Environmental dependence on galactic properties traced by Lyα absorptions

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※ Momose et al. 2020a, b
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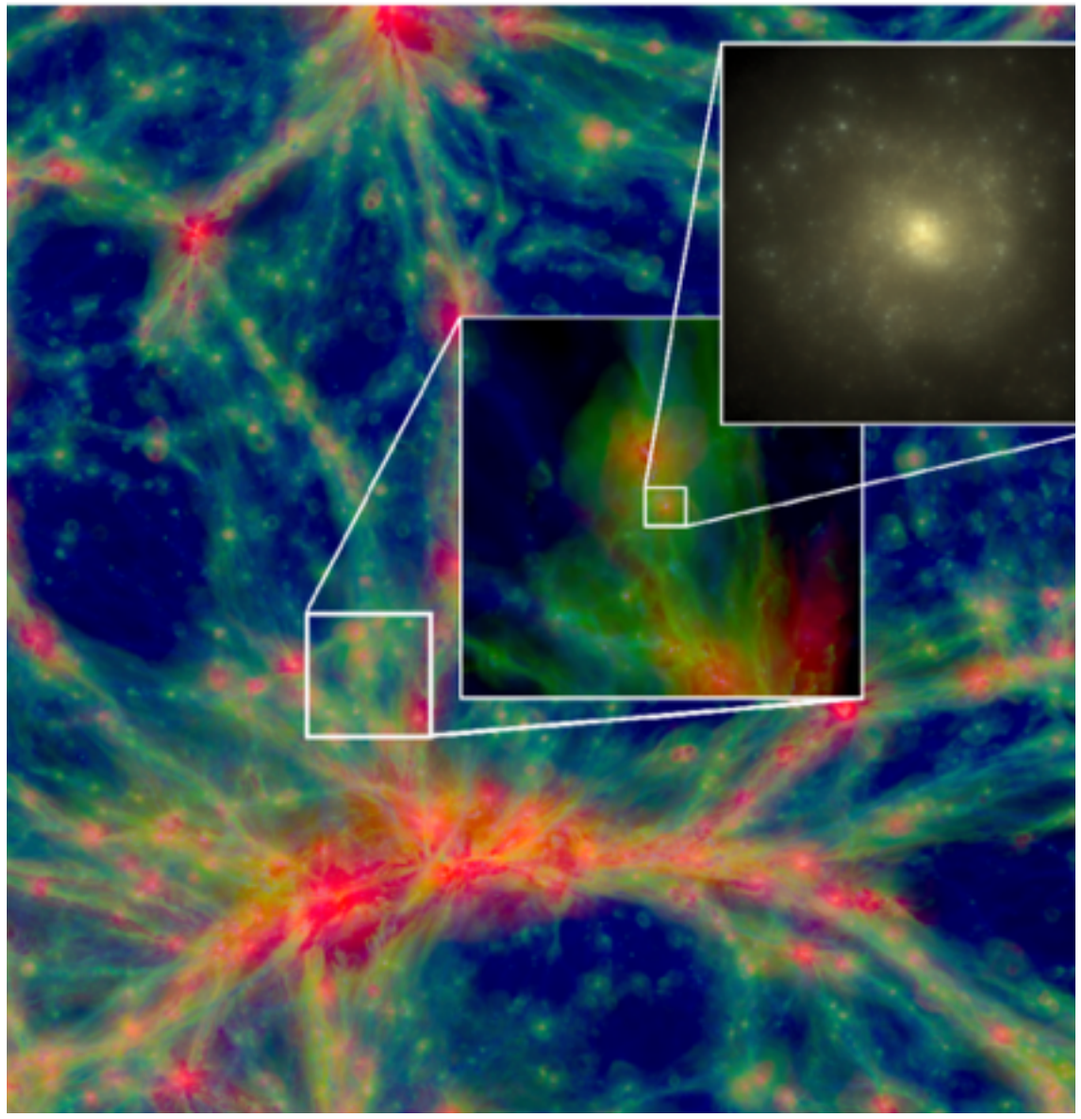
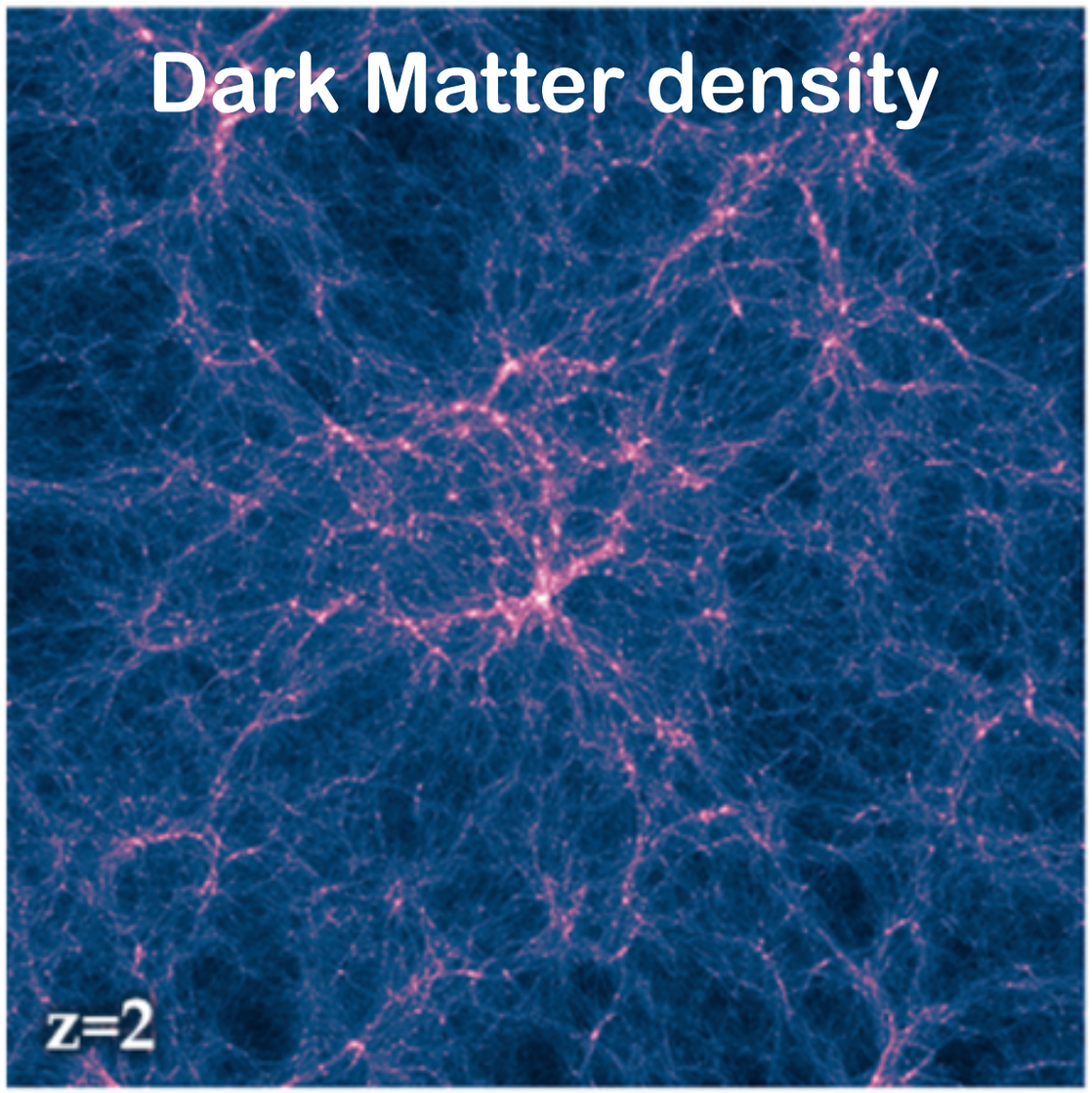
Galaxy formation in the large-scale structure

