Physical Drivers of Emission Line Diversity of SDSS Seyfert 2s and LINERs After Removal of Contributions by Star Formation

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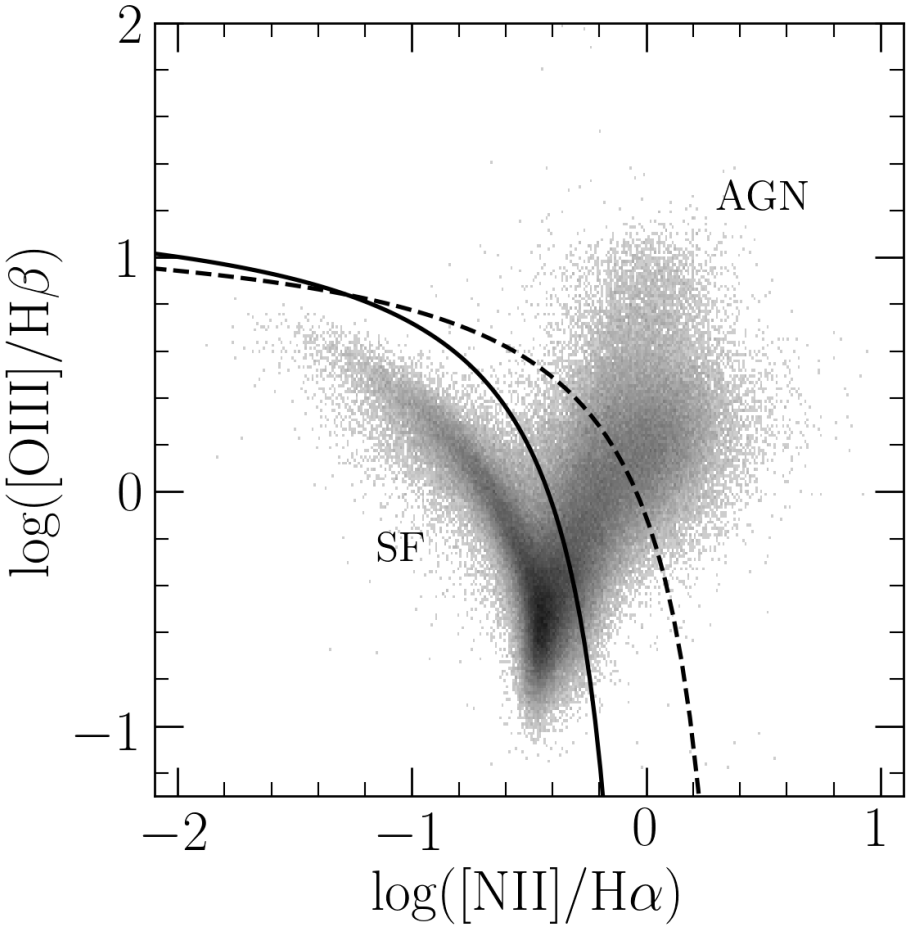
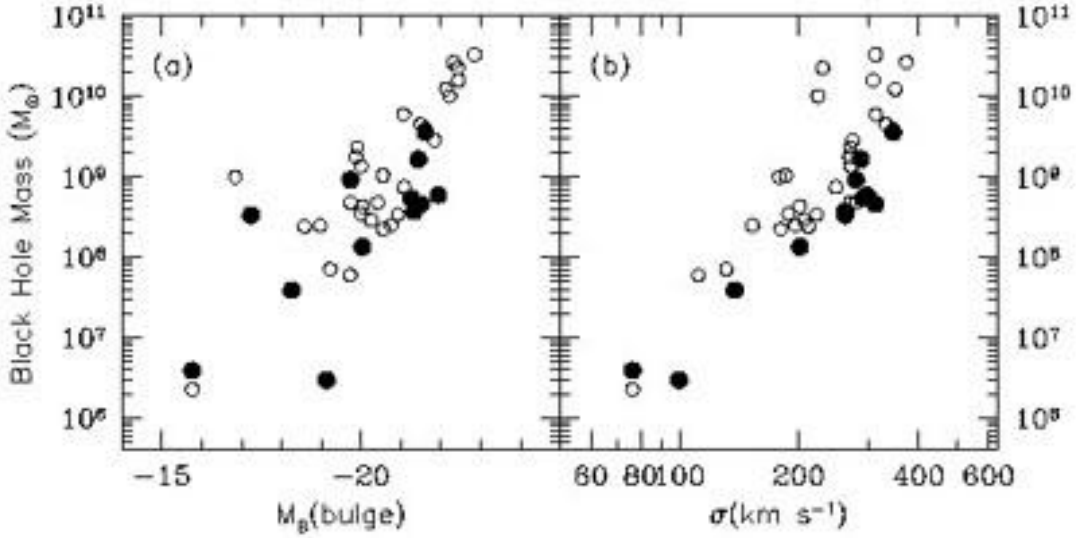
Overview

-What drives the observed variety in the BPT emission line ratios of SDSS Seyfert 2s and LINERs?



Background

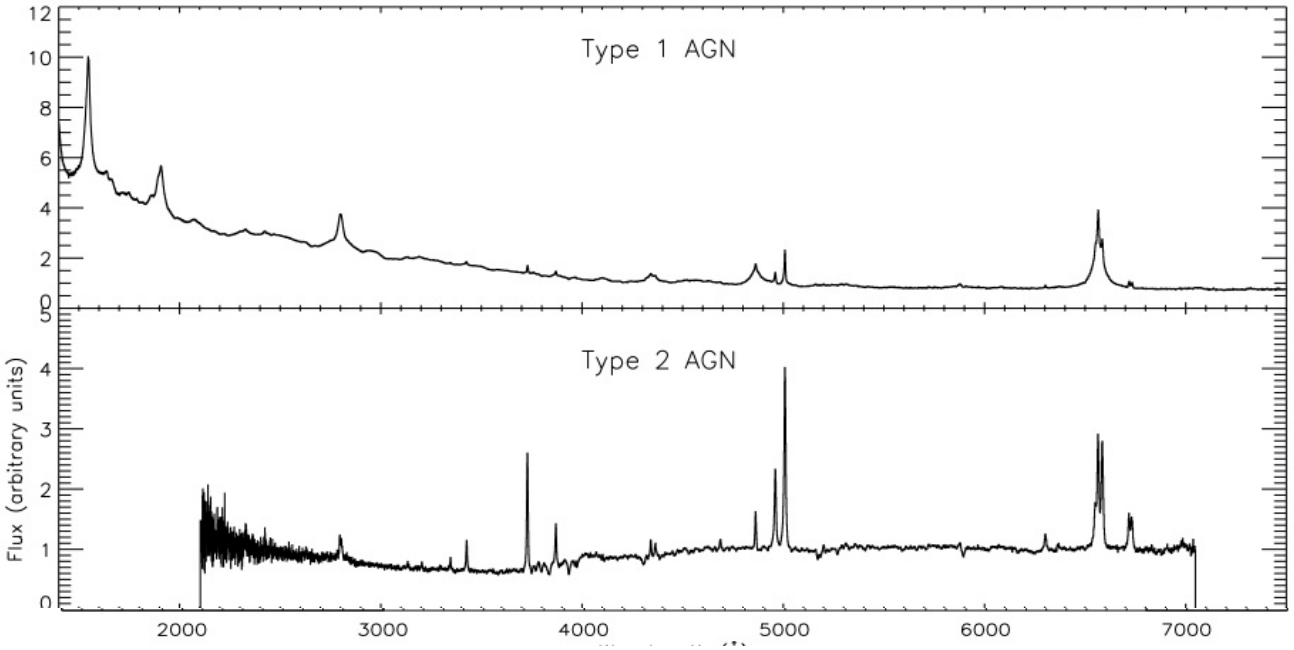
- Most massive galaxies have supermassive black holes (SMBHs) in their centers
- The growth of SMBHs often invoked through the process of feedback to explain phenomena in galaxies: mass function, quenching, M-sigma
- Studying their effect on host galaxies requires an understanding of how their growth affects the hosts, how do we identify actively growing ones? What are their (optical) signatures?



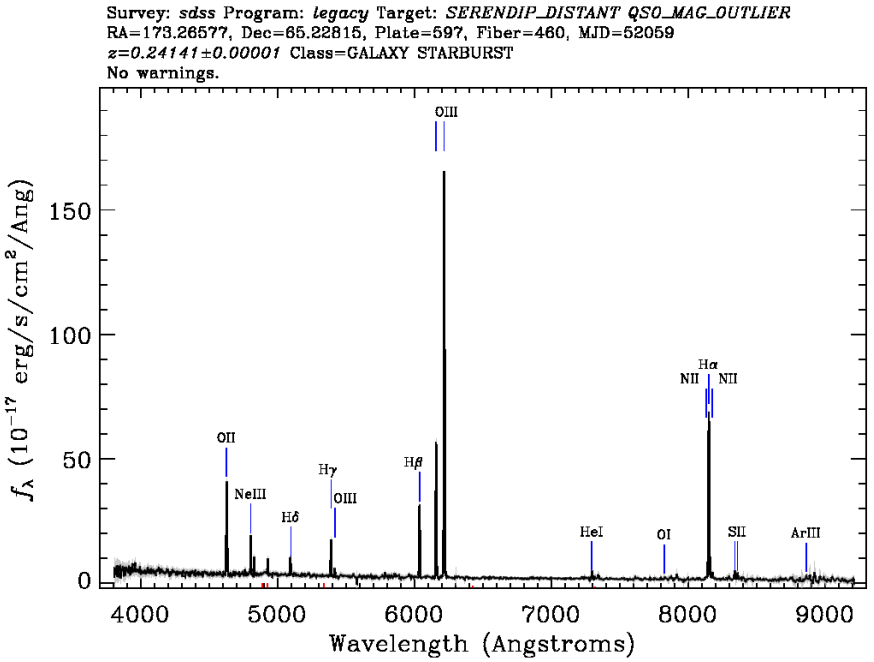
Merritt & Ferrarese (2001)

Background

- Type 2 AGN are much more common than type 1 (QSOs), so they are useful for statistically studying impact of AGN on galaxy evolution, but they lack broad emission lines, blue colors
- Type 2 AGN spectra look like those of star-forming galaxies: how to differentiate?



