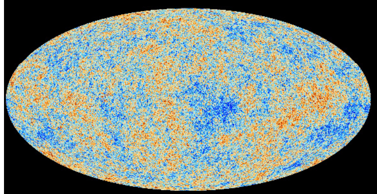
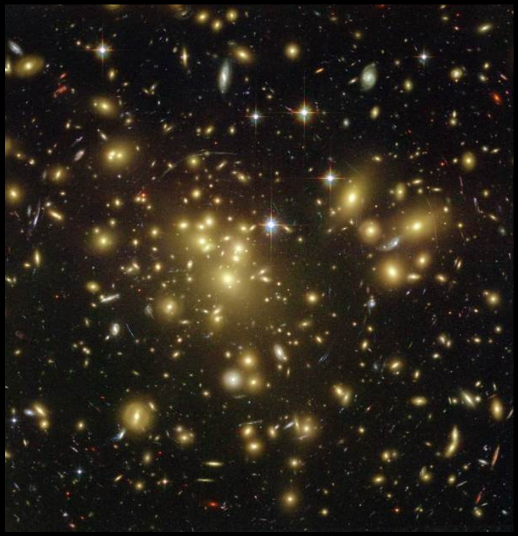
An Exploration of High-ρ at High-z: First Results from the VIMOS Ultra-Deep Survey

Brian C. Lemaux and the VUDS Team

LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE



?



z=1100

z=2-6

Very few known…
Toshikawa et al. 2012
Hatch et al. 2011 (RG)
Lemaux et al. 2009
Kang & Im 2009
Miley et al. 2006 (RG)
Ouchi et al. 2005
Capak et al. 2011 (RG)

z=1.5-2

10's confirmed
Stanford et al.
Papovich et al.
Henry et al.
Gobat et al.
Tozzi et al.
Andreon et al.

z~0.8-1.5

~100 confirmed
EDisCS
ORELSE
GCLASS

z<0.8

1000s confirmed
MCXC
SDSS
IMACS Cluster Survey
GAMA

The number of combined redshifts for the LSSs at z>2 to date is of order ~200…

Some Motivation

Why study large scale structures at high redshift (z~2-6)?

- Epoch of formation for massive ellipticals, should be able to observe the first seeds of nascent galaxy clusters as traced by the galaxies themselves.

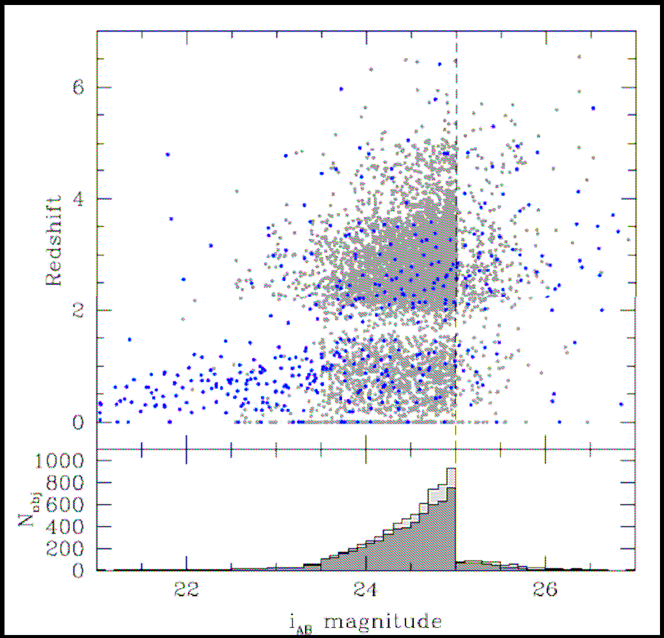
- Reversal of the SFR-density/color-density relationships. This almost certainly happens as the redshift of observation increases. May have been already observed (e.g., Tran et al. 2010), but galaxies in z>2 clusters should be *extremely* active.

- Already seeing environmental quenching at these redshifts? If so, what causes it?

How to find them?

- X-Ray Observations: Unlikely. Surface brightness dimming is painful at these redshifts. Time enough to form ICM?
- Sunyaev-Zeldovich Observations: Unlikely. Surface brightness dimming not a problem (apparently?), but still have the problem of no hot ICM
- Galaxy Red Sequence Densities: Universe is only 1.5-2.5 Gyr. Transition to the RS takes ~ 1 Gyr
- Photo-zs: Can be used as supplemental evidence, but as primary evidence they are suspect. Lots of issues with purity, completeness, and known and unknown biases
- Spec-zs: Great!…if you have enough. So…

The VIMOS Ultra Deep Survey

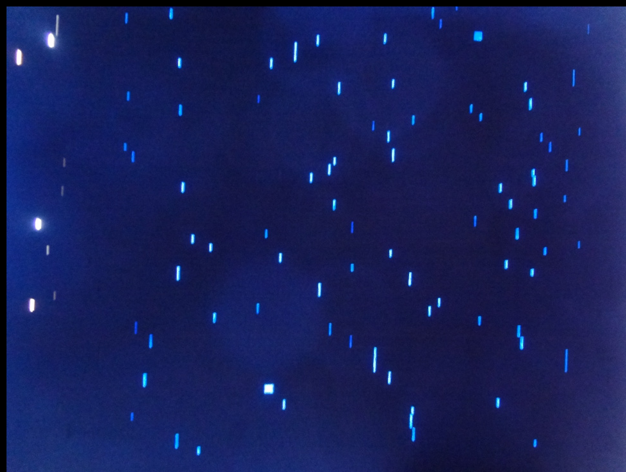


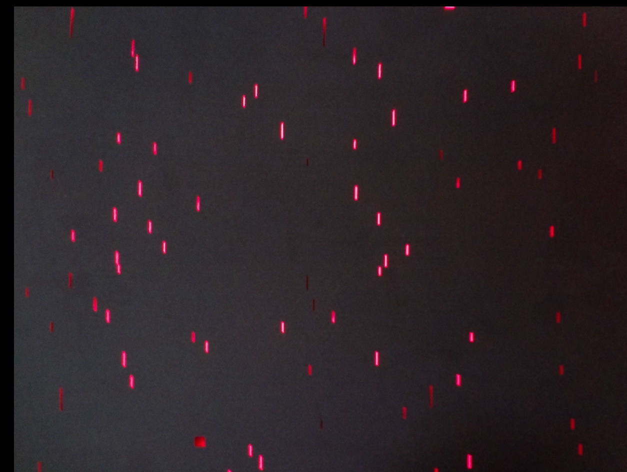
Targeted ~10000 Objects in 1 deg^2 over three fields (CFHTLS-D1, ECDFS, COSMOS), all with >= 10-band imaging

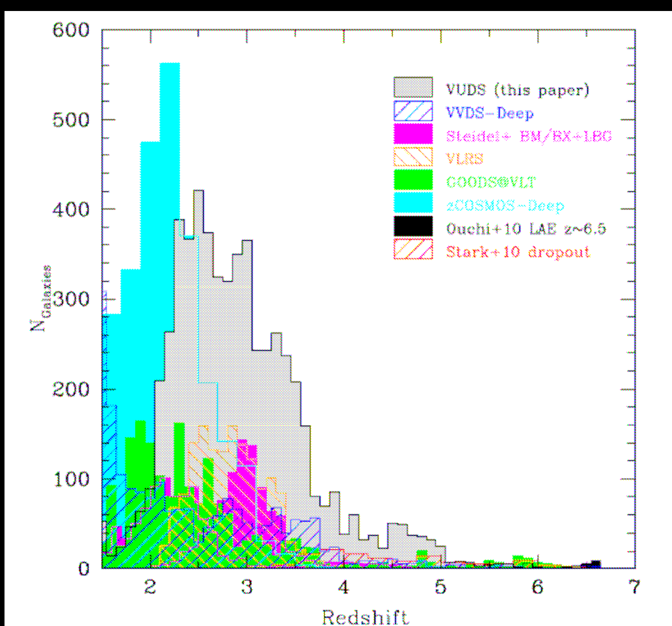
Mostly photo-z+magnitude with some color cuts

Peak of the magnitude distribution at i´=25.

