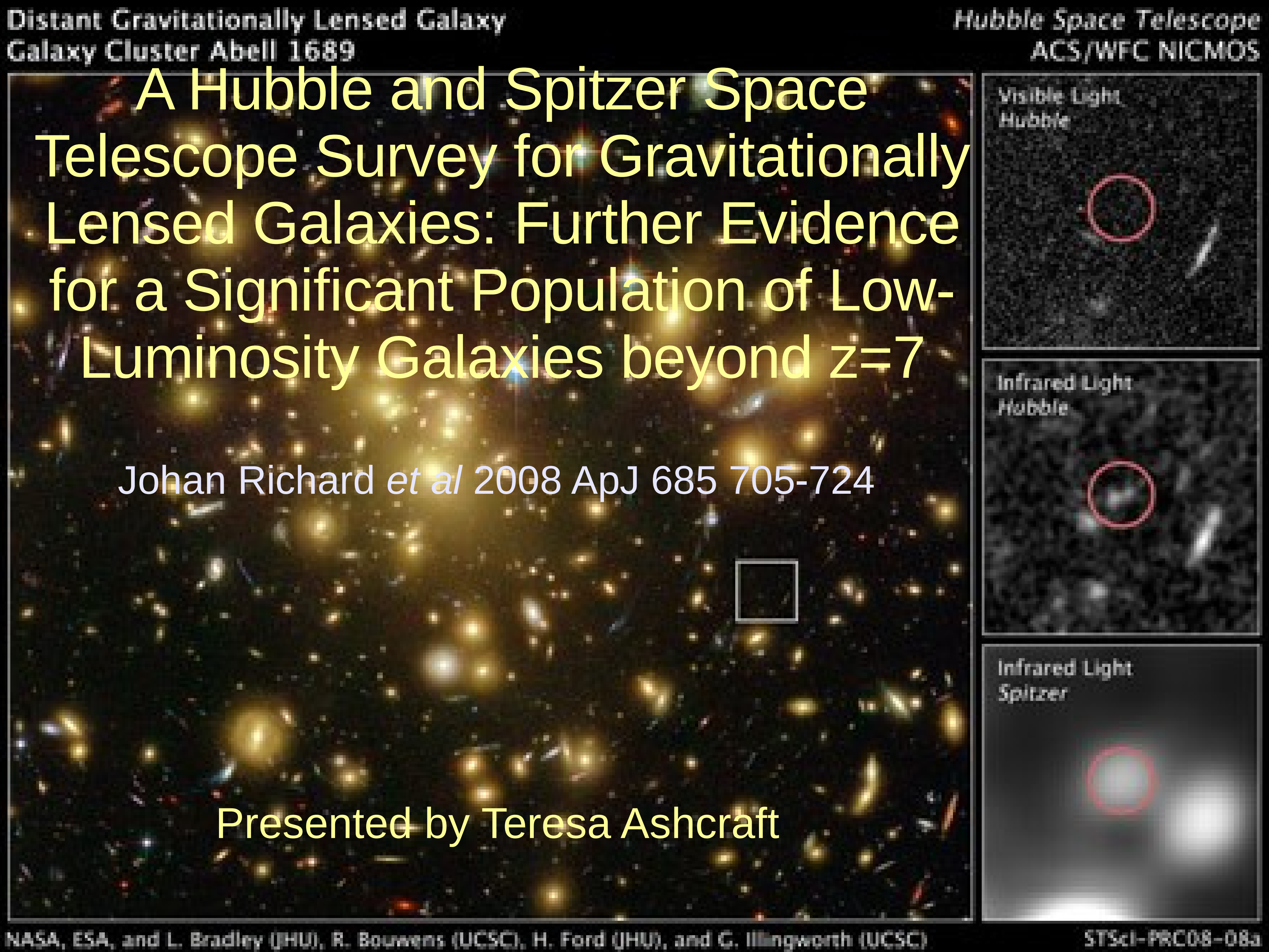
A Hubble and Spitzer Space Telescope Survey for Gravitationally Lensed Galaxies: Further Evidence for a Significant Population of Low-Luminosity Galaxies beyond z=7

Johan Richard *et al* 2008 ApJ 685 705-724

Presented by Teresa Ashcraft



WHY YOU SHOULD CARE!

You need to understand the past before you can fully understand the present.

-the role that young galaxies may play in cosmic reionization,

-how feedback and other poorly understood processes shape the early distribution of galaxy luminosities and sizes from which later systems evolve

