Understanding the Variability of Optical Spectra of H_2O Megamasers

William St. John

JMU Research Advisor: Dr. Anca Constantin
MRGS Research Advisor: Ms. Jennifer Moyers

Megamaser Physics

- **MASER: M**icrowave **A**mplification by **S**timulated **E**mission of **R**adiation
  - Water molecules present
  - Detected in 22 GHz (radio frequency)
- "Mega" masers
  - Extragalactic masers that are a **million times as luminous** as masers seen in the Milky Way
- ~3% of all galaxies host maser emissions
  - Fraction of these megamasers are in disk-like configuration
    - Calculate distances (constrain geometry of universe) (very difficult)
    - Mass of the supermassive black hole

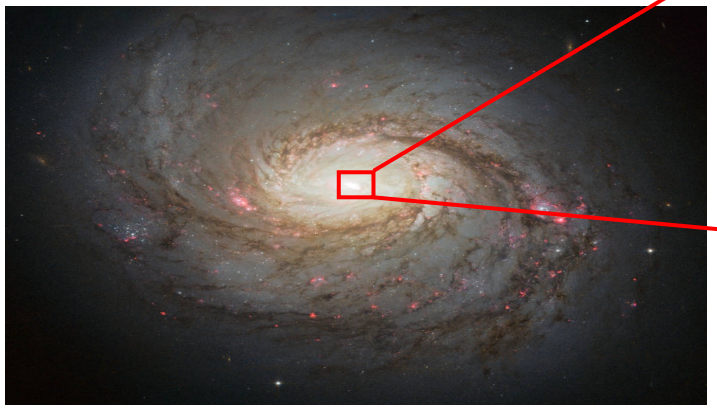


Figure 2
Image of NGC 1068 (NASA, 2017)

Figure 1
Stimulated Emission Diagram (Lovegrove, 2013)

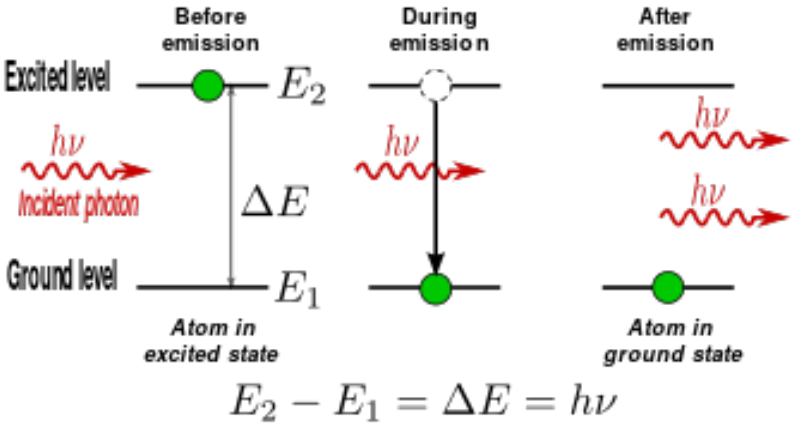
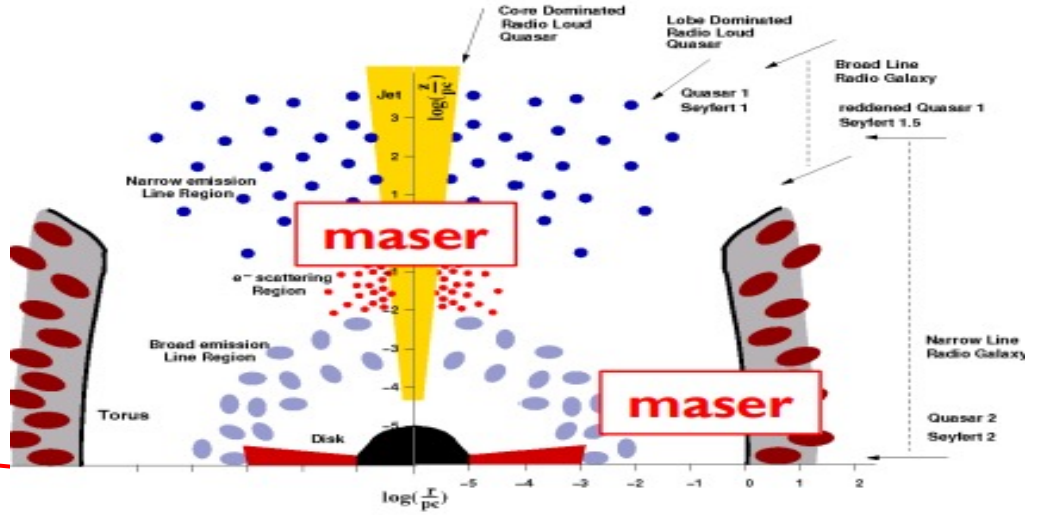