The VIMOS Ultra Deep Survey



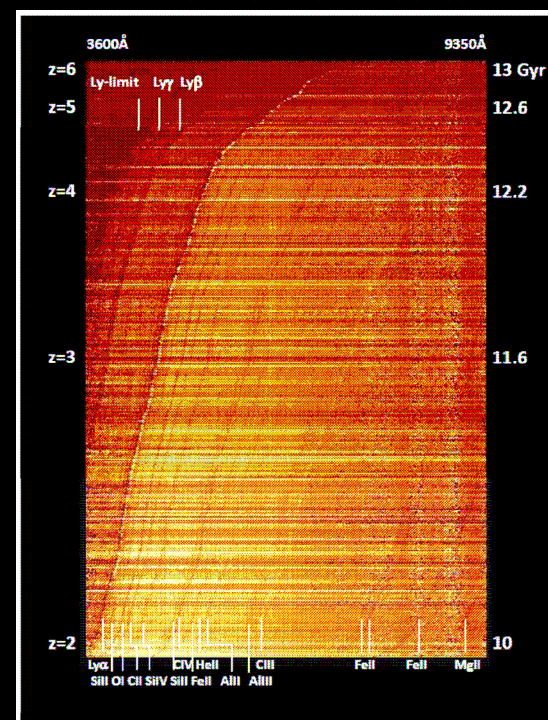




14 h exposure time in blue and red VIMOS grisms, per grism

Typical wavelength Coverage 3800-9400Å, R~230
⇒Low-Resolution Spectroscopy

It worked!

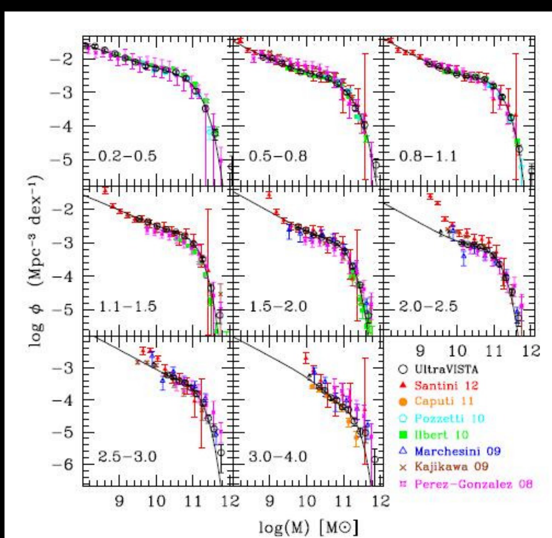


A Journey Through Space and Time

Methodology:

- Step 1: Get a lot of redshifts at z>2
- Step 2: Step through redshift slices of Δz~0.1 from z=2-5. Generate spectral density images
- Step 3: Iterate around redshift slice bounds. Search for $\geq$ 7 concordant galaxies within 2 h_{70}^{-1} Mpc and $\Delta\chi < 25\ h_{70}^{-1}$ Mpc
- Step 4: Supplement with photo-z information (density maps)
- Step 5: Calculate luminosity- and unit-weighted centers and velocity dispersions
- Step 6: Compare galaxies in different environments…?

Filter Choice…?

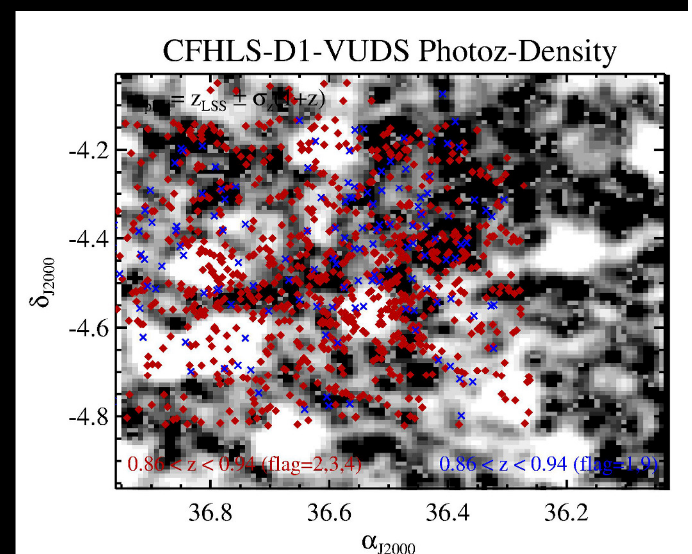


Ilbert et al. 2013

Co-moving distance is a wonderful metric if you want to compare progenitors of galaxies attached to the Hubble flow, but is it proper to use here?

Cluster science done using proper distances since gravity acts over those scales

A galaxy at ~1000 km/s reaches the center of the filter in ~10 Gyr

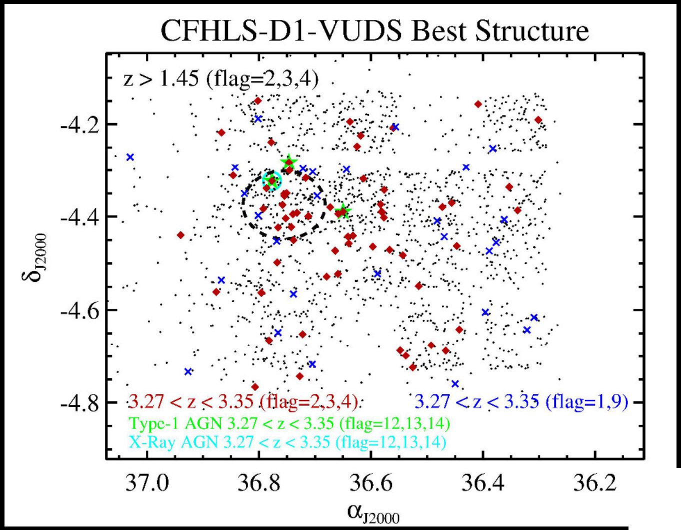


A Journey Through Space and Time

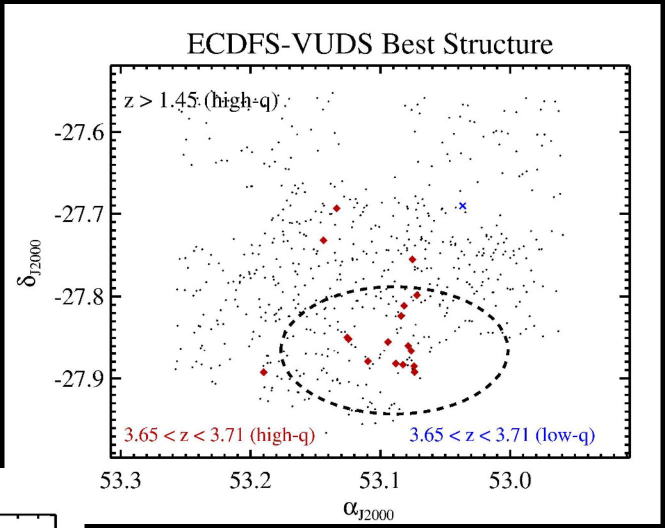
Did I find anything?

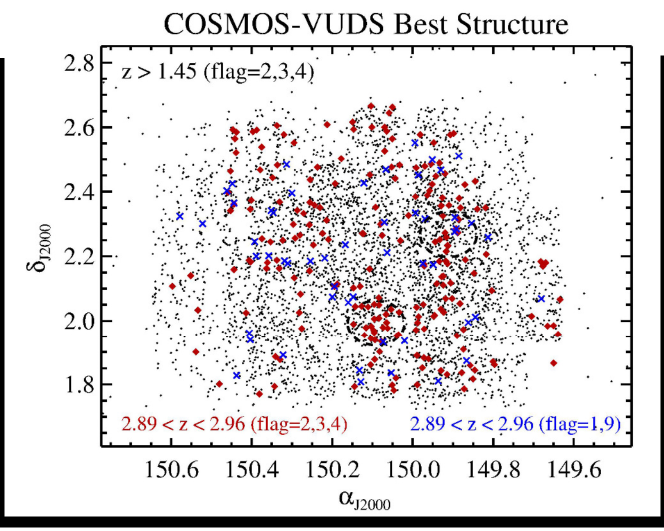
Yes! To date:

- 14 “protostructure candidates” in the CFHTLS-D1 field
- 21 protostructure candidates in the COSMOS field
- 7 protostructure candidates in the ECDFS field



