Proto-groups at 1.8<z<3 in zCOSMOS-deep

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The epoch at z~2 is when the universal star formation rate reaches its peak and the first massive structures appear. The emerging group environment may start to influence its member galaxies. We constructed a catalogue of 42 proto-groups from the spectroscopic zCOSMOS-deep survey and study the properties of these associations in both a dark matter simulation and, observationally, in comparison with the galaxy field population at z~2.

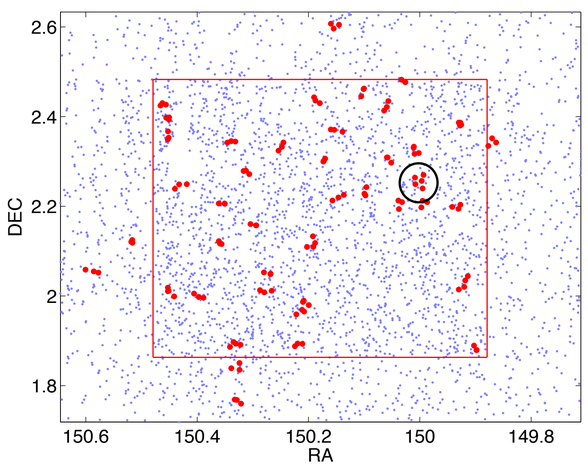
zCOSMOS-deep

Large spectroscopic survey (VLT/VIMOS), observing BzK and ugr selected galaxies. This targets star-forming galaxies at z>1.4 (Lilly et al. 2014, in prep.)
- Covering a 0.92x0.91deg area in the COSMOS field with a central, densely sampled 0.6x0.62deg region
- Sampling rate: 50% (central area)
- Spectroscopic redshift error: dv=300km/s
- ~3500 galaxies at 1.8<z<3 with reliable redshifts

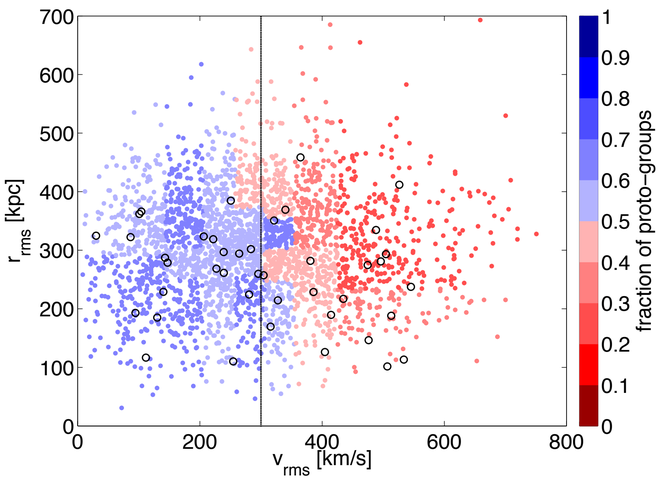
Group-finding algorithm

The ~3500 tracer galaxies with spectroscopic redshifts and the 50% sampling rate of zCOSMOS-deep allow a FOF group-finder
- Calibrated with Kitzbichler et al. (2007) mocks
- Linking lengths: dr=500kpc and dv=700km/s
- Resulting in 42 candidate (proto-)groups with richnesses N=3-5
- Quality assessment: The smaller the spread in velocity of the candidate (proto-)groups the less interlopers, i.e. wrongly identified members, they have

Diener et al. 2013, ApJ, 765, 109



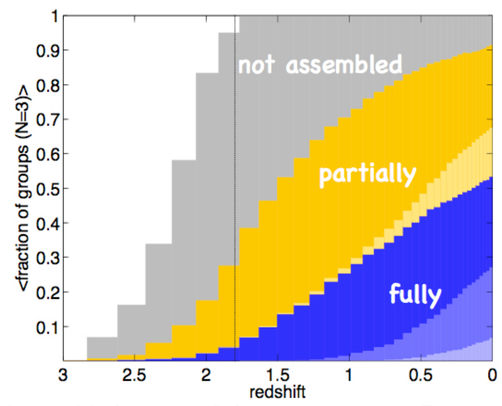
The 42 zCOSMOS-deep candidate groups. Most of them are triplets. The red square shows the central, more densely sampled area of zCOSMOS-deep. The black circle indicates the position of a z=2.45 proto-cluster (see below).



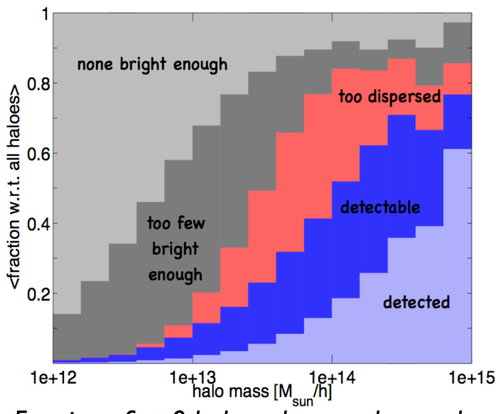
Fraction of pure proto-groups in the mocks as a function of their radial size (r_{rms}) and velocity spread (v_{rms}). Clearly the purity is a function of v_{rms}. This can be used as a quality criterion. The 42 observed proto-groups are shown in black.

