2nd production of public catalogs

multiwavelength catalogs of the Frontier Fields

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ASTRODEEP

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ABSTRACT

In this document we present the analysis of the data foreseen by the plan and the relevant catalogs (including rest frame quantities). The catalogs will be made available on the ASTRODEEP website and at CDS. This release is part of the first generation of ASTRODEEP processed data.
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Multiwavelength catalog of the Frontier Fields

We describe here the procedures and the early results obtained in our effort to extract high quality catalogs of the first two complete Frontier Fields, Abell 2744 and MACS 0416. This project builds on the experience gathered with the analysis of the CANDELS fields but faces new challenges in the dense FF cluster fields. Its goals are:

a) To extend the detection of even the faintest galaxies down into to the very central regions of the clusters, in order to exploit the full power of lensing magnification, beating as much as possible the contamination from cluster members;
b) To obtain multiwavelength photometric catalogs in all available bands from UV to NIR, i.e. adding available groundbased and Spitzer data to the ACS and WFC3 images.

The conceptual and technical challenges are substantial to extract maximal information from the ultra-deep images obtained in the field of a dense field dominated by bright, extended sources of the lensing cluster.
To this end we have performed a careful subtraction of bright cluster members, including also an estimate of the Intra Cluster Light (ICL) contribution that we describe in some detail. This has allowed us to identify and properly measure faint galaxies in the core of the cluster. We then performed a properly optimized detection and photometry using a combination of public codes (SExtractor and T-PHOT, the latter developed within our ASTRODEEP project). The final catalogs include photometry in all available bands, photometric redshifts, stellar masses and other intrinsic parameters derived from the photometry. All catalogs will be made publicly available. Our analysis confirms that the FF initiative can effectively lead to the detection of high redshift galaxies with intrinsic magnitudes fainter than H~32, anticipating some of the scientific results expected from JWST.

The subtraction of ICL and bright cluster galaxies:

Bright cluster galaxies and the ICL have been removed by performing a fit with GALFIT (Peng et al. 2002) and GALAPAGOS (Barden et al. 2009). Each component has been described with a suitable set of functions: Ferrer profiles for the ICL, multiple Sérsic profiles for bright galaxies. The goal is not to make a morphological analysis of the cluster members, but to model and eventually remove the halo of bright galaxies and the smooth, large-scale component of the ICL. The residual images have been median-filtered to remove the remaining residuals. At the end of this procedure, faint galaxies observed through the halo of bright clusters member are clearly identified. Only the central cores of bright galaxies remain inaccessible.

Optical and NIR HST images:

The complete procedure applied to the HST images can be summarized in 4 steps:

1. In Step 1 we use the HST F160W (H) band to produce a first model for the ICL, as illustrated in Fig. 1. After masking-out all the objects in the field above a given threshold we use GALFIT to model the ICL emission of the Cluster with one or two modified Ferrer profiles which follow the overall shape of the emission with the help of a few bending modes.

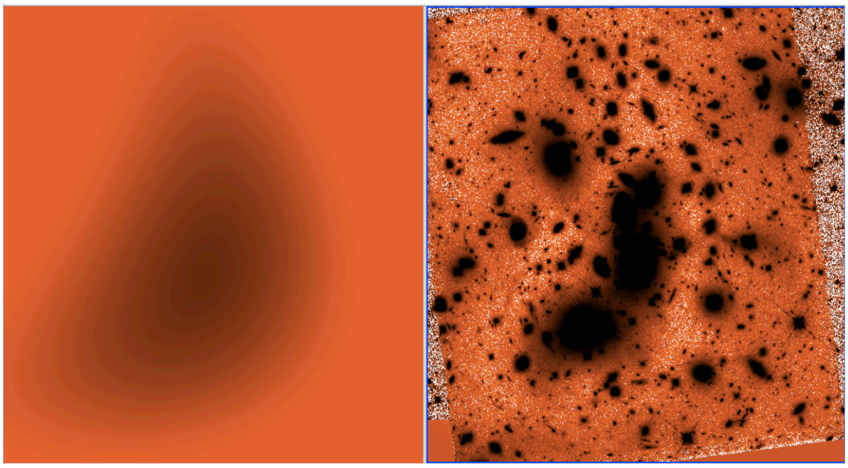

Fig. 1: Fit the ICL with Ferrer profiles using "masked" image.

