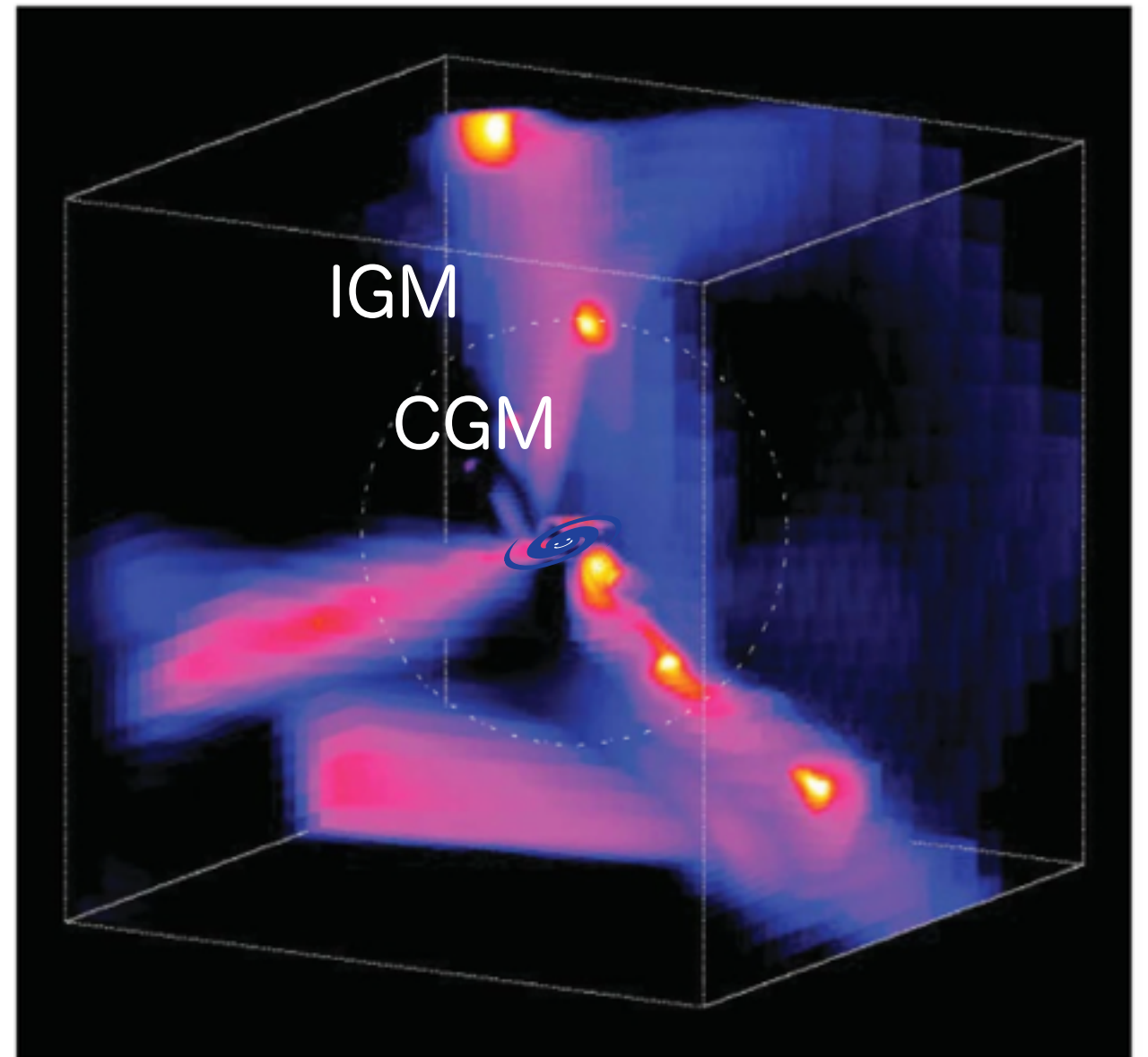
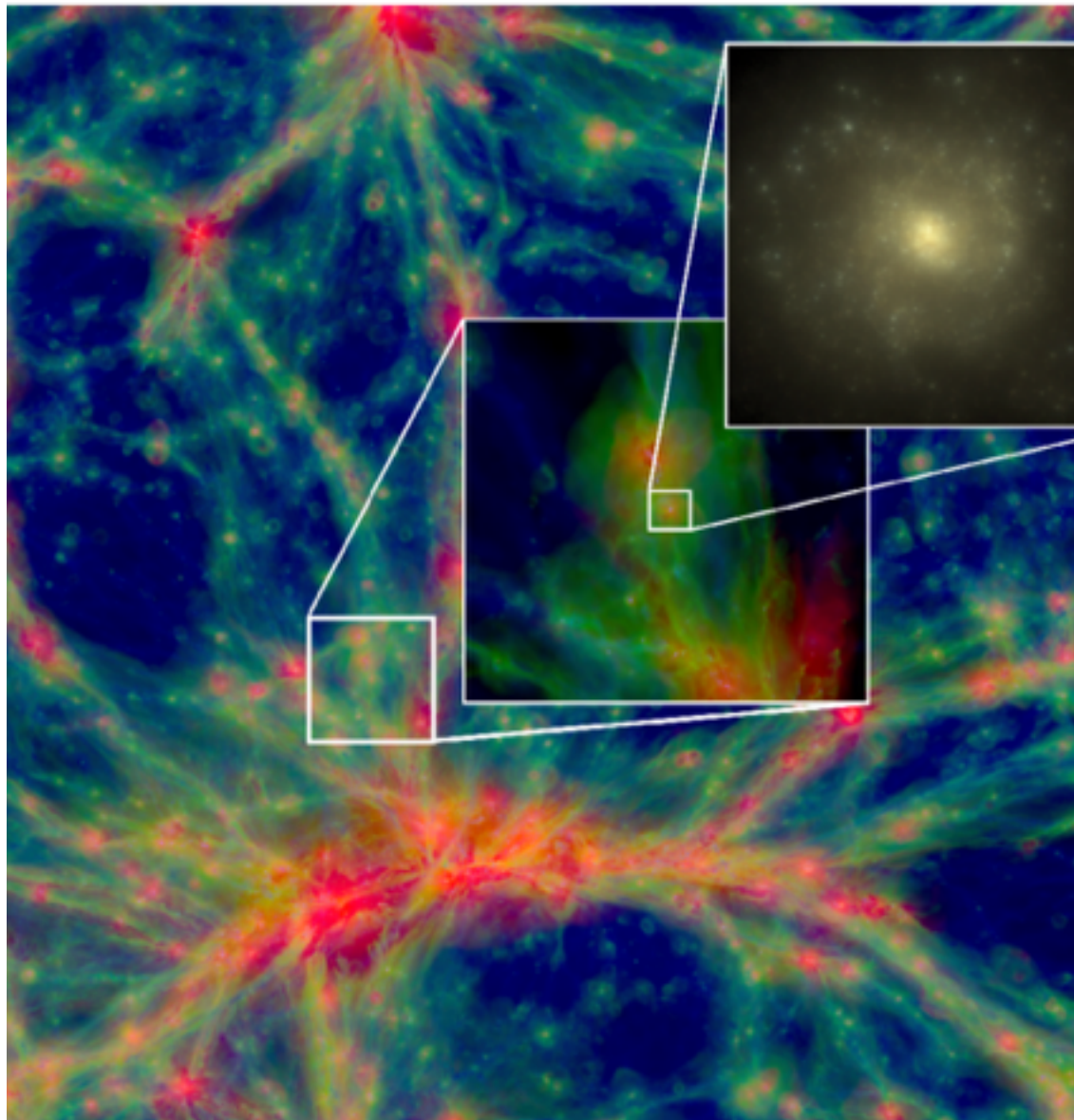


Environmental dependence on galactic properties traced by Ly α absorptions

Rieko Momose (JSPS/U.Tokyo)
✧ Momose et al. 2020a, b
(arXiv:002.07334, 002.07335)

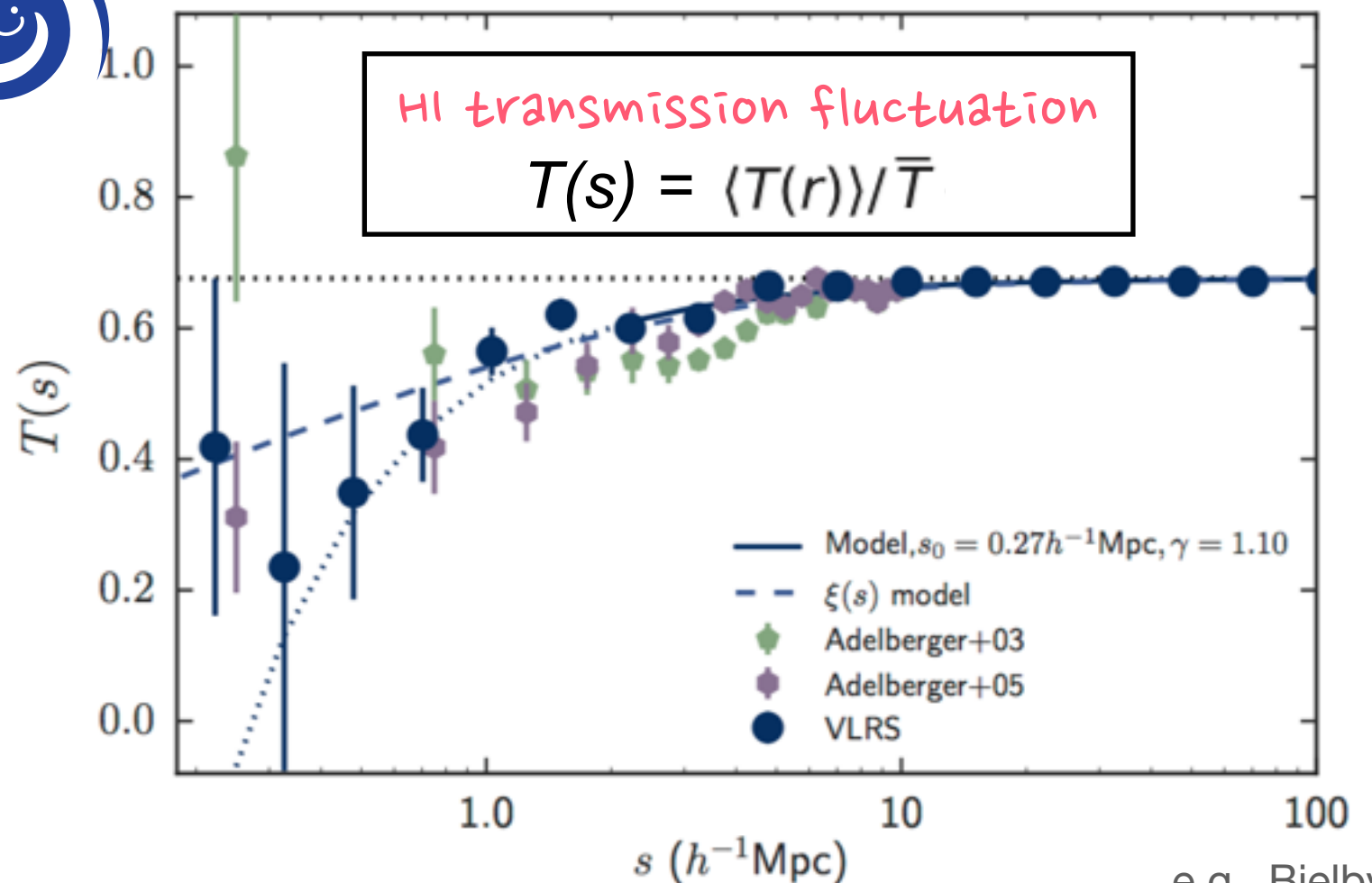
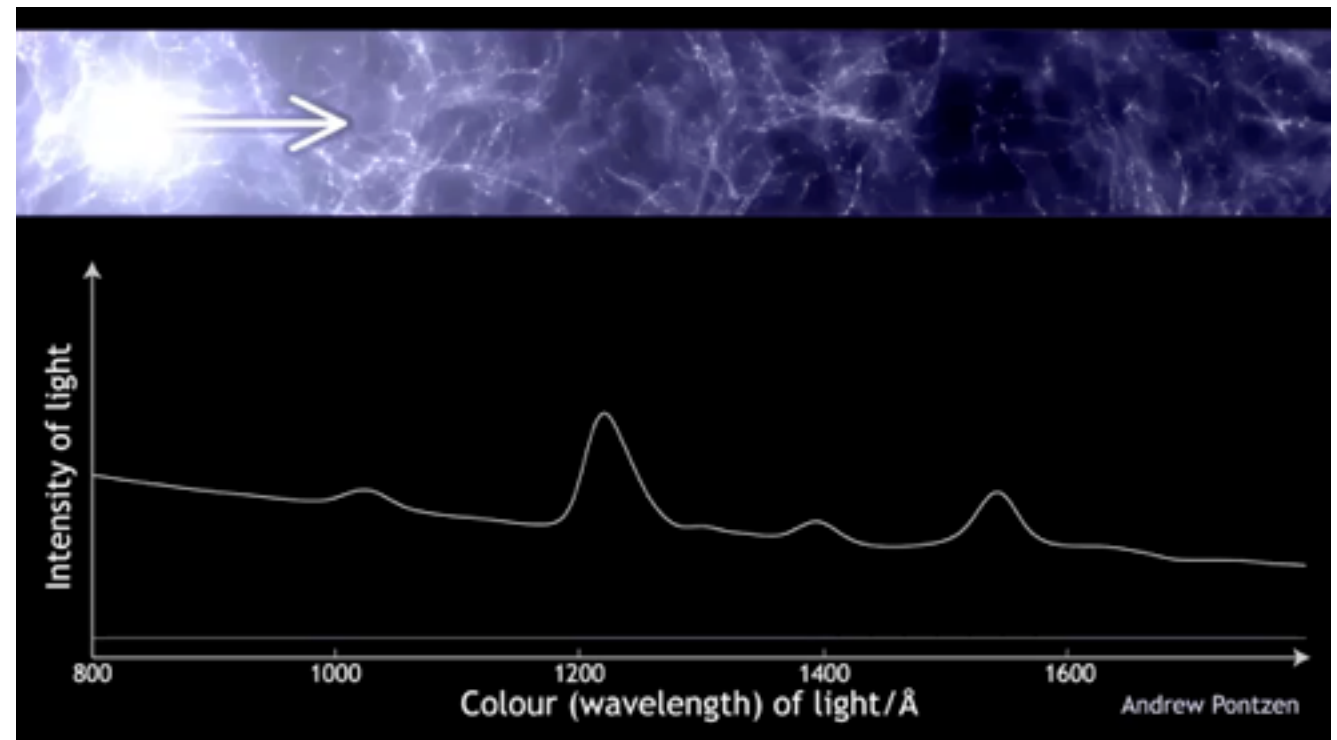
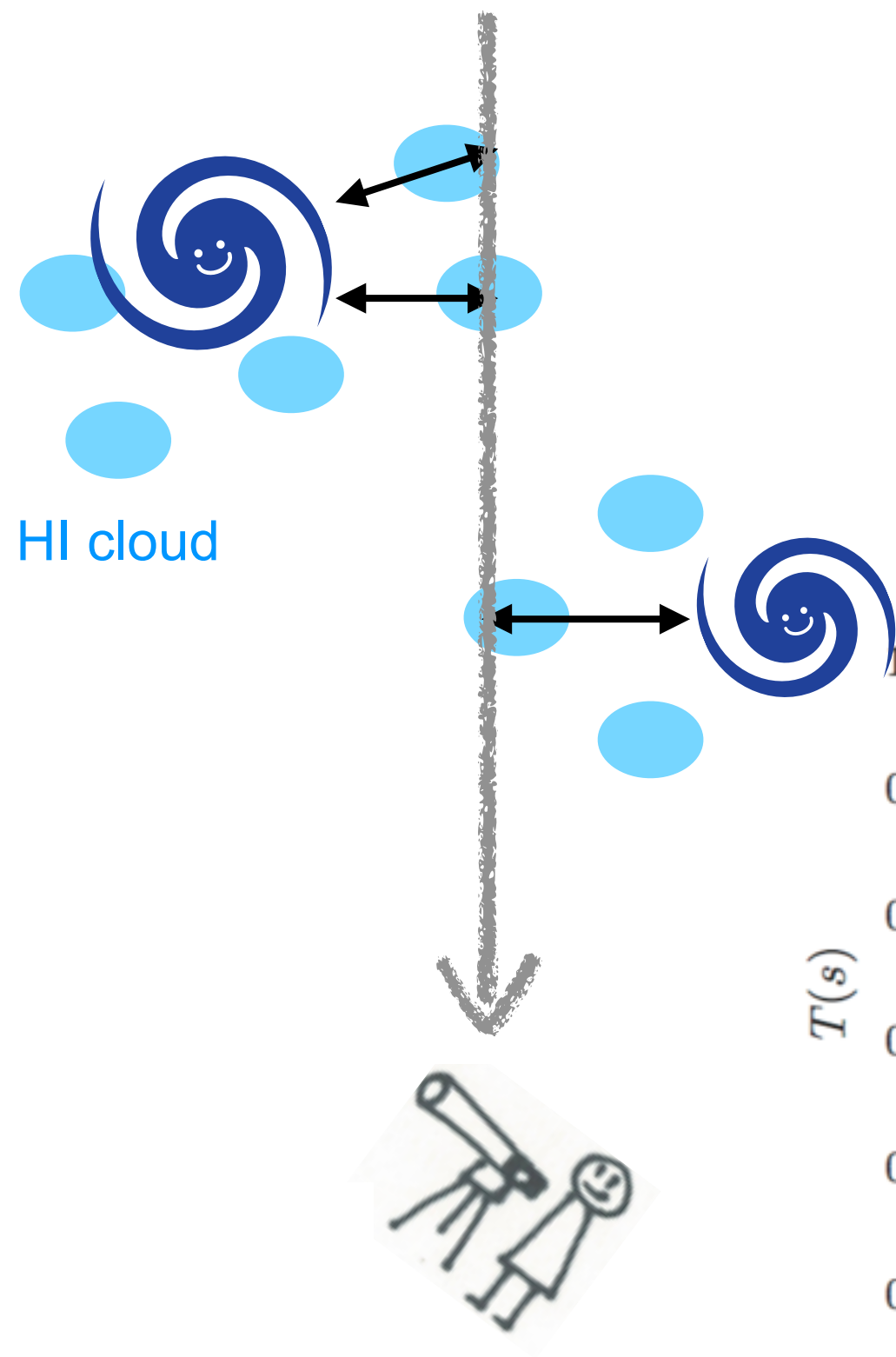
K. Shimasaku (Uinv. Tokyo), K. Nagamine (Osaka Univ.), I. Shimizu (NAOJ),
N. Kashikawa (Uinv. Tokyo), K. Nakajima (Uinv. Copenhagen), H. Kusakabe (Uinv. Geneva),
Y. Terao, K. Motohara, M. Ando (Uinv. Tokyo), L. Spitler (Macquarie Univ.)

