MIRACLES

Mapping of **I**onizing **RA**diation on the **C**osmic web with **L**yα **E**mission and **S**hadow

S21A-114I

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(Page 1)

Subaru Telescope
National Astronomical Observatory of Japan

Semester	S21A
Proposal ID	S21A0114QI
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Application Form for Telescope Time
(Queue Normal+Intensive Programs)

1. Title of Proposal
Mapping of ionizing radiation on the cosmic web with Lya emission and shadow

2. Principal Investigator
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3. Scientific Category
- [ ] Solar System
- [ ] Normal Stars
- [ ] Local Group
- [ ] Gravitational Lenses
- [ ] High-z Galaxies(LAEs, LBGs)
- [ ] Extrasolar Planets
- [ ] Metal-Poor Stars
- [ ] Nearby Galaxies
- [ ] Clusters and Proto-Clusters
- [ ] High-z Galaxies(others)
- [ ] Star Formation and Young Disk
- [ ] Compact Objects and SNe
- [★] IGM and Abs.Line Systems
- [ ] Galaxy Properties and Environment
- [ ] AGN and QSO Activity
- [ ] ISM
- [ ] Milky Way
- [ ] Cosmology
- [ ] Miscellaneous

4. Abstract *(approximately 200 words)*
We propose direct Lyα imaging of the cosmic web toward the $z = 3.09$ SSA22 protocluster with HSC. This program will map out the spatial distribution of both ionized HII gas (via Lyα emission) and neutral HI gas (via Lyα absorption) simultaneously in and around the protocluster in a cosmological volume of $180 \times 180 \times 50$ comoving Mpc by using the same, deepest NB497 image. We will unveil (1) the physical properties of the gas filaments, (2) the connection between the cosmic web and galaxies/AGNs, and (3) the role of the cosmic web on cluster formation. To identify HII gas filaments down to Lyα surface brightness of $SB_{Ly\alpha} = 3 \times 10^{-19}$ ergs s^{-1} cm^{-2} arcsec^{-2} with a 3-σ level at a 3-arcsec resolution, we request 63 hours integration for NB497, in addition to 6 hours for g-band, and 9 hours for r-band images for precise continuum correction. To trace HI gas overdesity with a 5 cMpc resolution, we request 3 hours integration for NB527 to select $\sim$400 LBGs at $z = 3.3$ with Lyα emission as background light sources. This special combination of emission and absorption line studies will enable us to constrain the total mass of main gas reservoir and radiative feedback process during the peak epoch of galaxy, super massive black hole, and cluster formation.

5. Co-Investigators
4 more Co-Is

Name	Institute	Name	Institute
Hideki Umehata	RIKEN	Michele Fumagalli	Durham University
Ken Mawatari	Univ. of Tokyo	Ian Smail	Durham University
Hidenobu Yajima	Univ. of Tsukuba	David Alexander	Durham University
Masayuki Umemura	Univ. of Tsukuba	Yoichi Tamura	Nagoya Univ.
Masao Mori	Univ. of Tsukuba	Keiichi Matsuda	Nagoya Univ.
Takuya Hashimoto	Univ. of Tsukuba	Satoshi Kikuta	NAOJ
Scott Chapman	Dalhousie University	Kentaro Nagamine	Osaka Univ.
Tomoki Hayashino	Tohoku Univ.	Masami Ouchi	Univ. of Tokyo
Toru Yamada	JAXA	Yoshiaki Ono	Univ. of Tokyo
Charles Steidel	Caltech	Kotaro Kohno	Univ. of Tokyo

6. Thesis Work
- [ ] This proposal is linked to the thesis preparation of _____

7. Subaru Open Use Intensive Programs
- [★] This is a proposal for Intensive Programs.

(Page 3)   Proposal ID S21A0114QI

Title of Proposal
Mapping of ionizing radiation on the cosmic web with Lya emission and shadow

12. Observing Run

Instrument	Hours	Moon phase	Moon distance	Seeing	Transparency	OnSrc Hours
HSC	98	dark/gray	120	3	0.7	81

comments:

Total Requested Number of Hours **98**   Minimum Acceptable Number of Hours 9

13. Instrument Requirements *Specify the set of filters to use (HSC).*
We are going to use g, r, $NB497$ and $NB527$ filters.

14. List of Targets

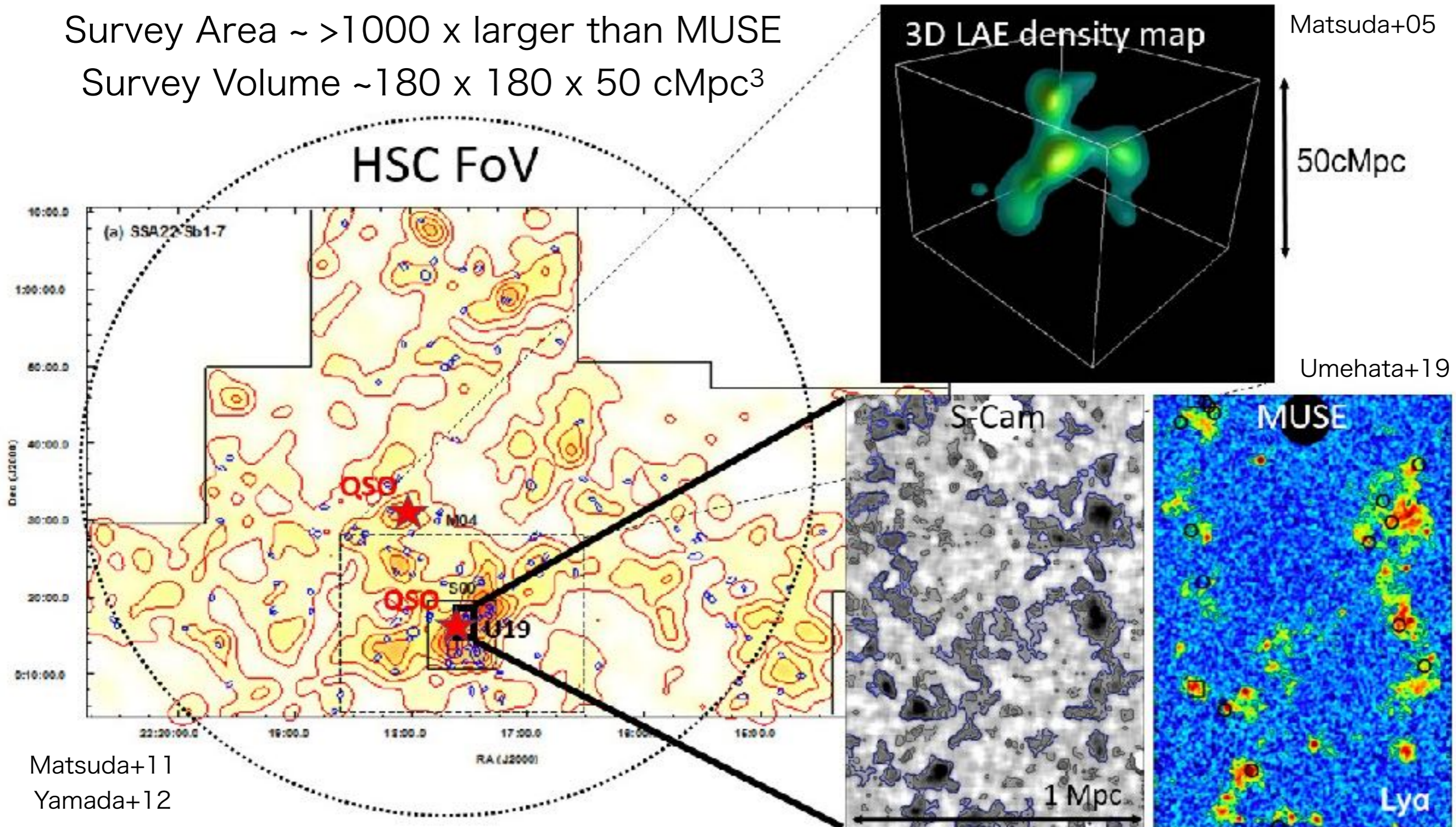| Target Name	RA	Dec	Magnitude (Band)
SSA22	221734.00	+001700.0	30.4 ABmag arcsec^{-2} ($NB497$)

