[CII] outflows in z = 6 QSOs are there: investigating AGN feedback and host galaxy properties in very luminous high-redshift QSOs

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High-luminosity QSOs: hunt for powerful outflows

In this talk: **Luminous + Hyper-luminous QSOs ($L_{Bol} > 10^{46}$ erg/s)**

Theory: "strength" of an outflow increases as $L_{Bol}^{0.5}$
(e.g. Menci+08, Faucher-Giguère+12, Zubovas & King+12)

Observations: Large-scale outflow momentum rate is ~20-50 x L_{Bol}
(e.g. Cicone+14, Feruglio+15)

↓

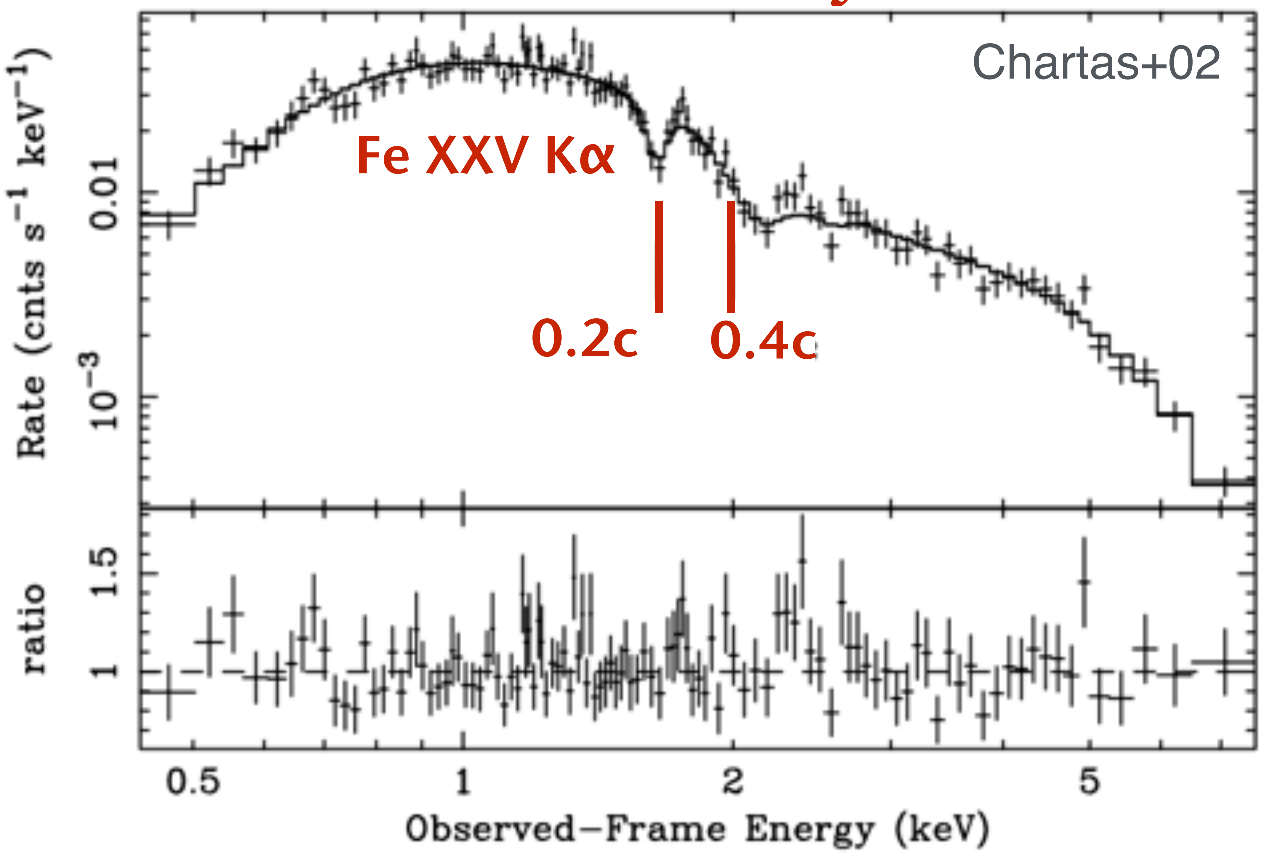
The most luminous QSOs are primary targets to hunt for powerful AGN-driven outflows

ALMA [CII] observations
- Cold outflows in z>4.5 QSOs
- Early SMBH and host galaxy assembly

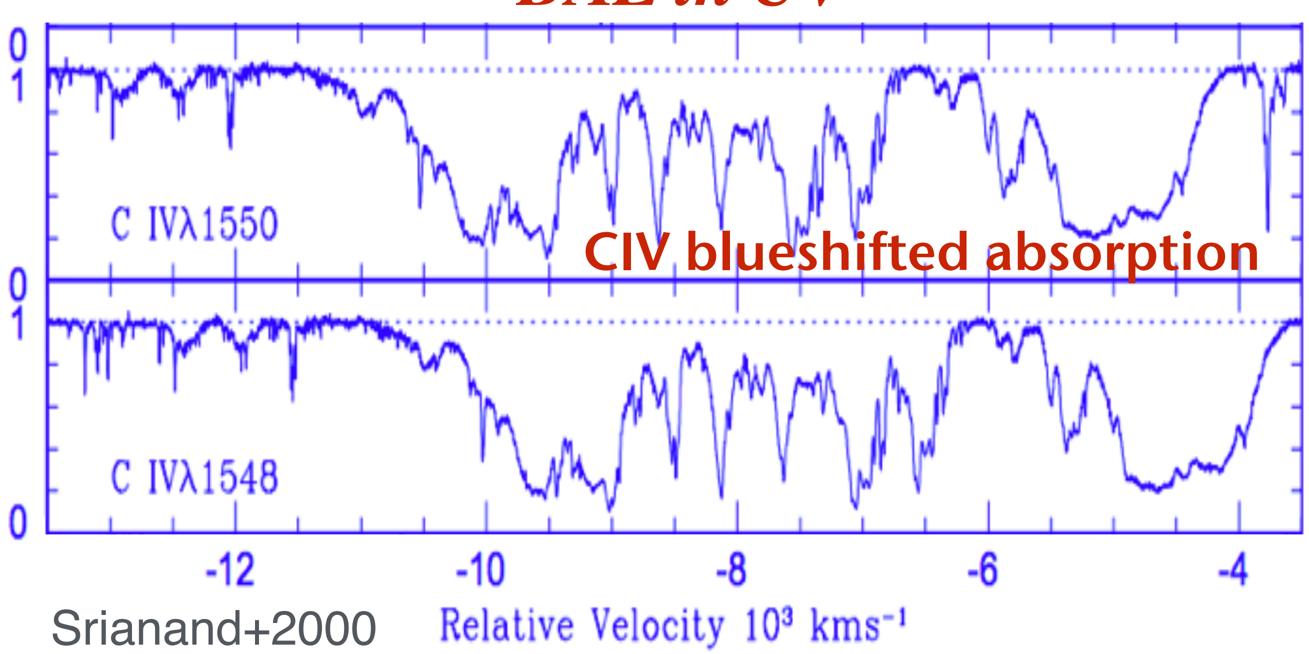
Multiphase outflows in APM08279

Hyper-luminous (L_{Bol} ~ 10^{48} erg/s) lensed QSO at z = 3.91

UFO in X-rays



BAL in UV



Srianand+2000

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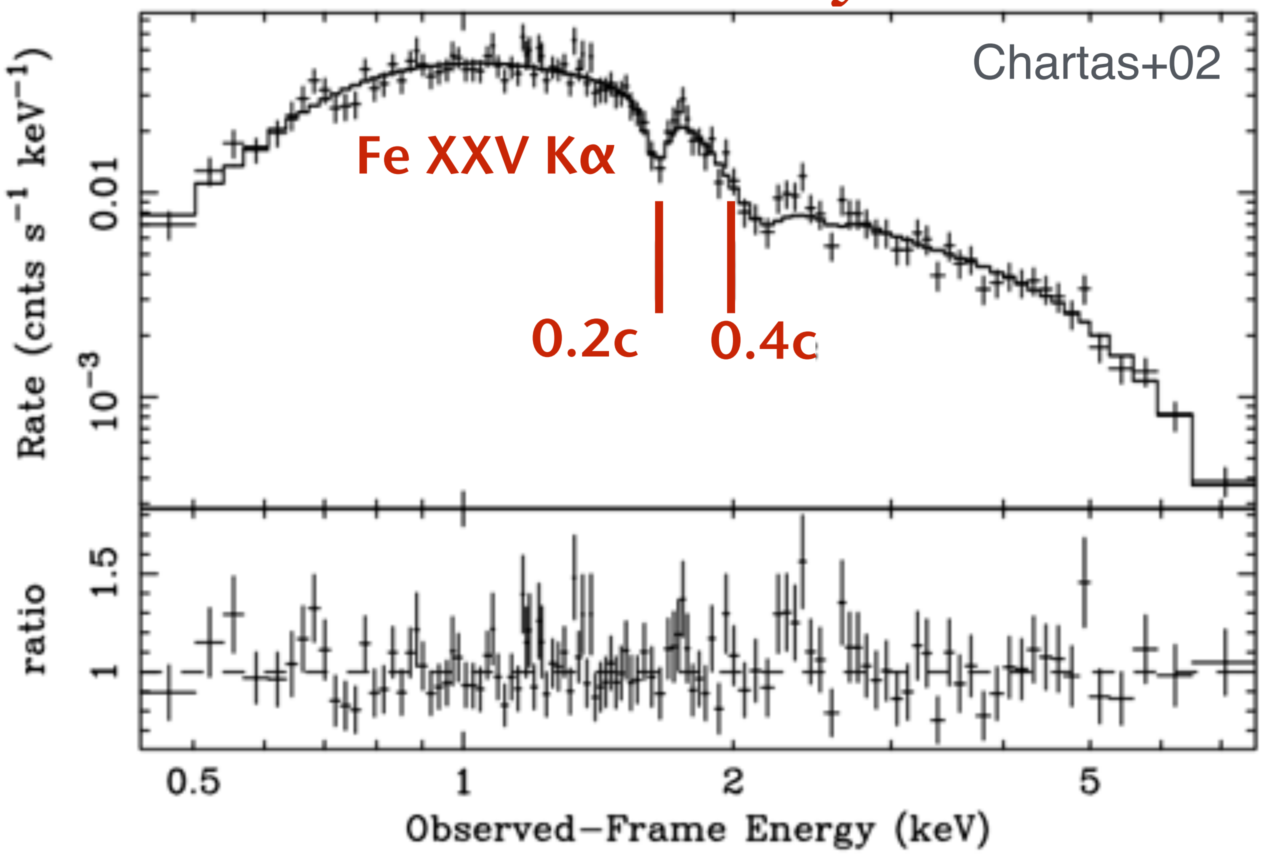
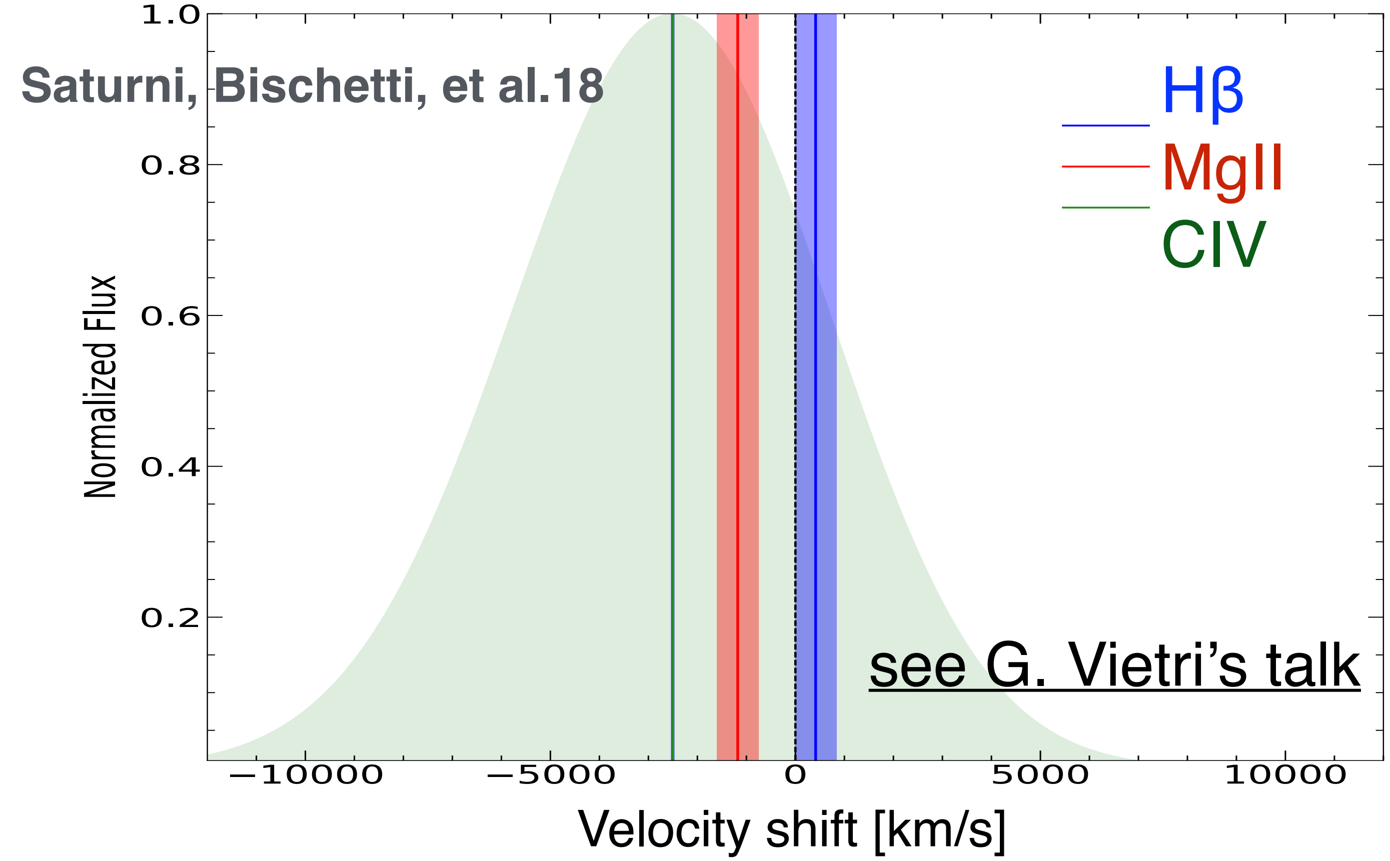


