Probing the Epoch of Re-ionisation with the Hubble Frontier Fields Clusters

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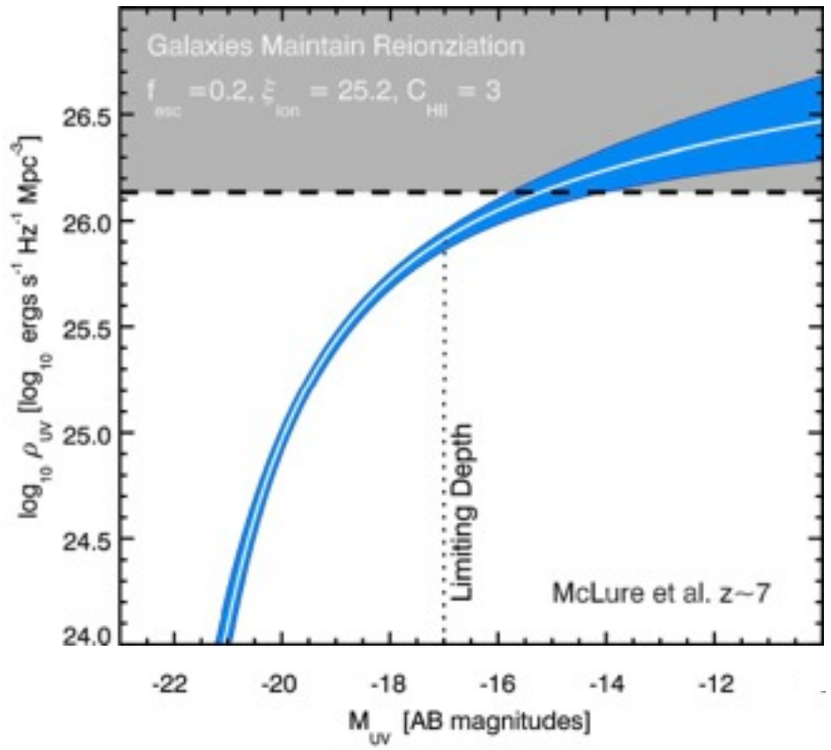
Star-forming Galaxies and Cosmic Re-ionisation

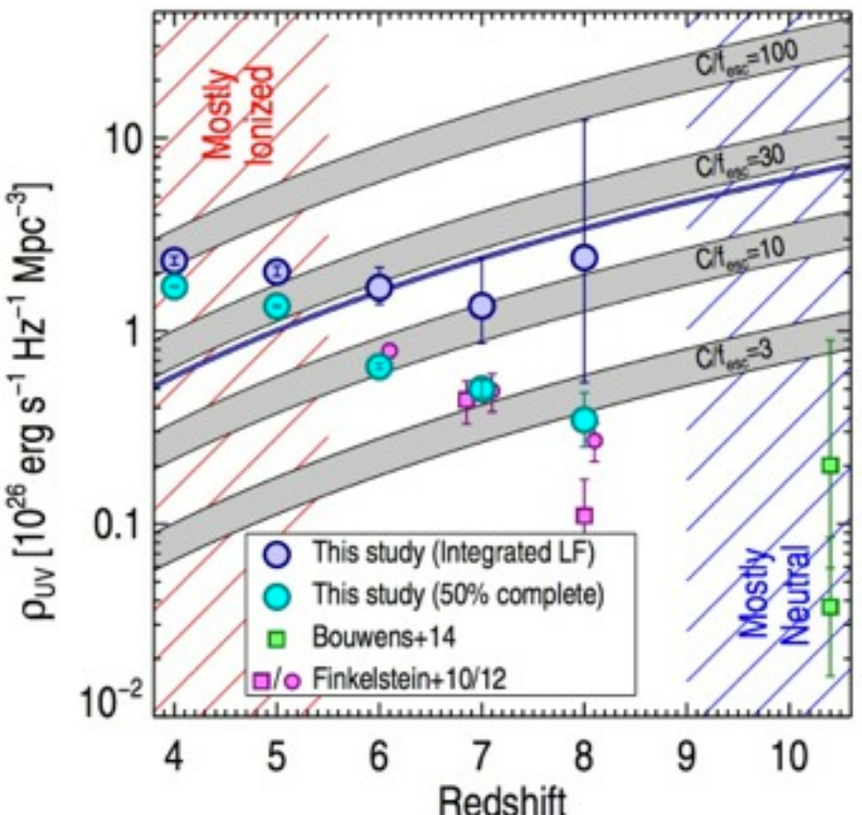
- Star-forming galaxies are thought to be the responsible of the ionising background Universe mostly (90%) ionised at z~6
- The exact contribution and the underlying physics (C, f_{esc} ...) depends on the faint end slope of the luminosity function.
- Use cluster lenses as natural telescopes to probe deeper in the Universe:

The Hubble Frontier Fields Clusters

Robertson et al. (2013)

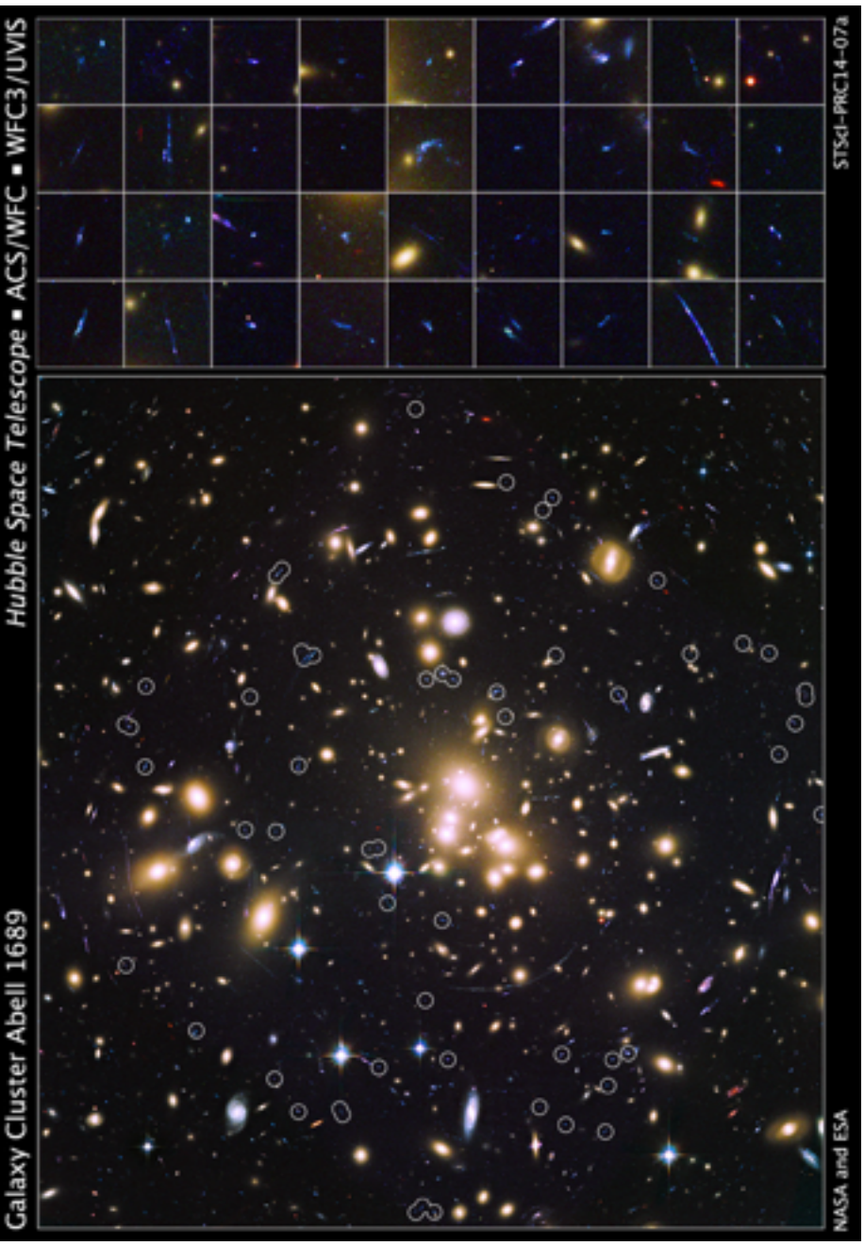


Finkelstein et al. (2014)

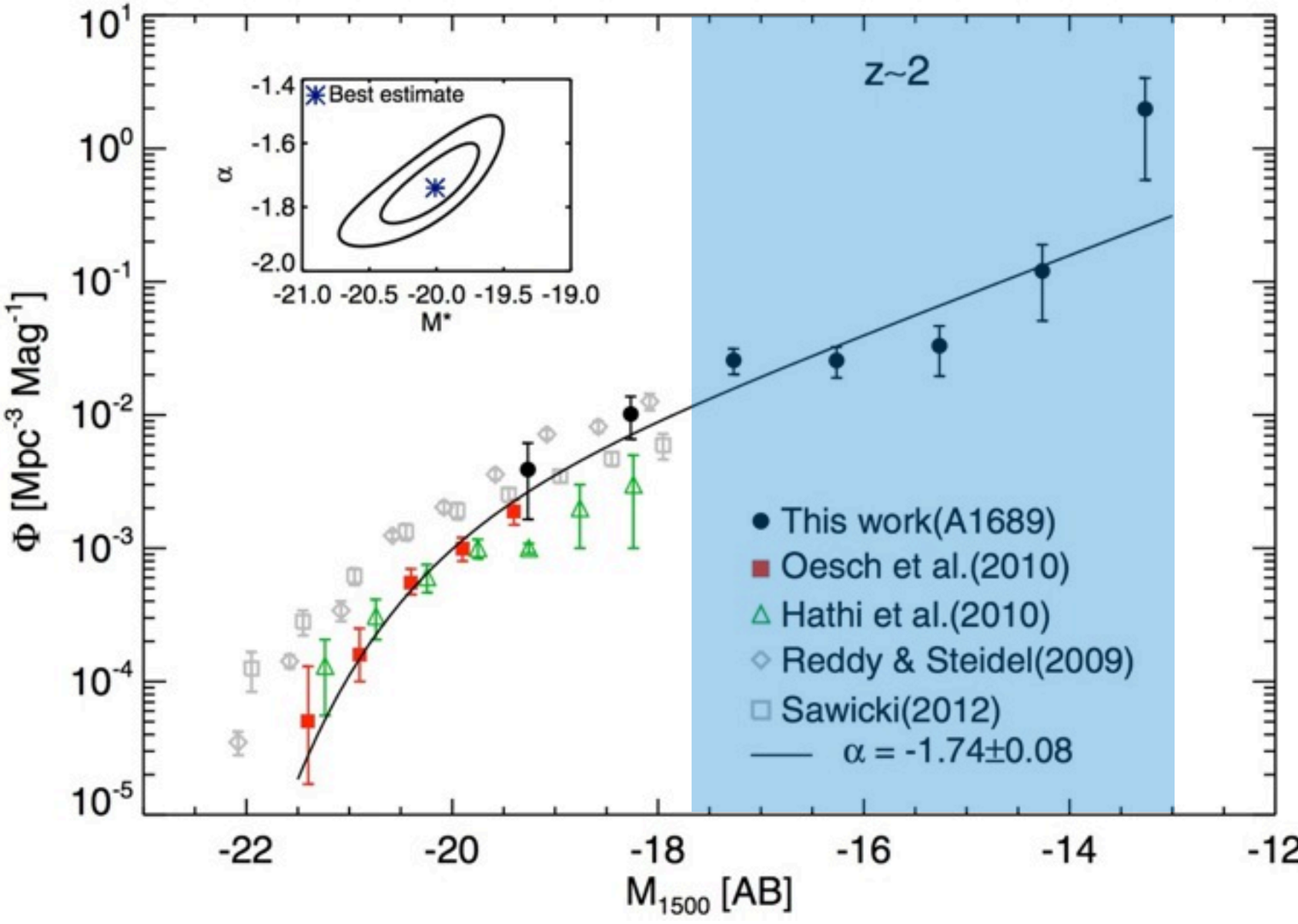


The Faintest Galaxy Population through "Gravitational Telescopes"

