Background:
Hercules A / 3C348
HST +VLA

Joint MUSE-JWST-ALMA view of distant radio-loud AGN

Wuji Wang
Caltech/IPAC

MUSE 10yr discoveries

22 Nov. 2024

Background:
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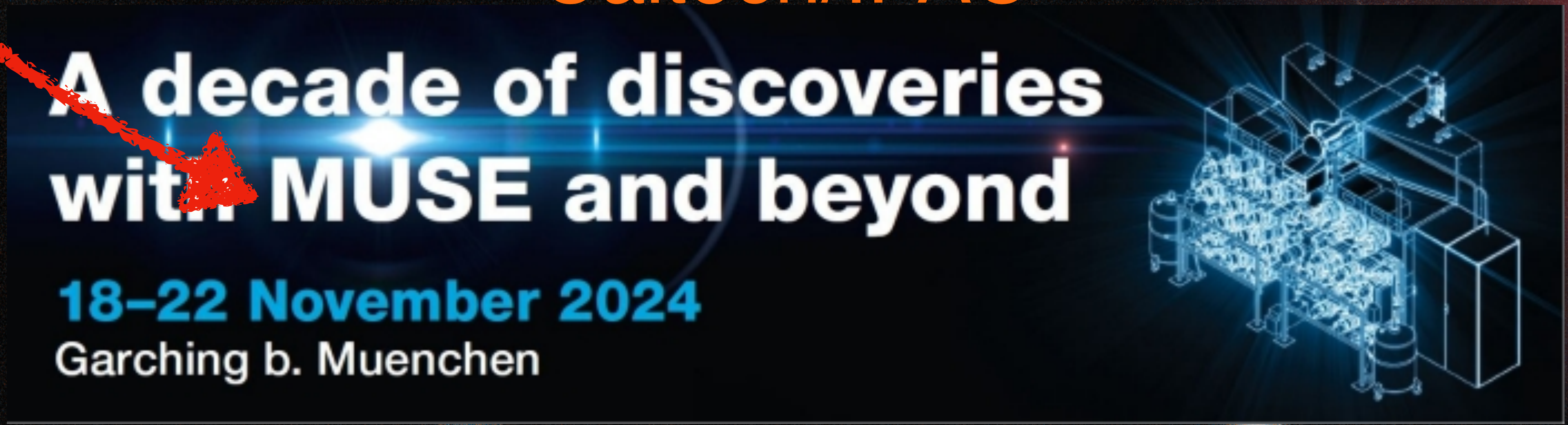

22 Nov. 2024

Background:
Hercules A / 3C348
HST +VLA

And more...

Joint MUSE-JWST-ALMA view of distant radio-loud AGN

Wuji Wang

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A decade of discoveries with MUSE and beyond

18–22 November 2024

Garching b. Muenchen

22 Nov. 2024

Background:
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Joint MUSE-JWST-ALMA view of distant radio-loud AGN

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A decade of discoveries with MUSE and beyond
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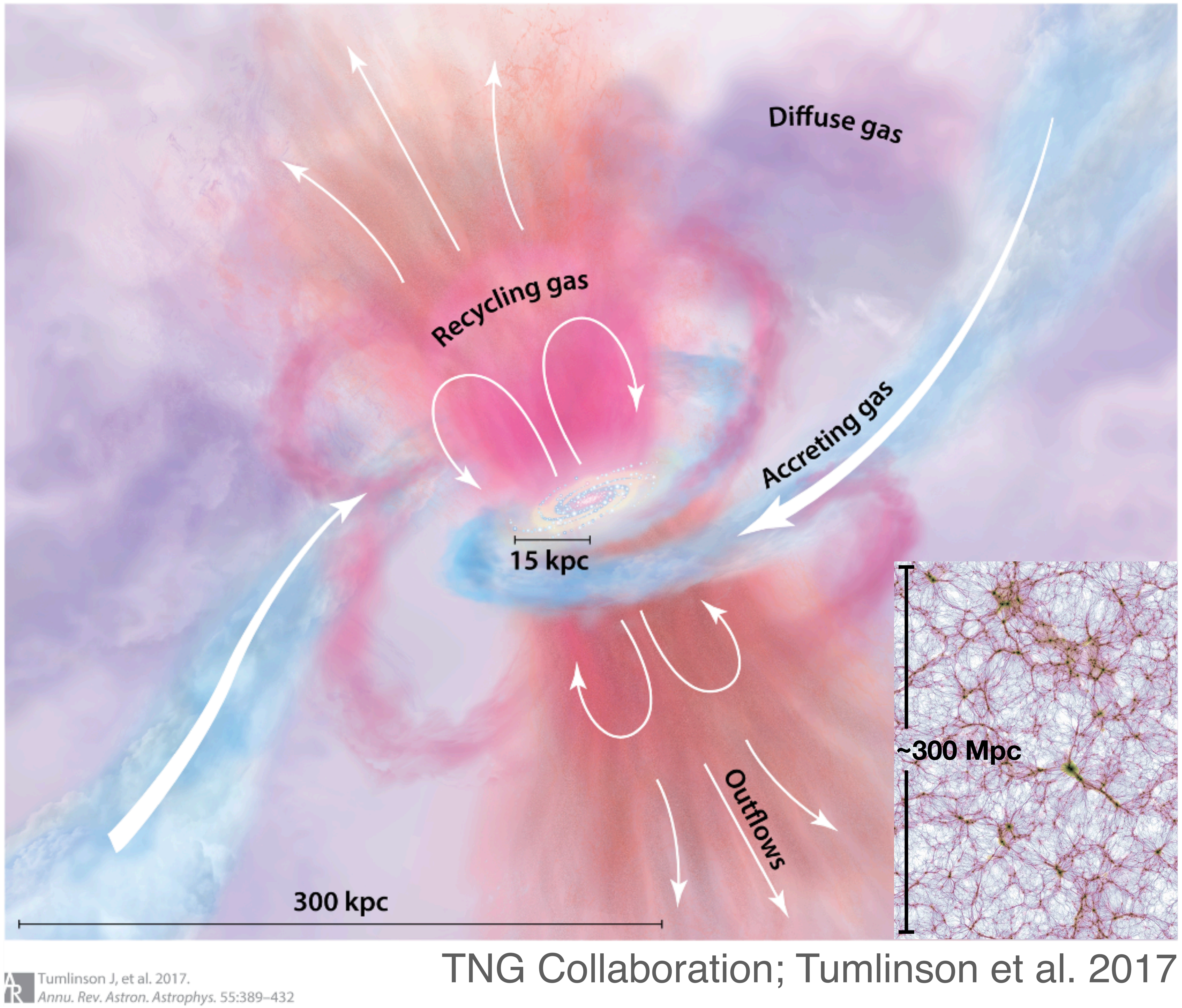
Garching b. Muenchen

22 Nov. 2024

Galaxy evolution & gaseous medium

- Matters (gas, dust, star, …) distribute along cosmic filamentary structures

- Surrounding medium is the important venue for inspecting feeding and feedback



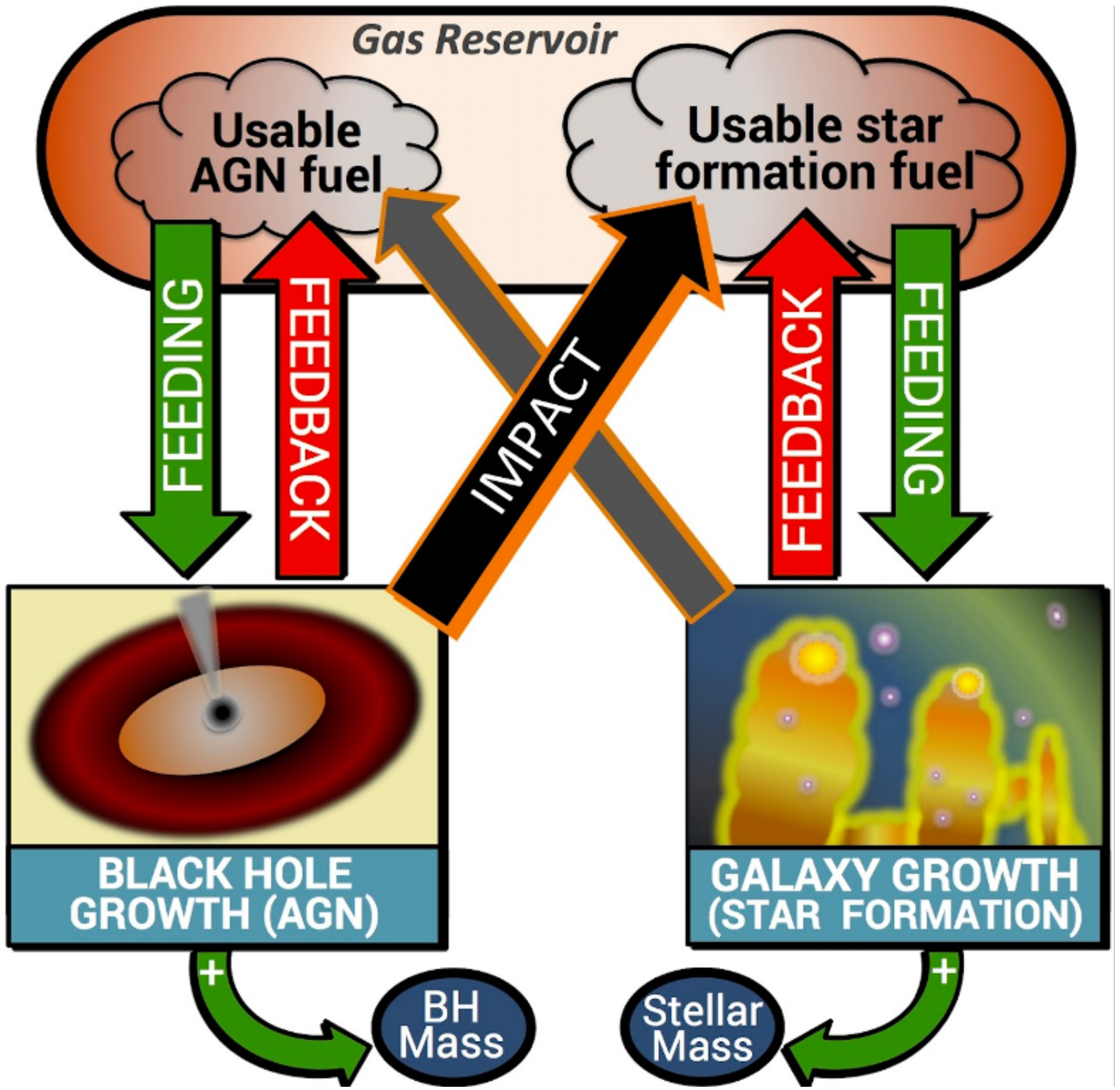
TNG Collaboration; Tumlinson et al. 2017

Galaxy evolution & AGN feedback

- Gas accretion fuels star formation and black hole growth

- Feedback ejects material/energy back to the surrounding medium

*AGN: active galactic nuclei



Harrison 2017

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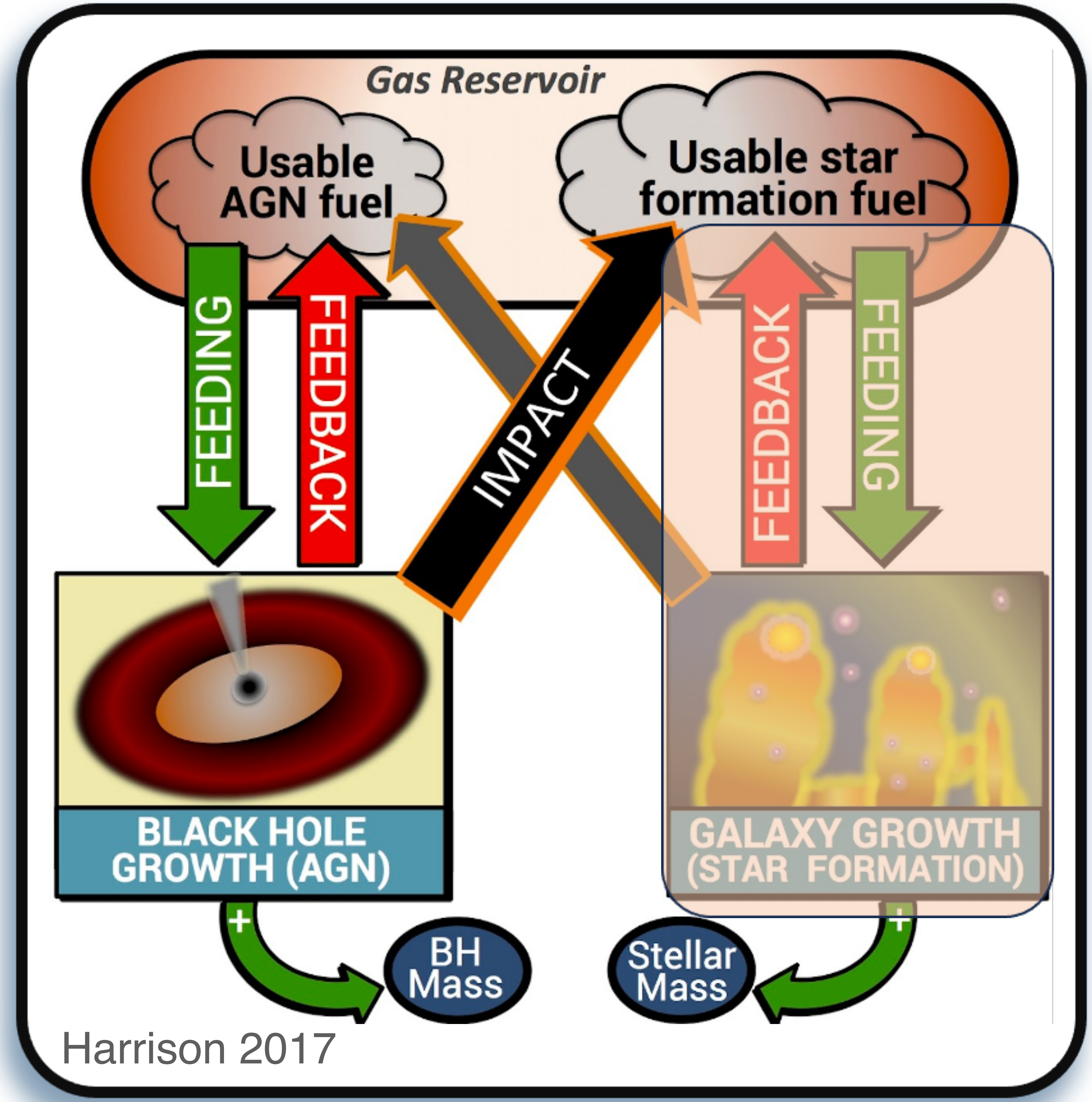
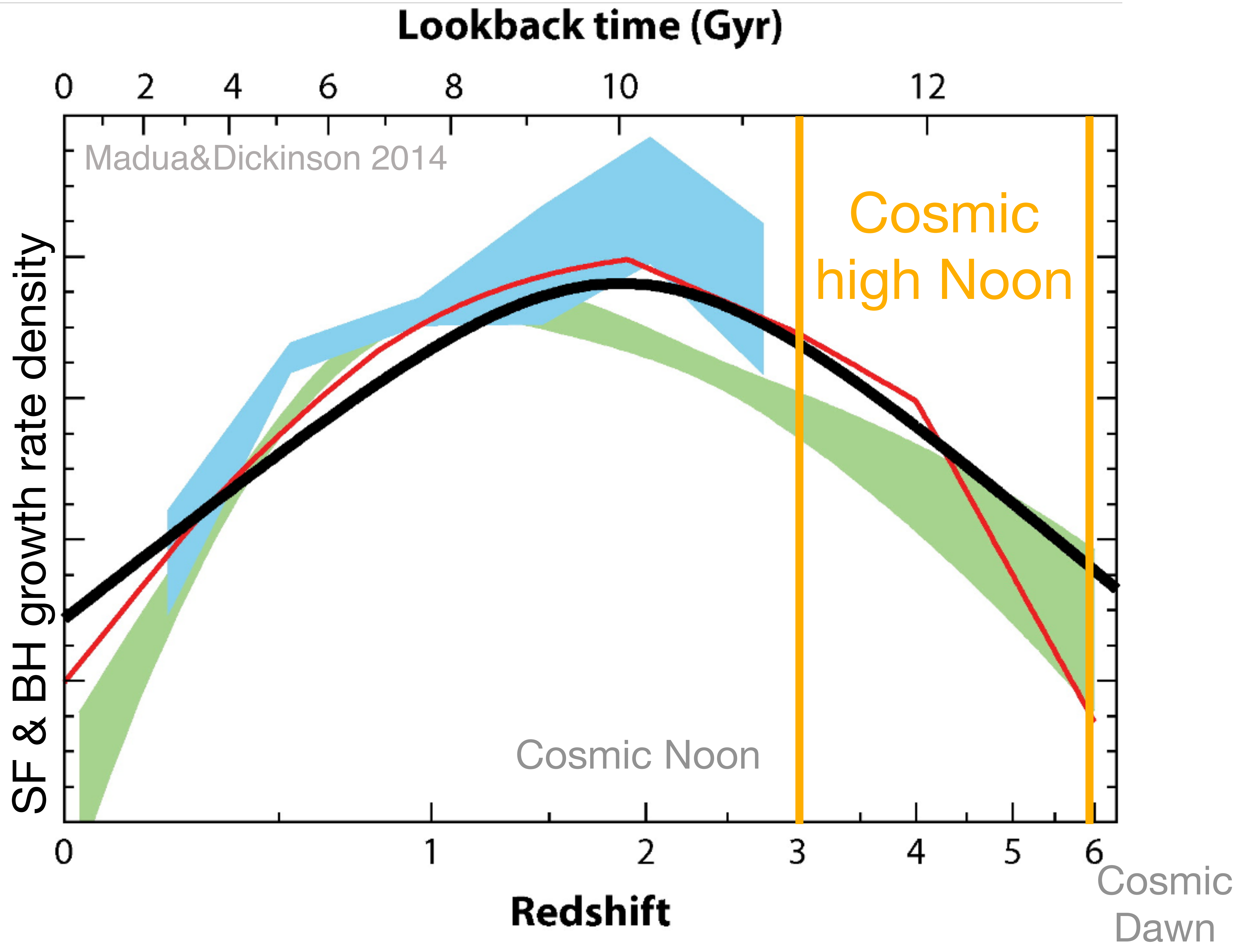


