The UltraVISTA project

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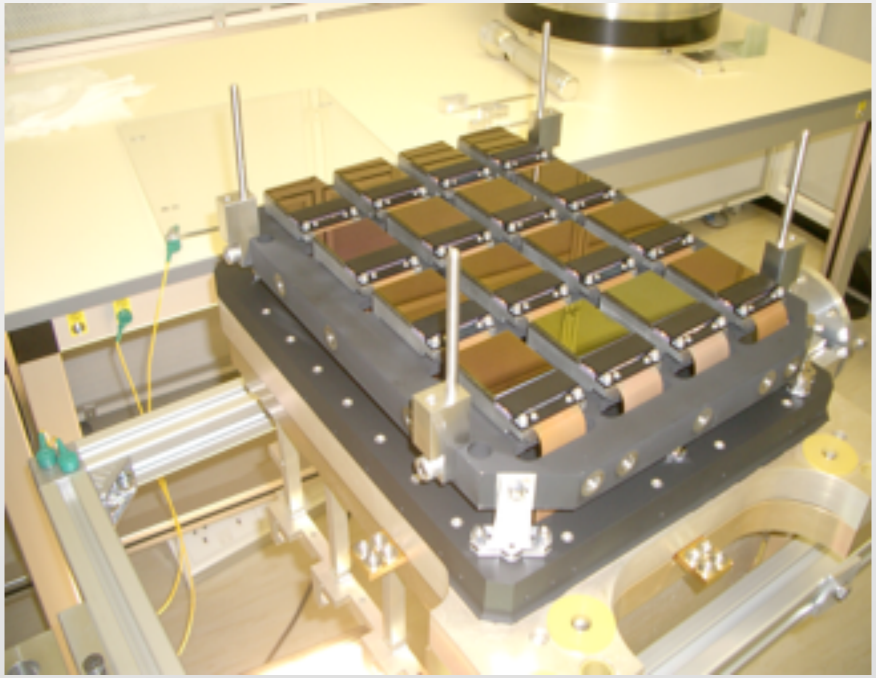
and UltraVISTA and TERAPIX teams

VISTA: Paranal, Chile

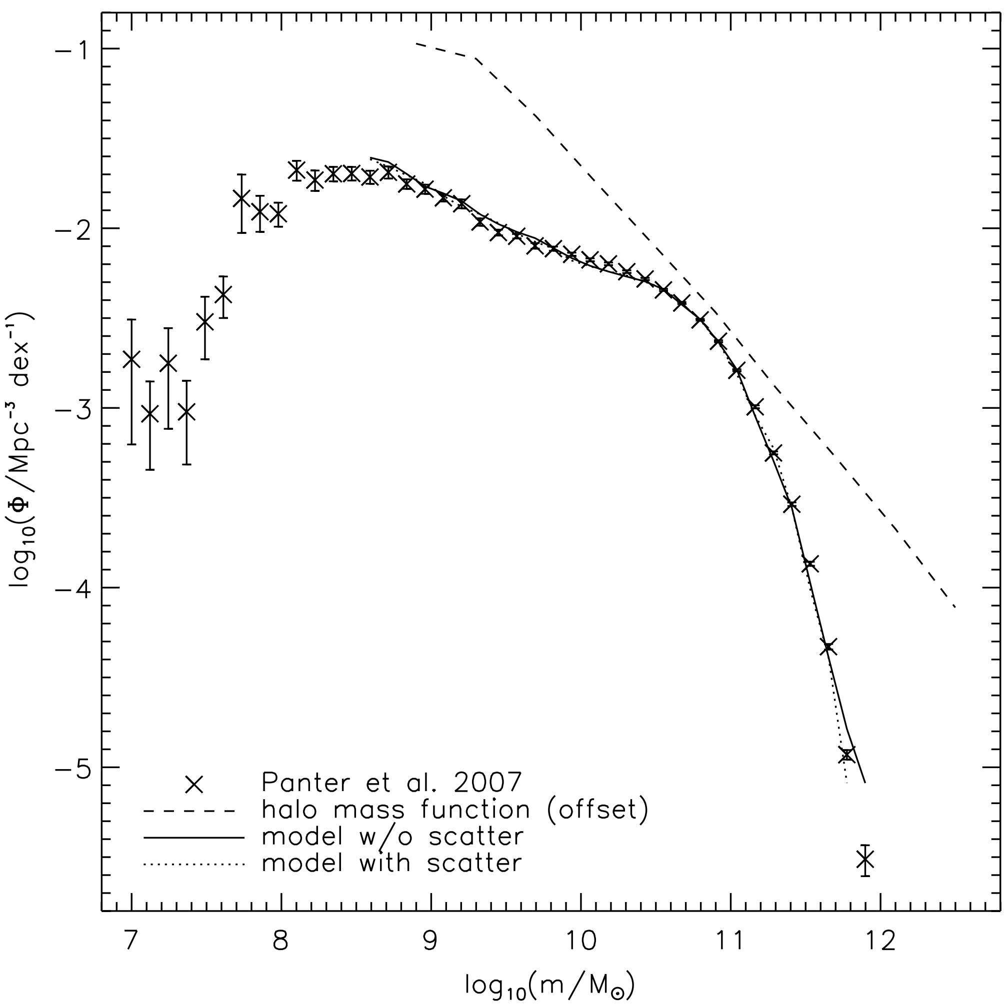


VIRCAM: 67 mega-pixel camera (1.5 sq. deg)
About ~3-4 more efficient than any other current NIR camera

Open questions

- **When did the first galaxies form? What is the galaxy luminosity function at very high redshift? What is the galaxy mass function at high redshifts?**
- **How did mass build up in galaxies? What is the relationship between dark matter halo mass and galaxy mass? How does star-formation depend on halo mass? What are the physical processes which suppress star-formation in massive haloes?**

Galaxy formation is an inefficient process....



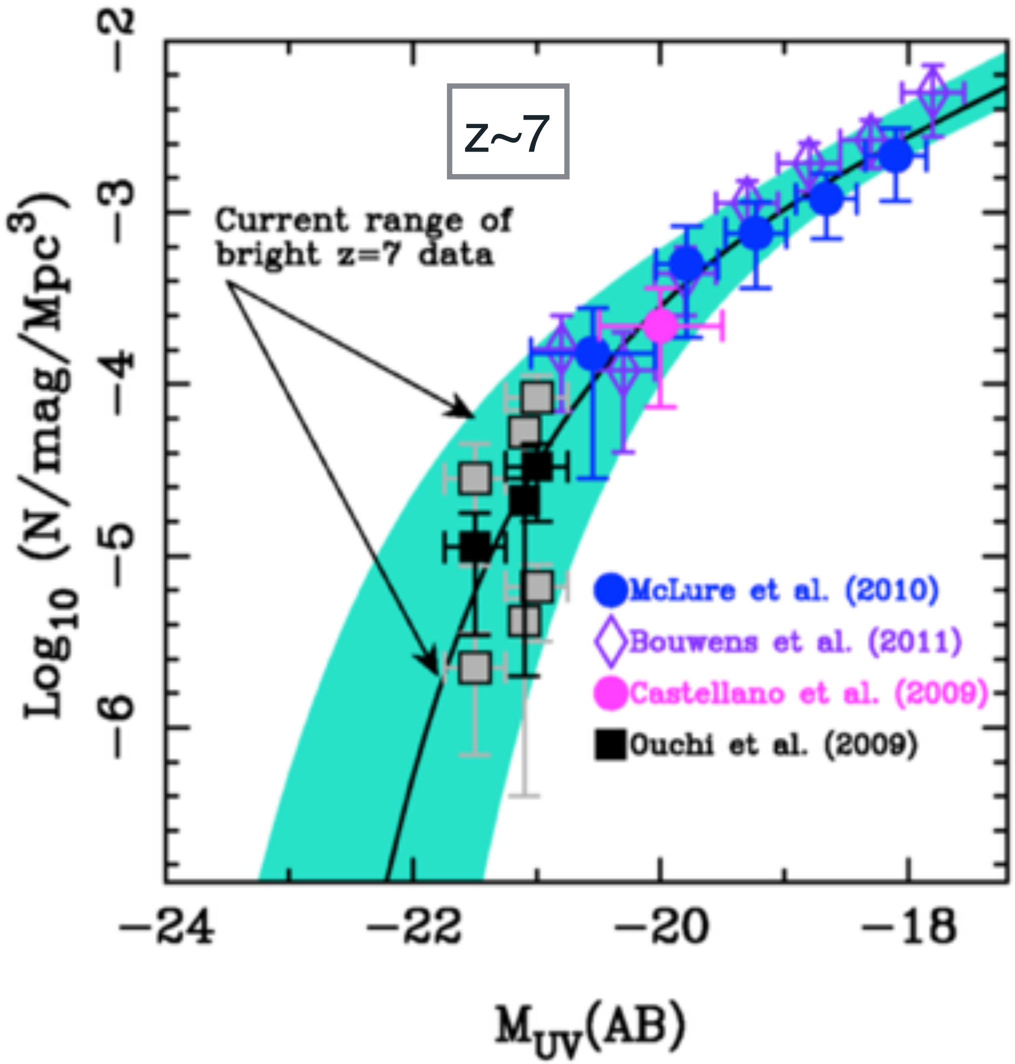
- Several orders of magnitude separate the galaxy mass function and the halo mass function
  - What are the physical processes which **suppress star-formation** in massive and low-mass haloes?

Galaxies and haloes: key to understanding galaxy formation

- Halo mass is a key driver in galaxy evolution.
  - Host halo mass controls halo star-formation rate: least massive and more massive haloes have different star-formation efficiencies
  - Origin and nature of these physical processes uncertain and greatly debated (is AGN feedback, supernovae et al.)
- Want to understand **how host halo mass relates to key observables: star formation and galaxy clustering**

How does the high-redshift luminosity function evolve?

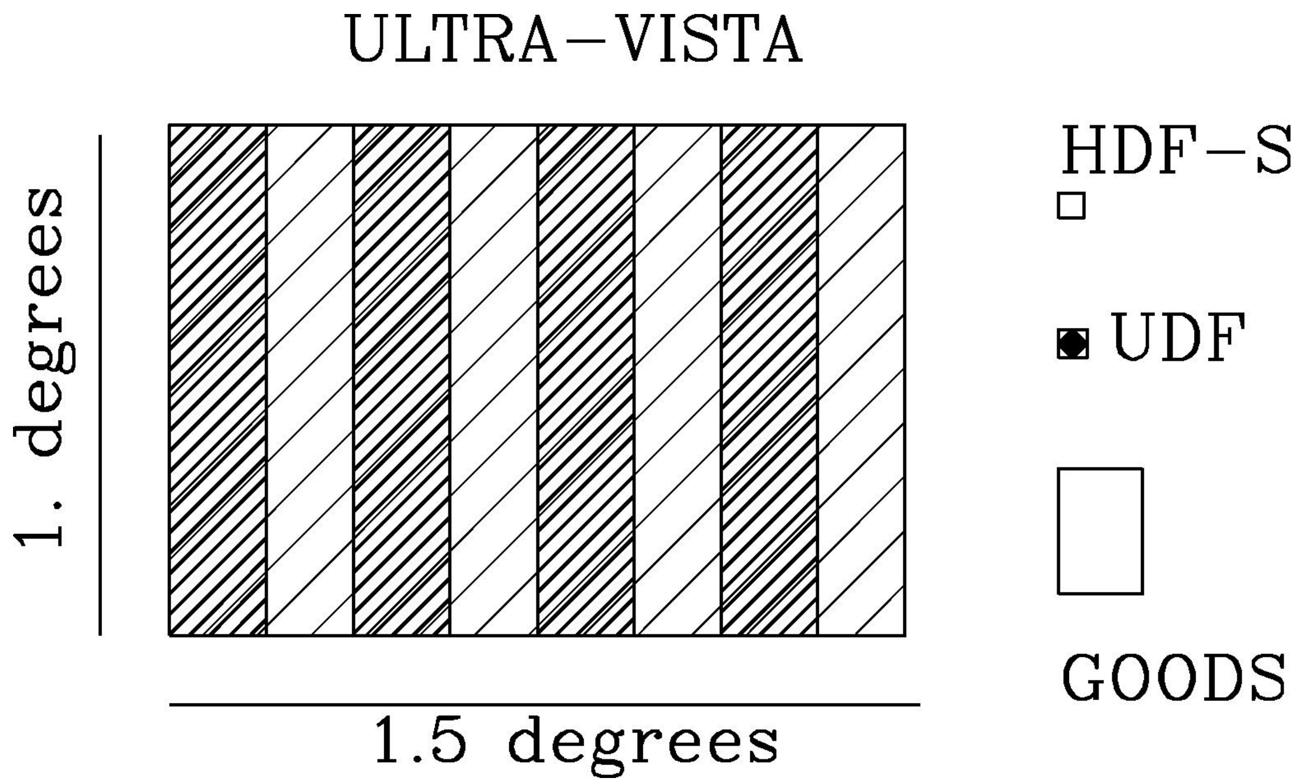
- Bright end is poorly constrained by space-based data
  - Determining bright end important to understanding influence of AGN on galaxy formation process
- **Only ground based data can probe the bright end of the MF/ LF**



What kind of survey do we need?

- Ability to probe the rest-frame optical at high redshifts
  - E.g., use colour or template fitting criteria to select galaxies at the highest redshifts.
- Ability to to measure distribution of galaxies as a function of stellar mass and redshift
  - Calculate stellar masses for large selection of galaxies (hard to make complete spectroscopic sample between $1<z<2$

➡ Large area near-infrared (2-micron) selected survey



Depth goals of UltraVISTA survey

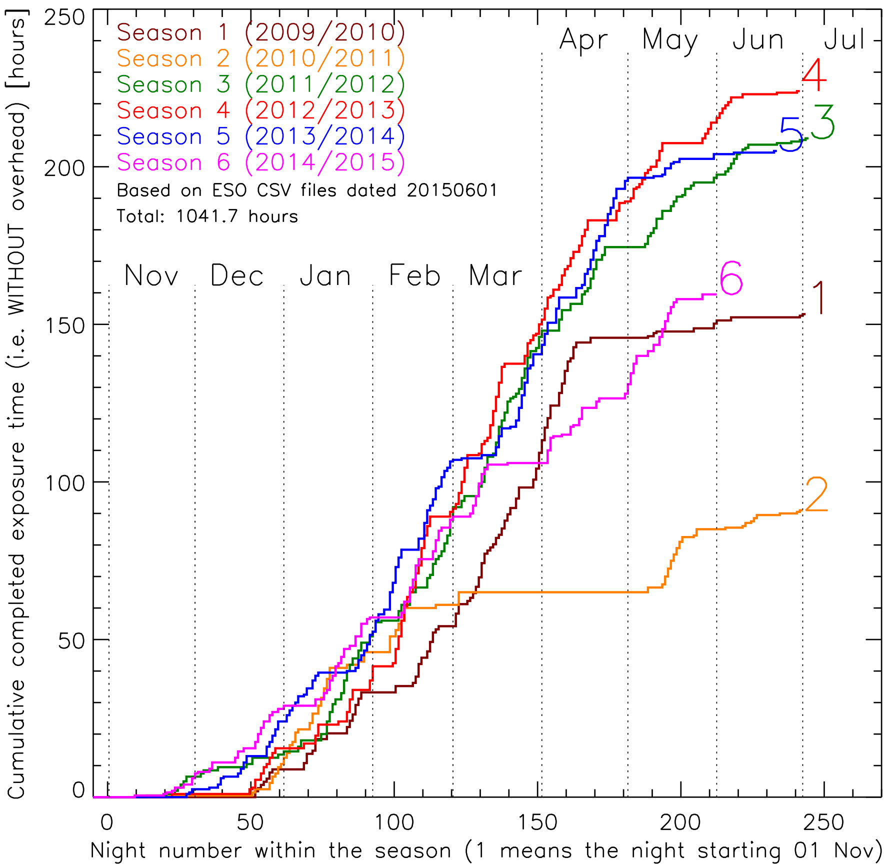
Ultra-deep: 0.73 sq. deg: Y=26.7, J=26.6, H=26.1, K=25.6 (1408hr)

Deep: 1.50 sq. deg: Y=25.3, J=25.2, H=24.7, K=24.2 (212 hr)

Narrow band: NB118=26 (180 hr)

(All depths AB, 5sig, 2”, from the original proposal)

Current status of UltraVISTA (June 2015)



courtesy B. Milvang

Execution time: **with overhead**

Number of hours of execution time (i.e. with overhead)
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Split by region:

