What current samples of z=9-10 candidates from CANDELS, the HUDF, and the Frontier Fields tell us about future science with WISH

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Joint WISH + First Galaxies International Workshop

HUDF NICMOS J_{110}+H_{160}

144 orbits

HUDF WFC3/IR Y_{105}+J_{125}+JH_{140}+H_{160}

4 z > 6.5 galaxies (before WFC3/IR)
(first 850 Myr of universe)

↓

120 z > 6.5 galaxies (after WFC3/IR)
(first 850 Myr of universe)

ALL FIELDS

15 z > 6.5 galaxies (before WFC3/IR)

↓

~ 800 z >~ 6.5 galaxies (after WFC3/IR)

255 orbits

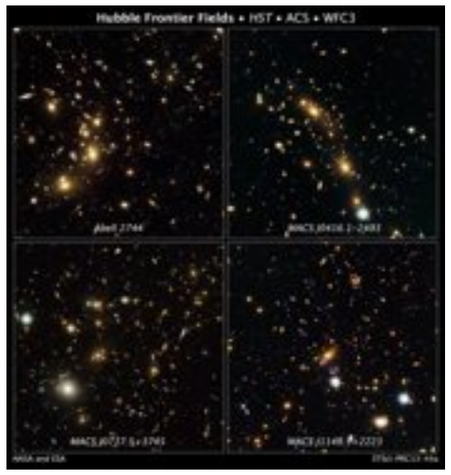
Large Samples of z~6.3-10.0 Galaxies Now Exist:

>~ 800 z>~6.2 galaxies known from HUDF + CANDELS + other fields

~20 z~9-10 galaxies

Hubble Ultra Deep Field

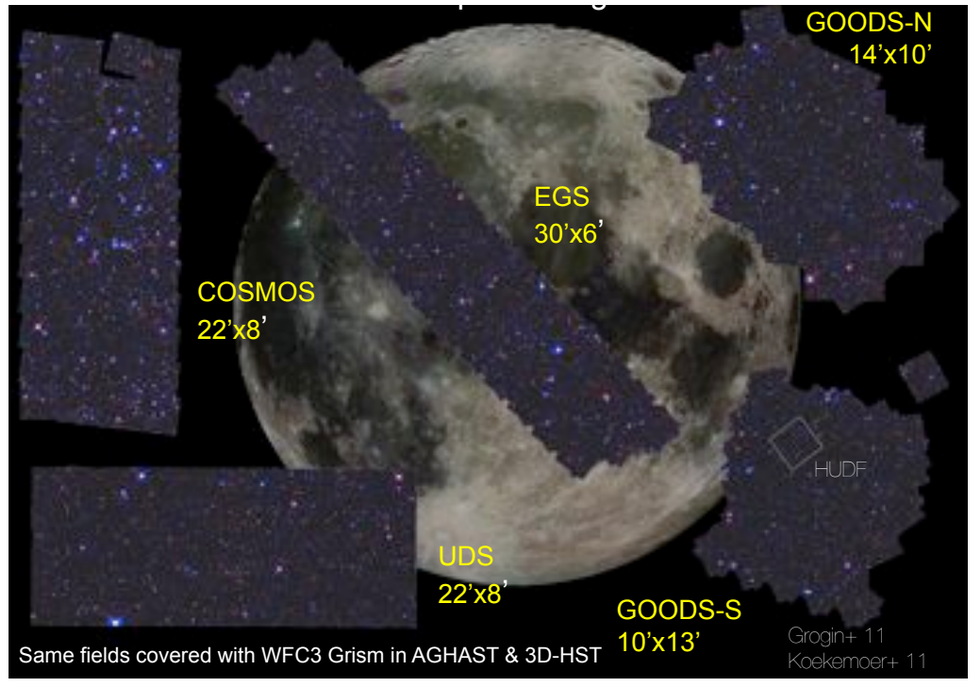
Hubble Frontier Fields



HUDF Parallel Fields

Area

Wide-Area CANDELS

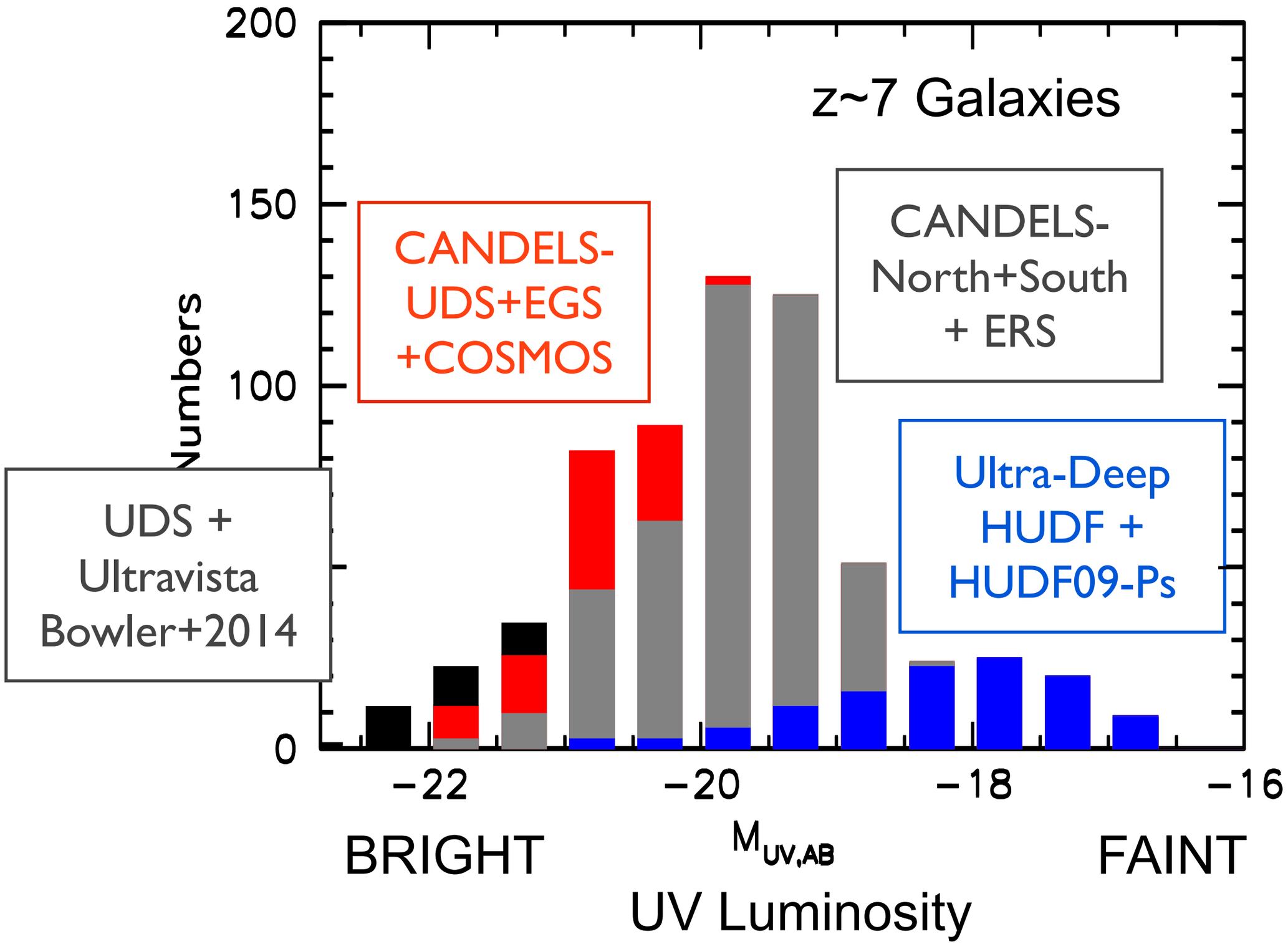


Depth

\+

UKIDSS UDS / UltraVISTA

Large Numbers of Galaxies at all Luminosities



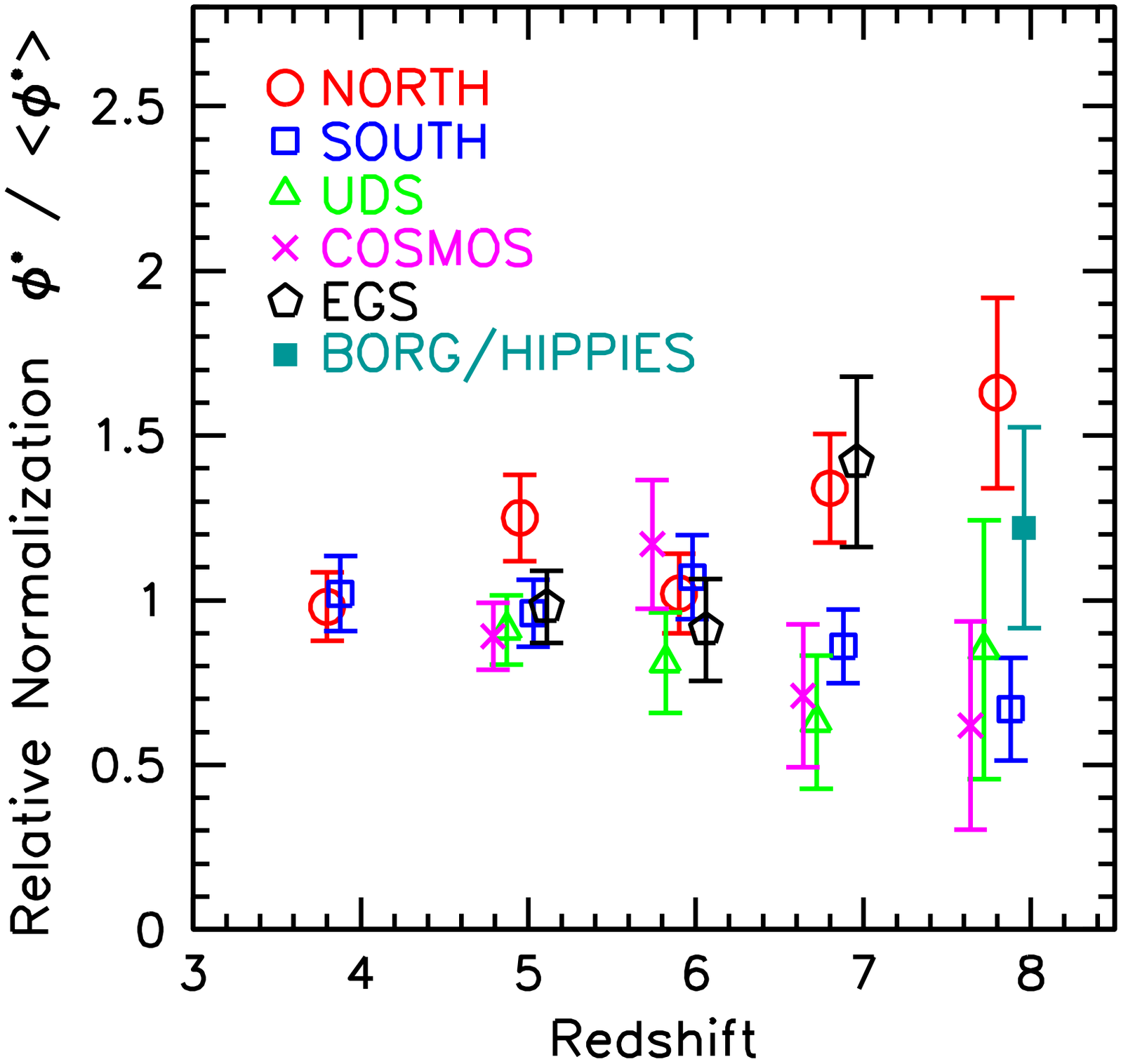
Bouwens+2014

Independent Search Fields allow us to Overcome Large Field-to-Field Variance Observed at High Redshift

Estimated field-to-field variance for z~4-8 samples.

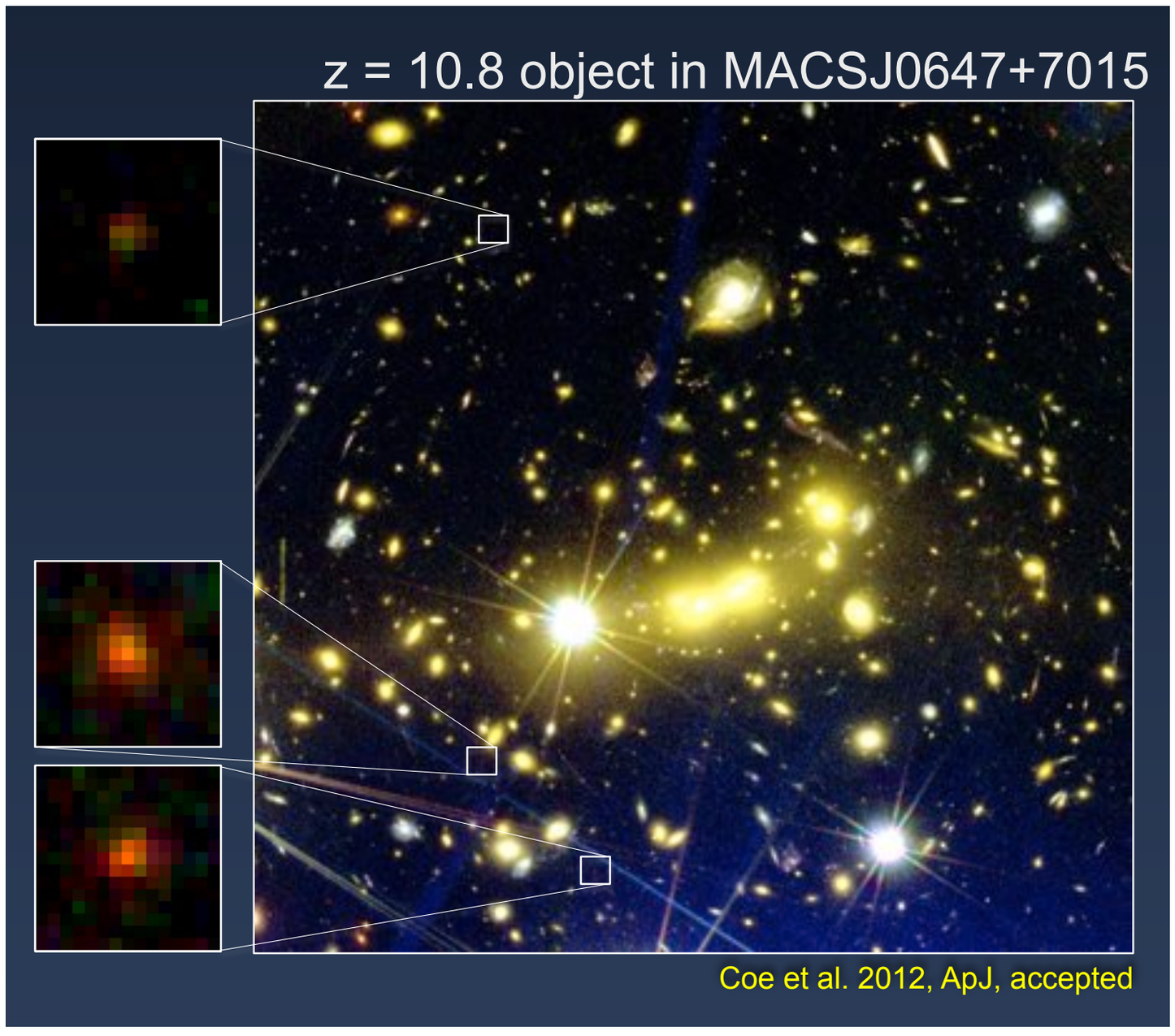
Field-to-field variance is substantial,

especially at high redshifts and at the bright end of the LF.



Bouwens+2014

What source is the likely/plausibly the highest redshift galaxy currently identified?



Triply-Imaged z~10.8 Galaxy behind MACS0647+7015

Bright ~26 mag

Both photometric evidence for this redshift as well as evidence from lensing model

Magnified by ~10x

Coe+2013

Why are studies of galaxies at very high redshifts interesting?

-- It is when galaxies first form...
(halos of L* and sub-L* galaxies built up from z~30+ to z~3)

-- It is when the universe was reionized...
(galaxies are most likely driver, so by studying the formation of first galaxies perhaps we can gain insight)

-- It is when the stellar populations of galaxies change rapidly
(from metal and dust build up)

WISH Science Interest #1:
How Fast Do Massive / Luminous Galaxies Build up?

