# Probing AGN-feedback and host-galaxy properties in the most luminous QSOs up to z~6

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# At the brightest end of the AGN luminosity function

**Hyper-luminous QSOs**
**$L_{Bol} \sim 10^{47}$ erg/s**

***By targeting the highest $L_{Bol}$ the most extreme accretion regime, host galaxies and environment can be probed***

- **Luminous QSOs allow to study the growth of the most massive SMBHs and galaxies**
  $M_{BH}$-$M_{dyn}$ correlation: The most massive SMBHs lie in the most massive galaxies
  (Magorrian+98, Kormendy & Ho+13)

- **The most luminous QSOs are primary targets to hunt for powerful AGN-driven outflows**
  Huge radiative output. The strength of an outflow increases with $L_{Bol}$
  (Faucher-Giguère+12, Zubovas & King+12, Cicone+14, Bischetti+17, Fiore+17)

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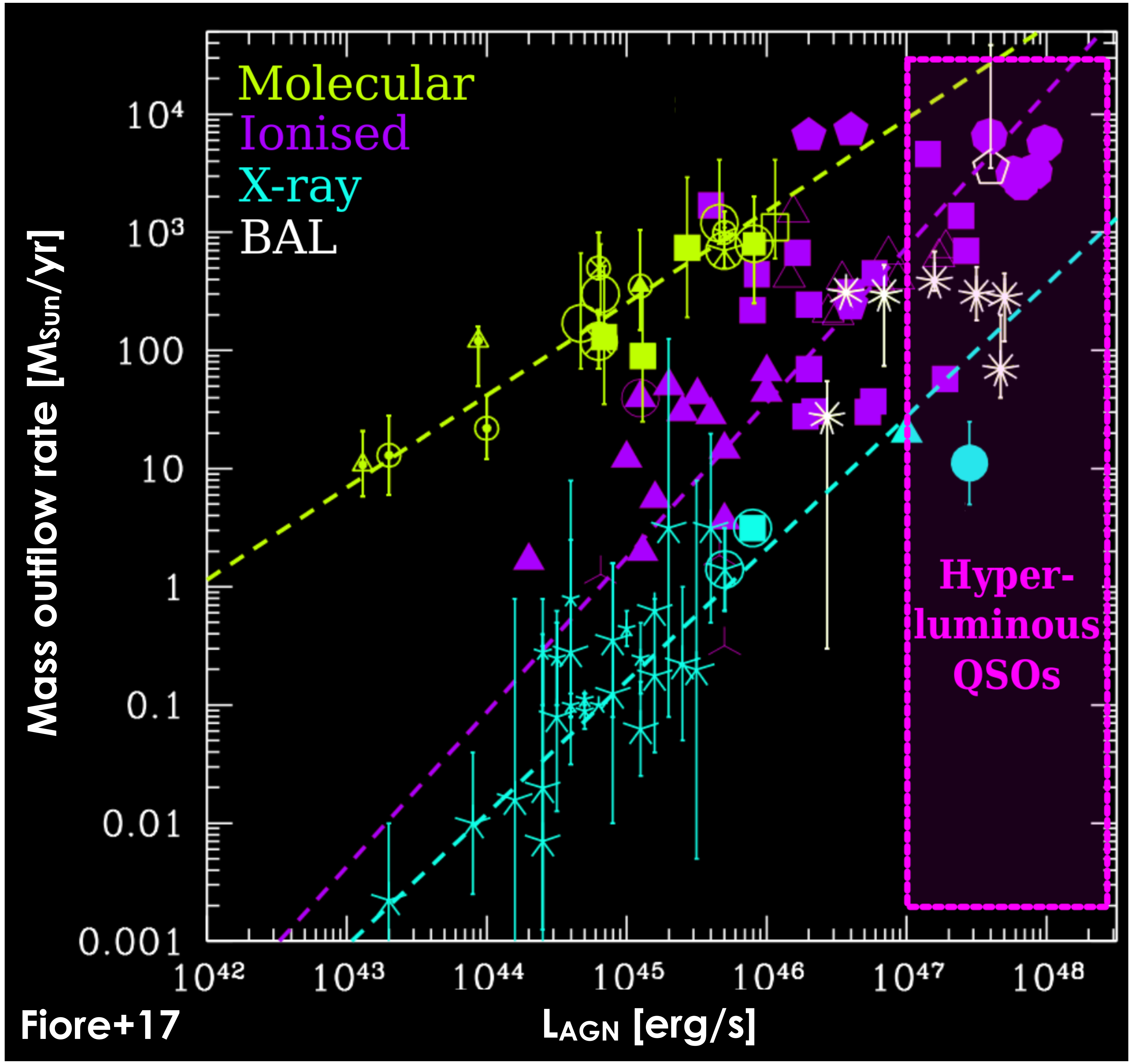



- **Ionised phase**
  Hyper-luminous QSOs up to z~4 studied at INAF OAR: the WISE/SDSS selected hyperluminous (WISSH) quasars project (Bischetti+17, Vietri+18, Travascio +19 sub.)

- **Cold gas phase: direct fuel for SF**
  Mostly limited to low-moderate luminosity, local AGN (e.g. Cicone+14, Feruglio+15, Fluetsch+19)
  Outflows extremely challenging to probe at high z

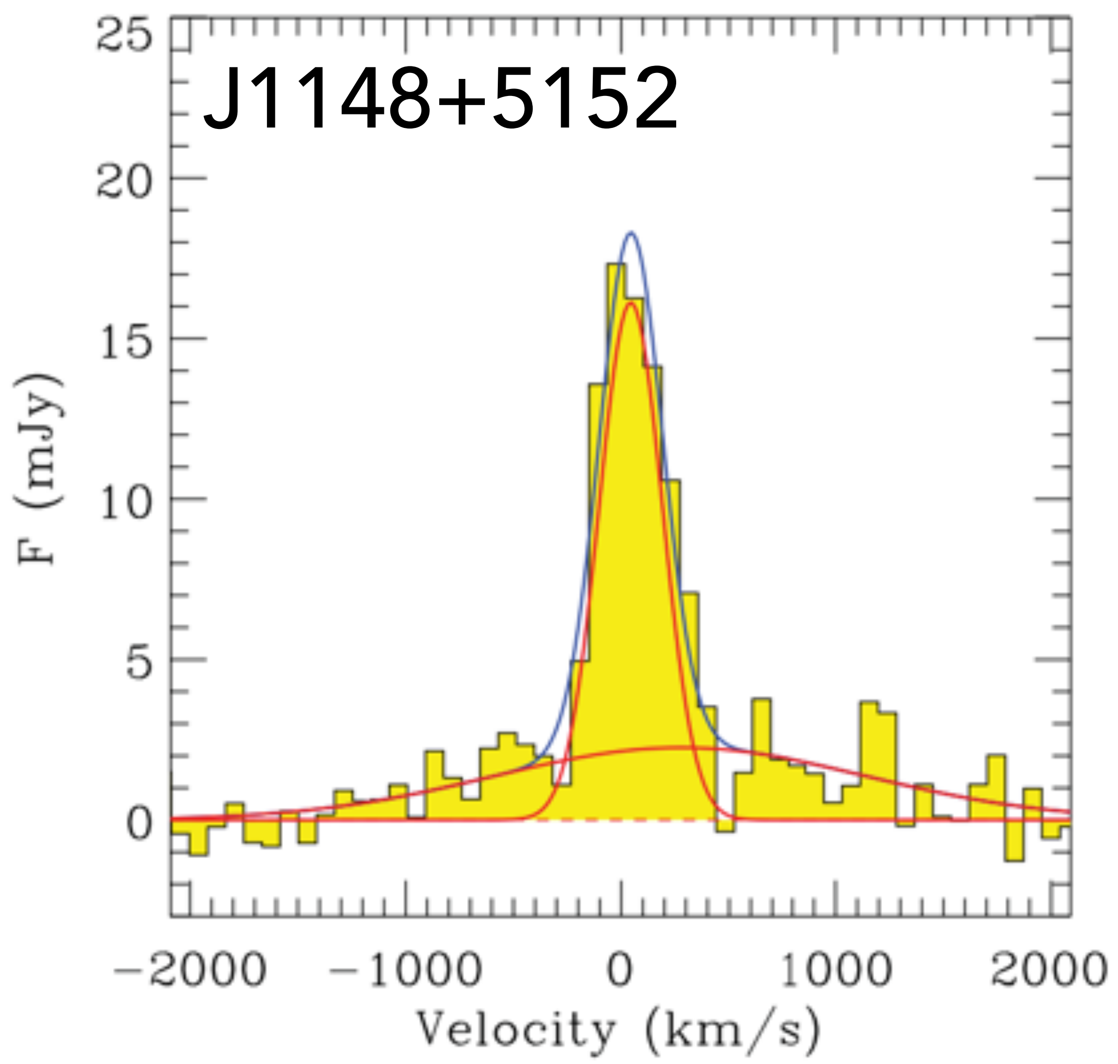
# QSO-driven outflows (un)detected in the early Universe

The existence of massive, quiescent systems observed already at $z \sim 3$ indicates that a feedback mechanism must have been in place at very early epochs ($z \sim 5 - 6$)

## First investigation of the occurrence of AGN-driven outflows in the first QSOs population

**Stacking analysis: 48 high-z QSOs observed with ALMA**

- [CII] 158 μm ALMA detection at $\gtrsim 5\sigma$ significance
- $46 < \mathrm{Log}(L_{Bol}\ /\mathrm{erg\ s^{-1}}) < 48$
- $5 < z < 7$
- Equivalent to 34h of on-source time




Only one detection so far!

