A Multi-Parameter Statistical Analysis of the Connection Between H_2O Maser Emission and Nuclear Galactic Activity

– or –

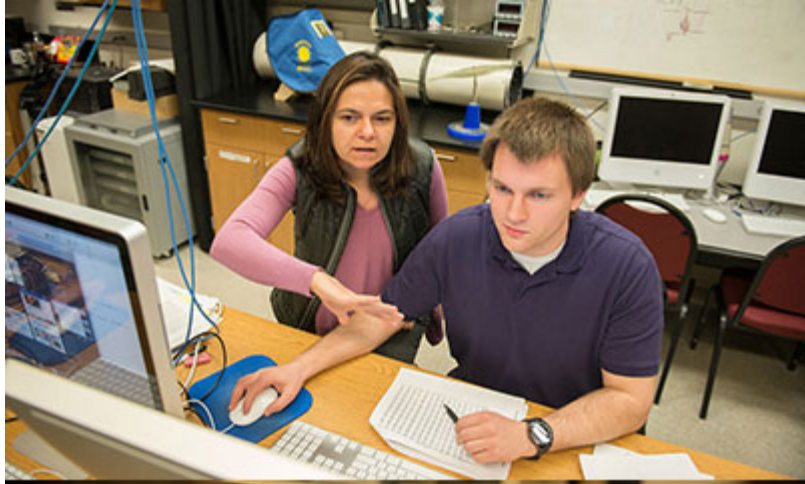
How to Hunt Masers with Statistics

Emil Christensen

Department of Physics and Astronomy

James Madison University

This work benefitted from collaboration with James Corcoran, Nathan DiDomenico, Robert Roten, Emily Dick and members of the Mega-Maser Cosmology Project (MCP) and from the generous advice and support of Dr. Anca Constantin



Article published on www.jmu.edu/stories (March 2013)

Motivation

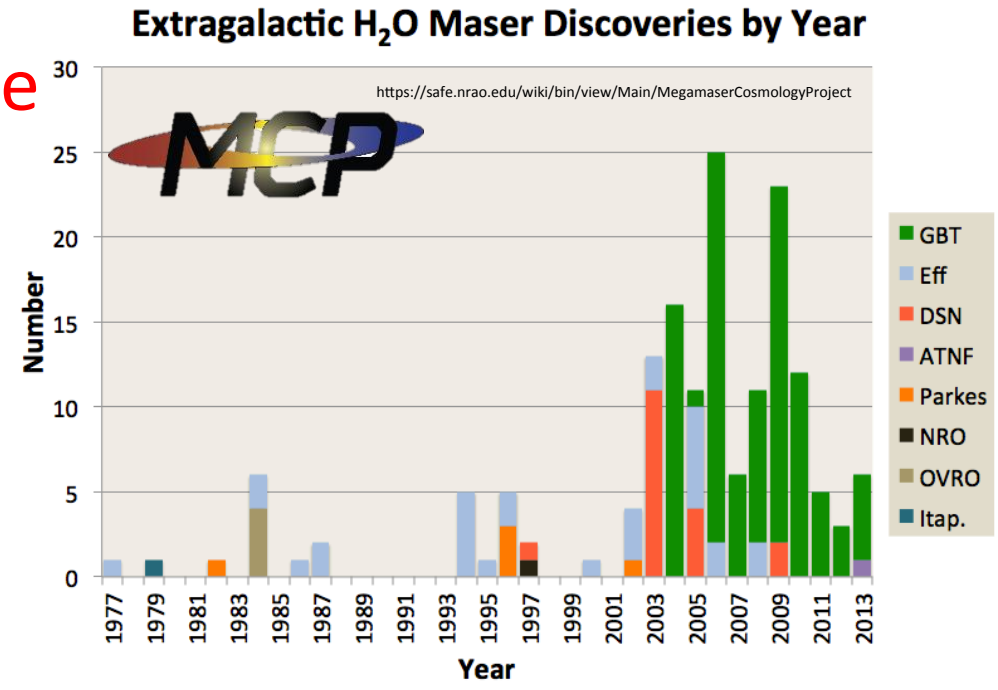
> 3500 objects surveyed

150 masers found!

≈ 4% maser detection rate

≈ 2% mega-maser ($L_{H2O} > 10\ L_{SUN}$)

< 1% in crucial disk like configuration



Optical Spectral Data

“The Literature”


THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 112:315–390, 1997 October

A SEARCH FOR “D[illegible] SEYF[illegible] PA[illegible]METERS AND PROPERTIES OF THE HOST GALAXIES

LUIS C. HO[1] AND ALEXEI V. FILIPPENKO
Department of Astronomy, University of California, Berkeley, CA 94720-3411
AND
WALLACE L. W. SARGENT
Palomar Observatory, 105-24 Caltech, Pasadena, CA 91125
Received 1996 December 10; accepted 1997 May 1

ABSTRACT

We have completed an optical spectroscopic survey of the nuclear regions ($r \lesssim 200$ pc) of a large sample of nearby galaxies. Although the main objectives of the survey are to search for low-luminosity active galactic nuclei and to quantify their luminosity function, the database can be used for a variety of other purposes. This paper presents measurements of the spectroscopic parameters for the 418 emission-line nuclei, along with a compilation of the global properties of all 486 galaxies in the survey. Stellar absorption generally poses a serious obstacle to obtaining accurate measurement of emission lines in nearby galactic nuclei. We describe a procedure for removing the starlight from the observed spectra in an efficient and objective manner. The main parameters of the emission lines (intensity ratios, fluxes, profile widths, and equivalent widths) are measured and tabulated, as are several stellar absorption-line and continuum indices useful for studying the stellar population. Using standard nebular diagnostics, we determine the probable ionization mechanisms of the emission-line objects. The resulting spectral classifications provide extensive information on the demographics of emission-line nuclei in the nearby regions of the universe. This new catalog contains over 200 objects showing spectroscopic evidence for recent star formation and an equally large number of active galactic nuclei, including 46 that show broad Hα emission. These samples will serve as the basis of future studies of nuclear activity in nearby galaxies.
Subject headings: galaxies: active — galaxies: fundamental parameters — galaxies: ISM — galaxies: nuclei — galaxies: Seyfert

1. INTRODUCTION

We have recently completed an extensive optical spectroscopic survey of the nuclei ($r \lesssim 200$ pc) of nearby galaxies. The main goals of the survey are to systematically search for and to investigate the physical properties of low-luminosity, or “dwarf,” active galactic nuclei (AGNs), but the rich database can be used for a variety of other applications. In previous papers in this series, we have outlined the scientific objectives and observational parameters in greater detail (Filippenko & Sargent 1985, hereafter Paper I; Ho, Filippenko, & Sargent 1995, hereafter Paper II), and several companion papers present various aspects of the analysis (Ho, Filippenko, & Sargent 1997a, 1997b, 1997c, 1997d; Ho et al. 1997e). In brief, high-quality, long-slit, optical spectra of moderate resolution were obtained of the nucleus of almost every bright galaxy in the northern ($\delta > 0°$) sky. The chosen magnitude limit is $B_T = 12.5$ mag, and the objects were selected from the Revised Shapley-Ames Catalog of Bright Galaxies (RSA; Sandage & Tammann 1981). The spectra were acquired using the Hale 5 m telescope at Palomar Observatory and cover the regions ~4230–5110 Å and ~6210–6860 Å, with spectral resolutions of approximately 4 and 2.5 Å, respectively. Paper II presents a complete spectral atlas of the 486 galaxies contained in the Palomar survey.

