Highlights on Spanish Astrophysics IX, Proceedings of the XII Scientific Meeting of the Spanish Astronomical Society held on July 18 – 22, 2016, in Bilbao, Spain. S. Arribas, A. Alonso-Herrero, F. Figueras, C. Hernández-Monteagudo, A. Sánchez-Lavega, S. Pérez-Hoyos (eds.)

Magnification with wide-field photometric surveys

Manuel Garcia-Fernandez[1], Eusebio Sánchez[1], and Ignacio Sevilla-Noarbe[1]

[1] Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain

Abstract

A methodology to detect and measure magnification using the galaxy number count technique designed to be used at present and future photometric galaxy surveys is described. The method is tested with the N-body simulation MICE-GC showing that it allows to clearly detect magnification and showing agreement with the theory for sky areas of at least 110 deg^2.

1 Introduction

Weak gravitational lensing of distant objects by the near matter distribution in the Universe has been established as a key probe for Dark Energy as well as for General Cosmology [1][15]. It has two different signatures: magnification and shear.

Magnification occurs when clumps of matter act as if they where convergent lenses. It increases the observed size of distant objects at the same time that surface brightness is conserved, leading to the change in three observational properties of those objects: size [8], magnitude [13] –or flux [9]– and density [14].

The change of the spatial density of galaxies due to gravitational lensing is known as number count magnification. It is due to the increase of the observed flux of background galaxies in such a way that allows to detect objects that, in the absence of magnification, would be beyond the detection threshold, increasing the number density behind the gravitational lenses. At the same time the solid angle behind the gravitational lens is stretched, leading to a decrease in the observed density of background objects. This two effects compete between them and which one prevails over the other depends on the slope of the number count of background galaxies.

Since the low signal-to-noise ratio of the magnification signal requires accurate determination of the redshifits of the lenes as well as the sources, most of the magnification measurements has been made in spectroscopic surveys [14]. Nevertheless the huge rise of wide-field photometric surveys with an strong focus on weak lensing analysis, such as DES[1] [4], PAU[2] [2] and the future LSST[3] [12], requires de development of techniques that allow the accurate measurement of magnification under these conditions.

2 Number count magnification

Number count magnification can be detected and quantified by the deviation of the galaxy count in the spatial correlation of a lens (foreground) and a source (background) sample.

The observed two-point angular cross-correlation function between two redshift bins including magnification is defined as

$$\omega_{ij}(\theta) = \langle \delta_O(\hat{n}, z_i, f_i)\delta_O(\hat{n}', z_j, f_j)\rangle_\theta, \tag{1}$$

where θ is the angle subtended by the two unit direction vectors $\hat{n}, \hat{n}'$ and the observed density contrast δ_O is given by

$$\delta_O(\hat{n}, z_i, f_i) = \delta_g(\hat{n}, z_i) + \delta_\mu(\hat{n}, z_i, f_i); \tag{2}$$

where δ_g describes the fluctuations due to the intrinsic galaxy clustering at redshift z_i and δ_μ incorporates the fluctuations due to magnification. The galaxy density contrast in the linear bias approximation is given by

$$\delta_g(\hat{n}, z_i) = b_i \delta_M(\hat{n}, z_i), \tag{3}$$

where b_i is the galaxy-bias at redshift z_i and δ_M the matter density contrast. At the weak lensing regime, the fluctuations do to magnification are given by

$$\delta_\mu(\hat{n}, z, m) = 2\kappa(\hat{n}, z, m)[\alpha(m) - 1]. \tag{4}$$

Here κ is the convergence field given by

$$\kappa(\hat{n}, z) = \int_0^\infty dz' \frac{r(z')[r(z) - r(z')]}{r(z)} \nabla_\perp^2 \Phi[r(z'), \hat{n}], \tag{5}$$

where $r(z)$ is the radial comoving distance at redshift z and Φ is the gravitational potential. The number count slope (α) is given by

$$\alpha(m) = 2.5 \frac{d}{dm}[\log N_\mu(m)], \tag{6}$$

where N_μ is the cumulative number count, i.e. the number of galaxies with magnitude $m' < m$. If it is assumed that the observer is located at $z = 0$ and that $0 < z_L < z_S$, with z_L the

