CLASH: Accurate photo-z with 14 HST bands in massive galaxy cluster cores

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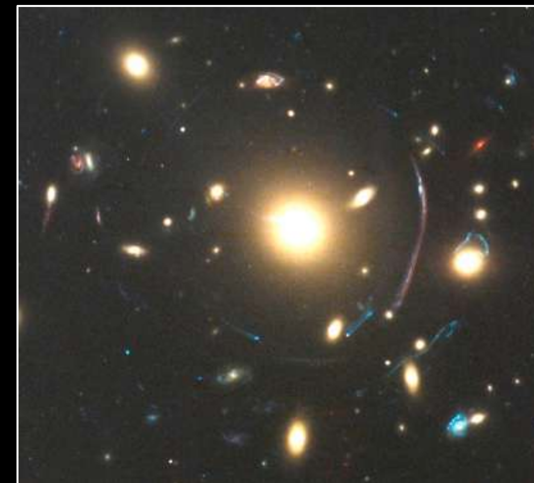
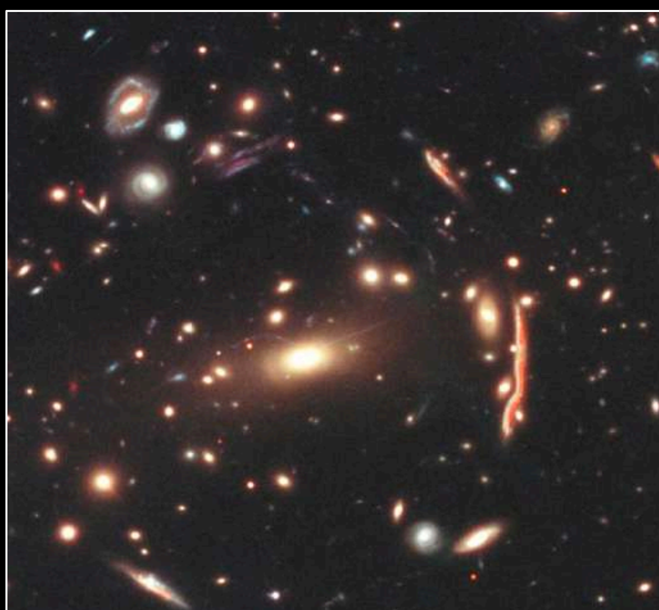
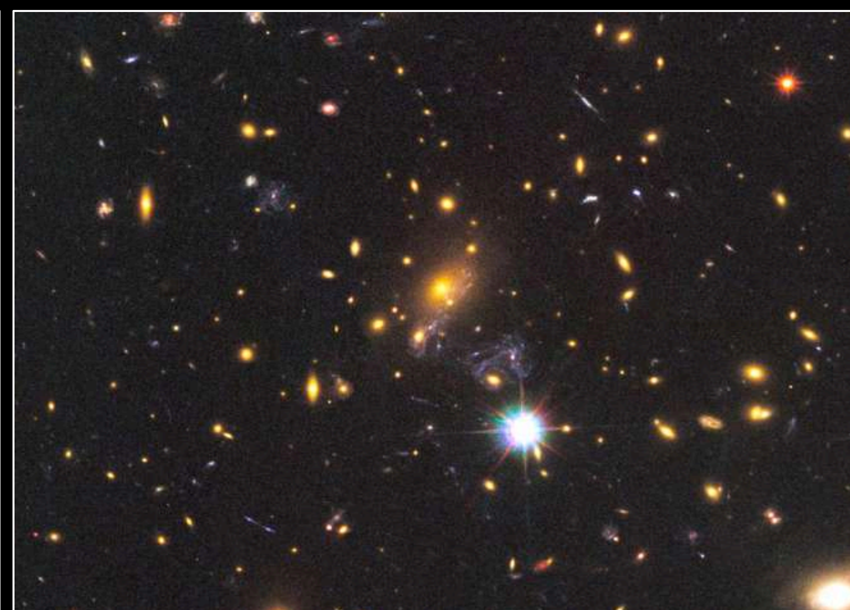
Cluster Lensing And Supernova survey with Hubble

CLASH







Cluster Lensing And Supernova survey with Hubble

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THE CLUSTER LENSING AND SUPERNOVA SURVEY WITH HUBBLE: AN OVERVIEW

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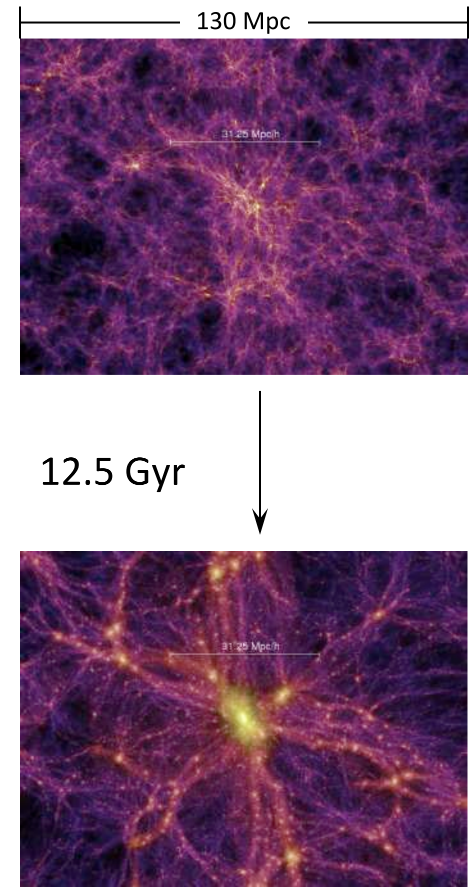
CLASH Team at RAS, London, Sept 2013

Fundamental Questions That Remain Unanswered or Unverified

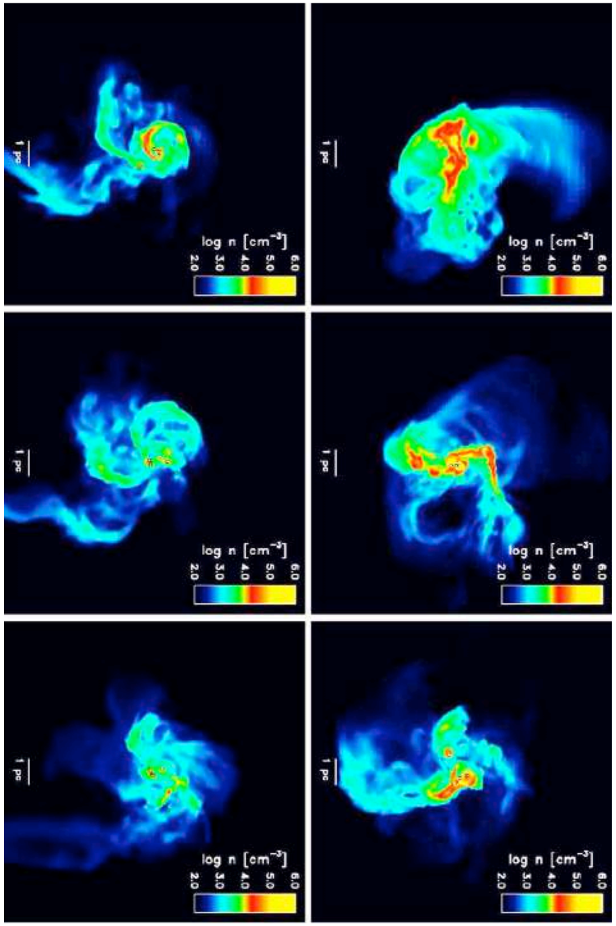
- How is **dark matter distributed** in cluster & galaxy halos?
  - How centrally concentrated is the DM? Implications for epoch of formation.
  - What degree of substructure exists? And on what scales?
  - How well do DM profiles match those predicted from simulations?
  - What correlations exist between the distribution of baryonic matter and DM?



"Millennium" simulation of DM
Springel et al. 2005

Fundamental Questions That Remain Unanswered or Unverified

- When was the epoch of **first galaxy formation**?
  - What are the characteristics (mass, “metal” abundance, star formation rates, global structure) of the most distant galaxies in the universe (t_U < 800 Myr)?
  - What was their role in ionizing the intergalactic medium?
  - How do galaxies build up and evolve at the earliest times?



Simulating the First Galaxies
Safranek et al. 2013

Fundamental Questions That Remain Unanswered or Unverified

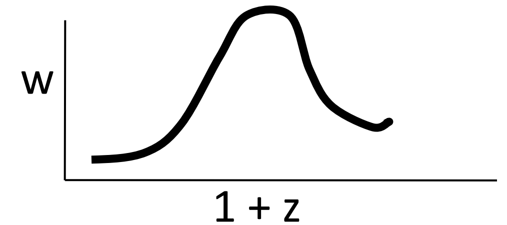
- What is the physical nature of the **Dark Energy**?
  - Is it something other than Λ?
  - What are the parameters of the dark energy equation of state?
  - What is the rate of high-z type Ia supernovae? What does the rate tell us about their progenitors?
  - How standard are our "standard" candles (cosmic distance indicators)? Need better measurements of systematic effects at large lookback times.

$w = P / \rho c^2$

$w = -1$ (cosmo constant)

$w \neq$ constant; scalar field

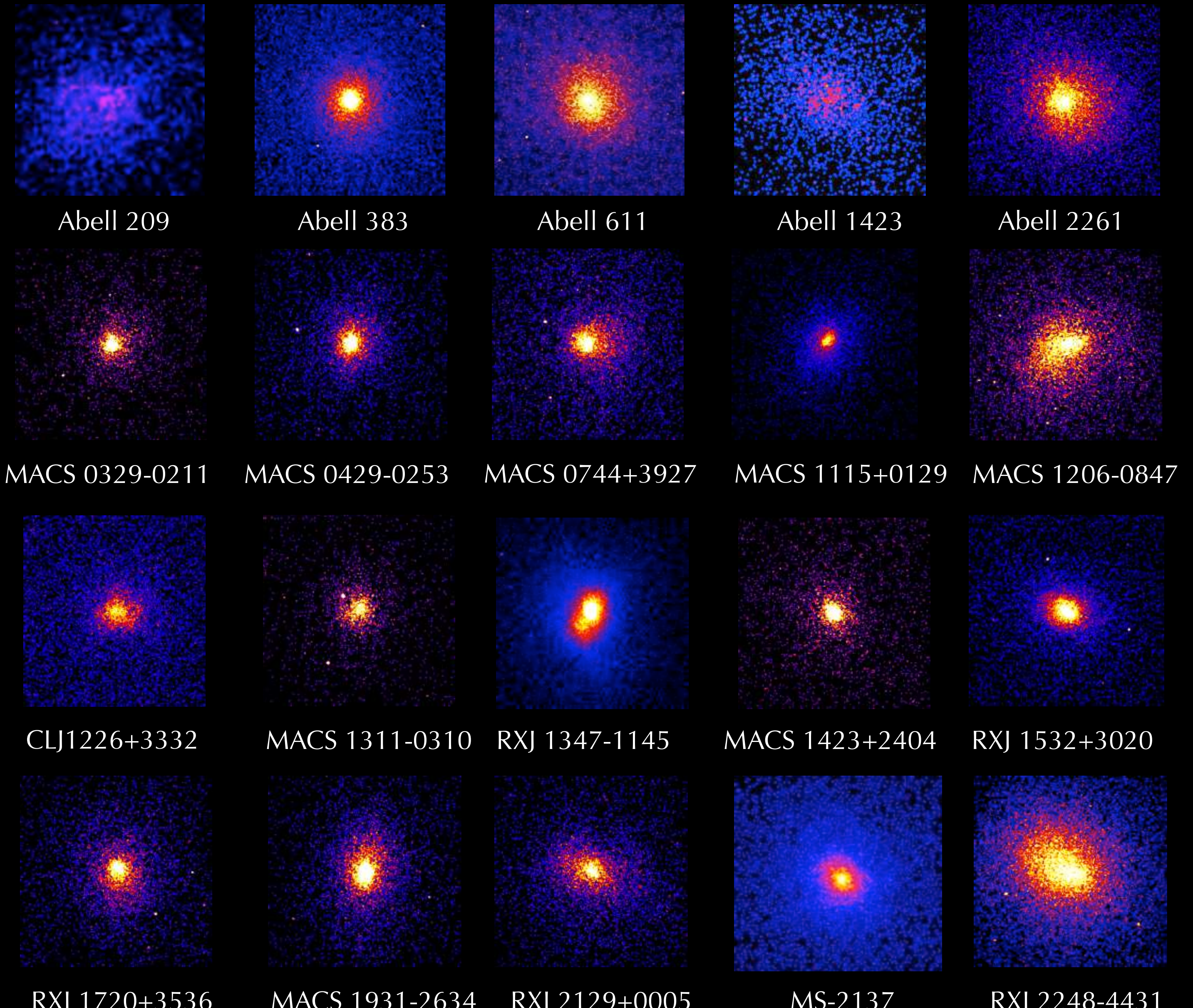
e.g. Quintessence, k-essence

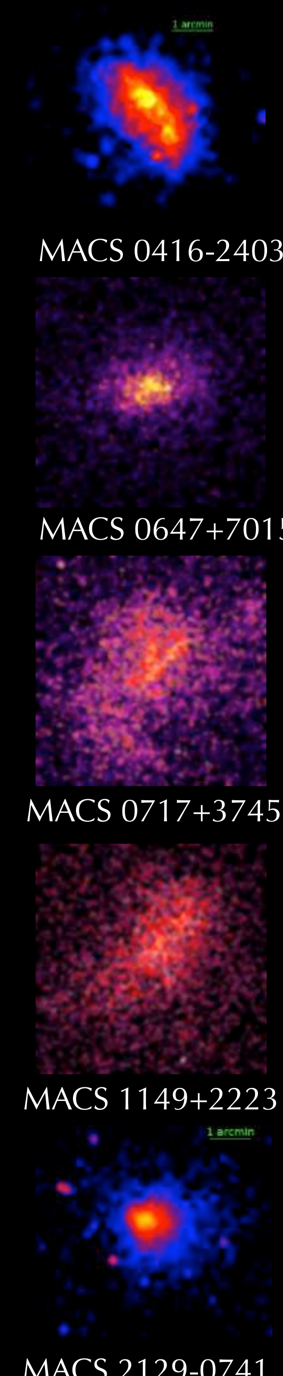


Is w a f(z)?

$w(z) = w_o + w_a\, z/(1+z)$

(e.g., Linder 2003)





X-ray images of the 25 CLASH clusters. 20 are selected to be “relaxed” clusters (based on their x-ray properties only). 5 (last column) are selected specifically because they are strongly lensing $\theta_E > 35''$. **All CLASH clusters have Tx > 5 keV.**

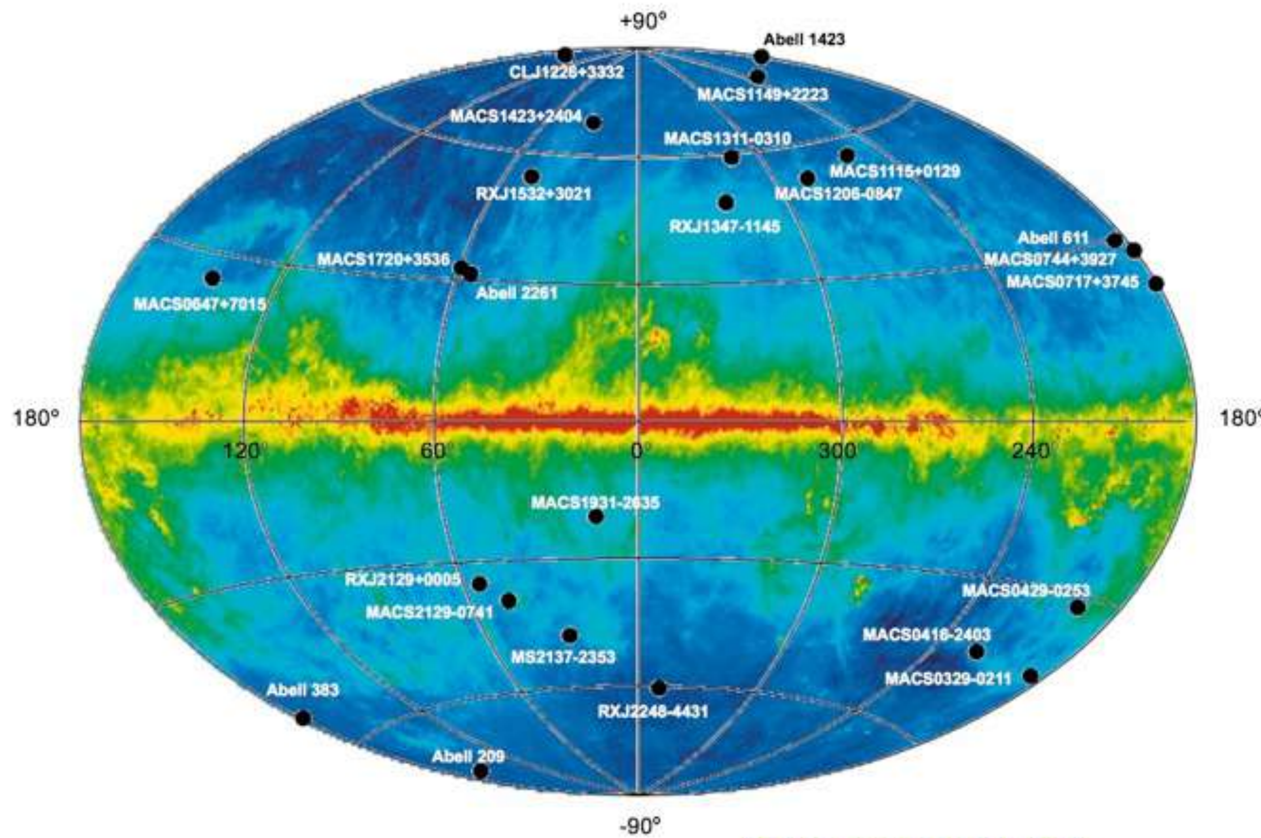
The CLASH (HST) Gallery

20 clusters are x-ray selected (Tx > 5 kev, low asymmetry),

5 clusters are very strong lenses (Einstein radii > 30 arcsec) .