Figure 3
Maser Emission Diagram (adapted from McNeill, 2019)



AGN and Variability

- Active Galactic Nuclei (AGN)
  - Supermassive Black Hole
  - Accretion Disk
    - Source of seed photons for maser emission
  - Line emission activity
    - Visible range
  - Emission variability is expected for AGNs

- Why Study Variability?
  - ~3% of all galaxies host megamaser emissions
    - ~20% of all megamaser host galaxies are in a disk-like configuration
  - Only 180 megamasers have been identified
  - Constrain accretion models (continuous vs episodes)
  - Add limits to NLR detectability
  - Constrain geometry and emission region models
- Visible line variability offers insight into megamaser emission

(McNeill, 2019; Green, n.d.)

Figure 4

Unified model of AGN (NASA, 2016)

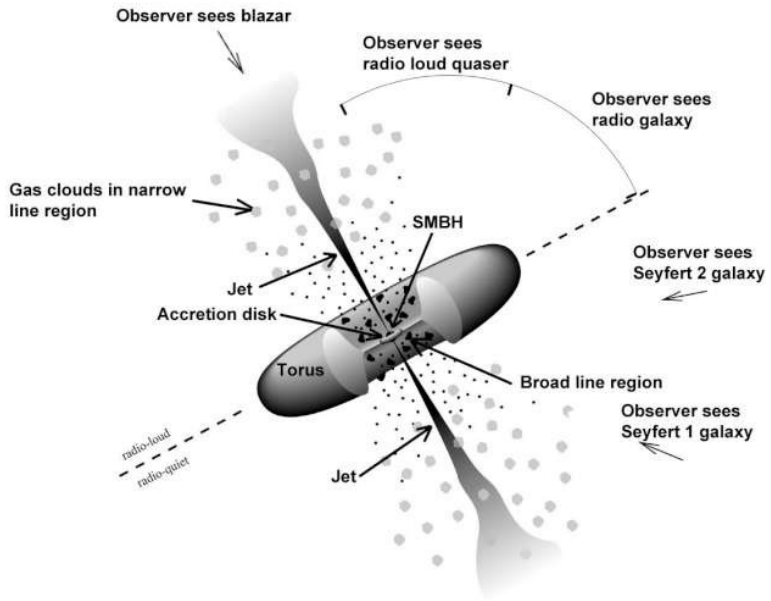
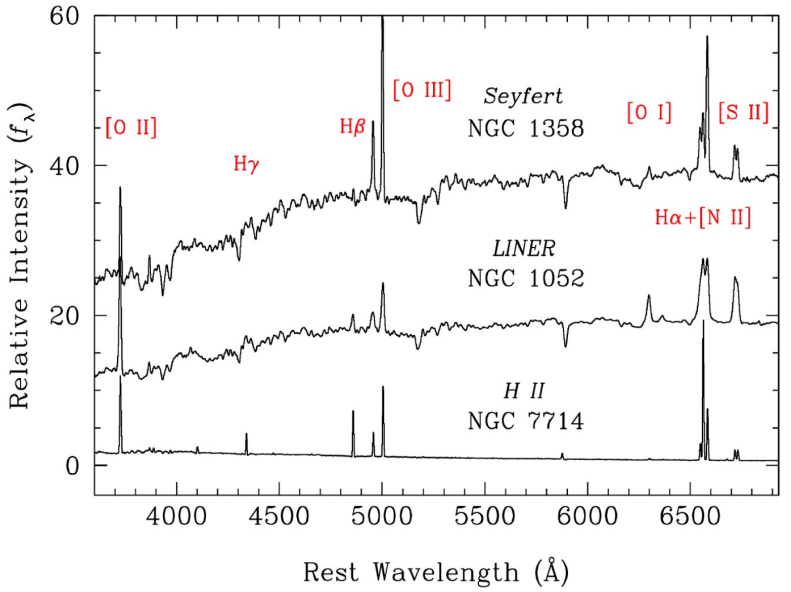


