Dark Matter helps Breaking Cosmic Dawn

Maruša Bradač

DARK SIDE OF THE UNIVERSE

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The anti-social Universe

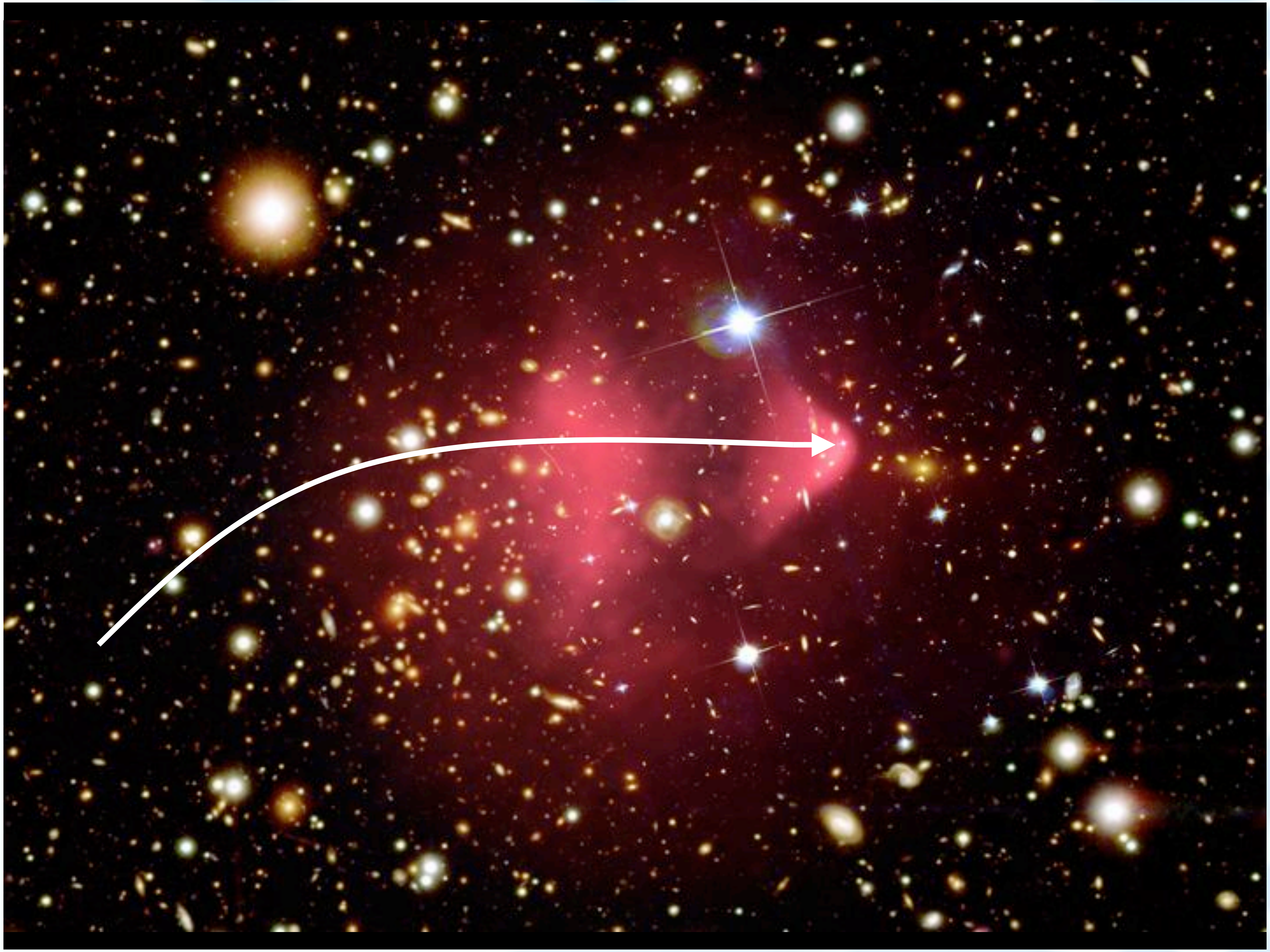
Clusters as Astroparticle Physics Laboratories

* Clusters of galaxies consist of approximately 13% of hot gas, 2% of stars and 85% of dark matter.
* The bullet cluster is no exception of this. But because of its unique geometry we are able to study the effects of each of these separately.
* Unique astroparticle physics laboratory - study dark matter distribution and its properties.

The Bullet Cluster 1E0657-56

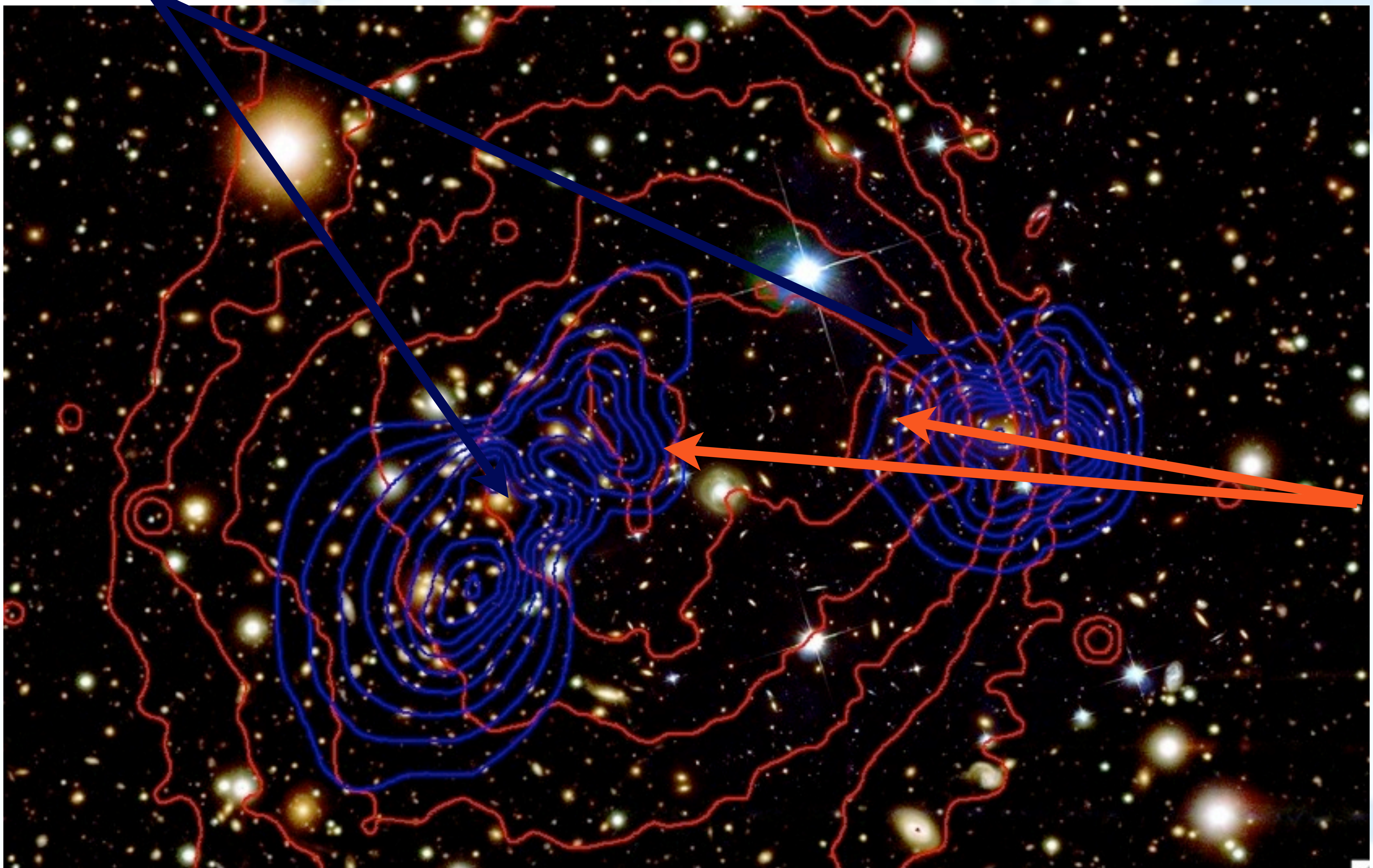
- One of the hottest and most luminous X-ray clusters known.
- Unique case of a major supersonic cluster merger occurring nearly in the plane of the sky (i < 15° , Markevitch et al. 2002).
- Using the gas density jump at the shock we derived a shock Mach number of 3.2 ± 0.8, which corresponds to a shock velocity 4500 ± 1000 kms^{-1}
- Subcluster velocity ~2700 kms^{-1} (Springel & Farrar 2007)

