The relevance of lensing-convergence terms for photo-z surveys

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Contents

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- the direction $\mathbf{n}$ is perturbed by weak lensing of foreground structures (Matsubara 2000). Topic of this talk!
- On larger scales there are additional light cone effects (e.g. the Shapiro time delay, the Doppler term and more, (Yoo et al., 2009, Bonvin & Durrer, Challinor & Lewis 2011), but these are mainly visible close to the Hubble scale or at very low redshift, $z \leq 0.1$.

Galaxy number counts

We count the number of galaxies inside a redshift bin dz and a solid angle as seen at the observer $d\Omega_o$,

$$dN = A(z, \mathbf{n}) dz d\Omega_o \,, \qquad \Delta(z, \mathbf{n}) = \frac{A(z, \mathbf{n}) - \bar{A}(z)}{\bar{A}(z)}$$

$$A(z, \mathbf{n}) = \rho(z, \mathbf{n}) \frac{dV}{dz d\Omega_o} = \bar{\rho}(\bar{z})(1 + \rho'/\rho \delta z)(1 + \delta(\bar{z}, \mathbf{n})) \frac{dV}{dz d\Omega_o}$$

$$dV = r(z, \mathbf{n})^2 dr d\Omega_s = \bar{r}(\bar{z})^2 \left(1 + 2\frac{\delta r}{\bar{r}}\right) \frac{dr}{dz} \left|\frac{d\Omega_s}{d\Omega_o}\right| dz d\Omega_o$$

$$\frac{dr}{dz} = \left(\frac{d\bar{r}}{d\bar{z}} + \frac{d\delta r}{d\bar{z}}\right)\left(1 - \frac{d\delta z}{d\bar{z}}\right) \simeq H(z)^{-1}\left(1 - v_r - H^{-1}\frac{dv_r}{dr}\right) , \qquad \frac{\delta z}{1+z} = v_r \,.$$

This is the term which generates the well known RSD.

$$\begin{aligned}
\left|\frac{d\Omega_s}{d\Omega_o}\right| &= 1 + \frac{d\delta\theta^a_s}{d\theta^a_o} \\
\delta\theta^a_s &= -2\nabla^a \int_o^s \frac{dr(r_s - r)}{r_s r}\Psi_W \qquad \Psi_W = \frac{1}{2}(\Phi + \Psi) \\
\frac{d\delta\theta^a_s}{d\theta^a_o} &= -2\Delta \int_o^s \frac{dr(r_s - r)}{r_s r}\Psi_W = -2\kappa \qquad r_s = r(z) \\
\left|\frac{d\Omega_s}{d\Omega_o}\right| &= 1 - 2\kappa\,.
\end{aligned}$$

In addition to this purely geometrical effect there is the magnification bias $5s(z)\kappa$, where

$$s(z, m_*) = \frac{2}{5}\frac{d\bar{n}(z, L)}{d\log L}\,.$$

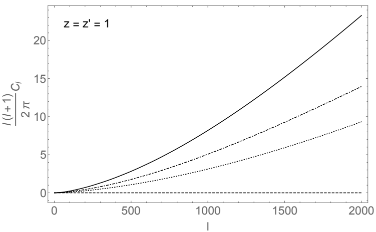
The galaxy number counts power spectrum

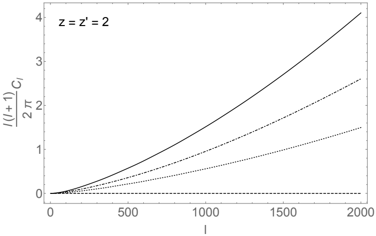
$$\Delta(z,\mathbf{n}) \simeq b\delta_z(z,\mathbf{n}) + \frac{1}{H(z)}v_r(z,\mathbf{n}) - (2-5s(z))\kappa(z,\mathbf{n})$$

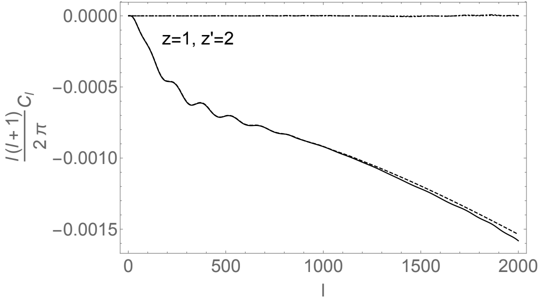
$$\Delta(z,\mathbf{n}) = \sum a_{\ell m}(z)Y_{\ell m}(\mathbf{n})\,, \quad \langle a_{\ell m}(z)a^*_{\ell' m'}(z')\rangle = \delta_{\ell\ell'}\delta_{mm'}C_\ell(z,z')$$

$$\langle\Delta(z,\mathbf{n})\Delta(z',\mathbf{n}')\rangle = \frac{1}{4\pi}\sum_\ell(2\ell+1)C_\ell(z,z')P_\ell(\mathbf{n}\cdot\mathbf{n}')$$

The observable angular matter power spectrum: slim redshift bins



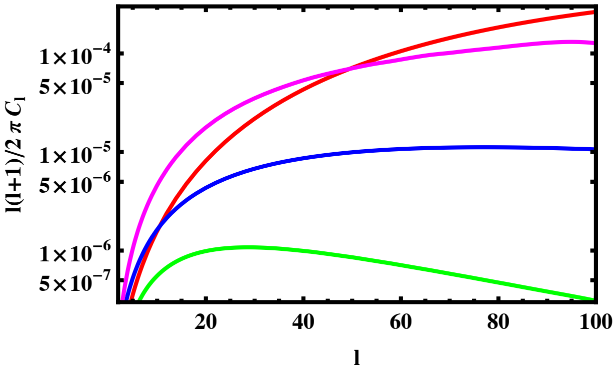




—— the full result
· · · density only
-·-· RSD and RSD-density correlation
- - - - terms containing κ
($b = 1$ and $s = 0$).

