The background of the slide is a deep space image showing a vast field of distant galaxies. These galaxies appear as small, glowing points of light in various colors (yellow, orange, red, and blue) against a black background. Some galaxies show distinct spiral or elliptical structures, while others are more diffuse. The distribution of galaxies is sparse, with large gaps between them, emphasizing the scale of the universe.

# $z \sim 9-10$ Galaxies in the Hubble Frontier Fields and CLASH Surveys

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University of Edinburgh

Supervisors: Ross McLure, Jim Dunlop

arxiv : 1602.05199



# Previous $z \sim 9-10$ Searches

HUDF12 (PI Ellis)

Six  $z \sim 9$  candidates found  
(McLure+13)

Constraints on the faint end  
of the LF at  $z=9$





# Previous $z \sim 9-10$ Searches

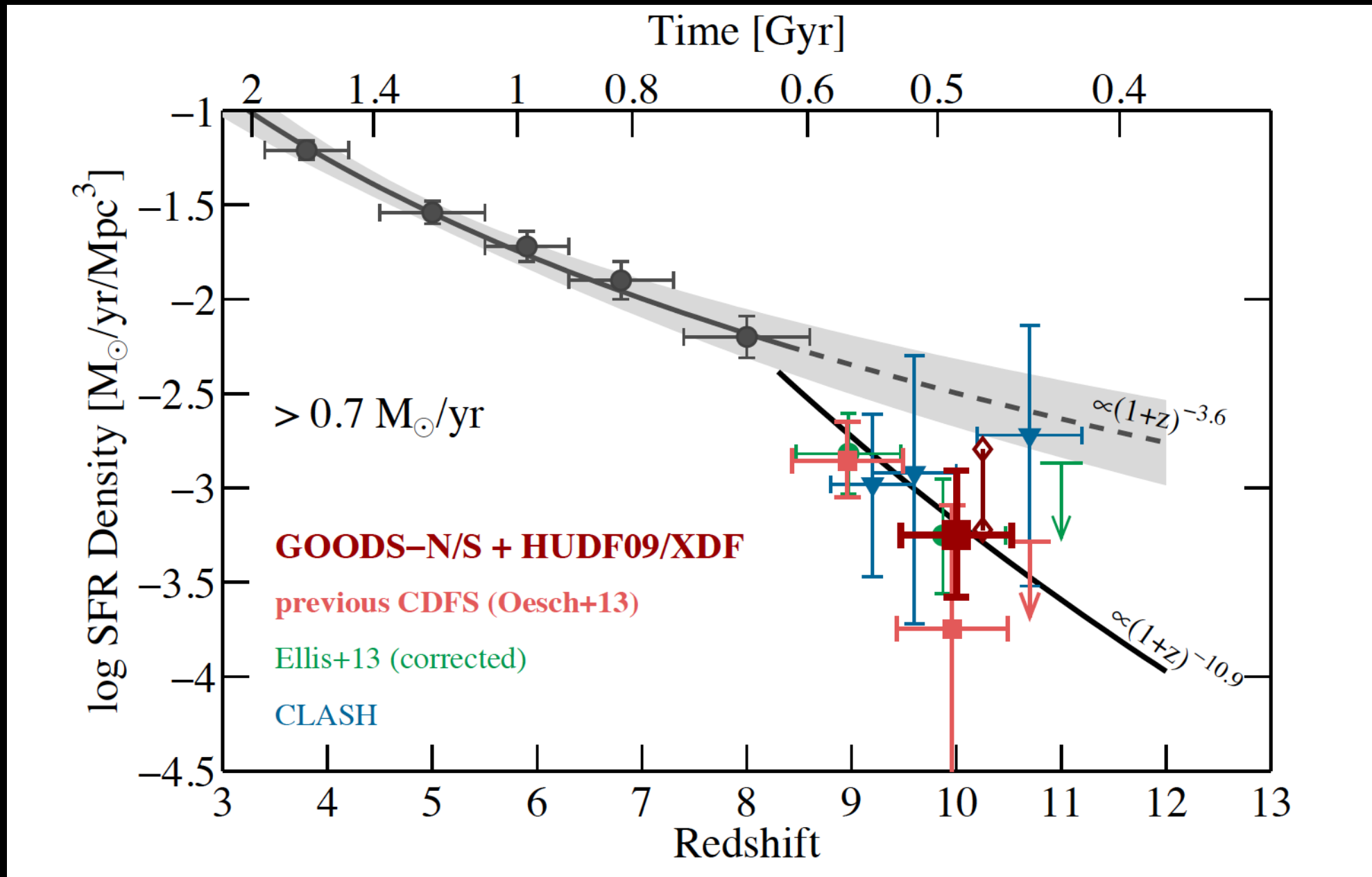
CANDELS GOODS-North:  
Bright  $z \sim 10$  candidates  
(Oesch+14,15; Bouwens  
+15)

Steep decline in the  
luminosity density at  $z > 8$

CLASH: Three  $z=9-10$   
candidates found  
(Bouwens+14)



# Previous Studies at $z \sim 9$



Oesch + (2014)



