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First-epoch VIMOS VLT Deep Survey results: The evolution of the galactic bias up to redshift z=1.5

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Deep surveys of the universe provide the basic ingredients needed to compute the probability distribution function of galaxy fluctuations and to constrain its evolution with cosmic time. When this statistic is combined with analytical CDM predictions for the PDF of mass, useful insights into the biasing function relating mass and galaxy distributions can be obtained. In this paper, we present the Vimos-VLT Deep Survey preliminary measurements of the evolution of the biasing function between galaxy and matter overdensities from galaxies distributed in a deep cone $0.4 < z < 1.5$ covering 0.4×0.4 deg. We show that the ratio between the amplitude of galaxy fluctuations and the underlying mass fluctuations declines with cosmic time, and that its evolution rate is a function of redshift: biasing evolution is marginal up to $z \sim 0.8$ and more pronounced for $z \gtrsim 0.8$.

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One of the central goals of modern cosmology is to gain a quantitative understanding of the complex mechanisms which, on various cosmological scales, regulate the formation and the evolution of luminous structures within the underlying dark-matter distribution. A first step towards the overall solution of this problem consists in a comprehensive explanation of the evolution of the clustering of structures in the universe and of the relationship between galaxies and the underlying dark mass on large scales (biasing scheme).

Many approaches have been used to characterize the clustering of galaxies and to understand its relation with the clustering of matter. A complete specification of galaxy clustering may be given by the full set of galaxy N-point correlation functions (*e.g.* [1]). This approach, has been explored over the past decade as better and deeper redshift surveys have become available.

An alternative description may be given in terms of the probability distribution function (PDF) of a random field. A PDF of the cosmological density fluctuations is the most fundamental statistic characterizing the large-scale structure of the universe. In principle, it encodes much of the information contained within the full hierarchy of correlation functions, thus providing valuable information about gravitational evolution of density fluctuations. While the shape of the PDF of mass fluctuations at any given cosmic epoch is theoretically well constrained from CDM simulations, little is known about the observational PDF of the general population of galaxies in the high redshift universe. Even locally, this fundamental statistic has been often overlooked (but see [2]).

Using the first-epoch Vimos-VLT Deep Survey data [3] we have derived the functional shape of the PDF of galaxy overdensities studying its evolution over the wide redshift range $0.4 < z < 1.5$. In particular we have shown how to derive the biasing relation $\delta_g = \delta_g(\delta)$ between galaxy and mass overdensities from their respective PDFs $g(\delta_g)$ and $f(\delta)$. As a matter of fact, assuming a one-to-one mapping between mass and galaxy overdensity fields, conservation of probability implies

$$\frac{d\delta_g(\delta)}{d\delta} = \frac{f(\delta)}{g(\delta_g)}. \quad (1)$$

The advantage over other methods is that we can explore the functional form of the relationship $\delta_g = b(z,\delta,R)\delta$ over a wide range in mass density contrasts, redshift intervals and smoothing scales R without specifying any *a-priori* parametric functional form for the biasing function.

In pursuing our approach, we have assumed that the current theoretical understanding of how clustering of DM proceeds via gravitational instability in the expanding universe is well developed, *i.e.* the PDF $f(\delta)$ of mass fluctuations can be safely derived via analytical models or N-body simulations. In particular, in what follows, we will consider a ΛCDM background mass distribution locally normalized to $\sigma_8(z=0) = 0.9$.

1. The First-Epoch VVDS Redshift Sample

The Vimos-VLT Deep Survey (VVDS) is a spectroscopic survey primarily designed for measuring more than 100,000 galaxy redshifts in the range $0 < z < 5$. The VVDS is actually two surveys in one: a *wide* survey which covers 16 deg^2 down to the limiting magnitude $I_{AB} = 22.5$ and a *deep* survey covering about 1.3 deg^2 down to $I_{AB} = 24$. The strength of the VVDS, compared to other currently undergoing deep surveys of the universe, is that it has been conceived as a purely

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flux-limited survey, *i.e.* no target pre-selection according to colors, morphology or compactness is implemented.

