Environmental Dependence of the Mass–Metallicity Relation in Cosmological Hydrodynamical Simulations

arXiv: 2305.08161

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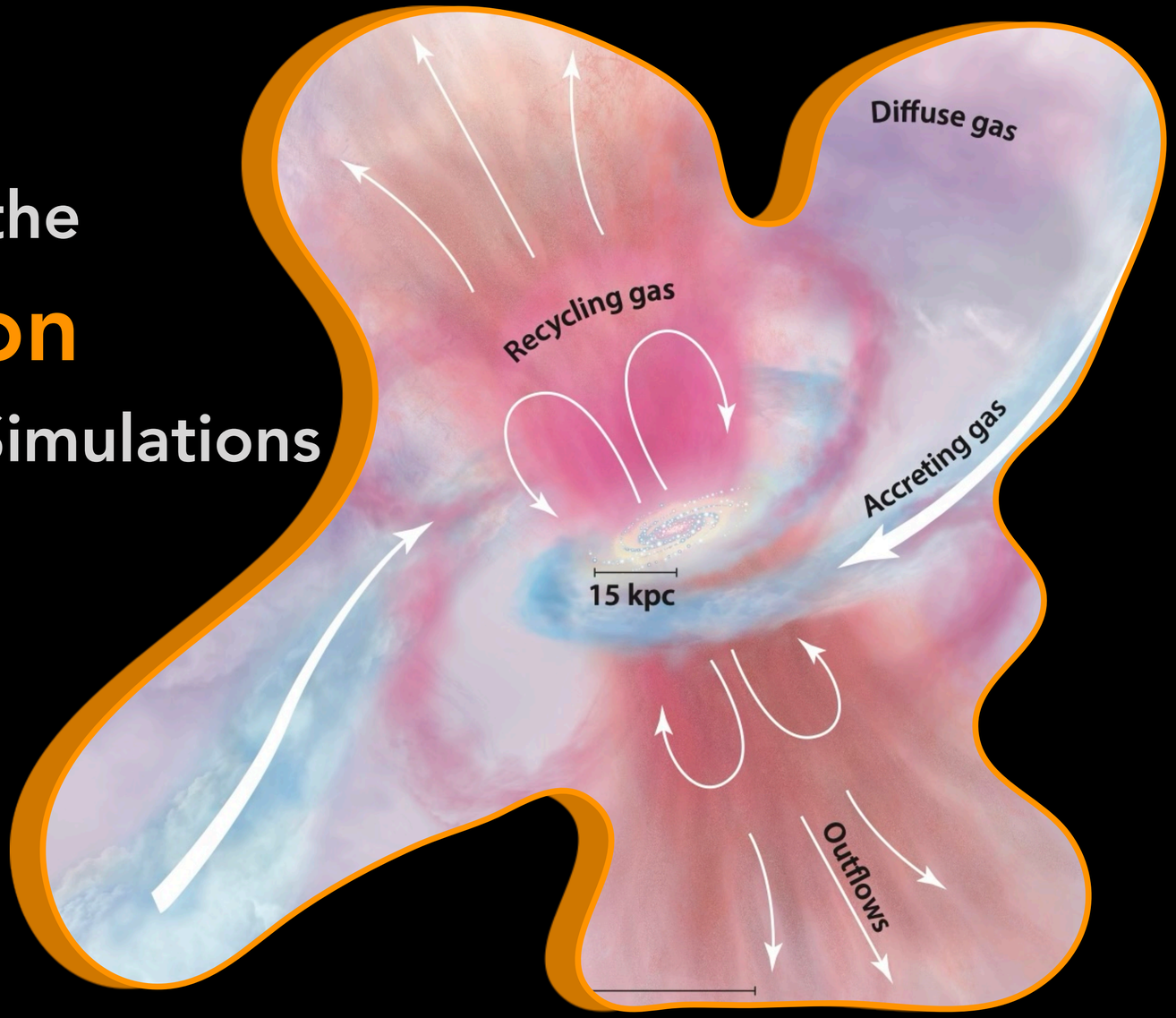
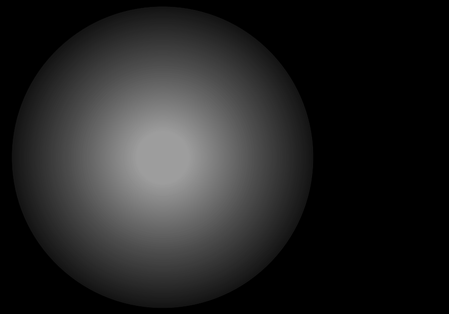
ICC & CEA, Durham University
with **Xin Wang, Yangyao Chen**

