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PREPARING JWST OBSERVATIONS AT THE FRONTIERS OF THE UNIVERSE

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Abstract. Pushing even further the limits of the observable Universe is one of the most exciting challenge of modern astronomy. During the last decade, several space and ground-based telescopes have been involved in this quest leading to the discovery of hundred of objects at z>6. Therefore, the physical properties of the galaxies emitting light during the first billion years of the Universe are better constrained and we are just starting to understand their role during the reionization process. In the following, we discuss how the last flagship program of the *Hubble* Space Telescope, namely the *Frontier Fields*, is preparing the first JWST observations at the frontiers of the Universe and how the exceptional capabilities of this future space telescope will benefit to the study of the early Universe.

Keywords: Galaxies: distances and redshifts, Galaxies: evolution, Galaxies: formation, Galaxies: high-redshift, Galaxies: photometry, Galaxies: star formation

1 Introduction

One of the main questions of modern astronomy is undoubtedly the study of the earliest stages of the Universe, and more particularly the study of the first luminous objects. Within the last ten years, considerable advances have been made to push ever further the limits of the observable Universe. To date the most distant object confirmed by spectroscopic observations has emitted light around 600 million years after the Big-Bang (Zitrin et al. 2015), and it is $\sim$ 60 times less massive than the Milky Way. However, only a dozen secured objects are currently known at such early epoch, making the conclusions on their properties, environment or evolution during cosmic times difficult. The arrival of large surveys aiming to study the most distant objects, such as the *Hubble Ultra Deep Field* or the on-going *Frontier Fields*, has strongly increased the number of very high-redshift candidates (e.g. Ellis et al. 2013, Bouwens et al. 2015). Moreover, the arrival of the future *James Webb Space Telescope* (JWST - Gardner et al. 2009) by the end of 2018, will open a new cosmic time window allowing to study in details the properties of the primeval galaxies.

2 The HST Frontier Fields

In October 2013, the *Hubble* Space Telescope started observations of six massive galaxies clusters as part of its new flagship program, "The Frontier Fields", aiming to obtain the deepest data using strong gravitational lensing. The data are reduced by the *Space Telescope Science Institute* and released few days after observations. The *Spitzer* Space Telescope is also involved in this project allowing to increase the wavelength coverage with extremely deep data up to $\sim$5μm. Several teams have also provided lens models and amplification maps for all clusters (Bradač et al. 2009, Richard et al. 2014, Merten et al. 2011, Zitrin et al. 2013, Johnson et al. 2014 and Mohammed et al. 2014). To date, four clusters have been already observed by *Hubble* : Abell 2744, MACSJ0416.1-2403, MACSJ0717.5+3745 and MACS1149.5+2223 reaching a depth of 29.0 AB at 5σ.

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2.1 *Search for z>6.5 objects*

The most popular method used to identify very high-z sources on a photometric dataset is the Lyman Break technique (Steidel et al. 1996) combining color selection with strong non-detection criteria in bands bluewards of the break. Our team applied this method for the three first Frontier Fields clusters, namely Abell 2744 (Laporte et al. 2014), MACSJ0416.1-2403 (Laporte et al. 2015b, Infante et al. 2015) and MACSJ0717+3745 (Laporte et al. in prep) and selected ∼100 objects at z>6.5. Recently, several studies (e.g. Smit et al. 2014) have shown that z∼8 objects display two breaks in magnitude in their Spectral Energy Distribution (SED) : one around the Lyman-α emission, called Lyman break, and another one around 4μm, the 4000Å break. Among all the z∼8 objects selected on FF images, 3 display such a break between HST and *Spitzer* data (Figure 1) confirming the high-z hypothesis for these sources. All the z>8 galaxies spectroscopically confirmed so far display these two breaks (Finkelstein et al. 2013, Oesch et al. 2015, Zitrin et al. 2015). Therefore, the detection of both the Lyman-α and 4000AA breaks strongly reduce the probability for these objects to be low-z interlopers.

