The early growth of massive galaxies and how it is shaped by black hole feedback

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September 1st 2023 - Cosmology 2023 in Miramare

Collaborators: C. Feruglio, R. Tripodi, F. Fiore, V. D'Odorico…& many others

AGN Feedback at z>6 via Broad Absorption Line winds

Bischetti et al. 2022, Nature, 605, 244

Bischetti et al. 2023, ApJ, 952, 44

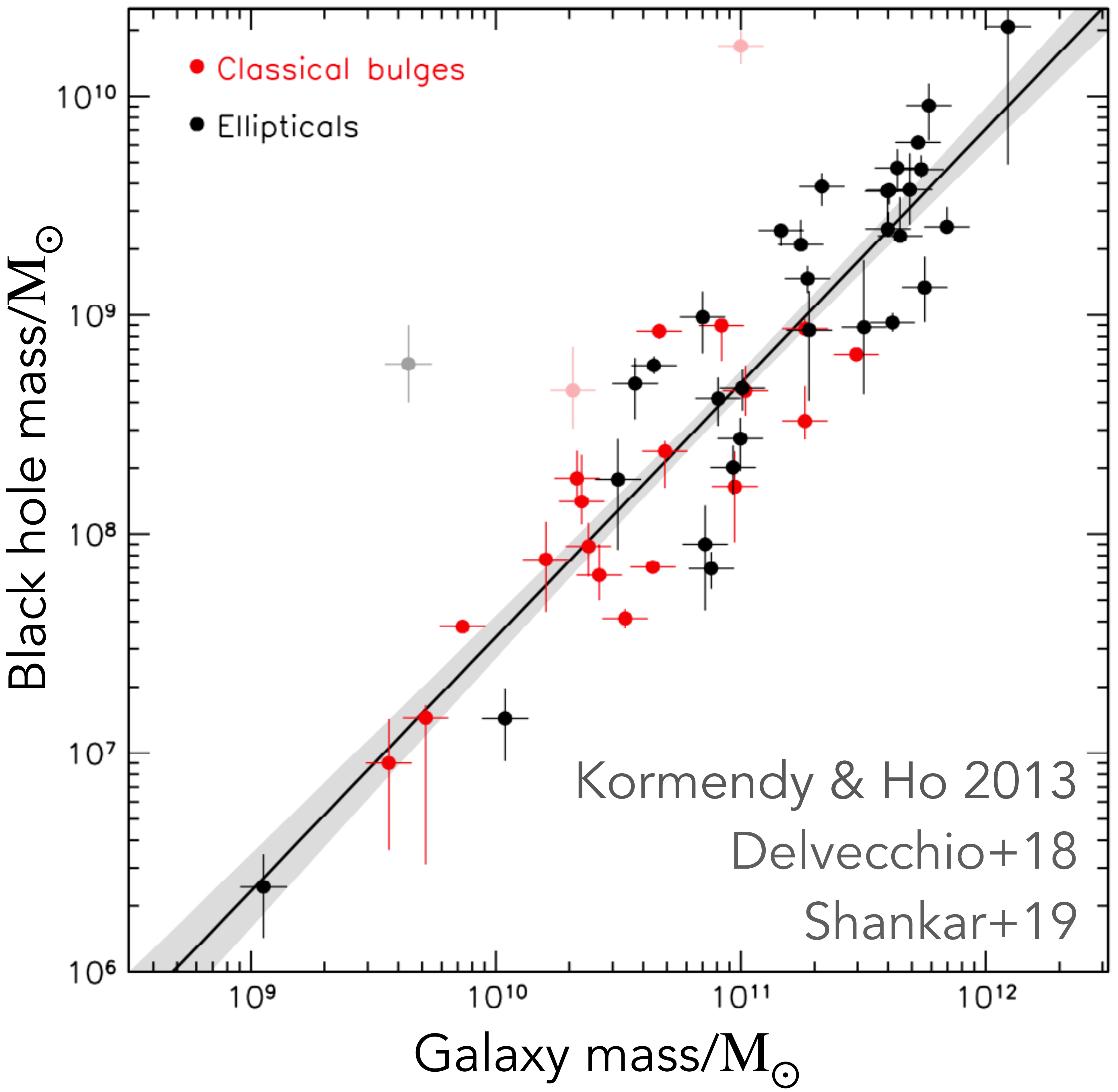
SFR and cold gas properties in the host galaxies of z>6 quasars

Feruglio et al. 2023, ApJL, 954, L10

Tripodi et al. 2023, arXiv:2306.01644

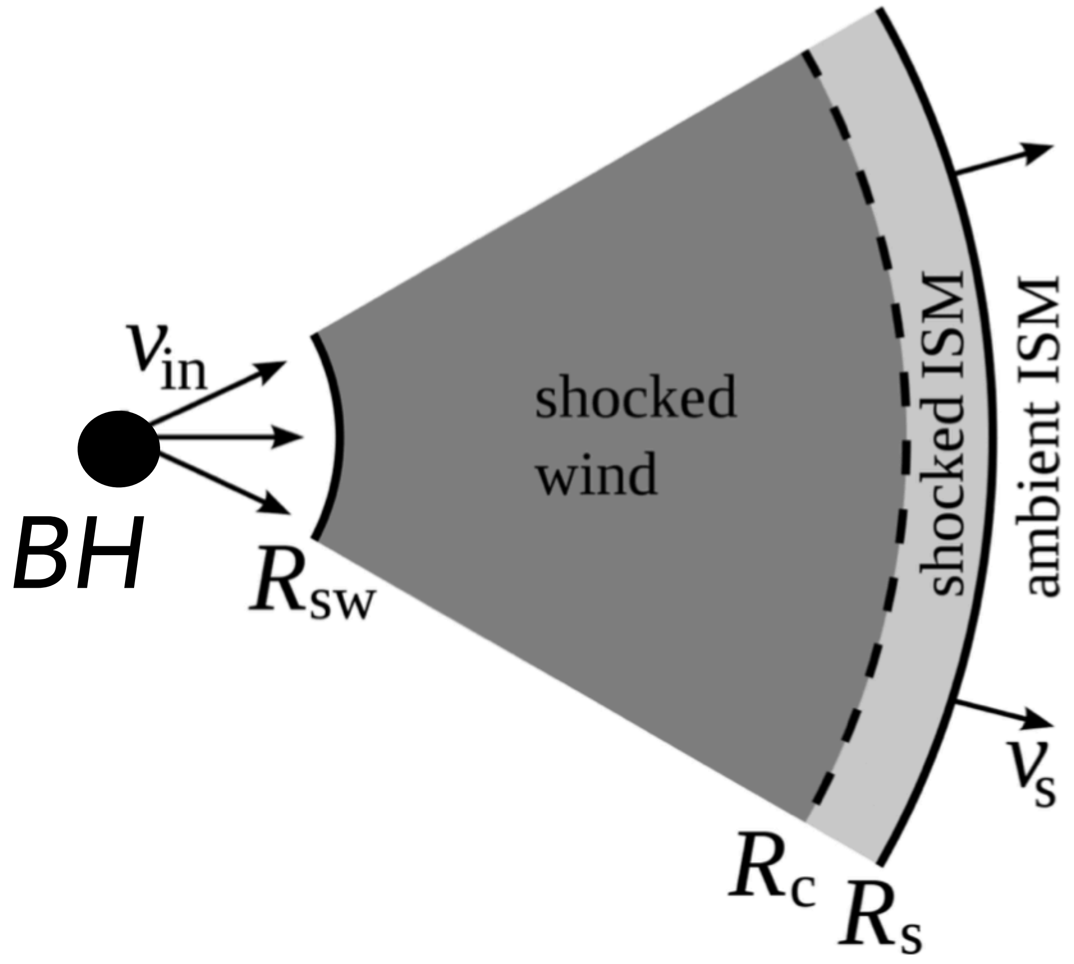
Black-hole and host-galaxy scaling relations

BH mass and host-galaxy mass in the local Universe are closely linked: **symbiotic growth**



A BH close to the local relation is expected to drive a mildly relativistic wind.

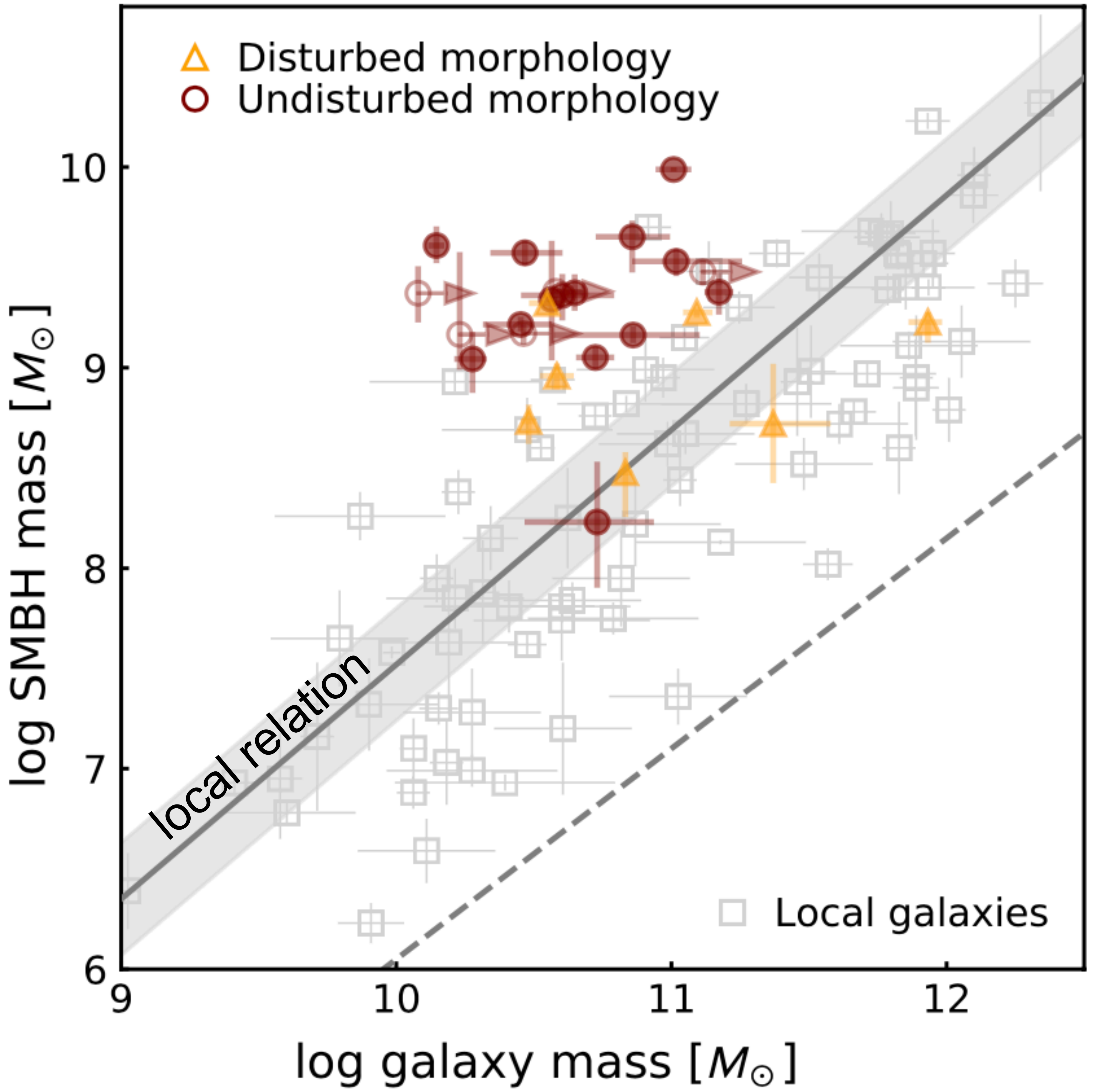
The wind creates a shocked region which expands and sweeps/heats the BH surroundings and the galaxy medium



e.g. Zubovas&King 2012
Richings & Fauchér-Giguère 2018

BH Feedback regulates the relative BH and host-galaxy growth

Black-hole and host-galaxy scaling relations at z~6



Neeleman et al. 2021

Mazzucchelli, Bischetti et al. 2023

Quasars at z~6 are powered by billion solar masses BHs. These BHs are ~10x overmassive with respect to their host galaxies: they must have grown more rapidly than their hosts during the first ~1Gyr

