On the environmental dependence of galaxy properties in dusty semi-analytical models

Massimiliano Parente
SISSA, Trieste
INAF - OATs

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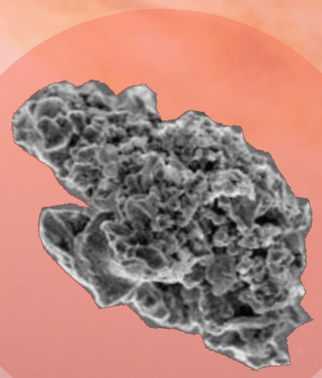
Cinthia Ragone-Figueroa (IATE)
Andrea Lapi (SISSA)

30th August 2023
Cosmology in Miramare
Trieste

dust in galaxies

ID card of a dust grain



Size: from ~ A to micron

Composition: metals
(C, O, Mg, Si, Fe…)

How much? ~1% of ISM

dust in galaxy evolution

H2 formation

proto-planetary disks

Radiation reprocessing

Clouds shielding

Cooling

strong recent effort in studying dust in both observations

e.g. DeVis+19, Donevski+20, Inami+22

and galaxy evolution models

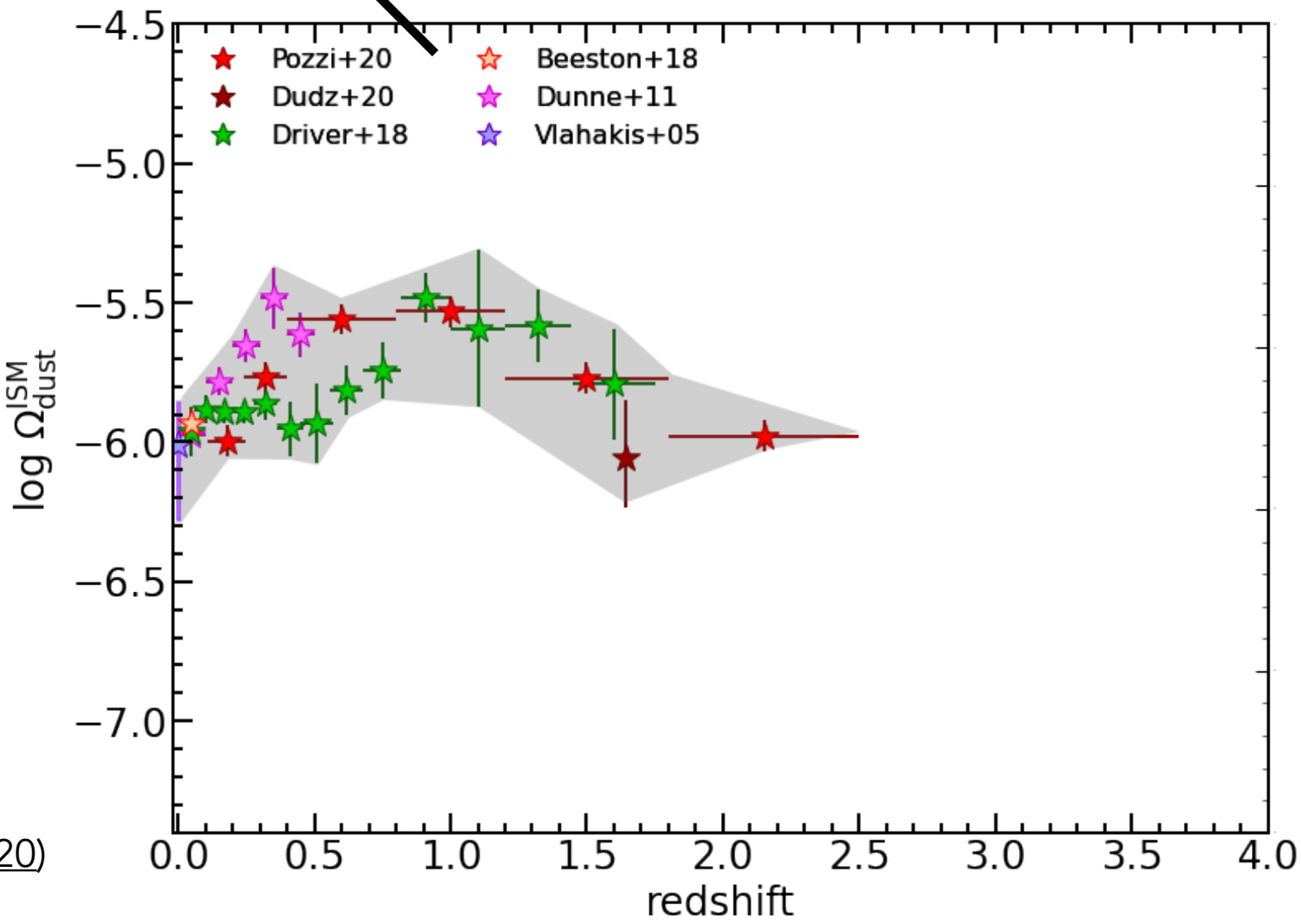
e.g. McKinnon+17, Popping+18, Vijayan+19, Graziani+20, Triani+20, Granato+21, Parente+22,23

credits: ESA/Hubble & NASA

Problem: the $z \lesssim 1$ drop of cosmic dust abundance

observations of galactic dust
from SED fitting

$$\Omega_{\rm dust} = \frac{\rho_{\rm dust}}{\rho_{\rm c,0}}$$



(see Péroux & Hawk 2020)

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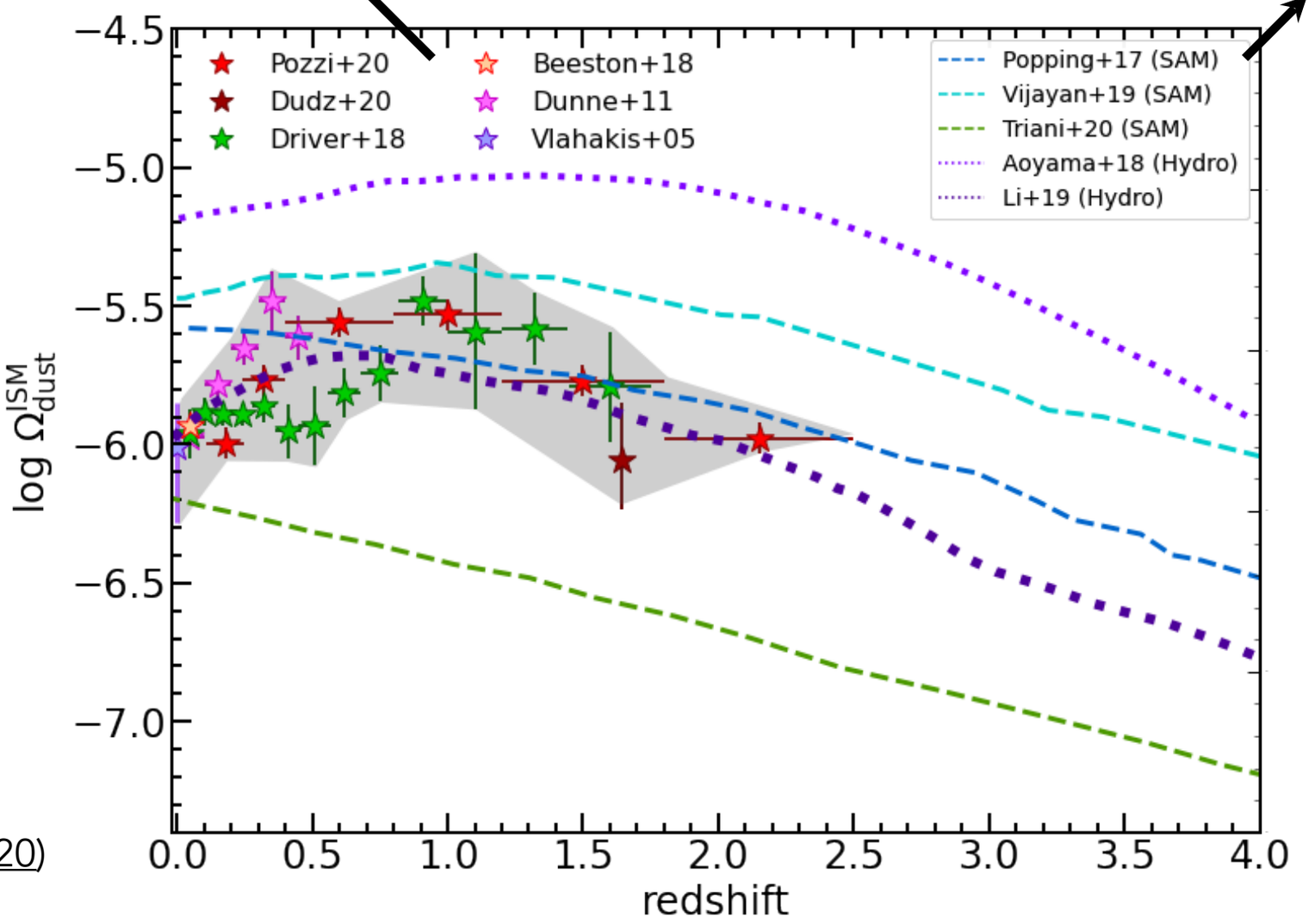
SAMs/hydroSims including dust



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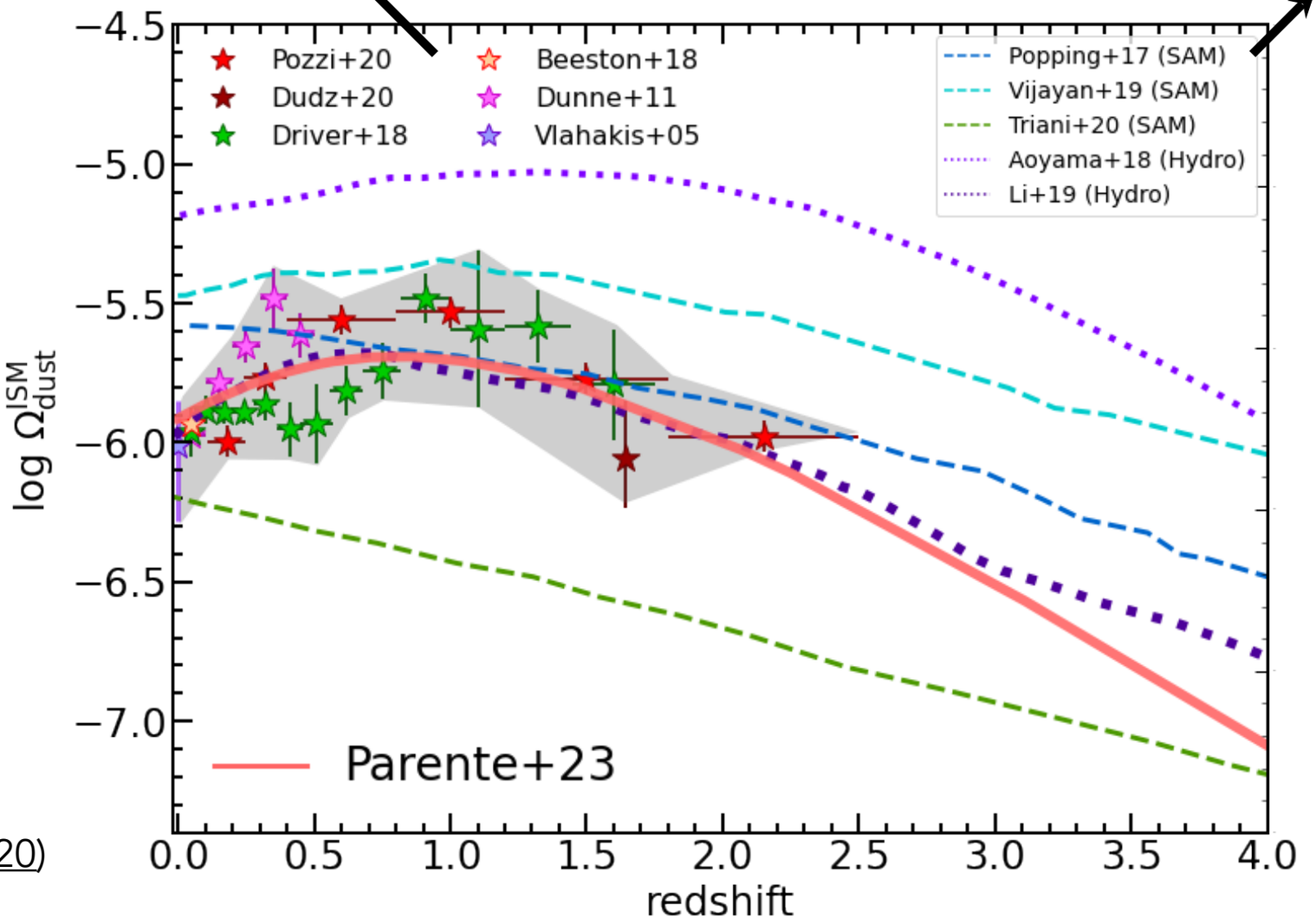
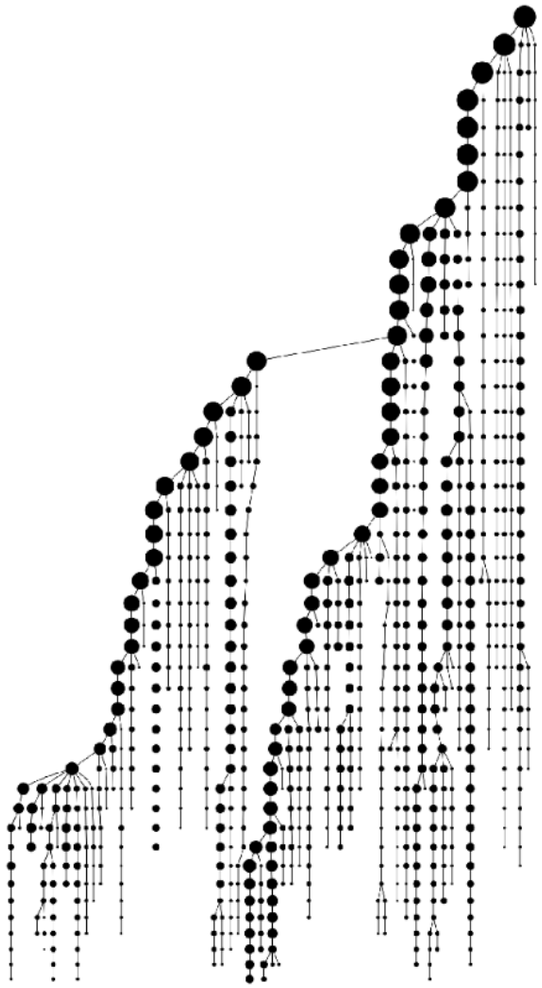


