Galactic Scale Outflows in MaNGA Survey

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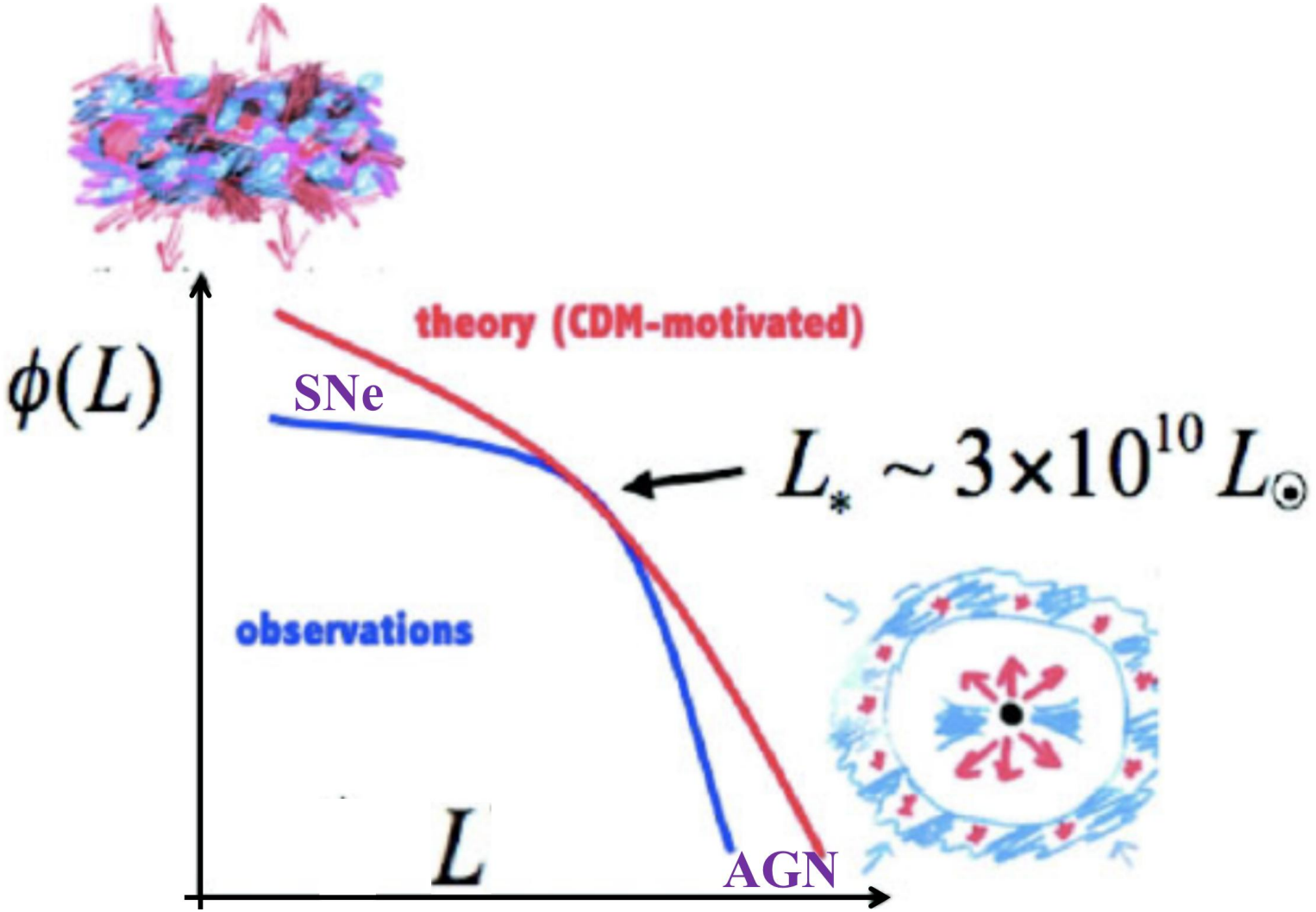
Collaborators: Zhi-Jie Zhou, Min Bao, Xiao Cao, Alexei Moiseev, Yong Shi et al.

Outline

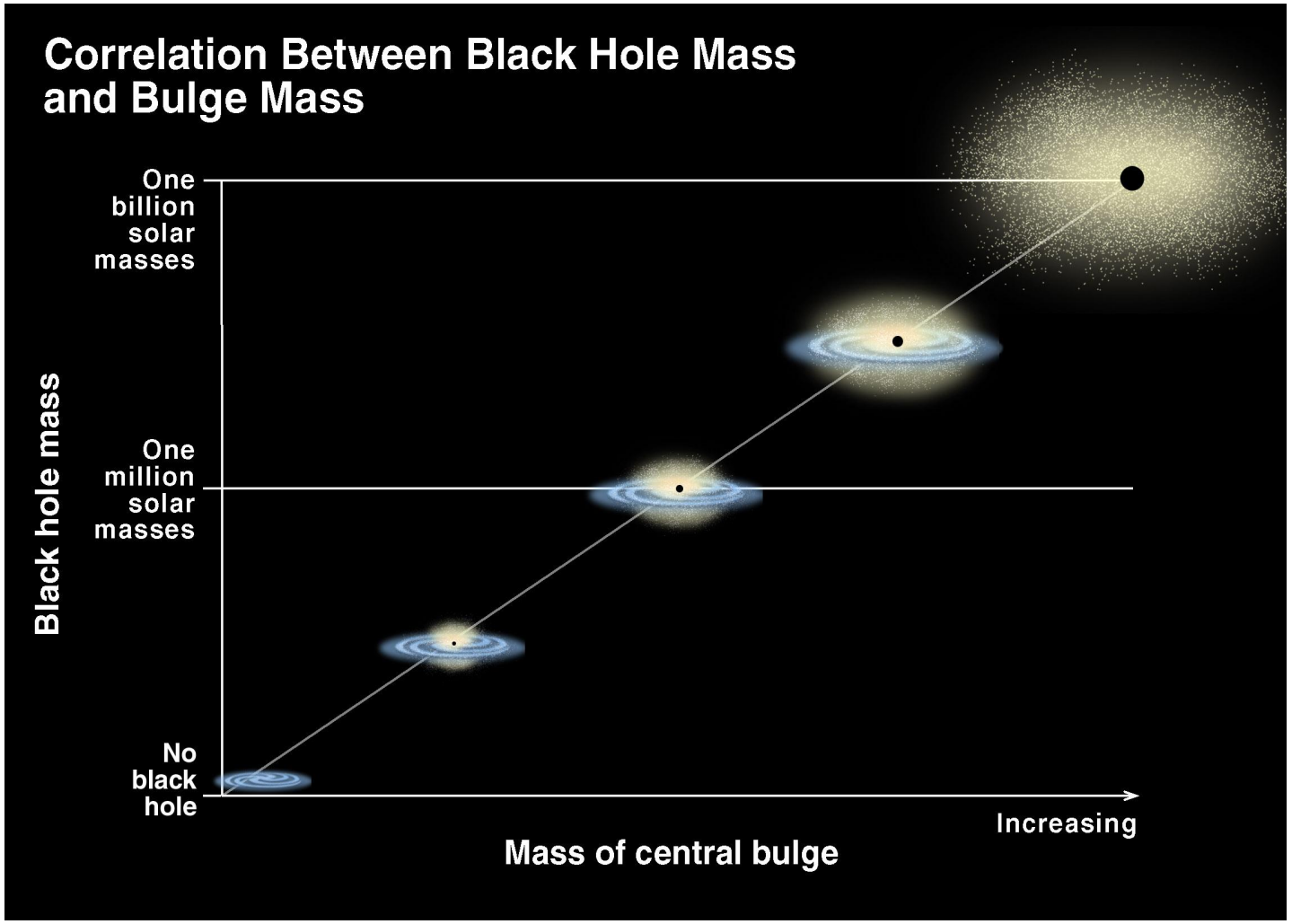
- ✓ Background
- ✓ Sample selection
- ✓ Morphologies of outflows
- ✓ Primary driven mechanisms of the outflows
- ✓ Detailed gas kinematic studies of one/two galaxies with galactic scale outflows

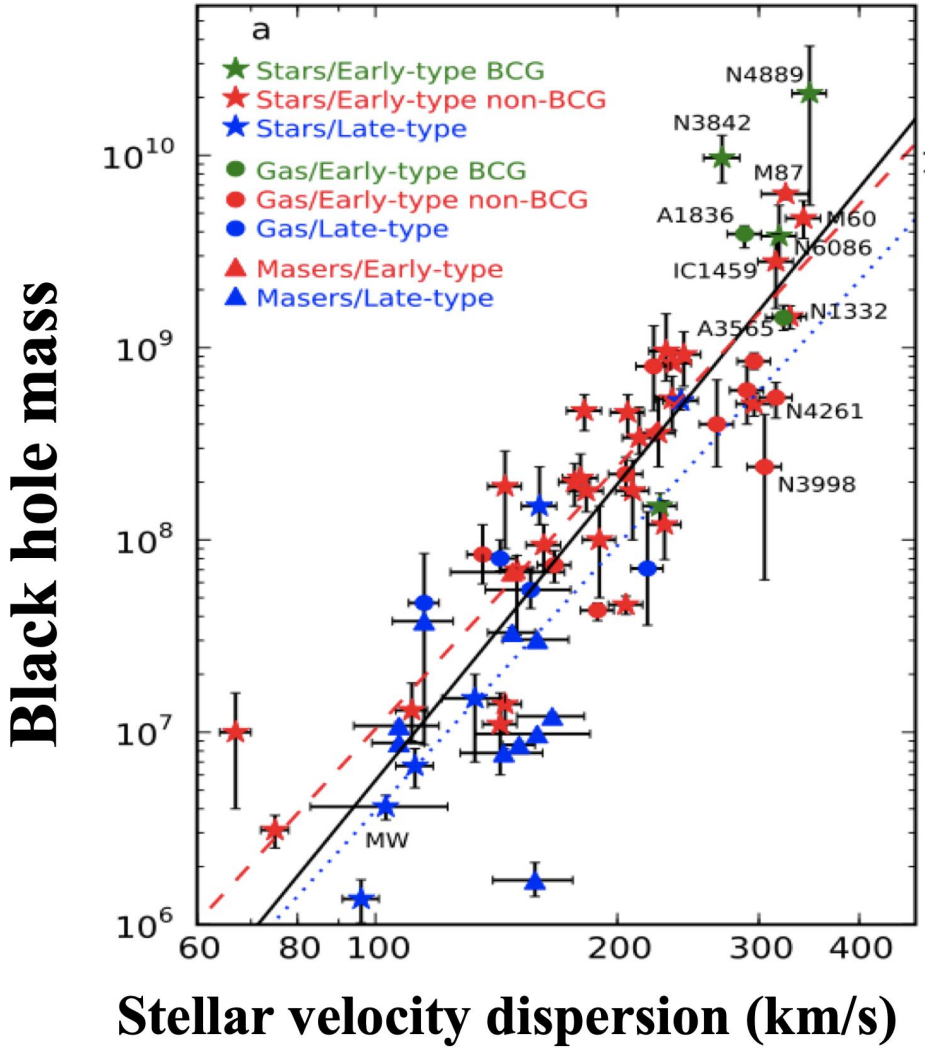
Background: Why we need feedback?



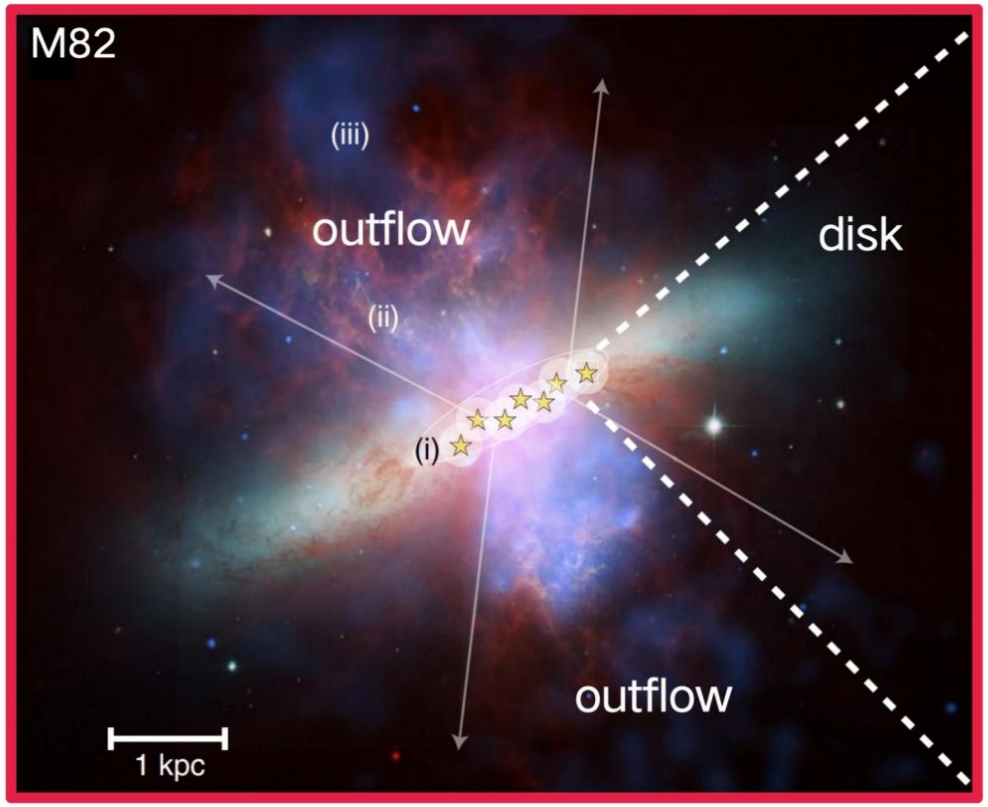
Inconsistency between the observed galaxy luminosity function and ΛCDM theoretical prediction requires incorporating feedback

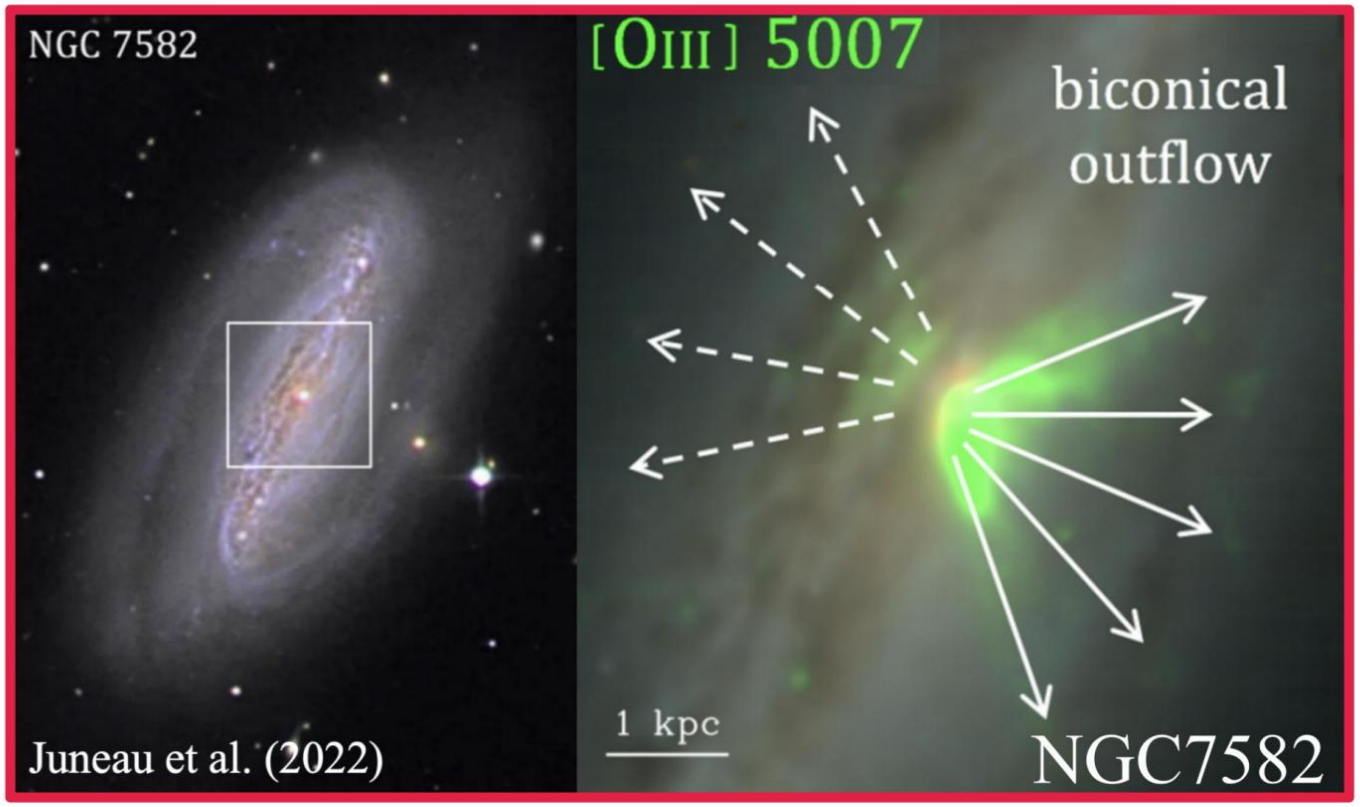
Background: Why we need feedback?





Background: Outflow observations

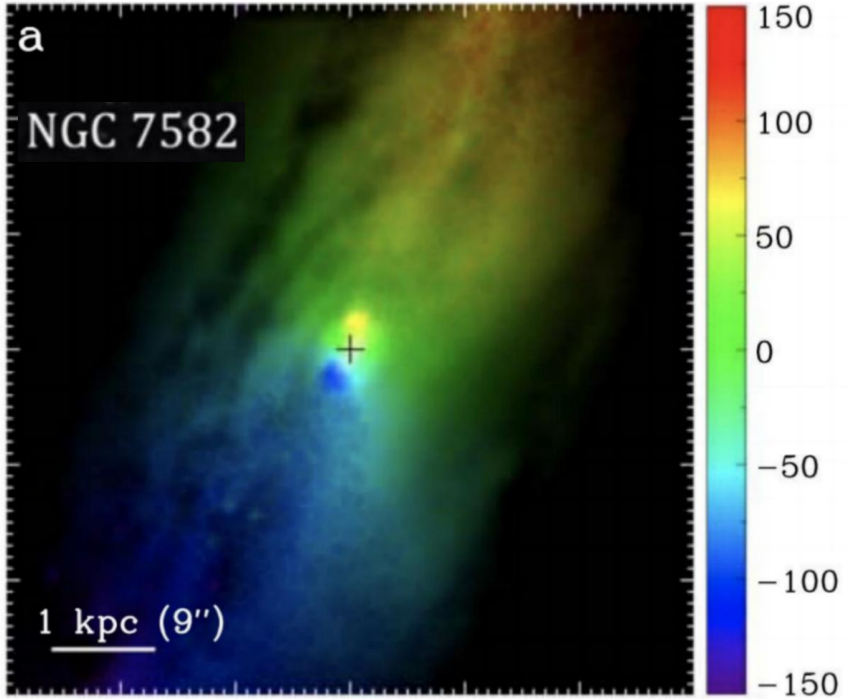




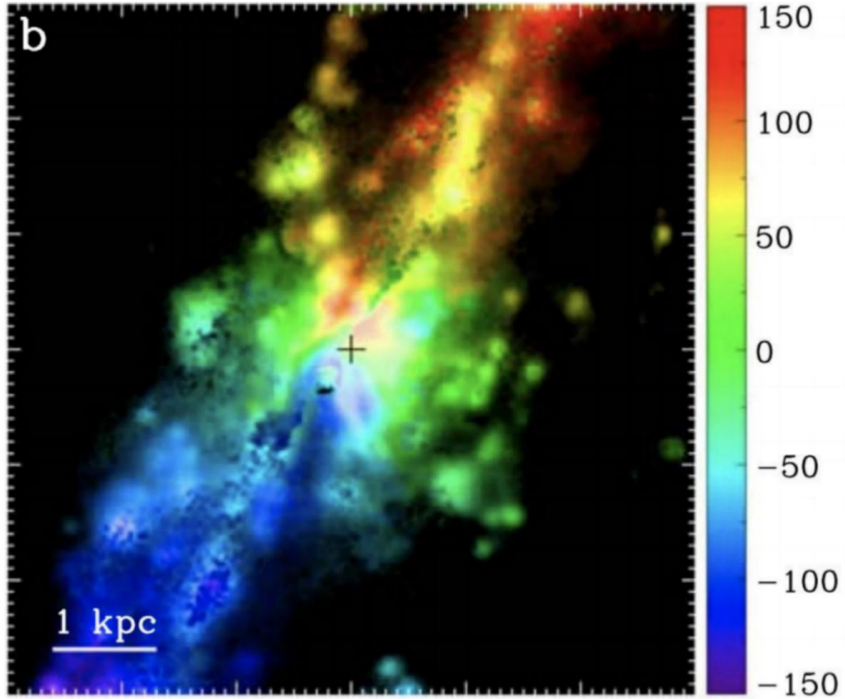
Outflow driven by stellar feedback

Outflow driven by AGN feedback

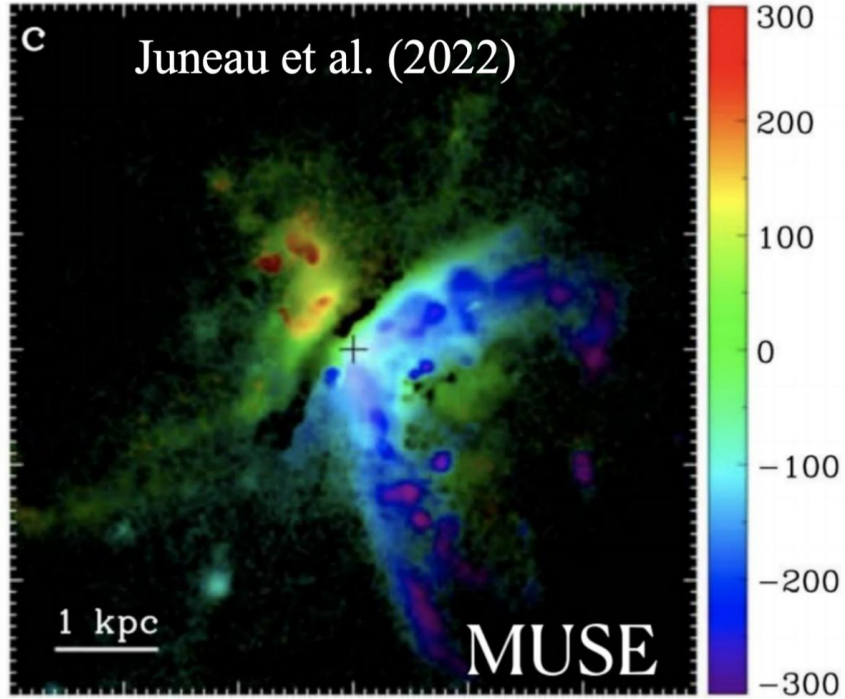
Background: Outflow kinematics observed by IFU



