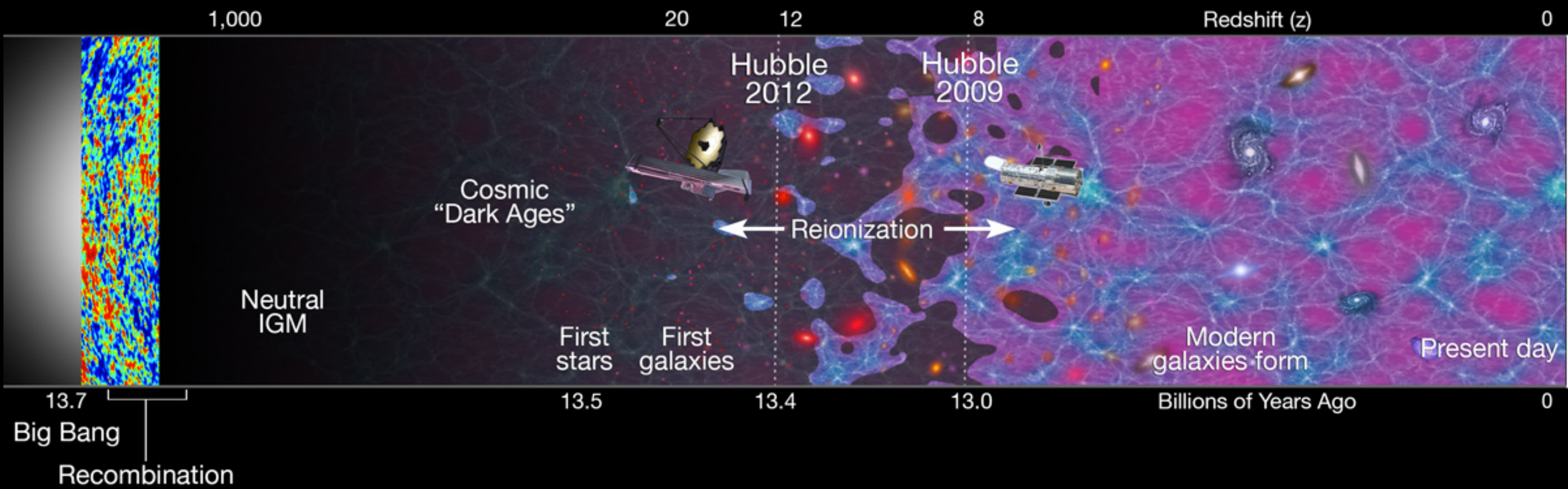
LFs, ρ_{SFR}, reionization etc



James Dunlop

Institute for Astronomy, University of Edinburgh

Sesto Jan 2016

"The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 312725"

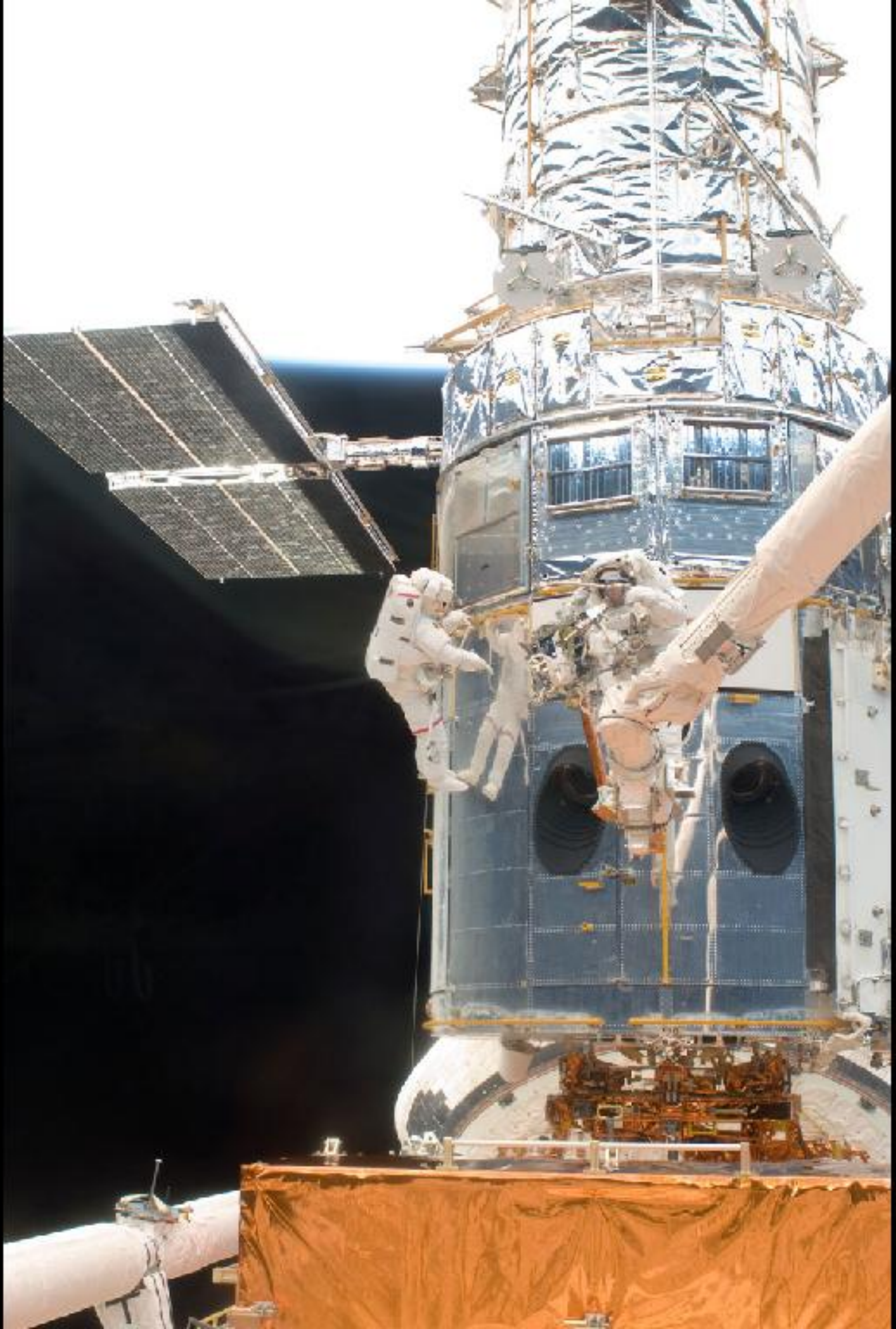
PLAN

1. Demographics – the galaxy luminosity function to z = 9
2. Early evolution of UV luminosity density – reionization
3. A complete history of cosmic star formation ?

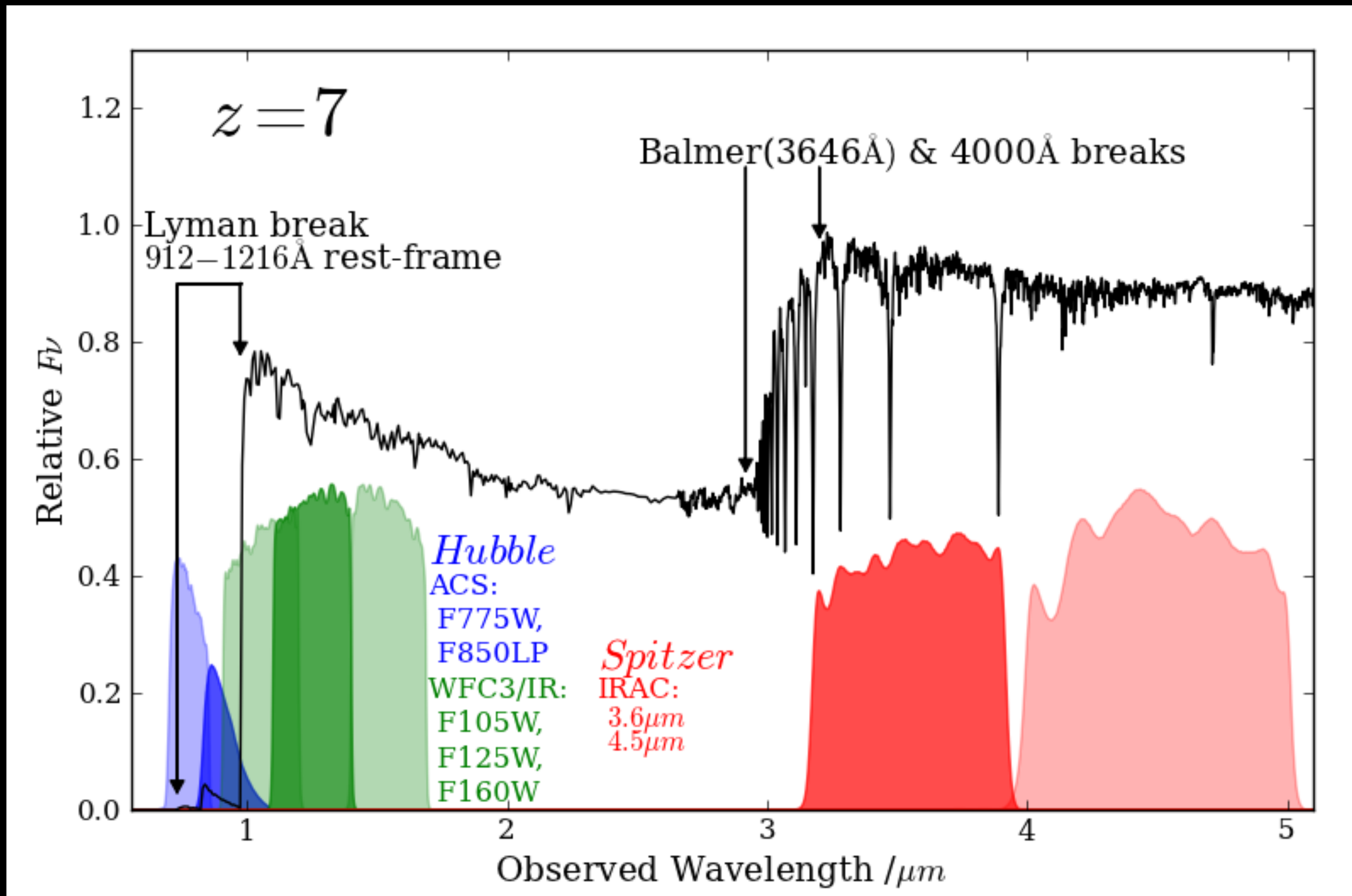
Lyman-break at 1216 Angstrom shifted to ~ 1 micron by z = 7

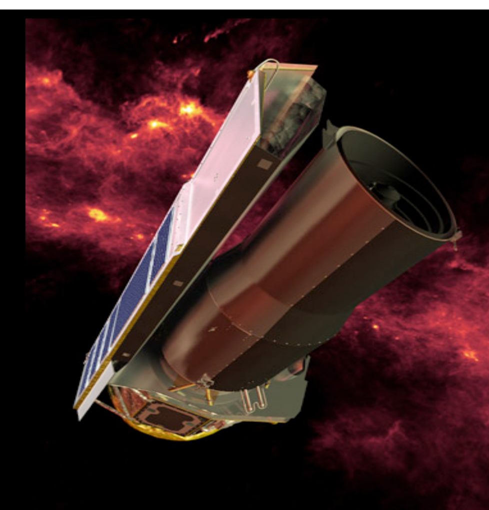
So, exploration of the first billion years (z > 6) had to await the advent of sensitive near-IR imaging.

In practice, WFC3 on Hubble (fitted in 2009)



