

# Absorption line studies with Cross-correlation Intensity Mapping

鹿熊亮太

The University of Tokyo ICRR

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# ■ Today's agenda

## 1 My study

- Ly $\alpha$ -emission Cross-correlation Intensity Mapping

## 2 Absorption line studies with Cross-correlation Intensity Mapping

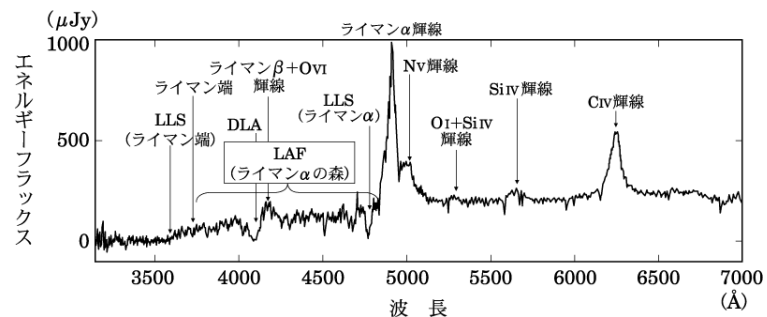
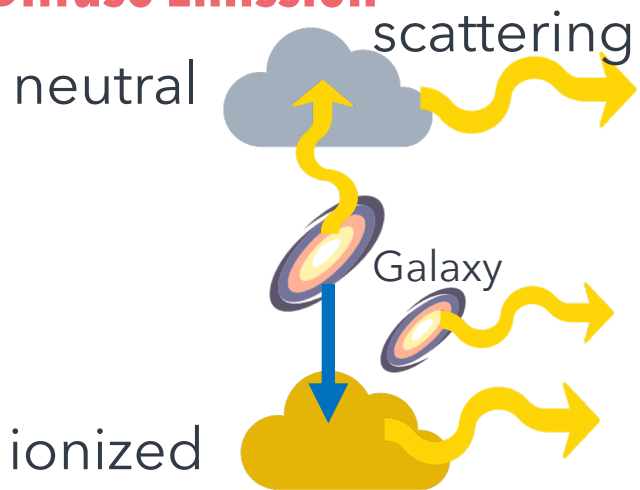
- Review of "Croft et al. 2018"
  - Ly $\alpha$ -forest Cross-correlation Intensity Mapping
- Future study