The analysis presented in this paper is based on data collected in the deep VVDS-02h field. In this field (0.7×0.7 deg) VIMOS observations have been performed using 1" wide slits and the LRRed grism which covers the spectral range $550 < \lambda(\mathrm{nm}) < 940$ with an effective spectral resolution $R \sim 227$ at $\lambda = 750$nm. The accuracy in redshift measurements is ∼275 km/s. Details on observations and data reduction are given in [3, 4].

For the purposes of this study we have defined a VVDS sub-sample with galaxies having redshift $z < 1.5$ and selected in a contiguous sky region of 0.4×0.4 deg homogeneously targeted four times with VIMOS slitmasks. Even if we measure redshifts up to $z \sim 5$ and in a wider area, the conservative angular and redshift limits bracket the range where we can sample in a denser way the underlying galaxy distribution and, thus, minimize biases in the reconstruction of the density field. This subsample contains 3448 galaxies with secure redshift and the redshift sampling rate is $\sim 30\%$ *i.e.*, down to $I_{AB} = 24$, we measure redshifts for nearly one over three galaxies.

2. Results

It seems now well established (*e.g.* [5, 6]) that, in the local universe, the distribution of baryonic matter does form a faithful representation of the spatial properties of the dominant species of matter (*i.e.* collisionless weakly interacting dark matter). On the contrary, very little is known about the rate of evolution as a function of redshift of the biasing relationship.

We have derived the redshift-, density-, and scale-dependent biasing function $b(z,\delta,R)$ between galaxy and matter fluctuations in a ΛCDM universe, by analyzing the Jacobian transformation between their respective PDFs (see eq. 1). With this approach, we loose information on the eventual stochasticity characterizing the biasing function. The advantage is that we can provide a preliminary measure, on some characteristic scales R, of the *local*, *non-linear*, *deterministic* biasing function.

Particular attention has been paid a) to assess the completeness of the VVDS sample and to test the statistical reliability of the PDF of VVDS galaxy fluctuations and b) to devise an optimal strategy so that the comparison of the PDFs of mass and galaxies can be carried out in an objective and accurate way. Specifically, following [7], we have corrected the lognormal approximation, which describes the mass density PDF, in order to take into account redshift distortions at early cosmic epochs where the mapping between redshifts and comoving positions is not linear. In this way, theoretical predictions can be directly compared to observational quantities derived in redshift space.

Our results about the evolution of the galaxy biasing are presented and discussed in detail in [8]. Here we briefly summarize our main findings:
i) non-linear effects in the biasing relation are detected at a level of $\lesssim 10\%$ and their weak strength confirms a general prediction of CDM-based hierarchical models of galaxy formation (*e.g.* [9]).
ii) The biasing function rises sharply in underdense regions (the local slope is $b(\delta) > 1$) indicating that below some finite mass density threshold the formation efficiency of galaxies brighter than $\mathcal{M}_B < -20 + 5\log h$ drops to zero. This threshold shifts towards higher values of the mass density field as the luminosity or the redshift of the galaxy population increases.