BLR winds in UV



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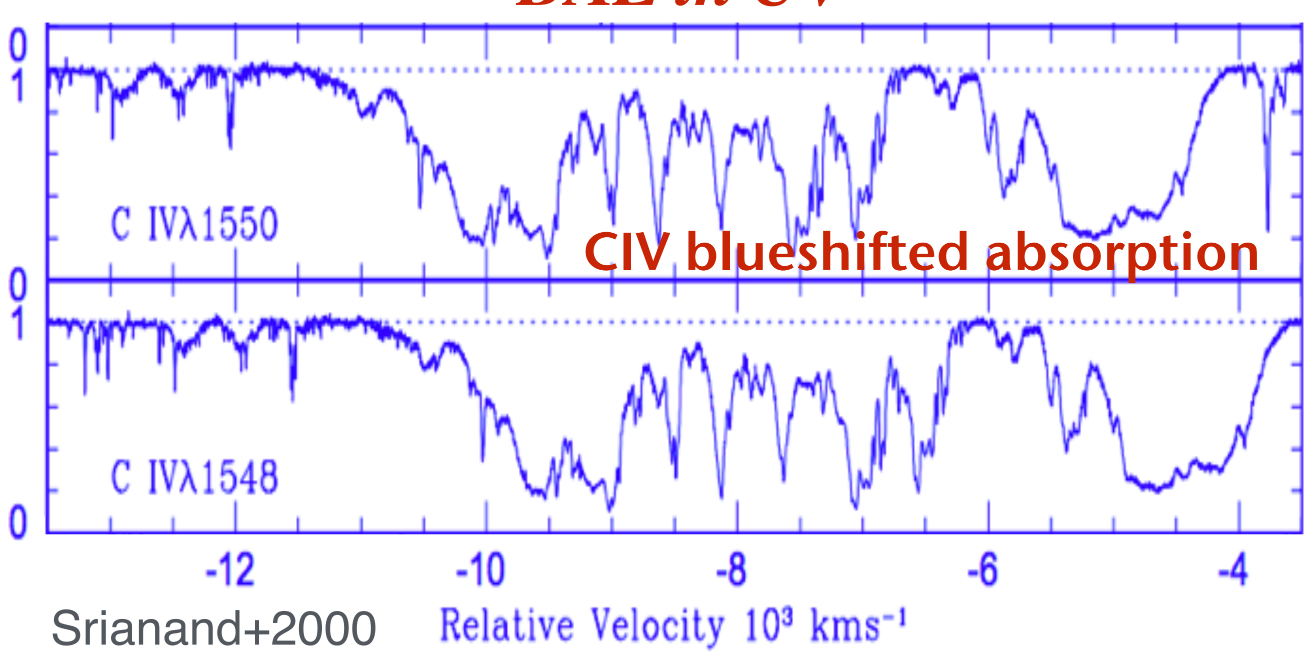
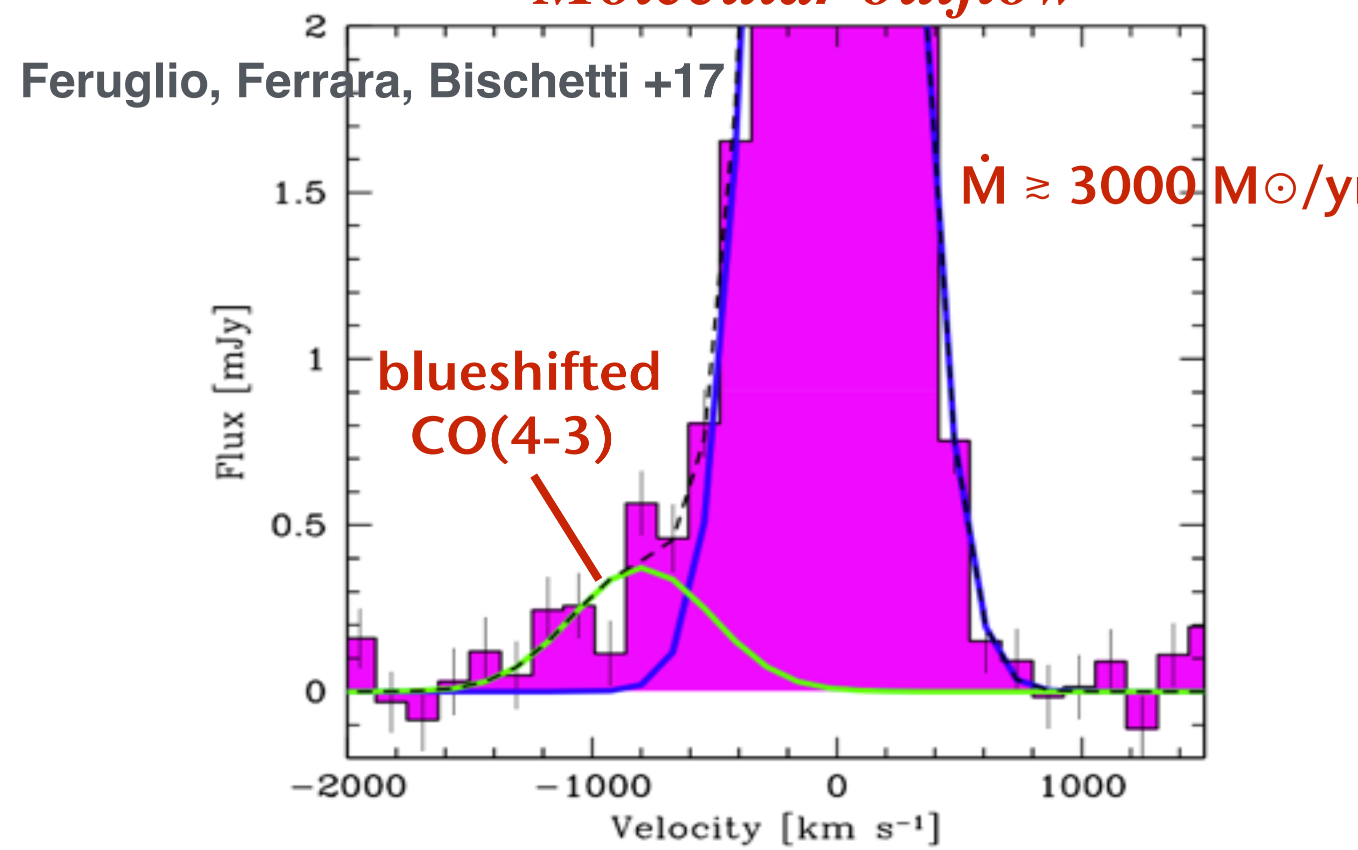


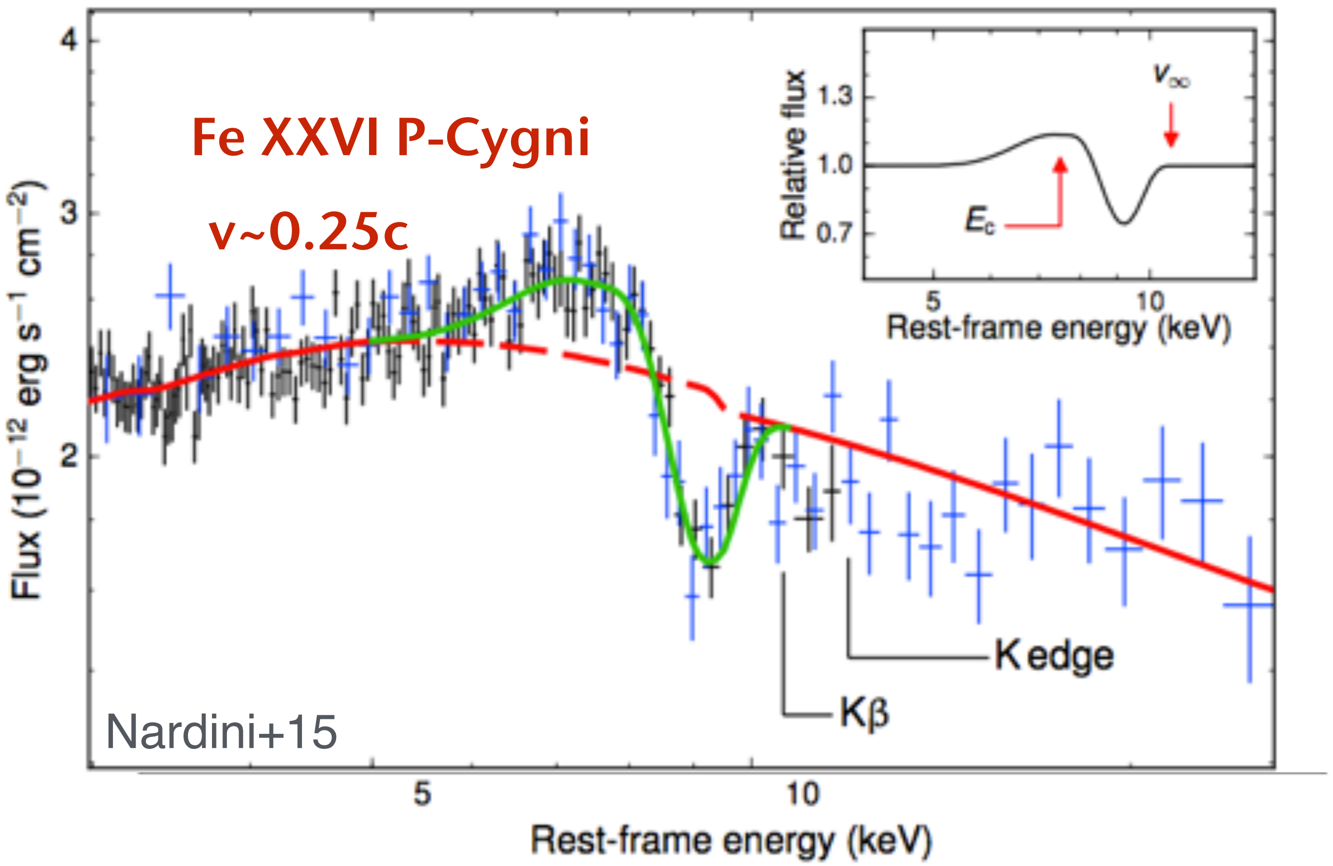
Molecular outflow



The most luminous radio-quiet AGN in the local Universe

Hyper-luminous QSO (L_{Bol} ~ 2x10^{47} erg/s) PDS456 at z = 0.185

UFO



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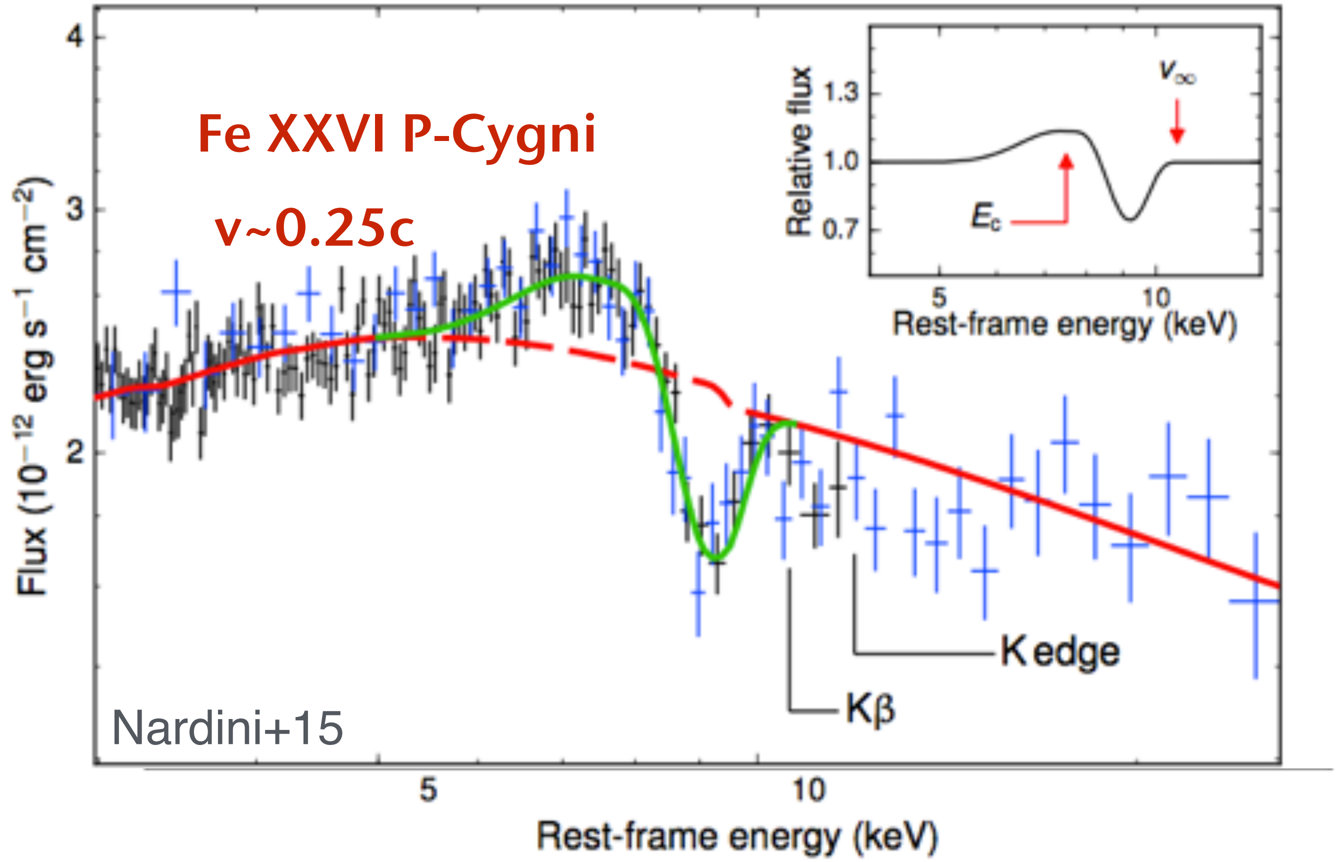
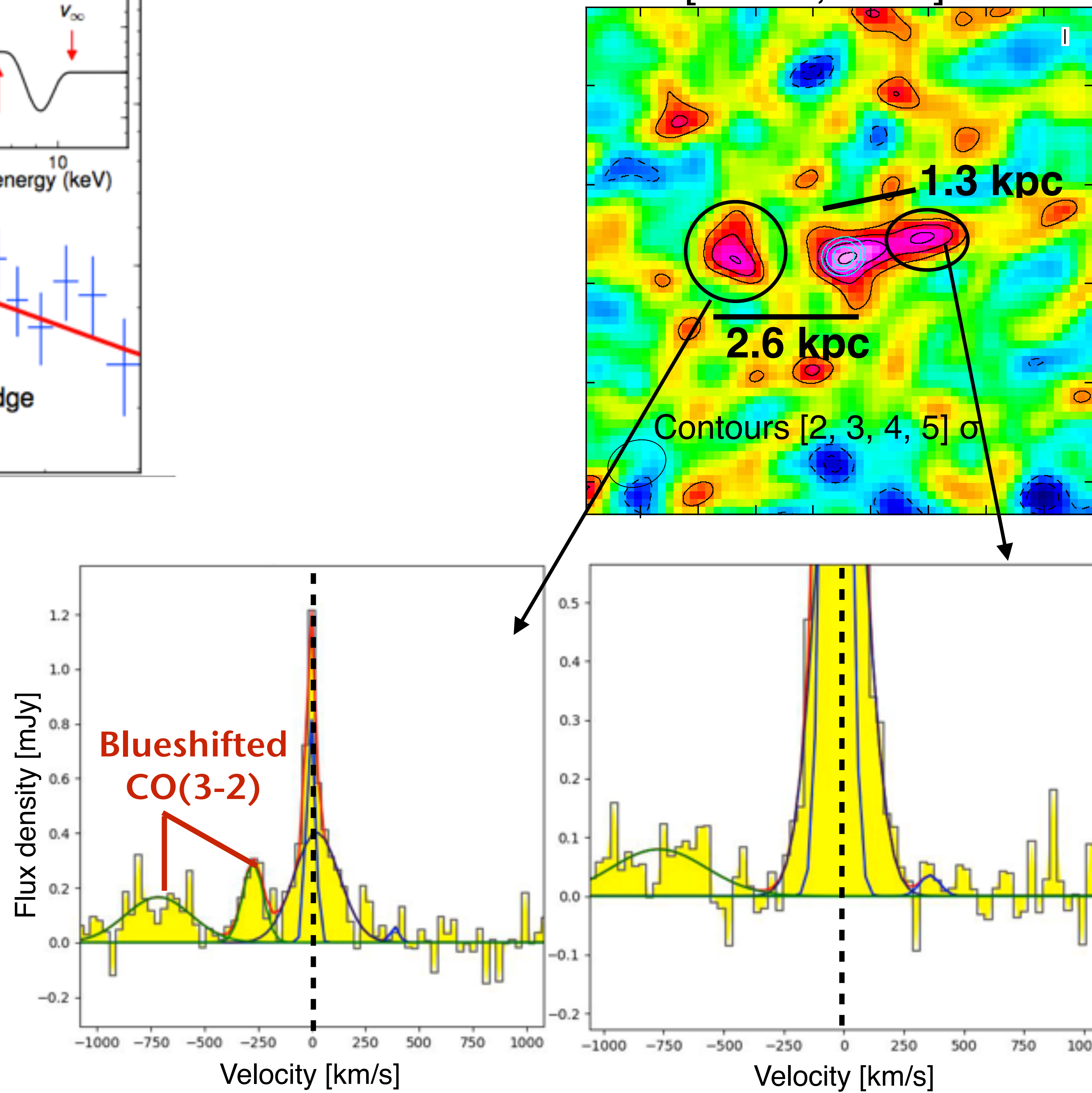


