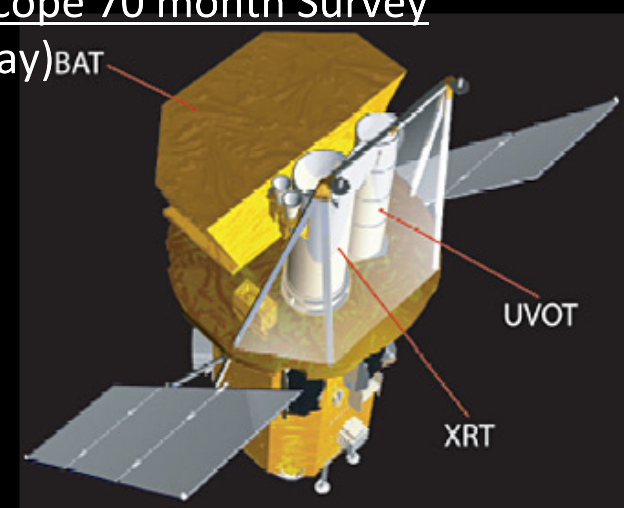
Chandra Source Catalog
0.1-10 keV (soft X-ray)

ROSAT All-Sky Survey (RASS)
0.1-2.4 keV (soft X-ray)

Swift Burst Alert Telescope 70 month Survey
14 – 195 keV (hard X-ray)

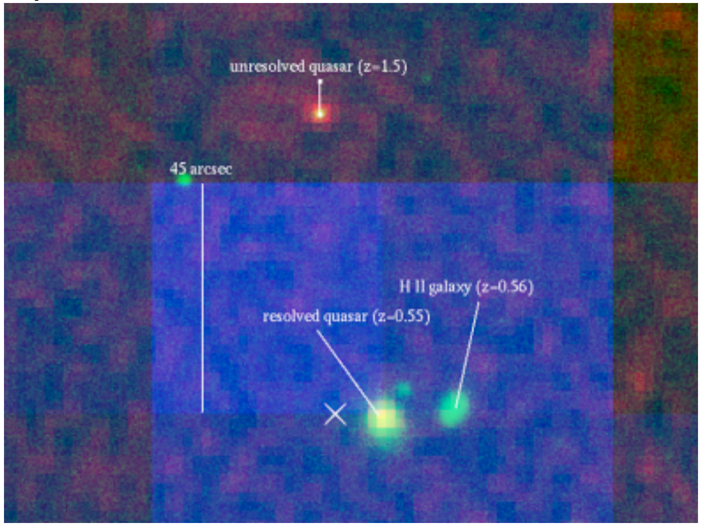


Integral IBIS 7 year Survey
17 – 60 keV (hard X-ray)



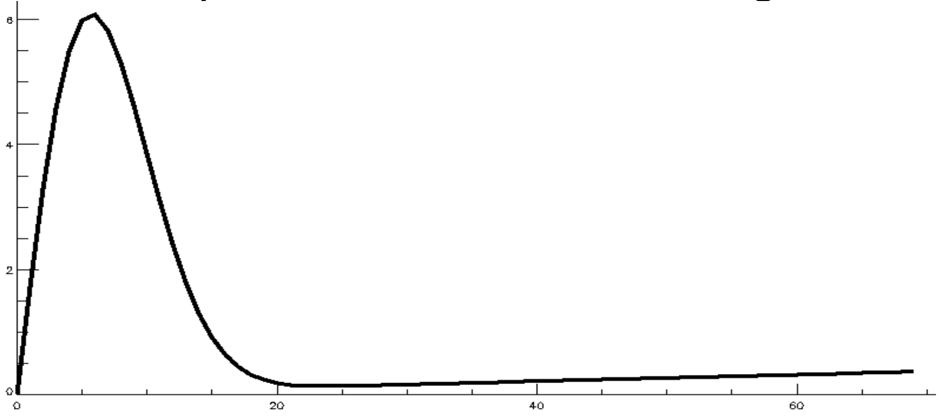
Cross-matching X-ray catalogs

- MCP objects identified by finding objects in X-ray catalog within given angular separation.
- Telescopes’ varying accuracies make crossmatching difficult.
- Must select angular separation that avoids mismatches and includes positive matches.