The observable angular matter power spectrum: wide redshift bins

Contributions to the transverse power spectrum at redshift $z = 3, \Delta z = 0.3$ (from Bonvin & RD 2011)



$C_\ell^{\delta\delta}$ (red), C_ℓ^{RSD} (green), $2C_\ell^{\delta RSD}$ (blue), $C_\ell^{lensing}$ (magenta).

More than a decade ago Zhang et al. (2007) have proposed the so called E_g statistics which is very sensitive to deviations from Einstein gravity. It consists of measuring the lensing potential, the density-lensing correlation and the redshift space distortion independently.

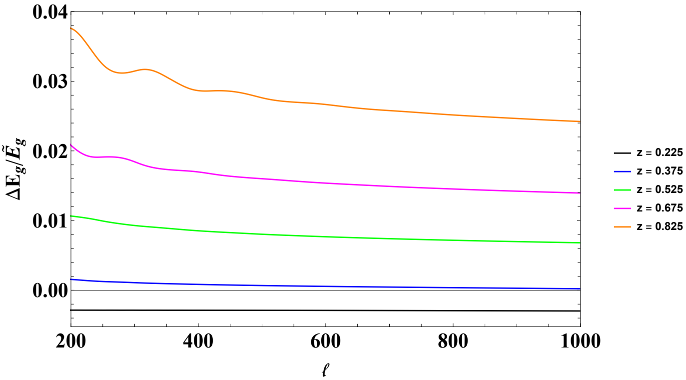
$$E_g(\ell, z) = \Gamma(z) \frac{C_\ell^{\kappa g}}{\beta C_\ell^{gg}} \qquad \left(= \frac{\Omega_{m0}}{f(z)} \right)$$

The last equal sign holds for GR: E_g is independent of the galaxy bias and of scale. But $C_\ell^{\kappa g}$ and C_ℓ^{gg} are not directly measurable! But $C_\ell^{\kappa\Delta}(z, z')$, $C_\ell^{\Delta\Delta}(z, z')$ and $C_\ell^{\kappa\kappa}(z, z')$ are.

$$C_\ell^{\kappa\Delta}(z, z') \simeq C_\ell^{\kappa g}(z, z') - (2 - 5s(z'))C_\ell^{\kappa\kappa}(z, z')$$

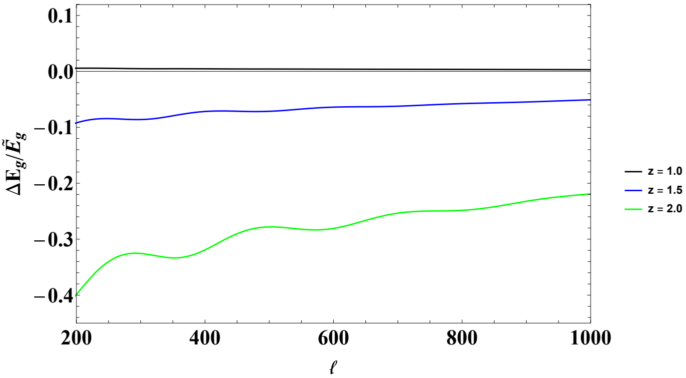
$$\begin{aligned} C_\ell^{\Delta\Delta}(z, z') \quad \simeq \quad & C_\ell^{gg}(z, z') - (2 - 5s(z'))C_\ell^{g\kappa}(z, z') - (2 - 5s(z))C_\ell^{\kappa g}(z, z') \\ & +(2 - 5s(z'))(2 - 5s(z))C_\ell^{\kappa\kappa}(z, z') \end{aligned}$$

The corrections can be considerable!



The corrections for the 1st year DES results setting (the unknown) $s(z) = 0$.
(From Ghosh & Durrer 2019)

E_g statistics corrections for Euclid



The corrections for the Euclidphotometric survey with $s(z)$ taken from Montanari & Durrer (2015). (From Ghosh & Durrer 2019)

Conclusions

- Gravitational lensing does not only generate shear, but it affects galaxy number counts by enhancing the transversal volume (reducing the observed density) and enhancing the flux of sources (enhancing the observed density).
- This effect must be taken into account especially for photometric redshift surveys with relatively large bin widths, $\Delta z/(z+1) > 0.01$, or when correlating different redshifts.
- In high precision spectroscopic surveys, lensing is only relevant at high redshifts and for sparse populations.
- When correlating shear and galaxy counts the lensing effect cannot be neglected.
- Lensing seriously affects e.g. E_g statistics in future surveys.
- Interestingly for the Euclid specifications at $z \simeq 1$, we have $s(z) \simeq 0.4$ and the two effects cancel to good approximation.