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CCAPP's 20th Anniversary Conference

The Role of Large-Scale Environment in Shaping the Mass-Metallicity Relation of Galaxies

A research collaboration with

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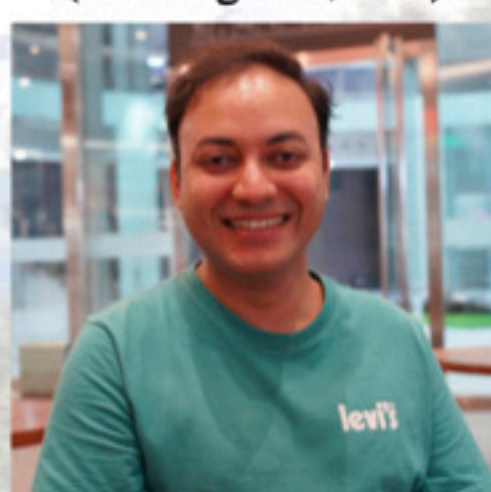

Wednesday June 10, 2026

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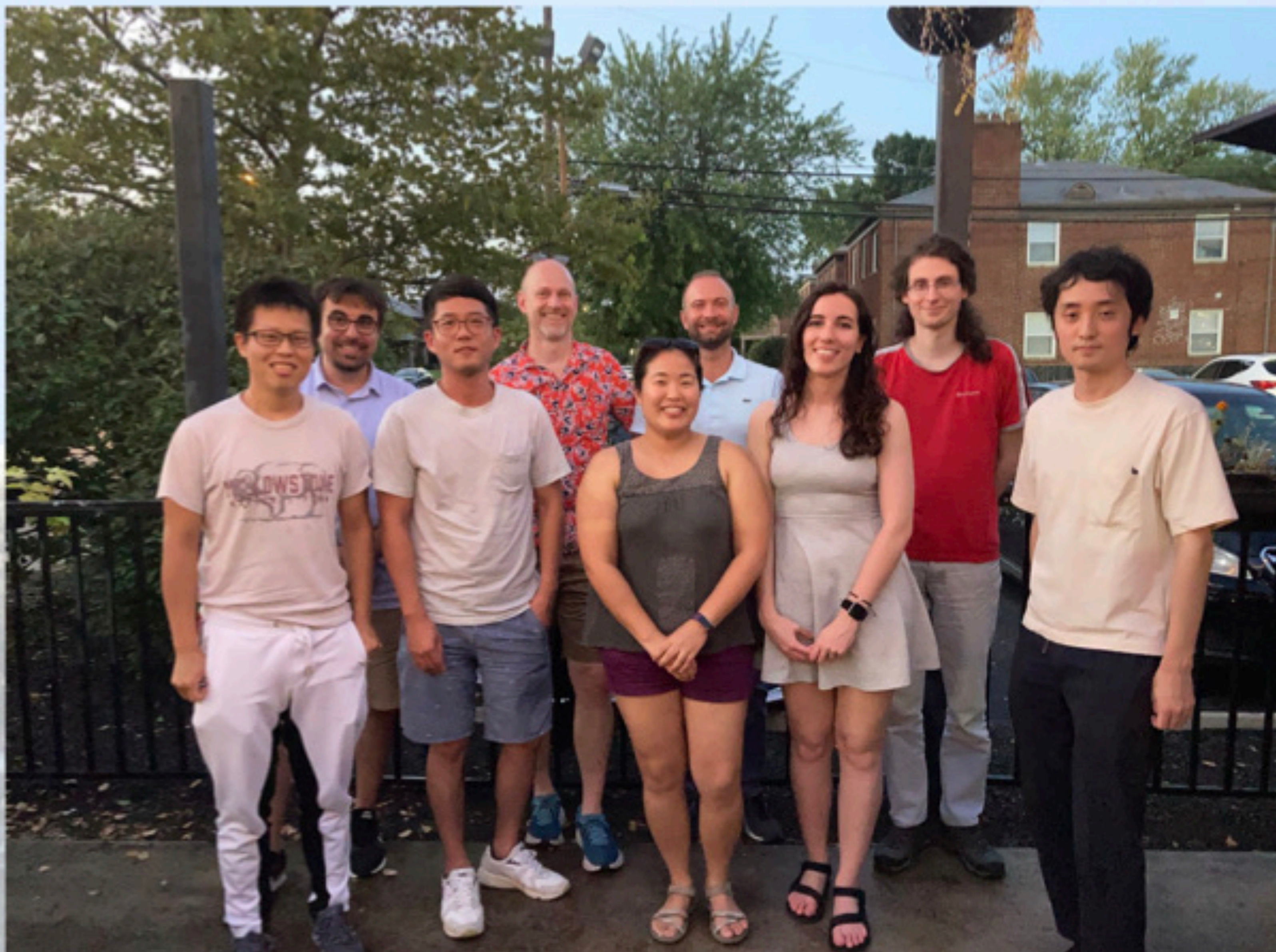
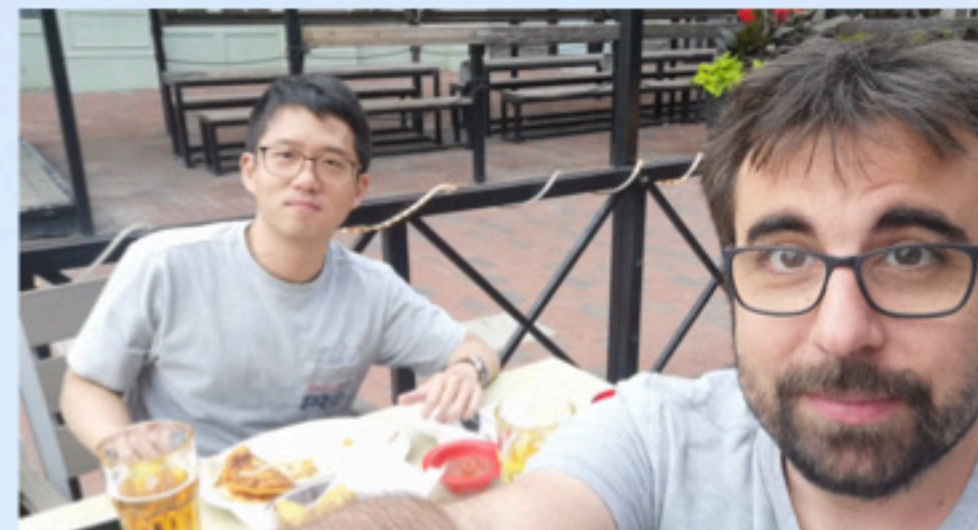
My memories of CCAPP

