Roberto Decarli
INAF-OAS Bologna

The assembly of quasars and their host galaxies in the early Universe

Quasars at z>6: Why should we care?

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z=6 → age of the universe: 1 Gyr

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Not much time to …

put black holes together

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form metals and dust

form structures

ionize the Universe

Quasars at z>6: Why should we care?

$z=6 \rightarrow$ age of the universe: 1 Gyr

Not much time

Extremely luminous and star-forming

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ideal background sources for abs studies

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$z=6 \rightarrow$ age of the universe: 1 Gyr

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Extremely luminous and star-forming

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ideal background sources for abs studies

conditions absent in the local universe

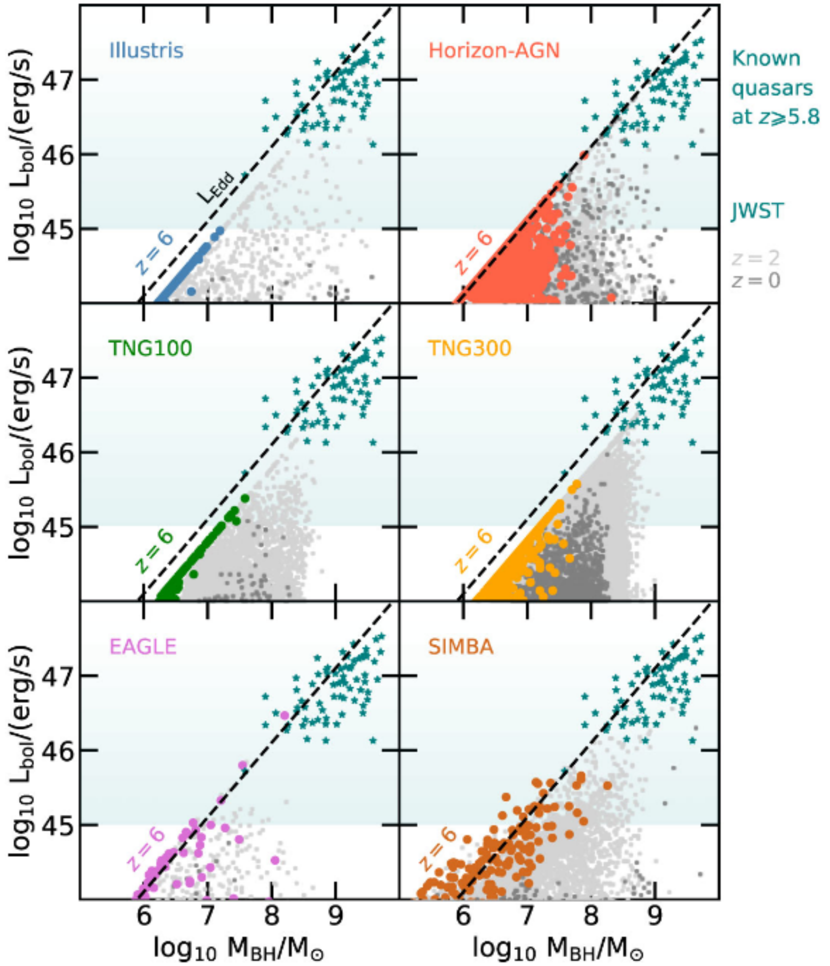
How do quasars and their host galaxies form?

How do quasars and their host galaxies form?

Numerical predictions limited by:

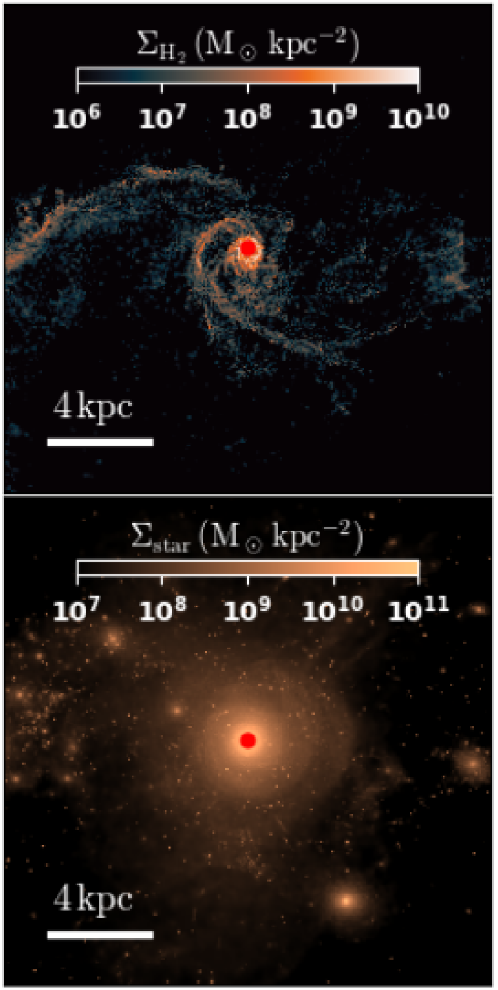
- volume
- prescriptions on BH seeds
- prescriptions on BH feeding
- prescriptions on feedback

Habouzit et al. (2022)



How do quasars and their host galaxies form?

z=7 quasar host galaxy



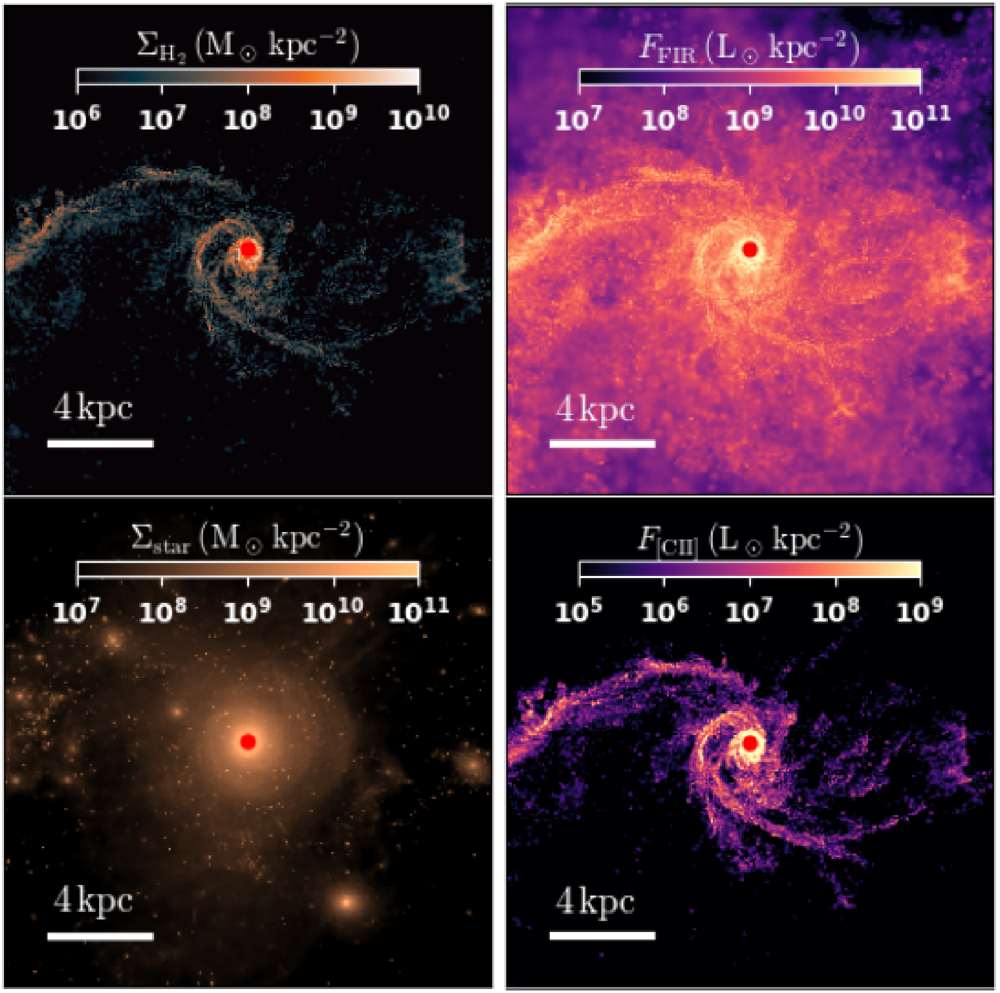
Zoomed-in sims predict:

- morphology
- size
- ISM conditions (n, T, U, …)
- abundances
- CGM
- environment

Lupi et al. (2021)

How do quasars and their host galaxies form?

z=7 quasar host galaxy



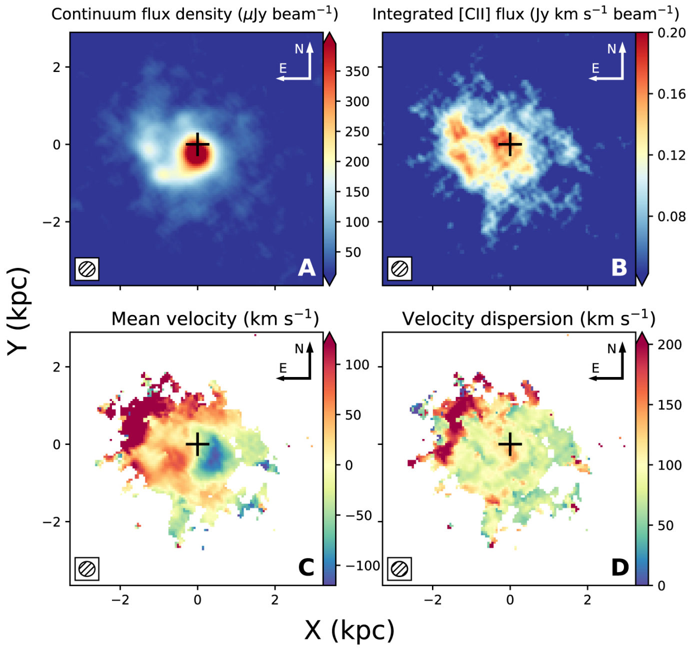
Zoomed-in sims predict:

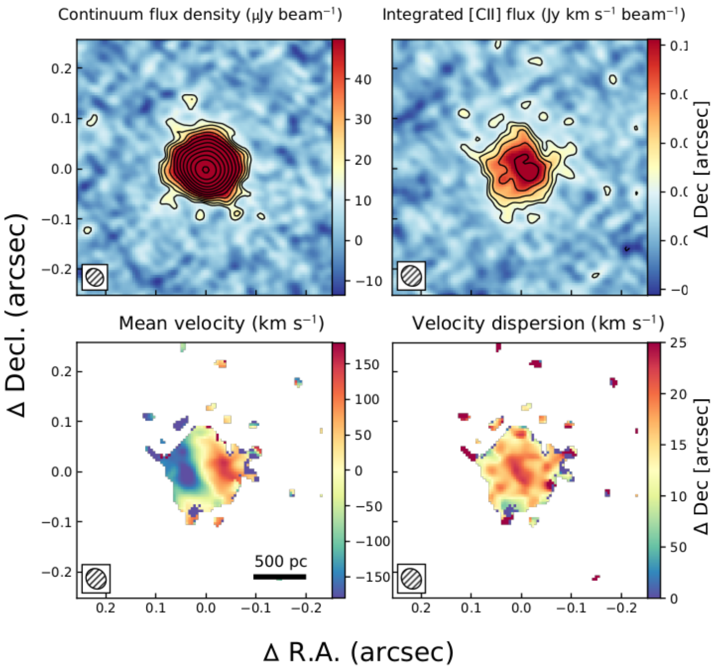
- morphology
- size
- ISM conditions (n, T, U, …)
- abundances
- CGM
- environment

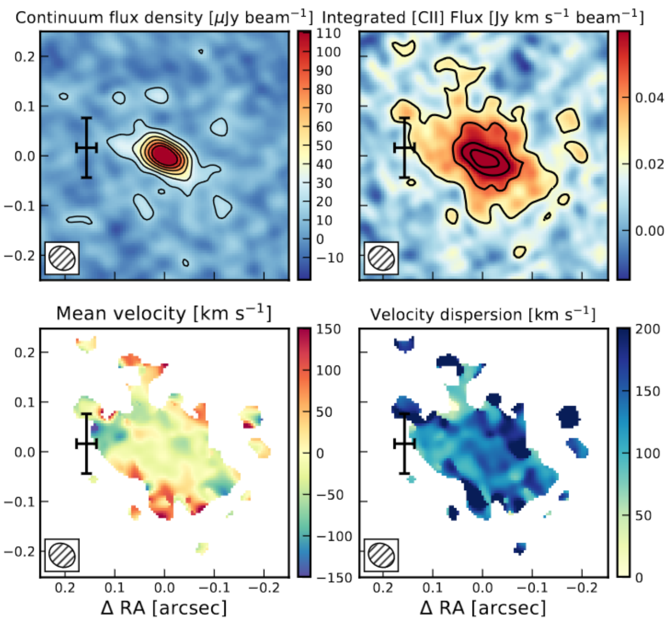
→ Observable quantities!

Lupi et al. (2021)

Imaging dust and gas at 100s pc resolution







J0305-3150 (z=6.6)

Resolution:

76 mas ~ 400 pc

Venemans et al. (2019)

J2348-3054 (z=6.9)

Resolution:

36 mas ~ 200 pc

Walter et al. (2022)

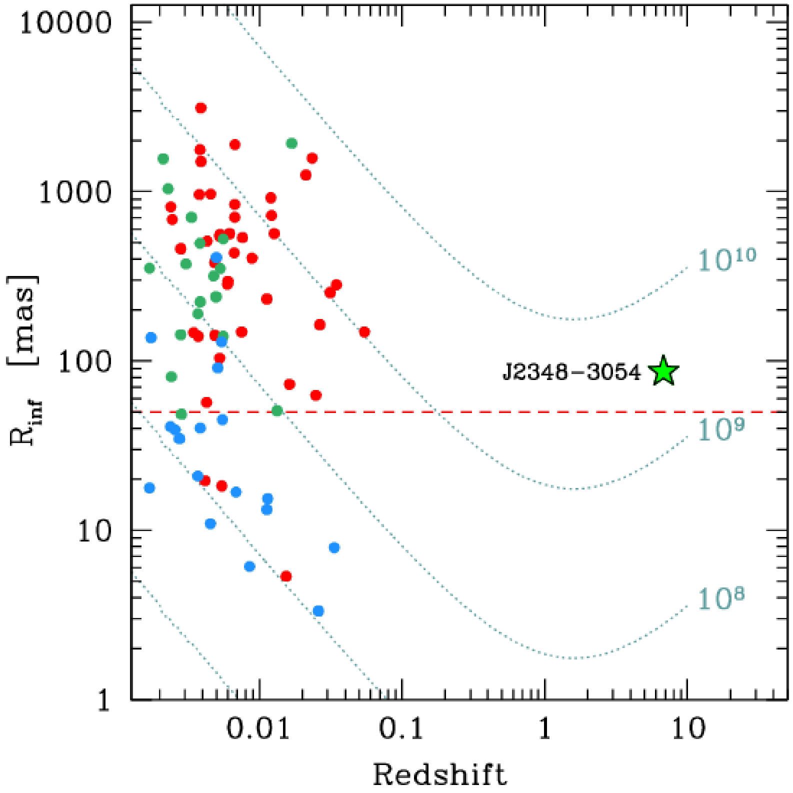
J0109-3047 (z=6.8)

Resolution:

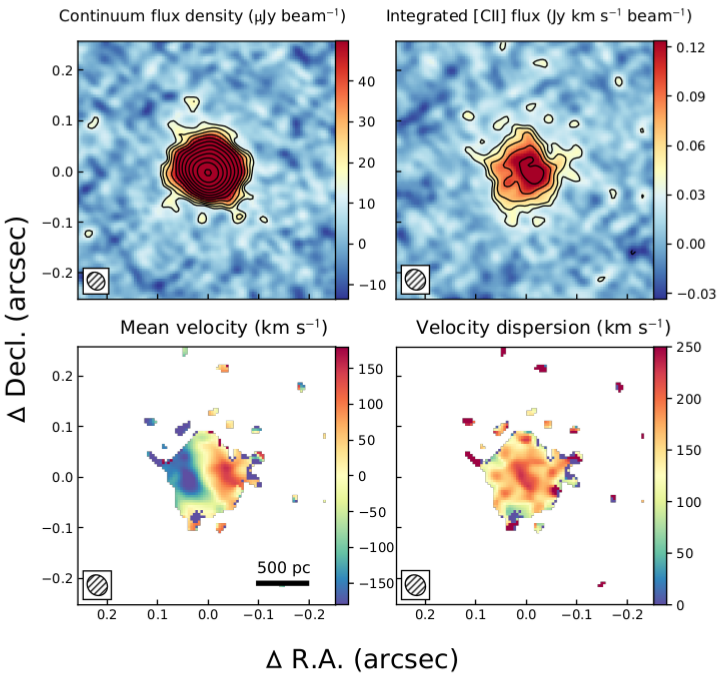
45 mas ~ 300 pc

Meyer et al. (2023)

Imaging dust and gas at 100s pc resolution



Could resolve sphere of influence!



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Walter et al. (2022)

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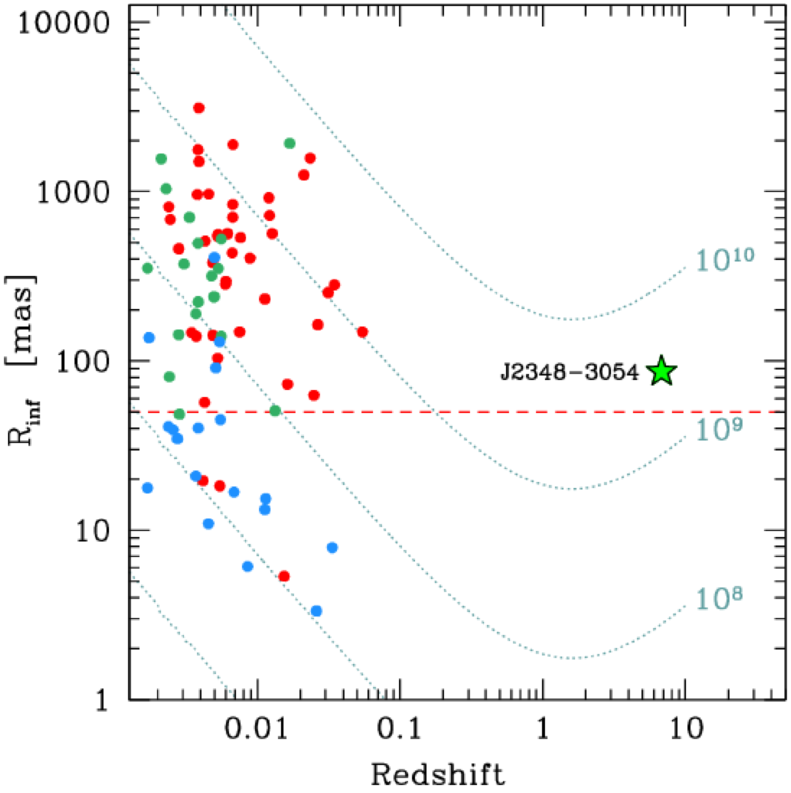
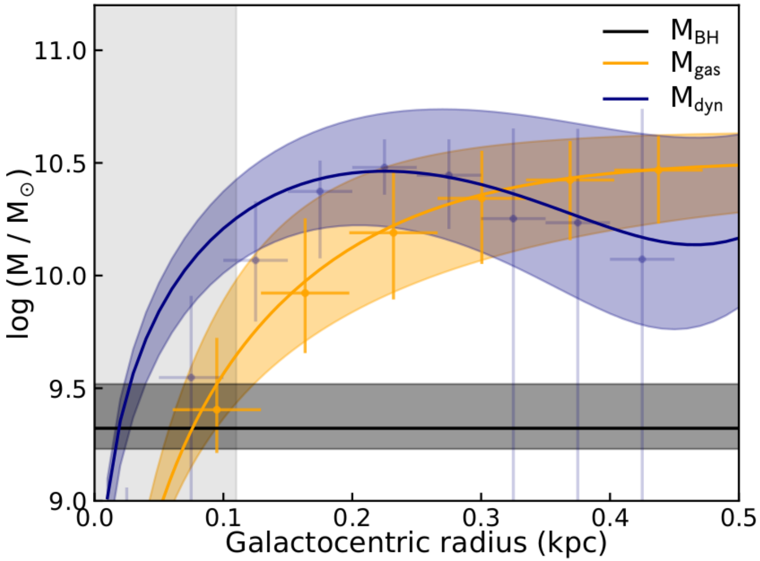


Could resolve sphere of influence!

