

Prime Focus Spectrograph Galaxy Evolution Survey

On behalf of the PFS Galaxy Evolution Working Group

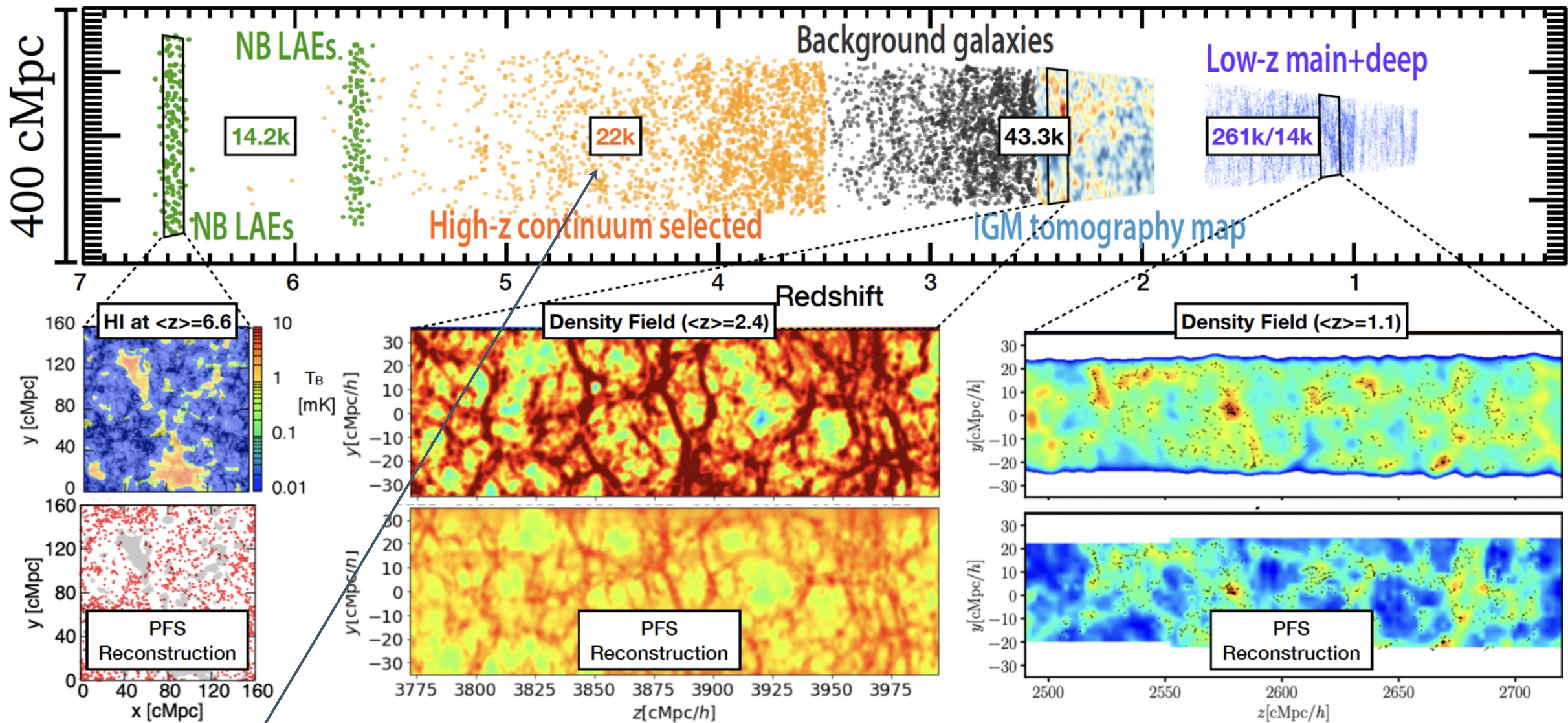
Rachel Bezanson, Jenny Greene, Masami Ouchi, John Silverman (co-Chairs)

Greene+2022 arXiv:2206.14908

The Prime Focus Spectrograph Galaxy Evolution Survey

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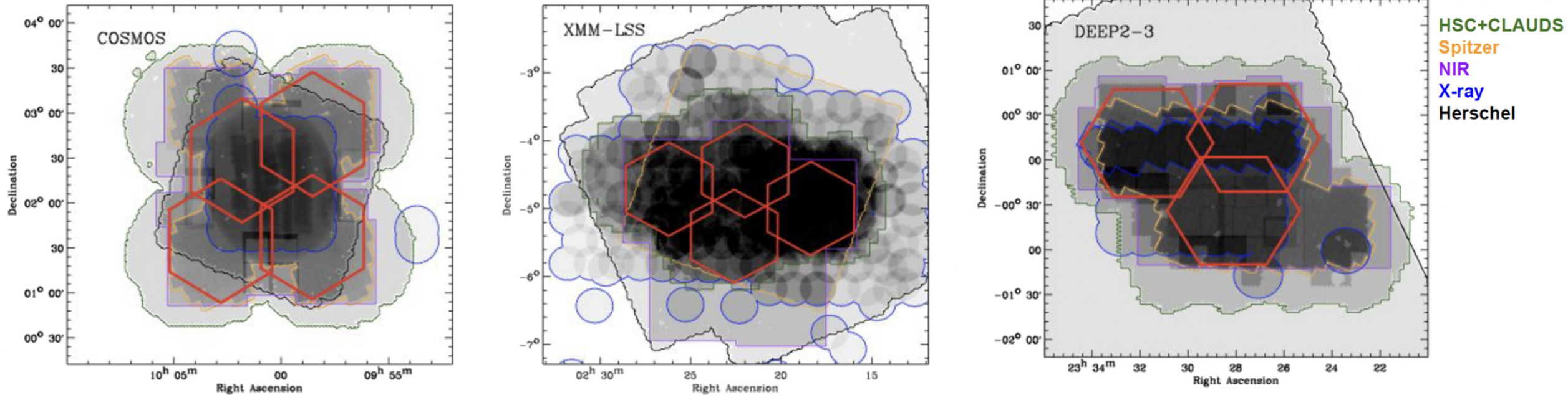
The PFS Galaxy Evolution Survey