2. In Step 2 we use the ICL subtracted image of the cluster in the H band to fit the bright cluster galaxies using GALAPAGOS (Fig. 2).

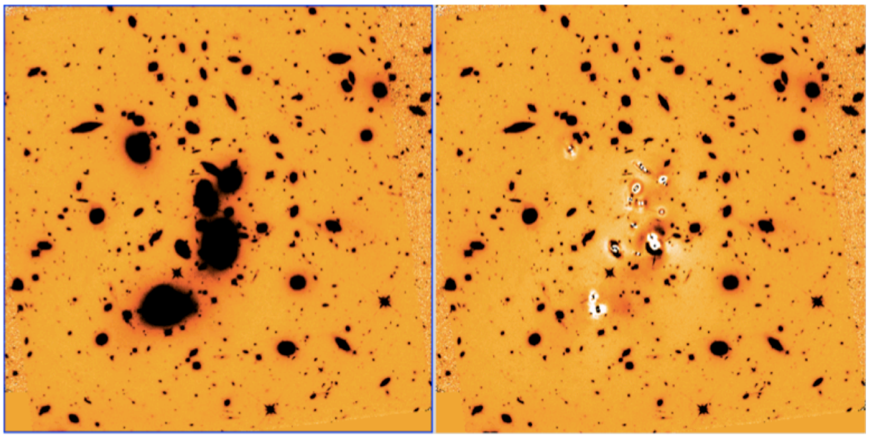

Fig.2: Fit of cluster bright galaxies with Galapagos on the ICL subtracted image.

3. In Step 3 we use GALFIT to fit both bright galaxies and ICL iteratively. This procedure produces the final models and residuals (Fig. 3).

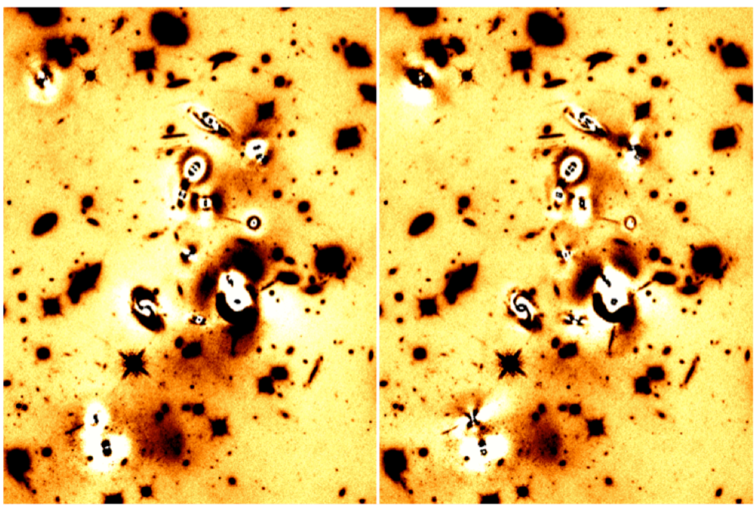

Fig.3: Iterative fit of ICL+ galaxies with GALFIT.

4. In Step 4 the residual image from Step 3 i.e. an image of the field without the light of the bright galaxies and the ICL, has been median filtered to remove the remaining residuals from the GALFIT fitting (Fig. 4).