The observational distinction between low-luminosity and high-luminosity AGNs is largely arbitrary. Our survey contains mostly nearby galaxies and is designed to select objects on the faint end of the luminosity function. Thus, our study probes much lower luminosities than in other, more conventional AGN samples. The Palomar AGNs have a median (extinction-corrected) Hα luminosity of only 2×10^{39} ergs s^{-1}, and over 85% of the sources lie below $L(H\alpha) = 10^{40}$ ergs s^{-1} (Ho et al. 1997a). By contrast, the typical Seyfert nucleus in the widely-studied Markarian catalog emits roughly 10^{41} ergs s^{-1} in Hα (estimated from the compilations of Mazzarella & Balzano 1986 and Whittle 1992a). Operationally, we will henceforth define “low-luminosity” or “dwarf” AGNs to be those with $L(H\alpha) \leq 10^{40}$ ergs s^{-1}.

This paper focuses on the quantification of spectroscopic parameters from the Palomar survey. The measurements of the emission lines are presented in § 2, where we also discuss in depth our method of starlight subtraction. Section 3 describes our method of spectral classification and the results of applying it to our survey, while § 4 presents the measurements of several stellar absorption-line and continuum indices useful for studying the stellar population. Finally, for easy reference and subsequent analysis, we summarize in § 5 a number of global properties of the host galaxies.

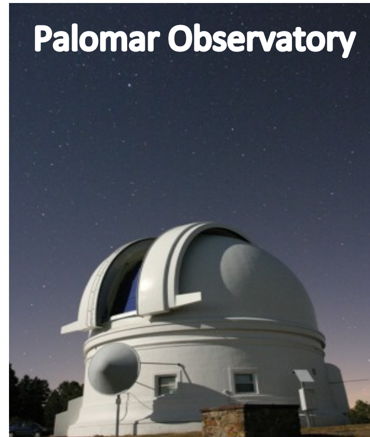
2. EMISSION LINES

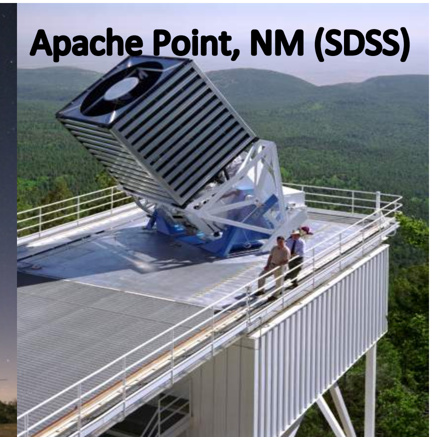
2.1. *Starlight and Continuum Subtraction*

The optical spectra of many emission-line nuclei, particularly those residing in host galaxies of early to intermediate Hubble types (Sbc and earlier), are contaminated heavily, and often dominated, by the stellar component. As late-type

[1] Present address: Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138.

315





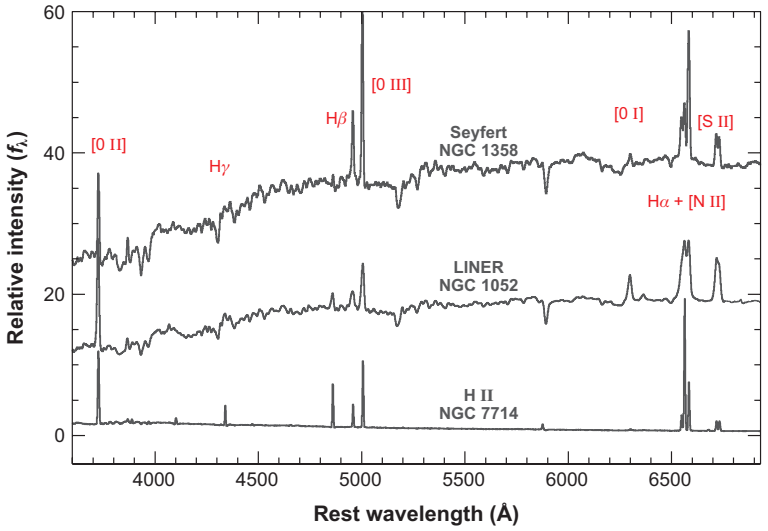
Source	Control	Masers	Mega-masers	Disks
SDSS	1181	46	34	7
Palomar	183	26	11	4
Palomar & SDSS[a]	25	7	2	1
Other[b]	0	27	22	5
Total	1339	92	65	15

[a] Galaxies with both Palomar and SDSS spectra; in these cases, we adopt the Palomar spectra and measurements.
[b] Bennert et al. (2004); Dahari & De Robertis (1988); Kim et al. (1995); Whittle (1992); Neugebauer et al. (1976); Adams & Weedman (1975); Phillips et al. (1983); Osterbrock & De Robertis (1985); Goodrich & Osterbrock (1983); De Robertis & Osterbrock (1986); Moustakas & Kennicutt (2006); Buttiglione et al. (2009)

So what are we looking at again?

Line Fluxes — Line Ratios — [O III]/Hβ, [N II]/Hα, [S II]/Hα, [O I]/Hα — BPT Diagrams

Line Luminosities
- [O III] → $L_{[O\ III]} / L_{edd}$
- Hα → Star Formation Rate
- [O I]