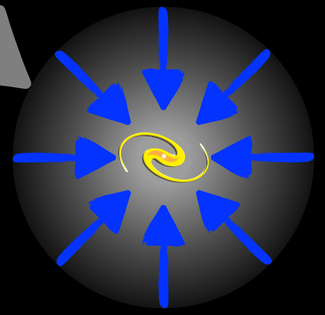


(12 mins) ***National Astronomical Meeting*** Jul. 9, 2025 @ Durham

- **Galaxy formation and evolution**

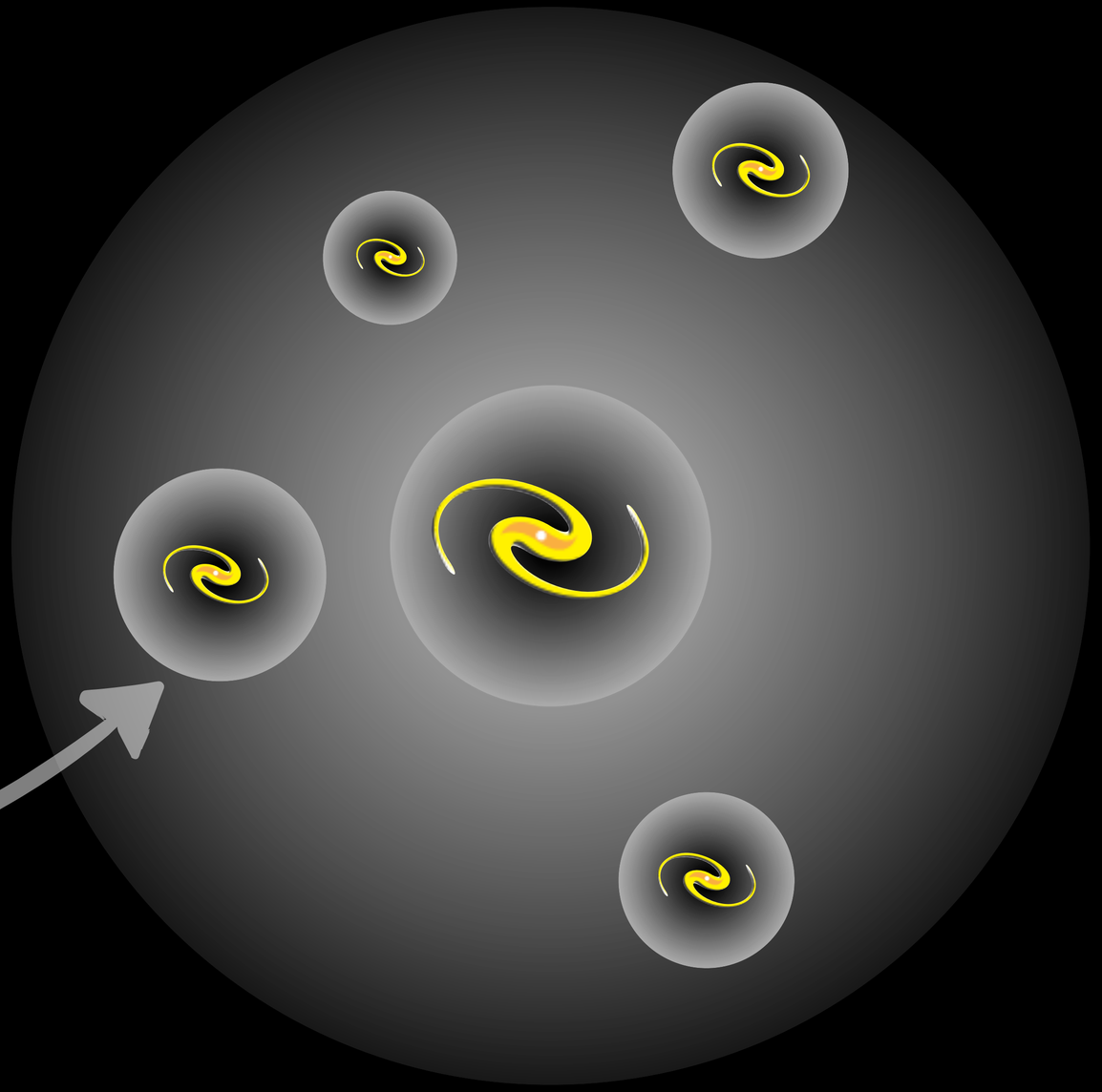
1. Collapse of dark matter halo



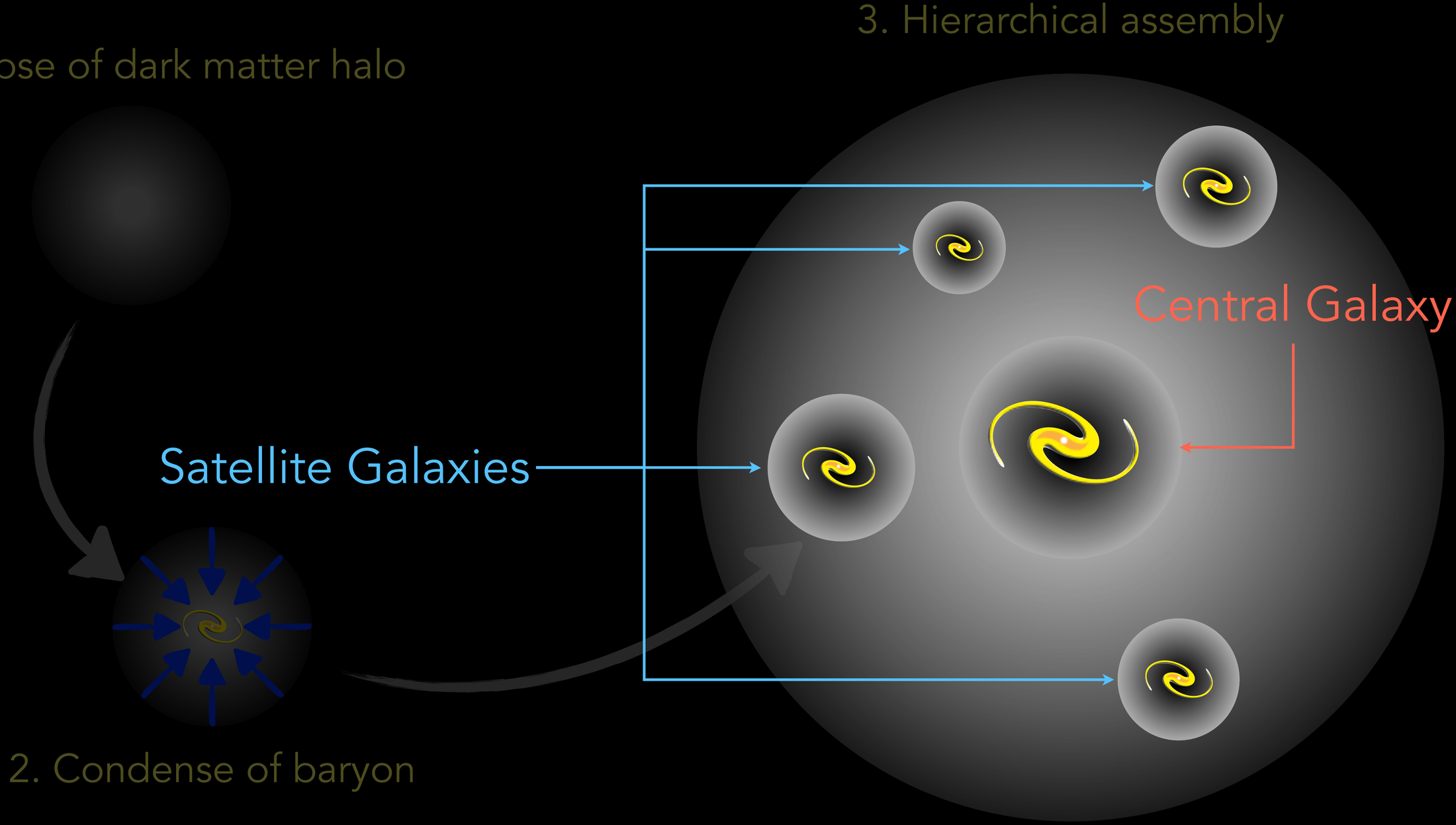


2. Condense of baryon

3. Hierarchical assembly

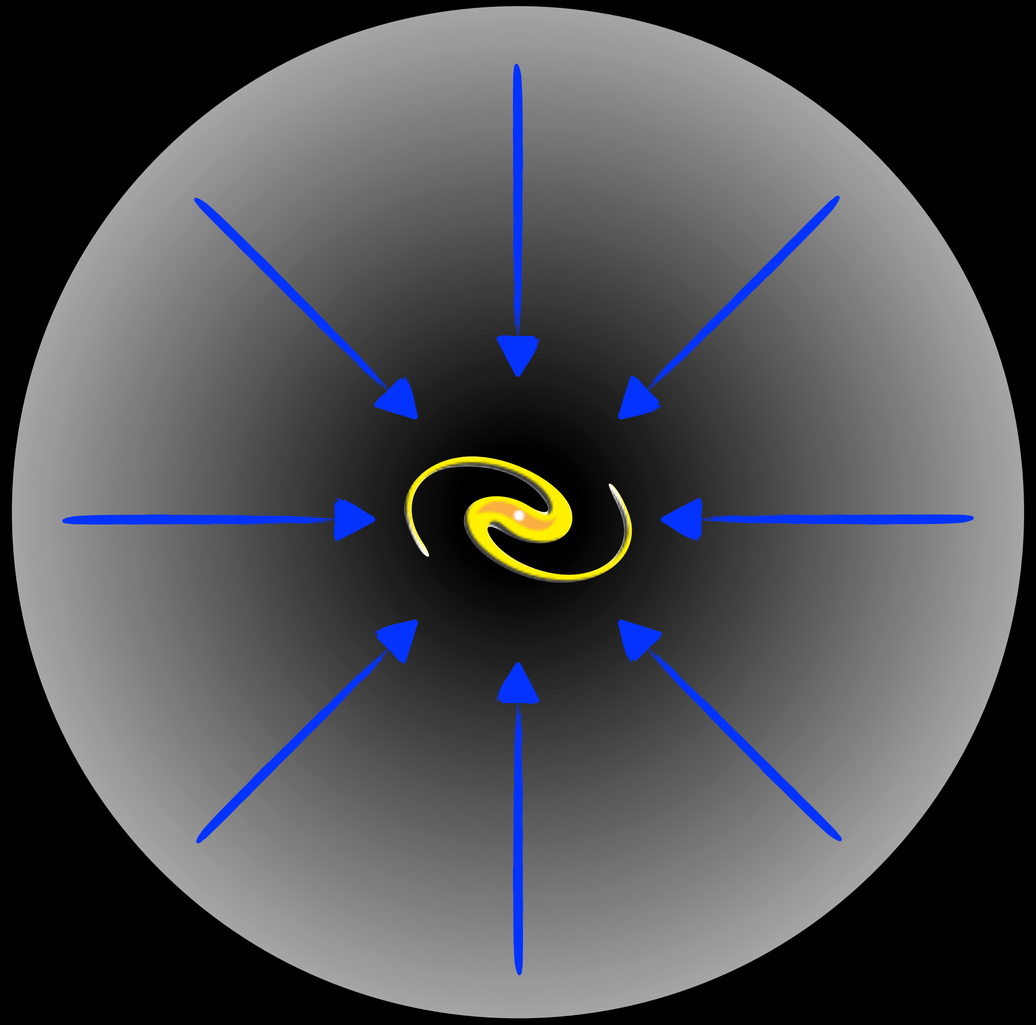


- **Galaxy formation and evolution**



- **Galaxy formation and evolution traced by metals**

Gas inflow
Z↓☹️



Gas outflow
Z?😵‍💫

Star formation
Z↑😀

Gas stripping
Z?😵‍💫

- **Mass-Metallicity Relation (MZR)**

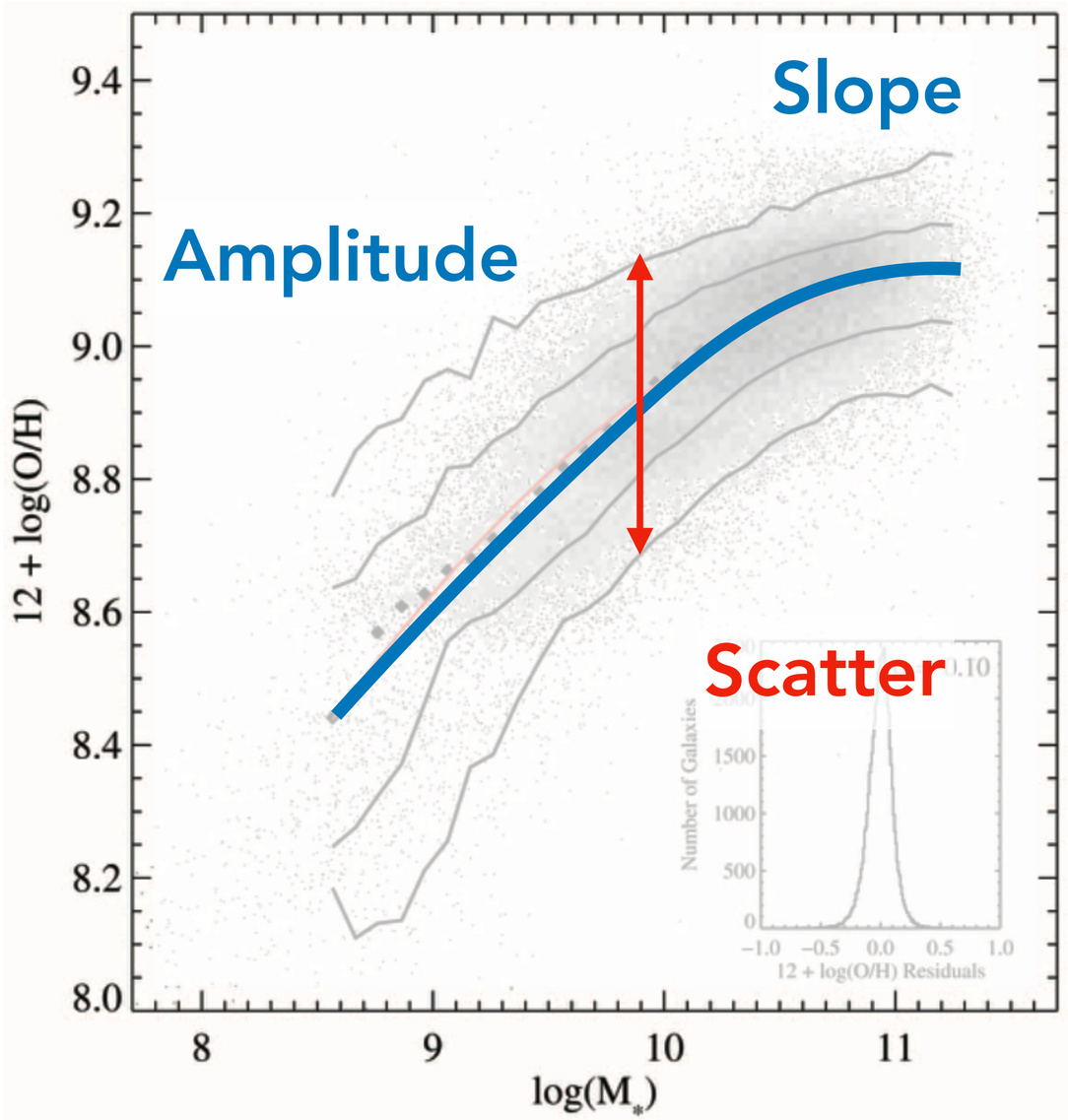
Gas inflow
Z↓☹️

Star formation
Z↑😀

Gas outflow
Z?😵‍💫

Gas stripping
Z?😵‍💫

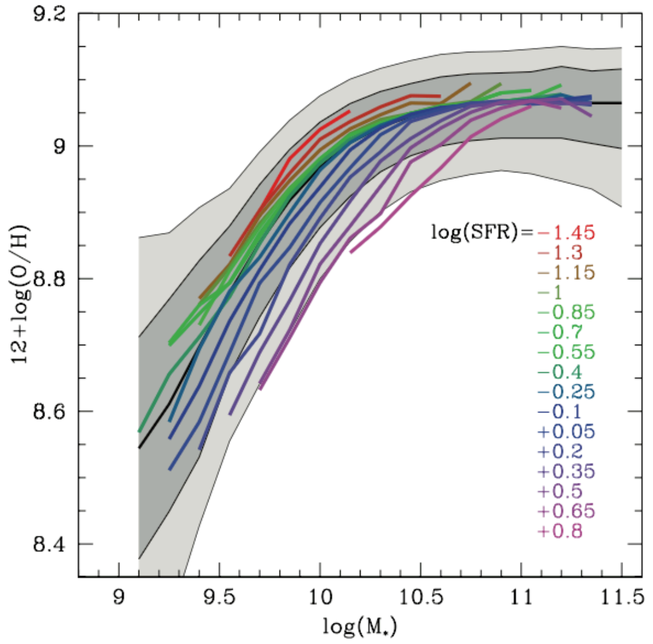
Lequeux+79, Tremonti+04, Mannucci+10, Pérez-Montero+13, Lian+15, Garnett+02, Brooks+07, Maiolino+08, Zahid+11, Bouché+10, Lilly+13, Peng&Maiolino 14, Dekel+13, Dekel & Mandelker 14, Davé+11, Somerville+12, De Rossi+17 etc.



- Origin of the scatter in MZR

- Origin of the **scatter** in **MZR**

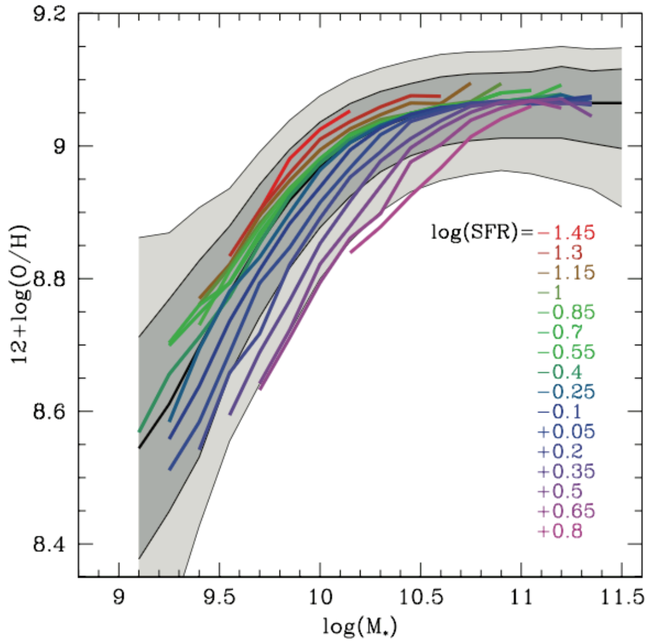
SFR



Mannucci+10

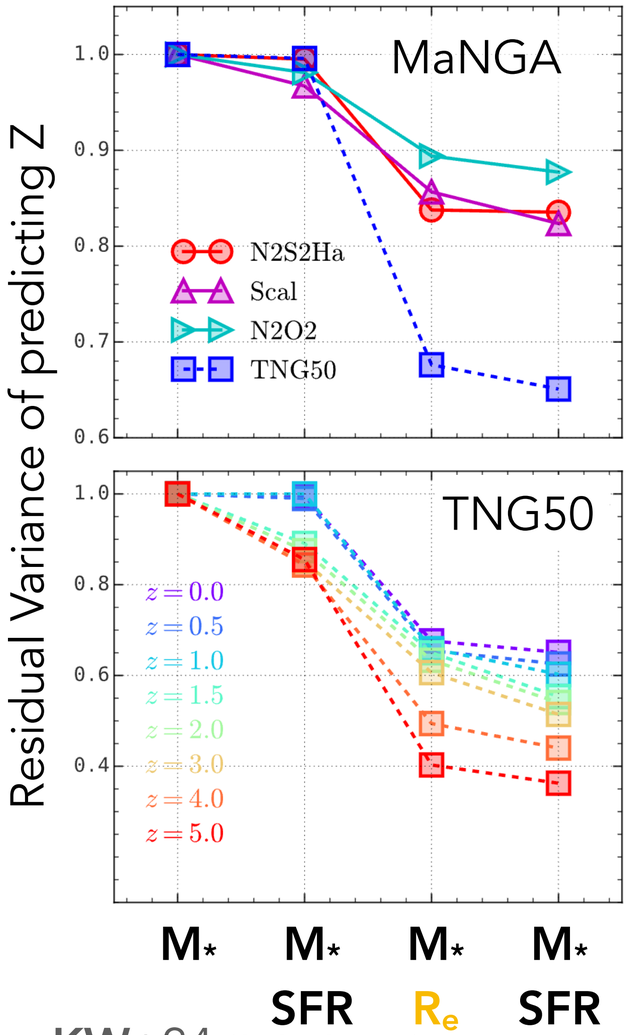
- **Origin of the scatter in MZR**

SFR



Mannucci+10

Size(R_e)