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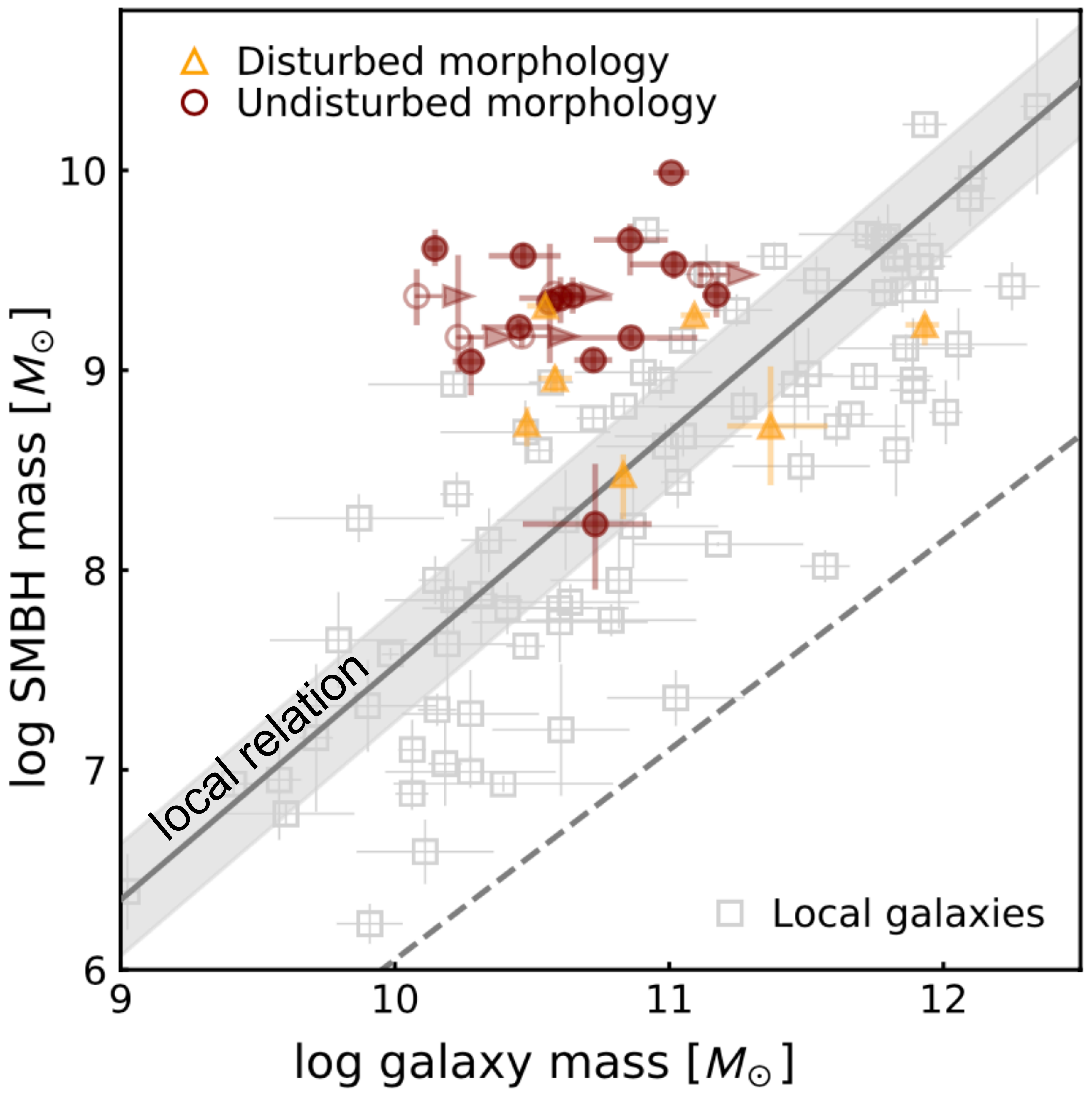
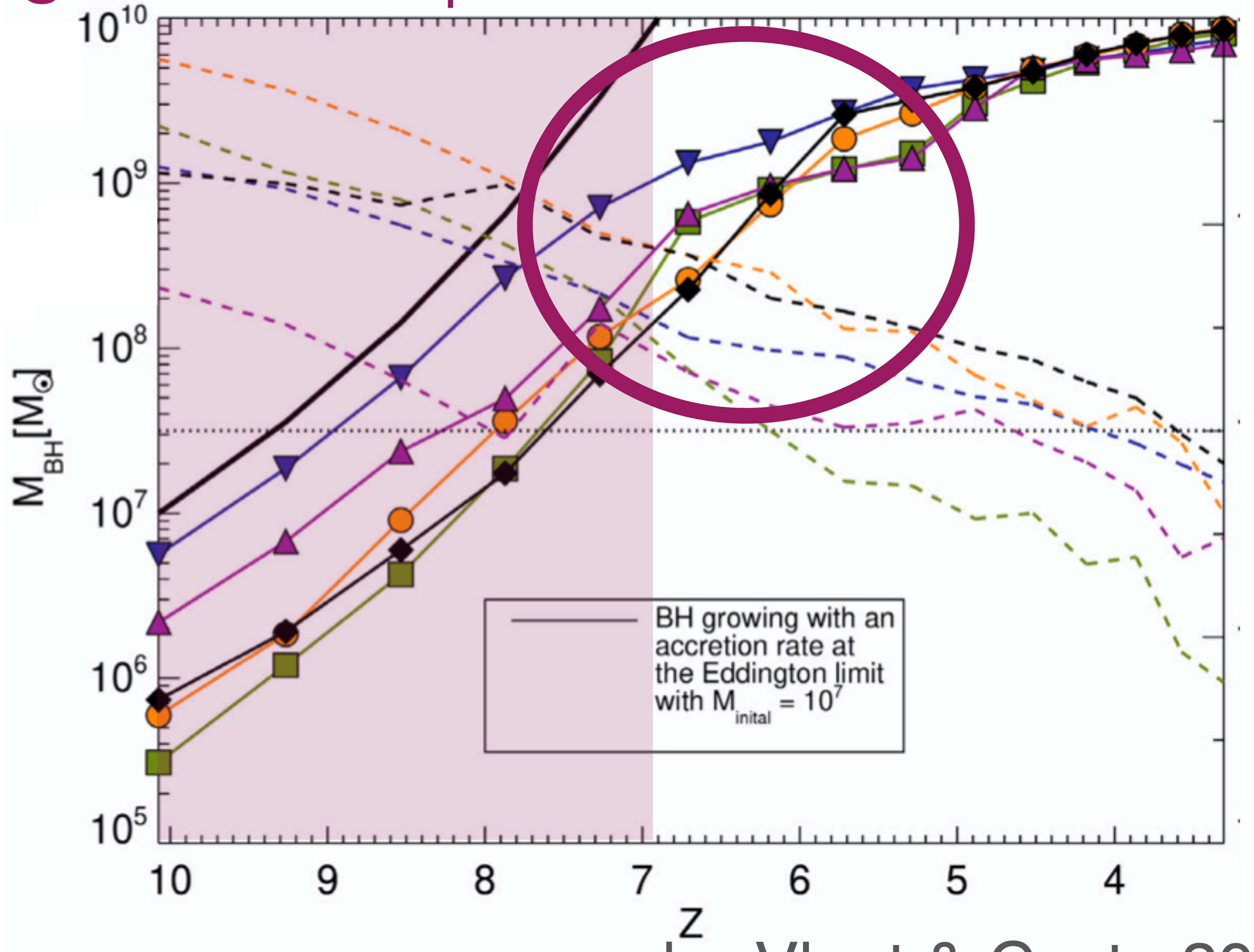


Neeleman et al. 2021

Mazzucchelli, Bischetti et al. 2023

Quasars at z~6 are powered by billion solar masses BHs. These BHs are ~10x overmassive with respect to their host galaxies: they must have grown more rapidly than their hosts during the first ~1Gyr

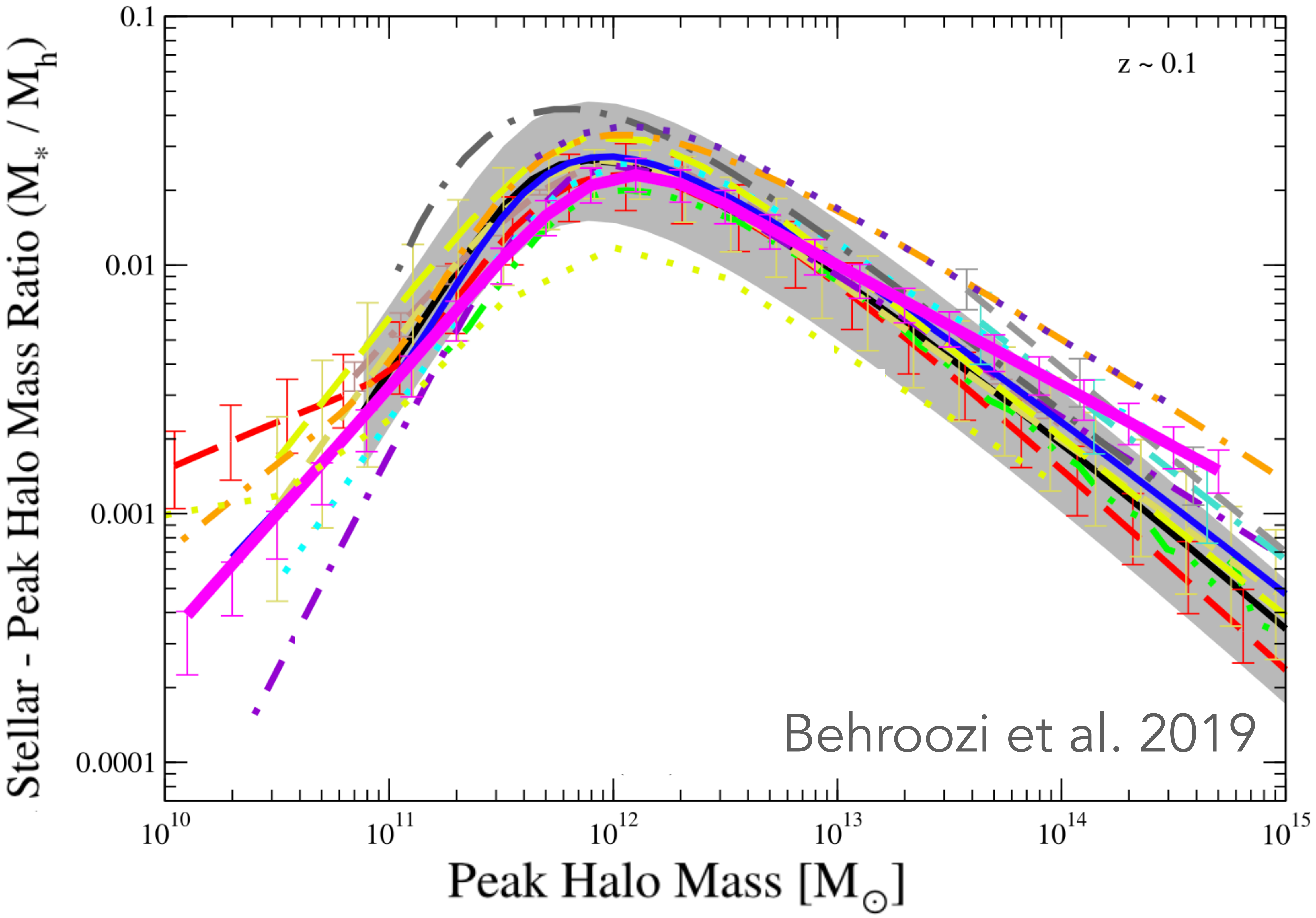
BH growth is expected to slow down at z~6