Spatially extended molecular outflow

v ∈ [-1000, -600] km/s

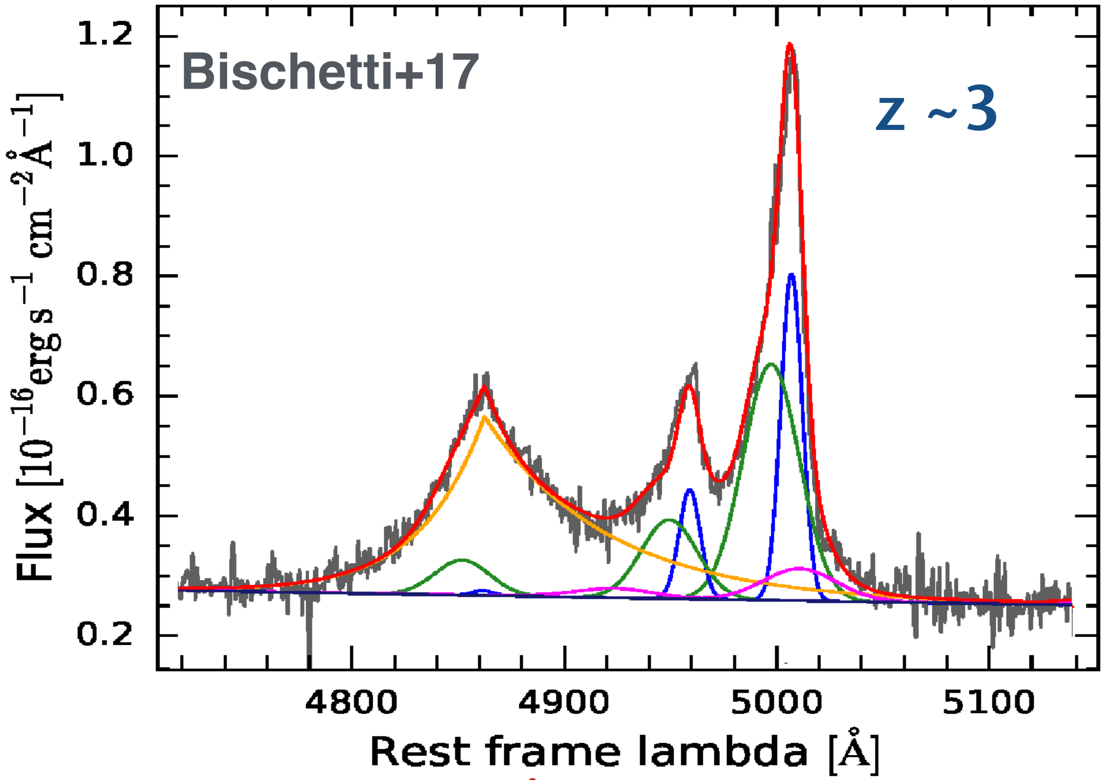


Associated $\dot{M}$ ~ 1300 $M_\odot$/yr

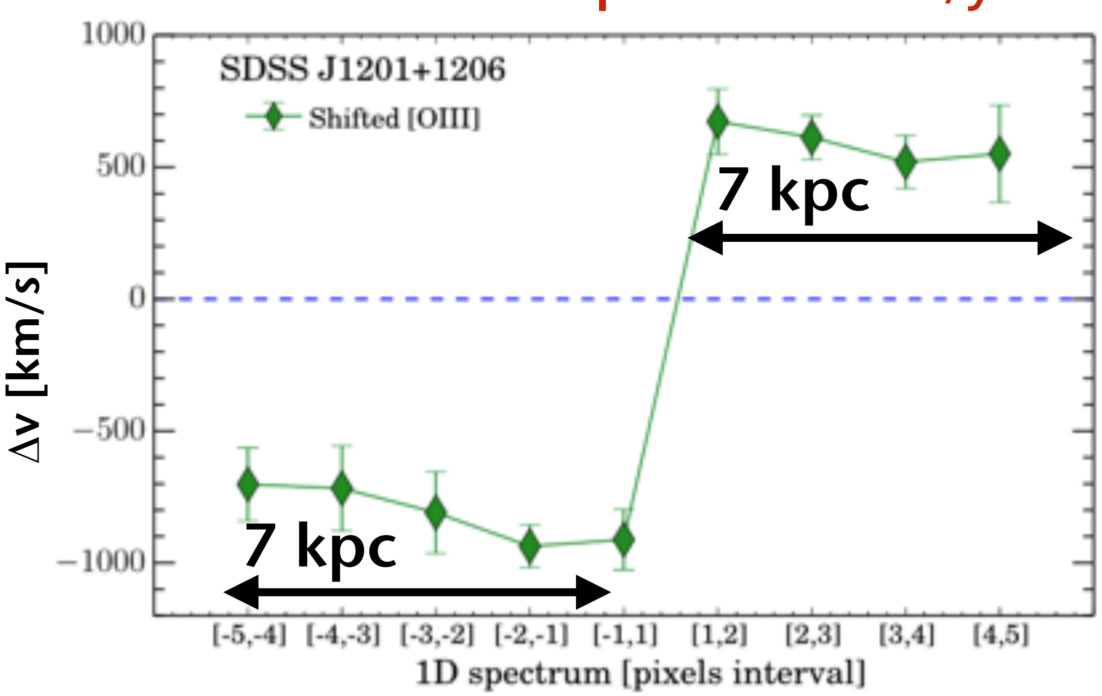
Bischetti, Piconcelli+18 in prep.