The Bullet Cluster 1E0657-56



Strong and Weak Lensing United

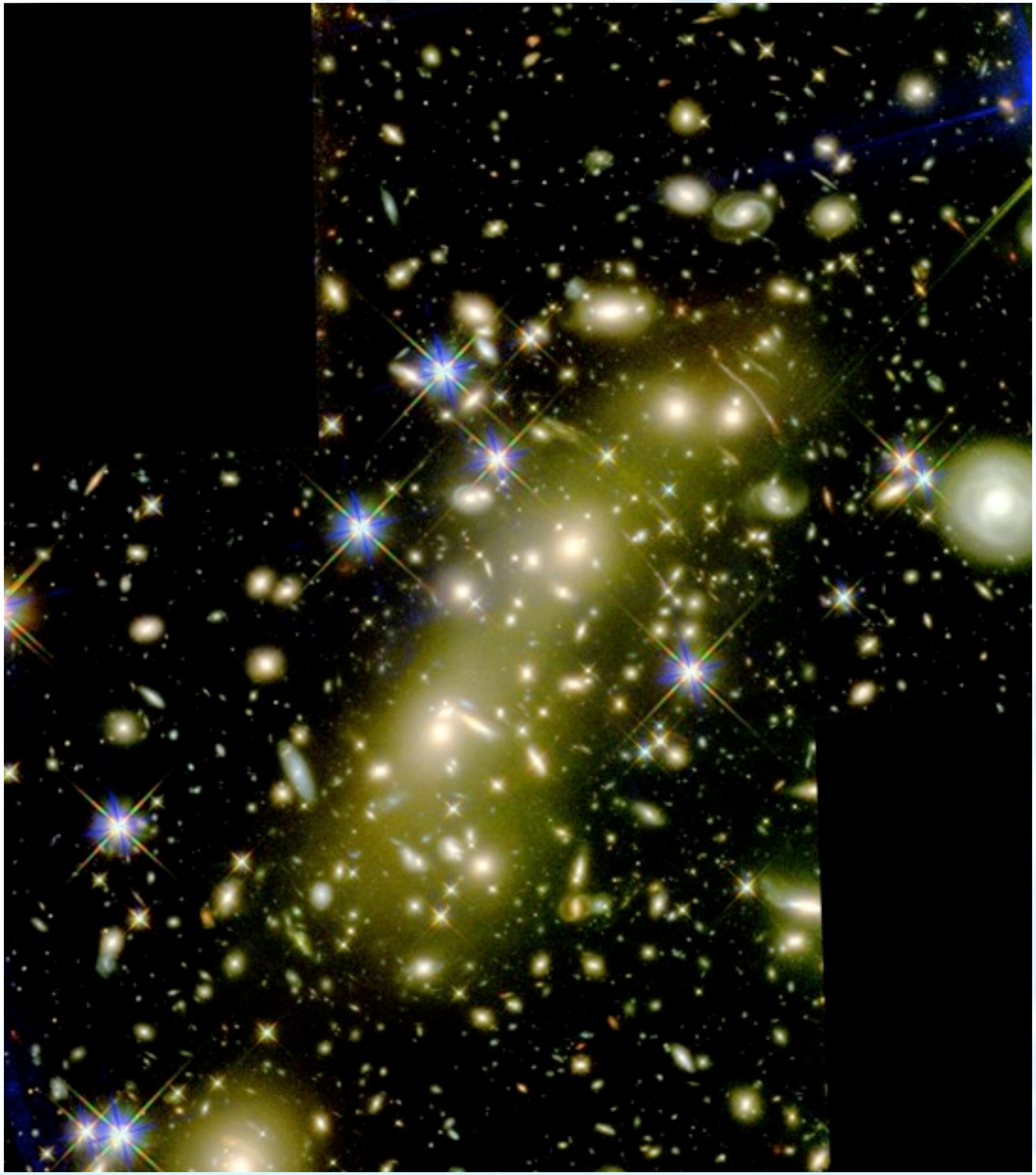
Total Matter



Gas

Bradač et al. 2006

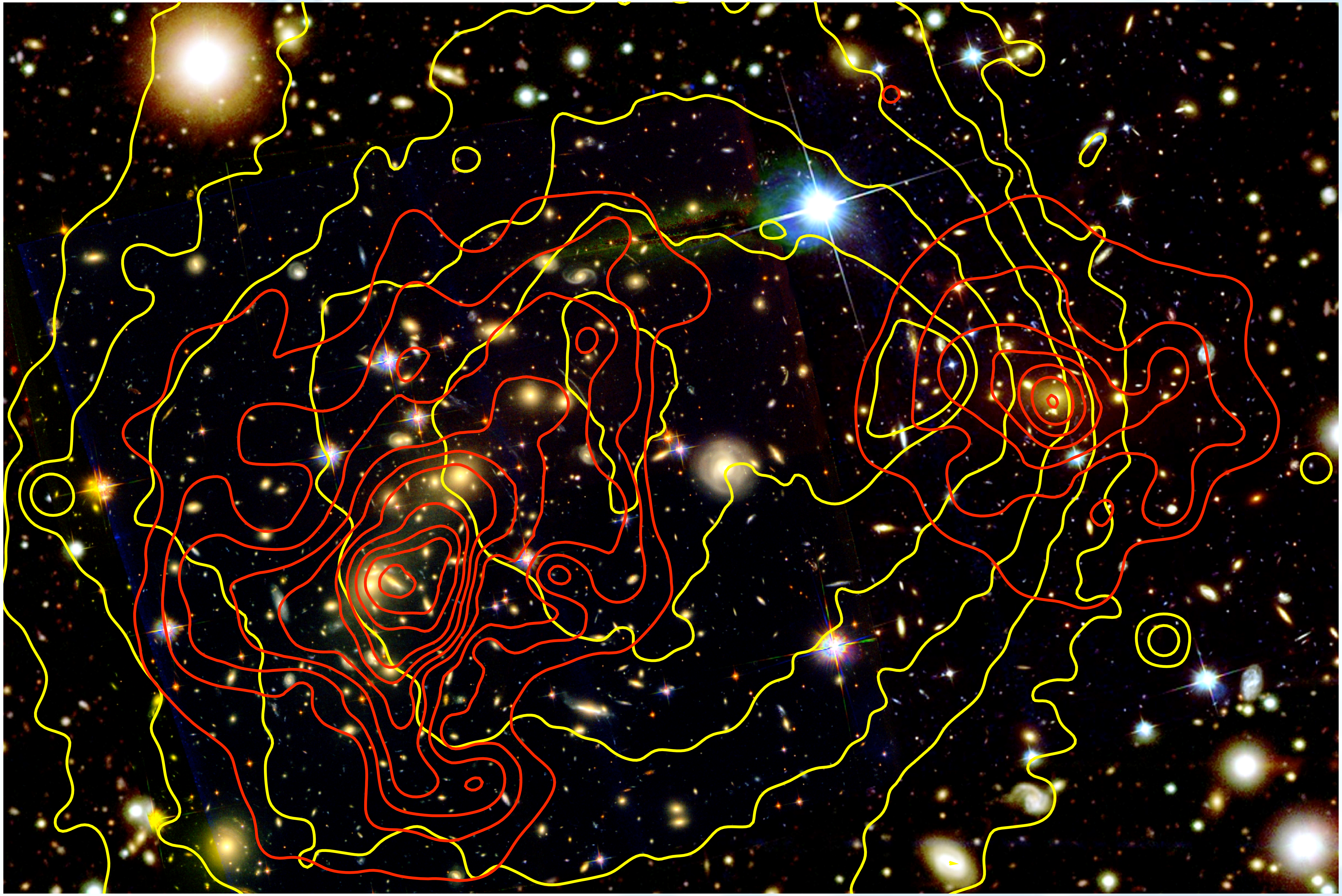
New data for the Bullet Cluster



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

Hall, MB et al. 2012

SW United goes adaptive



Hall, MB et al. 2012

Dark Matter Properties

* Combining the Chandra data with lensing mass maps -> place an upper bound on the dark matter self-interaction cross section $\sigma/m < 1\ cm^2g^{-1} = 1.8 barn/GeV$ (Markevitch et al. 2004).

  -> Significant offset between subcluster X-ray gas core and dark matter peak gives $\sigma/m < 10\ cm^2g^{-1}$

  -> Survival of the subcluster dark matter peak during interaction gives $\sigma/m < 3\ cm^2g^{-1}$

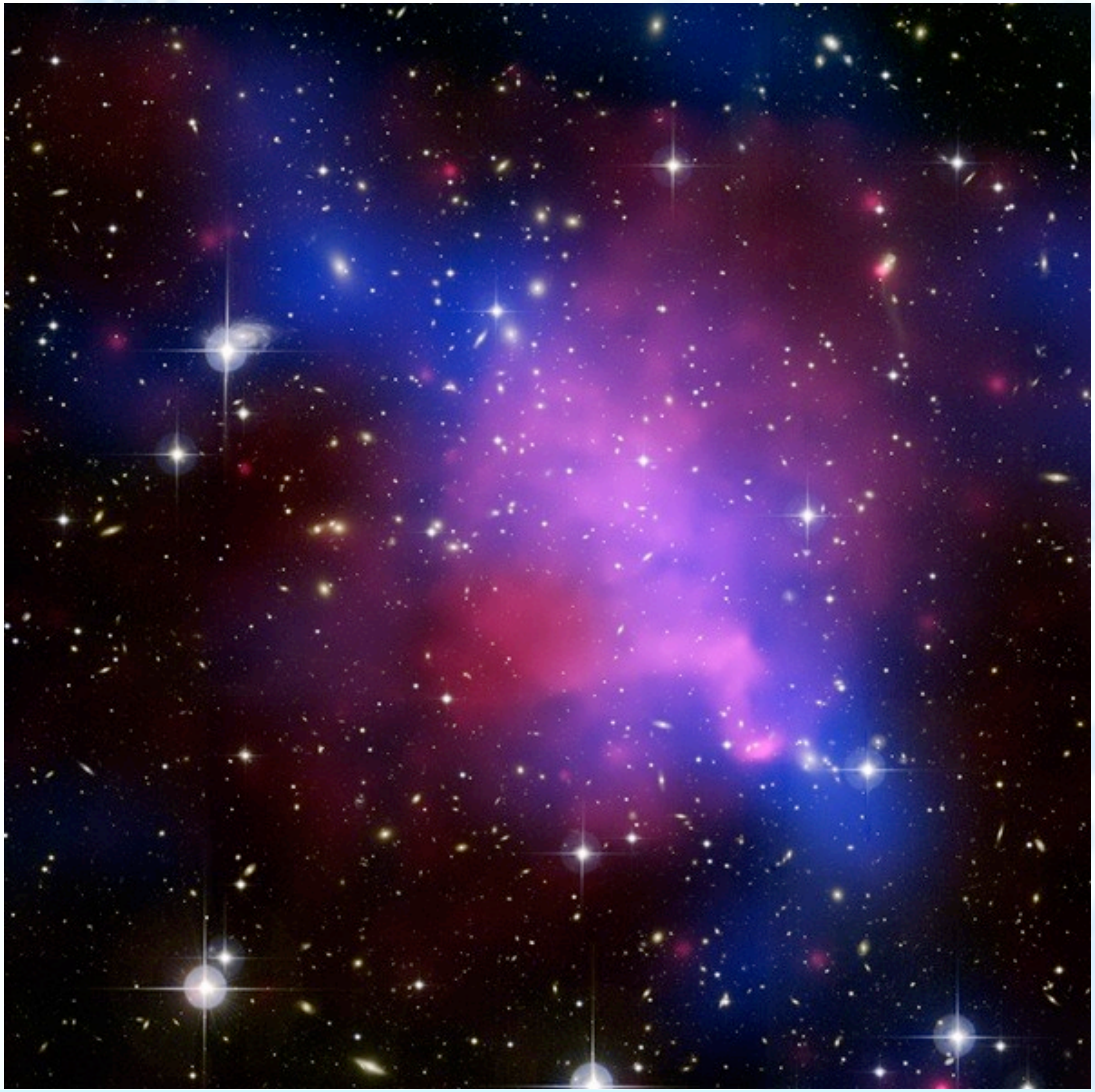
  -> No loss of mass from subcluster during interaction gives $\sigma/m < 0.8\ cm^2g^{-1}$

* $\sigma/m < 0.7\ cm^2g^{-1} = 1.3 barn/GeV$ (Randall et al.2008)

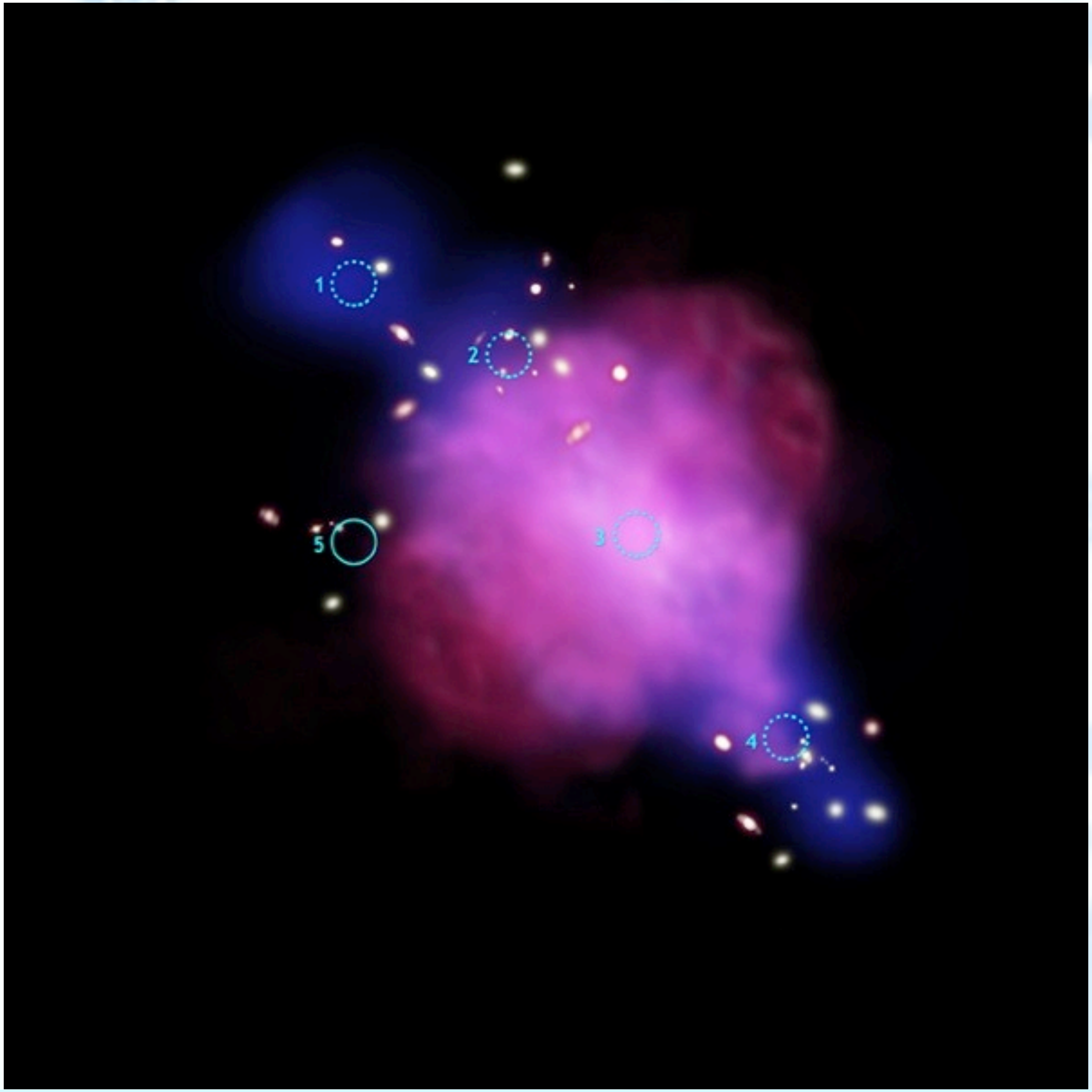
* SI dark matter $\sigma/m < 0.5 - 5 cm^2g^{-1}$ (Davé et al. 2001).