Cosmic (high) Noon

- Cosmic (high) Noon is the epoch of the fastest build-up of the most massive galaxies

- The epoch of powerful feedback from the most energetic AGN



AGN feedback at Cosmic (high) Noon

- Evidence of quenching is found in z~3.5 massive galaxies (Suzuki+22), consuming/expelling gas fast ~100s Myr

- Powerful jet (life time ~100 Myr) at Cosmic (high) Noon could have such ability

quenching: stop forming stars

AGN feedback at Cosmic (high) Noon - jets

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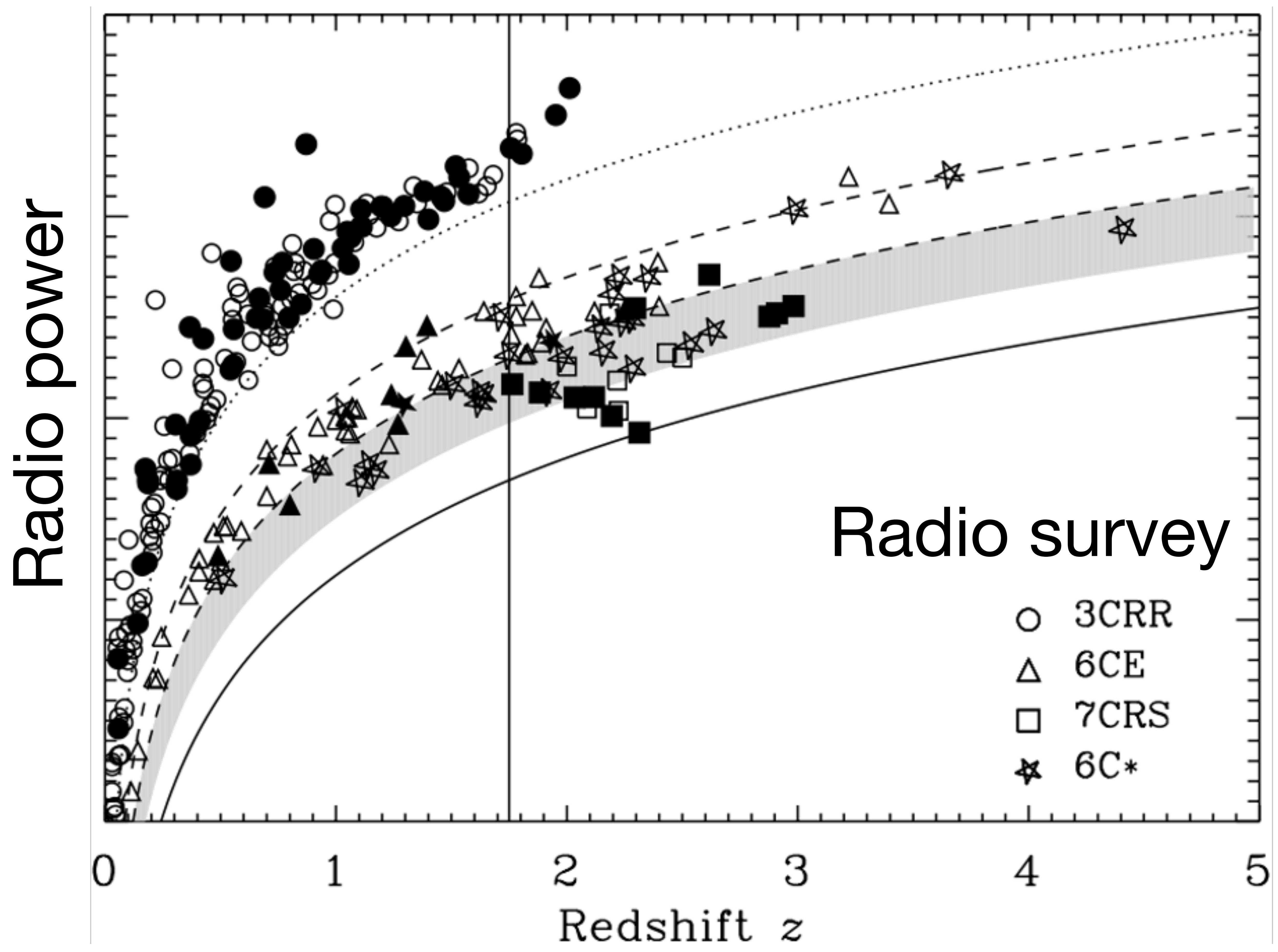
quenching: stop forming stars

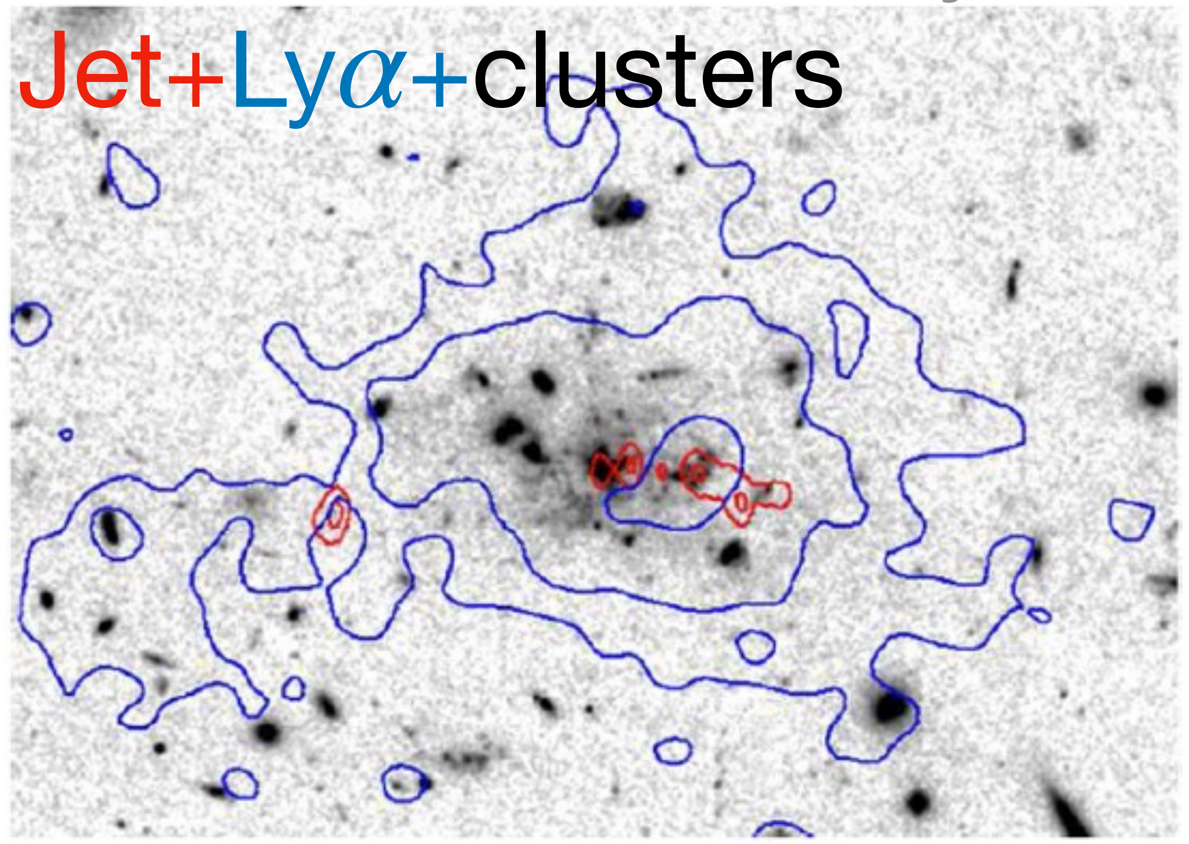
Jarvis et al. 2001



High-redshift Radio Galaxies (HzRGs)

- Type-2 quasars (luminous AGN) + the most powerful jets, $z > 1$

Spiderweb@z=2.1
Miley+08



McCarthy 93; Seymour+07; Venemans+07; Miley & De Breuck+08; De Breuck+10; Wylezalek+13, 14; Nesvadba+17; Falkendal+19; Kolwa+23

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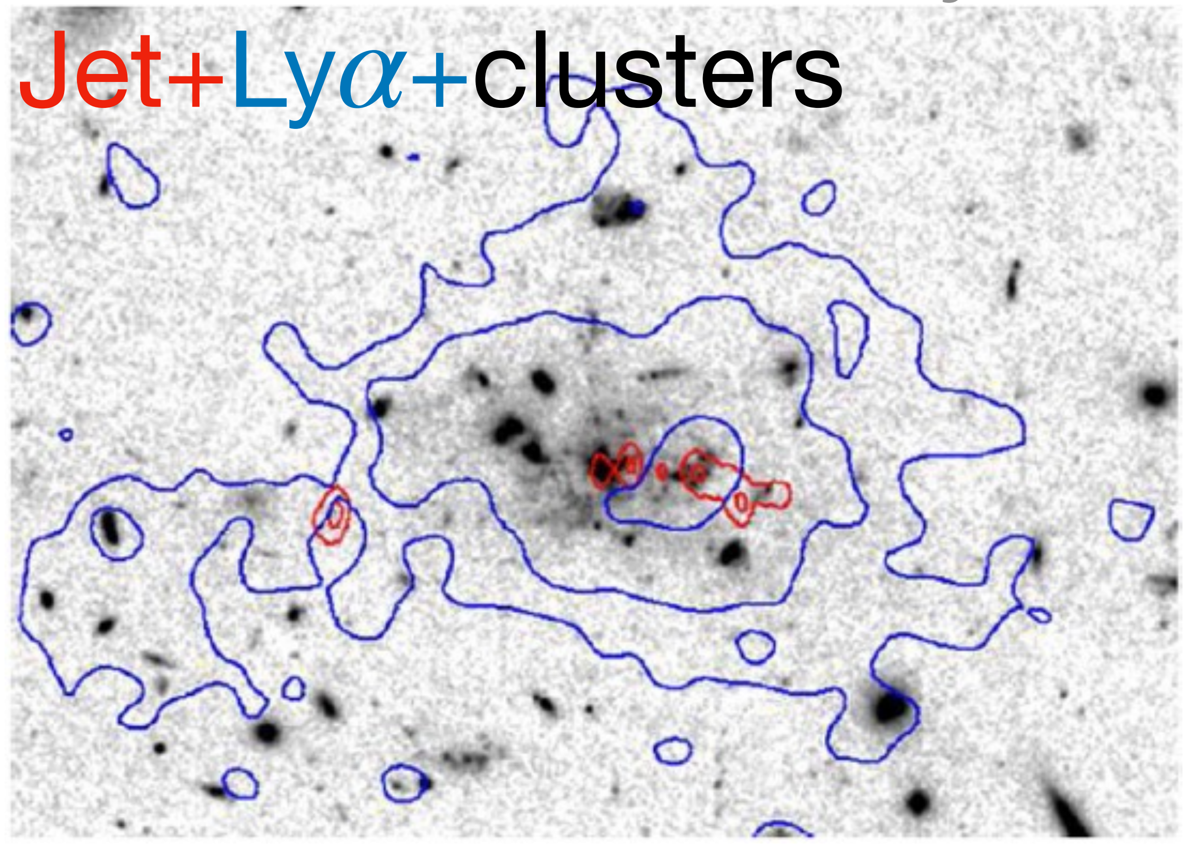

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- Hosted by massive galaxies ($M_\star \sim 10^{11} M_\odot$)

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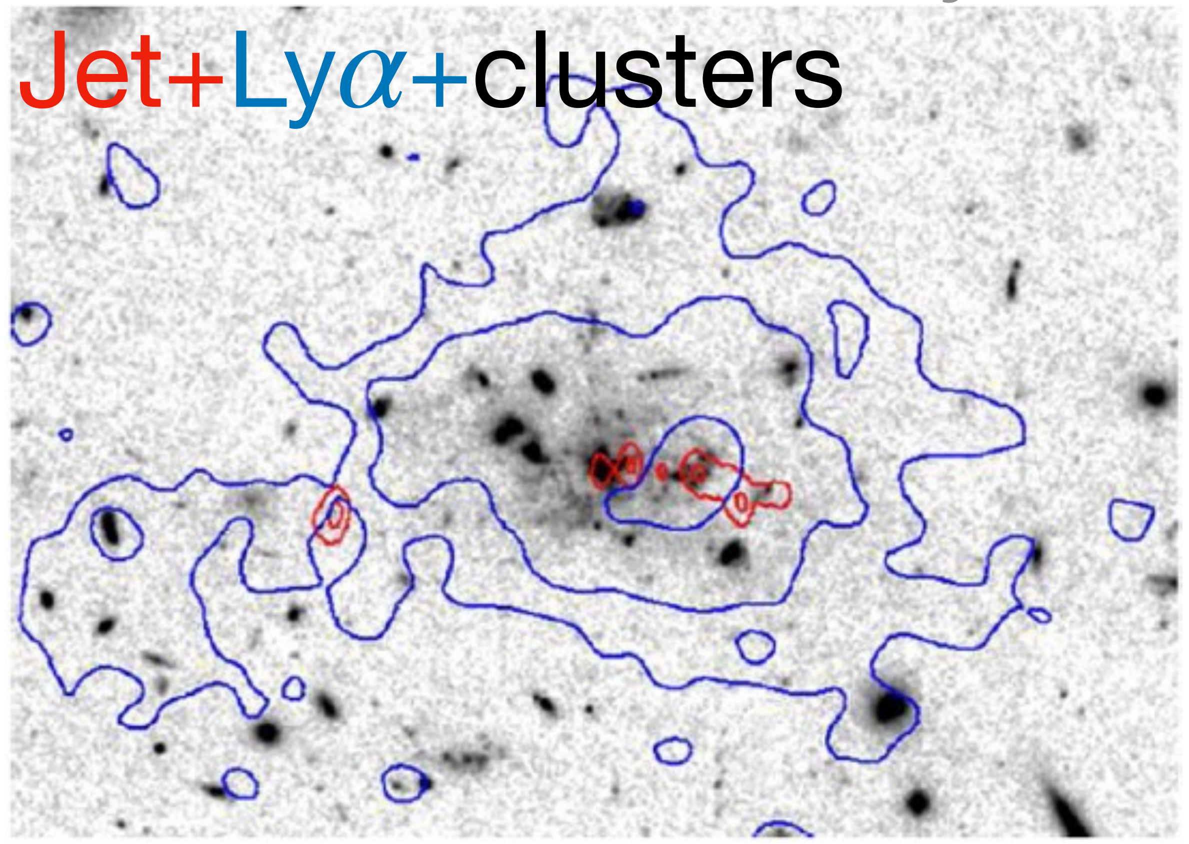

- Type-2 quasars (luminous AGN) + the most powerful jets, $z > 1$
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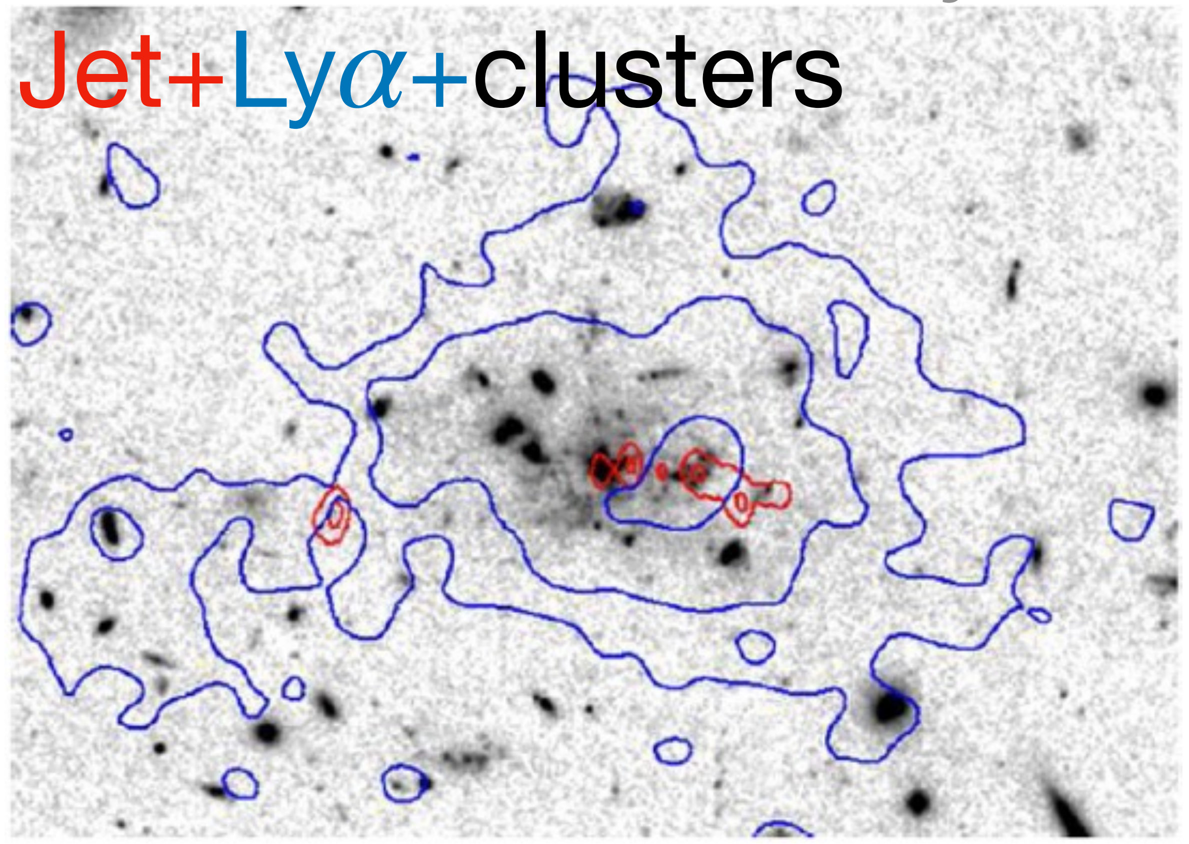