Cluster	z_s
CLASH	
Abell 383	0.187
Abell 209	0.206
Abell 1423	0.213
Abell 2261	0.224
RXJ2129+0005	0.234
Abell 611	0.288
MS2137-2353	0.310
RXJ1532.8+3021	0.345
RXJ2248-4431	0.348
MACSJ1931-26	0.352
MACSJ1115+0129	0.352
MACSJ1720+3536	0.387
MACSJ0429-02	0.399
MACSJ0416	0.420
MACSJ1206-08	0.439
MACSJ0329-02	0.450
RXJ1347-1145	0.450
MACSJ1149	0.544
MACSJ0717	0.548
MACSJ2129+0005	0.570
MACSJ0647	0.584
MACSJ0744+39	0.686
CLJ1226+3332	0.890

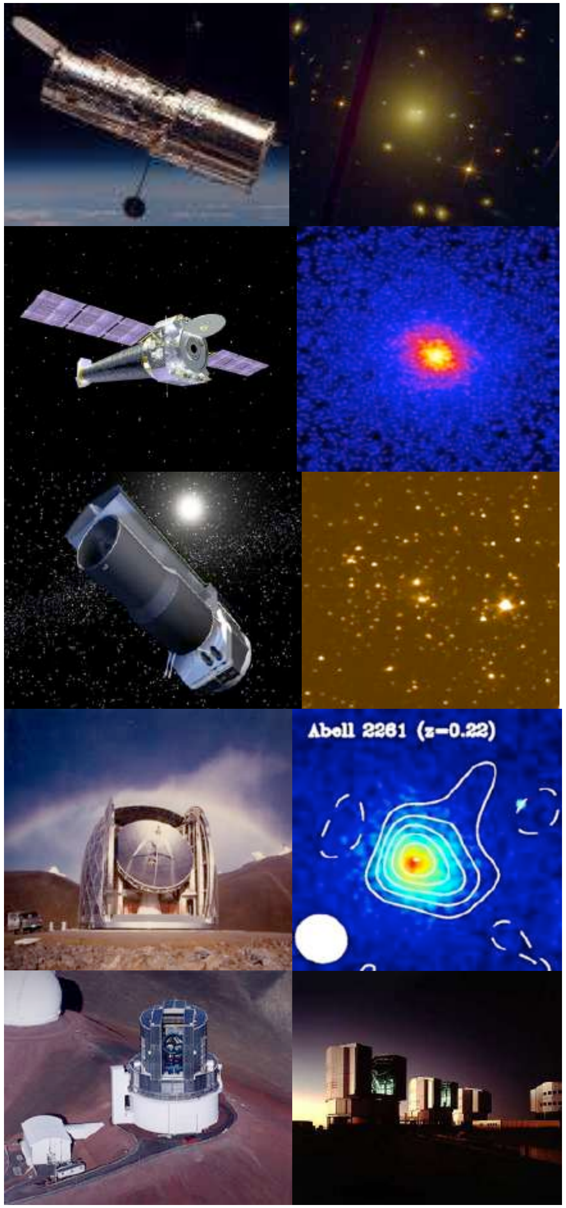
25 x-ray selected relaxed massive galaxy clusters at intermediate 0.1<z<0.9



CLASH CLUSTER SAMPLE
(Galactic Coordinates)

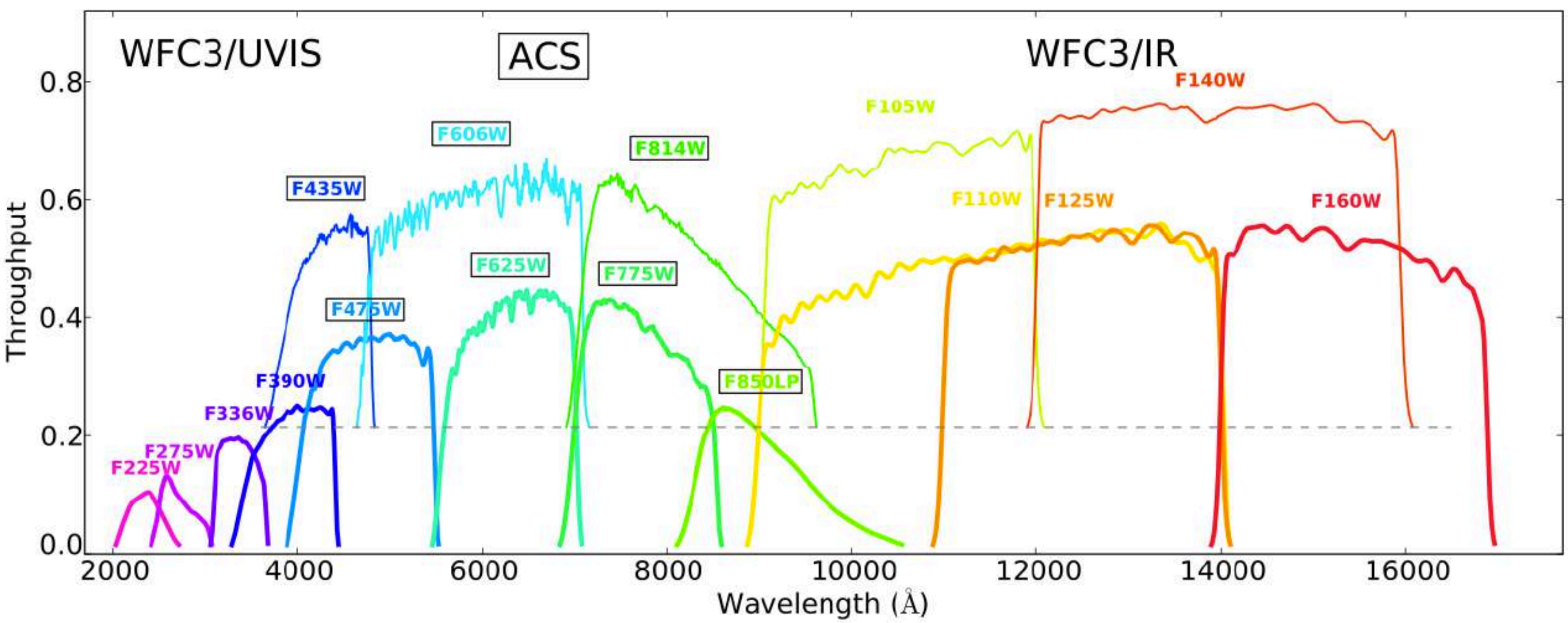
Comprehensive Multi-wavelength Coverage

- **HST** 524 orbits: 25 clusters, each imaged in 16 passbands. (0.23 – 1.6 μm) ~20 orbits per cluster. HST survey complete.
- **Subaru** wide-field imaging (0.4 – 0.9 μm)
- **Chandra** x-ray Observatory archival data (0.5 – 7 keV) and XMM data.
- **Spitzer** Space Telescope archival and new cycle 8 data (3.6, 4.5 μm)
- SZE observations (**Bolocam**, Mustang) to augment existing data (sub-mm)
- **VLT**, LBT, Magellan, MMT, Palomar Spectroscopy (~30,000 spectra)

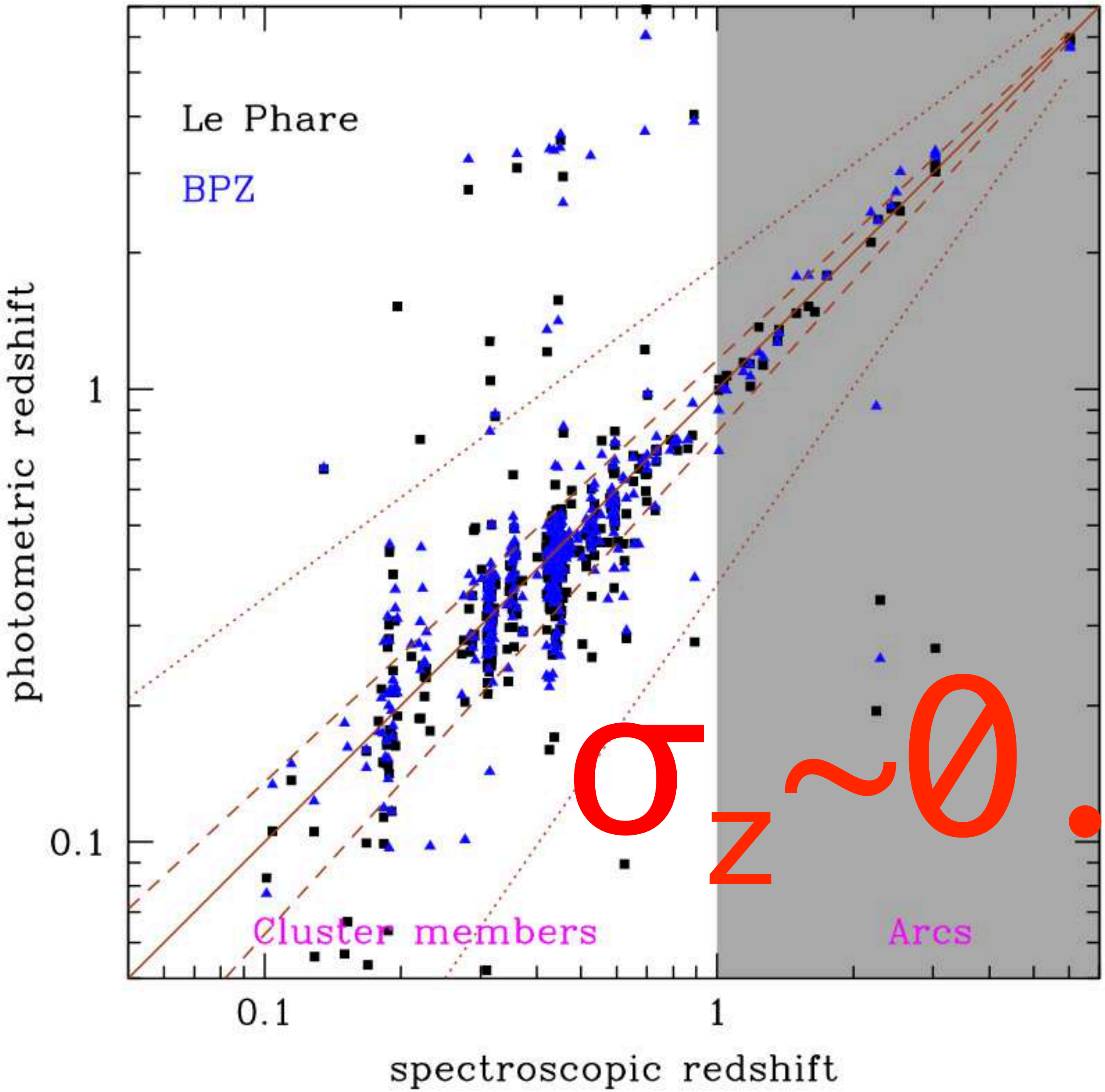


Theoretical expectations for CLASH Photometric redshifts using 16 bands.

- $\Delta z \sim 0.02(1+z_s)$ for 80% galaxies with F775W < 26 AB.
- Resolve Lyman-Balmer break degeneracies (UVIS-NIR).
- N(phz)/N(spz)~6 for z>1 galaxies.
- Secure identification of z>7 galaxies.

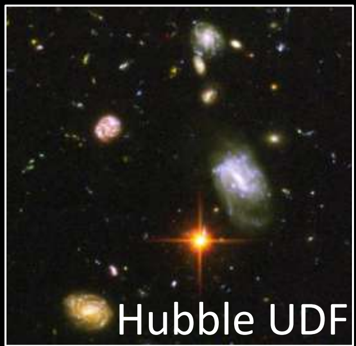


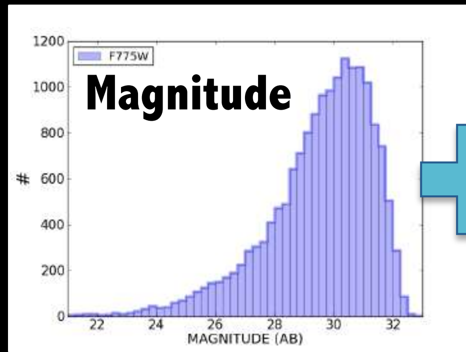
Jouvel+14

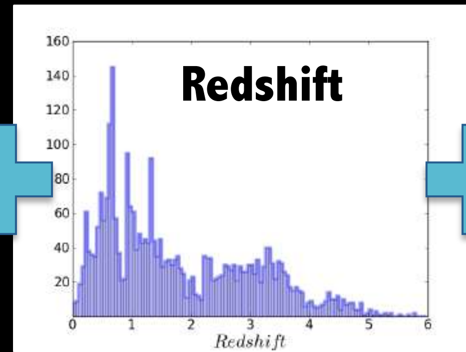


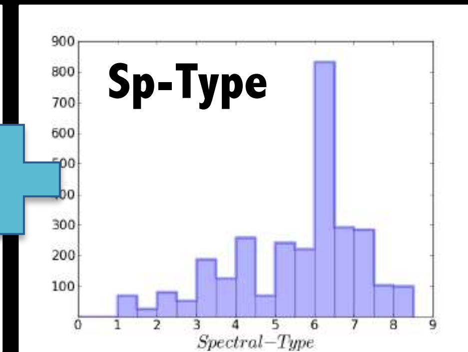
$\sigma_z \sim 0.04$!

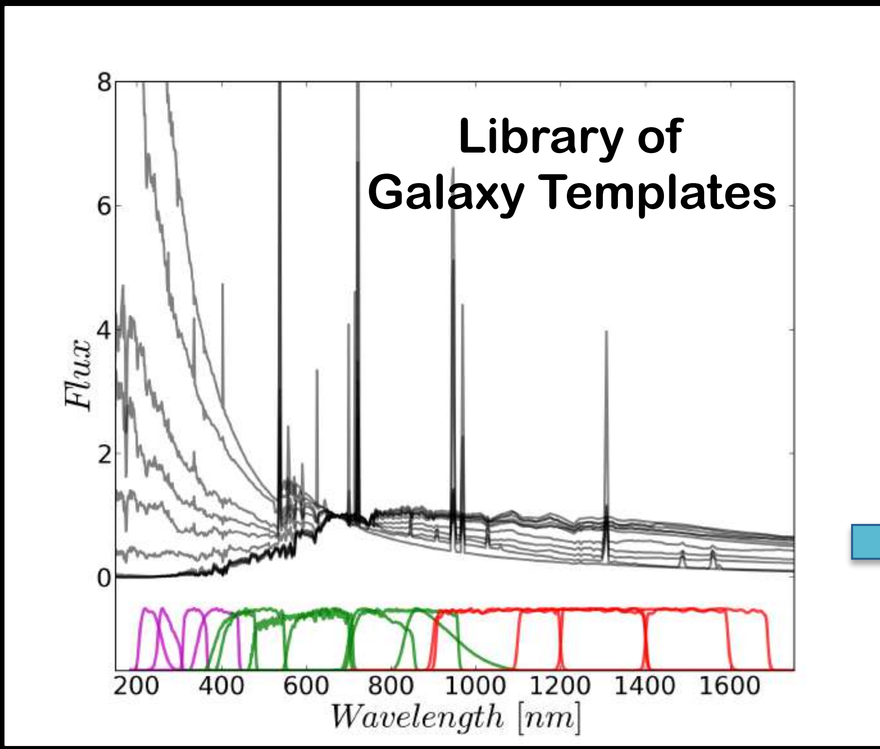
Standard Photo-z Simulations assume…





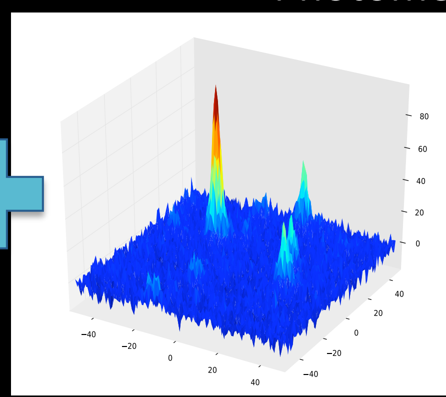


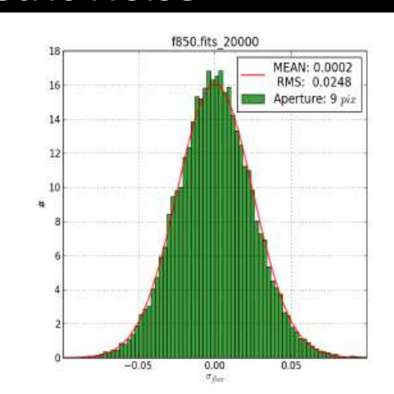




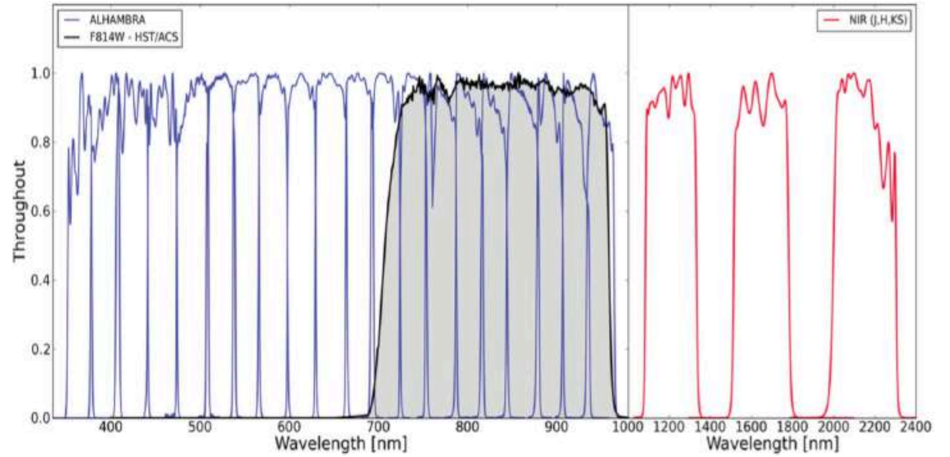
$$m_i = m_i^o + \delta m_i^{RMS}$$

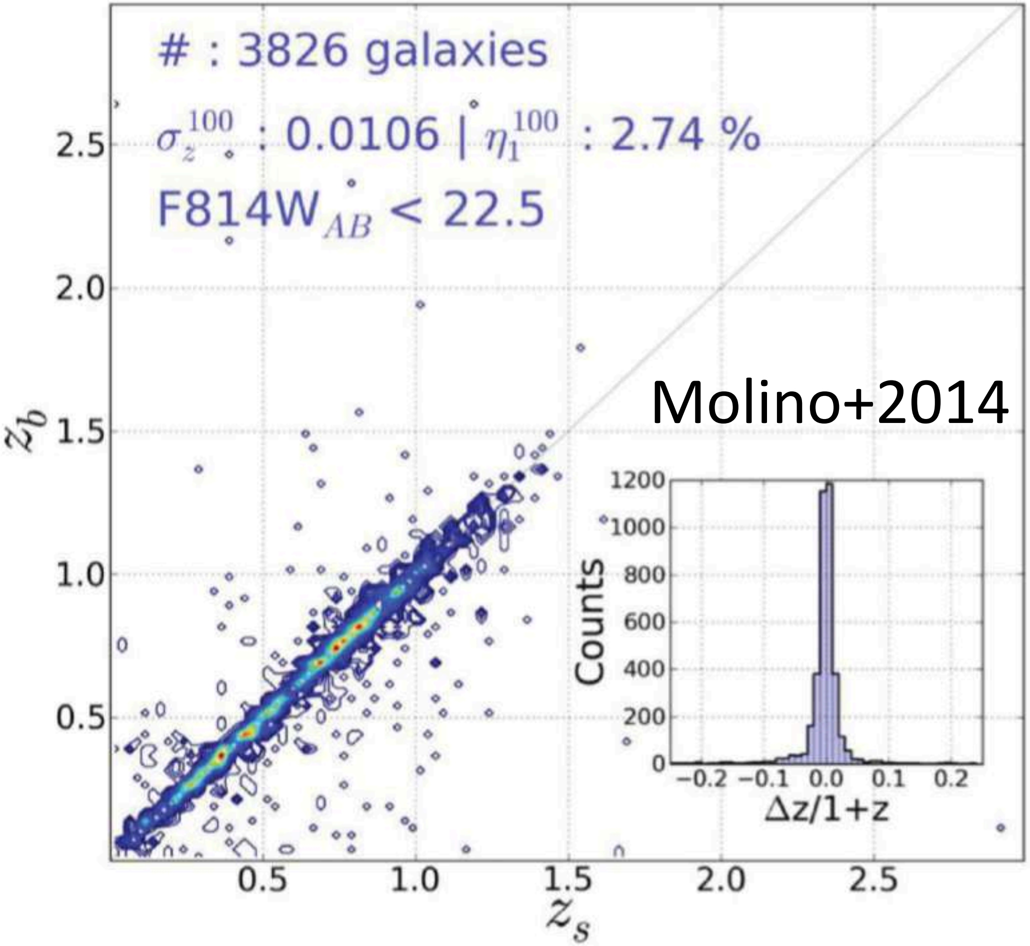
Photometric Noise



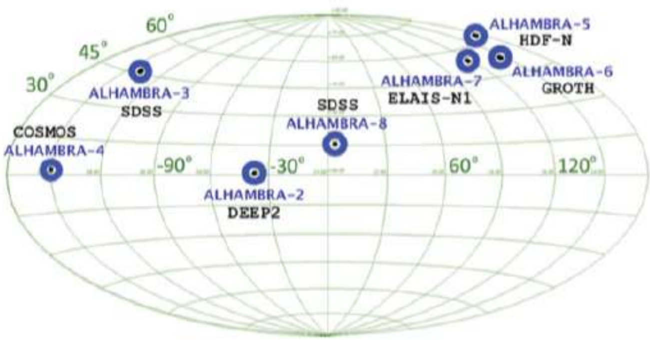


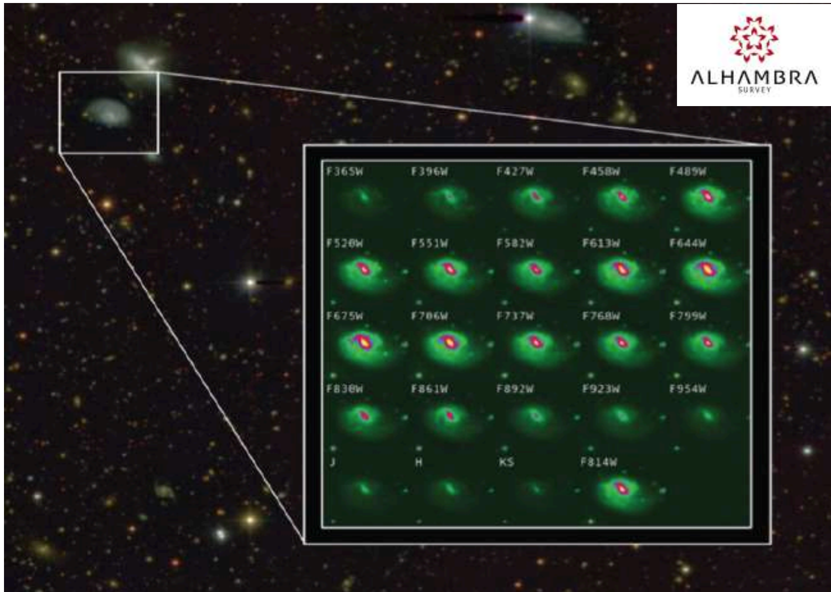
Predictions based on simulations do work !