WISH Science Interest #1:
Large Numbers of Luminous Galaxies at z=7-15

Essential to Make Optimal Use of Current Surveys to Predict the Evolution of the LF to high redshift

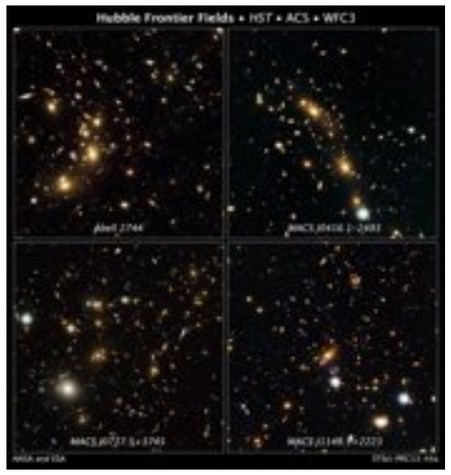
Large Samples of z~6.3-10.0 Galaxies Now Exist:

>~ 800 z>~6.2 galaxies known from HUDF + CANDELS + other fields

~20 z~9-10 galaxies

Hubble Ultra Deep Field

Hubble Frontier Fields



HUDF Parallel Fields

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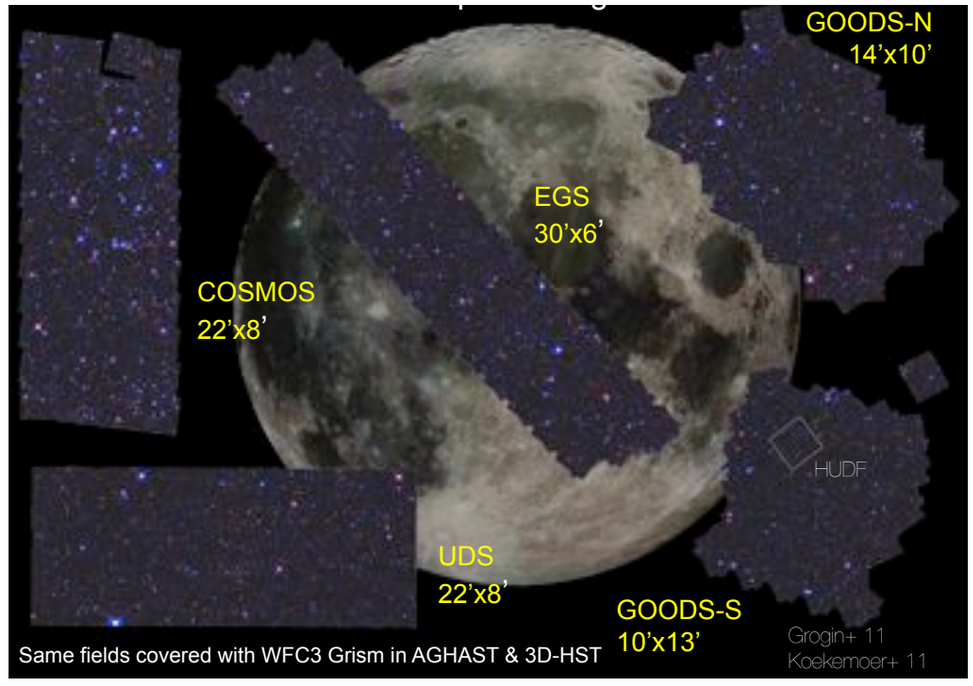


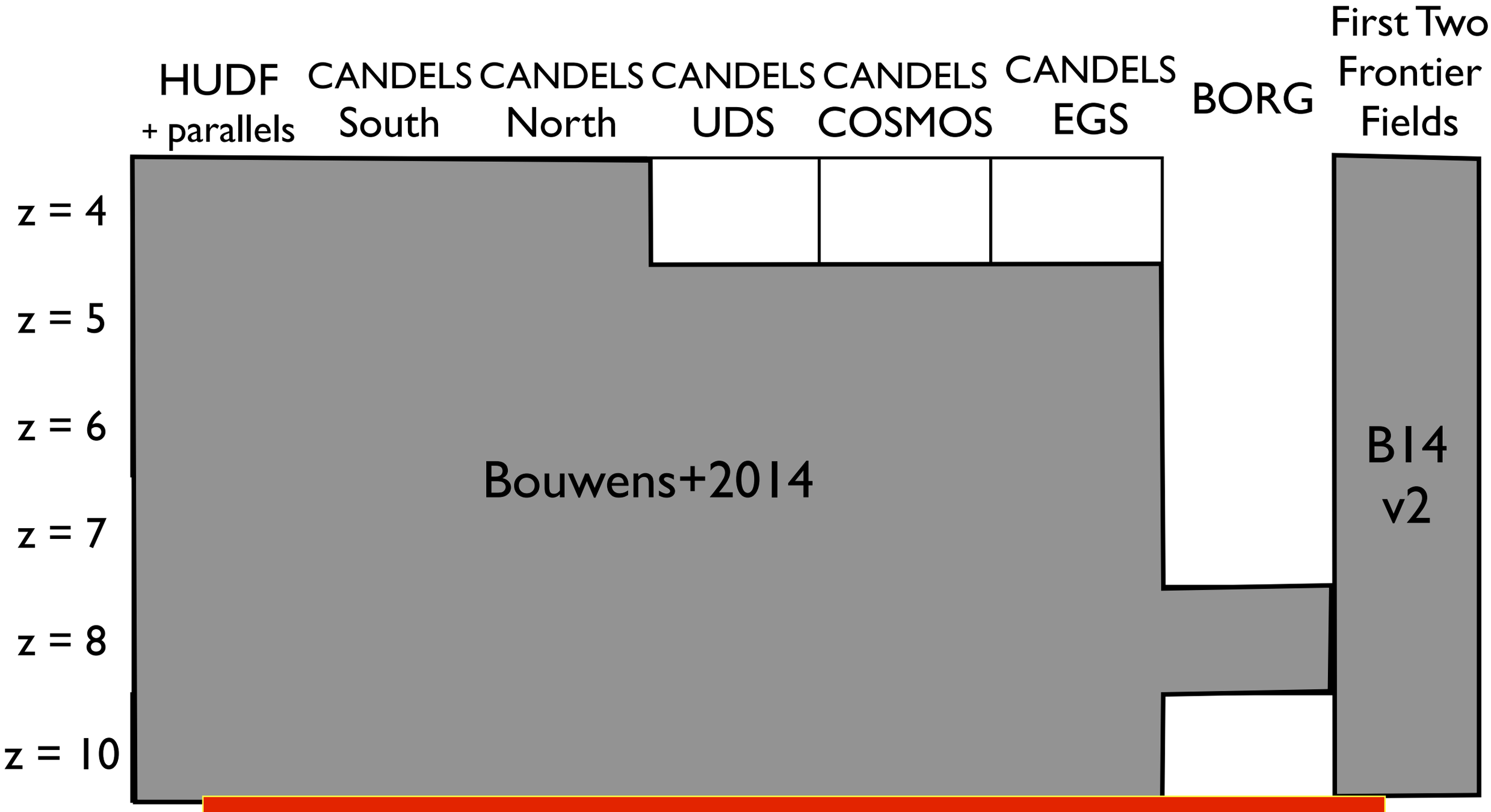
Depth

\+

UKIDSS UDS / UltraVISTA

z~4-10 LFs from all CANDELS + HUDF + other legacy fields

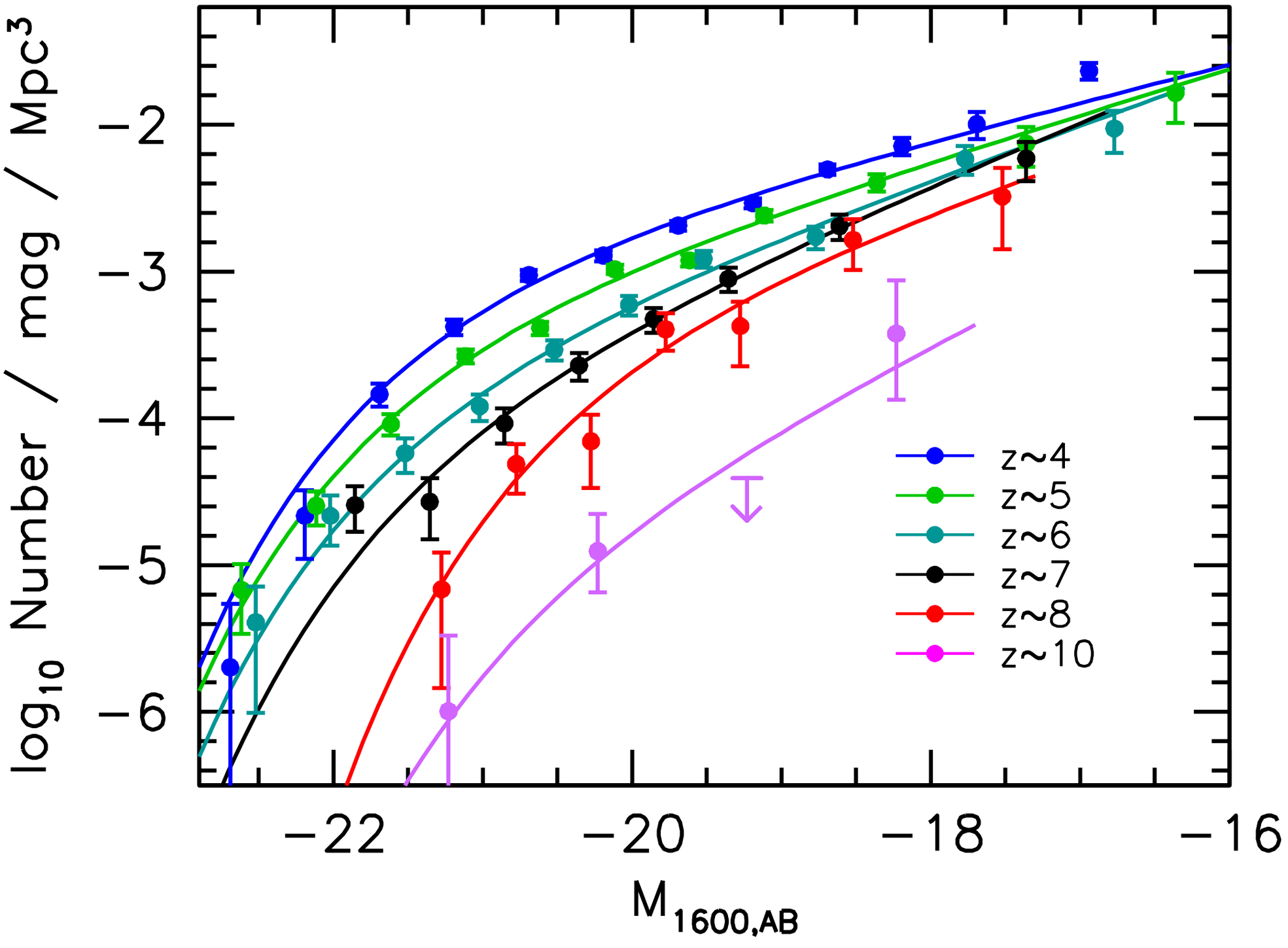
(Bouwens et al. 2014, arXiv:1403.4295, 48 pages)



In Bouwens+2014, we made use of a sample of >~11000 galaxies in total over ~1000 arcmin^2

New determinations of UV LF at z~4, 5, 6, 7, 8, 10 from all HST Legacy Fields

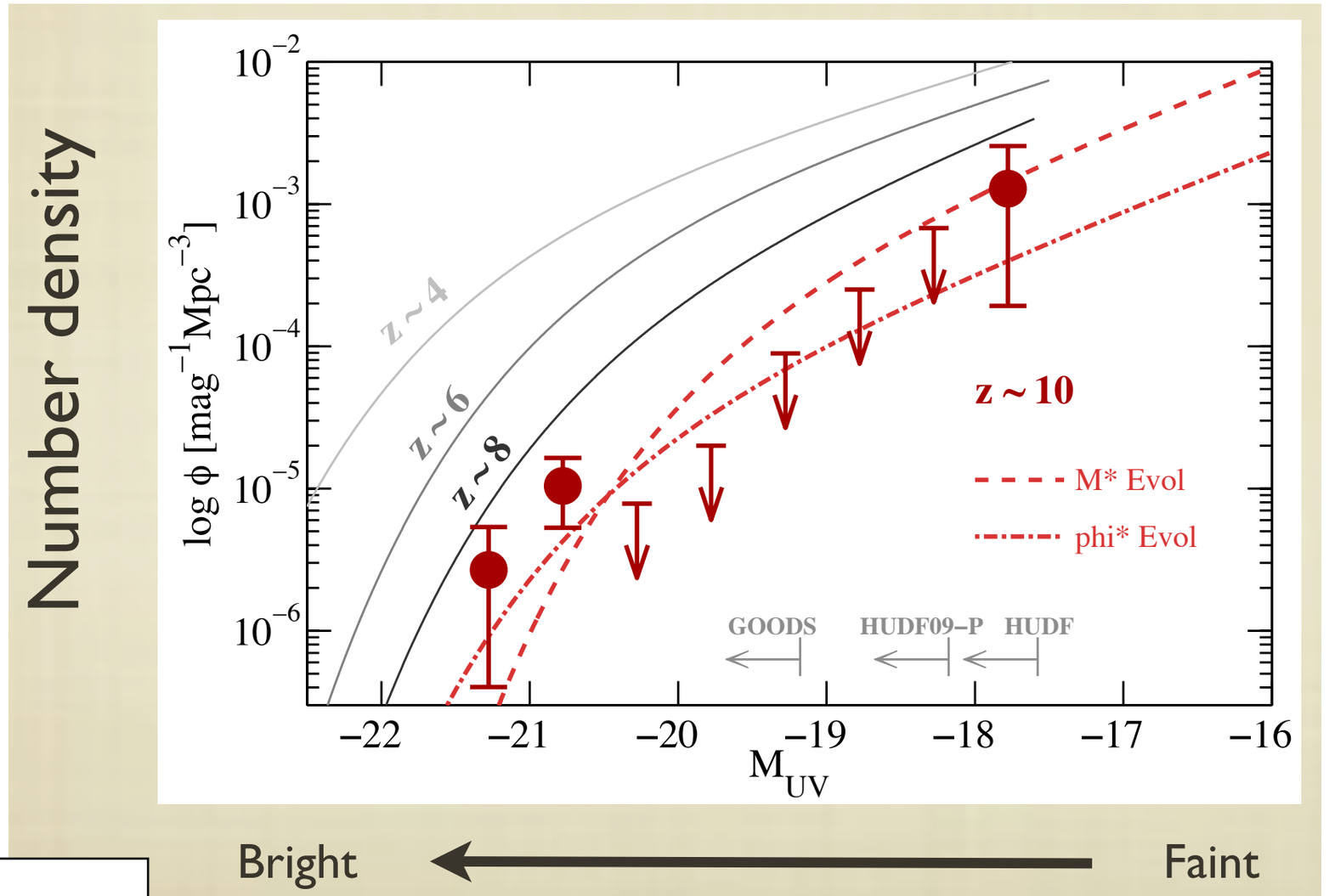
(Bouwens et al. 2014, arXiv:1403.4295), >11000 galaxies



Volume Density of Bright z~9-10 Galaxies

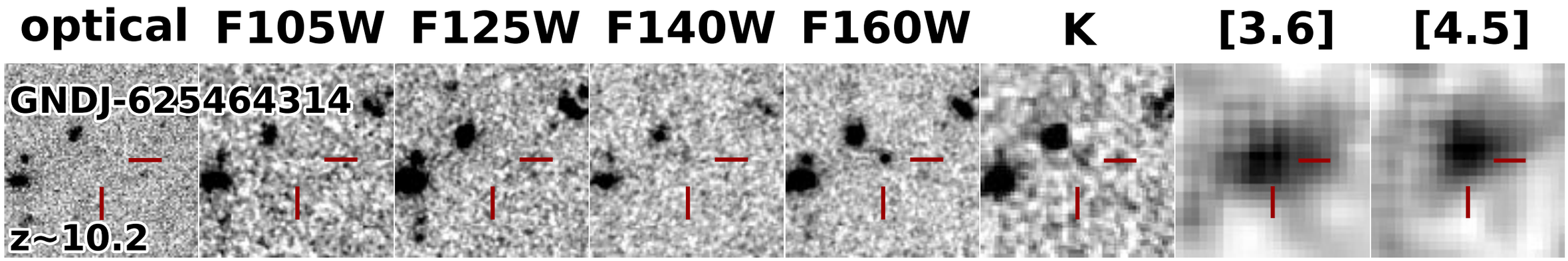
Of particular interest for the new WISH surveys are the prevalence of z~9-10 galaxies

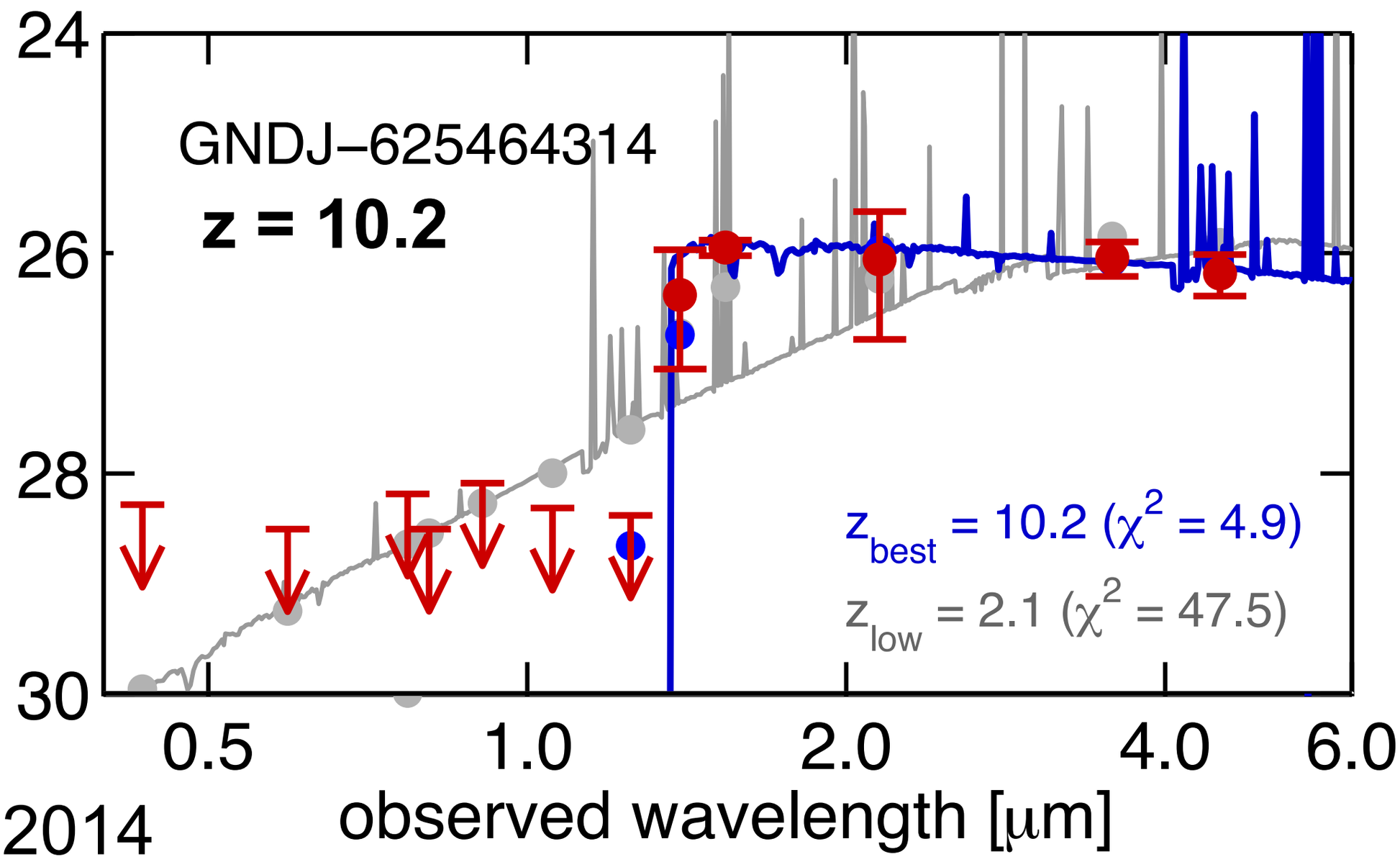
What work has been done on this?