	__ultra-deep stripes = paws 1,2,3__						____deep stripes = paws 4,5,6_____					
Season	Y	J	H	Ks	NB118	All	Y	J	H	Ks	NB118	All
1	19.9	21.1	28.4	24.9	10.1	104.4	21.1	21.1	26.9	24.9	0.0	94.0
2	20.5	10.6	1.5	73.0	10.1	115.6	0.0	0.0	1.5	0.0	0.0	1.5
3	54.7	28.6	70.0	111.8	14.9	280.1	0.0	0.0	0.0	0.0	0.0	0.0
4	37.2	73.3	122.3	16.2	43.3	292.3	0.0	0.0	0.0	0.0	0.0	0.0
5	46.3	46.8	71.6	77.8	29.0	271.6	0.0	0.0	0.0	0.0	0.0	0.0
6	39.8	23.2	34.0	0.0	15.1	112.1	0.0	0.0	0.0	104.3	0.0	104.3
All	218.3	203.6	327.8	303.8	122.6	1176.1	21.1	21.1	28.4	129.2	0.0	199.7
SIQ	39.5	59.5	27.2	0.0	17.7	143.8	0.0	0.0	0.0	51.0	0.0	51.0
OnH	0.0	0.0	0.0	36.4	0.0	36.4	0.0	0.0	0.0	0.0	0.0	0.0

All regions (i.e. ultra-deep and deep stripes combined):

Season	Y	J	H	Ks	NB118	All
1	41.0	42.1	55.3	49.8	10.1	198.3
2	20.5	10.6	3.0	73.0	10.1	117.1
3	54.7	28.6	70.0	111.8	14.9	280.1
4	37.2	73.3	122.3	16.2	43.3	292.3
5	46.3	46.8	71.6	77.8	29.0	271.6
6	39.8	23.2	34.0	104.3	15.1	216.4
All	239.4	224.7	356.2	433.0	122.6	1375.8
SIQ	39.5	59.5	27.2	51.0	17.7	194.7
OnH	0.0	0.0	0.0	36.4	0.0	36.4

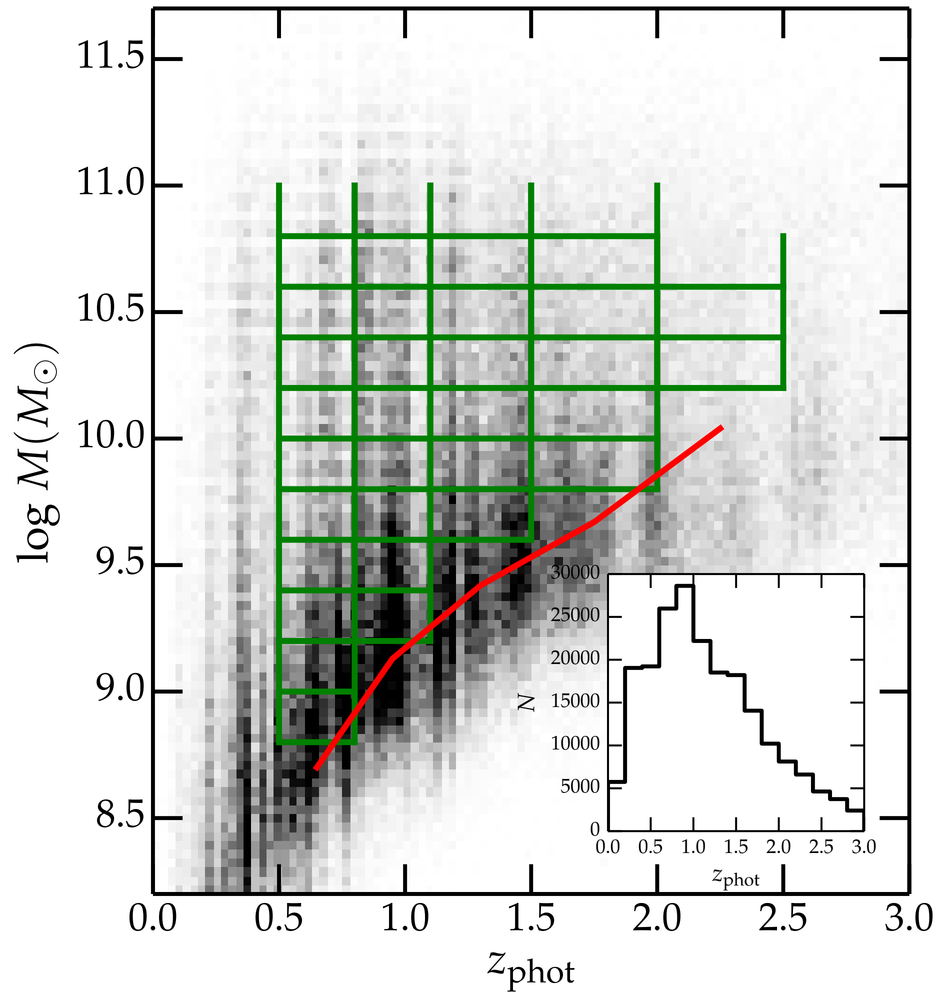
Deep stripe data

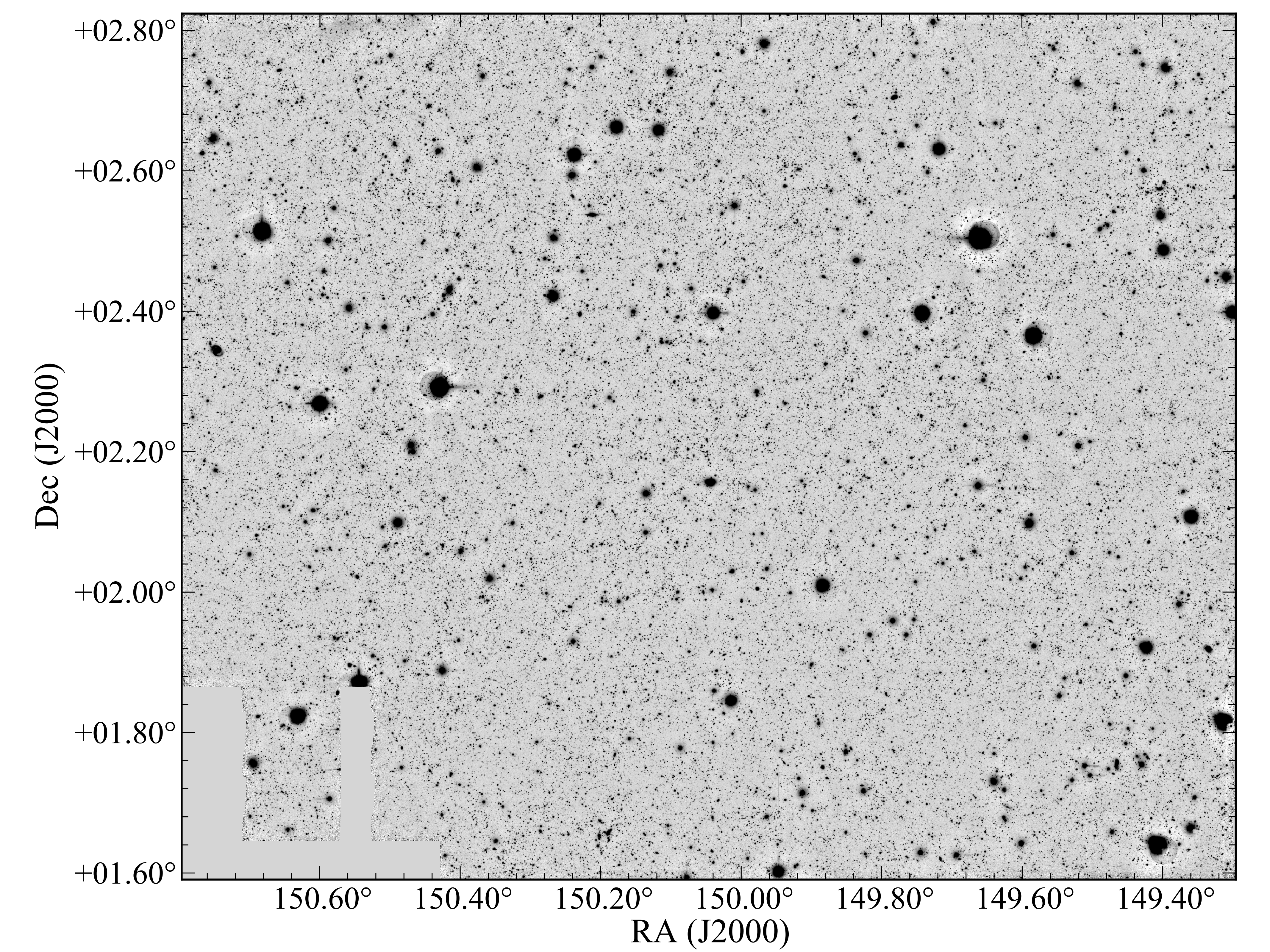
UltraVISTA data releases

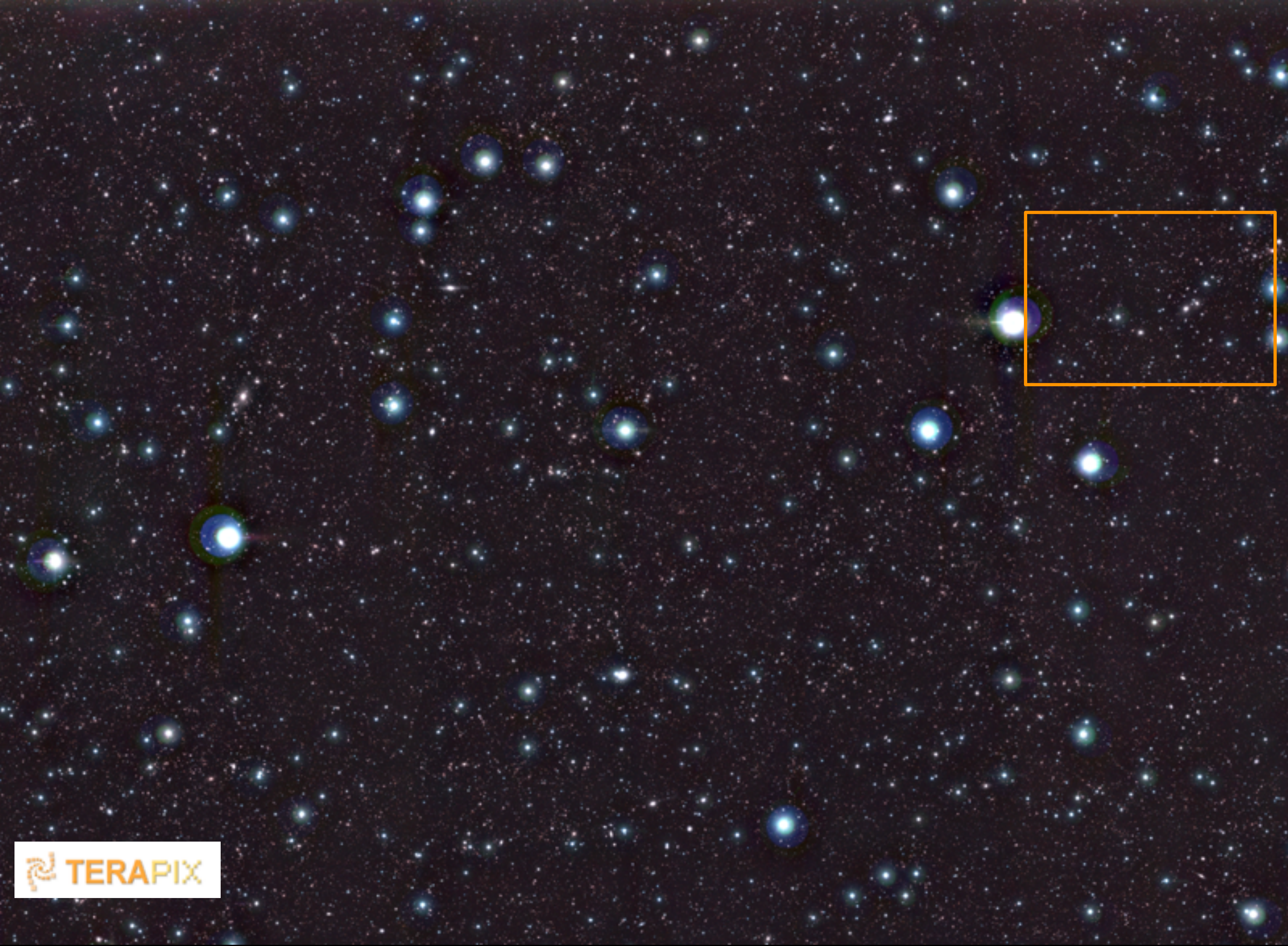
- **DR1 (2011, 2012)**
  - First observing season. Images, catalogues, photometric and phot-zed catalogues made publicly available (see terapix.iap.fr pages)
- **DR2 (Jan 2014)**
  - All data from the **first three observing seasons** was reprocessed. Catalogues, images, documentation available through "ESO phase 3".
  - **New multi-band photo-zed catalogue to be released very shortly:** watch out for **Laigle et al.** paper to be on astro-ph shortly.
- **DR2 (Oct.-Nov 2015)**: all data from first five seasons reprocessed

UltraVISTA-COSMOS DR1

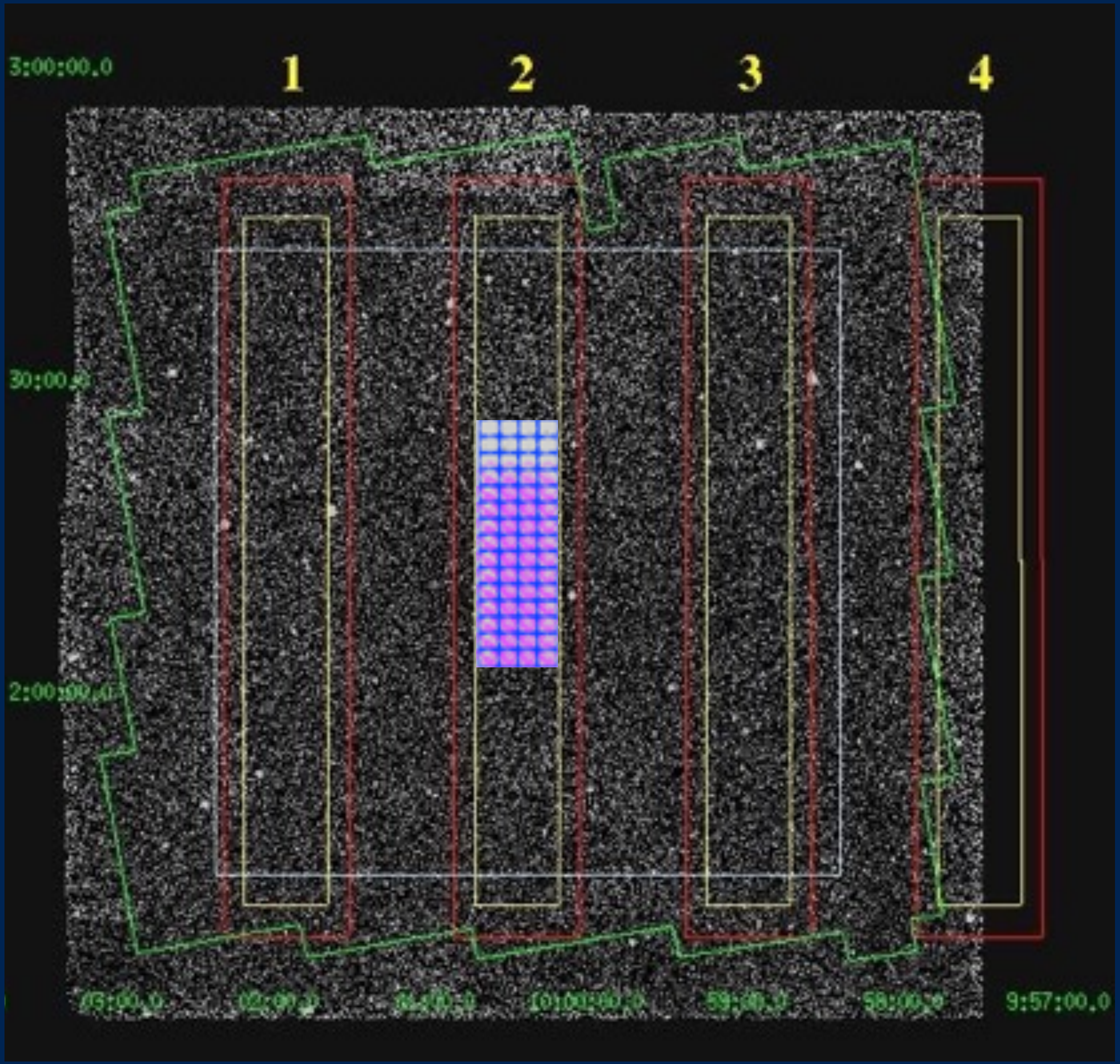
- A unique **mass-selected** sample of 200,000 galaxies in the COSMOS field
  - Highly precise photometric redshifts
  - **Ultra-deep** YJHK NIR data means we can measure precise (log sigma M ~ 0.3) stellar masses at least until z~2-3
  - Very large dynamic range: **can easily see M* galaxies until z~2**