VVDS, VUDS (Le Fevre et al. 2005, 2015) over a wider area

Deep HSC+Multi-Wavelength Imaging

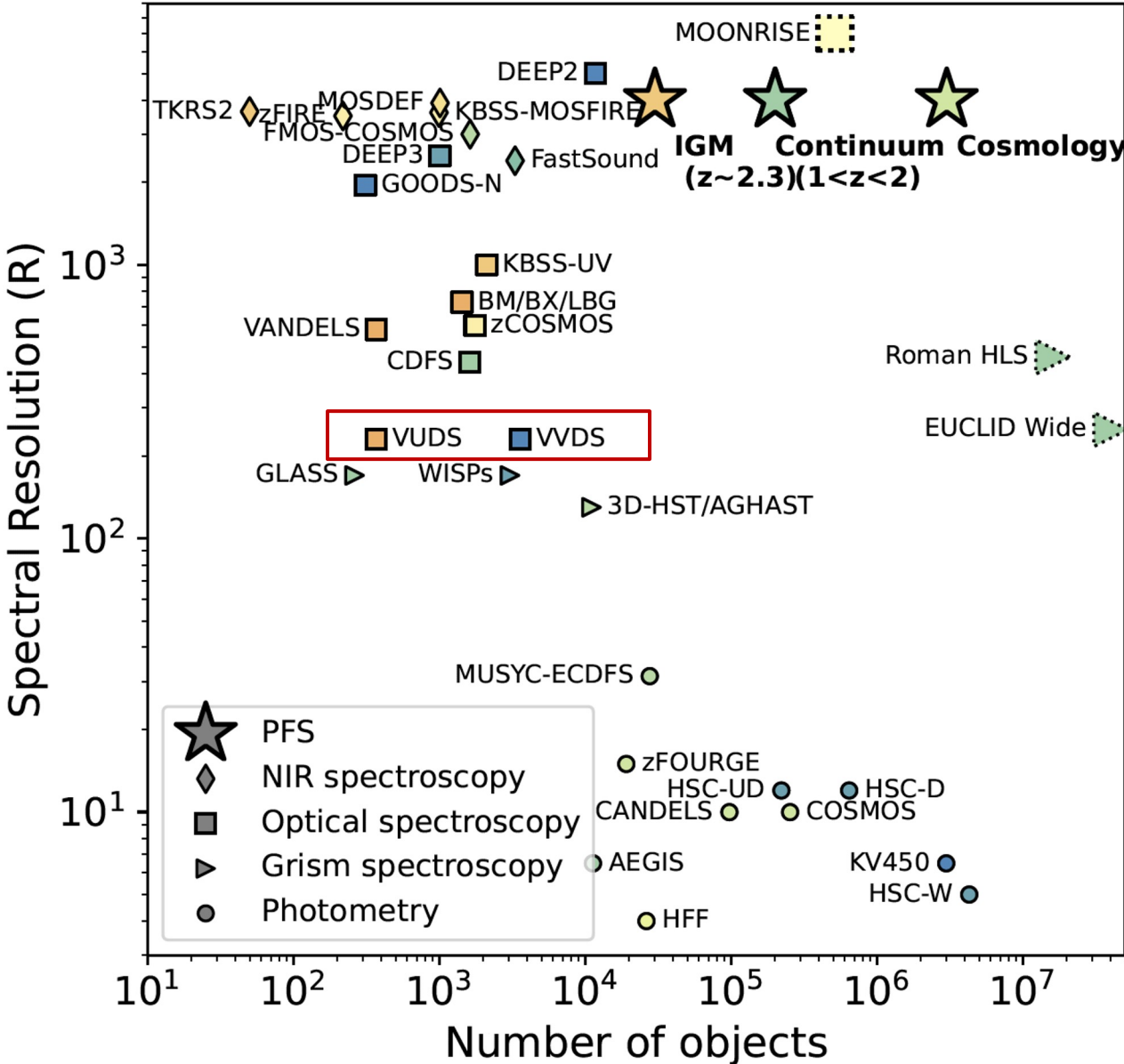
12.3 sq. degrees

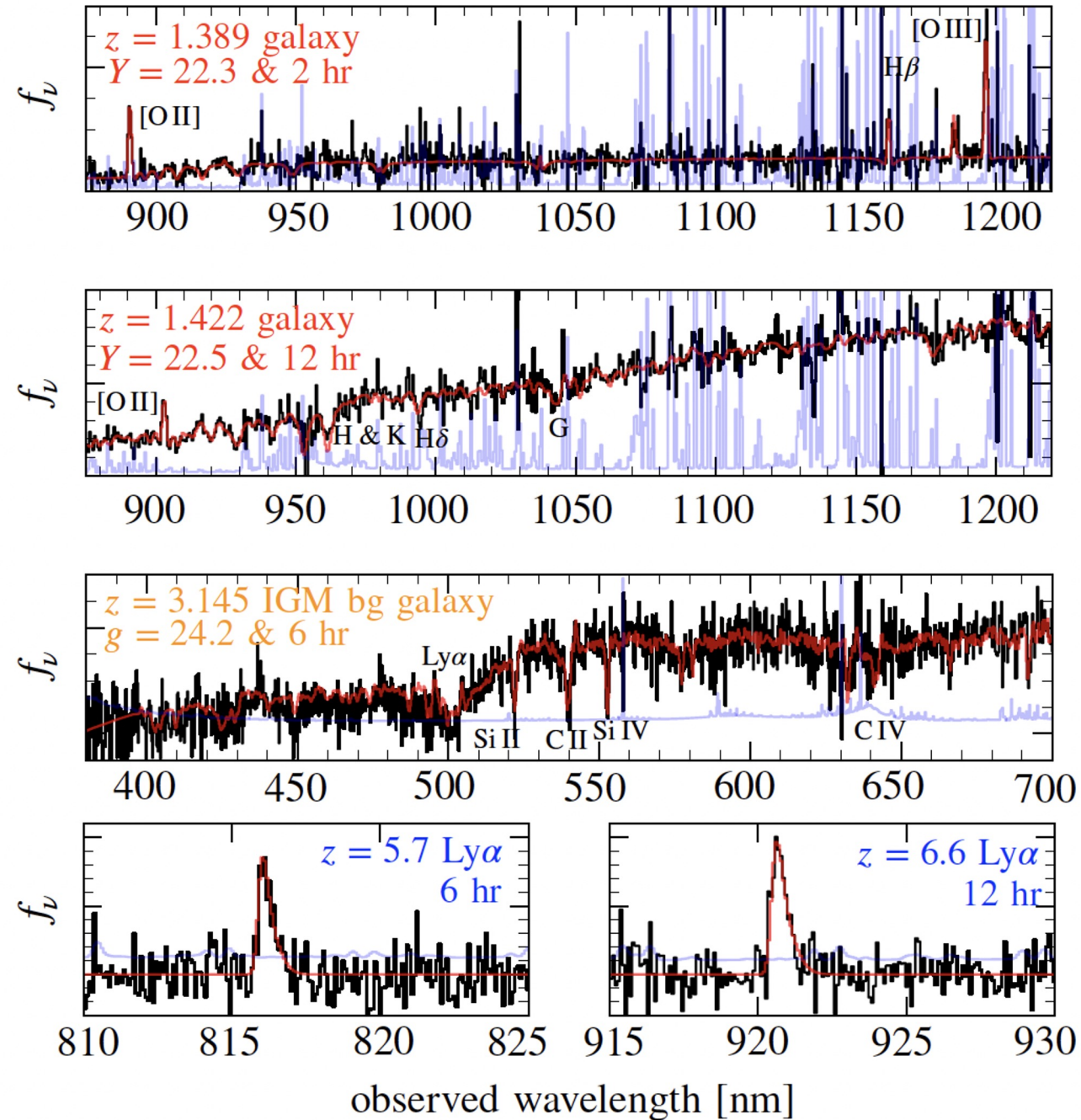
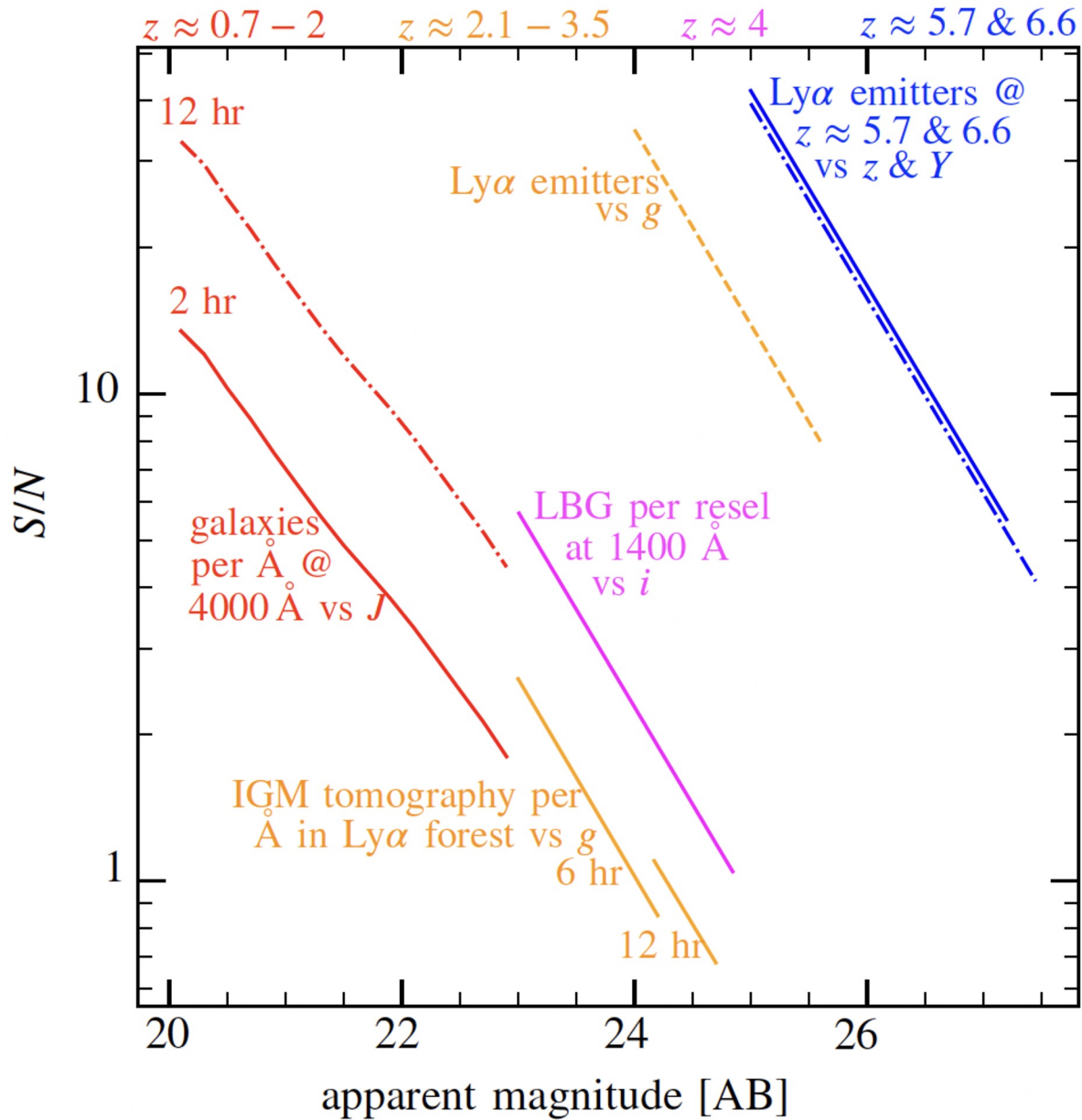


Goulding

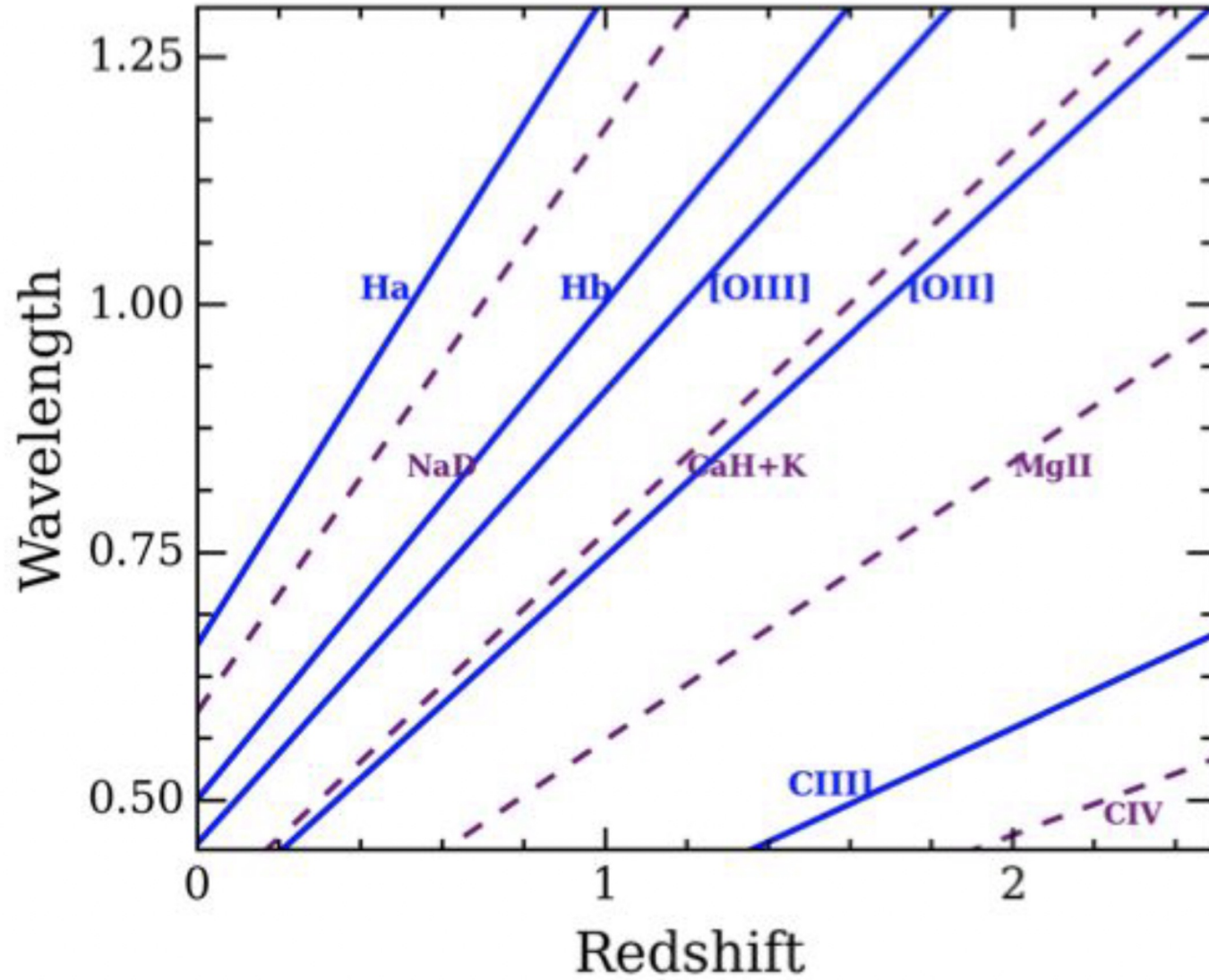
grizy HSC imaging to $1=27$, u-band (CLAUDS), Spitzer and J (< 23.7)

Unprecedented combination: multi-plex, depth, wavelength coverage and spectral resolution





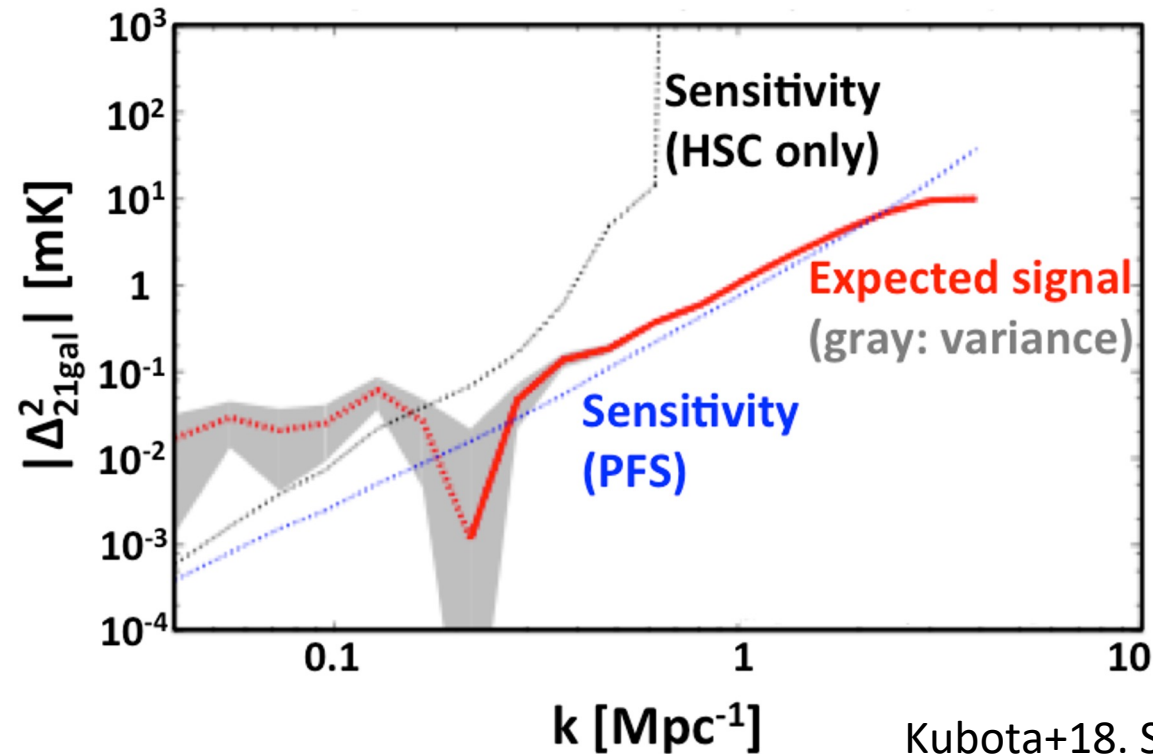
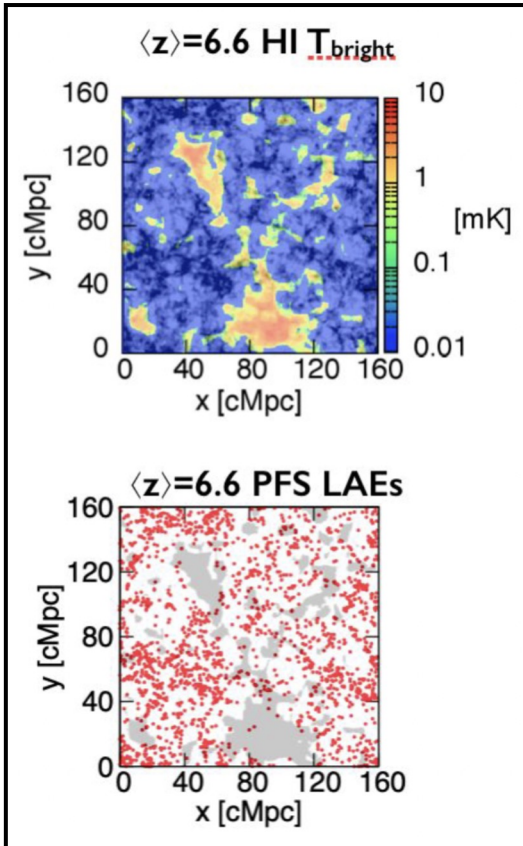
Wide range in redshift for diagnostic emission lines



How was the Universe reionized?