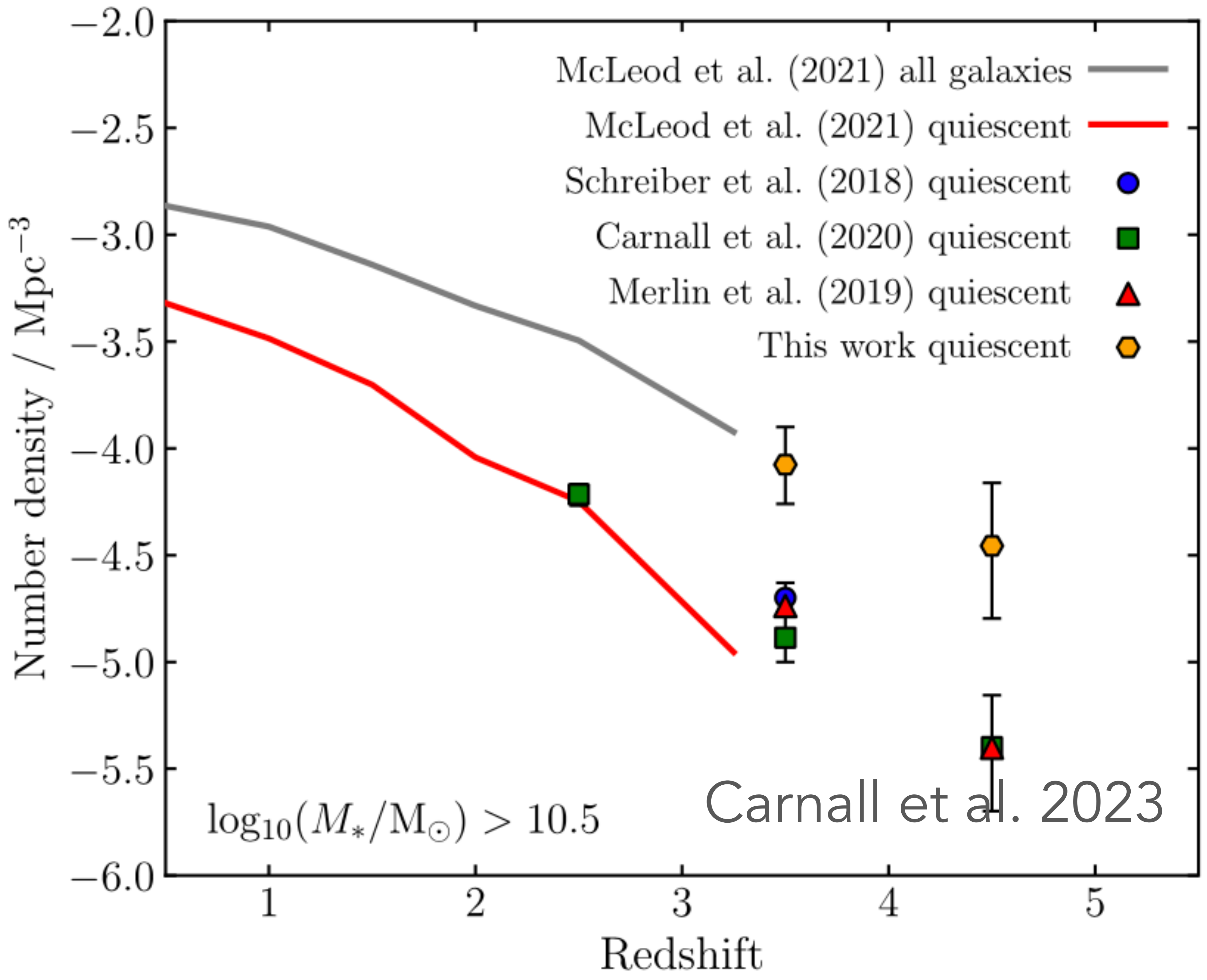
van der Vlugt & Costa 2019

Black-hole feedback in massive galaxies evolution

Feedback from accreting supermassive black-holes (BHs) is typically invoked to explain the low efficiency of star formation in massive galaxies.

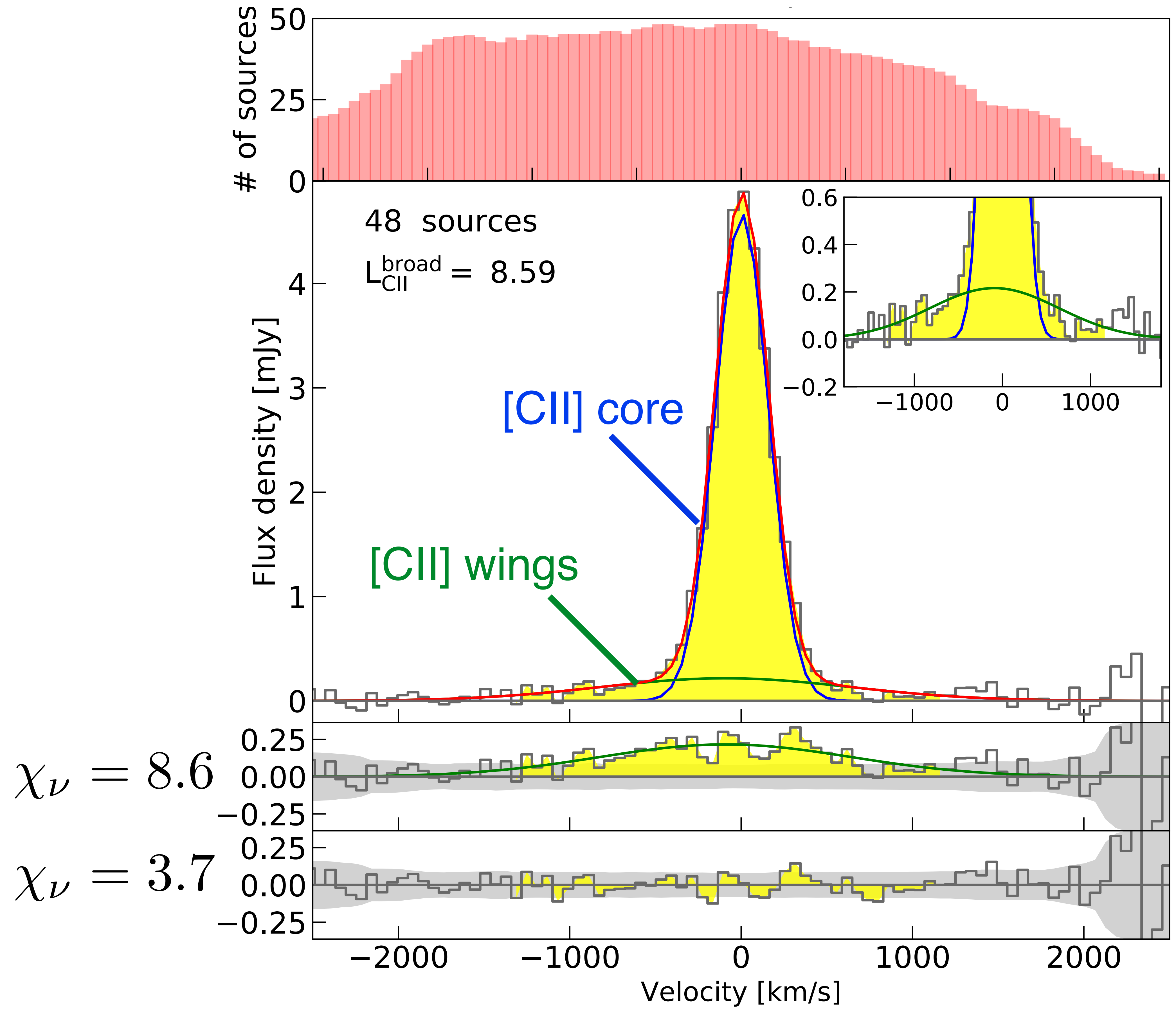


Passive candidates in JADES



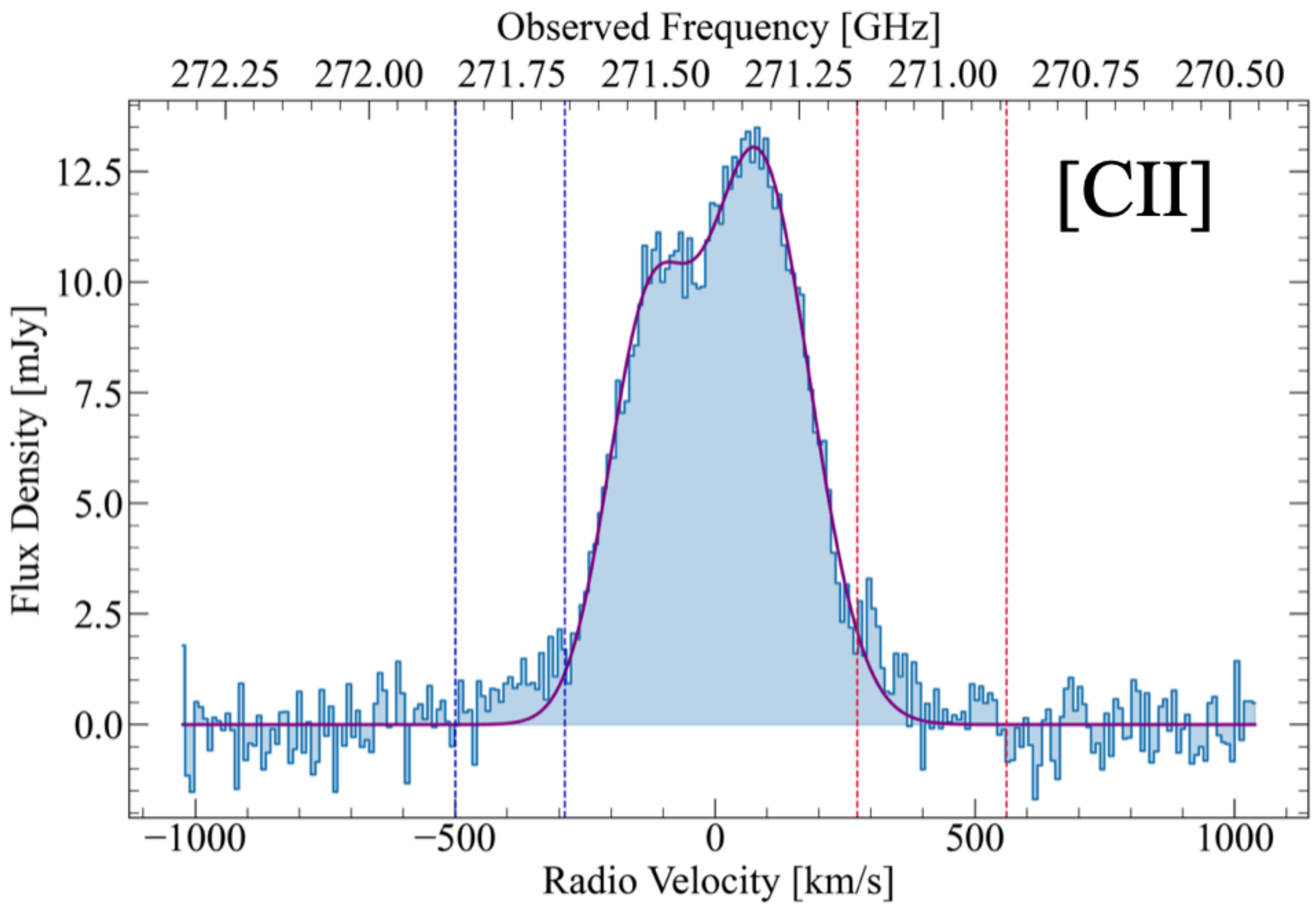
The existence of massive, quiescent systems observed at z ~ 3 - 5 indicates that a feedback mechanism had to be already in place at early epochs ($z \gtrsim 6$)

