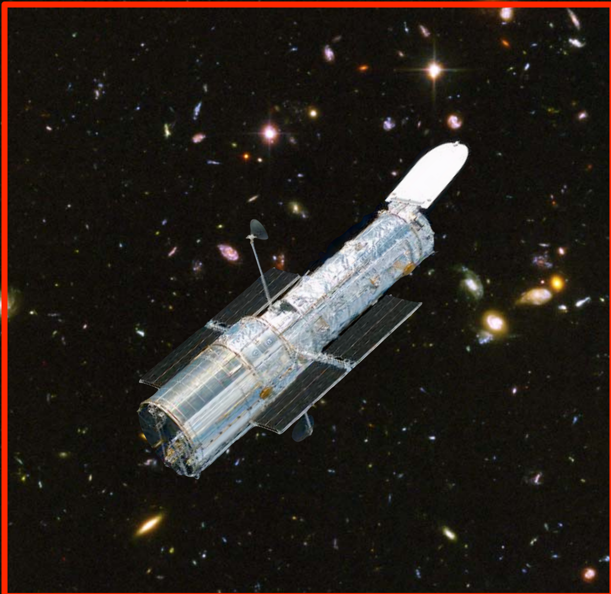
AAS January 2010 Washington DC
Science with the New HST



The HUDF09 program: exploring the nature of galaxies in the first 700 million years with WFC3 and ACS

Garth Illingworth
(UCO/Lick Obs & University of California, Santa Cruz)
and the HUDF09 team

the HUDF09 team

TEAM

These results are based on data from the original HUDF and the WFC3/IR and ACS cameras as proposed under GO11563 by the HUDF09 team:

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M. Carollo (Swiss Federal Institute of Technology, Zurich)
M. Franx (Leiden University)
I. Labbe (Carnegie Institution of Washington)
D. Magee (University of California, Santa Cruz)
P. Oesch (Swiss Federal Institute of Technology, Zurich)
M. Stiavelli (STScI)
M. Trenti (University of Colorado, Boulder)
P. van Dokkum (Yale University)

a resource for high-redshift galaxies see:
firstgalaxies.org
http://firstgalaxies.org/

for astro-ph links to papers see:
http://firstgalaxies.org/hudf09
firstgalaxies.org/hudf09

revealing galaxies 13 billion years ago

what WFC3 enabled

Hubble's new Wide Field Infra-Red Camera (WFC3/IR) has revealed redshift z~8 galaxies, just 600-700 million years after recombination.

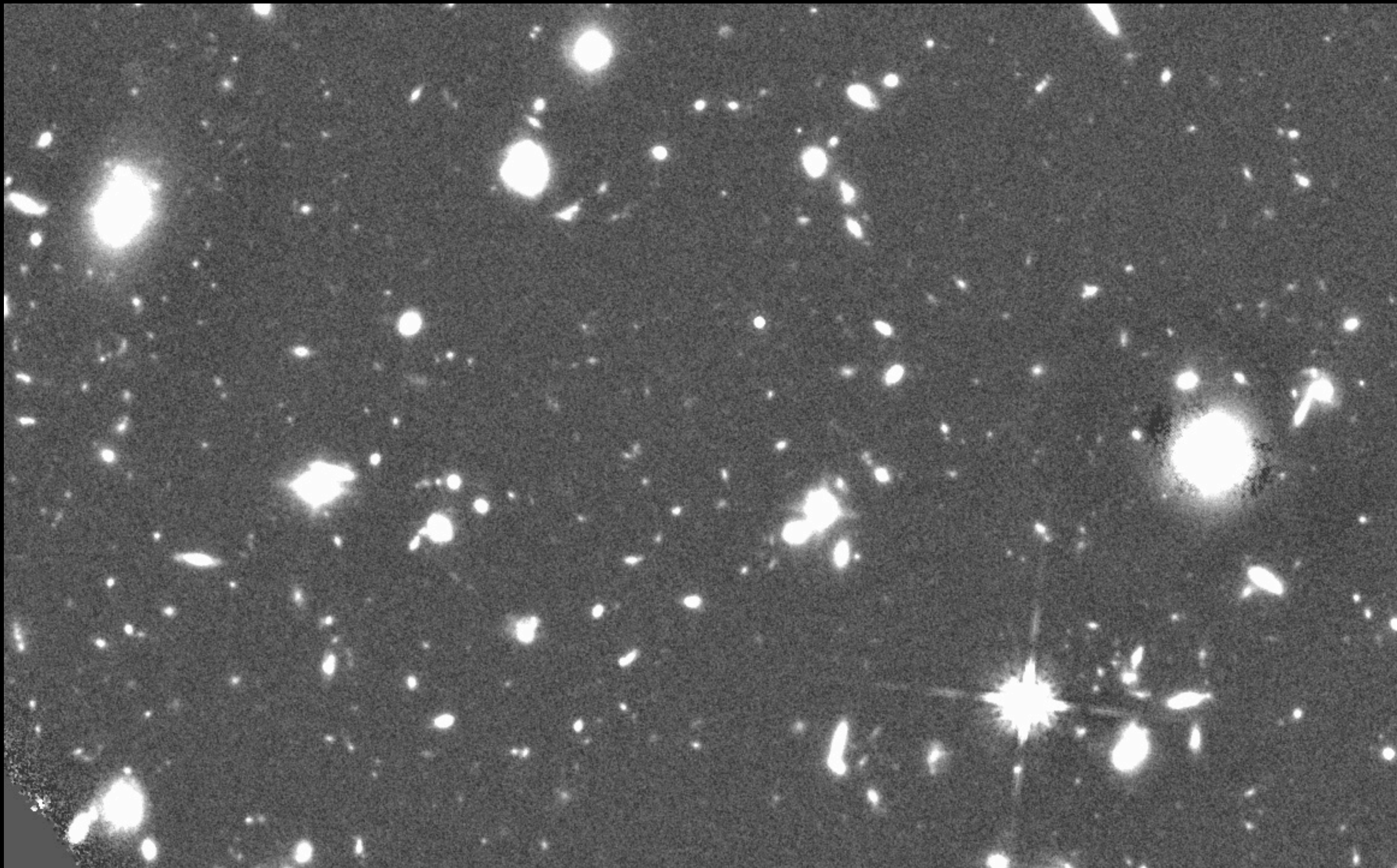
This is just 6 years after Hubble revealed z~6 galaxies (950 million years after recombination) using the Advanced Camera for Surveys (ACS)

data and results

- substantial samples of z~7 & z~8 galaxies are being derived from both the still-incomplete HUDF09 program and the ERS program
- the z~7 and z~8 samples are enabling a characterization of the properties of galaxies just 600-800 Myr from recombination
- these galaxies lie in the heart of the reionization epoch and will provide further constraints on the role played by galaxies
- combining Hubble data with Spitzer data is setting constraints on the mass density and on even earlier populations at z~10-11