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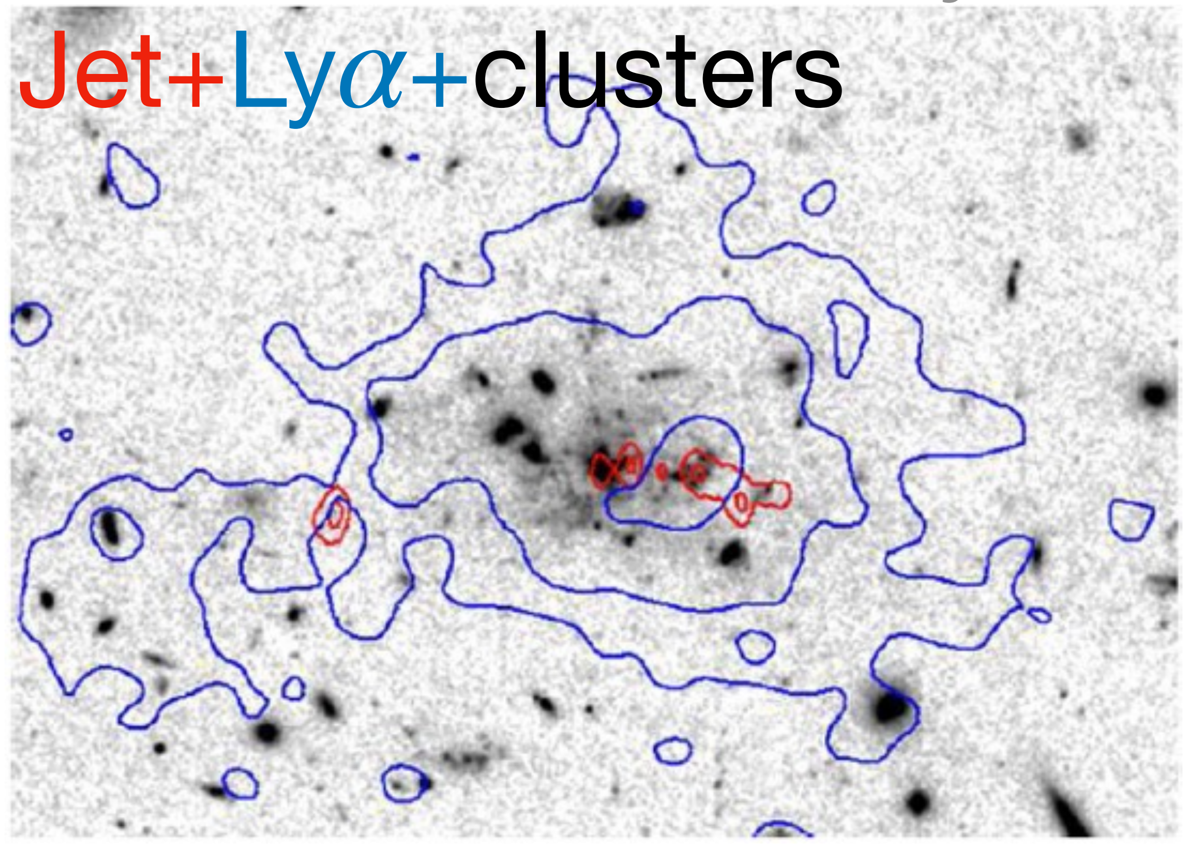

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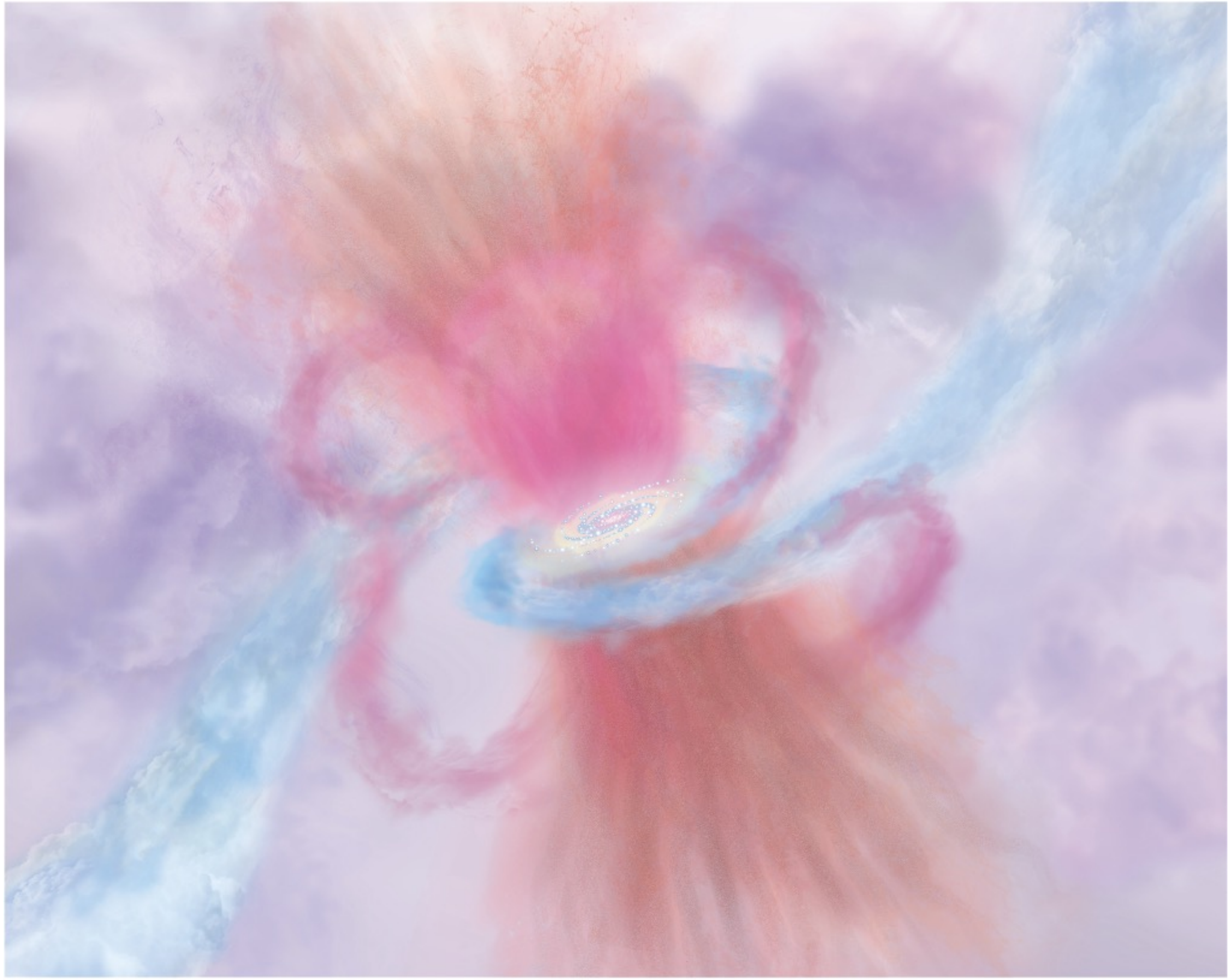
- Hosted by massive galaxies ($M_\star \sim 10^{11} M_\odot$)
- Live in dense proto-cluster environment
- Evidence of quenching (below main sequence; low molecular gas)
- Best candidate for radiative-mode & jet-mode feedback & host galaxy study

AGN feedback

McCarthy 93; Seymour+07; Venemans+07; Miley & De Breuck+08; De Breuck+10; Wylezalek+13, 14; Nesvadba+17; Falkendal+19; Kolwa+23

High-redshift Radio Galaxies (HzRGs)

Missing:
systemic observational view of the gaseous medium across different scales & detailed view at sub-kpc

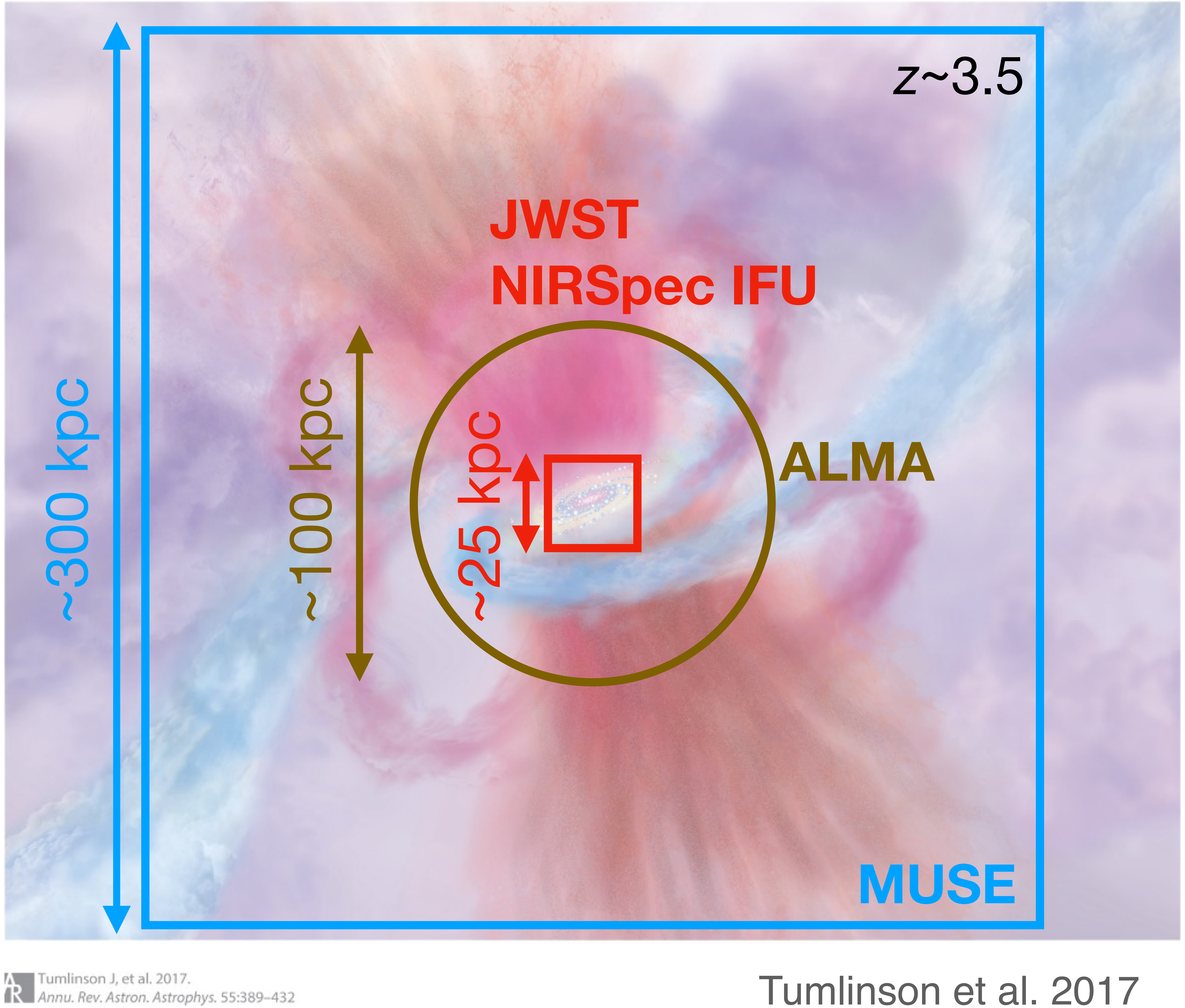


Tumlinson J, et al. 2017.
Annu. Rev. Astron. Astrophys. 55:389–432

High-redshift Radio Galaxies (HzRGs)

Missing:
systemic observational view of the gaseous medium across different scales & detailed view at sub-kpc

My contribution:
Using state-of-the-art IFUs to study the <u>multiphase</u> feedback processes and environment of HzRGs



Tumlinson et al. 2017

MUSE: Circumgalactic medium (CGM)

- Key questions:
  - ~100 kpc feeding and feedback
  - undisturbed gaseous halos, i.e., gaseous halo distribution

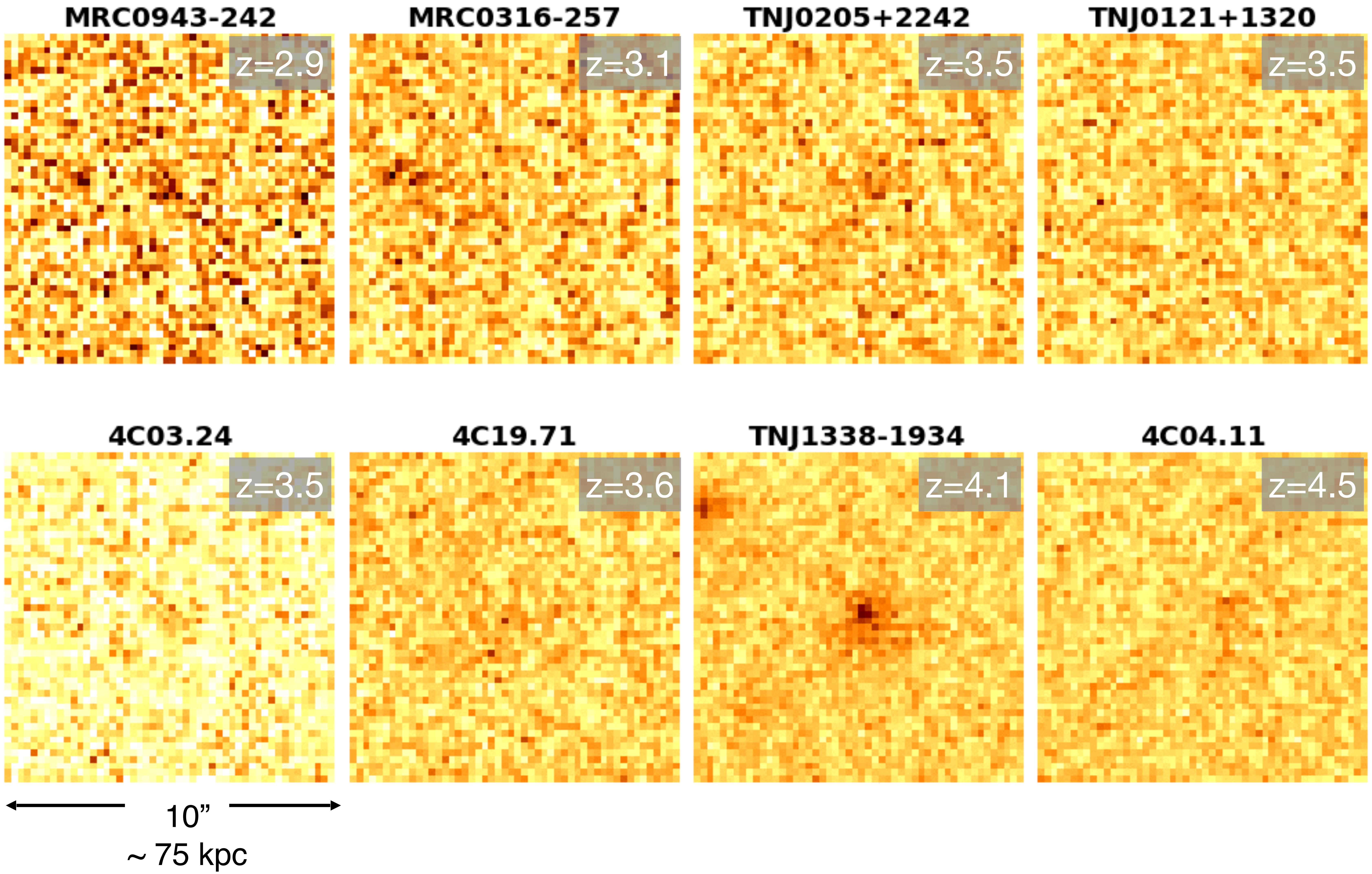
Tumlinson J, et al. 2017. Annu. Rev. Astron. Astrophys. 55:389–432

Tumlinson et al. 2017

Our HzRGs sample

PI (J. Vernet)

- 8 HzRGs with (~4h each) MUSE observation
- Giant gaseous halos commonly with HI absorption (Lyα, ~ 50 kpc)