The Nature of Dark Matter
Really collision-less?
Cosmic Train Wreck A520

A520 - Cosmic "Train Wreck"



A520 - Cosmic "Train Wreck"



A520 - Cosmic "Train Wreck"

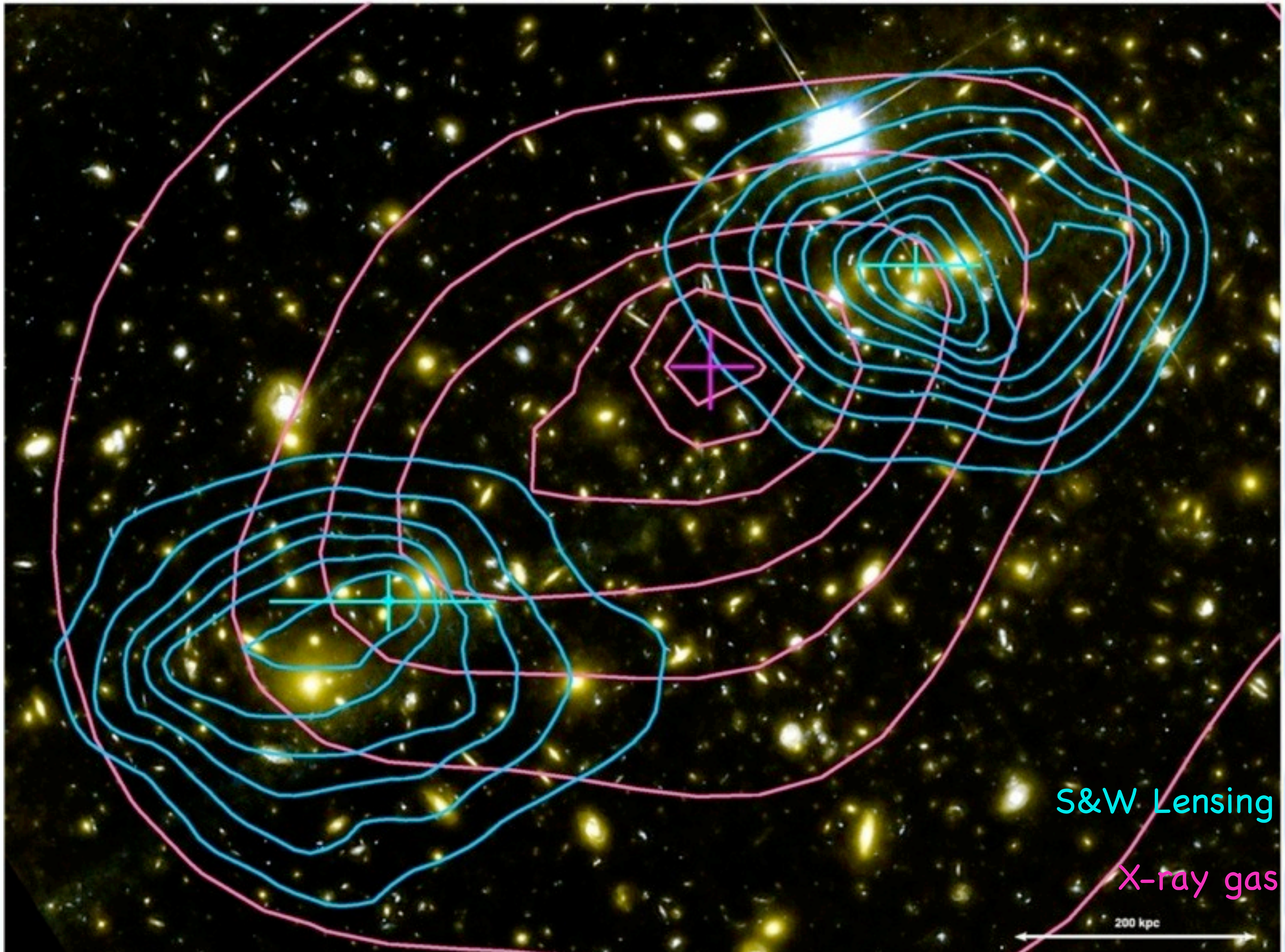
* The galaxies originally in the dark core could have been ejected through a multiple-body interaction
* Weakly self-interacting dark matter: requiring $3.8 \pm 1.1\ \mathrm{cm^2 g^{-1}}$ (Bullet cluster constraints $\sigma/m < 0.7\ \mathrm{cm^2 g^{-1}} = 1.3\mathrm{barn/GeV}$)
* New HST data

Weight Loss Program

- New multi color HST data
- No dark core at position #3 (lower M/L than Jee et al. 2012)
- Twice the light, 60% the mass

Clowe et al. (MB) 2012
(submit. to ApJ)

Baby Bullet* Cluster MACSJ0025-1222



* Neither baby nor bullet

Bradač et al. 2008b

Dark Matter Properties

* Combining the Chandra data with lensing mass maps -> place an upper bound on the dark matter self-interaction cross section $\sigma/m < 4\ cm^2g^{-1} = 8$ barn/GeV.

  -> Significant offset between subcluster X-ray gas core and dark matter peak

$$\tau = \Sigma \frac{\sigma}{m}$$

  -> ~~Survival of the subcluster~~ (need velocity info)

  -> ~~No loss of mass from subcluster~~

* The Bullet Cluster: $\sigma/m < 0.7\ cm^2g^{-1} = 1.3$barn/GeV (Randall et al.2008)

Musket Ball Cluster: DLSCL J0916.2+2951

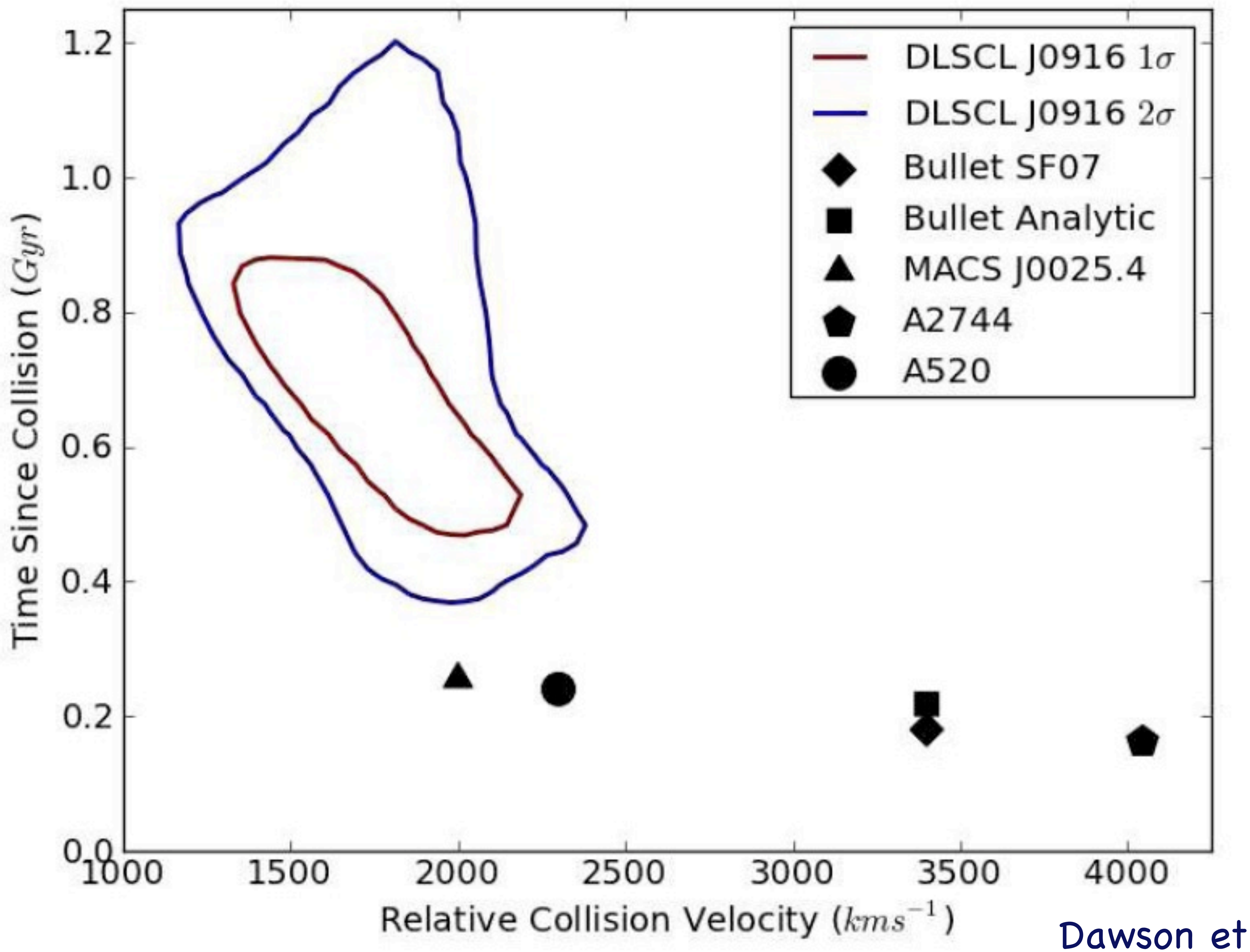
Dawson et al.(MB) 2012

DLSCL J0916.2+2951

* Discovered from Deep Lens Survey
* A merger at a later stage
* $\sigma/m < 7\ cm^2g^{-1} = 15$ barn/GeV.
* z=0.58

Dawson et al.(MB) 2012

And another one: DLSCL J0916.2+2951



Dawson et al.(MB) 2012

Have we learned all there is about dark matter?

