Galaxies at z=9-10 in the Hubble Frontier Fields and CLASH Surveys

Derek McLeod,
Ross McLure & Jim Dunlop

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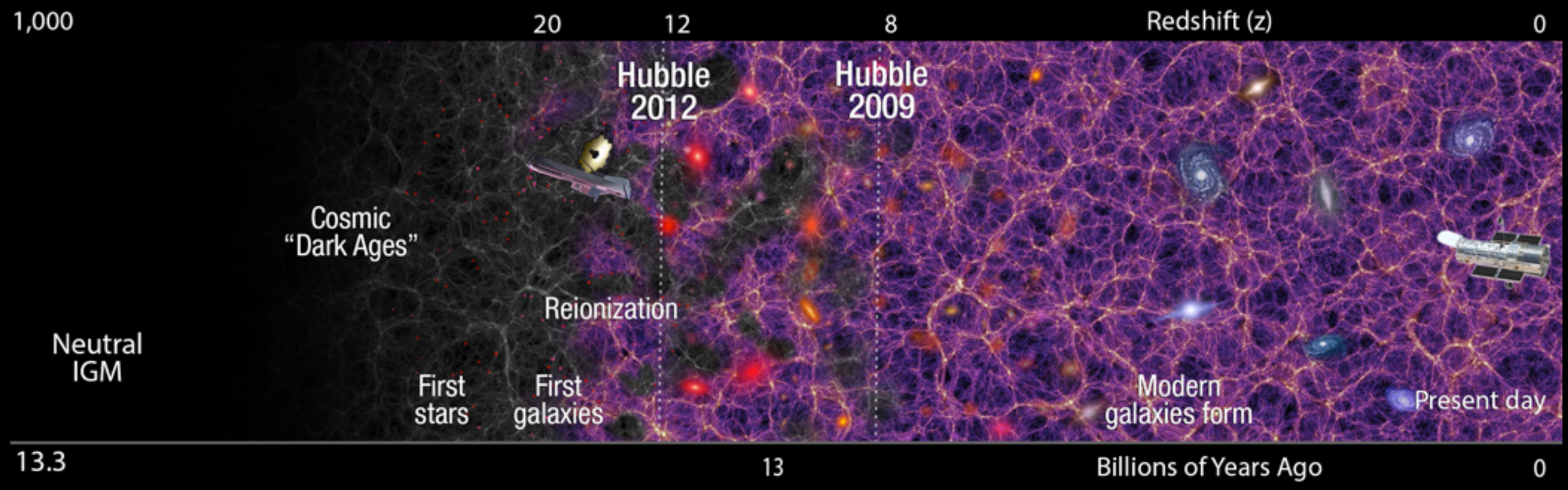


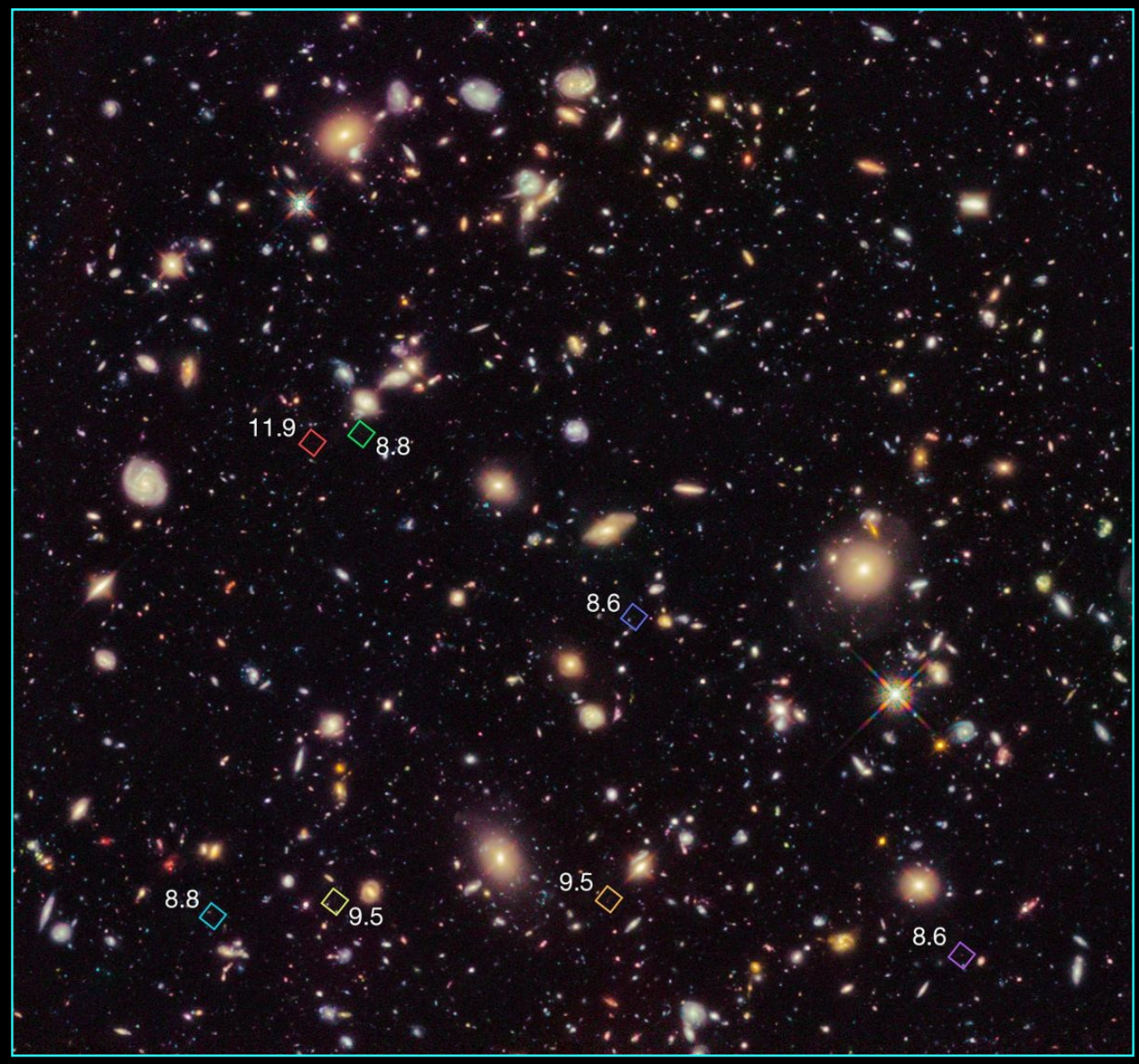
Motivation:

1. Galaxy evolution within the first 500 Myrs
2. Reionization (luminosity function ➡ $\rho_{UV}.f_{esc}$ ➡ $\dot{N}_{ion}$)
3. JWST follow-up of course

