

# Intensity Mappingによる $z \sim 6$ 宇宙において LAE 周囲 $1\text{pMpc}$ まで広がる $\text{Ly}\alpha$ 巨大構造の初検出

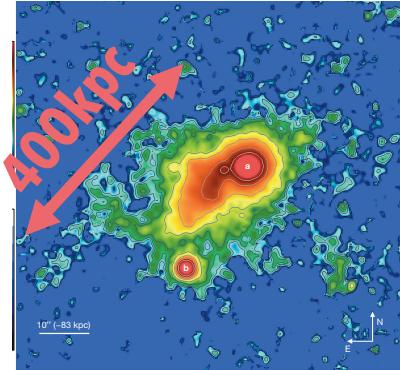
銀河・銀河間ガス研究会 2018

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The University of Tokyo, ICRR

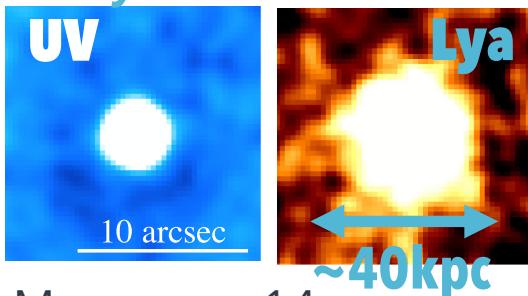
# Ubiquitous (?) diffuse Ly $\alpha$ emission