Galaxy formation in the large-scale structure



- ▶ Galaxy formation occurs within the densest parts of the cosmic web
- ▶ Large-scale dark matter distribution correlates with that of baryon

IGM-galaxy connection probed by cross-correlation analysis



IGM-galaxy connection

◆ What type of galaxies (M_* , SFR) strongly connect to the IGM?

◆ How is the connection vary among different galaxy populations?



Methodology: cross-correlation analysis

- Cross-correlation between HI transmission excess δ_F and galaxies

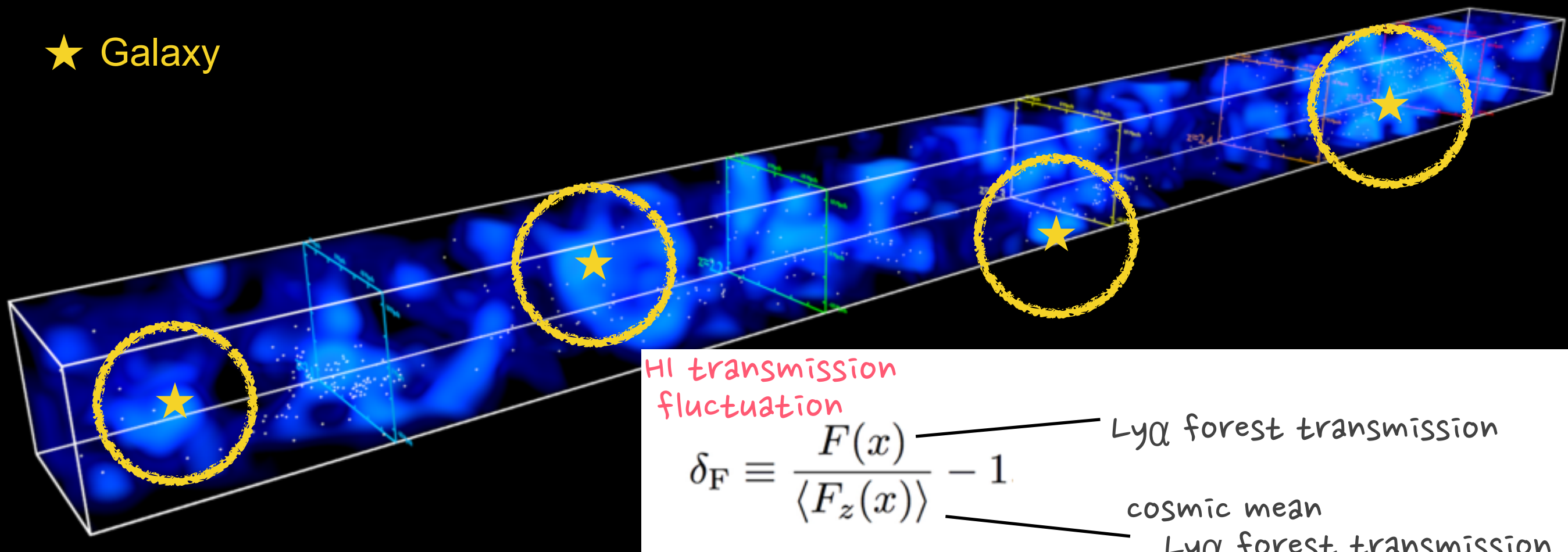
$$\xi_{\delta F}(r) = \frac{1}{\sum_{i=1}^{N(r)} \omega_{g,i}} \sum_{i=1}^{N(r)} \omega_{g,i} \delta_{g,i} - \frac{1}{\sum_{j=1}^{M(r)} \omega_{ran,j}} \sum_{j=1}^{M(r)} \omega_{ran,j} \delta_{ran,j}$$

Galaxies
Random points

HI transmission excess ($\delta_F = F(z) / F_{\cos}(z) - 1$)

- $F(z)$: Ly α forest transmission
- $F_{\cos}(z)$: Cosmic mean Ly α forest transmission (Faucher-Giguère+08)

★ Galaxy



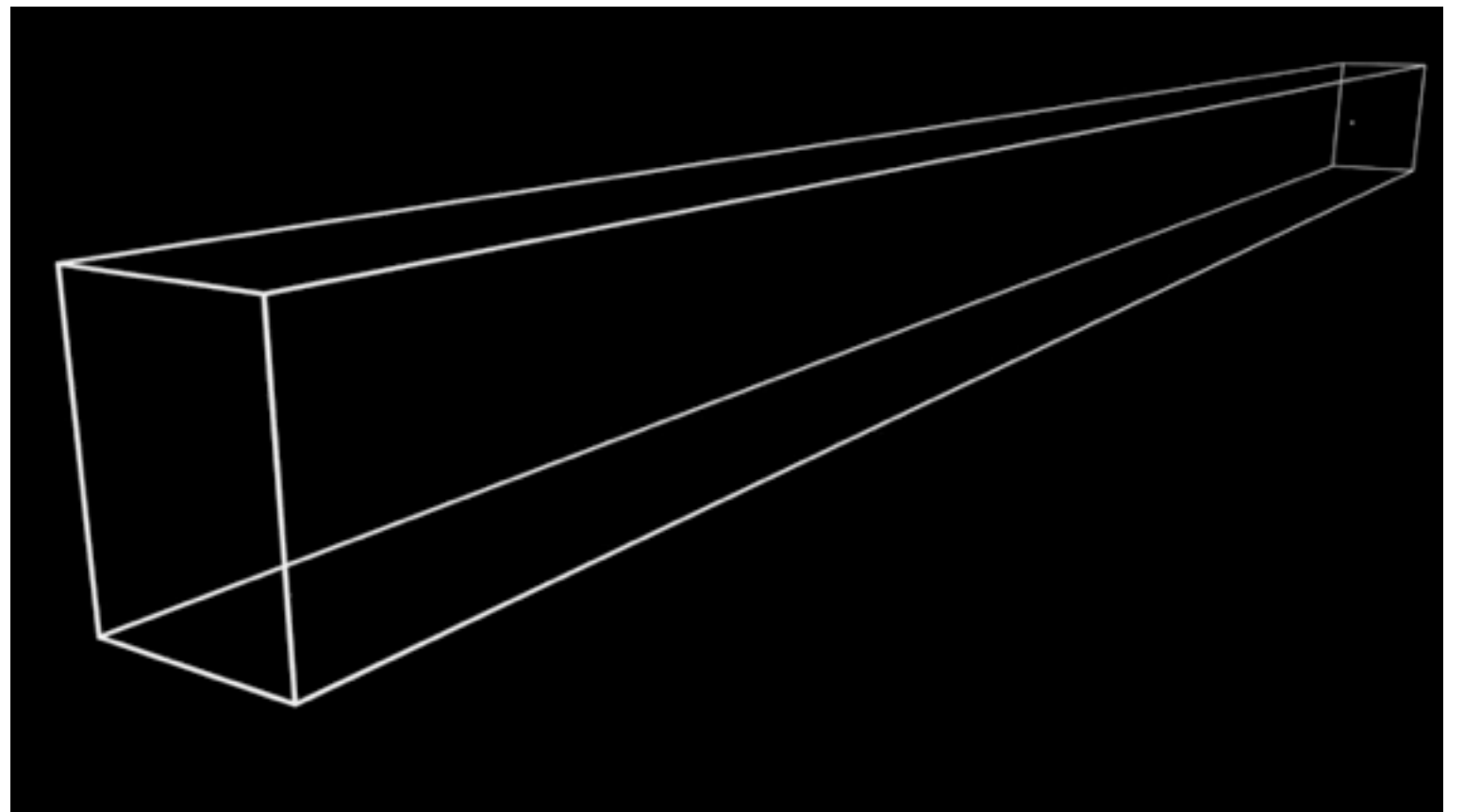
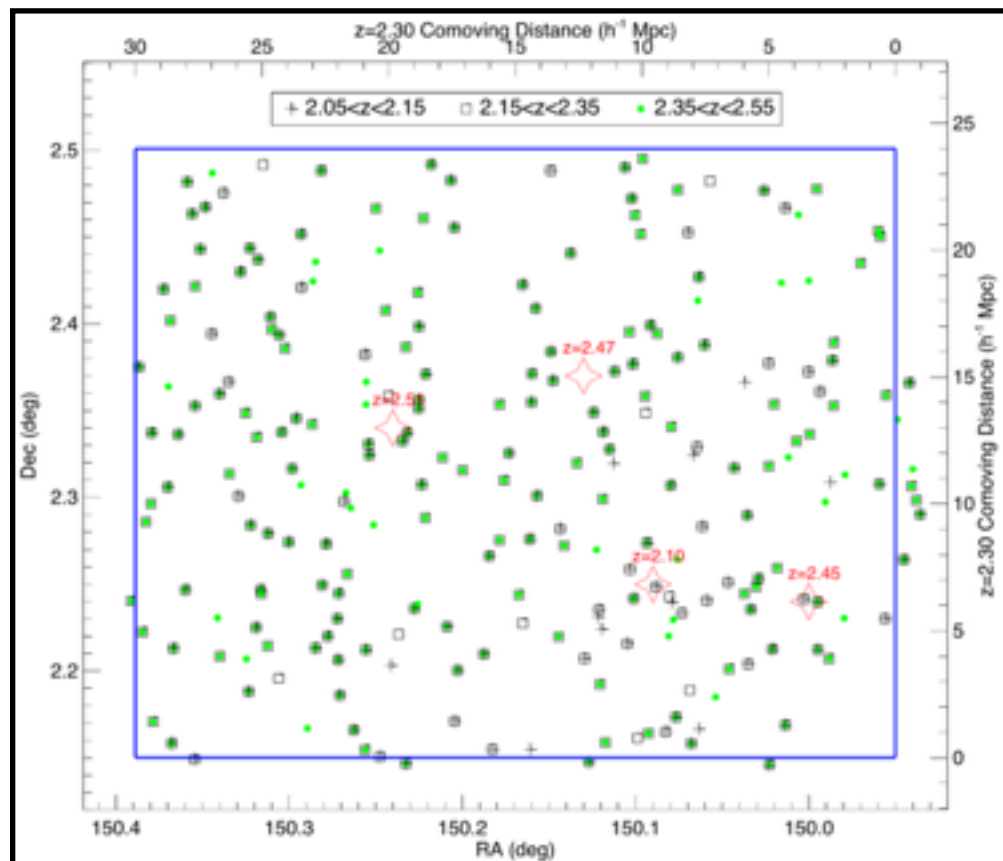
Data

