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Do Angular Momentum Induced Ellipticity Correlations Contaminate Weak Lensing Measurements?

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Abstract: Alignments in the angular momentum vectors of galaxies can induce large scale correlations in their projected orientations. Such alignments arise from the tidal torques exerted on neighboring protogalaxies by the smoothly varying shear field. Weak gravitational lensing can also induce ellipticity correlations since the images of neighboring galaxies will be distorted coherently by the intervening mass distribution. Comparing these two sources of shape correlations, it is found that for current weak lensing surveys with a median redshift of $z_m = 1$, the intrinsic signal is a contaminant on the order of 1–10% of the measured signal. However, for shallower surveys with $z_m \leq 0.3$, the intrinsic correlations dominate over the lensing signal. The distortions induced by lensing are curl-free, whereas those resulting from intrinsic alignments are not. This difference can be used to disentangle these two sources of ellipticity correlations. When the distortions are dominated by lensing, as occurs at high redshifts, the decomposition provides a valuable tool for understanding properties of the noise and systematic errors.

Keywords: gravitational lensing — galaxies: statistics

1 Introduction

Gravitational lensing can be used to map the detailed distribution of matter in the universe over a range of scales (Gunn 1967). Systematic distortions in the shapes and orientations of high redshift background galaxies (weak lensing) induced by mass inhomogeneities along the line of sight can be measured statistically (Gunn 1967; Blandford et al. 1991; Miralda-Escude 1991; Kaiser 1992; see a recent review by Bartelmann & Schneider 1999).

The lensing effect depends only on the projected surface mass density and is independent of the luminosity or the dynamical state of the mass distribution. Thus, this technique can potentially provide invaluable constraints on the distribution of matter in the universe and the underlying cosmological model (Bernardeau, van Waerbeke & Mellier 1997). There has been considerable progress in theoretical calculations of the effects of weak lensing by large-scale structure, both analytically and using ray-tracing through cosmological N-body simulations (Kaiser 1992; Bernardeau et al. 1997; Jain & Seljak 1997; Jain, Seljak & White 2000).

Recently, several teams have also reported observational detections of 'cosmic shear' — weak lensing on scales ranging from an arcminute to ten arcminutes (see Figure 1; van Waerbeke et al. 2000; Bacon, Refregier & Ellis 2000; Wittman et al. 2000; Kaiser, Wilson & Luppino 2000). At present, these studies are limited by observational effects, such as shot noise due to the finite number of galaxies and the accuracy with which shapes can actually be measured given the optics and seeing (Kaiser 1995; Bartelmann & Schneider 1999). In addition, the intrinsic ellipticity distribution of galaxies and their redshift distribution is still somewhat uncertain. These observational difficulties can be potentially overcome with more data.

However, an important theoretical issue remains. In modelling the distortion produced by lensing, it is assumed that the *a priori* intrinsic correlations in the shapes and orientations of background galaxies are negligible. Correlations in the intrinsic ellipticities of neighbouring galaxies are expected to arise from the galaxy formation process, for example as a consequence of correlations between the angular momenta of galaxies when they assemble. The strength of these correlations can be computed in linear theory, in the context of Gaussian initial fluctuations.

2 Schematic Outline

We briefly outline the calculation here, details can be found in Crittenden et al. (2001a,b). To estimate the strength of intrinsic ellipticity correlations, we approximate the projected shape of a galaxy on the sky by an ellipsoid with semi-axes a, b ($a > b$). The orientation of the ellipsoid is given by the angle ψ between the major axis and the chosen coordinate system, while its magnitude is given by $|\epsilon| = (a^2 - b^2)/(a^2 + b^2)$. Both the magnitude of the ellipticity and its orientation can be concisely described

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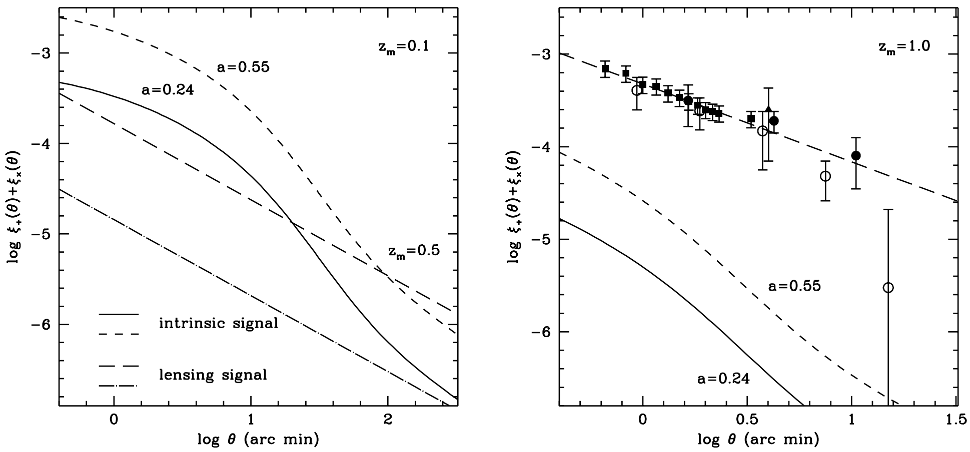