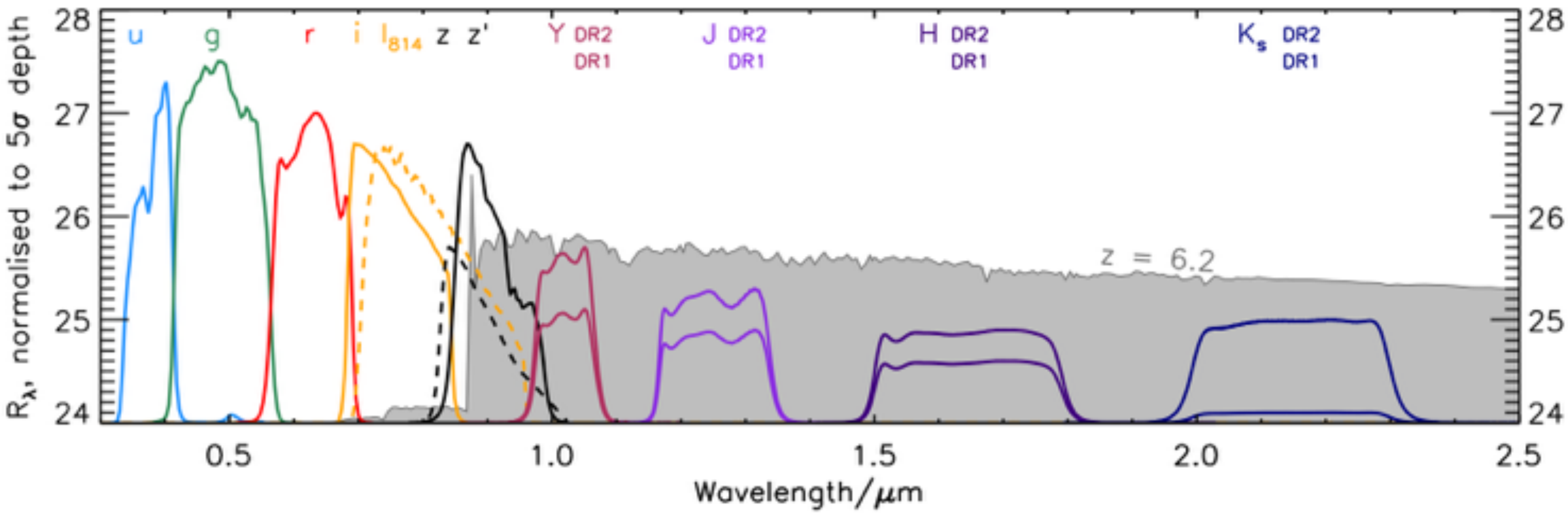

Dec (J2000)
+02.80°
+02.60°
+02.40°
+02.20°
+02.00°
+01.80°
+01.60°
RA (J2000)
150.60°
150.40°
150.20°
150.00°
149.80°
149.60°
149.40°


TERAPIX

UltraVISTA–CANDELS



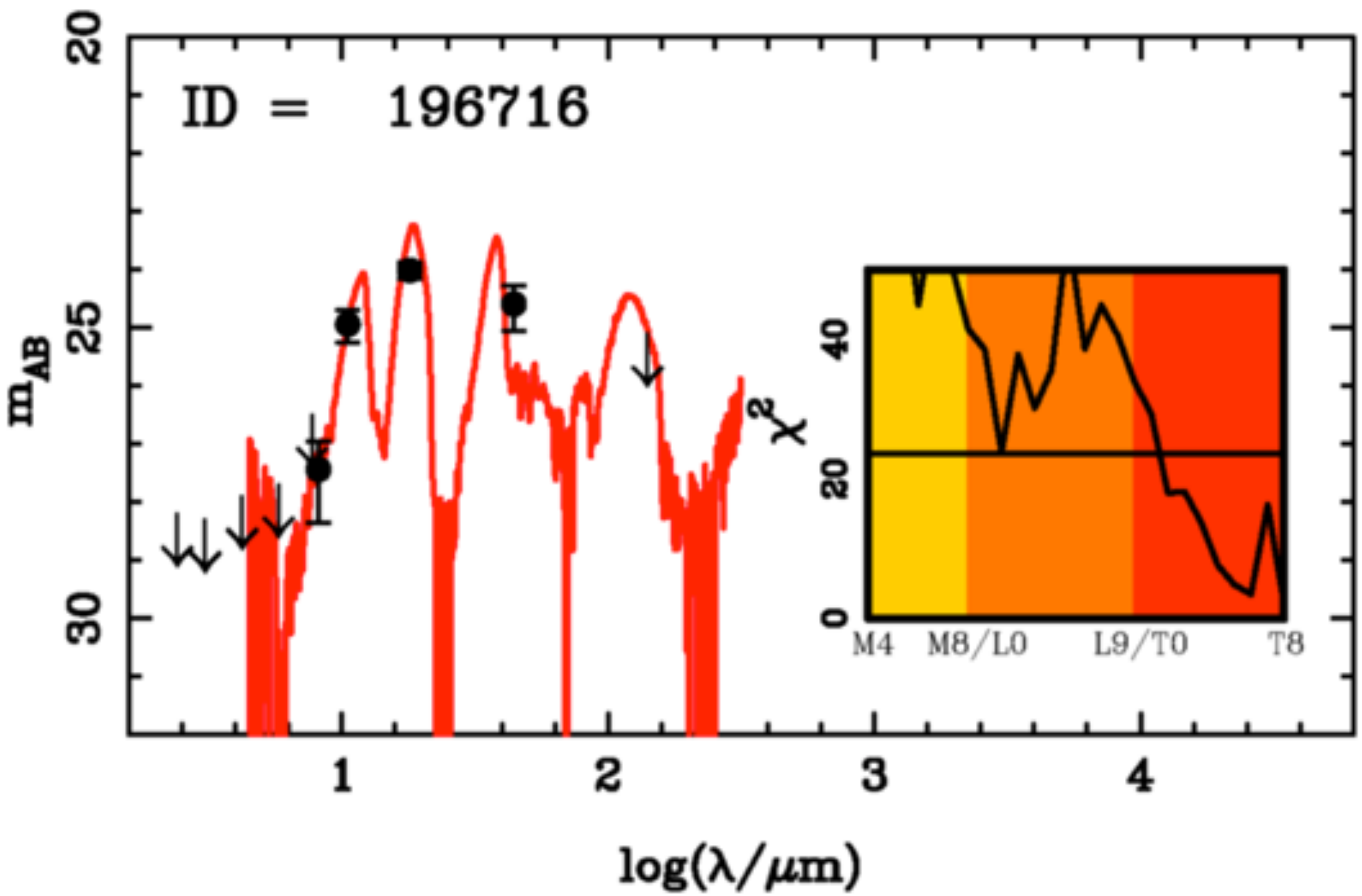
Selecting z~6 galaxies



Bowler et al. 2014, 2015

- z~6 galaxies are detected in z* band, **undetected in optical bands.**

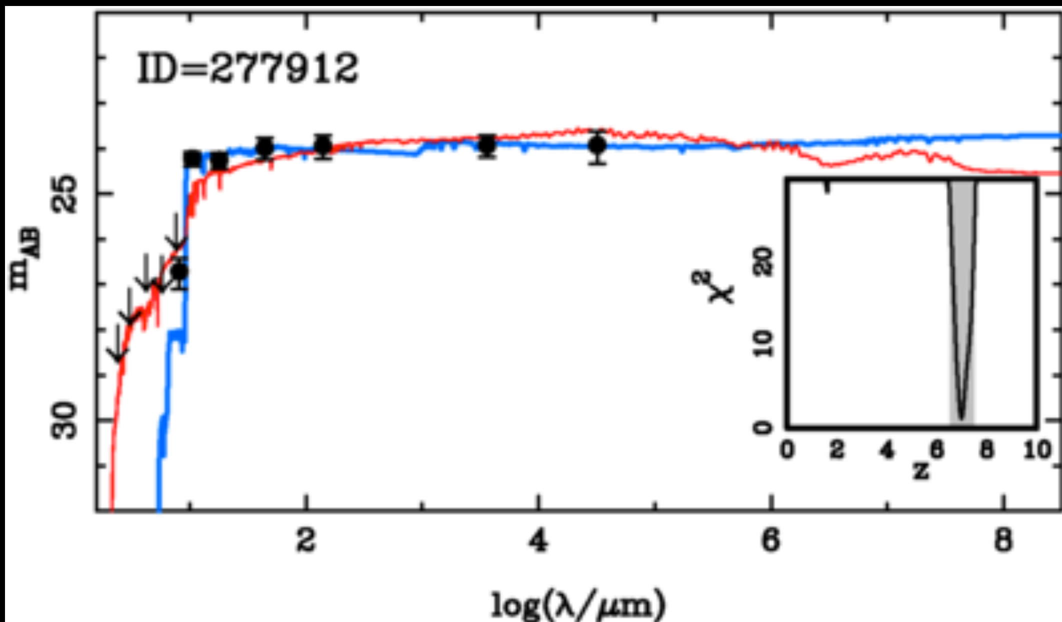
Need to distinguish between T-dwarfs and galaxies…

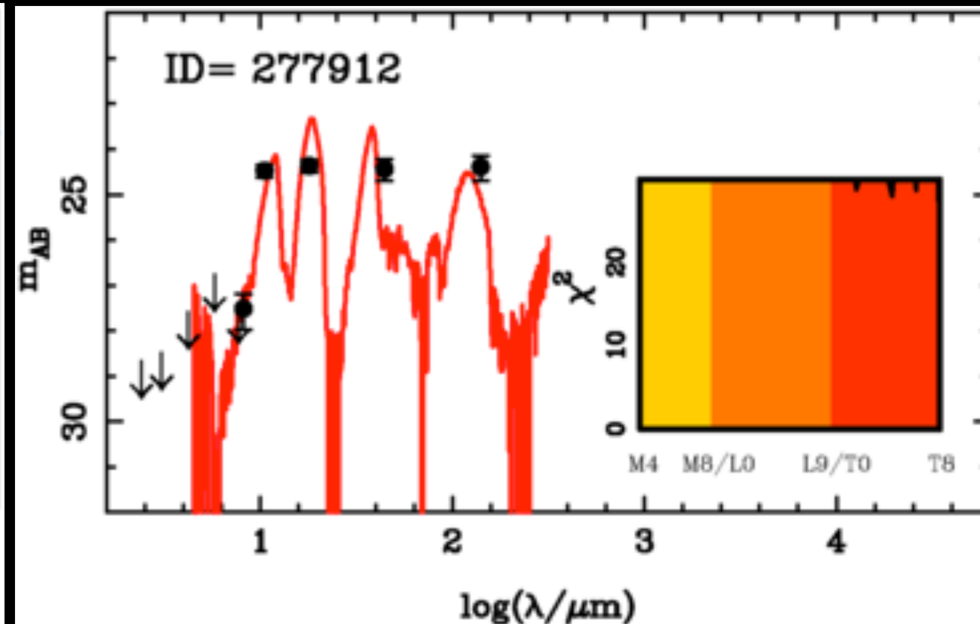


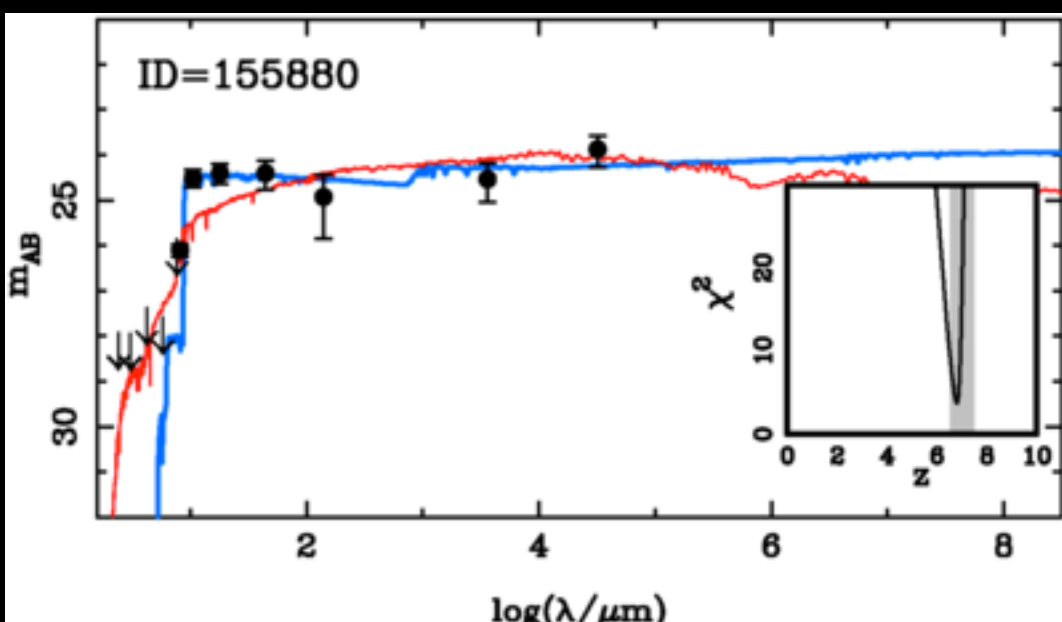
- deep Y or J based data helps to distinguish between dwarfs and high-redshift

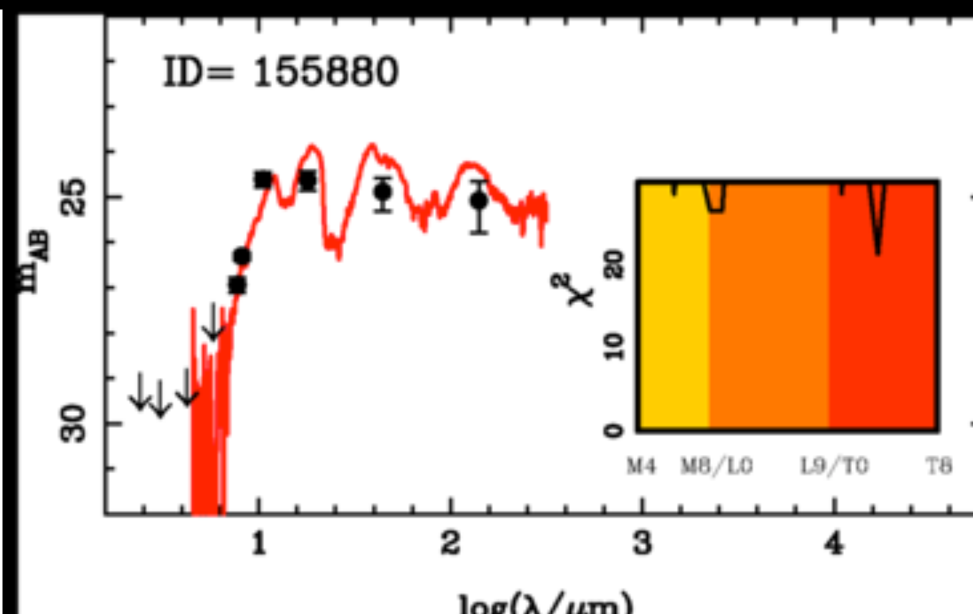
UltraVISTA robust z ~ 7 galaxies

Bowler, Dunlop et al. (2012)