Our HzRGs sample

A Decade

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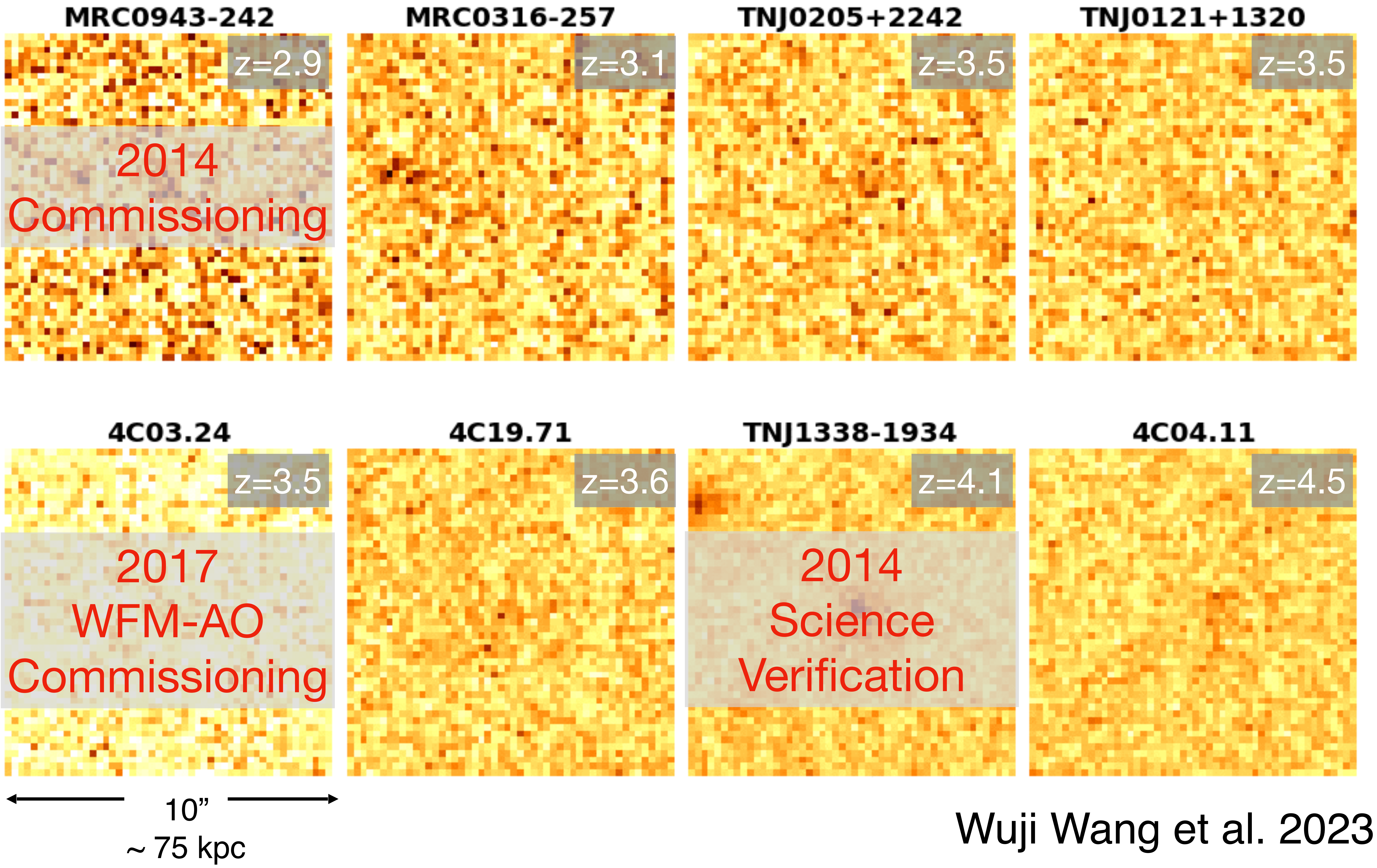
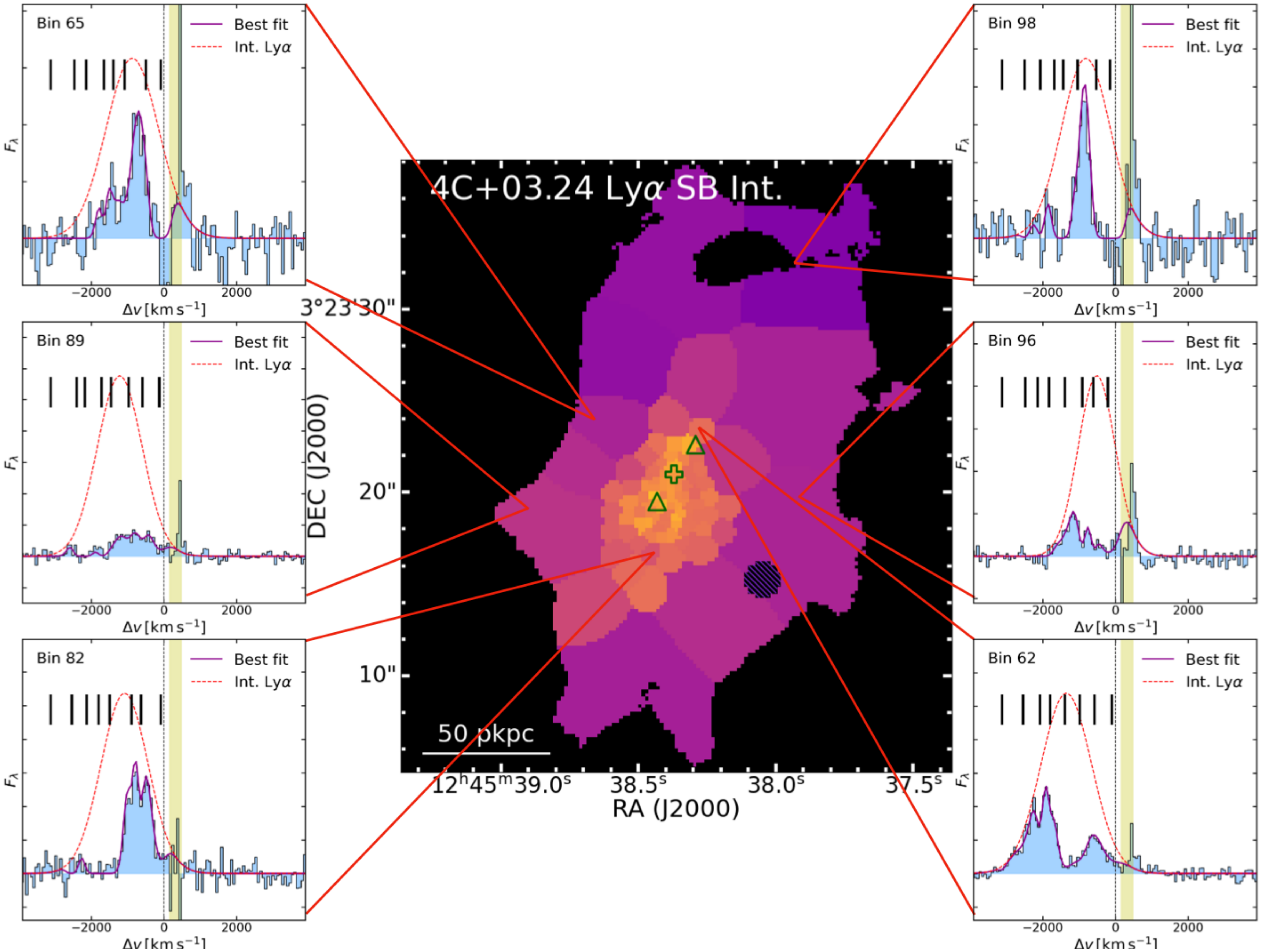


Wuji Wang et al. 2023

Mapping Intrinsic Lyα (=corrected for absorption) nebulae

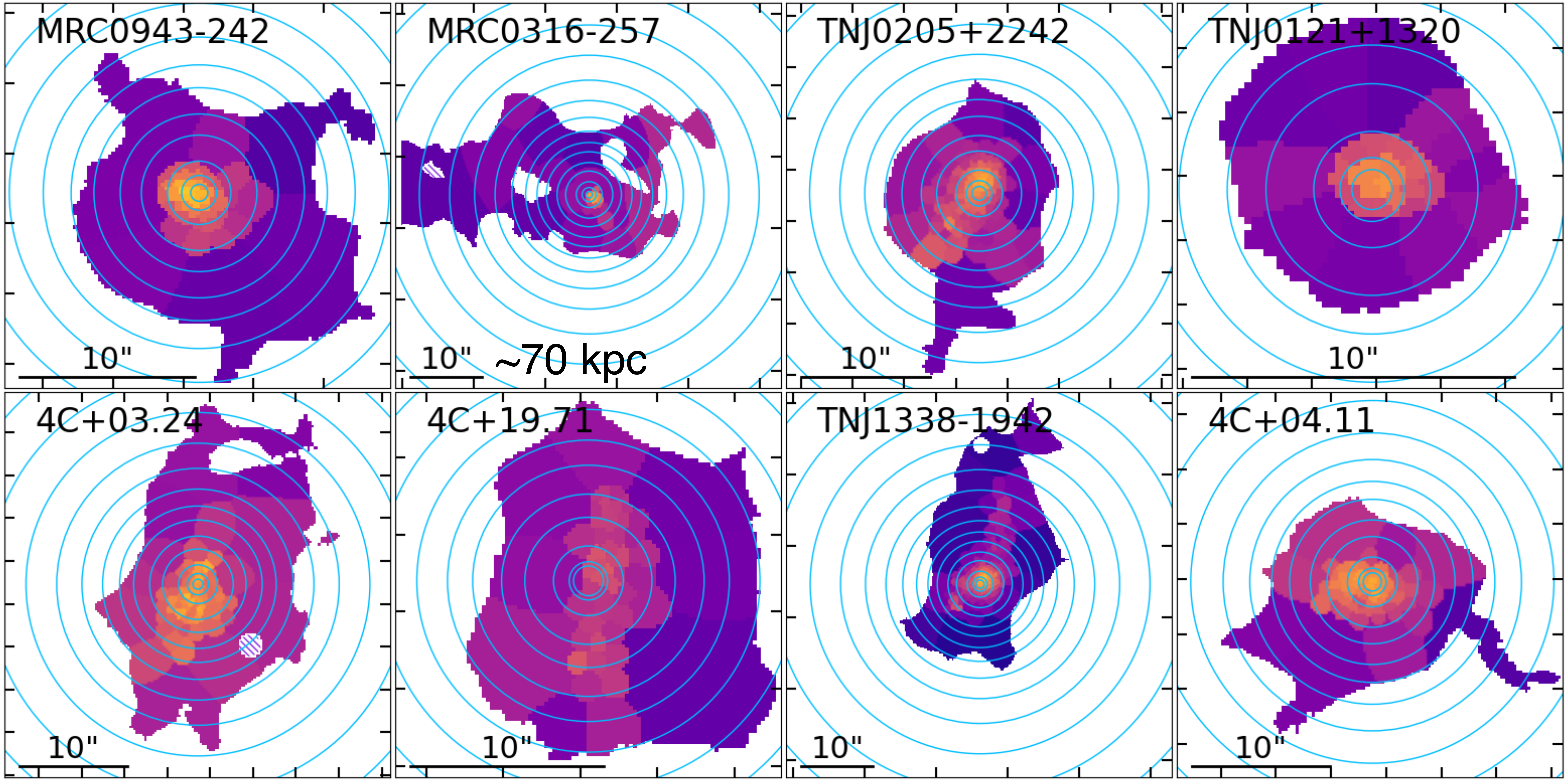
Wuji Wang et al. 2023



Intrinsic Lyα nebulae: radial profile

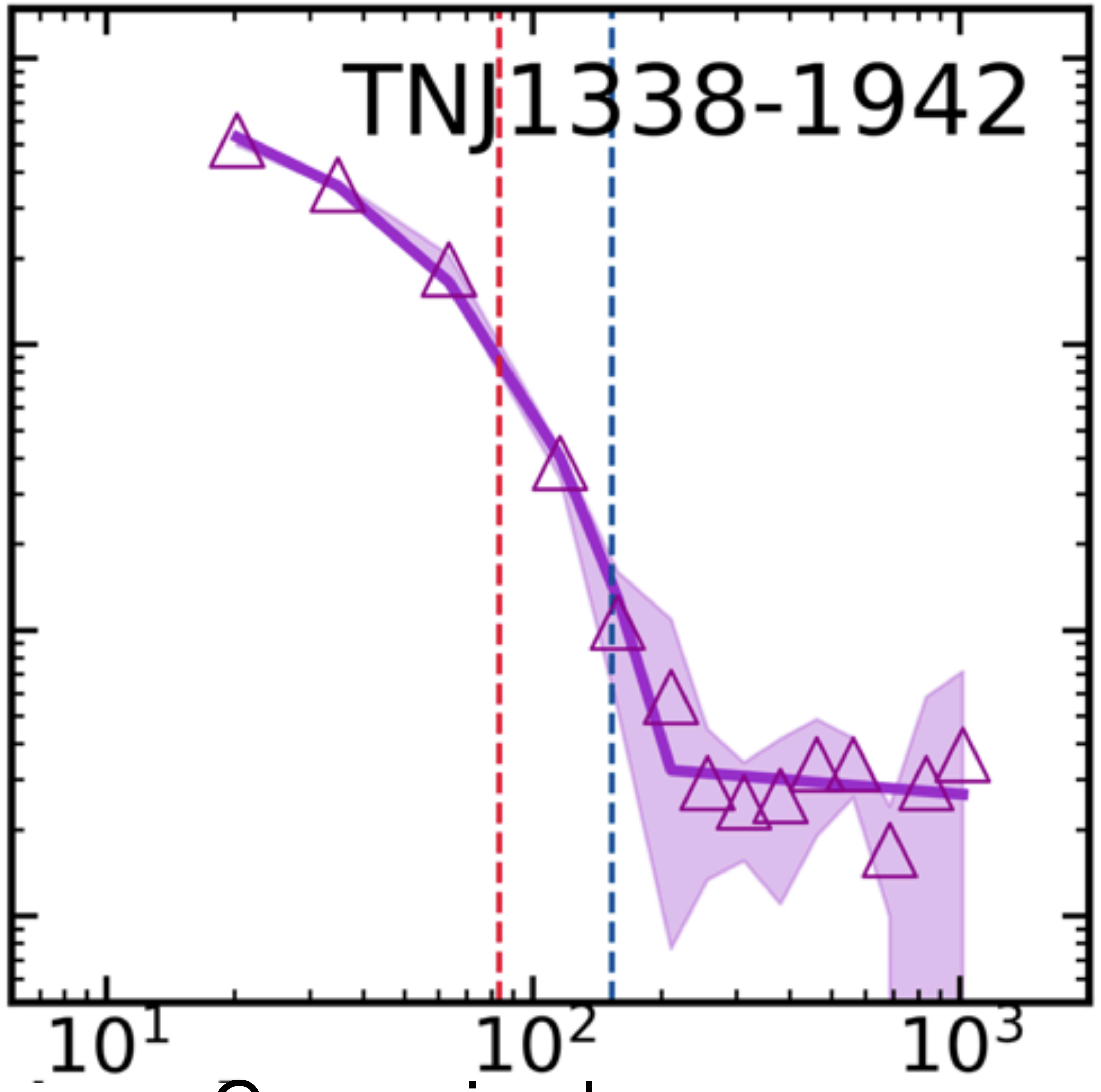
- Radial profile from circular annuli

Wuji Wang et al. 2023



Intrinsic Lyα surface brightness radial profile

Wuji Wang et al. 2023



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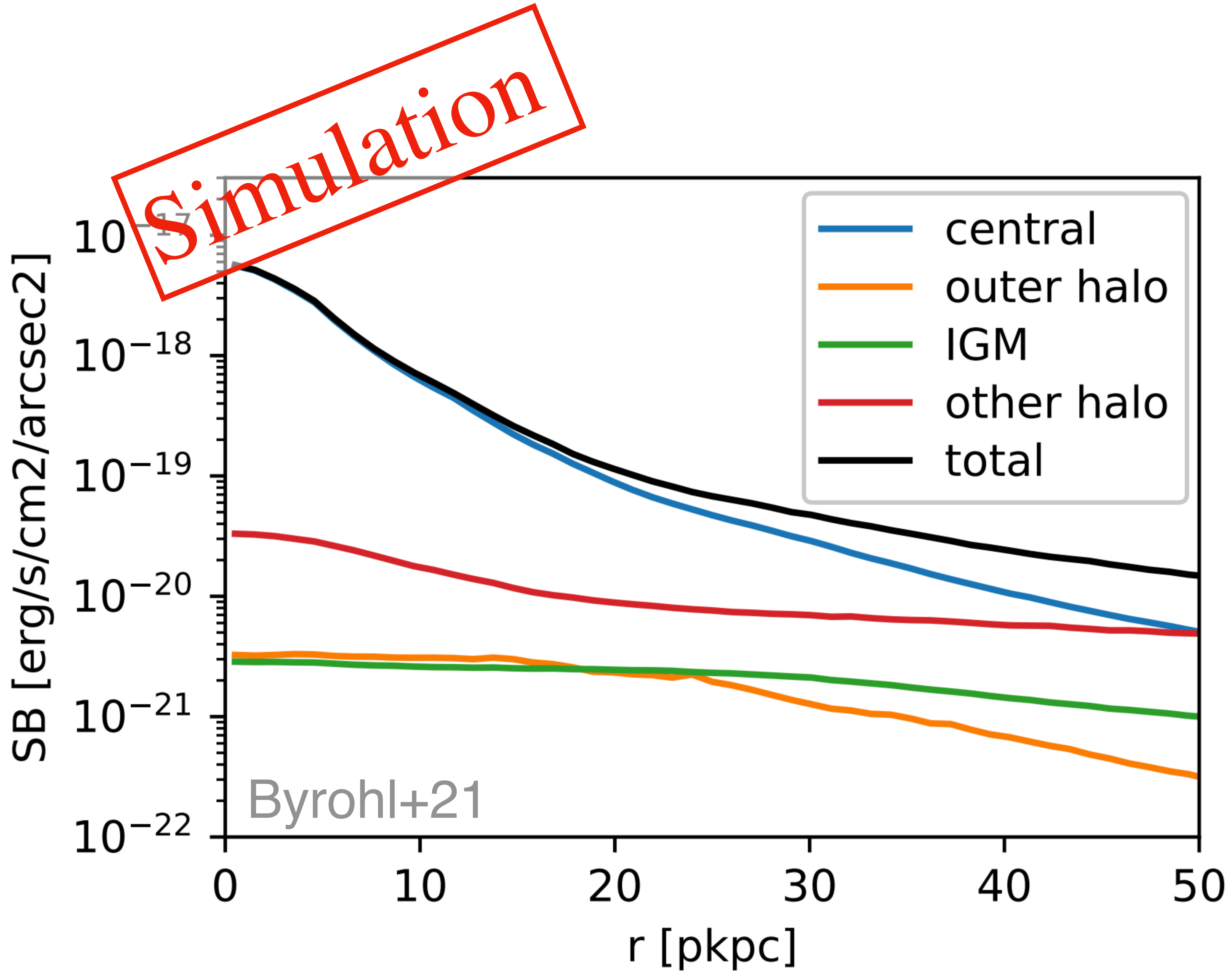
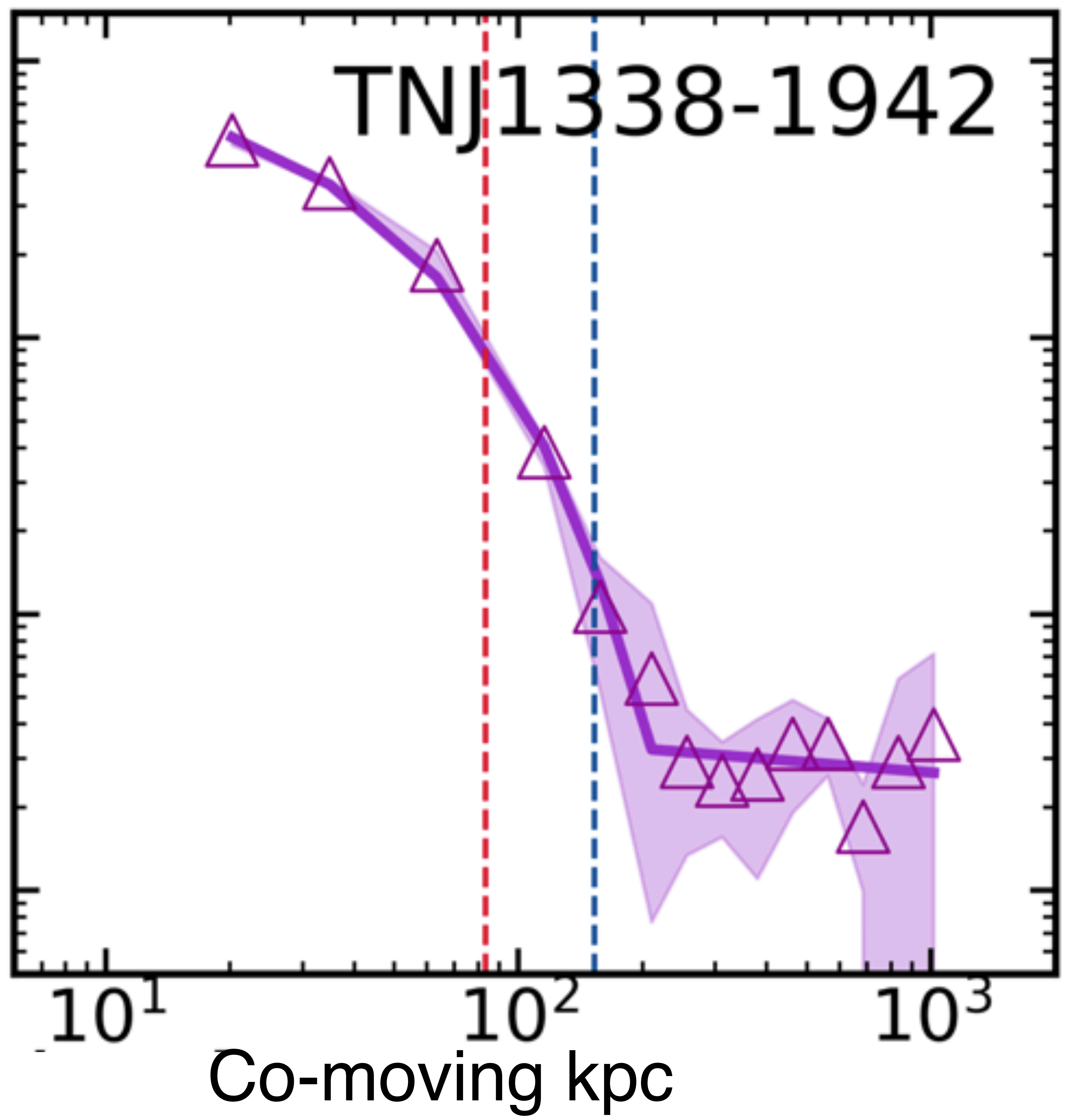


