Kitt Peak

Correlation between galaxy and IGM at z=2.2 based on MAMMOTH overdensities mapped by HSC

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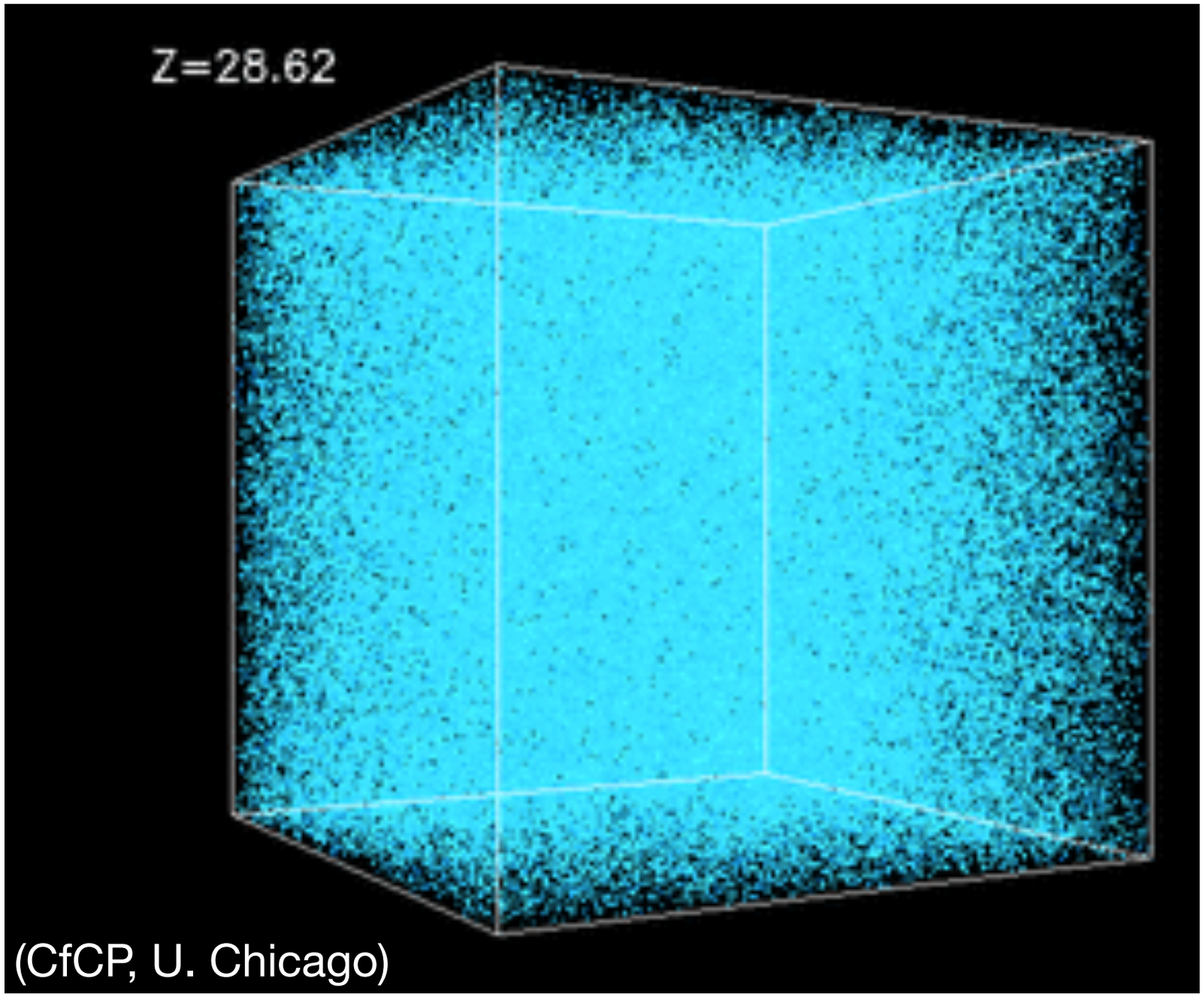
(Galaxy Evolution Workshop@Kavli IPMU, 2019/06/07)

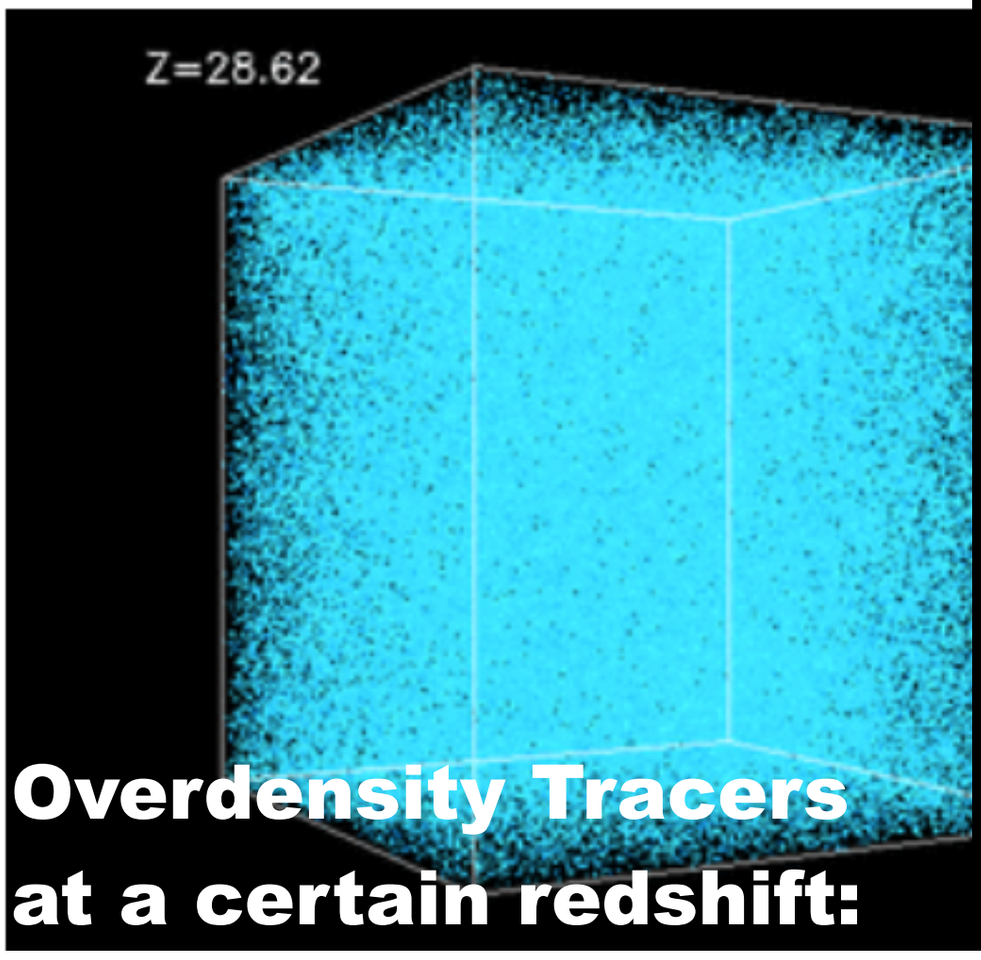
Structure formation & Evolution:

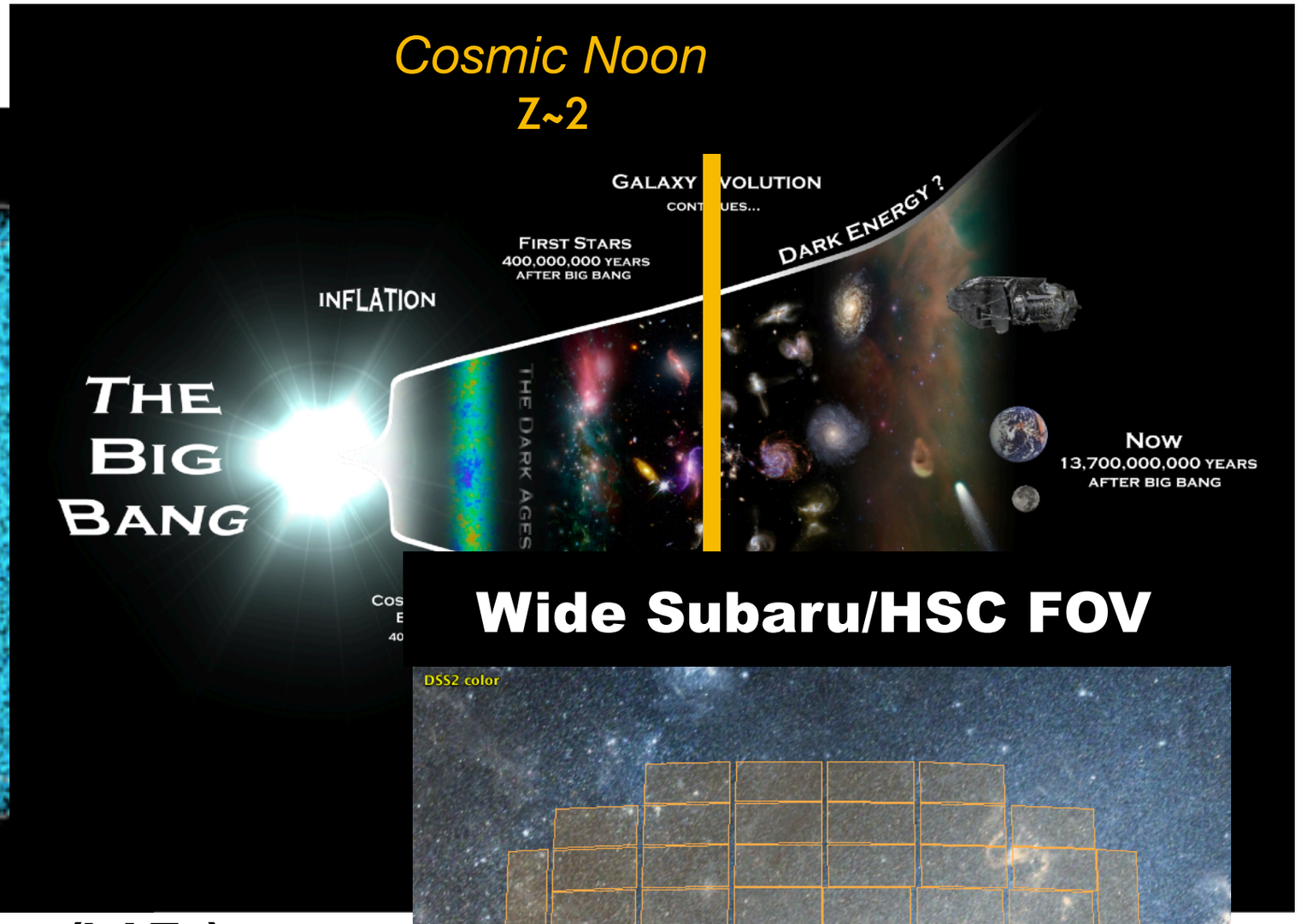
Cases in Galaxy and Gas?



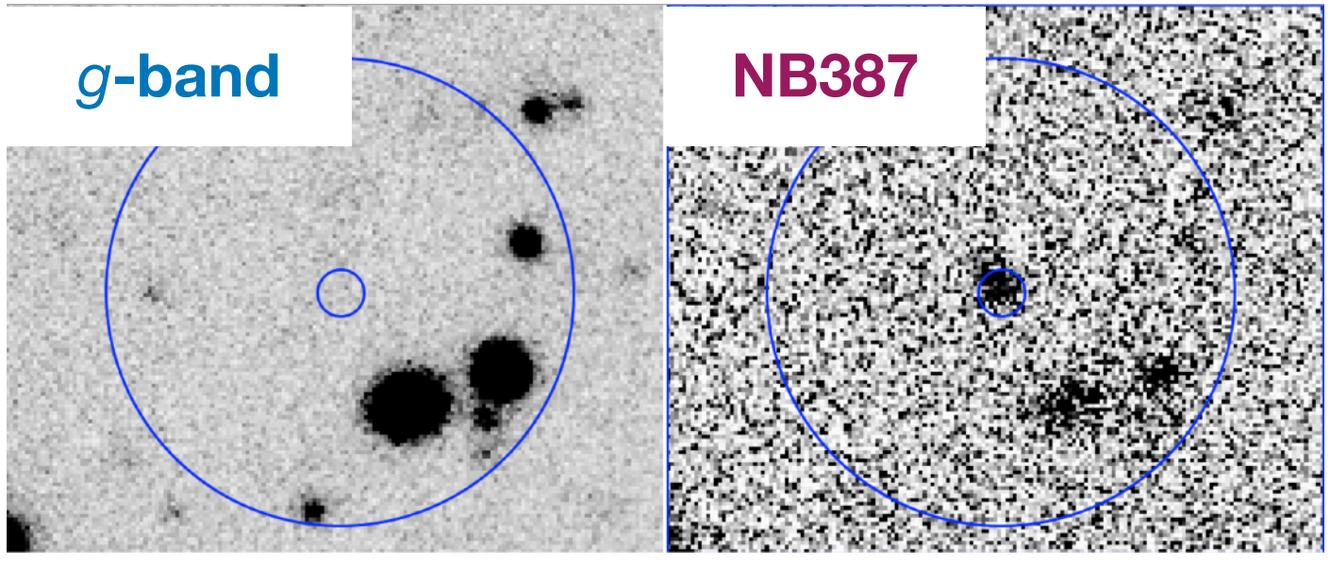
Structure formation & Evolution:

Cases in Galaxy and Gas?