(see Péroux & Hawk 2020)

The semi-analytic model



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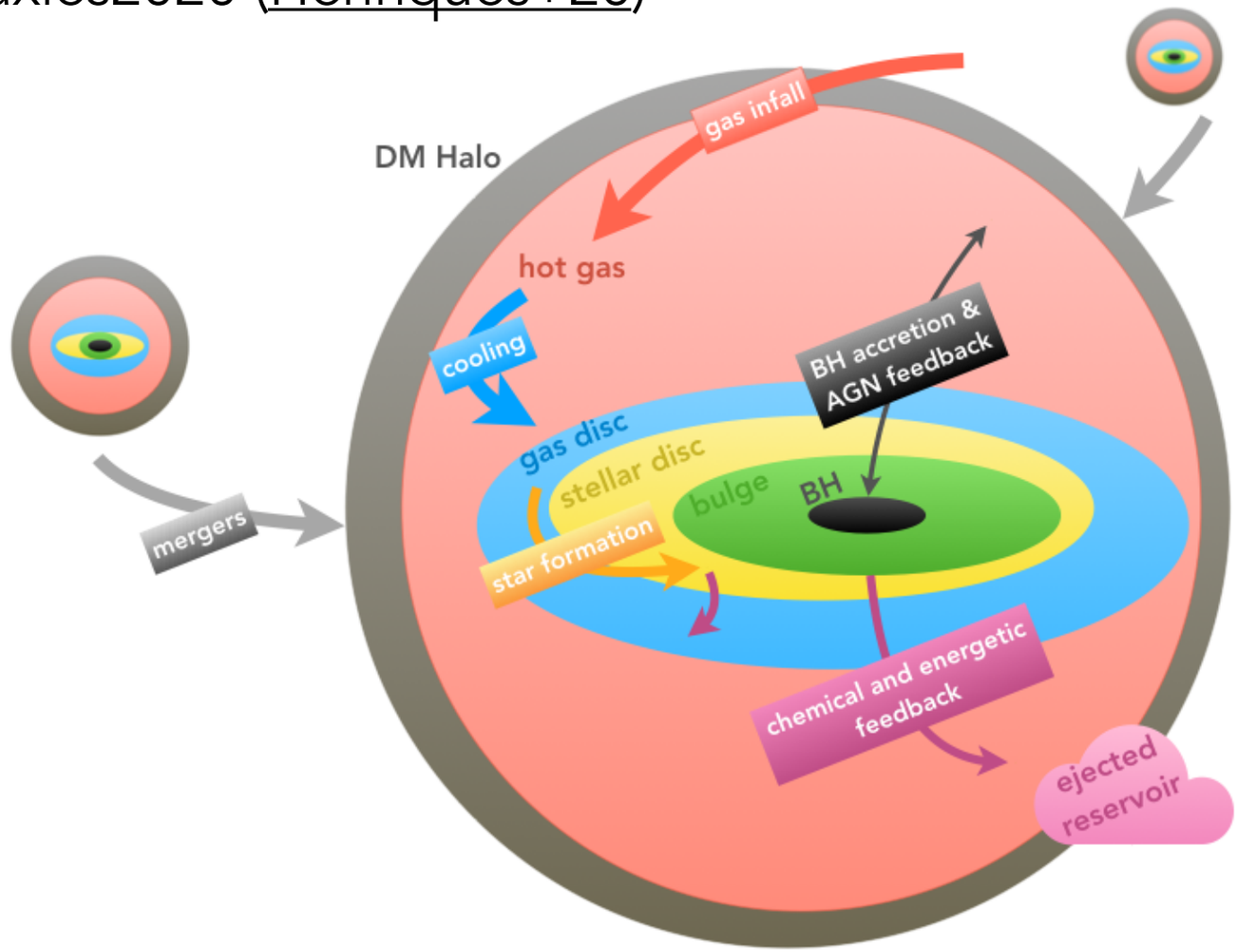
L-Galaxies2020 (Henriques+20)



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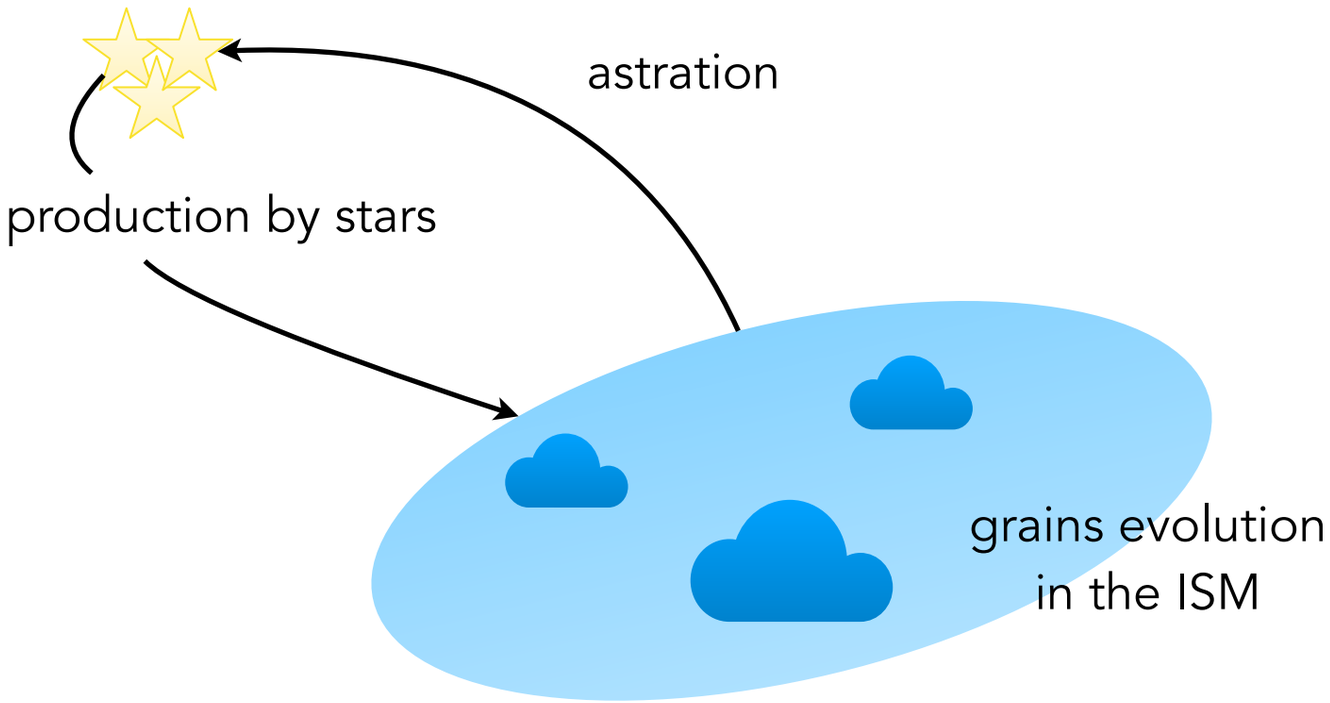
dust evolution and **updated disc instabilities** (Parente+23)

The semi-analytic model

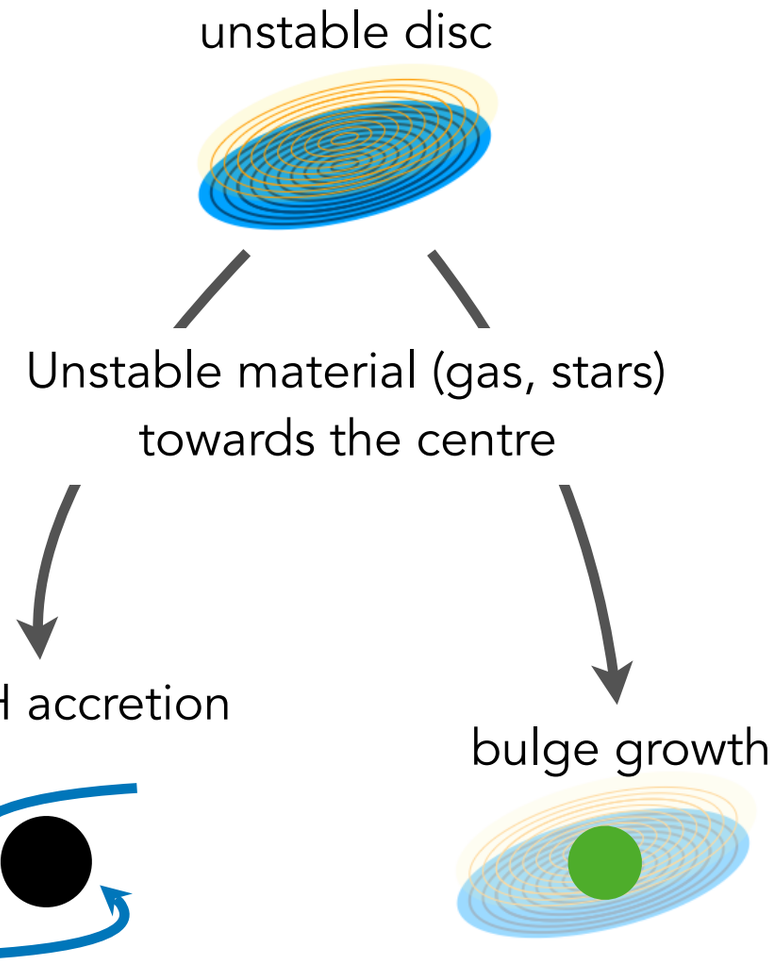
Dust model

(Gjergo+18, Granato+21, Parente+22)



e.g. grains accretion, destruction in shocks, sputtering, shattering, coagulation

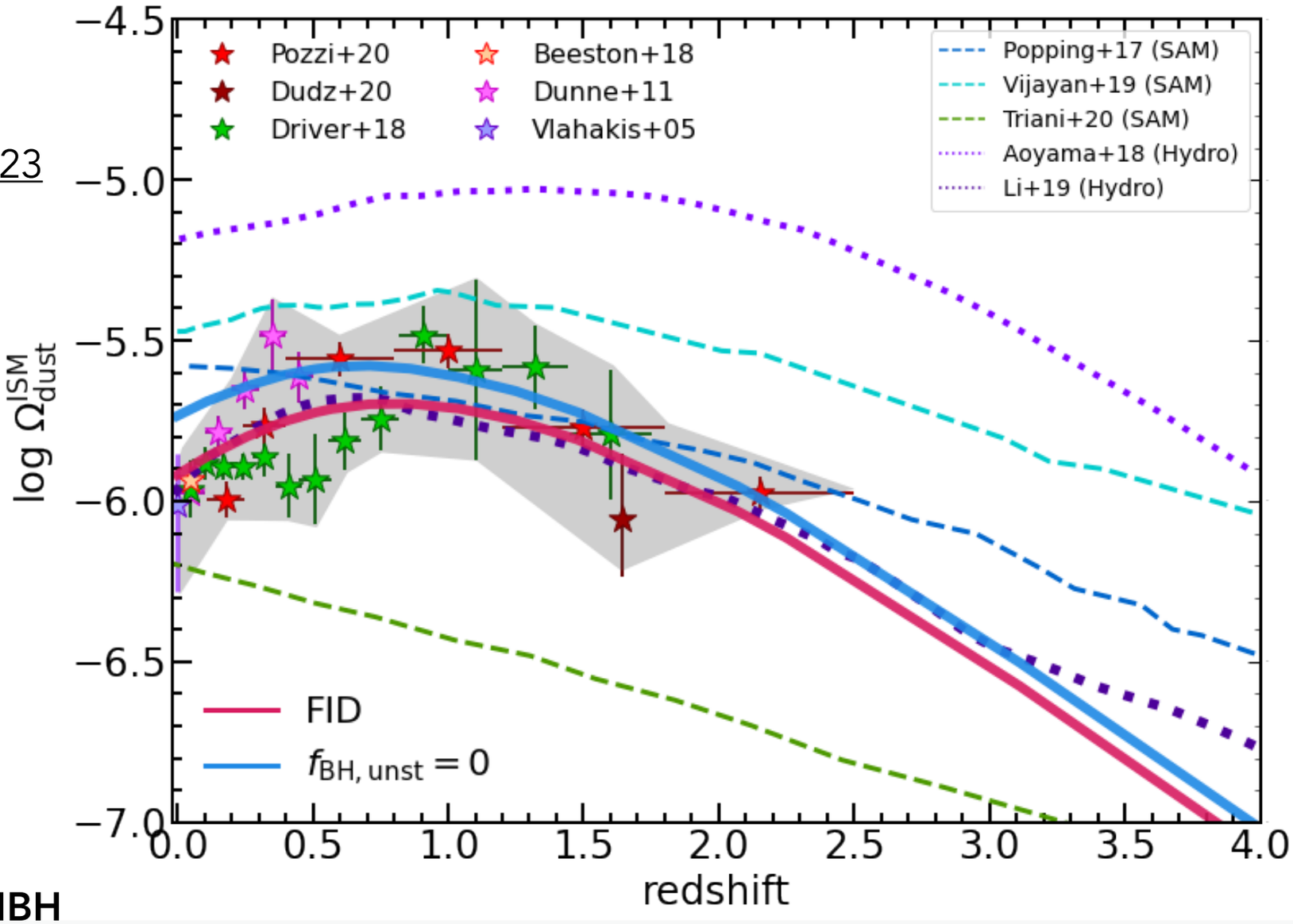
Disc instability model



dust evolution and **updated disc instabilities**
(Parente+23)

The cosmic dust drop

Parente et al. 2023



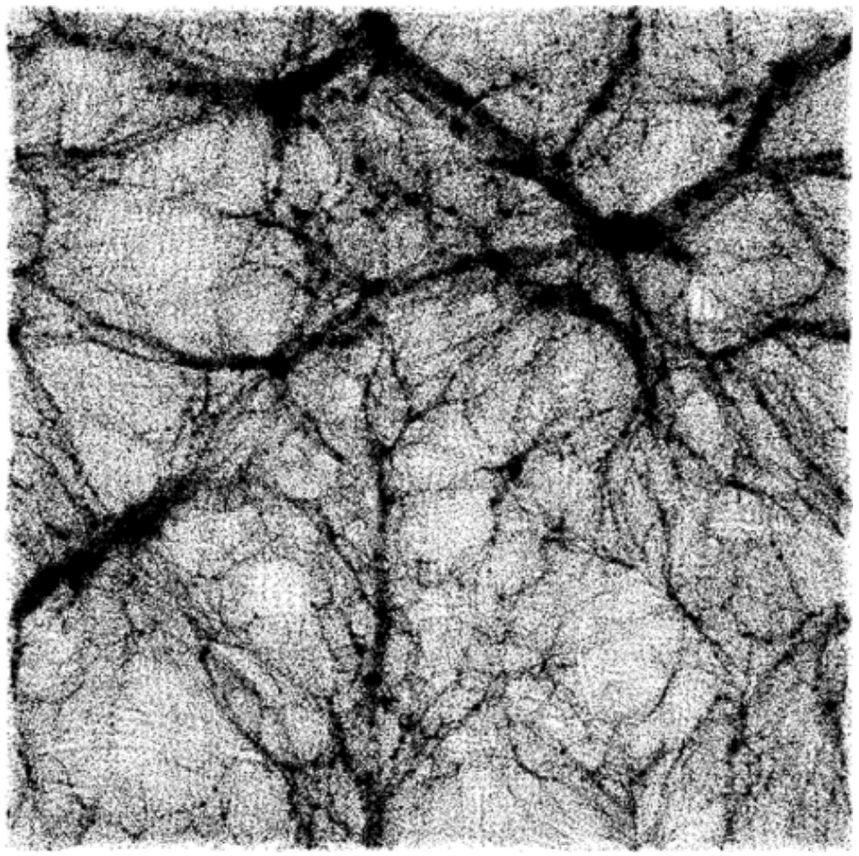
The key is the **SMBH growth** during DIs

