From Cold Filaments to Hot Nodes: Protocluster Assembly Pathways at Cosmic Noon with Roman

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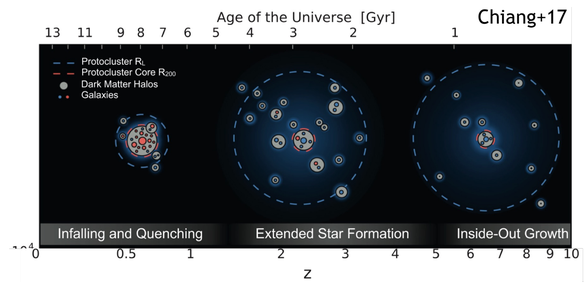
Abstract

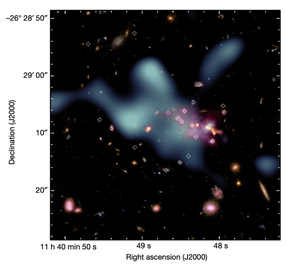
Massive protoclusters at z~2 are the progenitors of today's richest galaxy clusters, yet systems with comparable descendant halo masses show very different baryonic states, from cold IGM filaments and giant Lya nebulae to starburst-heated CGM and nascent thermal ICM. Does this diversity trace a single evolutionary sequence, or genuinely distinct assembly pathways? We address this question with the Roman CCS/HLWAS Deep tier, which delivers multi-band WFI imaging and G150 slitless spectroscopy over ~19 deg^2 of legacy fields. Automated 3D density mapping of bright tracers ([OIII] grism emitters, passive galaxies, and photo-z samples) is forecast to identify hundreds of protoclusters with descendant halo masses above 3x10^14 Msun at z~2-3. The same data then provide homogeneous diagnostics of metallicity, quenching, AGN incidence, morphology, and cosmic-web structure, onto which archival multiphase gas tracers can be registered, with benchmark systems such as Hyperion and Cl J1001 as anchors. Together, these public data enable a population-level test of how the most massive halos assemble at cosmic noon.

1. Single vs. Distinct Paths

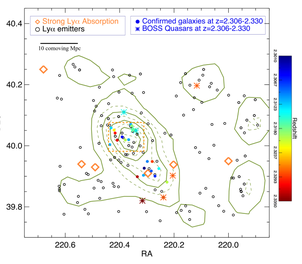
✦Protocluster (PC) evolution suggests a critical epoch at Cosmic Noon at z~2



✦ **Diversity** was revealed in the PCs: Forming heated intracluster medium (ICM) vs. Prinstine cold interfalactic medium (IGM)



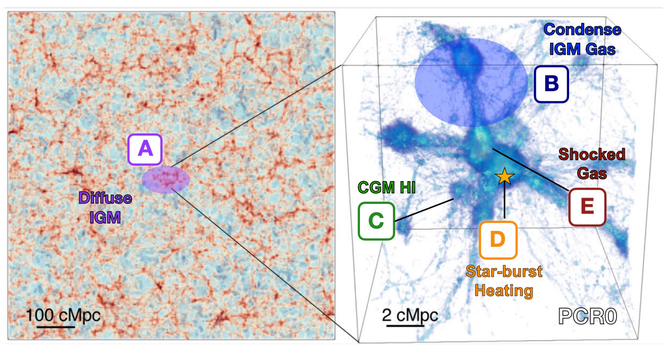
Di Mascolo+23



Cai+17

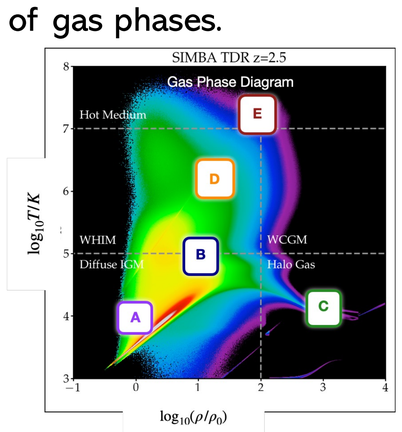
2. Gas-Phase Category

❑ Different gaseous reservoirs locate at diverse locations on distinct scales



Adapted from Yajima+2022

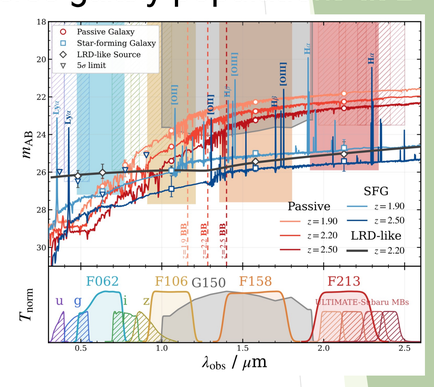
❑ These reservoirs spans a diversity of the stage of gas phases.