First Detection of EoR HI 21cm Signal by LAE-21cm Cross Correlation

Masami Ouchi



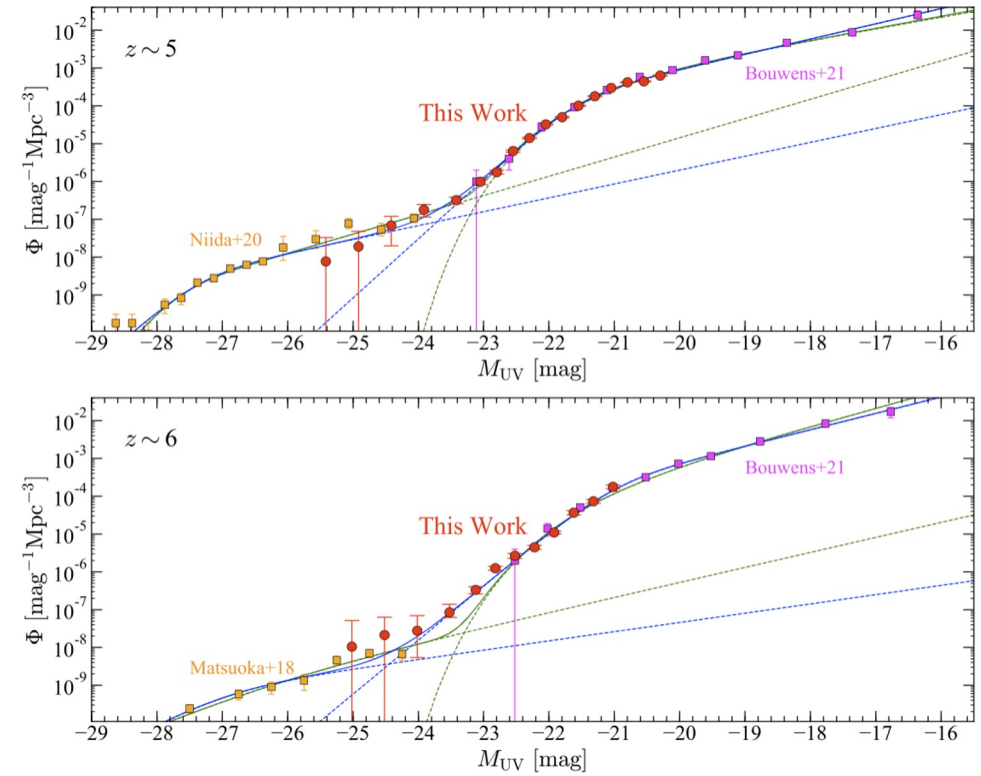
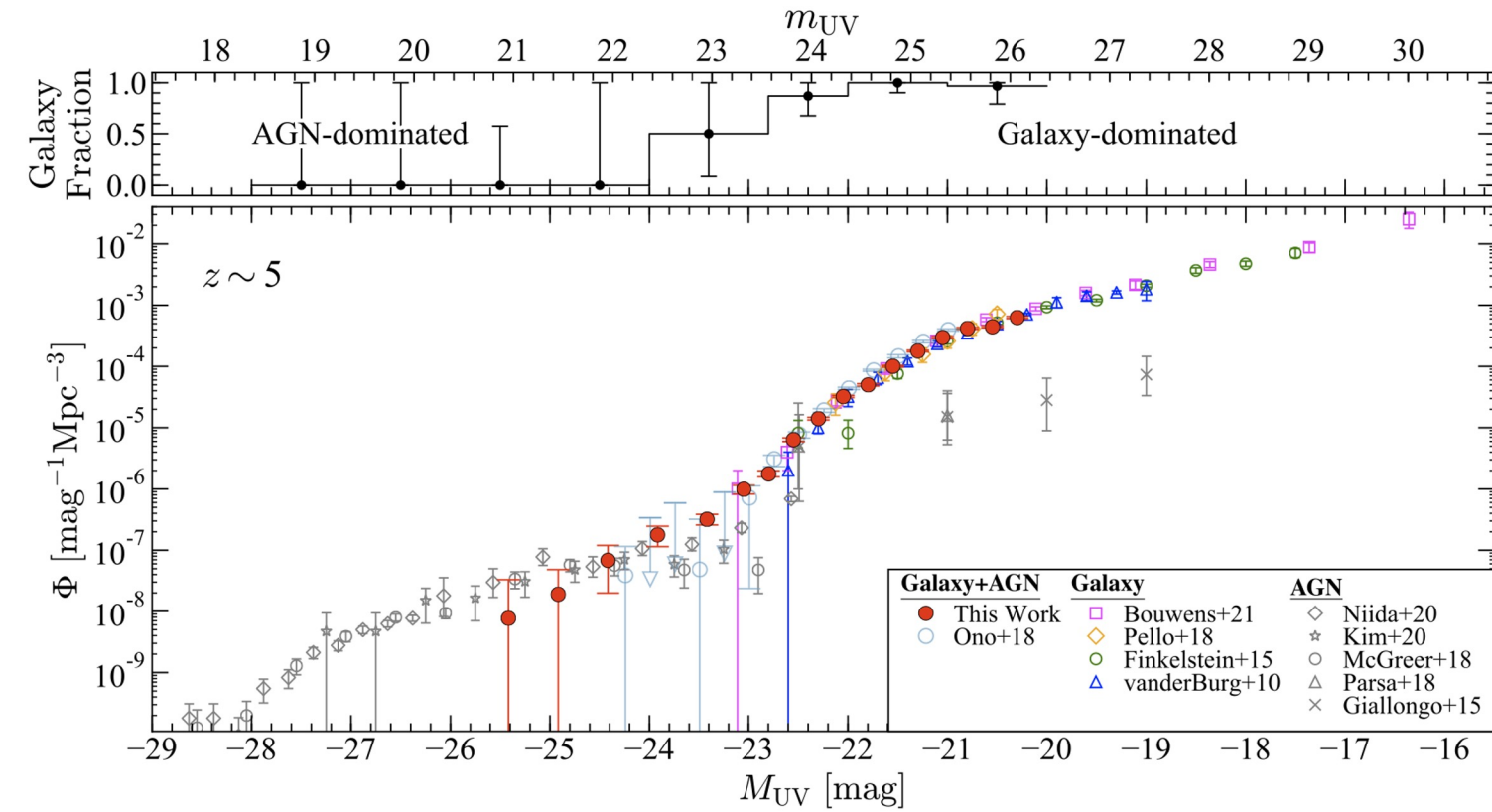
21cm: MWA, SKA

Kubota+18. See similar predictions (Sobacchi&Mesinger+16, Hutter+18)

- Goal-1: Detection of the cross-correlation signals -> Evidence of early cosmic HI structure
 - Positive cross-correlation at $k \sim 0.4 \text{ Mpc}^{-1}$ at ~ 5 sigma
 - Negative cross-correlation at $k \sim 0.1 \text{ Mpc}^{-1}$ at ~ 3 sigma
- Goal-2: Determination of the CPST scale at $z=6.6$ with $\Delta k \sim 0.1$ accuracy
 - First definitive evidence of cosmic ionized bubbles

Bright-End UV LF ($2 < z < 7$)

AGN vs. Star-formation

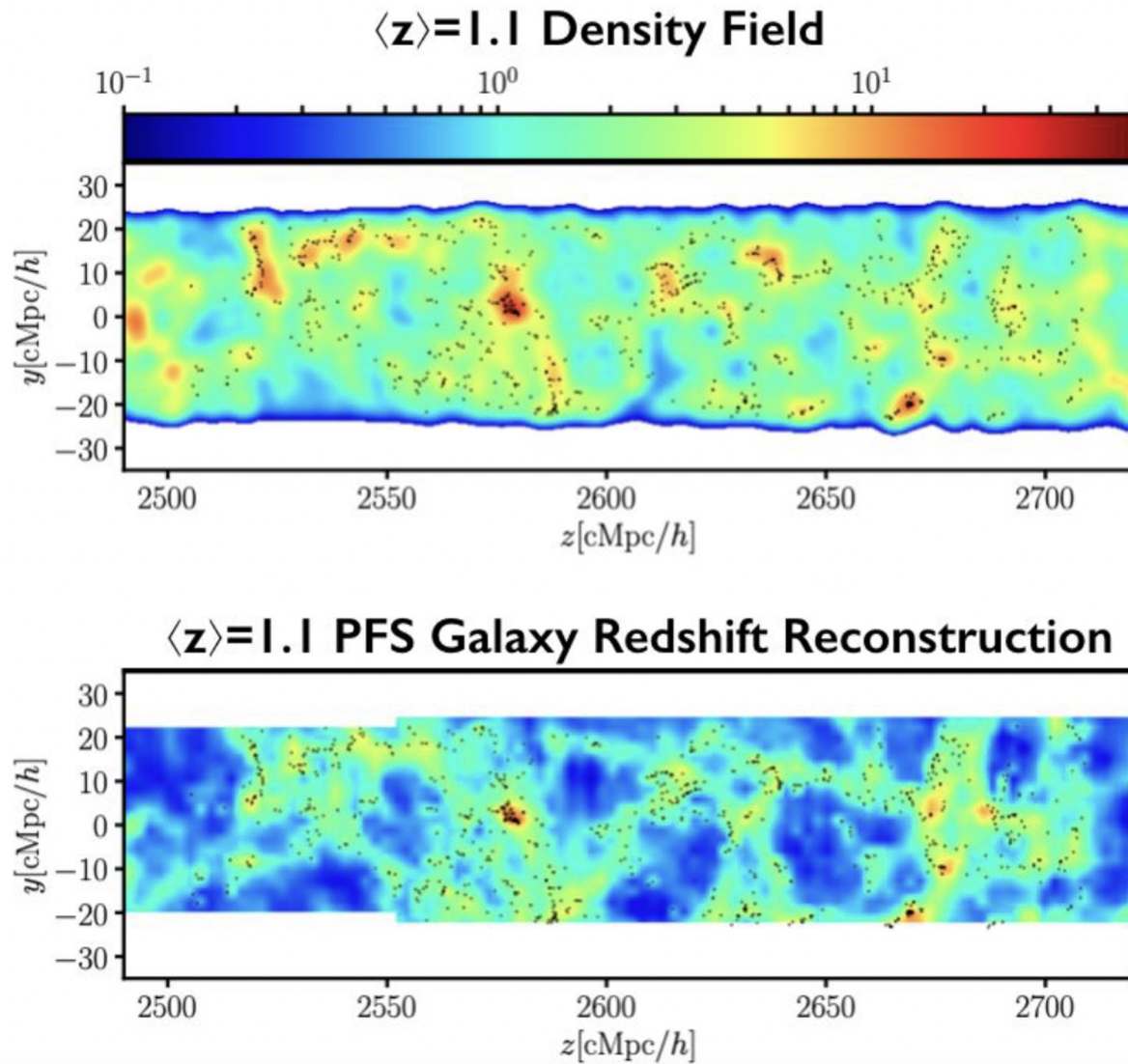


Harikane et al. 2022

~ 4 million galaxies at $z \sim 2-7$

Galaxies and their dark matter halos

Characterization of the large-scale environment

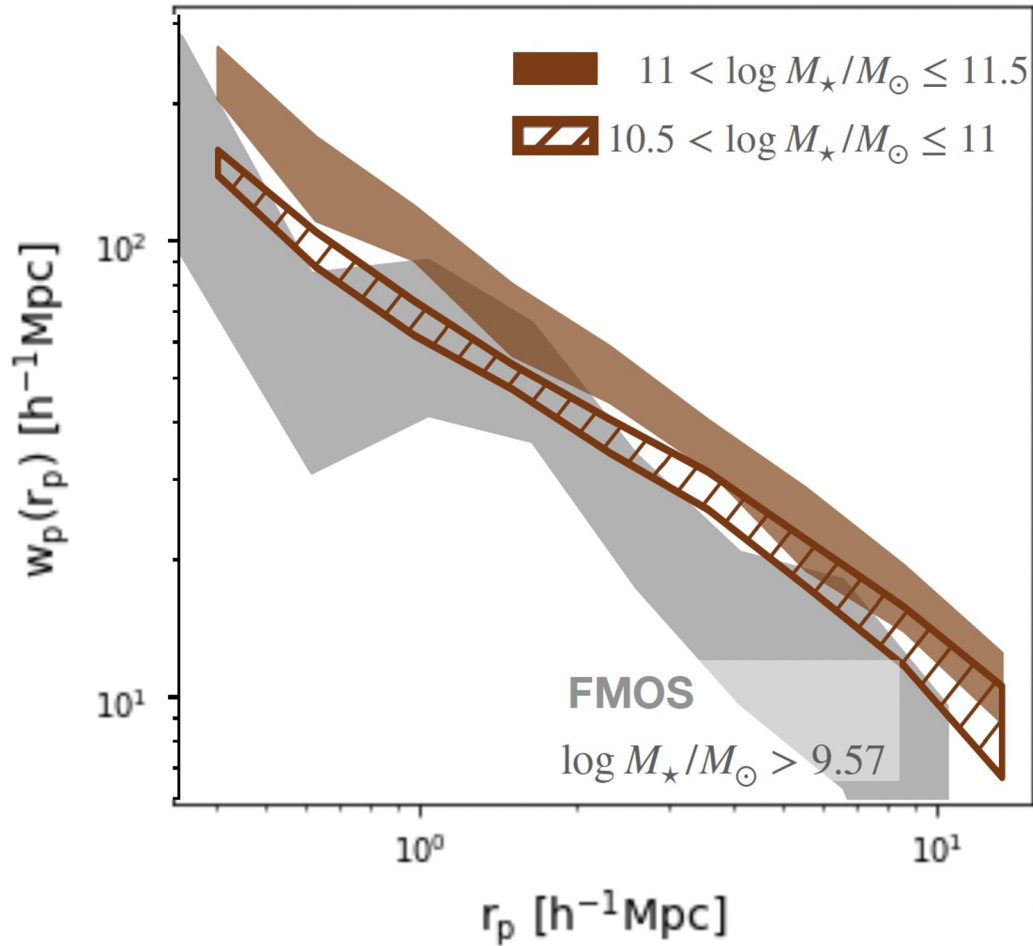


Large Scale Structure

Component of the Web	Expected Number
$M_{\text{halo}} > 10^{13}$	2200
$M_{\text{halo}} > 10^{13.5}$	450
$M_{\text{halo}} > 10^{14}$	35
Voids ($z < 2, r > 7$ cMpc)	132,000
Voids ($z < 2, r > 20$ cMpc)	3,000
Voids ($z > 2, r > 7$ cMpc)	1000
Protoclusters ($2 < z < 6$)	100