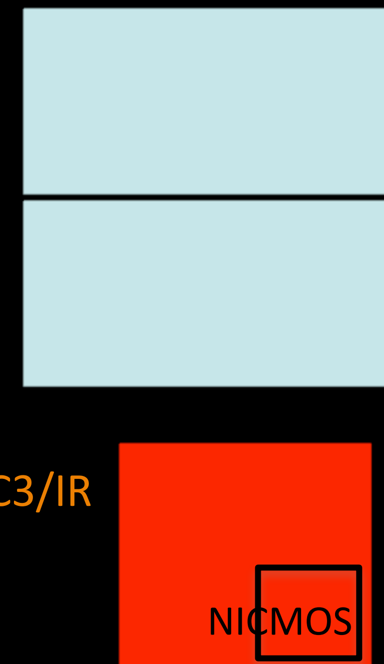
NICMOS – 72 orbits

WFC3/IR – 16 orbits



WFC3/IR *vs* NICMOS

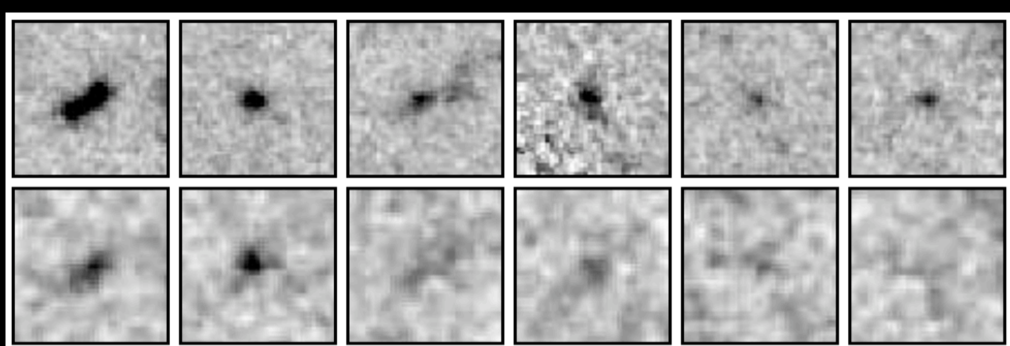
WFC3/IR is ~6X larger in area than NICMOS and much better matches ACS



to find a z~7 galaxy took ~100 orbits with NICMOS – with WFC3/IR it takes a few orbits

WFC3/IR has a discovery efficiency ~40X NICMOS

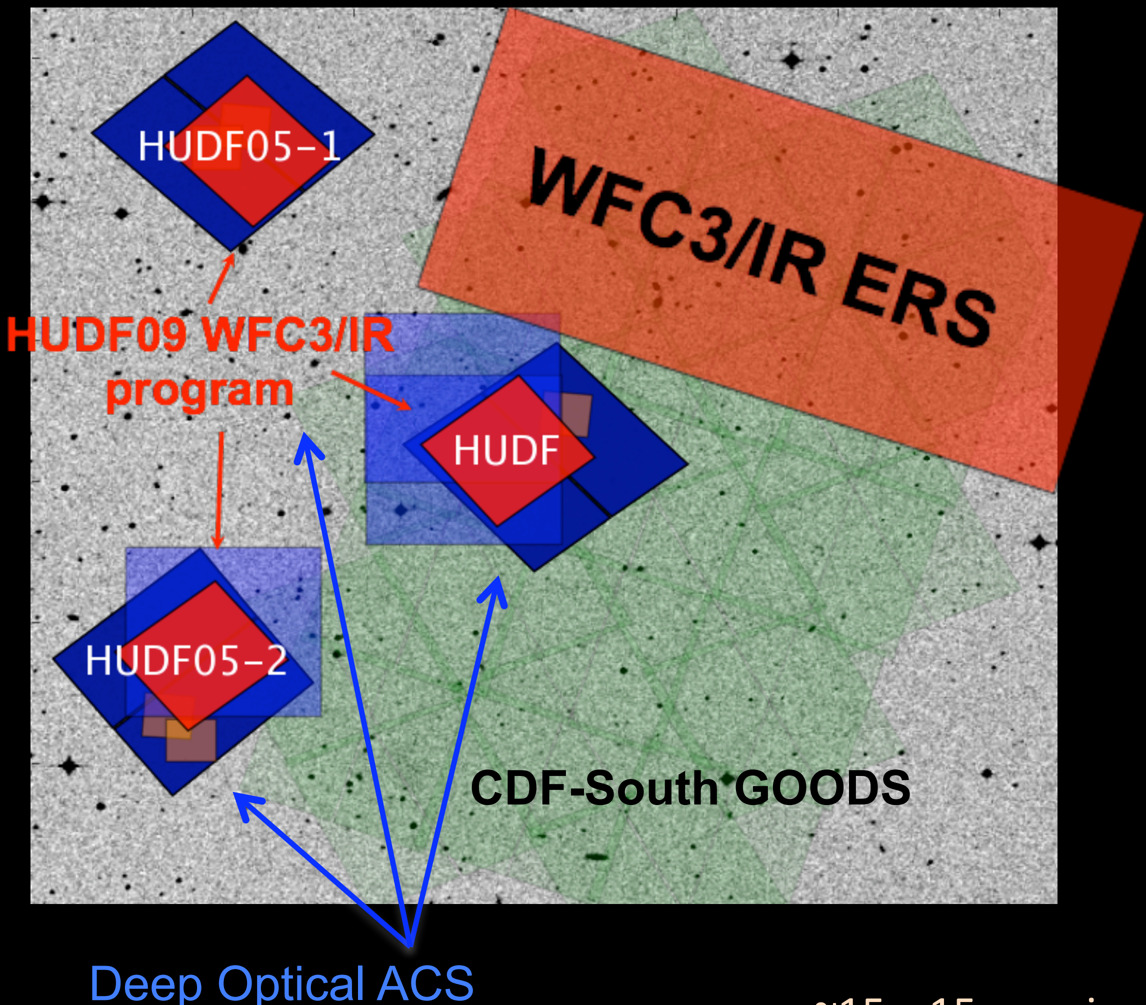
comparing the old and new Hubble infrared cameras



z~7 galaxies 2.2" x 2.2"