Akio Inoue, Ikki Mitsuhashi, Mariko Kubo

Rieko Momose, Satoshi Yamanaka

HSC Observations of Cosmic Web [3]

(1) The physical properties of the cosmic web (width, length, mass, & ionizing radiation field)
(2) The connection between the cosmic web and galaxy / black hole growths
(3) The role of the cosmic web on cluster formation

Survey Area ~ >1000 x larger than MUSE

Survey Volume ~180 x 180 x 50 cMpc^3

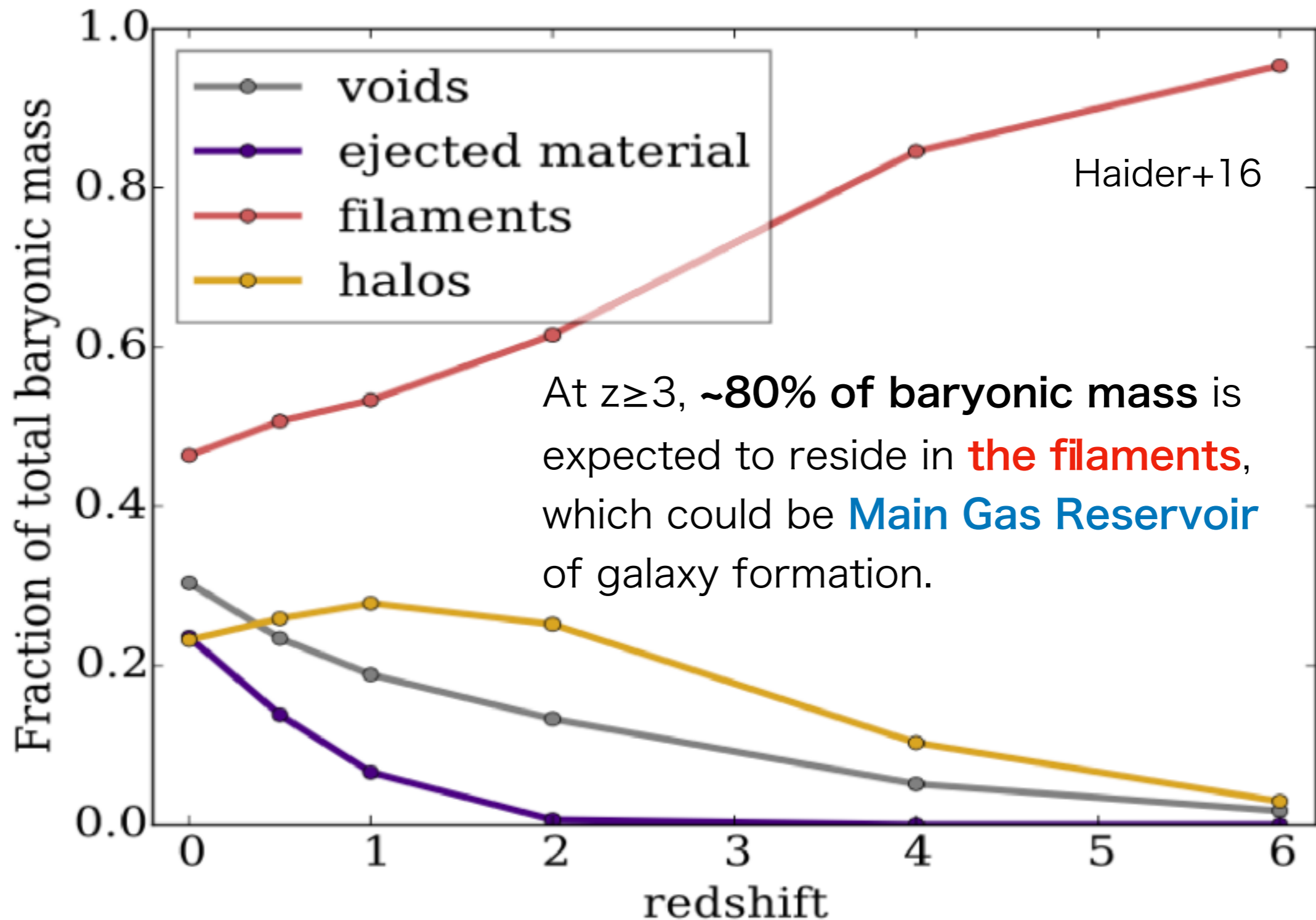3D LAE density map

Matsuda+05

50cMpc

HSC FoV

Umehata+19

(a) SSA22 Sb1-7

QSO

M04

QSO

SSA22

S00

U19

S-Cam

MUSE

1 Mpc

Lyα

Matsuda+11
Yamada+12

Why Cosmic Web?

