Stellar Mass Density at z~7, SFR density at z>7, Use of Lensing to Study High-Redshift Galaxies

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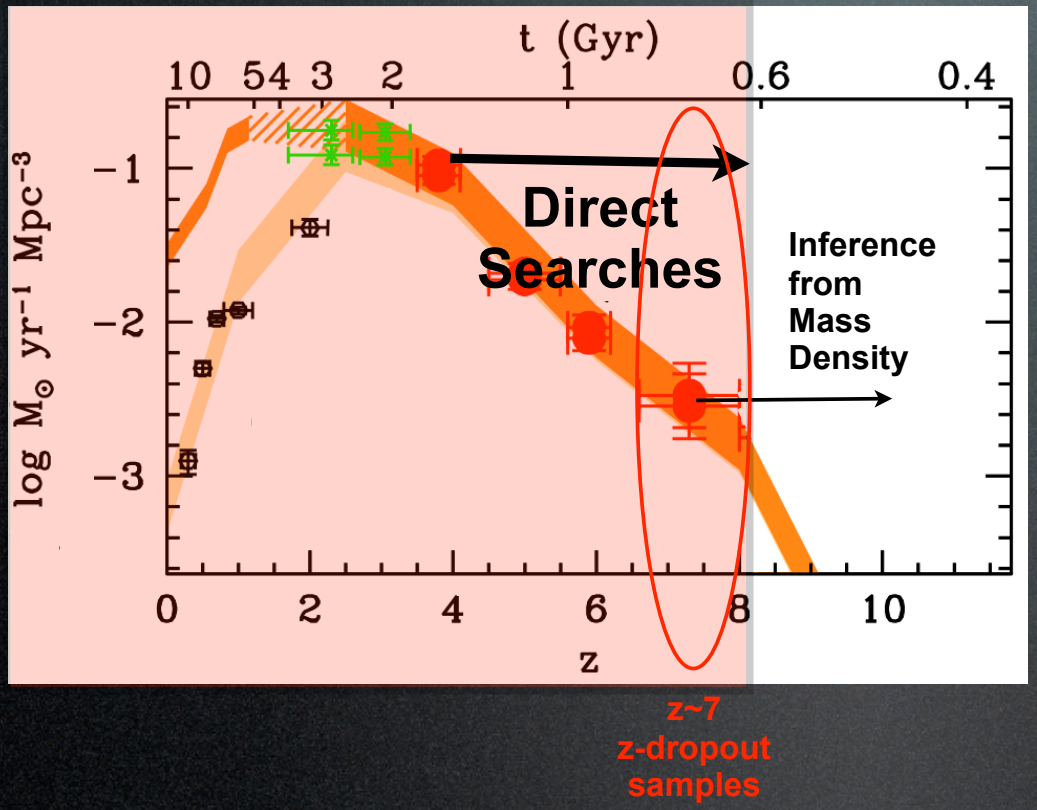
SFR density at z>7



Challenge:
Difficult at present to determine SFR density at z>7 from direct searches

Solution:
Infer SFR density at z>7 from stellar mass density estimates at z~7

Bouwens et al. 2008, 2009; Magnelli et al. 2009; Reddy & Steidel 2009; Schiminovich et al. 2005; and much other work...

Stellar Masses of z~7-8 Galaxies

Spitzer data are key for stellar mass estimates

~4μm IRAC images → rest-frame optical at z~7 → Stellar Mass

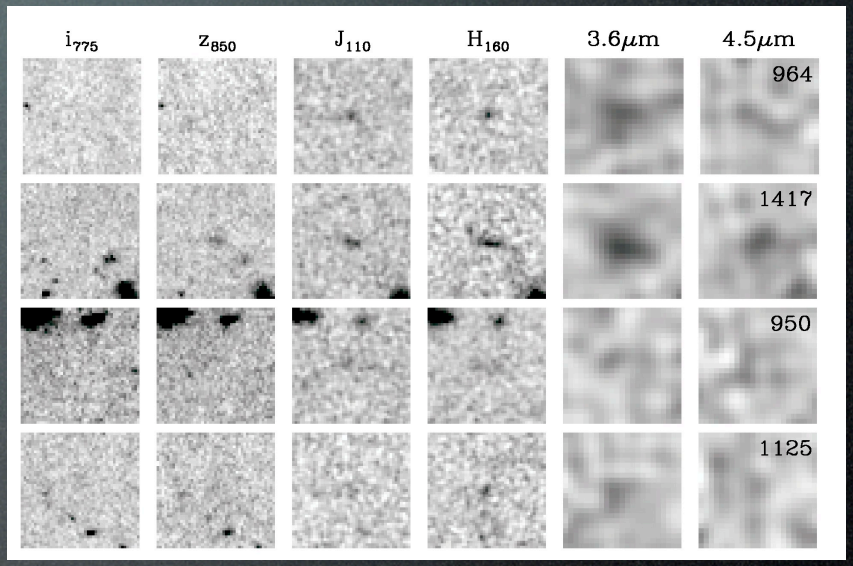
In 2006, we estimated the stellar masses of z~7 galaxy candidates using the HUDF data