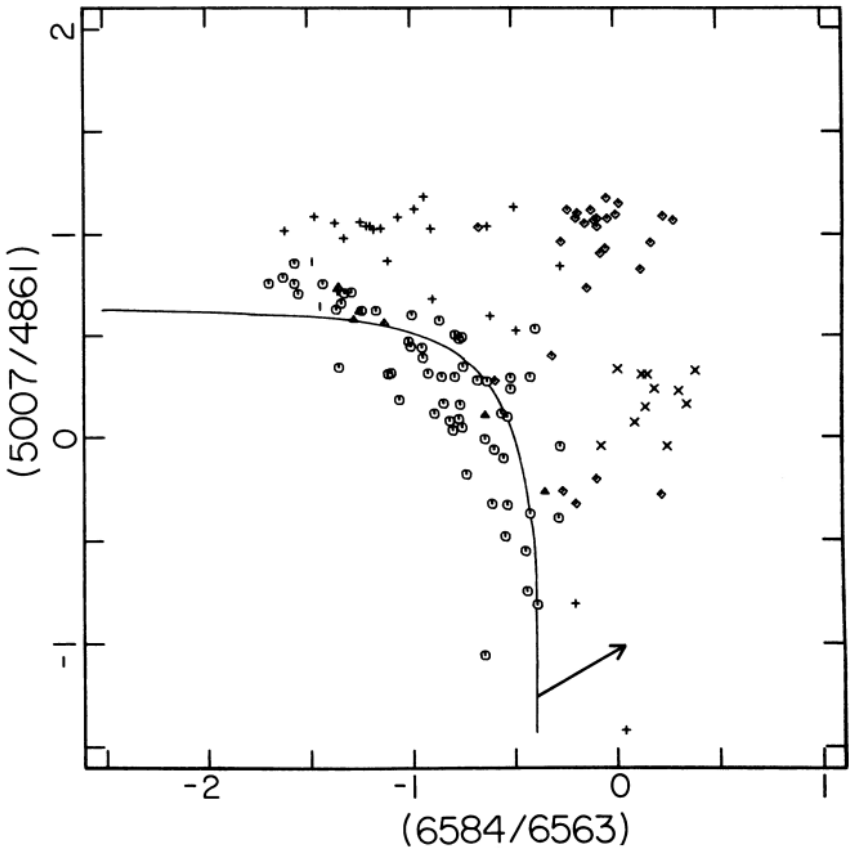
Trump et al. (2008)



SDSS

Background

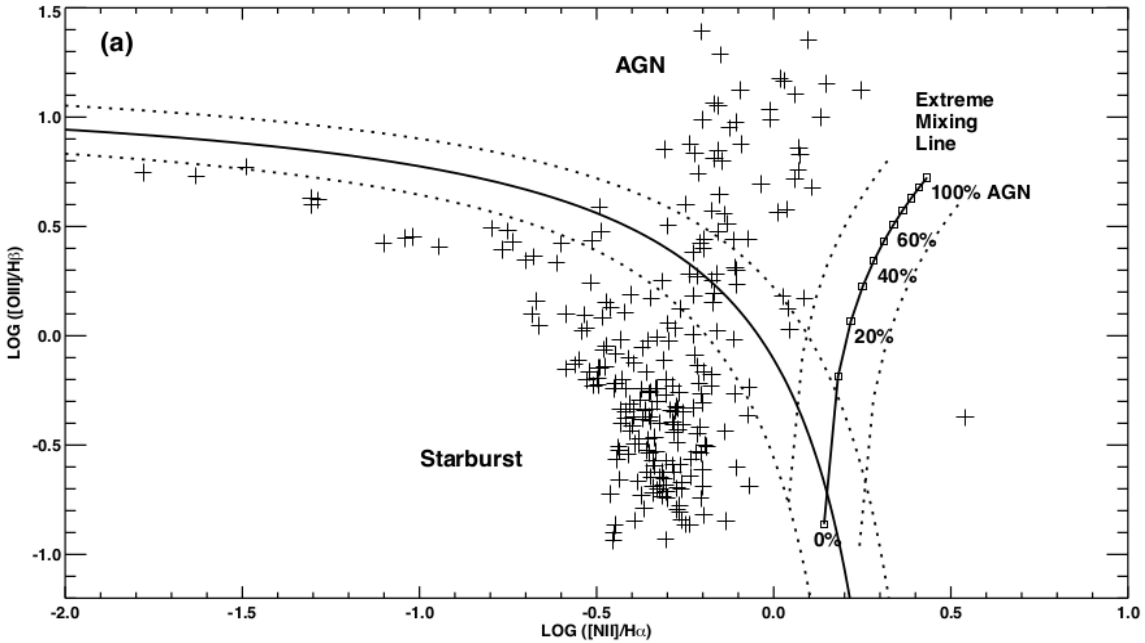
- Baldwin, Phillips, and Terlevich (1981) compared different line ratios for HII regions, planetary nebulae, type 2 AGN.
-Fluxes of high ionization forbidden lines like [OIII] and [NII] versus nearby Balmer lines
-AGN reside at high [NII]/Hα and [OIII]/Hβ because the higher energy photons produced by accretion processes can induce more heating in the narrow line region



Baldwin et al. (1981)

Background

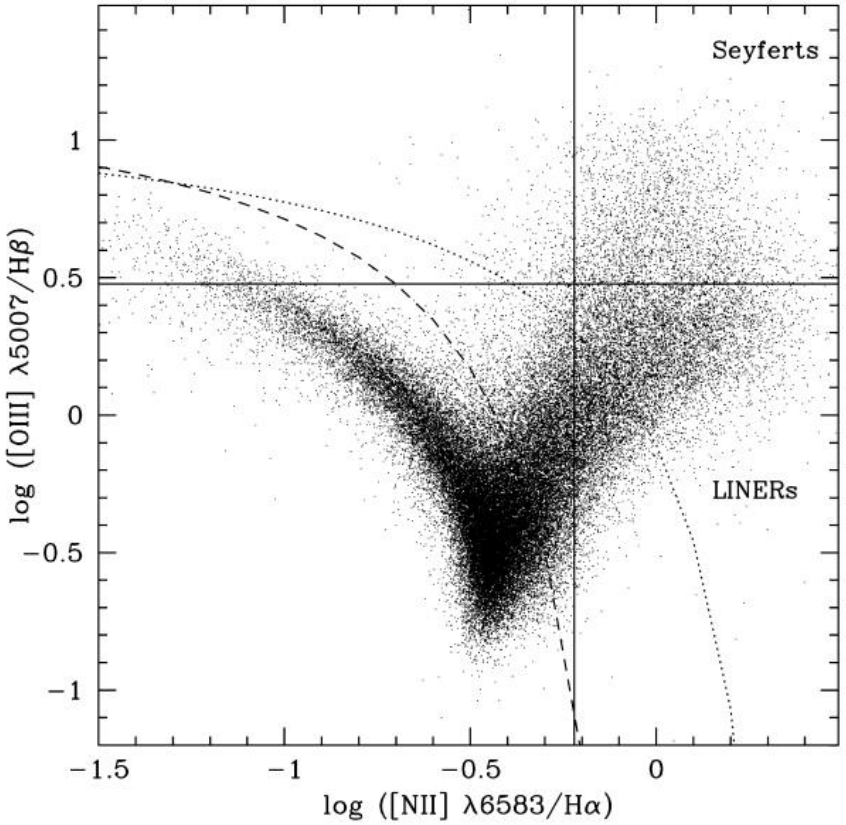
-Kewley et al. (2001) introduce a classification scheme based on starburst models
-Suggest that the variety of the BPT line ratios among AGNs is due to a "mixing" between star formation and AGN
-They also suggest intrinsic variation in ionizing source properties can account for it but prefer the mixing scenario because of the known composite nature of Infrared-selected AGN



Kewley et al. (2001)

Background

- Kauffmann+(2003) provided empirical demarcation between AGN/SF regions based on SDSS
- The region in between the Kewley and Kauffmann lines is often called the "composite" region.
- To what extent is the mixing really responsible for the variation?
- Many studies do not include such objects in AGN samples: Can pure AGN lie here?
- Do objects above the Kewley line have significant star formation?
- Why do the AGN-like objects have such a wide variety of line ratios?