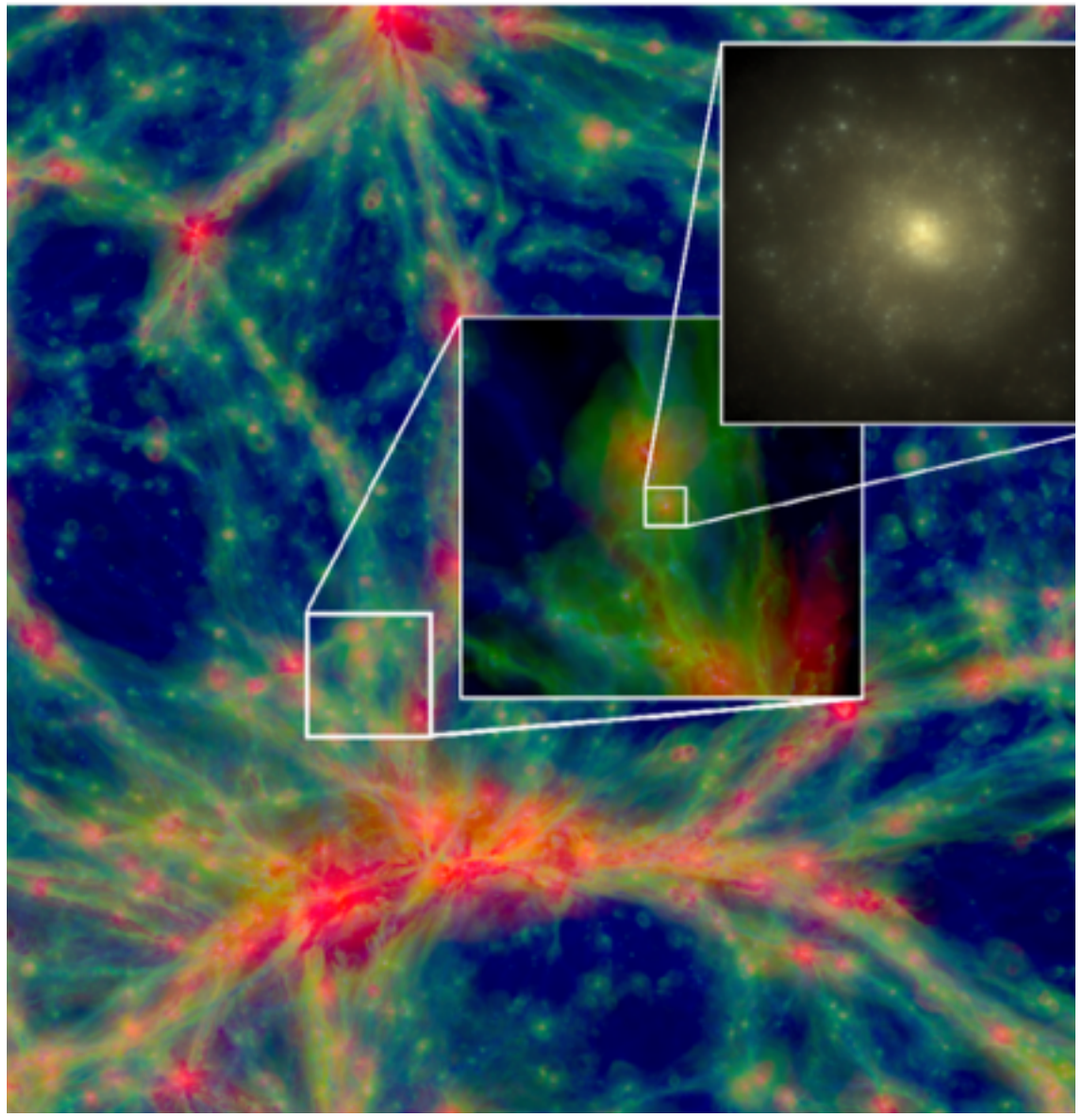


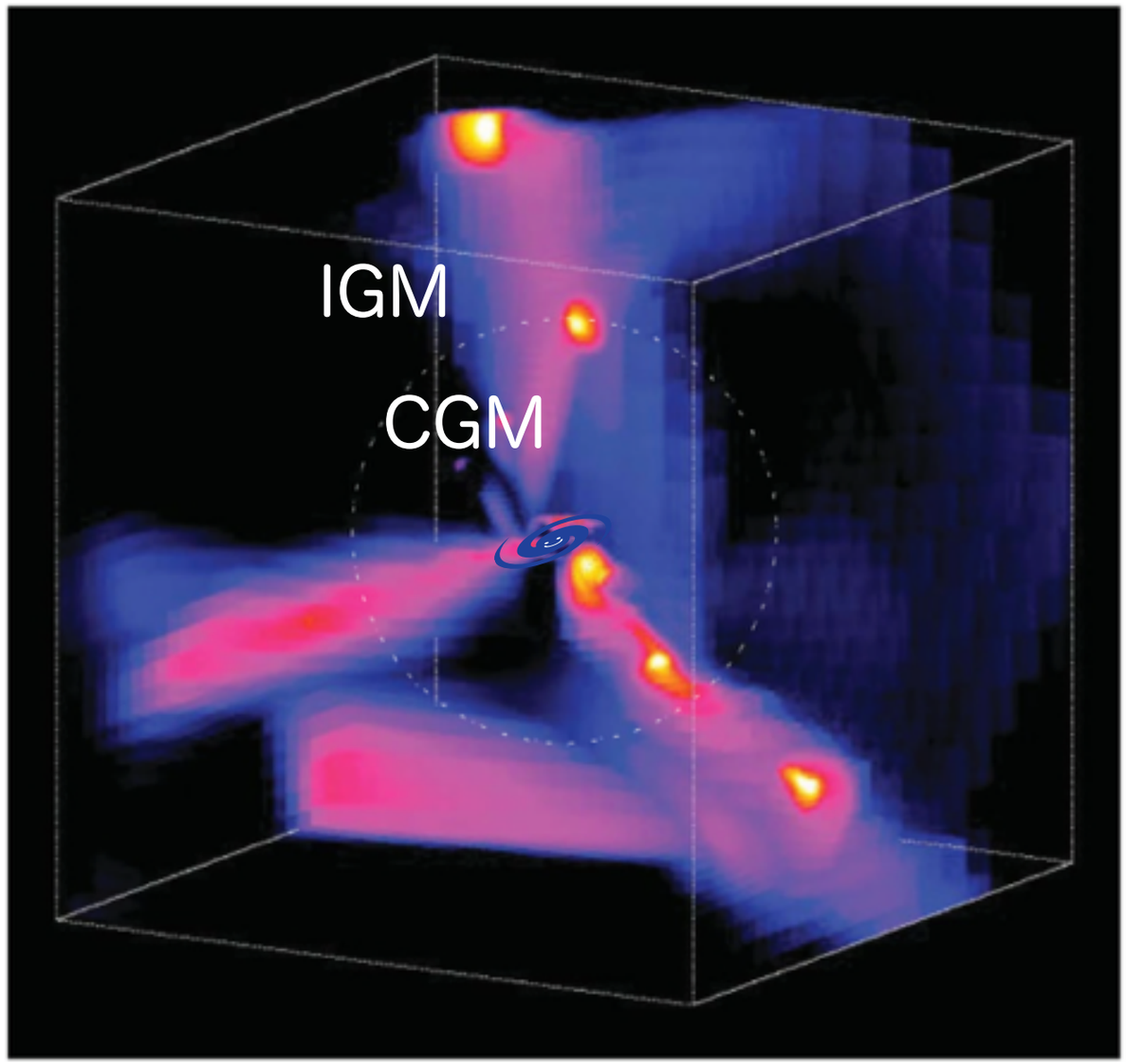


- Galaxy formation occurs within the densest parts of the cosmic web
- Large-scale dark matter distribution correlates with that of baryon

Vogelsberger+2014; Schaye +2014

Galaxy formation in the large-scale structure





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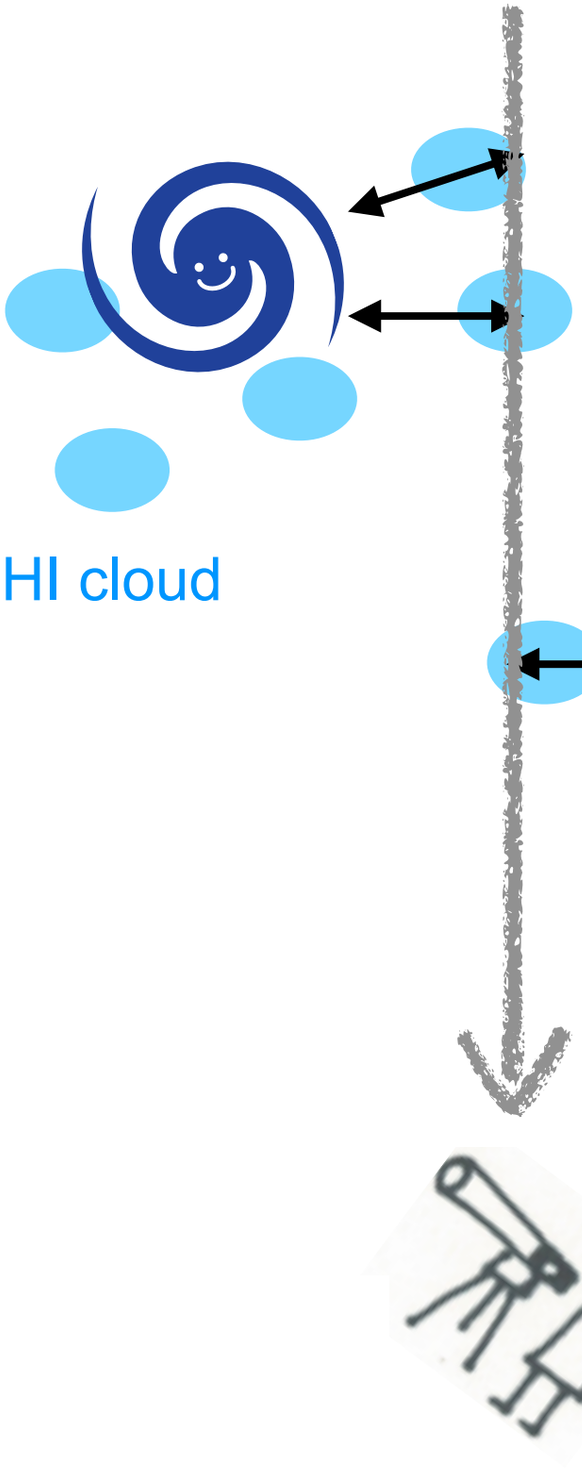
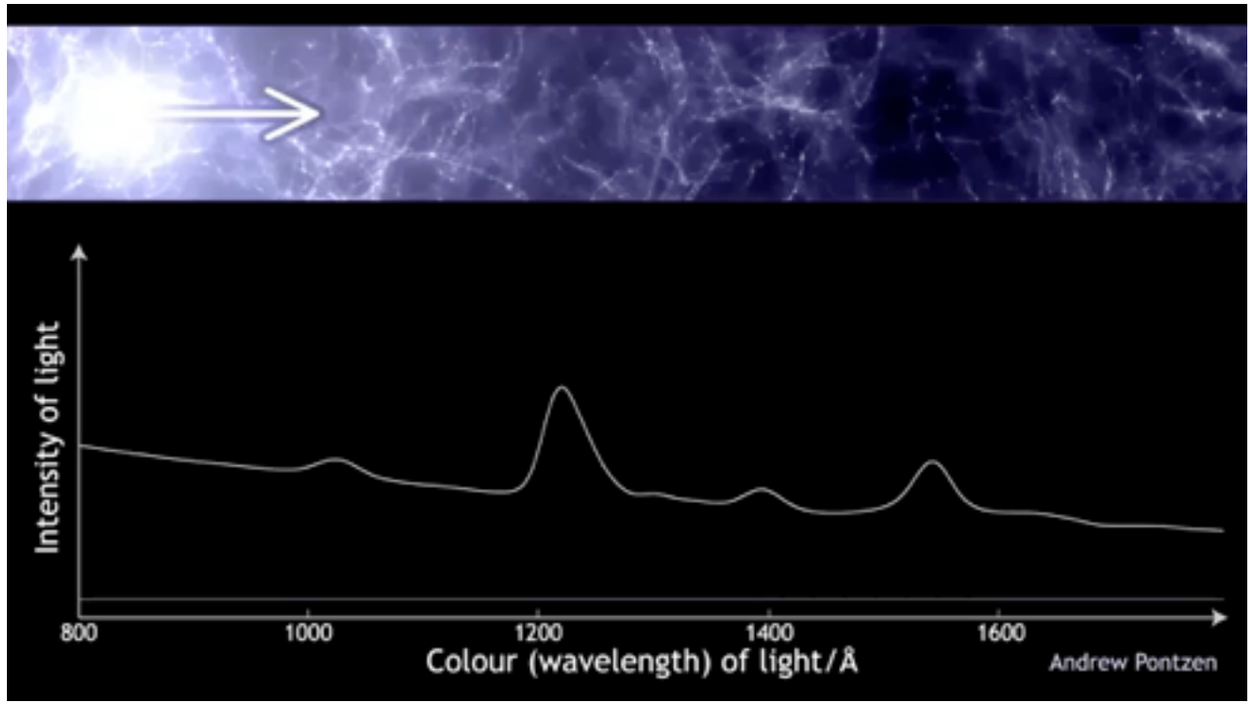
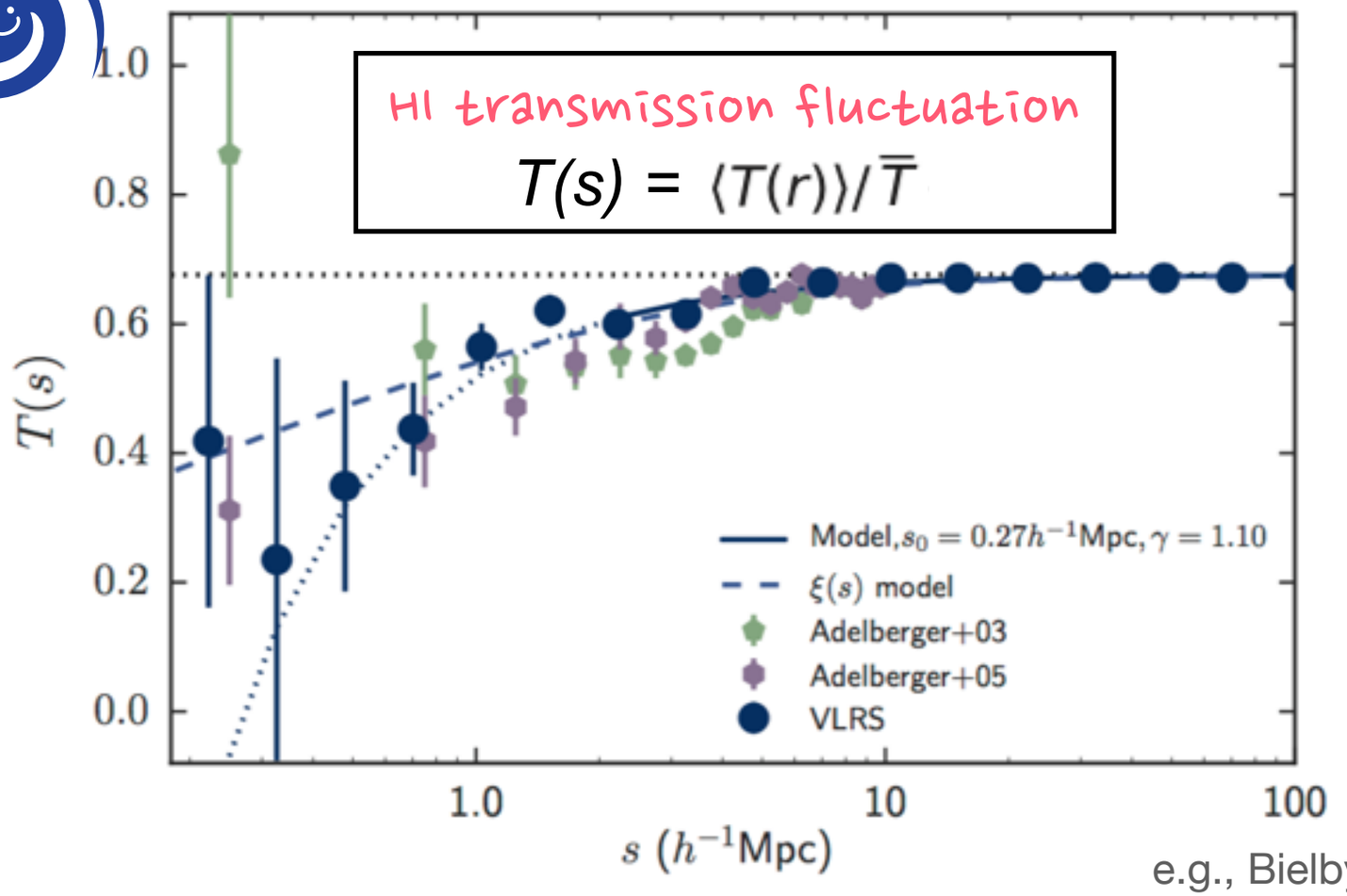
IGM-galaxy connection probed by cross-correlation analysis







