Galaxies point at each other and mess up measurements of the Universe.
Now with rainbows*!

~~Redshift-dependent RSD bias from Intrinsic Alignment with DESI Year 1 Spectra~~

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People all over the world
collaborated to get the data
we use in this paper

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INFORMATION-DENSE SUMMARY

ABSTRACT

We estimate the redshift-dependent, anisotropic clustering signal in DESI's Year 1 Survey created by tidal alignments of

There will be an unusual clustering pattern in DESI's map of galaxies. It's created by two effects: galaxy orientations are correlated with the underlying dark matter, and galaxy orientations are biased by the way we choose galaxies. Both effects are correlated with galaxy distance, which we can now measure with DESI's spectra. This clustering pattern is the same pattern we use to measure how fast the cosmic web grows, and the balance between dark energy and gravity! This is a problem but we can fix it with the results here.

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*by "rainbows" I mean spectra. More on this later...

BACKGROUND.INFO

You may have heard before that telescopes are time machines because light takes time to travel. Light from a star that's one light year away takes a year to get to Earth, so we see that star as it existed one year in the past.

If aliens 10 light years away are detecting Earth TV signals, they are just about to watch the final season of Breaking Bad...

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Cosmologists take this idea to the extreme and look at how the Universe itself changes over millions of years.

We do this by mapping out the massive web of dark matter in the Unviverse, as traced by glowing galaxies. Over time, gravity draws stuff together and the web becomes more webby.

illinium

To figure out more, we need a very big map of galaxies...

However, it's growing slightly slower than you'd expect from gravity alone...
So what's up? Is gravity slacking? Is Einstein a liar?

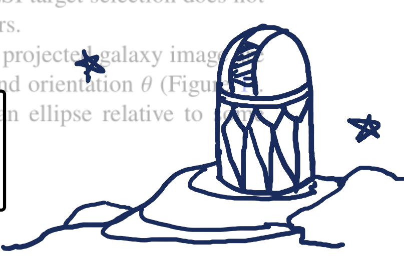
Probably not.

This is where "DESI" comes in, the Dark Energy Spectroscopic Instrument.
We're measuring the positions of 40 million galaxies and making the most complete map of the nearby Universe.

There's a mysterious force out there acting against gravity:
Dark Energy

DESI will measure how fast the cosmic web grows, revealing the balance between gravity and dark energy. In this paper, we explore an effect that will bias these important measurements.

There are easier ways to explore time...



For a similar paper summary on Dark Energy, see this link
For a similar paper summary on a related paper, see this link.

This is what a galaxy looks like to a cosmologist (my apologies to other astronomers)

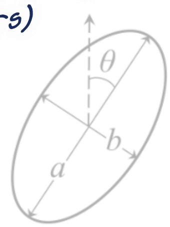


Figure 1. The parameters used to describe the shape and orientation of the ellipse created by projecting an elliptical galaxy. Here, the ellipticity is measured relative to North. For our measurement, ellipticity is measured relative to the positions of a tracer sample.

GALAXY PICTURES

direction usi[illegible]:

We have lovely pictures of each galaxy, which is how we get information about their shape.

$$\epsilon_+ = \frac{a-b}{a+b}\cos(2\theta) \tag{1}$$

DESI's LRG target selection from this catalog includes a cut based on the expected flux which falls within a DESI fiber, which corresponds to a [illegible] The [illegible] tude within the aperture is limited to $z_{\rm fiber} < 21.61$ in the Northern Galactic Cap and $z_{\rm fiber} < 21.60$ in the Southern Galactic Cap. For more information [illegible] al. (2020); Zhou et al. (2020, 2022).

To us, every galaxy is an oval and this is the math we use to describe its shape and orientation.