Community of fellow researchers who made me feel right at home, even though I was very far from my own

Freedom to do my research, backed by strong support from admin and faculty





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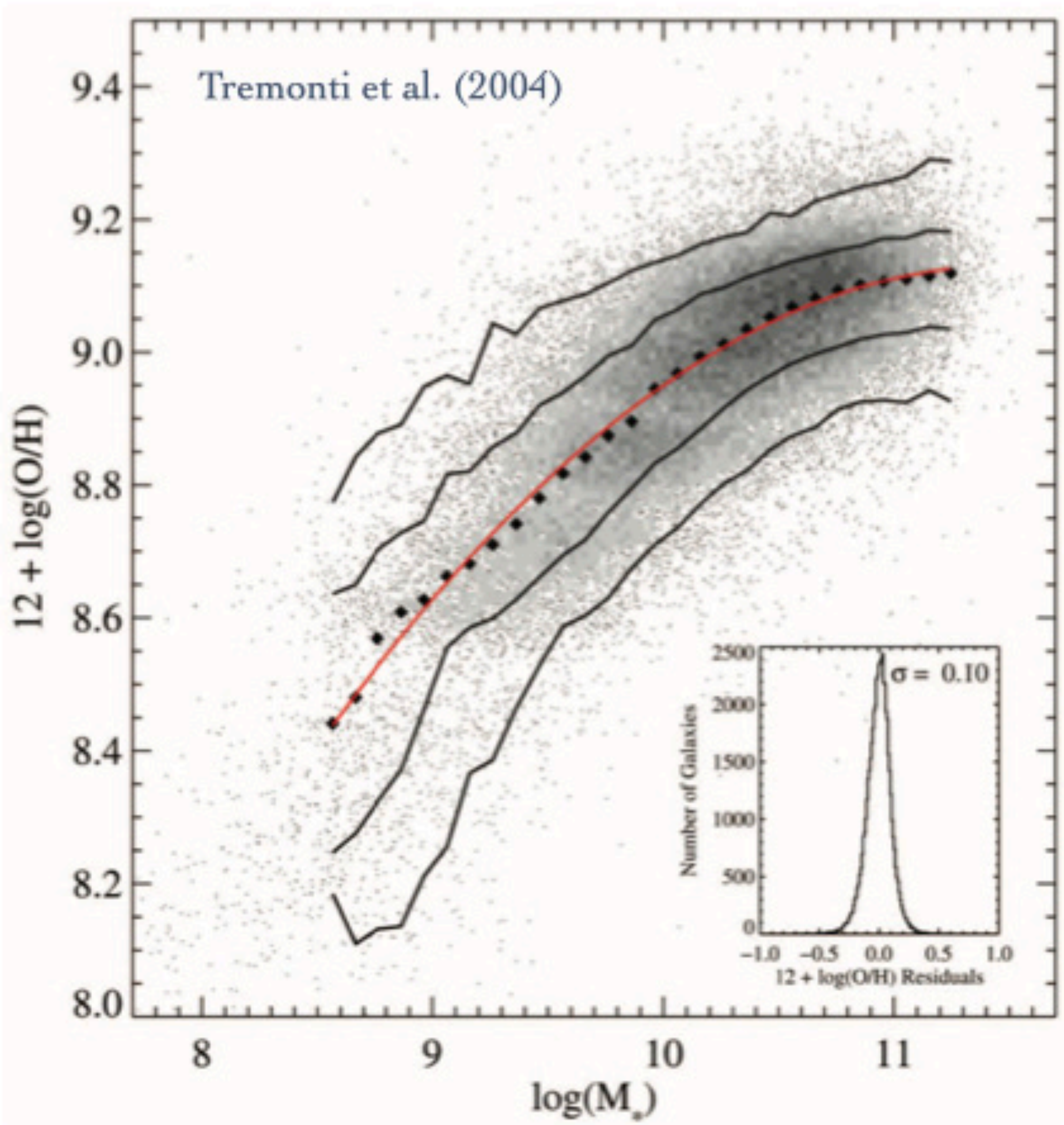
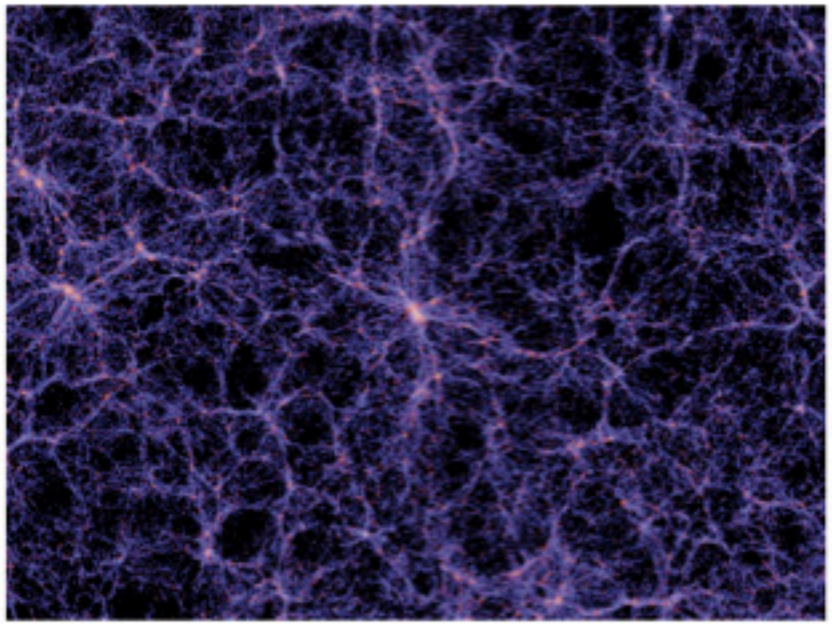
What am I presenting today?

