Recovering the real-space correlation function from photometric redshift surveys

Pablo Arnalte-Mur, Alberto Fernández-Soto, Vicent J. Martínez and Enn Saar

Abstract The error on the redshift determination associated to photometric redshift surveys produces a smaller correlation and a loss of isotropy in the observed galaxy distribution. We present a method to recover the real-space correlation function, $\xi(r)$ from this kind of observations. The method is similar to that used in spectroscopic surveys to avoid the effects of peculiar velocities, and uses the fact that correlations are conserved in the plane perpendicular to the line-of-sight. We apply this method to mock photometric surveys with errors $\Delta z/(1+z) = 0.05 - 0.005$ obtained from the cosmological simulation of Heinämäki et al. (2005). Our method allows to recover $\xi(r)$, within the error, for the cases with smaller Δz. For $\Delta z/(1+z) = 0.05$, the need to integrate a long range in the line-of-sight direction makes the method fail for $r > 2\,h^{-1}\,$Mpc.

1 Introduction

There are several deep photometric redshift surveys recently completed or in progress. One of the aims of this kind of surveys is to extend large-scale structure studies towards high redshift. This kind of studies have already been carried out, mainly using spectroscopic surveys, at low redshift.

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In the design of such surveys, a compromise has to be achieved between the depth of the survey, and the accuracy with which they can measure photometric redshifts. This is mainly determined by the choice of either broad-band or medium-band filters.

Some of such surveys are the Hubble Deep Fields (HDF) [6], which used broad-band filters, obtaining a very deep catalogue (up to $z < 6$), but with a relatively large error in z ($\Delta z \simeq 0.05(1+z)$); the COMBO-17 (*Classifying Objects by Medium-Band Observations*) survey [7], which used a mixed set of broad-band and medium-band filters, reducing the error in z to $\Delta z \simeq 0.03$, and the ALHAMBRA (*Advanced Large Homogeneous Area Medium Band Redshift Astronomical*) survey [5] (see also A. Fernández-Soto's invited contribution in this volume), which uses a set of 20 medium-band filters in the optical, and 3 broad-band filters in the near-infrared. It is expected that it will achieve an accuracy of $\Delta z \simeq 0.015(1+z)$ for its sample with 'good' redshifts.

In this work, we focused on the possibility of measuring accurately the two-point correlation function, $\xi(r)$, using photometric surveys. The main problem in this case is given by the large errors in z. These introduce large uncertainties in the measured positions of galaxies, and prevent us from measuring $\xi(r)$ directly.

This problem is somewhat similar to the effect of peculiar velocities in spectroscopic redshift surveys (although the effect is much smaller in the latter). In the case of spectroscopic redshifts, a method based on the 'projected correlation function' [2] is commonly used. We explored if this method is also applicable to the case of photometric redshift surveys. For this study, we used a dark matter halos simulation from Heinämäki et al. [3]. We produced three mock photometric redshift catalogues, and applied the 'projected correlation function' method here. We then compared the $\xi(r)$ obtained with that method to the $\xi(r)$ measured directly in the original real-space catalogue.

2 Simulated Data Used

The ΛCDM simulation of Heinämäki et al. covers $2^\circ \times 0.5^\circ$ in the sky. We considered only the $z \in [2,3]$ bin, and hence the volume we used is $864\,h^{-1}\,$Mpc long along the line-of-sight, and $160 \times 40\,h^{-1}\,$Mpc in the transverse plane, with a total volume of $4.56 \times 10^6\,h^{-3}\,\mathrm{Mpc}^3$. The catalogue contains $\sim 180,000$ halos in this volume.

In order to simulate the effect of photometric redshift errors, we created three mock photometric catalogues from the simulation. These catalogues were obtained shifting randomly the position of halos along the line-of-sight direction. In each case, we assumed the redshift errors to be Gaussian-distributed, with constant $\Delta z/(1+z)$. This assumption is valid for samples selected to have 'good' redshift determinations. The three 'typical' cases considered were:

- $\Delta z = 0.05(1+z)$, corresponding to a classical broad-band filter survey (as, e.g., the HDF)

- $\Delta z = 0.015(1+z)$, corresponding to the 'good' sample expected from ALHAMBRA
- $\Delta z = 0.005(1+z)$, corresponding to a possible future survey, with similar characteristics to the PAU Survey [1]

3 Description of the Method

The first step of our de-projecting method to obtain $\xi(r)$ is to measure the two-dimensional correlation function, $\xi(\sigma,\pi)$, as a function of the transverse distance, σ, and the line-of-sight distance, π. For each pair of galaxies, with observed redshift-space positions $\mathbf{s_1}$ and $\mathbf{s_2}$, we define these transverse and line-of-sight distances as

$$\pi \equiv \frac{|\mathbf{s}\cdot\mathbf{l}|}{|\mathbf{l}|} \quad , \quad \sigma \equiv \sqrt{\mathbf{s}\cdot\mathbf{s} - \pi^2}\,,$$

where $\mathbf{s} \equiv \mathbf{s_2} - \mathbf{s_1}$, and $\mathbf{l} \equiv \mathbf{s_1} + \mathbf{s_2}$. Then, we obtain $\xi(\sigma,\pi)$ using the standard Landy-Szalay estimator [4].

