Galaxy-IGM Workshop 2020
Groupwork IGM観測班

“Panoramic observations of multi-phase gas components in z~2 clusters”

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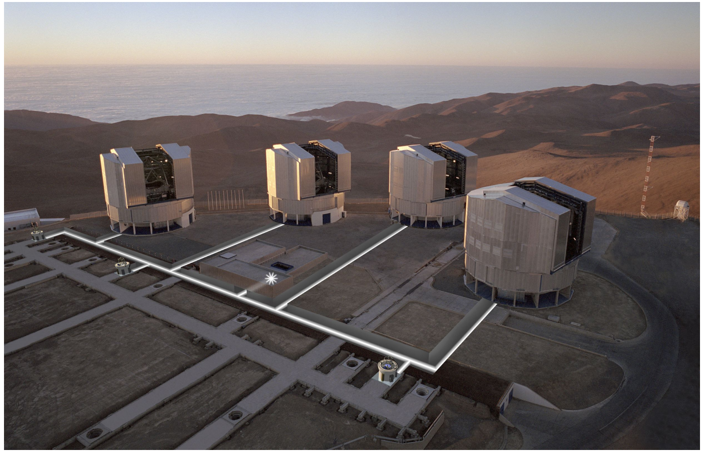
Theme

Propose an observational study of the CGM and/or IGM utilizing the Subaru Telescope's strength

"Panoramic observations of multi-phase gas components in z~2 clusters"

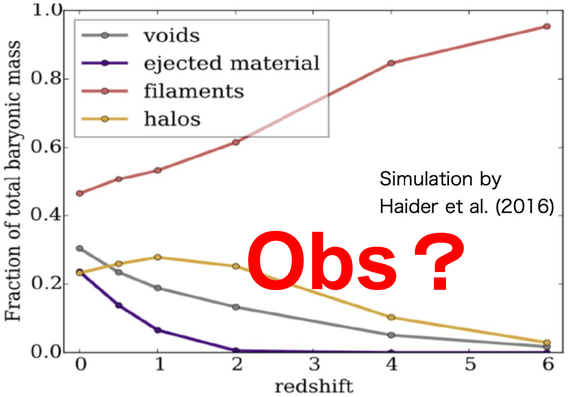


Introduction / Motivation

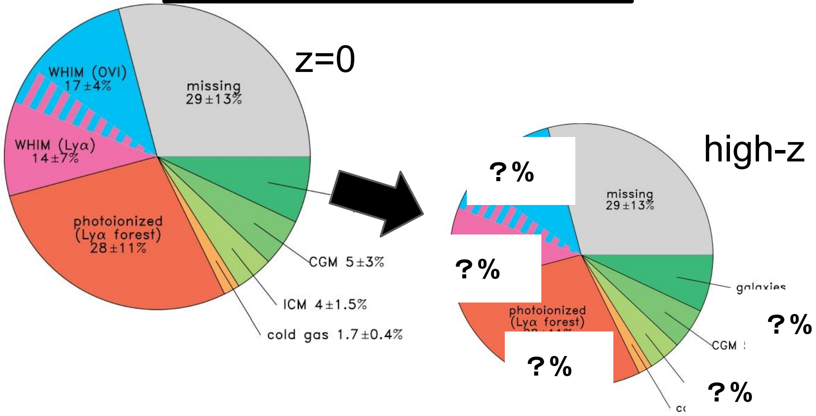
- Where's majority of baryon? ("Missing baryon problem")
  - Gases and stars. The theoretical value of Ωb, derived from BBN, CMB and observations from Planck, is larger than the sum of all the known baryonic matter, which is known as the missing baryon problem.
  - It is believed that ~10% of all baryons are collapsed objects and the remaining baryons reside in IGM, CGM (large scale gas structures), of which 30% are still missing in local universe (shully et al.2012).

Q1. Is baryon missing at *high-z* too?

Q2. *Multi-phase*?