Oesch+2014

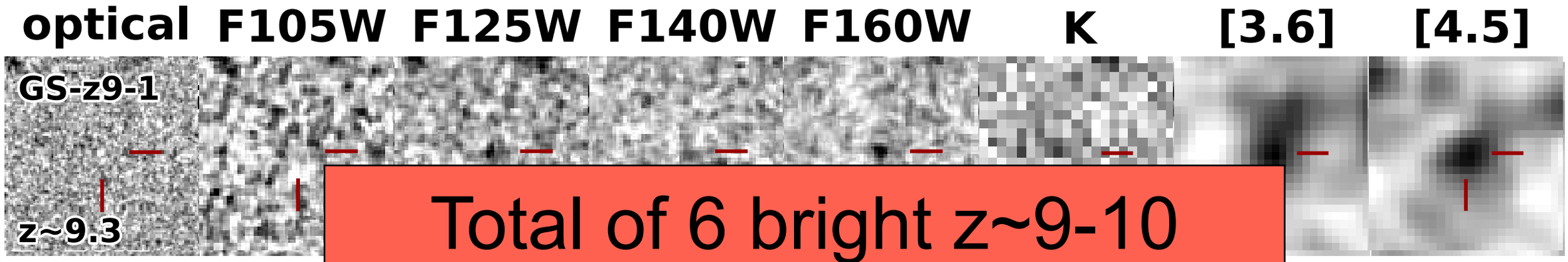
One of Six Bright z~9-10 Galaxies in CANDELS



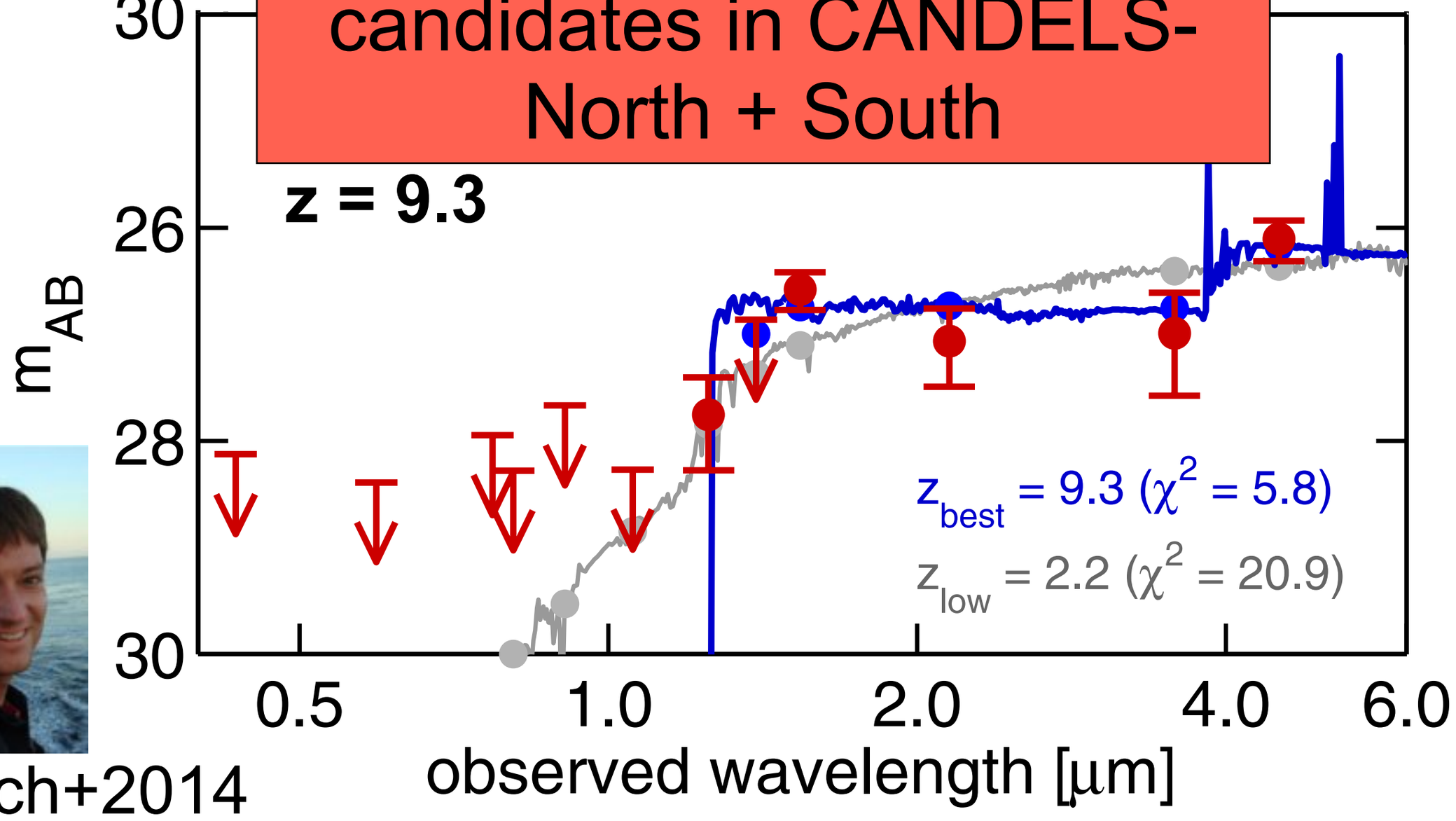


Oesch+2014

Another Bright z~9-10 Galaxy in CANDELS



Total of 6 bright z~9-10 candidates in CANDELS-North + South

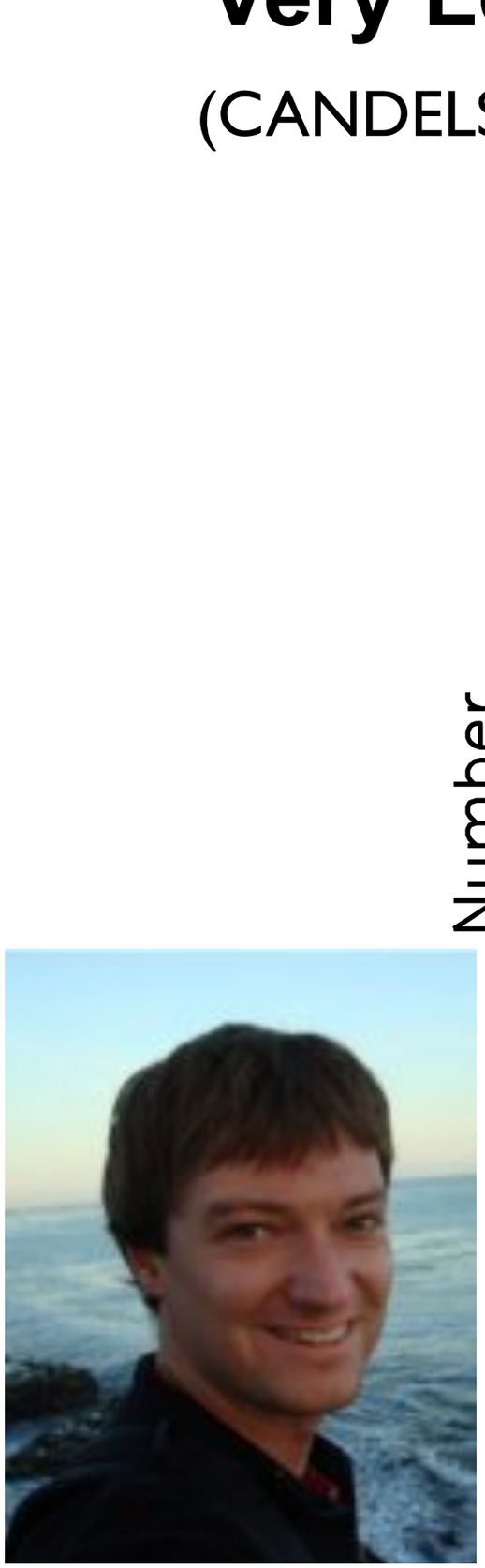


Oesch+2014

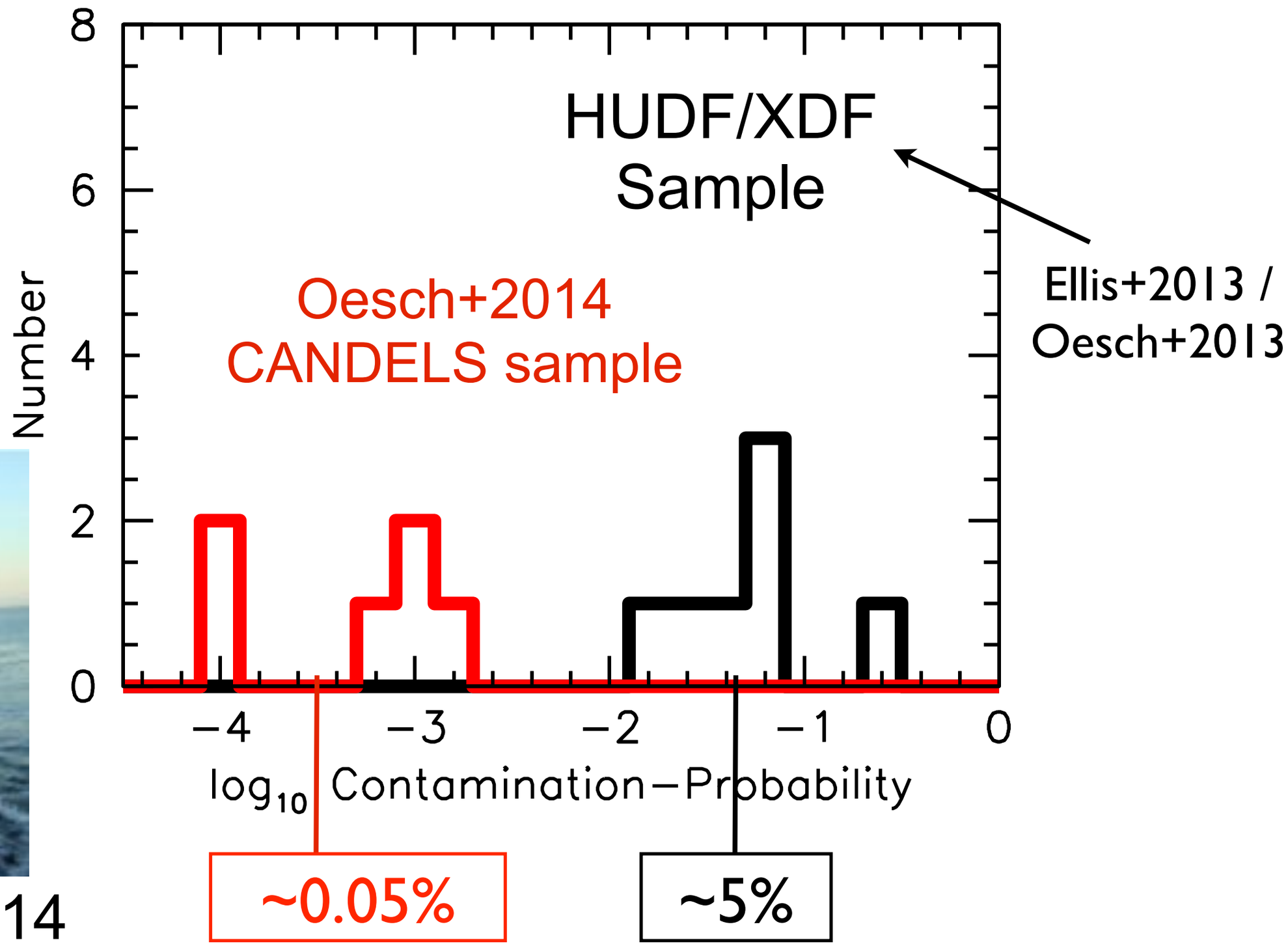
Are the bright z ~ 9-10 galaxy candidates from Oesch+2014 plausible / reliable?

Very Low Formal Probability of Contamination

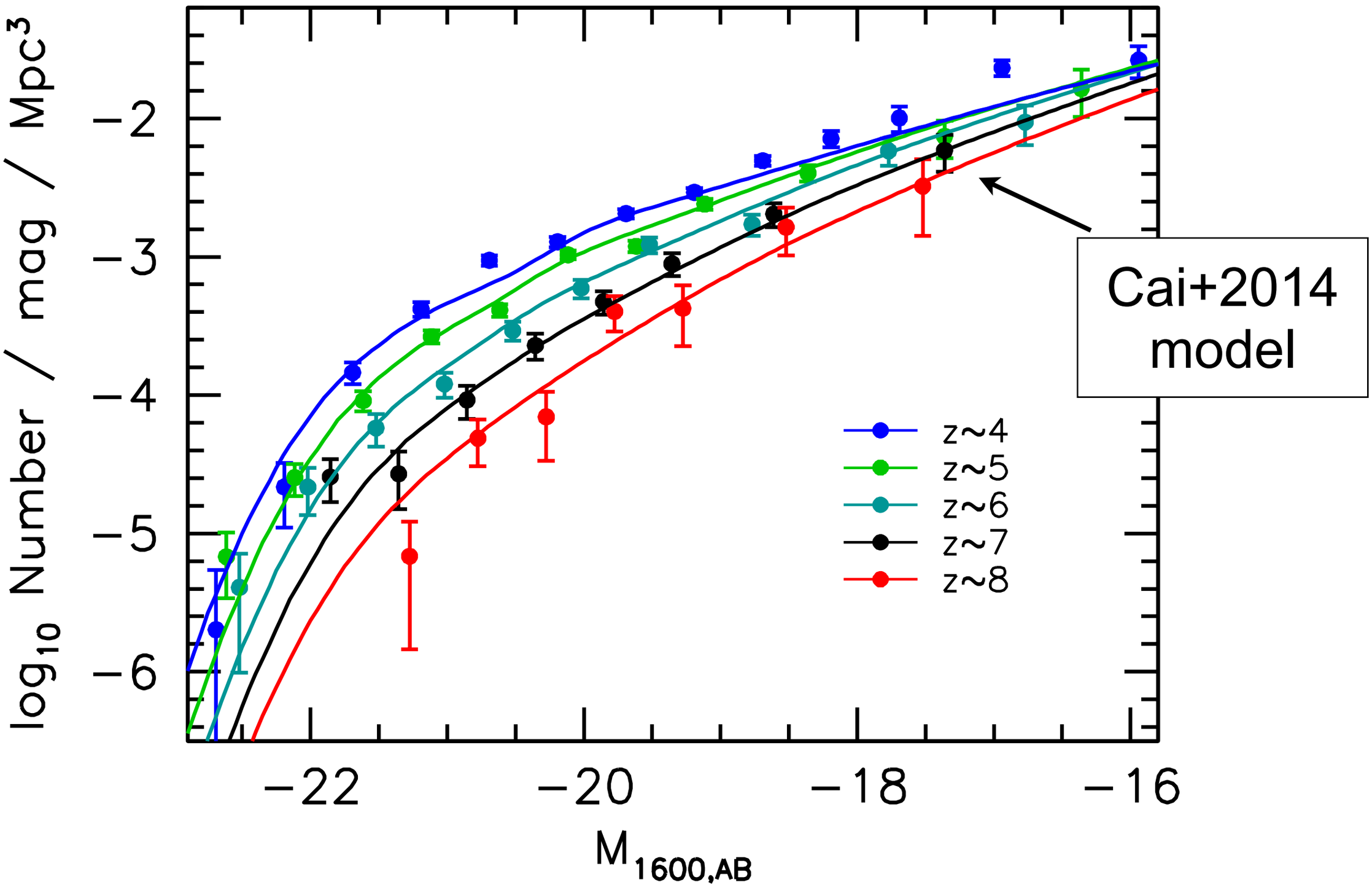
(CANDELS z~9-10 sample much more robust than HUDF z~9-10 sample)



Oesch+2014



How does the observed z~10 LF compare with extrapolations from lower redshift?