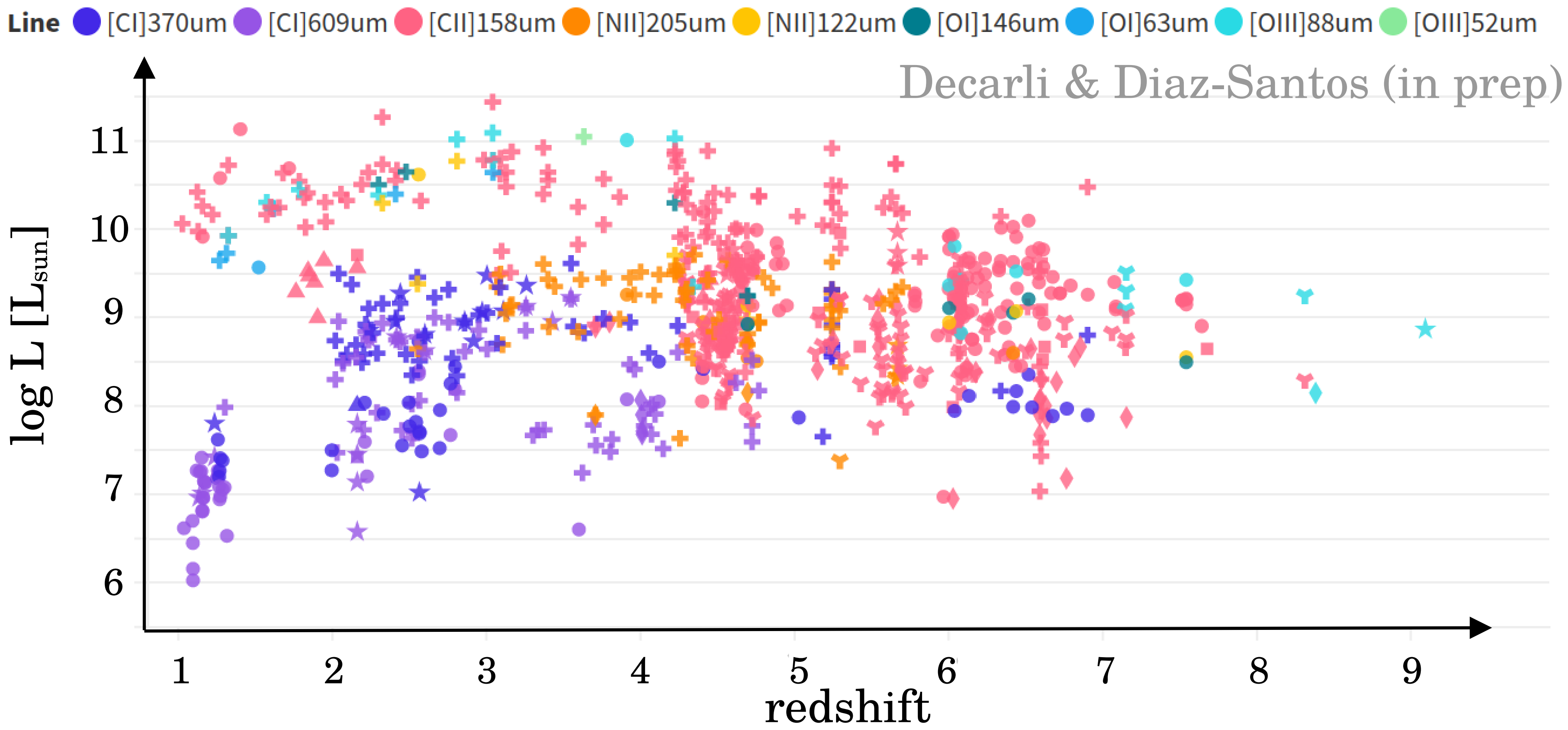
No BH signature on gas dynamics

The central beam is gas dominated!

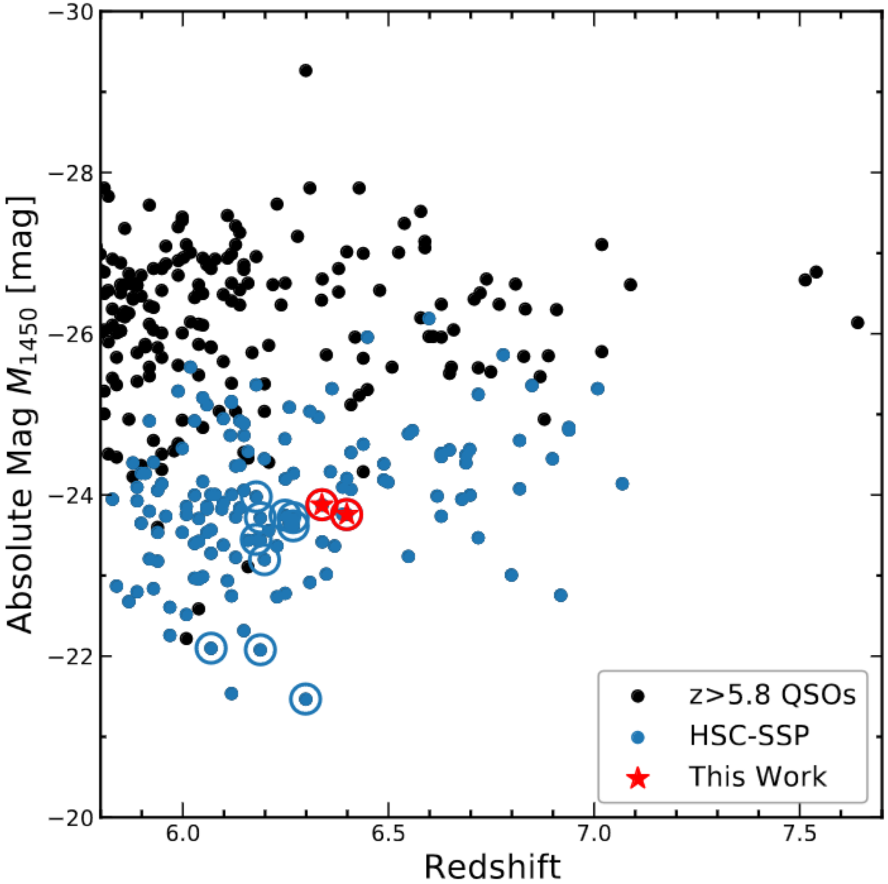


Walter et al. (2022)

Multi-λ campaigns

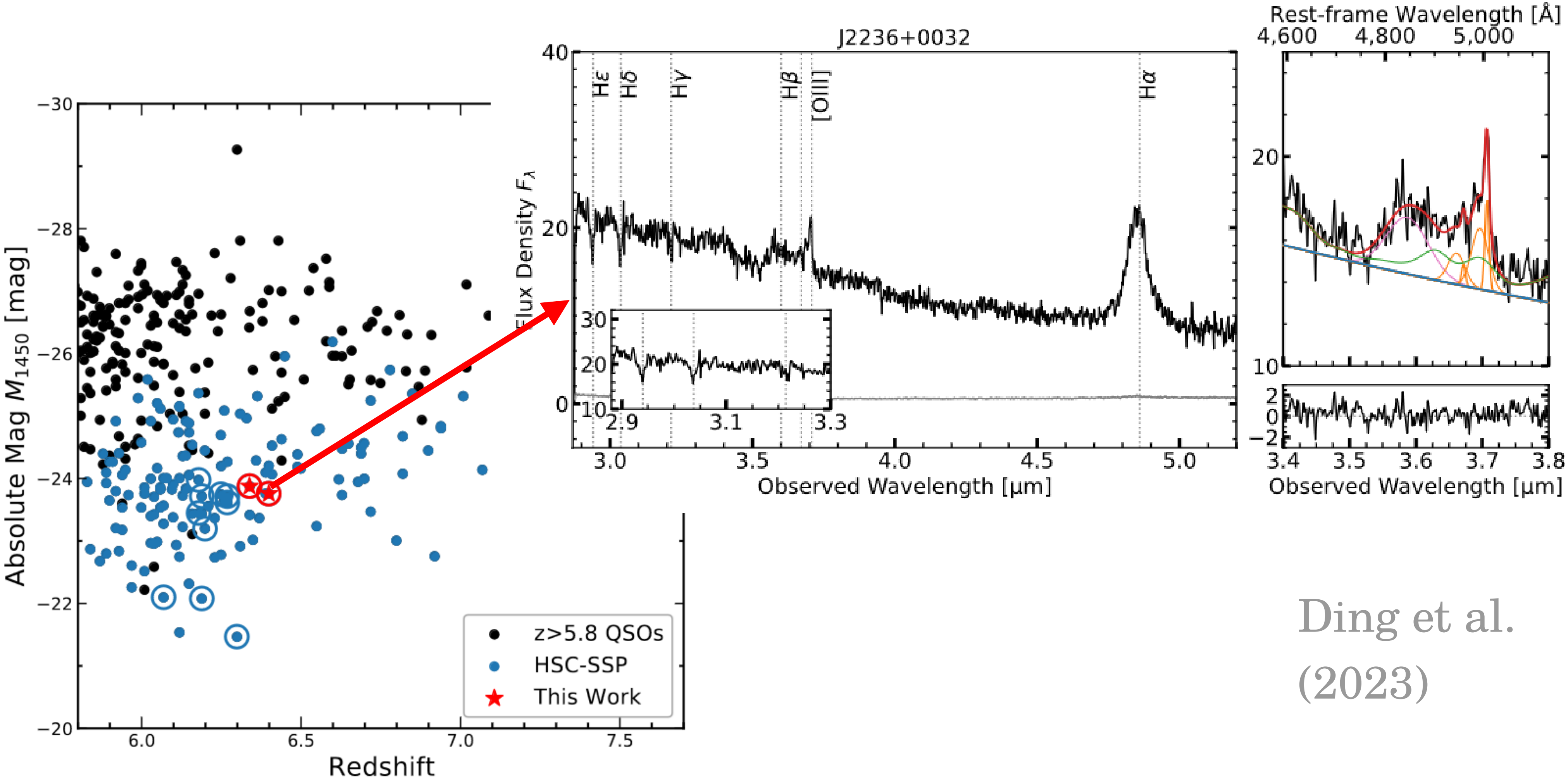


The advent of JWST



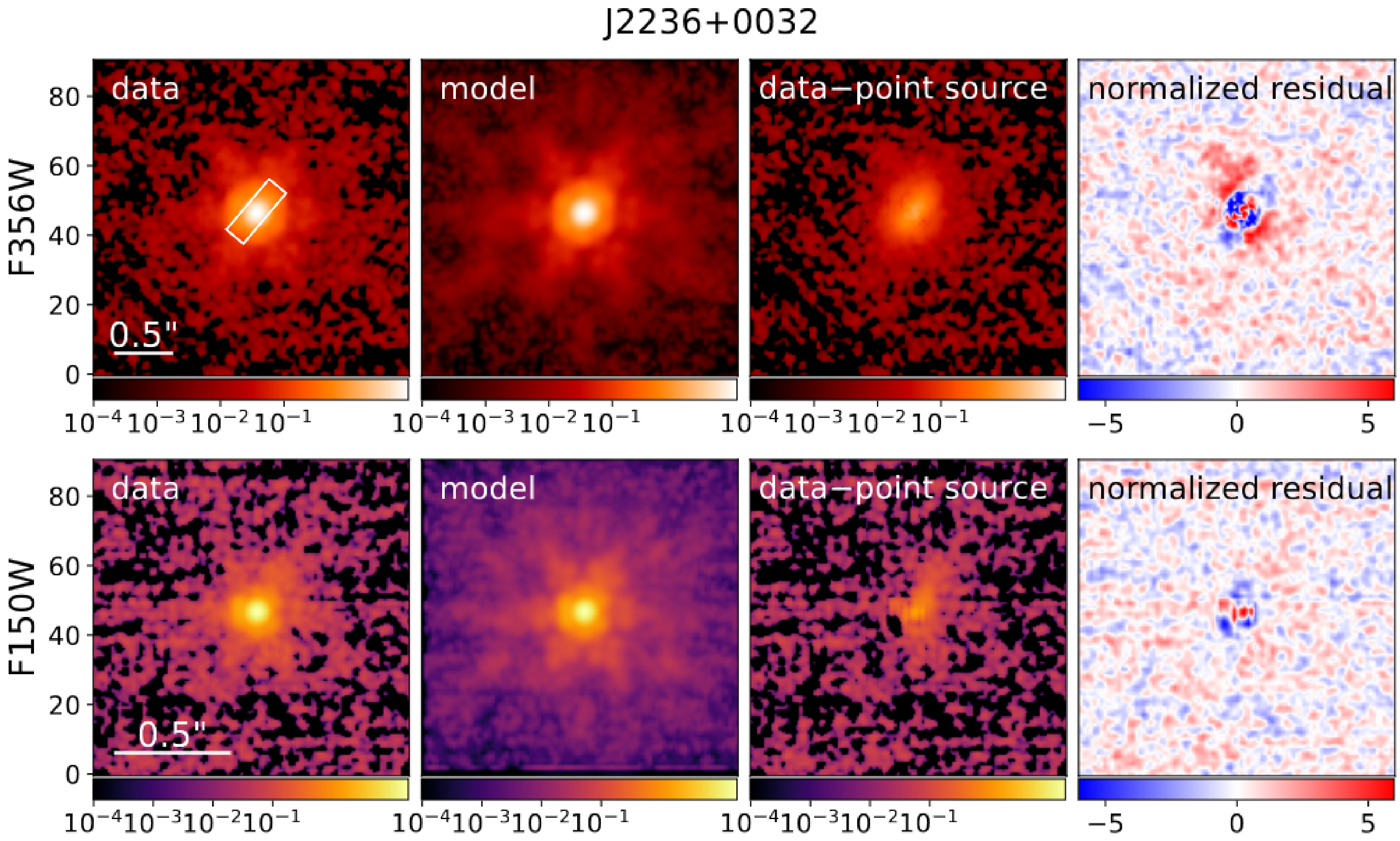
Ding et al. (2023)

The advent of JWST



Ding et al. (2023)

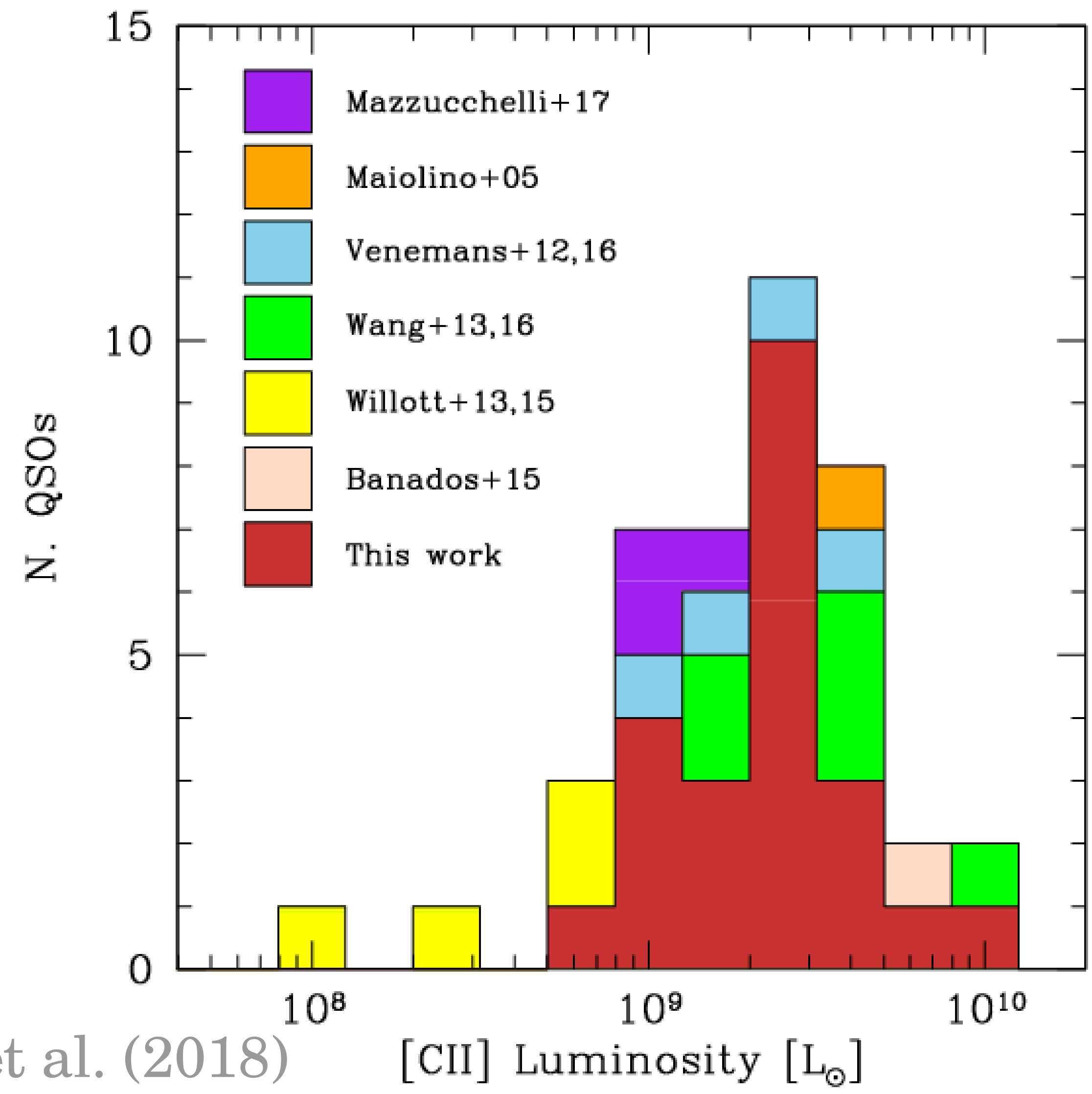
The advent of JWST



Ding et al. (2023)

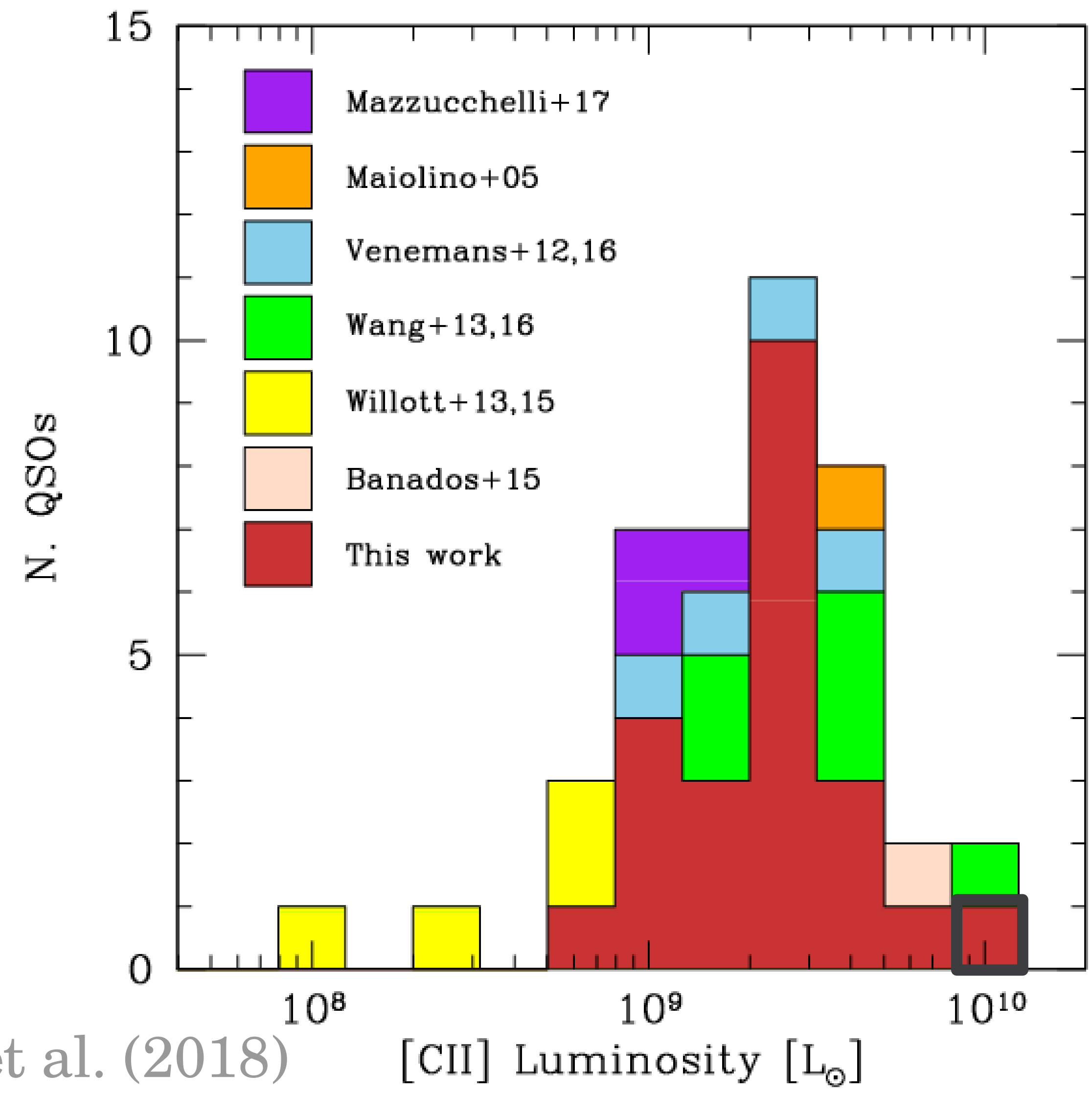
Project I:
Multi-line investigation of the ISM of a quasar host at z~6.5

[CII] luminosity distribution



Decarli et al. (2018)

