UV Luminosity Evolution z=4 to z=10

Past Results

and

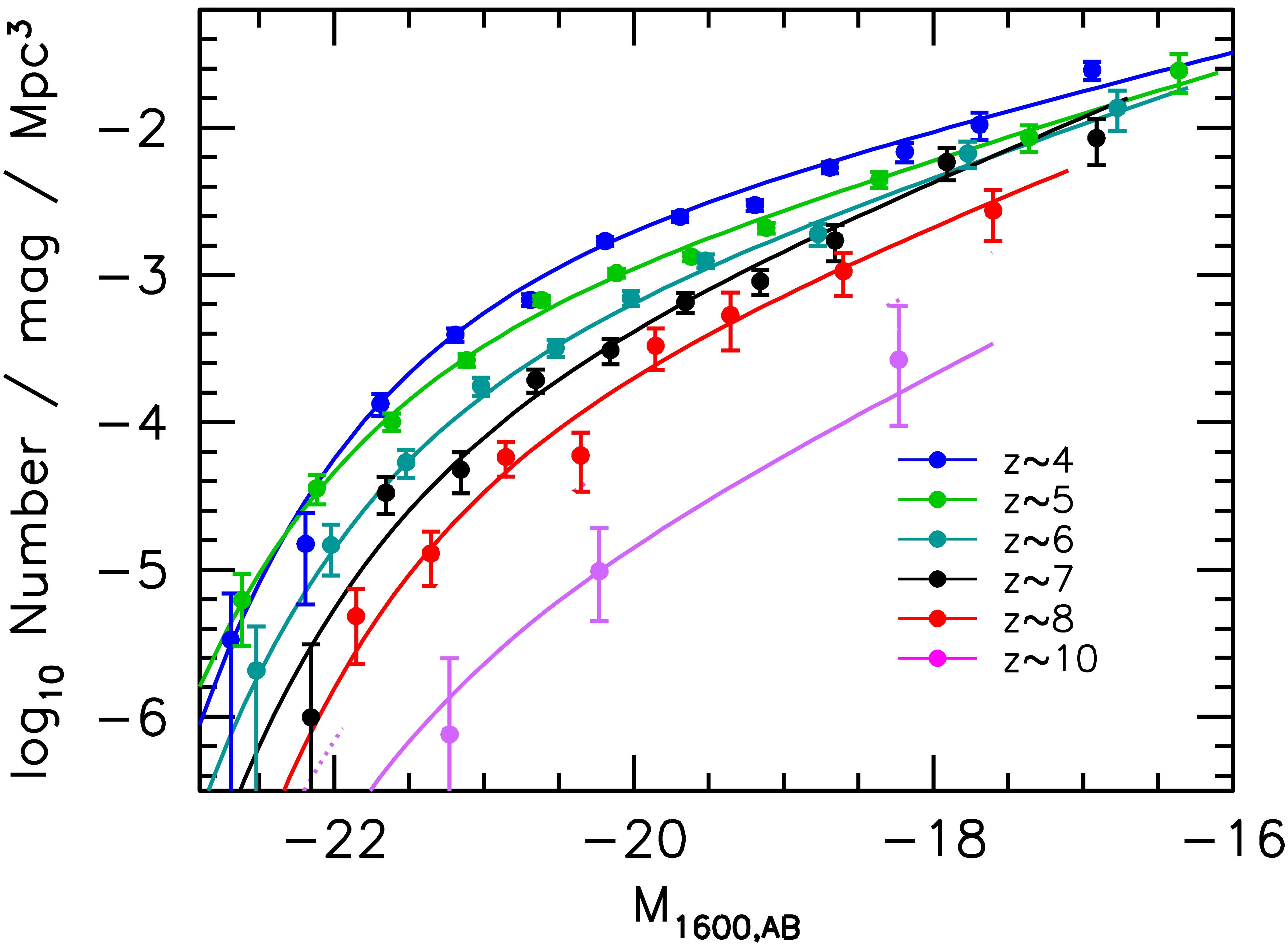
Future Results Including the Frontier Fields

Rychard Bouwens
(Leiden University)

Frontier Fields Workshop, Yale University, 11/12/2014

z~4, 5, 6, 7, 8, and z~10 LF Results (submitted 8 months ago)

(latest update)



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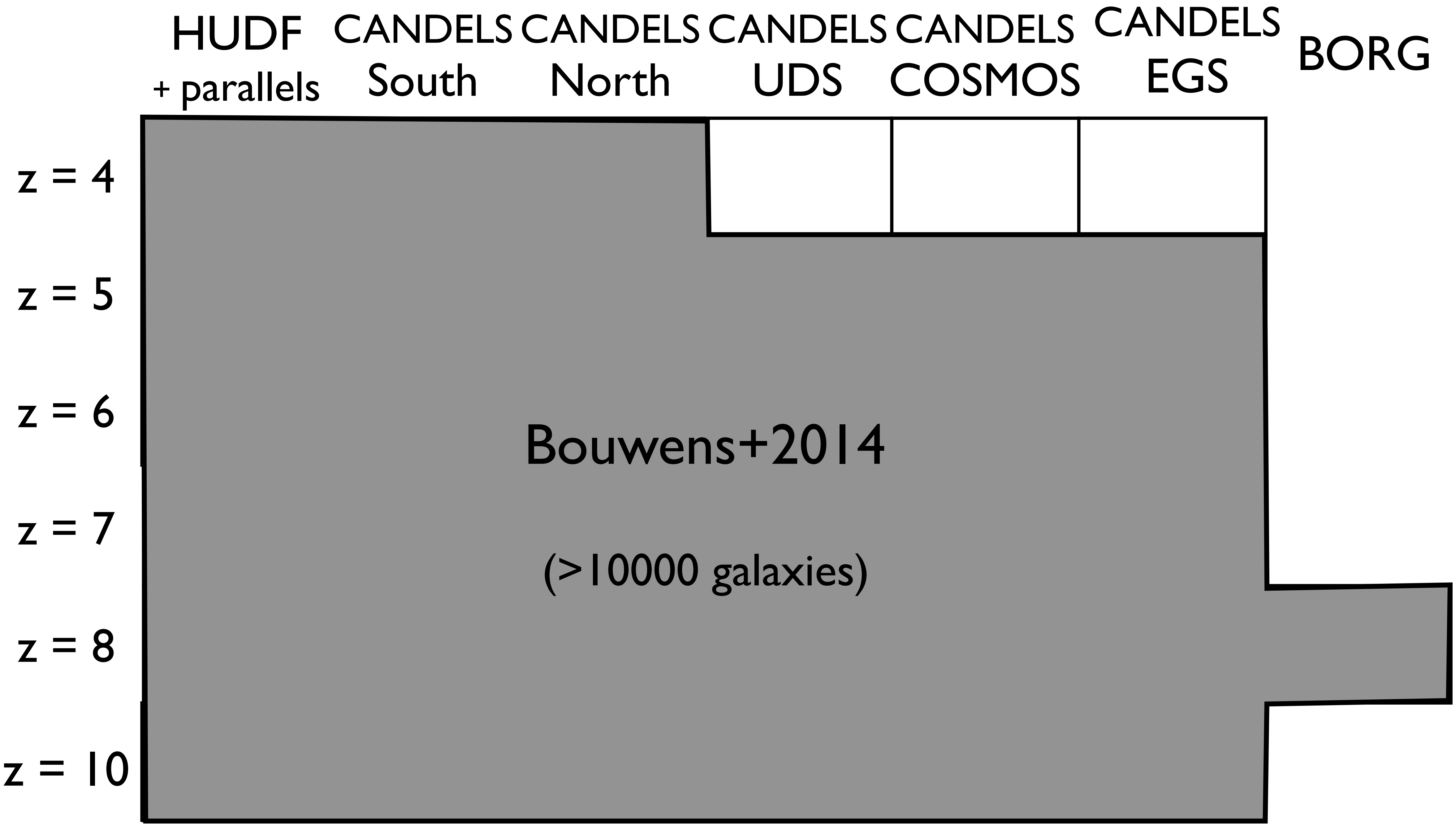
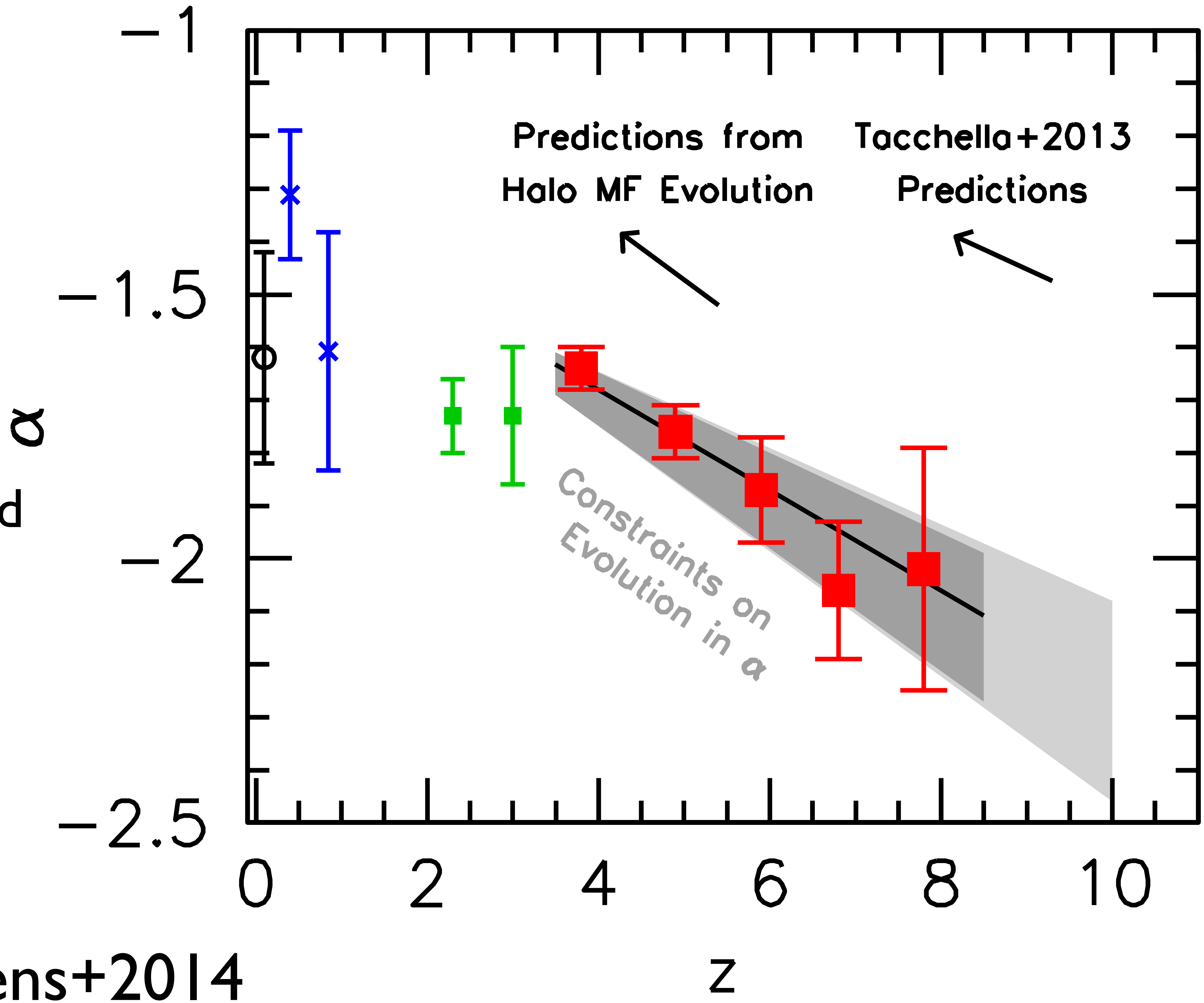
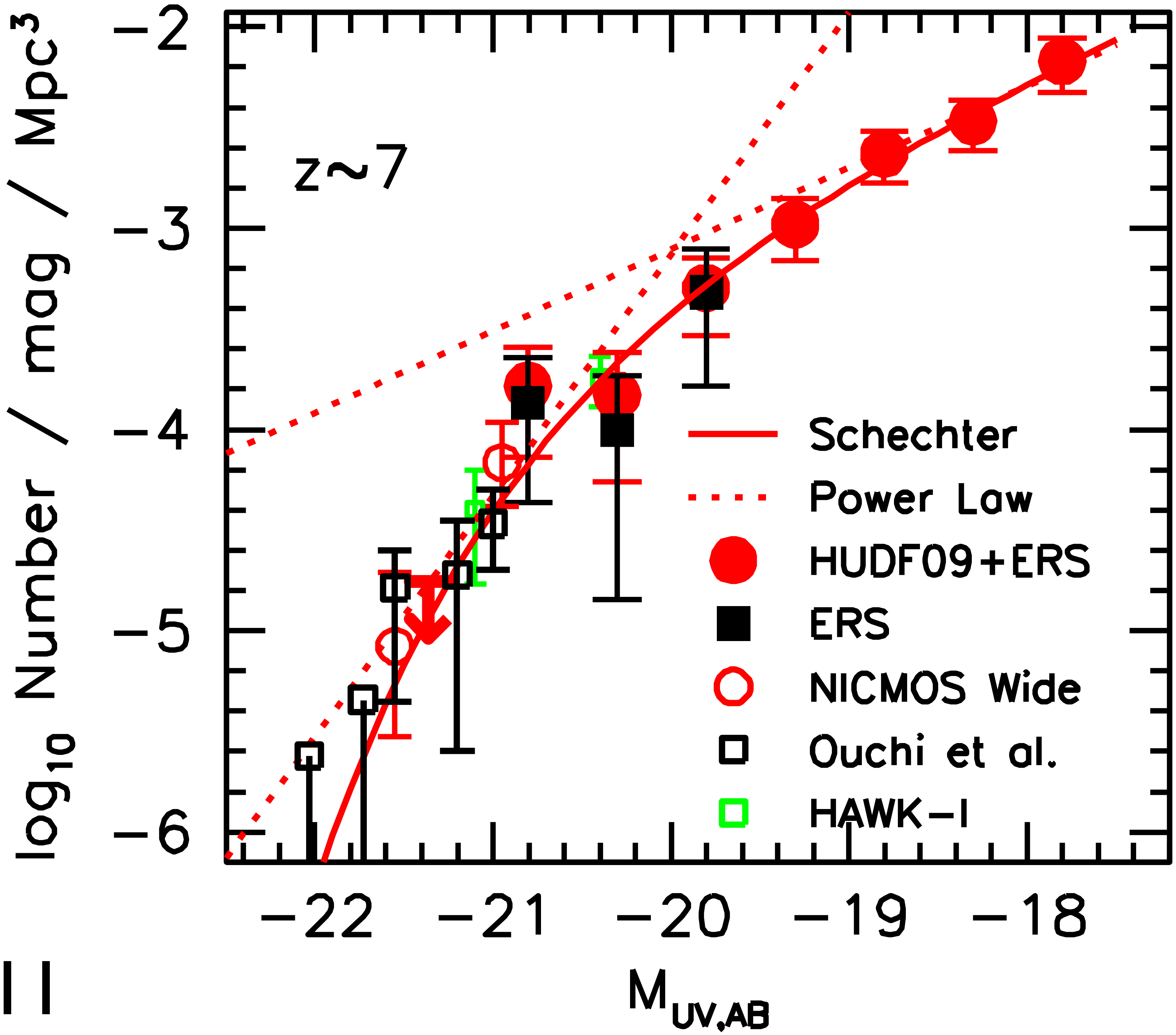


