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

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INAF OAR E. Piconcelli, F. Duras

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)

↓

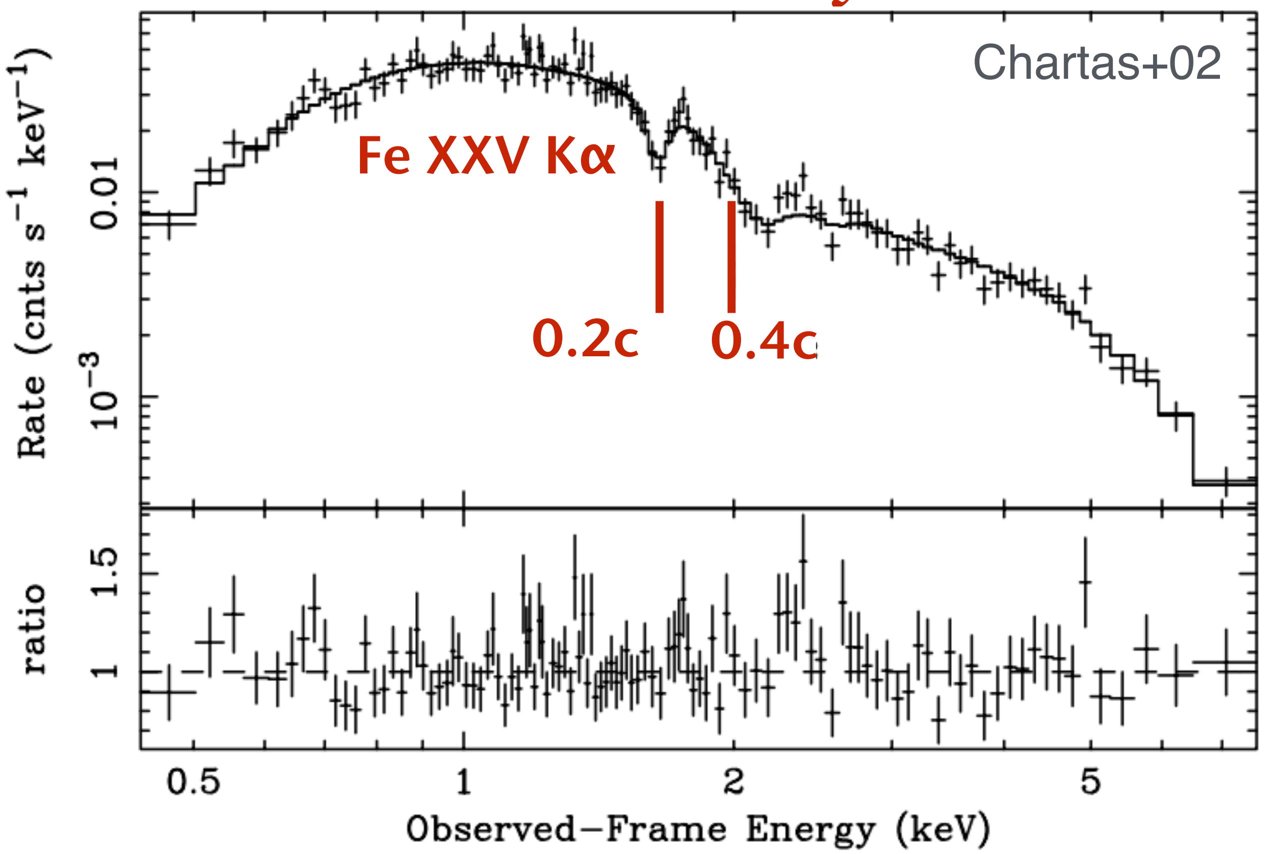
The most luminous QSOs are primary targets to hunt for powerful AGN-driven outflows

ALMA [CII] 158 μm observations:
- Cold outflows in z>4.5 QSOs
- Early SMBH and host galaxy assembly

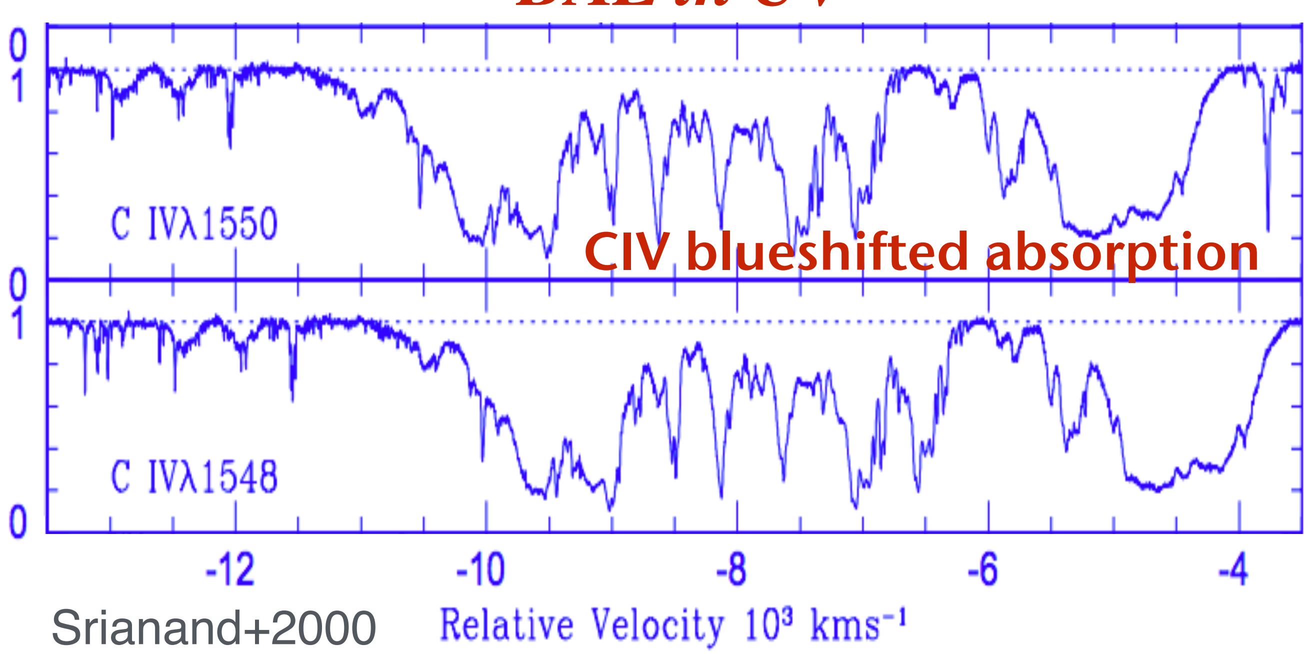
Multiphase outflows in APM08279

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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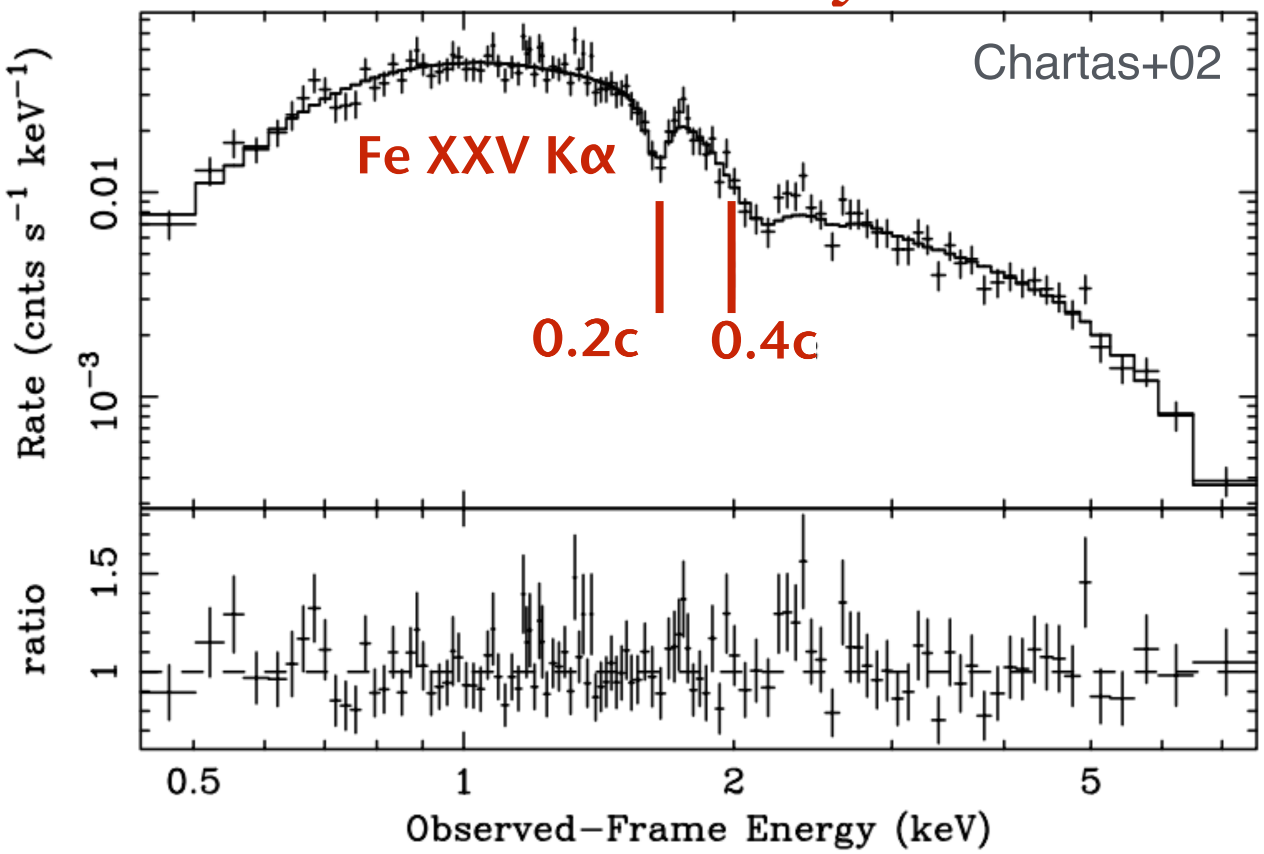
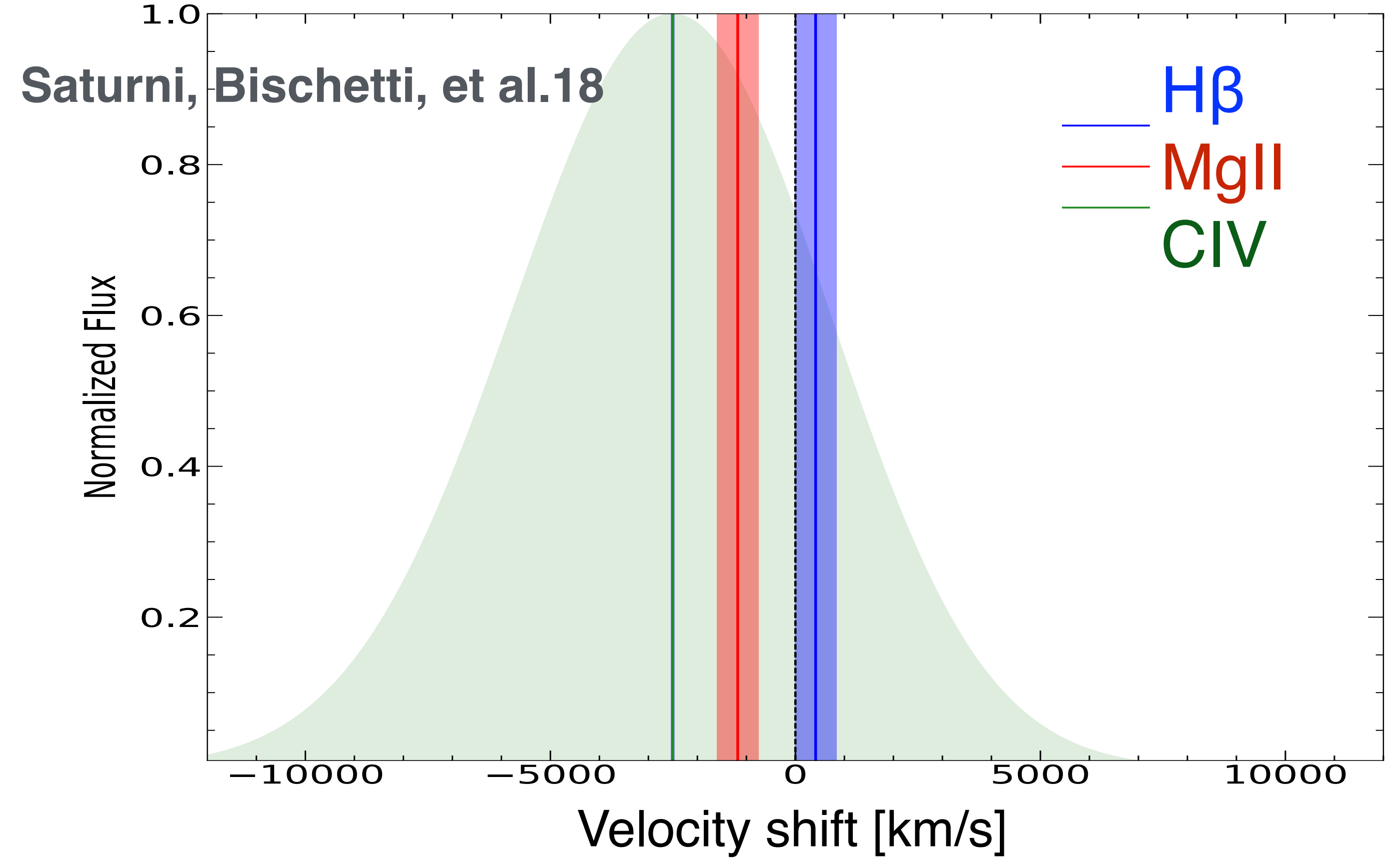
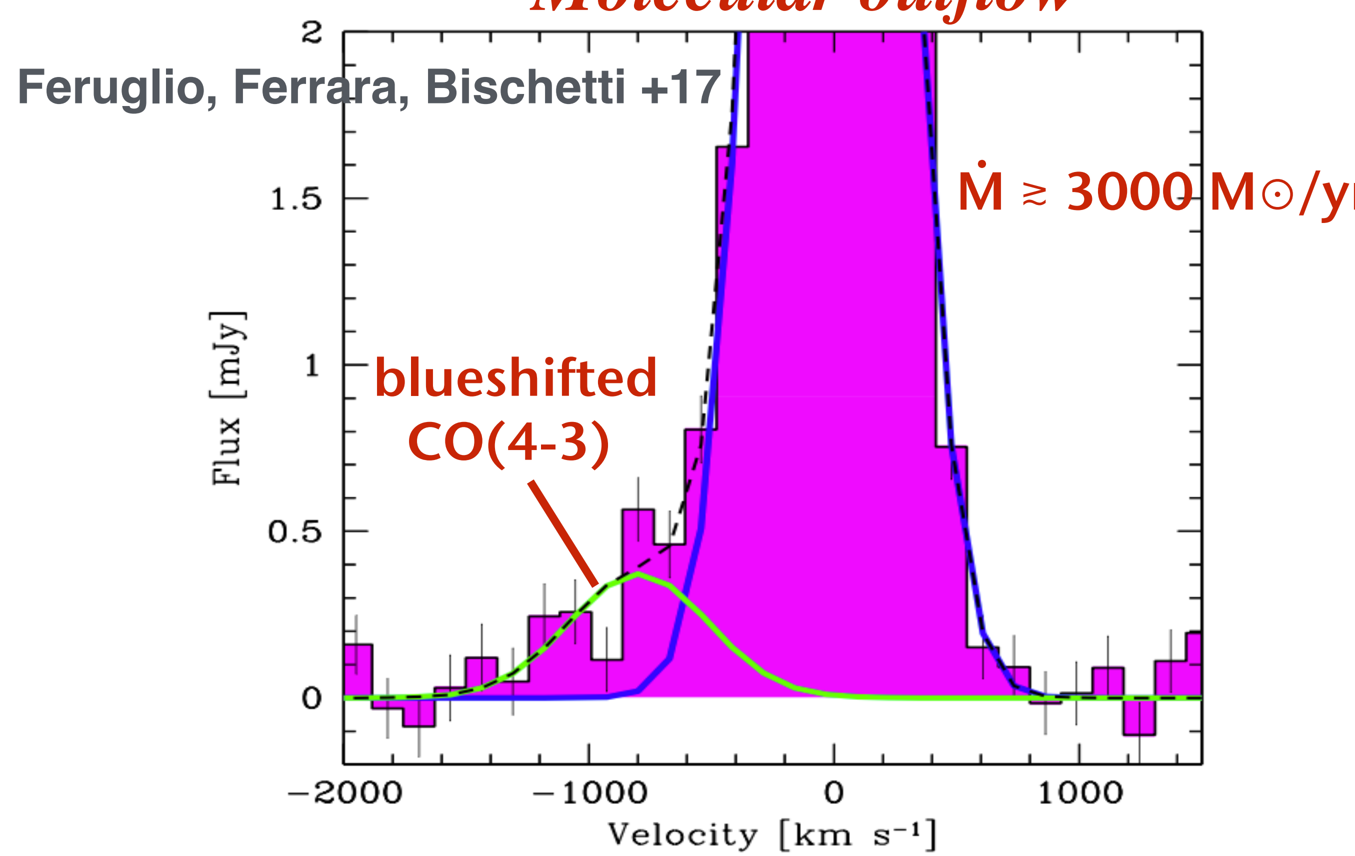