Observing a high-redshift Lyman-break galaxy

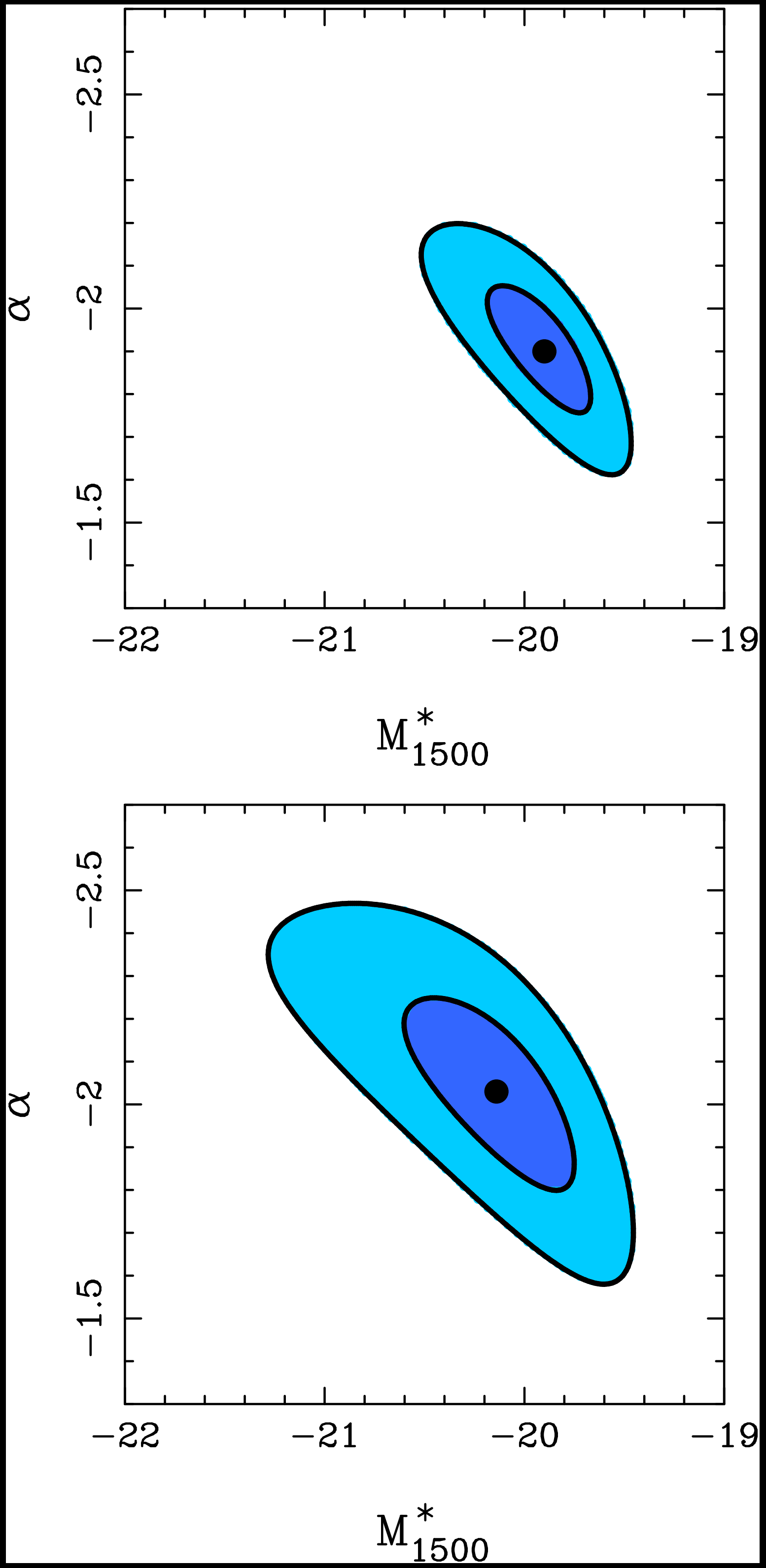


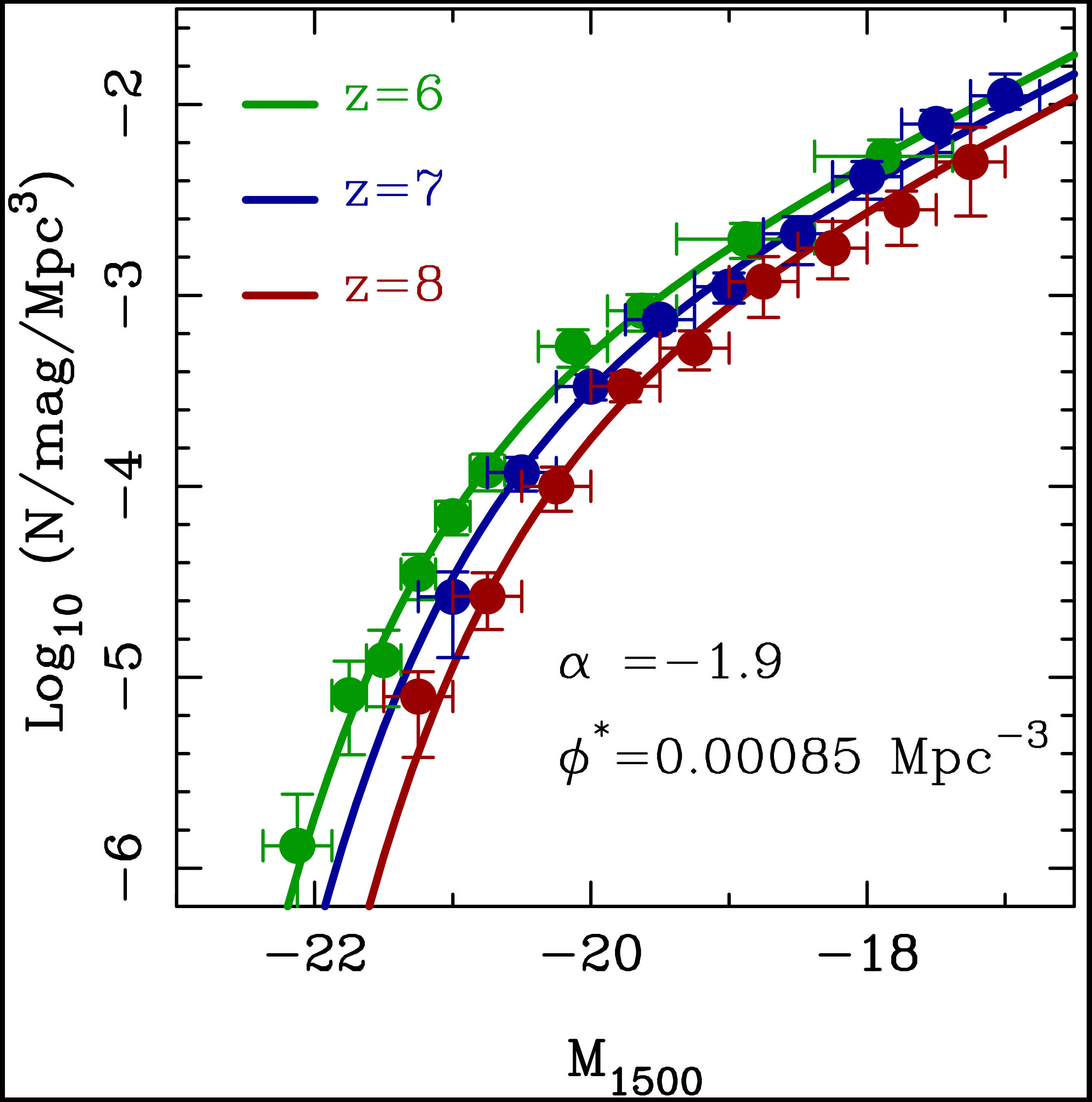


And now VISTA delivering degree-scale imaging of z ~ 7 Universe

UV galaxy LFs out to z = 8 from UDF12

McLure Dunlop, et al. 2013, MNRAS, 432, 2696





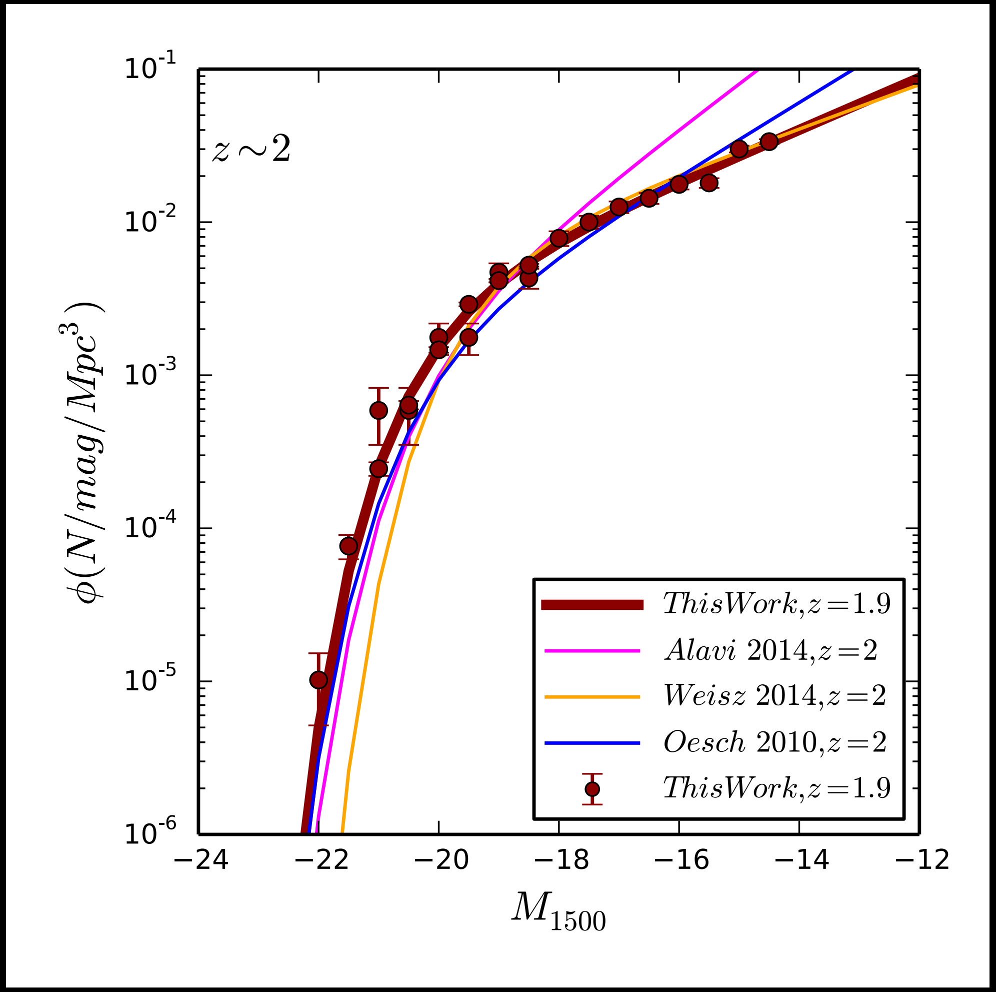
Luminosity evolution still looks okay:
α and ϕ^* fixed, M^* evolving: $\delta m = 0.3\delta z$

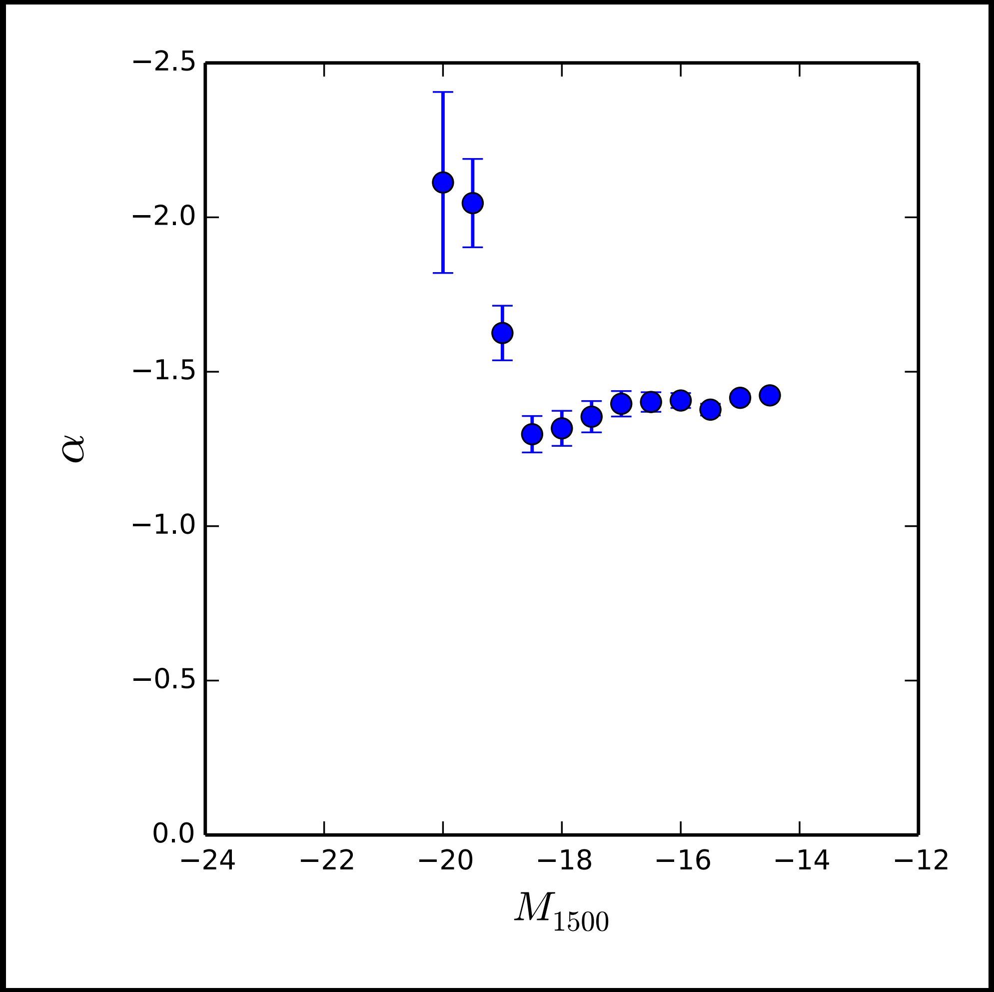
Faint-end slope of the UV LF

So, α = -2 at z = 8.

Means luminosity density diverges if no lower limit, and is dominated by faint galaxies – implications for reionization.

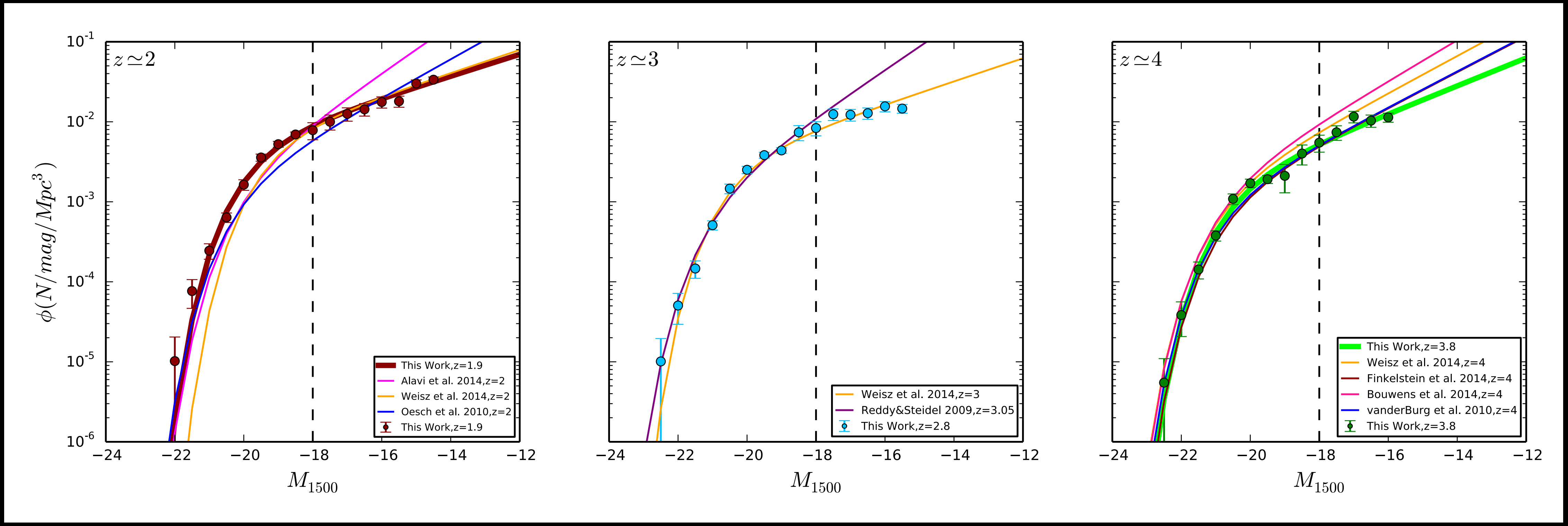
LF is not nearly as steep as this at z = 2 (Parsa, Dunlop et al. 2015)