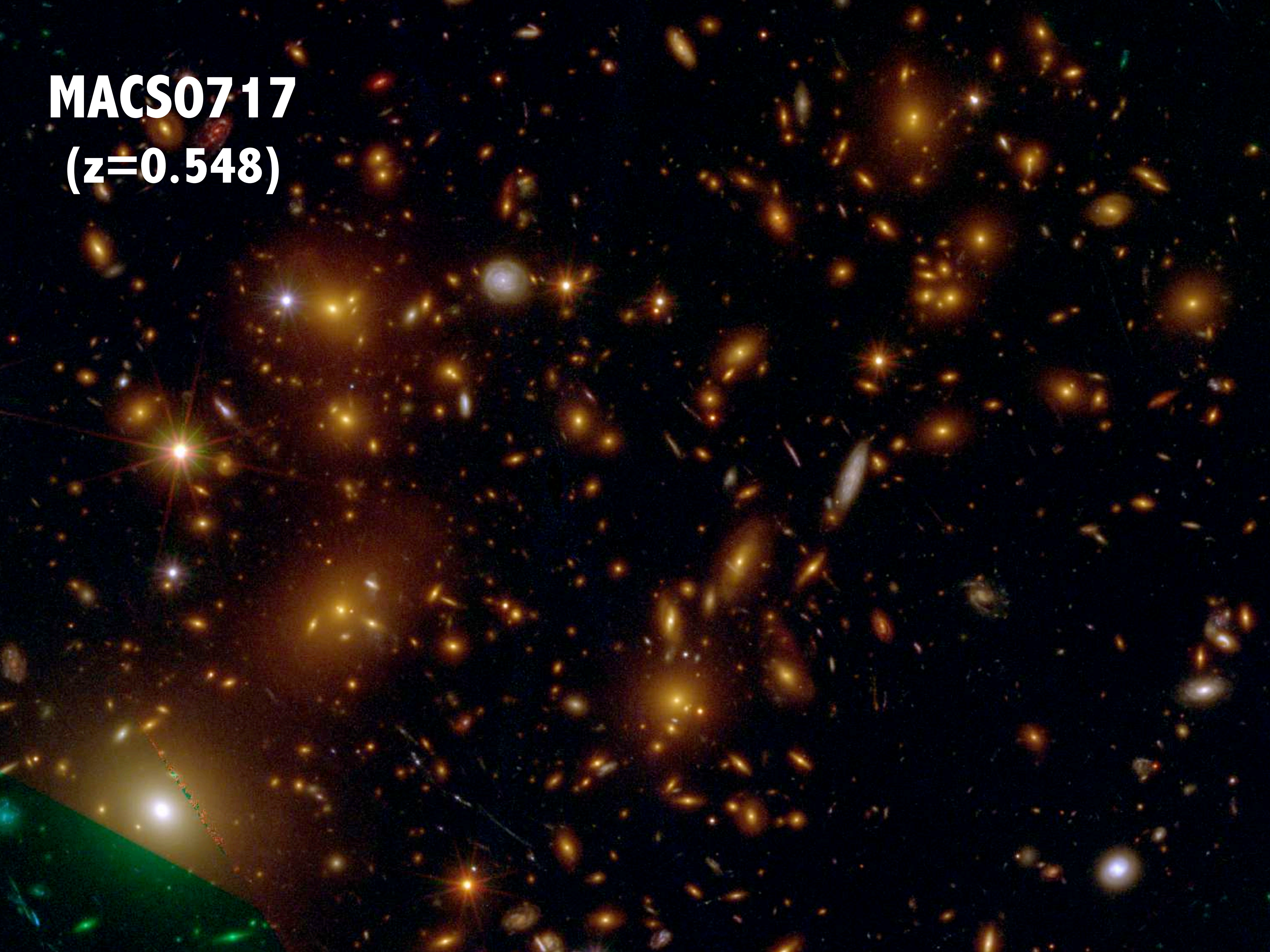




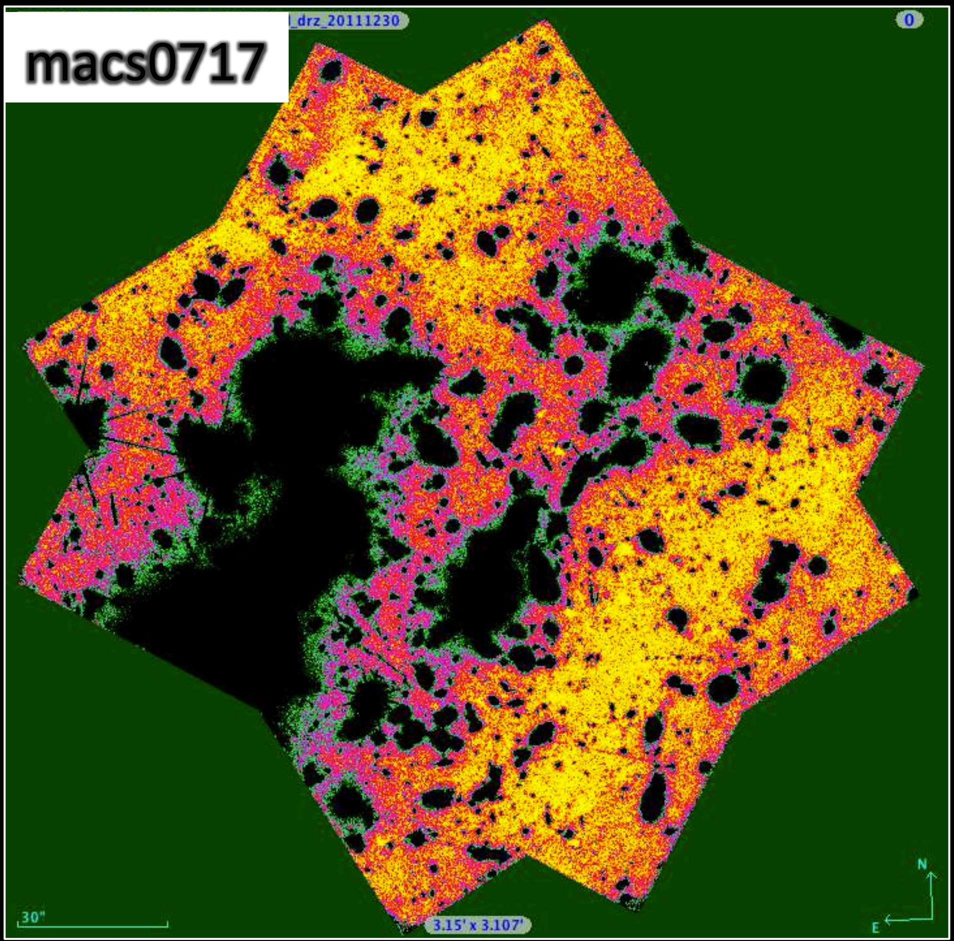
Molino+2014






MACS0717
(z=0.548)

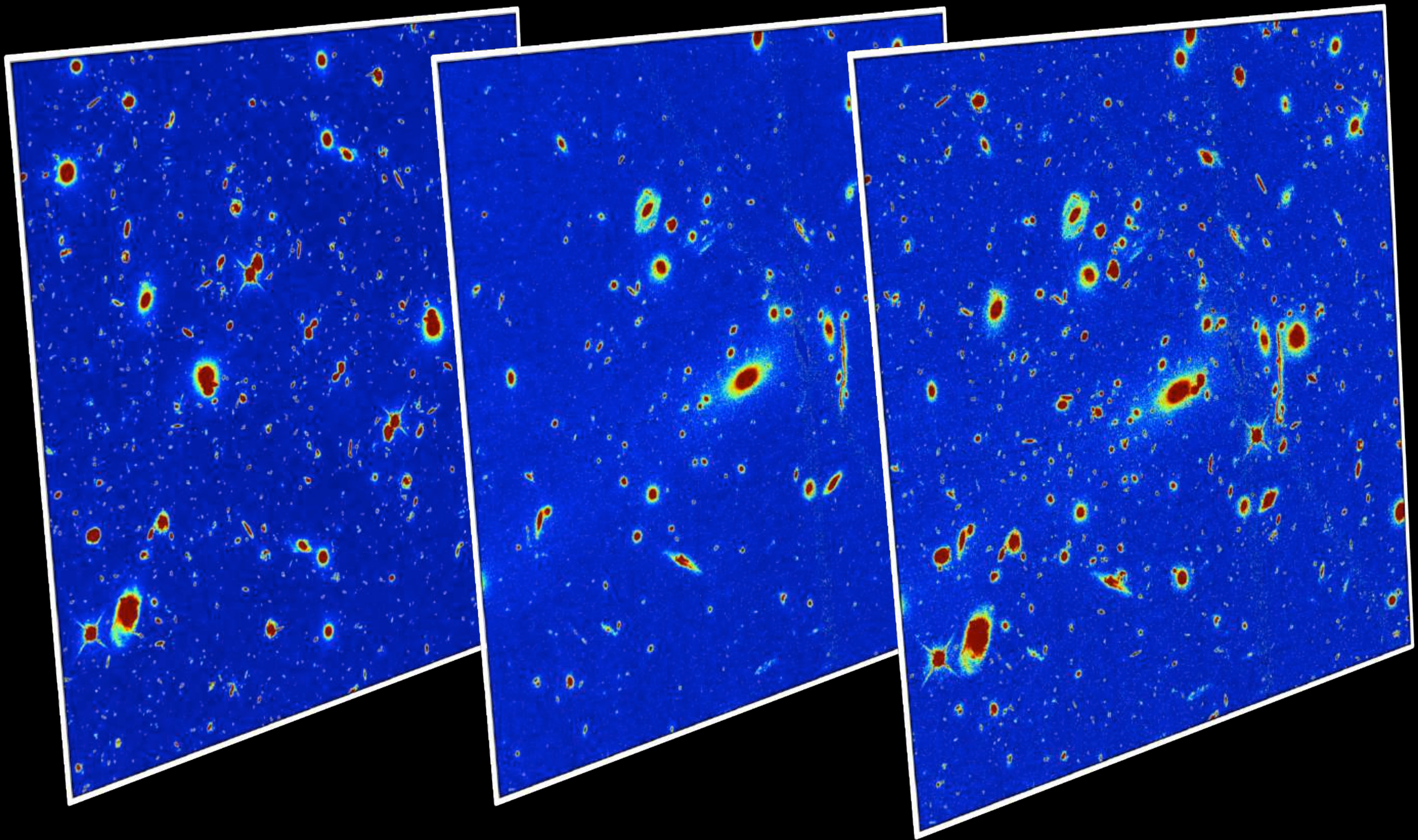
The PROBLEM to deal with: An strong additional and slippery source of photometric uncertainties arises from the background.



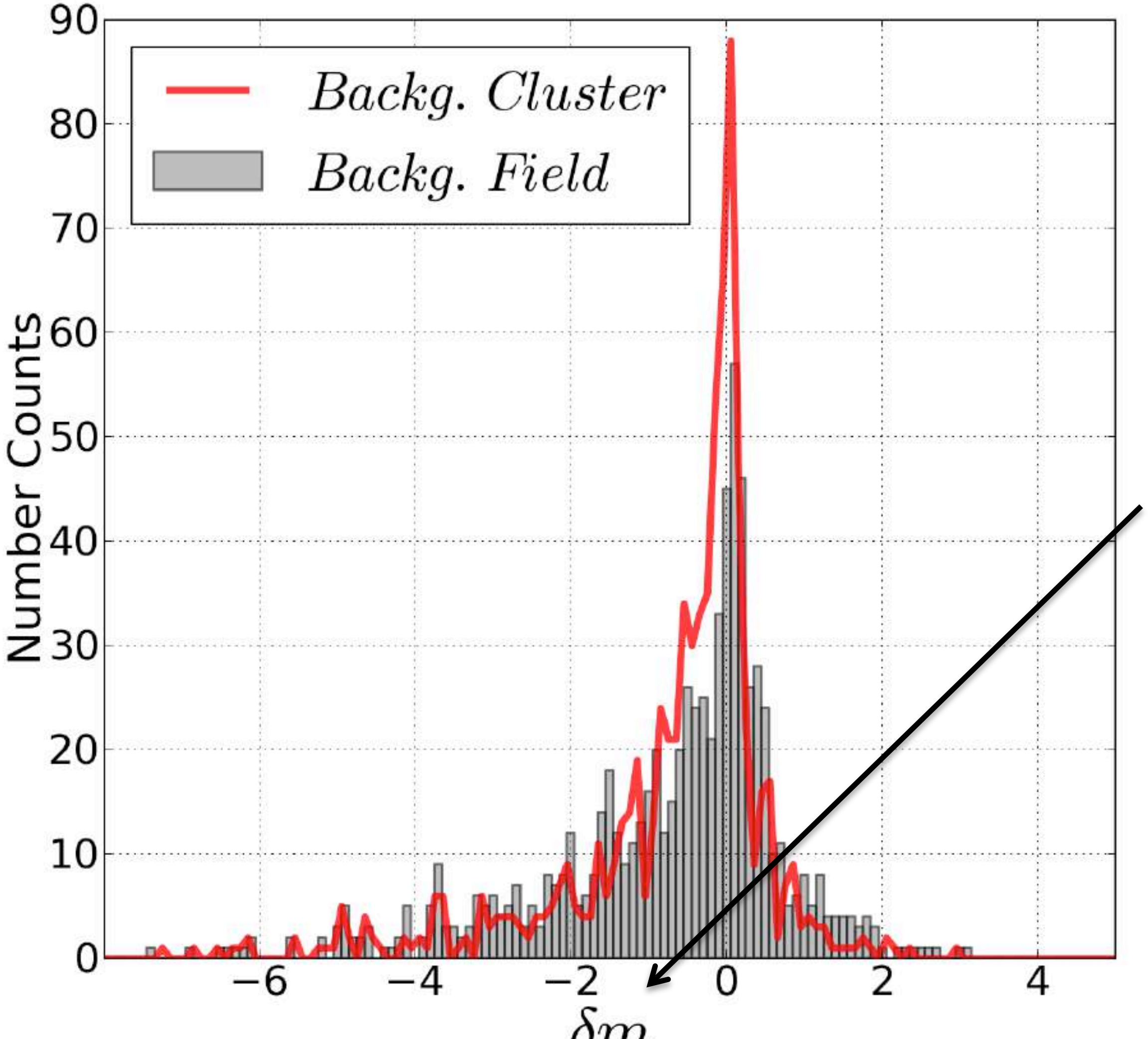
$$m_i = m_i^o + \delta m_i^{RMS} + \delta m_i^{BCG}$$

- Different per each cluster.
- Contaminates other galaxies.
- Spatially inhomogeneous.
- Wavelength-dependent.
- Small and large-scale effect.
- Makes photometric noise highly non-Gaussian for NIR.

UDF + CLASH = GLOBAL



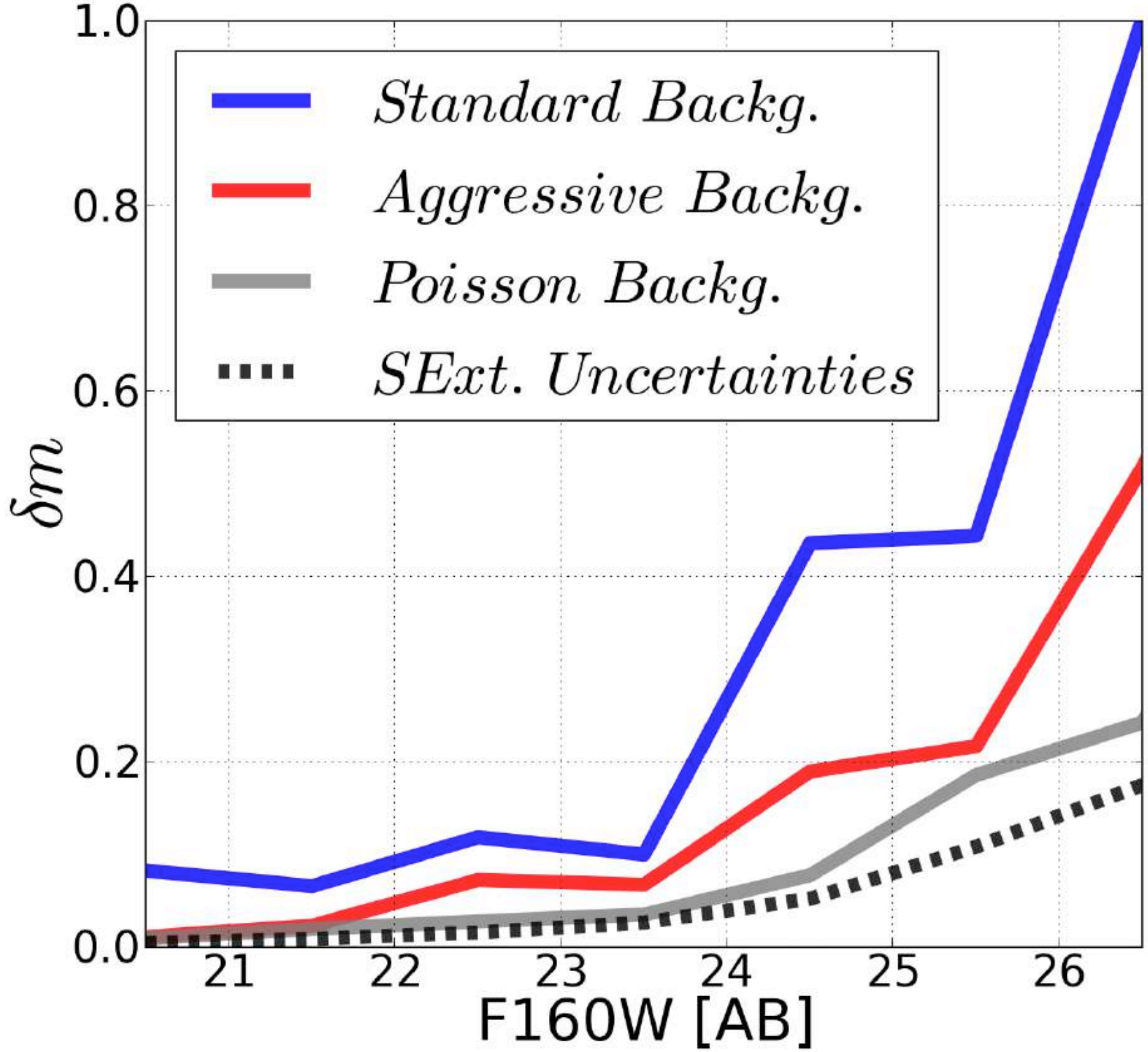
An aggressive Background subtraction retrieved closer colors to the originals