BLR winds in UV



Molecular outflow



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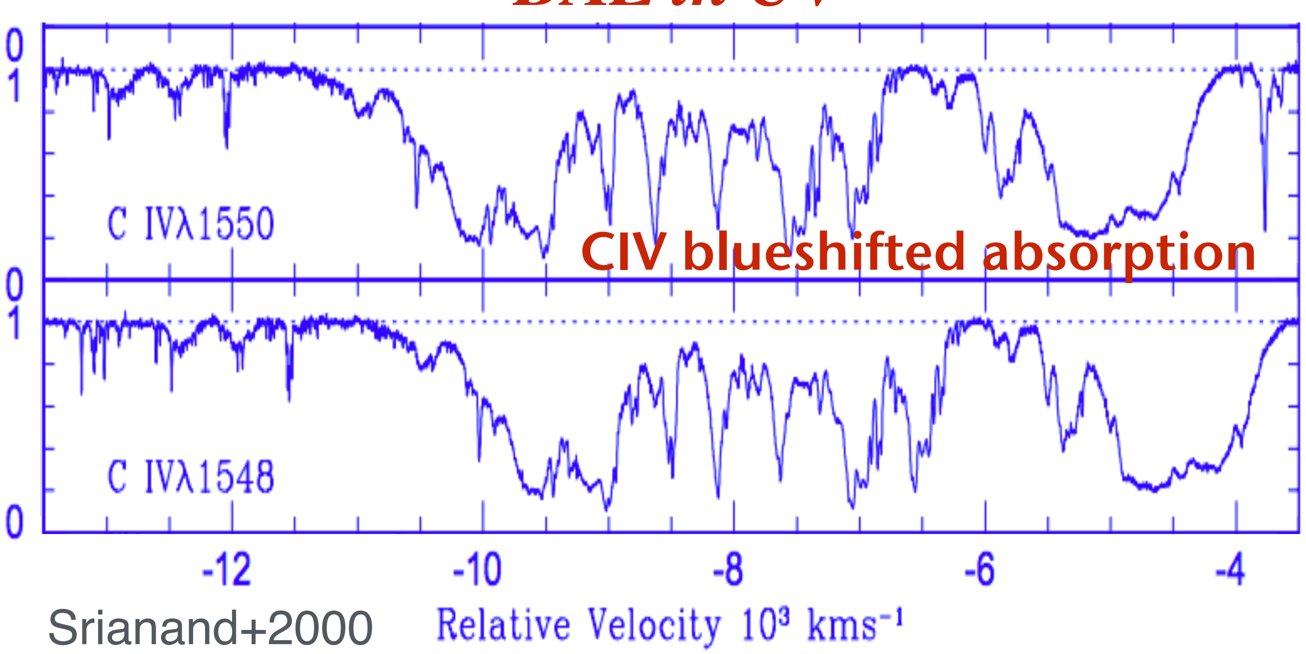
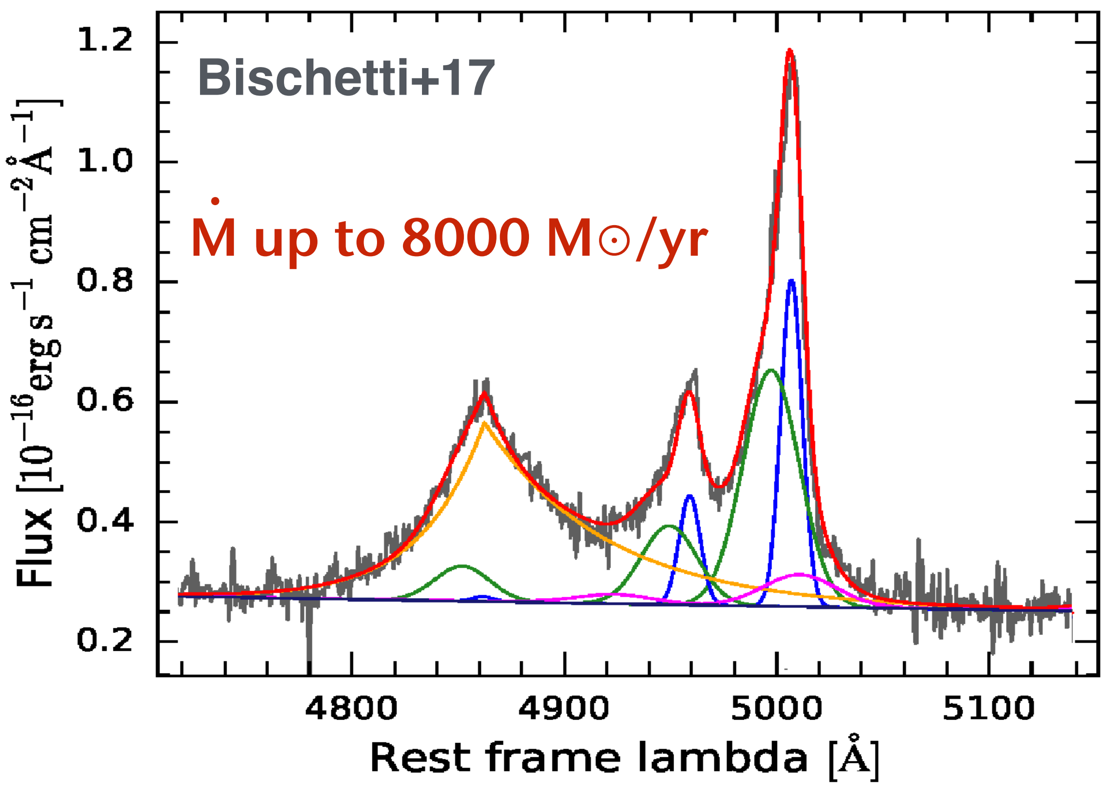
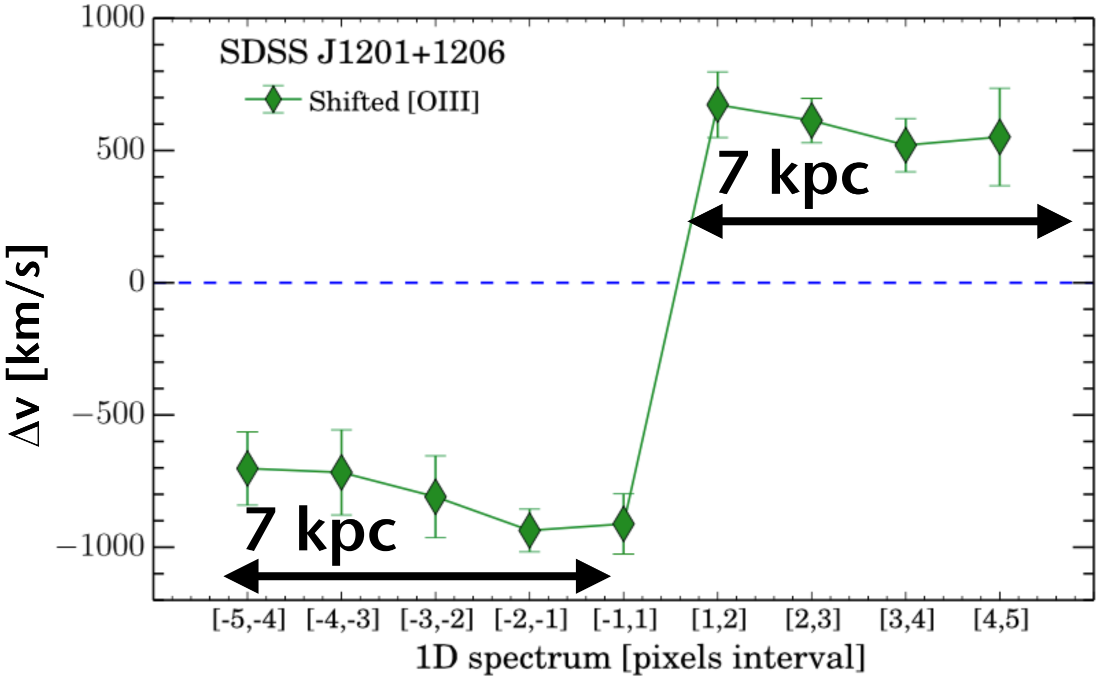