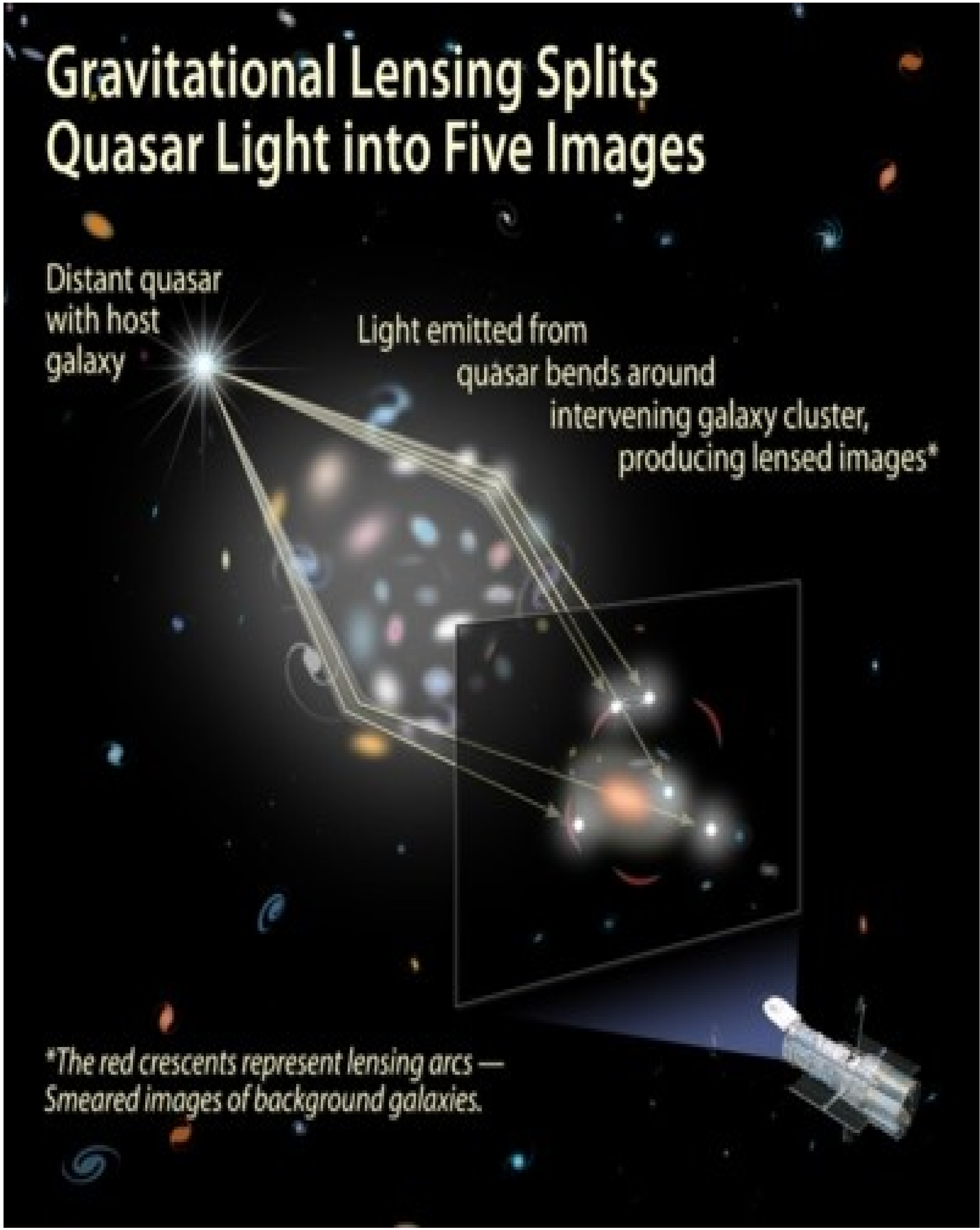
Gravitationally Lensing

The gravity from a massive object like a galaxy cluster can bend the light rays from a bright background source. This alters the time taken for the light to reach an observer, and can both magnify and distort the apparent image of the background source.

Maximum bending occurs closest to, and minimum bending furthest from, the center of a gravitational lens.

Can produce multiple images of the same source. The number and shape of these depends upon the relative positions of the source, lens, and observer, and the shape of the gravitational well of the lens object.

Lensing allows us to study distant objects that would otherwise be too faint.

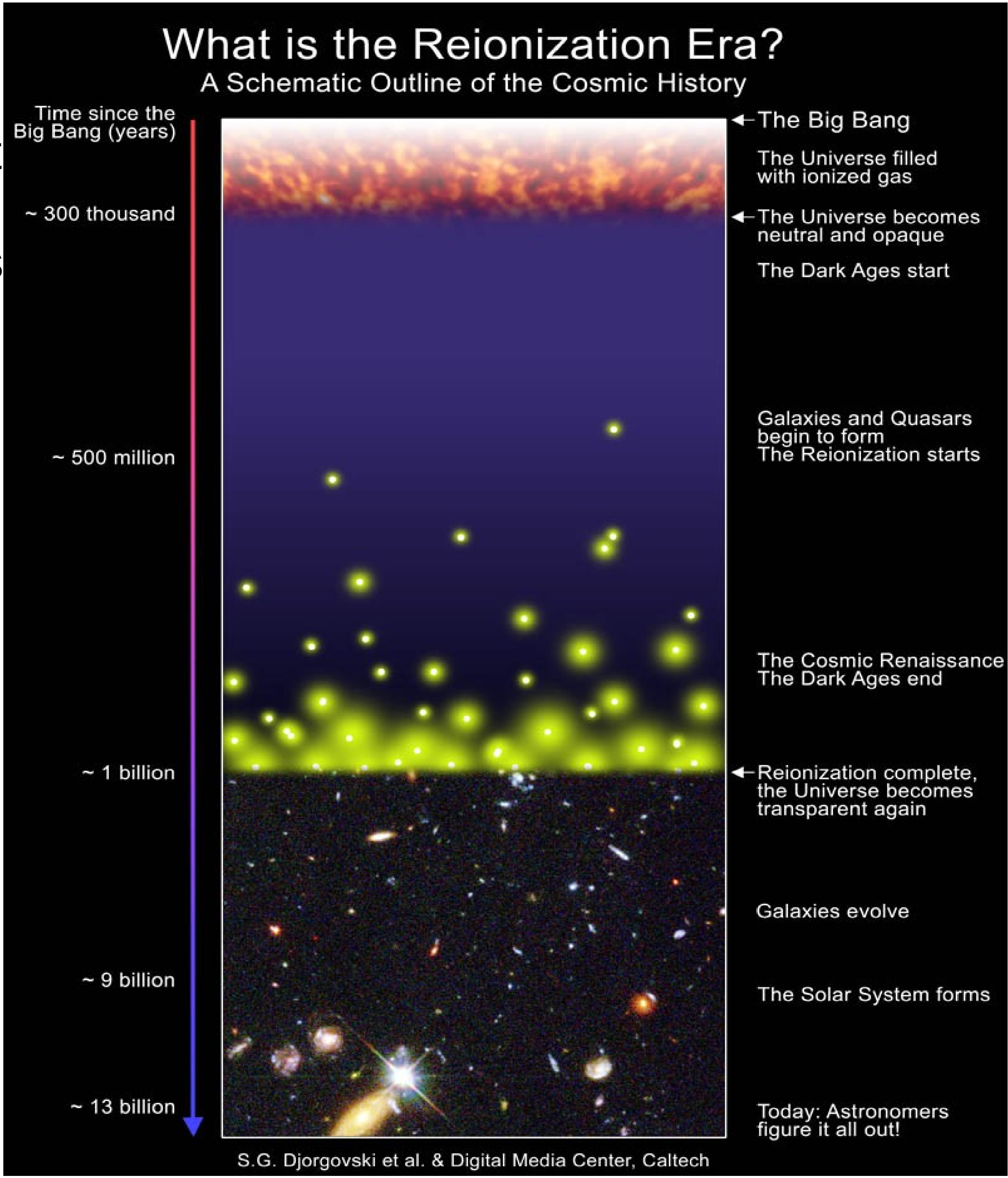


Credit: NASA, ESA, and A. Feild (STScI).