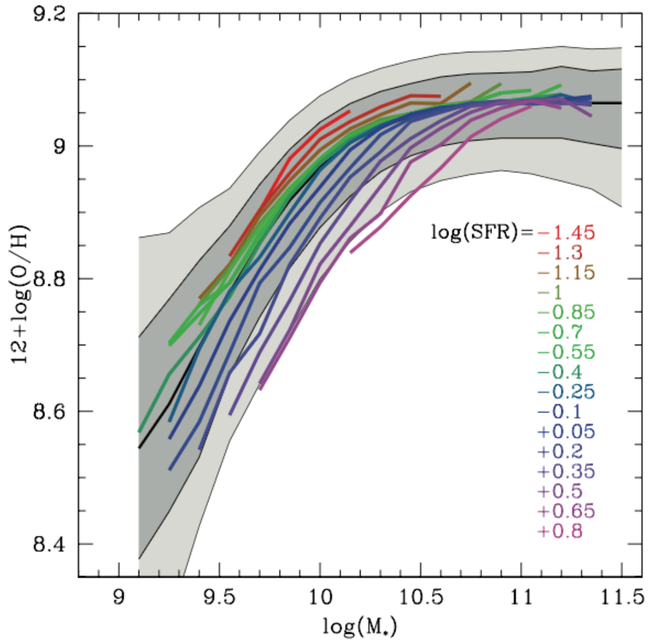


Ma, **KW**+24 (2407.21716)

Jia (incl. **KW**)+25 (2504.18820)

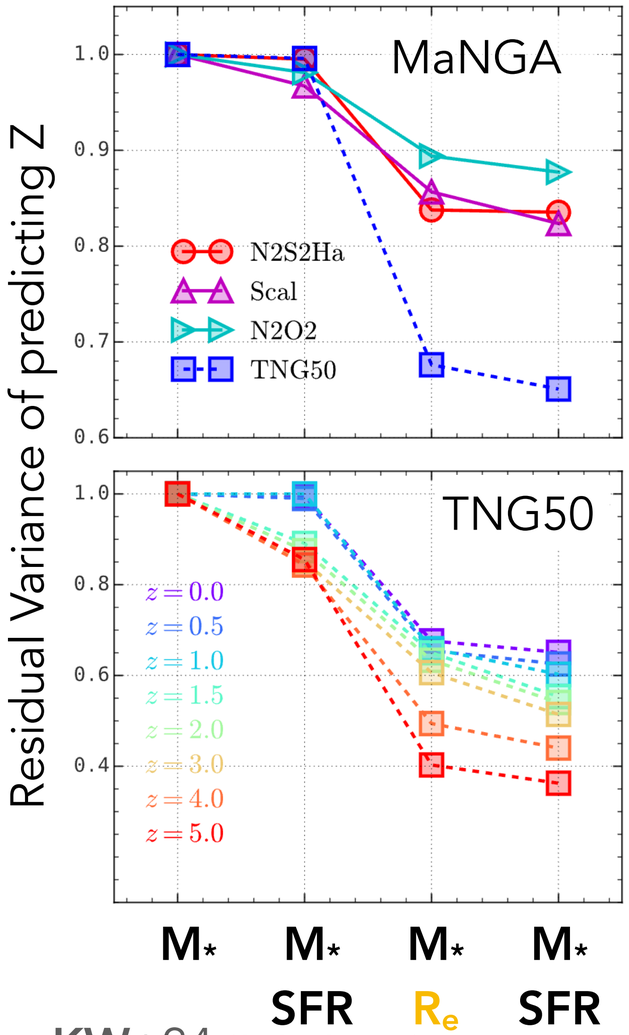
- **Origin of the scatter in MZR**

SFR



Mannucci+10

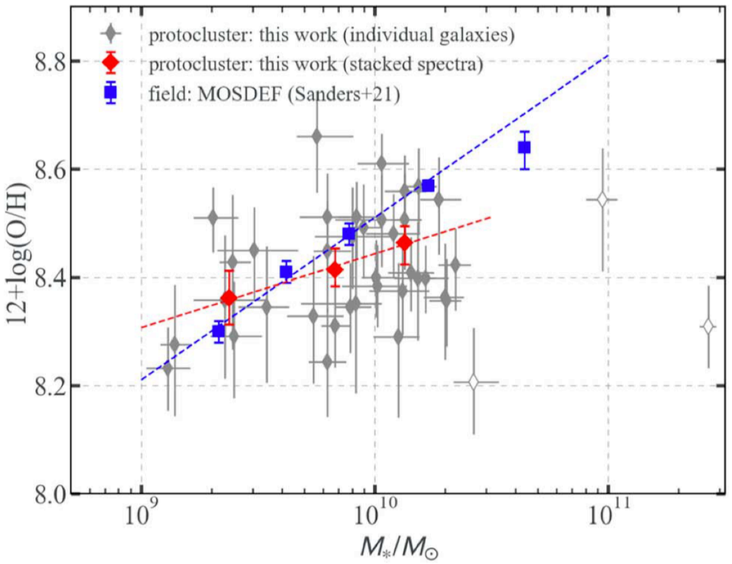
Size(R_e)



M* M* M* M*
SFR R_e SFR
R_e

Ma, **KW**+24 (2407.21716)
Jia (incl. **KW**)+25 (2504.18820)

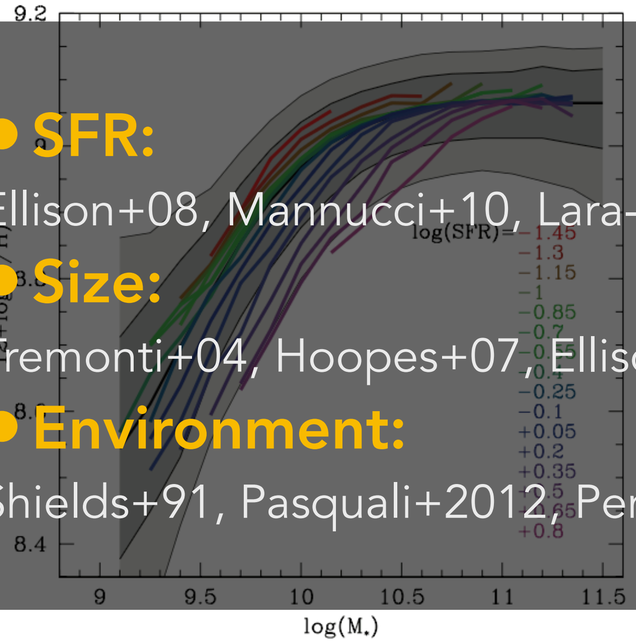
Environment



Wang+22
KW+24

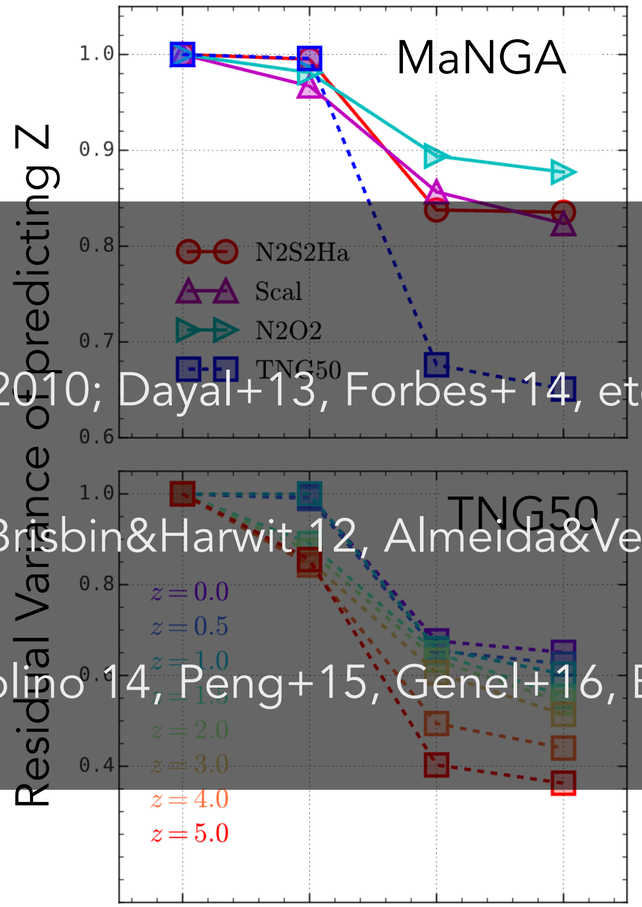
- **Origin of the scatter in MZR**

SFR



Mannucci+10

Size(R_e)

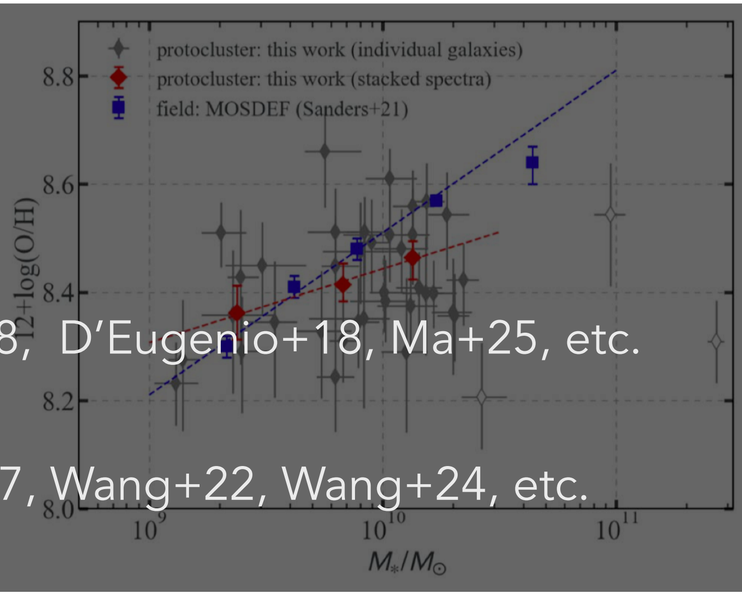


M* | M* SFR | M* R_e | M* SFR R_e

Ma, **KW**+24 (2407.21716)

Jia (incl. **KW**)+25 (2504.18820)

Environment



Wang+22

KW+24

- **SFR:**

Ellison+08, Mannucci+10, Lara-López+2010; Dayal+13, Forbes+14, etc.

- **Size:**

Tremonti+04, Hoopes+07, Ellison+08, Brisbin&Harwit 12, Almeida&Vecchia 18, D'Eugenio+18, Ma+25, etc.

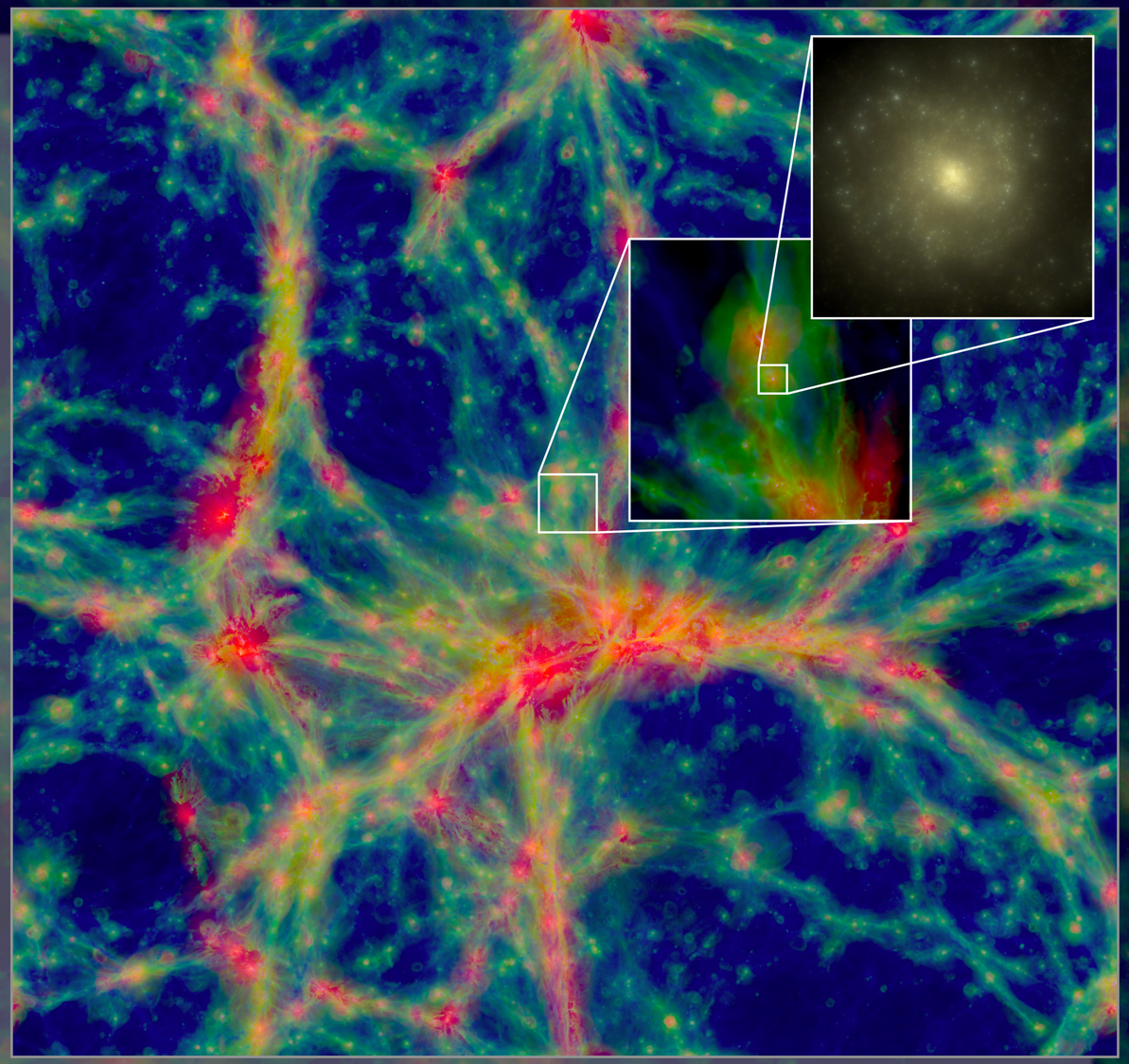
- **Environment:**

Shields+91, Pasquali+2012, Peng&Maiolino 14, Peng+15, Genel+16, Bahé+17, Wang+22, Wang+24, etc.