Detecting BH driven outflows at z~6 in the cold gas is challenging



Stacking analysis: 48 high-z quasars at 5<z<7 observed in [CII] 158 μm with ALMA

Bischetti et al. 2019b



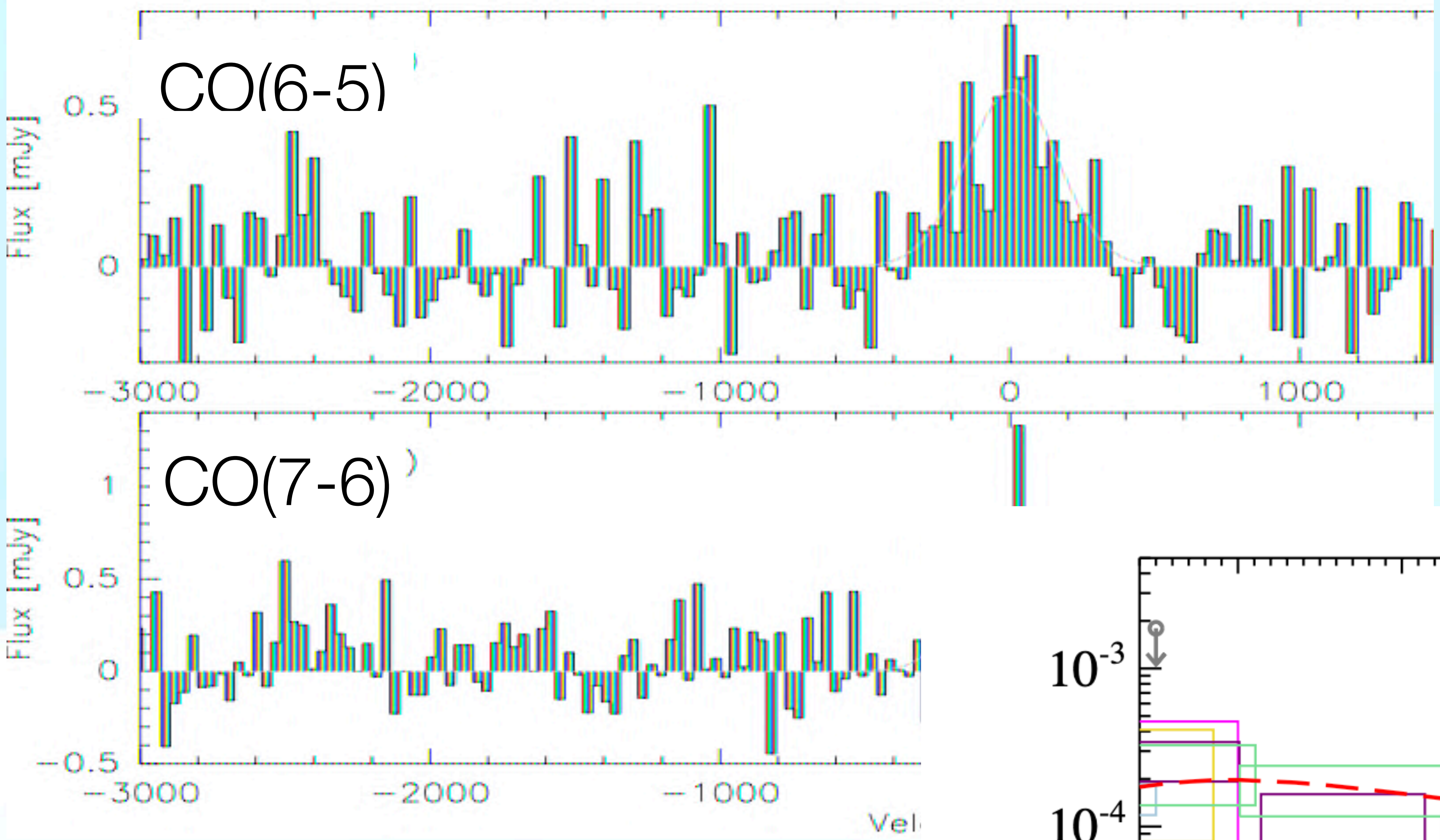
Deep dedicated observations

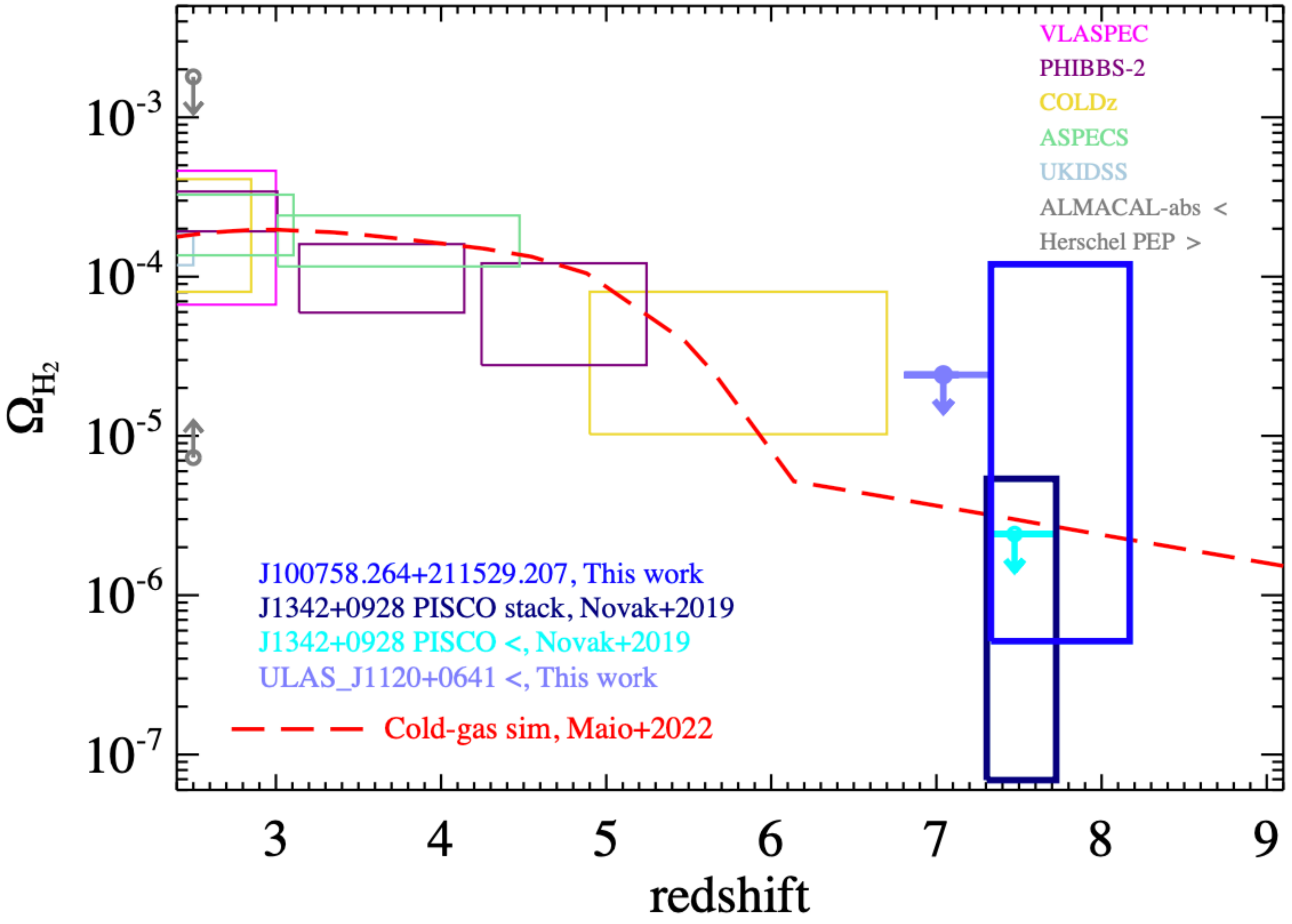
Tripodi et al. 2022, A&A 665, A107

see also Maiolino et al. 2012, Izumi et al. 2021,2022

No detection of cold gas outflows at z>7 up to now

H_2 in z=7.5 quasar Pōniuāʻena





Feruglio et al. 2023

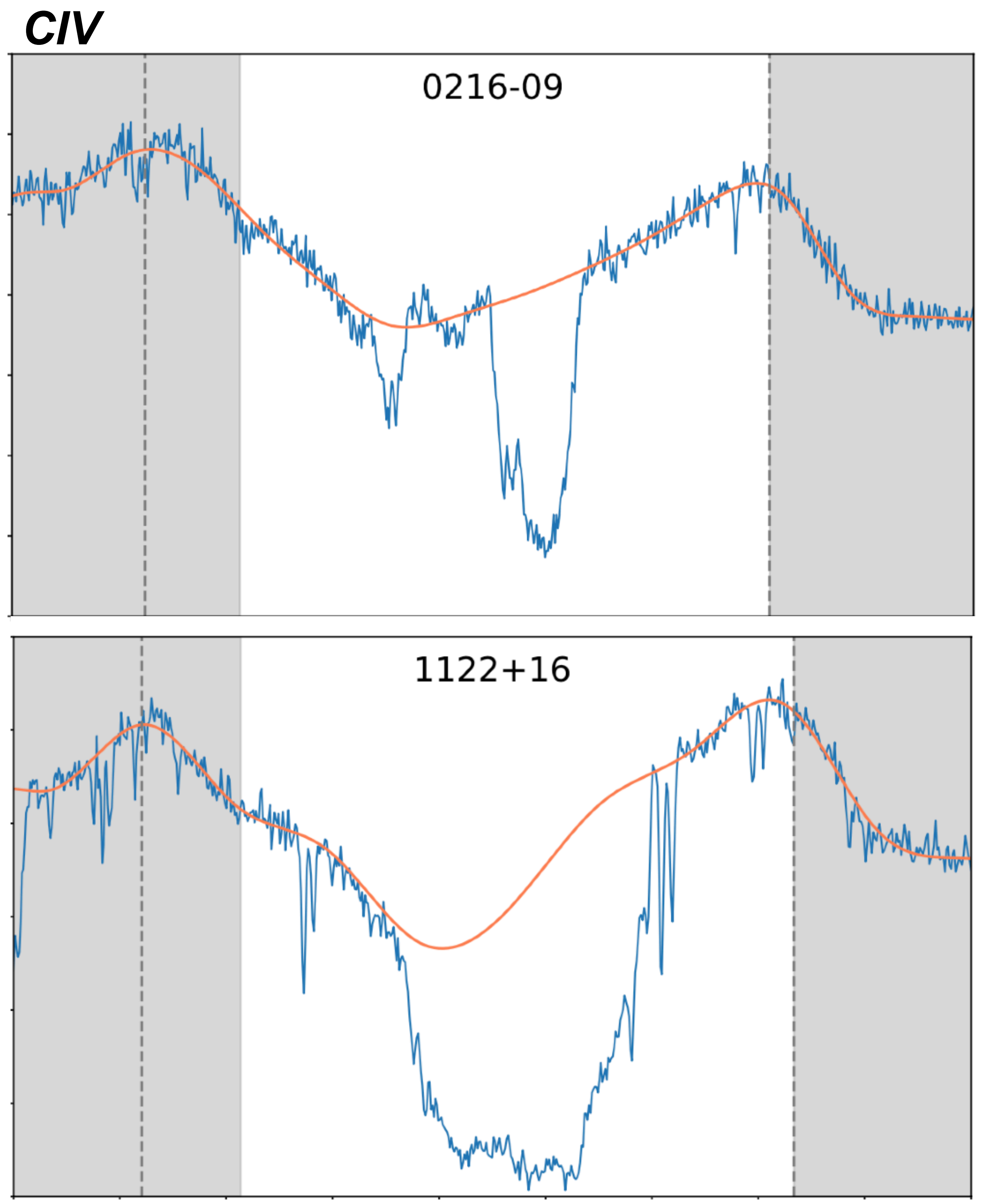
8 quasars known at z>7

- No cold outflows detected so far at z>7
- First constraint on H_2 abundance at z>7