This shape [illegible] selection is dependent upon imaging quality, which varies across sky regions. To qualify the effect of imaging quality on shape parameters, we separate the LRGs into three sky regions: The MzLS and BASS region, the DECaLS region which does not contain DES imaging, and the DES region. We compare the reported axis ratio, b/a, of the reported galaxy shapes in each region in Figure 2. The MzLS and BASS region reports more eccentric LRG shapes than the other regions, and the region with highest-quality imaging, DES, reports the roundest shapes. While this may indicate an over-correcting of the PSF in MzLS and BASS imaging, we measure the IA signal independently in these regions and do not [illegible] impact on final results (Section 3.2).

GALAXY RAINBOWS

The Universe is expanding. As distant galaxies move away from us, their light becomes stretched and reddened.

We used spectra from DESI's internal data release, Iron, which is comprised of data from commissioning through Year 1 of the survey (DESI Collaboration, in prep). It contains spectra of 2.9 million LRGs [illegible] ations taken during December 14th, 2020 through June 13th 2022 (Zhou et al. 2022; Raichoor et al. 2023; Guy et al. 2023). We used Iron's large-scale structure catalog [illegible] conditions. The catalog contains weights to account for completeness [illegible] also have a weight to account for redshift failures. From this catalog, we ran a basic redshift-quality cut to obtain our final samples of 2.5 [illegible]

Generally:
Redder = farther away.

But it's a little more complicated than that. DESI can gather the light of each galaxy and split it up into a "rainbow", or spectrum.

Rainbows are important because each galaxy has a "spectral fingerprint" we can use to measure exactly how much the light is shifted and how far away the galaxy is.

The projected correlation functions used to calibrate our measurements (Section 3.1) were made with this Year 1 data. Due to internal blinding policies, our estimation of DESI's ξ_2 measurements are calibrated with the smaller, publicly available spectroscopic catalog from DESI's Survey Validation (DESI Collaboration et al. 2023a,b; Lan et al. 2023). Our determination of the ξ_2 signal which arises from IA is independent of the RSD ξ_2 signal.

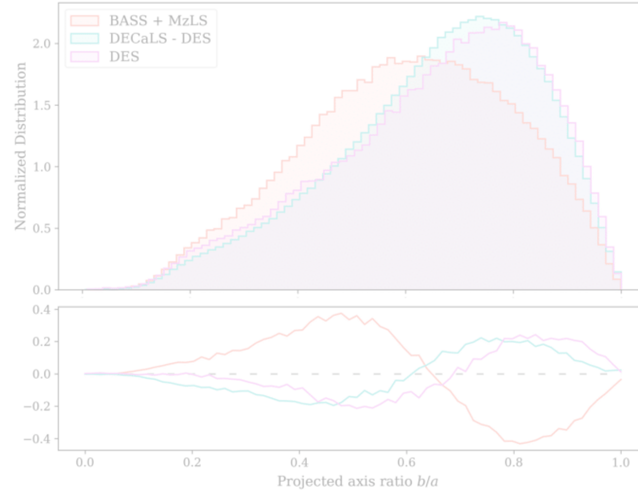


Figure 2. The distribution of projected axis ratios for LRGs in three DESI imaging regions: the North Galactic cap, which contains imaging from MzLS and BASS, the portion of the South Galactic cap which contains DECaLS but no DES imaging, and the DES region. Residuals from the mean are plotted below. These reported shapes have been deconvolved with a point spread function to account for imaging conditions. The region with the highest quality imaging, DES, reports the least eccentric shape.

3 INTRINSIC ALIGNMENT MEASUREMENT

3.1 IA Formalism

As in Lamman et al. (2023b), we measure the correlation between galaxy shapes and density by averaging the ellipticity of each LRG relative to the separation vector between it and nearby galaxies in the tracer sample[1].

$$\mathcal{E}(r_p) = \langle \epsilon_+(a, b, \theta) \rangle \tag{2}$$

For a given galaxy-tracer pair, a and b are the axis lengths of the galaxy shape and θ is the orientation of the galaxy relative to the separation vector between it and the tracer. This is measured as a function of the projected separation between them, r_p.

We limit the separation of pairs along the LOS, r_Π, to $\pm\Pi_{\rm max} = 30h^{-1}$ Mpc. This, along with clustering, is taken into account in our model when estimating how far along the LOS the IA measurement is averaged over.