The obtained $\xi(\sigma,\pi)$ for the original real-space catalogue, and for the three mock photometric catalogues is shown in Fig. 1. In that figure, we observe the effects of photometric redshift errors on the galaxy distribution. On one side, the isotropy of the distribution is lost, and this is seen here as a loss of the circular symmetry of $\xi(\sigma,\pi)$. On the other side, there is an overall decrease of the correlation amplitude.

Integrating $\xi(\sigma,\pi)$ along the π direction, we obtain the 'projected correlation function' as

$$\Xi(\sigma) = 2\int_0^\infty \xi(\sigma,\pi)\mathrm{d}\pi\,. \tag{1}$$

As the angles considered here are always small, σ is not significantly affected by redshift errors and, therefore, $\Xi(\sigma)$ is not affected either. In calculating numerically the integral in equation (1), a finite upper bound, π_{max} is needed. We found the optimal value to be $\pi_{\mathrm{max}} \simeq 4\Delta z$.

The projected correlation function, $\Xi(\sigma)$, can be related to the real-space correlation function, $\xi_r(r)$. Assuming that the real-space distribution of galaxies is isotropic, this relation is given by

$$\Xi(\sigma) = 2\int_\sigma^\infty \xi_r(r)\frac{r\mathrm{d}r}{(r^2-\sigma^2)^{1/2}}\,.$$

This relation can be inverted, and thus we obtain $\xi_r(r)$ in terms of $\Xi(\sigma)$ as the Abel integral

$$\xi_r(r) = -\frac{1}{\pi}\int_r^\infty \frac{\mathrm{d}\Xi(\sigma)}{\mathrm{d}\sigma}\frac{\mathrm{d}\sigma}{(\sigma^2-r^2)^{1/2}}\,. \tag{2}$$

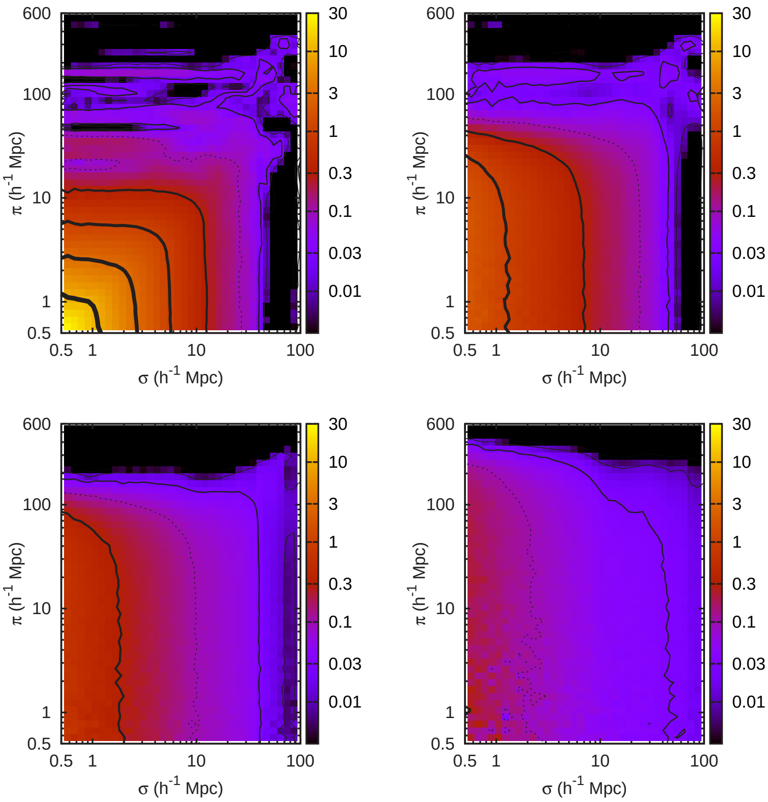

Fig. 1 The two-dimensional correlation function $\xi(\sigma,\pi)$ obtained for the real space catalogue (top left), and for the mock photometric catalogues with $\Delta z = 0.005(1+z)$ (top right), $\Delta z = 0.015(1+z)$ (bottom left) and $\Delta z = 0.05(1+z)$ (bottom right). The circular symmetry of the real-space result is seen as a 'boxy' shape in this logarithmic scale plot.

Again, to evaluate equation (2) numerically, we need to set an upper bound, $\sigma_{\max}$. In this case, it is defined by the maximum transverse separation allowed by the survey geometry.

4 Results and Conclusion

The de-projected $\xi(r)$, obtained following the method described in Sect. 3 for our three mock photometric catalogues, is shown in Fig. 2. We compared these results with $\xi_r(r)$ measured directly from the real-space catalogue.