Kauffmann et al. (2003)

Motivation

- ~10% of X-ray selected AGN are found in the star-forming region of the BPT diagram

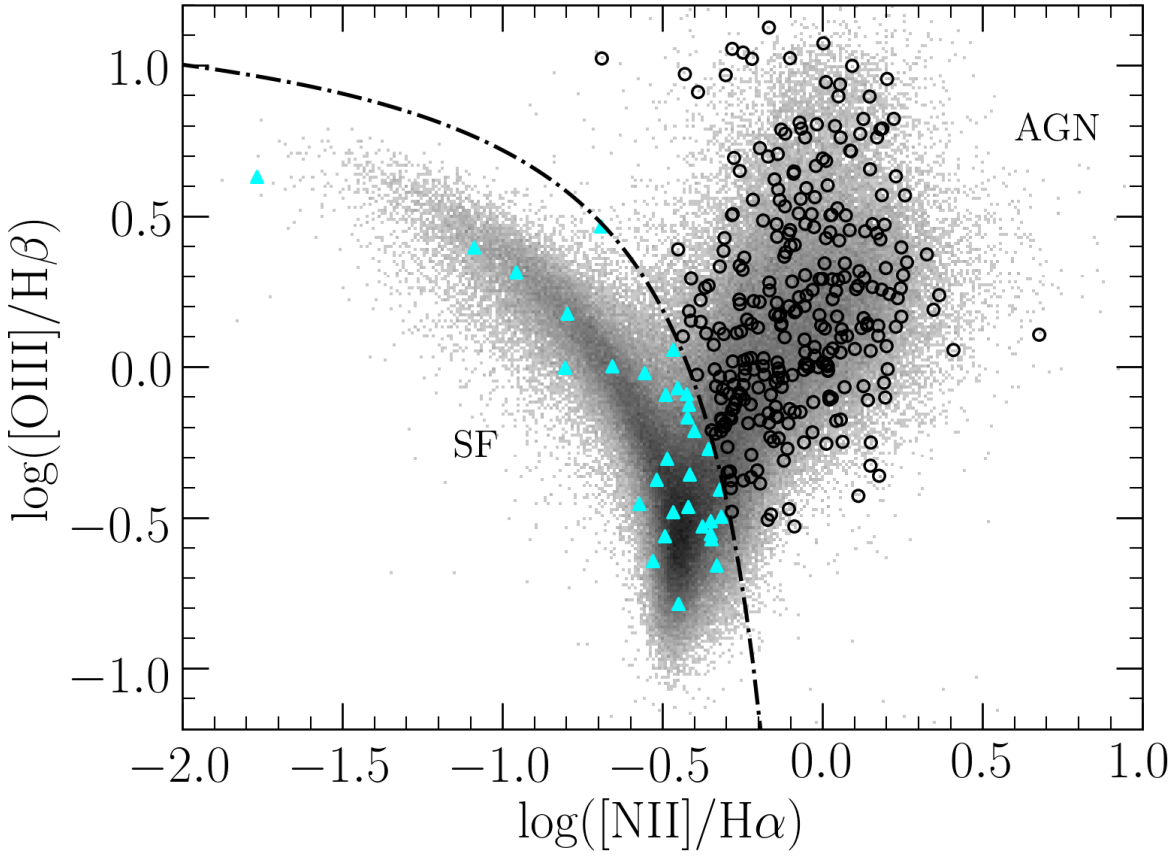
-Are they misclassified because of mixing? If so, they should be preferentially in hosts with higher amounts of star formation compared to correctly classified objects

Crossing the Line: Active Galactic Nuclei in the Star-forming Region of the BPT Diagram

Christopher J. Agostino[1] and Samir Salim[1]

Published 2019 April 26 •

The Astrophysical Journal, Volume 876, Number 1



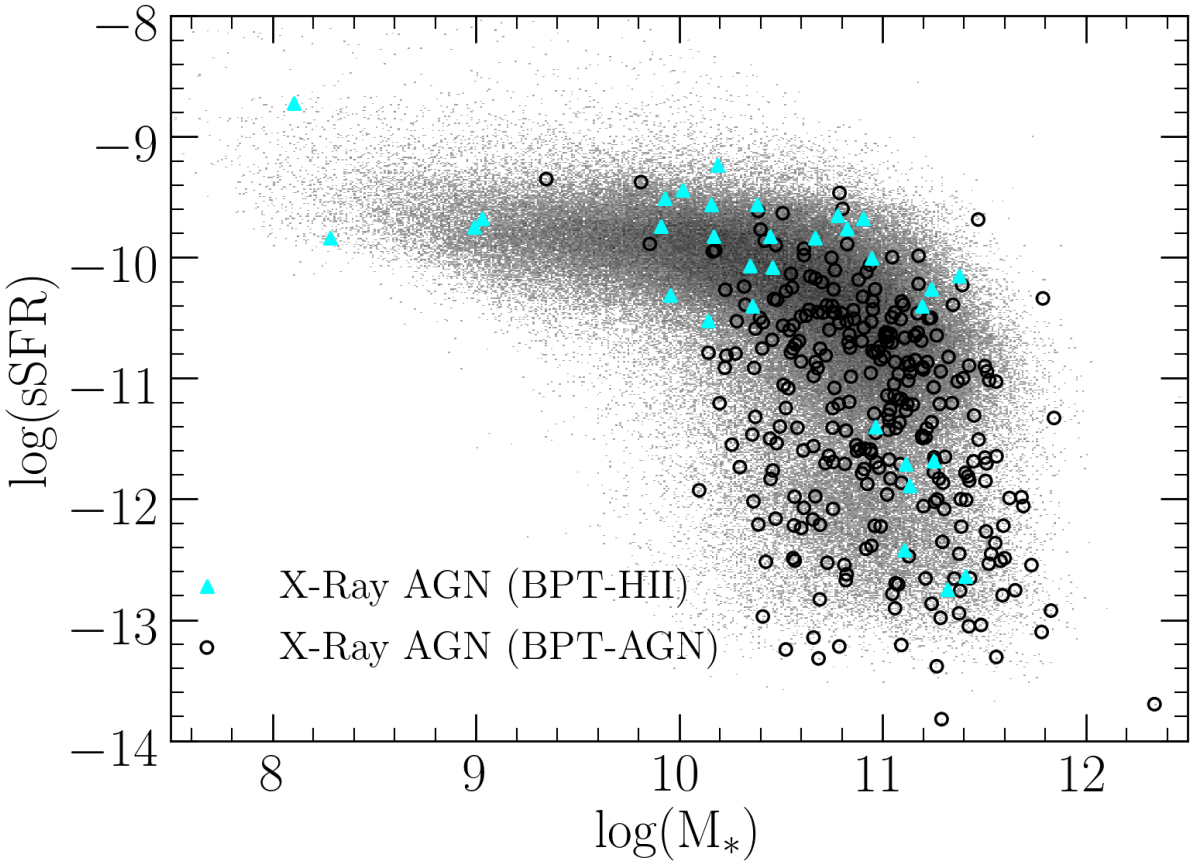
Agostino & Salim (2019)

Star Formation Dilution

-Misclassified X-ray AGN have high sSFRs, but so do many correctly classified BPT AGN .

-High sSFR appears to be a requirement for misclassification but cannot explain entirely.

-Could they simply lack AGN lines? 40% of our X-ray AGN lack lines, where do they fit in here?



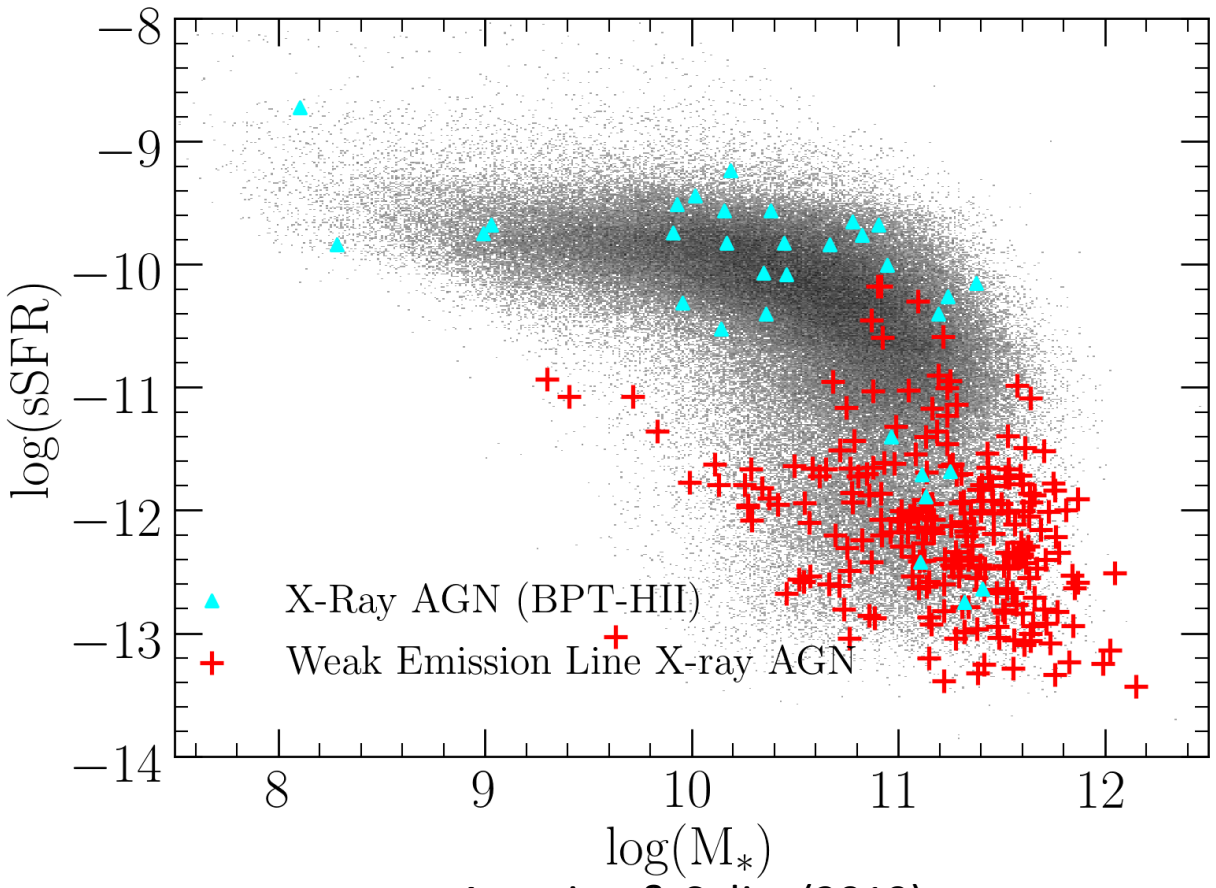
Agostino & Salim (2019)

AGN with no emission lines?

