Probing the Epoch of Reionization with Gravitational Lensing

Hakim Atek

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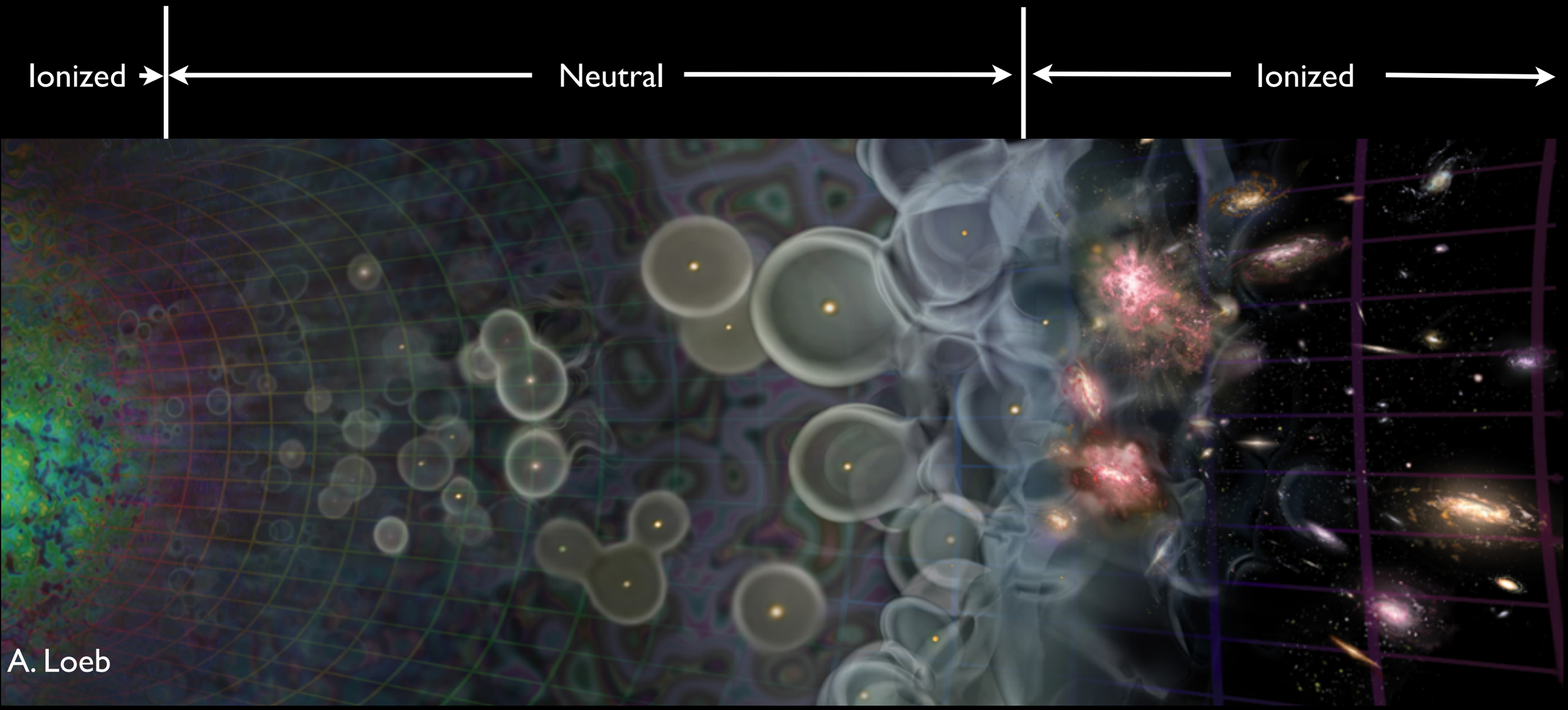
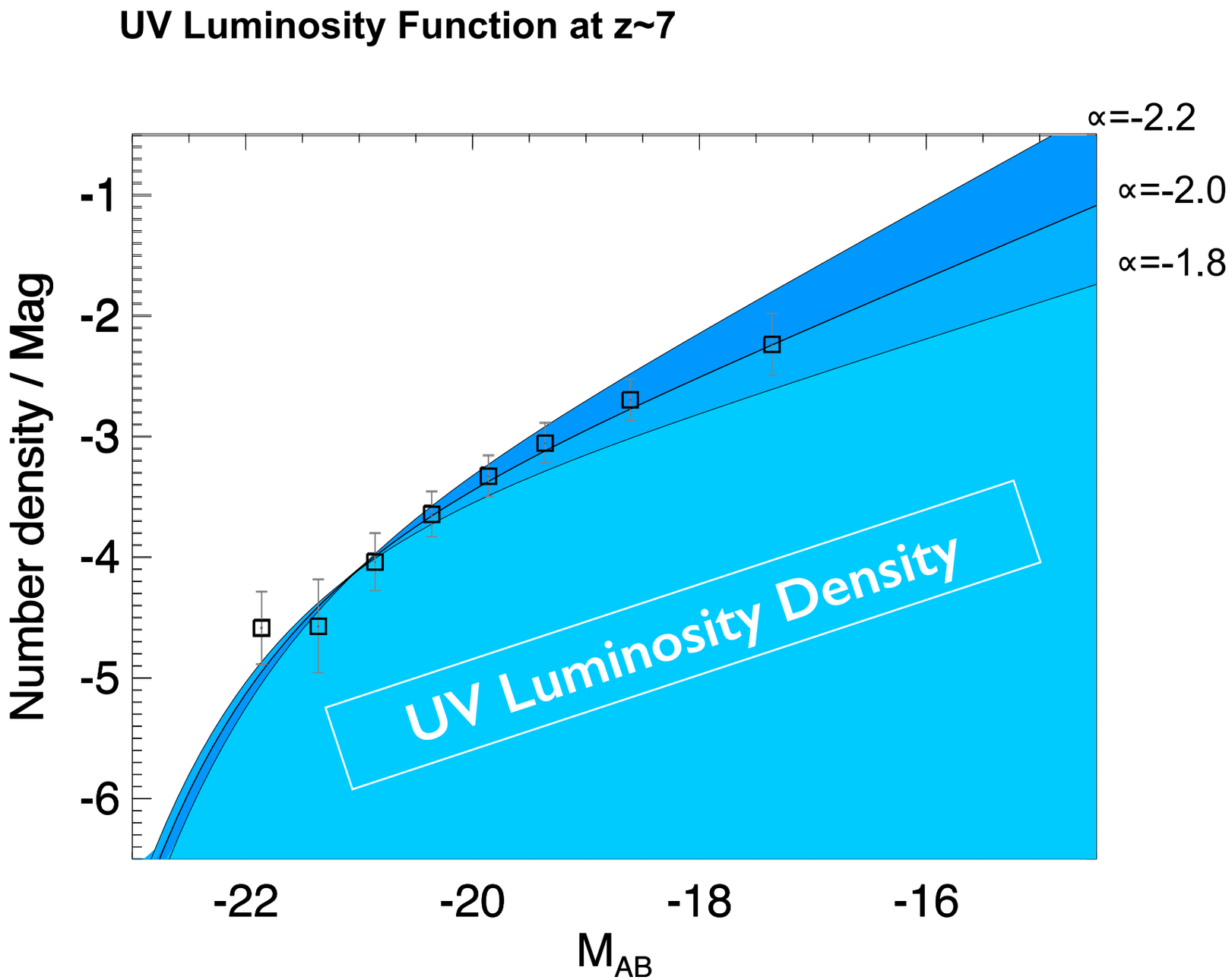
Yale University


Ionized
Neutral
Ionized
A. Loeb
z=1100
z~30
z=10
z=6
z=2
z=0
CMB
Dark Ages
Epoch of Reionization

The UV Luminosity Function



change in the faint-end slope 1sigma

Change in UV Luminosity Density by a factor of 5

Constraints from Blank Field Surveys

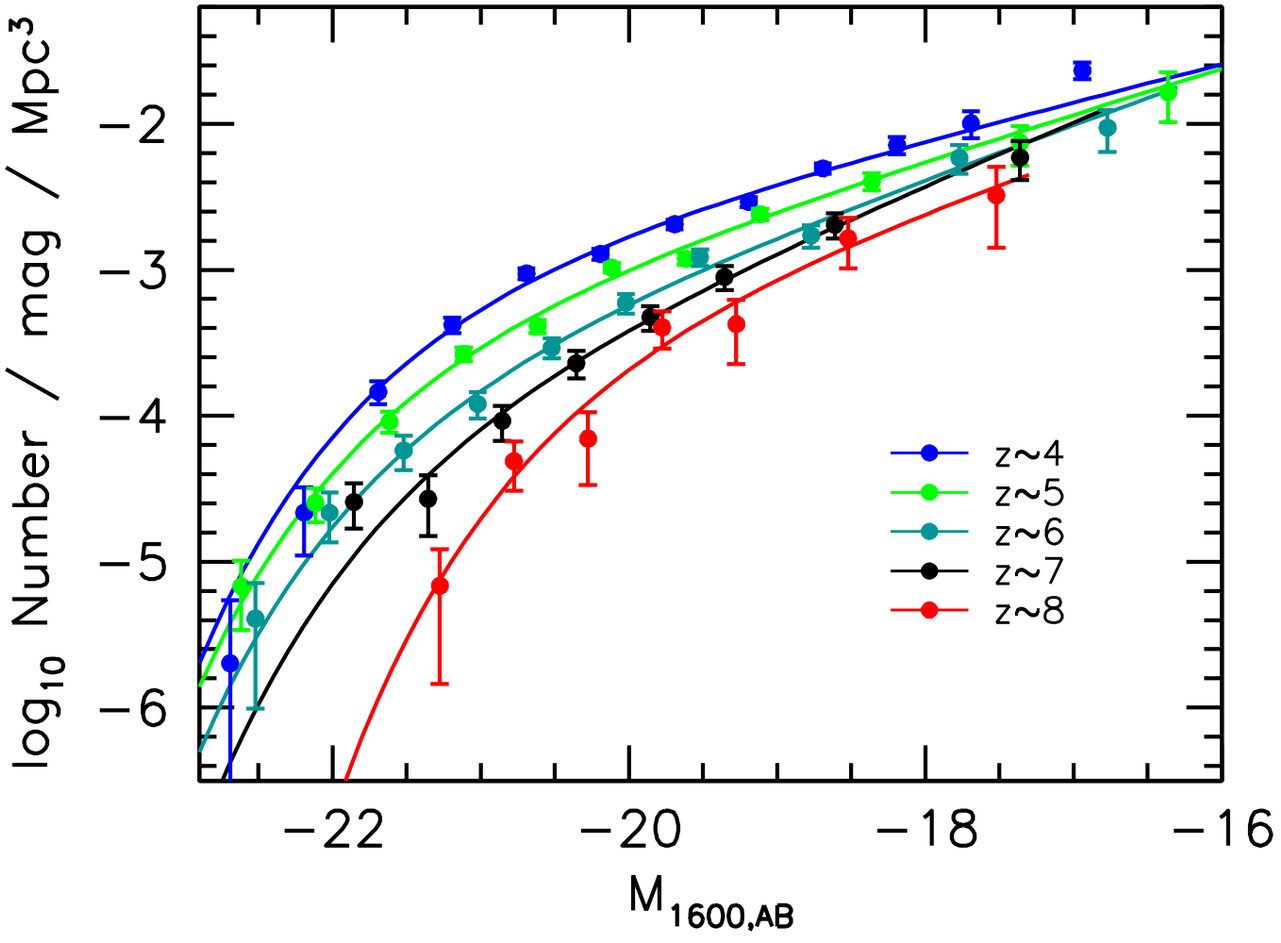
more than 800 galaxies at z >7
from all HST legacy fields