	Observation	Simulation
?	M_* , SFR? Galaxy populations?	M_* , SFR?
IGM	CLAMATO 30 x 24 x 438 (cMpc) ³ Lee+18	Light cone from GADGET3-Osaka 100 x 100 x 438 (cMpc) ³ at $z \sim 2$ Shimizu+19; Nagamine+ in prep.
Galaxy catalogs	Cont. spec- z (570), LAEs (19), HAEs (7), O3Es (85), AGNs (8, 21), SMGs (4)	90,000 star-forming galaxies with $M_* \geq 10^9 M_\odot$

Observations: CLAMATO

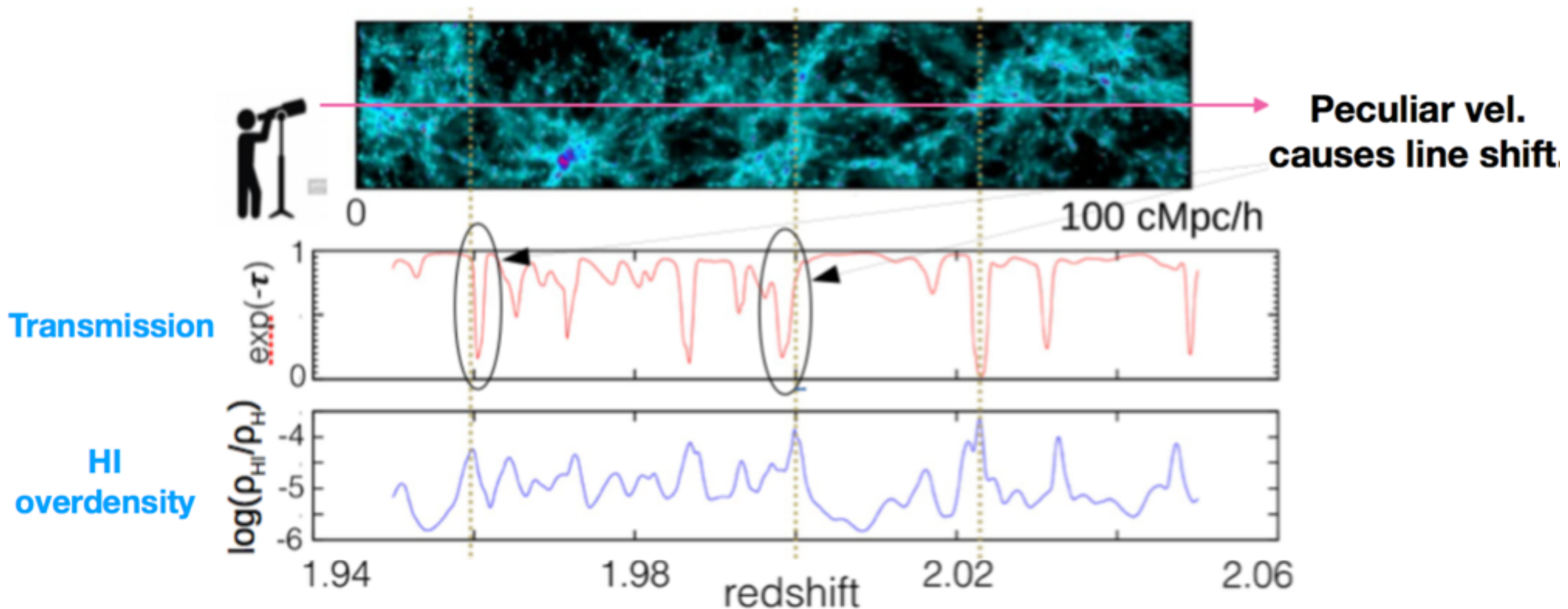
► CLAMATO

- COSMOS Ly α Mapping And Tomography Observations
- Used 240 galaxies and QSOs as background lights
- 30 x 24 x 438 cMpc cube over $2.05 < z < 2.55$



Simulations: GADGET3-Osaka

- GADGET3-Osaka (Shimizu+19, Nagamine+ in prep)
 - $(100 \text{ cMpc})^3$ cubic
 - Produce mock Ly α forest data and measure δ_F at each position