UV LF at z~2 down to Muv=-13 thanks to A1689 magnification
No sign of turnover in the UV LF



Alavi et al. (2014)



The *Hubble Frontier Fields*

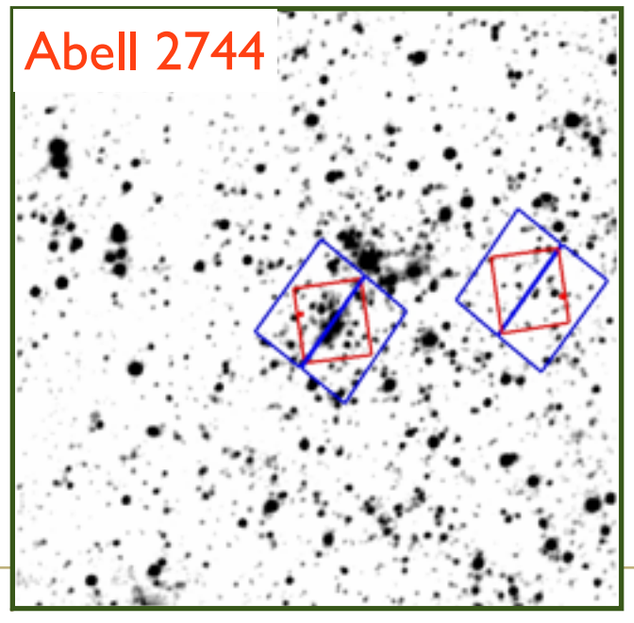
Combining the power of gravitational lensing with the unique HST observing capabilities

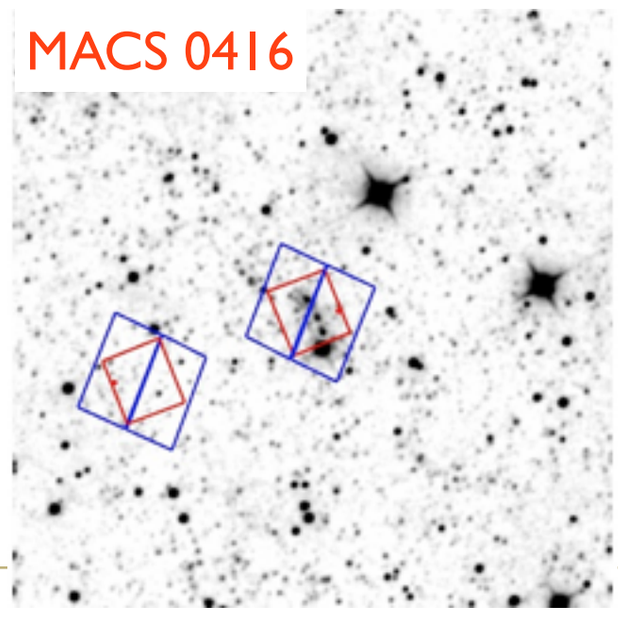
DDT time of 840 orbits to observe 6 lensing clusters and parallel fields in Cy21/22/23

- WFC3/IR and ACS/optical imaging
- Spitzer, ALMA, VLT, Spectroscopy, etc.
- Lensing maps publicly available

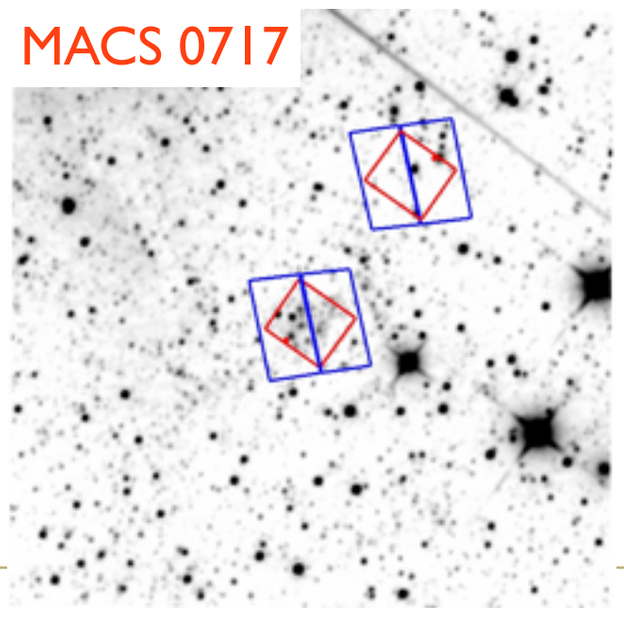
ACS: (70 orbits per position)			WFC3/IR: (70 orbits per position)		
Filter	Orbits	AB_mag	Filter	Orbits	AB_mag
F435W	18	28.8	F105W	24	28.9
F606W	10	28.8	F125W	12	28.6
F814W	42	29.1	F140W	10	28.6
			F160W	24	28.7

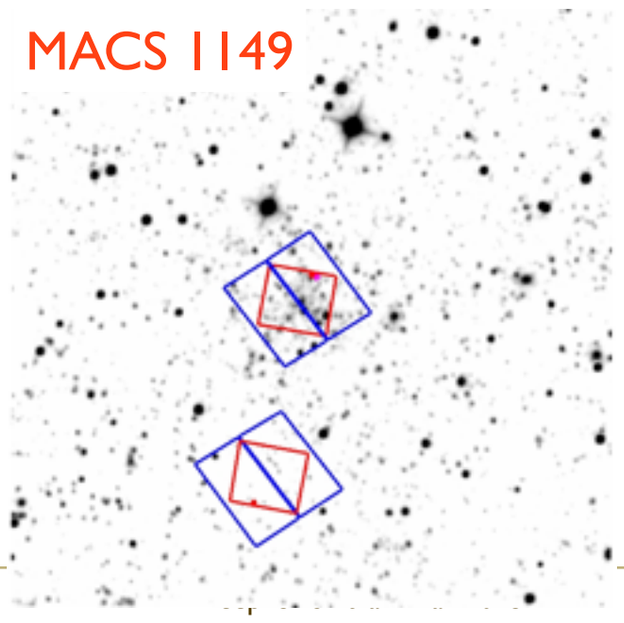
Completed





Nearly Completed





First Results from Abell 2744

Observations

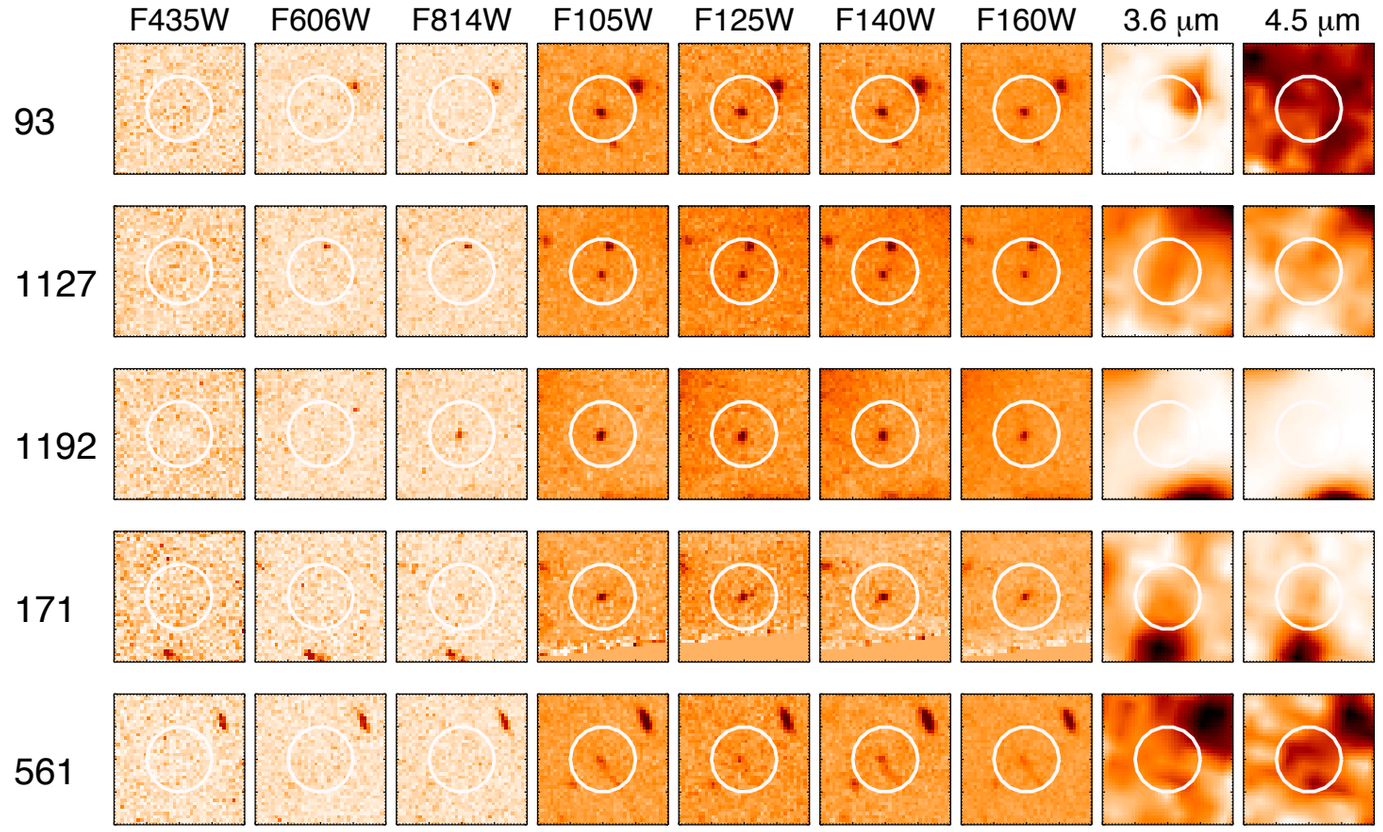
– HFF ACS & WFC3:

- A total of 140 orbits down to 29 AB mag.

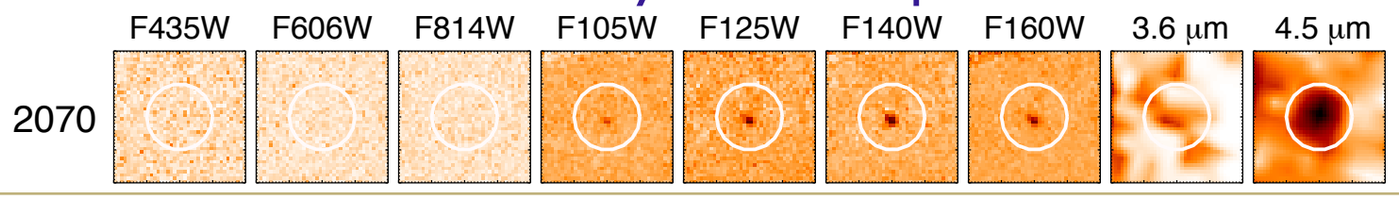
- The UDF reaches a depth of 30 AB mag.