# Absorption vs. Emission

## Absorption

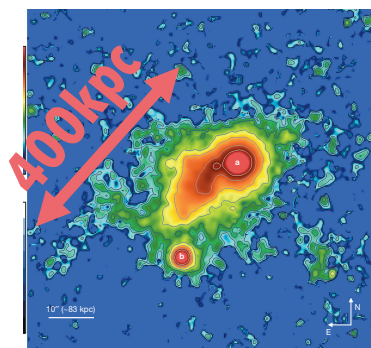


## Diffuse Emission



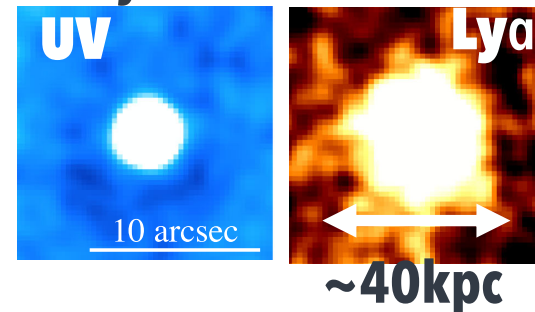
シリーズ現代の天文学

## Enormous Ly $\alpha$ Nebulae



Cantalupo +14

## Lyman- $\alpha$ Halo



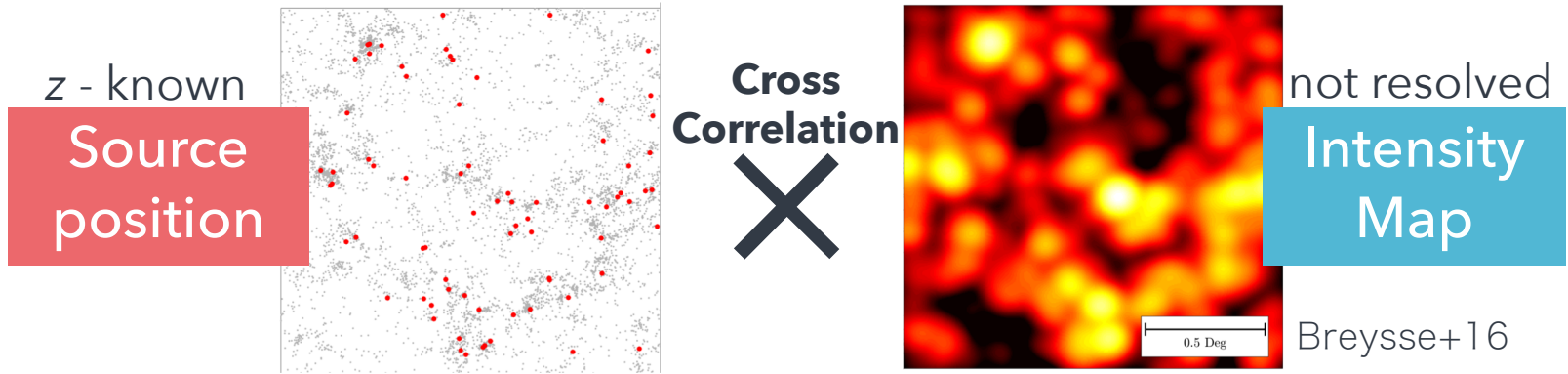
Momose +14

**Absorption & Emission**

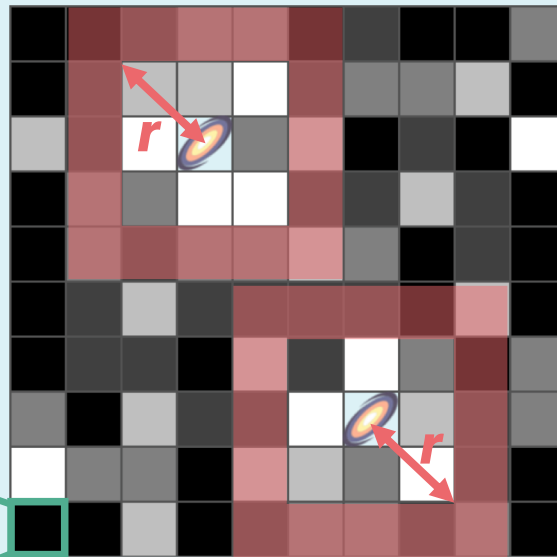
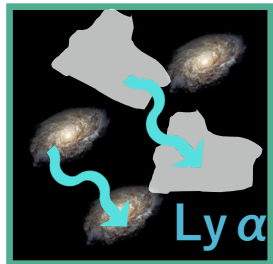


