Kinematics in a z = 7.15 LBG Revealed by the [OIII] 88 μm and [CII] 158 μm Detected with ALMA

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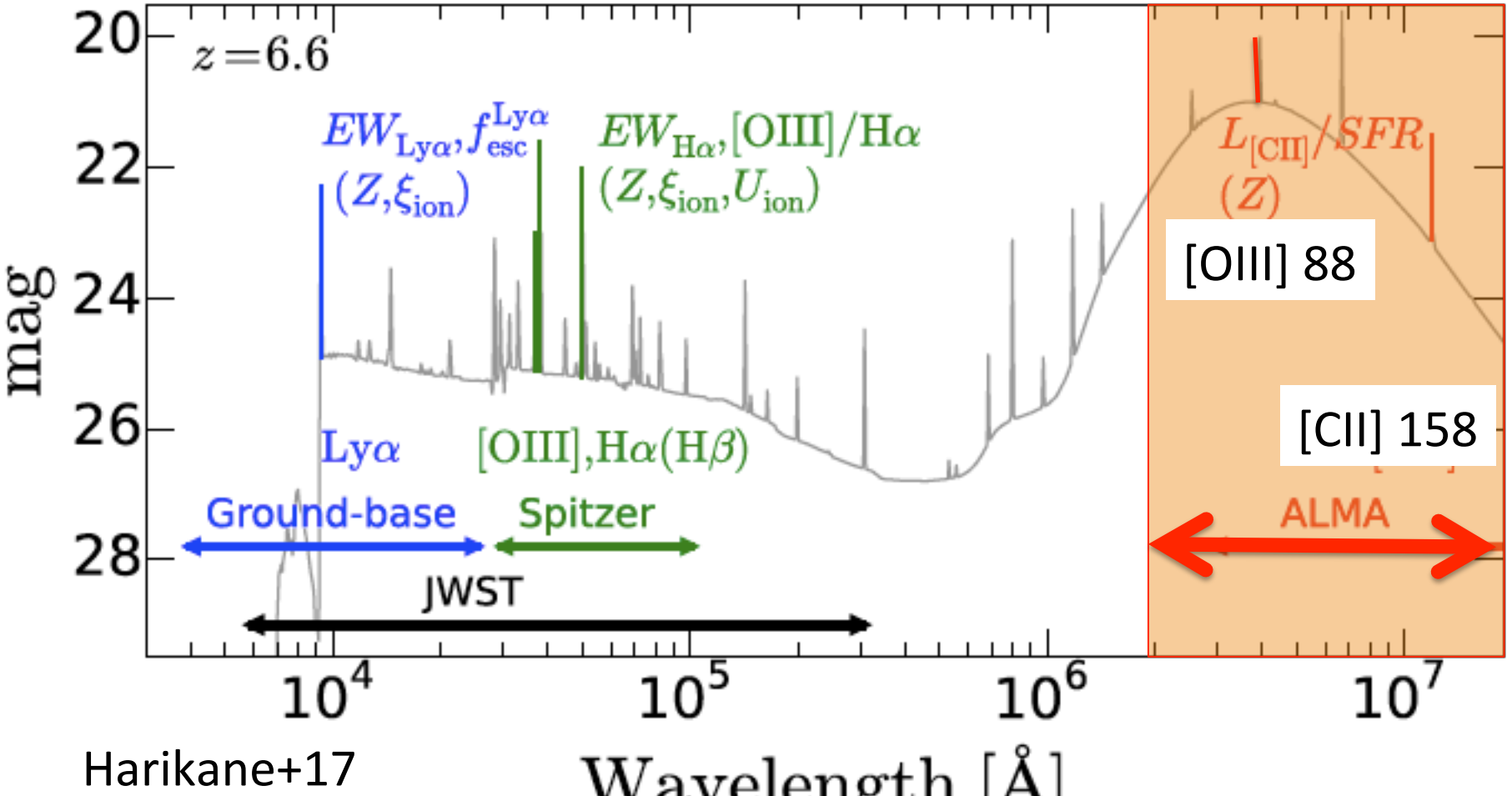
Introduction

- Lyα velocity offset at z > 6 is important to understand reionization, but difficult to measure:
  We need Lyα + non-resonant line(s) (e.g., Tommaso's talk, Laura's talk, Dan's talk, Stark+15, 17, Mason+18)