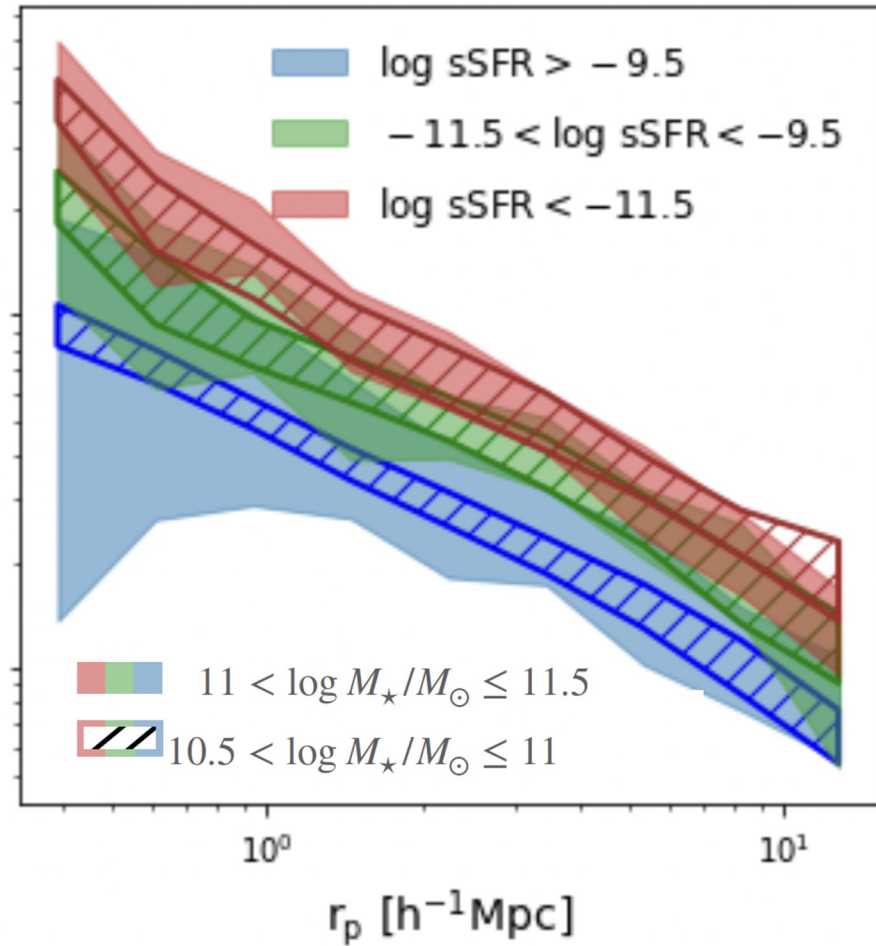
Standard HOD Model

$$P(M_{\star} | M_{halo})(M_{\star})$$



Model with Assembly Bias

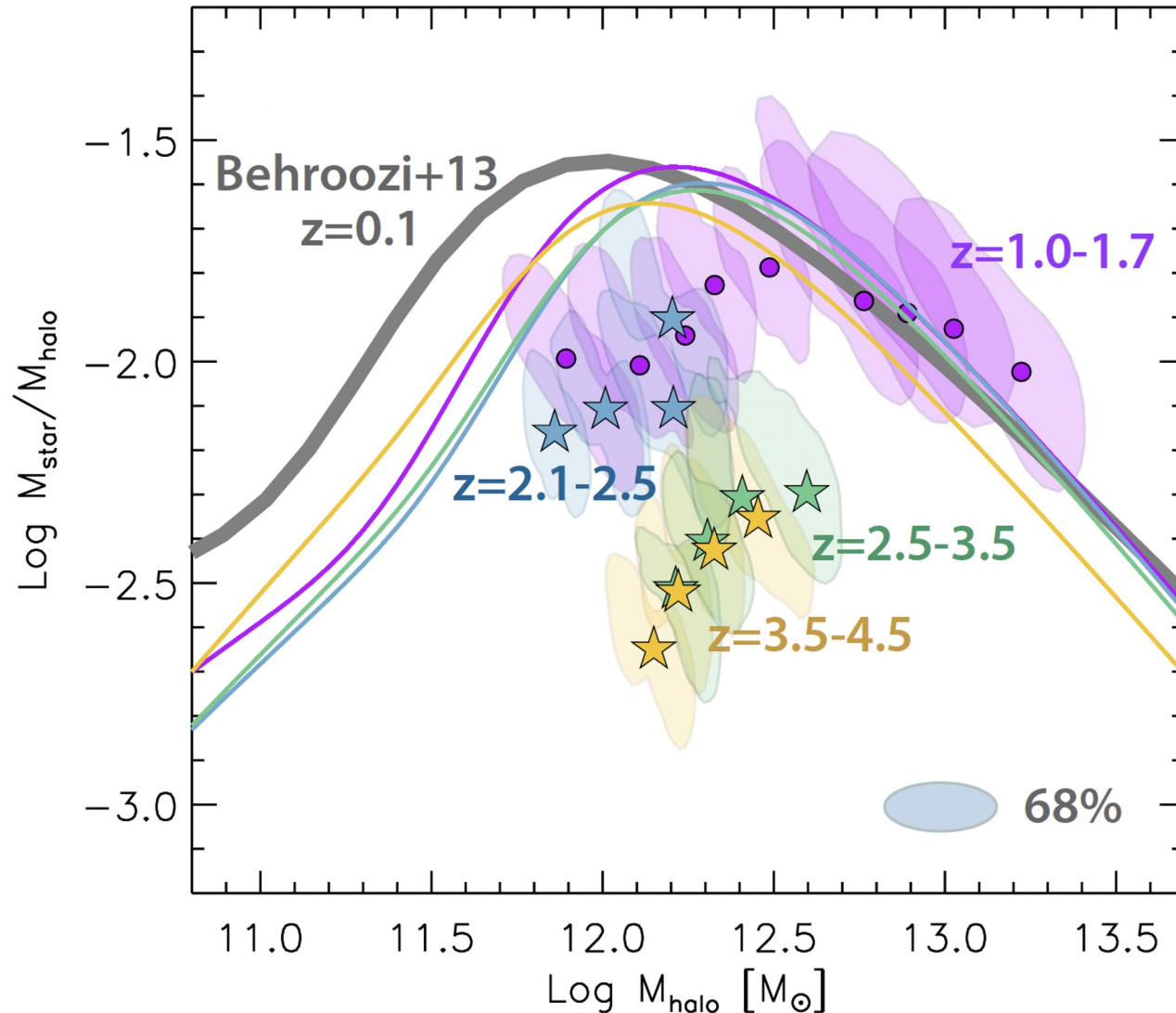
$$P(M_{\star} | M_{halo})(M_{\star}, sSFR | M_{halo}(t))$$



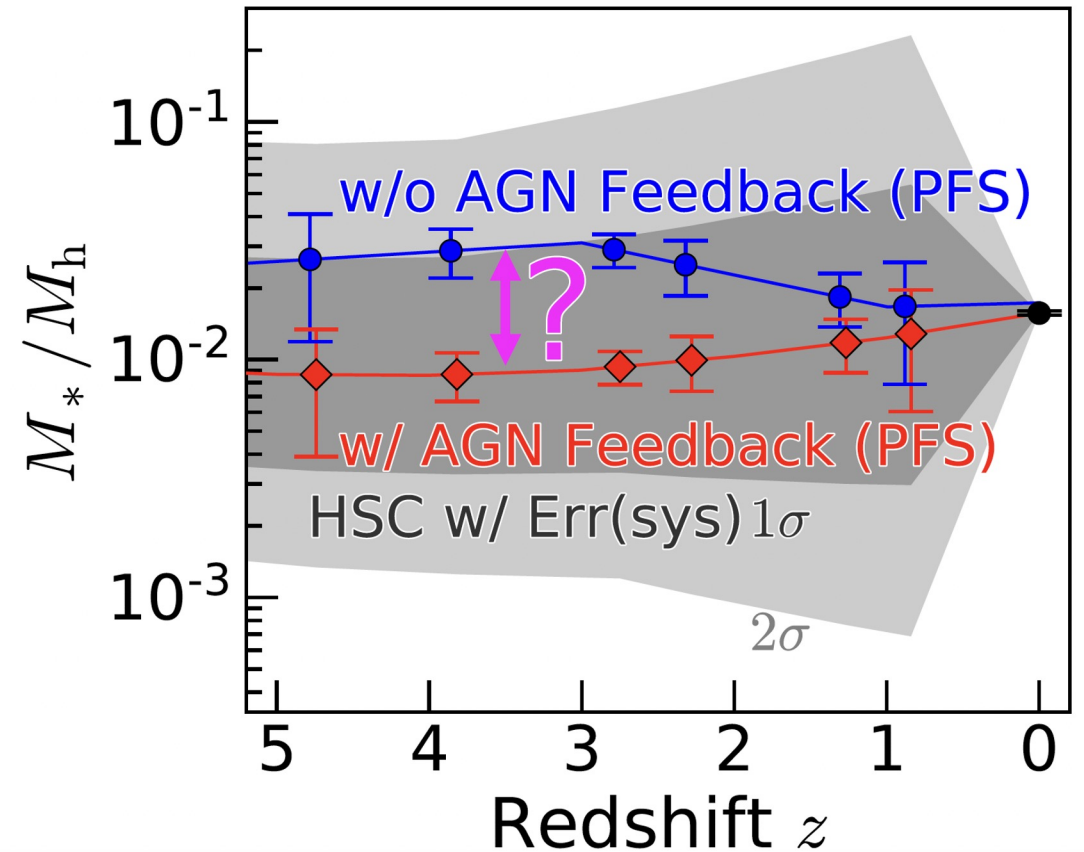
Connection between galaxies and structure formation

Stellar-to-halo mass (M^*/M_h) ratio with the model comparisons over $z \sim 1 - 5$

Daichi Kashino (Nagoya)