Previous z~9-10 Searches

HUDF12:
Ellis+13, McLure+13

Six z~9 candidates



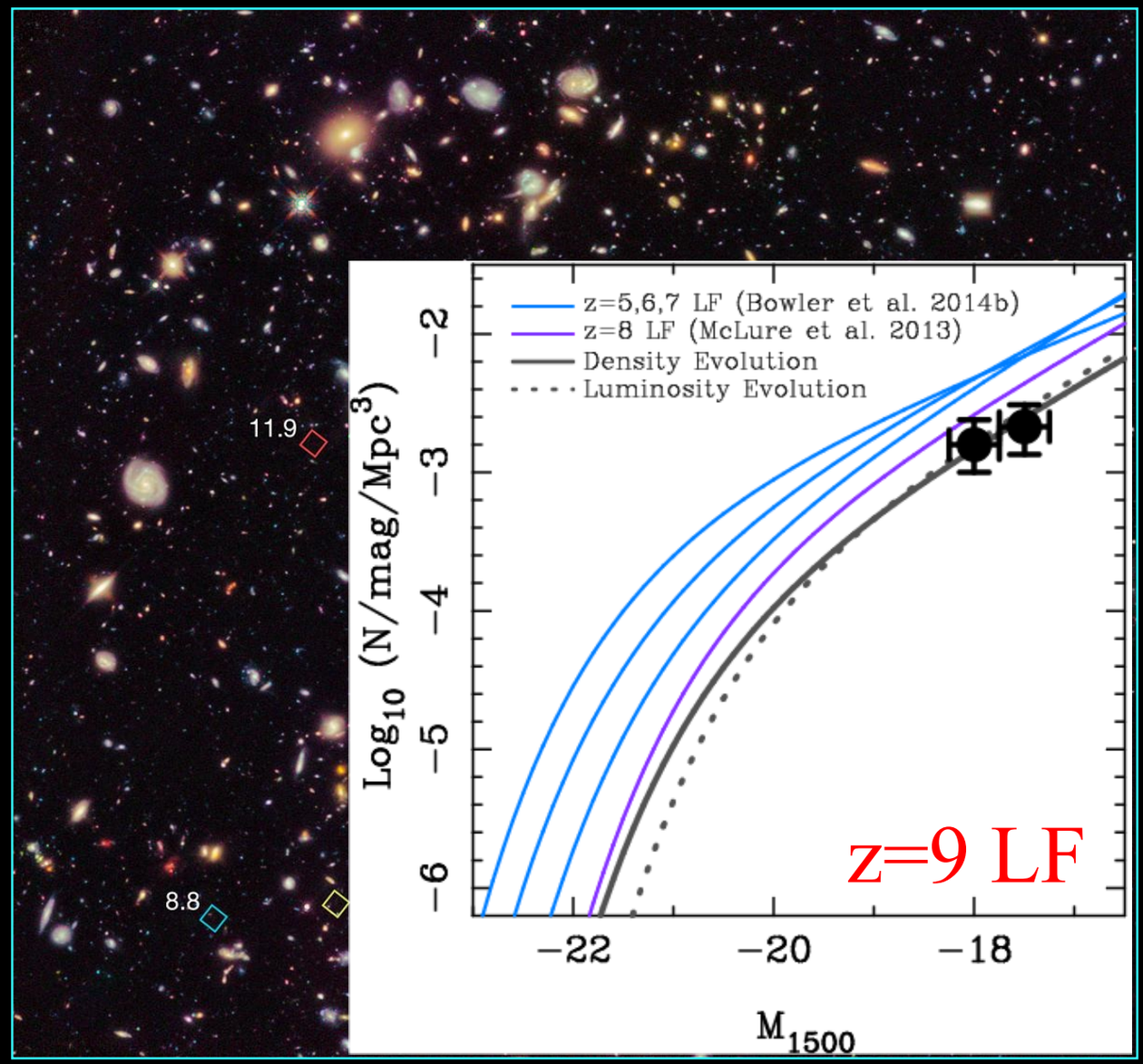
Previous z~9-10 Searches

HUDF12:
Ellis+13, McLure+13

Six z~9 candidates

Initial constraint on the faint-end of the z=9 LF

No constraint on bright-end



Previous z~9-10 Searches

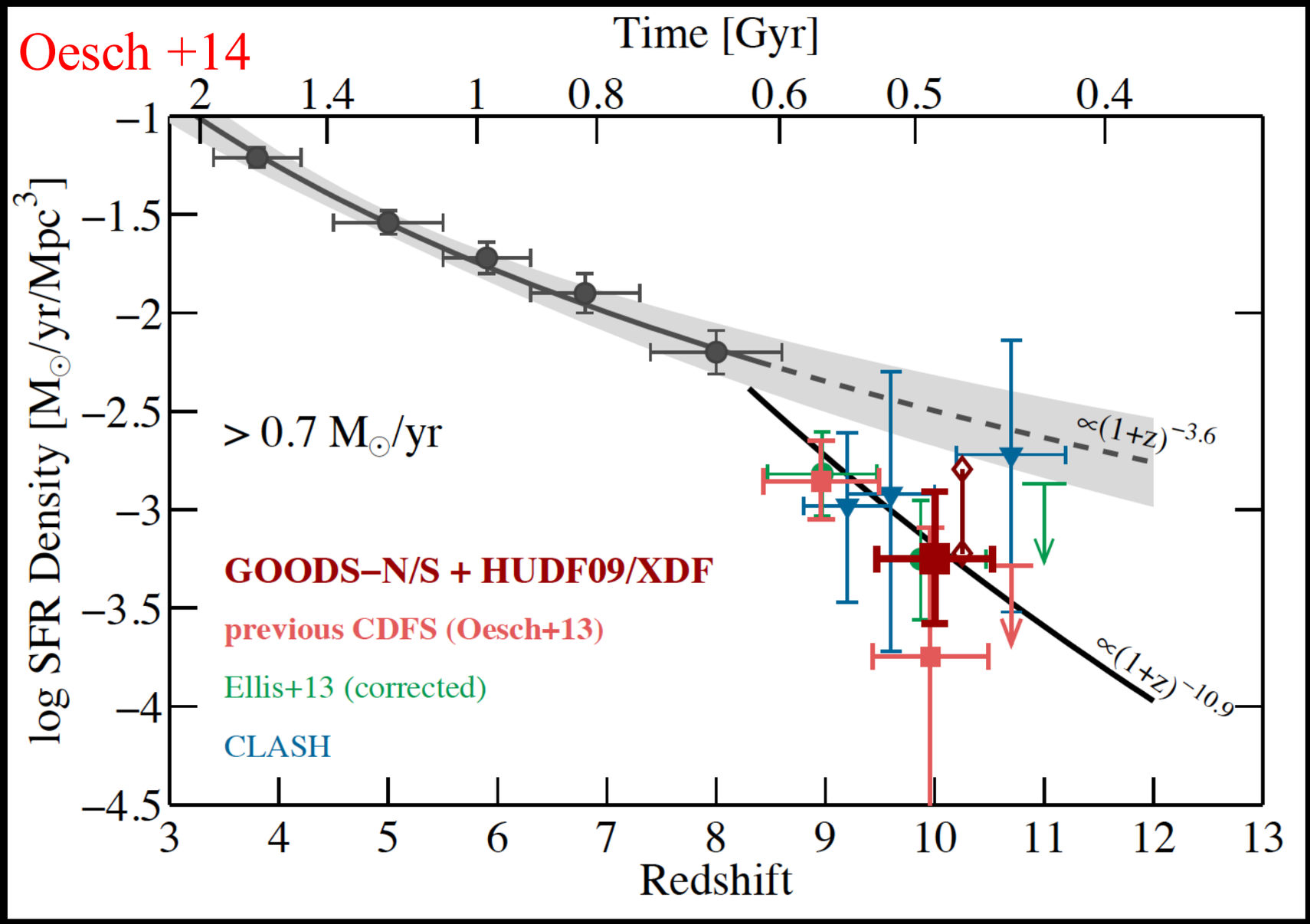
CANDELS GOODS-N:
bright z~10 candidates
Oesch+14,15; Bouwens+15

CLASH: three z=9-10 candidates
Bouwens+14

Steep decline in the luminosity density at z>8?

CANDELS imaging in GOODS-N

Luminosity density evolution at z>8

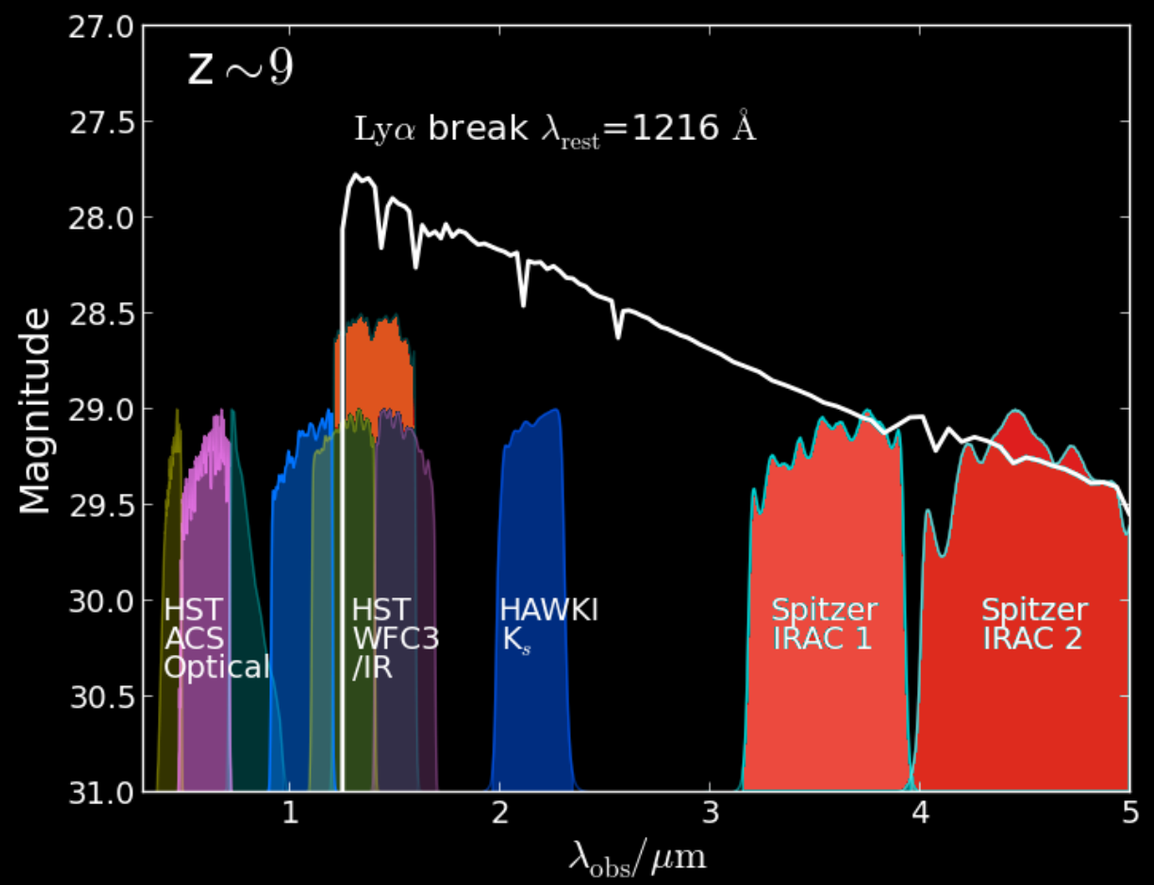


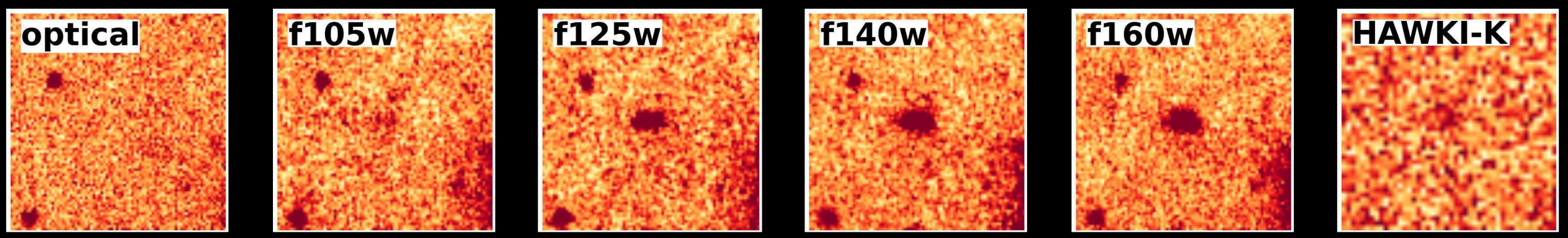
are we seeing "*epoch of galaxy formation*" ?