Quenching by Radio-mode Feedback
(hot gas is heated)

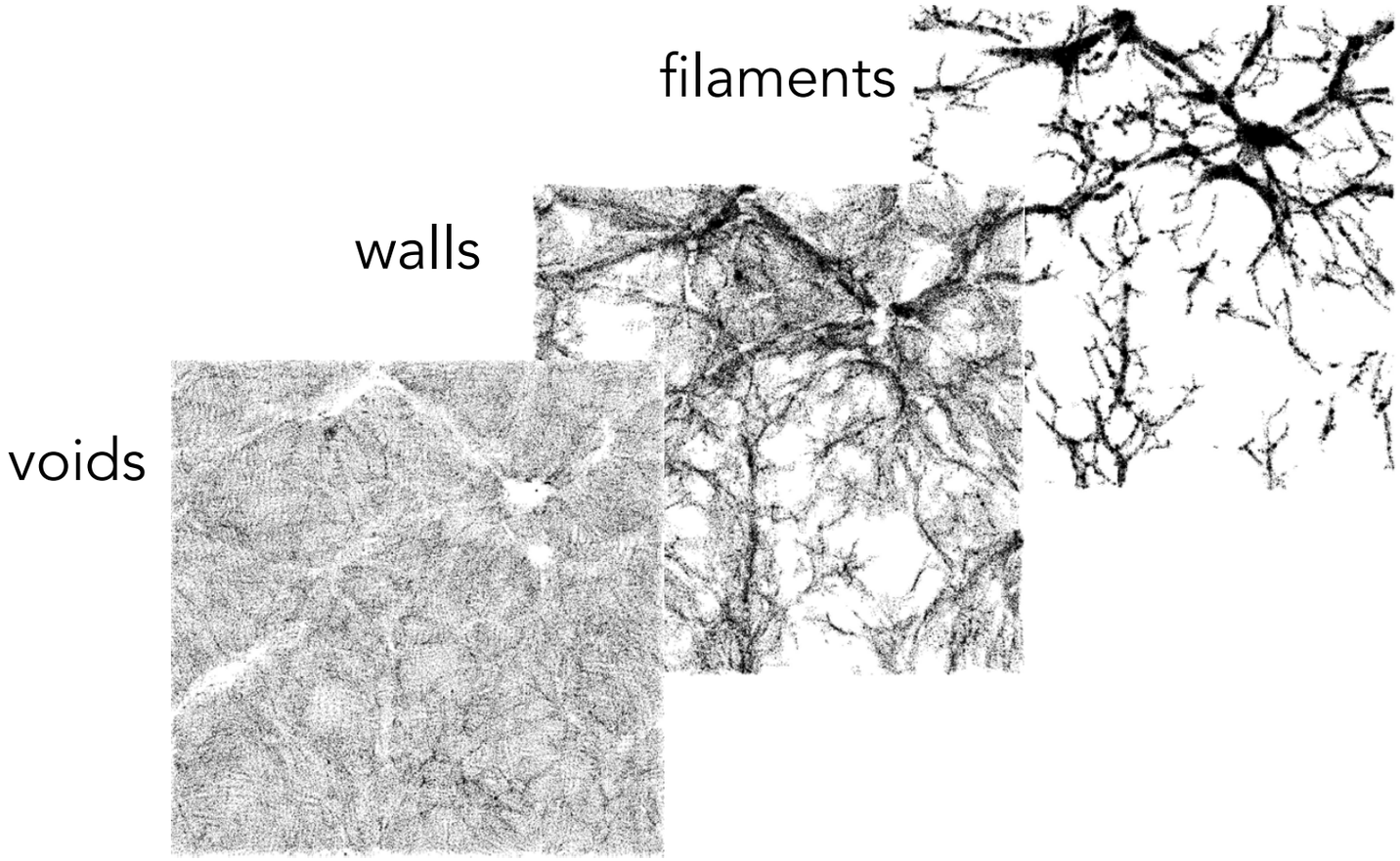
unstable disc → SMBH accretion → → Cooling reduced, lower gas and dust content

Galaxies in the cosmic web

cosmic web



and its environments



from Cautun+14

Environment	Mass fraction (per cent)	Volume fraction (per cent)
Clusters	8.0	0.027
Filaments	51.3	4.35
Walls	24.0	16.8
Voids	16.7	78.8

How do the **galaxy properties** depend on the **cosmic environment**?

Still not a clear picture

(e.g. Croton+05, Hoyle+12, Ricciardelli+14, Tonnesen & Cen 15, Poudel+17, Martizzi+20, Xu+20, Florez+21, Jian+22, Alfaro+20, Rosas-Guevara+22, Rodriguez-Medrano+23, Dominguez-Gomez+23, Jaber+23)

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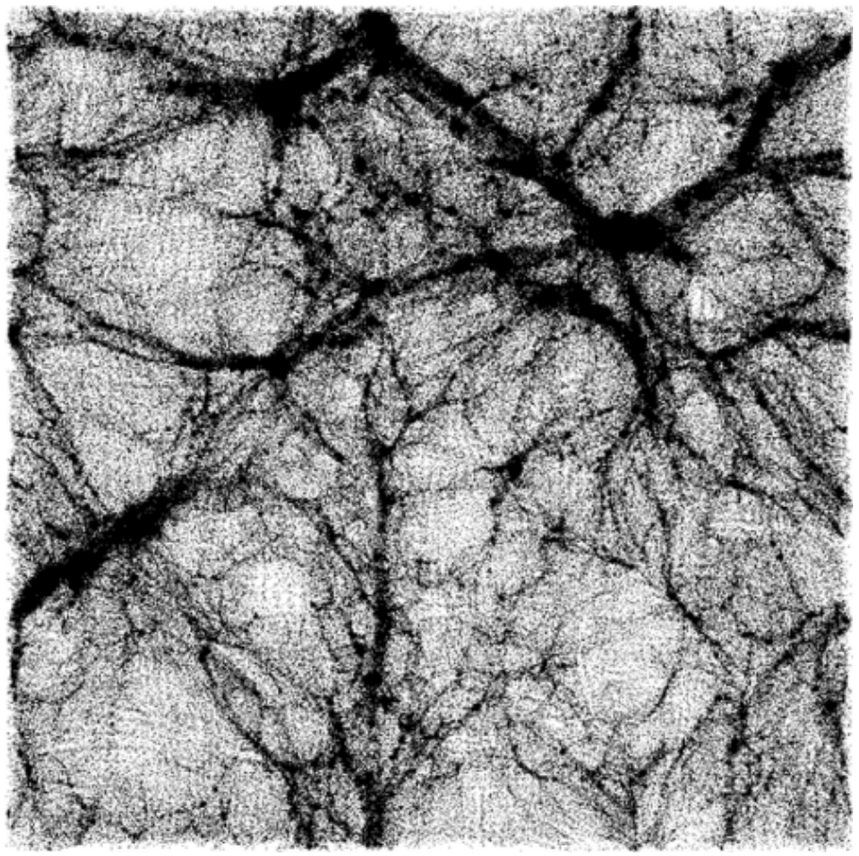

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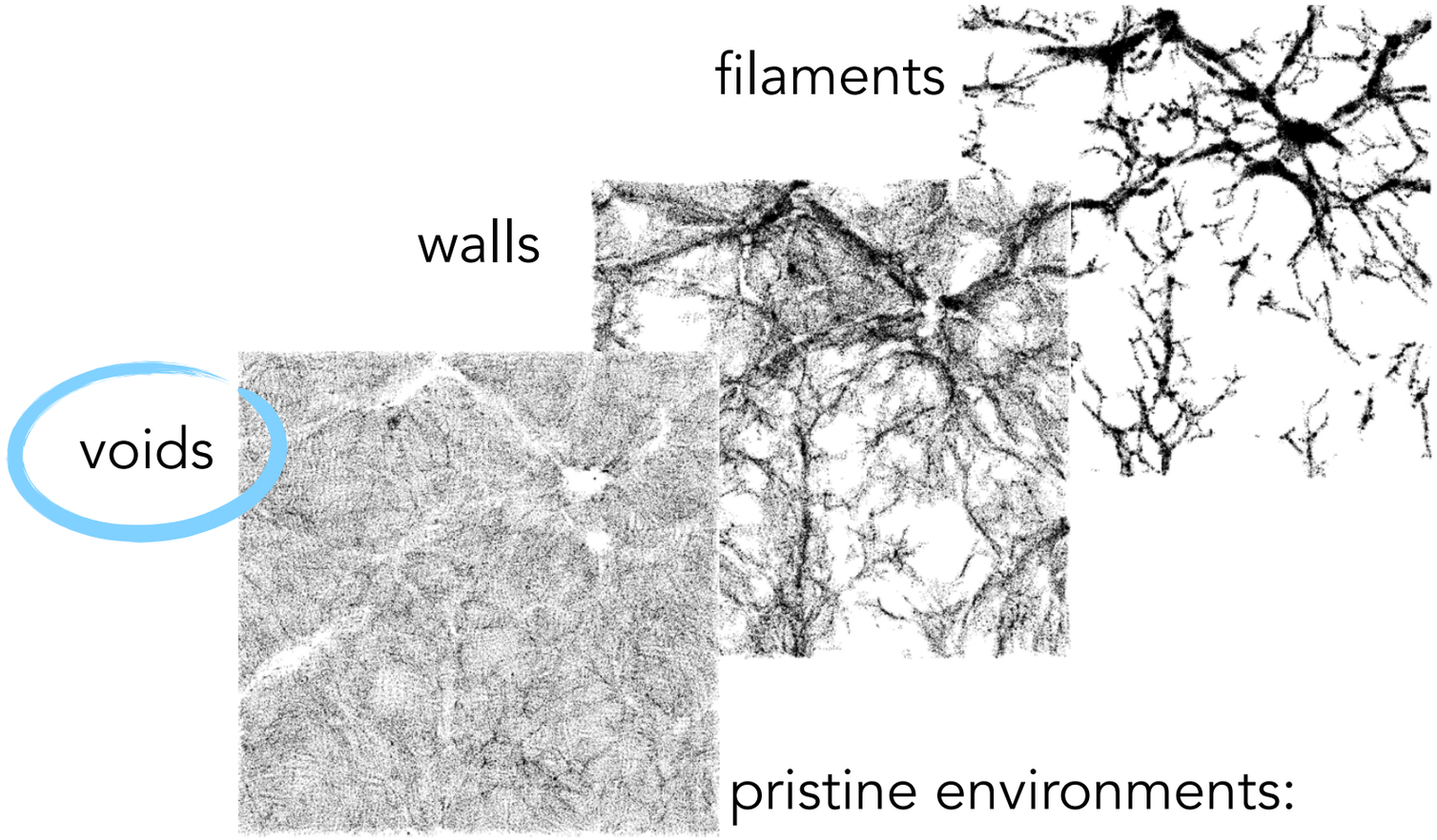

pristine environments:
ideal for studying galaxy evolution

from Cautun+14

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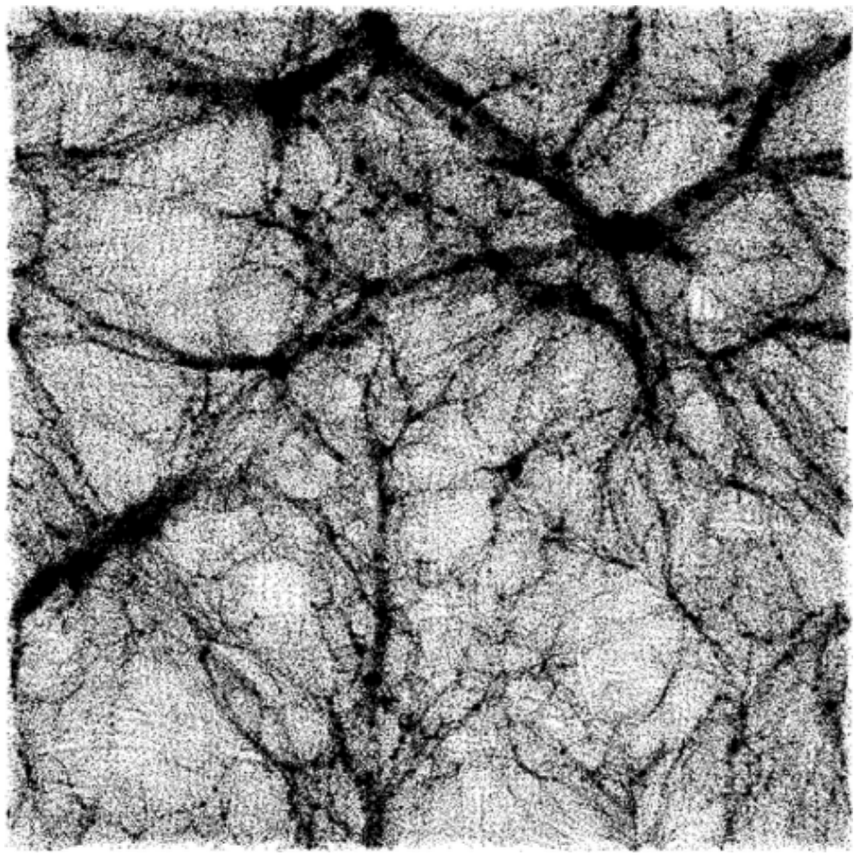