Cosmic Reionization

Reionization is the process that reionized the matter in the universe after the "dark ages." It is the second of two major phase changes of hydrogen gas in the universe. The first is recombination.

Reionization occurred once objects started to form in the early universe energetic enough to ionize neutral hydrogen. As these objects formed and radiated energy, the universe went from being neutral back to being ionized, between redshift $6 < z < 20$.



Problem/Solution

Declining abundance of luminous star-forming sources beyond is insufficient to account for reionization

Stark et al. 2007 solution - Although there is no guarantee that star-forming sources did reionize the universe, a possible solution is that the bulk of the early star formation resides in an undetected population of intrinsically subluminous sources

Goal of Project

"The overall goal of this project has been to constrain the abundance of low-luminosity star-forming galaxies at , selected as *z*- and *J*-band dropouts in the fields of six lensing clusters observed with ACS and NICMOS on board the *Hubble Space Telescope*, and the IRAC camera on board the *Spitzer Space Telescope...* and to derive constraints on the possible contribution of low-luminosity sources to cosmic reionization, independently of Lyα searches in blind or narrowband surveys."

Prior Attempts

Richard et al. (2006) and Stark et al. (2007b) both papers from same authors of this paper did similar searches for lensed dropout galaxies at z>6. Both had candidates but the nature of these objects is still unconfirmed. There are many caveats to these works, similar issues are problems arise in Richard et al. 2008.

Lensing Cluster Sample

Well-understood mass models

Capable of producing areas of large magnification that match imaging area of HST

Value of the magnification factor for z=7 sources

Six clusters selected to minimize the effects of cosmic variance

Cluster		z
Abell 2218	....	0.176
Abell 2219	....	0.226
Abell 2390	....	0.228
Abell 2667	....	0.233
Cl 0024+16	....	0.39
Cl 1358+62	....	0.328

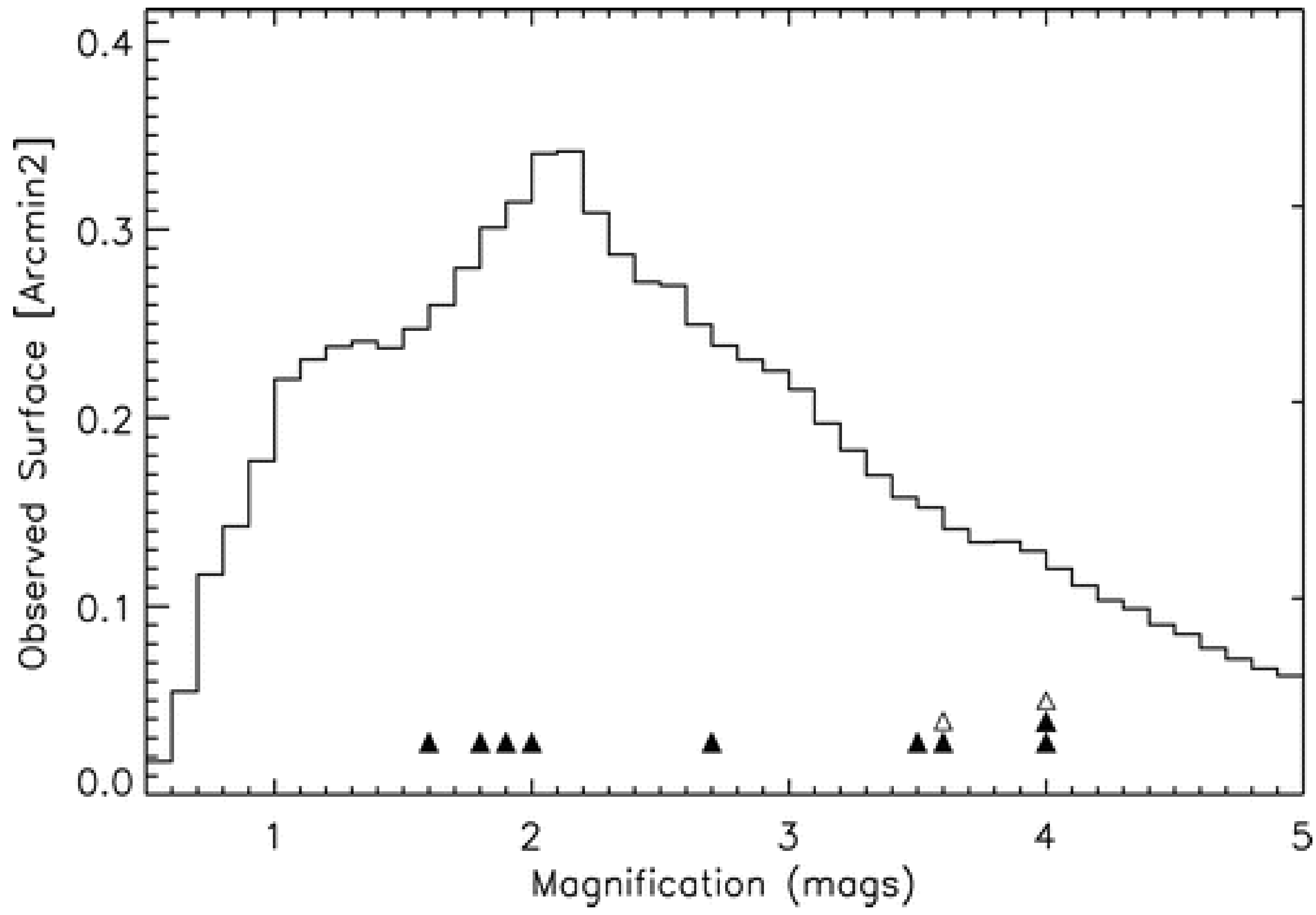
Data

- HST observations in the z850, J100, and H160 bands using ACS and NICMOS
- Each critical line region was covered by two NICMOS pointings per cluster, to ensure a magnification gain of μ=1 to 4 mag, with a typical value μ~ 2 mag.