What's the influence of cosmic environment on the mass-metallicity relation of galaxies?

FIG. 6.—Relation between stellar mass, in units of solar masses, and gas-phase oxygen abundance for ~53,400 star-forming galaxies in the SDSS. The large black filled diamonds represent the median in bins of 0.1 dex in mass that include at least 100 data points. The solid lines are the contours that enclose 68% and 95% of the data. The red line shows a polynomial fit to the data. The inset plot shows the residuals of the fit. Data for the contours are given in Table 3.



Every galaxy we see lives somewhere in the **cosmic web** ⟶ that location leaves a chemical fingerprint



Millenium Simulation (Springel et al., 2005)

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The simulation

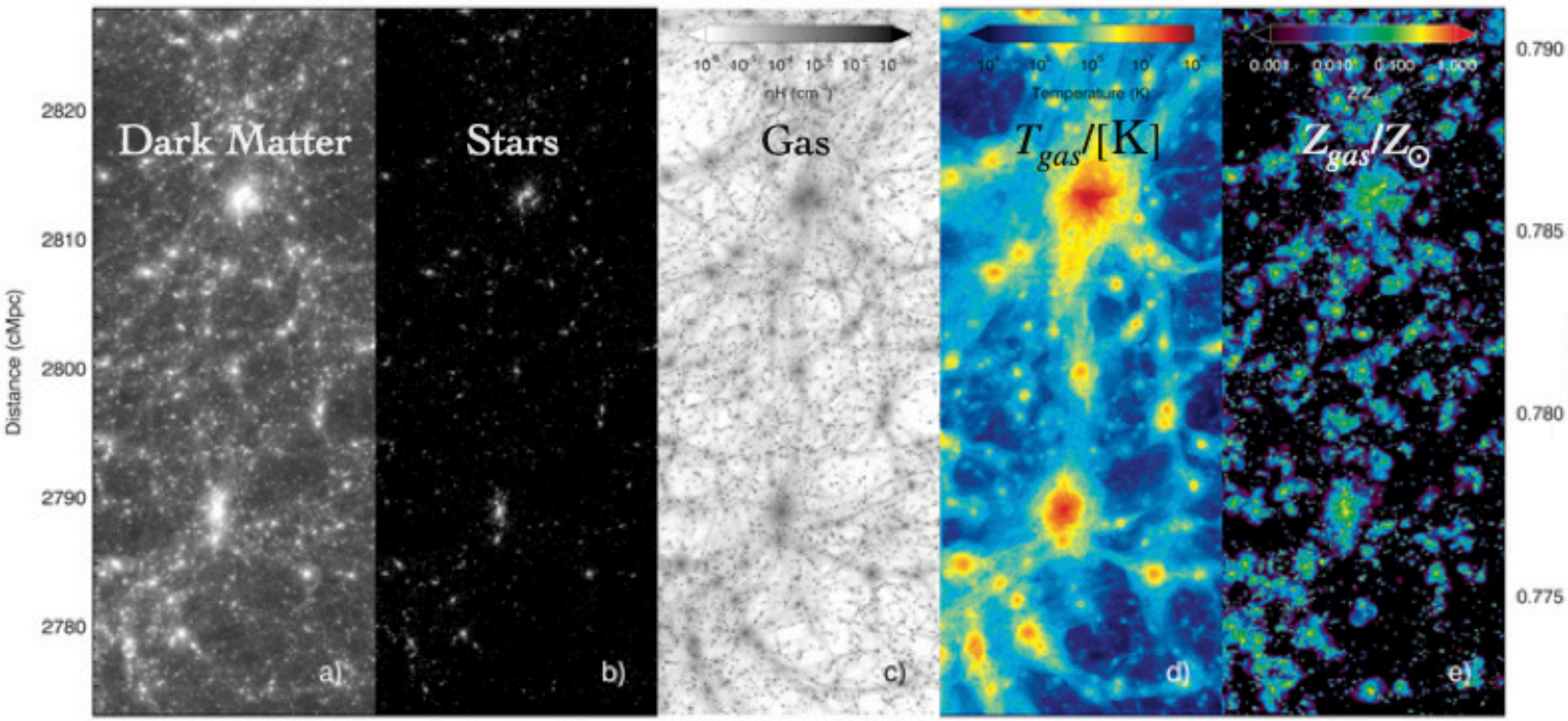
Analysis of the **Horizon Run 5** (HR5) cosmological hydrodynamical simulation (**Lee et al., 2021**)

Run with the adaptive mesh refinement simulation code: **RAMSES** (**Teyssier 2022**)

Simulation box of the Universe with volume of $(1049\,\mathrm{cMpc})^3$ from $z = 200$ to 0.625

High-resolution cuboid with volume of $(1049 \times 119 \times 127)\ \mathrm{cMpc}^3$

Stellar yields of Kobayashi et al. (2006, **massive stars**), Karakas (2010, **AGB stars**), and Iwamoto et al. (1999, **SNe Ia**)



Projections of a lightcone region for dark matter, stars, gas density, gas temperature, and gas metallicity (from left to right)