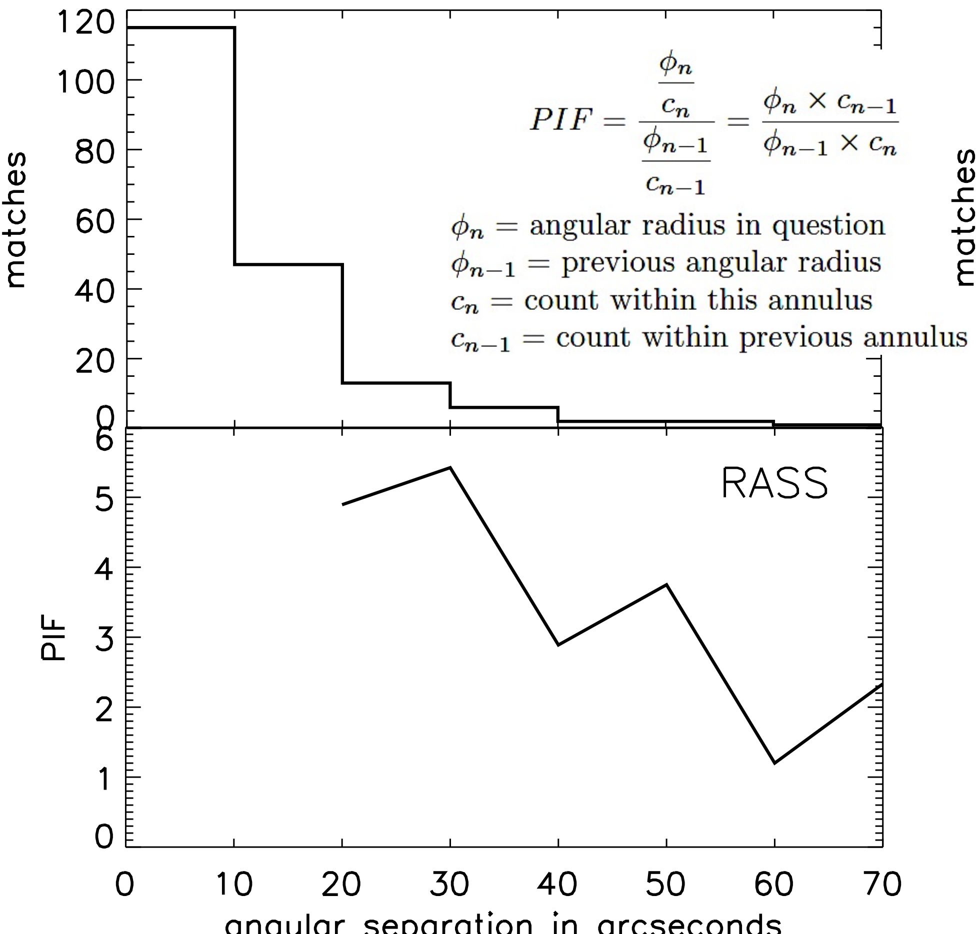
Parejko et al. 2008

- Histogram of all matches fits Rayleigh distribution with linear component for randoms.
- Ideal search should identify where random matches begin to dominate.