[1] www.darkenergysurvey.org
[2] www.pausurvey.org
[3] www.lsst.org

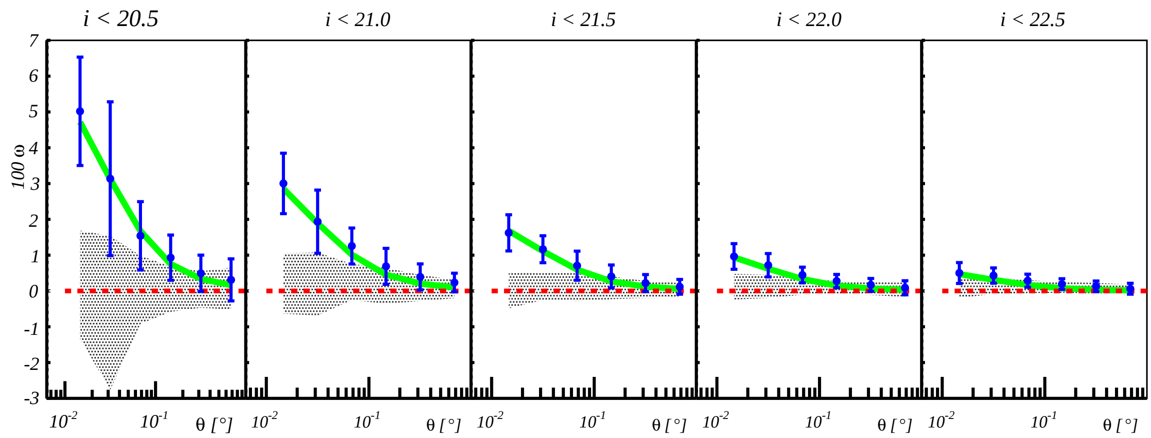

Figure 1: Number count magnification measured on the I sample of the MICE simulation. Blue dots are the measured two-point angular cross-correlation at the realization with lensing. Shaded region denotes the 1σ confidence interval for the realization without lensing. Red dotted line is an eye-guide for zero.

redshift of the lens sample and z_S the redshift of the source sample, this leads to

$$\omega_{LS}(\theta) = b_L[\alpha(m_S) - 1]\frac{3H_0^2\Omega_M^0}{c^2}\int_0^\infty dz_L \frac{\phi_L(z_L)}{1+z_L}\int_0^\infty dz_S\phi_S(z_S)\frac{r(z_L)[r(z_S)-r(z_L)]}{r(z_S)} \times \quad (7)$$

$$\int_0^\infty \frac{dkk}{2\pi}P_M(k, z_L)J_0(k\theta r(z_L)),$$

where ϕ_L, ϕ_S are the redshift distributions of the lens and source sample respectively, P_M is the matter power spectrum, H_0 the Hubble's constant, Ω_M^0 the critical matter density contrast today, c the speed of light and J_0 the zero-th order Bessel function.

3 Application to a simulated galaxy survey

In order to test the methodology described previously in a systematic-free environment, the MICECAT v1.0 galaxy sample is used [5][3][6]. This mock is the first catalog of the N-body simulation MICE-GC[4] that is a ΛCDM universe with $\Omega_M = 0.25$, $\Omega_b = 0.044$, $h = 0.7$ and $\sigma_8 = 0.8$ covering 1/8 of the celestial sphere. The advantage of using this simulation is that, among other properties, provides lensed and unlensed coordinates as well as the convergence and shear fields, allowing the availability of two realizations of the same universe: one with gravitational lensing and the other without it.

3.1 Lens sample

The following cuts are imposed to select the unique common lens sample:

[4] www.ice.cat/mice

- $0.2 < z_{\rm sp} < 0.4$,
- $18.0 < i < 22.5$,

where z_{sp} is the spectroscopic redshift including redshift-space distortions and i denotes the i-band magnitude.

3.2 Source sample

Three source samples are defined, one per each riz-band respectively:

- R: $0.7 < z_{\rm sp} < 1.0$ and $r < 23.0$;
- I: $0.7 < z_{\rm sp} < 1.0$ and $i < 22.5$;
- Z: $0.7 < z_{\rm sp} < 1.0$ and $z < 22.0$.

Within each R, I, Z source sample five sub-samples are defined,

- $\rm R_1$: $r < 21.0$; $\rm R_2$: $r < 21.5$; $\rm R_3$: $r < 22.0$; $\rm R_4$: $r < 22.5$; $\rm R_5$: $r < 23.0$.
- $\rm I_1$: $i < 20.5$; $\rm I_2$: $i < 21.0$; $\rm I_3$: $i < 21.5$; $\rm I_4$: $i < 22.0$; $\rm I_5$: $i < 22.5$.
- $\rm Z_1$: $z < 20.0$; $\rm Z_2$: $z < 20.5$; $\rm Z_3$: $z < 21.0$; $\rm Z_4$: $z < 21.5$; $\rm Z_5$: $z < 22.0$.