**Matter distribution  
Physical property**

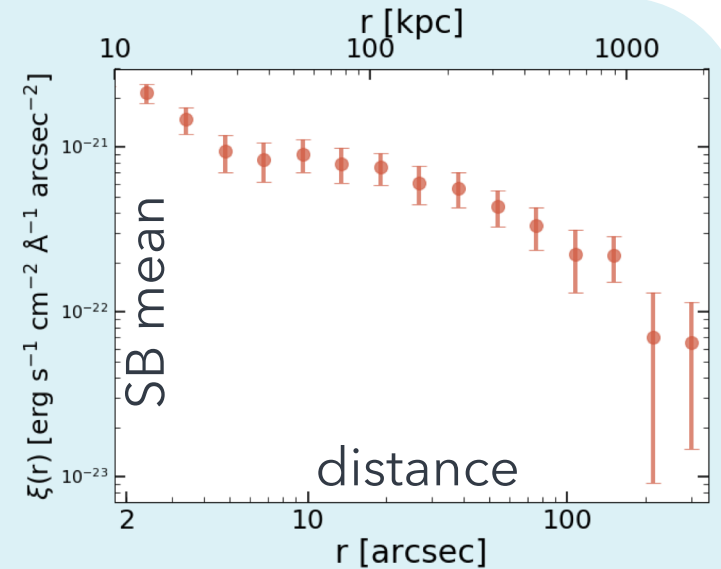
# Cross-Correlation Intensity Mapping



Cross Correlation



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



Noise & contamination  
→ 0

# Data

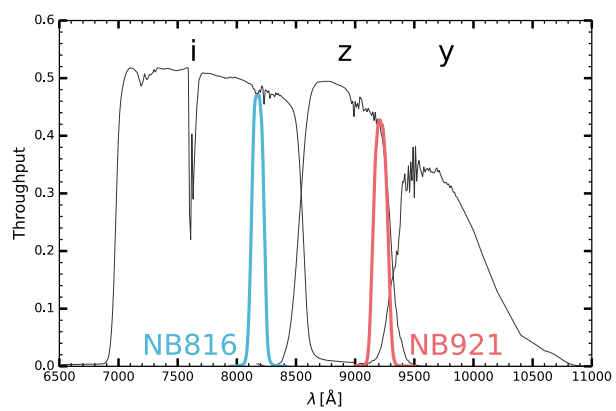
## The Hyper-Suprime-Cam Strategic Subaru Program (s18a data release)

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



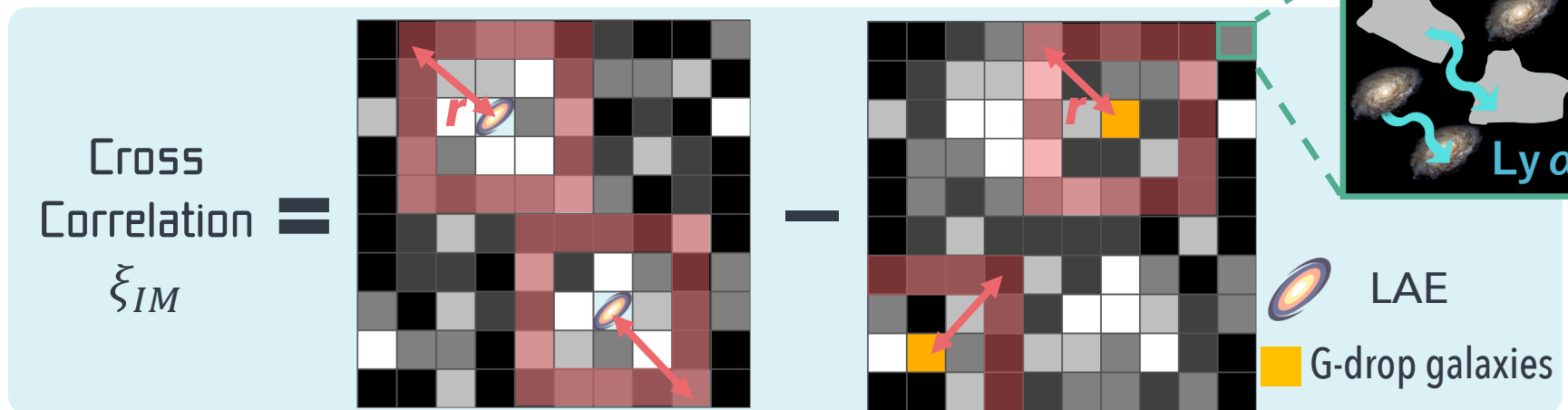
UD COSMOS      UD SXDS

- ✓ Mask
  - Bright source
  - Detected (S/N > 5)
- ✓ 5 $\sigma$  clipping



Source position	Cross Correlation	Intensity Map
z = 5.7 LAEs (N = 425)	✗	NB816 Image (z=5.7 Ly $\alpha$ map)
z = 6.6 LAEs (N = 396)	✗	NB921 Image (z=6.6 Ly $\alpha$ map)