	ACS			WFC3			
Filter	F435W	F606W	F814W	F105W	F125W	F140W	F160W
Depth	28.8	29.4	29.4	28.6	28.6	29.1	28.3

z~6-7 Galaxies I-814 dropouts

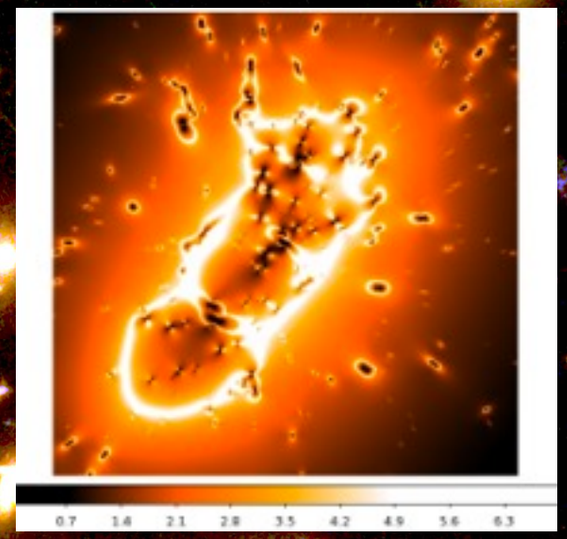


z~8 Galaxy Y-105 dropouts



Modelling A2744

Magnification map



10”

North

East

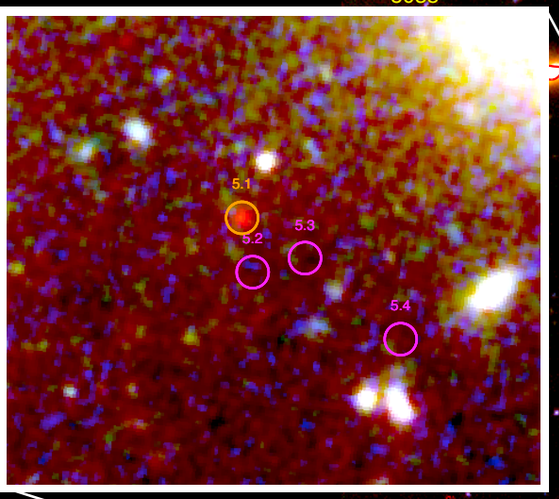
~150 multiple images

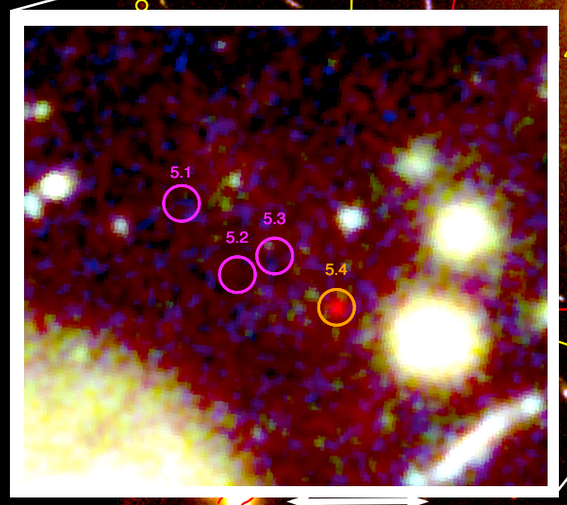
<1% precision in the modelling

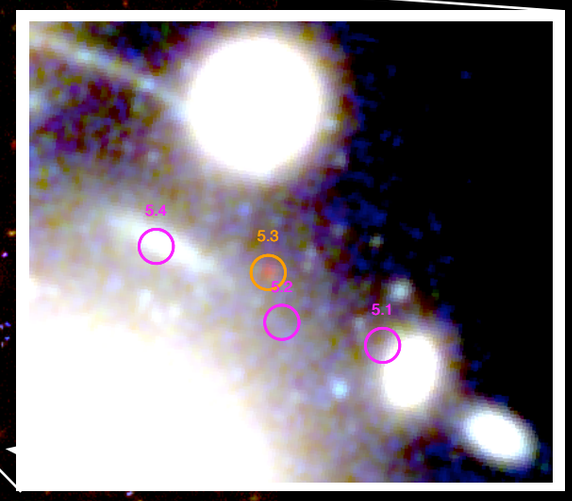
Jauzac et al. 2014

A2744: Quadruply Imaged z~7 Drop-out

also z~10 triple found by Zitrin et al







East

The UV Luminosity Function at z>6

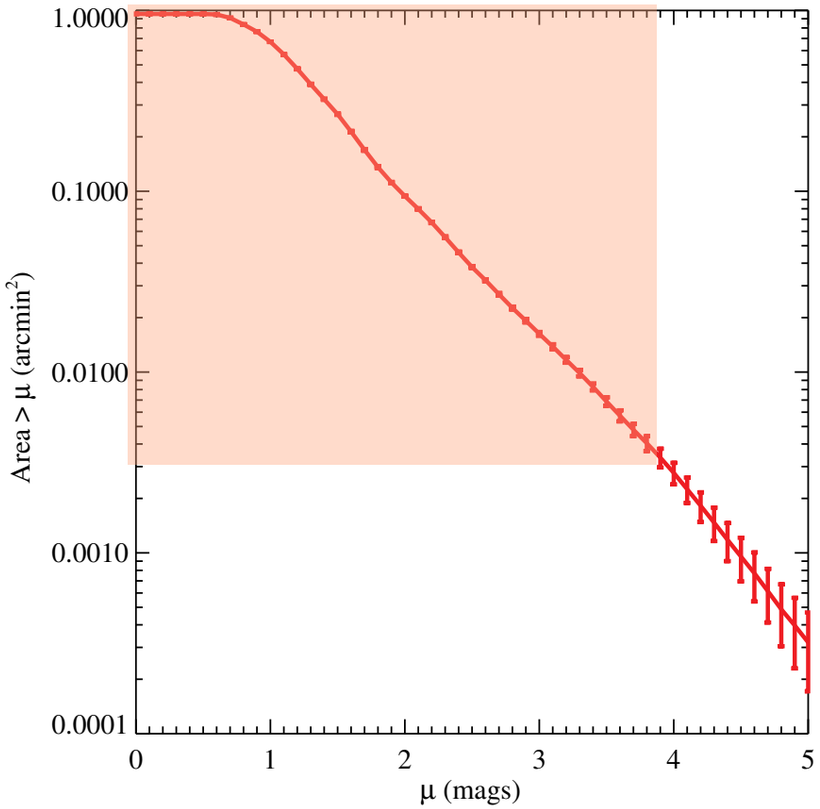
Luminosity distribution of the sources:

$$\phi(M)dM = \frac{N_i}{V_{eff}(M_i)}$$

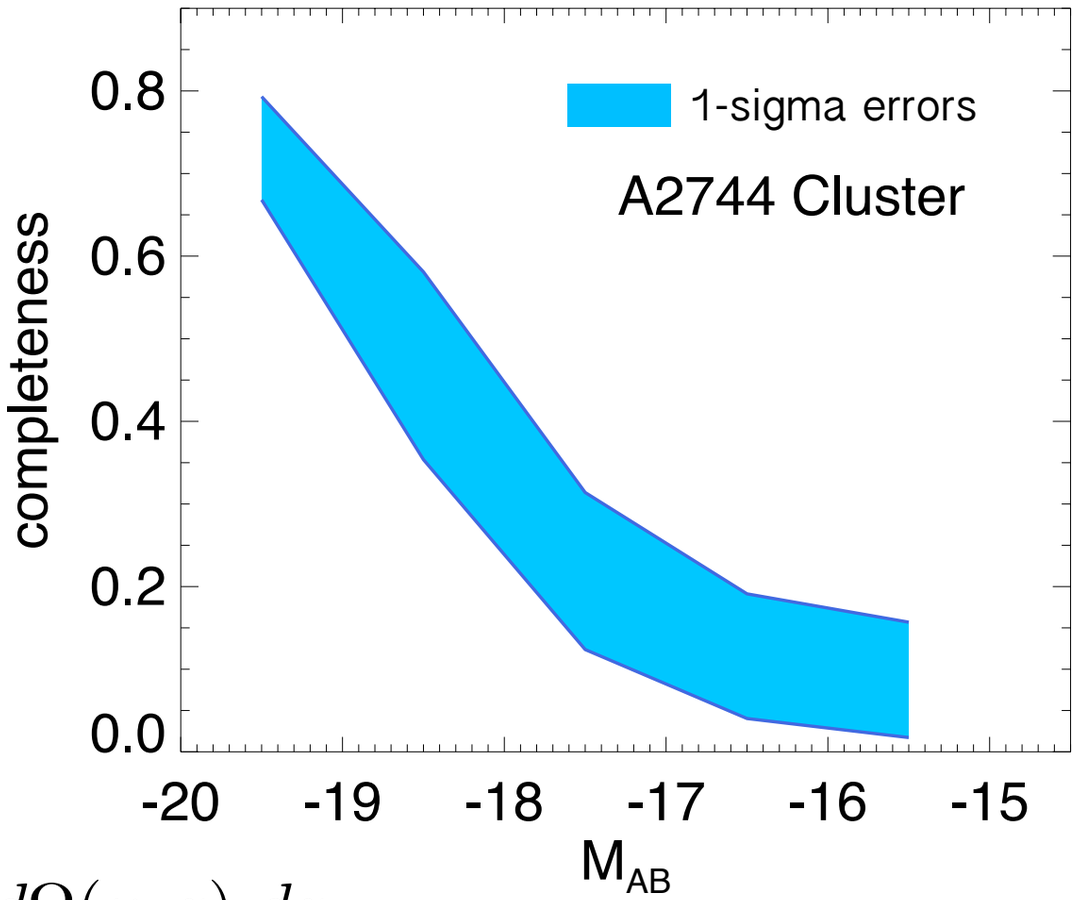
- Completeness is a function of magnification

e.g., source area reduction, sky position …

and **lensing distortion**



Jauzac et al. (2014)



Effective survey volume

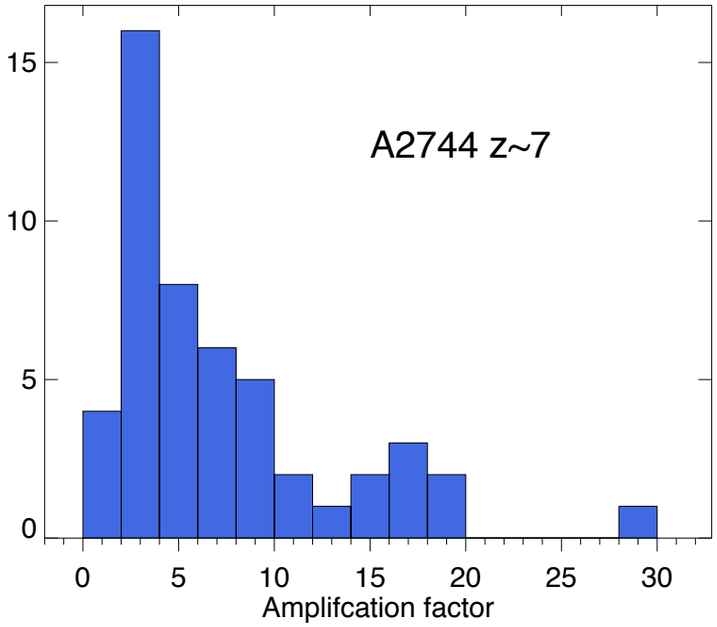
$$V_{eff} = \int_0^\infty \int_{\Omega > \Omega_{min}} \frac{dV_{com}}{dz}\, f(z, m, \mu)\; d\Omega(\mu, z)\; dz$$

