



#### A galaxy cluster caught right after birth at z = 2.50—unveiling a key phase of massive cluster formation

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## Outline

- Introduction
- Discovery of a galaxy cluster at z = 2.50
- Unique properties of the structure and its member galaxies
- Its implications on our understanding of galaxy and cluster formation

## Why hunting for galaxy clusters (protoclusters) at z > 2: structure formation



Harrison et al. 2013

The most massive progenitor of a present-day Coma-like cluster (M\_200 >  $10^{15} M_{\odot}$ ) reached  $10^{14} M_{\odot}$  at z ~2.

#### Why hunting for galaxy clusters (protoclusters) at z > 2: environmental effects on massive galaxy formation



environmental effects on star formation and quenching

#### Why hunting for galaxy clusters (protoclusters) at z > 2: environmental effects on massive galaxy formation



z~2 Strazzullo+2013 environmental effects on structural properties (size evolution): accelerated evolution

### Two types of high-z structures

#### mature clusters: a massive collapsed halo concentration of ellipticals

### protoclusters:

low galaxy densities multiple (less massive) halos



### How to identify high-z structures: overdensities of massive galaxies



HIEROs: H - [4.5] > 2.25

Wang et al. arxiv:1512.02656



Wang et al. arxiv:1512.02656

# The most significant overdensity of massive galaxies (DRGs, 2 < z < 3) in COSMOS



### One of the brightest Herschel/SPIRE sources



# A remarkable concentration of massive galaxies at z = 2.50



#### Wang et al. submitted

### Evidence of a massive halo: cluster-like mass density profile



### Evidence of a massive halo: extended X-ray emission



$$M_{200} \sim 10^{13.9 \pm 0.2} M_{\odot}$$

### Properties of member galaxies



#### ALMA 870 um + IRAM-NOEMA CO[5-4]



Combined SFR~3400M⊙ yr^-1 in the central 80 kpc, with a gas depletion time~200 Myr



### mass-size relation



# cosmological context



Millennium simulation

Casey+2015



The probability of finding one halo with M200 > 1(0.5)e14 Msun at z > 2.5 in COSMOS is 0.01(0.3) with Planck cosmology (twice lower with WMAP 7 cosmology)

# Conclusions

The structure unveils a key phase of massive cluster formation (with both a cluster-size halo and vigorous star formation), bridging the gap between mature clusters and young proto-clusters. Its unique properties shed light on some of the most fundamental questions on cluster(and member galaxies) formation

- Cluster ellipticals form through short, vigorous star formation.
- Most of them only stop forming stars after having been accreted into a cluster-size halo, providing constraints on the effects of "pre-processing" mechanisms
- Cluster ellipticals are born compact.
- More follow-ups: CO[1-0] (JVLA), CO[3-2] (IRAM-NOEMA), and NIR spectroscopy(KMOS)