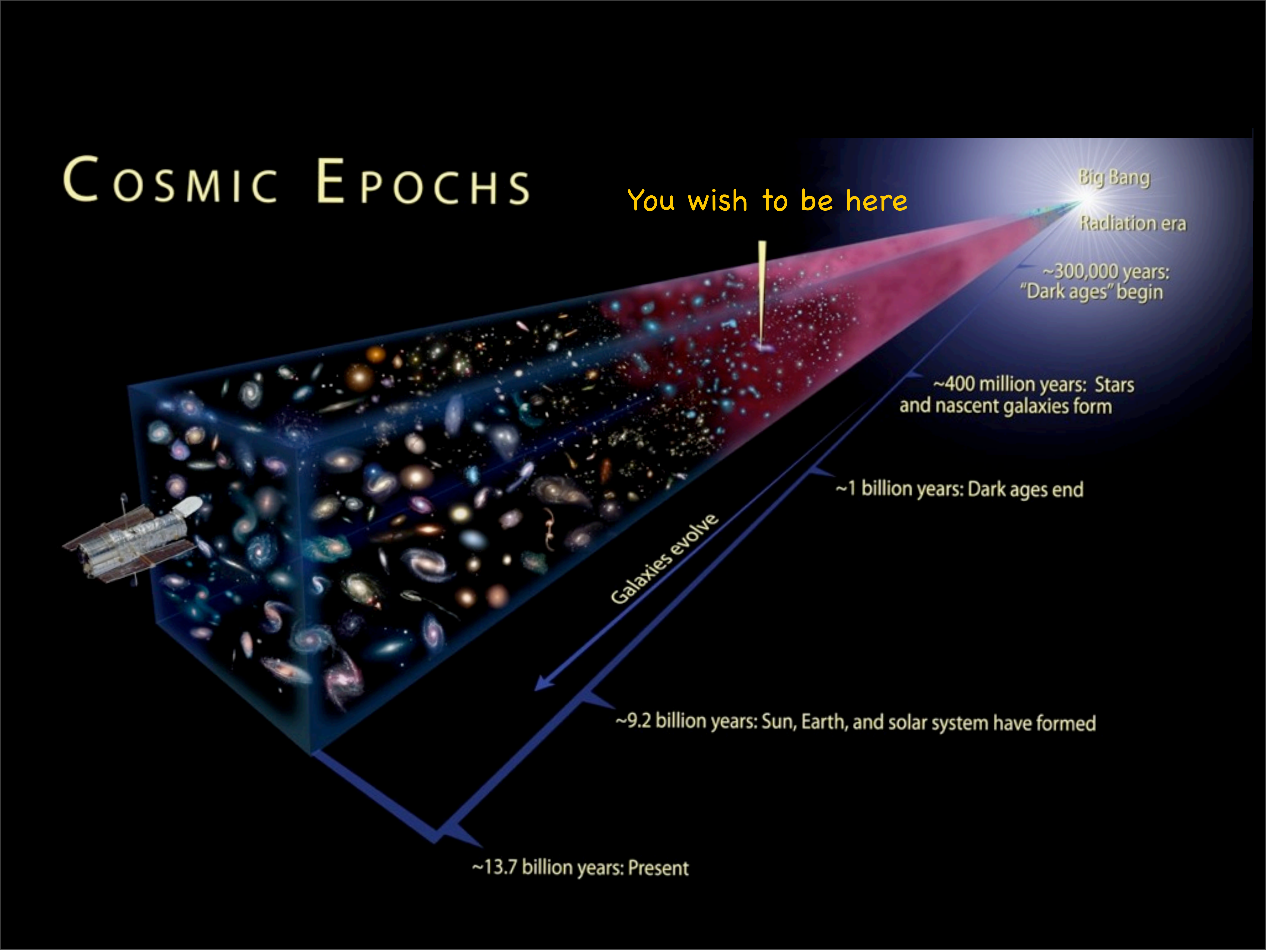
Focusing Cosmic Telescopes

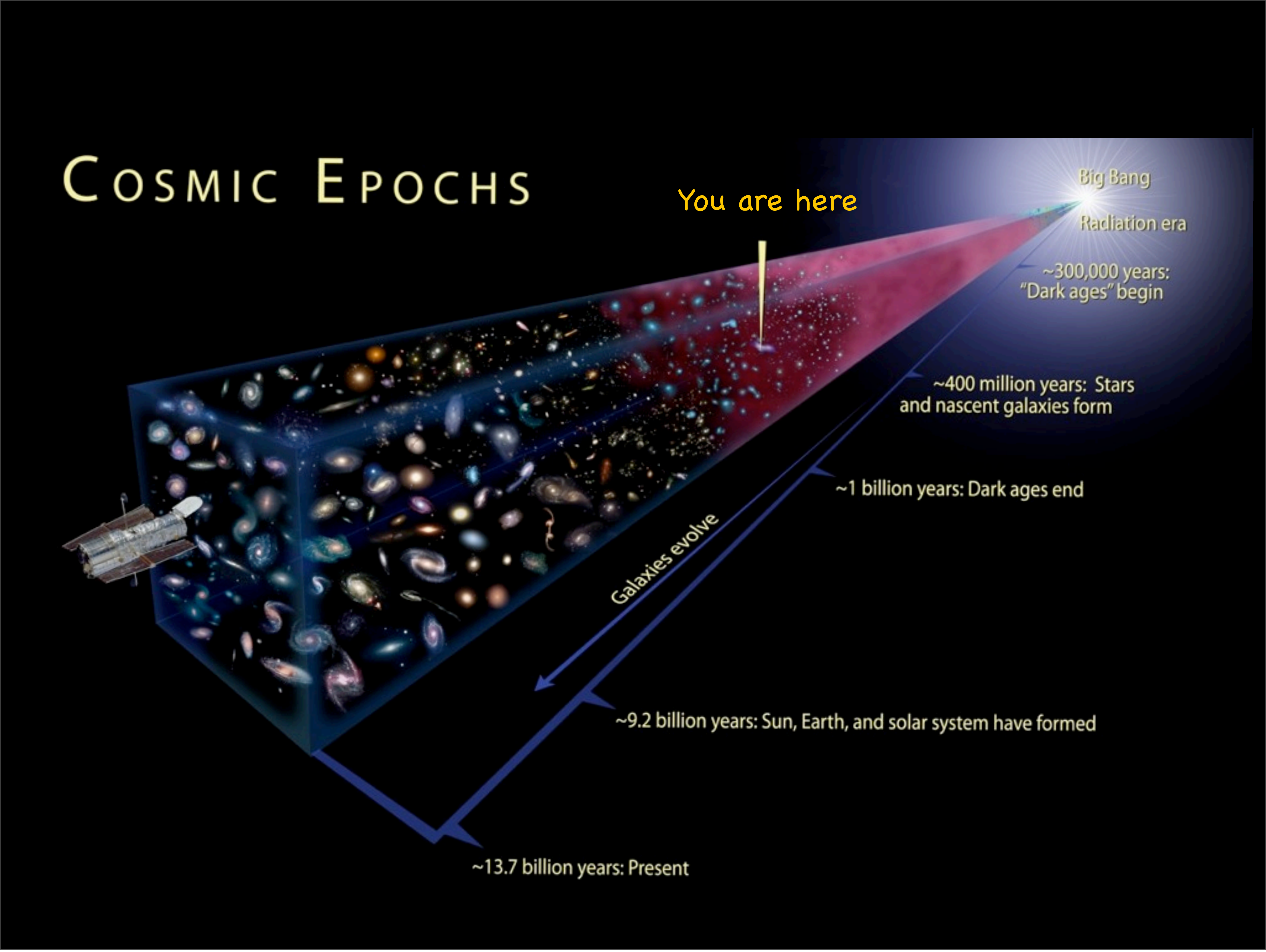
To Explore Redshift 5-10 Universe

Maruša Bradač

Nicholas Hall, **Douglas Clowe**, Anthony Gonzalez, Dennis Zaritsky, Christine Jones, Phil Marshall, Tommaso Treu, Douglas Applegate, Peter Schneider



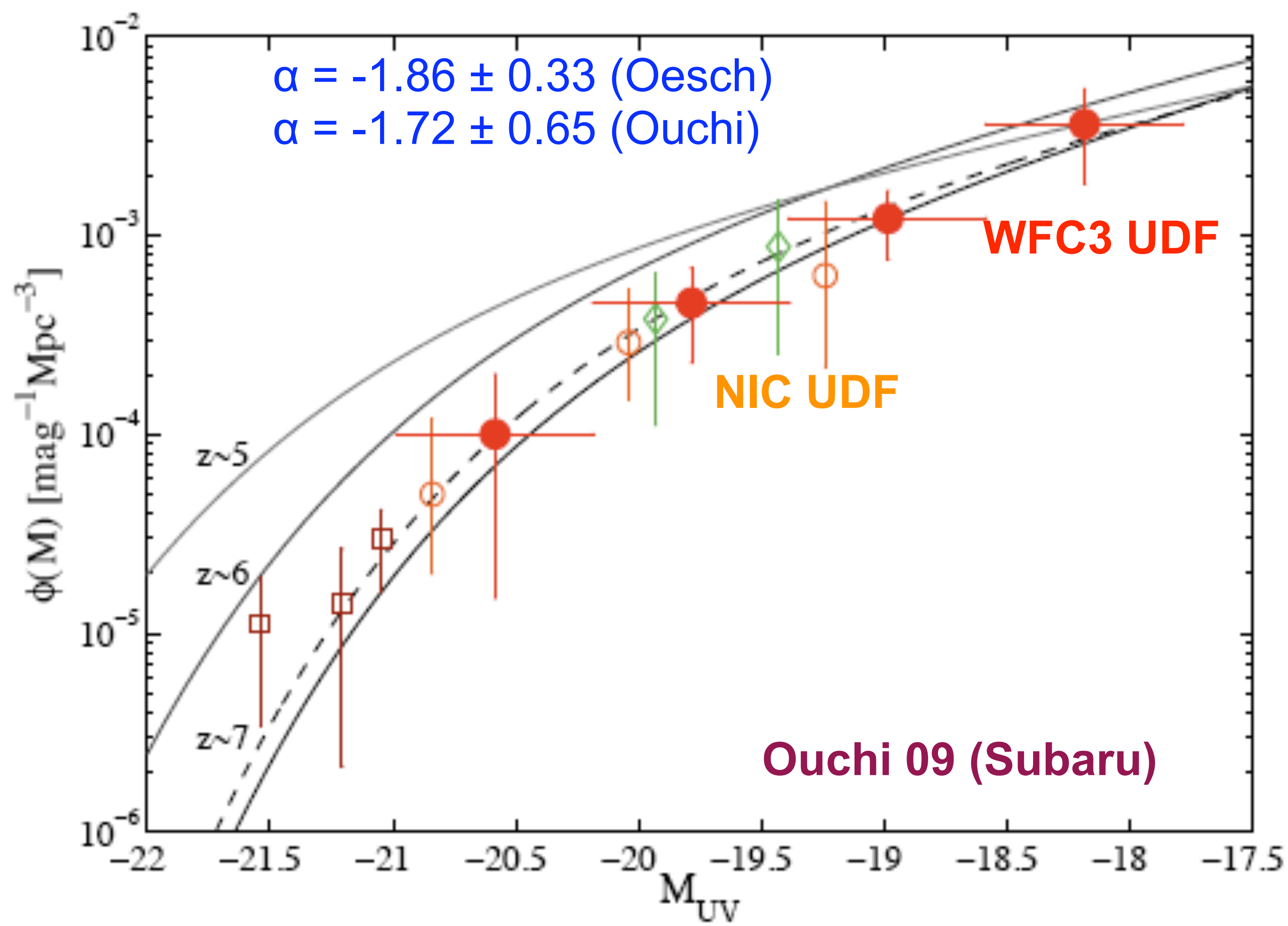
COSMIC EPOCHS
You wish to be here
Big Bang
Radiation era
~300,000 years:
"Dark ages" begin
~400 million years: Stars
and nascent galaxies form
~1 billion years: Dark ages end
Galaxies evolve
~9.2 billion years: Sun, Earth, and solar system have formed
~13.7 billion years: Present


Cosmic Epochs
You are here
Big Bang
Radiation era
~300,000 years:
"Dark ages" begin
~400 million years: Stars
and nascent galaxies form
~1 billion years: Dark ages end
Galaxies evolve
~9.2 billion years: Sun, Earth, and solar system have formed
~13.7 billion years: Present

