Arxiv: 2109.07696

Spectroscopic Confirmation of a Protocluster at $z = 3.37$ with a High Fraction of Quiescent Galaxies

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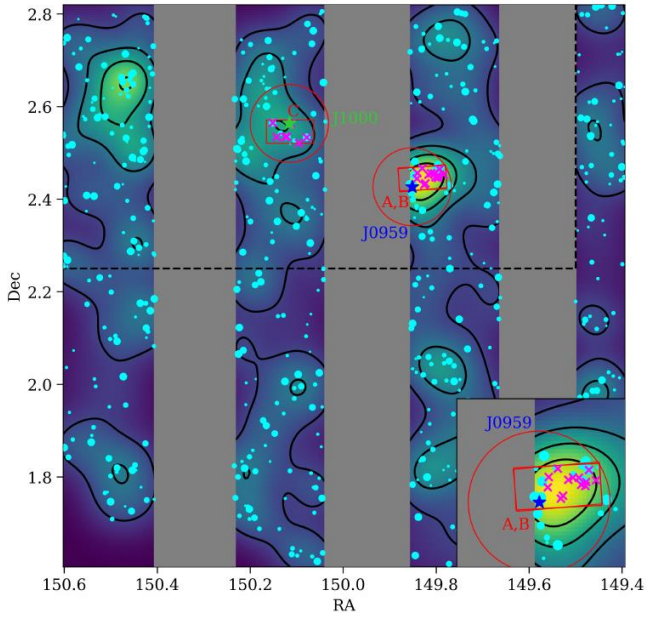
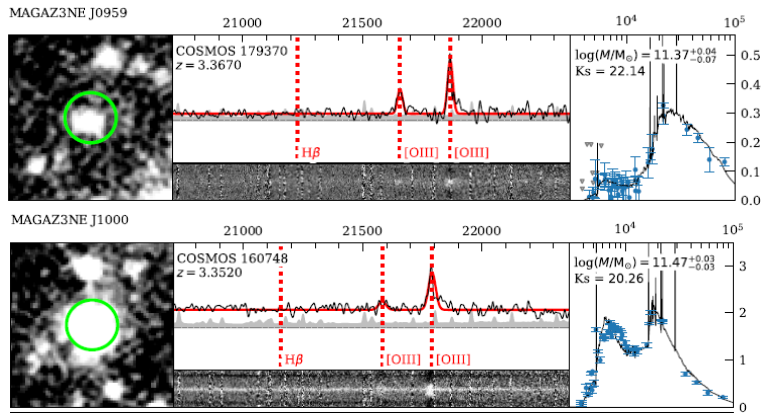
Abstract

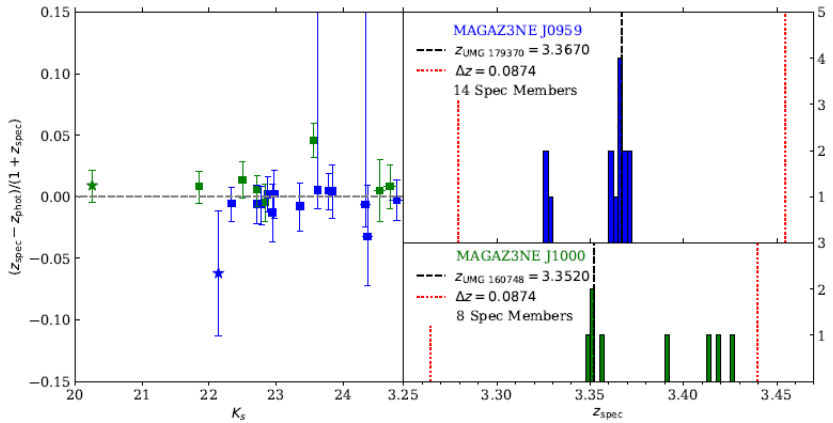
We report the discovery of MAGAZ3NE J095924+022537, a spectroscopically-confirmed protocluster at $z = 3.3665^{+0.0009}_{-0.0012}$ around a spectroscopically-confirmed UVJ-quiescent ultra-massive galaxy (UMG; $M_\star = 2.34^{+0.23}_{-0.34} \times 10^{11}$ $M_\odot$) in the COSMOS UltraVISTA field. We present a total of 38 protocluster members (14 spectroscopic and 24 photometric), including the UMG. Notably, and in marked contrast to protoclusters previously reported at this epoch which have been found to contain predominantly star-forming members, we measure an elevated fraction of quiescent galaxies relative to the coeval field ($73.3^{+26.7}_{-16.9}$% versus $11.6^{+7.1}_{-4.9}$% for galaxies with stellar mass $M_\star \geq 10^{11}$$M_\odot$). This high quenched fraction provides a striking and important counterexample to the seeming ubiquitousness of star-forming galaxies in protoclusters at $z > 2$ and suggests, rather, that protoclusters exist in a diversity of evolutionary states in the early Universe. We discuss the possibility that we might be observing either "early mass quenching" or non-classical "environmental quenching." We also present the discovery of MAGAZ3NE J100028+023349, a second spectroscopically-confirmed protocluster, at a very similar redshift of $z = 3.3801^{+0.0213}_{-0.0281}$. We present a total of 20 protocluster members, 12 of which are photometric and 8 spectroscopic including a post-starburst UMG ($M_\star = 2.95^{+0.21}_{-0.20} \times 10^{11}$ $M_\odot$). Protoclusters MAGAZ3NE J0959 and MAGAZ3NE J1000 are separated by 18 arcminutes on the sky (35 comoving Mpc), in good agreement with predictions from simulations for the size of "Coma"-type cluster progenitors at this epoch. It is highly likely that the two UMGs are the progenitors of Brightest Cluster Galaxies (BCGs) seen in massive virialized clusters at lower redshift.