e.g., Bielby+17

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

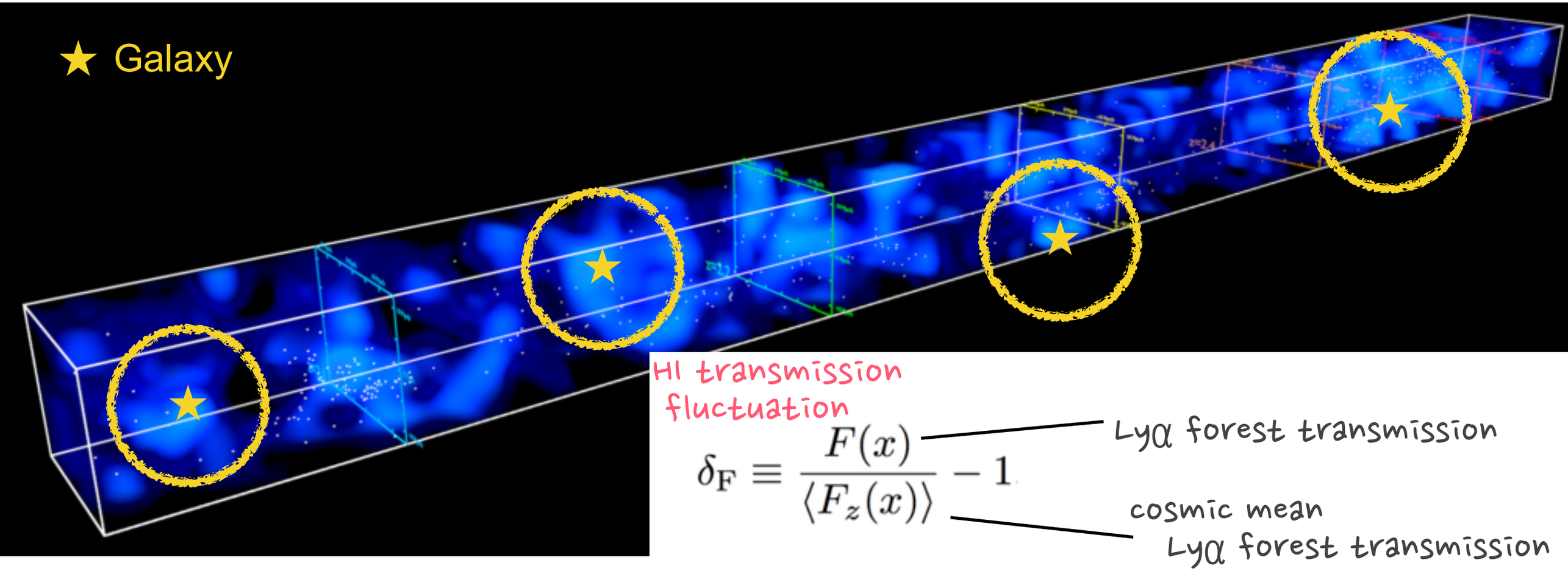
- Cross-correlation between HI transmission excess δ_F and galaxies

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

Galaxies — Random points

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

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



HI transmission fluctuation

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

Lyα forest transmission

cosmic mean Lyα forest transmission

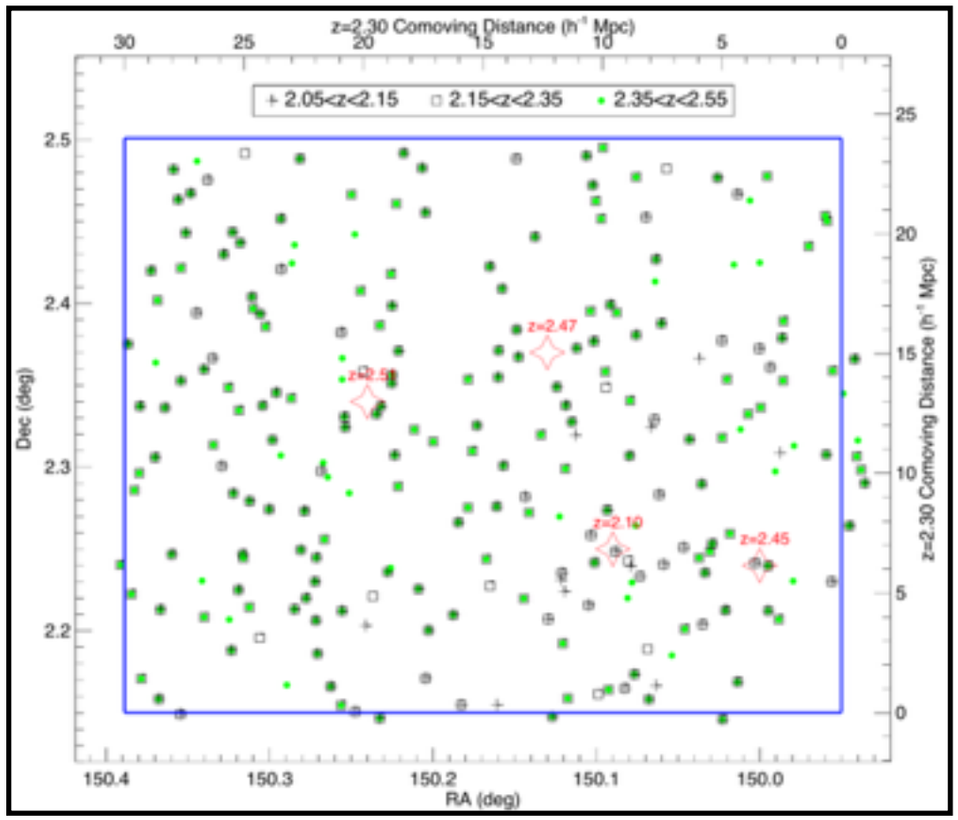
Lee+16, 18

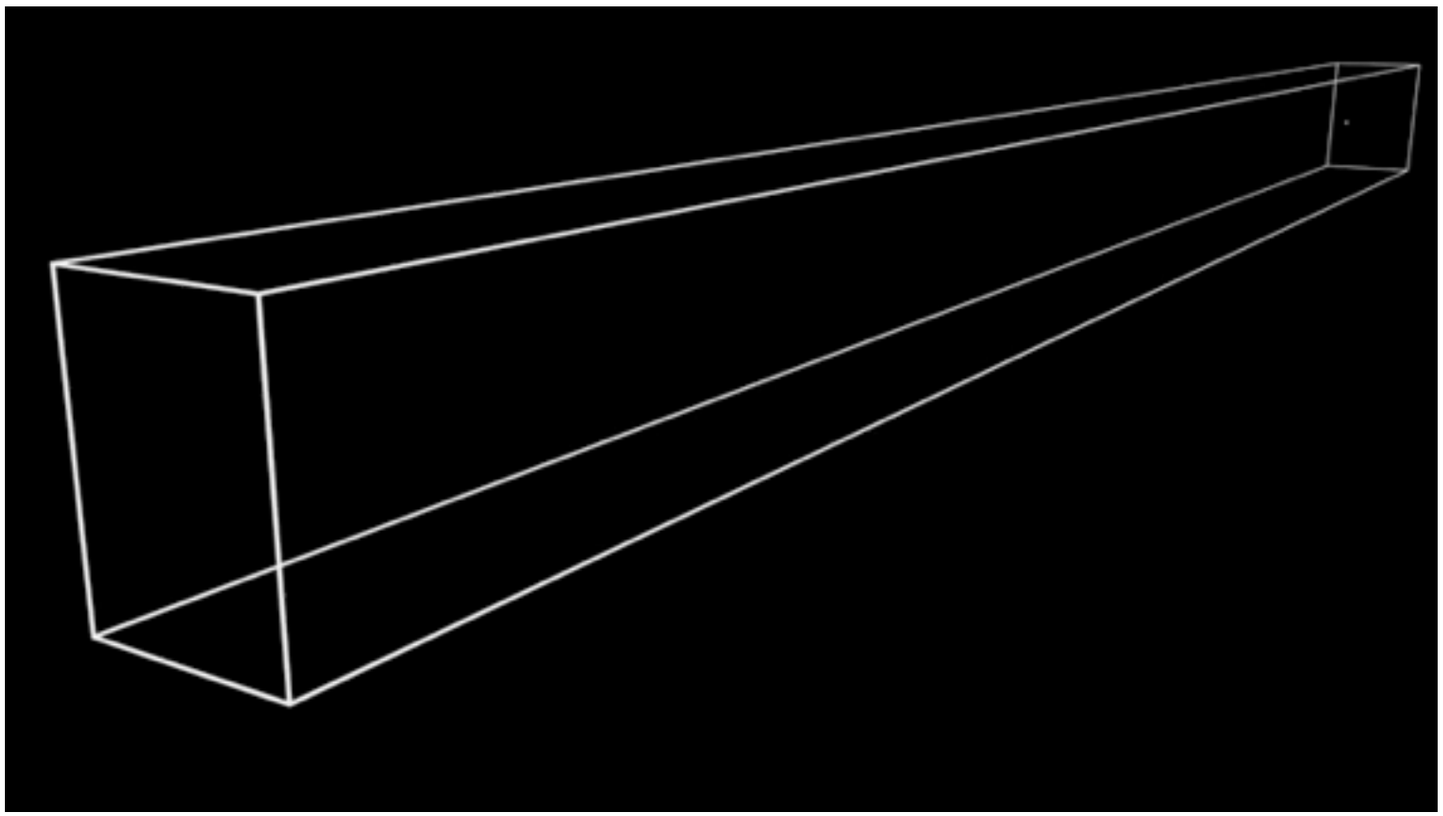
Data

	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~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 $M_* \geqq 10^9$ $M_\odot$