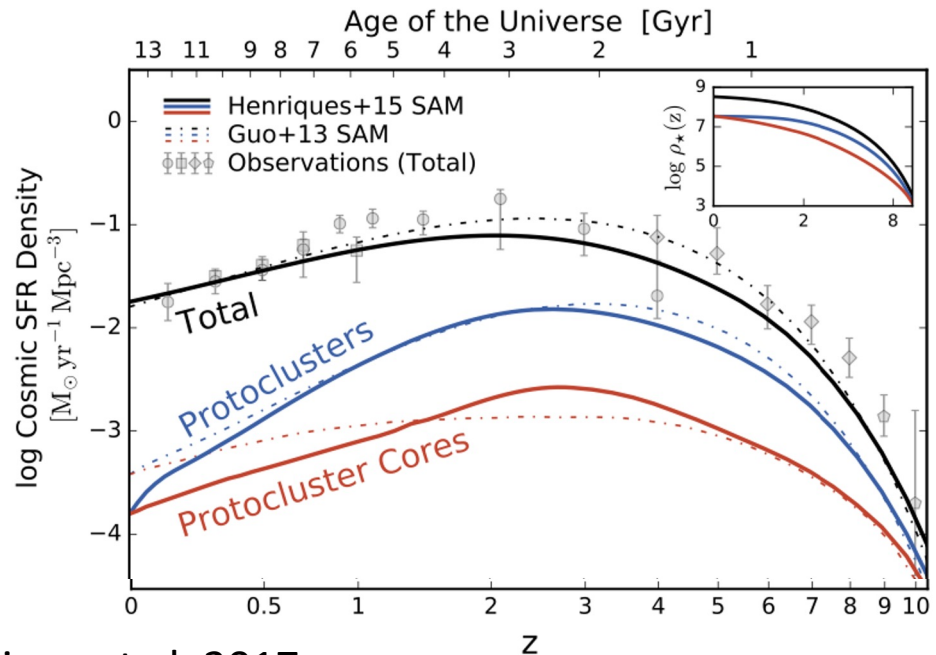
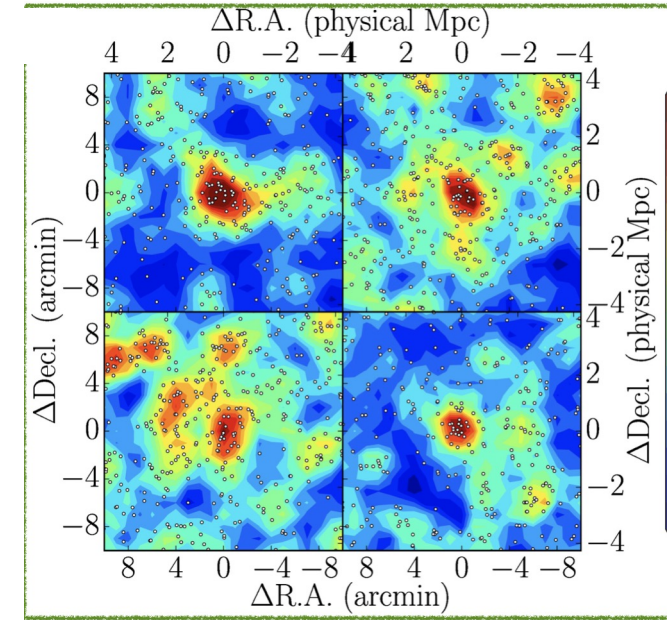
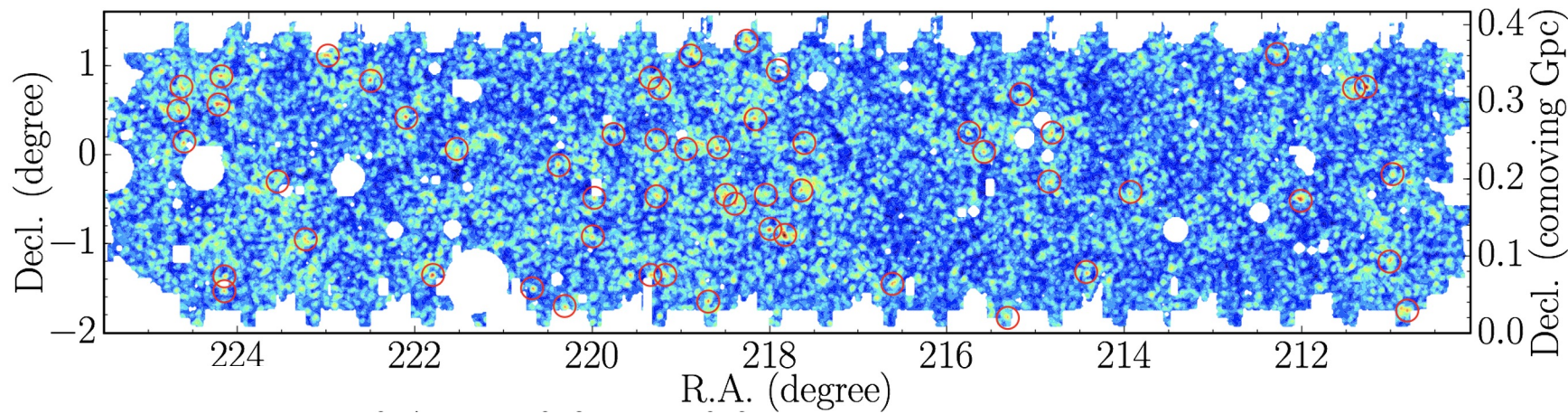


Yuichi Harikane (Univ. of Tokyo)



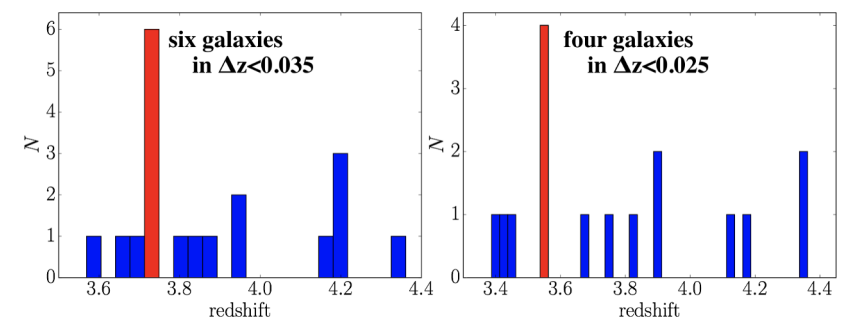
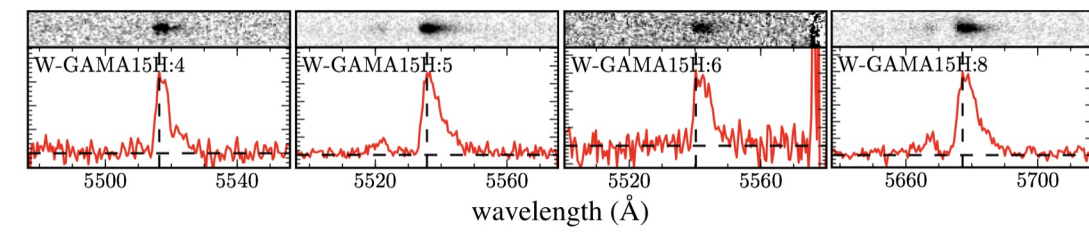
Proto-clusters at $z \sim 4$ with HSC

Toshikawa et al. 2018



Chiang et al. 2017

Followup spectroscopy

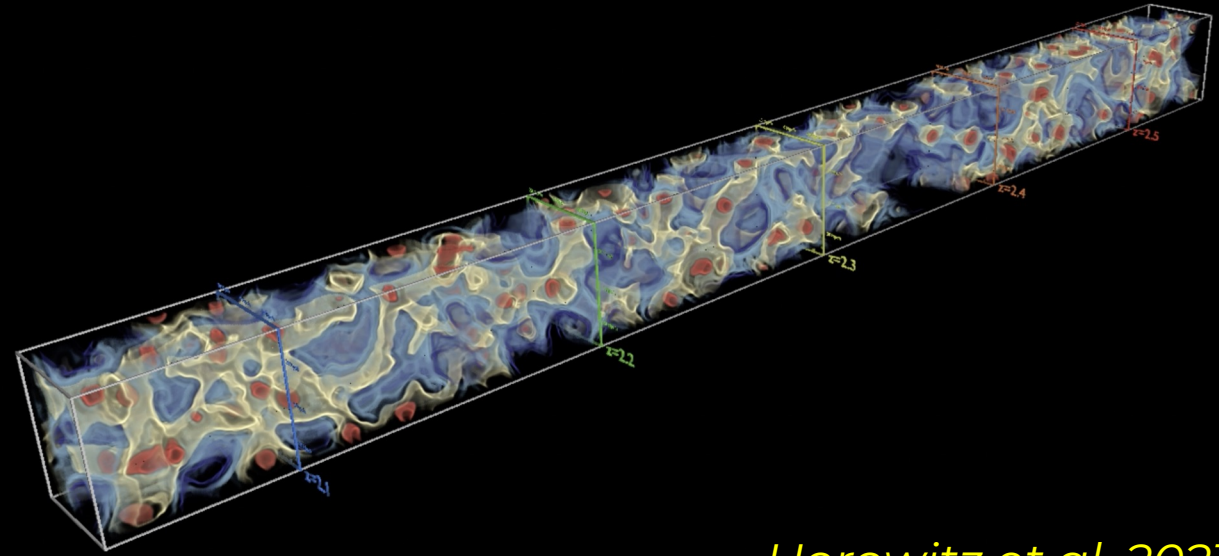


Galaxies within the large-scale gas distribution

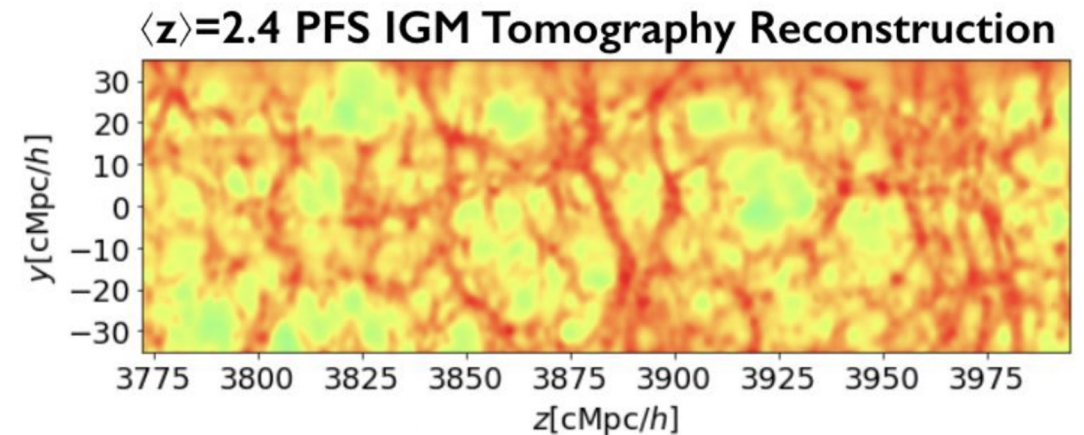
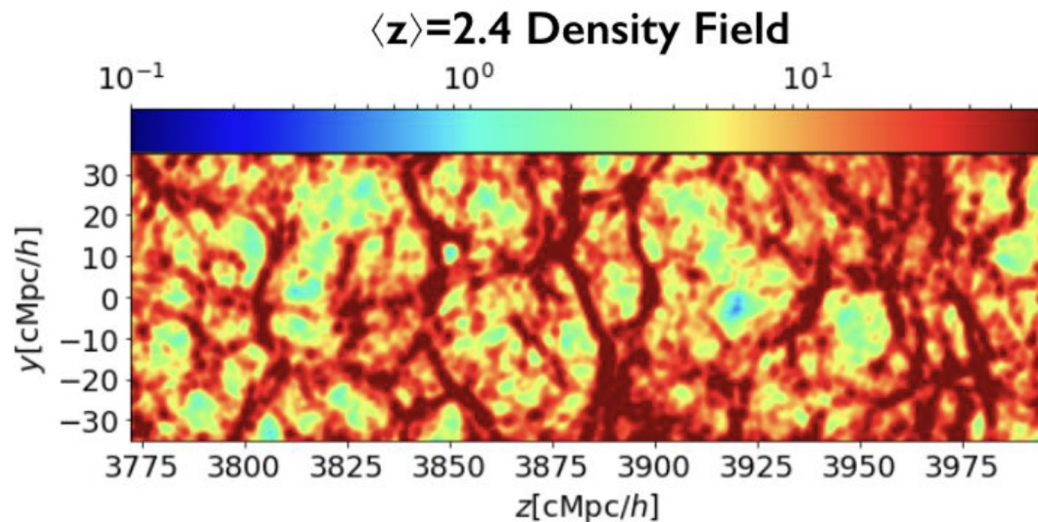
IGM Tomography

- Lyman- α forest absorption in background spectra from HI in the IGM
- Observe 970 galaxies per deg^2 probing $2.1 < z < 2.5$ IGM
- Sightline separation of 4.2 cMpc which allows 3D tomographic reconstruction on similar scales!
- Unique reconstruction of the cosmic web at $z \sim 2.5$ (Lee & White 2016)

CLAMATO Survey with Keck (Lee et al 2017)