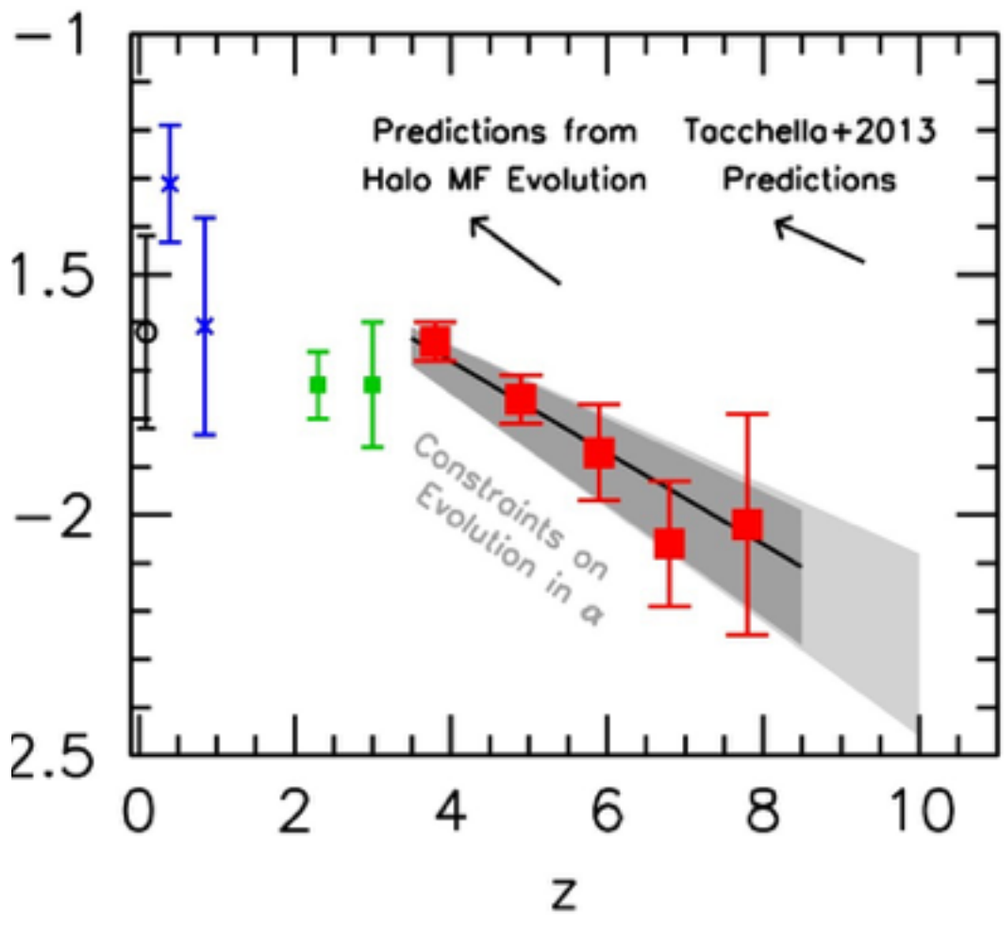
see Rychard's talk

better constraints on the overall
shape of the luminosity function.

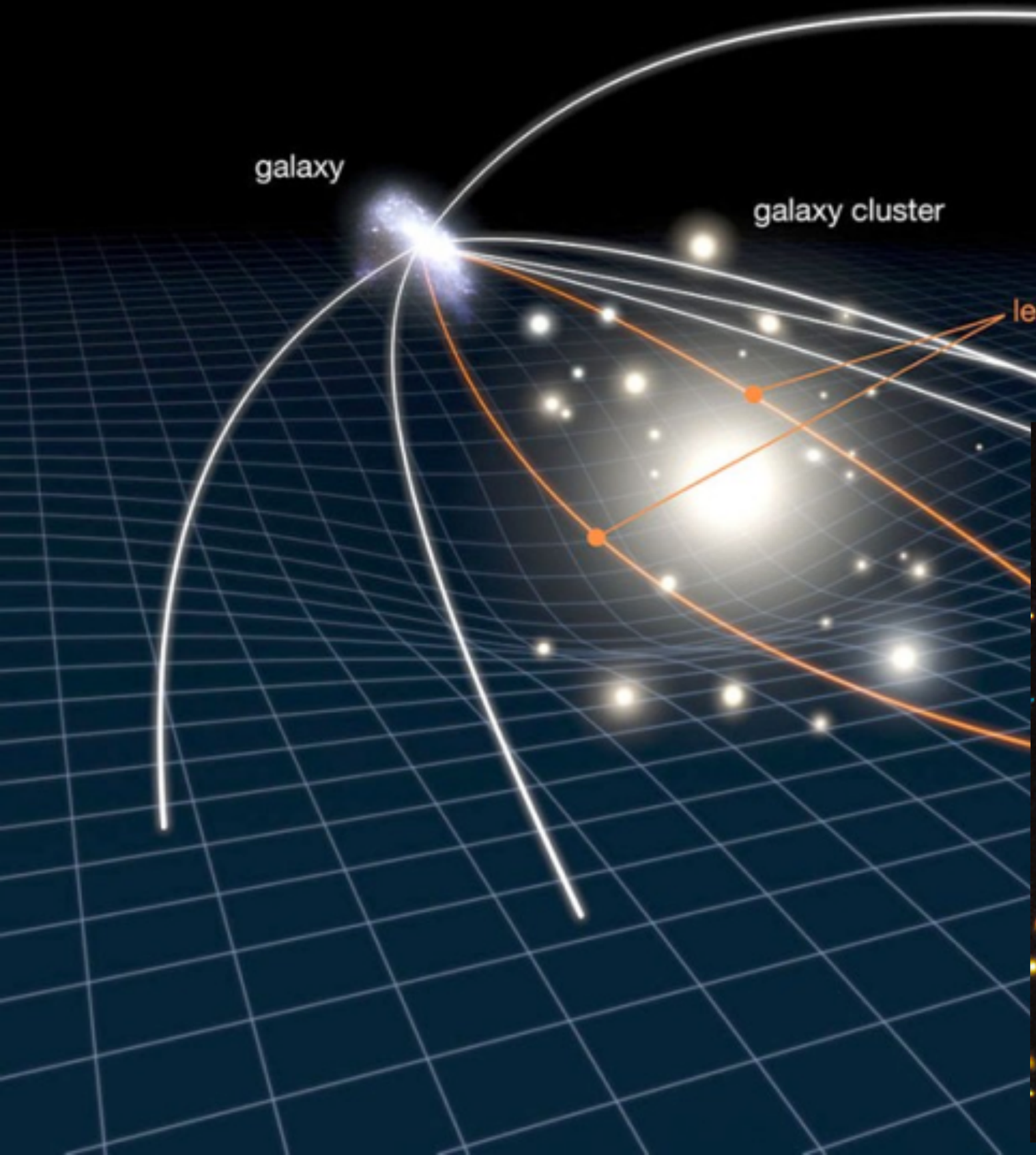
redshift evolution of the
UV LF faint-end slope

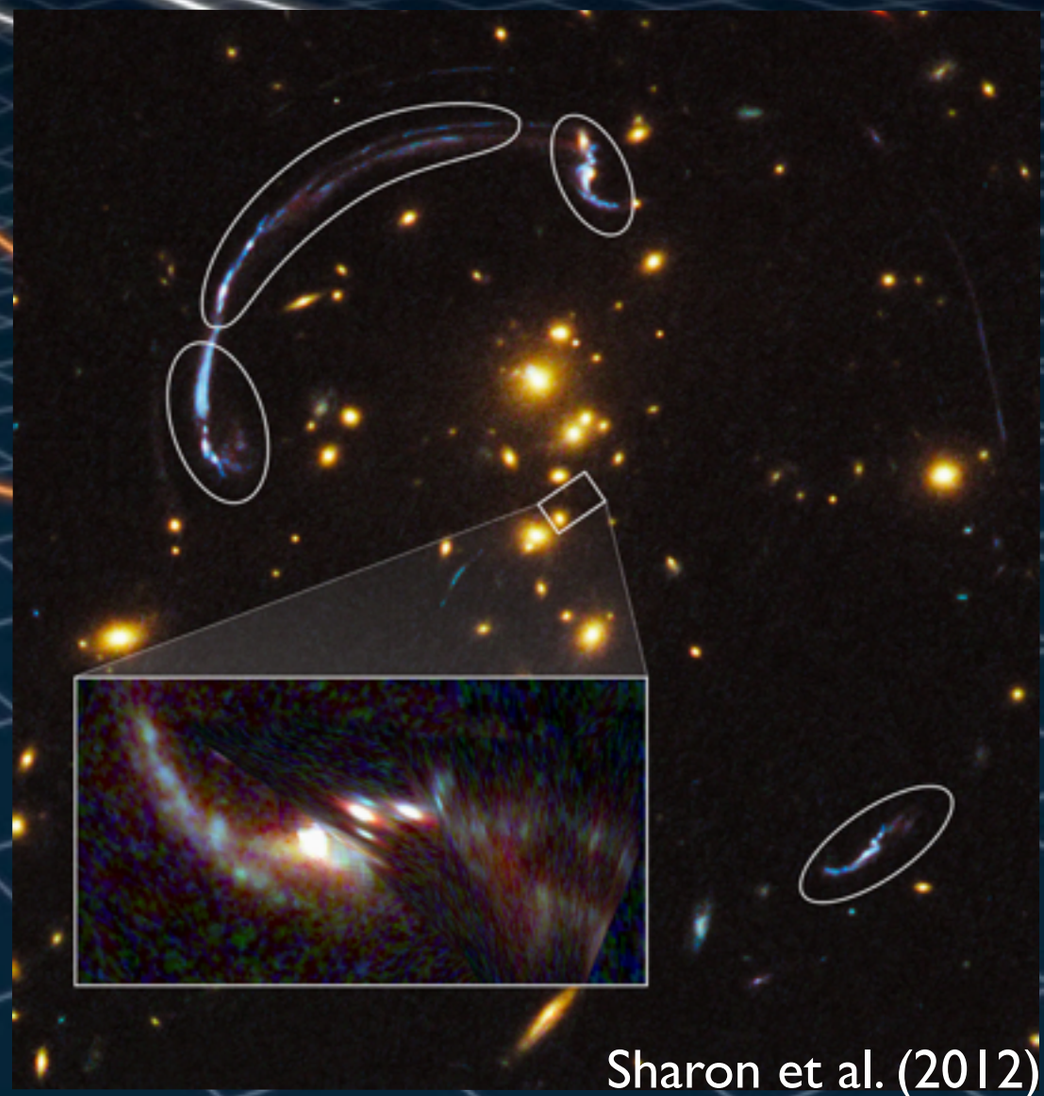
Bouwens et al. (2014)





Cosmic Telescopes





Sharon et al. (2012)

The Hubble Frontier Fields

Slide courtesy J. Lotz

6 strong-lensing clusters

+ 6 adjacent parallel fields

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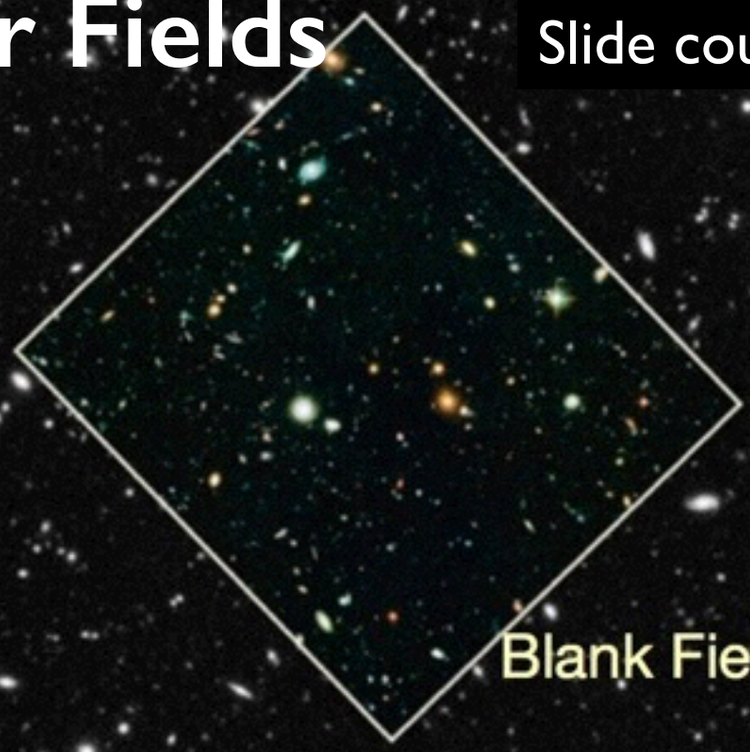
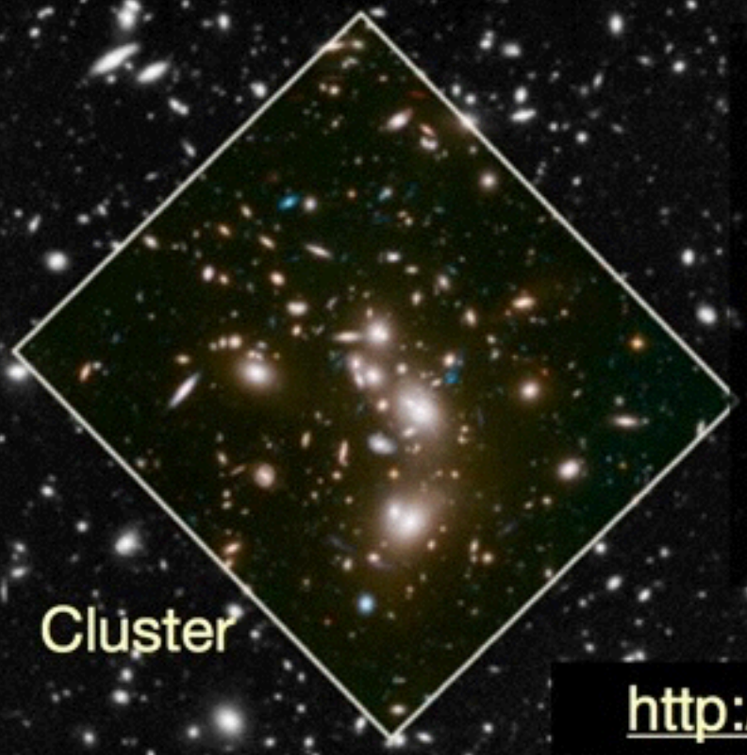
140 HST DD orbits per pointing