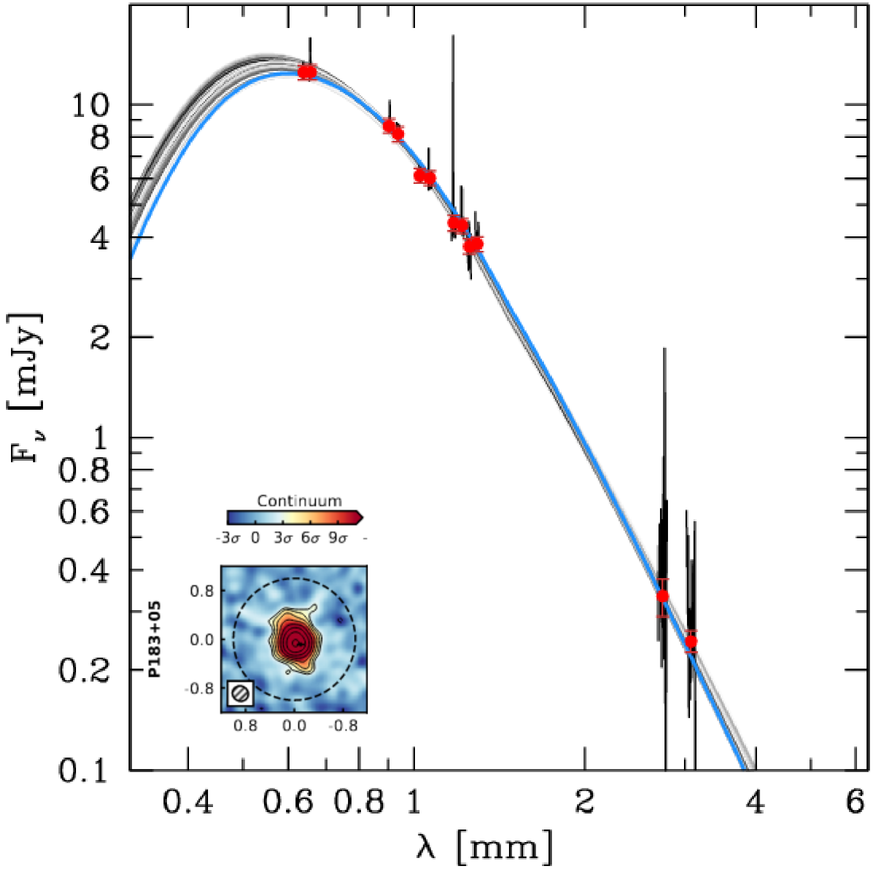
The luminous QSO PJ183+05 @ z=6.44



Decarli et al. (2018)

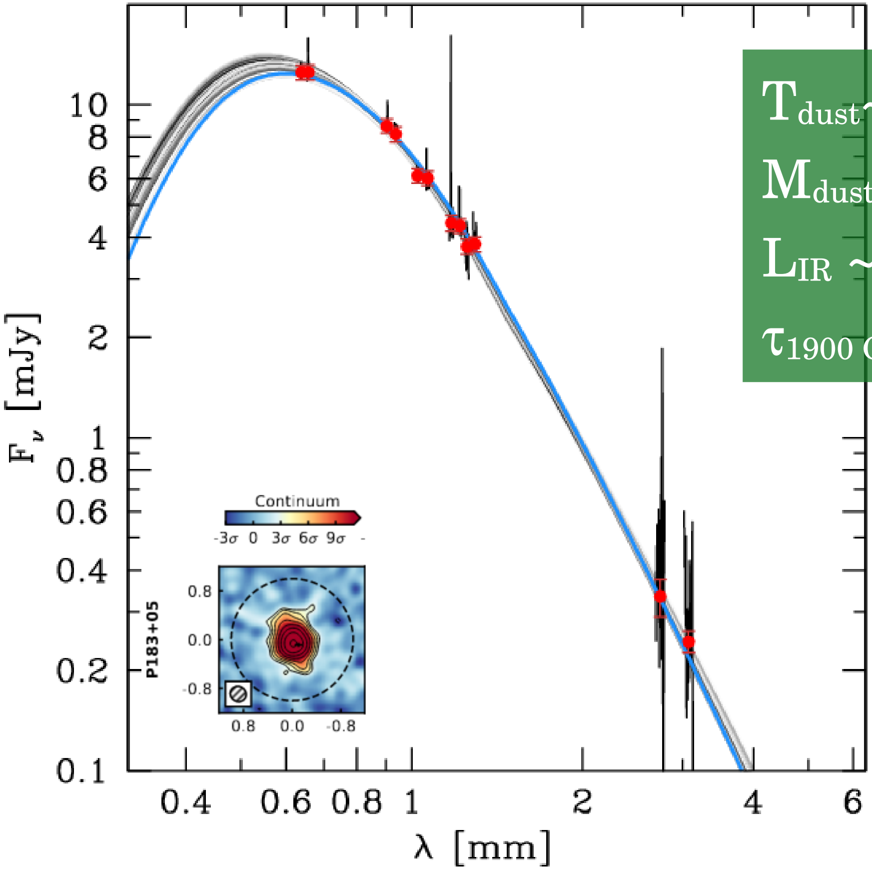
Multi-λ campaign: Dust continuum

Decarli et al. (2023)



Multi-λ campaign: Dust continuum

Decarli et al. (2023)

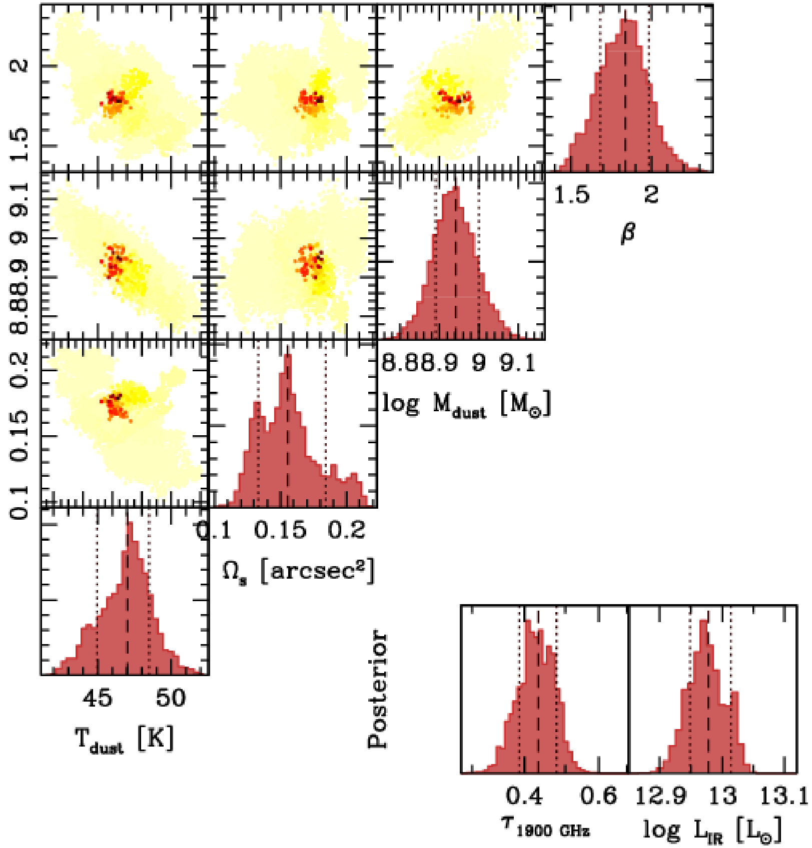


T_{dust}~47 K

M_{dust} ~ 10^9 M_o

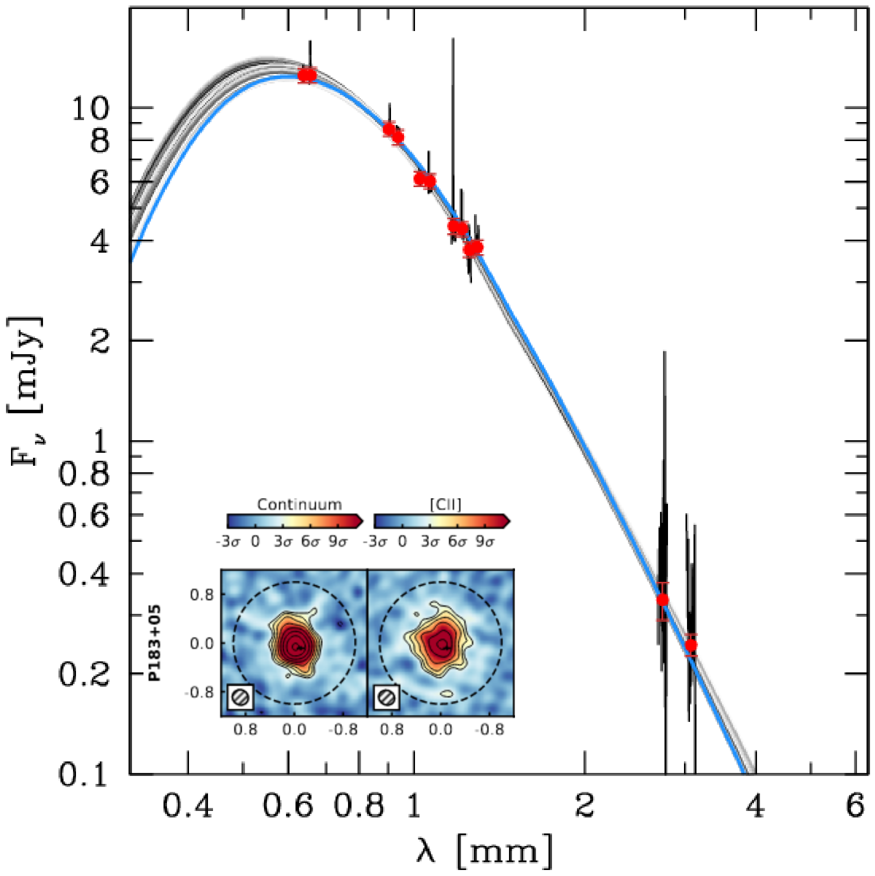
L_{IR} ~ 10^{13} L_o

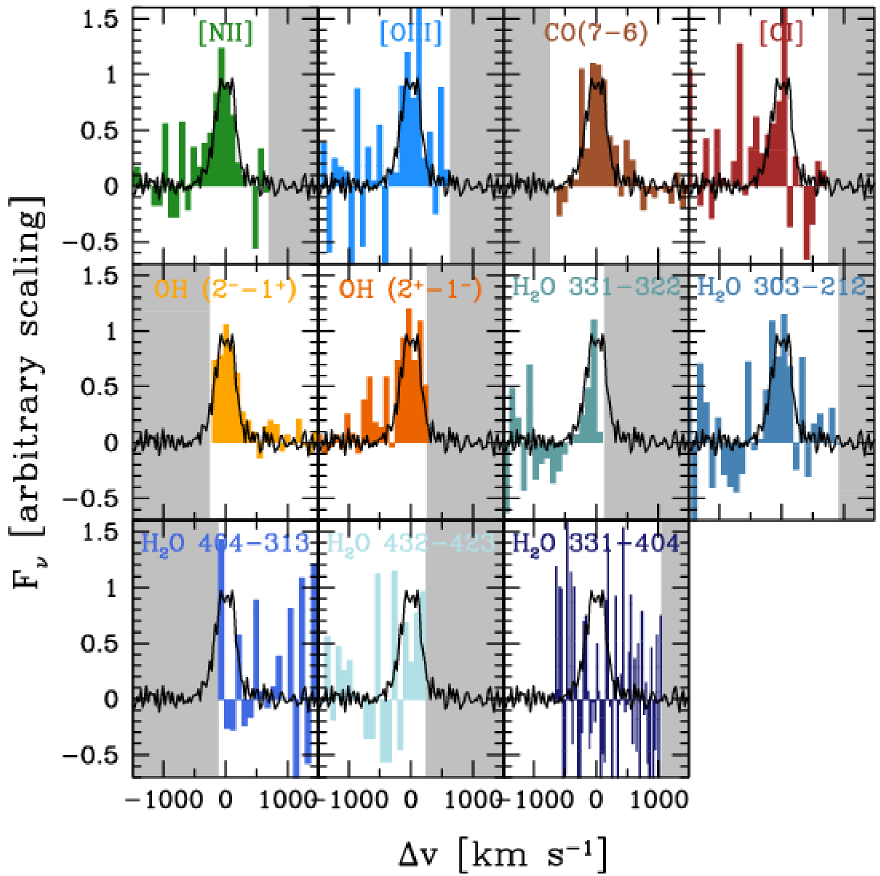
$\tau_{1900\ GHz}$~0.4



Multi-λ campaign: Lines

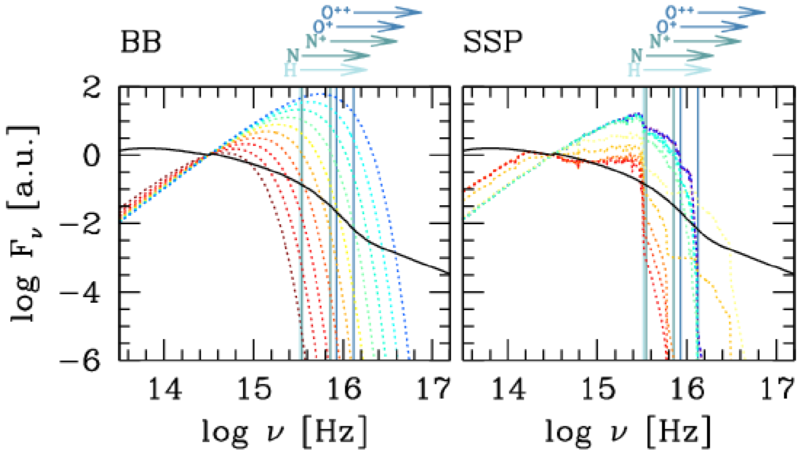
Decarli et al. (2023)





Emission line predictions

Radiation field templates



Decarli et al. (2023)

Emission line predictions

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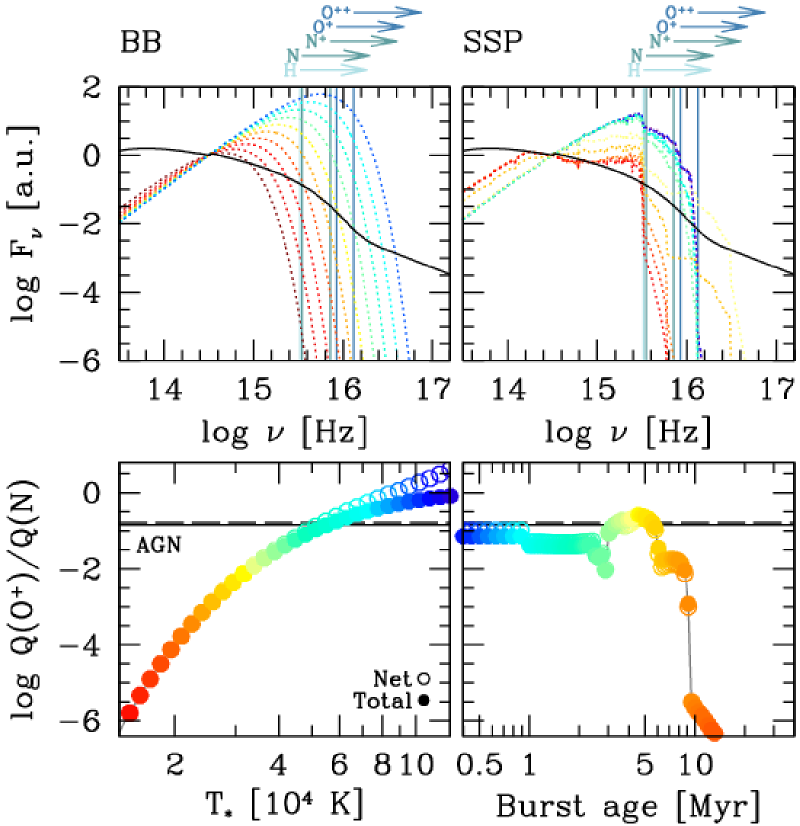

Decarli et al. (2023)

Emission line predictions

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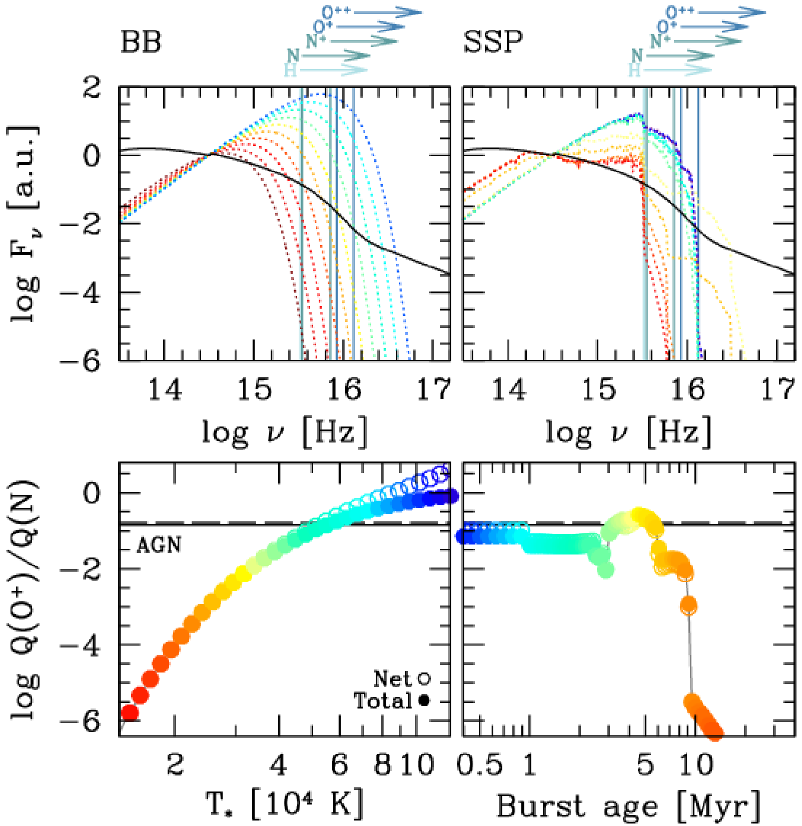
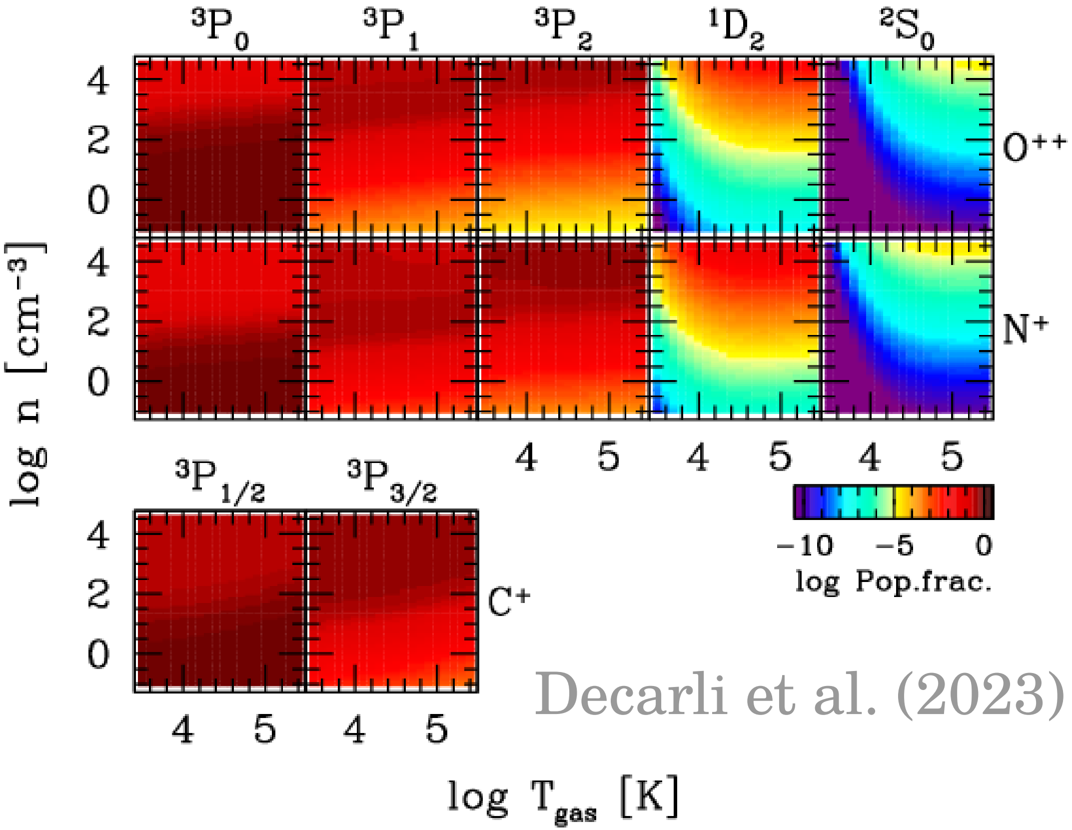
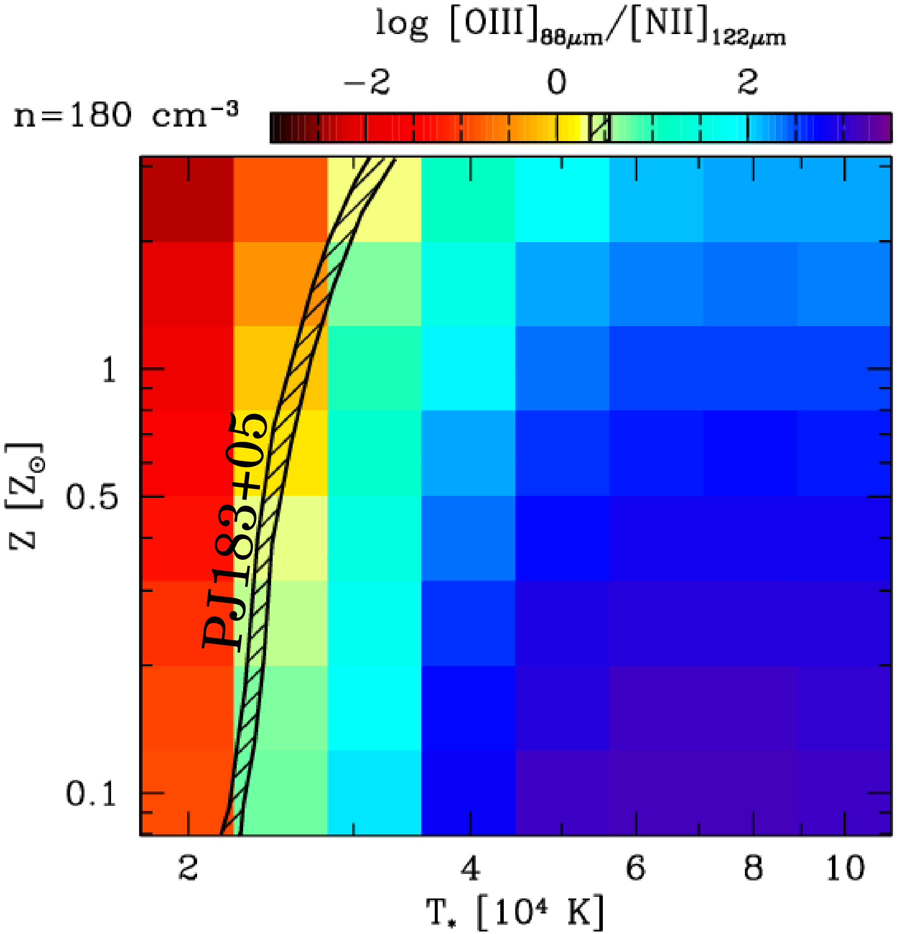