Here $\rm S_j$ with $\rm j = 1, 2, 3, 4, 5$ are the sub-samples of sample S with $\rm S \in R, I, Z$.

3.3 Measurement

To estimate the cross-correlation functions, the tree-code TreeCorr[5] [10] with the Landy-Szalay estimator [11] is used:

$$\omega_{\rm LS_j}(\theta) = \frac{D_{\rm L}D_{\rm S_j}(\theta) - D_{\rm L}R_{\rm S_j}(\theta) - D_{\rm S_j}R_{\rm L}(\theta)}{R_{\rm L}R_{\rm S_j}(\theta)} + 1, \tag{8}$$

where $D_{\rm L}D_{\rm S_j}(\theta)$ is the number of pairs from the lens data sample L and the source data sub-sample $\rm S_j$ separated by an angular distance θ and $D_{\rm L}R_{\rm S_j}(\theta)$, $D_{\rm S_j}R_{\rm L}(\theta)$, $R_{\rm L}R_{rmS_j}(\theta)$ are the corresponding values for the lens-random, source-random and random-random combinations normalized by the total number of objects on each sample. To provide the most accurate fiducial measurement, correlation functions are computed using the whole footprint of the simulation, 5000 $\rm deg^2$.

The covariance matrix is computed for each two-point angular correlation function using jack-knife re-sampling

$$C_{\rm S}(\omega_{\rm LS_i}(\theta_\eta); \omega_{\rm LS_j}(\theta_\nu)) = \frac{N_{\rm JK}}{N_{\rm JK}-1} \times \sum_k^{N_{\rm JK}} [\omega^k_{\rm LS_j}(\theta_\eta) - \omega_{\rm LS_j}(\theta_\eta)][\omega^k_{\rm LS_j}(\theta_\nu) - \omega_{\rm LS_j}(\theta_\nu)], \tag{9}$$

[5] github.com/rmjarvis/TreeCorr

where $\omega^k_{\mathrm{LS_j}}$ stands for the cross-correlation of the k-th jack-knife re-sample and $\omega_{\mathrm{LS_j}}$ is the cross-correlation of the full sample. In order to have an estimate for a footprint amounting the area of ongoing surveys –such as the DES Science Verification data or the final PAU footprint–, 90 jack-knife regions are defined over 110 deg^2 of the simulation.

The number count slope parameter α_{S} is computed independently using the measured cumulative number count and applying Equation 6.

On Figure 1 the measured cross correlation-functions for the cases with and without magnification for the I sample can be seen. Measured cross-correlation functions for the realization with magnification agrees with the theoretical predictions from weak lensing and is clearly different from the case where magnification is absent.

4 Conclusions

A methodology to detect magnification on photometric surveys using the number count technique is described. Covariance matrices were estimated for a 110 deg^2 footprint. Results obtained predict that magnification can be detected at ongoing photometric surveys such as DES or PAU. Currently, the detection and systematic analysis of magnification at DES Science Verification is being studied [7].

Acknowledgments

We are very grateful to the MICE team for the access to the simulation and their useful advise.

References

[1] Bartelmann M., Schneider P., 2001, Phys. Rep., 340, 291

[2] Castander F. J., SF2A-2011: Proceedings of the Annual meeting of the French Society of Astronomy and Astrophysics

[3] Crocce M., Castander F. J., Gaztañaga E., Fosalba P., Carretero J., 2015, MNRAS, 453, 1513

[4] Flaugher B., 2005, International Journal of Modern Physics A, 20, 3121

[5] Fosalba P., Gaztañaga E., Castander F. J., Crocce M., 2015a, MNRAS, 447, 1319

[6] Fosalba P., Crocce M., Gaztañaga E., Castander F. J., 2015b, MNRAS, 448, 2987

[7] Garcia-Fernandez M., et al., 2016, in preparation

[8] Huff E. M., Graves G. J., 2014, The Astrophysical Journal Letters, 780, L16

[9] Jain B., Lima M., 2011, MNRAS, 411, 2113

[10] Jarvis M., Bernstein G., Jain B., 2004, MNRAS, 352, 338

[11] Landy S. D., Szalay A. S., 1993, ApJ, 412, 64

[12] LSST Dark Energy Science Collaboration, 2012, preprint, (arXiv:1211.0310)

[13] Ménard B., Scranton R., Fukugita M., Richards G., 2010, MNRAS, 405, 1025

[14] Scranton R., et al., 2005, The Astrophysical Journal, 633, 589

[15] Weinberg D. H., et al., 2013, Physics Reports, 530, 87