ACS/ WFC3-IR in parallel

~29th ABmag in 7 bands





2 clusters per year x 3 years

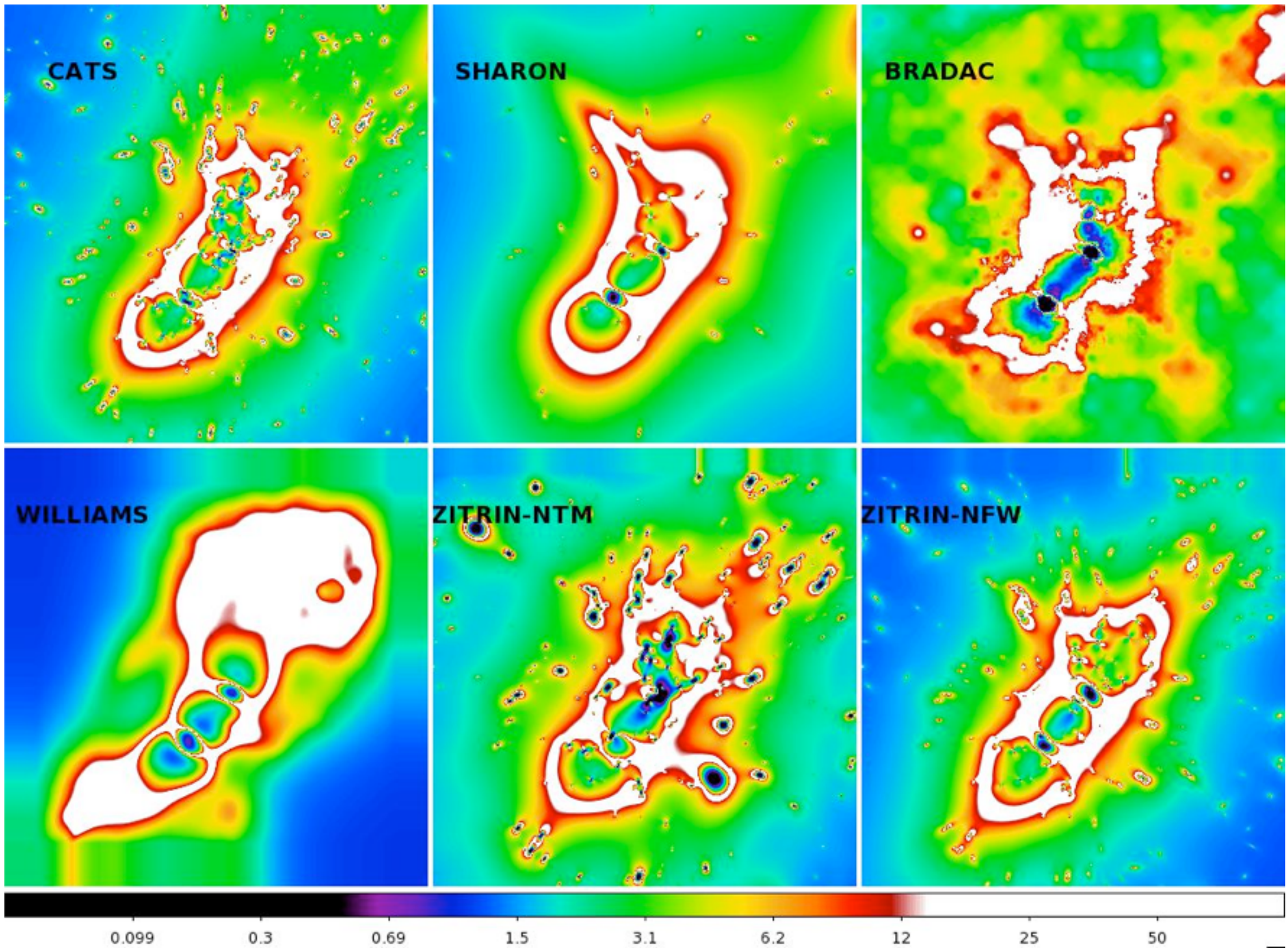
→ 840 total orbits

1000 hours Spitzer DD time for

~26.5 ABmag in IRAC 3.6, 4.5 μm

http://www.stsci.edu/hst/campaigns/frontier-fields/

Lensing Model



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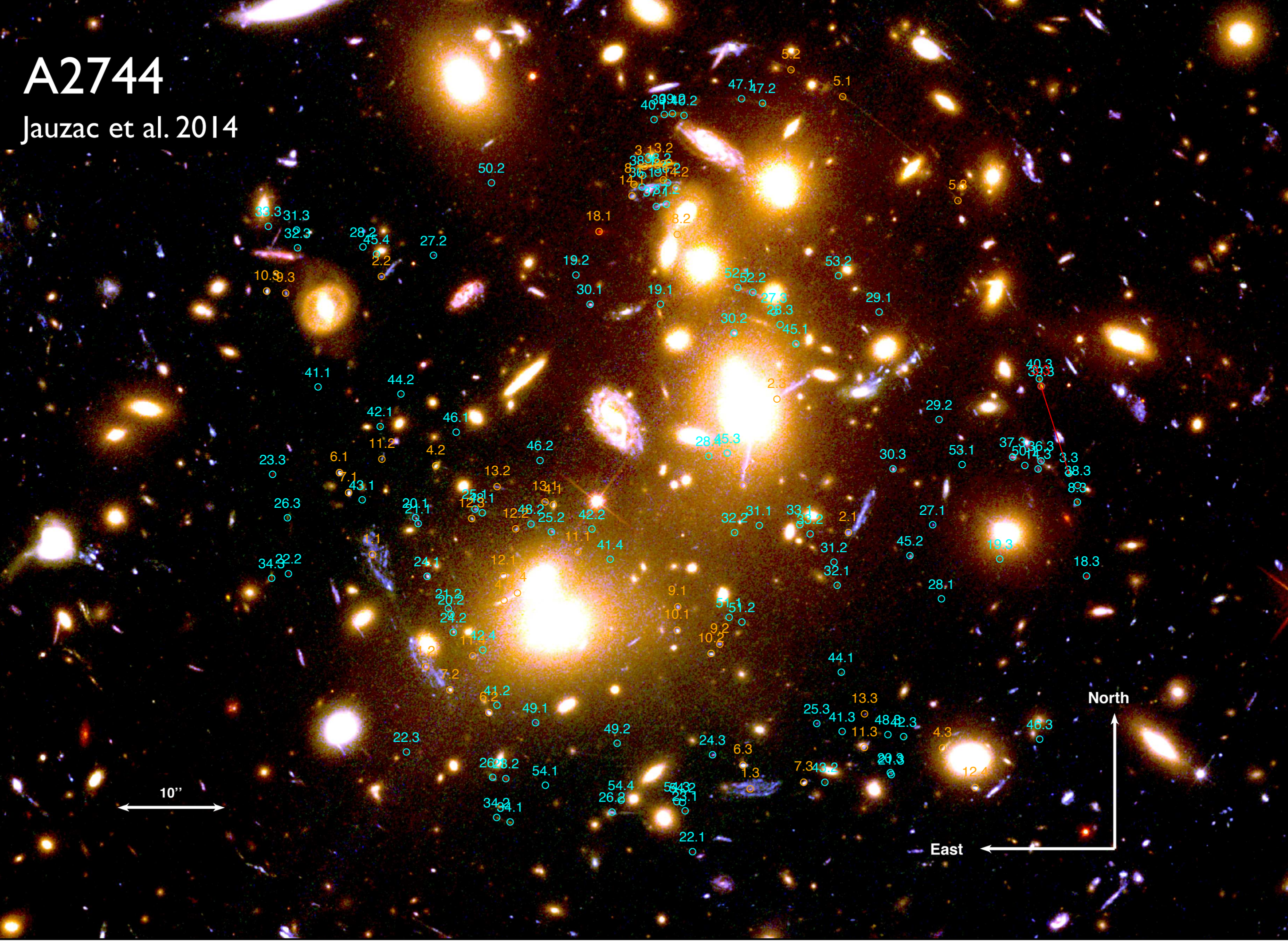
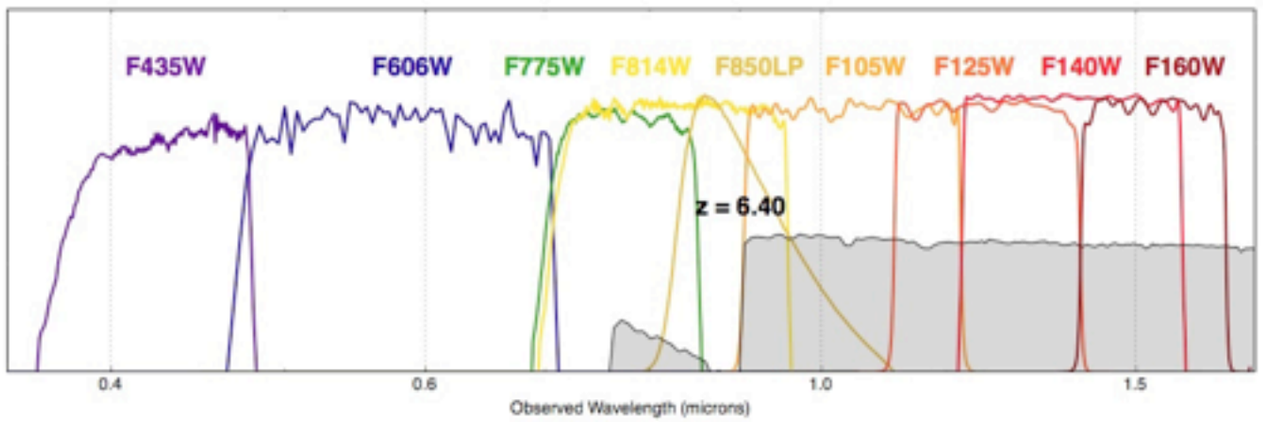
Jauzac et al. 2014