Energy level population

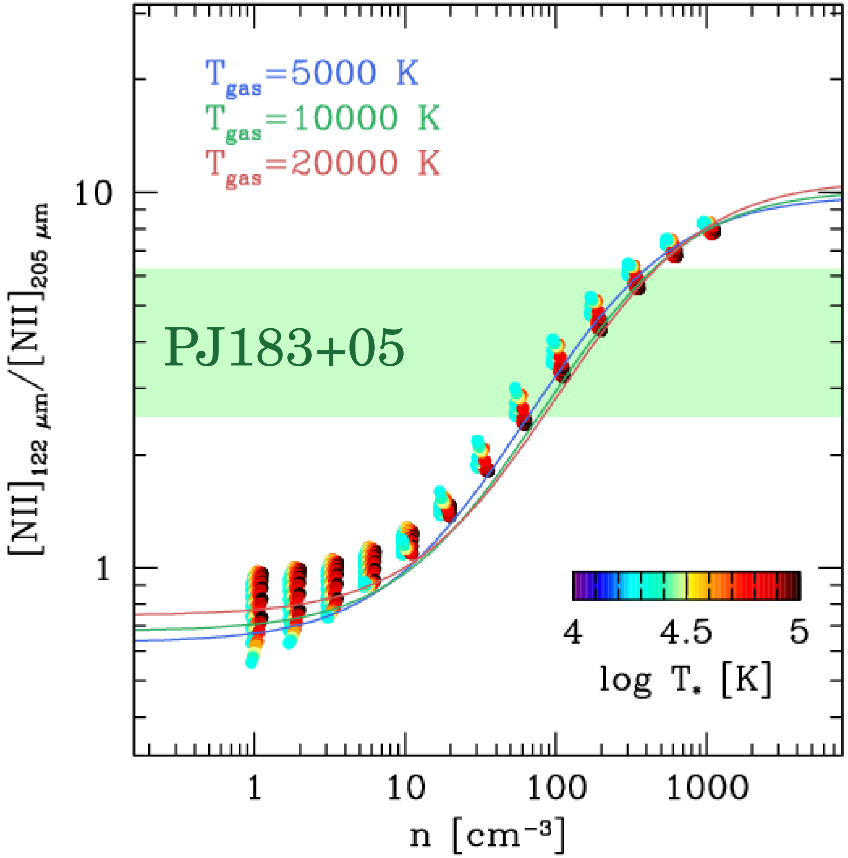


Decarli et al. (2023)

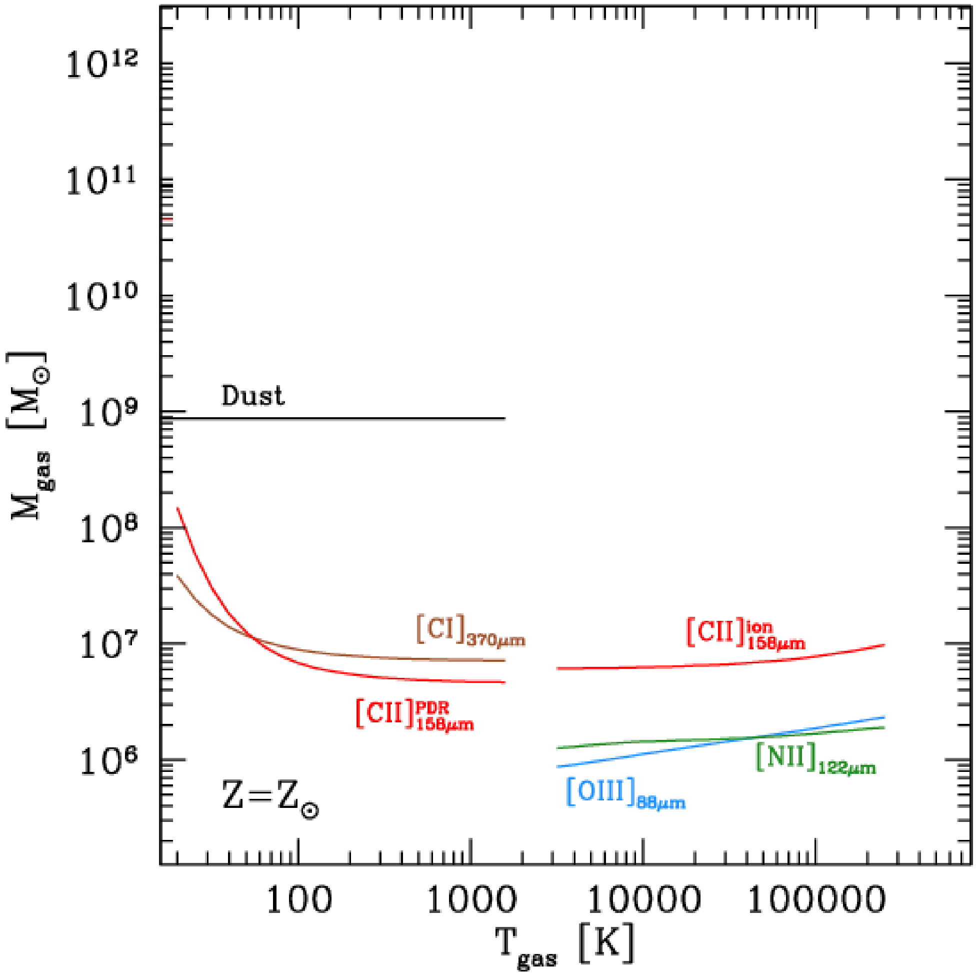
Data vs Radiative Transfer models



Decarli et al. (2023)



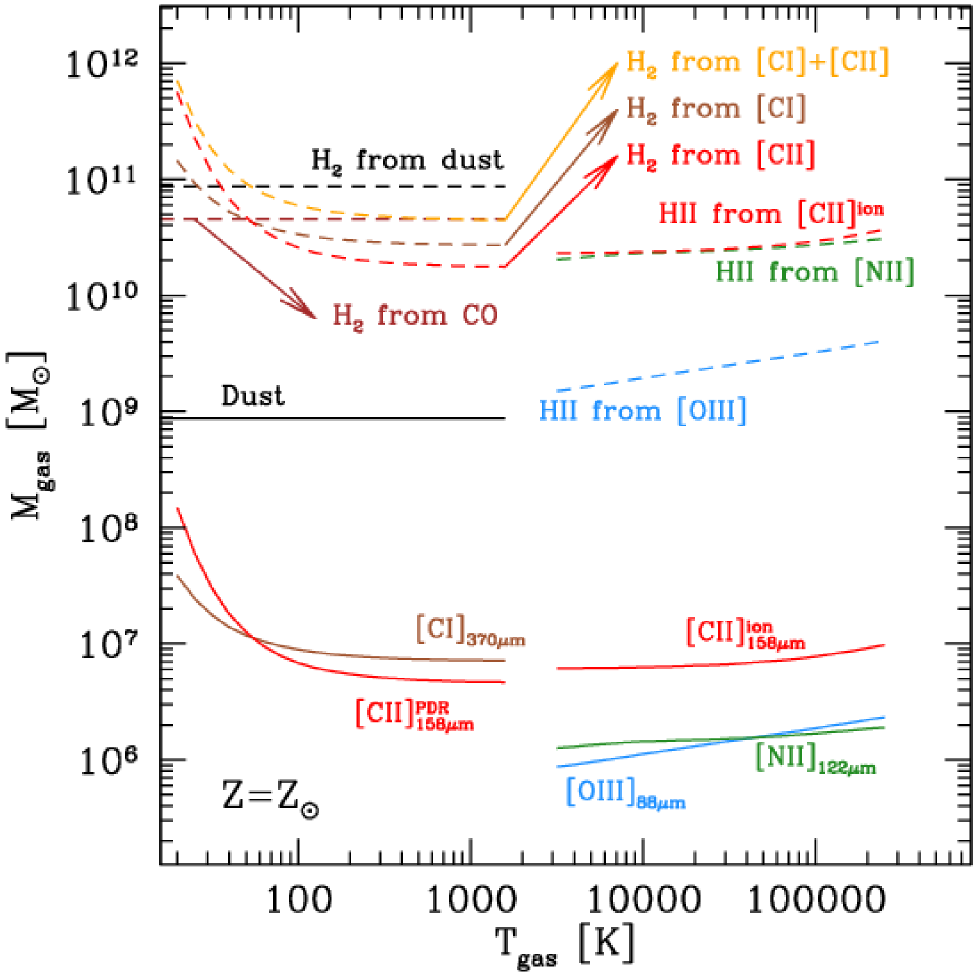
Mass budget



PJ183+05 @ z=6.4386

Decarli et al. (2023)

Mass budget



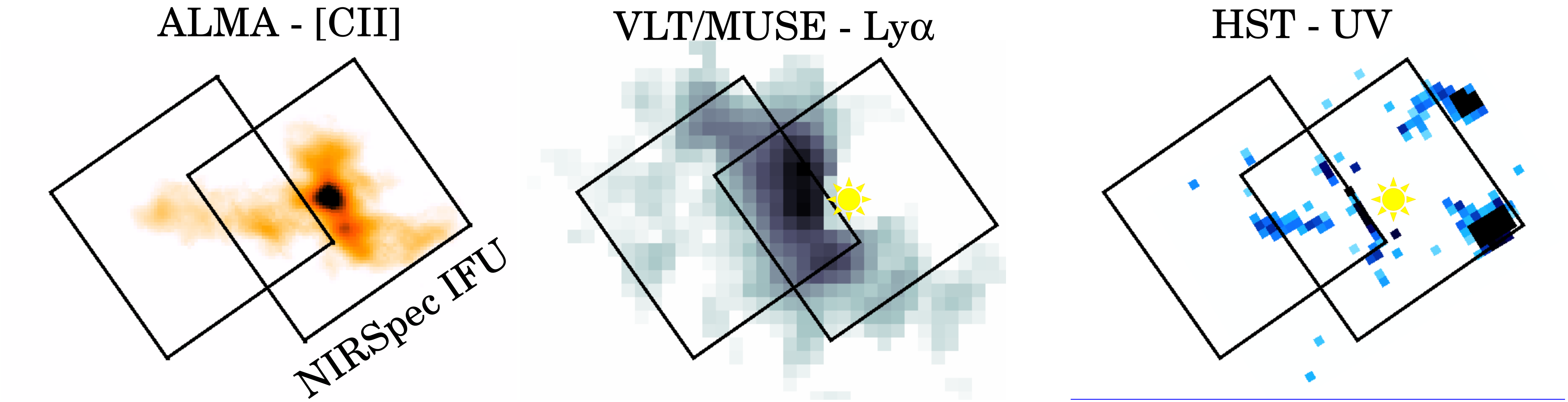
Multi-phase mass budget

PJ183+05 @ z=6.4386

Decarli et al. (2023)

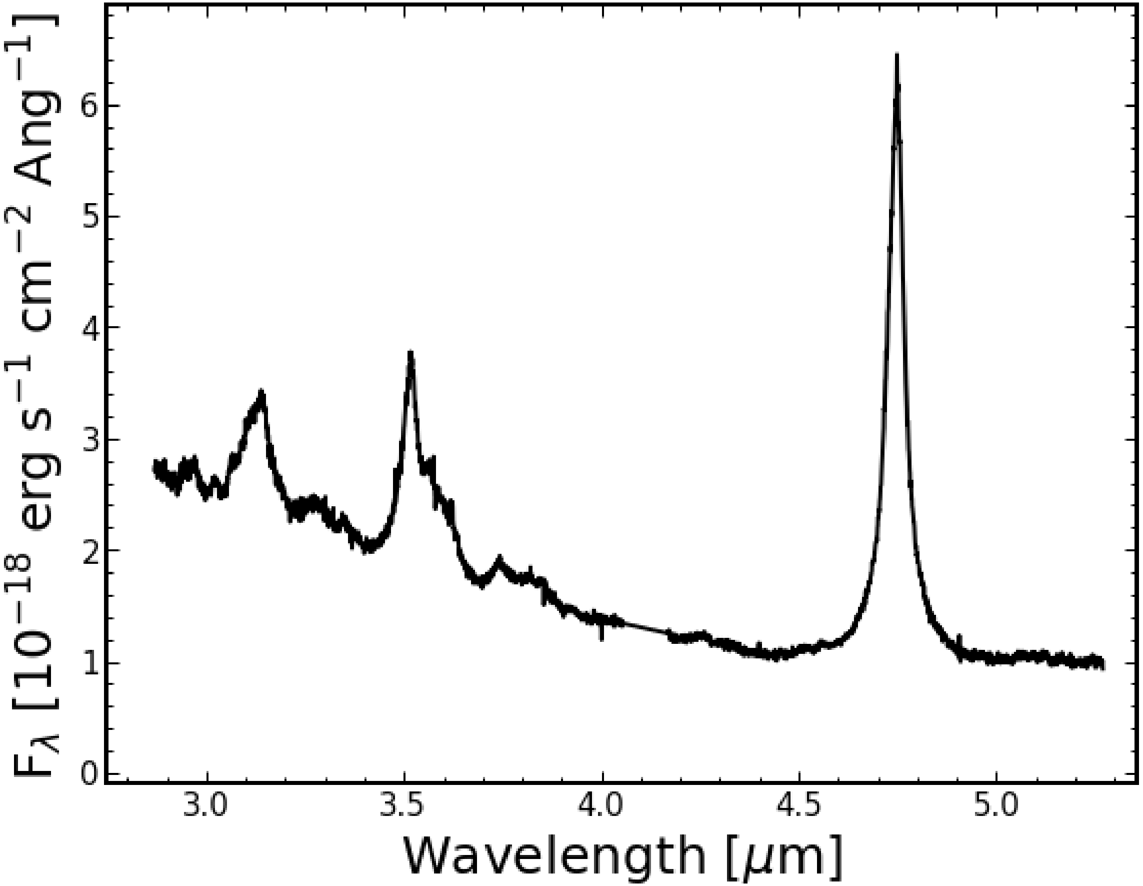
Project II:
A quasar-satellite merger at $z=6.2$

A quasar-satellite merger at z=6.2



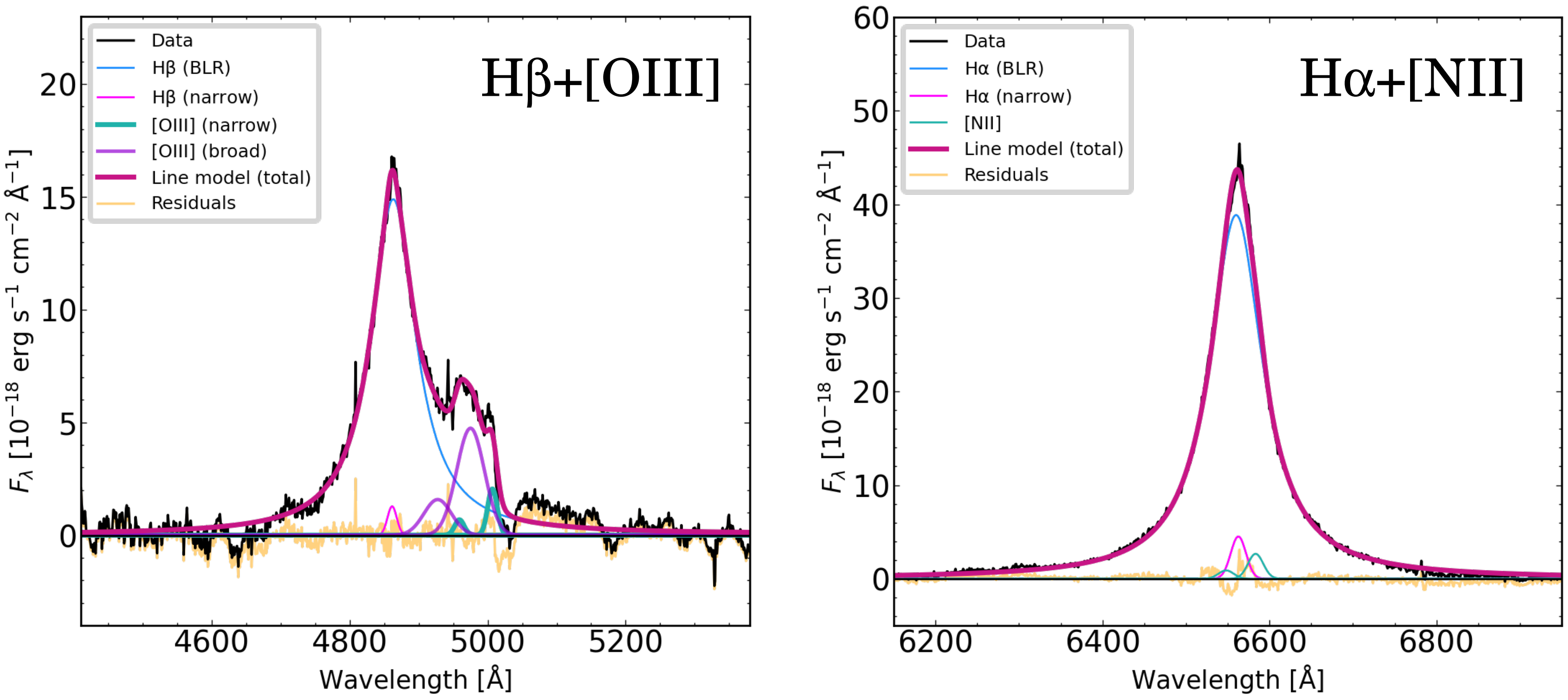
Decarli et al. (2019),
Farina et al. (2019)

Rest-frame optical spectroscopy of the quasar



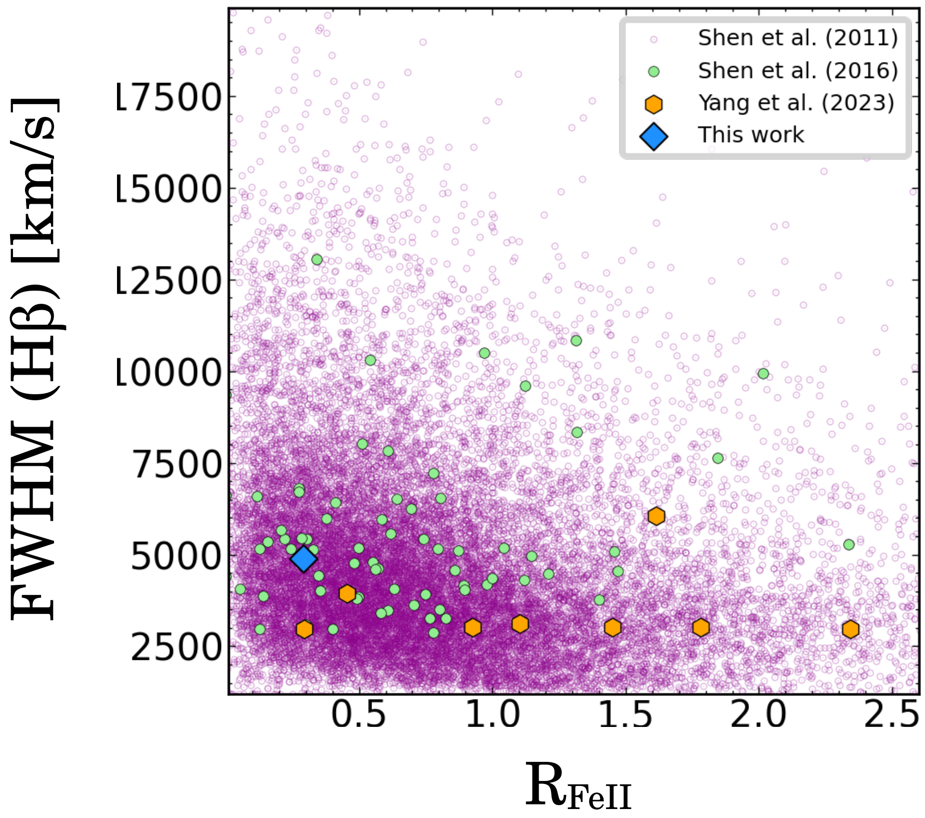
Loiacono et al. (in prep)