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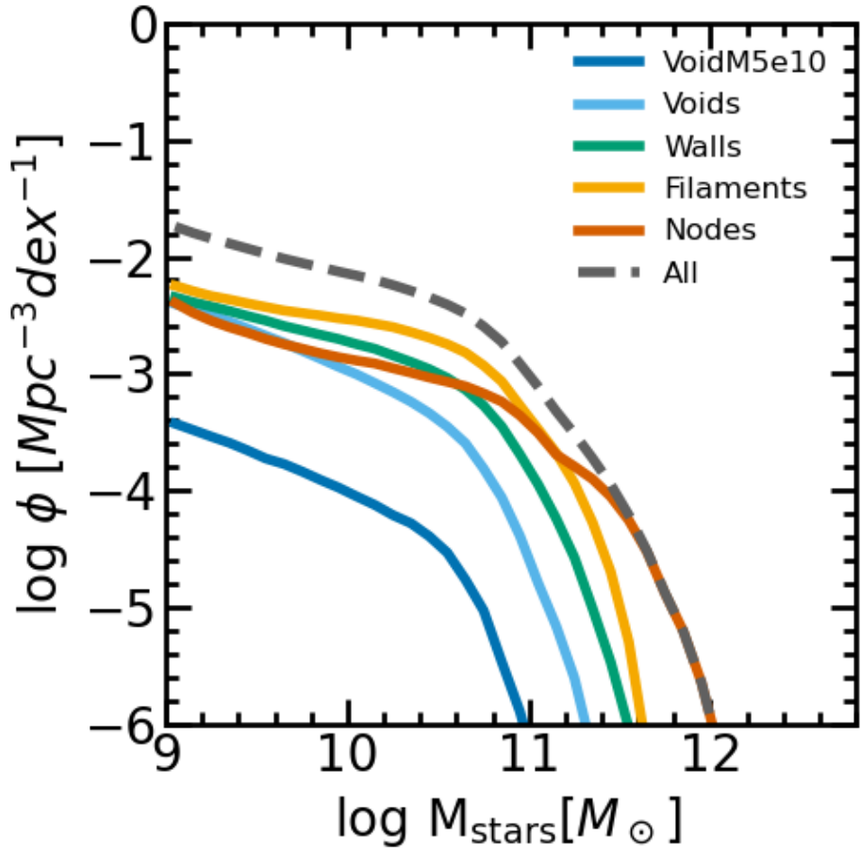
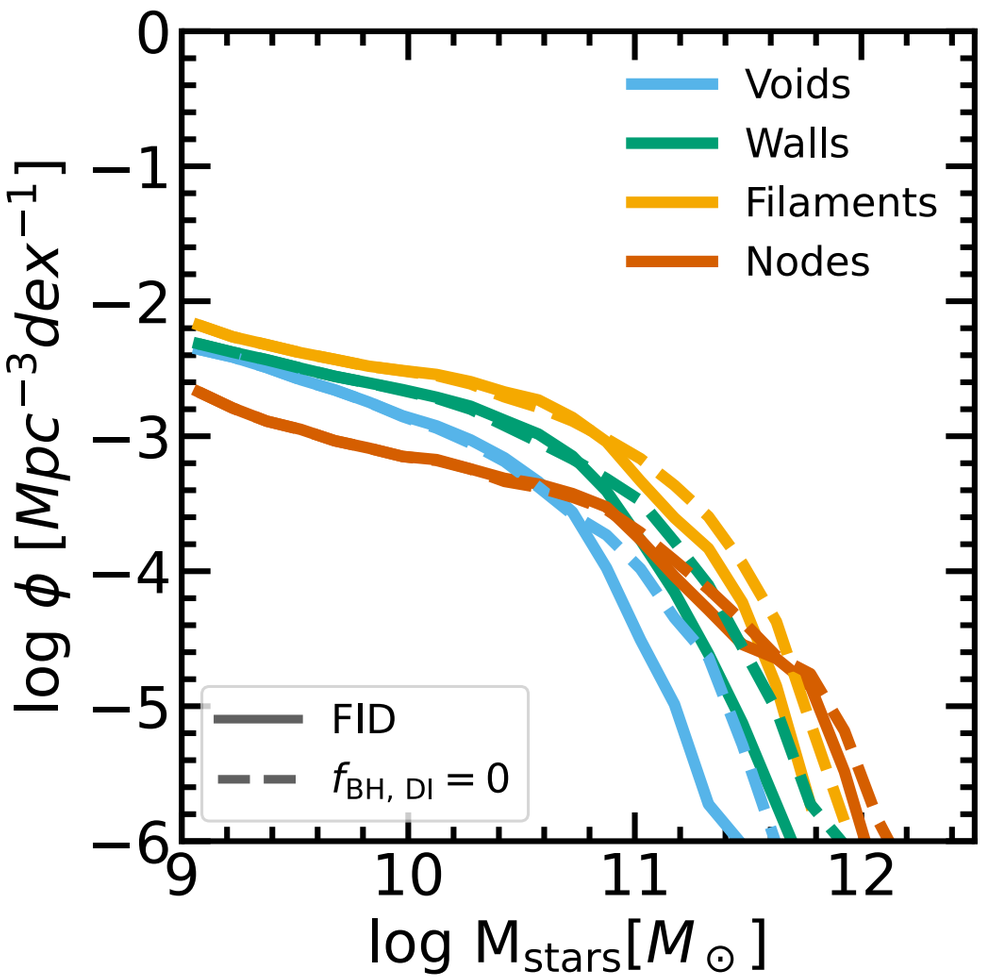
Identifying cosmic web environments with **NEXUS** (Cautun+14) and **spherical voids** with the Ruiz+15 algorithm starting from the DM haloes distribution



Parente et al. in prep.

In collaboration with: P. Lopez, H. J. Martinez, V. Coenda, F. Rodriguez, A. Ruiz, L. Ceccarelli (IATE, Cordoba)

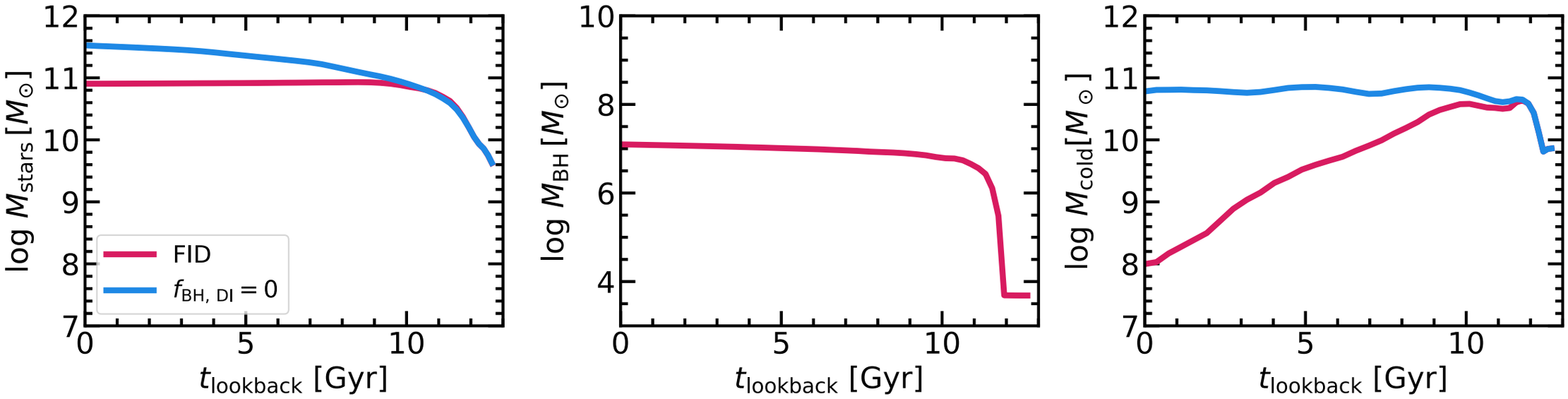
The impact of SMBH on isolated galaxies evolution



Parente et al. in prep.

The impact of SMBH on isolated galaxies evolution

$$N_{\text{mergers (z=0)}} = 0$$



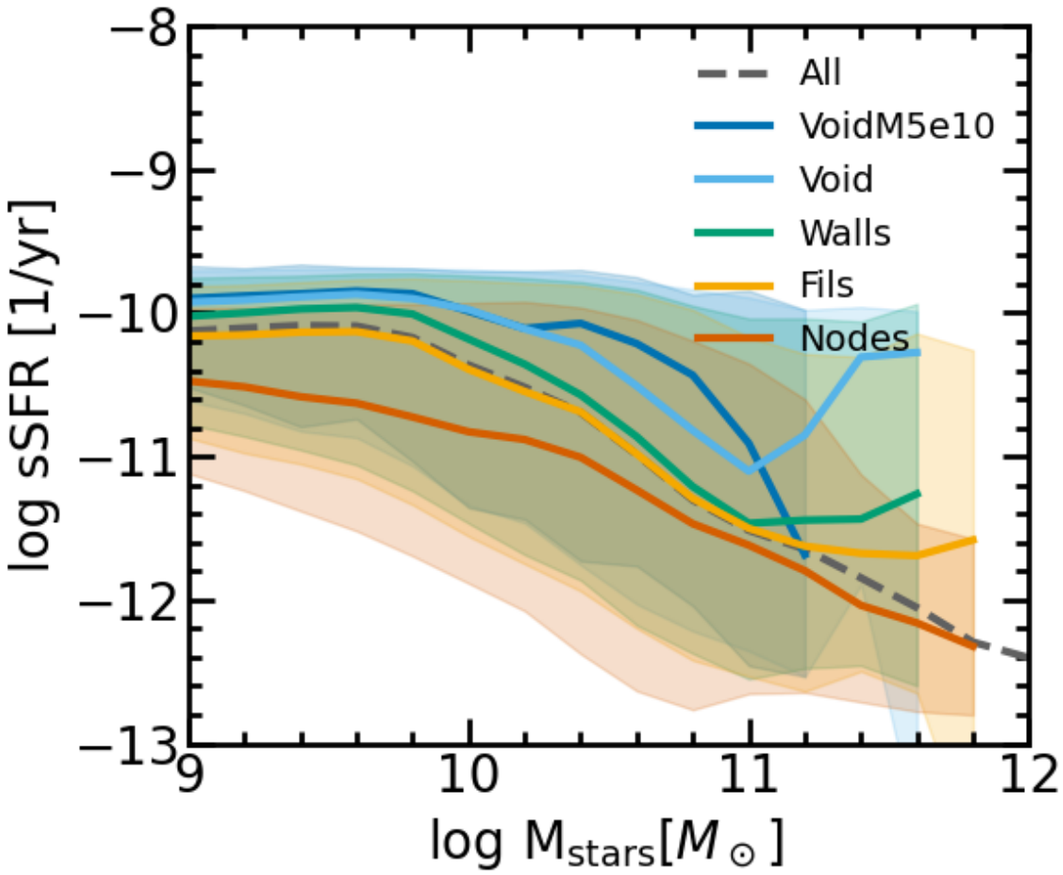
The impact of the **instability-driven SMBH growth** is more relevant on **isolated galaxies**

Parente et al. in prep.

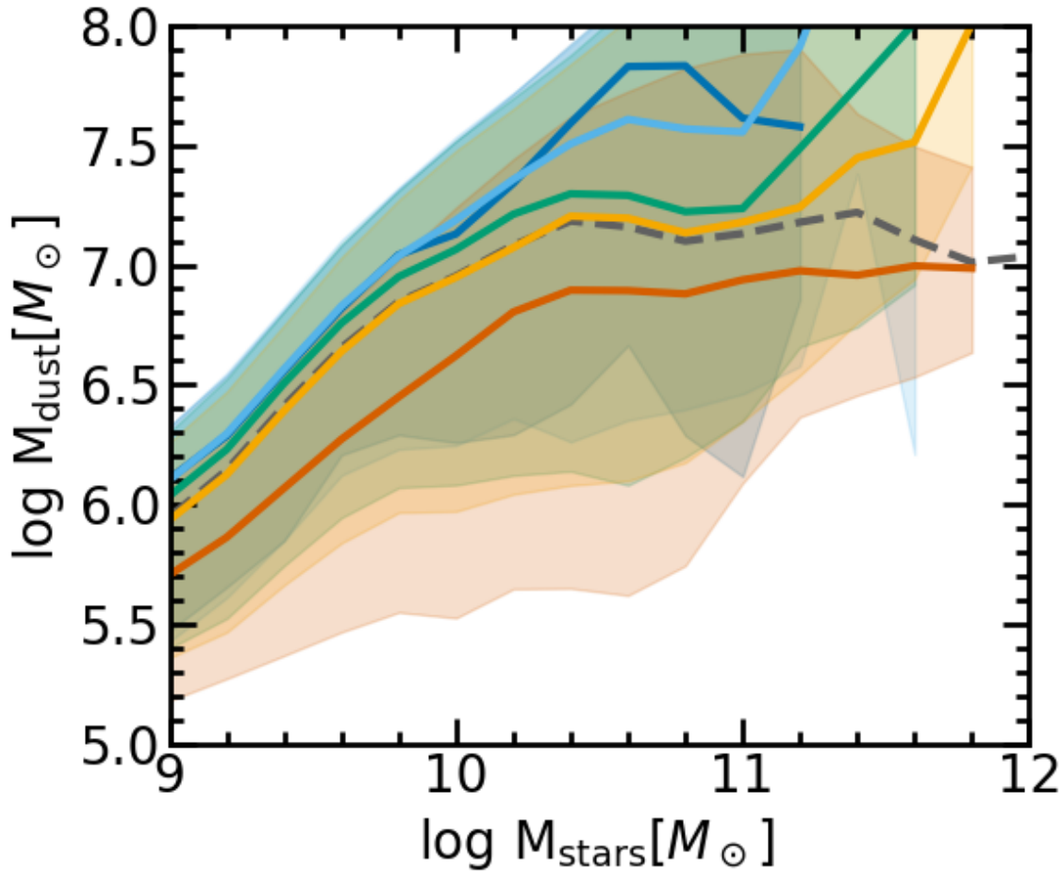
Star formation and dust across environments

SMBH growth in DIs OFF

SFR



dust



Void galaxies are more **dust rich**, more **star forming** (e.g. Rojas+05, Moorman+16, Ricciardelli+14, Florez+21)