Lemaux et al. 2014





Cucciati et al. 2014

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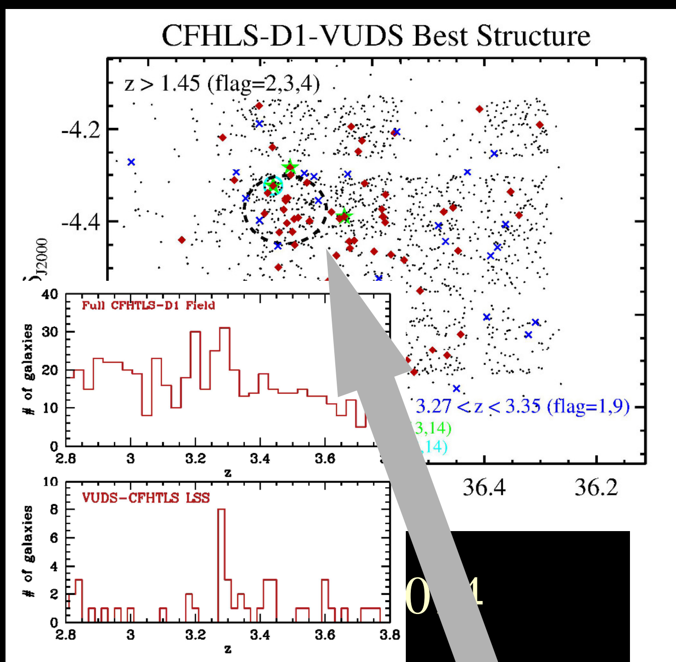
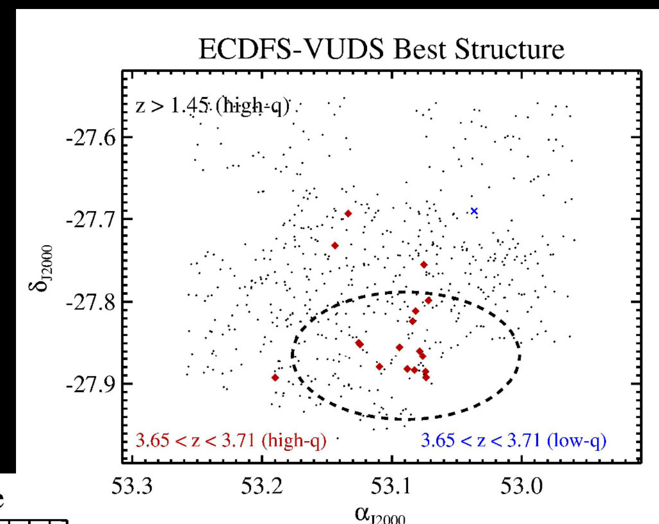
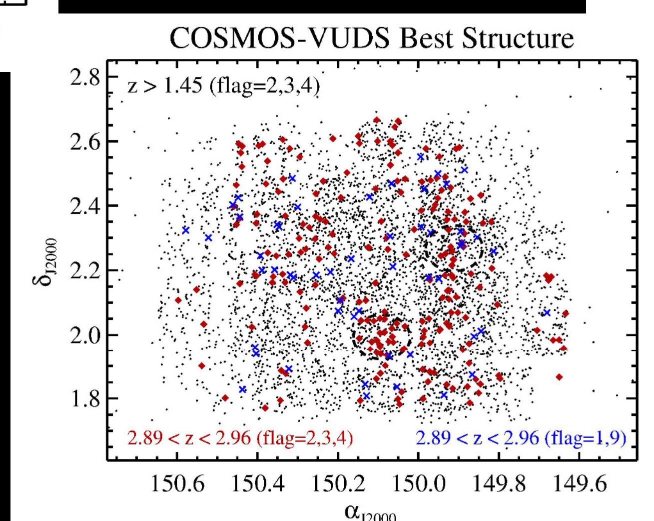


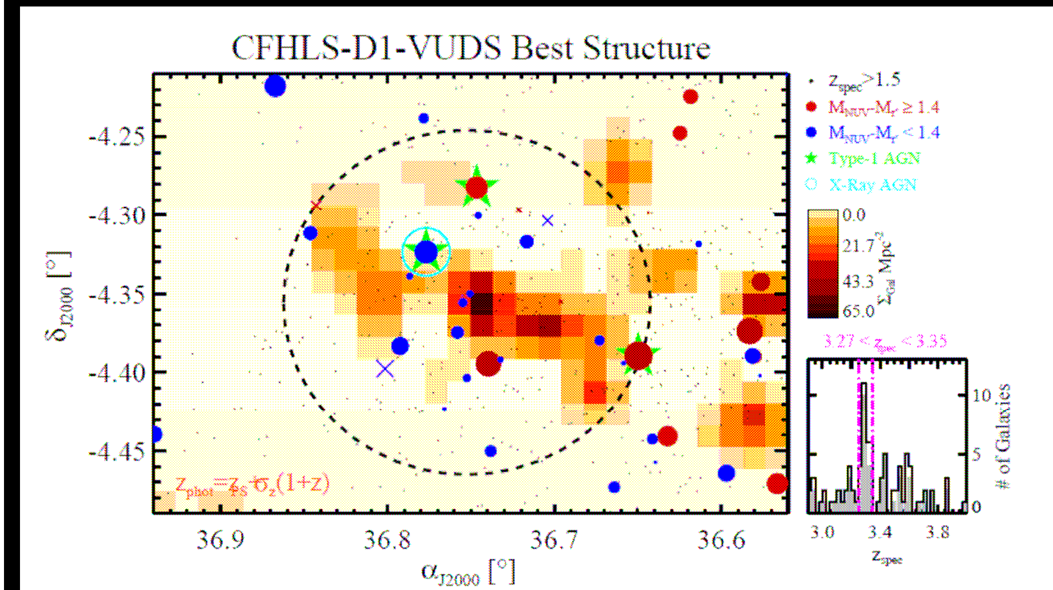


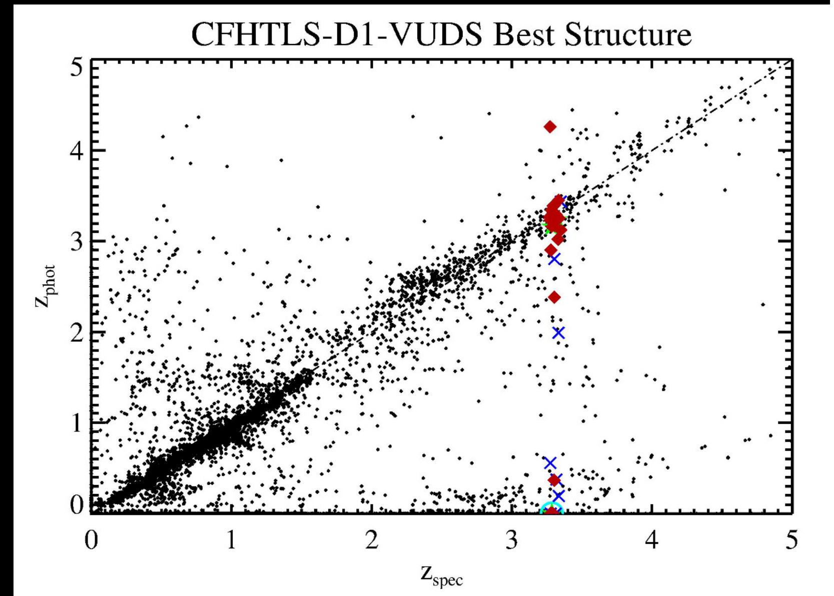
The journey begins here



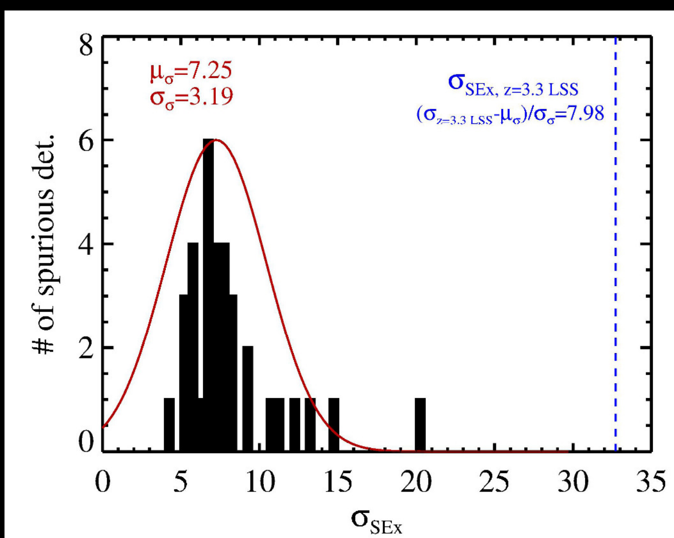
Cucciati et al. 2014

How to Characterize an "Overdensity"?

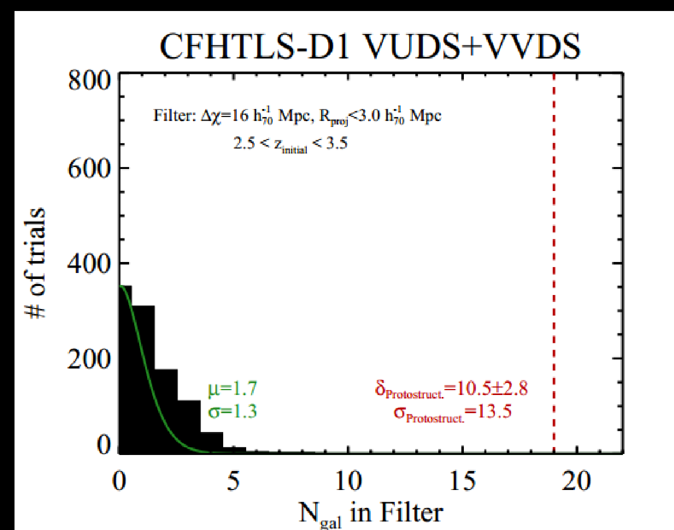




Through photometric redshifts?