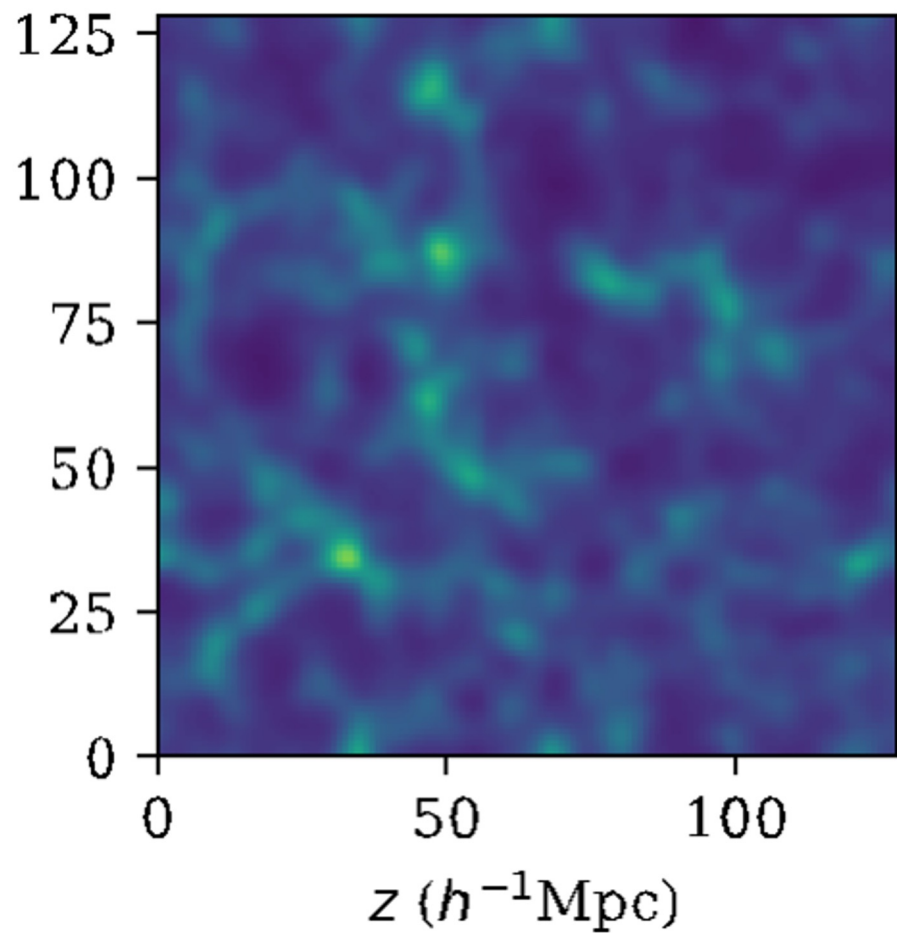
Horowitz et al. 2021



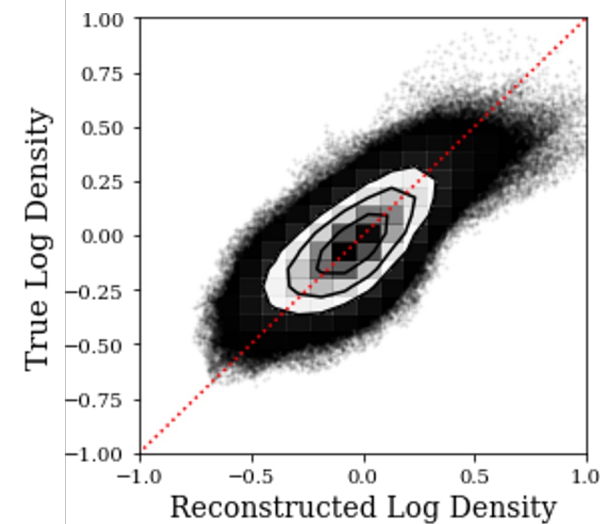
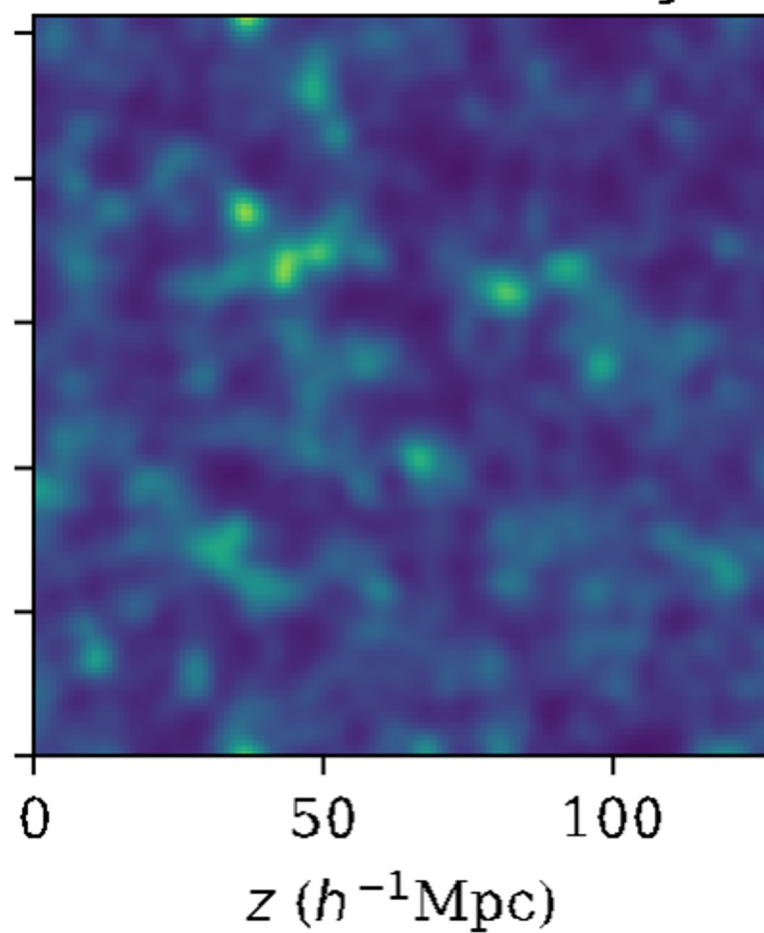
Zoom-in comparison

Ben Horowitz, K. G. Lee

Truth



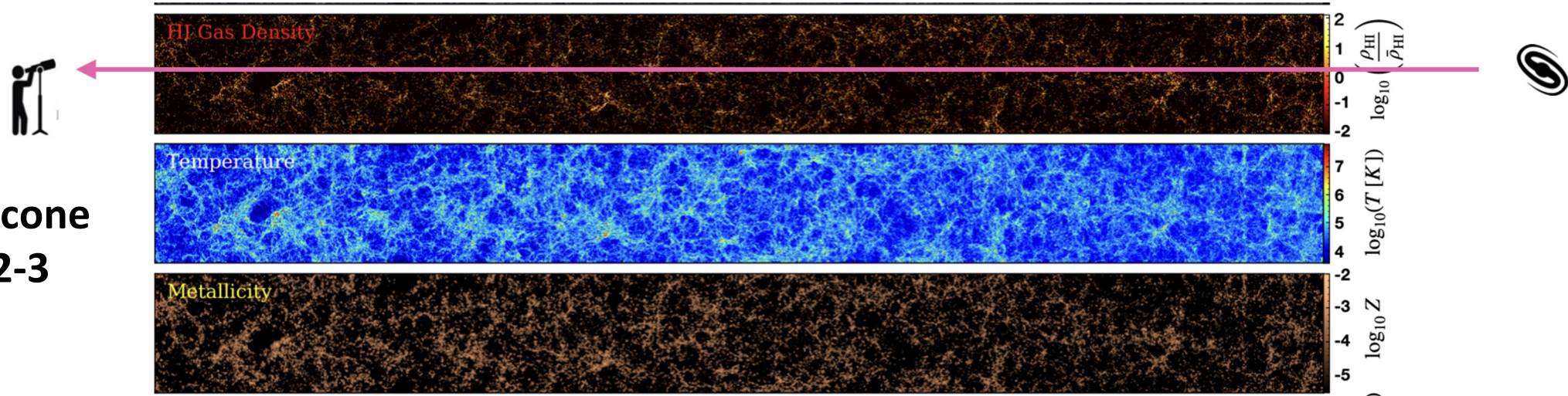
PFS IGM Survey



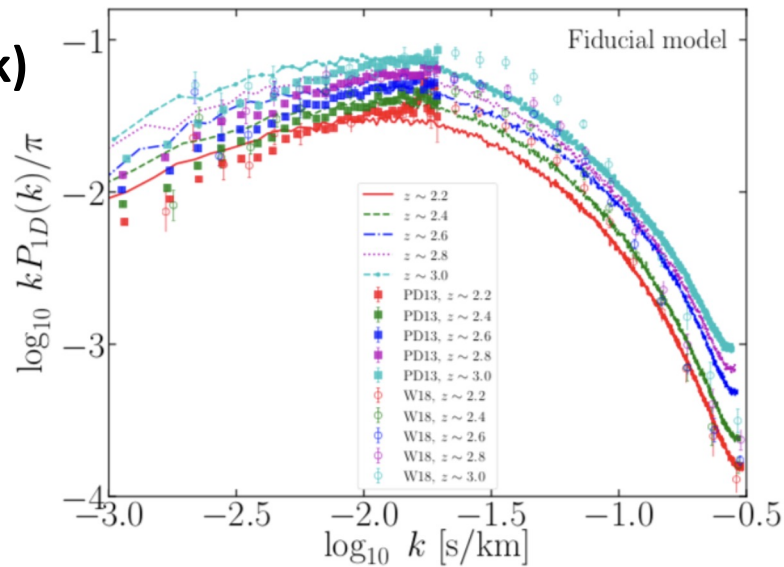
IGM Tomography & Galaxies

Osaka simulations
Nagamine et al. 2021

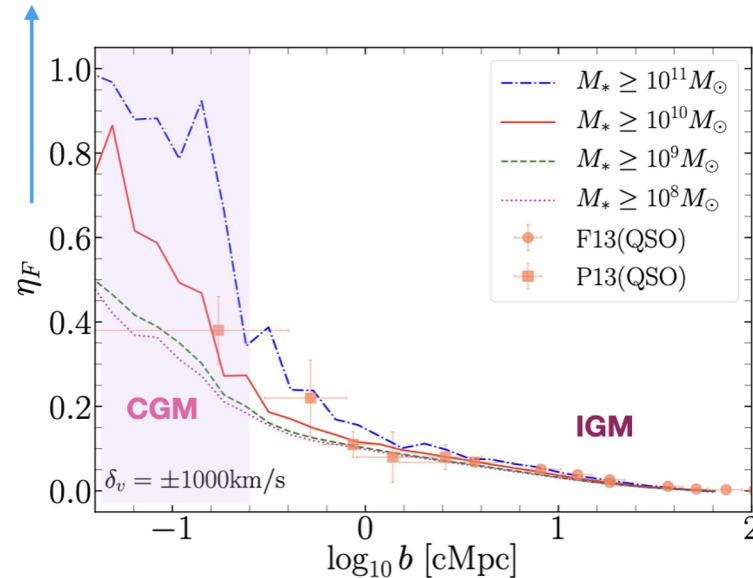
Comparison w/ more realistic hydro simulation including SF & feedback.



1D Ly α P(k)