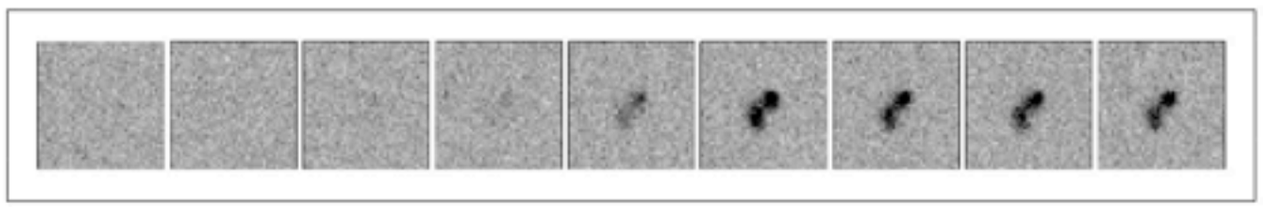


High-z Candidate selection

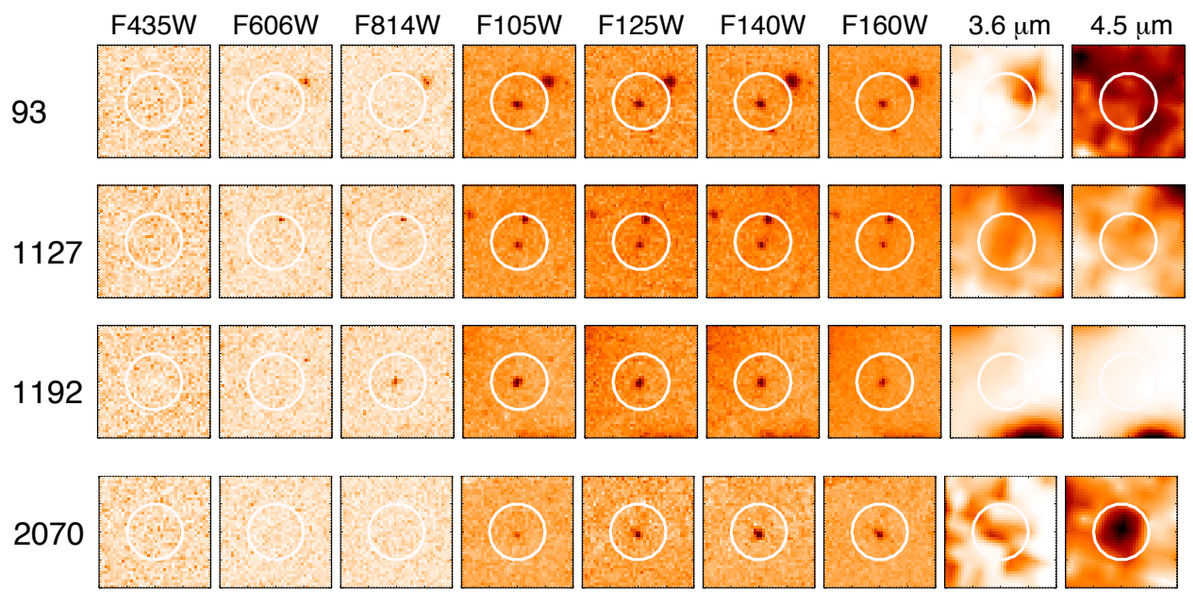
from the XDF team

Lyman Break Selection

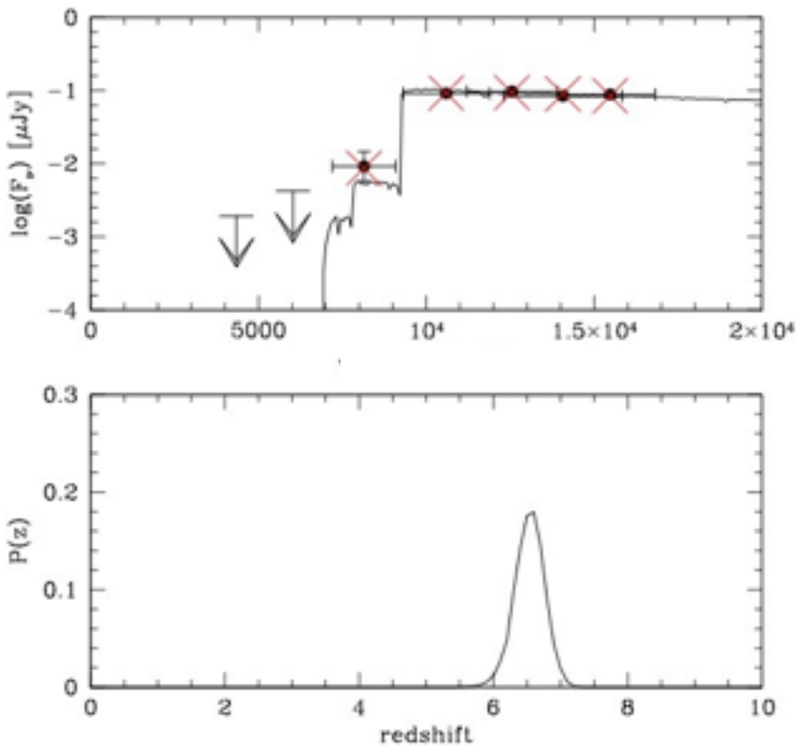




Atek et al. (2014b)

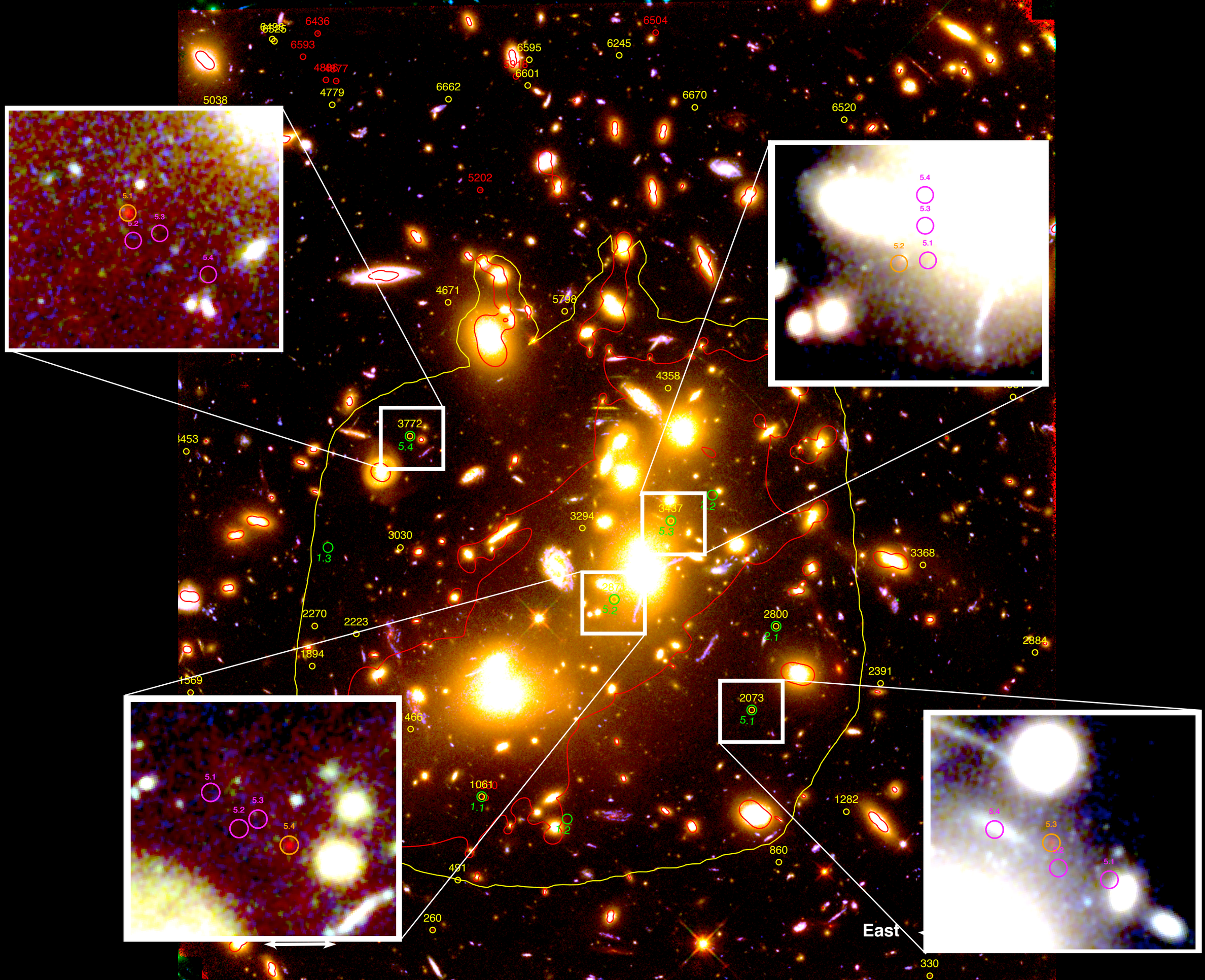


Dropout candidates at z>6



Photometric Redshifts

Fitting galaxy SED templates with stellar population models

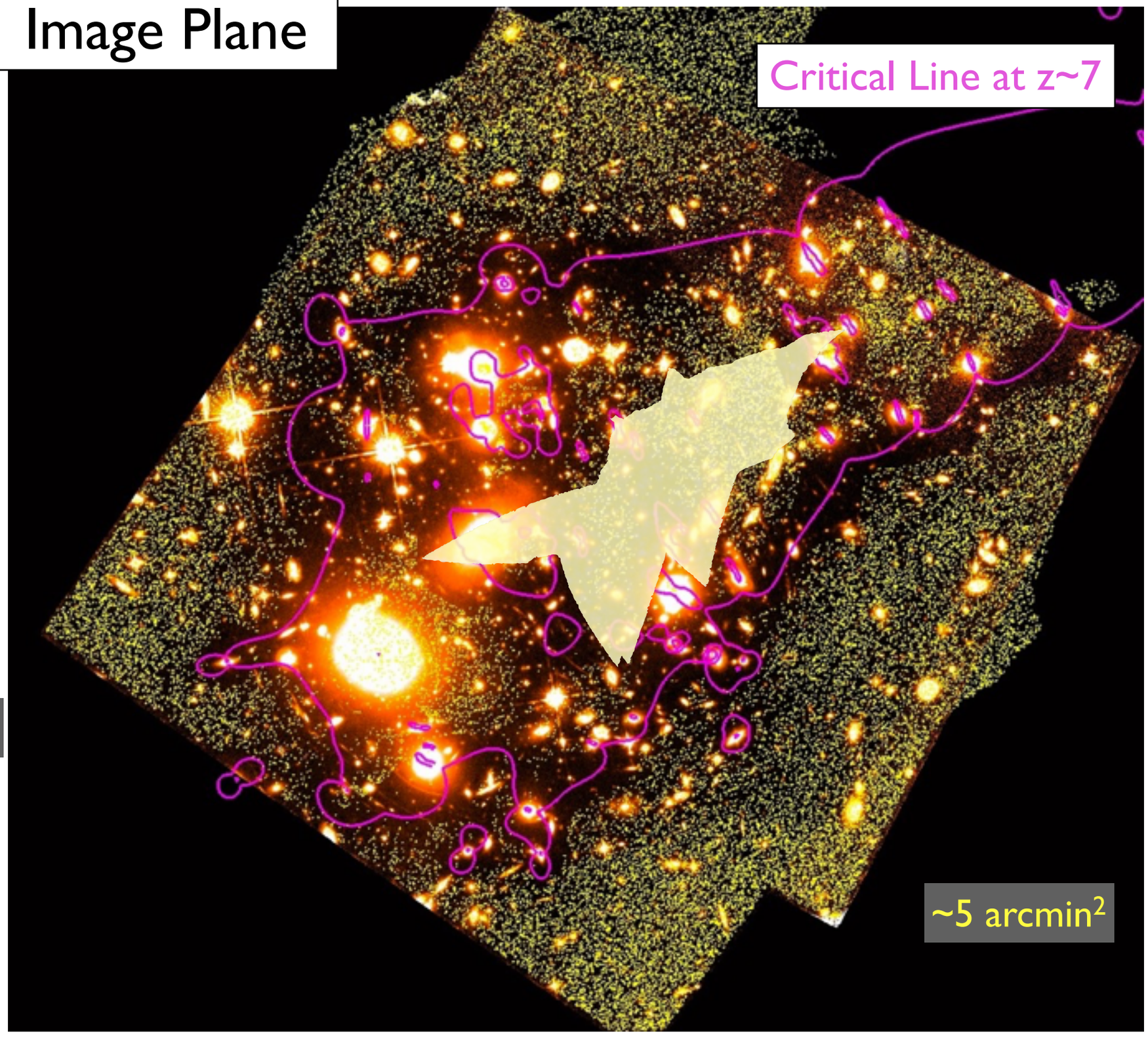

6436
6504
6593
6595
6245
4779
6662
6601
6670
6520
5038
5202
4671
5798
4358
3772
5.4
3437
5.3
3294
3030
1.3
3368
2270
2223
5.2
2800
2.1
1894
2884
1569
2391
2073
5.1
466
1061
1.1
1282
860
491
260
East
330
5.1
5.2
5.3
5.4