Figure 1 The intrinsic correlation signal versus the predictions from weak lensing and current observations. Left panel: predictions for a shallower survey such as SDSS and 2dF with $z_m = 0.1$. The intrinsic signal is plotted for two values of a, and the theoretical prediction for weak lensing is the long-dashed line (for $z_m = 0.1$) and dotted-long-dashed (for $z_m = 0.5$). The lensing prediction for $z_m = 0.1$ is extrapolated from the Jain & Seljak (1997) fit beyond the stated range of validity. For such low redshifts the intrinsic signal dominates on most scales. Right panel: $\xi_+(\theta) + \xi_\times(\theta)$ the intrinsic signal for $z_m = 1$, compared to the measured shear correlation function. At small separations, the intrinsic signal is approximately 1% of the lensing signal. The amplitude depends on the assumed average galaxy thickness (α) and the parameter a that describes how well the angular momentum of the galaxy is correlated with the distortion field. We plot $a = 0.24$ (full line) and $a = 0.55$ (short-dashed line) which correspond to the values inferred from the numerical simulations of Lee & Pen (2000) and Heavens, Refregier & Heymans (2000). $\alpha = 0.73$ corresponds to the value determined from the observed distribution of ellipticities. The data are: van Waerbeke et al. (2000) — solid squares ; Wittman et al. (2000) — filled circles ; Kaiser et al. (2000) — open circles; and Bacon et al. (2000) — filled triangle. The long-dashed line is the extrapolated theoretical prediction from Jain & Seljak (1997) computed for a $\Omega_\Lambda = 0.7$ galaxy cluster normalised flat universe, $\sim 4.75 \times 10^{-4}(\theta/\text{arc min})^{-0.84}$.

by the complex quantity $\epsilon^{(o)}$,

$$\epsilon^{(o)} = |\epsilon^{(o)}|e^{2i\psi} = \epsilon_+^{(o)} + i\epsilon_\times^{(o)} \tag{1}$$

where the superscript $^{(o)}$ denotes the observed shape.

In the linear regime and under the assumption of weak lensing, the lensing equation can be written as

$$\epsilon^{(o)} = \frac{\epsilon + g}{1 + g^*\epsilon}, \tag{2}$$

where g is the complex shear and ϵ the intrinsic shape of the source (Miralda-Escude 1991). Furthermore, in the weak regime, correlations of this distortion field are

$$\begin{aligned}\langle \epsilon^{(o)}(\mathbf{x_1})\, \epsilon^{(o)*}(\mathbf{x_2})\rangle \simeq \langle \epsilon(\mathbf{x_1})\, \epsilon^*(\mathbf{x_2})\rangle + \langle g^*(\mathbf{x_2})\epsilon(\mathbf{x_1}) \\ + g(\mathbf{x_1})\epsilon^*(\mathbf{x_2})\rangle + \langle g(\mathbf{x_1}) g^*(\mathbf{x_2})\rangle\end{aligned} \tag{3}$$

where the * denotes complex conjugation. The first term is the contribution that arises from intrinsic shape correlations. Previous analyses have focused on the third term of this expression, correlations due to weak lensing.

We assume in the calculation that shape correlations arise primarily from correlations in the direction of the angular momentum vectors of neighbouring galaxies. Spiral galaxies are disk-like with the angular momentum vector perpendicular to the plane of the disk, so that angular momentum couplings will be translated into shape correlations. We will assume that for ellipticals the angular momentum vector also lies along its shortest axis on average, as it does for the spirals. However, since elliptical galaxies are intrinsically rounder, the correlation amplitude will be smaller. We use the observed ellipticity distributions of each morphological type (from the APM survey) in the computation of the shape correlations. For weak lensing, in contrast, the induced shape correlations are independent of the original shapes of the lensed galaxies.

3 Results

The amplitude and shape of the computed ellipticity correlation function can be understood intuitively. The ellipticity is a function of the shear tensor, which is the second derivative of the potential. By virtue of Poisson's equation, the trace of the shear tensor is the density. Therefore, we expect the correlation of the other components of the shear field will drop at the same rate as the density correlation function. Since the ellipticities are quadratic in the shear field, correlations in them will fall as the density correlation function *squared*, $\langle \epsilon(\mathbf{x_1})\epsilon^*(\mathbf{x_2})\rangle \propto \xi_\rho^2$ (see Figure 1).

Comparing the strength of the intrinsic correlation to that expected for weak lensing, we find that the intrinsic signal **grows** as the depth of the survey **decreases** (the projected intrinsic shape correlation function scales as z_m^{-2} whereas the weak lensing correlation function scales as $z_m^{1.52}$), because in that case galaxies close on the sky are also on average physically closer, and are hence more correlated. The weak lensing signal, on the other hand, drops off, since typically there is less matter between us and the lensed objects. For typical weak lensing surveys, however, with a median redshift of $z_m = 1$, the intrinsic signal is 1–10 per cent of the weak lensing amplitude. For surveys such as the SDSS the intrinsic signal may dominate the lensing one, on small scales (see left panel of Figure 1). Recently, Brown et al. (2000) have measured the intrinsic correlation function measured from the COSMOS survey and find good agreement with our theoretical predictions.

The intrinsic ellipticity depends on the square of the tidal field, whereas the lensing distortion is linear in the shear. As a direct consequence, the distortion field is curl-free when induced by lensing, but not when intrinsic correlations are present as well (Crittenden et al. 2001b). Angular momentum couplings produce E- and B-modes in comparable amounts and one might expect that noise, telescope distortions and other sources of systematic errors will produce curl modes as well. The detection of such 'magnetic' modes will be an invaluable way of separating lensing from intrinsic correlations. Details on how to unambiguously do so are presented in Crittenden et al. (2001b).

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