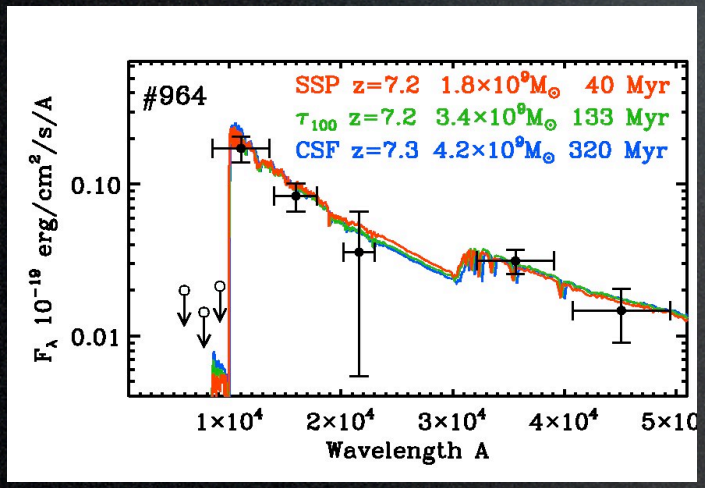
HUDF

z-dropouts

HST/NICMOS Rest-frame UV

Spitzer/IRAC Rest-frame Optical





Stellar Masses of 0.3 - 1.0 x 10^{10} $M_\odot$

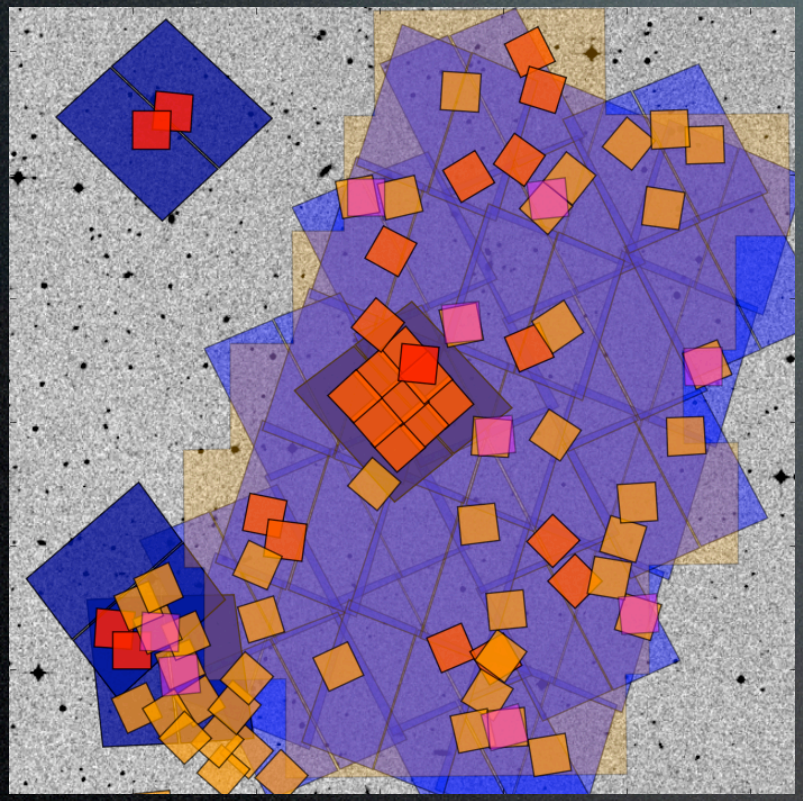
Ages of ~50-200 Myr

Stellar Mass Density at z~7.4 (> 0.3 L*) is 20-60% of z~5-6 values

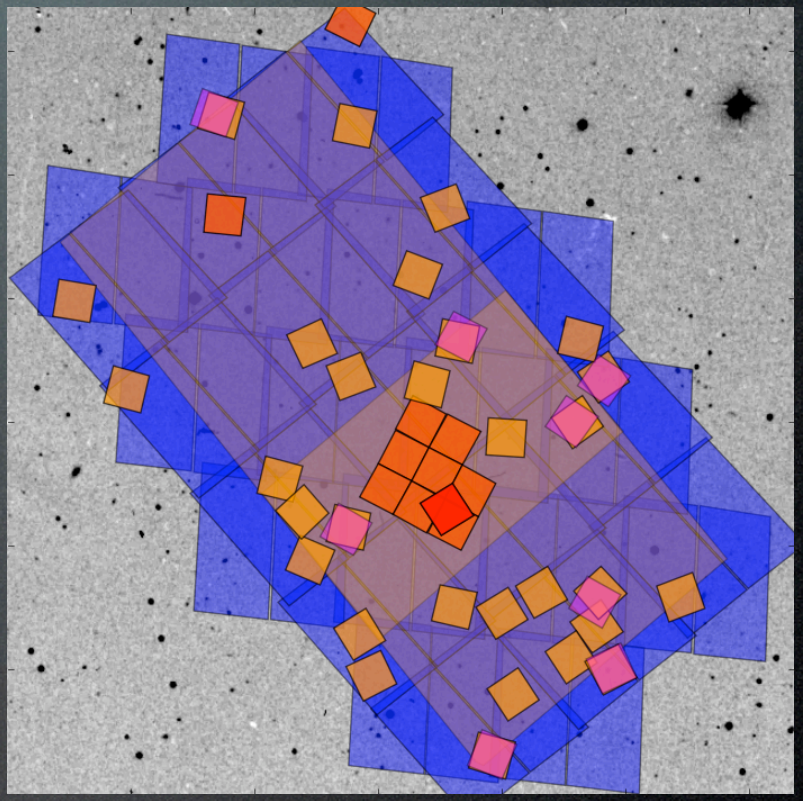
Labbe, Bouwens, Illingworth, Franx, *Ap.J.*, 2006

Very wide area, deep near-IR data available now to expand searches for z~7 galaxies

>= 80 arcmin^2 of Deep (J_{110} ~ H_{160} >= 26.5 AB mag) NICMOS coverage



CDF-S GOODS

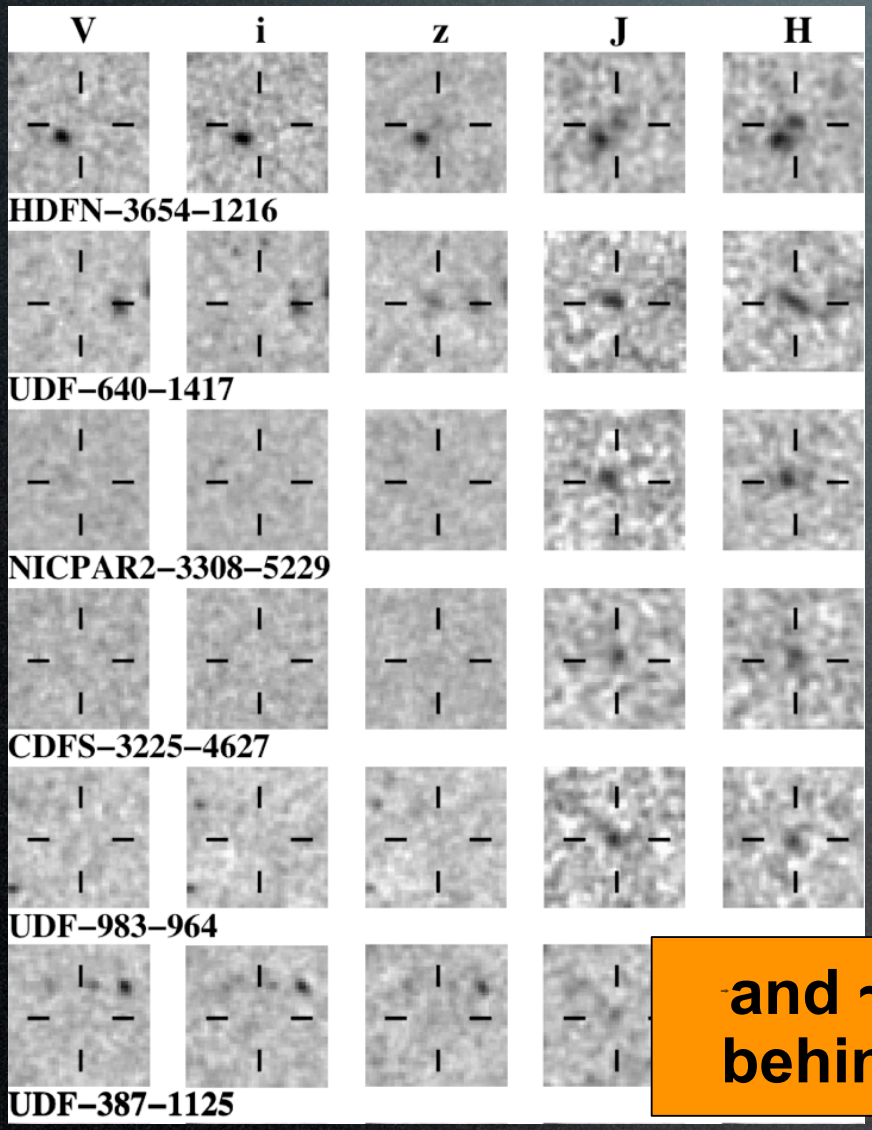


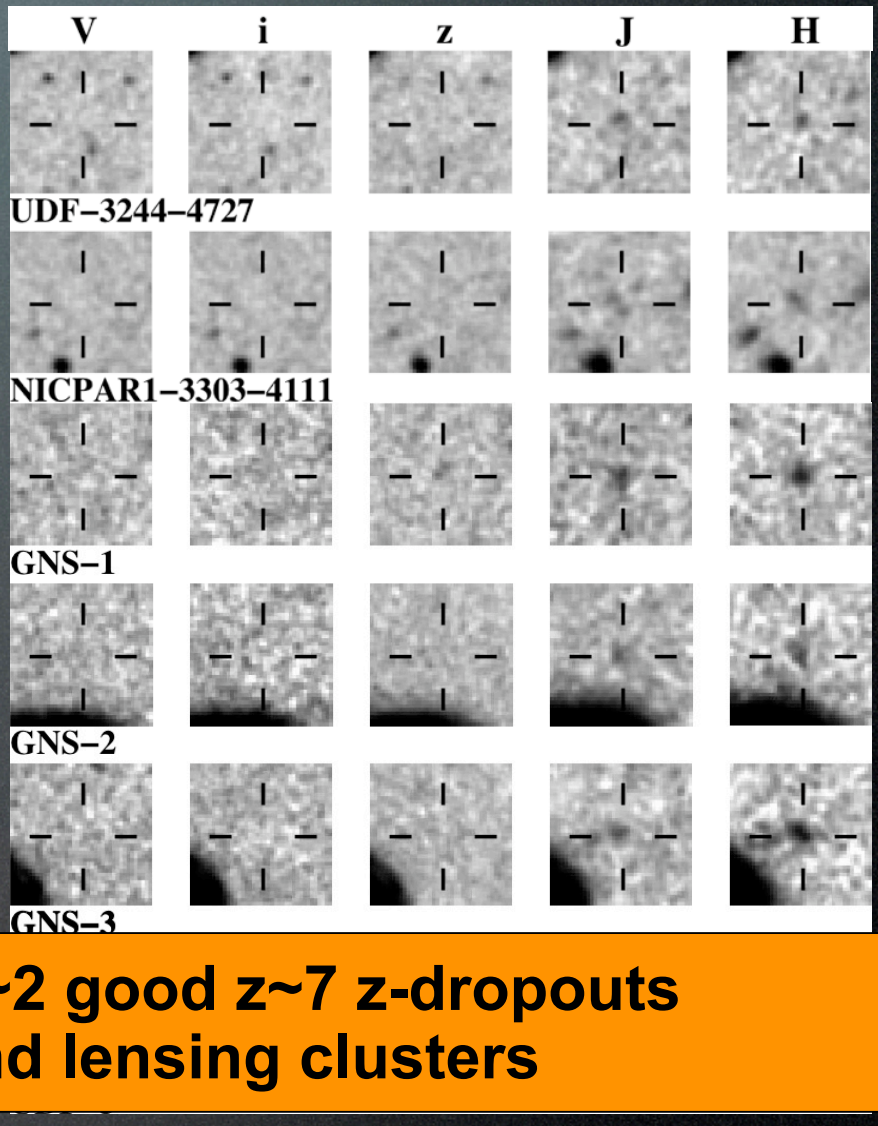
HDF-N GOODS

Bouwens et al. 2009

15 candidate z~7 z-dropouts

(12 shown here)