HI transmission fluctuation

$$\delta_F \equiv \frac{F(x)}{\langle F_z(x) \rangle} - 1$$

Ly α forest transmission

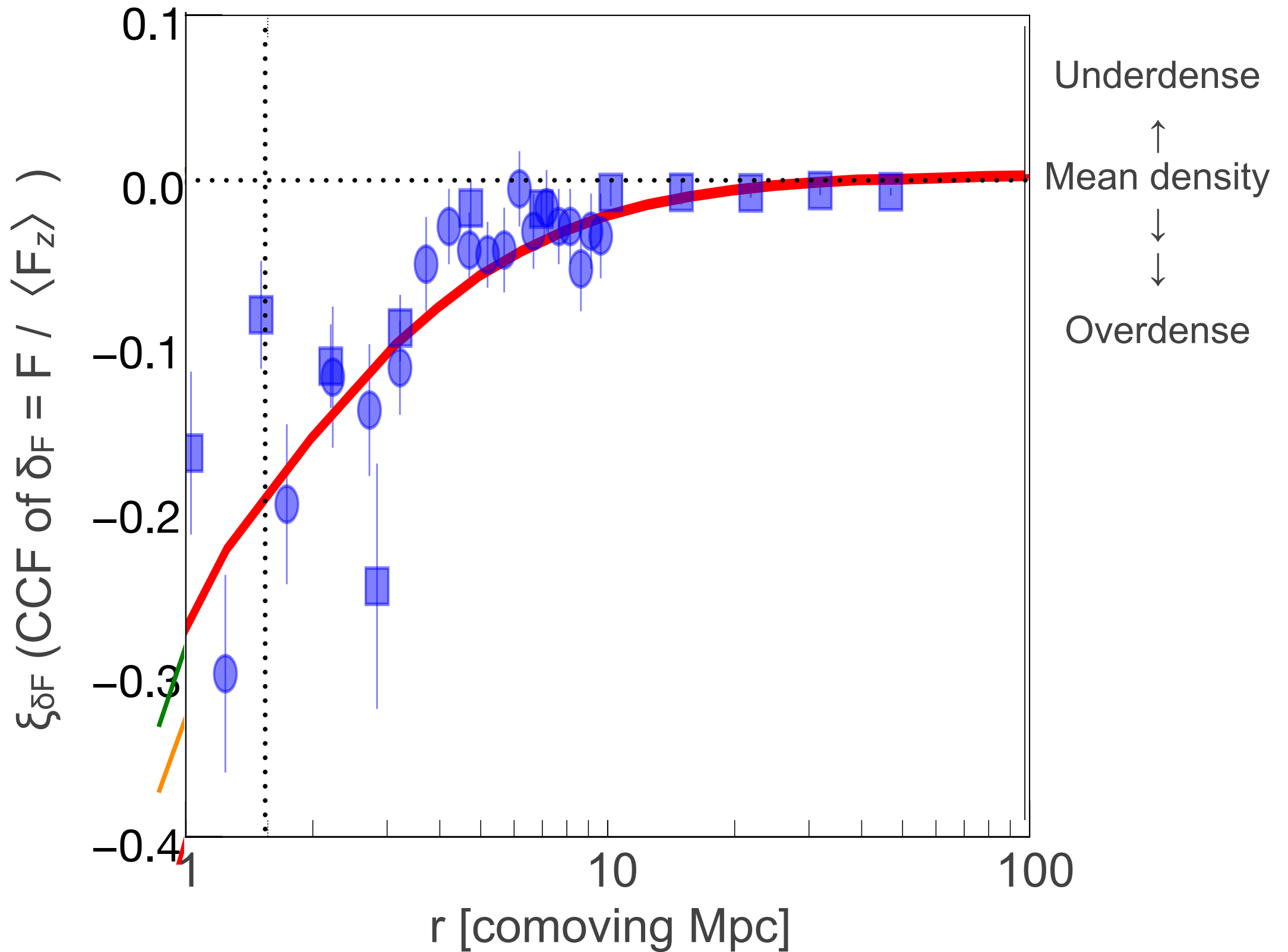
cosmic mean

Ly α forest transmission

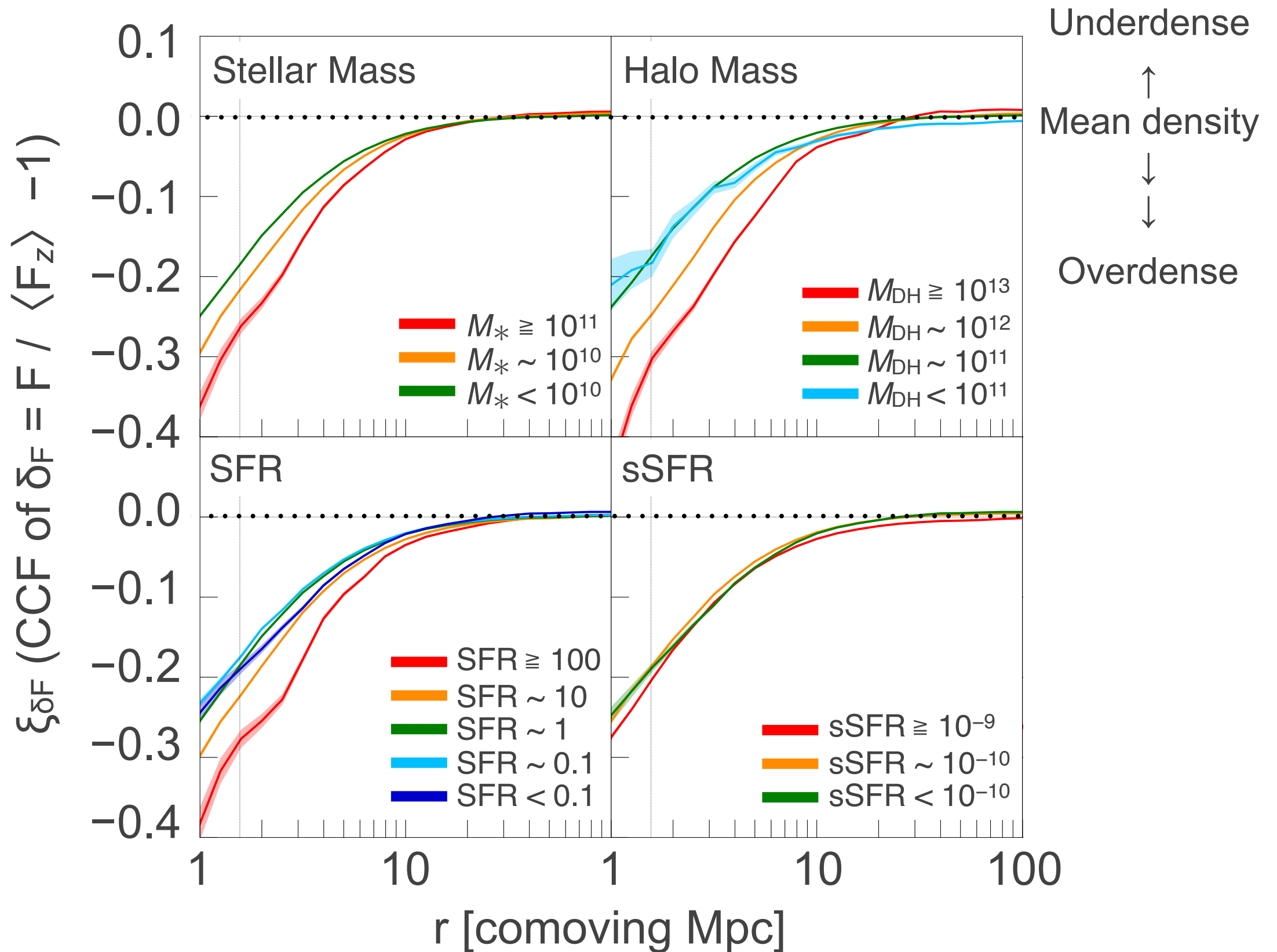
Results & Discussions



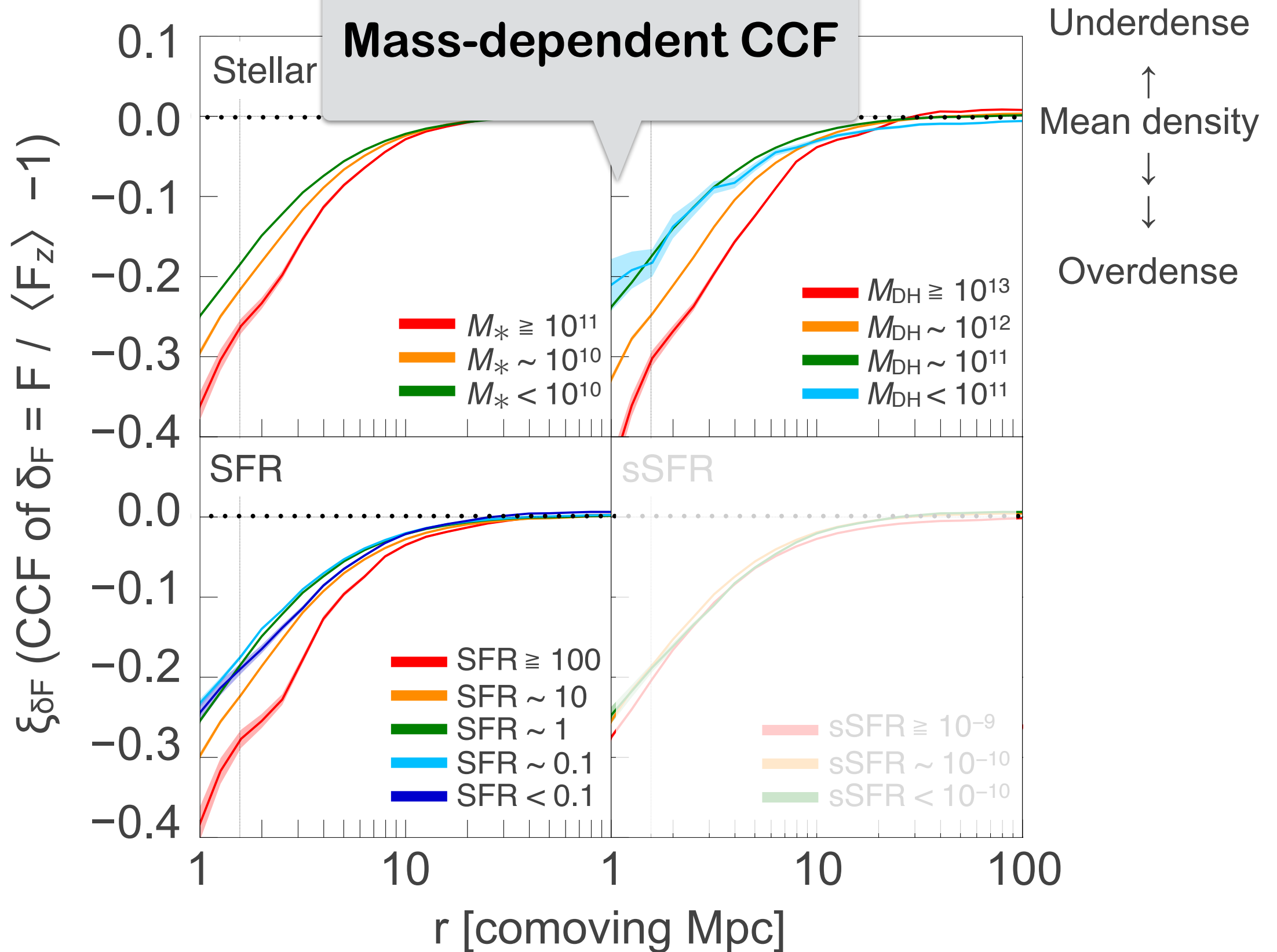
The CCF of all galaxies in our simulation



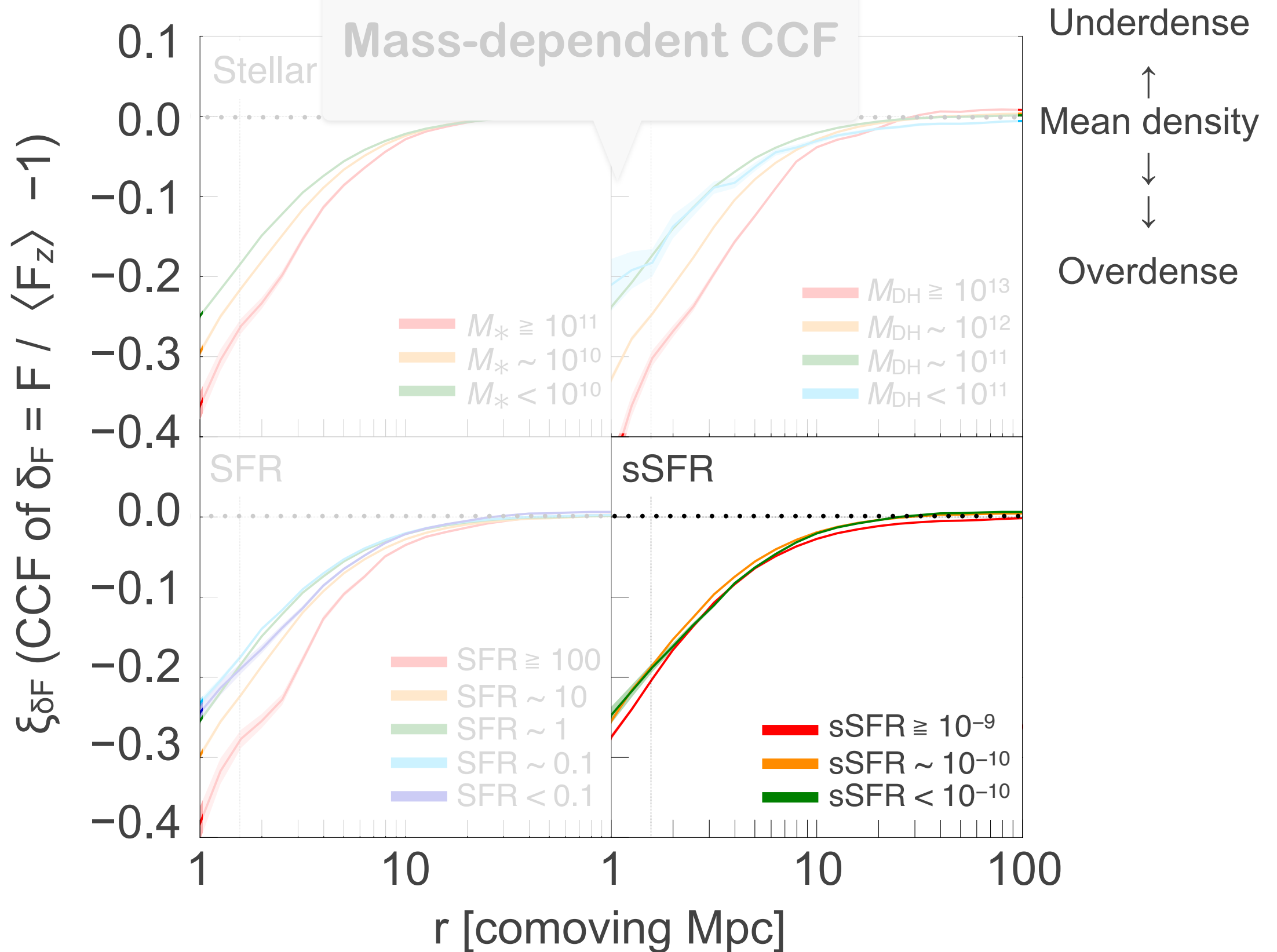
M_* , SFR? CCFs of galaxies depending on their M_* , M_{DH} , SFR and sSFR



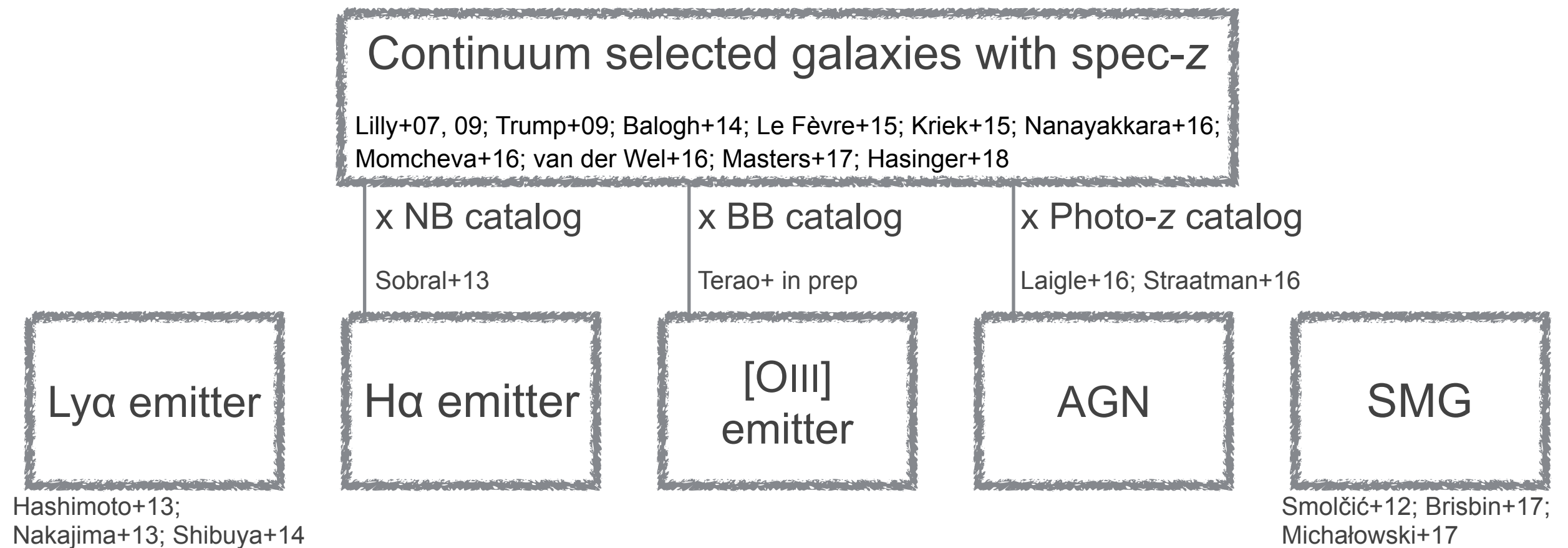
M_* , SFR? CCFs of galaxies depending on their M_* , M_{DH} , SFR and sSFR



M_* , SFR? CCFs of galaxies depending on their M_* , M_{DH} , SFR and sSFR

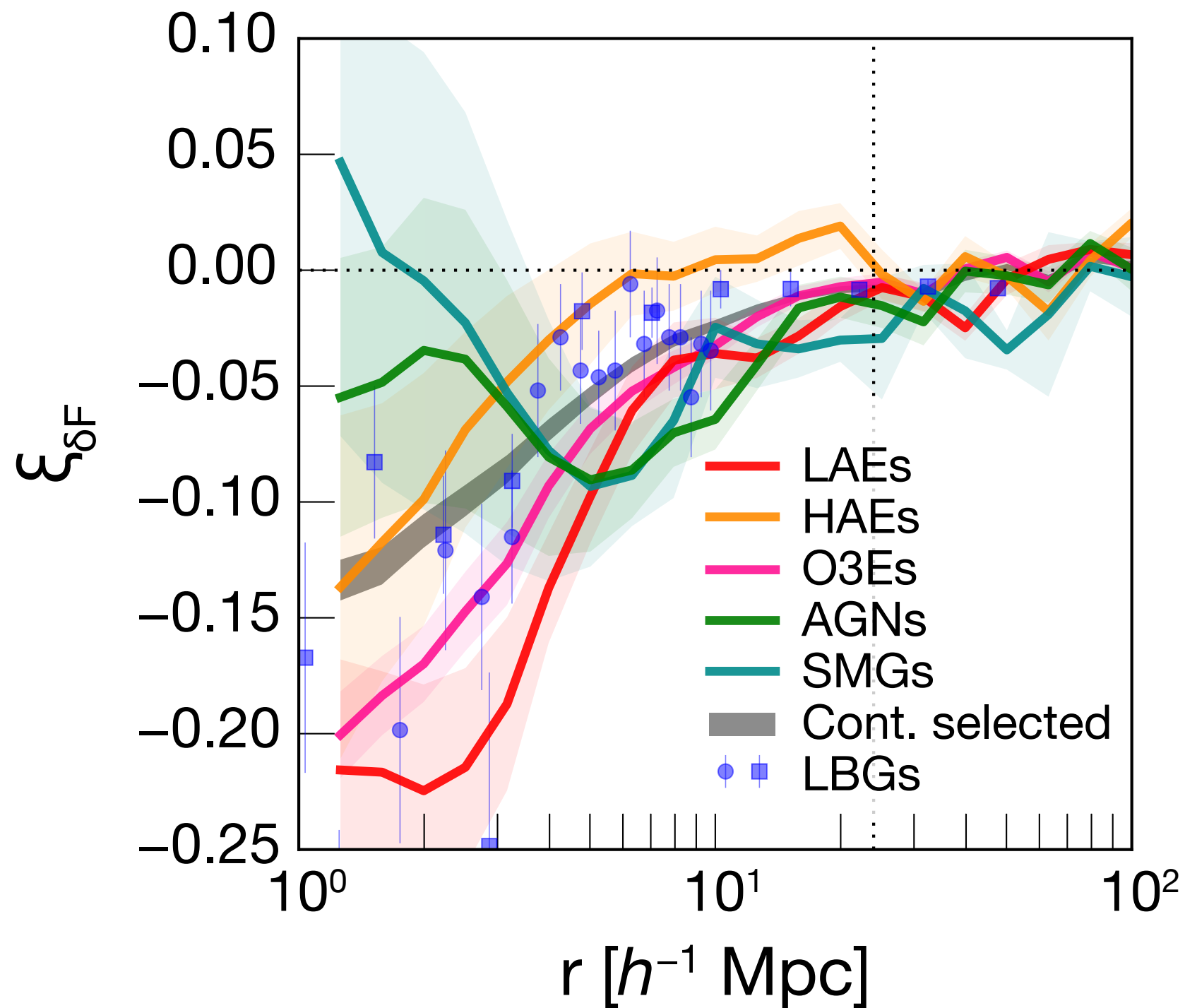


Galaxy populations? Preparation for calculations



- ▶ LAEs and SMGs measured spec-z by follow-up observations
- ▶ Cross-match with compiled spec-z catalog and give spec-z measurements