For measuring the IA of our full LRG sample, we divide the tracer catalog into 100 sky regions based on right ascension and declination with an equal number of galaxies in each. $\mathcal{E}(r_p)$ is measured independently in each region using its tracers and the full shape catalog, then averaged over every pair. This average included the catalog weights described in Section 2.2 for both the shape and tracer sam[illegible] our final measurement.

IA is often quantified using a form of correlation functions generalized to include information about galaxy shapes (Mandelbaum et al. 2006). The IA correlation function relating galaxy shapes and density is

$$\xi_{g+}(r_p, \Pi) = \frac{S_+D - S_+R_D}{R_S R_D}. \tag{3}$$

S_+D is the count of data-data pairs weighted by the orientation

[1] code available here: github.com/cmlamman/ellipse_alignment

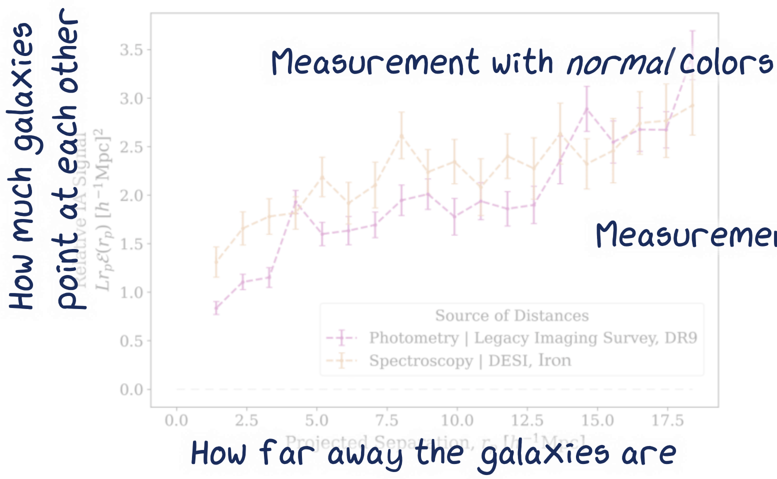


Figure 3. The IA signal of LRGs over the entire redshift range, $0.4 < z < 1.1$, compared to the estimate made in (Lamman et al. 2023b) with photometric distances. The photometric estimate was made with 17.5 million galaxies, compared to 2.5 million LRGs for the spectroscopic sample, but necessarily averaged over a larger radial distance. This is adjusted for here, which shows the "relative" IA signal that has been calibrated by the effective radial depth L.

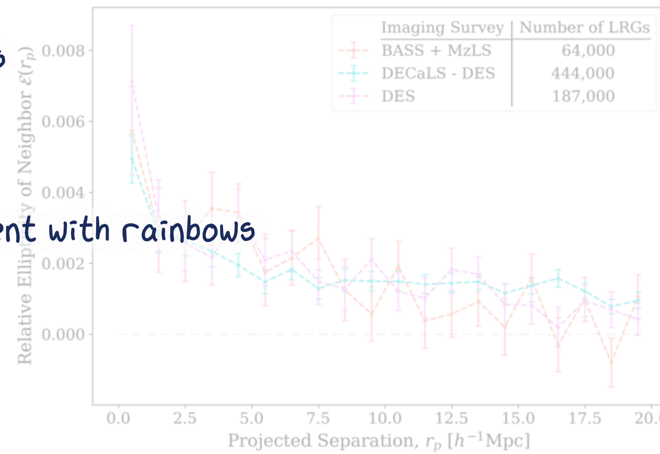


Figure 4. Measurement of the tidal alignment of LRG shapes made independently in areas from three regions of DESI's Legacy Imaging Survey described in Section 2.2. DES has the highest quality imaging, but there is no significant effect on our total averaged IA signal.

