GALAXY-GALAXY LENSING PREDICTIONS FROM THE SEMI-ANALYTIC GALAXY FORMATION MODELS

J.GUZIK[†], U.SELJAK[‡]
[†]*Astronomical Observatory, Jagiellonian University, Orla 171, 30-244 Kraków, Poland*
[‡]*Department of Physics, Jadwin Hall, Princeton University, Princeton, NJ 08544, USA*

We use semi-analytic galaxy formation models in combination with the high resolution N-body simulations to make predictions for galaxy-galaxy and magnification bias measurements. We show that the amplitude of the lensing signal depends strongly on the luminosity of the sample (luminosity bias) and on the color of the sample. Dark matter halo parameters cannot be directly inferred from the galaxy-galaxy lensing because halos of different mass dominate at different scales of the correlation. A more detailed modelling is needed to interpret the results of the Sloan Digital Sky Survey and other observations. We also compute the correlation coefficient between galaxies and dark matter and show it approaches unity on scales above $1\ h^{-1}$ Mpc. This means that galaxy-galaxy lensing or magnification bias in combination with galaxy correlations can be used to extract bias and dark matter power spectrum on large scales.

1 Introduction

Understanding the dark matter distribution in the Universe over the whole range of spatial scale, from galactic (a few kpc) to large scale structure (hundreds of Mpc) is one of the fundamental goals of current cosmological investigations. One serious obstacle to this comes from the fact that one can directly observe only luminous content of the Universe. The dark matter distribution can only be studied indirectly, for example via its gravitational influence on nearby structures (dynamical effects) or propagation of light (gravitational lensing). The latter method, through the galaxy-galaxy lensing effect, seems to be a promising tool for measuring galaxy-dark matter correlations on scales from several kpc up to a Mpc. In our work we assume a cosmological model and galaxy formation model to make predictions for galaxy-galaxy lensing in the observationally interesting range. We restrict ourselves to the flat, cosmological constant dominated model with $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$ and $H_0 = 70$ km s^{-1}Mpc^{-1}.

2 Galaxy-galaxy lensing

We use N-body simulations performed by GIF collaboration in a 141 h^{-1}Mpc box to trace the dark matter distribution and the semi-analytic galaxy formation models to identify galaxies in the dark matter haloes [1]. Carrying out the spectral analysis of the dark matter and galaxy distributions allows us to obtain the power spectra and correlation functions for the dark matter, galaxies and their cross-correlation [2]. We are especially interested in the cross-correlation function which measures the average dark matter distribution around the galaxies.

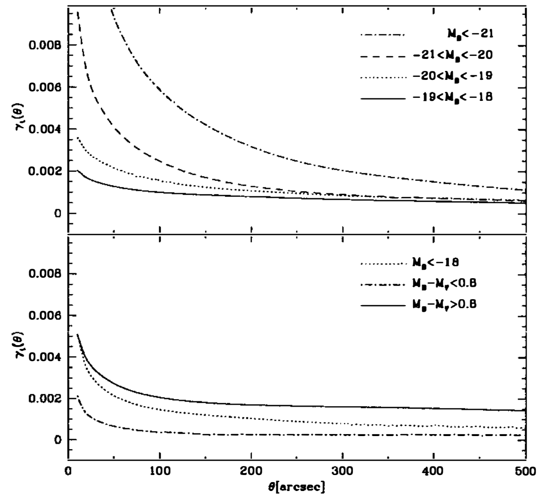

Figure 1: Mean tangential shear as a function of angular distance from the lens galaxy.

Applying the cross-correlation analysis to the galaxy-galaxy lensing studies allows us to perform a comparison with the present measurements of the effect [3] and make predictions for achievable galaxy-galaxy lensing signal from future observations. In galaxy-galaxy lensing one measures the tangential deformations of images of distant galaxies relative to the lens galaxy. The relation between the mean projected matter density expressed in terms of the mean convergence $\overline{\kappa}(\theta)$ inside a given circular aperture of radius θ and the mean tangential shear along the aperture boundary $\langle\gamma_t(\theta)\rangle$ is given by the expression [4]: $2\langle\gamma_t(\theta)\rangle = -d\,\overline{\kappa}(\theta)/d\ln\theta$. The mean convergence associated with a given galaxy type is expressed by the respective cross-correlation function. For simplicity we model lens and source galaxies as being at fixed redshifts $z_l = 0.16$ and $z_s = 0.32$, which corresponds to the mean values of galaxy redshift distributions measured by the SDSS team [3], but we also performed the analysis including galaxy redshift distribution [2]. In Fig.1 we show the mean tangential shear as a function of angular distance from the lens galaxy of a given type. For cosmological model considered here the angular separation of 100 arcsec corresponds to the physical distance about $0.22\ h^{-1}$Mpc in the lens plane.

As shown in the upper panel of the Fig.1 the shear depends strongly on the galaxy luminosity, reflecting the fact that more luminous galaxies reside in more massive haloes. These results are consistent with the predictions of the Tully-Fisher relation. The slope of the shear steepens with increasing luminosity and depends on the scale considered. The shear profile is not well fitted by power-law halo profiles $\rho \propto r^{-\alpha}$. Our results are in rough agreement with the SDSS measurements [3], as galaxies with luminosities $L > L_\star$ ($L_\star \approx -20.3$) which are brighter than $m_B \approx 19$ for assumed lens redshift corresponding to the SDSS sample of lens galaxies. We note however that the predictions are very sensitive to detailed galaxy formation modelling, so we expect galaxy-galaxy lensing to be one of the most powerful discriminators of such models.