The ΛCDM cosmological model predicts that galaxies form along the cosmic web and galaxy clusters form at their intersections

(a) 2D dark matter map at z=3

(b) 3D gas map in protocluster

HSC FoV (1.5 deg)

100 cMpc

2 cMpc   Yajima+21
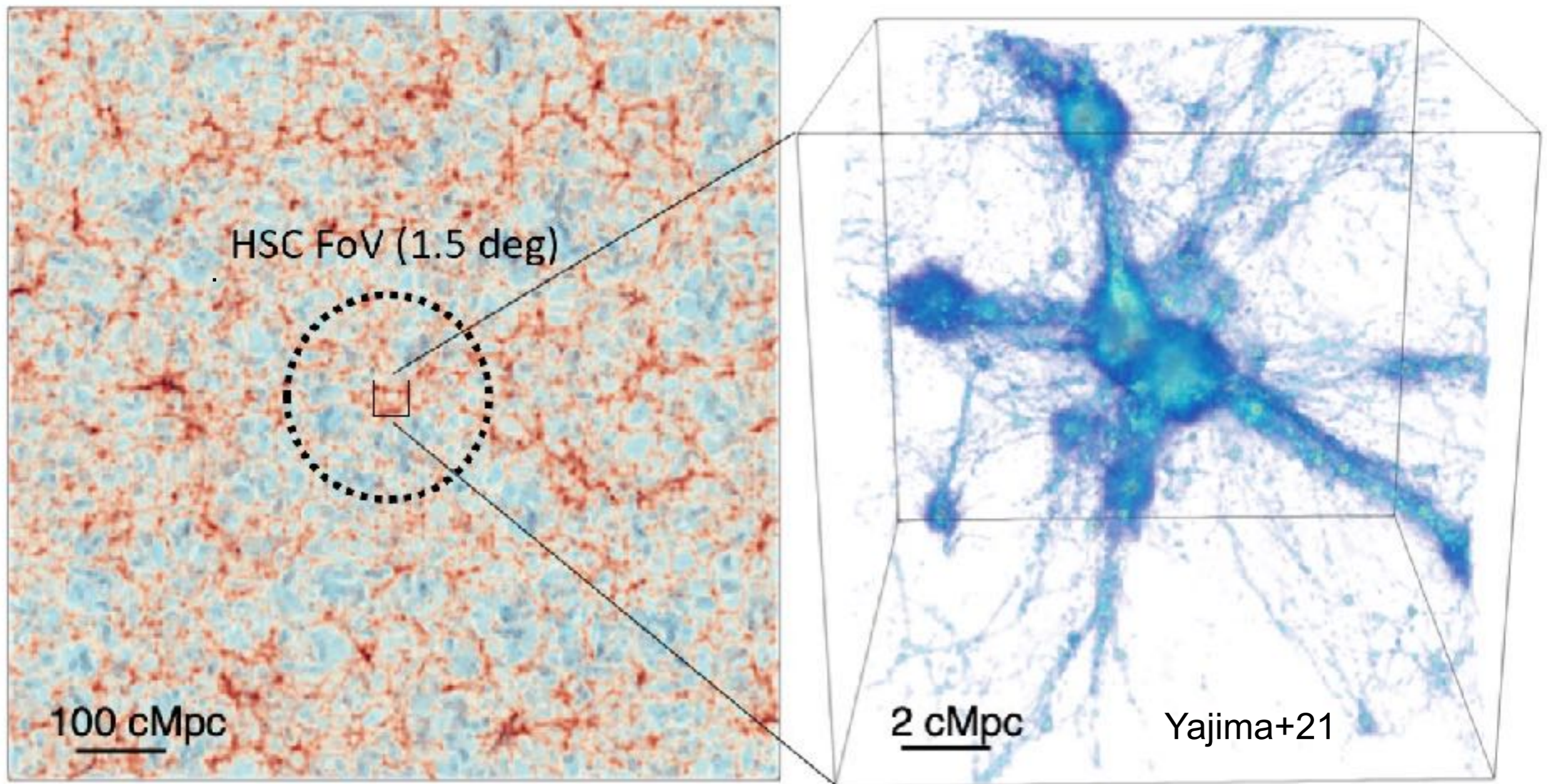
Baryonic Cosmic Web

Predicted evolution of baryonic mass in the cosmic structure

Haider+16

At z≥3, **~80% of baryonic mass** is expected to reside in **the filaments**, which could be **Main Gas Reservoir** of galaxy formation.

HII gas mapping (emission)