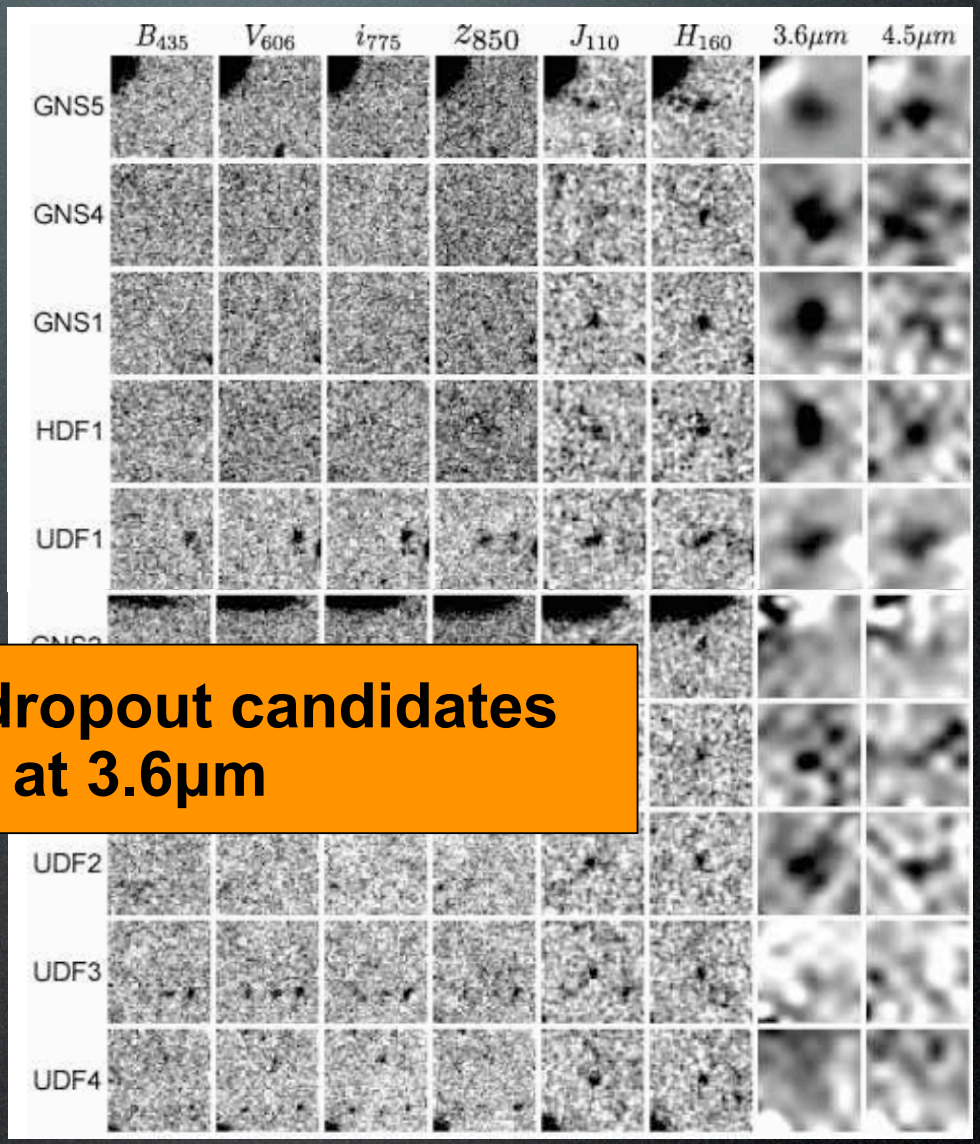




and ~2 good z~7 z-dropouts behind lensing clusters

Bouwens et al. 2009

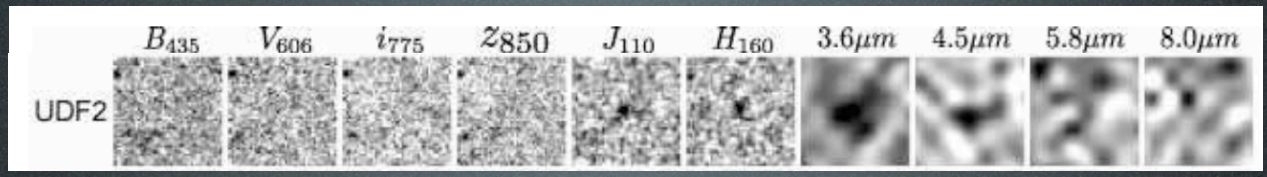
Image cutouts of new sample of z-dropouts