## Enormous Ly $\alpha$ Nebulae

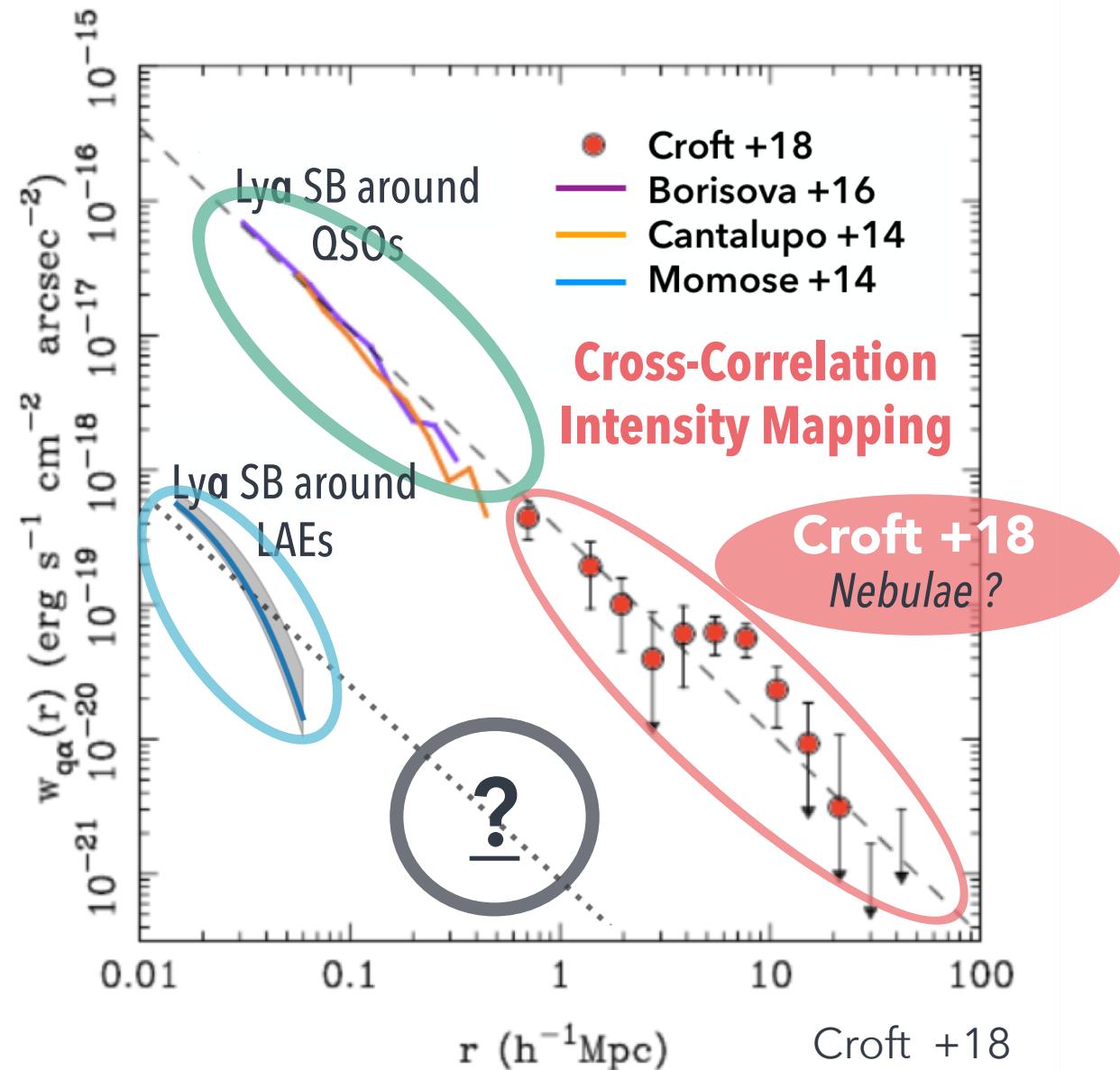


Cantalupo +14

## Lyman-alpha Halo

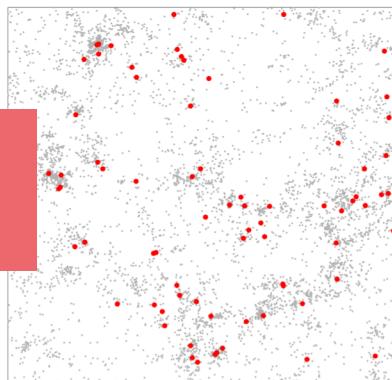


Momose +14



# Cross-Correlation Intensity Mapping

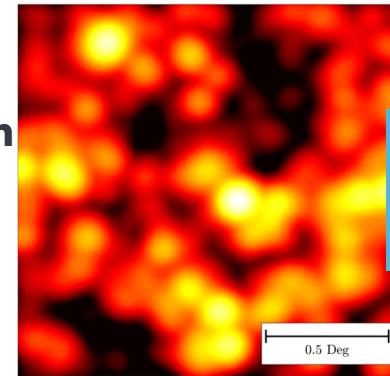
z-known  
Source  
position



Cross  
Correlation

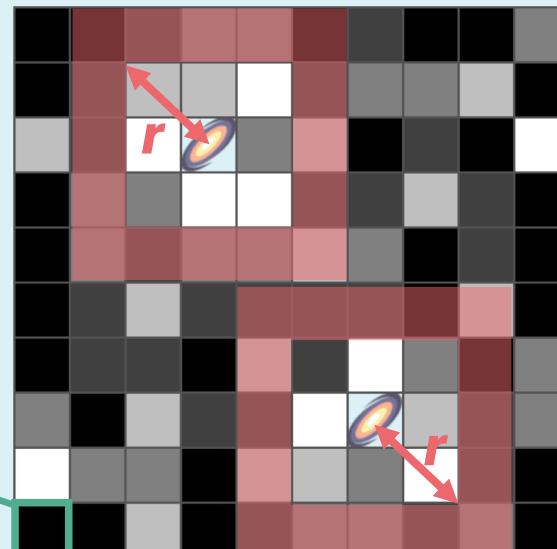
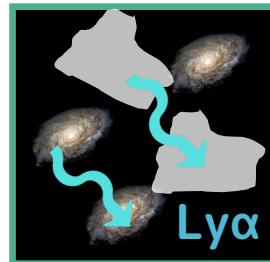


not resolved  
Intensity  
Map

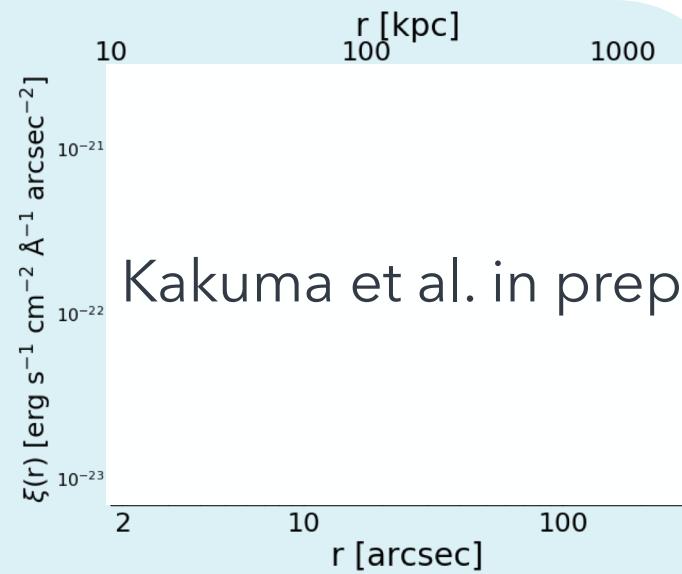


Breysse+16

Cross  
Correlation



SB mean of pixels which are  
separated by  $r$  from LAEs



Noise & contamination  
 $\rightarrow 0$

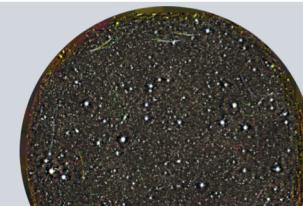
# The Hyper-Suprime-Cam Strategic Subaru Program (HSC-SSP)

Area : 4 deg<sup>2</sup>

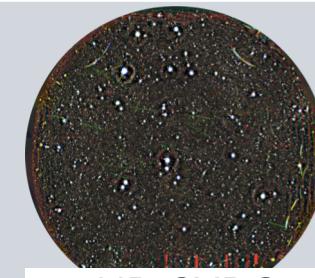
||



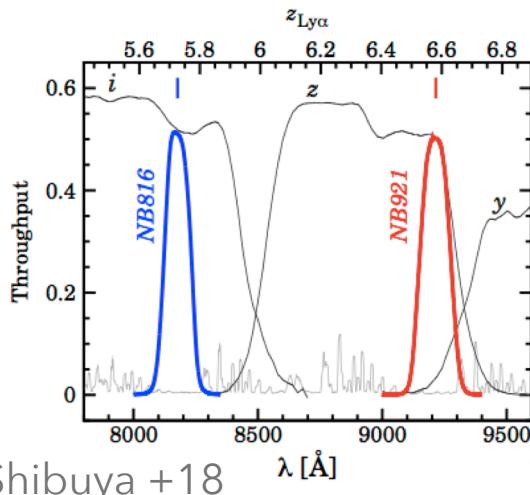
**x32 !!**



UD COSMOS  
~2deg<sup>2</sup>



UD SXDS  
~2deg<sup>2</sup>



Source position

$z = 5.7 \text{ LAEs}$   
(N = 425)

Cross Correlation

Intensity Map

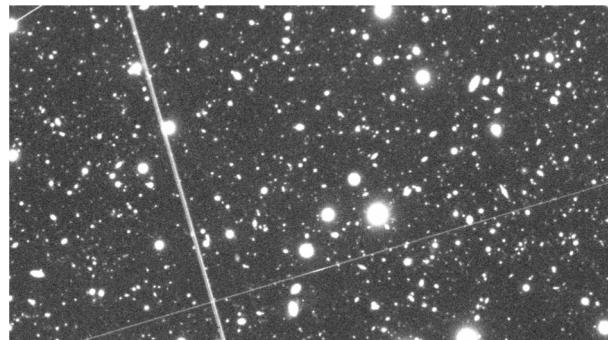
NB816  
Image

$z = 6.6 \text{ LAEs}$   
(N = 396)