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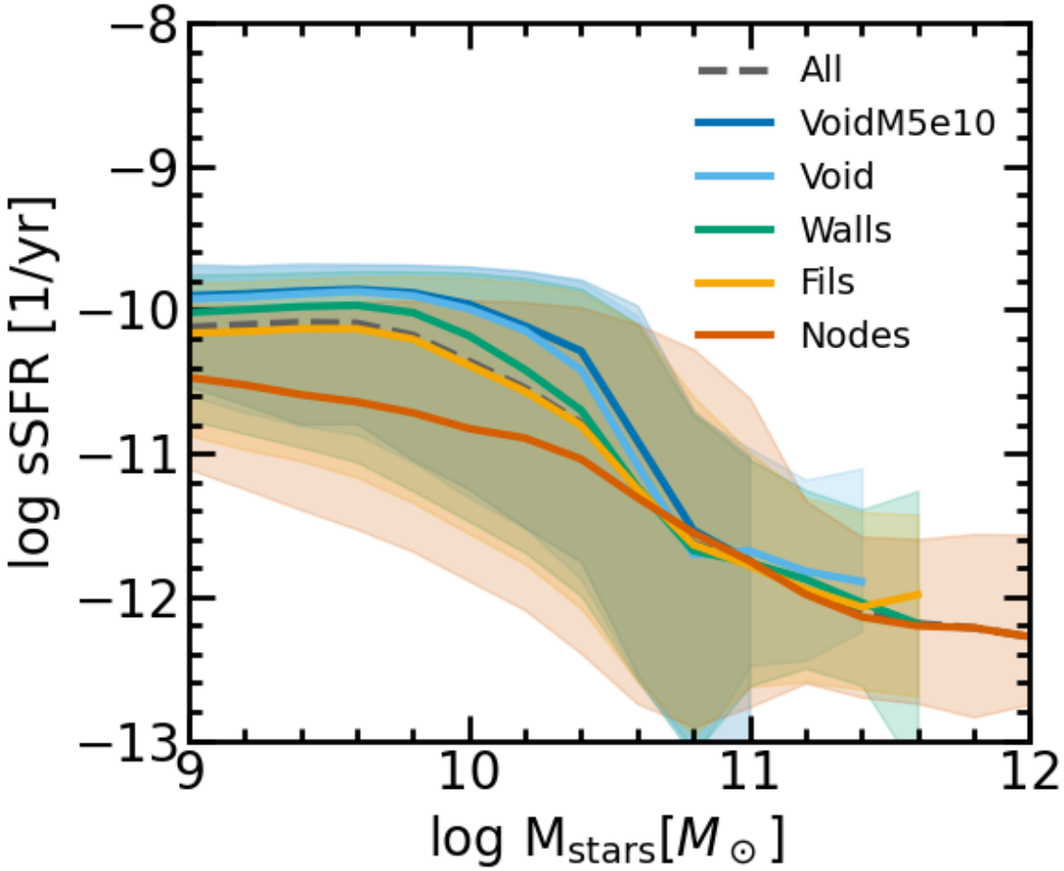

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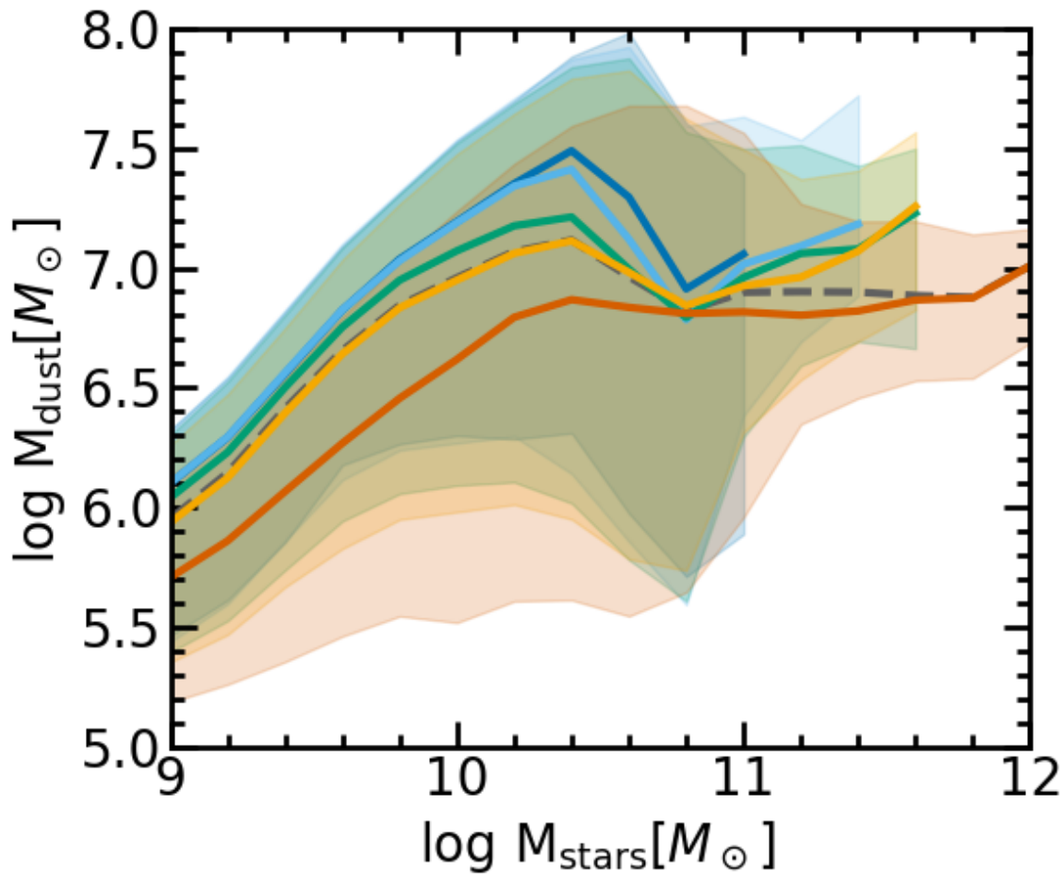

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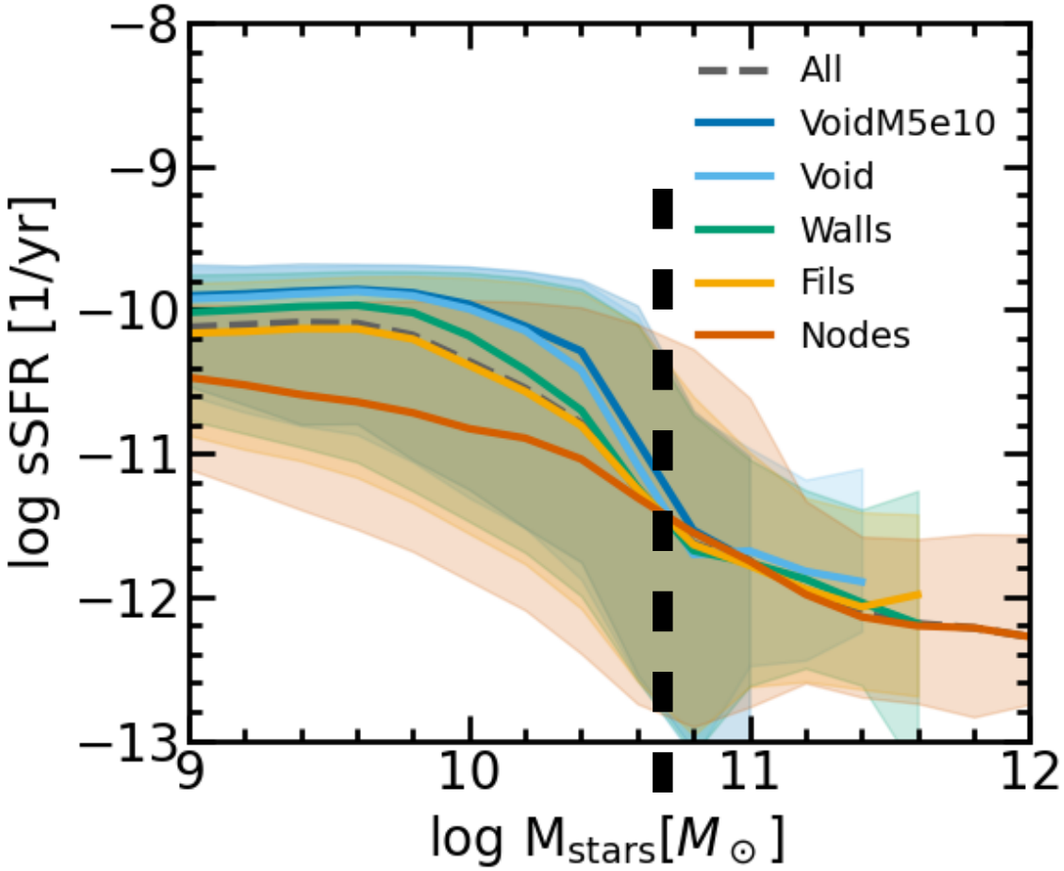

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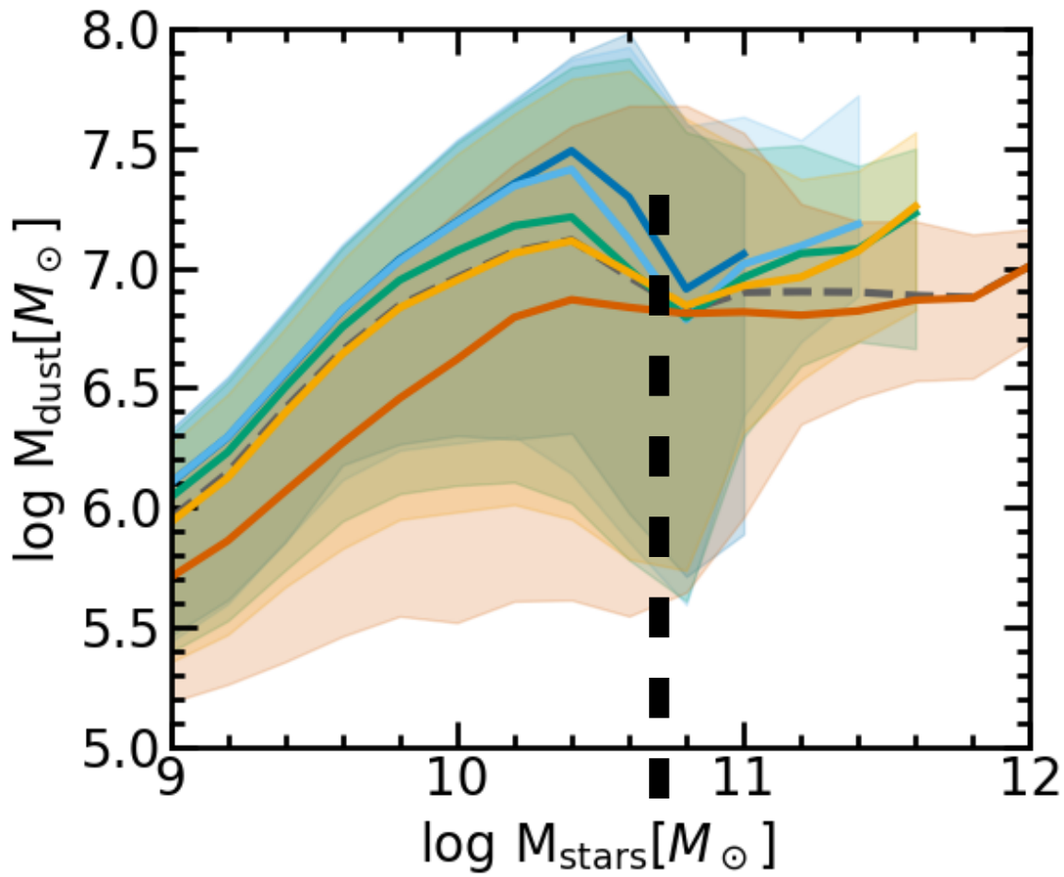

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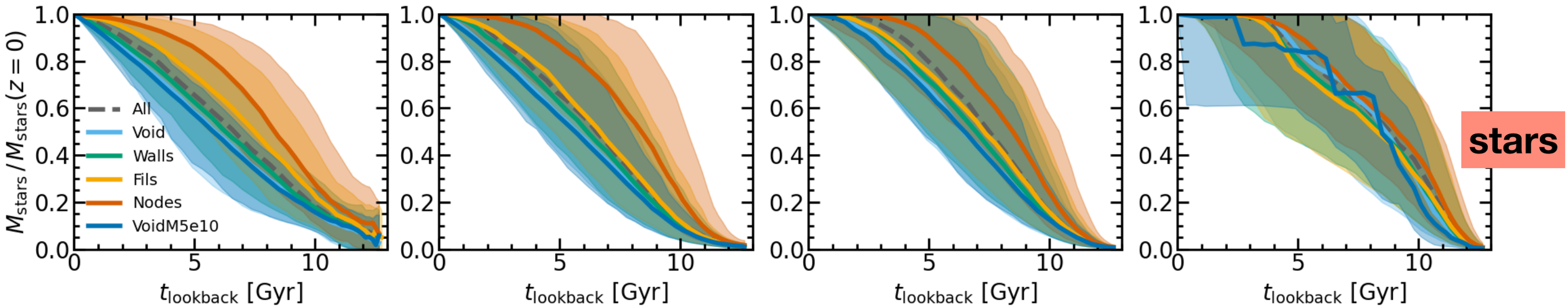
Void galaxies are younger

galaxy mass at z=0

$M_{\mathrm{stars},\,z=0} = 10^{9} M_{\odot}$ $M_{\mathrm{stars},\,z=0} = 10^{10} M_{\odot}$ $M_{\mathrm{stars},\,z=0} = 10^{10.5} M_{\odot}$ $M_{\mathrm{stars},\,z=0} = 10^{11} M_{\odot}$



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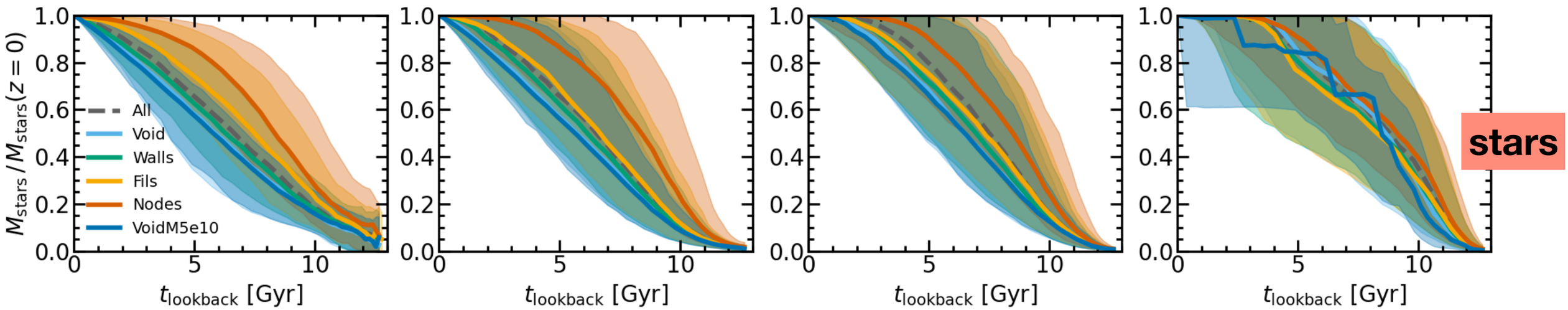