Lyman-Alpha Emitters (LAEs)



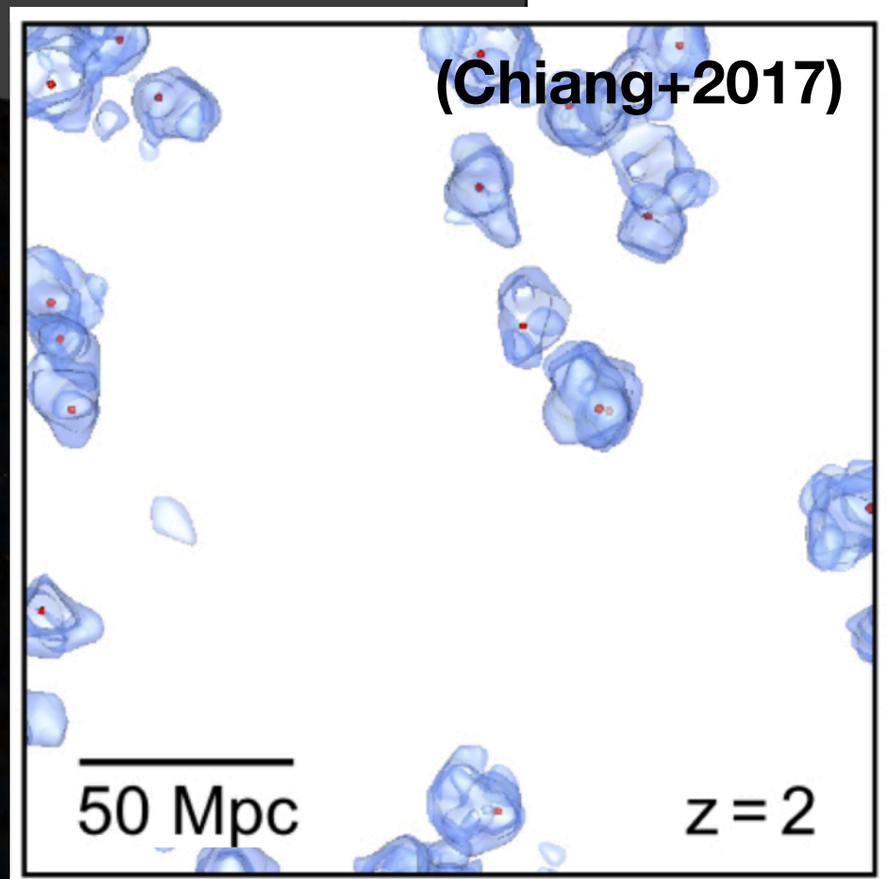
DSS2 color

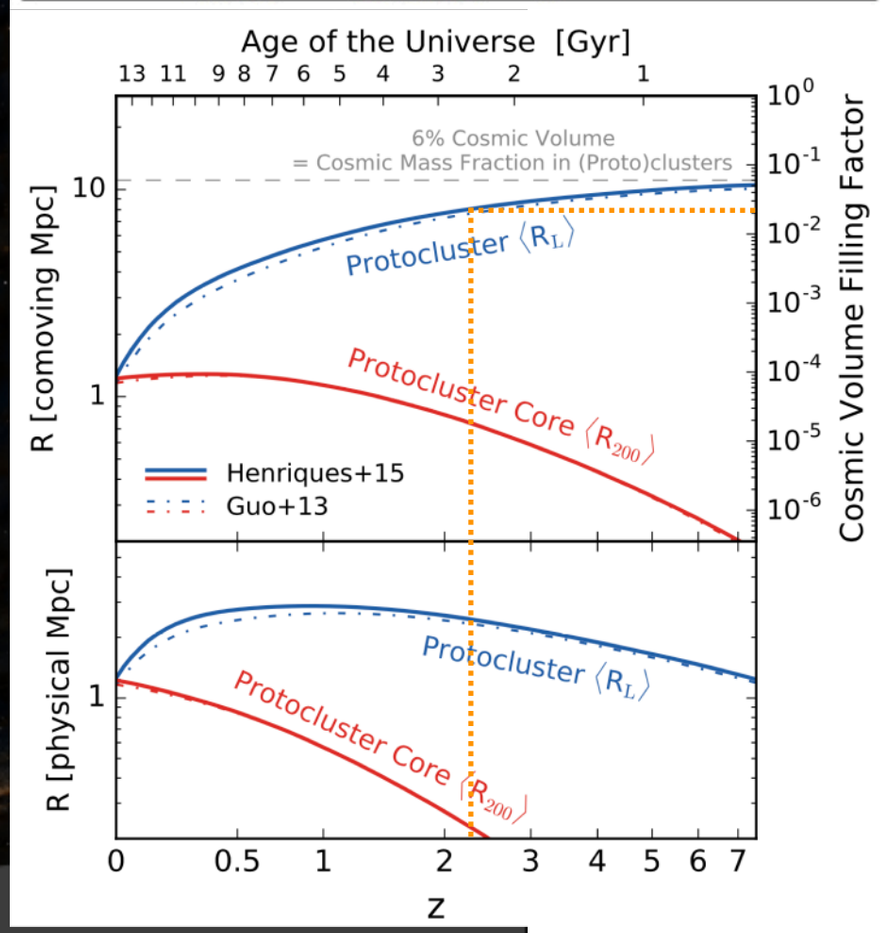
The HSC Field of View (FoV)

Search for Overdensities
=
Look for a pin in the ocean ?