stellar velocity field



Hα traced gas
velocity field



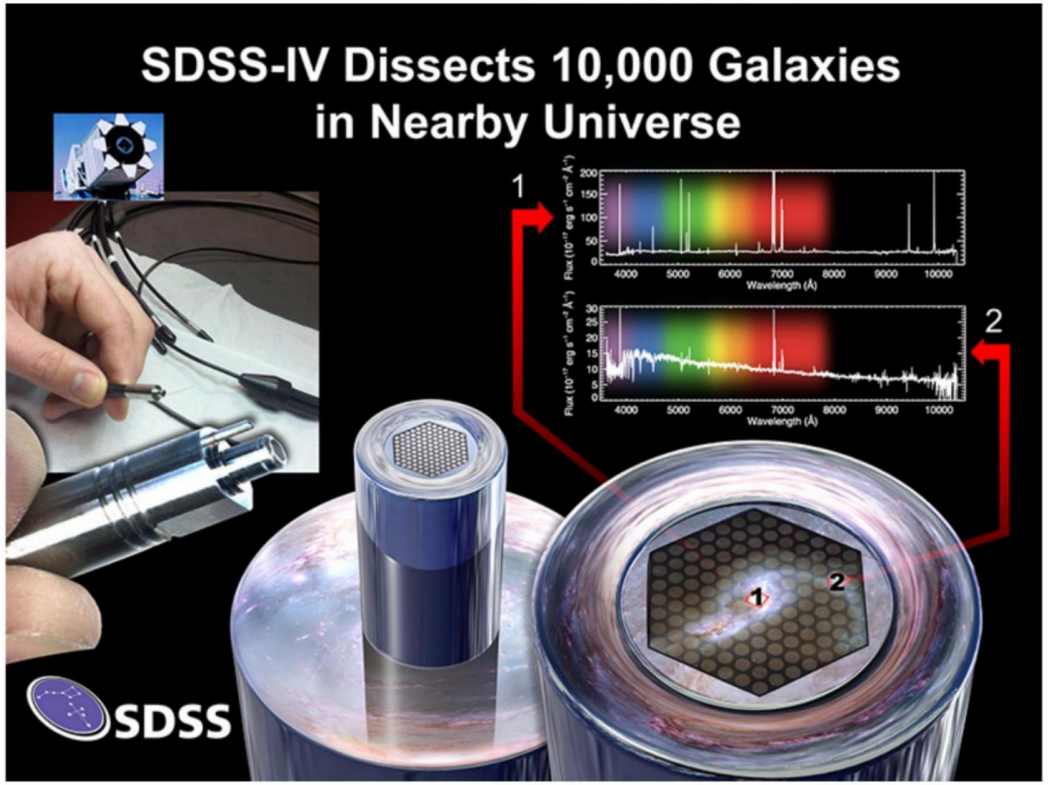
[OIII] traced gas
velocity field

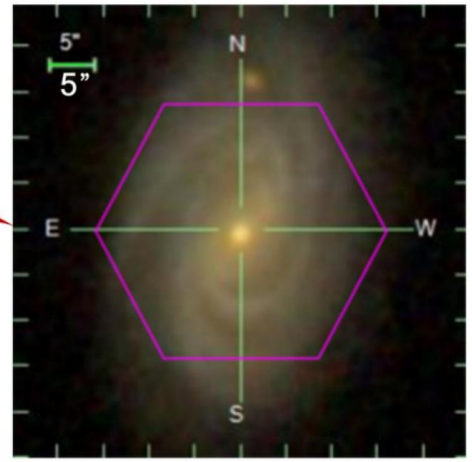
Hα emission dominates in the disk while [OIII]λ5007 dominates in the outflow

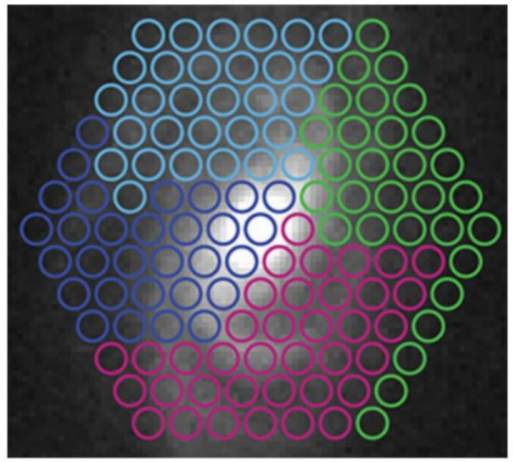
Mapping **N**earby **G**alaxies at **A**pache Point Observatory

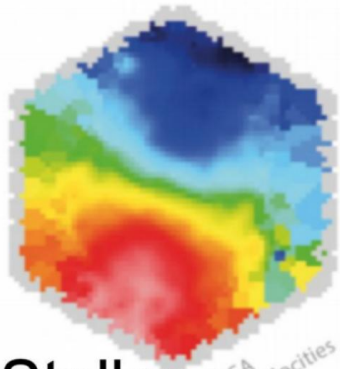
SDSS 2.5m telescope

- $z \sim 0.03$
- $r \sim 1.5\ r_e$
- R ~ 2000
- $\lambda \sim 3600 - 10000$ Å
- $M_\star > 10^9\ M_\odot$
- ~10,000 galaxies

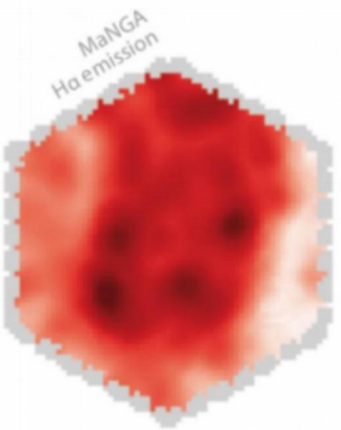




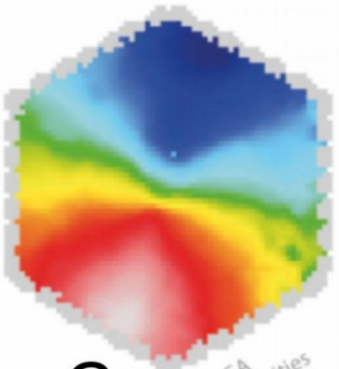




Stellar velocity field

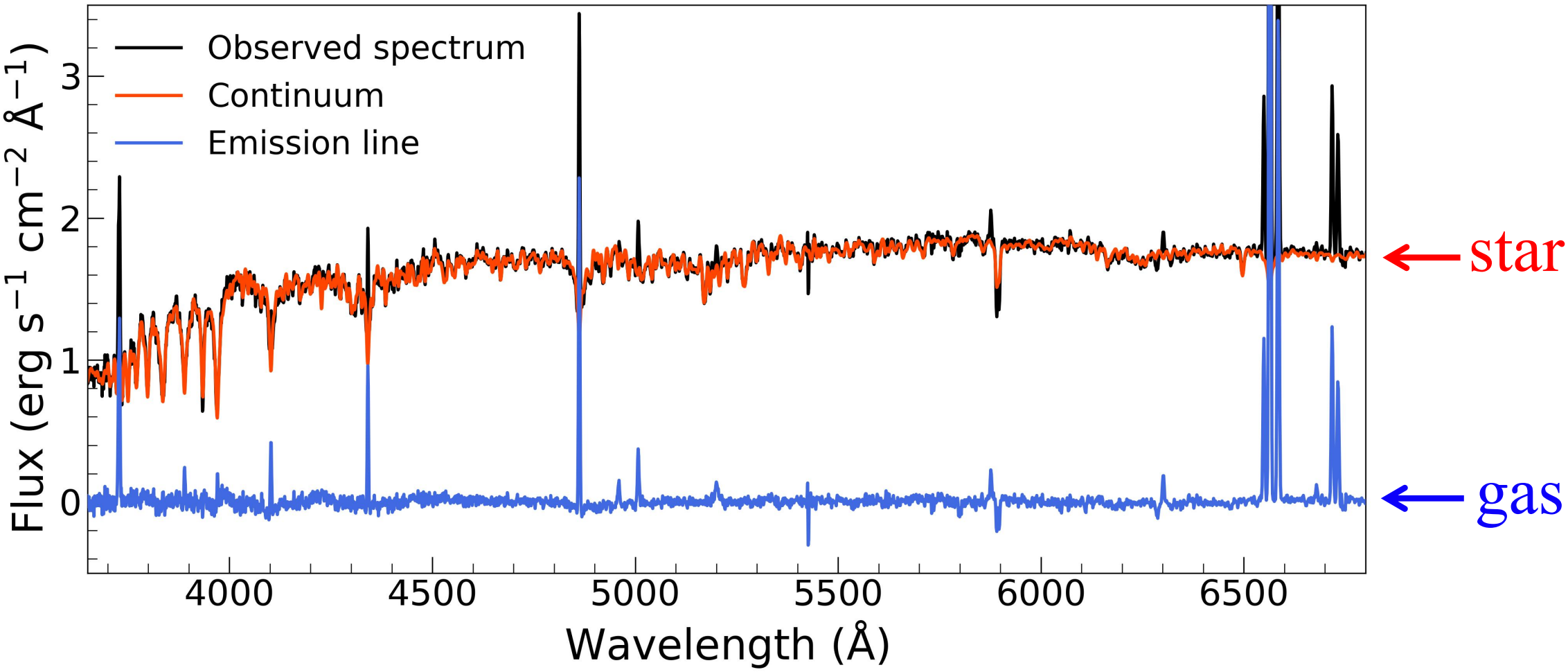


Hα intensity

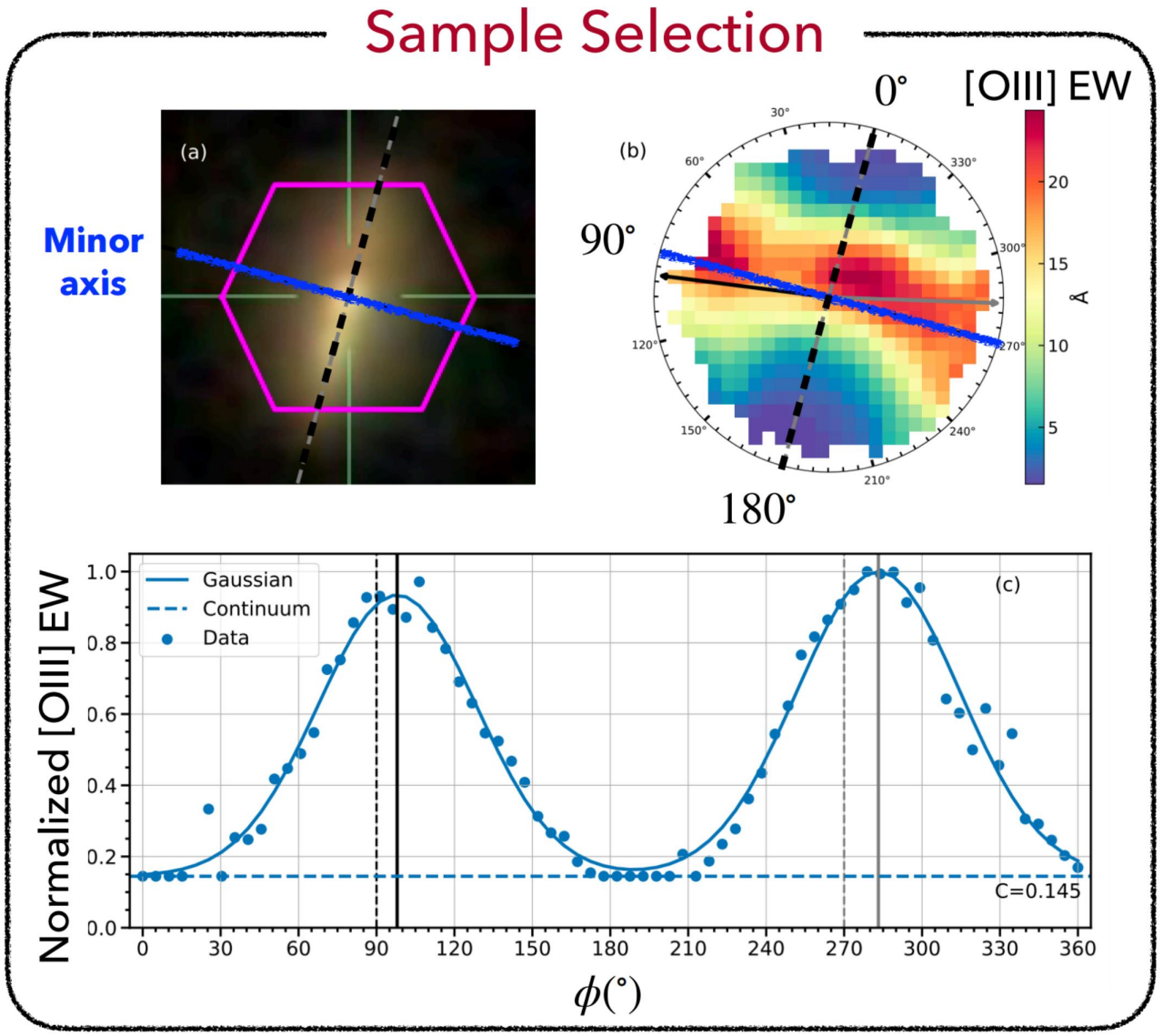


Gas velocity field

Spectrum fitting example



Sample selection method

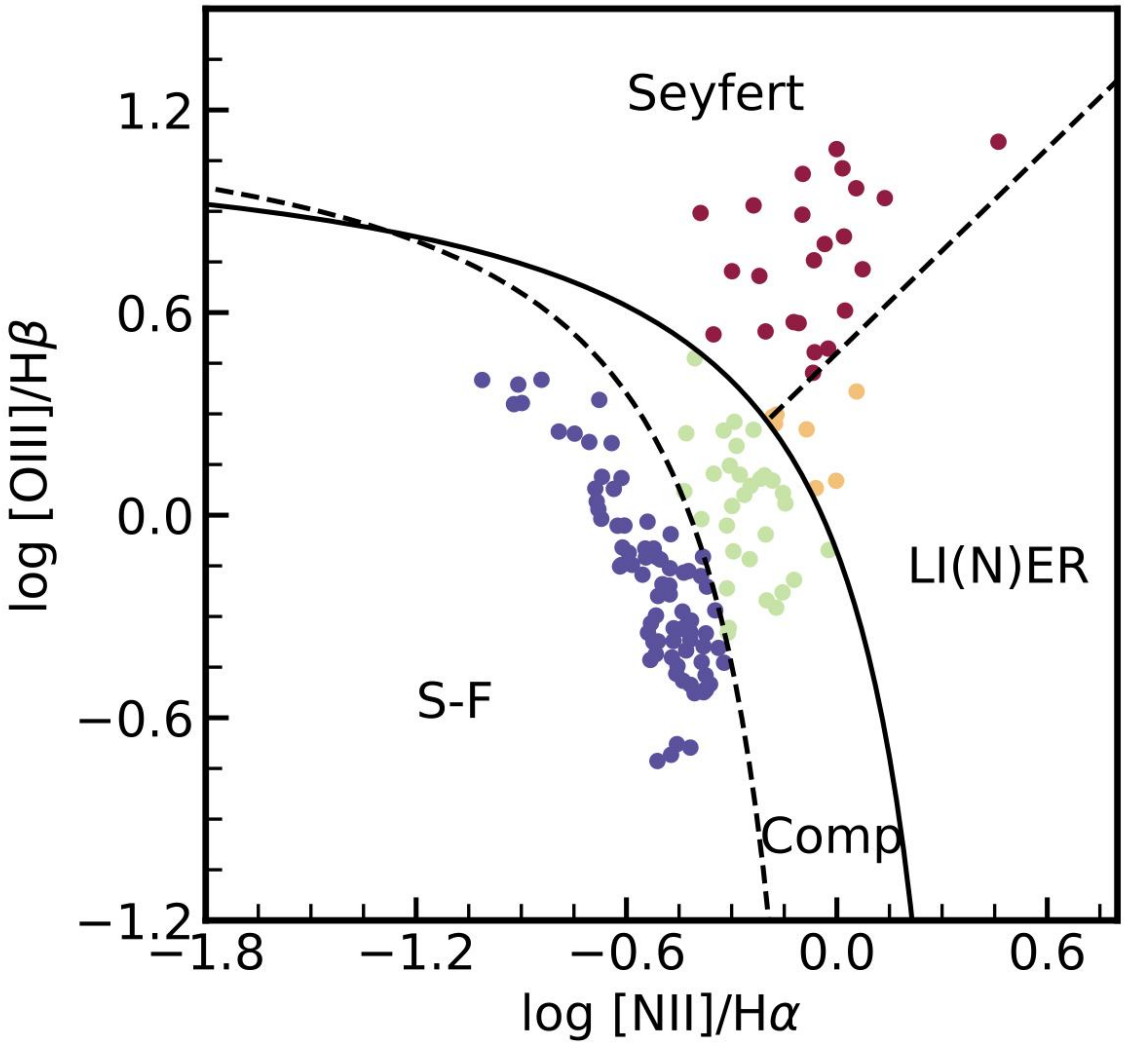


Criteria:

- ✓ edge-on galaxies with inclination greater than 60°
- ✓ equivalent width of [OIII]λ5007 ($EW_{[OIII]}$) enhanced along photometric minor axis

Zhou, Chen et al. 2024, MNRAS

Classification of outflow candicates

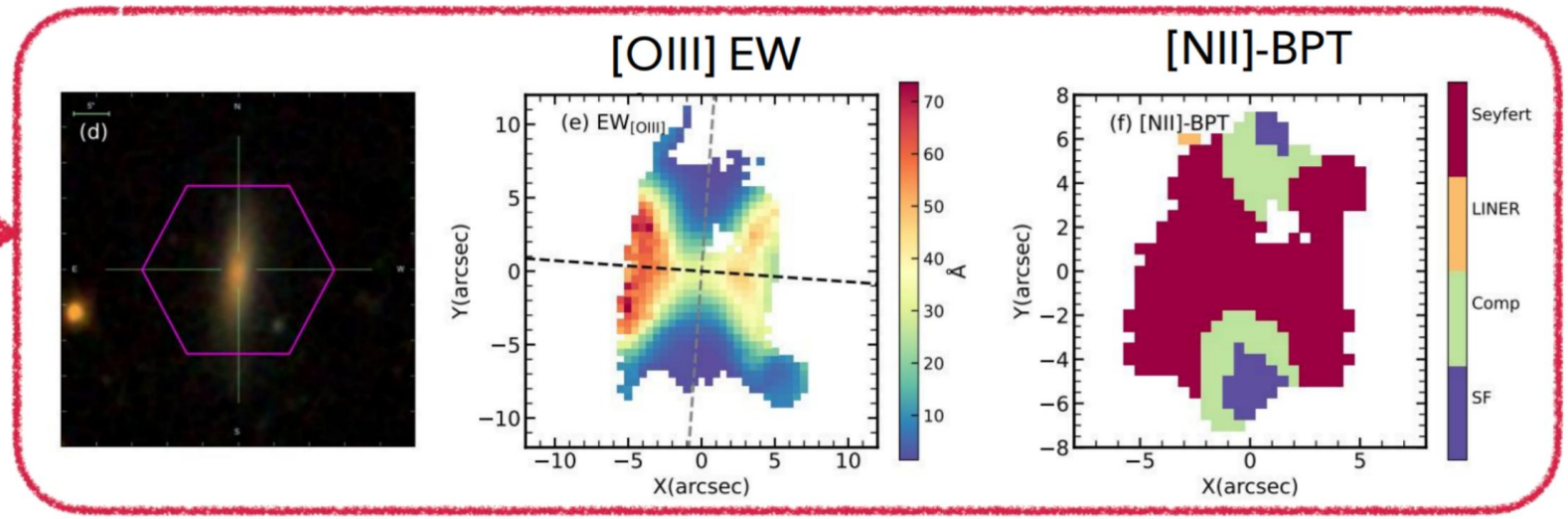


142 outflow candicates:

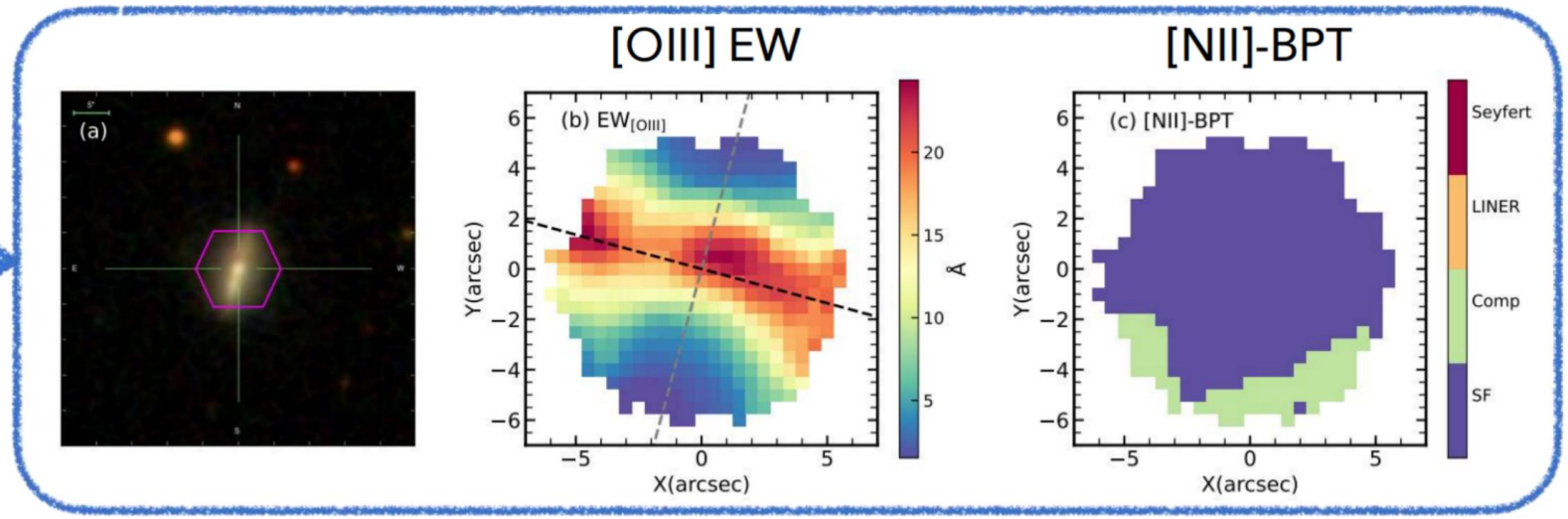
- **81 star forming**
- **31 composite**
- **23 Seyferts**
- **7 LIERs**

Morphologies of the [OIII]5007 ionization structures

Seyfert:
"hourglass" shape

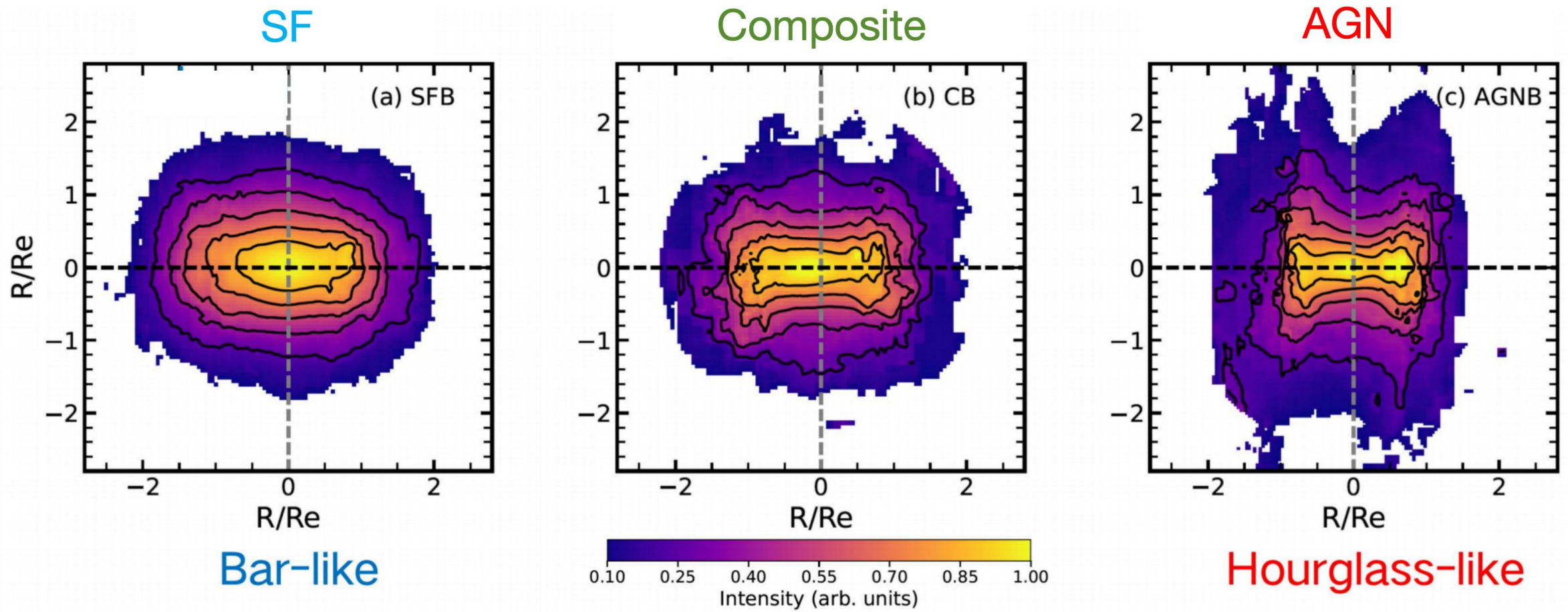


star forming gals:
"bar" shape



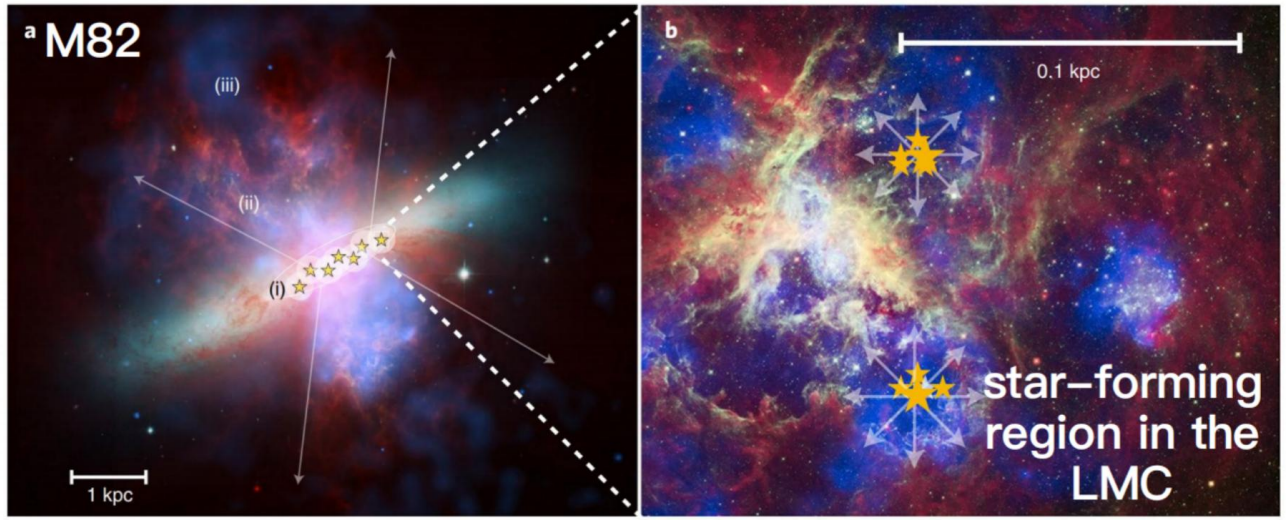
Morphologies of the [OIII]5007 ionization structures

Stack $EW_{[OIII]\lambda5007}$ map with the same central ionization states



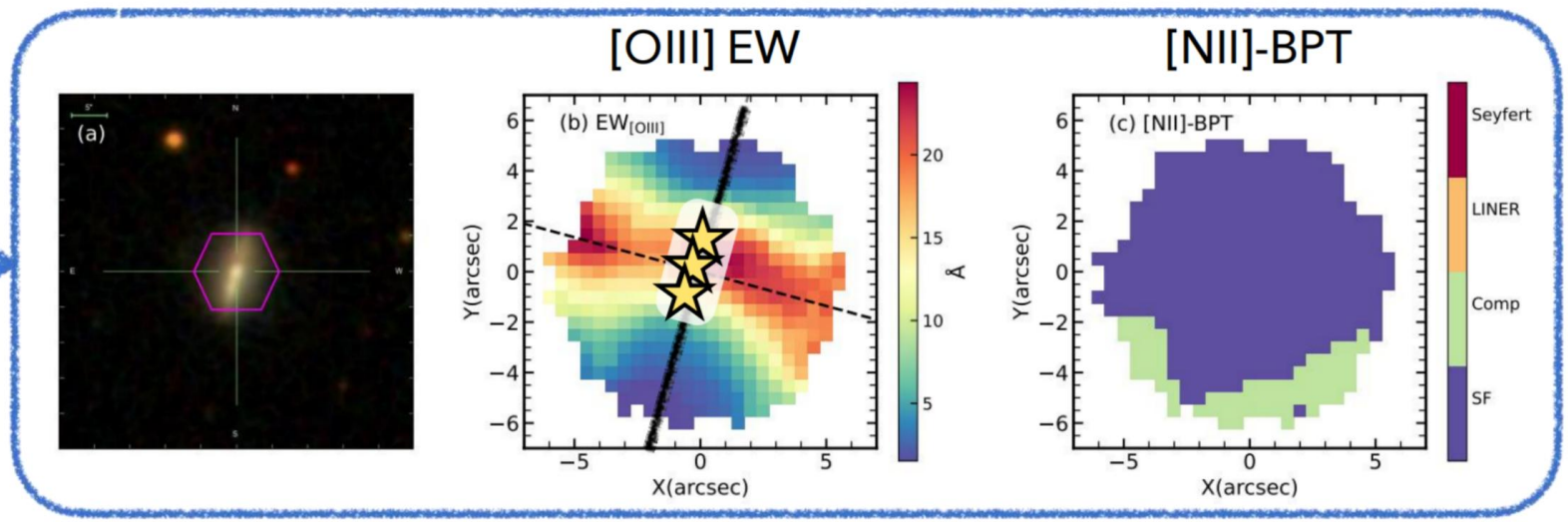
Zhou, Chen et al. 2024, MNRAS

Morphologies of the [OIII]5007 ionization structures



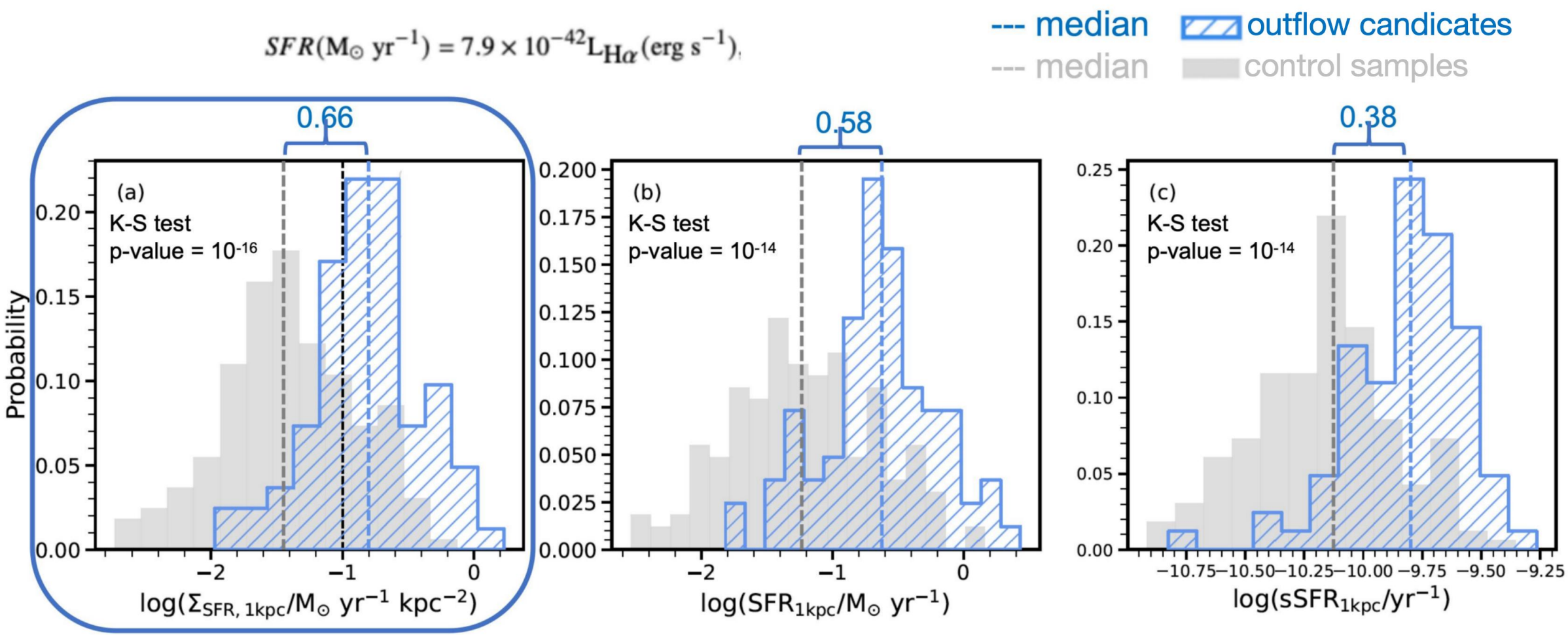
Collins & Read et al. (2022)

star forming gals:
"bar" shape



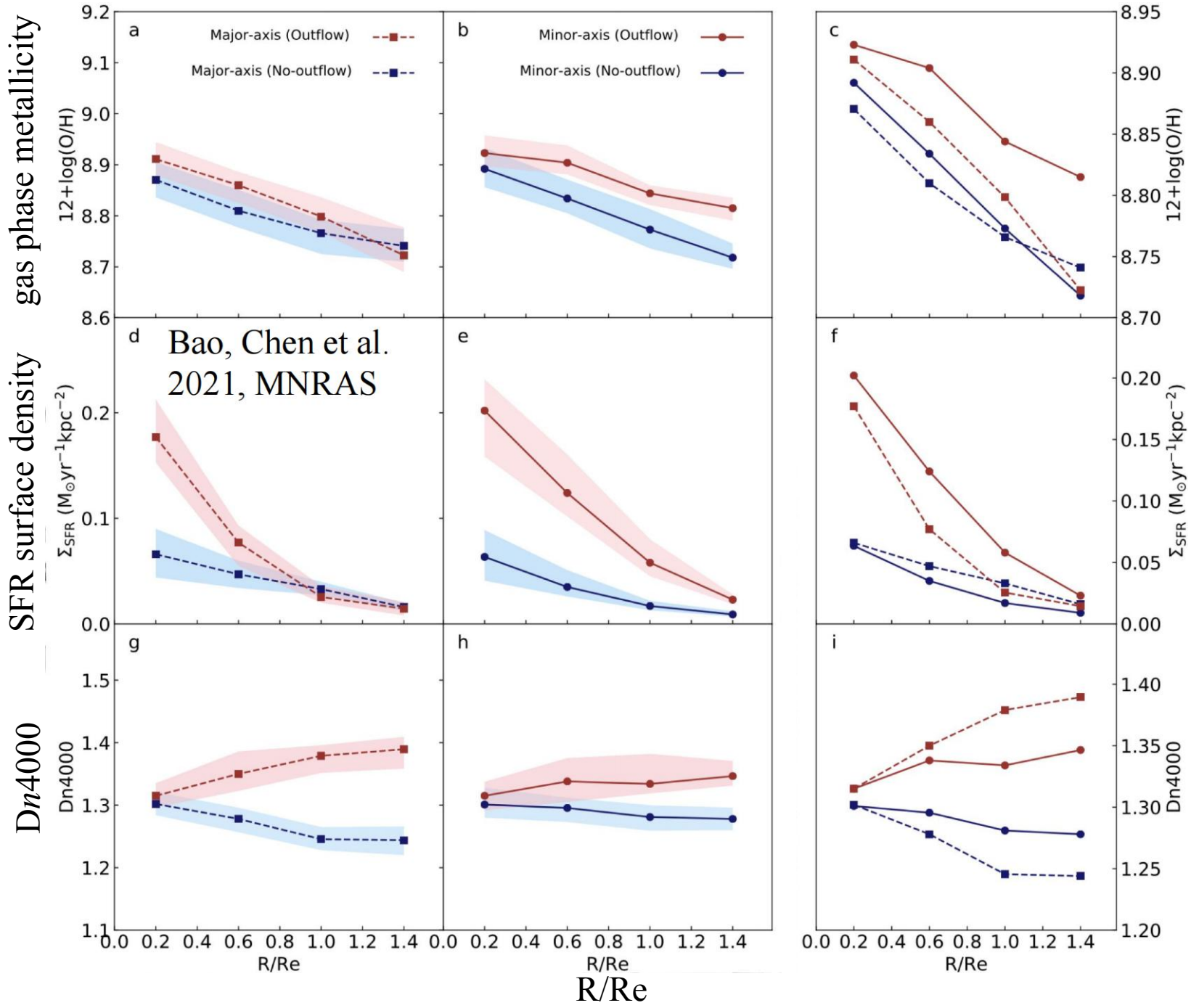
Primary driver of [OIII] ionization structures in SF gals

$$SFR(\mathrm{M_\odot\ yr^{-1}}) = 7.9 \times 10^{-42} \mathrm{L_{H\alpha}(erg\ s^{-1})}$$



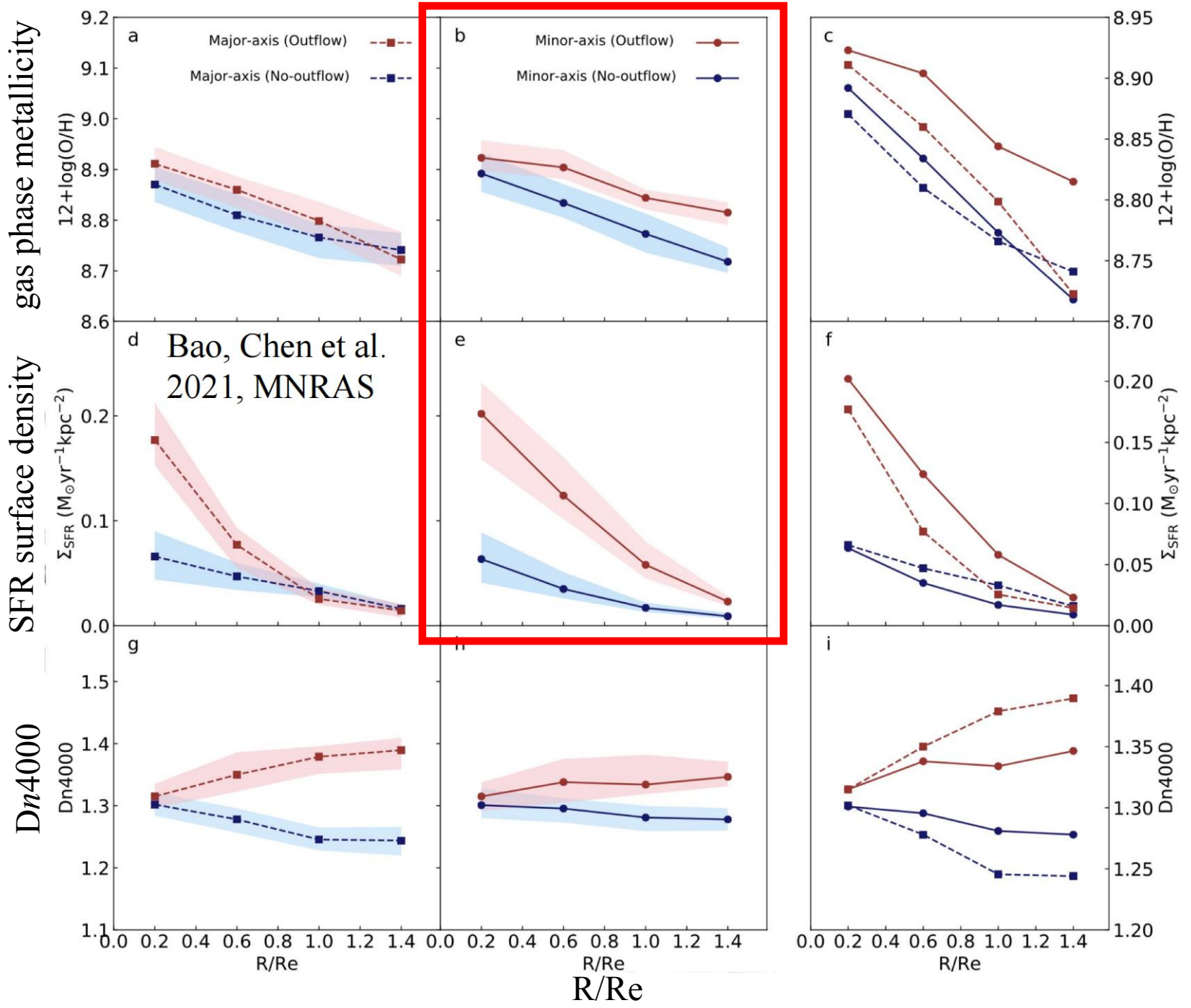
Central Σ_{SFR} is the primarily driver

Outflow candicates in star forming gals have:



Outflow candicates in star forming gals have:

- higher gas phase metallicty, higher SFR surface density along the minor axis (outflow direction) than the control samples with similar M* and SFR, but without outflows