Recently confirmed by observations!
Domiguez-Gomez et al. 2023

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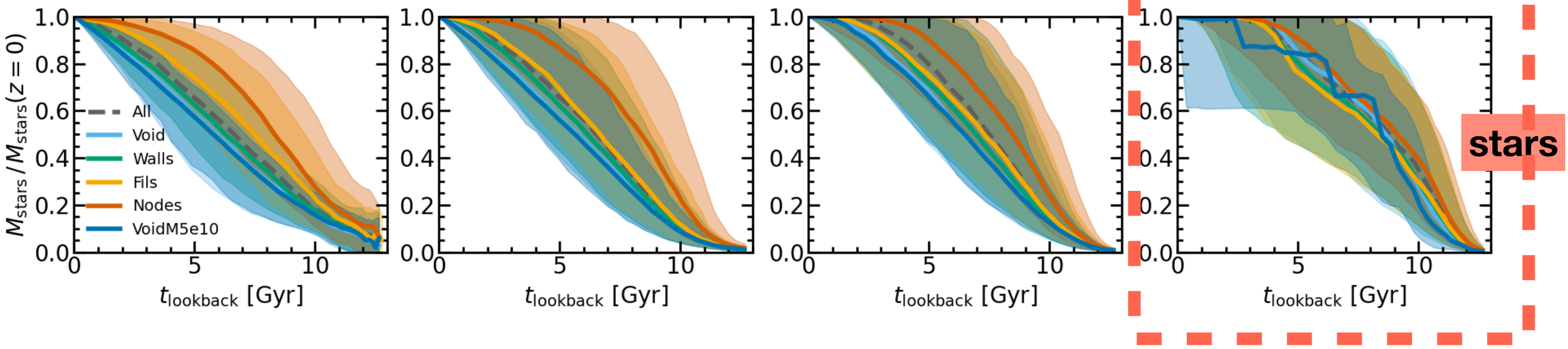

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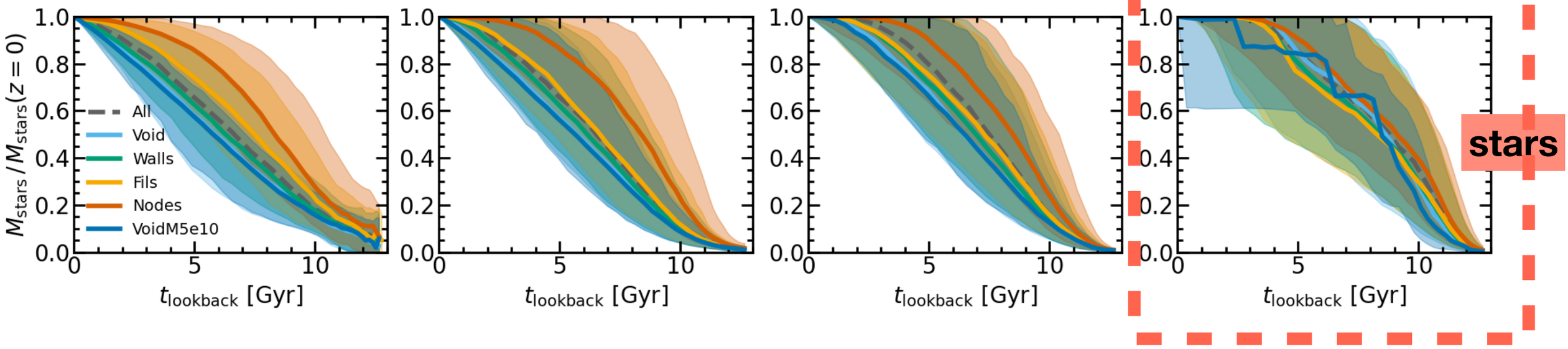

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$10^{9}\,M_{\odot}$ $10^{10.5}\,M_{\odot}$ $10^{11}\,M_{\odot}$

Environmental assembly bias

SMBH driven quenching erases environmental differences

Parente et al. in prep.

The observational POV

Stellar masses and dust from observations

SDSS-DR16: SFR and stellar masses from spectroscopic measurements
(Kauffmann+03)
GAMA/*H*-ATLAS: stellar and dust mass from photometry
(Driver+18; Beeston+18)

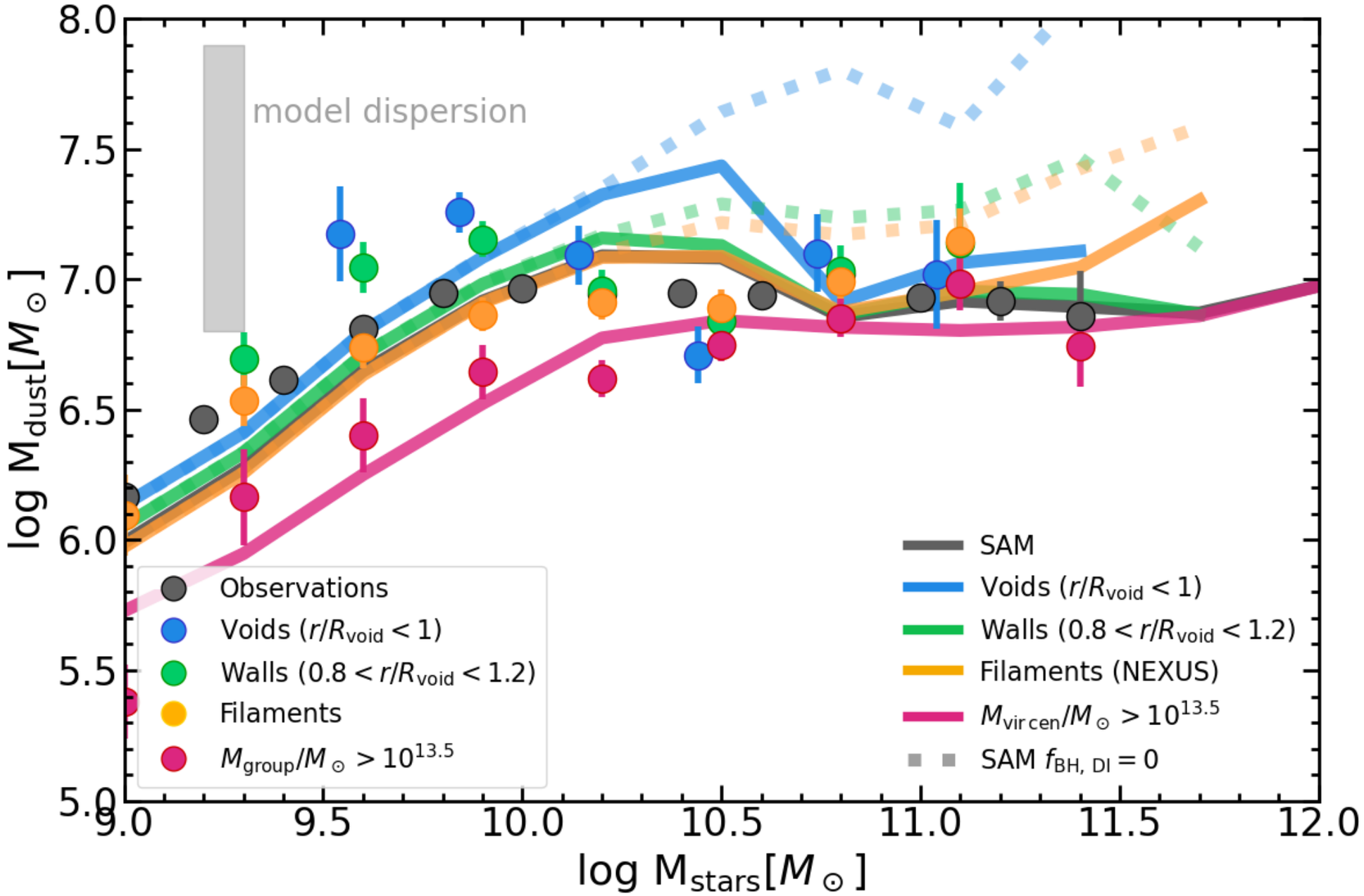
Environmental classification
on the SDSS-DR16 catalog

Voids - Ruiz+15,+19
Filaments - Martinez+16
Groups - Rodriguez & Merchàn 2020

keep in mind:
Not perfect match betwen simulated and observed environments!
The comparison is qualitative!

The observational POV: dust

Parente et al. in prep.



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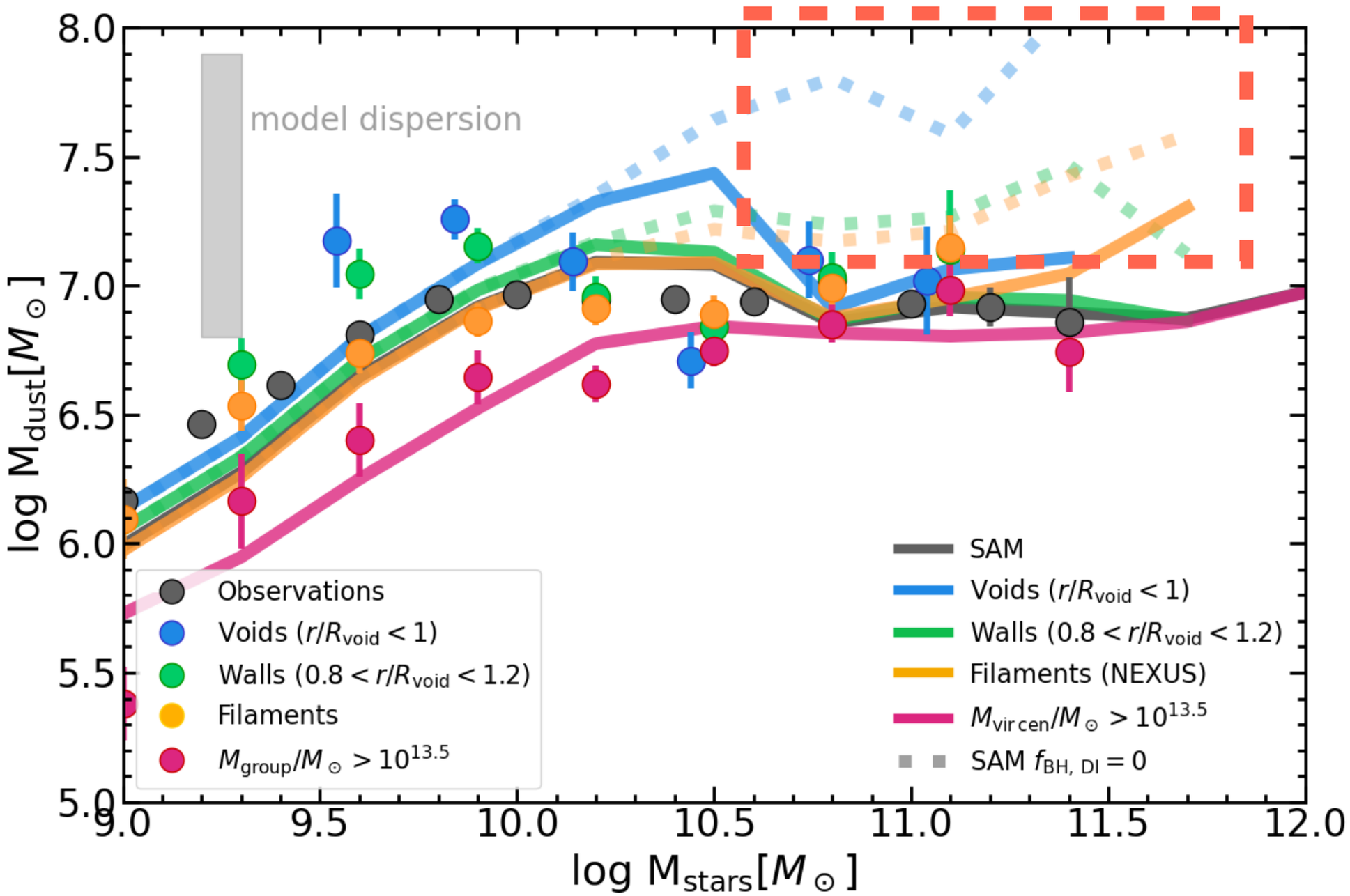

Conclusions

SMBH growth during ***in-situ*** processes is needed to **avoid** the presence of **massive**, **isolated**, **dust rich galaxies**, which are **NOT observed**

Studying **galaxy evo** in different **cosmic environment** is an **extraordinary test for this** (and possibly other physical mechanisms)

thank you
and enjoy Trieste!
:)