Observing z>5 Universe Through Gravitational Telescopes

* Lensing is fantastic!
* Large magnification factors, allows us to get larger number counts (provided the luminosity function is steep)

$$-\mathrm{d}(\log \mathrm{d}\Phi)/\mathrm{d}(\log \mathrm{L}) \gtrsim 1$$



Oesch et al, Bunker et al 2009

Observing z>5 Universe Through Gravitational Telescopes

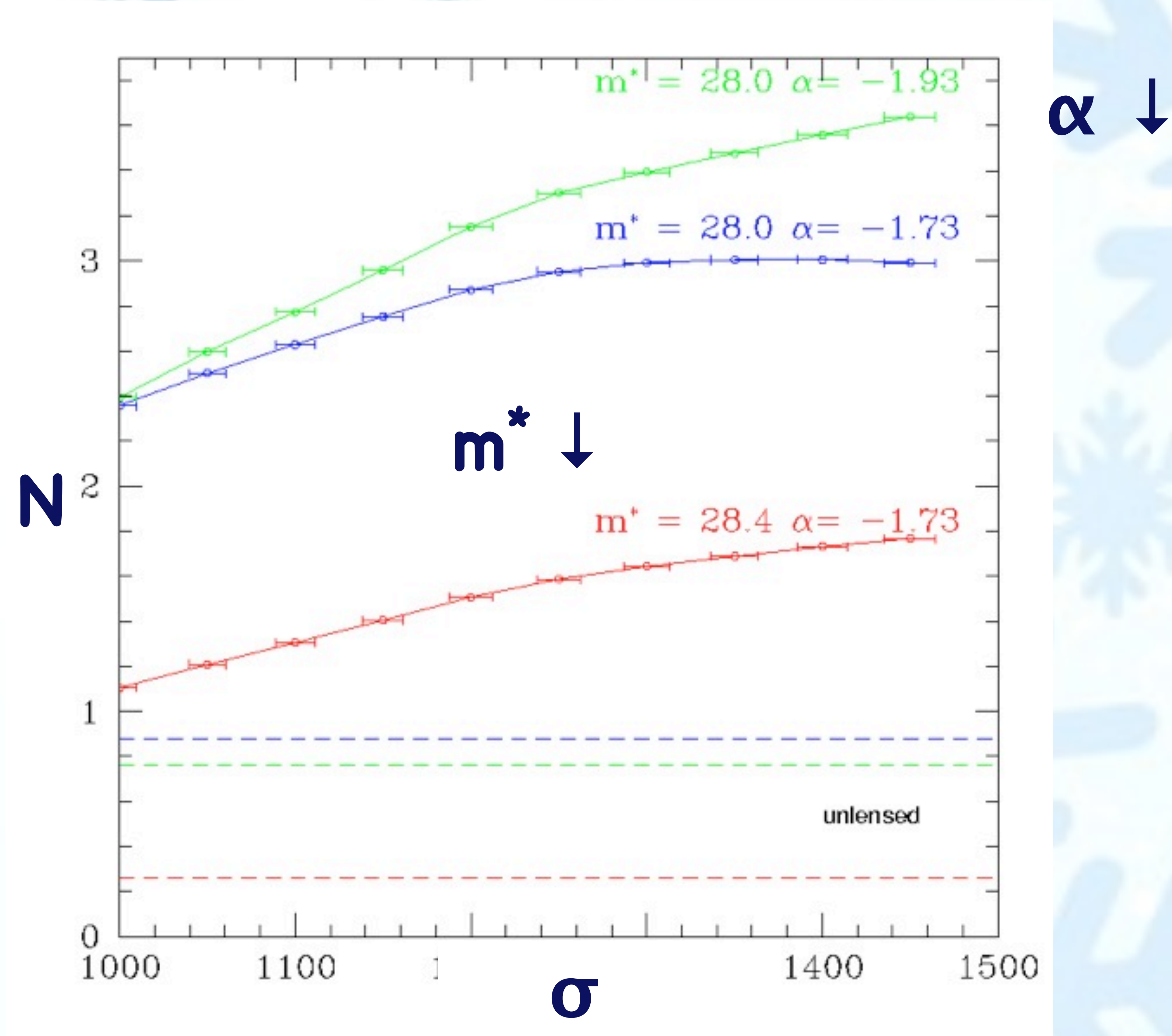
- Large areas with observed multiple images - much eased identification; no need for often prohibitive spectroscopy

- Spectroscopy at z>7
  - → UDF - ultra difficult specroscopy
  - → GOODS - very difficult spectroscopy
  - → 1E0657-56 - difficult spectroscopy

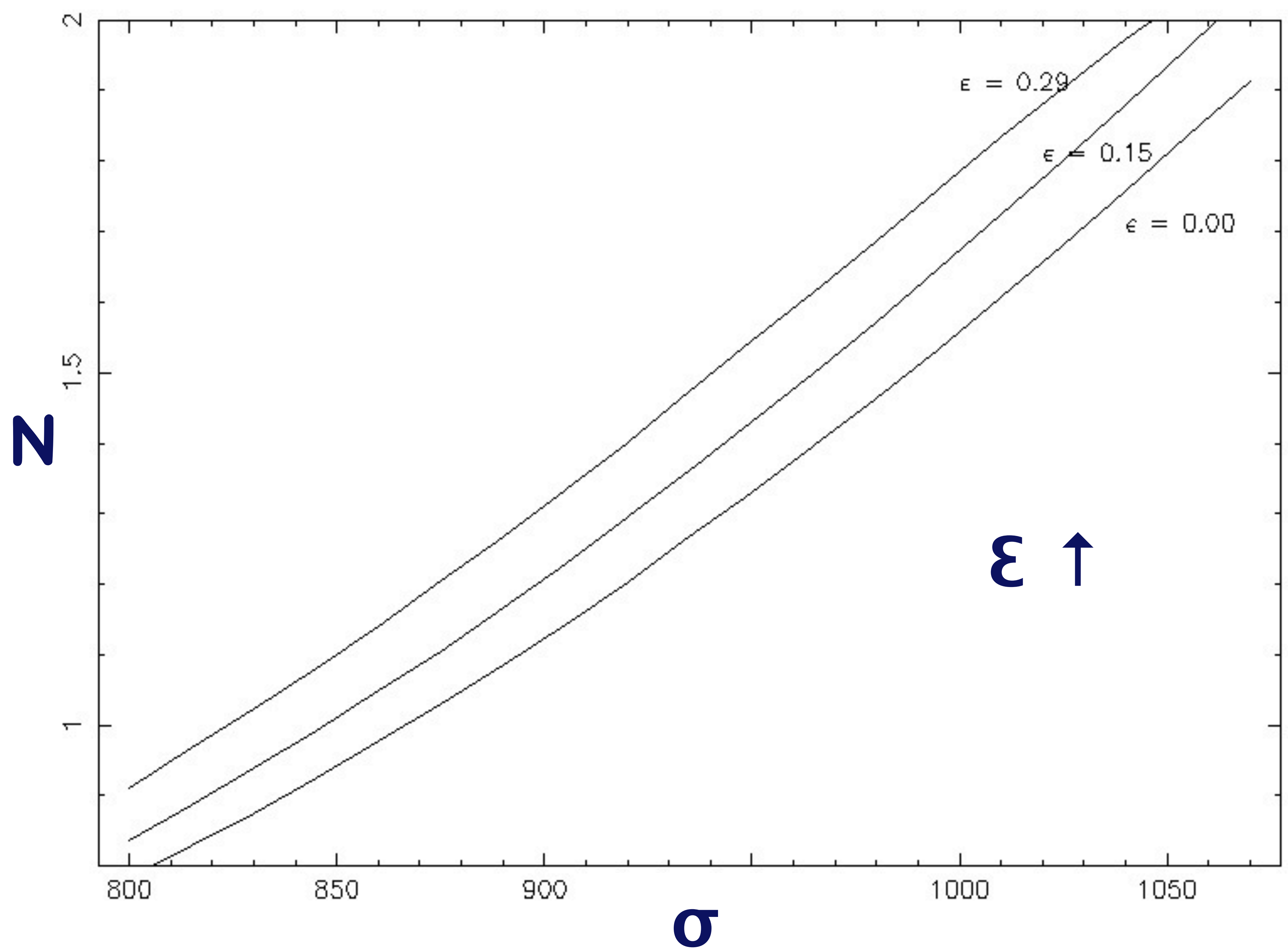
- Magnification maps need to be known to sufficient accuracy to constrain the number counts (and for best cases also individual luminosities)

Observing z~7 Universe Through Gravitational Telescopes

How steep?