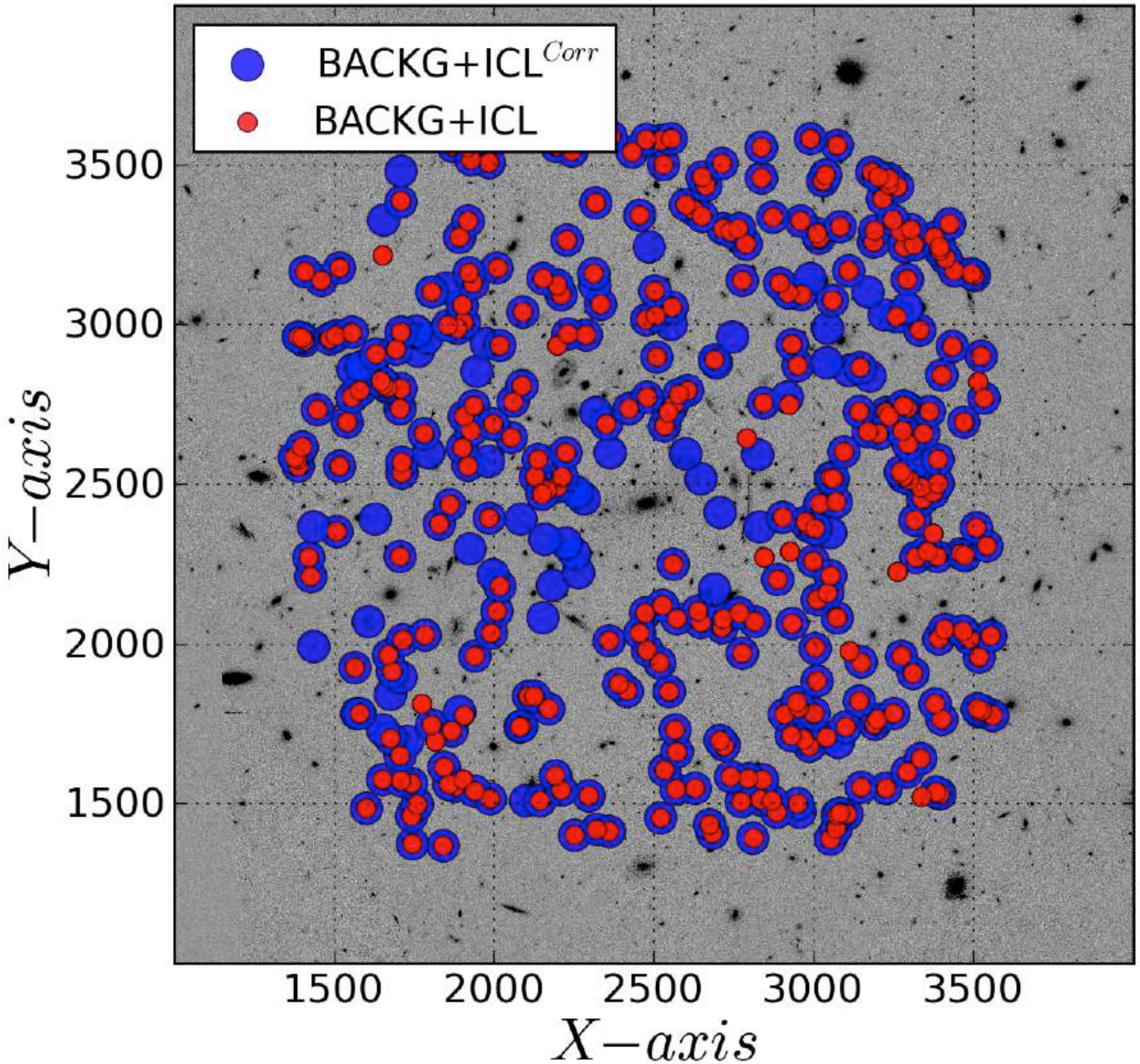
Input-output magnitudes

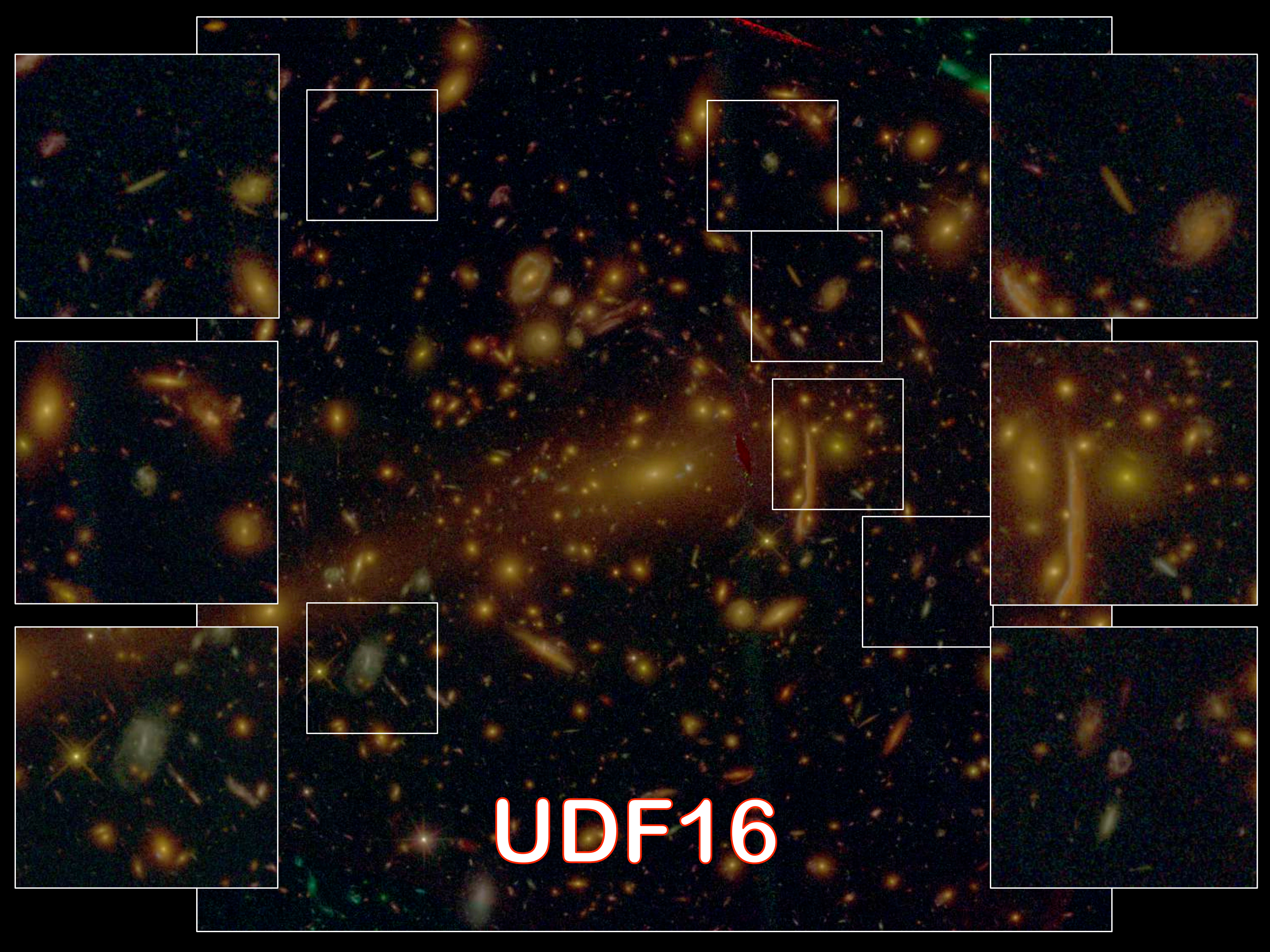
`SExtractor` was enormously **underestimating** the real photometric Uncertainties.

Input-output magnitudes

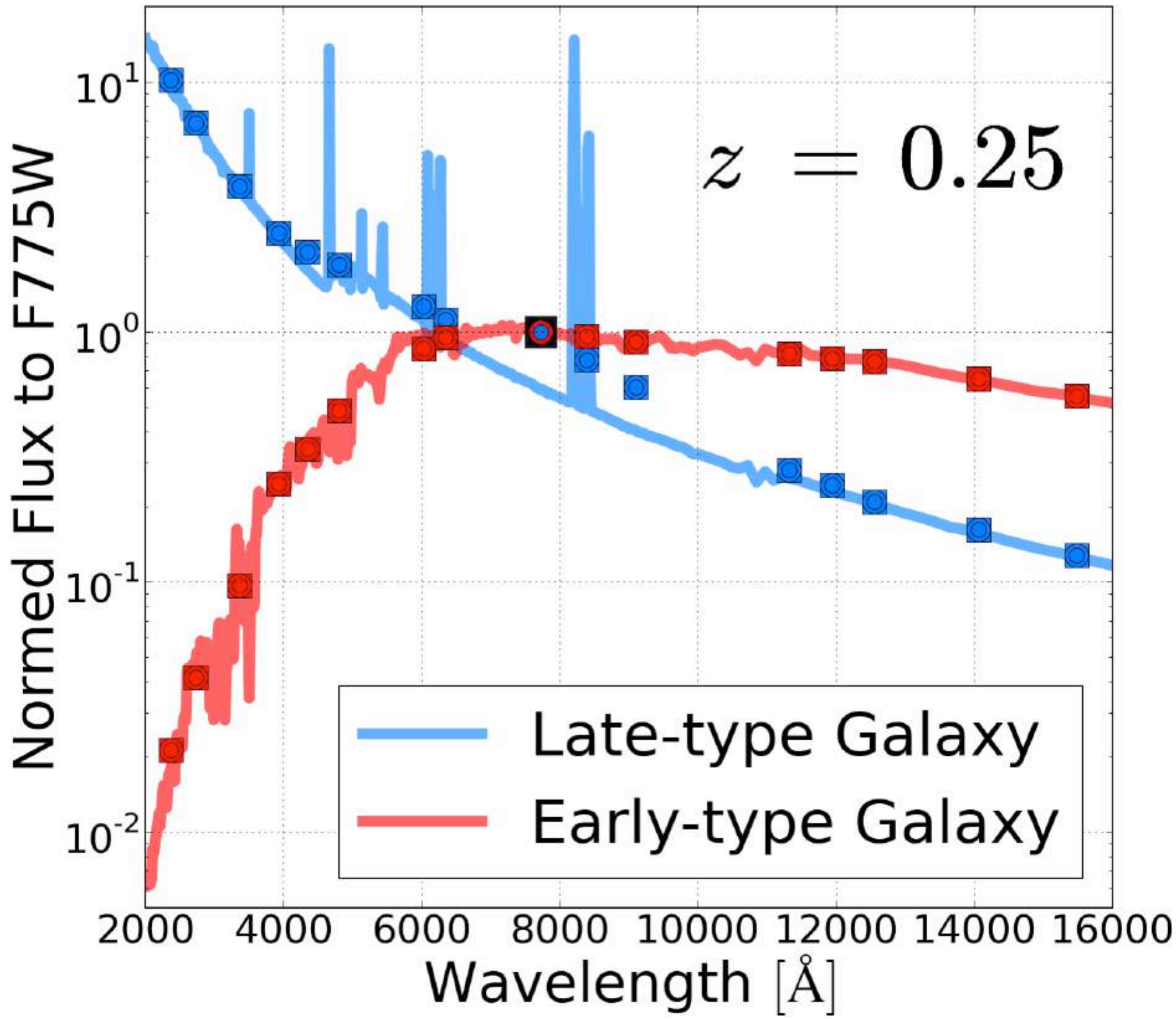


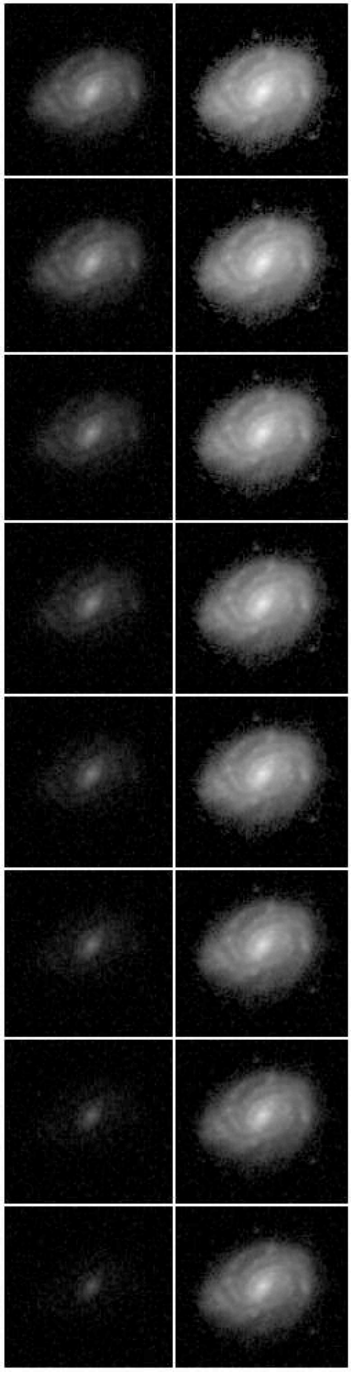
The fraction of retrievable sources was also background-dependent




UDF16

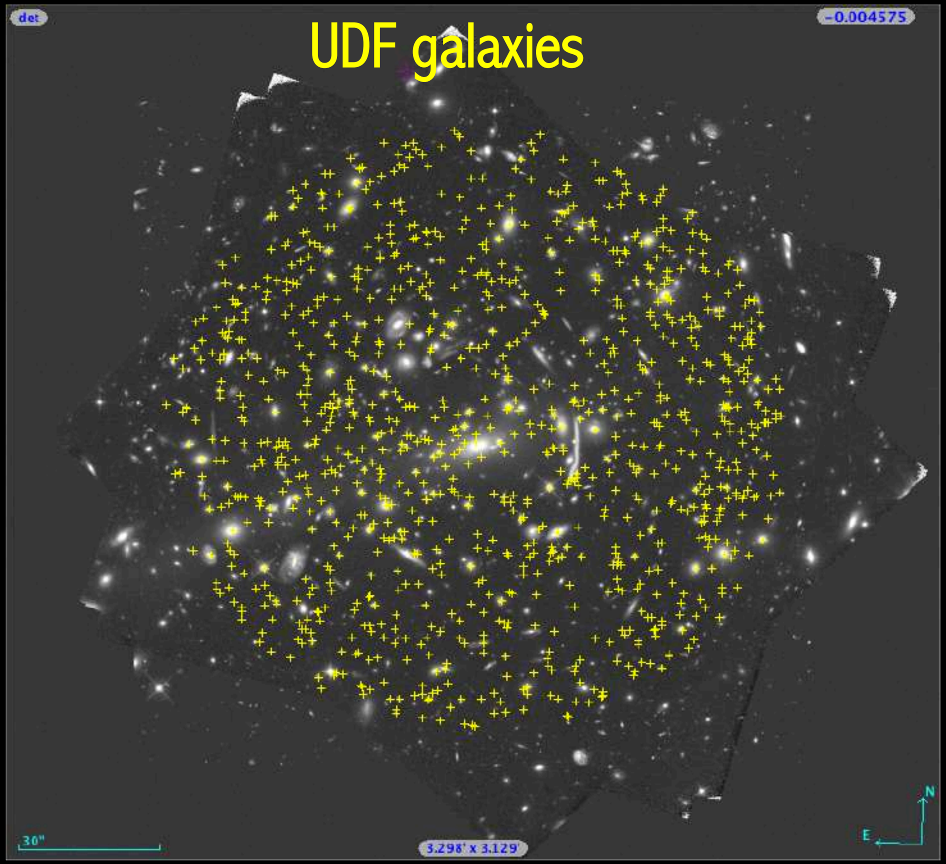
Galaxy colors are recreated using the BPZ library of templates

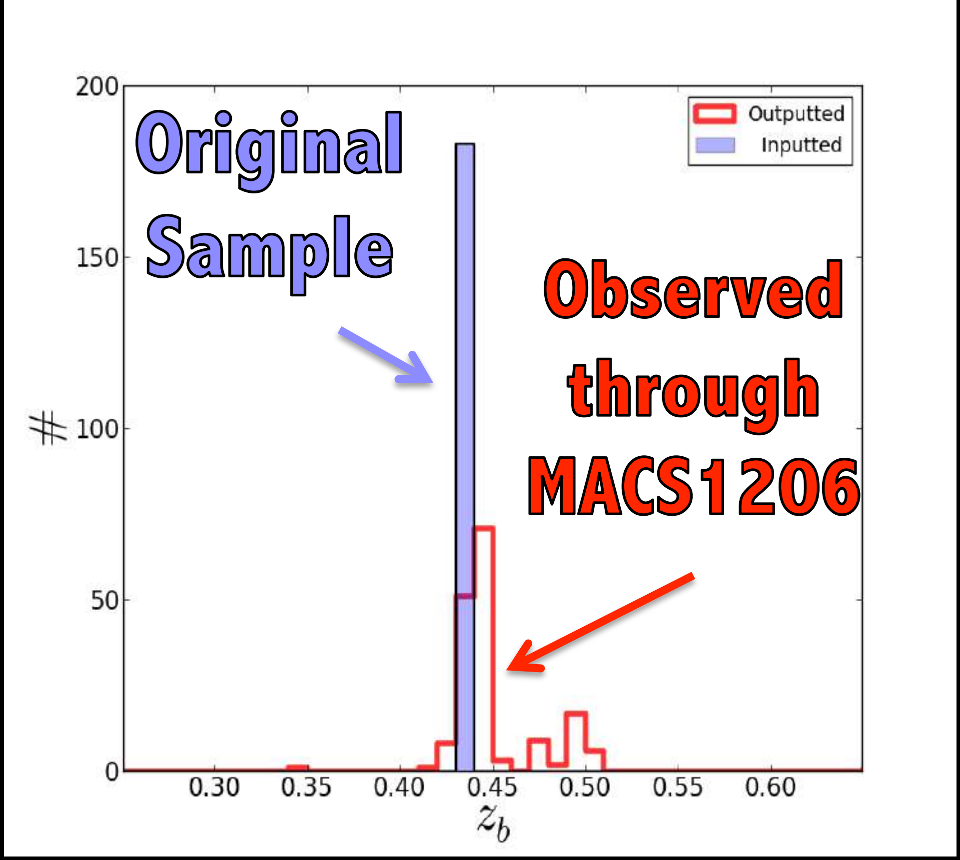




We initially quantified the bias on photo-z's simulating a galaxy cluster and injecting it in the CLASH images.

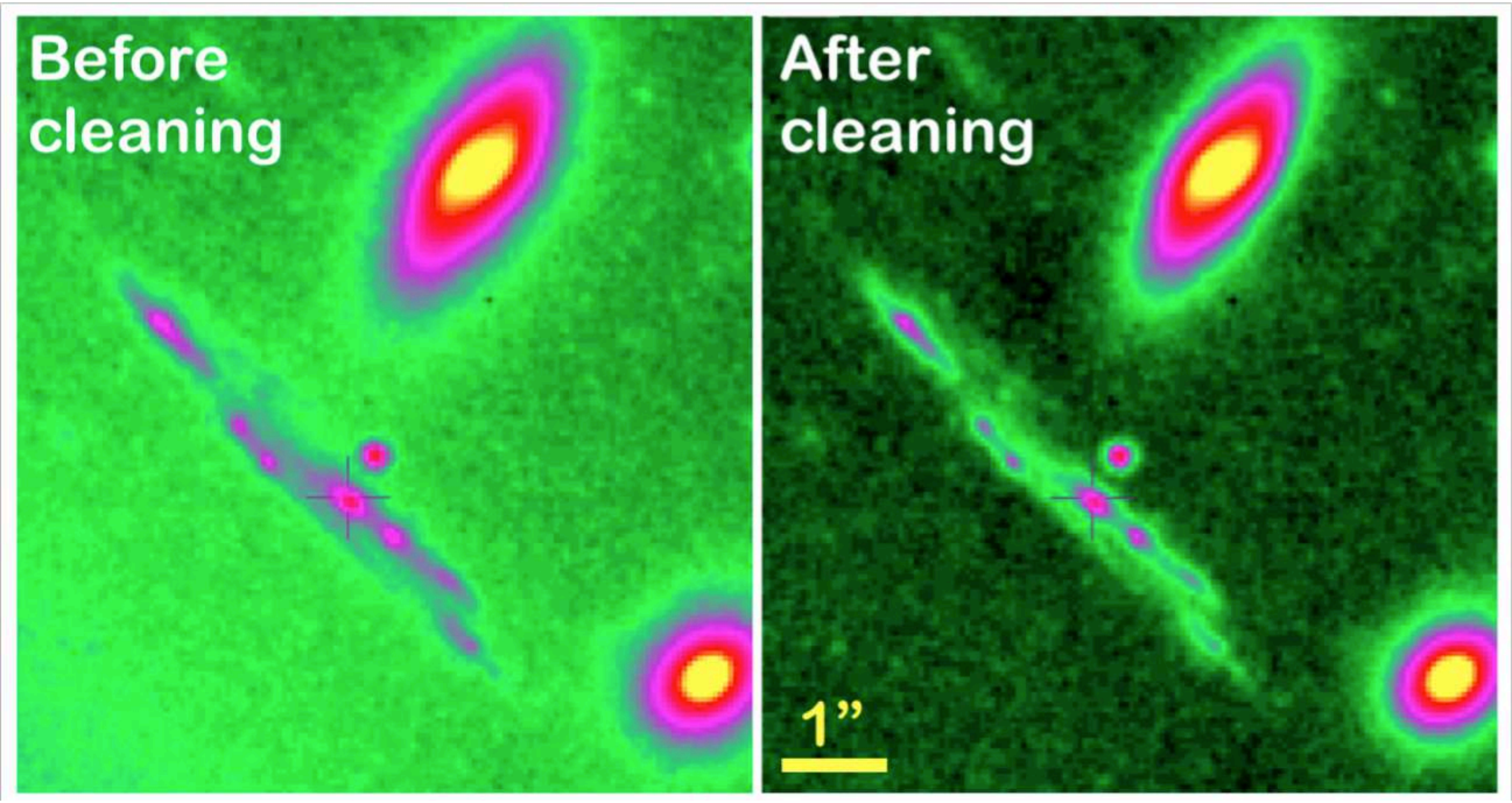
- The ICL+BACKG was distorted the performance up to **~0.02(1+z)** !!