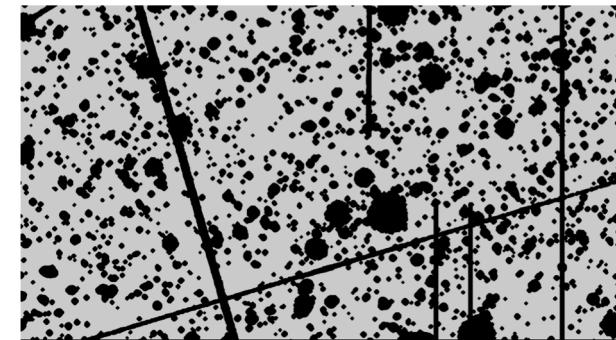


NB921  
Image

# Mask



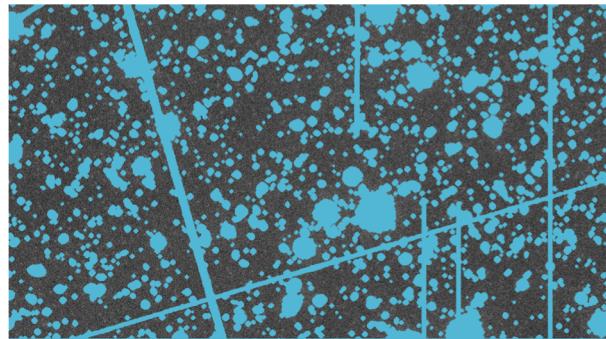
Image



Mask

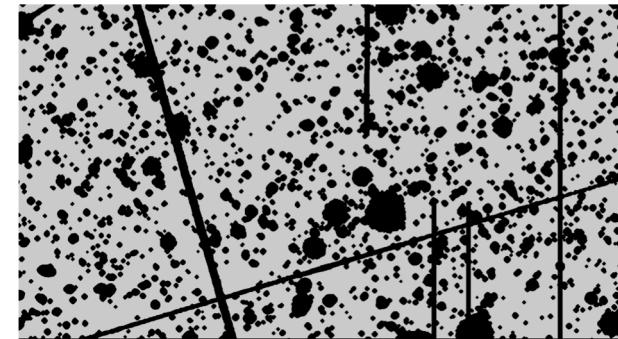
- ◆ Bad pixel
- ◆ Cosmic ray
- ◆ S/N > 5 e.t.c...

# Mask



Masked Image

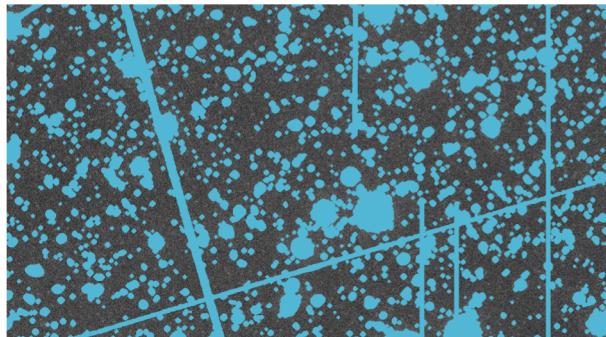
Remove bright foreground  
contamination beforehand



Mask

- ◆ Bad pixel
- ◆ Cosmic ray
- ◆ S/N > 5 e.t.c...

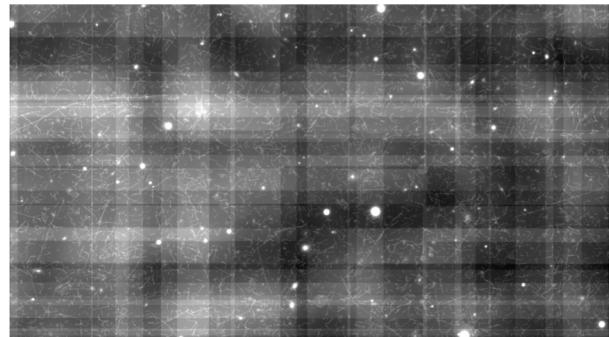
# Cross-Correlation



Masked Image

 $f$  (intensity)

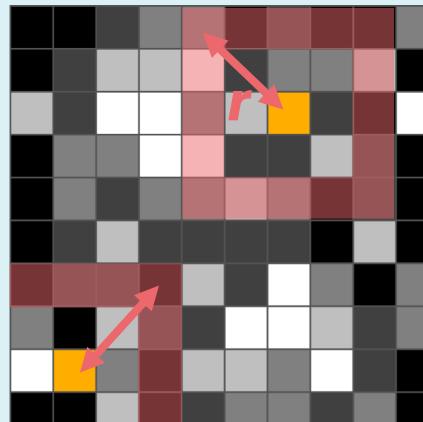
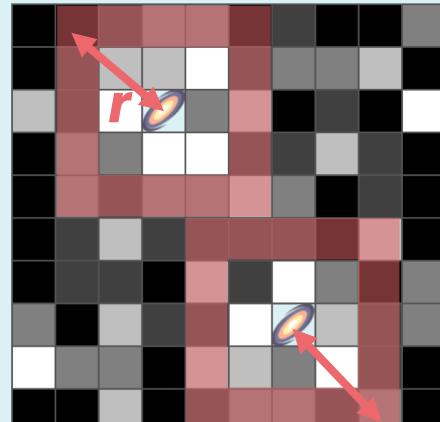
$$\xi_{IM} = \left[ \frac{1}{\sum_{r,i} w_{r,i}} w_{r,i} f_{r,i} \right]_{LAE} - \left[ \frac{1}{\sum_{r,i} w_{r,i}} w_{r,i} f_{r,i} \right]_{random}$$

Variance :  $\sigma$ 

(Systematics + Statistics)

 $w = 1/\sigma^2$  (weight)