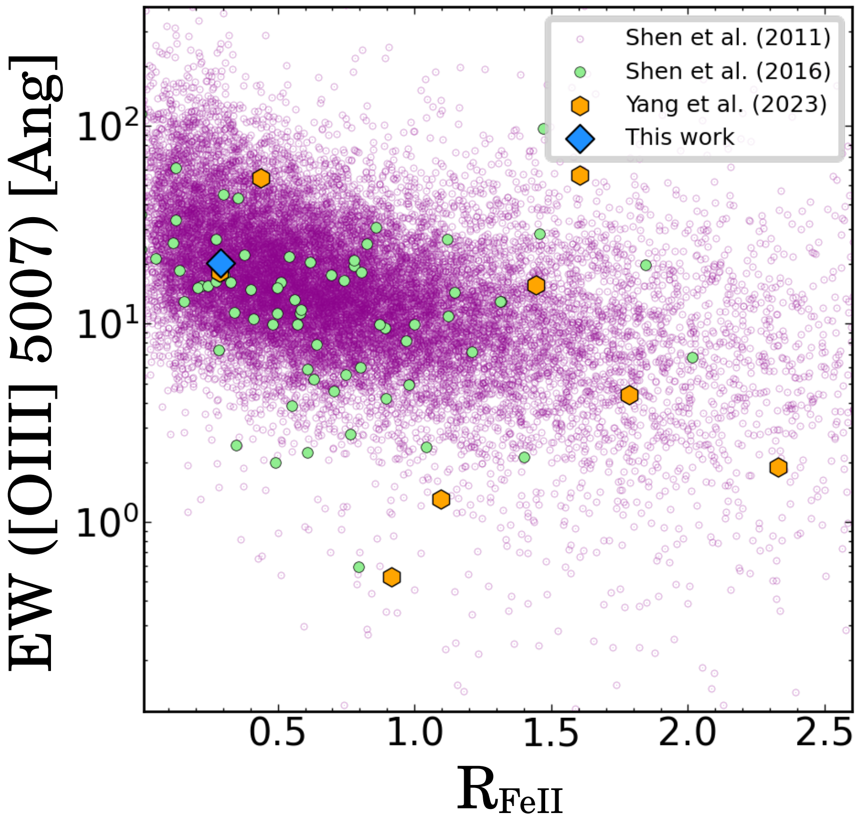
Rest-frame optical spectroscopy of the quasar



Loiacono et al. (in prep)

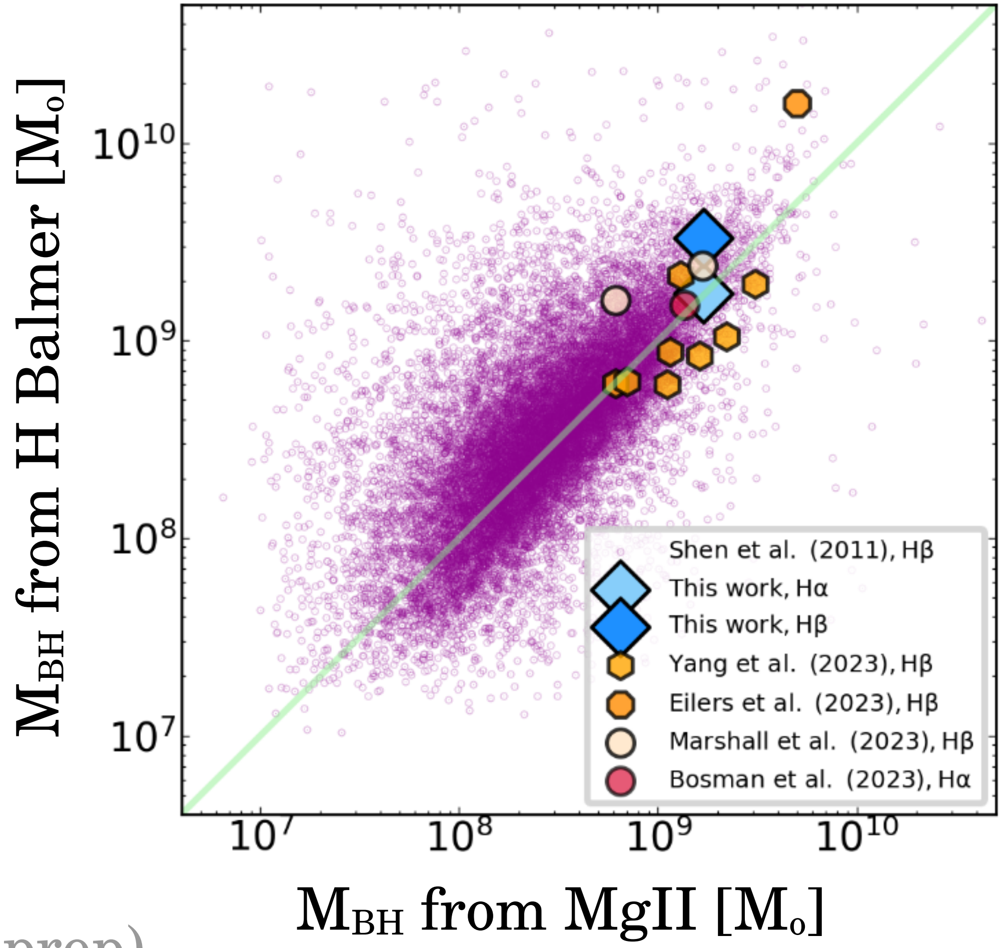
Eigenvector analysis





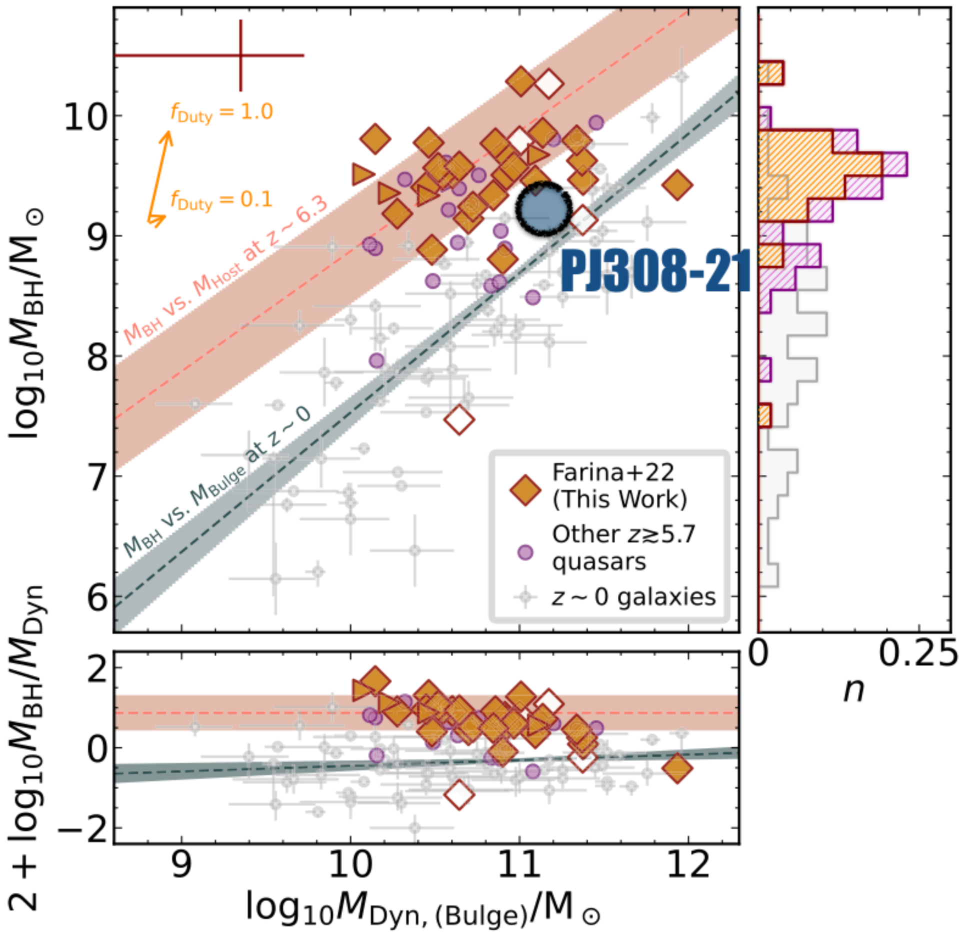
Loiacono et al. (in prep)

Black hole mass estimates



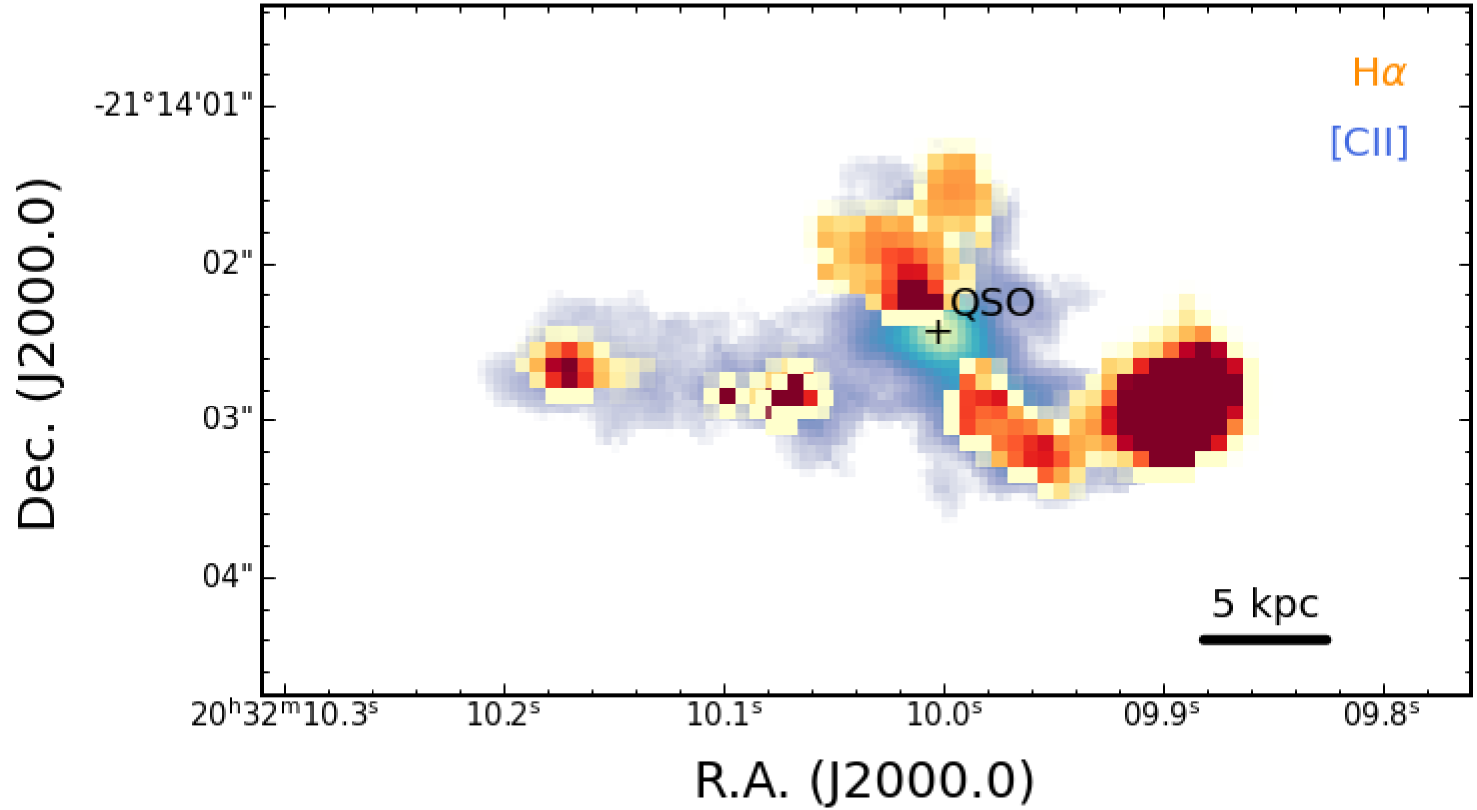
Loiacono et al. (in prep)

BH-host galaxy relation at z=6.2



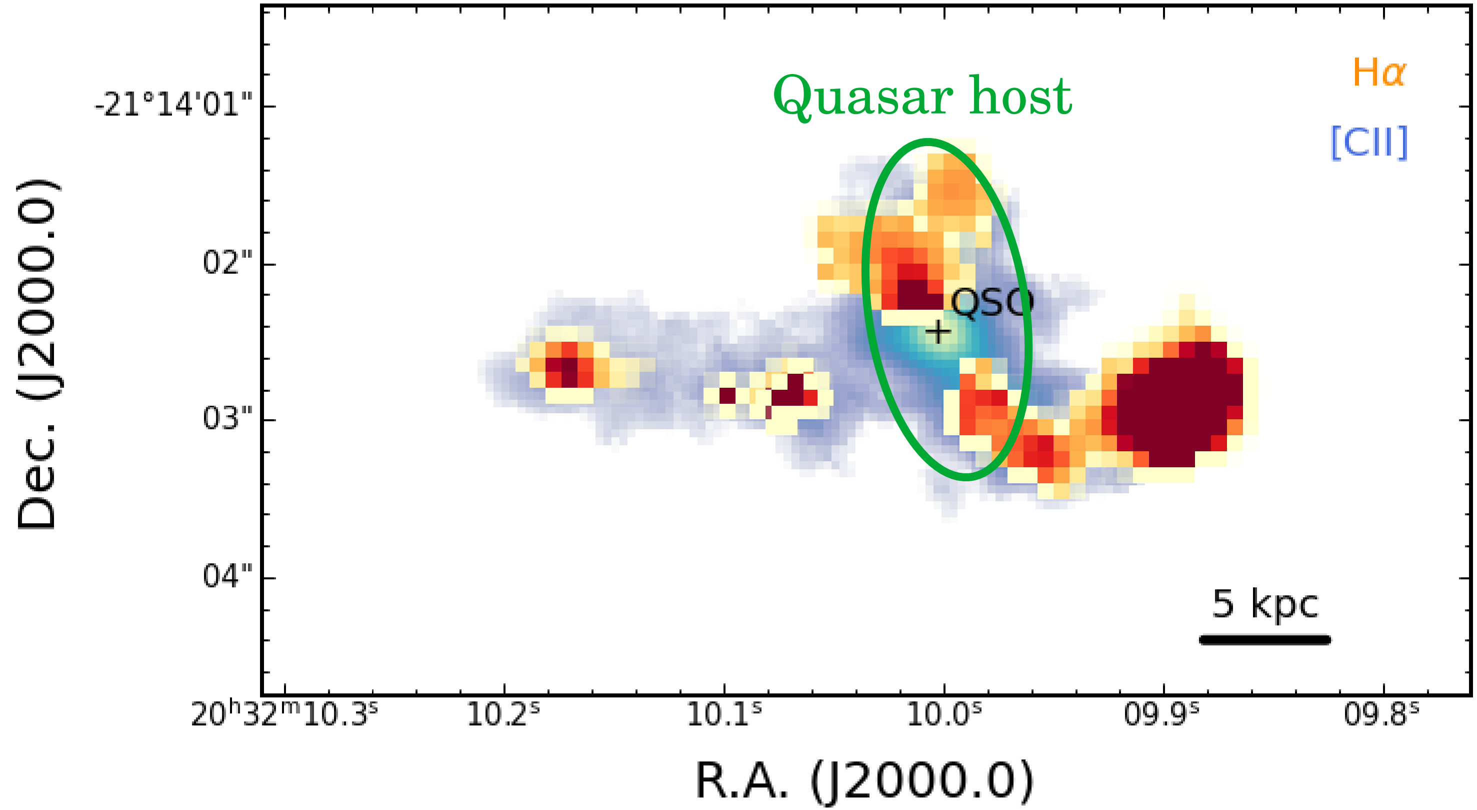
Loiacono et al. (in prep), Farina et al. (2022)

The extended line emission



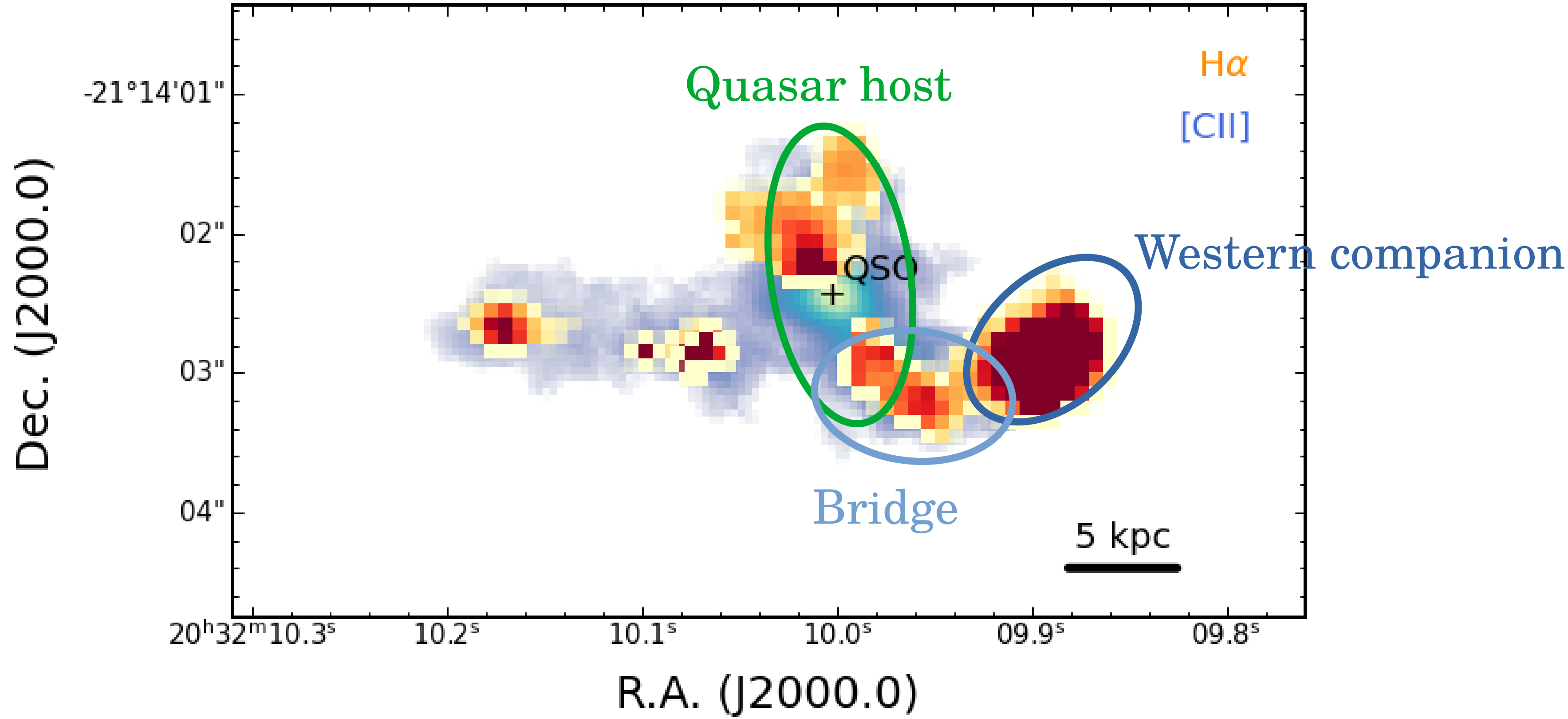
Decarli et al. (in prep)

The extended line emission



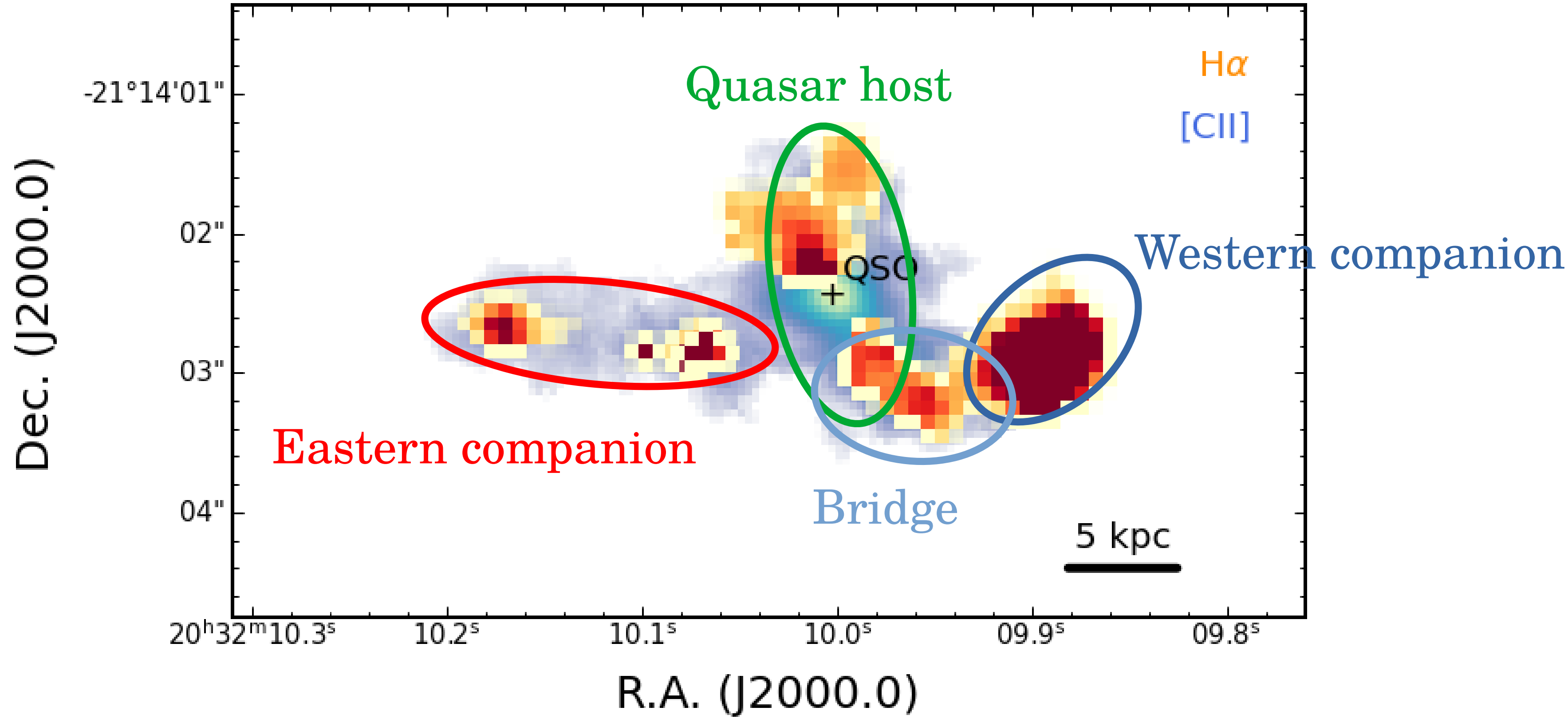
Decarli et al. (in prep)