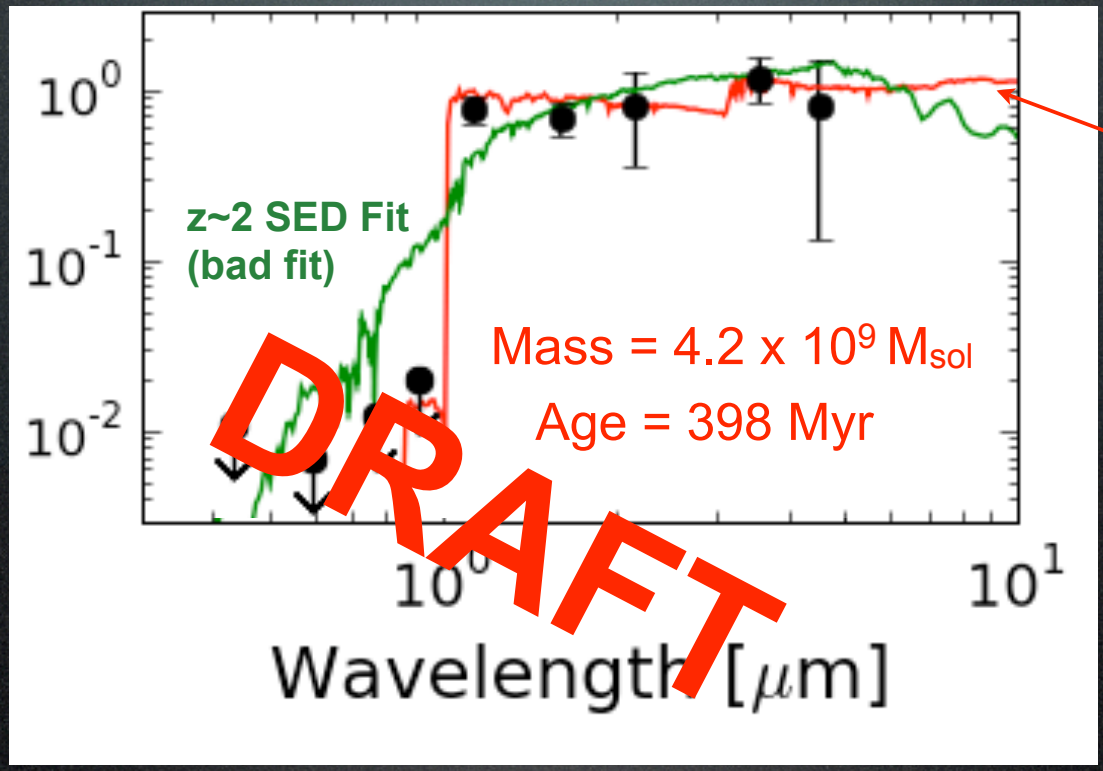


> 50% of z~7 z-dropout candidates clearly detected at 3.6μm

Gonzalez et al. 2009

SED Modelling of z~7 Galaxy Candidates

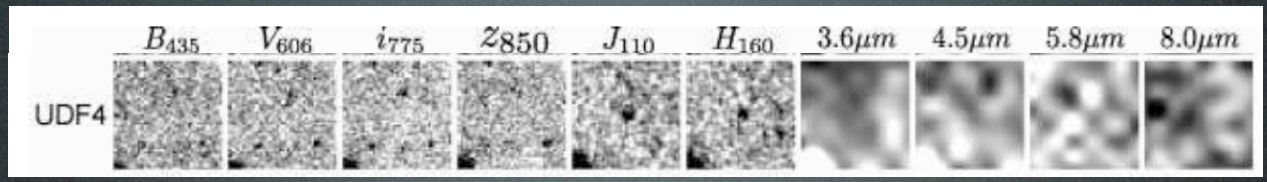


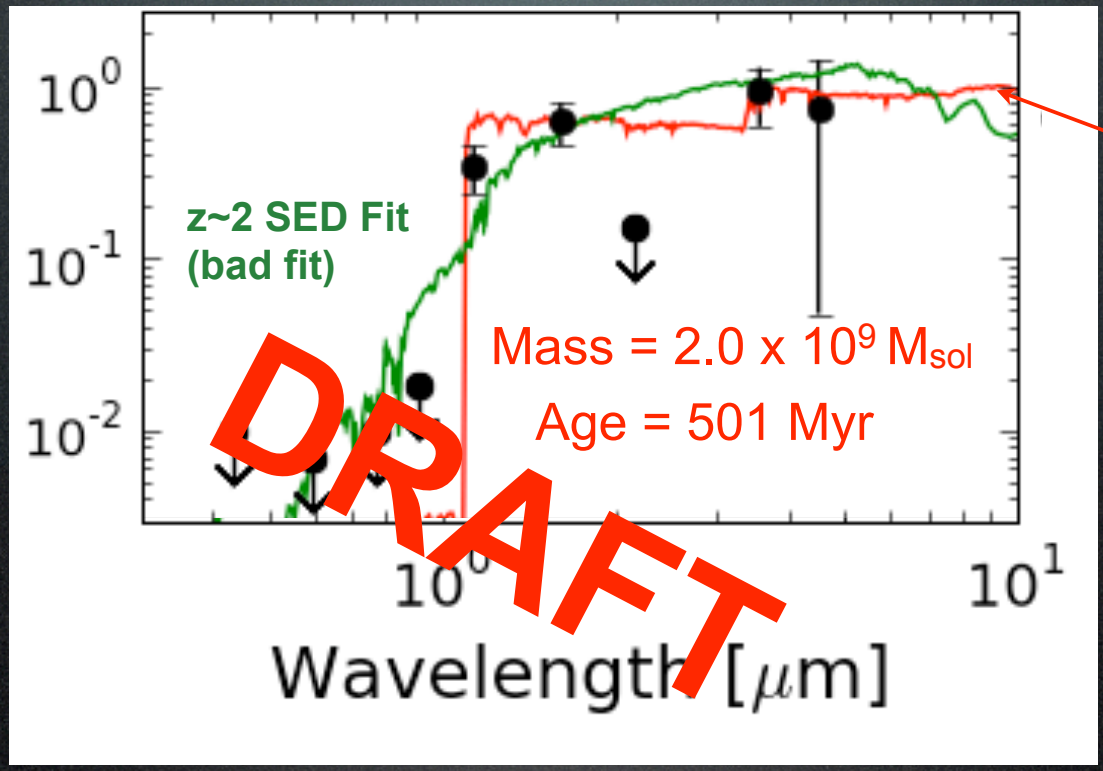


Flux
10^{30} ergs s^{-1} cm^{-1} Hz^{-1}

Gonzalez et al. 2009

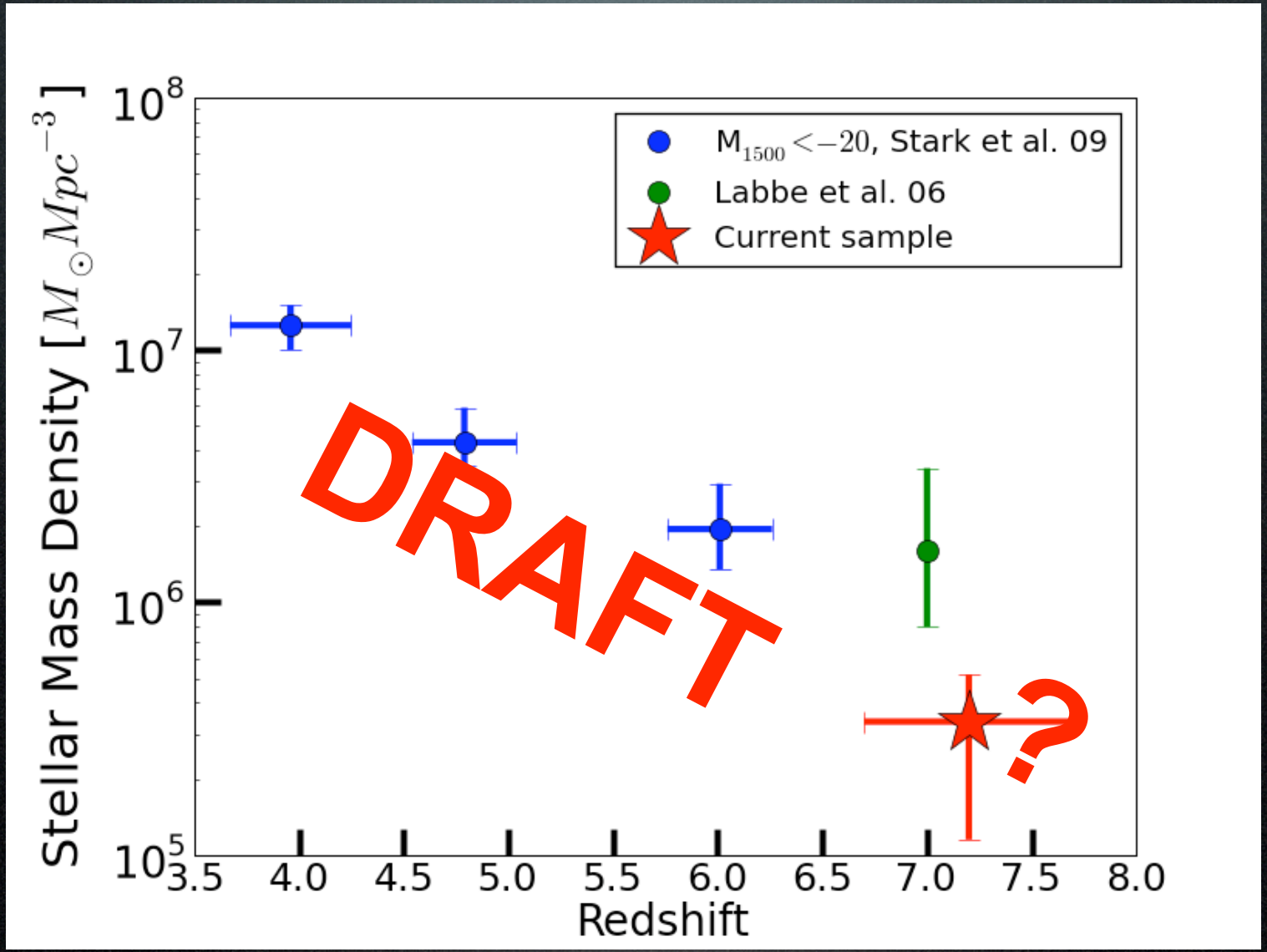
SED Modelling of z~7 Galaxy Candidates





Gonzalez et al. 2009

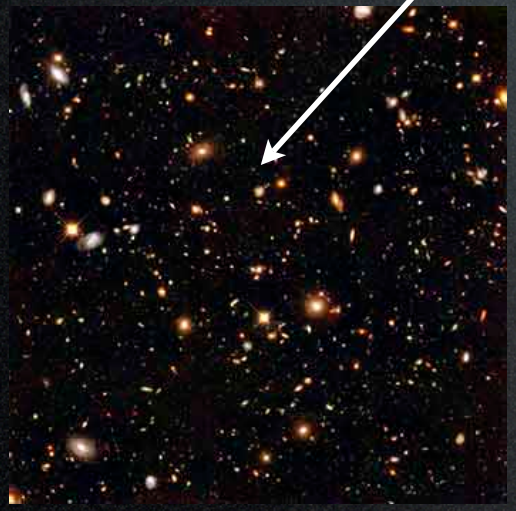
Stellar Mass Density



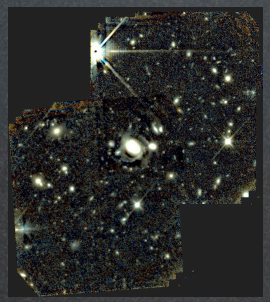
Gonzalez et al. 2009

Probing further down the mass function with deeper Spitzer data

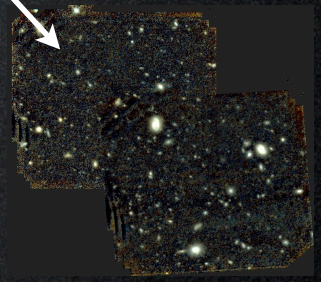
HUDF



HUDF05-1



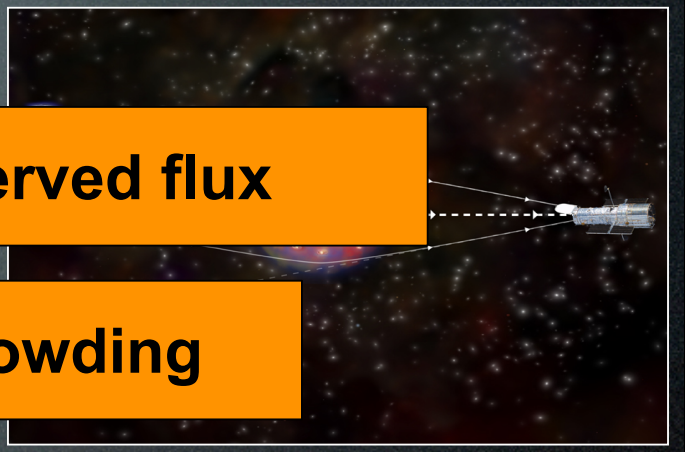
HUDF05-2



z>=4 galaxies from gravitational lensing

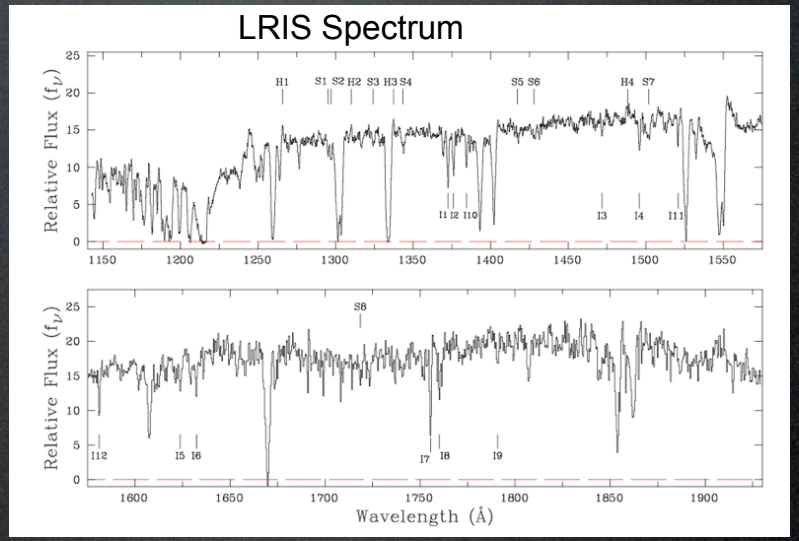
Abell 1689

Using gravitational lensing by clusters to look at mass in lower luminosity galaxies