-Unclassifiable X-ray AGN have weak lines and low sSFRs: are the AGN in the misclassified objects similar?

-Misclassified X-ray AGN have no detectable NLR, because of obscuration, intrinsic weakness, or time lag for setting up NLR.

-Misclassified X-ray AGN are likely only classifiable because of their host SF component.



Agostino & Salim (2019)

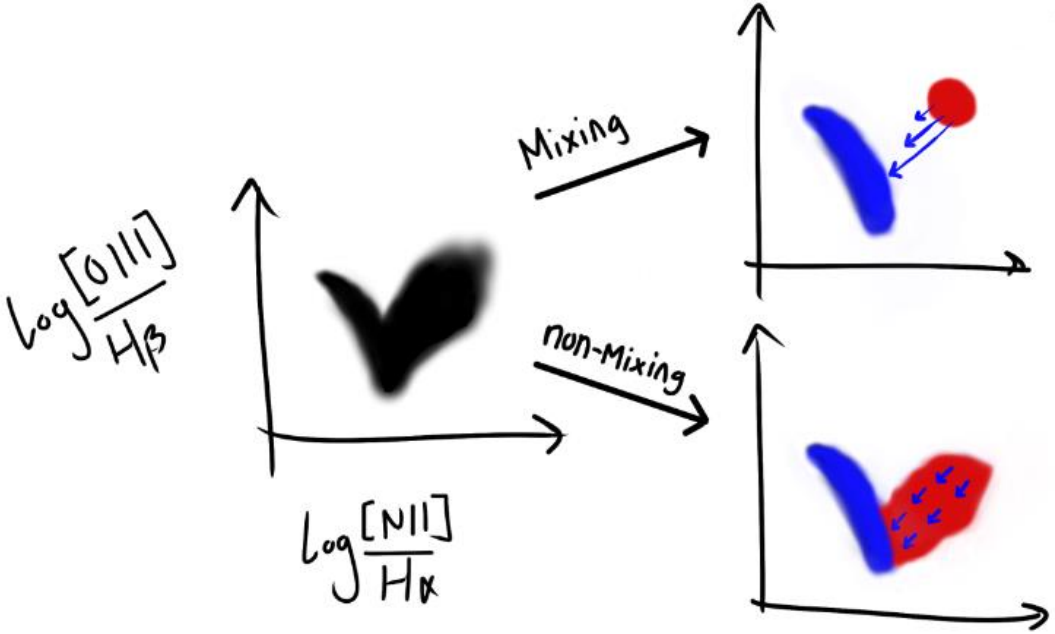
Motivation

-**What we want to answer:**

- Is the SDSS Seyfert/LINER (S/L) branch on the BPT diagram a mixing sequence of contributions from star-formation and S/L?

- If the contributions from host star formation are removed, are the "pure" S/Ls confined to a small region?

-Or do they span the full range of the S/L branch on the BPT diagram with their variety arising due to variation in intrinsic S/L properties?



Agostino et al. (2021, Accepted to ApJ) preprint at arXiv:2108.07812

Doppelganger method

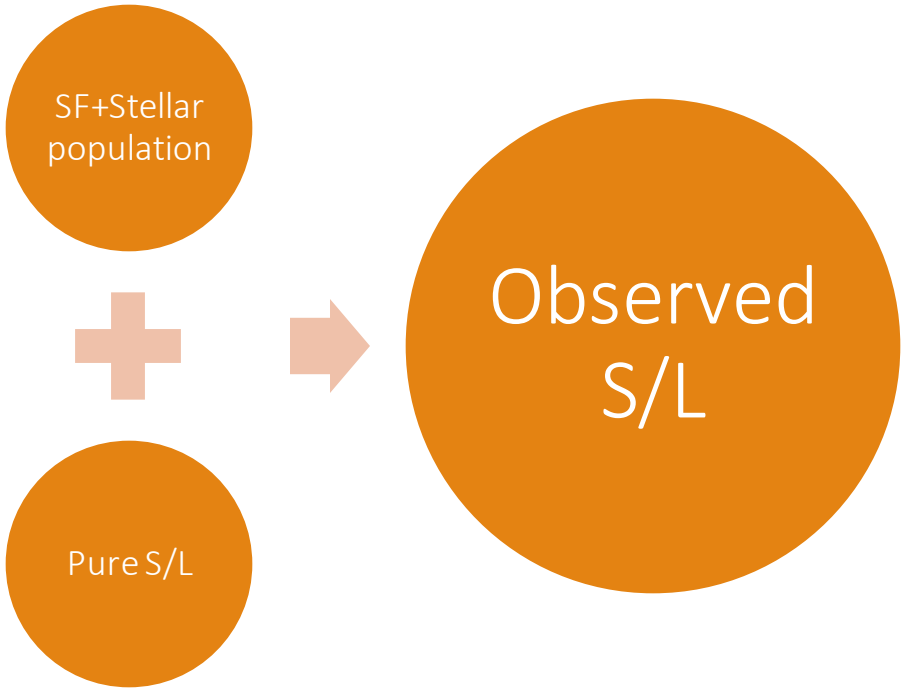
-Match S/Ls to non-S/Ls at similar redshifts and with similar properties related to their star formation+stellar population: SFR, stellar mass, stellar mass contained within SDSS fiber, stellar continuum dust attenuation.

Click to add text

-Require fluxes in the non-S/L match to be less than those in the AGN for all four BPT lines.

-Use the fluxes from non-S/Ls to remove the star formation component of the AGNs.

-Place resultant pure S/Ls on the BPT diagram



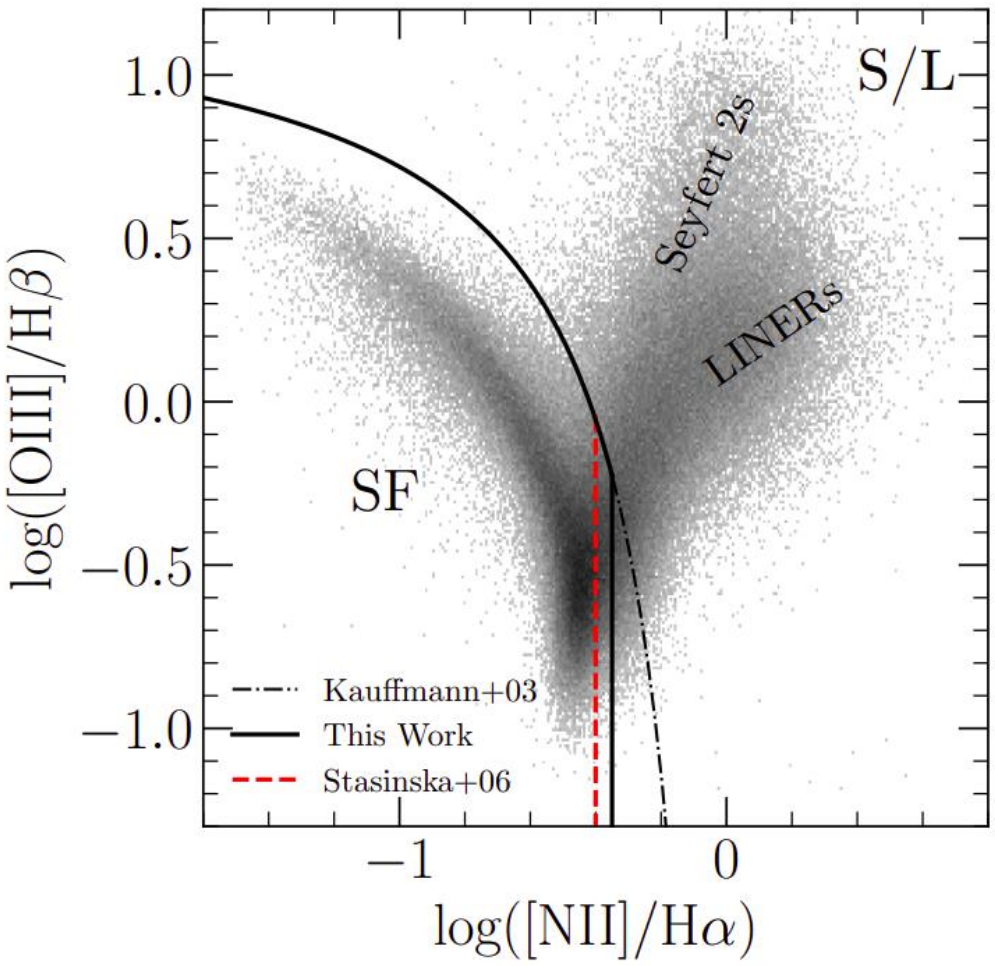
Sample Selection

-GSWLC-M2 (Salim+2016, 2018) galaxies which can be reliably placed on the BPT diagram (S/N>2 in all 4 lines). GSWLC-M2 provides stellar masses, SFRs, continuum dust attenuation from SED fitting

-S/L sample: galaxies above Kauffmann+(2003) line or with log([NII]/Ha)>-0.35, based on decomposition of branches.

-non-S/L sample are all objects in star-forming part of the BPT, those with log([NII]/Ha)<-0.4 (Stasinska+2006) if they have low S/N [OIII]/Hbeta, or those which are unclassifiable with either method (~"lineless")

-Leave out objects in –0.4<log([NII]/Ha)<-0.35.