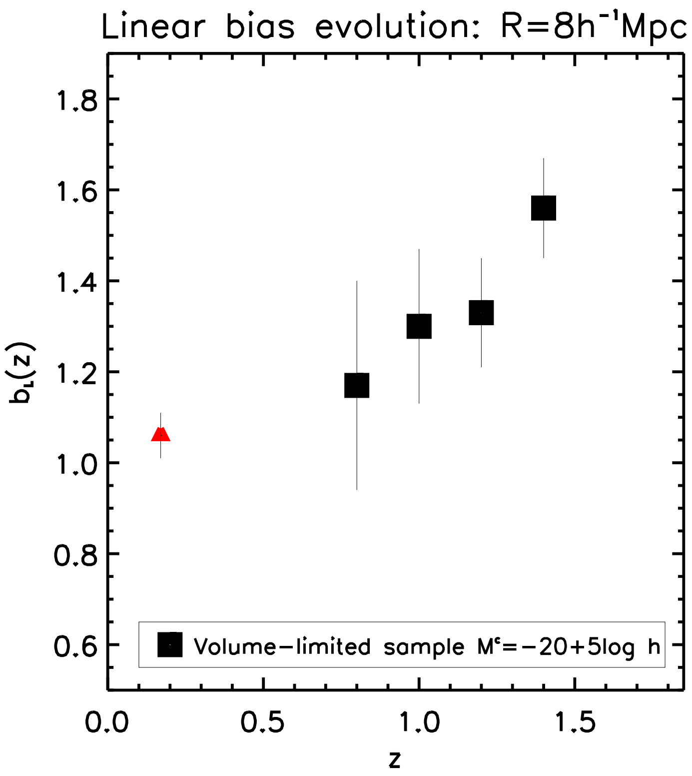

Figure 1: Redshift evolution of the linear biasing parameter b_L computed on a scale R=8h^{-1} Mpc for the volume-limited ($\mathcal{M}^c$ <-20+5logh) VVDS subsample (squares). The triangle represents the $z \sim 0$ bias inferred using the results of [5, 10] for the 2dFGRS [11] sample having the same median luminosity of the volume-limited VVDS sample ($L/L^* \sim 2$).

iii) We do not observe the imprints of scale-dependency in the biasing function a behavior in agreement with results derived from more local surveys at z$\sim$ 0 (*e.g.* [5]).
iv) By representing the biasing function in linear approximation, we have found that the linear biasing parameter b_L evolves with cosmic time: biasing was systematically greater in the past. The difference between its value at redshift z$\sim$1.5 and z$\sim$ 0 is significant at a confidence level greater than 3σ ($\Delta b =\sim 0.5 \pm 0.14$) (see Fig. 1).
v) Over the redshift baseline investigated, the rate of biasing evolution is a function of redshift: z$\sim$0.8 is the characteristic redshift which marks the transition from a "minimum-evolution" late epoch to an early period where the biasing evolution for a population of $\mathcal{M}_B < -20 + 5\log h$ galaxies is substantial ($\sim$ 33% between redshift 0.8 and 1.4).
vi) Brighter galaxies are more strongly biased than less luminous ones at every redshift and the dependence of biasing on luminosity at z $\sim$0.8 is in good agreement with what is observed in the local universe (*e.g.* [10]).
vii) By comparing our results to predictions of theoretical models for the biasing evolution, we have shown that the galaxy *conserving* model (*e.g.* [12]) and halo *merging* (*e.g.* [13]) model offer a poor description of our data. This result could suggest that the gravitational debiasing and the

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hierarchical merging of halos may not be the only physical mechanisms driving the evolution of galaxy biasing across cosmic epochs. At variance with these results, the *star forming* model (*e.g.* [14]) seems to describe better the observed redshift evolution of biasing.
viii) Splitting the first-epoch redshift catalog into red and blue volume-limited subsamples, we have found that a color-density relation on scales R=8h^{-1}Mpc is well in place at $z = 1.5$ and evolves weakly with redshift.
ix) The red sample is systematically a more biased tracer of mass than the blue one in every redshift interval investigated, but the relative biasing between the two populations is nearly constant in the redshift range 0.7$< z <$1.5 ($b^{red}/b^{blue} \sim 1.4 \pm 0.1$), and comparable with local estimates. Moreover, we have found that the bright red subsample is biased with respect to the general red population in the same way as the bright sample of blue objects is biased with respect to the global blue population thus indicating, that biasing as a function of luminosity might be, at first order, independent of colors.
x) Due to the large errorbars which still affect our results, the bias of our sample of bright and moderately red objects at z$\sim$1 is not statistically dissimilar from that expected for EROS of similar luminosity, even if the EROS biasing appears to be systematically larger.

One key aspect of our analysis is the measure of evolution in the distribution properties of galaxy overdensities from a continuous volume sampled with the same selection function over a wide redshift baseline. However, our preliminary analysis is still limited by large errors associated to cosmic variance. Further studies on larger samples using this promising technique will be reported as the VVDS observational program progresses.

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