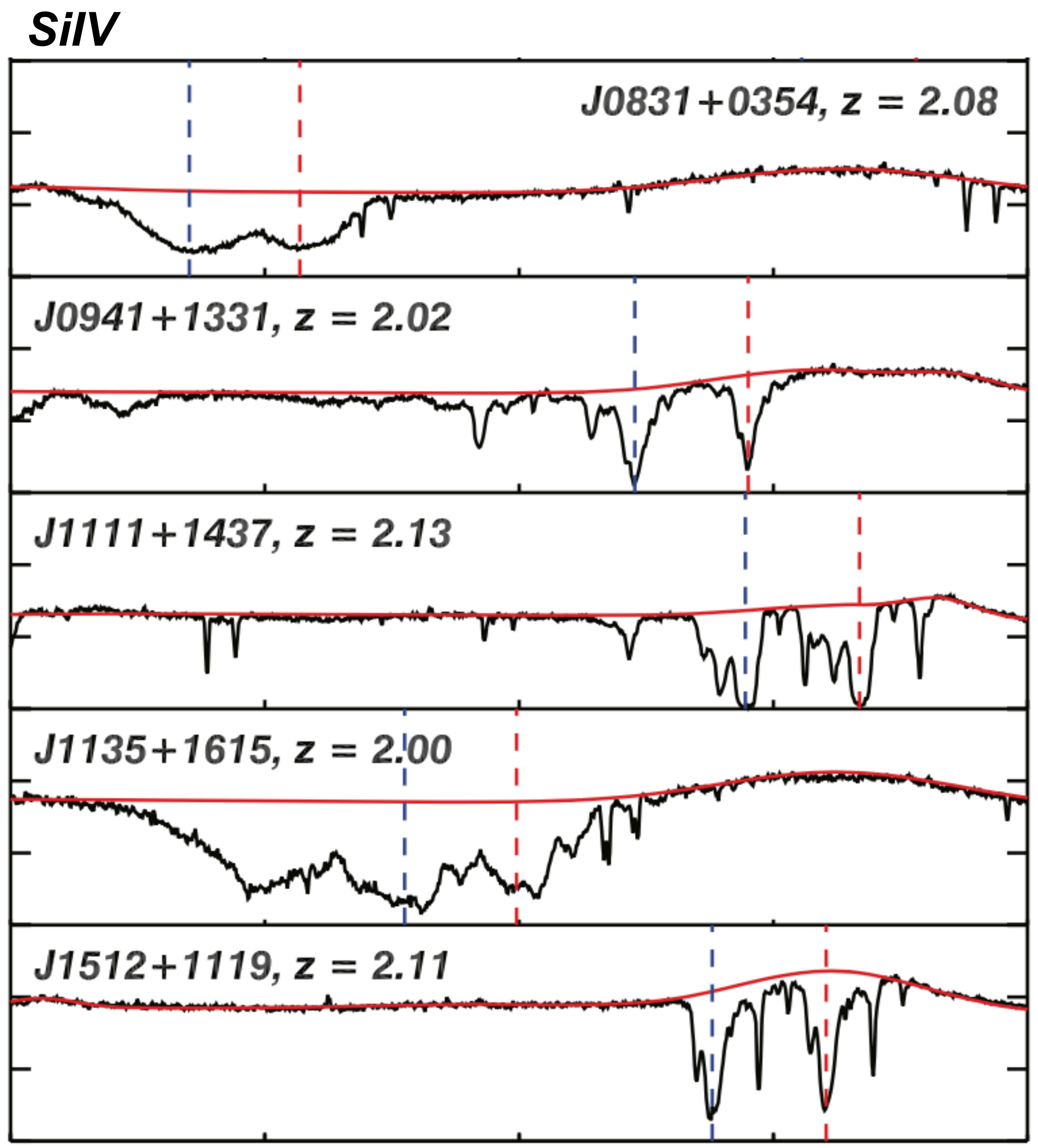
Detecting BH driven outflows at z~6: an alternative approach

BH outflows in the ionized gas phase can be probed as **Broad absorption line (BAL)** features in the UV spectra of quasars up to z~6-7

(Bruni+19, Wang+18,21, Schindler+20, Yang+21)



Bruni+2019



Xu+2020

At z~2-4:

Observed in 10-20% of quasars

Typical BAL velocity ~10000 km/s

Trump+2006, Dai +2008, Gibson+2009, Allen + 2011, Paris+2018, Bruni +2019

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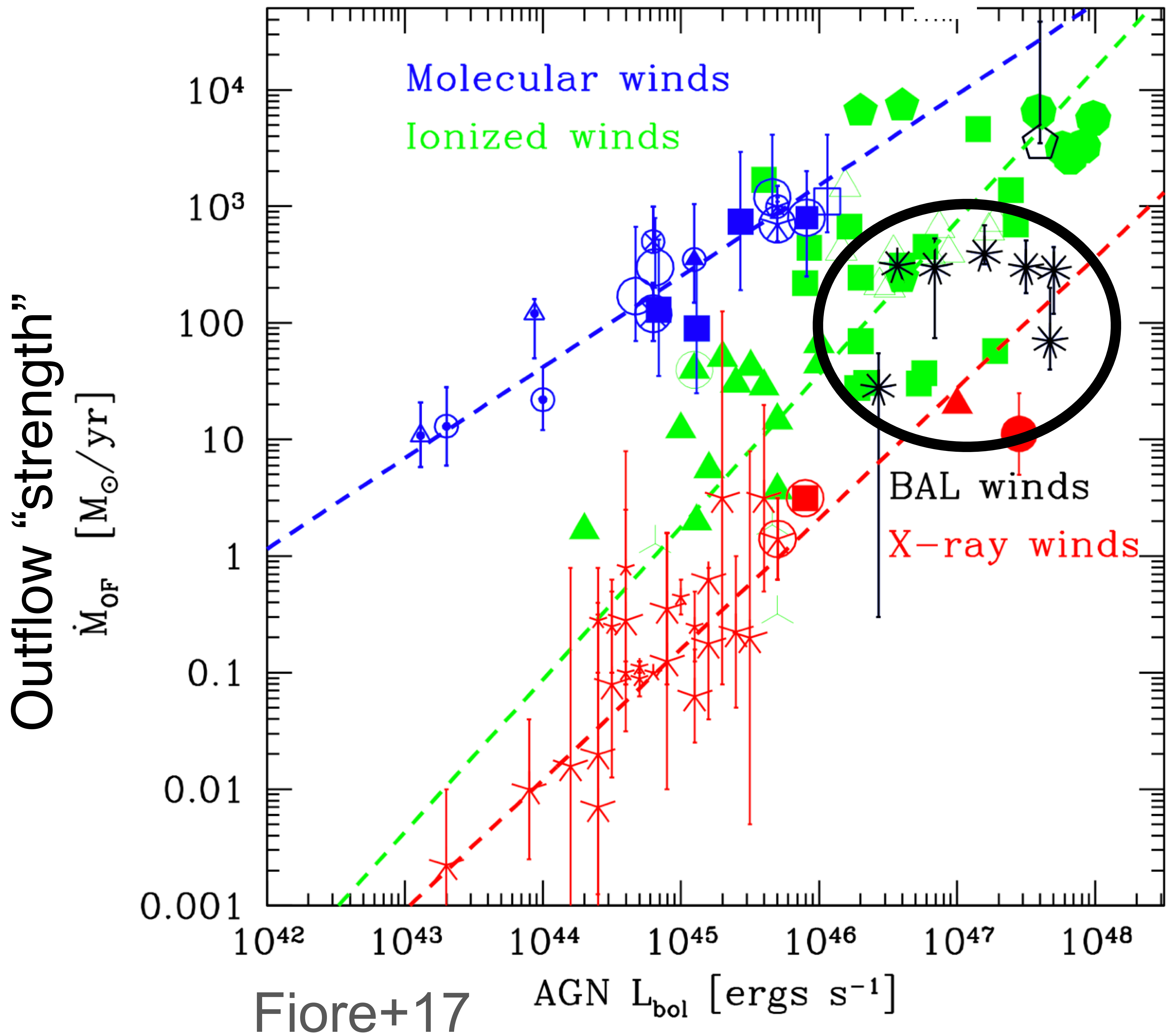


Fiore+17

Accretion disk winds (~1pc), absorption can occur at distances up to 100-1000 pc from the BH

Large mass outflow rates of 100-1000 M/yr

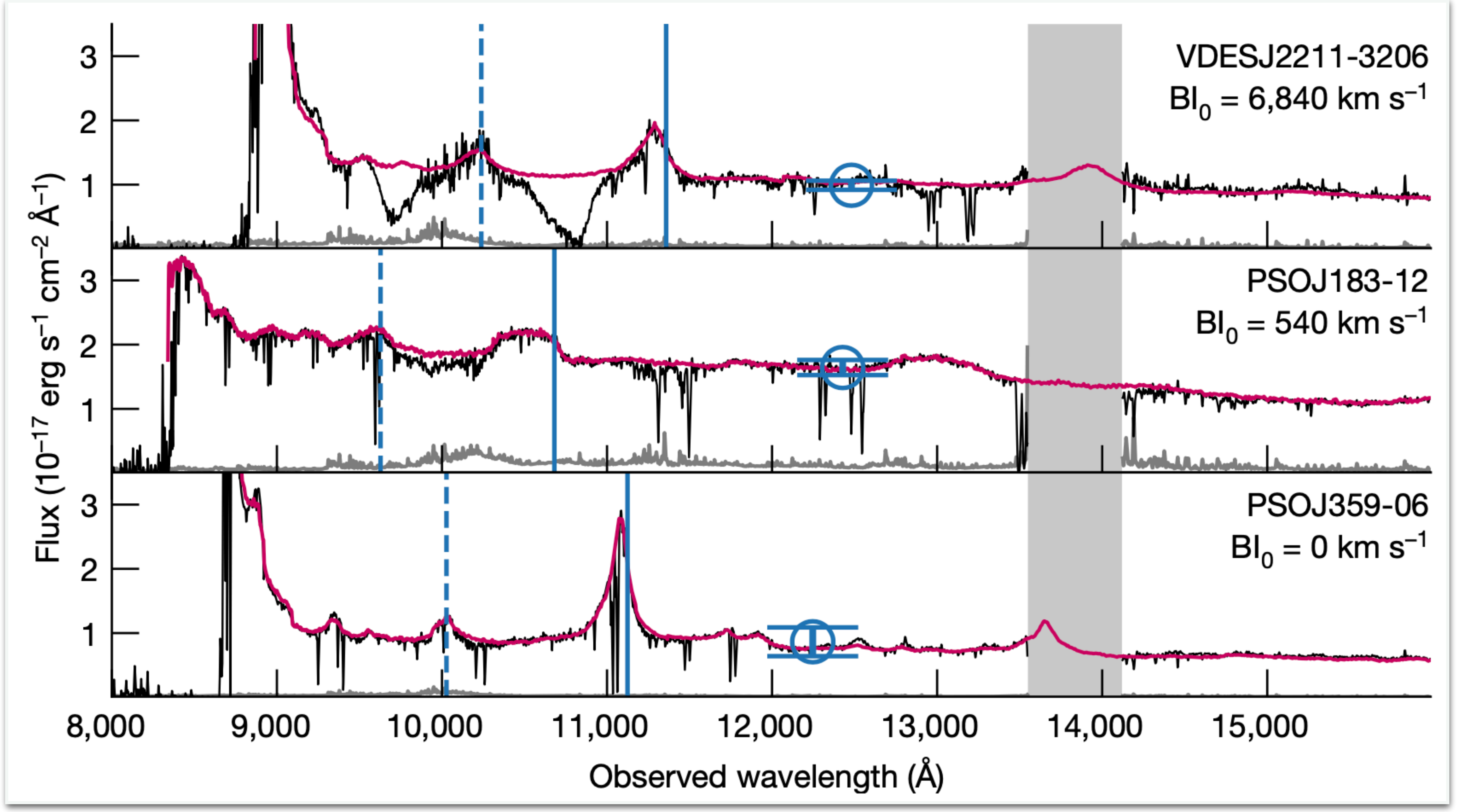
Dunn et al. 2010, Borguet et al. 2013, Arav et al. 2018, Byun et al. 2022, Vietri et al. 2022

BALs can be important sources of feedback on both BH and host-galaxy growth

XQR-30: The X-Shooter legacy survey of Quasars at Reionization

ESO LP ~250 hr (P.I. V. D'Odorico)

- 30 quasars at 5.8<z<6.6
- Selected to be bright in the rest-frame UV (J band) and in the rest-frame optical (W1, W2 bands)
- Typical S/N>25 per 50 km/s pixel