Critical lines-smaller regions of very high magnification

- Spitzer archival data of the clusters in 3.6 and 4.5 μm IRAC channels
- Deep optical images are also looked at to verify dropout candidates

Distribution of magnification factors μ for the survey

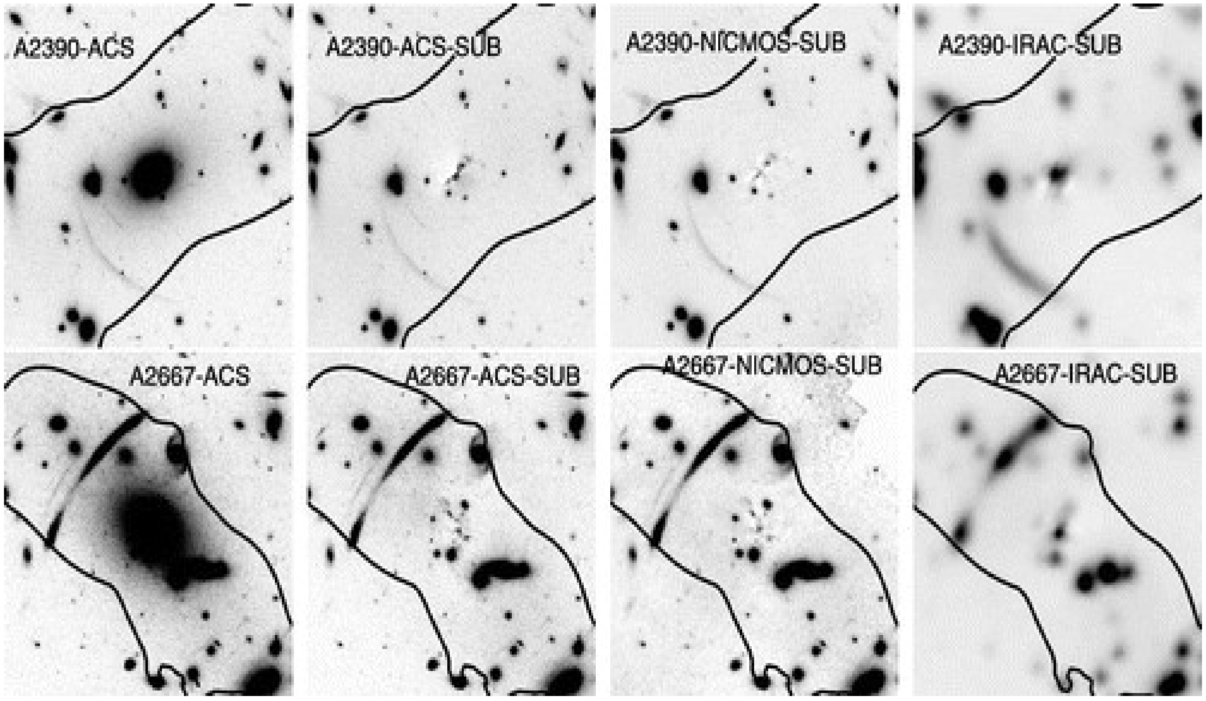


BCG Subtraction

Central regions of clusters dominated by bright spheroidal galaxies.

They obstruct the view and increase the background level of light which affects the photometry of fainter sources

Modeled the brightest galaxy cluster (BCG) and subtracted the light



High Redshift Candidates

Primary selection based on z-J color for z dropouts (z=7-8) and J-H color for J dropouts (z=8-10)

Nondetection in the optical band

Worry about contamination from lower redshift objects

-early-type galaxies

-dust-reddened objects

-low-mass Galactic stars-not significant contaminant

Star-forming galaxies at high z should display a prominent

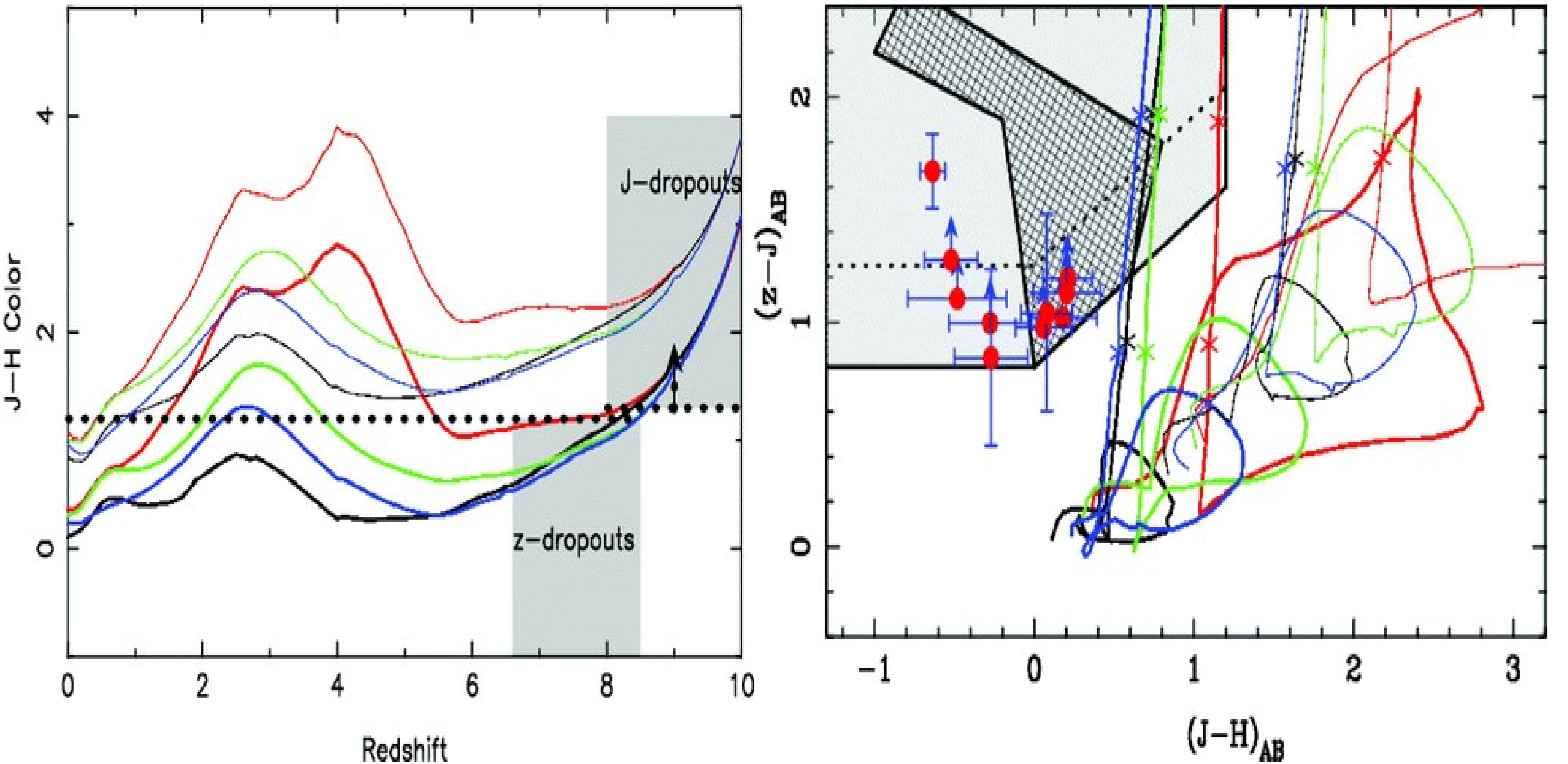
discontinuity in z - J while remaining blue in J -H