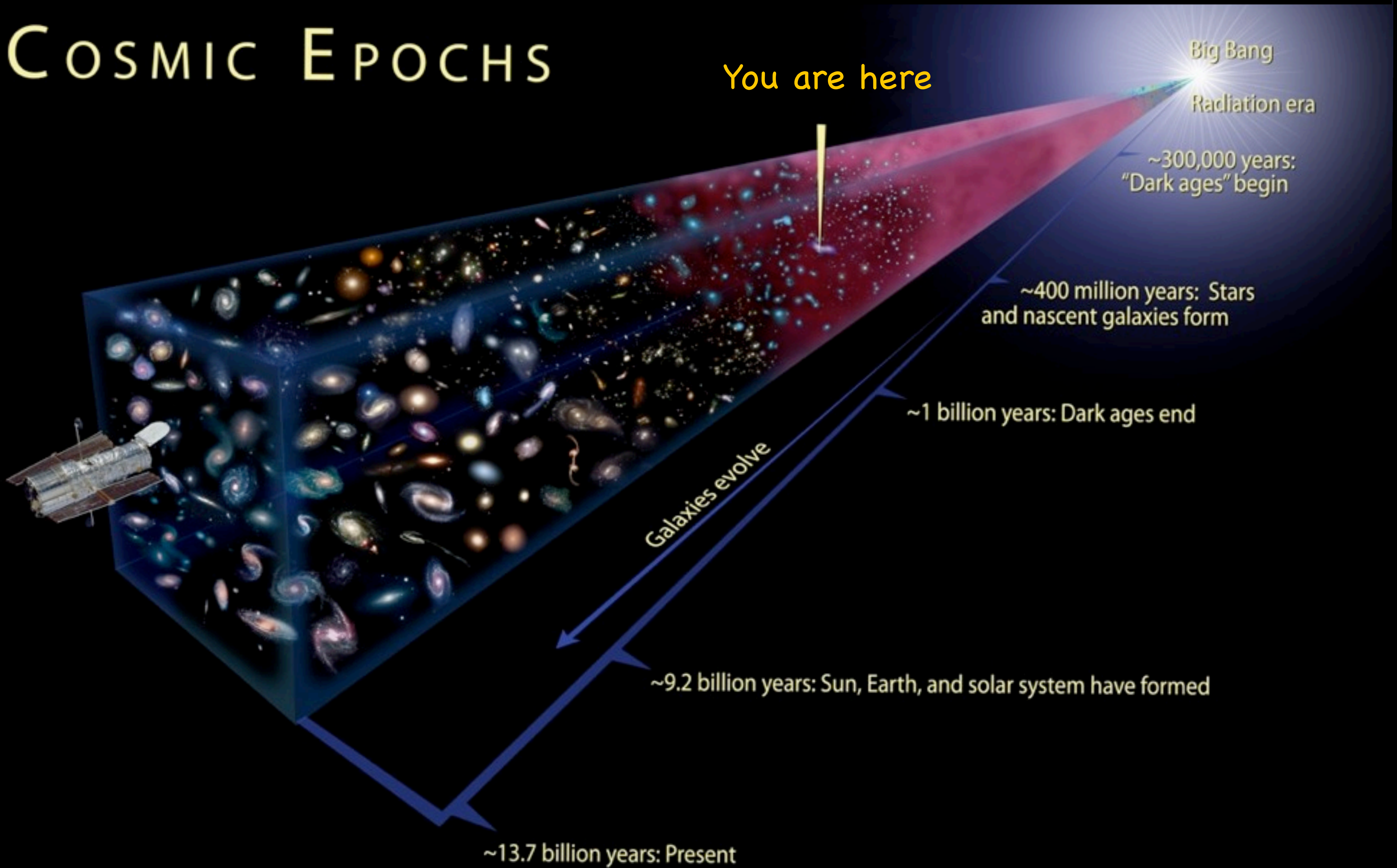
* No
* Merging Cluster Collaboration-MC^2
* UC Davis - UC Irvine collaboration led by PI Dawson (jump started by HIPPAC)

MERGING CLUSTER COLLABORATION

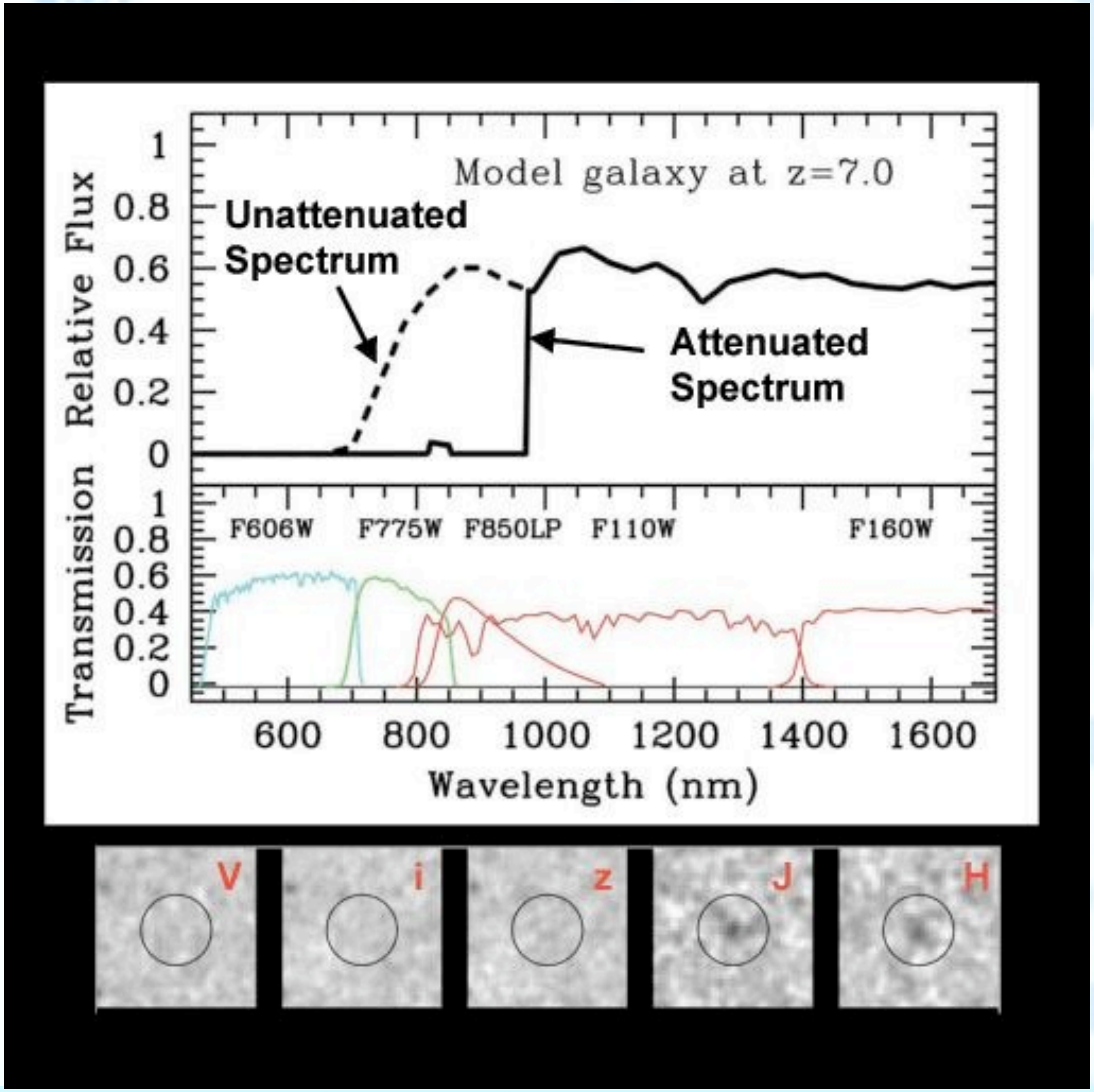

DARK MATTER
Most of the universe can't even be bothered to interact with you.
S.Caroll

Breaking Cosmic Dawn

Cosmic Epochs



High-z Universe

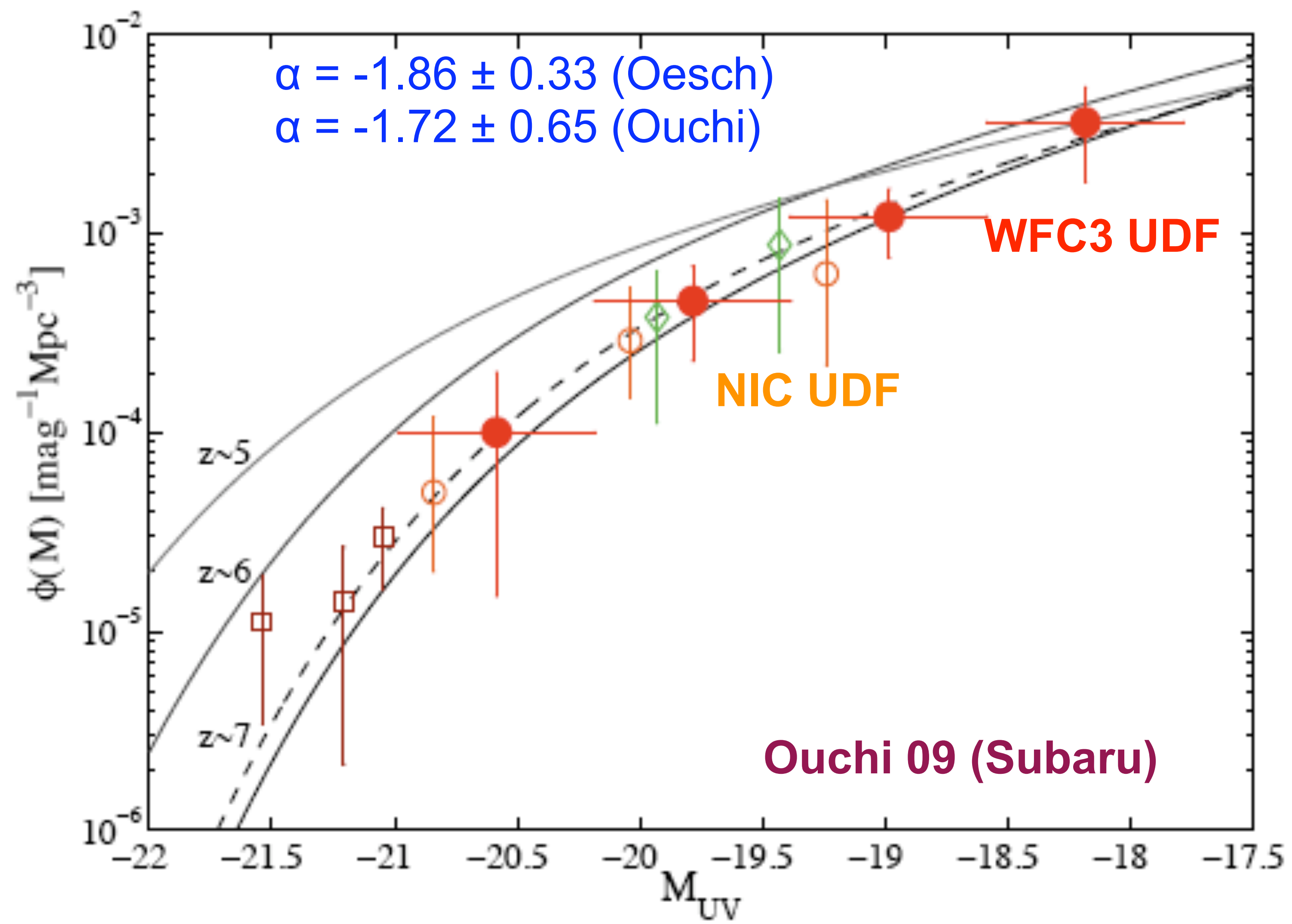


Observing z~7 Universe Through Gravitational Telescopes

* Large magnification factors, allows us to get larger number counts (provided the luminosity function is steep)
* Areas with observed multiple images - much eased identification
* Magnification maps are known to sufficient accuracy to constrain the number counts (and for best cases also individual luminosities) Bradač et al. 2009