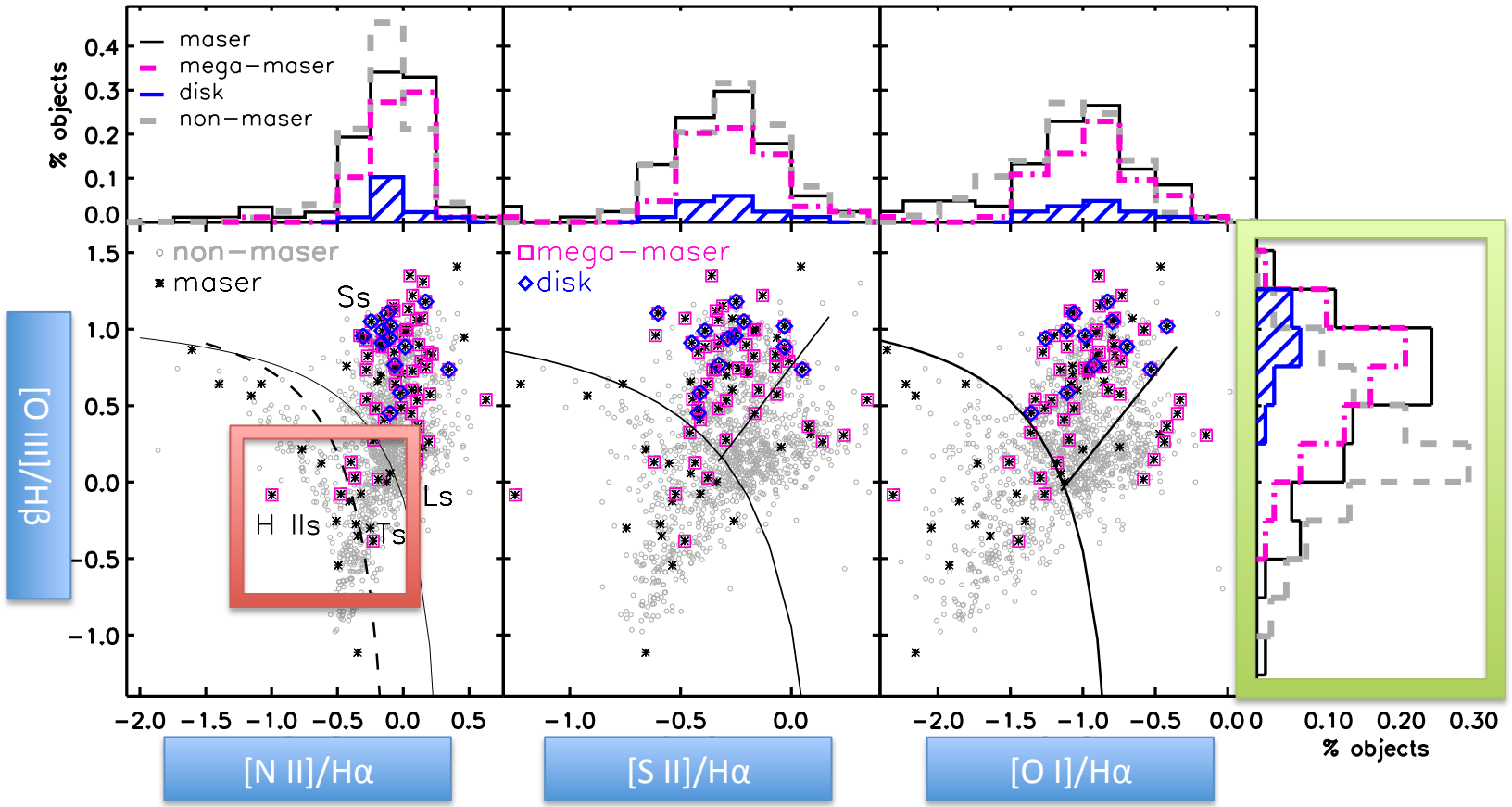
Stellar Properties
- D_{4000} (Age of stellar population)
- M_{star} (Total stellar mass)
- σ* (Stellar Velocity Dispersion)

Emitting Gas Parameters
- [S II] Ratio (N_e) (λλ 6716/6731 Å)
- Hα / Hβ (Balmer Decrement)

Line Diagnostic Diagram

– or –

"What's Under the Hood"