Matsuda-san's slide



shully et al.2012

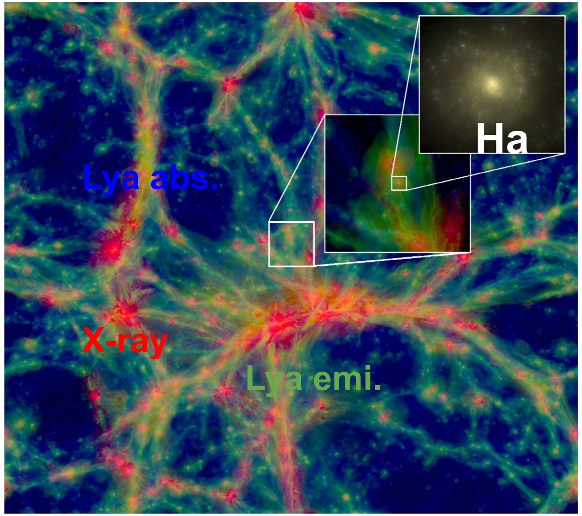
What should we observe?

・Multi-phase:

1. Hot gas -> X-ray
2. Diffuse warm gas -> Lya emission
3. Diffuse cold gas -> Lya absorption
4. Dense cold(?) gas in galaxy -> Ha emission

・Environment?

- Rich clusters (with X-ray detection)
- Proto-clusters (without X-ray detection)



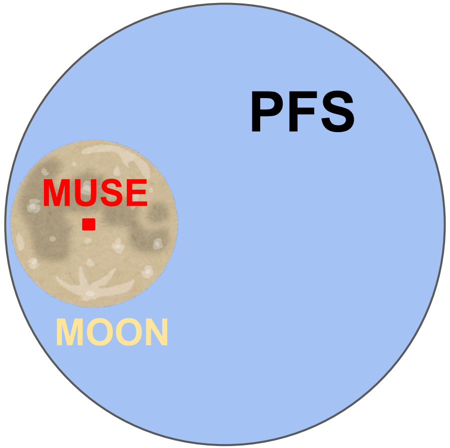
Dayal+18

※Assume most of baryon are in cluster H (at high-z)

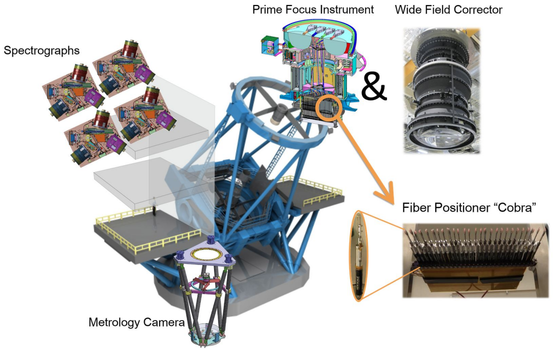
Subaru/PFS vs. VLT/MUSE

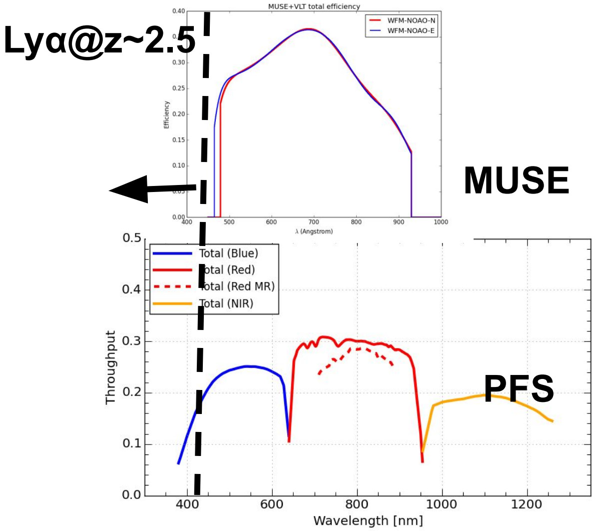
- **PFS Wide FoV (WIN)**
  PFS: ~ 1.3 deg^2
  MUSE/WFM: ~ 1 arcmin^2
  (* typical proto-cluster > 10 arcmin)