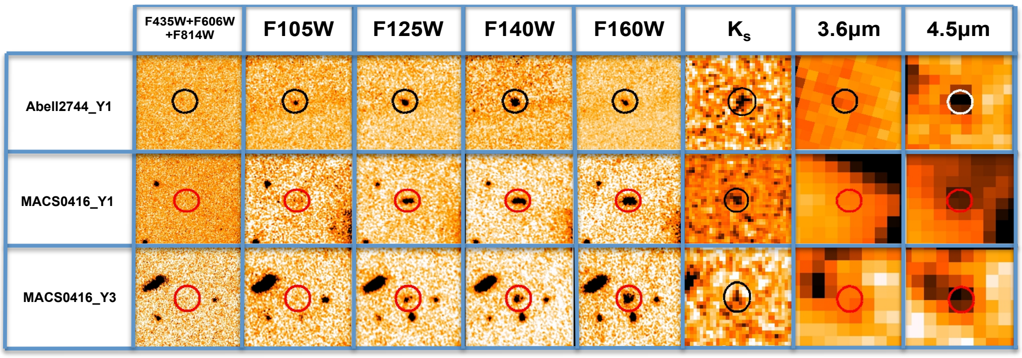

Fig. 1. z∼8 candidates displaying a break around 4μm that could be associated to the 4000Å break at high-redshift (from Laporte et al. 2014, Laporte et al. 2015b).

2.2 *Properties of the z>6.5 candidates*

We adopted a SED-fitting approach to estimate the photometric properties of sources in our sample, such as the redshift, Star Formation Rate (SFR), dust content or stellar mass, using "new Hyperz"* (Bolzonella et al. 2000). We also took benefit from the high quality of HST data to measure their size following the method described in Oesch et al. (2010), and then to study the evolution of their size as a function of the UV luminosity (Figure 2.a). The huge number of z>6.5 candidates selected in the 3 first *Frontier Fields* allows to give robust constraints on the evolution of their physical parameters, and on the evolution of the luminosity distribution of objects as well. We computed the UV Luminosity Function in the redshift range covered by the FF survey using a method taking into account the uncertainties on photometric redshift (see details in Laporte et al. 2015a). Thanks to the depth of this new survey, we are able to probe the faint end of this function up to very high redshift (z∼10 - Figure 2.b - Infante et al. 2015).

3 The need for a JWST Frontier Fields

The HST *Frontier Fields* will strongly increase the number of objects with redshift ranging from 7 to 9, and thus will provide robust constraints on the properties and evolution of objects up to ≈ 0.5 billion years after the Big-Bang. However according to the current paradigm, the first galaxies were formed at higher redshift and are expected to be extremely faint, i.e. well below the limit of current telescopes (Lacey et al. 2011). Therefore the future *James Webb Space Telescope*, thanks to its 6.5m diameter mirror, will play a crucial role in the study of the early Universe by opening a new cosmic time window. Moreover, the NIRCam instrument (Rieke et al. 2003) will provide high data quality over a continuous wavelength range from 0.6 to 5μm enabling to detect Lyman-α and 4000Å breaks, as described in the previous section, up to z ∼12 (Figure 3), and therefore to identify robust primeval galaxies.

*latest version available at : www.ast.obs-mip.fr/users/roser/newhyperz/

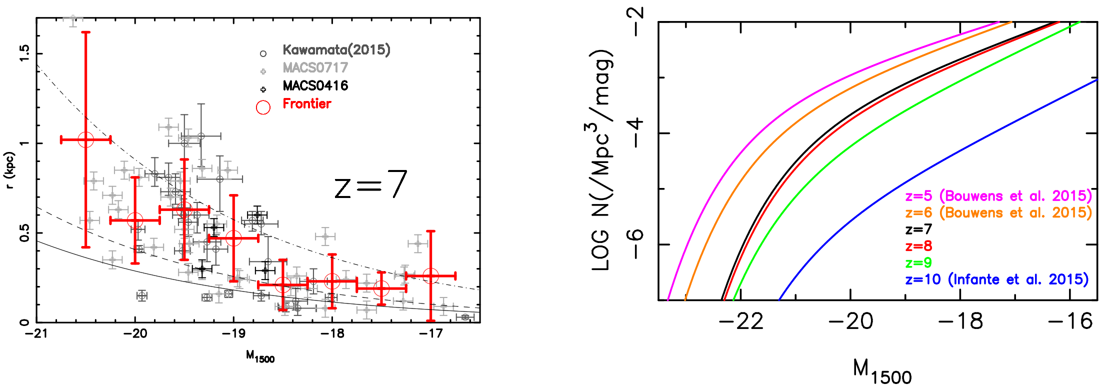

Fig. 2. Left : (a) Evolution of the half-light radius as a function of the UV luminosity for all $z \sim 7$ objects selected on the 3 first *Frontier Fields* dataset (see Laporte et al. in prep for more details). **Right** : (b) Evolution of the UV Luminosity Function estimated from *Frontier Fields* samples.