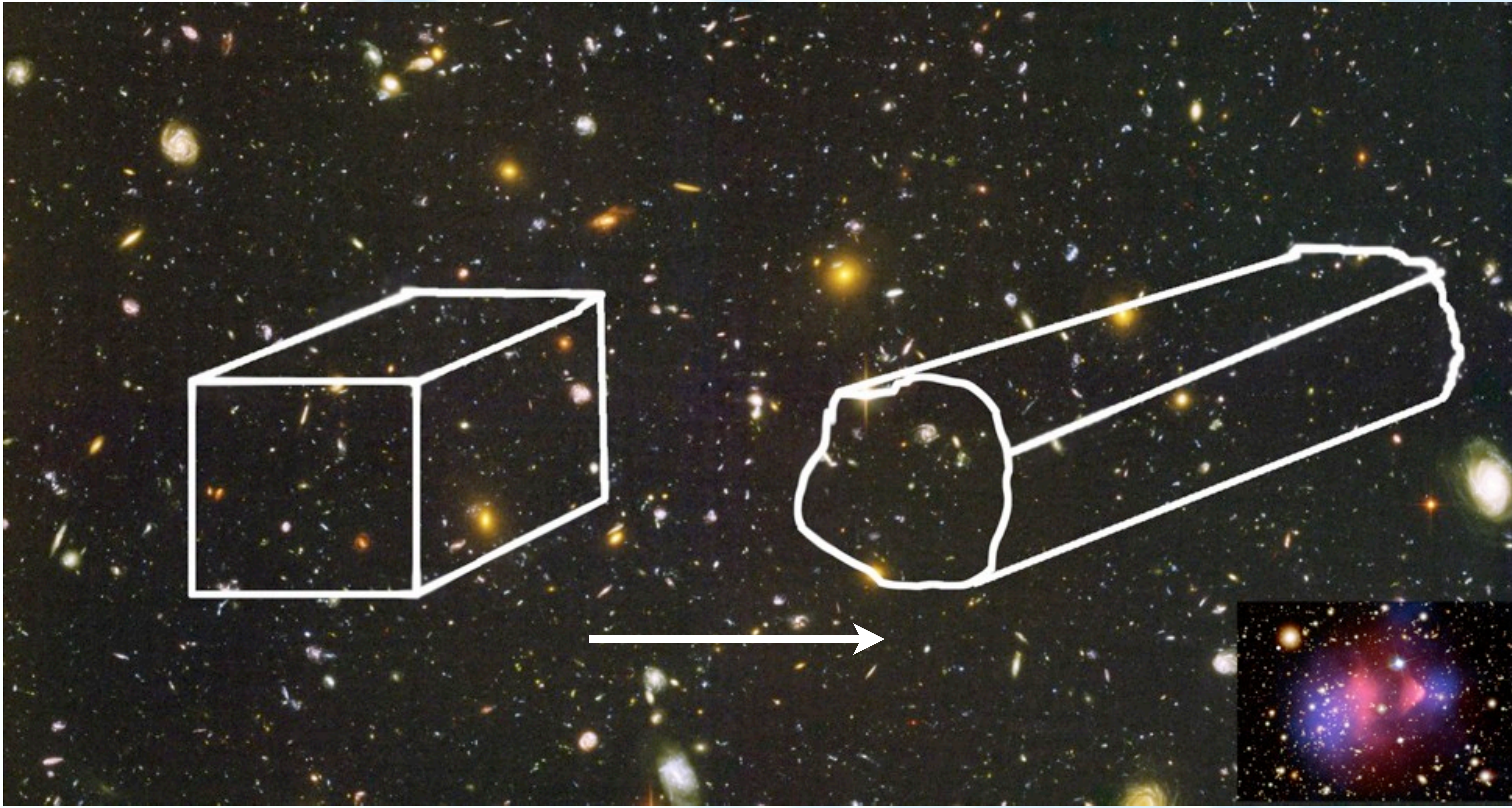
Pick Ideal Gravitational Telescopes



Finding Ideal Cluster

Finding Ideal Cluster

Focusing your Cosmic Telescope



Tuesday, July 20, 2010

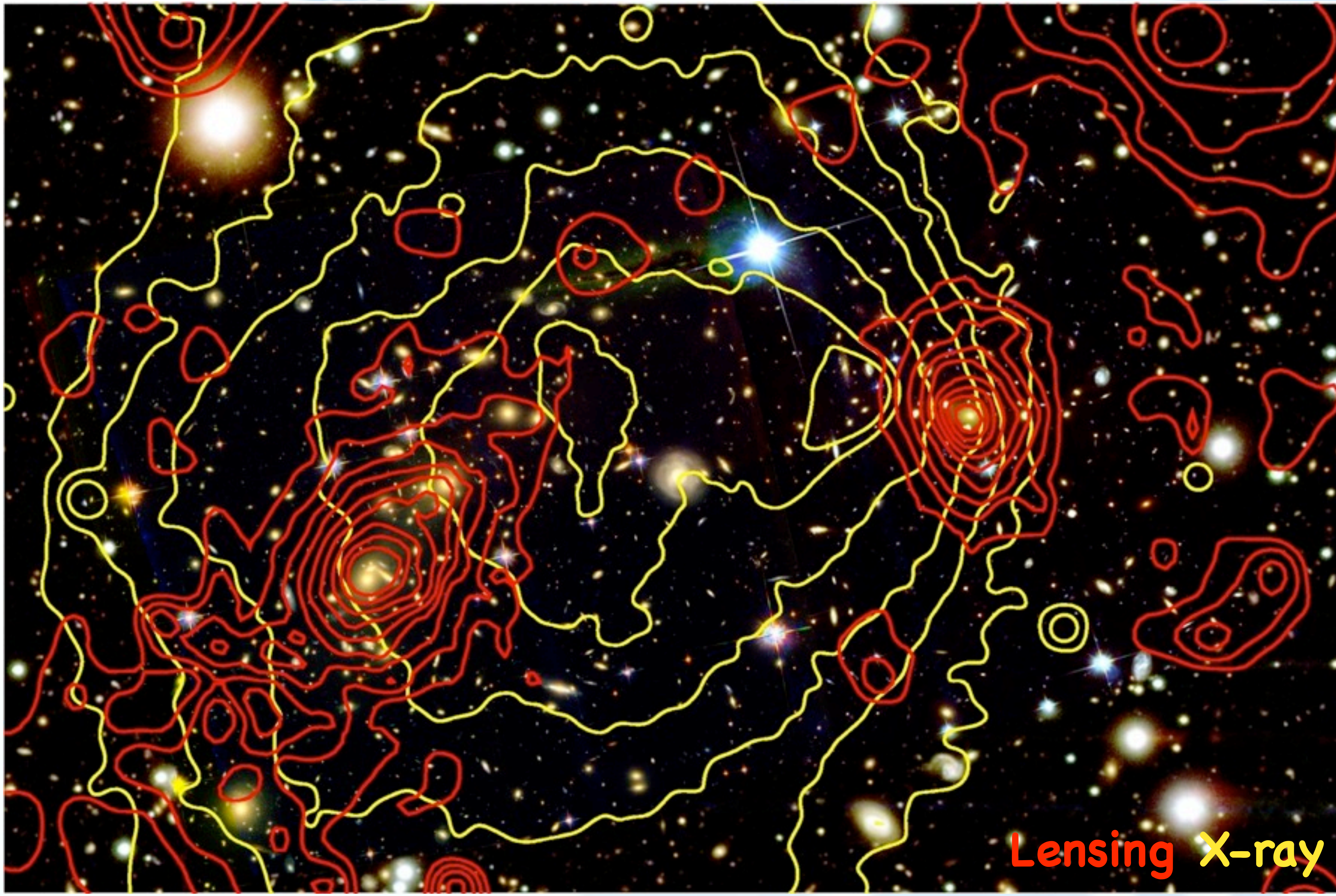
Mass (Magnification) Modeling

* We combine strong and weak lensing constraints using a parametrisation that allows a high flexibility of the mass models.
* Adapt resolution - weak lensing at much lower resolution than strong lensing

Bradač et al 2005, Bradač et al 2009

SW United and 1E0657-56

Bradac et al. 2009



Lensing vs. Blank Fields

* Errors on magnification map:

    -> Substructure

    -> Strong lensing multiple image

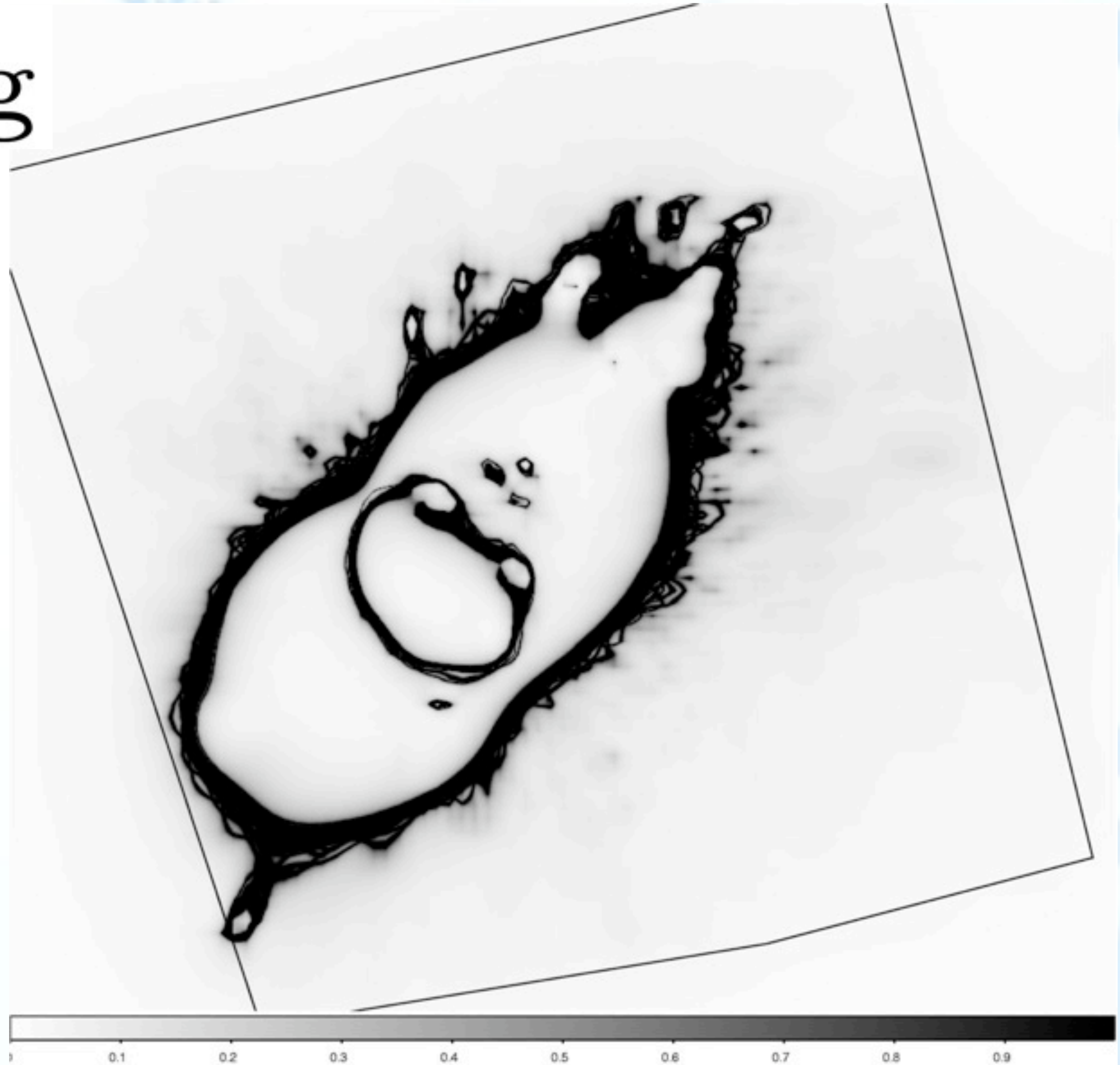
* Image recovery is a good indication on errors (if multiple systems present)

* Typical rms per image -> 4″

* SWUnited adaptive -> rms per image 1.4″

Magnification errors

σ_{mag}



ACS field

Lensing vs. Blank Fields

* Errors on individual magnifications can be potentially large, but on average small
* Errors on surface change even smaller

  ->ACS field centered on the main cluster 0.25±0.2

* And don't forget the other advantages...

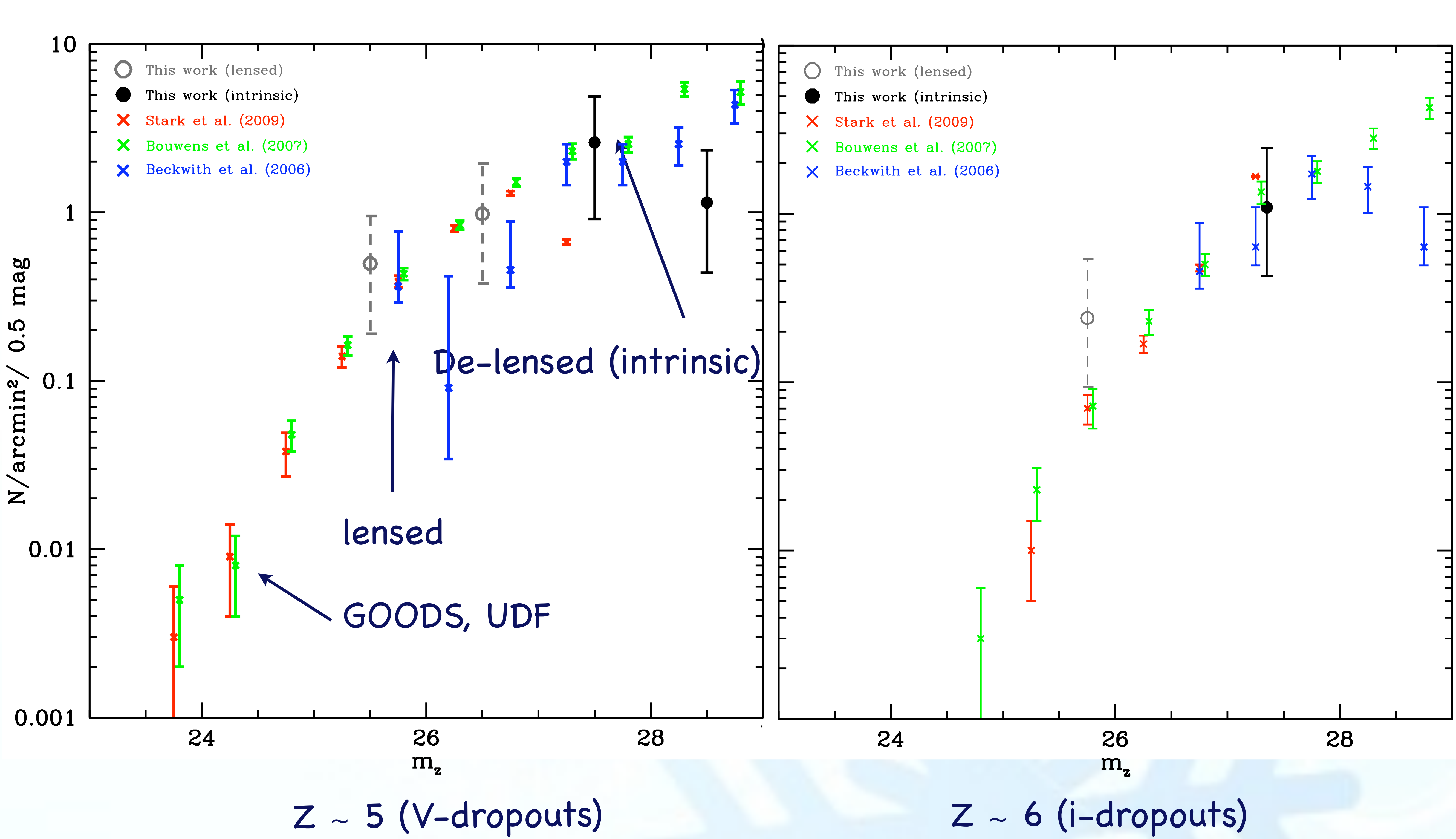
z>5 Universe through 1E0657-56

- Deep ACS data: F606W (V , 2340s), F775W (i, 10150s), and F850LP (z, 12700s)
- Search for V and i-band dropouts -> z=5-6 population, compare with blank surveys