Stronger HI absorption



Impact Parameter from galaxies

Cross-correlation btw gal, HI, metals

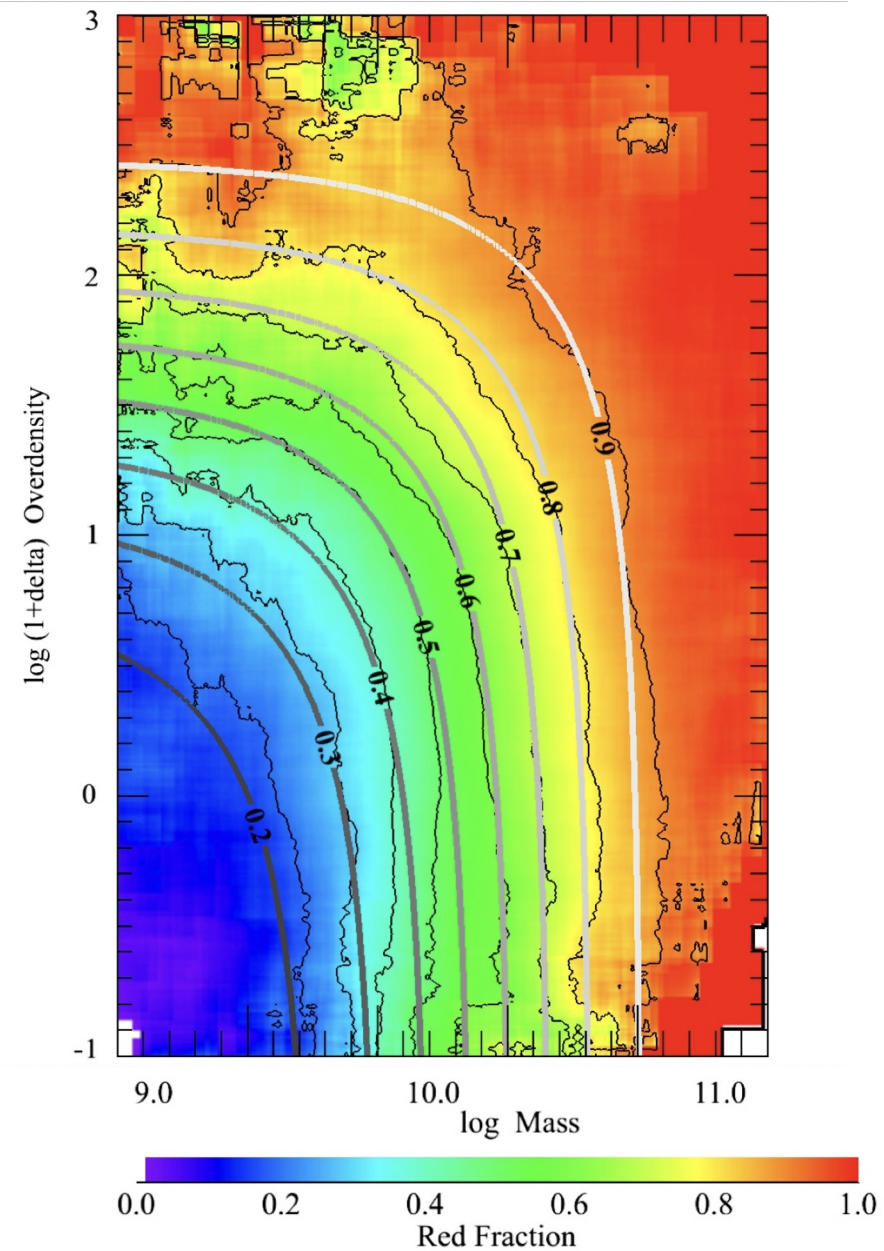
Flux Contrast

$$\eta_F \equiv -\delta_F = 1 - \frac{F}{\langle F \rangle}$$

$$F = e^{-\tau}$$

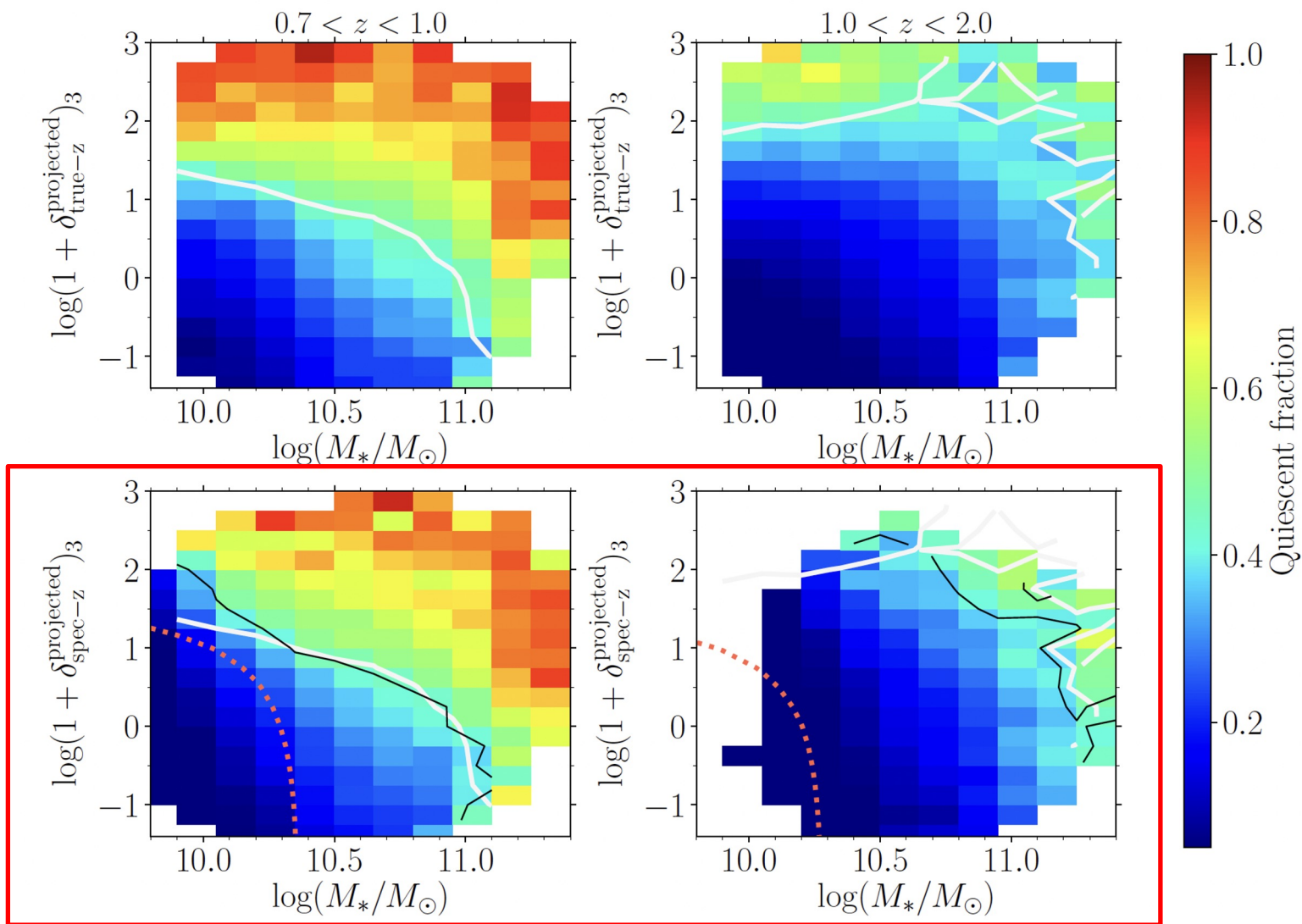
Internal properties of galaxies

SDSS (Peng et al. 2010)



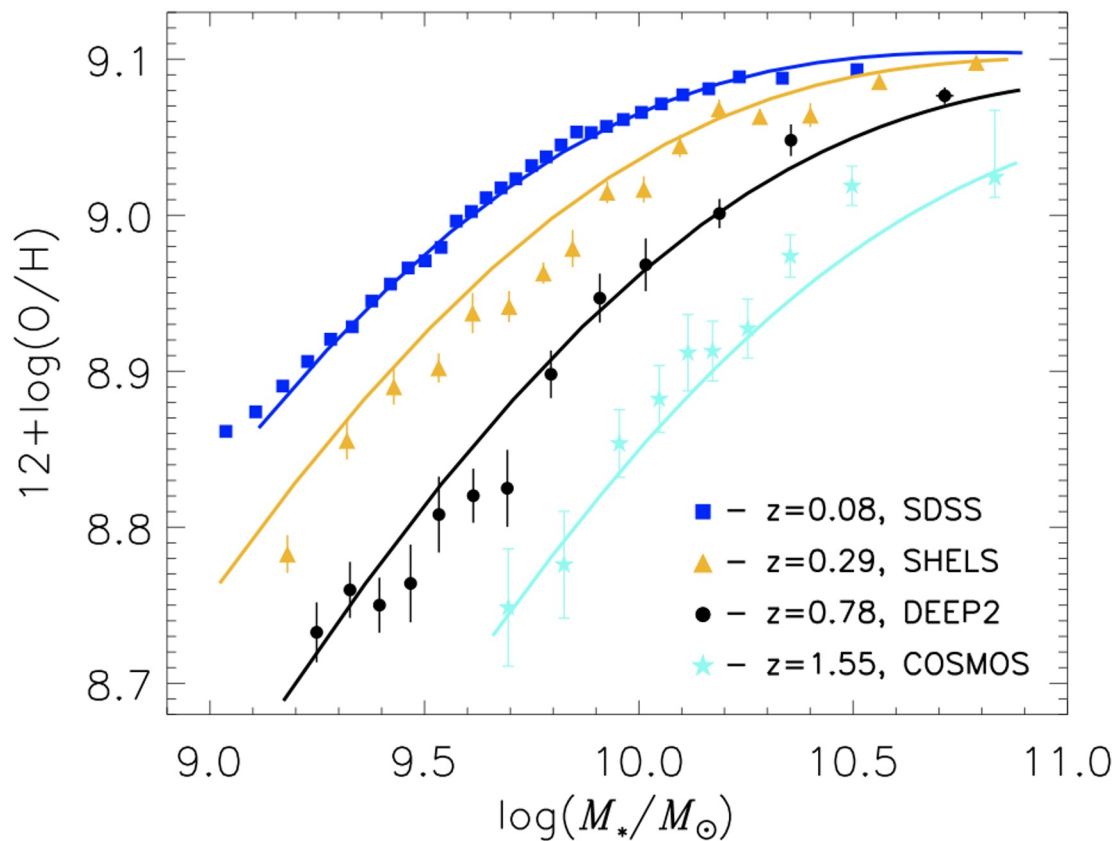
Quenching

Predictions for PFS



Chemical enrichment (strong line diagnostics)

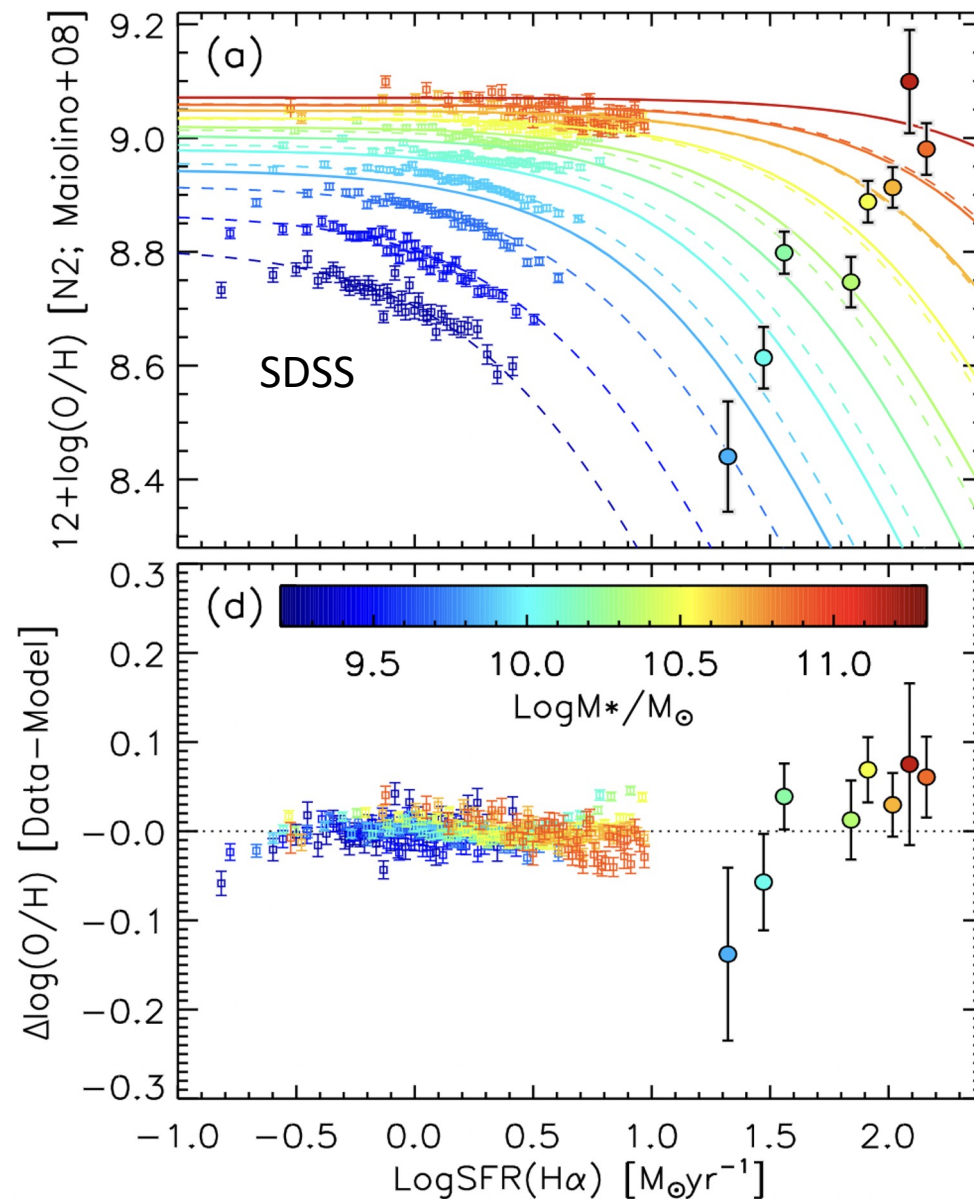
Kashino et al. 2017
FMOS-COSMOS



Zahid et al. 2014

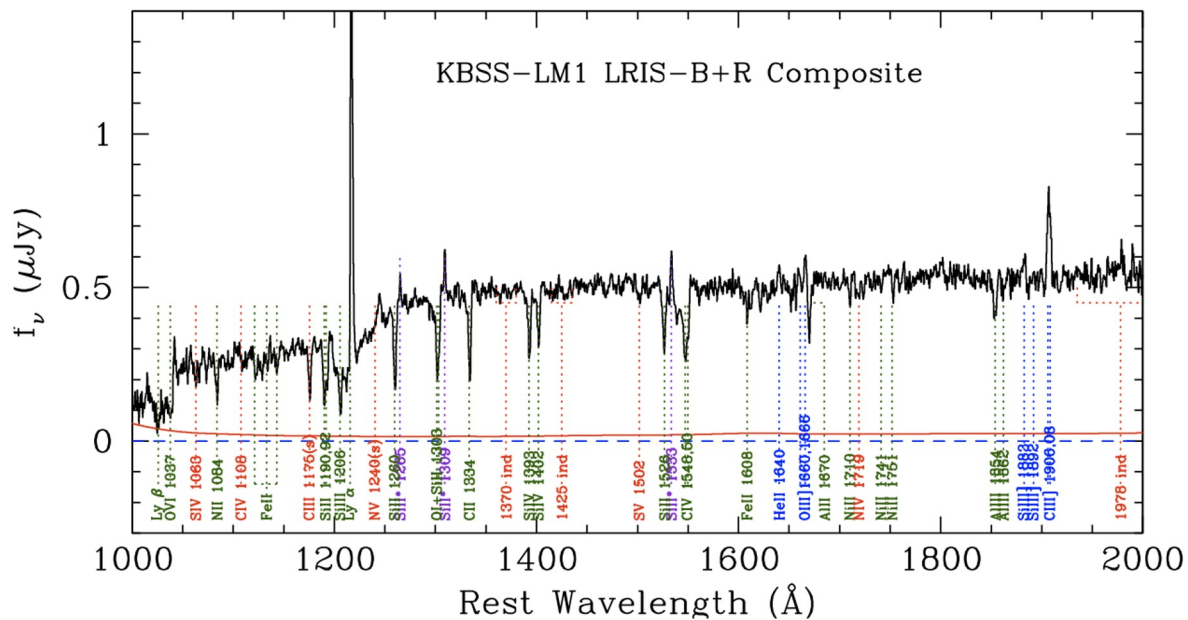
e.g., Tremonti et al. Sanders et al. 2021; Strom et al. 2022