# Cross-Correlation and systematics



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

## Test for All systematic errors

Source position

G-dropout  
( $z \sim 4$ )

Cross  
Correlation



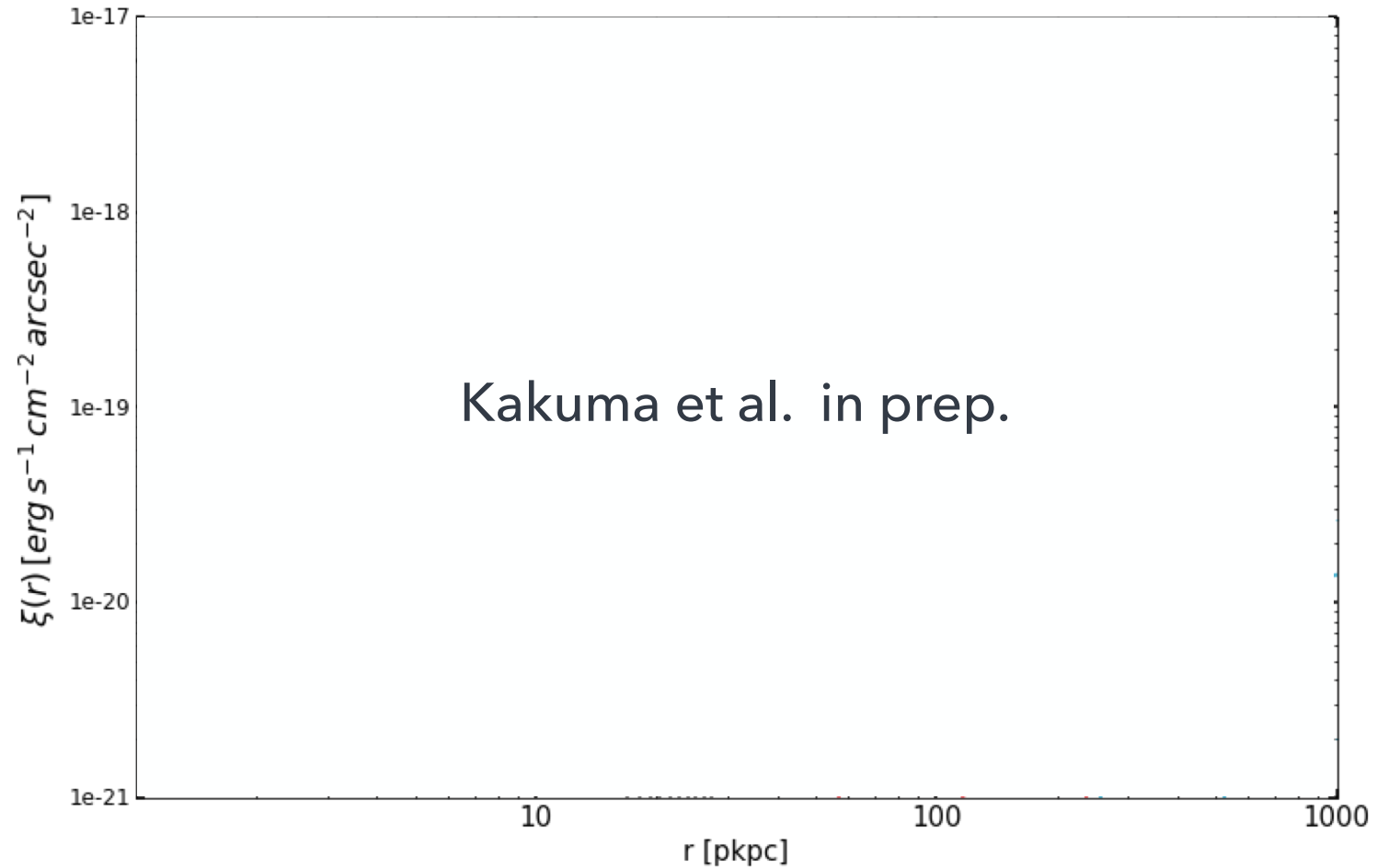
Intensity Map

NB Images  
(NB816, NB921)