- Environmental dependence of MZR in EAGLE

EAGLE simulation:

- ✦GADGET-3 tree-SPH code
- ✦25-50-100 comoving Mpc
- ✦Model variations:
  - ✦no/weak/strong AGN feedback
  - ✦weak/strong stellar feedback
  - ✦different EOS
  - ✦.....
- ✦Single-mode AGN feedback



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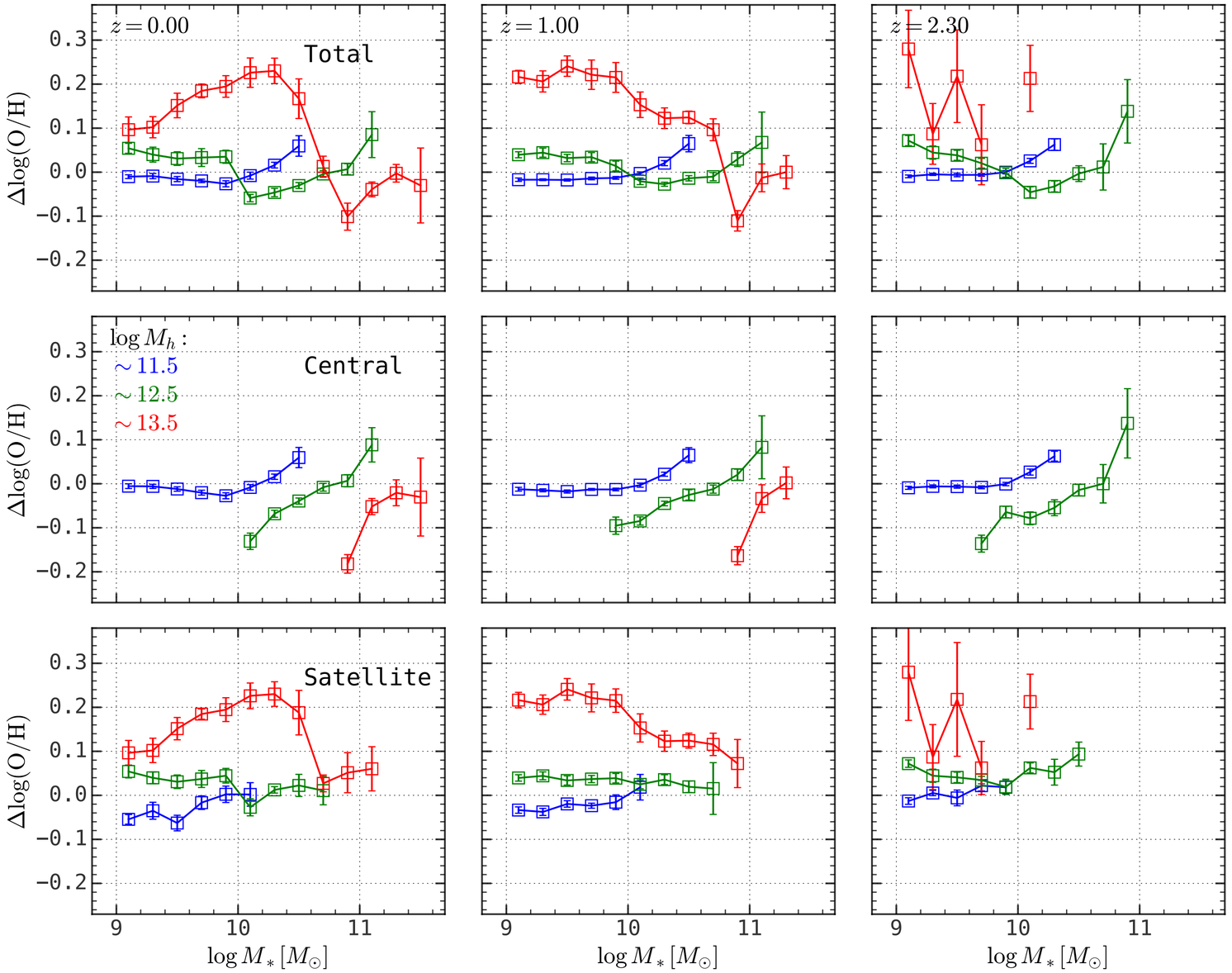

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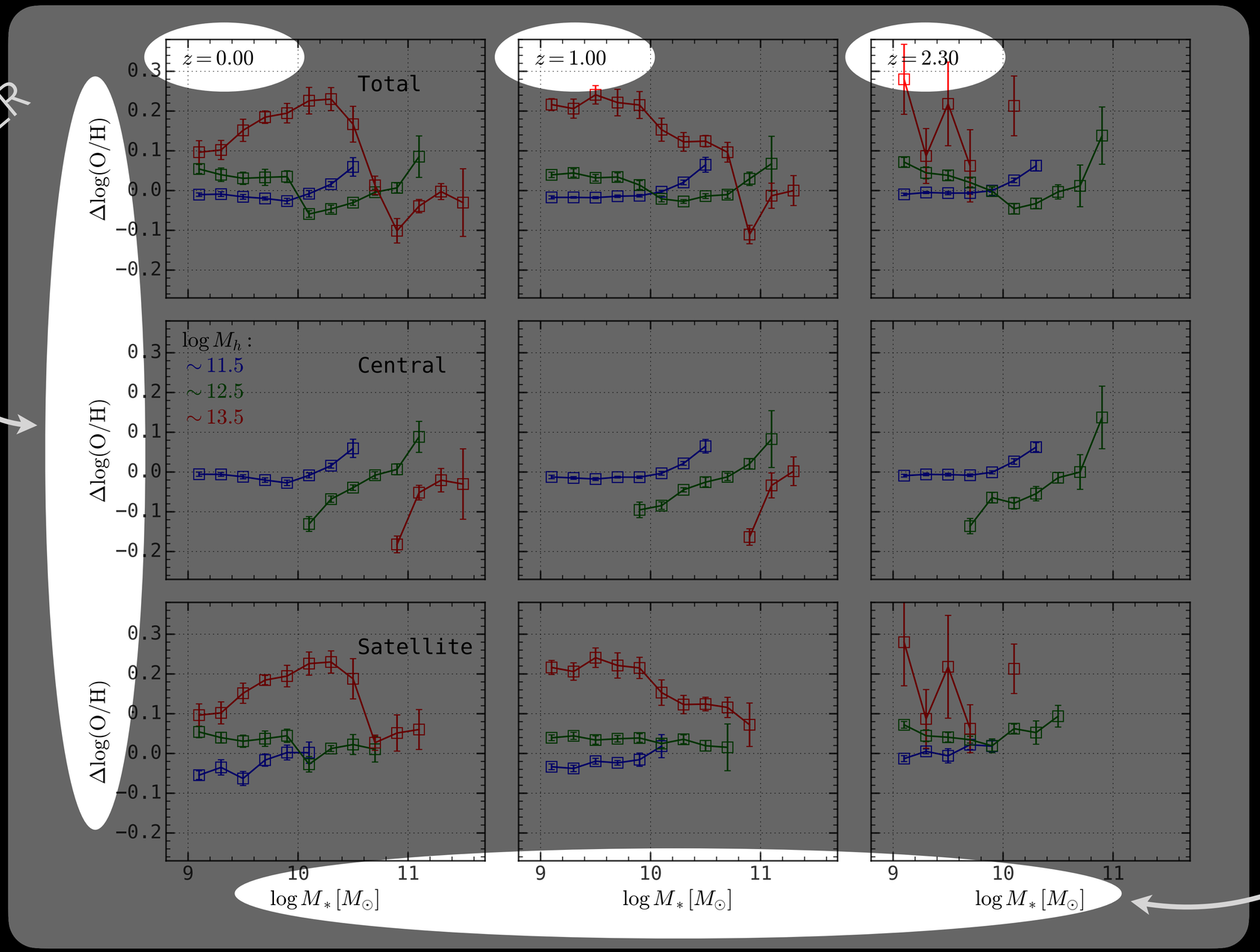


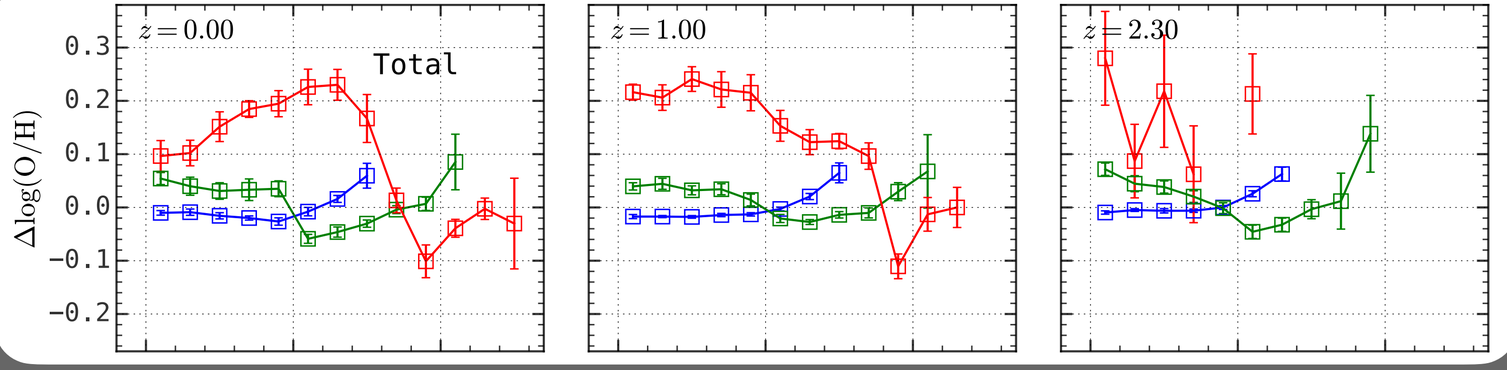
• Environmental dependence of MZR in EAGLE

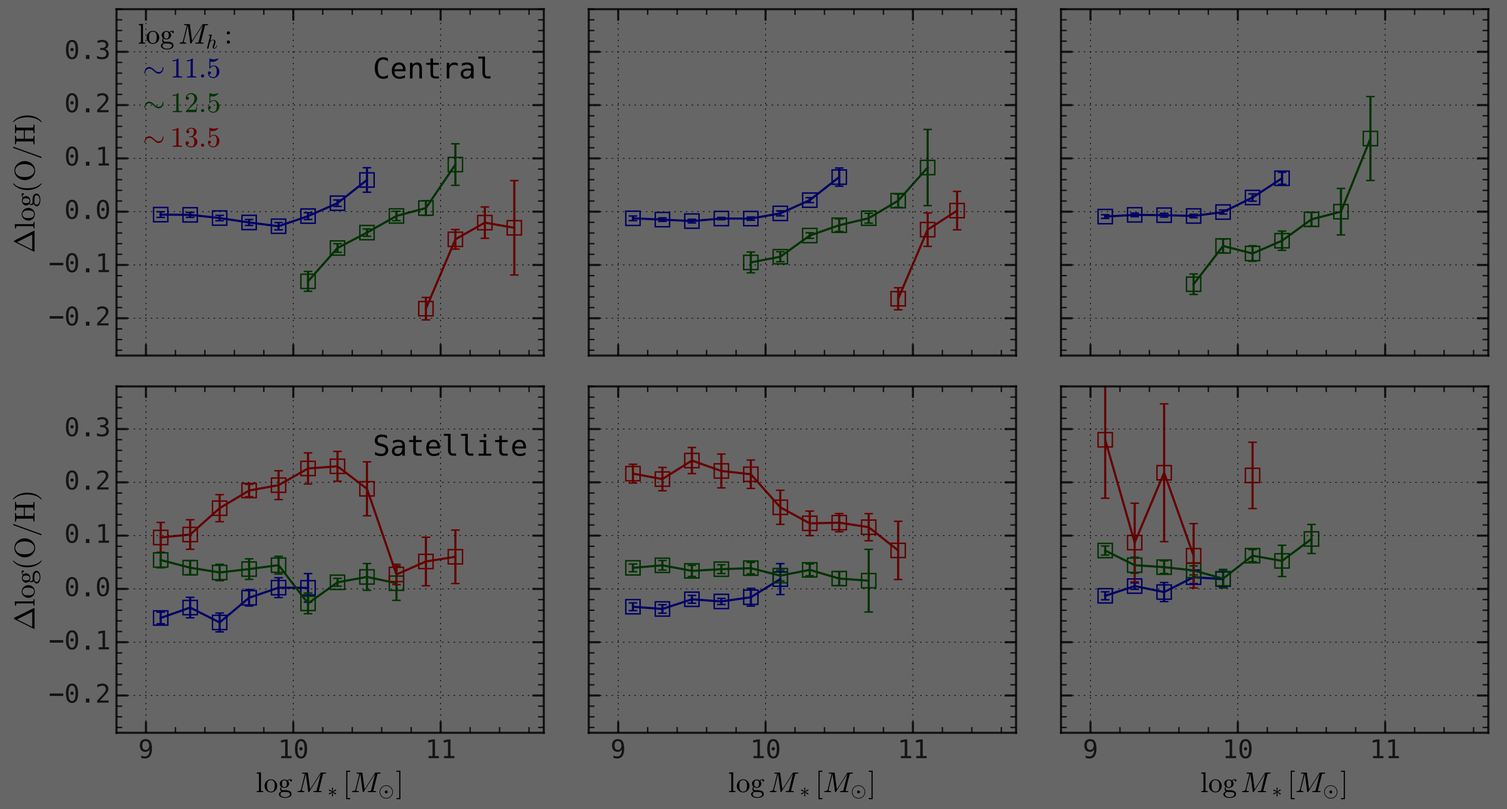
M_{halo}:

$\sim 10^{11.5} M_{sun}$

$\sim 10^{12.5} M_{sun}$

$\sim 10^{13.5} M_{sun}$





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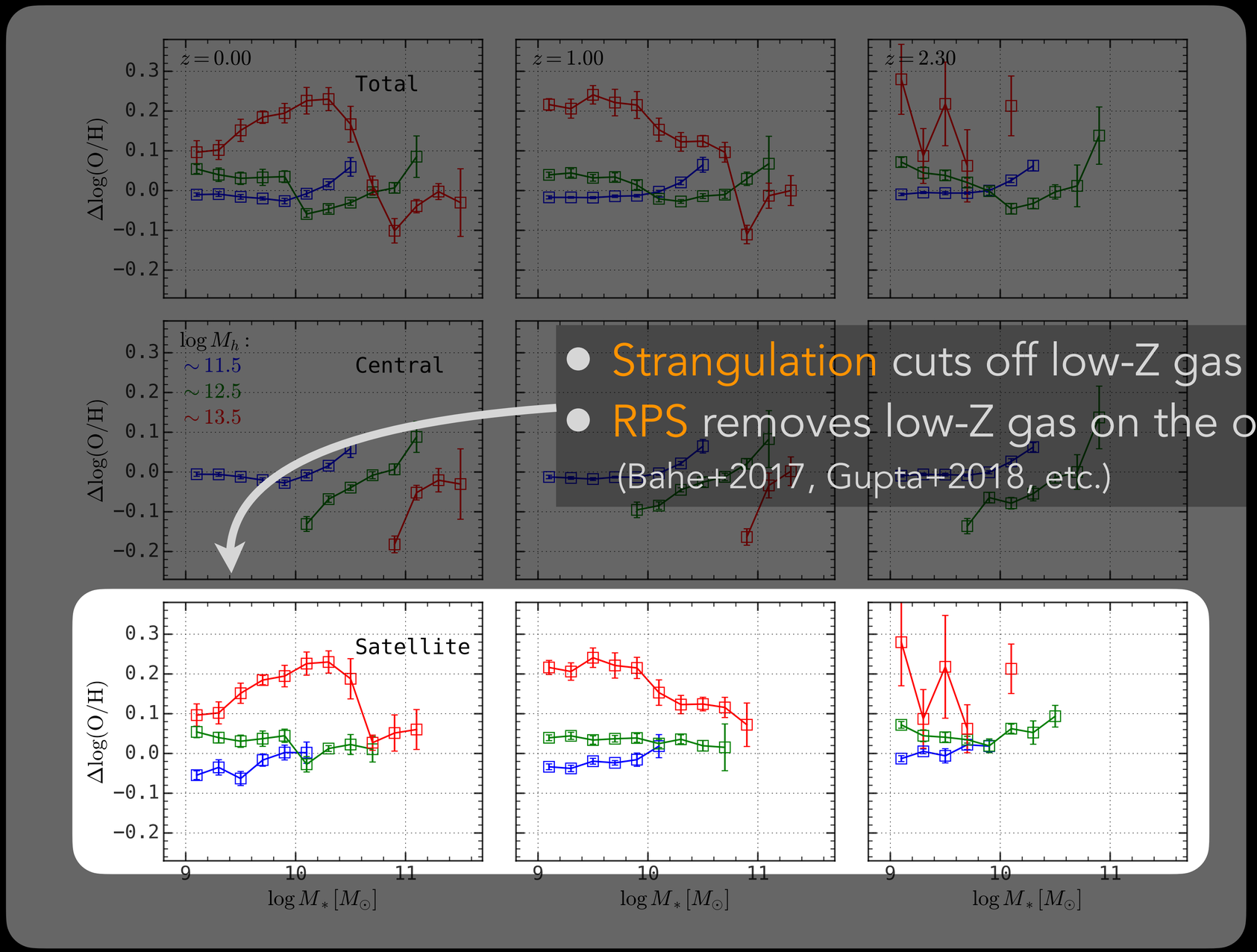

- Strangulation cuts off low-Z gas replenishment
- RPS removes low-Z gas on the outskirt
  (Bahe+2017, Gupta+2018, etc.)

• Environmental dependence of MZR in EAGLE

M_{halo}:

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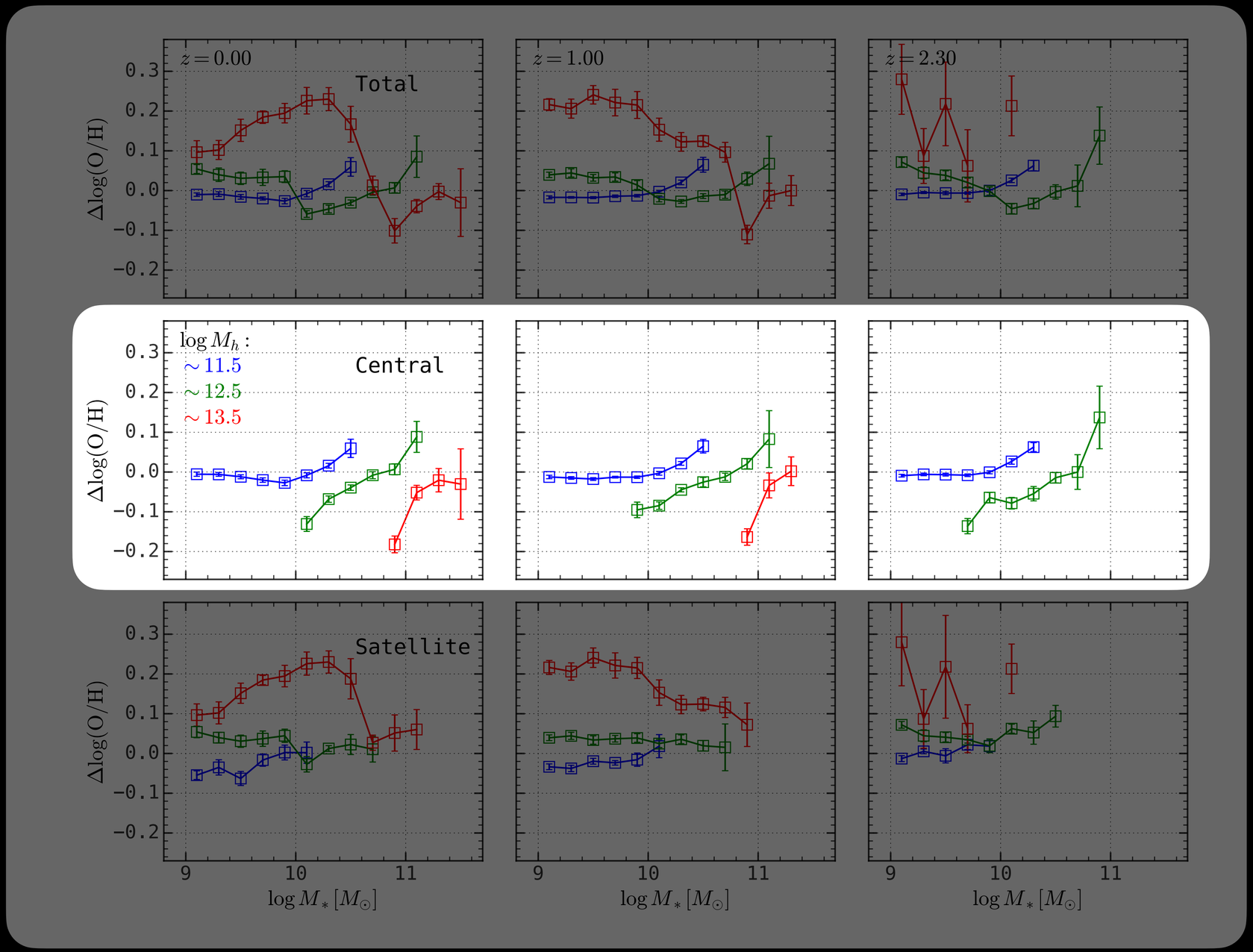
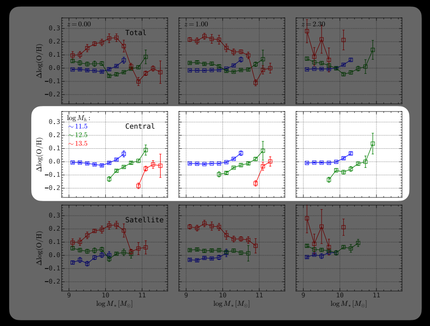
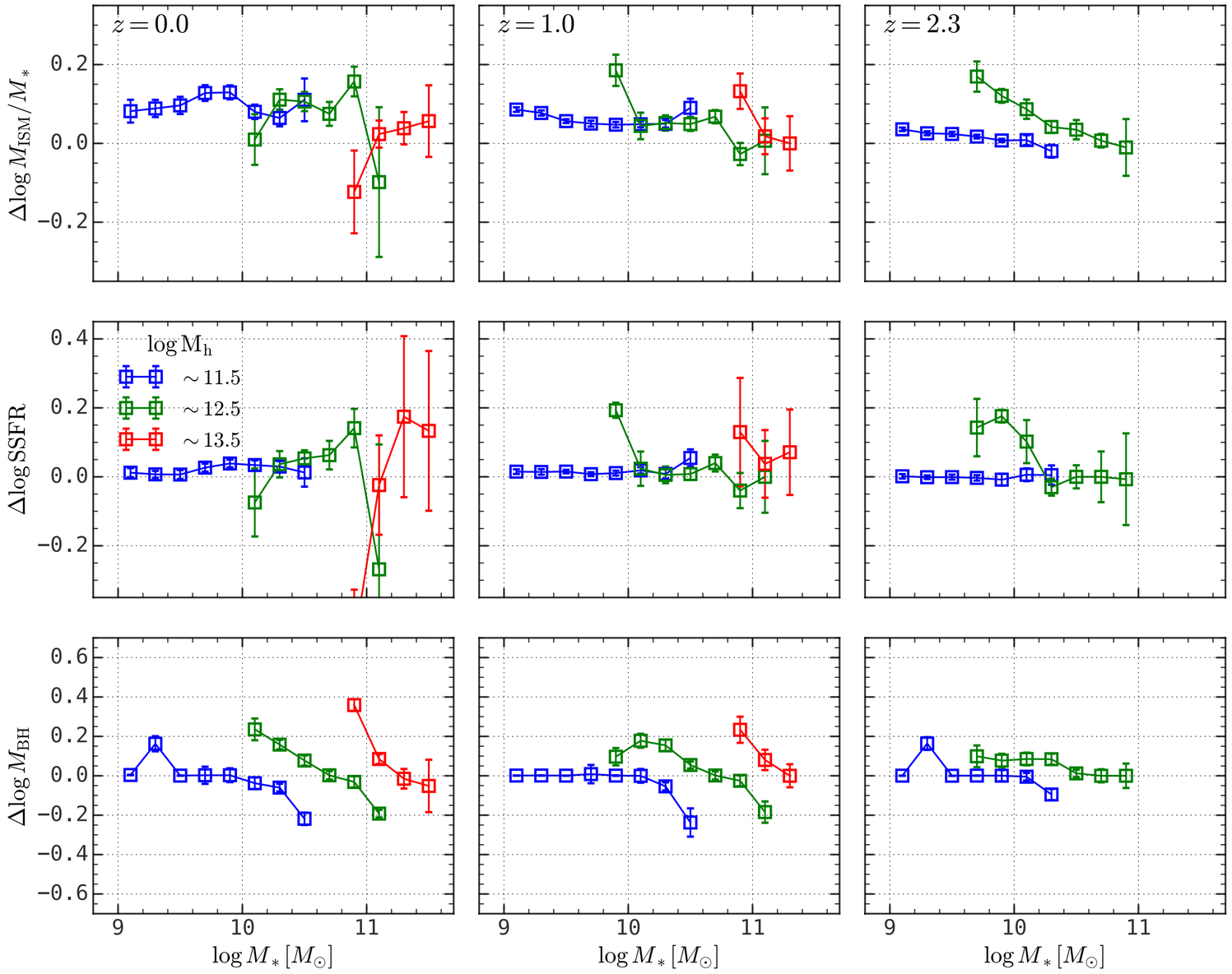