(see Maiolino & Mannucci 2019 for a review)

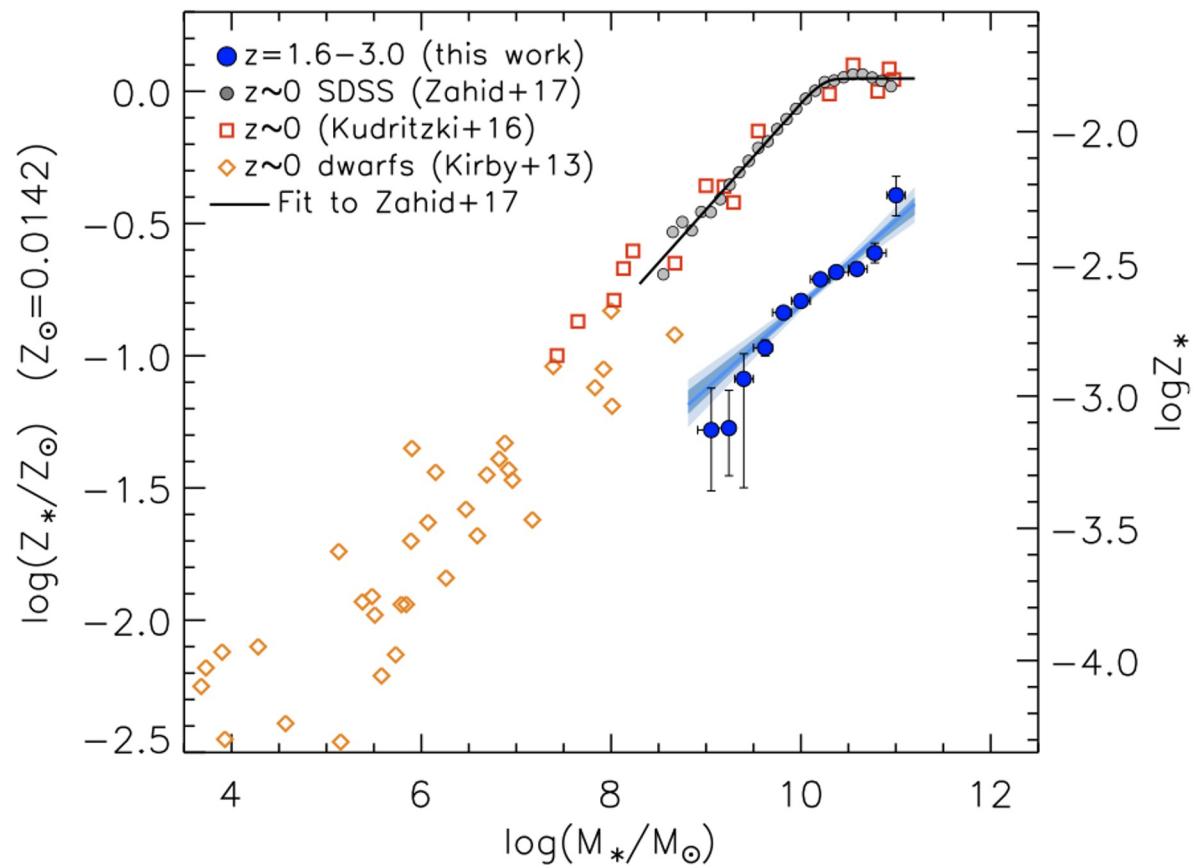


Rest-frame UV spectra and stellar metallicities

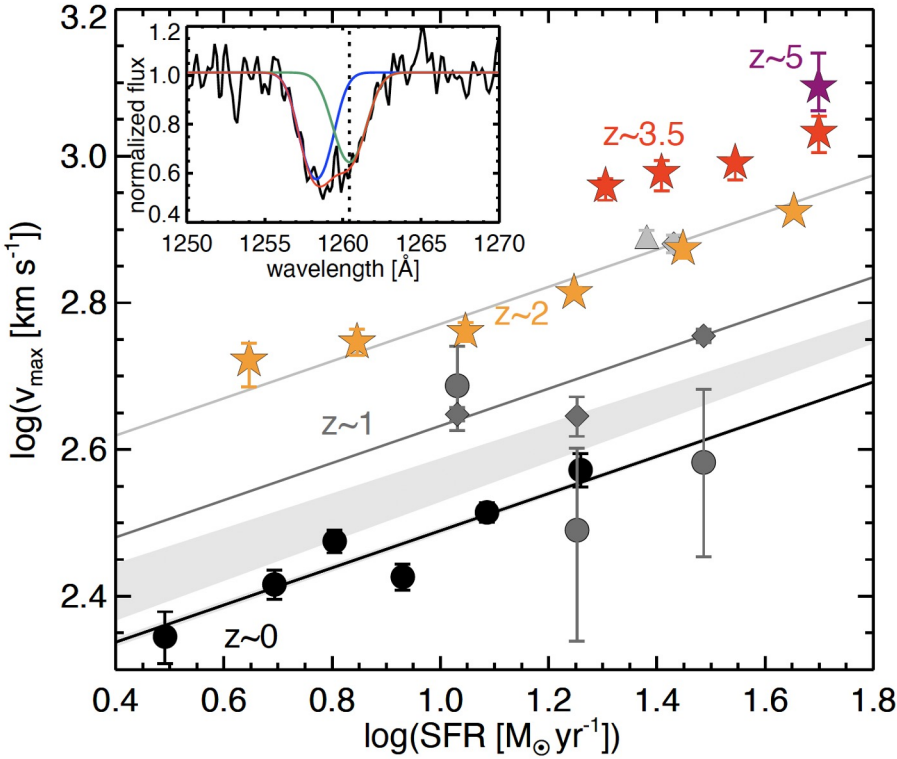
Steidel et al. 2016



zCOSMOS Deep (Kashino et al. 2021)

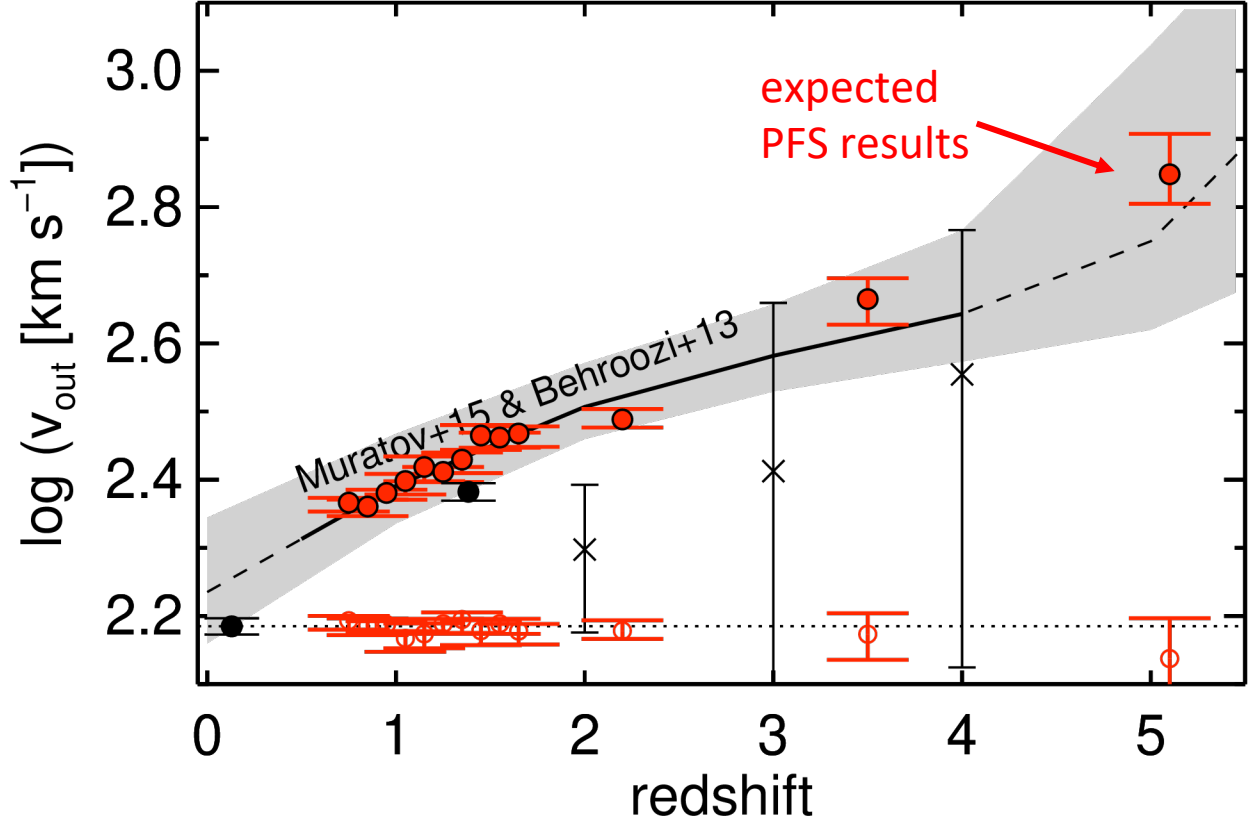


Kinematics and outflows



Yuma Sugahara

Outflow velocity (halo circular velocity from clustering) evolution for $M^* \sim 10^{10.5} M_\odot$

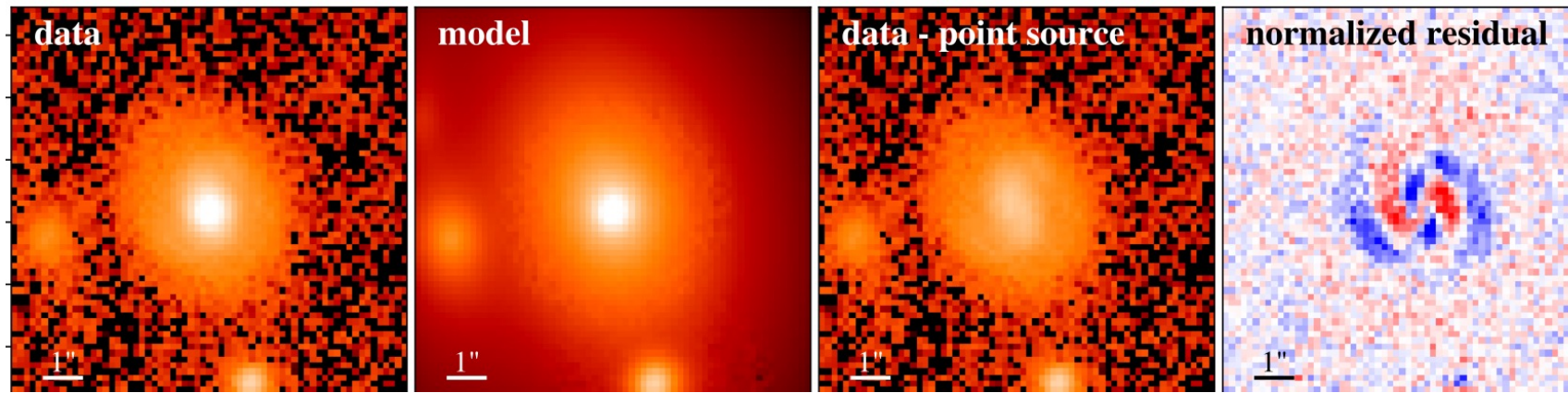


- Outflow velocity (v_{out} [50%] or v_{max} [95%] velocity) over $z \sim 1-5$.
- Testing the hypothesis that the correlation of outflow velocity and circular velocity holds over $z \sim 1-5$, which suggests the halo mass density increase towards high- z .

Final remarks

- Exploit remarkable image quality with Subaru HSC
- AGN science

GaLight arXiv:2111.08721 (Ding et al. 2021)



Li, JDS et al. 2021a,b; JDS, Li & Ding 2022

- Coordination with MOONs ($z > 2$)
- PFS – role in science with ROMAN, Euclid?, Rubin/LSST

Stay tuned for PFS.