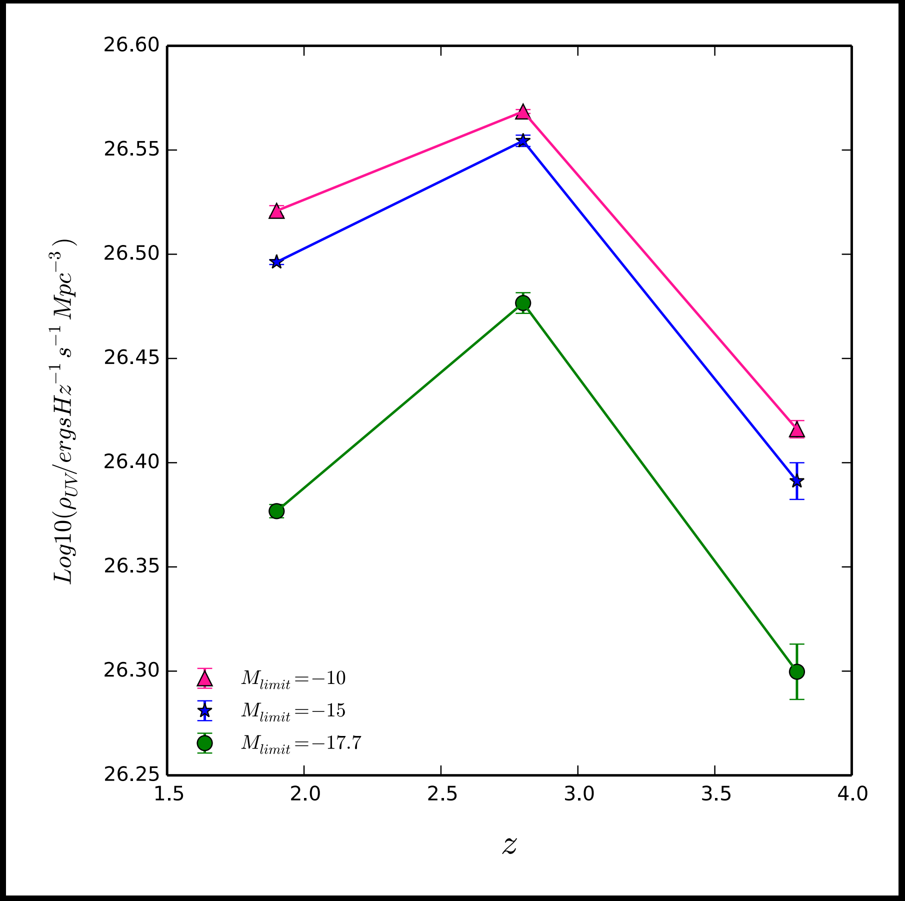




Reddy & Steidel (2009) got the slope wrong – data not deep enough

LF and raw UV luminosity density z = 2 – 4

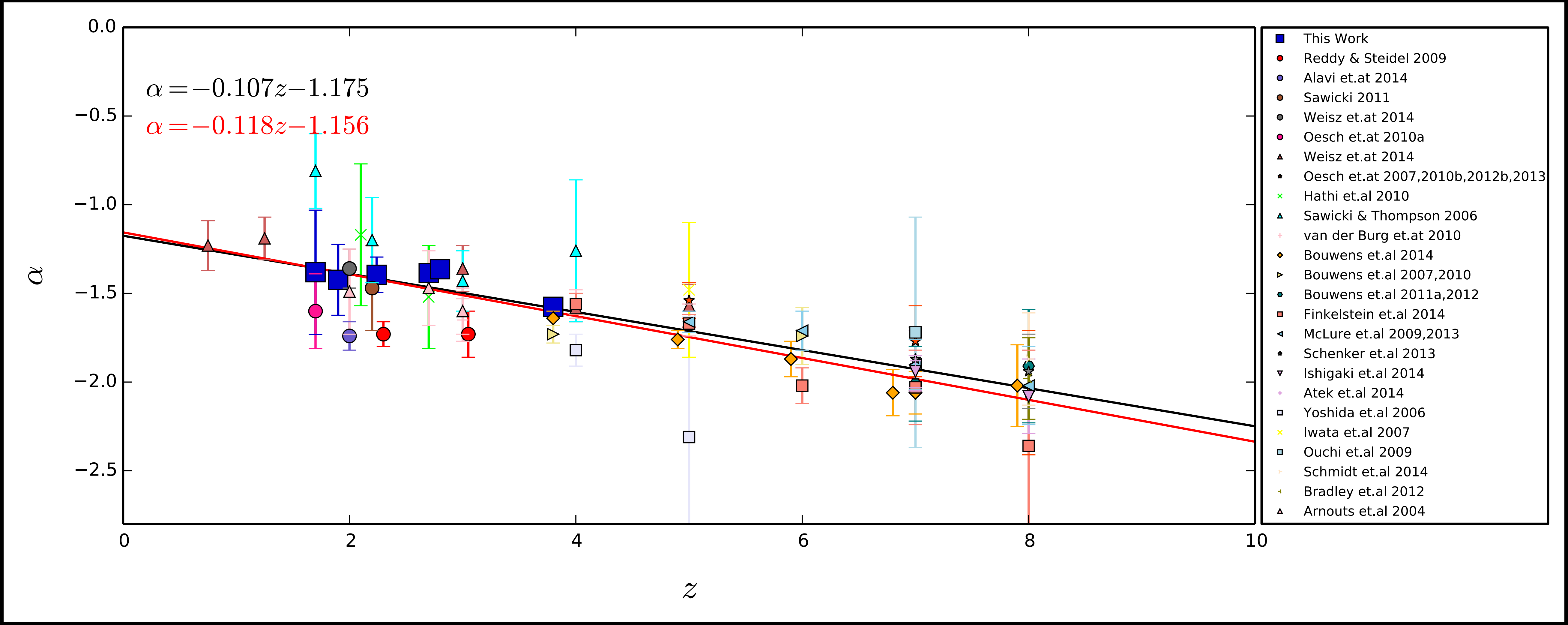




Parsa, Dunlop et al. 2015

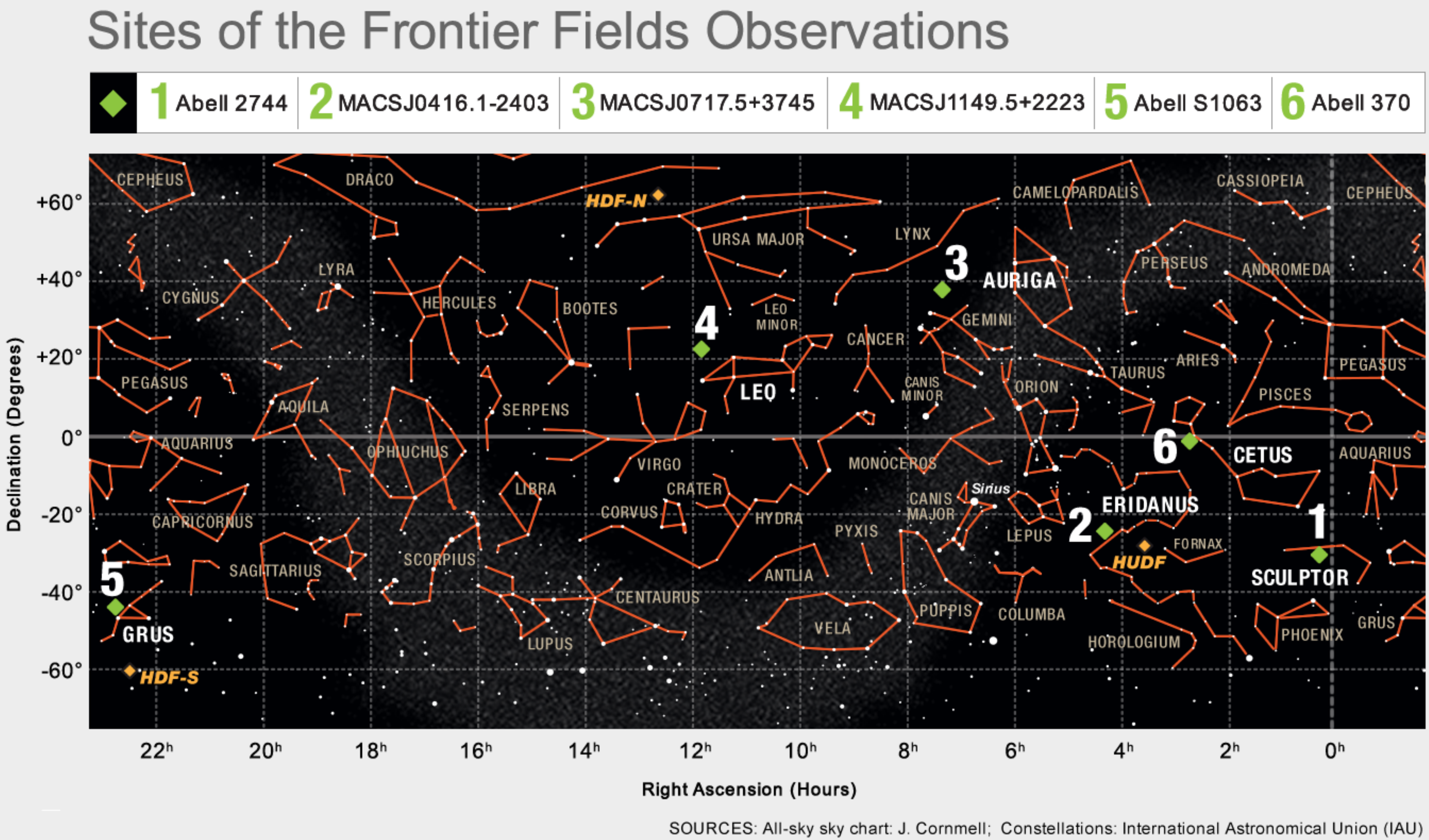
Faint-end slope of the UV LF

The evolution of α – see Parsa, Dunlop, et al. 2015



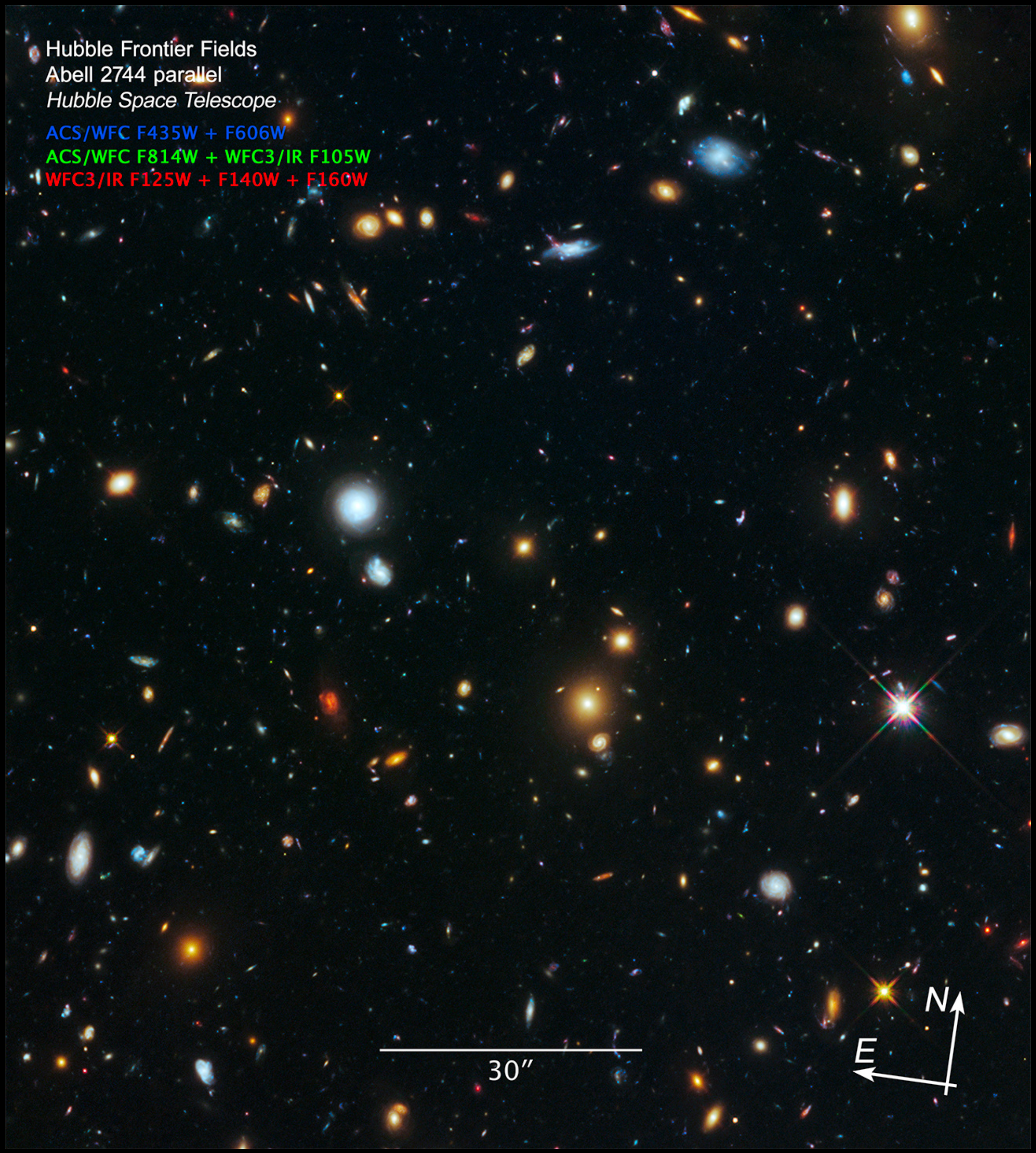
The luminosity function at z = 9
New results from the Hubble Frontier Fields