Cross  
Correlation =  
 $\xi_{IM}$



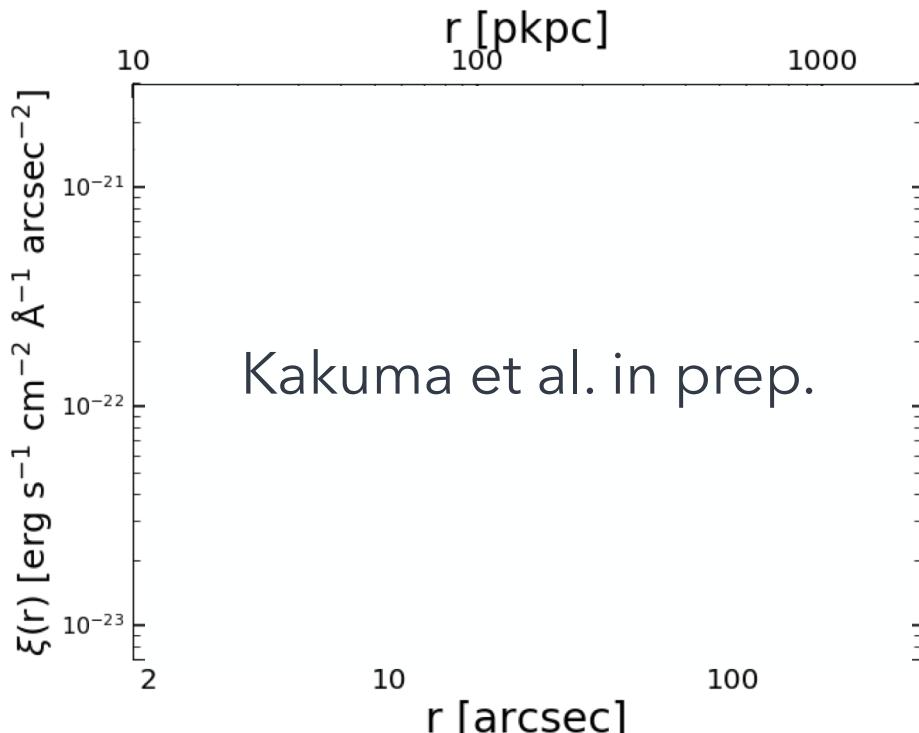
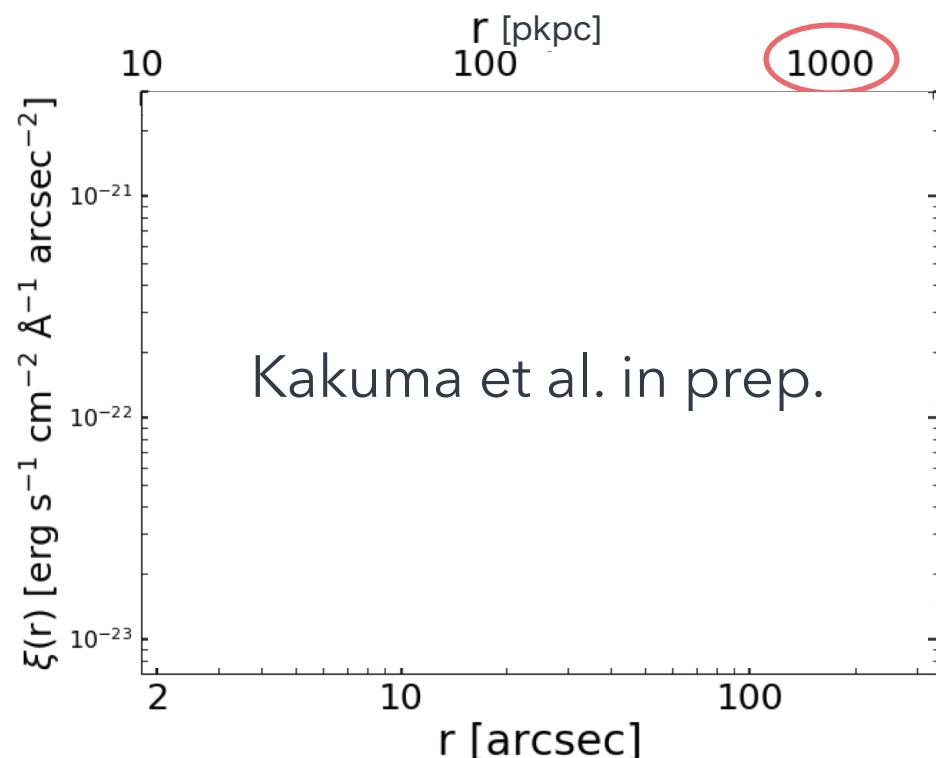
LAE



Random point

# Results

Errors are estimated  
by jack-knife method



Extended Ly $\alpha$  to  $\sim 1000$  pkpc !?

Any systematics mimicking the signals ?

# Test for All systematic errors (null test)

Source position

**Non-LAEs**

G-dropout ( $z \sim 4$ )

Cross  
Correlation



Intensity Map

NB Images  
(NB816, NB921)

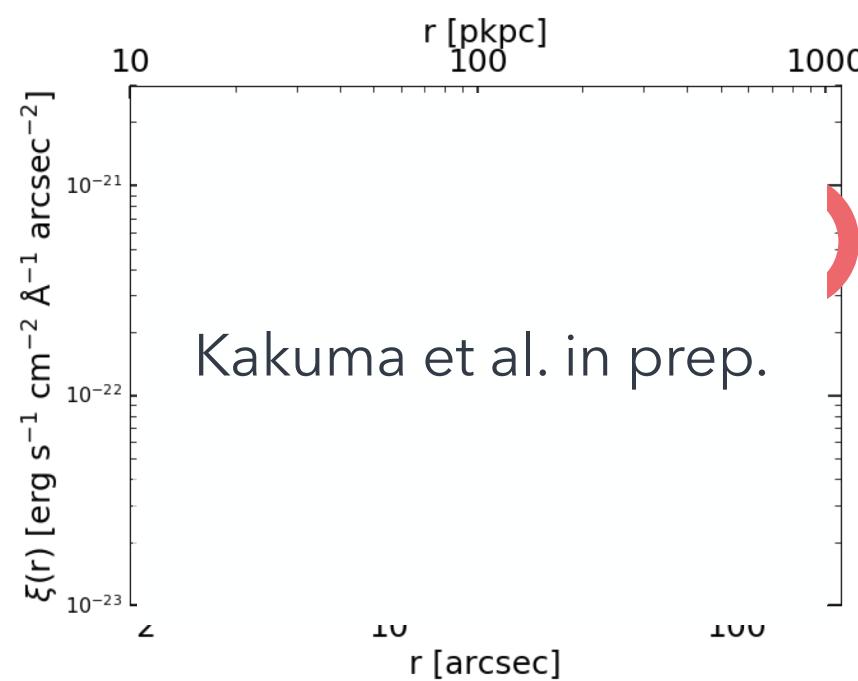
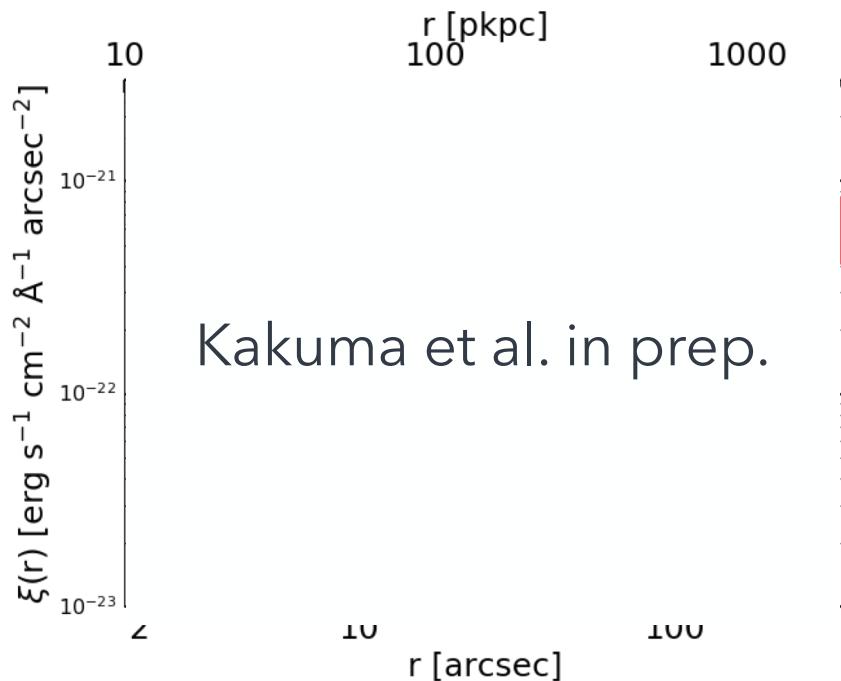
PSF