Through spectral redshifts?



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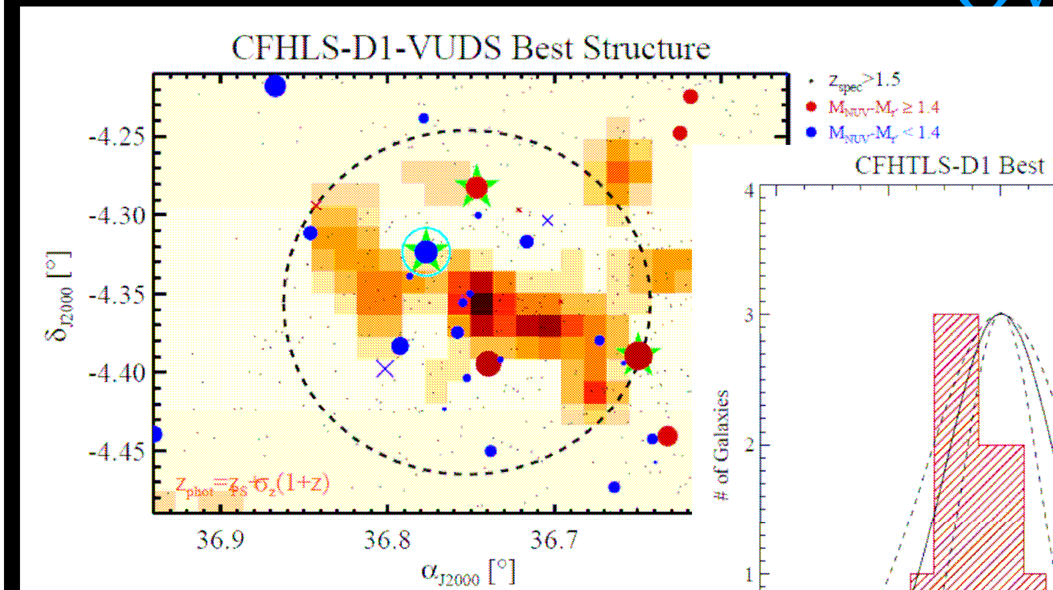

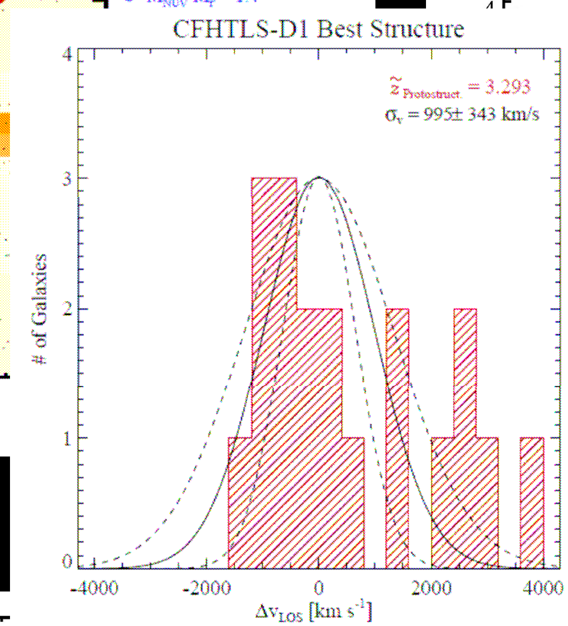

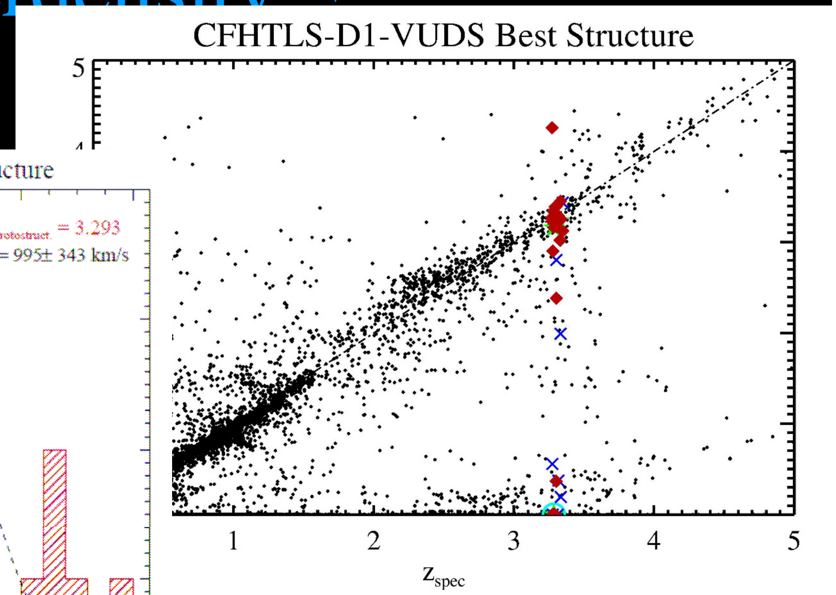

Through photometric redshifts?

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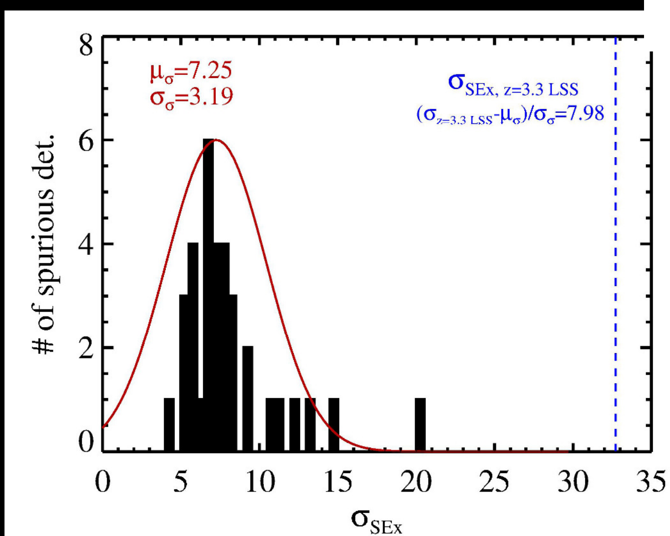
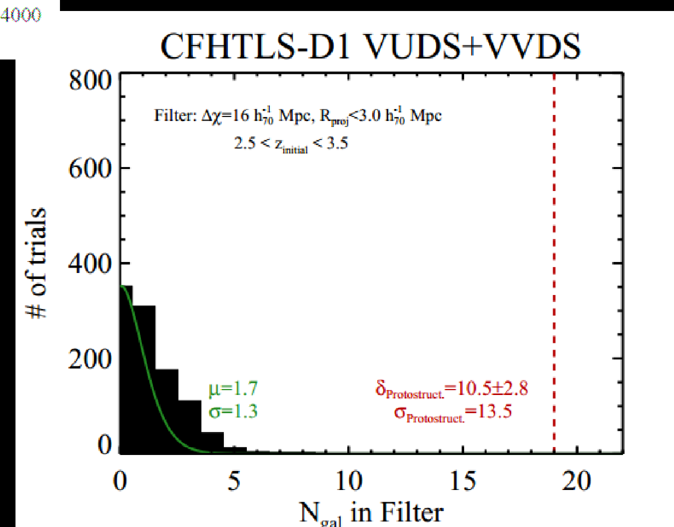


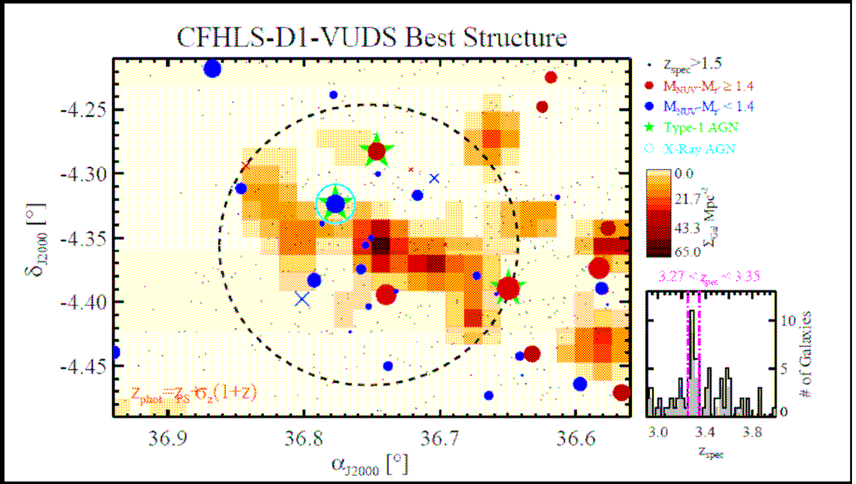
A variety of methods were used to attempt to constrain the halo mass:
$M_{z=3.3}$~$3x10^{14}$ $M_\odot$
$M_{z=0}$~ $4x10^{15}$ $M_\odot$