Observations: CLAMATO

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

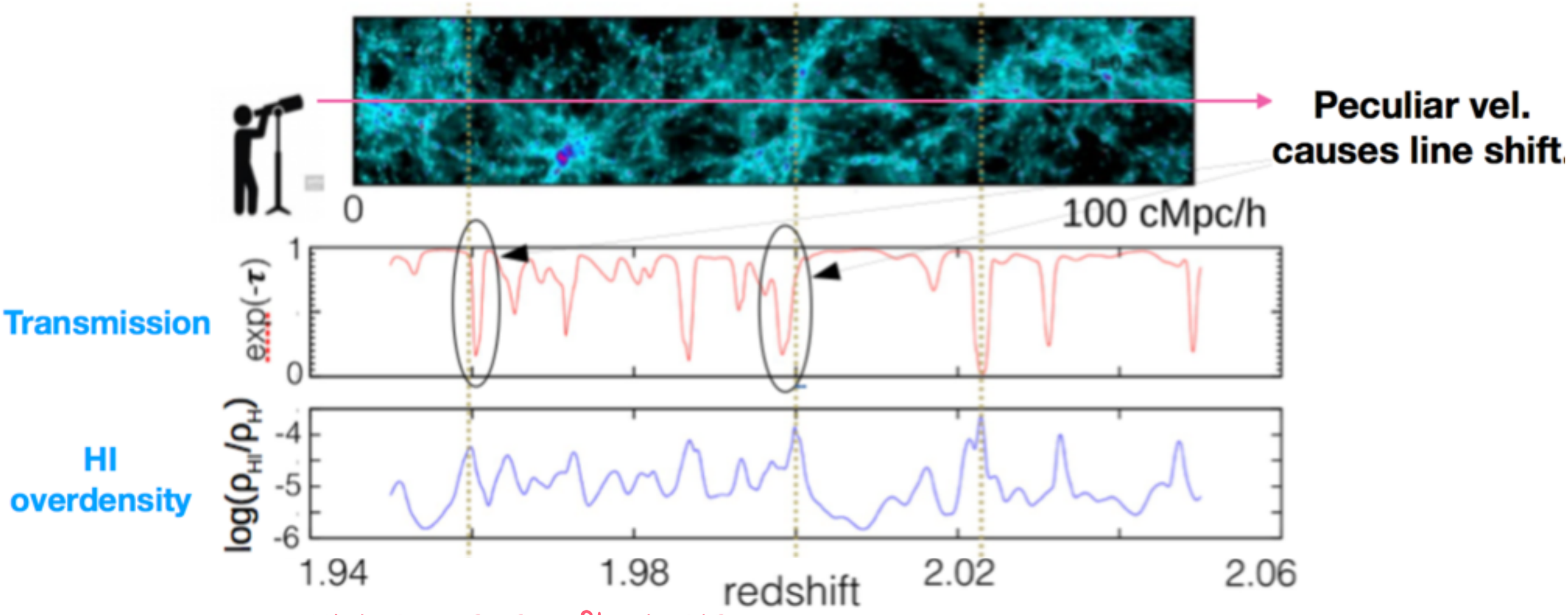




Lee+16, 18

Simulations: GADGET3-Osaka

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



HI transmission fluctuation

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

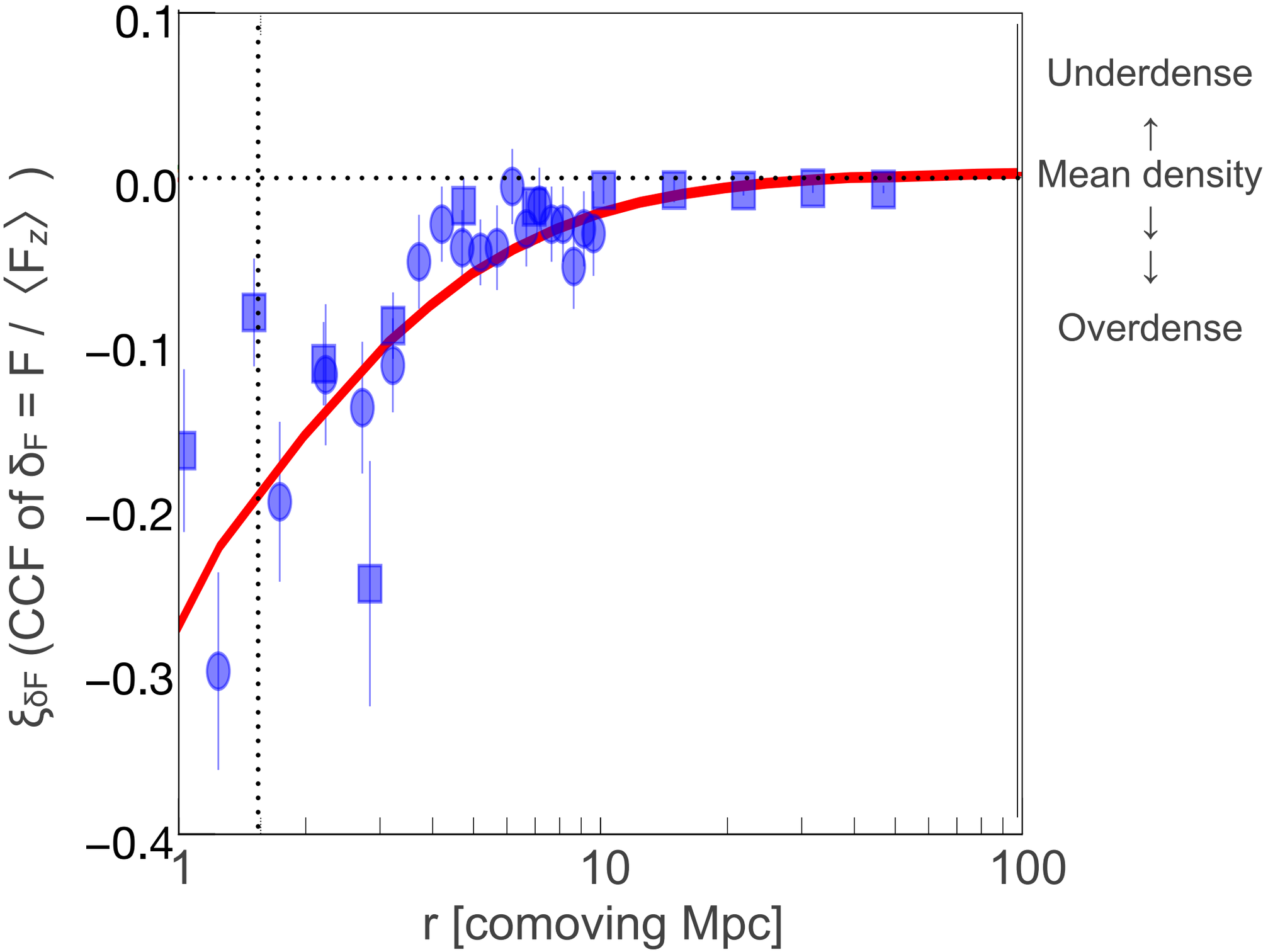
Lyα forest transmission

cosmic mean Lyα forest transmission

Slide from Prof. Nagamine

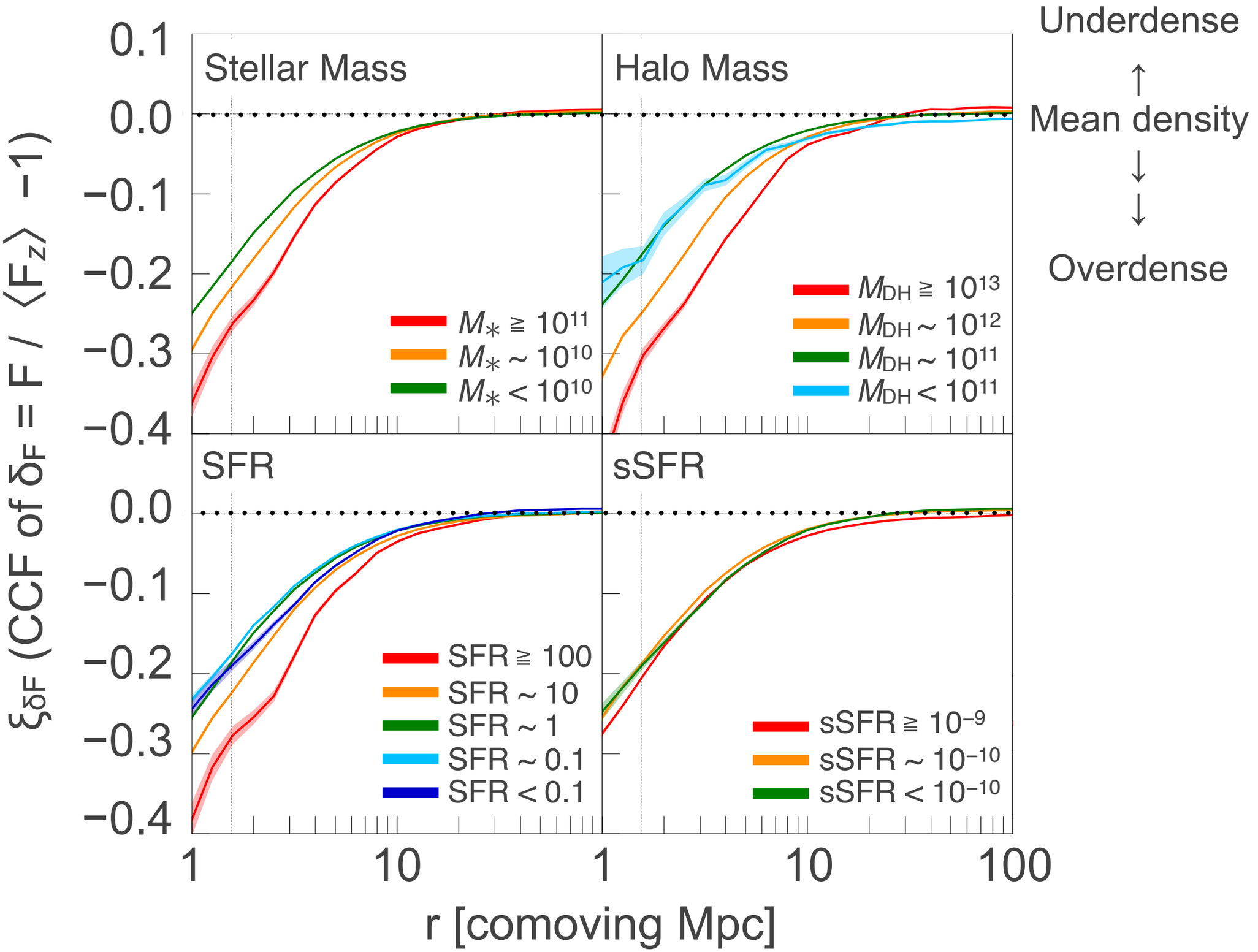
Results & Discussions

The CCF of all galaxies in our simulation

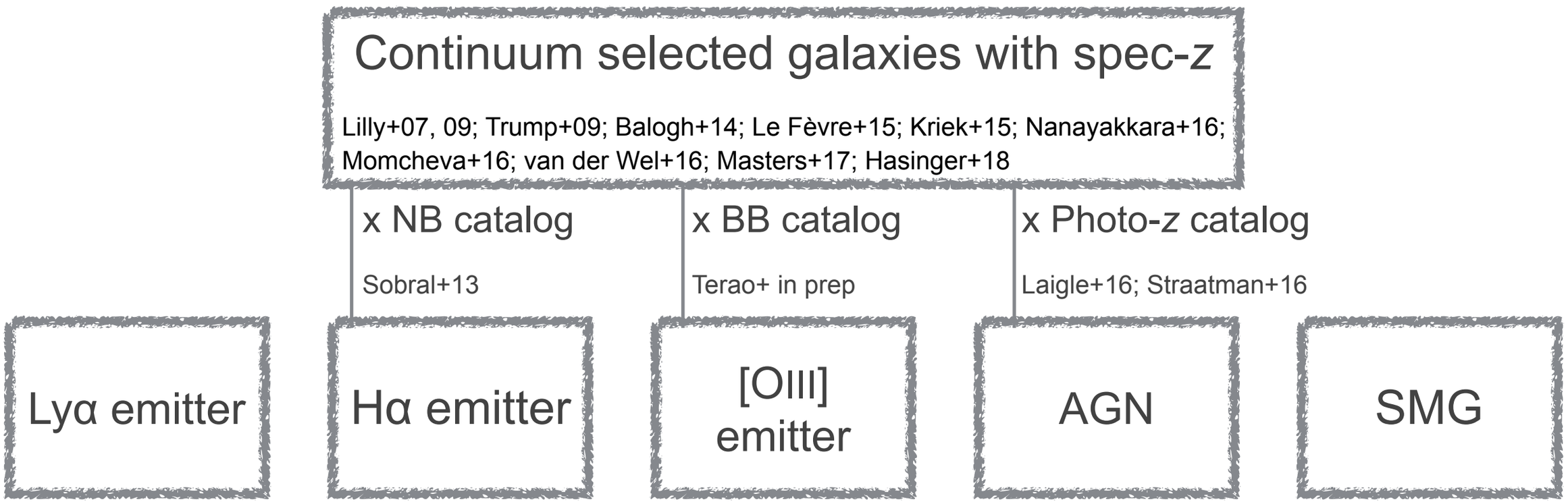