# Hubble Frontier Fields

Six lensing clusters with six  
blank parallel fields

Deep imaging of area  $\sim 4.5$   
square arcminutes in seven  
filters

Benefit of magnification due  
to gravitational lensing

Parallel fields provide  
significant extra cosmic  
area to search



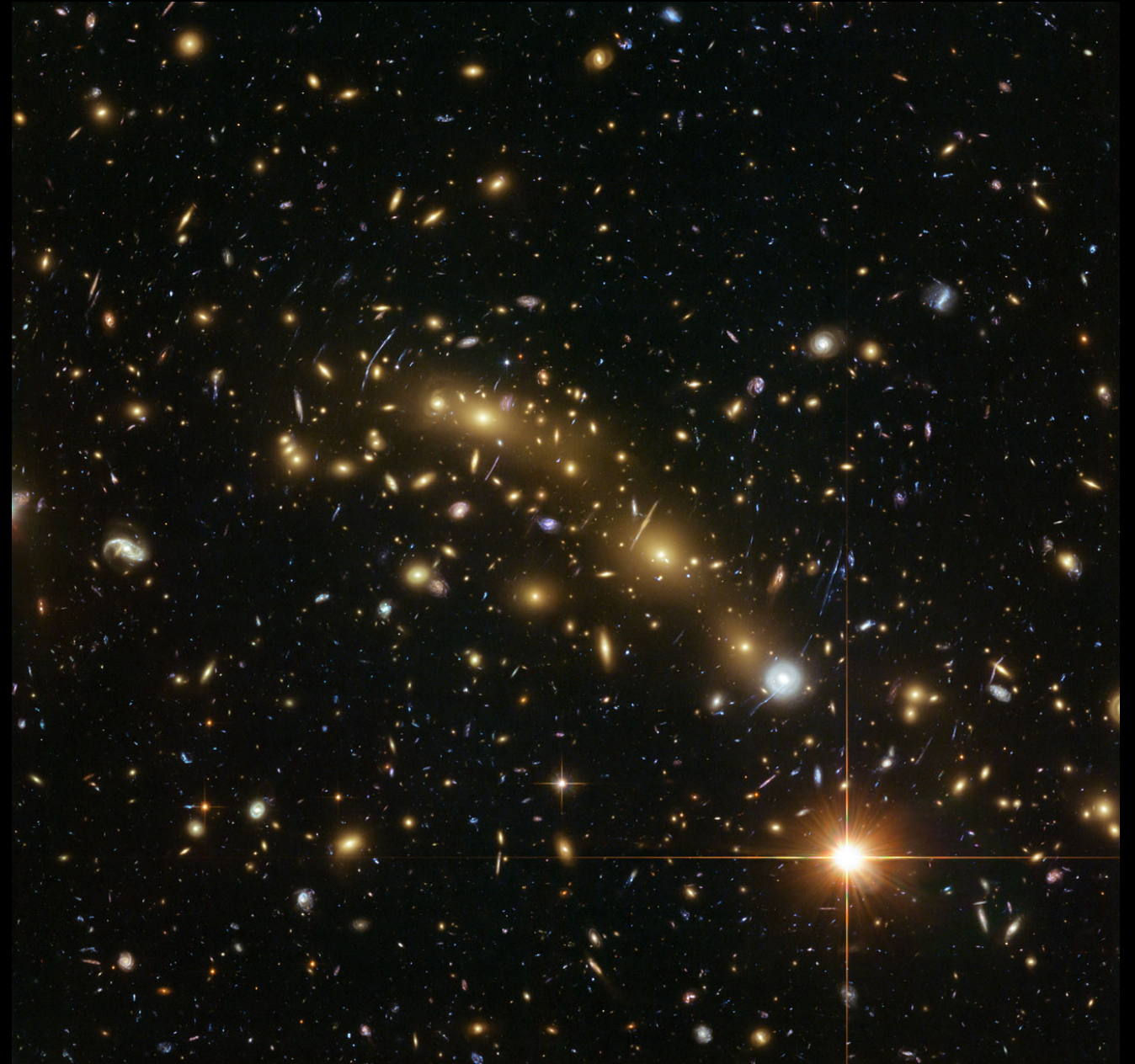


# Hubble Frontier Fields

First two data releases  
Abell2744 and MACS0416  
and their parallels

Discovery of twelve  $z > 8.4$   
galaxies in these four fields  
(McLeod+15)

Further constraints on LF at  
 $z=9$  and evidence for  
smooth decline in luminosity  
density at  $z > 8$





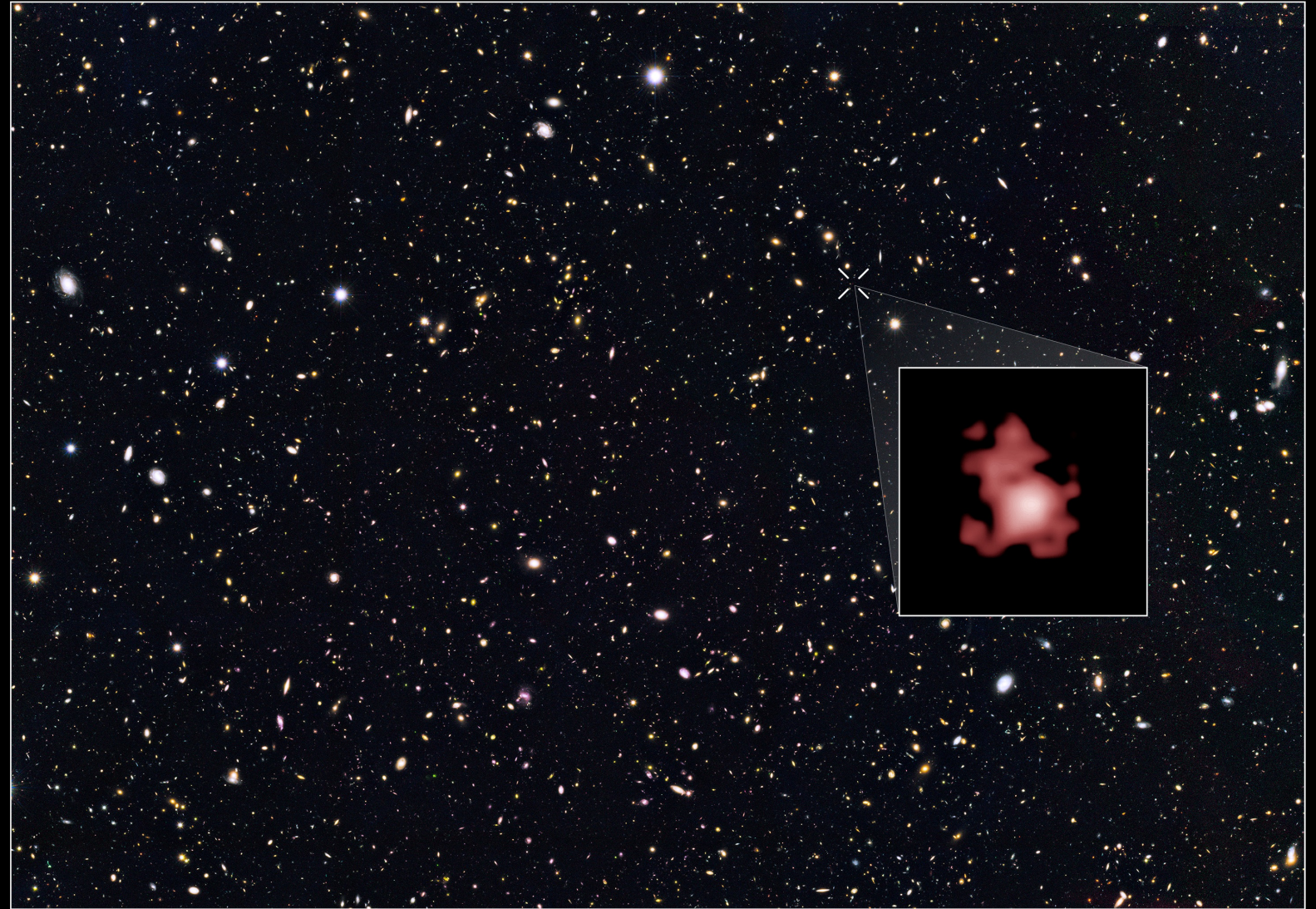
# Previous $z \sim 9-10$ Searches

CANDELS GOODS-North:  
Bright  $z \sim 10$  candidates  
(Oesch+14,15; Bouwens  
+15)