Luminosity Function Steeper at Early Times



Bouwens+2014

UV LF follows a clear power law at the faint end, but shows an apparent cut-off at the bright end



Bouwens+2011

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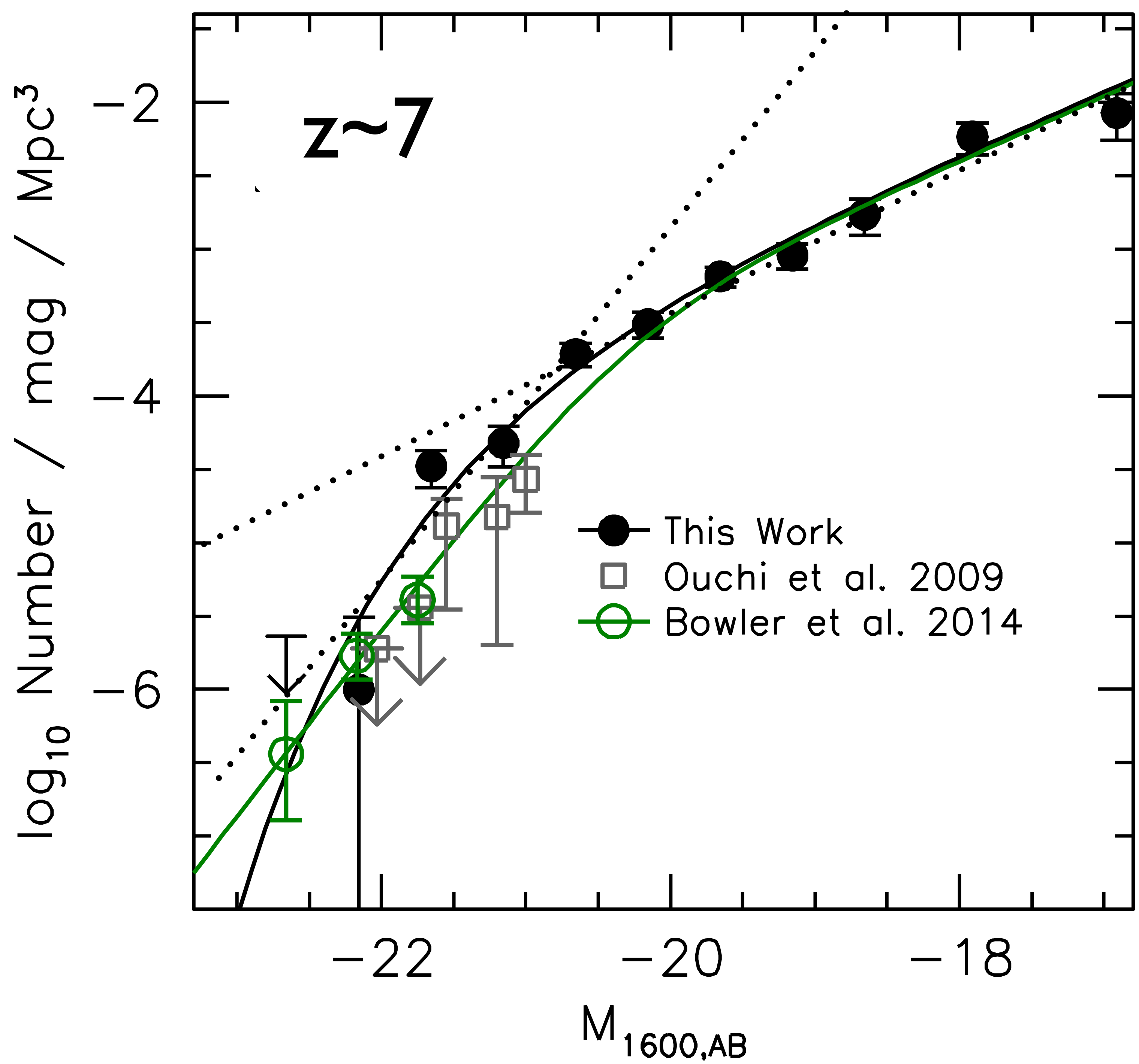
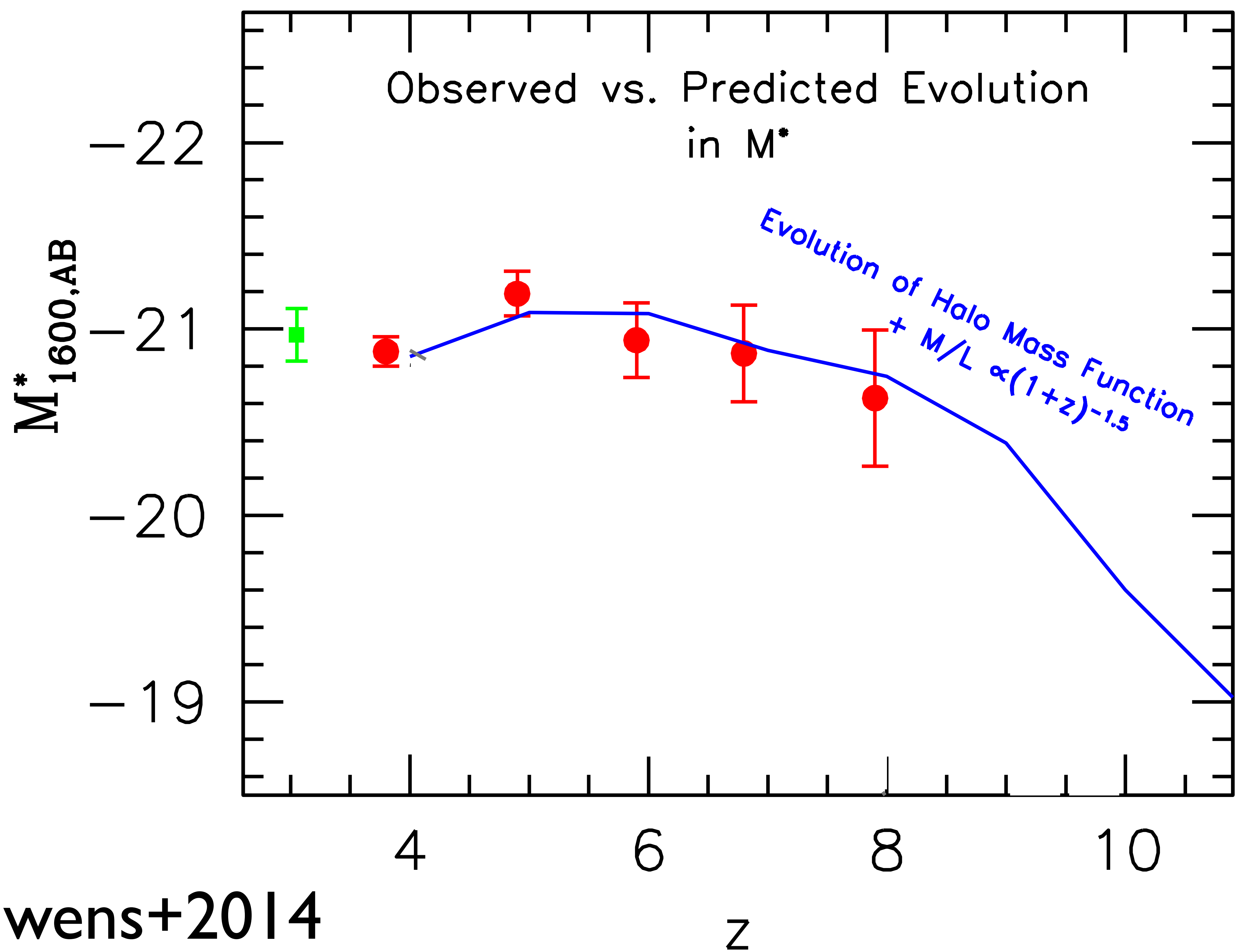