Completeness Simulations in the Source Plane

Source Plane

0.6 arcmin^2

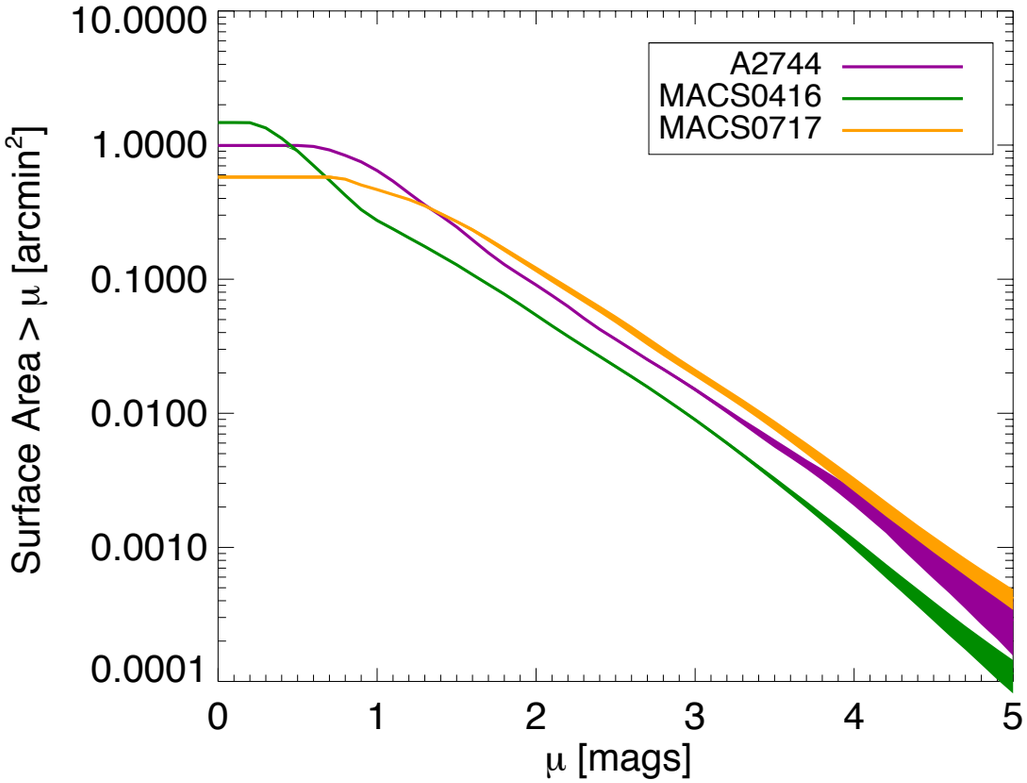
Image Plane



The UV Luminosity Function at z>6

Luminosity distribution of the sources:

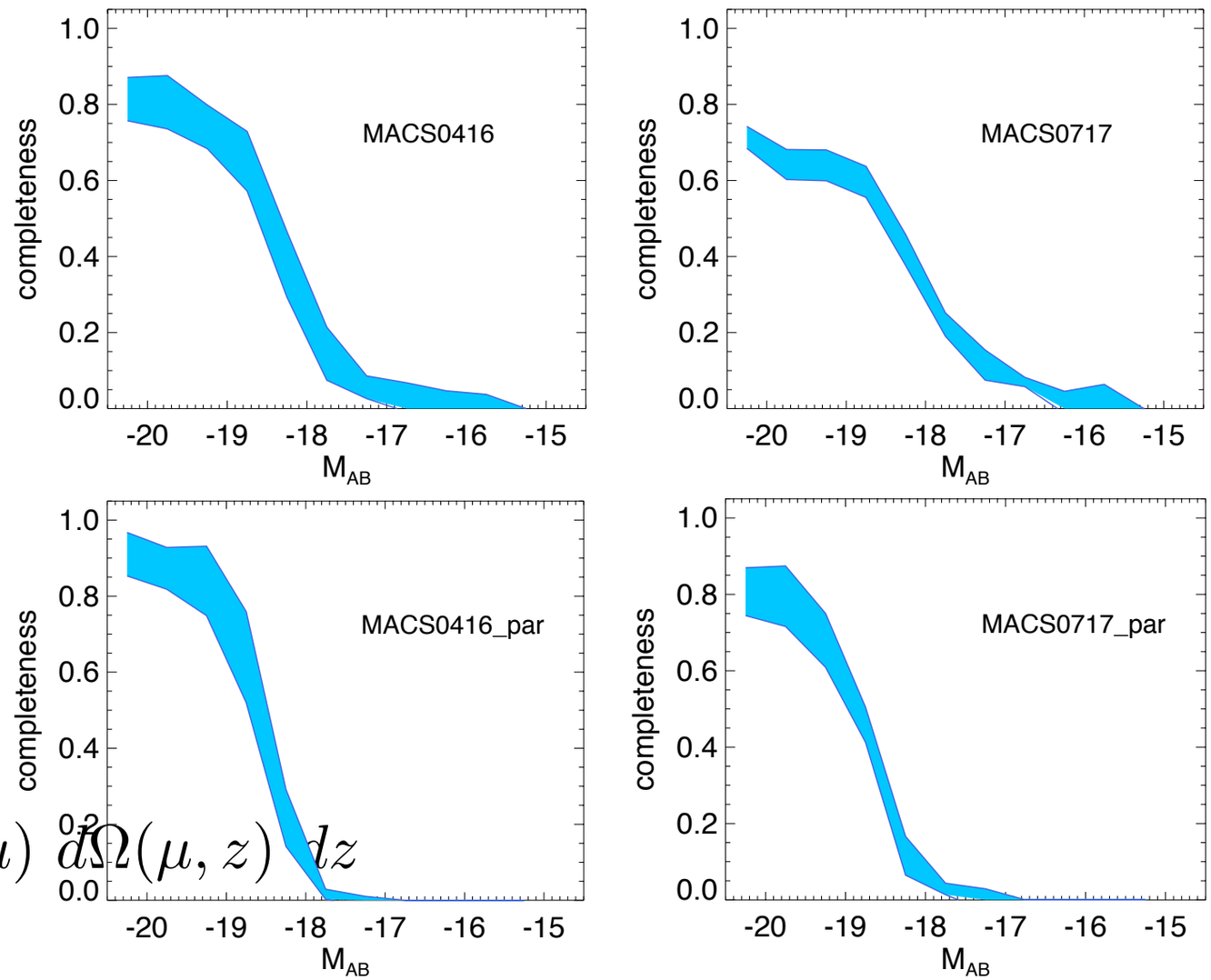
$$\phi(M)dM = \frac{N_i}{V_{eff}(M_i)}$$



- Completeness is a function of magnification

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

and **lensing distortion**



Effective survey volume

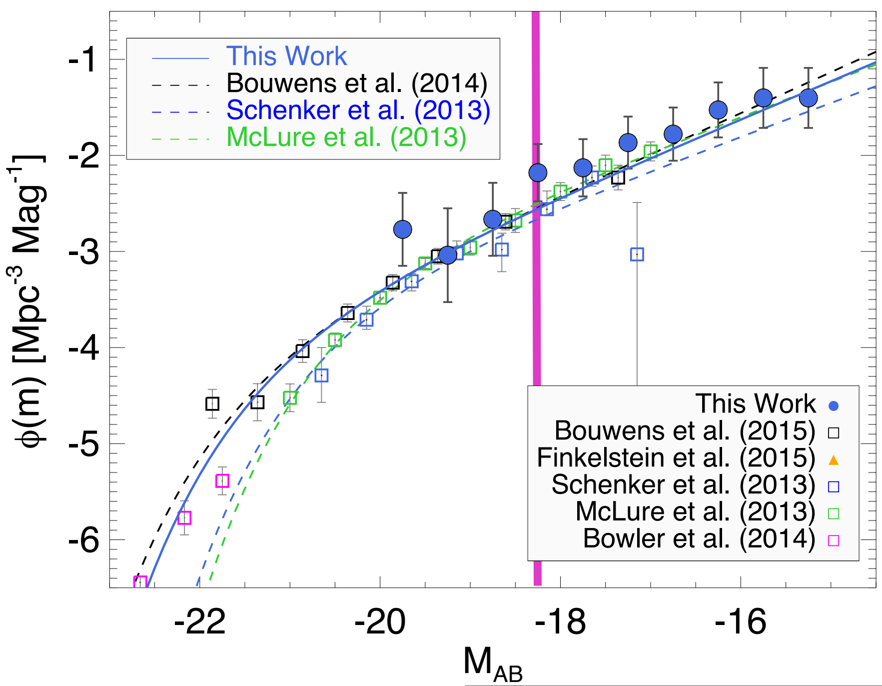
$$V_{eff} = \int_0^\infty \int_{\Omega > \Omega_{min}} \frac{dV_{com}}{dz}\, f(z, m, \mu)\, d\Omega(\mu, z)\, dz$$

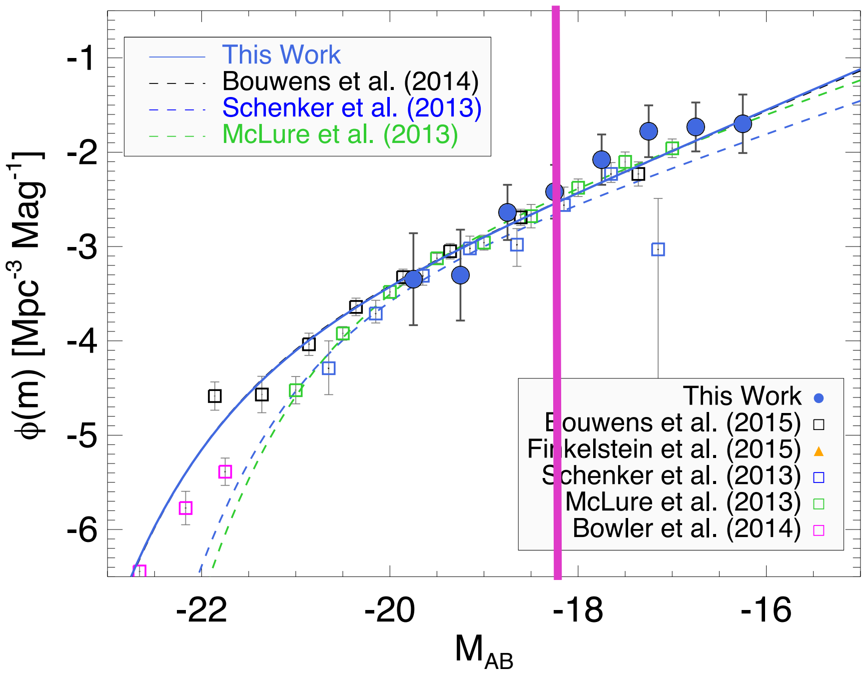
The Best Constraints on the UV LF at z~7