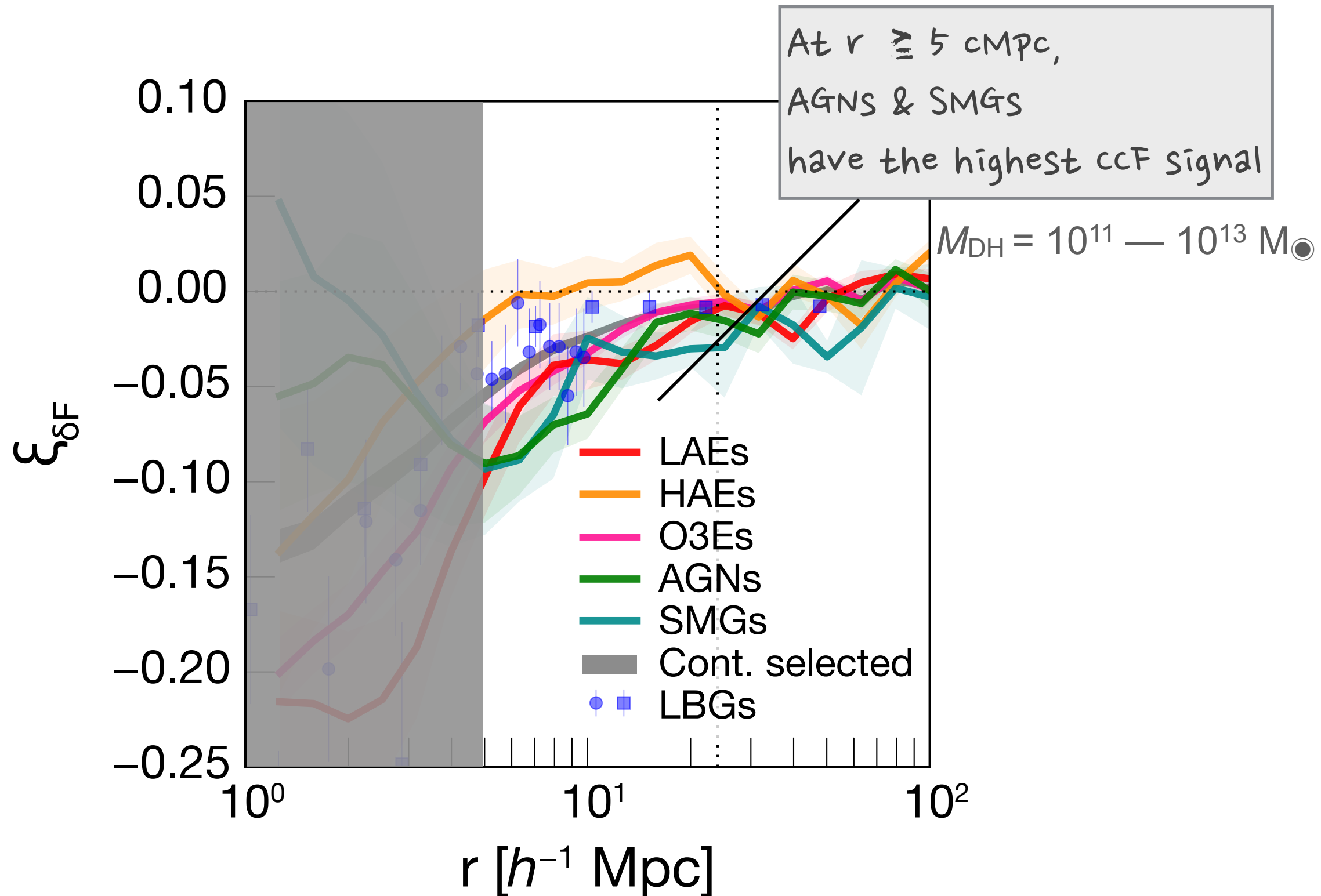
Galaxy populations? CCFs



Myers+07; Weiß+09; Guaita+11;
Allevato+11, 12, 14; Hickox+12;
Koutoulidis+13; Plionis+18;

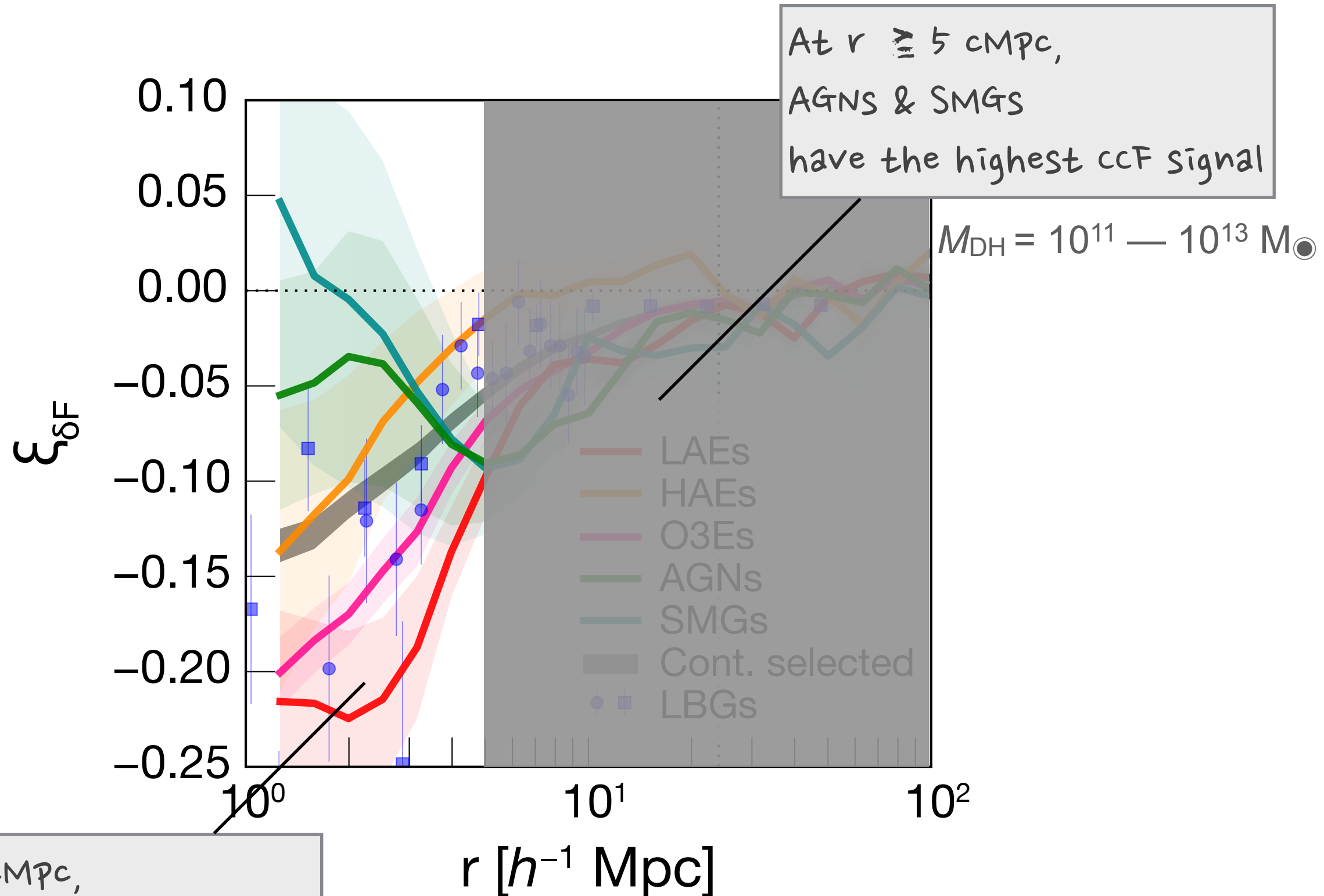
Kusakabe+18; Khostovan+19; Suh+19

Galaxy populations? CCFs



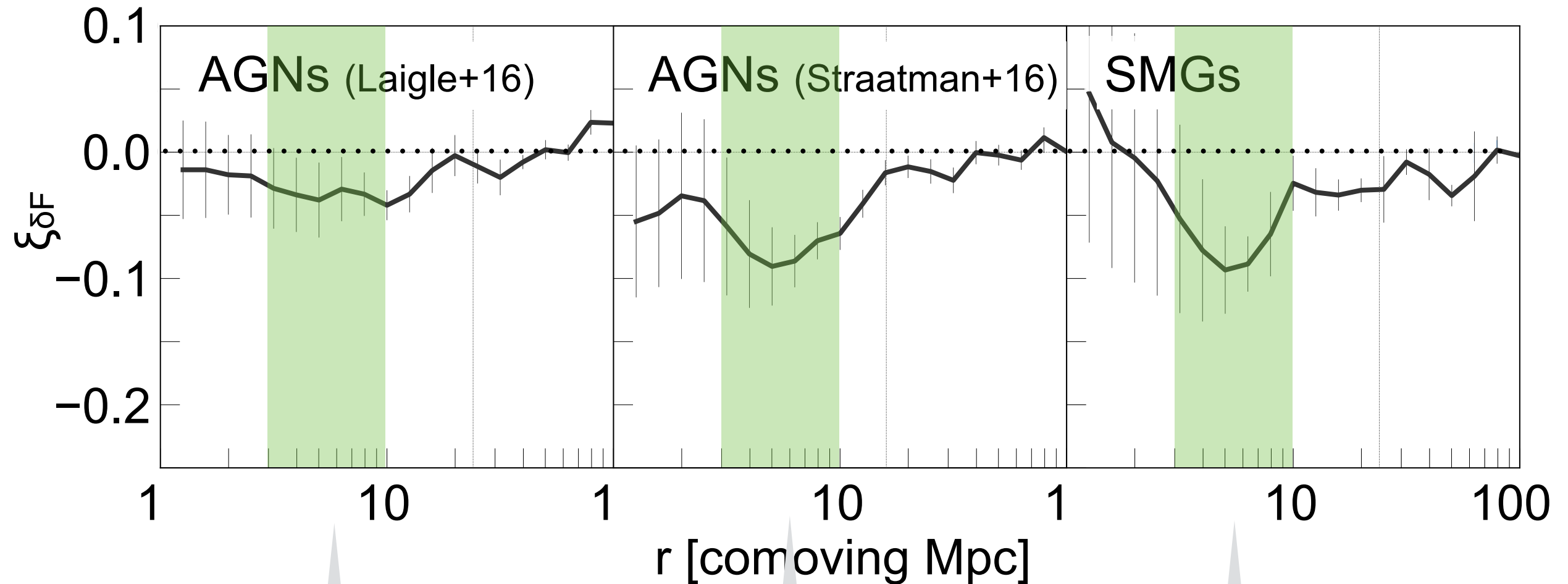
Myers+07; Weiß+09; Guaita+11;
Allevato+11, 12, 14; Hickox+12;
Koutoulidis+13; Plionis+18;
Kusakabe+18; Khostovan+19; Suh+19

Galaxy populations? CCFs



Myers+07; Weiß+09; Guaita+11;
Allevato+11, 12, 14; Hickox+12;
Koutoulidis+13; Plionis+18;
Kusakabe+18; Khostovan+19; Suh+19