Observing z~7 Universe Through Gravitational Telescopes

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

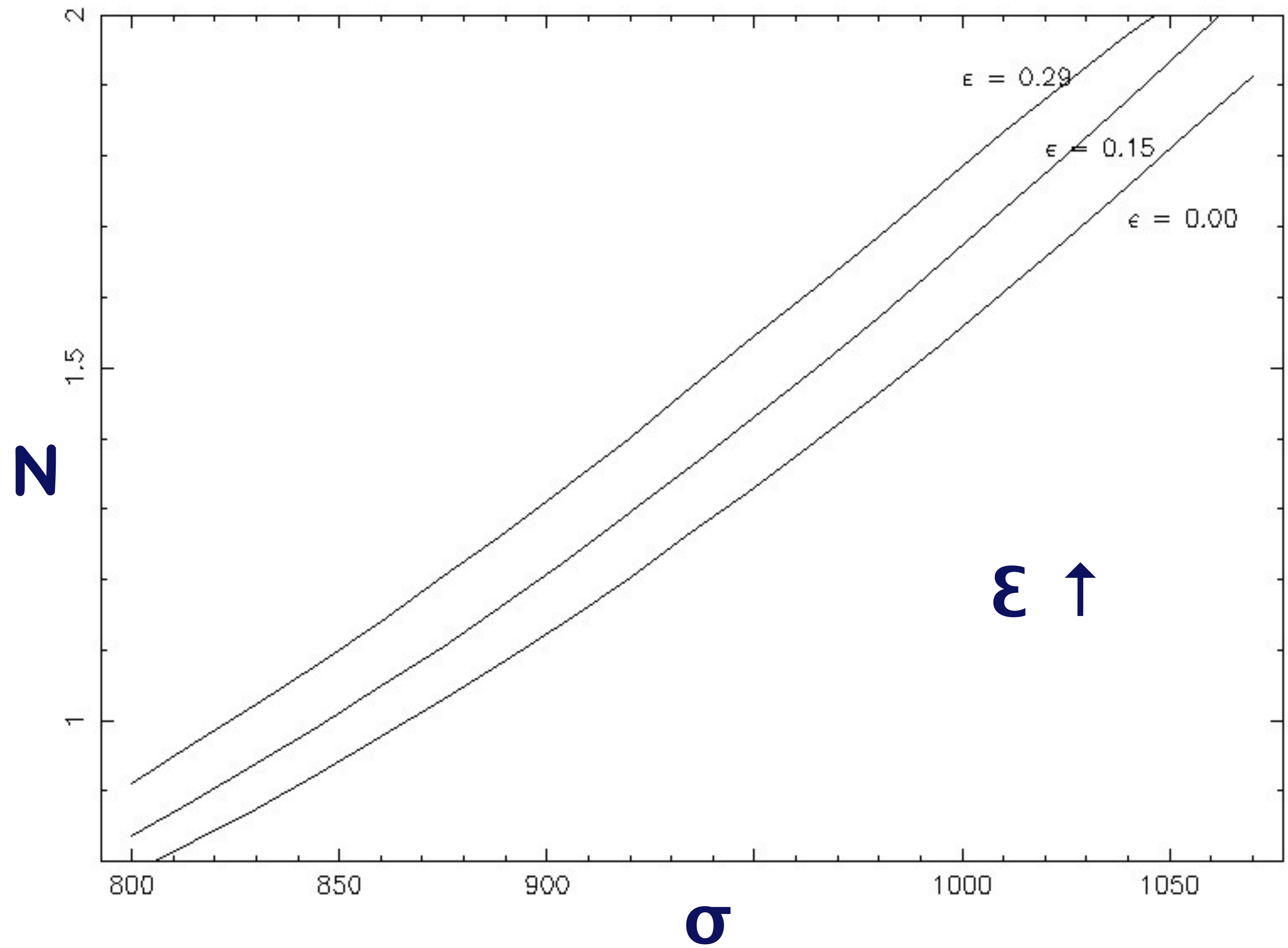


Oesch et al, Bunker et al 2009

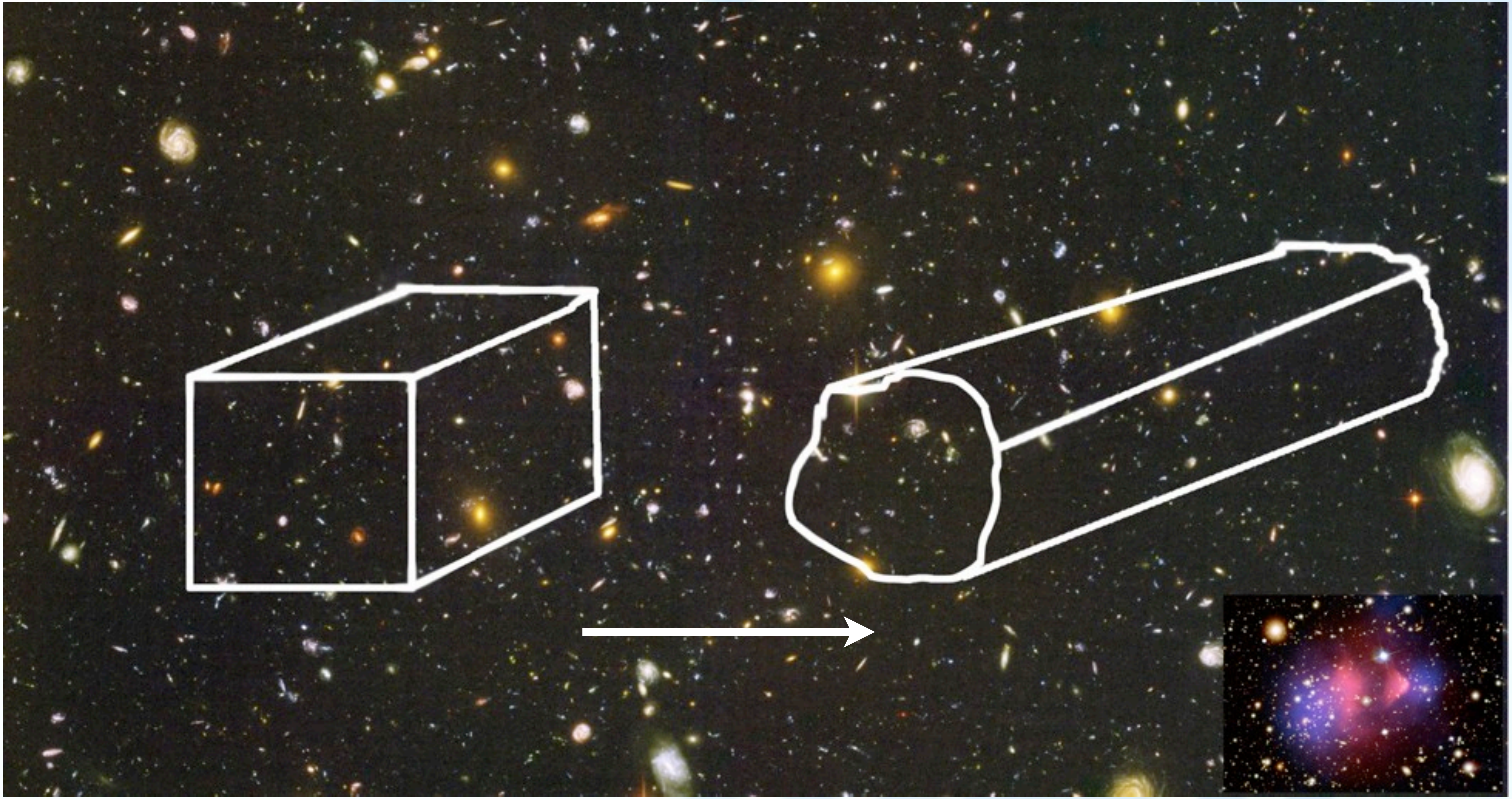
Finding Ideal Cluster

Finding Ideal Cluster

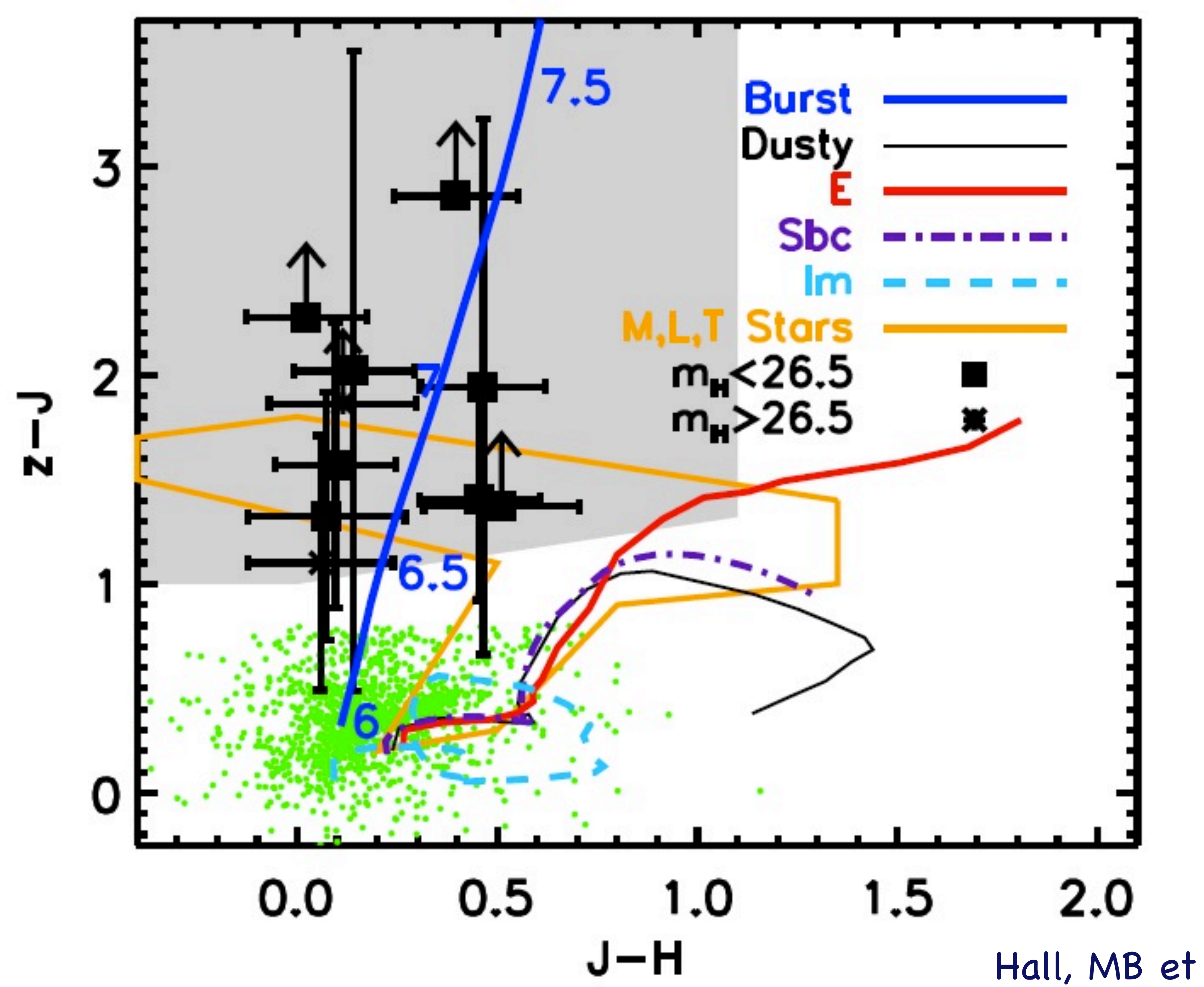
Pick Ideal Gravitational Telescope



Focusing your Cosmic Telescope

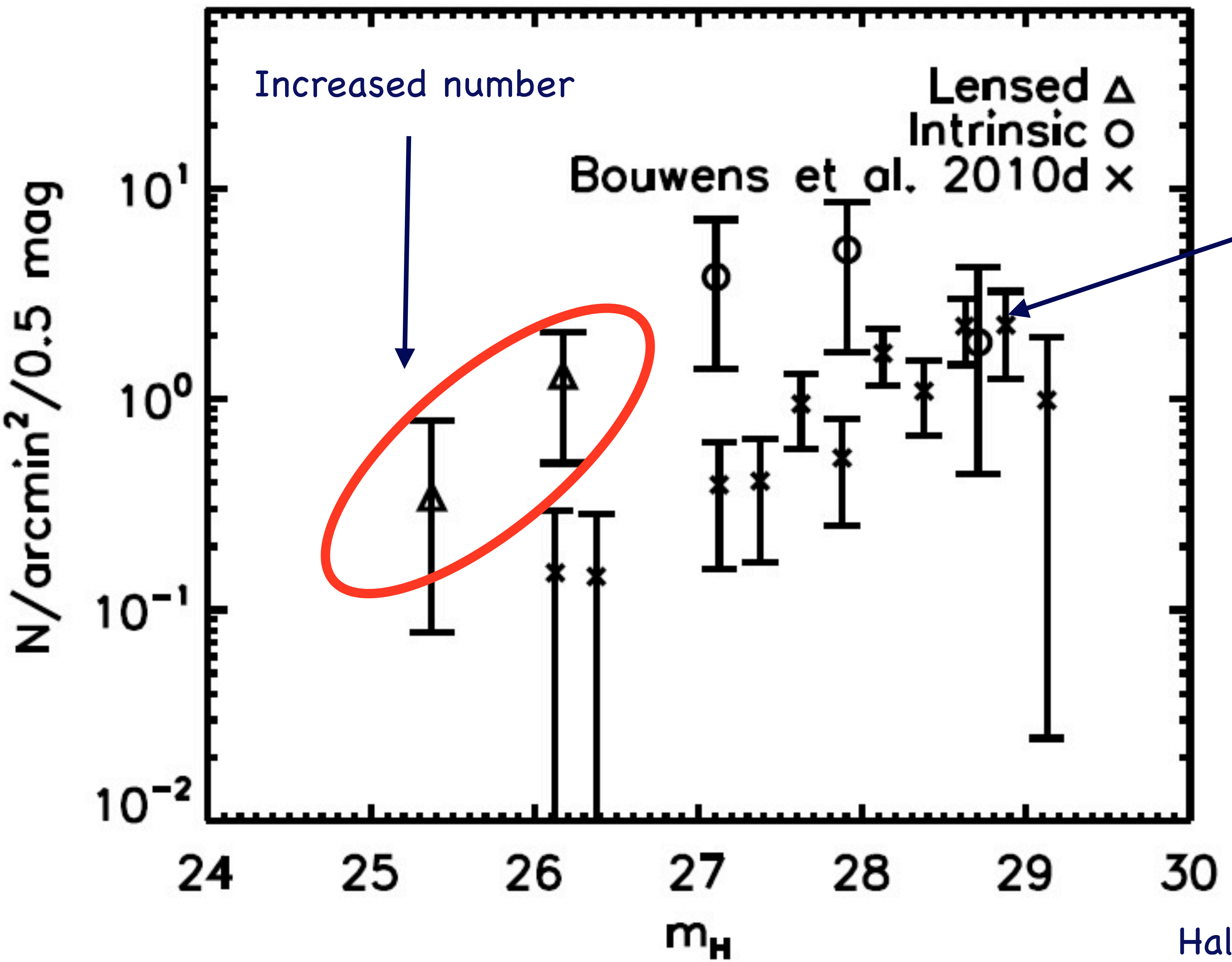


z~7 Universe through 1E0657-56



Hall, MB et al. 2012

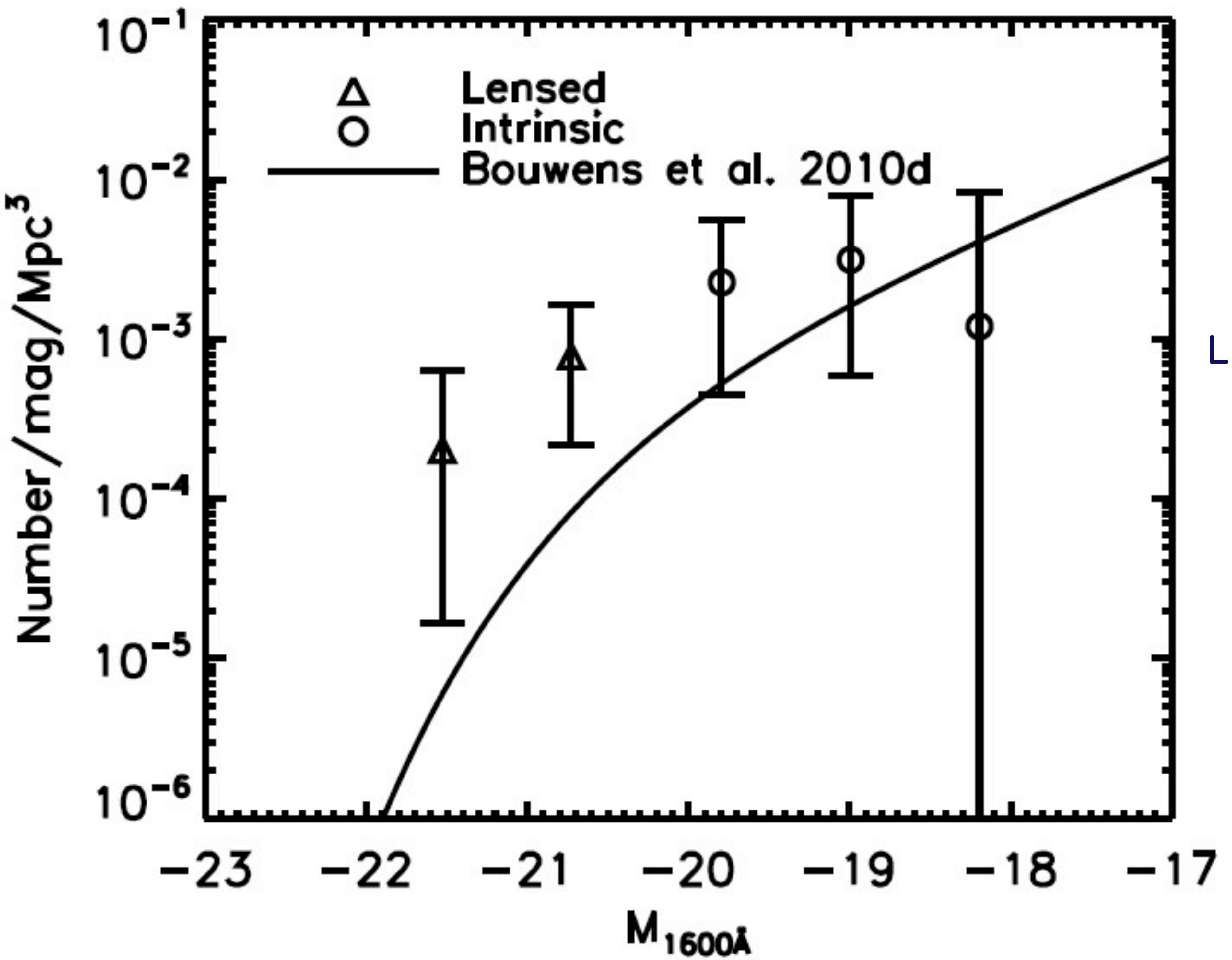
z~7 Universe through 1E0657-56



As "deep" as UDF