GALAXY SHAPES CONNECTED TO WEB

of shapes, S_+, relative to a tracer sample D. Measuring this as function of projected separation and averaging over each data pair, $S_+D(r_p)/DD(r_p)$, is equivalent to $\mathcal{E}(r_p)$. S_+R represents the data shapes relative to a random sample, which has an expectation value of 0. R_SR_D is the random-random count. Integrating ξ_{g+} along the LOS direction, Π, produces the projected IA correlation function:

The first part of our measurement is how the shapes of galaxies are connected to the cosmic web. They typically point towards other galaxies and areas of higher density, aligning along large strands of dark matter.

$$w_{g+}(r_p) = \int_{-\Pi_{max}}^{\Pi_{max}} d\Pi\, \xi_{g+}(r_p, \Pi). \quad (4)$$

For predicting the RSD bias that arises from IA, $\mathcal{E}(r_p)$ is the most direct [illegible] pairs, not randoms. DD can be expressed as

$$DD(r_p) = RR \int_{-\Pi_{max}}^{\Pi_{max}} d\Pi \frac{DD(r_p,\Pi)}{RR}$$
$$= RR \int_{-\Pi_{max}}^{\Pi_{max}} d\Pi(1 + \xi(r_p, \Pi)) = RR(2\Pi_{max} + w_p(r_p)). \quad (5)$$

Here ξ and w_p are the typical correlation function and projected correlation function, as opposed to those weighted by shape alignments. w_{g+} can be expressed as

The math we use to describe how these shapes are connected to the cosmic web.

$$w_{g+}(r_p) = \frac{1}{RR} \int_{-\Pi_{max}}^{\Pi_{max}} d\Pi\, S_+D(r_p, \Pi) = \frac{S_+D(r_p)}{RR}. \quad (6)$$

Therefore, a given w_{g+} and $\mathcal{E}$ made with the same Π_{max} and same clustering w_p are related as

$$w_{g+}(r_p) = (2\Pi + w_p(r_p))\mathcal{E}(r_p) = L\mathcal{E}(r_p) \quad (7)$$

Here we have introduced L, which can be understood as the effective LOS distance that $\mathcal{E}$ is measured over, adjusted to account for clustering which [illegible] of pairs. L is included in our final model of the RSD bias (Section 5)[2]. While $L\mathcal{E}$ is functionally equivalent to w_{g+}, we notate L and $\mathcal{E}$ separately to be explicit about [illegible]

We take care to describe other ways people measure this and how they're related to our method.

We can compare our spectroscopic IA measurement with a similar one made with photometric data (Lamman et al. 2023b) by scaling by L, as shown in Figure 3. Although made with seven times fewer galaxies, the spectroscopic sample from Iron can be measured in smaller LOS bins and provide us with similar level of precision.

Spectroscopic data also allows us to better isolate the sample in radial bins and explore redshift-dependence. To compare our IA signal between samples of different target classes and redshift distributions, $\mathcal{E}(r_p)$ needs to be calibrated by L as well as the galaxy clustering bias, b. For bias-independent comparisons, we scale by a relative bias. The bias of a sample 2 relative to sample 1 is

$$\frac{b_2}{b_1} = \frac{D(z_1)}{D(z_2)}\left(\frac{w_{p2}}{w_{p1}}\right)^{1/2}, \quad (8)$$

where $D(z)$ is the linear growth function.

Therefore, when comparing IA measurements across samples we use the value $(L/b_{rel})\mathcal{E}(r_p)$. While L is taken into account when estimating the final RSD bias, b does not affect the final result. This is because the amplitude of the power spectrum quadrupole effect arises from the correlation of the galaxy density field and the selection-induced shape polarization, the latter of which is independent of bias.

When calculating distances and the growth factor, we assume a flat ΛCDM cosmology with $\Omega_m = 0.286$, $\Omega_\Lambda = 0.714$ and $H_0 = 69.6\ \mathrm{km\ s^{-1} Mpc^{-1}}$.

DO BAD PICTURES = BAD MEASUREMENTS?