Maiolino+12, Cicone+15

# Cold outflows in the early Universe are there!

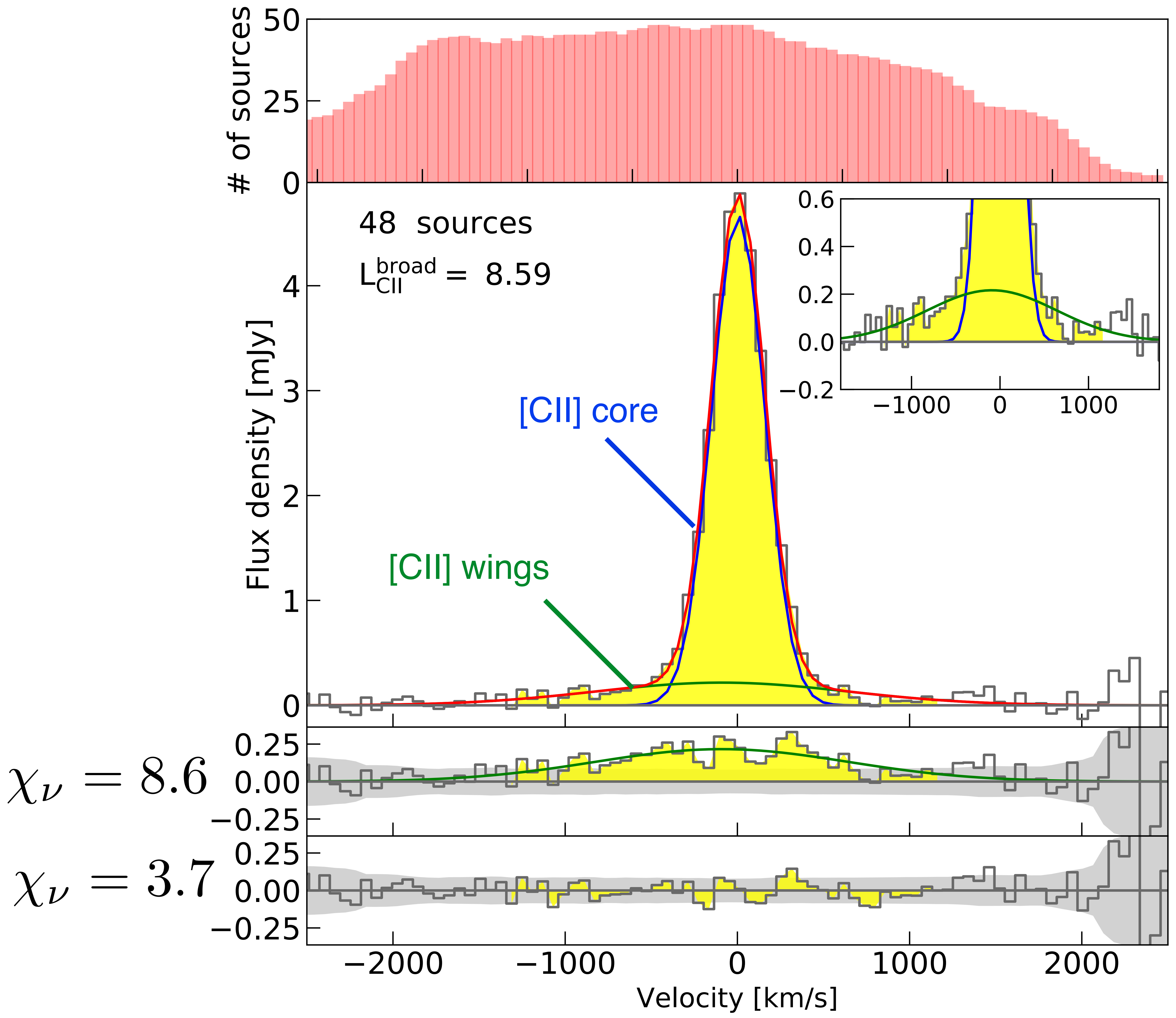
Variance-weighted stack of the [CII] spectra

**Broad emission detected with SNR~6 up to |v| ~ 1000 km/s associated with [CII] outflowing gas**

Wings/peak ~ 1/20

$FWHM_{broad}$ ~ 1700 km/s

Bischetti+19, arXiv1806.00786, next week on A&A



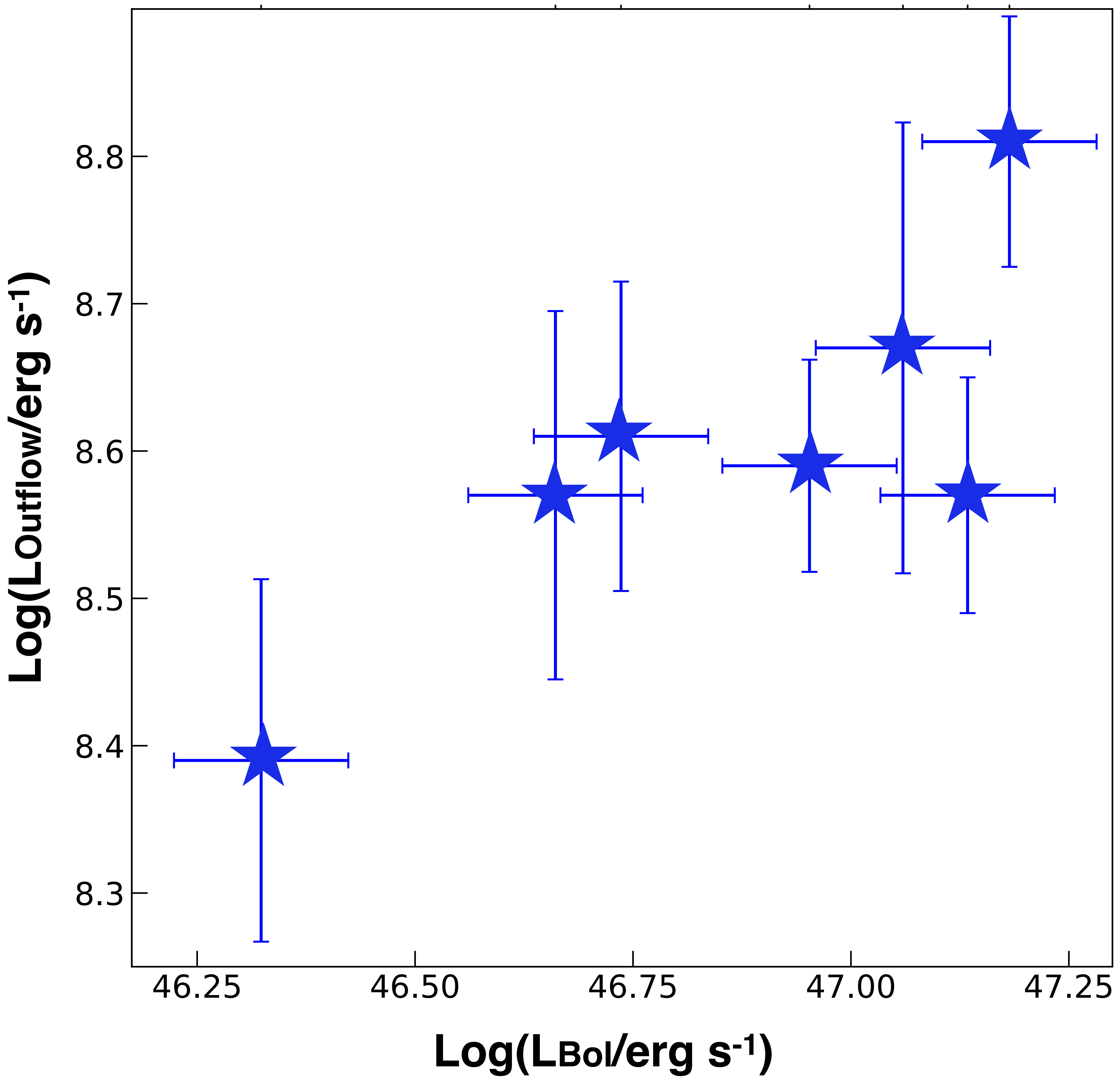
# QSO-driven outflows in the early Universe

Stack in bins of AGN bolometric luminosity :

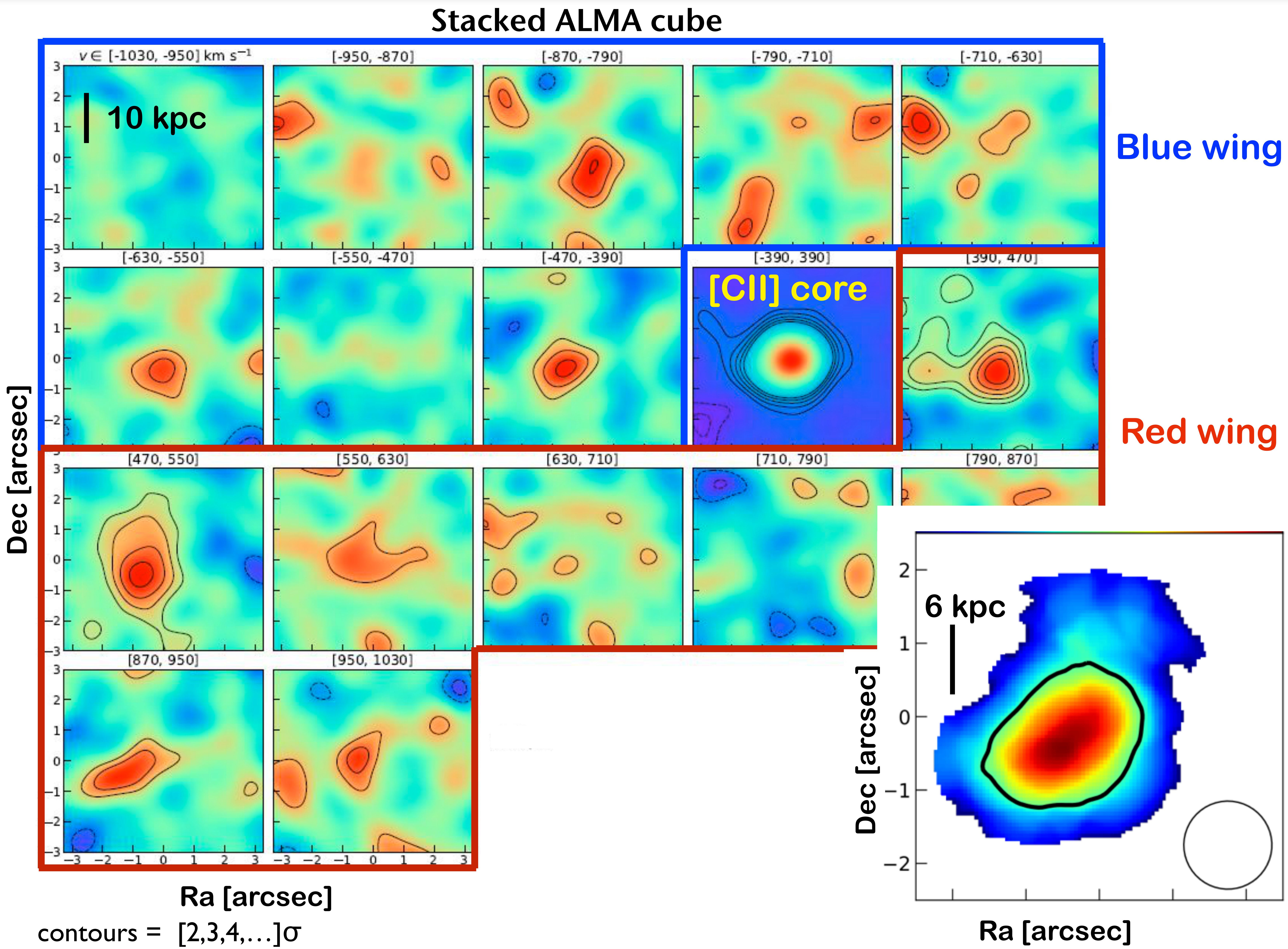
The luminosity of the broad [CII] wings correlates with $L_{Bol}$
(but not with SFR)