The extended line emission



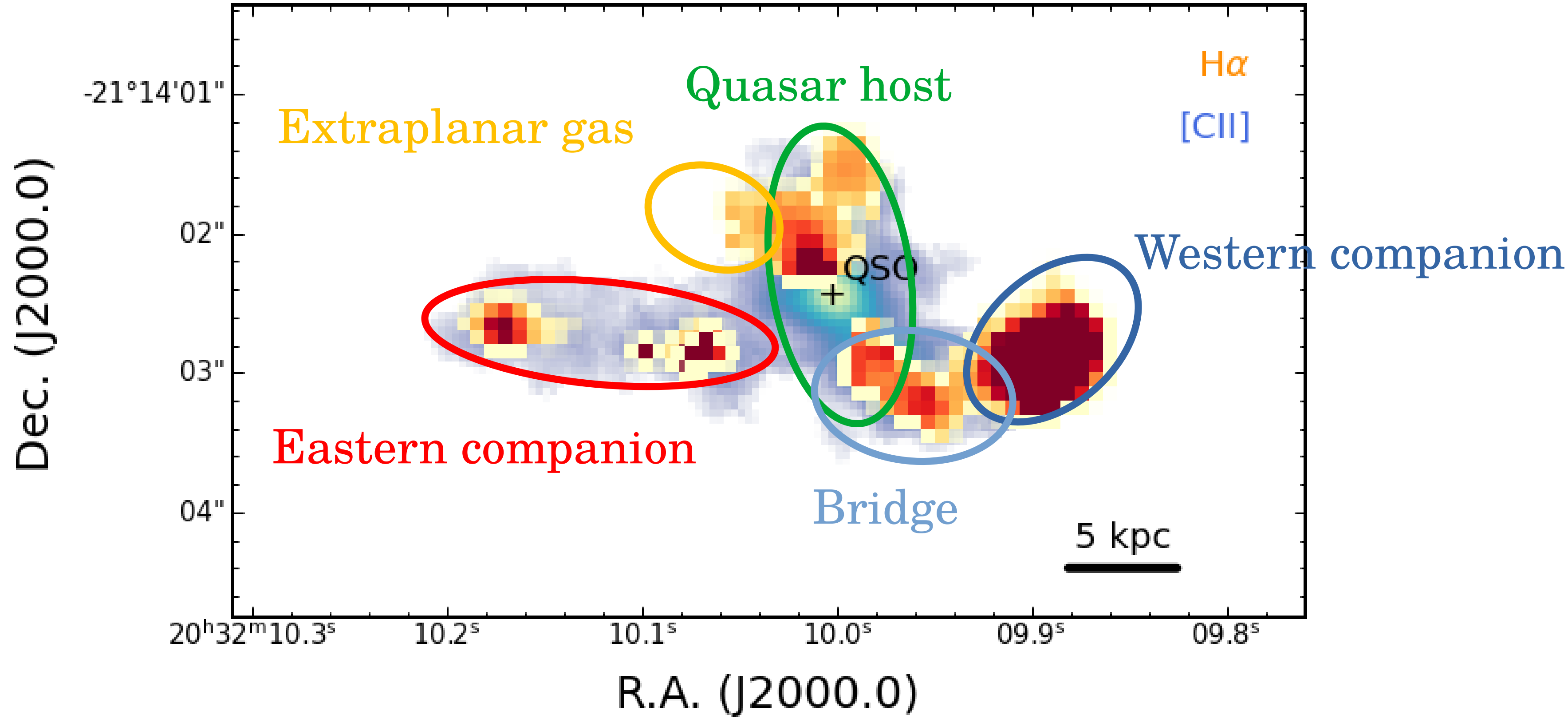
Decarli et al. (in prep)

The extended line emission



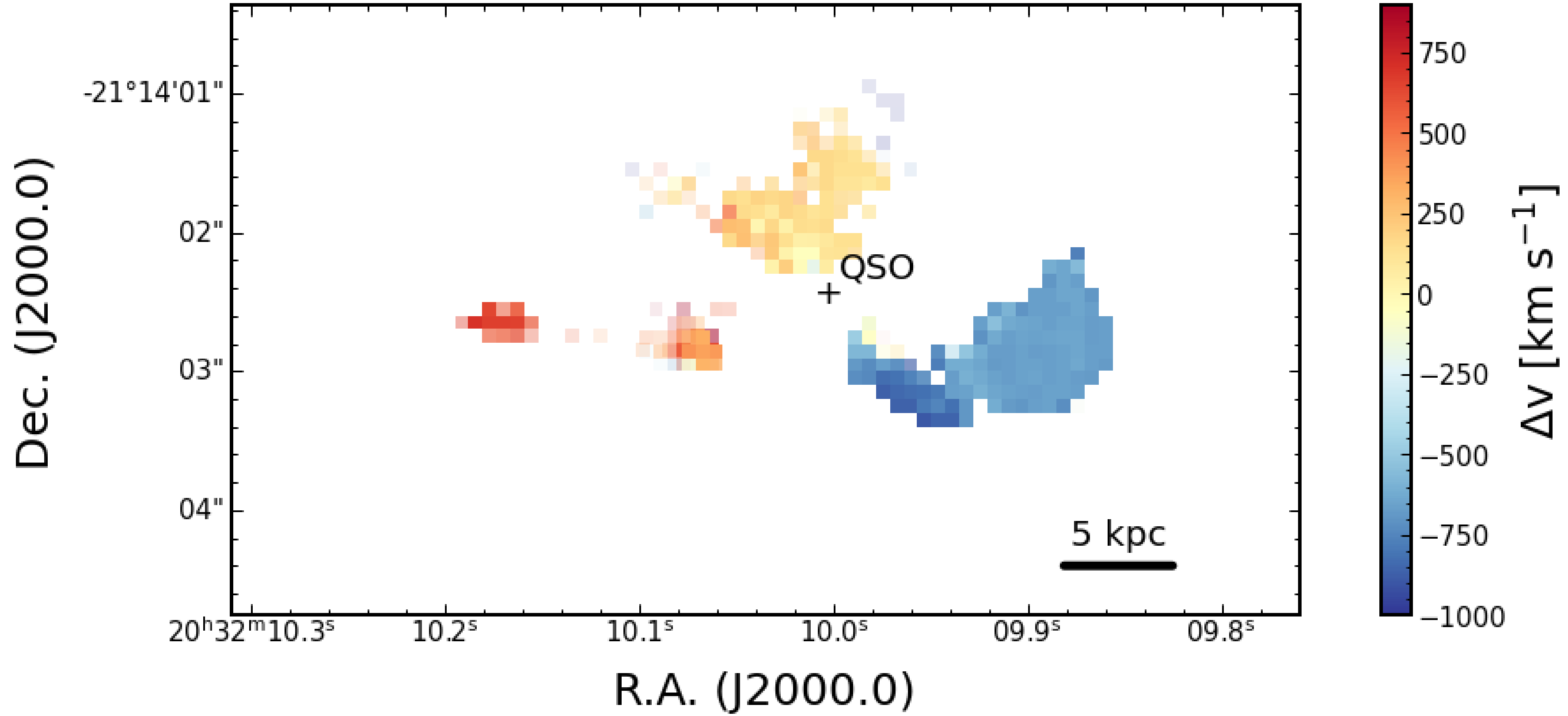
Decarli et al. (in prep)

The extended line emission



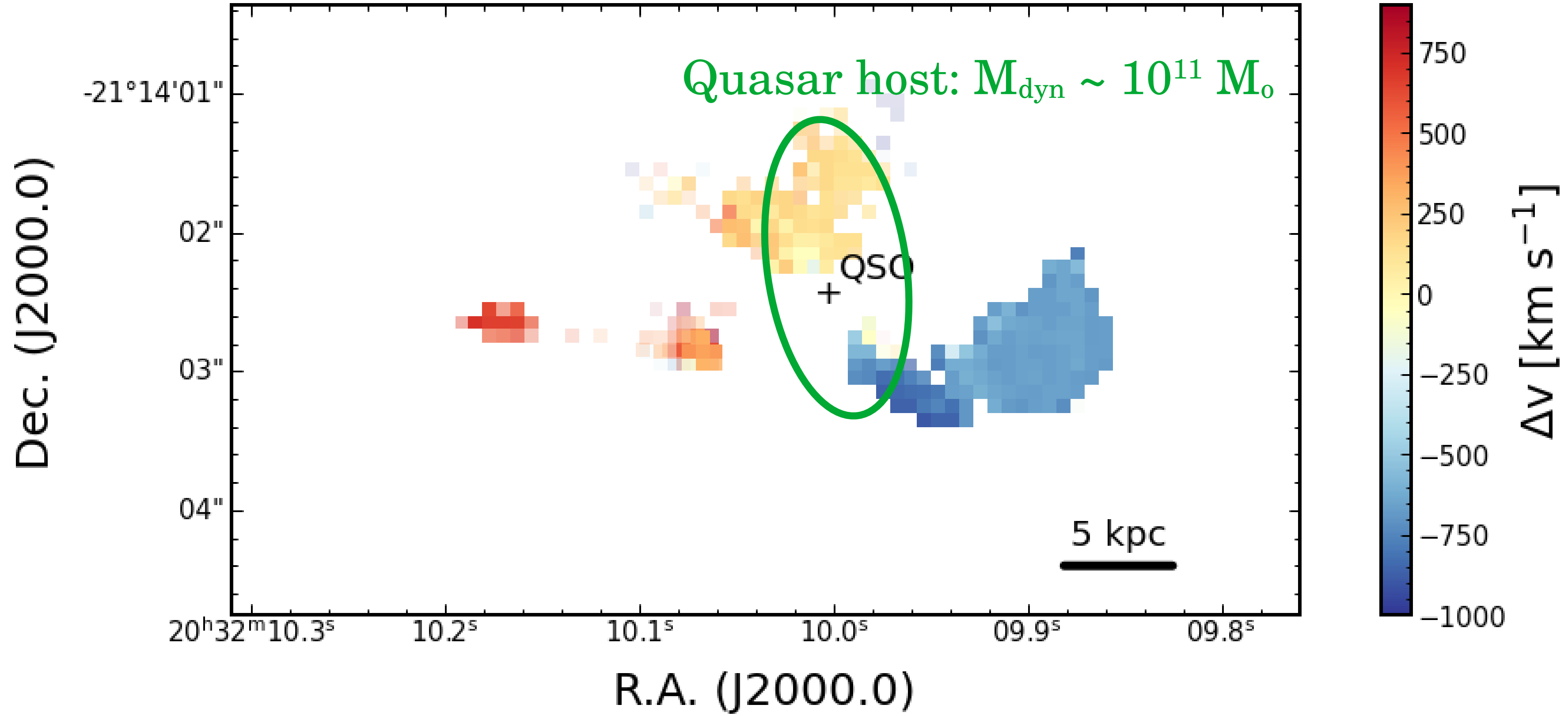
Decarli et al. (in prep)

The extended line emission



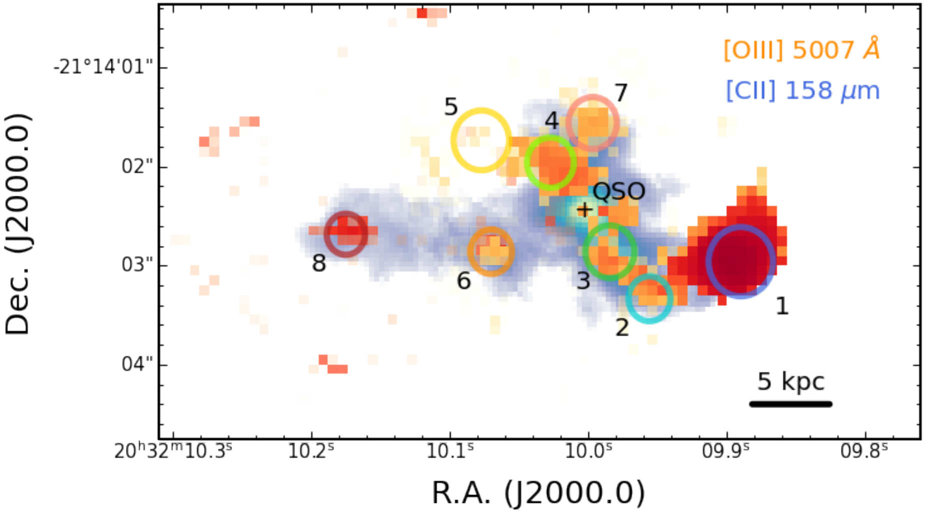
Decarli et al. (in prep)

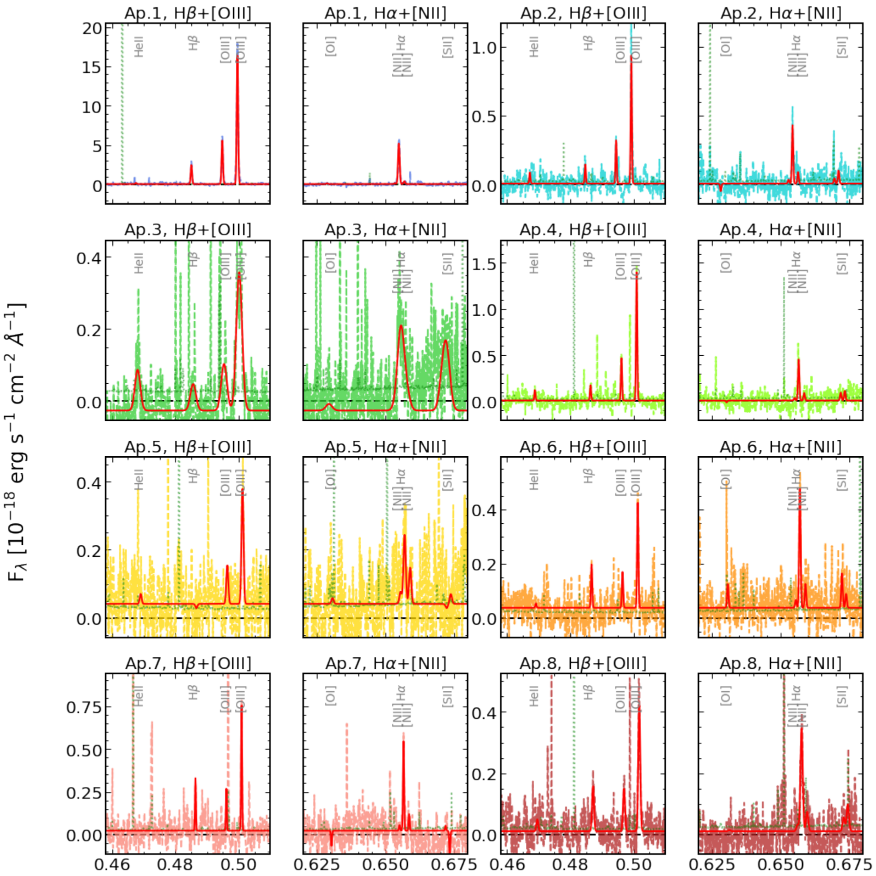
The extended line emission



Decarli et al. (in prep)

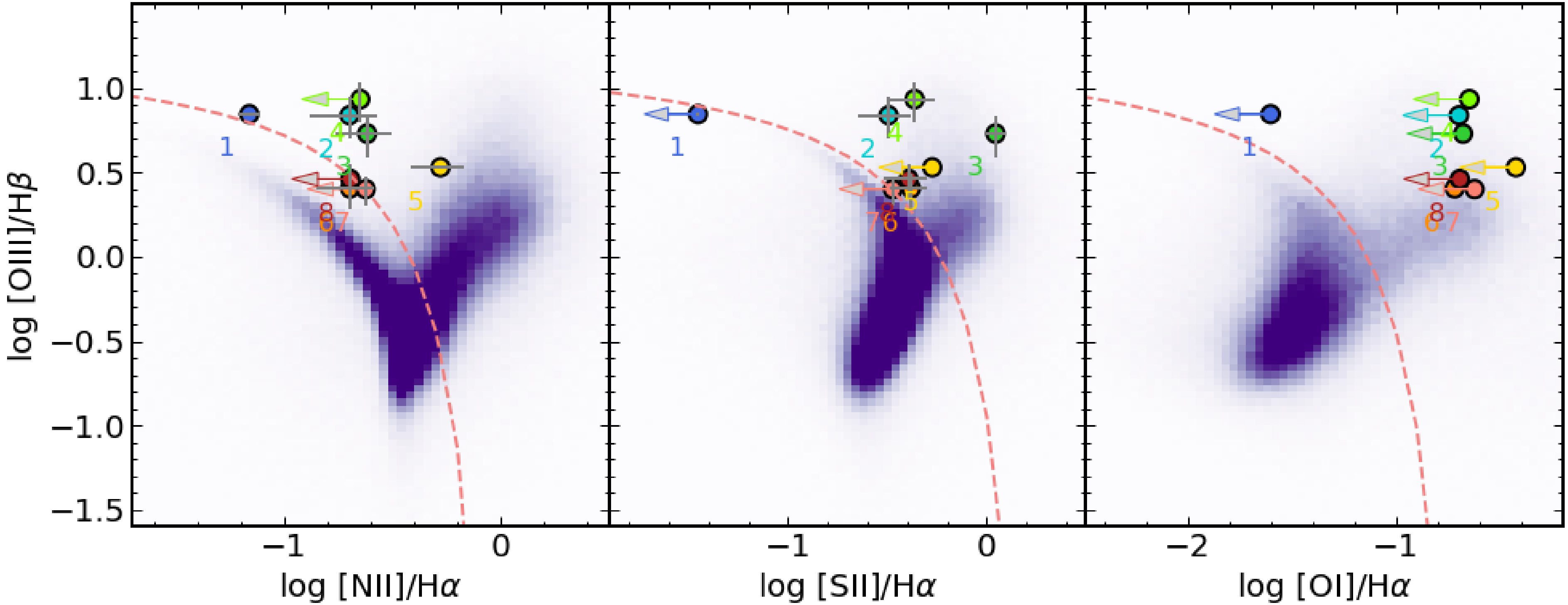
Spectral properties throughout the system





Decarli et al. (in prep)

BPT diagrams



Decarli et al. (in prep)

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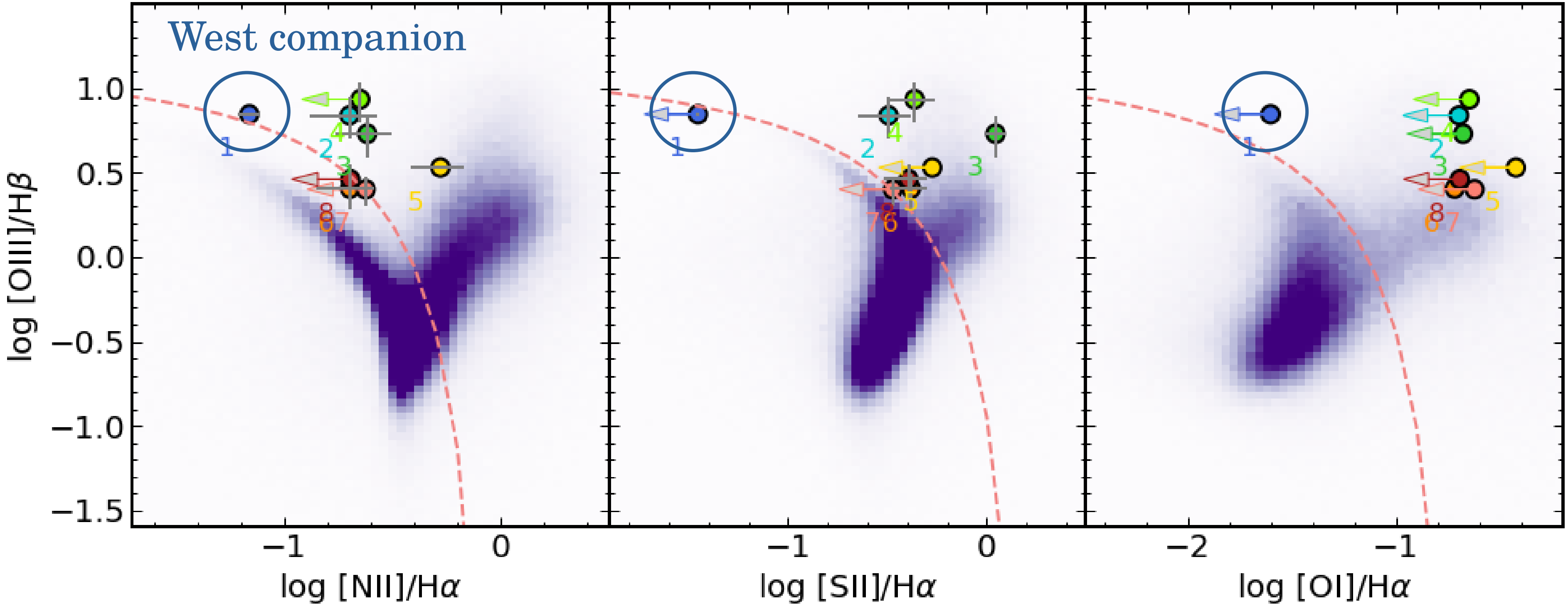
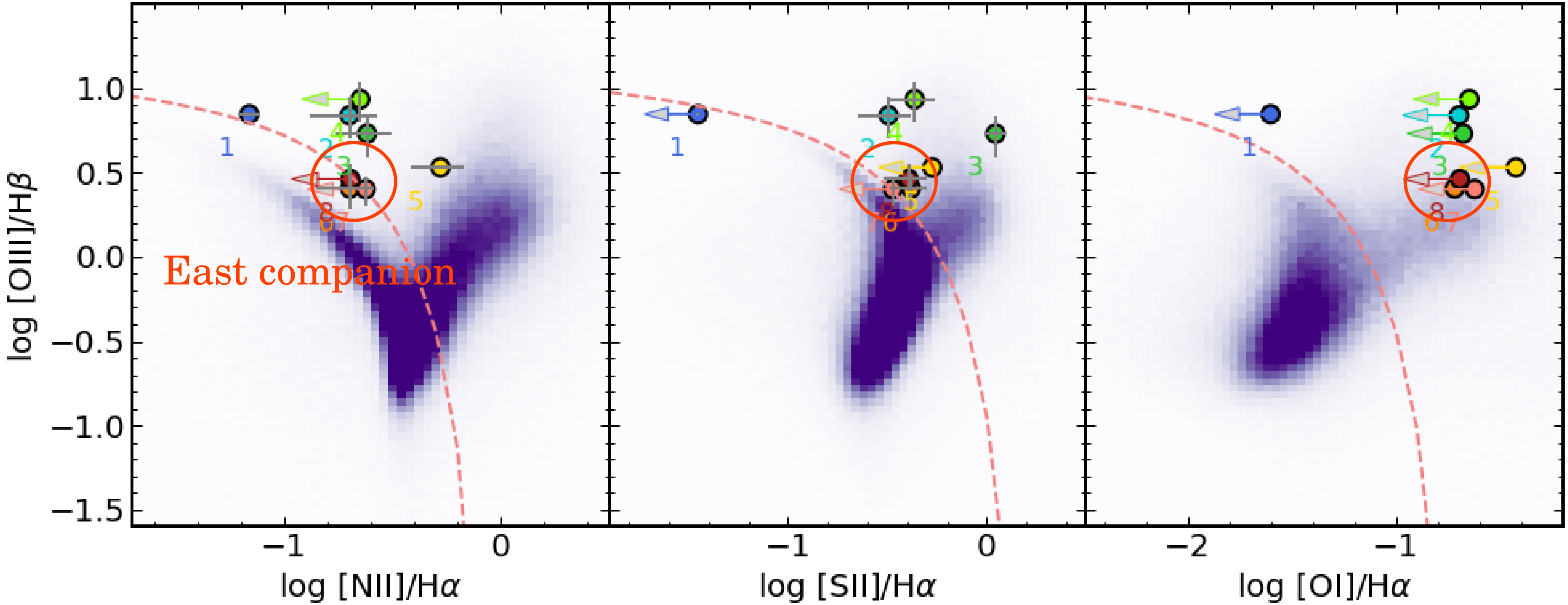