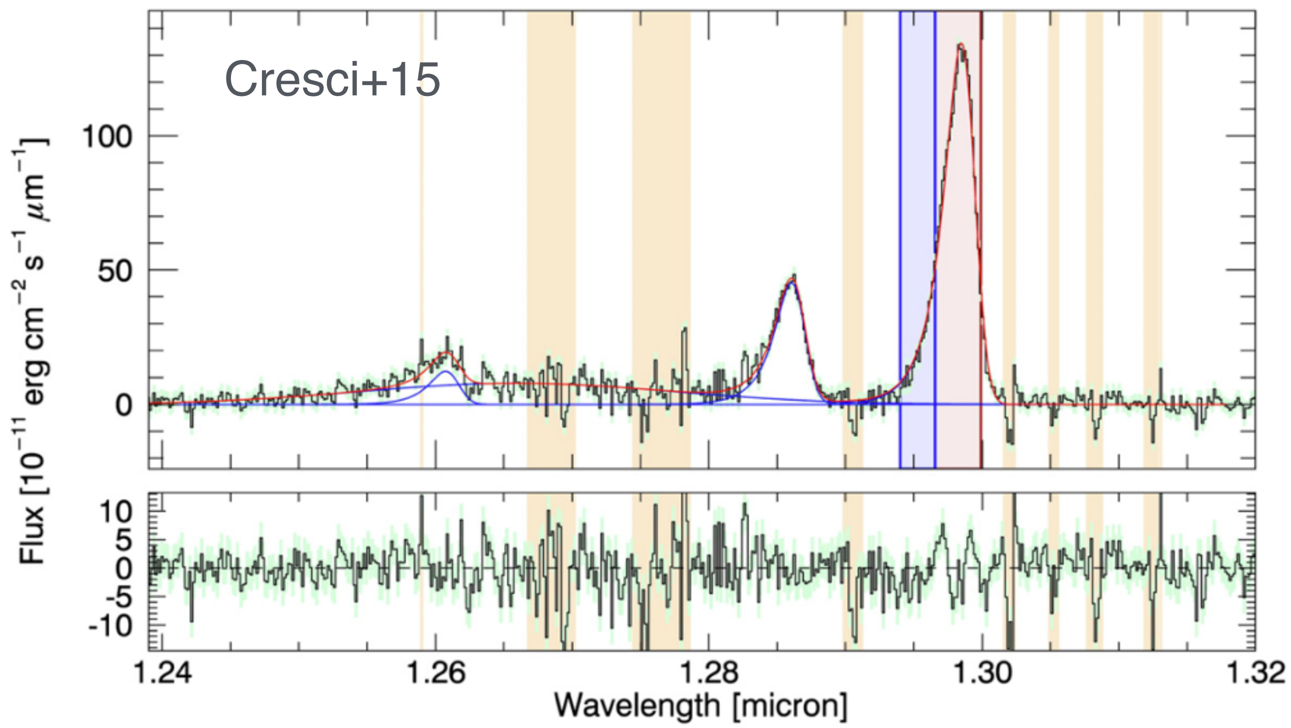
Ubiquitous presence of galaxy-wide [OIII]outflows

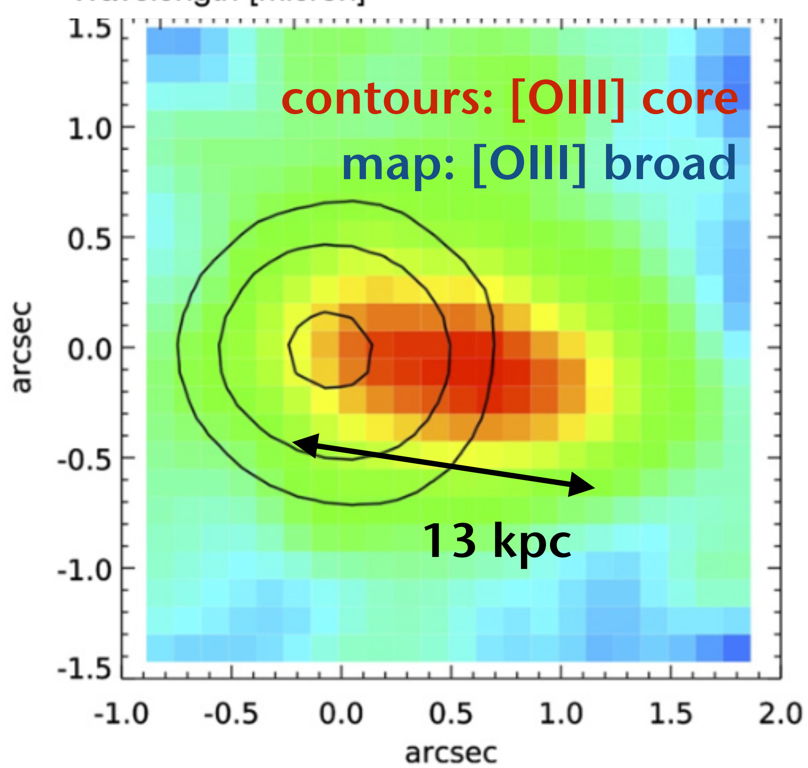
WISE-SDSS selected hyper-luminous (WISSH) QSOs





COSMOS QSO XID2028 at z = 1.59

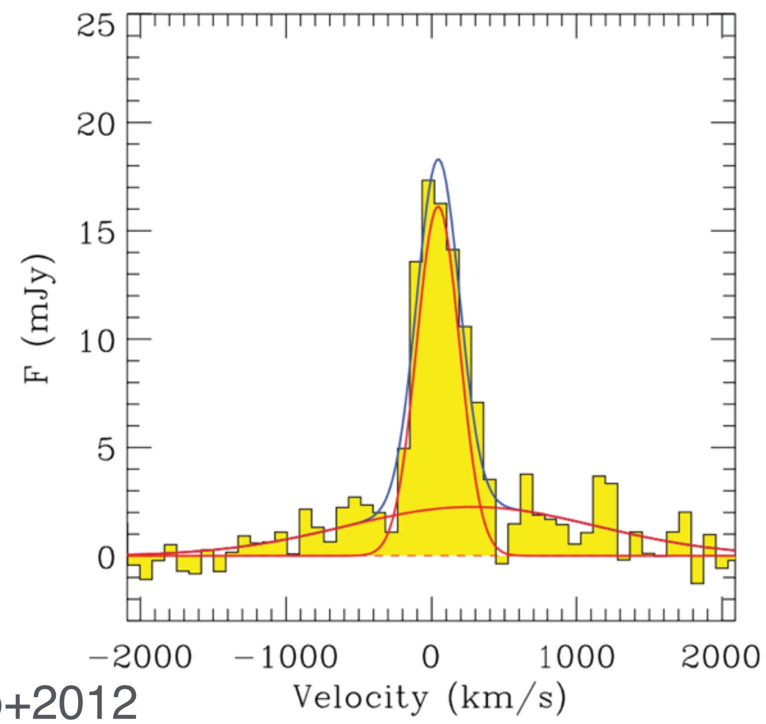




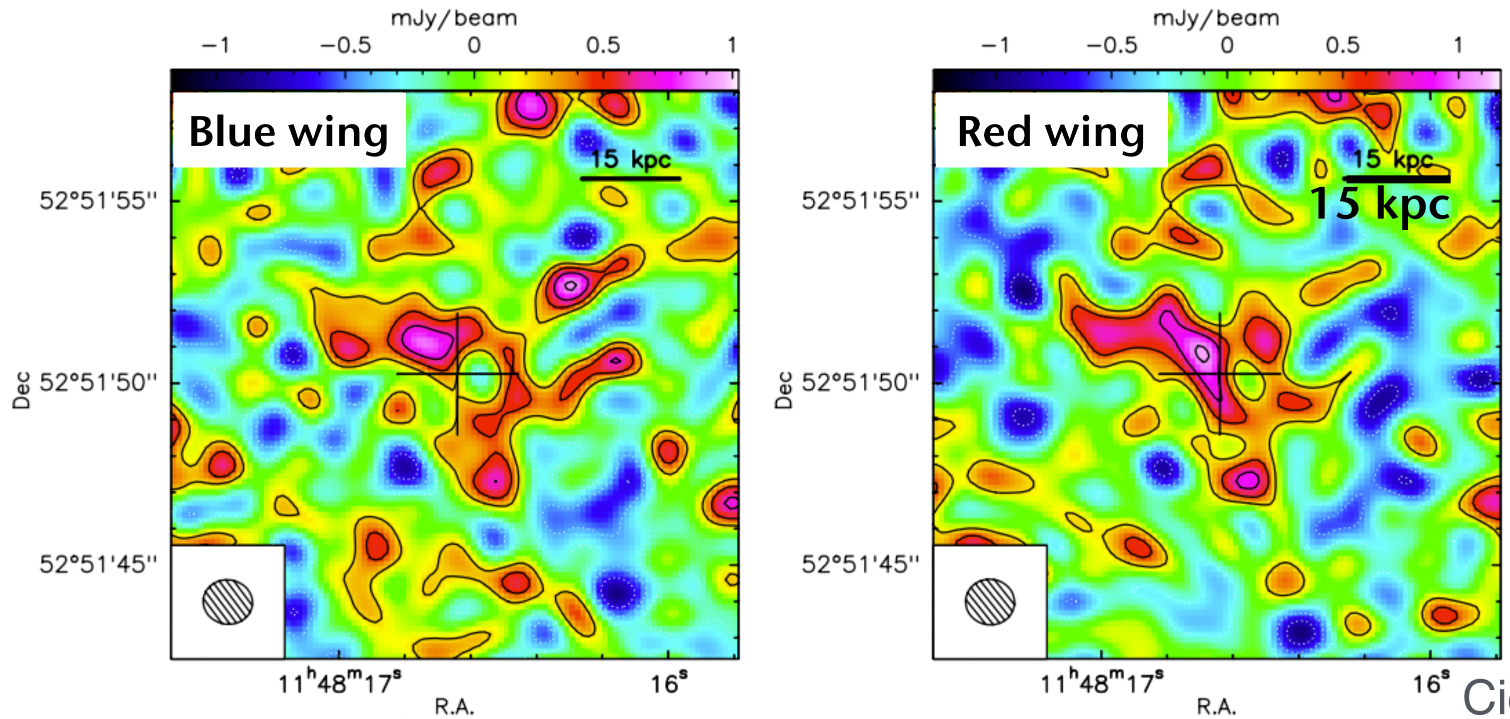
see talks by G. Vietri, A. Travascio, F. Duras

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 clear detection of broad wings despite tens of QSOs targeted in [CII]!