**AGN identified as the main driving mechanism**

Bischetti+19, arXiv1806.00786, next week on A&A



# Cold outflows extended on galactic scales




**typical extent of the [CII] outflows ~ 3.5 kpc**

(half-light radius)

# Typical mass outflow rates of the [CII] outflows

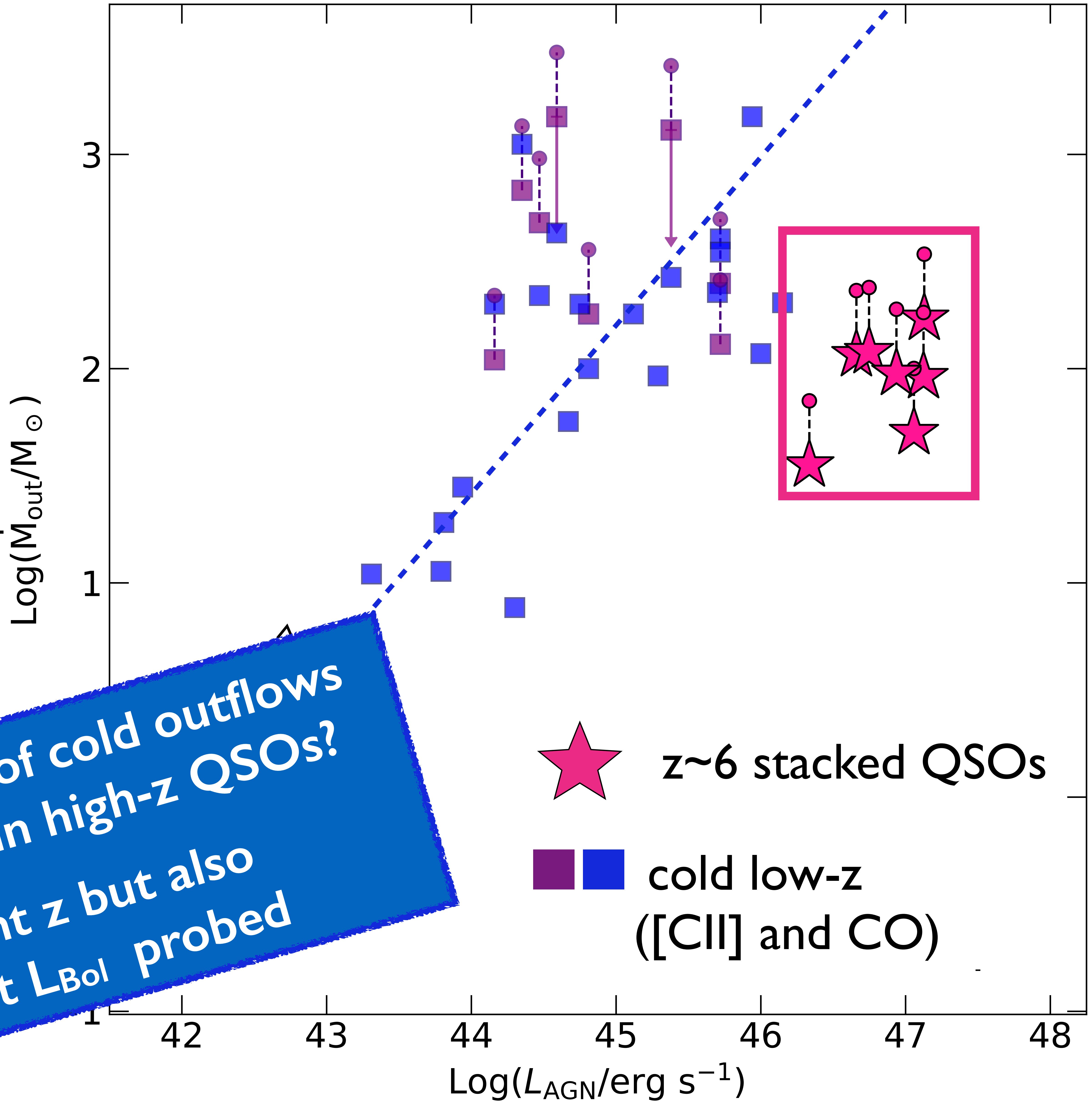
$$\dot{M}_{\rm neutral} \simeq 100 - 200\ M_{\odot}{\rm yr}^{-1}$$

↓

Comparable to cold outflows
in lower-z
+
lower-luminosity AGN

**Cold outflows at high-z might be less effective in removing gas than in local AGN**

Bischetti+19, arXiv1806.00786, next week on A&A



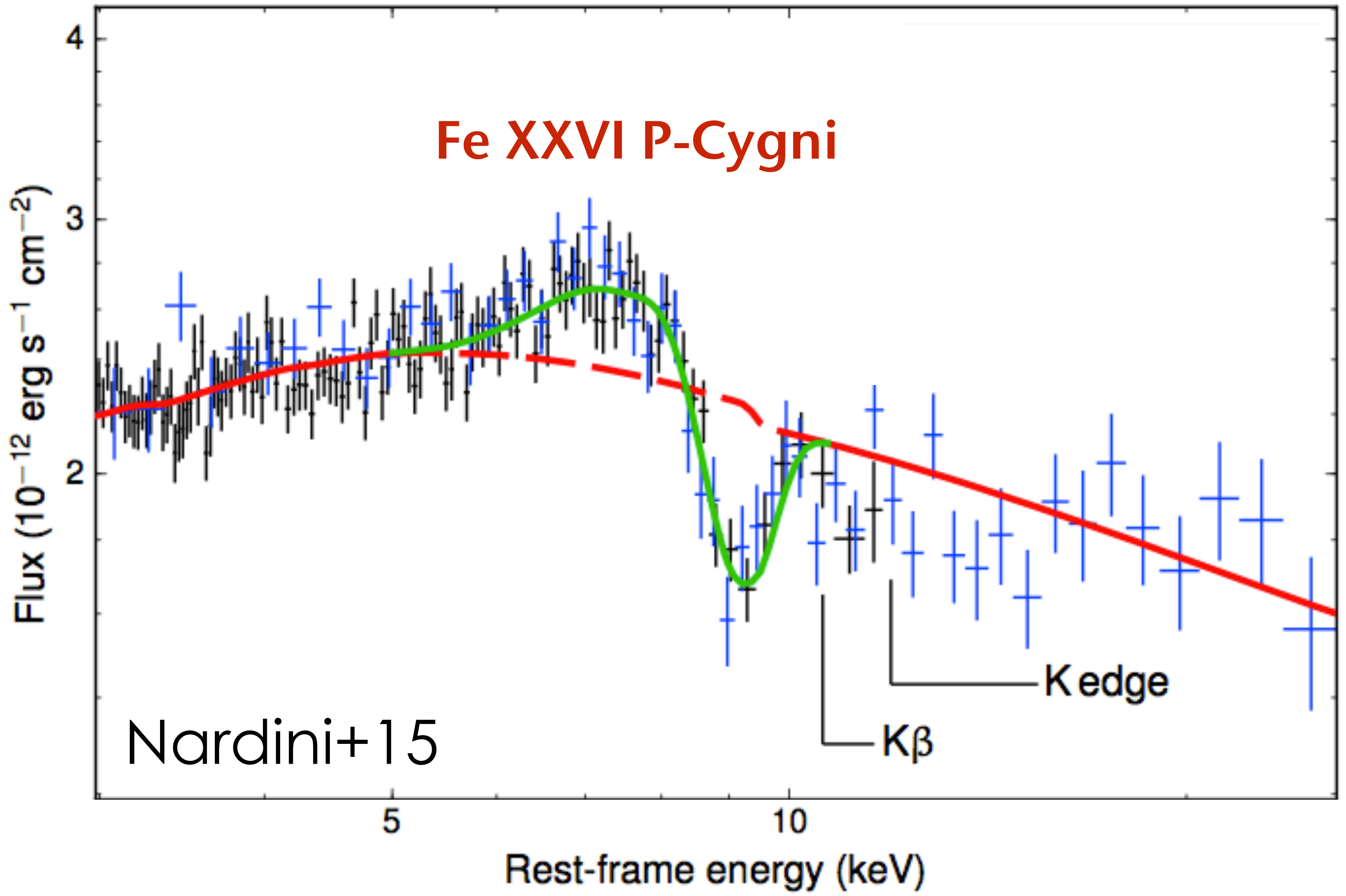

Small coupling of cold outflows with the ISM in high-z QSOs?

Different z but also different $L_{Bol}$ probed

# A deeper insight: the most luminous QSO of the local Universe (z=0.185)

- **A local analogue of the hyper-luminous QSOs dominating the SMBH growth at z>2**
  $L_{Bol} = 10^{47}$ erg/s, $M_{BH} \sim 2 \times 10^{9}\ M_{Sun}$, $L_{Bol}/L_{Edd} = 1$

- **The prototype of massive and persistent ultra-fast outflow (UFO)**
  quasi-spherical relativistic wind with kinetic power ~ 20% $L_{Bol}$
  UFOs proposed as likely origin of galaxy-scale outflows