Bouwens+2014

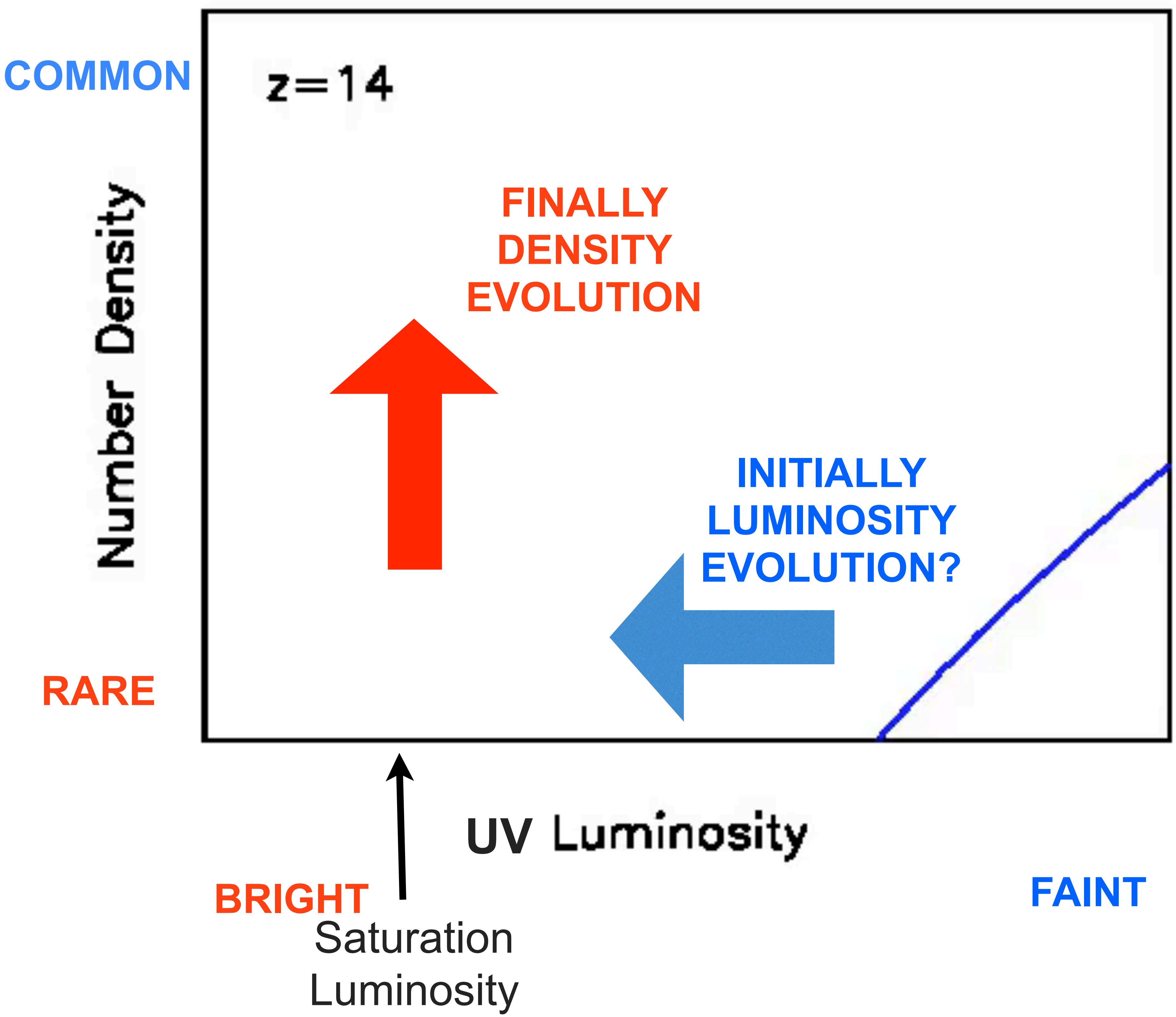
Bright End cut off (M*) does not evolve rapidly

(but becomes fainter at high redshift?)



Bouwens+2014

Schematically how does the LF evolve?



Assume galaxy light traces the the halo mass evolution

but UV light cannot exceed some maximum value

What does the Frontier Fields parallel program add?

z~4, 5, 6, 7, 8, and z~10 LF Results (submitted 8 months ago)

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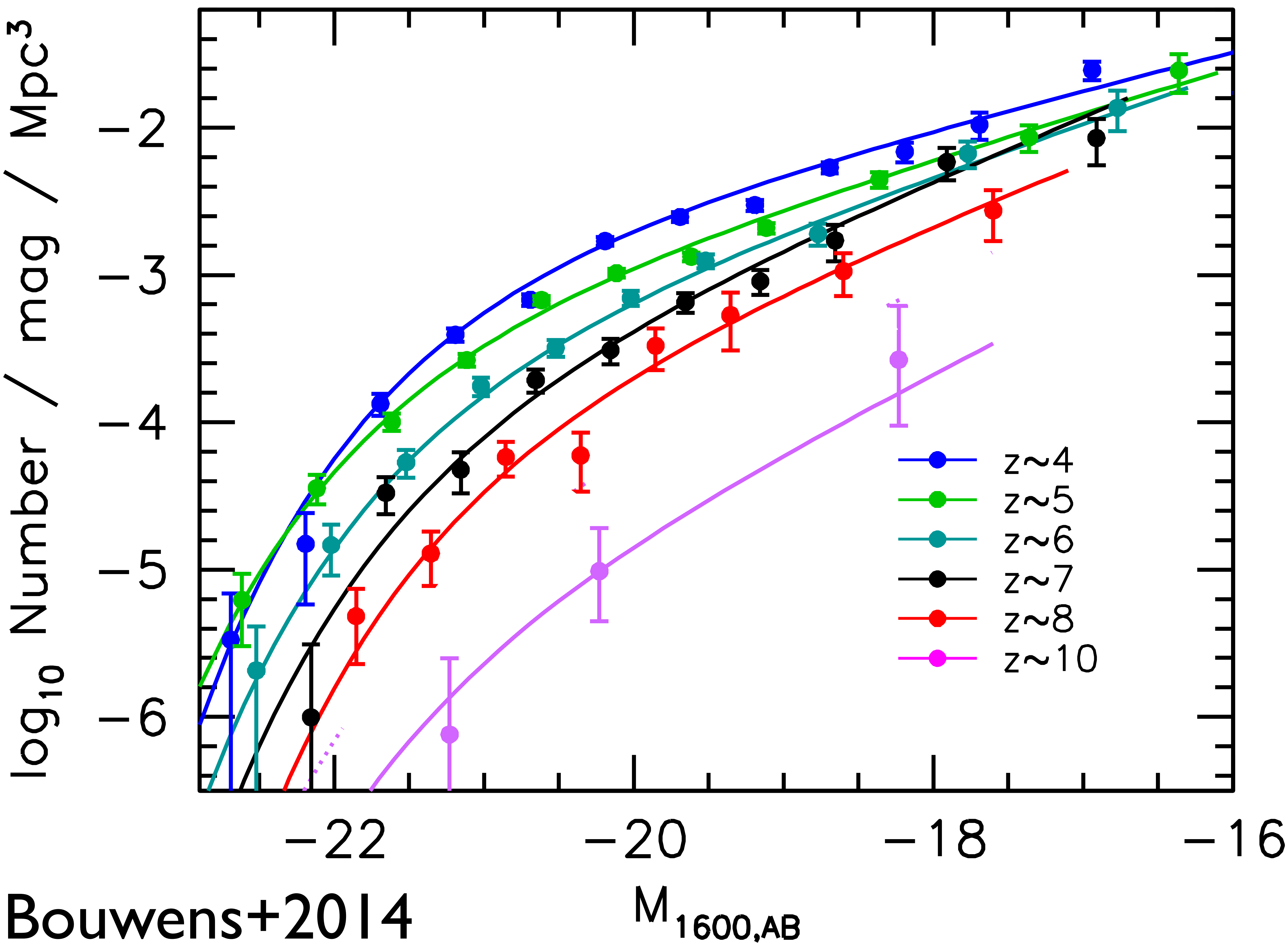

