COMMENT ON THE CLAIMED RADIAL BAO DETECTION BY GAZTAÑAGA ET AL.

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ABSTRACT

Gaztañaga et al. have recently claimed to measure the Baryon Acoustic Oscillation (BAO) scale in the radial direction from the publicly available SDSS DR6 data. They focus on the correlation function of Luminous Red Galaxies (LRG) close to the line-of-sight direction to find a feature that they identify as the BAO peak, arguing that a magnification bias effect from gravitational lensing increases the amplitude of the BAO peak, facilitating its detection. In this Comment, we clarify that lensing has a negligible impact on the measurement of the BAO peak, and that the interpretation by Gaztañaga et al. is incorrect. The feature they identify in the LRG correlation function near the line-of-sight cannot be explained by any known physical effect and is in fact consistent with noise.

Subject headings: cosmology: theory – galaxies: large-scale structure – gravitational lensing

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The Baryon Acoustic Oscillation peak in the galaxy correlation function was first detected for the Luminous Red Galaxy (LRG) sample of the Sloan Digital Sky Survey (SDSS) by Eisenstein et al. (2005). This detection was still at low statistical significance and was therefore made using the monopole term only, from the angle-averaged correlation function $\xi(r)$, where $r^2 = \sigma^2 + \pi^2$, and $\sigma$ and $\pi$ are the comoving separation across and along the line-of-sight in redshift-space. As the size of future surveys increases, and the covariance and shot noise of the measurements of the correlation function near the BAO scale are reduced, the BAO peak should be fully detectable in redshift-space and its predicted dependence on the angle as well as $r$ should become testable.

Recently, Gaztañaga, Cabré, & Hui (2008, hereafter GCH) have examined the redshift-space LRG correlation function from the Data Release 6 of SDSS, as a function of both $\pi$ and $\sigma$. In their Figures 6 and 7, the Kaiser effect (which squashes the contours of the correlation function owing to peculiar velocities in the linear regime; see Kaiser 1987) seems clearly present out to scales approaching the BAO peak, and the BAO peak seems to be present over the whole sphere in redshift-space. Future analyses should examine the significance at which the BAO peak can be independently detected in different angular intervals. Our comments in this note will be restricted to the claim by GCH of a detected BAO peak close to the line-of-sight.

In their study, GCH focus their attention to the LRG correlation function in a very narrow region ($\sim 0.05$ radians) close to the line-of-sight, to claim the detection of a BAO peak within this region with an amplitude that is much higher than the theoretical expectation. They attribute the large amplitude of their claimed BAO peak to a gravitational lensing magnification effect. They then measure the central position of the peak, which leads them and Gaztañaga, Miquel, & Sánchez (2008) to infer various cosmological implications. The purpose of this note is to clarify that there is no lensing magnification effect that can appreciably impact the BAO peak measurement, and that the feature in the correlation function near the line-of-sight pointed to by GCH as a BAO peak cannot be due to any known physical effects and is consistent with noise.

GCH measure the LRG correlation function near the line-of-sight by averaging over square pixels with side $\Delta \sigma = \Delta \pi = 5h^{-1}$ Mpc, centered at $\sigma = 3h^{-1}$ Mpc and varying $\pi$. They find a peak of this correlation function at $\pi \approx 110h^{-1}$ Mpc with an amplitude $\Delta \xi \approx 0.05$ (see their Figs. 8 and 12). The theoretically expected BAO peak amplitude for a galaxy bias factor $b = 2$ (approximately the correct value for LRGs in the SDSS; e.g., Eisenstein et al. 2005) is about 10 times smaller. GCH nevertheless claim that the peak they find is the BAO peak, attributing this factor of 10 discrepancy in the peak amplitude to a non-linear gravitational lensing effect. However, as discussed in Yoo & Miralda-Escudé (2008, hereafter YM08), the effects of gravitational lensing on the BAO peak are negligible, causing changes in the position and amplitude of the peak of $\sim$ one part in $10^4$ only.

We first clarify the gravitational lensing effect expected in linear theory. The cross-correlation of galaxy density and magnification bias by lensing contributes an additive term to the measured correlation function of LRGs of luminosity greater than $L_\alpha$ at redshift $z$ which, close to the line-of-sight ($\pi \gg \sigma$), is approximated by

$$\xi_{gl}(\sigma, \pi) = 3H_0^2\Omega_m\alpha(1+z)bc_{gm}\pi w_p(\sigma),$$

where the slope $\alpha = -d\log n_g/d\log L - 1$, $n_g(L, z)$ is the number density of galaxies at redshift $z$ with luminosity above $L$ (the derivative in $\alpha$ is evaluated at the luminosity threshold $L_\alpha$ for inclusion in the survey), $b$ is the bias factor, $c_{gm}$ is a galaxy-mass cross-correlation bias, and $w_p$ is the projected mass correlation function. For the SDSS LRG spectroscopic sample, the value of the slope is $\alpha \approx 2$, as inferred for example using the Brown et al. (2007) luminosity function to evaluate $\alpha$ at the threshold luminosity $L_\alpha = 3L_\alpha$ (which yields a LRG density $n_g(L_\alpha) \approx 10^{-2}h^3$ $\text{Mpc}^{-3}$). The cross-correlation bias $c_{gm}$ should be close to unity on the scales that are relevant here, which are larger than the size of virialized halos, unless large-scale galaxy fluctuations are caused by other factors in addition to mass fluctuations. Using $b = 2$ and $c_{gm} = 1$, one finds that $\xi_{gl}$ at the mean redshift of the SDSS sample, averaged within a transverse distance $\sigma < 5.5h^{-1}$ Mpc, has a value $\xi_{gl} \approx 10^{-3}$ at the BAO scale, $\pi = r_BAO$, and is a slowly varying function of $\pi$ (see Figs. 2 and 3 in YM08).