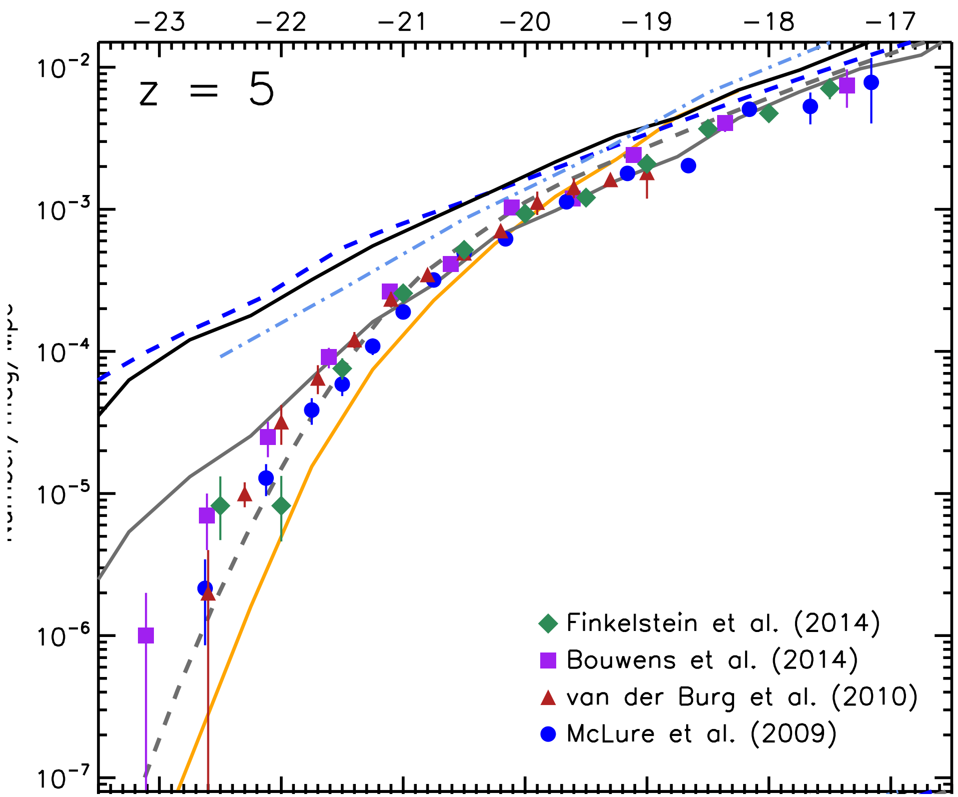




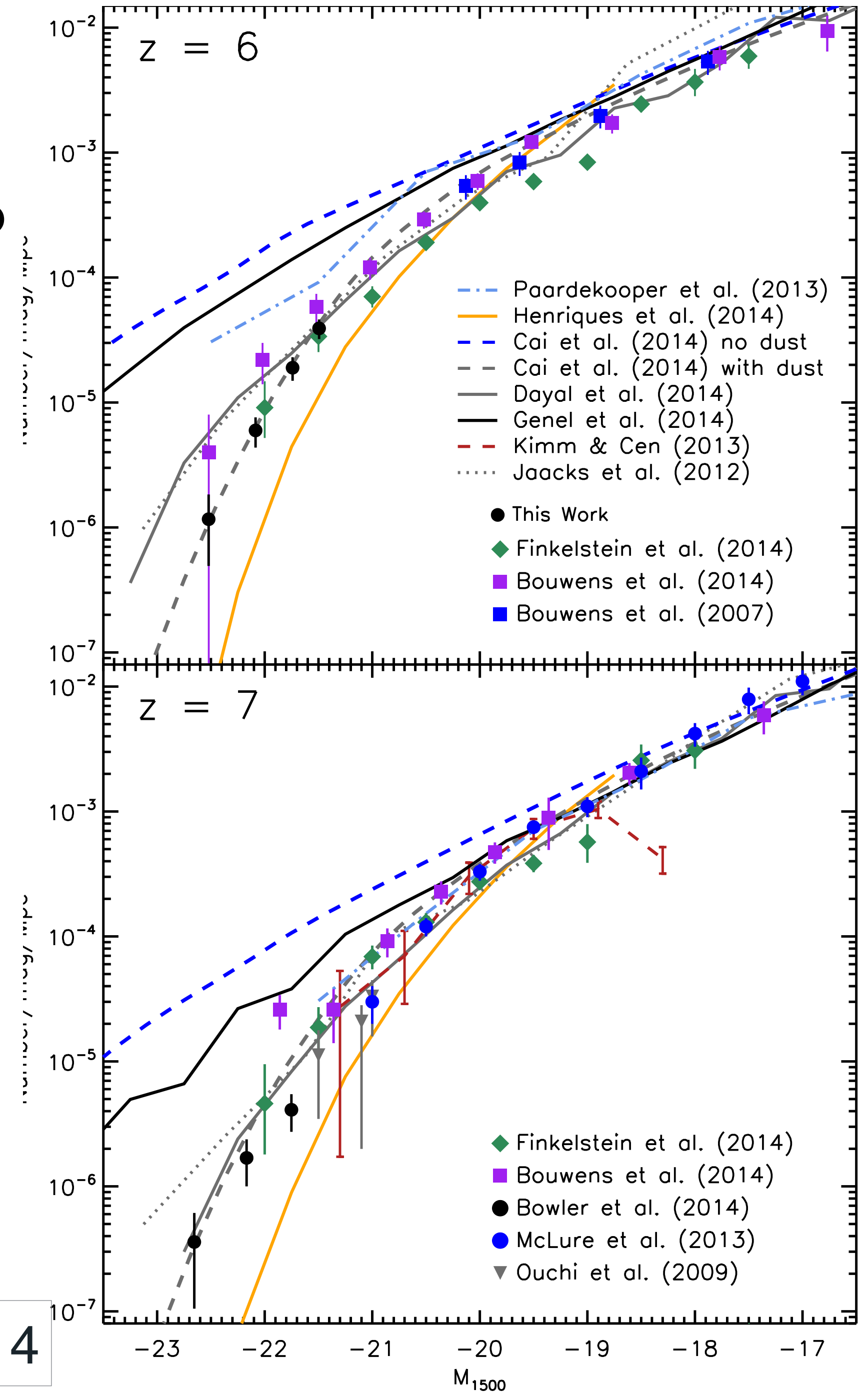




High redshift luminosity functions UDS/COSMOS



Bowler et al. 2015

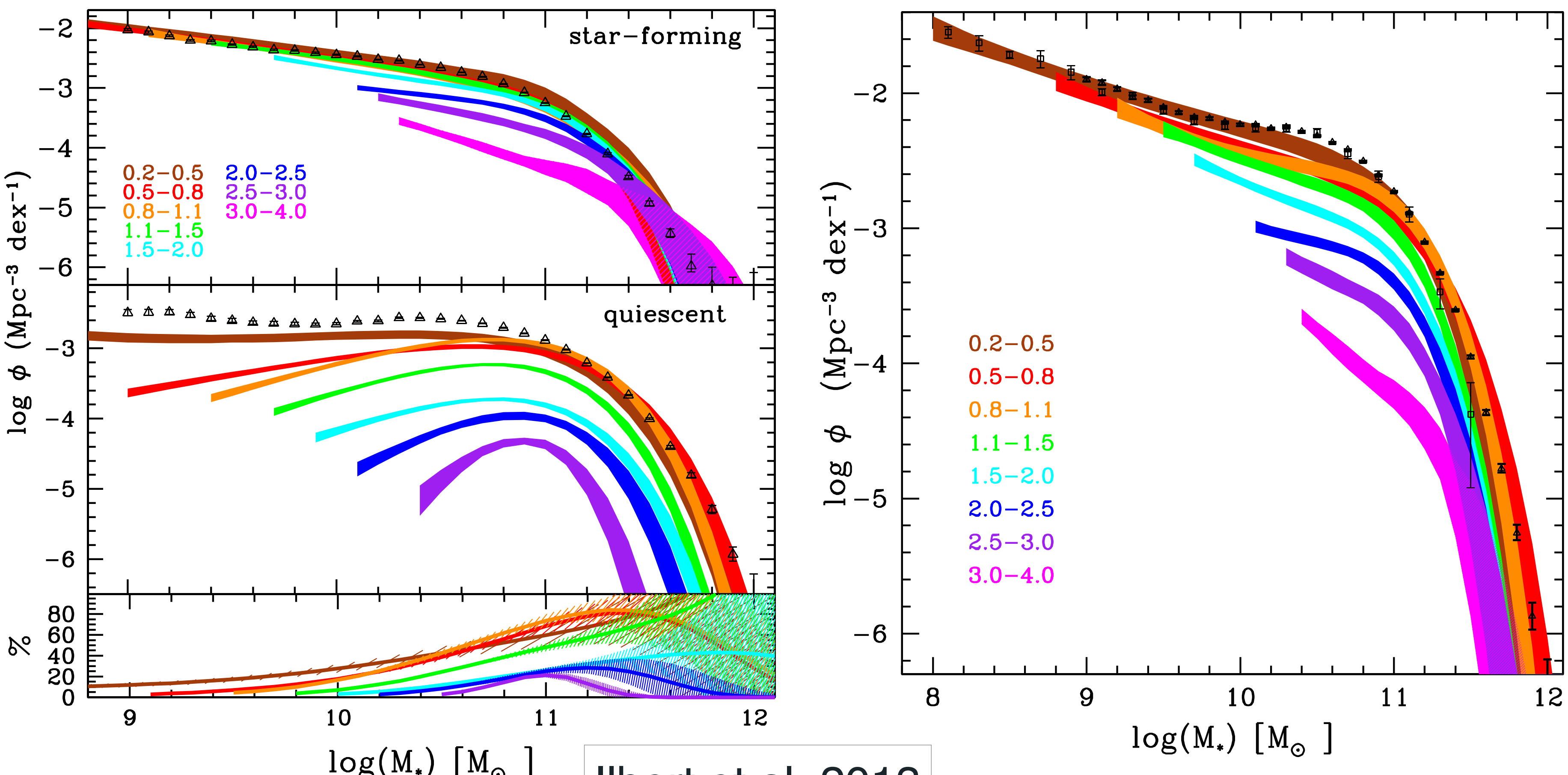


Bowler et al. 2014

Conclusions: 1

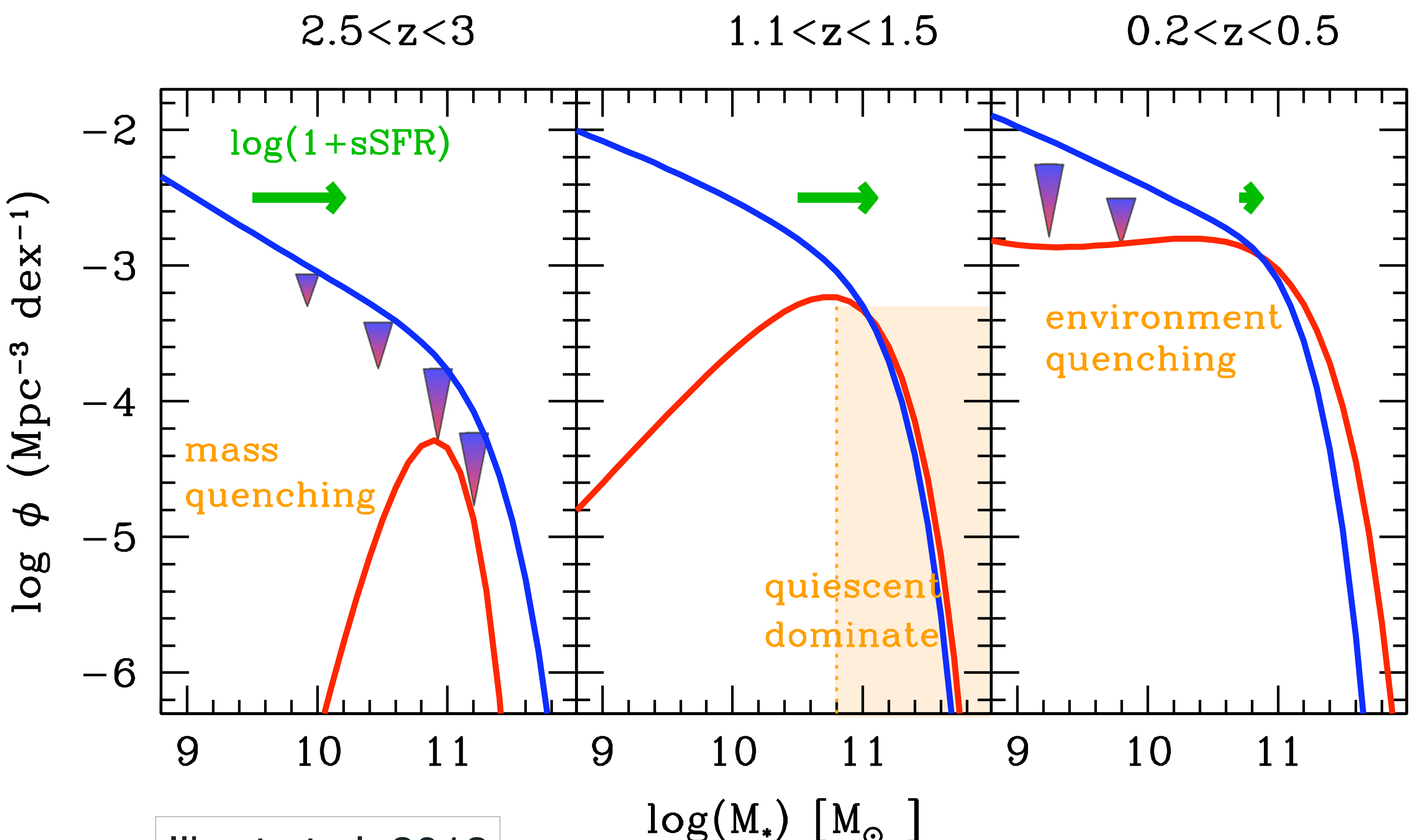
- Cosmic variance is still important at z~6 (see comparisons between UDS / COSMOS/ CANDELS)
- All theoretical models have a hard time reproducing correctly the bright end of the luminosity function
  - So, we need to work more on modelling feedback processess, probably
- Some evidence for steeping of bright end of mass function (onset of mass quenching process)?

Galaxies and haloes: key to understanding galaxy formation



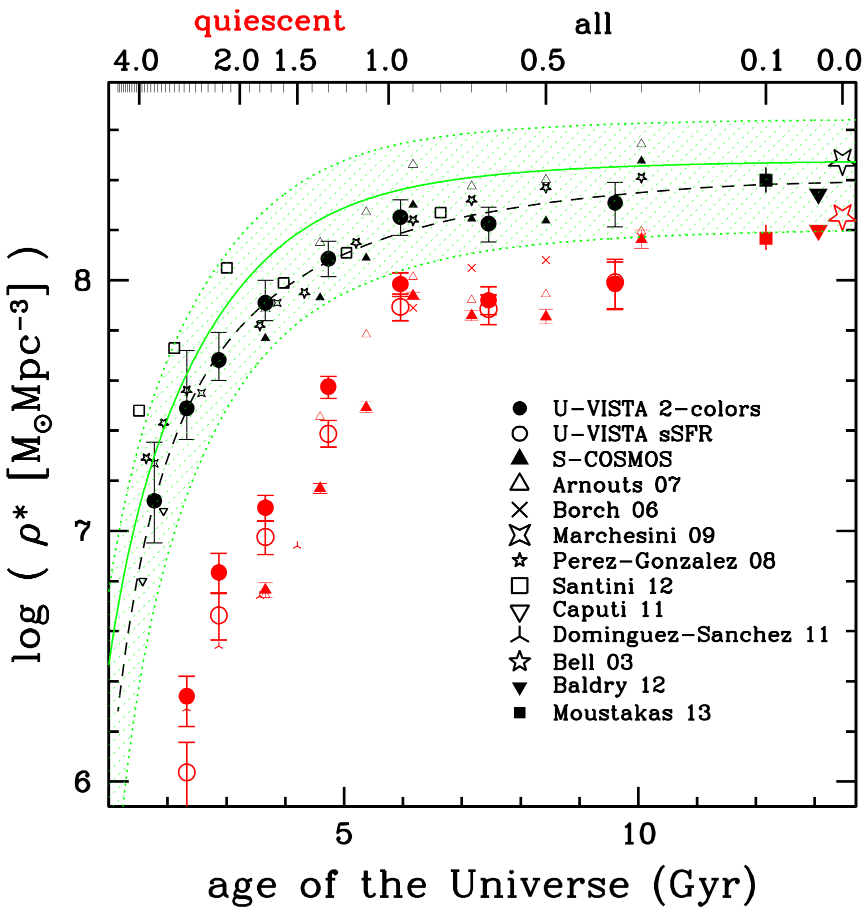
Ilbert et al. 2013

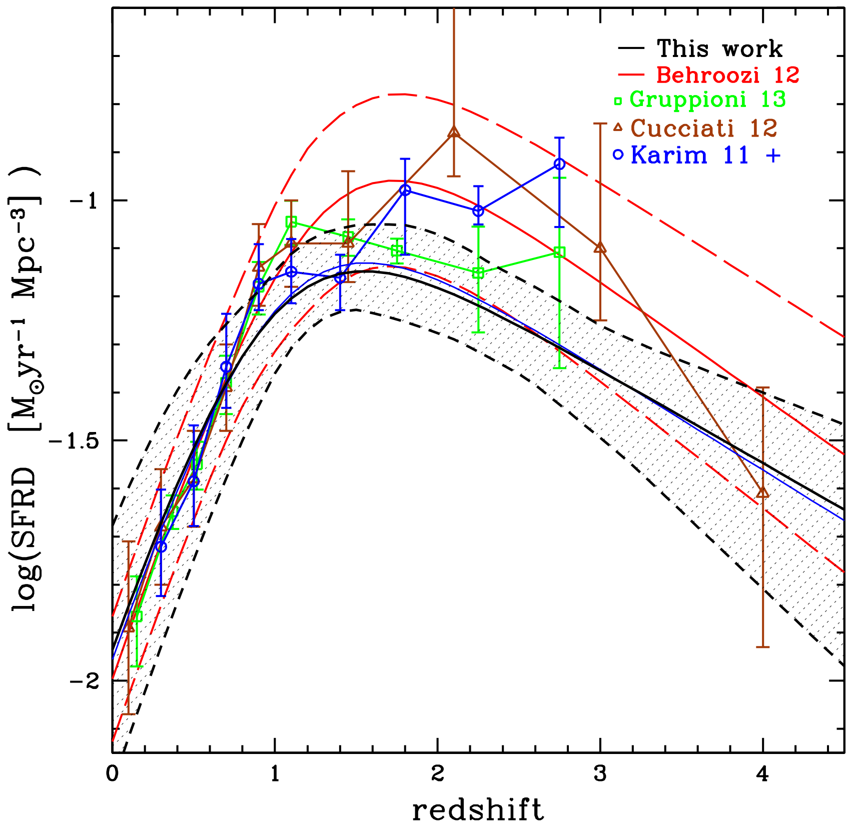
Growth of galaxies (I)