Adelberger+03; Bielby+17

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

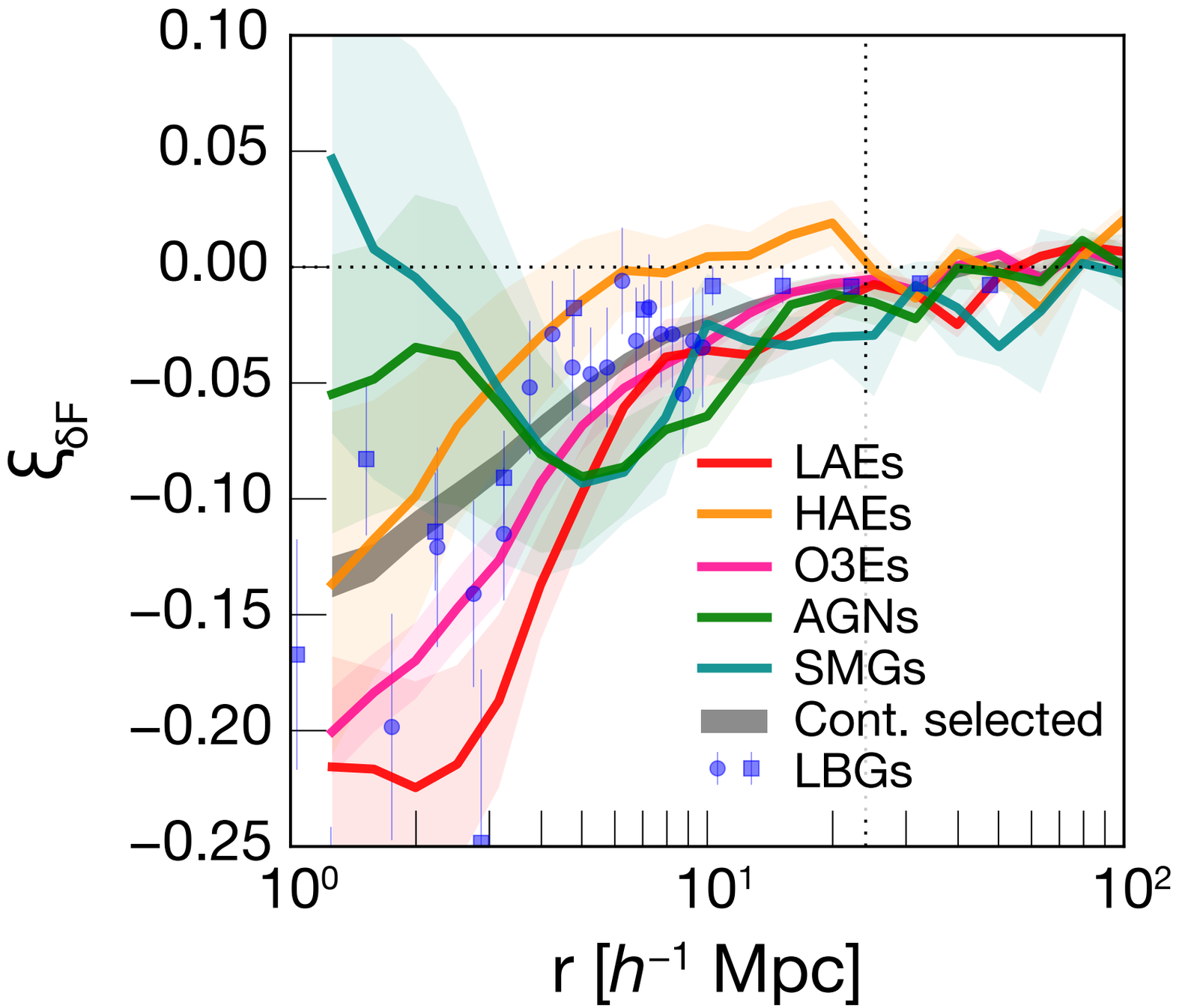


Galaxy populations? Preparation for calculations



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

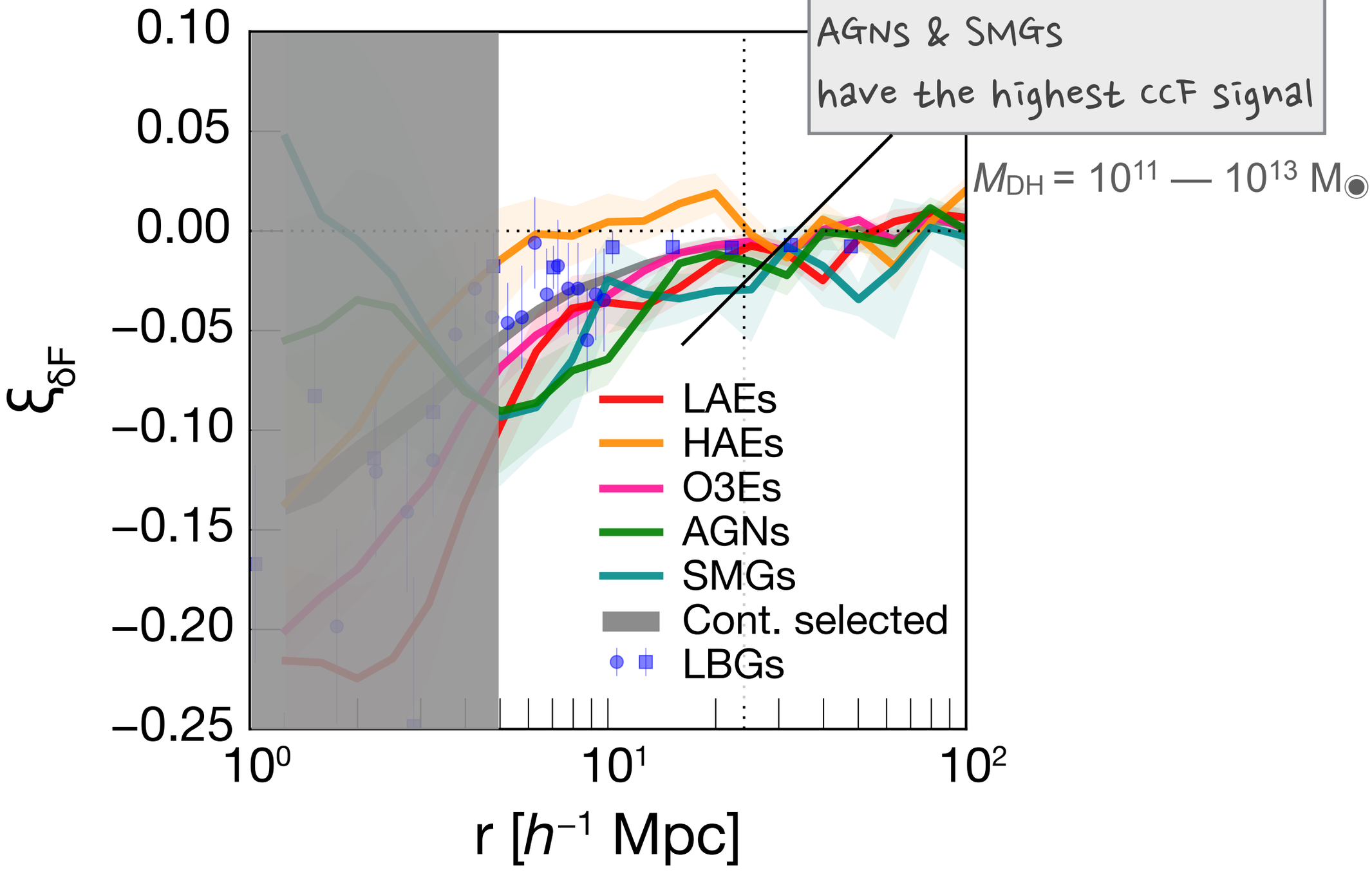
Galaxy populations? CCFs



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

Galaxy populations? CCFs

At $r \gtrsim 5$ cMpc,
AGNs & SMGs
have the highest CCF signal



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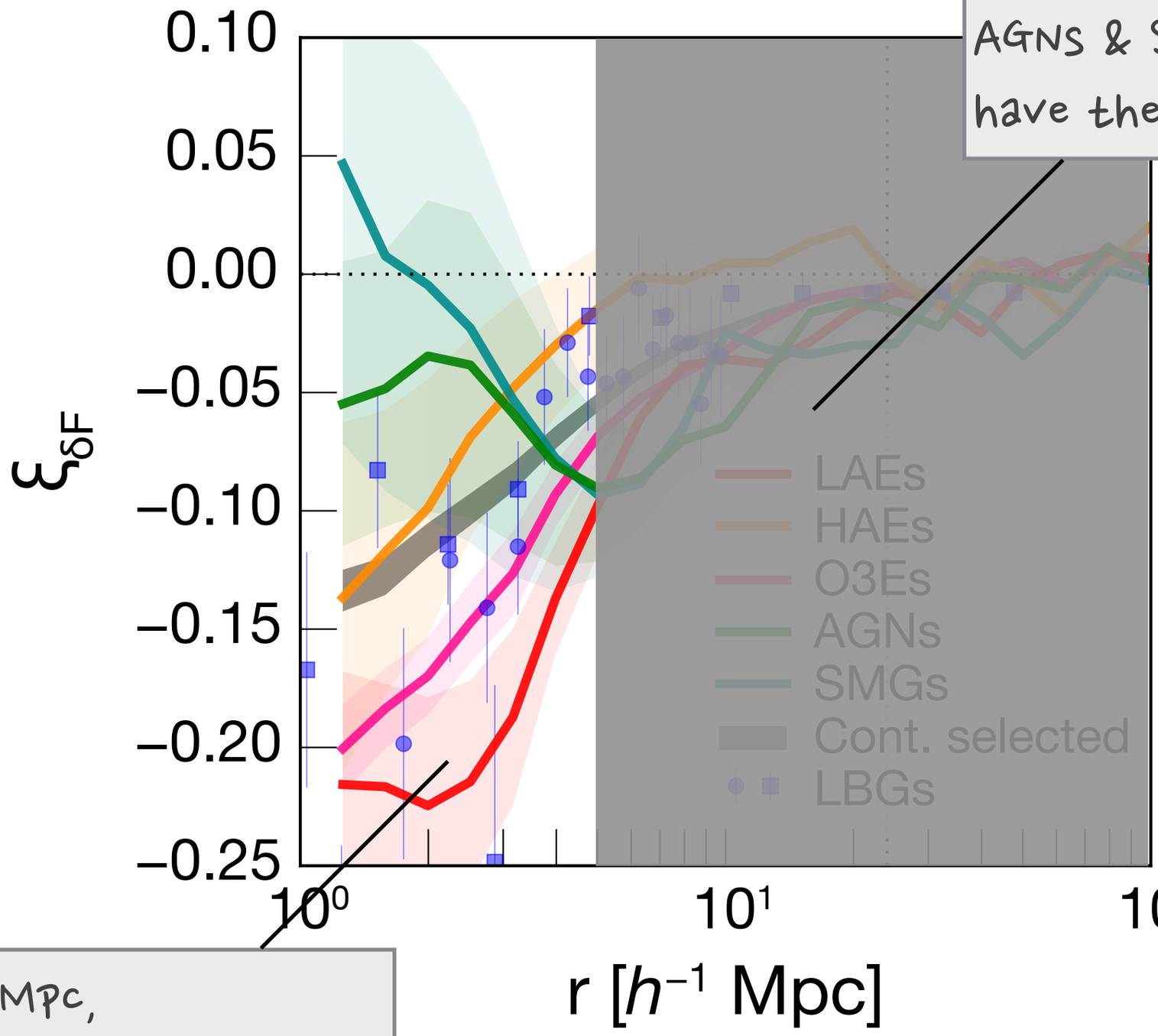
Galaxy populations? CCFs