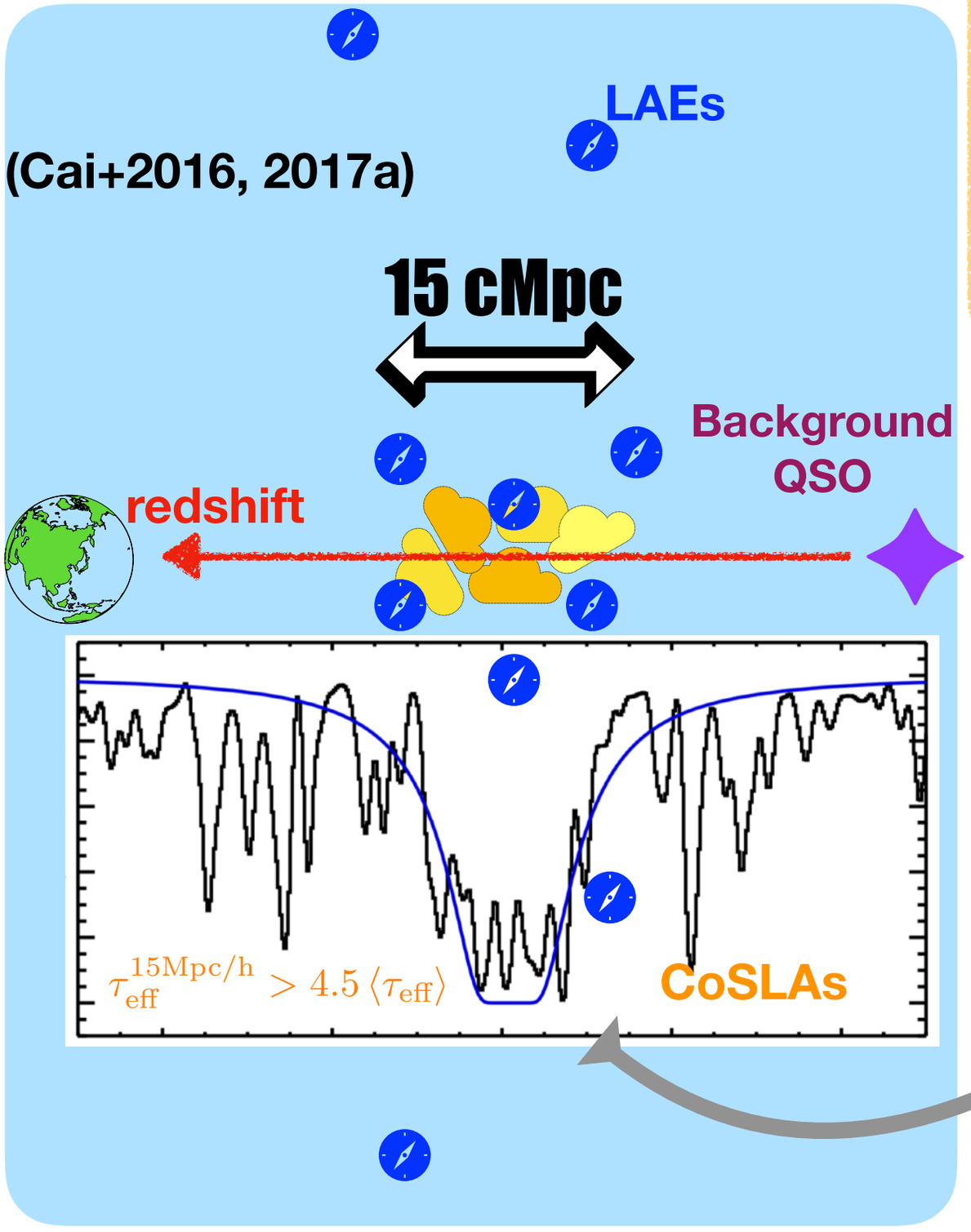
Powered by Aladin

178.6° x 180°



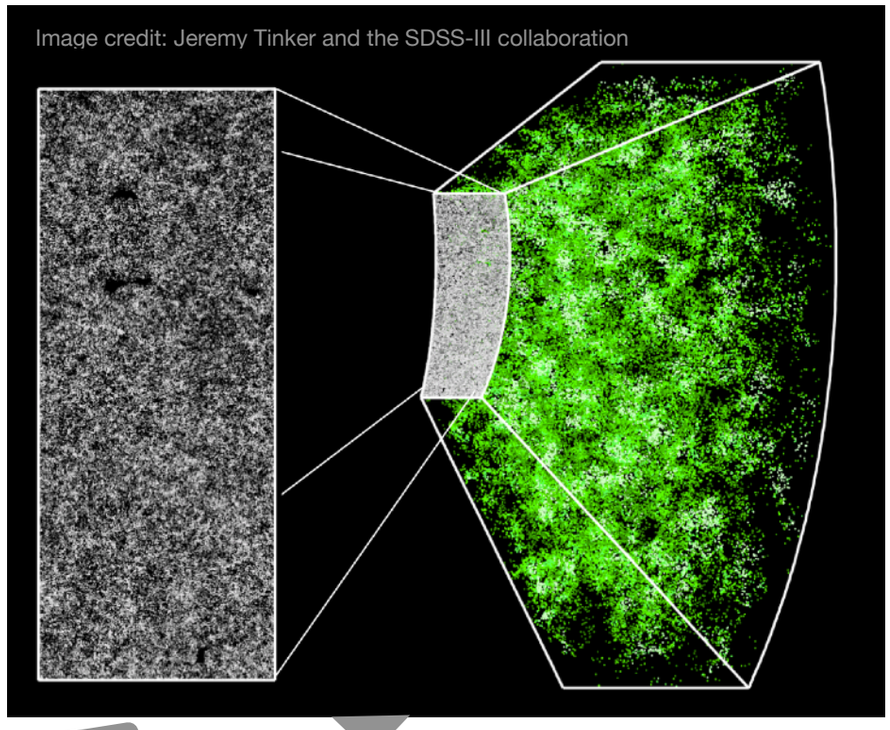


MAMMOTH project:
Basic idea



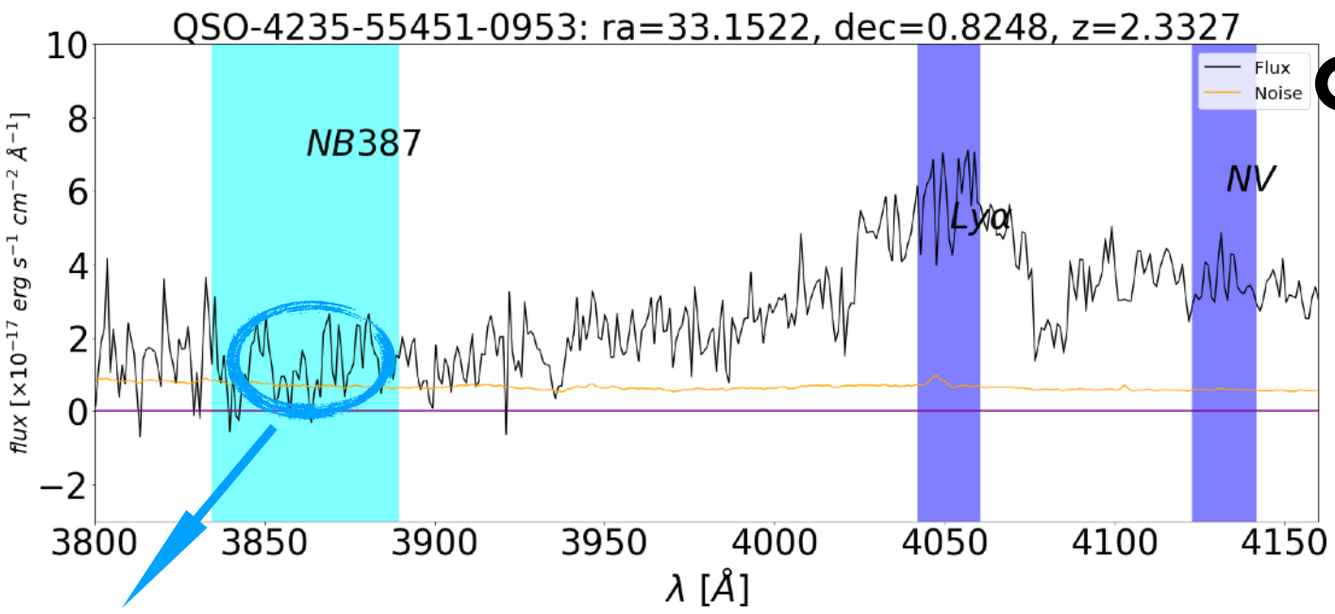
Lya Forest Sample: SDSS-III/BOSS

- **Resolution:**
  ~ 2000 from 3,600 Å - 10,400 Å
- **Volume:**
  160,000 quasars over **10,000 deg²**
  ~1 Gpc³ @z=2
- **Density:**
  ~20 in one HSC FoV at z=2.5



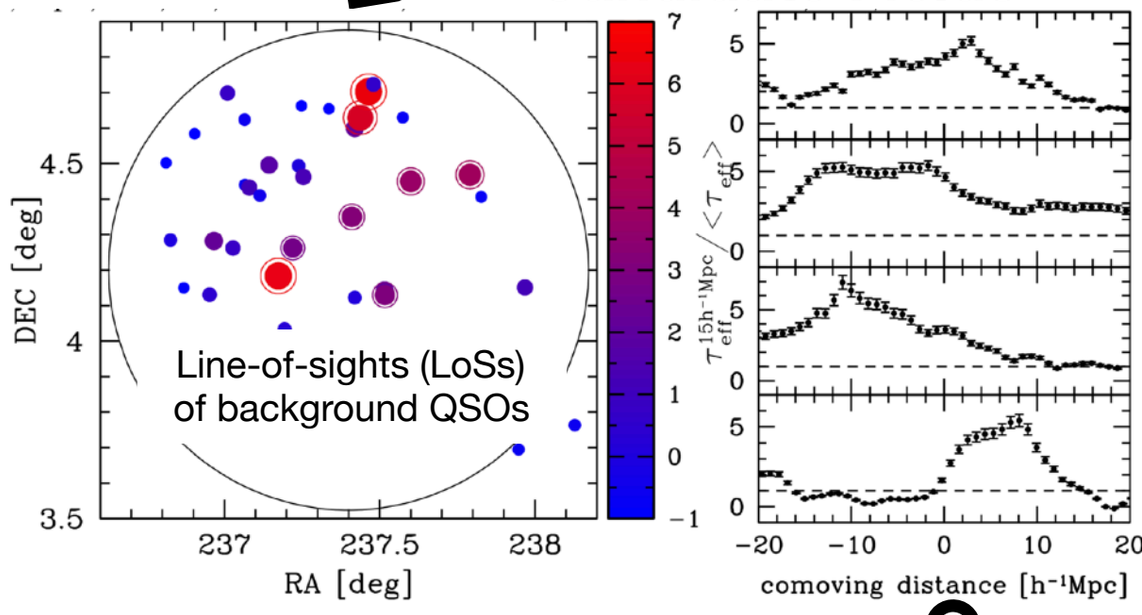
✓ **Candidate fields**

Subaru/HSC observations



Groups of overlapped Lya absorption (CoSLAs)

Candidate Fields



S17B Queue (30%, 2 fields)
S18B Queue (0%)
S19A On-site (2 fields)
...

g-band: 4 shots x 10 min , ~40 min in total

NB387: 12 shots x 15 min, ~3 hrs in total

LAE Selection

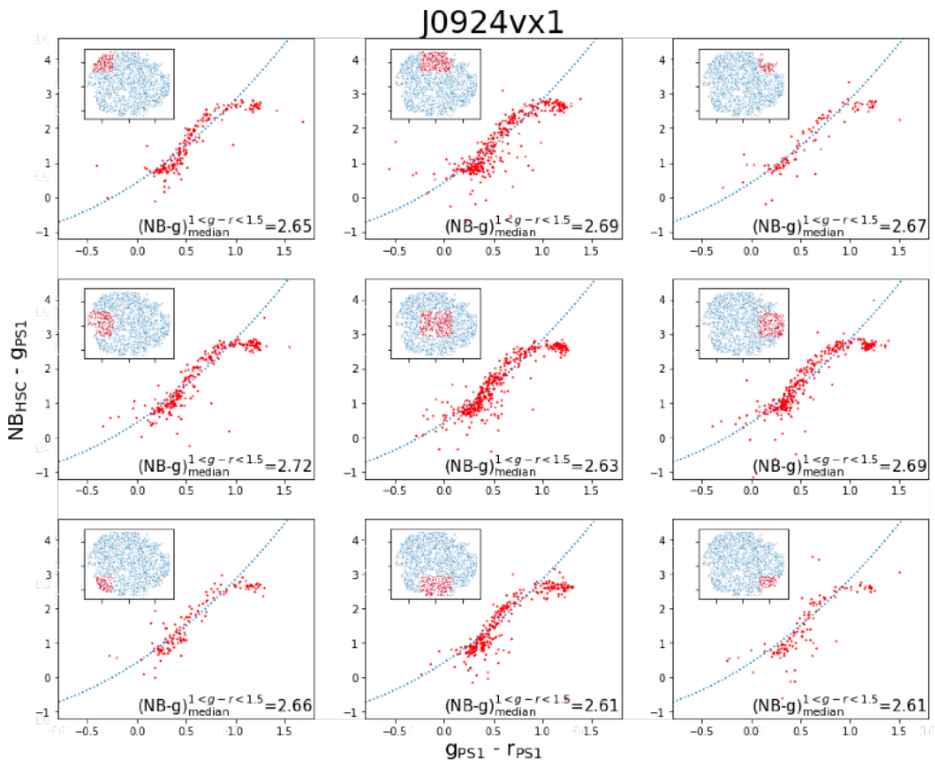
Data processing

1. **Data reduction is mainly performed with HSC Pipeline v5 & v6.**
2. **Photometric catalog is obtained from SExtractor.**

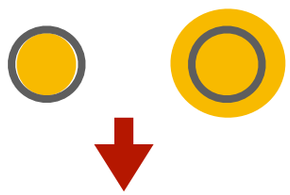
*** Zero-point: Pan-STARS DR1 photometry data**

1. Expected NB_HSC from filter transmission for Pickle Stars w. Spectra
2. NB w/ PS1 g, r for fitting curve: NB-g = A + B x (g-r) + C (g-r) ^{2}

Field	Obs Period	$\mathrm{FWHM}_{PSF,NB}$	$\mathrm{FWMH}_{PSF,g}$	$m_{\mathrm{NB},5\sigma}$	$m_{g,5\sigma}$	Pipeline version
J0210	S17B	1.25”	0.90”	24.8	25.9	v5.4+v6.6
J0222	S17B	0.90”	0.90”	25.5	26.9	v5.4
J0924	S19A	0.84”	0.79”	25.1	26.3	v6.6
J1419	S19A	0.86”	0.70”	25.1	26.4	v6.6



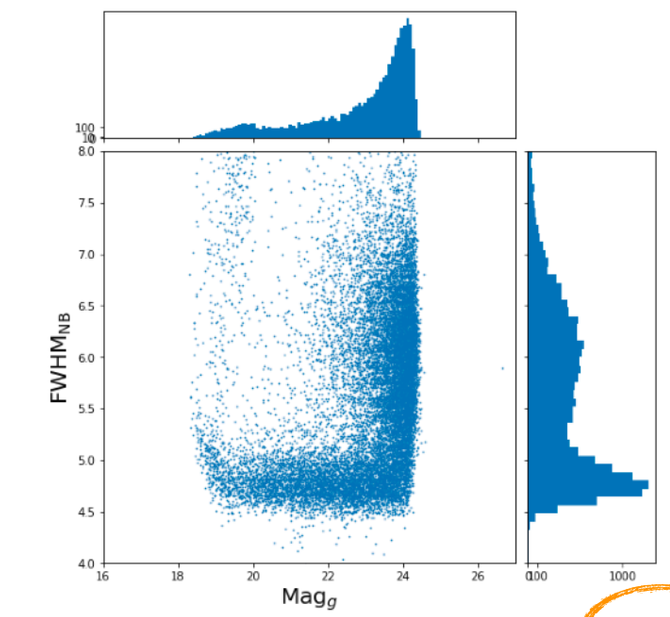
*** PSF matching before the**



May cause systematic color bias

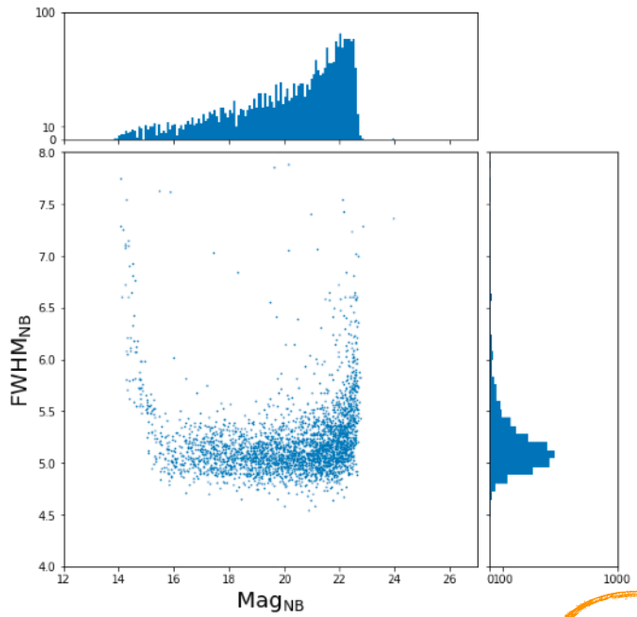
The good quality image (normally HSC-g image) convolves a Gaussian kernel to get smoothed to match that of the other image.