- **Wide wavelength coverage (WIN)**
  (* highest-z X-ray cluster @z~2.5)



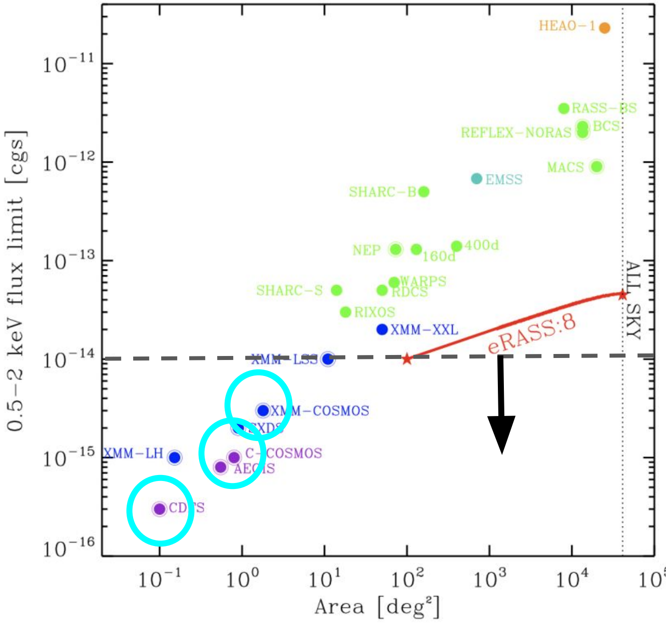
FoVs





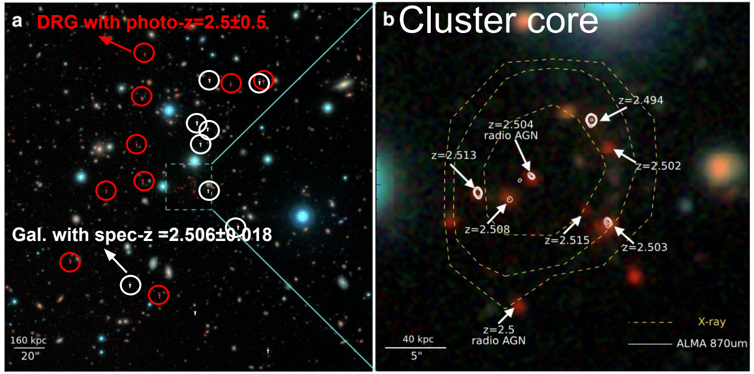
→ **Feasibility: Achieve our goal with reasonable time.**

X-ray data & Target: the rich cluster

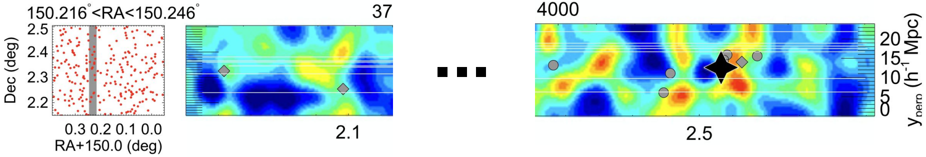


- Fields with deep X-ray in need
  → Lx / the upper limit of Lx
- Chandra/XMM-Newton deep fields

- The most distant cluster with X-ray emission to date:
  CL J1001+0220 @z=2.5 (Wang+16)
  * Size: ~ 16 arcmin^2 (Core: 80 arcsec^2).
  * Selected tracer: **Distant red gal. (DRGs) with X-ray**
  * Data: 1) Available: Multi-wave incl. X-ray, 3D HI map
  2) To obs.: Lα emi., Hα emi.



* 3D HI map available from CLAMATO DR1 (Lee+18)



Target: the protoclusters

(1) E-CDFS z2.80 - 2.84 PCs: 6σ Significance (Zheng+16).