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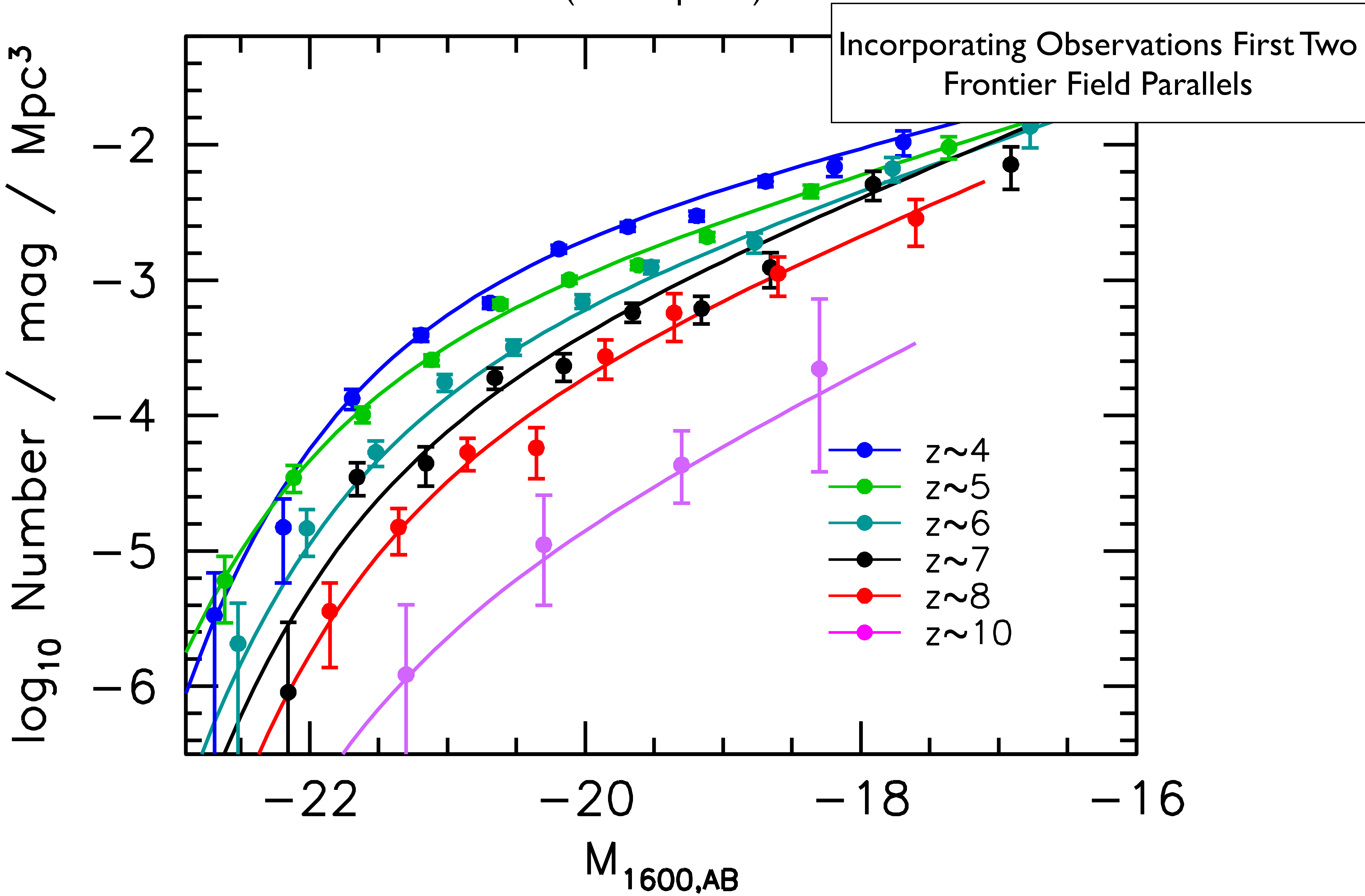

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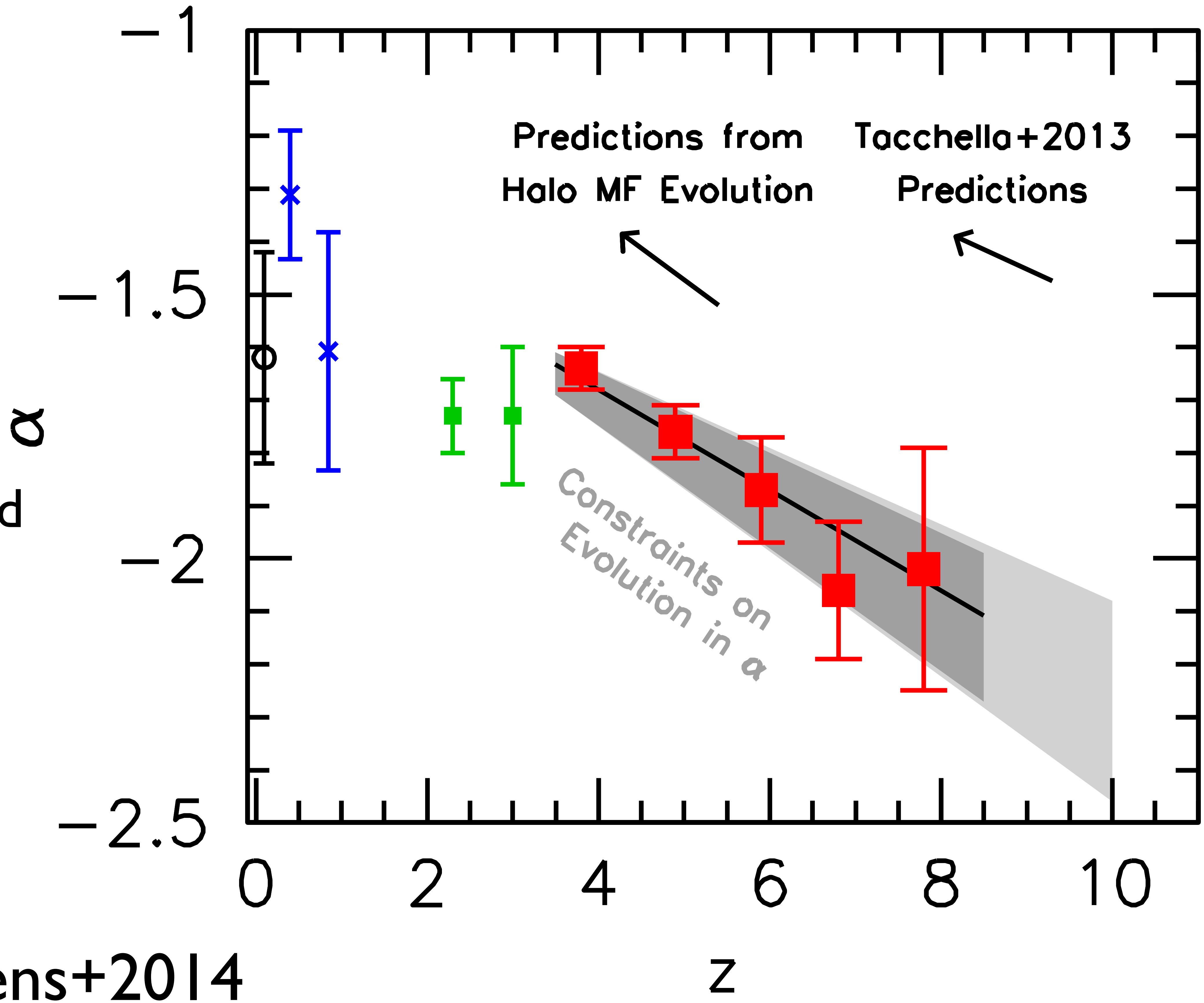

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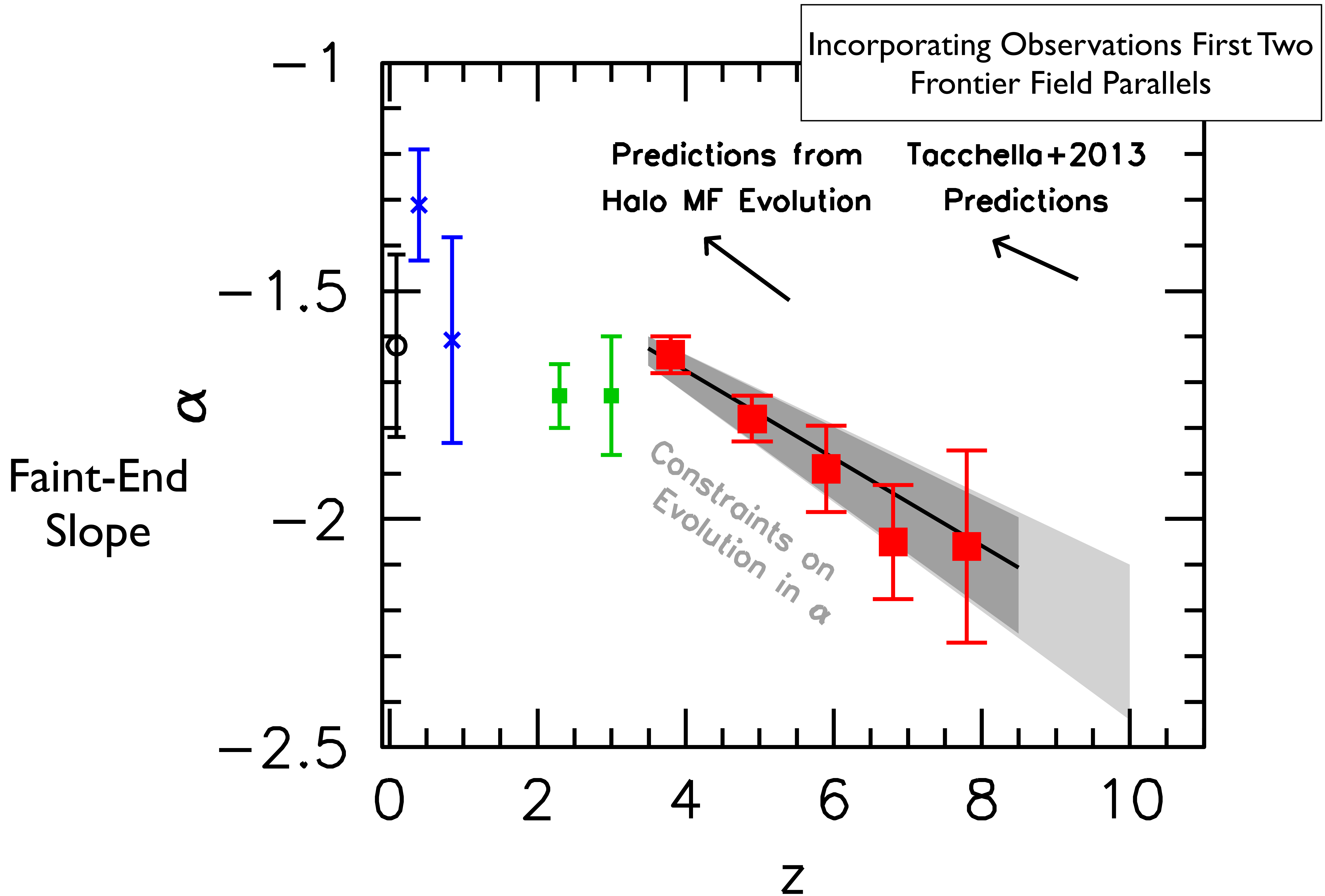