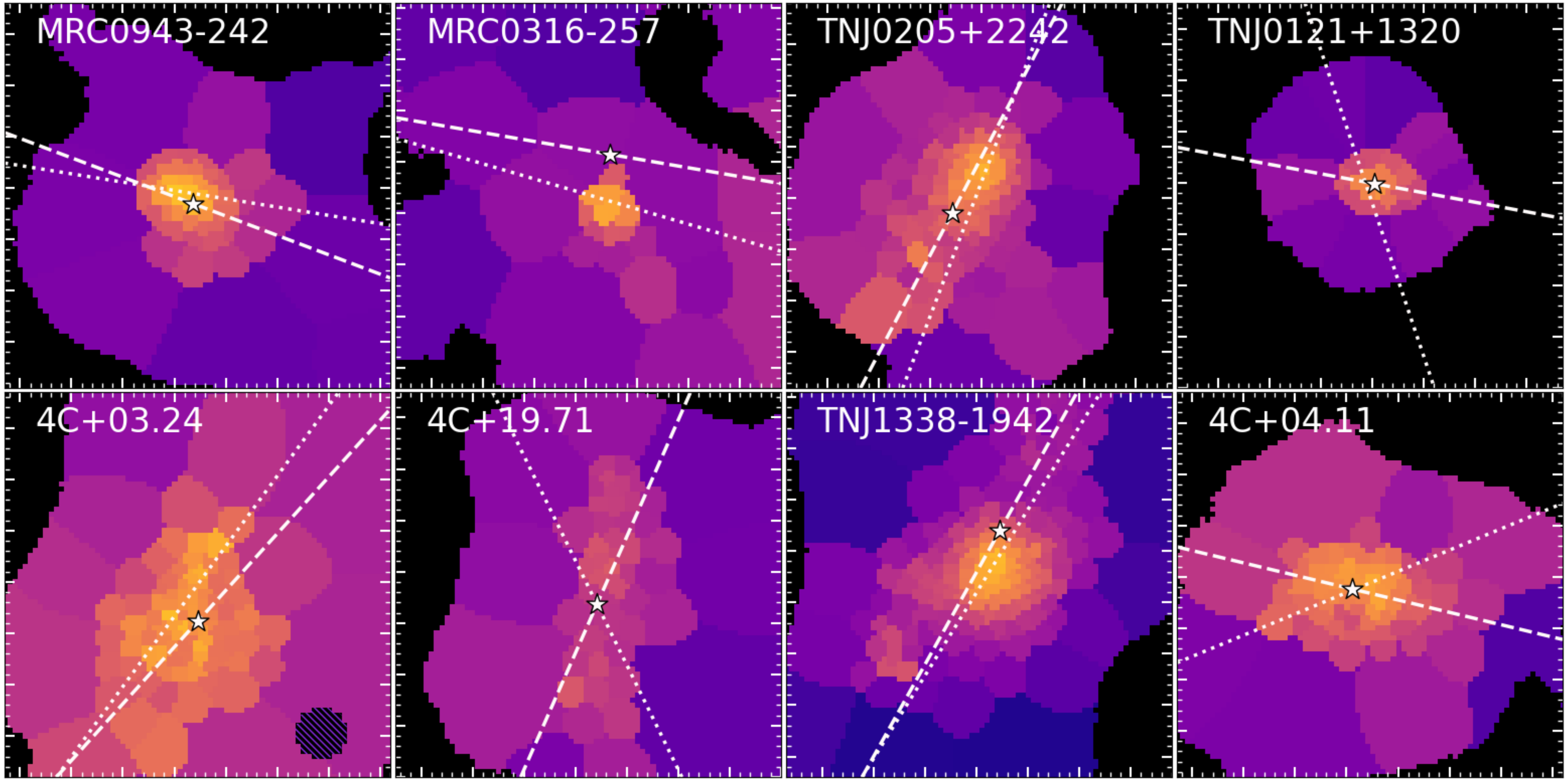
Wuji Wang et al. 2023



- Scattered photons from companions results in the outer flattening?

Lyα nebulae position angle v.s. jet

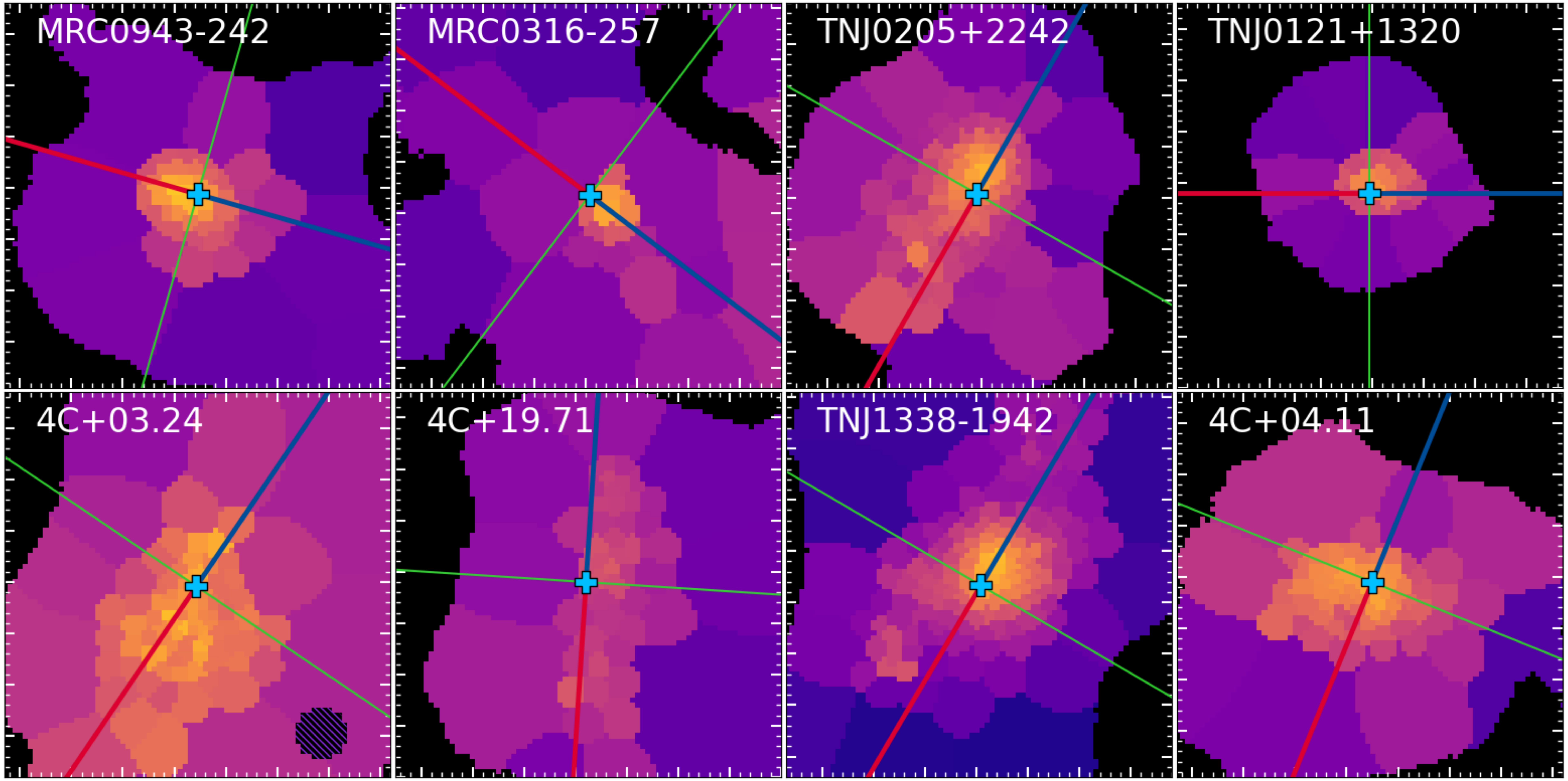
- Quantified nebulae orientation direction



Wuji Wang et al. 2023

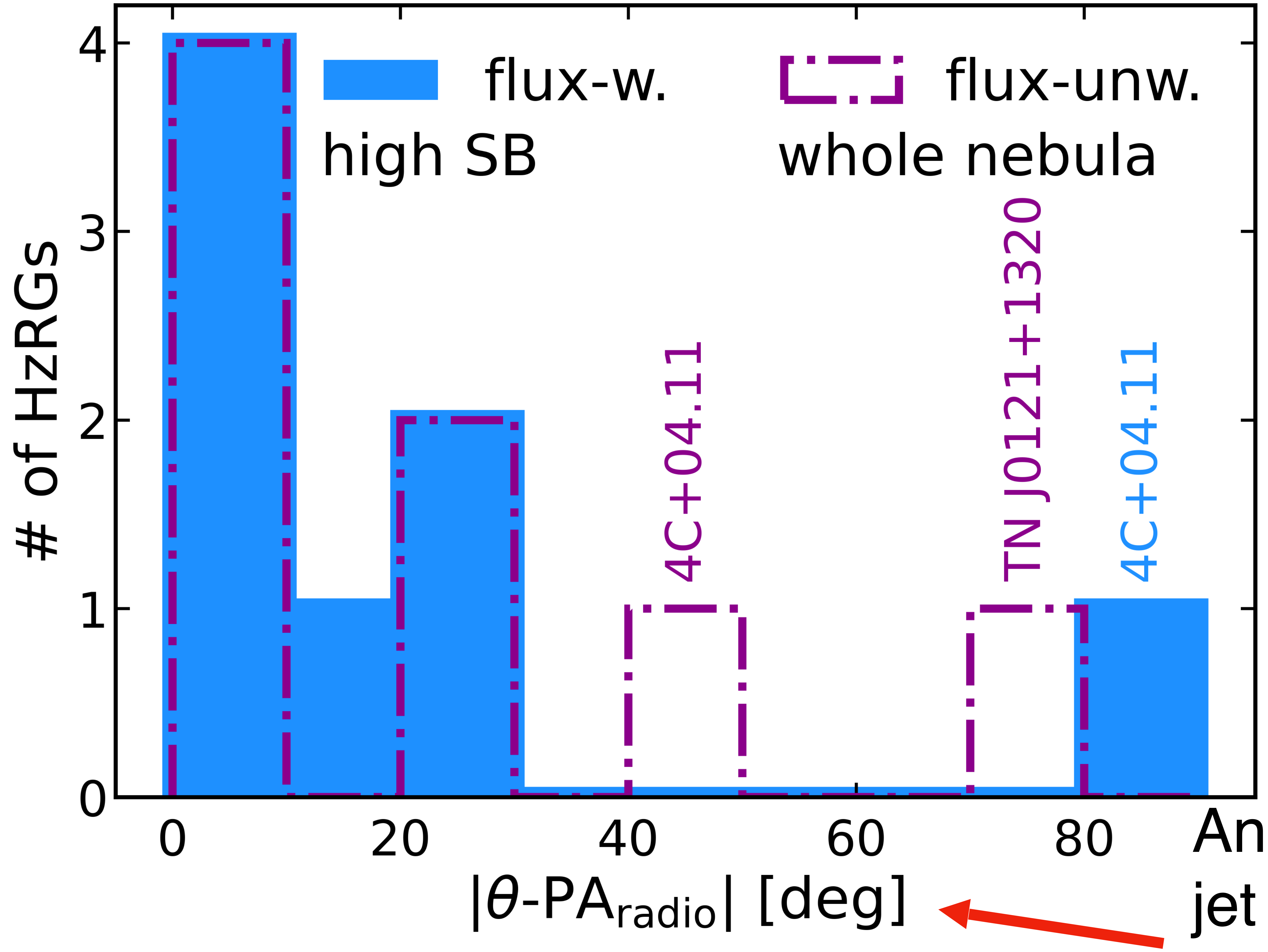
Lyα nebulae position angle v.s. jet

- Jet position angle in red blue (green perpendicular direction)



Wuji Wang et al. 2023

Lyα nebulae position angle v.s. jet

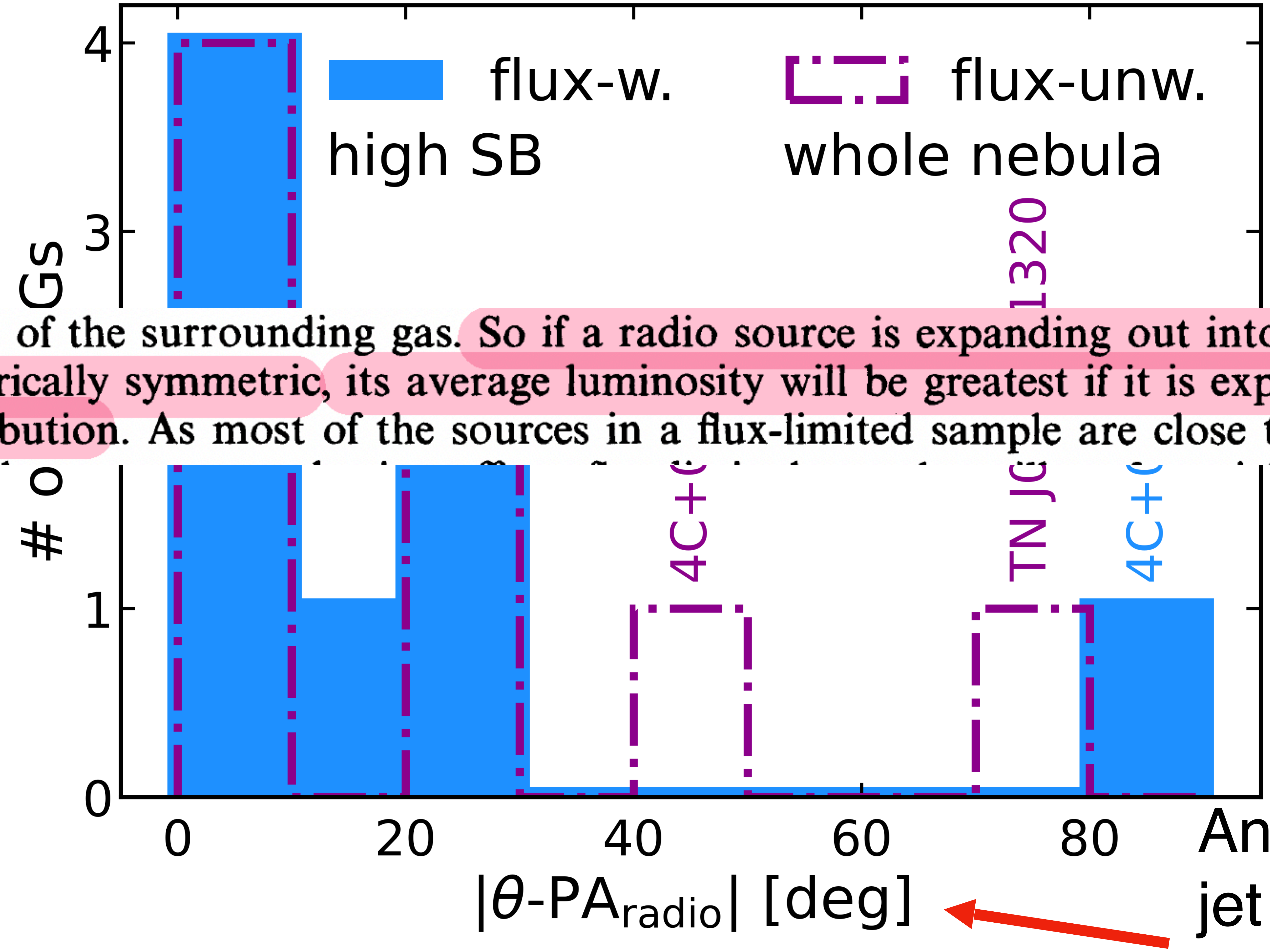


Wuji Wang et al. 2023

Angle difference between jet direction and nebula direction

Lyα nebulae position angle v.s. jet

Wuji Wang et al. 2023



with the density of the surrounding gas. So if a radio source is expanding out into gas whose density distribution is not spherically symmetric, its average luminosity will be greatest if it is expanding along the major axis of the gas distribution. As most of the sources in a flux-limited sample are close to the lower flux limit of the