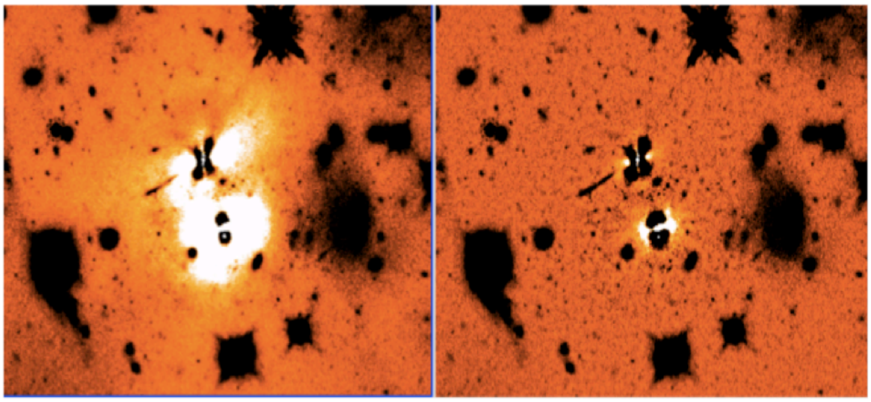

Fig.4: Median Filter on residuals.

The above procedure leaves us the processed image of the cluster, which is used as a detection image. Thus, all galaxies in the field have been detected in the F160W (H) band, after removing the ICL and bright cluster members as described above. As shown in Fig. 5, the detection on these "subtracted" images can reveal many faint galaxies that are otherwise hidden in the bright halos of cluster members. The number of galaxies detected this way is much larger than using even an optimized detection on the original images. Between H=24 and H=28 we increase the number of detected sources (over the whole WFC3 field) by nearly a factor of two.

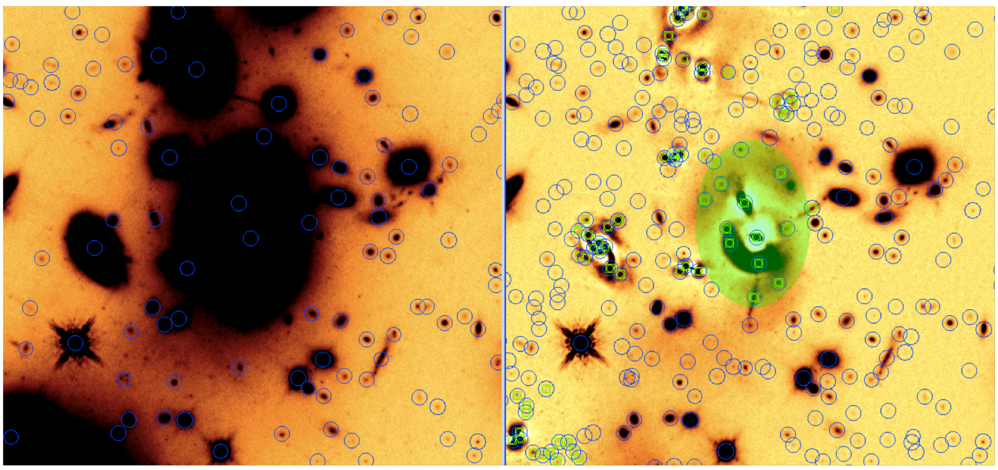

Fig.5: Left: Blue circles show the objects detected in the original image with an optimized SExtractor run**. Right:** objects detected on the same image after removal of the fitted ICL and bright galaxies. Green points represent objects that are too close to the core of bright galaxies to be reliable: they are removed from the final catalog. As an example, the green area highlights the central region of a bright galaxy where the detection is affected by residual features and hence removed from the final catalog**.**

The other HST bands

To remove foreground galaxies we have adopted the same procedure used for the H band in an iterative fashion. Starting from the J_{125} band, we have used the best-fit solution of the image immediately redder as a starting guess for the fit, and let the ICL and bright galaxies free to vary. The fit converged well in all bands from J_{125} to B_{435}. The net computing time of the whole process is of the order of 4 days for each cluster field. Two examples are shown in Fig. 6, where in each band the original images are on the left, and the processed ones are on the right.

