PROPERTIES OF HIGH-Z GALAXIES SEEN THROUGH LENSING CLUSTERS

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Abstract. We present new results obtained on the identification and study of high-z galaxies seen through lensing clusters used as gravitational telescopes. The amplification effect provides a tool to study the spectrophotometric and morphological properties of such galaxies 1 to 3 magnitudes deeper with respect to field surveys. Distant sources with $1 \leq z \leq 7$ typically are selected close to the critical lines in clusters where the mass distribution is well known, using photometric redshifts computed on a large wavelength interval, as well as lens-inversion criteria. We focus here on the recent results obtained on AC114 and MS1008-1224, two lensing clusters at $z = 0.31$.

Keywords: High-z galaxies, Gravitational Lensing

1. Clusters of Galaxies as Gravitational Telescopes

The identification and study of extremely high-z galaxies remains an interesting method to constrain models of galaxy formation and evolution. The amplification close to the critical lines in lensing clusters is typically $\Delta m \sim 2$ to 3 mags, and it is still $\sim$ 1 mag in the inner $1'$-$2'$ core of the lens, for typical intermediate redshift lensing clusters, used as Gravitational Telescopes (GTs). Thanks to this amplification effect, clusters of galaxies can be used to construct *independent* and complementary samples of high-z galaxies with respect to field surveys. Such a technique has been applied succesfully to studies in various wavebands, from the optical/UV domains (Ebbels *et al.*, 1998; Pelló *et al.*, 1999) to the Mid-Infrared (Altieri *et al.*, 1999) and Submm (Smail *et al.*, 1998; Blain *et al.*, 1999). Besides, number of $z \gtrsim 4$ lensed galaxies have been found recently, and these results strongly encourage our approach (Trager *et al.*, 1997; Franx *et al.*, 1997; Frye and Broadhurst; Pelló *et al.*, 1999).

Astrophysics and Space Science **277** (Suppl.): 547–550, 2001.

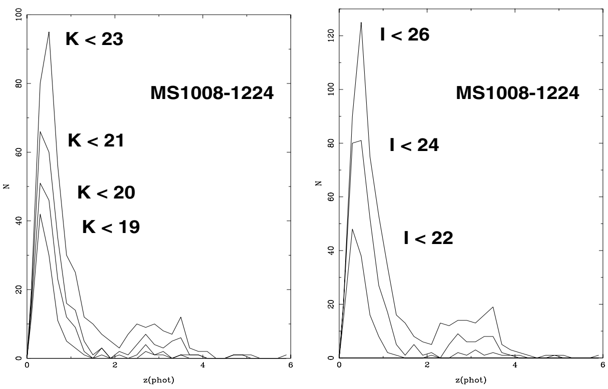

Figure 1. $N(z_{phot})$ distributions of 559 gravitationally amplified sources in the core of MS1008-1224, selected in K' and I bands. z_{phot}s were obtained from BVRIJK' photometry.

Among the main goals of the GTs are to determine the z distribution of the very faint subsample of high-z lensed galaxies, invisible otherwise, and to take benefit from the amplification factor to study the properties of the distant background population of lensed galaxies. The advantage is that this sample is less biased in luminosity than the field. Background sources are selected close to the high-z critical lines, using photometric redshifts (hereafter z_{phot}s) and lensing inversion techniques. The z_{phot} examples presented here were produced with our public code *hyperz*, based on a standard SED fitting, but most results should be completely general when using other z_{phot} tools. *hyperz* is available on the web at http://webast.ast.obs-mip.fr/hyperz (see Bolzonella *et al.*, 2000). The typical uncertainties when applying *hyperz* to the spectroscopic samples available on the HDF are $\delta z/(1+z) \sim 0.1$. The photometric spectral energy distributions (SEDs) are obtained on a large wavelength interval, from B (U when available) to near-IR, in order to reduce the biases towards or against particular objects or redshift intervals (Bolzonella *et al.*, 2000).

2. N(z) Distribution of Arclets: MS1008-1224

We have obtained the (photometric) N(z) distribution of arclets in several well known clusters (A2390, A370, Cl2244-02, AC114, ...). Figure 1 displays the z_{phot} distribution for several K' and I selected samples in MS1008-1224 (Athreya *et al.*, 1999). z_{phot}s were derived from VLT BVRI (FORS) and JK' (ISAAC) public data obtained during the SV phase (see http://www.hq.eso.org/science/ut1sv). The typical number of high-z sources found in the inner $1.2'$ radius region is ~ 70 to 80 at $1 \leq z \leq 7$, for $I \lesssim 24$. Clusters with well constrained mass distributions enable to recover precisely the $N(z_{phot})$ distribution of lensed galaxies, by correcting the relative impact parameter on each redshift bin.