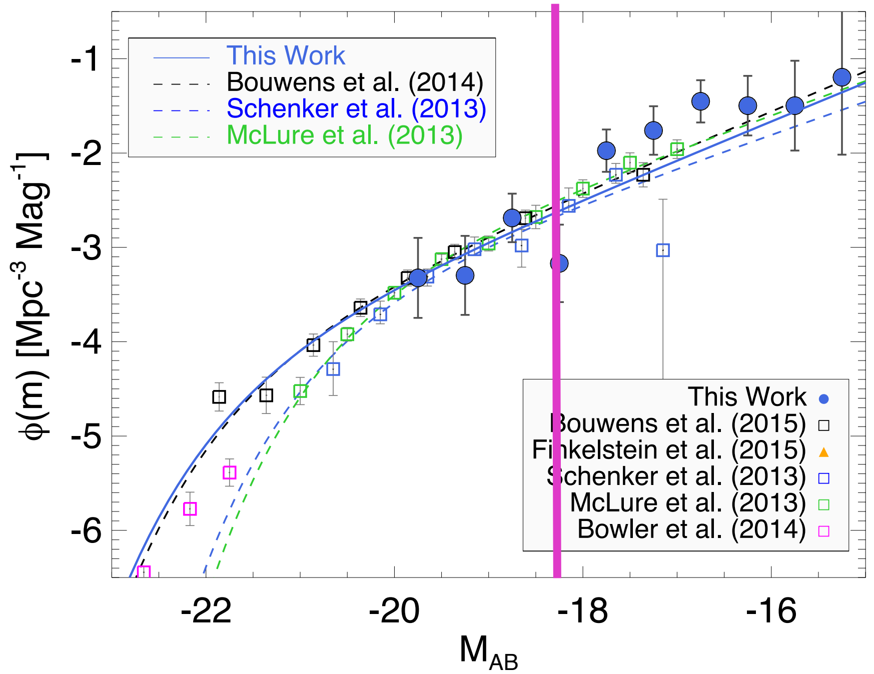
Atek et al. 2015b, arXiv:1509.06764

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

Clusters







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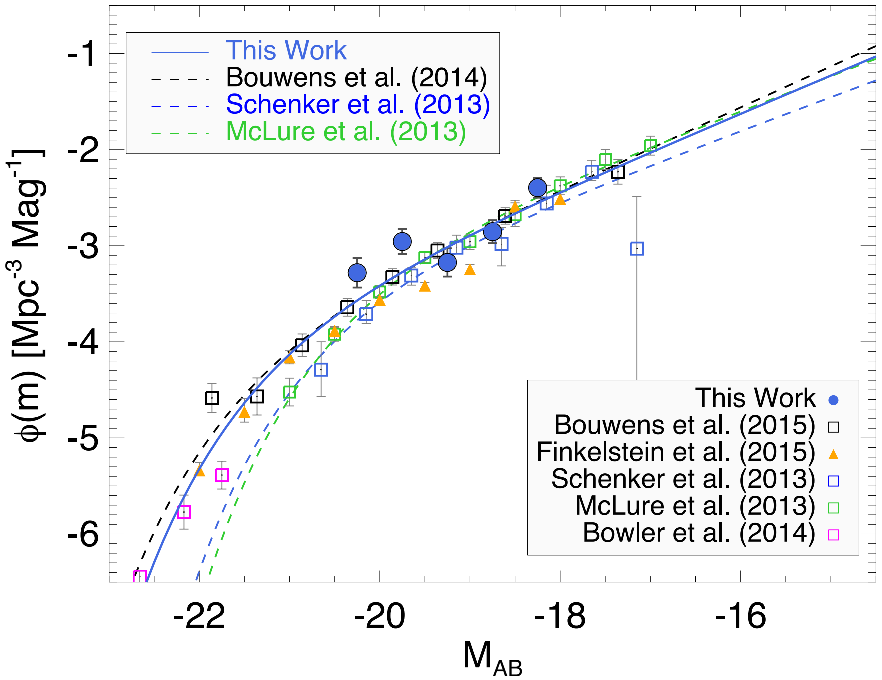
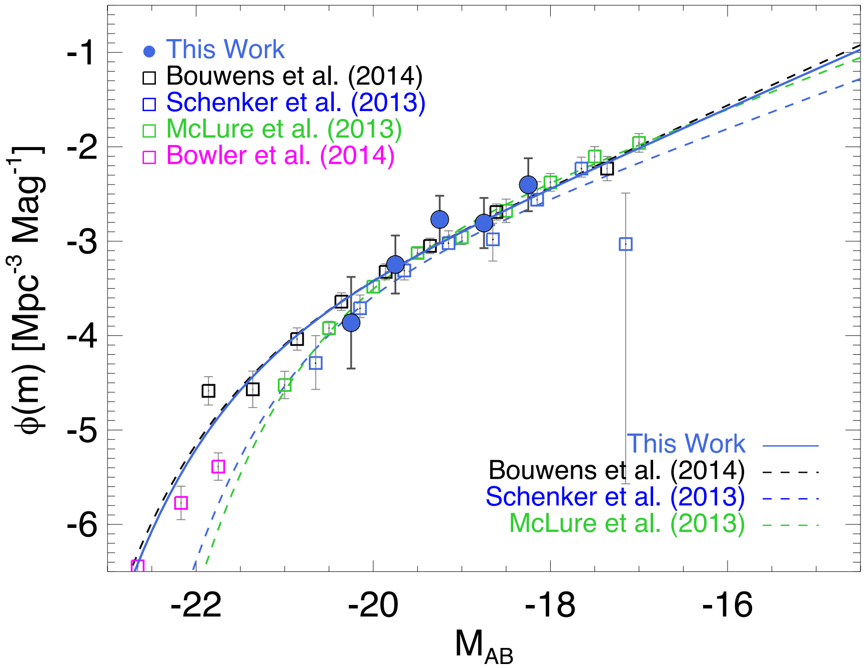
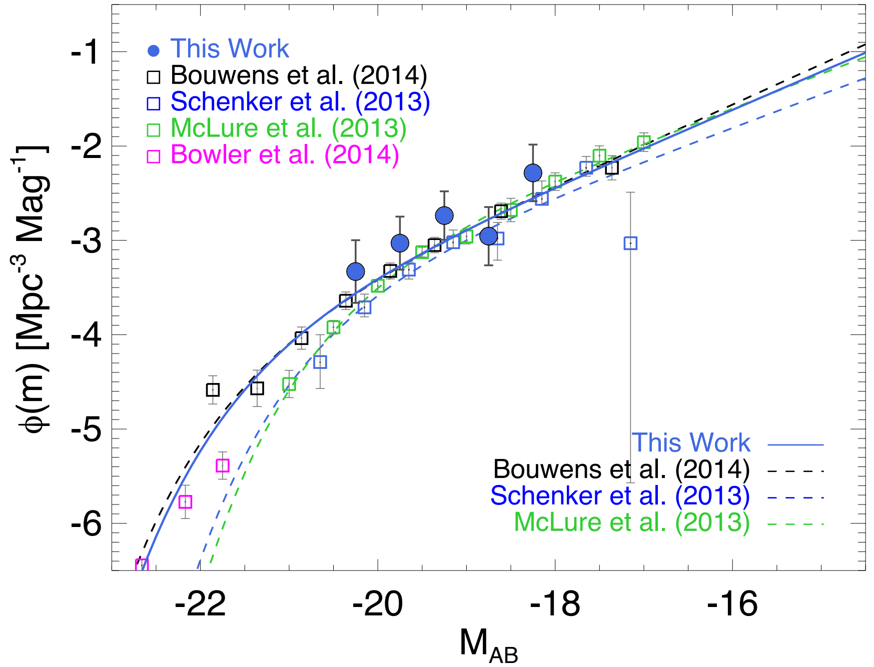
Parallels