McLeod et al. (2015, 2016): strategy

29 separate WFC3/IR pointings

Total area: 130 sq. arcmins





Example z=9 candidate from HFF

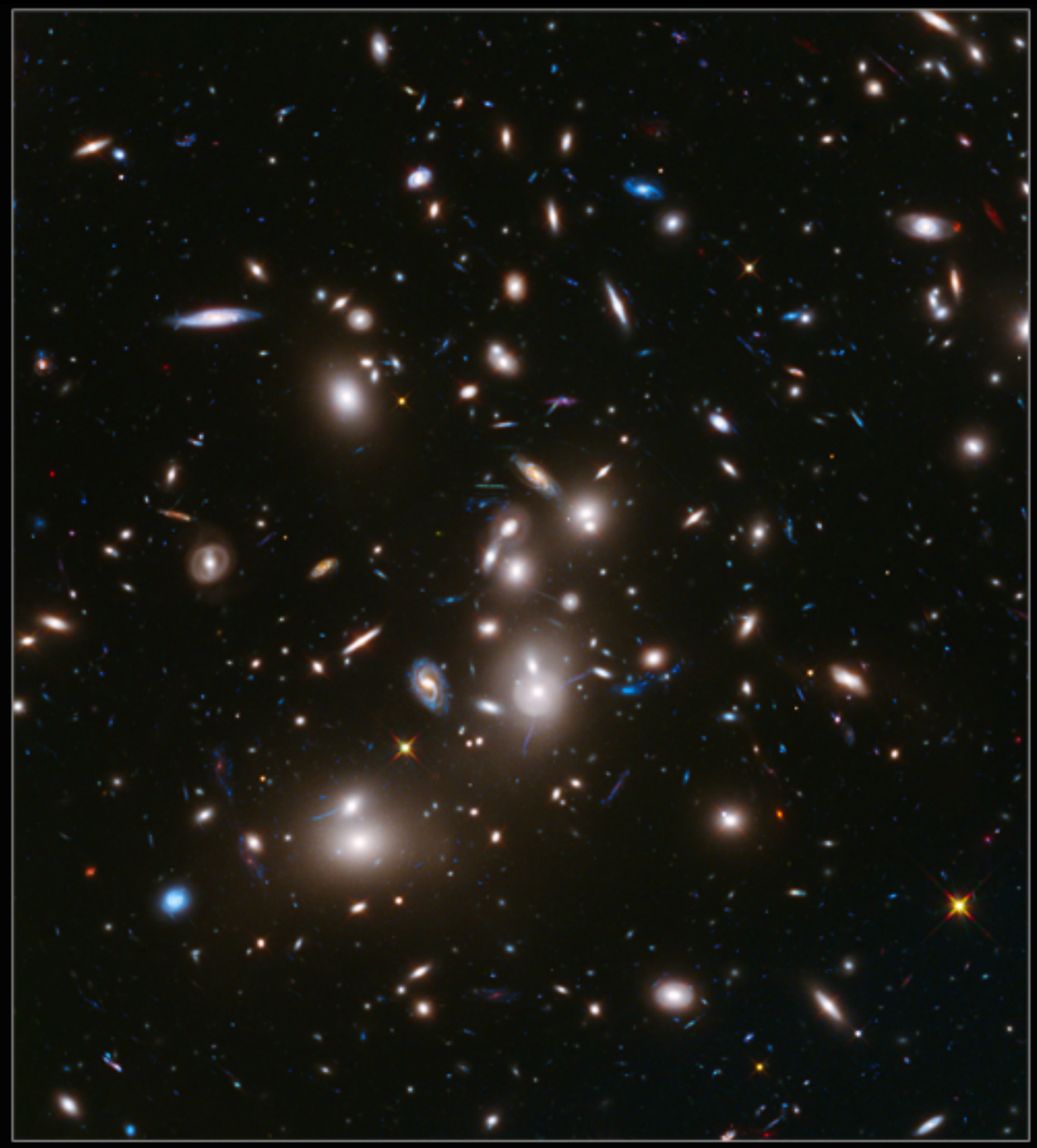
Hubble Frontier Fields

Six lensing clusters with six blank parallel fields

Deep imaging in seven filters (optical+nearIR)

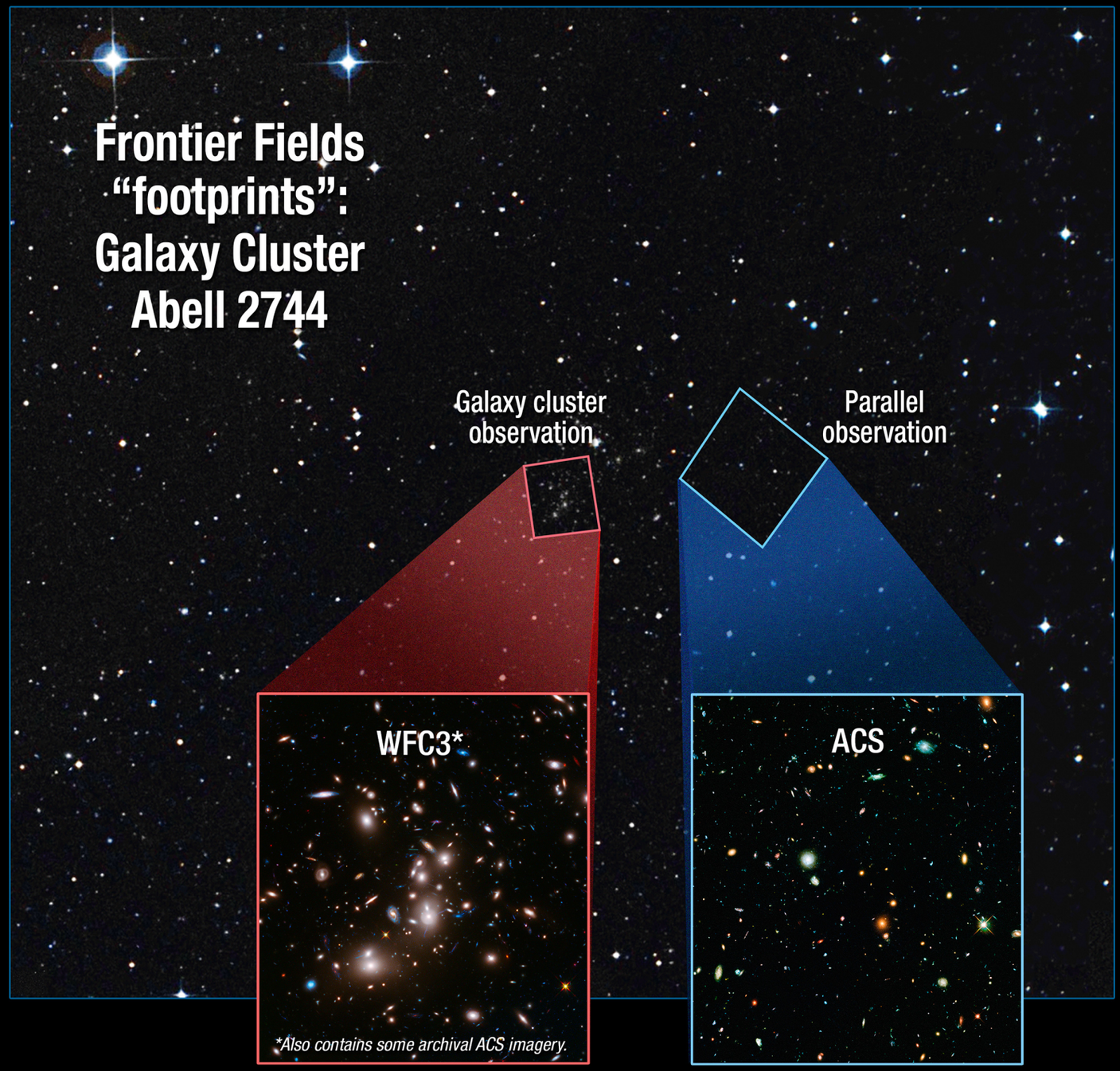
Benefit of magnification due to gravitational lensing

Parallel fields provide significant extra area



NASA and ESA STScI-PRC14-01a

Hubble Frontier Fields Survey



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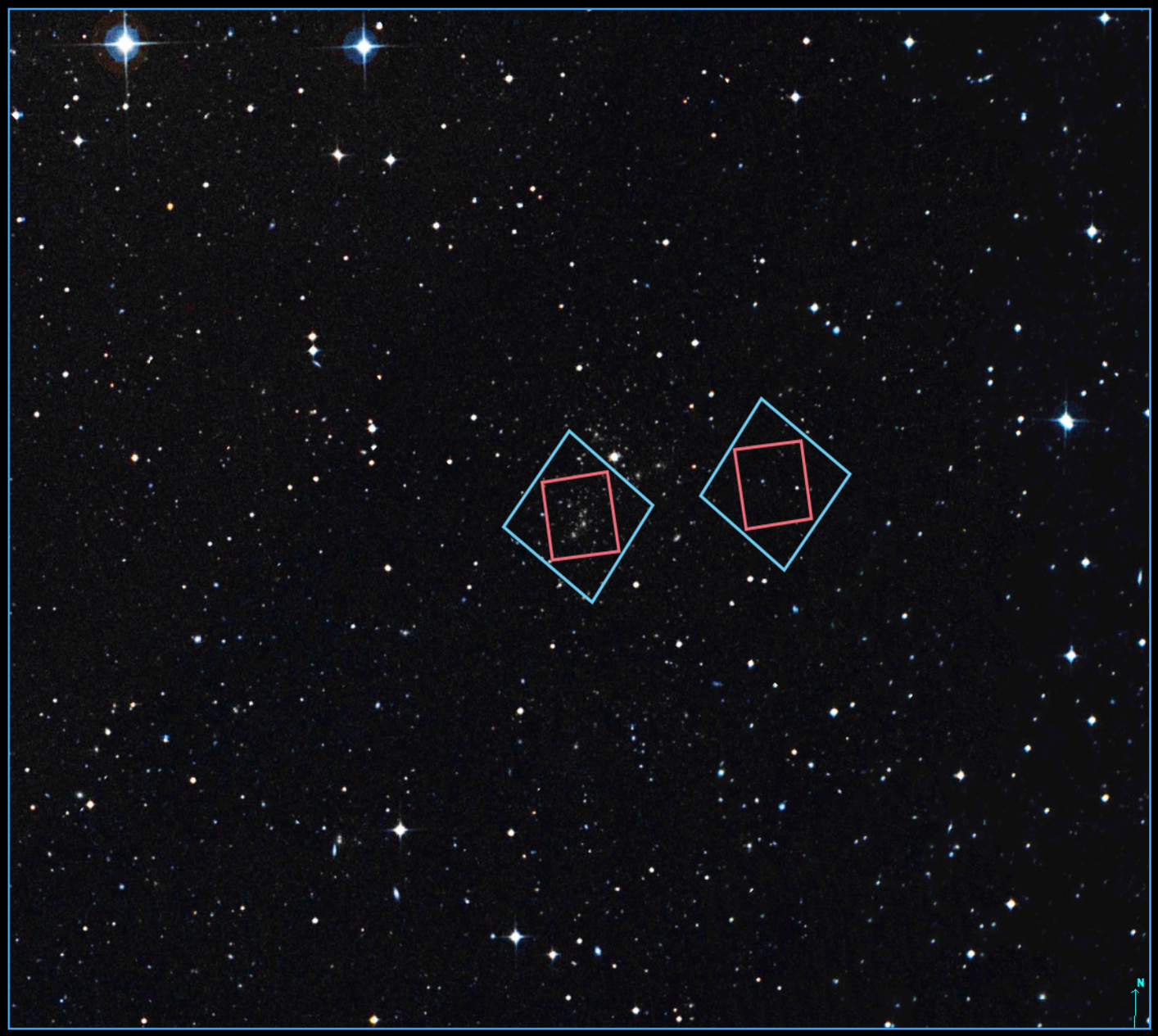