Ubiquitous presence of galaxy-wide [OIII]outflows

WISE-SDSS selected hyper-luminous (WISSH) QSOs

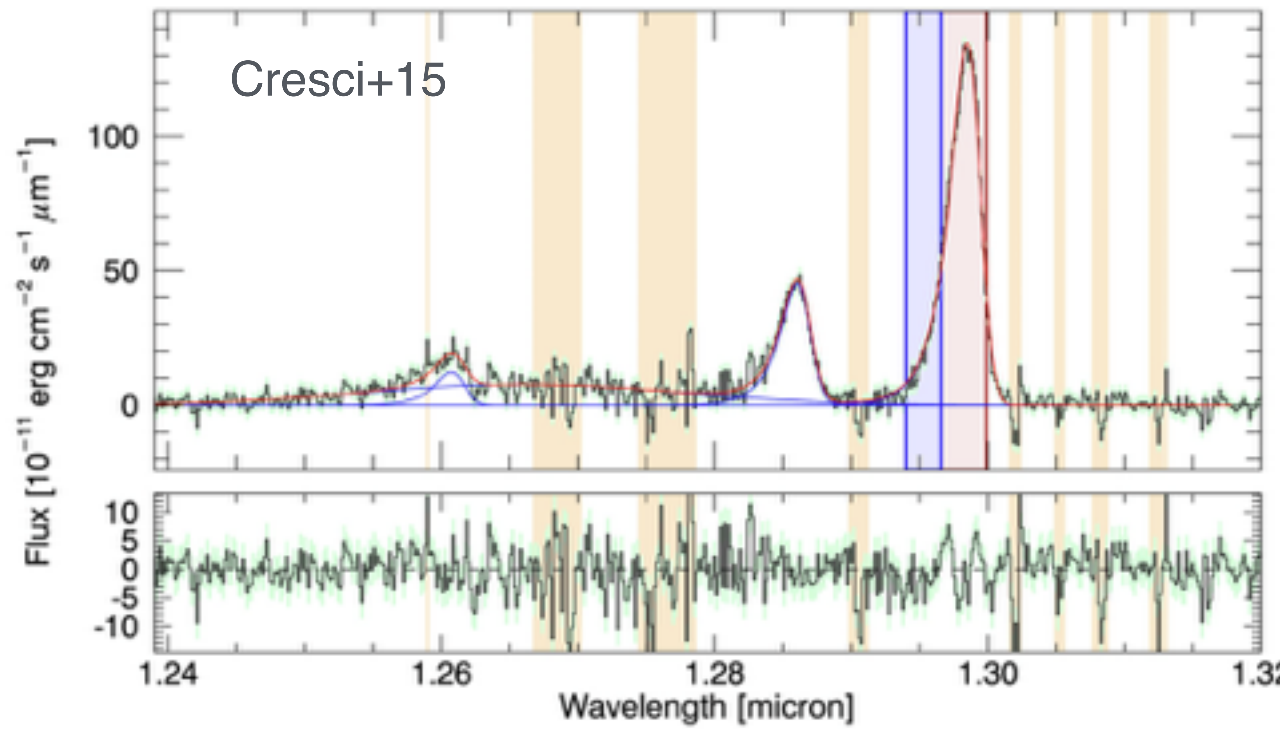


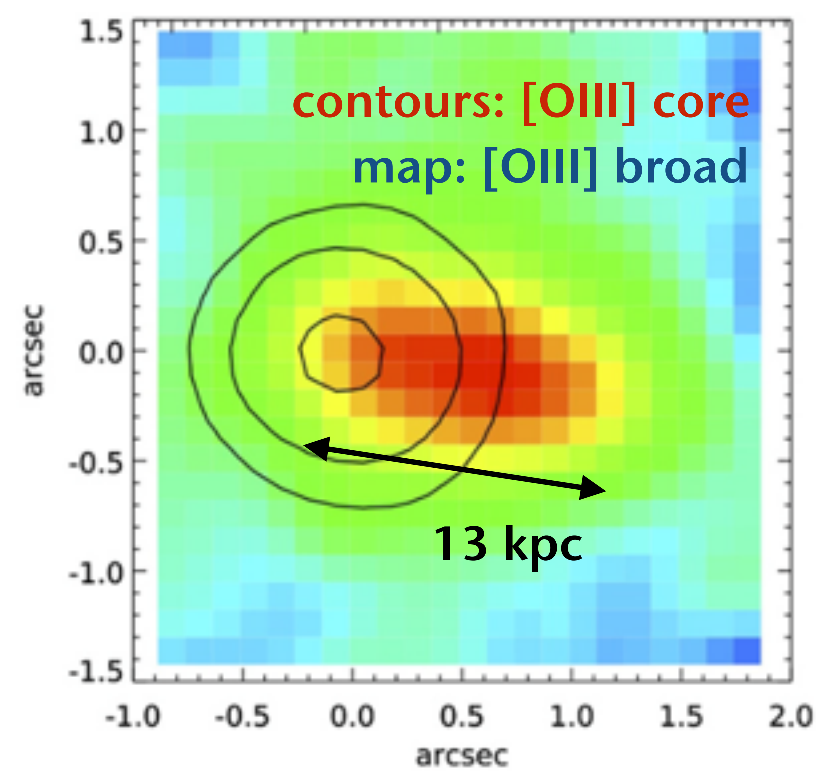
Associated $\dot{M}$ up to 8000 M⊙/yr



see G. Vietri's talk

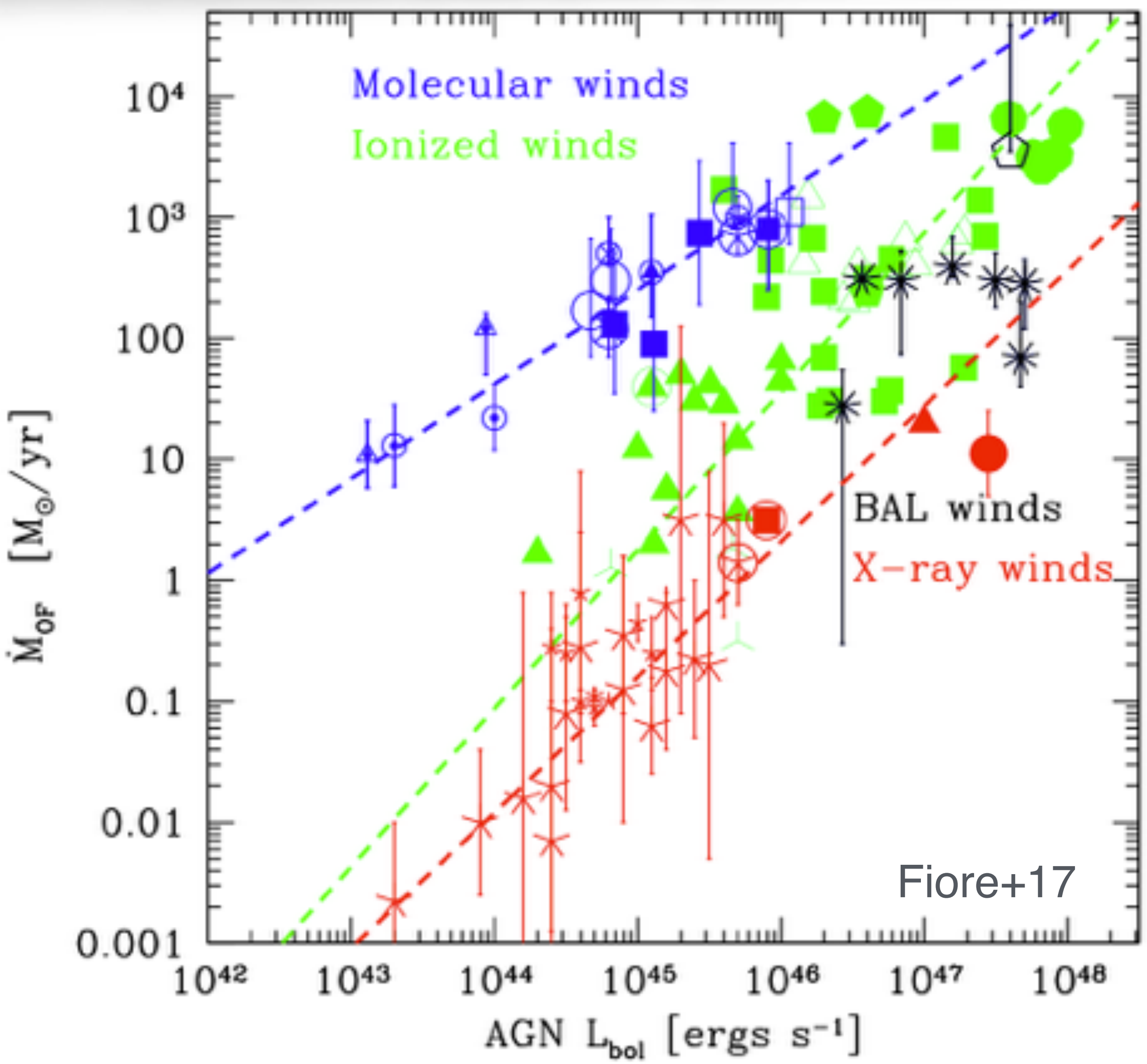
COSMOS QSO XID2028 at z = 1.59





see G. Cresci's talk

Role of AGN luminosity in driving outflows



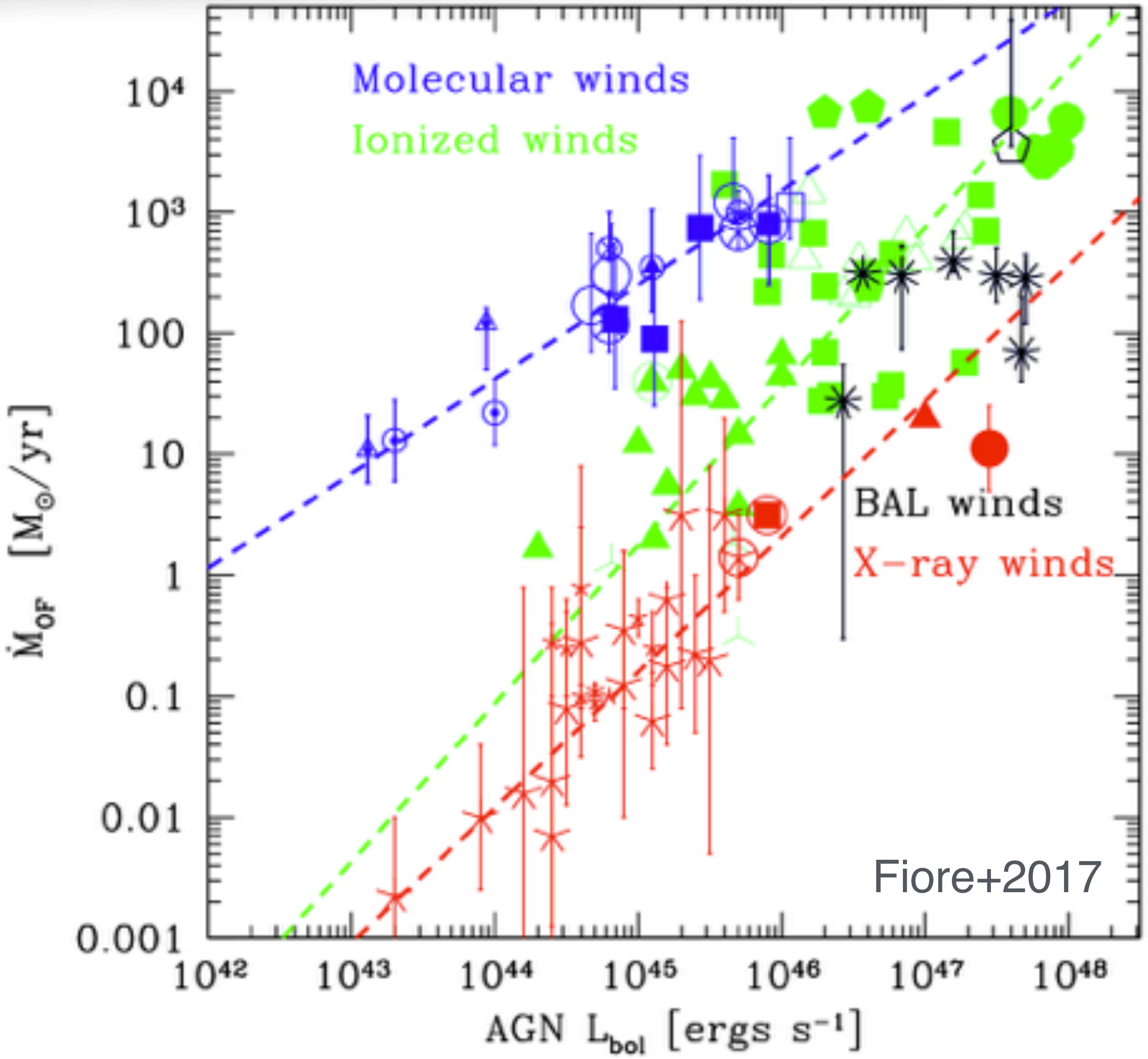
The mass outflow rate correlates with the AGN luminosity

Molecular: $\dot{M} \propto L_{\rm Bol}^{0.76}$

Ionised: $\dot{M} \propto L_{\rm Bol}^{1.29}$

Larger ionised fraction at high L_{Bol}

Driving mechanisms and the role of AGN luminosity



Molecular: $\dot{M} \propto L_{\rm Bol}^{0.76}$

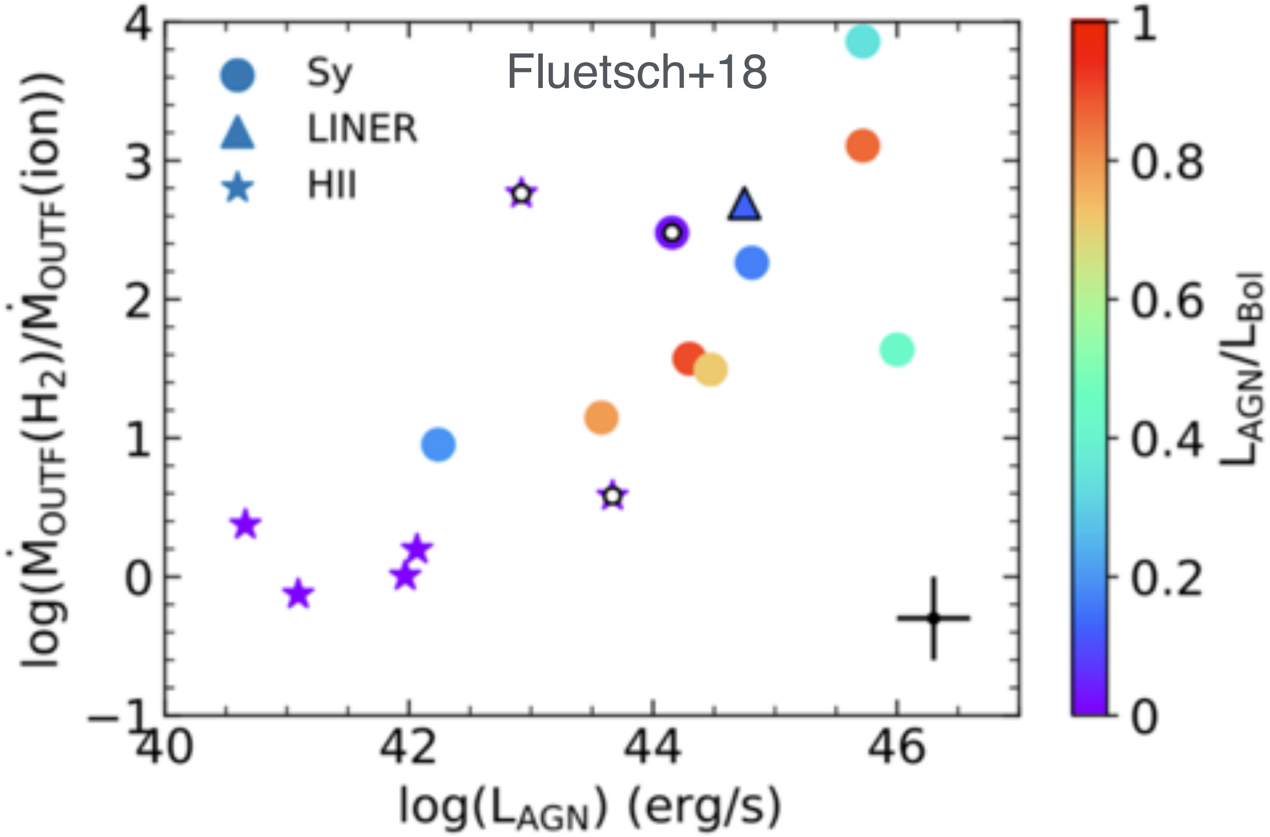
Ionised: $\dot{M} \propto L_{\rm Bol}^{1.29}$

Larger ionised fraction at high L_{Bol}

Outflow "strength" increases with the AGN luminosity

Mass outflow rate correlates with L_{Bol}

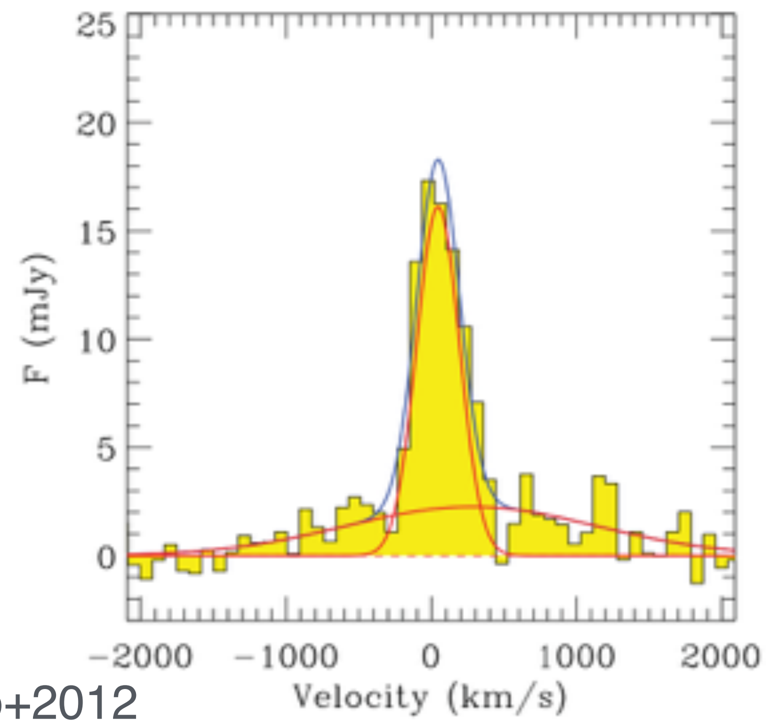
Different samples: opposite relative contribution of different phases to the total $\dot{M}$



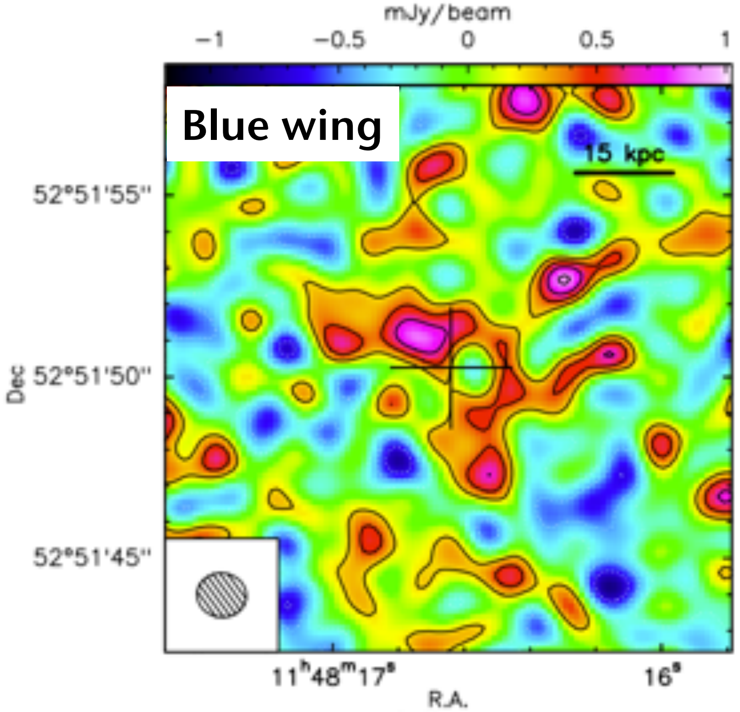
Larger molecular fraction at high L_{Bol}

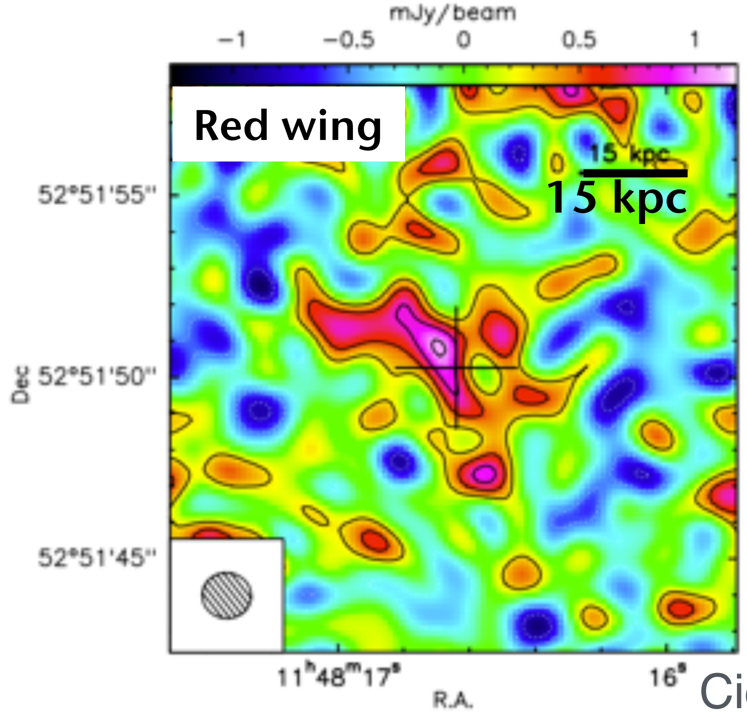
QSO-driven outflows (un)detected in the early-Universe

Massive [CII] outflow detected in J1148+5251 at z = 6.4 on kpc scale (L_{Bol} ~ 2x10^{47} erg/s)



Maiolino+2012





Cicone+2015

But….only broad wings detection despite tens of QSOs targeted in [CII]!

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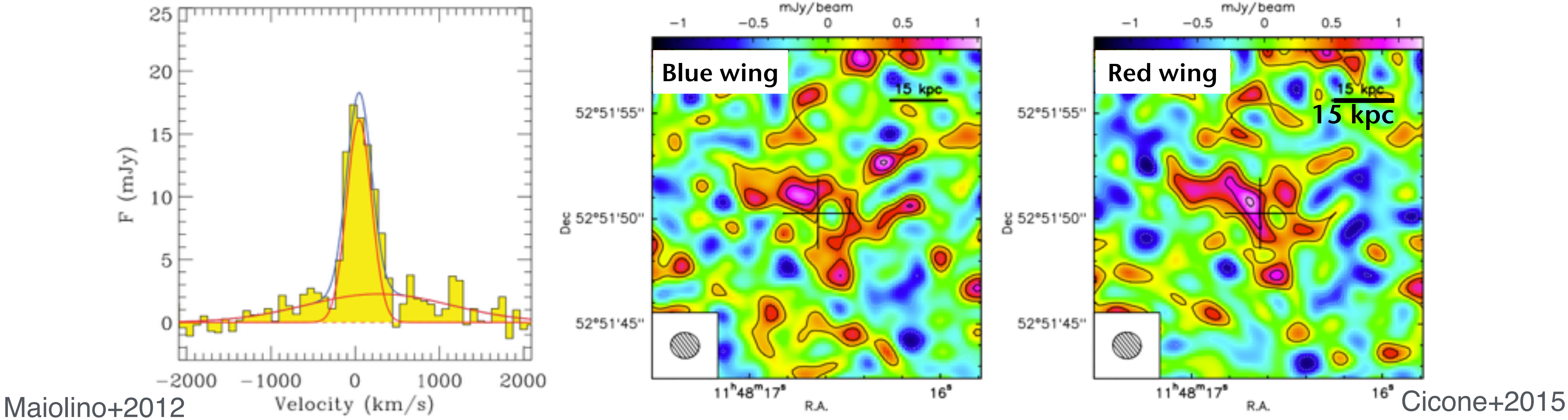

But….only broad wings detection despite tens of QSOs targeted in [CII]!