Sky subtraction

Unknown systematics

Same number and mag.  
distribution as LAEs

×100 times



~ $2.5\sigma$  significant from systematics !

# Broad Band (Continuum)

Source position

$z = 5.7$  LAEs

$z = 6.6$  LAEs

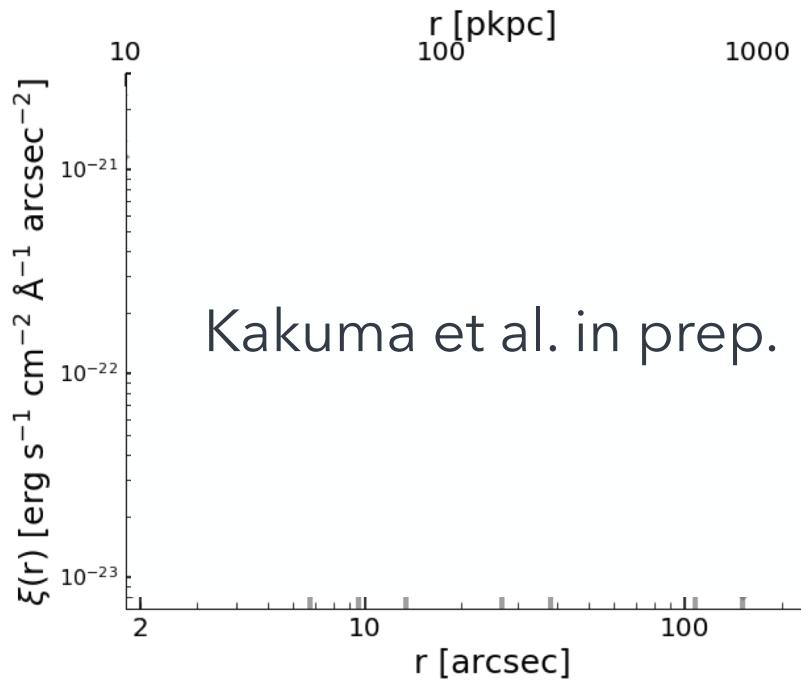
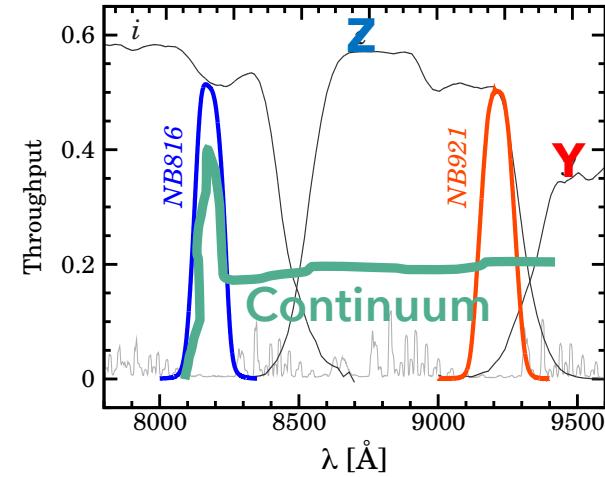
Cross  
Correlation