GN-z11 (Oesch+16)

Distant Galaxy GN-z11 • Redshift 11.1 • GOODS North Survey

HST • ACS/WFC WFC3/IR



NASA, ESA, and P. Oesch (Yale University)

STScI-PRC16-07a

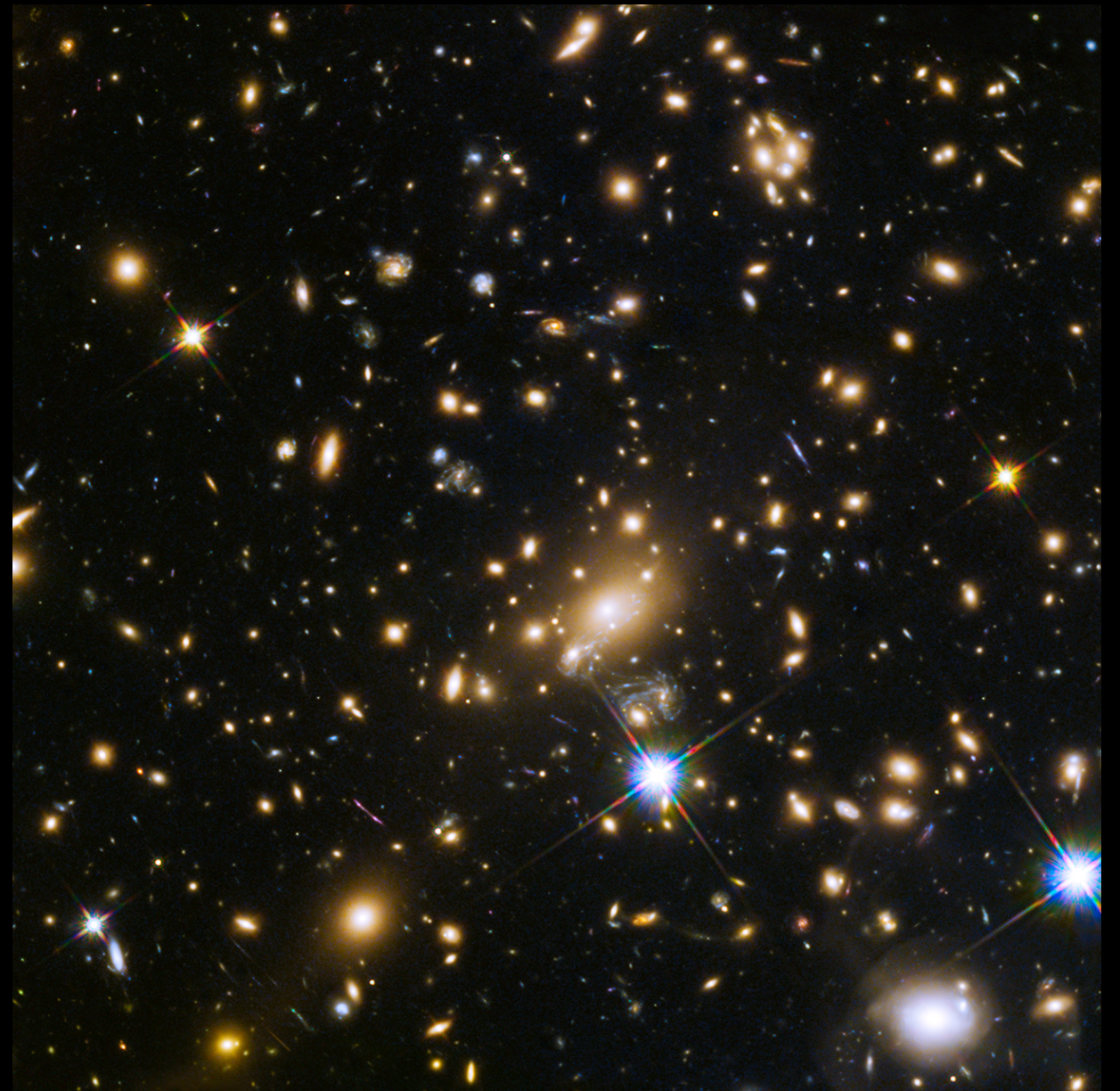


# Hubble Frontier Fields

A new search for  $z=9-10$  galaxies in the first four HFF data releases

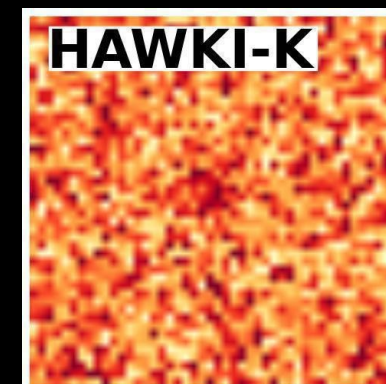