Stacking analysis:
Investigate the presence of faint, broad [CII] wings

SAMPLE: 48 high -redshift QSOs observed with ALMA

- [CII] 158 μm ALMA detection at ≳ 5σ significance
- $45.9 < \mathrm{Log}(L_{Bol} / \mathrm{erg\ s^{-1}}) < 47.7$
- $4.6 < z < 7.1$

Cold outflows in the early Universe are there

Variance-weighted stack analysis

$$W'_{\mathrm{k}} = \sum_{j=1}^{n} w_{\mathrm{j,k}} = \sum_{j=1}^{n} \frac{1}{\sigma^2_{\mathrm{j,k}}} = \frac{1}{\sigma'^2_{k}}$$

source ($j=1$) — channel (k)

$$I'_k = \frac{\sum_{j=1}^{n} \left(i_{\mathrm{j,k}} \cdot w_{\mathrm{j,k}} \right)}{W'_k}$$

48 QSOs = 34h on source

>10x improved sensitivity than J1148+5251

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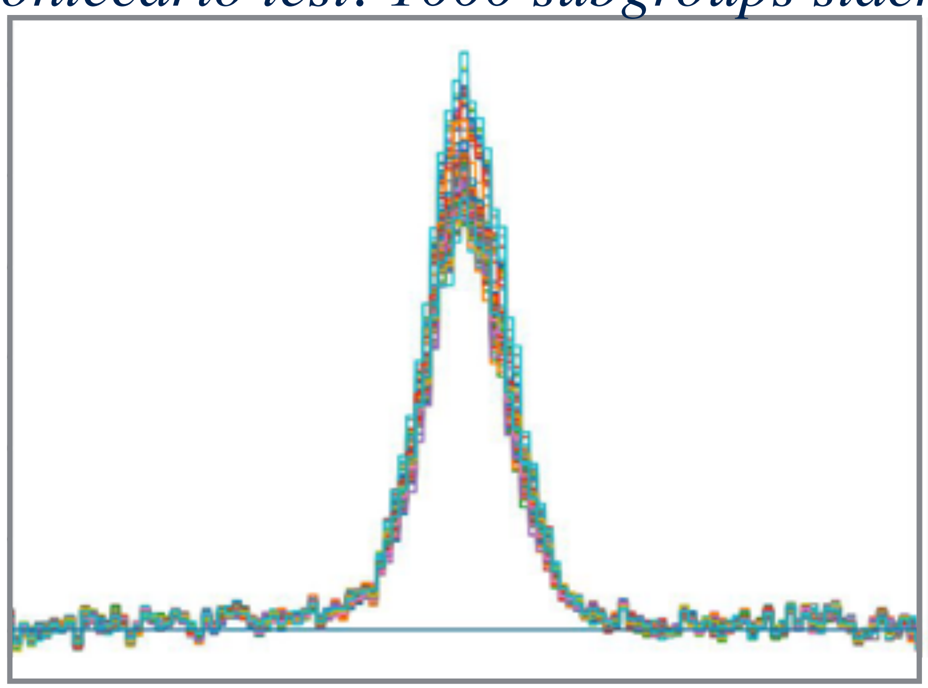
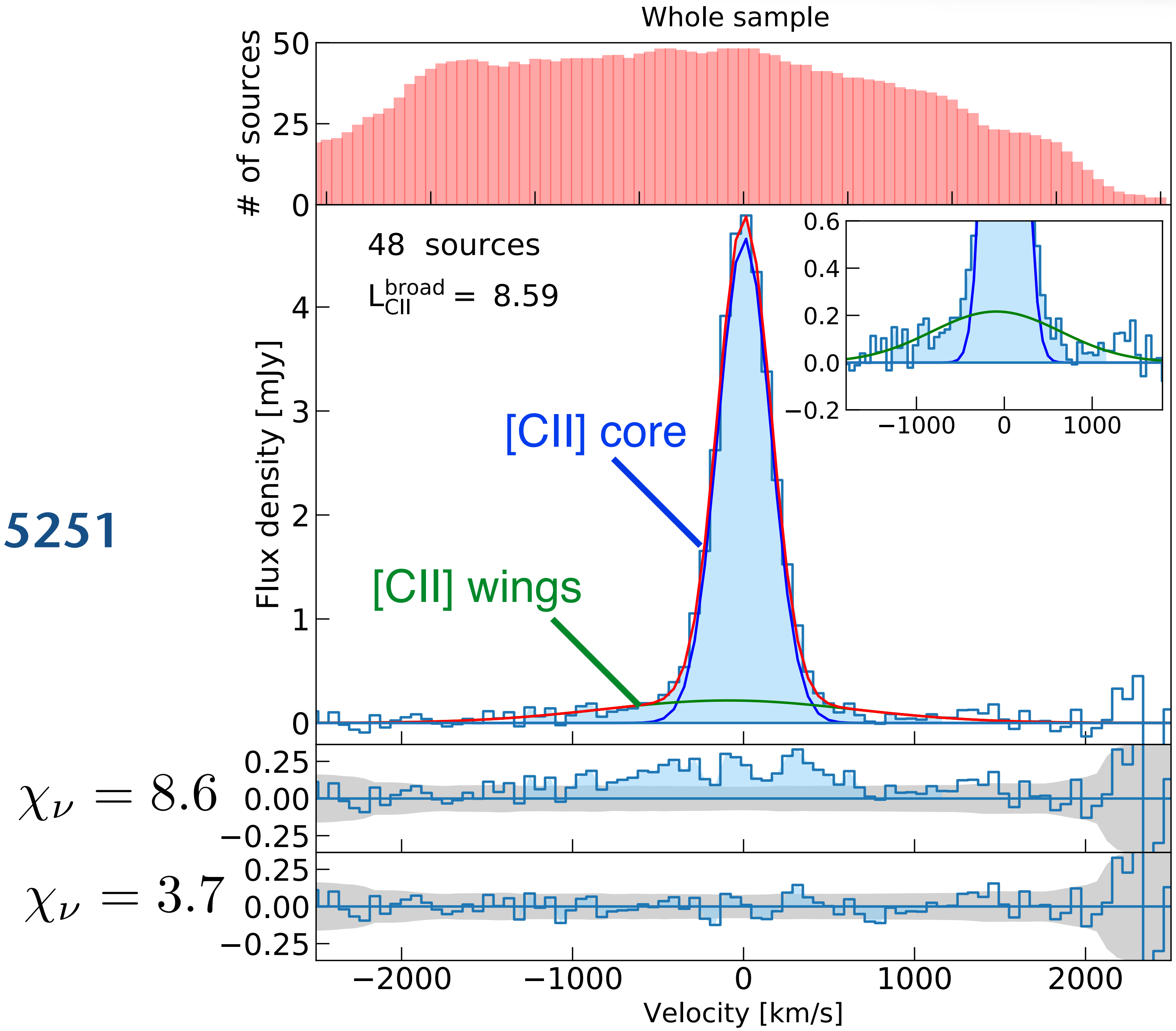
Montecarlo test: 1000 subgroups stacked



wings rms variation of 20%



Wings : peak ~ 1: 20

$FWHM_{broad}$ ~ 1700 km/s

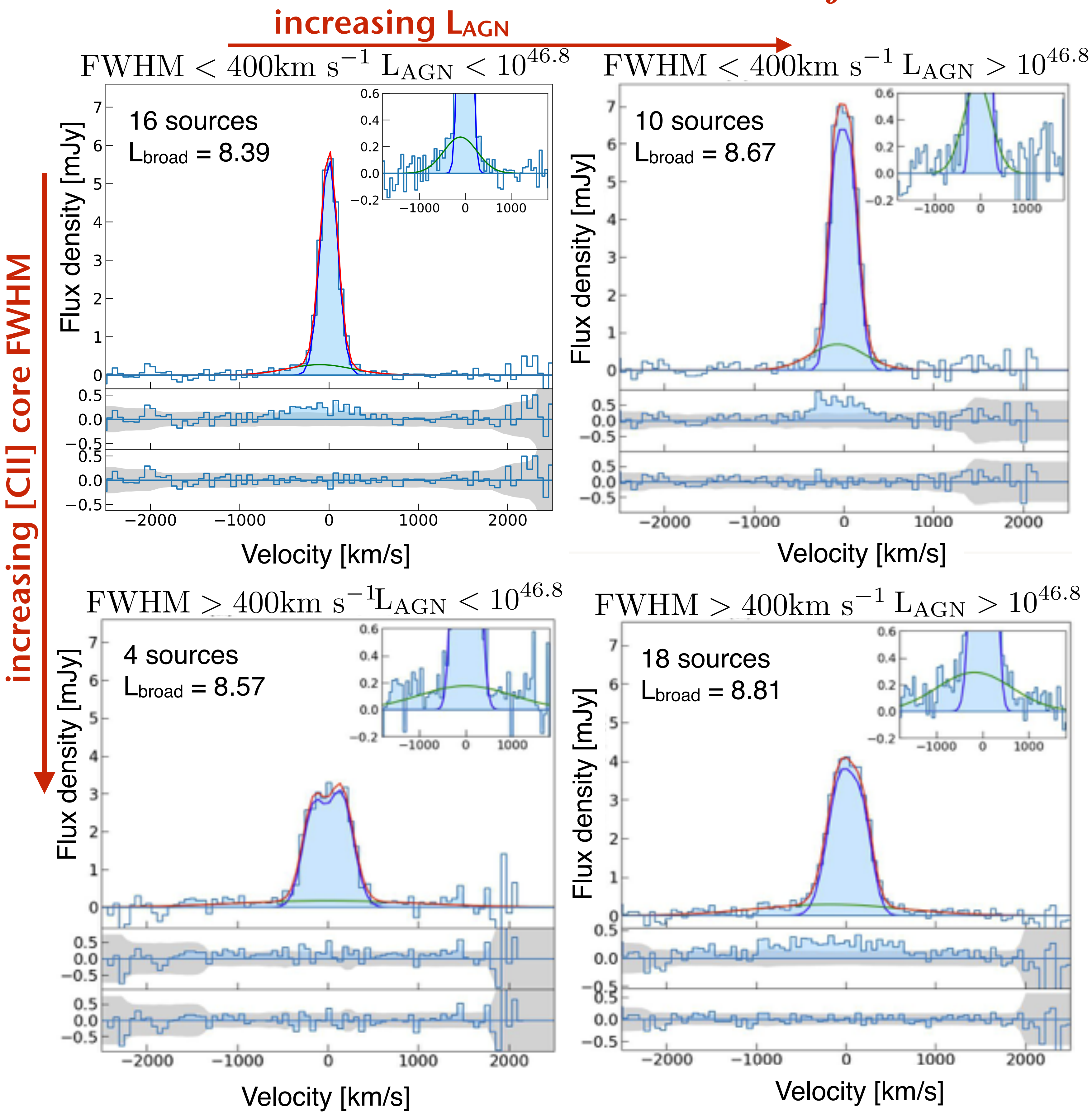
Δv_{broad} ~ -100 km/s

Optically thick [CII]?

Bischetti+18, arXiv1806.00786

AGN-driven [CII] outflows in high-z QSOs

Stack in bins of FWHM and L_{AGN}:



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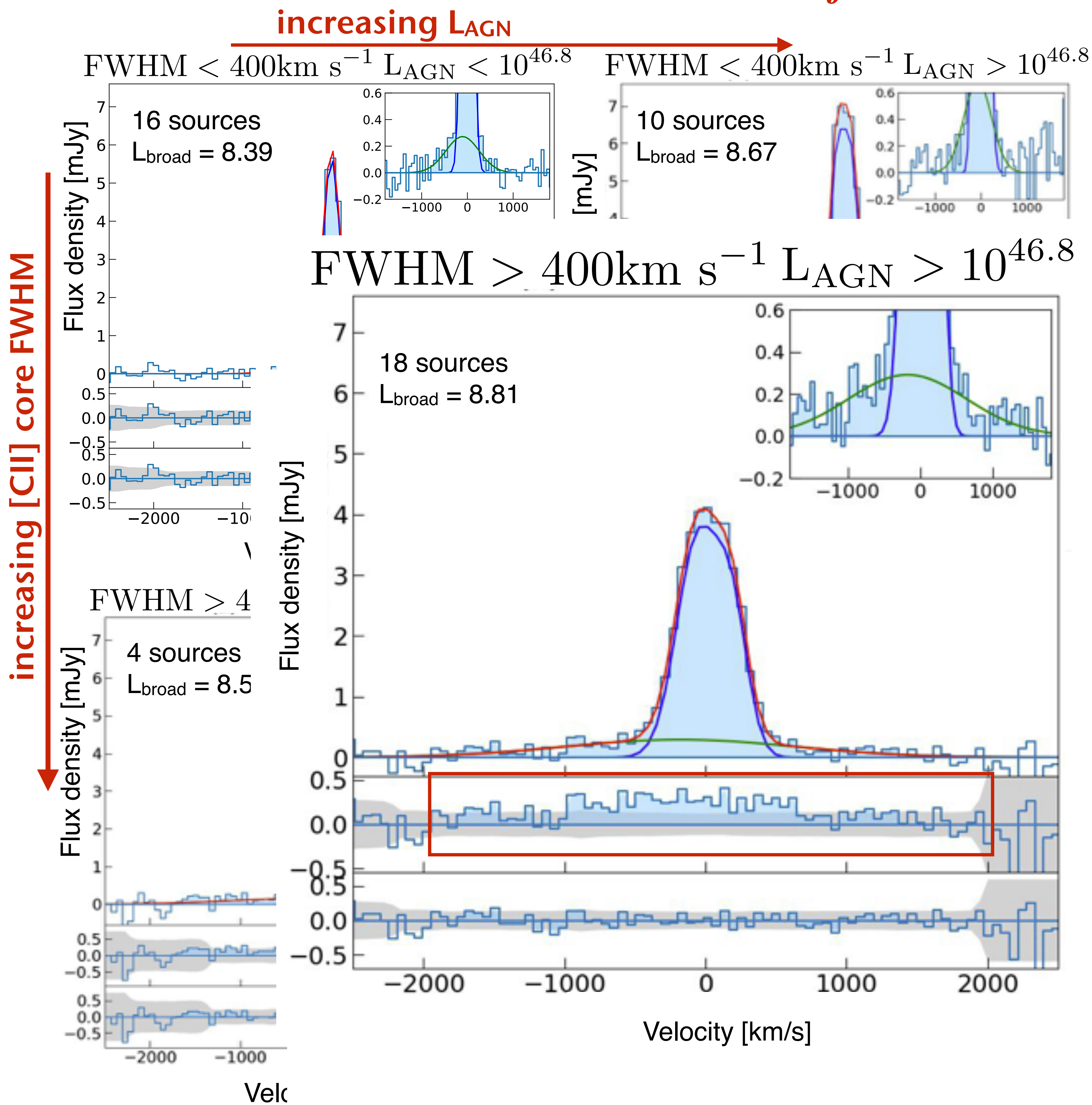