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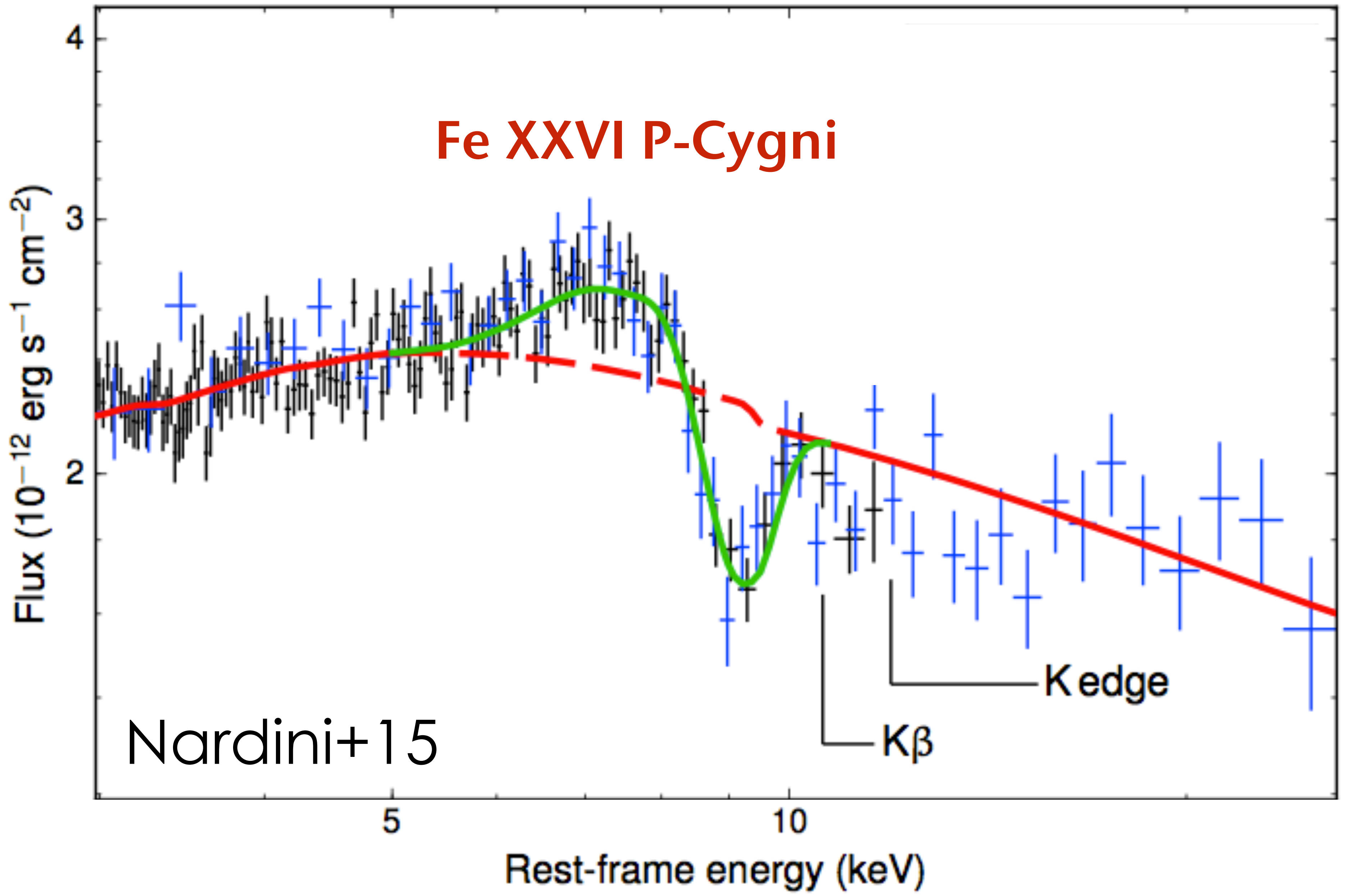


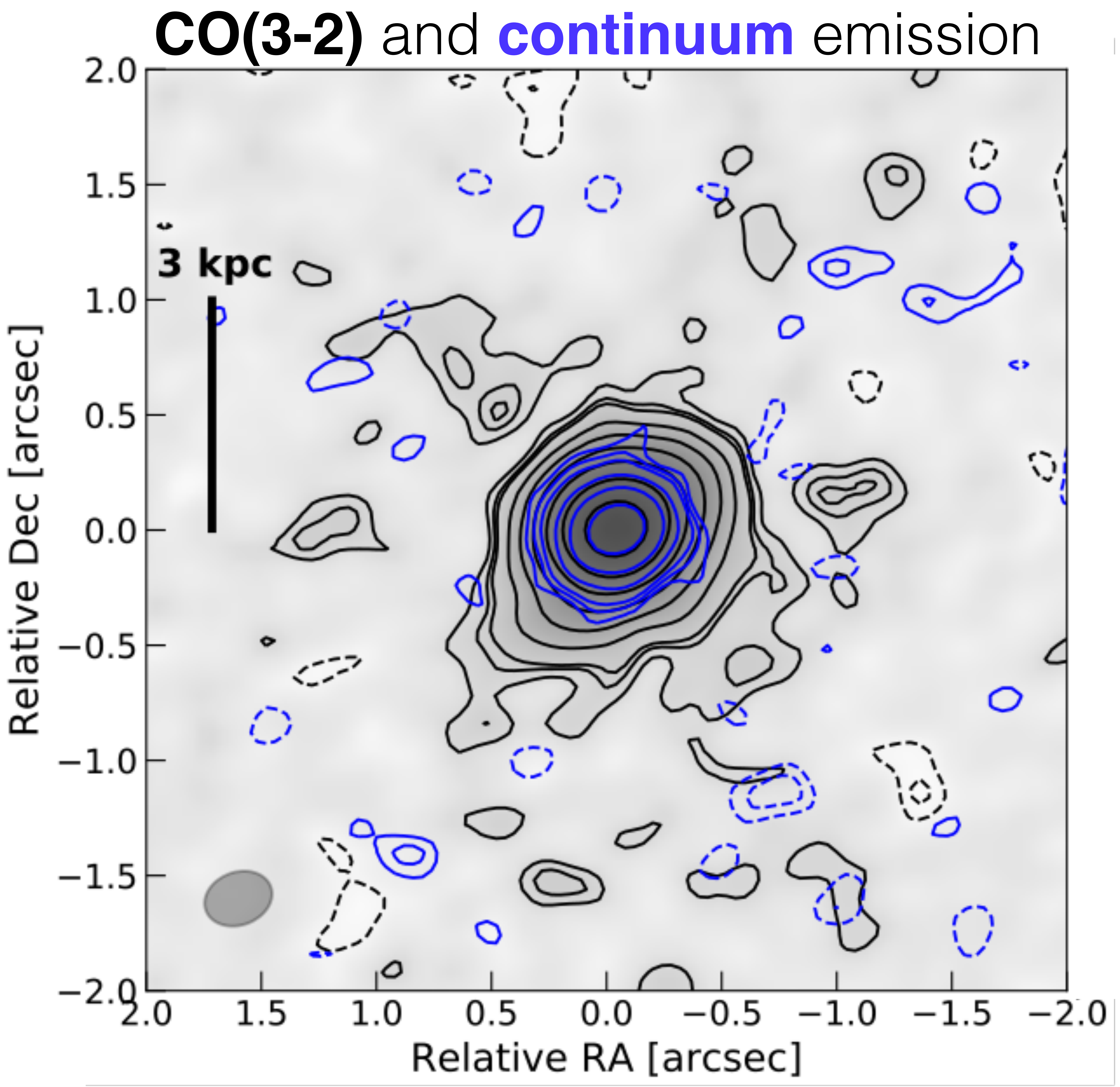

ALMA follow-up
with 0.2 arcsec ~ 600 pc resolution

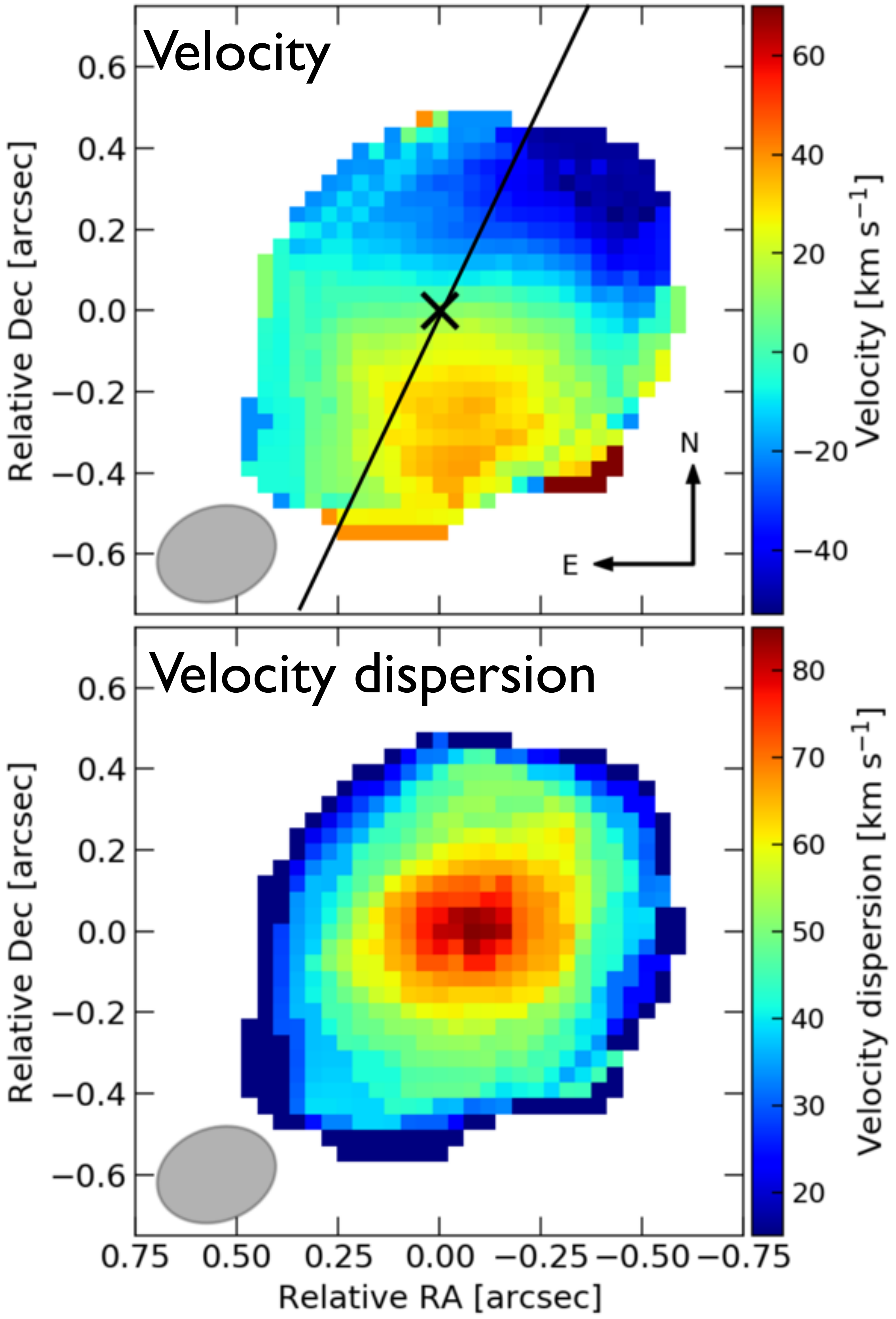
Investigating the molecular gas properties and kinematics in the hyper-luminous QSO with the most powerful nuclear wind

!!Very compelling science case!!