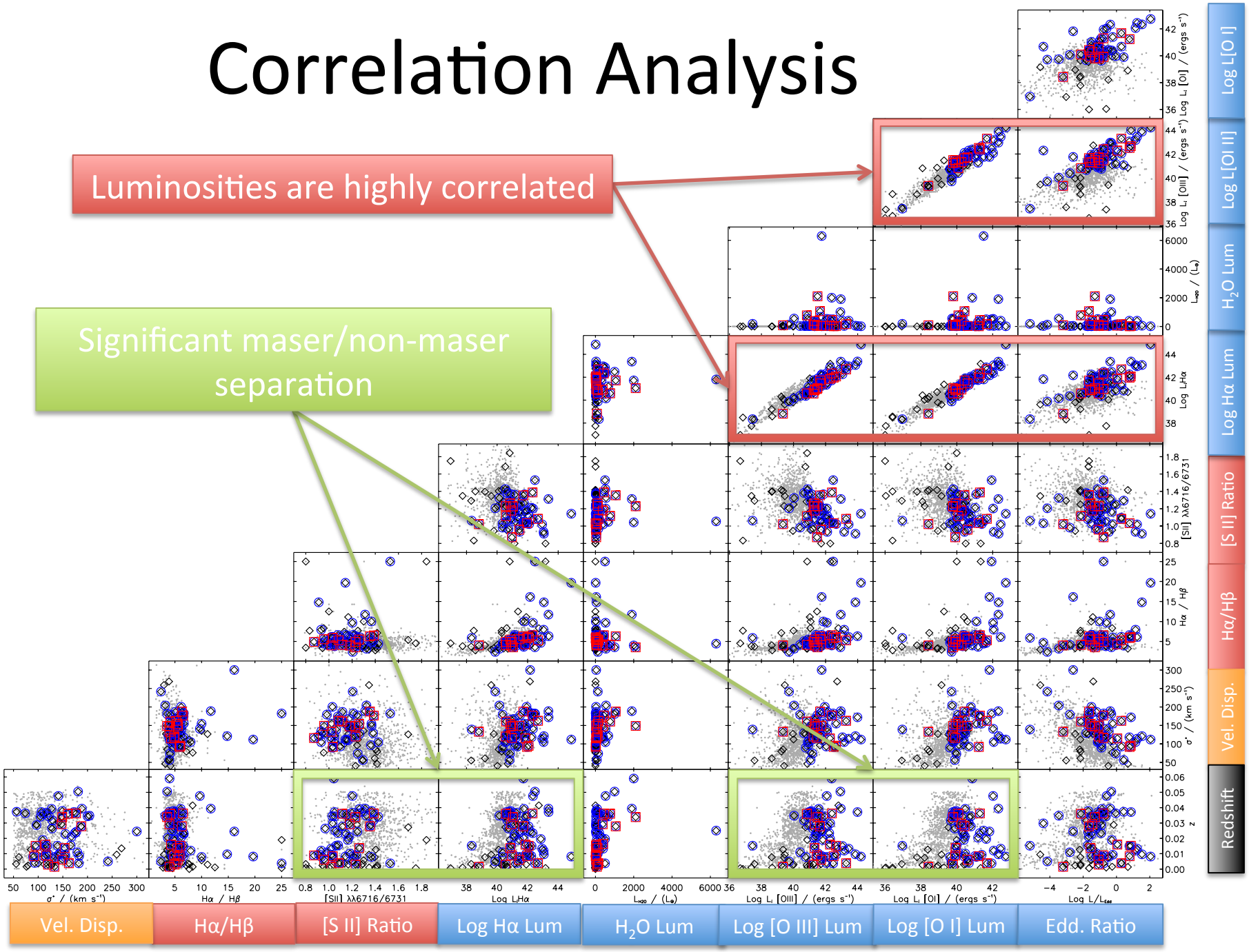
Not all masers are Seyferts

Potential observational bias

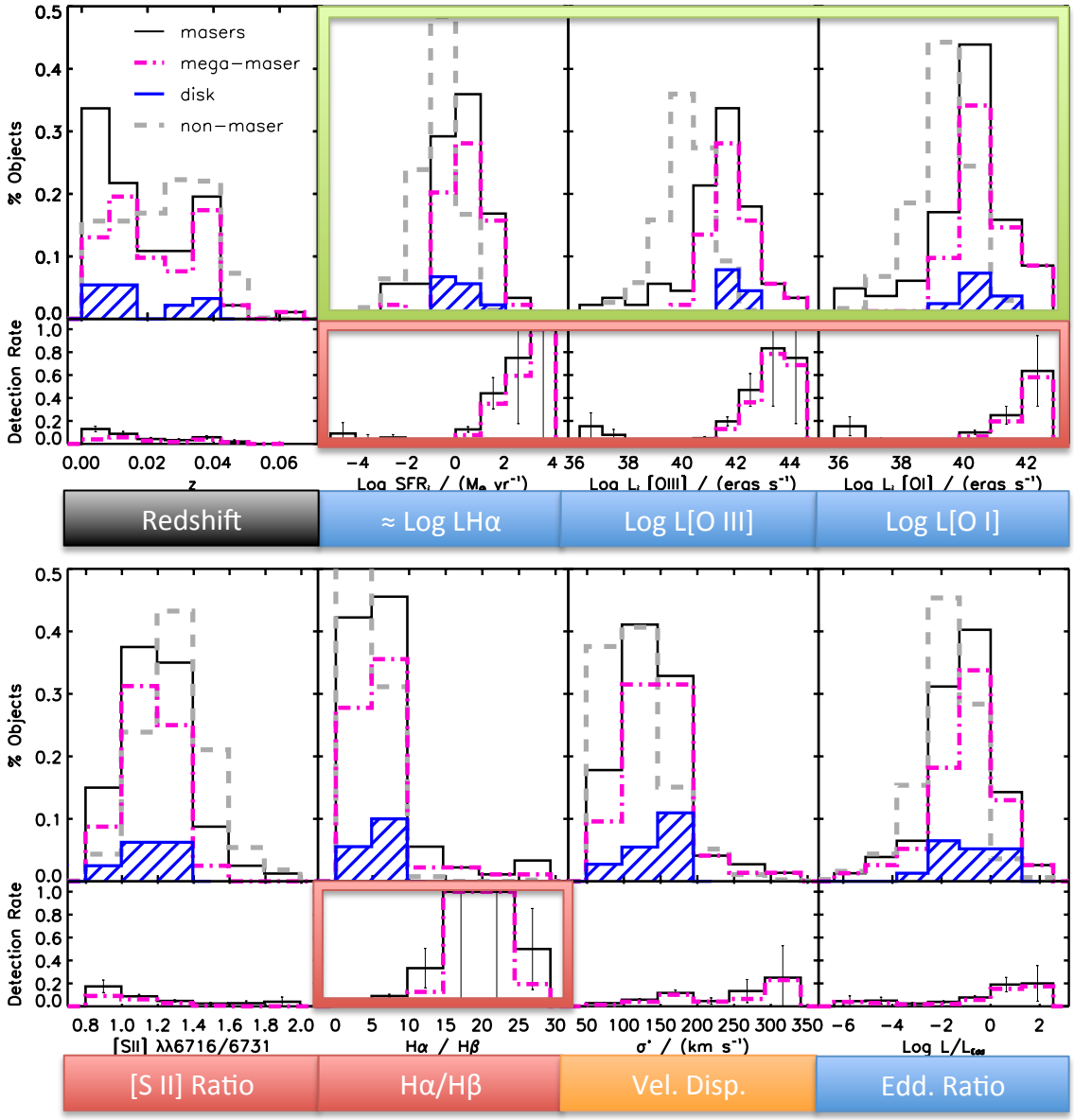
Correlation Analysis

Luminosities are highly correlated

Significant maser/non-maser separation



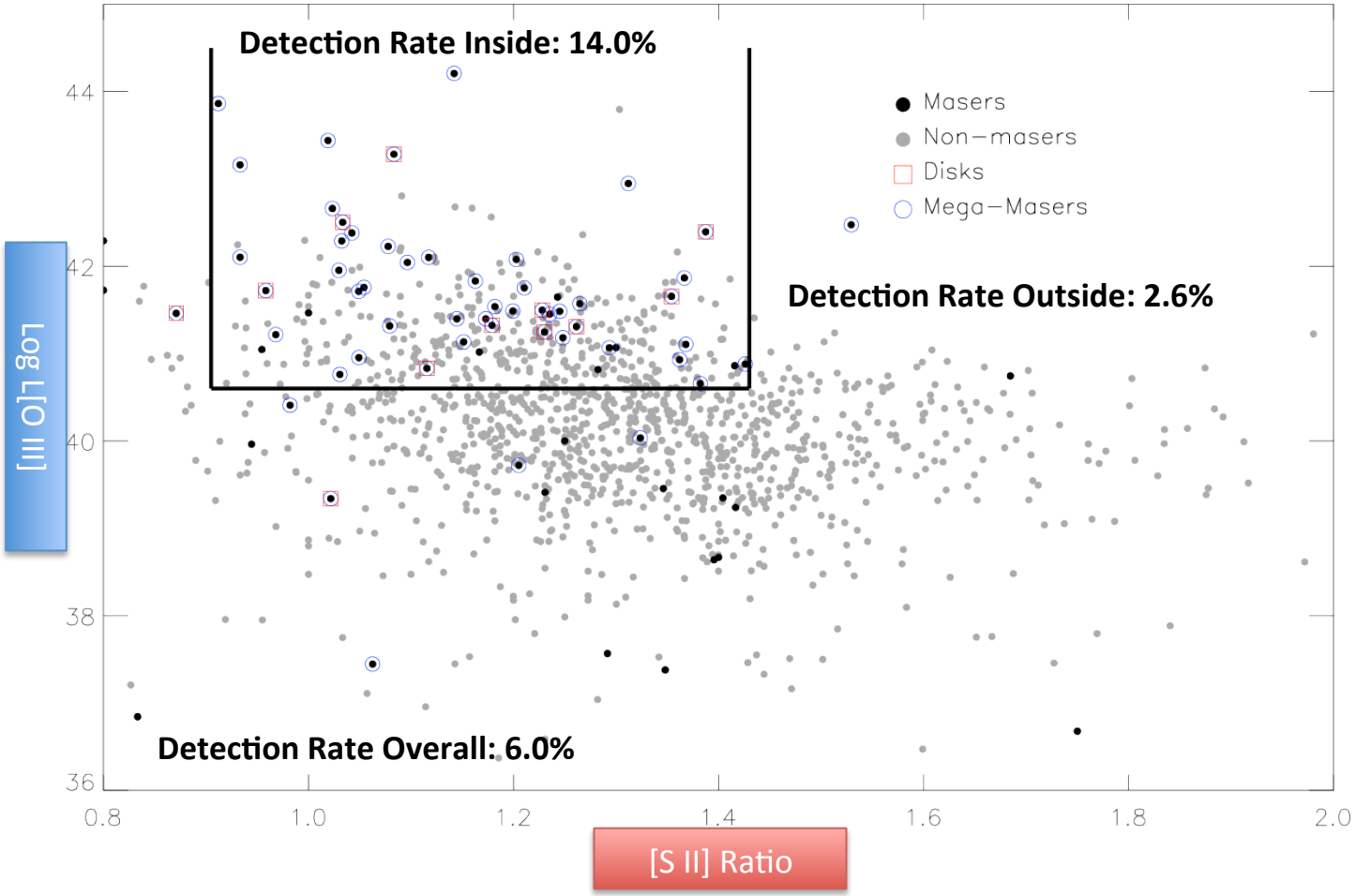
Individual Parameter Comparisons



Hα, [O III] and [O I] luminosity distributions clearly different as we would expect!

High detection rates for certain “goldilocks regions.”

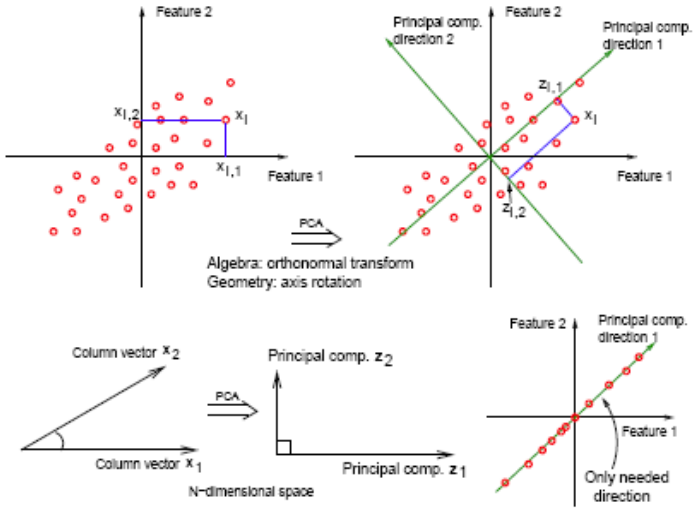
Ok, they're different. So what?