Predicted Lya emission from the cosmic web
(Yajima+21)
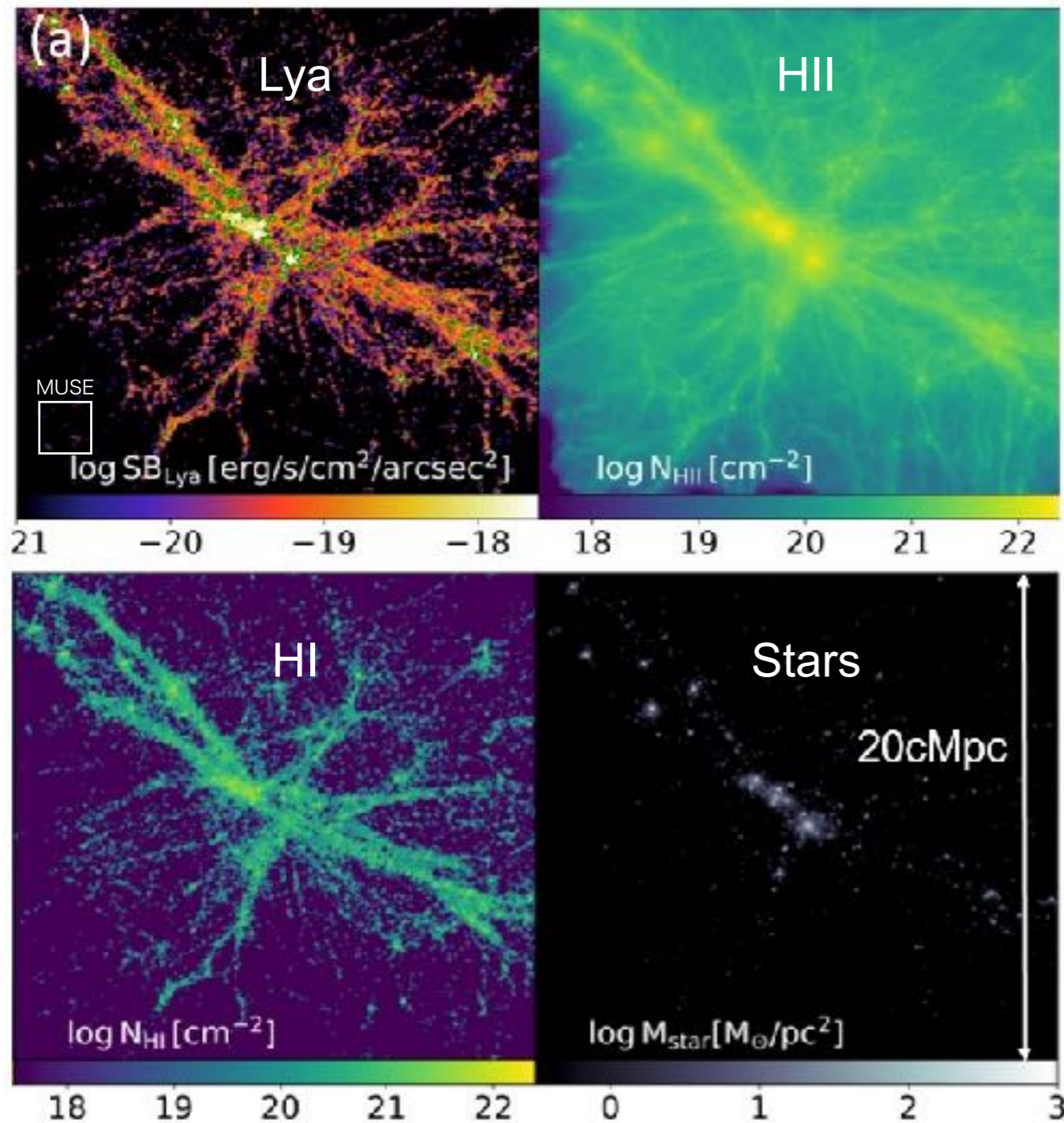
We can measure the strength of the ionizing radiation which illuminate the surface of the gas filaments.
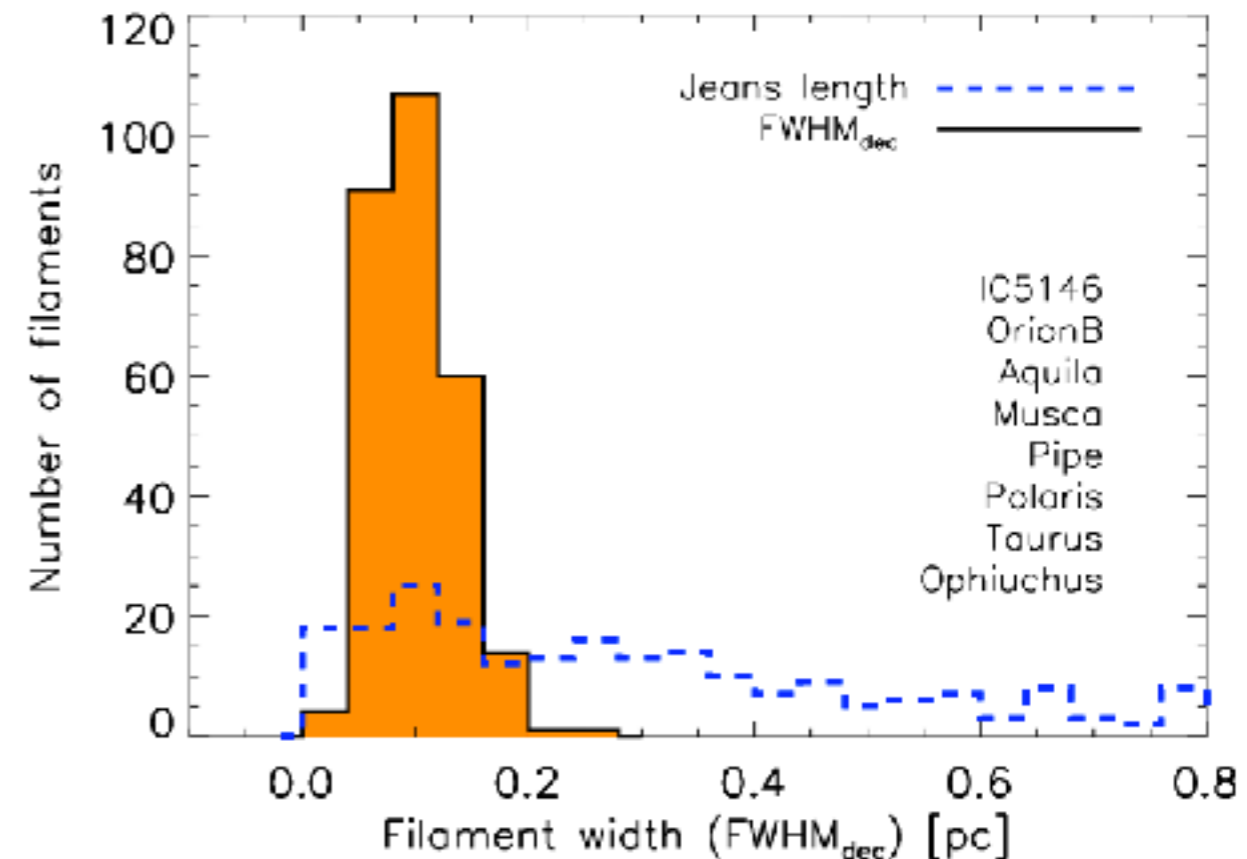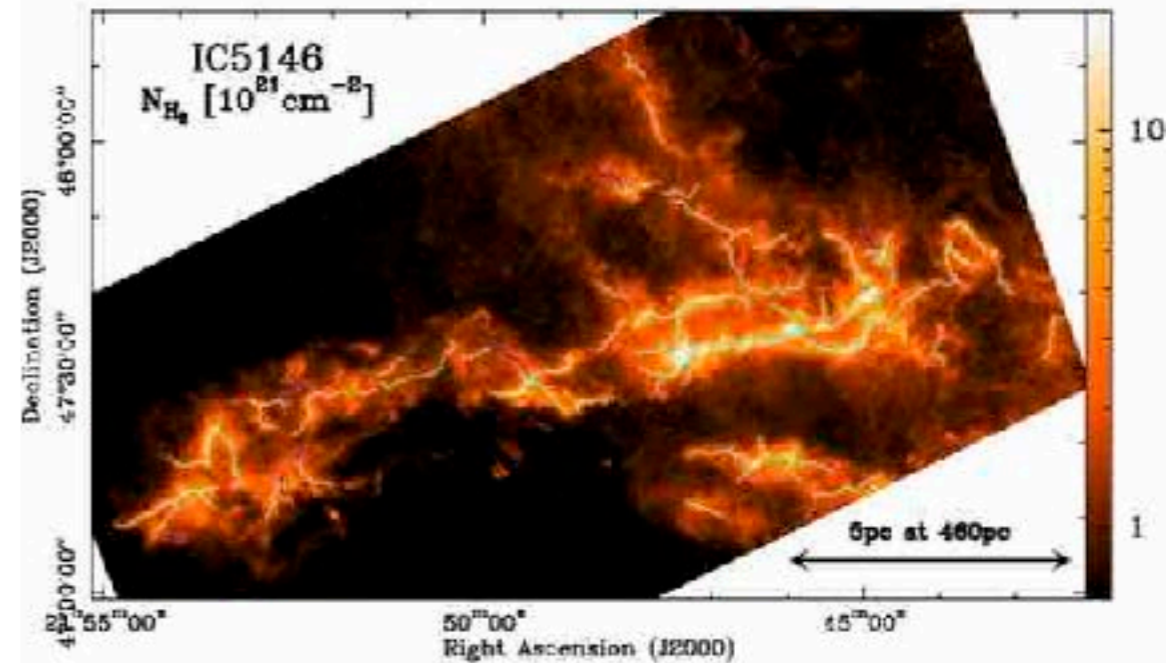
Umehata+19