The mass-metallicity relation in HR5

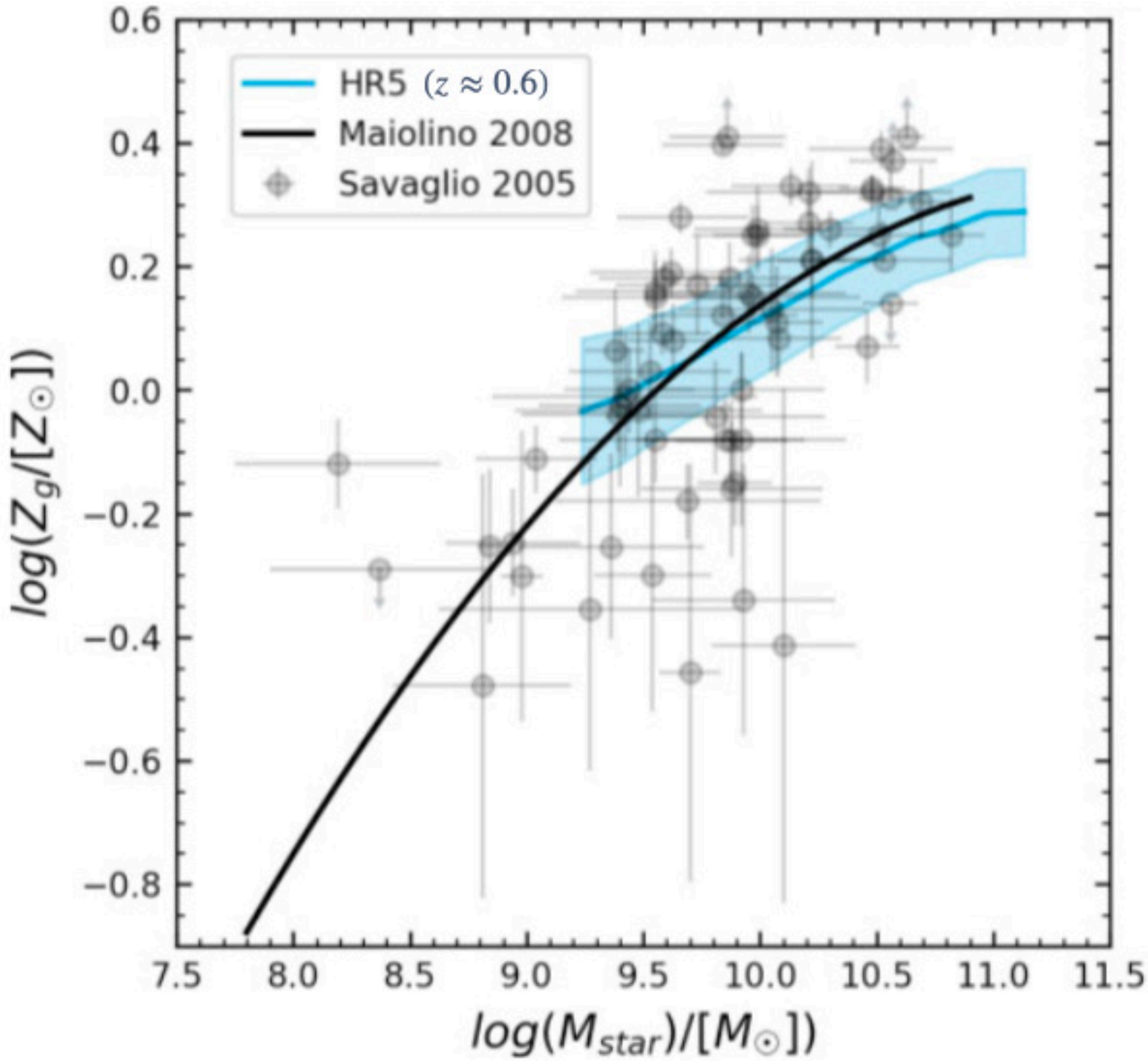


Figure from Rowntree et al. (2024)

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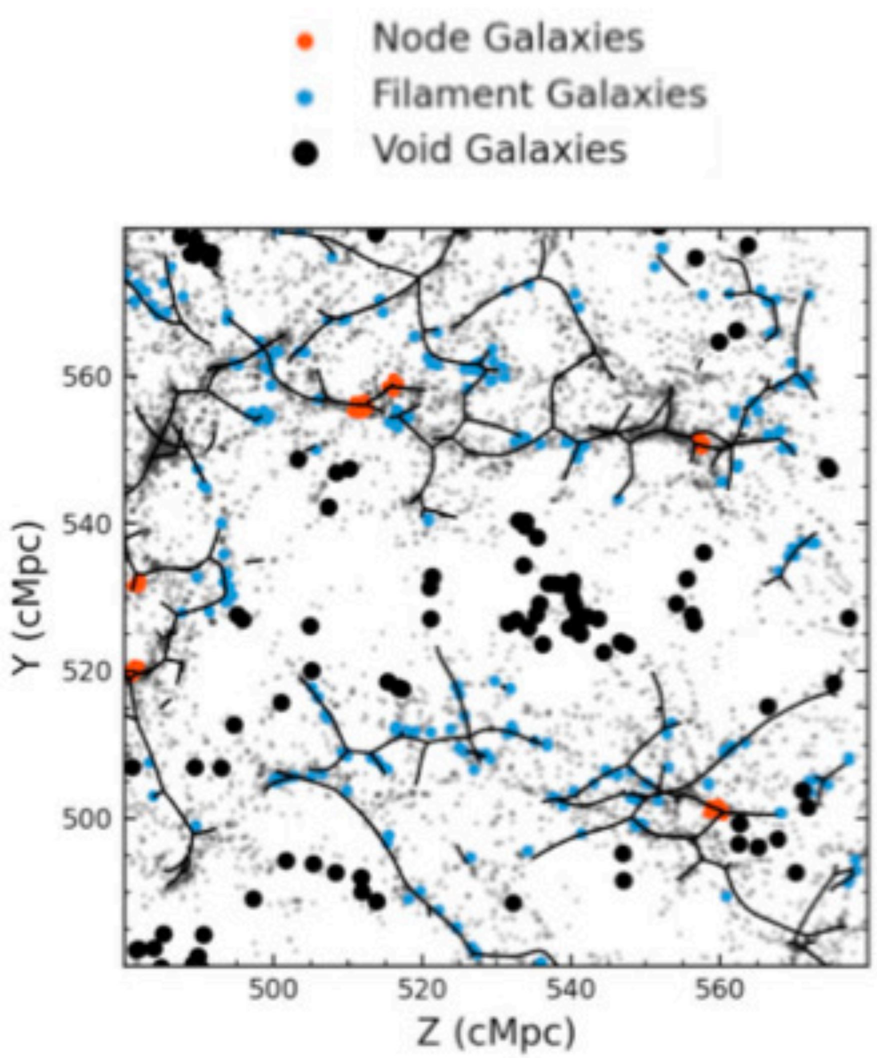
Filament finder