σ_v = 995 ± 343 km/s
N_{gal}=19
but…



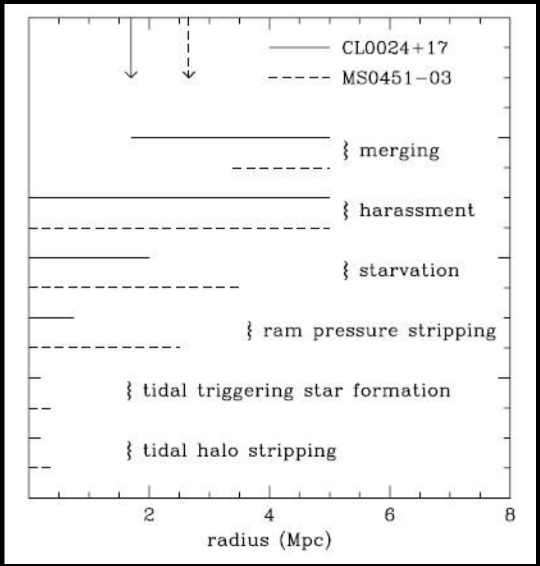
But you don’t make friends with salad…

The Meat:



It doesn’t REALLY matter what these protostructure candidates are. What matters is they are overdense with respect to the “field”.

Environmental effects can act over a large range of distances and galaxy densities. We should be able to observe differences amongst galaxy properties, but which ones?



Moran et al. 2007

Metrics which are traditionally available at lower redshift are largely absent or untested at high redshift:

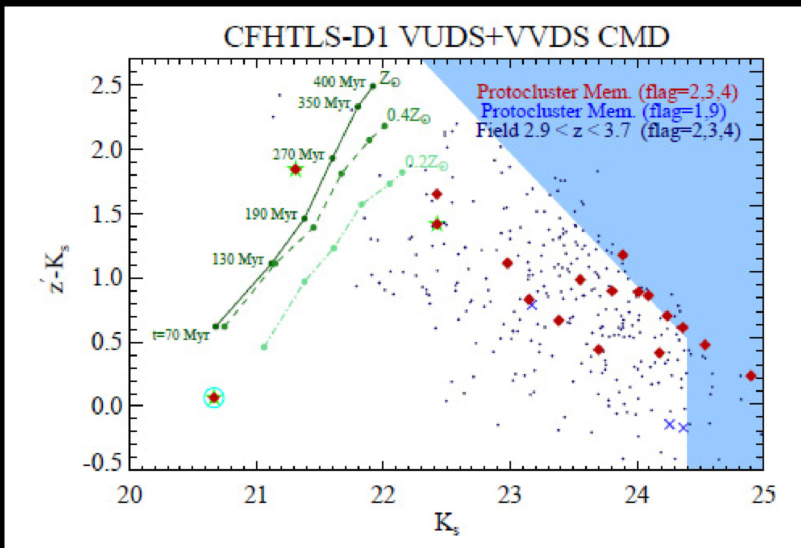
- Does SED fitting work well for high redshift objects?

- What parameters can be trusted? What limitations do they have?

- What physical properties can be determined from spectra?

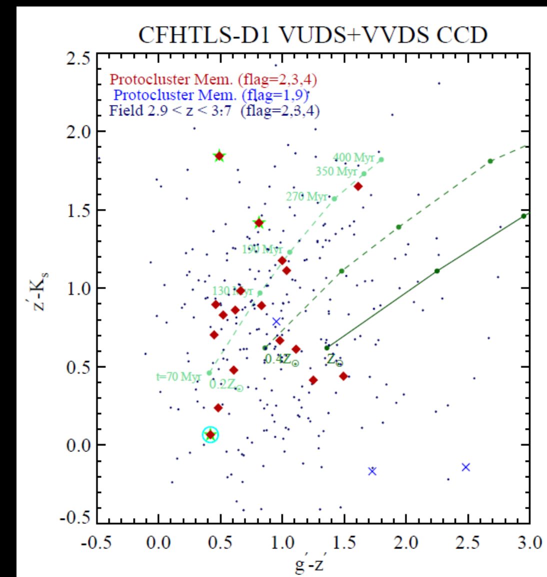
Environmental Effects?

- A pilot study with the members of ClJ0227-0421, membership $R_{proj} < 3\ h_{70}^{-1}$ Mpc, $3.27 < z < 3.35$
- Field sample is defined over the extended redshift range $2.9 < z < 3.7$, but same median redshift



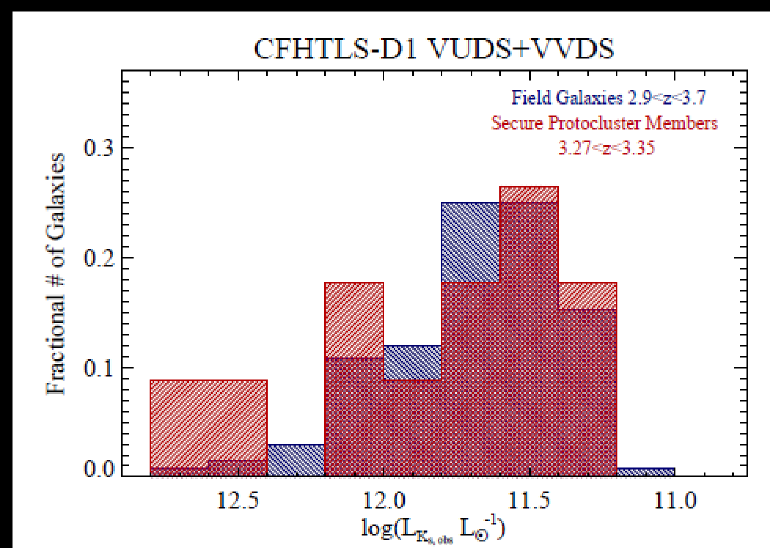
Beginning with observed quantities…

…and adding some level of sophistication



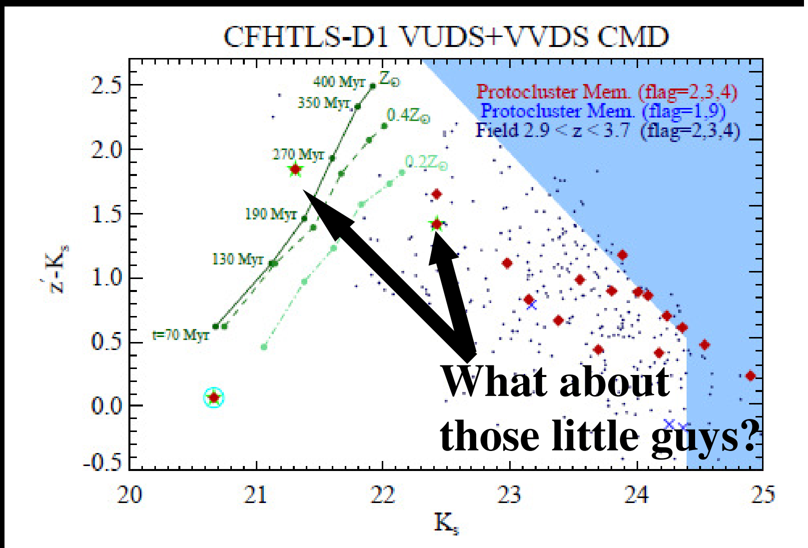
There appears to be an excess of brighter and generally redder galaxies within the protocluster bounds, but how to characterize these galaxies?