Strength of Ionizing Radiation
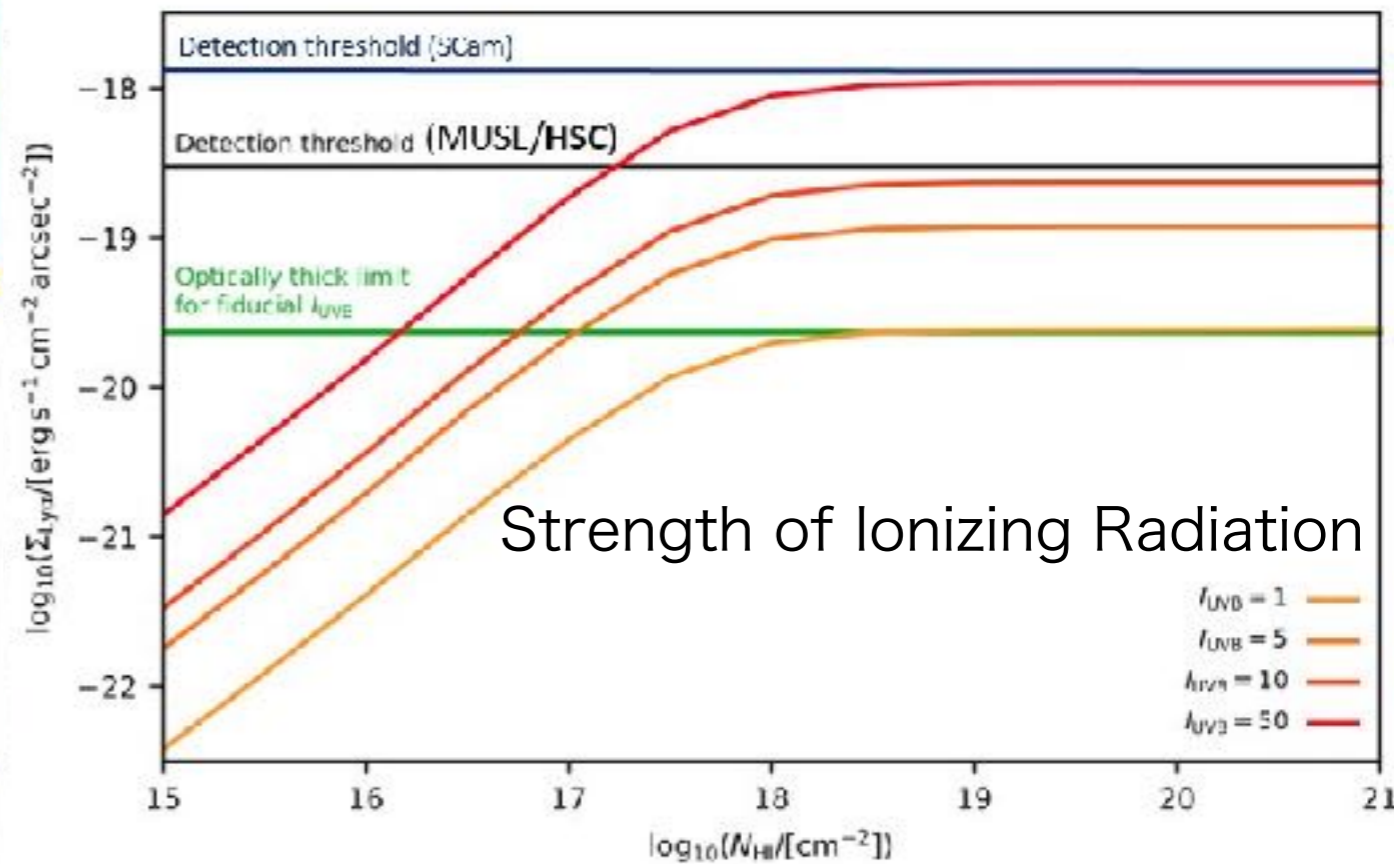
Do the filaments have a characteristic width?