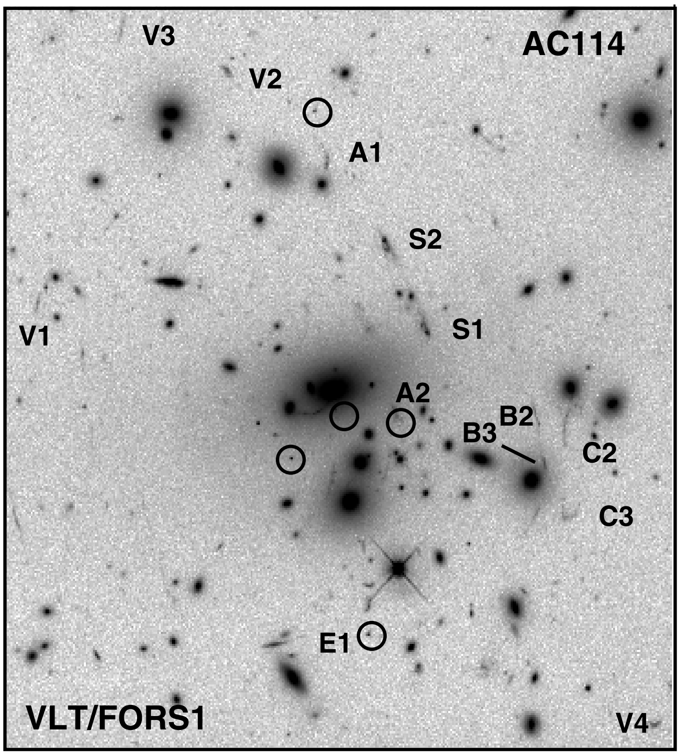

Figure 2. HST/WFPC2 F702W image (R) of the AC114 core, 73"×73", showing the multiple images and amplified sources identified in our VLT/FORS1 spectroscopic survey. Identifications are given according to Natarajan *et al.*(1998) when available. The 5 circles correspond to the 5-image multiple system E, at z=3.347 (Campusano *et al.*, 2000).

3. VLT FORS Spectroscopic Survey of Lensed Sources: AC114

A spectroscopic survey has been carried out by our group on the lensing cluster AC114, using FORS1 at the UT1/VLT (Campusano *et al.*, 2000), with the selection techniques described above. AC114 (z=0.312) is a rich lensing cluster showing many multiple-images at high-z (see Fig. 2). A mass model was obtained by Natarajan *et al.*(1998), based on the redshift of S1/S2 (z=1.87, Smail *et al.*, 1997). 20 background sources were identified spectroscopically on AC114, and 9 of them are located on the cluster core (Table I). We have confirmed the z of S1/S2, and we have determined the z of A, B and C, plus a new multiple image (E) at z=3.347. Absolute M_B magnitudes are mostly $M_B \gtrsim -21$, after correction for amplification, thus substantially fainter than in the present conventional studies. Whatever the z_{phot} method, a crucial test is the comparison between z_{phot} and the spectroscopic z, thus cluster lenses could be used to enlarge the training sample towards the faintest magnitudes.

TABLE I

Characteristics of the background sources studied in the core of AC114. M_B are corrected for lensing amplification ($H_0 = 50 km\ s^{-1} Mpc^{-1}$, $\Omega_0 = 0.2$ and $\Lambda = 0$). Error bars in z_{phot} correspond to 1σ. (1) Also z_{phot}= 4.29, with corrected M_B=-22.54.

Objects	A1	B2	B3	C3	E1	S2	V1	V2	V3	V4
z_{spec}	1.69 :	1.50	1.50	2.84	3.35	1.87	?	1.21	2.08	2.9 :
z_{phot}	1.48	1.63	–	3.15	3.15	2.27	0.58[1]	1.41	2.10	2.50
Δz	0.4 2.0	1.3 1.9	–	2.9 3.2	2.9 3.3	2.0 2.5	0.3 0.8	1.1 1.6	1.2 2.4	2.2 2.7
M_B	–21.4	–20.6	–20.6	–20.7	–20.9	–21.4	–17.5	–20.9	–22.6	–22.3

Acknowledgements

This work was supported by the TMR *Lensnet* ERBFMRXCT97 – 0172 (www.ast.cam.ac.uk/IoA/lensnet), the ECOS SUD Program, the French *CNRS*, and the French *Programme National de Cosmologie* (PNC).

References

Altieri, B., *et al.*: 1999, *A&A* **343**, L65..
Athreya R., Mellier Y., Van Waerbeke L., *et al.*: *A&A* submitted, astro-ph/9909518.
Blain, A.W., Kneib, J.-P., Ivison, R.J. and Smail, I.: 1999, *ApJ* **512**, L87.
Bolzonella, M., Miralles, J.M. and Pelló, R.: 2000, *A&A* submitted, astro-ph/0003380.
Campusano, L.E., Le Borgne, J.F., Pelló, R., Kneib, J.P., *et al.*: in preparation.
Ebbels, T.M.D., *et al.*: 1998, *MNRAS* **295**, 75.
Franx, M., *et al.*: 1997, *ApJ* **486**, 75.
Frye, B. and Broadhurst T.: 1998, *ApJ* **499**, 115.
Natarajan, P., Kneib, J.P., Smail, I. and Ellis, R.S.: 1998, *ApJ* **499**, 600.
Pelló, R., *et al.*: *A&A* **346**, 359.
Smail, I., Ivison, R.J. and Blain, A.W.: 1997, *ApJ* **490**, L5.
Smail, I., Ivison, R.J., Blain, A.W. and Kneib, J.-P.: 1998, *A&AS* **192**, 4813.
Trager, S.C., Faber, S.M., Dressler, A. and Oemler, A. Jr.: 1997, *ApJ* **485**, 92.