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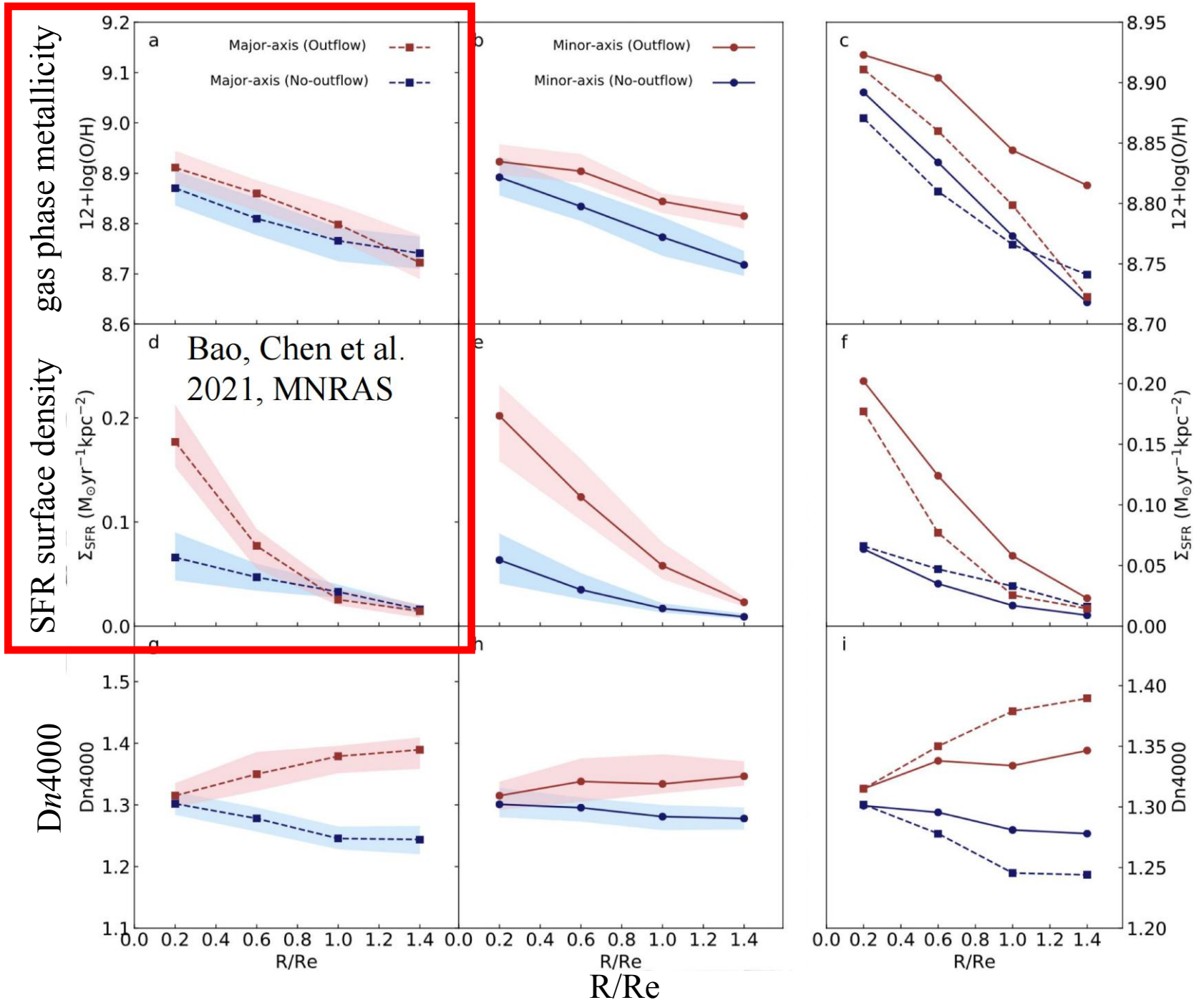

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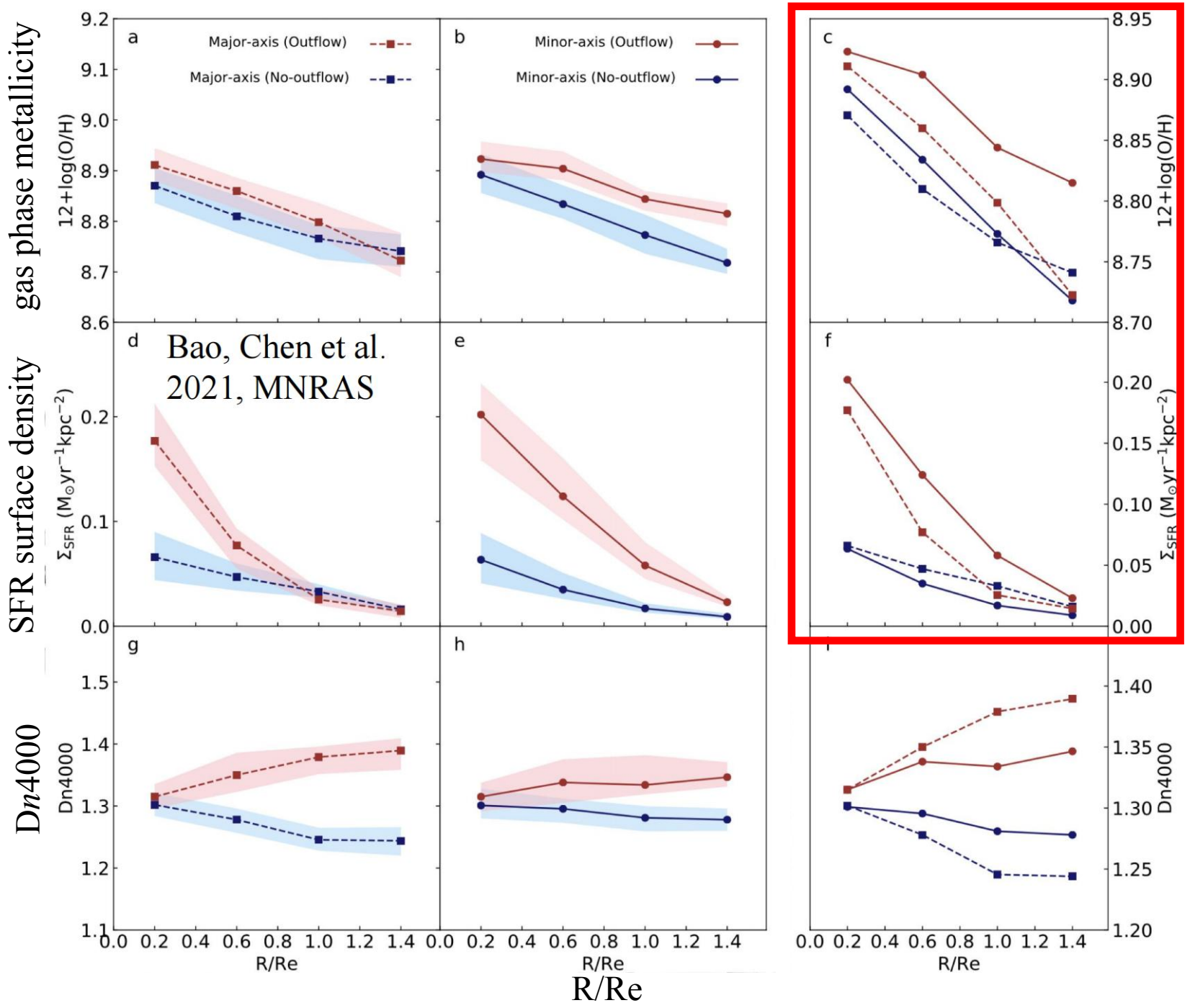
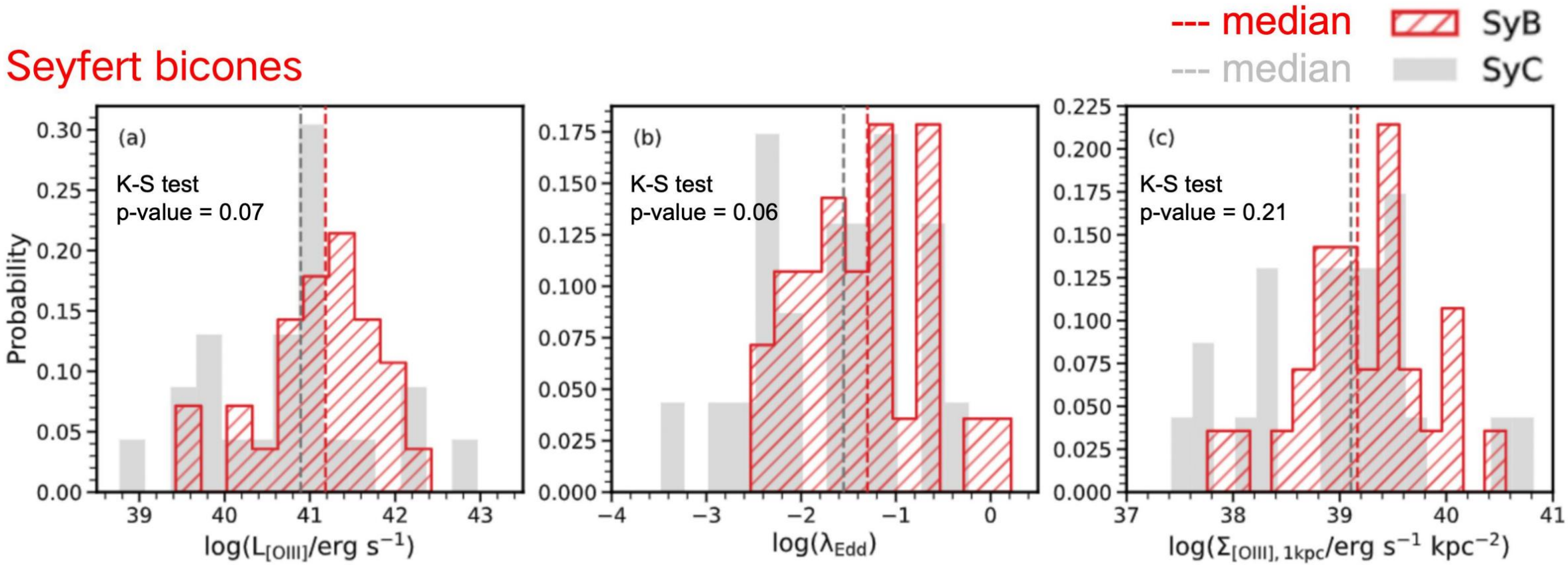
- higher gas phase metallicty, higher SFR surface density along the minor axis (outflow direction) than major axis (disk direction)

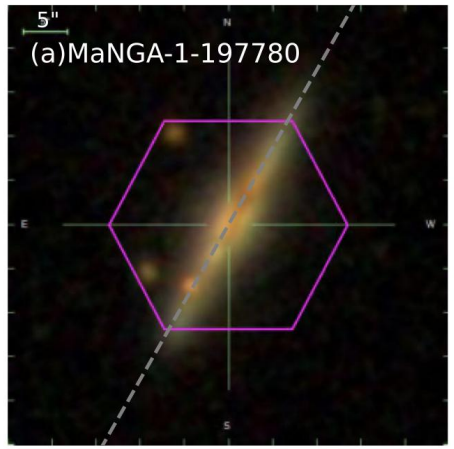


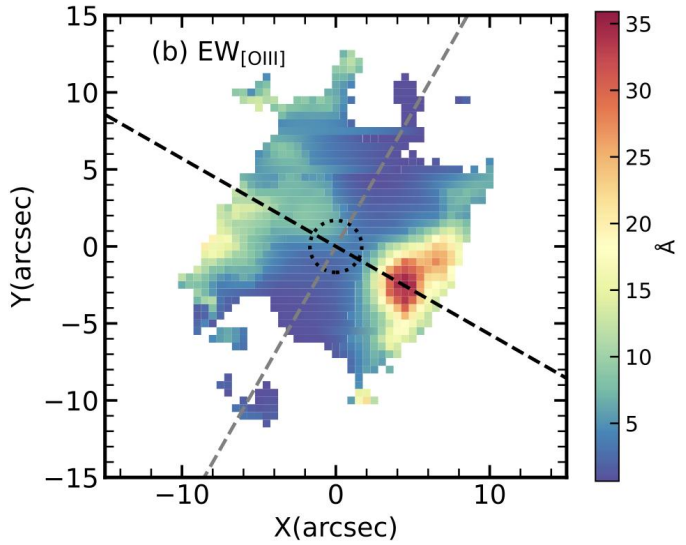
The primary driver of Bicones in Seyferts (SyB)

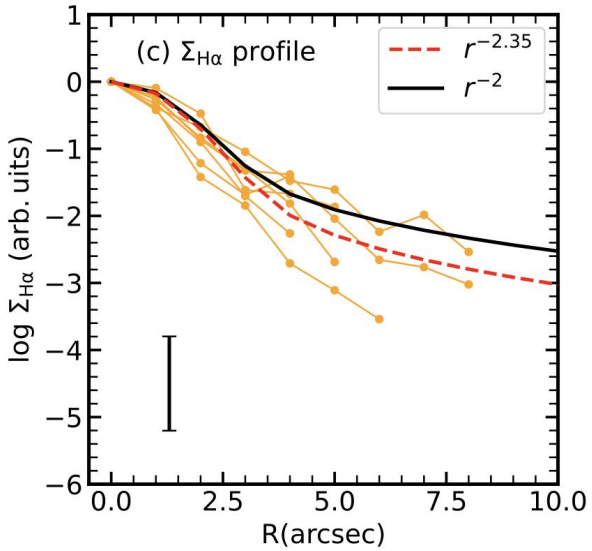


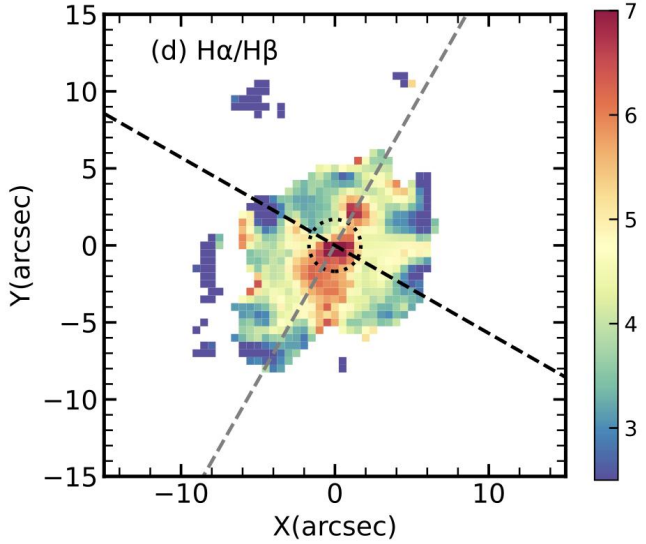
Lack of difference in BH activity strength between SyBs and SyCs: the accretion disk and the galactic disk are not necessarily coplanar

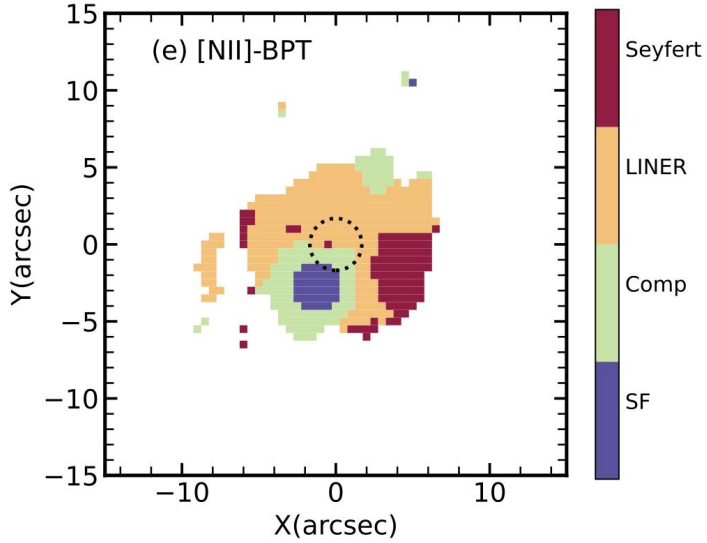
The primary driver of bicones in LI(N)ERs

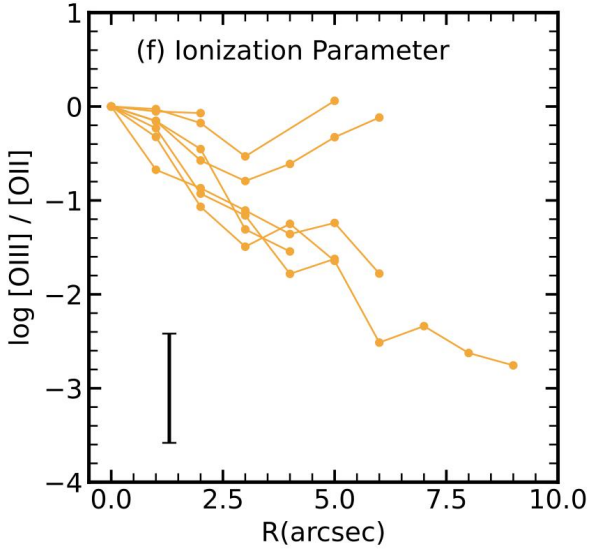










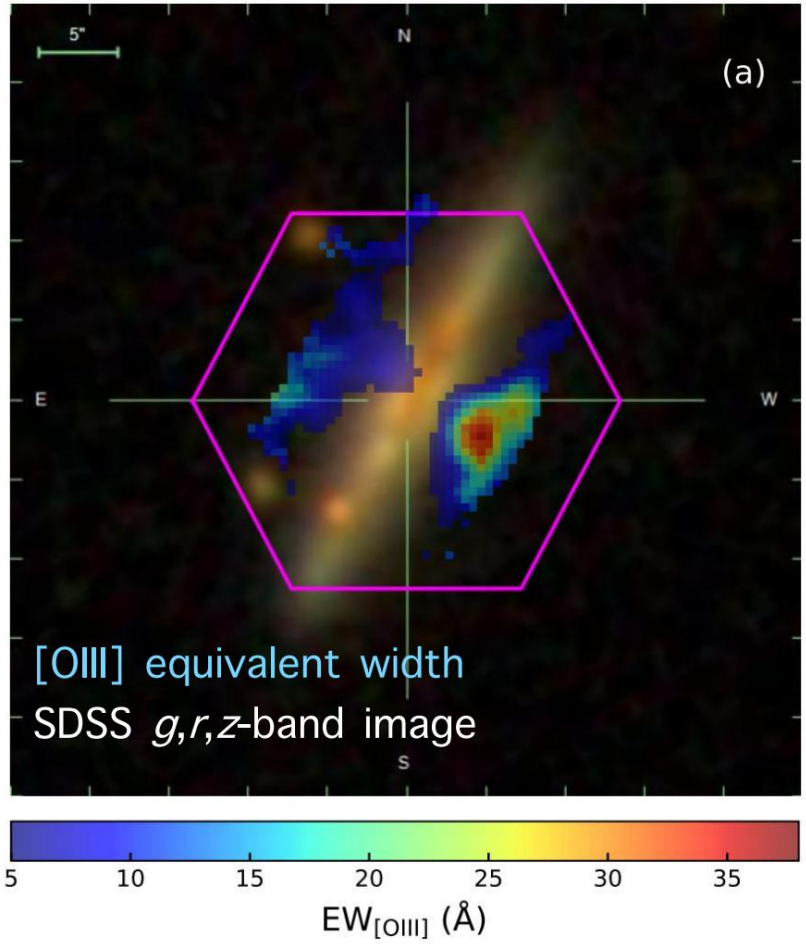


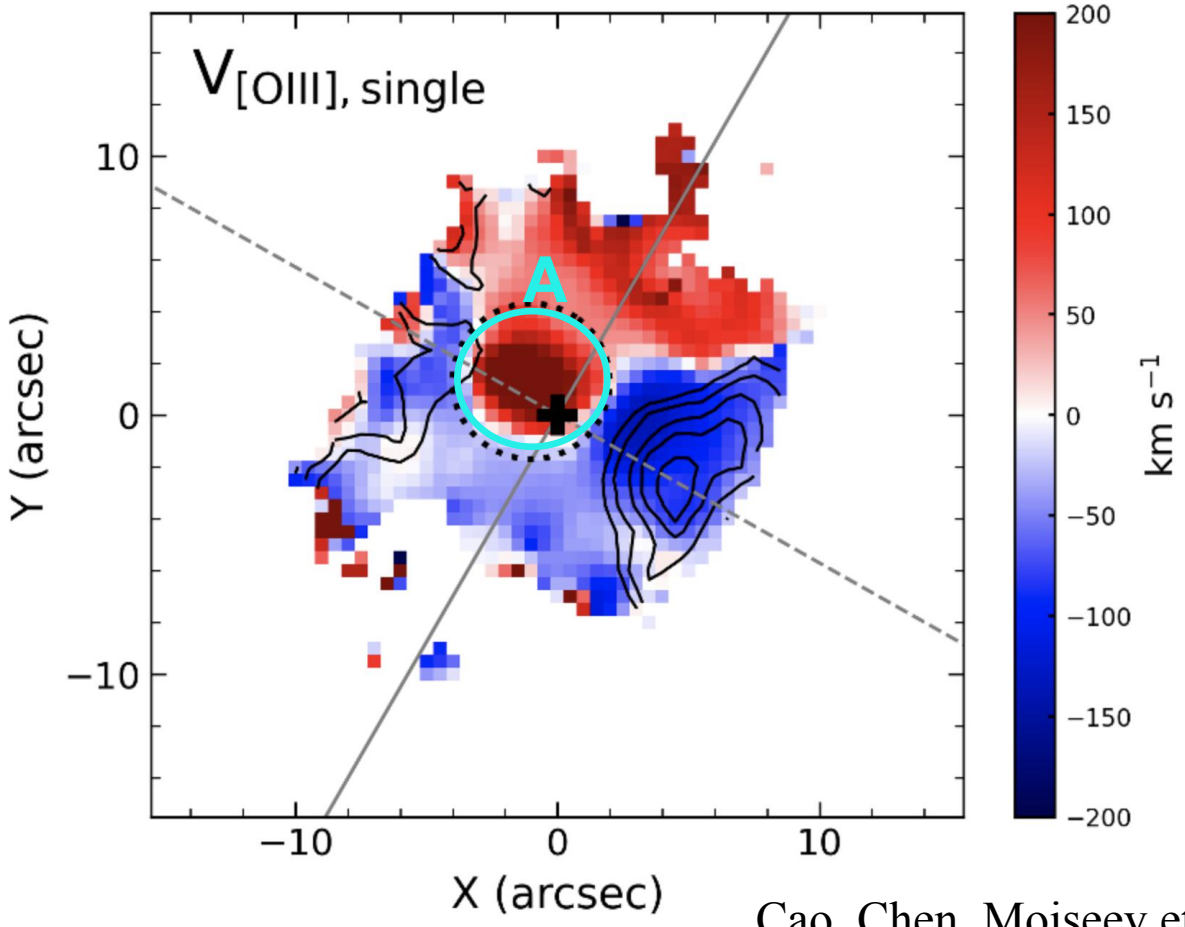
LI(N)ERs in our sample are Seyferts obscured by galactic disks