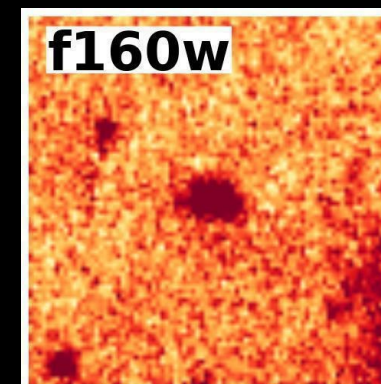
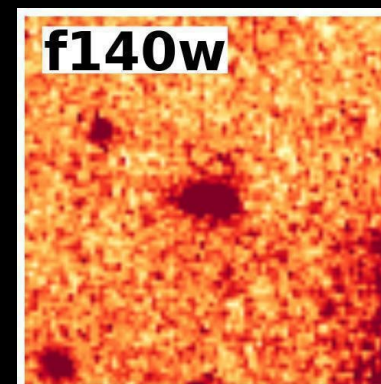
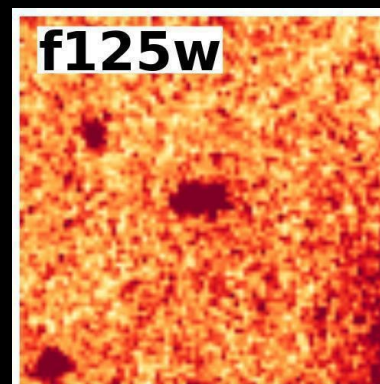
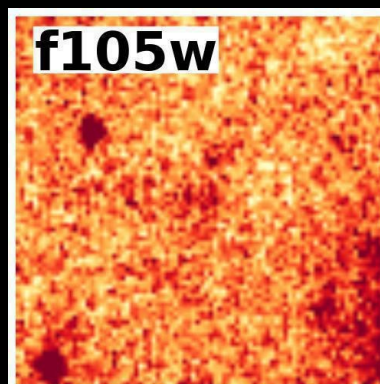
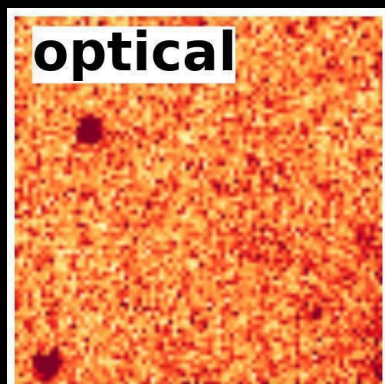
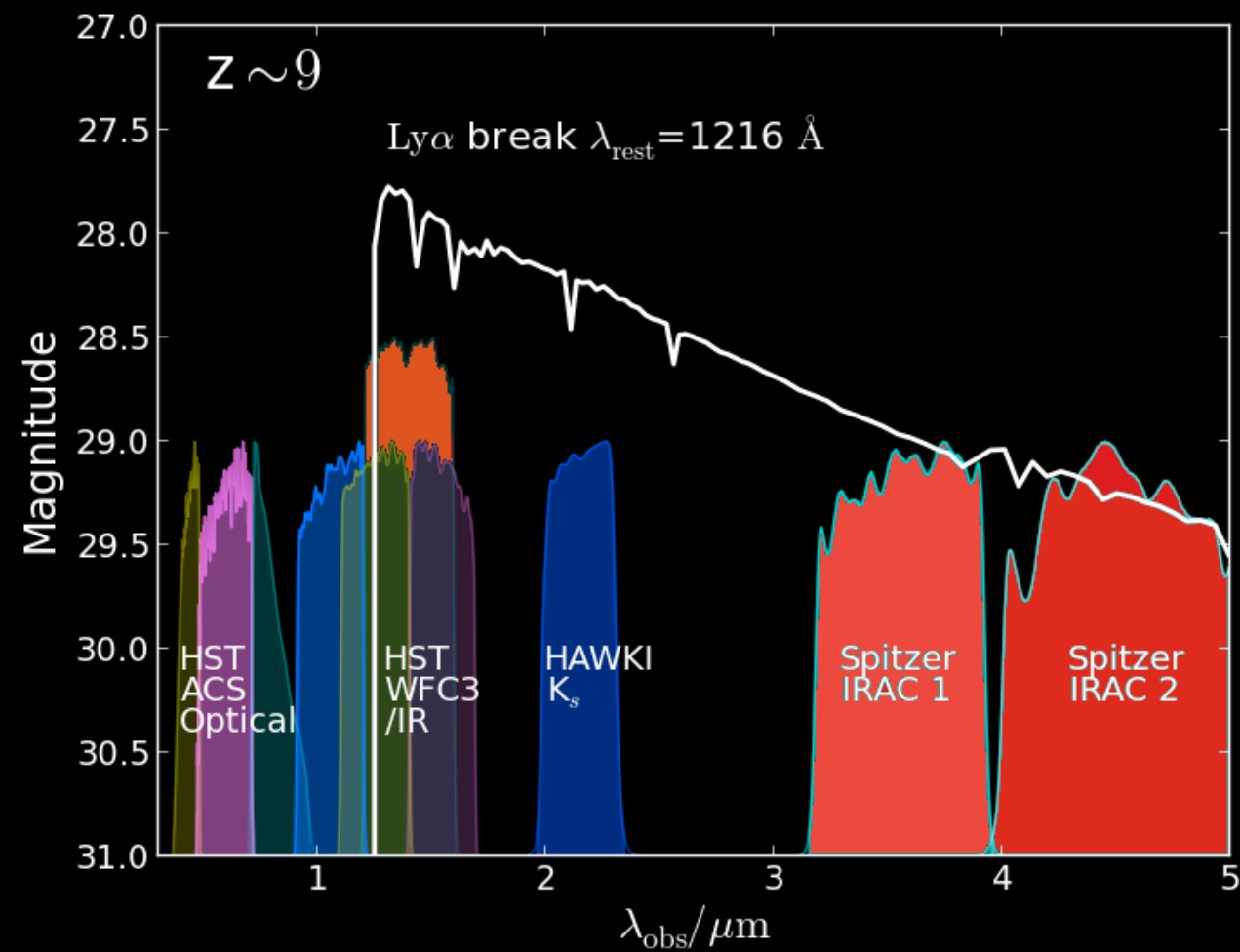
Supplemented with a search in twenty CLASH fields

Total raw search area of  $\sim 130$  sq. arcmin.