Figure 5

Sample Optical Spectra (Ho, 2008)



Project Goal

Link visible variability with properties of maser emissions

Data and Methods

Megamaser Cosmology Project

Catalogue of over **6000 galaxies** observed by the Green Bank Telescope

180 are H_2O maser galaxies

Sloan Digital Sky Survey

Database containing a wide variety of information pertaining to galaxies observed in 3000-9000 angstroms (visible) by the Apache Point Observatory ie

Spectra, celestial coordinates, **date of observation**, luminosity, **line emission fluxes**…

Structured Query Language (SQL)

Creating data tables

Crossmatching catalogues

SDSS CasJobs

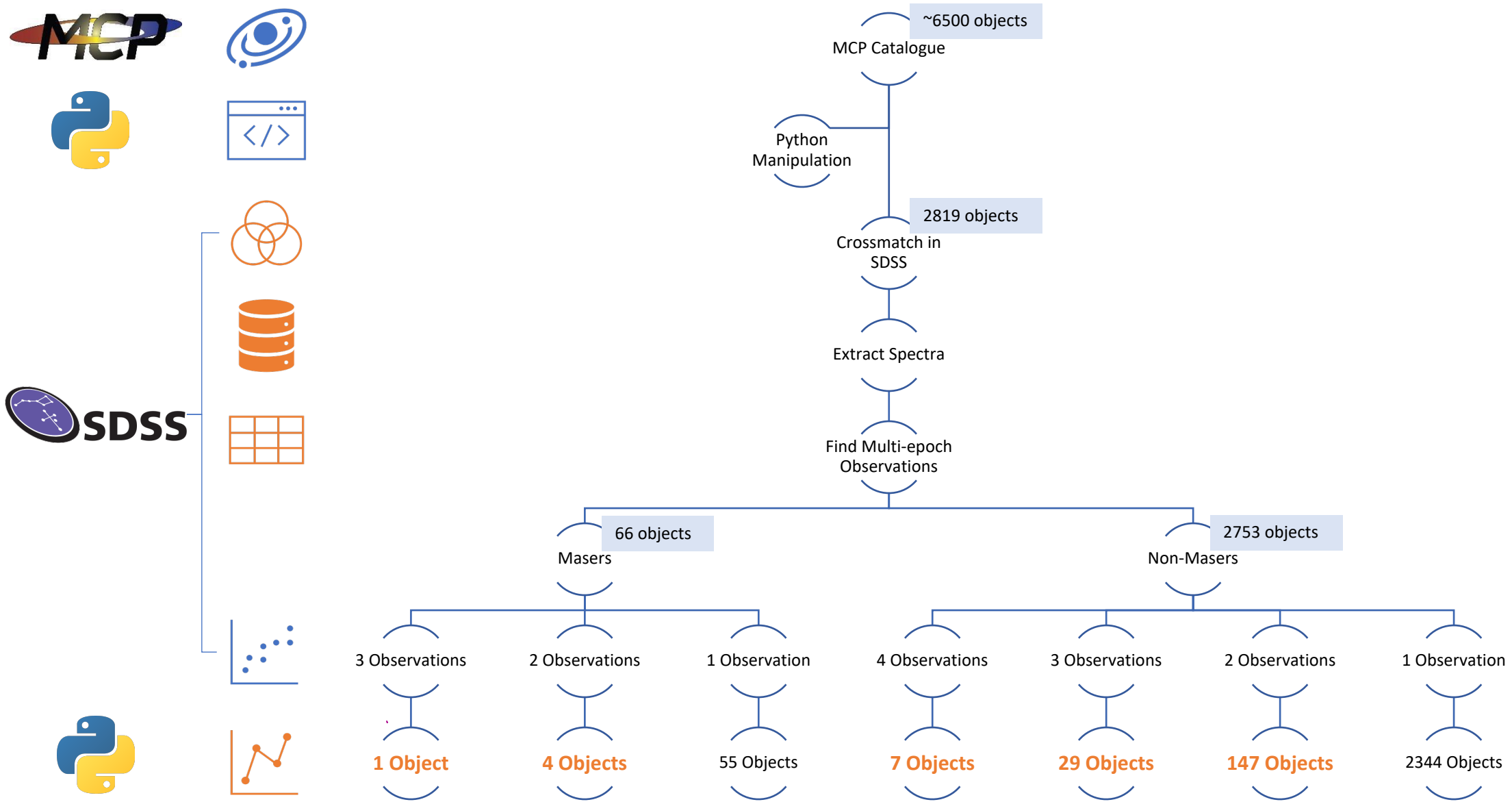
Python

Reading and writing files

Manipulating data

Creating figures and models

Data Mining Process



Emission Line Diagnostic Diagrams

Figure 7
Sample Optical Spectra (Ho, 2008)