The Faint-end of the UV LF at z>6

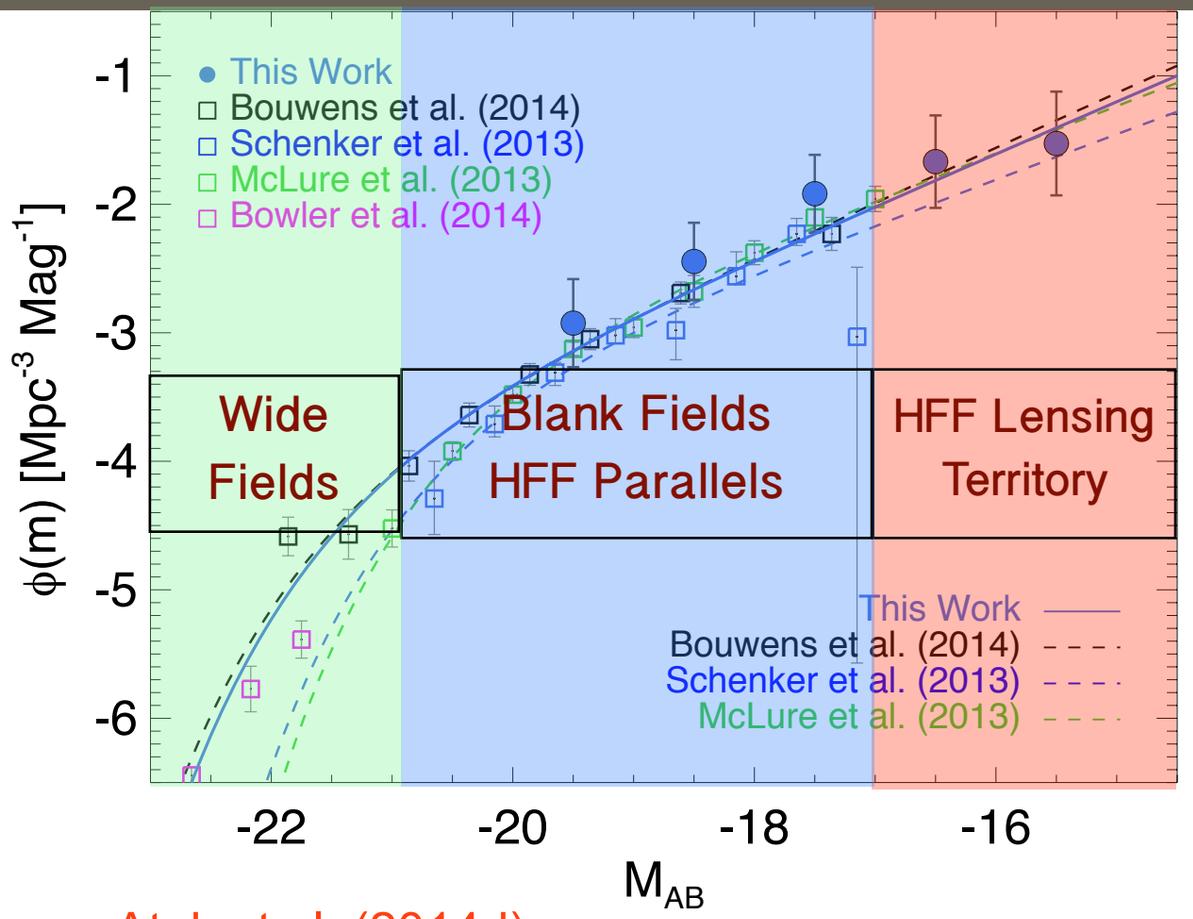
- Results in general agreement with blank fields
- Reaching down to $M_{abs,UV}$ ~ -15.5

this is 0.01L* at z=7

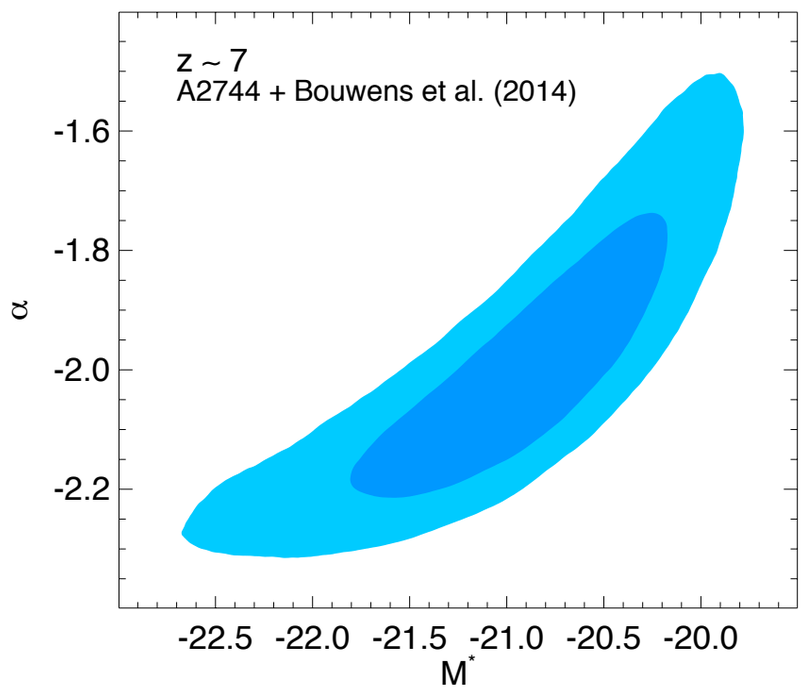
- Faint-end slope alpha=-2.01. The steep faint-end slope holds to very faint magnitudes
- **No sign of turnover in faint-end slope**



ref	**This work**	Bouwens et al. (2014)	Schenker et al. (2013)	Ishigaki et al. (2014)
α	**-2.01** ***(-0.28,+0.20)***	-2.0 ±0.14	-1.87 ±0.18	-2.10 (-0.15,+0.3)



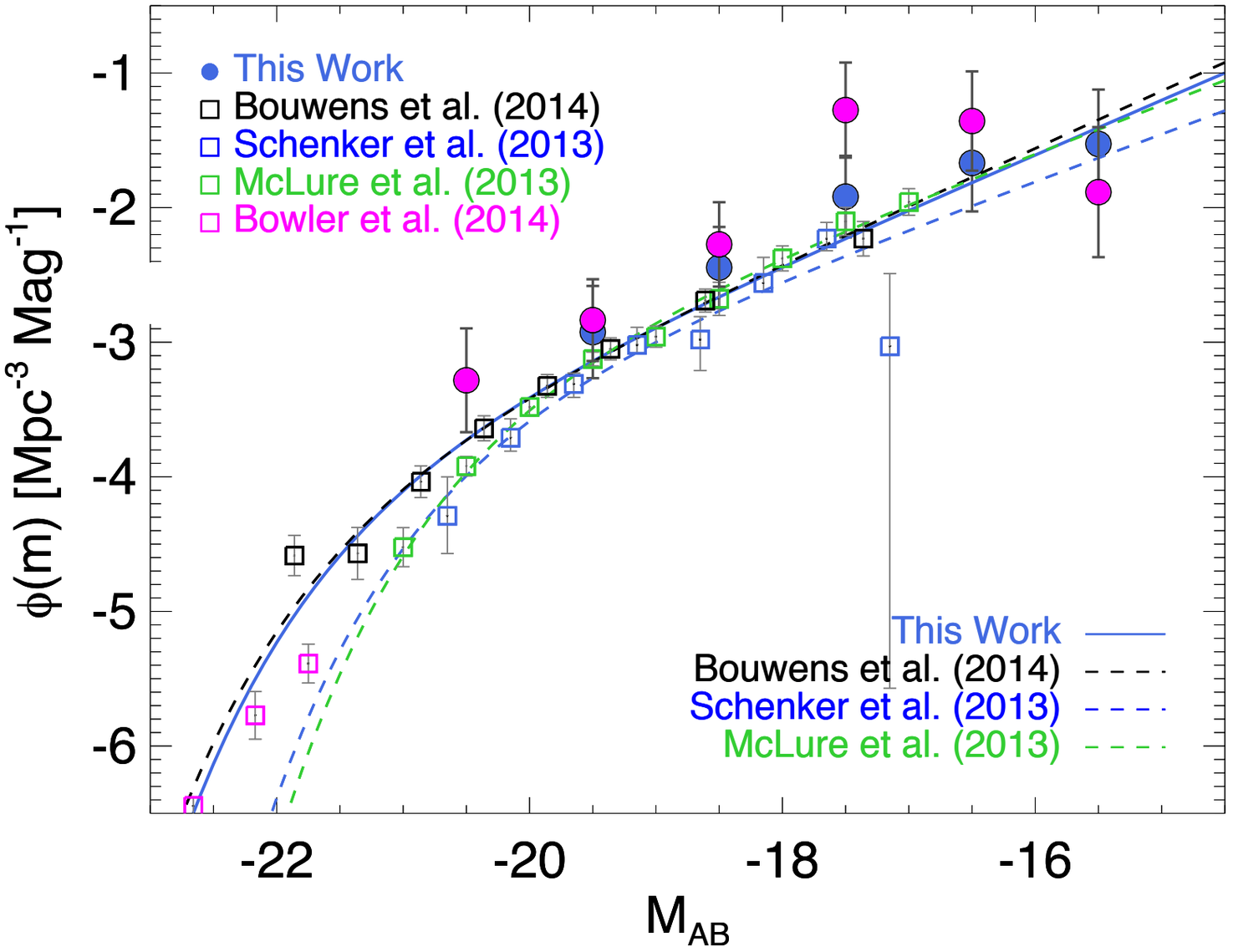
Atek et al. (2014d)



Lensing Model Uncertainties

- impact of model uncertainties on the UV LF
comparison between pre-HFF and HFF based model of A2744
=> complex interplay between magnification, survey area, completeness

Atek et al. (2014b,d)
Jauzac et al. 2014c
Richard et al. 2014a

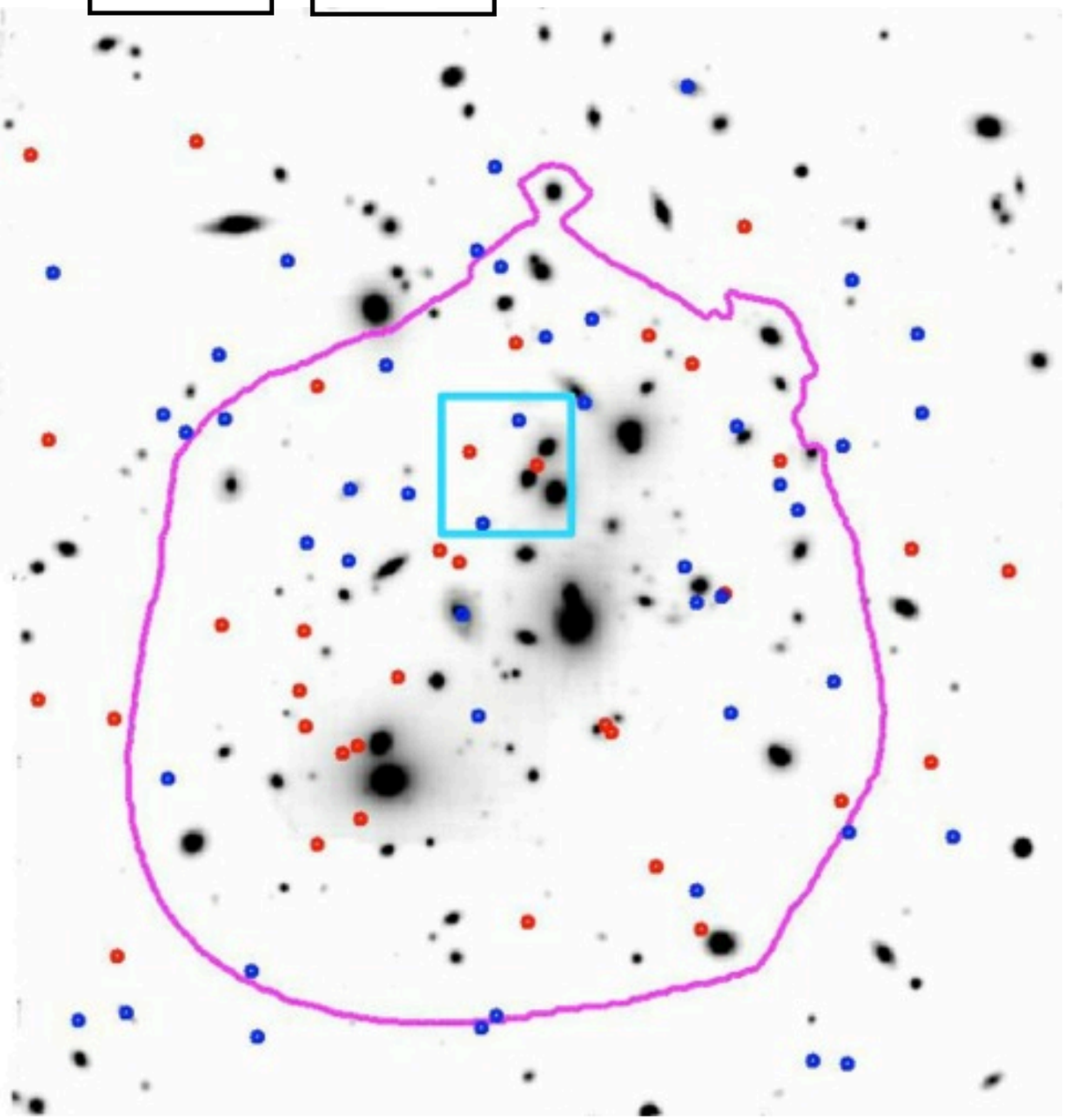


Importance of validating the lens model further:
improve modelling technique and lensing information (redshift)