Summary of [OIII]λ5007 ionized structures

- Hour-glass like morphologies in AGN; bar-like shape in SF gals
- The primary driver of outflow in star forming gals is central SFR surface density
- Enhanced SF and gas-phase metallicity in SF gals along photometric minor axis
- The lack of difference in BH activity strength between Seyfert bicones and their controls is due to the accretion disk and the galactic disk are not coplanar
- LI(N)ERs in our sample are Seyferts obscured by galactic disks

Case study 1:
An outflow Seyfert with peculiar redshifted gas component



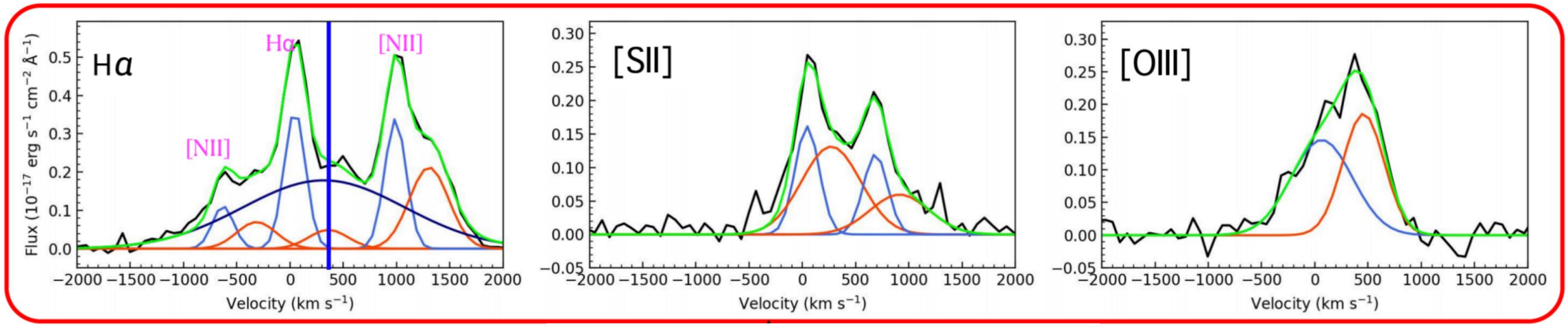


Cao, Chen, Moiseev et al., submitted to ApJL

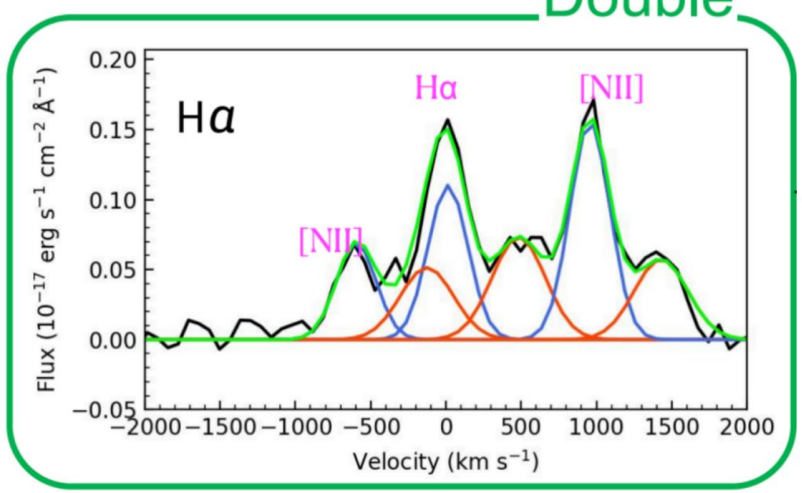
- An edge-on galaxy ($i = 72^{\circ}$)
- Obvious blueshift outflow is consistent with the enhanced [OIII]λ5007 equivalent width region

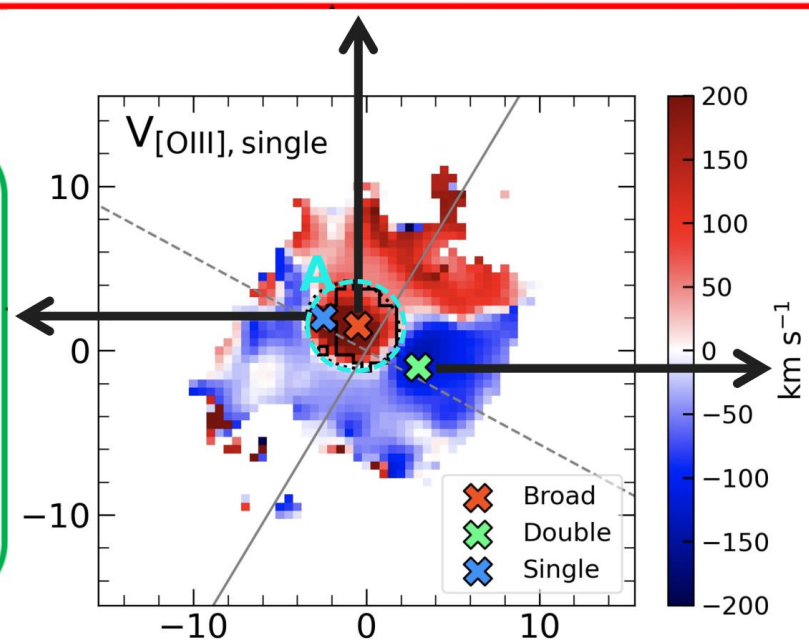
Emission line features

Hα have obvious broad emission at the unexpected redshift region

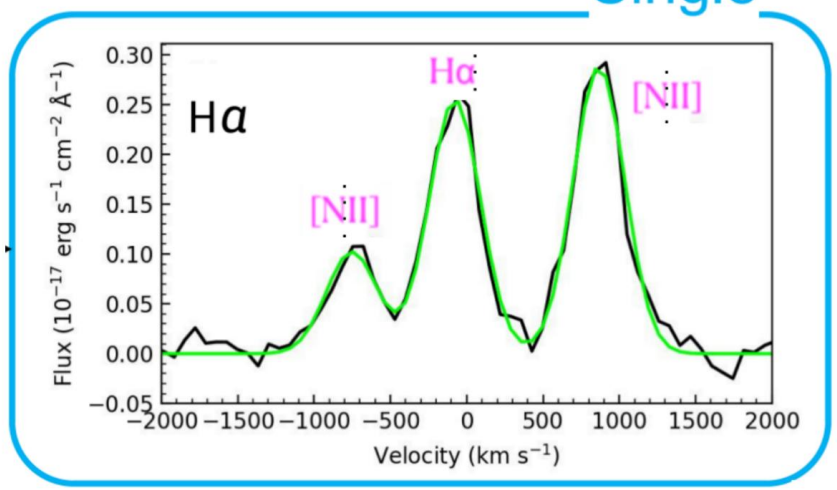


Double

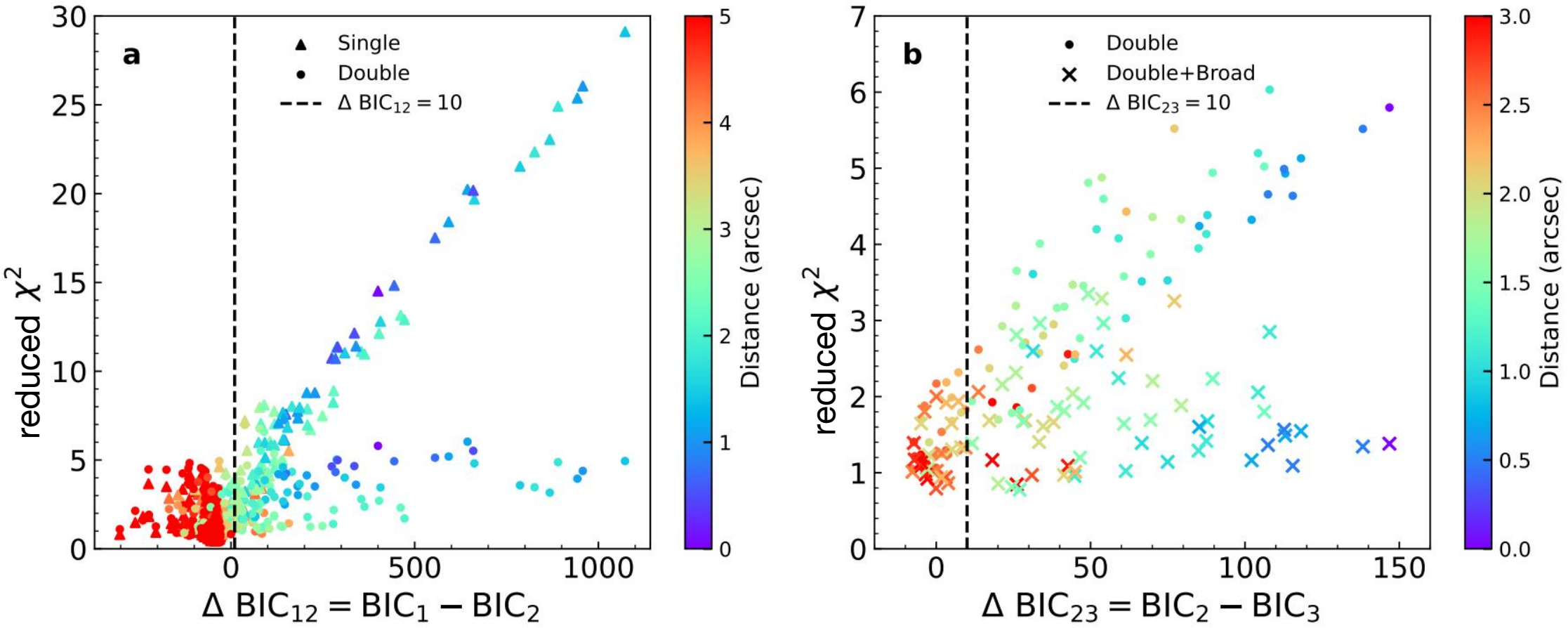




Single



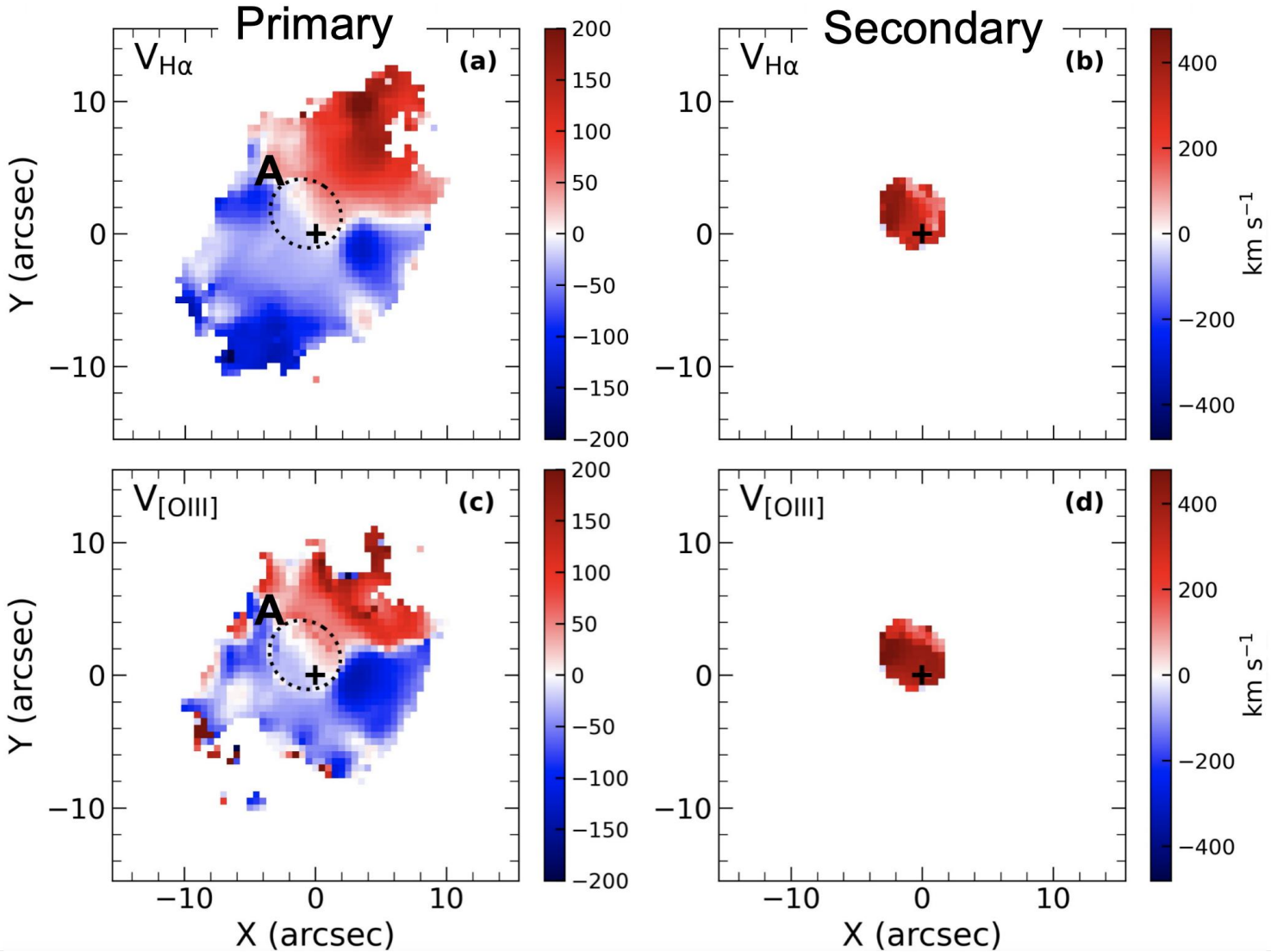
Selection of Gaussian Models

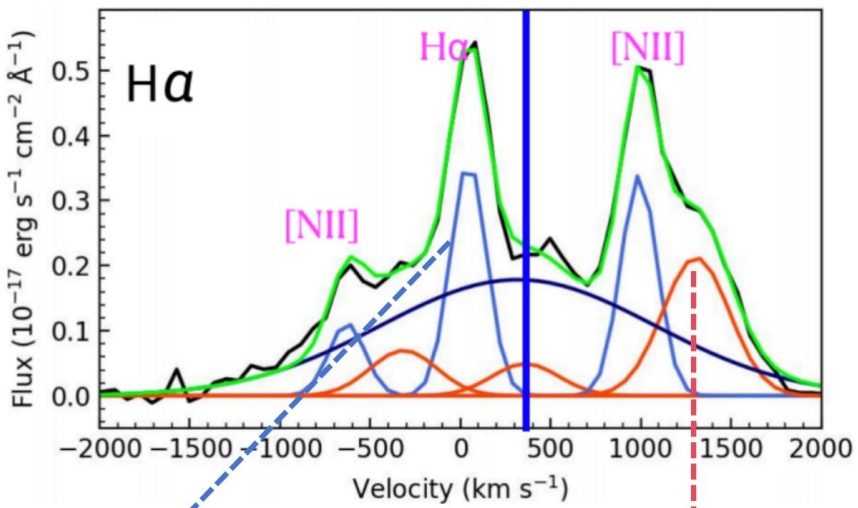


Bayesian Information Criterion: $\mathrm{BIC} = \chi^2 + k \ln N$

Kinematics

Velocity fields of Primary and Secondary emission line components



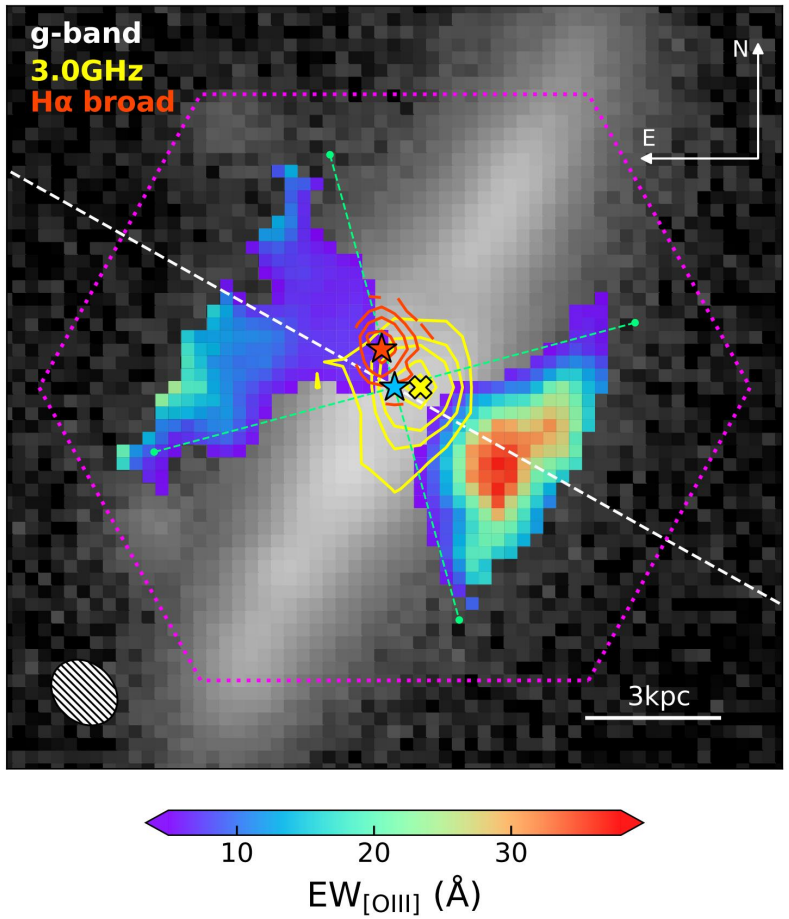


Primary: follows the gas disk rotation

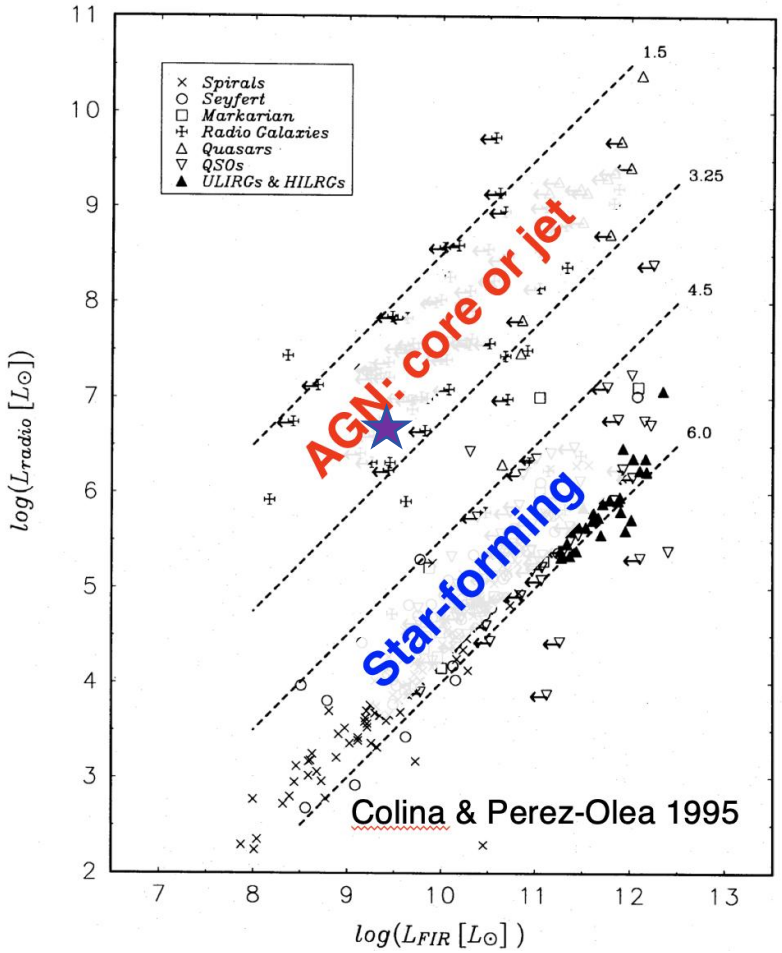
Secondary: redshifted by ~400km s^{-1}

Broad Hα components have similar velocities as the secondary components

Properties of outflow driven by the central BH



Very Large Array Sky Survey (VLASS)