Color Cuts:

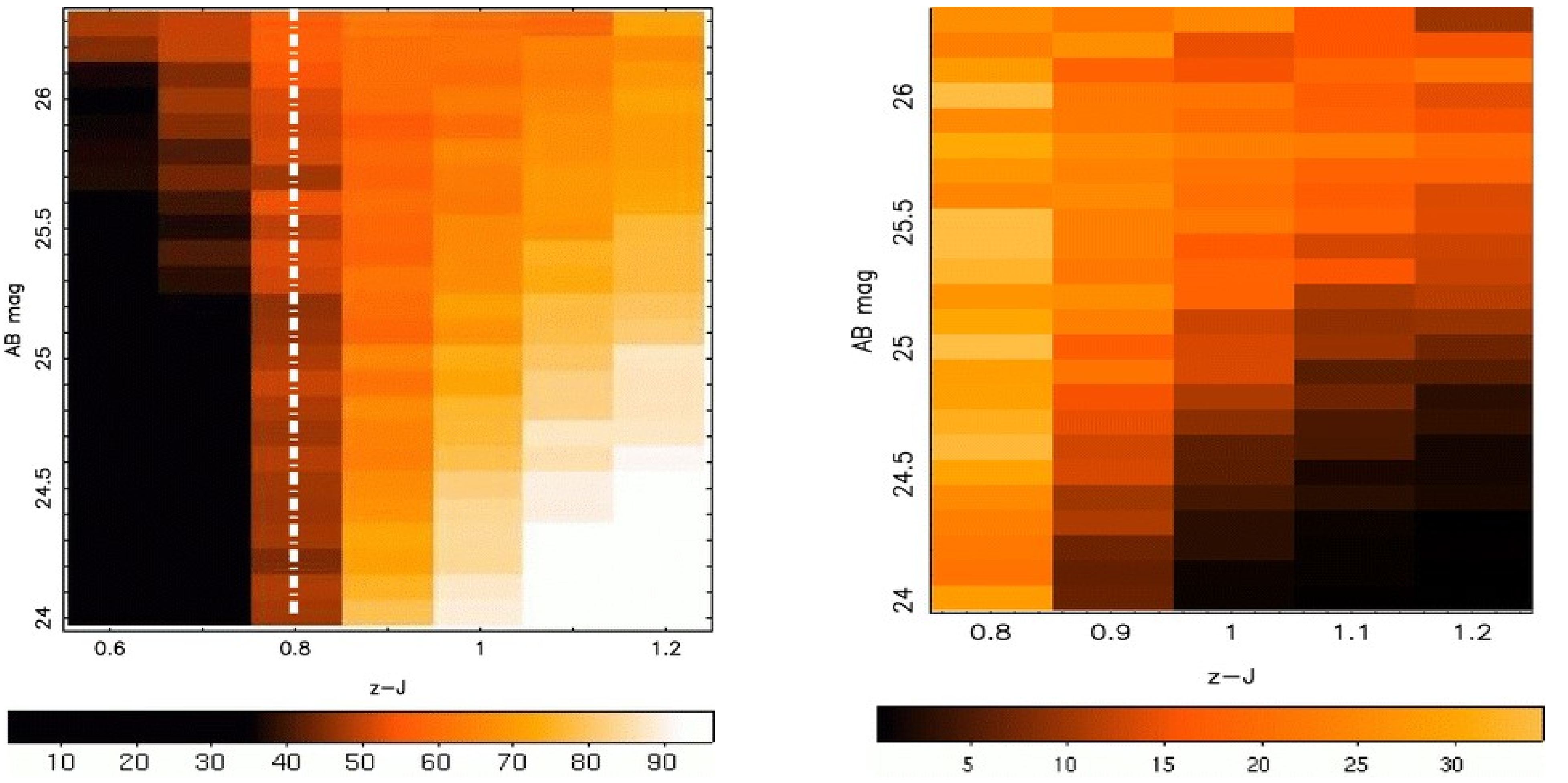
$(z850 - J110) > 0.8$; $(z850 - J110) > 0.66$

$(J110 - H160) + 0.8$; $(J110 - H160) < 1.2$

Color-Color Plot



Color selection Completeness/Contamination



Selection completeness fraction (left) represents the fraction of objects of a given magnitude and break color that are recovered in the selection window. The contamination fraction (right) accounts for the fraction of objects with a lower break (z - J <0.8) that are photometrically scattered in the color-color diagram so that their observed magnitude and color would allow them to enter the selection window