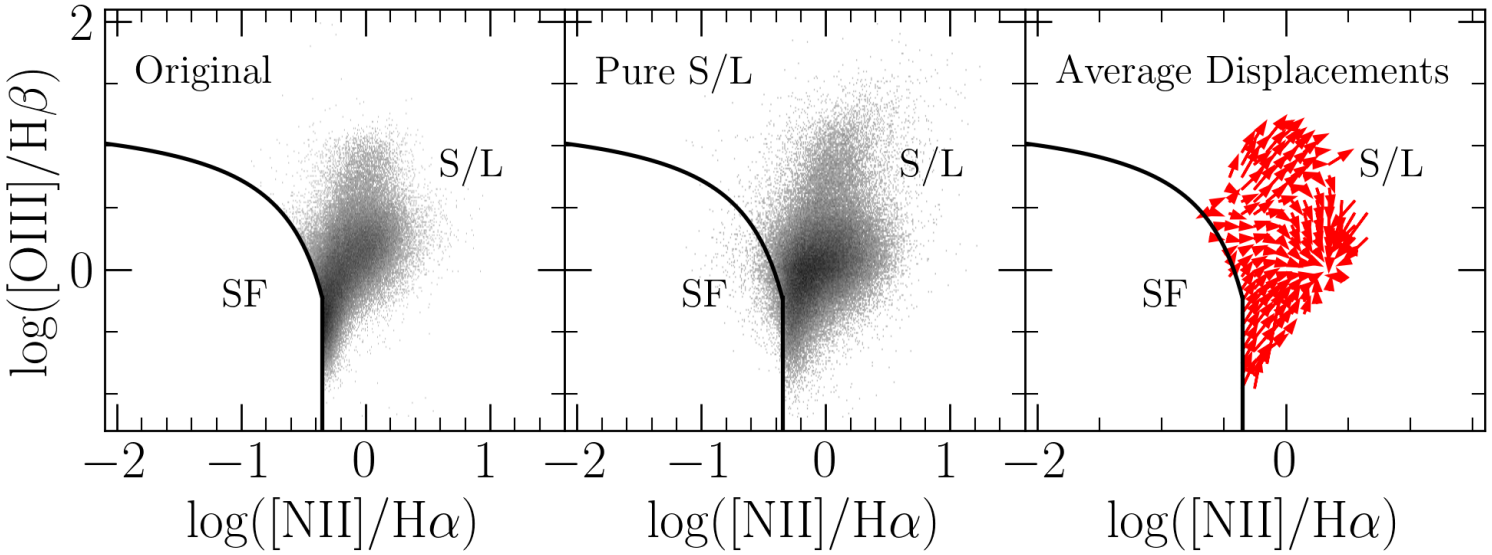


Agostino et al. (2021)

Testing the Mixing Scenario

-S/L branch remains populated after SF component is removed: mixing cannot explain this

-If S/L branch is due to mixing, objects lower on the S/L branch should on average shift more significantly than those at the top but objects higher on the S/L branch shift similarly to those at the bottom.

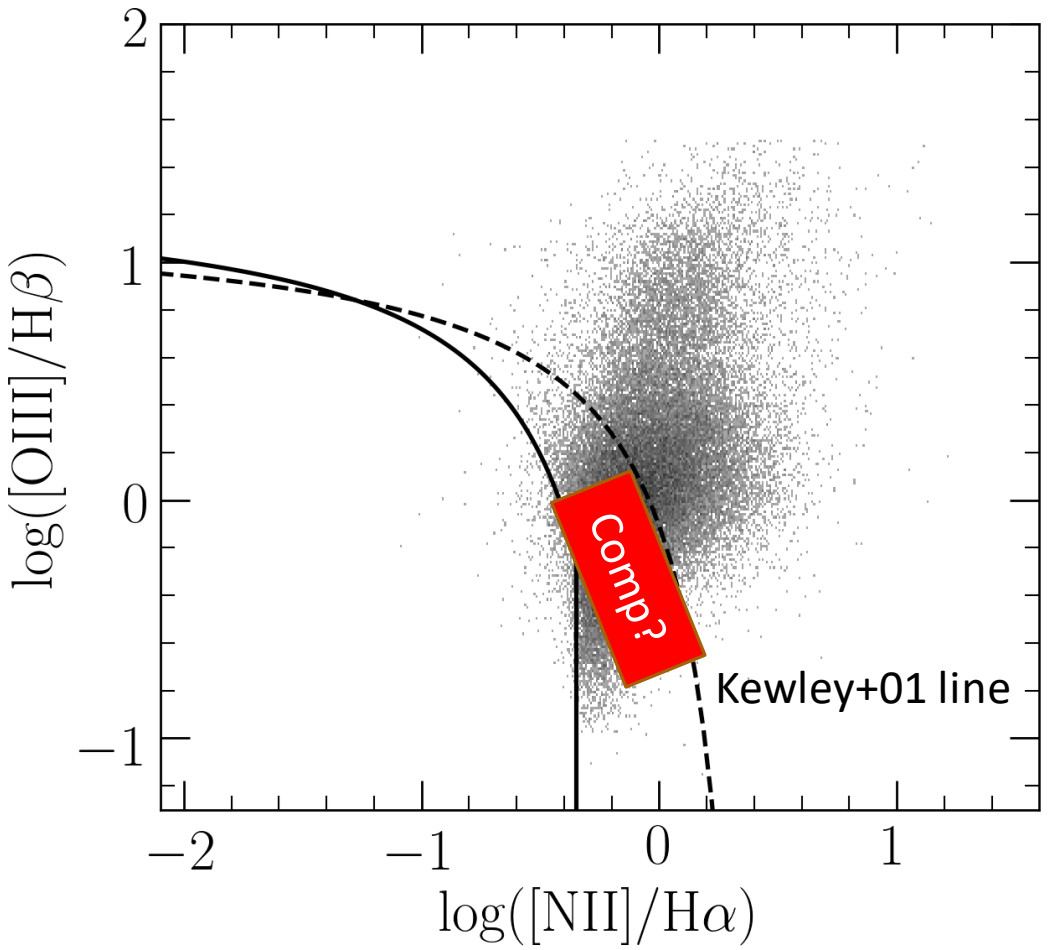


Agostino et al. (2021)

Implications

-Without the mixing scenario, a division of the S/L branch into "composites" and "secure AGNs" below and above Kewley+2001 starburst line seemingly lacks an empirical basis: galaxies with serious ongoing SF lie above it and those without any lie below it.

-While host contributions are not main driver in emission line diversity, they do still affect them (0.2 dex on average) and should ideally be removed for proper interpretation of S/L spectra

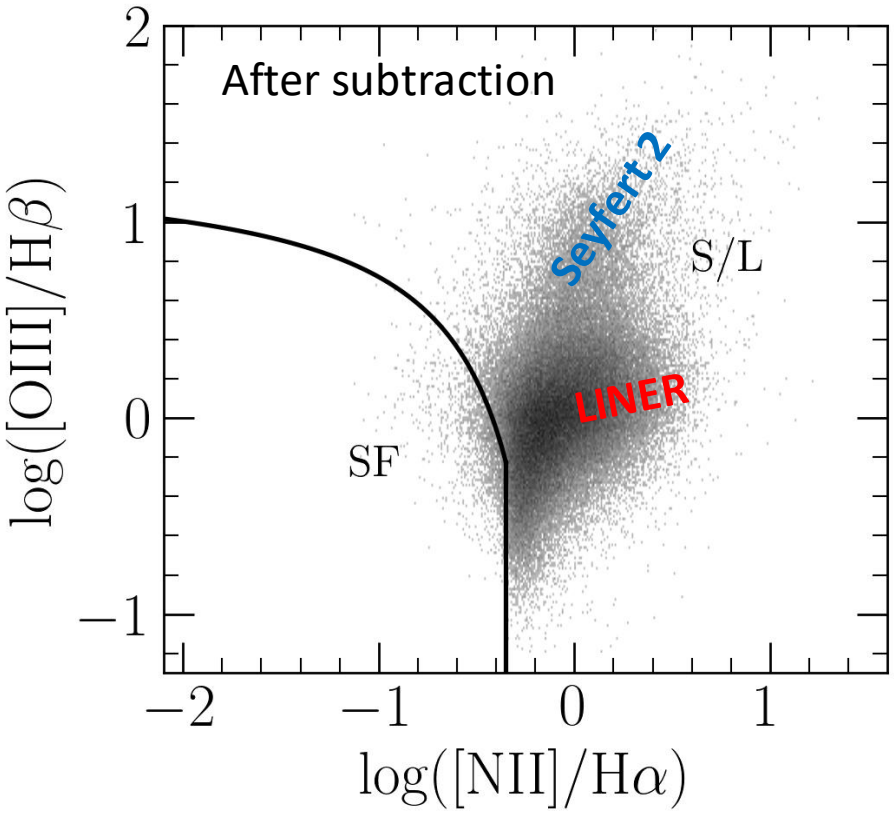


Non-mixing scenario

-Want to analyze properties among similar AGNs

-Often considered that two types of AGNs exist: LINERs and Seyfert 2s

-With pure S/Ls, LINER and Sy2 sub-branches seem more well-defined. What about the pure S/L lower on the branch: are they Sy2? LINER? Or something else?