* Size: ~ 900 arcmin^2
* Selected tracer:

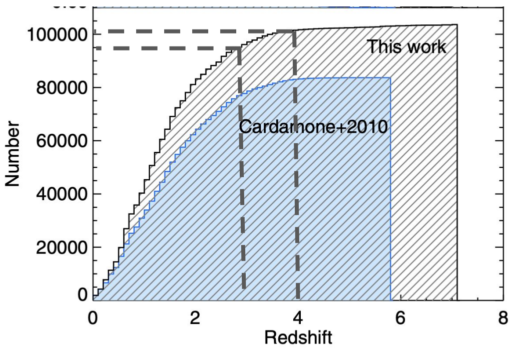
LAEs

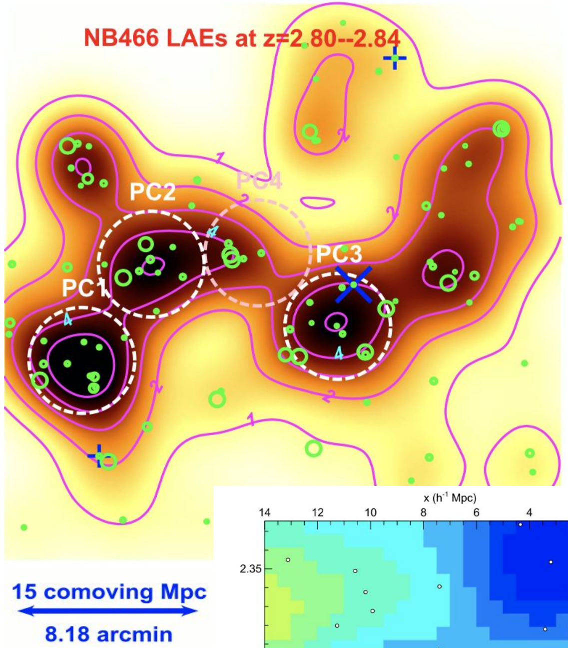
* Visibility: 5-6 hr/nt @ MK.
* Data:

1) Available:
Multi-wave incl. X-ray

2) To obs.:
Opt spec for Lyα forest,
Lyα emi., Hα emi.

* 2.8<photo-z<4 Obj: ~5 K (Tsu+14)





(2) COSMOS z2.44 PC from IGM tomography (CLAMATO; Lee+16).

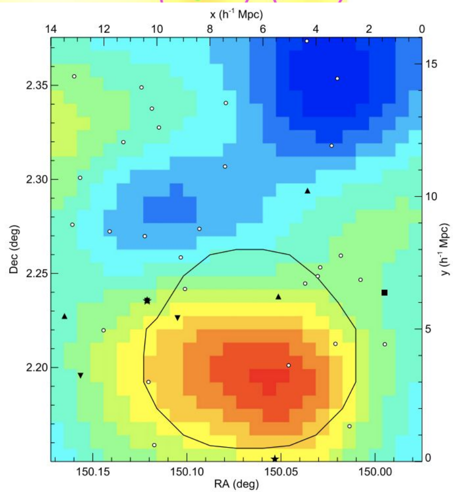
* Size: D ~ 160 arcmin^2
* Selected tracer:

HI from Lyα abs.

* Data:

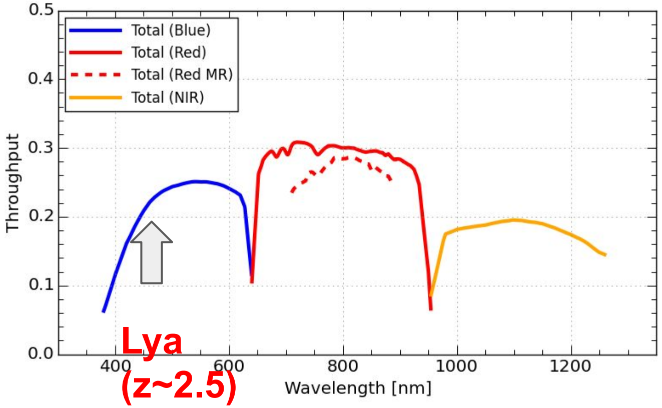
1) Available:
Multi-wave incl. X-ray, 3D HI map,

2) To obs.:
Lyα emi., Hα emi.