In order to quantify the quality of the recovery, we calculated an 'average normalized residual', $\Delta\xi$, comparing the real-space $\xi_r(r)$ to the deprojected $\xi_{\rm dep}(r)$ in each case as

$$\Delta\xi = \frac{1}{N}\sum_i \left|\frac{\xi_{\rm dep}(r_i)-\xi_r(r_i)}{\xi_r(r_i)}\right|,$$

where the sum is over the bins in r considered, and N is the total number of such bins. The values of $\Delta\xi$ obtained in each case, for different scale ranges, are shown in Table 1.

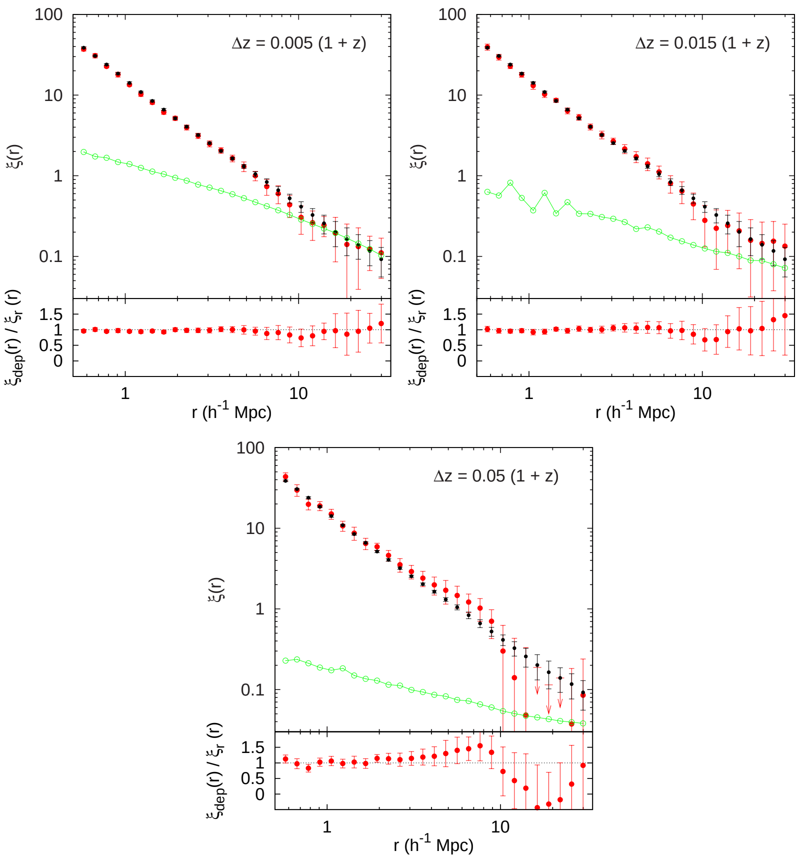

Fig. 2 Comparison between the deprojected correlation function, $\xi_{\rm dep}(r)$ (red circles), and the real-space correlation function, $\xi_{\rm r}(r)$ (black dots), for each mock photometric catalogue. For reference, we also show (green line) the observed redshift-space correlation function, $\xi(s)$, that would be measured directly from the photometric catalogues.

From Fig. 2 and Table 1, we observe that the projected correlation function method can recover the true correlation function within $\sim 5\%$ for $r < 10\,h^{-1}\,$Mpc and $\Delta z \leq 0.015(1+z)$. The method also works for larger scale for those values of Δz, although with worse accuracy. However, for the case with $\Delta z = 0.05(1+z)$, the

Table 1 Average normalized residual, $\Delta\xi$, obtained for the three mock photometric redshift catalogues, for different scale ranges.

Range (h^{-1} Mpc)	$\frac{\Delta z}{(1+z)} = 0.005$	$\frac{\Delta z}{(1+z)} = 0.015$	$\frac{\Delta z}{(1+z)} = 0.05$
$0.5 < r < 30$	0.07	0.09	0.36
$0.5 < r < 2$	0.04	0.04	0.07
$2 < r < 10$	0.05	0.05	0.28
$10 < r < 30$	0.12	0.20	0.79

method fails for scales $r > 2\,h^{-1}$ Mpc, with a truncation of $\xi_{\rm dep}$. This is due to the fact that, in this case, the value of $\pi_{\rm max}$ used for the integration in equation (1) is of the order of the line-of-sight length of the volume considered.

In conclusion, we have shown that the real-space correlation function can be recovered reliably from photometric redshift surveys. The accuracy of the recovery depends on the redshift error and on the scales considered, but it is around 5% for small and medium scales when we assume redshift errors achievable by the ALHAMBRA survey or better.

However, for larger redshift errors ($\Delta z \simeq 0.05(1+z)$), the method fails (for medium and large scales), due to the fact that we need to integrate along a long range in π. This integration constraint imposes a ‘minimum box length’ to measure $\xi(r)$ as a function of Δz.

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