Non-mixing scenario

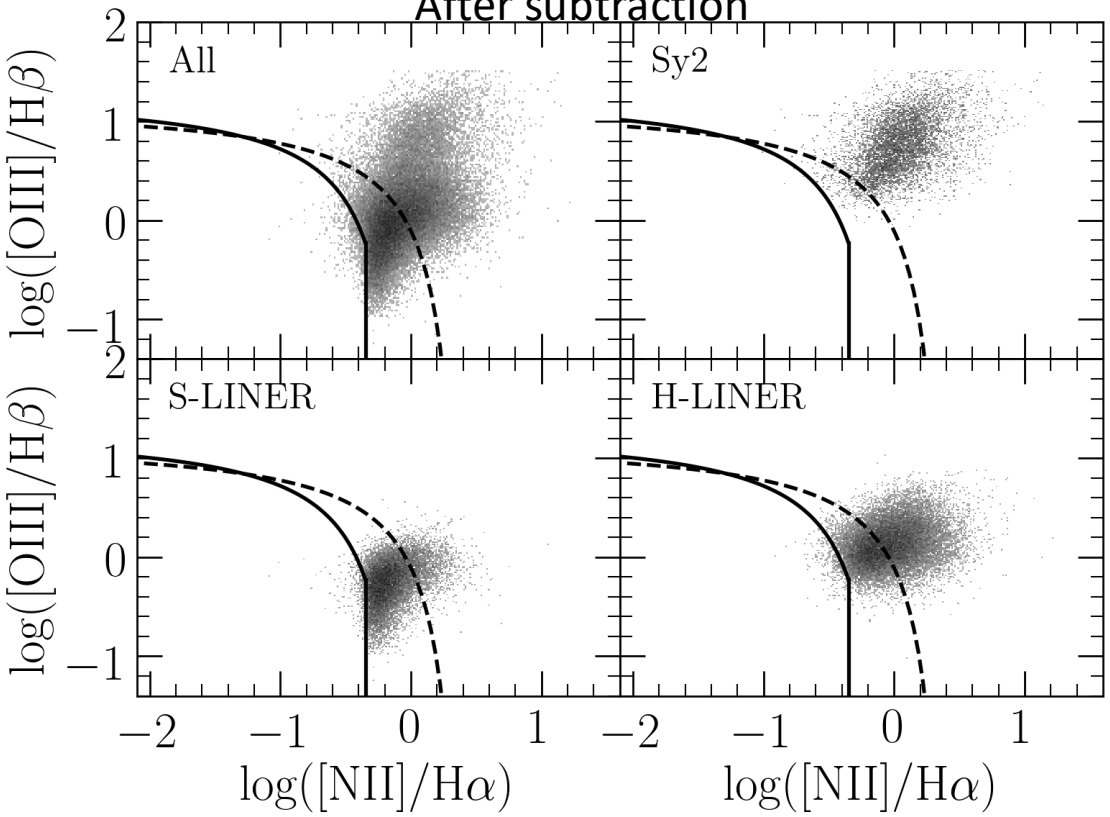
-Use k-means to separate pure S/Ls into subgroups based on emission lines

-Use dust-corrected lines [OIII], [OII], [OI], [NII], [SII], Halpha, Hbeta

-Find three subgroups which we denote as Sy2, Soft LINER (S-LINER), and Hard LINER (H-LINER)

-Yesuf+Ho(2020) perform a clustering with observed fluxes and host properties and find groups with similar qualities to those here.

After subtraction



Agostino et al. (2021)

Non-mixing scenario

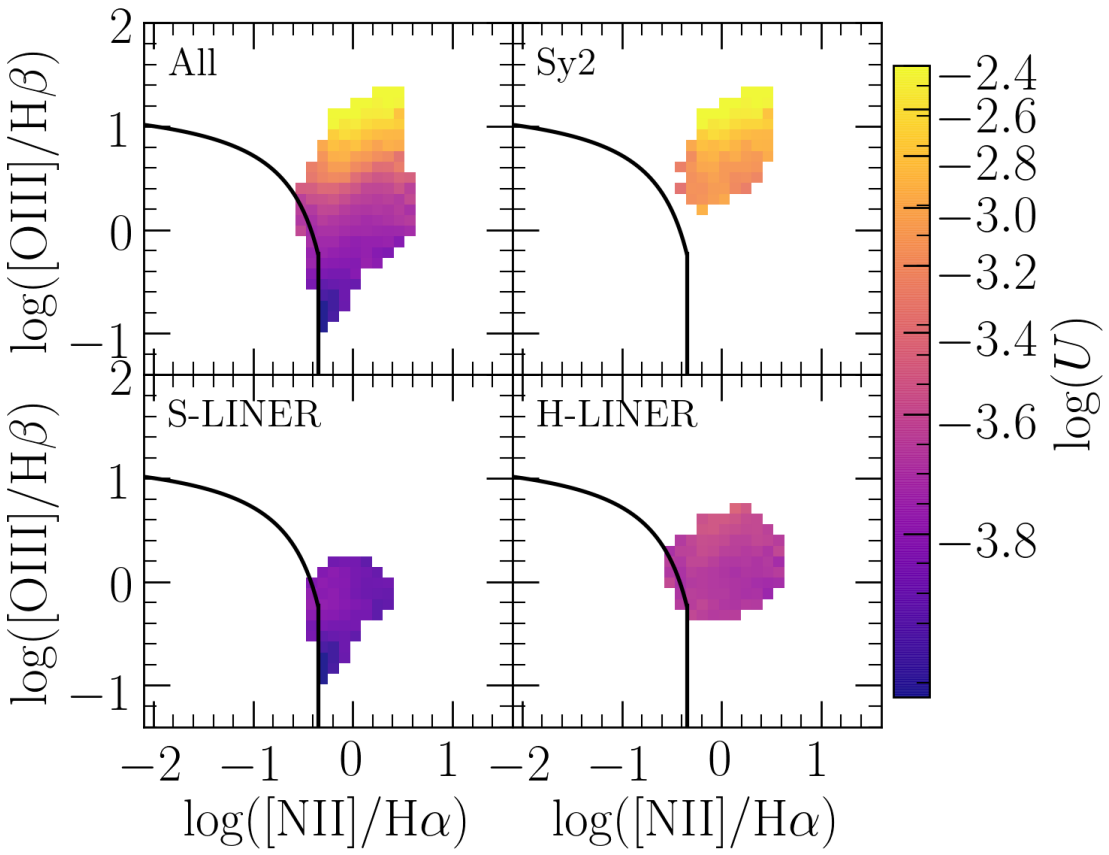
1. Properties of the ionizing source

2. Properties of the narrow line region

Ionizing Source Properties

-Use [OIII]/[OII] to estimate the ionization parameter, log(U): number of ionizing photons produced by AGN, using calibration from Carvalho+2020.

-[OIII]/Hbeta of S/L dependent on ionization parameter, not much change with [NII]/Ha



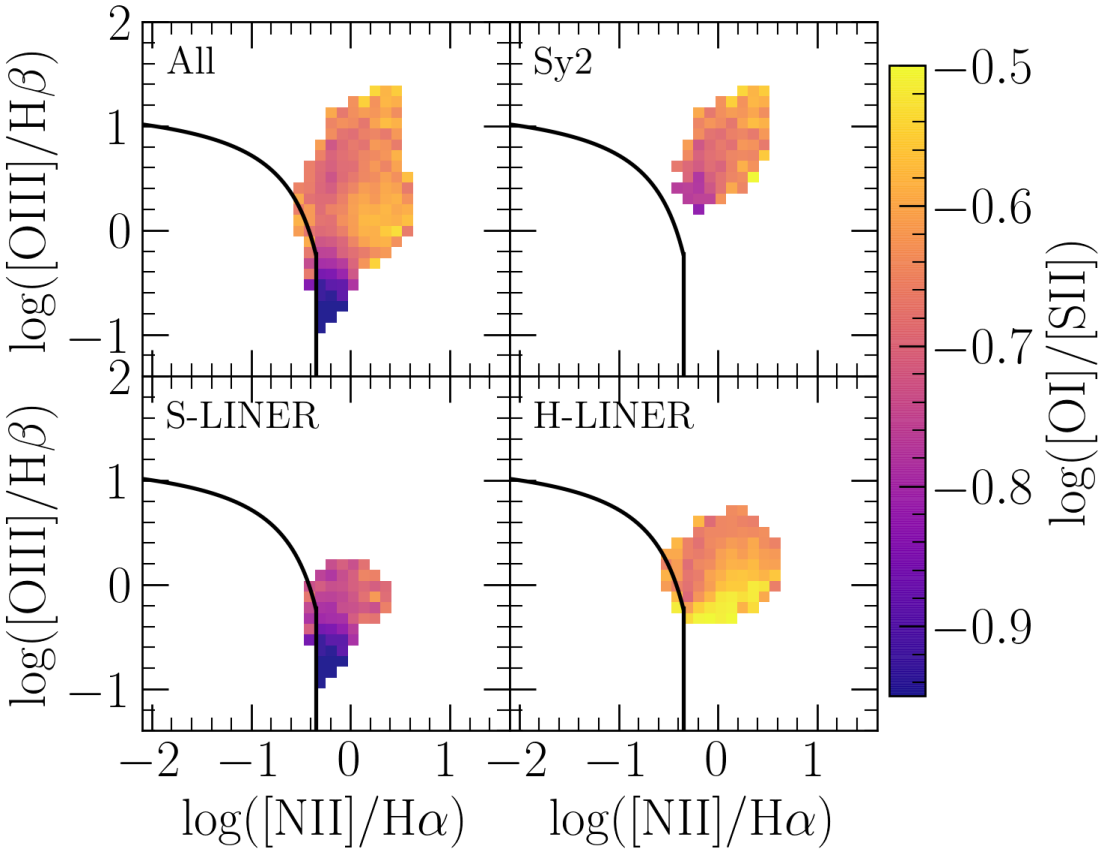
Agostino et al. (2021)

Ionizing Source Properties

-Use [OI]/[SII] to probe the hardness of ionizing radiation. [OI] is primarily produced in partially ionized zones which increase in size when the hardness of ionizing source increases.