Hall, MB et al. 2012

z~7 Universe through 1E0657-56



Luminosity Function

Hall, MB et al. 2012

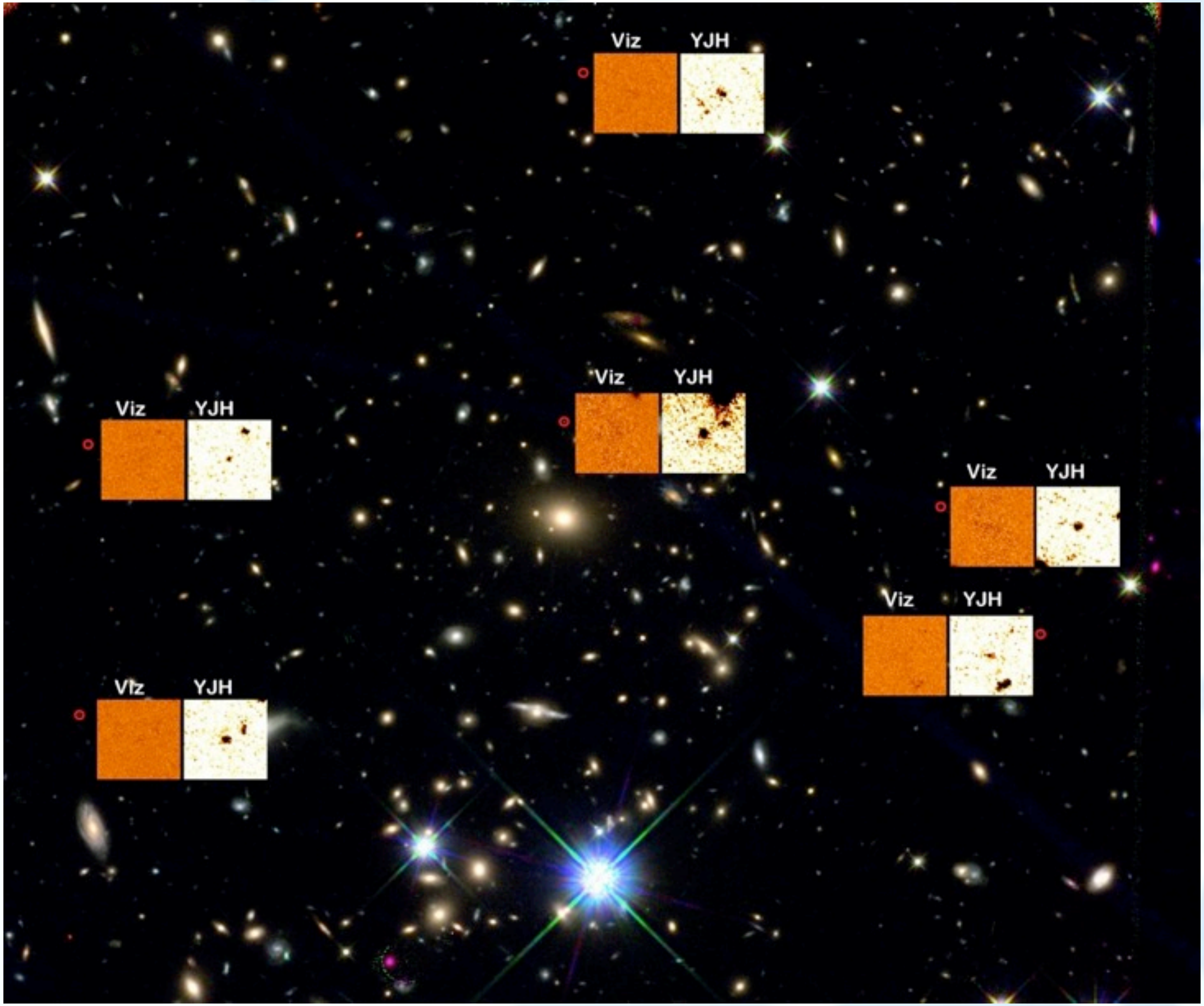
Need for spectroscopy

- Confirm redshifts
- Reionization:
    - Ratio of LAE/LBG will decline when we reach reionization era
    - Distribution of Lyman-α line strength
- Galaxy properties at $z \sim 7$

Observing z~7 Universe Through Gravitational Telescopes

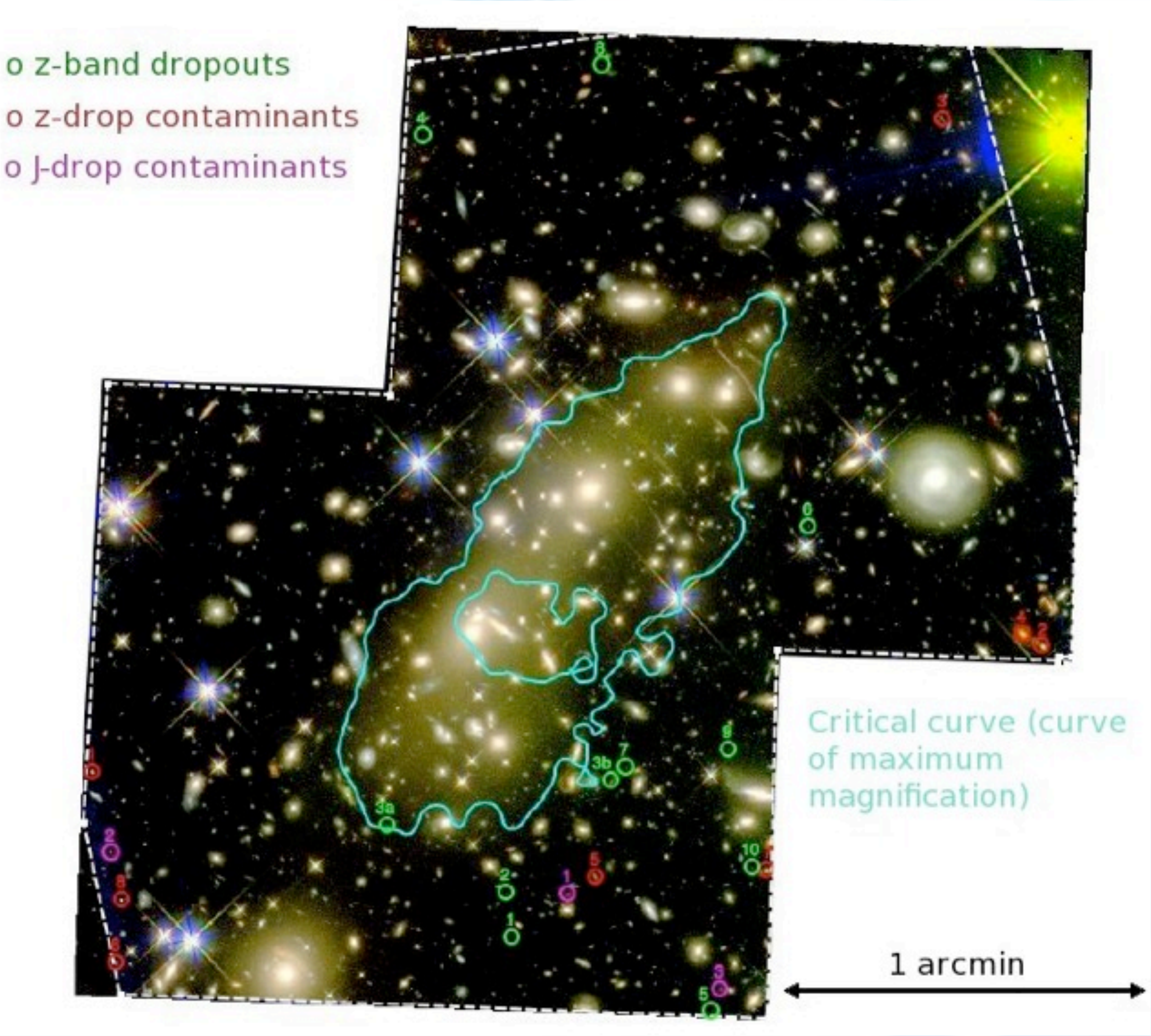
* Spectroscopy at z~7
    - → UDF - ultra difficult specroscopy
    - → GOODS - very difficult spectroscopy
    - → Lensing - difficult spectroscopy