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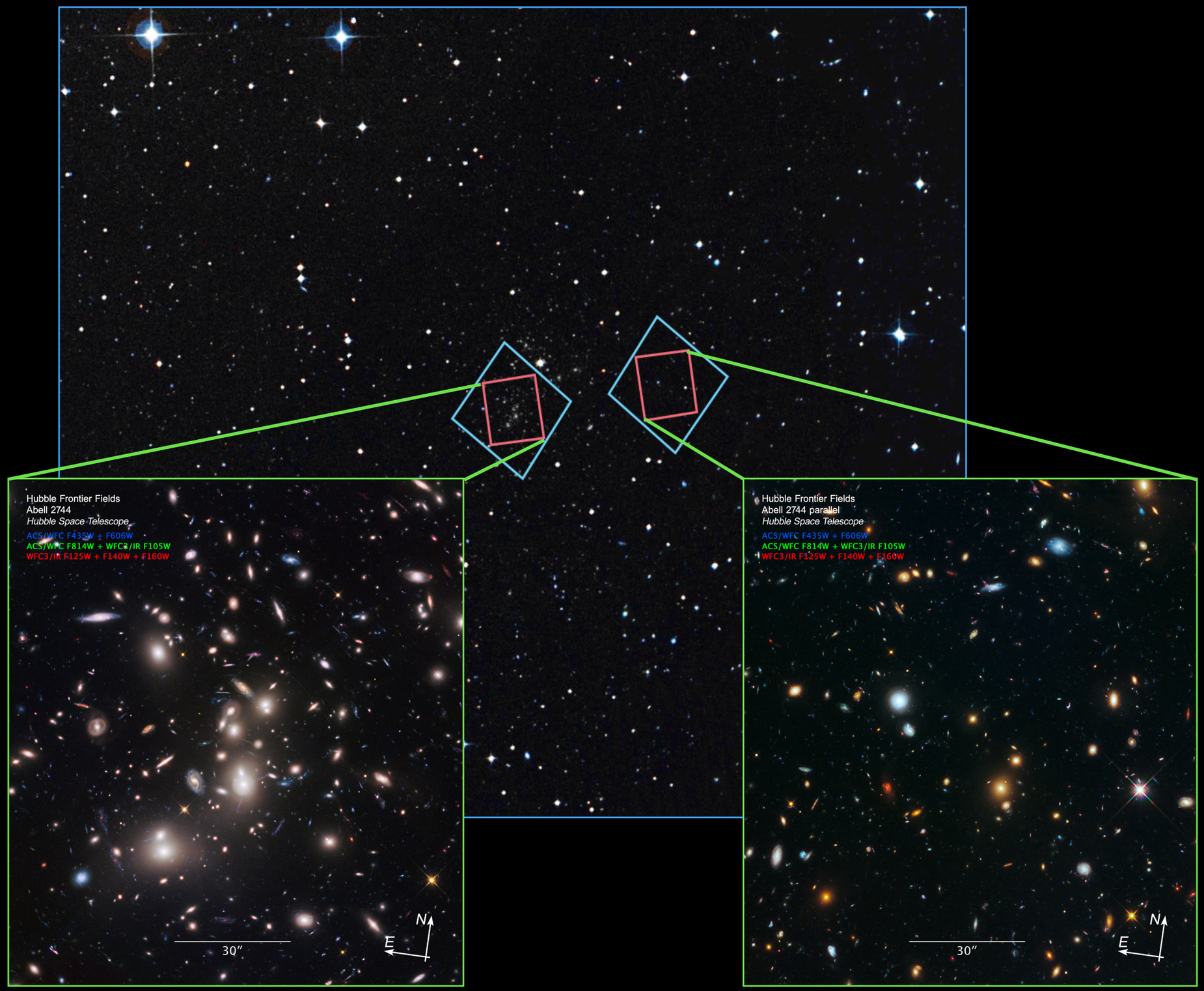
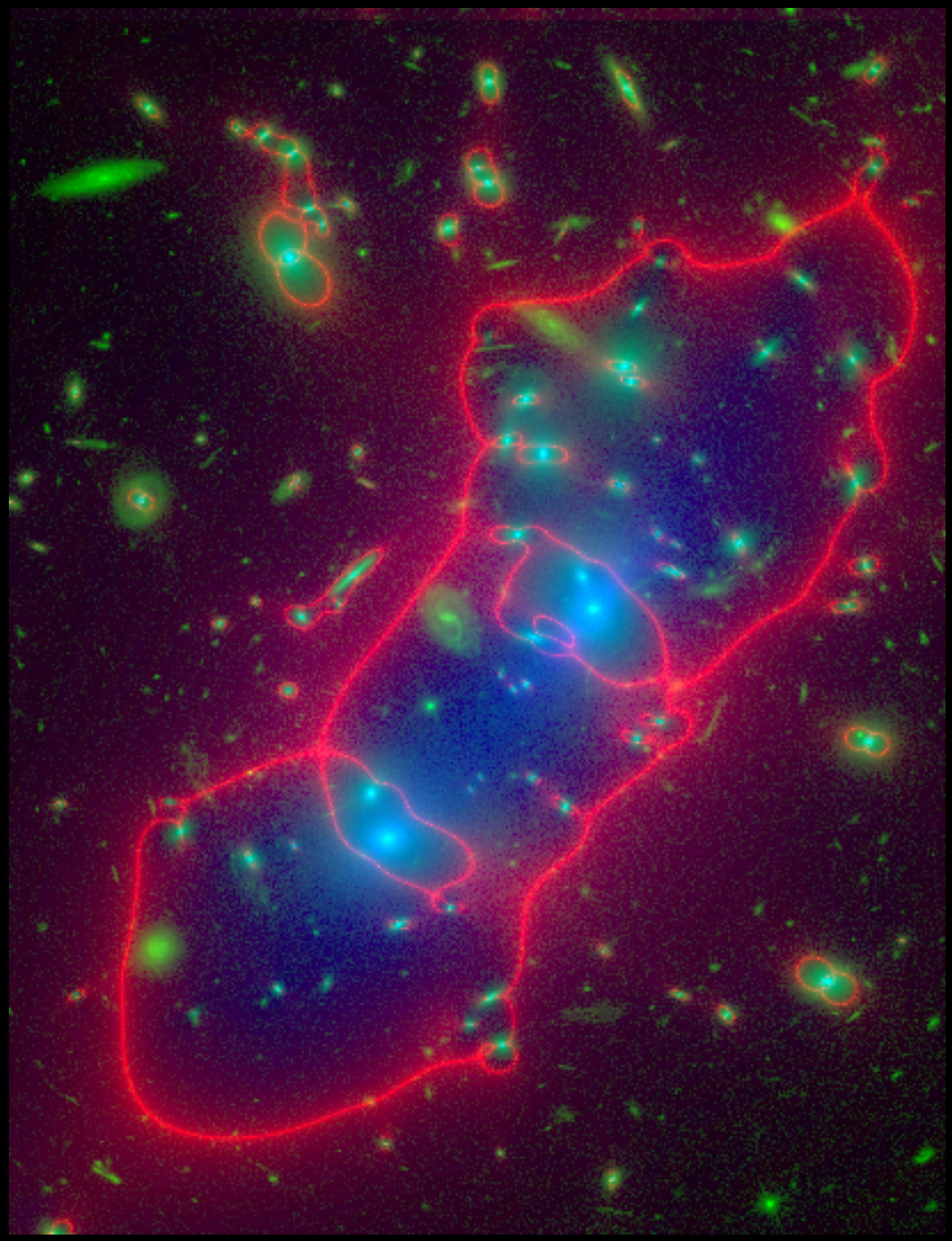


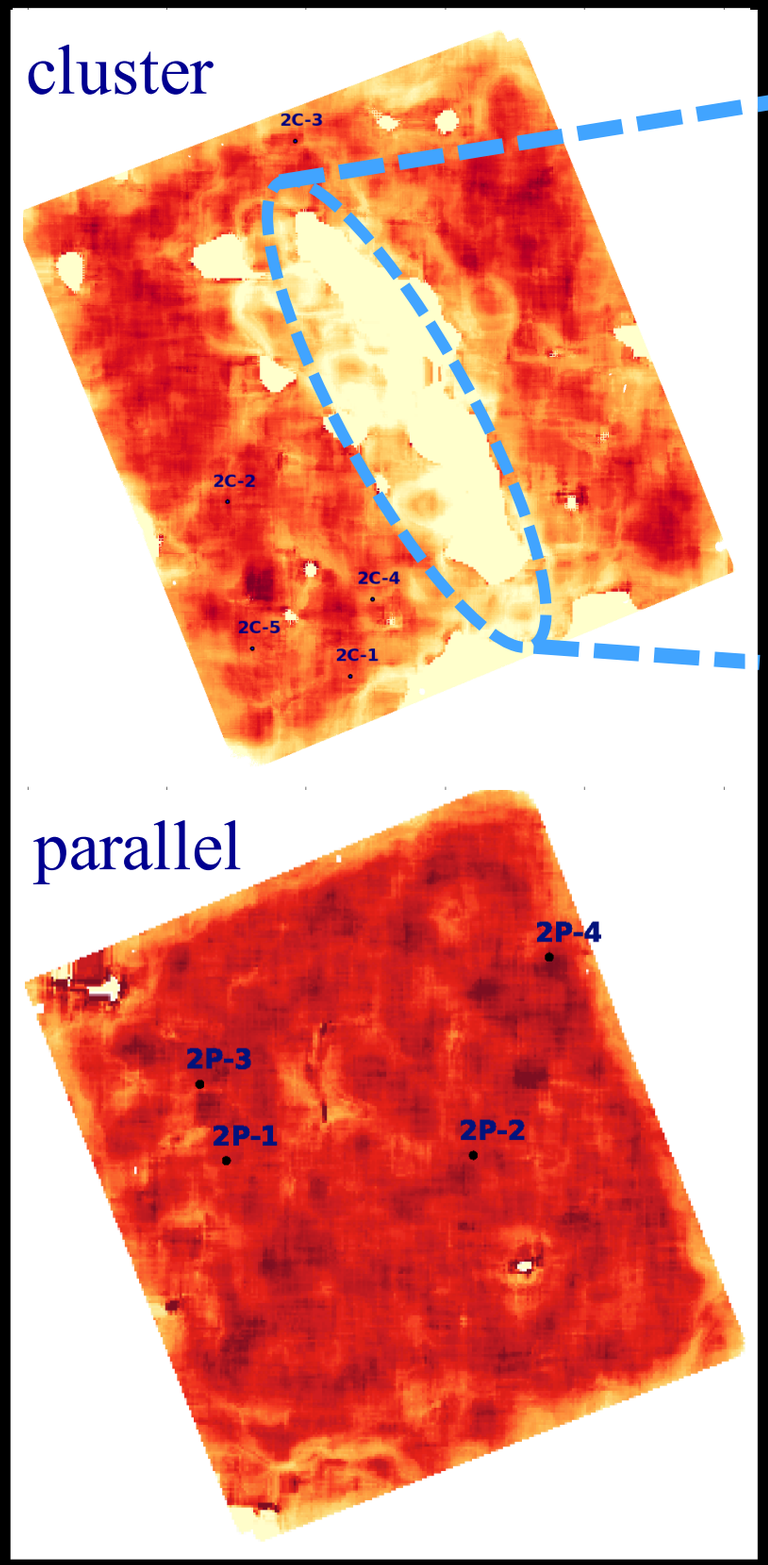
Gravitational lensing – the full "horror…."