Need For Spectroscopy (improving model)

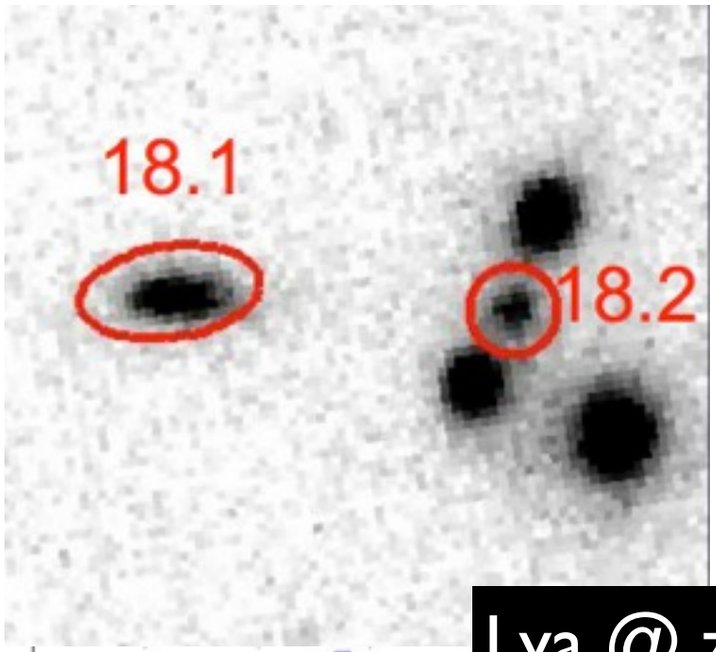
A2744 first analysis (Richard et al. in prep)

z<1.5 z>1.5

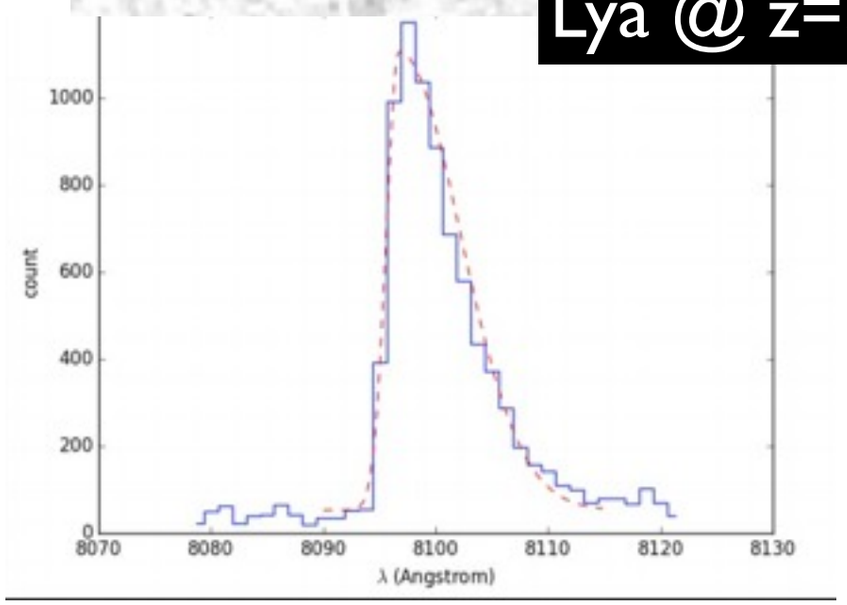


VLT/MUSE

83 spectroscopic redshifts



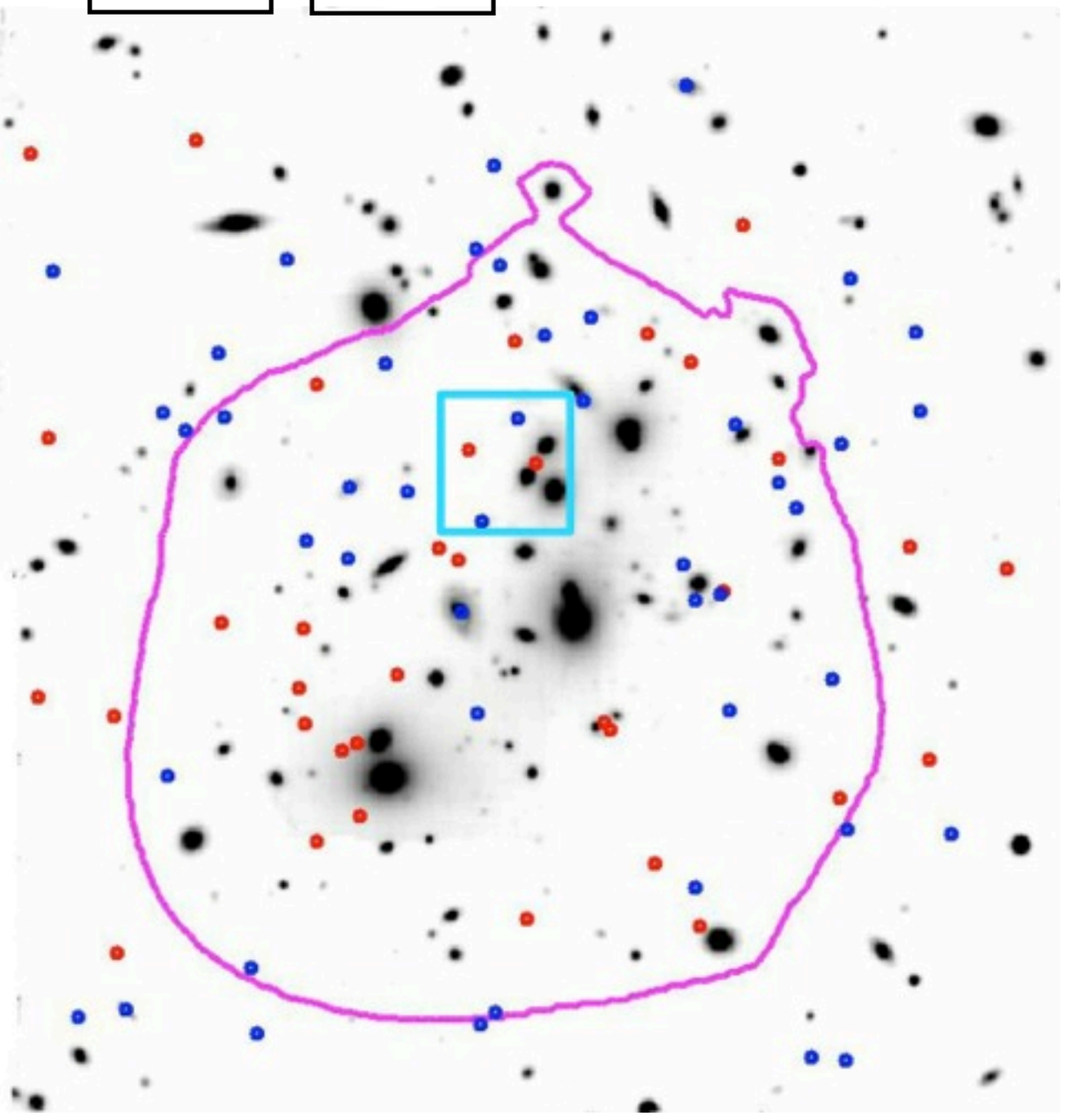
Lya @ z=5.66

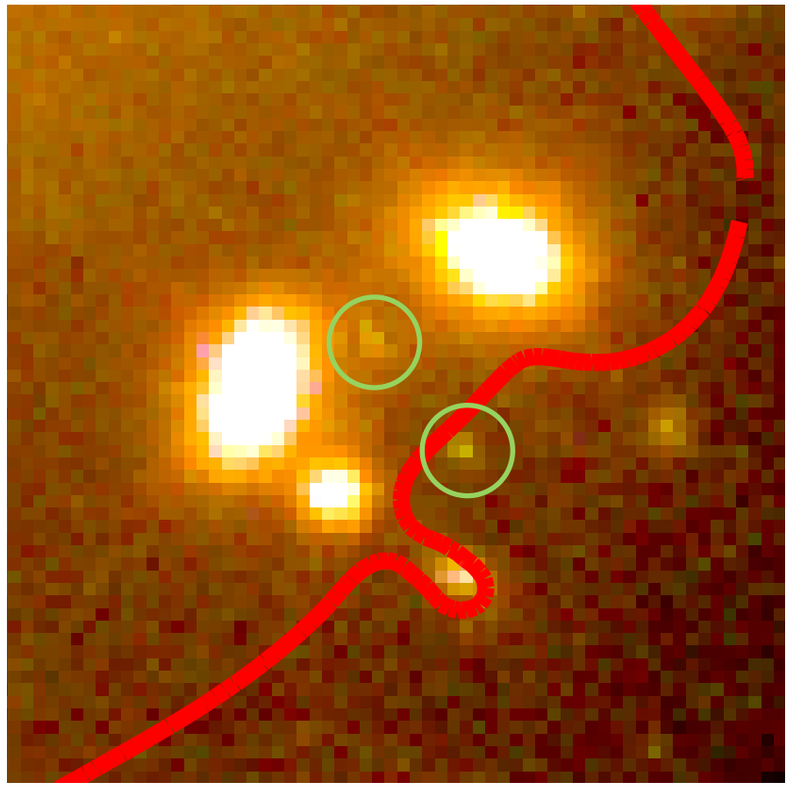


Need For Spectroscopy (hi-z confirmation)