Introduction

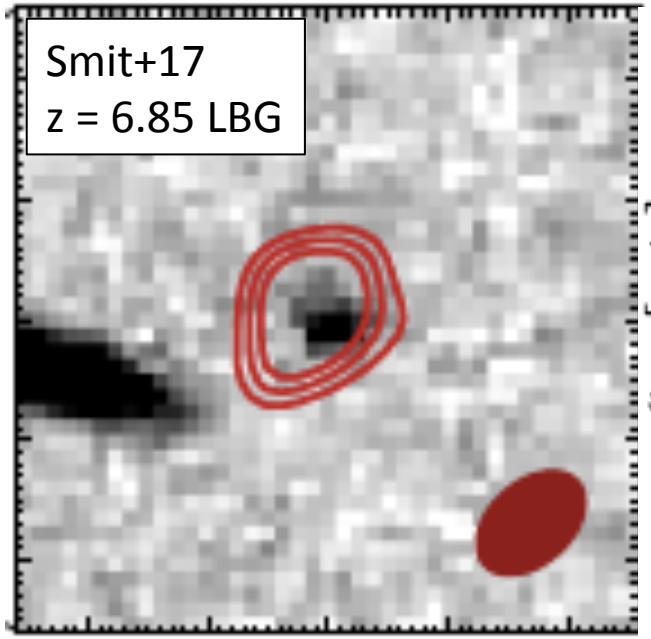
- With ALMA, one can target rest-frame FIR lines [CII] 158 μm (PDR) or [OIII] 88 μm (HII region)
- Dust continuum can be simultaneously targeted

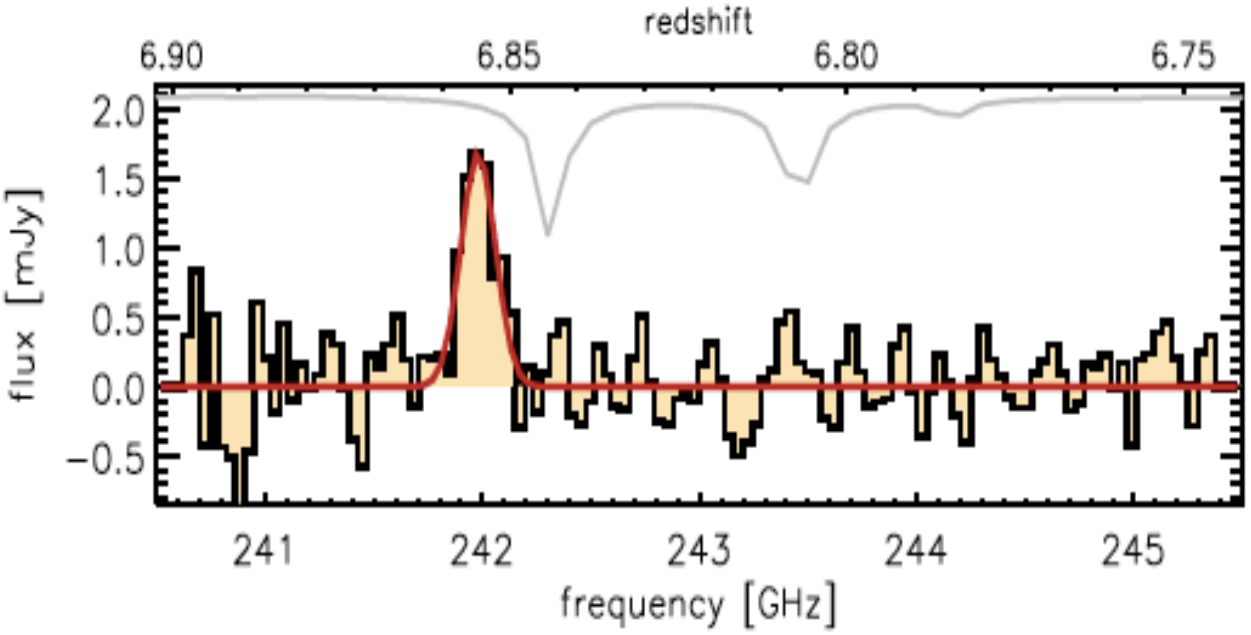


Harikane+17

[CII] 158 µm as a traditional tool at high-z

[CII] is one of the strongest FIR line in local galaxies (e.g., Malhotra+97)
21 [CII] detections at z > 5 (e.g Capak+15, Pentericci+16, Carniani+17a, b)