Spectroscopic follow-up



KECK follow up

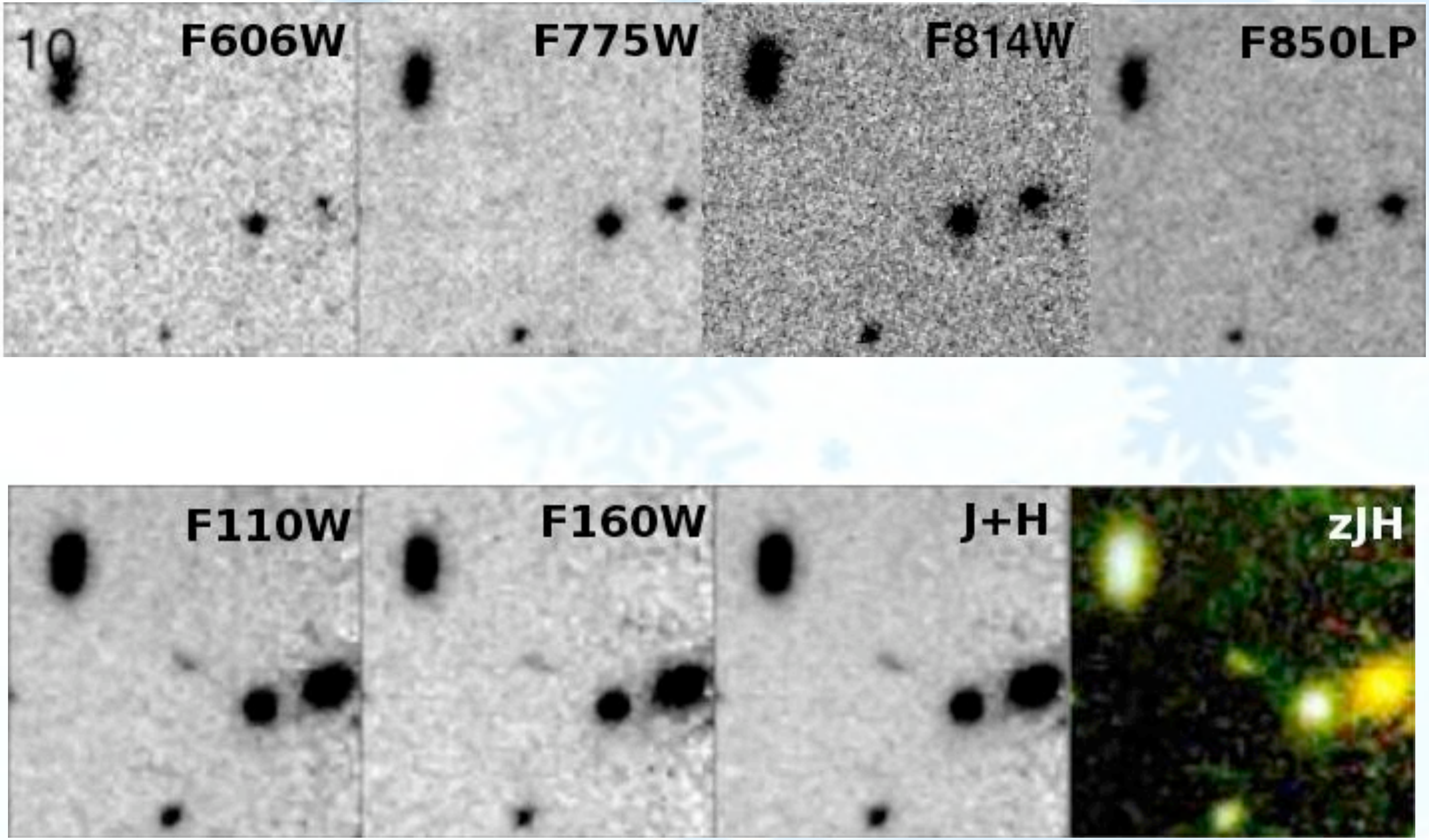
Bullet Cluster

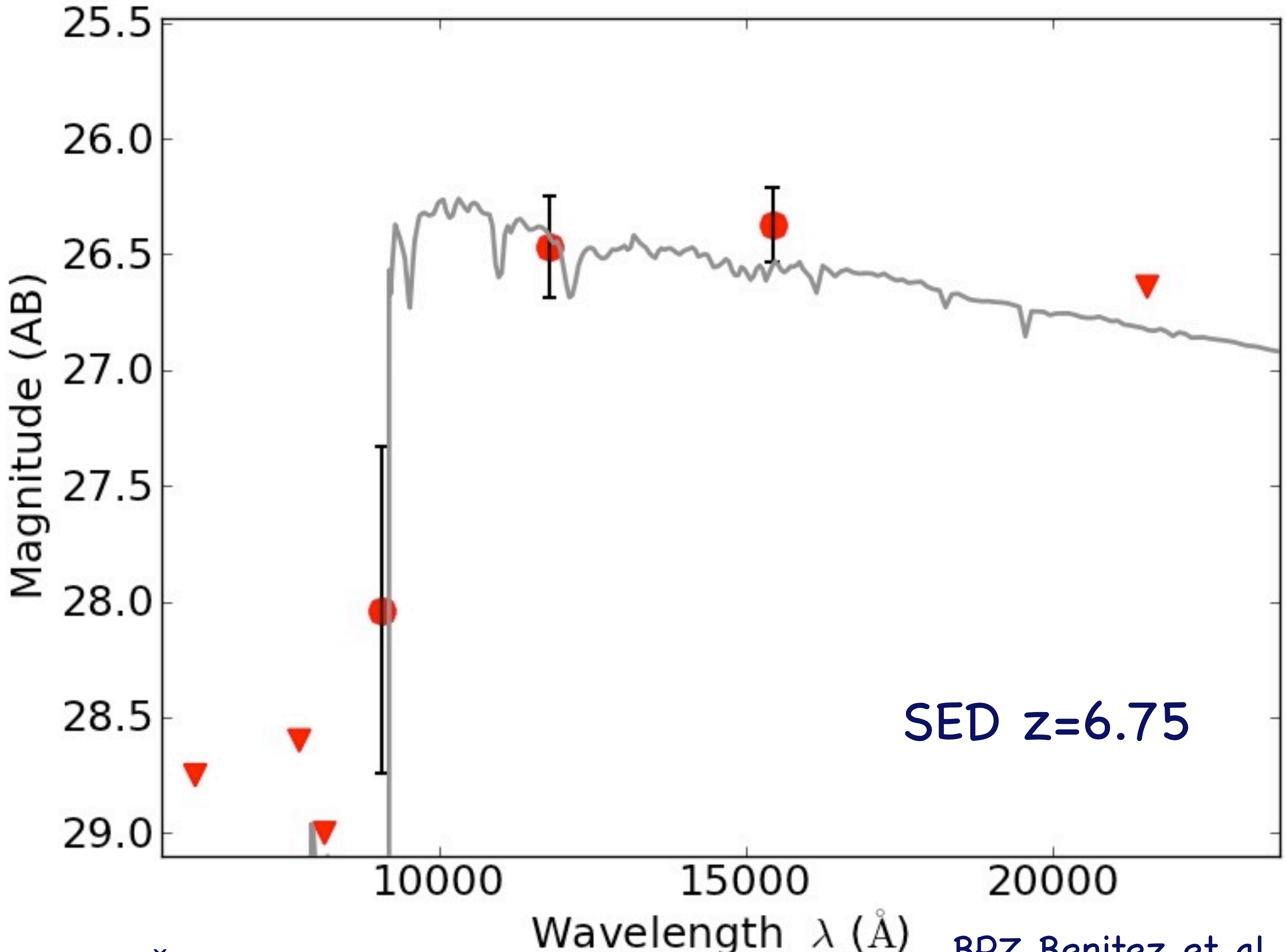


F850LP (ACS)
F110W (WFC3)
F160W (WFC3)