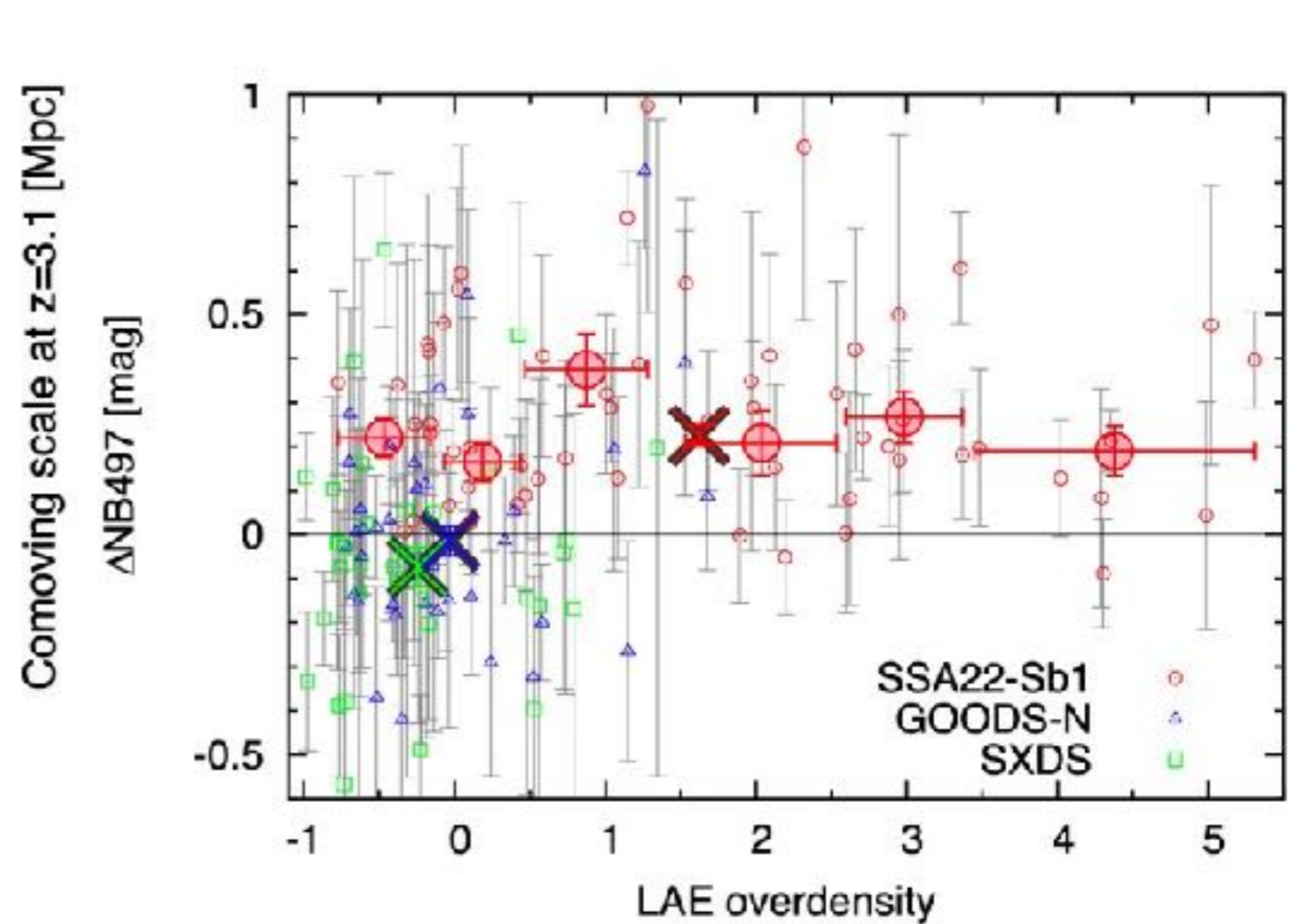
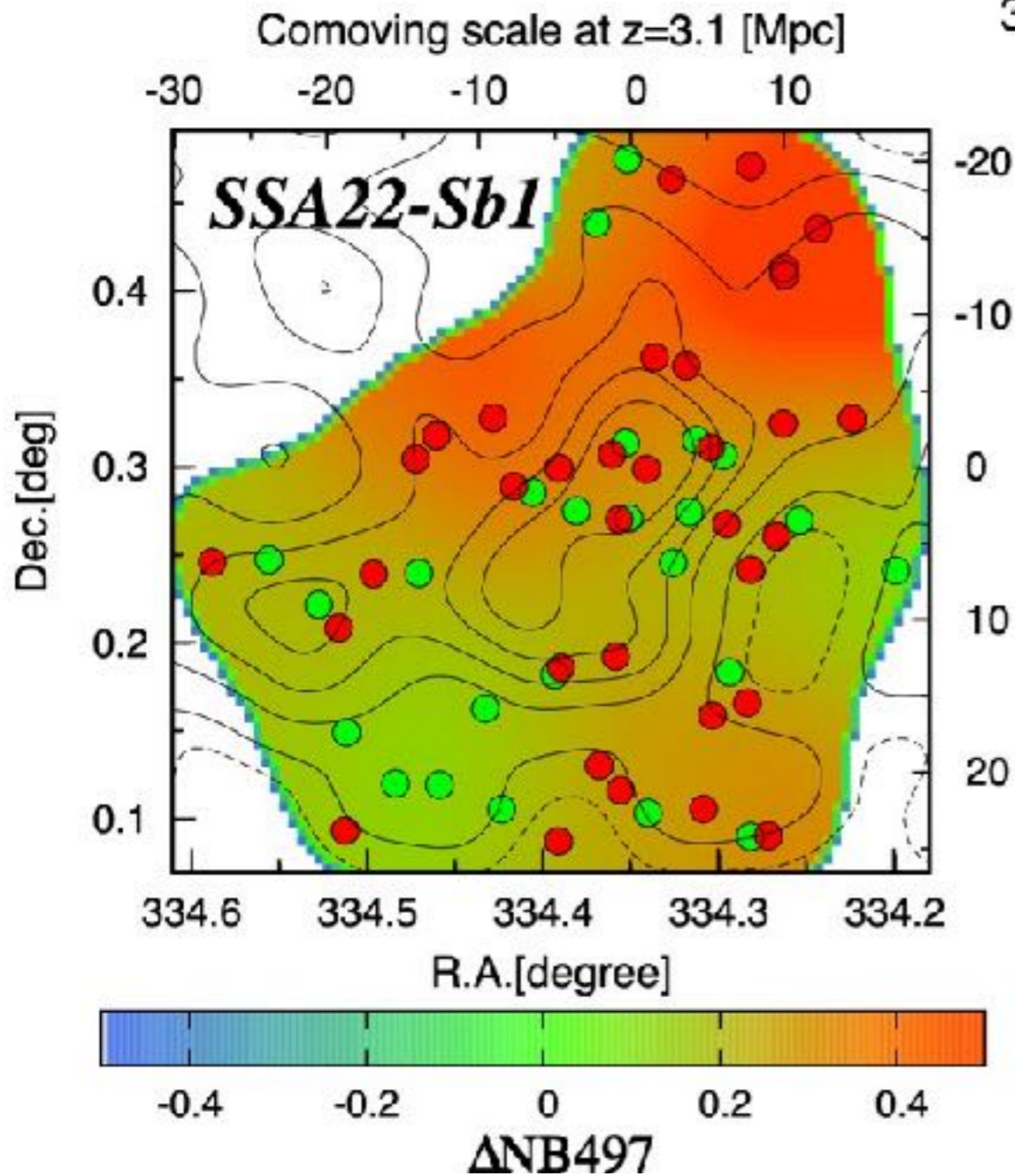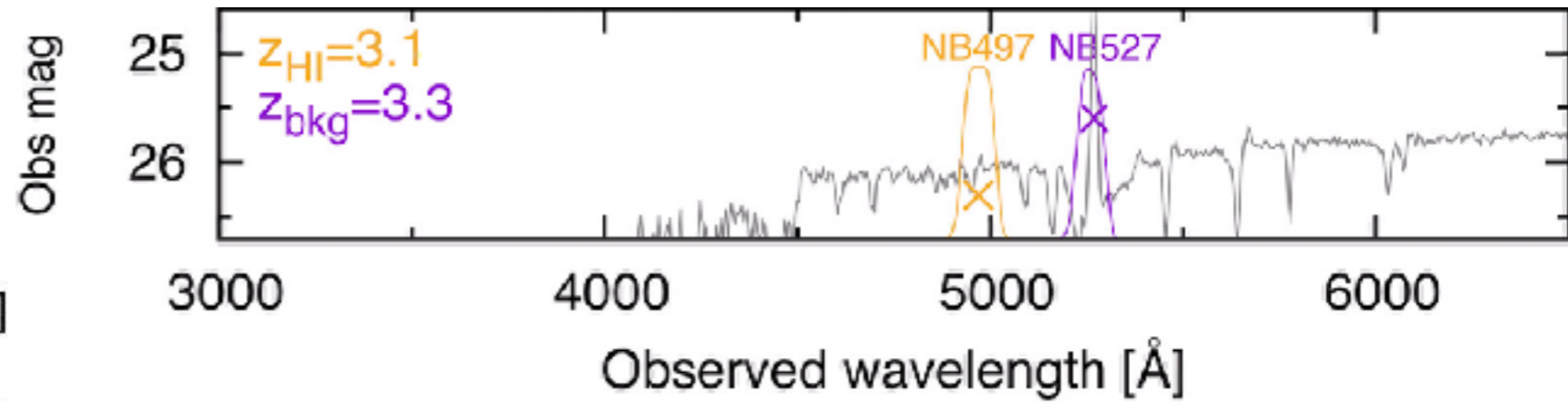3D structure of Lya emitting filaments