- PSF
- Sky subtraction
- Unknown systematics

Same number and mag.  
distribution as LAEs

# RESULT

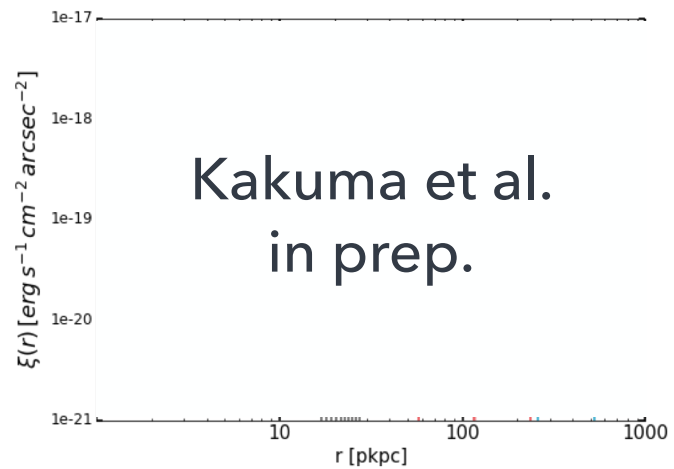
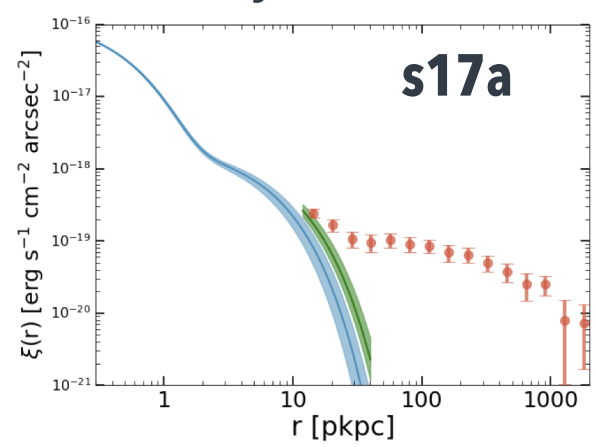


- Consistent with Ly $\alpha$  Halo studies at  $\lesssim 20$  pkpc scale
- More extending to  $\sim 100$  kpc