Six Hubble Frontier Fields planned

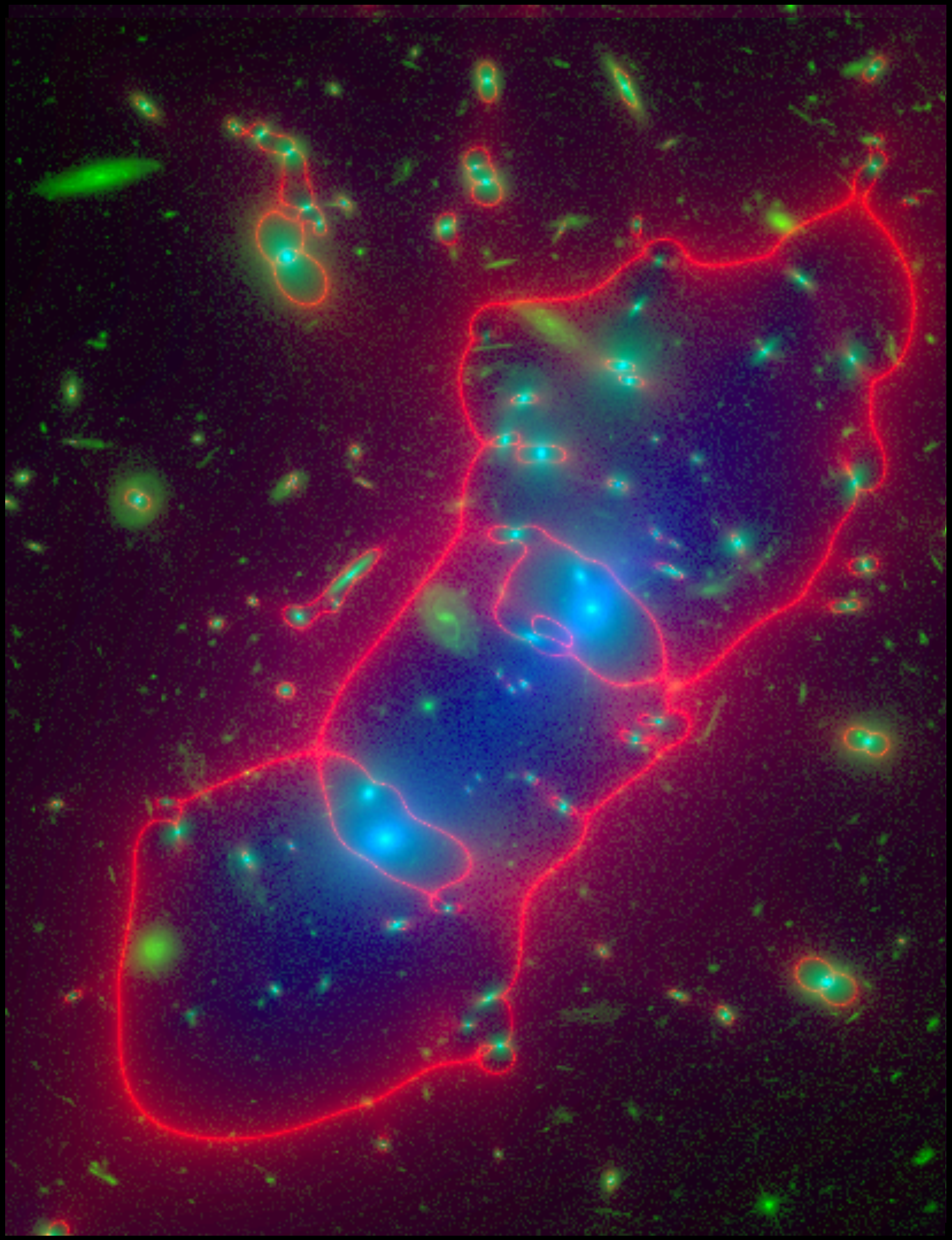


Observations of first four now completed

e.g. Abell 2744



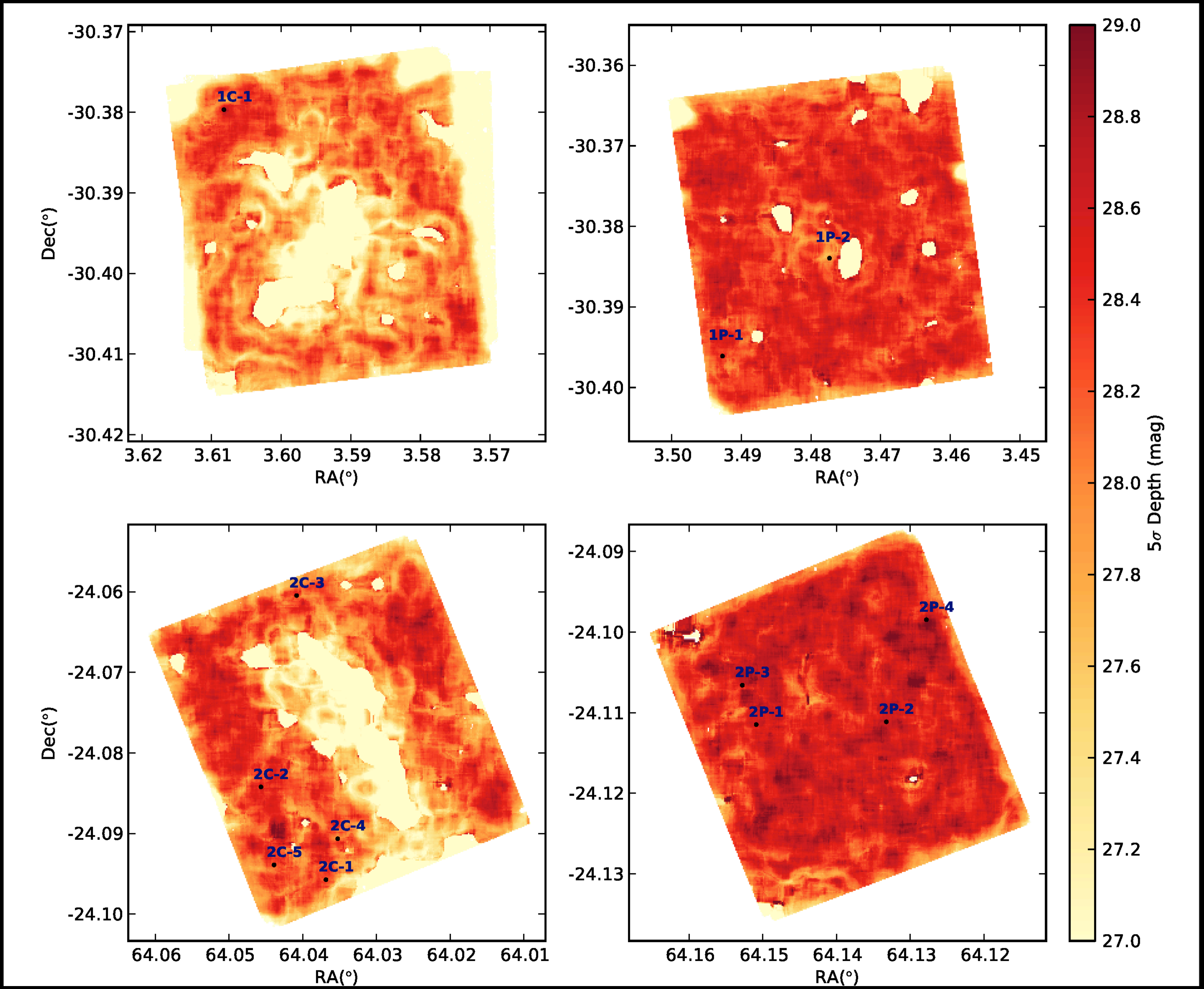
Gravitational lensing – the tricky reality….



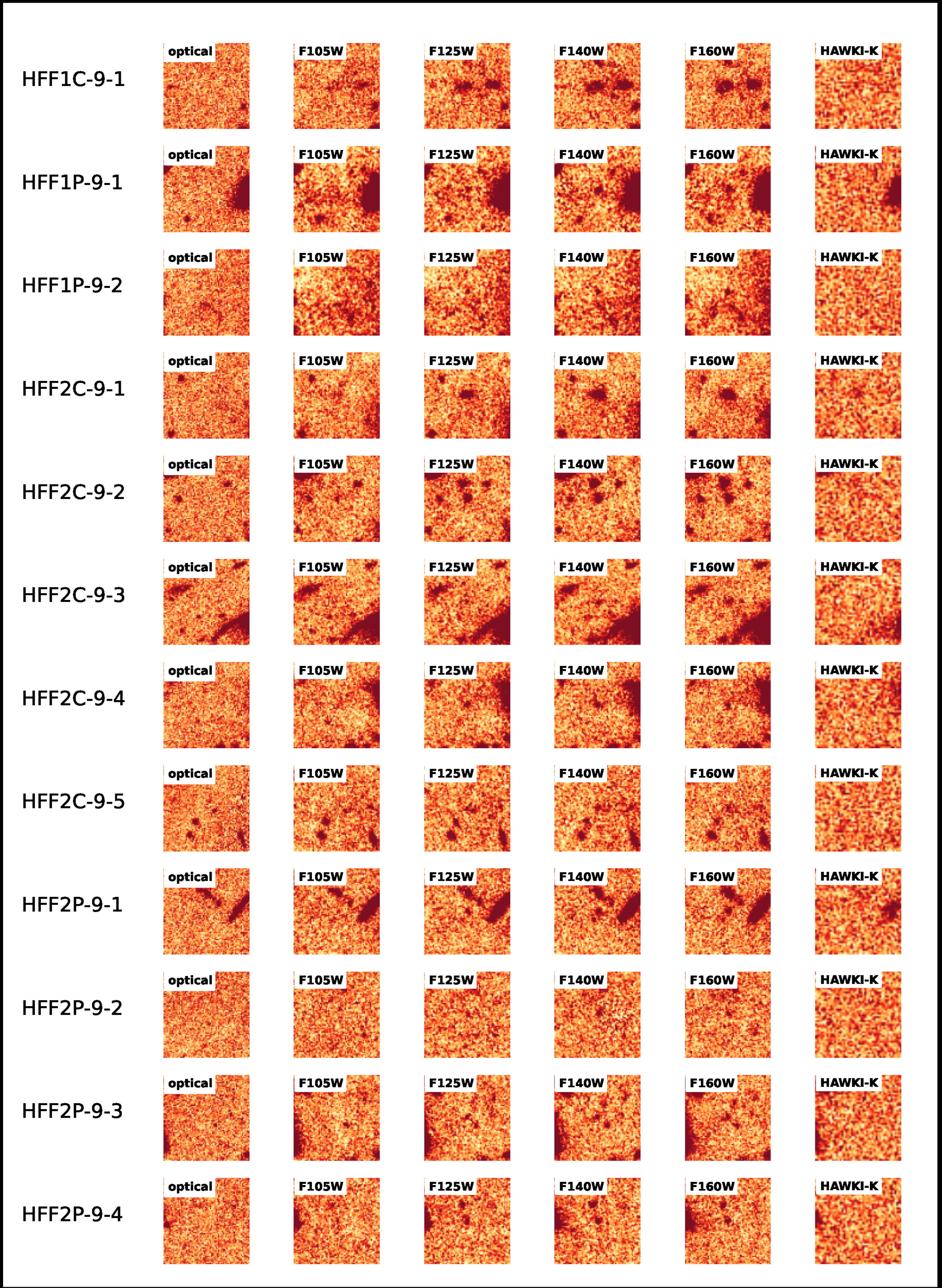
Alternative published magnification maps for Abell 2477

So we have deliberately avoided inner cluster regions / high magnification areas, exploiting the blank areas to obtain new determination of z = 9 luminosity function

McLeod, McLure, Dunlop et al. 2015, MNRAS, 450, 3032

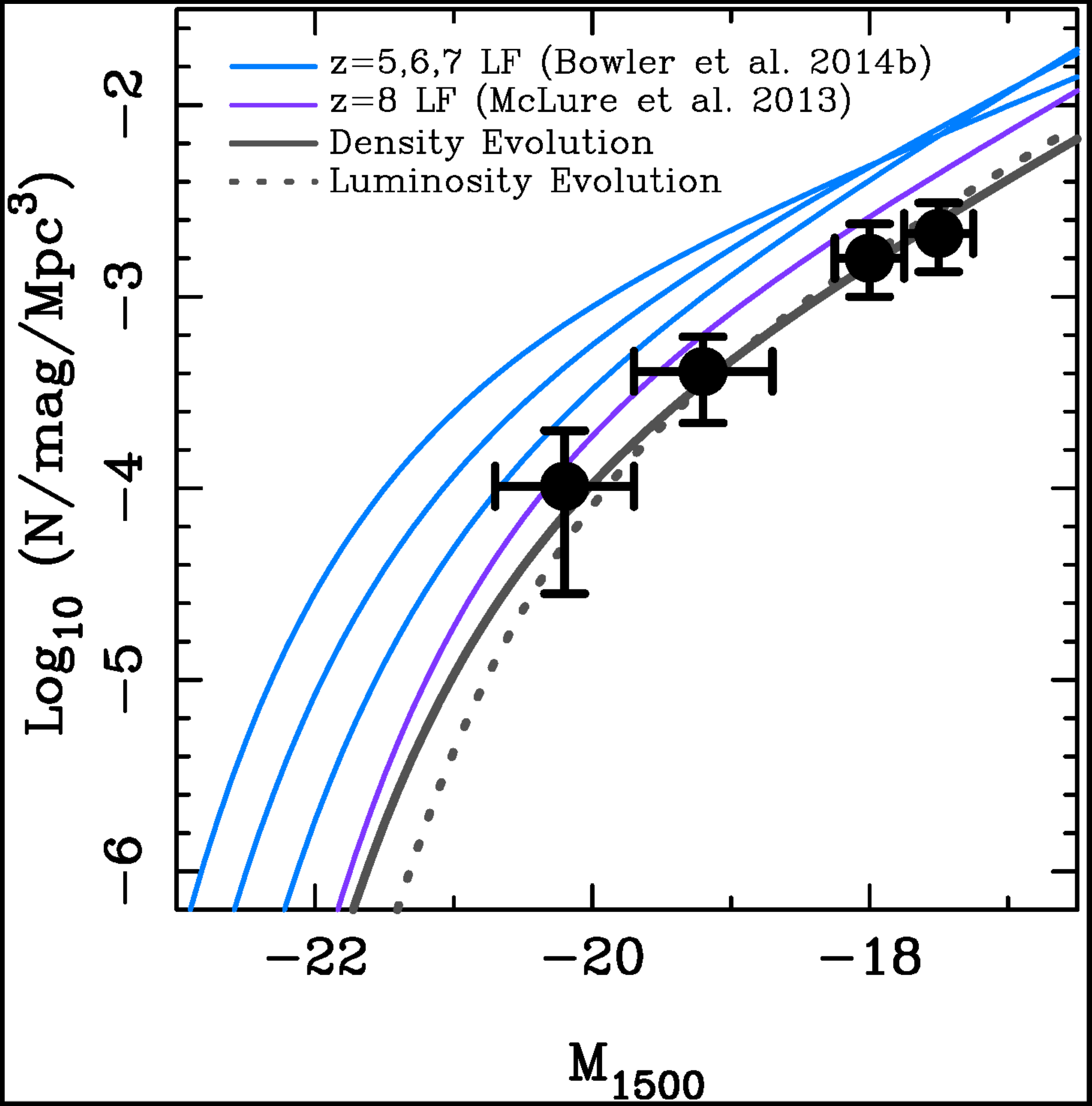


12 galaxies at 8.4 < z < 9.5 in the 4 fields



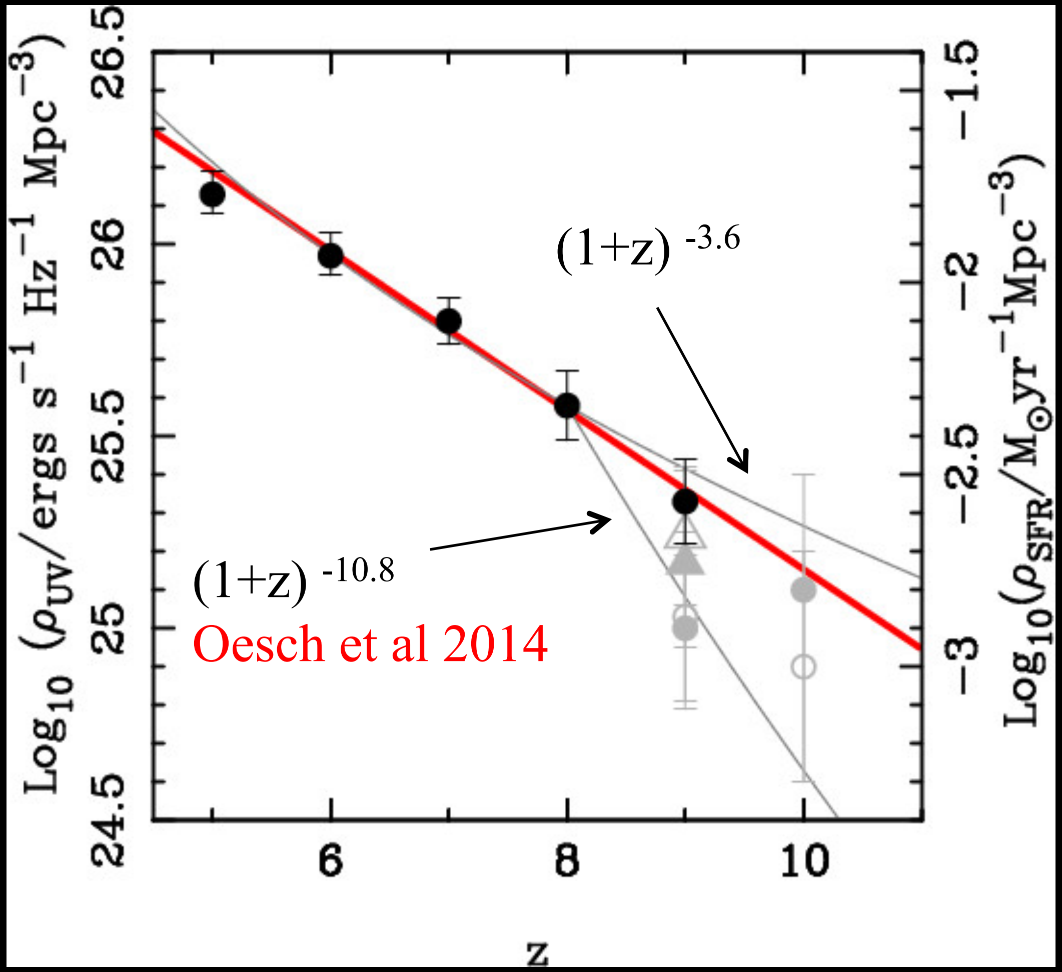
Inferred z = 9 galaxy UV luminosity function