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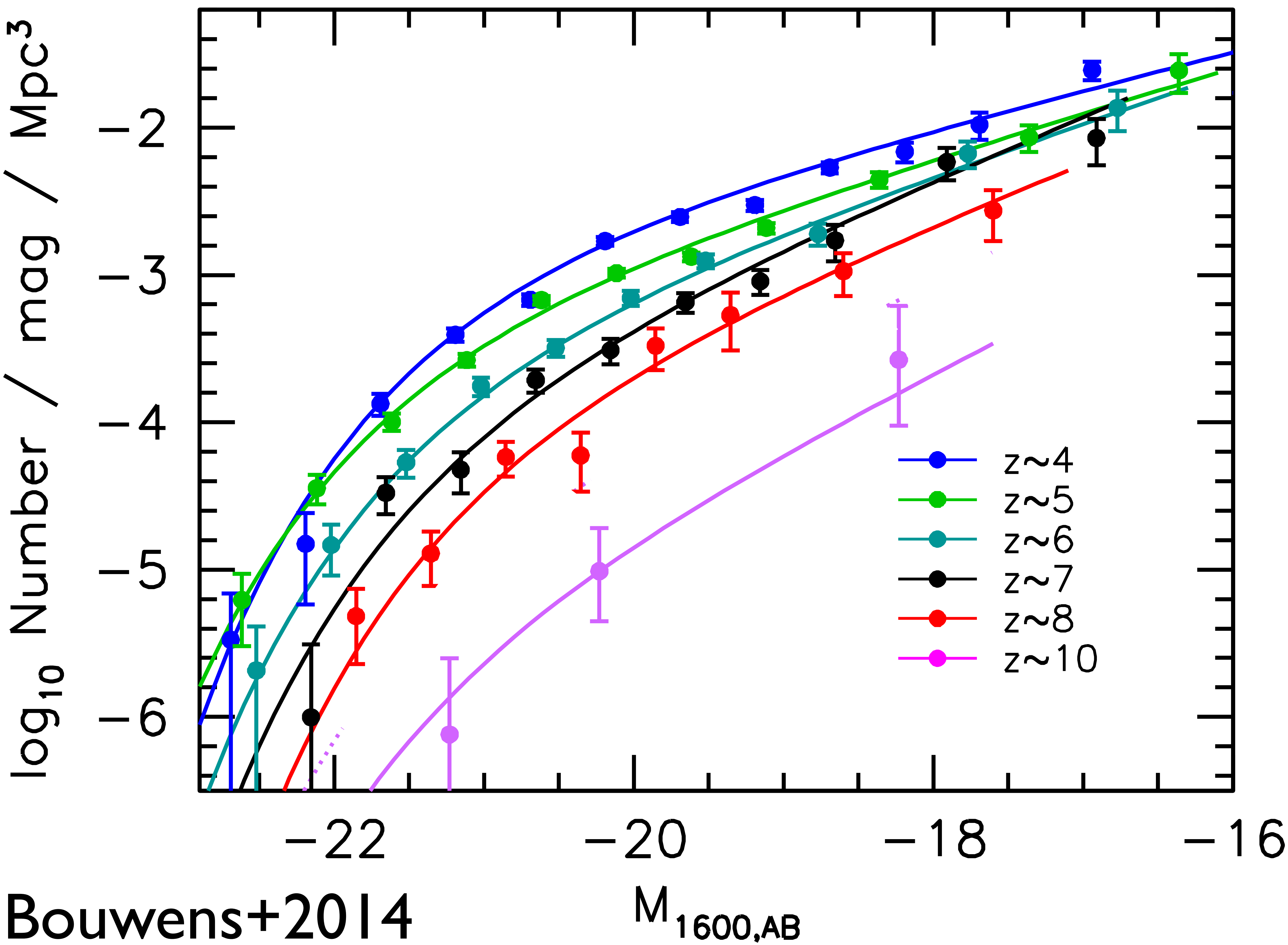

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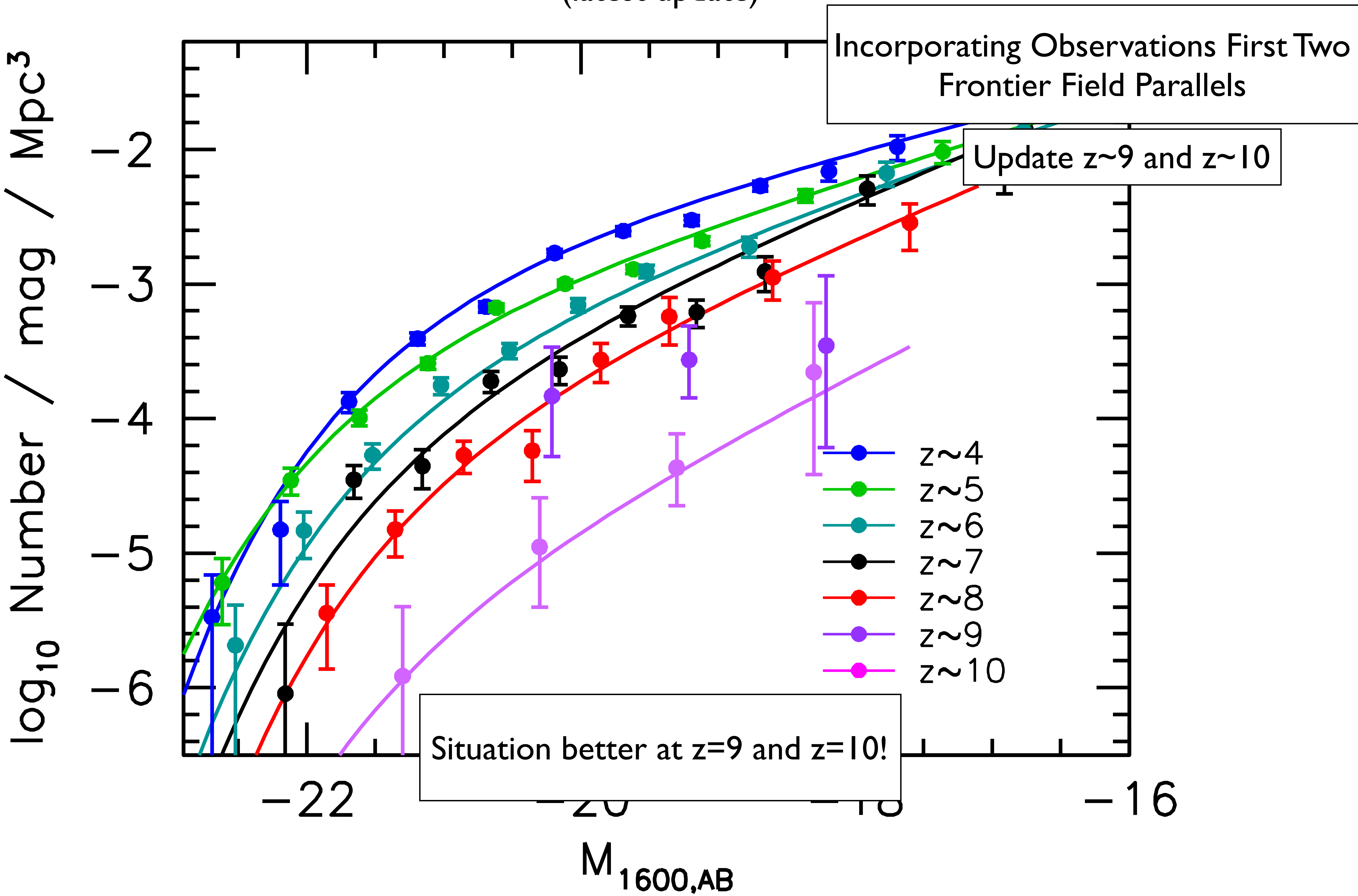
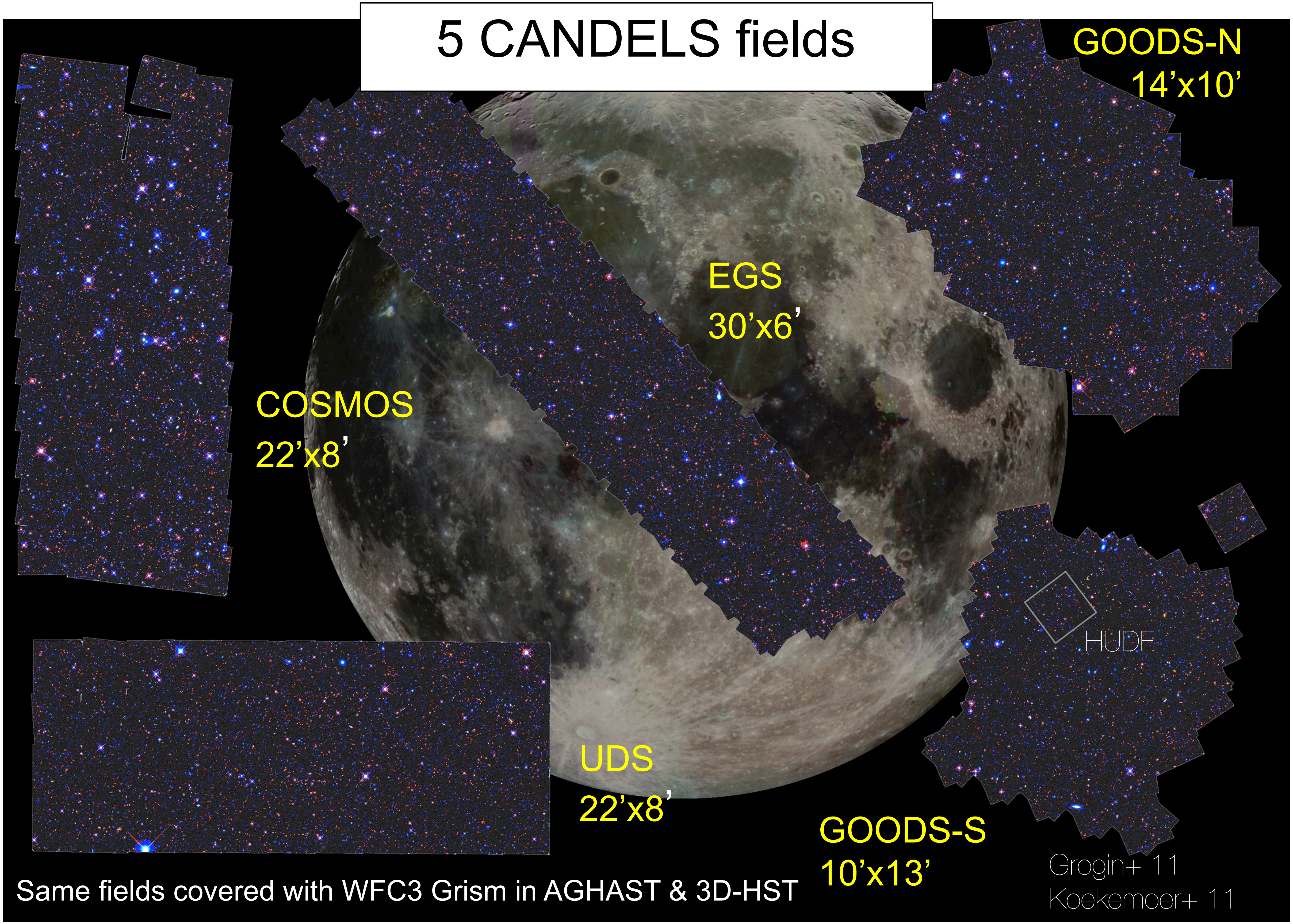


Important to have good constraints on volume density of luminous galaxies

Particularly at $z=9$ and $z=10$!