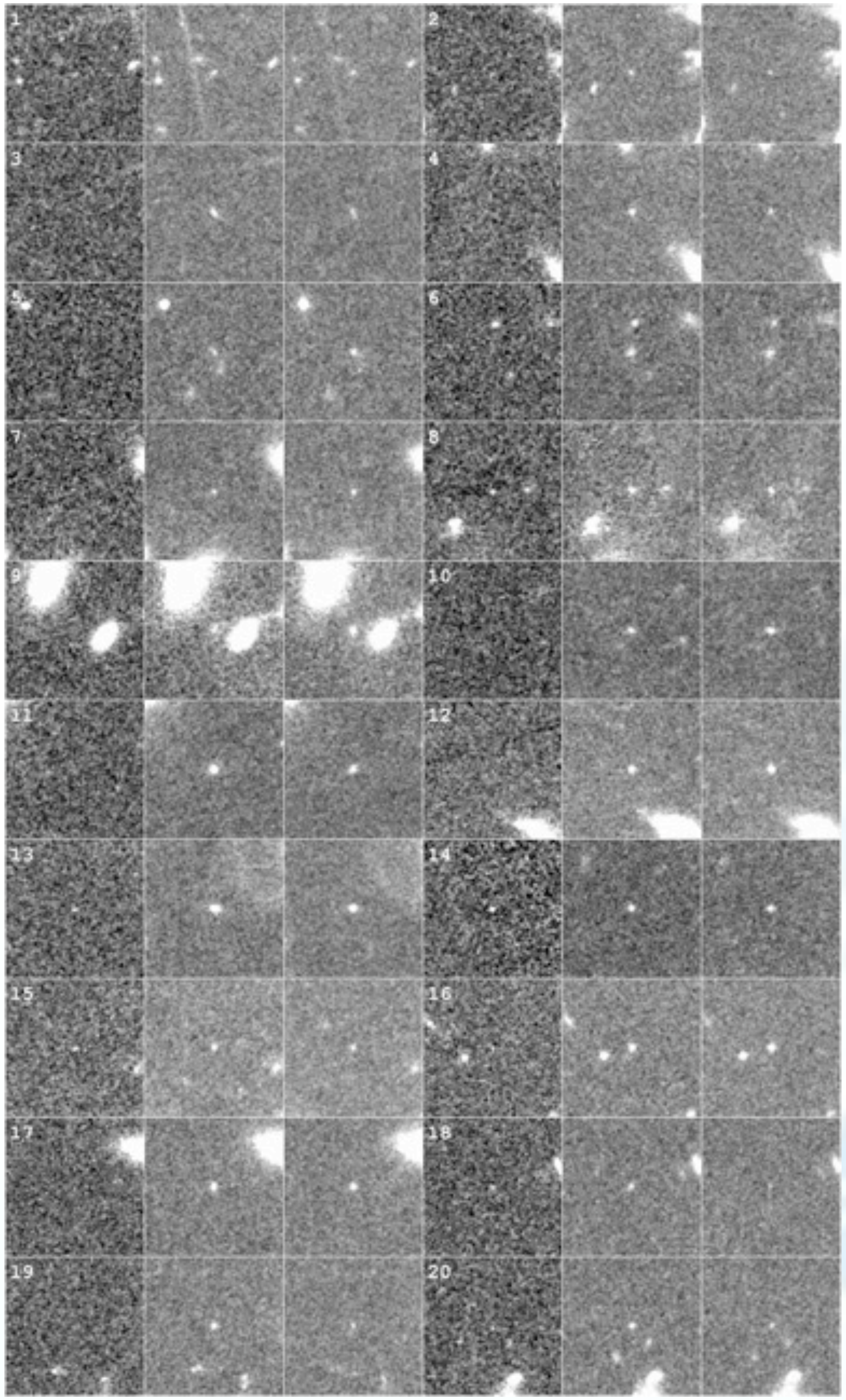
    -> GOODS (v1): V - 5000s, i - 5000s, z - 10660s (320 arcmin2)

    -> HUDF: V - 135ks, i - 347ks, z - 347ks (10 arcmin2)

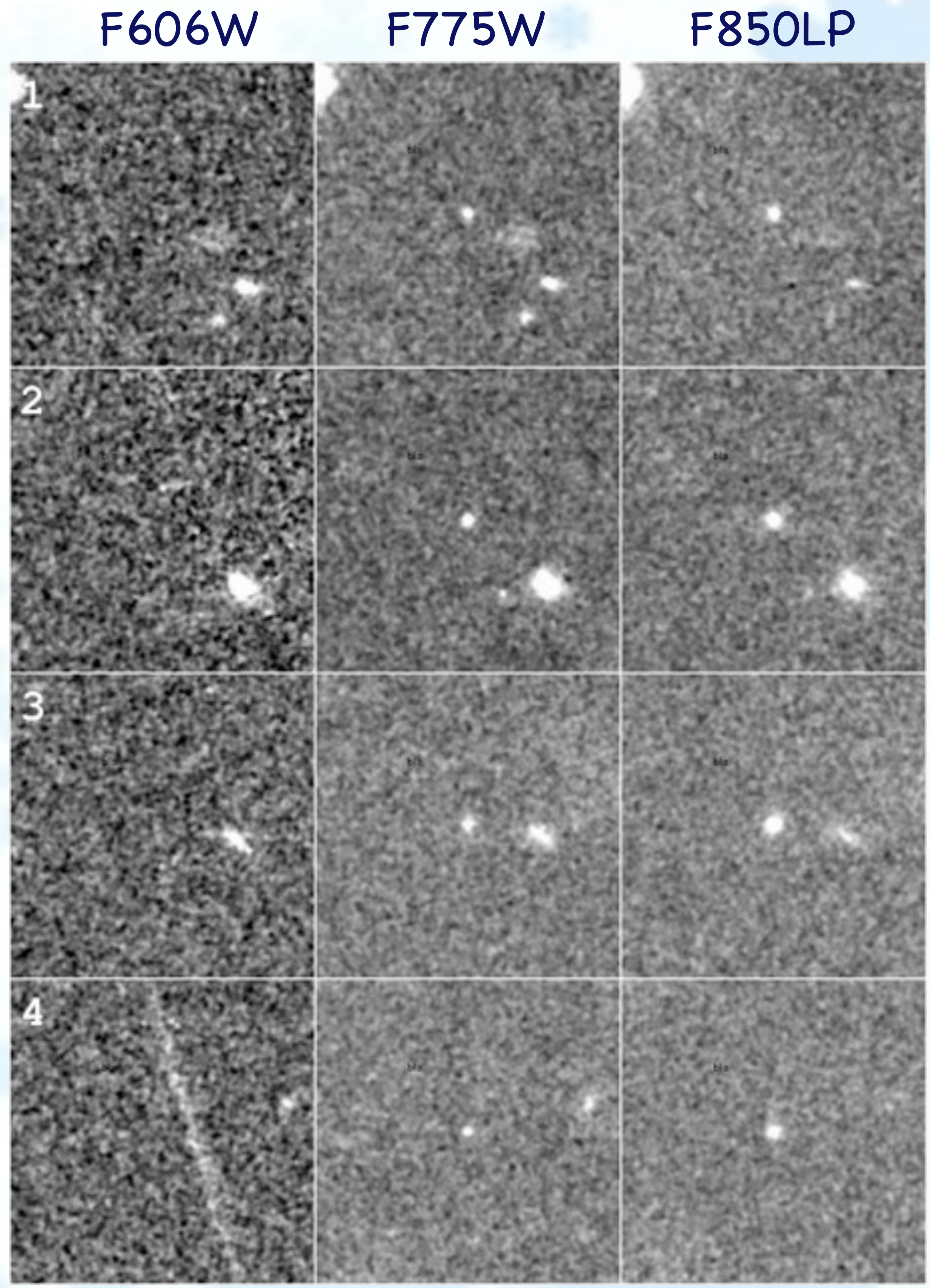
It Works! Galaxies at z=5-6



Bradač et al. 2009



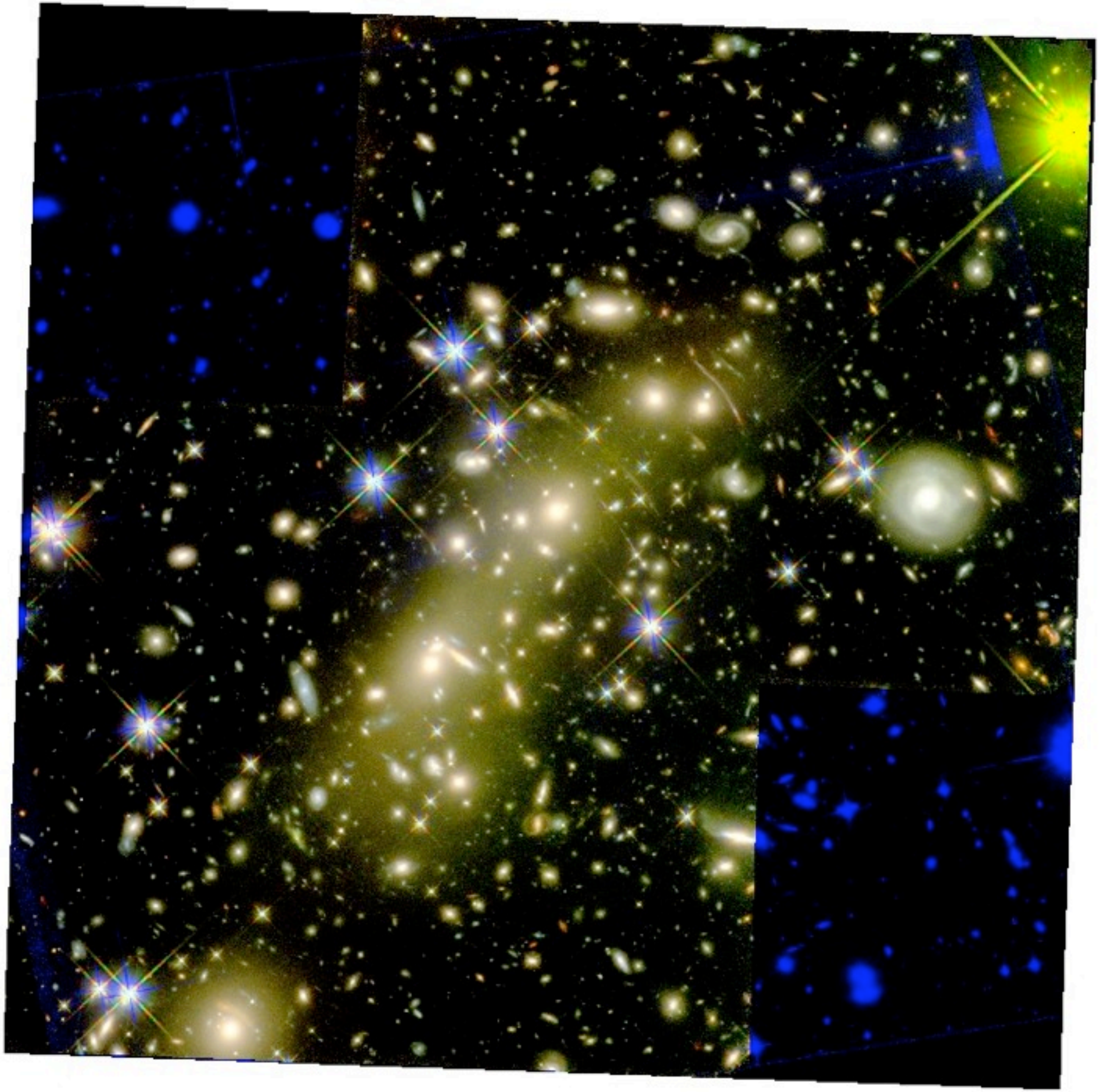
Z ~ 5 (V-dropouts)



Z ~ 6 (i-dropouts)