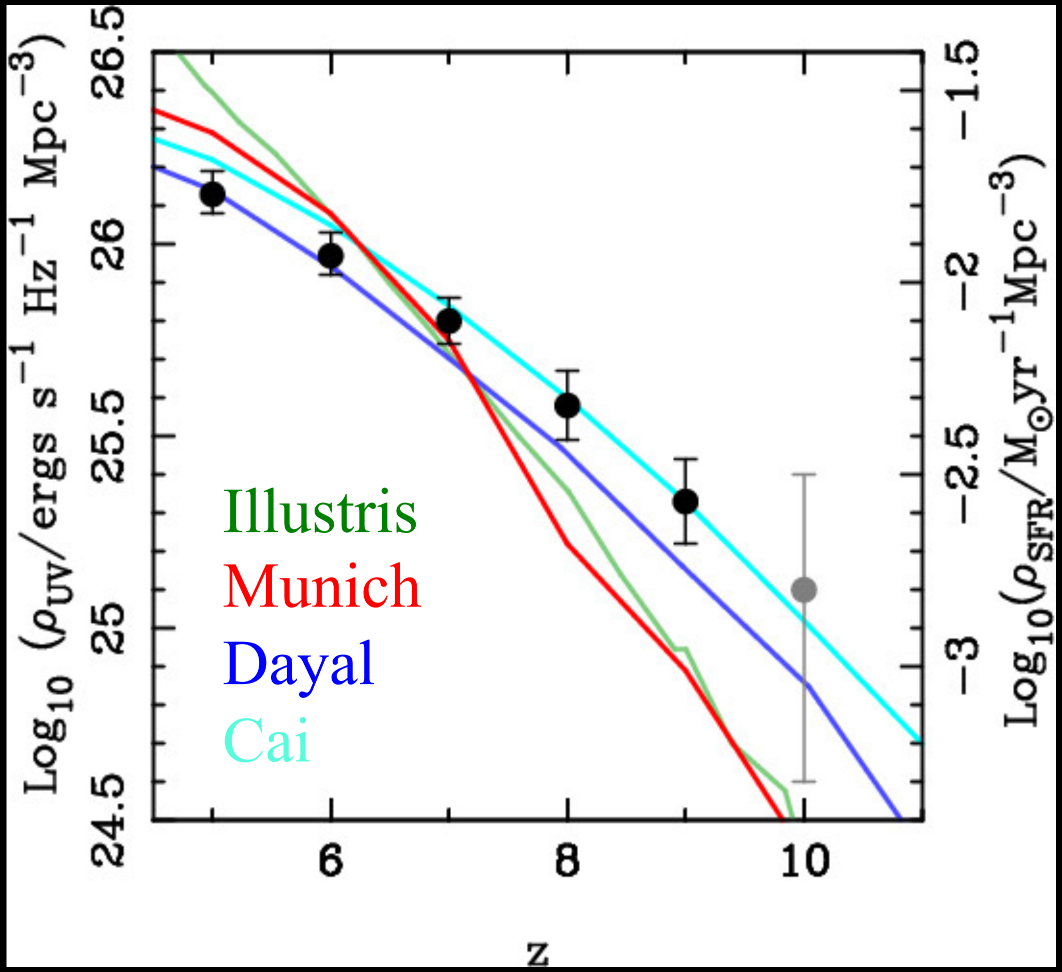
McLeod, McLure, Dunlop et al. 2015, MNRAS, 450, 3032



High-redshift decline of UV luminosity/star-formation rate density

McLeod, McLure, Dunlop et al. 2015, MNRAS, 450, 3032



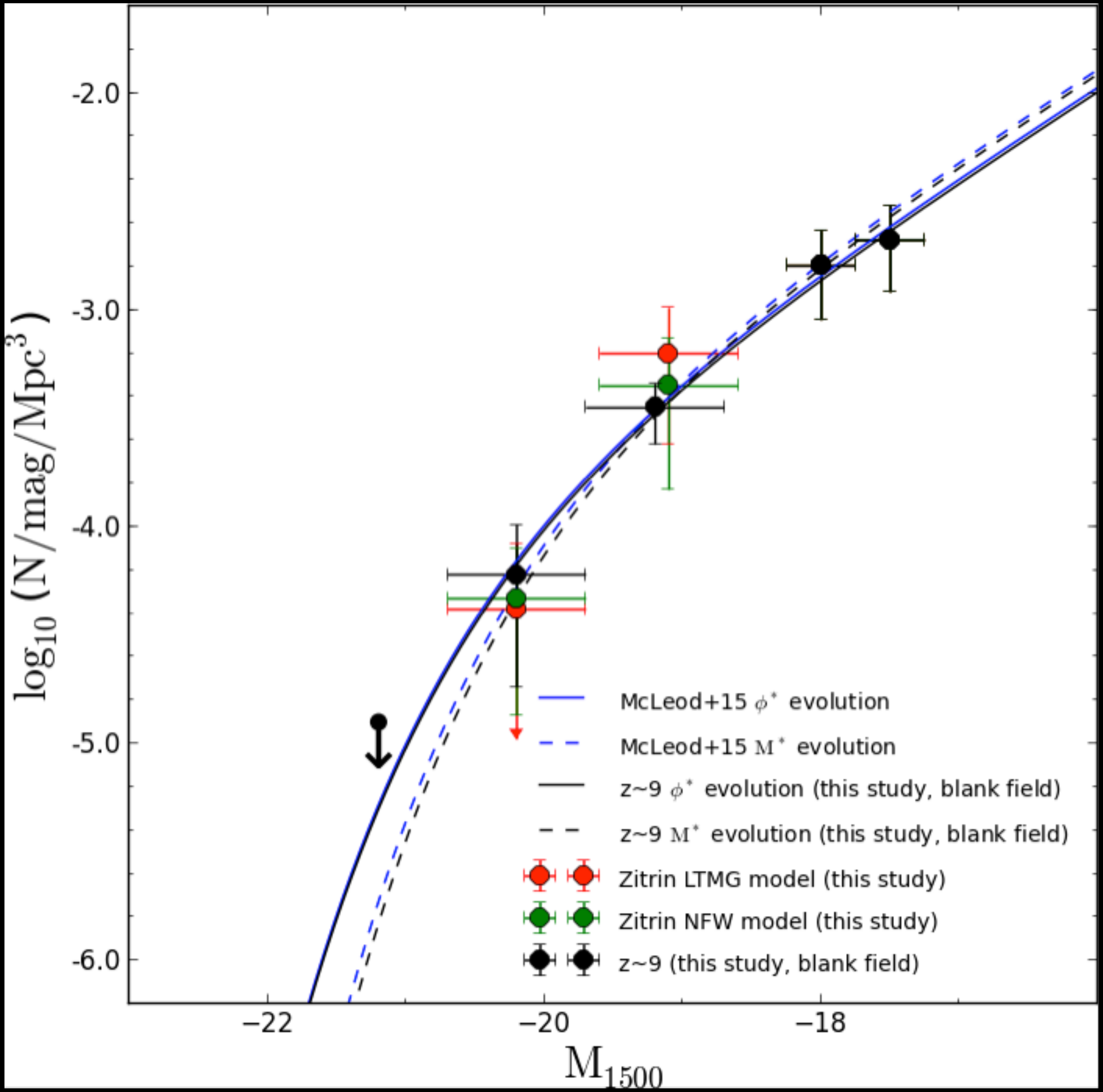


Confirms continued smooth decline in star-formation density out to z ~ 9

At least some models struggle to drop off so gradually

New z = 9 & 10 results from McLeod, McLure, Dunlop et al. 2016

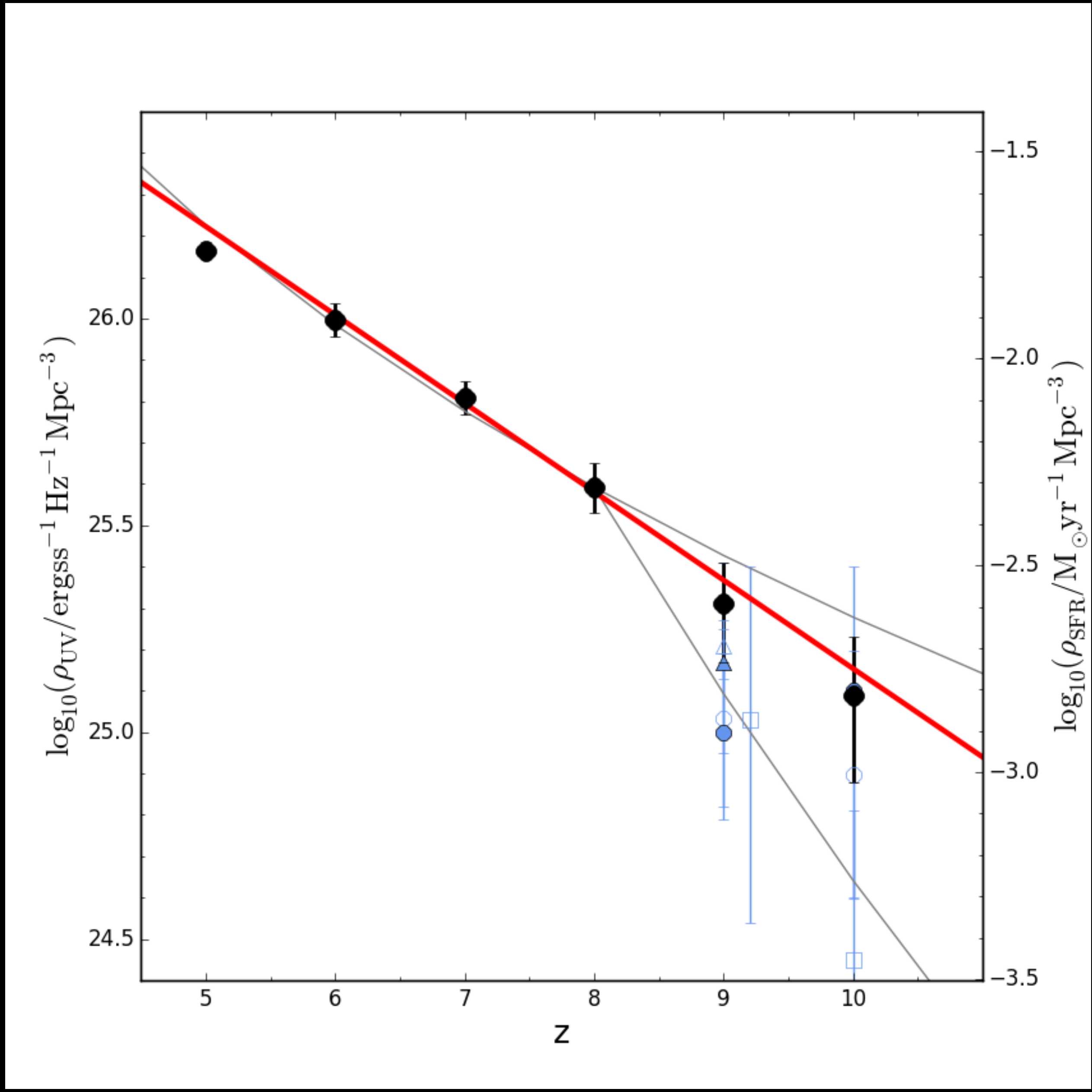
Now, with 4 FF (4 cluster + 4 parallel) + CLASH (blank and lensed)
> 30 objects at z > 8.4



McLeod, McLure, Dunlop et al. 2016

High-redshift decline of UV luminosity/star-formation rate density

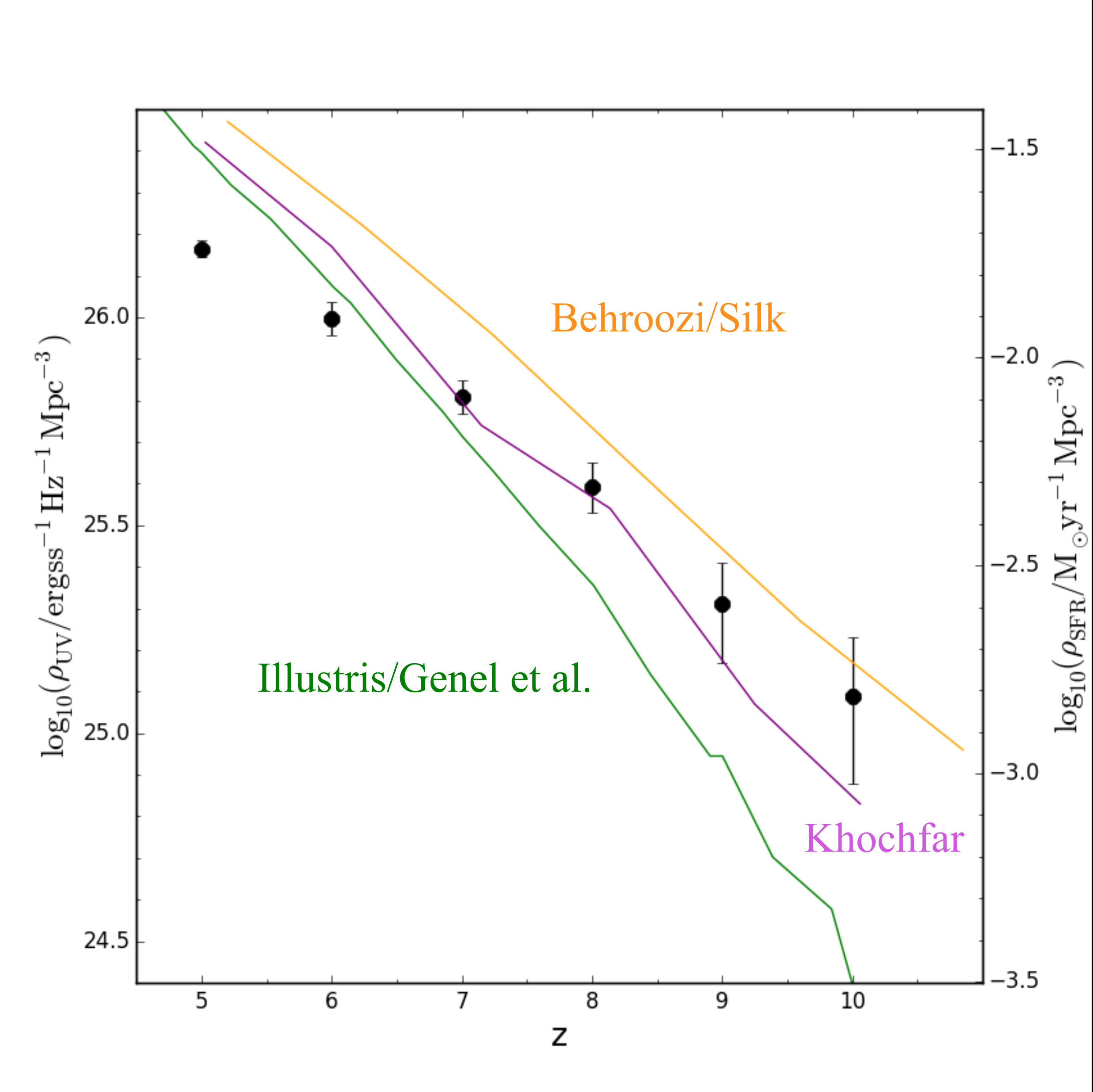
Now, with 4 FF (4 cluster + 4 parallel) – confirms smooth trend to z = 10