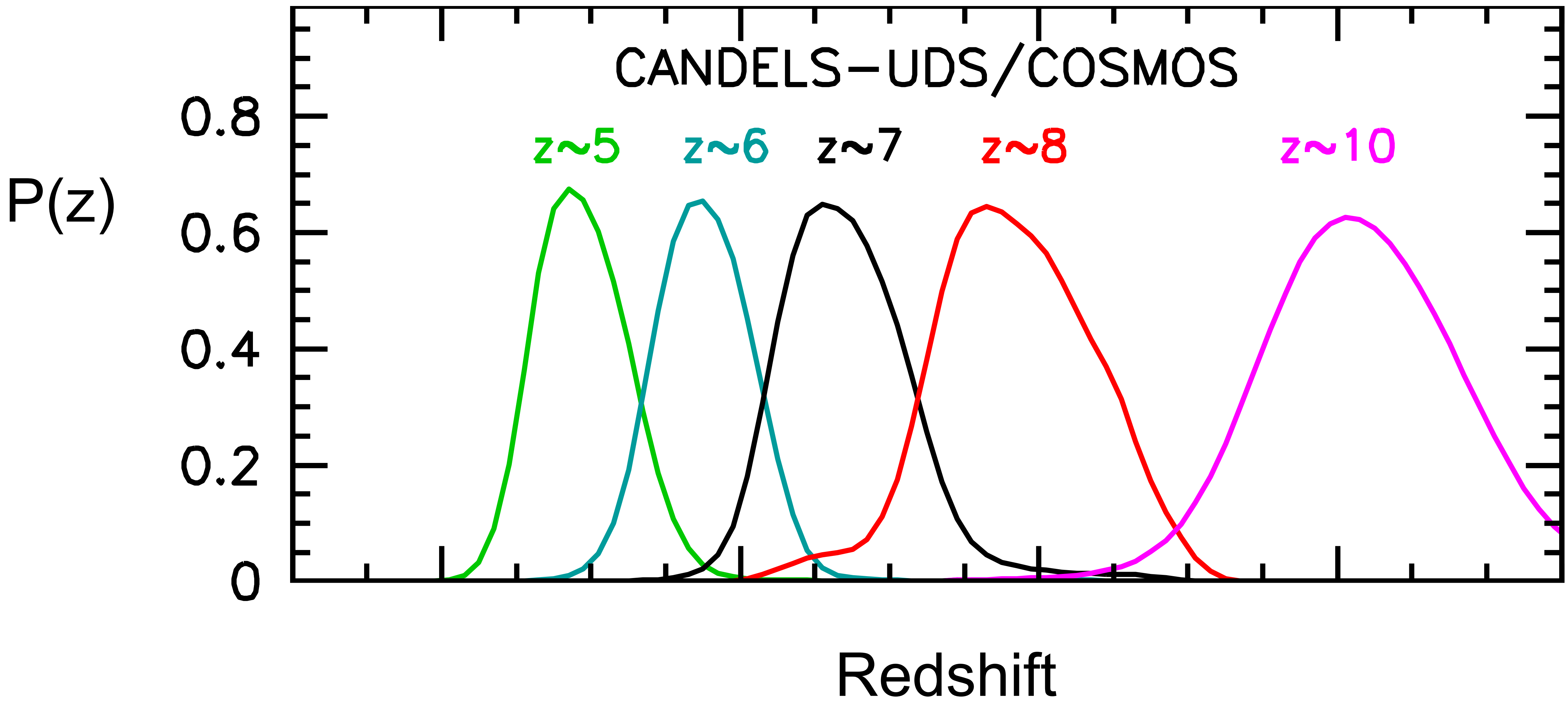
To obtain the best constraints, we fold in the widest area data that are available...



Question: Can We Use Full CANDELS program?

(as all do not have contiguous wavelength coverage with HST):

End-to-End Simulations Show Accurate Redshift Discrimination is Possible



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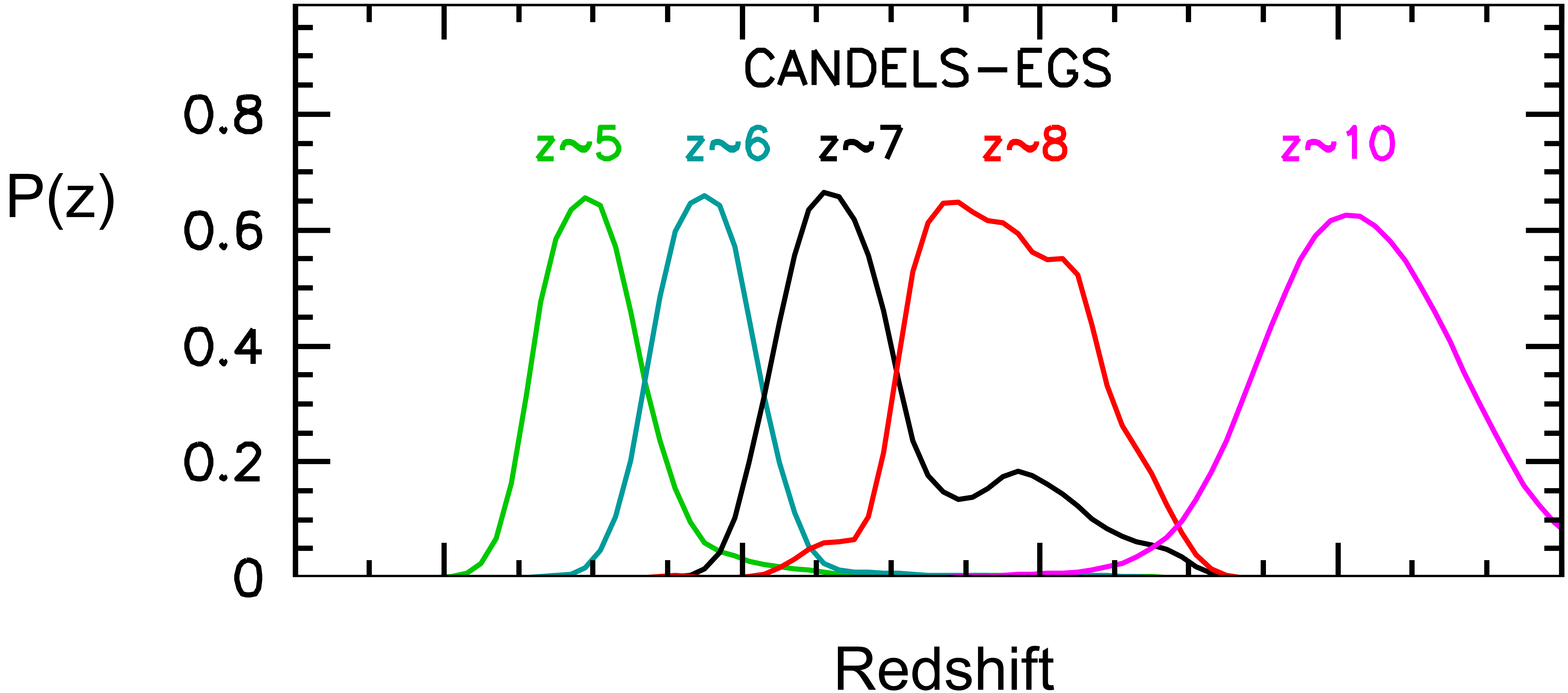
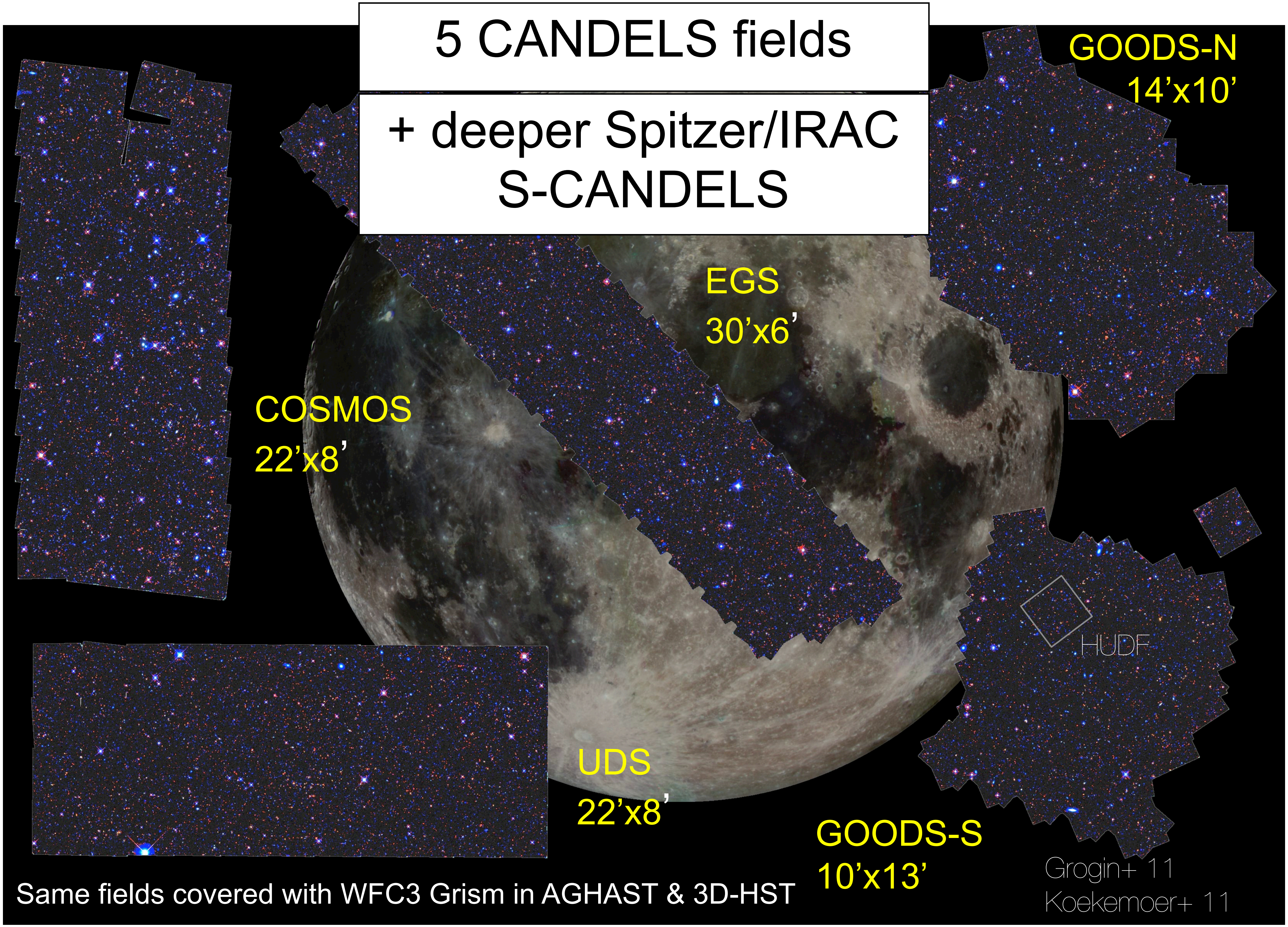


Also want good constraints on bright galaxies at $z=9$ and $z=10$!