Oesch et al

CDF-S region is rich in data (HST, Spitzer, Chandra, etc)



ERS data taken

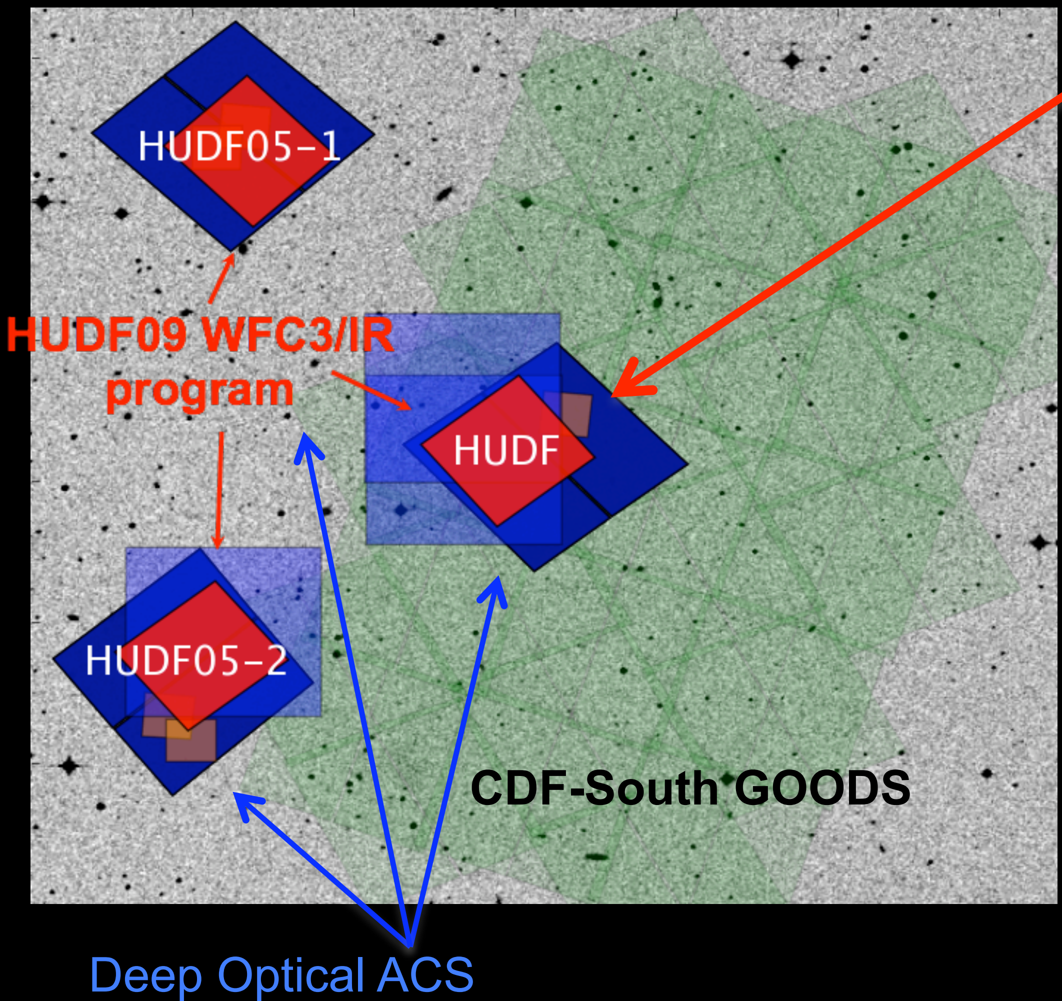
only ~1/3 of HUDF09 data taken (on HUDF)

February 2010 HUDF05-2 data to be taken

remainder to be taken later in 2010

~15 x 15 arcmin

searches for z~7-8 objects in HUDF09



HUDF09 WFC3/IR data taken in late August 2009

very competitive area!

within two weeks three groups had submitted papers on z~7-8 galaxies, followed within a month by a fourth group, and recently by a fifth group