At r ≳ 5 cMpc,
AGNs & SMGs
have the highest ccF signal



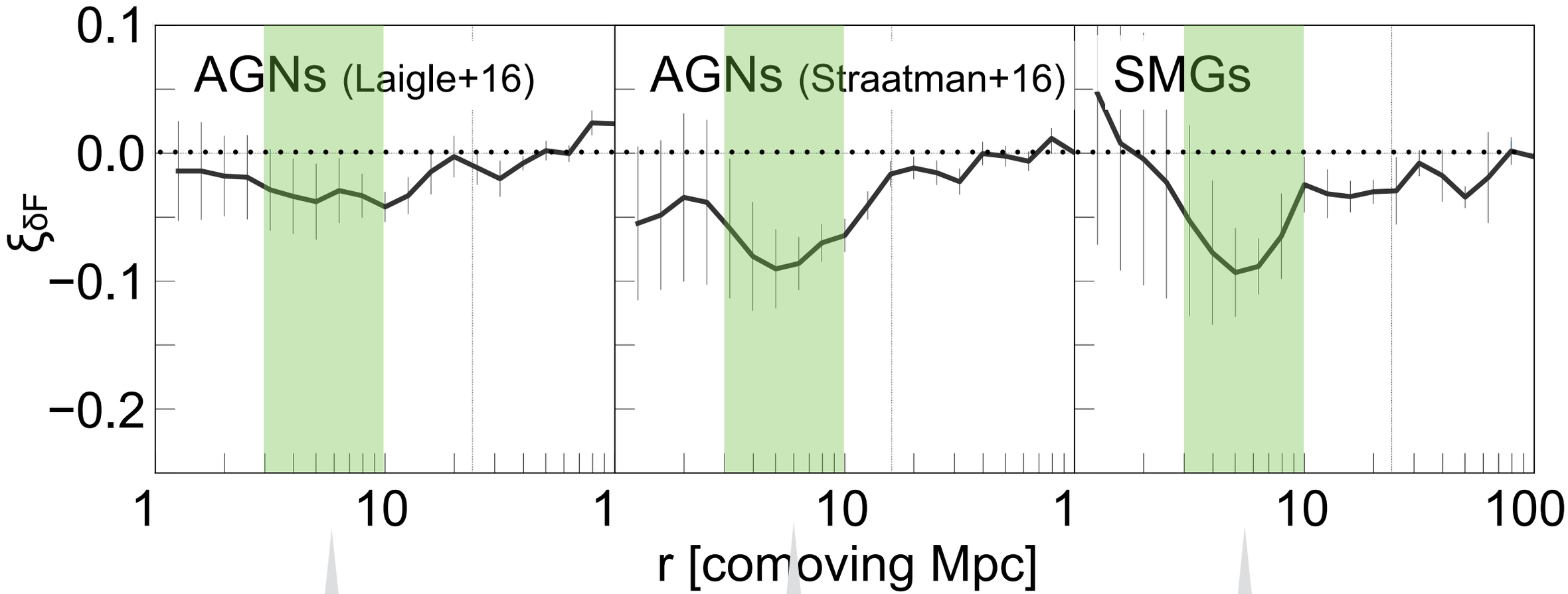
$M_{DH} = 10^{11}$ — 10^{13} $M_\odot$

At r ≲ 5 cMpc,
LAEs have the highest signal

$M_{DH} = 10^{10}$ — 10^{11} $M_\odot$

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

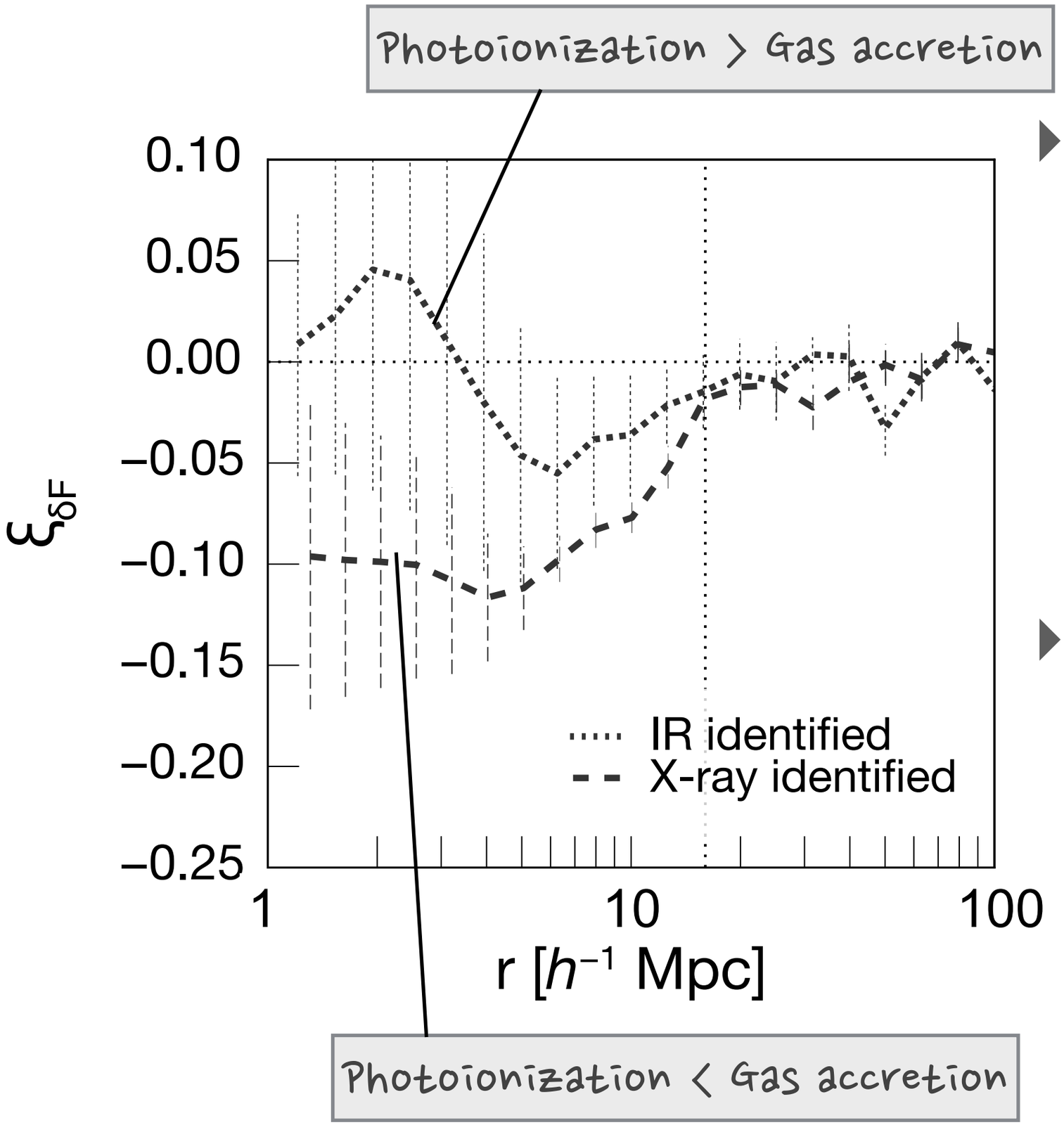
Galaxy populations? AGNs and SMGs



A negative bump at **r ~ 5–7 Mpc/h**

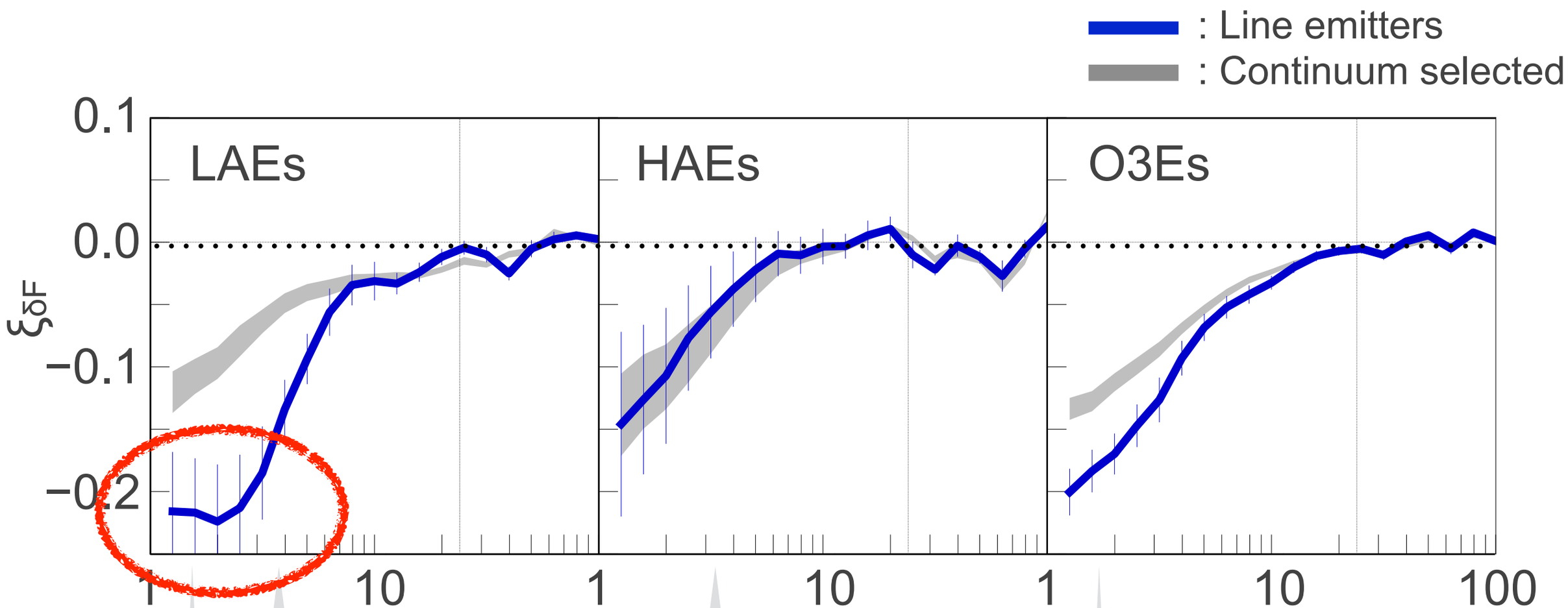
Located several Mpc away from a density peak ➡ **Proximity effects**