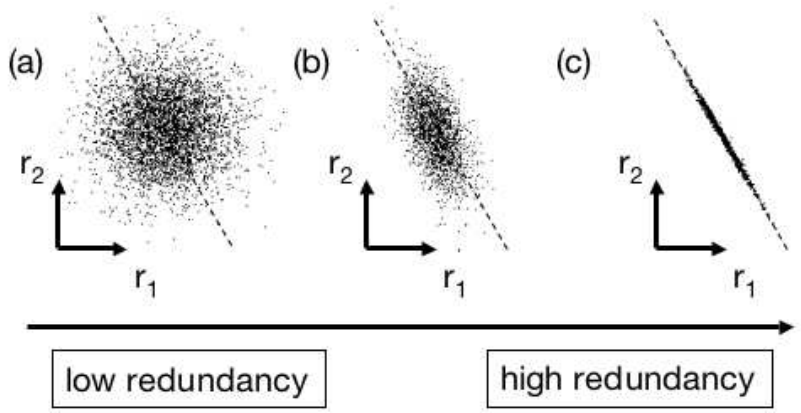
More than double the detection rate for a simple 2 parameter constraint!

N-parameters Part I:

Principal Component Analysis



https://onlinecourses.science.psu.edu/stat857/book/export/html/11



http://www.cs.cmu.edu/~elaw/papers/pca.pdf

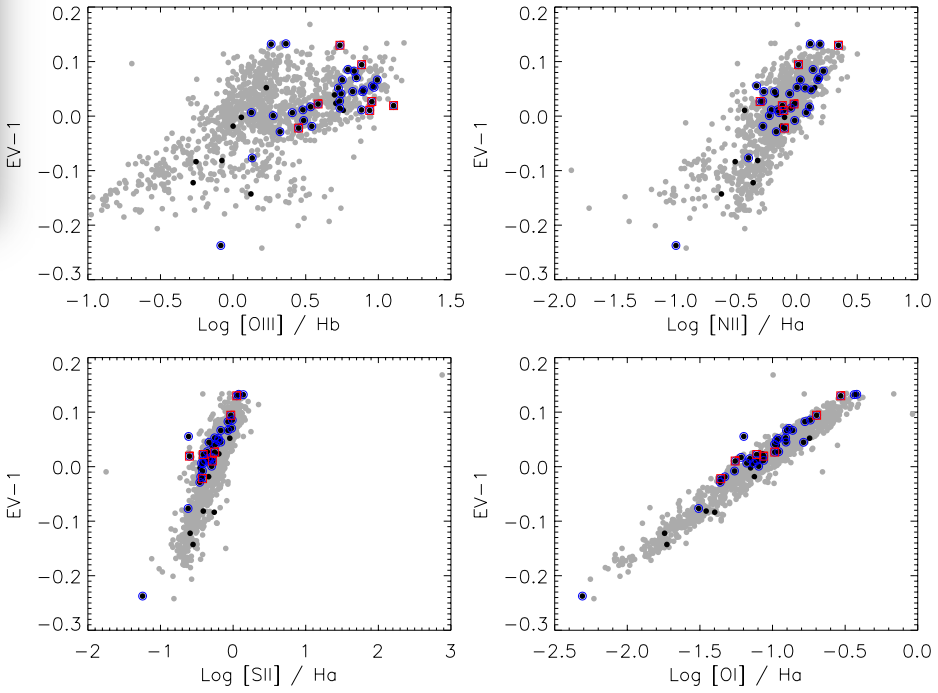
- A transformation of the variables into new linearly uncorrelated variables called principal components (PCs).
- Each PC attempts to account for as much of the variance as possible
- Reduces dimensionality and information redundancy