Ilbert et al. 2013

Growth of galaxies (II)

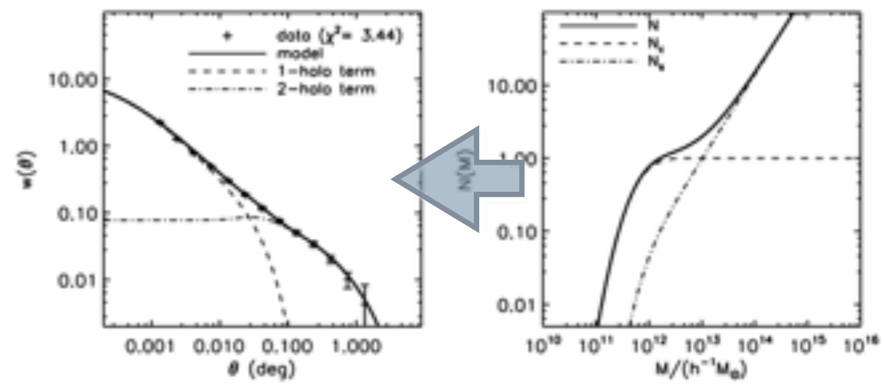


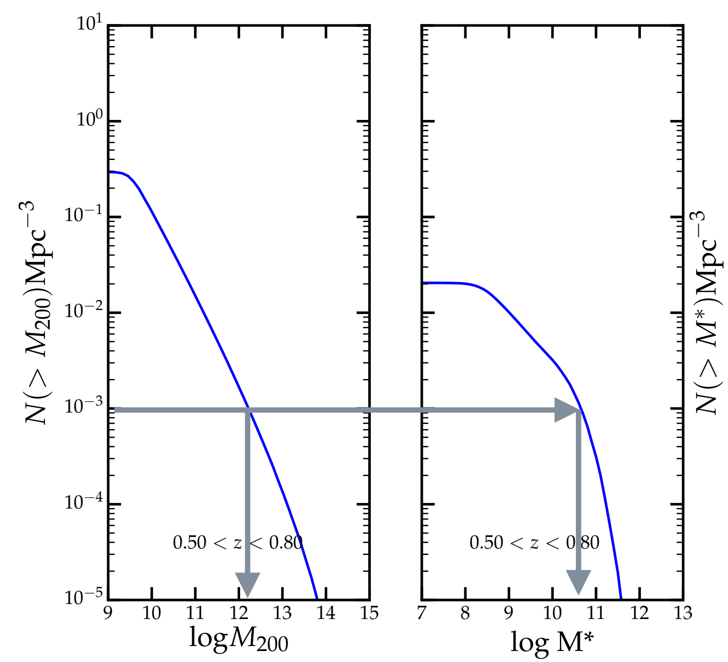


Ilbert et al. 2013

How to measure halo masses?

- Phenomenological models: **halo model**
  - Find parameters of halo occupation distribution (HOD) which can reproduce observed **abundance** and **clustering**
- Shortcut: **Sub-halo abundance matching** using N-body simulation
  - Approximately equivalent. Less information (e.g., satellite fraction)



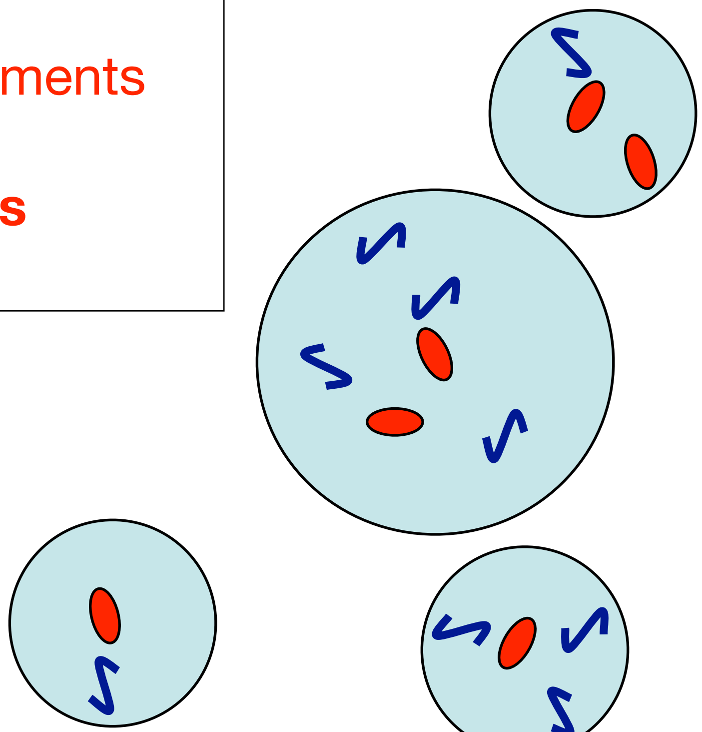


One slide about the halo model

Galaxy clustering statistics measure the number of pairs **in excess of a random distribution**

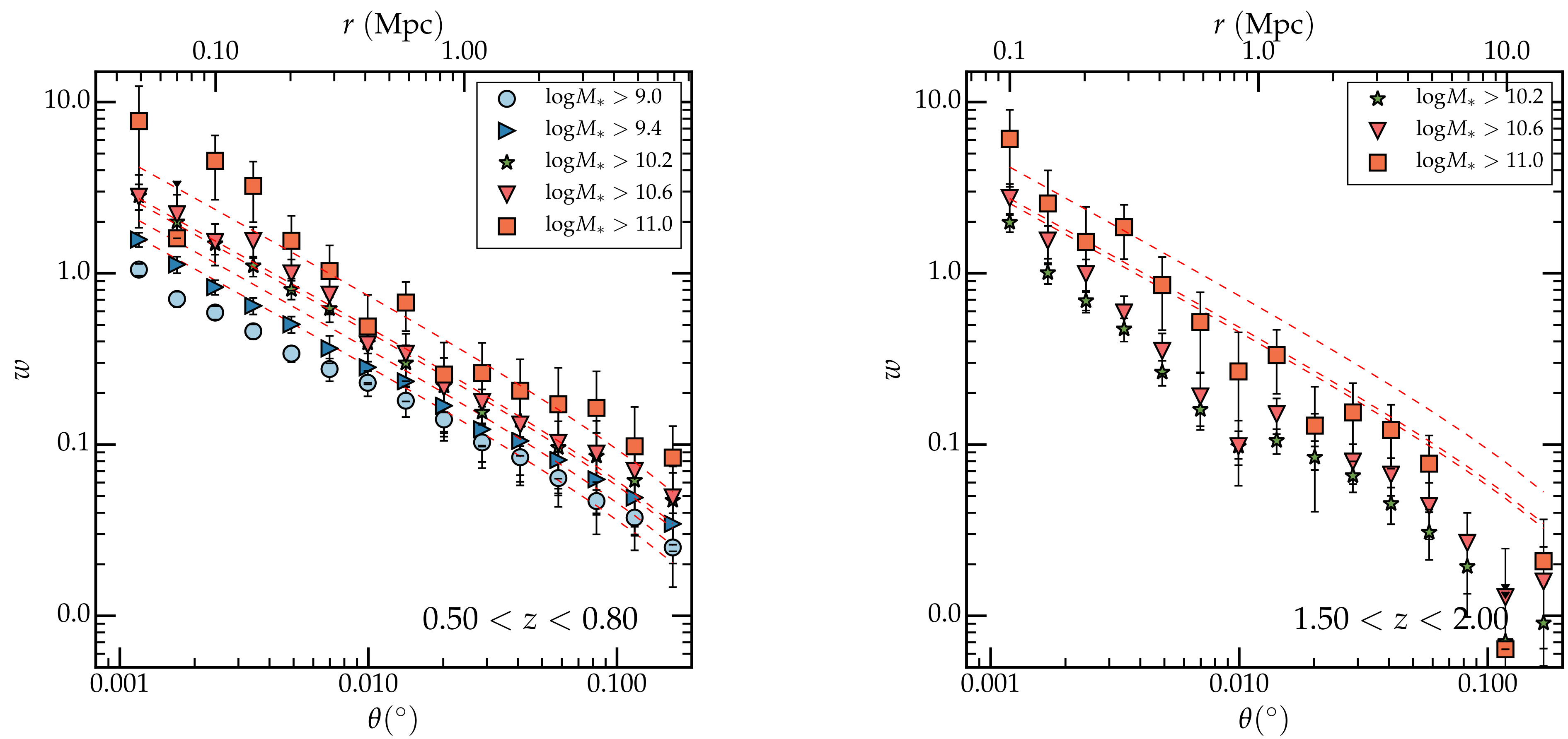
In the "**halo model**" we suppose that the pair counts come from galaxies **inside the same halo** and galaxies **in separate haloes**

By comparing galaxy clustering measurements with halo model predictions can derive **characteristic dark matter halo masses**



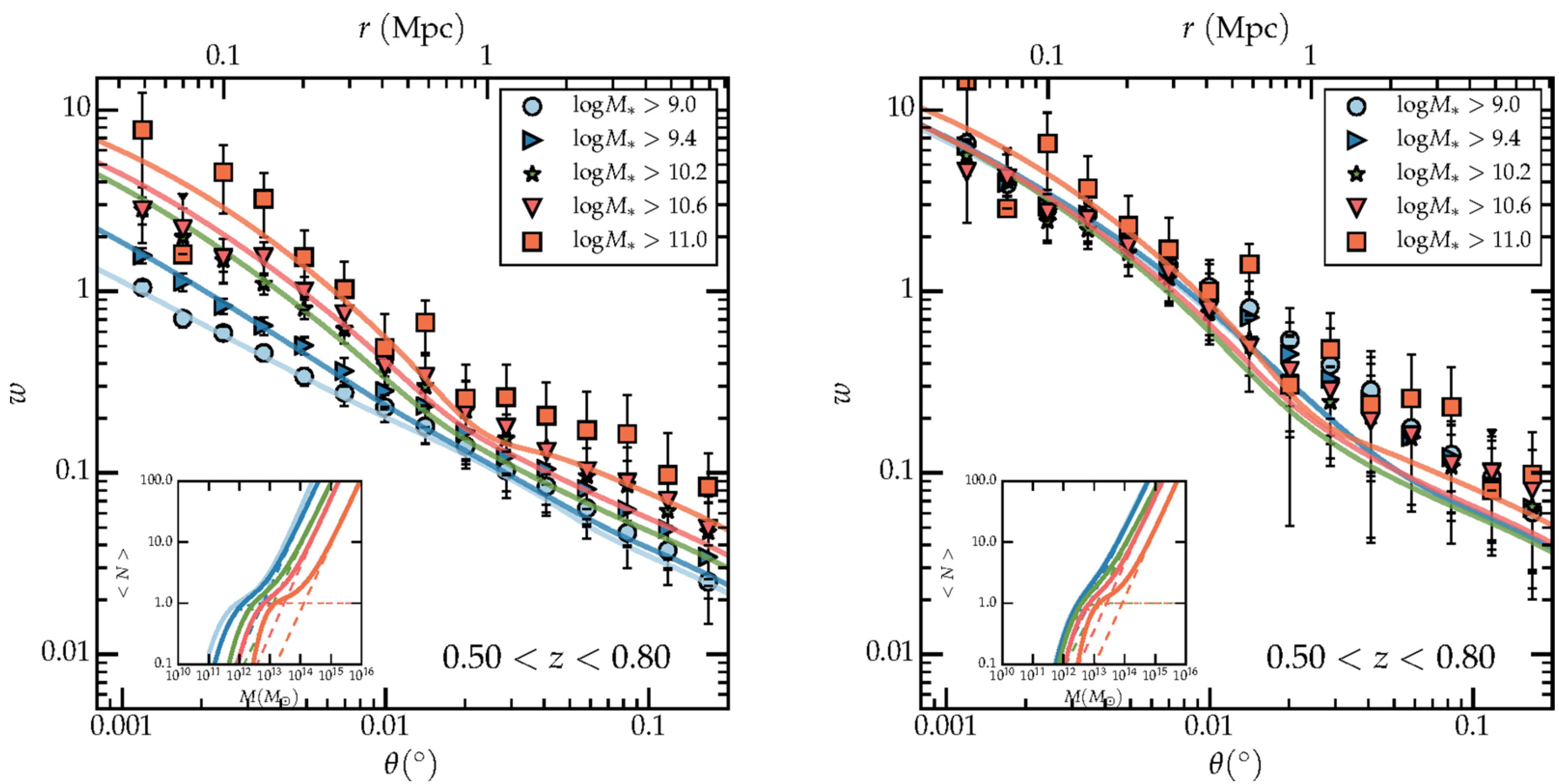
Halo model can tell us about the relative numbers of **central galaxies** and