z>7 Universe through 1E0657-56

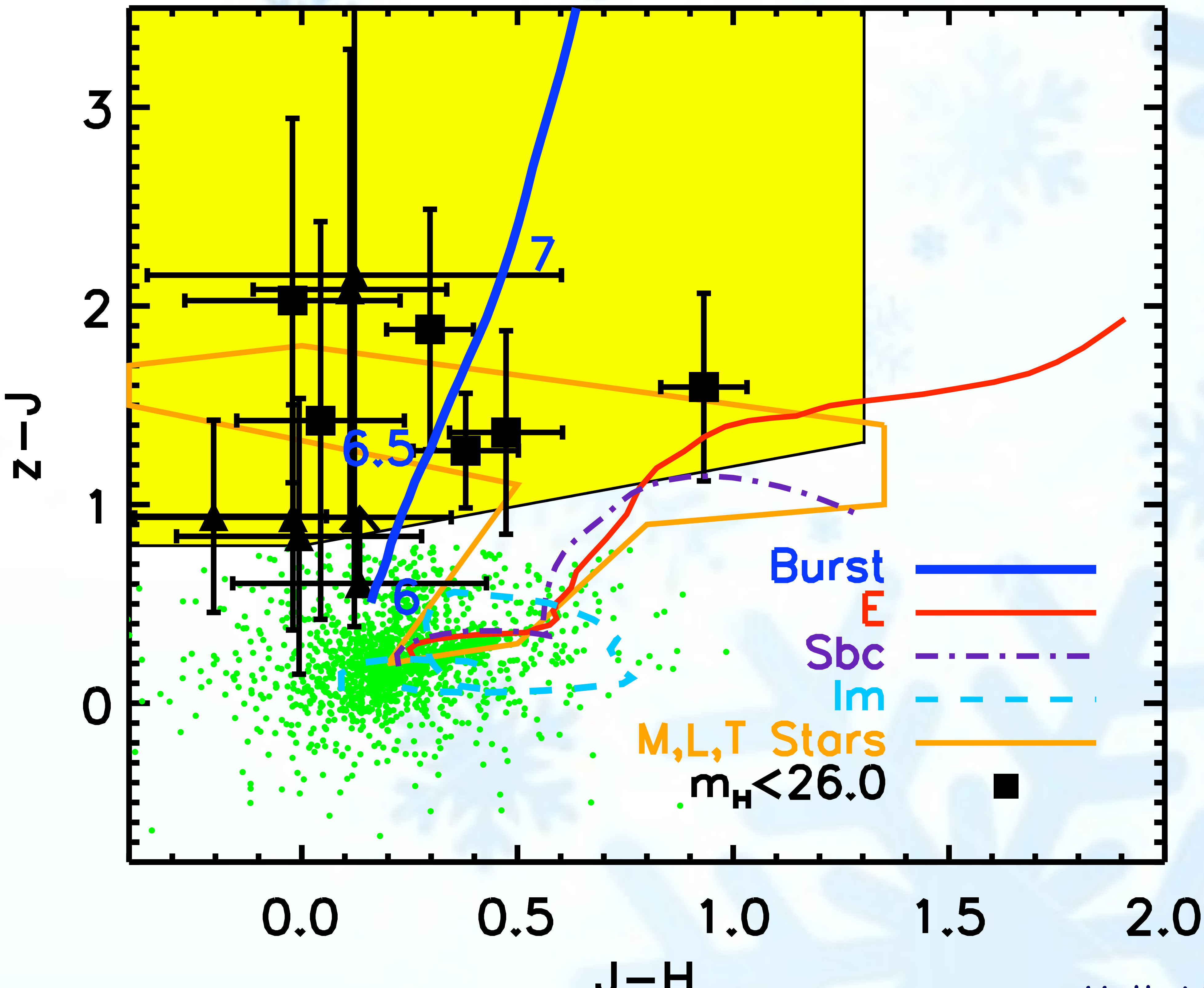
* Deep ACS data: F606W (V, 2340s), F775W (i, 10150s), and F850LP (z, 12700s)
* WFC3 data: F110W (J, 13000s), F160W (H,14000s)



F850LP (ACS)
F110W (WFC3)
F160W (WFC3)

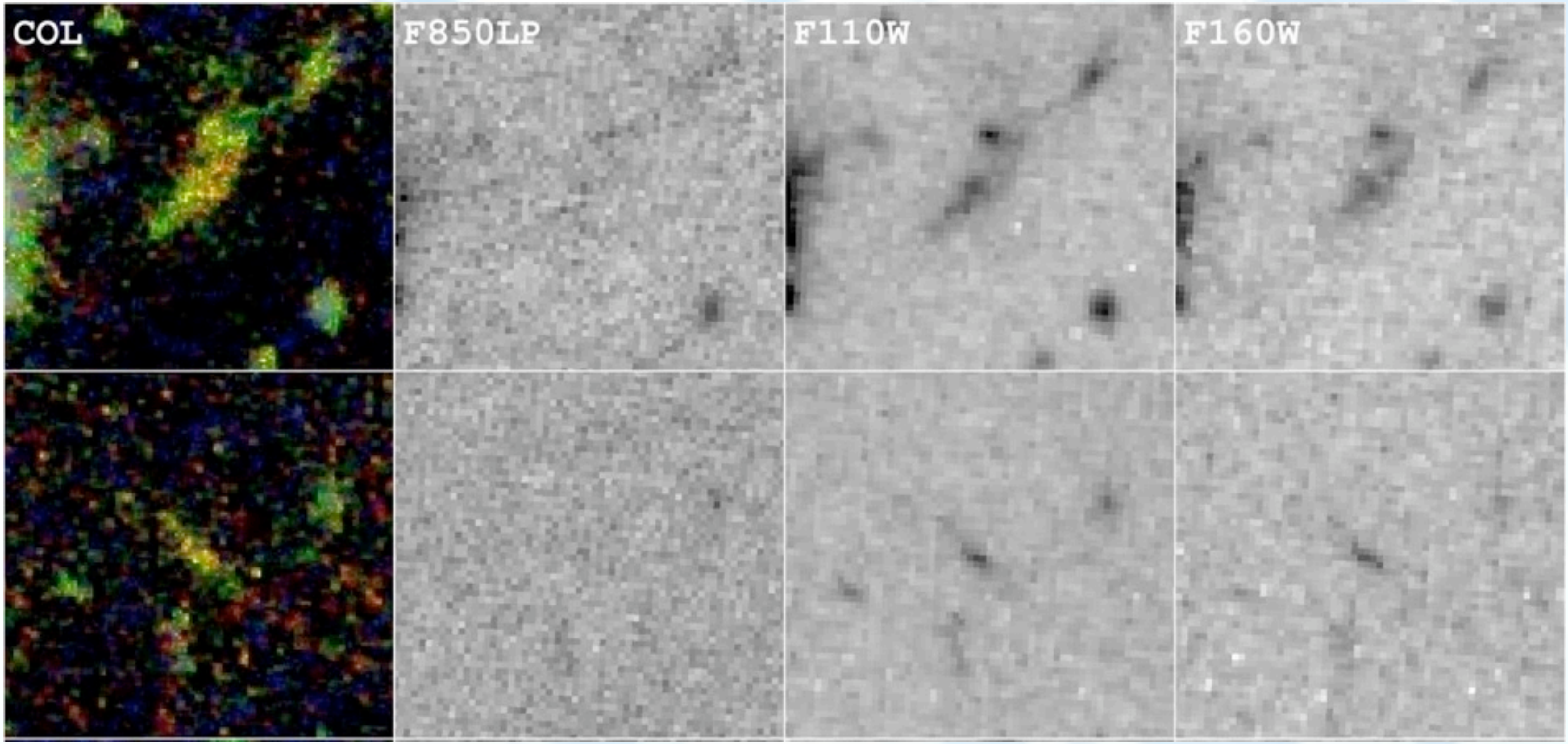
Hall, MB et al in prep.

z>7 Universe through 1E0657-56

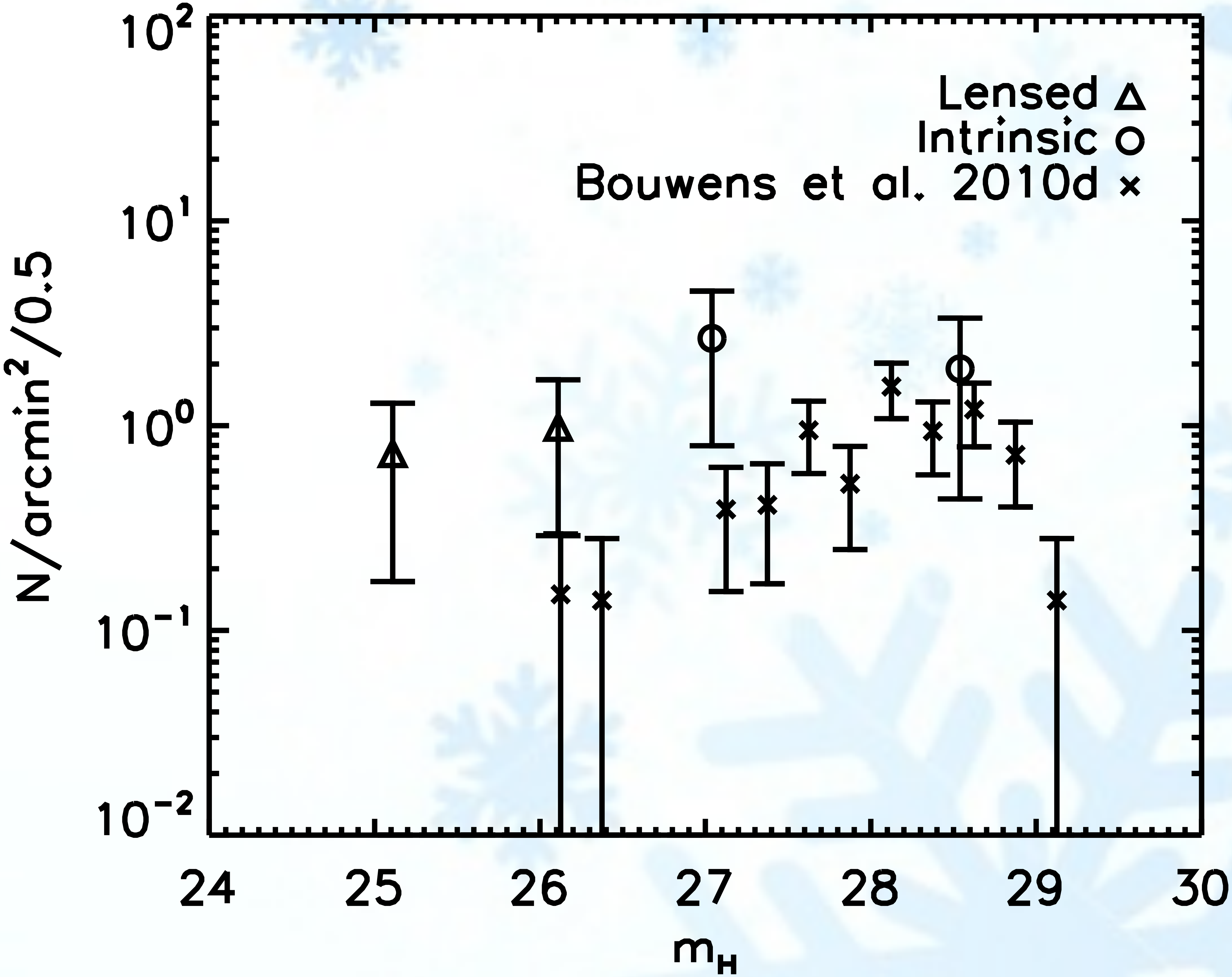


Hall, MB et al in prep.