Bouwens et al, Oesch et al

Bunker et al

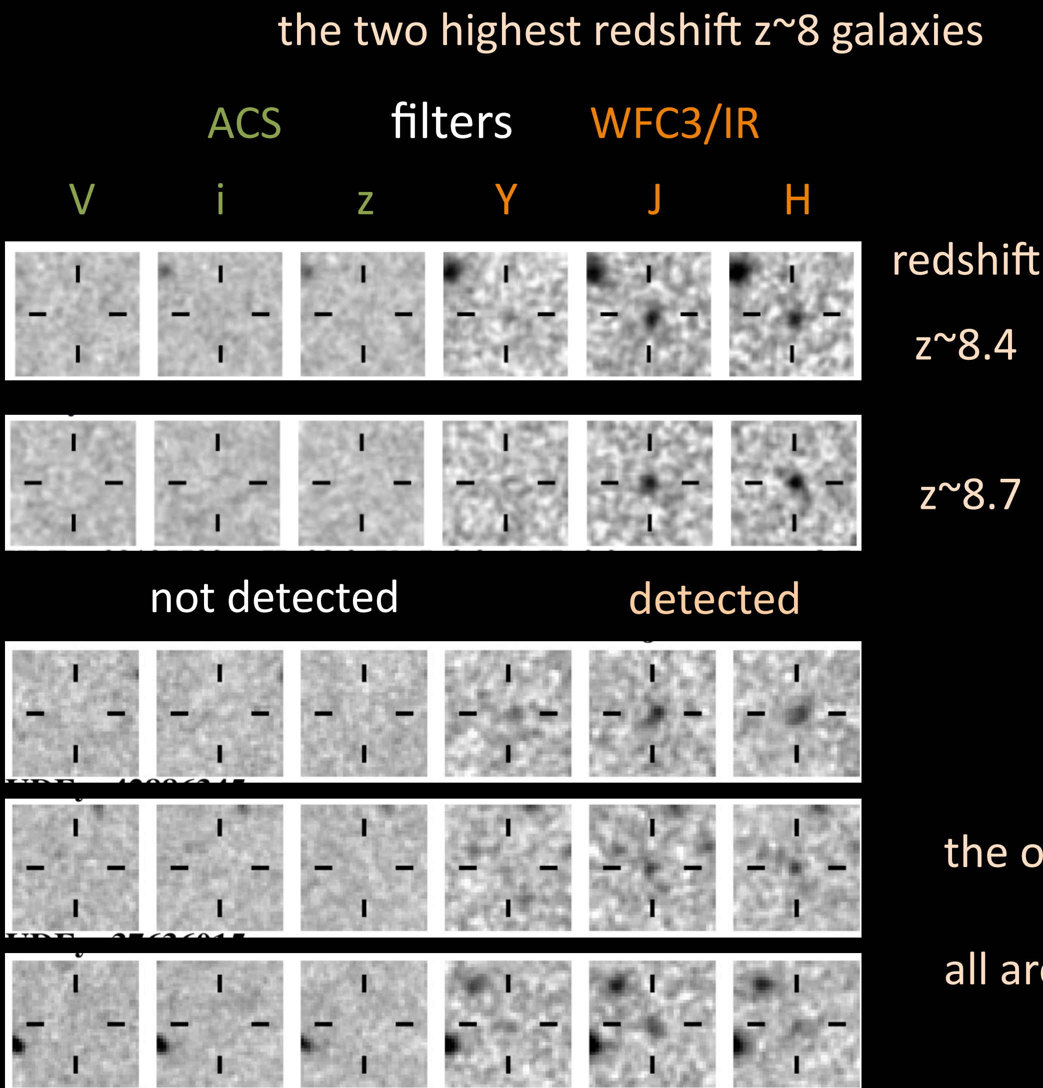
McLure et al

Yan et al

Finkelstein et al

z~7-8 galaxies are just 600-800 million years from the big bang

galaxies at z~8 from the HUDF09 team



2.4" x 2.4"

searches conducted using the very robust and well-tested photometric "dropout" technique

verified spectroscopically at z~2-6

extensive testing for contamination from photometric scatter, spurious sources, lower redshift sources….

WFC3/IR resolution helps separate galaxies from (rare) faint stars

the other three z~8 galaxies

all are H~28-29 mag sources!