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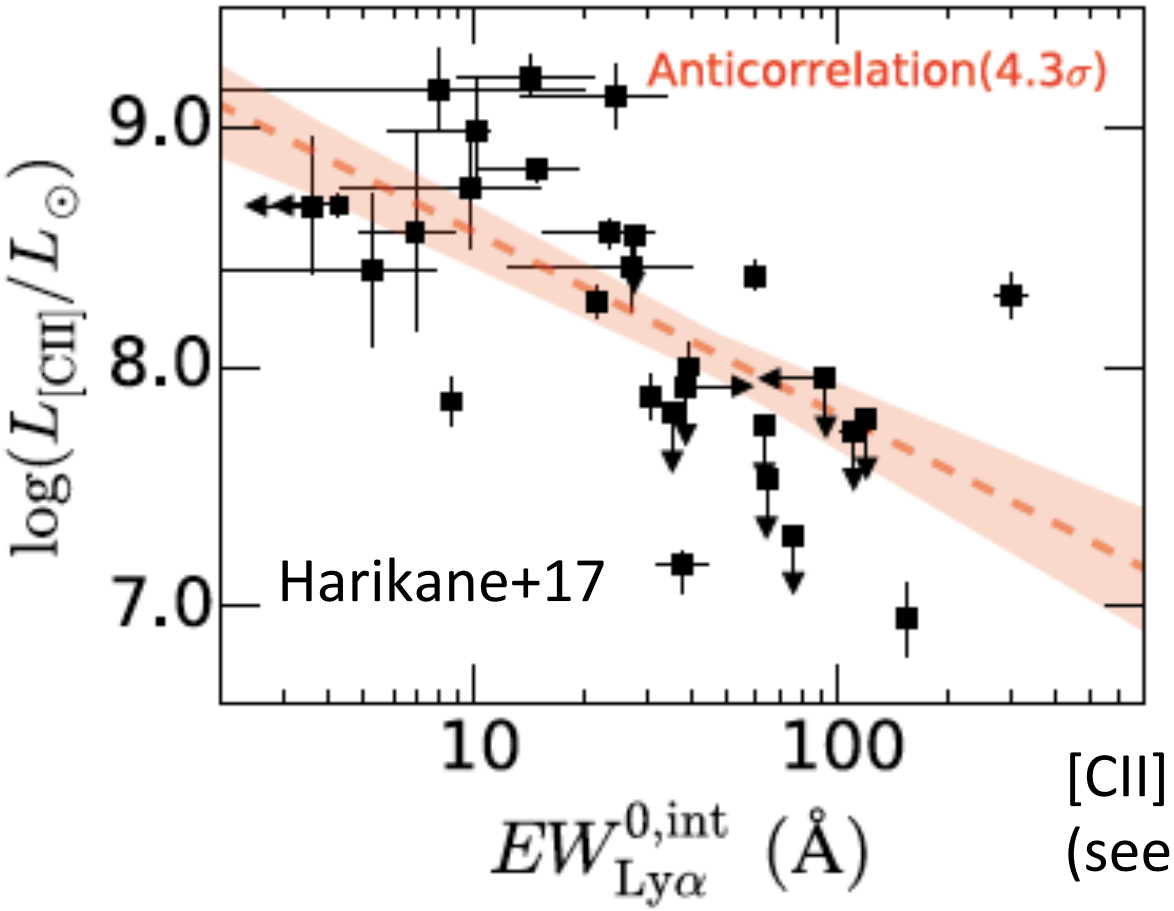
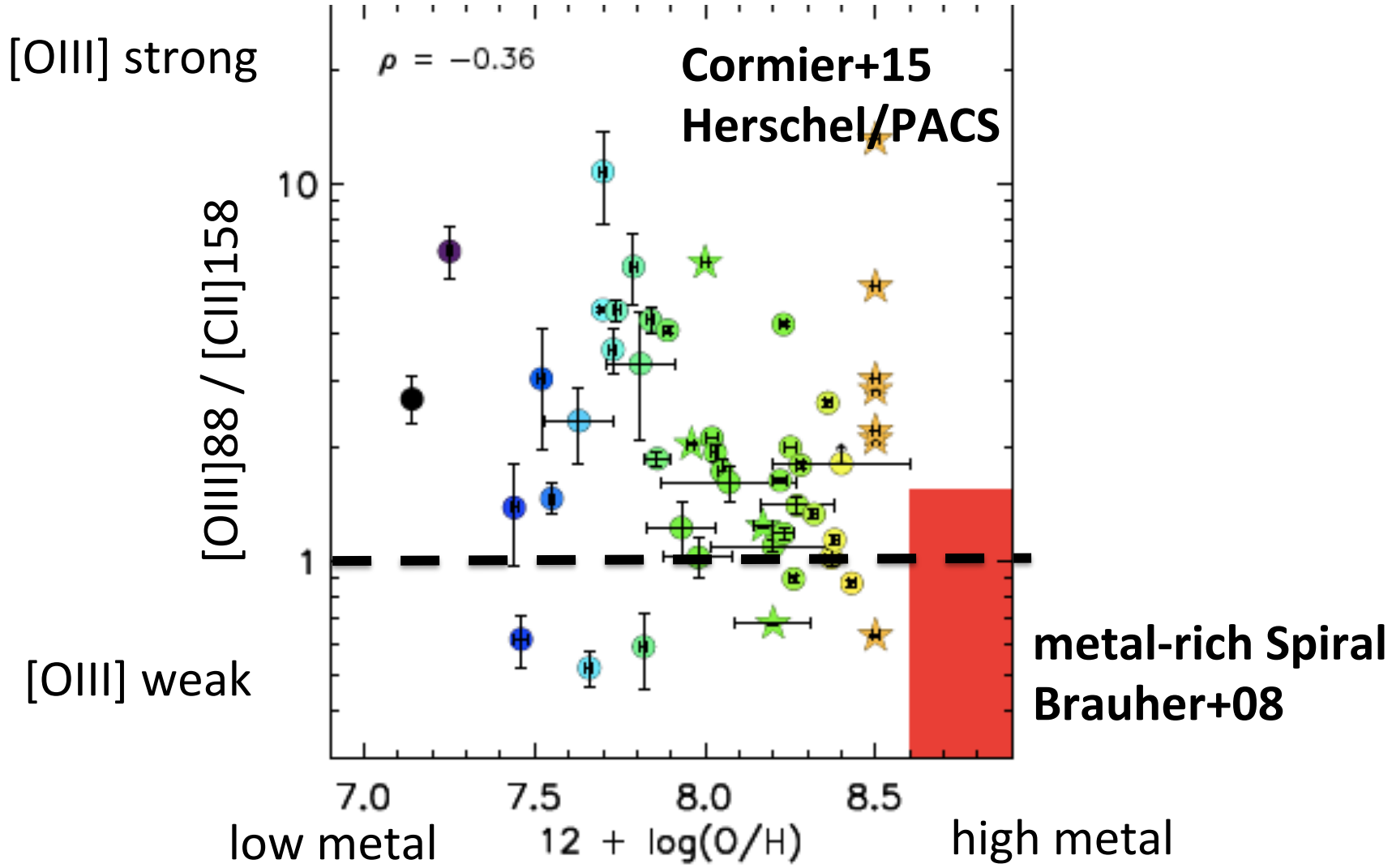