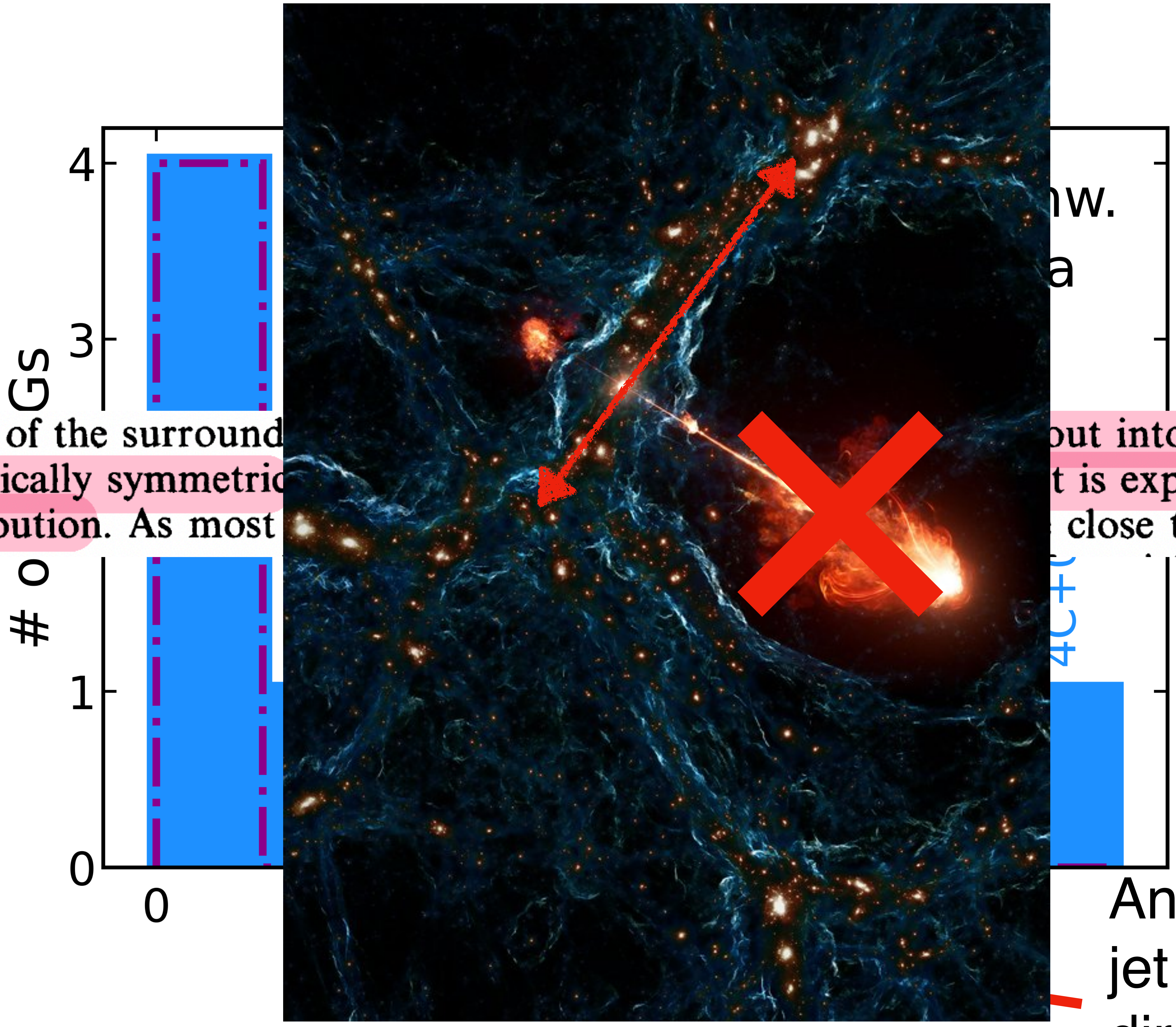
Eales 1992

Angle difference between jet direction and nebula direction

Lyα nebulae position angle v.s. jet

Oei+24
Credit: E. Wernquist / D. Nelson (IllustrisTNG Collaboration) / M. Oei

Wuji Wang et al. 2023



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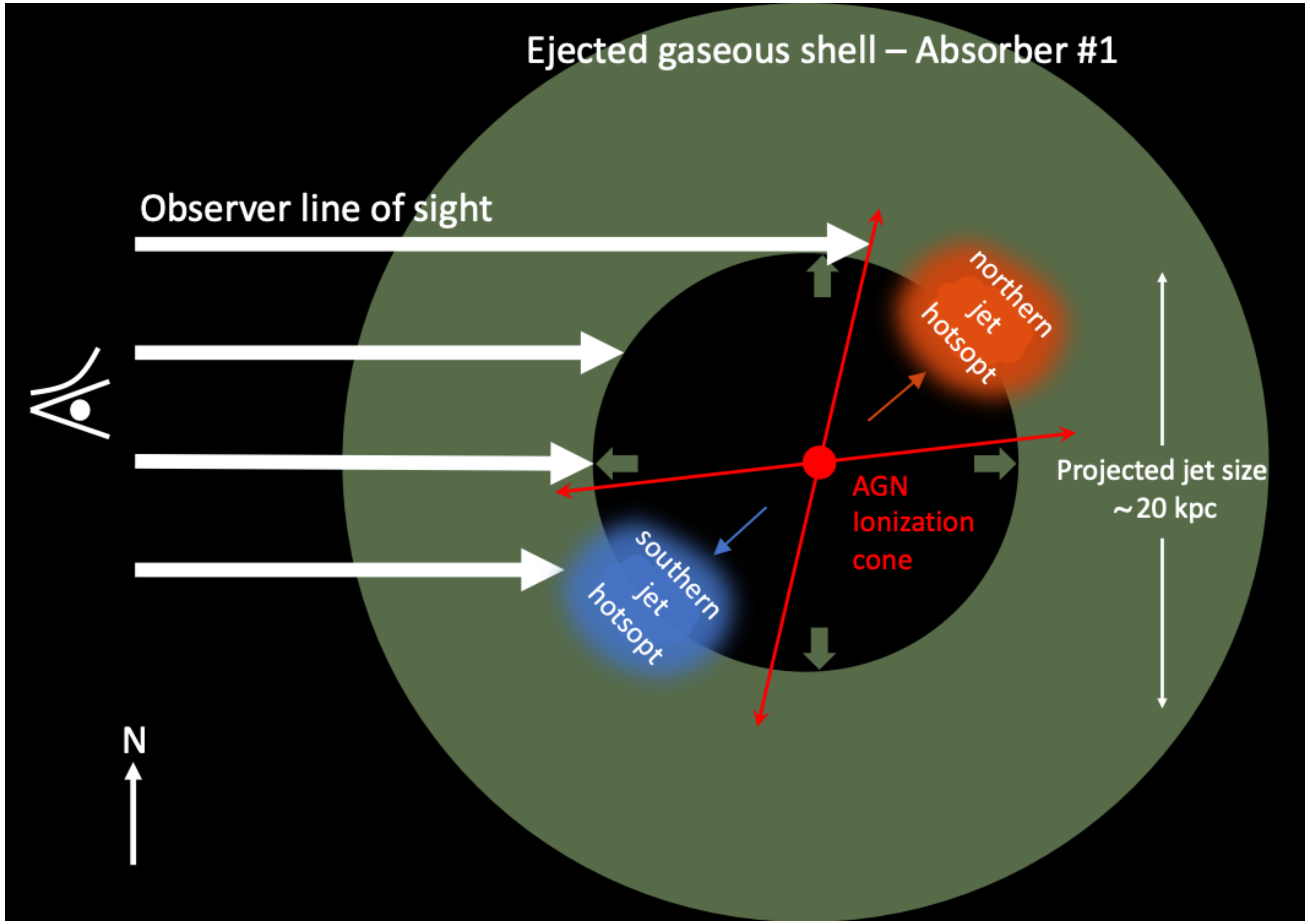
Eales 1992

Angle difference between jet direction and nebula direction

Jet redistributes metals into CGM at z~4.5

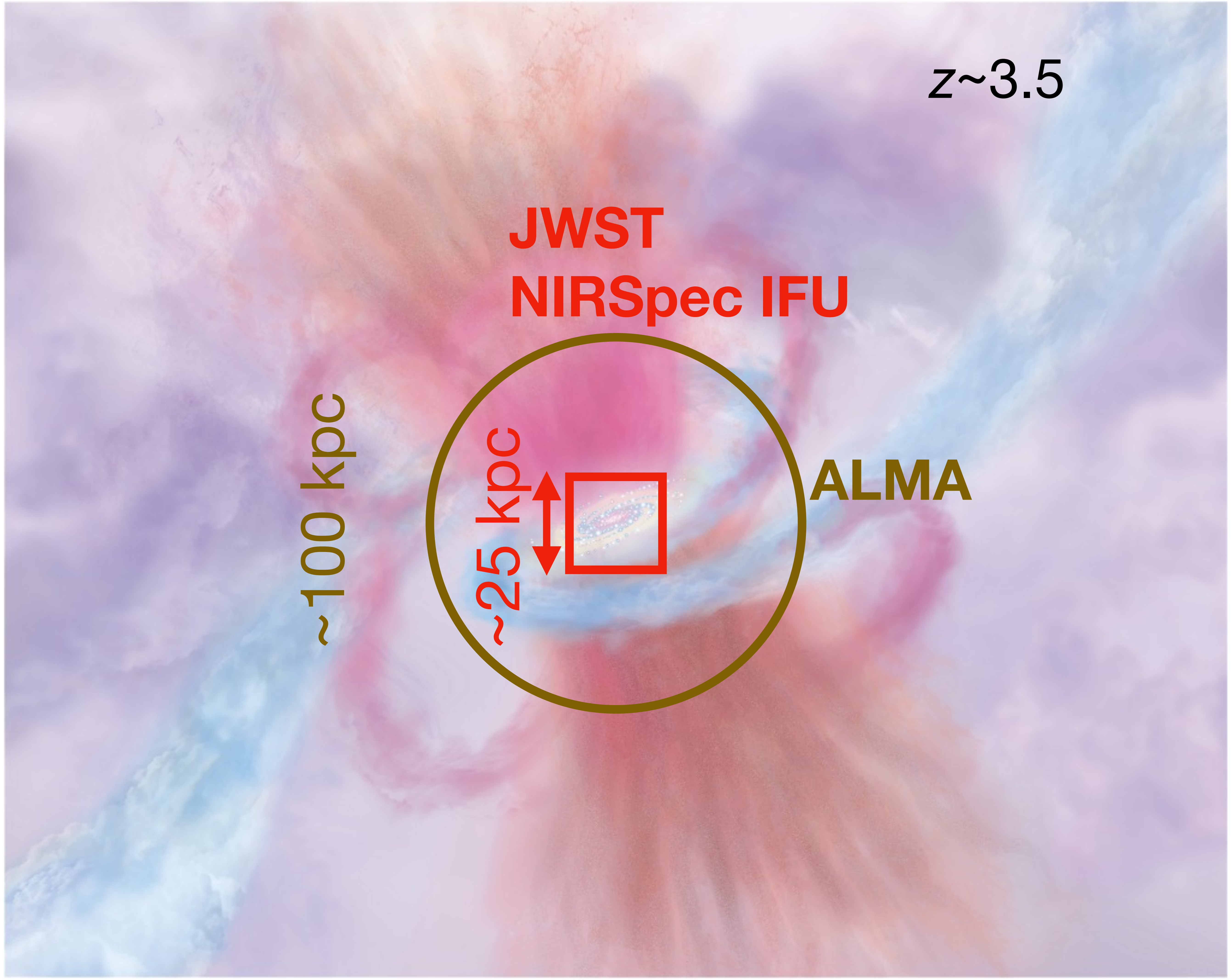
Wuji Wang et al. 2021

- For the z=4.5 HzRG, we spatially analysed the absorbing gas
- Neutral hydrogen + metal absorptions
- Evidence of metal redistribution on ~20kpc



Beyond MUSE: Interstellar medium (ISM)

- Key questions:
  - Gas motions at galactic scales
  - Ionisation, enrichment
  - Stellar populations, star formation
  - Nearby companions



Tumlinson J, et al. 2017.
Annu. Rev. Astron. Astrophys. 55:389–432

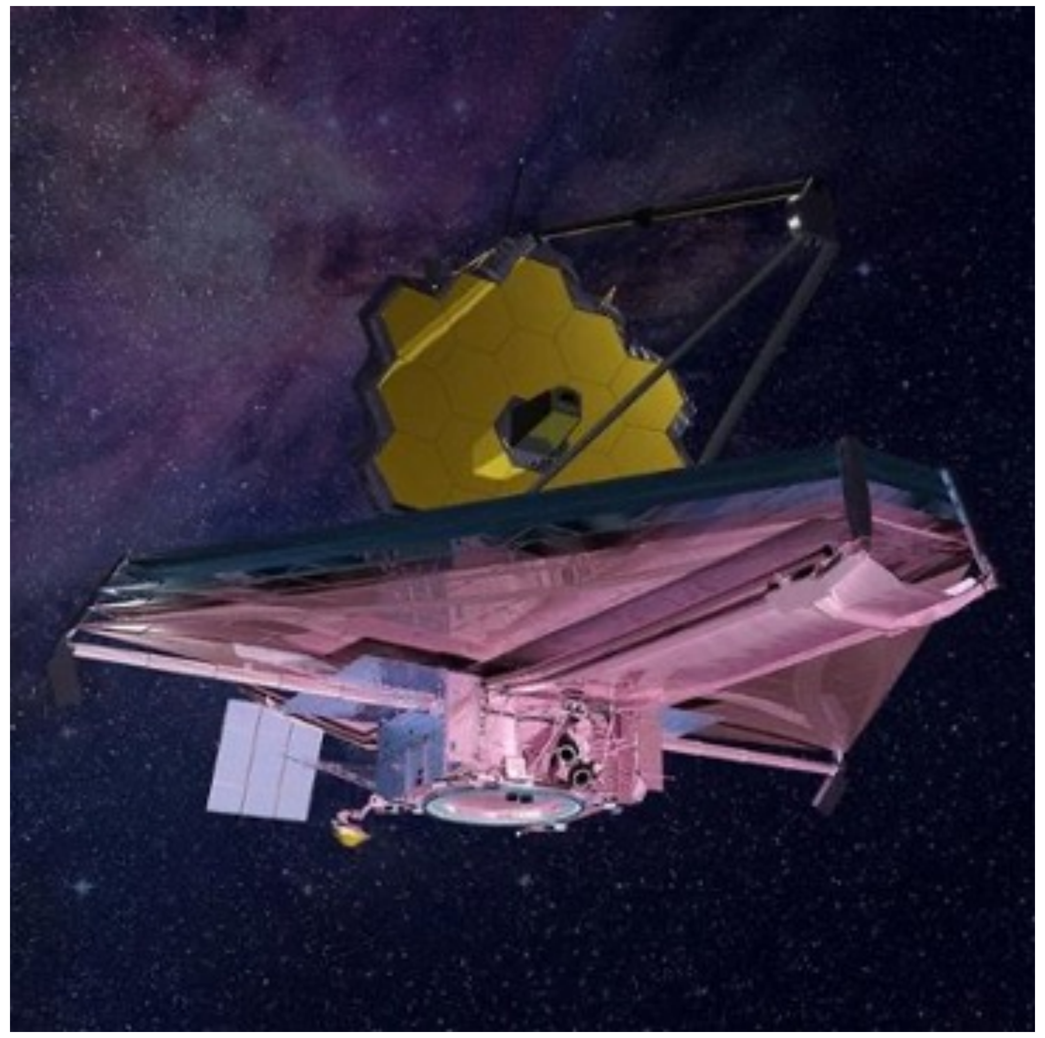
Tumlinson et al. 2017

Multiwavelength HzRGs observations

- JWST: rest-frame optical, e.g., [OIII], Hα,…
- ALAM: rest-frame FIR, e.g., [CII]158μm, dust continuum

At matched sub-kpc resolution

PI: Wuji Wang
Cycle 1
JWST



credit: ALMA collaboration; NASA

MUSE (part I)

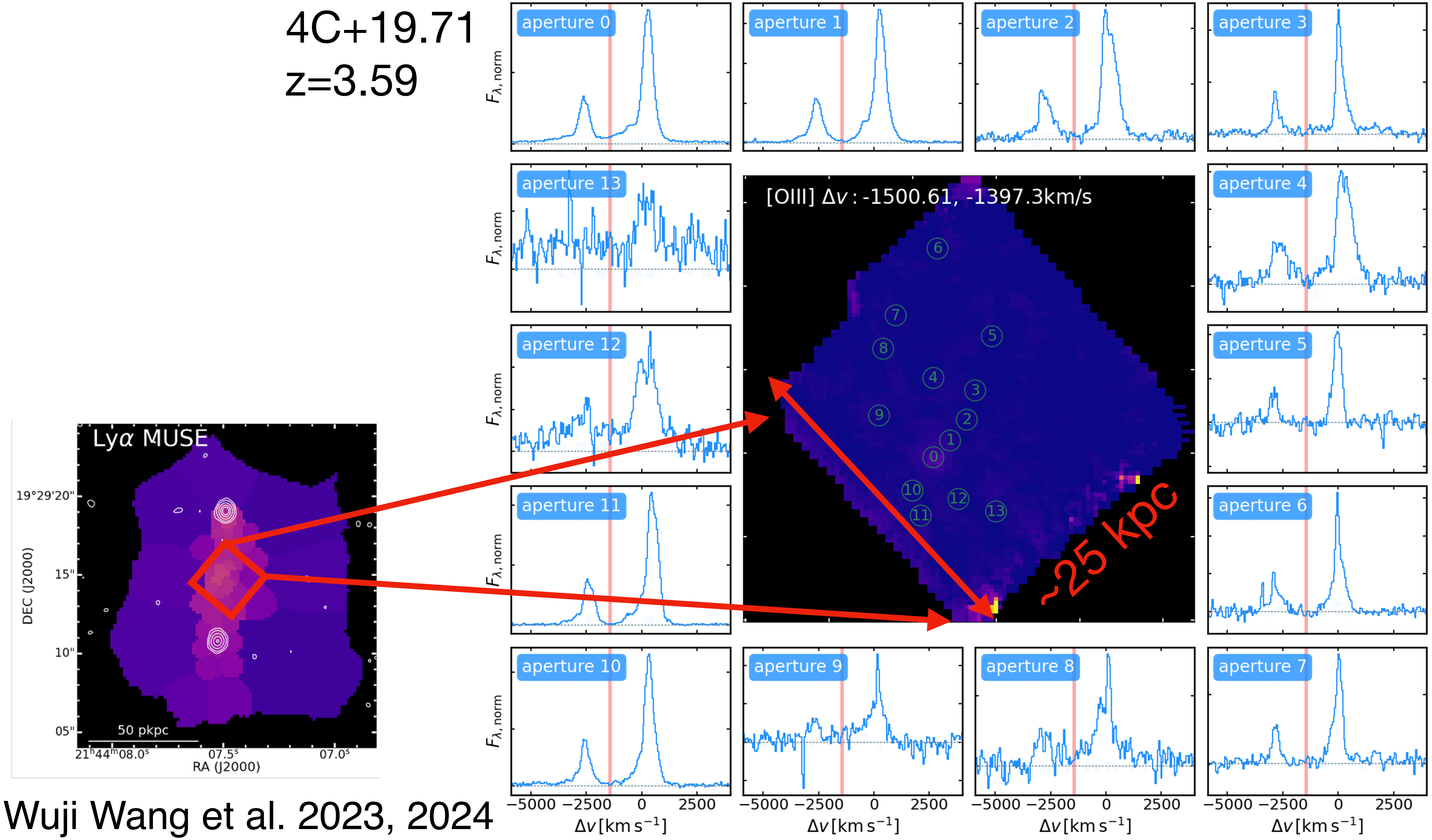
UVES, PI: Wuji Wang
(J. Ritter+in prep.)