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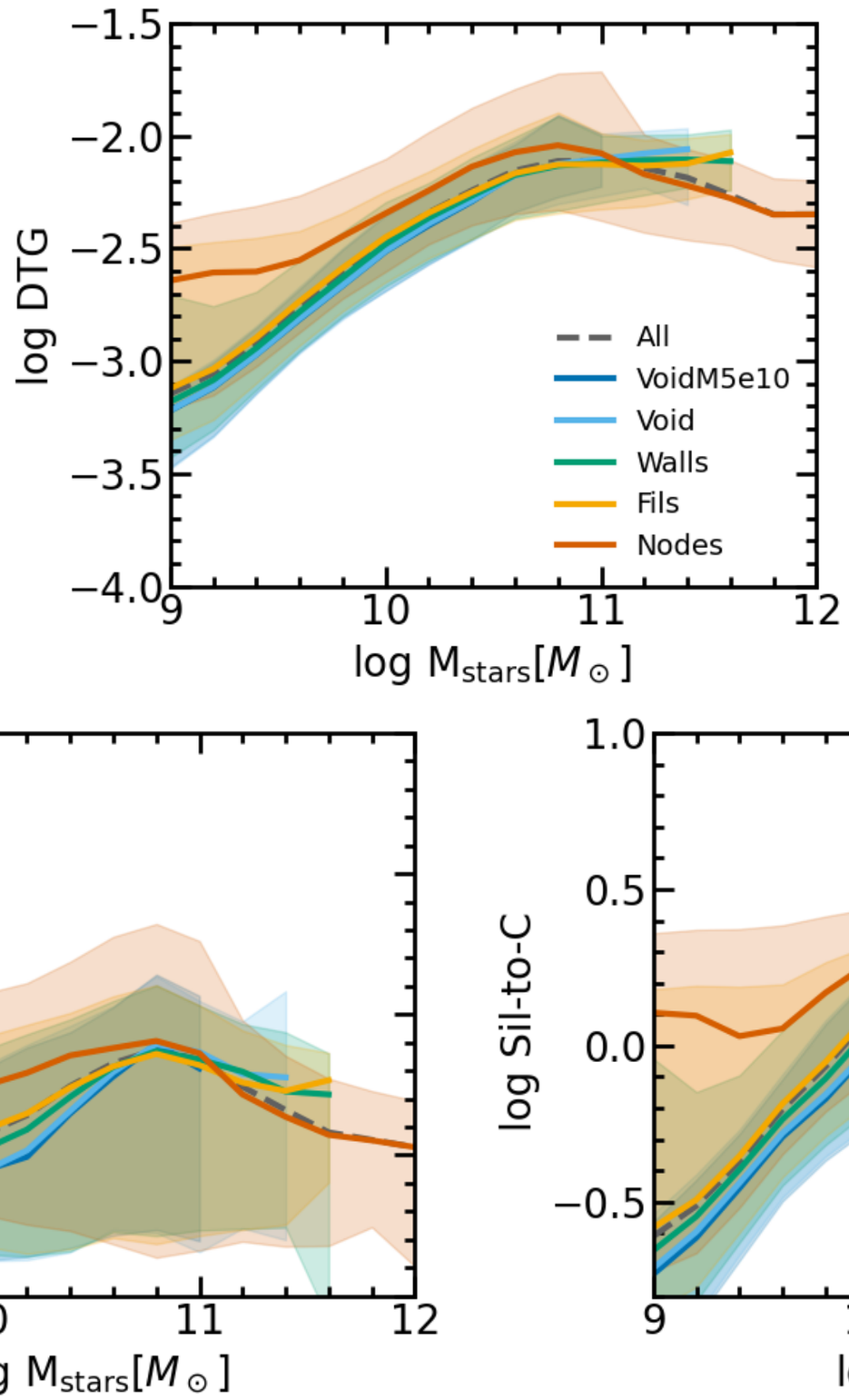
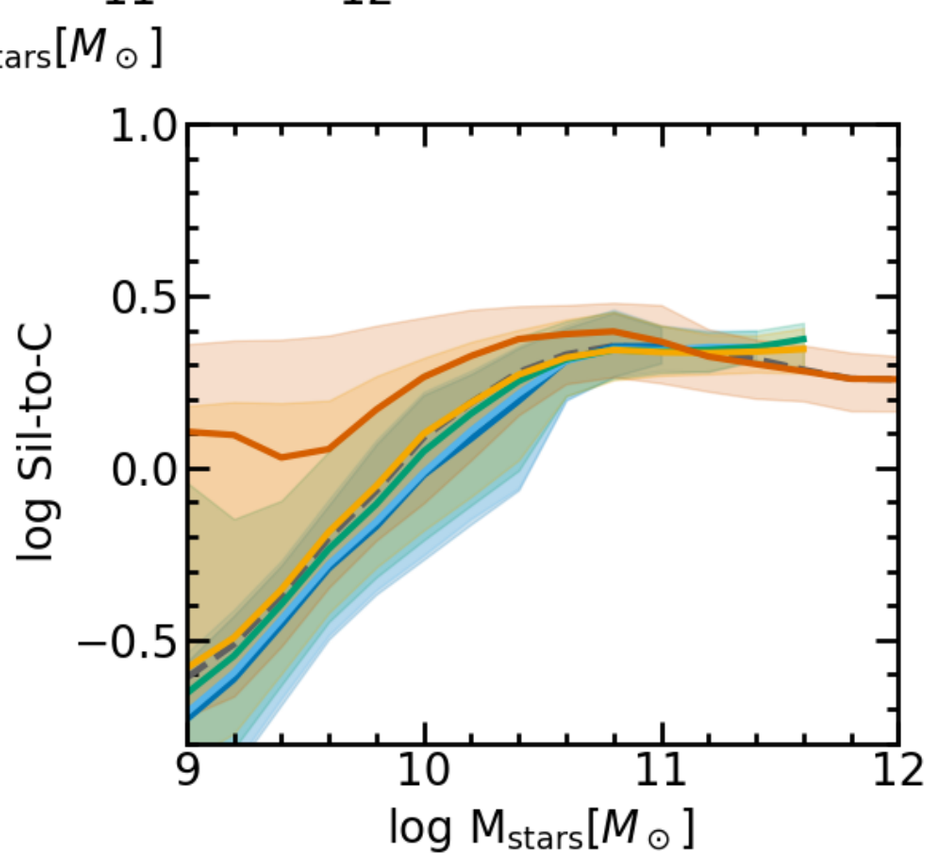
Backup slides