Cai+2014; Oesch+2014; Bouwens+2014

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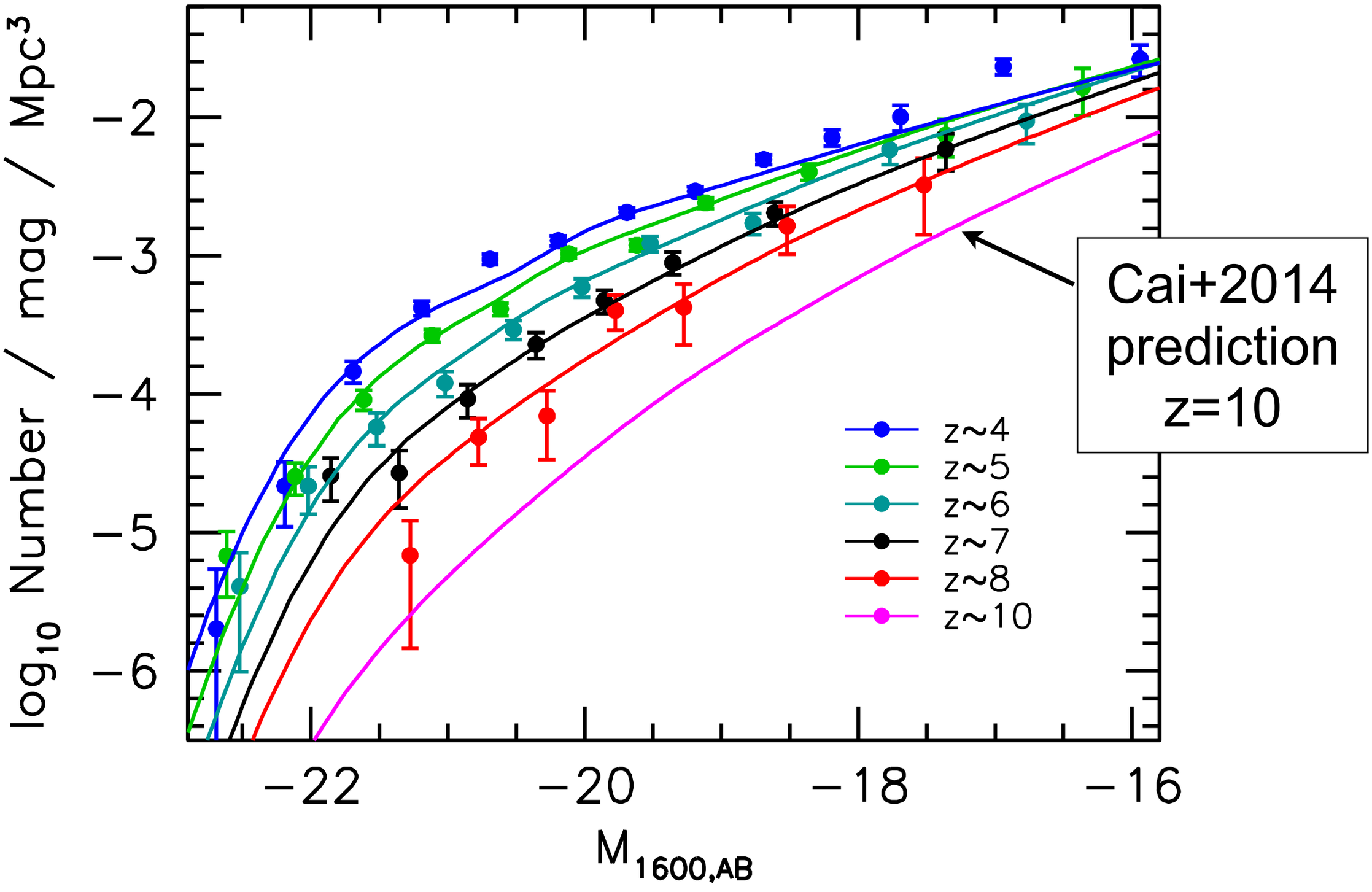

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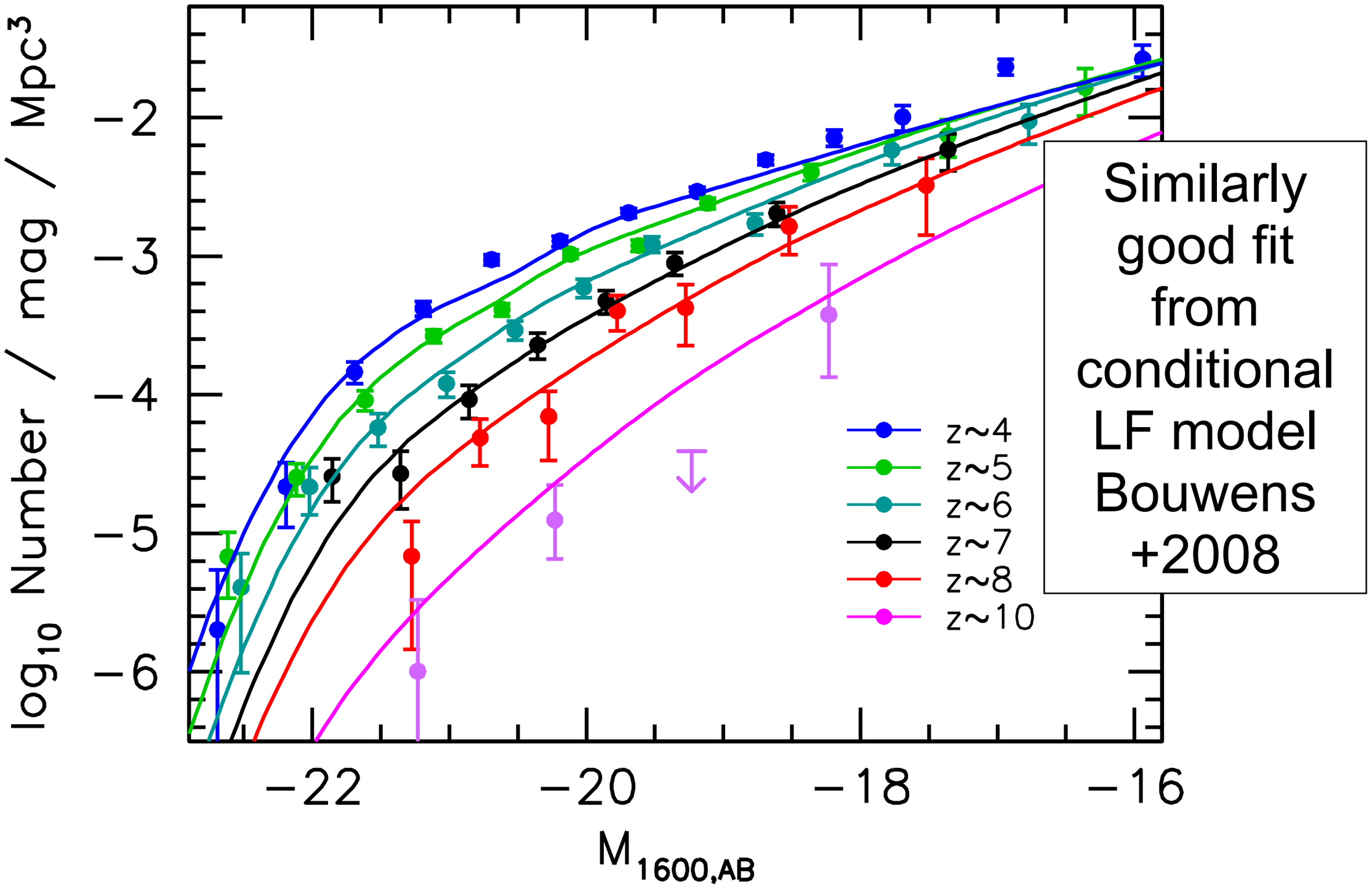
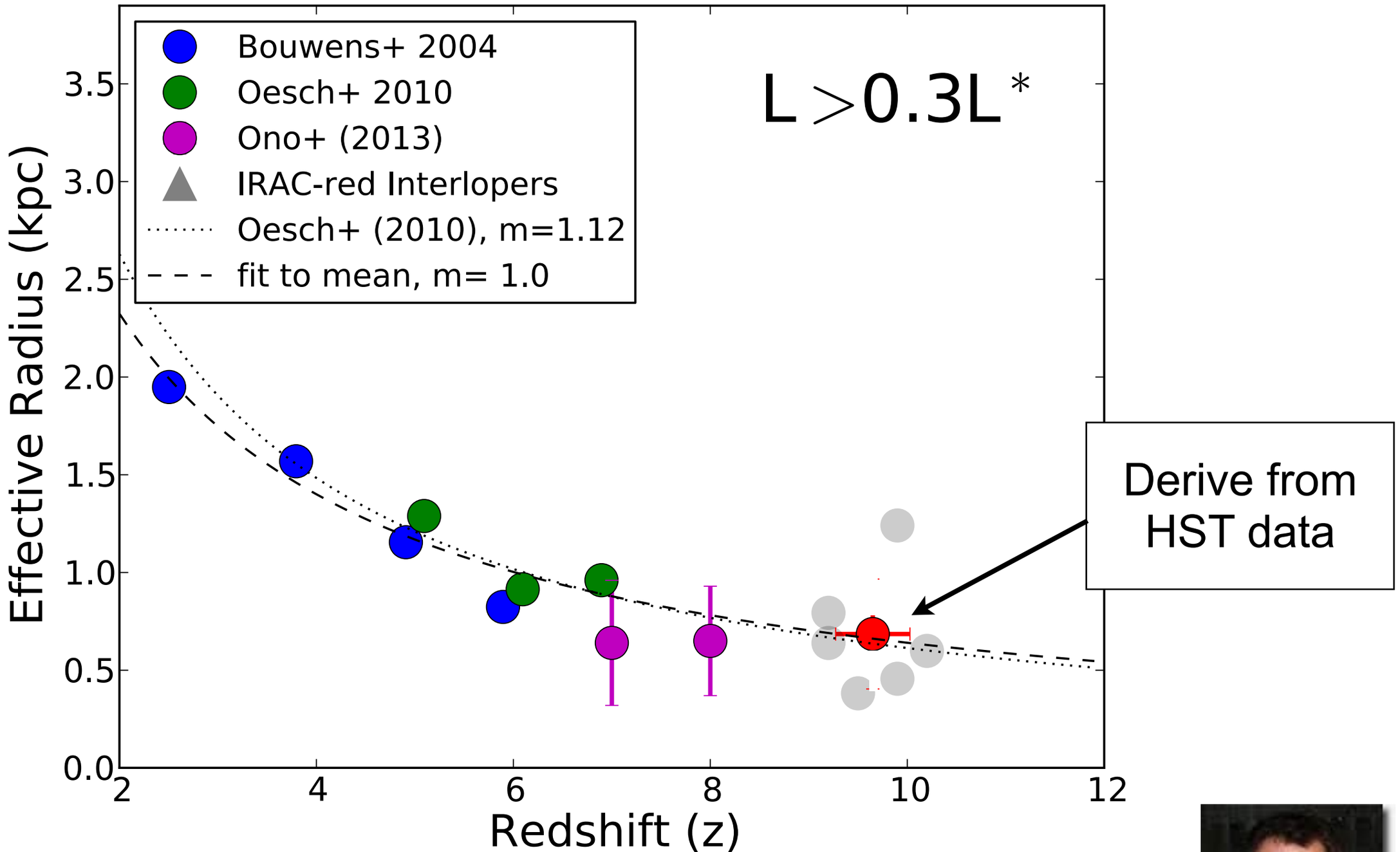


Cai+2014; Oesch+2014; Bouwens+2014

The sizes of these z~9-10 candidates are exactly what we would expect...



Holwerda+2014 (resubmitted to ApJL after responding to referee report)