Are these groups? A story in simulations

Through comparison with the Millennium mocks we examine the found structures and their future fate:
- Most associations are not yet assembled at the epoch of observation, but the vast majority will become groups by z=0. This means that their member galaxies will occupy the same DM halo. We are therefore observing "proto-groups" in the process of assembling into groups
- We detect a representative fraction of todays $>10^{14}M_{sun}/h$ mass clusters already at z~2



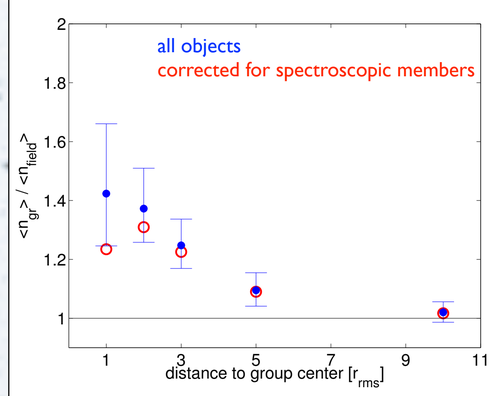
Assembly history of the proto-groups: Fraction of assembled (in blue and yellow) structures as a function of redshift. When observed most proto-groups are not assembled. They undergo the assembly process to z=0 when >90% of them become groups with their members occupying the same DM halo.



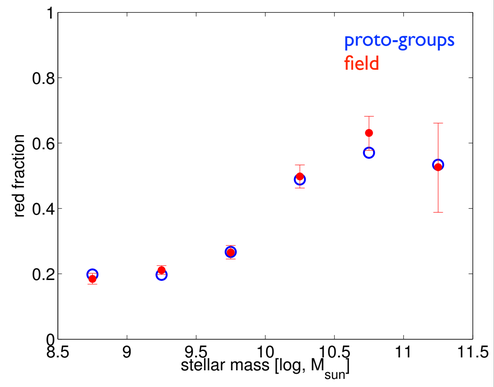
Fraction of z=0 haloes that we detect already at z~2 (blue). A representative fraction of the highest mass haloes are detectable and catalogued in our sample. Not all haloes are detectable as they are inhabited by galaxies that are too faint to meet the zCOSMOS selection criterion (grey).

Galaxy population

Search for an environmental differentiation in proto-groups:
We use a photo-z sample due to the limitations of the colour-colour selected zCOSMOS-deep survey
- Proto-groups are also confirmed as overdensities in the photo-z sample
- No hint for environmental differentiation: The red fraction for the proto-group galaxies and the field galaxies is the same at all stellar masses



The proto-groups in the photo-z sample. There is a clear excess of galaxies in the photo-z sample at the proto-group positions (up to $3r_{rms}$). Away from the proto-groups the galaxy density approaches field density.

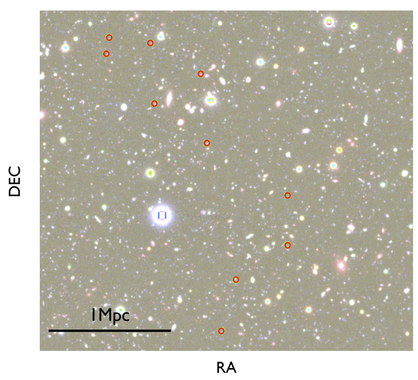


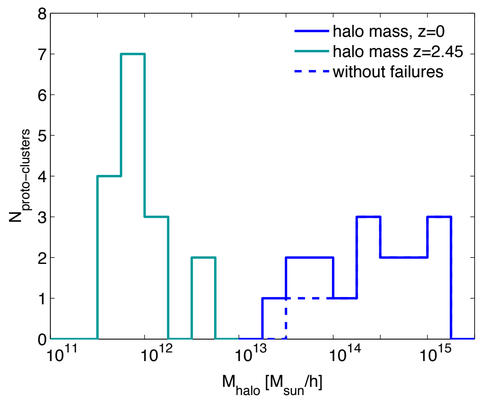
Red fractions in the proto-groups (blue) and the field population (red). These are consistent with each other at all stellar masses, meaning that we detect no sign for environmental differentiation.

Proto-cluster at z=2.45

- Discovered in a VLT/FORS2 follow-up of 5 of the zCOSMOS-deep proto-groups
- So far 11 spectroscopically confirmed members within r=1.4Mpc and dv=700km/s
- Likely not assembled, but will evolve into a very massive z=0 cluster

Diener et al. 2014, in prep.





Left: The proto-cluster members (red) in a Subaru RGB image.

Right: The evolution of the halo masses of the proto-cluster counterparts in the Henriques et al. (2012) mocks. Whilst at z=2.45 the candidate member galaxies occupy rather unremarkable haloes of $\sim 10^{12}M_{sun}/h$, the proto-clusters will evolve into the most massive clusters by z=0.