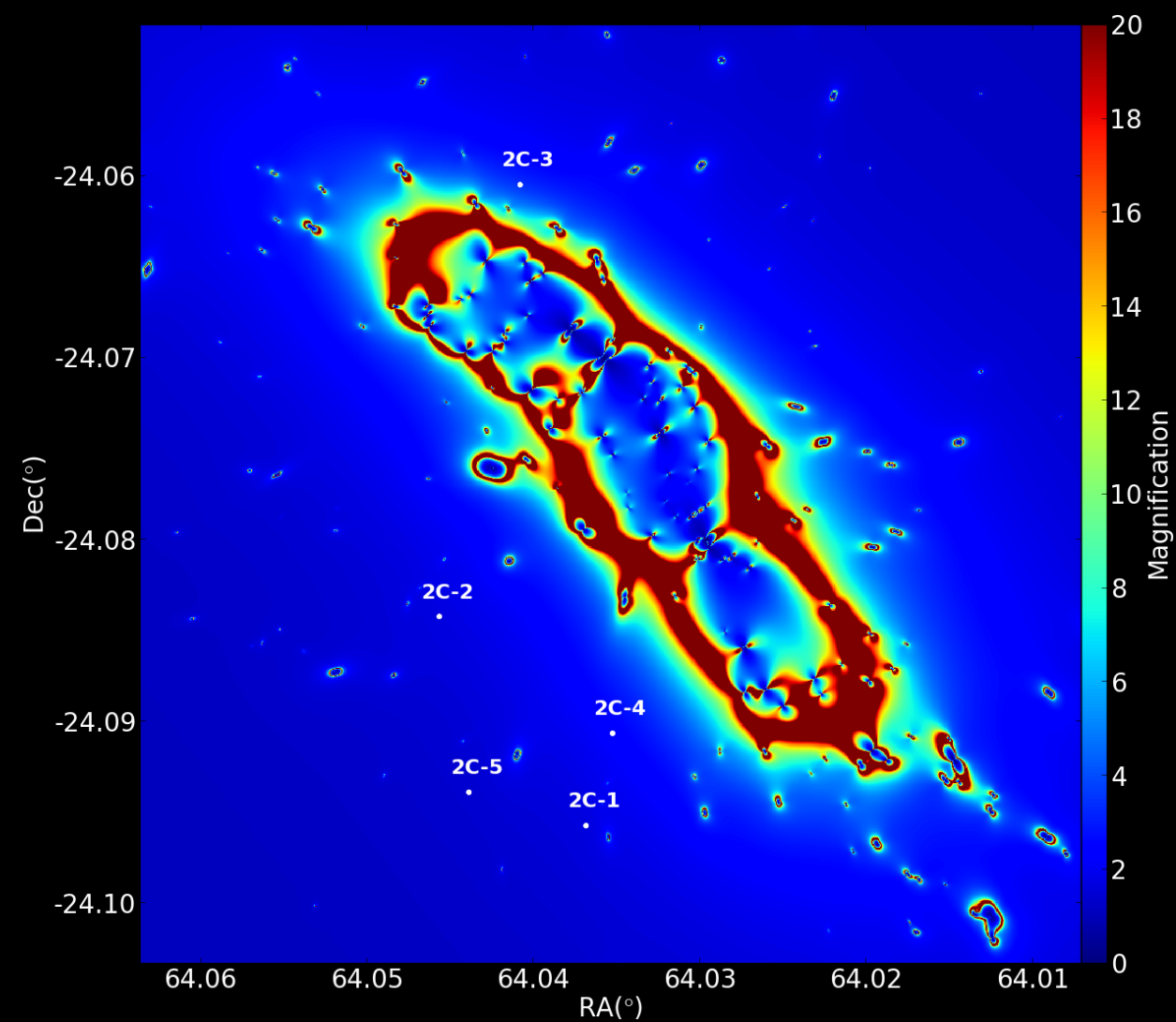
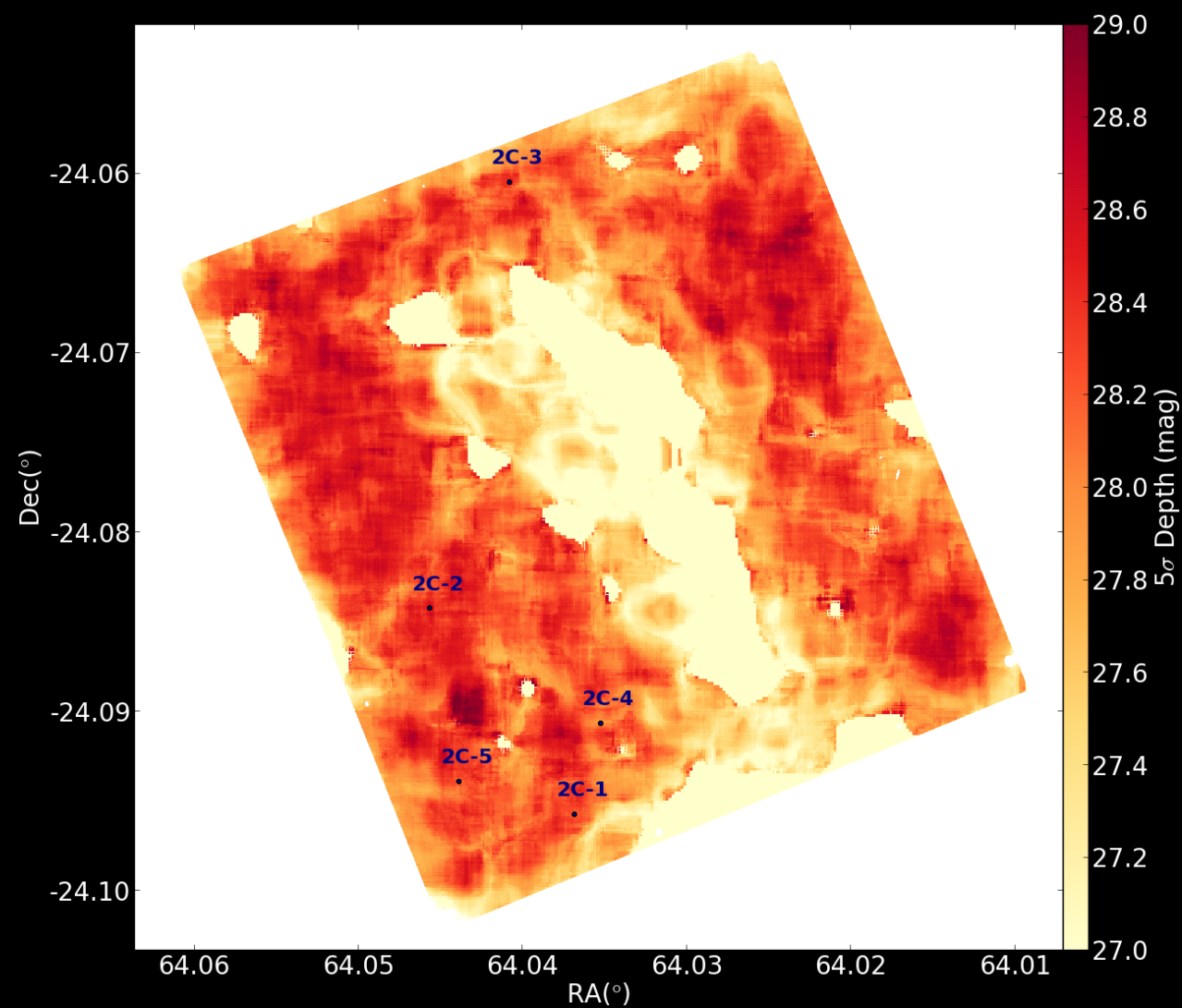