-For Sy2 and S-LINERs, [OI]/[SII] increases along the direction of the S/L branch

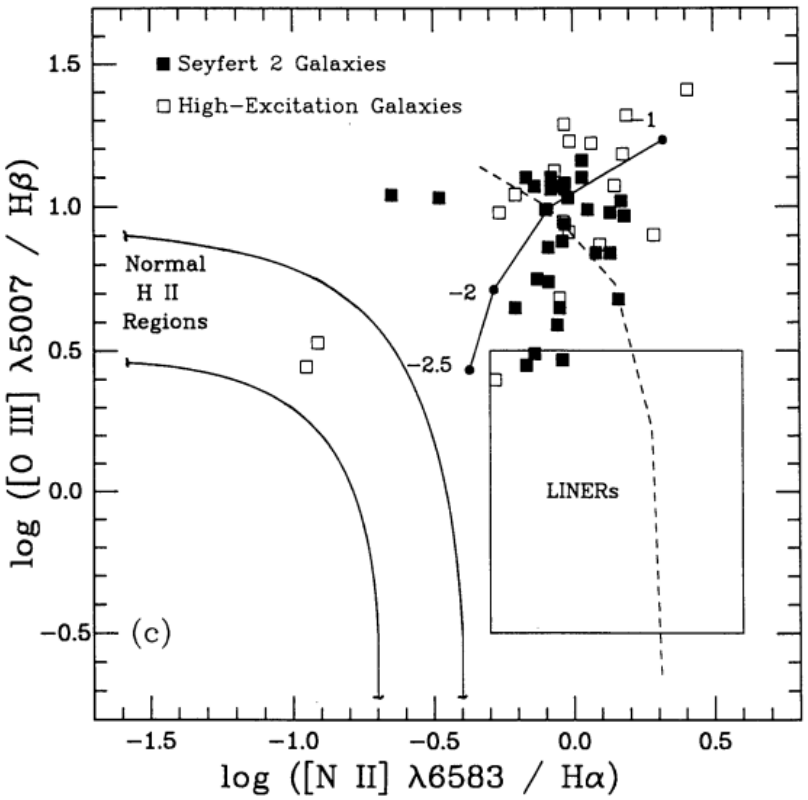
-With H-LINERs: [OI]/[SII] increases transverse to the direction of branch



Agostino et al. (2021)

Hardness

- Modeling efforts from Ho et al. (1993) suggest the variety in the Seyfert part of the AGN branch is due to a range in the power law slopes (related to hardness) of the ionizing sources

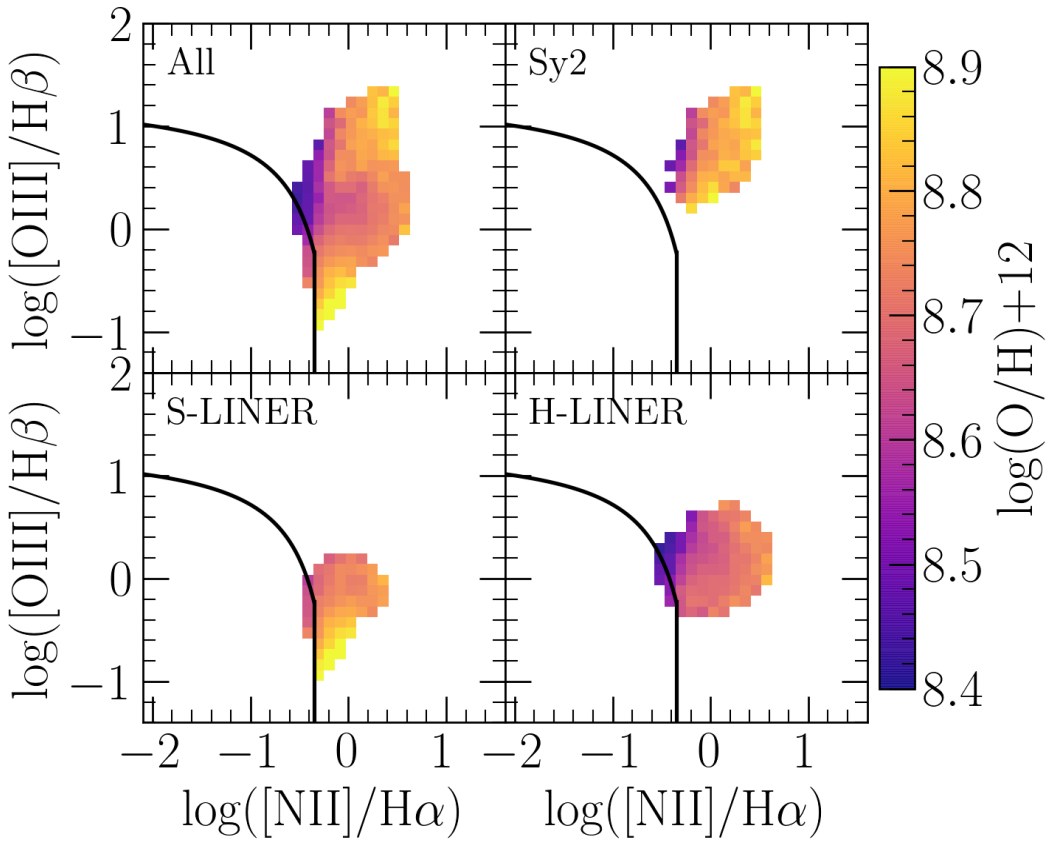


Ho et al. (1993)

NLR Conditions

-Use [NII]/[OII] and Castro+2017 calibration to probe the Oxygen abundance in narrow-line region.

-Oxygen abundance increases transverse to S/L branch direction for Sy2, S-LINERs, and H-LINERs.



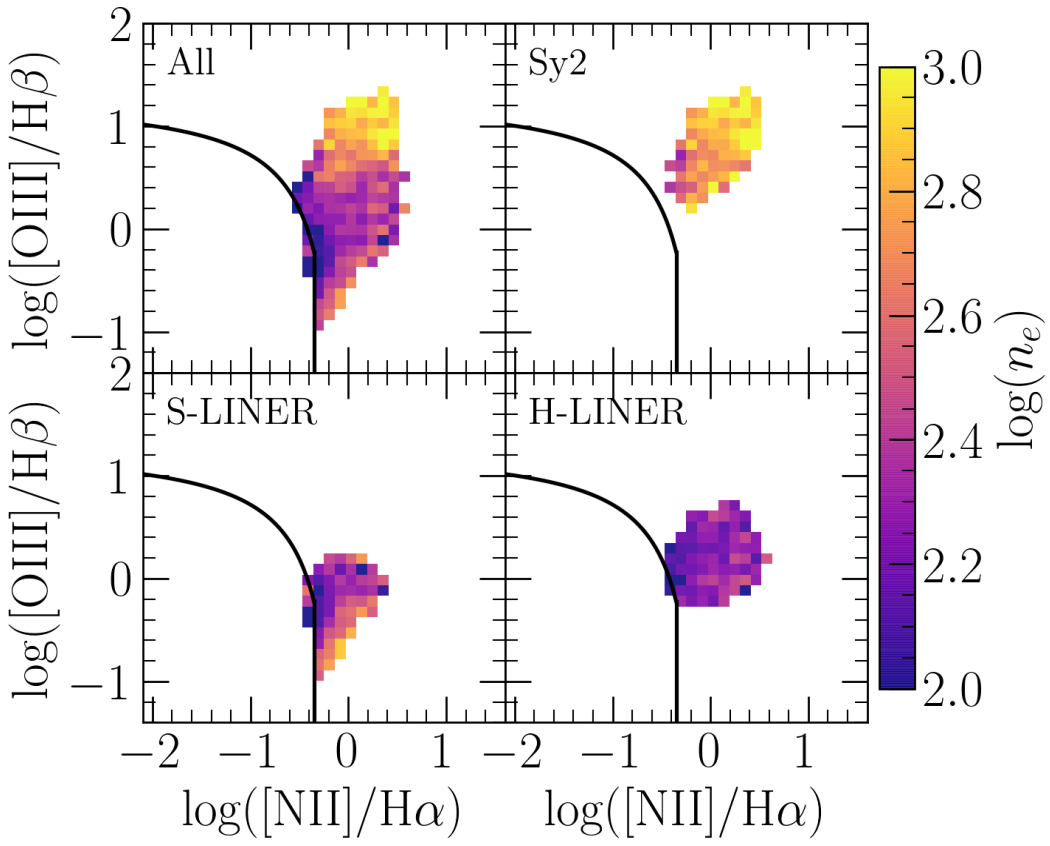
Agostino et al. (2021)

NLR Conditions

-Use [SII]6717/6731 to probe electron density in narrow-line region, with calibration from Proxauf+2014