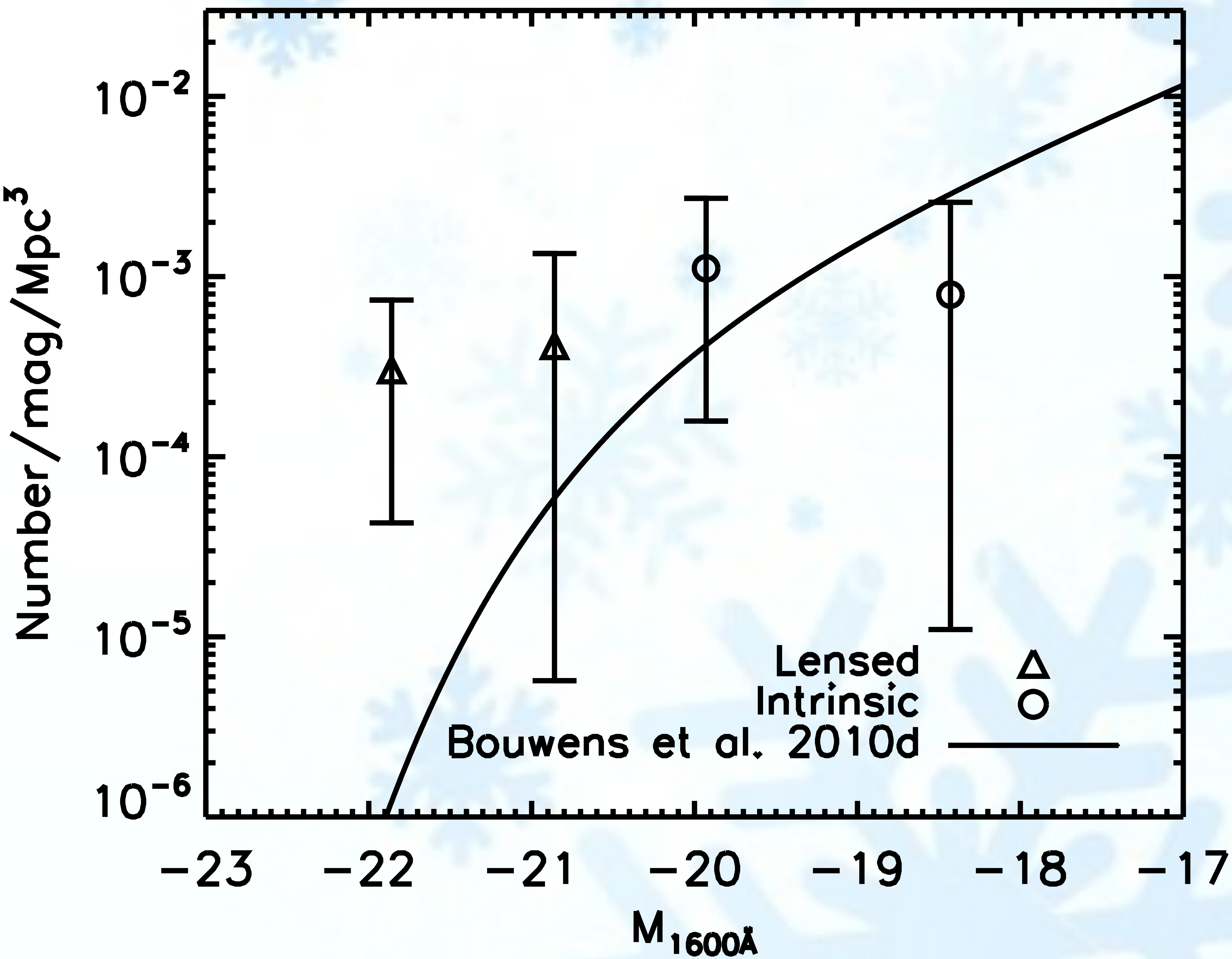
z>7 Universe through 1E0657-56



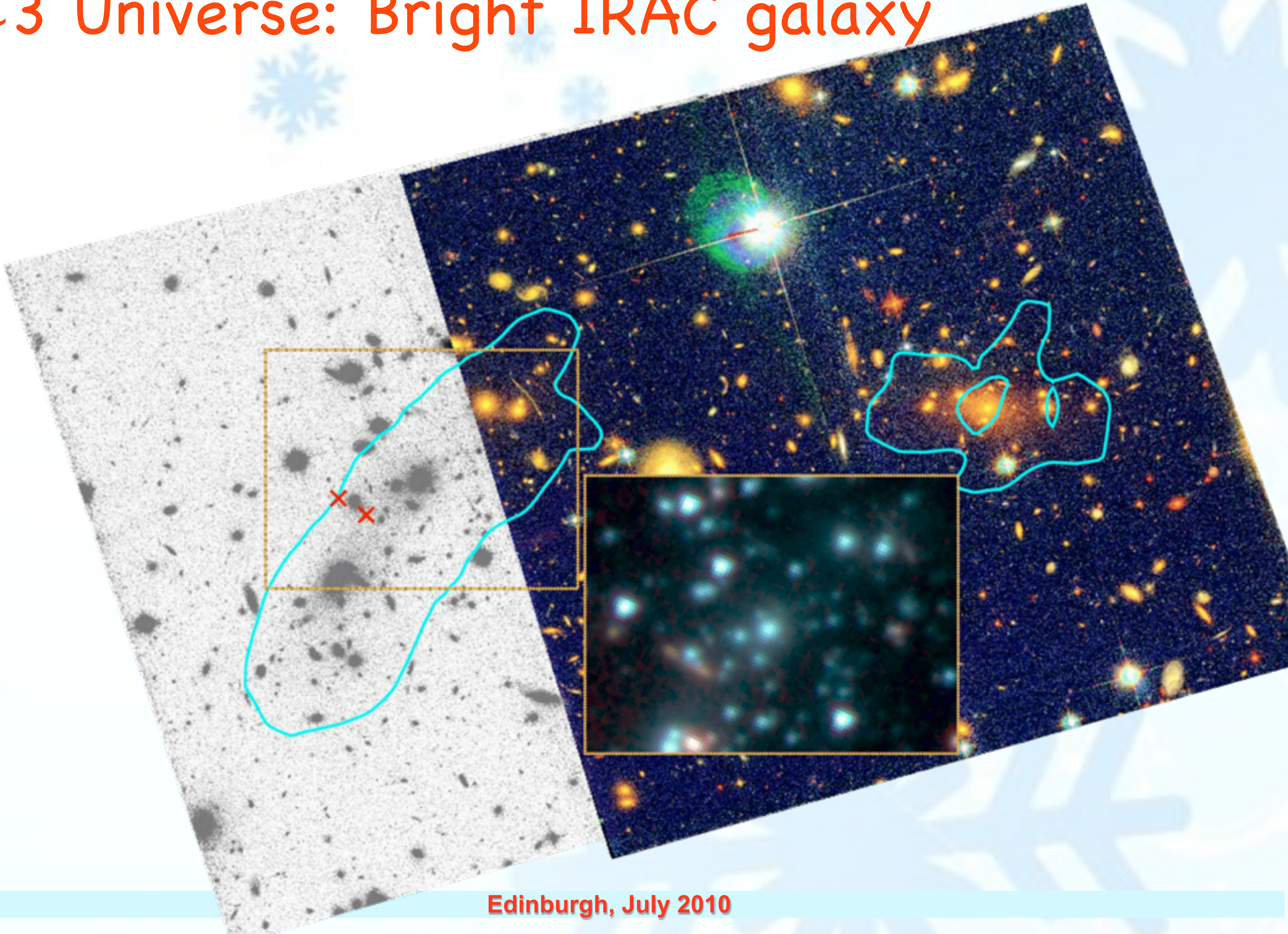
z>7 Universe through 1E0657-56



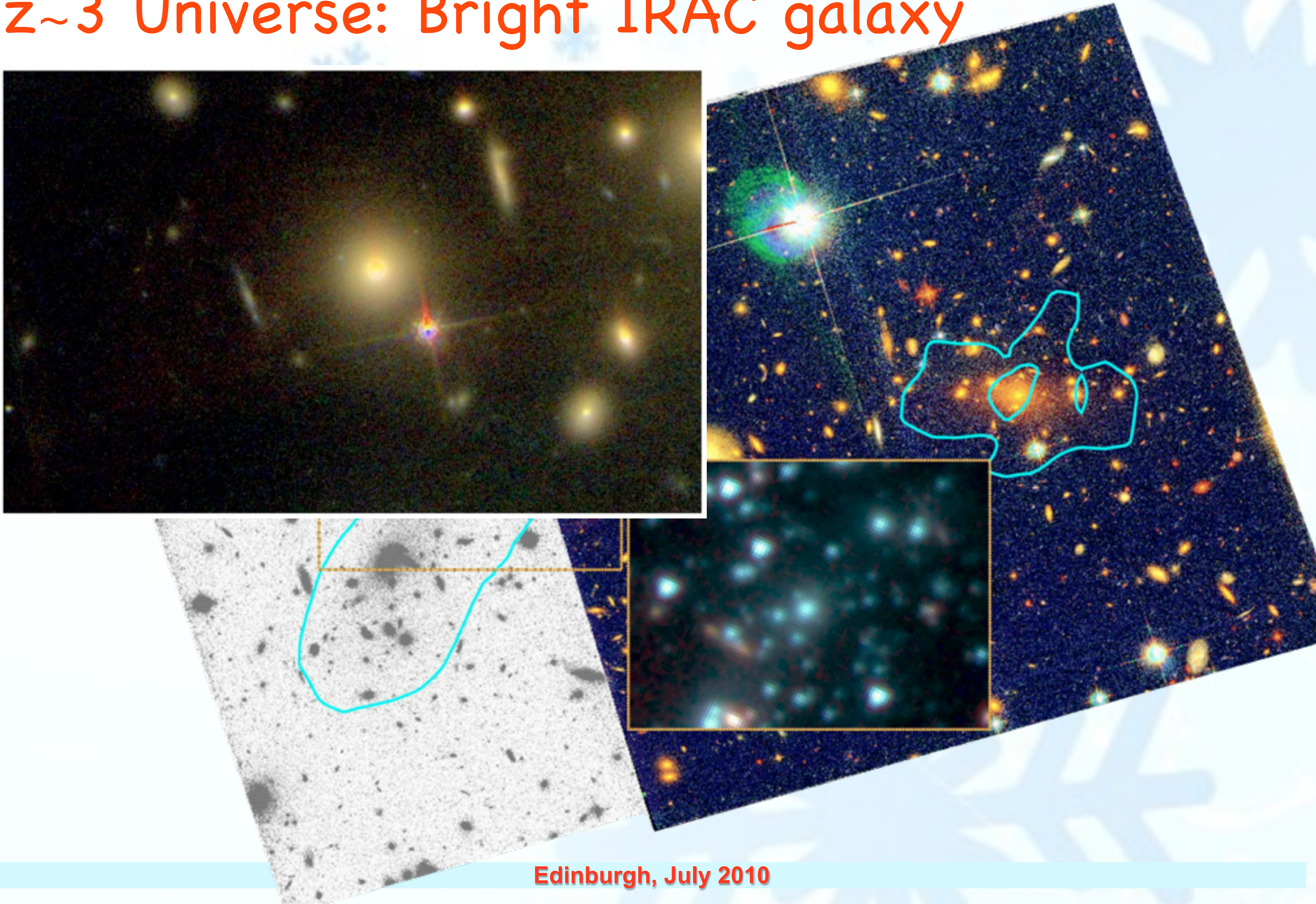
z>7 Universe through 1E0657-56



z~3 Universe: Bright IRAC galaxy

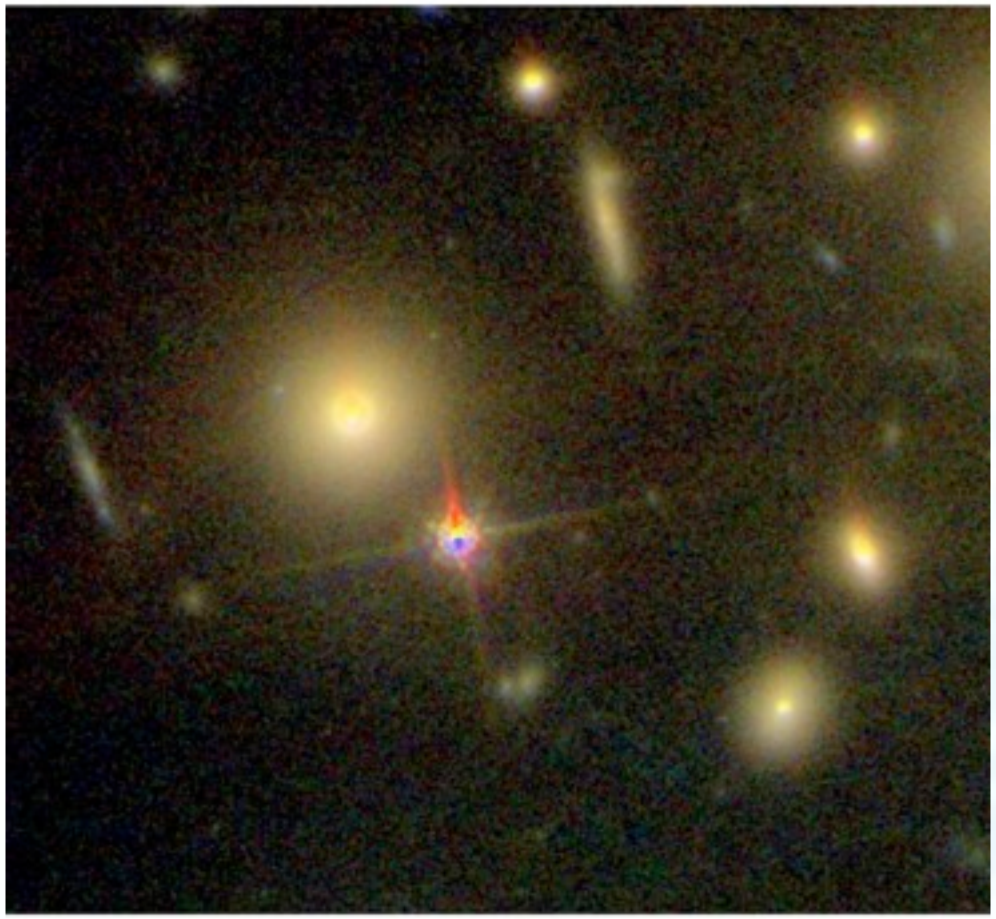


z~3 Universe: Bright IRAC galaxy

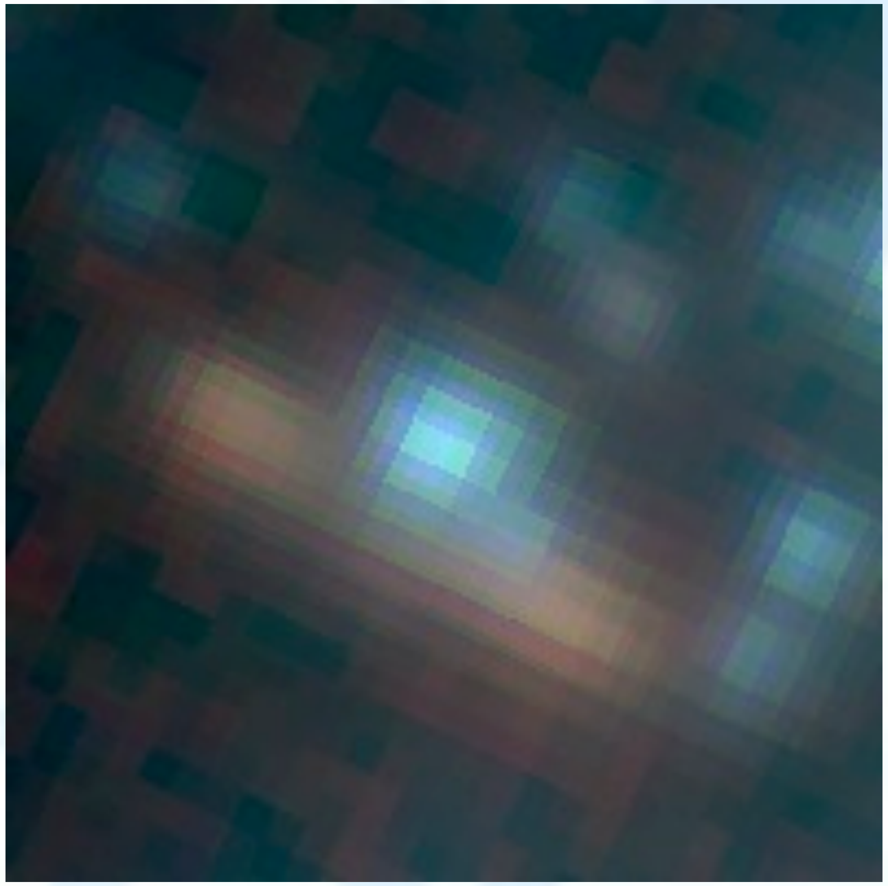


Tuesday, July 20, 2010

Dust Bunny - Ordinary, yet exceptional



ACS



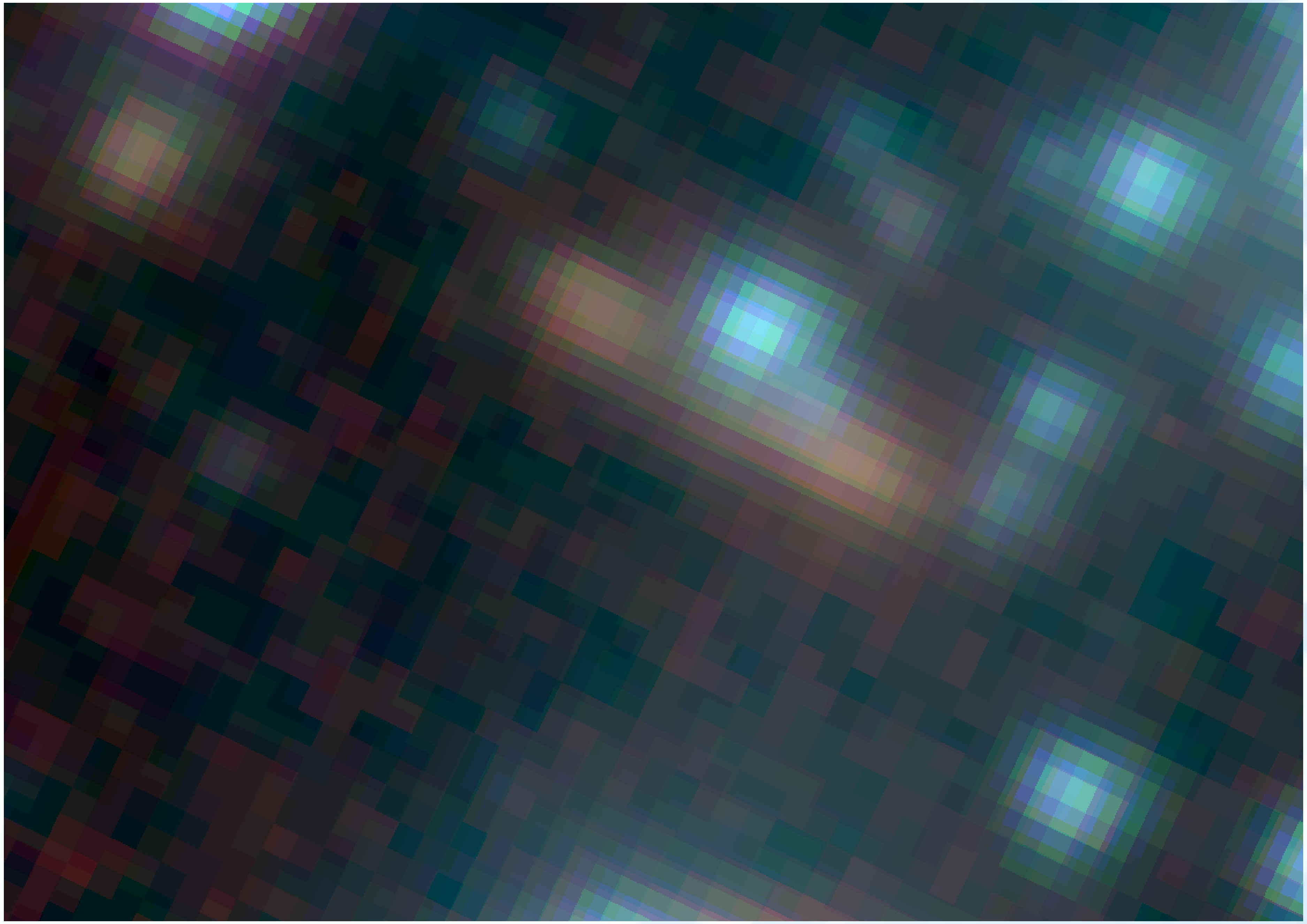
IRAC 3.6μm 4.5μm 8μm

$|\mu|$ = 50 and 25

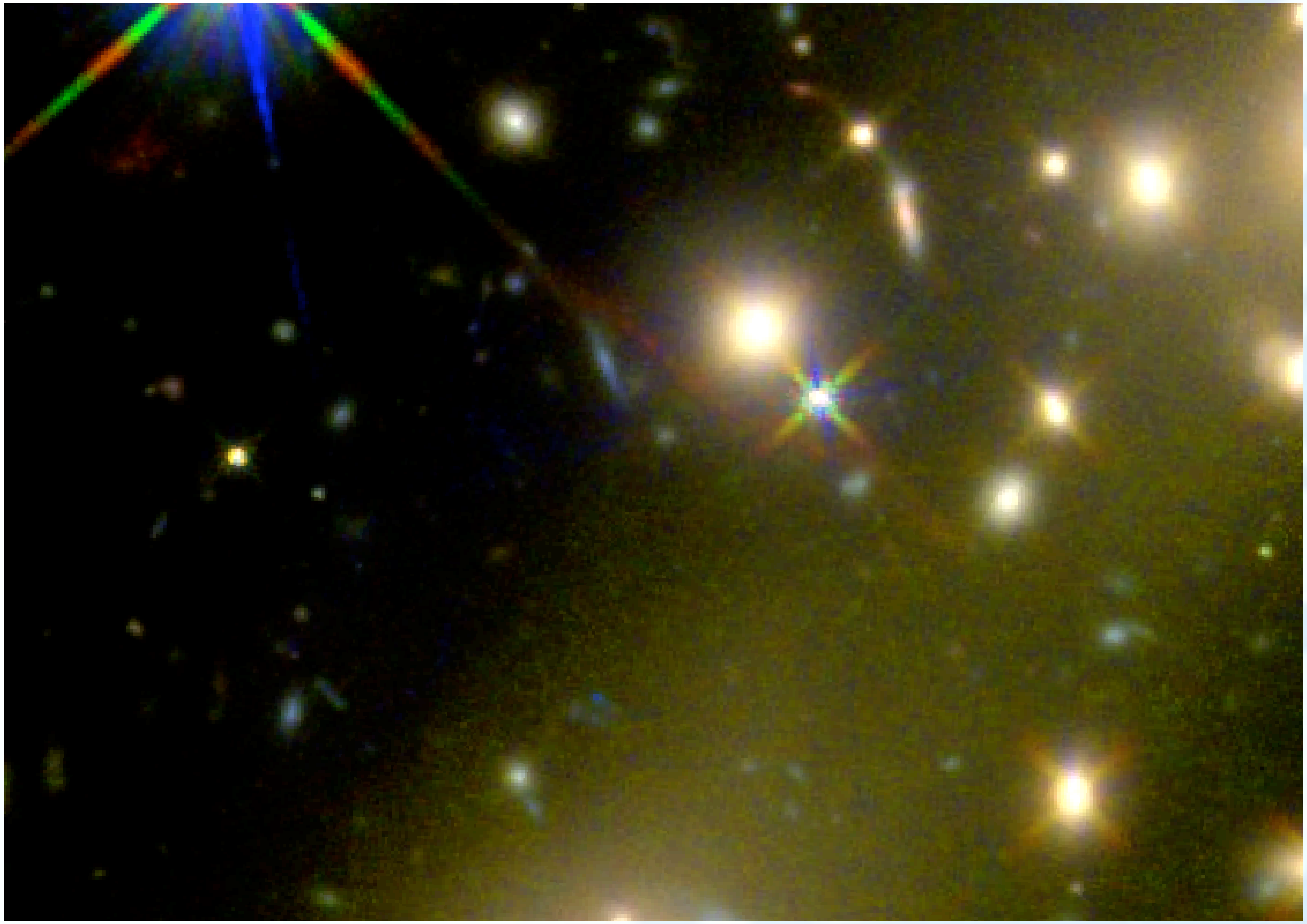
z=2.8

Gonzalez, MB et al 2009, 2010

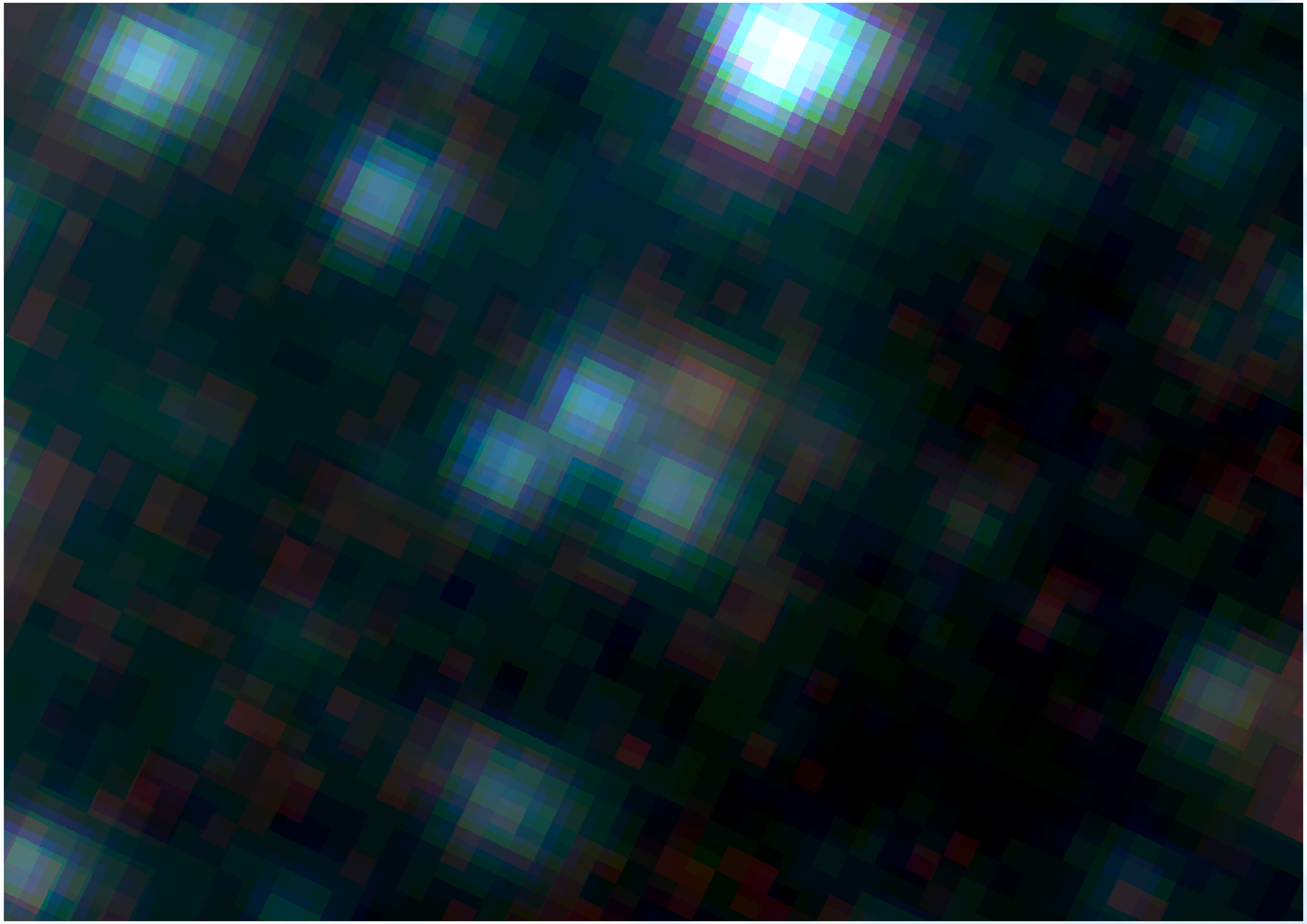