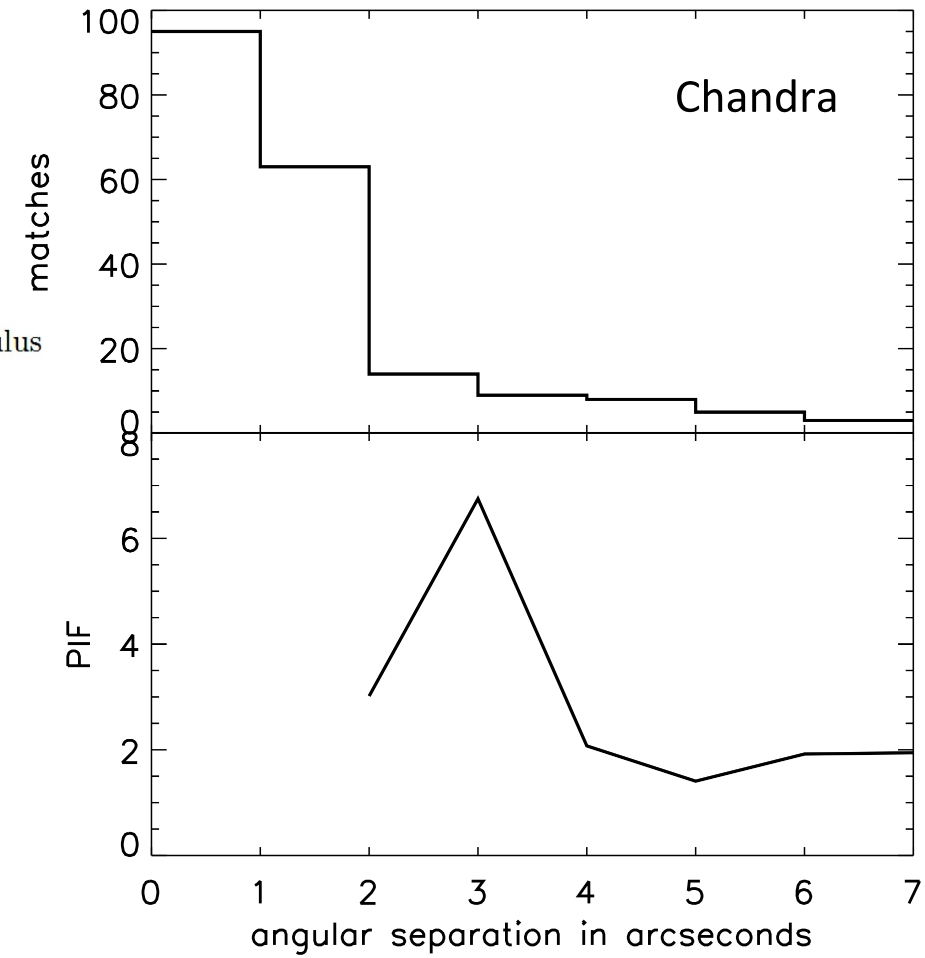
Selecting Angular Separation

- Percent Increase Factor (PIF): Novel method developed to aid angular separation selection.
- Represents rate of change of number of matches per annulus between search radii.
- Maximum approximates inflection points over curve that would fit histogram.
- Inflection point signals beginning of dominance of random matches (linear component).