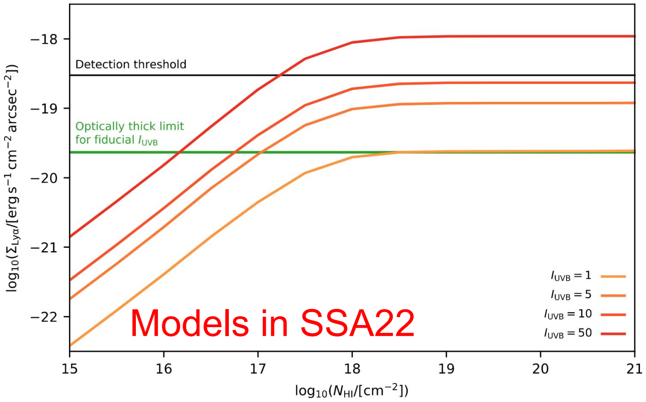


Lya diffuse emission

- Subaru/PFS Blue



Sensitivity (5σ, 1hr, whole area of cluster)



Umehata+19

CL J1001

Possible to be detected w/ UVB

E-CDFS PC
COSMOS PC

✓ Likely to be detected
✓ Can see spatial variance too

- SB_Lya -> M_H assuming n_H

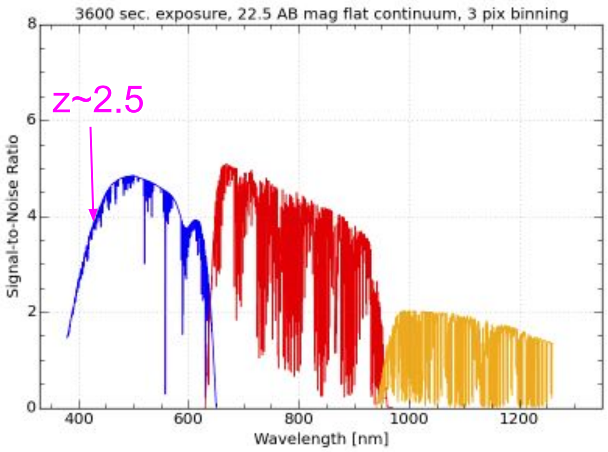
Lya diffuse absorption w/ PFS

	Area @z=2.5	N of FoVs	Tomographic resolution	Target bkg brightness	Δλ after smoothing	Time/FoV	Required nights
w/ PFS	Pi x (70cMpc)^2	2	~3cMpc	<24.8 in UV < 25.1 in Lya-forest range	4Å ~ 3cMpc	18hours To detect 25.1mag with 2sigma	5 ~ 7

Essential requirement

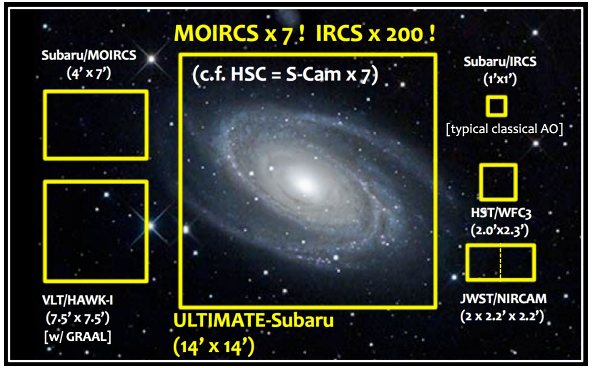
Enough for clusters
And surrounding LSS

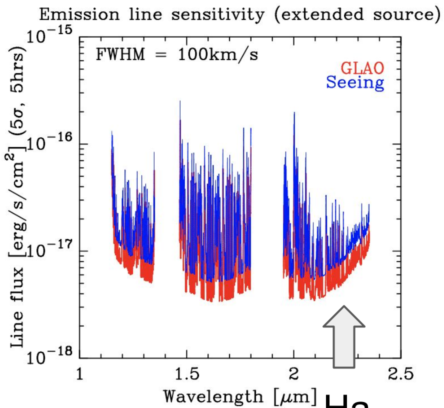
Absorption strength map -> HI column density map
Spatially integrate HI column density to obtain HI mass