Bouwens, Illingworth et al

HUDF09 team found 16 z~7 and 5 z~8 galaxies

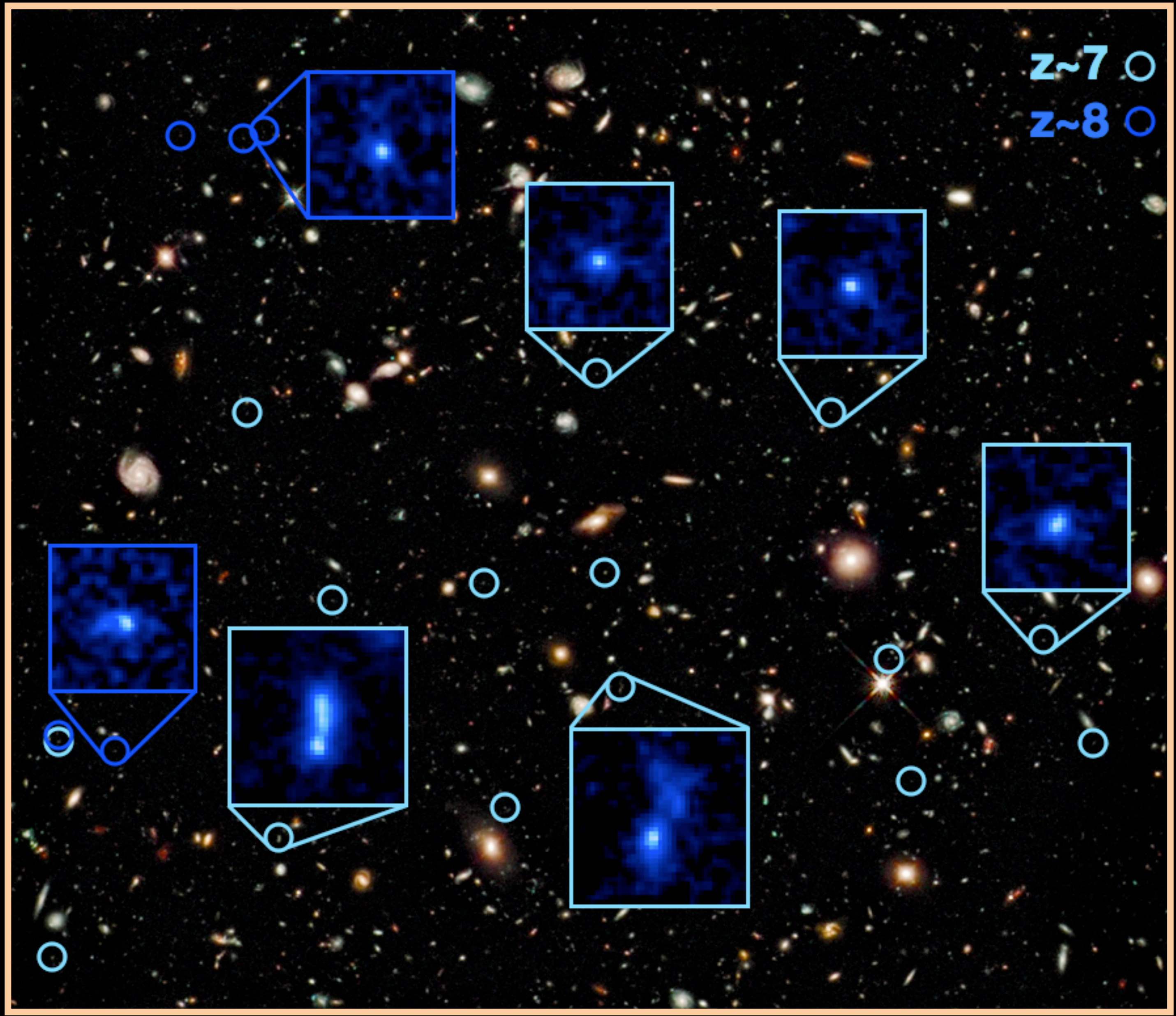
HUDF09
WFC3/IR

HUDF09
image ~2.2′

boxes ~2.5″

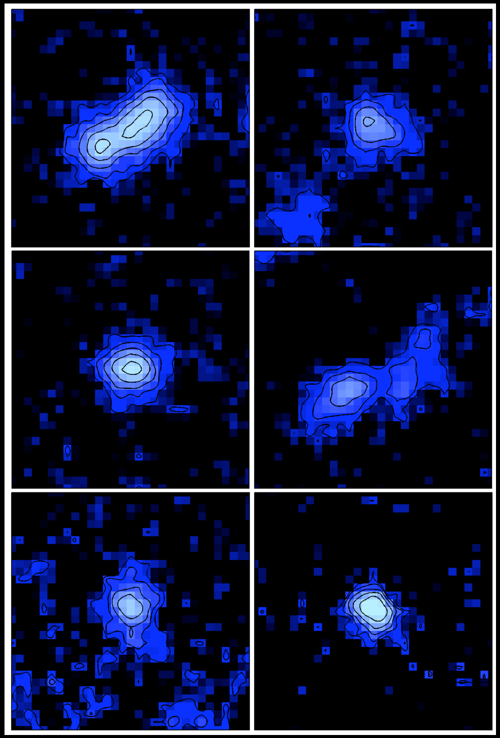
z~8
Bouwens et al

z~7
Oesch et al



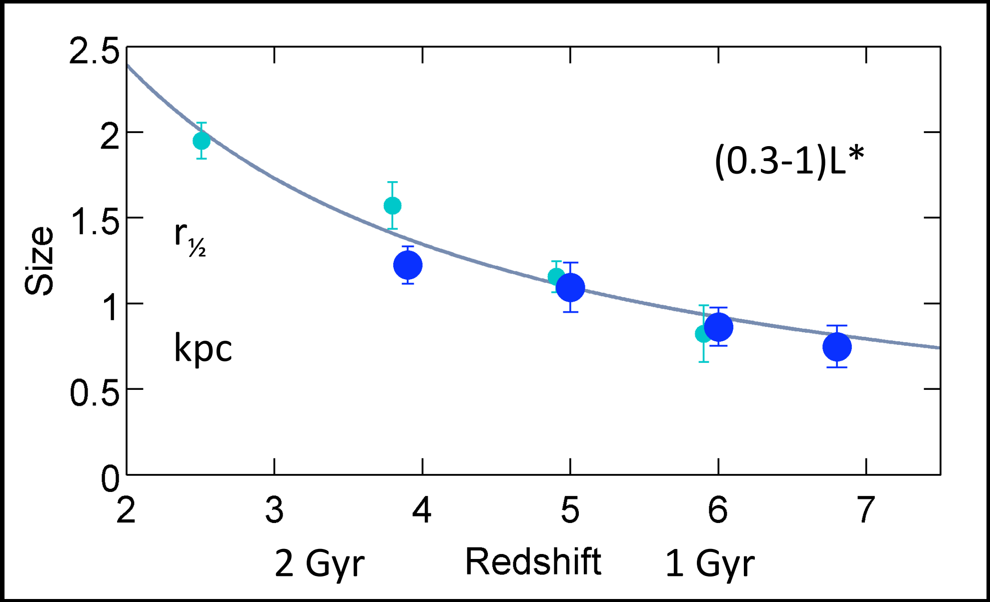
AAS *galaxies in the first 700 million years* GDI *firstgalaxies.org*

these early galaxies are small



1.8″ x 1.8″

Oesch/Carollo et al

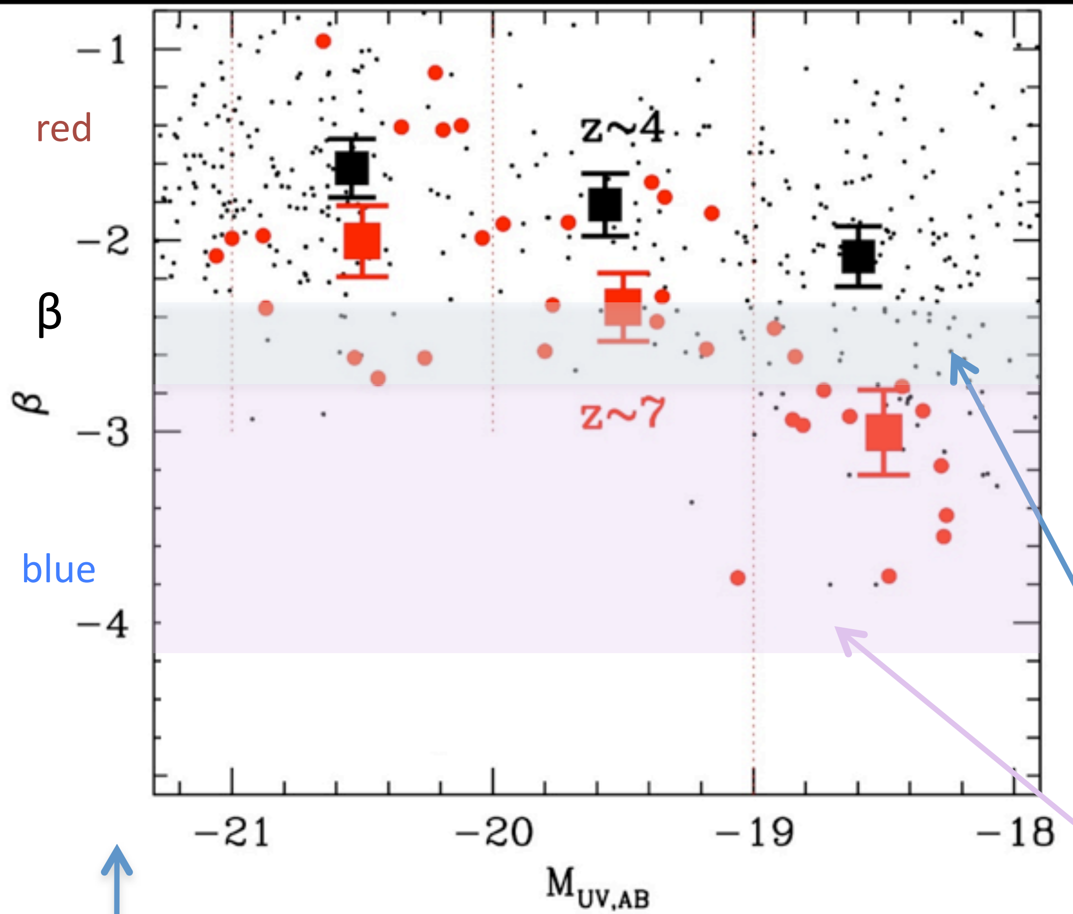


z~7 galaxies show considerable sub-structure

size scales as $(1+z)^{-m}$ where m = 1.12 ± 0.17

galaxies become very small at early times – does not appear to be a surface brightness effect (from simulations on lower redshift sources and stacking analysis)

these early galaxies are very blue



UV-continuum slope β depends upon the age, metallicity, and dust content of a star-forming population

UV-continuum slope β most sensitive to changes in dust content

but recent studies have shown that the dust content of lower luminosity, z>6 galaxies must be essentially zero