HSC-g



Mode of FWHM of stars(class>0.9) is 4.7 pixel, or 0.785"

NB387



Mode of FWHM of stars(class>0.9) is 5.04 pixel, or 0.842"

Photometric Catalog

SExtractor configutations:

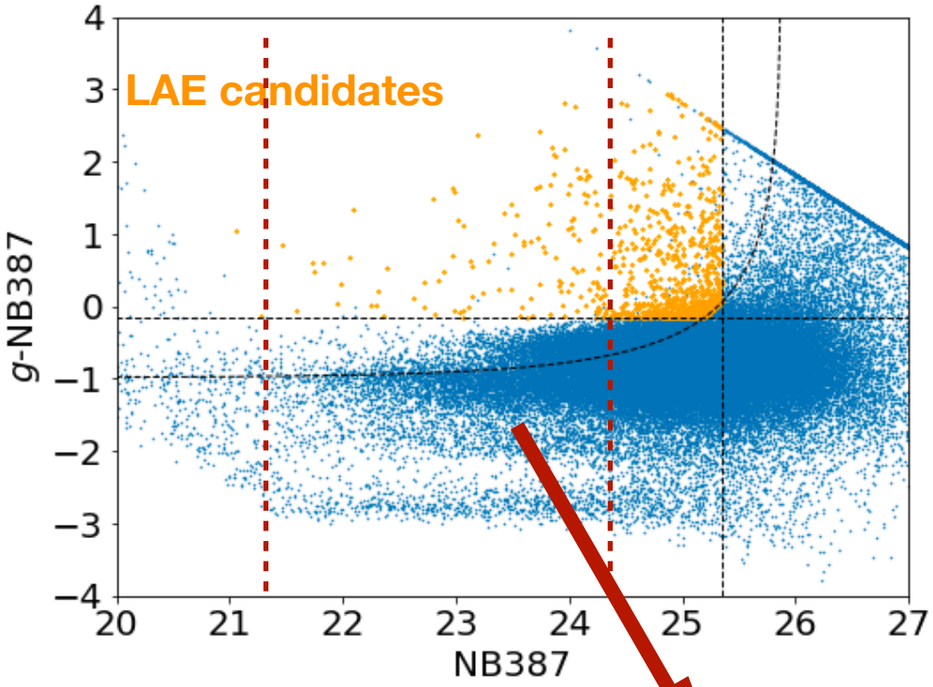
(1) Dual-image mode with NB387 image as detection image.

(2) Background r.m.s. as weight map to minimize the effect from photometric fluctuation.

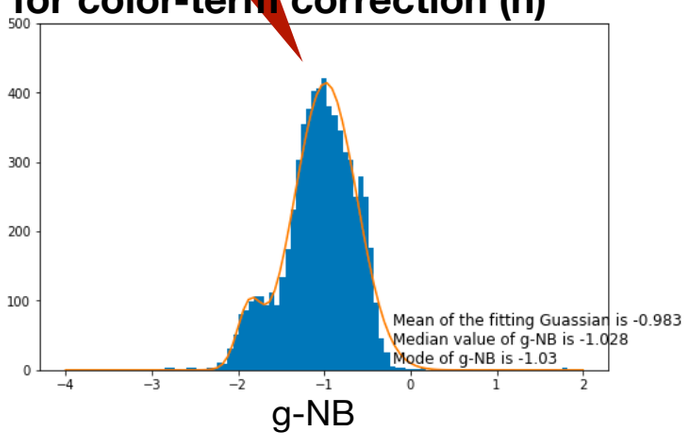
(3) The weight maps also work as flag to exclude masked regions (low S/N, saturations, etc.)

* MAG_APER for color: d=10 pix (1.7”) except for J0210 with d=15 pix (2.5”)

LAE selection



for color-term correction (h)



Selection criteria:

$$\begin{cases} g - \mathrm{NB387} > 0.83 + h \Leftrightarrow EW_0 > 20\mathring{A}, \\ \mathrm{NB387} < m_{\mathrm{NB}.5\sigma} \\ g - \mathrm{NB387} > 3\sigma_{\mathrm{color}} + h \end{cases}$$

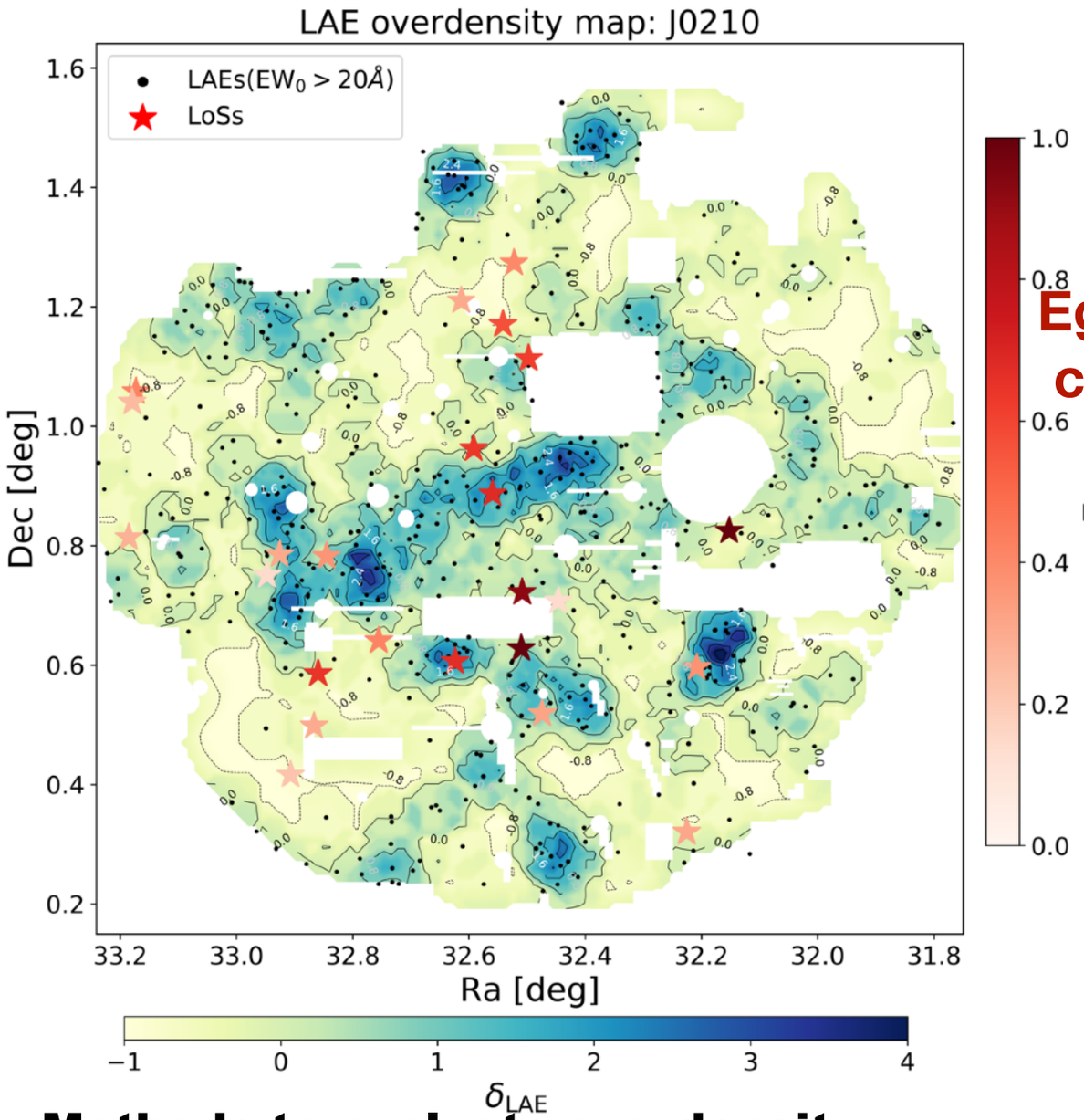
LAE candidate sample summary

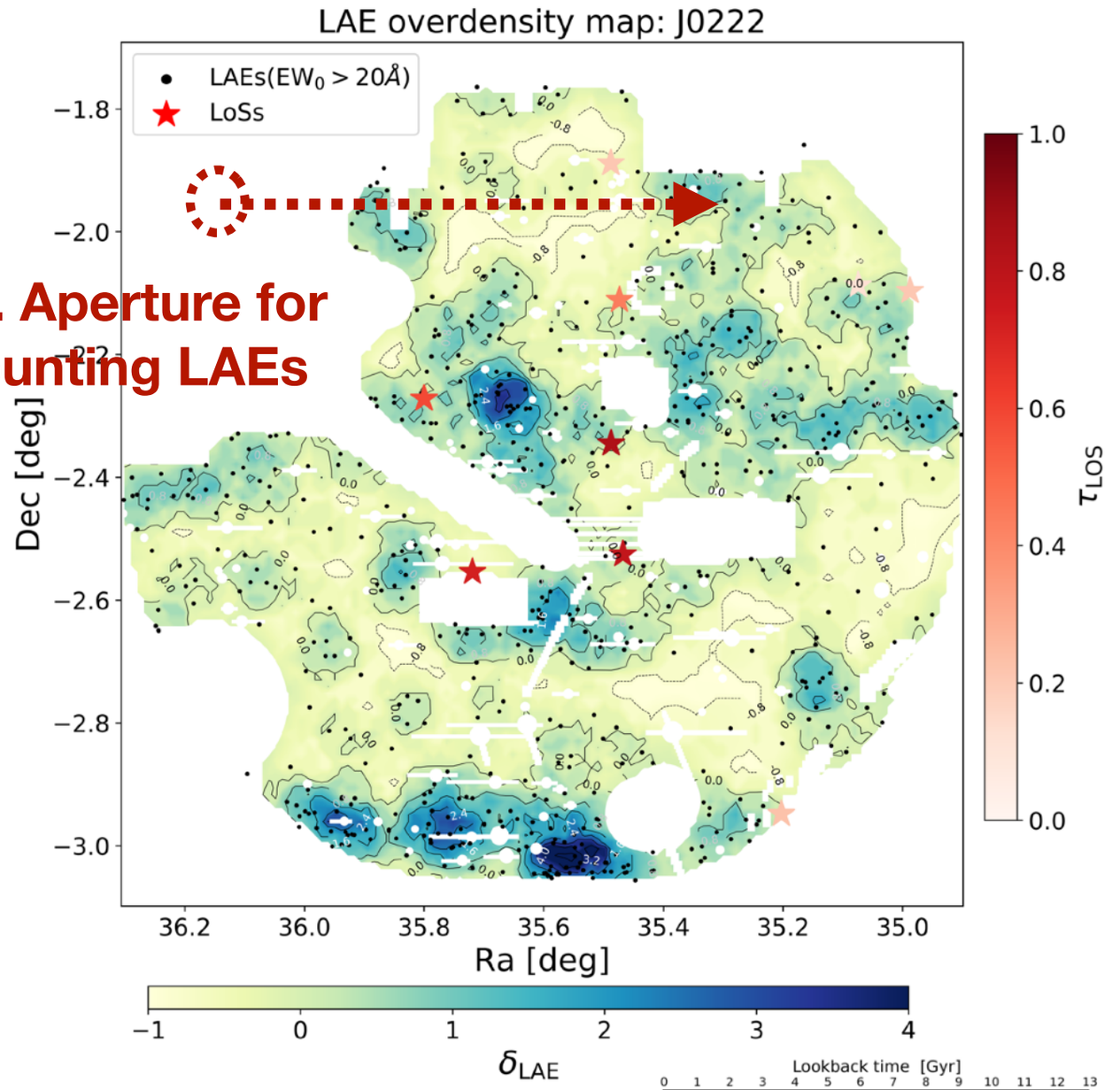
Field	Obs Period	N_{LAE}	A_{eff} / deg^2
J0210	S17B	481	1.34
J0222	S17B	619	1.13
J0924	S19A	747	1.47
J1419	S19A	724	1.45
Total	\	2571	5.39

(Catalog version: 201905c)

Latest Results

1. Revised Overdensity Map: J0210, J0222 (Overdensity: $\delta = \frac{N_i}{\overline{N}} - 1$)





Methods to evaluate overdensity:

1). Fixed aperture (Toshikawa+2016) √

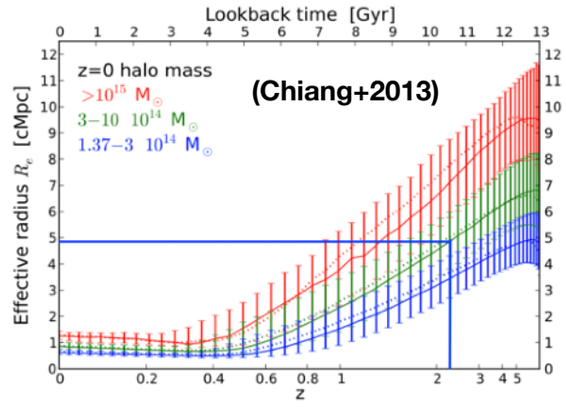
2). Nearest neighbor distance (Cooper+2005):

- 5th nearest neighbor distance $\Sigma_{5\mathrm{th}} = \frac{5}{\pi r_{5\mathrm{th}}^2}$

3). Gaussian kernel smoothing (Shi+2019)