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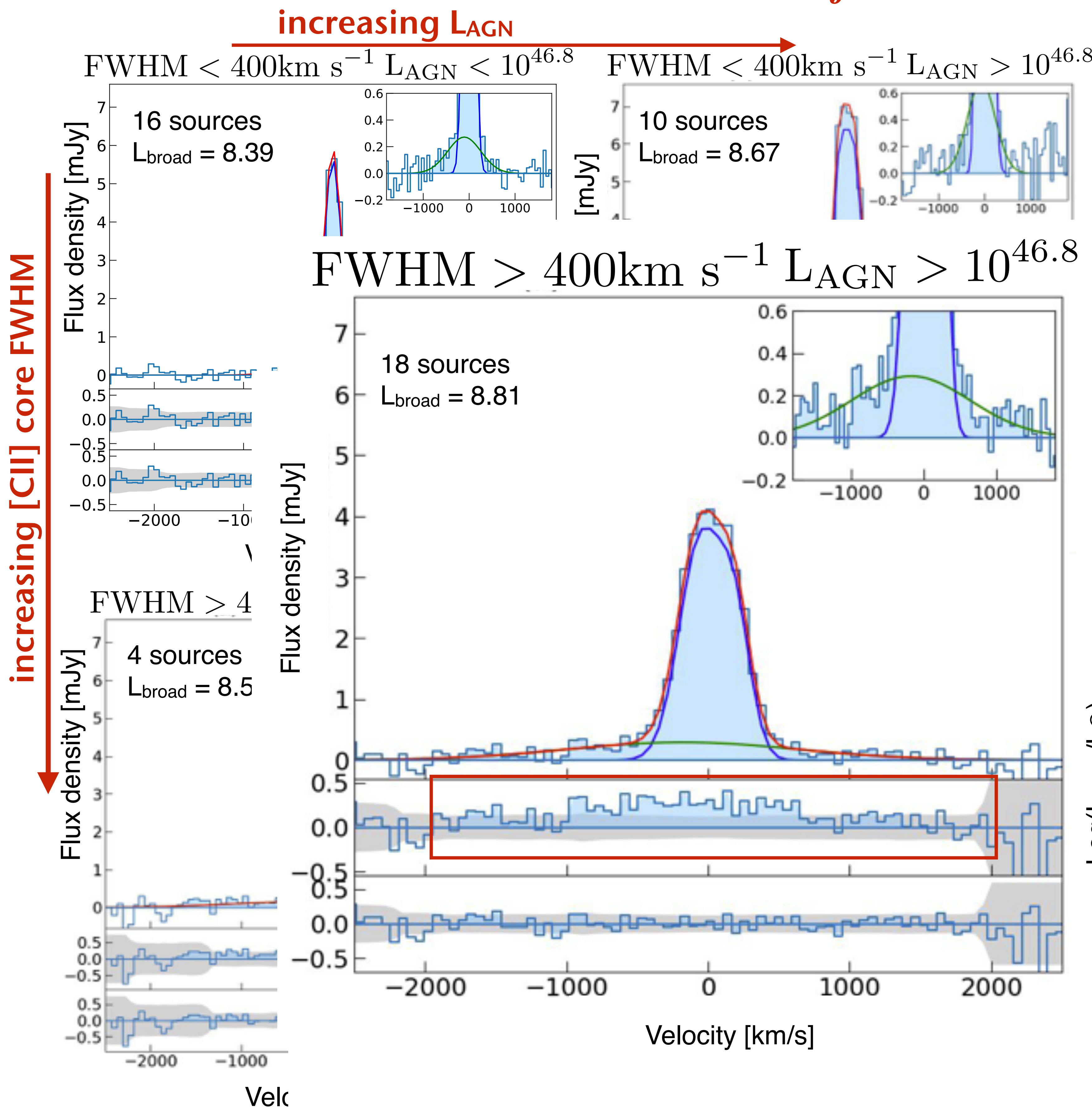
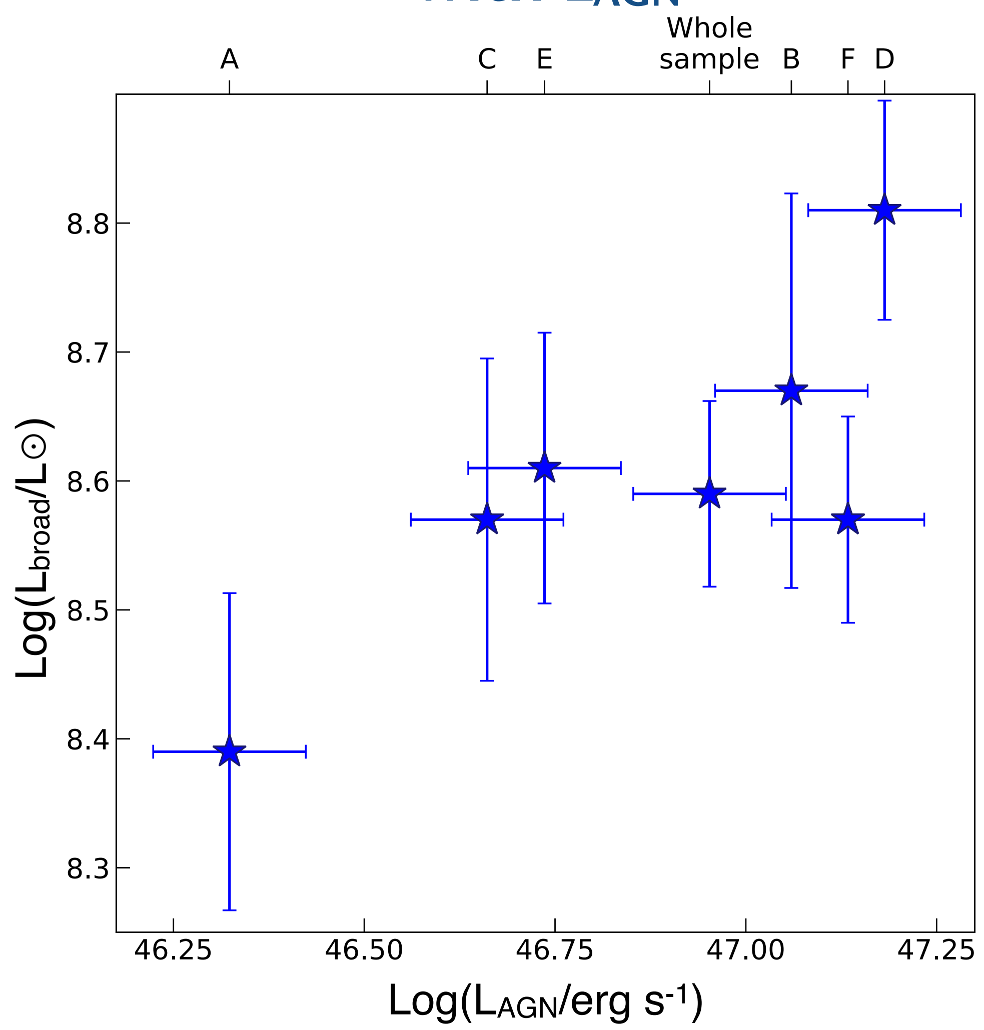
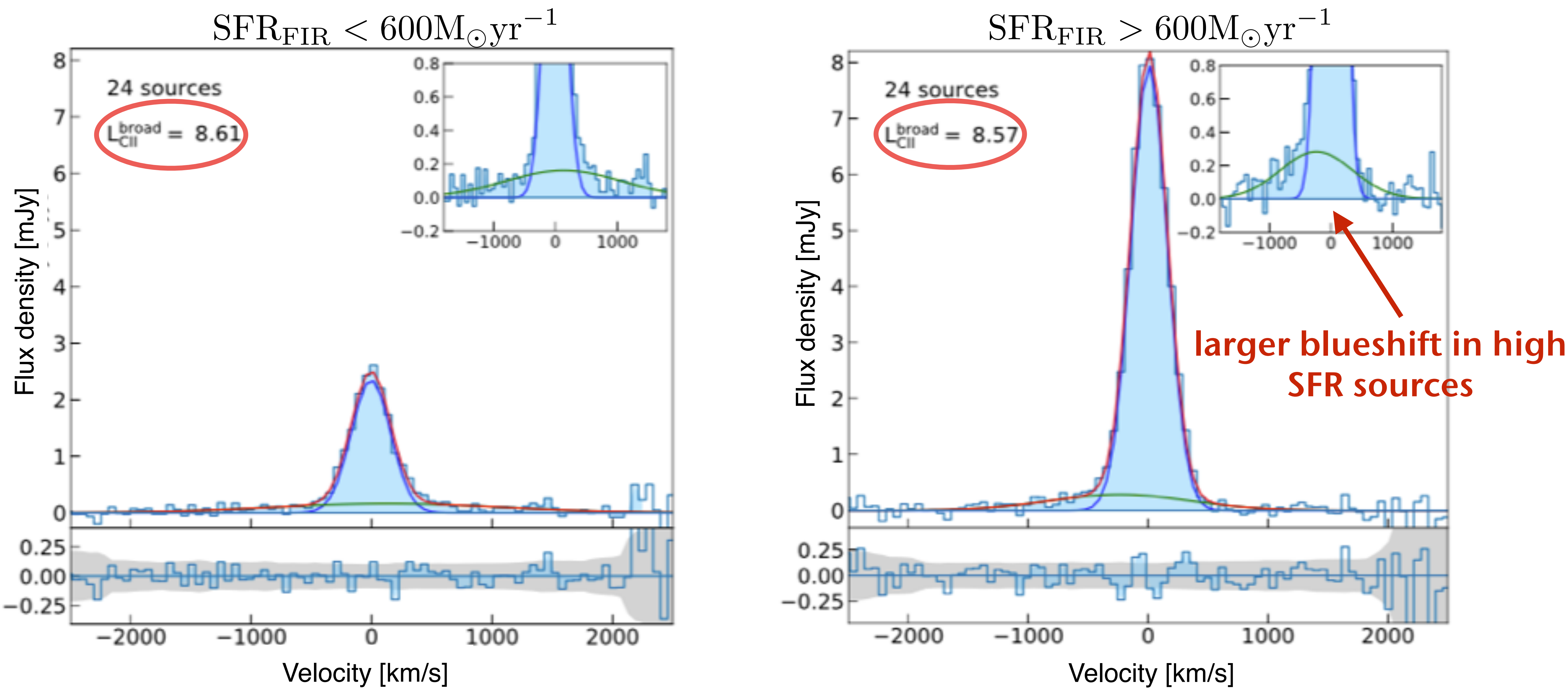


The luminosity of the [CII] broad wings correlates with L_{AGN}



AGN-driven [CII] outflows in high-z QSOs

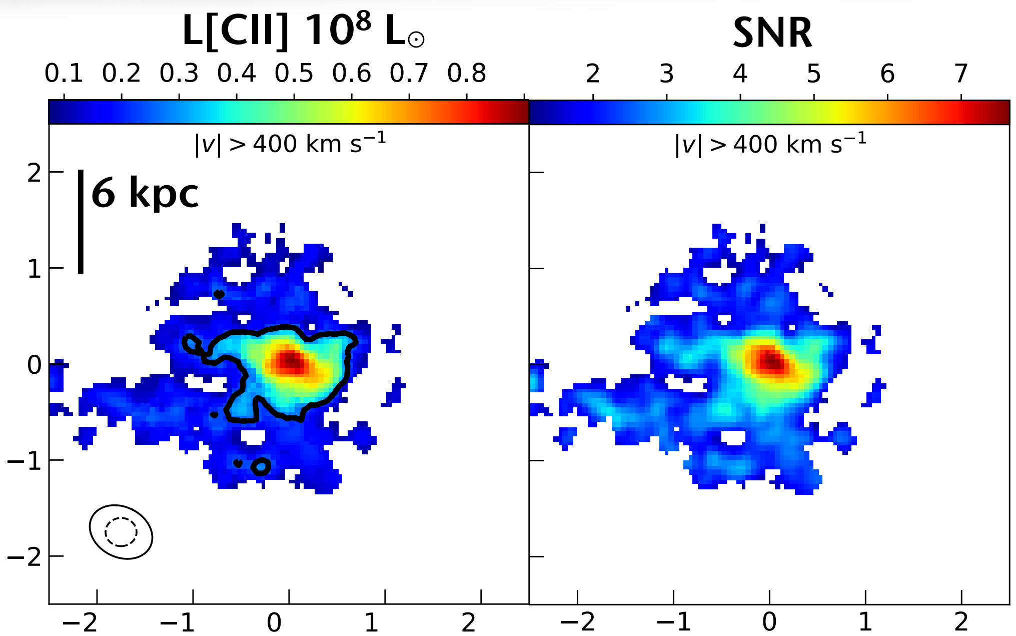
Stack in low-SFR and high-SFR sources:



Correlation between L_{broad} and L_{AGN}
+ NO dependance on SFR (same luminosity)

The AGN is the main driving mechanism of the [CII] outflows

Energetics of [CII] outflows in high-z QSOs



L_{broad} **+** $$M_{outf}/M_{\odot} = 0.77\left(\frac{0.7L_{[CII]}}{L_{\odot}}\right)\left(\frac{1.4\times10^{-4}}{X_{C^{+}}}\right)\times\frac{1+2e^{-91K/T}+n_{crit}/n}{2e^{-91K/T}}$$ **+**

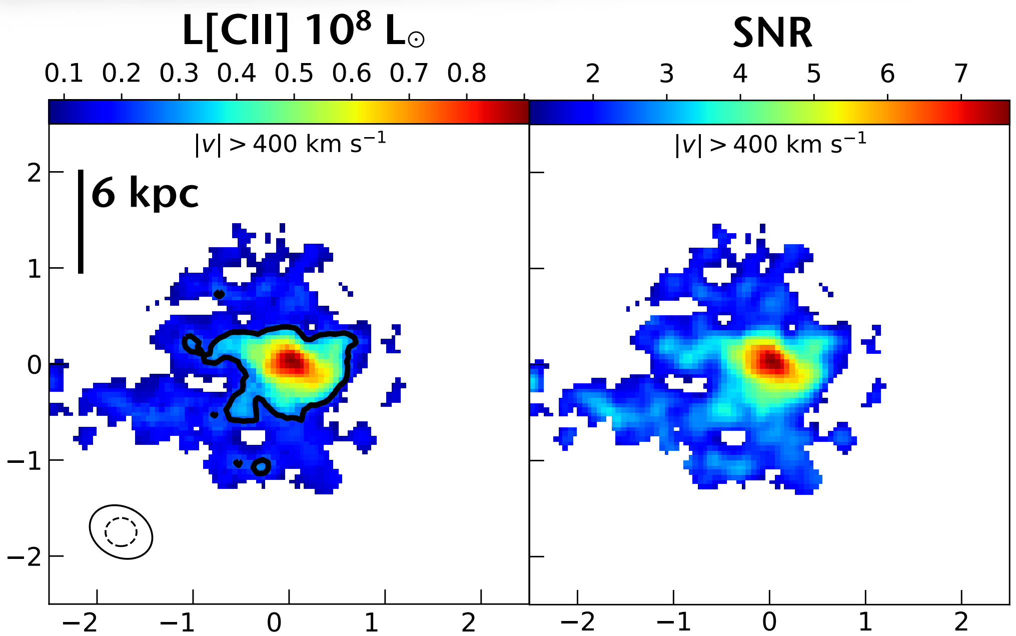
Hailey-Dunsheath+2000

half light radius
~ 2 kpc
(we might be losing
a significant
fraction of extended flux)