Filament finders: **T-Rex** (Tree-based Ridge eXtractor, **Bonnaire et al., 2020**)

Fitting **a minimum spanning tree** to the spatial distribution of galaxies
The tree is **regularised** with Gaussian mixtures, so that it runs smoothly through the middle of the tracers



Projected 20 cMpc slice of HR5

Figure from Rowntree et al. (2024)

Filaments

All galaxies with

$d_{skel} \leq 1\,\mathrm{cMpc}$

Measured perpendicularly from the nearest edge on the skeleton

Voids

All galaxies with

$d_{skel} \geq 8\,\mathrm{cMpc}$

Measured perpendicularly from the nearest edge on the skeleton

Nodes

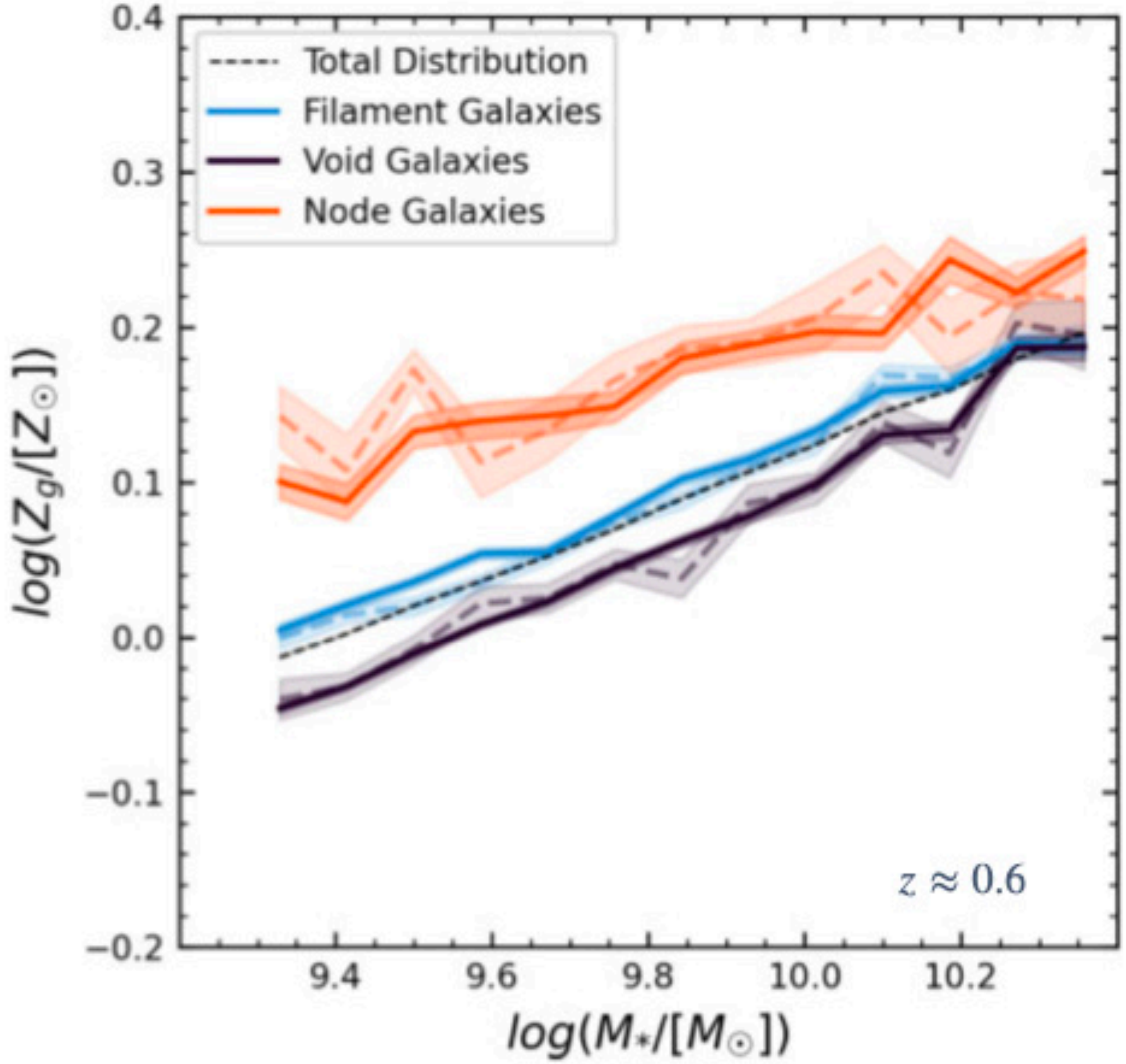
(1) All galaxies with distance from the FoF centre $d_{FoF} < 2 \times R_{200}$

(2) Large clusters: DM halos with M_{tot} above the 99.97th percentile

(3) Central galaxy with $\Delta_r \equiv d_{FoF}/R_{200} < 0.05$ for 'relaxed' halos