PCA Results

EIGENVECTORS FOR COMBINED MASERS AND CONTROL

Variable	EV-1 31.6%	EV-2 47.2%	EV-3 59.0%	EV-4 69.4%	EV-5 78.2%
z	0.218	**-0.448**	-0.164	-0.404	-0.320
σ^*	0.276	0.182	0.254	-0.008	0.062
Hα/Hβ	0.002	0.111	**0.664**	-0.238	-0.625
$\lambda\lambda$6716/6731	-0.090	0.146	-0.357	-0.792	0.043
Log L [OIII]	0.275	**-0.620**	0.025	0.021	-0.012
Log [OIII]/Hβ	**0.389**	-0.337	-0.001	0.147	0.044
Log [NII]/Hα	**0.450**	0.282	0.057	-0.022	-0.083
Log [SII]/Hα	**0.442**	0.309	-0.178	-0.037	0.034
Log [OI]/Hα	**0.489**	0.217	-0.119	0.013	0.036
L H_2O	0.070	-0.113	**0.540**	-0.358	0.700

EV's provide good separation between masers and non-masers

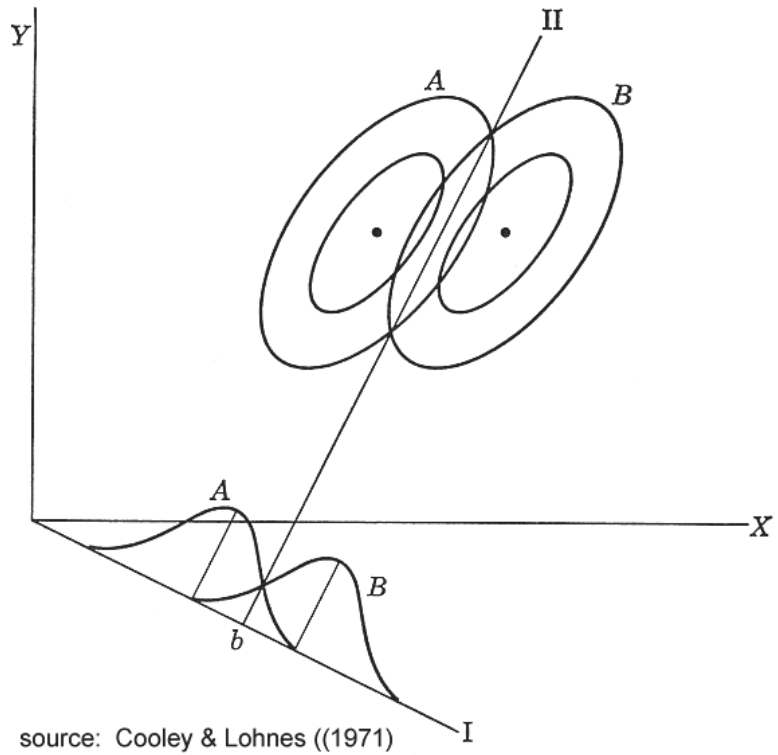


PC-1 –> Correlation of the four line ratios confirming the Line Diagnostic Diagram.

PC-2 –> Correlation of redshift and [OIII] luminosity (distant objects are more intrinsically luminous)

PC-3 –> Correlation of Hα/Hβ (reddening due to dust) and H_2O luminosity (maser strength)

N-parameters Part II:
Discriminant Analysis

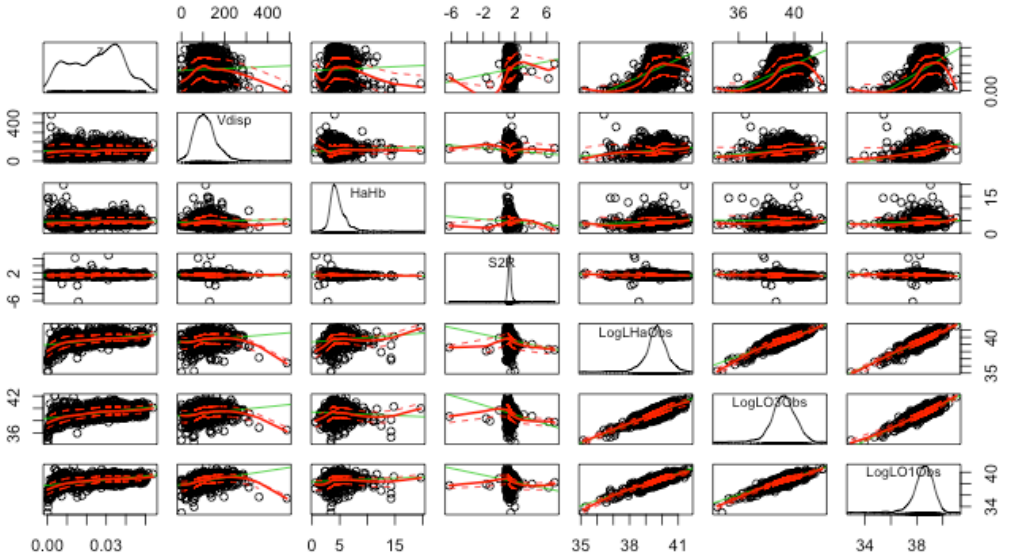


source: Cooley & Lohnes ((1971)

- Finds a linear combination of variables that optimizes the separation of two or more groups
- We desire to construct a Discriminant function which can then be applied to new data

DA Preliminary Results

	Classified as maser	Classified as non-maser	Total
Actual maser	17	51	68
Actual non-maser	11	1297	1308
Classification Accuracy	25%	99.2%	



Optimal maser detection rate: 60.7%
Maser misclassification rate: 75%

Type	Maser			Mega-Maser			Disk		
	Masers	Control	% of Total Masers	Masers	Control	% of Total Masers	Masers	Control	% of Total Masers
Total	1735	298851	100%	1191	299395	100%	888	299698	100%
HII	1088	210881	63%	573	211396	48%	612	211357	69%
Transition	126	52848	7%	113	52861	9%	16	52958	2%
Seyfert	389	12142	22%	383	12148	32%	238	12293	27%
LINER	129	22978	7%	119	22988	10%	21	23086	2%

Conclusions

- ✓Clear separation of maser and non-maser distributions
- ✓Should be able to double or triple the detection rate
- ✓Still fine tuning the DA
- ✓ Future work will expand the parameter space into other wavelengths

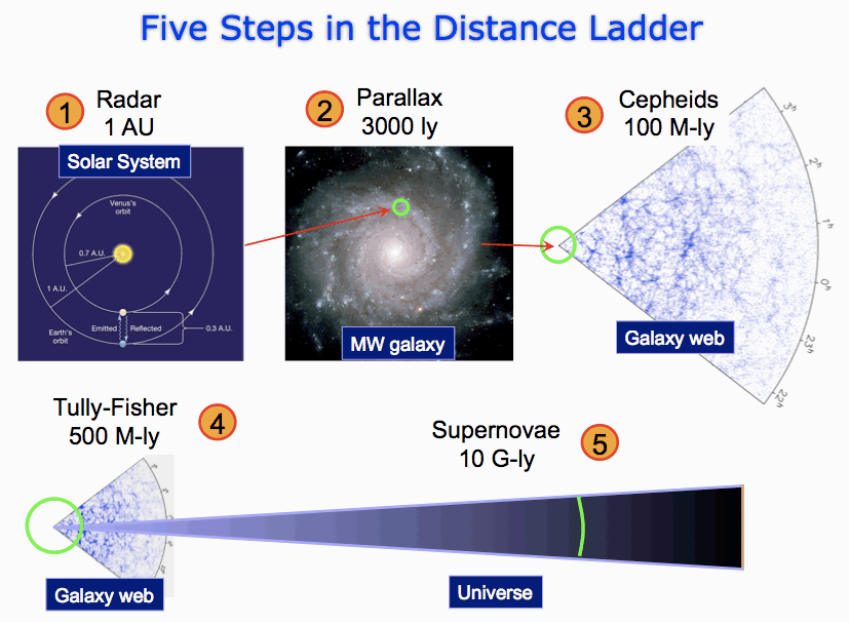
Thank You!