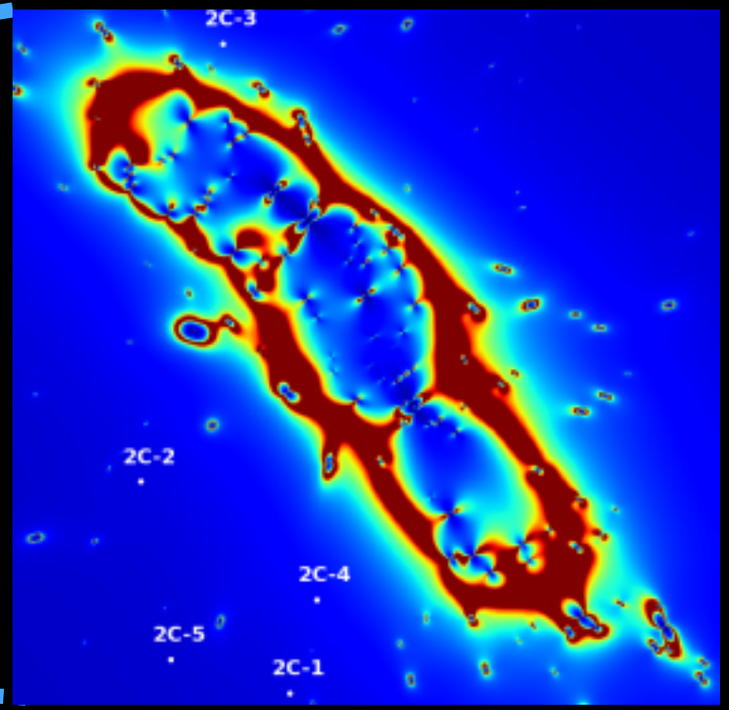
Alternative published magnification maps for Abell 2477

Redshift z=9-10 galaxy selection

DEPTH MAPS



HFF: MACS0416



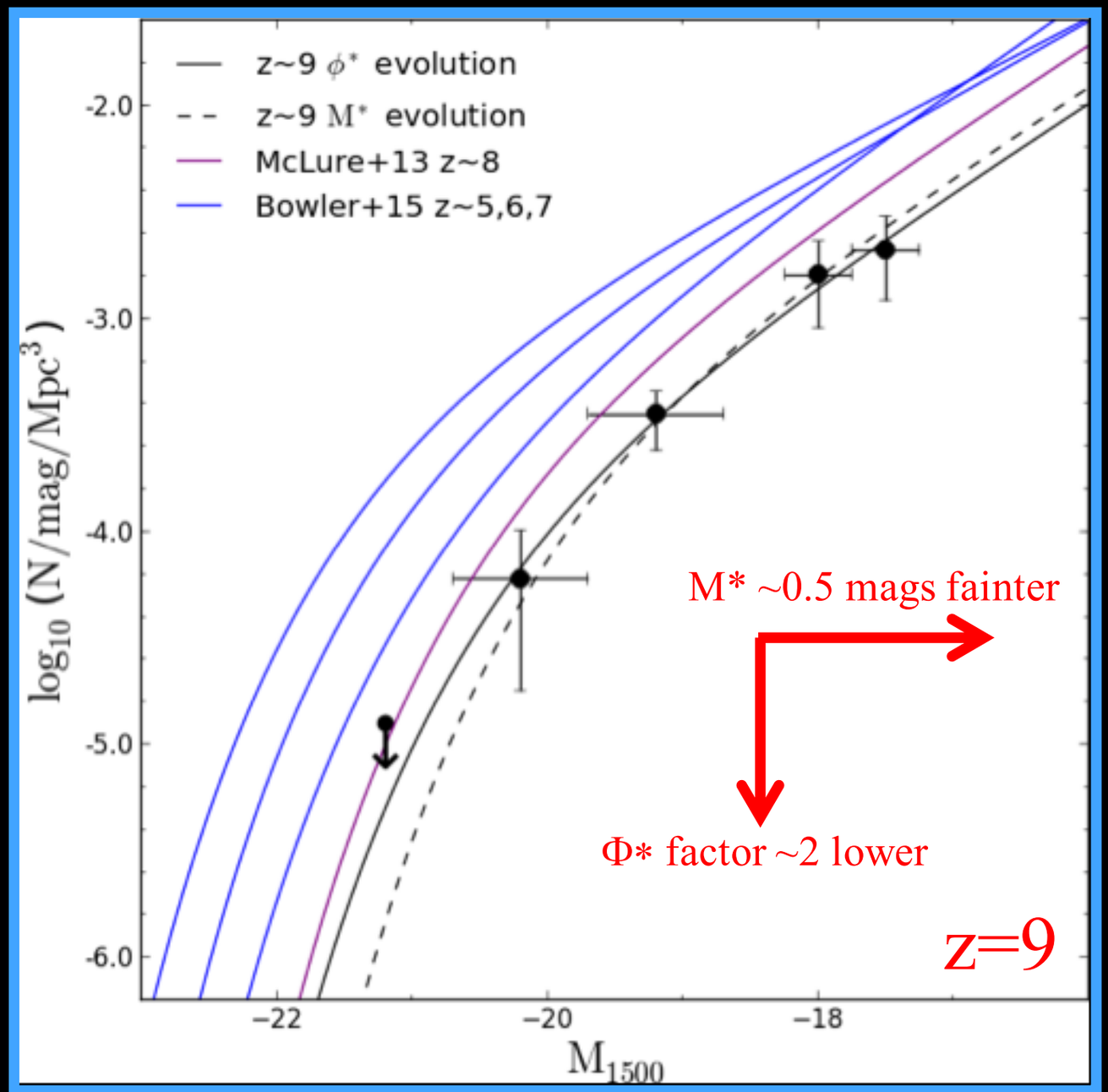
- focus on low magnification areas of HFF+CLASH+UDF (effectively a blank field survey)
- additional constraints at z~10 using magnified regions of CLASH

Results: Luminosity Function

~30 galaxies found at z>8.4 within a raw search area of around 130 sq. arcmin.

including five galaxies at z~10

constraints on the LF and luminosity density at z=9-10



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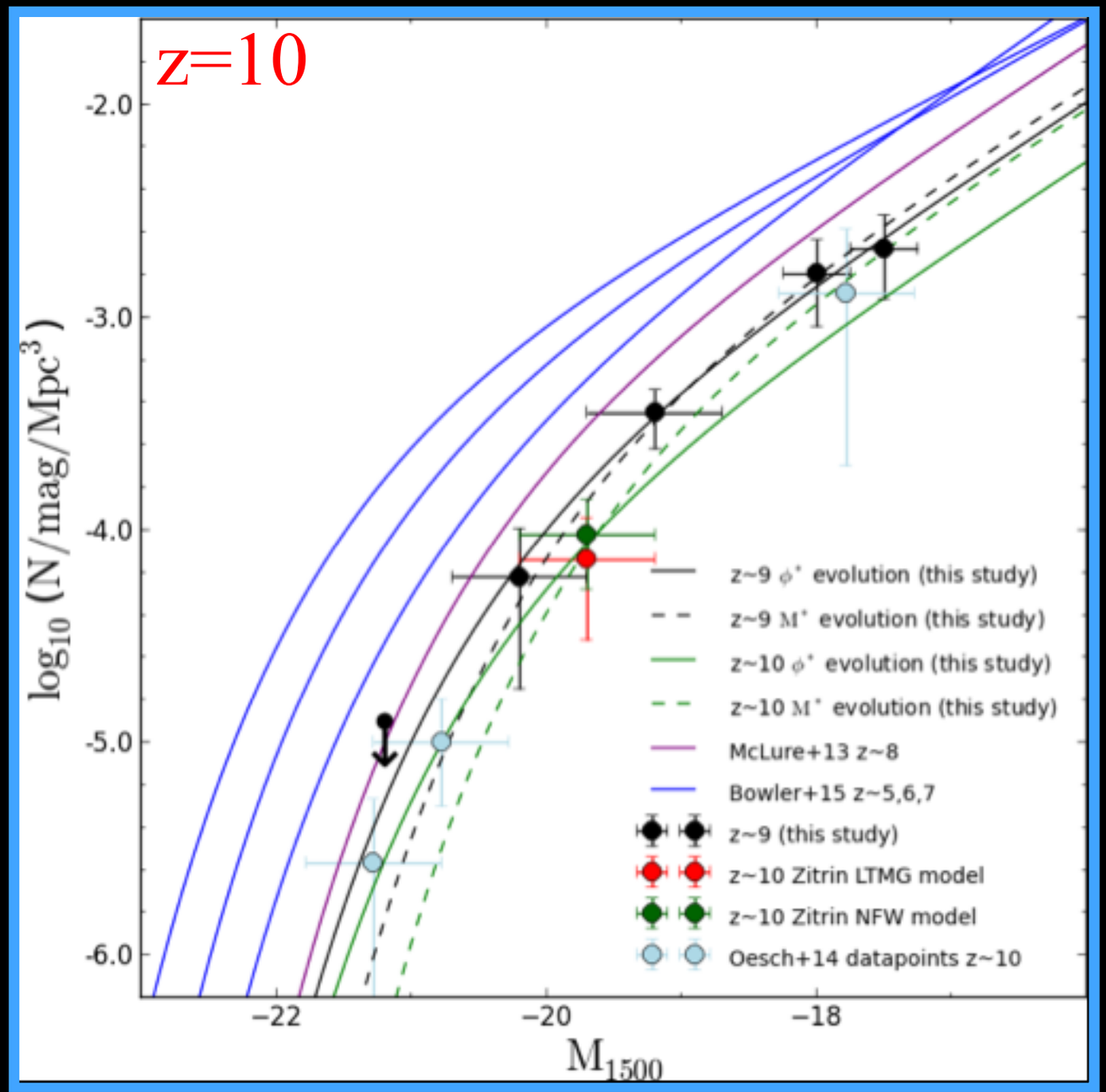