Spurious Detections

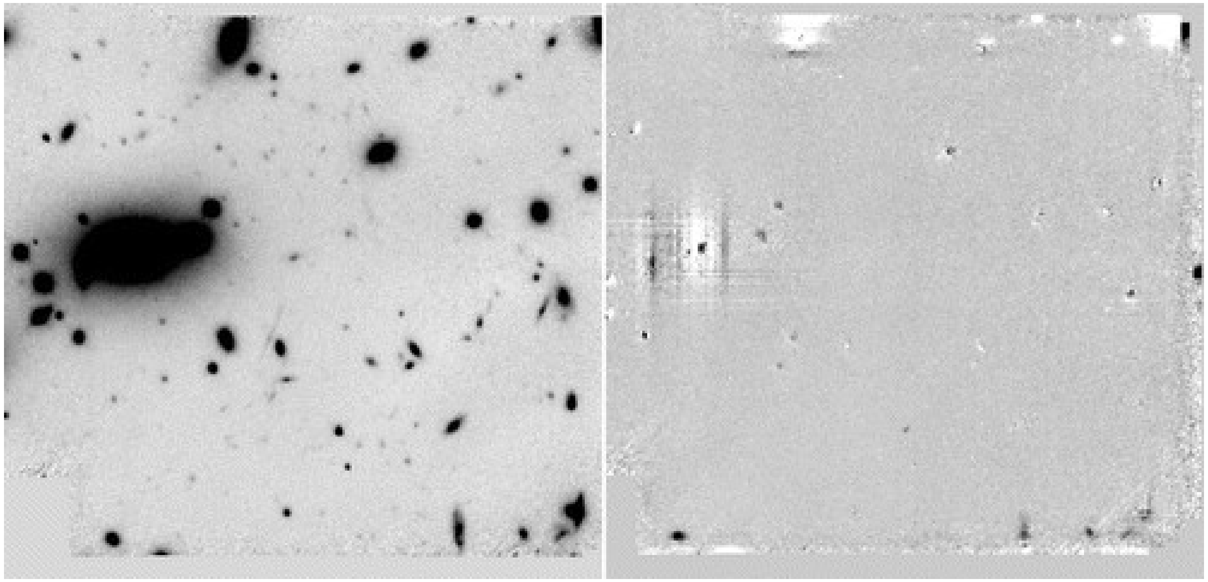
Candidates rejected if close to BCG or other light contaminations

Hot and dead pixels can cause spurious sources

NICMOS image of the cluster CL 1358 (*left*) compared with a noise image (*right*) in order to estimate the fraction of spurious sources in sample

Noise properties similar except for edges and where BCG removal

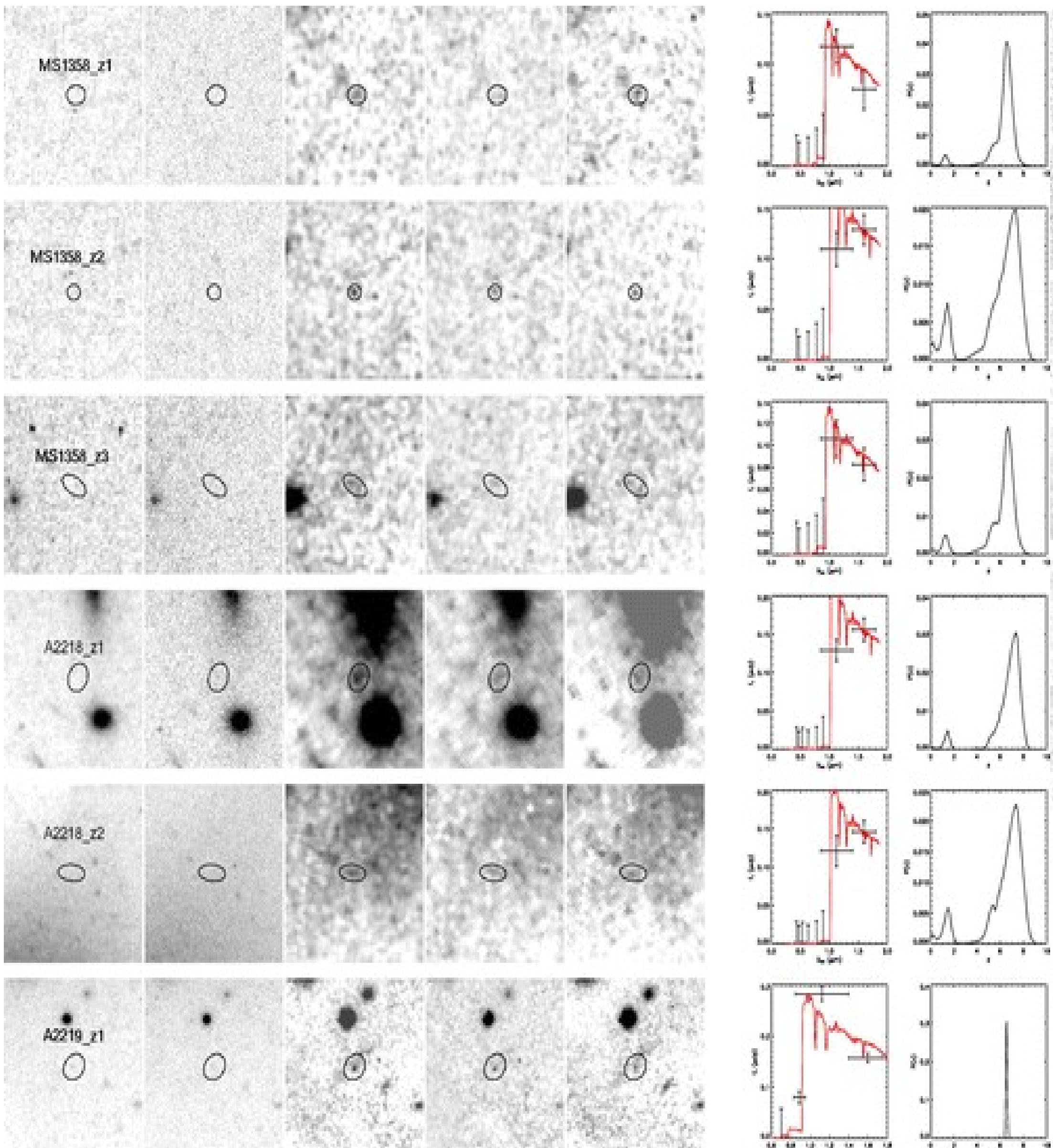
90% of candidates false astronomical detections