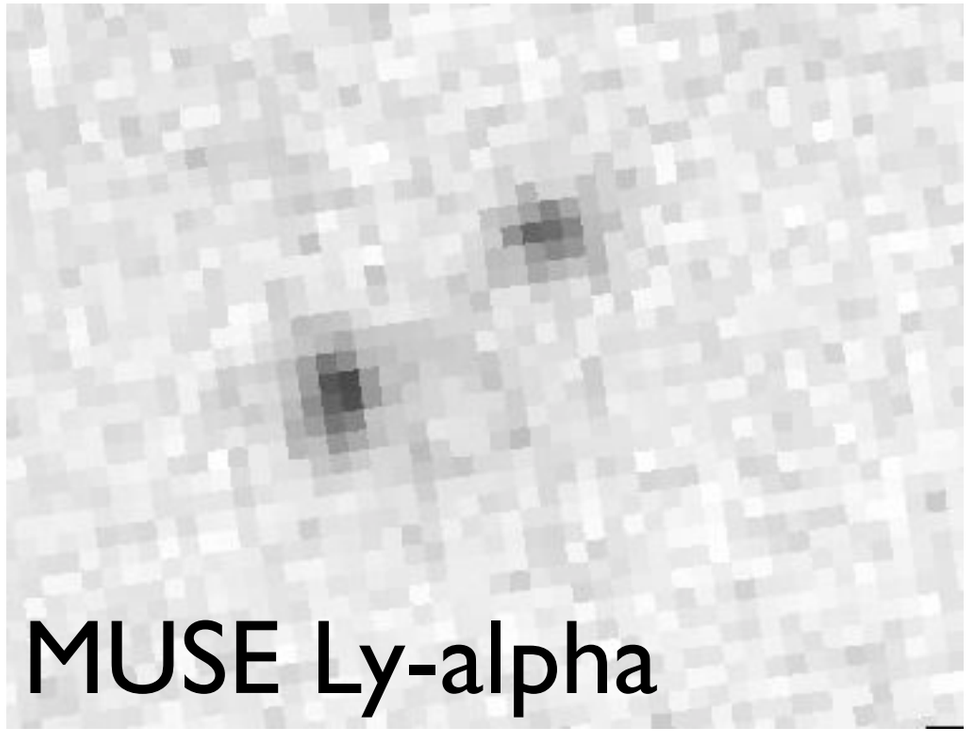
A2744 first analysis (Richard et al. in prep)

z<1.5 z>1.5





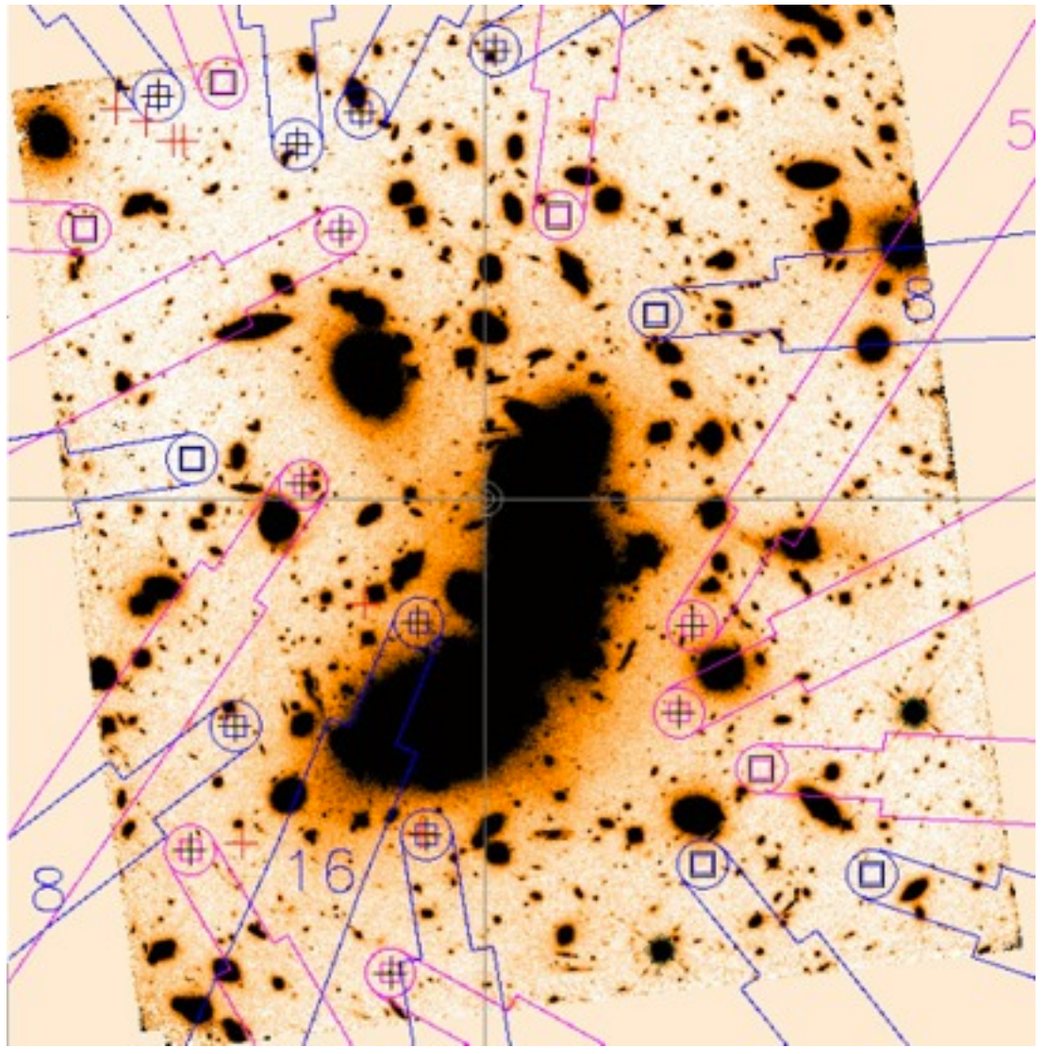
z~6 dropout with μ~30



Need For Spectroscopy

VLT KMOS IN PROGRESS
SPECTROSCOPY OF A2744, A1689, AS1063

Richard et al., Atek et al. in prep



- Redshift confirmation of High-z dropout galaxies at z>6

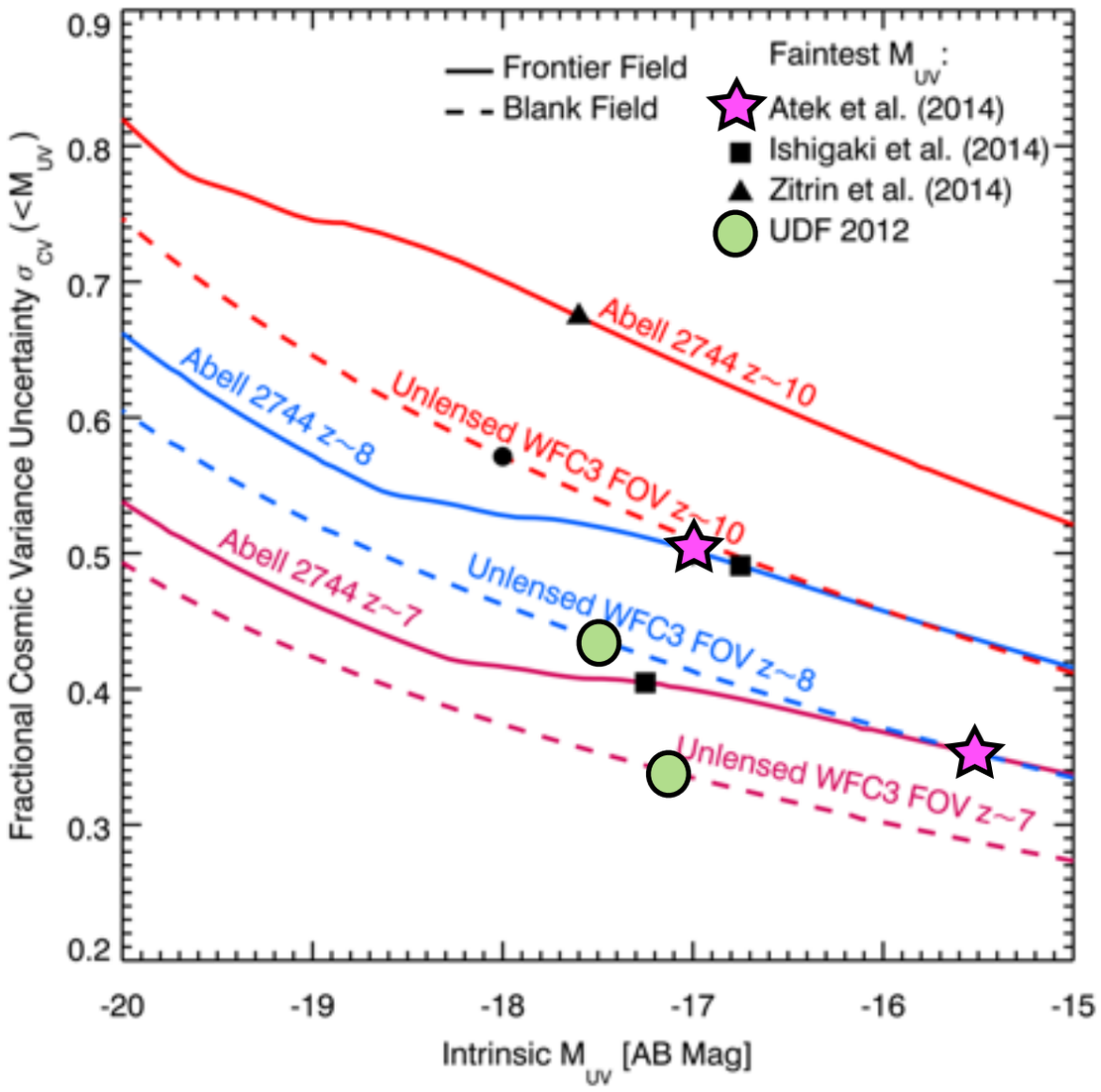
- Emission line measurements of multiple-image systems at z=1-3