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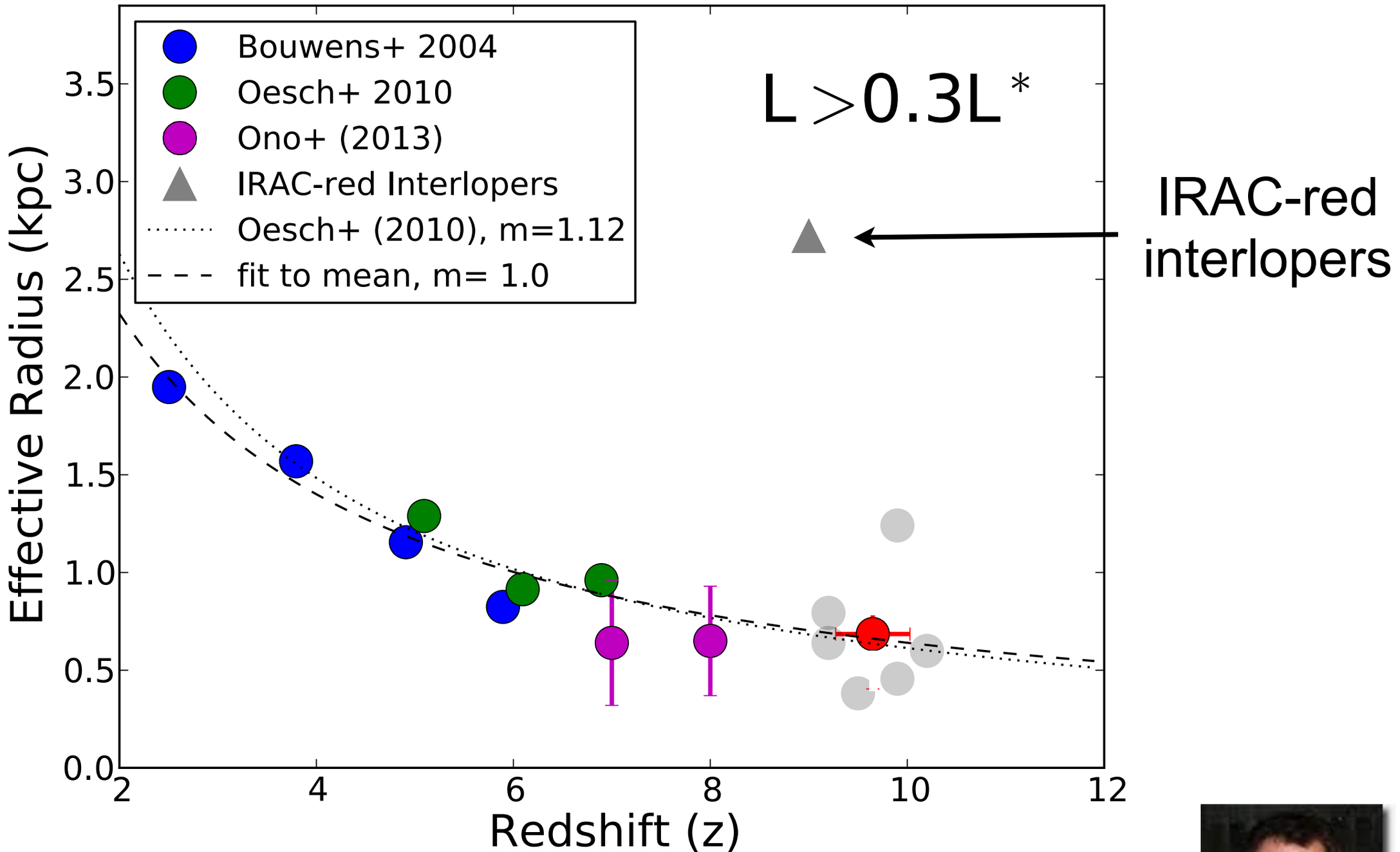
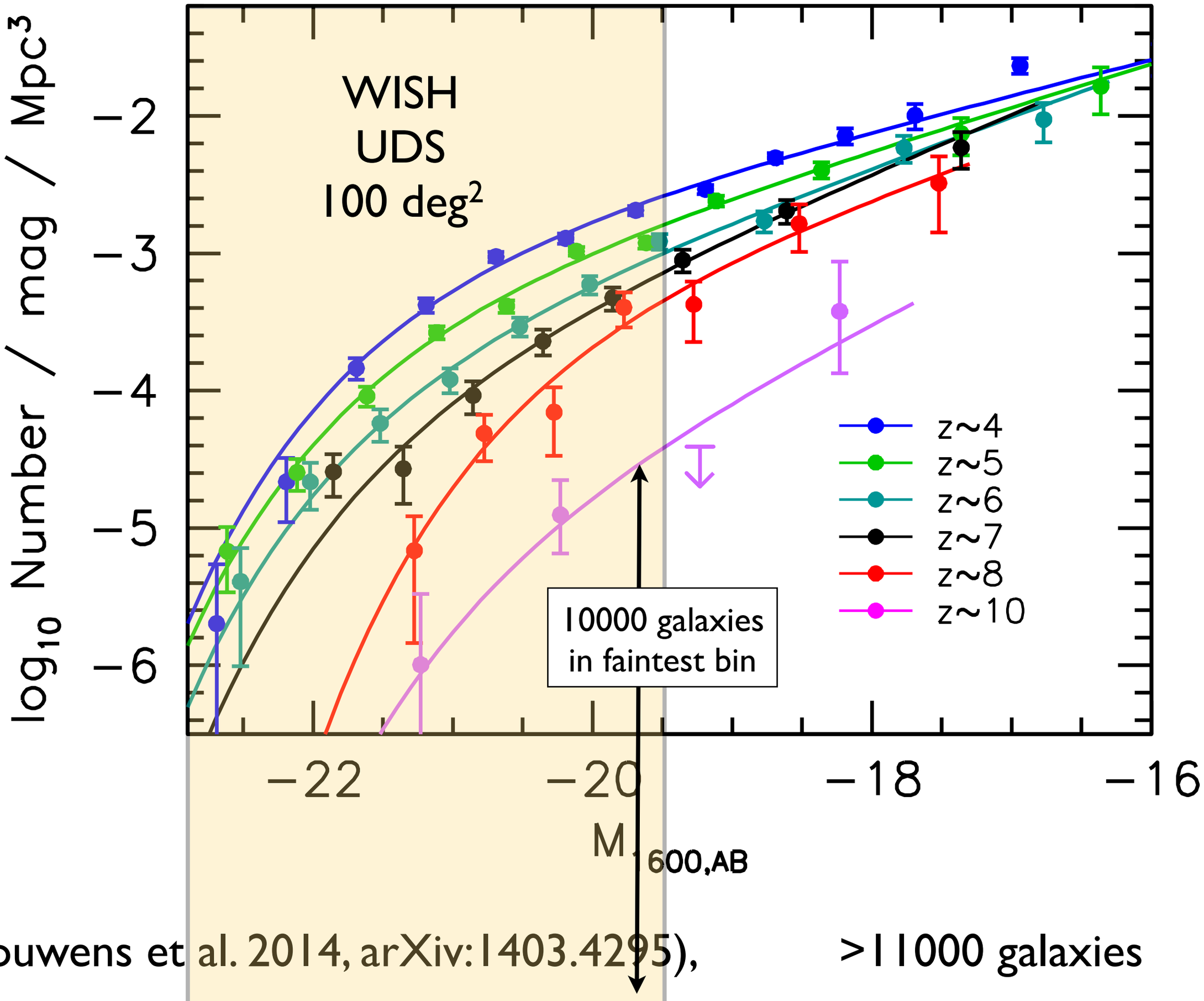
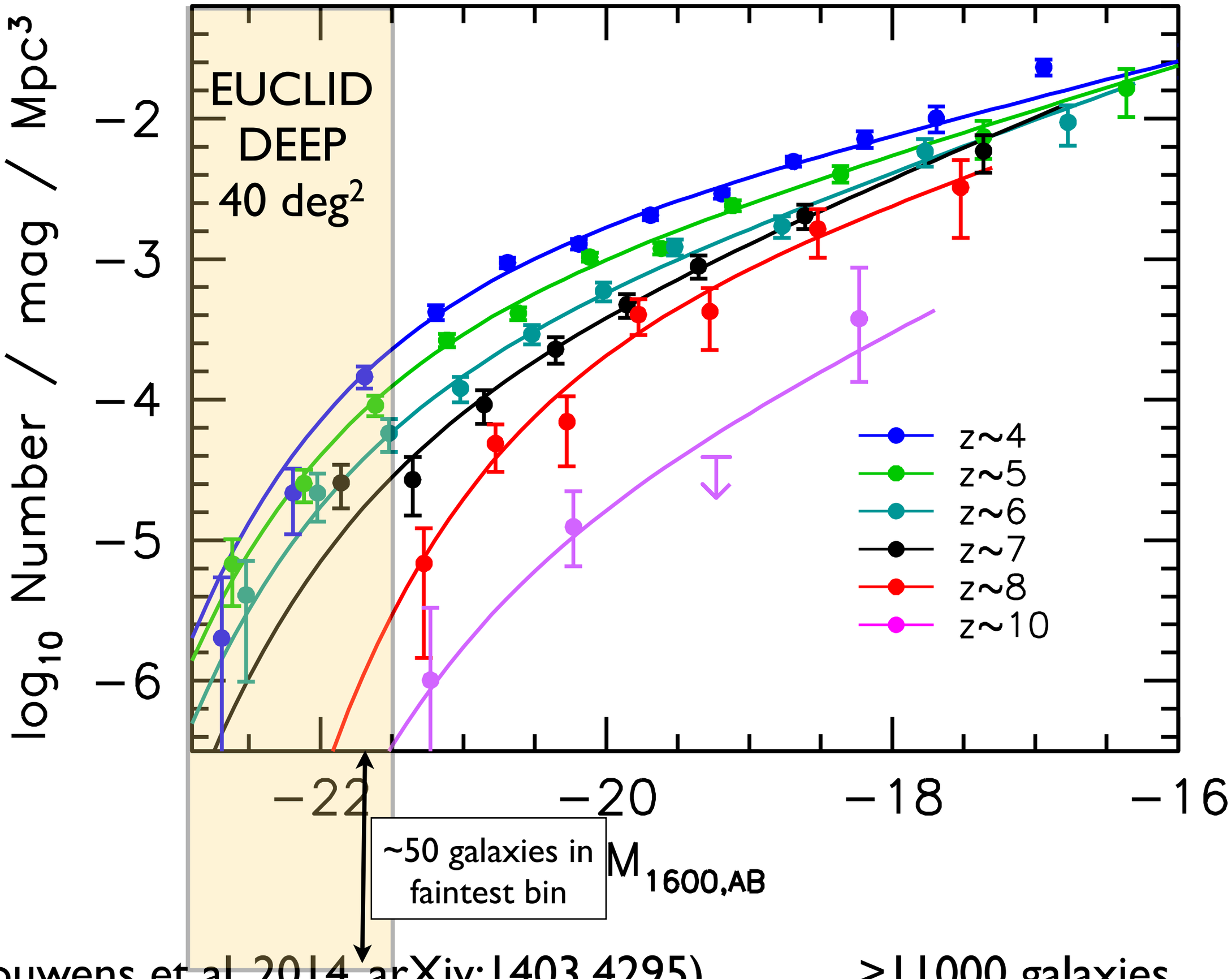


Holwerda+2014 (resubmitted to ApJL after responding to referee report)

How many z~10 galaxies would we expect in the WISH UDS survey (5σ depth of 28 mag over 100 deg^2) based on existing LFs using CANDELS (Bouwens+2014)?



(Bouwens et al. 2014, arXiv:1403.4295), >11000 galaxies



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What progress can we expect in future in constraining prevalence of z=9-10 galaxies?

Follow-up bright z~10 galaxy with the HST Grism

PI: P. Oesch


Hubble Space Telescope Cycle 22 GO Proposal 160

A Spectroscopic Redshift for the Most ...us Galaxy Candidate at z~10

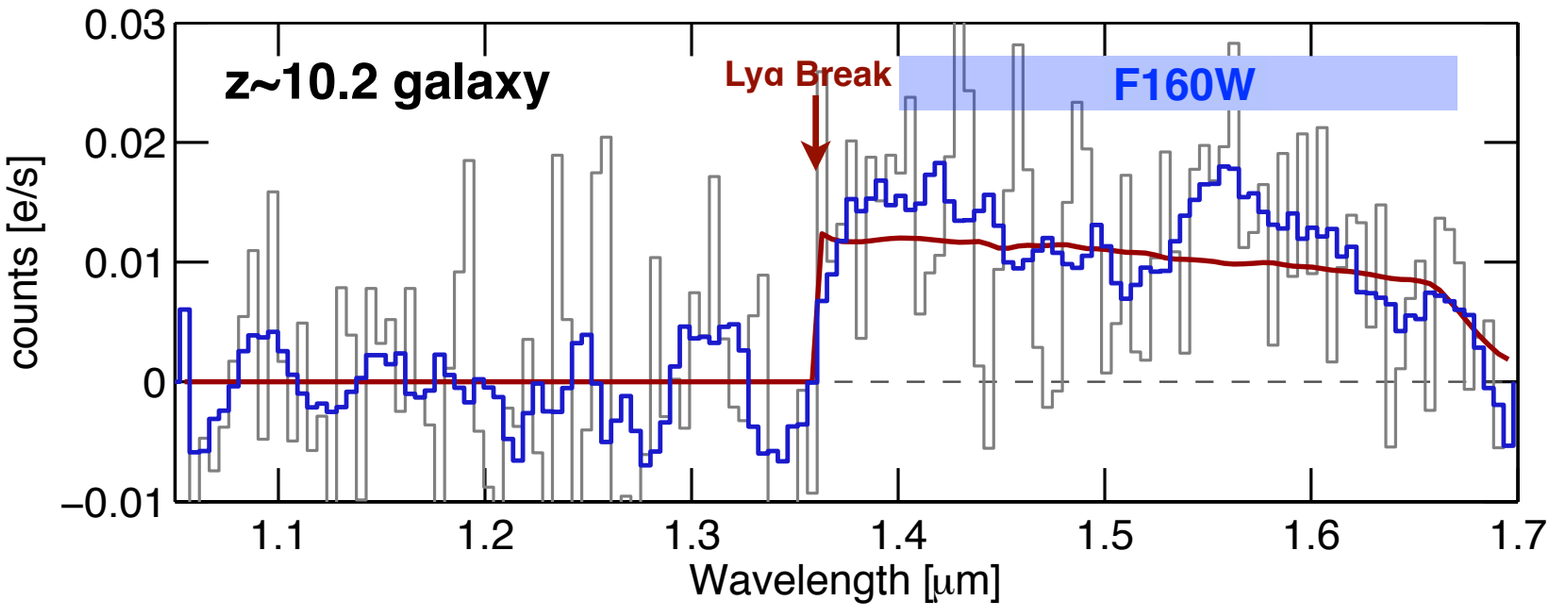
Scientific Category: COSMOLOGY
Scientific Keywords: Galaxy Formation And Evolution,
Instruments: WFC3
Proprietary Period: 12
Orbit Request
Cycle 22

Abstract

We recently discovered an unexpe...axy candidate in the GOODS-North field (GN-z10-1; Oesch et ...est-redshift z>9 candidate in the complete 900-orbit CANDEL... is robustly detected in both Spitzer 3.6 and 4.5 micron channe... the rest-frame UV to optical spectral energy distribution for s... luminous and massive source at z~10, just 500 Myr after the Bi... understanding of early galaxy formation: it would imply that ... than hitherto thought. Our comprehensive photometric test... r, without a spectroscopic redshift, we can not exclude other... with very unusual continuum and emission line properties. ...gether with the unique continuum sensitivity of the WFC3/IR ...troscopic confirmation with HST. Because of its high redsh... ground due to very low atmospheric transparency at the wavele... re JWST, HST with the WFC3/IR G141 grism is uniquely capable am... lishing a breakthrough in high-redshift galaxy spectroscopy by enabling a spec... ion at z~10.

Spectroscopic Confirmation

Expected WFC3/IR Spectrum



What progress can we expect in future in constraining prevalence of z=9-10 galaxies?

Follow-up bright z~10 galaxy with the HST Grism

PI: P. Oesch

~7 more bright z~9-10 candidates using remaining CANDELS fields

PI: R. Bouwens

Hubble Space Telescope Cycle 22 GO Proposal 160

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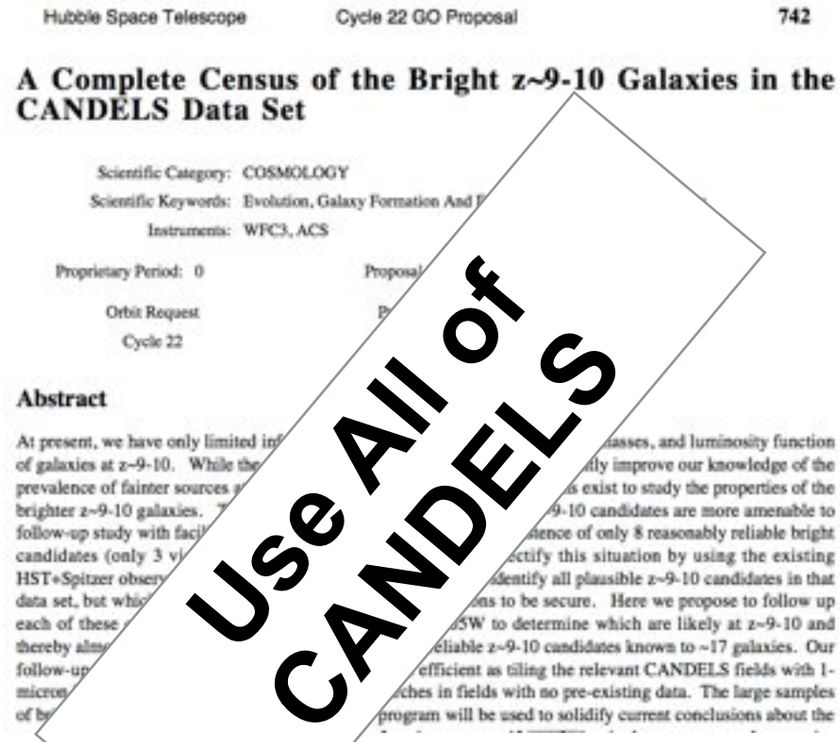


Hubble Space Telescope Cycle 22 GO Proposal 742

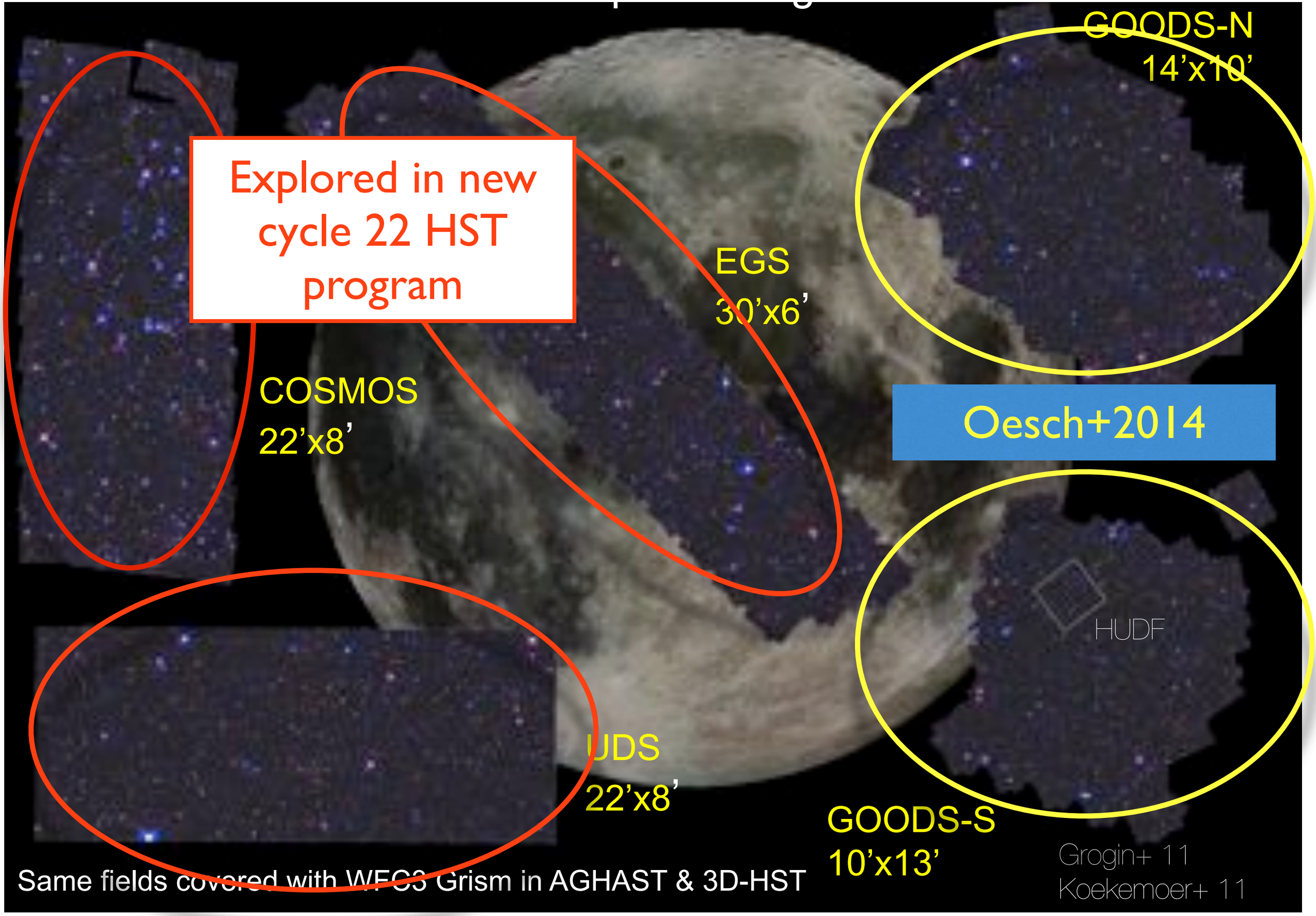
A Complete Census of the Bright z~9-10 Galaxies in the CANDELS Data Set

Scientific Category: COSMOLOGY
Scientific Keywords: Evolution, Galaxy Formation And ...
Instruments: WFC3, ACS
Proprietary Period: 0 Proposa...
Orbit Request ...
Cycle 22

Abstract

At present, we have only limited inf... masses, and luminosity function of galaxies at z~9-10. While the... ly improve our knowledge of the prevalence of fainter sources ... s exist to study the properties of the brighter z~9-10 galaxies. ...9-10 candidates are more amenable to follow-up study with faci... sence of only 8 reasonably reliable bright candidates (only 3 v... ctify this situation by using the existing HST+Spitzer obser... dentify all plausible z~9-10 candidates in that data set, but whi... ons to be secure. Here we propose to follow up each of these ...5W to determine which are likely at z~9-10 and thereby alm... eliable z~9-10 candidates known to ~17 galaxies. Our follow-up ... efficient as tiling the relevant CANDELS fields with 1-micron ... ches in fields with no pre-existing data. The large samples of b... program will be used to solidify current conclusions about the

Use All of CANDELS


GOODS-N
14'x10'
Explored in new cycle 22 HST program
EGS
30'x6'
COSMOS
22'x8'
Oesch+2014
HUDF
UDS
22'x8'
GOODS-S
10'x13'
Grogin+ 11
Koekemoer+ 11
Same fields covered with WFC3 Grism in AGHAST & 3D-HST

What progress can we expect in future in constraining prevalence of z=9-10 galaxies?