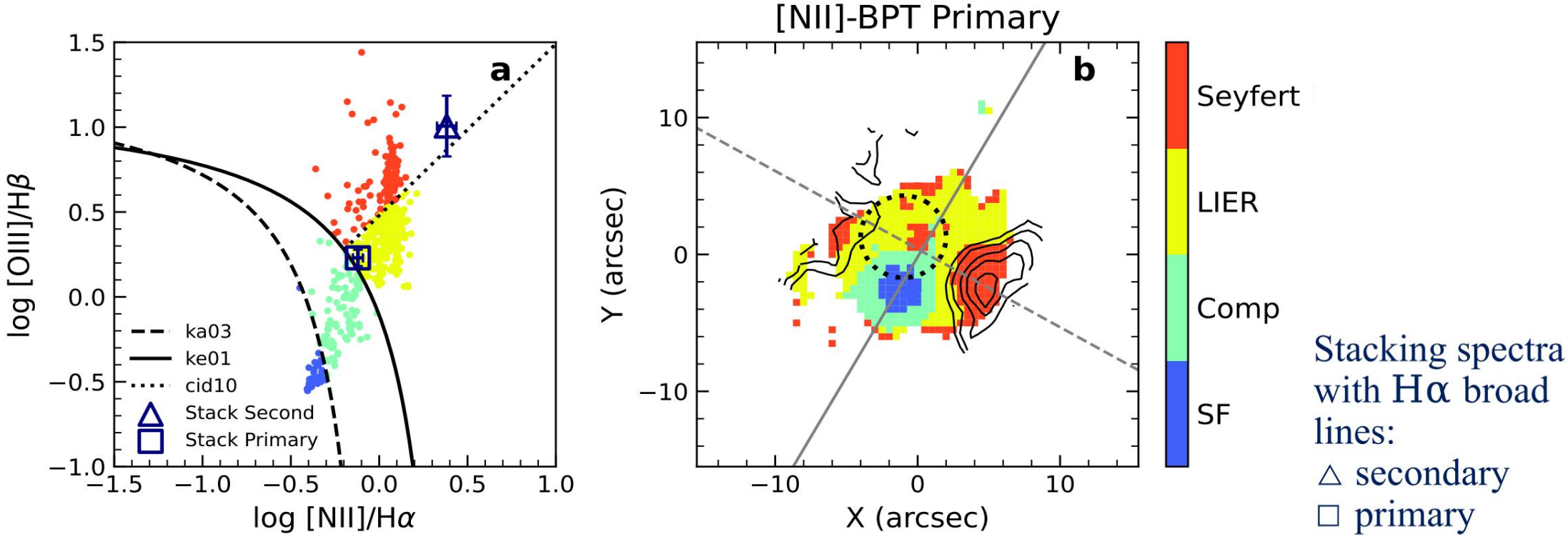
- ✓ the galaxy center is consistent with the 3GHz flux peak observed by VLASS
- ✓ the two biconical structure is symmetrical relative to the galaxy center

The galacitic scale outflow is driven by the central BH ($10^7\ M_\odot$):

- projected cone size ~5.7kpc
- half opening angle ~45deg
- max LOS velocity within the bicones ~145km s^{-1}

Ionization Mechanism

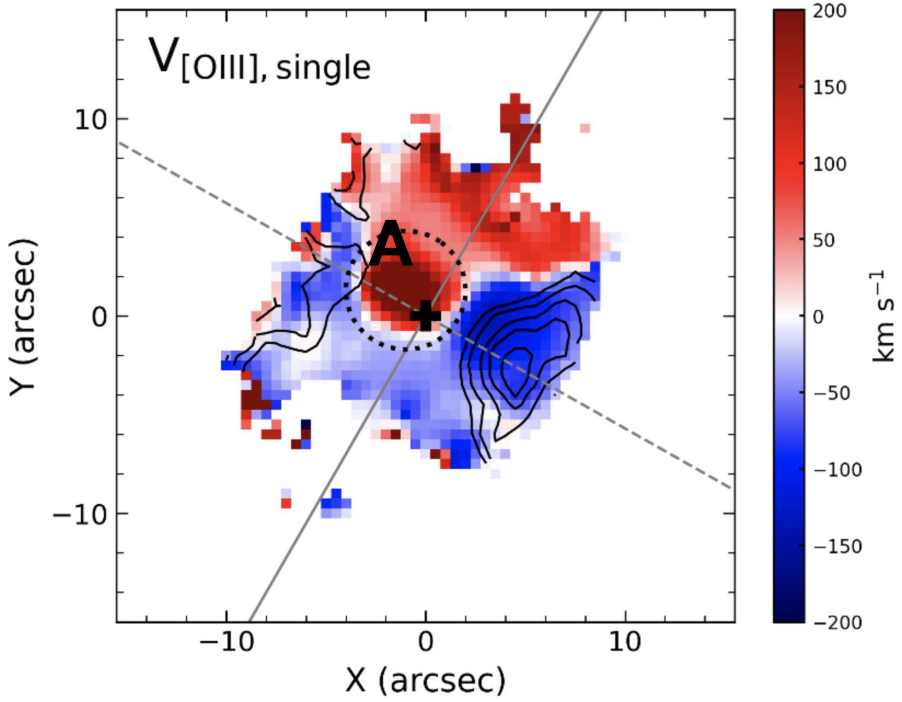
AGN-driven galactic scale outflow

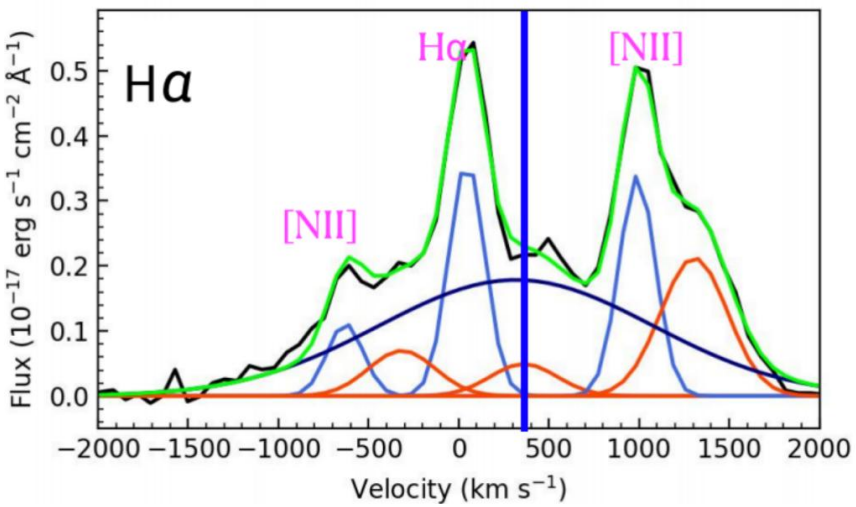


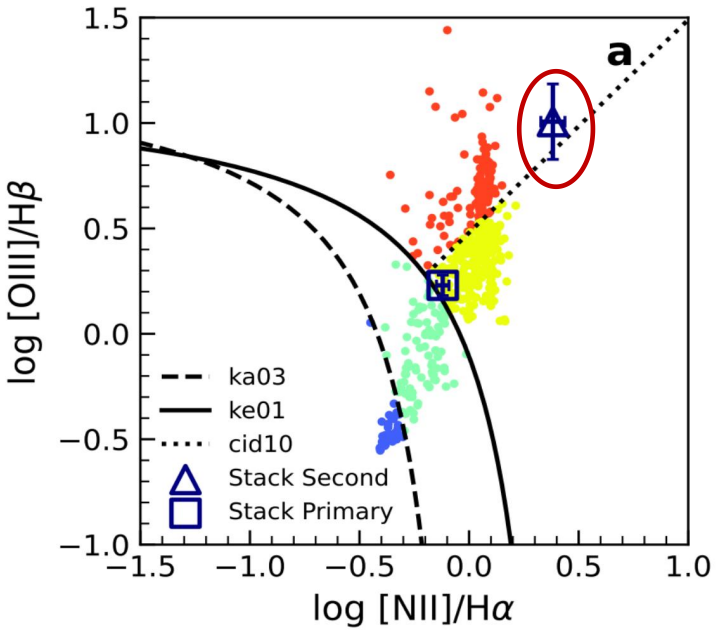
Stacking spectra with Hα broad lines:
△ secondary
□ primary

- The bi-conical blueshift outflow is ionized by Seyfert
- Extinction corrected [OIII] luminosity of the Seyfert region is ~8.3×10^{39}erg/s
- The secondary component is ionized by Seyfert

Off-centered black hole







- The broad Hα has similar redshifted velocity as the secondary component
- The line ratios of the secondary component located in the Seyfert region in [NII]-BPT diagram
- A black hole mass of $10^6 M_\odot$ ~1kpc from the galaxy center

Origin of the off-centered black hole

Internal: growth of the in-situ IMBH

External:
- Capturing a Wondering BH
- Minor Merger

Origin of the off-centered black hole

Internal: growth of the in-situ IMBH ☒

300~400 km s^{-1} receding velocity

External:
- Capturing a Wondering BH
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Origin of the off-centered black hole

Internal: growth of the in-situ IMBH ☒

300~400 km s^{-1} receding velocity

External:

- Capturing a Wondering BH ☒
  we saw the narrow line region
- Minor Merger

Origin of the off-centered black hole

Internal: growth of the in-situ IMBH ☒

300~400 km s^{-1} receding velocity

External:

- Capturing a Wondering BH ☒
  we saw the narrow line region
- Minor Merger ☑

lack of merger remnant feature:

(1) edge-on disk galaxy, obscuration

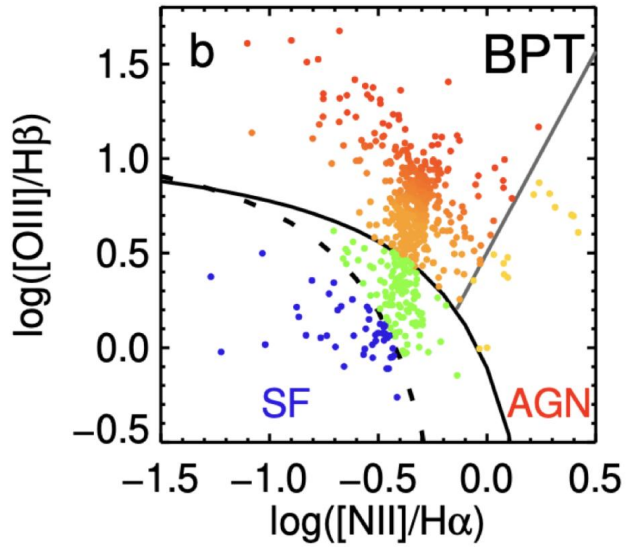
(2) simulation predicts there is no observable merger remnant features with surface brightness smaller than 28 mag $arcsec^{-2}$ in *r*-band for mergers of mass ratio 10:1 (Ji, I. A&A, 2014)

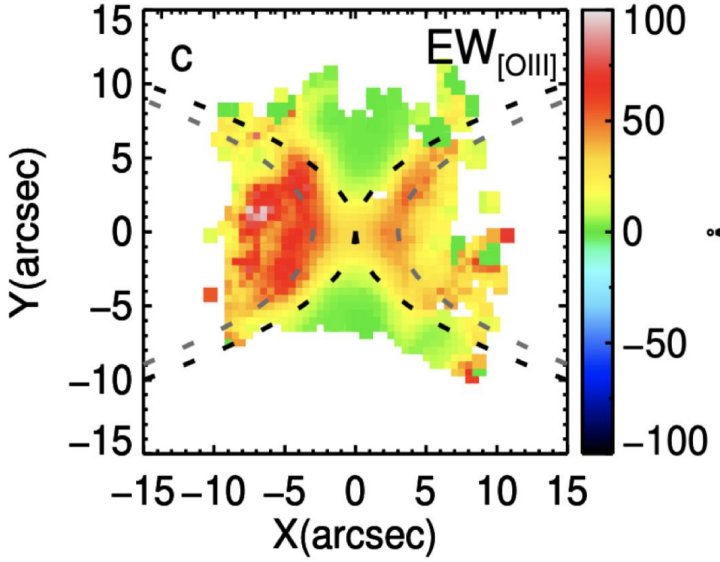
Summary of the dual AGN system

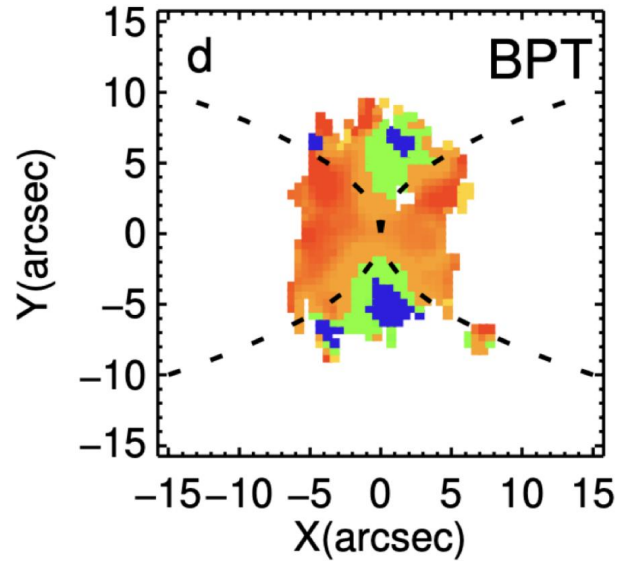
- Evidence for the central BH:
  - ✓ Flux peak position of radio emission is consistent with the galaxy center
  - ✓ The two biconical structures are symmetrical relative to the galaxy center
- Evidence for the off-centered BH:
  - ✓ Broad Hα emission
  - ✓ Similar kinematics between the broad Hα and secondary narrow emission line components
  - ✓ Seyfert-like narrow emission line ratios for the secondary components
- Origin of this dual AGN system with mass ratio 10:1 is minor merger

Case study 2:
Gas-star counter rotators with biconical outflows

- ✓ half opening angle of the outflow: ~40°
- ✓ projected cone size: ~8.3kpc
- ✓ driven mechanism: AGN activity

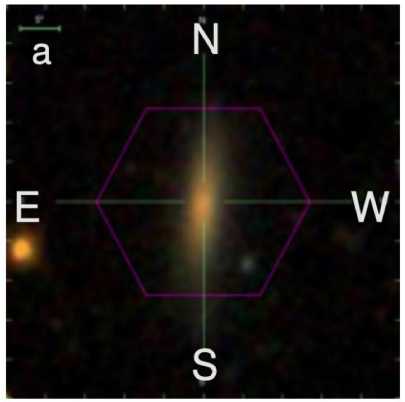


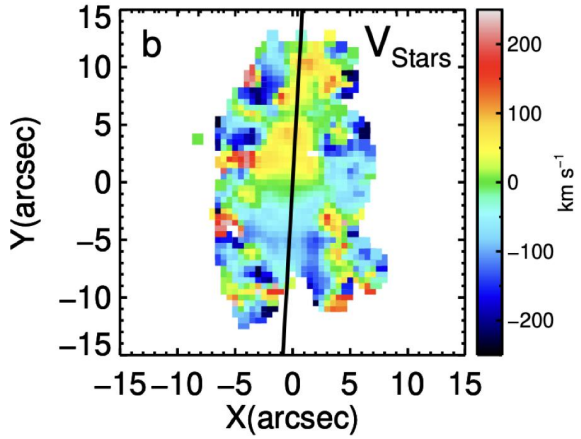


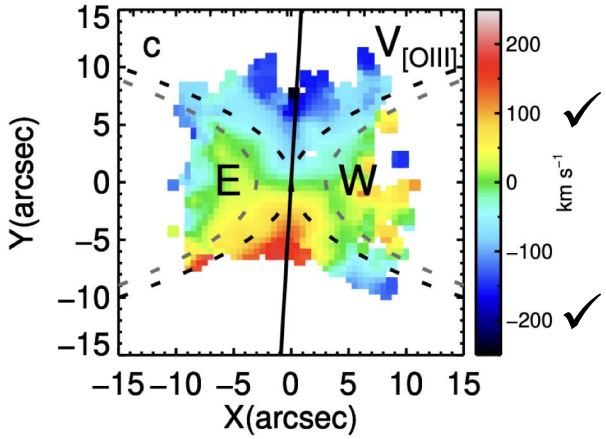


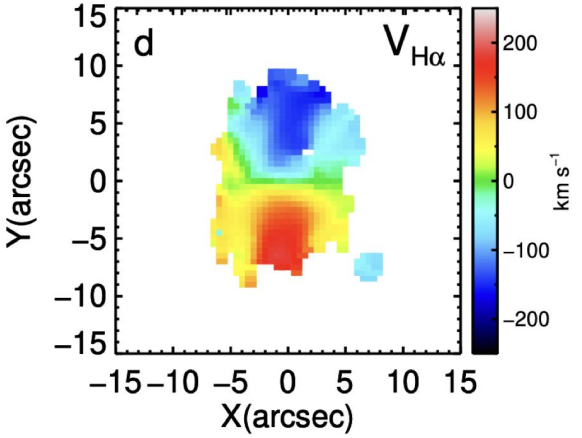
Bao, Chen et al. 2019, MNRAS

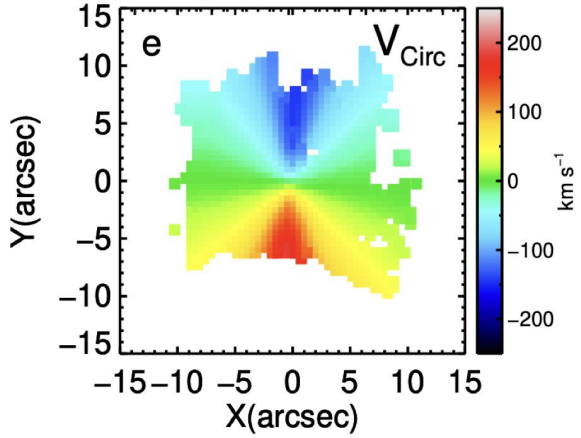
Stellar and gas kinematics

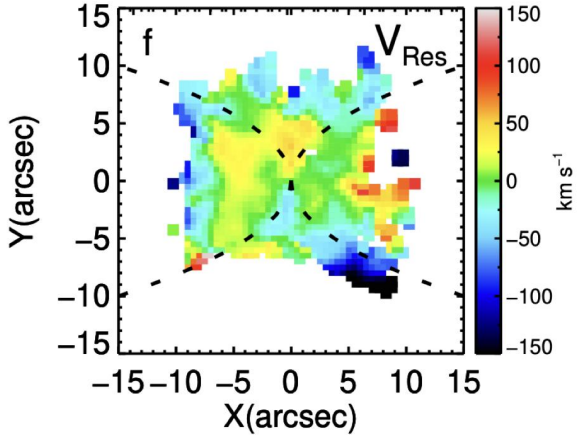










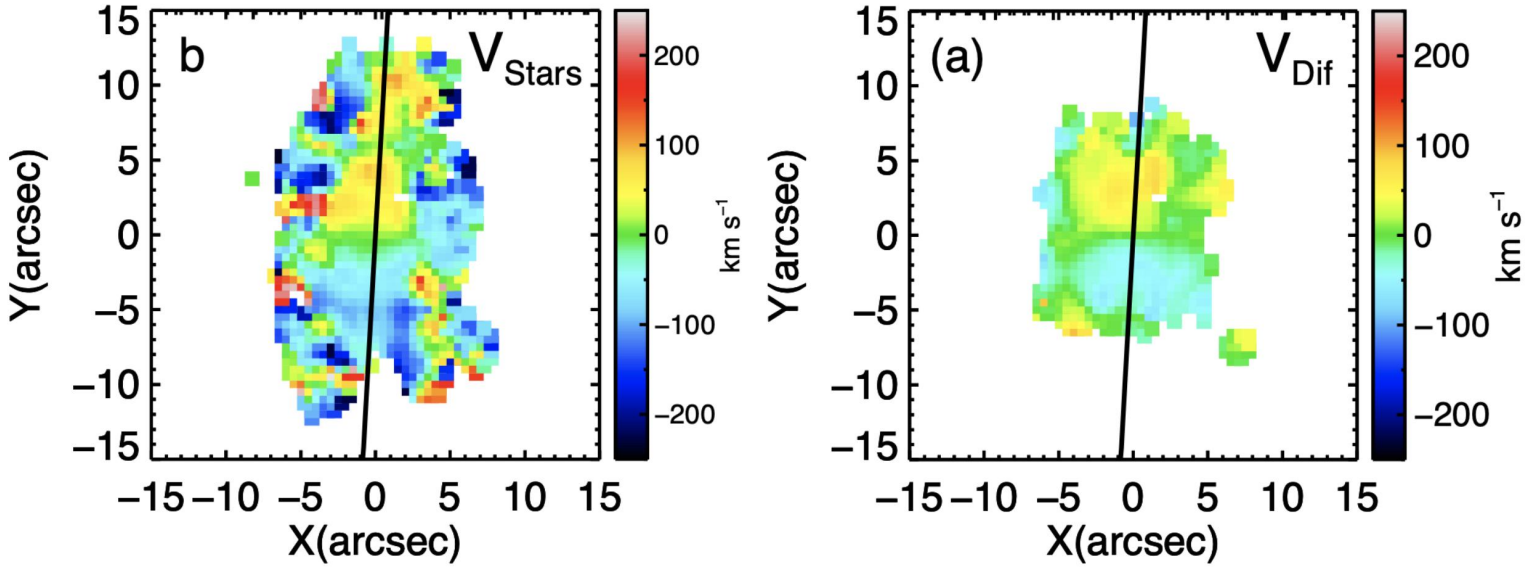


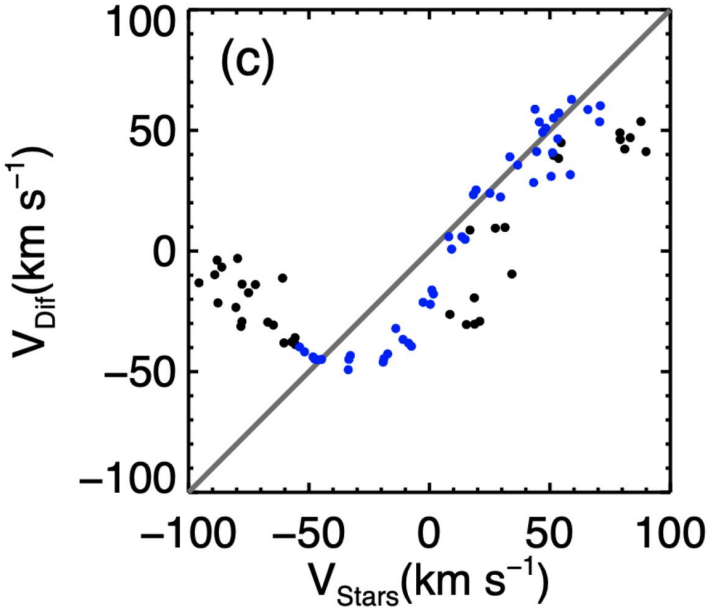
✓ gas-star CR

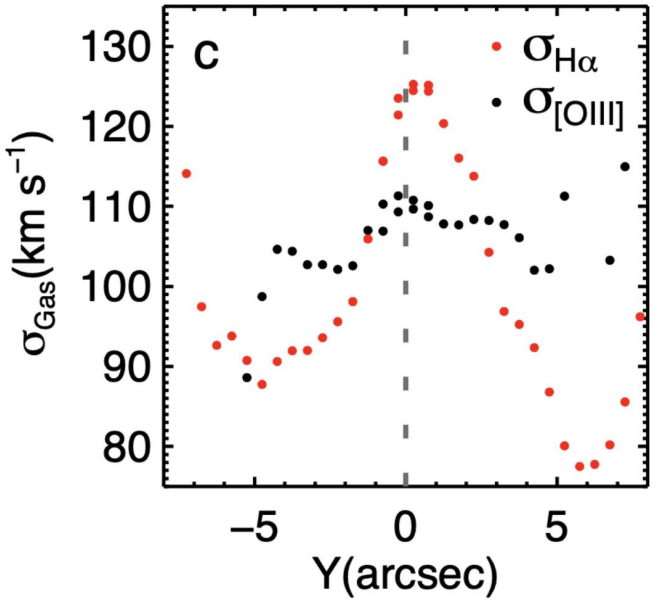
✓ two unique kinematic features:

(1) redshifted gas in the bicones

Stellar and gas kinematics







- ✓ gas-star CR
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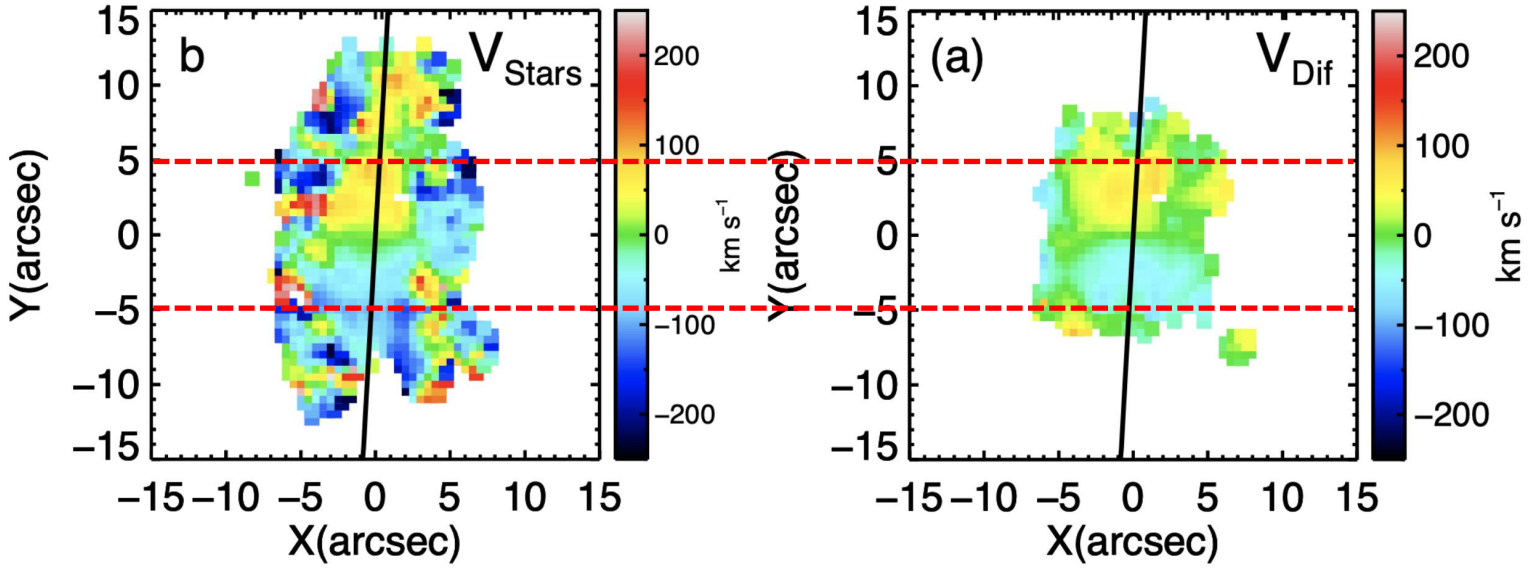
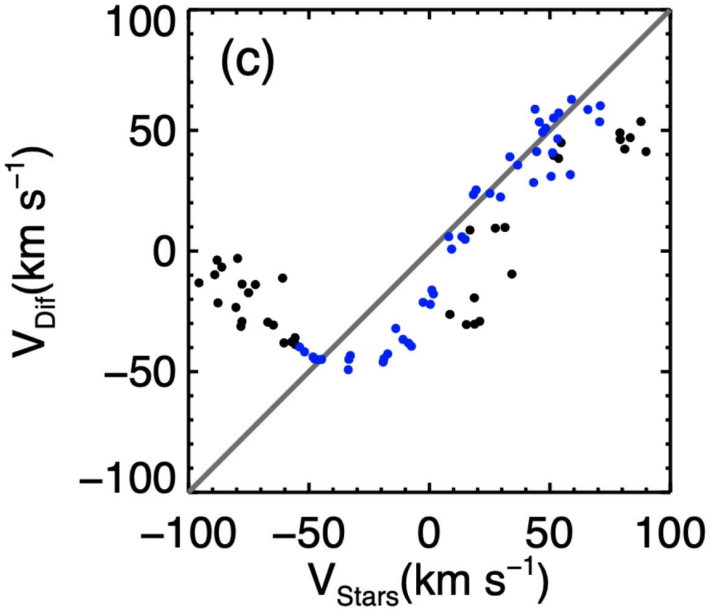
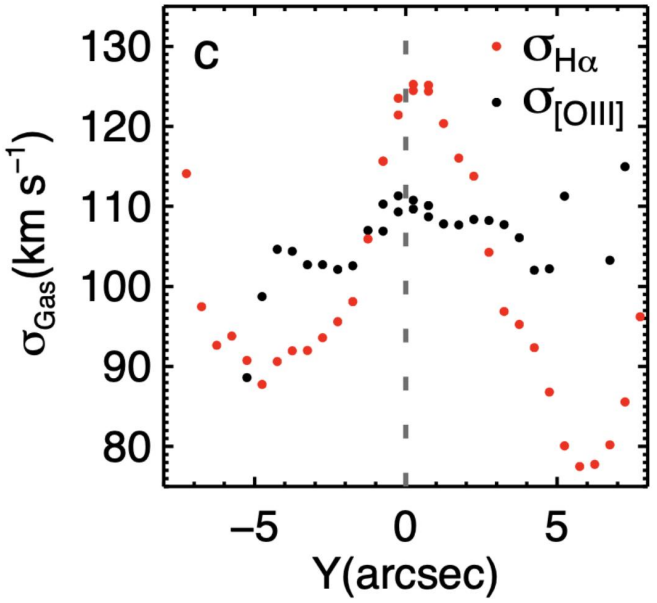
  (2) different kinematics between Hα and [OIII]λ5007 (?)

Stellar and gas kinematics







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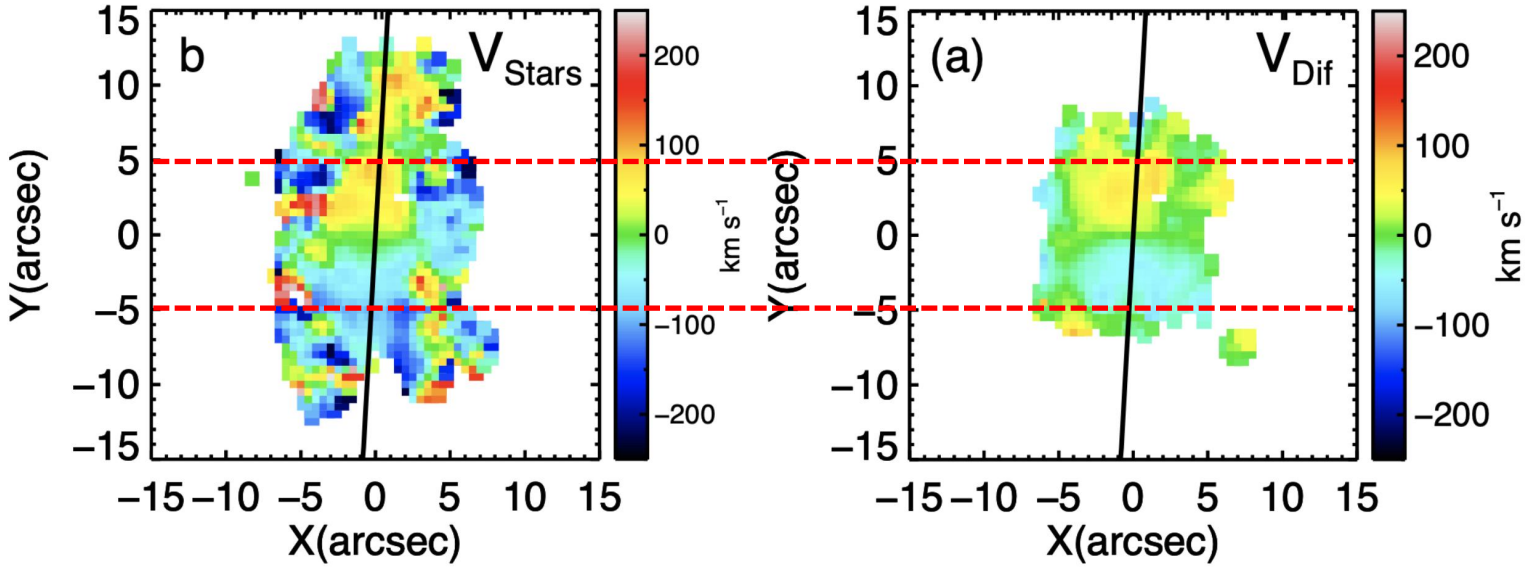
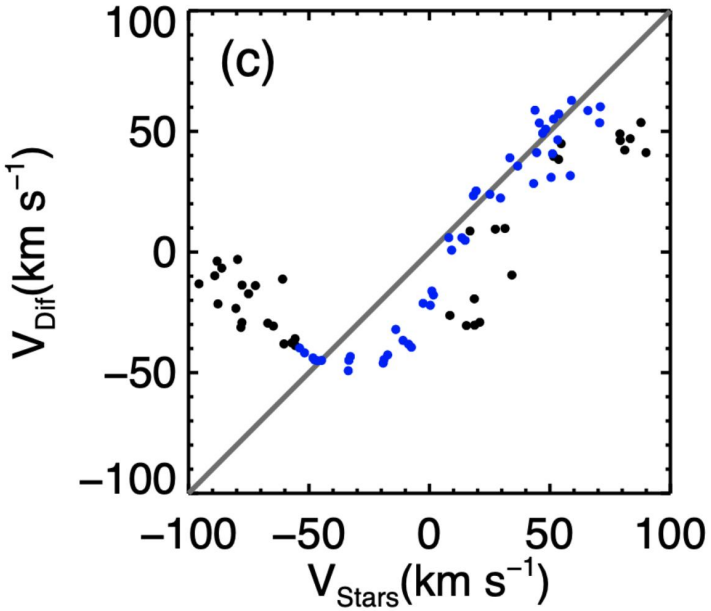
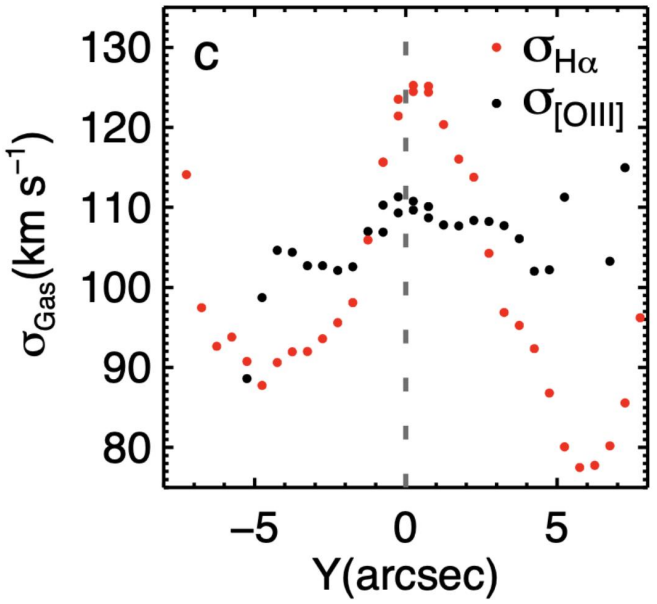
Stellar and gas kinematics







✓ gas-star CR

✓ two unique kinematic features:

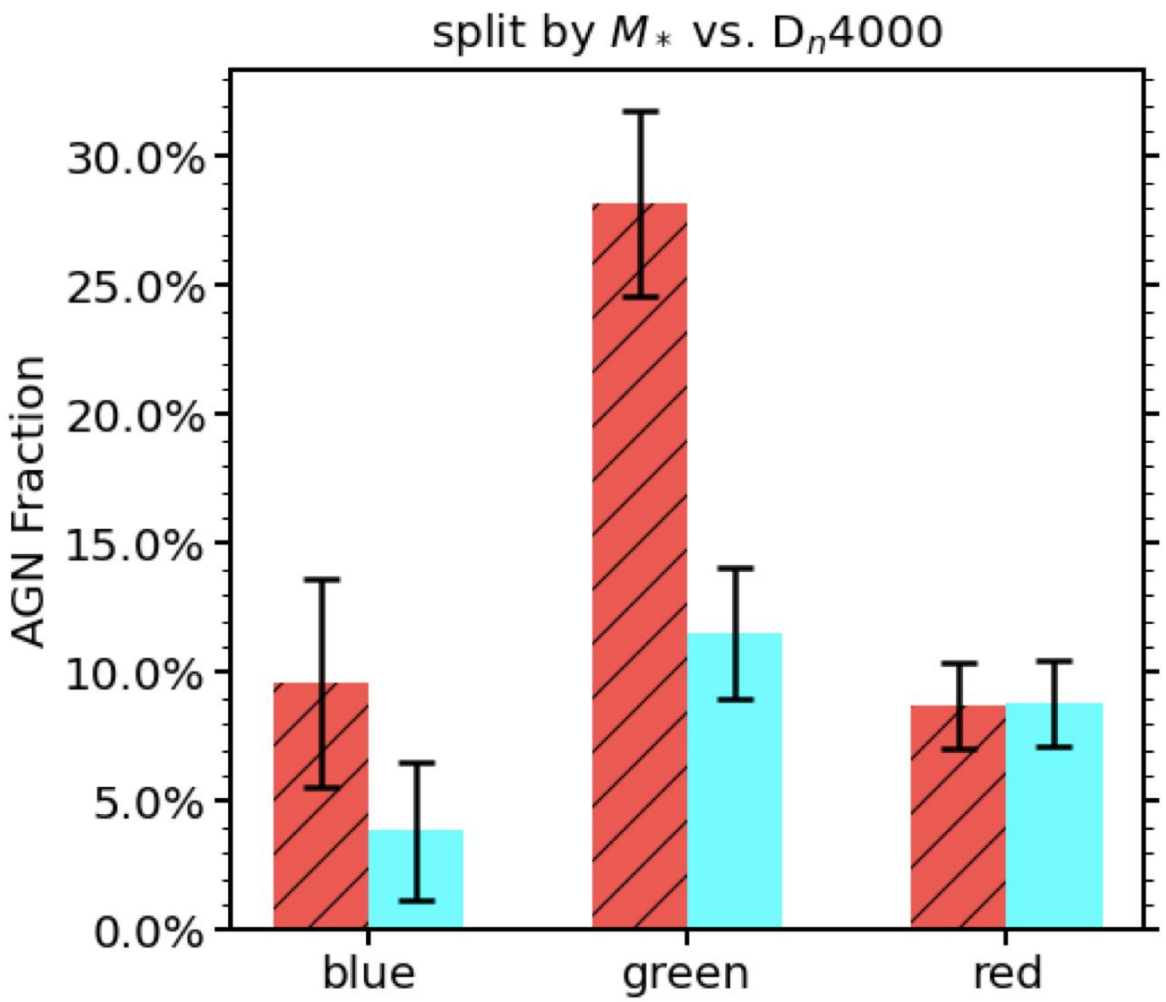
(1) redshifted gas in the bicones
(2) different kinematics between Hα and [OIII]λ5007 (?)

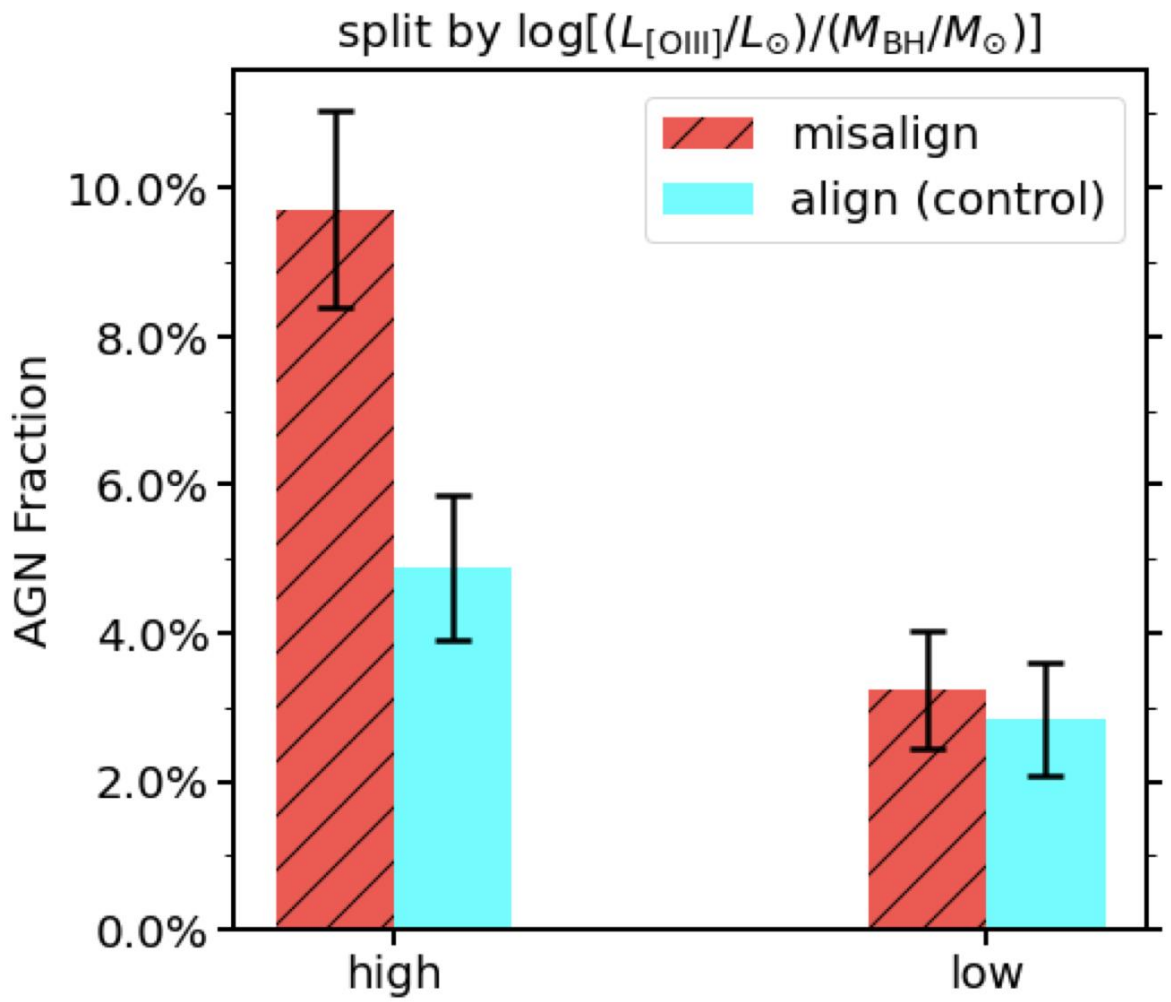
- The phenomenon of different kinematics between Hα and [OIII]λ5007 is ubiqutious in outflow galaxies

- The fraction of galaxies with outflows is much higher in gas-star kinematic decoupled galaxies than kinematic aligned controls

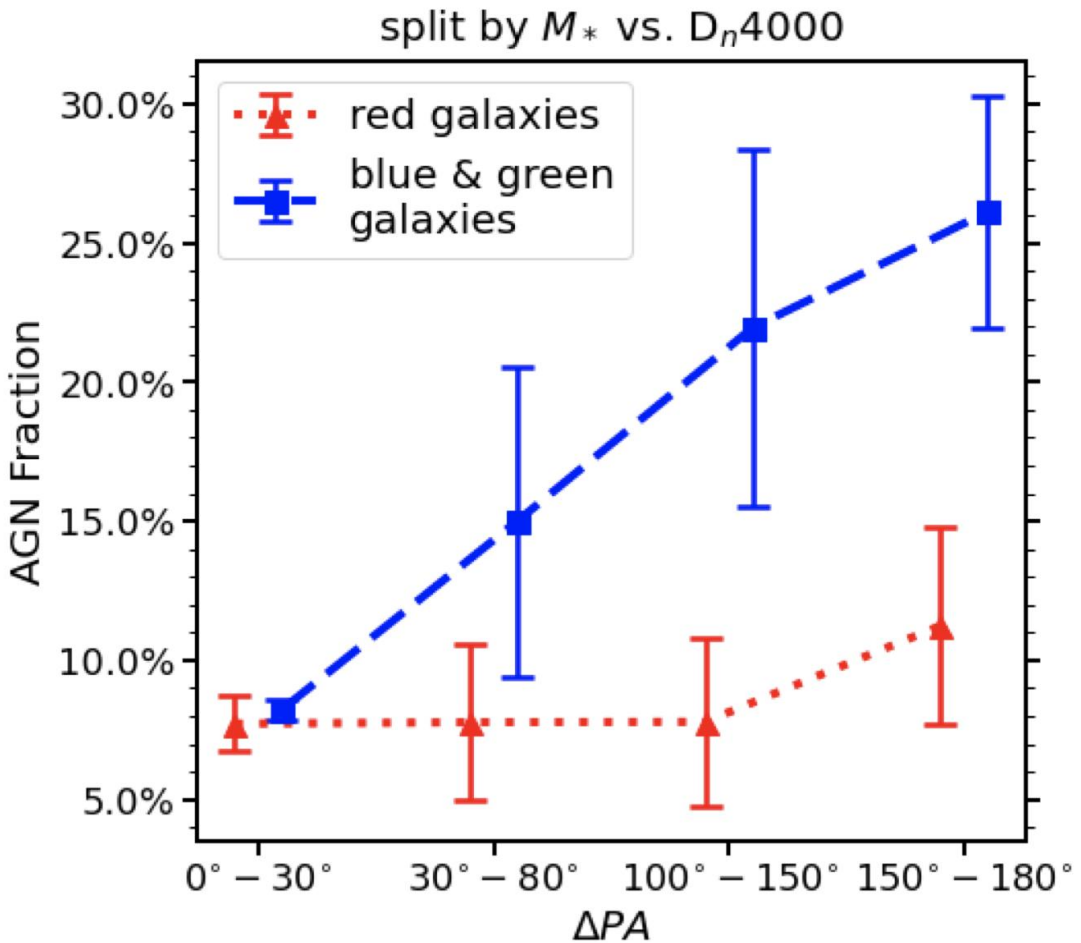

Thanks !