# $z \sim 9-10$ Galaxies





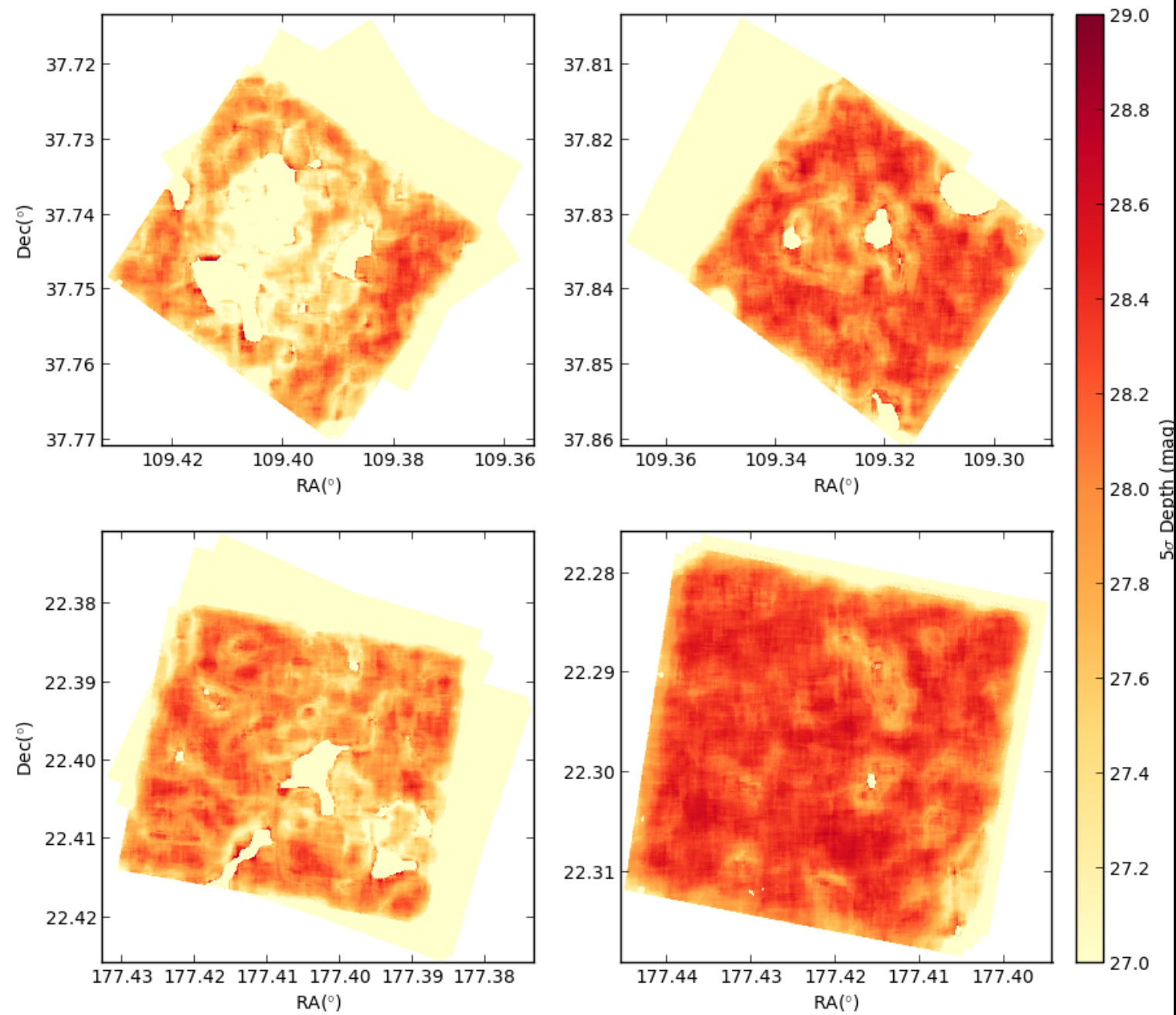
# $z \sim 9-10$ Galaxies



$z \sim 9$  galaxies in MACS0416: see McLeod et al. (2015)