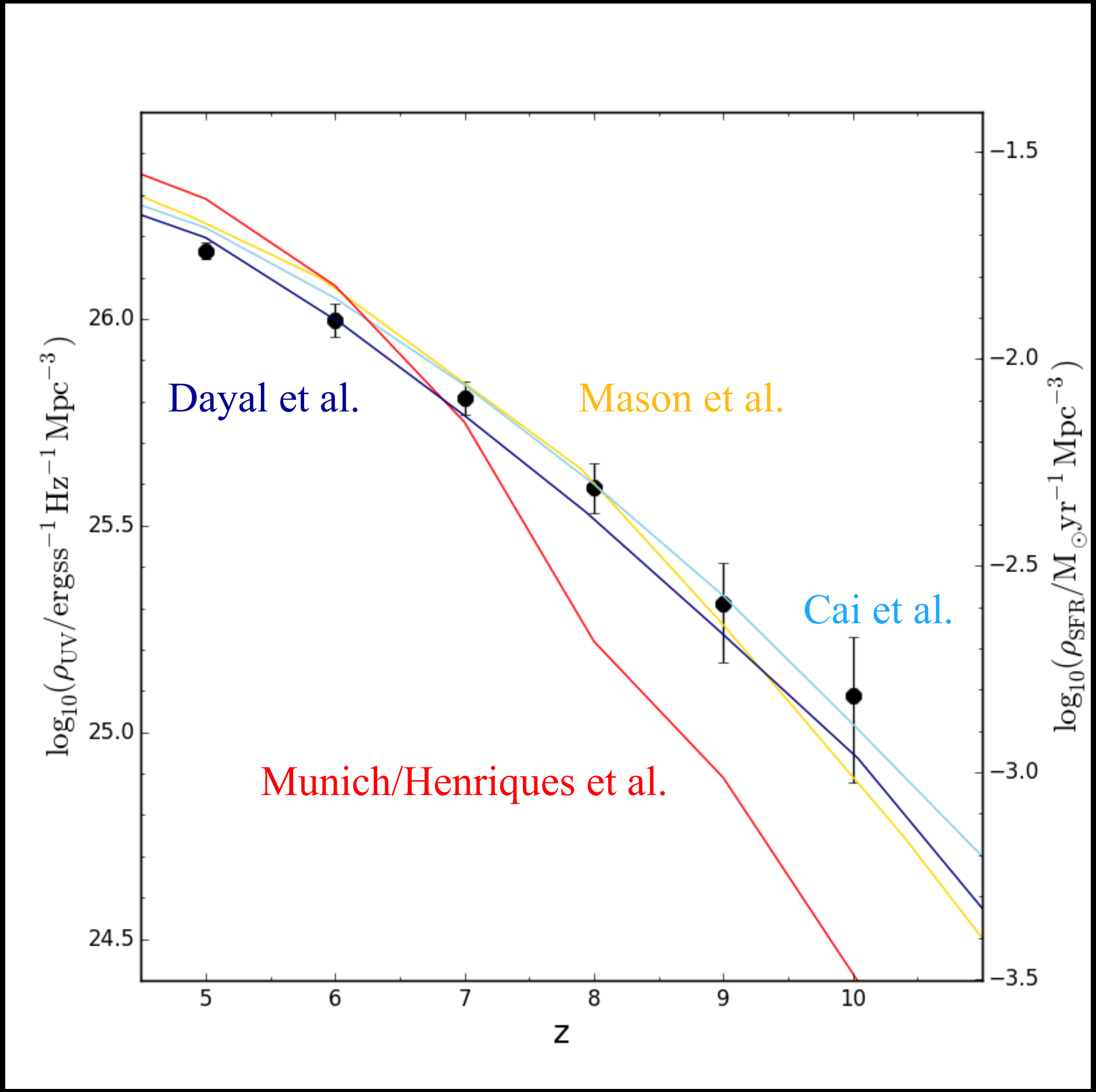


McLeod, McLure, Dunlop et al. 2016

High-redshift decline of UV luminosity/star-formation rate density

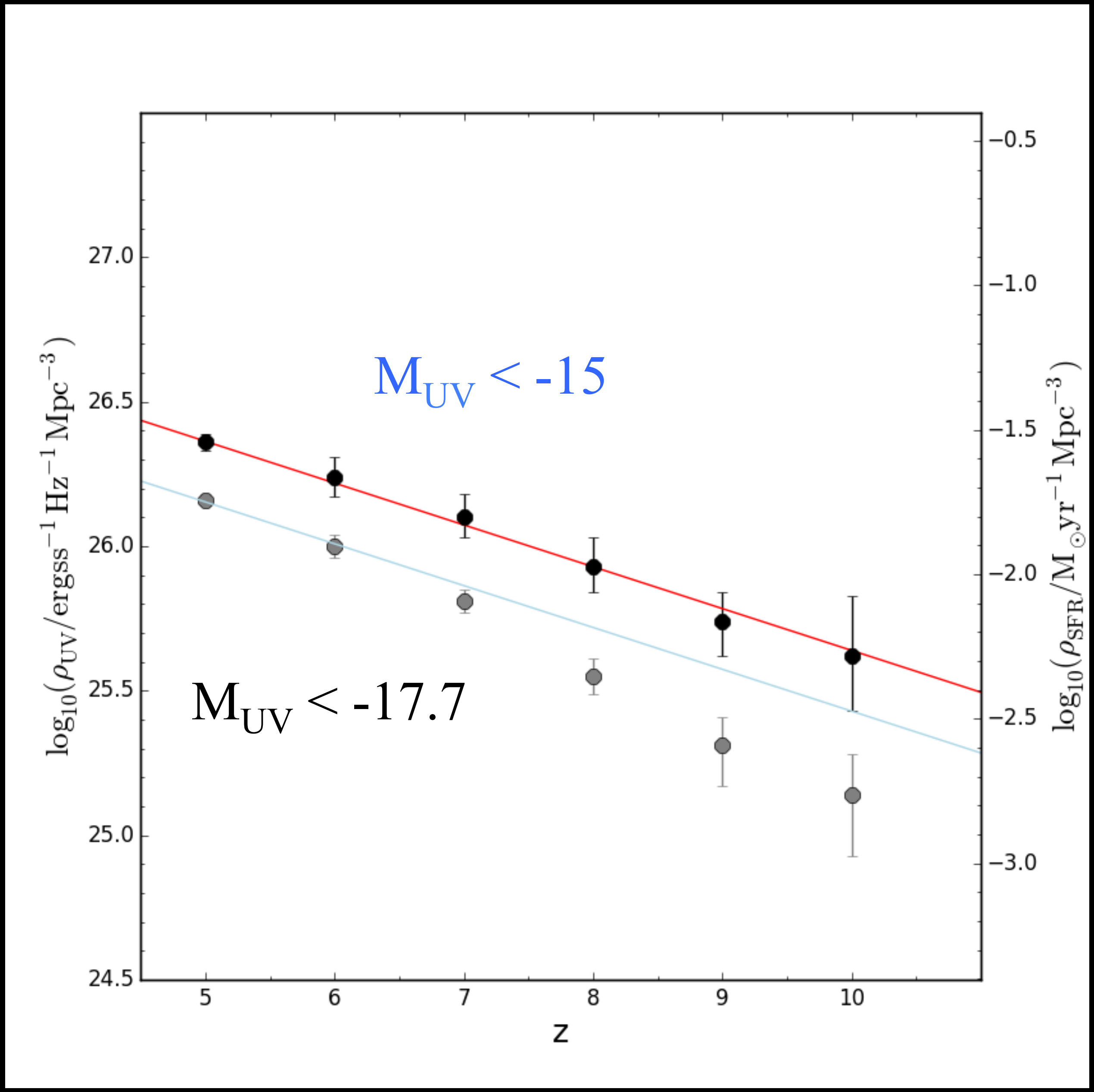
Updated model comparisons





McLeod, McLure, Dunlop et al. 2016

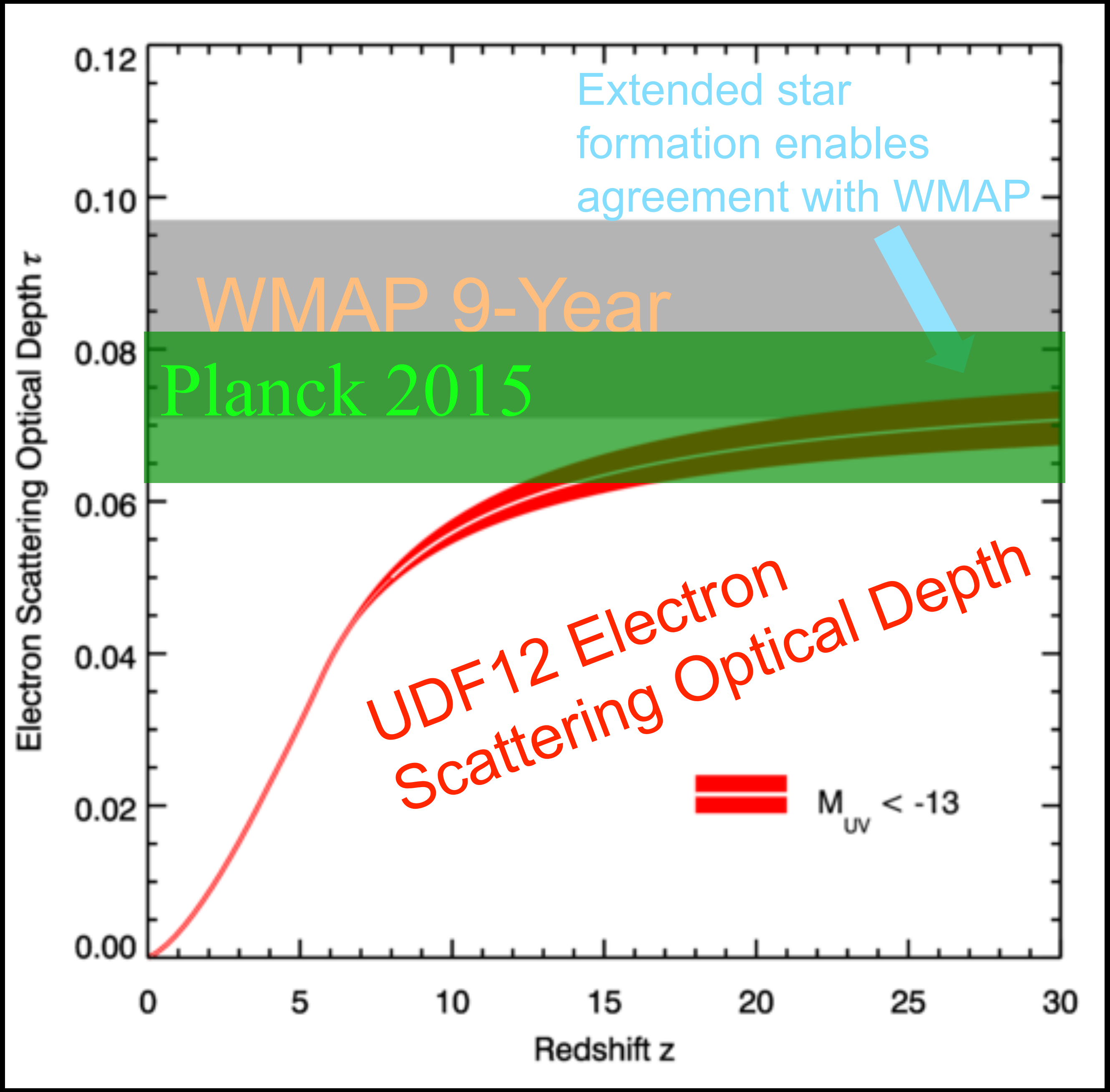
Integrate down further
- slope reflects the Hernquist & Springel analytical prediction



McLeod, McLure, Dunlop et al. 2016

Link to Cosmic Reionization

Agrees (just!) with WMAP-9, and even better with new Planck results (although see Addison et al. 2015) if LF extended to $M_{uv} \sim -13$



See

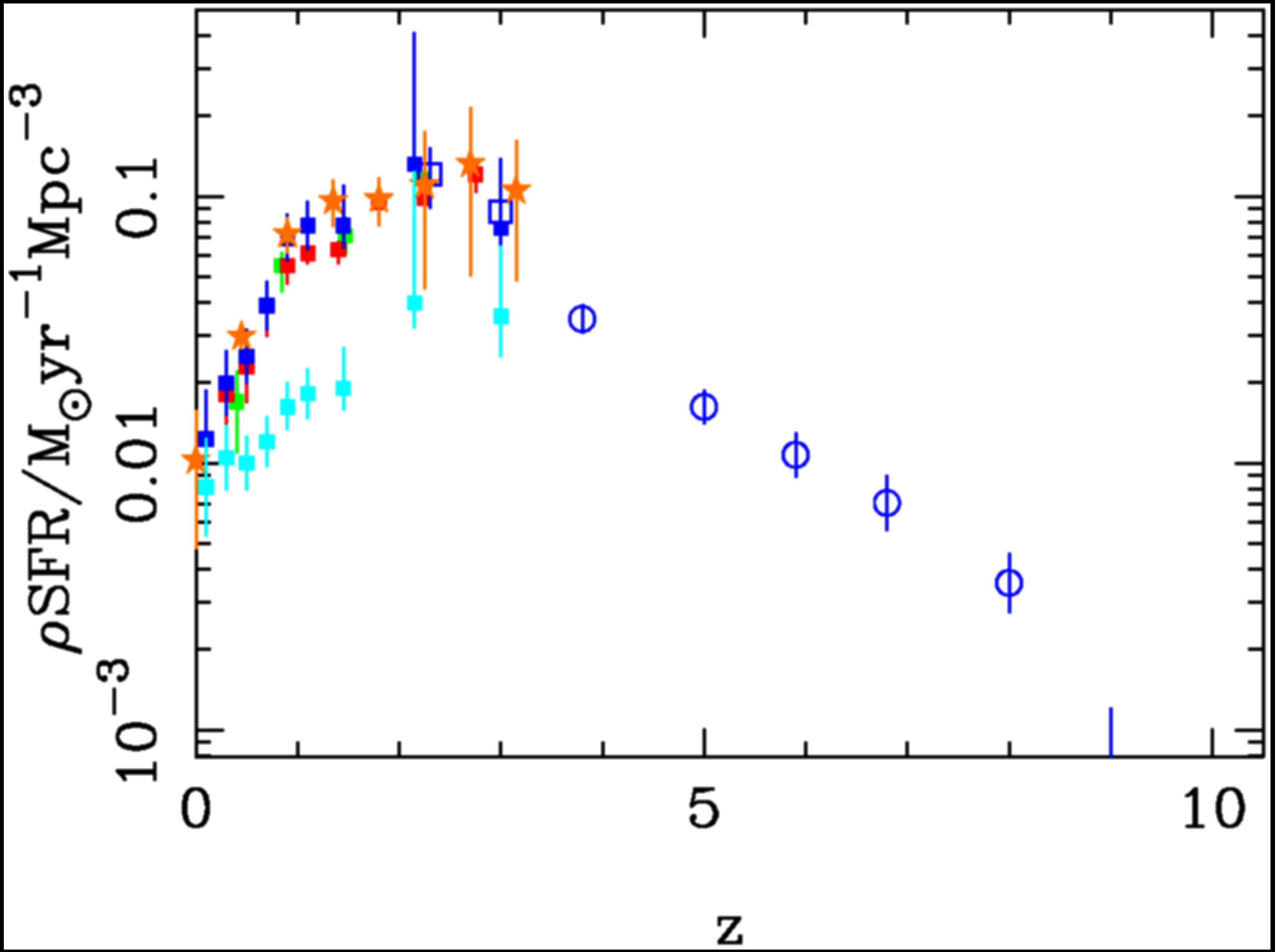
Robertson et al. 2013, ApJ, 768, 71

and now

Robertson et al. 2015, ApJ. 802, L19

The reionization history implied by the high-redshift galaxy population matches the constraints from *Planck*, observations of the Lyman-α Forest, and the evolving fraction of Lyman-α emitting galaxies.