PI: Wuji Wang
Cycle 8
ALMA

ISM seen by JWST

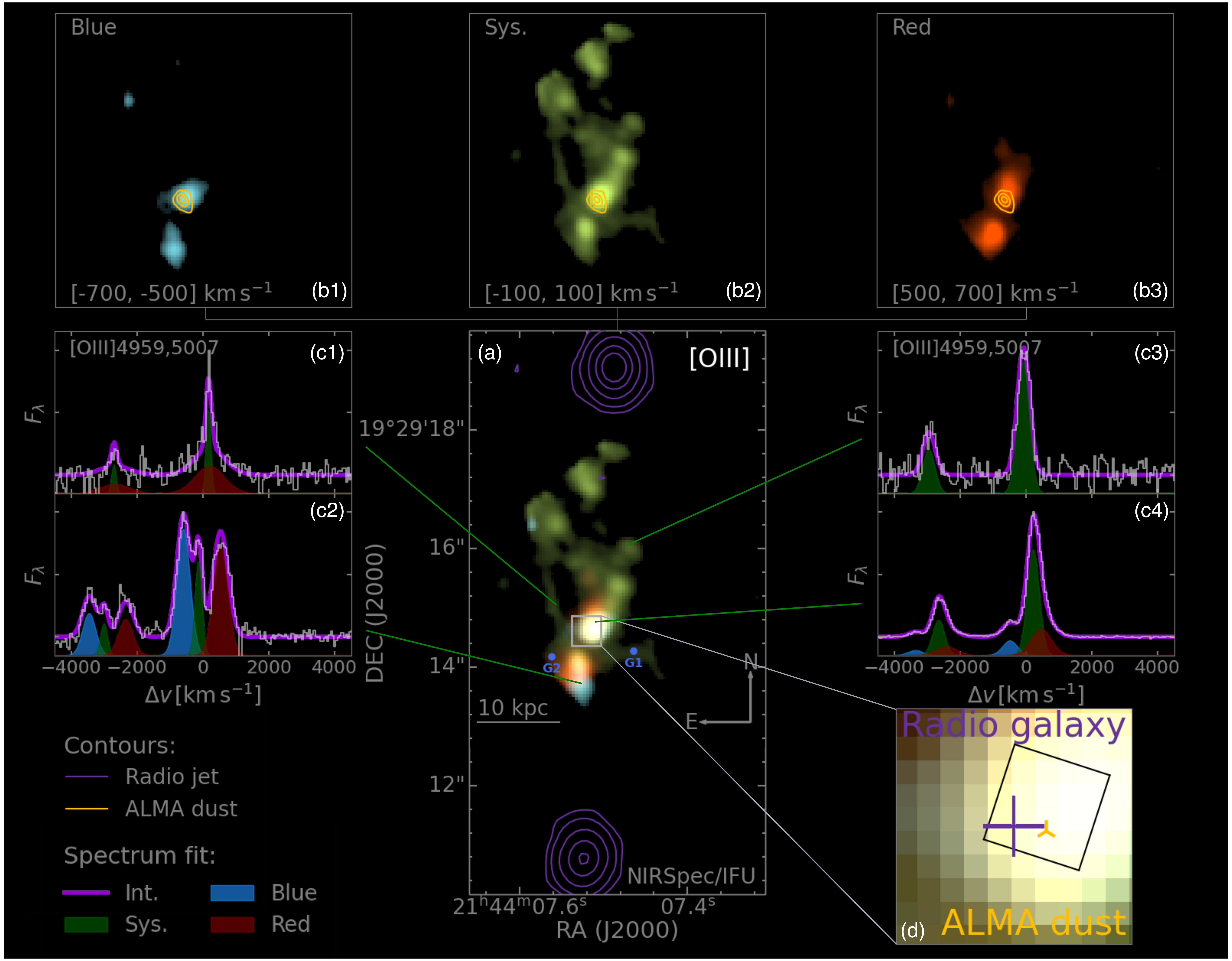
4C+19.71
z=3.59

Wuji Wang et al. in prep.



Wuji Wang et al. 2023, 2024

Weak radiative-drive feedback in one HzRG

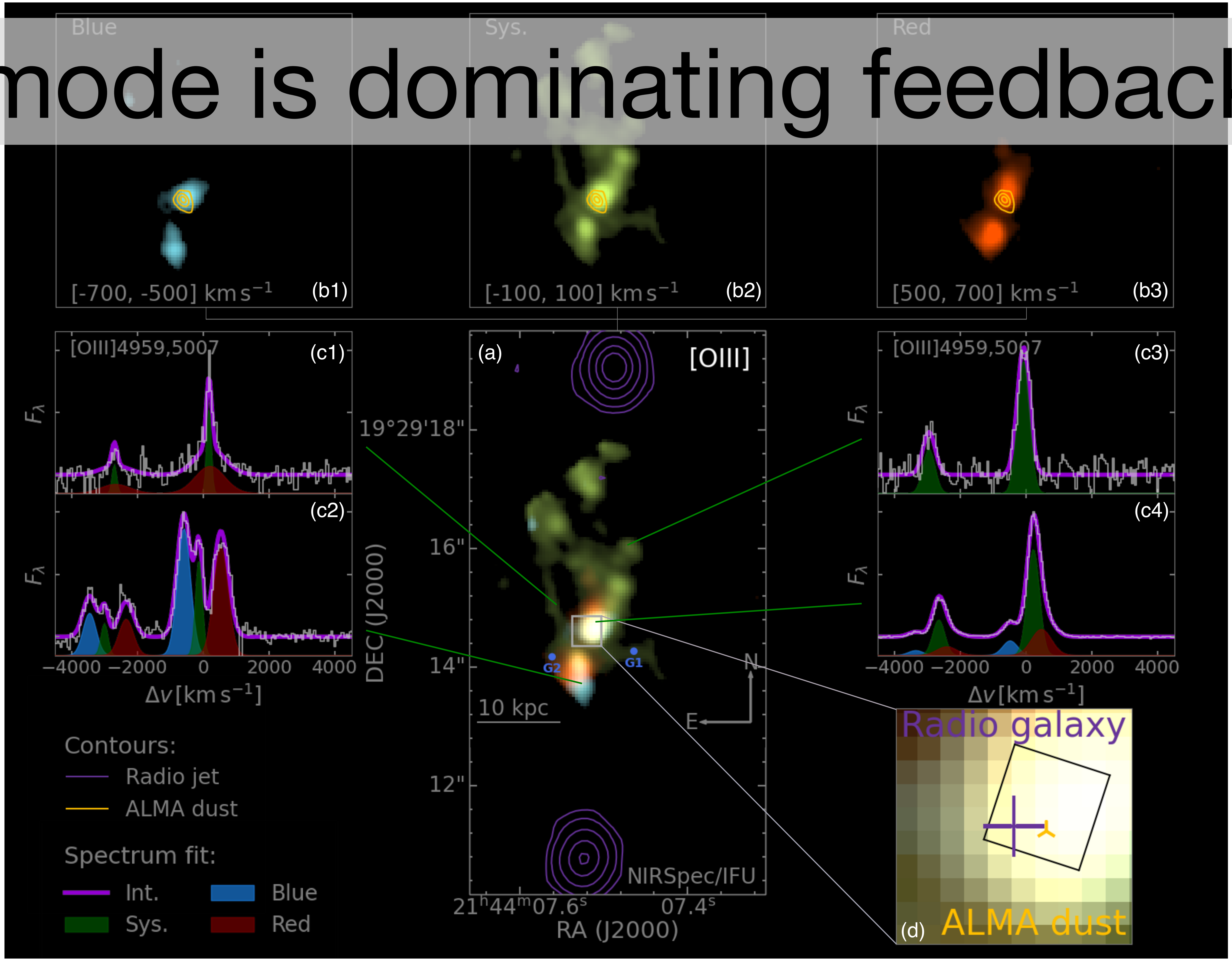


- [OIII]5007 kinematics
- No strong outflow ~10 kpc

Wuji Wang et al., 2024

Weak radiative-drive feedback in one HzRG

Jet-mode is dominating feedback



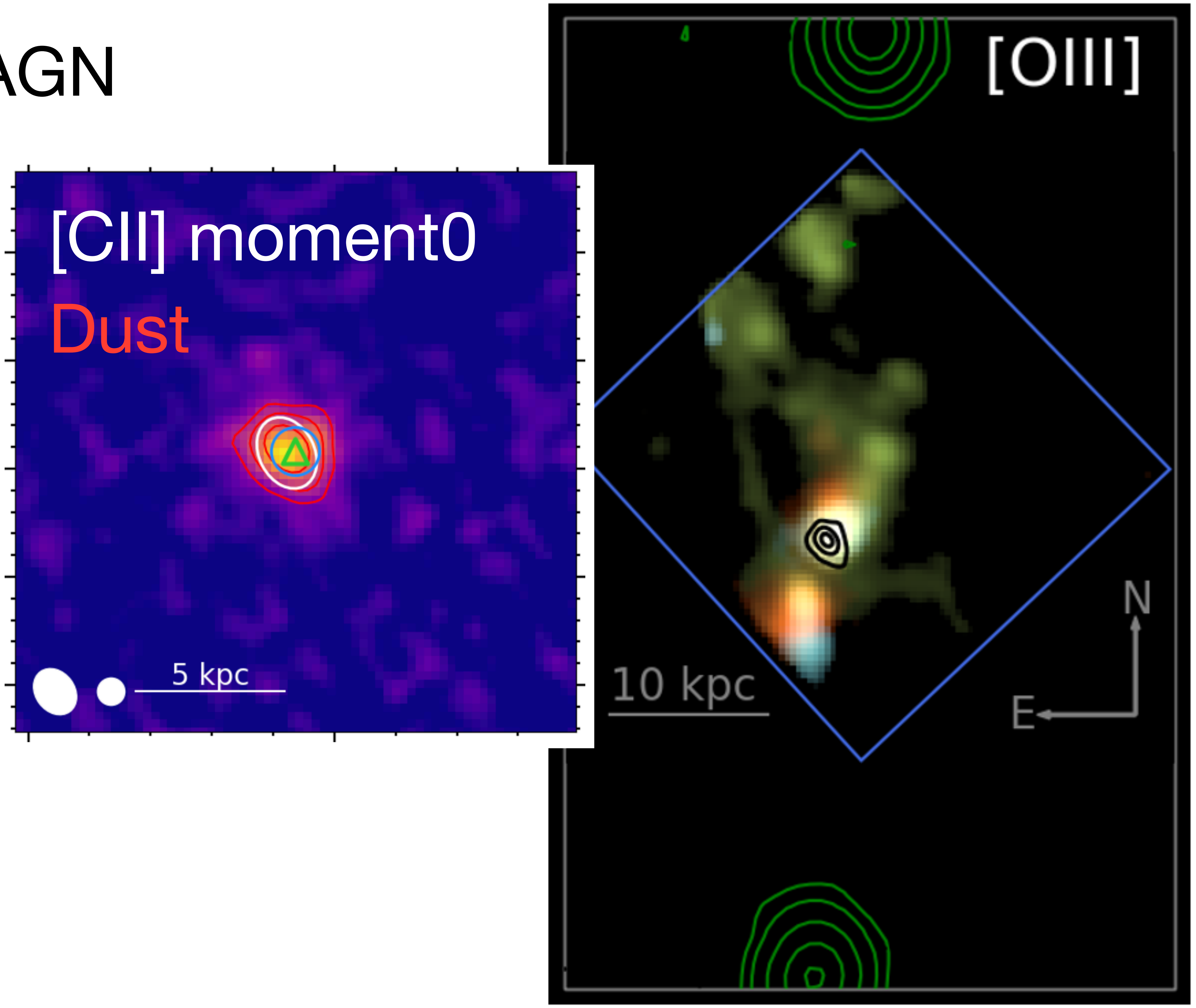
- [OIII]5007 kinematics
- No strong outflow >10 kpc

Wuji Wang et al., 2024

ALMA kinematic: rotation disk

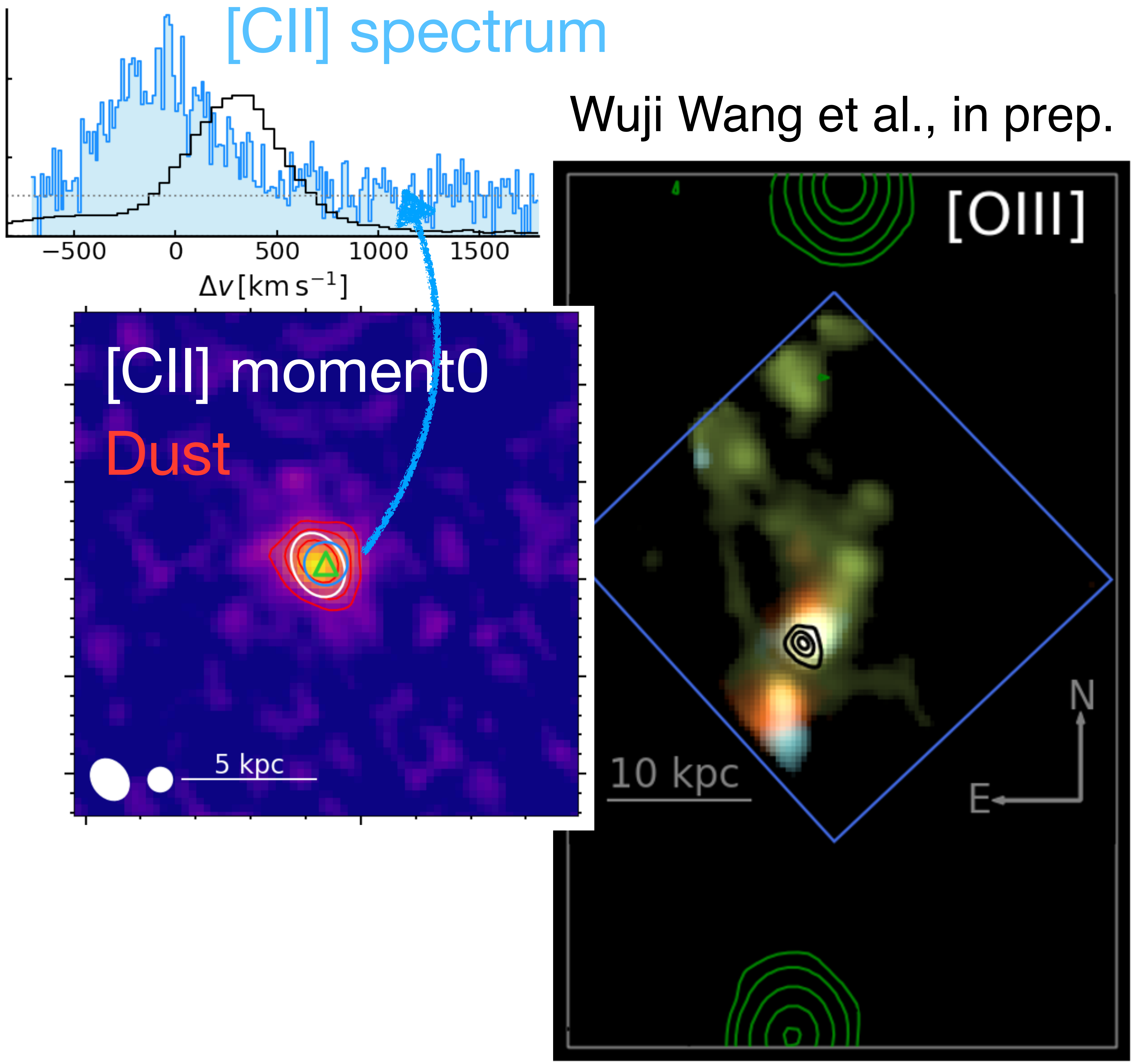
- [CII]158μm, tracer of ordered gas kinematics, i.e., less disturbed by AGN

Wuji Wang et al., in prep.



Rotation disk seen in cold gas

- [CII] moment1 velocity shift map
- Model with ^{3D}Barolo
- Rotation disk?



Wuji Wang et al., in prep.