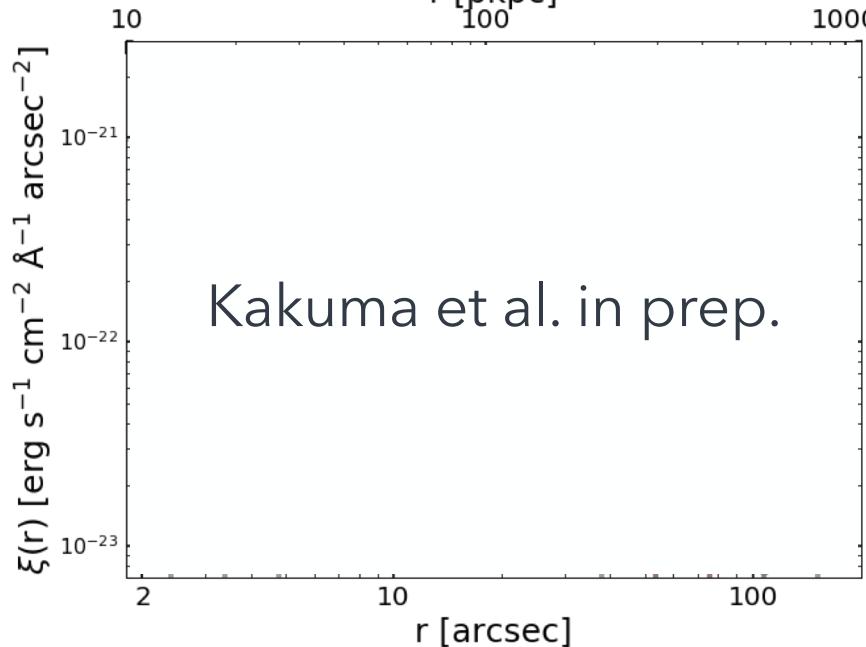
Intensity Map

Z Image

Y Image

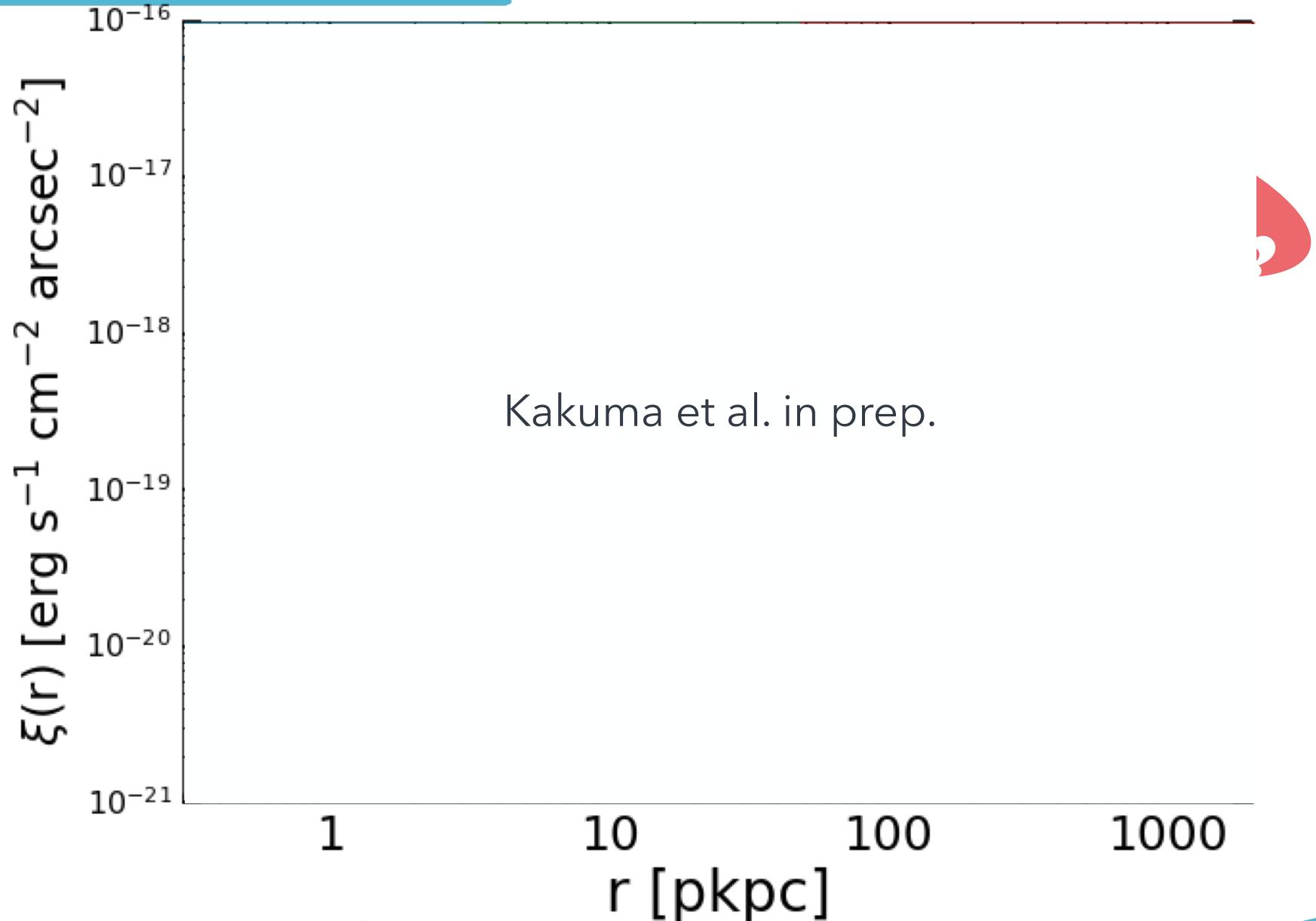


Weaker than Ly $\alpha$  emission

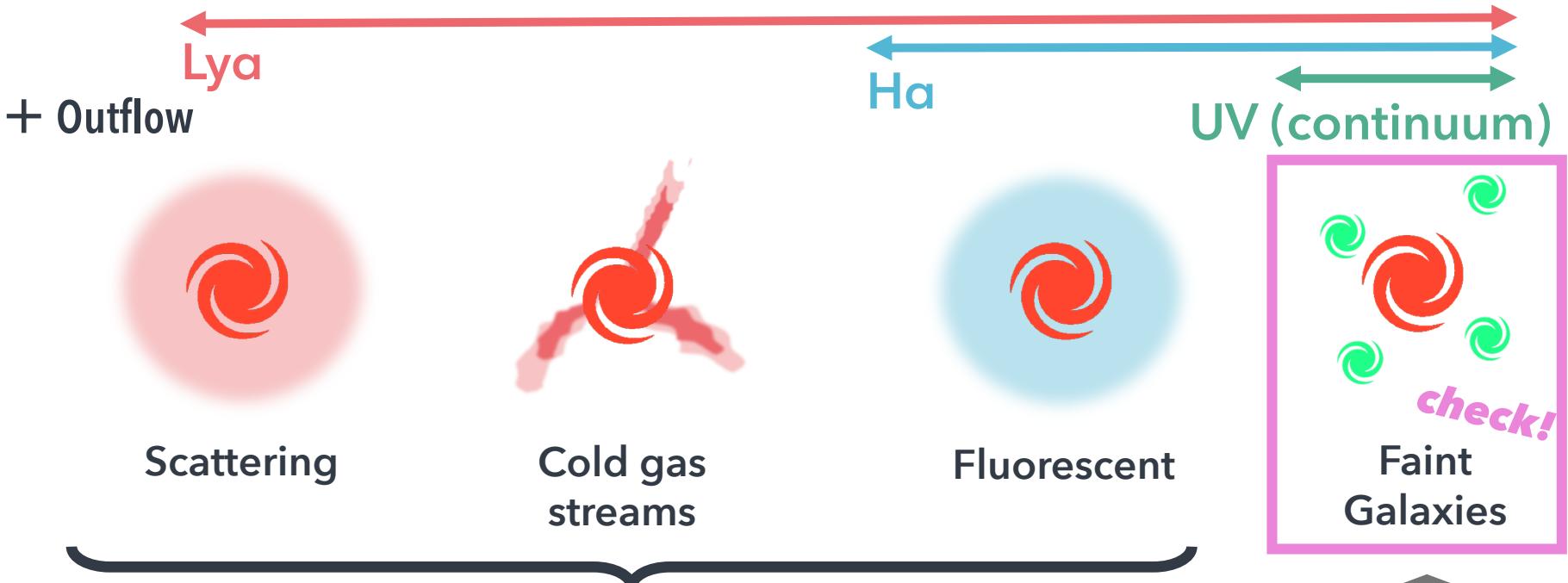


Surrounding faint galaxies  
→ also LAE like galaxies

# Comparison with previous studies

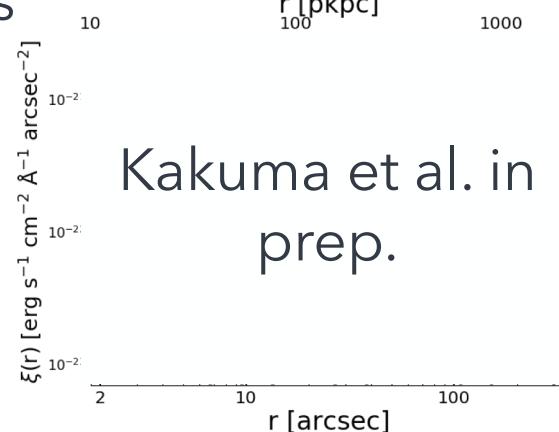


# The origin of Ly $\alpha$ large structure (仮)



- Very sensitive to CGM, IGM (H gas) parameters
  - Depends on tuning
- ✓ Need more information & Simulation

→ Qualitative limitation ×



# Faint LAEs Clustering

 $\xi_{IM}$  $\epsilon_{Ly\alpha}$  $\rho_{SFR}$ 