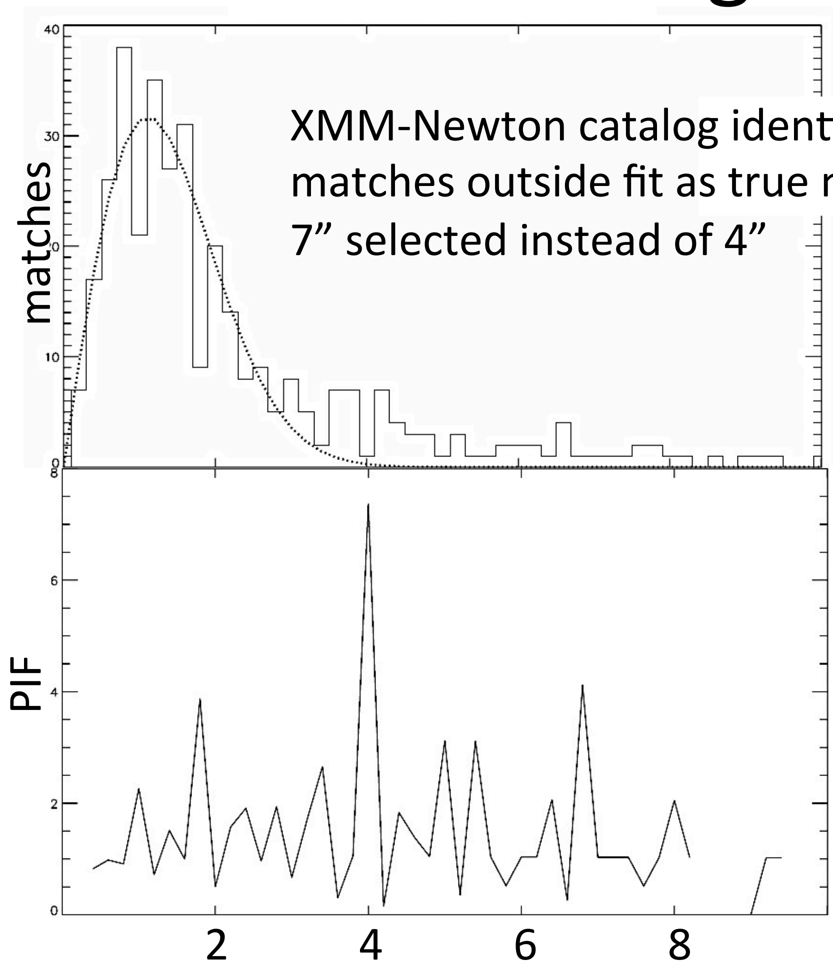


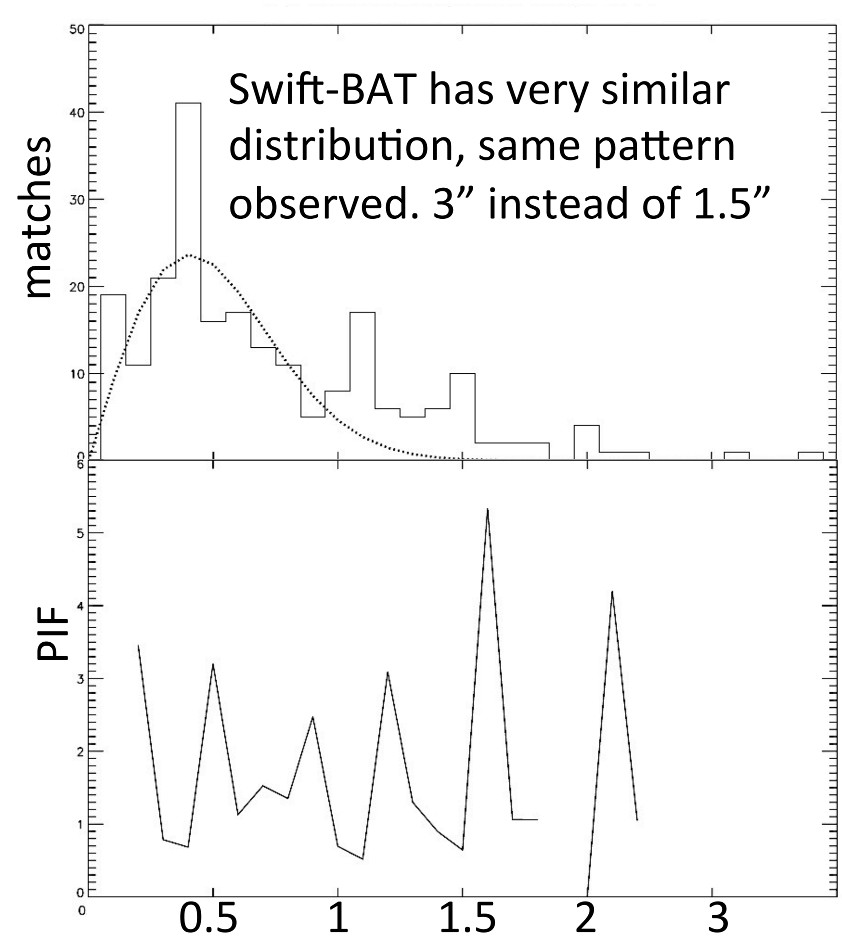
$$PIF = \frac{\frac{\phi_n}{c_n}}{\frac{\phi_{n-1}}{c_{n-1}}} = \frac{\phi_n \times c_{n-1}}{\phi_{n-1} \times c_n}$$

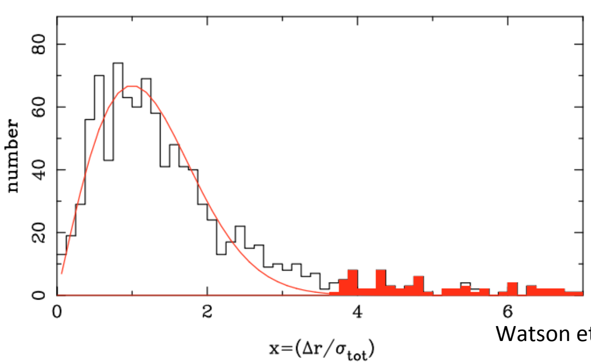
ϕ_n = angular radius in question
ϕ_{n-1} = previous angular radius
c_n = count within this annulus
c_{n-1} = count within previous annulus