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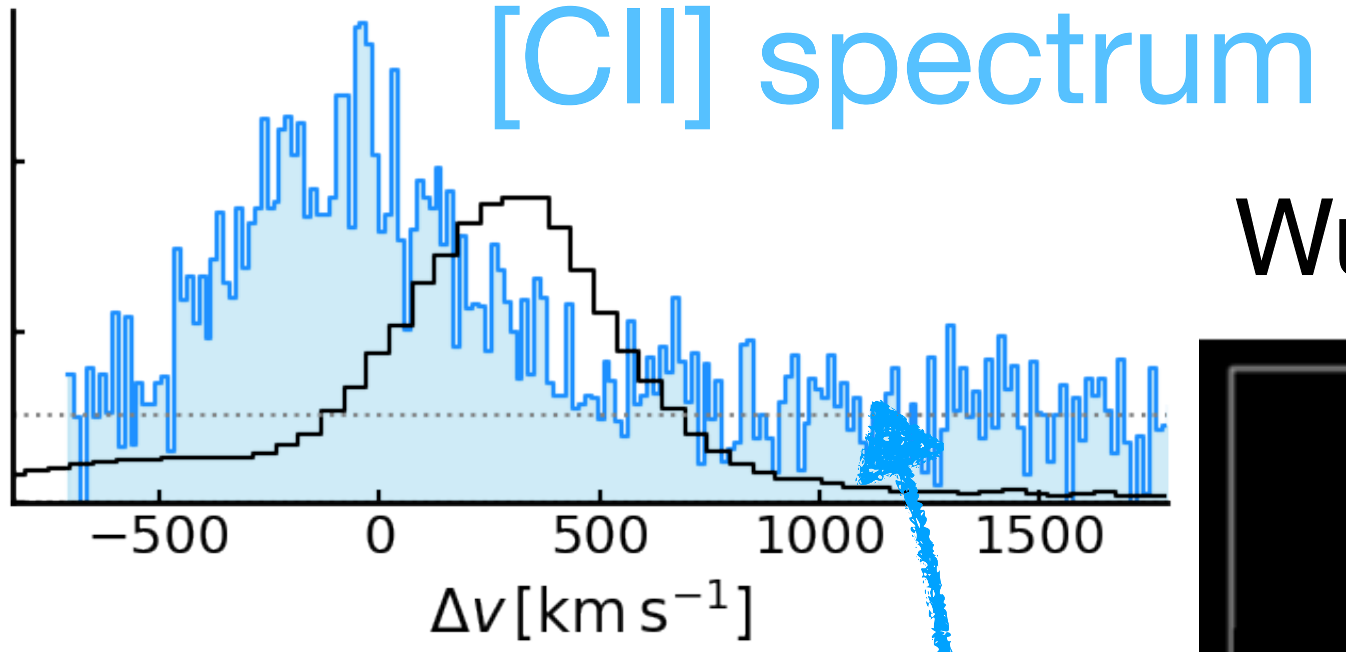
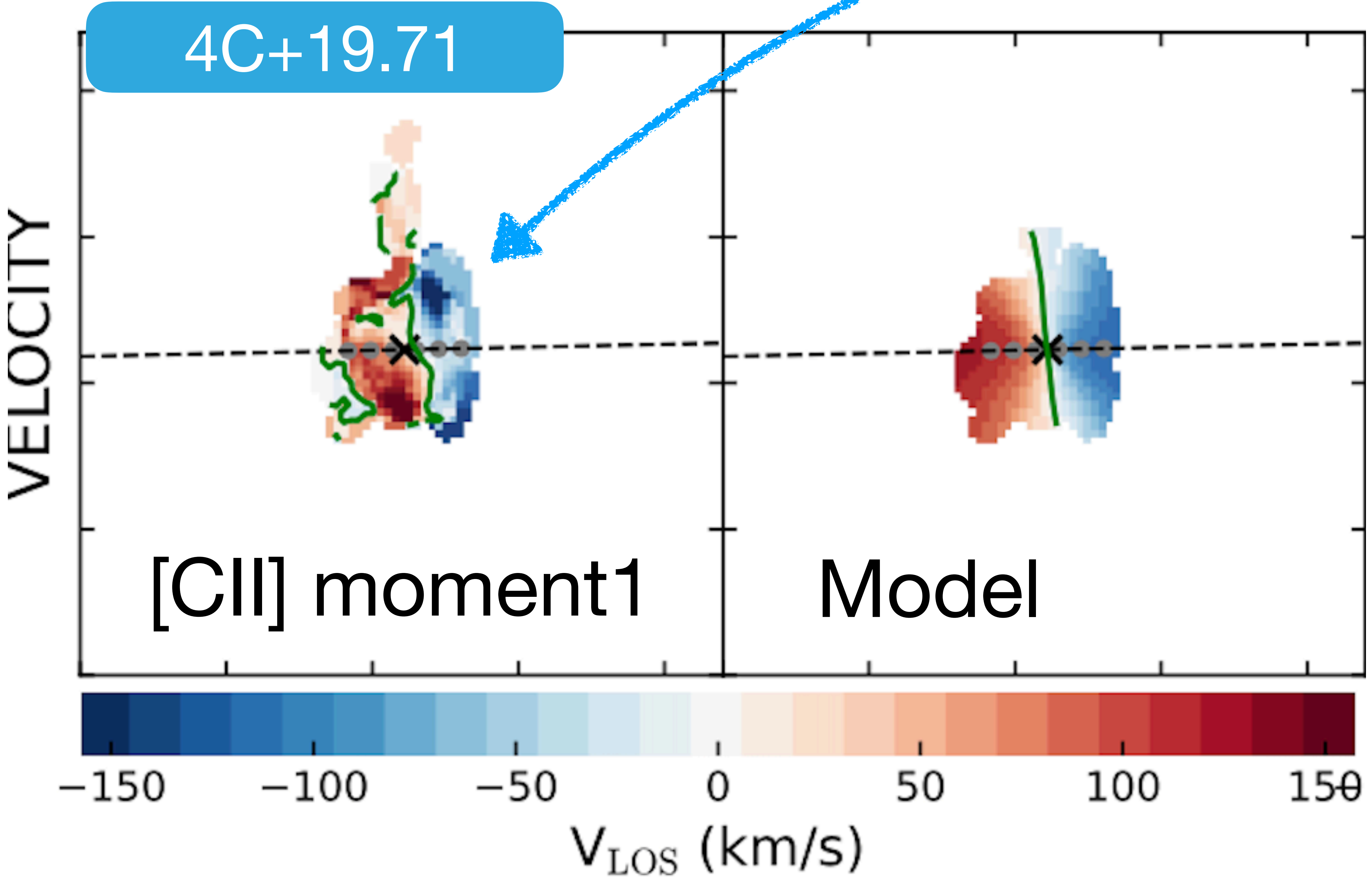
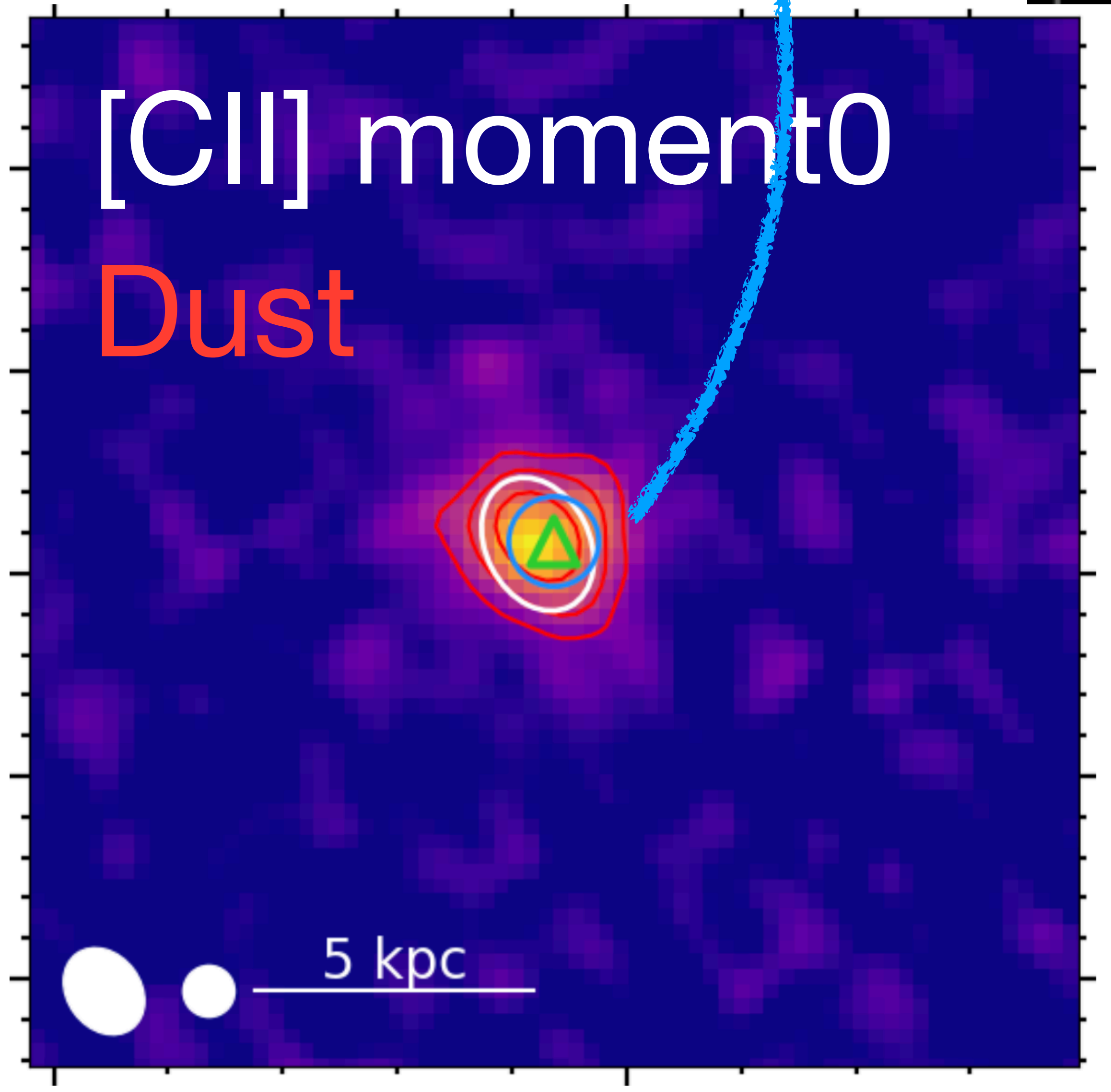
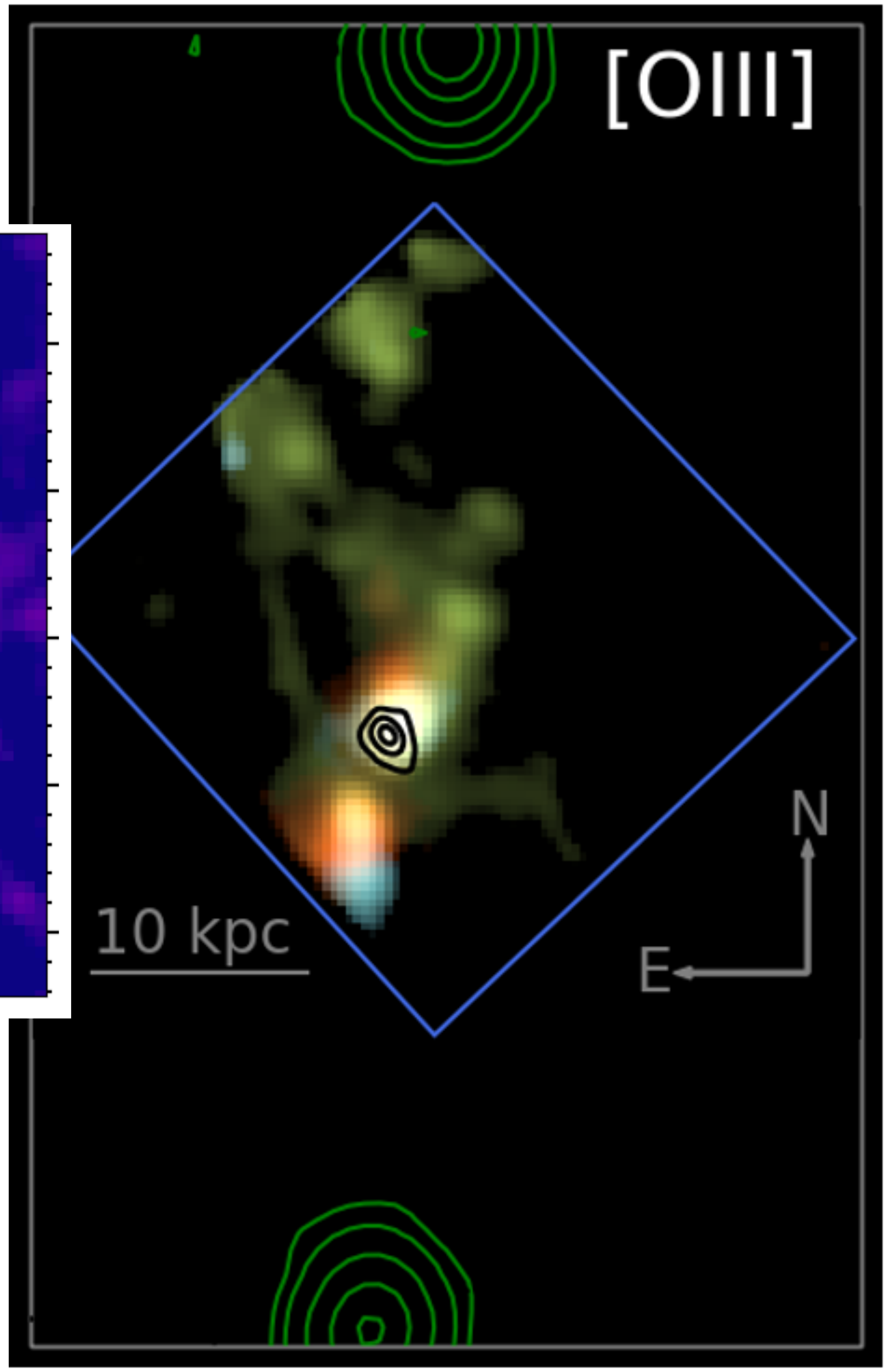


Wuji Wang et al., in prep.





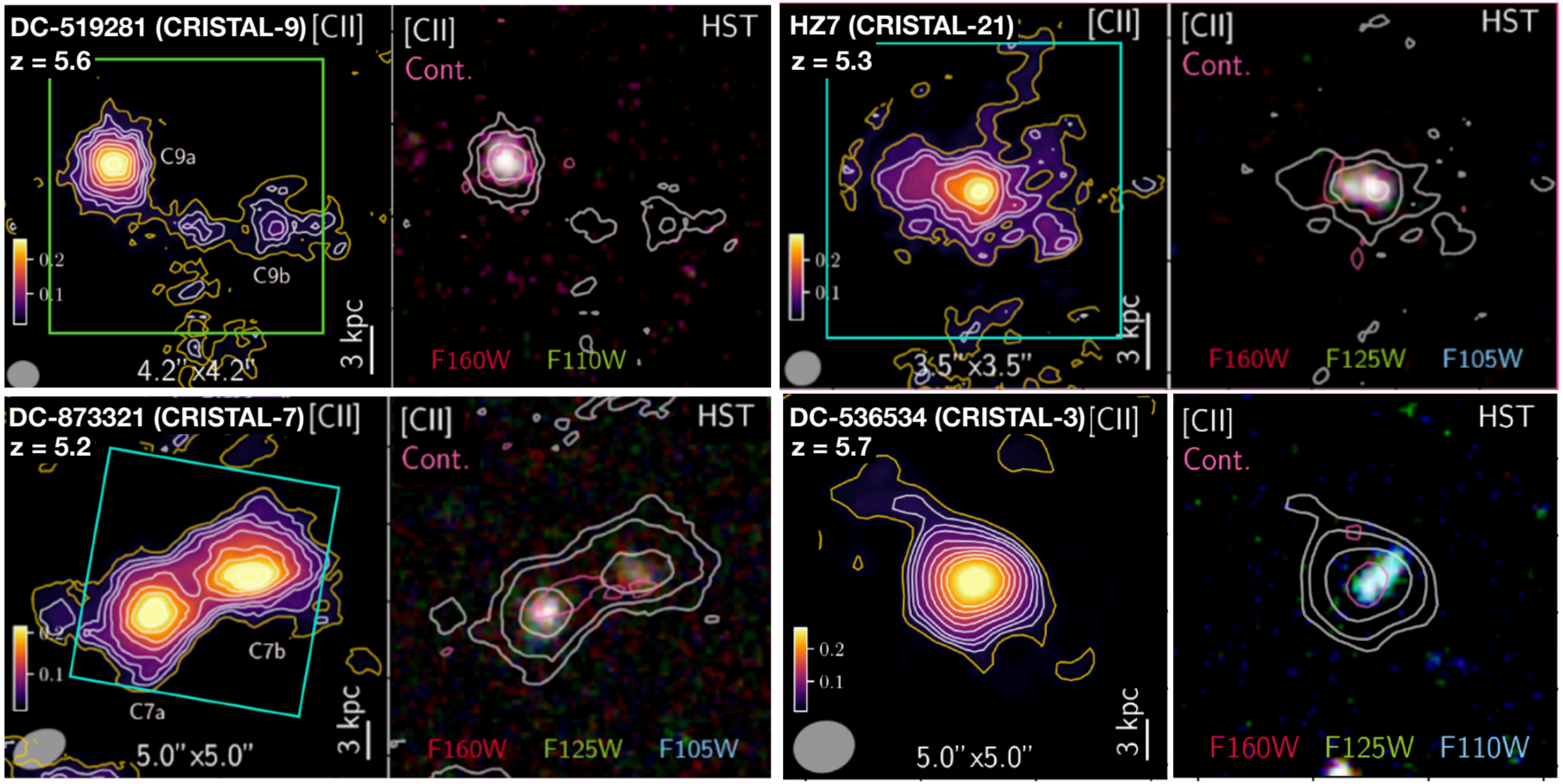


Done by Lingrui Lin, PhD student at Nanjing University/ESO

And Beyond: KCWI+ALMA+JWST IFU

- ALPINE+CRISTAL: 4<z<6 star forming MS galaxies
- Lyα+[CII]+optical (Hα) in 3D

Faisst et al.; Herrera-Camus et al.



Summary

- MUSE Lyα nebulae:
  - Emission nebulae reveals CGM gas distribution, complex kinematics (Wang+23)
  - Evidence of companions (Wang+23)
  - Together with metal lines shows evidence of metal redistribution at z=4.5 by powerful radio AGN (Wang+21)
- JWST + ALMA ISM:
  - Weak radiative-driven feedback (Wang+24)
  - Rotation disk (Wang+in prep.)
  - Ubiquitous close-by companion: [OIII] + [CII] kinematics (Wang+in prep.)
- Future:
  - Shock-driven outflow, metallicity, SED (star+dust), …

Thank you!