Follow-up bright z~10 galaxy with the HST Grism

PI: P. Oesch

~7 more bright z~9-10 candidates using remaining CANDELS fields

PI: R. Bouwens

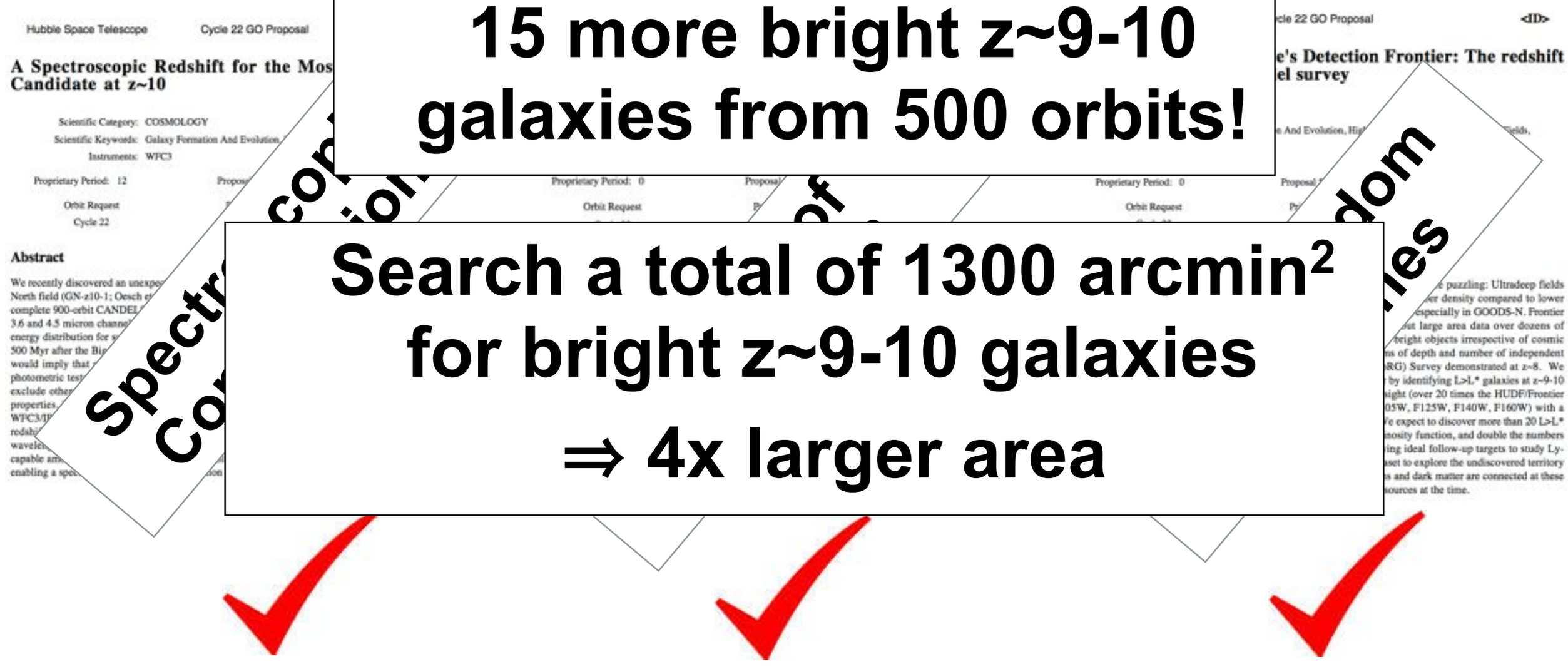
~9 more bright z~9-10 candidates using ambitious pure-parallel program

PI: M. Trenti

15 more bright z~9-10 galaxies from 500 orbits!

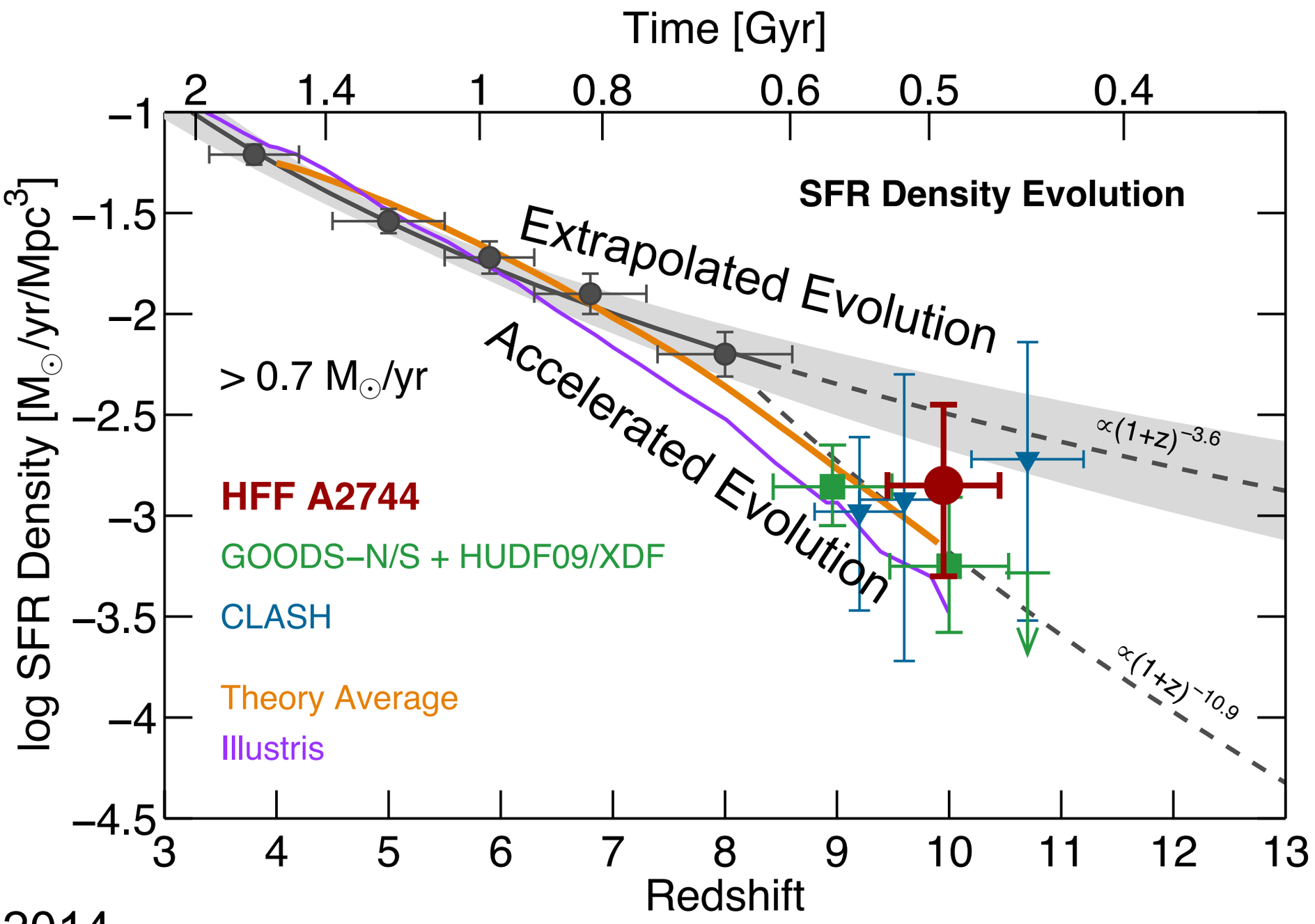
Search a total of 1300 arcmin² for bright z~9-10 galaxies

⇒ 4x larger area



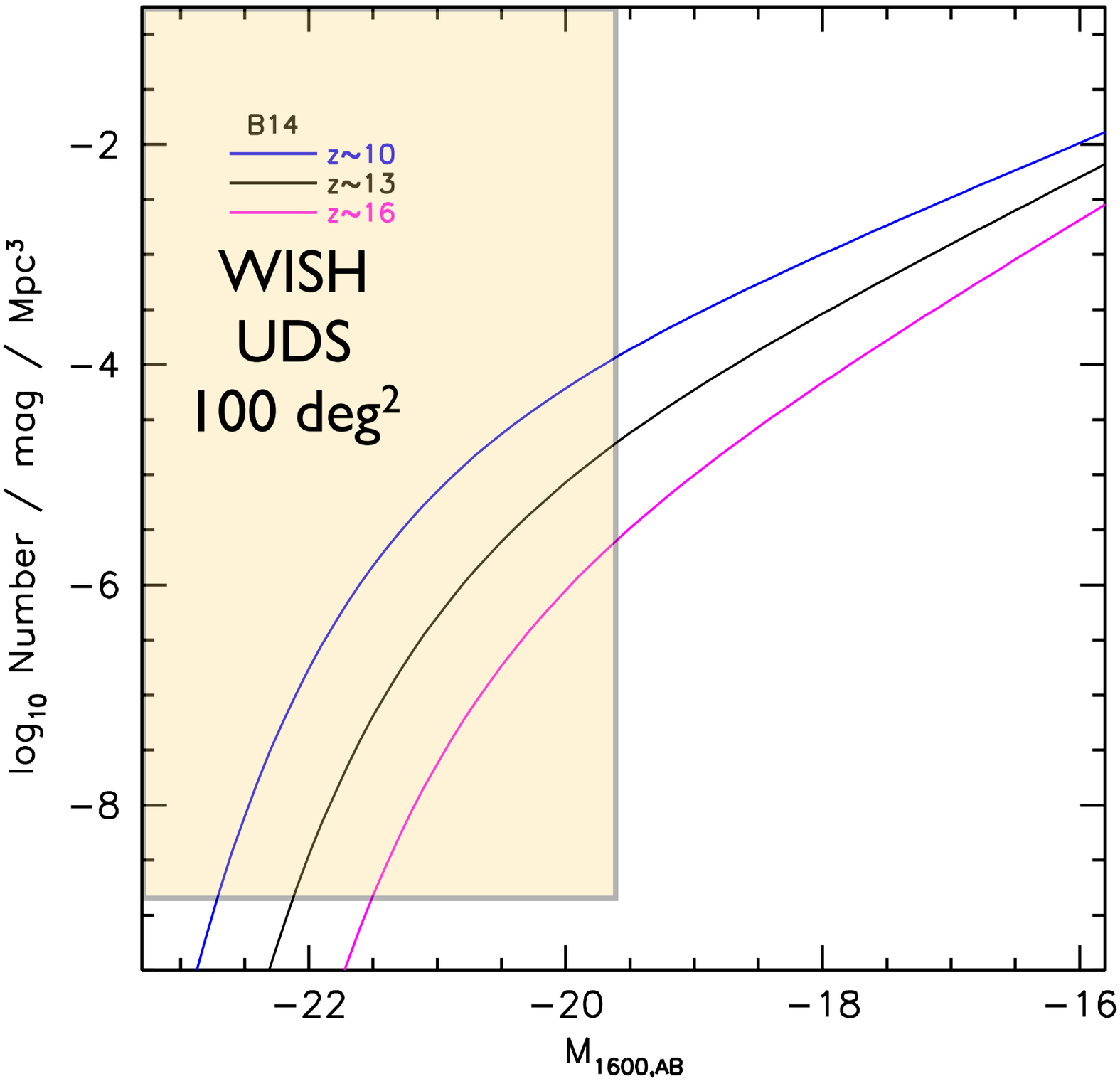
Refining our constraints on the prevalence of z~9-10 galaxies is important for extrapolations to z > 10...

As there is some uncertainty as to whether the evolution of the LF is faster (in units of redshift) at z > 8 than at z<8...

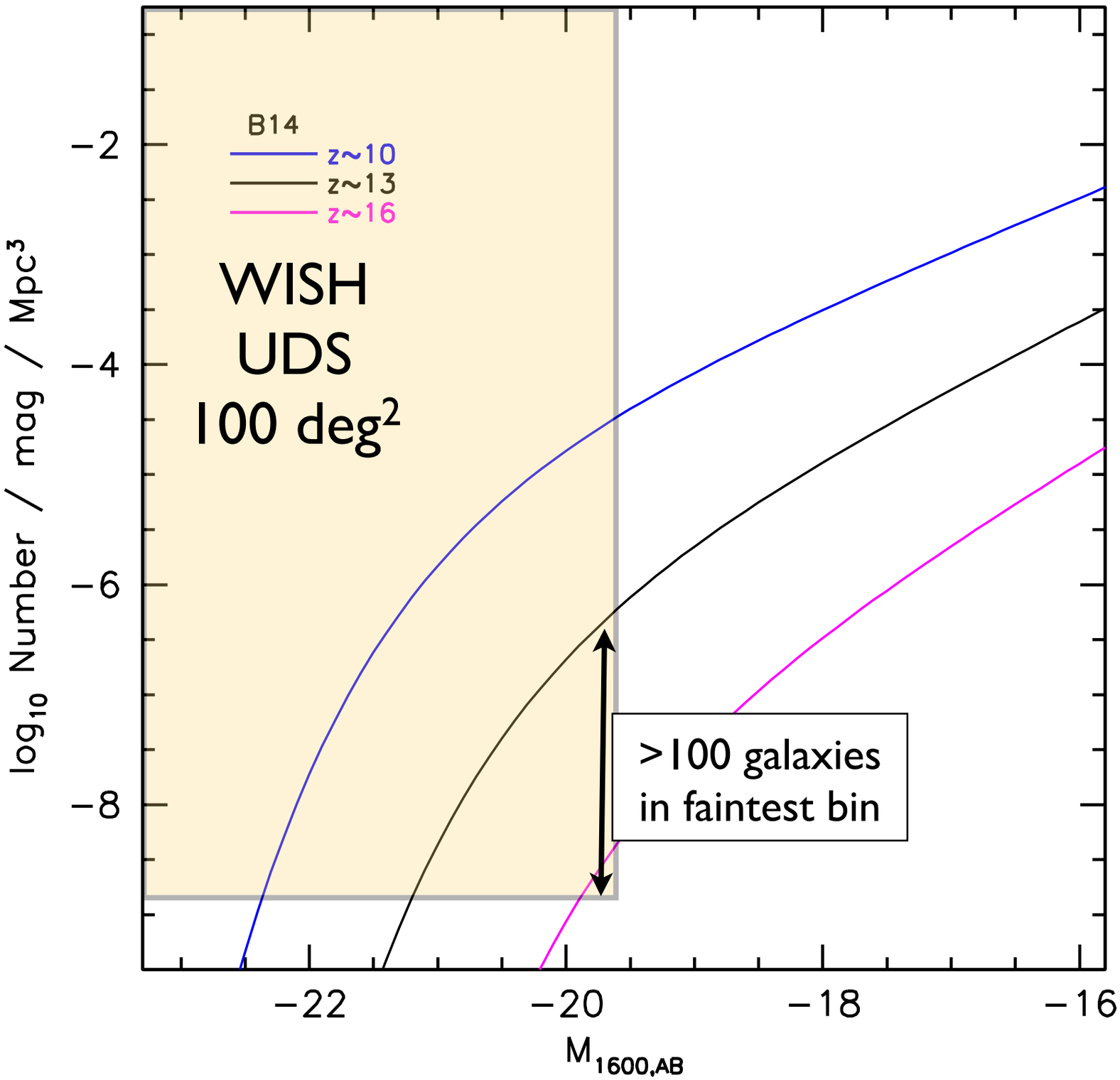


Oesch+2014

If we assume no acceleration in the evolution, here are the predicted LFs...