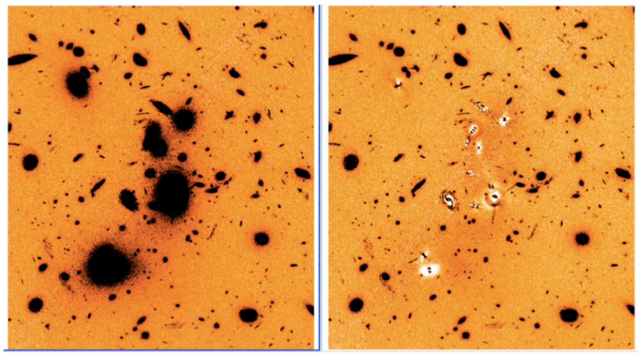

Fig.6a: Original image on the left and processed image on the right panel in F606W.

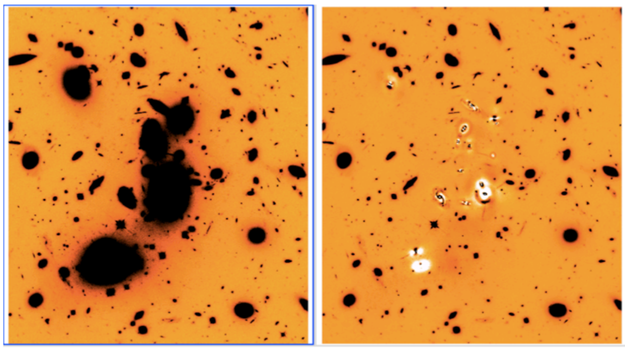

Fig. 6b: Original image on the left and processed image on the right panel in F105W.

K band and Spitzer IRAC images

Including the K and especially the IRAC 3.6 and 4.5μm images is an even tougher challenge, because of the poorer image quality and increasingly large ICL contribution. To properly derive a robust photometry in these cases we adopt a prior-based approach. Briefly, the position and shape of the objects detected in the H band (including the ICL) are used as priors to fit the flux in the K and IRAC bands. This is accomplished using a newly developed tool, named T-PHOT that is one of the first products of ASTRODEEP (Merlin et al 2015).

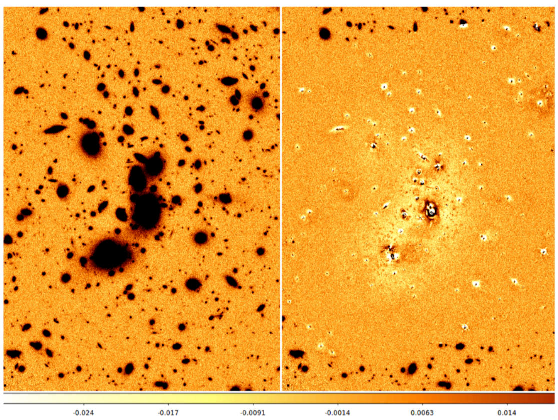

Fig. 7a: *Left:* Deep K-band image from HawkI@VLT (Brammer et al.). **Right:** residual image after fitting all H-detected sources with the TPHOT code.

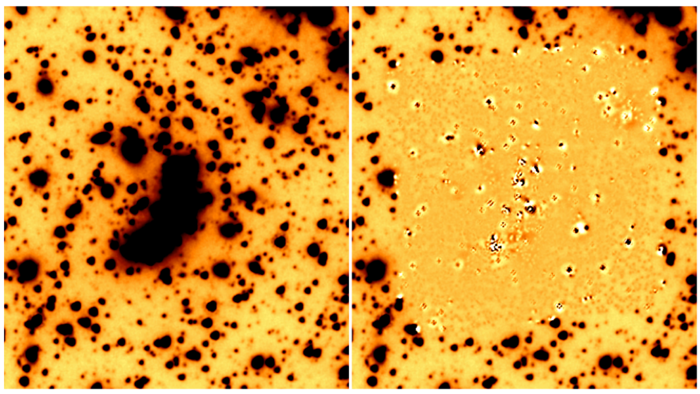

Fig. 7b: *Left:* IRAC 4.5μm image from Spitzer (Capak et al.). ***Right***: residual image after fitting of all H-detected sources with the TPHOT code.