+ $v_{out} = |\Delta v_{broad}| + FWHM_{broad}/2$

Mass outflow rate of the [CII] outflows

Energetics of [CII] outflows in high-z QSOs



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Hailey-Dunsheath+2000

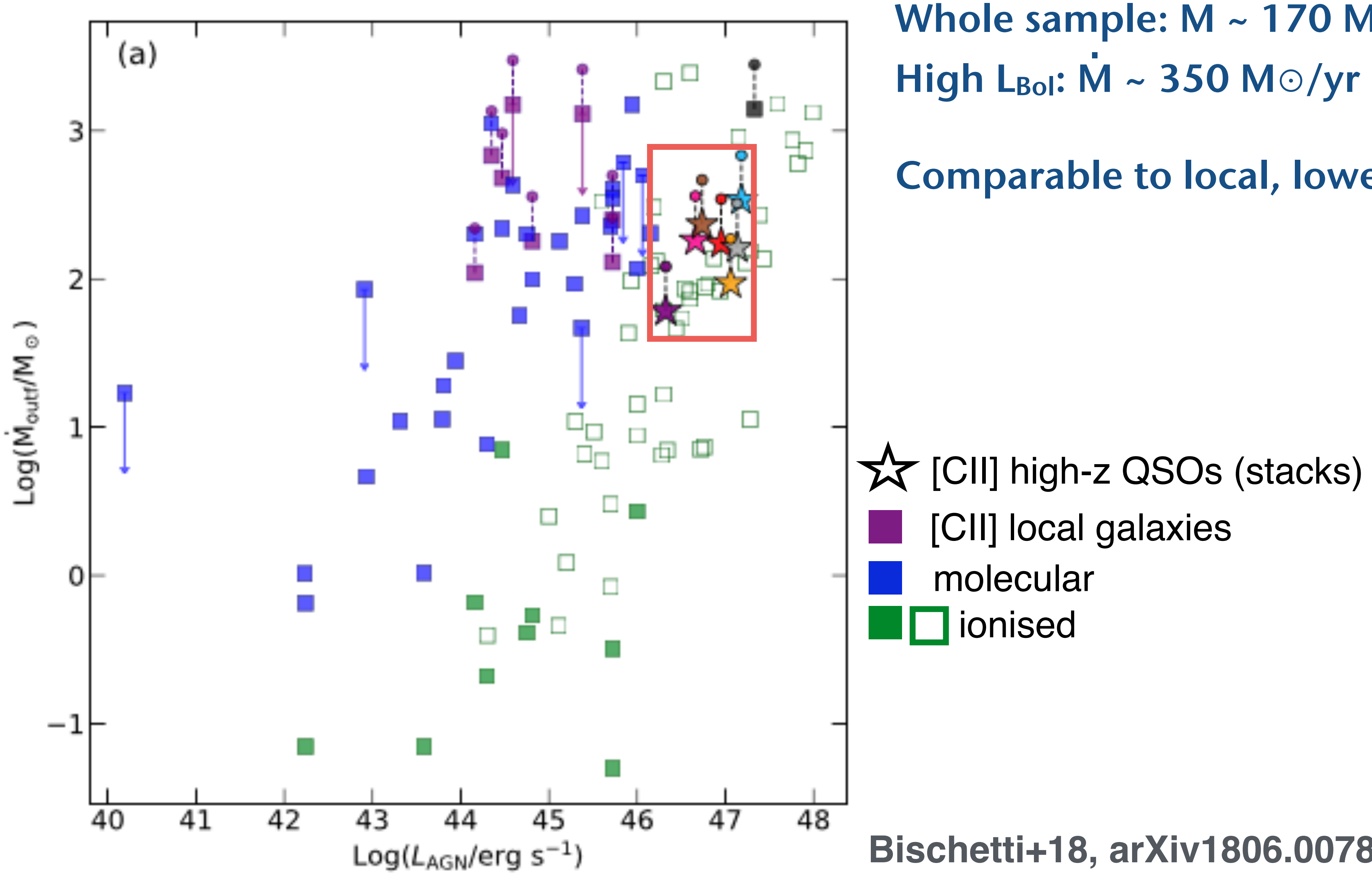
half light radius ~ 2 kpc (we might be losing a significant fraction of extended flux) + $v_{out} = |\Delta v_{broad}| + FWHM_{broad}/2$

Atomic mass outflow rate of the [CII] outflows

Whole sample: $\dot{M}$ ~ 170 M⊙/yr

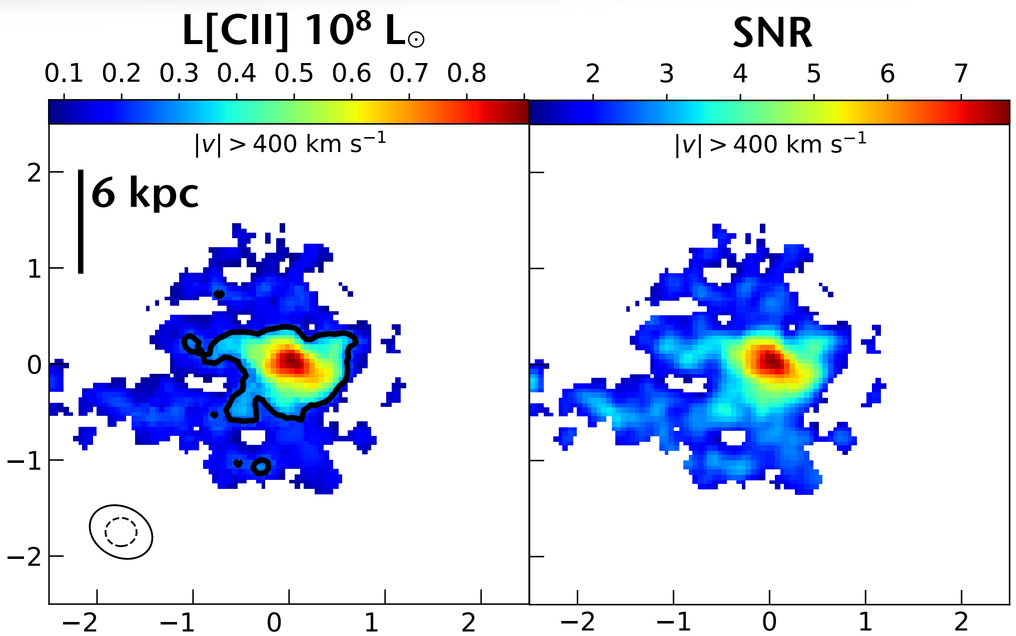
High L_{Bol}: $\dot{M}$ ~ 350 M⊙/yr

Comparable to local, lower luminosity AGN



Bischetti+18, arXiv1806.00786

Energetics of [CII] outflows in high-z QSOs



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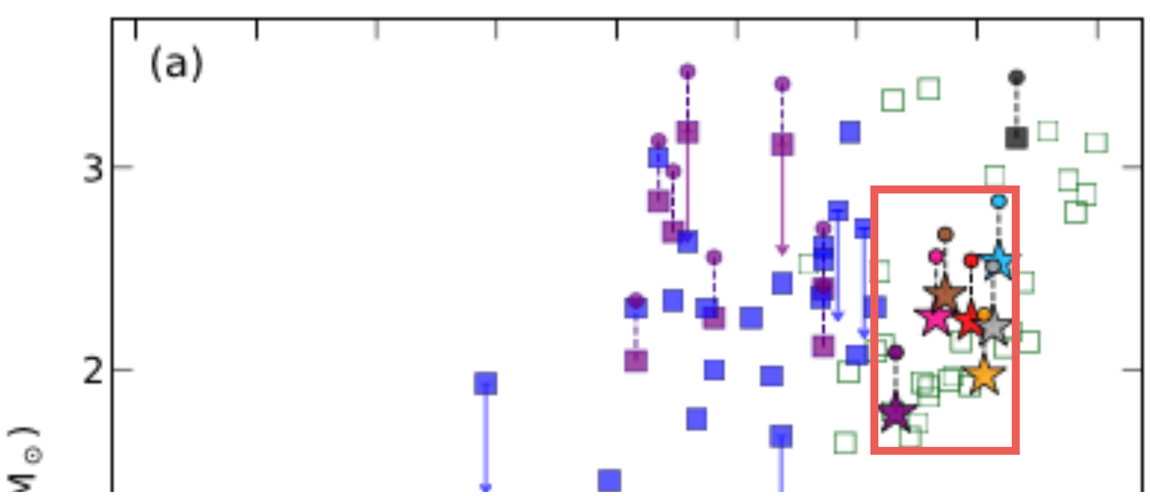


Cold outflows at high-z might be less effective in removing gas than local AGN

However:

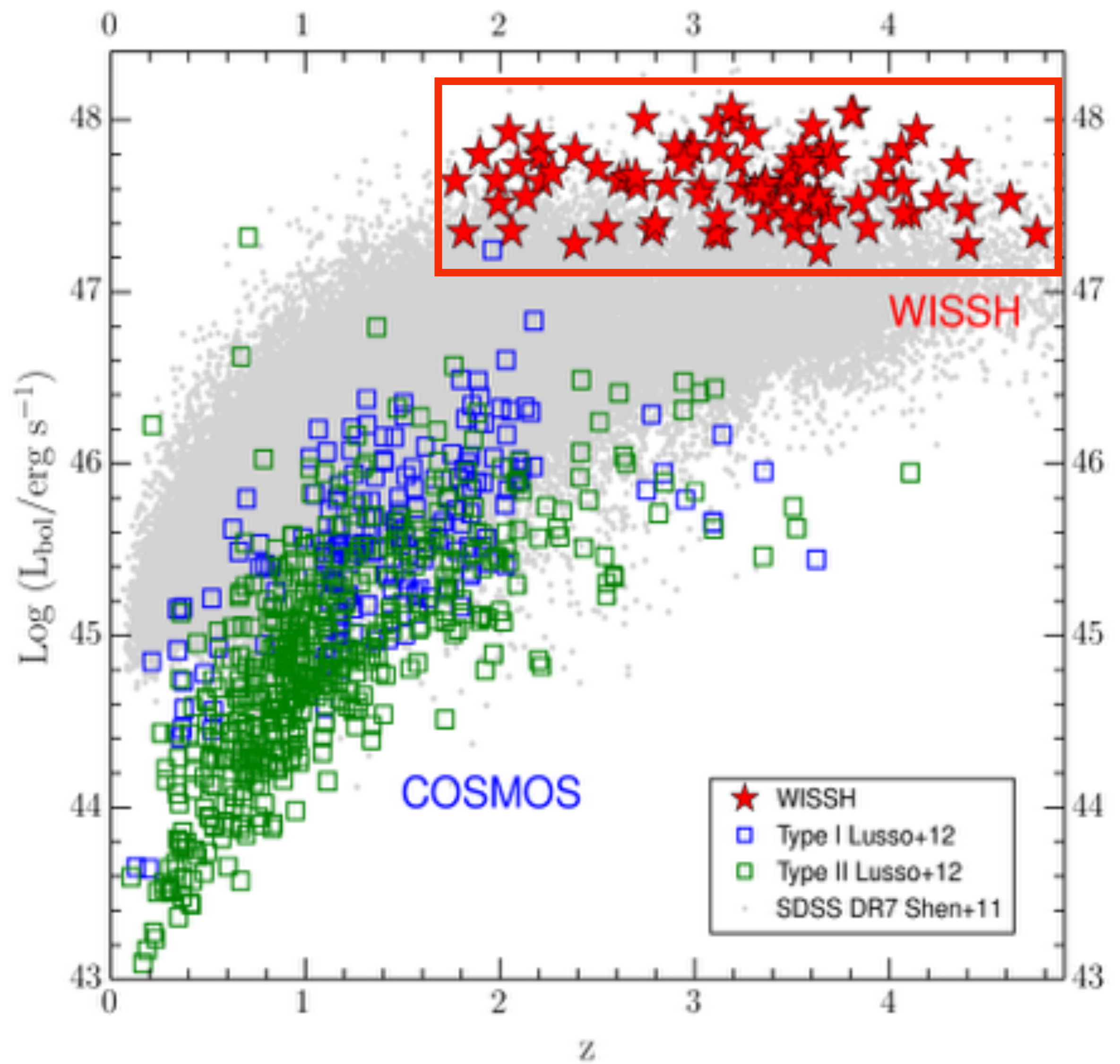
- Possible flux losses
- Range of L_{Bol} unexplored so far for molecular and neutral outflows in local AGN

The WISSH QSOs project: the ALMA view

SAMPLE: 86 WISE/SDSS Selected Hyper-luminous (WISSH) QSOs

see G. Vietri's talk

- SDSS DR7 broad-line QSOs with S(22 μm) > 3 mJy
- $\text{Log}(L_{Bol} /\text{erg s}^{-1}) > 47.2$
- $1.5 < z < 4.5$
- Lensed objects removed



The most luminous broad-line IR-loud AGN at cosmic noon

- available BH mass
- SED-based SFR
- evidence for nuclear and galaxy-wide outflows

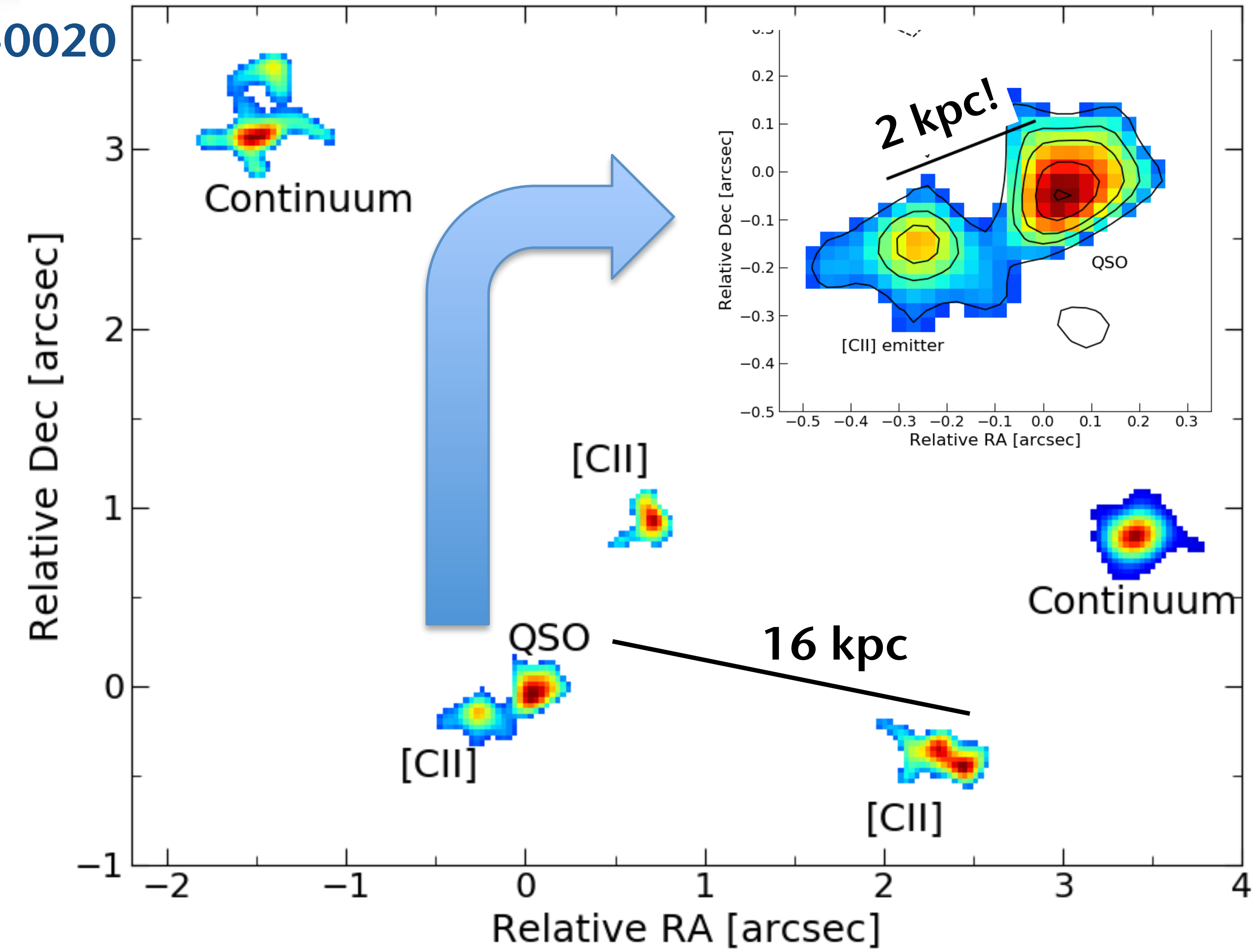
(Bischetti+17, Duras+17, Vietri+18, Bruni+18)