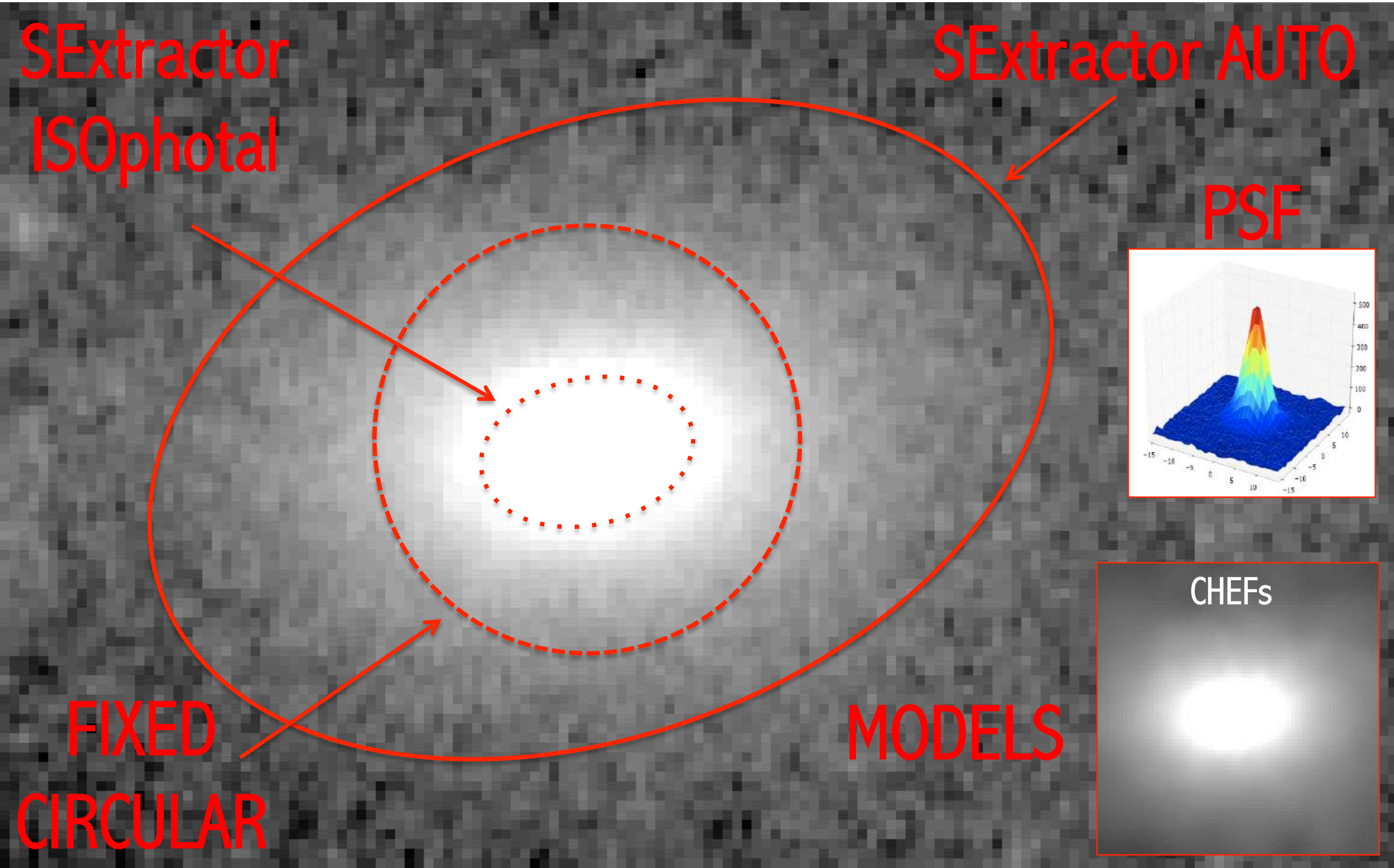
Update 1:
An optimal background subtraction per each cluster.

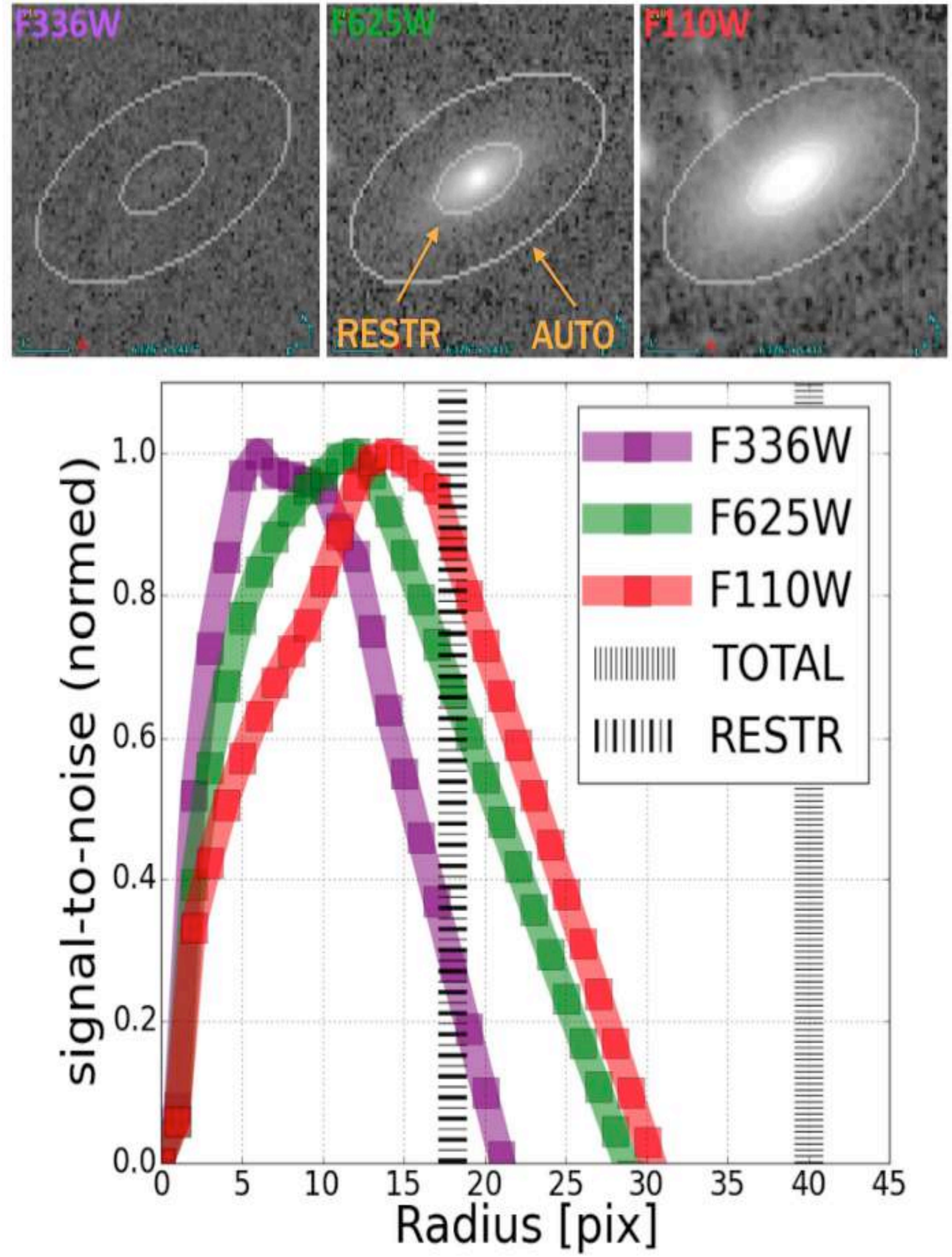
CHEFs software (Jiménez-Teja 2012, 2015 & 2016) to model+subtract galaxies and remove the ICL



Update 2:
A double **total-restricted**
& **total-moderate**
aperture photometry
for cluster galaxies.

How to (properly) measure galaxy fluxes?

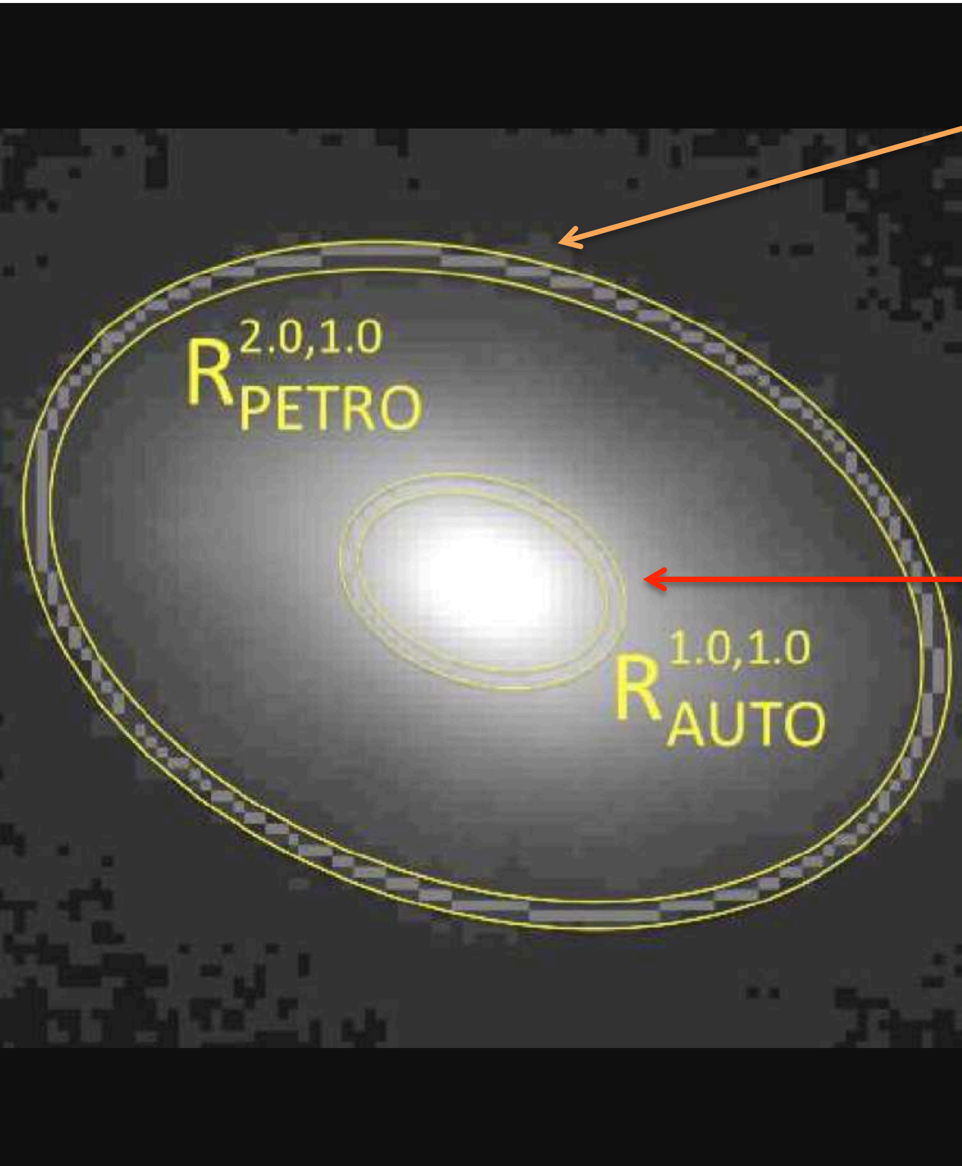




For cluster galaxies, the enormous magnitude evolution in between the UV and the NIR filters makes standard aperture photometry inefficient.

Detecting on NIR-bands leads to an artificial deterioration of the signal-to-noise in the shorter wavelengths.

Twice is better than just one: a **total-moderate** and a total-**restricted** photometric apertures.

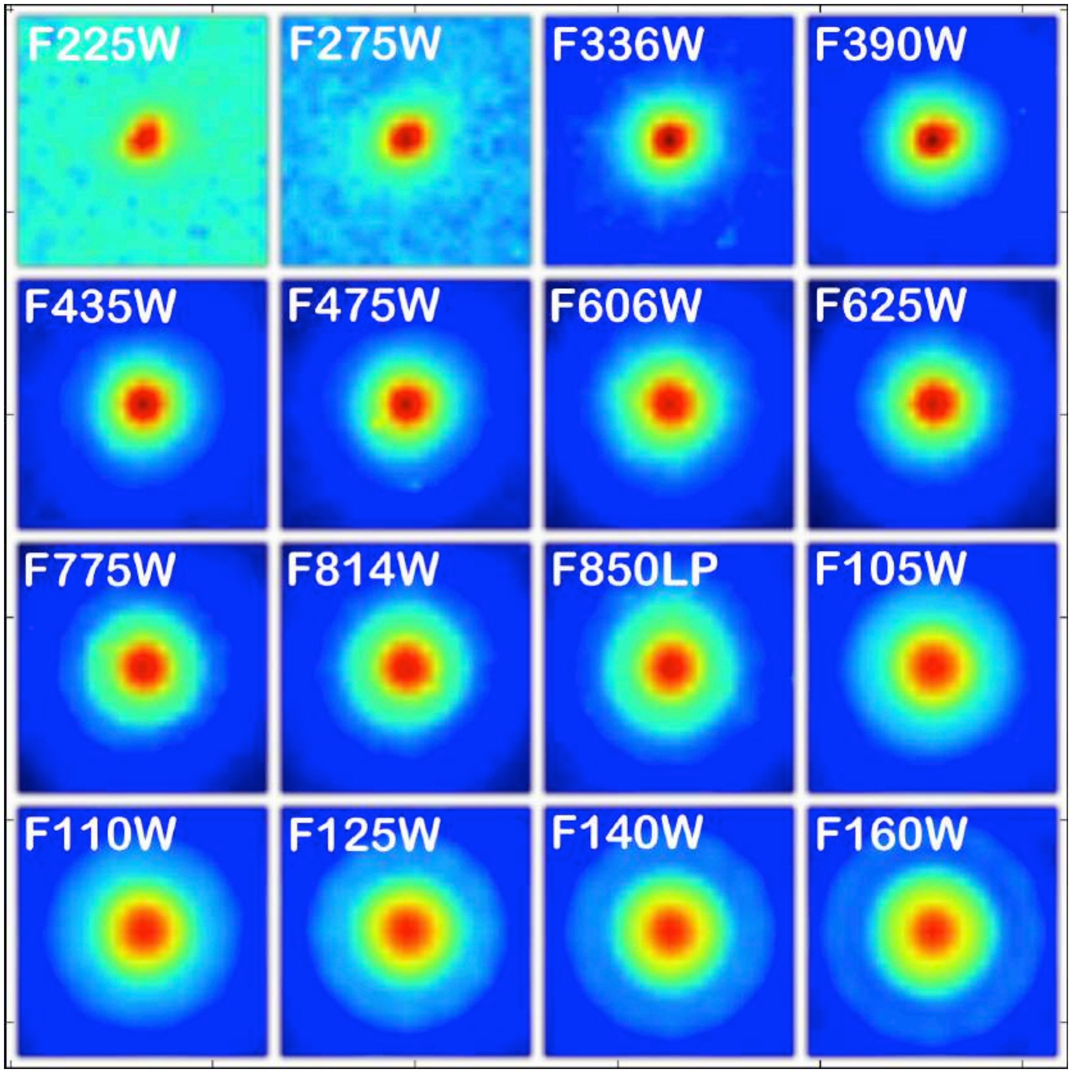


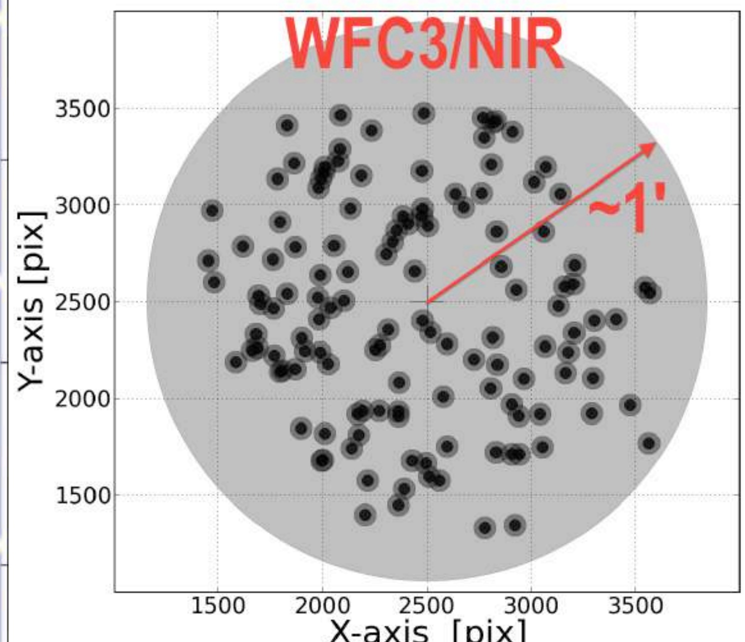
MODERATE: More convenient for the estimation of physical parameters such as stellar masses, ages, metallicities…

RESTRICTED: Optimal for photo-z since it enhances the S/N in the shortest wavelengths and retrieve accurate colors.