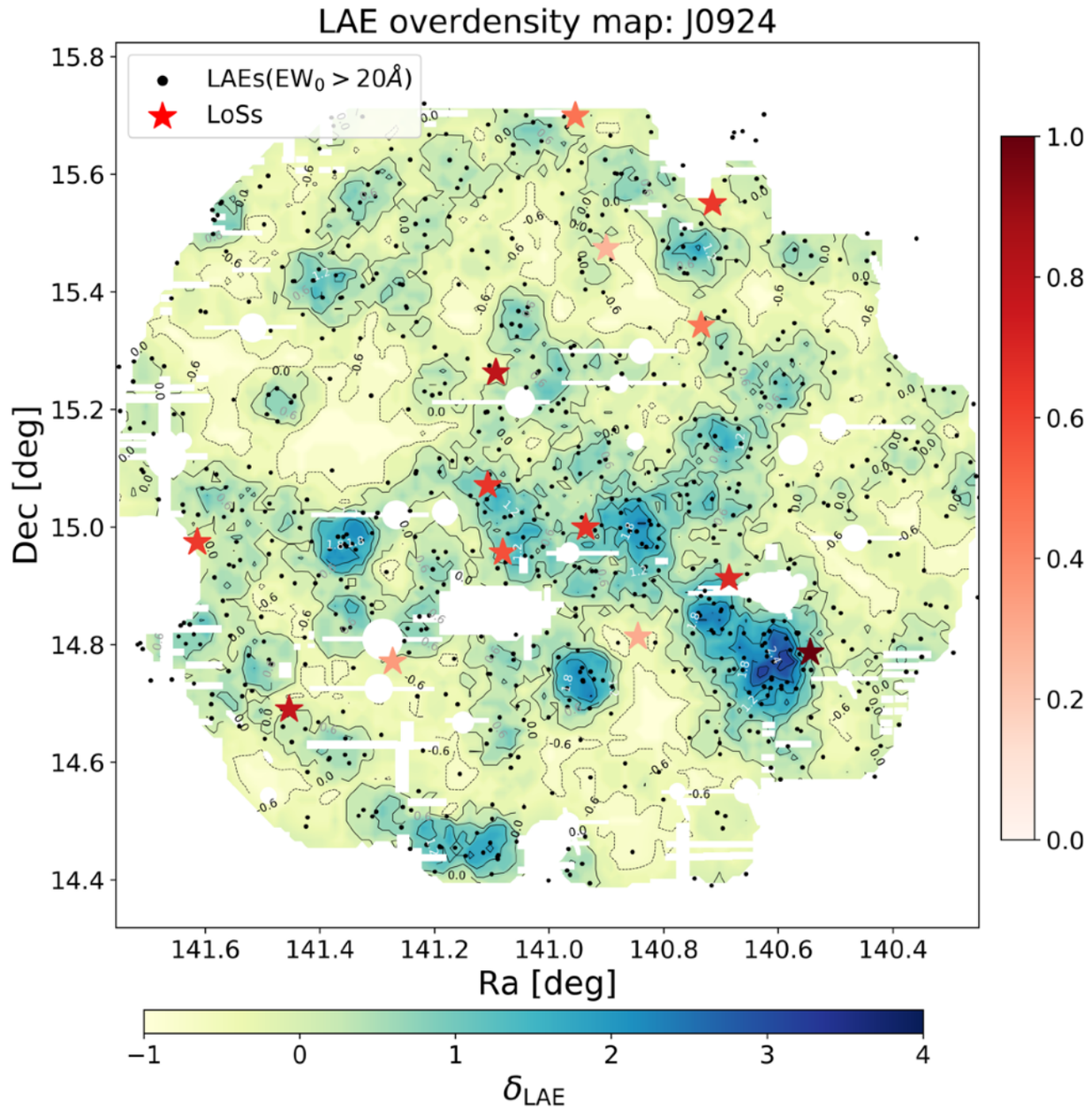
Aperture size: 5 cMpc

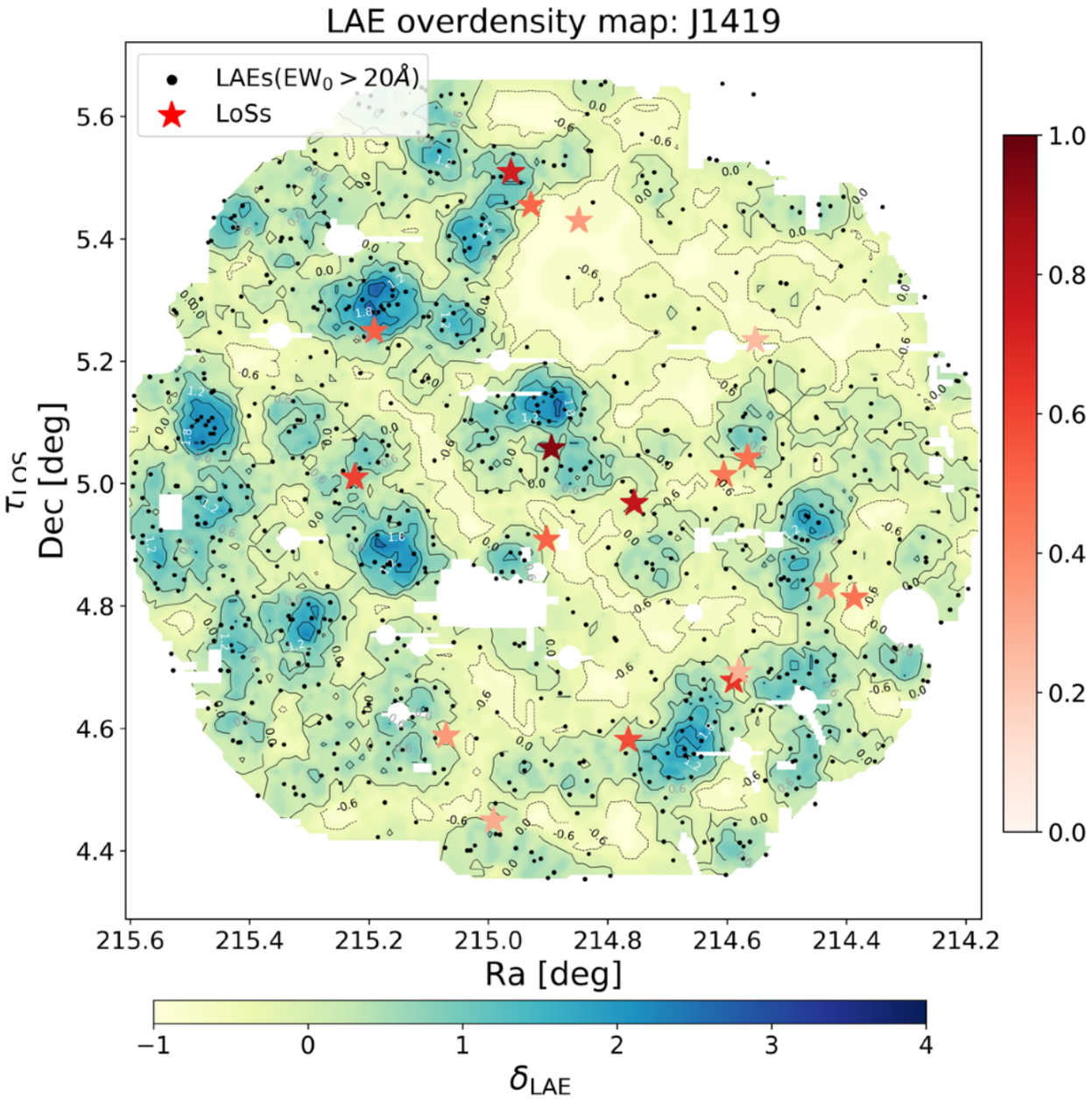
- The typical size for proto-cluster@z~2.2



Latest Results

1. Overdensity Map: J0924, J1419



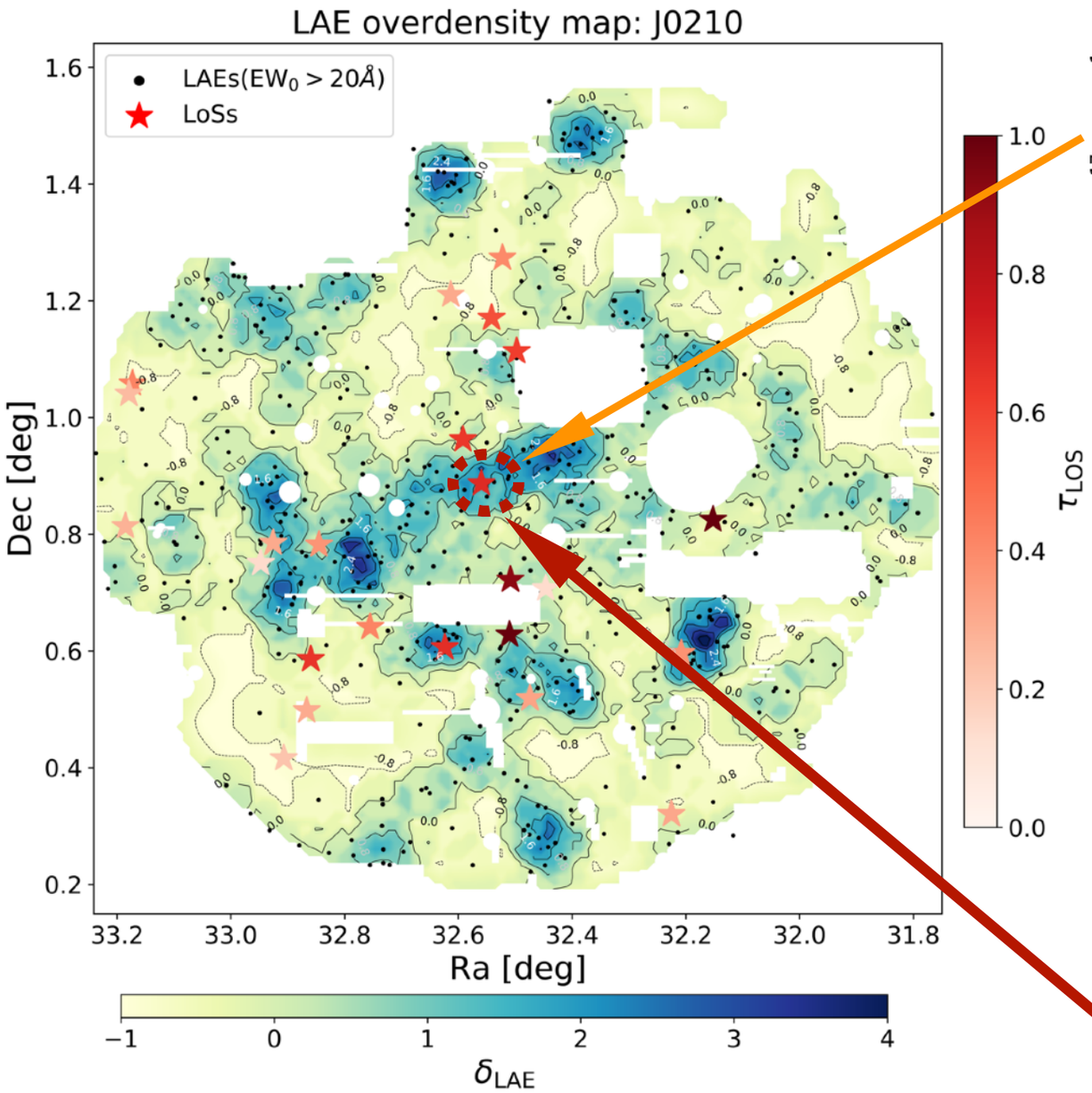


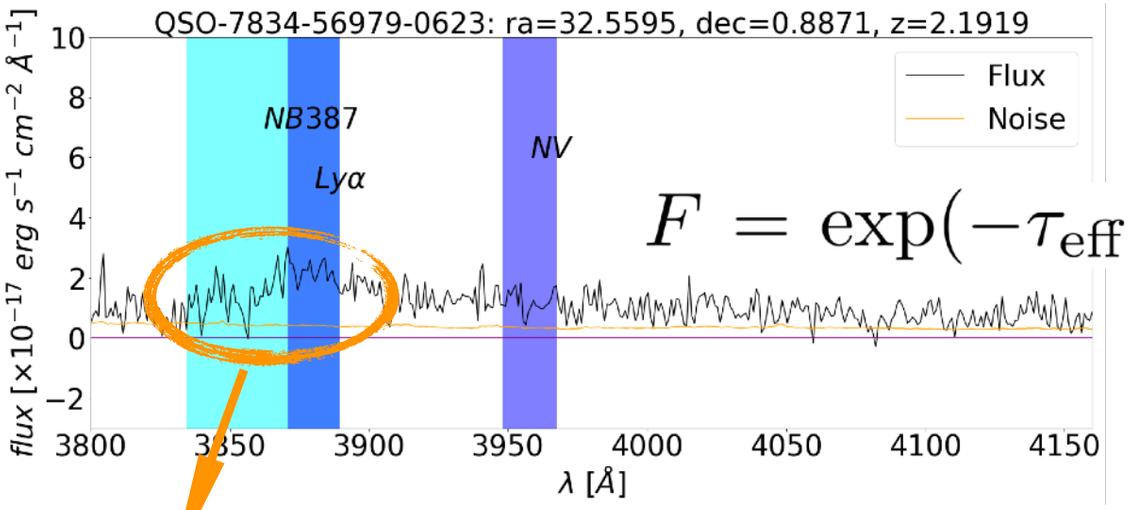
***Notes for the maps:**

1. Considering the large HSC FoV, the mean number density are calculated from each field respectively, with apertures masked over 10% discarded.
2. For J0222, J0924, J1419, the mean number of LAEs in one aperture is all 4.0, while this number is 2.9.
3. Typically, e.g. for J0924, overdensity of 1.8 (2.4) corresponds to significance of 3.5 (5.7) sigma.