• Environmental dependence of MZR in EAGLE

M_{halo}:
~$10^{11.5}M_{sun}$
~$10^{12.5}M_{sun}$
~$10^{13.5}M_{sun}$

Central Galaxy





M_{gas}

SFR

M_{BH}

• Environmental dependence of MZR in EAGLE

M_{halo}:
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~$10^{12.5}M_{sun}$
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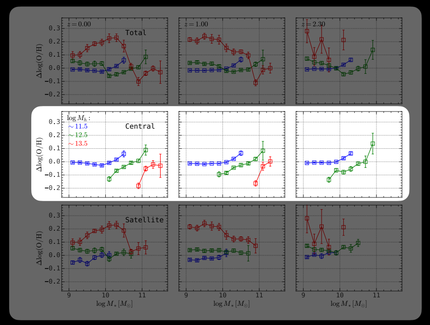
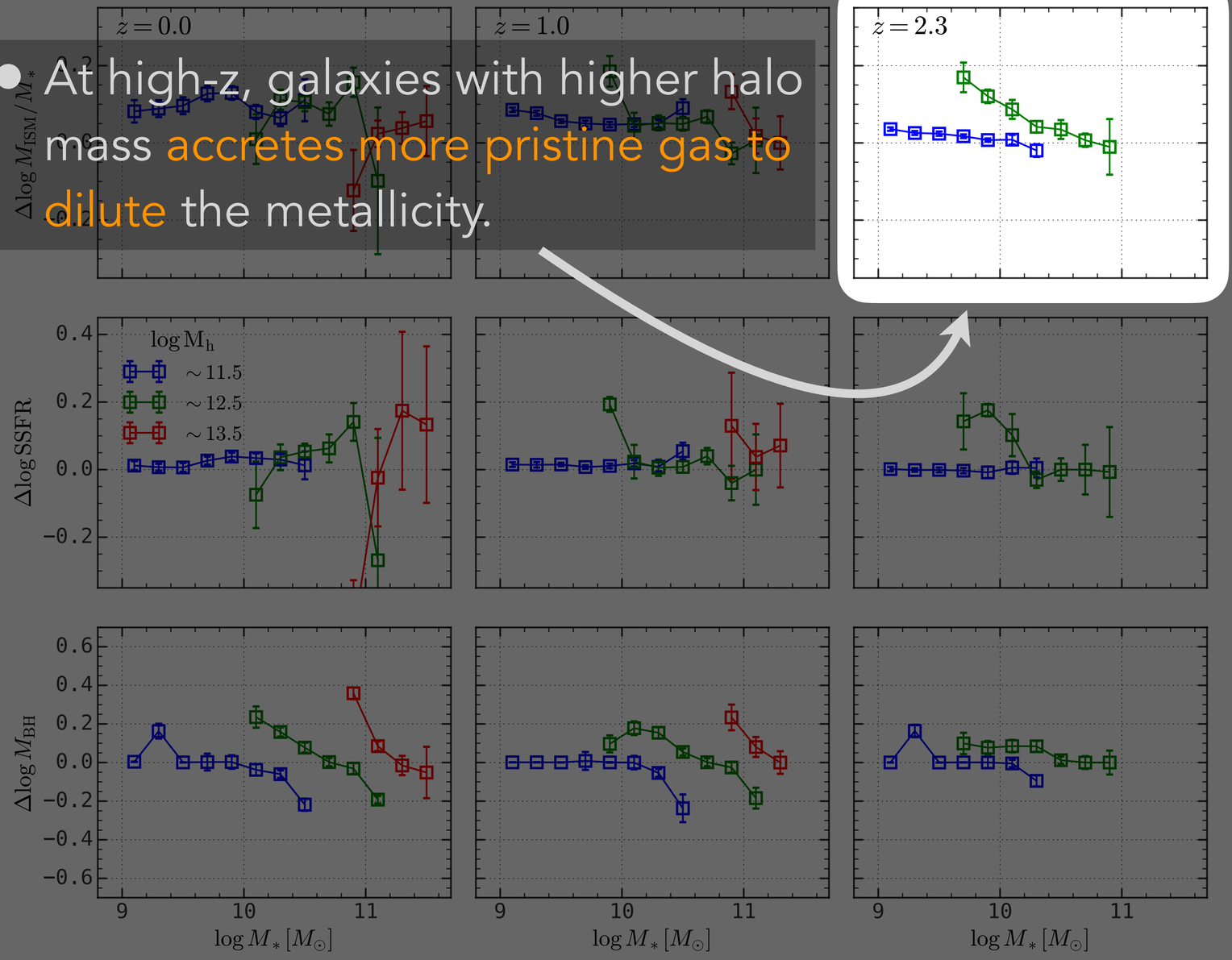
Central Galaxy



- At high-z, galaxies with higher halo mass accretes more pristine gas to dilute the metallicity.



M_{gas}

SFR

M_{BH}

• Environmental dependence of MZR in EAGLE

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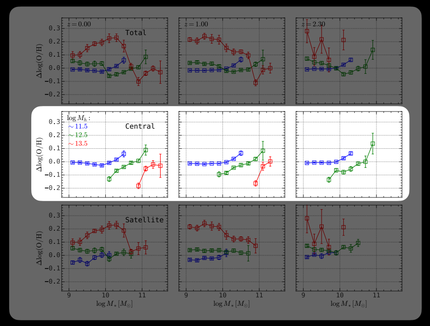
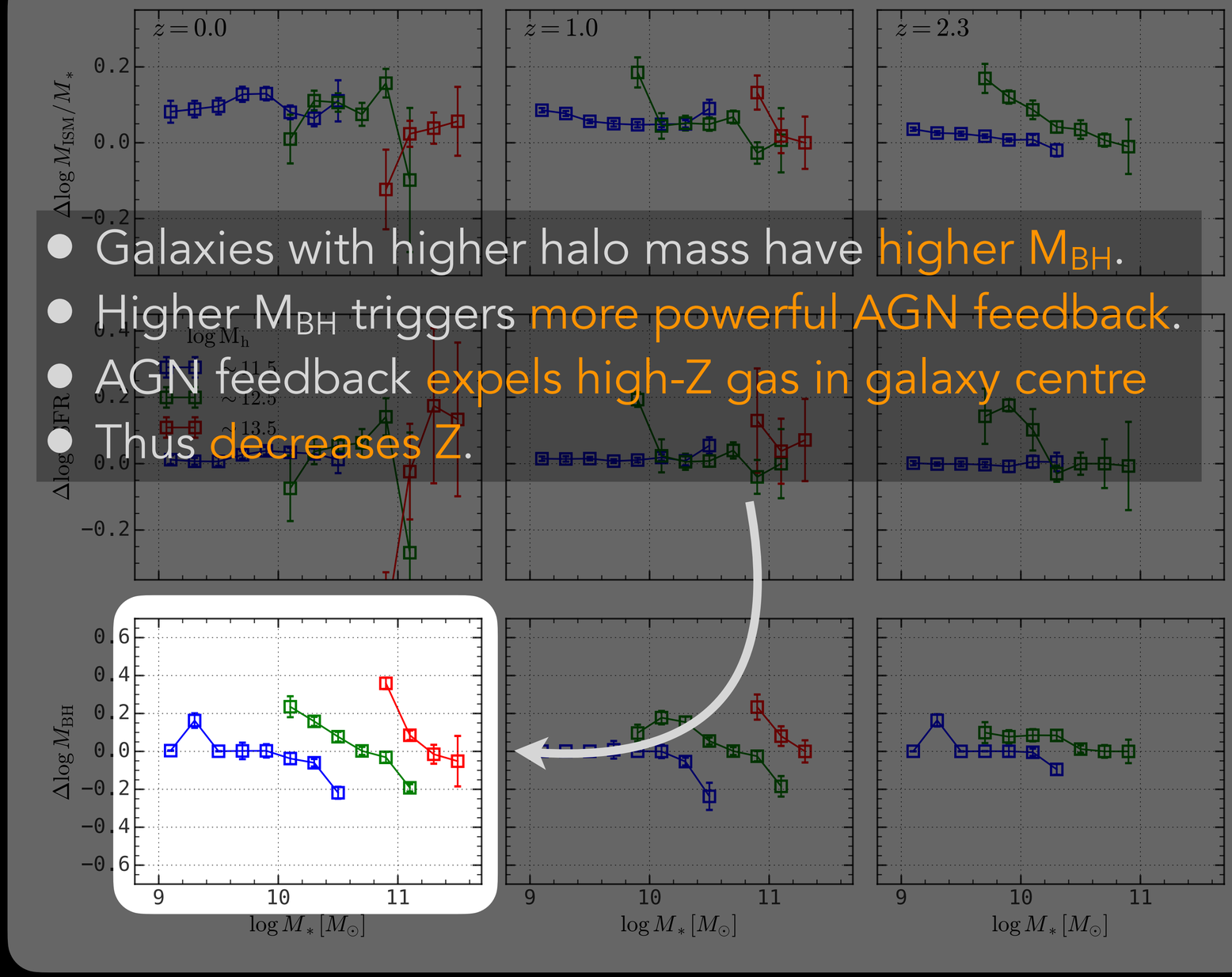
Central Galaxy





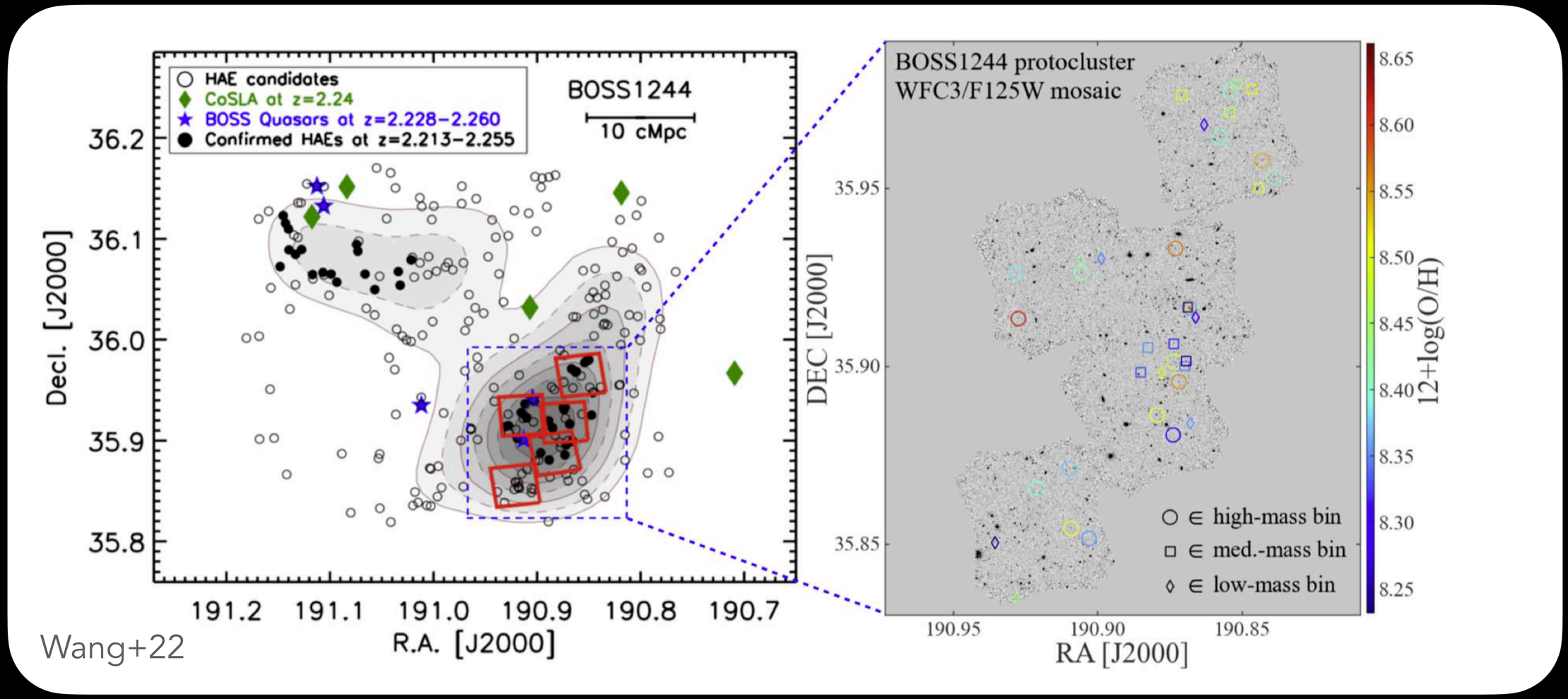
- Galaxies with higher halo mass have higher M_{BH}.
- Higher M_{BH} triggers more powerful AGN feedback.
- AGN feedback expels high-Z gas in galaxy centre
- Thus decreases Z.