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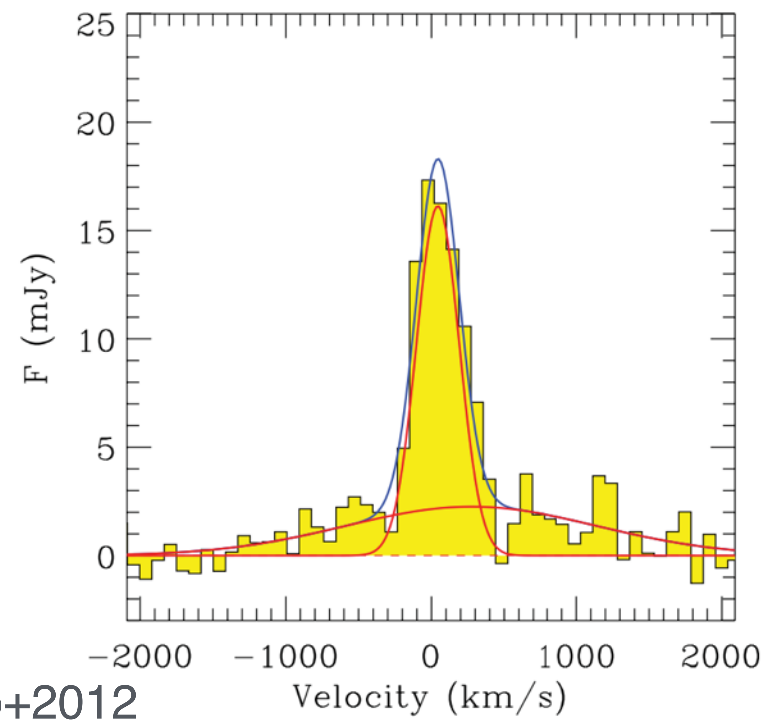

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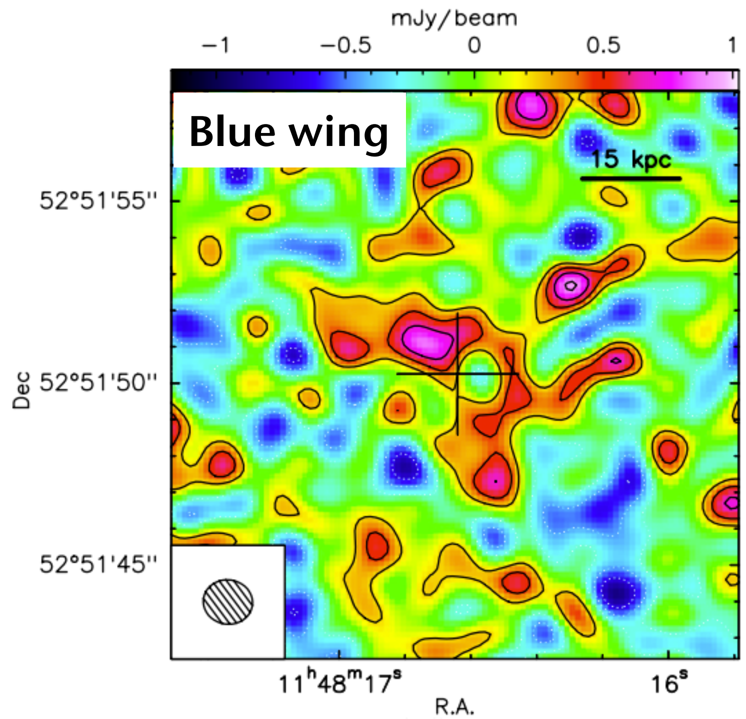

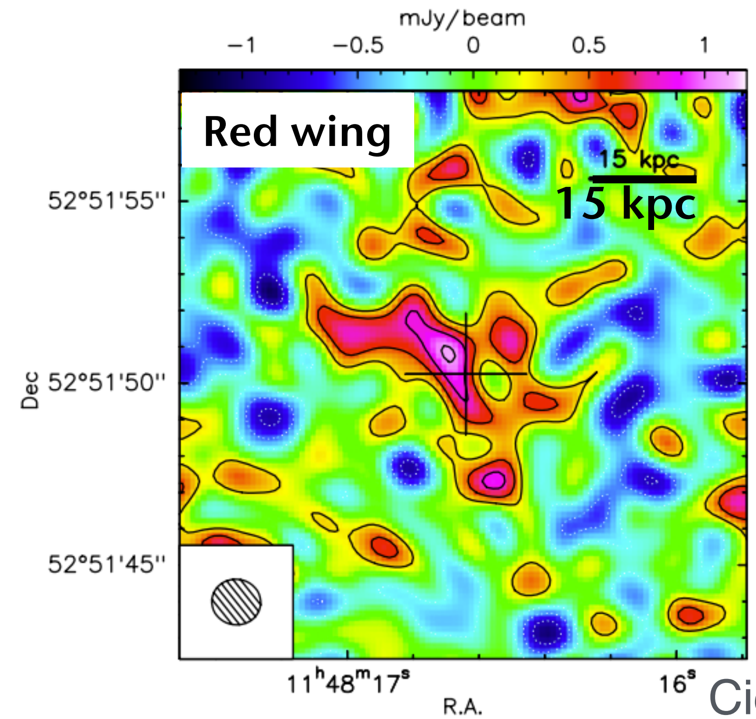

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But….only clear detection of broad wings despite tens of QSOs targeted in [CII]!

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

SAMPLE: 48 high -redshift QSOs observed with ALMA

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

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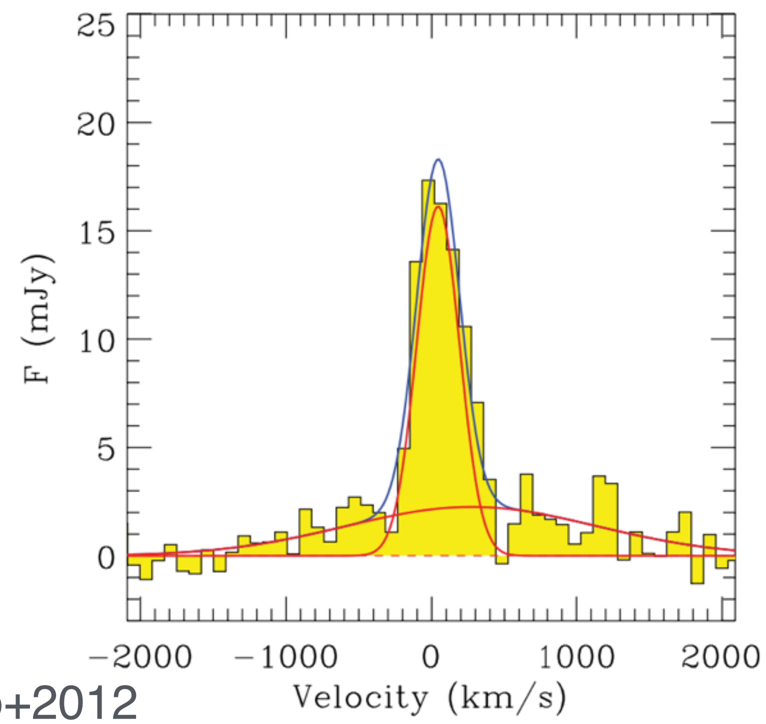

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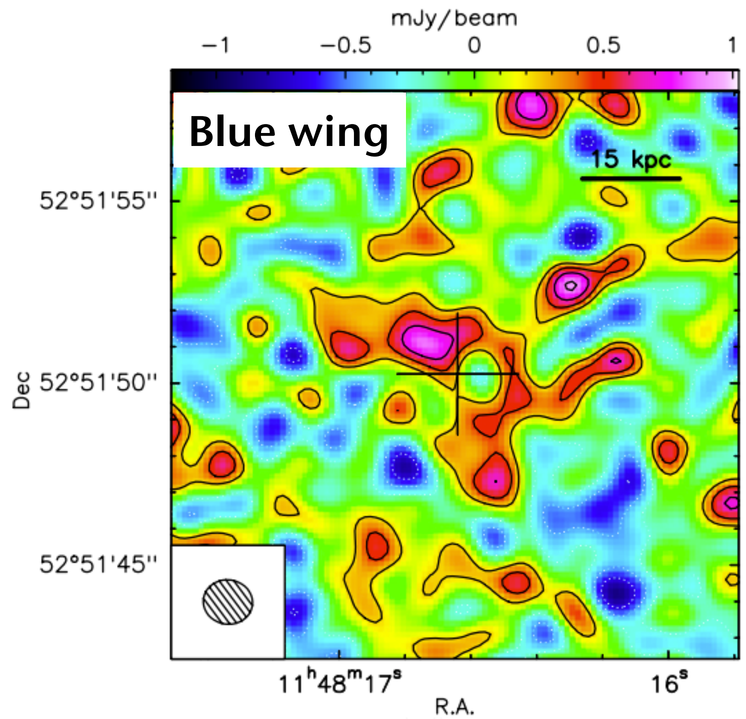

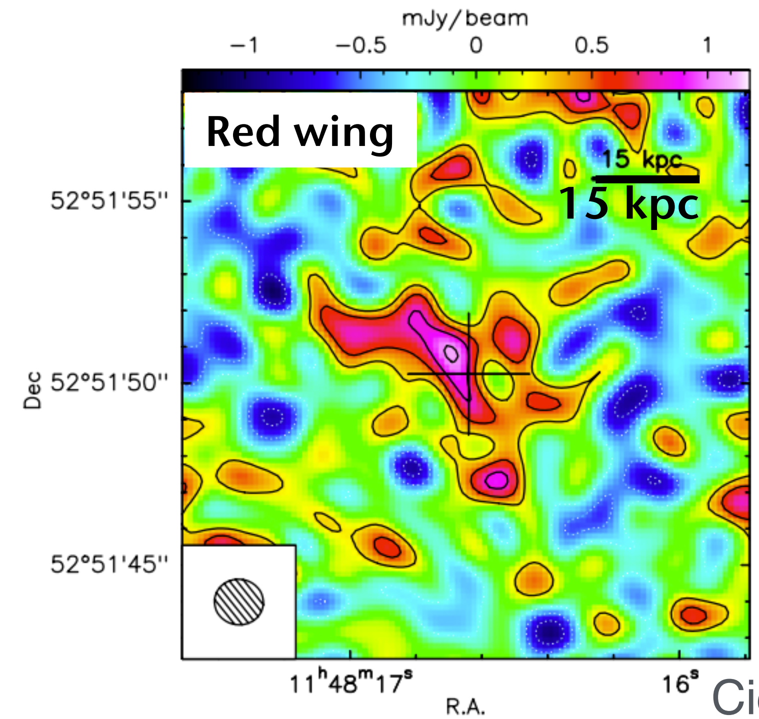

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Discussion about new tentative detections in individual z~6 QSOs

see talk by Stefano Carniani

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

channel

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

48 QSOs = 34h on source

>10x improved sensitivity than J1148+5251

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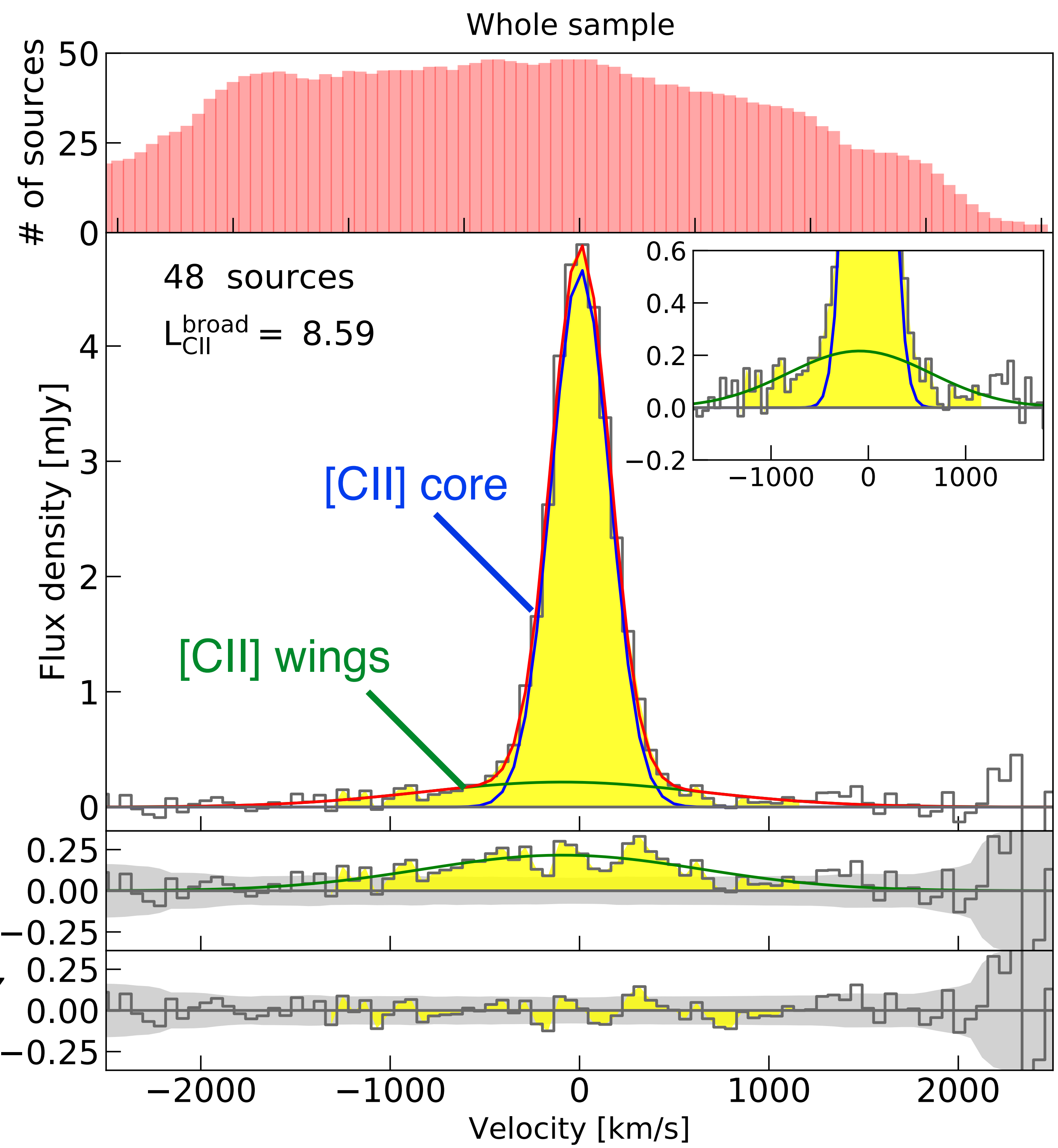