[CII] is weak for LAE
(see also Carniani+17b)

[OIII] 88 µm as a new tool at high-z

[OIII] > [CII] for local dwarf galaxies



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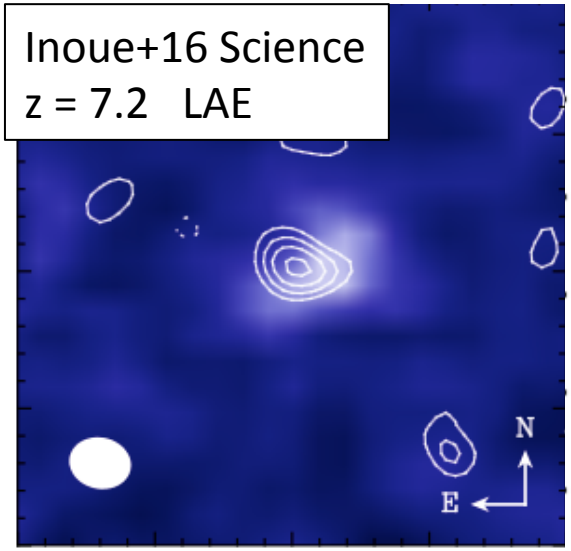
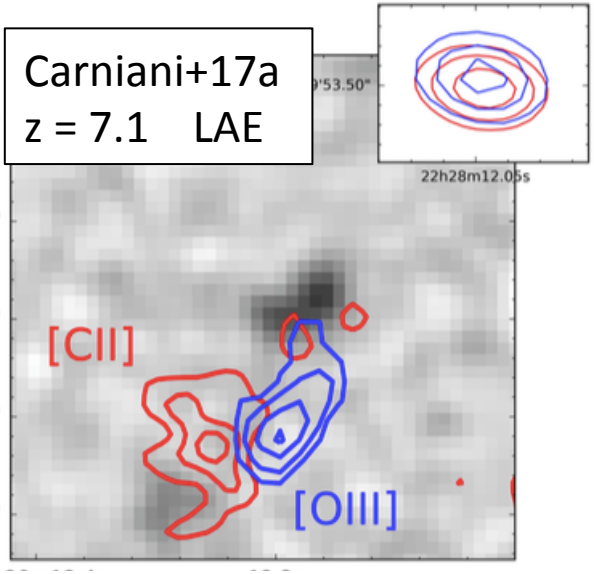
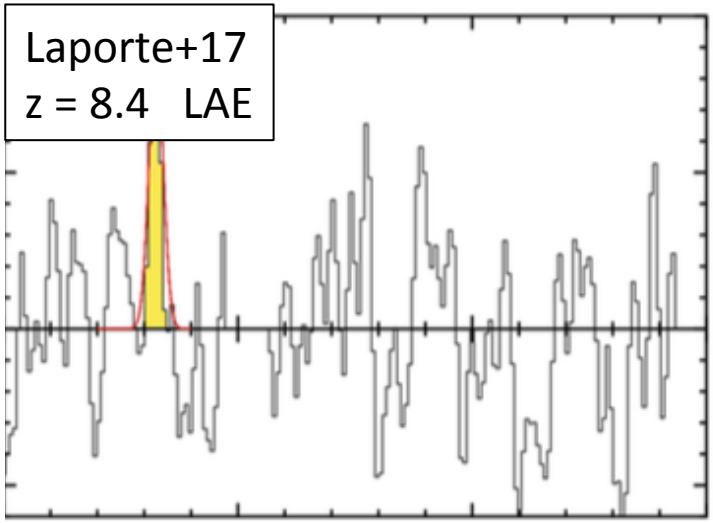
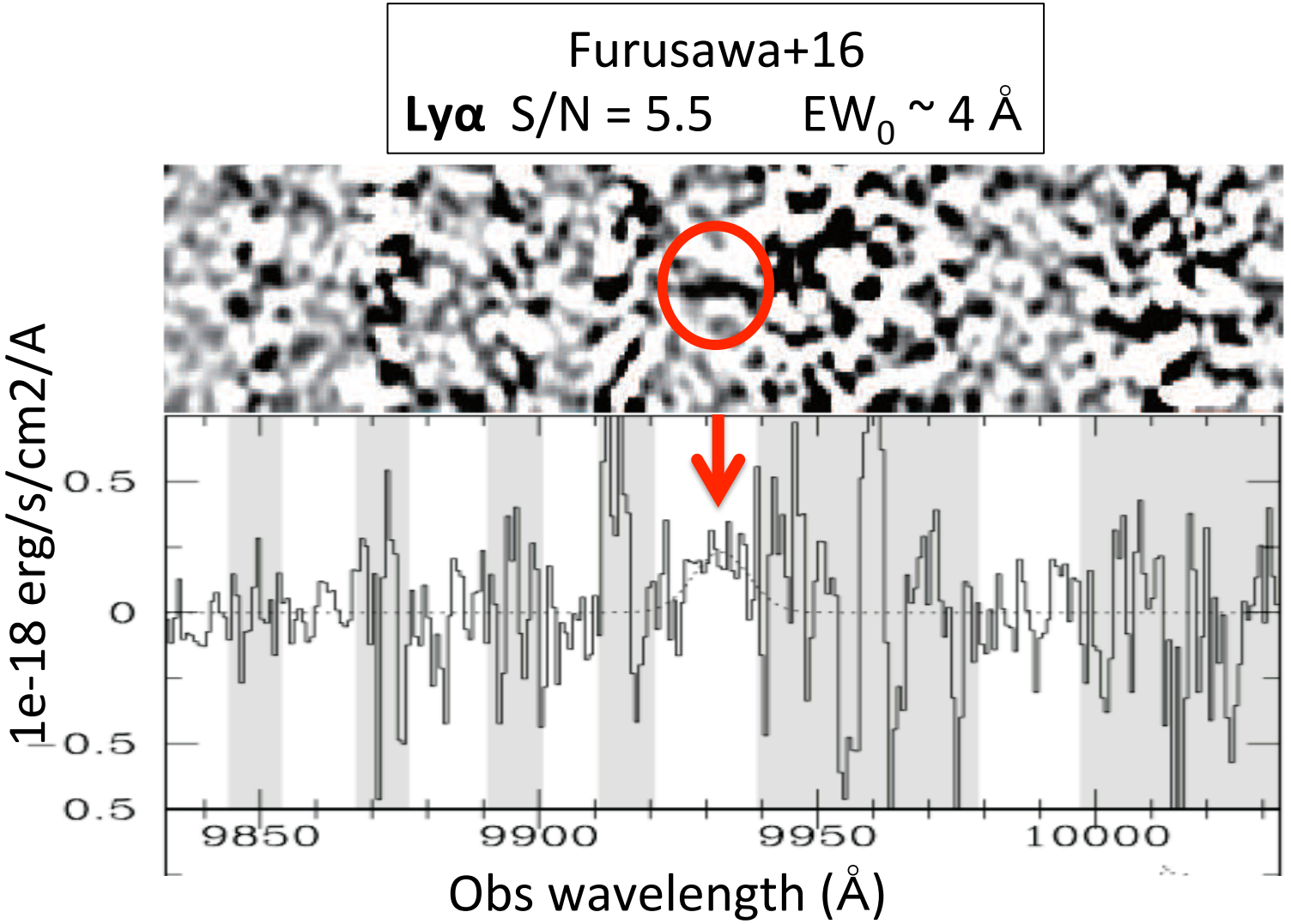