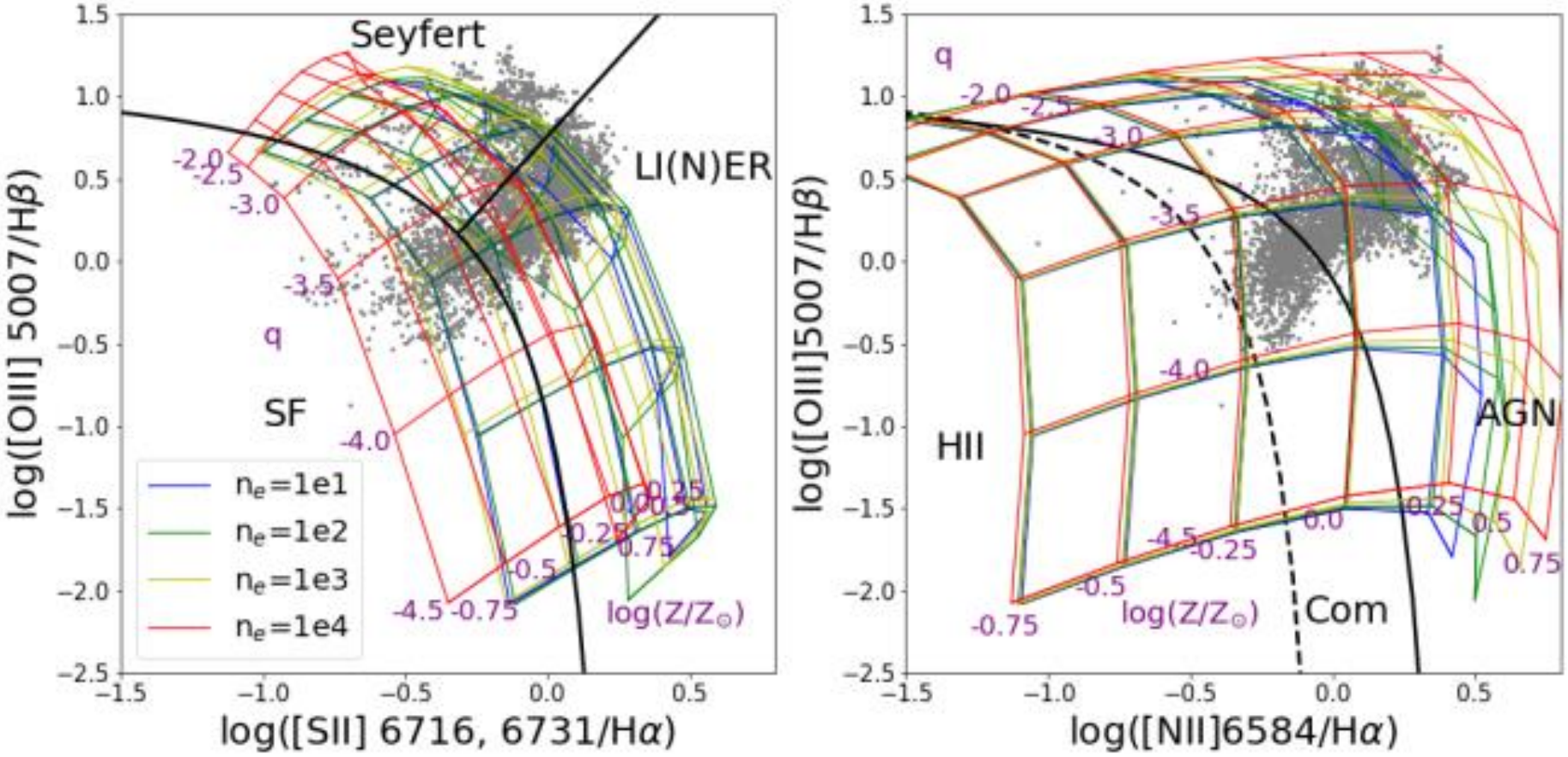
-For Sy2, electron density increases up the S/L branch.

-A clear trend is not present for either S-LINERs or H-LINERs



Agostino et al. (2021)

Ji et al. (2020) Photoionization Grids



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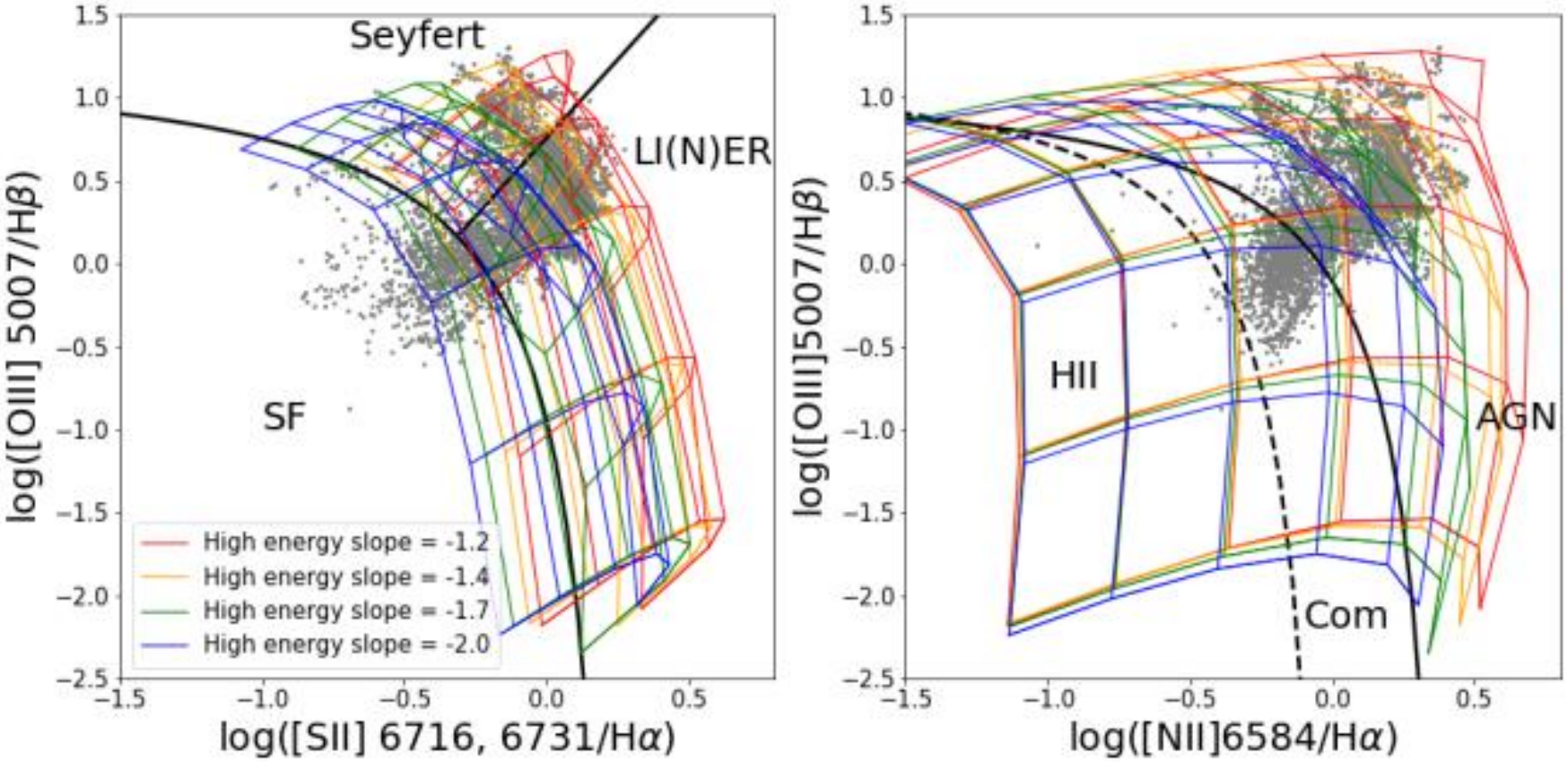
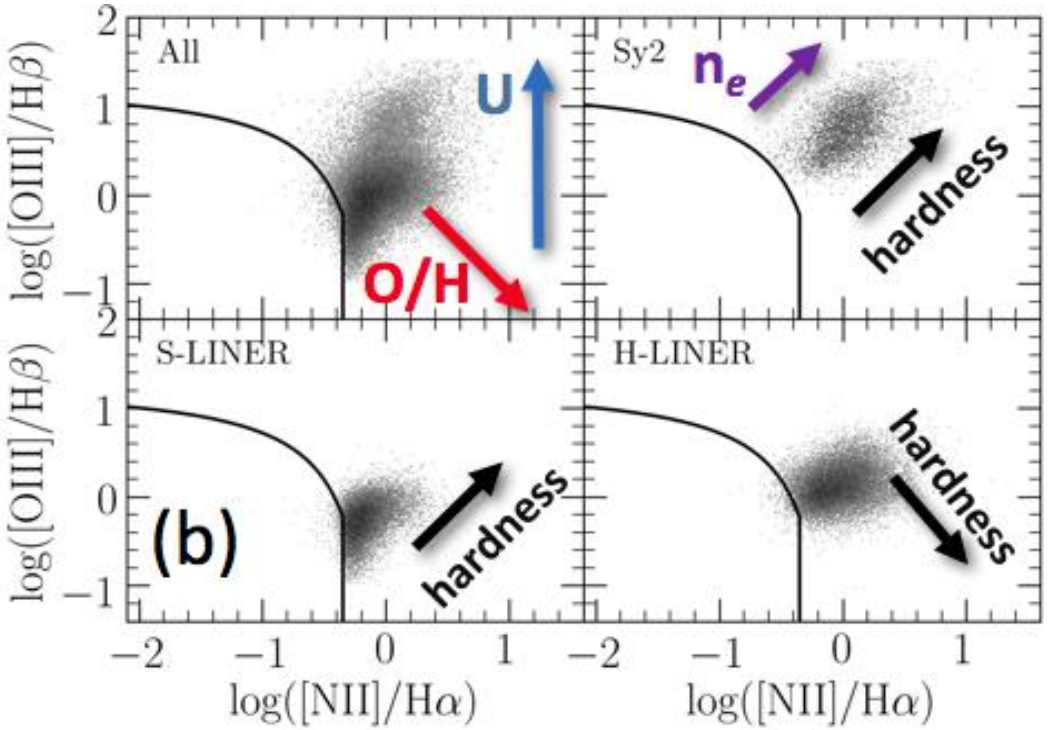


Conclusions

-Mixing cannot account for the variety of line ratios observed in the pure S/L branch. Distinguishing between "composites"/"AGNs" using the extreme starburst line biases samples of Seyferts/LINERs and not based on empirical evidence

-Pure S/Ls separate into three groups: Seyfert 2s and two types of LINERs

-Pure S/L branch exhibits a wide range of ionizing source parameters and narrow-line region conditions



preprint at arXiv:2108.07812