MACS0416

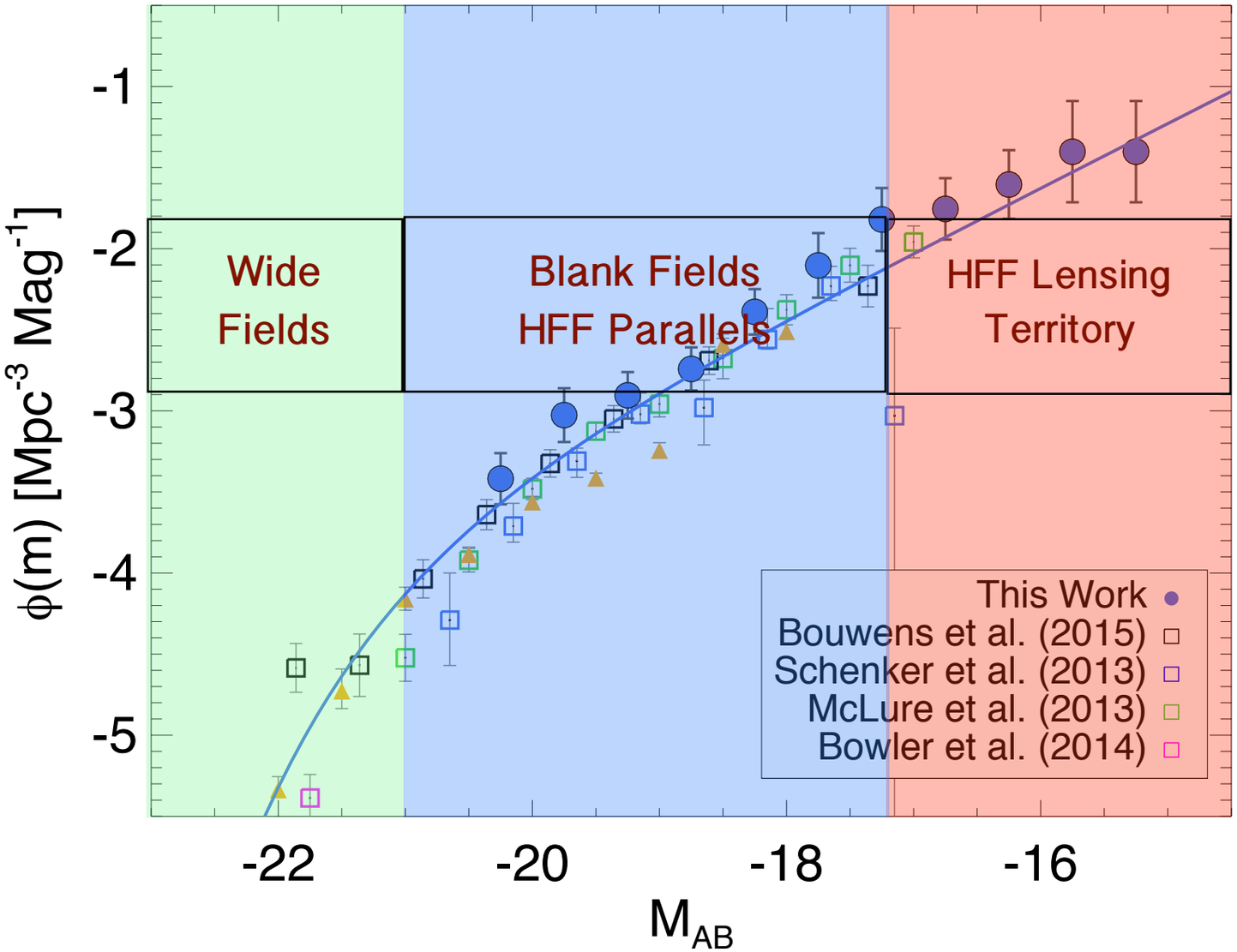
MACS0717

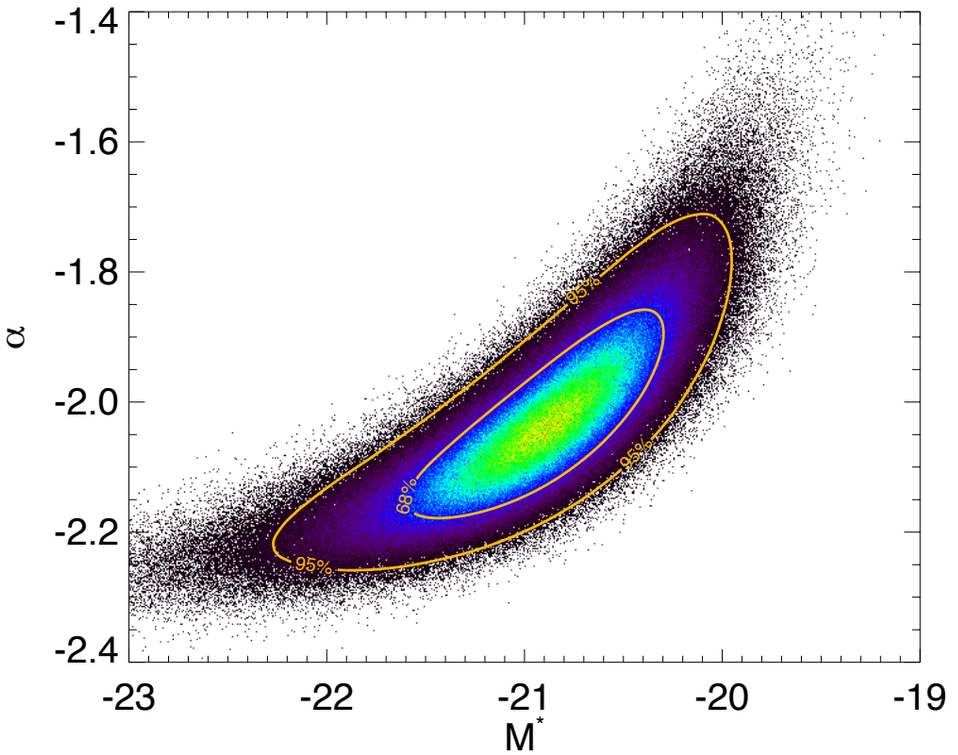


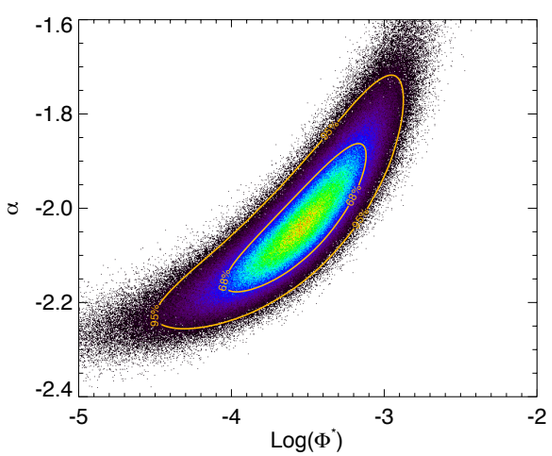


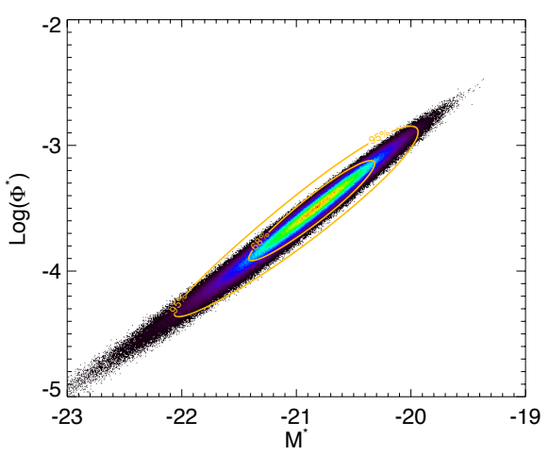


The Faint-end of the UV LF at z>6





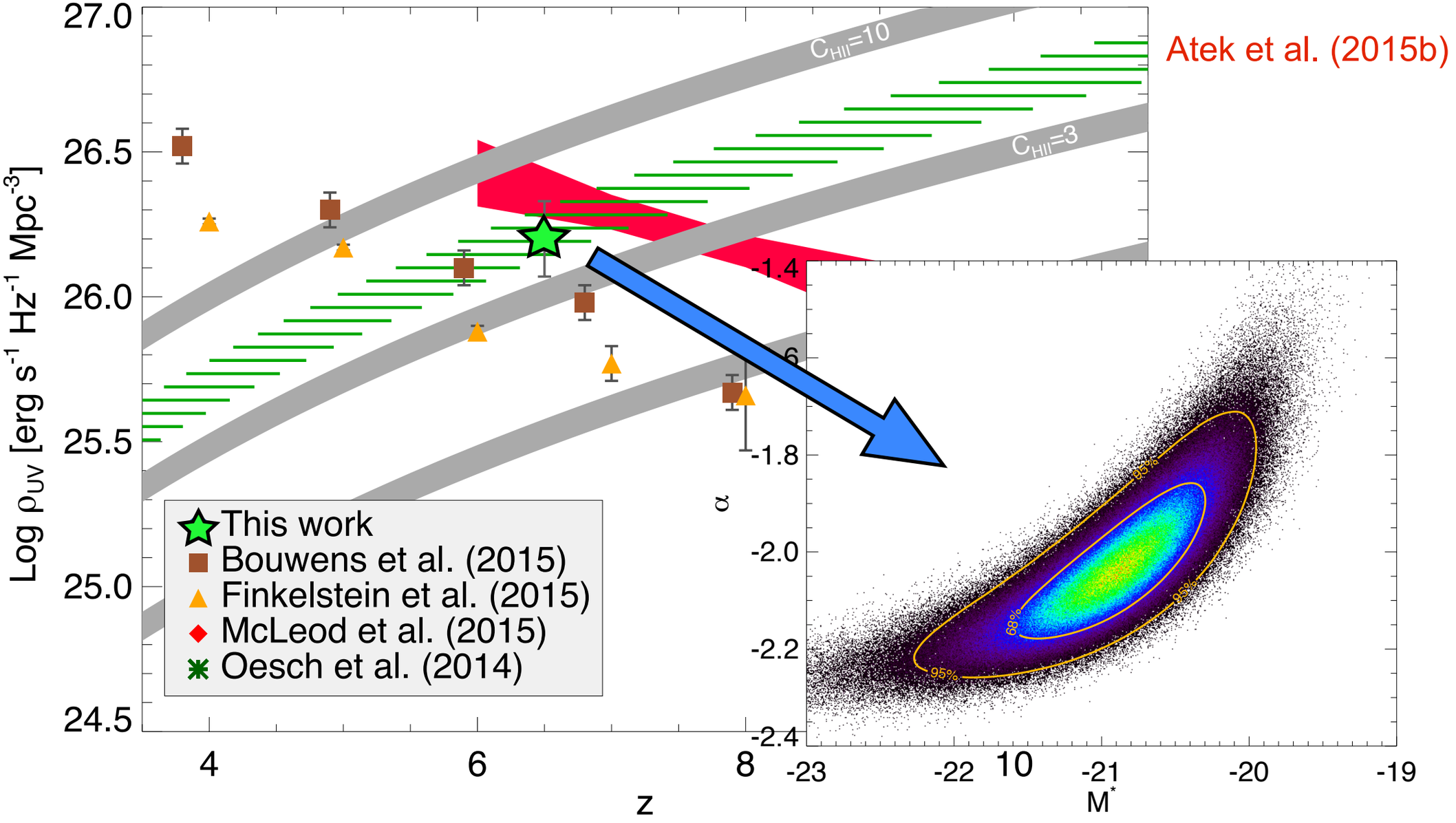




ref	This work	Bouwens et al. (2014)	Schenker et al. (2013)	Ishigaki et al. (2014)
α	-2.04 (-0.17,+0.13)	-2.0 ±0.14	-1.87 ±0.18	-2.10 (-0.15,+0.3)

UV Luminosity density and Reionization

- Evolution of the UV luminosity density:
  depends on faint-end slope + integration limit
- Ionizing emissivity from galaxies :
  depends on fesc, clumping factor, ionizing conversion factor

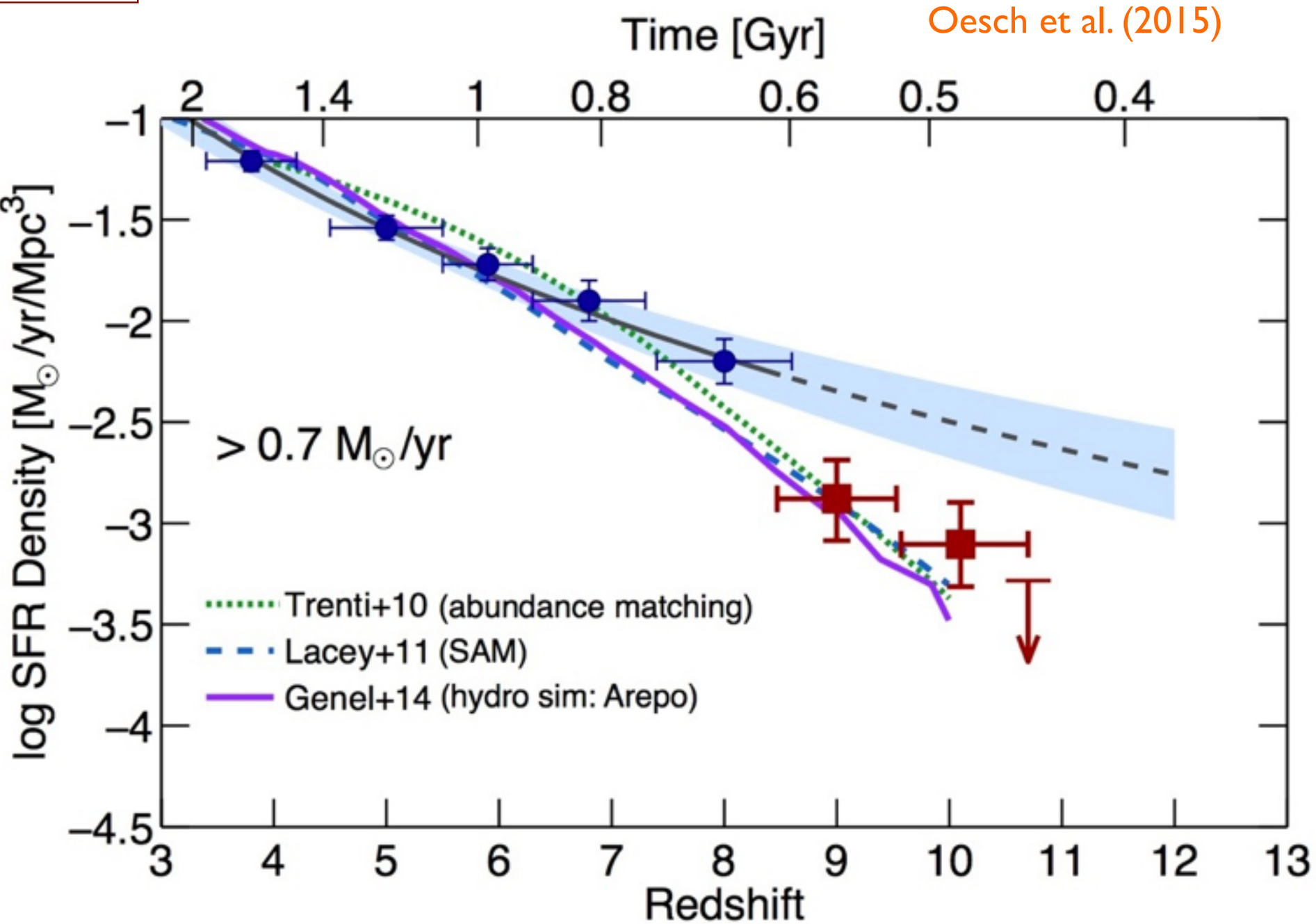


Atek et al. (2015b)

Evolution of the SFR Density at z>8

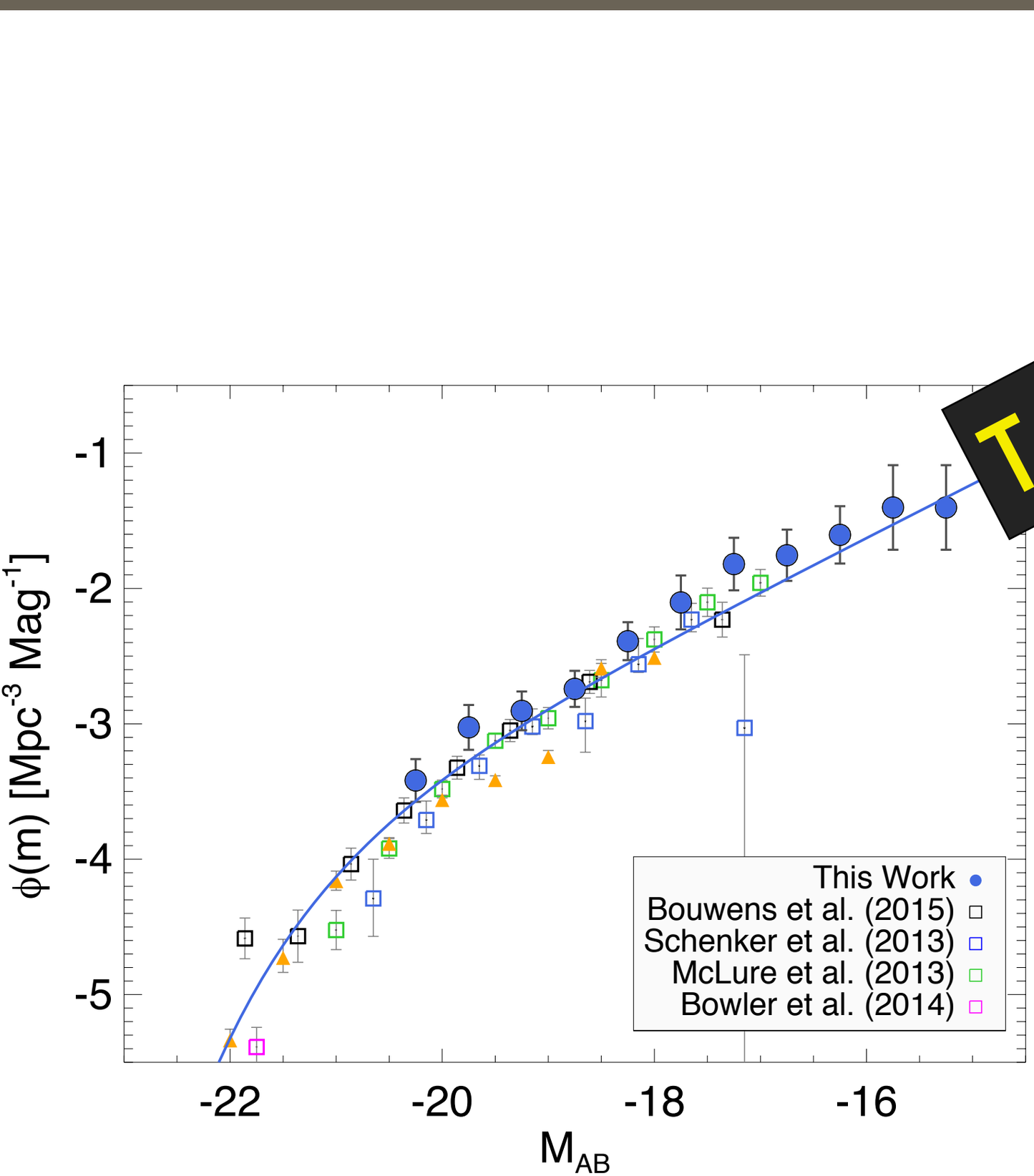
see Pascal's talk

Oesch et al. (2015)



see also Zheng et al (2012), McLure et al. (2013), Coe et al. (2013), Bouwens et al. (2015), Ishigaki et al. (2015)