First systematic search for BAL outflows in z~6 quasars

Bischetti et al. 2022, Nature, 605, 244

Suppression of black-hole growth by strong outflows at redshifts 5.8–6.6

https://doi.org/10.1038/s41586-022-04608-1

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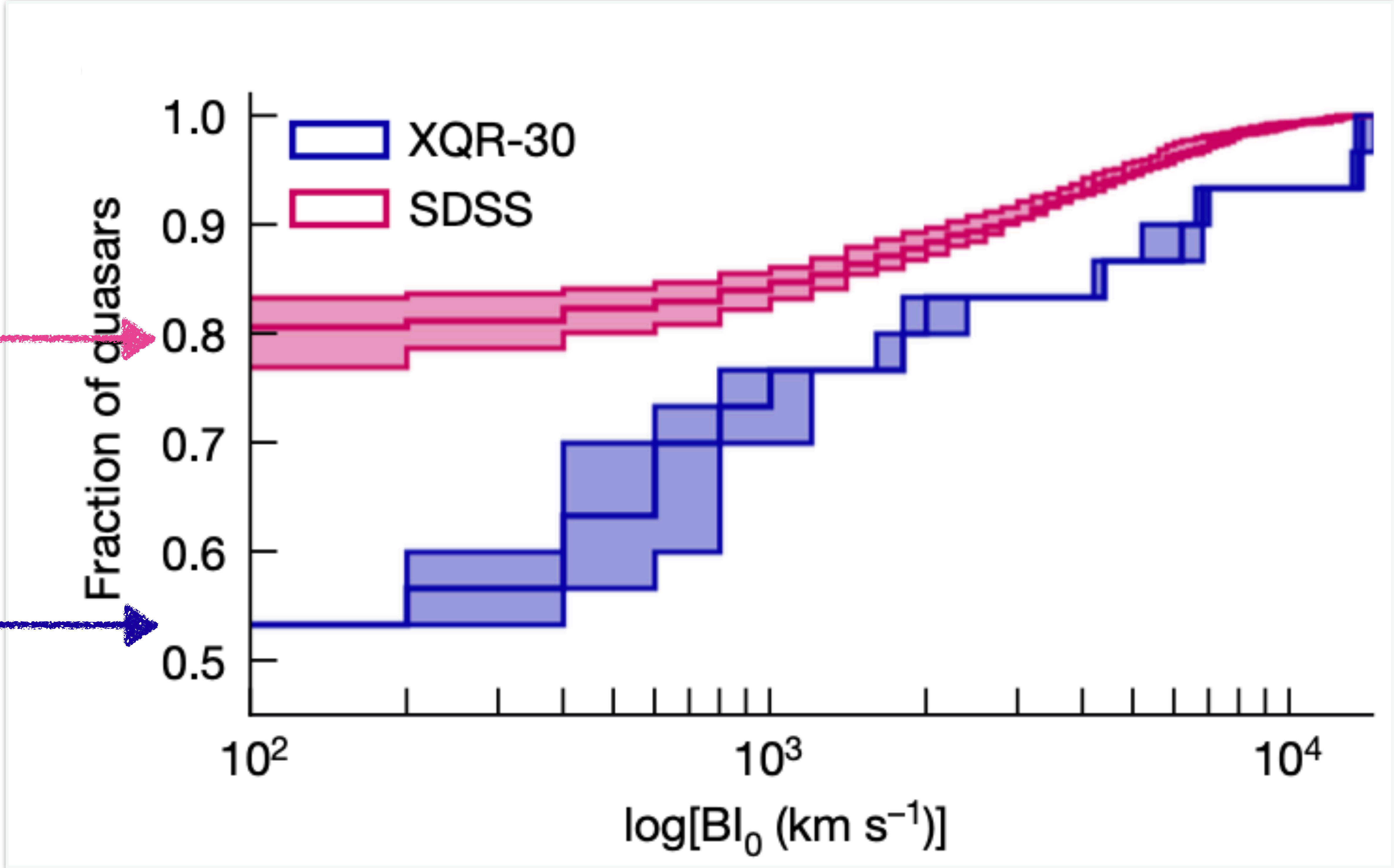
M. Bischetti[1✉], C. Feruglio[1,2], V. D'Odorico[1,2,3], N. Arav[4], E. Bañados[5], G. Becker[6], S. E. I. Bosman[5], S. Carniani[3], S. Cristiani[1], G. Cupani[1], R. Davies[7,8], A. C. Eilers[9], E. P. Farina[10], A. Ferrara[3], R. Maiolino[11], C. Mazzucchelli[12], A. Mesinger[3], R. A. Meyer[5], M. Onoue[5], E. Piconcelli[13], E. Ryan-Weber[7,8], J.-T. Schindler[5], F. Wang[14], J. Yang[15], Y. Zhu[6] & F. Fiore[1,2]

Quasars hosting BAL winds are a major population at z~6

Almost half of $z \gtrsim 6$ quasars show BAL winds associated with C IV

19%
$z \lesssim 4.5$

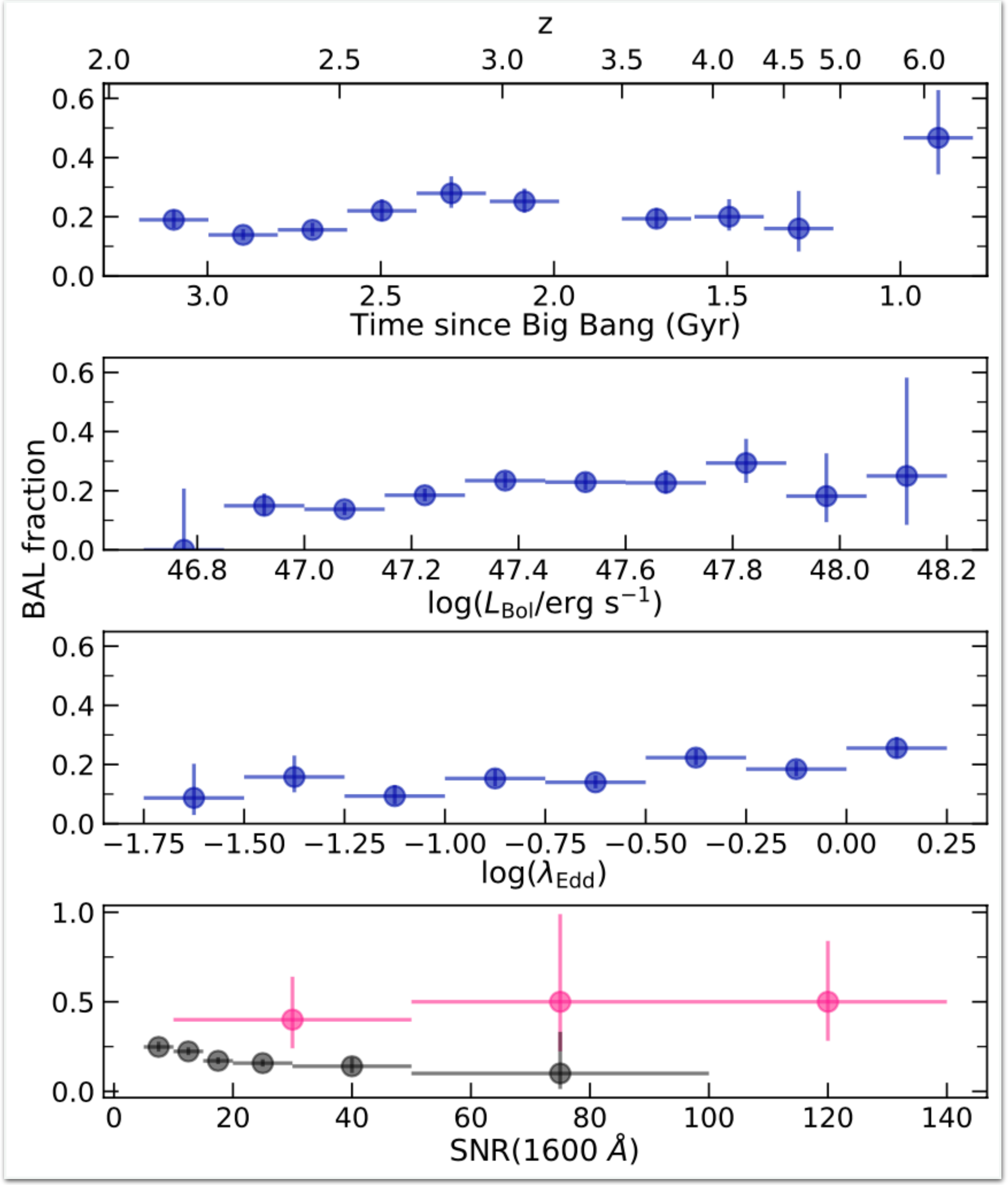
47%
$z \gtrsim 6$



BAL fraction at z~6 is a factor of ~2.5 higher than in z~2-4.5 quasars

Bischetti et al. 2022

The fraction of BAL quasars evolves with redshift

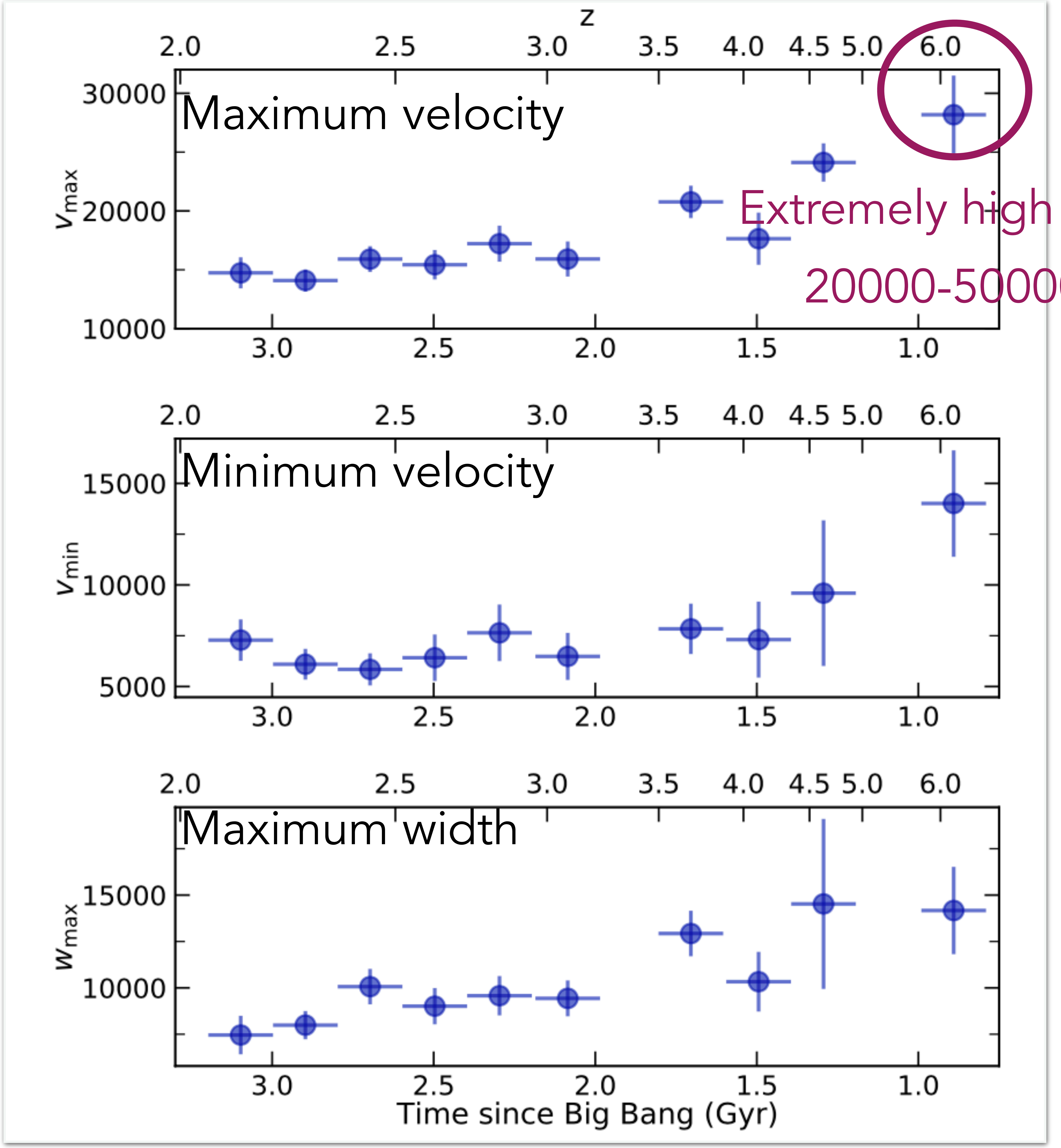


BAL fraction at z~6 is a factor of ~2.5 higher than in z~2-4.5 quasars

This difference in the BAL fraction cannot be due to differences in terms of quasar properties (luminosity, accretion rate), suggesting a **genuine redshift evolution**

Bischetti et al. 2023

The fraction of BAL quasars evolves with redshift



BAL outflows at z~6 are more efficiently accelerated (~2-3 times higher velocity) than in z~2-4.5 quasars

Bischetti et al. 2023

BAL quasars trace strong BH feedback at z~6

$$\langle \dot{E} \rangle_{BAL} \propto f_{BAL} M_{BAL} v_{max}^3$$

BAL outflows at z~6 globally inject >**20 times more energy** in their host-galaxies than at later epochs:

Strong BH feedback likely inhibiting gas accretion and suppressing BH growth

BAL quasars at z~6 may trace the onset of BH-galaxy coevolution

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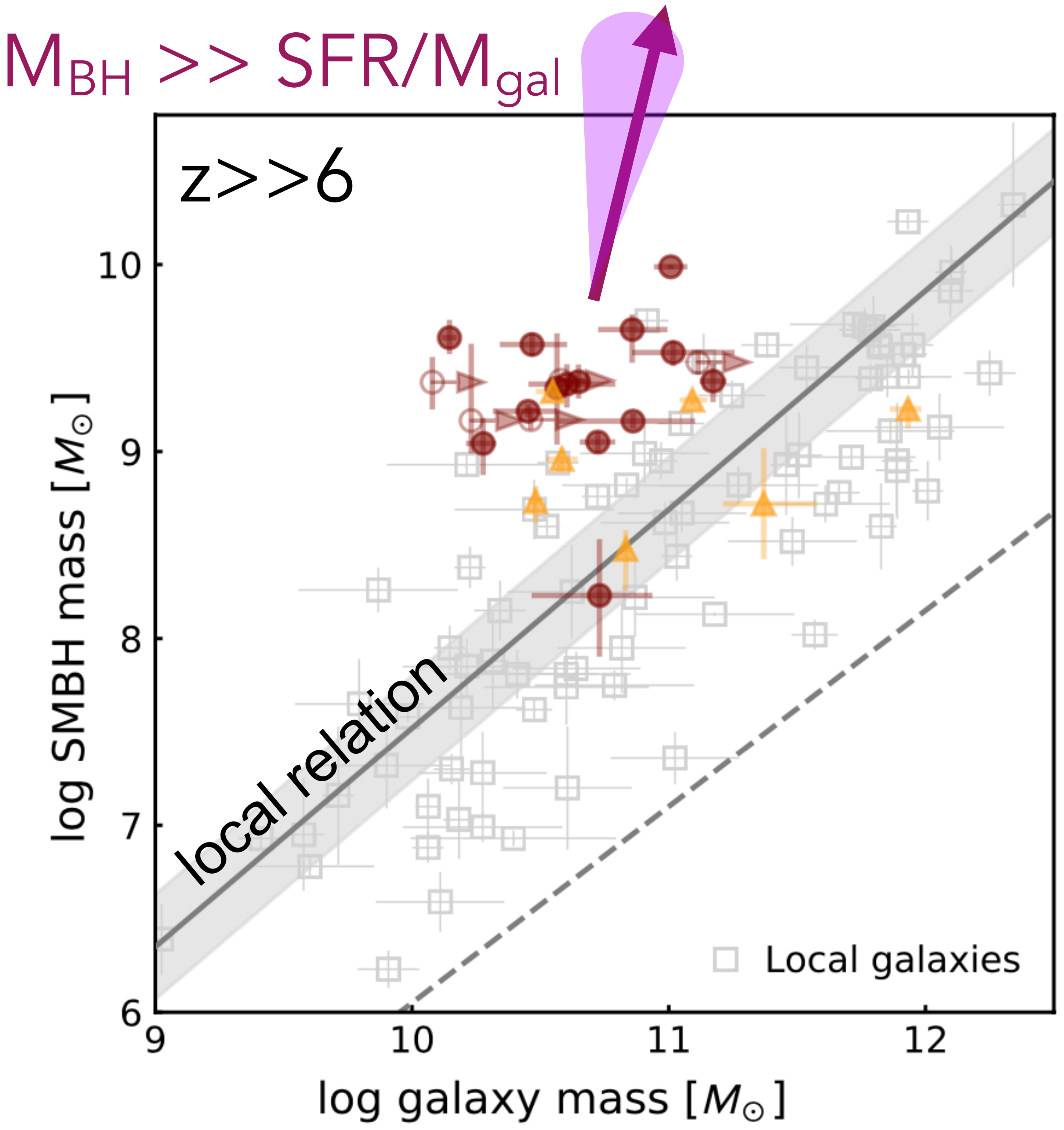
BH dominance