- **Significantly enhance observed flux**
- **Significantly reduce crowding**

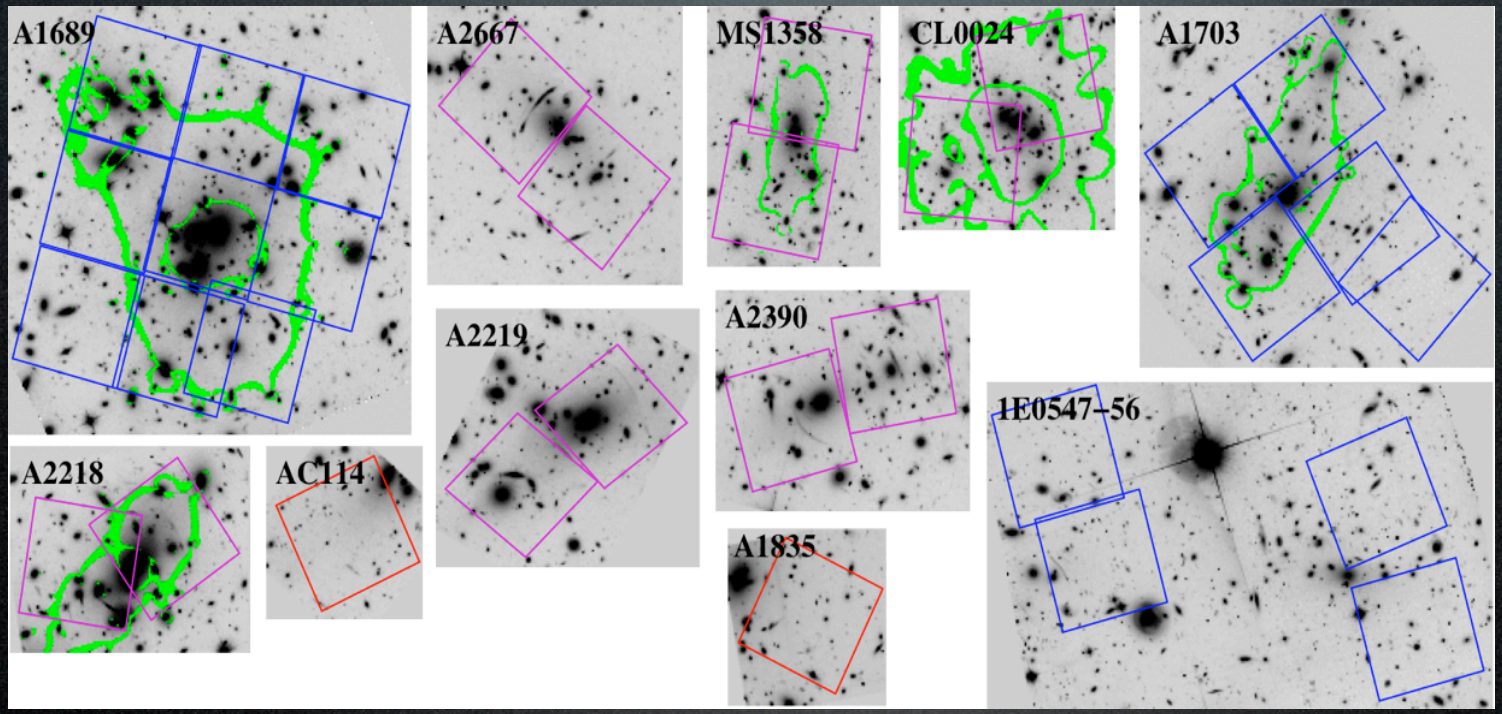
Massive galaxy clusters have certainly proven useful for magnifying the fluxes of faint galaxies that would have too low of fluxes for detailed studies, e.g., cB58 at z=2.72



Substantial magnification of the flux from cB58 allows us to study it in great detail

Searching for Lower Luminosity Galaxies that have been highly magnified by massive galaxy clusters

Cluster Search Fields:
-- 23 arcmin^2 search area (11 clusters)

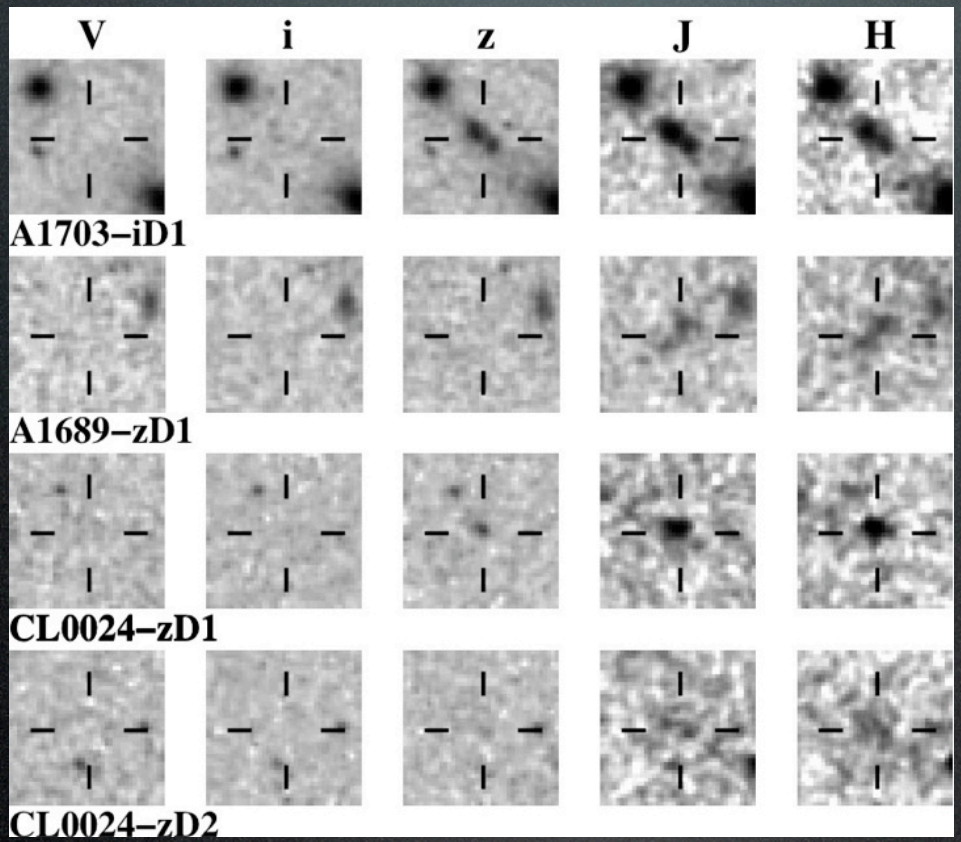


Bouwens et al. 2009; Zheng et al. 2009; see also Richard et al. 2008

Searching for Lower Luminosity Galaxies that have been highly magnified by massive galaxy clusters

Cluster Search Fields:

-- 4 bright z~6-7 candidates found + Kneib et al. 2004 z~6.5 candidate



z~6.1

z~7.6

z~6.5

z~6.8

4 other z>=7 candidates (but which do not have deep enough optical data to be sure)