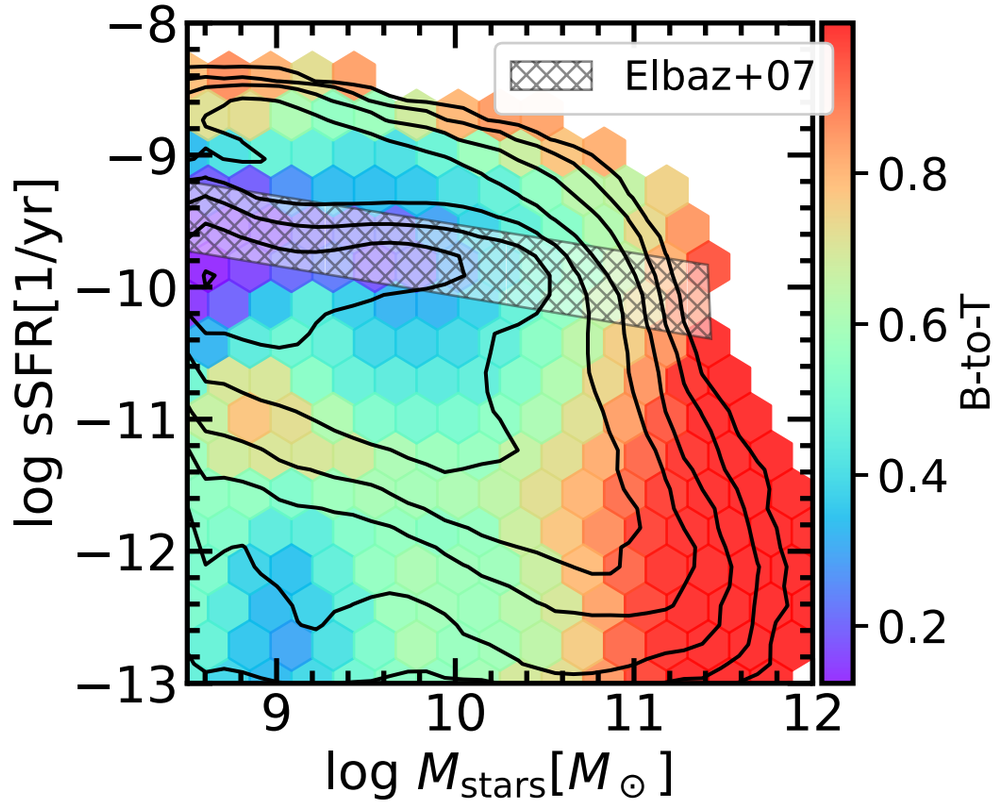
Dust properties

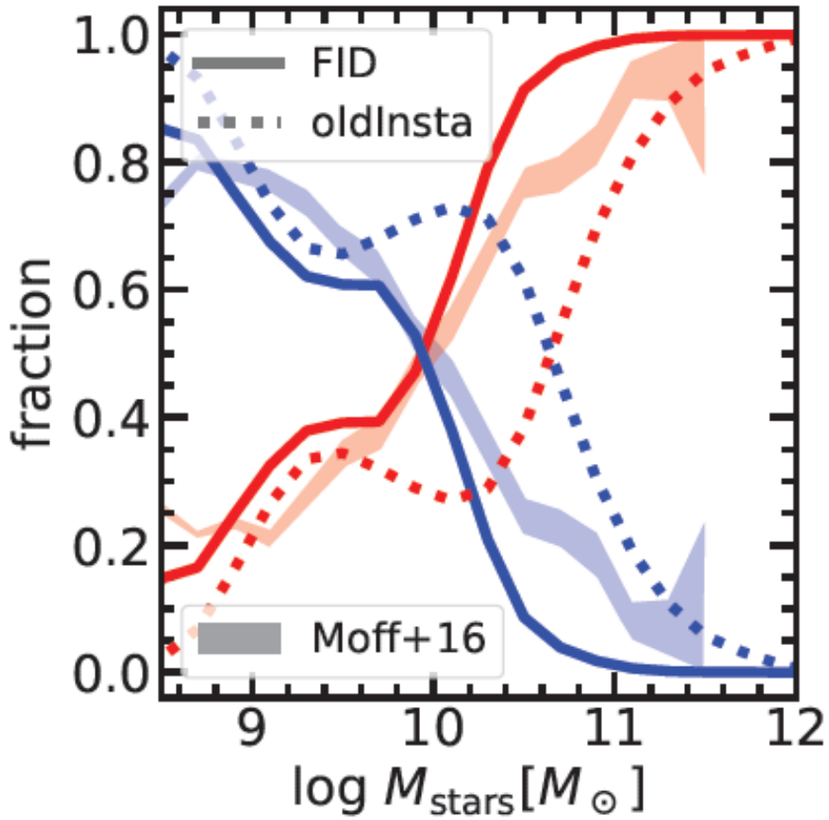


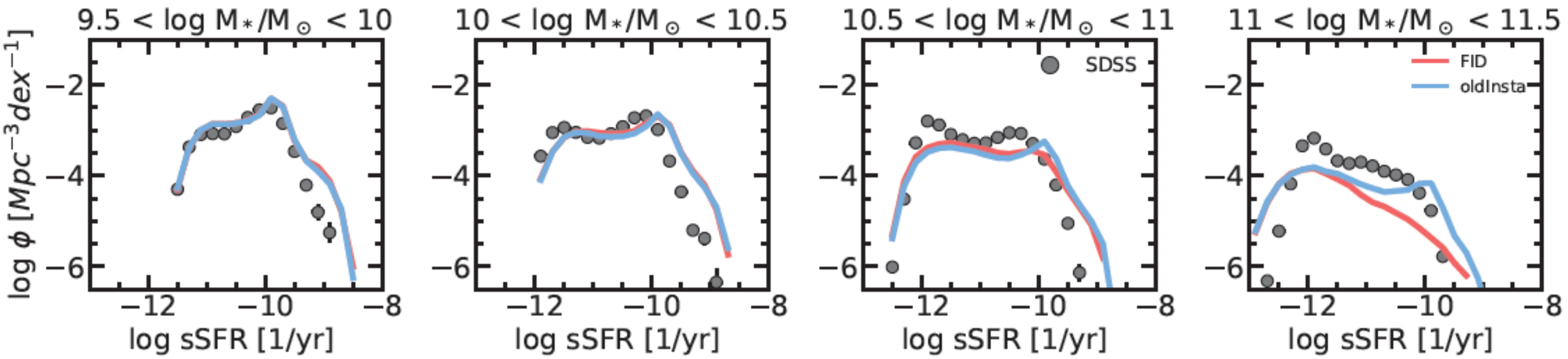


Dust chemical and geometrical properties depend on the environment

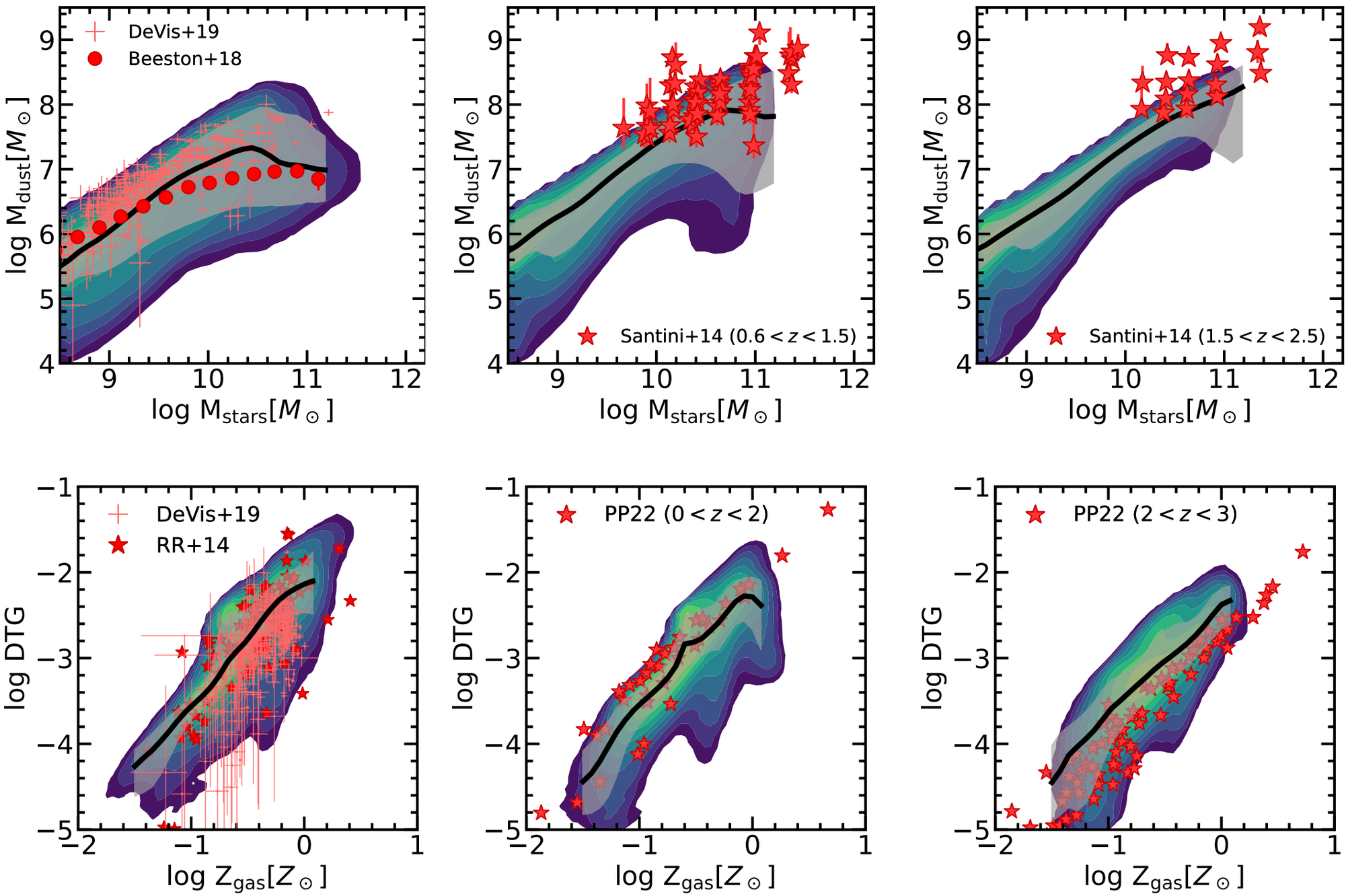
Star formation & Morphology



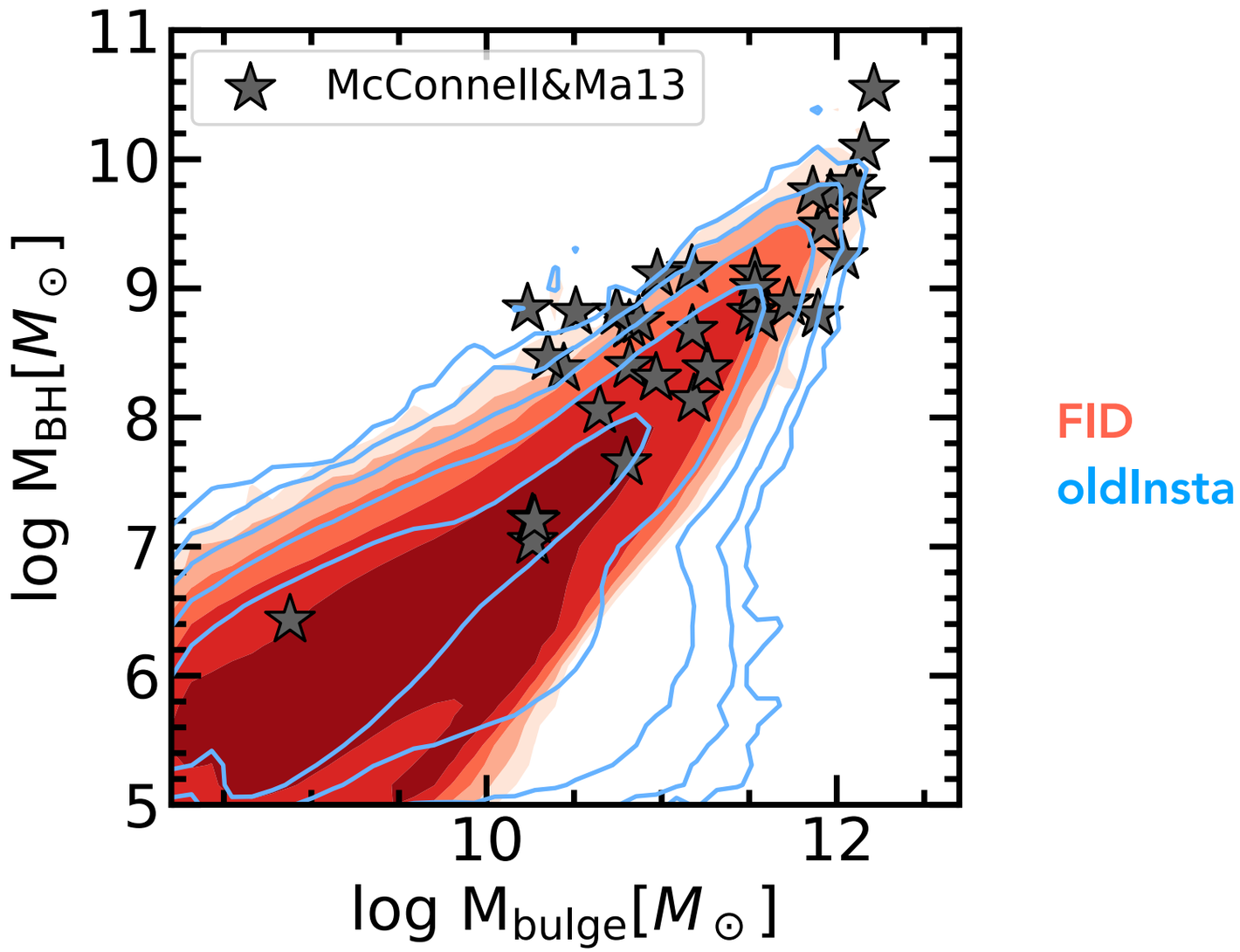




Galactic dust: scaling relations



BH-Bulge relation



The Dust Model

(inspired by Hydrosims Gjergo+18, Granato+21, MP+22)

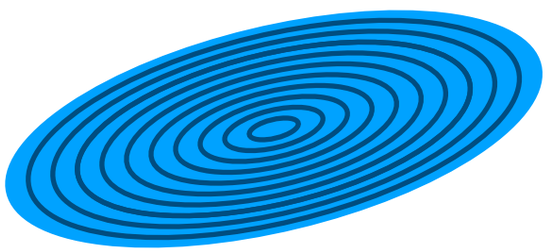
The dust model follows the stellar production and evolution of dust grains with two different **sizes** (small, large) and **chemical compositions** (carbonaceous and silicate)

C $MgFeSiO_4$

1. Production by stars

AGB and **SNII** from disc, bulge, and ICM
enrich both cold and hot gas with large dust grains

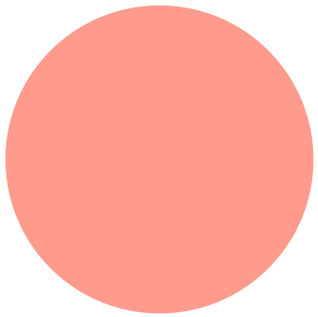
2. Evolution in the cold gas (=ISM)



Dust evolution is modeled in each ring of the cold disc

- **Accretion** of gas-phase metals in molecular clouds $\propto f_{H_2}, Z_{gas}$] Mass
- Grains **destruction** in SN shocks $\propto \mathrm{SNRate}$
- **Shattering** of large grains $\propto \rho_{gas}$] Size
- **Coagulation** of small grains $\propto f_{H_2}$] Size

3. Evolution in the hot gas (~CGM)



In the hot medium dust grains are eroded by
thermal sputtering

$$\propto \rho_{gas}, T, a_{grain}^{-1}$$

The Disc Instability (DI) model

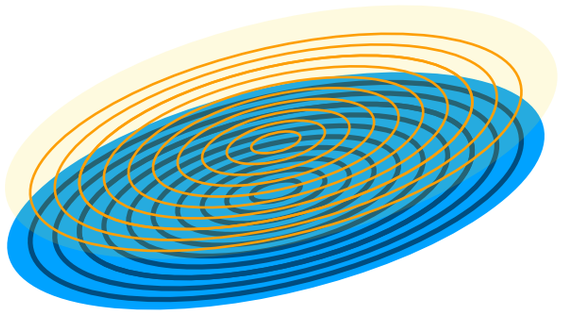
- **The original Henriques+20 model**

When the **stellar disc** is unstable to bar formation $V_{\rm max} < \sqrt{\frac{GM_{\rm stellardisc}}{3R_{\rm stellardisc}}}$ (Efstathiou+82)

$$\text{disc stars} \xrightarrow{\text{transfer}} \text{bulge stars}$$

This prescription neglects the cold gas disc!

- **Our new treatment of disc instabilities** (e.g. Irodotou+19)



We consider the stability of the whole disc (gas+stars)

$$M_{\rm disc,tot}\epsilon_{\rm tot} = M_{\rm disc,stars}\epsilon_{\rm stars} + M_{\rm disc,gas}\epsilon_{\rm gas} \qquad \epsilon_{\rm i} = \left(\frac{GM_{\rm disc,i}}{V_{\rm c}^2 R_{\rm disc,i}}\right) i = \{\rm gas, stars\}$$

if $\epsilon_{\rm tot} > 1$ the disc is **unstable**

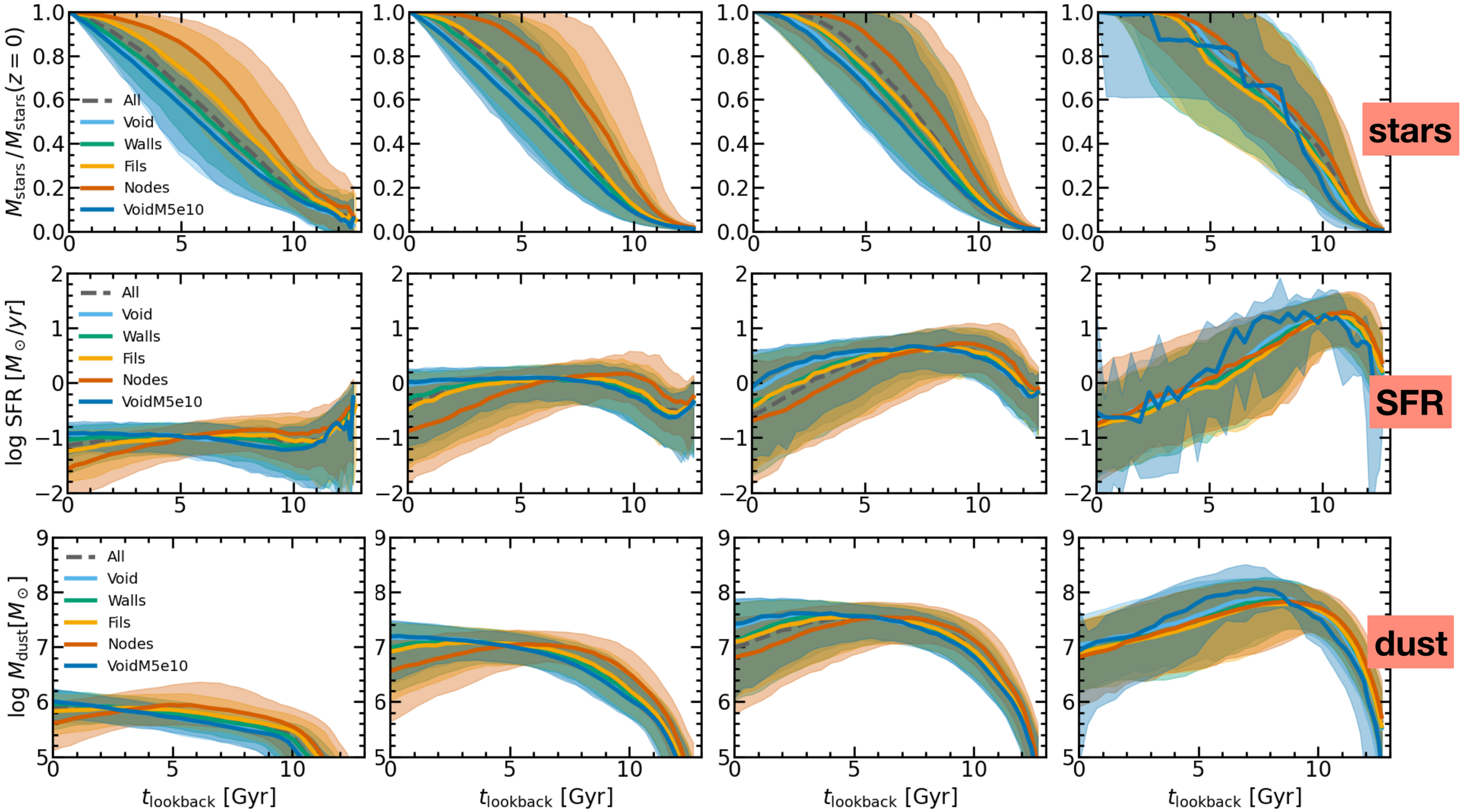
- unstable **gas** ⟶ makes a **starbust** and **accretes** the central **SMBH**
- unstable **stars** ⟶ transferred to the **stellar bulge**

$$f_{\rm BH,unst} = \frac{f_{\rm BH}}{1 + \left(\frac{V_{\rm BH,\,DI}}{V_{\rm vir}}\right)^2}$$

(see also Izquierdo-Villalba+19, Husko+22)

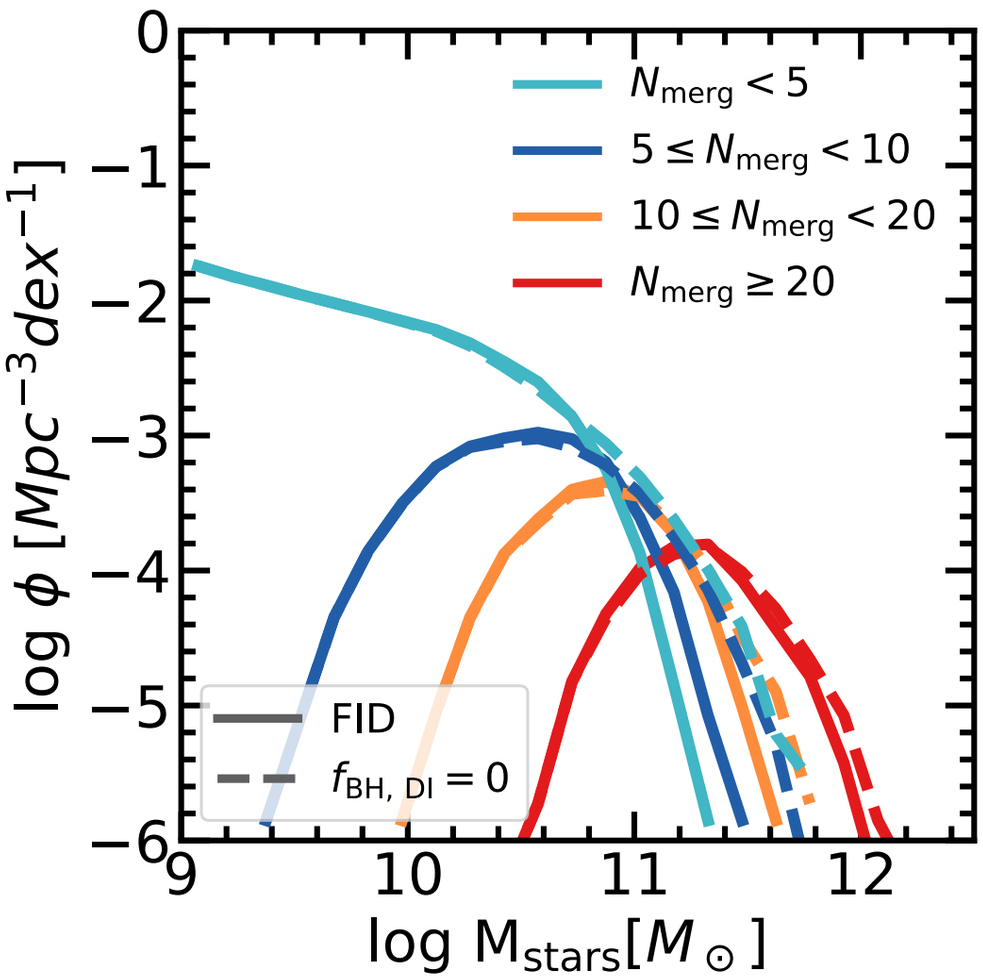
The galaxy assembly bias: void galaxies are younger

$M_{\mathrm{stars},\,z=0} = 10^{9} M_{\odot}$ $M_{\mathrm{stars},\,z=0} = 10^{10} M_{\odot}$ $M_{\mathrm{stars},\,z=0} = 10^{10.5} M_{\odot}$ $M_{\mathrm{stars},\,z=0} = 10^{11} M_{\odot}$



Parente et al. in prep.

The impact of SMBH on isolated galaxies evolution



Parente et al. in prep.