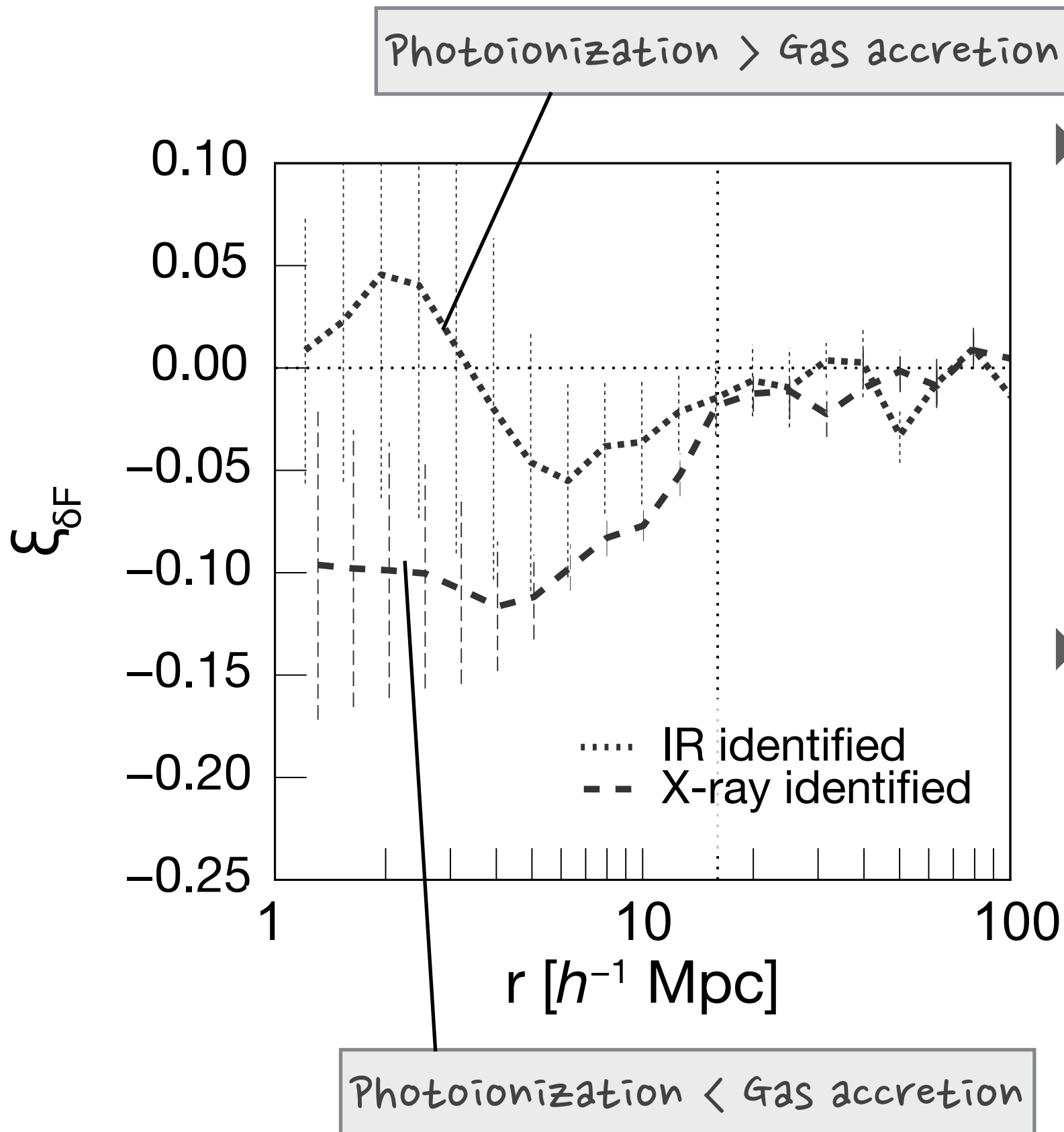
Galaxy populations? AGNs and SMGs



A negative bump at $r \sim 5-7$ Mpc/h

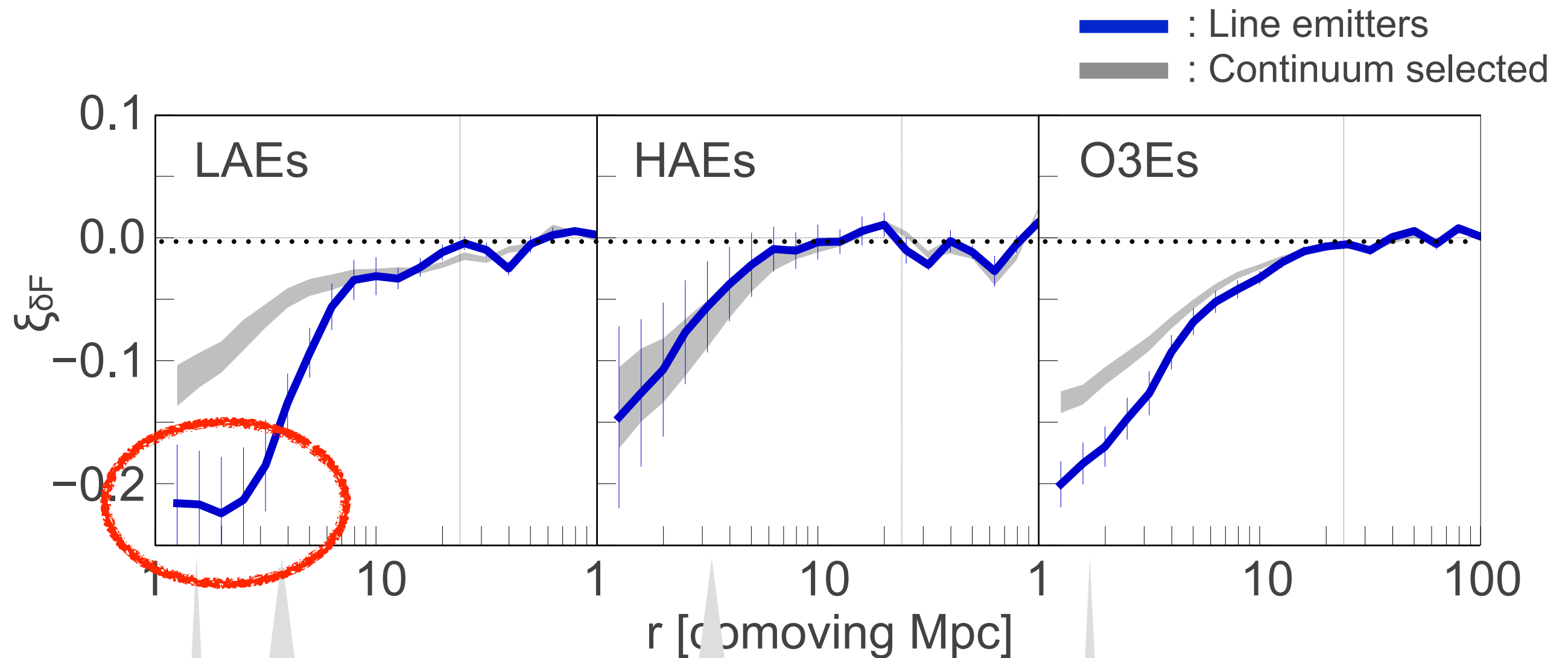
Located several Mpc away from a density peak $\Rightarrow$ **Proximity effects**

Galaxy populations? AGN types



- ▶ Different CCF trend depending on AGN types
 - IR identified: positive $\xi_{\delta F}$ (underdense)
 - X-ray identified: negative $\xi_{\delta F}$ (overdense)
- ▶ HI gas density of the proximity of AGNs may be determined by the balance
 - IGM photoionization rate
 - Gas accretion rate

Galaxy populations? Line emitters



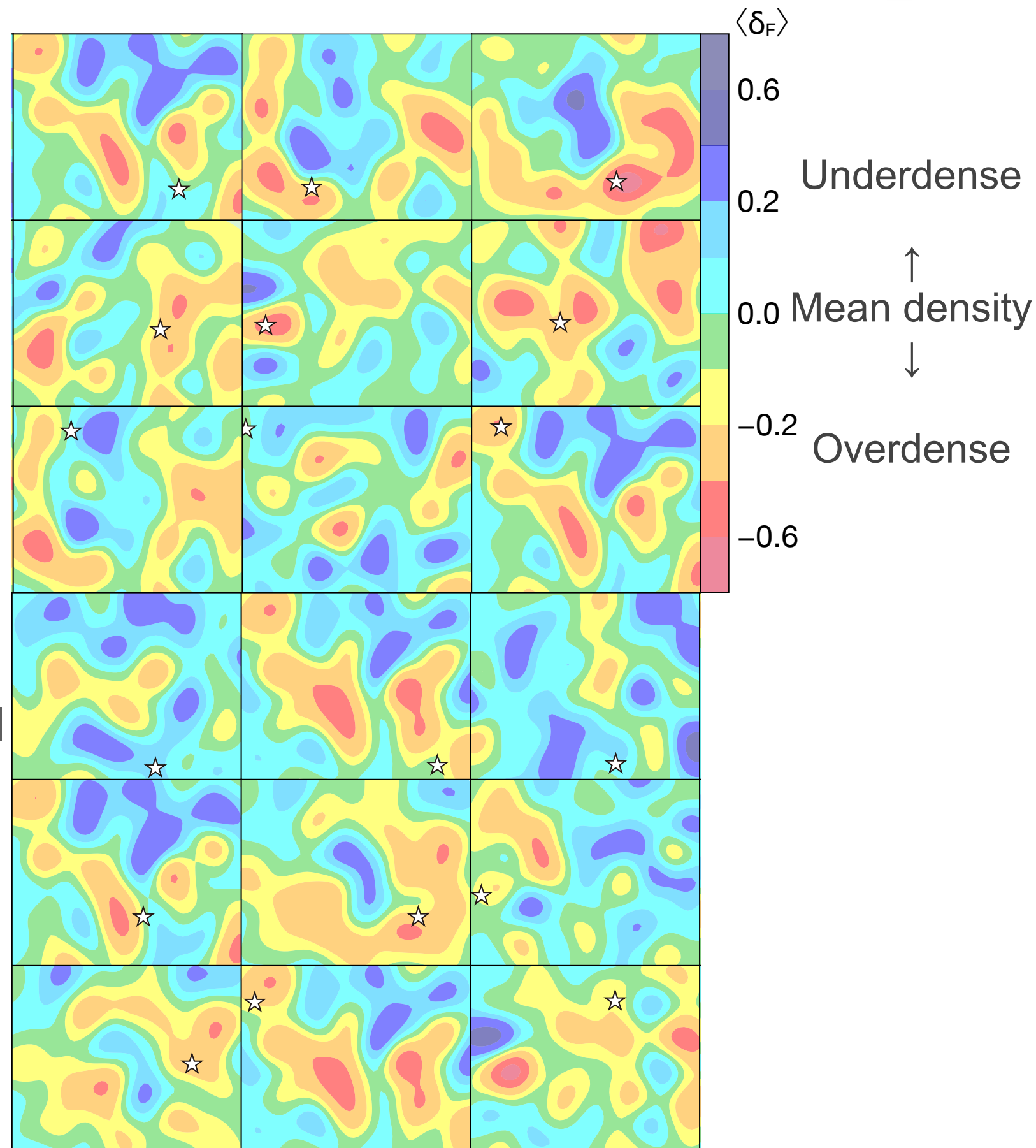
A few Mpc offset
from a density peak

Comparable CCF
➡ Similar IGM density

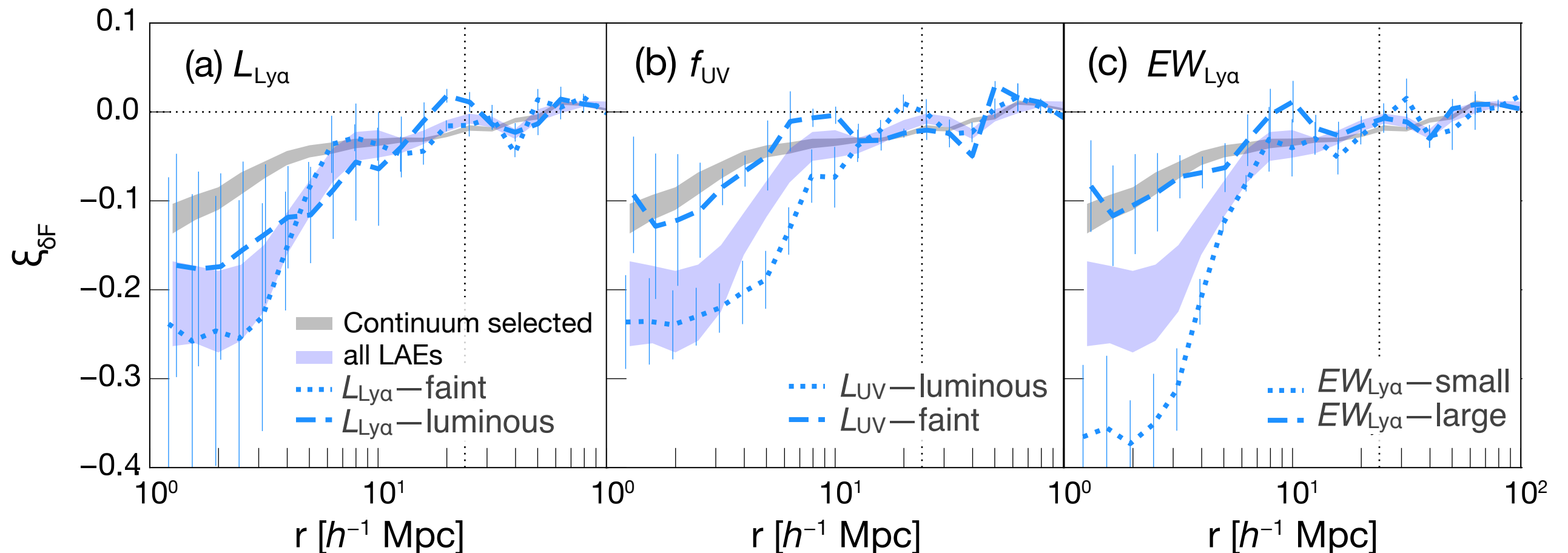
Stronger signal ➡ Denser IGM

Galaxy populations? LAEs

- ▶ Projected HI density maps
 - Collapsing $\Delta z = 2$ cMpc around LAEs
 - Map size: 30×24 cMpc²
- ▶ LAEs tend to be off-peaks
- ▶ LAEs may not trace the same underlying IGM HI which is traced by other galaxy populations



Galaxy populations? LAEs — further investigations



- ▶ **$L_{\text{Ly}\alpha}$ —faint, L_{UV} —luminous, and $EW_{\text{Ly}\alpha}$ —small** subsamples have **higher CCF signal** than their opposite subsamples
 - They tend to be more massive than the opposite
- ▶ **Massive LAEs can reside in high density regions** than less massive one

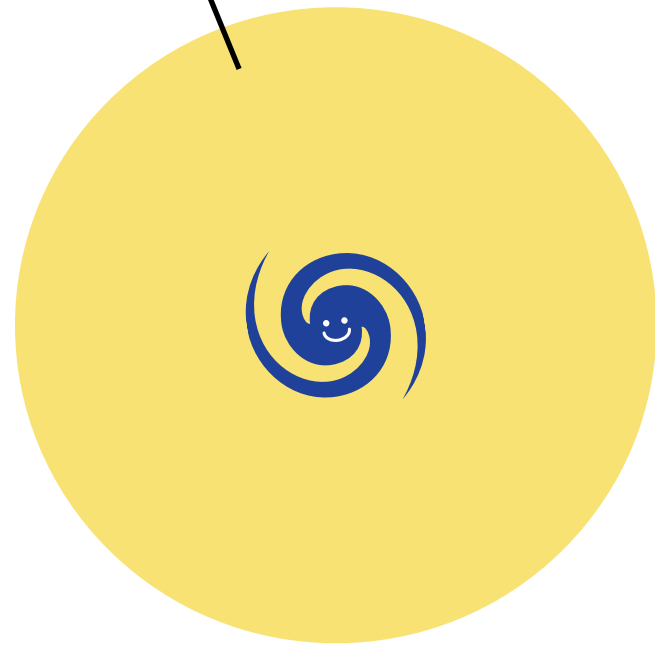
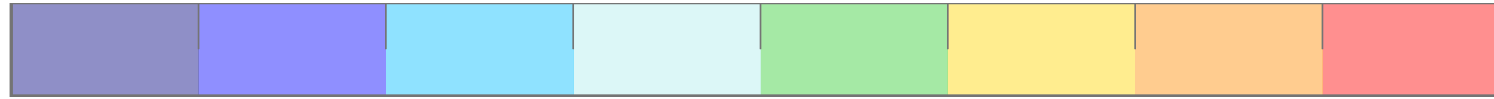
Summary: What can we learn about the IGM-galaxy connection?