$\chi_\nu = 8.6$

$\chi_\nu = 3.7$

Wings : peak ~ 1: 20

$\mathrm{FWHM_{broad}}$ ~ 1700 km/s

$\Delta v_{\mathrm{broad}}$ ~ -100 km/s

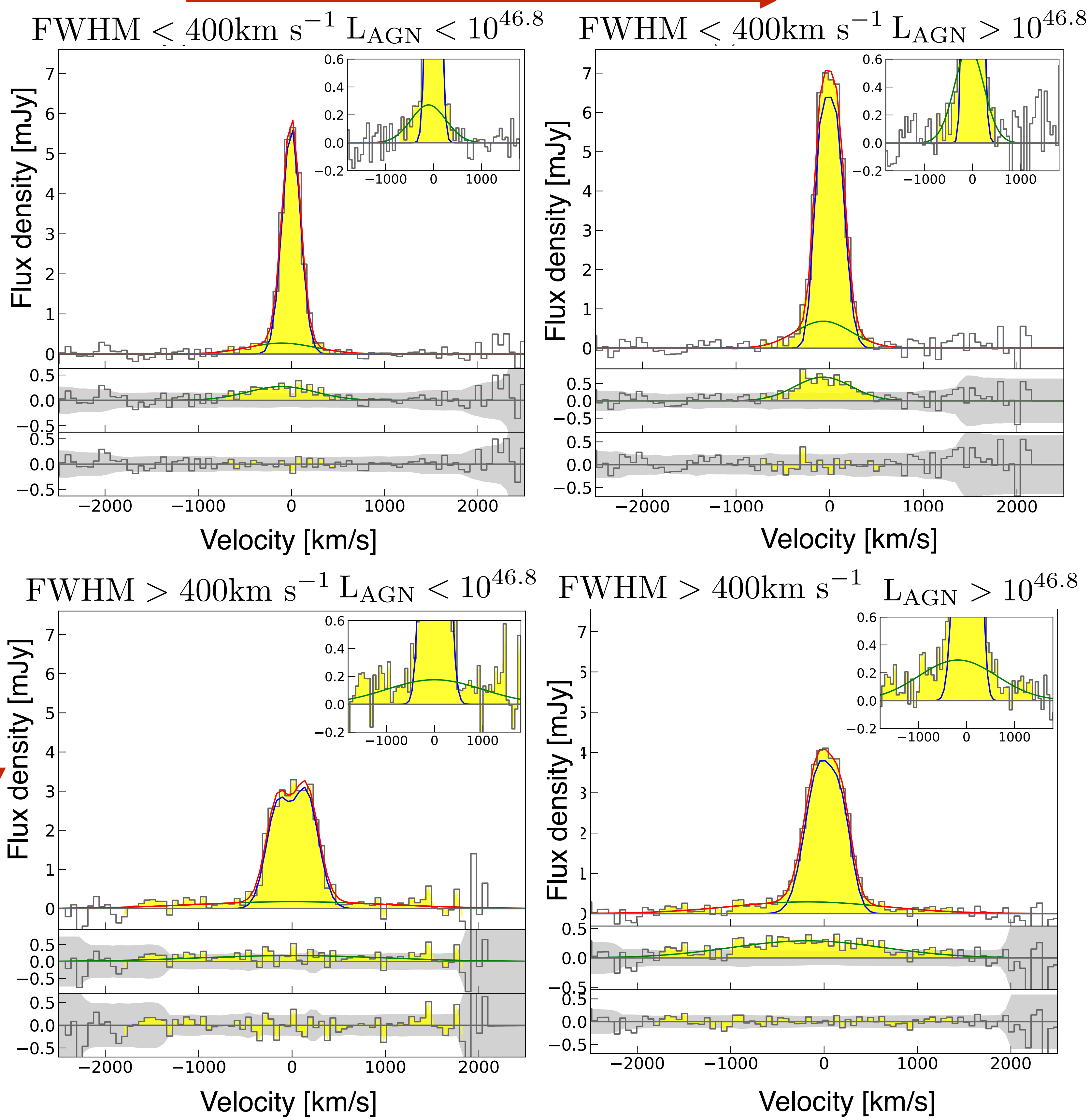
Optically thick [CII]?

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

Stack in bins of FWHM and L_{AGN}:

increasing L_{AGN}

increasing [CII] core FWHM



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

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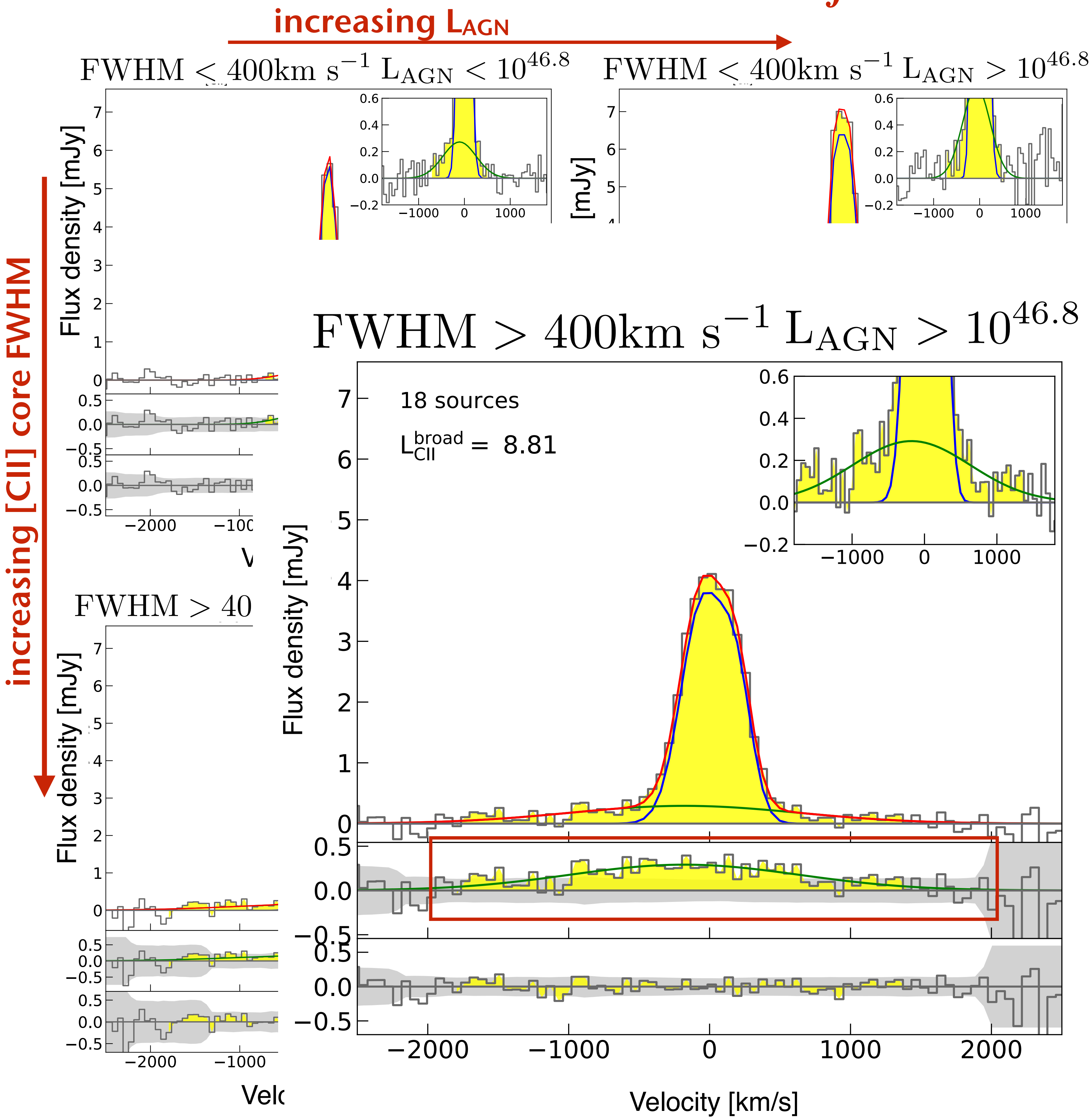