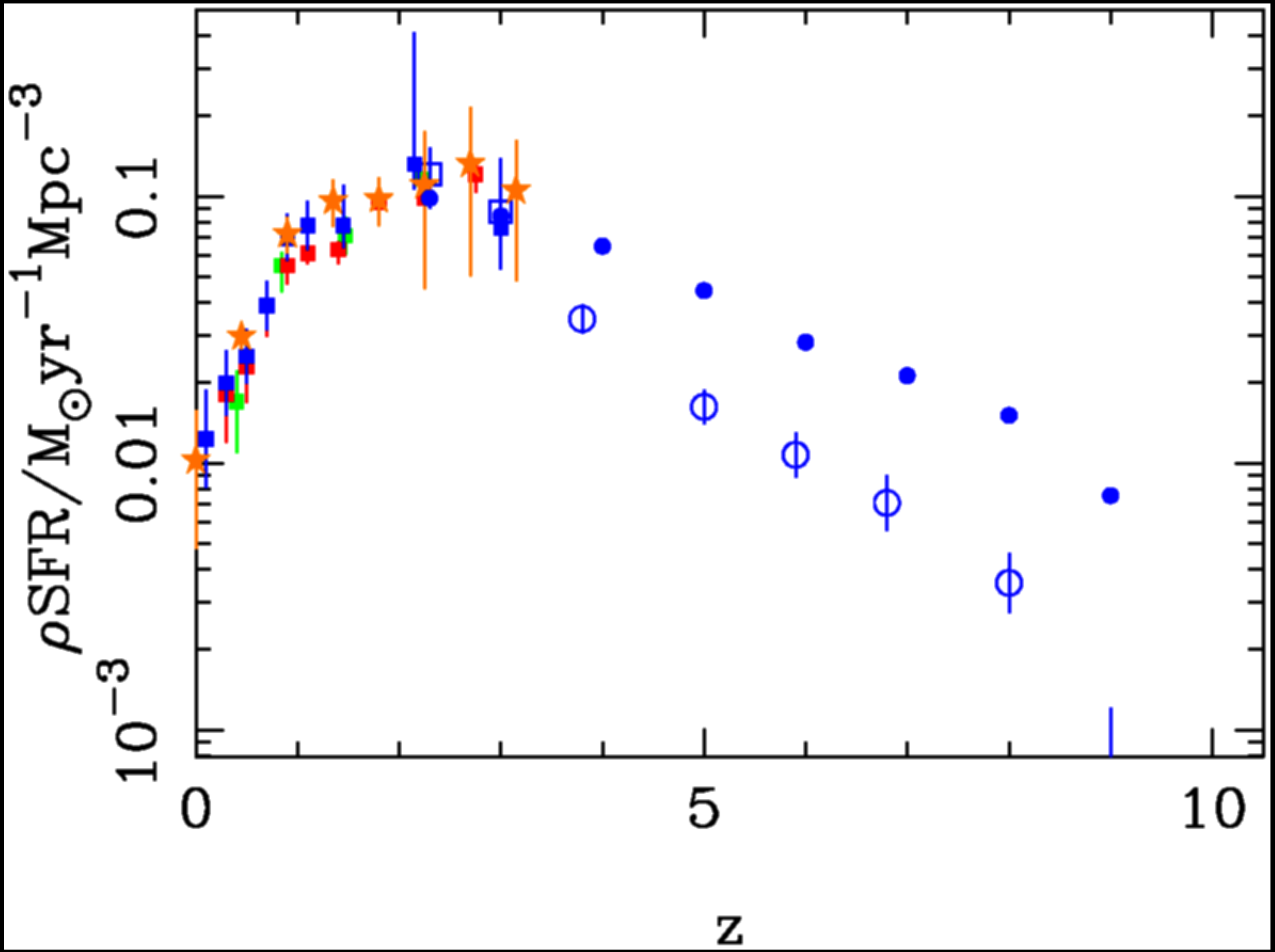
A complete cosmic history of SFR density?



Bouwens et al. 2007
Bouwens et al. 2012
Oesch et al. 2013
- Dust corrected
- Chabrier IMF

Dunlop 2016

A complete cosmic history of SFR density?

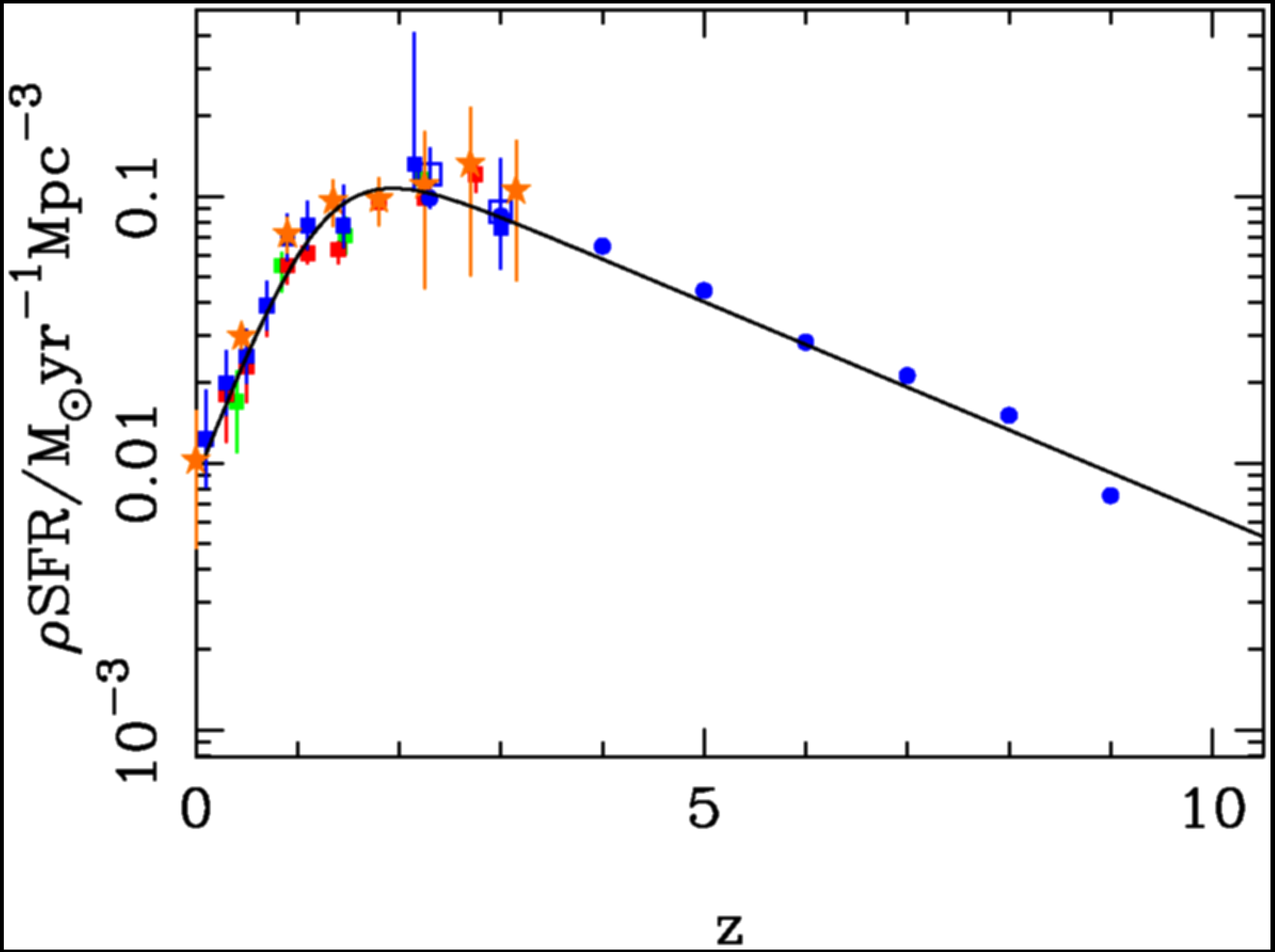


Bouwens et al. 2007
Bouwens et al. 2012
Oesch et al. 2013
- Dust corrected
- Chabrier IMF

McLure et al. 2013
Dust corrected UV
to M = -13
Redshift indep dust

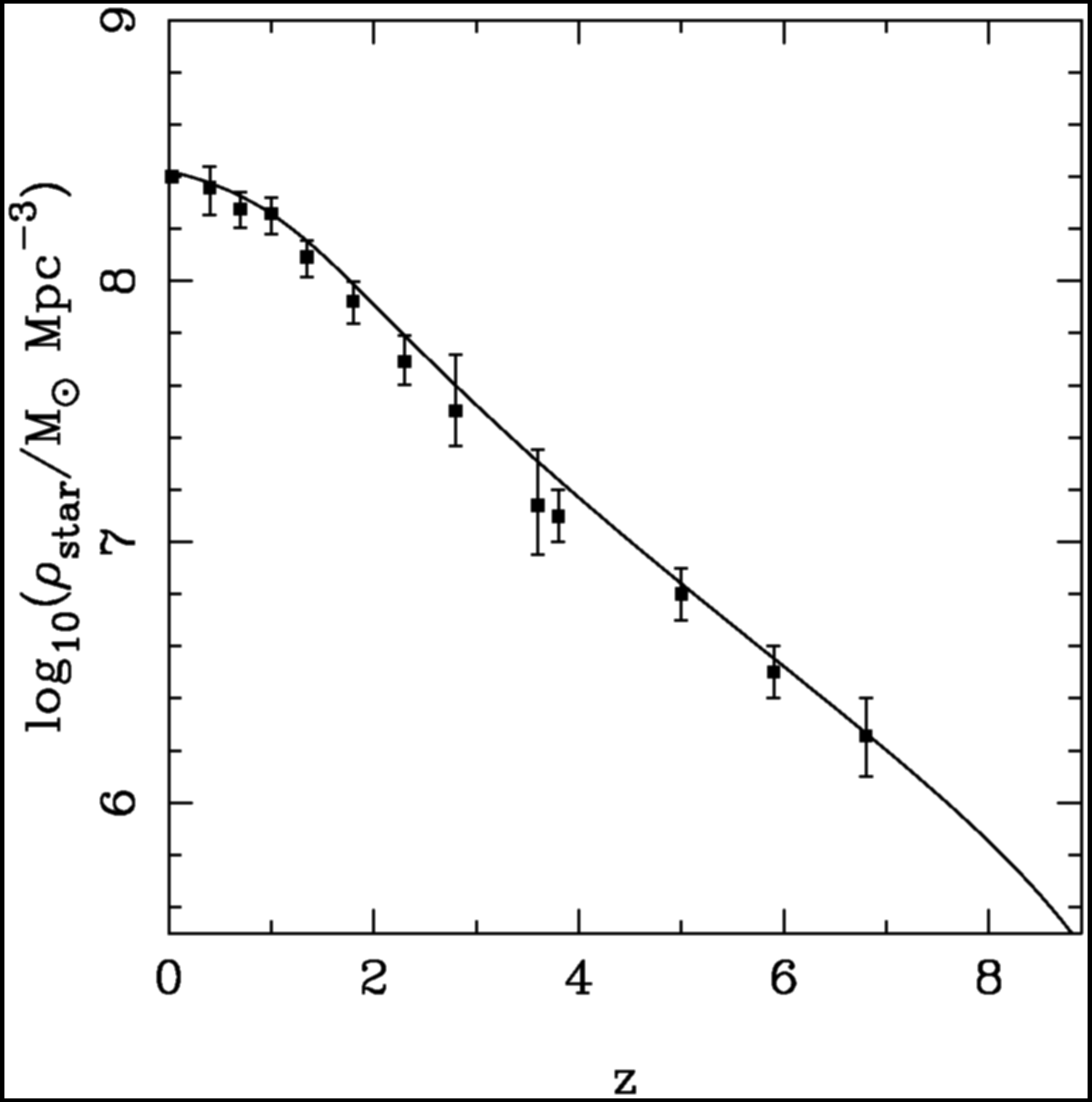
Dunlop 2016

A complete cosmic history of SFR density?