- Spatially-resolved studies of star formation in lensed galaxies

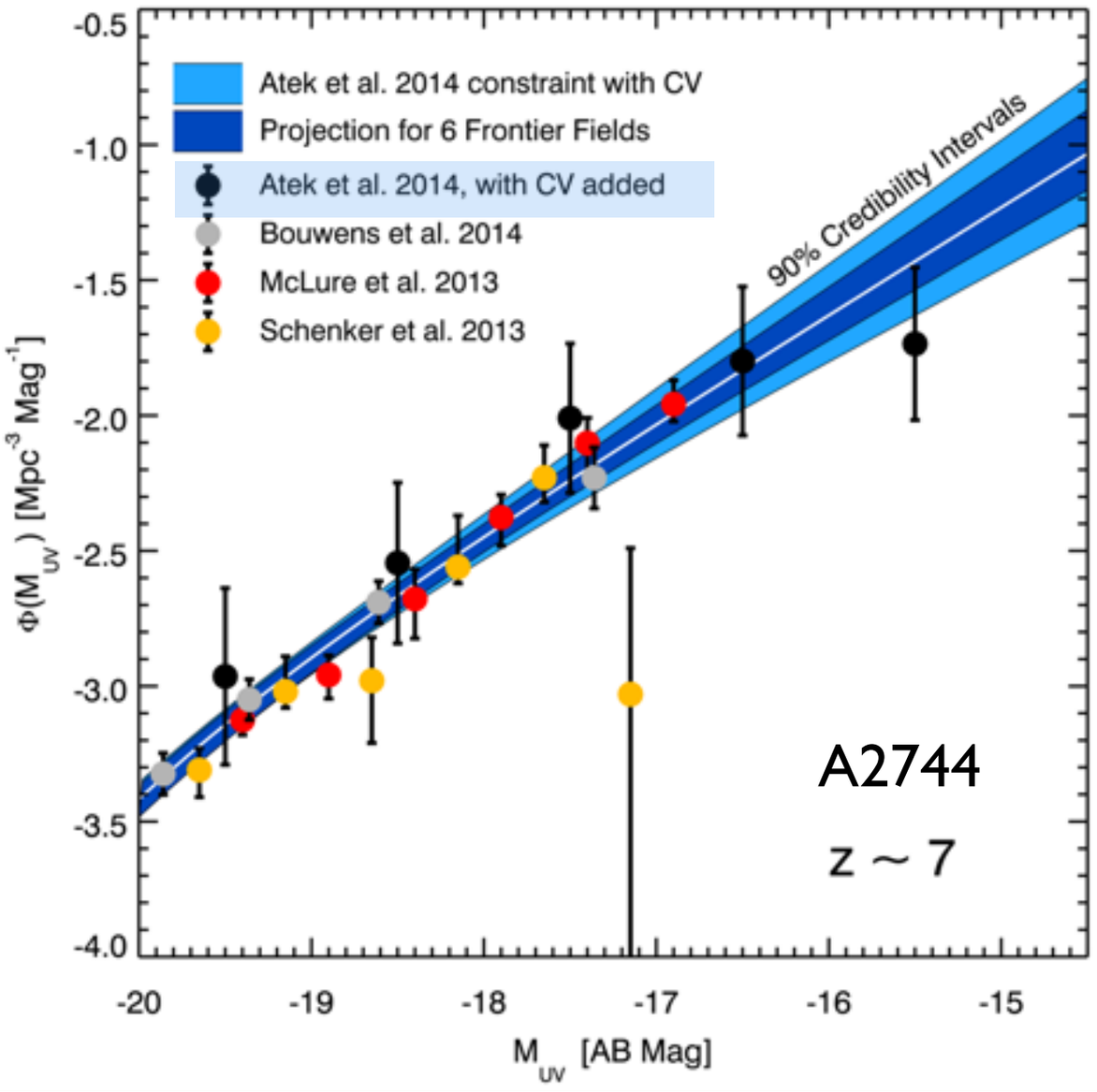
The Faint-end of the UV LF at z>6

- **cosmic variance** increases in lensed fields
- but **lensing probes fainter galaxies**
- **at z~7, small CV difference** between UDF and A2744

Robertson et al. (2014)



- z~7 UV LF projection for 6 Frontier Fields
- down to 0.05 precision on faint-end slope
- 30% uncertainty on the UV luminosity density

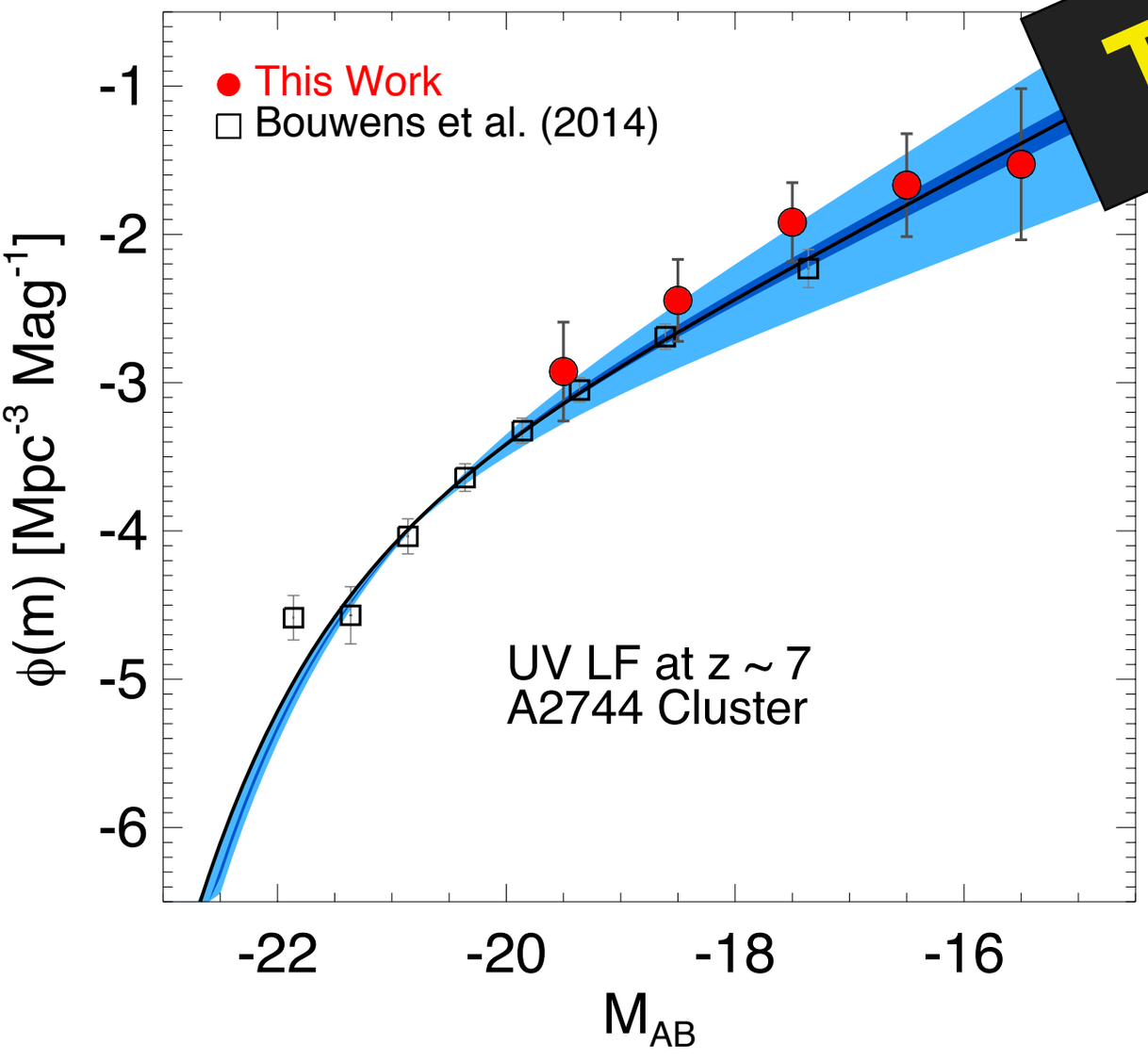


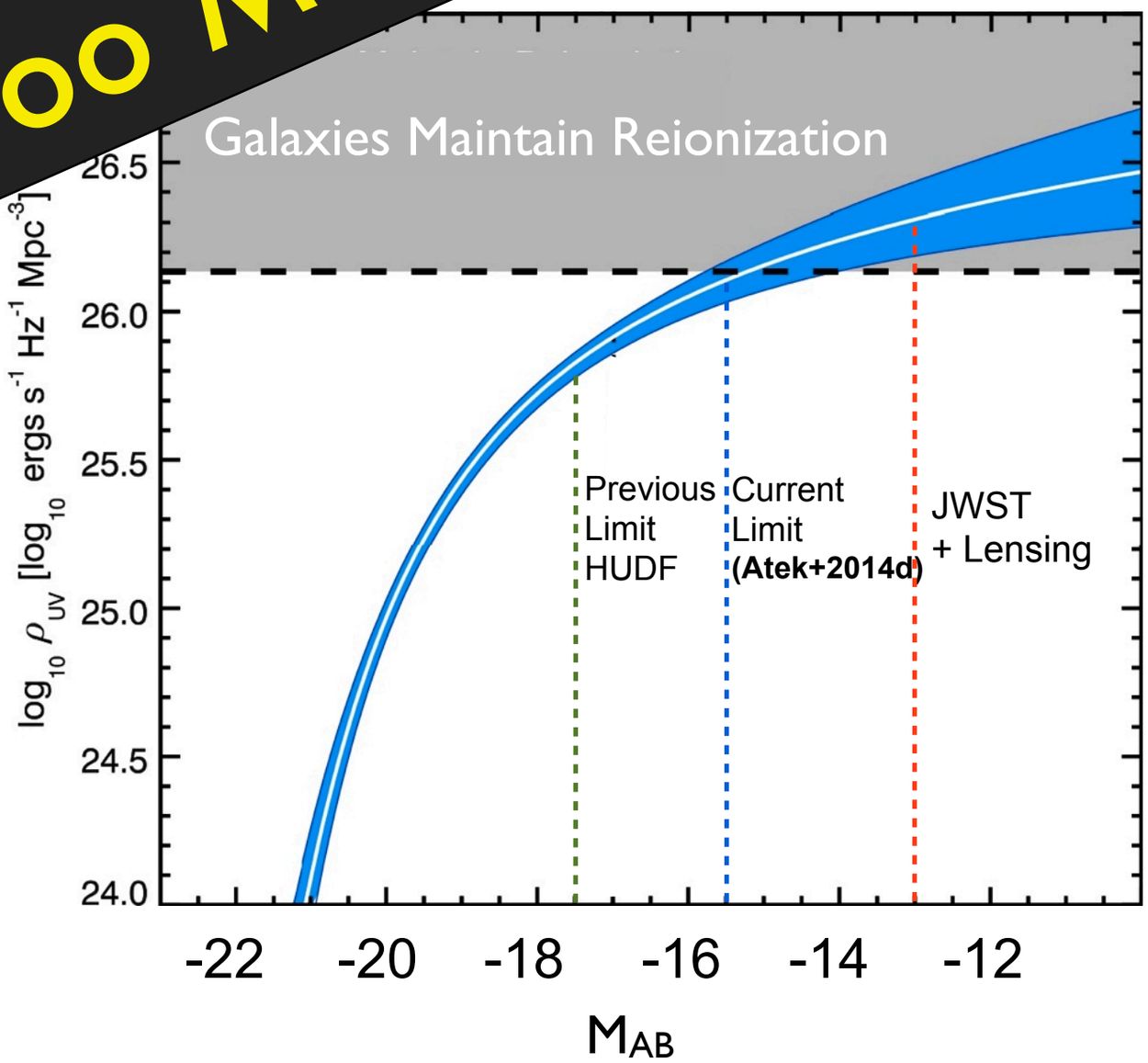
UV Luminosity density and Reionization

- z~7 UV LF projection for 6 Frontier Fields
- down to 0.05 precision on faint-end slope
- 30% uncertainty on the UV luminosity density

Too Many to Fail ?

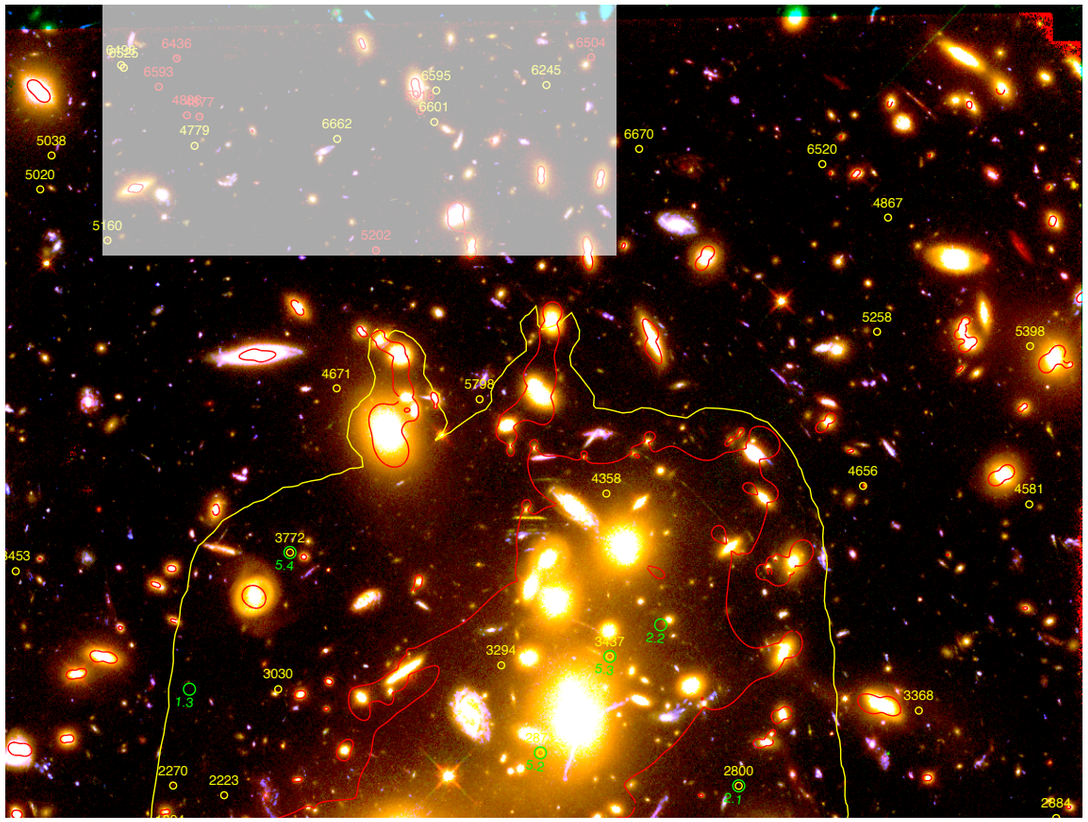
Robertson et al. (2013)