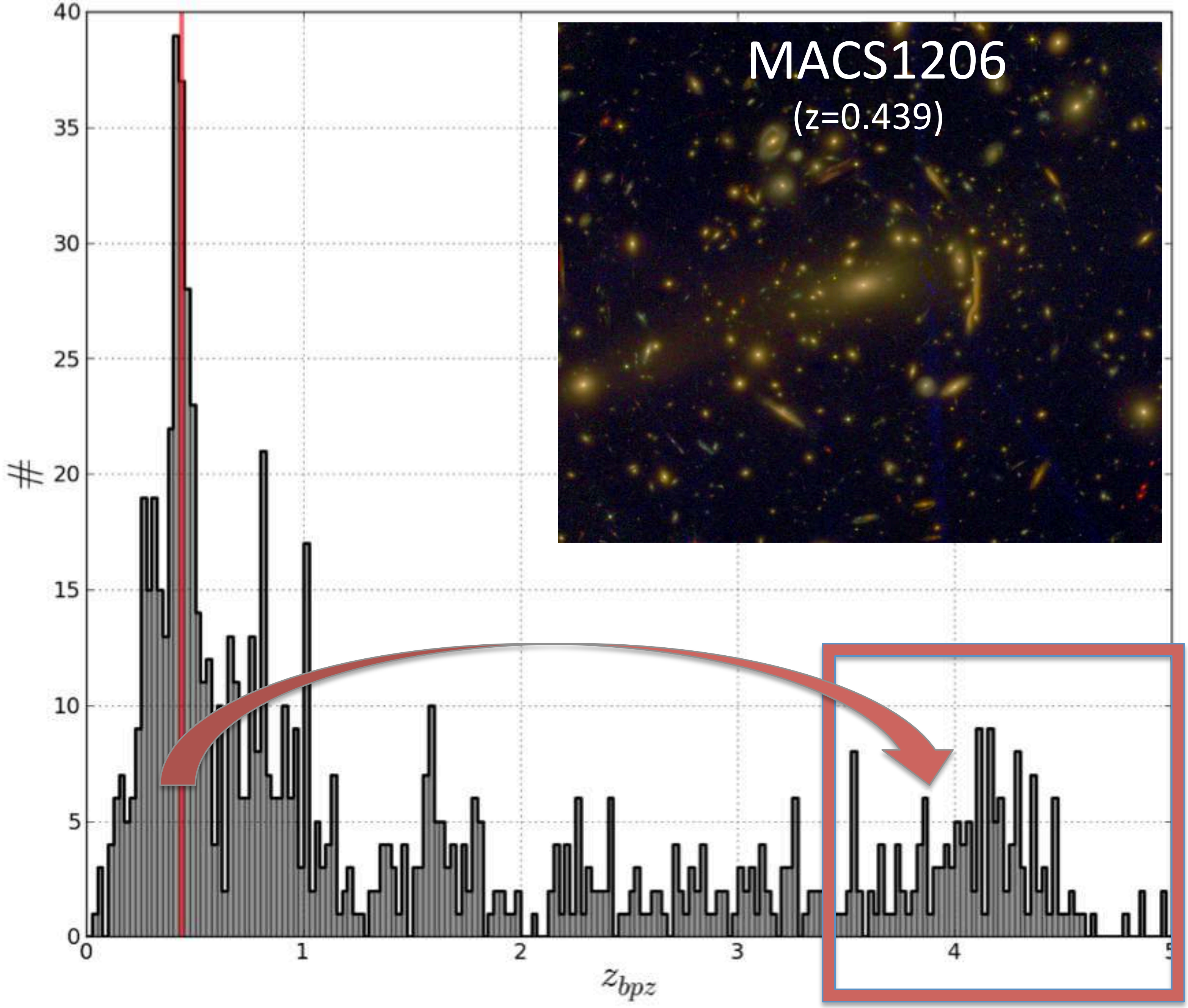
Generating new PSF-models for all clusters

Visually selecting >100 stars from all clusters within 1' (WFC3/NIR FoV)



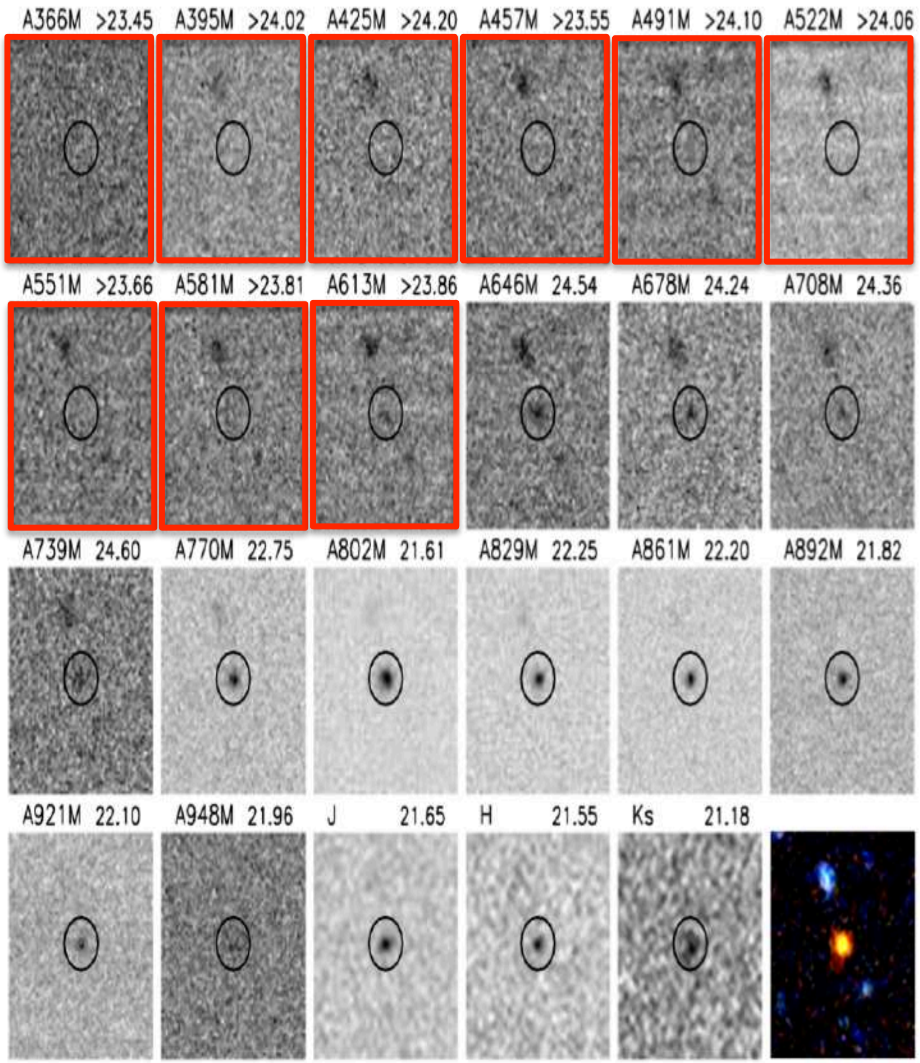


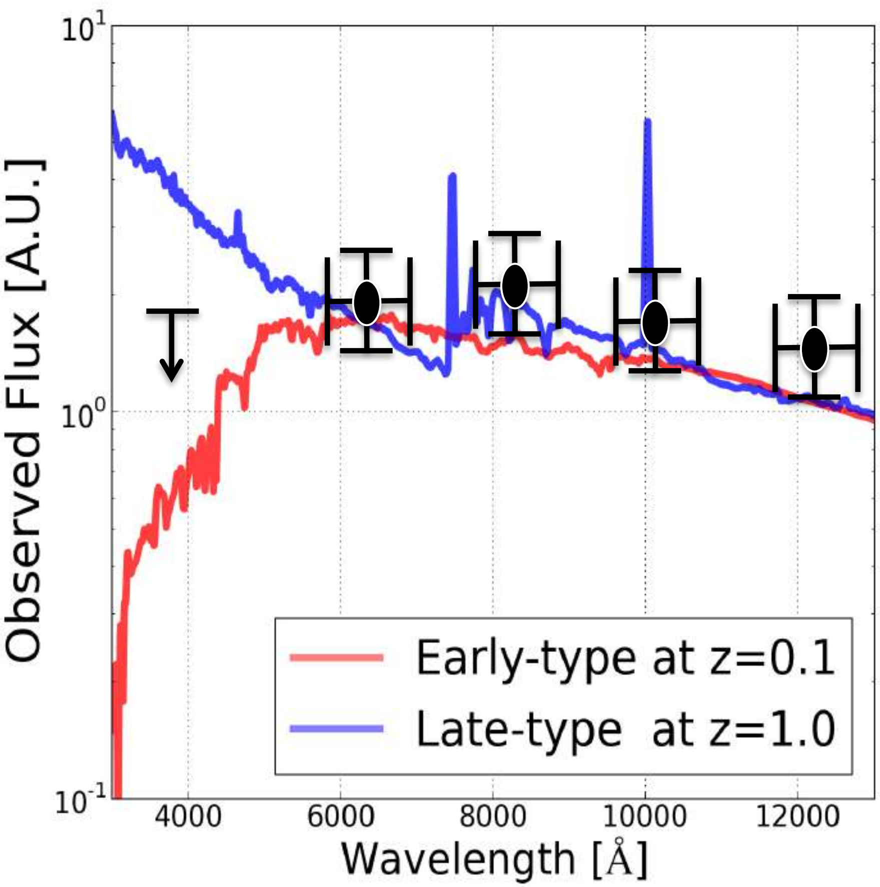
Update 3:
De-biasing photometric **upper-limits** for photo-z estimations


MACS1206
(z=0.439)
#
z_{bpz}
0
1
2
3
4
5
10
15
20
25
30
35
40

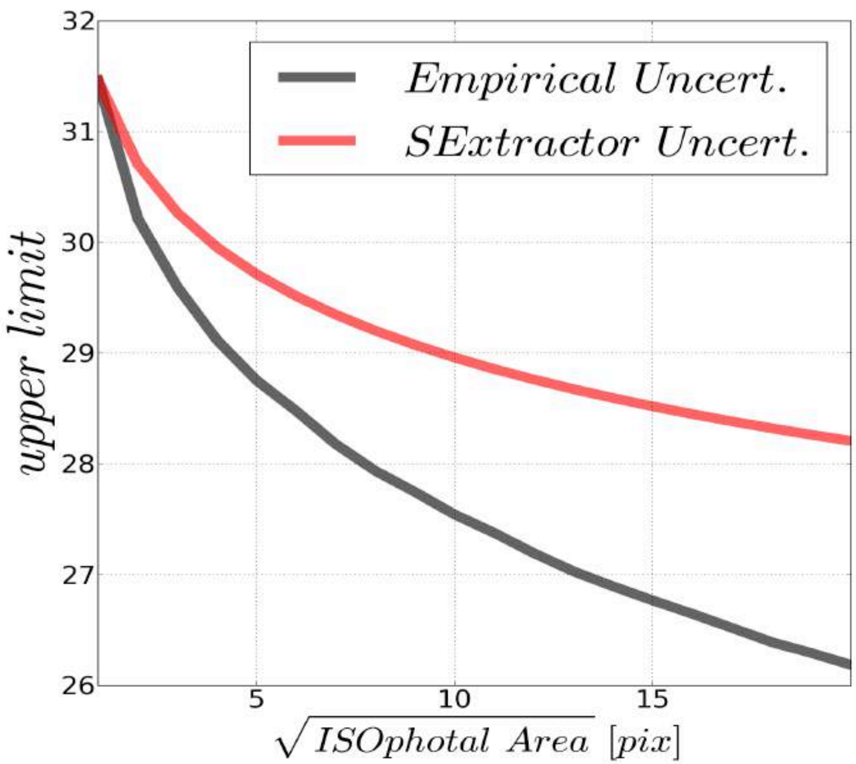
Non-detected galaxies: photometric **upper-limits** serve to break degeneracies.

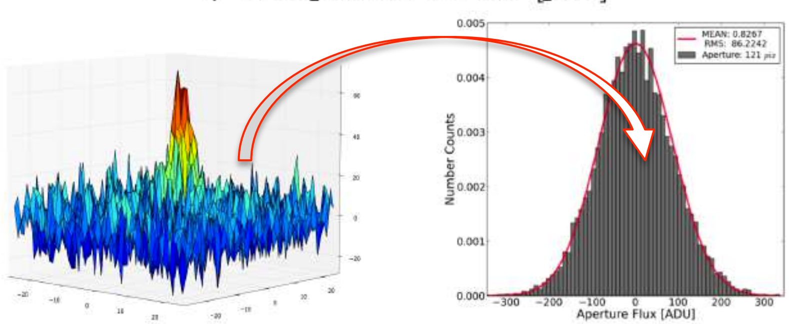
Matute et al. (2013)

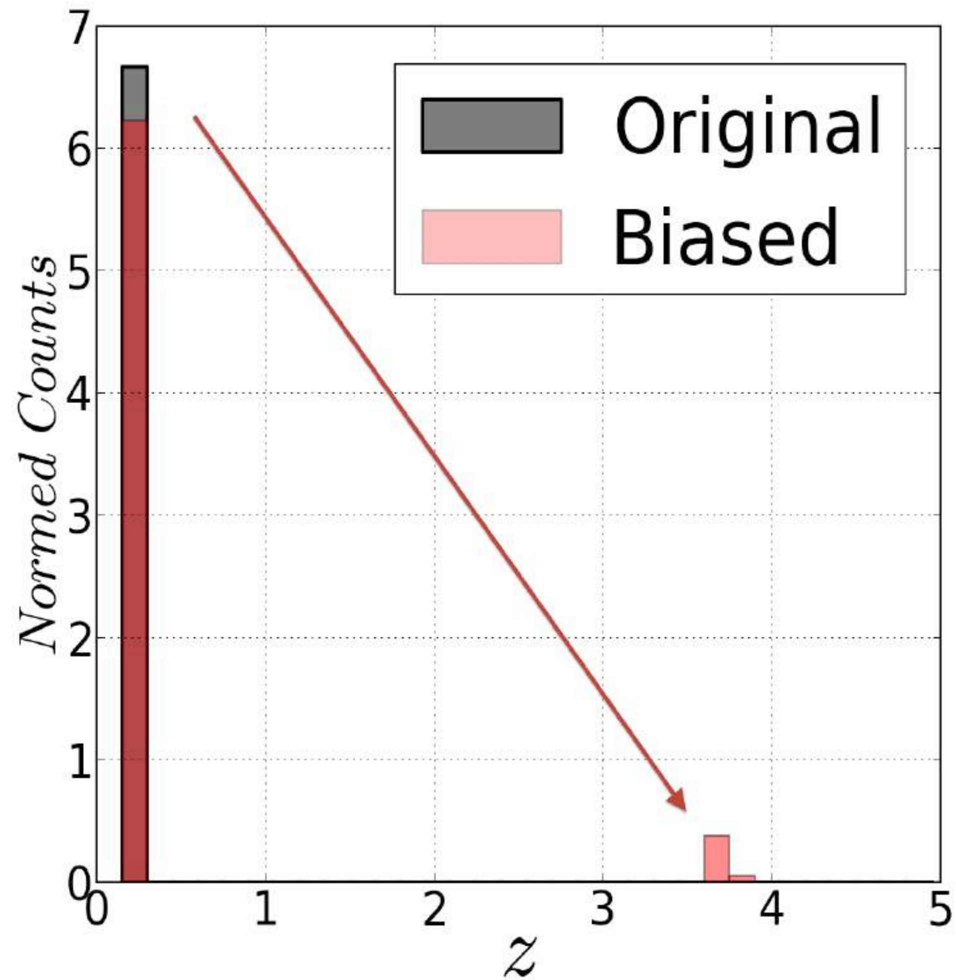




Underestimated uncertainties overestimate photom. Upper-limits, favoring (artificial) high-z solutions

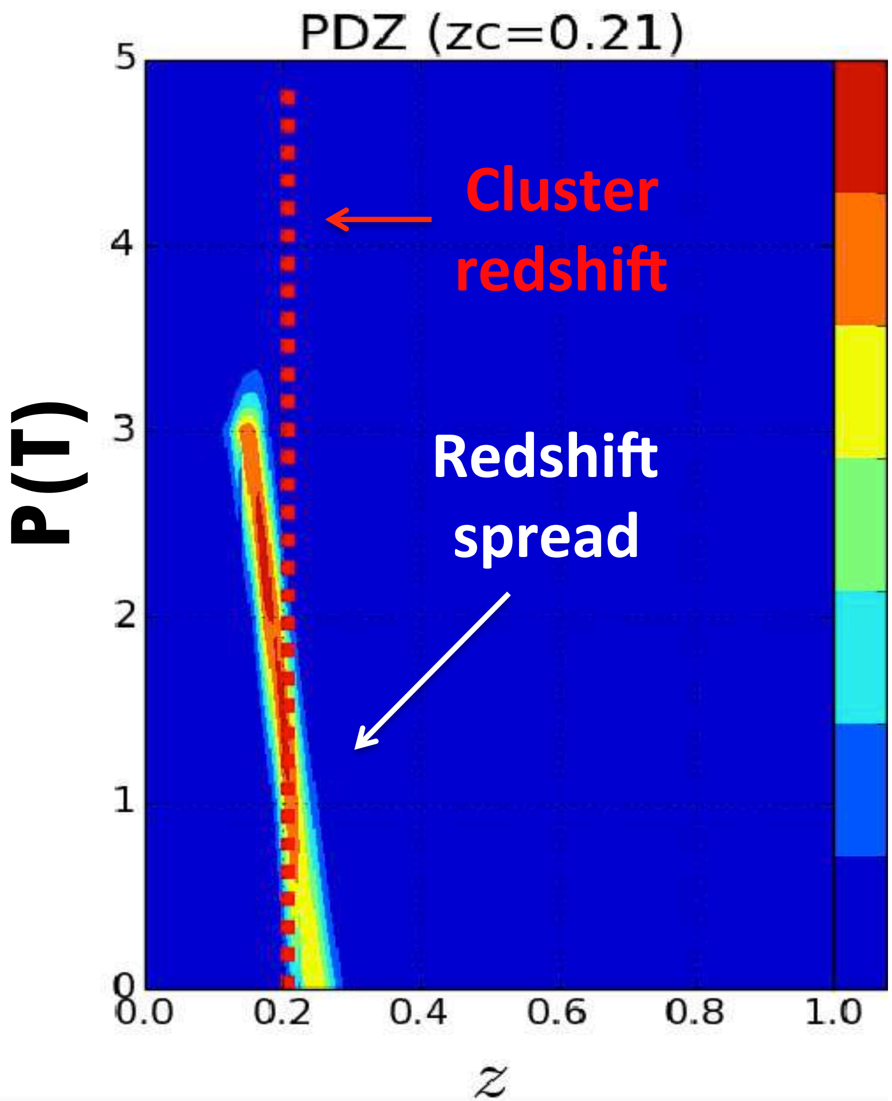


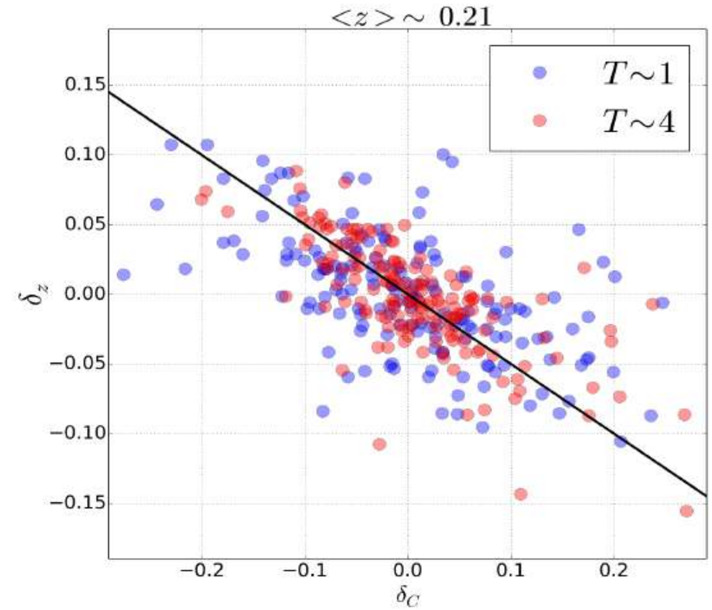


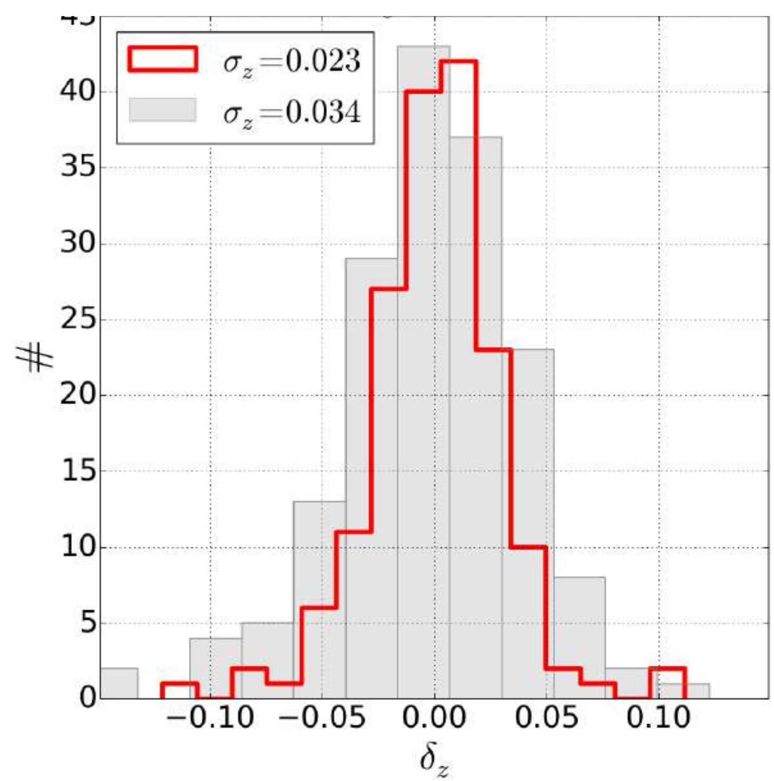


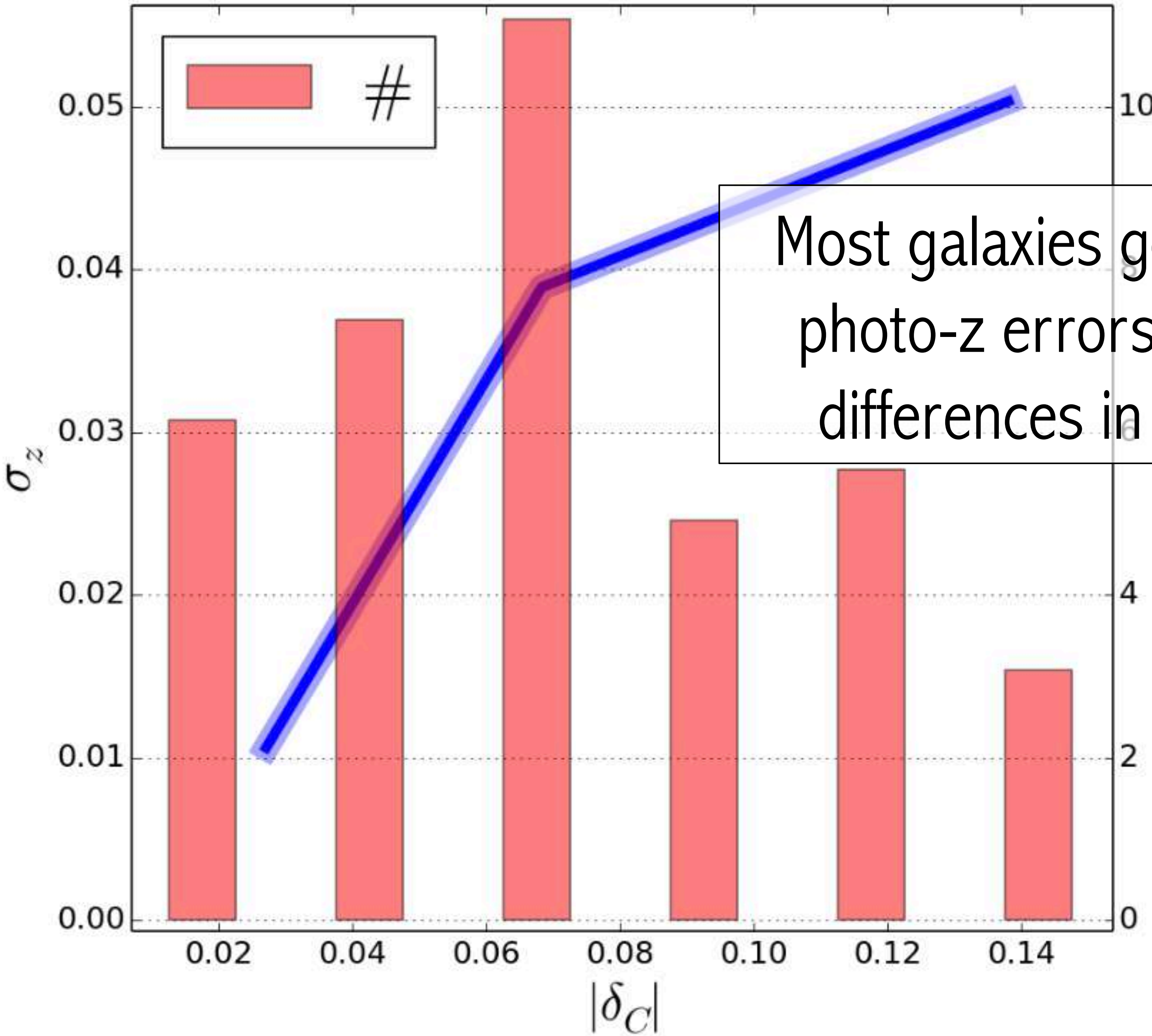
Update 4:
Exhaustively mapping out the **color-space** in massive galaxy clusters

Color-dependent bias related to the photo-z precision.