M_{gas}

SFR

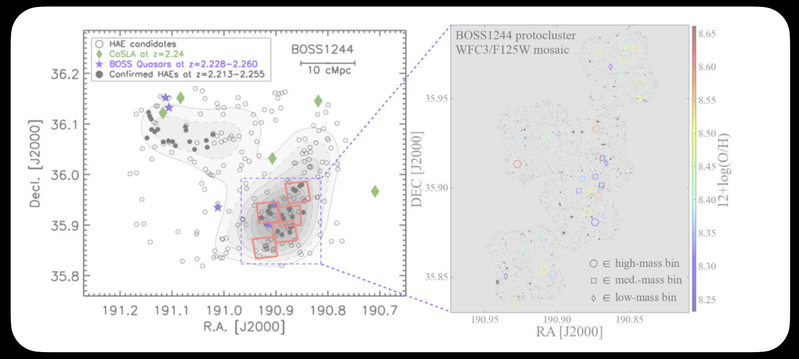
M_{BH}

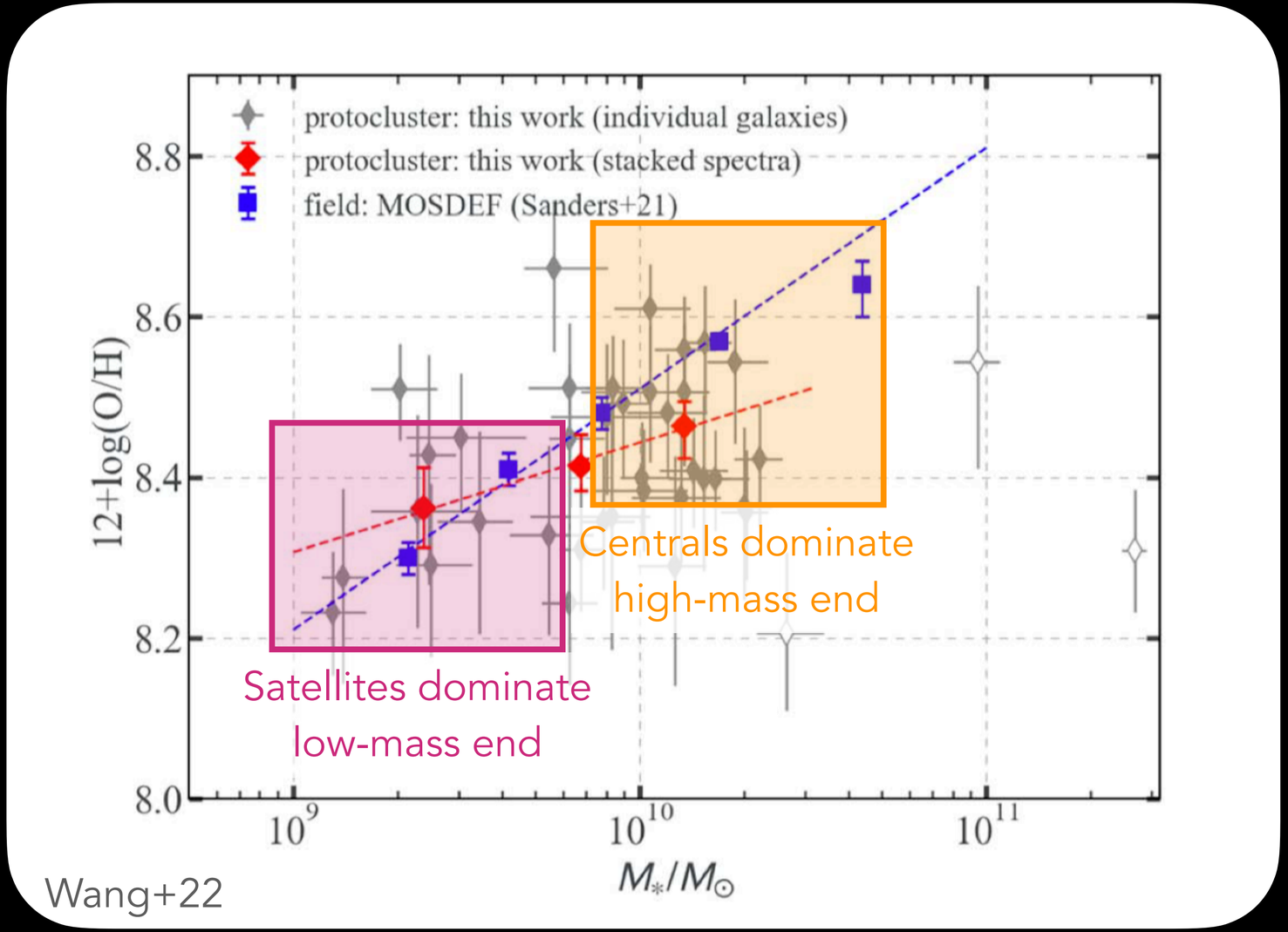
- **Environmental dependency of MZR at z~2.3**



Wang+22

- **Environmental dependency of MZR at z~2.3**





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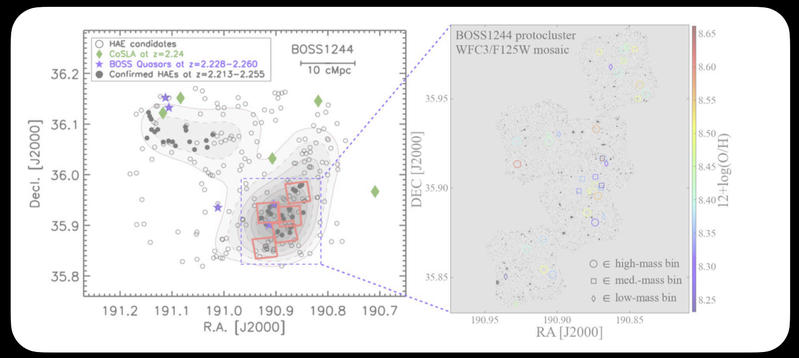

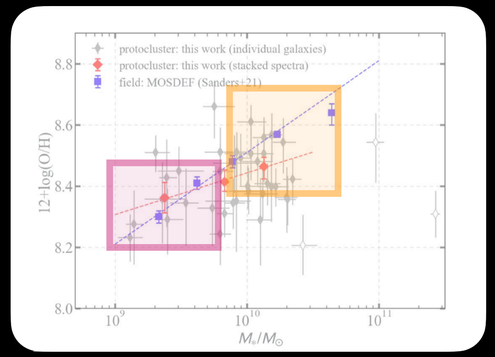

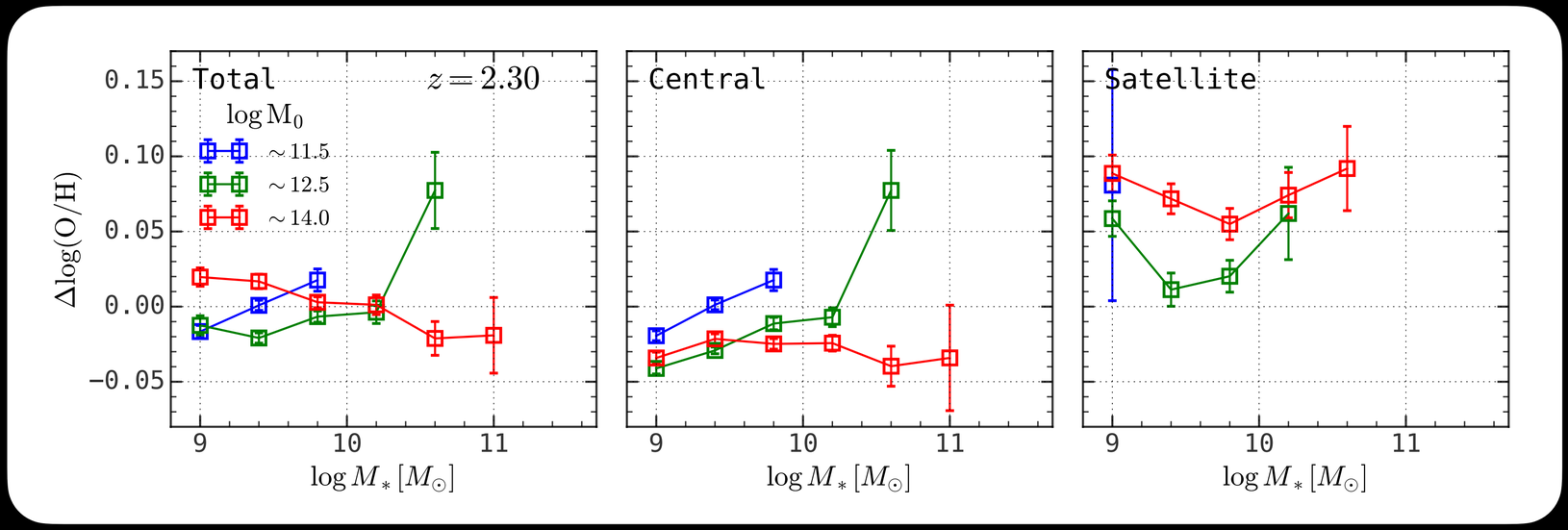

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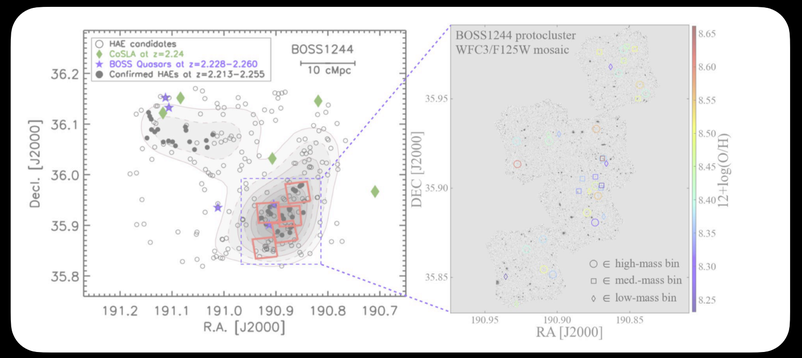