- ◆ What type of galaxies (M_* , SFR) strongly connect to the IGM?
 - Galaxies with higher mass (and SFR) tend to reside in higher density regions
- ◆ How is the connection different among different galaxy populations?
 - AGNs and SMGs are in the highest density regions over $r > 5$ cMpc
 - HI depletion around several cMpc can be due to the proximity effect
 - LAEs are in the highest density regions within $r = 5$ cMpc
 - They are not in peaks of the cosmic web, but in a few cMpc off-peaks
 - HAEs and O3Es trace the HI density structure well, though O3Es are in higher density

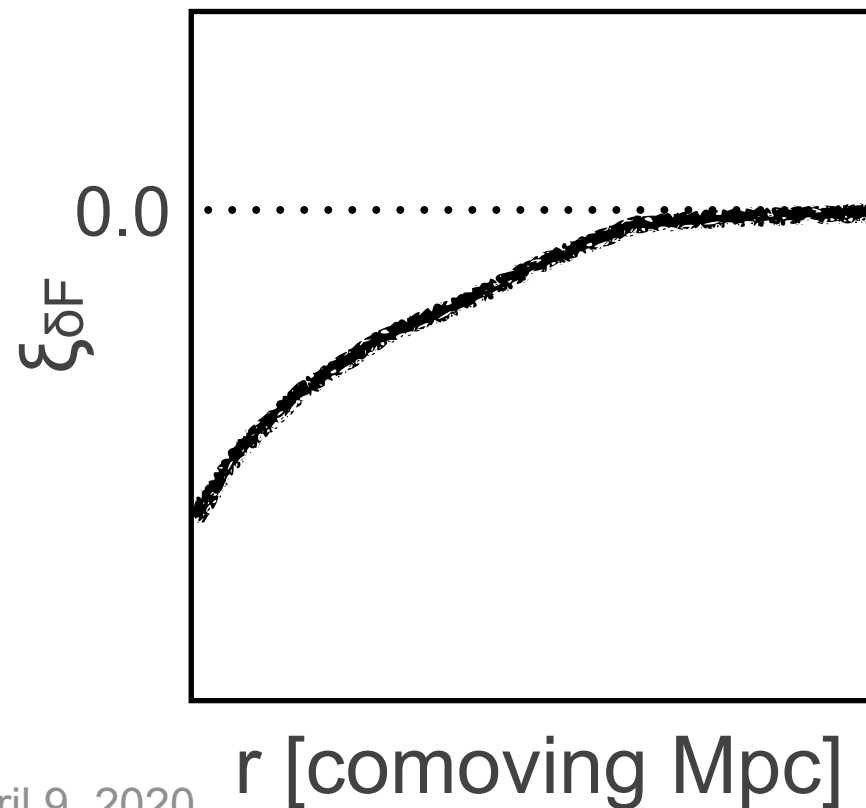
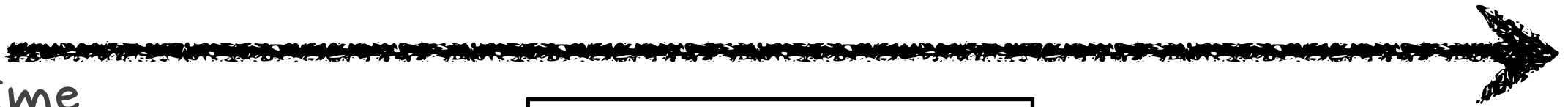
Hypothesis of the IGM-galaxy connection depending on evolutionary stage

Mpc-Scale
HI density

low $\leftarrow$ IGM HI density $\rightarrow$ high

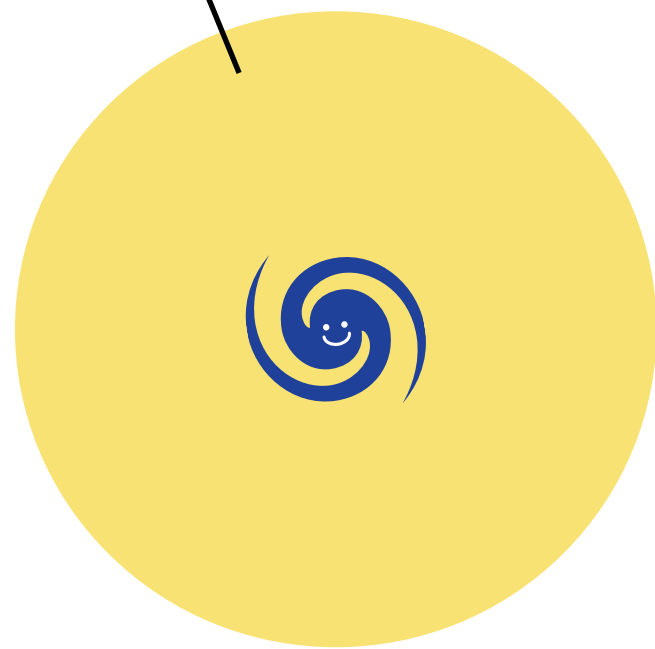
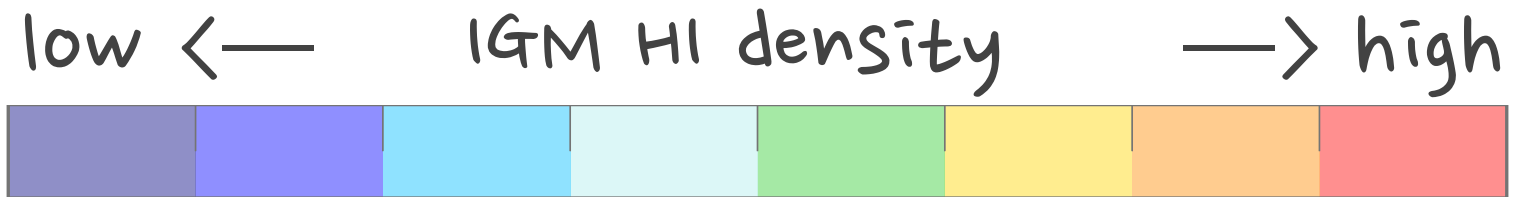