3.2 Dependence on Imaging Region

The amplitude of IA can strongly depend upon imaging quality and the methods used to estimate shapes. This is in part due to difficulties in accurately modeling imaging processes, and in part due to isophotal twisting (Fasano & Bonoli 1989), which causes the outer regions of galaxies to have a stronger alignment signal than the inner regions. This has been explored in BOSS LOWZ, DES, and LSST (Singh et al. 2015; Zuntz et al. 2018; Leonard et al. 2018; Georgiou et al. 2019; MacMahon & Leonard 2023). This is a concern for our imaging catalog, as imaging quality and depth vary across regions (Figure 2). A lower signal due to poor imaging will result in an underestimate of our final estimate of the RSD bias.

Unfortunately, real galaxies are more complicated than just ovals.

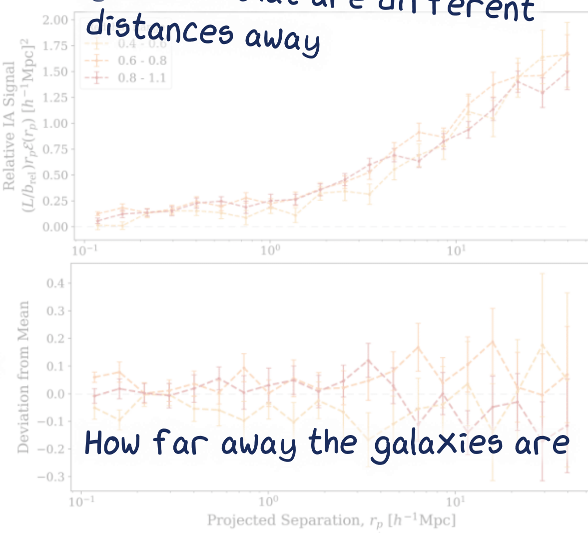
In this section we check that the way we measure galaxy shapes won't affect our final results.

To quantify the impact of imaging quality, we compare our IA signal across the three different imaging regions used in the Legacy Imaging Survey: DES, DECaLS, and MzLS+BASS. Each region has varying survey completeness, so to avoid edge effects we made these

[2] L here is equivalent to L_{eff} in Lamman et al. (2023b)

Measurements made with galaxies that are different distances away

How much galaxies point at each other

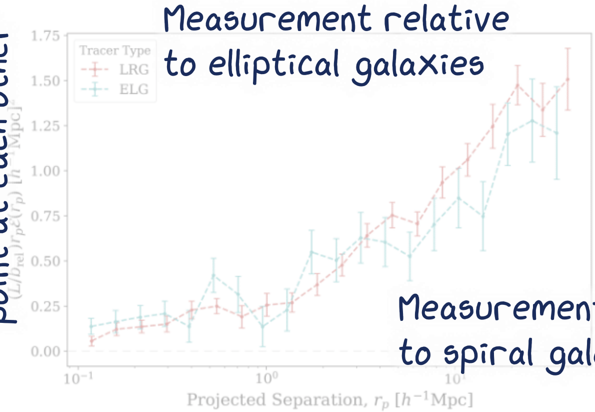


How far away the galaxies are

Figure 5. Comparison of the intrinsic alignment of LRGs between spectroscopic redshift bins. The y-axis is scaled by the effective depth of the measurement L and the galaxy bias $b_{\rm rel}$, which here is defined as $b_{\rm rel}(z = 0.7) = 1$. These were calculated using the projected correlation function from DESI's Year one data. Errors here only include the statistical difference of the signal between sky regions and not from b or L. Nearby galaxies broadly display a weaker alignment, though here we have not accounted for luminosity differences across samples.

Measurement relative to elliptical galaxies

How much galaxies point at each other



Measurement relative to spiral galaxies

How far away the galaxies are

Figure 6. Correlation between LRG shapes and the underlying galaxy density, as traced by both LRGs and ELGs. These samples are both in the redshift range $0.8 < z < 1.1$. For comparison, this IA signal is scaled by the samples' clustering, as described in 3.1.

measurements in a limited area with the most completeness in each region. The result and size of each sample is shown in Figure 4. We do not find a significant difference in the signals, which is in part due to measurement noise. Additionally, although the BASS and MzLS imaging may be over-correcting for the PSF and producing more eccentric shapes, systematic imaging effects are uncorrelated with the tidal field. A small change in ellipticity doesn't propagate as an order-unity error on this signal, which is a very small response to the tidal shear. This may be still be an issue for higher signal-to-noise detections beyond DESI Year 1.