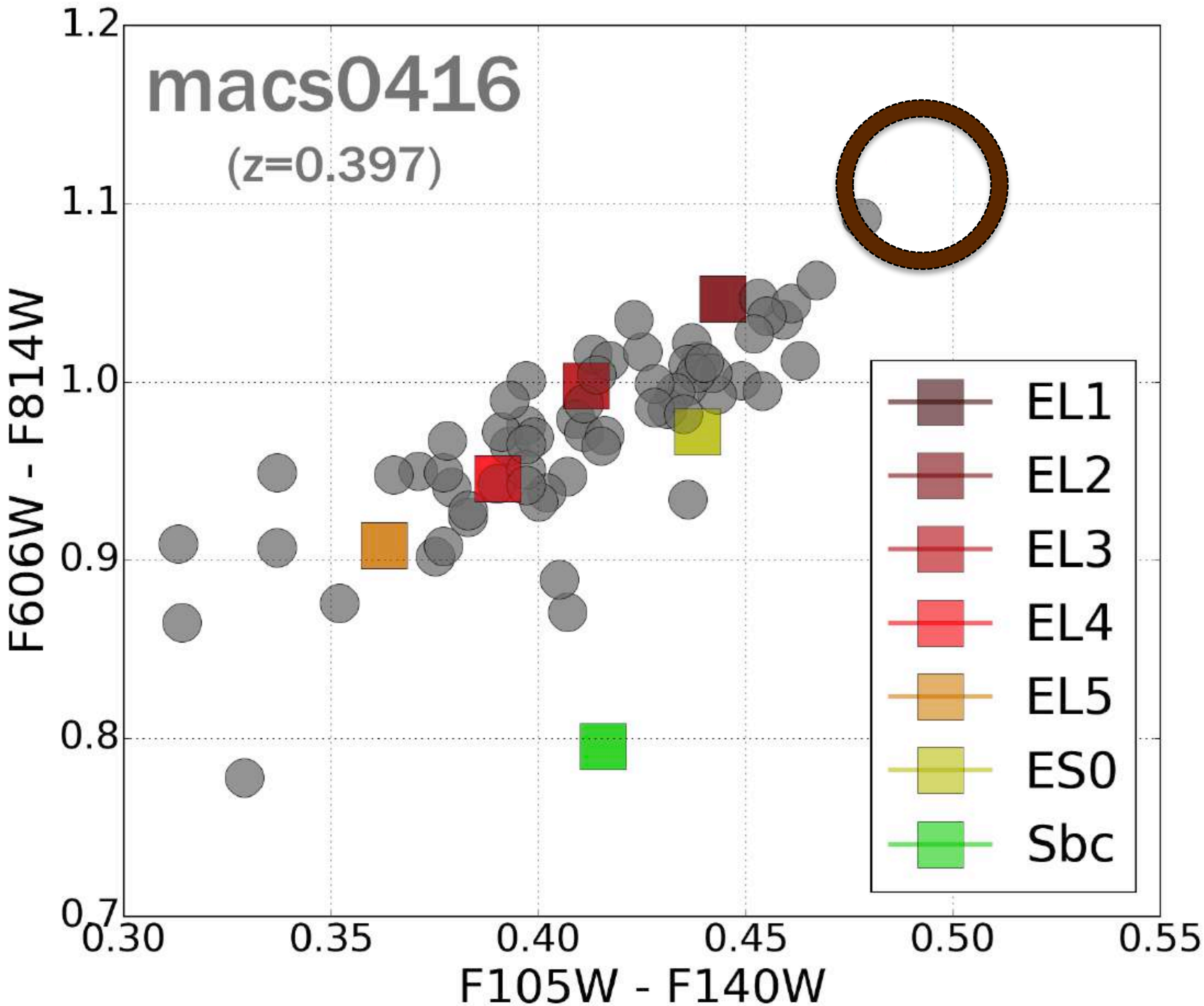




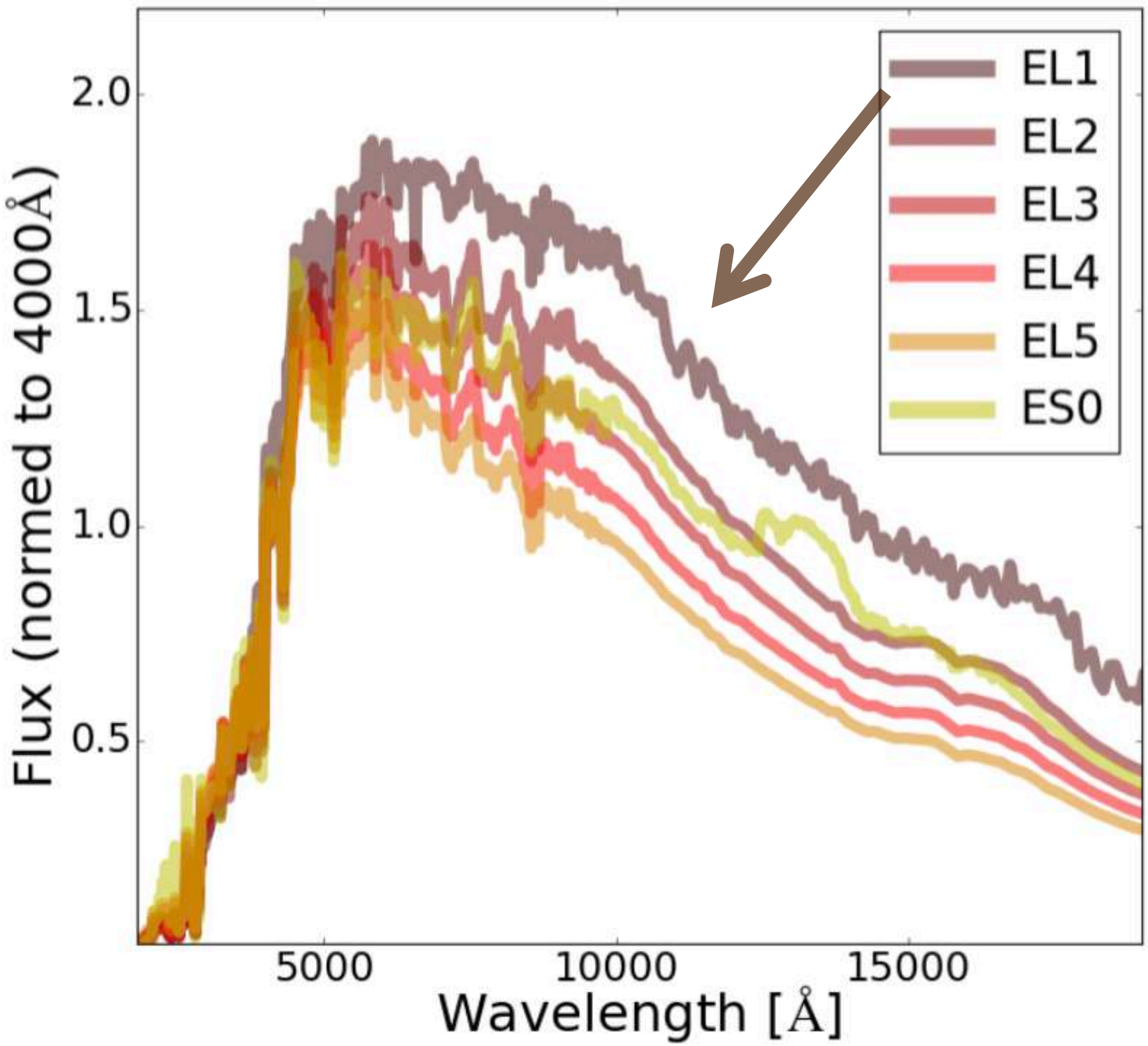


Most galaxies got **3-4%** photo-z errors due to differences in colors

Observed tension to cover the color-space in clusters

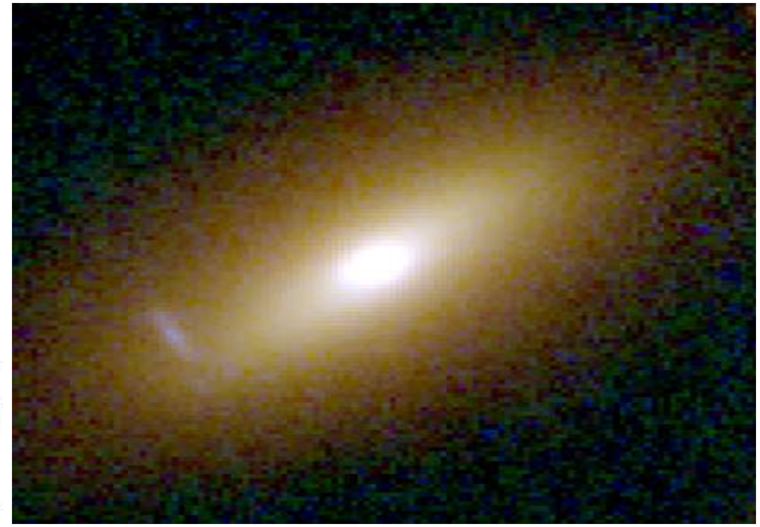


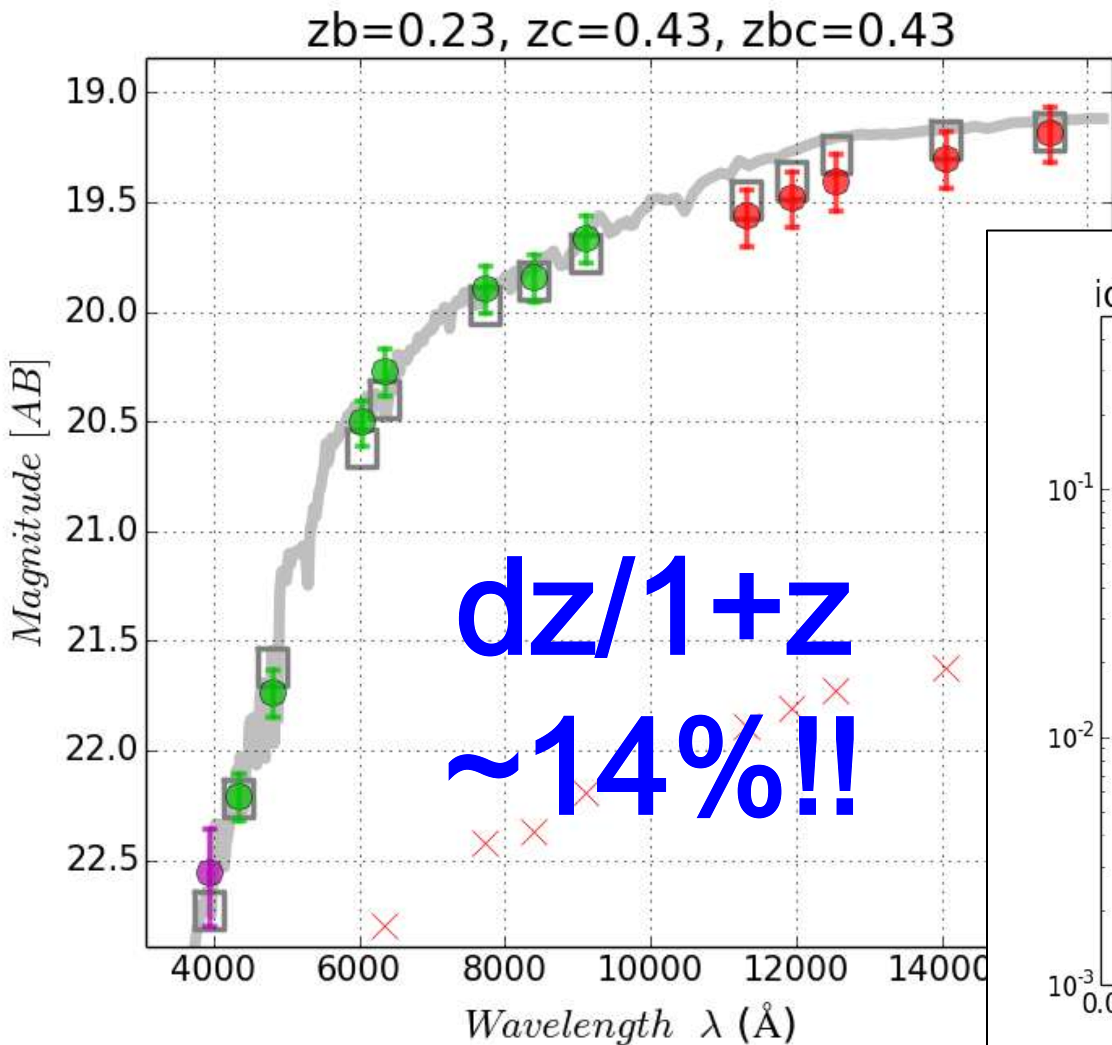
BPZ has been complemented with an additional template.

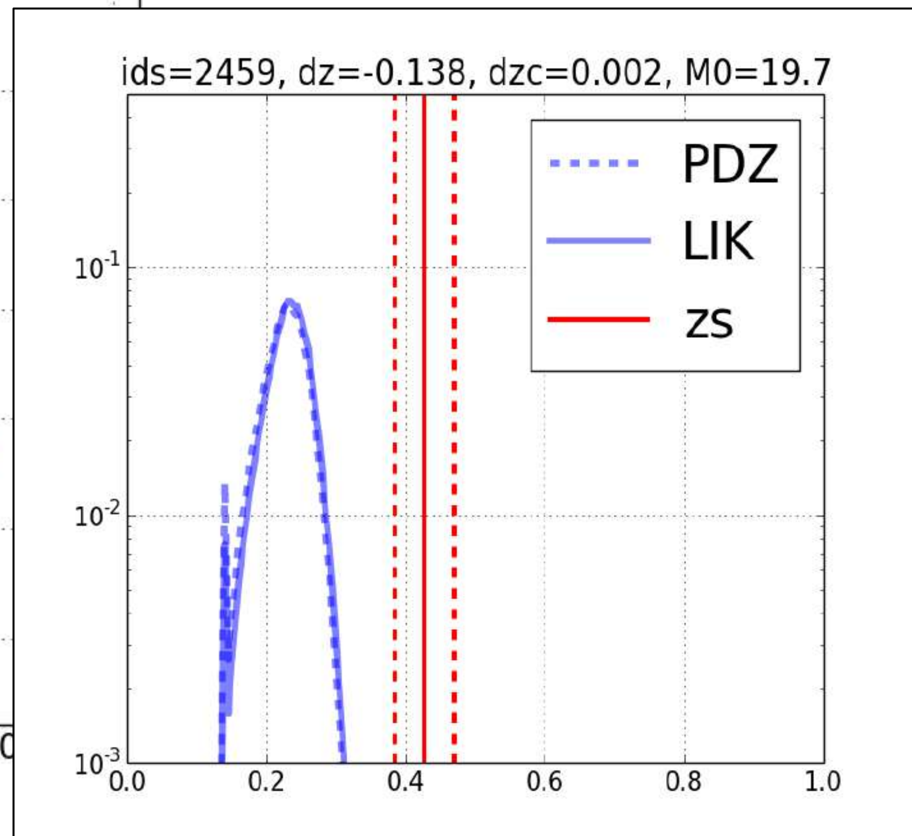


Update 5:
Incompatible p(z) with observed colors for very bright cluster galaxies

Several bright well-isolated elliptical galaxies got **totally wrong** photo-z!!