To obtain the best constraints, we fold in the widest area data that are available...



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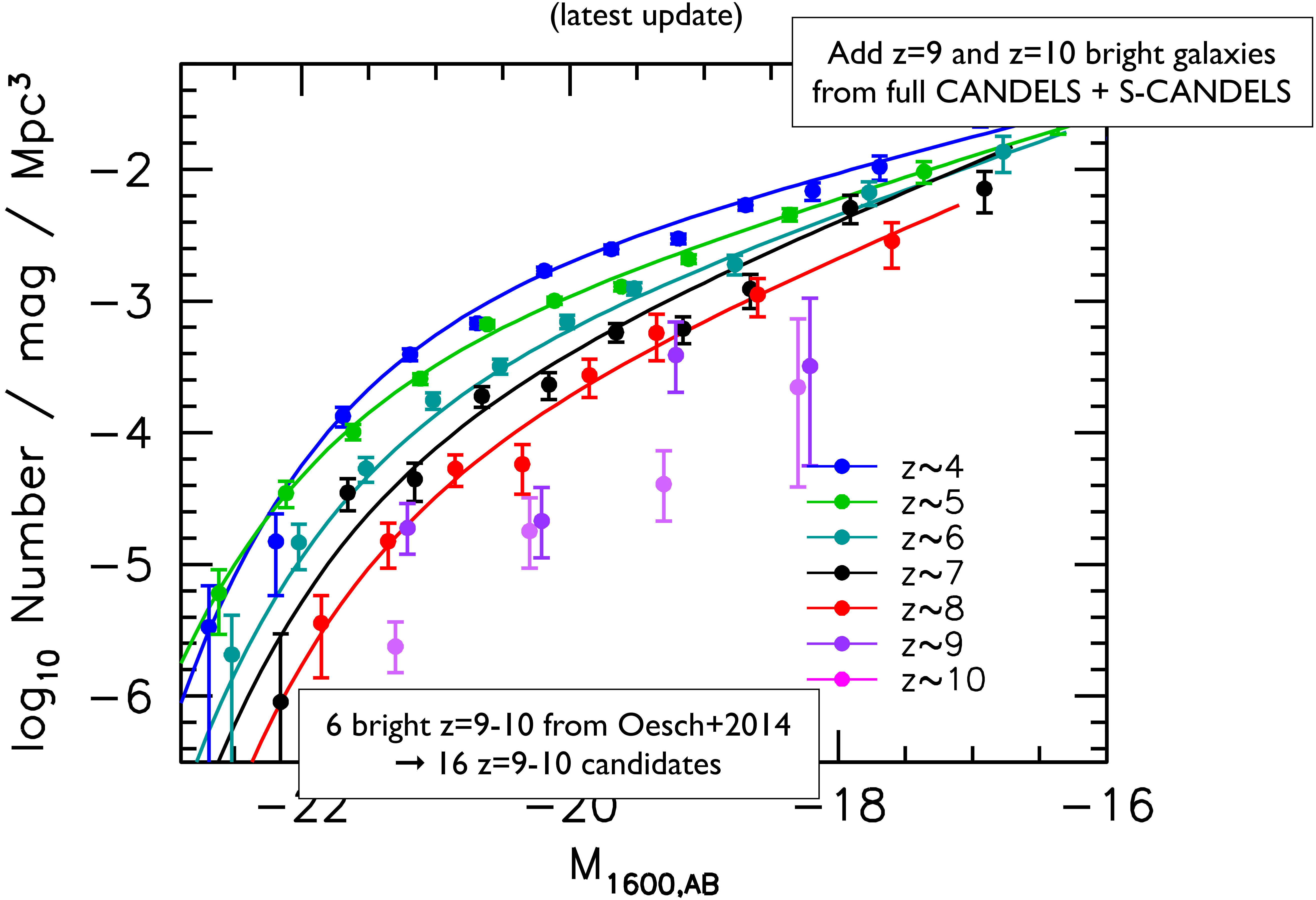

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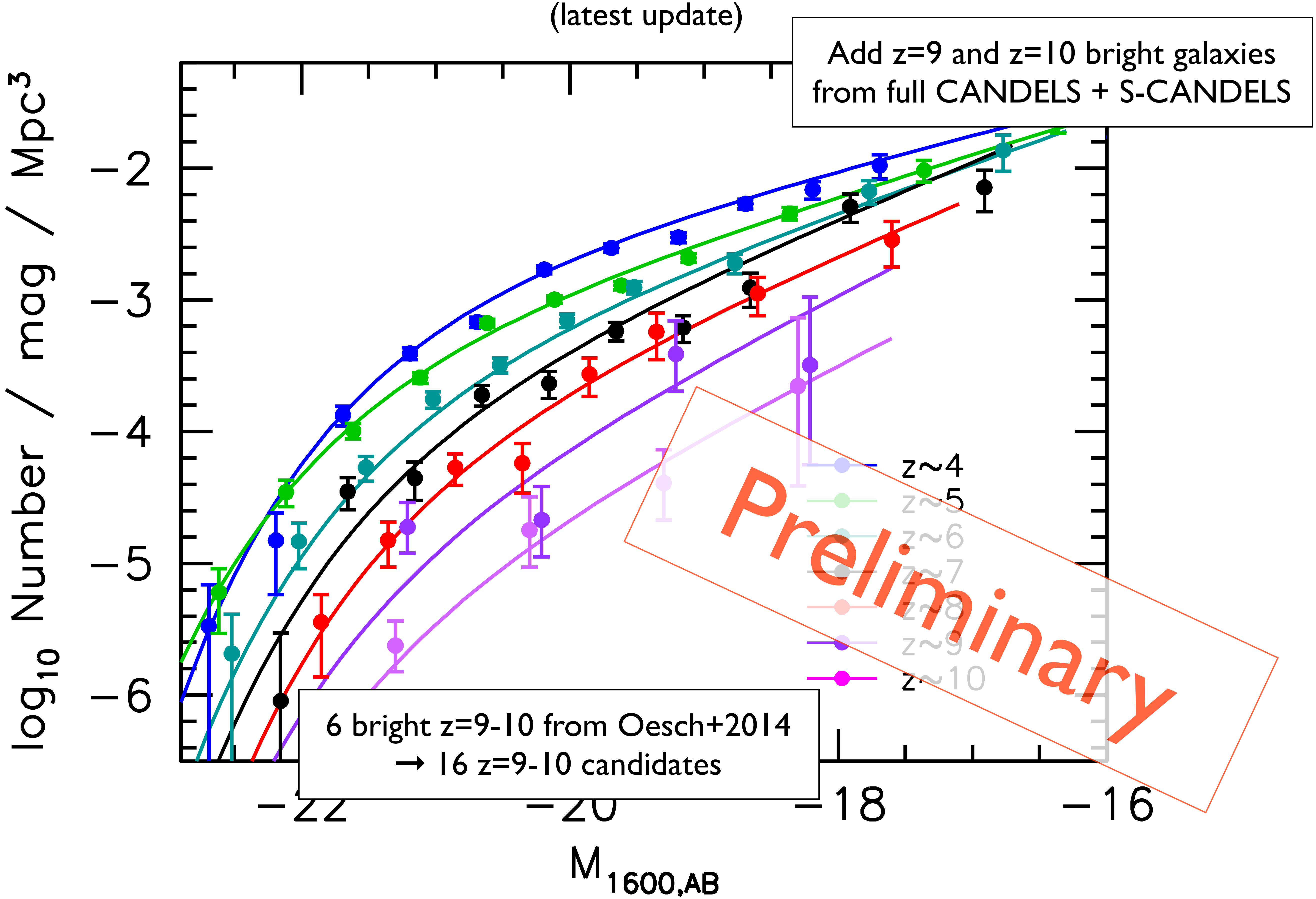


Follow-up of bright z=9-10 candidates over CANDELS WIDE fields

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 Evolution, High Redshift Galaxies
Instruments: WFC3, ACS

Proprietary Period: 0　　Proposal Size: Small

Orbit Request	Prime	Parallel
Cycle 22	11	10

Abstract

At present, we have only limited information on the spectral properties, stellar masses, and luminosity function of galaxies at z~9-10. While the new Frontier Fields Initiative will significantly improve our knowledge of the prevalence of fainter sources at these epochs, no comparable HST programs exist to study the properties of the brighter z~9-10 galaxies. This is unfortunate given that the brighter z~9-10 candidates are more amenable to follow-up study with facilities such as Spitzer and ALMA and the existence of only 8 reasonably reliable bright candidates (only 3 visible to ALMA). Fortunately, we can rectify this situation by using the existing HST+Spitzer observations over the full CANDELS program to identify all plausible z~9-10 candidates in that data set, but which lack sufficiently deep 1-micron observations to be secure. Here we propose to follow up each of these candidates with WFC3/IR at 1-micron F105W to determine which are likely at z~9-10 and thereby almost certainly doubling the number of bright, reliable z~9-10 candidates known to ~17 galaxies. Our follow-up strategy is very efficient, e.g., >~10x more efficient as tiling the relevant CANDELS fields with 1-micron F105W data and ~40x more efficient as searches in fields with no pre-existing data. The large samples of bright z~9-10 galaxies we will select with our program will be used to solidify current conclusions about the