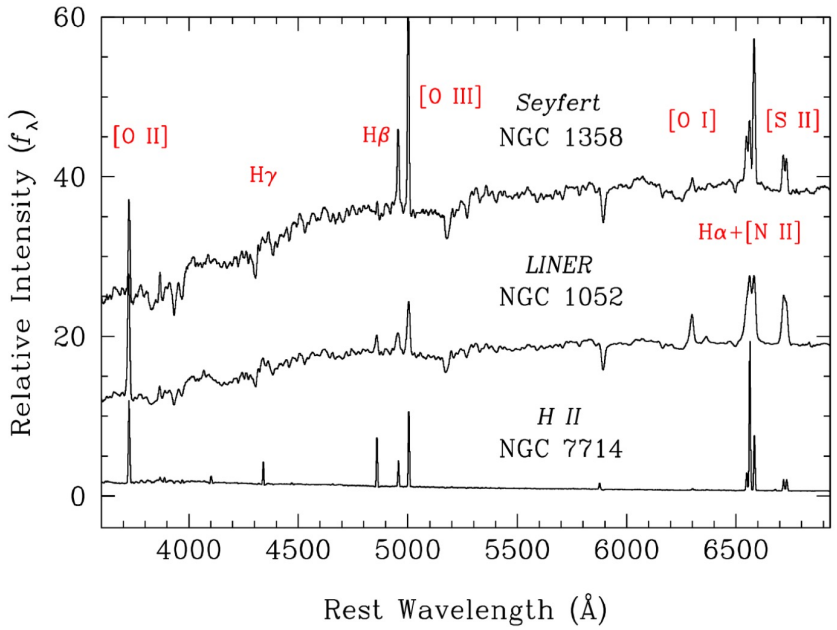
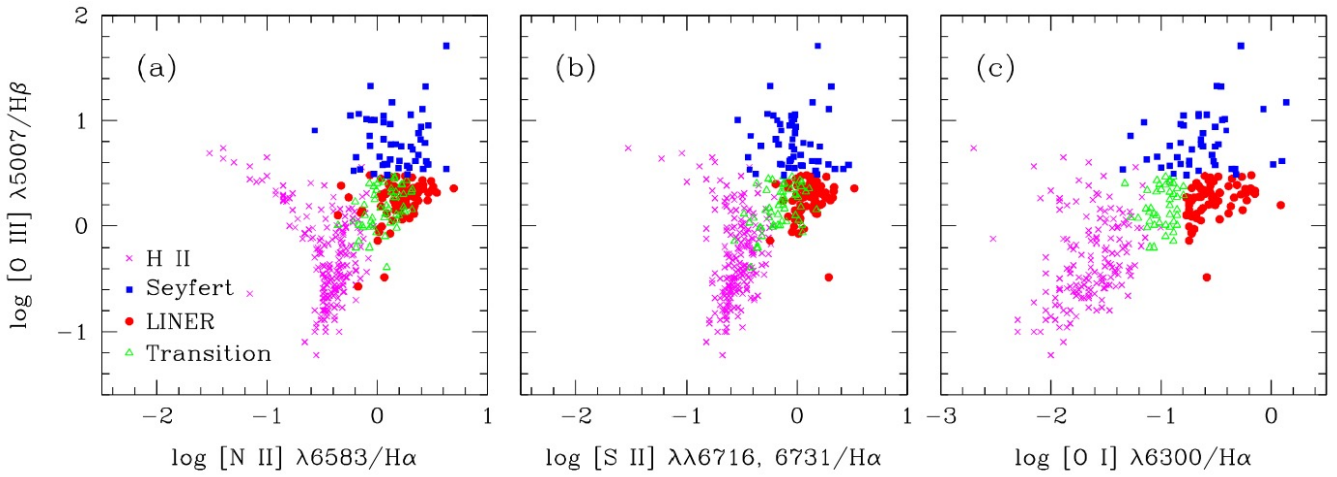


Figure 8
Diagnostic Diagram (Ho, 2008)



FLUX RATIOS → EMISSION LINE DIAGNOSTIC DIAGRAMS

- Used to determine **dominant ionization mechanism**
  - Gives information regarding seed photon/maser emission
    - Accreting blackhole, star formation, or combination?