Dust bunny through WFC3



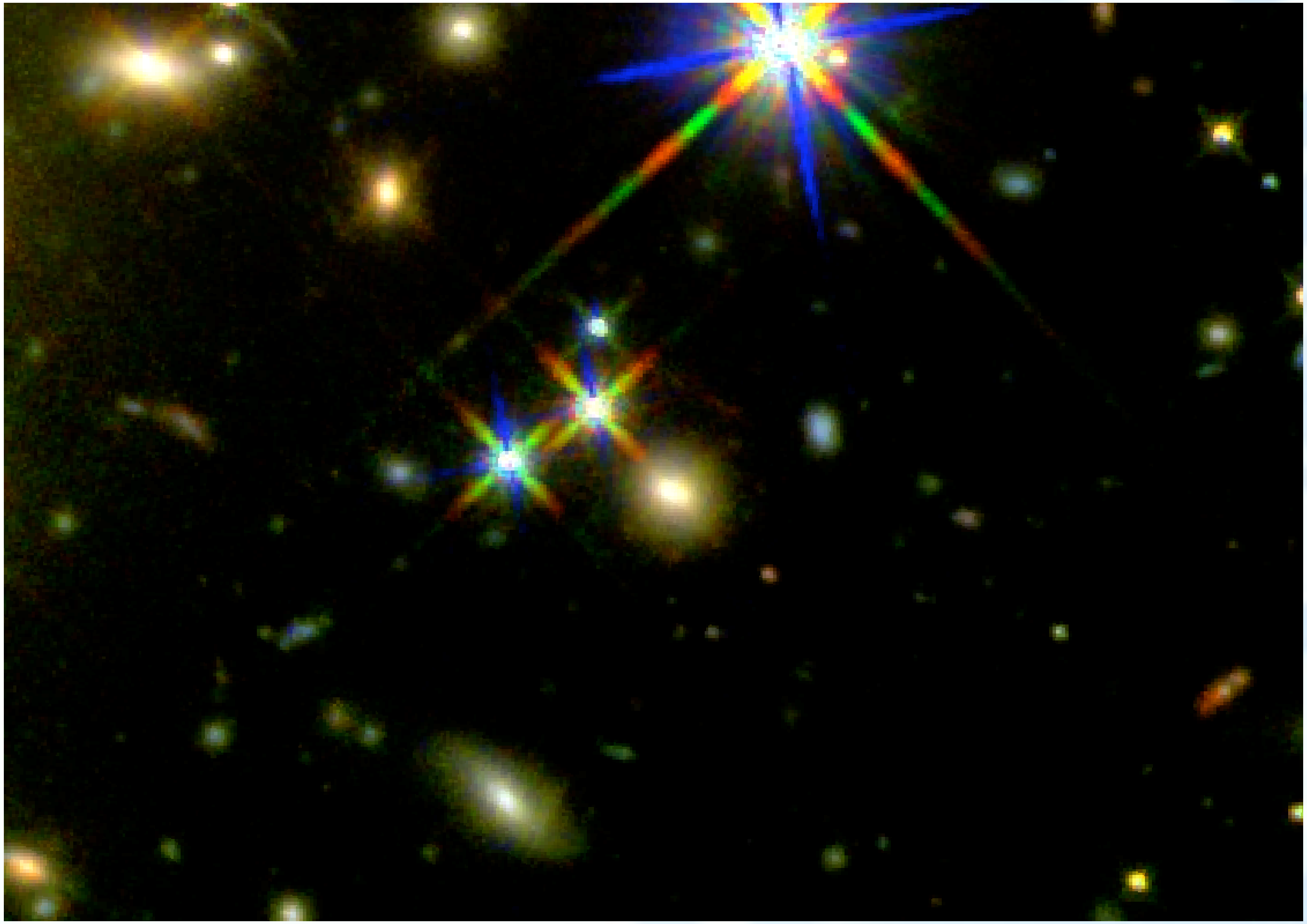
Dust bunny through WFC3



Dust bunny through WFC3

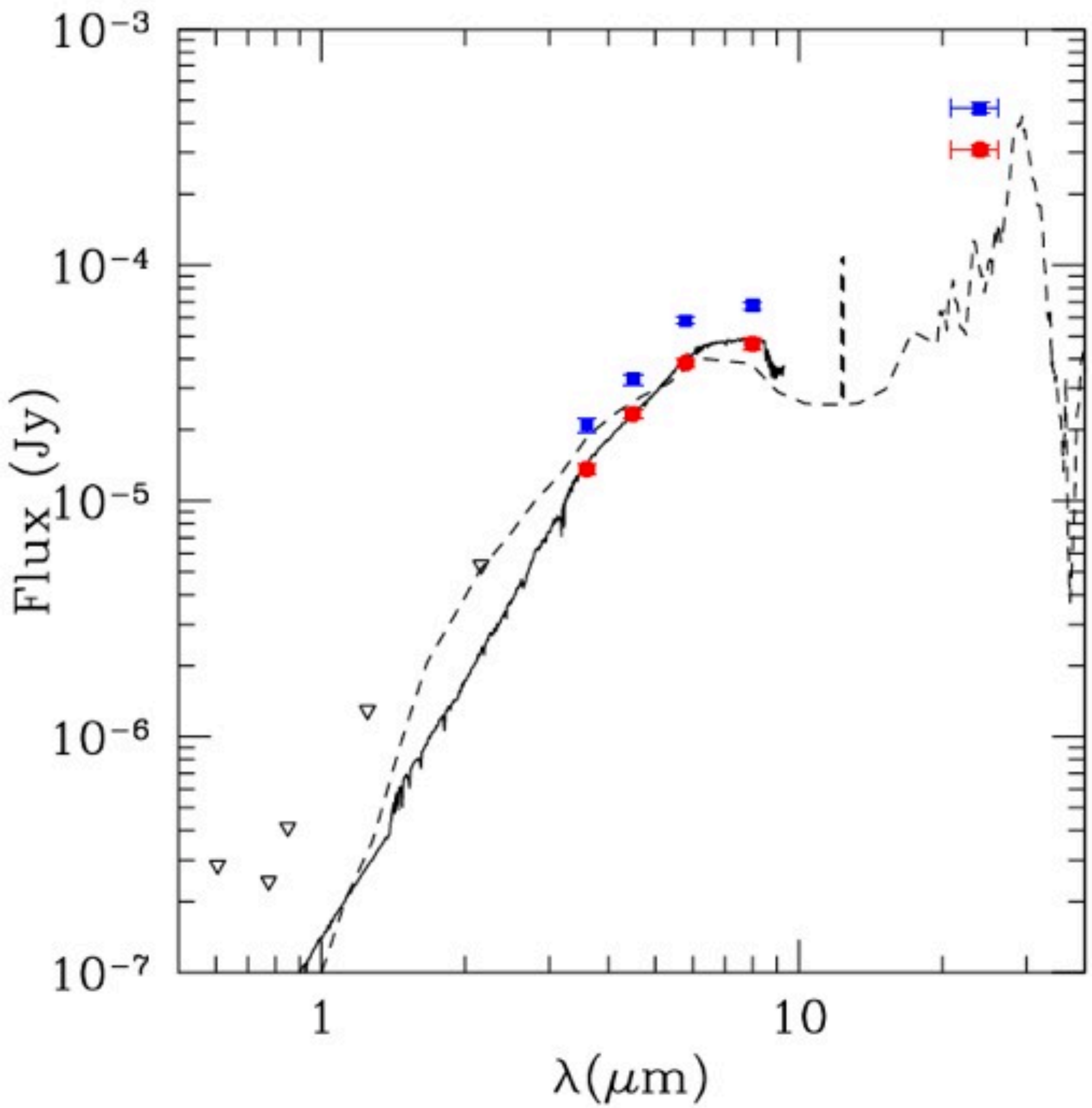


Dust bunny through WFC3

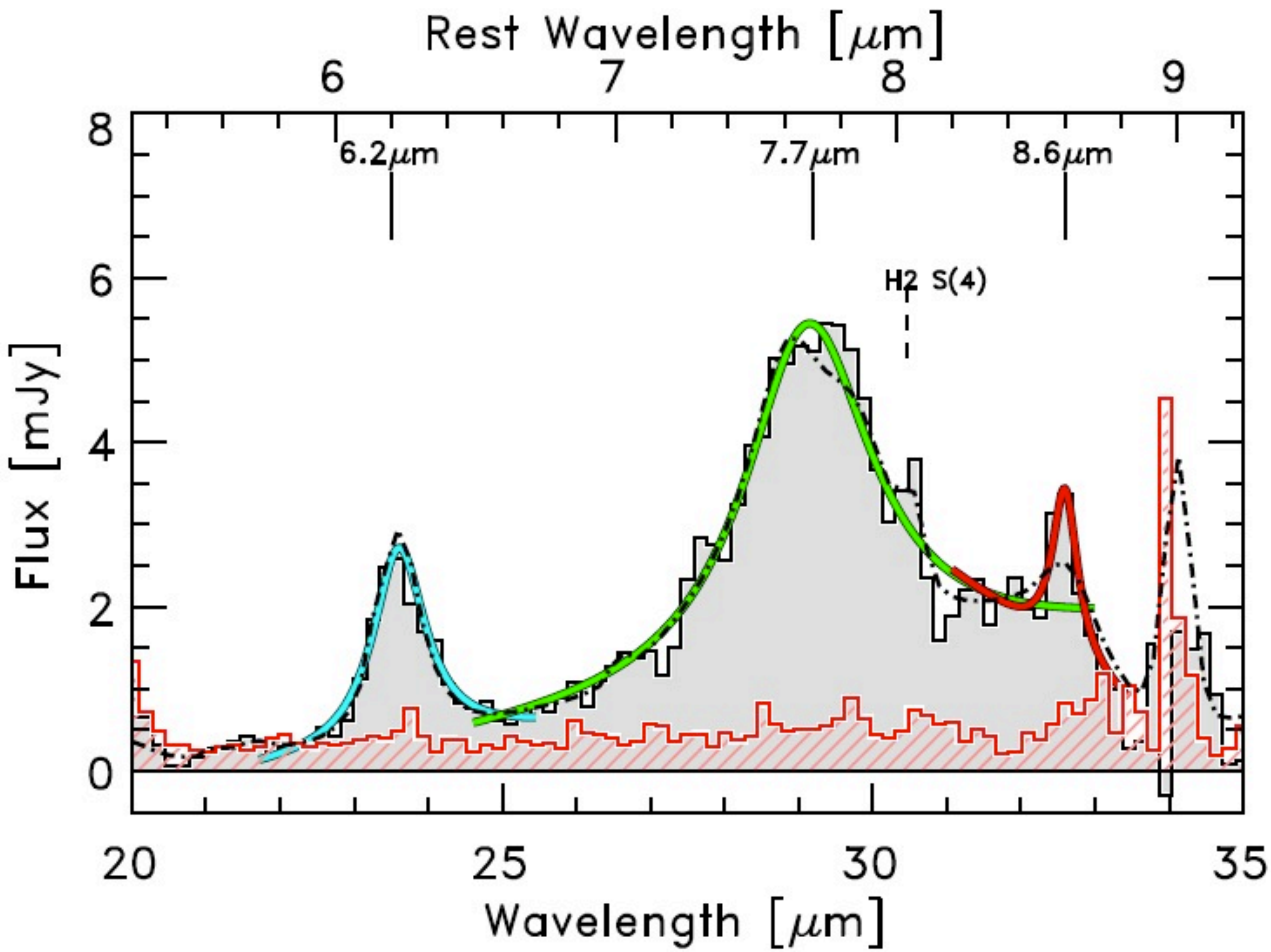


Dust Bunny

- Bright in IRAC (3.6μm, 4.5μm, 8μm, and 24μm) and not detected at (3-σ) in optical imaging.
- Gravitational lensing and SED fitting both agree: z = 2.8
- Ultra bright submm source (AzTEC - Wilson et al 2008, BLAST - Rye et al. 2009, Herschel - Rex et al. 2009)



IRS spectrum



Gonzalez, MB et al 2010

Dust Bunny

* A low-mass dwarf galaxy
* $M = 4 \times 10^9 (\mu/100)^{-1} M_\odot$
* The far-infrared thermal emission is star-formation dominated.
* The inferred specific star formation rate: SSFR $\sim 25 - 40$ Gyr^{-1}

Silver Bullet for High-z Universe

* The future is bright (WFC3, JWST) -> magnified by lensing
* SW United goes adaptive -> improved accuracy of the image positions - rms/image 4"->1.4" (current limitations - lack of redshifts)
* Efficient cosmic telescope
* We find results consistent with blank field surveys, despite using much shallower data.
* Bouwens et al. 2010d HUDF blank fields: ~ **0.1 dropouts/orbit(zYH)**

  Using 1E0657-56: ~ **0.7 dropouts/orbit (zJH)**
* Need better statistics, especially at faint end.