ALMA pilot follow-up program:
high-res [CII] 158μm map of a
z=4.4 WISSH QSO

GOAL: study the SMBH and host galaxy growth at early epochs when both processes are maximised

The early assembly of a giant galaxy

SDSSJ1015+0020
z = 4.4



Exceptional overdensity over 20 kpc
Discovery of the closest (2 kpc!) companion of a high-z QSO

- **3 [CII]-detected companions** + 2 physically-associated continuum emitters

- *Most of stellar mass assembly occurs outside of the QSO host galaxy!*

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

(Bischetti+2018 DOI201833249)

The early assembly of a giant galaxy

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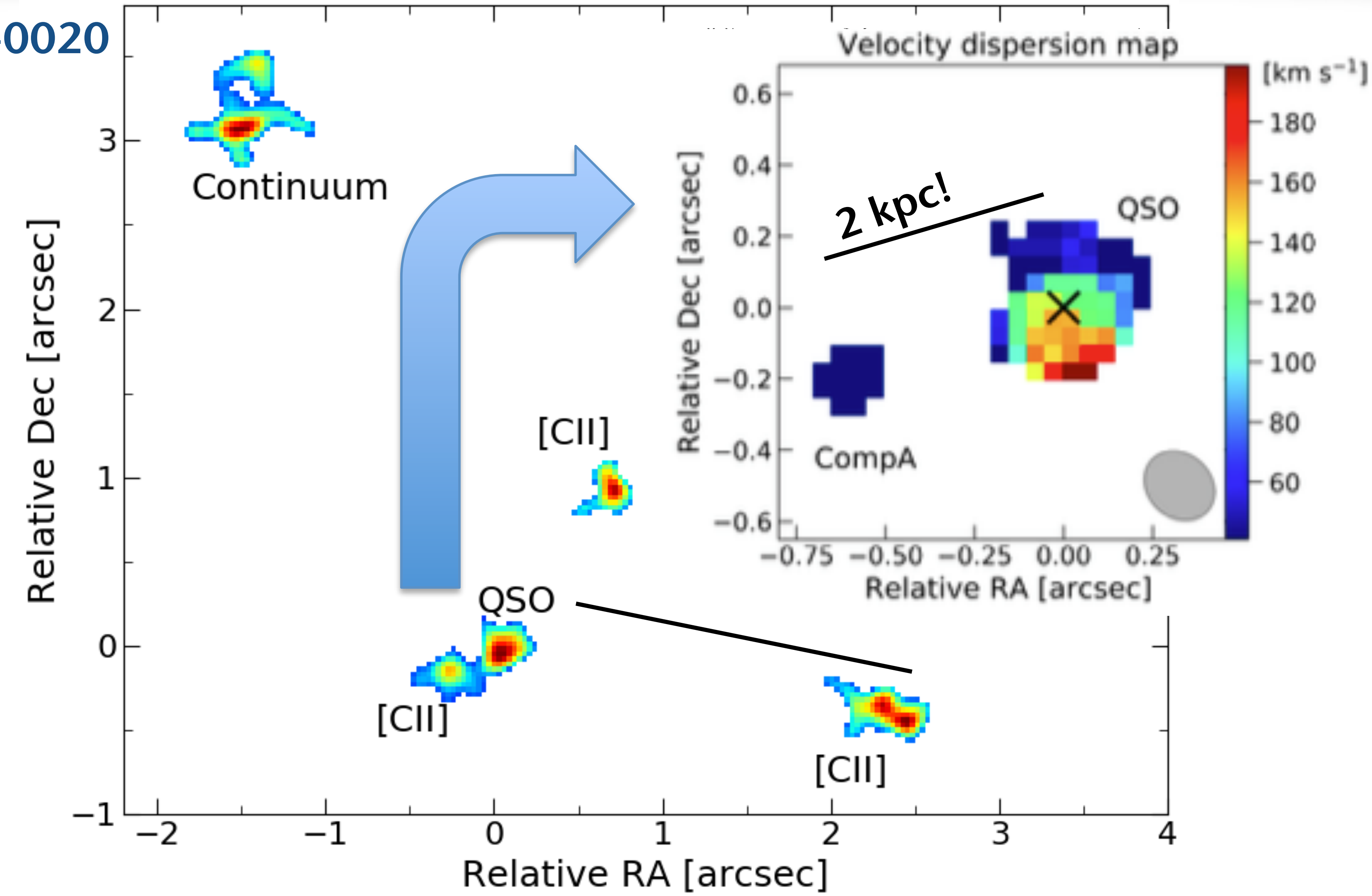

Merging systems

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

(Bischetti+2018 DOI201833249)

The early assembly of a giant galaxy

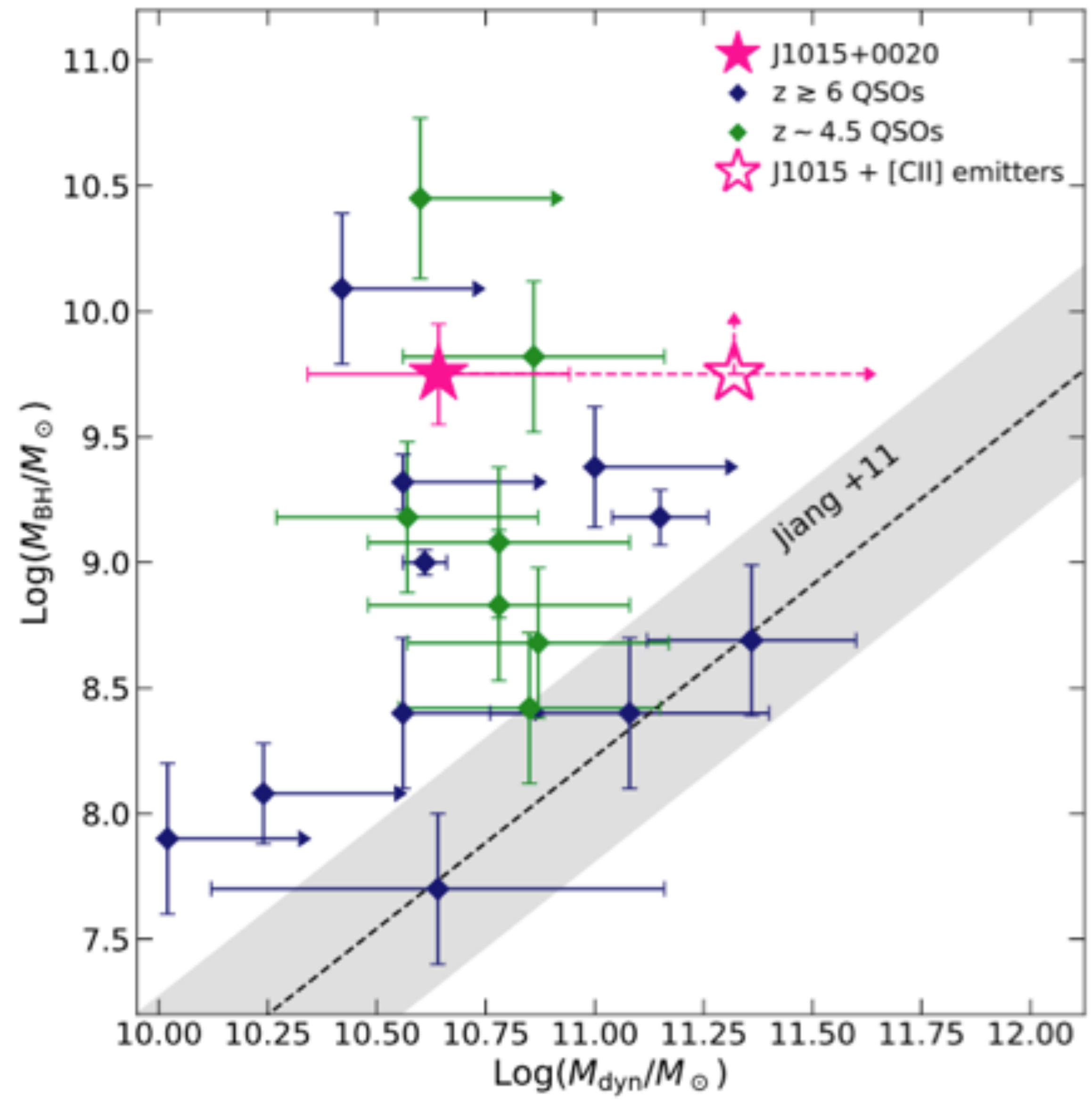
Single epoch M_{BH} ~ 5 x 10^9 M⊙

M_{BH} : M_{dyn} = 1:7

Two orders of magnitude smaller than local relations!

M_{dyn} ~10^{12} at z = 0

M_{dyn} ~$10^{11.3}$ already in place
at z = 4.4 adding up QSO and [CII] emitters



(Venemans+16,17, Willott+15,17, Trakhtenbrot+17, Kimball+15, Wang+16)

High-z QSOs: what to expect about outflows

Question: are 4.5 < z < 7 QSOs able to drive massive outflows?

Answer: assuming local relation to hold at higher z —> YES

(Fiore +17)

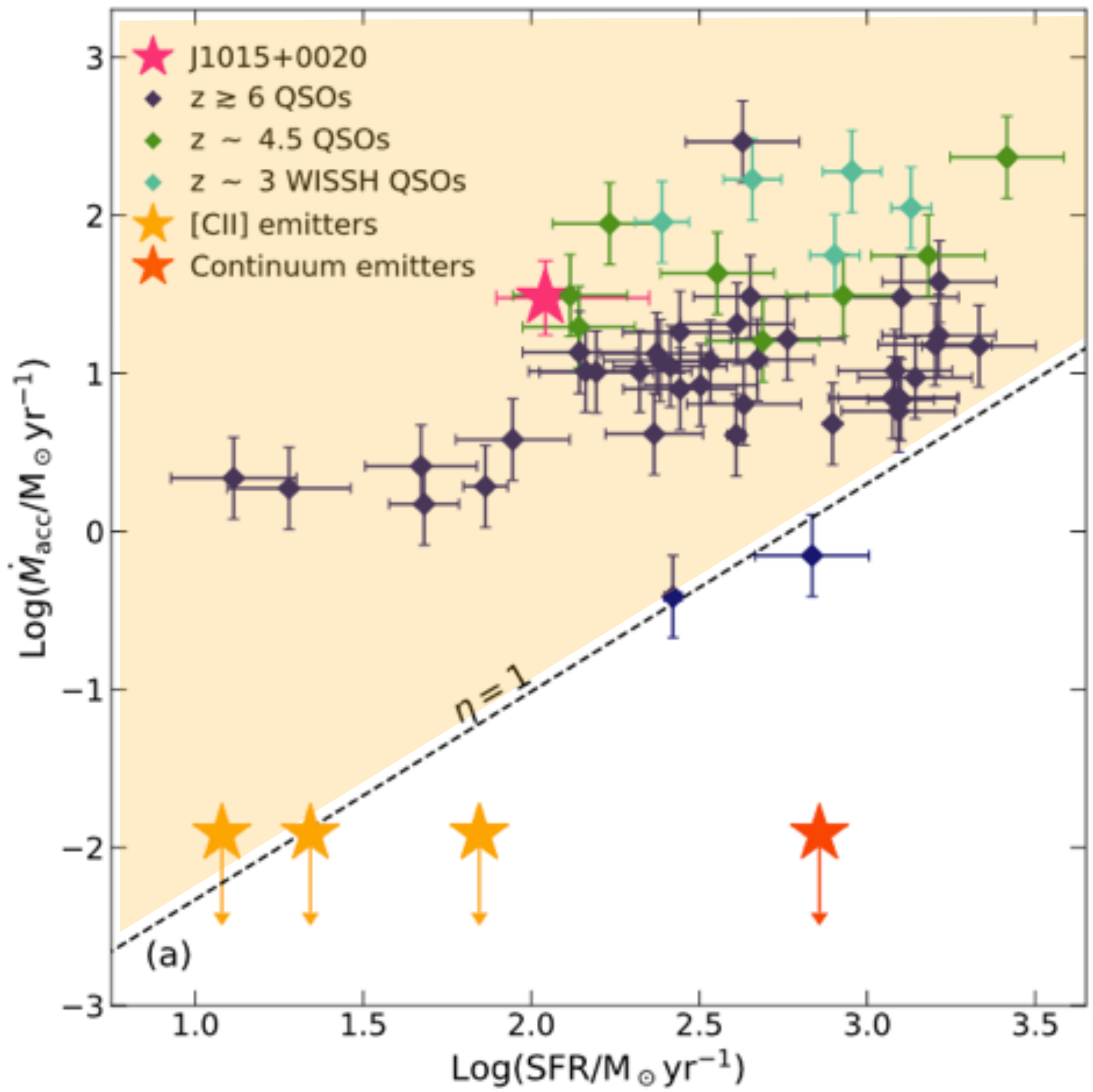
The molecular mass outflow rates in local AGN correlate with L_{Bol}:

$$\mathrm{Log}(\dot{M}_{out}/M_{\odot}yr^{-1}) = 0.76\times \mathrm{Log}(L_{Bol}/\mathrm{erg\ s^{-1}}) - 32$$

$$\dot{M}_{acc} = L_{Bol}/\epsilon c^2$$

$$\eta = \dot{M}_{out}/SFR = 1$$

$$\dot{M}_{acc} = 1.32 \times \mathrm{Log(SFR)} - 3.64$$



(Bischetti+18, Vietri+18, Duras+17,Venemans+16,17, Decarli +17,18, Willott+15,17, Trakhtenbrot+17, Kimball+15, Wang+13,16)

if $\eta > 1$ the outflow is potentially able to affect the QSO host galaxy

But…observations are difficult to achieve! (e.g., Feruglio+17, 18)

Summary and Conclusions:

Stack of 48 luminous QSOs with ALMA [CII] detection

cold outflows are there!

The outflow luminosity and $\dot{M}$ increase with L_{AGN}

High-z QSO-driven outflows may be less efficient in removing gas than local AGN

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Early assembly of giant galaxies: the case of J1015+0020

Overdense region around the QSO

Merging companion at only 2 kpc!

Bulk of SFR **outside** of the QSO host galaxy

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To do next:

Cold outflows in high-z QSO: the search for outflow in the early Universe has just begun!

- deeper [CII] and CO observations —> statistics of detected outflows (in individual sources or by stacking larger samples), energetics, morphology, driving mechanism, impact on the host

Assembly of high-z QSO hosts

- High res [CII] and CO —> location and scatter of the M_{BH}-M_{dyn} correlation at high z. Molecular vs neutral gas fraction