# $z \sim 9-10$ Galaxies





# Results

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

Includes five galaxies with photo  $z \sim 10$

Able to place constraints on the LF and luminosity density at  $z = 9-10$

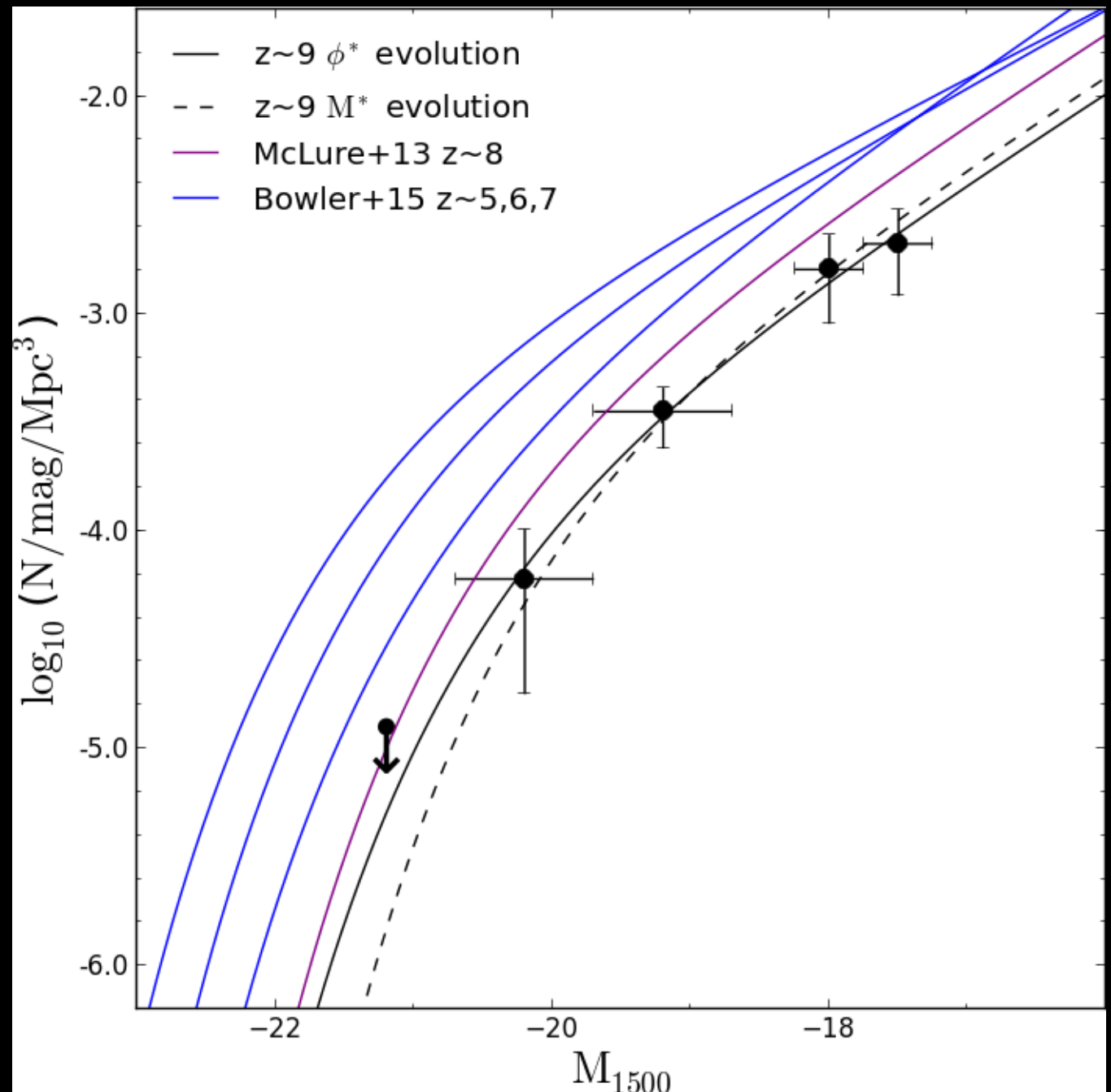


# Luminosity Function

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

Includes five galaxies at  $z \sim 10$

Able to place constraints on the LF and luminosity density at  $z=9-10$



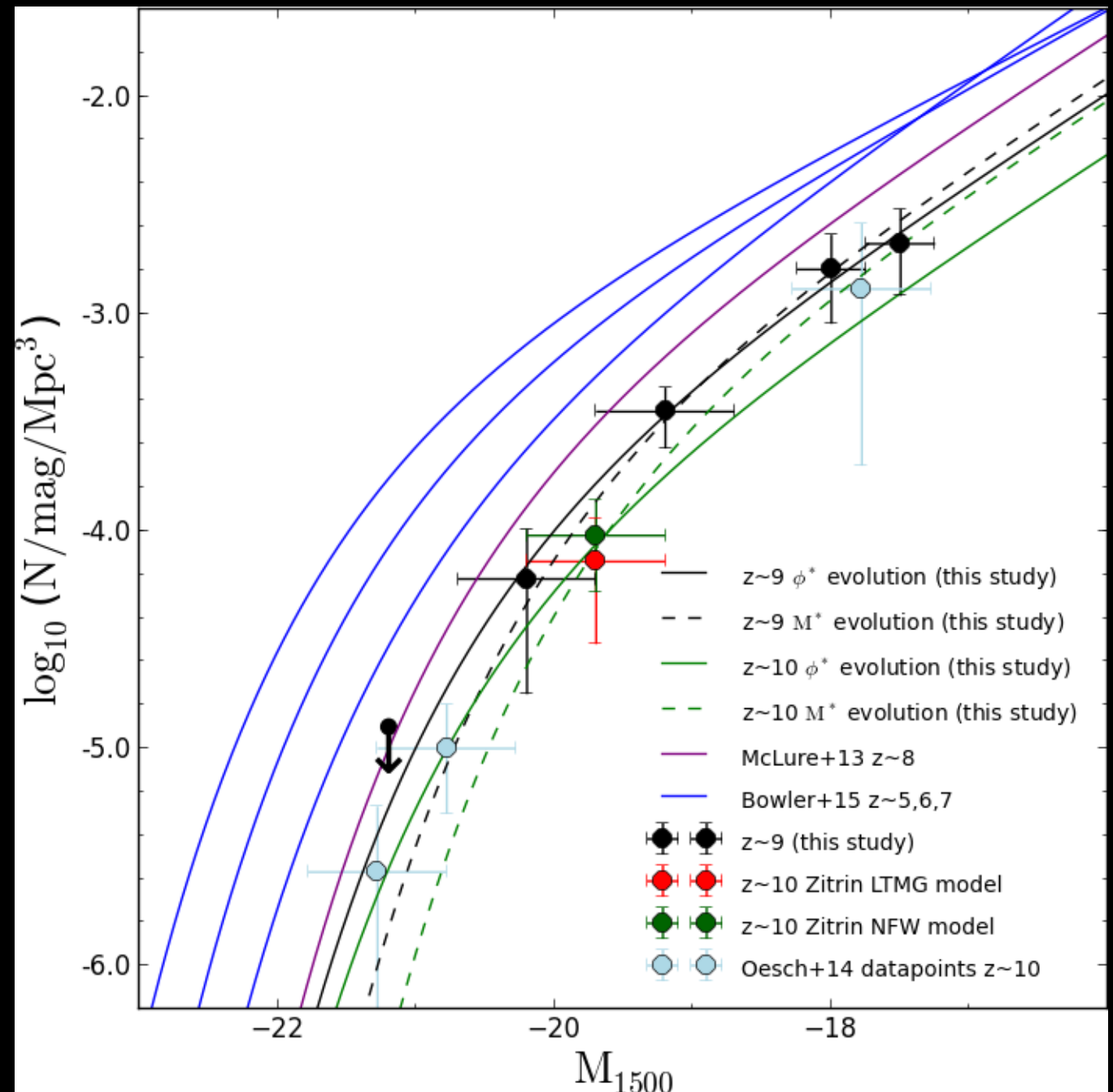


# Luminosity Function

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

Includes five galaxies at  $z \sim 10$

Able to place constraints on the LF and luminosity density at  $z=9-10$





# Luminosity Density

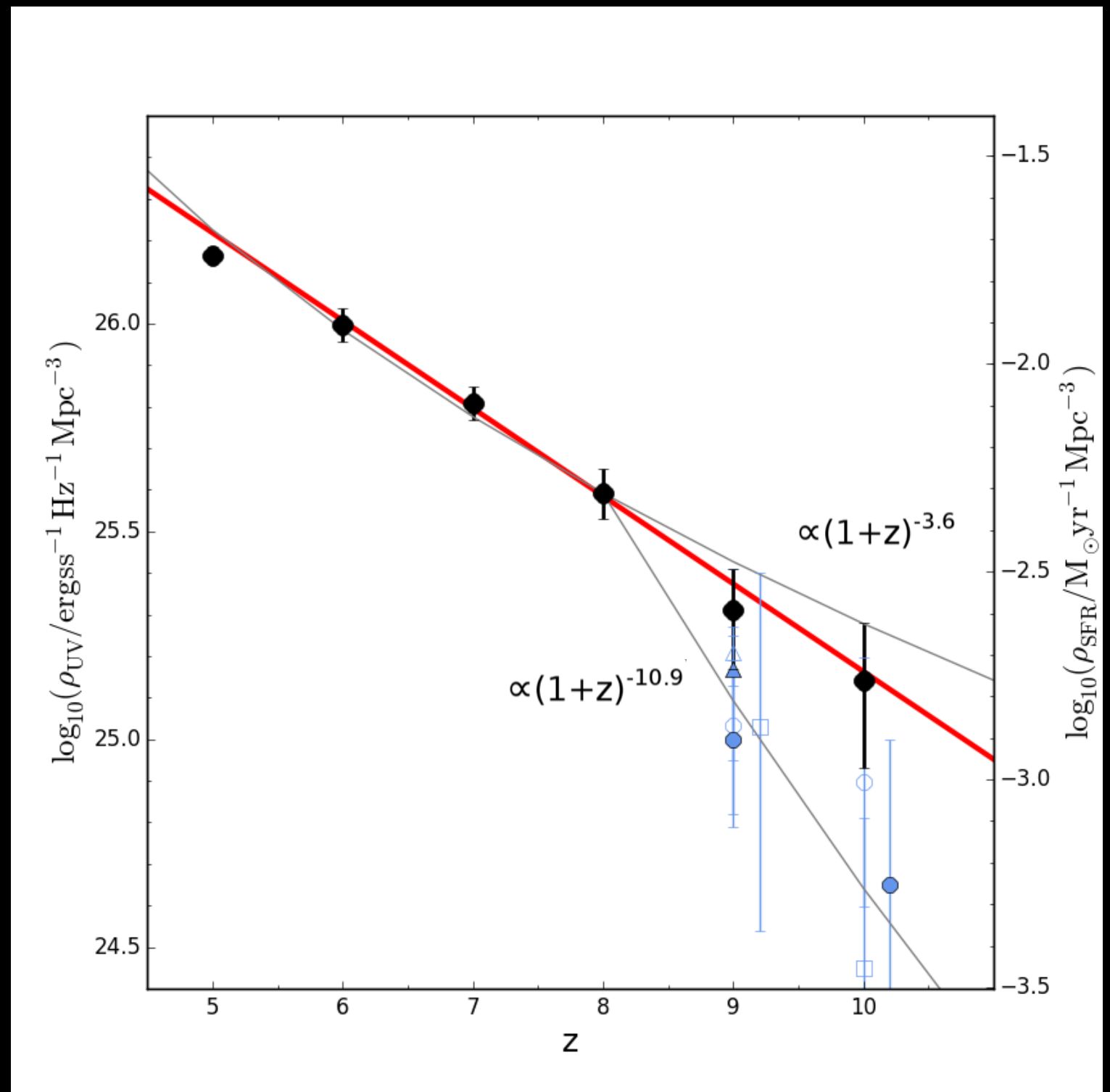