Angular correlation functions



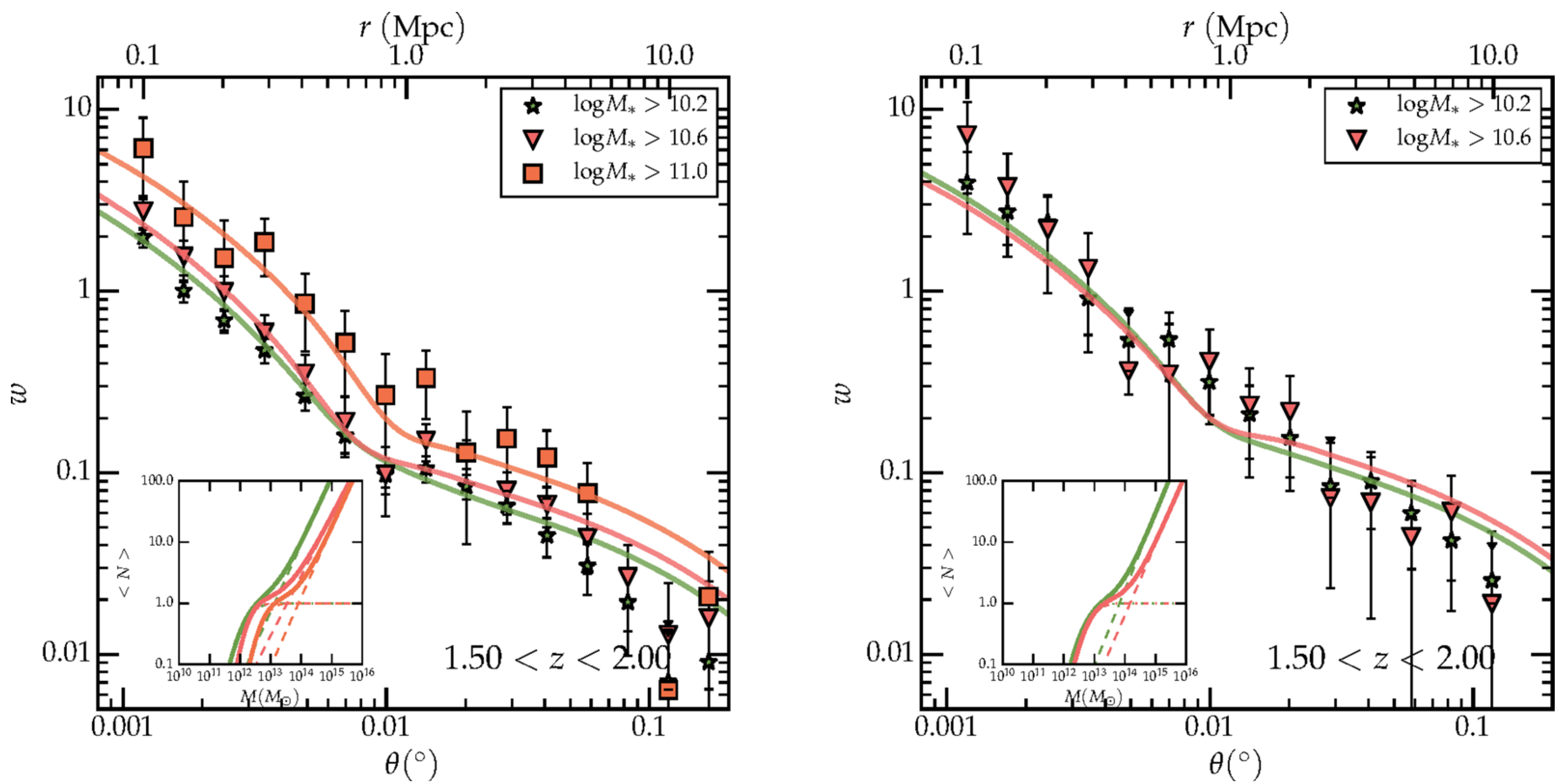
McCracken et al. 2015

Fits with the halo model



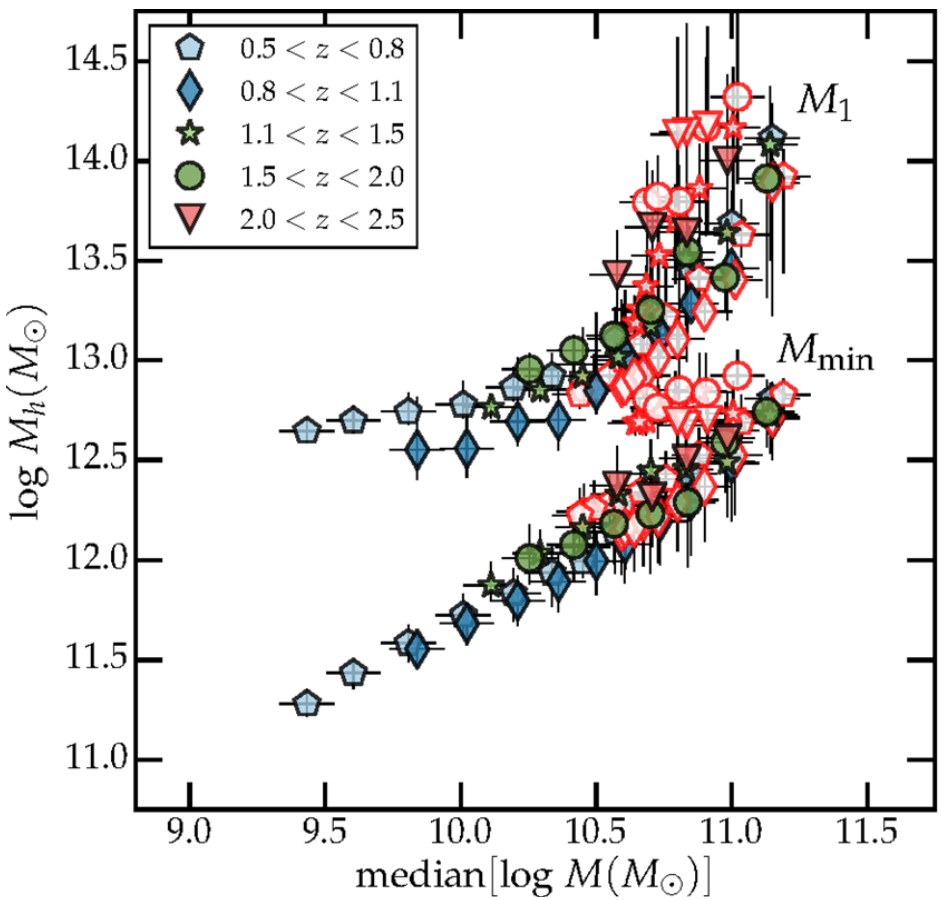
McCracken et al. 2015

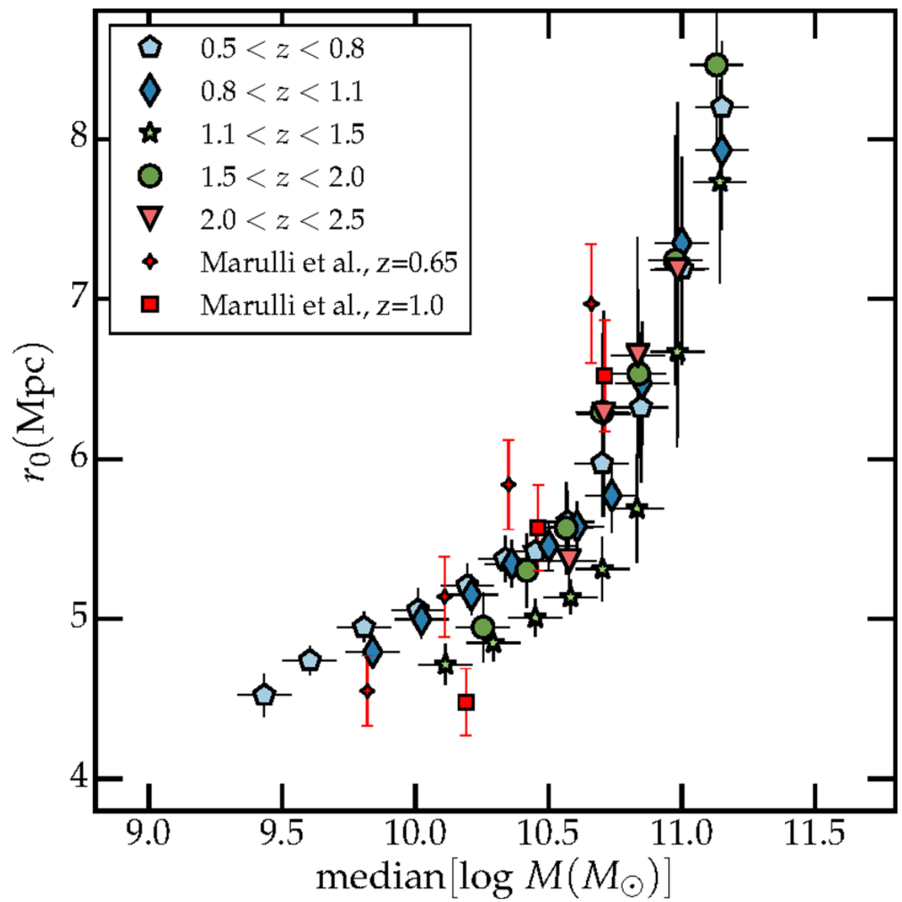
Fits to halo model (2)



McCracken et al. 2015

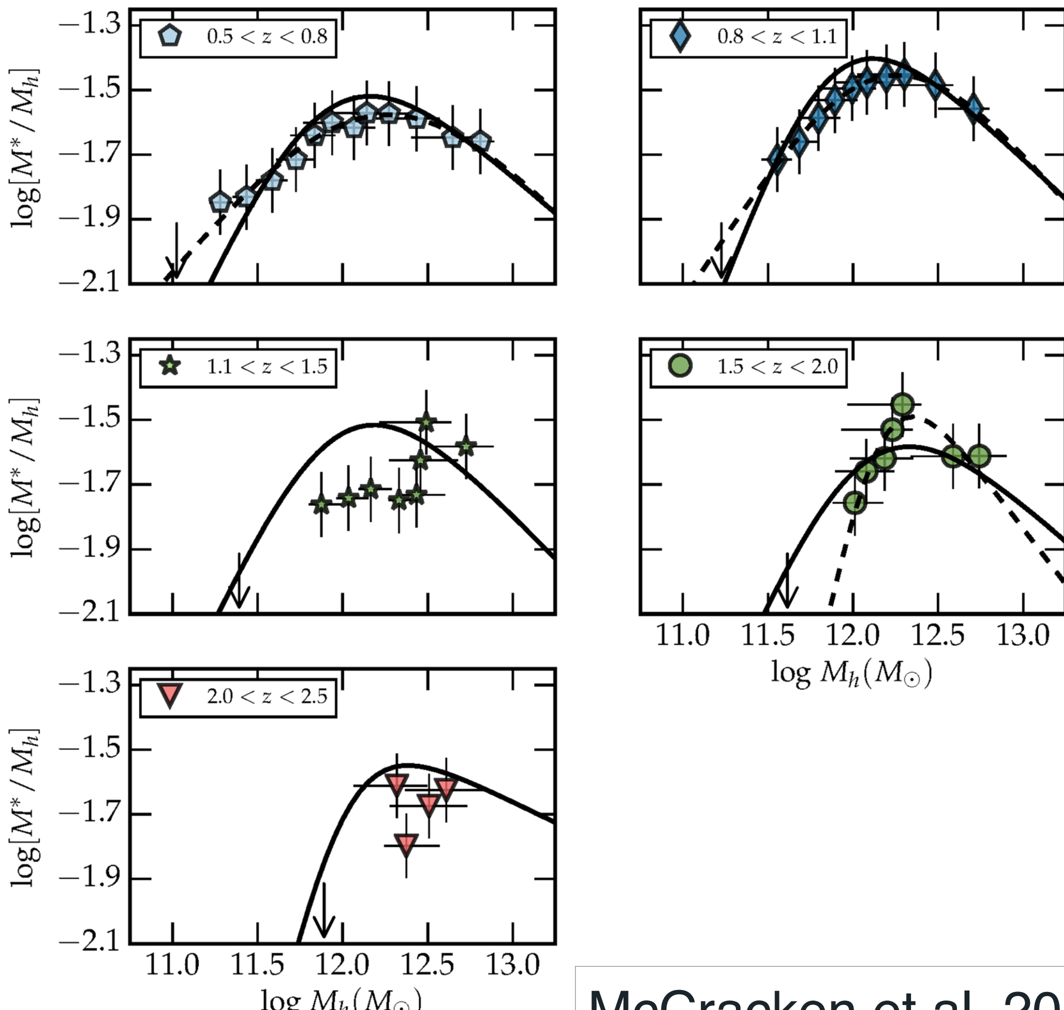
Halo mass and clustering length





McCracken et al. 2015

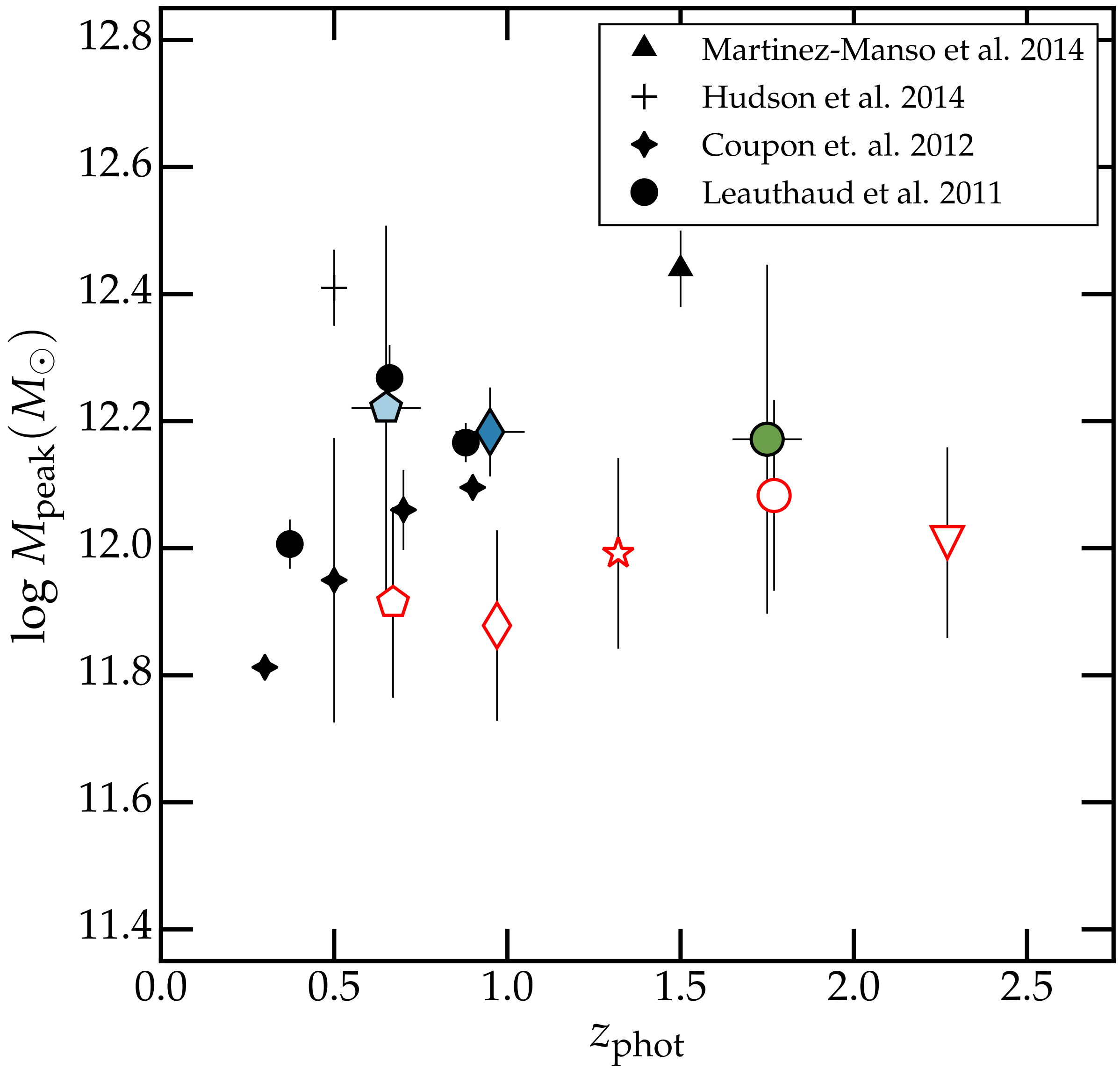
Abundance matching / halo model comparisons



McCracken et al. 2015

- Solid points: HOD fits; solid line: abundance matching.
- Abundance matching allows us to fill in missing slices. Works surprising well !