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



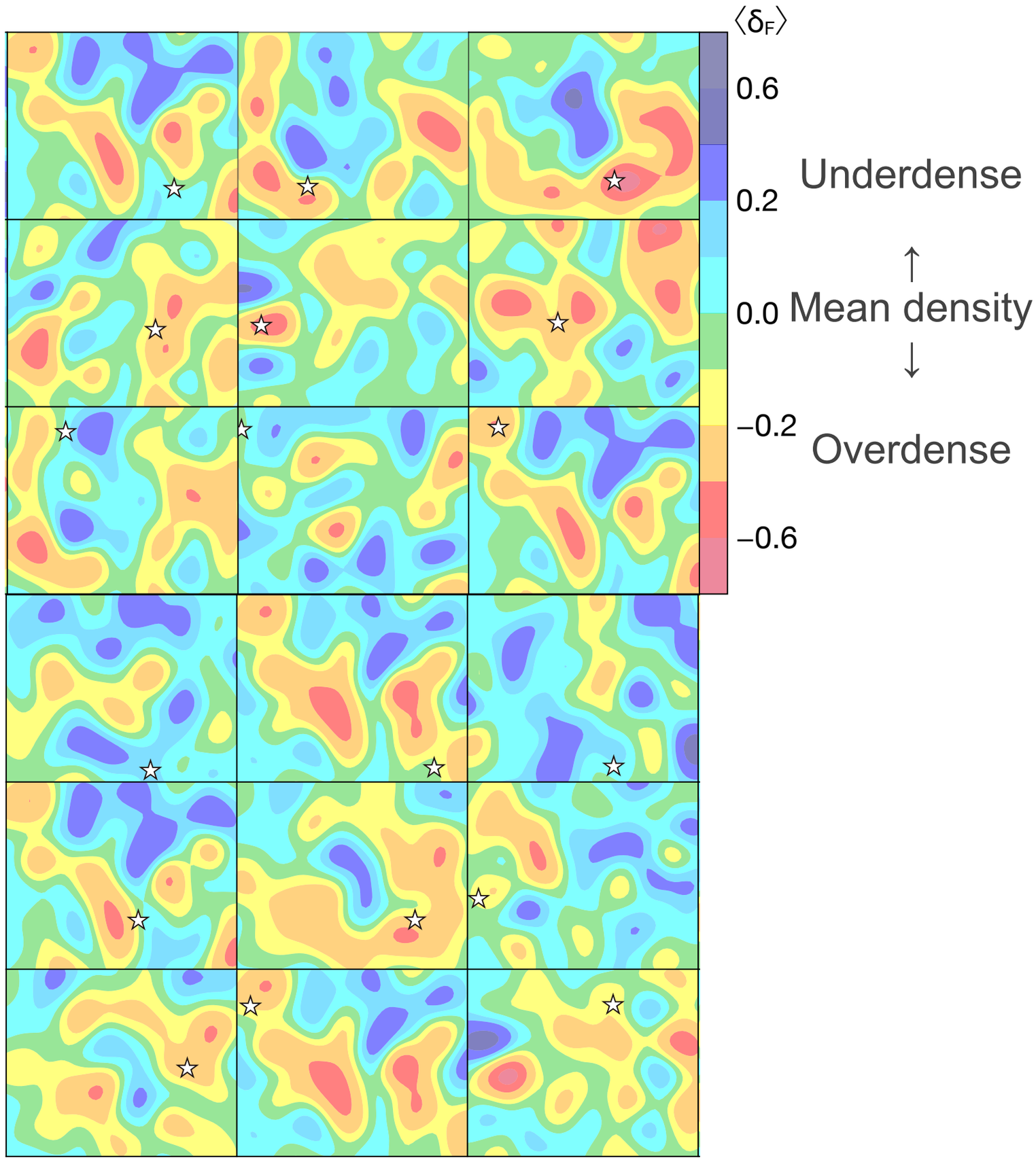
A few Mpc offset from a density peak

Comparable CCF
➡ Similar IGM density

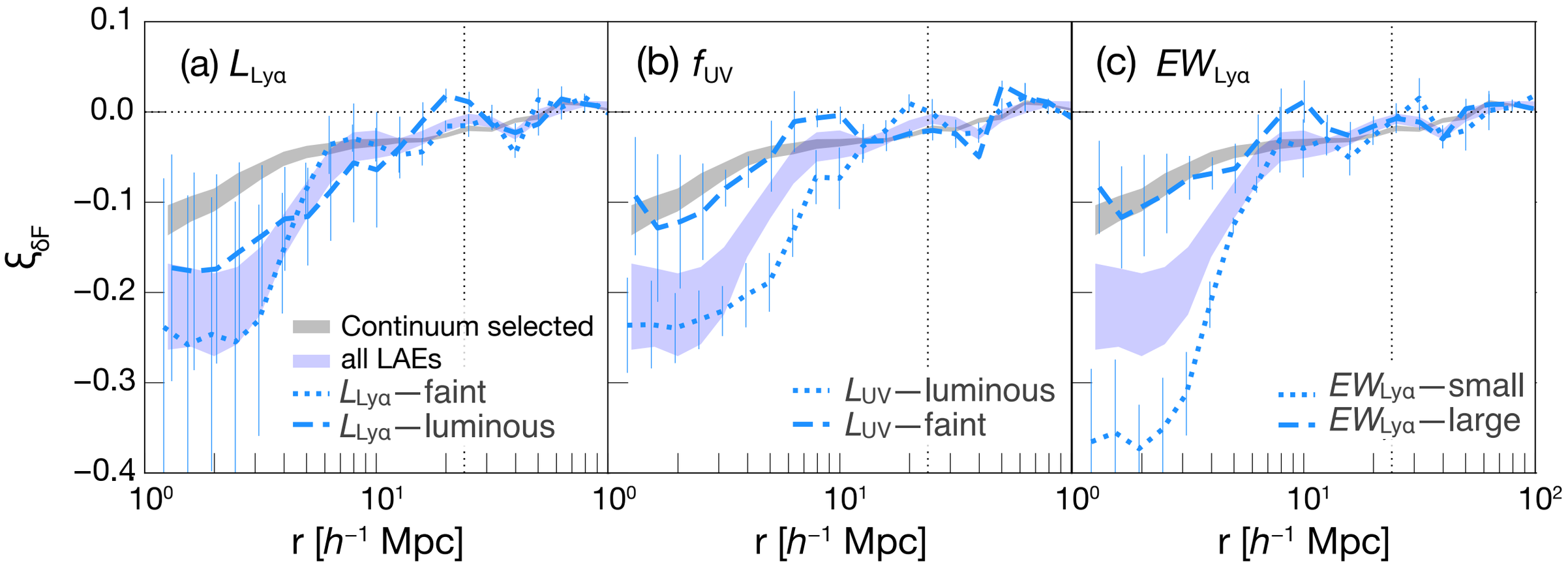
Stronger signal ➡ **Denser** IGM

Galaxy populations? LAEs

- Projected HI density maps
  - Collapsing Δz = 2 cMpc around LAEs
  - Map size: 30 x 24 cMpc^2
- 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



- **$L_{Ly\alpha}$—faint, L_{UV}—luminous,** and **$EW_{Ly\alpha}$—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

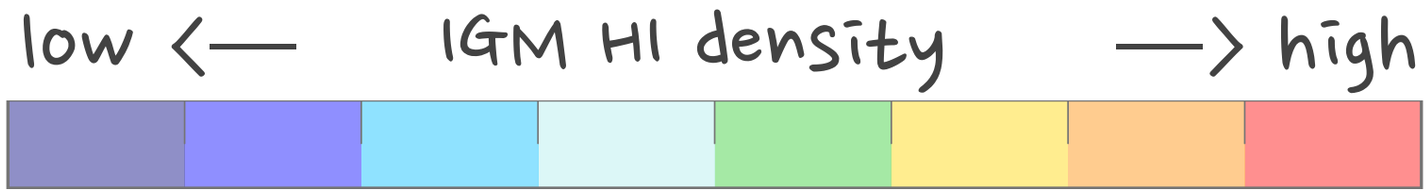
Kusakabe+19; Khostovan+19

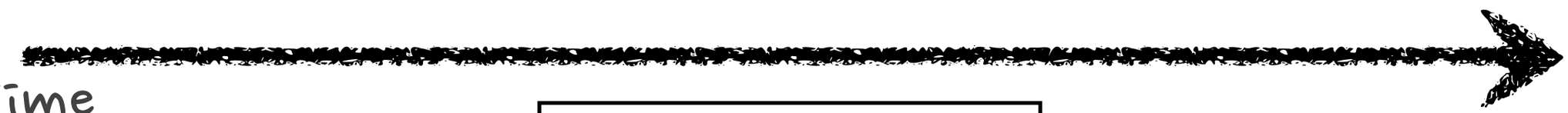
Summary: What can we learn about the IGM-galaxy connection?

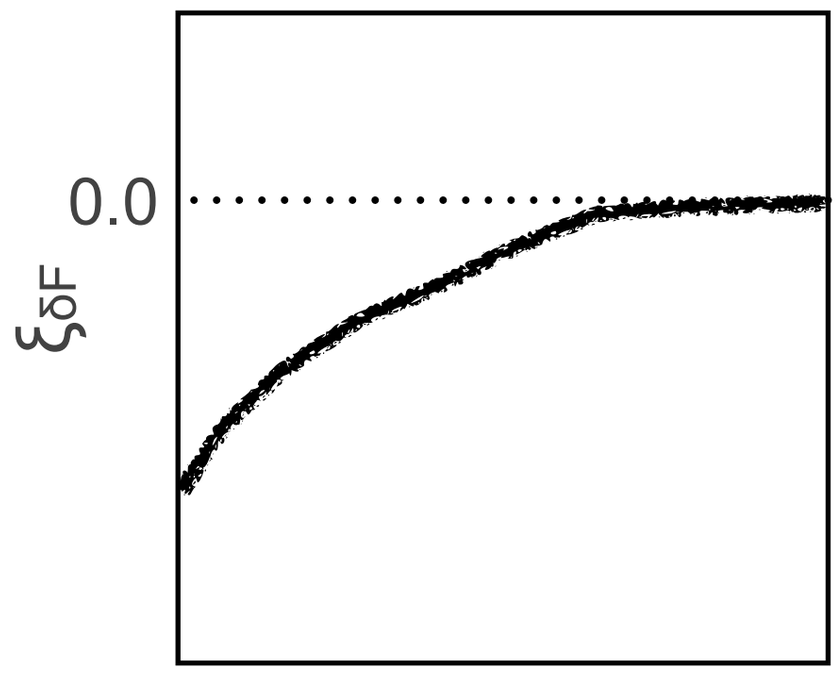
- **What type of galaxies (M_*, SFR) strongly connect to the IGM?**
  - Galaxies with higher mass (and SFR) tend to reside in higher density regions