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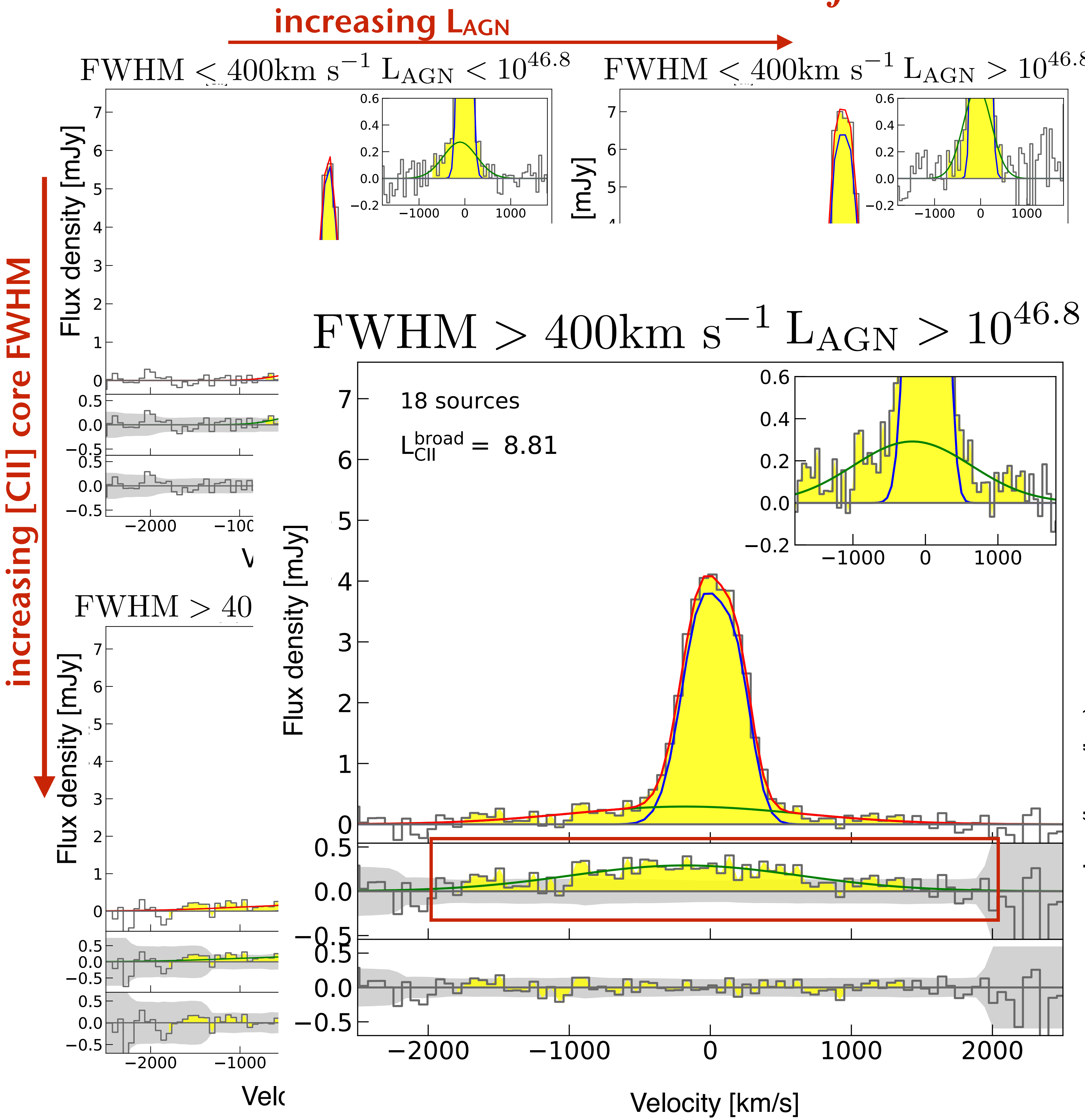
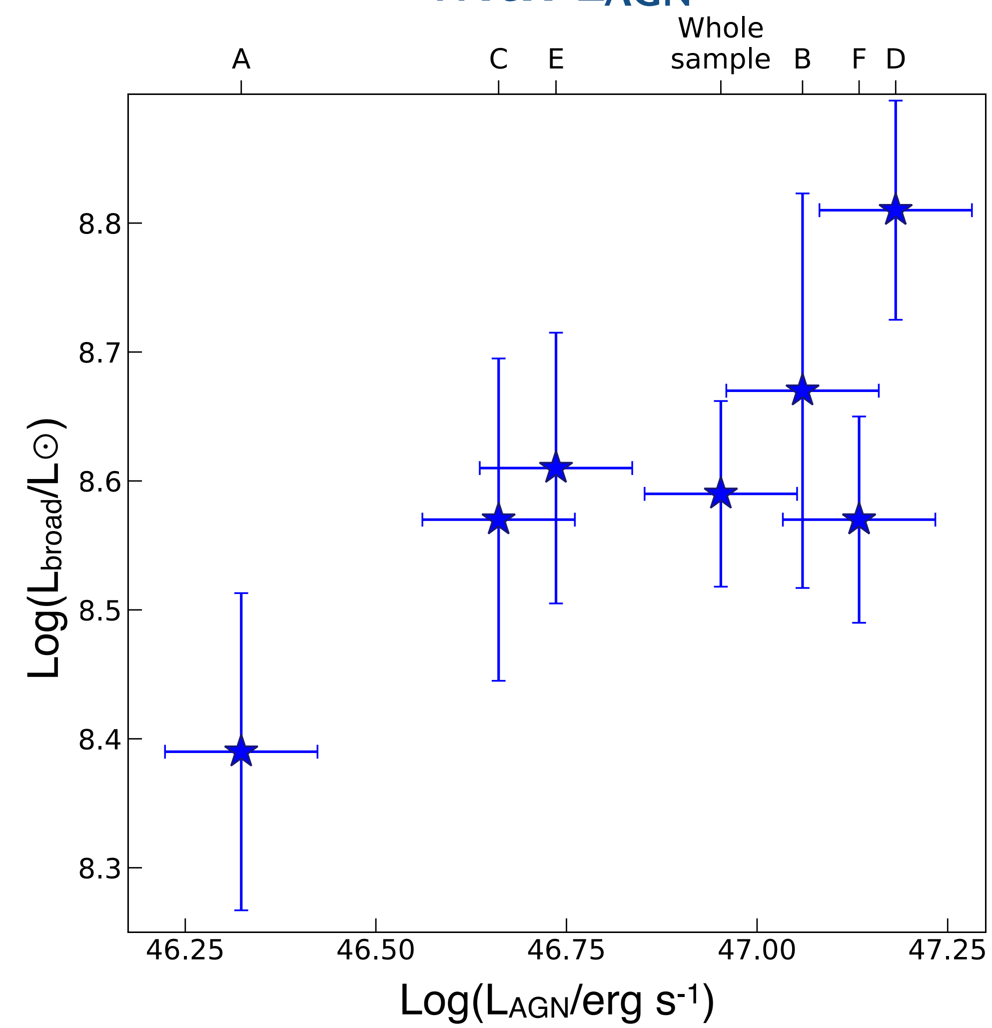
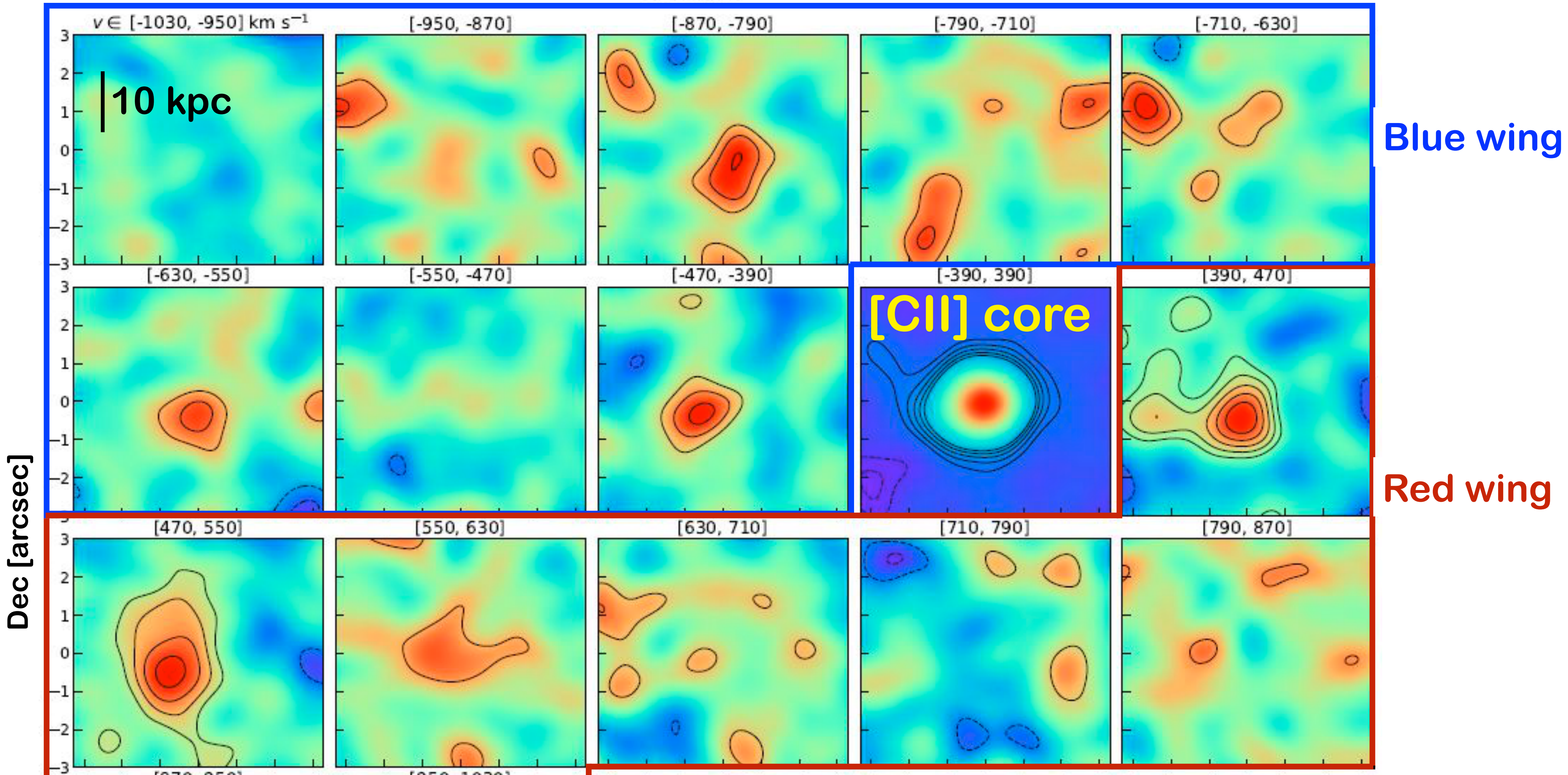


The luminosity of the [CII] broad wings correlates with L_{AGN}

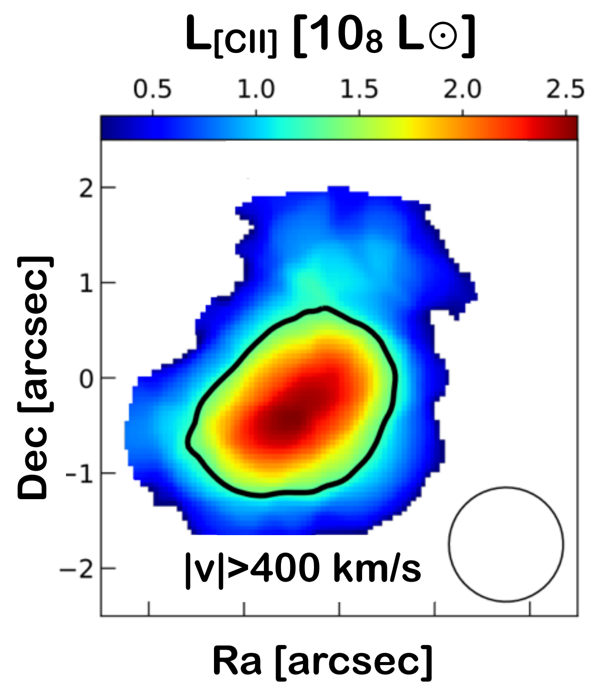


Energetics of [CII] outflows in high-z QSOs

Stacked ALMA cube



contours= [2,3,4,...]σ



beam-corrected half-light radius ~ 3.5kpc

Energetics of [CII] outflows in high-z QSOs

L_{broad} + $M_{outf}/M_{\odot} = 0.77\left(\frac{0.7L_{[CII]}}{L_{\odot}}\right)\left(\frac{1.4\times10^{-4}}{X_{C^+}}\right)\times\frac{1+2e^{-91K/T}+n_{crit}/n}{2e^{-91K/T}}$ + half light radius ~ 3.5 kpc + $v_{out} = |\Delta v_{broad}| + FWHM_{broad}/2$

Hailey-Dunsheath+2000

(we might be losing a significant fraction of extended flux)

Mass outflow rate of the [CII] outflows (atomic phase)