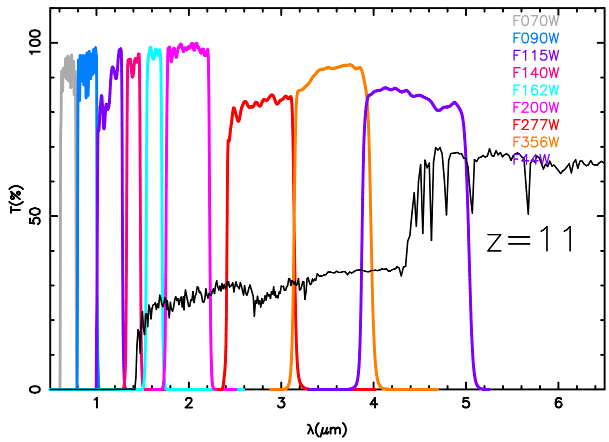

Fig. 3. Filters transmissions of the future JWST NIRCam instrument covering a continuous wavelength range from 0.6 to 5μm. SED of a starburst at $z \sim 11$ is overplotted showing the capabilities of the JWST to detect Lyman-α and 4000Å breaks at such high redshift.

We estimated the number of Lyman Break Galaxies expected in the full *Frontier Fields* survey by integrating the UV Luminosity Function evolution equations published in Bouwens et al. (2015) over the comoving volume explored assuming the mass models provided by the CATS team (Richard et al. 2014). About 200 objects at $z > 7.5$ are expected in the $\sim$35 arcmin^2 covered by these 1000h *Hubble* survey. Assuming the same amount of observing time, the depth that will be reached by NIRCam images will be 30.5 AB at 5σ, and the expected number of $z > 7.5$ objects expected in a FF like survey will be about 5 times more than what is expected in the HST FF (Table 3). More particularly, at the highest redshift, only $\sim$10 galaxies at $z > 10.5$ are expected in the HST survey, whereas >100 would be detected in a JWST *Frontier Fields* survey, allowing to study properties of objects emitting light ≈350 million years after the Big-Bang.

4 Conclusions

The HST *Frontier Fields* survey has already demonstrated its huge capabilities by identifying >100 objects at $z > 6.5$, with several at $z \sim 10$ (Zitrin et al. 2014, Infante et al. 2015). The use of gravitational lensing, that

Redshift range	N_{obj} *HST FF*	N_{obj} *JWST FF*
$7.5 < z < 8.5$	98^{+150}_{-36}	505^{+929}_{-216}
$8.5 < z < 9.5$	46^{+105}_{-20}	273^{+772}_{-139}
$9.5 < z < 10.5$	21^{+72}_{-11}	148^{+623}_{-86}
$10.5 < z < 11.5$	10^{+47}_{-6}	81^{+495}_{-53}
$11.5 < z < 12.5$	1 ± 1	44^{+392}_{-30}

Table 1. Comparison between the expected number of LBGs in the HST *Frontier Fields* survey (left) and in a similar observing time survey using JWST (right) assuming the UV Luminosity Function evolution published in Bouwens et al. (2015).

amplified light coming from background sources, allows to put the first constraints on the faint-end of the UV Luminosity Function at very high-redshift, and thus to better constrain the role played by the first galaxies during the Epoch of Reionization. However, the number of >10 sources highlighted is not sufficient to study in details properties of primeval galaxies that are expected to be extremely faint, i.e. well below the limit of current telescopes. The arrival of the *James Webb Space Telescope* by the end of 2018 will open a new luminosity window and thus will be able to detect >100 galaxies at z>10.5 in a *Frontier Fields* like survey.

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