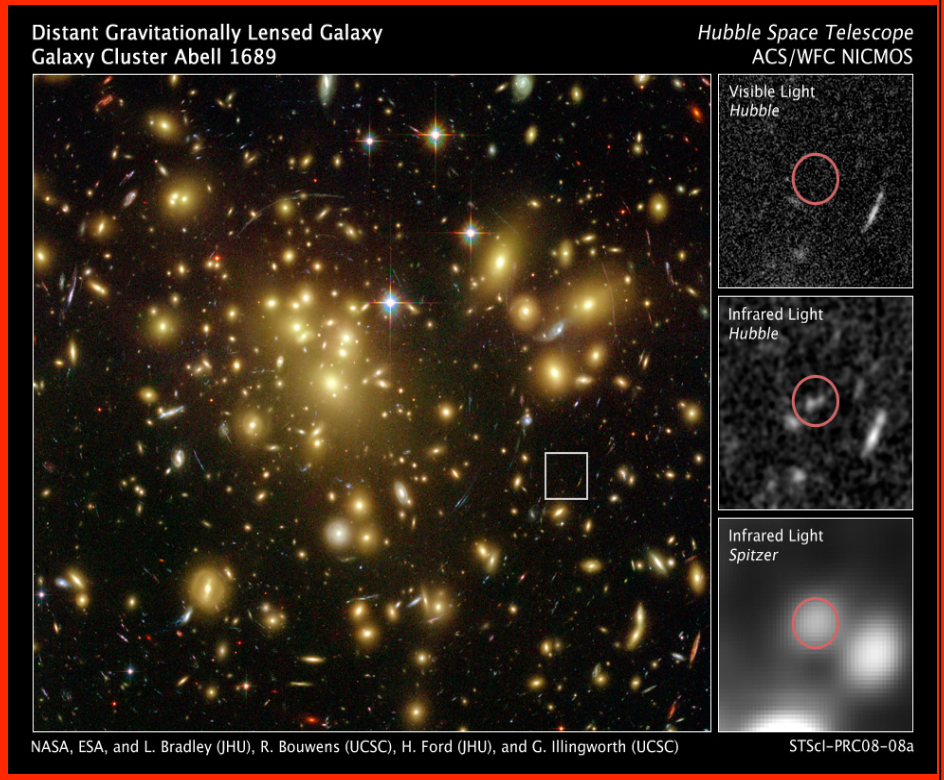
Bouwens et al. 2009; Zheng et al. 2009; see also Richard et al. 2008

Searching for Lower Luminosity Galaxies that have been highly magnified by massive galaxy clusters

Cluster Search Fields:

-- 4 bright z~6-7 candidates found +

z~7.6 candidate (Bradley et al. 2008)



4 other z>=7 candidates (but which do not have

Bouwens et al. 2009; Zheng et al. 2009

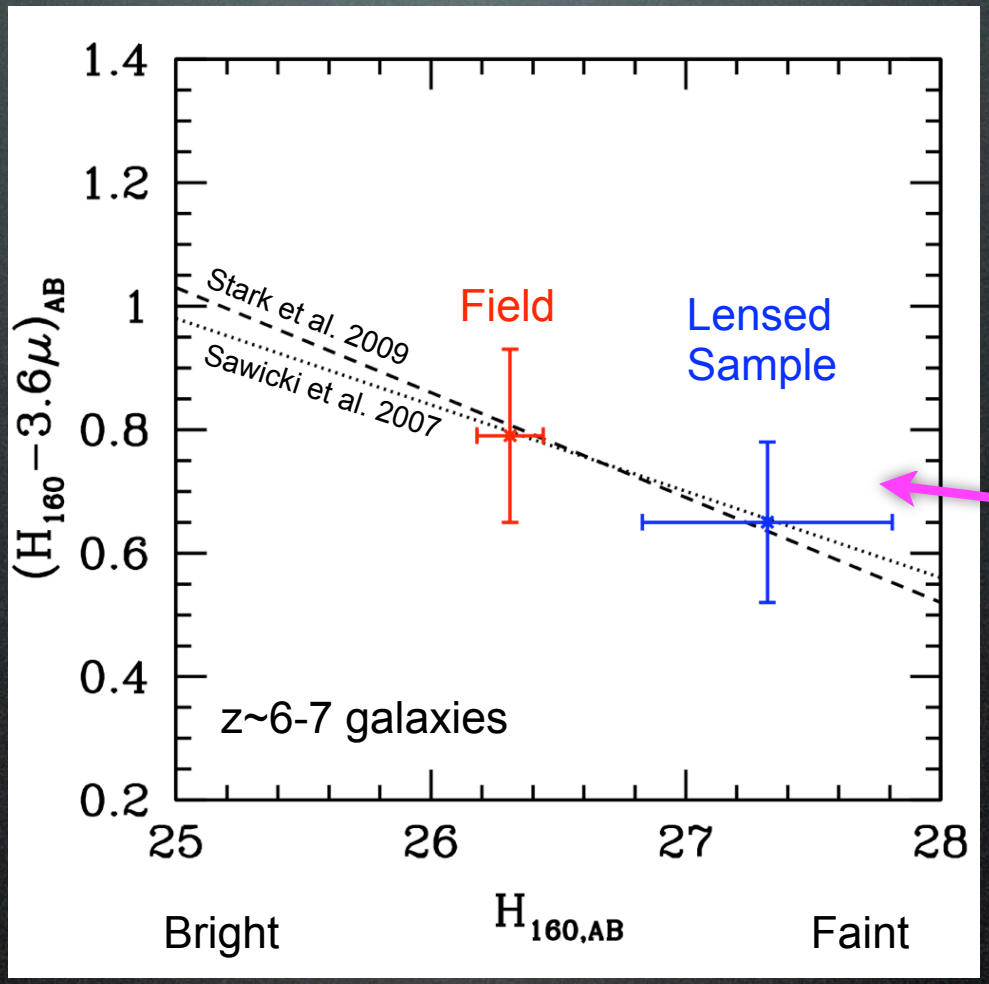
z~6.5 candidate (Kneib et al. 2004)

How do lower luminosity lensed galaxies differ from brighter field galaxies in terms of their Balmer Breaks?

Old
High
M/L

Balmer
Break

Young
Low
M/L



Fainter
Galaxies
Have Lower
M/L ratios

Zheng, Bradley, Bouwens et al. 2009

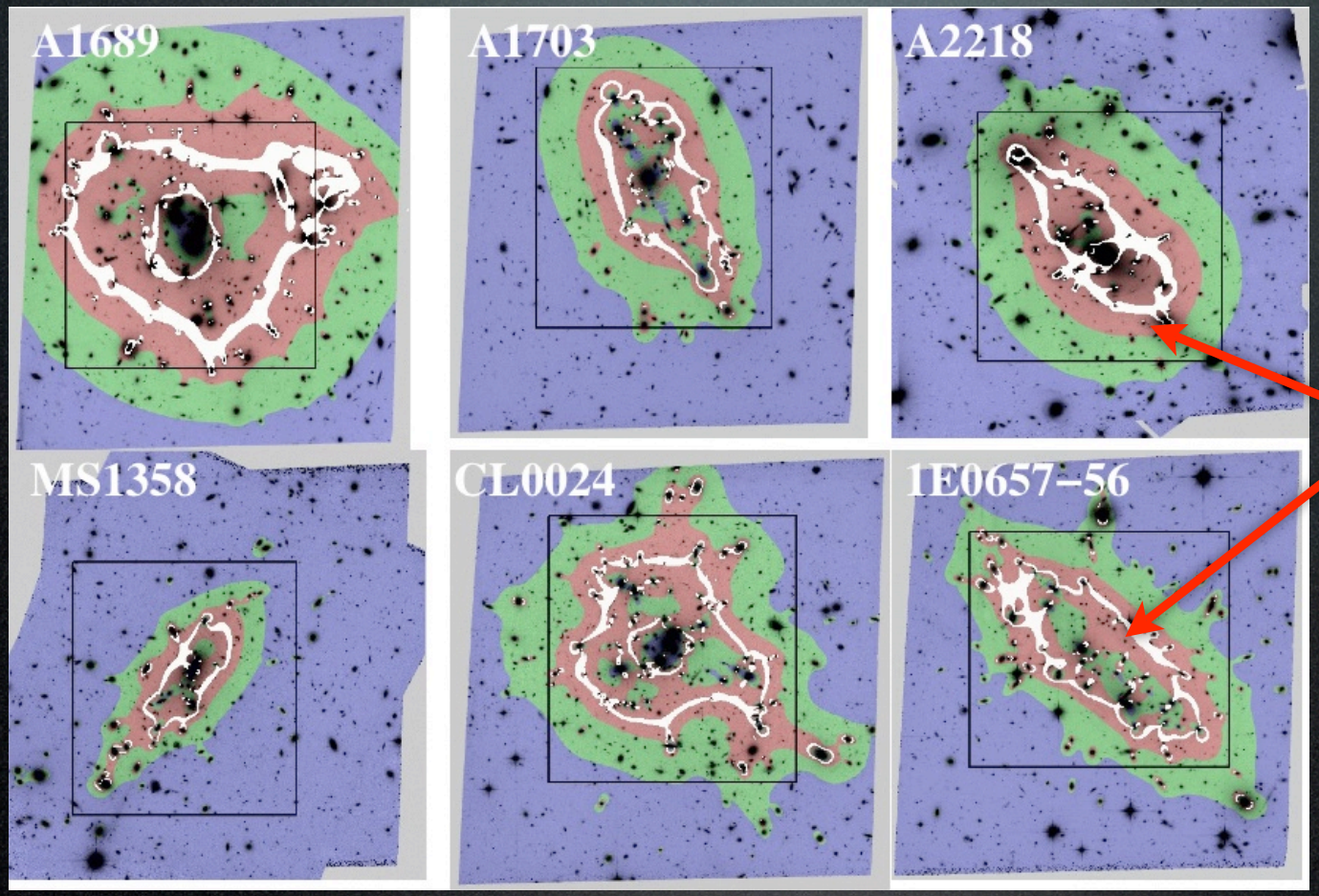
Not only search for
lensed galaxies at z~6-8

But also

Search for lensed galaxies at
z~4-6 behind galaxy clusters...