# S18a data release

□ I told some of you different result from **HSC-SSP s17a** release



□ **HSC-SSP s18a** data was released this summer

● Difference : **Global Sky Subtraction**

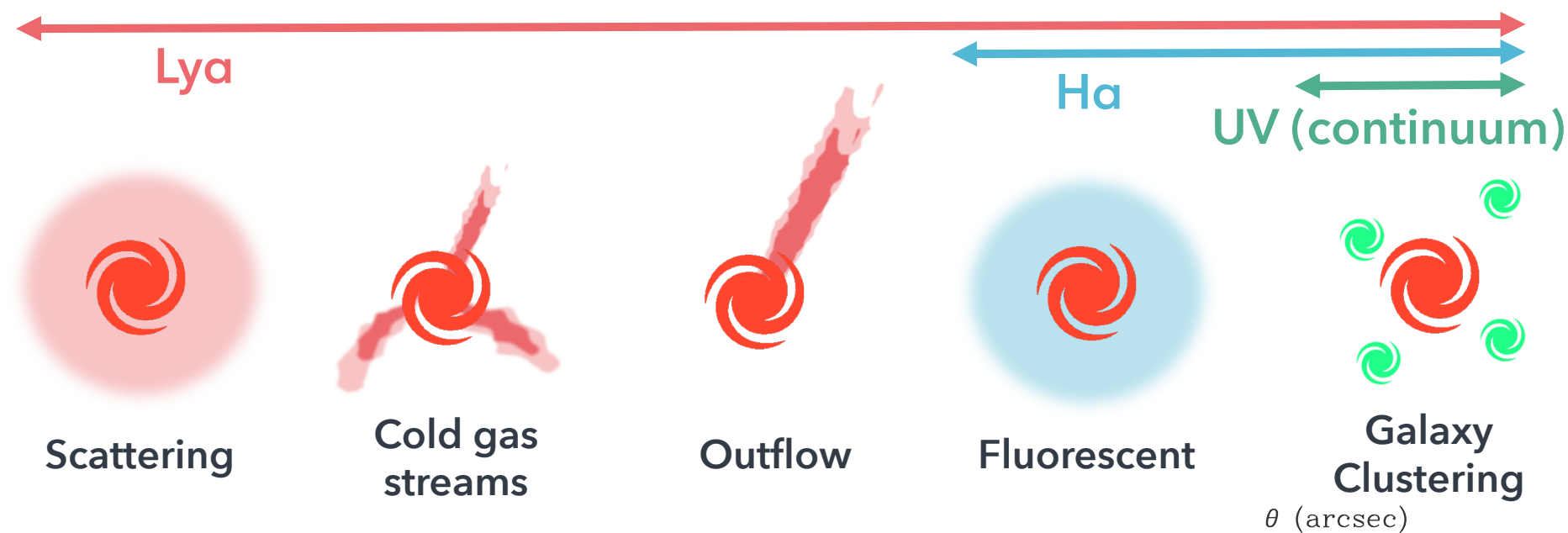
global sky subtraction

```

1 a = mosaickedPostSkyPatternSub
2 bg1 = polynomialBackground(a, order=3)
3 objectMasks = detectObjects(a - bg1) # mask very very large Objects
4
5 bg2 = AkimaSplineBackground(a, mask=objectMasks)
6
7 result = a - bg2 # with very large binSize
8
9
10
    
```

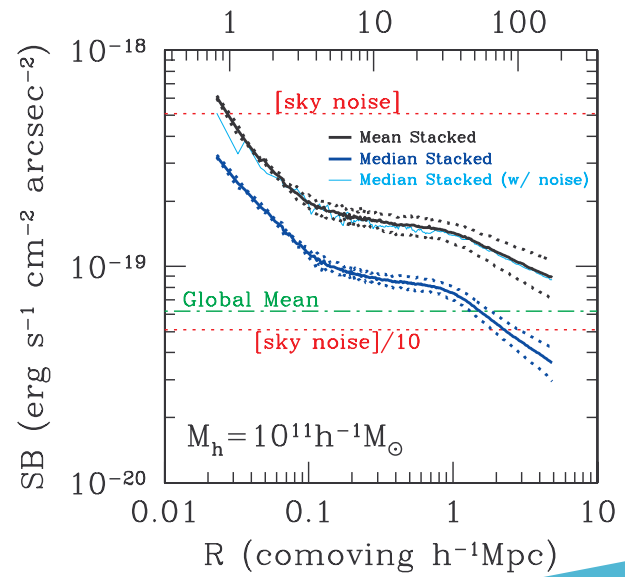
- Large mesh grid size
- Estimate sky level beyond each patches
- ✓ May be better than previous method... (still checking)

# Origin of diffuse Ly $\alpha$ emission



- ❑ Many possibility and Many explanation (observation & simulation)
- ✓ We need multiple information