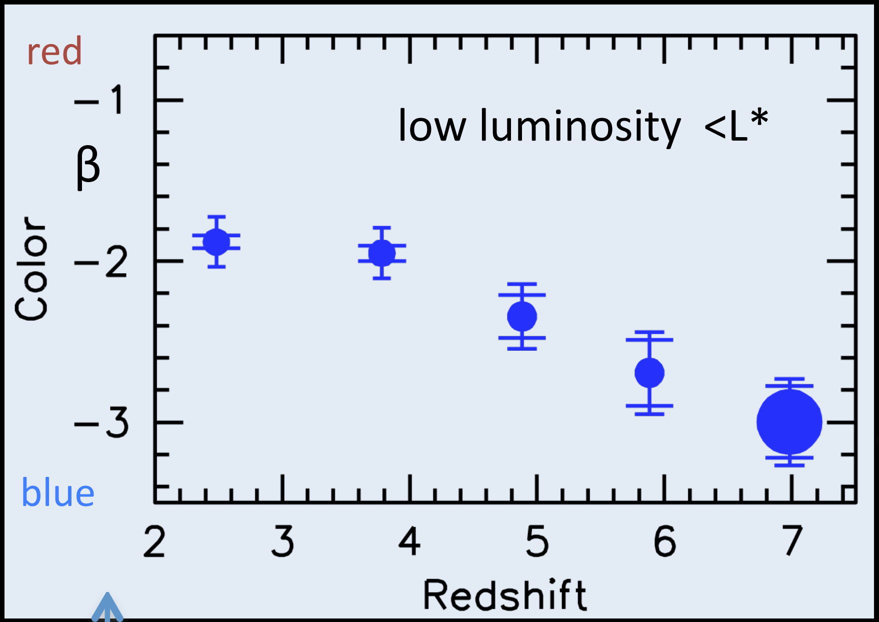
dust free at β < ~-2.4

at β < ~-2.8 standard population models do not fit (even low metal abundance models)

β is the power law slope of the UV continuum: $f_\lambda \sim \lambda^\beta$

Bouwens/Illingworth et al

these early galaxies are very blue



UV-continuum slope β most sensitive to changes in dust content – but dust content of lower luminosity, z>6 galaxies is zero

so changes at z>6 must be due to other effects

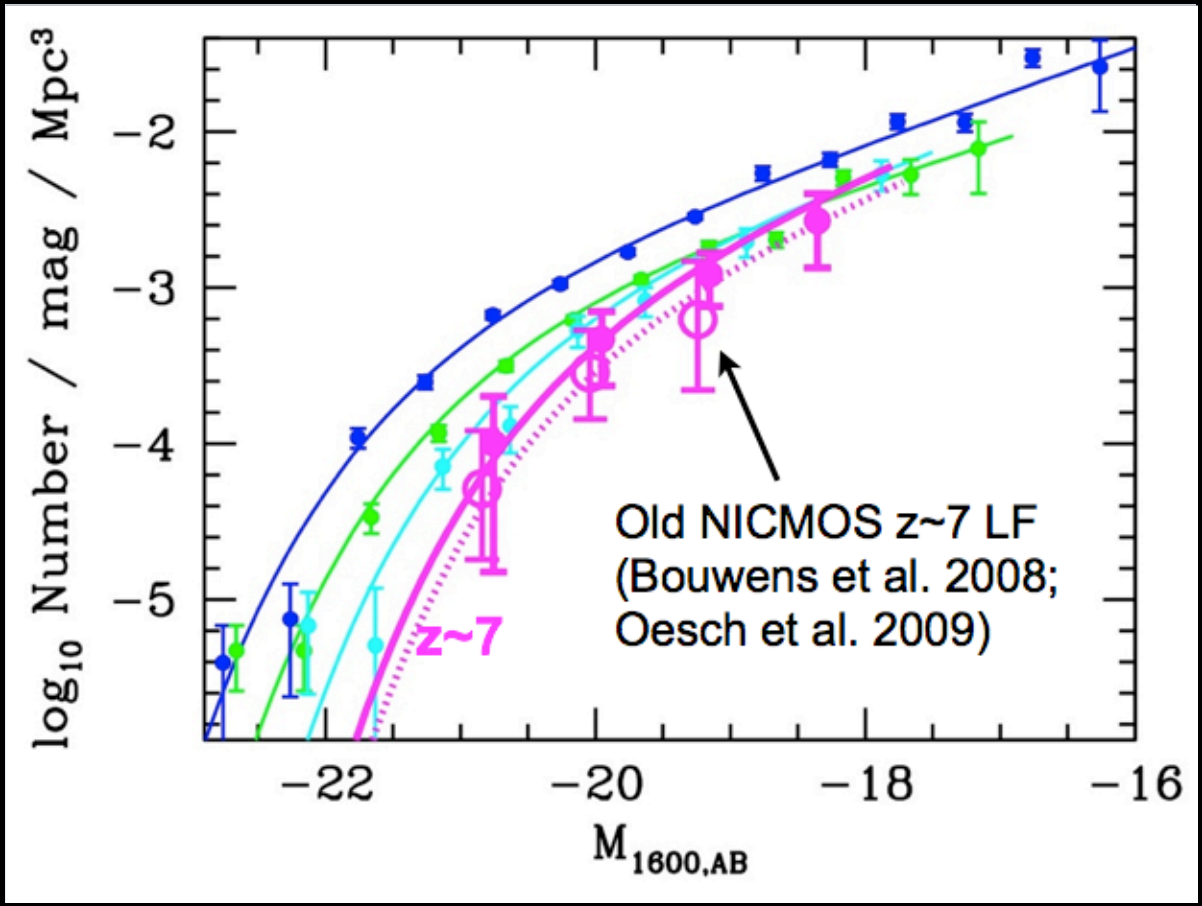
cannot be fit with standard population models

β is the power law slope of the UV continuum: $f_\lambda \sim \lambda^\beta$

galaxies become very blue at early times – suggesting possibly that metals are very deficient

Bouwens/Illingworth et al

luminosity functions



the new z~7 luminosity function indicates that the very steep slope persists to higher redshift