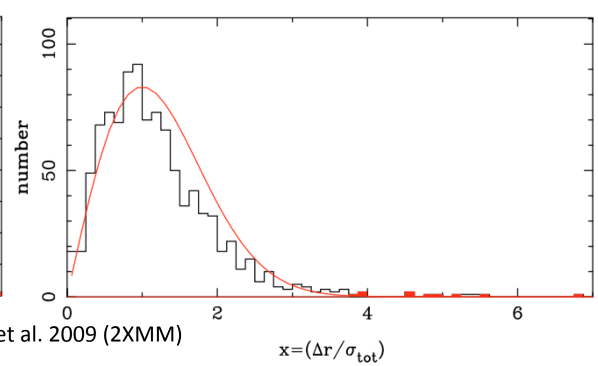


Accounting for Positional Error

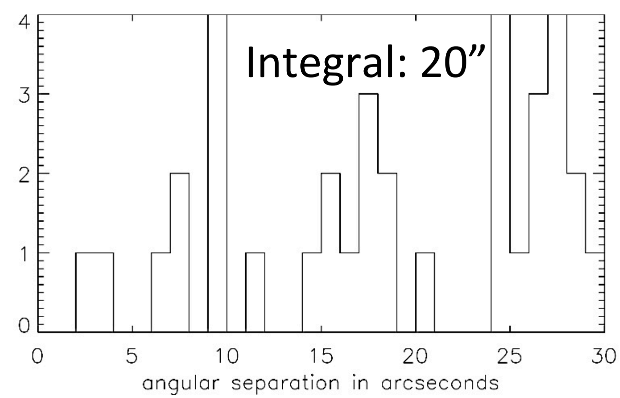








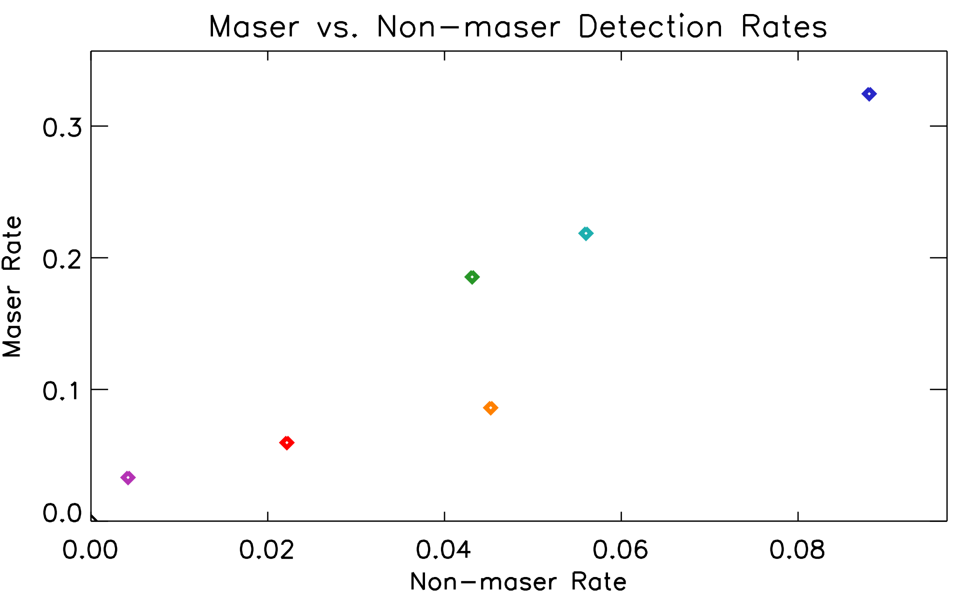
Watson et al. 2009 (2XMM)