# The highest resolution map of the molecular gas in a hyper-luminous QSO

- The molecular gas reservoir is located in a compact (D ~ 1.3 kpc), rotating ($v_{rot}$~ 280 km/s) disk seen close to face-on (*i* = 25 deg)

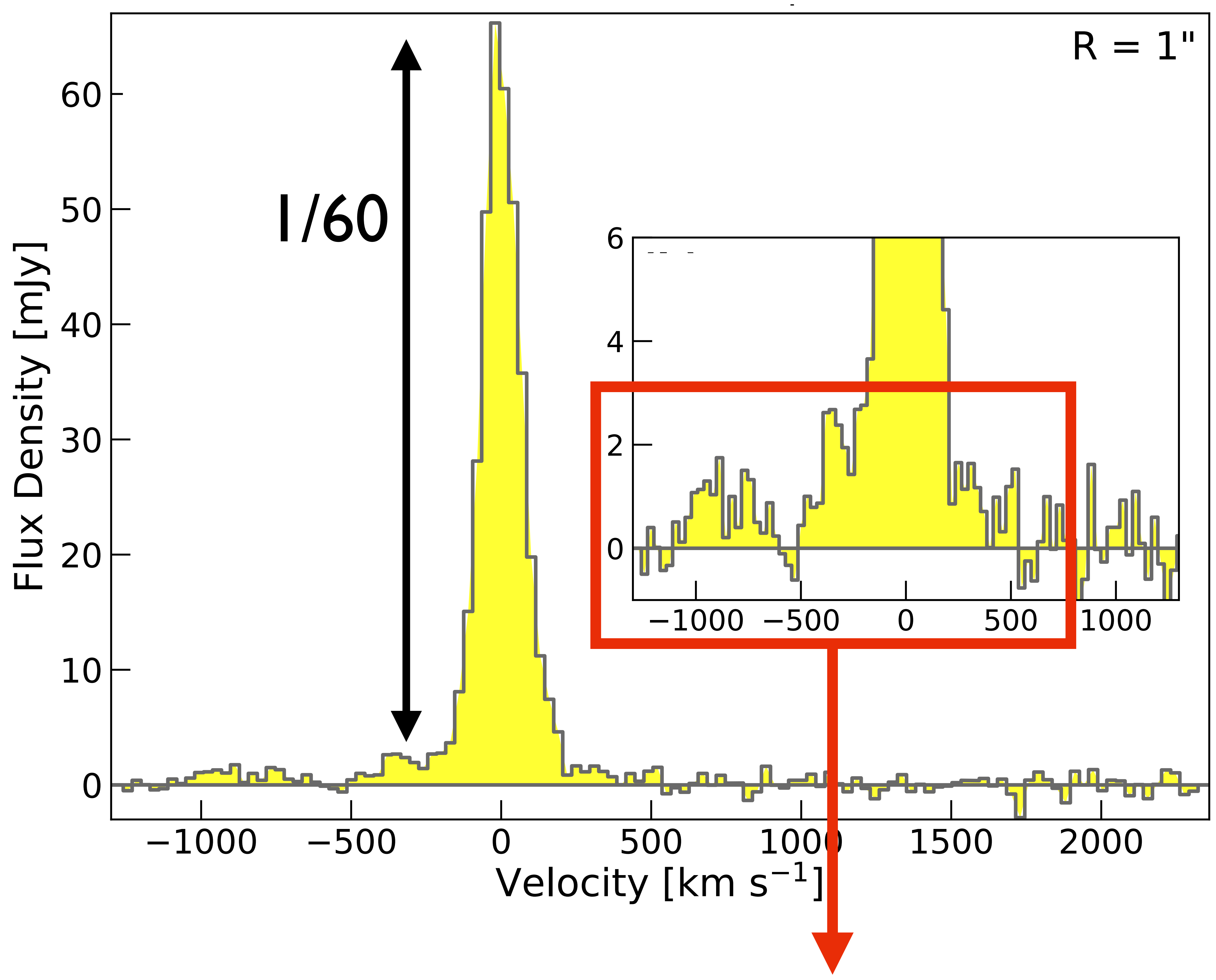


# Kinematics of CO(3-2) emission in PDS 456

- The molecular gas reservoir is located in a compact (D ~ 1.3 kpc), rotating ($v_{rot}$~ 280 km/s) disk seen close to face-on (*i* = 25 deg)

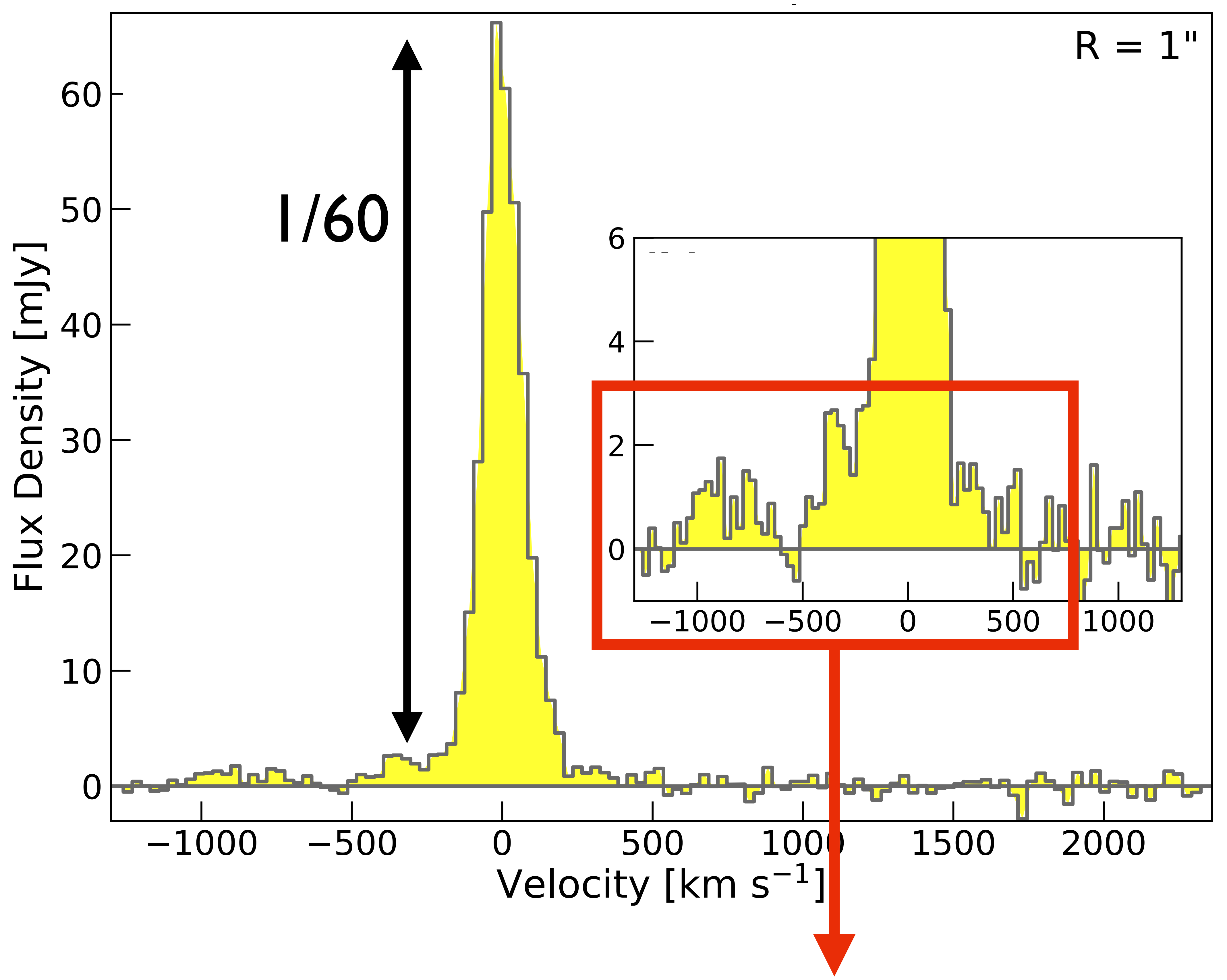
However…




**CO(3-2) emission associated with high-velocity gas |v| ~1000 km/s**

# Anatomy of the kpc-scale molecular outflow in PDS 456

- Blue- and red-shifted outflow extended up to 5 kpc scale from the nucleus

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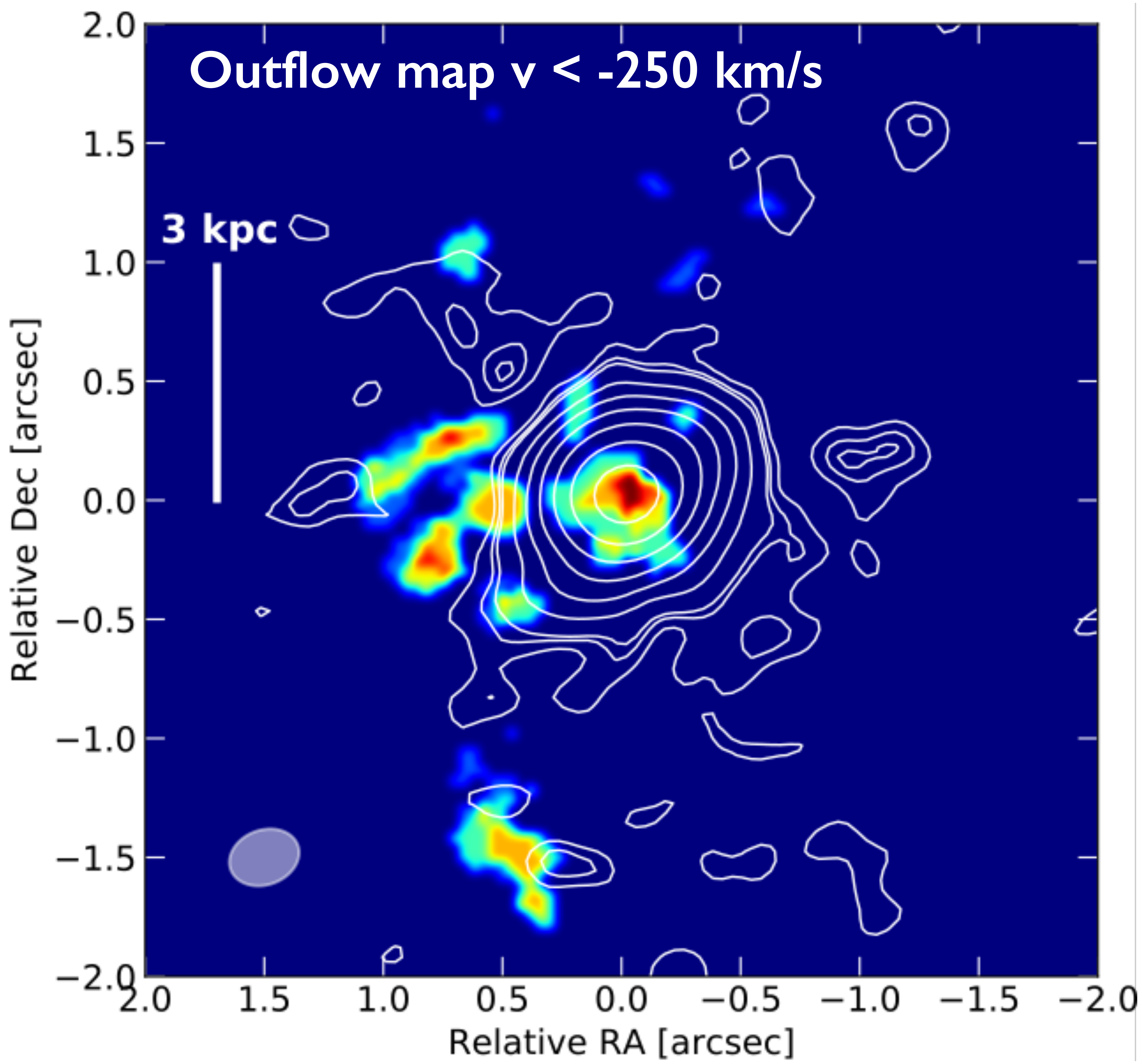