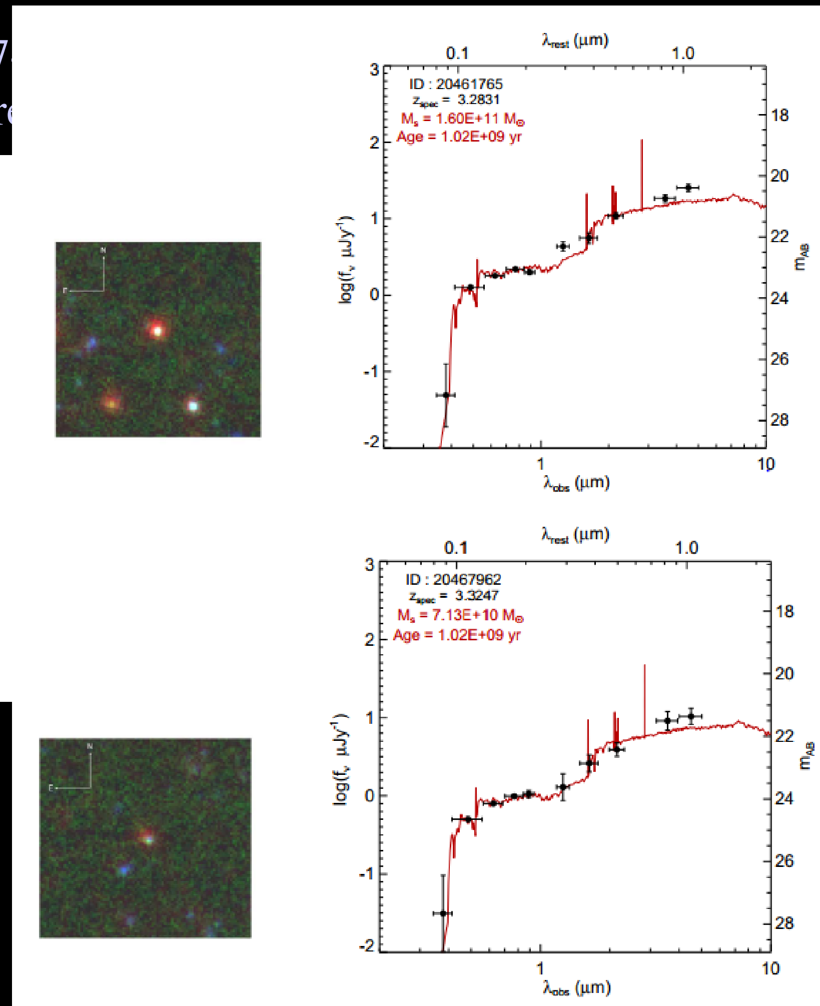
Would like to use SED fitting, but…

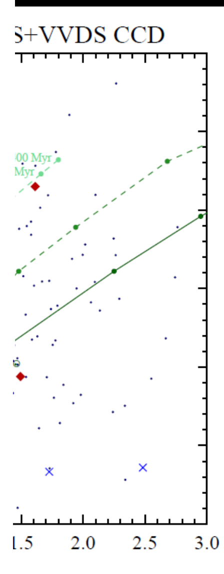


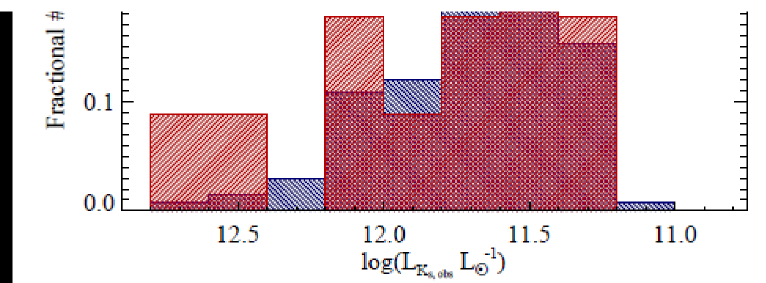
Environmental Effects?

- A pilot study with the members of ClJ0227 … z < 3.35
- Field sample is defined over the extended r … redshift









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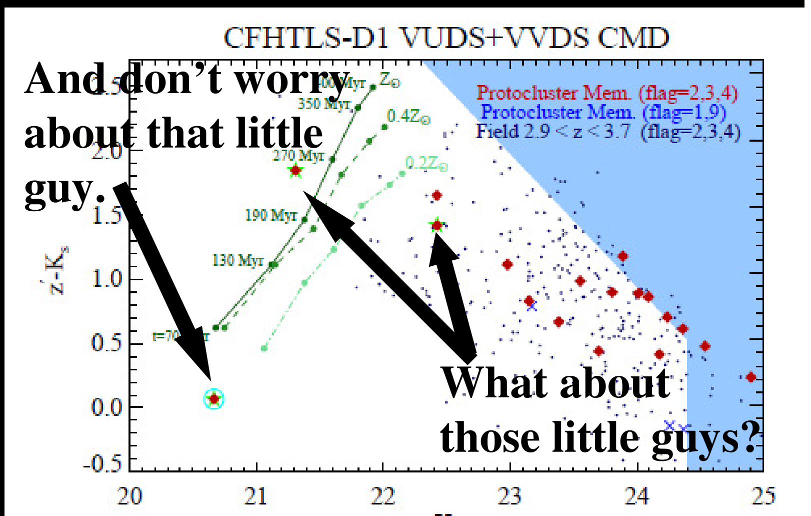
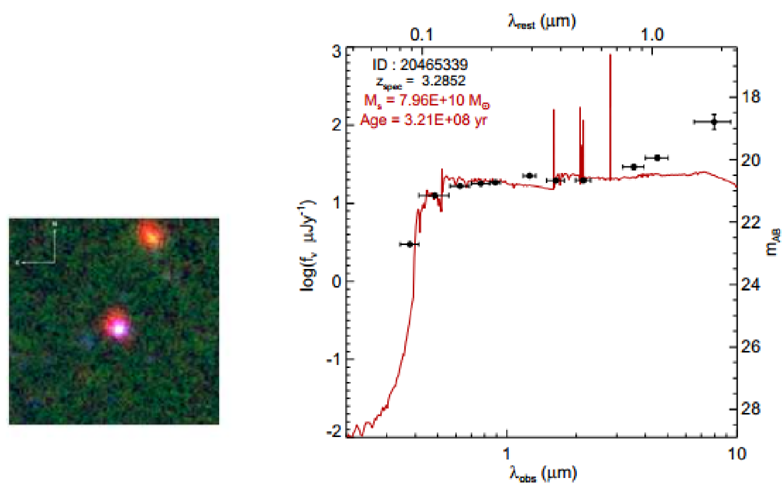
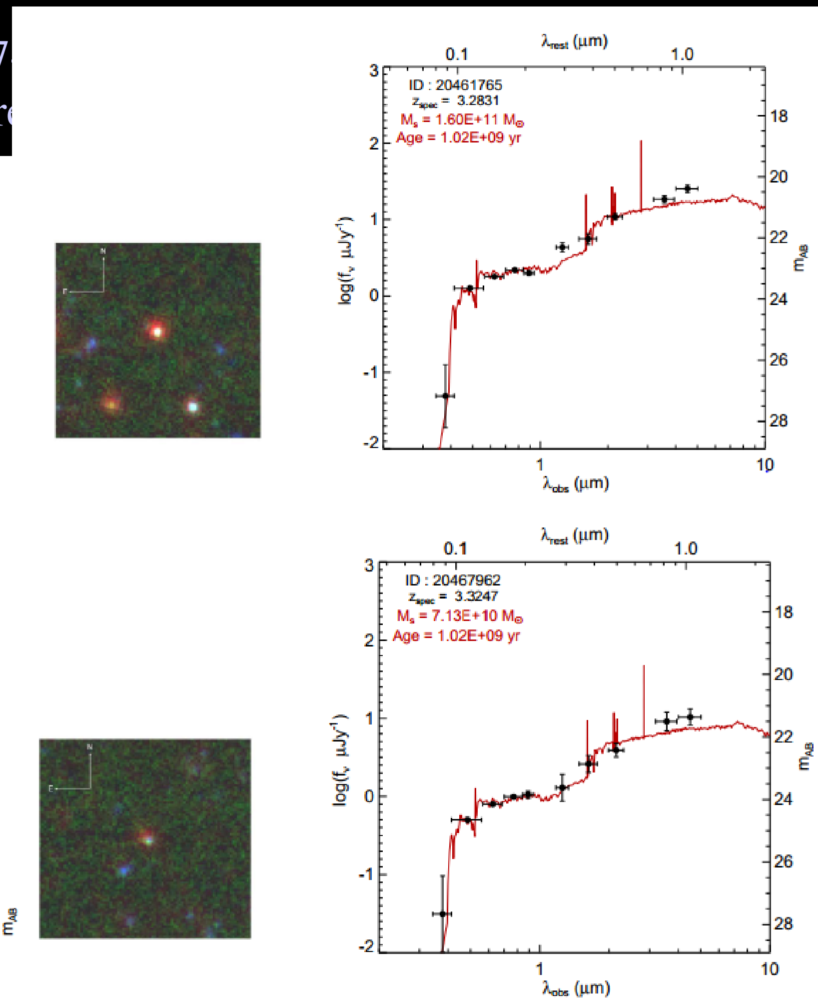
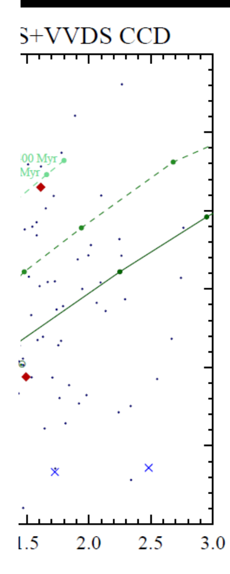
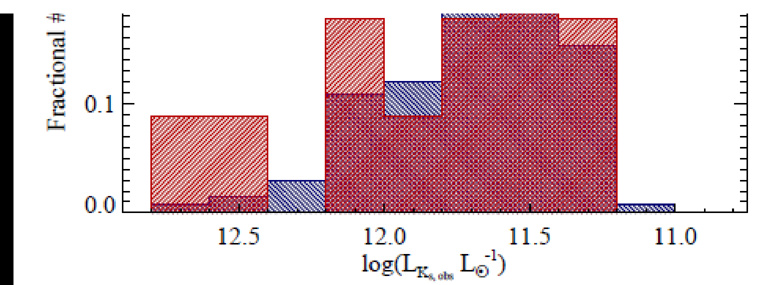