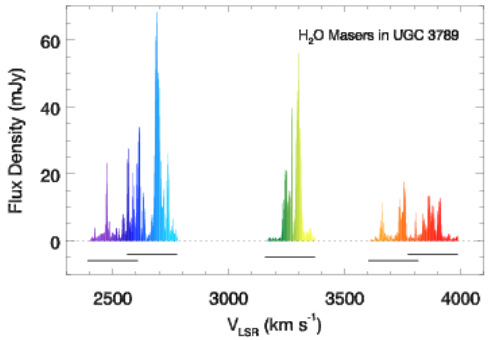
Questions?

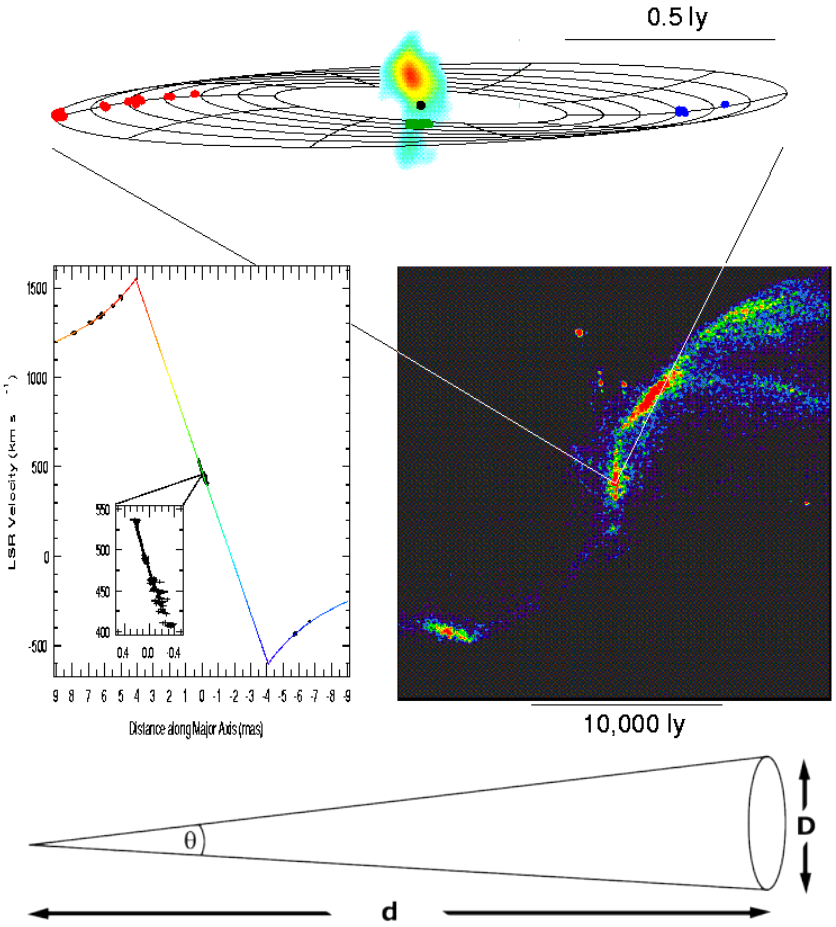
Why We Care About Mega-Masers

The ONLY direct distance measurements

The MOST accurate measurement of black hole mass







$$M_\bullet = \left(\frac{|v_K|^2\theta}{G}\right) D_A = \left(\frac{\pi v_l^2}{6.48\times10^8\,G}\right) D_A$$

$$D_a = r/\theta = v_r^2/(a\theta)$$

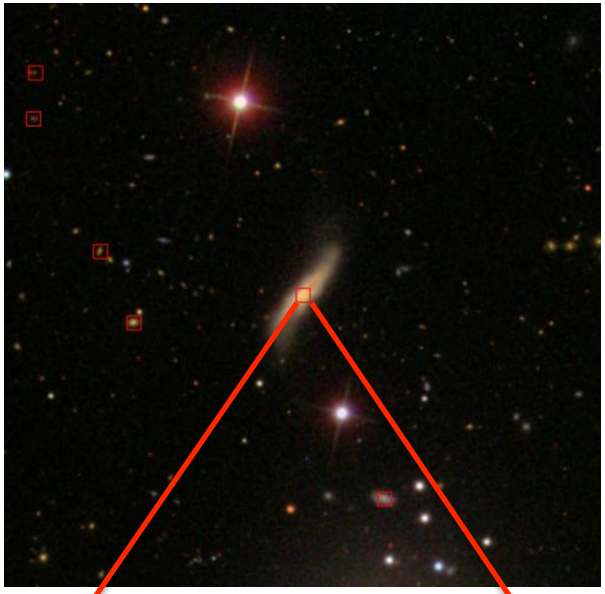
Attempt to fill the gaps

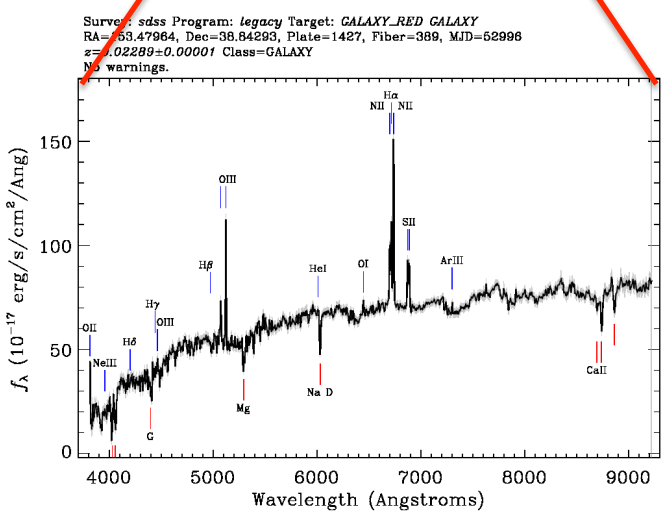
Co-Investigator on optical spectroscopy proposals for 75 masers