GCH find a value for $\xi_{gl}$ larger by a factor of several because they use $b = 5.8$ and $\alpha = 2.75$ instead (in the notation of GCH, $s = (\alpha + 1)/2.5 = 1.5$; they use $b = 2$ for the galaxy
correlation function is consistent with a roughly constant bias down to the scales that are relevant here, and one should use a consistent value of the bias factor for computing the galaxy correlation function and the galaxy-magnification cross-correlation. The value of $\alpha \approx 2.75$ used by GCH is obtained from the overall slope of the galaxy counts at all redshifts at a fixed apparent magnitude, but the slope of the luminosity function at a fixed redshift should be used instead because the correlation function is measured at a specific redshift from a spectroscopic sample. Even the overestimated lensing effect of GCH is still much smaller than the amplitude of their claimed BAO peak. Moreover, the lensing effect adds a slowly varying function to the galaxy correlation, which does not appreciably change the amplitude or position of the BAO peak. We note in particular that the galaxy correlation function happens to be close to zero near the line-of-sight and at the maximum of the BAO peak, and so the lensing contribution may appear to be large as a fractional change of $\xi(r_{BAO})$; this fractional change is however irrelevant for the purpose of measuring the BAO peak. It is shown in YM08 that the actual fractional amount by which the position and amplitude of the BAO peak are modified by lensing at $z \sim 0.3$ is $\sim 10^{-4}$ within 15 degrees of the line-of-sight, increasing rather slowly as the distance to the line-of-sight is reduced.

GCH argue for the presence of non-linear effects arising from the coupling of galaxy peculiar velocities and lensing magnification. Actually, no such effect may possibly introduce new terms in the correlation function that are larger than the linear effect calculated from equation (1). The lensing contribution $\xi_{gl}$ arises from the correlation of the magnification bias on one line-of-sight with the galaxy density on the other. This is calculated using the non-linear mass correlation $\xi_{mm}$, so the only non-linear effects that are not included are the peculiar velocities on the line-of-sight where the galaxy density is evaluated. Non-linear peculiar velocities can only redistribute the galaxies along the line-of-sight over a scale that is much smaller than the BAO scale $r_{BAO}$, but cannot change the total integrated number of galaxies. Any effects in the galaxy density caused by this redistribution along the line-of-sight become washed out by the integration that is involved in computing the lensing magnification.

Furthermore, the correctness of the theoretical calculation of the lensing effects on the galaxy correlation function using equation (1) is observationally tested by measurements of the average lensing shear around foreground galaxies (Sheldon et al. 2004), as discussed in YM08. This confirms that lensing can introduce only tiny corrections for the measurement of the BAO peak.

In agreement with the GCH analysis, the peak in the LRG correlation function along the line-of-sight near the BAO scale found in the SDSS DR6 is consistent with a noise spike with a probability of $\sim 2\%$ of occurring randomly. For the purpose of estimating this probability, it is sufficient to roughly evaluate the shot-noise contribution to the correlation function error: the number density of LRGs used in SDSS is $n \sim 10^{-3} h^3 \text{Mpc}^{-3}$, and the number of the pixels used by GCH to measure the correlation function is $\sim 500(h^{-1} \text{Mpc})^3$, so each LRG has an average number of pairs in each pixel of $\sim 0.05$. The total number of LRGs used is $\sim 7 \times 10^4$, so the average number of pairs contributing to a pixel is $\sim 3000$. This yields a relative error due to shot-noise of $(3000)^{-1/2} \sim 2\%$ for the correlation function in one pixel, assuming a homogeneous selection function over the survey volume. The values of the correlation in different pixels are of course correlated. The shot noise in this case is dominant, but may be increased by the tendency of LRGs to occur in massive clusters (implying that the correlation function errors may be affected by the presence of a few pairs of massive clusters in the survey with a separation that happens to be close to the BAO scale along the line-of-sight), and by an inhomogeneous galaxy density (due to sampling selection) in the survey. This rough estimate is consistent with the errors calculated in GCH (see their Figs. 8 and 11). In fact, GCH admit that the probability for the peak occurring randomly in their full sample is $3\%$, as obtained from simulations that use the full selection function.

It is important to note that this probability should be considered to be a posteriori, because it is only after having noticed the presence of an unexpectedly high peak in the data for the correlation function near the line-of-sight that one wonders how to explain this peak. An a posteriori probability of $3\%$ should not be considered statistically significant, especially taking into account that there are a number of parameters one may play with, such as the pixel size, the region near the line-of-sight selected for retrieving the correlation function, and the LRG sample redshift interval.

The way GCH obtain a value for the BAO scale $r_{BAO}$ is by using a smoothed version of the data for the correlation function near the line-of-sight as a model to fit the data itself. Their small error for $r_{BAO}$ arises from the fact that they consider a narrow noise spike to be real, and they use the same narrow spike as their theoretical model. The apparently high-precision cosmological constraints obtained by Gaztaña, Miquel, & Sánchez (2008) are a consequence of using the small error bar for $r_{BAO}$ obtained with this invalid method.

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