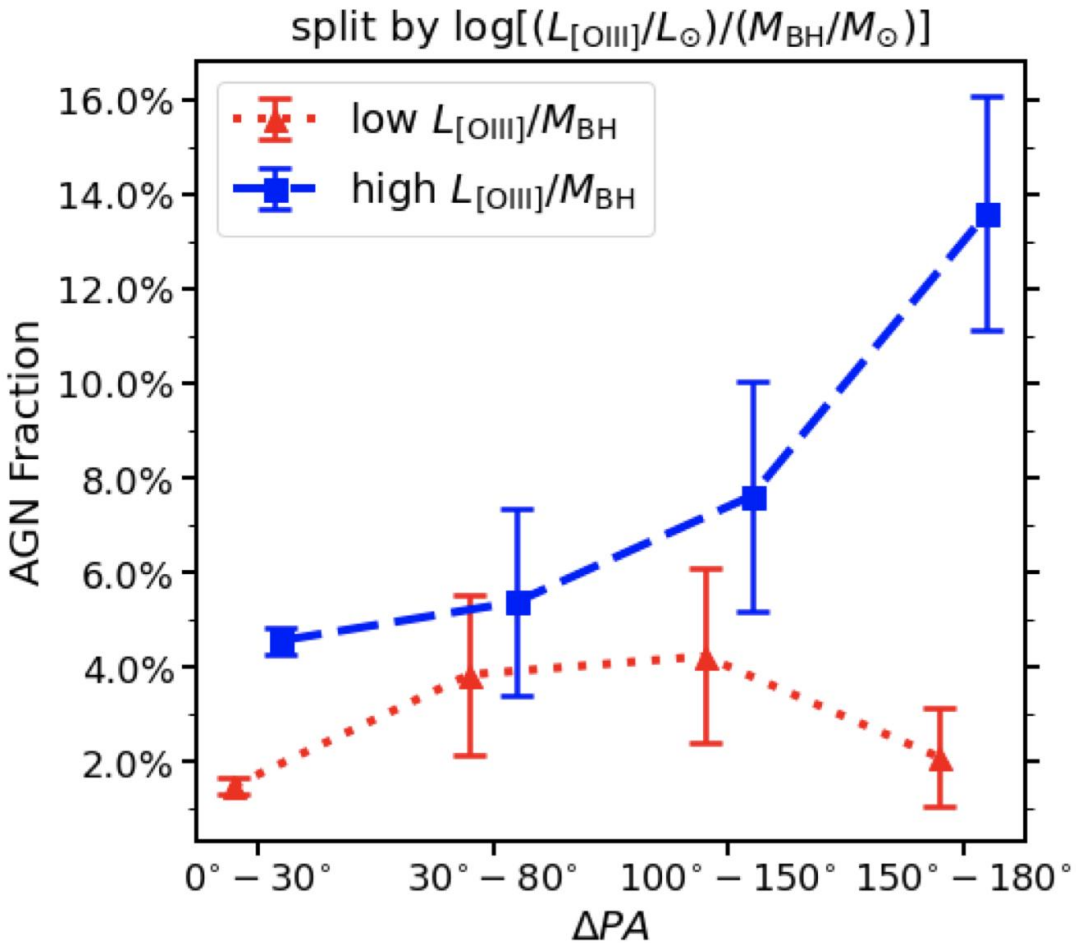
The higher AGN fraction in misaligned active galaxies



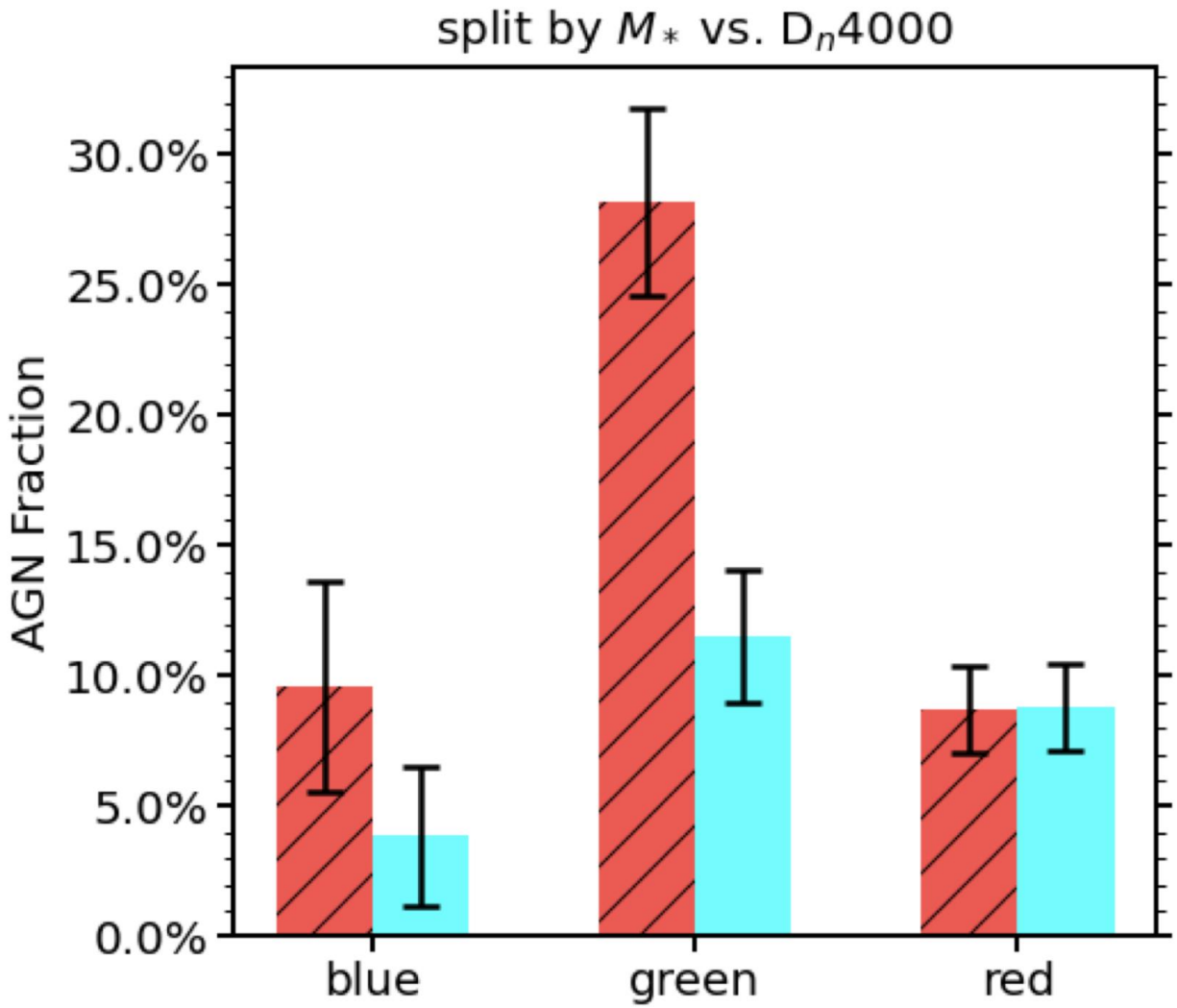


AGN fraction as a fn. of ΔPA



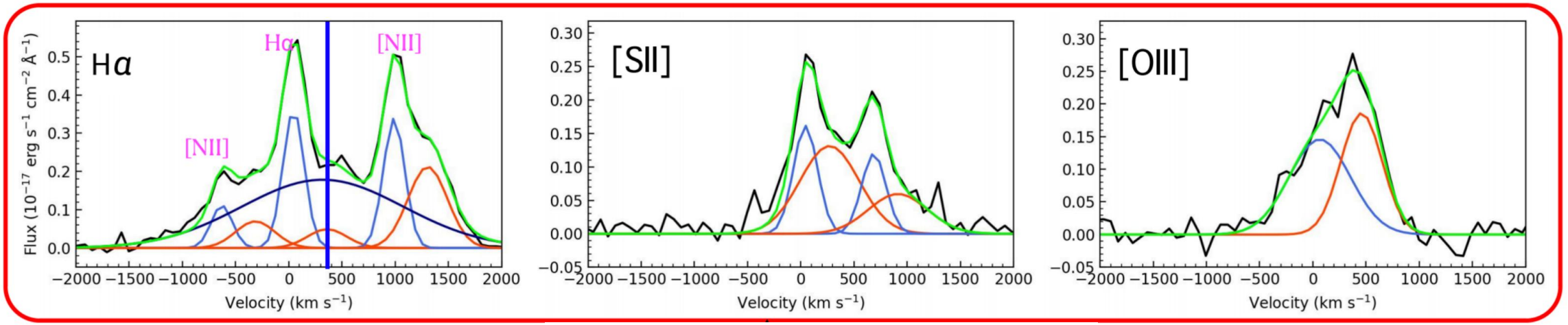


The higher AGN fraction in misaligned galaxies

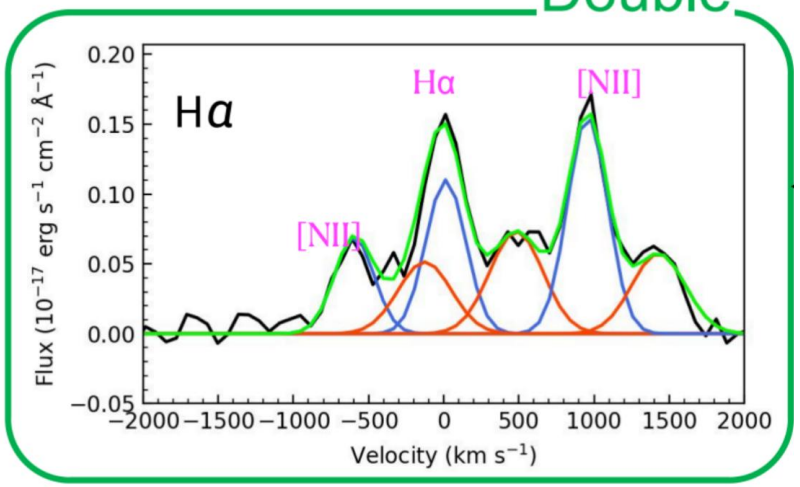


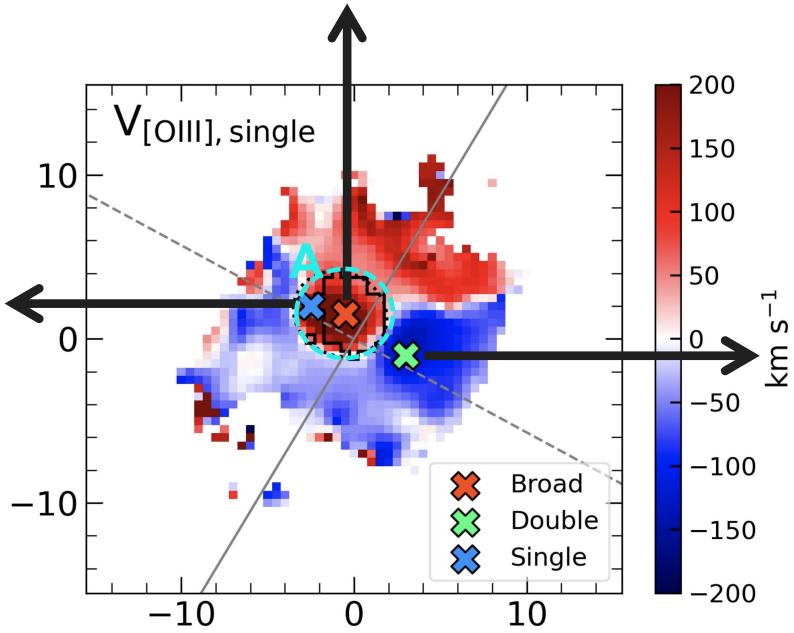
Emission line features

Hα have obvious broad emission at the unexpected redshift region

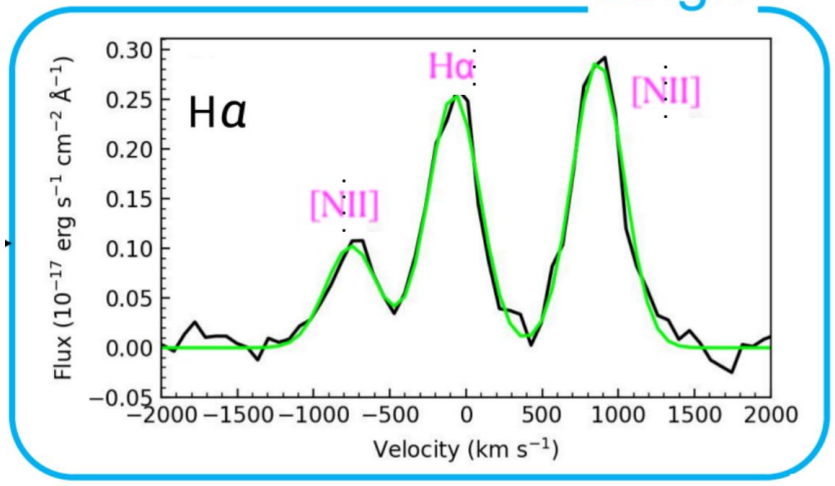


Double



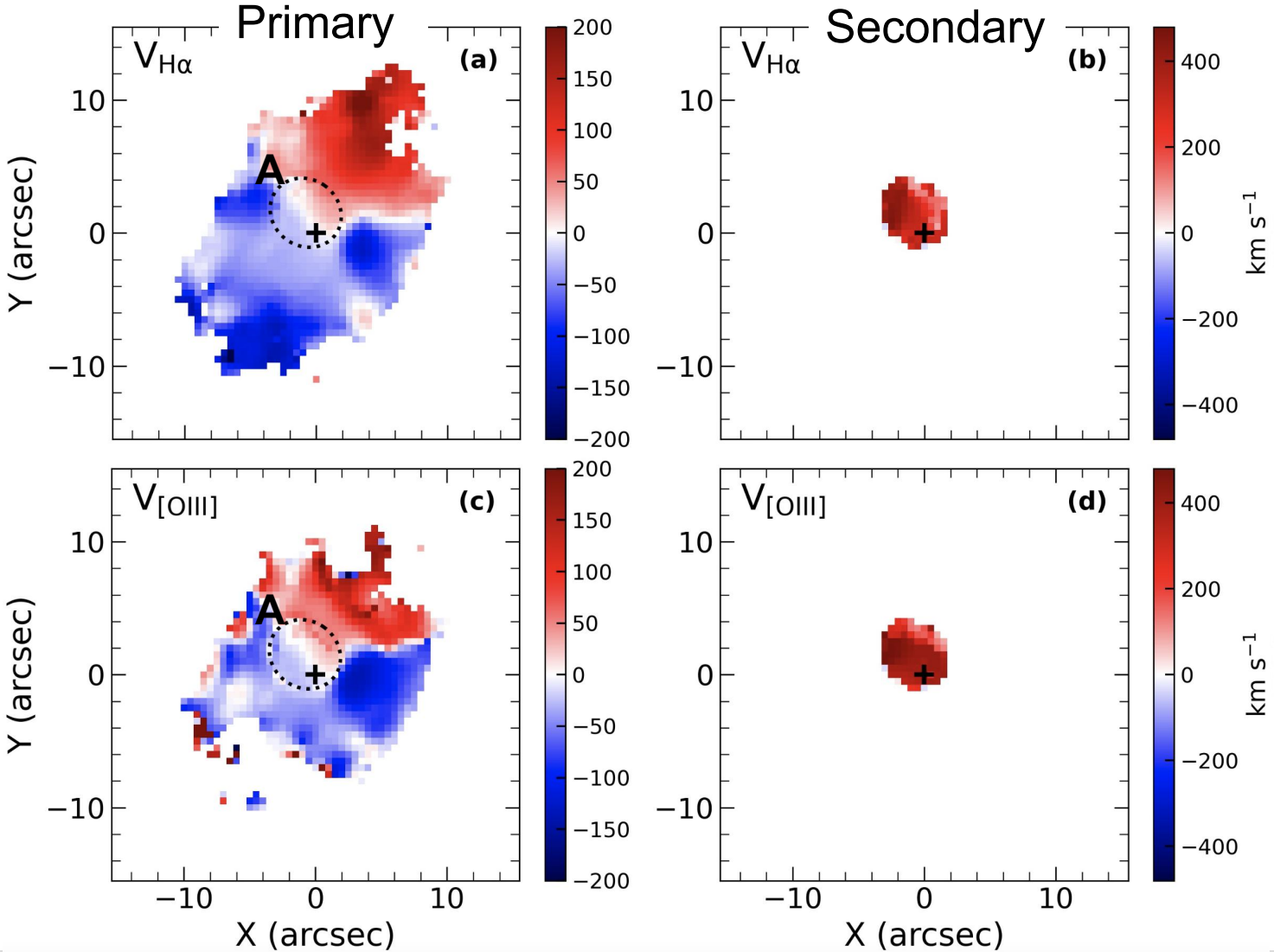


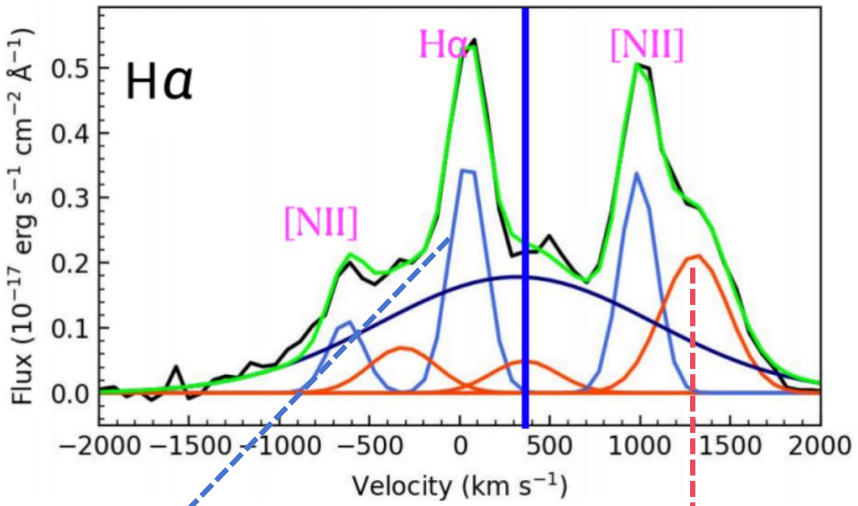
Single



Kinematics

Velocity fields of Primary and Secondary emission line components





Primary: follows the gas disk rotation

Secondary: redshifted by ~400km s^{-1}

Broad Hα components have similar velocities as the secondary components