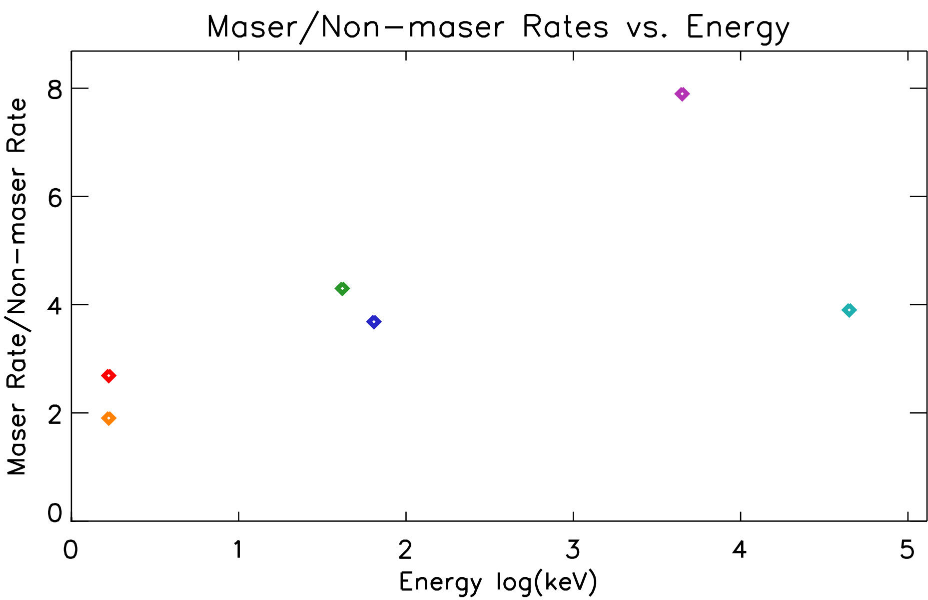


Detection rates

Catalog	Mean Energy (keV)	Non-masers count	Masers count	Non-maser detection rate	Maser detection rate	maser rate / non-maser rate
RASS Faint Source	1.25	74	9.0	0.022	0.060	2.689
RASS Bright Source	1.25	151	13.0	0.045	0.086	1.904
Chandra	5.05	144	28	0.043	0.185	4.300
XMM-Newton	6.10	294	49	0.088	0.325	3.685
Swift-BAT	104.50	187	33	0.056	0.219	3.902
Integral	38.50	14	5	0.004	0.033	7.897
MEAN	26.11	864	137.0	0.043	0.151	3.506