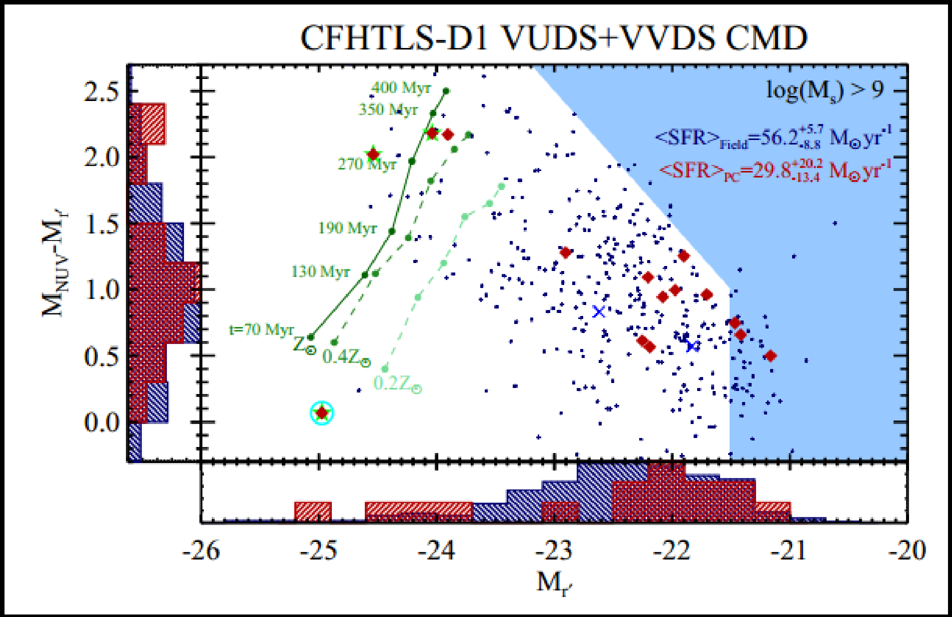






Environmental Effects?!

Adding a bit more sophistication…



Excess of bright/red galaxies of ρ_{pRSG}~25 in the protostructure relative to the field. Fractional excess too. Onset of environmental quenching? AGN quenching? Large uncertainties…

Some evidence of suppression of star formation among the protocluster members, but tentative and subject to methodology.

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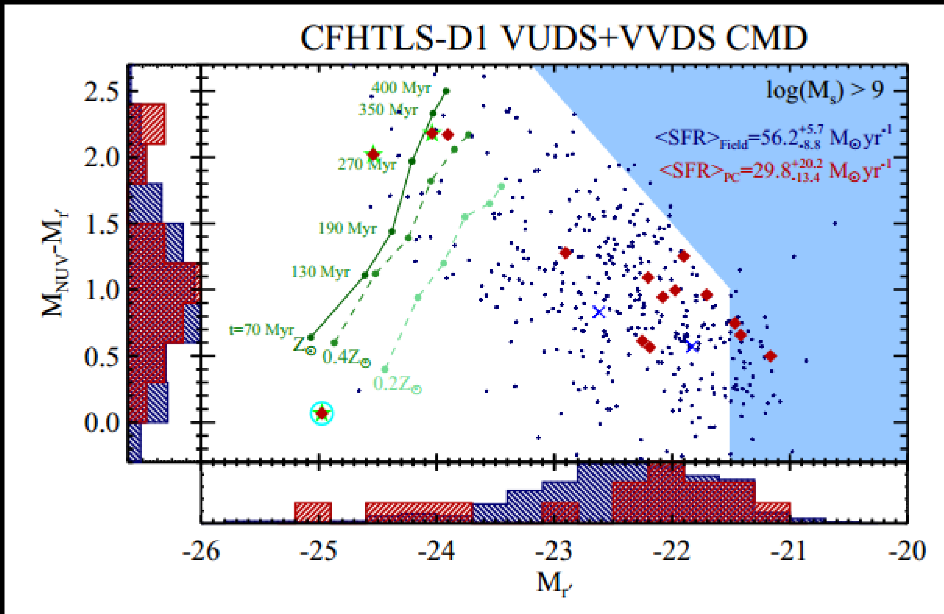

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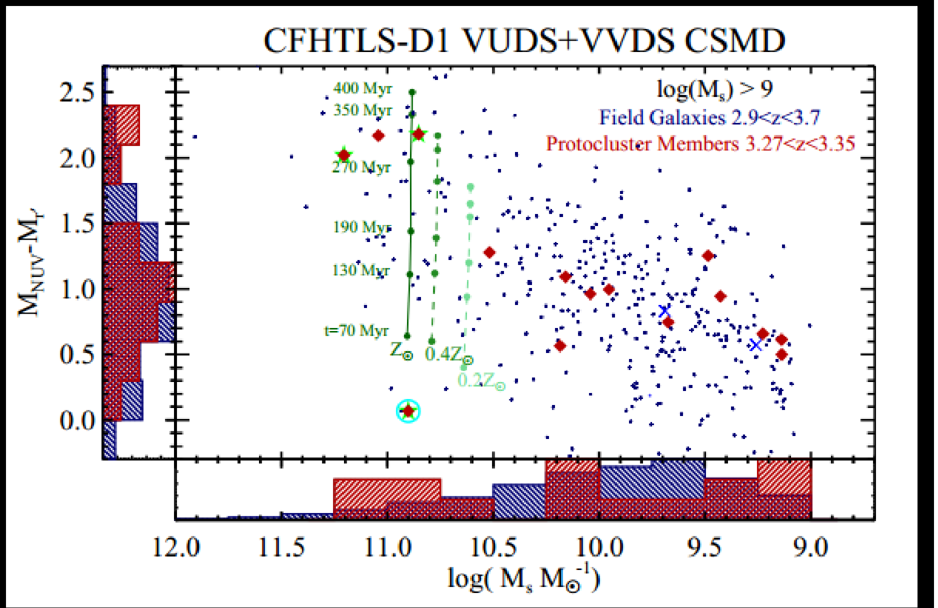
Brighter proto-red-sequence galaxies appear to be already massive (~10^{11} $M_\odot$ at z~3.3). Similarly massive field galaxies, but over a much larger volume (x250).

Other protocluster members have properties similar to coeval “field” galaxies.



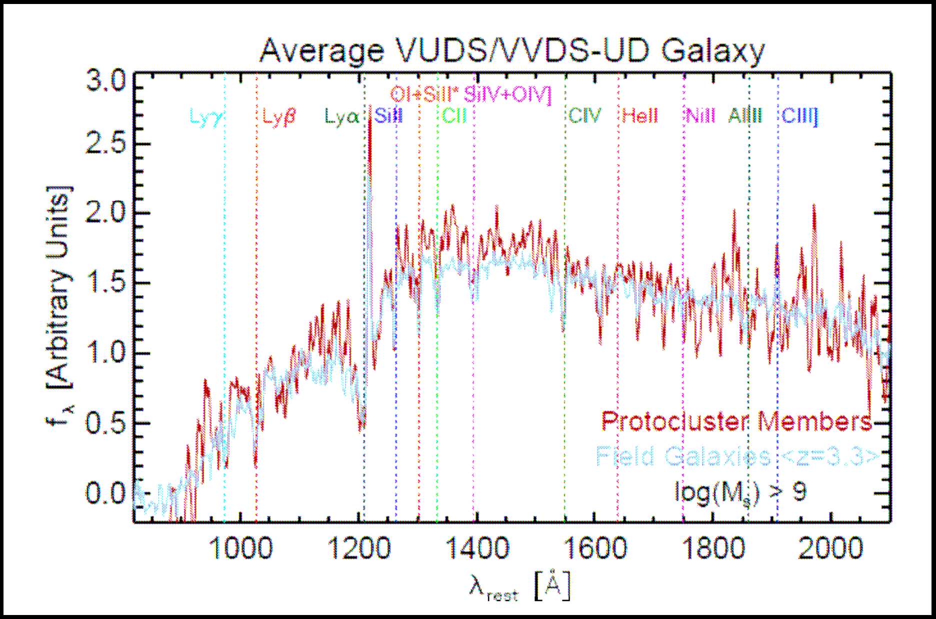
Environmental Effects?!?!?