Bischetti+19, A&A, 628, A118

# AGN feedback in action

$$\dot{M}_{\rm mol} \sim 300\ M_{\odot}/{\rm yr}$$

$$\tau_{\rm dep} = M/\dot{M}_{\rm mol} \sim 8\ {\rm Myr}$$

**Very short depletion timescale**

$$\dot{M}_{\rm mol}/SFR \sim 4 - 10$$

**Molecular gas removed before it forms stars**

**The QSO is able to affect the evolution of its host-galaxy!**

**Bischetti+19, A&A, 628, A118**

# Challenging the energy conserving scenario

$$\dot{M}_{\rm mol} \sim 300\ M_\odot/{\rm yr}$$

$$\tau_{\rm dep} = M/\dot{M}_{\rm mol} \sim 8\ {\rm Myr}$$

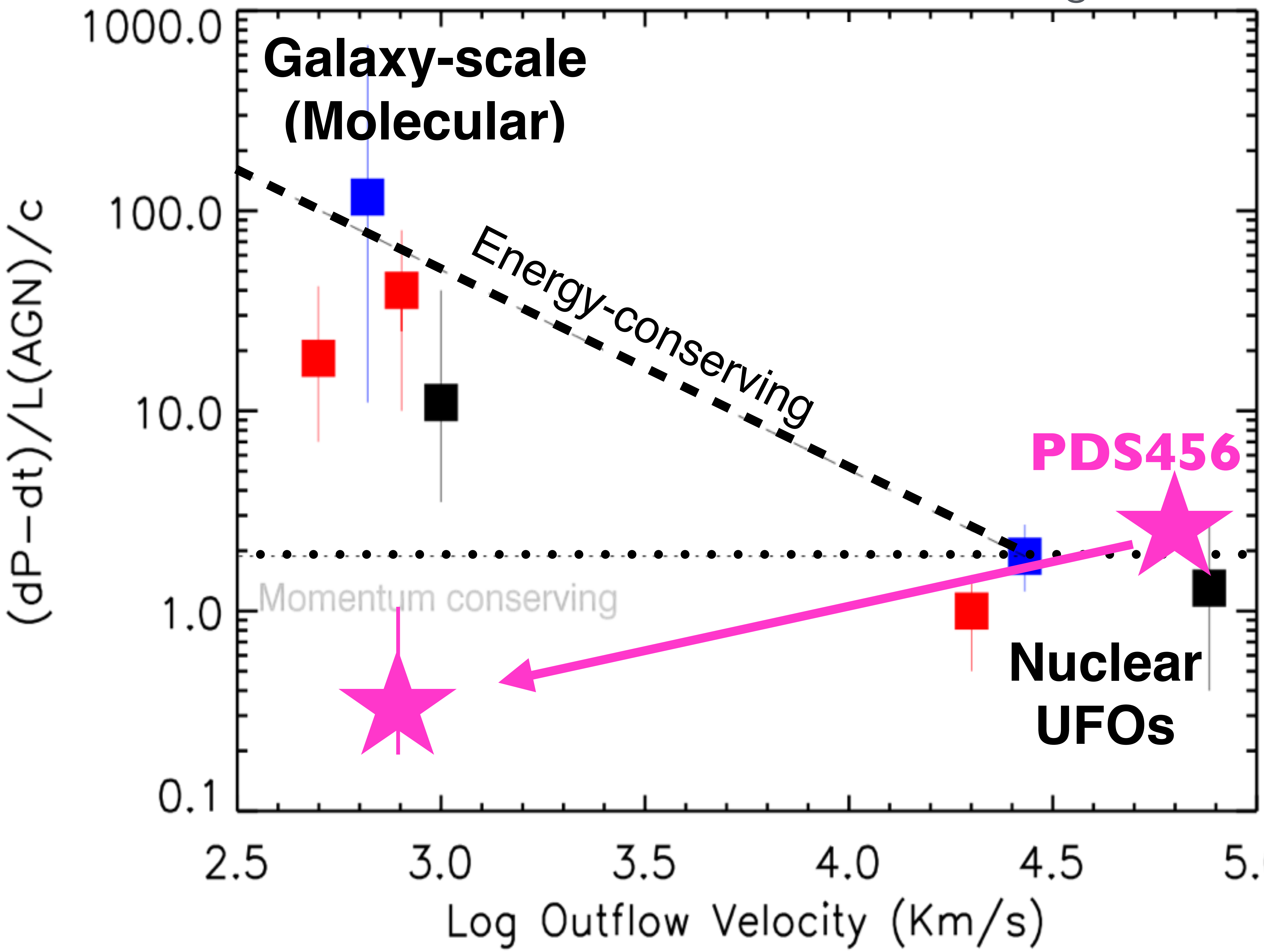
**Very short depletion timescale**

but…

momentum rate

$$\dot{P}_{\rm mol} \sim 0.4\ (L_{\rm AGN}/c)$$

Longinotti+18




**In clear contrast with energy conserving expectations: ($\dot{P}_{\rm mol}/(L_{\rm AGN}/c) >> 1$)**

**Bischetti+19, A&A, 628, A118**

(see also Reeves+19, Sirressi+19)

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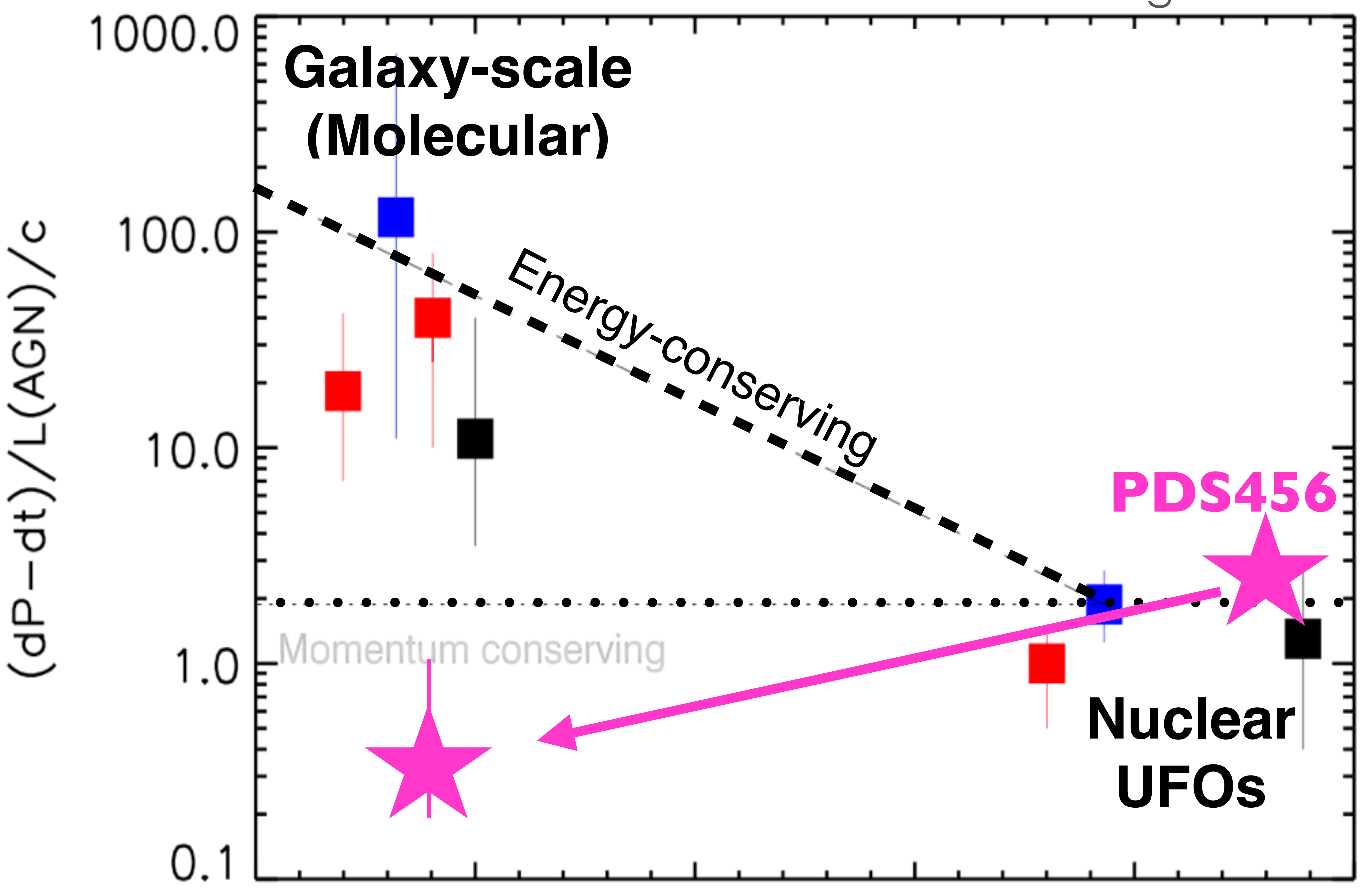
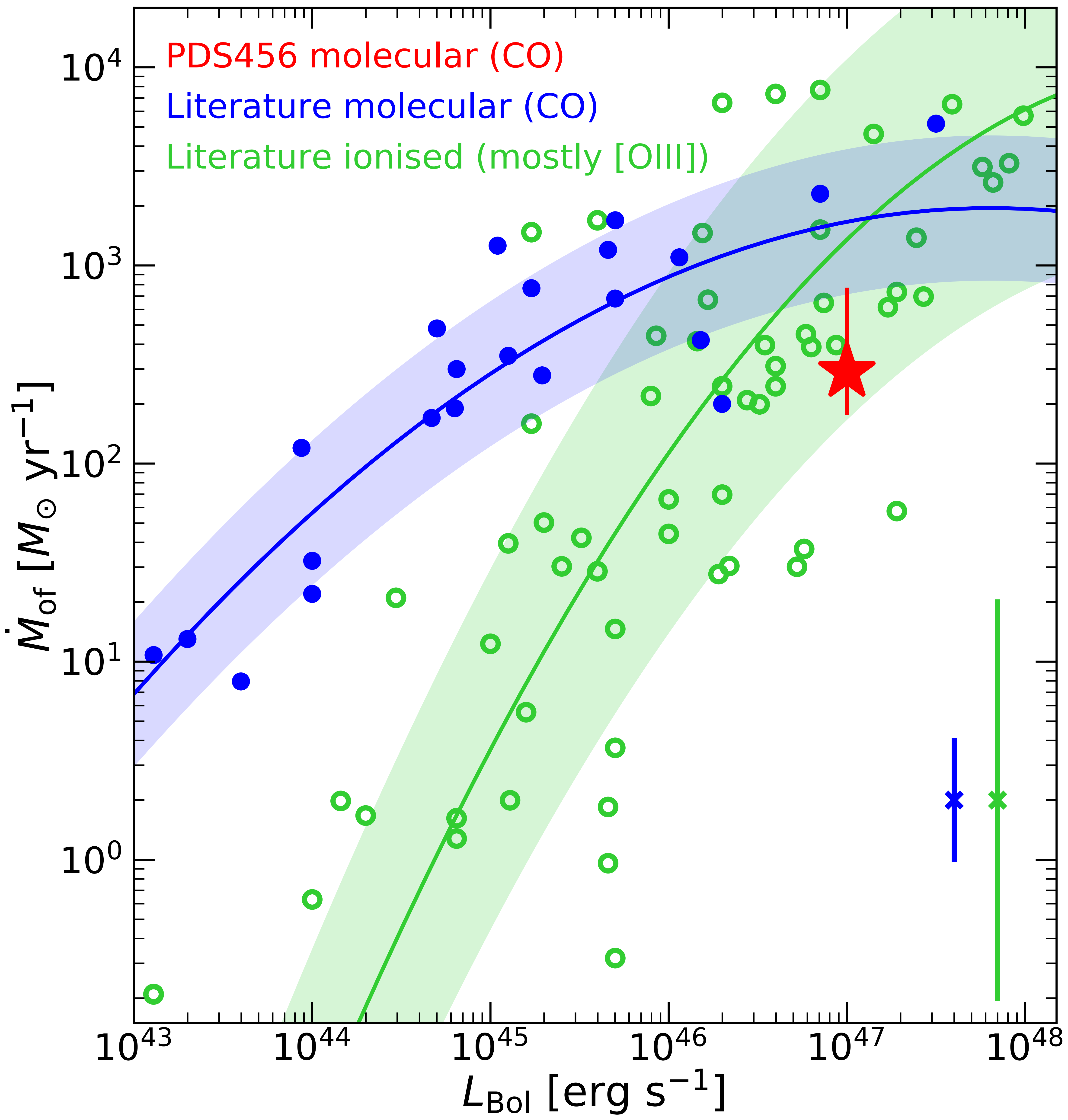