Bias for LAEs  
(~ 4 c.f. Ouchi +18)

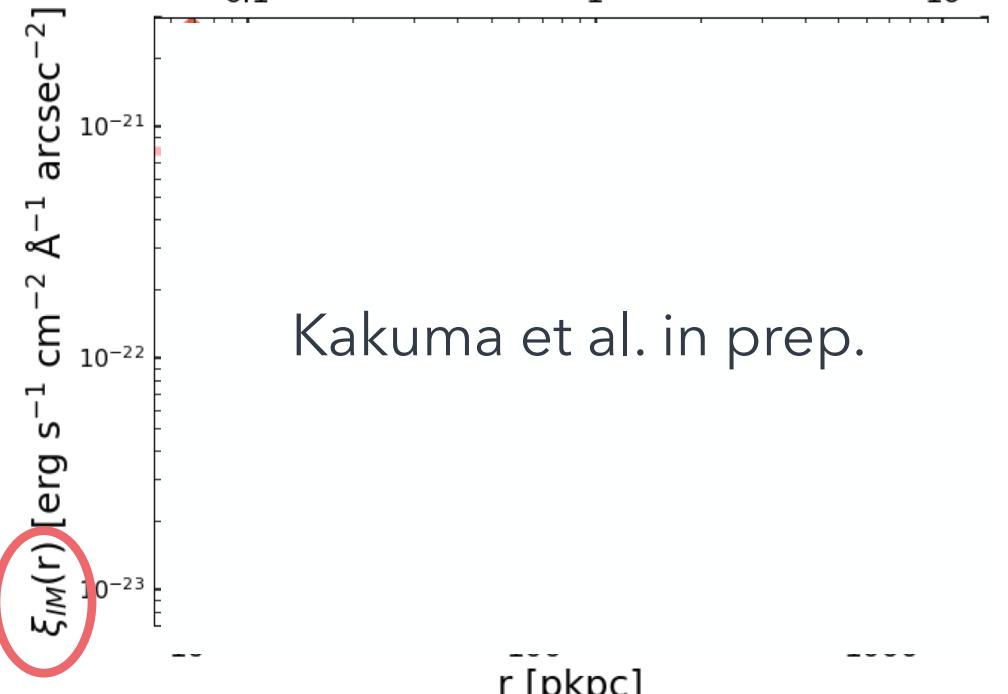
Mean of Ly $\alpha$  SB  
(free parameter)

 $\xi_{IM}$  $b_{LAE}$  $b_{f, Gal}$  $\langle \mu_{Ly\alpha} \rangle$  $\xi_{DM}$  $r [cMpc]$ 

Bias for faint LAEs

→ Assume this to be  
same to be  $b_{LAE}$   
<sub>10</sub>

DM ACF



$$\langle \mu_{Ly\alpha} \rangle \sim 1.0 \times 10^{-21} \text{ [erg/s/\AA/cm}^2/\text{arcsec}^2\text{]}$$

$$\frac{\epsilon_{Ly\alpha}}{\text{Cosmic Ly}\alpha \text{ luminosity density}} \sim 6.0 \times 10^{41} \text{ [erg/s/Mpc}^3\text{]}$$