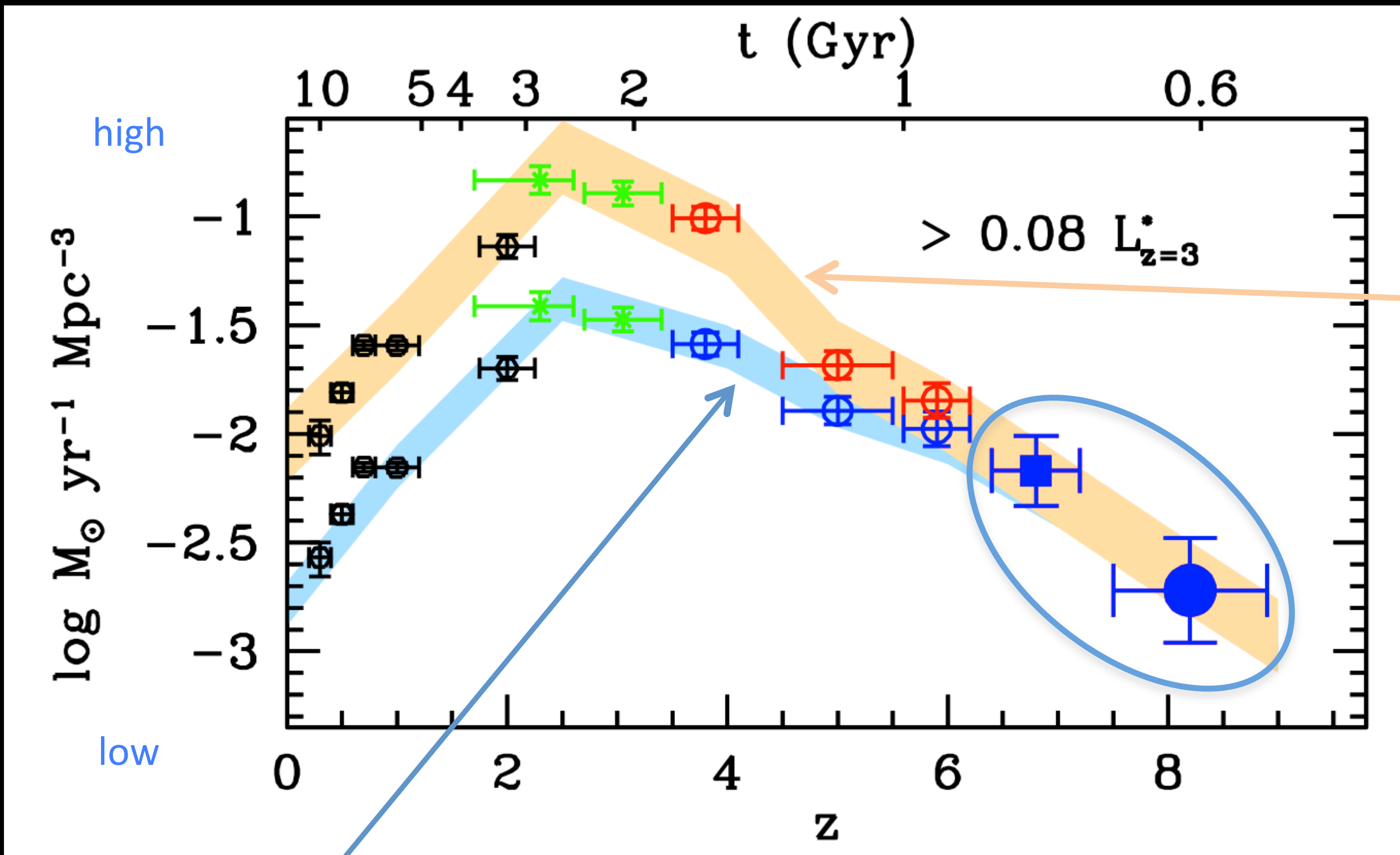
luminosity functions (LF) are key for determining the UV luminosity density and star formation rate densities

existing z~4-6 luminosity functions show that the slope is very steep at the faint end below L* (α ~ -1.75)

the bulk of the integrated UV flux at high-redshift comes from sub-L* low luminosity galaxies

the changes in the LF with redshift are primarily at the bright end.

the star formation rate density



dust-corrected SFR

our new results

UV luminosity density

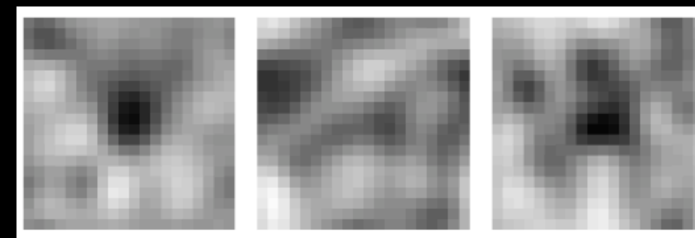
Bouwens/Illingworth et al

the history of star formation in galaxies in the universe

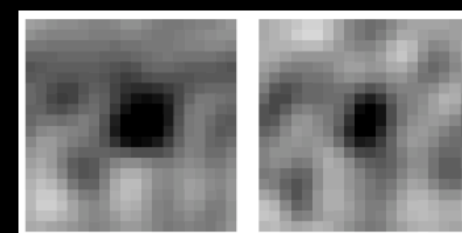
these galaxies formed stars much earlier

Hubble and Spitzer results combine to show us that z~8 galaxies could well have been forming stars two-three hundred million years earlier (at z>10-11)

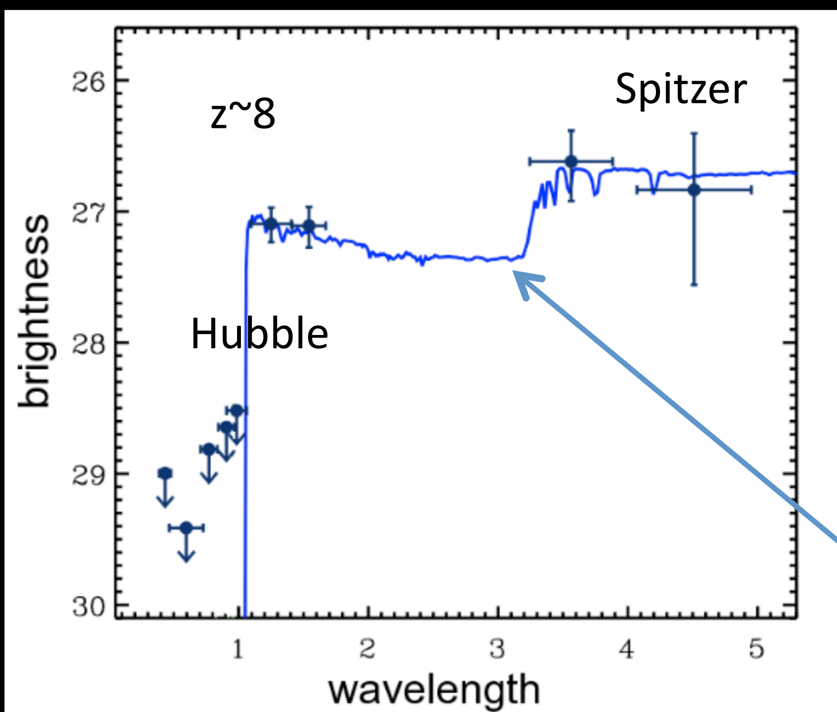
some individual z~8 Spitzer 3.6 µm images