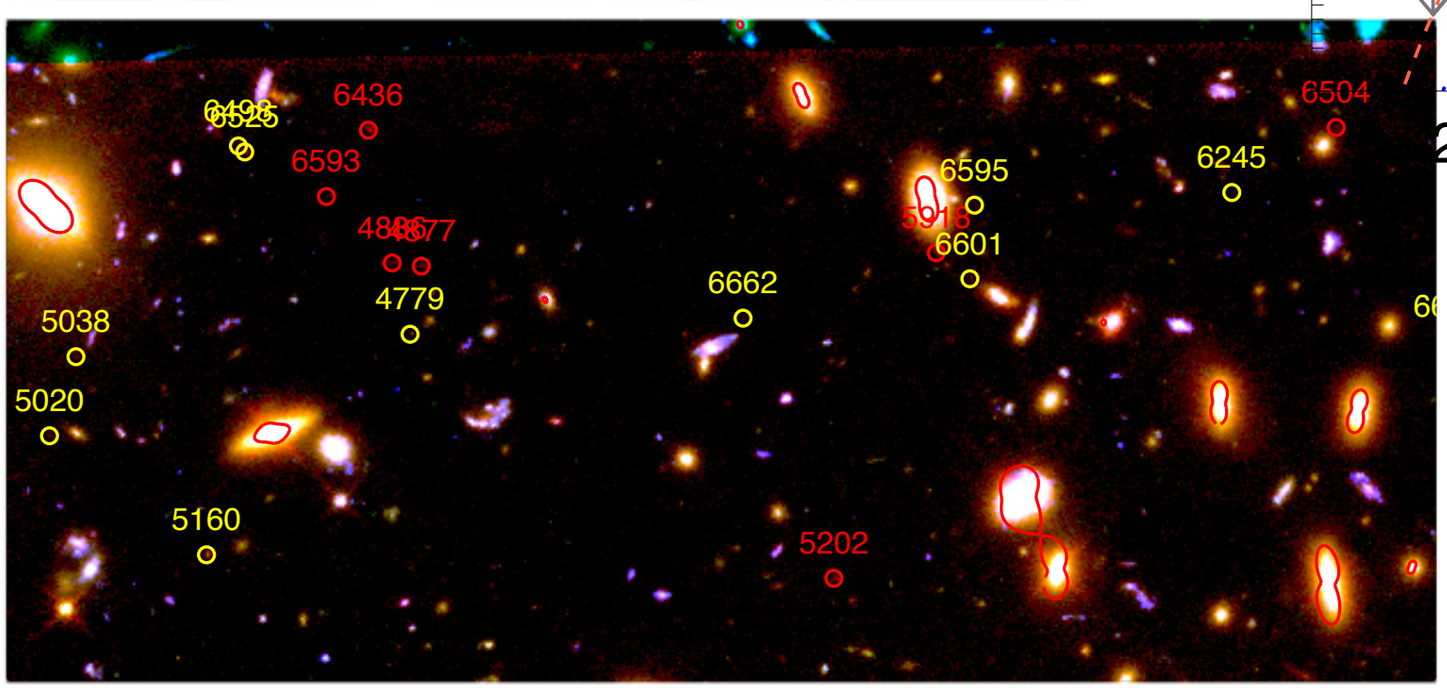


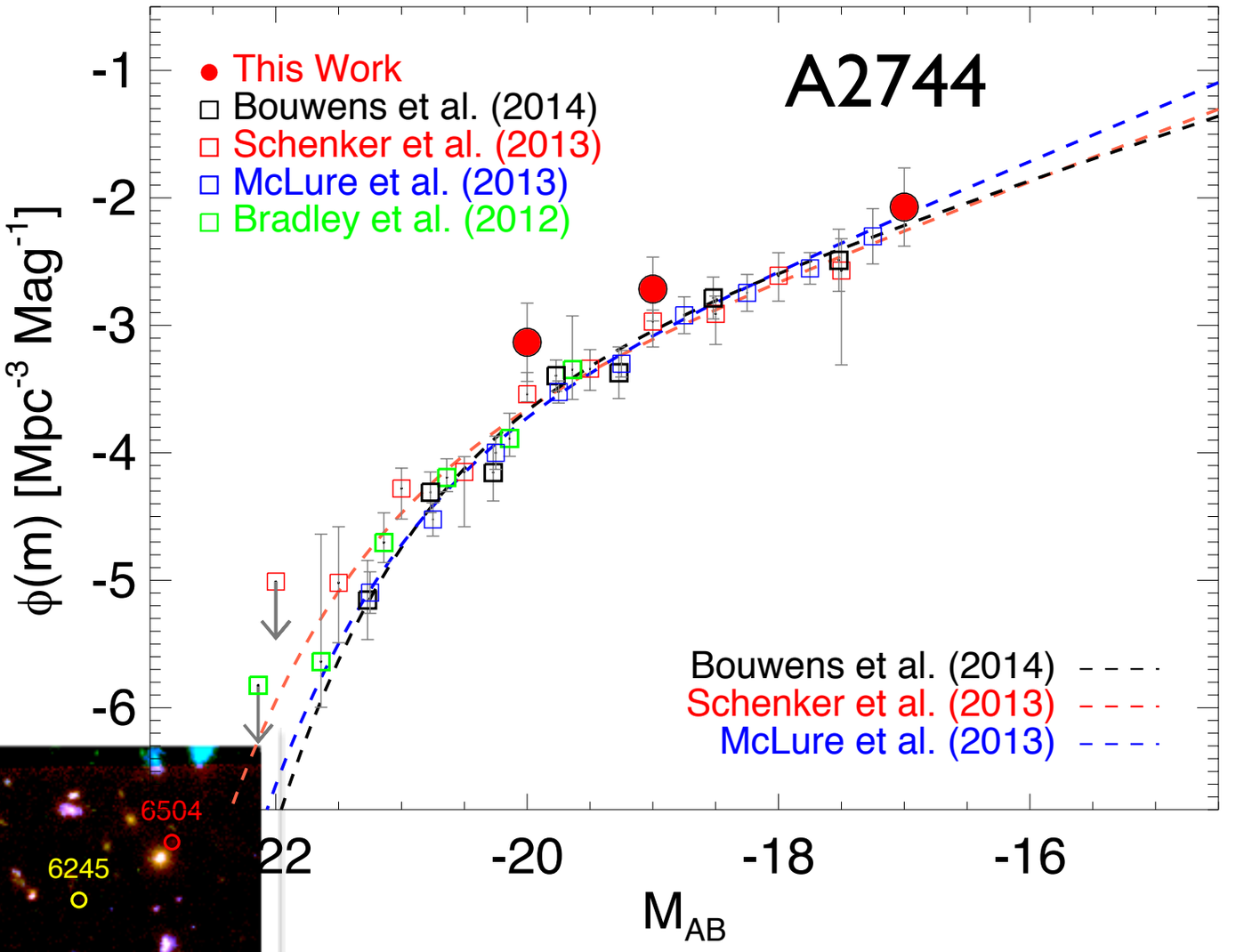


The Faint-end of the UV LF at z>8

Work in progress - using the first 4 HFF clusters ...

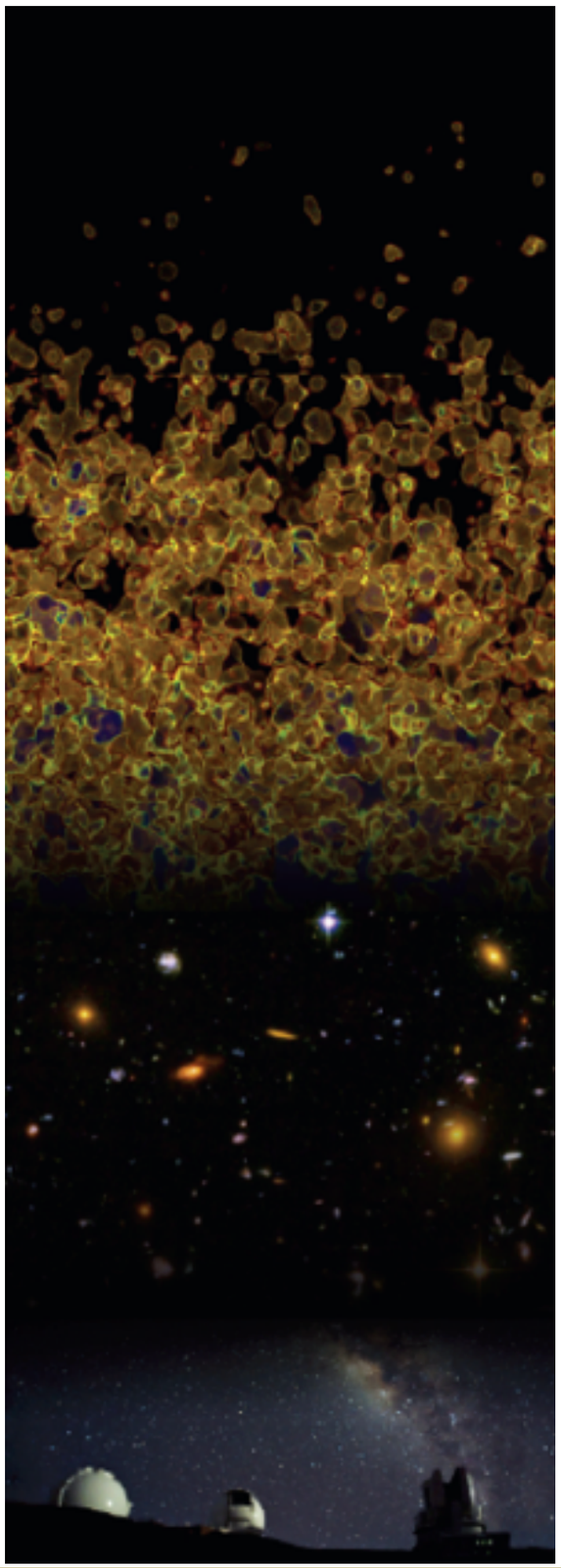






Check also
Derek McLeod presentation

Summary



- **Gravitational lensing** helps reach the faint galaxies likely responsible for cosmic re-ionisation

- **Galaxy UV LF down to Muv =-15.5 at z=7.** This is about 2 mag deeper than the deepest observations in blank fields

- **The faint-end slope remains steep (alpha =-2.01)** down to very faint luminosities of 0.01L*

- **Need for a better understanding of systematic uncertainties,** cosmic variance, and the differences between lensing models (more spectroscopy needed)

- **The full HFF sample of 6 clusters will reduce uncertainties on the integrated UV luminosity density, important to determine whether galaxies can effectively re-ionise the Universe**