(Umehata+19)
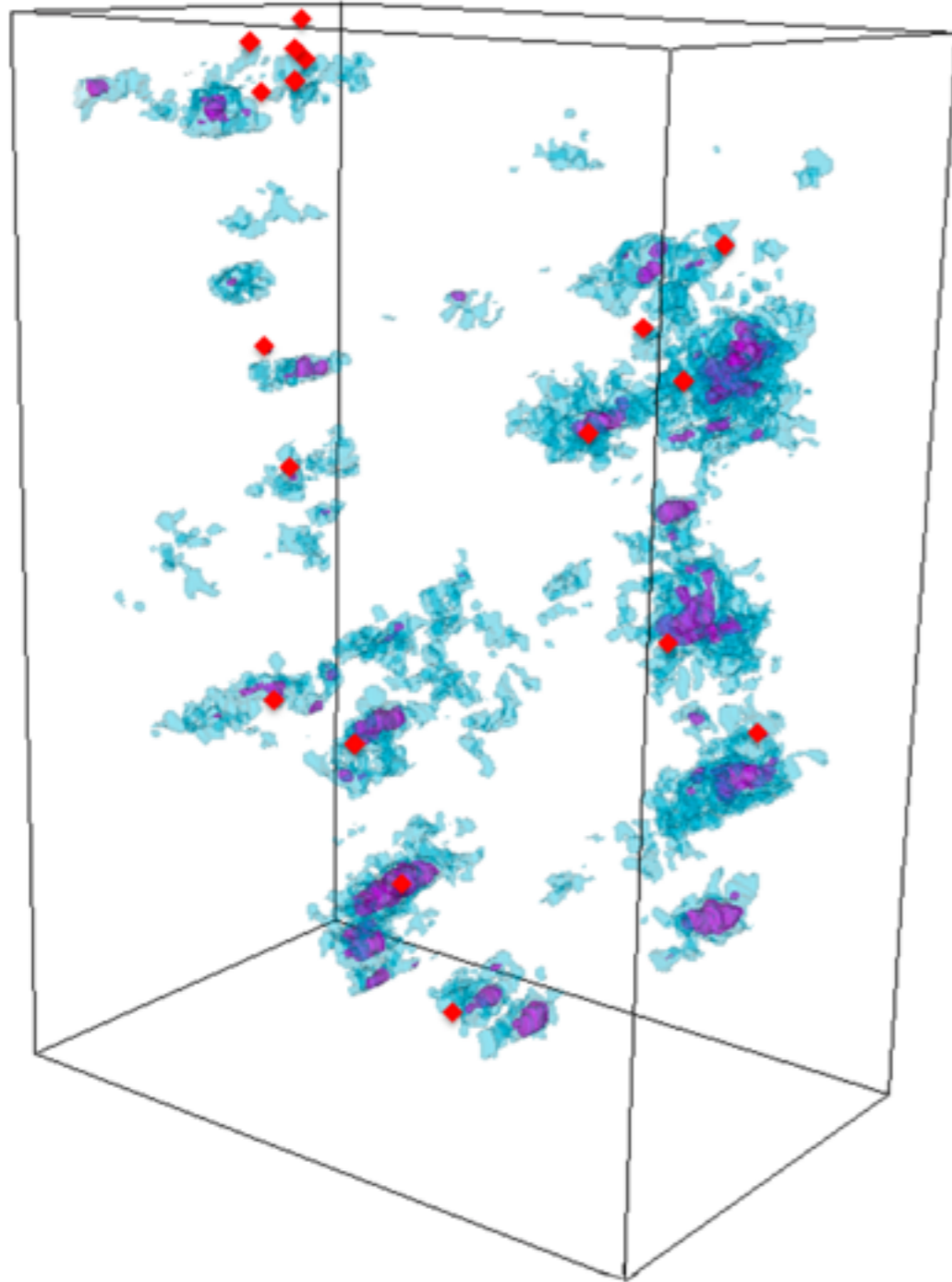
c.f Local Molecular Gas Filaments
(Arzoumanian+11/19, Shimajiri+19ab)