Latest Results

2. OD^2 relation (Optical Depth vs. Over-Density)





$$F = \exp(-\tau_{\rm eff})$$

Calculate the $\tau_{\rm eff}^{\rm 15Mpc/h}$ at the corresponding redshift range from (e)BOSS spectra

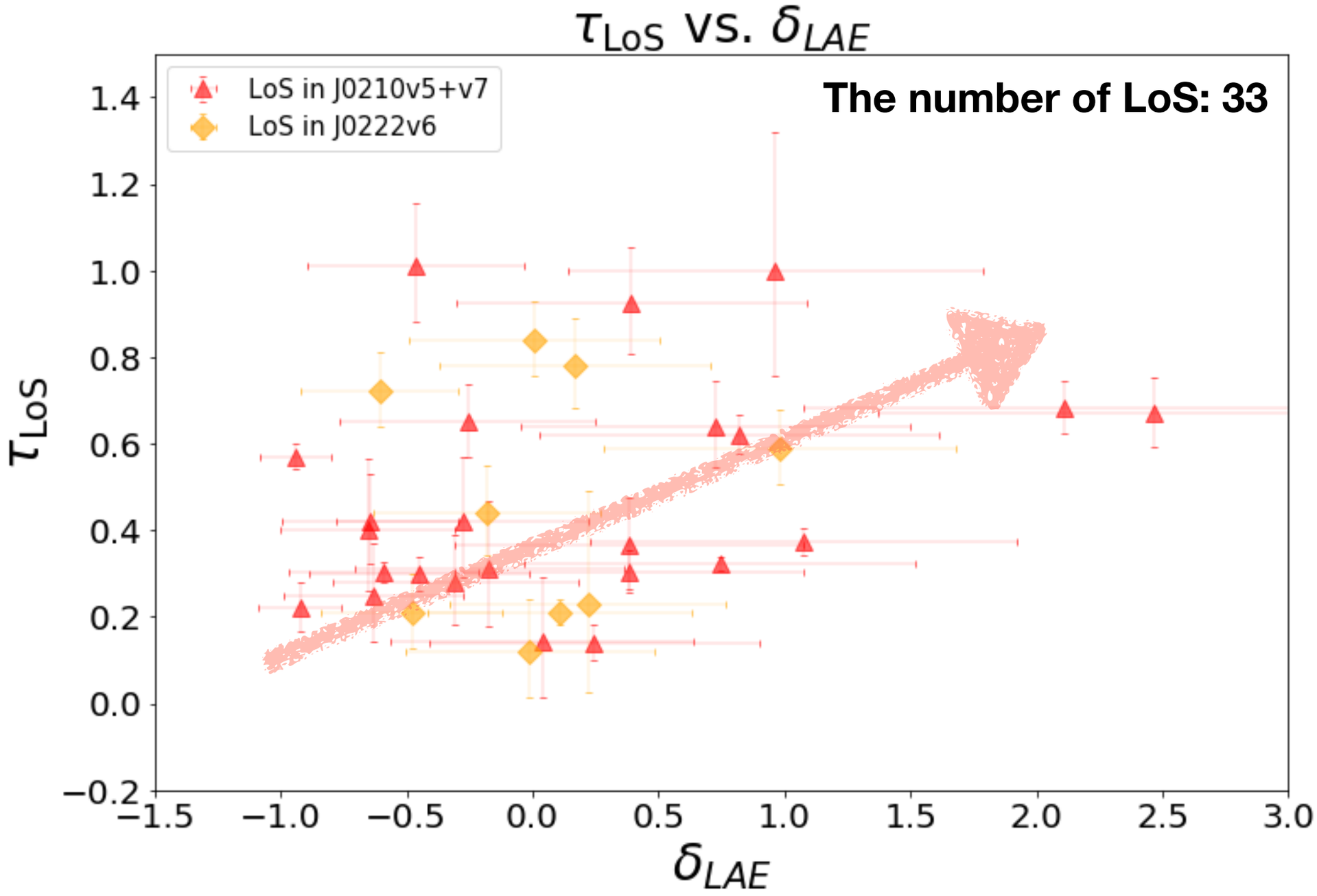
make comparison

Calculate the $\delta_{\rm LAE}$ at the corresponding position from our HSC LAEs catalog.

*** BALs and Strong DLAs are carefully checked and excluded.**

Latest Results

2. OD^2 relation (Optical Depth vs. Over-Density)

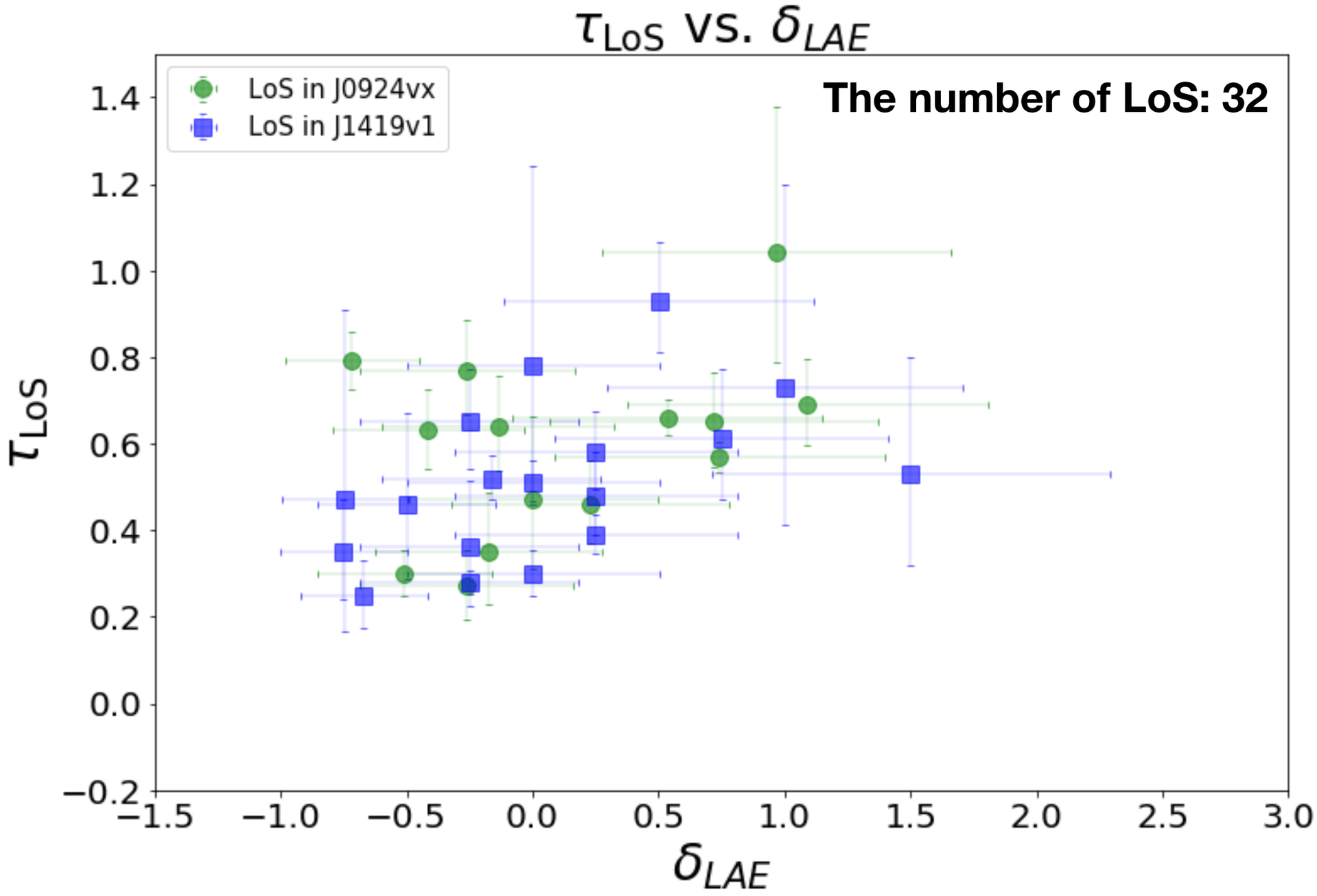


Previous 2 fields obtained from S17B

A tentative positive correlation ?

Latest Results

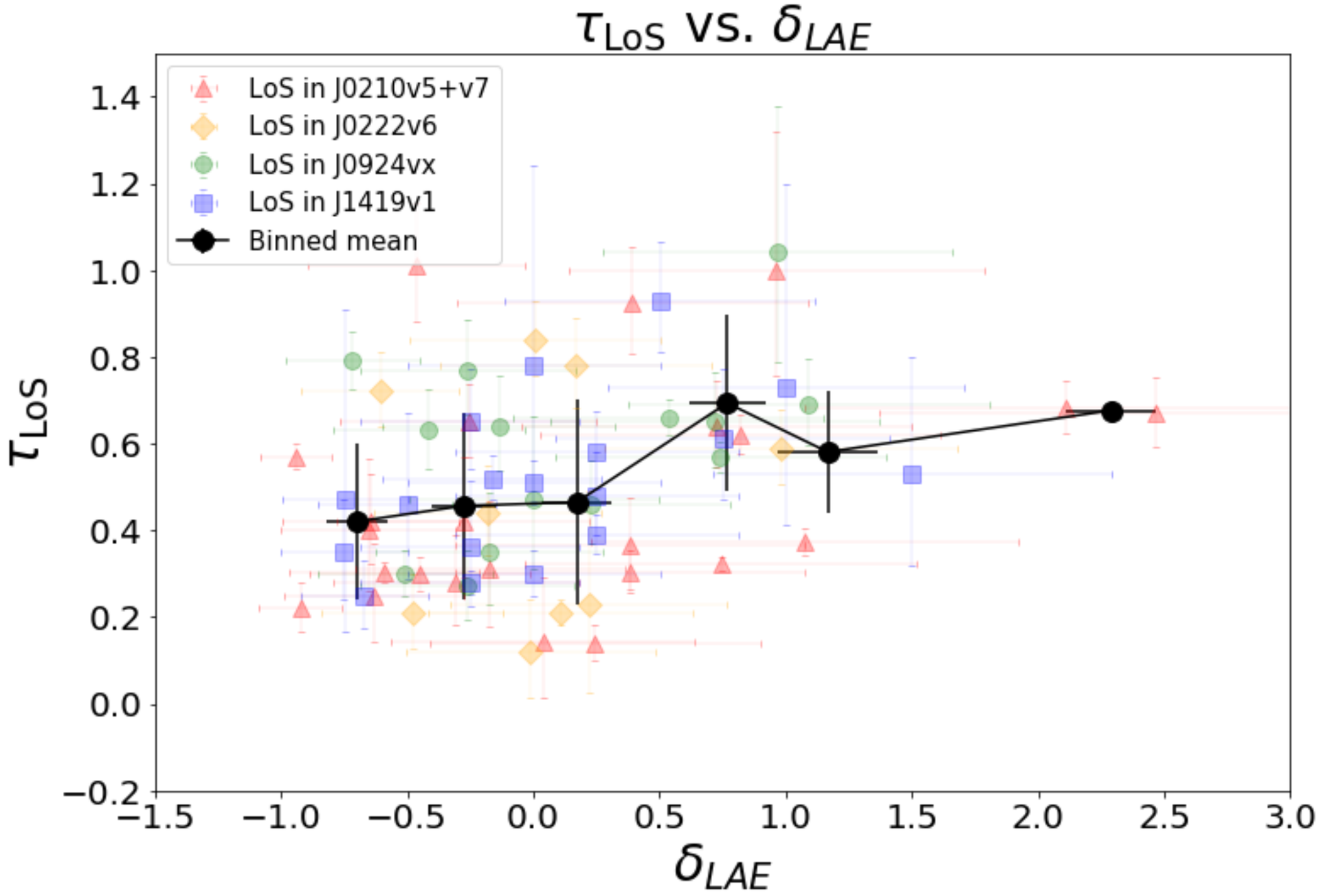
2. OD^2 relation (Optical Depth vs. Over-Density)