The SHMR relationship to z~2



McCracken et al. 2015

- The position of the peak in the SHMR relationship only slowly evolves with redshift
  - Can understand this as a consequence of the slow evolution of M* in the stellar mass function

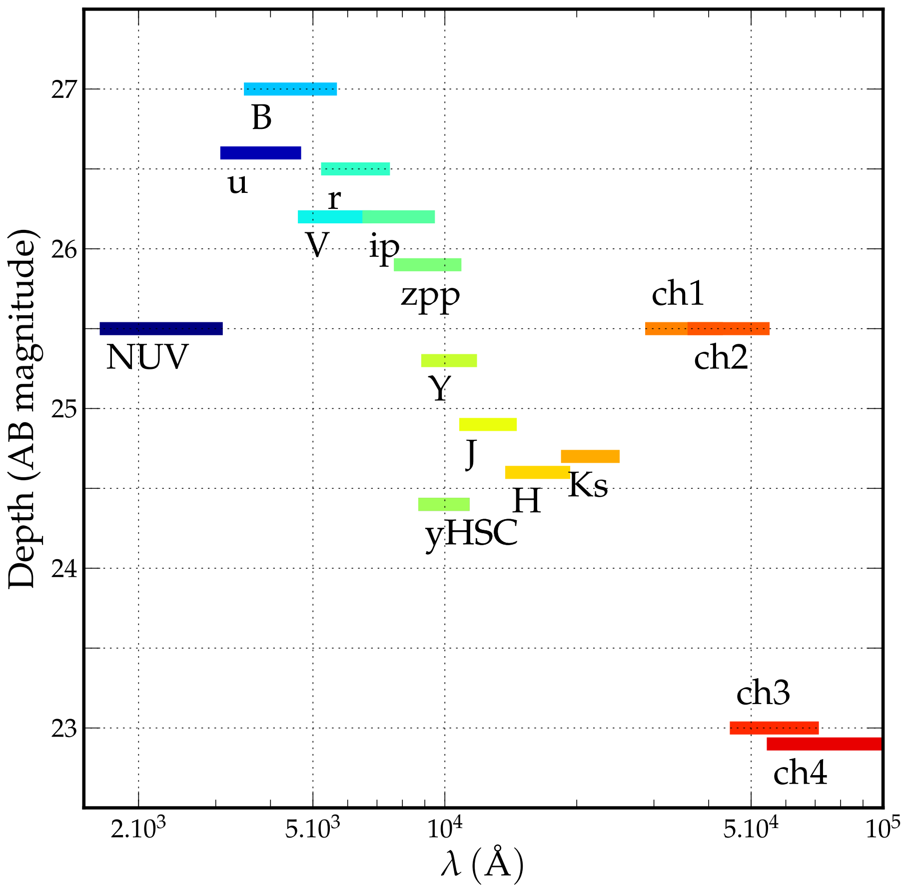
The future

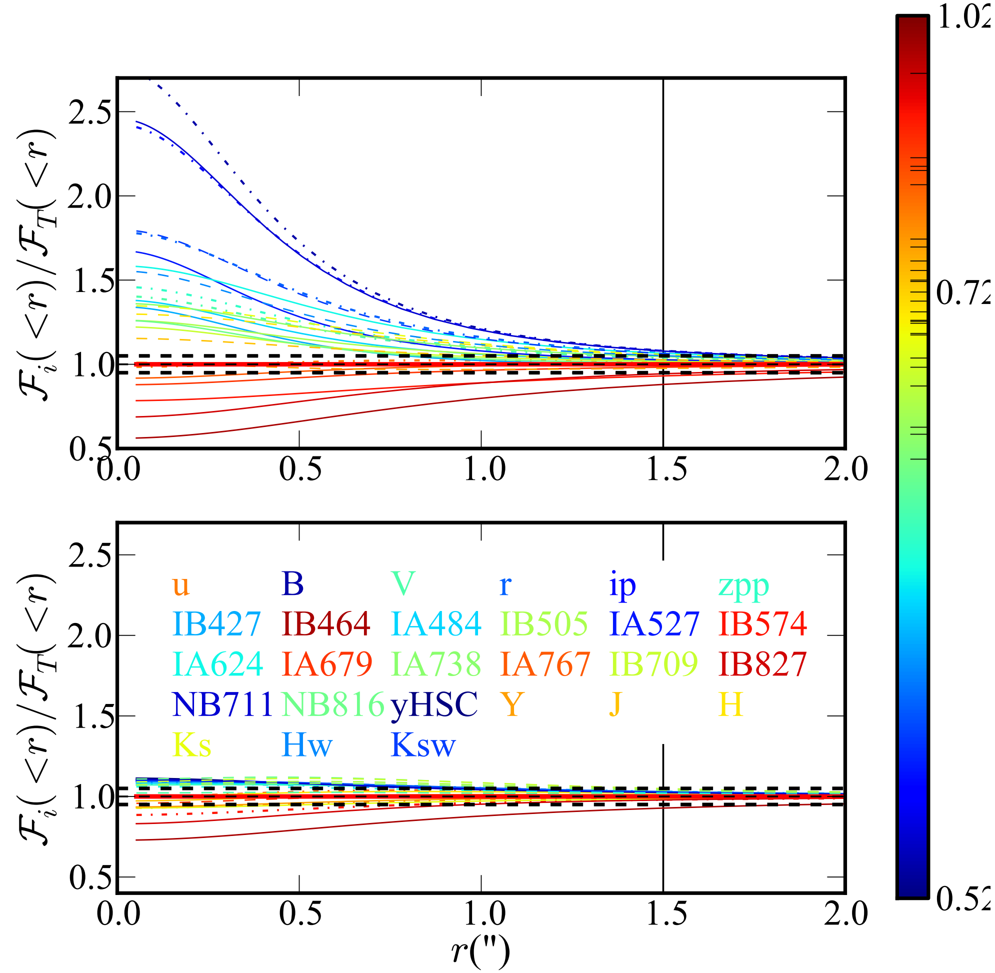
High redshifts: SPLASH+DR2

- **NEW** UltraVISTA **DR2** data+NEW COMOS data + Splash IRAC, **new PSF homogenisation**
- **Catalogue + photometric redshifts + stellar masses will be made public**
- We will produce the largest most precise **stellar-mass selected catalogue** at 2<z<4
- HORIZON-AGN lightcone and simulated images and catalogues

Laigle et al. 2015 in prep.