Six clusters with deep HST optical data + lensing models

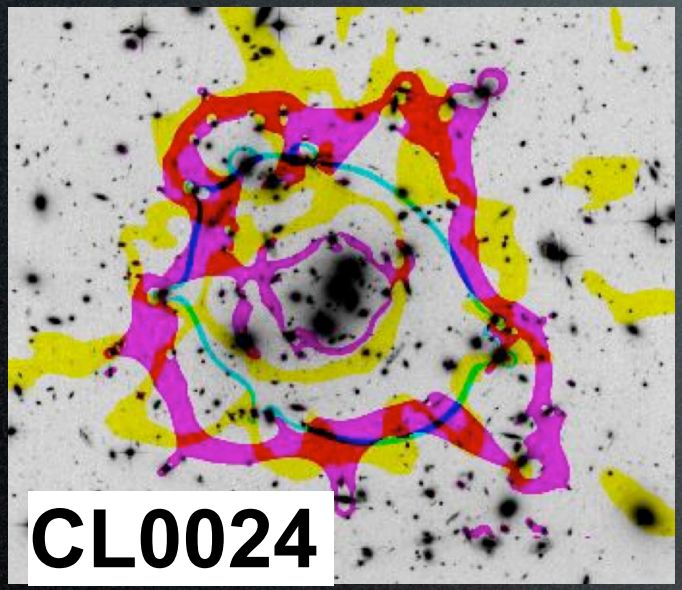
(reaching 27.5 AB mag)



Models: Limousin et al. 2007, 2009; Eliasdottir et al. 2008; Franx et al. 1997; Zitrin et al. 2009; Bradac et al. 2007

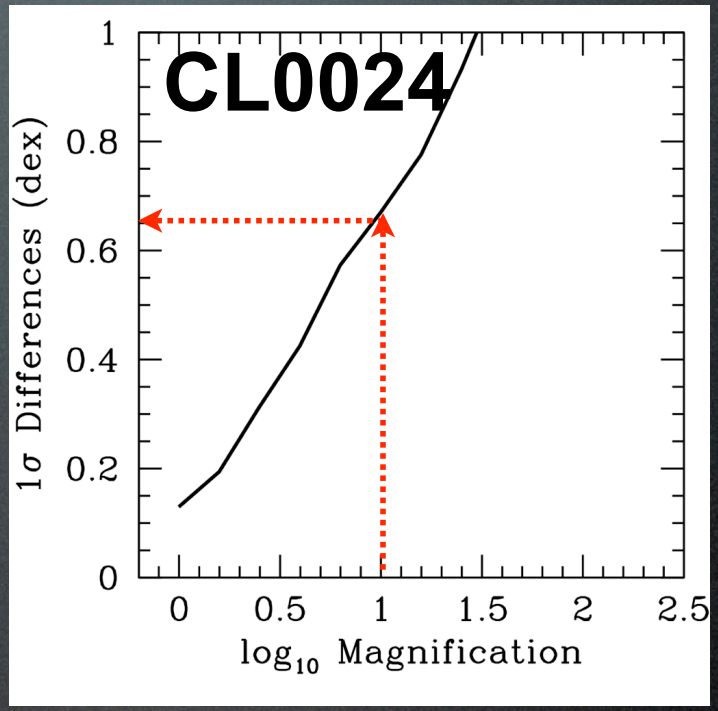
How well can we use lensing by clusters to find highly magnified (> 7x) galaxies?

Note that we consider all galaxies lensed by > factor of 7 together to be conservative



few sets of arcs
weak lensing constraints

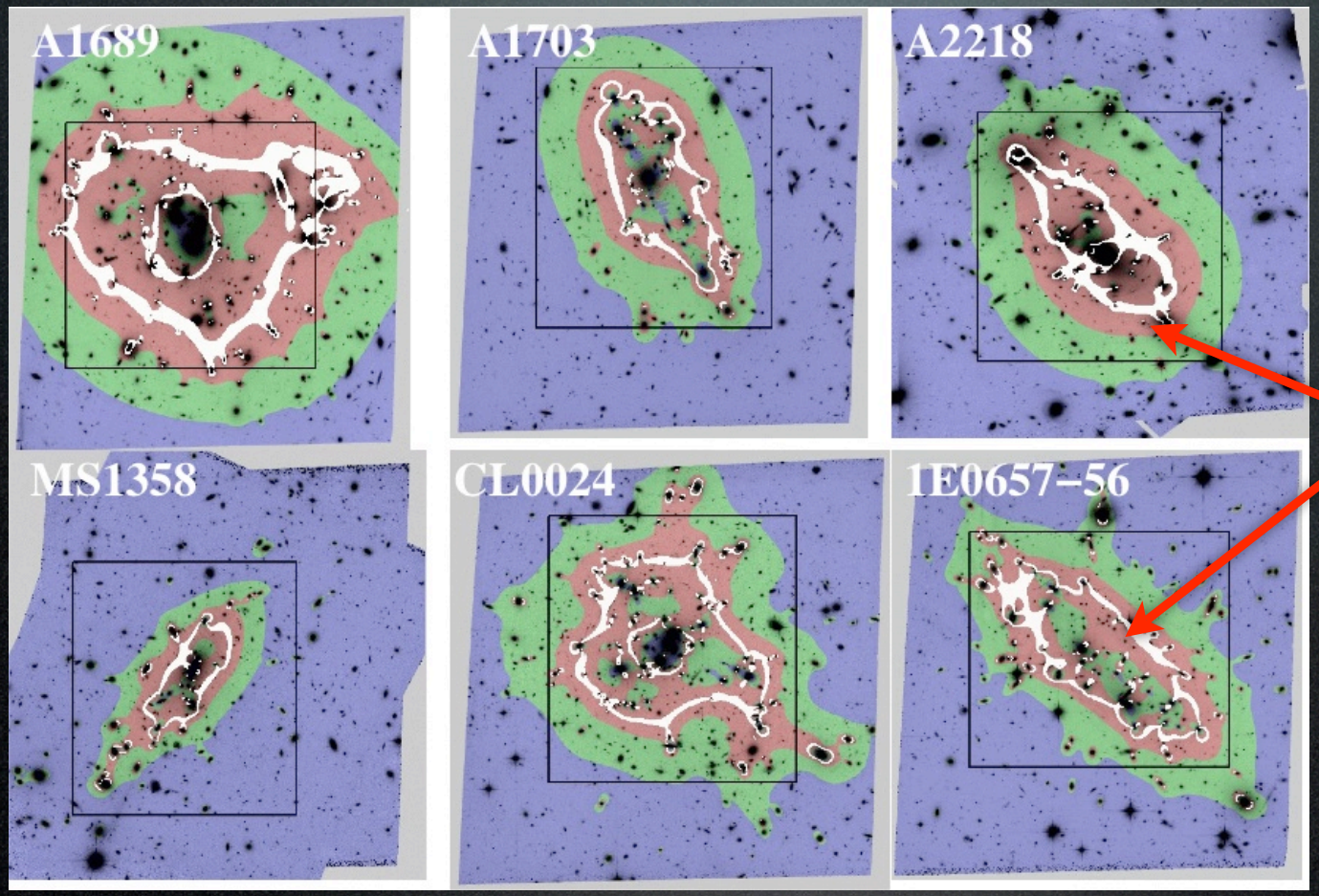
Model-to-model Dispersion in magnification maps



Factor of ~4 uncertainties at magnification factors of ~10....