Extraction of sources and catalogs

The catalogue is extracted using an HOT+COLD approach, where the "COLD" mode corresponds to the standard CANDELS-HOT parameters set, and the "HOT" mode parameter choice is a modification of the standard CANDELS-HOT with a more aggressive choice for background subtraction (we define it "HOTTER" mode selection).

First results

In the halo of bright galaxies: Faint galaxies detected in the haloes of bright ones are real and can be measured with good reliability at all wavelengths. In Fig.8 is shown an example of faint (H=24.8) Lyman-break galaxy with a photometric redshift z~4, as seen from the fit in Fig.9, sitting nearby a bright cluster member. It is magnified by a factor ~2.5 by the cluster potential.

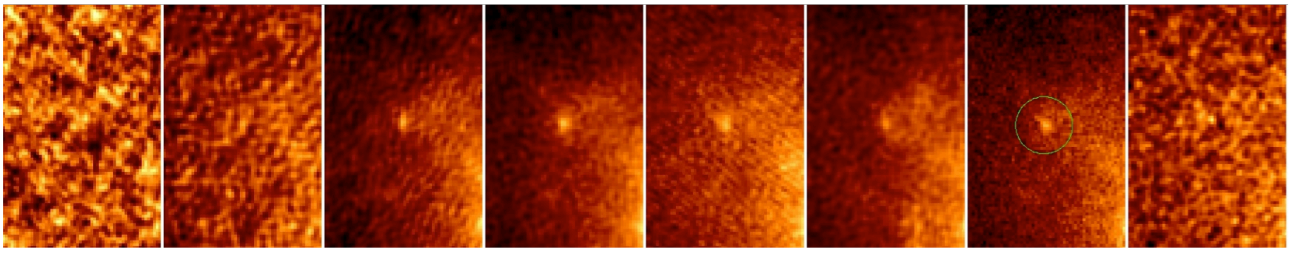

Fig.8: Detection of a very faint galaxy with photometric redshift z~4, laying in the halo of a bright one.

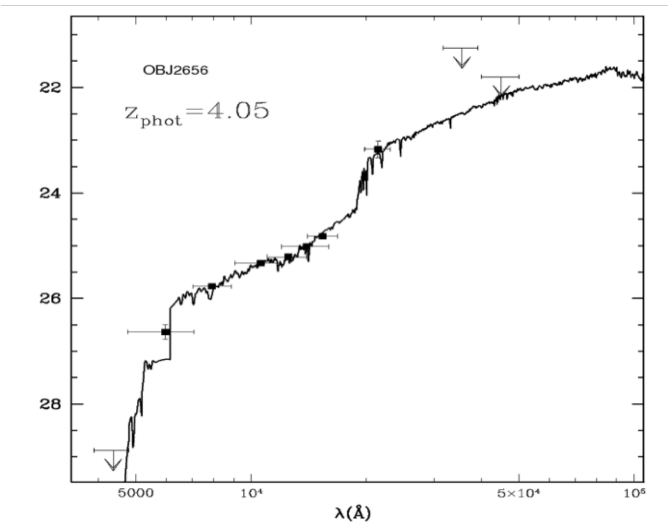

Fig.9: Photometric redshift measurement for the galaxy in Fig.8.

Photometric redshifts: We have computed photometric redshifts (e.g. Fontana et al. 2006) using the 7 HST bands and including also the K and IRAC bands. Our photometric redshifts are in excellent agreement with a small number of spectroscopic redshifts (Treu et al., priv. comm.) available in the Abell2744 field (σΔz/(1+z)~0.05), as can be seen in Fig. 10.