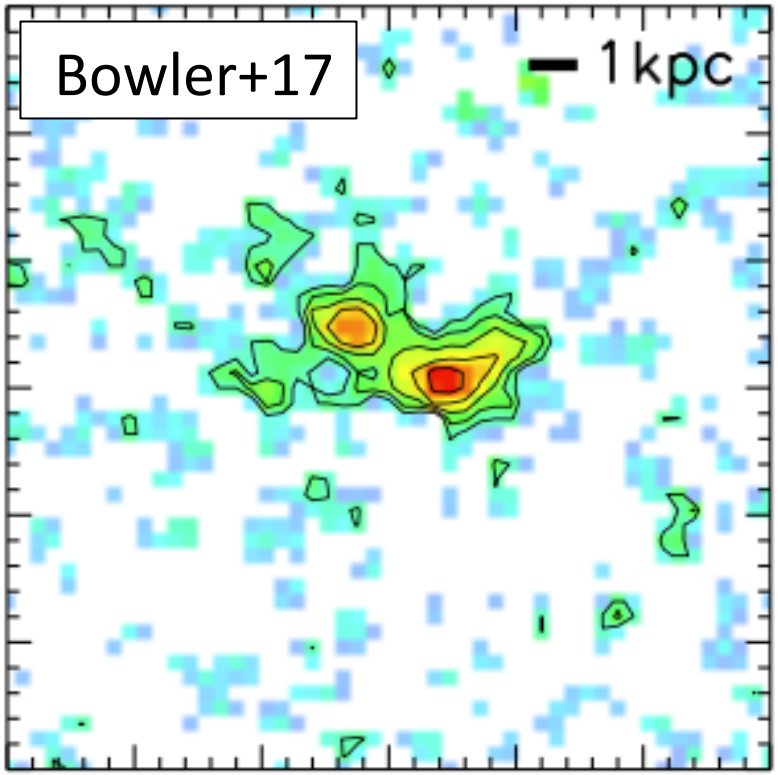
Thus far, **6** [OIII] detections at z >~ 7
(Marrone+18, **TH+18a accepted**, **Tamura incl TH+ in prep**)

This Study TH+18b in prep: a very luminous (Muv = -22.3) LBG

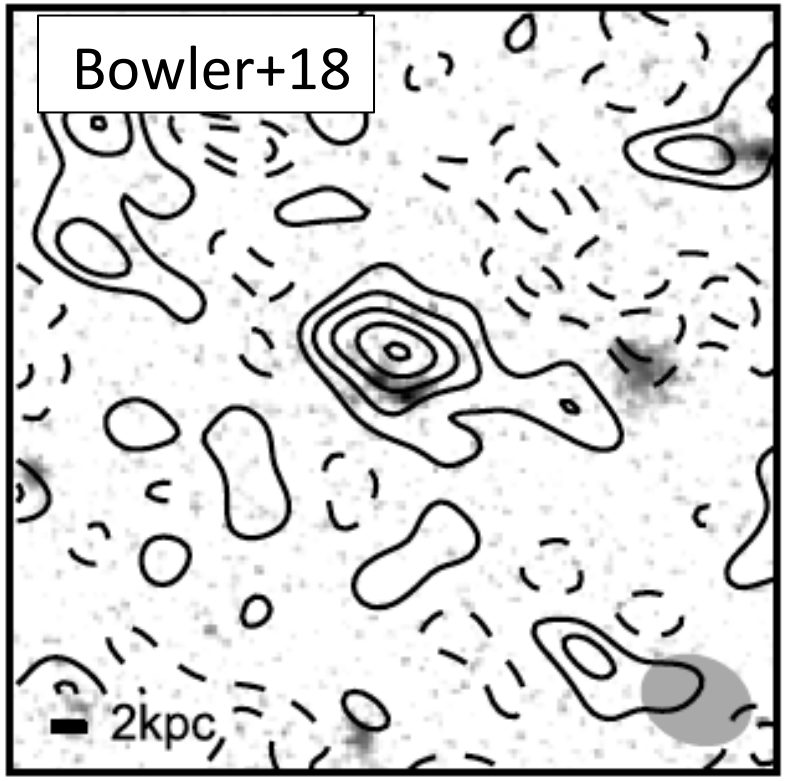


This Study TH+18b in prep: a very luminous (Muv = -22.3) LBG

HST F140W
Two rest-frame UV clumps indicative of merger



ALMA Band 6
Dust continuum (S/N = 5.3)