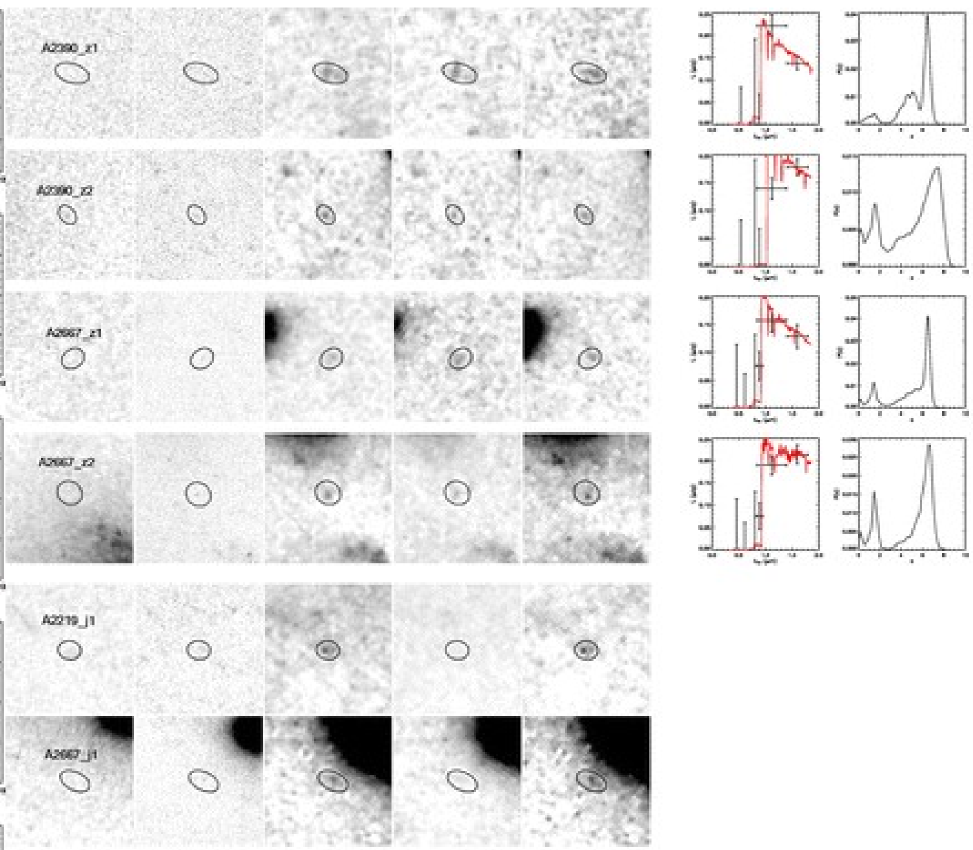


Images of Candidate Dropouts

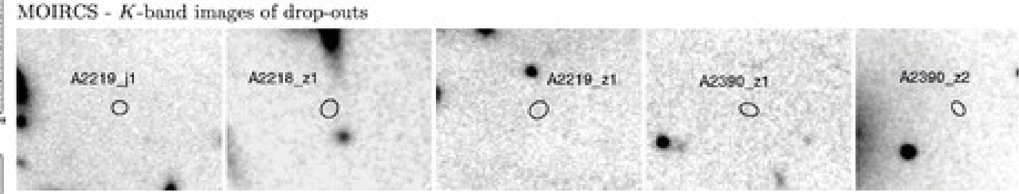
-10 z-band dropouts

-2 J-band dropouts





MOIRCS - K-band images of drop-outs

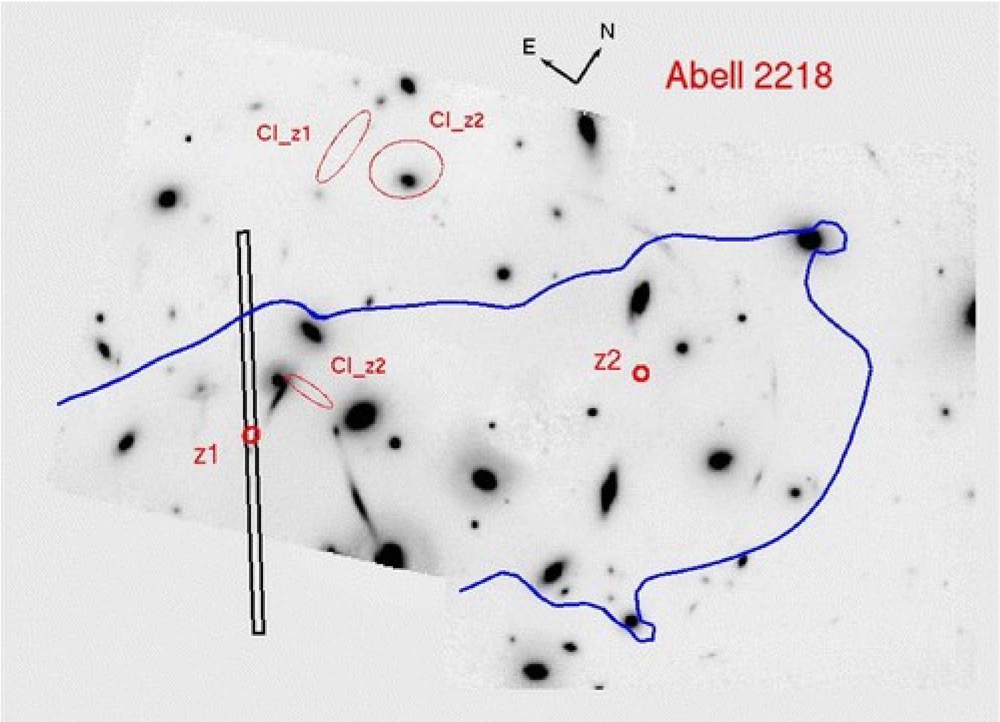


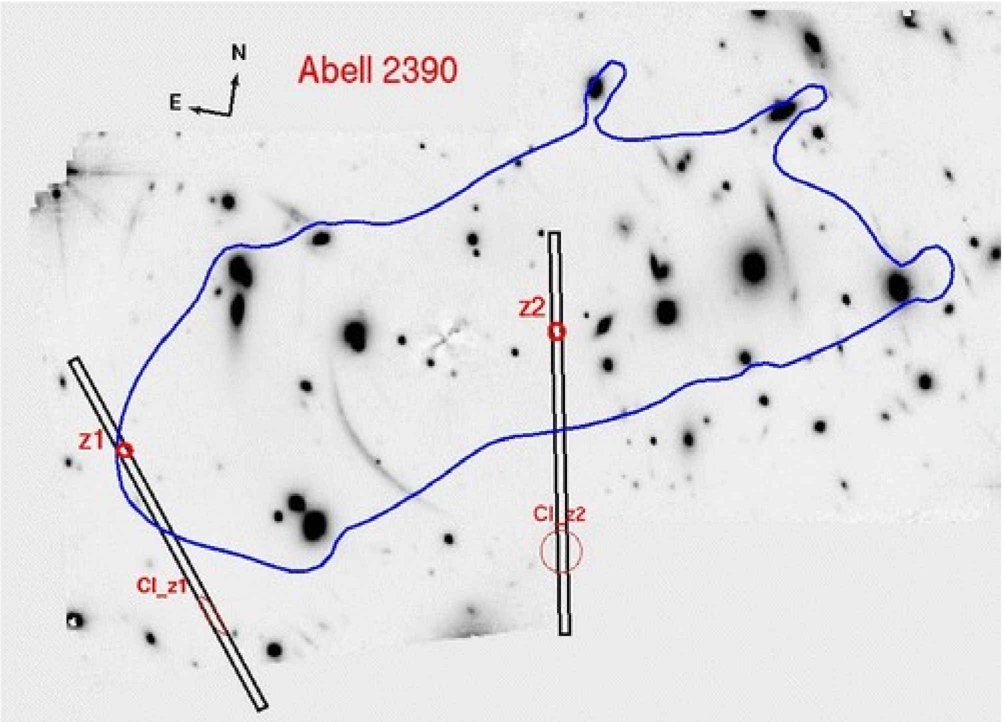
Multiple Image Search-Inconclusive

Model predicts pair of images with similar fluxes straddling the critical line for 7 of the 10

Most are outside area surveyed by NICMOS or at edge of detector

Only two cases too look for counterimage and neither were detected





Success Rate

Out of 10 sources

- -1 is spurious
- One is galactic star
- 35% contamination from z=2 sources

Expect 5 out of 10 to be z >6.8 star-forming galaxies

All candidates treated equally in these statistics

Candidates-A2219-z1 and A2390-z1, are resolved and satisfy the more rigorous color cut

However inspections in other bands raise doubts

Spectroscopic Follow-up

Lyα line provides a critical feature for confirming the nature of candidate high-redshift galaxies.

Can be obscured in star-forming galaxies

No signal was detected for any of the candidates

Does not provide evidence that candidates are not at high redshifts

Absence of emission from 7 sources

Implications on the IGM evolution at $z>6$

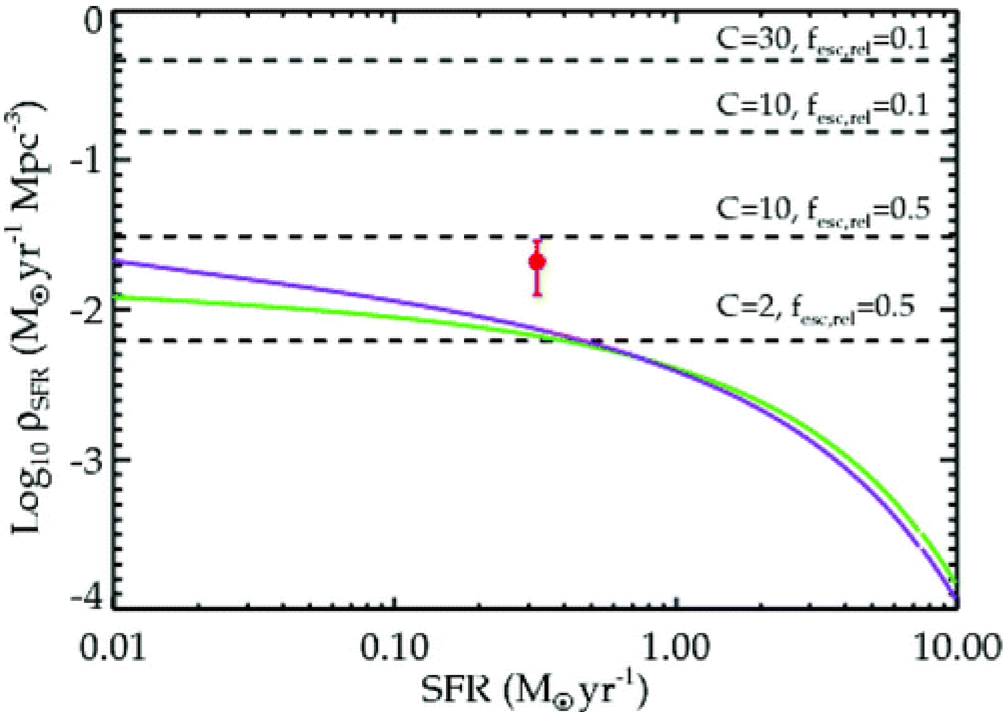
Reionization Contribution

Compare the comoving number density of sources necessary to keep the IGM reionized with amount derived from candidate high redshift low luminosity galaxies

Photon budget from star-formation to reionize IGM:

$$\dot{\rho}_{\rm SFR} \simeq \left(0.031\, M_{\odot}\ {\rm yr}^{-1}\ {\rm Mpc}^{-3}\right)\left(\frac{f_{\rm esc,rel}}{0.5}\right)^{-1}\left(\frac{C}{10}\right)\left(\frac{1+z}{8.5}\right)^{3}, \quad (1)$$

Cumulative comoving density of star formation rate at derived for the two extreme luminosity functions from Bouwens with faint end slopes of (*purple*) or (*green*). The constraints from the present survey are shown as a red circle, for the average and range of densities resulting when randomly selecting five candidates from our sample . The density necessary to keep the IGM reionized at , for a range of clumping factors *C* and escape fraction , is shown as the dashed lines



Summary/Conclusions

Identified 12 high-redshift candidates (10 *z*-band dropouts and two *J*-band dropouts)

Tests suggest that around five of our 10 *z* dropouts are possible high-redshift objects.

Found a UV spectral slope similar to that of higher luminosity candidates from the UDF. Such a slope suggests a very young stellar population with little reddening.

Searched for possible counterimages for candidates based on the most recent lensing models for each cluster. Results are inconclusive.

undertook follow-up spectroscopy for 7 *z*-band dropout candidates in the hope of seeing confirmatory Lyα emission. No emission was found in any candidate. One explanation is possible evolution in the Lyα rest-frame equivalent width distribution, such as might be expected if the neutral fraction rises with redshift.

If a modest fraction of sources are at high redshift, the results strengthen the suggestion that sources with star formation rates ~0.1-1.0 M yr^{-1} contribute significantly to cosmic reionization.