Figure 9

Maser Emission Line Diagnostic Diagram (St. John, 2022)

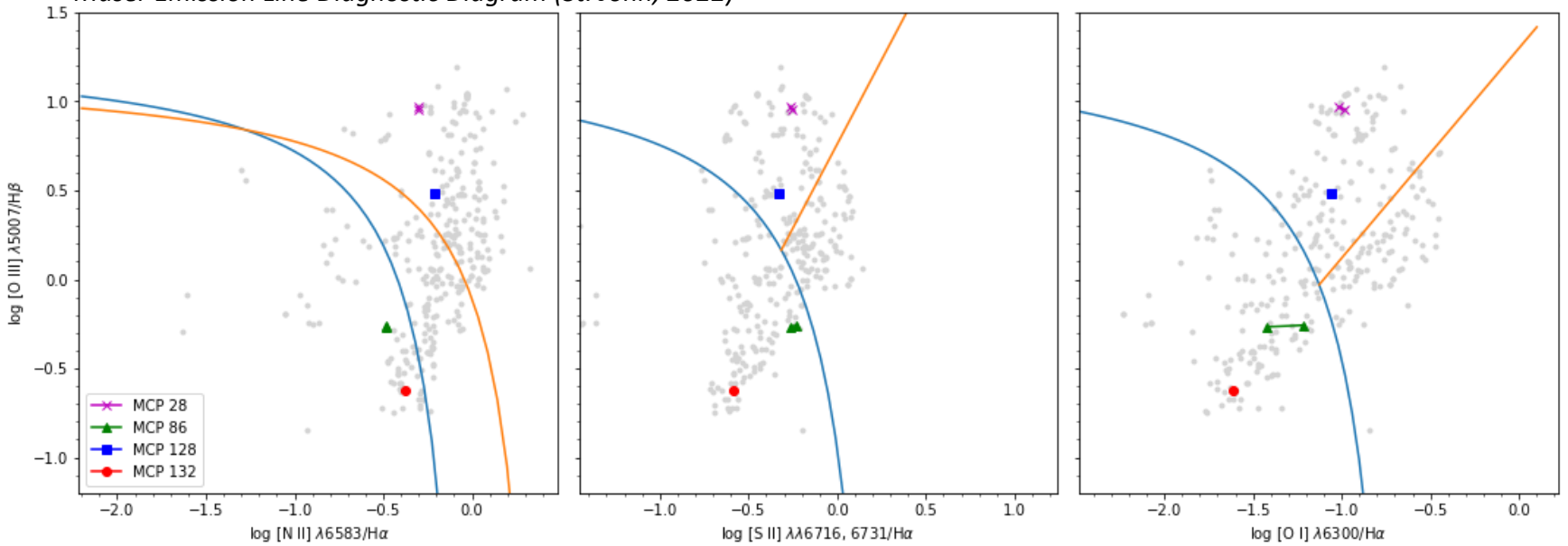
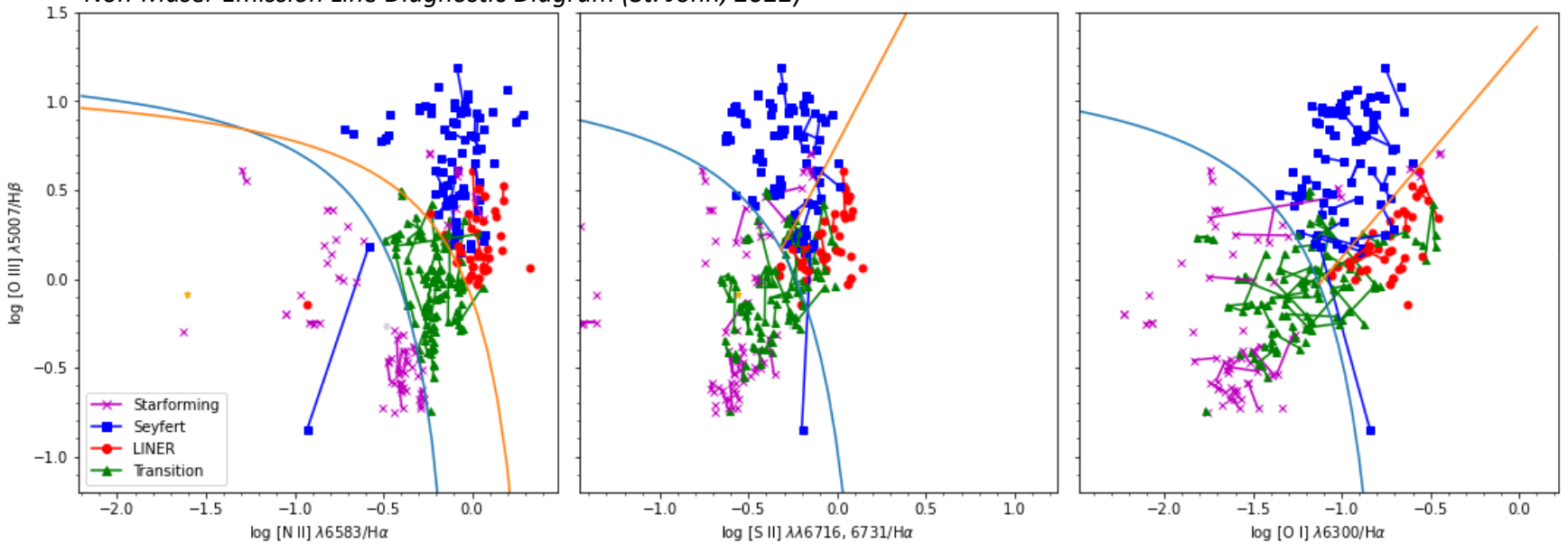