"Massive Ancient Galaxies At z > 3 NEar-infrared" → Finding UMGs
Accidentally identified two proto-clusters system around UMGs:
MAGAZ3NE J095924+022537 (COS-DR3-179370, AGN)
MAGAZ3NE J100028+023349 (COS-DR3-160748, PSB galaxy)



Two K-band masks (A and B, **14 objects**) centered on UMG 179370 were observed in November 2017 and one K-band mask (C, **8 objects**) centered on UMG 160748 was observed in March 2019.

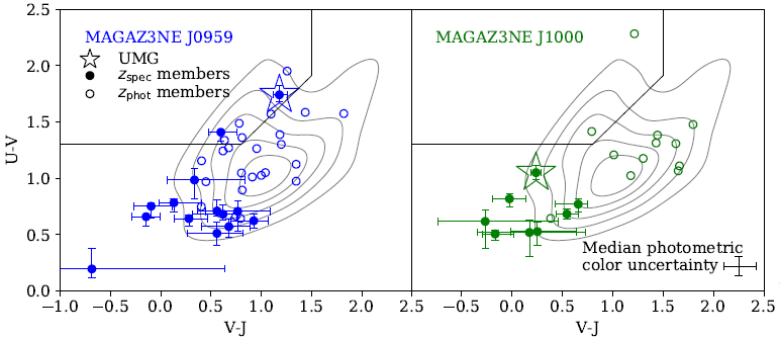




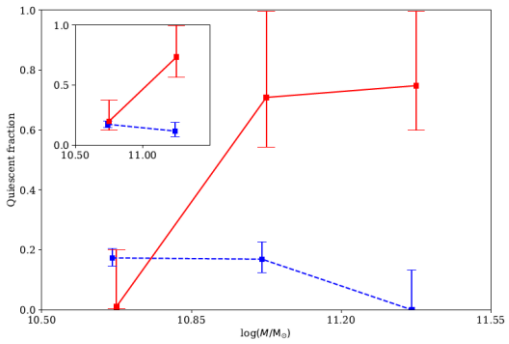
SED fitting: EAzY + FAST, exponentially-declining SFH;
Very good consistence between z_{spec} and z_{phot}
→ $|z_{spec} - z_{phot}|/(1 + z_{spec}) = 0.0058$

Red dashed lines: with line-of-sight velocities within $\pm$ 6000 km/s, usually used to determine spectroscopic membership for other high-redshift protoclusters

Parent sample selection: galaxies at $3.167 < z_{phot} < 3.567$ within $K_s < 24.5$ and $logM_* > 10.5$
→ 550 galaxies in COS-DR3 catalog
Photometric membership: galaxies within a radius of 10 comoving Mpc from UMG. (24+14 additional objects)



UVJ diagram:
MAGAZ3NE J0959: UMG179370 and another spectrum confirmed galaxy $logM_* > 10.5$ are in quiescent region.
MAGAZ3NE J1000: UMG 160748 experience rapid star formation quenching → blue UVJ colors
Quiescent Fraction of MAGAZ3NE J0959 and Field (contour in UVJ diagram) are based on UVJ diagram



The existence of such a high QF in MAGAZ3NE J0959 is contrast to the many known proto-clusters which are filled with star-forming galaxies.

Proto-clusters exist in a diversity of evolutionary states in the early Universe, and that some systems have quenched early.
The mass-dependent environmental quenching
→ "early mass quenching"

UMGs are progenitors of Brightest Cluster Galaxies (BCGs)
A halo of total mass equal to about $10^{13} M_\odot$
BCGs form most of their stars early, with most assembly at late times occurring via mergers/accretion.

The Extended Forming two Proto-clusters:
Close to each other (a physical separation of 7.95 Mpc at z = 3.37), evolve into a "Coma"-type (or even more massive) cluster by the present day.