Alternative scenarios:

- radiation-pressure driven winds in luminous QSOs (Costa+18, Ishibashi+18)
- the molecular gas may not trace the total outflow mass

# Challenging the energy conserving scenario

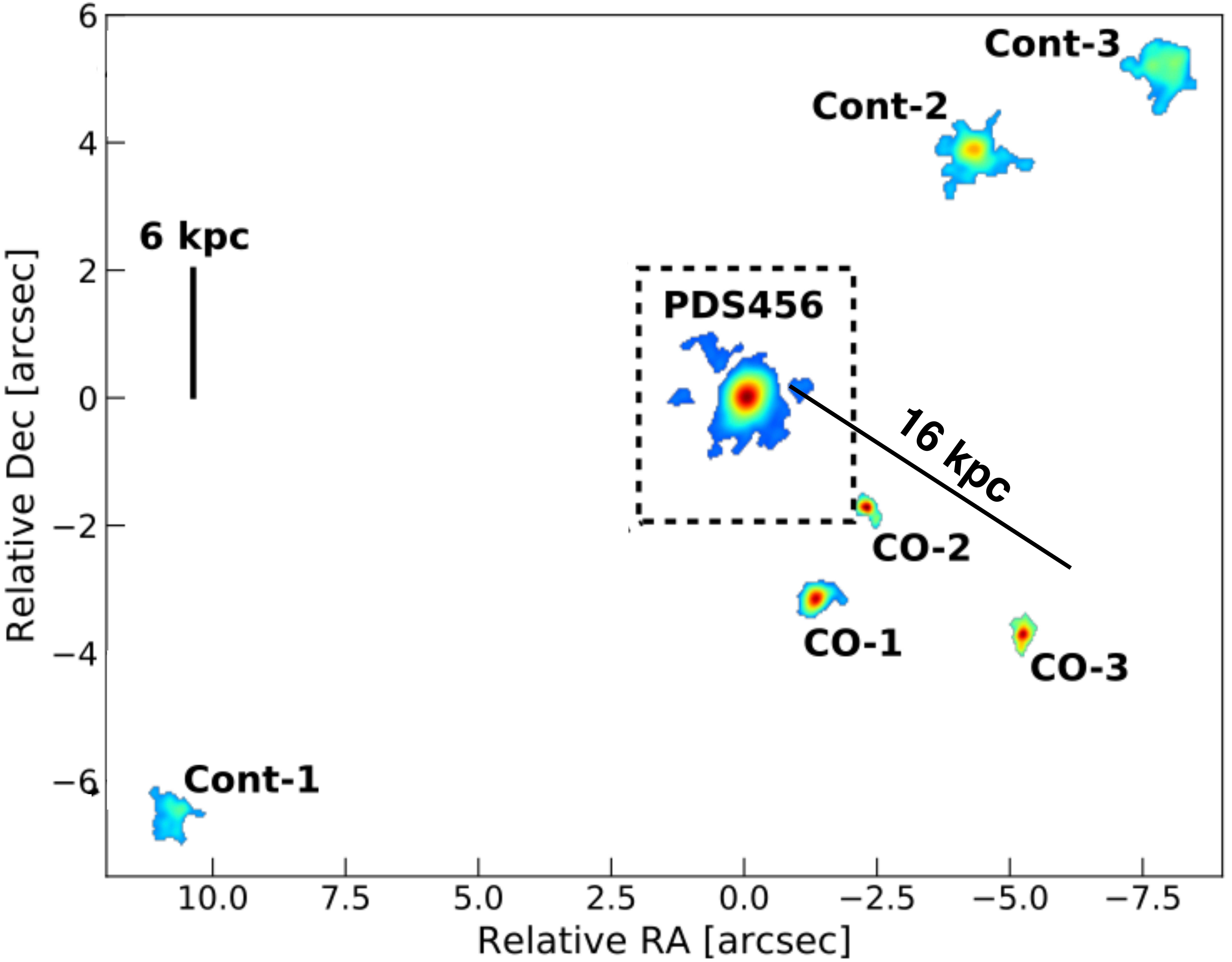



Most updated collection of AGN-driven outflows

- the molecular gas may not trace the total outflow mass

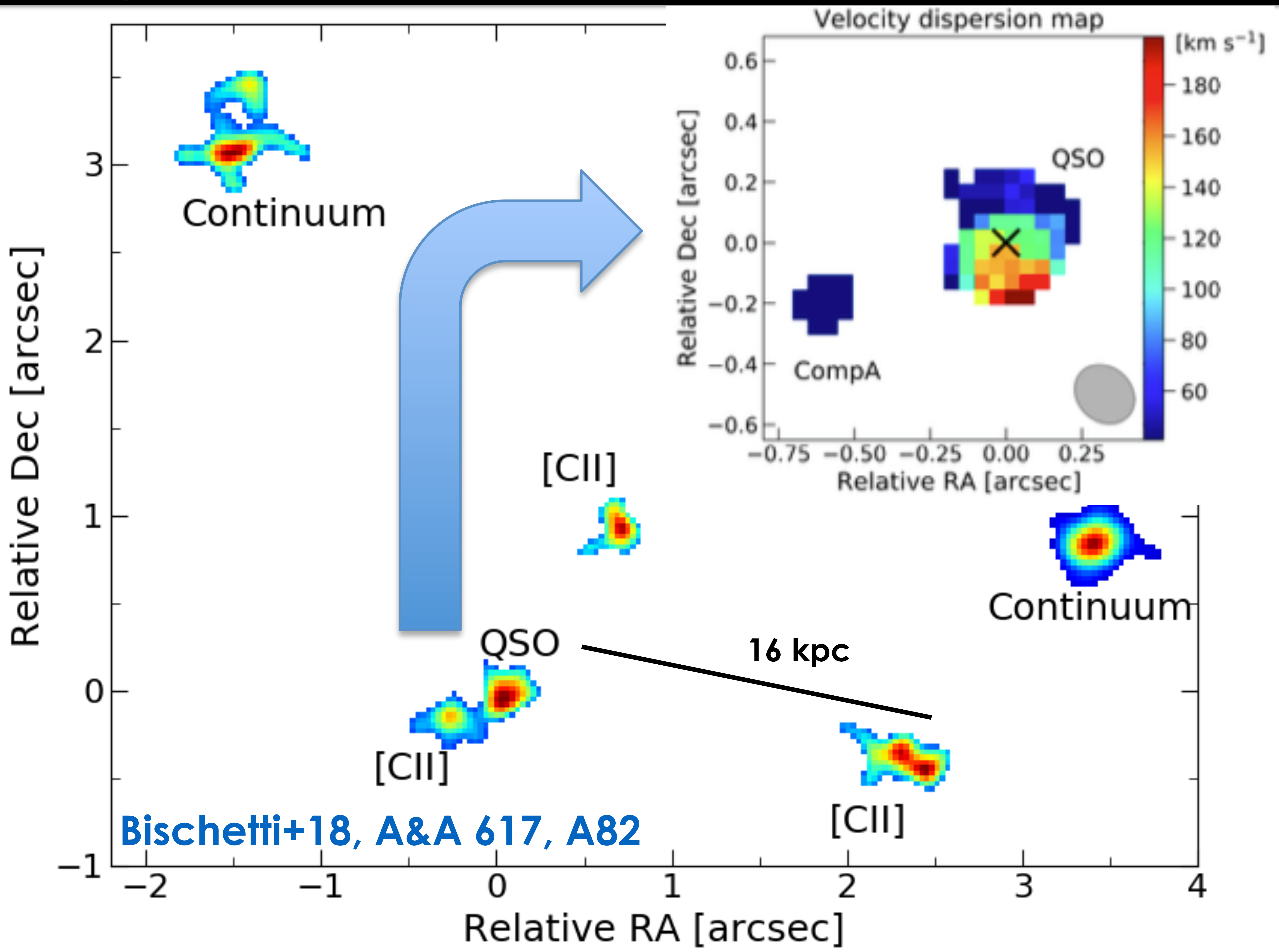
# QSOs as signposts of large overdensities