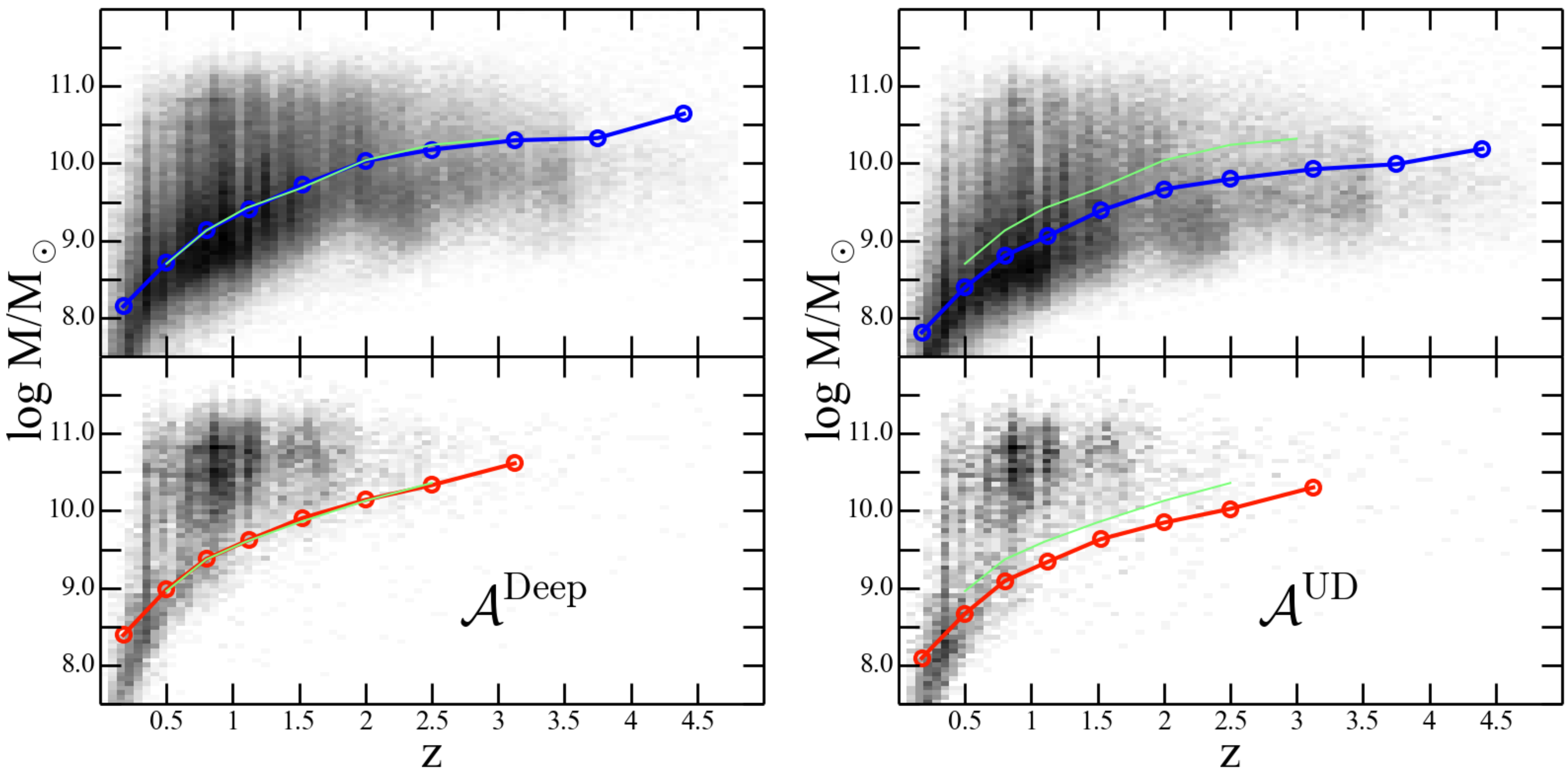
COSMOS2015





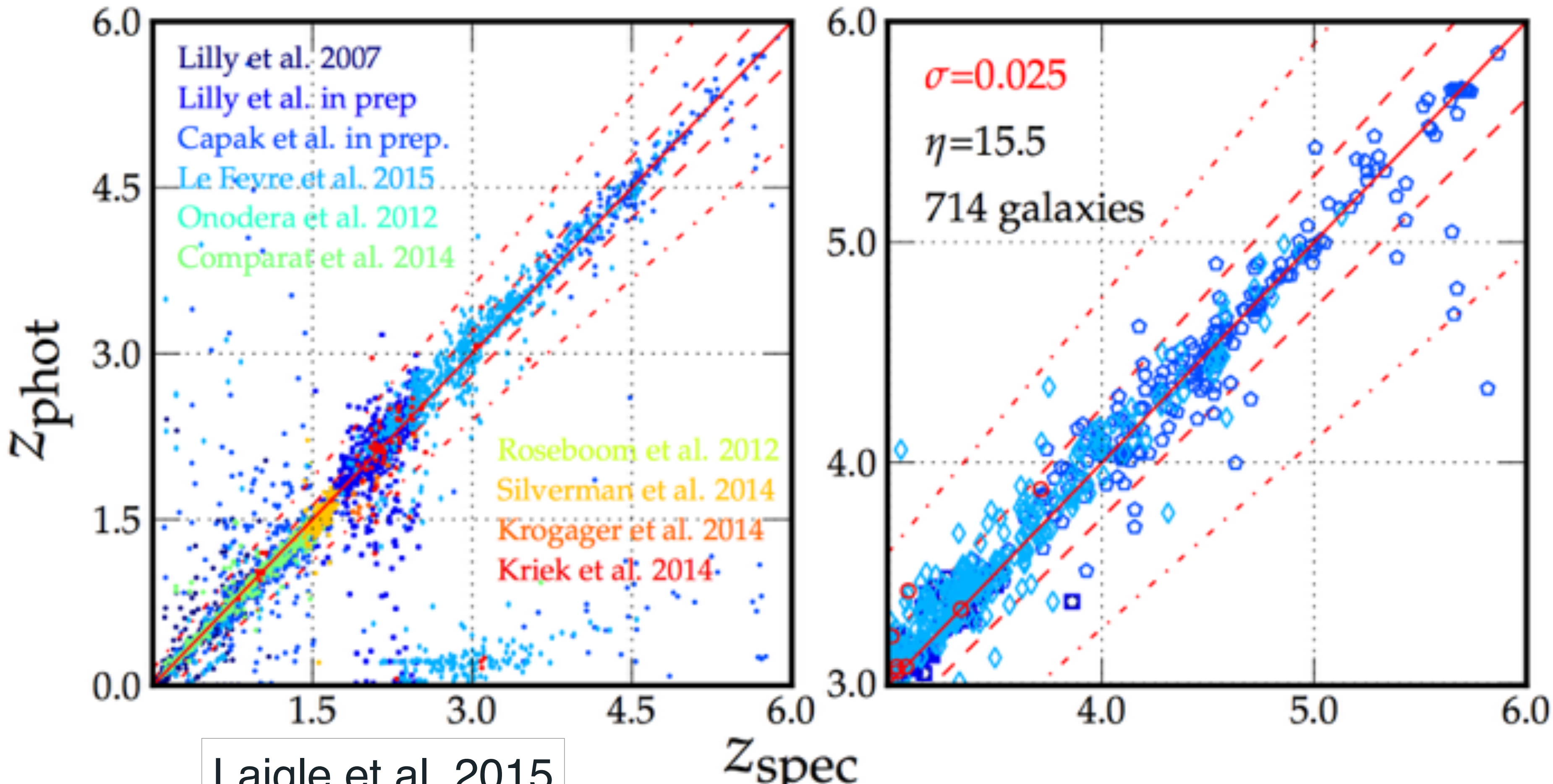
Laigle et al. 2015

Better stellar masses



Laigle et al. 2015

More precise photometric redshifts at z~4

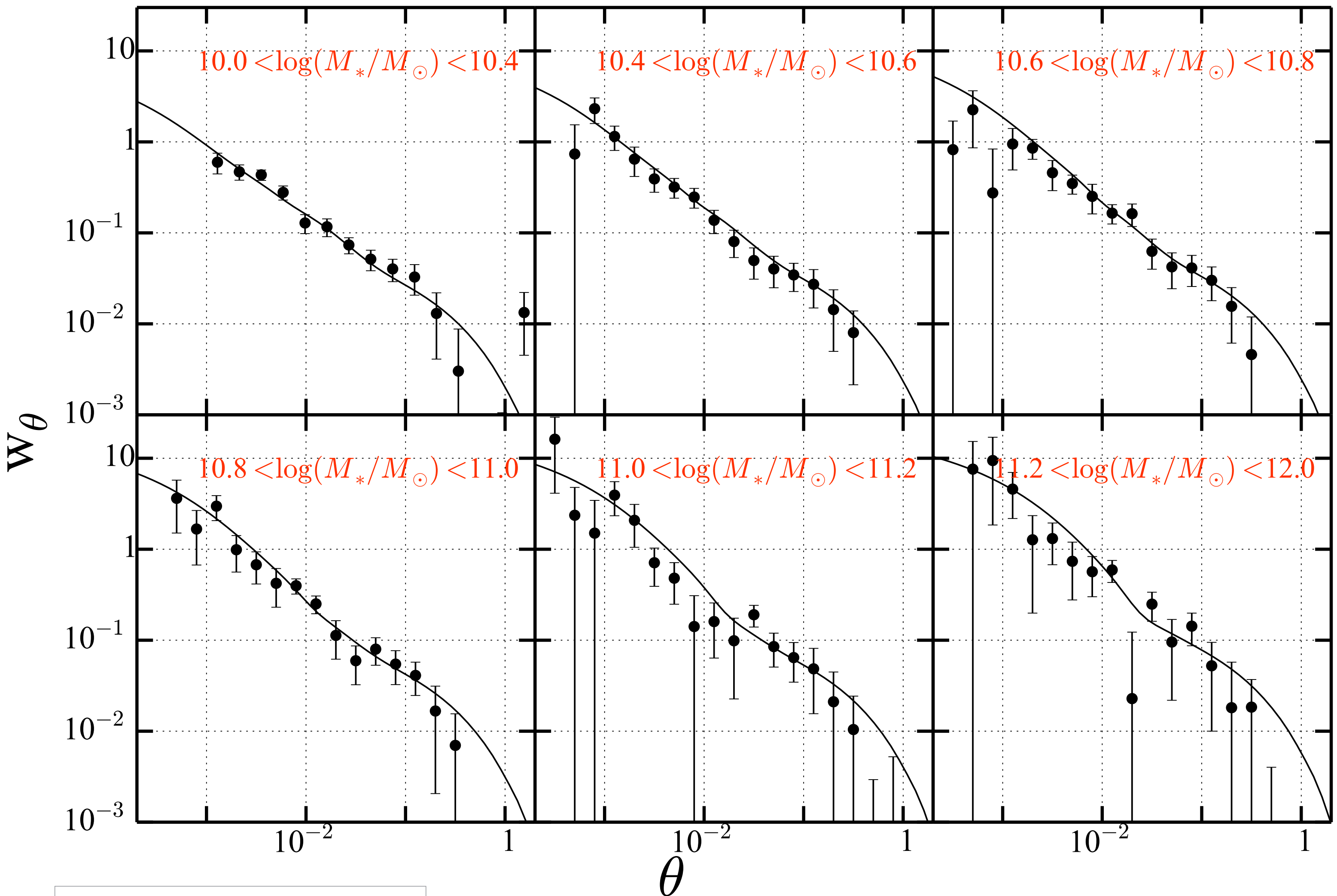


Laigle et al. 2015

Stellar mass functions at 4<z<6

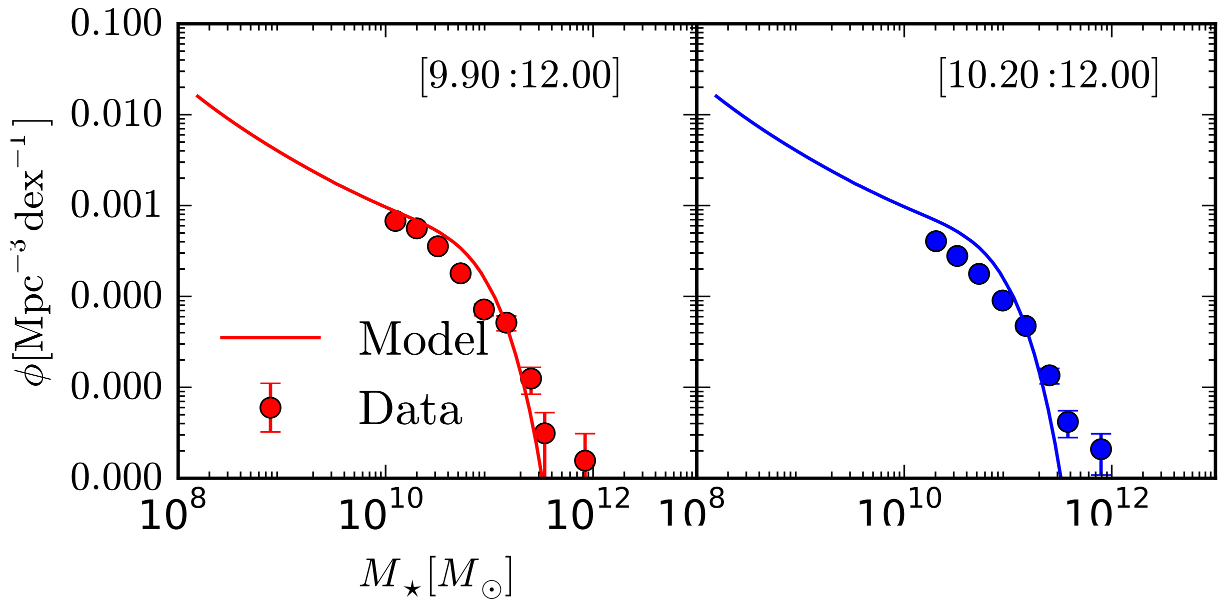
- Need to move to IRAC-selected galaxy samples at very high redshifts
  - Need to do a very careful job at deconvolving confused IRAC data, using UltraVISTA data
- All current high-redshift stellar mass determinations based on uncertain and poorly determined UV dust correction
- Objective is to push SHMR to very high redshifts.

Galaxy clustering in DR2



Laigle et al. 2015

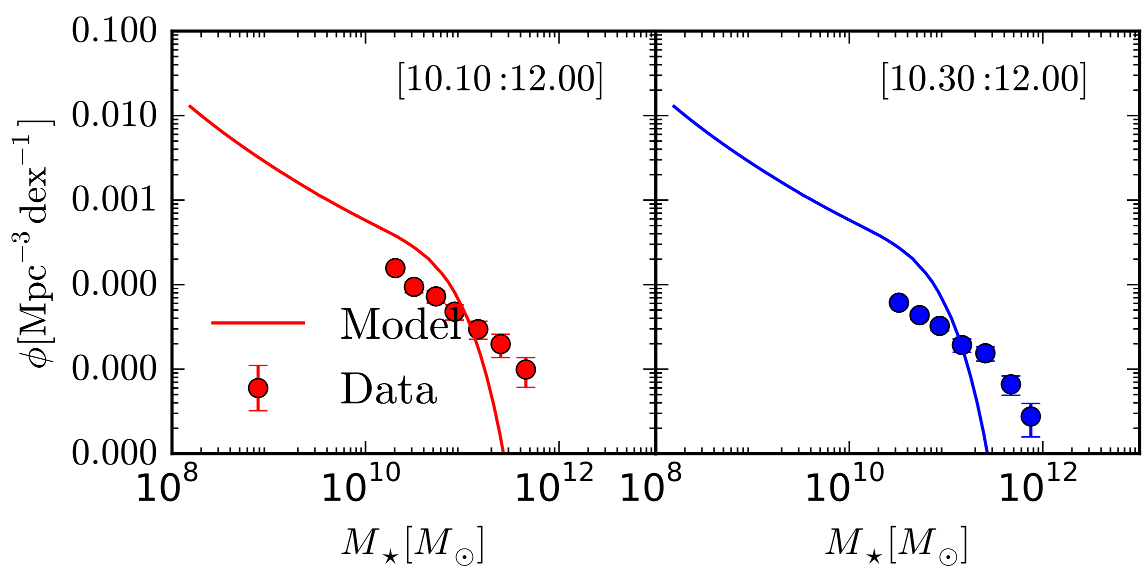
$3.10 < z < 3.70$



Mass-selected galaxy clustering at z~4

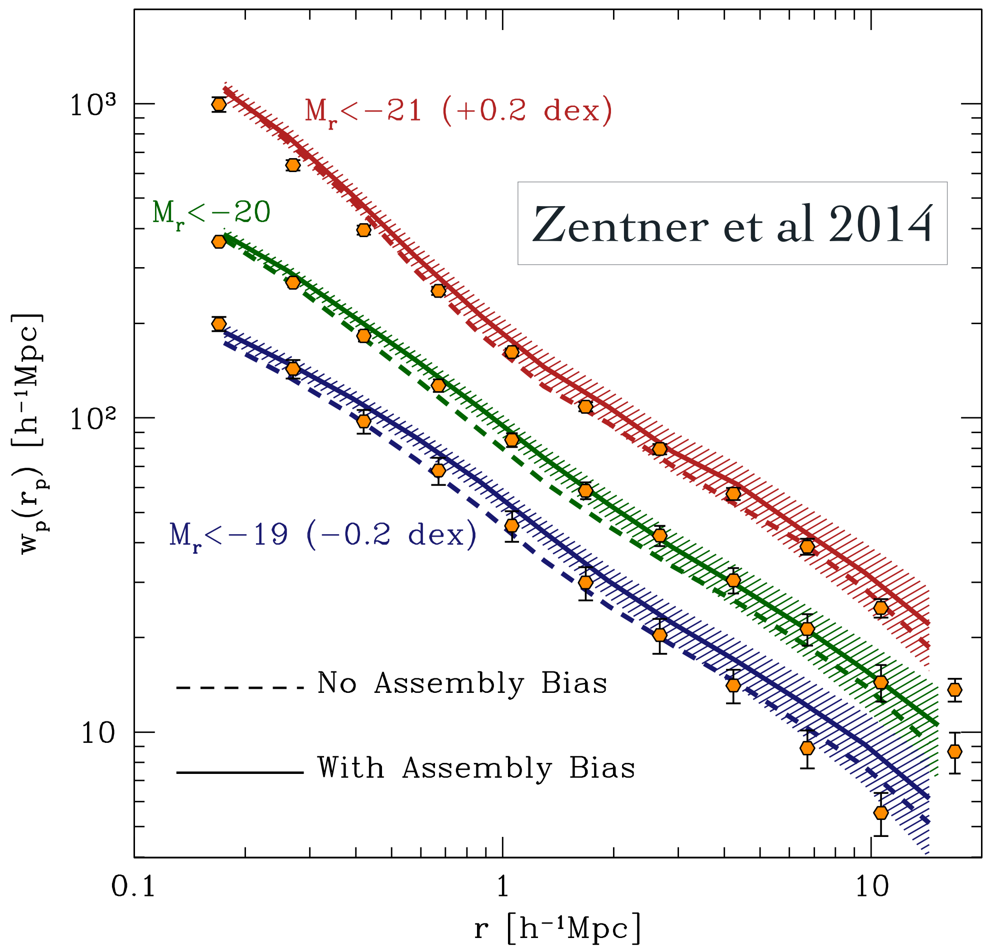
$3.70 < z < 4.30$

Remarkable agreement between model predictions and data – no fits !

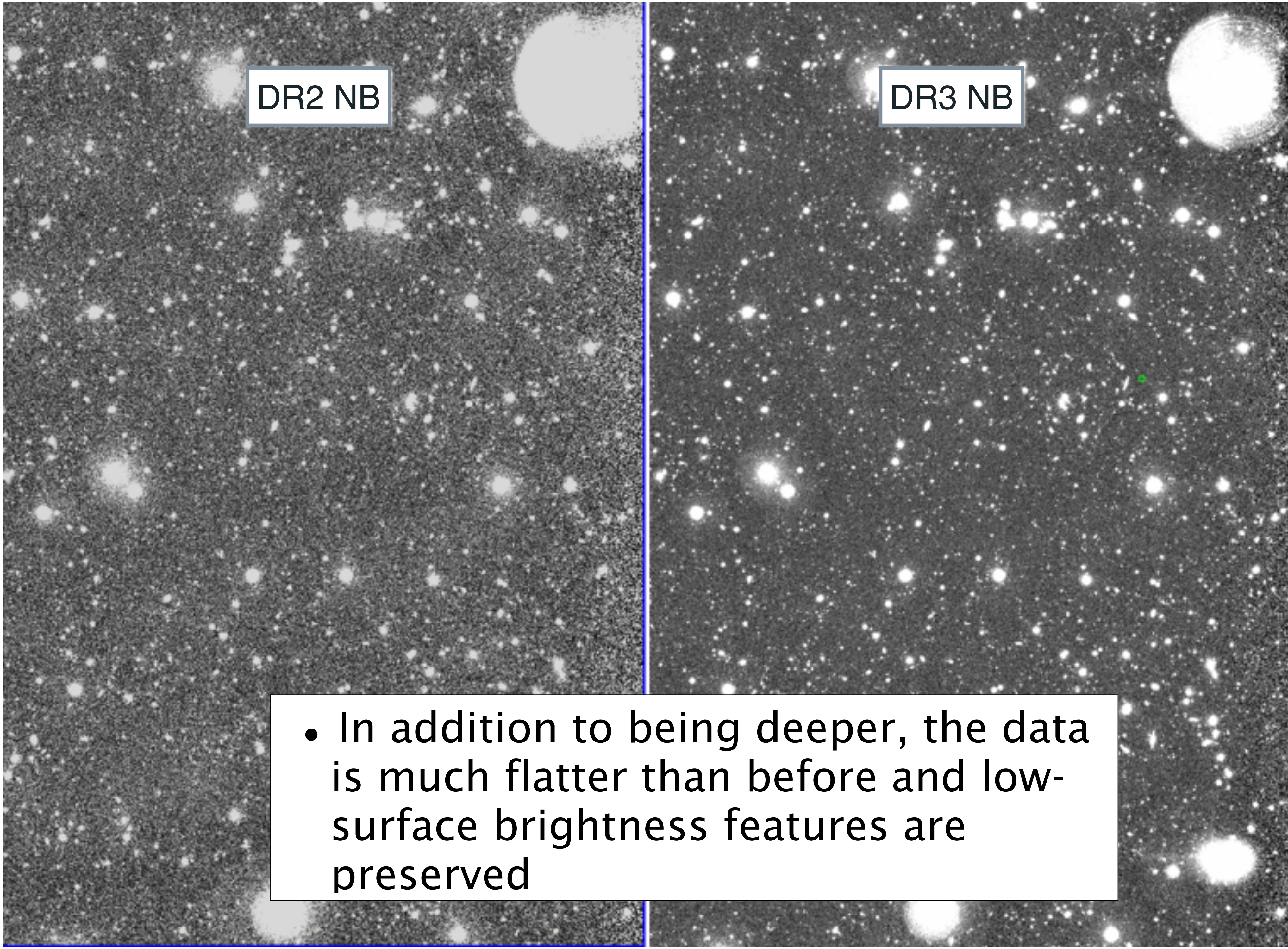


Is there "assembly bias"?

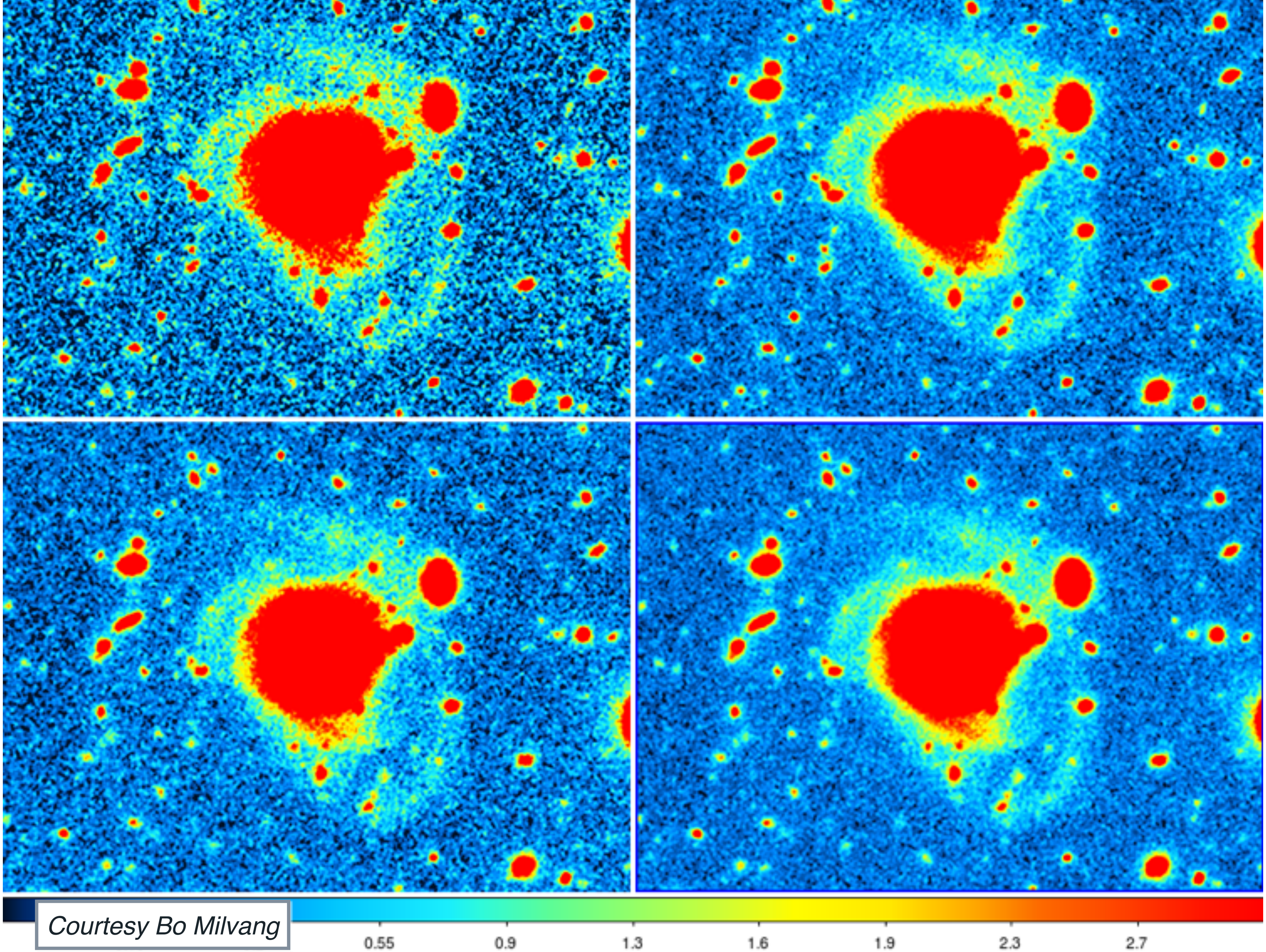
- Assembly bias is a generic feature of abundance matching simulations
- Attempts have been been made model it at fit to sloan data at z=0
- But maybe the effect is much stronger at higher redshifts?
  - Can check with hydro simulations?



DR3-4



- In addition to being deeper, the data is much flatter than before and low-surface brightness features are preserved



Courtesy Bo Milvang
0.55
0.9
1.3
1.6
1.9
2.3
2.7

Summary

- Little change in M* with redshift
  - Build-up in passive galaxy population now clearly observed
  - Discrepancy between MF derived star-formation rates and others seems to have gone away
- There slow evolution of in the peak of the M^*/M_h relation
  - No evidence for “Halo downsizing”
- **There is also remarkably slow evolution of distribution of galaxies in haloes**
- Bias evolves in such a way to counteract almost perfectly the reduction of clustering strength caused by projection effects: correlation lengths are constant.