If we assume accelerated evolution (pessimistic scenario), here are the predicted LFs...



It is possible that WISH will discover even more distant galaxies than JWST

Probing to the highest redshifts using wide-area surveys is remarkably competitive with ultra-deep surveys

Name	Redshift	Discoverer
MACS0647-JD	10.8	Coe et al. (2013)
XDFj-38113363	9.8	Oesch et al. (2013) + Bouwens et al. (2011)
MACS1149-JD	9.6	Zheng et al. (2012)
HUDF12-42657049	9.5	Ellis et al. (2013)
HUDF09-2_247	9.4	McLure et al. (2013)
HUDF09-2_50104	9.0	McLure et al. (2013)
HUDF12-42657049	8.8	Ellis et al. (2013)

Lensed CLASH ...

HUDF12 sources

Revived Bouwens+2011

BEFORE OESCH+2014

Probing to the highest redshifts using wide-area surveys is remarkably competitive with ultra-deep surveys

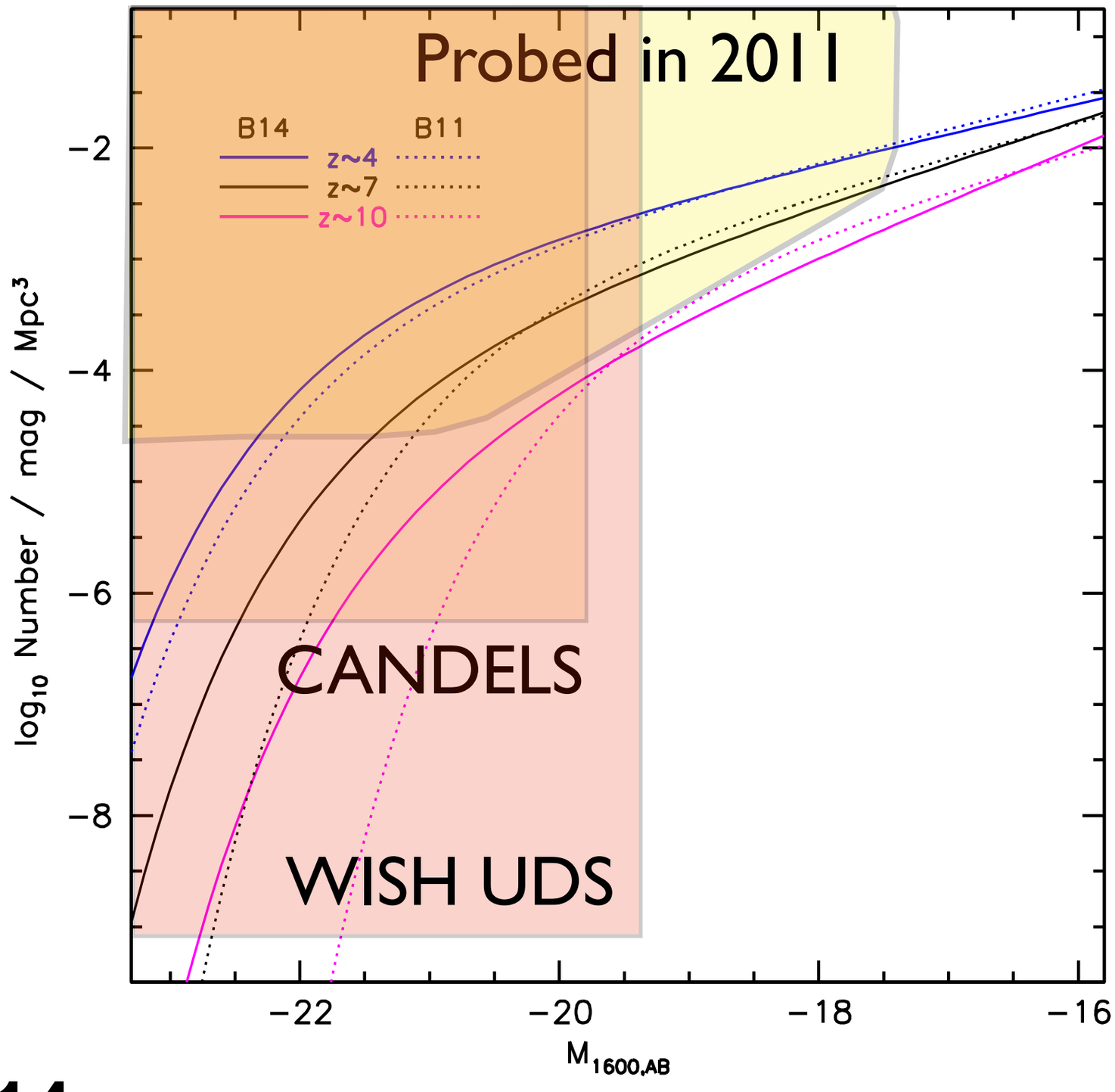
Name	Redshift	Discoverer
MACS0647-JD	10.8	Coe et al. (2013)
GN-z10-1	10.2	Oesch et al. (2014)
GN-z10-2	9.9	Oesch et al. (2014)
GS-z10-1	9.9	Oesch et al. (2014)
XDFj-		2013) + (2011)
MAC		(2012)
GN-z10-3	9.5	Oesch et al. (2014)

Three of the Four Most Distant Galaxies Known!

What is the value of the wide-area data like from the new WISH surveys in distinguishing LF evolution models?

Value of future wide surveys is illustrated by improvement in our own LF results using wide-area CANDELS fields...

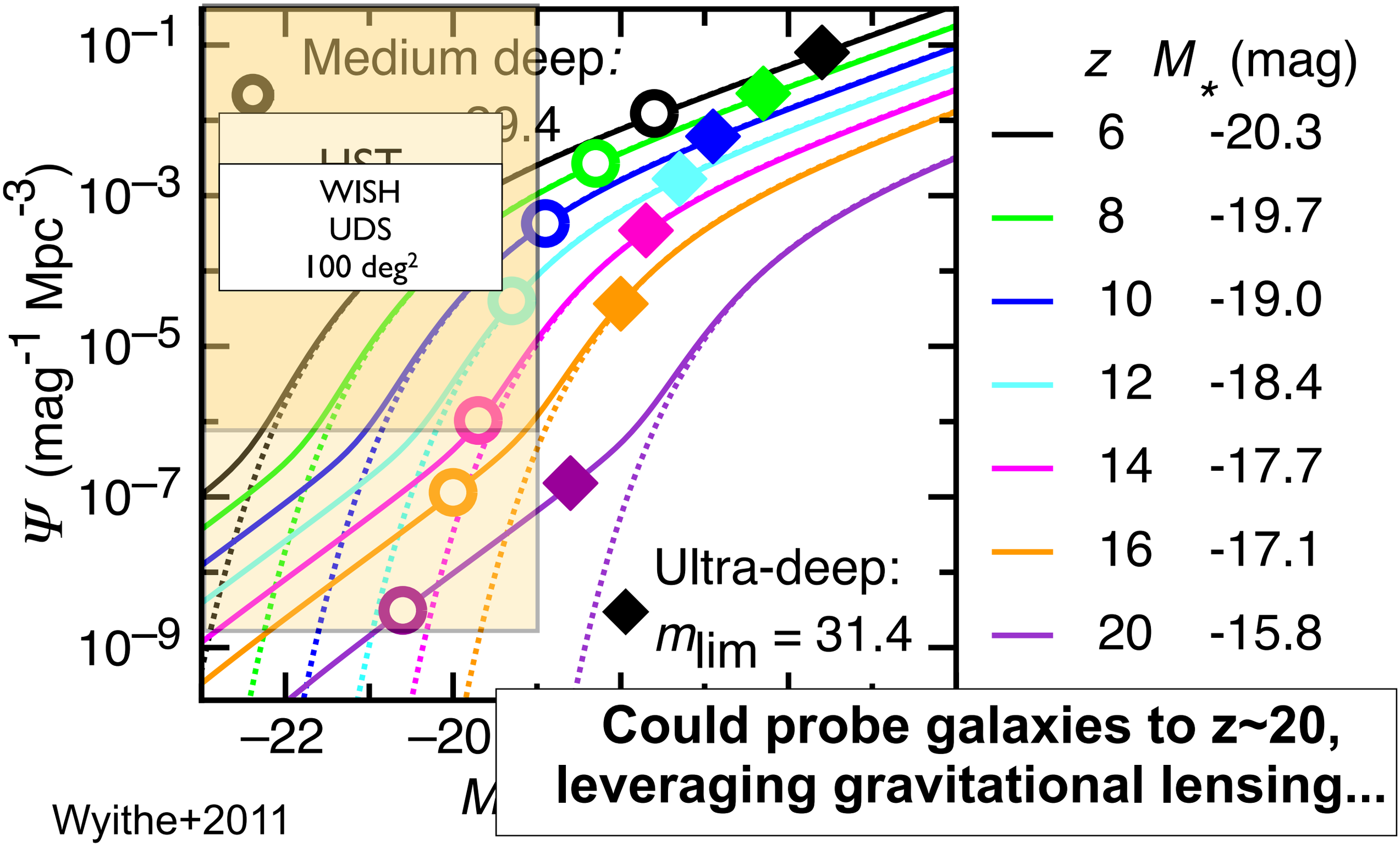
Until CANDELS in 2012, there had been only limited deep wide-area to probe bright end of z>~6.5 LFs



Bouwens+2011/2014

Is it possible that gravitational lensing by foreground galaxies will help us in WISH to find galaxies at z >~ 13?

Given the wide areas probed by WISH (100 deg^2), lensing magnification of z~8-20 galaxies by foreground galaxies will allow us to push to even higher redshifts



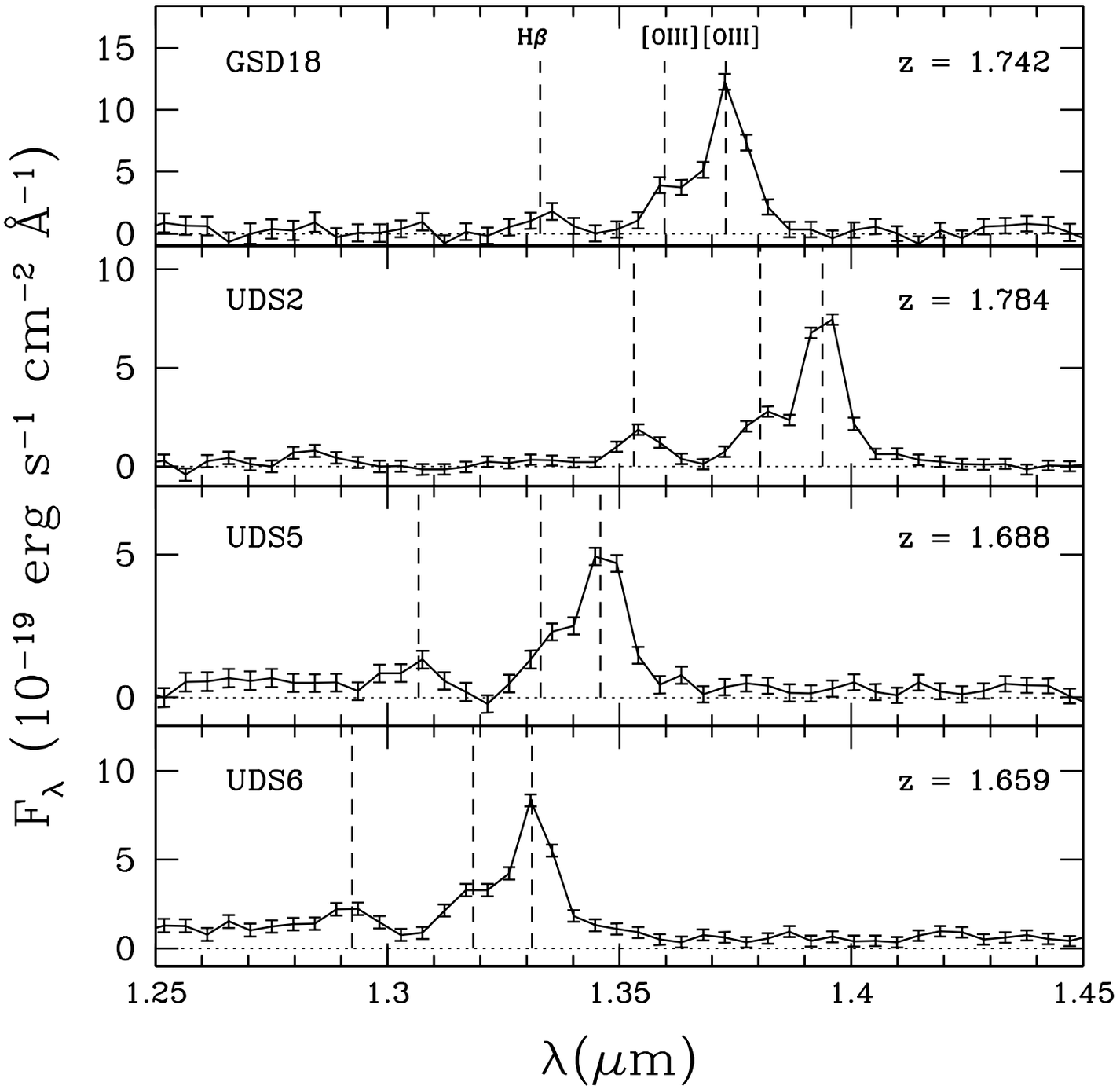
Could probe galaxies to z~20, leveraging gravitational lensing...

Wyithe+2011

WISH Science Interest #2:
What can we learn about the stellar populations of typical and/or rare galaxies at z>6?

Of particular interest are galaxies with stellar populations that are particularly different from at lower redshift...

One example of an unexpected population of galaxies with strong emission lines are the so-called EELGs



Many faint z~1-2 galaxies are found to have very strong OIII emission lines

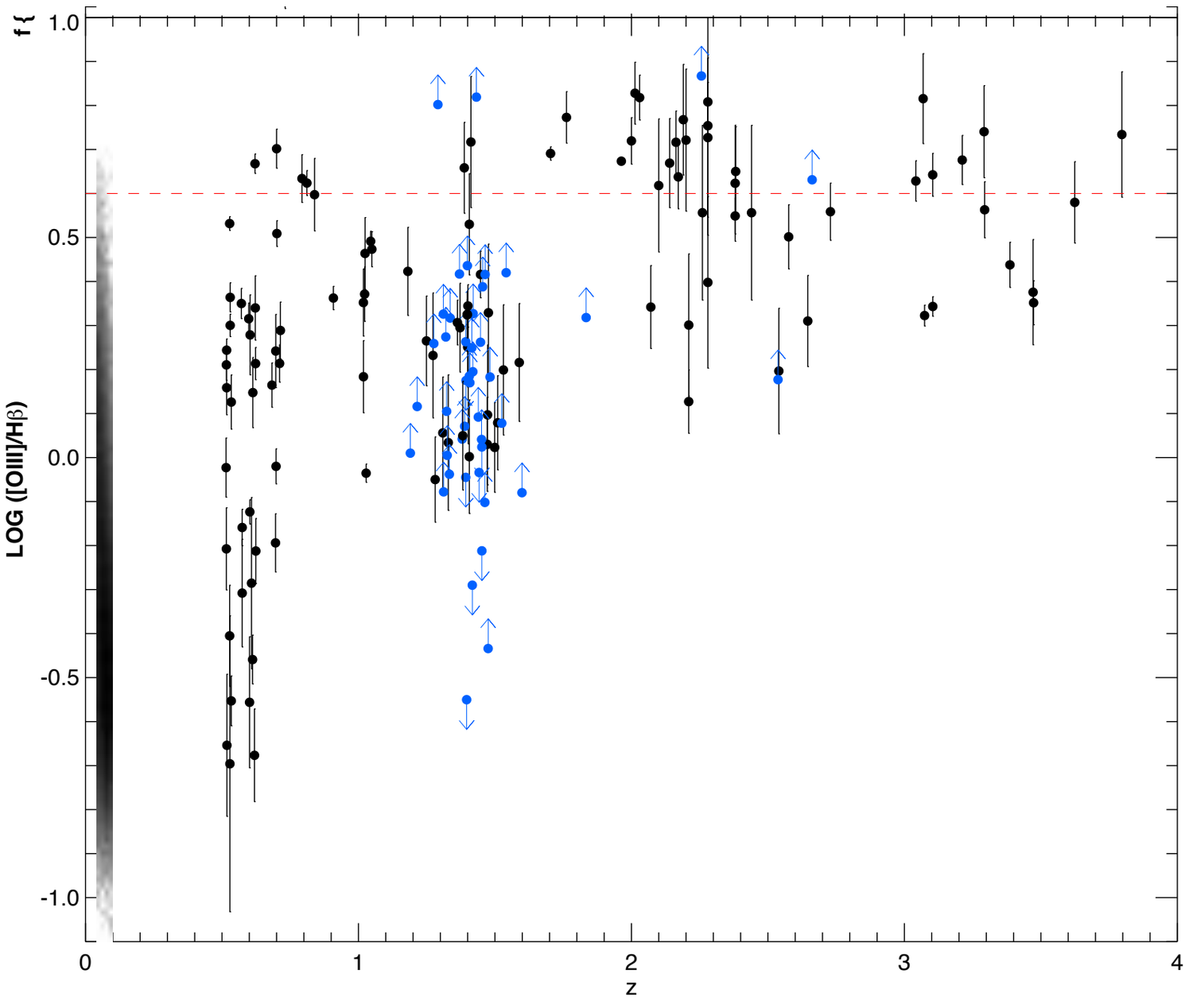
Most of the rest-frame EWs of these lines range up to 1000 Angstroms