Results: Luminosity Density

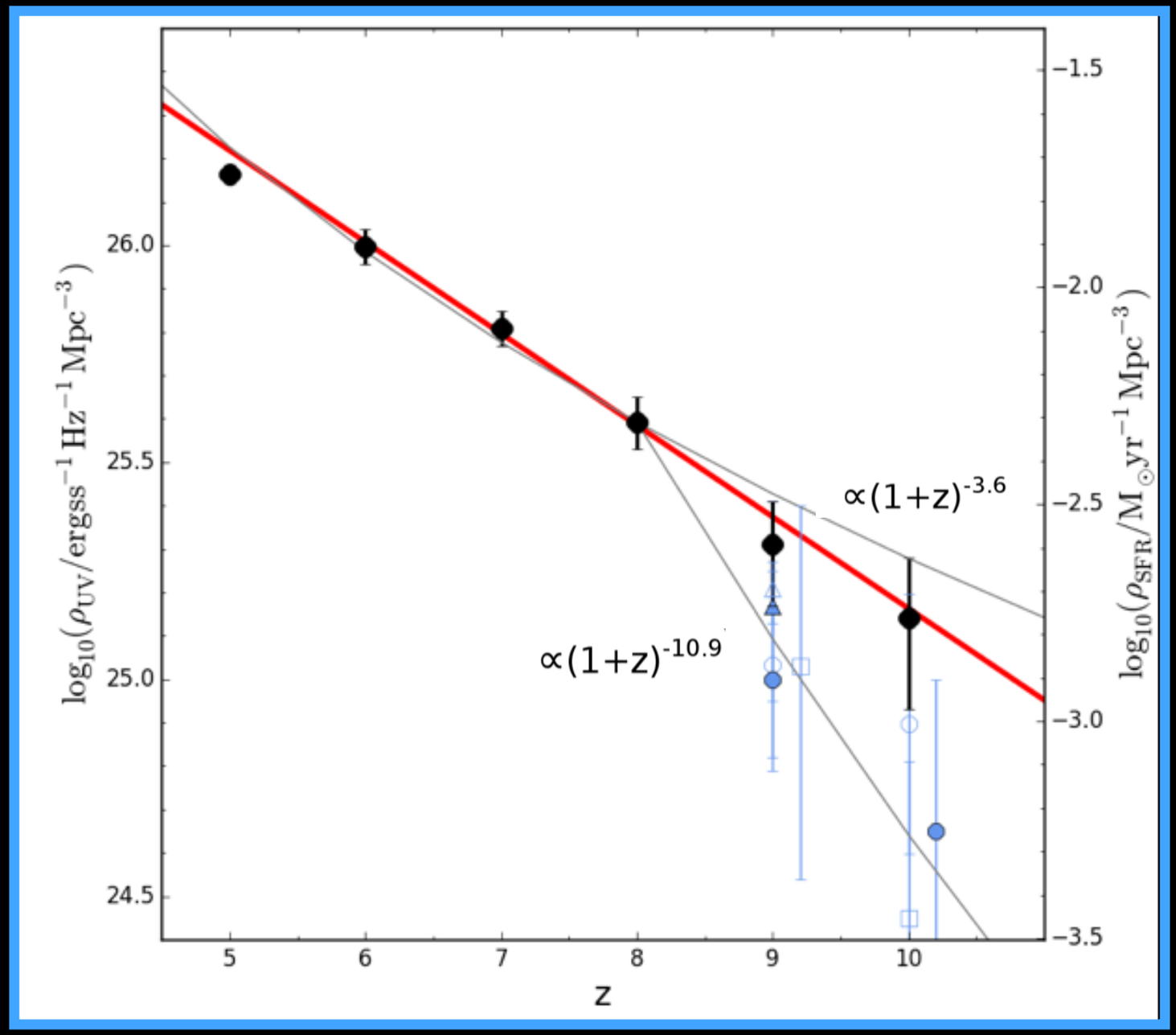
Shallower drop in luminosity density than some previous studies:

blue filled circle:
Oesch + (2014)

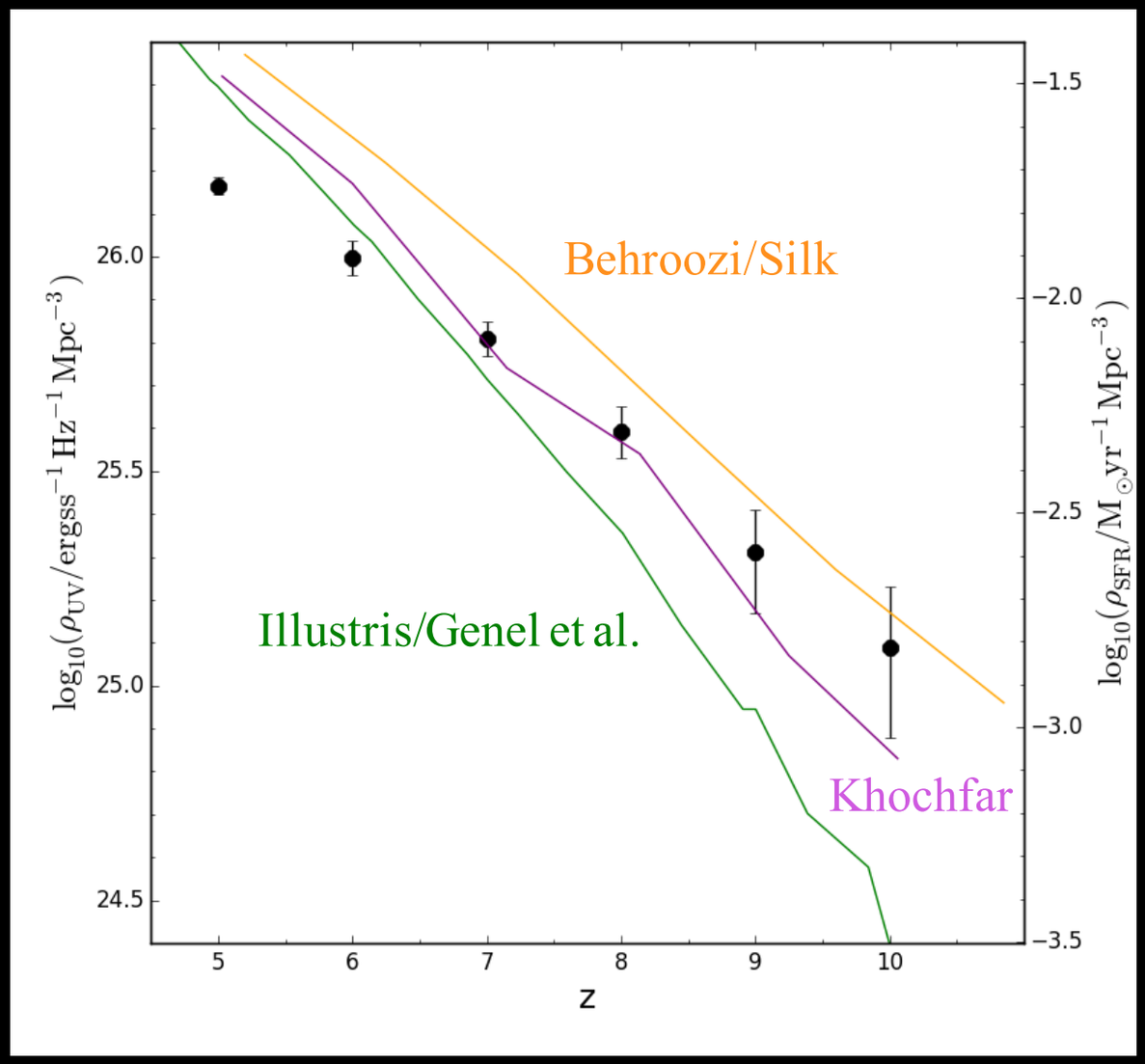
blue open circle:
Ellis + (2013)

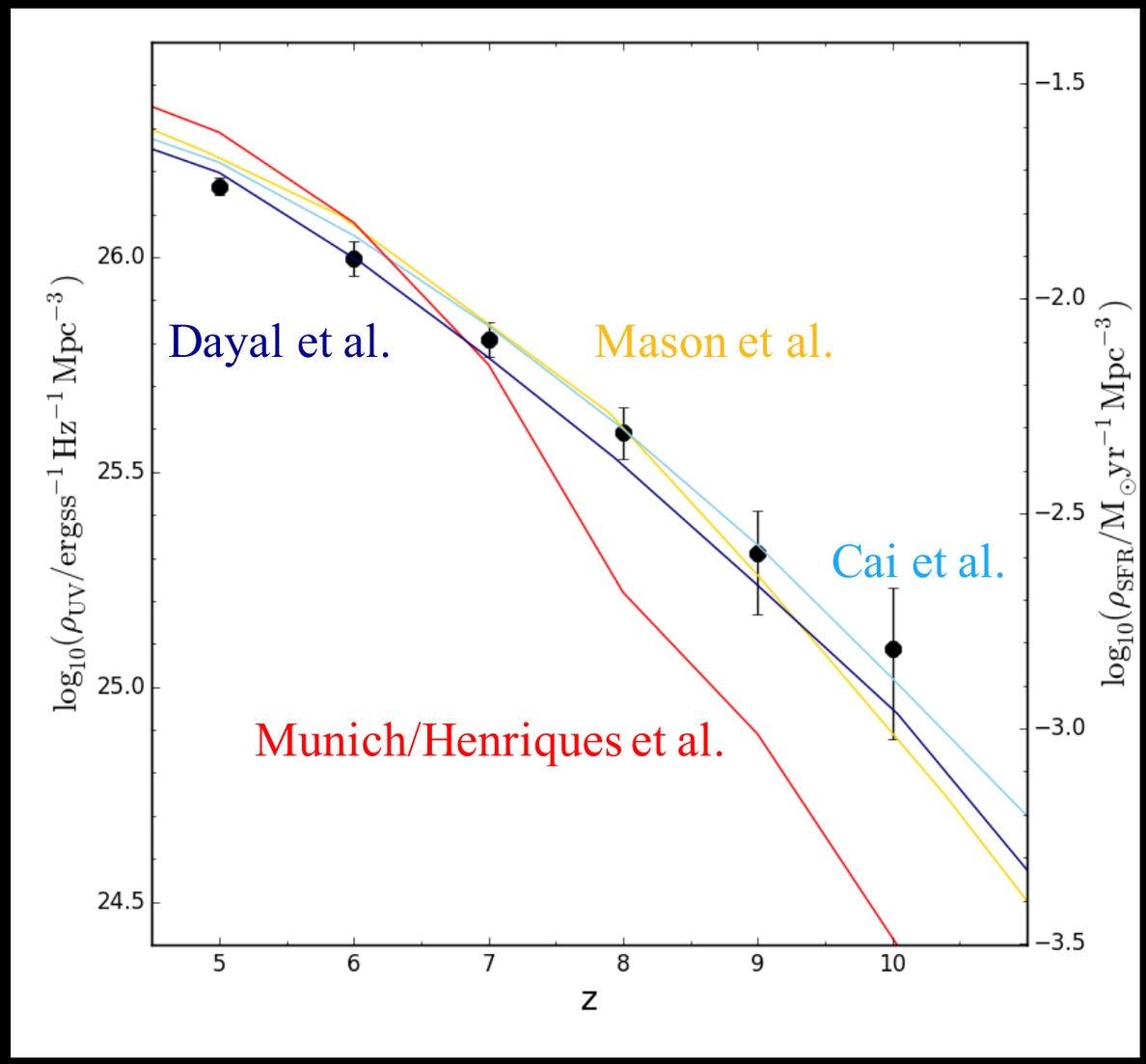
blue filled triangle:
Ishigaki + (2015)

blue open triangle:
McLure + (2013)



