Identification of low luminosity high redshift galaxies using galaxy clusters as cosmic telescopes

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Current models of structure formation suggest that the first galaxies formed at $z > 10$ when the universe was < 500 Myr old. The detection and characterization of galaxies at these early epochs is therefore critical to estimate the star formation rate density and their contribution to the reionization. The CLASH project (Cluster Lensing And Supernova survey with Hubble) combines an HST Treasury program to obtain panchromatic (ACS + WFC3) imaging of 25 carefully selected massive clusters, with other multi-wavelength observations, including a large spectroscopic campaign with VLT/VIMOS. Gravitational lensing, which is particularly powerful in several CLASH clusters, boost the efficiency of finding low-luminosity (i.e. L < L*) galaxies, which are thought to play a critical role in reionizing the Universe beyond $z \sim 10$. In this letter, we will give some highlights of the construction of a sample of ~ 200 magnified lensed galaxies at $2 < z < 7$, collected as part of the CLASH-VLT project, whose spectro-photometric data can be used to characterize the physical properties of the low-luminosity galaxy population at high-z.

Keywords: High-z galaxies; cluster galaxies; magnification map; gravitational lensing.

1. Building an array of cosmic telescopes

The epoch of reionization marks a major phase transition of the Universe, during which the intergalactic space became transparent to UV photons. Determining when this occurred, the physical processes involved and the sources of ionizing radiation represents one of the major goals in observational cosmology. The production of ionizing radiation is most probably driven by star formation and/or nuclear activity, but their global contribution to the ionizing background is still matter of debate.[1] Irrespective of the nature of ionizing radiation, the general consensus is that the faint sources dominate the ionizing background.[2,3] This implicitly assumes that ionizing photons are not trapped in faint sources and can escape. It is therefore important to push studies into low luminosity regimes (L < 0.1L*, which corresponds to $m_{1500} > 27.1$ at $z = 3$).

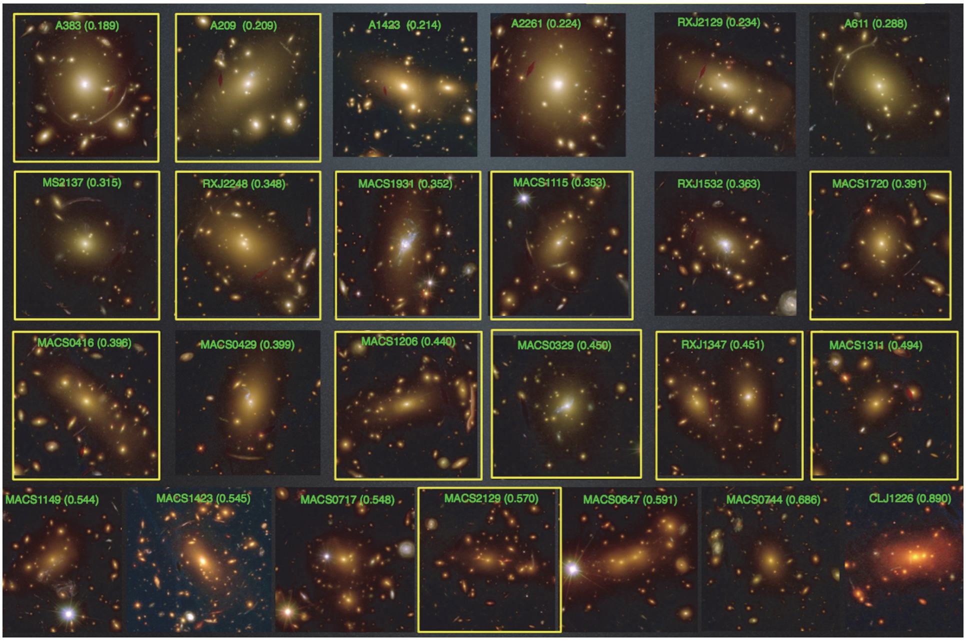

Fig. 1. HST gallery of 25 clusters from the CLASH survey (boxes indicate the 13 included in the CLASH-VLT survey).

Searching for low luminosities high redshift galaxies, thus complementing blank field studies, is a primary goal of surveys carried out through lensing clusters. Several spectroscopically confirmed high-z galaxies have recently been identified in deep field searches, e.g. Refs. 8, 9, 10, 11, 12 and 13. Gravitational lensing offer a unique opportunity to push these studies to significantly fainter luminosities, before the the advent of JWST and giant ground-based telescopes in the next decade.