All Ly $\alpha$  is originated from  
clustering faint LAEs

# Comparing with Luminosity Function

 $\epsilon_{Ly\alpha}$ 

◆ This study

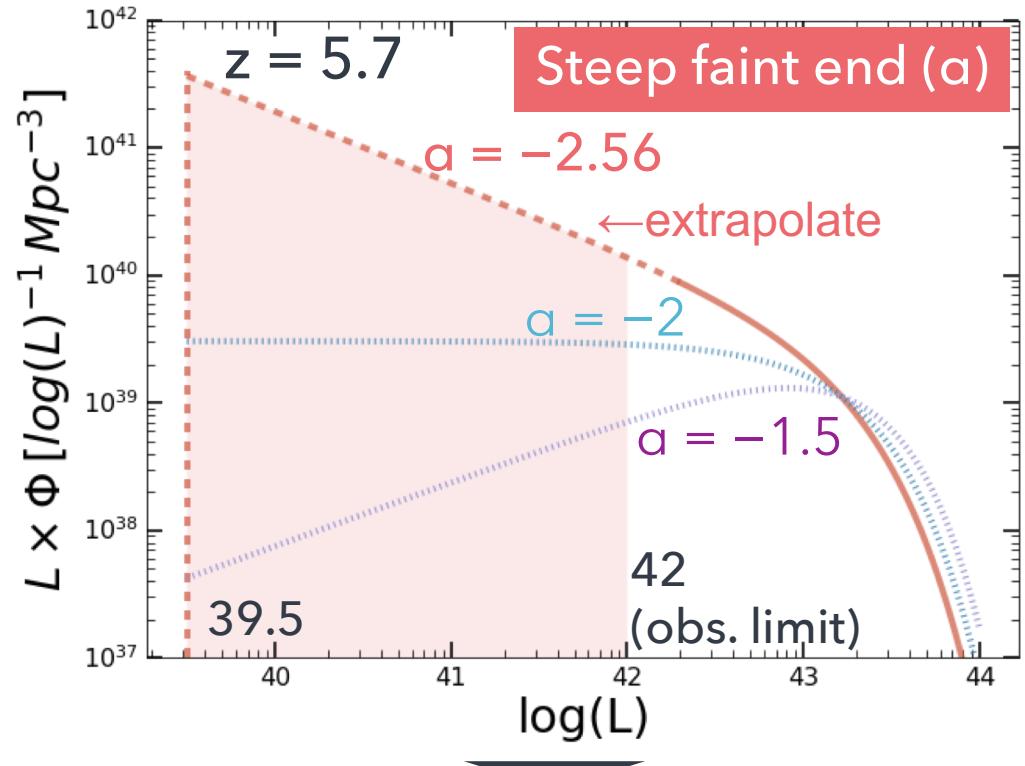
Cross-Correlation  
Intensity Mapping



$$\epsilon_{Ly\alpha} \sim 6.0 \times 10^{41} \text{ [erg/s/Mpc}^3]$$

Comparable

◆ Konno +18 (same LAE sample)



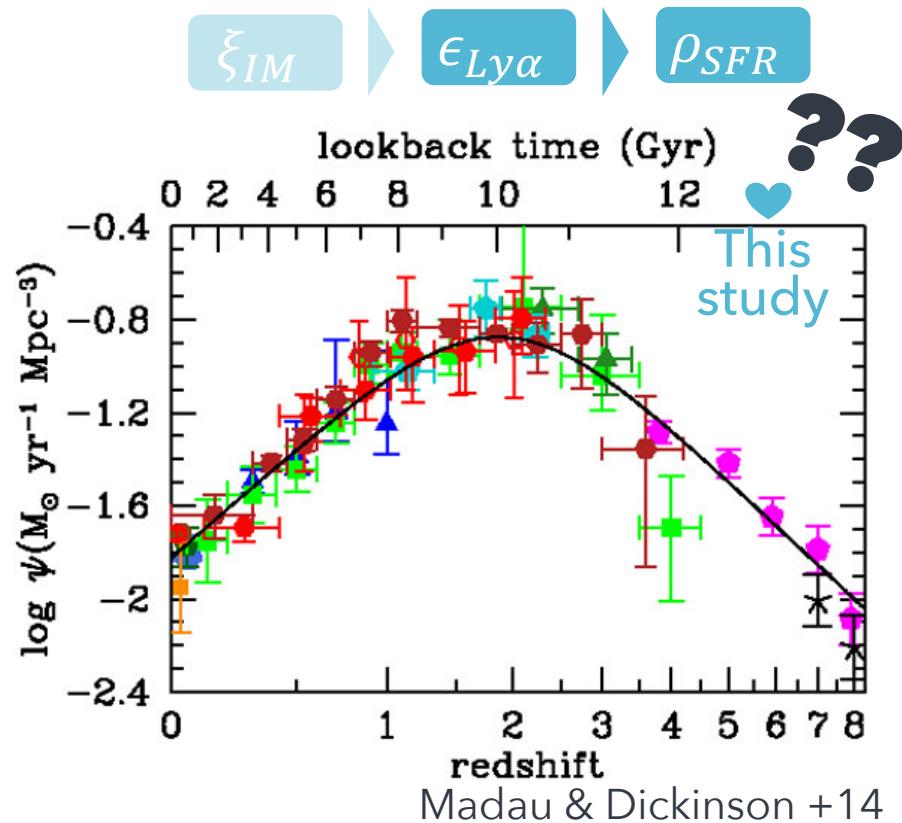
$$\epsilon_{Ly\alpha} \sim 6.1 \times 10^{41} \text{ [erg/s/Mpc}^3]$$

# Cosmic SFR density

$$\frac{\rho_{SFR}}{[\text{M}_\odot \text{ yr}^{-1} \text{ Mpc}^{-3}]} = \kappa_{Ly\alpha} \frac{\epsilon_{Ly\alpha}}{[\text{erg s}^{-1} \text{ Mpc}^{-3}]} \\ (\kappa_{Ly\alpha} = 9.1 \times 10^{-43})$$

▶  $\rho_{SFR} \sim 0.5$  [ $\text{M}_\odot/\text{yr}/\text{Mpc}^3$ ] ( $z=5.7$ )

$\times 20$  higher than Madau plot



Madau & Dickinson +14



1  $\kappa_{Ly\alpha}$  is different for high-z, faint galaxies

- Top heavy IMF, low metallicity, high escape fraction, etc.
  - More Ly $\alpha$  (ionizing) photons are emitted



2 Other contribution from H gas



# Summary

- First study to use Cross-Correlation Intensity Mapping @  $z \sim 6$
- The large NB data of HSC-SSP ( $\sim 4 \text{ deg}^2$ )

- ✓ First detection of Ly $\alpha$  Large structure ( $\sim 1000 \text{ pkpc}$ ) @  $z \sim 6$
- ✓ Faint Galaxy & H gas contribution