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

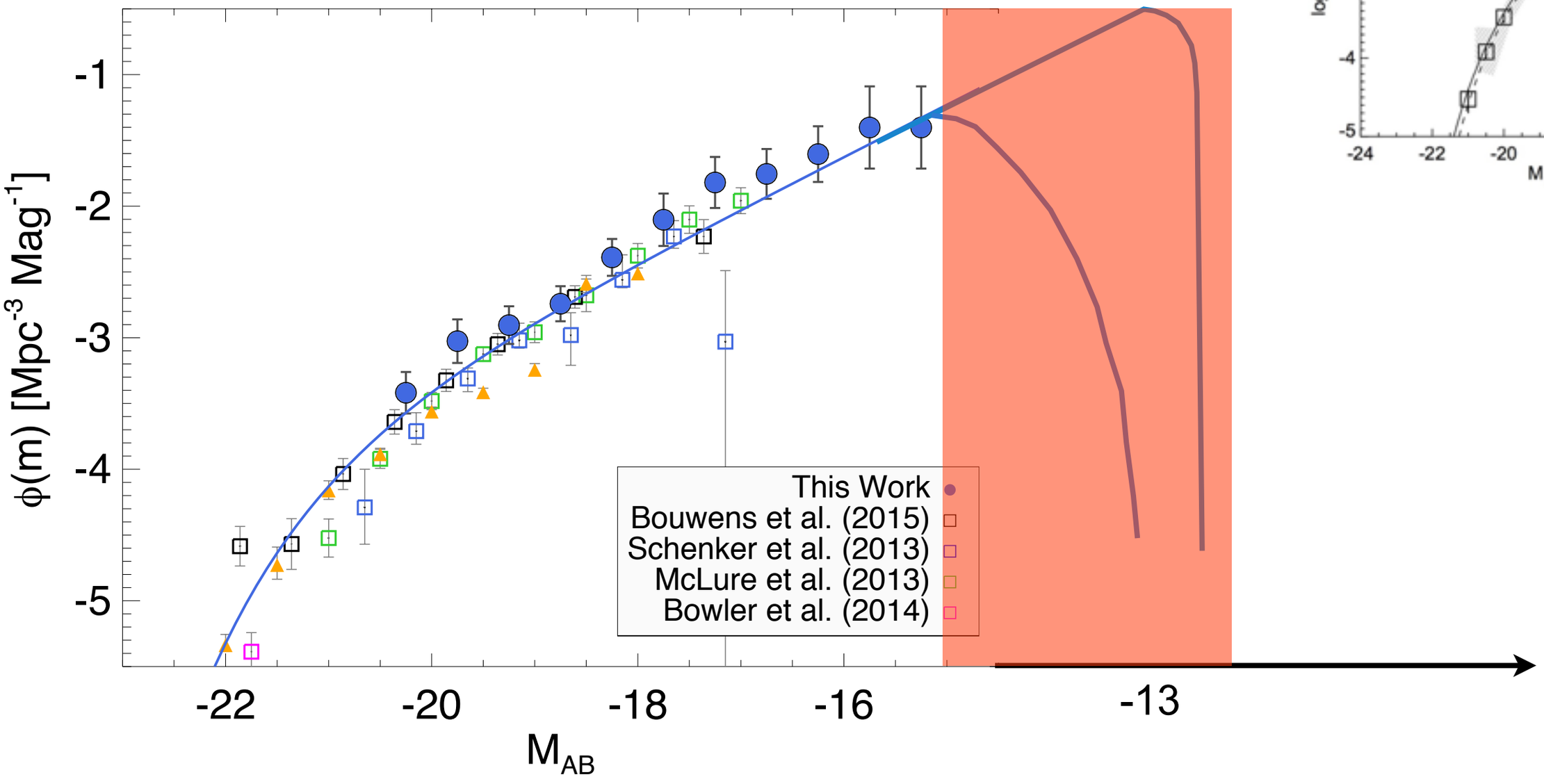


Too Many to Fail ?

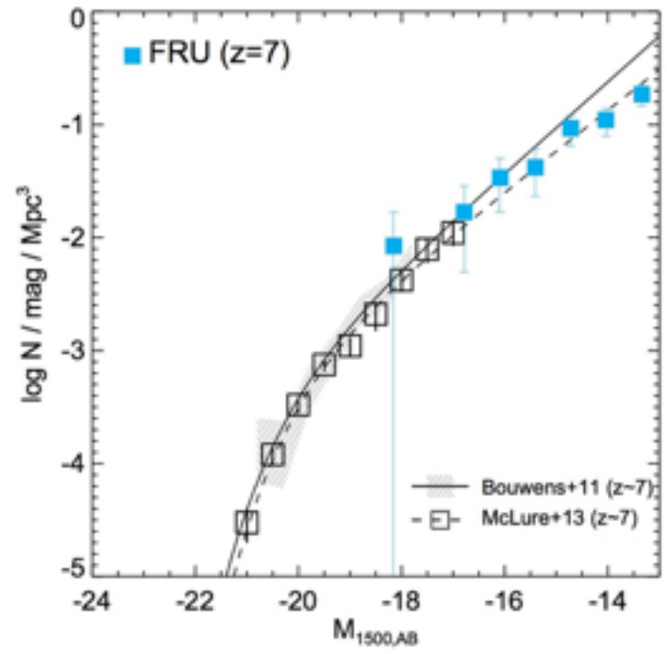
The Faint-end of the UV LF at z>6

Too Many to Fail ?

JWST



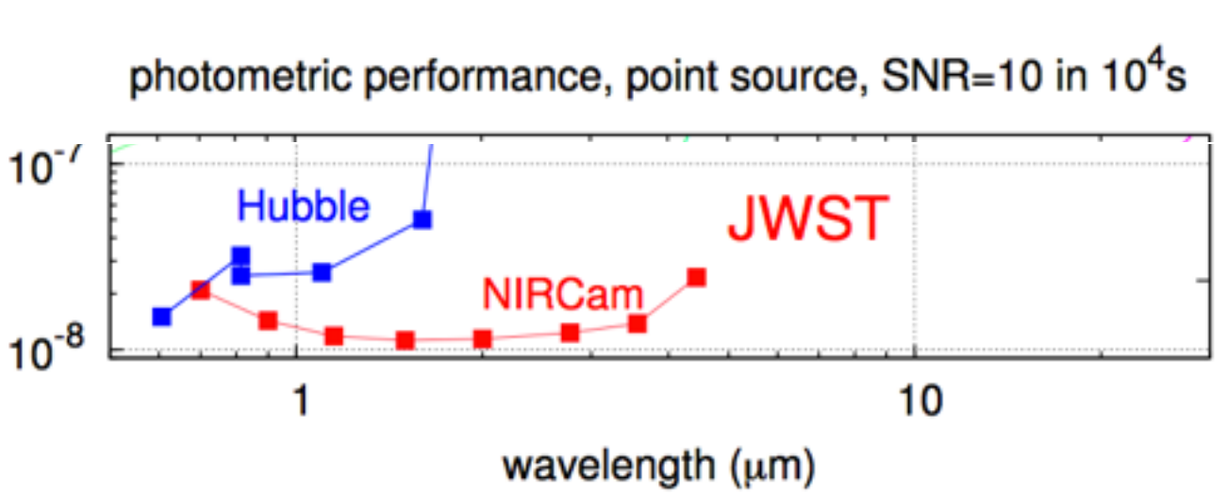
Kimm & Cen (2014)



JWST Imaging

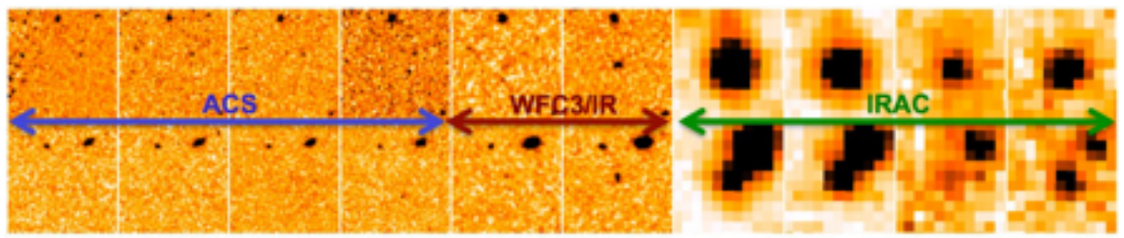
HST/WFC3 & ACS reaching AB=30 mag (5-σ) between 0.2–1.7 μm

JWST/NIRCam imaging to AB=31.5 mag at 1–5 μm



JWST 0.03–0.2" FWHM

Oesch et al. (2014)



JWST Imaging: Wide wavelength coverage and very reliable photometry requirement for accurate photometric redshifts and SED fitting to access the formation of early galaxies z>20
- Crucial for the Stellar mass estimate

Now what ?

The **JWST Ultra Deep Field Imaging Survey** will reach 31-31.5 AB in the UDF

But Lensing is already achieving similar depths

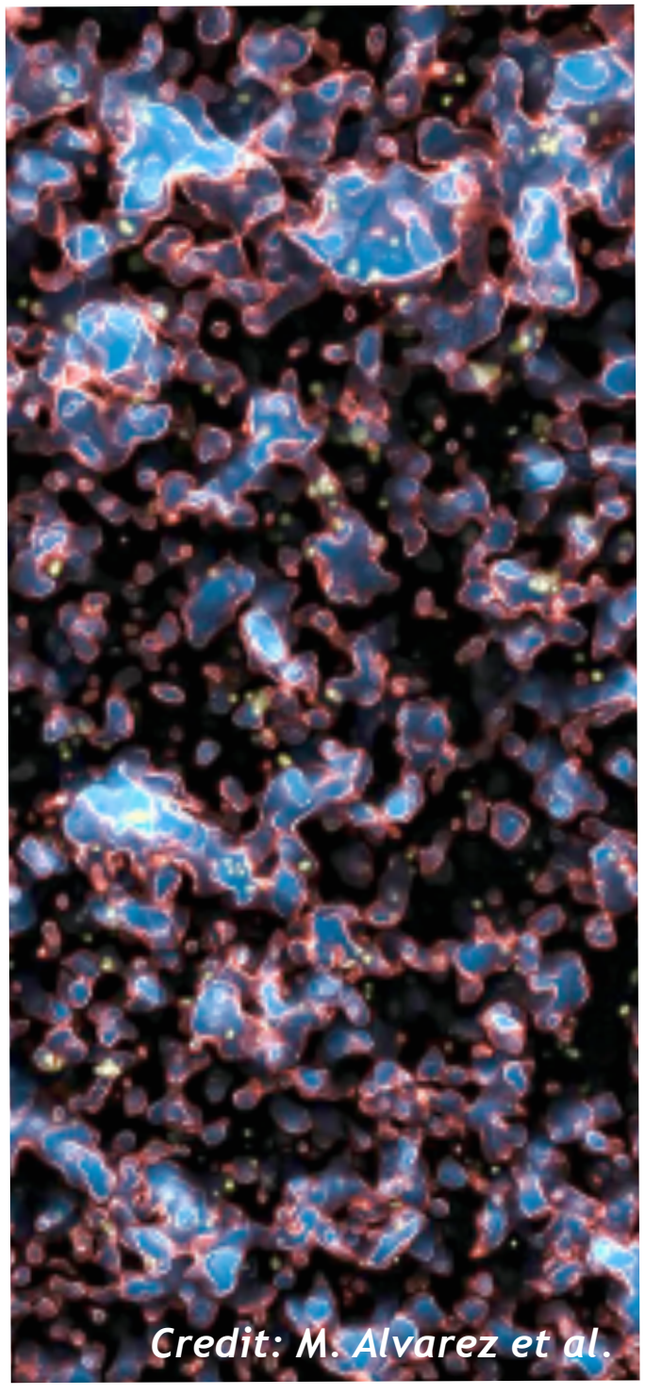
Need to combine JWST with Gravitational lensing

- Probe the faintest galaxy population at the epoch of reionization
- Detailed study of the first generation of galaxies

Multiple Spectroscopic solutions in the IR, an important shift from HST (and a much better spitzer)

If we want to target other clusters, there will be a coordinated effort with HST to obtain optical imaging in order to calibrate these cosmic lenses

Summary



- Gravitational lensing helps reach the faintest galaxies likely responsible for cosmic reionization

- Now the galaxy UV LF extends down to Muv ~-15 at z~7. This is about 2 mag deeper than the deepest observations in blank fields

- The faint-end slope remains steep (alpha =-2.04) down to very faint luminosities of 0.005L*. JWST will be able to probe down to 0.001L*

- The integrated UV luminosity density is sufficient to maintain reionization (with standard assumptions)

- Any progress in this direction with JWST will need the use of Gravitational lensing.