- **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 evolutional stage







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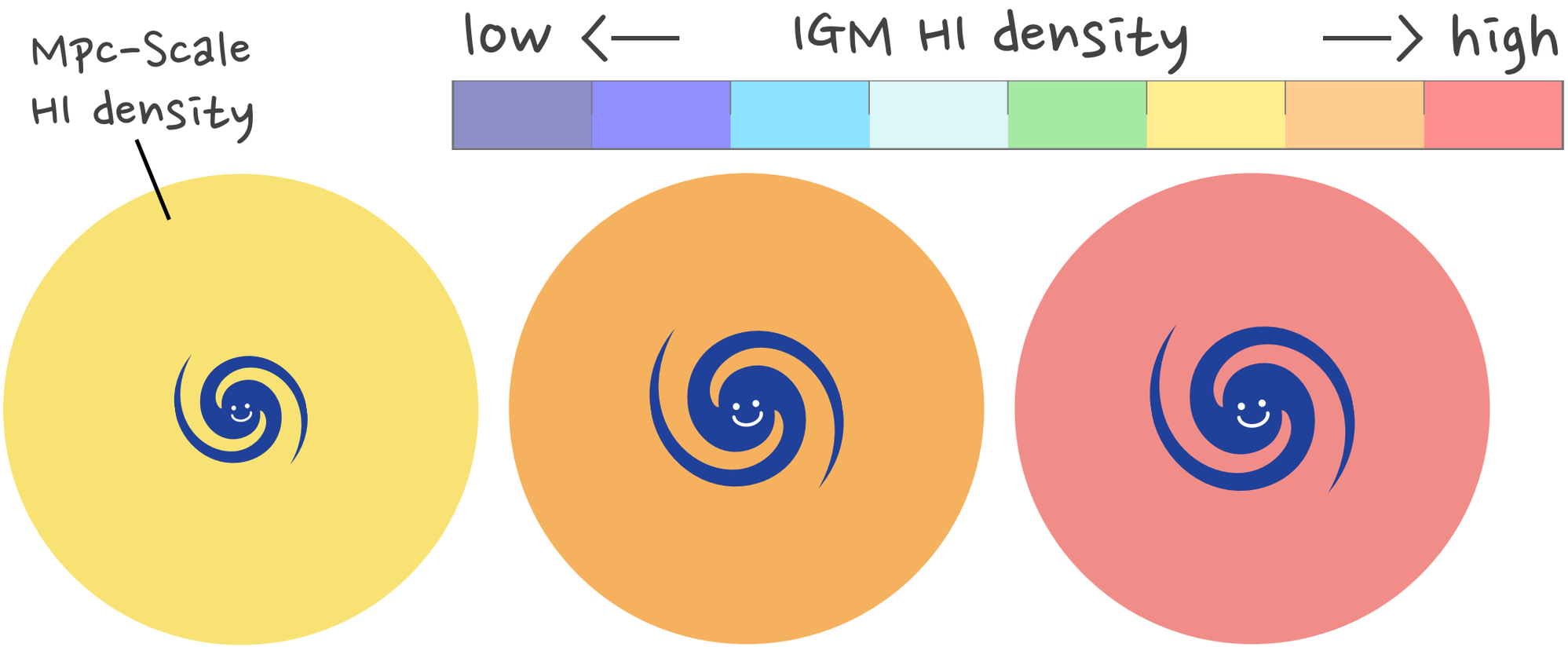
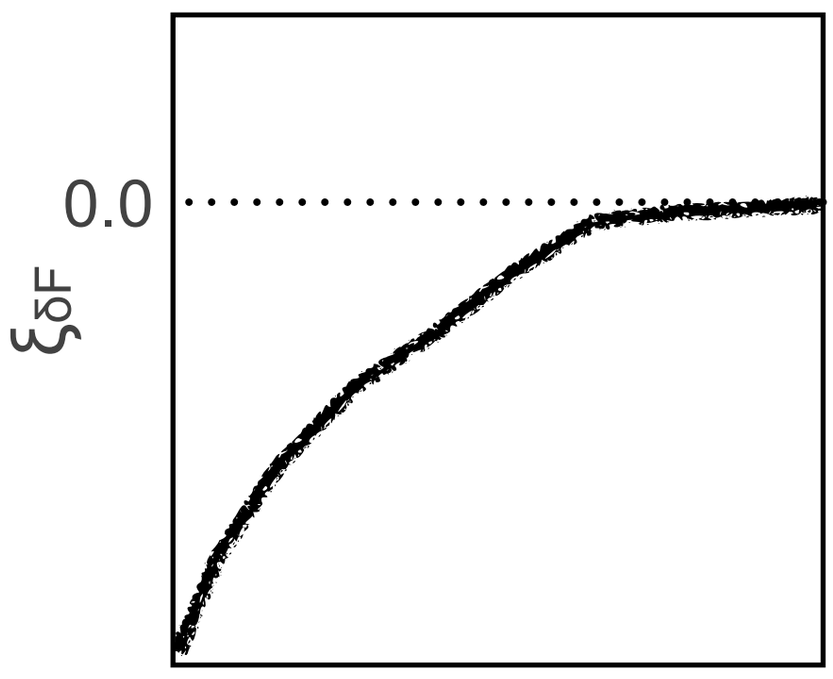


M_{DH}, Time



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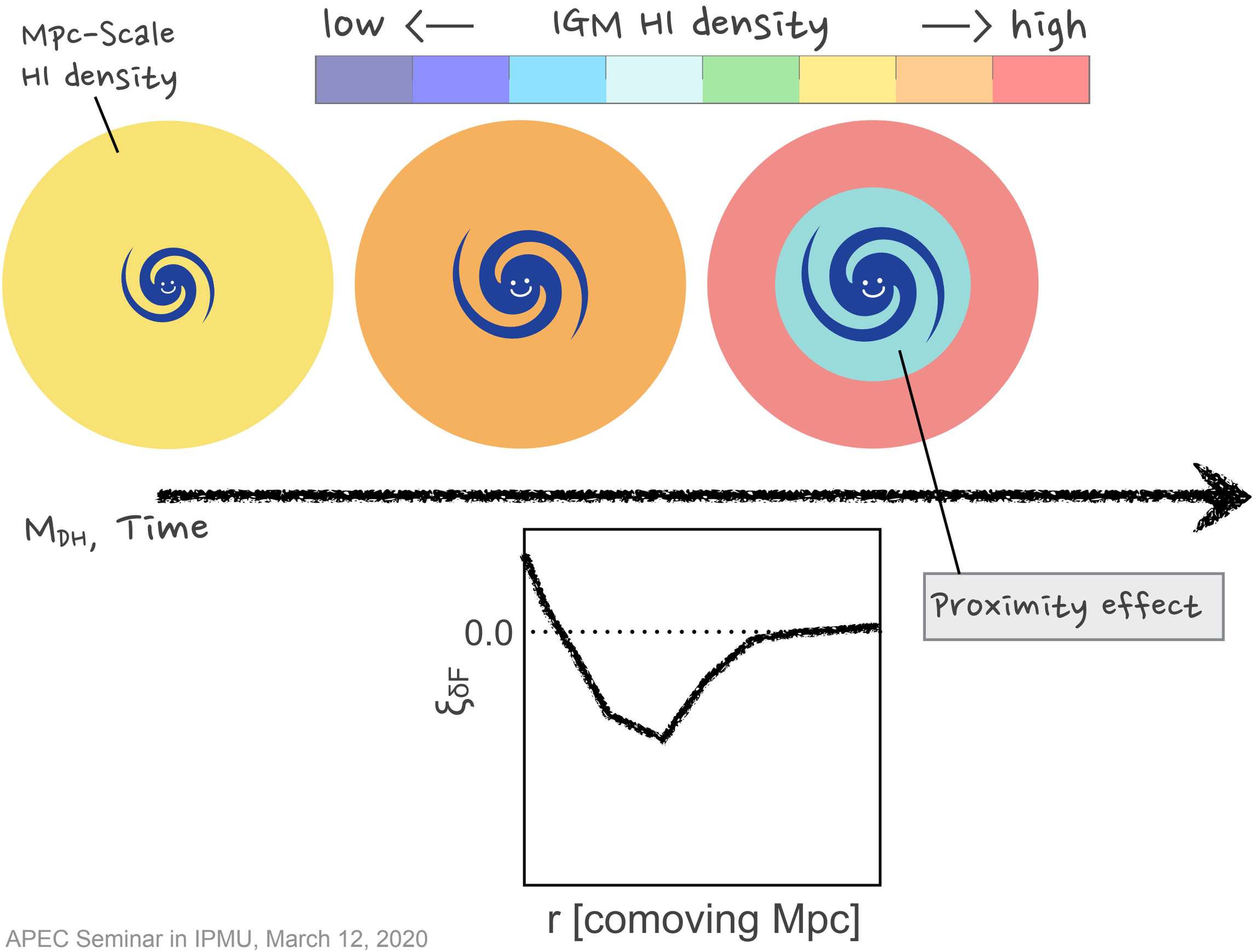
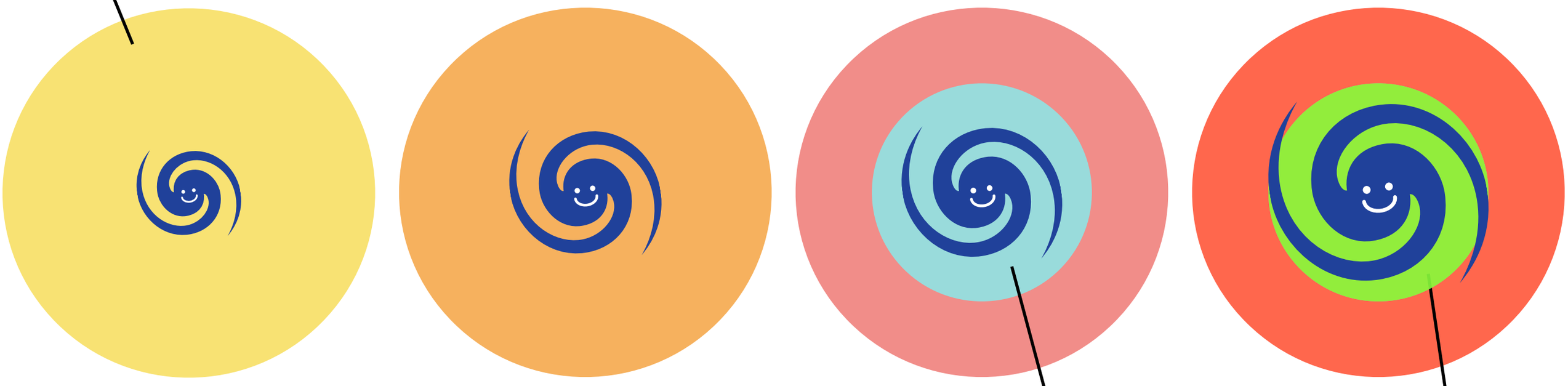


Hypothesis of the IGM-galaxy connection depending on evolutional stage

low <— IGM HI density —> high

Mpc-Scale HI density



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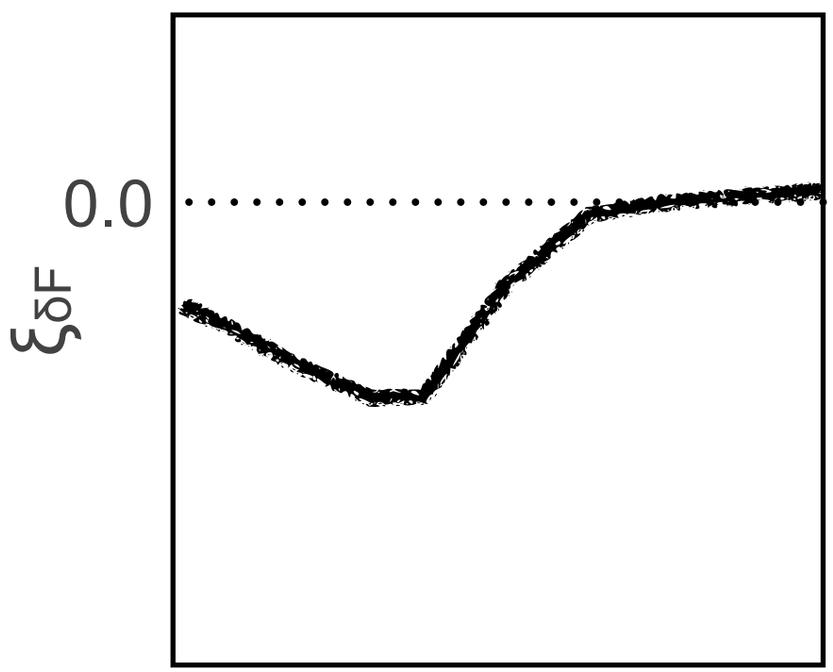

r [comoving Mpc]

Proximity effect

Accretion > Photoionization

Fin.