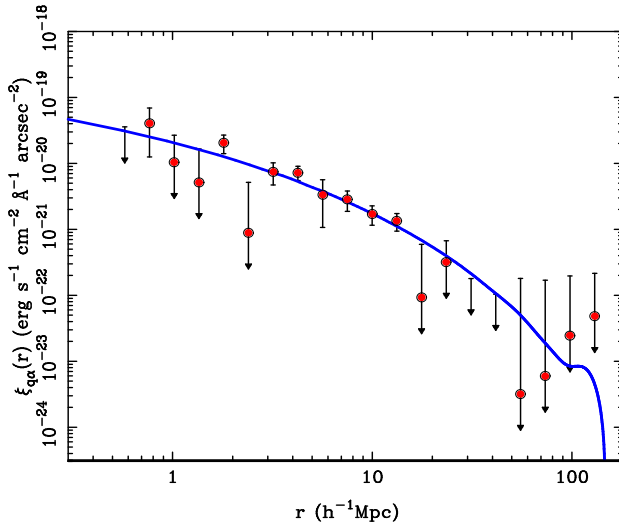
Zheng +11



# Croft et al. 2016

□ Cross-correlation between

**Lya emission (SDSS fiber spectra) × Quasar**



Croft +16

- Extended Ly $\alpha$  emission to  $\sim 15$  cMpc
- Clustering of galaxies

□ Problem

- Very high  $\rho_{\text{SFR}}$  ( $\sim 0.3$  @  $z = 2.5$ )
- Light from other quasars spatially clustered can contaminate nearby galaxy fibers



Revised in Croft et al. 2018

# Croft et al. 2018

- Cross-correlation between **Ly $\alpha$  emission**  $\times$  **Quasar** and **Ly $\alpha$  forest**  $\times$  **Quasar**

- Ly $\alpha$  forest : a tracer of the density field
  - Sensitive to very large scale

$$\xi_{f\alpha}(r) = \frac{1}{\sum_{i=1}^{N(r)} w_{ri}} \sum_{i=1}^{N(r)} w_{ri} \Delta_{\mu} \delta_F \quad \delta_F = \frac{F}{\langle F \rangle} - 1$$

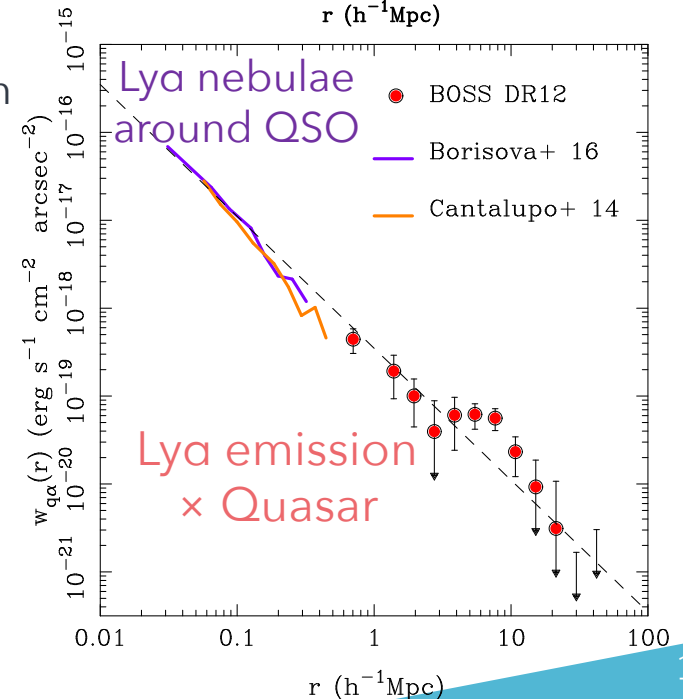
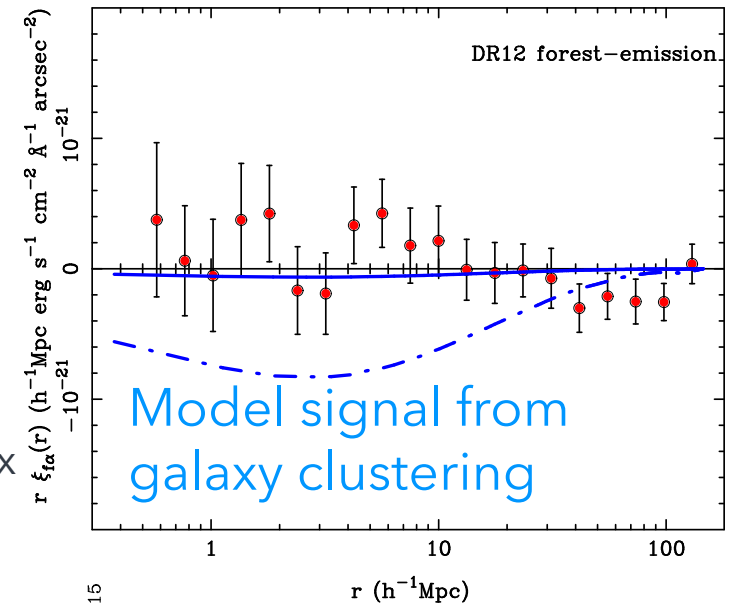
Observed flux
Fitted Continuum