Cy 4 ALMA Band 6 & 8 Observations
PI: A. K. Inoue

Band	# of anntena	T_{on} [min]	beam size [FWHM]	1σ continuum
Band 6 -[CII] 158	40	~120	0”.3 x 0”.2	10 μJy/beam
Band 8 -[OIII] 88	40	~50	0”.3 x 0”.3	62 μJy/beam

Band6

T. Hashimoto + 18 b in prep
The plots not open for public, sorry

- L([CII]) = (1.3 ± 0.13) x 10^9 Lsun

- $S_{160\mu m}$ = 130 ± 25 μJy (cf., 168 ± 56 μJy in Bowler+18)

Band8

T. Hashimoto + 18 b in prep
The plots not open for public, sorry

- L([OIII]) = $(2.9 \pm 0.5) \times 10^9$ Lsun

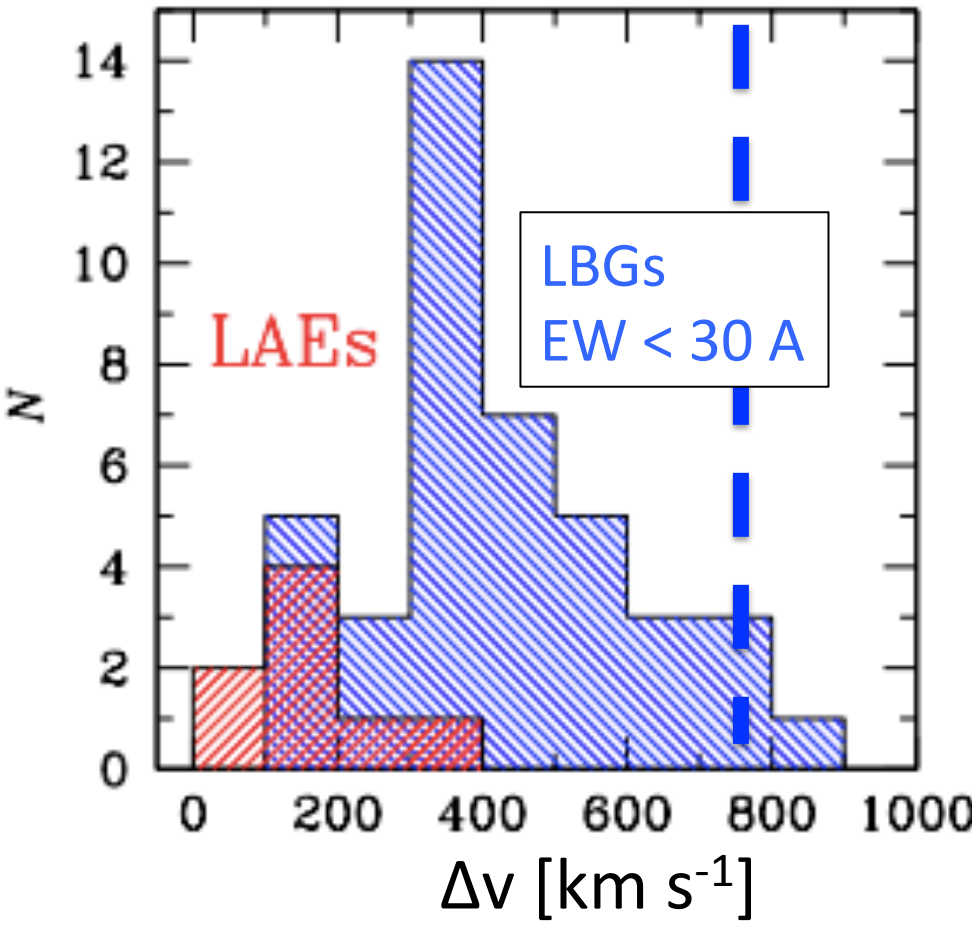
➔ [OIII]/[CII] = 2.2 ± 0.4

➔ **The first complete set of Lyα, [OIII], [CII], and dust**

The largest Δv at z > 6

T. Hashimoto + 18 b in prep
The plots not open for public, sorry

Δv at z ~ 2 – 3 (TH+13)



(cf., Steidel+10, McLinden+11, Chonis+13
Finkelstein+11, Erb+14, Shibuya+14)

Δv at z = 6-8

T. Hashimoto + 18 b in prep
The plots not open for public, sorry

UV CIII] : Dan's talk, Stark+15, 17, Mainali+17
FIR [OIII], [CII] : Willott+15, Knudsen+16, Inoue+16, Pentericci+16,
Carniani+17a,b, Bradac+17, Matthee+17, Laporte+18
Tommaso's talk and Mason+18 (*N* = 11)

The velocity structure at z = 7.15: merger ?