Masers have X-ray detection rate 3.5 times as great as non-masers

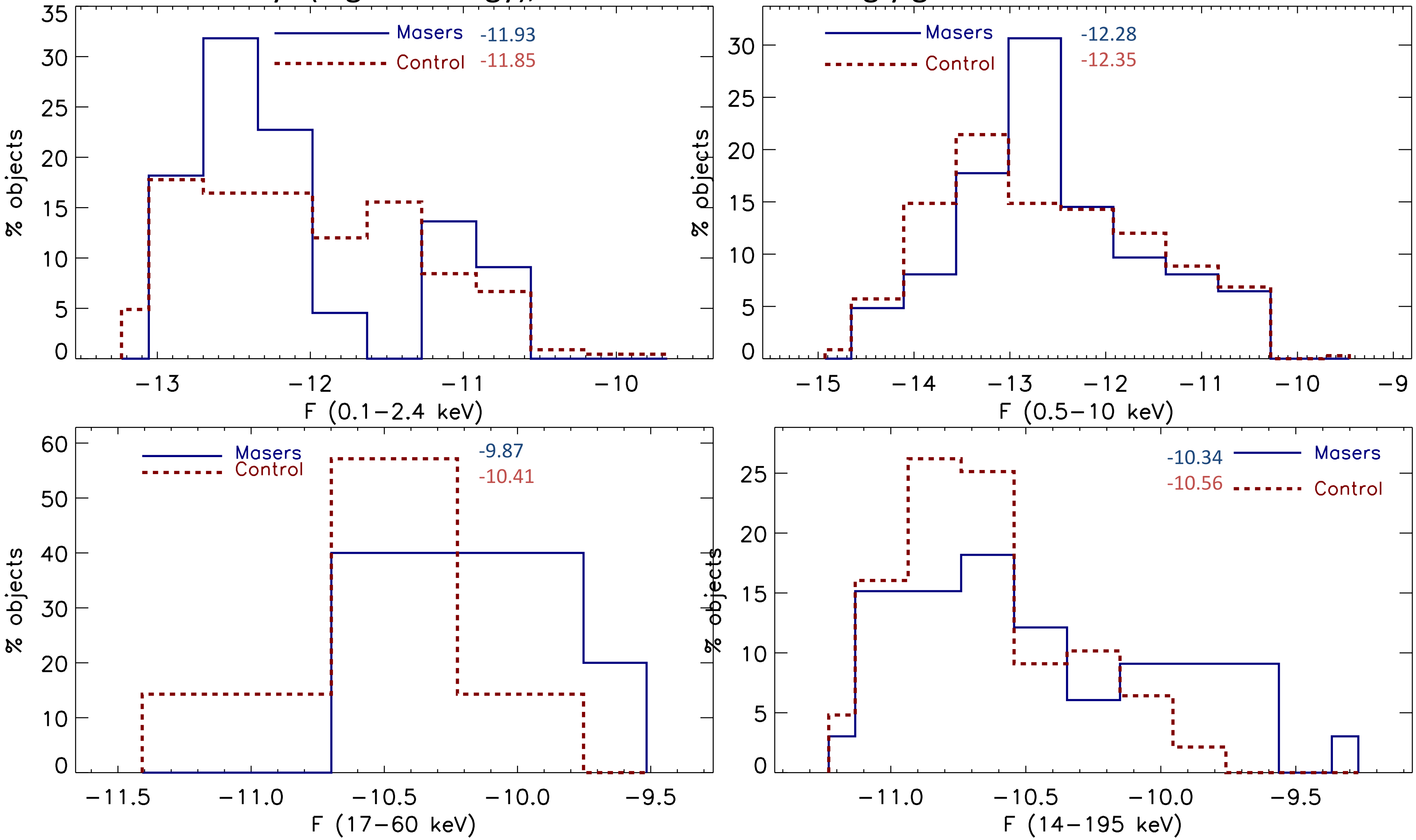




X-ray Fluxes :

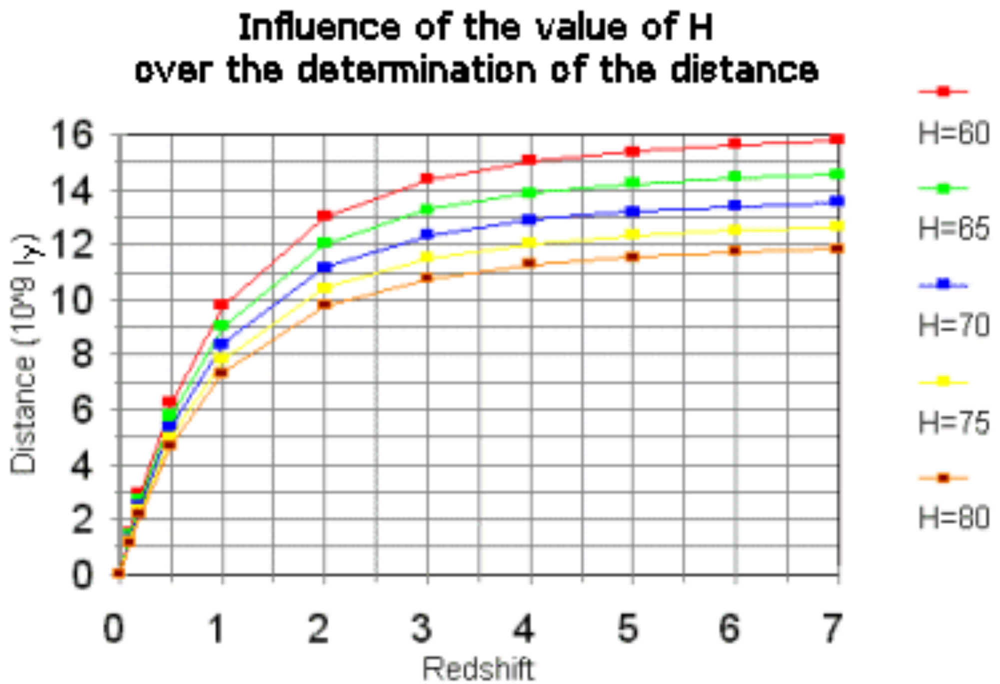
- Calculated flux for each object considering catalog's flux or count rate
- Used Galactic (Milky Way) N_H to account for absorption.
- Merged Chandra and XMM-Newton data for 0.5-10 keV range.

- Similar fluxes between masers and non-masers for soft X-rays. (mean flux values listed)
- In harder X-rays (higher energy), masers have increasingly greater flux than non-masers.