- No detection

- Consistent with extrapolation of quasar nebulae

## Fluorescent emission from Quasar

Croft +18 Ly $\alpha$  forest  $\times$  Quasar



# Future study

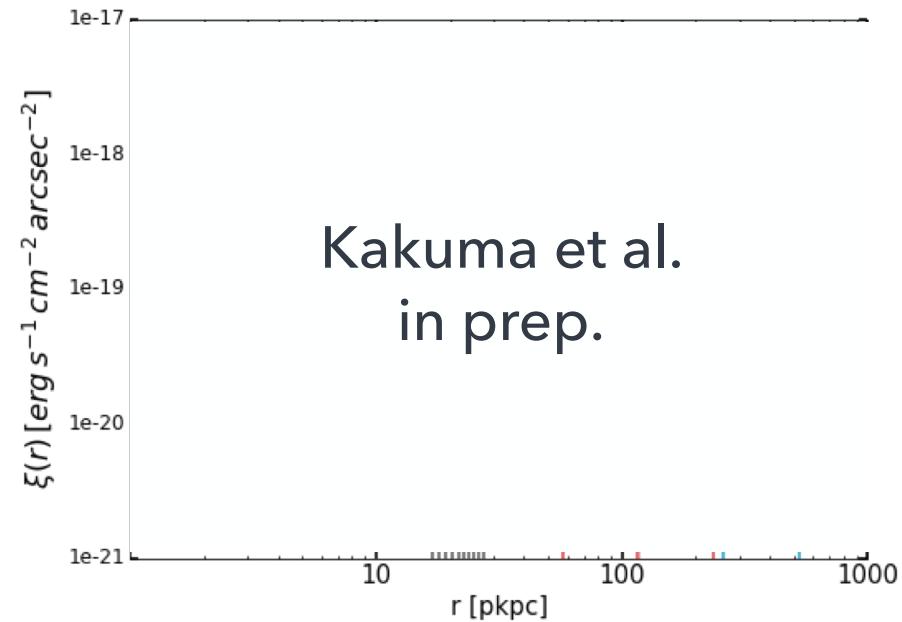
- ❑ We can cross-correlate with **ANYTHING**.
- Absorption line ×  
Quasar, Galaxy, emission (Ly $\alpha$ , metal line), e.t.c.
- ❑ **Synergy between absorption and emission**
- Large scale matter distribution and physical condition
- ◆ Ongoing or upcoming survey
  - HETDEX : 420 deg<sup>2</sup>, 350-550 nm
  - LAEPAU : 100deg<sup>2</sup>, 40NB+5BB,450-850nm
  - J-PAS : 8000 deg<sup>2</sup>, 56 NB
  - SPHEREx : Allsky, spectra, resoluton: 6"
- ◆ Already available data
  - SDSS fiber, Subaru NB, etc.



# Summary

## My study

- NEW sky estimating method
- Still checking now
- Ly $\alpha$  halo may be more extending
- We needs multiple information



## Absorption line studies w/ Cross-correlation Intensity Mapping

- Complementary study to trace a matter density distribution
- Abs. : neutral gas, Emi. : ionized gas (+ neutral gas)
- Many available and upcoming valuable data-set