z~8 summed Spitzer images



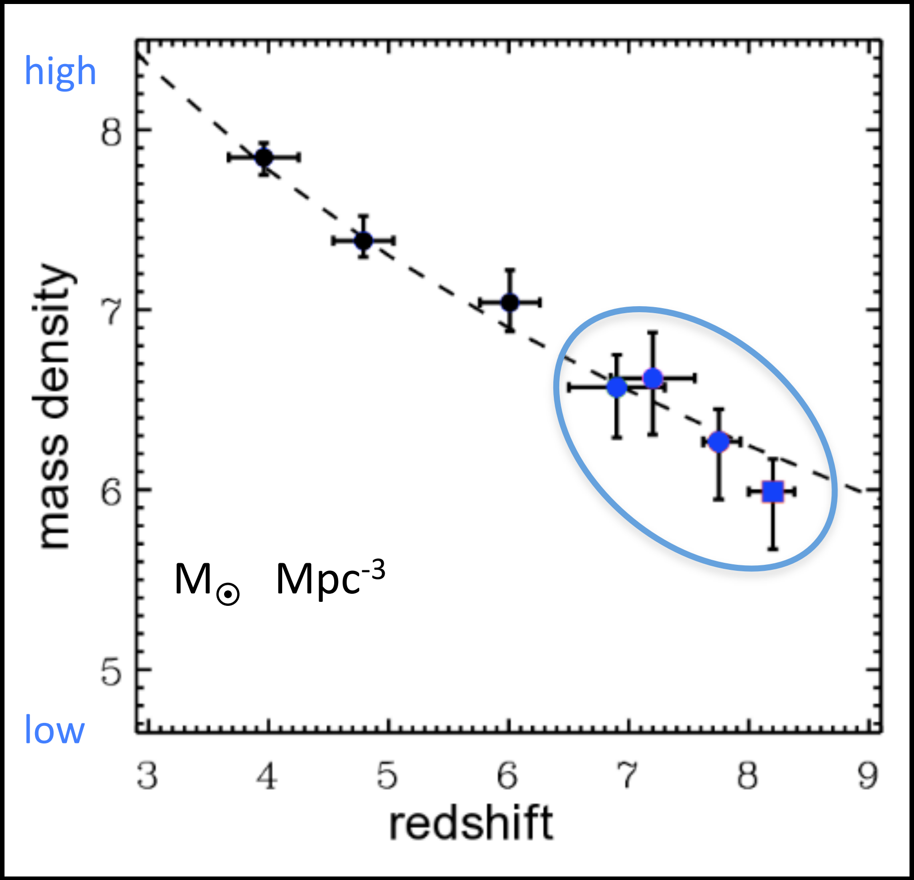
3.6 µm 4.5 µm



Labbé/Gonzalez et al

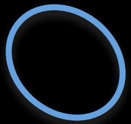
Model fit is BC03 CSF $0.2Z_\odot$ log M = 9.3
z~7.7 and 300 Myr (SFH weighted age = t/2)

mass buildup over time



the Hubble and Spitzer data allow us to establish the mass density at these early times

the history of the mass buildup in galaxies in the universe

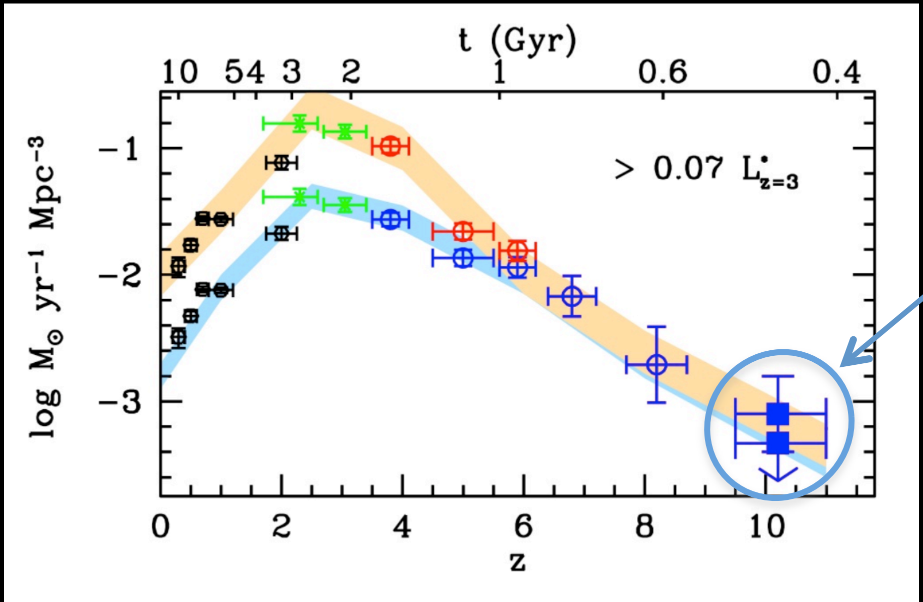


our new results

Labbé/Gonzalez et al

can we go beyond z~8 (to z~10?)

Bouwens/Illingworth et al



our SED fits suggest that star formation is underway at z~10-11 or even earlier – can we see higher redshift galaxies??

some early results from Yan et al suggested that z~10 galaxies existed in large numbers – this appears not to be the case

searches are still ongoing – we recently reported the possible detection of 3 z~10 sources

after correcting for our estimate of the contamination, we derived constraints on the star formation rate density, and also set an upper limit from the current HUDF09 data

what these new observations tell us

SUMMARY

Hubble's new Wide Field Infra-Red Camera (WFC3/IR) has revealed galaxies 13 billion years ago (at redshifts z~7 and z~8), just 600-800 million years from the big bang

these galaxies are small, low mass objects (half-light radii of just 0.7 kpc at z~7-8)

they are extremely blue in color and are probably very deficient in heavier elements

they give us estimates for the mass density and the star formation rate density that extends from just ~5% of the age of the universe

combining these results with Spitzer data suggests that these galaxies were forming stars ~300 million years earlier, at z>10-11 (with recent possible detections being found at z~10)

these galaxies fall in the heart of the "reionization" epoch, but our estimates are still low for the contribution of galaxies to reionization: we still don't know if galaxies could have reionized the universe!!