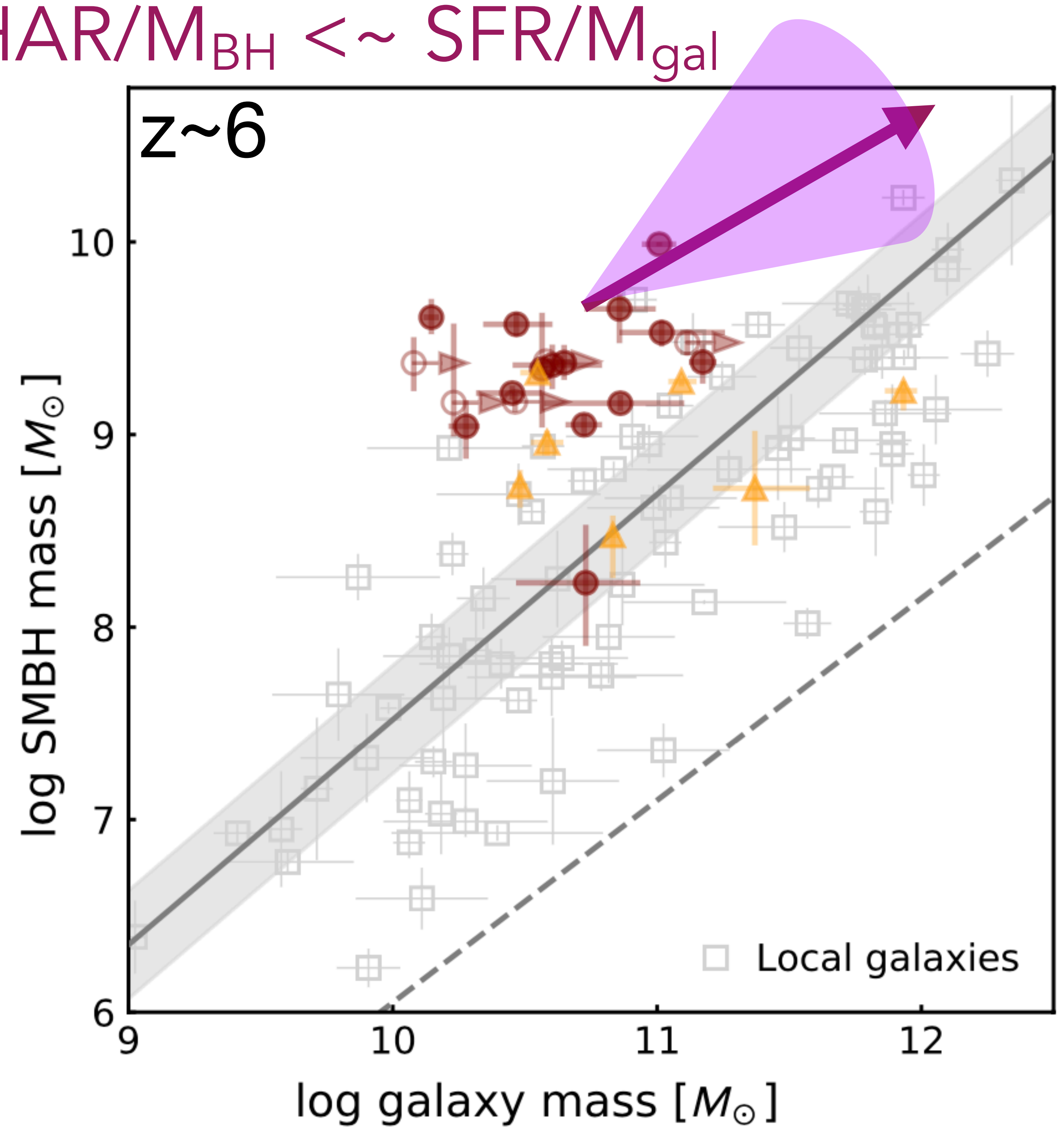
$BHAR/M_{BH} >> SFR/M_{gal}$



+ strong BH feedback

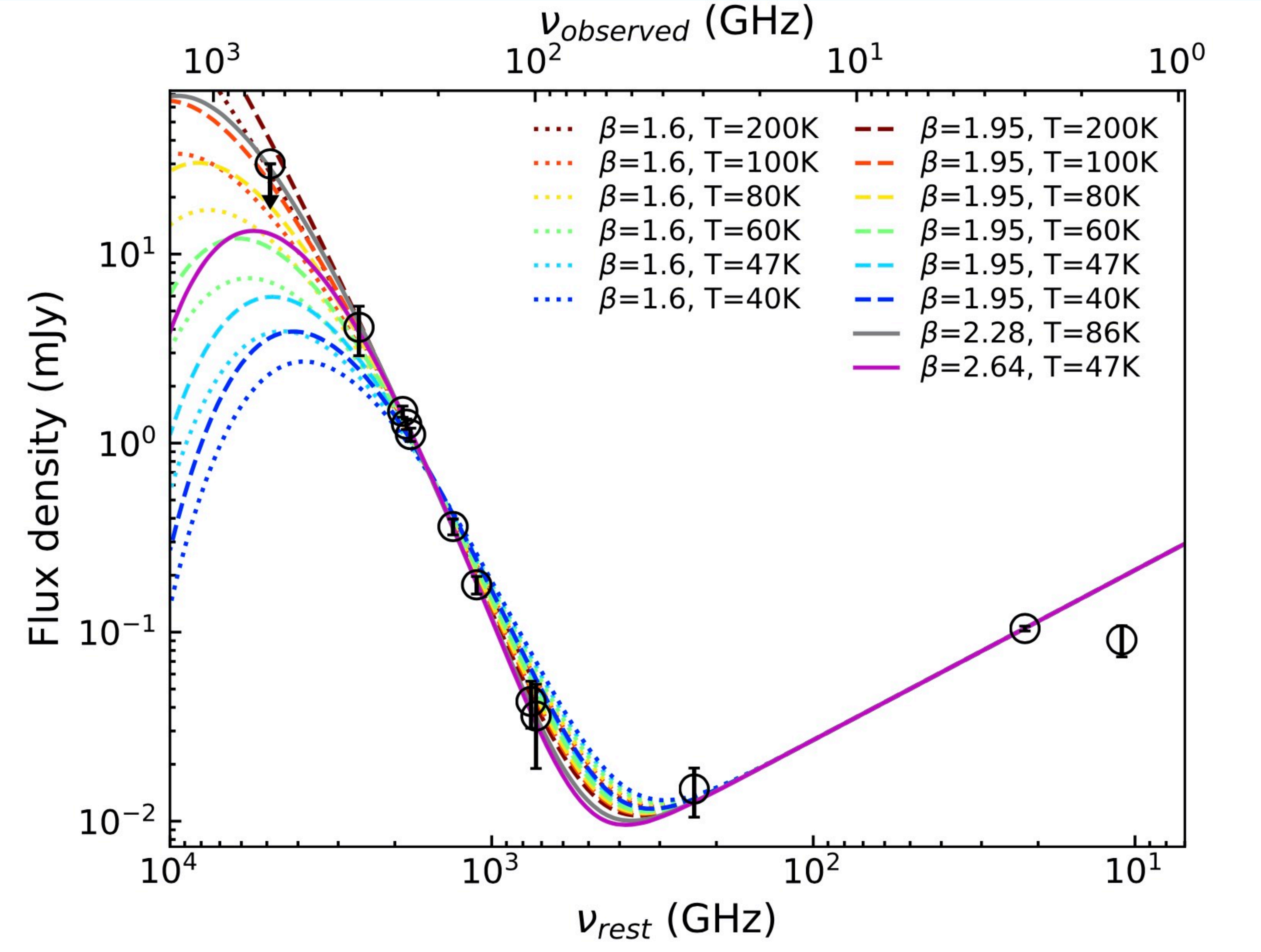
Symbiotic growth

$BHAR/M_{BH} <\sim SFR/M_{gal}$



Star formation rates at z>6

The need for high frequency



The most luminous z>6 quasar J0100+2802

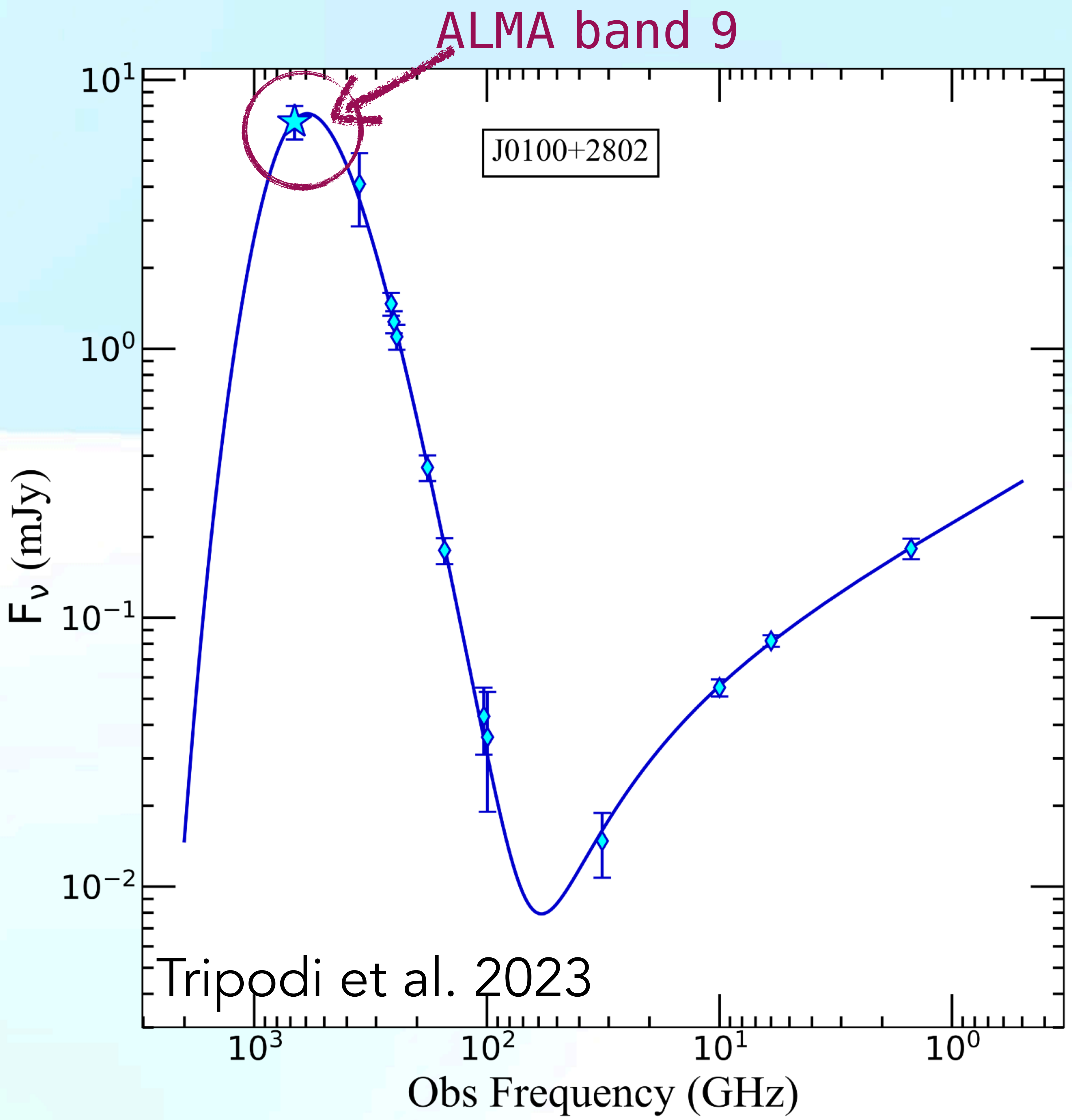
Example of our typical ignorance of SFR:

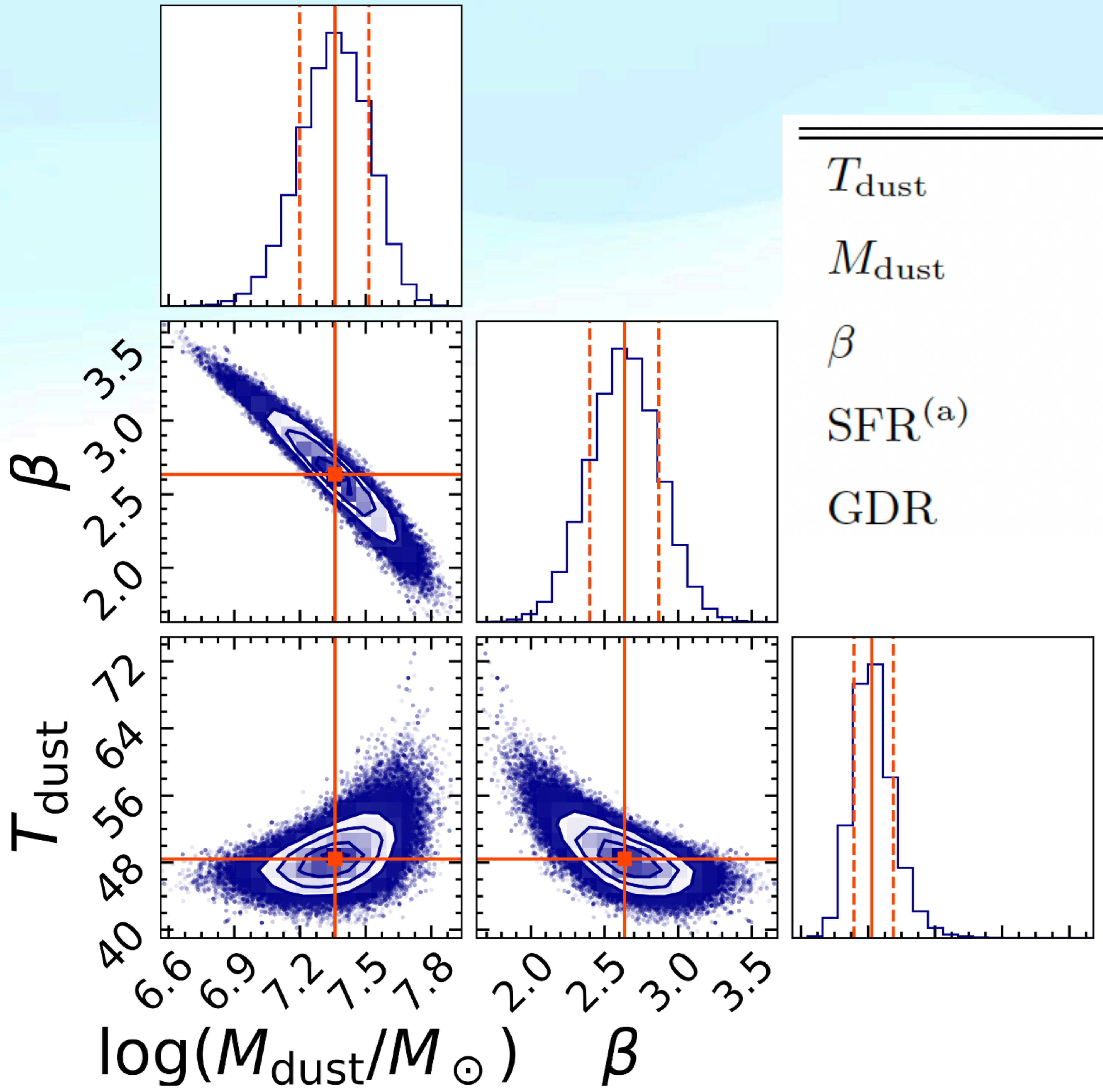
- Dust temperature 40-200 K
- SFR 100-4000 $M_{\odot}\ yr^{-1}$

e.g. Wang+2019

Star formation rates at z>6

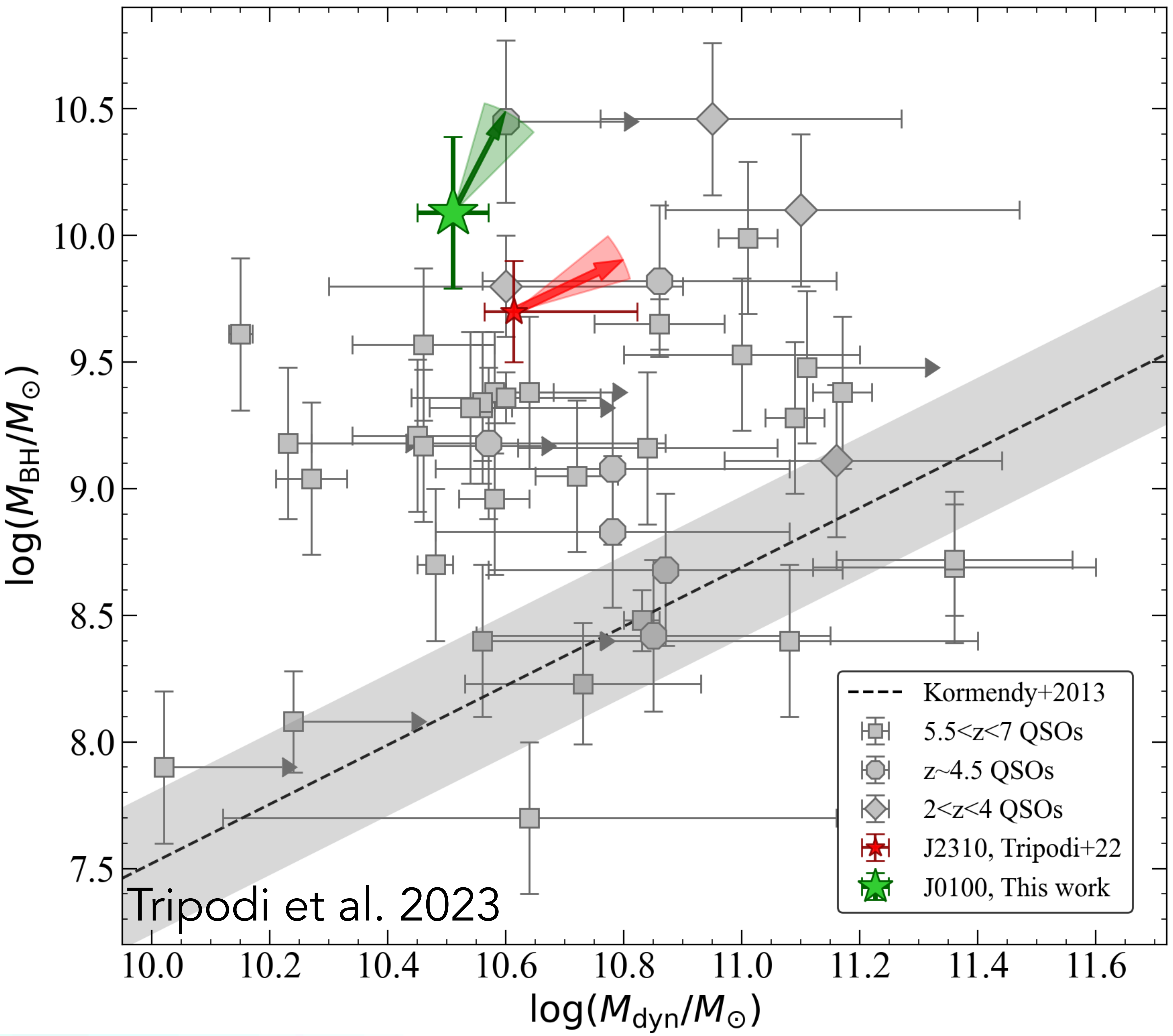
ALMA band 9 enables tight constraints on T_{dust} and SFR





T_{dust}	[K]	48.4 ± 2.3
M_{dust}	$[10^7\ M_\odot]$	2.29 ± 0.83
β		2.63 ± 0.23
SFR[(a)]	$[M_\odot\ yr^{-1}]$	265 ± 32
GDR		236 ± 155

BH-host galaxy concurrent growth



★ J0100+2802 z=6.3

BH growing faster

one of the most massive, fastest accreting BH at its epoch

★ J2310+1855 z=6 outflows

host growing faster

- Snapshot
- Larger sample with band 9 observations and (Tripodi+2023 in prep.)
- ALMA follow up studies of quasars with BAL winds

Conclusions

- Using smart approaches, we are now able to observe BH winds in statistical samples of z>6 quasars using today's optical/infrared spectrographs. We can assess what is the **impact of BH feedback on early BH and galaxy growth**.

- We detect wi**despread and powerful BH winds in z~6 quasars**. **These winds may be able to suppress BH growth and drive the onset of the symbiotic growth that we observe in the lower redshift Universe.**

- **What happens to the host galaxies?** We need to measure the mass build-up **i**n the host-galaxy. **Robust SFR can be measured** at z>6 thanks to high frequency ALMA observation and JWST(e.g. $H\alpha$)

Thank you for your attention!