**High-density region around PDS456: three CO and three continuum emitters**



# QSOs as signposts of large overdensities

**WISSH QSO**
**SDSS J1015+0020**
**z = 4.4**




**High angular resolution (0.16'' x 0.18'')**

- Exceptional overdensity in the 40 x 30 kpc$^2$ region around the QSO
- Discovery of the closest (2 kpc!) companion of a high-z QSO

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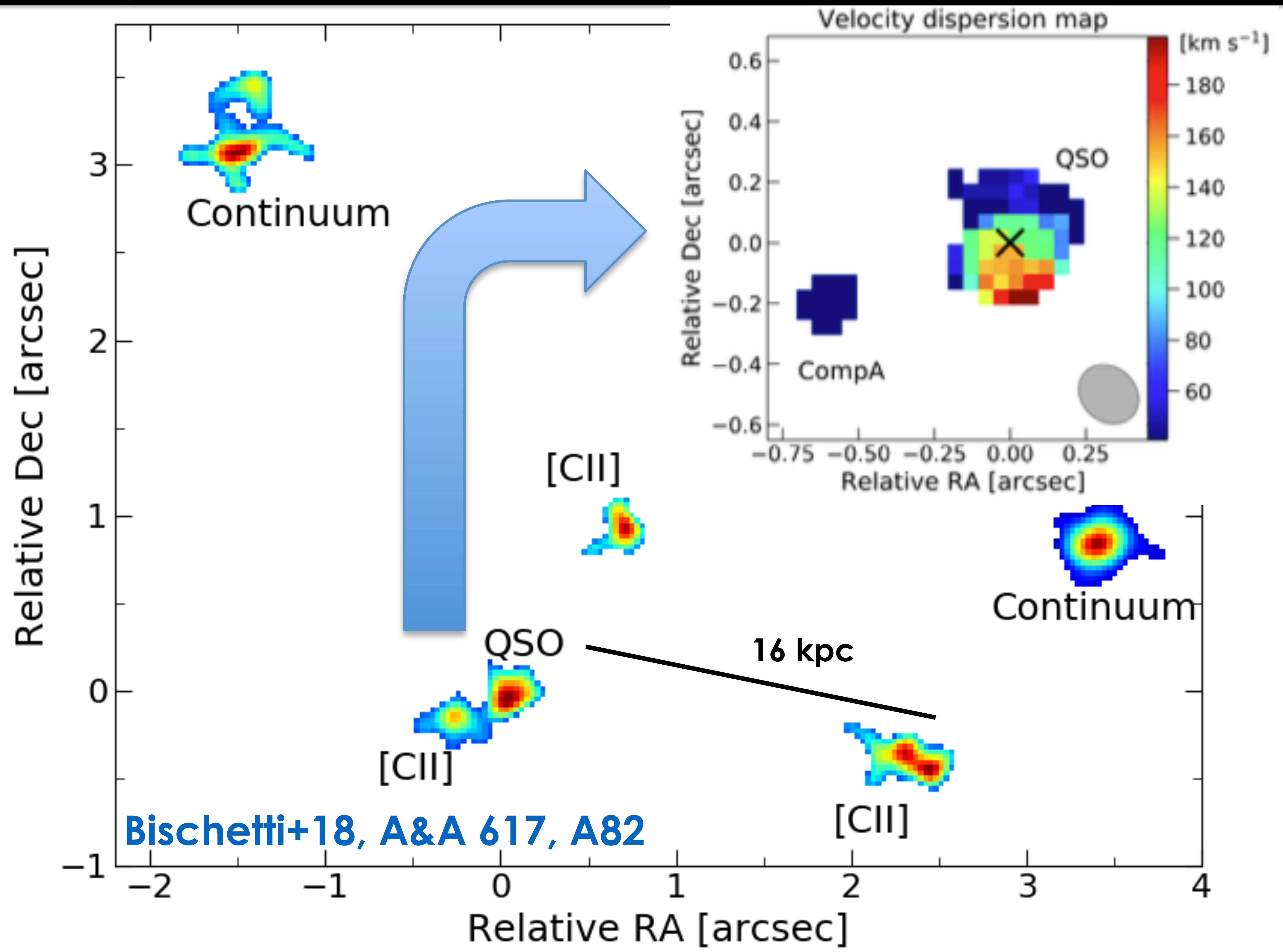
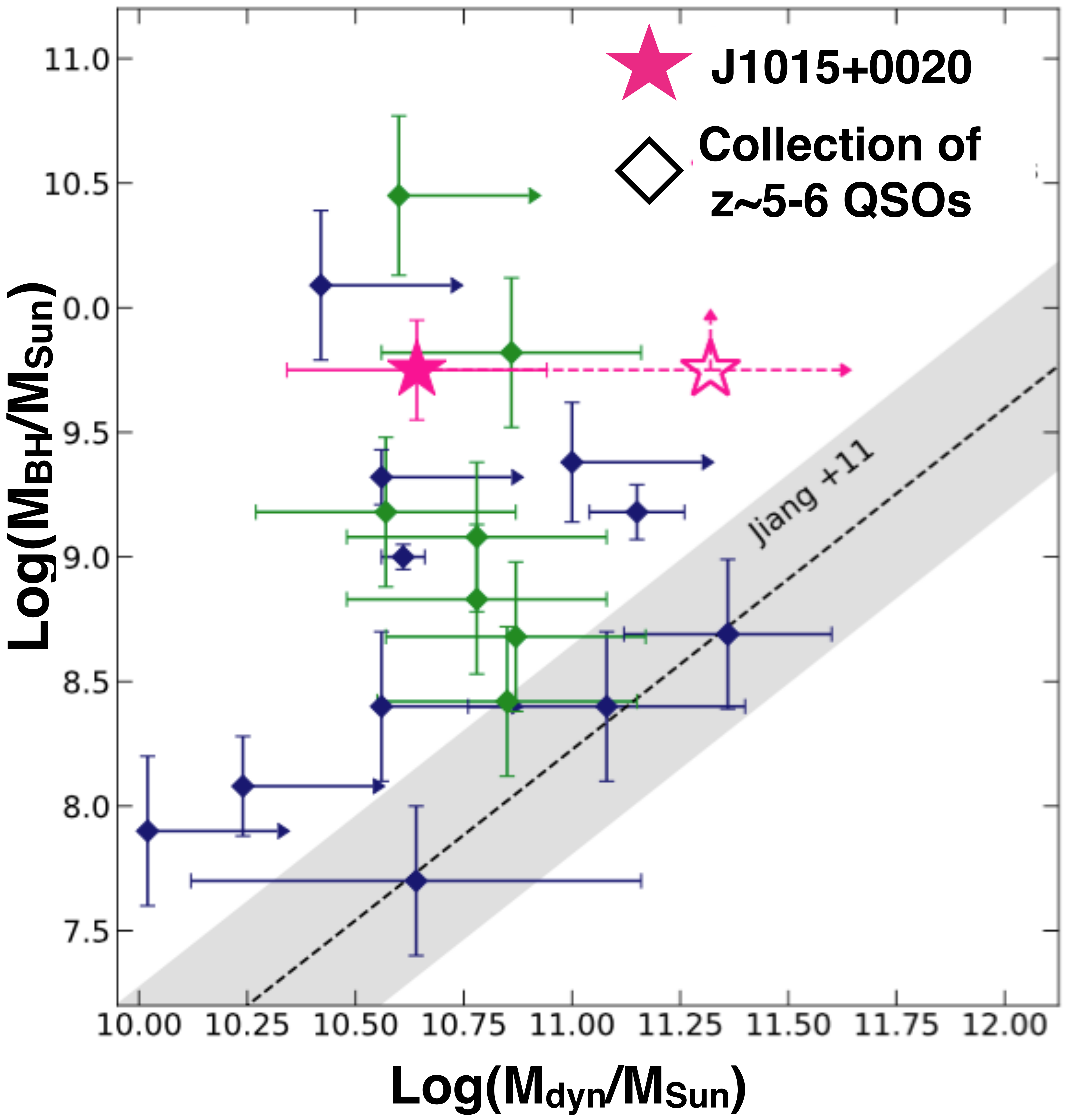



**High angular resolution (0.16'' x 0.18'')**

✱ Spatially resolved SF mostly occurring in the companions

**SFR(QSO) ~100 M⊙/yr**
**SFR(Total) ~1000 M⊙/yr**

# High-z QSOs probe the early growth phases of massive galaxies




- [CII] based dynamical mass of the galaxy
  $M_{BH}$ : $M_{dyn}$ = 1 : 7
  *Two orders of magnitude smaller than local relations*

- $M_{dyn}$ >$10^{11}$ $M_{sun}$ already in place at z = 4.4 adding the masses of QSO and [CII] emitters

**We are observing the cradle of a present-day giant galaxy**

Bischetti+18, A&A 617, A82

(see also Venemans+16,17, Willott+15,17, Trakhtenbrot+17, Kimball+15, Wang+16, Schramm+19)

# Summary & Conclusions

**Widespread presence of [CII] outflows in the early Universe**

Correlation between outflow and AGN luminosity

Outflows might be less efficient in removing gas than in local AGN

**Anatomy of the host-galaxy and molecular outflows in PDS456**

AGN feedback in action in hyper-luminous QSOs

Challenging the energy-conserving scenario

**Early assembly of giant galaxies around hyper-luminous QSOs**

Large overdensities with multiple companions

Early stellar mass assembly outside of the QSO host-galaxy

Big Eyes Telescopes (E-ELT + JWST + Athena) + ALMA will be fundamental to:

- enlarge the population of high-z, moderate luminosity AGN known
- provide AGN-outflows scaling relations in a wide range of $L_{Bol}$, without the drawback of different z
- multi-phase characterisation of AGN-driven outflows