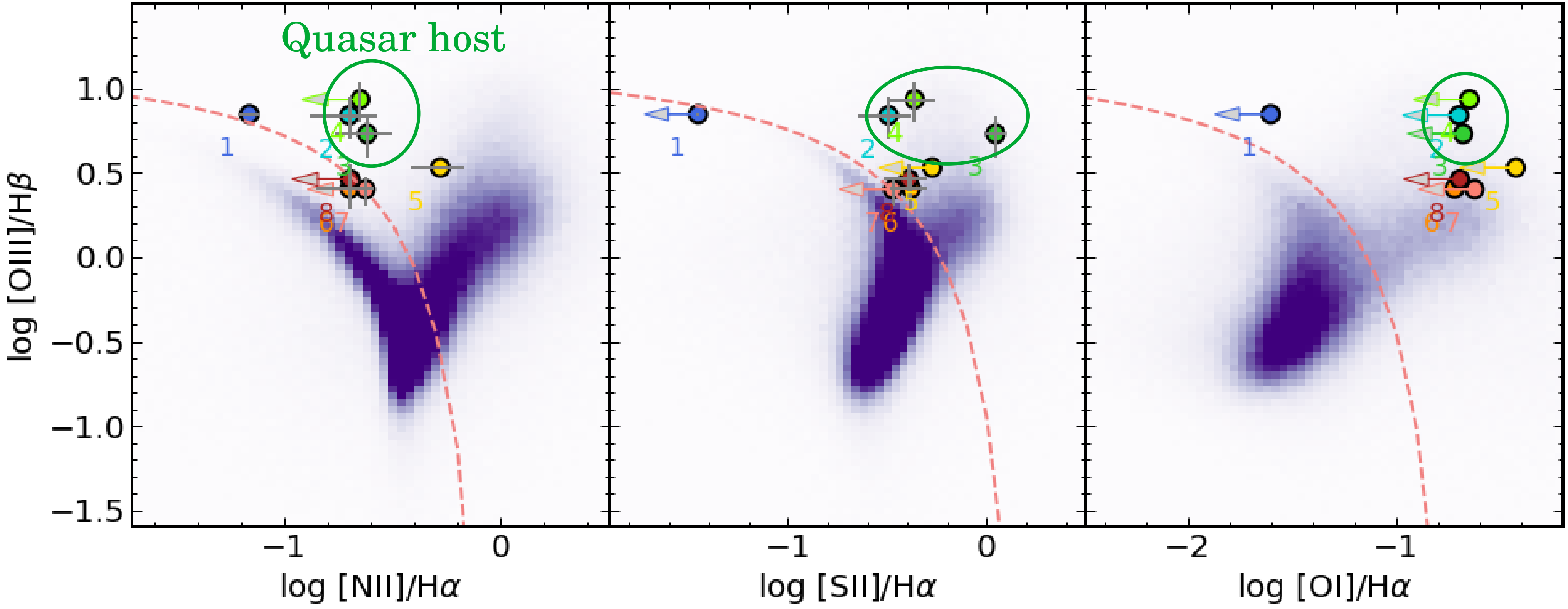
Decarli et al. (in prep)

BPT diagrams



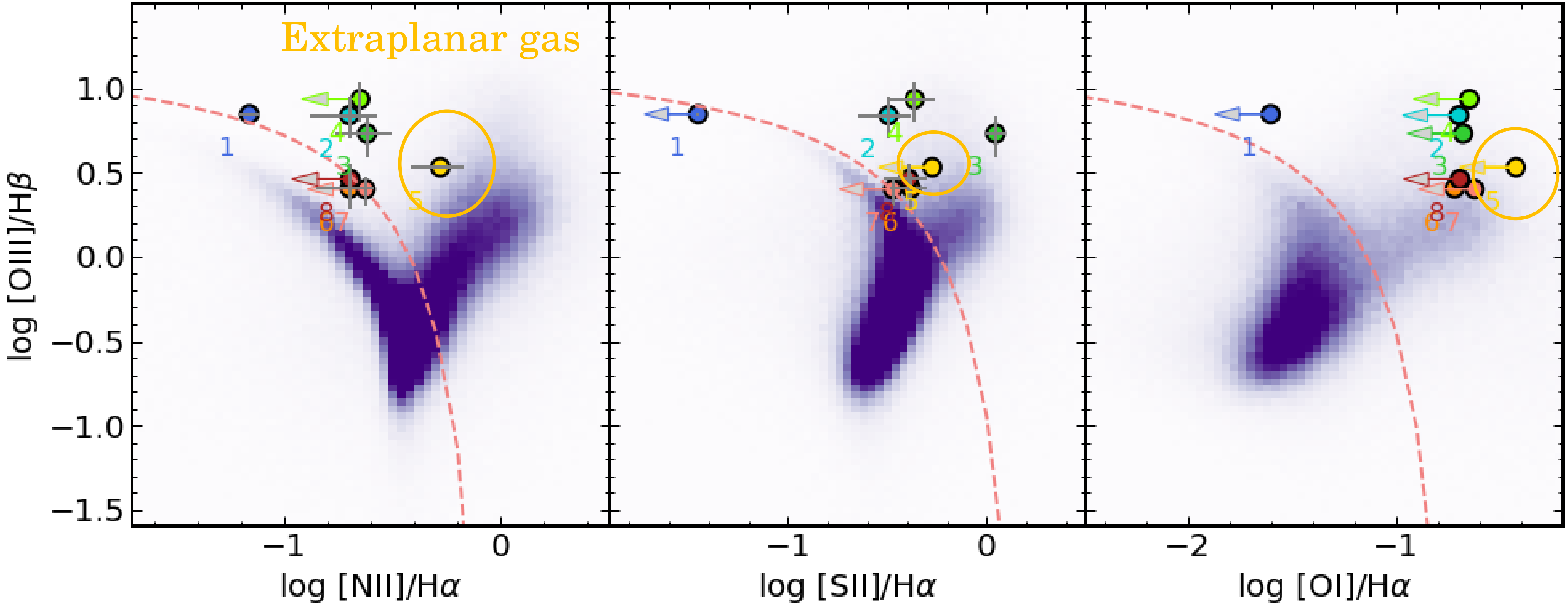
Decarli et al. (in prep)

BPT diagrams



Decarli et al. (in prep)

BPT diagrams



Decarli et al. (in prep)

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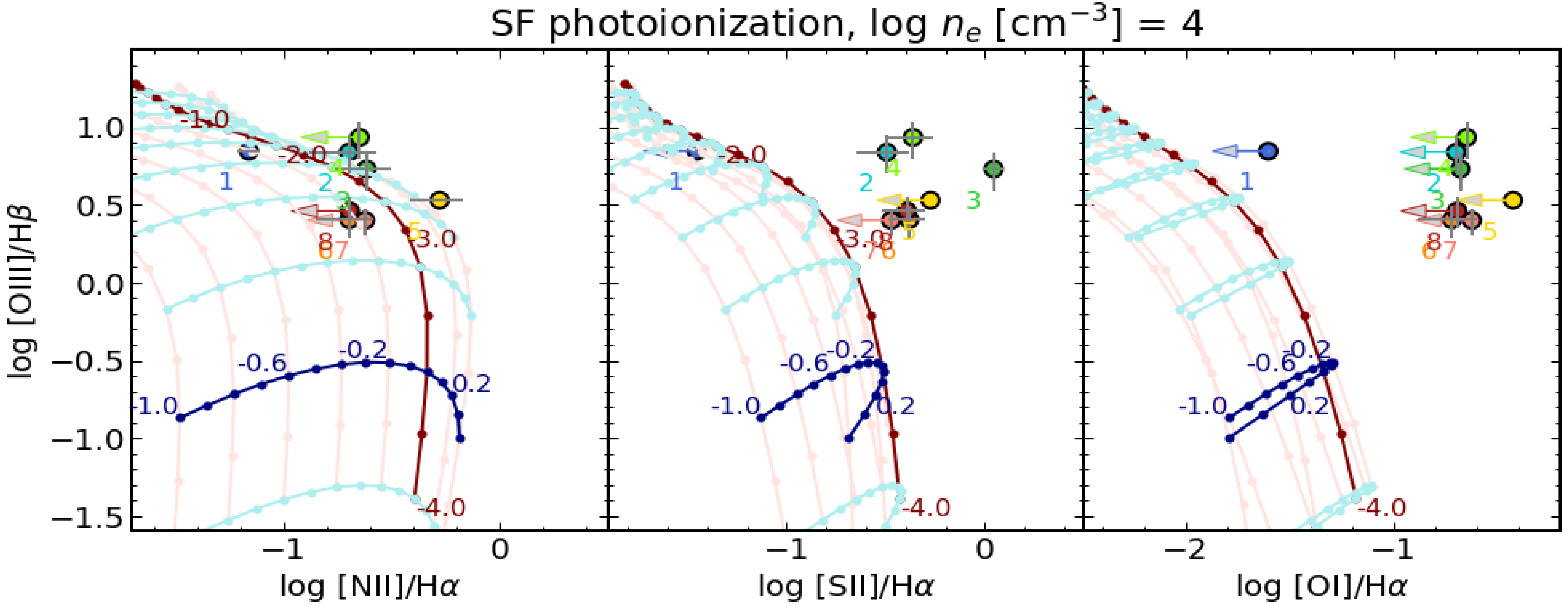

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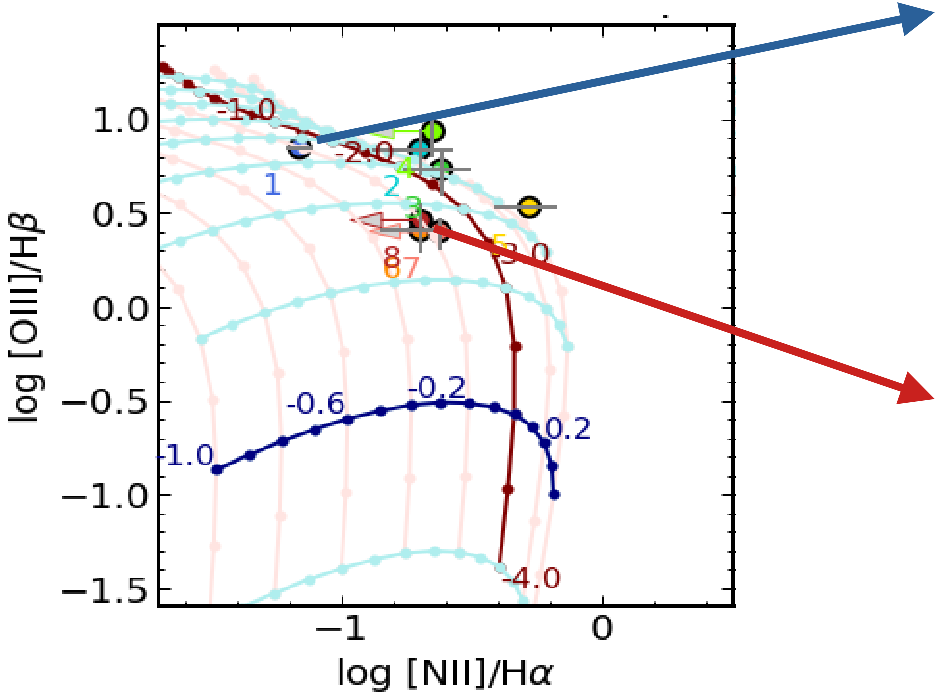


Decarli et al. (in prep)

West companion:

Z~0.6 Zo

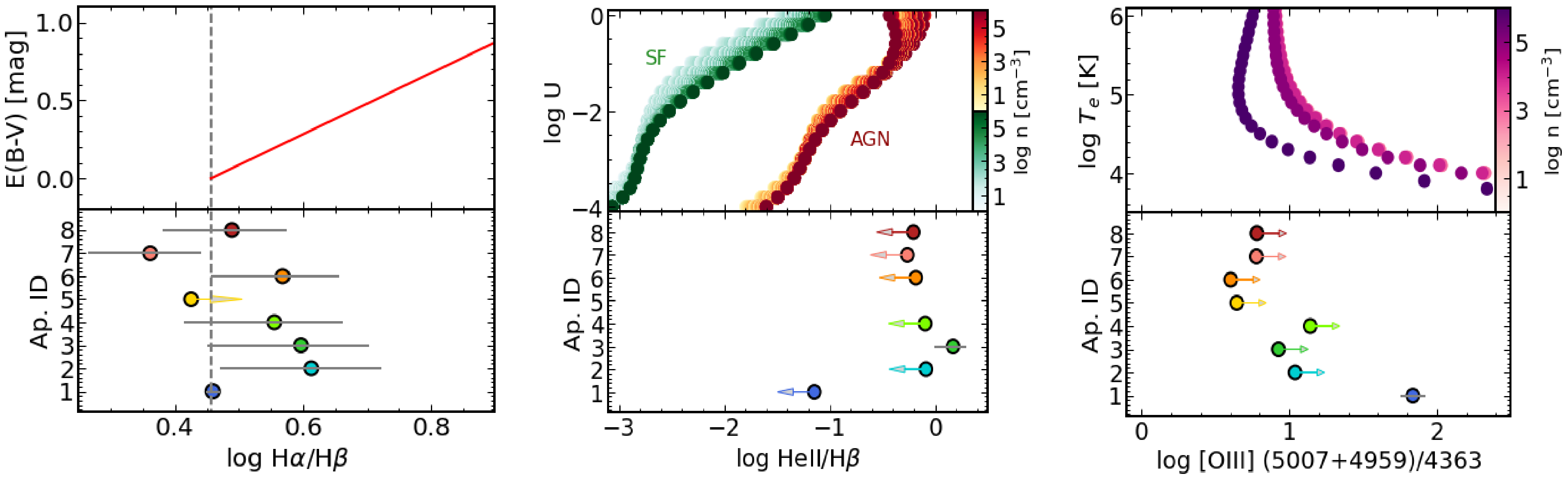
Log U ~ -1.9

East companion:

Z<0.6 Zo

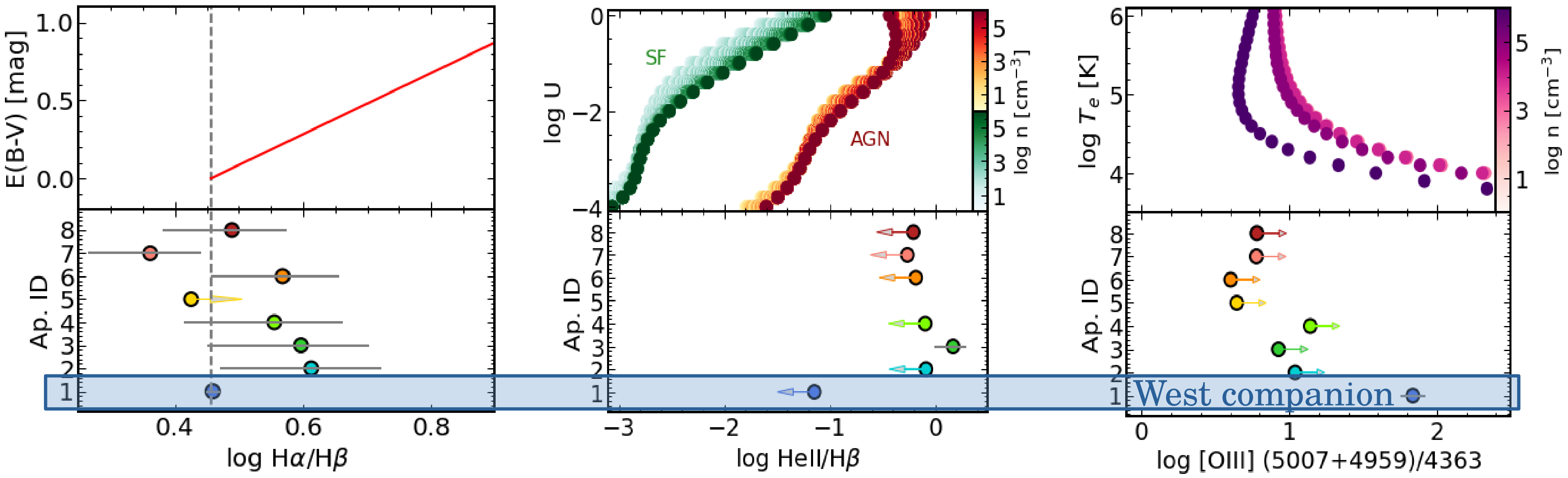
Log U ~ -3.0

Additional line diagnostics



Decarli et al. (in prep)

Additional line diagnostics



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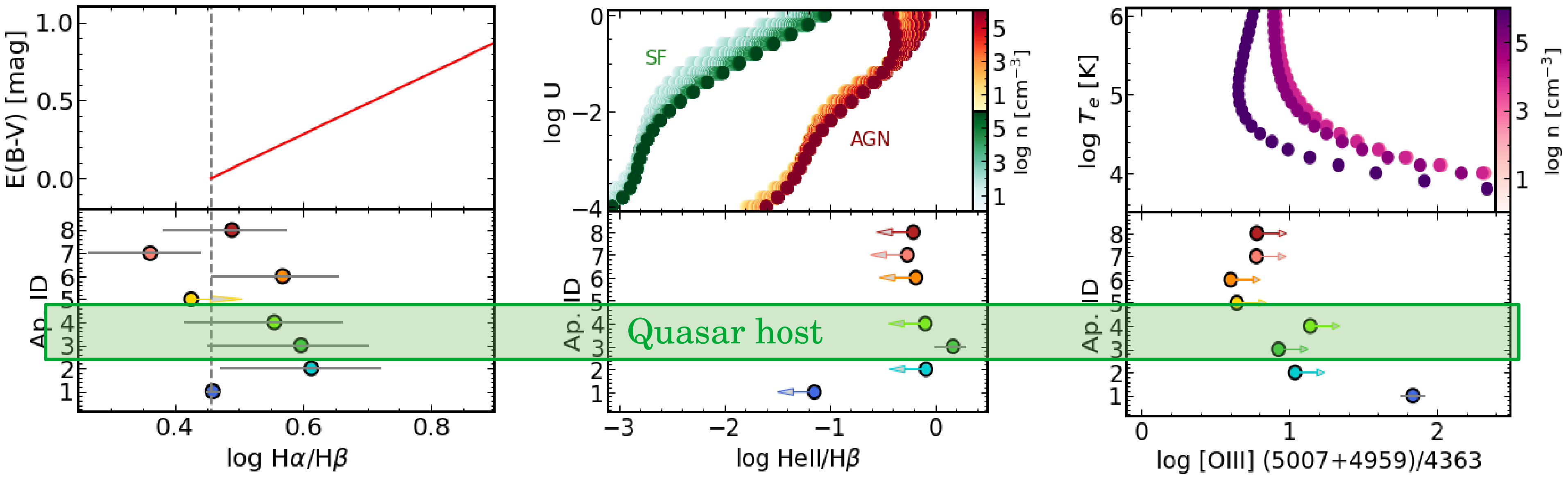
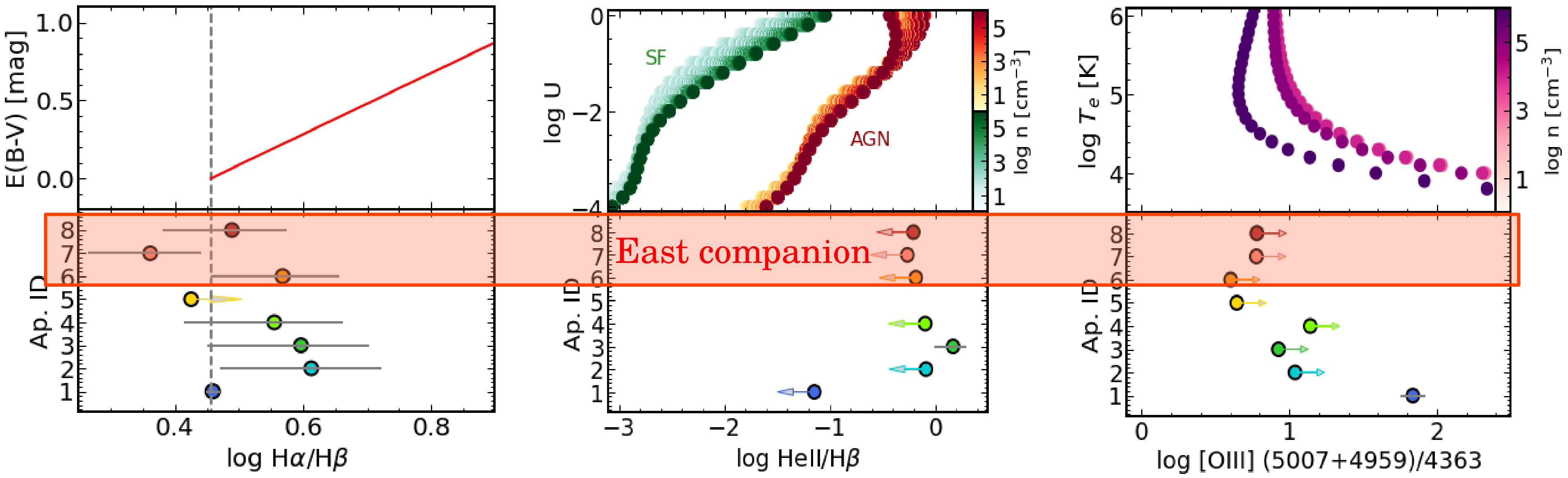
Additional line diagnostics