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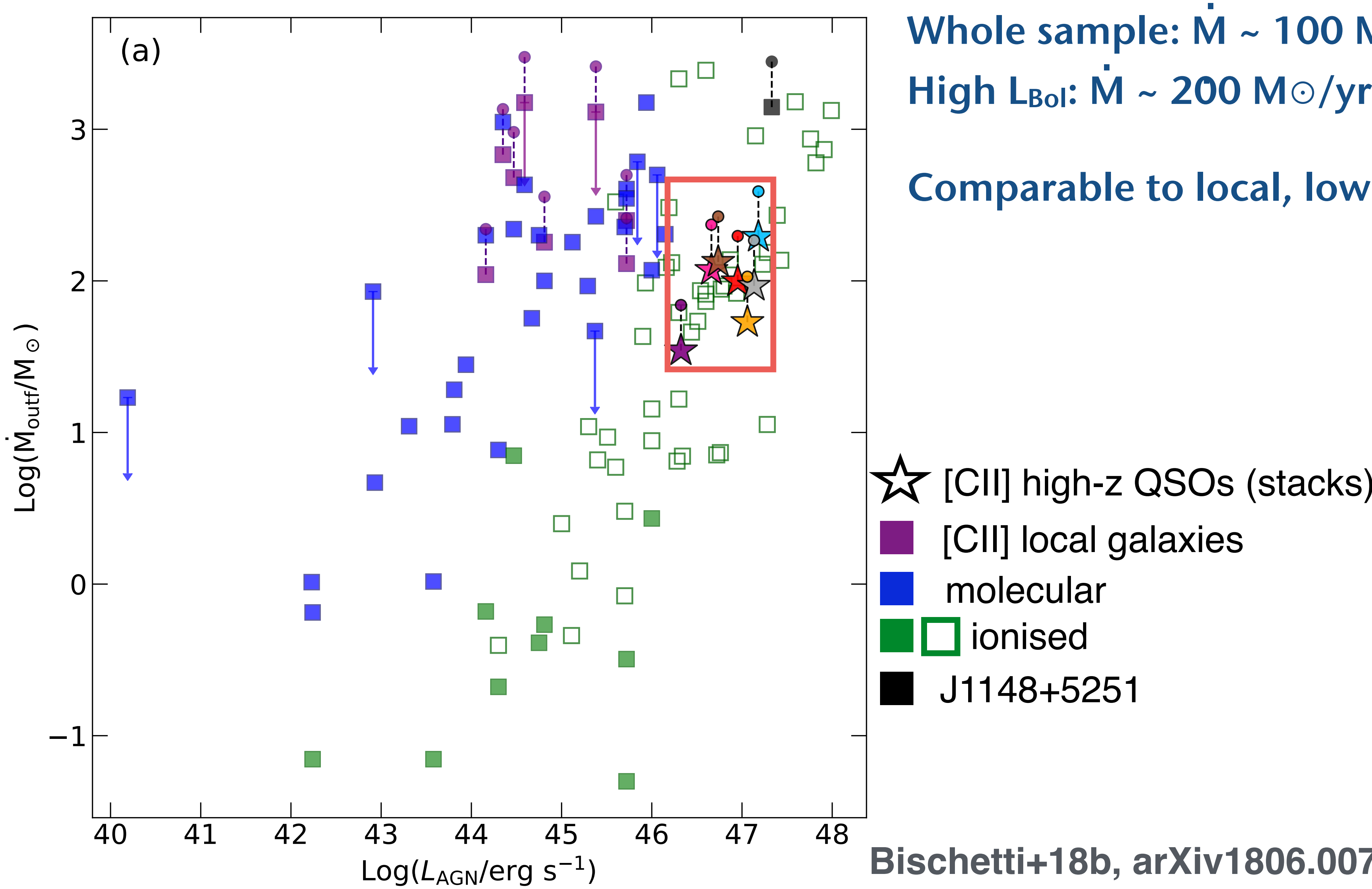

Whole sample: $\dot{M}$ ~ 100 M⊙/yr

High L_{Bol}: $\dot{M}$ ~ 200 M⊙/yr

Comparable to local, lower luminosity AGN

Bischetti+18b, arXiv1806.00786

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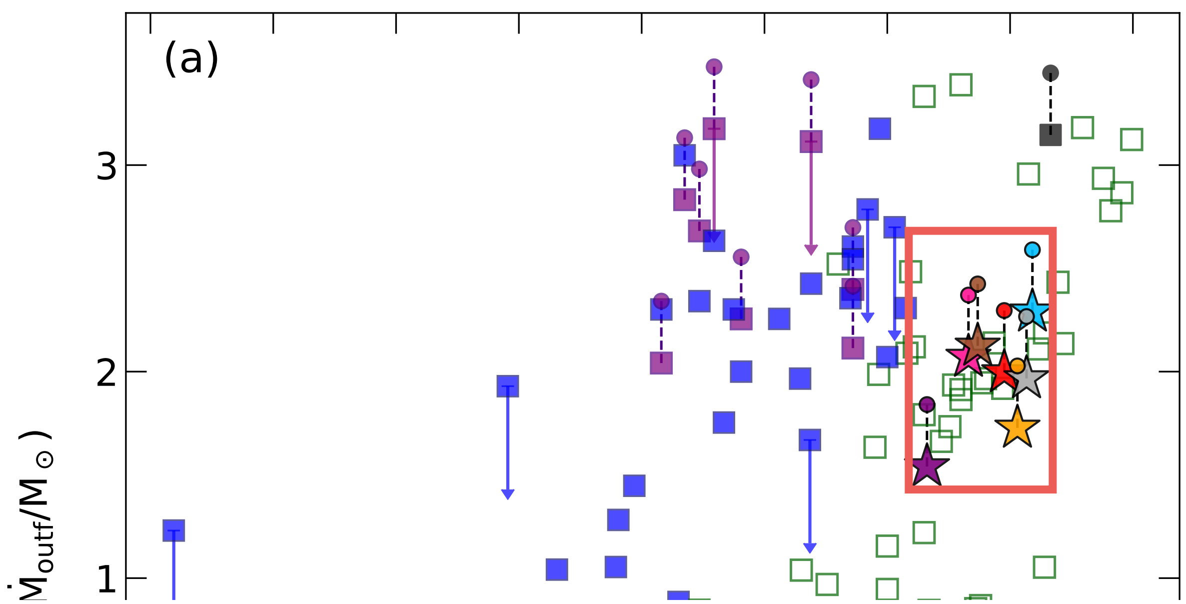


Whole sample: $\dot{M}$ ~ 100 M⊙/yr

High L_{Bol}: $\dot{M}$ ~ 200 M⊙/yr

Comparable to local, lower luminosity AGN

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

However:

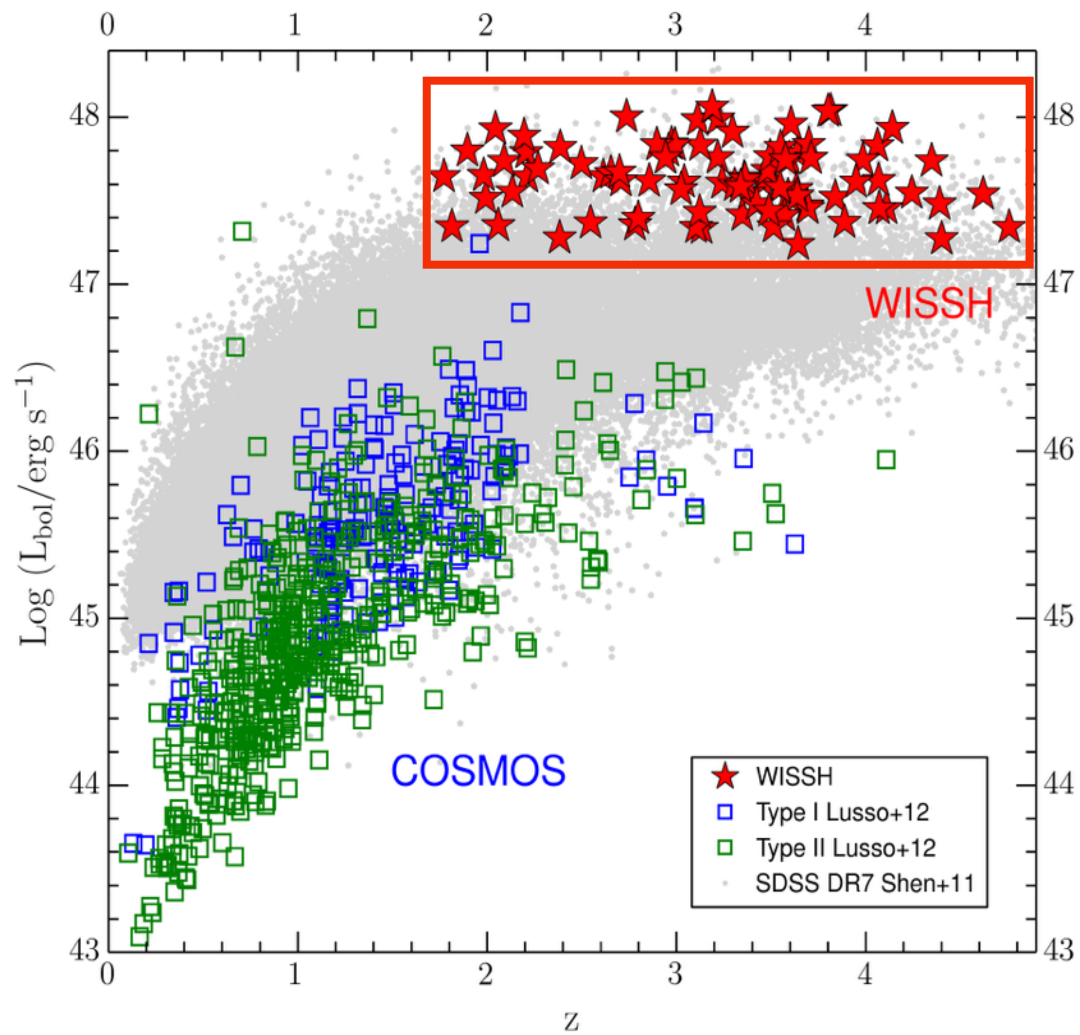
- Possible flux losses
- Range of L_{Bol} unexplored so far for molecular and neutral outflows in local AGN

except …see talk by E. Piconcelli

The WISSH QSOs project: the ALMA view

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

- $\mathrm{Log}(L_{Bol}/\mathrm{erg\ s^{-1}}) > 47.2$
- $1.5 < z < 4.5$
-



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, Travascio+18 in prep.)

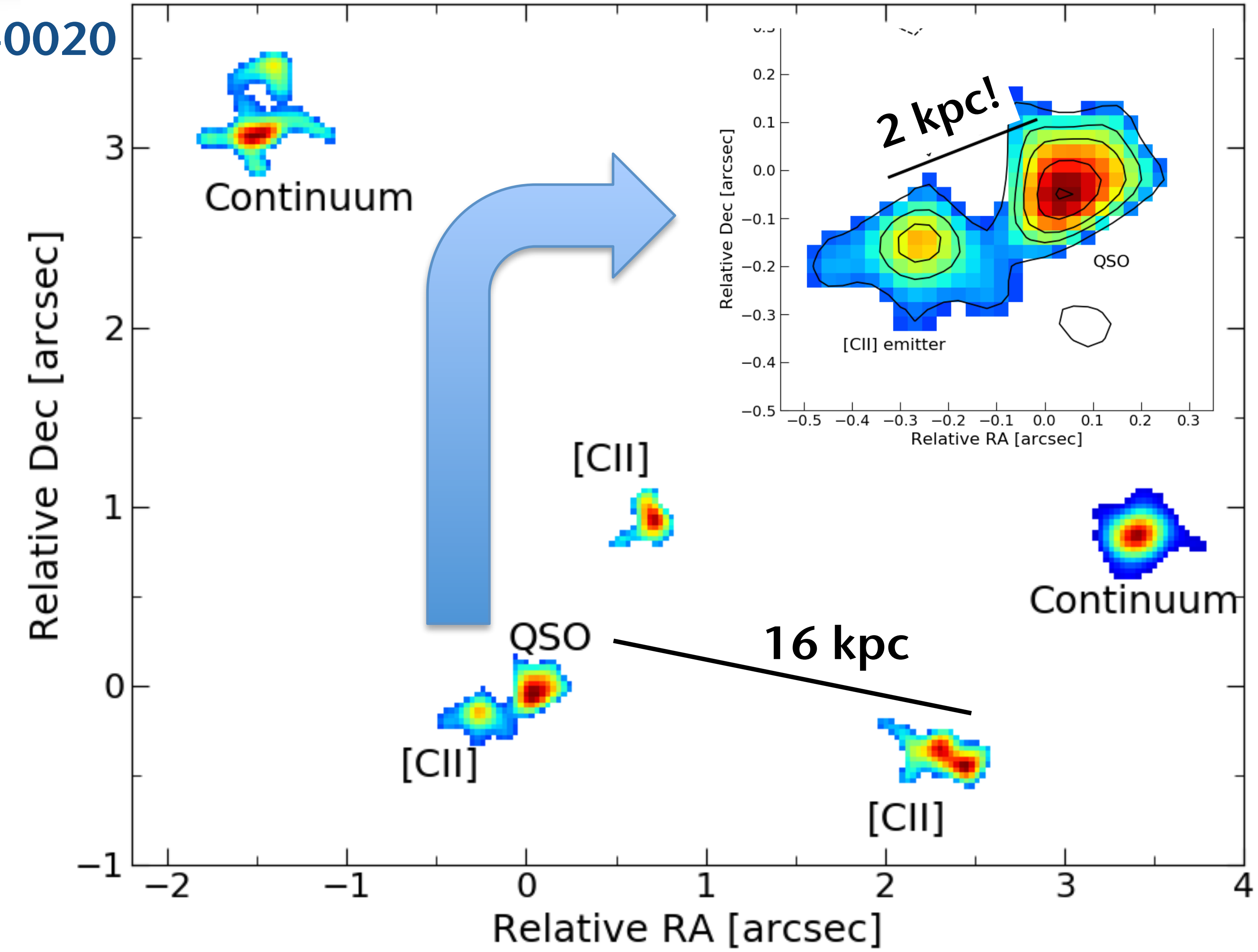
ALMA pilot follow-up program:
high-res [CII] 158μm map of a
z=4.4 WISSH QSO