[CII] flux-weighted velocity map

[OIII] flux-weighted velocity map

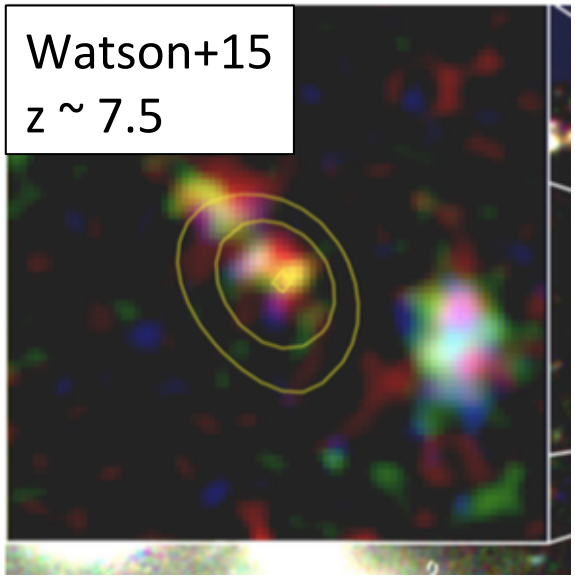
T. Hashimoto + 18 b in prep

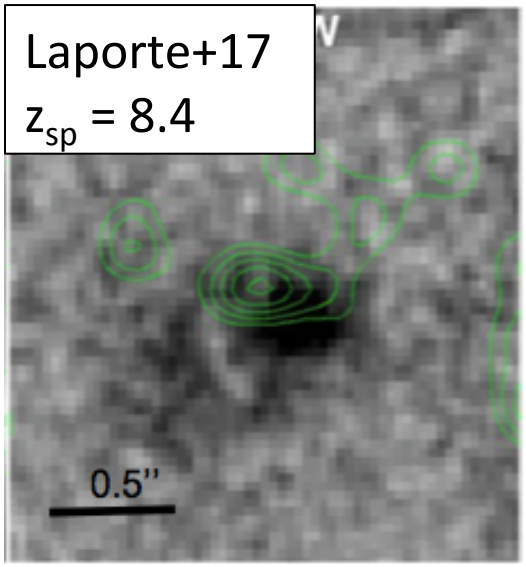
The plots not open for public, sorry

～200 km/s velocity structure

pixels with > 3σ

The 3rd dust in SF galaxies at z > 7





T. Hashimoto + 18 b in prep
The plots not open for public,
sorry

- L_{TIR} = [1.7 – 6.2] x 10^{11} L_{sun}

Modified black-body: T_d = 30 – 50 K, β_d = 1.5; Ouchi+13, Knudsen+17

- M_d = [1.2 – 5.6] x 10^7 M_{sun}

$$\kappa = \kappa_0 (\mu/\nu_0)^{\beta_d}$$
$$\kappa_0 = 10\ \mathrm{cm^2\ g^{-1}}\ \text{at}\ 250\ \mu\mathrm{m}$$ (Hildebrand83)

- M_* = a few x 10^9 M_{sun} (Salpeter IMF) ← SED-fit

- $\log(M_d/M_*)$ = -1.8 ~ -2.4 (Type II SNe + dust growth in the ISM)

Summary & Future prospects

- The first complete set of Lyα, [OIII] 88, [CII] 158, dust at z>6
  - [OIII]/[CII] = 2.2 ± 0.4
  - Δv(Lyα) = 770 ± 50 (± 100) km/s
  - [OIII] and [CII] velocity gradient 200 km/s
  - Dust-to-Stellar mass ratio $\log(M_d/M_*) = -1.8 \sim -2.4$
- With a compiled sample of 17 galaxies with Δv at z = 6-8...
  - Δv becomes larger for smaller EW(Lyα), brighter Muv, and brighter [CII]
- Accepted ALMA Cy5: LAEs+LBGs (Inoue) QSOs (Hashimoto)
- The rich data + Extended morphology → JWST NIRSpec/IFU