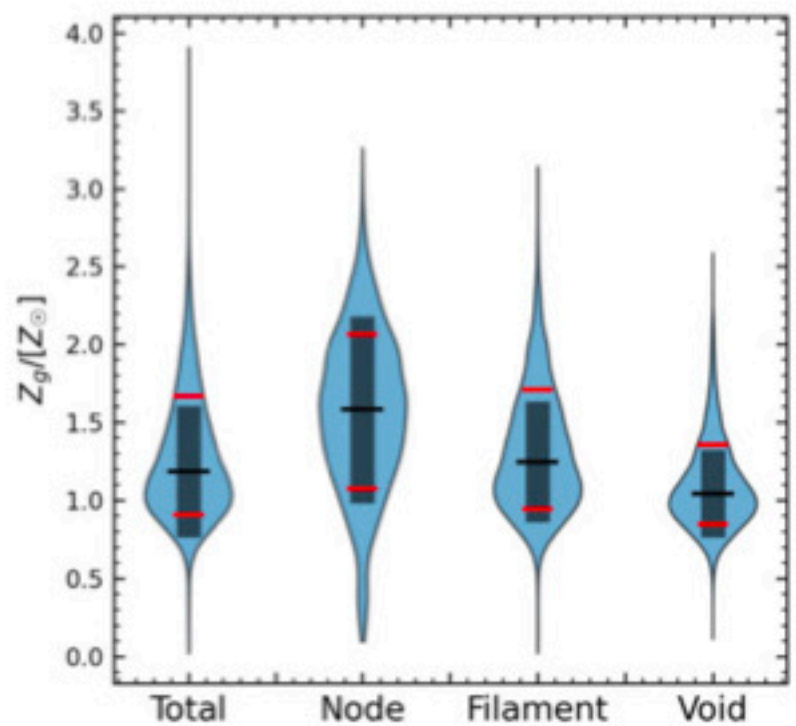
The environmental dependence of the mass-metallicity relation

Figures from Rowntree et al. (2024)



The coloured shaded regions show the standard error on the median for each of the three environments. The lighter dashed lines represent the MZR associated with the environments within a small range of ρ_G of $0.052 \pm 0.021\ \mathrm{cMpc}^{-3}$.

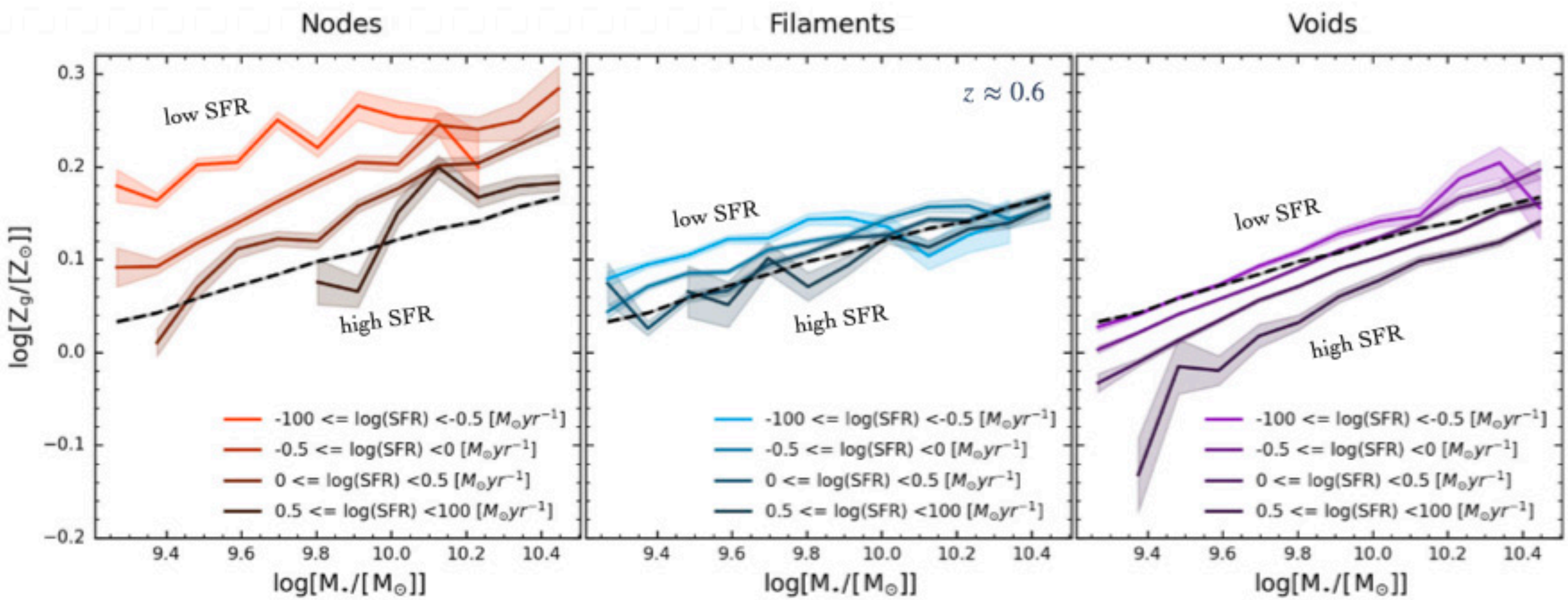
The metallicity scatter also depends on environment



Note: ρ_G around each galaxy is calculated from spherical hats within 3 cMpc

The environmental dependence of the mass-metallicity relation

What sets the scatter within each environment?



Figures from Rowntree et al. (2026a)

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Evolution of the MZR residual with time in different cosmic environments

The behaviour of the Z_g residual follows the assembly of large-scale structures as a function of time