However, there are reports of a few systems found in other surveys with EWs up to 10000 Angstroms

van der Wel+2011; see also Atek+2011; Brammer+2012

Substantial number of EELGs at z~1-2 due to substantial evolution in [OIII]/Hbeta ratio from z~3 to z~0

OIII/Hβ



Redshift

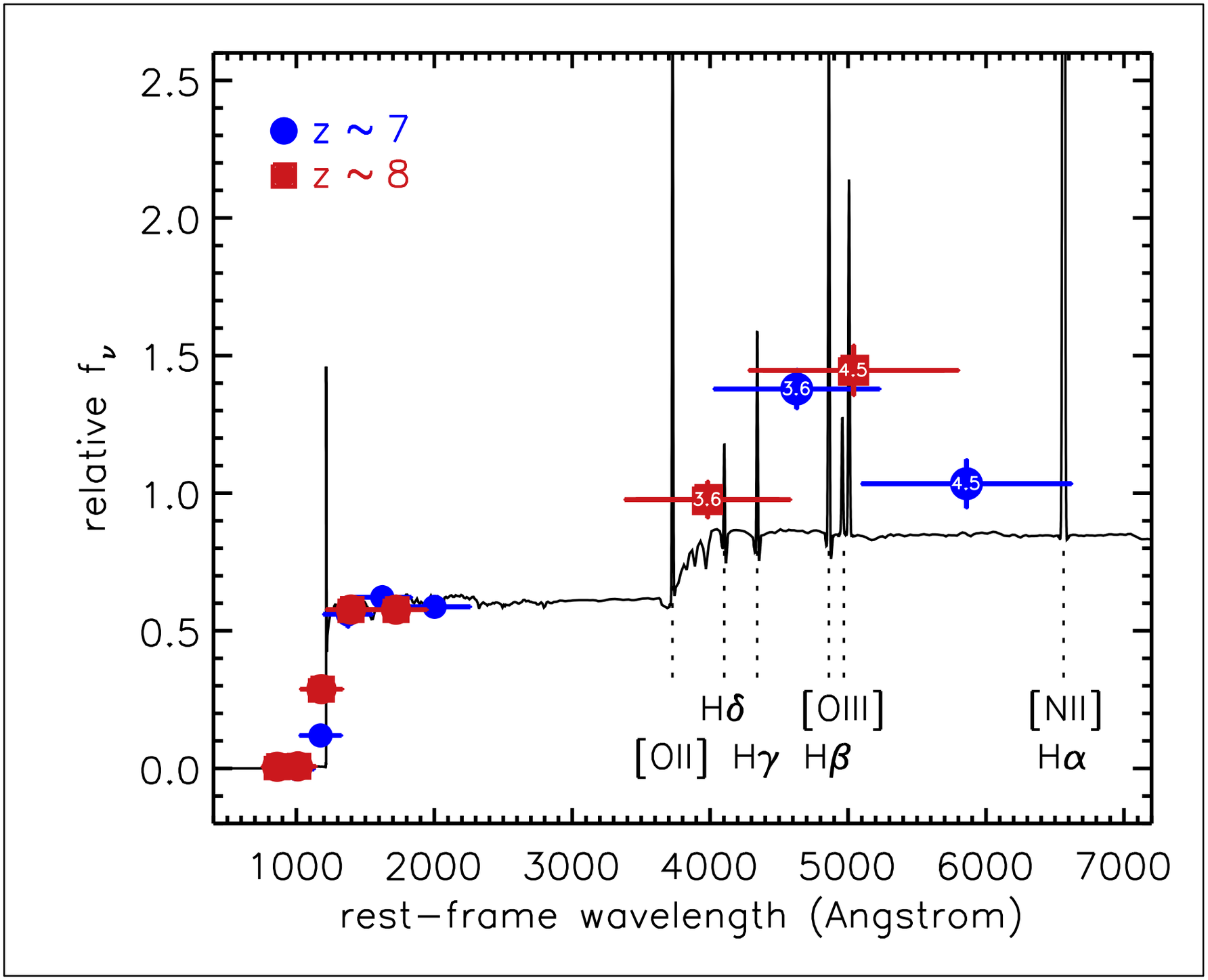
Kewley+2013; Shirazi+2013; Holden+2013; Schenker+2013

Do we find evidence for this type of line emission at High Redshift?

Challenging to investigate this question, since we cannot make use of spectroscopic data.

Must make use of deep imaging observations from the Spitzer Space Telescope

Evidence from Stacking the Fluxes for z~7-8 galaxies in the deepest fields



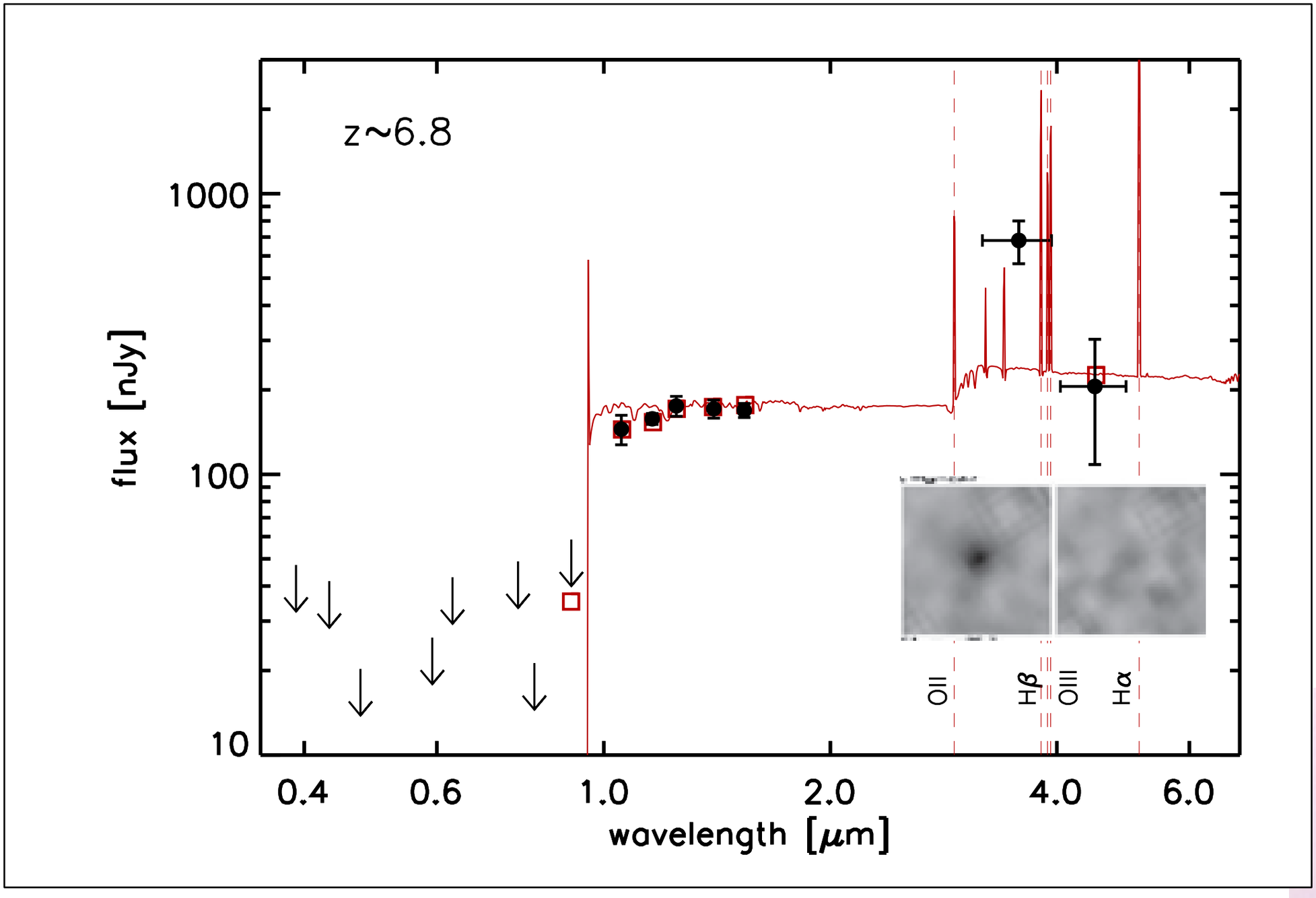
60 z~7 sources
30 z~8 sources
(Bouwens+2011; Oesch+2012 Sample)

Rest-Frame EW of OIII is ~600 Angstroms

Labbe+2013 (from HUDF)

Also evidence for extreme lines in individual sources....

Here's an example:

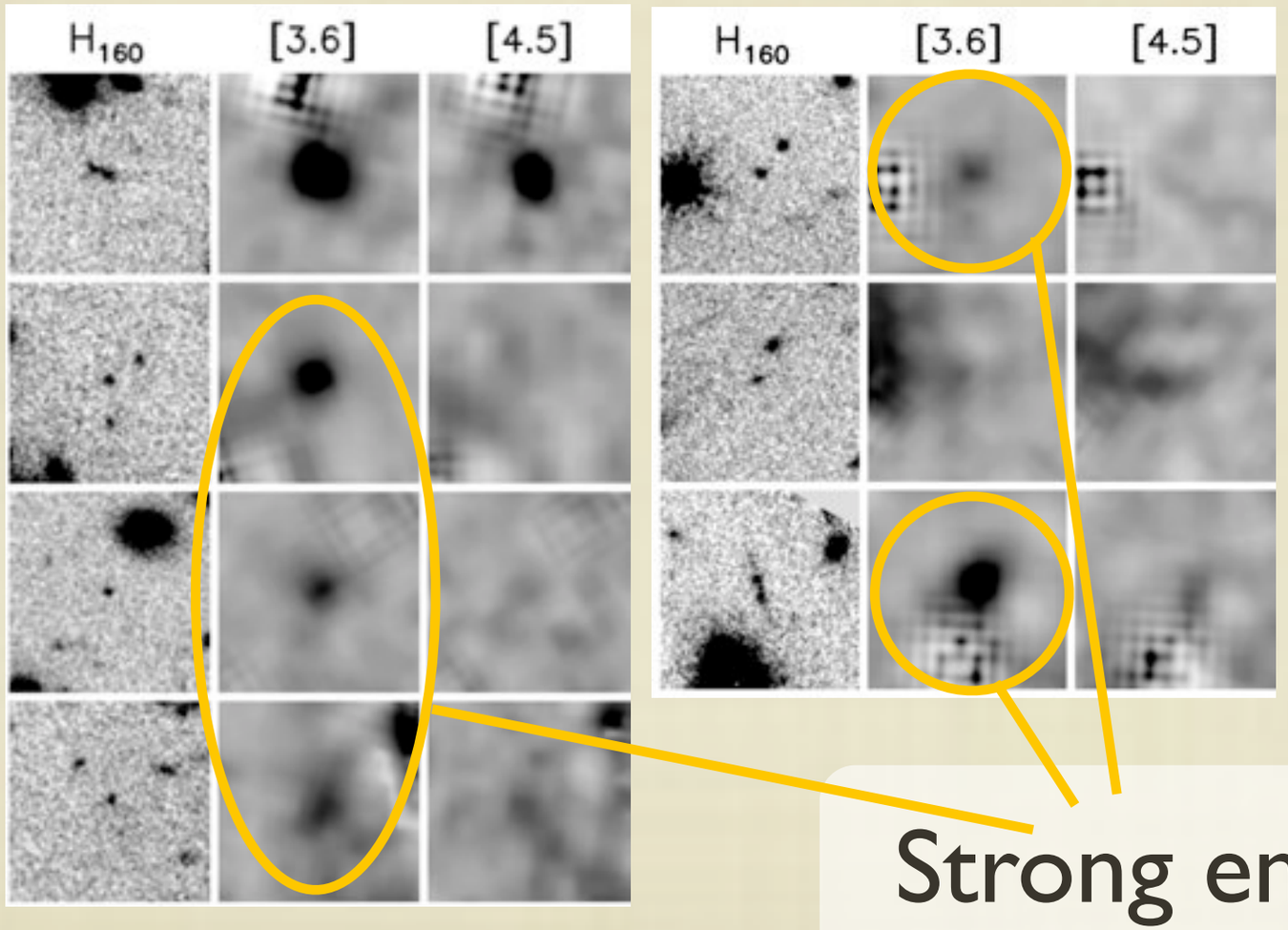


Smit et al. 2013

Renske Smit

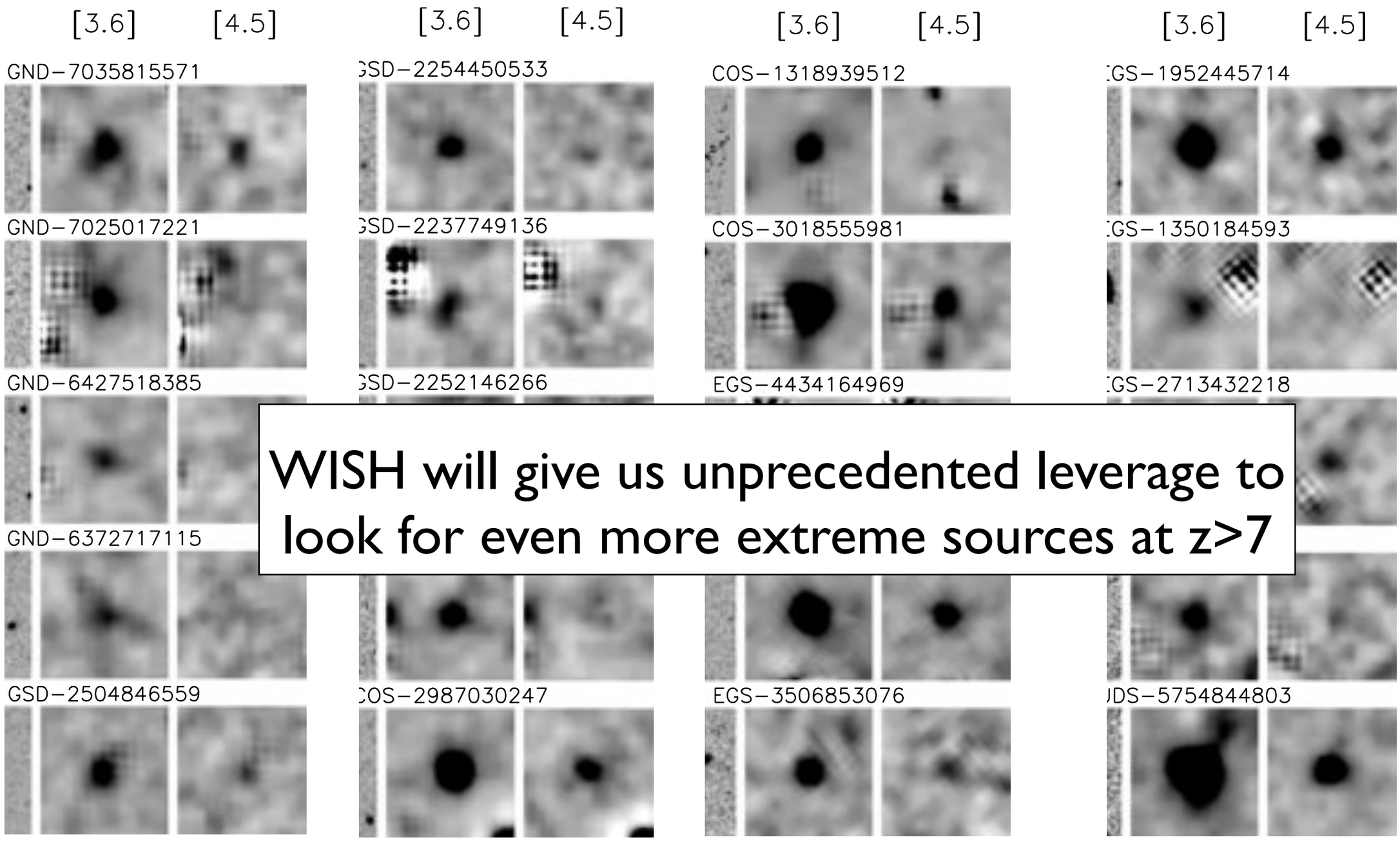
Large Numbers of Similar z~7 Galaxies Found behind Lensing Clusters

Entire sample (from CLASH)



Smit et al. 2014

Sample of 20 z~7 Galaxies with Ultra-Blue IRAC Colors over the full CANDELS program



WISH will give us unprecedented leverage to look for even more extreme sources at z>7

Smit+2014 submitted