Did you know: spectra can be used for more than redshifts! But…hmmm…I don't recognize most of these lines… How to get something meaningful?

Fraction of LAEs similar among field and protocluster galaxies, that's no help…

β-slope appears redder for the average protocluster member, what does that mean?

Is there a better way to do this?



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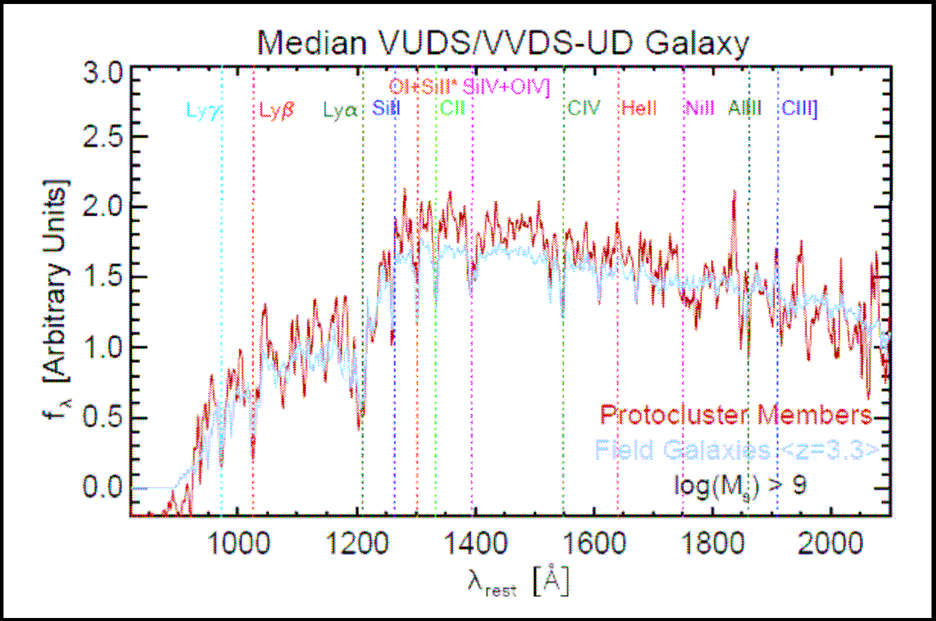
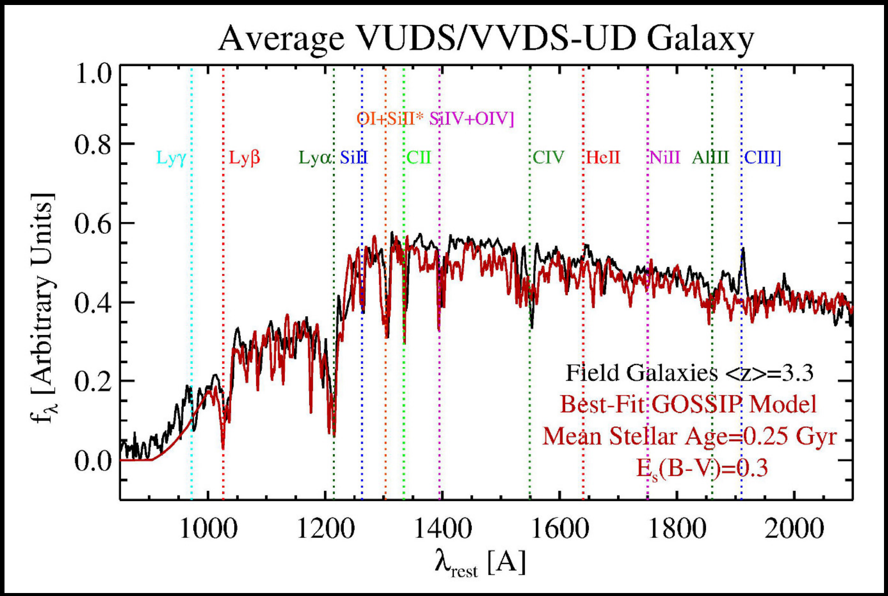




Maybe: Ask a graduate student who has worked three years on code fitting stellar synthesis models simultaneously to spectra and photometry (GOSSIP). Many things still to work out, but…

…pretty decent fits and (perhaps?) meaningful.

Maybe!

The results of the initial investigation are ambiguous. Hints of potential environmental influences, but low number of galaxies confounds interpretation.

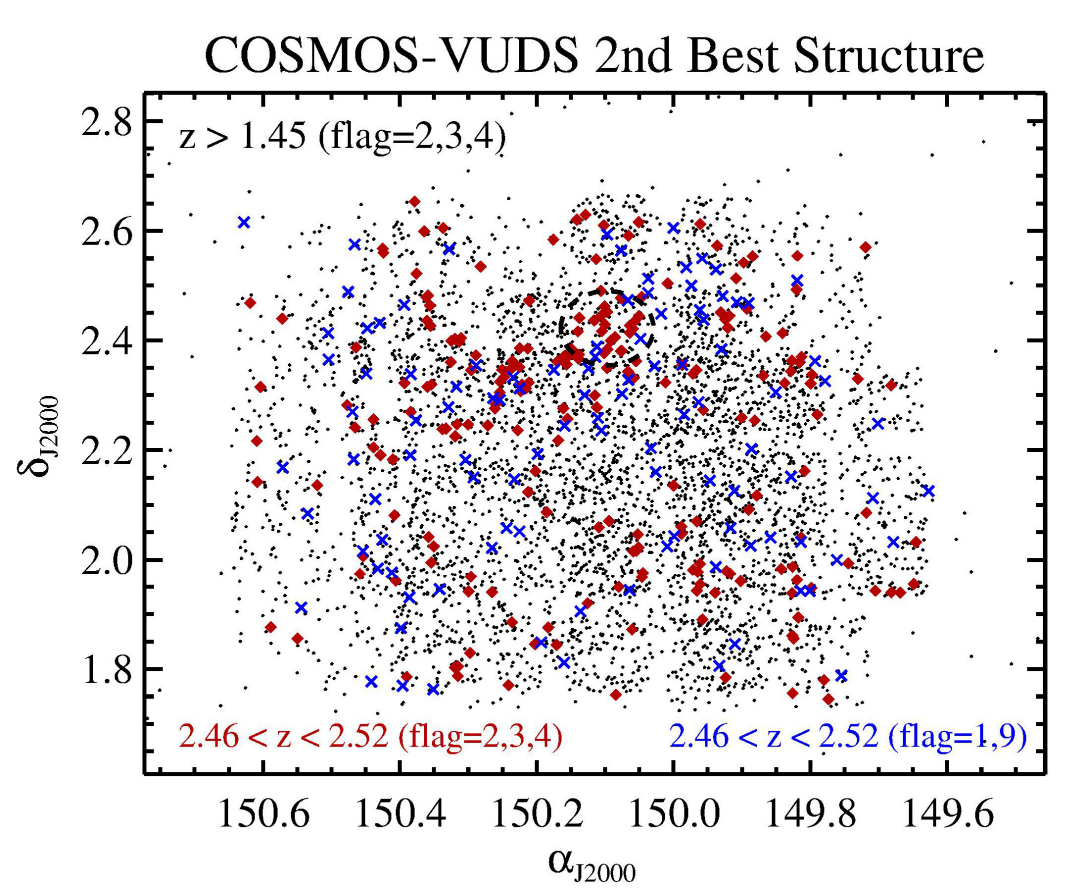
Luckily there's a lot more galaxies to play with: this is only one of ~50 potential proto-structure candidates that will be in the final VUDS database

The main tools of the analysis are up and running well and are demonstrated with ClJ0227-0421.

VUDS appears to be capable of finding protoclusters and characterizing their populations. Large extent helps.

Attempting to combine photometric and spectral redshifts intelligently, how best to do this?

Eventually SFR/color/morphology-density with combined analysis of all protostructures



More to come! Soon…