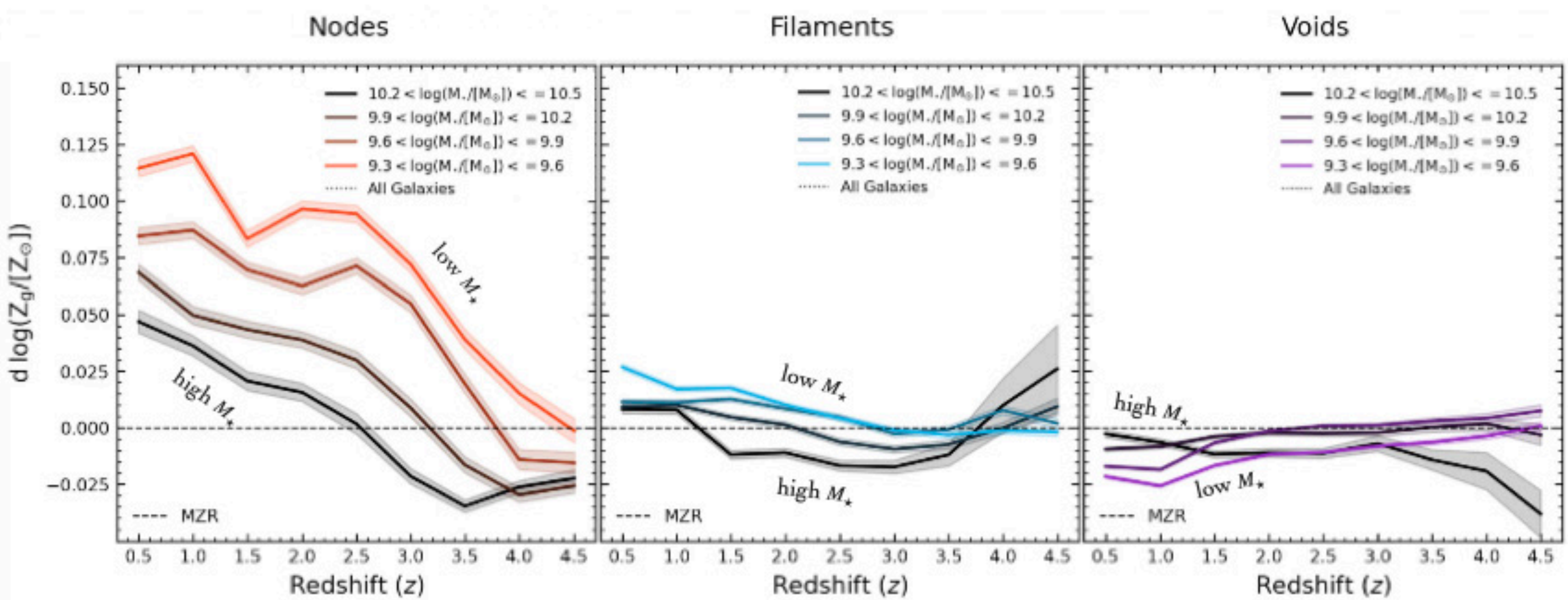
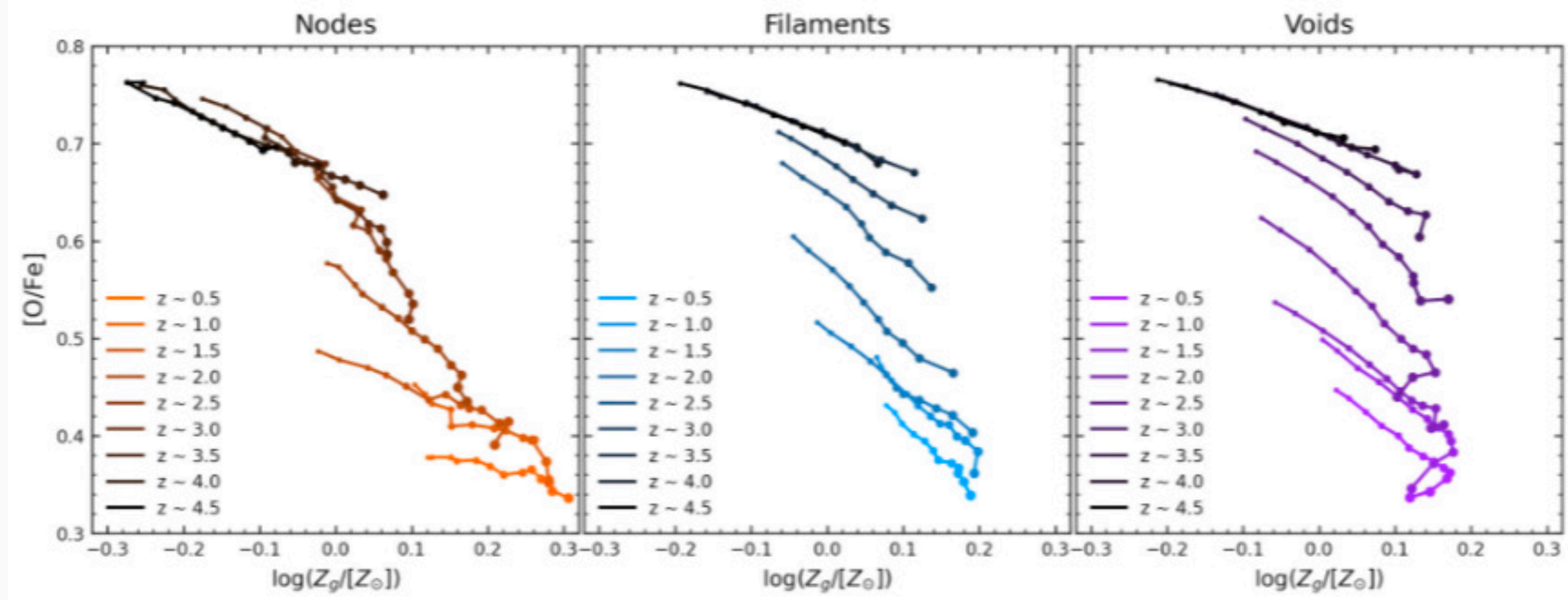


Figure from Rowntree et al. (2026a)

⟶ the location in the cosmic web leaves a chemical fingerprint

Evolution of [O/Fe] vs Z

Figure from Rowntree et al. (2026a)



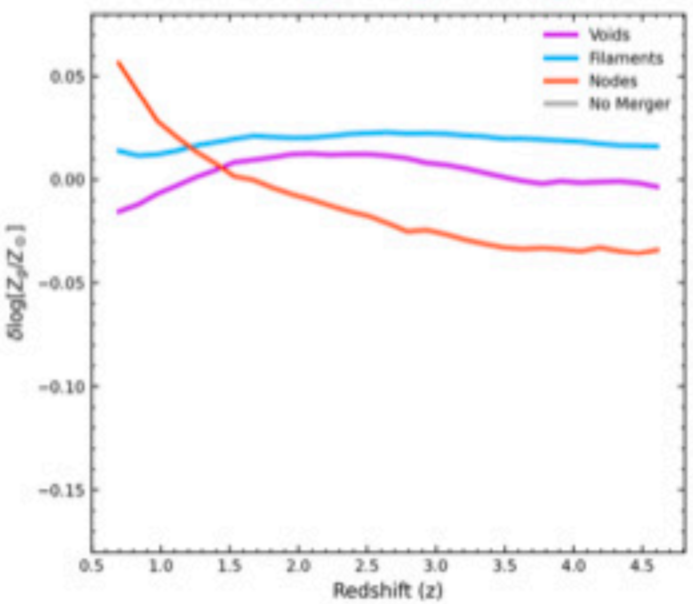
Colour: redshift **Point size: stellar mass**