Typical width of ~50-100kpc?

HI gas mapping (absorption)

We will make 2D HI map along the 100cMpc field of view with a 5cMpc resolution

$z_{HI}=3.1$
$z_{bkg}=3.3$

Obs mag

Observed wavelength [Å]

SSA22-Sb1

Comoving scale at z=3.1 [Mpc]

Dec.[deg]

R.A.[degree]

Comoving scale at z=3.1 [Mpc]

ΔNB497 [mag]

SSA22-Sb1
GOODS-N
SXDS

LAE overdensity

ΔNB497

Mawatari+17

Coordinated CFHT/MegaCam U-band 13.1 hours program (Chapman+)

Observation Plan & Status

- HSC Queue: S21A-S23A （18h/20h/20h/20h/20h)

  - HSC/NB497 - 63h (**2.3h**, 4%)

  - HSC/NB527 - 3h (**3h**, 100%)

  - HSC/g-band - 8h (**5h**, 63%)

  - HSC/r-band - 10h (**5.2h**, 52%)

  - MegaCam/u-band - 13h (**13h**, 100%)

- Add NB506/515 to increase number of background LBGs by factor of 3?

For S21A-S21B, 48% achievement (July/Dec runs were canceled by Earthquake/Storm)

Coadded NB527 image

9694-0.7

9695-7.3
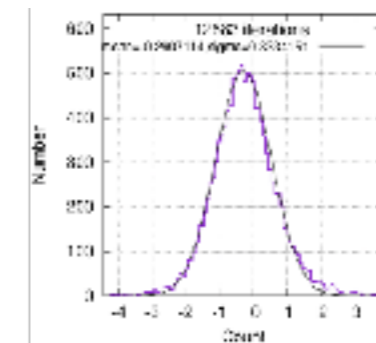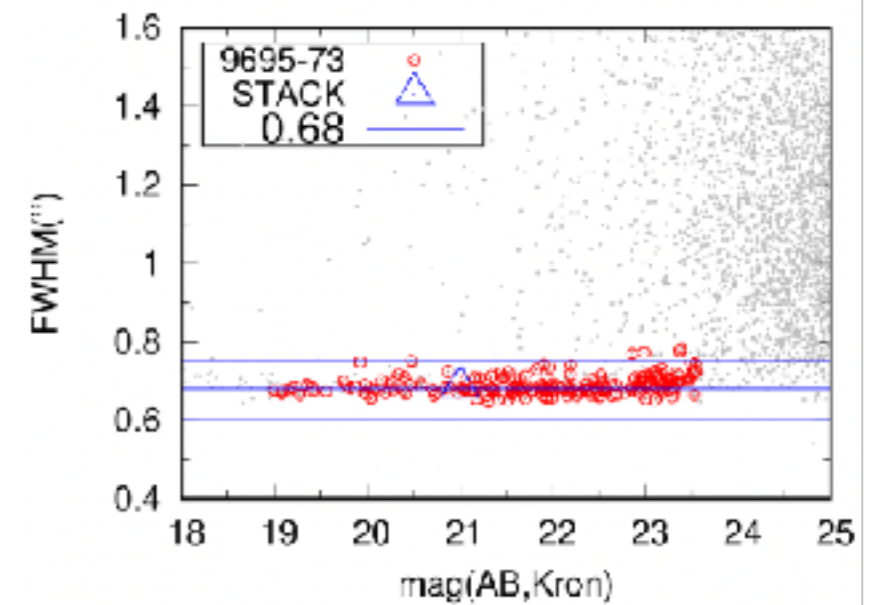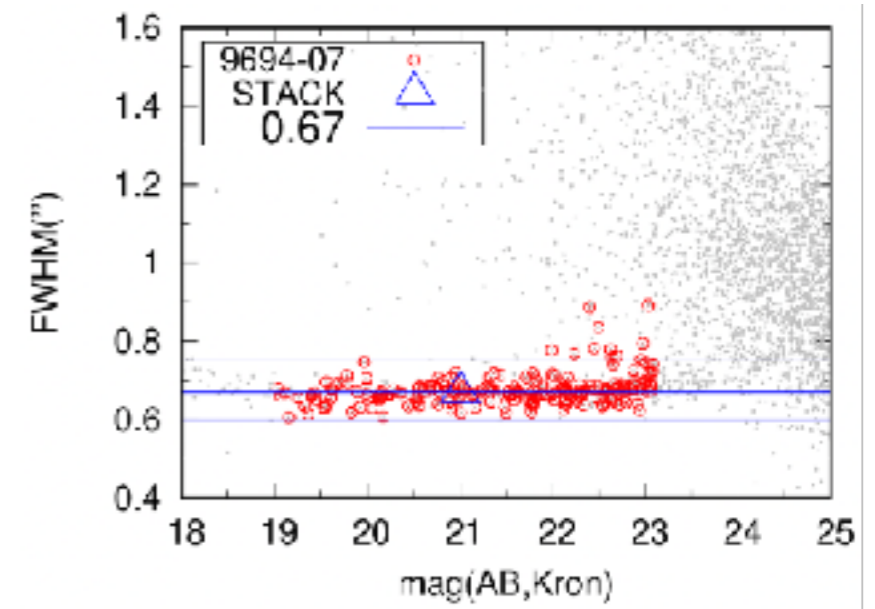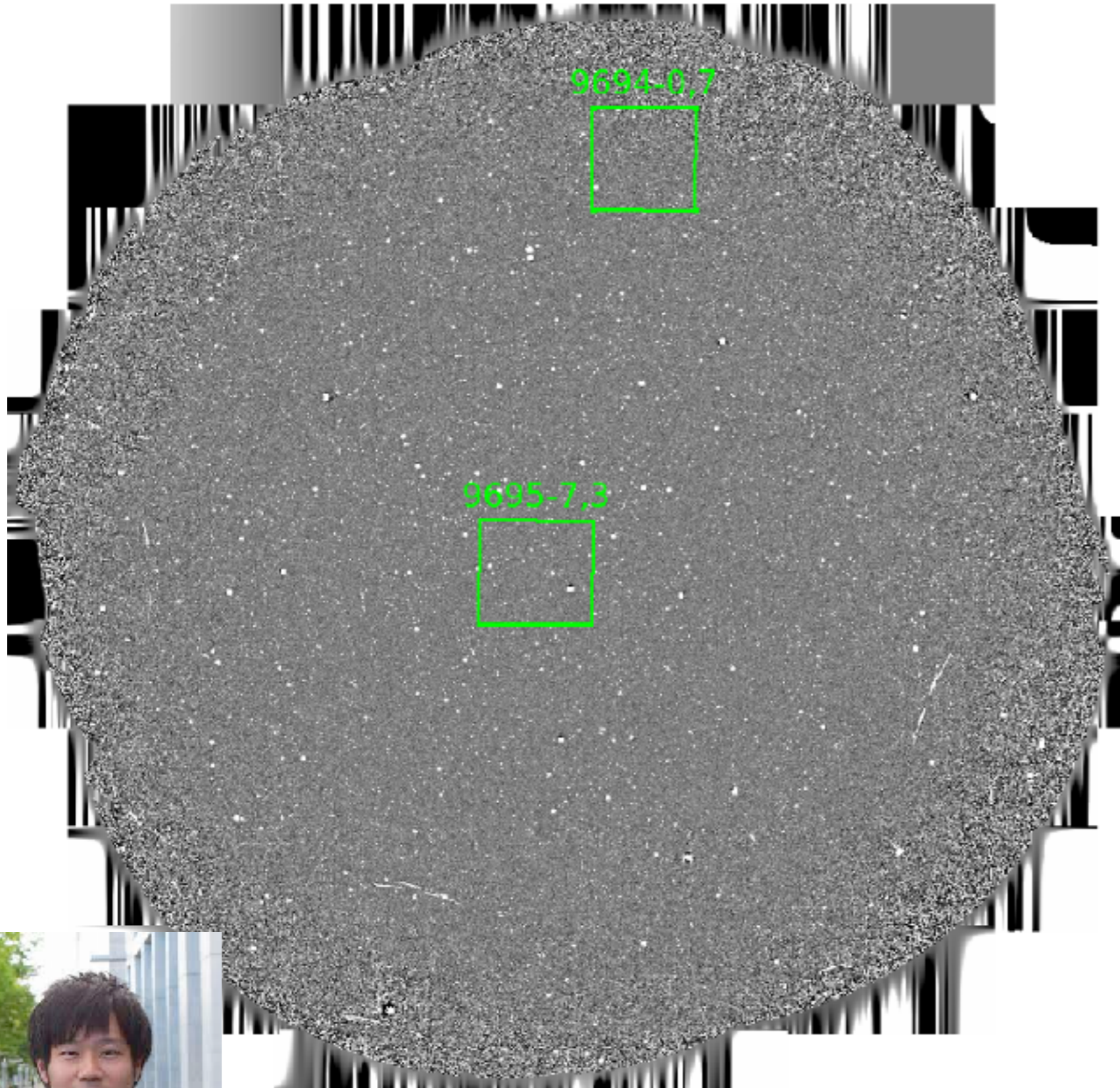
5σ=25.45AB
(2'' aperture)
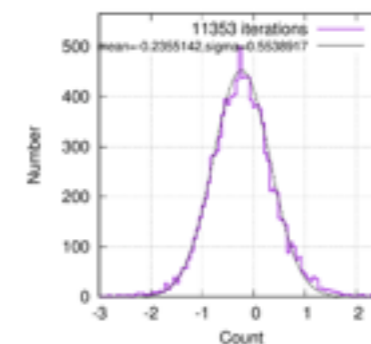
5σ=25.9AB
(2'' aperture)

Mawatari-san's analysis

MIRACLES

A 98 hours Subaru/HSC Intensive Program
to map out the baryonic cosmic web at high-z

Survey Area ~ >1000 x larger than MUSE

Survey Volume ~180 x 180 x 50 cMpc^3

3D LAE density map

Matsuda+05

50cMpc

HSC FoV

(a) SSA22 Sb1-7

QSO

M04

QSO

S00

U19

Matsuda+11

Yamada+12

RA (J2000)

Umehata+19

S-Cam

MUSE

1 Mpc

Lyα