Results: model comparison

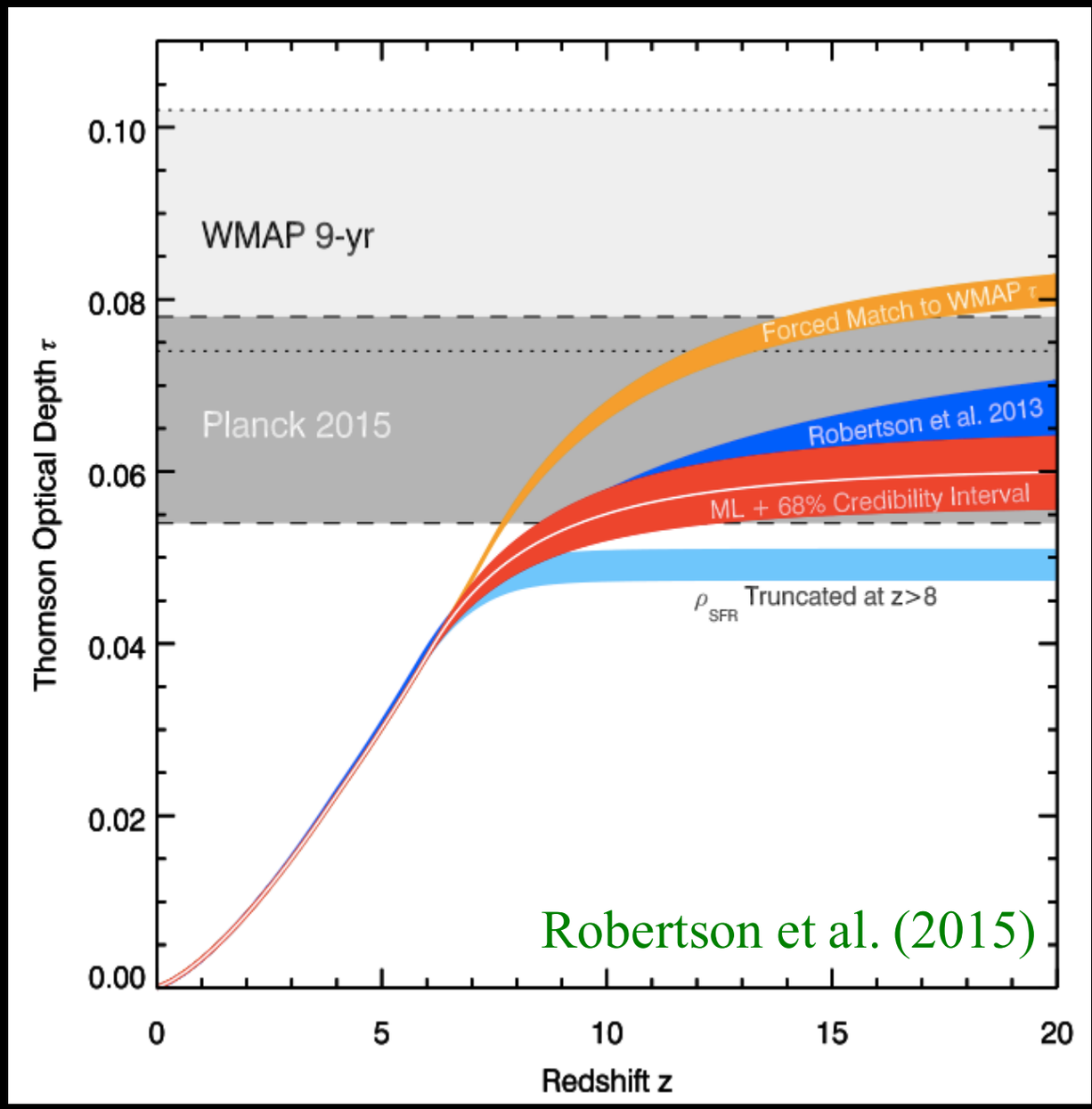




UV density fall-off in reasonable agreement with majority of galaxy evolution model predictions – but free to pick and choose...

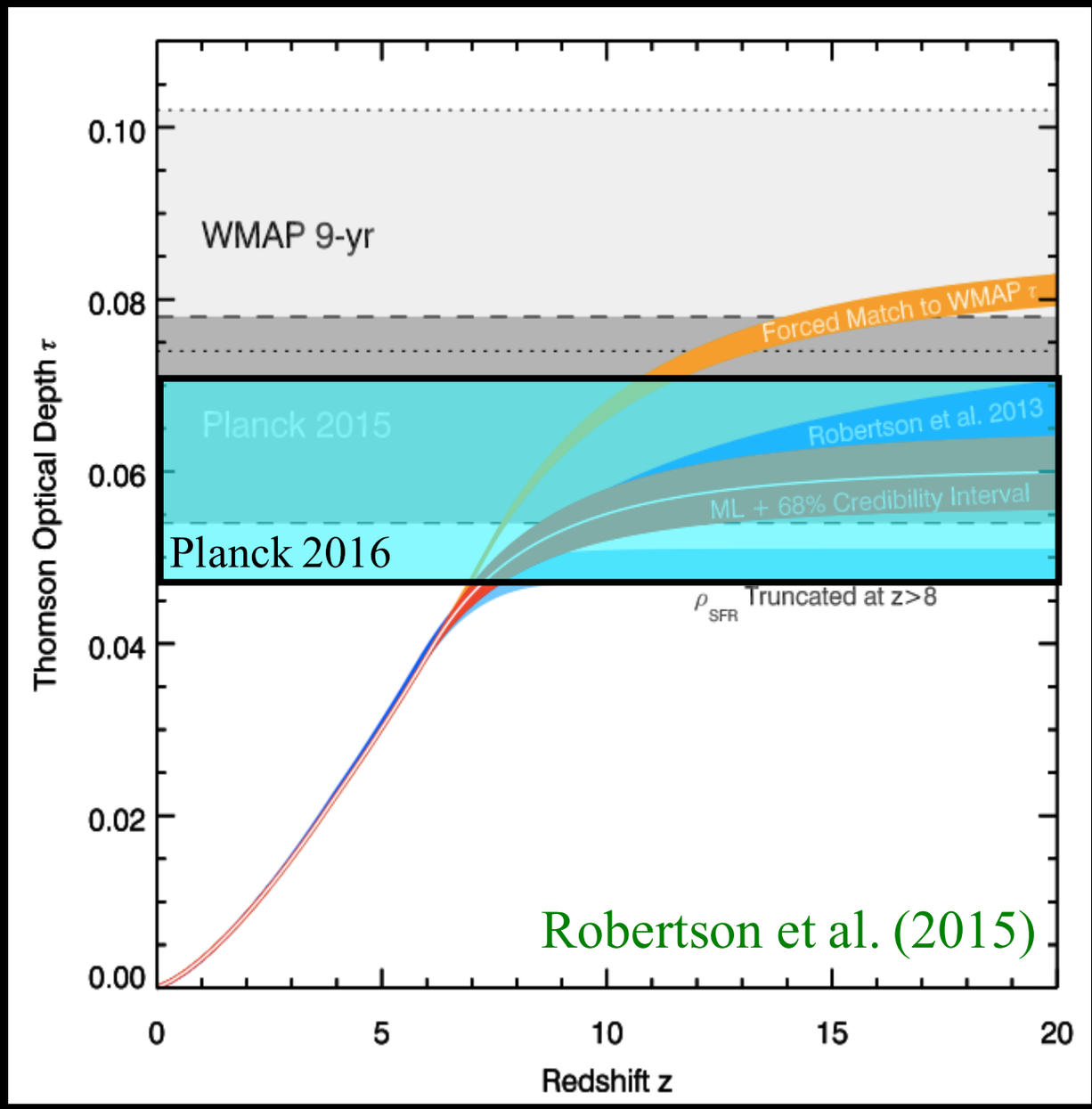
Results: comparison with Planck

- Used to be a real struggle to reach WMAP τ measurement
- Fairly comfortable with updated Planck 2015 results

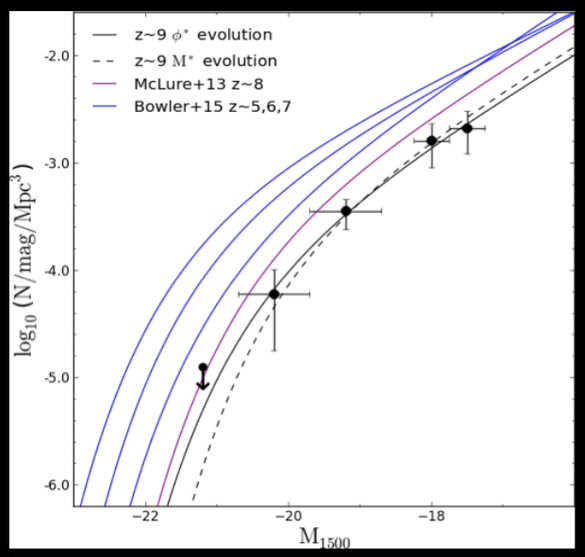


Results: comparison with Planck

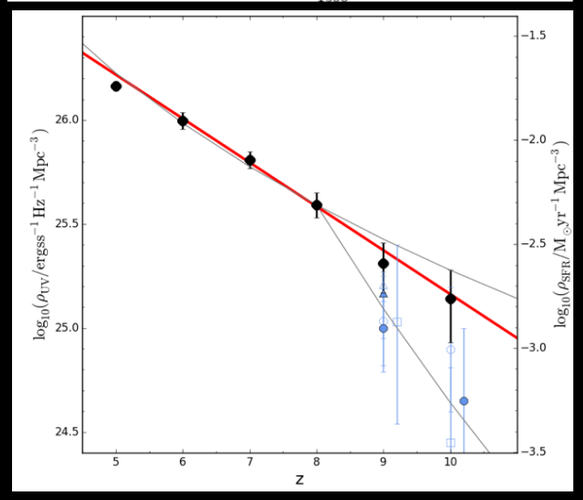
- Used to be a real struggle to reach WMAP τ measurement
- Fairly comfortable with updated Planck 2015 results
- Planck 2016 measurement of τ=0.058 is now very consistent with our latest estimate of ρ_{UV} evolution



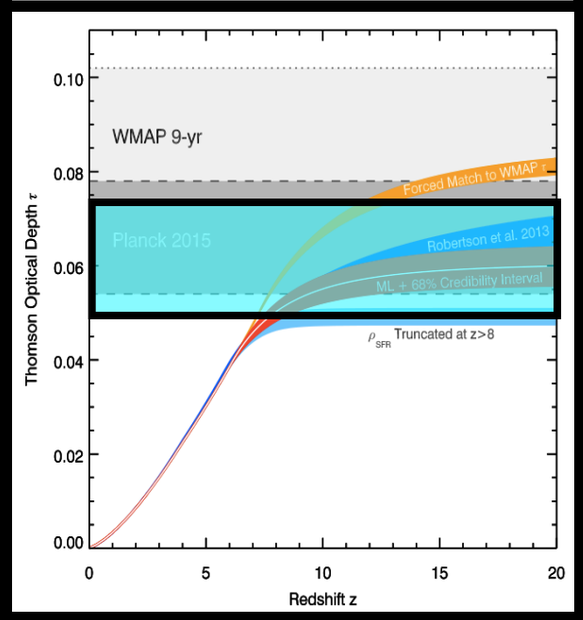
Summary



New sample of 30 z~9-10 galaxies in UDF+HFF+CLASH: improved measurement of z=9 LF and initial constraint at z=10 (see McLeod et al. 2015, 2016 for full details)