Latest 2 fields obtained from S19A

Latest Results

2. OD^2 relation (Optical Depth vs. Over-Density)



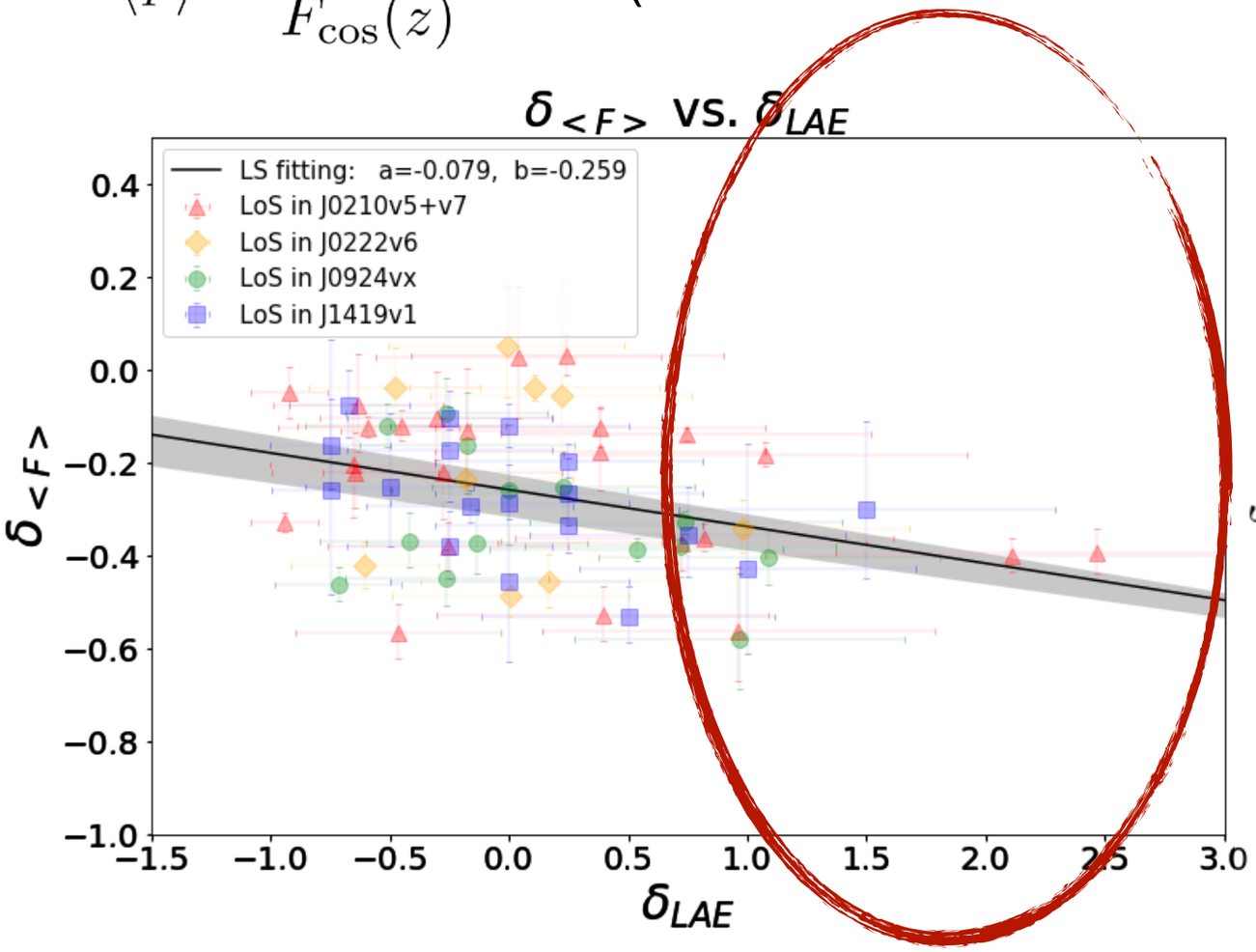
Total sample size: 33 -> 65

From the Spearman Test: Correlation: $\rho = 0.35$ with P-value $= 0.4\%$

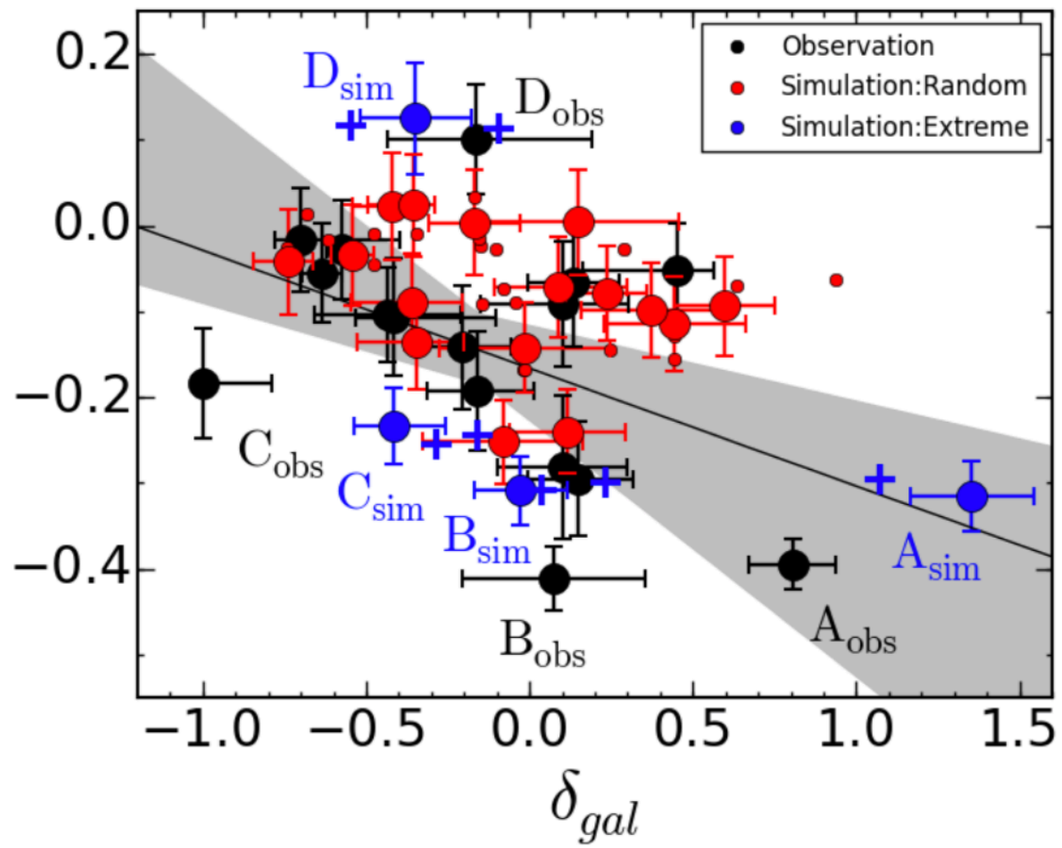
Latest Results

2. TF-OD relation (Optical Depth translated into Transmission Fluctuation)

$$\delta_{\langle F\rangle} \equiv \frac{\langle F\rangle_{dz}}{F_{\cos}(z)} - 1$$ (Note: Tracer & Scale are somehow different)



(Mukae+2016)



- **LAEs@z=2.2**
- **dz=0.04 (~20pMpc)**
- **4 MAMMOTH fields covering 5.39 deg²**

$$\delta_{\langle F\rangle} = -0.26^{+0.03}_{-0.06} - 0.079^{+0.007}_{-0.006} \times \delta_{\rm gal}$$

- **Photo-z galaxies@z=2-3**
- **dz=25pMpc**
- **COSMOS/Ultra VISTA covering 1.62 deg²**

$$\delta_{\langle F\rangle} = -0.17^{+0.06}_{-0.06} - 0.14^{+0.06}_{-0.16} \times \delta_{\rm gal}$$

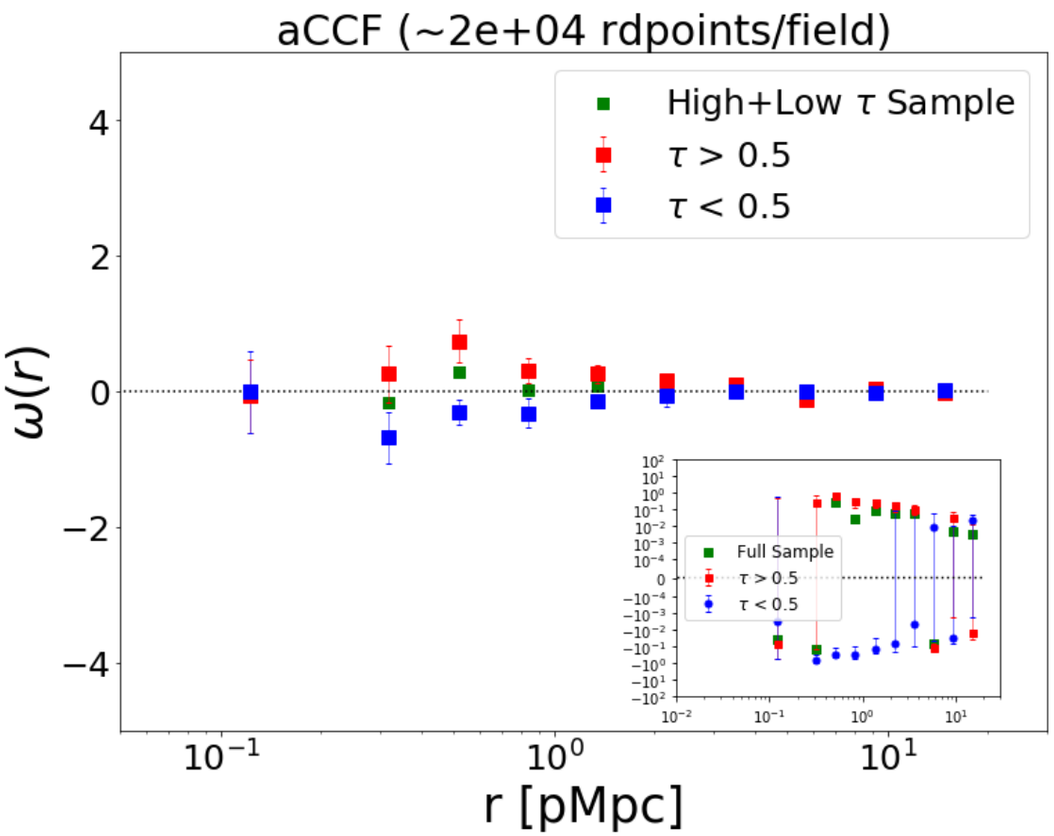
3. Cross-Correlation function (Relative)