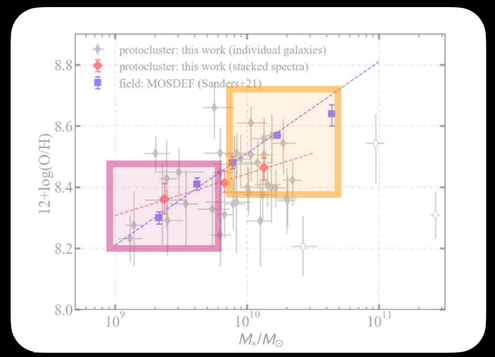

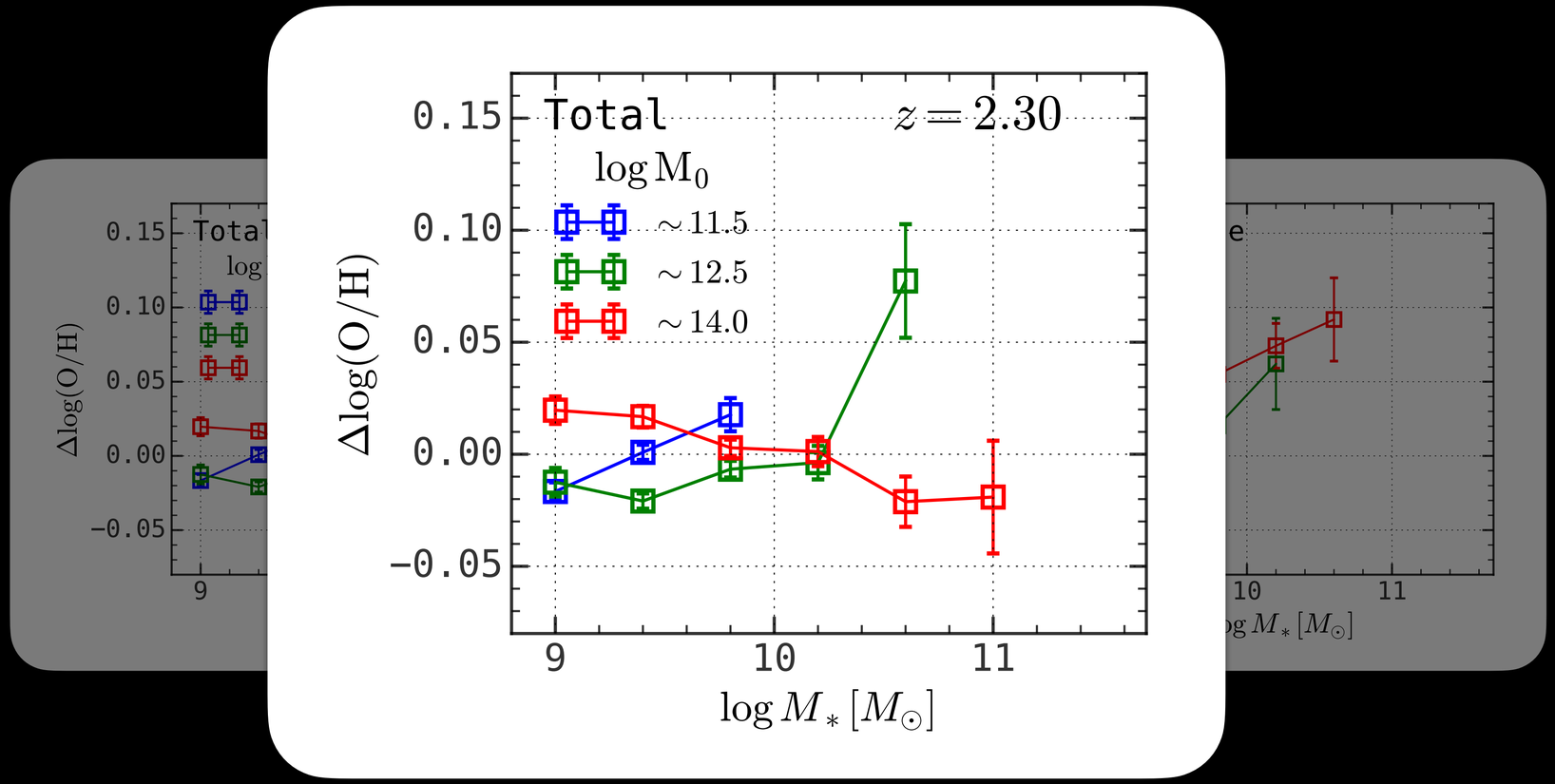

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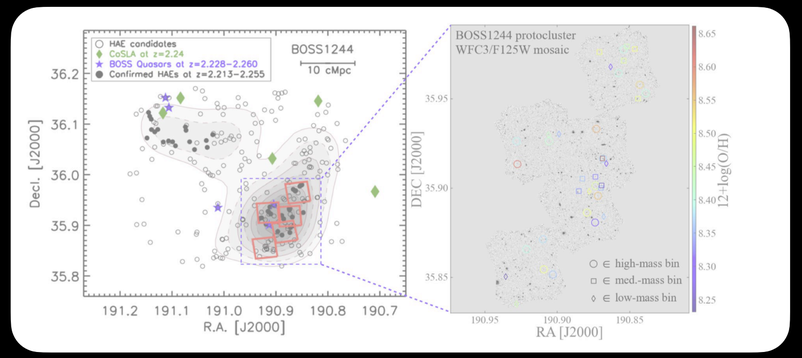
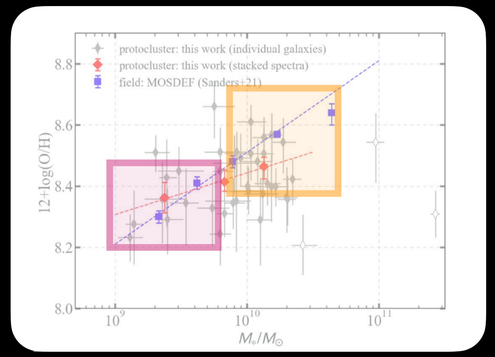
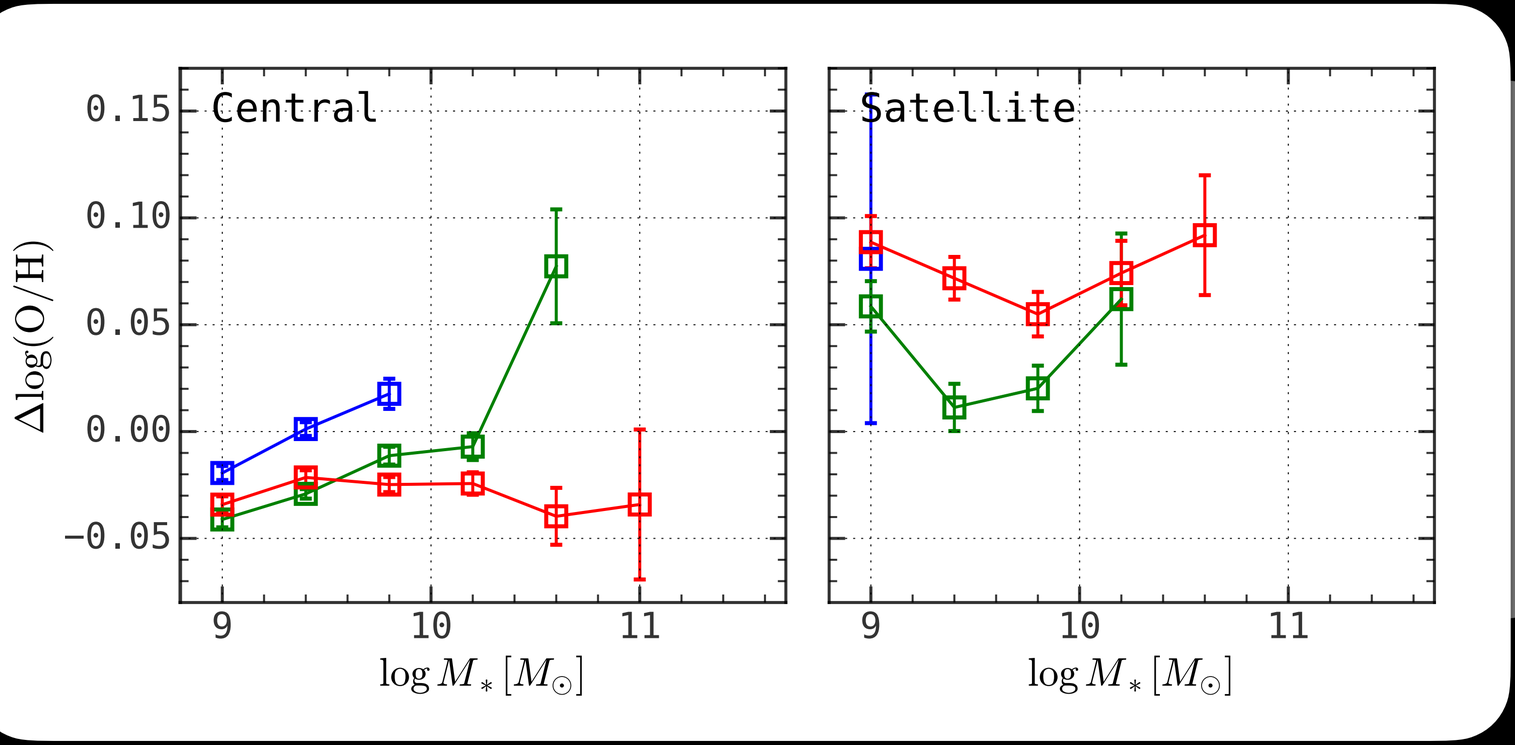
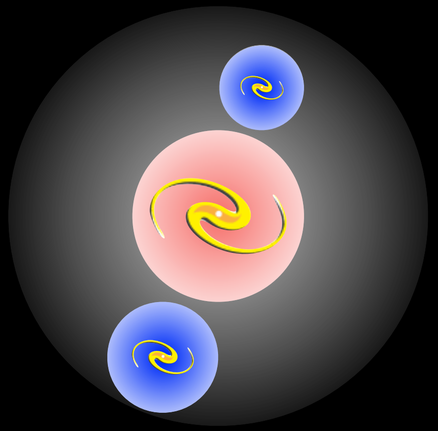




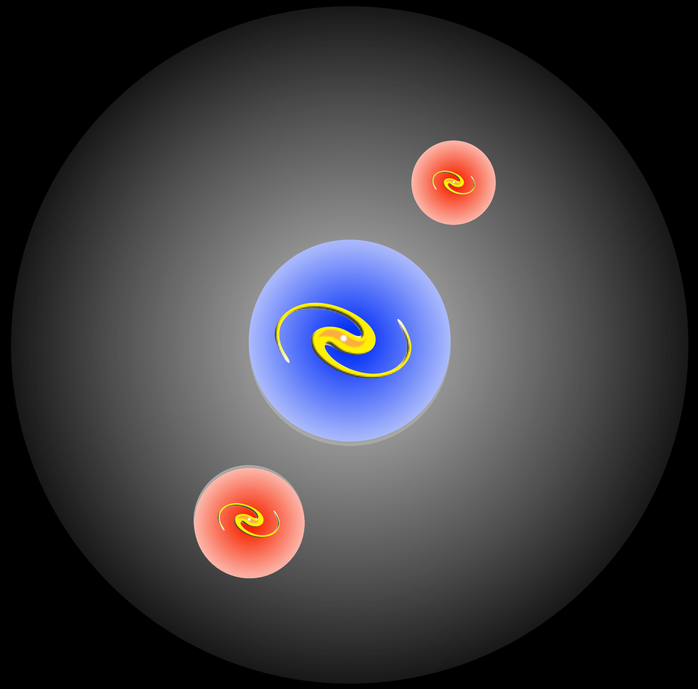


- **Take-home:**

At fixed stellar mass:



- **Centrals** in **more massive halos** have **lower-Z**, due to
  - ✦ more low-Z gas accretion to dilute the metal content
  - ✦ more powerful AGN feedback to expel central high-Z gas

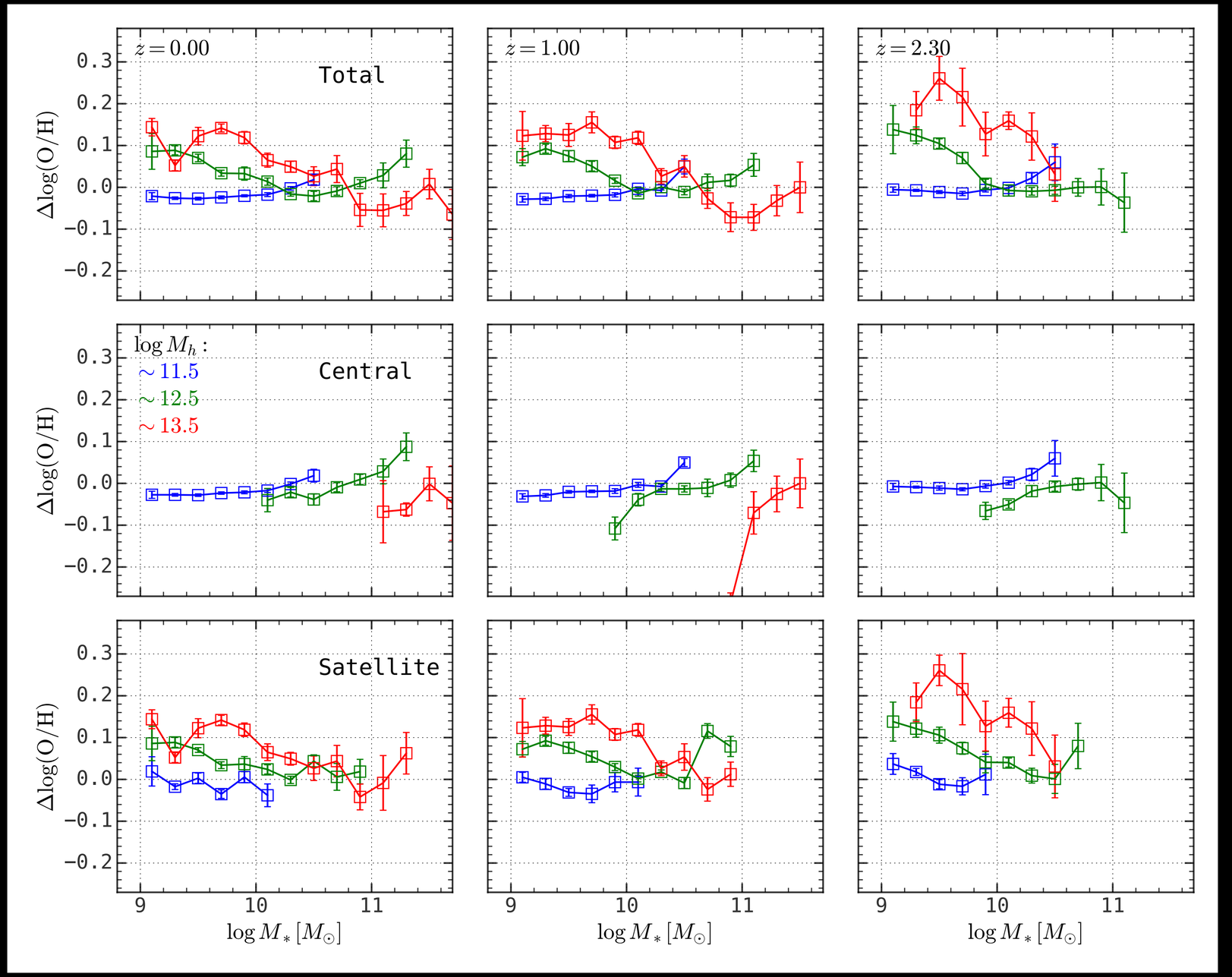


- **Satellites** in **more massive halos** have **higher-Z**, due to
  - ✦ strangulation cuts off low-Z gas replenishment
  - ✦ ram-pressure stripping takes away low-Z gas on the outskirt

more details in arXiv:2305.08161

see also 2407.21716 & 2504.18820 for the relationship to size

- **TNG100**


$z = 0.00$
$z = 1.00$
$z = 2.30$
Total
Central
Satellite
$\log M_h$:
~ 11.5
~ 12.5
~ 13.5
$\Delta\log(\mathrm{O/H})$
$\log M_* [M_\odot]$
0.3
0.2
0.1
0.0
−0.1
−0.2
9
10
11

- **EAGLE model variants**