Our collaboration has recently produced high precision lensing models of CLASH clusters, thanks to the redshift measurement of many multiply lensed systems from the CLASH-VLT spectroscopic campaign,[4] which are critical for strong lensing mass reconstruction techniques. This effort has complemented photometric redshift information readily available from the multi-band HST survey (524 HST orbits of Hubble with more 1000 hours observations of 25 clusters in 16 filters from the CLASH program).[5] CLASH-VLT has used the VIMOS wide-field spectrograph to obtain $\sim$ 30,000 redshifts in 12 CLASH Clusters at $z = 0.2 - 0.6$ in the south, with the spectroscopic identification of 500 - 1000 members per cluster. For example, in the case of MACS $J0416.1 - 2403$, we identified $\sim$ 800 clusters members[6] and 30 multiple images with redshifts between 1.6 and 3.2.[7] With these velocity data, we can measure the total mass density profile from the dynamical analysis with unprecedented accuracy (using the Jean equation) and compare it with the mass profiles derived from weak and strong lensing analyses, as well as X-ray hydrostatic masses from Chandra data.

2. Exploiting magnification to probe fainter fluxes

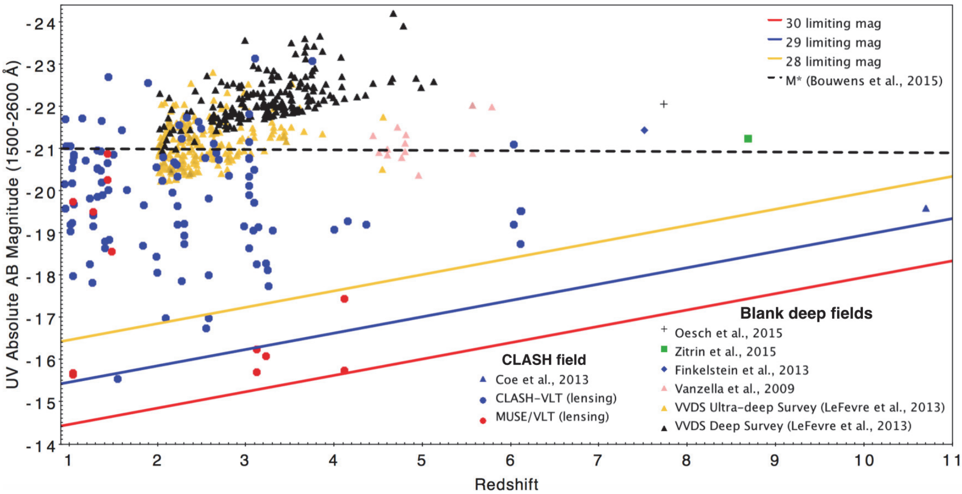

Fig. 2. Distribution of rest-frame UV absolute magnitudes and redshifts for samples of galaxies drawn from blank deep fields and lensed field surveys (CLASH-VLT).

Over the last decade, several groups have used galaxy clusters as cosmic lenses to investigate properties of distant sources,[15] most of them are galaxies,[14,16,17] in some rare cases quasars or more recently even transient objects, including a multiply imaged, highly magnified supernova, named *Refsdal*, lensed by MACS $J1149.6+2223$

cluster.[18] The accuracy with which the reappearance of the time-delayed image of *Refsdal* has been predicted by some strong lensing models,[19] involving positions, flux magnifications and time delays, underscores the high-level of precision that lensing models have reached when supported by abundant spectroscopic information.

As a result of our lensing models, accurate magnification maps (e.g. Refs. 20, 21) can be used to derived intrinsic (unlensed) properties of lensed galaxies as faint as ($M \sim -15$), i.e. ~ 5 mag fainter than M^* at high redshifts[22](see Fig. 2). By fitting stellar population synthesis models to the spectral energy distribution of these galaxies and using their spectra, we can derive in such unexplored luminosity regime: stellar masses, star formation rates, gas/dust content, and physical parameters of their interstellar medium (e.g. Ref. 23). These new datasets will help us to make significant progress in our understanding of galaxy formation at early times.

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