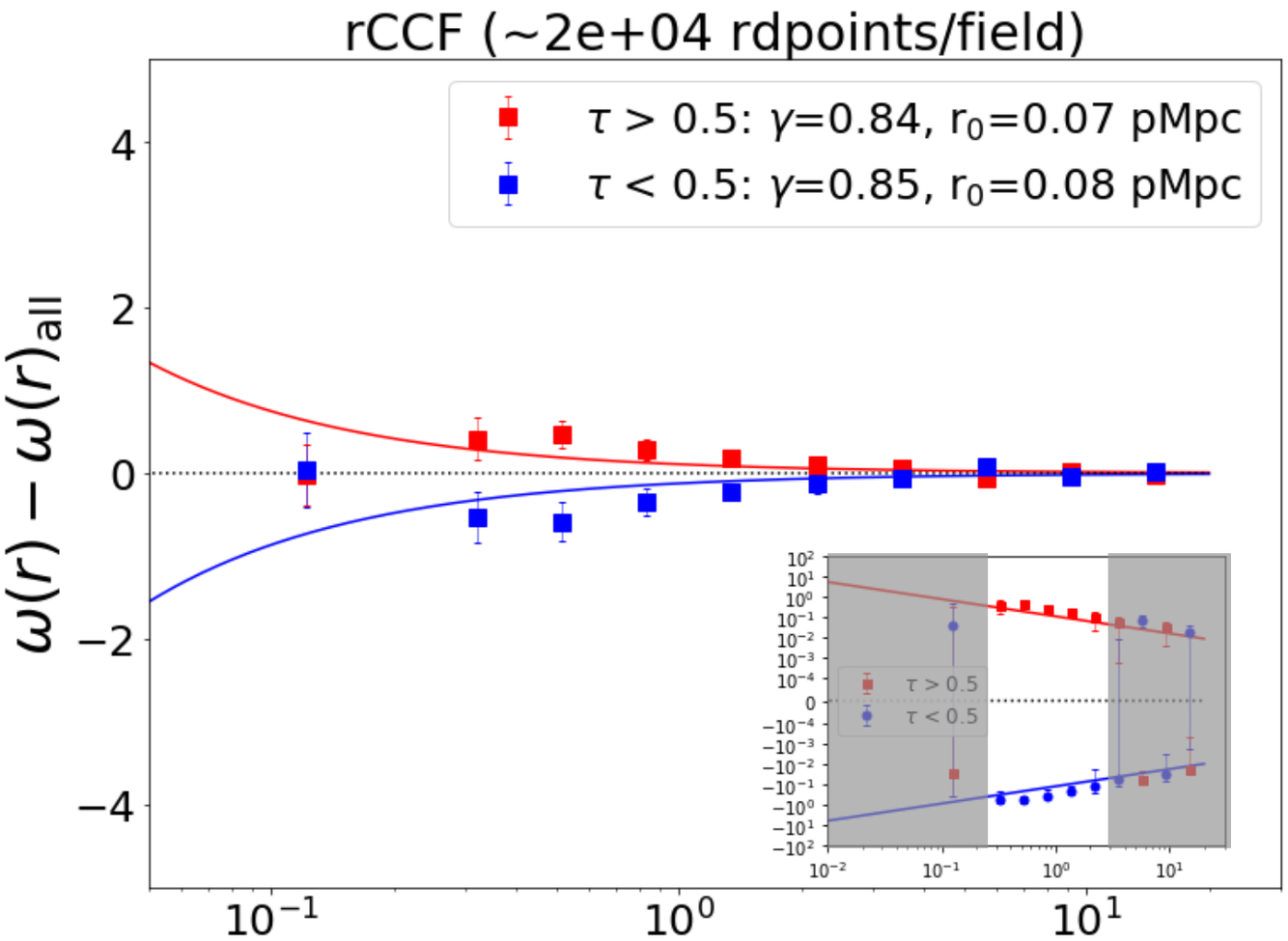
Estimator:

$$\widehat{\xi}_{\mathrm{LS}} = \frac{DD - 2DR + RR}{RR}$$

(Landy & Szalay,1993)

Errors are estimated from Jackknife resampling,
which could take the field variance also into account





LoS location itself has no meaning

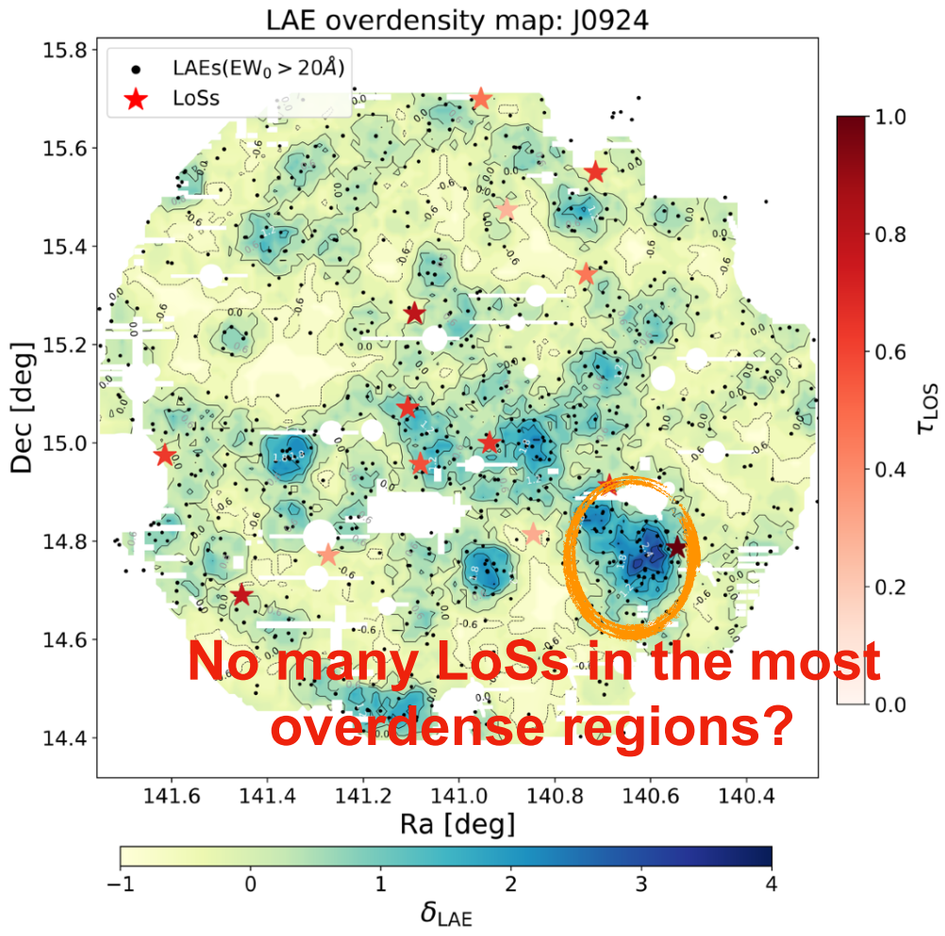
- **But a small sample size may involve the LoS 'correlation' signal?**

 # From the graph:

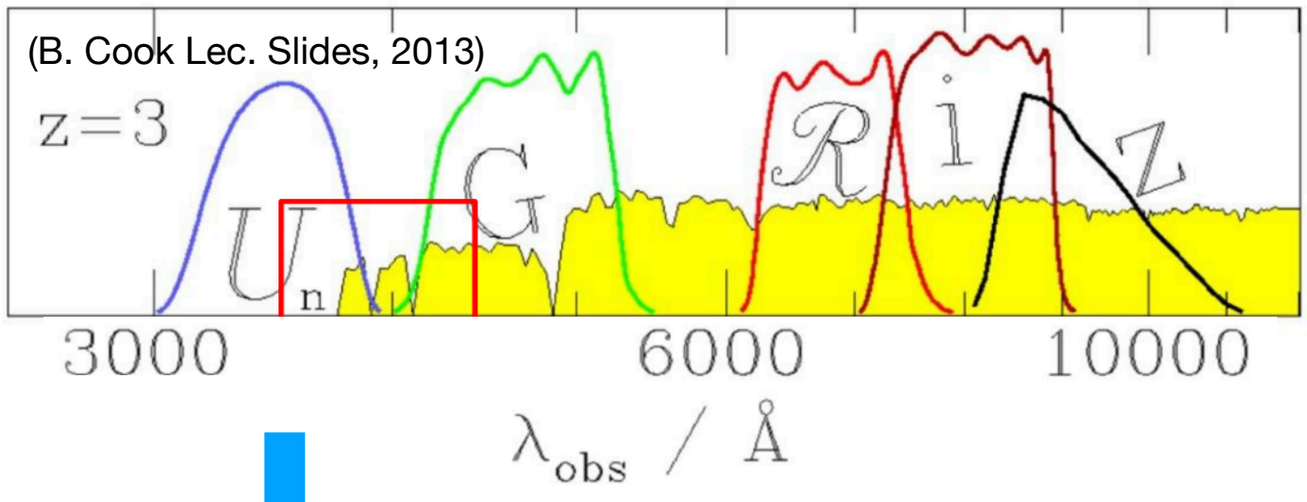
1) A statistically significant signal detected at a scale of 0.2 - 3 pMpc (@z=2.2):
   a. High optical depth LoSs (HI-rich) correlate with galaxies.
   b. Low optical depth LoSs (HI-poor) anti-relate with galaxies.

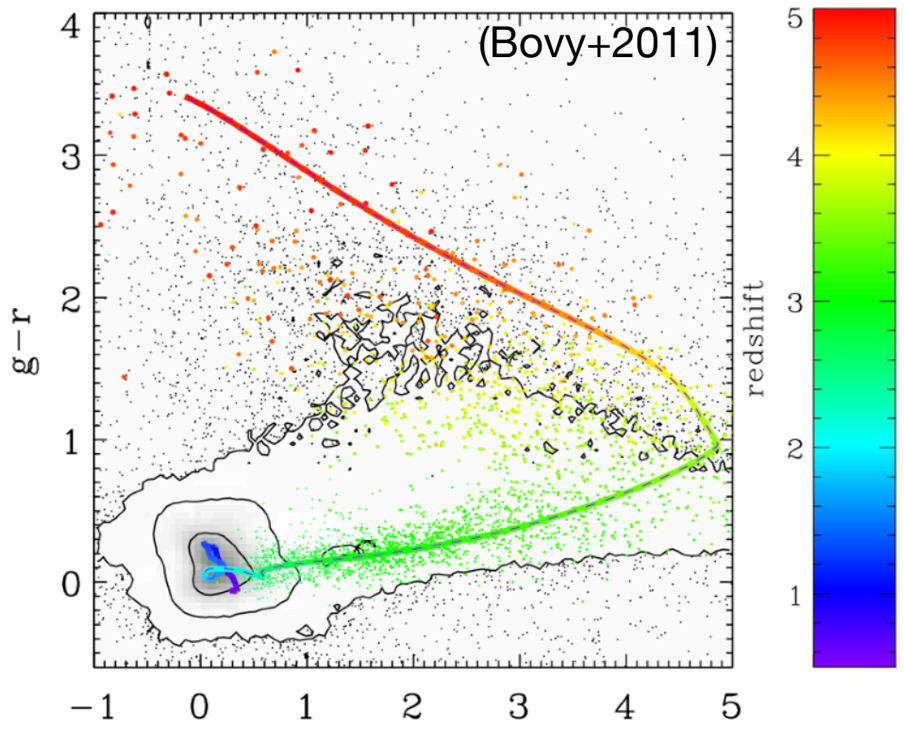
2) If there is any meaning for the power law fitting parameters here, the characteristic scale will be more than 1-order of magnitude smaller than normal halo CCF?

* UA 2-m Bok observation for fainter background candidates



u-drop sources (Background candidates at z~3)





20% random sampling with z>2.5 SDSS DR7 quasars

Surveys offering deep *g*-band (g<24), *r*-band(r<23.4):

- SCUSS, BASS (Zou +2017)

Deep *u*-band imaging obs using 2-m Bok

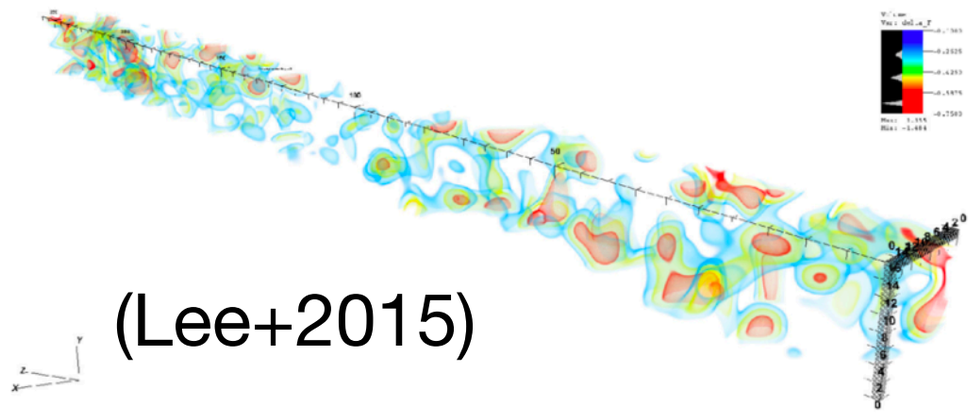
Multi-object spectroscopical obs on MMT/Binospec in the future

Summary

- **Deep NB387 imaging with Subaru/HSC to pick out LAEs in the candidate fields with massive overdensity traced by groups of strong Lya absorption (CoSLAs) in MAMMOTH.**
- **Built up galaxy overdensity sample.**
  - Massive large scale structures are mapped.
  - Such structures are well traced by CoSLAs
- **Compared the $\delta_{\rm LAE}$ and $\tau_{\rm eff}^{\rm 15Mpc/h}$ at the position of LoSs.**
  - A global positive correlation hint is found .
  - Now the sample size have arise from 33 to 65 due to S19A fields!
- **Cross-correlation analysis between galaxy & LoS with High/Low $\tau_{\rm eff}^{\rm 15Mpc/h}$.**
  - Higher $\tau_{\rm eff}^{\rm 15Mpc/h}$ LoSs tends to clustering around galaxies, while the lower one is opposite at up to 3 pMpc scale -> The constraints on structure formation?

In the future, maybe we can…

HSC/NB387、NB400
MAMMOTH Overdensities
+
Subaru/PFS



(Lee+2015)