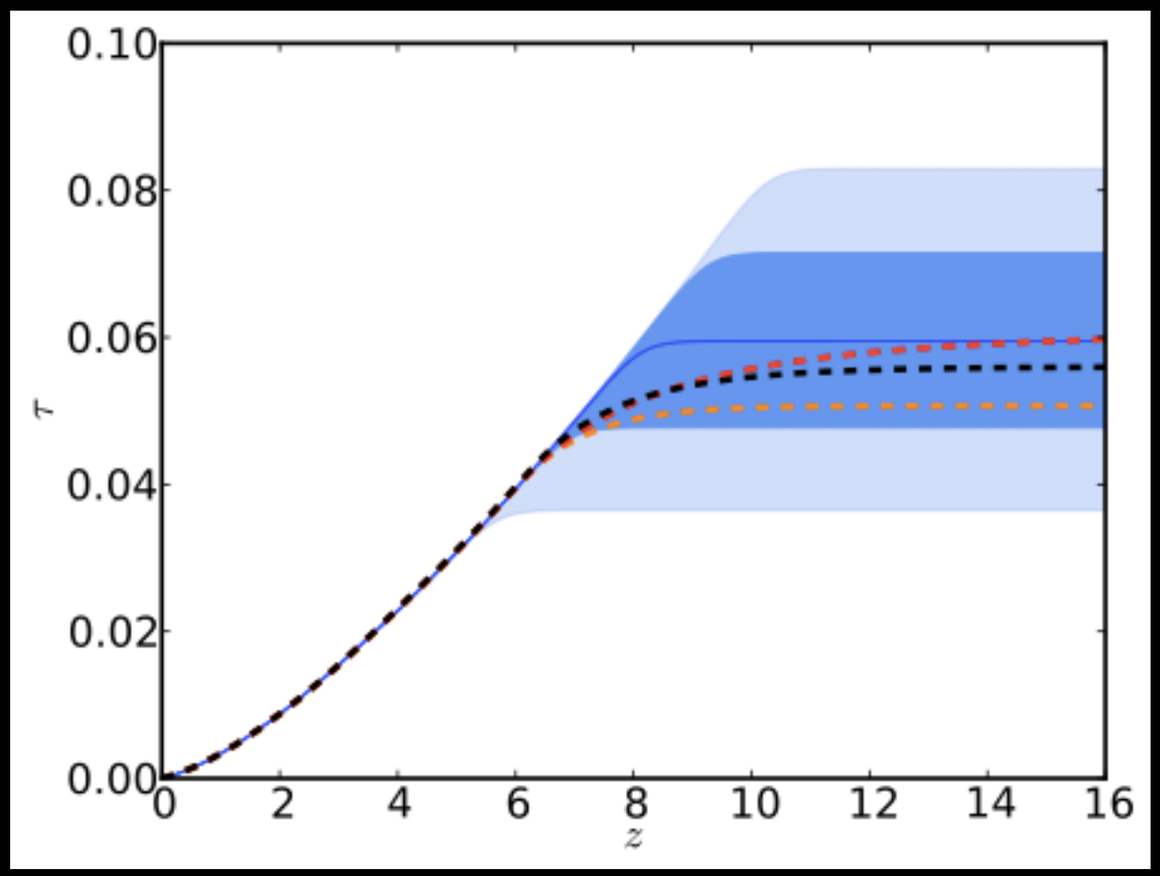


More evidence for smooth fall-off in UV luminosity density in redshift interval 8<z<10

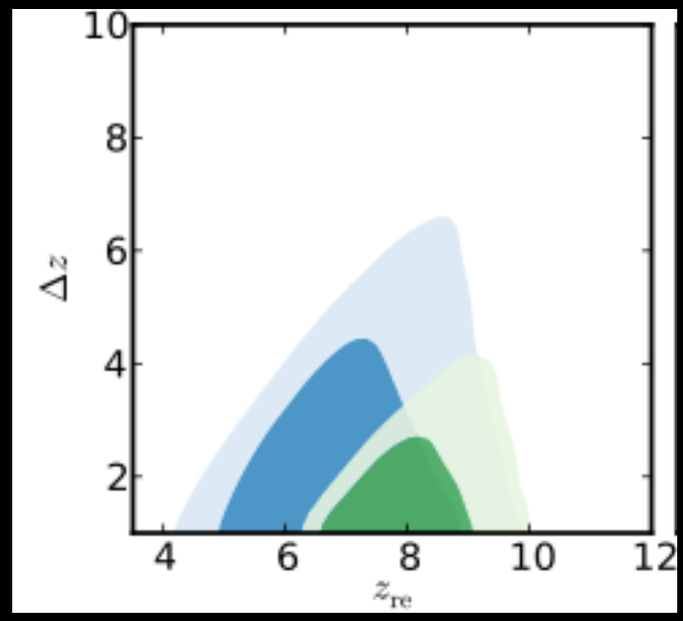


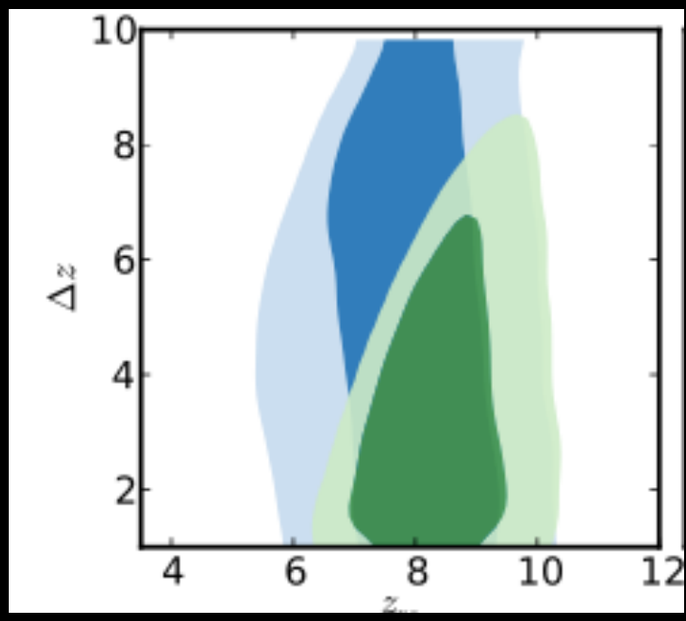
Evolution of UV luminosity density at high-redshift now in excellent agreement with Planck 2016 measurements of τ=0.058 and z_{RE}~8

Planck 2016 update



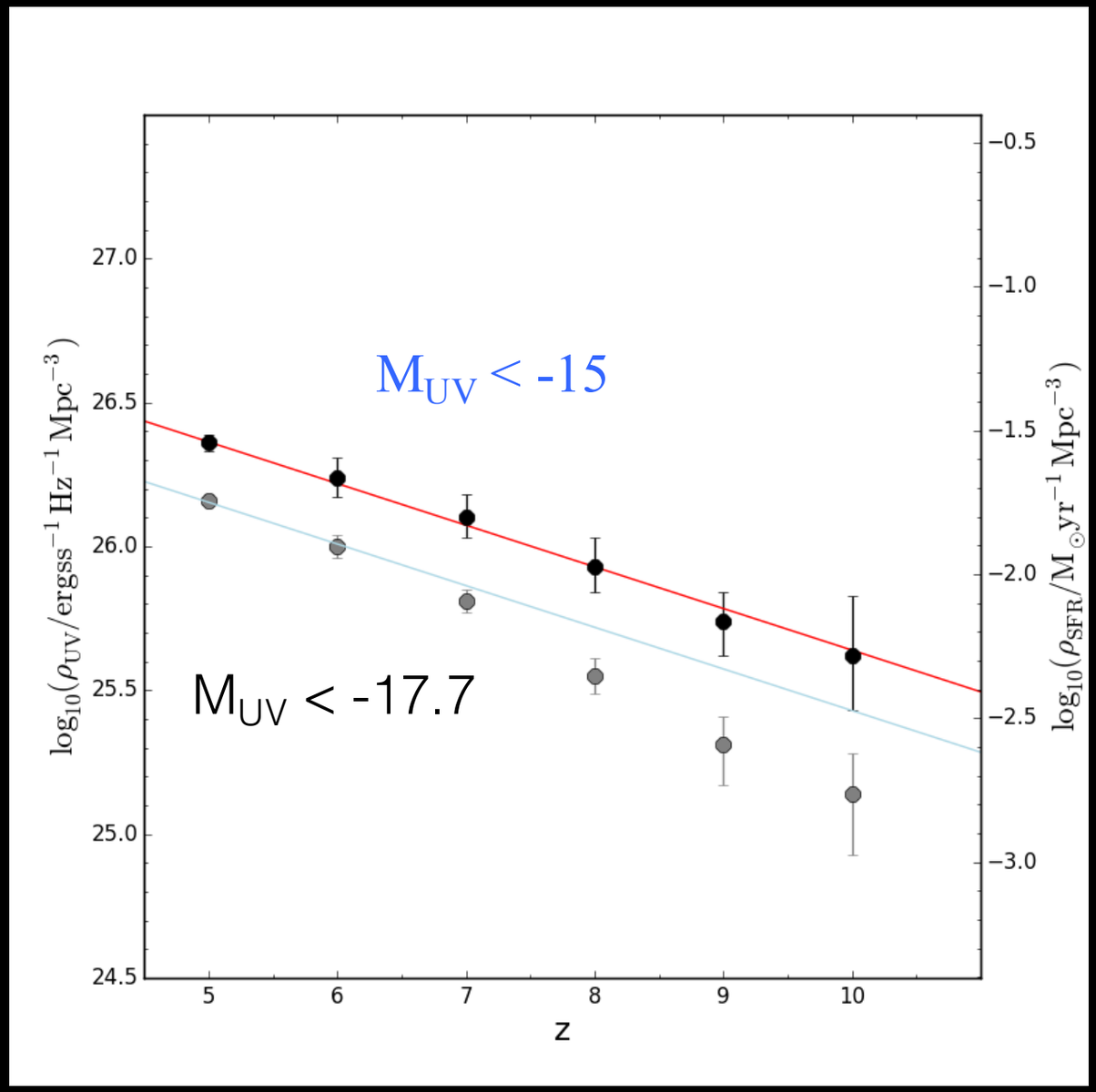
Adam et al. (2016)





Constraints on duration of reionization

Hernquist & Springel (2003) analytical prediction



ρ_{SFR} α exp(z/3) : following dark matter halo evolution with no dust