In void galaxies, metallicity drops at $z \approx 2$ for the most massive objects
$\longrightarrow$ A direct signature of (revived) pristine gas accretion diluting the ISM
This pathway does not operate in nodes at lower z

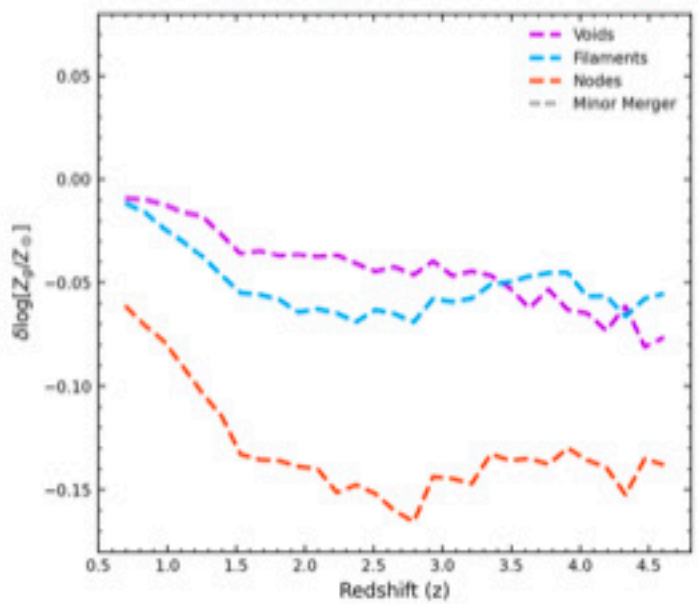
What drives chemical evolution in different environments with time?

Figures from Rowntree et al. (2026, in review)

No ongoing merger



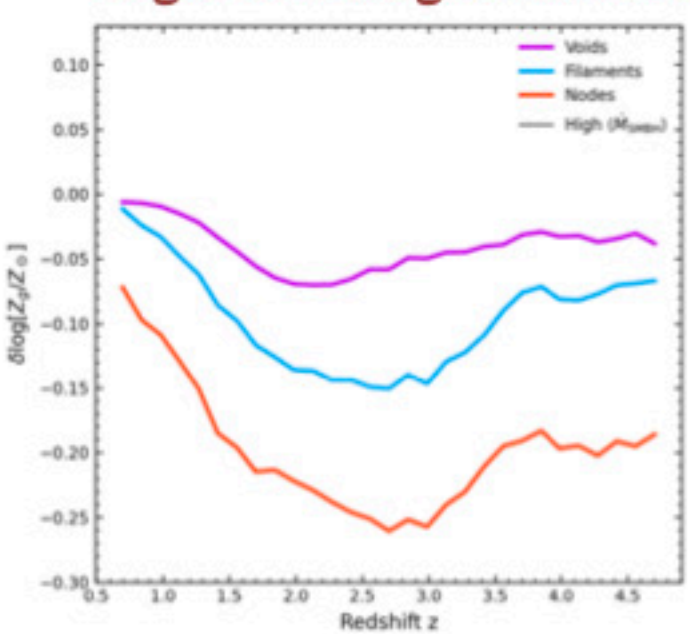
Undergoing minor mergers



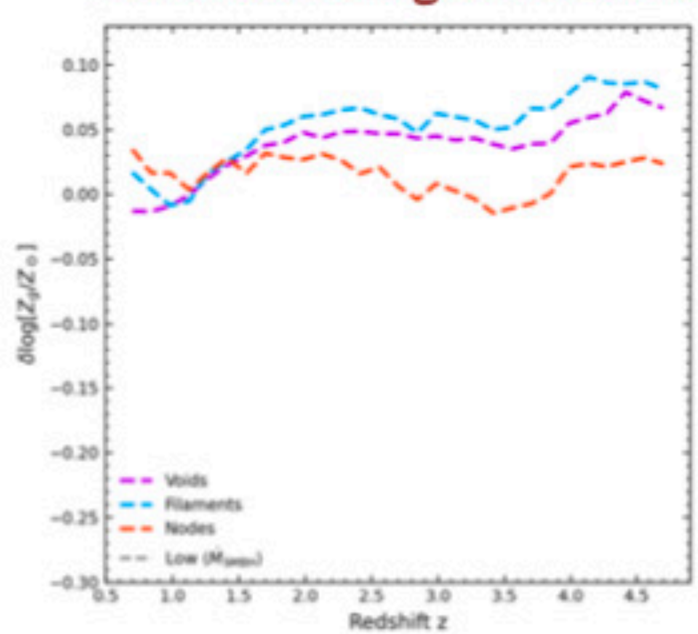
Minor mergers vs no ongoing mergers
⟹ more negative residuals (strongest in nodes)

Minor mergers act like accretion
of less chemically processed gas

High SMBH growth rate



Low SMBH growth rate



High vs low $\dot{M}_{SMBH}$
⟹ more negative residuals (strongest in nodes)

Driver: metal-rich AGN outflows

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Summary

Central theme — A galaxy's chemical evolution is also a fingerprint of its journey through the cosmic web

Where? — Denser environments $\longrightarrow$ more enrichment, more scatter

When? — Low-mass galaxies in nodes peel away first, the effect grows toward low z

How? — Star formation, gas accretion, minor mergers, metal-rich AGN outflows

Thank you, CCAPP, for 20 years!