Ha emission

- ULTIMATE-Subaru
  - 14’x14’ FoV, NIR

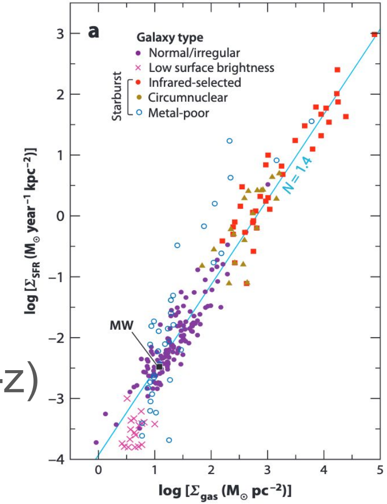




Ha
(z~2.5)

- Feasibility
  - CL J1001: 11 galaxies w/ f_Ha >~ 3e-17erg/s/cm2
  - If this holds also for other clusters, >5σ detection w/ 5hr
  - SWIMS also available w/ comparable feasibility but smaller FoV (3.3’x6.6’)

- How to estimate M_gas
  - SFR ∝ L_Ha
  - SFR ∝ M_gas^n (right fig.; assume this holds also at high-z)
  - => M_gas from L_Ha



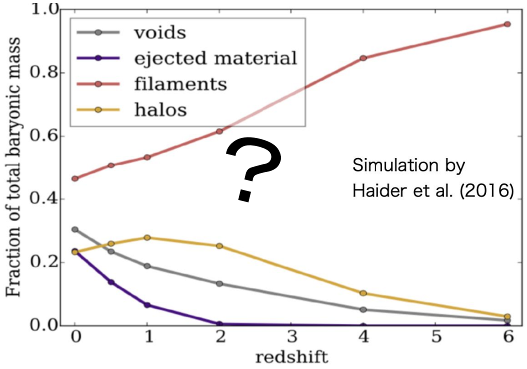
Obs. of Nearby Gals.

Kennicutt&Evans12

What we discuss

1. Total gas mass
   a. Hot plasma(X-ray) + HII (Lya em) + HI(Lya abs) + SF clouds (Ha em)
   b. Assuming majority of baryon in cluster hydrogen gas, estimate baryon density (Ω_b,obs)
   c. Comparison with theoretical value Ω_b(z~2) -> Confirmation of high-z missing baryon problem
2. Fraction of different phase (temperature) gas components
   a. Comparison with simulation -> History/process of cluster gas heating

Redshift	hot gas	WHIM	cold gas	star
Nicastro et al. (2018)[a]	9±4.5	≳24 & ≲55	29.7±11	7±2
Haider et al. (2016)[b]	6.5	53.9	32.8	-
z = 0	4.6±0.7 (4.6±0.1)	41.3±1.1 (38.3±1.0)	50.9±0.1 (50.6±0.2)	3.2±0.1 (6.5±0.2)
z = 0.6	2.4±0.4 (1.1±0.2)	34.9±1.1 (29.7±1.1)	60.2±0.1 (65.0±0.1)	2.5±0.1 (4.2±0.2)
z = 1.0	1.3±0.2 (0.3±0.0)	28.7±1.1 (21.9±1.0)	68.1±0.1 (74.8±0.1)	1.9±0.1 (2.8±0.1)
z = 2.1	0.2±0.0 (0.0±0.0)	10.8±0.5 (6.2±0.4)	88.2±0.1 (92.9±0.0)	0.8±0.0 (0.8±0.0)



Simulation by Haider et al. (2016)