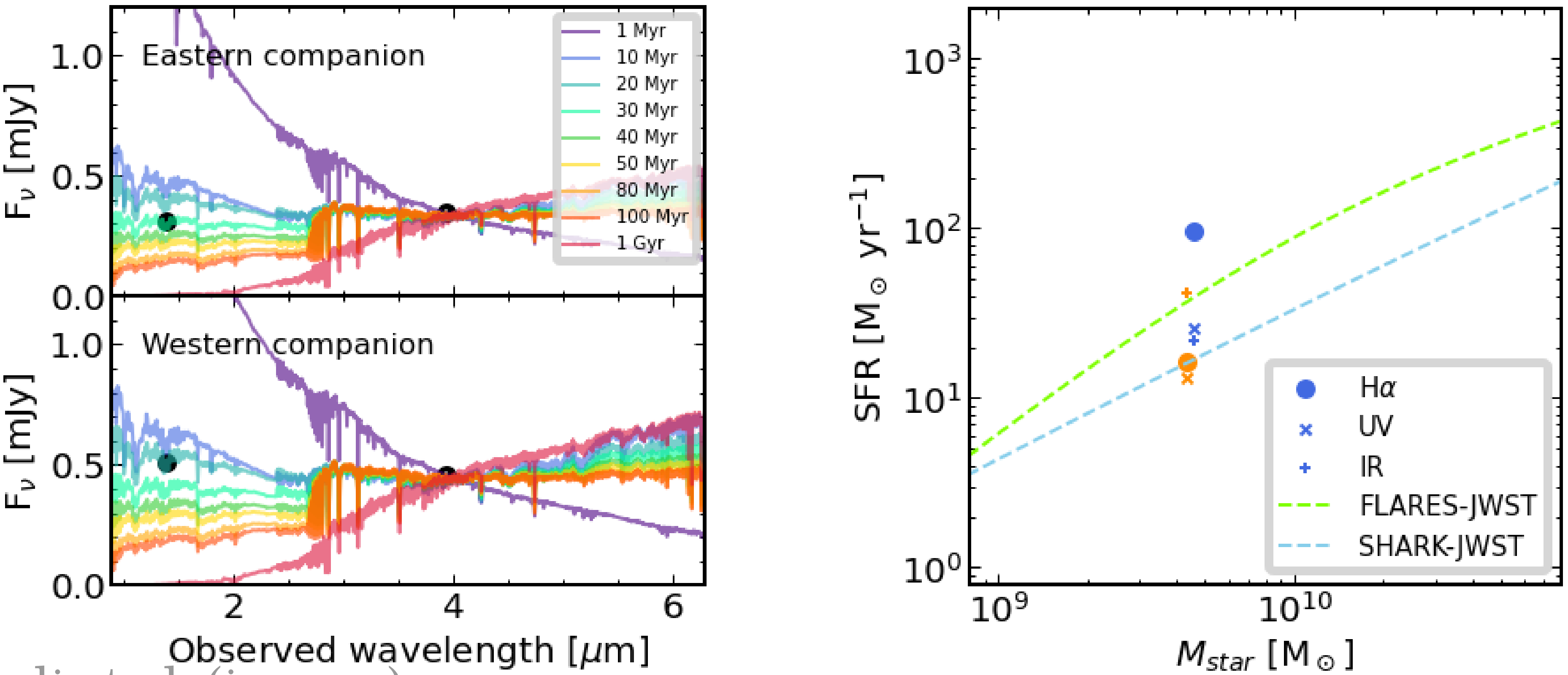
Decarli et al. (in prep)

Additional line diagnostics



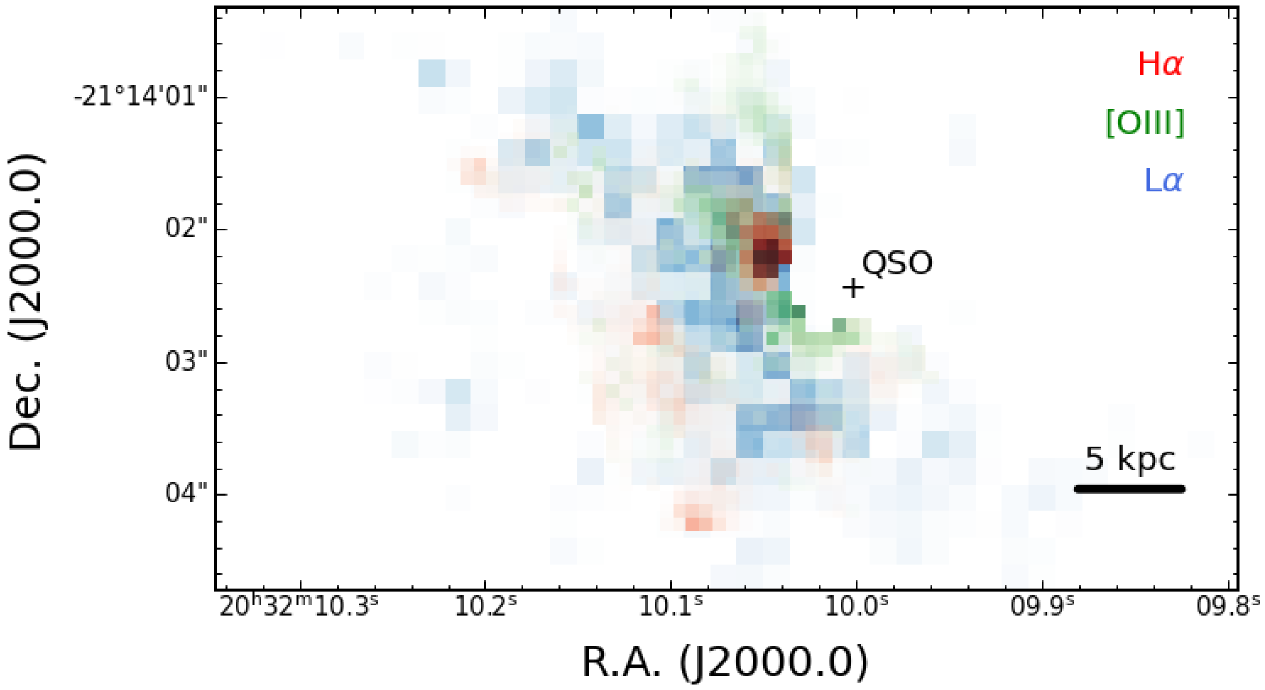
Decarli et al. (in prep)

Stellar mass and SFR of the companions



Decarli et al. (in prep)

Origin of the Lyα halo

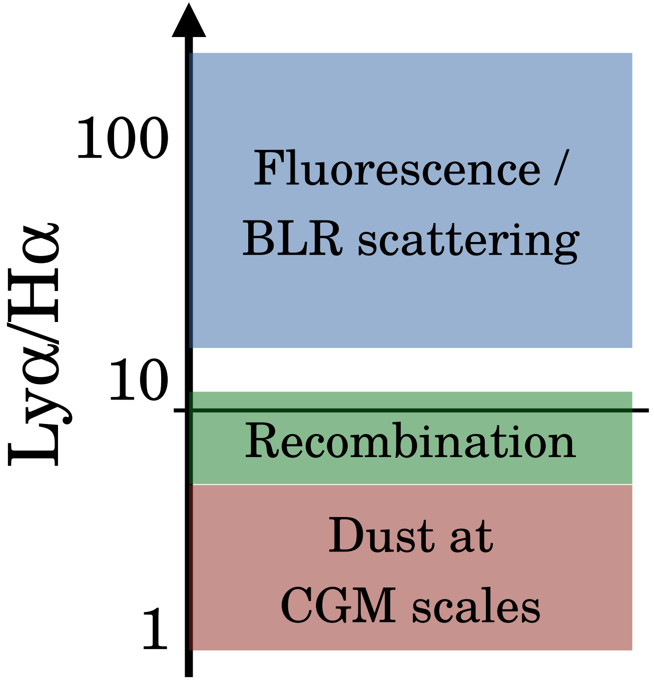


Lyα halo:

- Detected in Hα and [OIII]!
- But only close to the quasar

Farina et al. (in prep)

Origin of the Lyα halo



Lyα halo:

- Detected in Hα and [OIII]!
- But only close to the quasar

Farina et al. (in prep)

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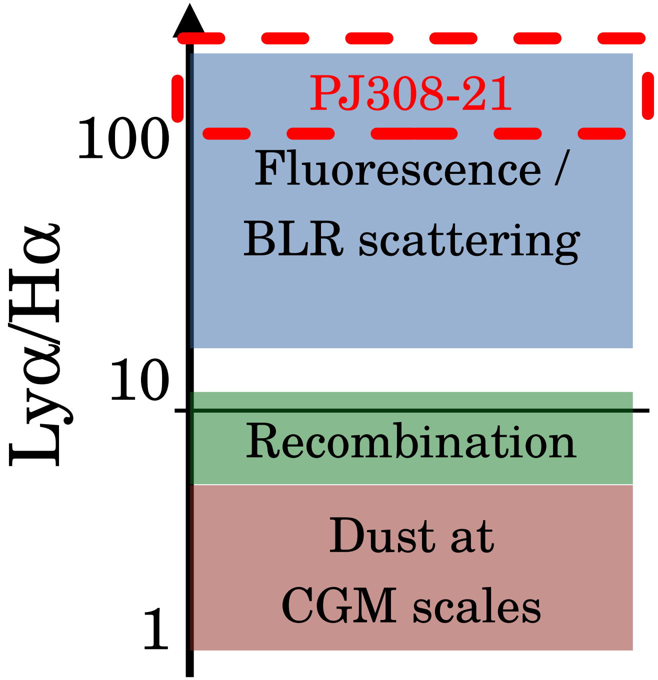

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Conclusions – Project I

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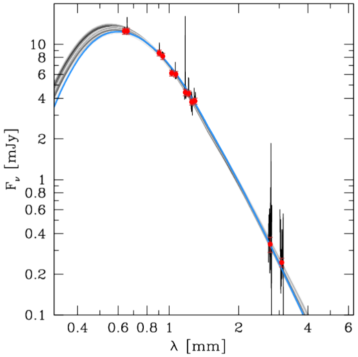
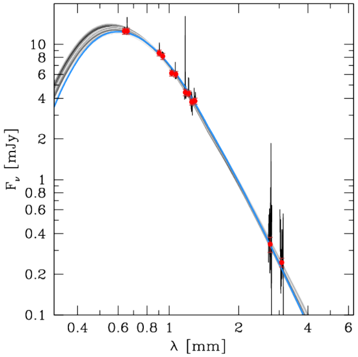


High dust content & opacity,

L_{IR}~10^{13} L_o, T_{dust}~47 K

Conclusions – Project I

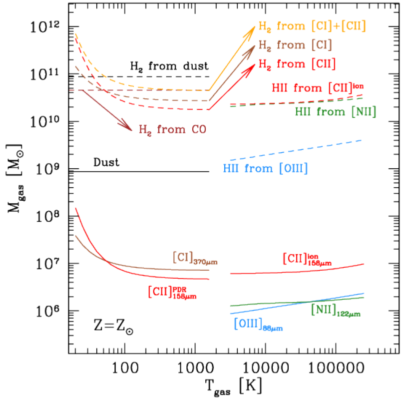


High dust content & opacity,

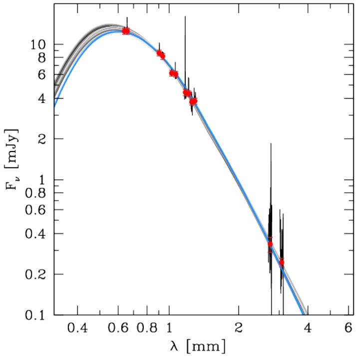
$L_{IR}\sim10^{13}$ L_o, $T_{dust}\sim47$ K

Copious gas reservoirs ($\sim10^{11}$ M_o),

both ionized and molecular



Conclusions – Project I



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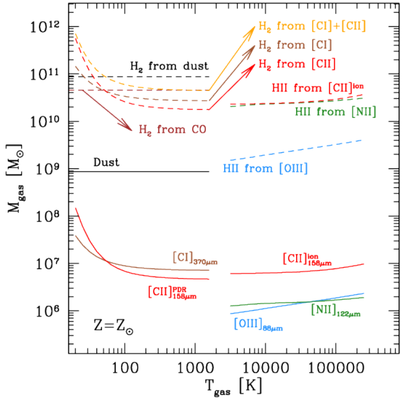
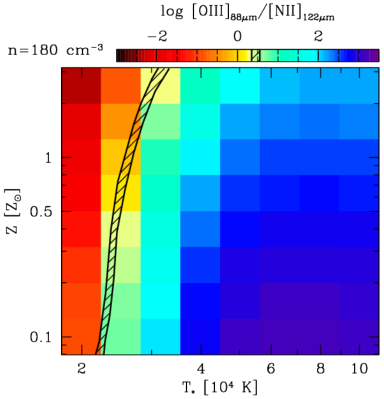


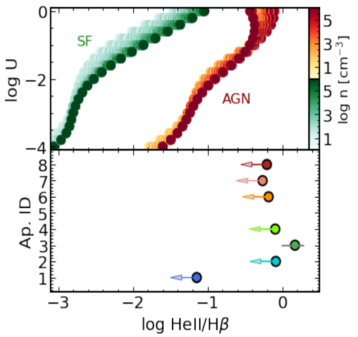


Quasar photoionization & excitation not required (but likely contributing)

Conclusions – Project II

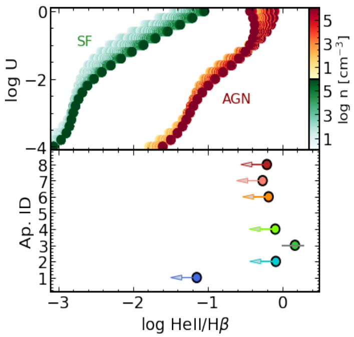
Quasar host:

Metal rich, ~10^{11} $M_{\odot}$, dominated by AGN photoionization



Conclusions – Project II

Quasar host:



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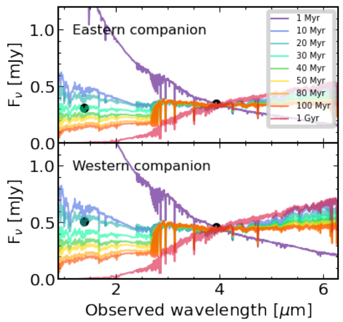

Companions:

About half solar metallicity, a few 10^{9} $M_{\odot}$, SF photoionization, very young burst

Conclusions – Project II

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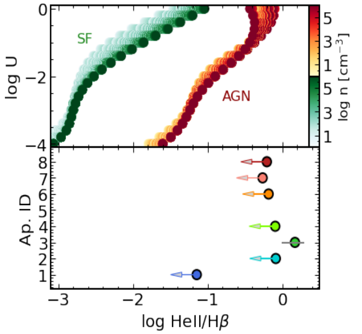
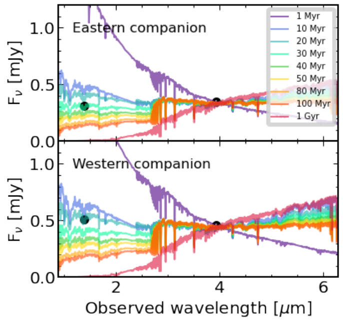


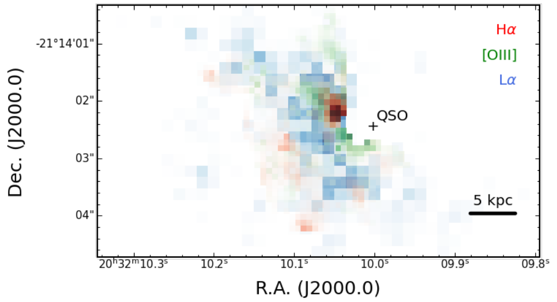


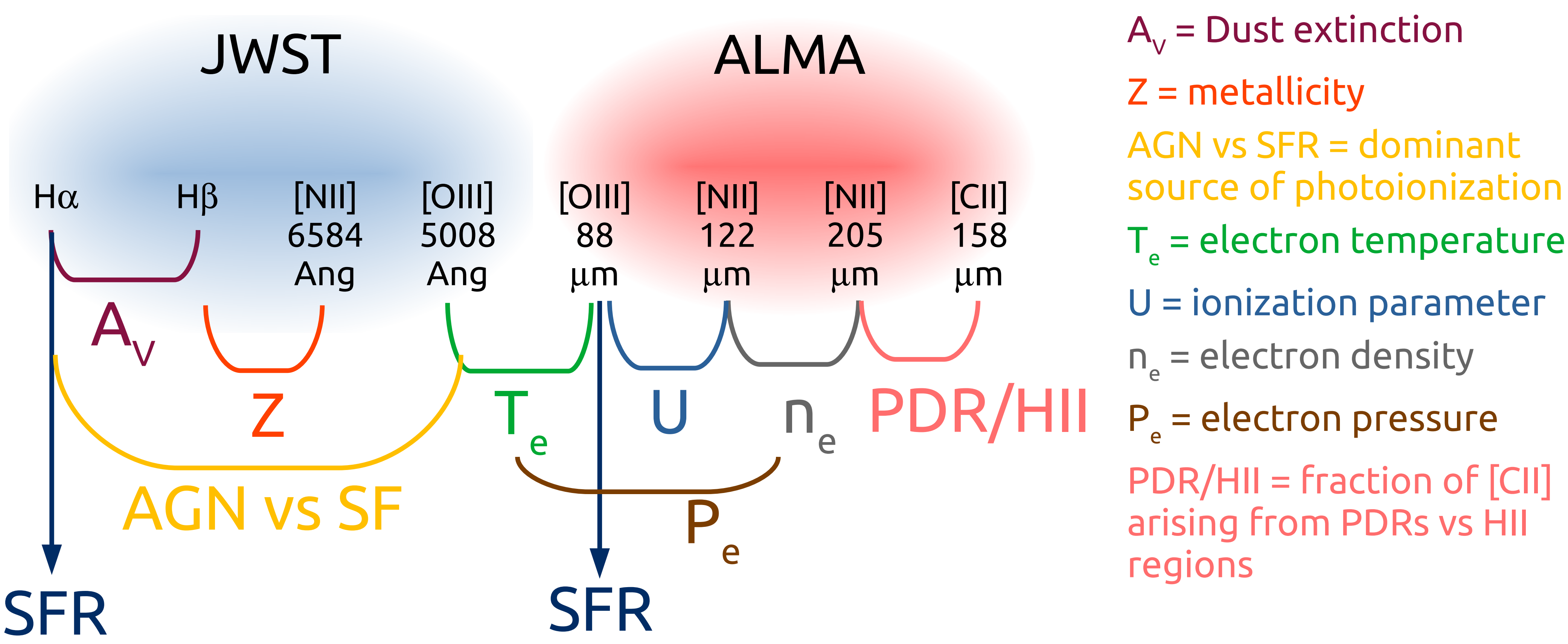
Companions:

About half solar metallicity, a few 10^9 $M_{\odot}$, SF photoionization, very young burst

Halo:

Outflow+BLR scattering rather than recombination




JWST
ALMA
Hα
Hβ
[NII] 6584 Ang
[OIII] 5008 Ang
[OIII] 88 μm
[NII] 122 μm
[NII] 205 μm
[CII] 158 μm
A_V
Z
T_e
U
n_e
PDR/HII
AGN vs SF
P_e
SFR
SFR
A_V = Dust extinction
Z = metallicity
AGN vs SFR = dominant source of photoionization
T_e = electron temperature
U = ionization parameter
n_e = electron density
P_e = electron pressure
PDR/HII = fraction of [CII] arising from PDRs vs HII regions