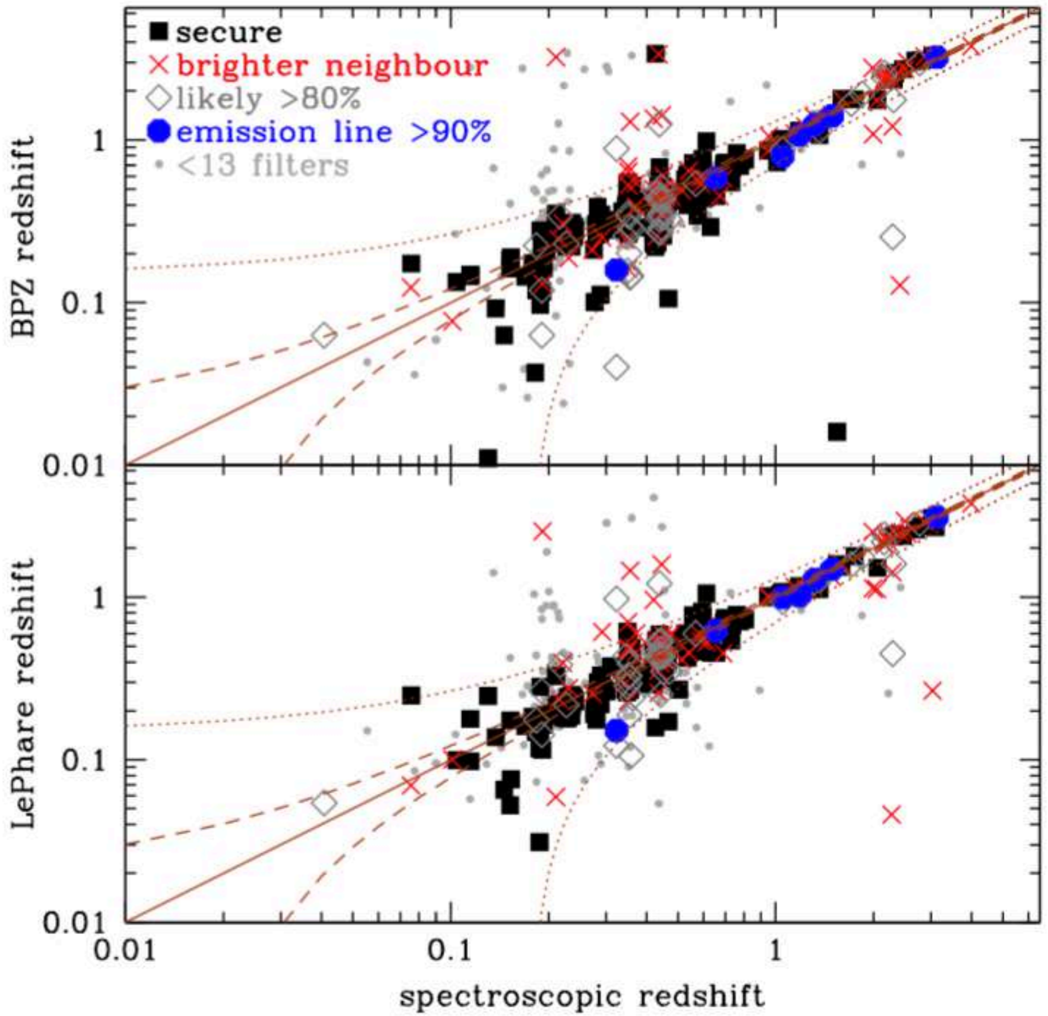


Update 6:
Magnitude-dependent zero-point recalibration

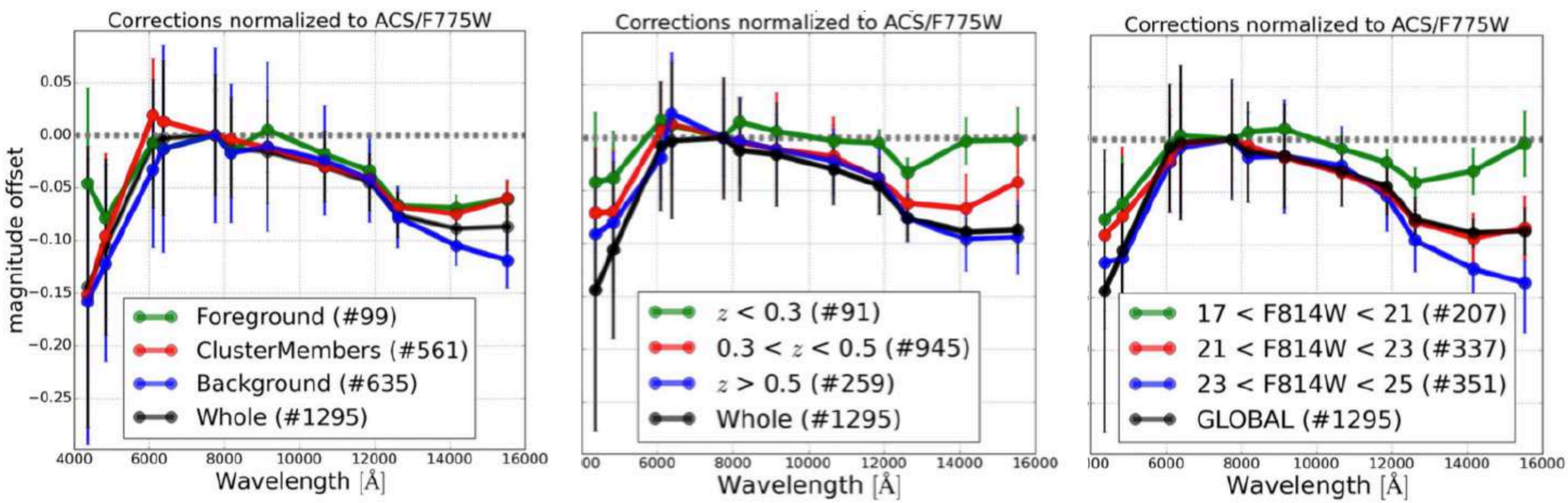
Standard (global) zero-point refinements did not improve the precision of all types of galaxies

Band	UVIS+ACS+NIR
F225W	0.65551
F275W	0.39279
F336W	0.20212
F390W	0.08715
F435W	0.00495
F555W	0.01920
F475W	0.04464
F606W	-0.01530
F625W	-0.06027
F775W	-0.08042
F814W	-0.04091
F850LP	-0.08952
F105W	0.04942
F110W	0.04591
F125W	0.08528
F140W	0.10459
F160W	0.00000

Jouvel+14



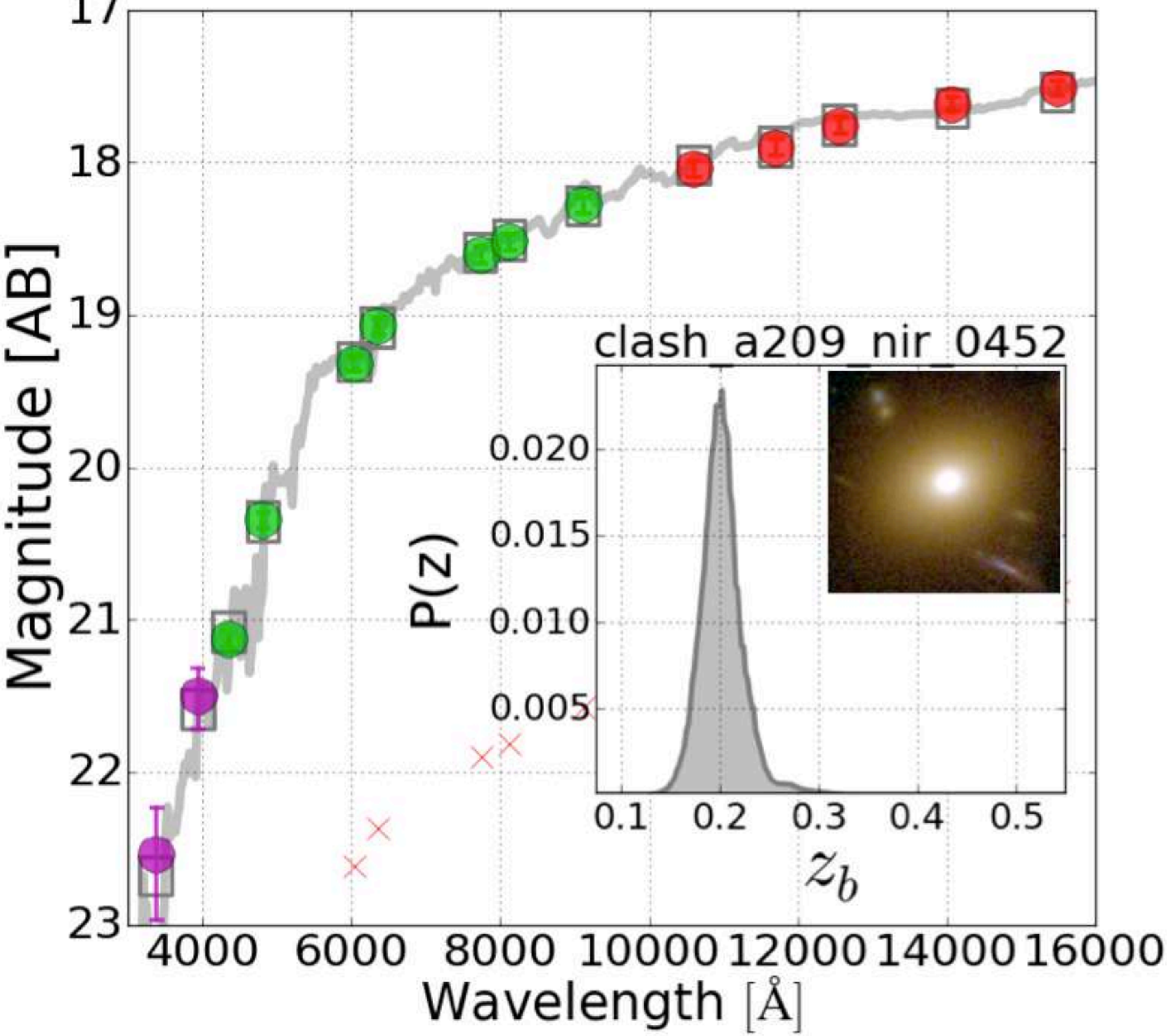
After a deep inspection, we identified a magnitude-dependent zero-point offset in the data.



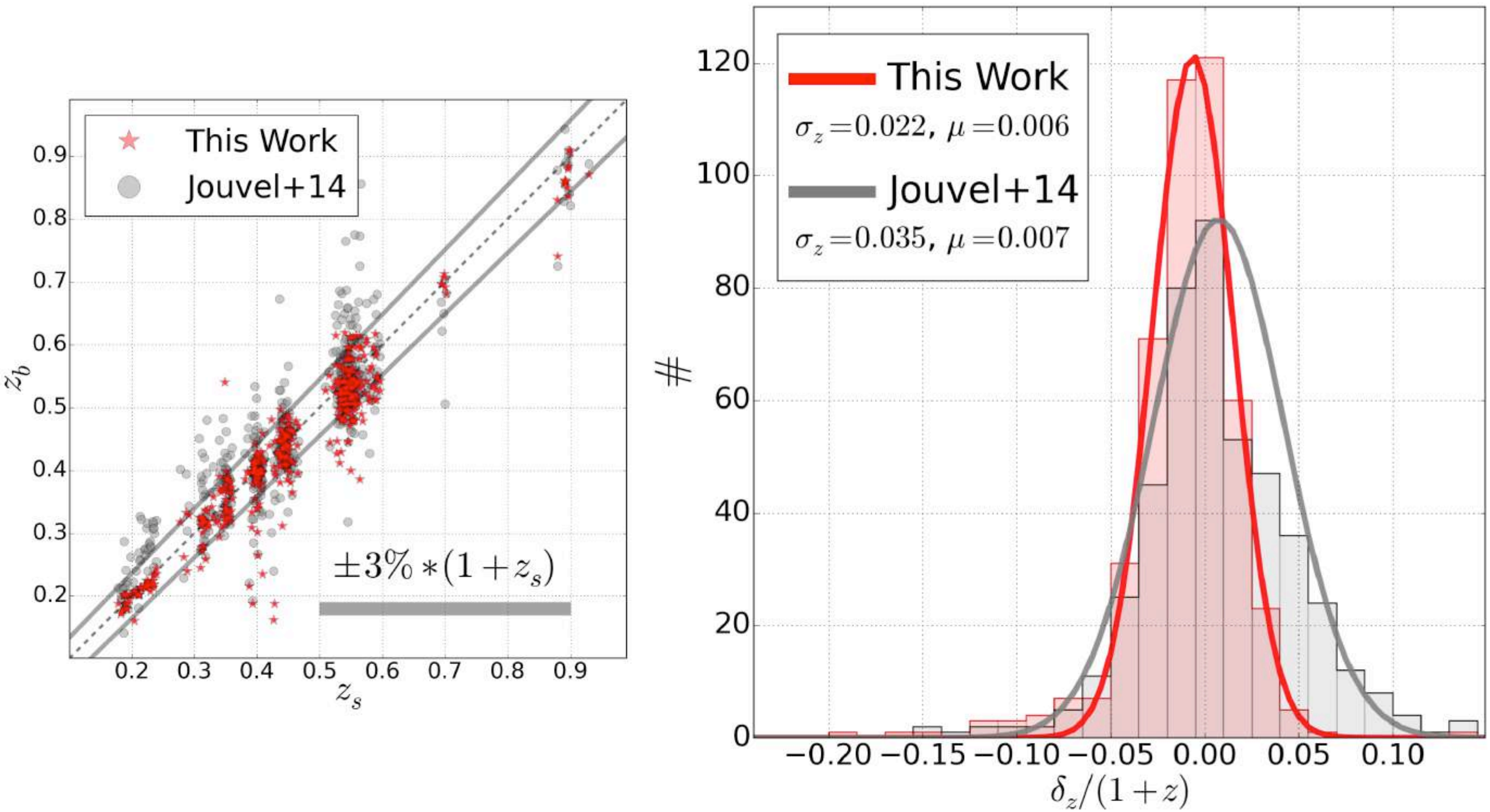
New

photo-z catalogues

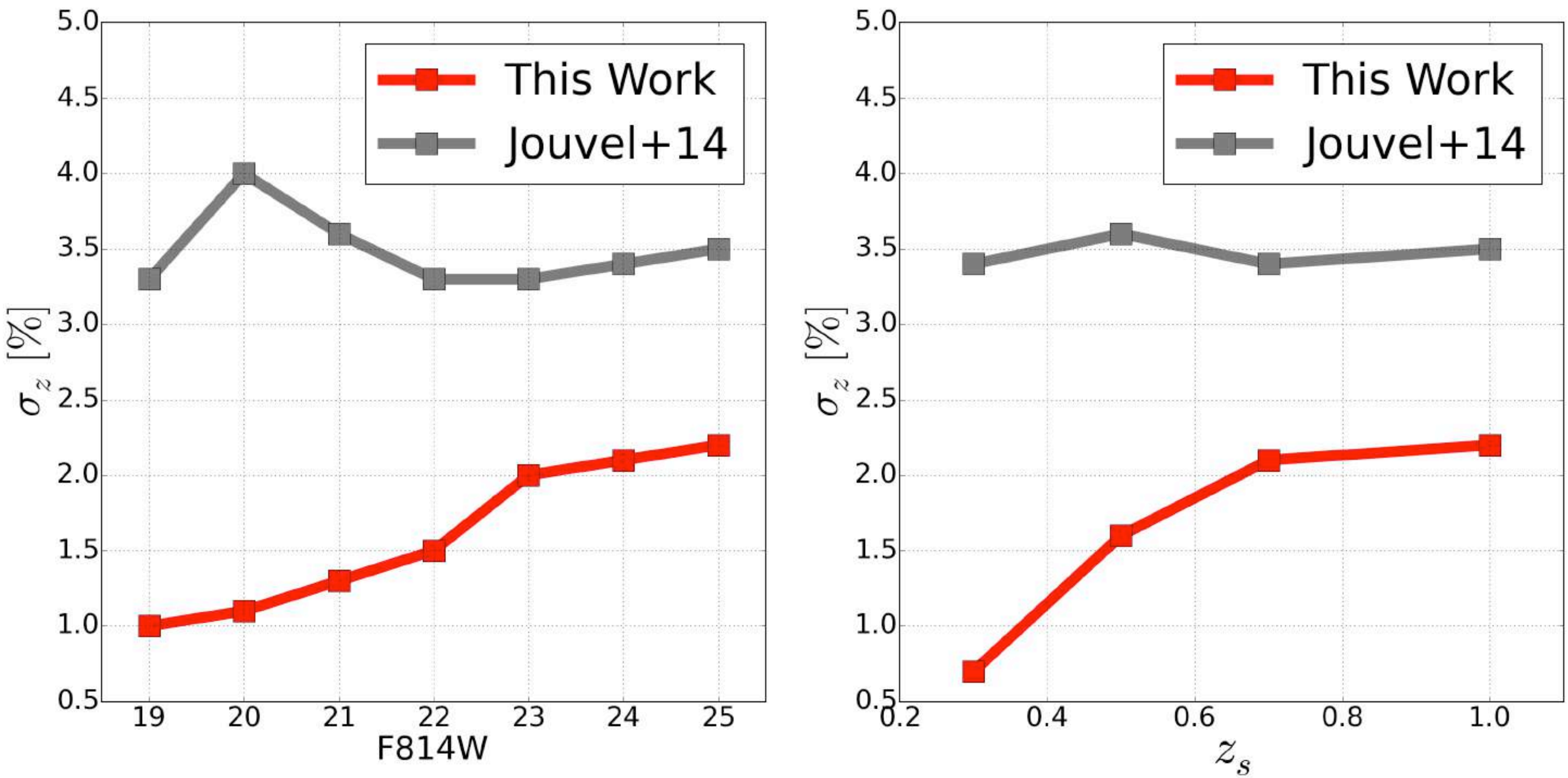
for the 25 CLASH clusters.



Magnitude [AB]
17
18
19
20
21
22
23
4000
6000
8000
10000
12000
14000
16000
Wavelength [Å]
clash_a209_nir_0452
P(z)
0.020
0.015
0.010
0.005
0.1
0.2
0.3
0.4
0.5
z_b



This Work
Jouvel+14
$\pm 3\% * (1+z_s)$
z_b
z_s
This Work
$\sigma_z = 0.022$, $\mu = 0.006$
Jouvel+14
$\sigma_z = 0.035$, $\mu = 0.007$
#
$\delta_z/(1+z)$



This Work
Jouvel+14
σ_z [%]
F814W
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
19
20
21
22
23
24
25
This Work
Jouvel+14
σ_z [%]
z_s
0.2
0.4
0.6
0.8
1.0

Take-home ideas

- The CLASH data represents the most accurate (**HST**) and homogeneous multi-wavelength dataset (UV+OPT+NIR) to explore several massive galaxy clusters at $0.1<z<0.9$

- An specific **background subtraction** has been found per each individual cluster, (mostly) restoring the original colours of galaxies embedded in the ICL.

- A new **"total-restricted" photometry** has defined to enhance the signal-to-noise of the bluest filters (200-500 nm), retrieving more accurate colours for photo-z estimations, pushing the photo-z depth to a deeper magnitudes.

Take-home ideas

- A secondary **“total-moderate” photometry** has also been performed to derive physical properties of galaxies.
- **Underestimated photometric uncertainties** were leading to an excess of high (>4.0) redshift galaxies. A better estimation of the uncertainties and a more conservative photometric upper-limits served to mitigate this bias in the n(z).
- **An additional galaxy template** was necessary for BPZ to better map out the colour-space of cluster galaxies. This template reduced the photo-z scatter around the cluster.

Take-home ideas

- The new results for the CLASH photo-z yields an accuracy (on cluster galaxies & using only 14 filters) of:
  - **dz/1+z < 0.8%** for magnitudes F814W<18 AB.
  - **dz/1+z < 1.0%** for magnitudes F814W<20 AB.
  - **dz/1+z < 1.5%** for magnitudes F814W<22 AB.
  - **dz/1+z < 2.0%** for magnitudes F814W<23 AB.
- *This results not only surpass those presented in Jouvel+2014 but also represent the most accurate photo-z catalogue up-to-date derived on galaxy clusters.*

Molino+17 also in arXiv: 1705.02265

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CLASH: accurate photometric redshifts with 14 *HST* bands in massive galaxy cluster cores

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ABSTRACT

We present accurate photometric redshifts for galaxies observed by the Cluster Lensing And Supernova survey with Hubble (CLASH). CLASH observed 25 massive galaxy cluster cores with the *Hubble Space Telescope* in 16 filters spanning 0.2–1.7 μm. Photometry in such crowded fields is challenging. Compared to our previously released catalogues, we make

Catalogues available at MAST

https://archive.stsci.edu/prepds/clash/

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Cluster Lensing And Supernova survey with Hubble (CLASH)

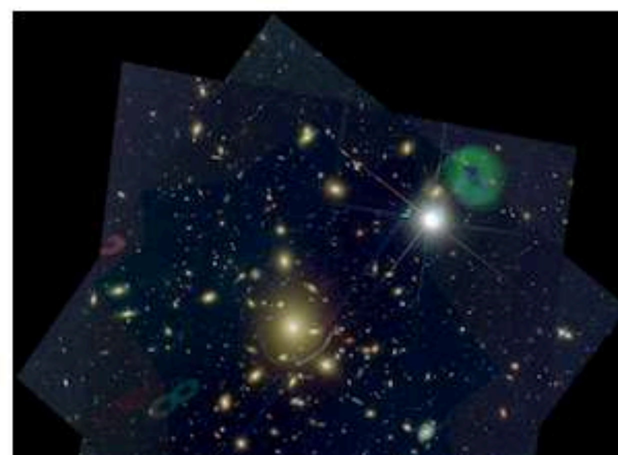
An Innovative Survey to Place New Constraints on the Fundamental Components of the Cosmos using the Hubble Space Telescope

Latest Updates

June 23, 2017: New redshift catalogs based on VLT and GLASS spectra have been added for six clusters. See the headers of the catalog files for references and acknowledgment information. Note that the MACS 0416 and MACS 1206 "_vlt_vimos_*zcat.txt" files are replaced by the "_vlt_muse_*zcat.txt" files.
May 8, 2017: New catalogs from Molino et al. (2017) have been added.
08 Dec. 2015: Corrected CRPIX1 and CRPIX2 values in Zitrin model FITS files for MACSJ1115+01.

By observing 25 massive galaxy clusters with HST's new panchromatic imaging capabilities (Wide-field Camera 3, WFC3, and the Advanced Camera for Surveys, ACS), CLASH will accomplish its four primary science goals:

- Map, with unprecedented accuracy, the distribution of dark matter in galaxy clusters using strong and weak gravitational lensing;
- Detect Type Ia supernovae out to redshift z ~ 2, allowing us to test the constancy of dark energy's repulsive force over time and look for any evolutionary effects in the supernovae themselves;
- Detect and characterize some of the most distant galaxies yet discovered



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- MSc on Astrophysics @ULL/IAC (1-year degree).
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