HOW THE MEASUREMENT CHANGES WITH DIFFERENT GALAXY SAMPLES

As a null test, we reproduced this measurement using the cross-component of shape, $e_\times = \frac{a-b}{a+b}\sin(2\theta)$ instead of e_+ in Equation 2. This was consistent with 0 on all scales.

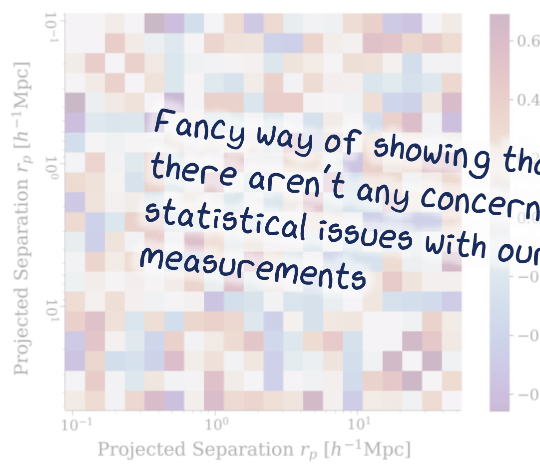
We split our galaxies into three samples based on how far away they are.

3.3 Dependence on Redshift and Tracer Sample

The redshift dependence of IA is unclear (Samuroff et al. 2021; Zhou et al. 2023; Samuroff et al. 2023), and cannot be directly observed without accounting for luminosity differences across redshift bins. DESI's LRG sample is designed to have a constant co-moving volume with redshift, which results in more luminous, and therefore more aligned, galaxies in high-redshift samples. However, since we are only inferring a systematic bias and not any physical trends, we only require the IA of each sample. The IA RSD bias is proportional to the amplitude of this signal, so if not properly accounted for, it could manifest in DESI's results as a false evolution of the growth rate as measured by the quadrupole of the correlation function. Therefore we separate our LRG tracer sample into three sub-samples based on redshift and measure the correlation of LRG shapes in each.

We see a slight different in the signal between these samples, which we'll take into account in our final results.

The samples are plotted in Figure 5 and displayed in Table 1. To compare the strength of tidal alignment between redshifts, the signal is adjusted based on the clustering in each sample, as described in Section 3.1. As expected, we find the weakest signal for nearby galaxies ($0.4 < z < 0.6$).



Fancy way of showing that there aren't any concerning statistical issues with our measurements

Figure 7. The reduced covariance matrix of $\mathcal{E}$ between bins of transverse separation for our IA measurement with LRG tracers across the full redshift range. The identity matrix has been subtracted from this plot. This demonstrates that there is no evidence for significant correlations between the measurements of $\mathcal{E}$ in each bin of projected separation.

We also measured the alignment of LRGs to the tidal field as traced by ELGs, [illegible] LRG sample (Figure 6). In the overlapping redshift range of the LRG and ELG samples, $0.8 < z < 1.1$, we find a similar IA signal once both samples are adjusted for clustering. Although some regions of DESI's Year one footprint are less complete for ELGs, this is accounted for in the catalog completeness weights described in Section 2 and we find no impact of this on our IA measurement.

Different types of galaxies trace the cosmic web in different ways. For example, big elliptical galaxies are more likely to be found in very dense areas over spiral galaxies.

A covariance matrix for the spectroscopic LRG measurement made over all redshift ranges is shown in Figure 7 and demonstrates no correlation between the bins of projected separation that the IA measurement $\mathcal{E}$ was made in.