Hall, MB et al. 2012

Dropout #10

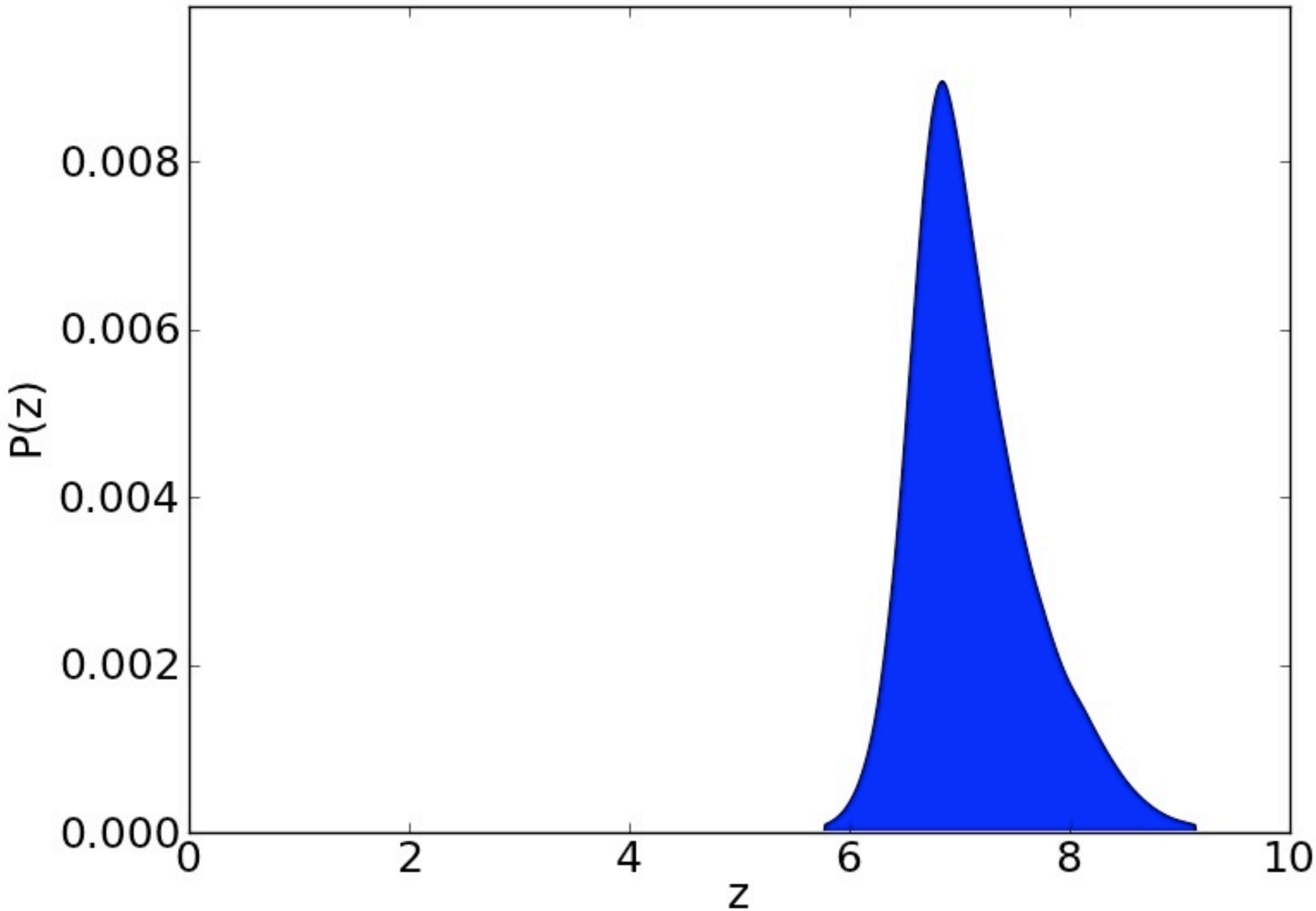




Bradač et al. 2012

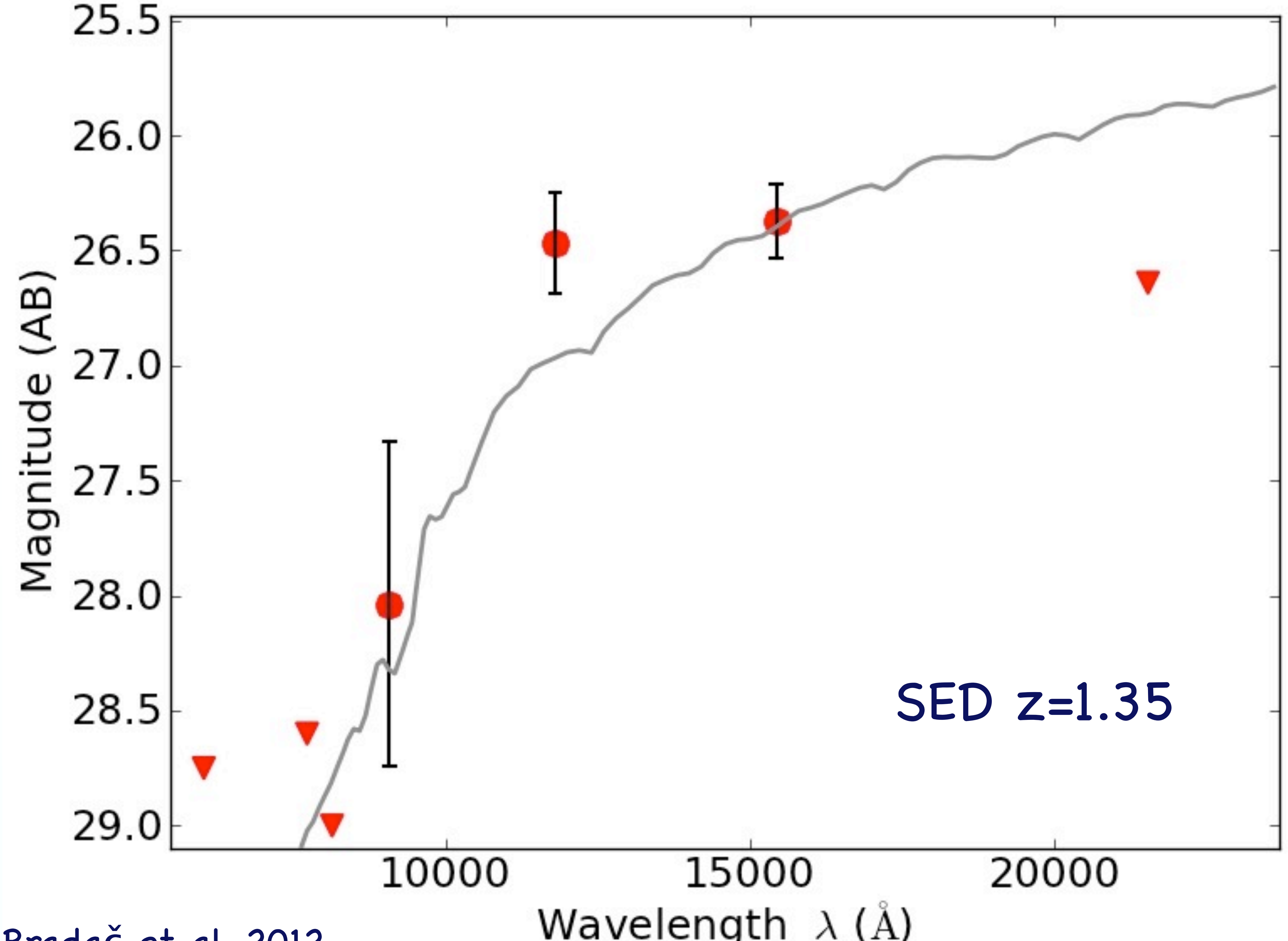
BPZ Benitez et al. 2000

Young Starburst (5Myr) @ z=6.8



Bradač et al. 2012

Very unlikely at low z



Bradač et al. 2012

Need for spectroscopy

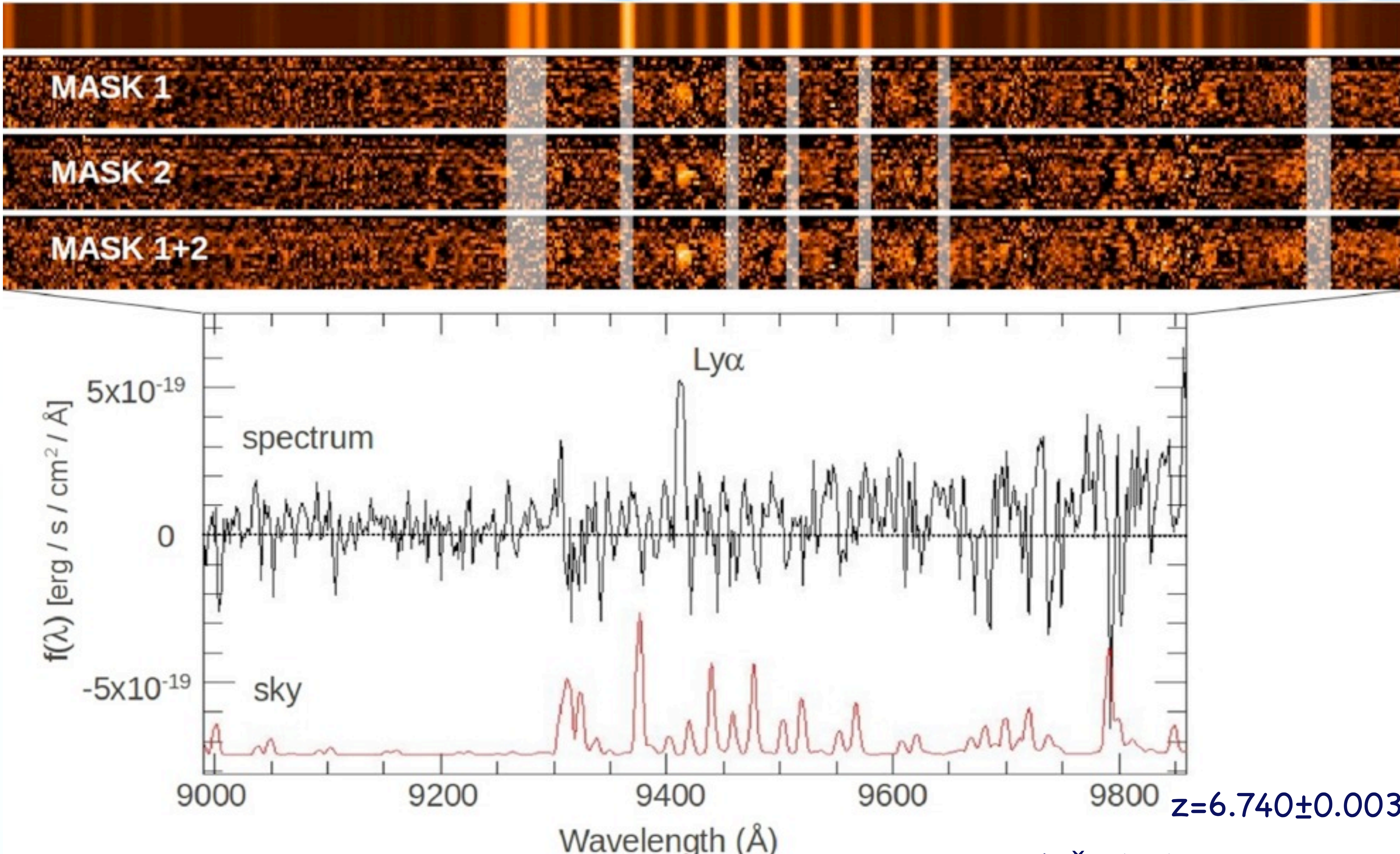
* Confirm redshifts
* Break the Cosmic Dawn

  Ratio of LAE/LBGs is sensitive to the details of reionization

  Distribution of EW (only spectroscopy)

* 22 hours of VLT FORS2 (16.3 hours effective on-source time) on the Bullet Cluster (Nov 2011-Jan 2012)

VLT Follow-Up: First results



z=6.740±0.003

Bradač et al. 2012

Source properties

* The faintest source with a measured redshift
* Intrinsic luminosity of LBG $0.5L^*$
* Using Kennicutt's relation we obtain
  - → $\mathrm{SFR(UV)} = (8.7 \pm 2.5)/\mu\ M_\odot/\mathrm{yr}$
  - → $\mathrm{SFR(Ly\alpha)} = (3.3 \pm 1.0)/\mu\ M_\odot/\mathrm{yr}$ (lower limit)
  - → $\mathrm{SFR(intrinsic)} \sim 2 M_\odot/\mathrm{yr}$
* Compact source ~ 0.8kpc FWHM

Silver Bullet for High-z Universe

* The future is bright (WFC3, JWST, MOSFIRE, VLT) -> magnified by lensing
* Probe LAE/LBG ratio at sub L^*!!!!
* (Insert a full Adriatic sea worth of salt here) LAE/LBG ratio seems to be declining at $z > 6.5$
* Big, merging clusters are efficient cosmic telescopes
* Only second sub-L^* $z>6.5$ spectroscopic detection (the other detection by Schenker et al. 2012 is lensed, too)

Silver Bullet for High-z Universe

- The future is bright (WFC3, JWST, MOSFIRE, VLT) -> magnified by lensing
- Probe LAE/LBG ratio at sub L^*!!!!
- Big, merging clusters are efficient cosmic telescopes
- 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)**

SURF'S Up: Spitzer UltRa Faint SUrvey

- Approved Exploration Science Spitzer Program for Cycle 9
- Over 550 hours with Spitzer for 10 clusters
- Think Spitzer-UDF depth, but assisted by lensing!
- Star formation rates and stellar masses of a large number of galaxies (50 at $z\sim7$ and 10 at $z\sim8$)

  → reconstructing the cosmic SFR
- Presence (or absence) of established stellar population.

Conclusions

* Lensing is fantastic!
* Clusters are useful tools for astrophysics!

→ "The apparently brightest source of any class will almost always be lensed." (P. Schneider)

→ Discovery of z~7 galaxies, spectroscopic follow-up for sub L* galaxies possible!

→ First steps in understanding reionization

→ Dark Matter properties

Teaching: Physics of California

- Physics of skiing, surfing, and scuba diving...