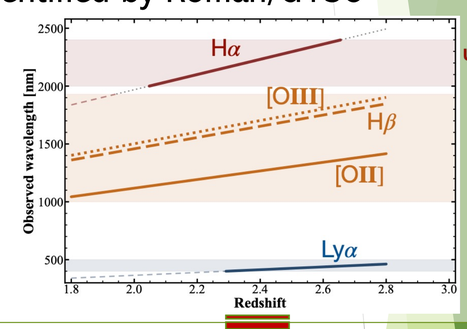
Cf. Dong+24

3. Wavelength Coverage

❑ WFI with Imaging + G150 can capture diverse galaxy populations at z~2-3



❑ Ground-based Subaru Imaging with upcoming HSC+ ULTIMATE Medium Band will recover the Lyα+Hα for SFGs identified by Roman/G150

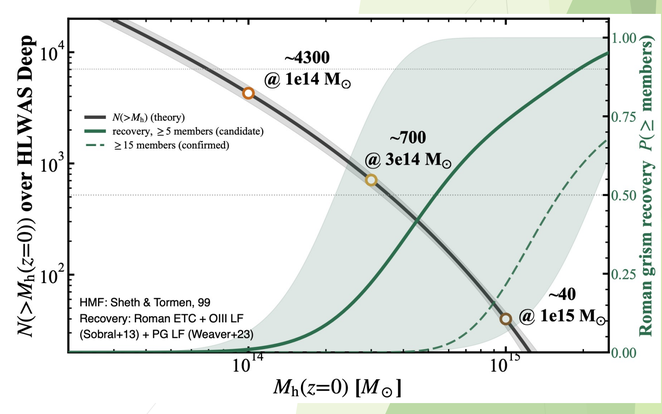


4. Number Evaluation

❑ The NUM of galaxies identified by Roman/WFI spectroscopically or photometrically in a single pointing

Target	*Selection*	Proxy	Limit	$N_{gal,PC}$/FoV	$N_{gal,all}$/FoV
O3E	[O III] emission	SFR ($M_\odot$ yr^{-1})	8.1	>165	~880
spec-PG	D_n4000	$\log(M_\star/M_\odot)$	10.97	>20	~120
phot-PG	BzK_{Roman} colors	$\log(M_\star/M_\odot)$	9.65	>135	~900
phot-z Gal	photo-z	m_{F213} (AB)	25.9	>2,350	~24,800

❑ The NUM of PC to be recovered by Roman/G150 selected [OIII] emitters over HLWAS Deep

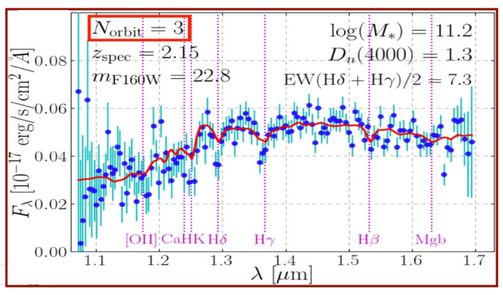


5. Spatial Trending of Galaxy Populations & Properties

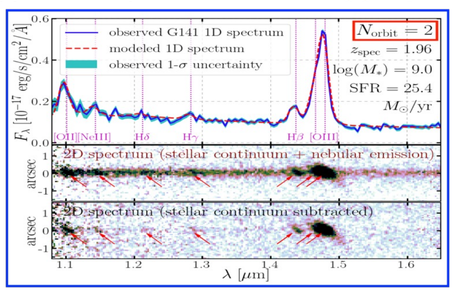
❑ ***Passive populations***: Dn4000 + Balmer absorption from stacked G150 spectra date the quenching epoch across each structure.

❑ ***Star-forming populations***: O23 metallicity index mapped along to cosmic nodes. filaments

(a) HST G141 Spectrum of a passive galaxy at z=2.15

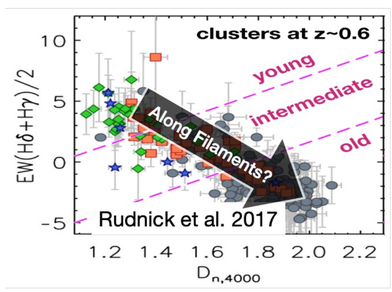


(b) HST G141 Spectrum of a star-forming galaxy at z~2



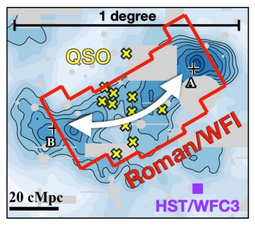
Observables: Dn4000 & Hδ+Hγ

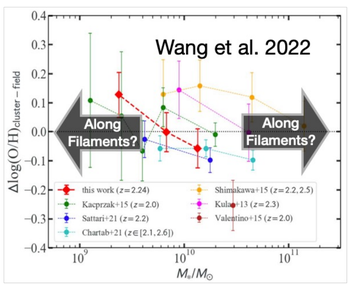
Observable: O23 index



(c) EW of Balmer absorption *vs.* Dn4000 diagram

An Overdensity Extending for tens of cMpc at z=2.2





(d) Metallicity offset in protocluster *vs.* field

❑ ***Diagnostics in Wide Area***: Different from the pointing diagnostics, spatial trending/gradient will reveal how galaxy-gas interplay evolves within individual structures.

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6. Summary & Future Aspect

1. ✦ **Census**: 3D density mapping of HLWAS Deep bright tracers ([OIII] emitters, passive and photo-z galaxies) identifies hundreds of PCs with > 3x10^14 Ms descendants at z~2-3.
2. ✦ **Diagnostics**: metallicity, quenching, AGN incidence, morphology, and cosmic-web structure measured homogeneously for every system.
3. ✦ **Gas registration**: archival multiphase tracers (IGM tomography, Lyα nebulae, X-ray/SZ) registered onto the galaxy-defined frame, anchored by Hyperion and Cl J1001.