Figure 10

Non-Maser Emission Line Diagnostic Diagram (St. John, 2022)



Conclusions

Methodology

- MCP observations were crossmatched with the SDSS
  - Multi-Epoch spectra extracted
    - OIII, NII, SII, OI, Hα, and Hβ flux ratios plotted and compared for both maser and non-maser galaxies

Results and Implications

- **Maser galaxies do not exhibit significant change in the dominant ionization mechanism**
  - Data remains in the realm of small number statistics
- **Non-Maser galaxies have generally consistent spectral classifications, however there are cases where optical variability turns from non-AGN into accreting sources**
  - These cases will be investigated in more detail

References

Constantin, A. (2020, October 29). *Spectra.* [Video lecture]. Department of Physics and Astronomy, James Madison University. https://www.youtube.com/watch?v=42on 2KvOdsc

Kuo, C. Y., Constantin, A., Braatz, J. A., Chung, H. H., Witherspoon, C. A., Pesce, D., Impellizzeri, C. M. V., Gao, F., Hao, Lei, Woo, J. -H., & Zaw, I. (2018, June 20). Enhancing the H_2O Megamaser Detection Rate Using Optical and Mid-Infrared Photometry. *The Astrophysical Journal, 860*(2), 169. https://doi.org /10.3847/1538-4357/aac498.

McNeill, S. & Constantin, A. (2019). *Spectral energy distributions of H2O megamaser disks.* James Madison University Department of Physics and Astronomy. http://csma31.csm.jmu.edu/physics/constaax/sloane_talk_2019.pdf

Green, J. & Constantin, A. (n.d.). *Modeling decade-scale broad emission variability in active galactic nuclei.* James Madison University Department of Physics and Astronomy. http://csma31.csm.jmu.edu/physics/constaax/JacobGreen_symposiumSP16.pdf

Figure 1. *Stimulated Emission Diagram.* Retrieved from https://astrobites.org/2013/10/28/giant-space-masers/

Figure 2. *Image of NGC 1068.* Retrieved from https://www.nasa.gov/feature/goddard/2017/messier-77

Figure 3. *Megamaser Emission Diagram.* Retrieved from http://csma31.csm.jmu.edu/physics/constaax/sloane_talk_2019.pdf

Figure 4. *Unified model of AGN.* Retrieved from https://fermi.gsfc.nasa.gov/science/eteu/agn/

Figure 5. *Sample Optical Spectra.* Retrieved from Ho, 2008.

Figure 6. *Non-Maser spectra vs photometry flowchart.* Created by William St. John

Figure 7. *Sample Optical Spectra.* Retrieved from Ho, 2008.

Figure 8. *Diagnostic Diagram*. Retrieved from Ho, 2008.

Figure 9. *Maser Emission Line Diagnostic Diagram.* Created by William St. John

Figure 10. *Non-Maser Emission Line Diagnostic Diagram.* Created by William St. John