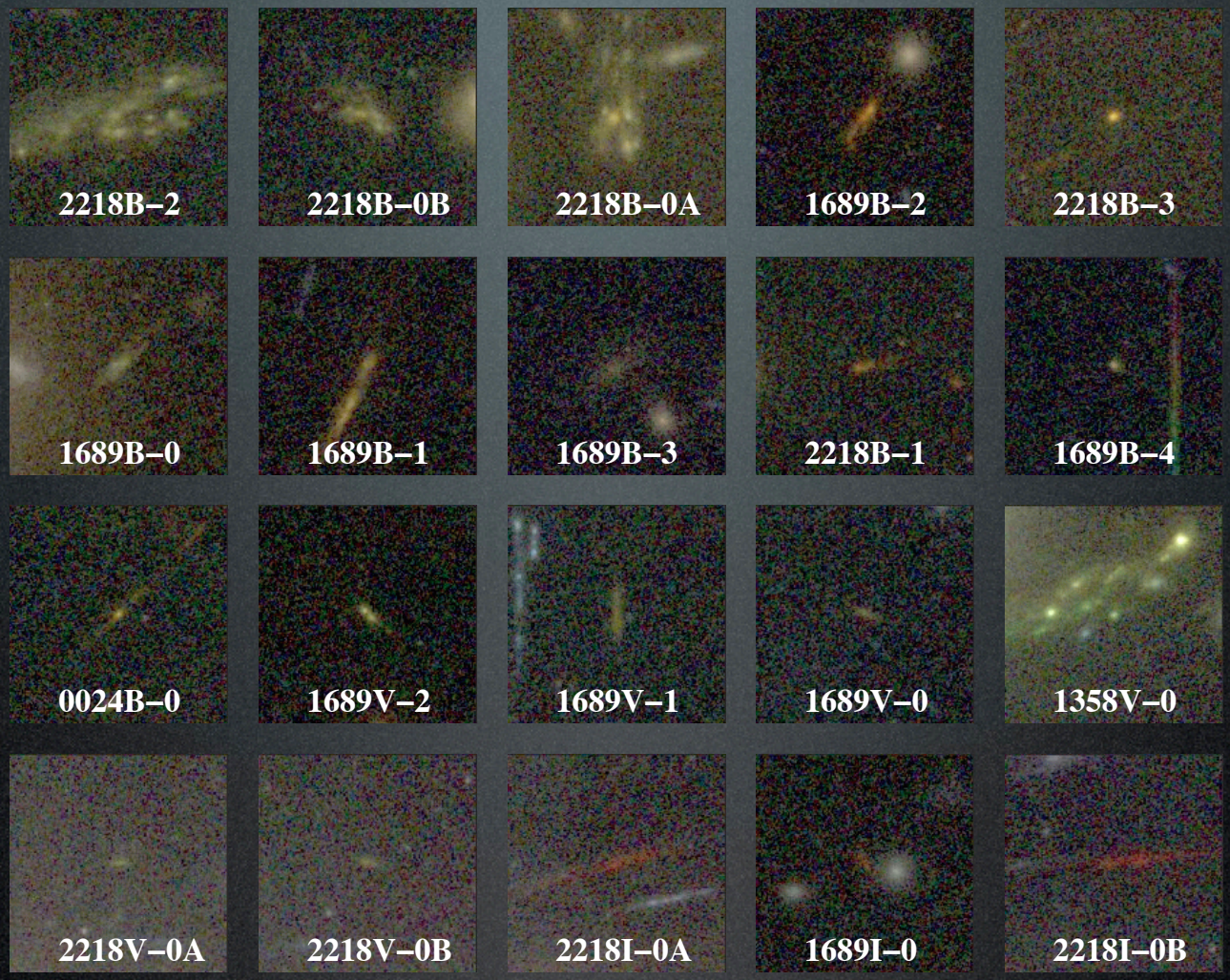
Six clusters with deep HST optical data + lensing models

(reaching 27.5 AB mag)



Models: Limousin et al. 2007, 2009; Eliasdottir et al. 2008; Franx et al. 1997; Zitrin et al. 2009; Bradac et al. 2007

Sample of 20 Highly Magnified (>7x magnification) z~4-6 Galaxies:

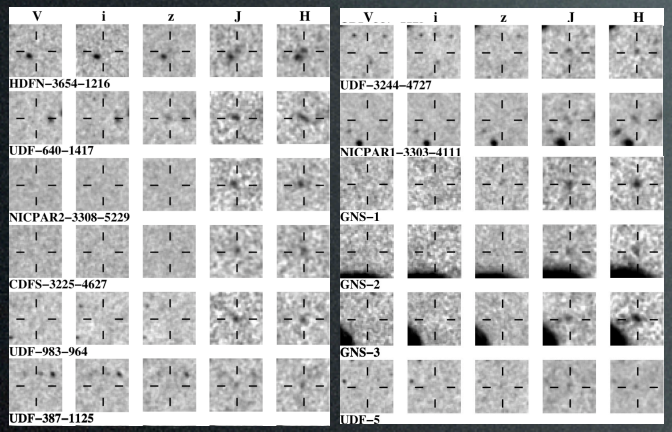


11 z~4 galaxies,
6 z~5 galaxies,
3 z~6 galaxies

IAP -- 7/8/2009

Summary

With current (~15 object) z-dropout selections, we can begin deriving much more robust estimates of stellar mass density at z~7

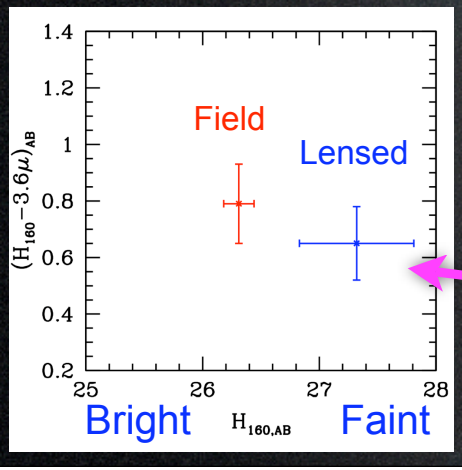


Gravitational Lensing by galaxy clusters is extremely useful for detailed studies of very faint z~4-8 galaxies, but may be challenging for conducting LF studies

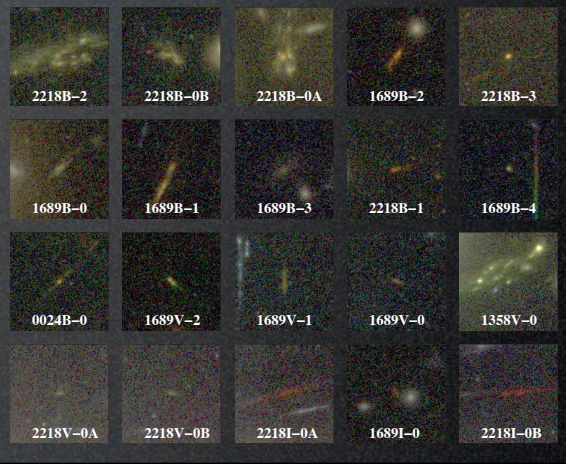
High

M/L ratio

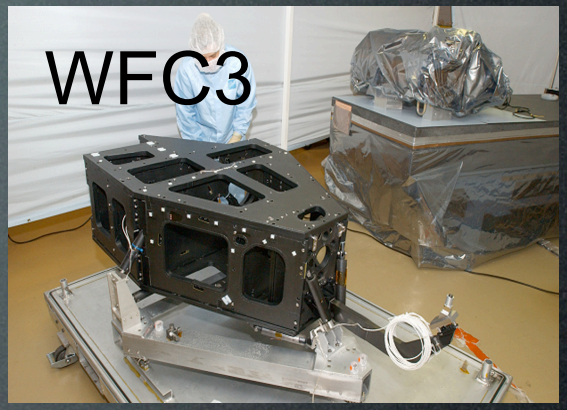
Low



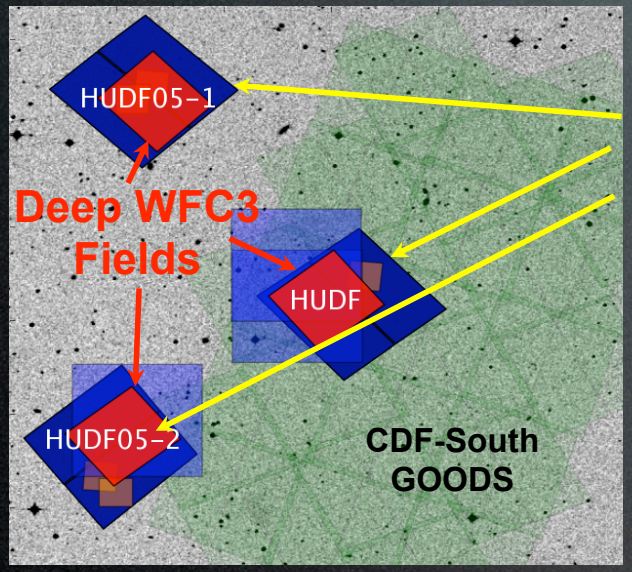
Fainter Galaxies Have Lower M/L ratios



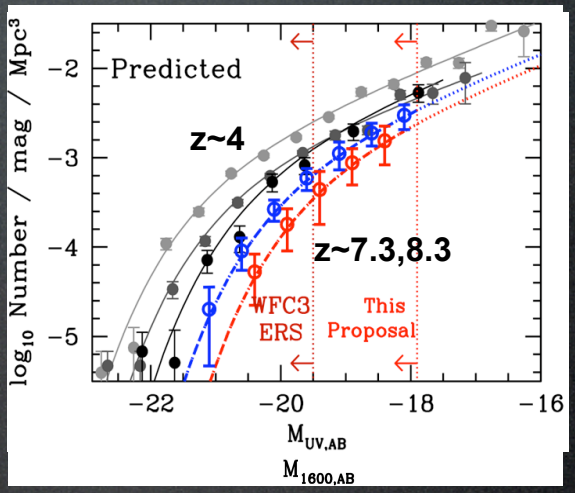
The Future



HUDF09 WFC3/IR program



Deepest optical data



192 WFC3/IR orbits:
96 orbits / 1 field
48 orbits / 2 fields

Will reach ~29 AB mag in near-IR (1.05,1.25,1.60 microns)
Should find 50-100 z>=7 galaxies