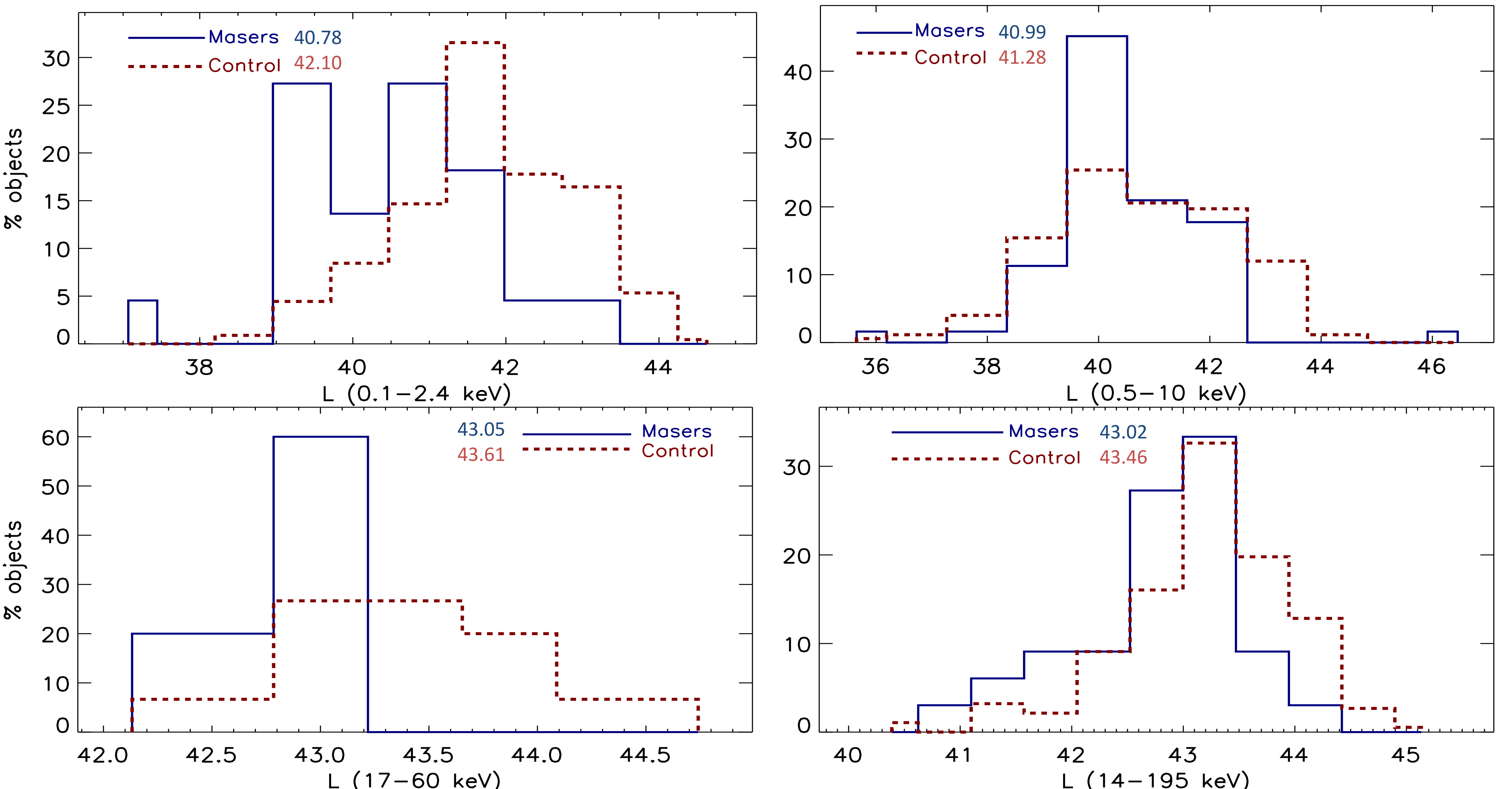
Luminosity Distance

- Calculating astronomical distances is tricky.
- Luminosity distance(d_L): Distance light has traveled, not necessarily actual distance.
- Modeled from redshift based on estimate of Hubble constant.
- Varies widely depending on model.
- Necessary to determine intrinsic luminosity of an object from its flux.
- Masers are important partly because they can give us a method to directly calculate this.



X-ray Luminosity

- $L = 4\pi \times d_L^2 \times F$
- Non-masers consistently more luminous (mean luminosity values listed).



Discussion

- Data resulting from crossmatch represents X-ray active subset of MCP all-surveyed.
- High maser detection rate suggests megamasers are more X-ray active than non-masers.
- Megamaser galaxies are increasingly active in harder X-rays.

- Among X-ray active sources, non-maser sources are more X-ray luminous than masers.
- Maser emission previously associated with obscuration.
- Lower intrinsic luminosities may represent X-ray obscuration, providing evidence for new constraint in megamaser search.