M_{DH} , Time

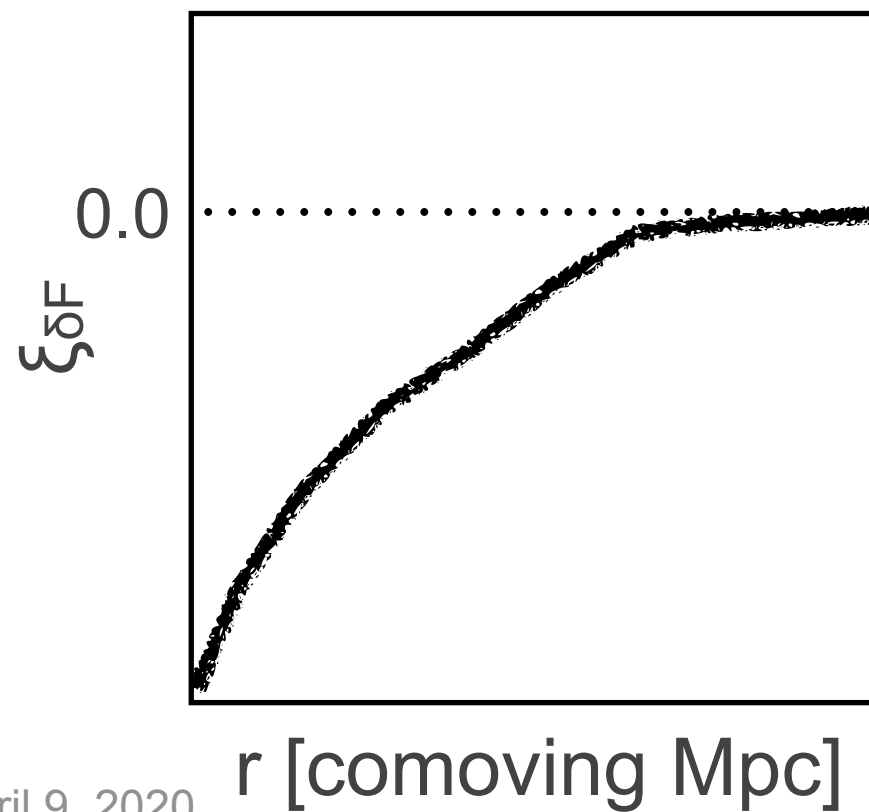


Hypothesis of the IGM-galaxy connection depending on evolutionary stage

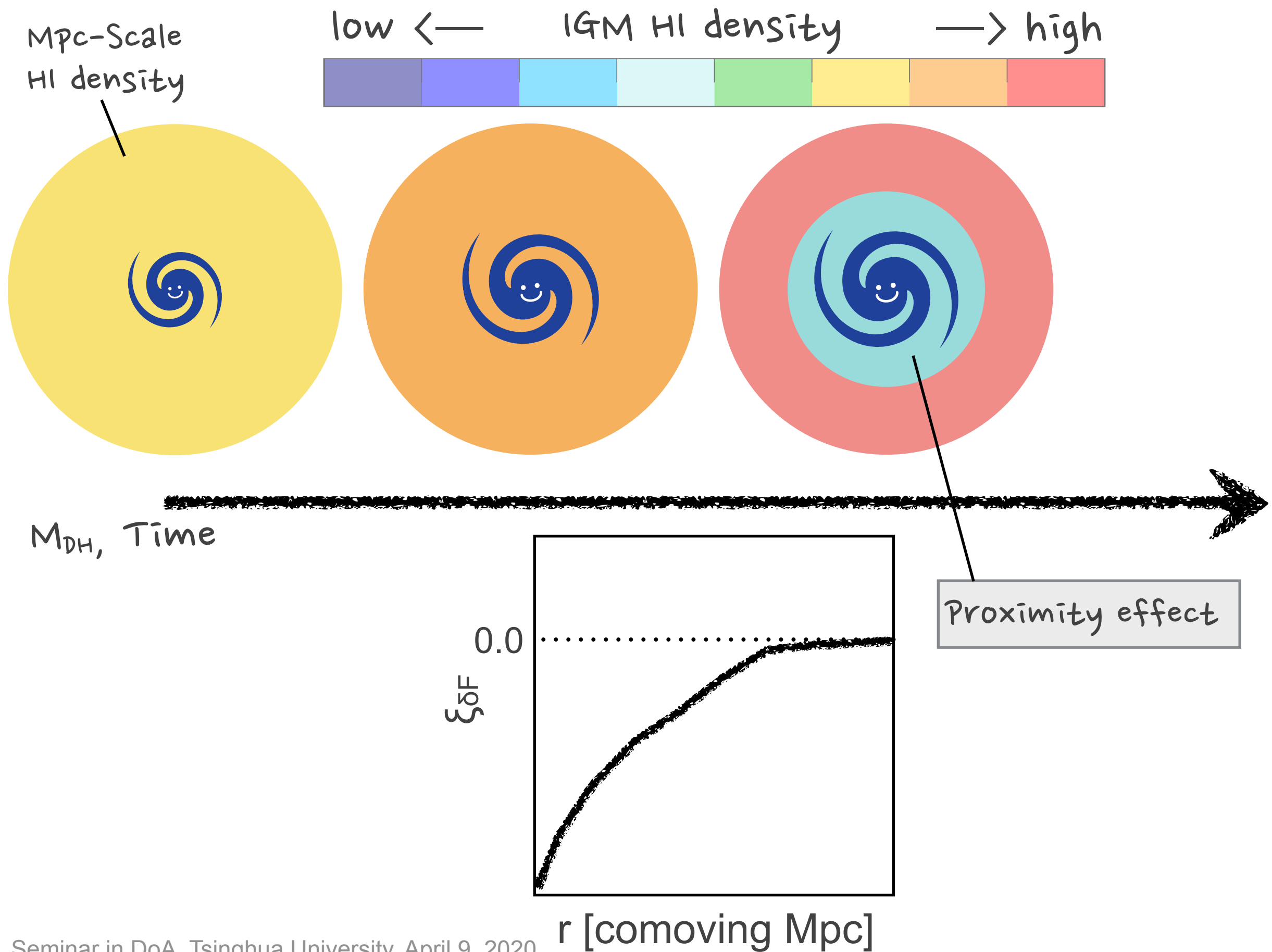
Mpc-Scale
HI density



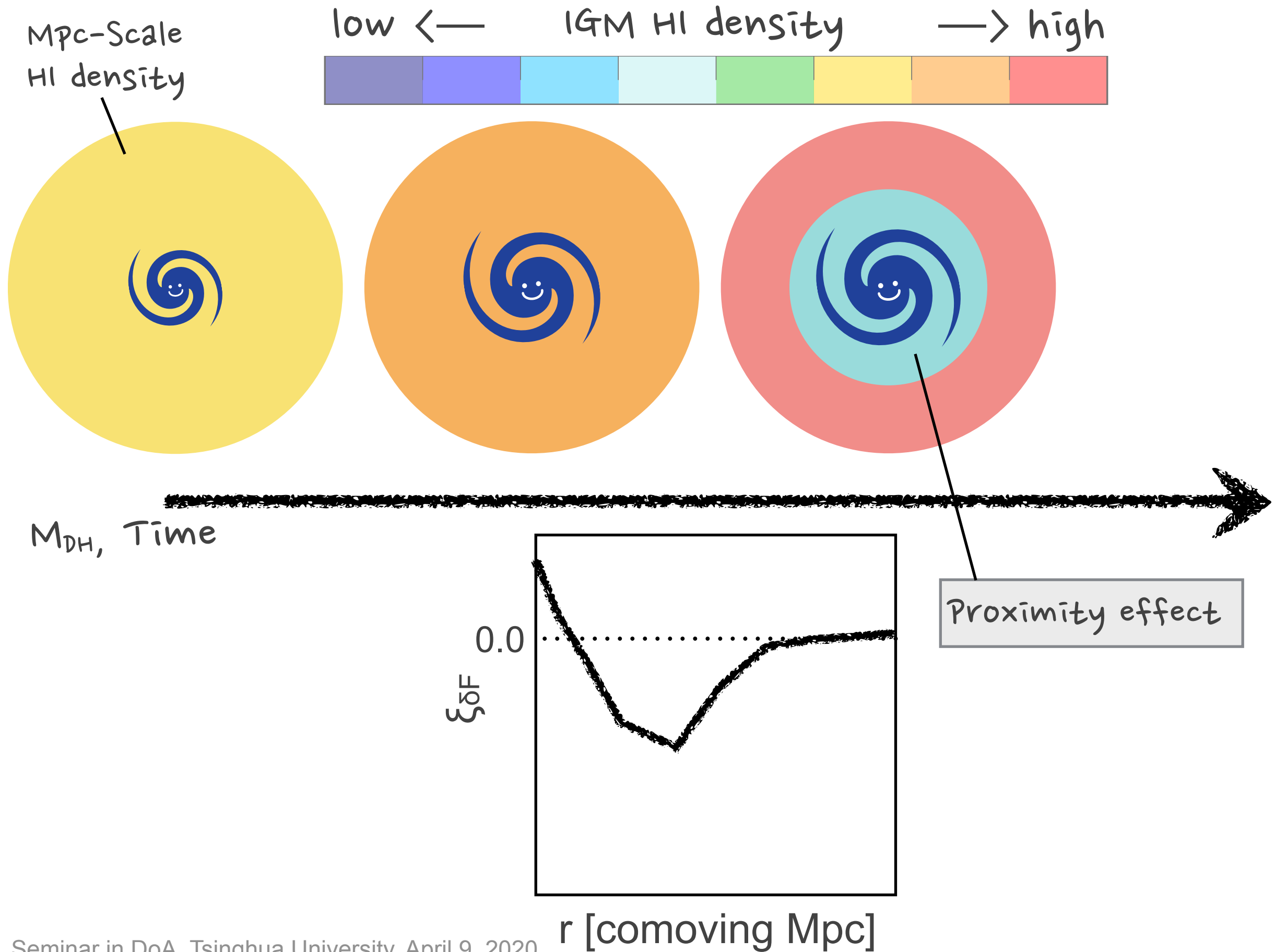
M_{DH} , Time



Hypothesis of the IGM-galaxy connection depending on evolutionary stage

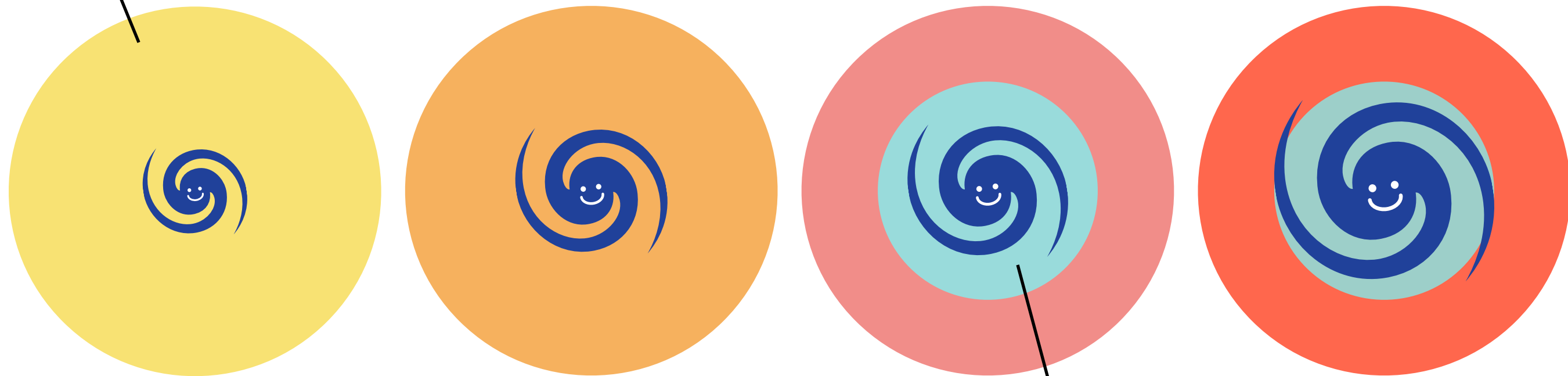
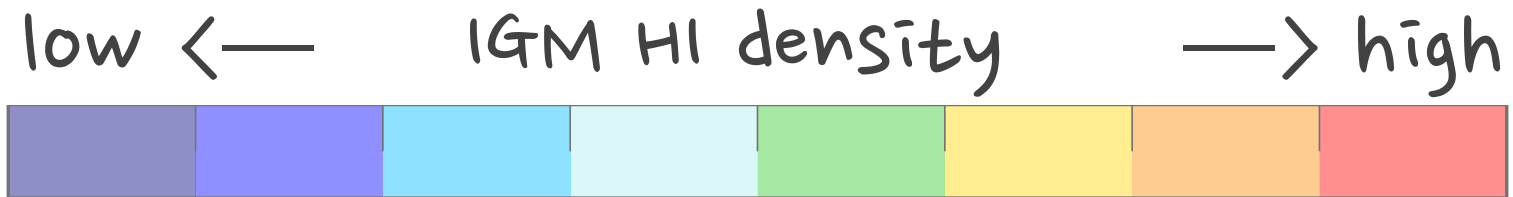


Hypothesis of the IGM-galaxy connection depending on evolutionary stage

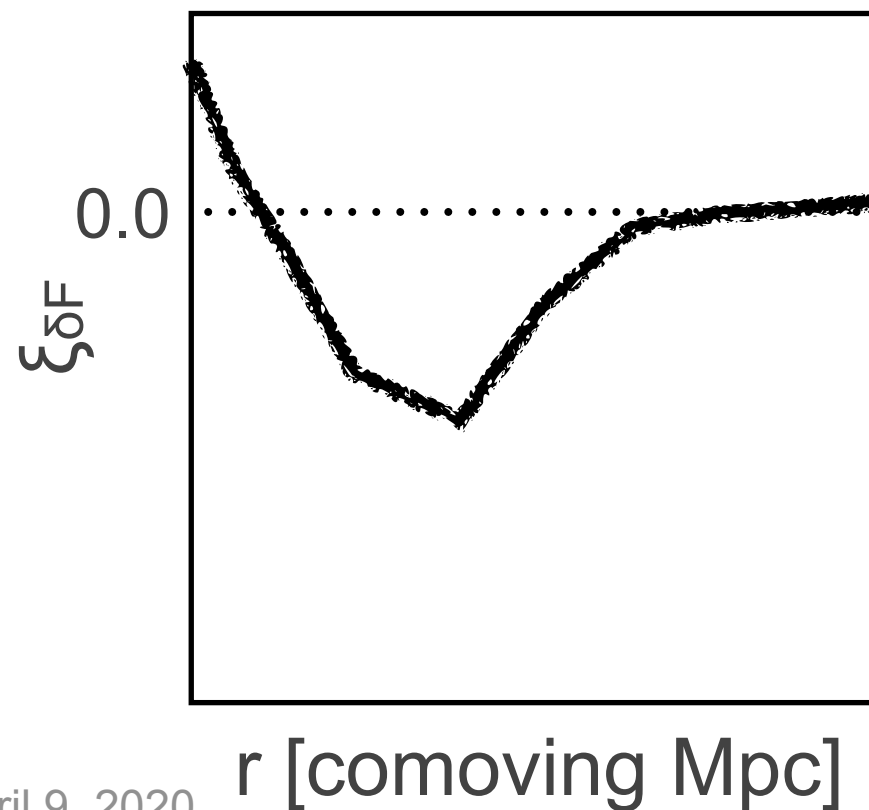


Hypothesis of the IGM-galaxy connection depending on evolutionary stage

Mpc-Scale
HI density

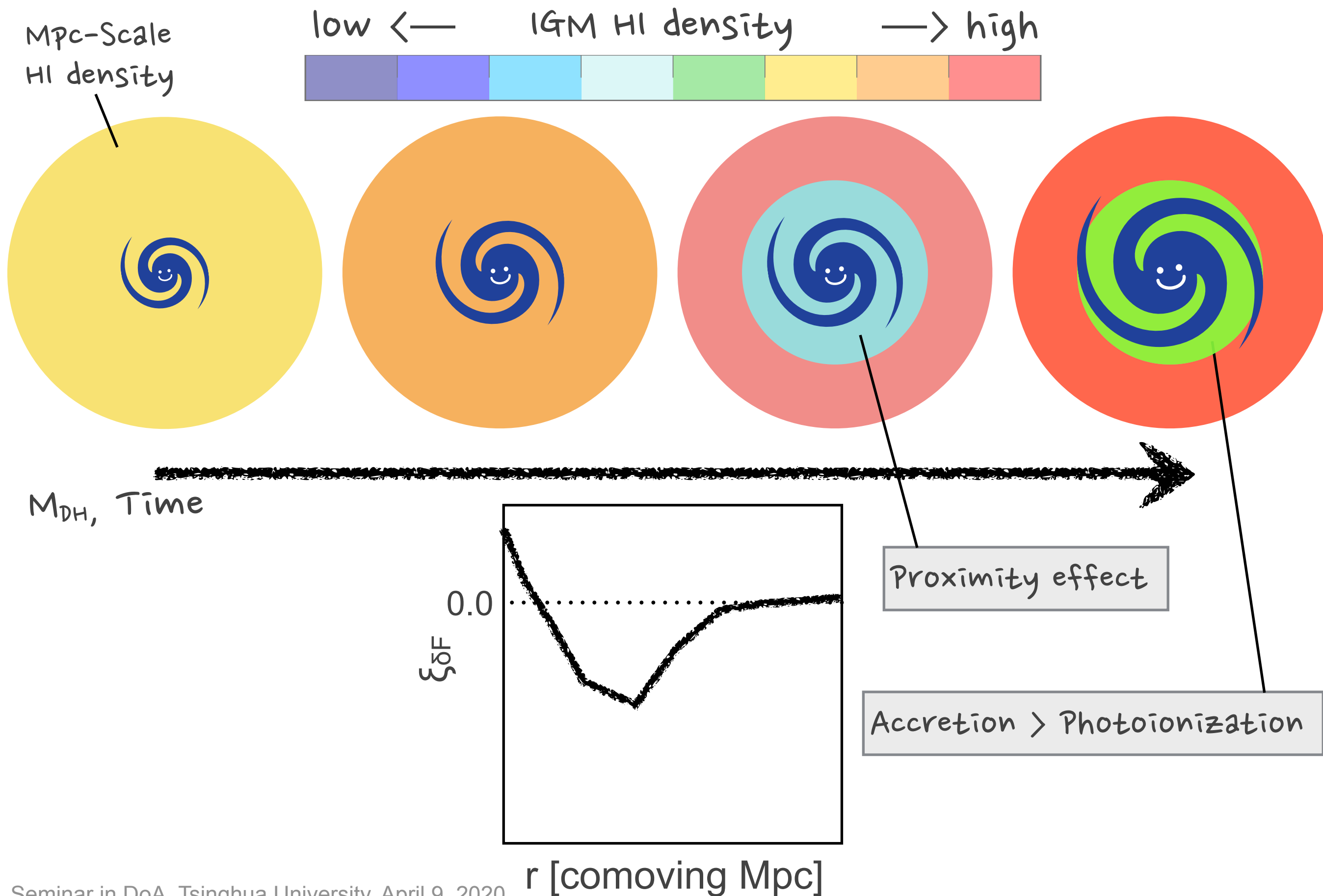


M_{DH} , Time

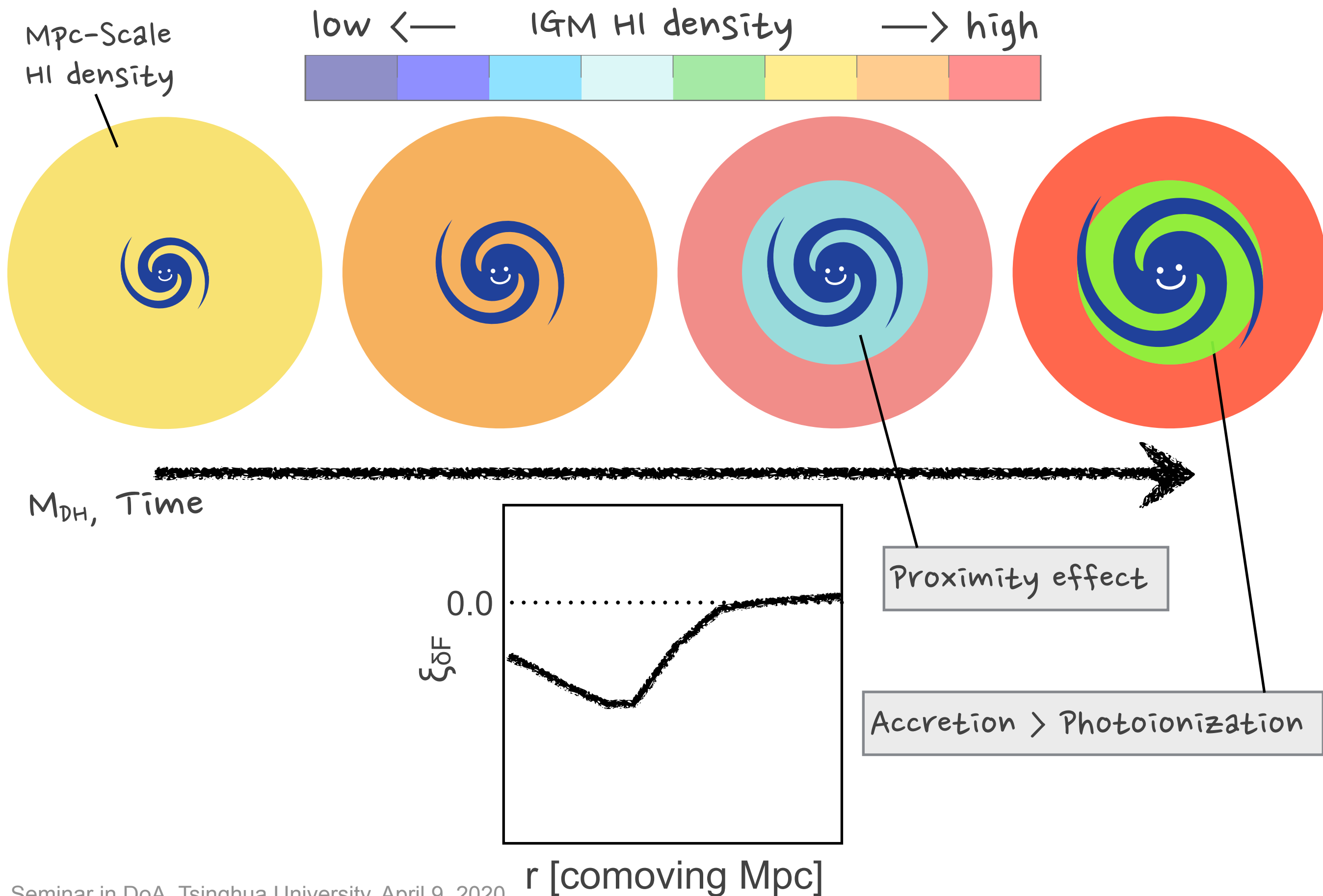


Proximity effect

Hypothesis of the IGM-galaxy connection depending on evolutionary stage



Hypothesis of the IGM-galaxy connection depending on evolutionary stage





Fin.