ESO New Technology Telescope (NTT)
La Silla, Chile

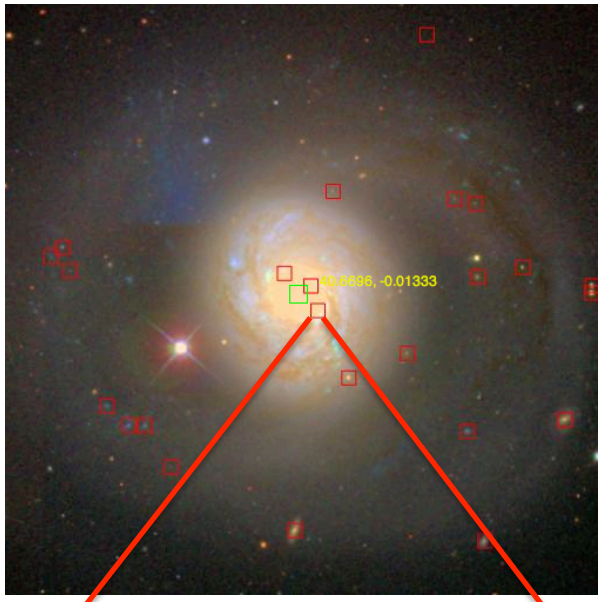
Southern Astrophysical Research (SOAR) Telescope
Cerro Pachón, Chile

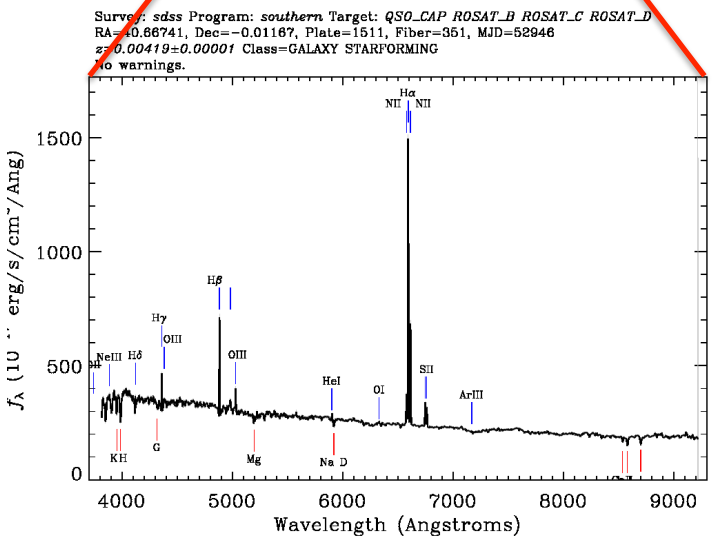
Good match



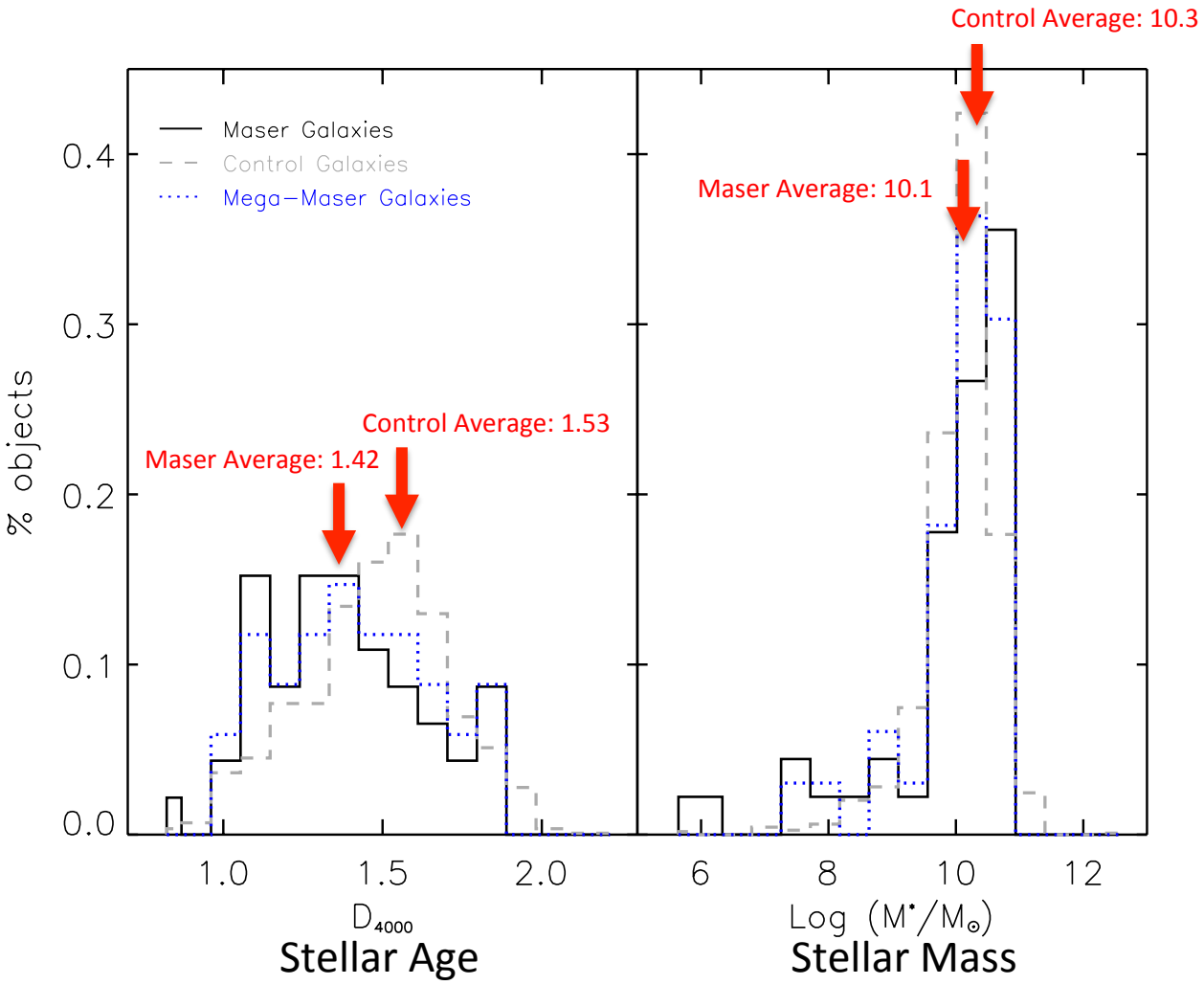


Bad match





SDSS Only


Maser Galaxies
Control Galaxies
Mega−Maser Galaxies
% objects
0.0
0.1
0.2
0.3
0.4
Maser Average: 1.42
Control Average: 1.53
1.0
1.5
2.0
D4000
Stellar Age
Control Average: 10.3
Maser Average: 10.1
6
8
10
12
Log (M*/M⊙)
Stellar Mass