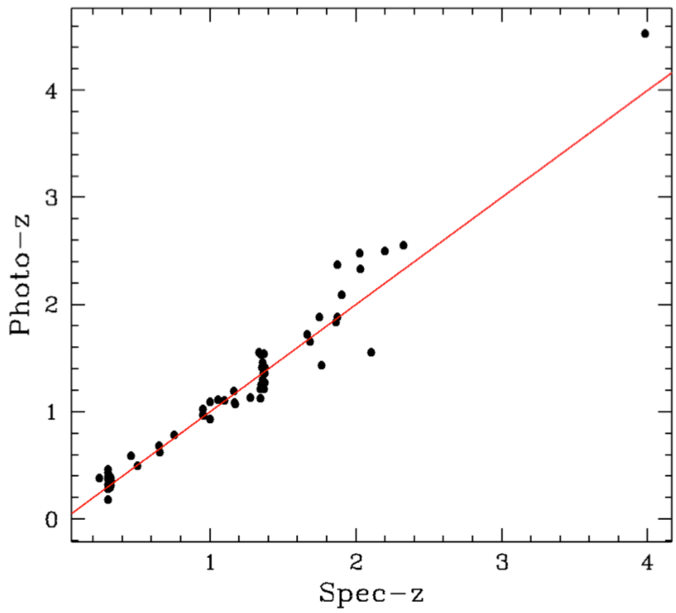

Fig.10: Photometric redshift estimates vs. spectroscopic redshift measurements. The above distribution shows that they are in excellent agreement.

Number counts: Number counts are an instructive way of looking at the quality of data. As shown in Fig.11 they reveal that:

i. Number counts in the FF parallel fields (blue and green lines) agree well with the CANDELS field data (red lines);
ii. Counts in the clusters (black line for Abell2744) show: 1) the expected "bump" at bright fluxes due to cluster members, and 2) a drop at the same limit (H~29) of the field counts, suggesting the completeness is comparable;
iii. After correcting for magnification (purple line for Abel 2744) the number counts reveal that the FF data can indeed detect galaxies as faint as H>32, realizing the original goal of the initiative.

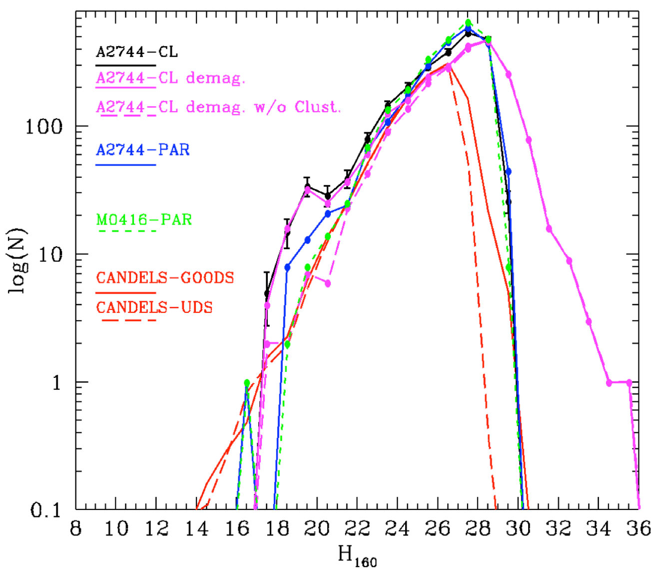

Fig.11: Number counts in the FF parallel fields.

TPHOT (Merlin et al. 2015, submitted)

TPHOT is an evolution of the TFIT code developed at STScI and used for the public CANDELS catalogs (Galametz et al. 201X, Guo et al.), and of the CONVPHOT code used for the GOODS-MUSIC catalog (Grazian et al. 2006).

With respect to these codes TPHOT has the following features:

- Built using a Python envelop and C/C++ cores, can handle large datasets with smart memory allocation
- Fast: ca. 30 mins. on a "standard" CANDELS field with TFIT parameters, and on WFC3 FF pointing with optimal parameters setting
- Versatile: includes all different choices and methods already present in TFIT and CONVPHOT concerning smoothing (pixel summation or FFT), fitting (cells vs. single fit, three methods for matrix solving, threshold, clipping of negative sources), dance stage for kernel registration
- Includes a cells-on-objects method, which combines the computational efficiency of TFIT cells approach and the robustness of CONVPHOT single fit method
- Can operate with three different types of priors: real 2-d cutouts from HRI, analytical models, or unresolved point-like sources