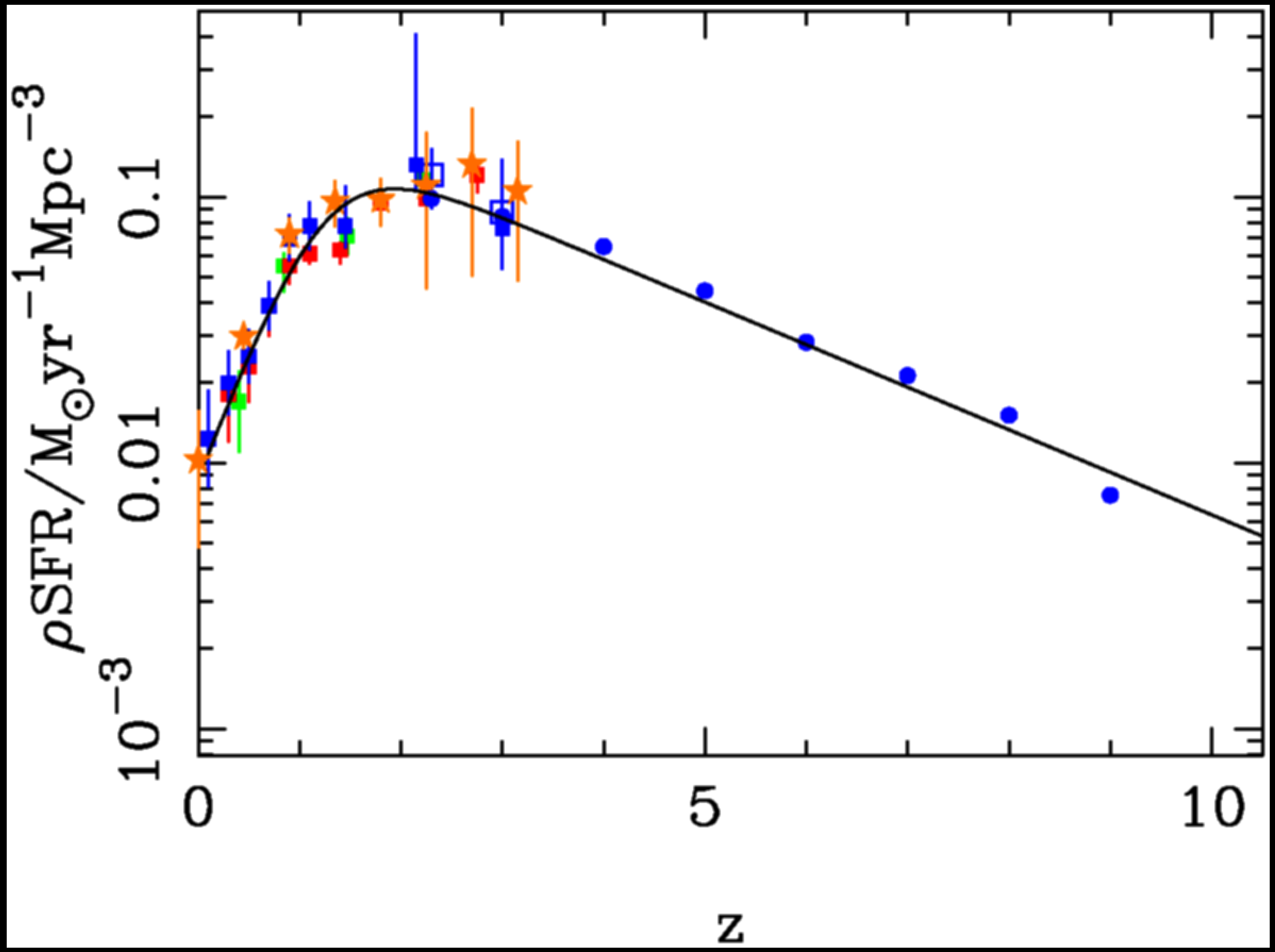
Dunlop 2016

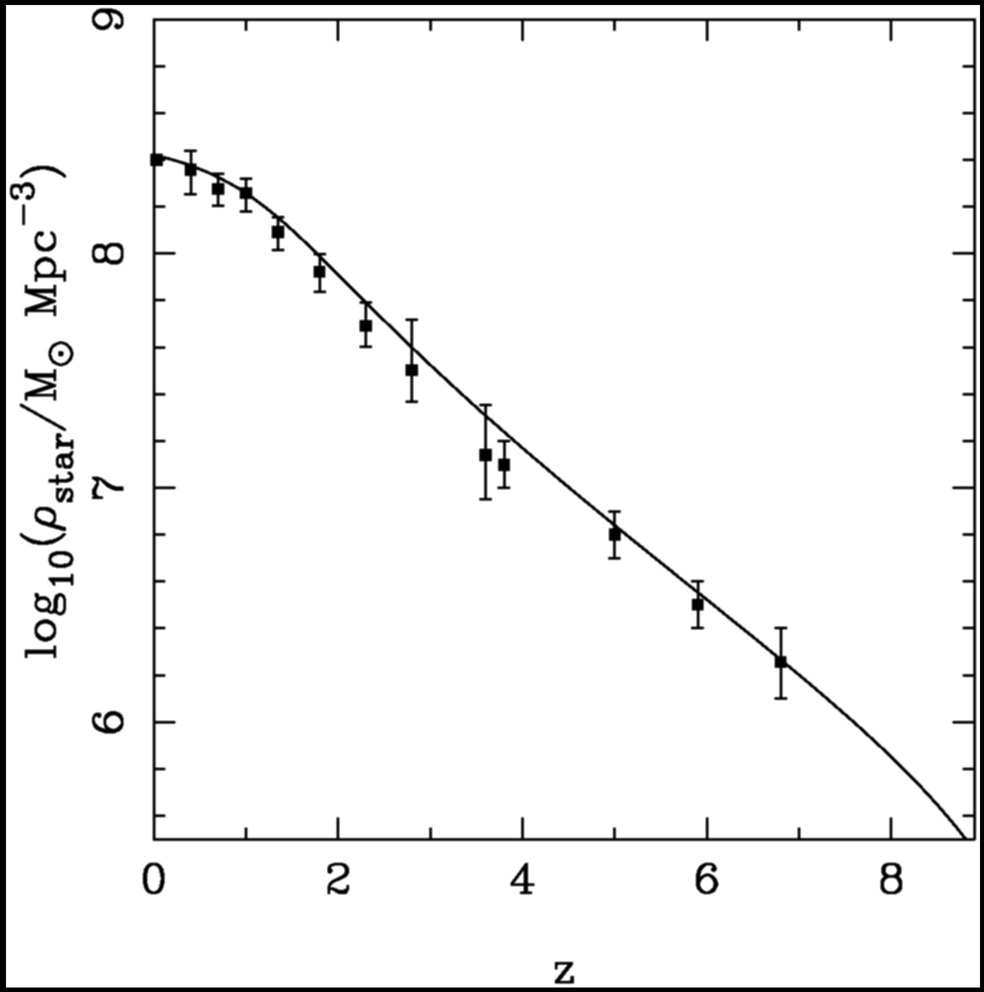
The growth of stellar mass



Data from Baldry et al. 2012, Ilbert et al. 2013 integrated to $M_* = 10^6\ M_{sun}$, Stark et al. 2013, and Dunlop 2016 prediction

A complete history of cosmic star formation ?





Star-formation rate density

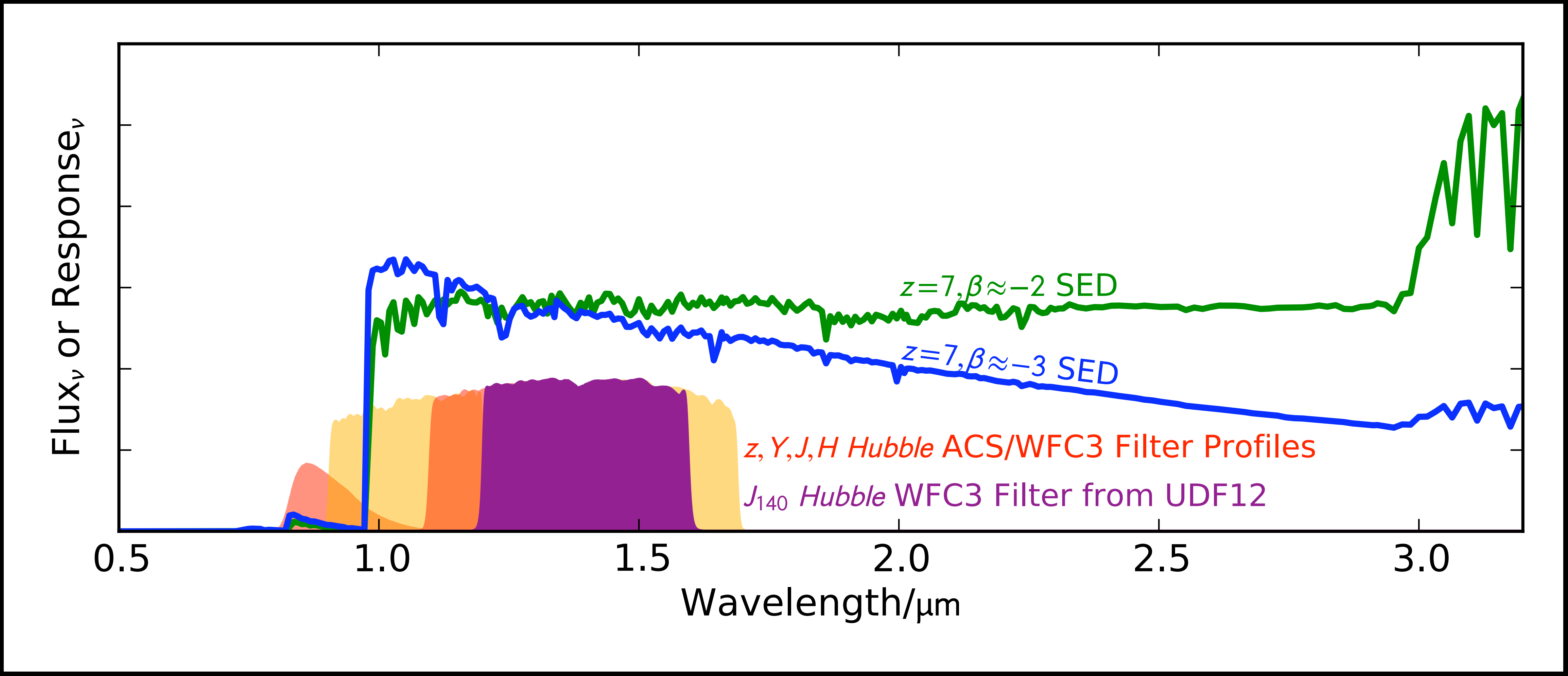
Growth of stellar mass density

Dunlop 2016

Evidence for dust at z ~ 7 ?

Broad-band colours enable unbiased measurement of UV continuum slope

β, where F_λ = const x λ^β

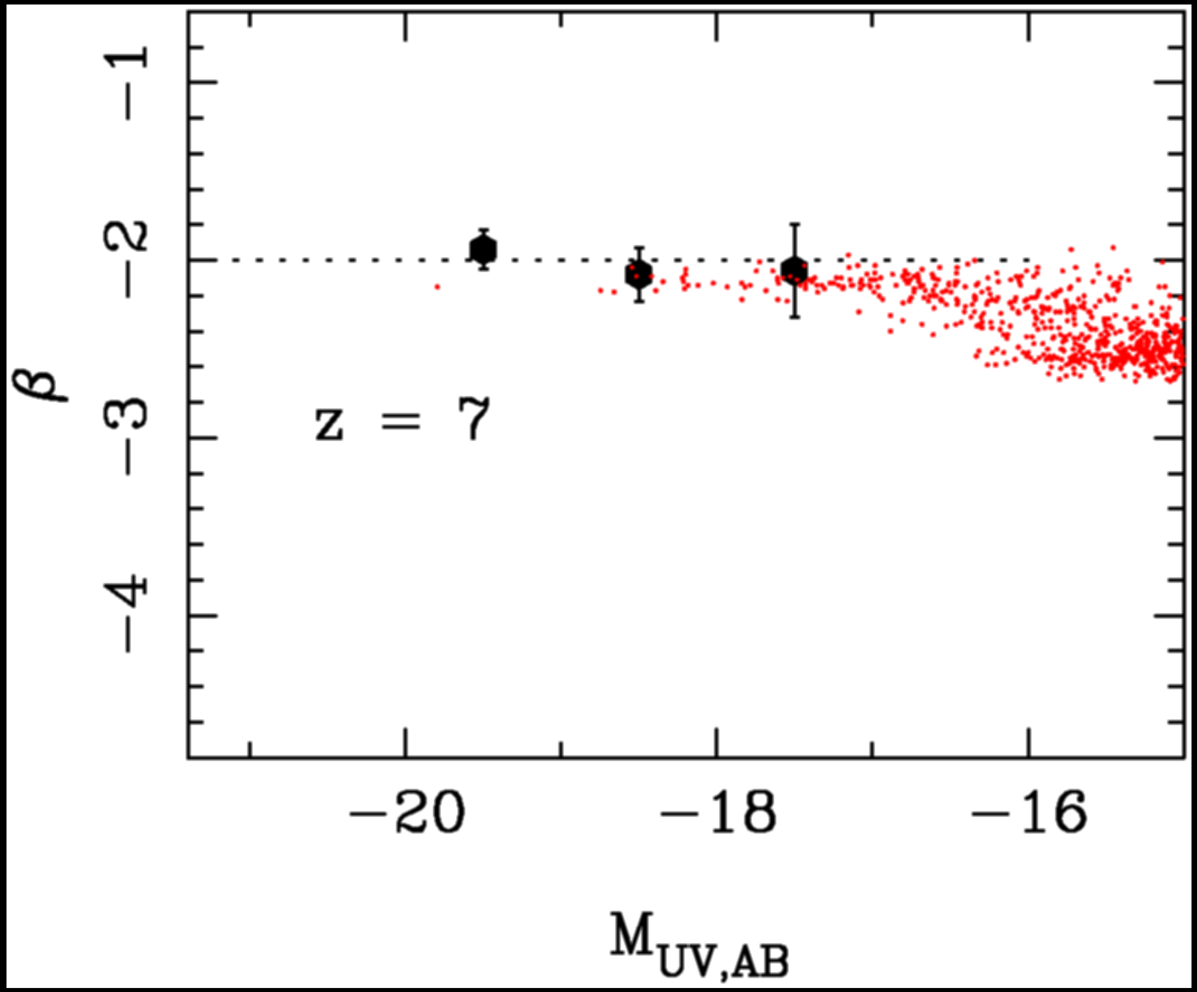


Aided by selection in new J140W filter

Evidence for dust at z ~ 7 ?

So, β = -2 at z = 7, not -3 as expected from Pop III

Dunlop et al. (2013)



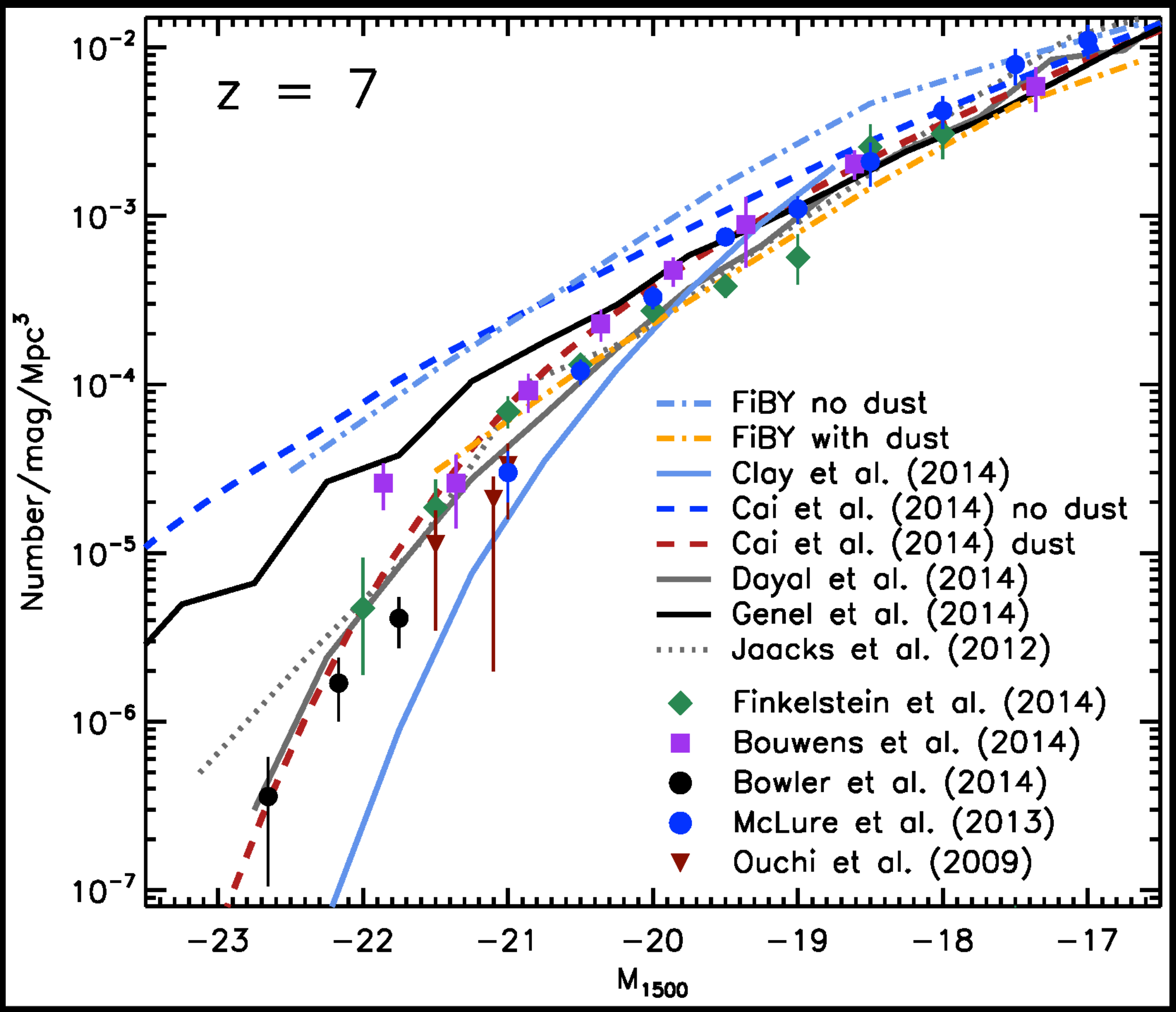
Indeed UV slope arguably redder than expected – cf predictions from galaxy formation simulation (Dayal, Dunlop et al. 2013)

Evidence for dust?

Evidence for dust at z ~ 7 ?

New results from UltraVISTA indicate bright end of LF at z = 7 flatter than Schechter function, but steeper than most model predictions without dust

Bowler, Dunlop et al. (2014, 2015)



More evidence for dust,
+ implications for mass quenching etc

Summary

UltraVISTA/UDS+CANDELS+UDF+HFF combination = powerful dynamic range

UV LF at z = 2 now measured down to M_{UV} ~ -14 without help of lensing

No break, but faint end slope flatter than some previous claims

Raw ρ_{UV} thus now well measured at intermediate redshift – peaks at z ~ 3

But total ρ_{SFR} peaks at lower z – see Nathan Bourne's talk next

UV LF now traced out to z ~ 9, 10 – smooth evolution to high z, no sudden drop in ρ_{UV}

This, plus smooth steepening of faint end slope can explain reionization

High-z evolution of ρ_{SFR} is exactly as expected based on growth of DM halo mass function

But many models struggle to reproduce this simplicity + huge variation in bright end of LF

Dust content of galaxies of a given mass may change only very slowly with redshift, and yet the evolution of the galaxy population results in dust-obscured SF going from dominant at z ~ 2 to negligible in the reionization epoch