The Redshift Distribution of Distant Sources from Gravitational Depletion in Clusters

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Abstract. Gravitational lensing can be used to analyze the redshift distribution of faint galaxies. In particular the magnification bias modifies locally the galaxy number density of lensed sources observed in lensing clusters. This depletion area probes the redshift distribution of galaxies beyond $B = 25$. In this proceedings I present this new tool to infer the redshift distribution of faint galaxies.

1. Introduction

With the coming of 10 meter class telescopes equipped with wide field multi-object spectrographs, deep redshift surveys will be extended to thousands of galaxies and will permit to explore in detail the evolution of clustering of galaxies, the history of star formation up to $z = 4$ for galaxies with $B \leq 25$.

The study of galaxies with magnitudes $B > 25$ are also important for the models of galaxy formation: we do not know yet whether they are all at large redshift or if there is a significant fraction of faint nearby dwarfs galaxies. The knowledge of their redshift distribution is also necessary for mass reconstruction using lensing inversion, and can be a major source of uncertainty in the mass determination for the most distant lensing clusters (see Luppino & Kaiser 1997). Bernardeau et al (1997) and Jain & Seljak (1997) have emphasized that even the study the large-scale mass distribution using weak lensing need the redshift distribution of the faintest galaxies, because the variance and the skewness of the magnification strongly depends of the redshift of the lensed background sources.

Unfortunately, beyond $B = 25$, even 10 meter class telescopes are unable to provide redshifts of a complete sample of galaxies. The possibility of using photometric redshifts which was proposed by the beginning of eighties is now re-investigated in great details. But observations as well as reliability tests are still underway (Connolly et al. 1995. Since they are based on theoretical evolution scenarios of galaxies, their predictions about faintest galaxies are not fully confirmed yet. Furthermore, there is no hope to calibrate the photometric redshifts of the faint samples with spectroscopic data.

An attractive alternative to spectroscopy consists in using of the magnification and distortion effects induced by gravitational lensing on extended objects. In particular, the magnification bias can eventually produces depletion areas in the projected galaxy number density of background sources observed in rich clusters whose size and shape depend on their redshift distribution. In the following section I present the basic principle of the technique and first results.
2. The distribution of faint galaxies from the magnification bias

The projected number density of galaxies through a lensing cluster at radial distance $r$ from the cluster center and with magnitude lower than $m$, $N(<m,r)$, results from the competition between the gravitational magnification that increases the detection of individual objects and the deviation of light beam that increases the area and thus decreases the apparent number density. Therefore the amplitude of the magnification bias depends on the slope of the galaxy counts, $\gamma$, as a function of magnitude and on the magnification factor of the lens (Broadhurst et al. 1995):

$$N(<m,r) = N_0(<m) \mu(r)^{2.5\gamma-1},$$

(1)

where $\mu(r)$ is the magnification factor of the lens, $N_0(<m)$ the intrinsic number density in a nearby empty field and $\gamma$ is the intrinsic count slope:

$$\gamma = \frac{d\log N(<m)}{dm}.$$  

(2)

when the slope is higher than 0.4 the number density increases, whereas below 0.4 is decreases and the radial distribution shows a typical depletion curve (see Figure 1).

When the slope is lower than 0.3, a sharp decrease of the number of galaxies is expected close to the critical radius of the lens corresponding to the redshift of the background sources. For a broad redshift distribution, it can result a shallower depletion between the smallest and the largest critical line which depends on the redshift distribution of the galaxies (Figure 1). Therefore, the analysis of the shape of the depletion curves provide a new way to sort out their redshift distribution. As the lensing inversion, this is a statistical method which can also infer redshift of very faint sources (up to $B = 28$) but does not need anymore information on the shapes of arclets. However, the need of a good lens modeling is still necessary.

This method was first used by Fort et al (1997) in the cluster Cl0024+1654 to study the faint distant galaxies population in the extreme range of magnitude $B = 26.5 – 28$ and $I = 25 – 26.5$. For these selected bins of magnitude they found on their CFHT blank fields that the counts slope was near 0.2, well suited for the study of the effect. After analysis of the shape of the depletion curve (figure 4), 60% ± 10% of the $B$-selected galaxies were found between $z = 0.9$ and $z = 1.1$ while most of the remaining 40% ± 10% galaxies appears to be broadly distributed around a redshift of $z = 3$. The $I$ selected population present a similar distribution with two maxima, but spread up to a larger redshift range with about 20% above $z > 4$ (Figure 1).

This first tentative must be pursued on many lensing clusters in order to provide significant results on the redshift distribution of the faintest distant galaxies. Though it is a very promising approach, it also need to be applied on clusters with simple geometry. Furthermore, the detection procedure demands ultra-deep exposures with subarcsecond seeing.
Figure 1. Depletion by a singular isothermal sphere as it would be observed on the sky and radial density of galaxies (top left). For a given redshift, the minimum of the depletion is sharp and its radial position is equivalent to a redshift (top right). The minimum increases with the redshift of sources but the depletion curves tighten and converge towards the curve corresponding to sources at infinity. In a realistic case, the redshift distribution is broad and the individual curves must be added. In this case, instead of the single peaked depletion we expect a more pronounced minimum between two radii (i.e. two redshifts; top left). The middle panels show the depletion curves observed in $B$ and $I$ in Cl0024. Since the mass distribution of this lens is well known, one can recover the redshift of the sources for the $B$ and $I$ populations (bottom panels: note that this is a fraction of galaxies. The width of boxes is the redshift range, not a total number of galaxies).
3. Conclusions

The redshift distribution of galaxies beyond \( B = 25 \) is a crucial scientific question for galaxy evolution and weak lensing studies for mass reconstruction. The depletion curves of galaxy number density produced by magnification bias is an innovative way which can probe the redshift distribution of galaxies as faint as \( B = 28 \). The first tentative by Fort et al (1997) demonstrates that depletion curves can be observed in Cl0024+1654 and A370. However, a good modeling of the lensing clusters is needed in order to infer the redshift distribution of the lensed sources. This method is still at its infancy and the first results are questionable. Hence, it must be considered jointly with other techniques like photometric redshifts or lensing inversion (Kneib et al 1994, 1996).

Whatever the method, how can we be sure that these redshifts obtained from non-standard and indirect techniques are correct? Preliminary deep spectroscopic and multicolor photometric surveys of arclets show that the faintest galaxies seem to have a redshift distribution like the ones predicted by Fort et al (Pelló, private communication). But this key issue demands ultra-deep CCD spectroscopic exposures with the VLTs. This should be in the future a major challenge for the gravitational telescopes.

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Figure 2. A magnitude-redshift diagramme showing the positions of the redshift surveys (dark symbols on the left), the arc(let)s spectroscopic surveys (large circles. Those concerning A2218 have been kindly provided by Pelló prior to publication), the predictions of lensing inversions for A370 and A2218 (small circles), of weak lensing studies by Bonnet et al. and Smail et al. (triangles) and finally, of the depletion curves in Cl0024 (large boxes). The spectroscopic redshift of Cowie et al. (1996) with Keck would be between $B = 22.5$ and $B = 24.5$. We see the potential interest of gravitational lensing which provide redshifts up to $B = 28$. The straight line on bottom right is the redshift of A370 which is a limit of the lensing inversion in this cluster.