More bright z~9-10 candidates using ambitious pure-parallel program BoRG$_{[z910]}$

Hubble Space Telescope | Cycle 22 GO Proposal | <ID>

Bright Galaxies at Hubble's Detection Frontier: The redshift z~9-10 BoRG pure-parallel survey

Scientific Category: COSMOLOGY

Scientific Keywords: Galaxy Formation And Evolution, High Redshift Galaxies, Hubble Deep Fields, Survey

Instruments: WFC3

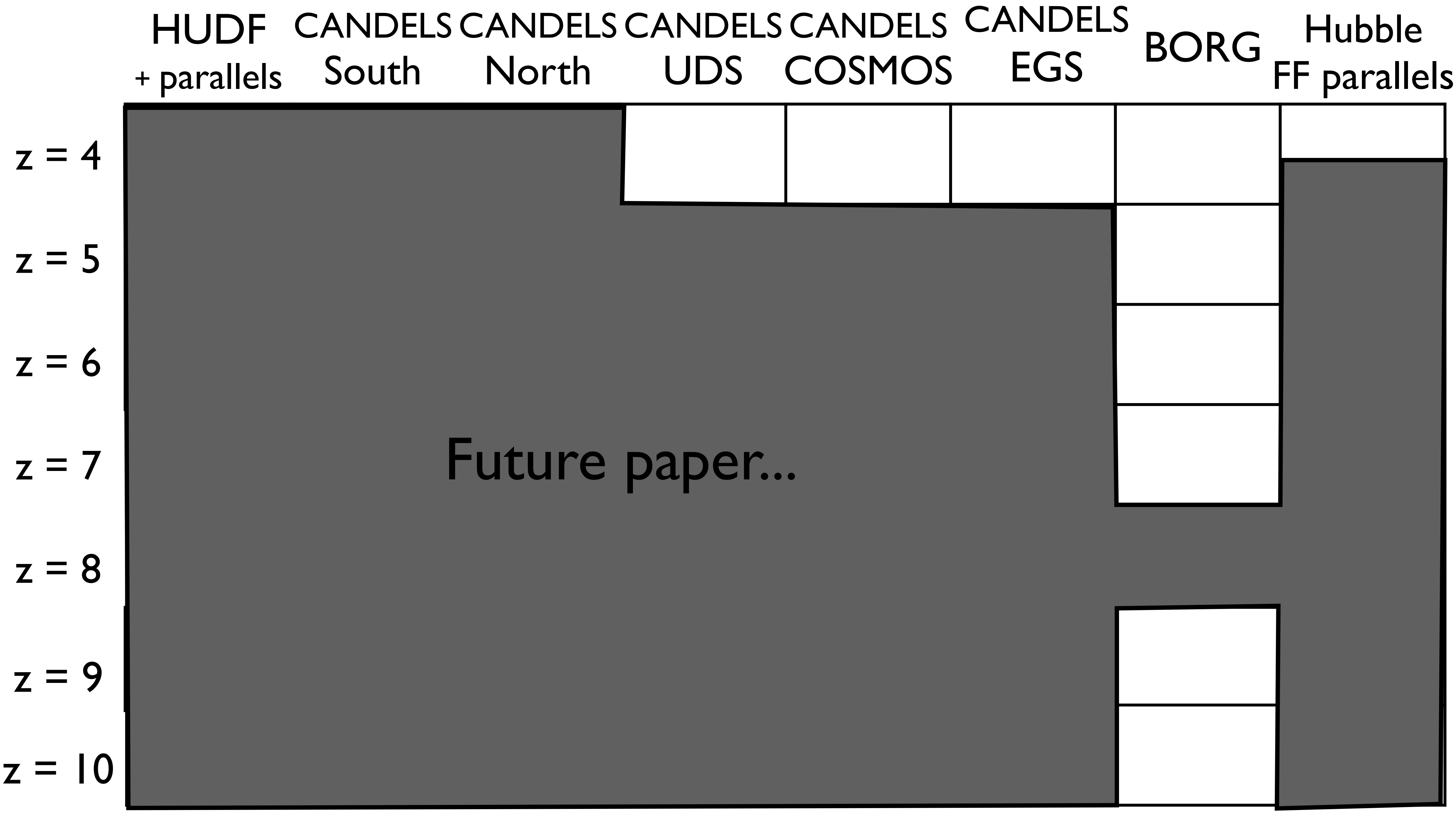
Proprietary Period: 0 | Proposal Size: Large

Orbit Request	Prime	Parallel
Cycle 22	0	480

Abstract

Current HST observations of galaxies at 500 Myr after the Big Bang (z~9-10) are puzzling: Ultradeep fields contain very few of them, indicating accelerated decrease in the galaxy number density compared to lower redshift, but bright galaxies at m_AB~26-27 are found in surprising numbers, especially in GOODS-N. Frontier Fields observations will constrain the luminosity function faint-end, but large area data over dozens of independent lines of sight are needed to determine the abundance of bright objects irrespective of cosmic variance. Such task is ideally suited for a pure-parallel survey in terms of depth and number of independent pointings, as our Cycle 17+19 Brightest of Reionizing Galaxies (BoRG) Survey demonstrated at z~8. We propose here to take WFC3 observations to Hubble's detection frontier by identifying L>L* galaxies at z~9-10 using redder filters. We will image ~550 arcmin^2 over 120 lines of sight (over 20 times the HUDF/Frontier Fields area), reaching up to m_AB=27.2 in five bands (F350LP, F105W, F125W, F140W, F160W) with a design optimized to select z~9 galaxies with minimal contamination. We expect to discover more than 20 L>L* galaxies at z~9-10, unequivocally measuring the bright-end of the luminosity function, and double the numbers of bright galaxies at z~8 (expected yield of ~60 new objects), identifying ideal follow-up targets to study Ly-alpha emission and reionization. BoRG[z9-10] will create a unique dataset to explore the undiscovered territory of bright galaxy formation and clustering at z>8, revealing how baryons and dark matter are connected at these early epochs and what is the impact of feedback in the most luminous sources at the time.

Future z~4, 5, 6, 7, 8, 9, 10 LF Results?



Summary / Conclusions

Current HST data allow us to select large numbers of galaxies at z~4-10 (>10000) and draw the following two conclusions about the evolution of the UV LF:

The faint-end slope flattens significantly from -2.1 to -1.6 (z=8 to z=4).

The bright-end cut-off M* remains fixed at ~-21 (z=4-6) and starts becoming fainter at z>6

How does the new FF program improve the situation?

Formally only modest improvements expected for z=4-8 galaxies from the parallels...

But useful gains at z=9-10, given the small number of sources in current samples

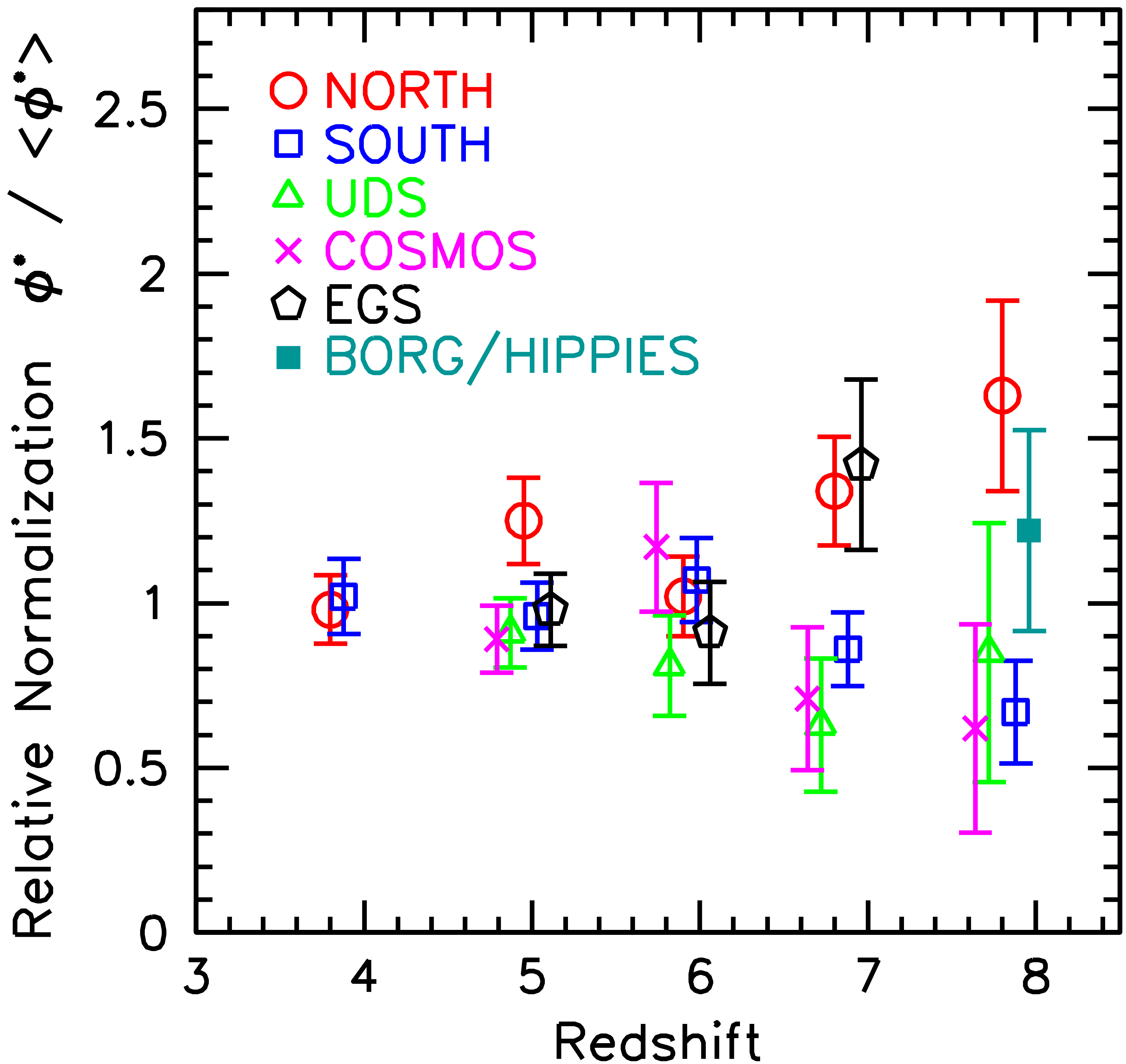
To maximize value of FF program, remember improvements coming at bright end from the analysis and follow-up of z=9-10 candidates over the full CANDELS program. This comes from an approved cycle-22 program (PI: Bouwens) and the $BoRG_{[z910]}$ (PI: Trenti).

Large Areas Required 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