Shallower drop in luminosity density than previous studies

blue filled circle:  
Oesch + (2014)

blue open circle:  
Ellis + (2013)

blue filled triangle:  
Ishigaki + (2015)

blue open triangle:  
McLure + (2013)





# Luminosity Density

Comparison with theoretical models:

Behroozi & Silk (2015)

Khochfar et al. (in prep.)

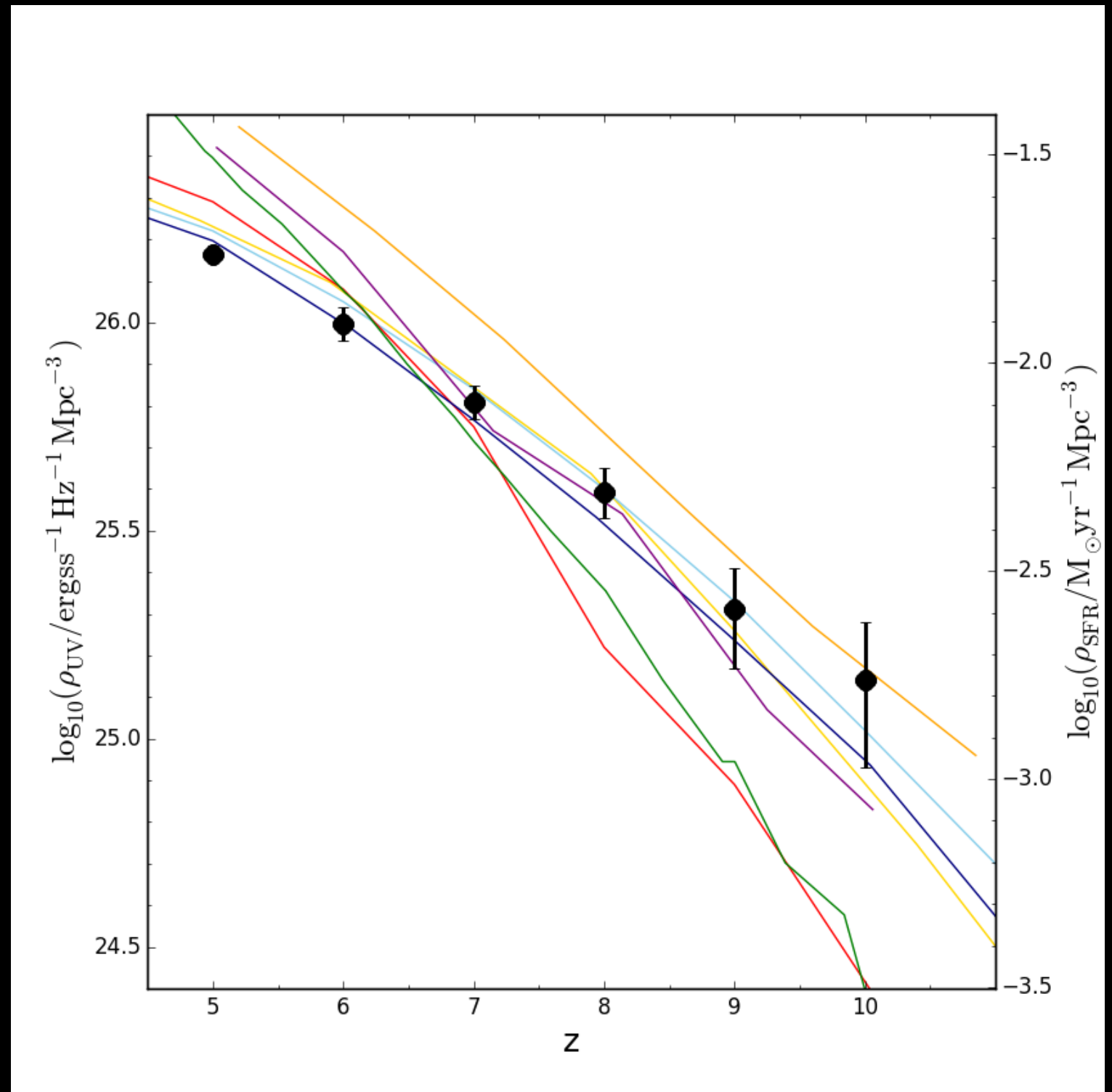
Genel et al. (2014)

Mason et al. (2015)

Cai et al. (2014)

Dayal et al. (2015)

Henriques et al. (2015)





# Summary

Discovery of  $\sim 30$  galaxy candidates at  $z \sim 9-10$  within the first four HFF releases + twenty CLASH fields

Further constraints on the LF at  $z=9-10$

Evidence for continued smooth decline in luminosity density at  $z > 8$ , following a linear relation