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

see talks by G. Vietri, A. Travascio, F. Duras

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

(Bischetti+2018a DOI201833249)

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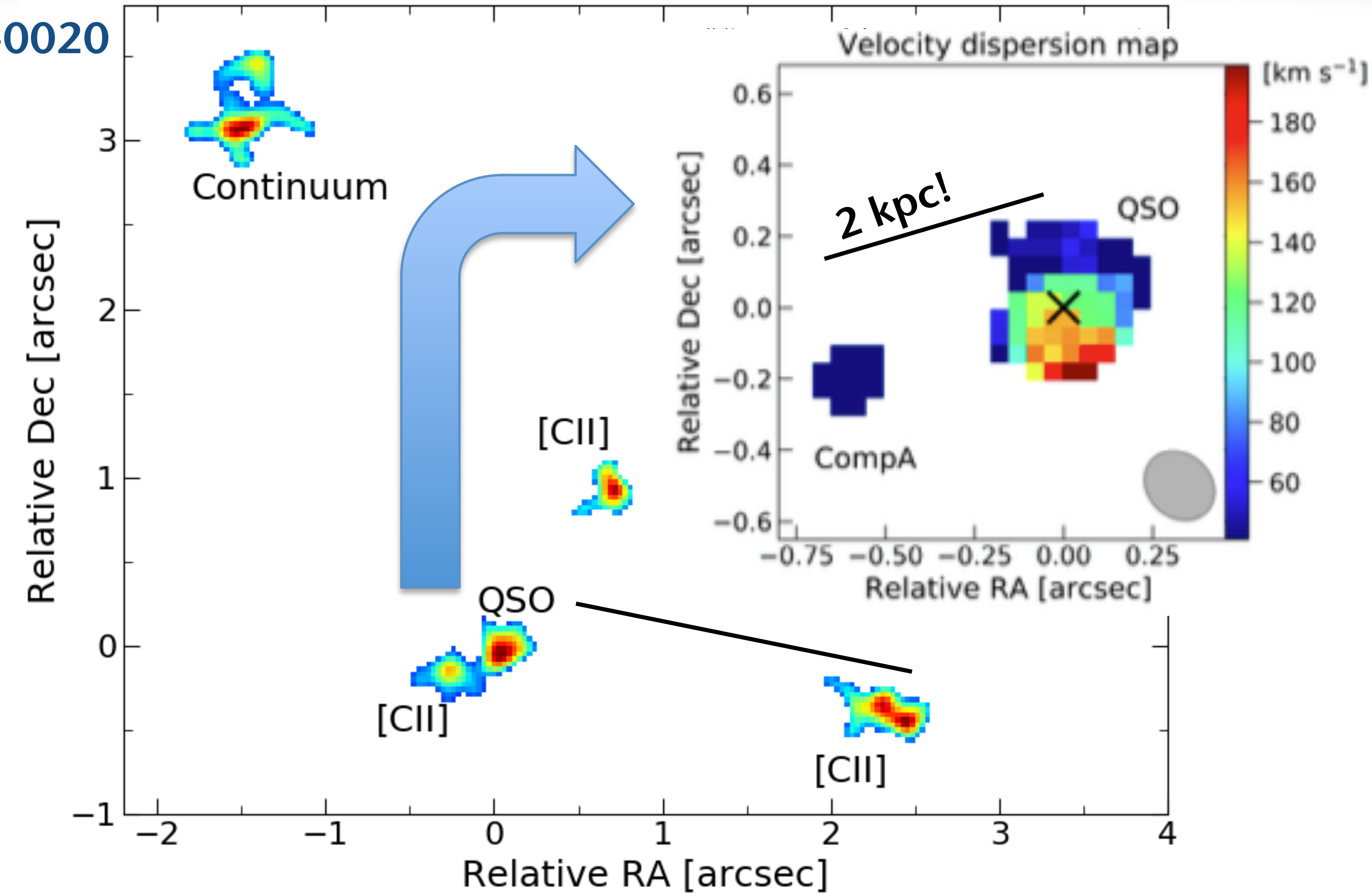

Merging systems

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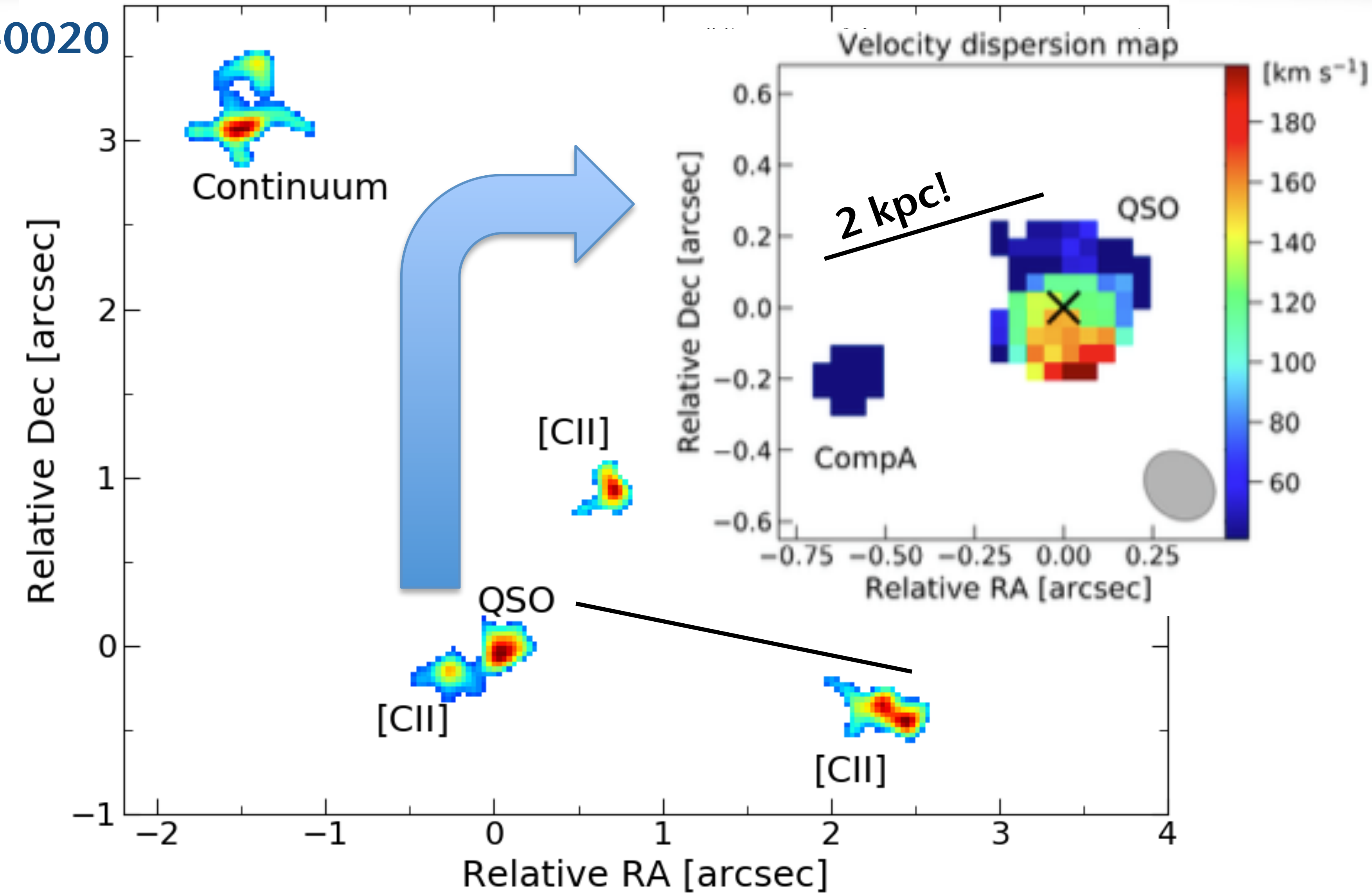


Merging systems

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

SFR(QSO) ~100 M⊙/yr

SFR(Total) ~1000 M⊙/yr

(Bischetti+2018a DOI201833249)
see also Duras+17

The early assembly of a giant galaxy

Single epoch M_{BH} ~ 5 x 10^9 $M_\odot$

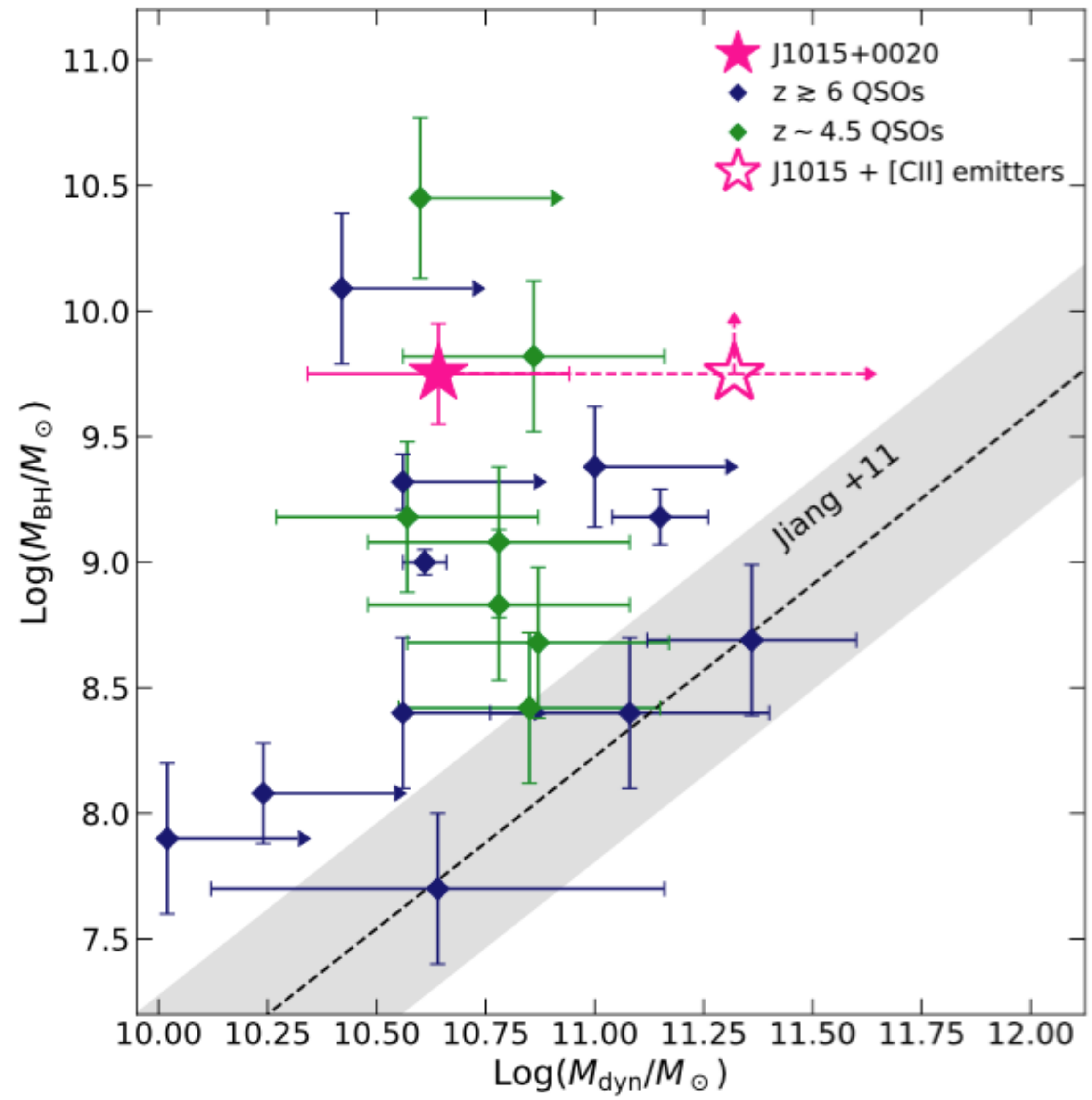
λ_{Edd} ~ 0.25

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

Two orders of magnitude smaller than local relations!

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

We are observing the cradle of a giant galaxy at z = 0



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

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

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