In the lower panel of the Fig.1 we present the shear for red, blue and all galaxies with the luminosity cut $M_B < -18$ imposed. The red galaxies sample ("ellipticals") seems to be more promising in galaxy-galaxy lensing detection as they give a few times stronger signal than the blue sample ("spirals") for the whole range of angular scales. Large value of the shear in the case of red sample for scales of order several hundred kpc does not mean that haloes of particular

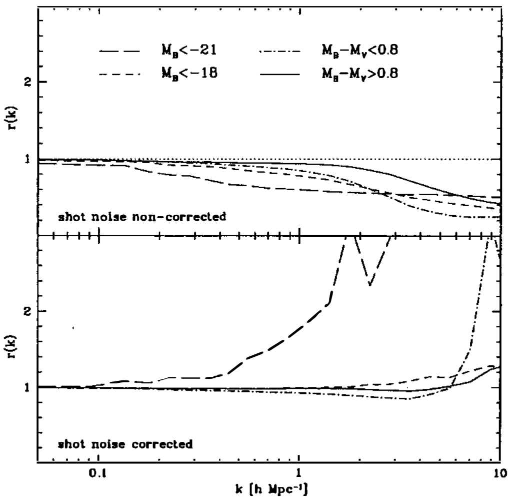

Figure 2: The correlation coefficient as a function of wavevector and galaxy sample.

galaxies extend to such large distances. Instead it argues that the red galaxies are more likely to be found in groups and clusters. The galaxy-galaxy lensing studies could be helpful in searches for galaxy groups and proving physical connections between the galaxies involved in apparent groups. On the other hand blue galaxies are more suitable for investigations of dark matter halo properties because they are mostly placed in the field and their shear profile reflects more the real profile of the dark matter haloes.

3 Cross-correlation coefficient

The cross-correlation analysis may be applied in studying the biasing between luminous and dark matter distributions. Not to confine to the simplest, linear bias relation we may account for the cross-correlation coefficient defined as $r^2(k) = P^2_{\mathrm{g,dm}}(k)/(P_{\mathrm{g,g}}(k)P_{\mathrm{dm,dm}}(k))$, where $P_{\mathrm{dm,dm}}(k)$, $P_{\mathrm{g,g}}(k)$ and $P_{\mathrm{g,dm}}(k)$ are power spectra for dark matter, galaxies and the cross-power spectrum respectively. The linear bias gives $r(k) = 1$. In Fig.2 we show the correlation coefficient as a function of scale for a few galaxy samples. In the upper panel we show $r(k)$ without shot noise correction in which case $r(k) < 1$ as expected. With the shot noise subtraction $r(k)$ is shown in the lower panel of Fig.2. This can be larger than unity on small scales because of shot noise subtraction. For large scales $r(k) \approx 1$ which allows one to extract the bias and the dark matter power spectrum from the galaxy and cross-power spectra. Thus galaxy-galaxy lensing which allows us to measure the galaxy-dark matter correlations should become a useful tool in determining the bias. The correlation coefficient is dependent on the abundance of galaxies in haloes, which is seen when one considers red and blue samples, especially on small scales of order hundreds of kpc. Blue galaxies, which are often the only galaxy in the halo, show stronger scale dependence of $r(k)$ than red ones, which are usually members of groups and clusters and roughly trace the dark matter distribution in the haloes. Large values of $r(k)$ for small scales occur because in the haloes with only one galaxy the cross-correlation is strongly enhanced with respect to the dark matter correlation. These results are supported by analytical treatment [5].

4 Summary

We have performed cross-correlation analysis of dark matter and galaxy distributions using N-body simulations coupled with the semi-analytic galaxy formation models. We have shown its importance in interpreting the observations of the galaxy-galaxy lensing effect. The cross-correlation function contains information not only on galaxy halo profiles but also on the halo mass function and galaxy abundance in haloes. Because of contributions from different mass haloes and clustering of galaxies the galaxy-galaxy lensing signal cannot be interpreted simply as a measure of the mean galaxy halo profile. The prospects can be improved if one selects galaxies by colour or clusters by richness. Moreover, cross-correlations together with the galaxy correlations can become a useful method to extract the bias parameter and the dark matter power spectrum on large scales, where the cross-correlation coefficient is approximately unity independently of the galaxy sample taken into considerations. The upcoming surveys such as SDSS or 2dF should be able to extract information on the dark matter-galaxy correlations via the galaxy-galaxy lensing with high precision, making them an important tool in galaxy haloes investigations.

Acknowledgments

We thank Guinevere Kauffmann and Antonaldo Diaferio for providing results of GIF N-body simulations and semi-analytic simulations and for help with H them. J.G. thanks Phil Fischer for encouraging discussions during the conference. J.G. was supported by KBN grants 2P03D00618 and 2P03D01417. U.S. acknowledges the support of NASA grant NAG5-8084.

References

1. G.Kauffmann, J.M.Colberg, A.Diaferio & S.D.M.White, *MNRAS* **303**, 188 (1999)
2. J.Guzik and U.Seljak, to be submitted (2000)
3. P.Fischer, et al., astro-ph/9912119 (2000)
4. G.Squires and N.Kaiser, *ApJ* **473**, 65 (1996)
5. U.Seljak, astro-ph/0001493 (2000)