Here we see how our results change if we measure galaxy shapes relative to the positions of spiral galaxies

4 SELECTION-INDUCED SHAPE POLARIZATION

The final RSD bias is proportional to both the degree to which galaxies are aligned along the tidal field (IA) and the degree to which galaxies are aligned along the LOS due to target selection, or "shape polarization". For DESI, the latter plays a strong role in the redshift

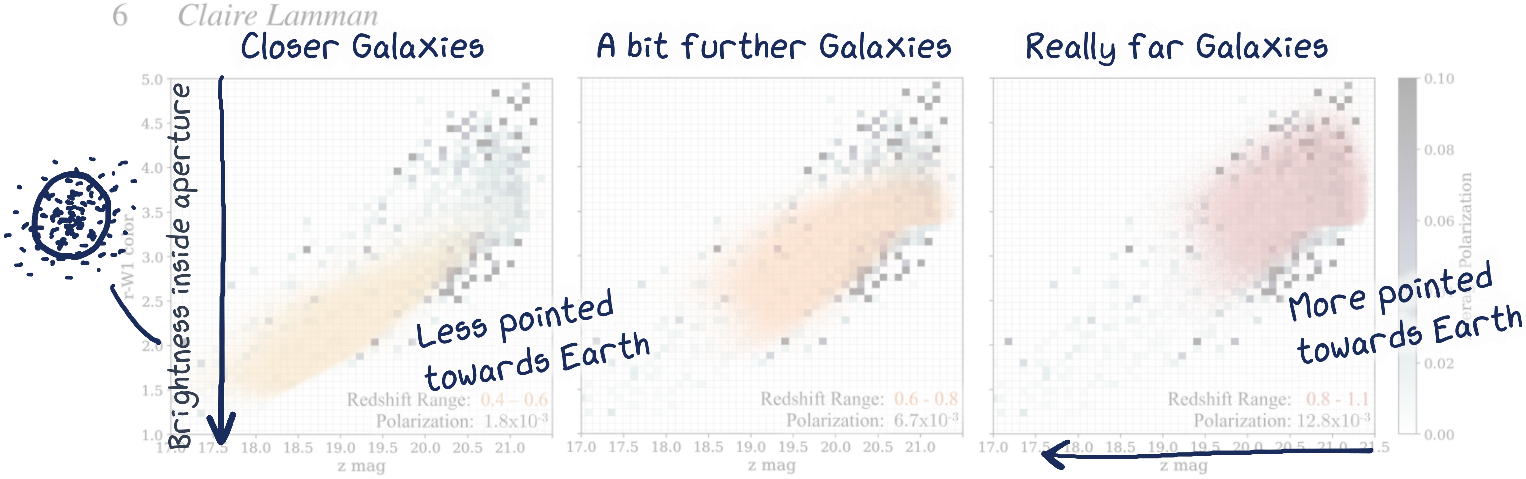


Figure 8. Estimates of shape polarization for each of the three redshift bins, or the tendency for these samples to have shapes aligned with the LOS due to an aperture magnitude cut. These are based on the model in (Lamman et al. 2023b), shown in grey, which estimates the polarization in bins of color and magnitude for a sample of LRGs ... redshift bin is the average of each galaxy's polarization corresponding to its respective color bin. The highest redshift sample contains redder, fainter galaxies which are closer to the survey cuts and therefore more likely to have biased galaxy orientations.

The redder, more distant galaxies are more affected by the bias in shape orientations.

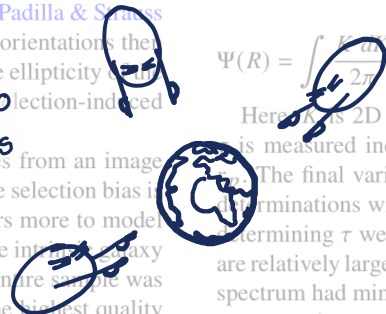
dependence of the RSD bias. Redder, fainter galaxies fall closer to the aperture-magnitude cut that is used to select DESI targets. Therefore their orientation will have a stronger impact on whether or not they are selected; an elongated galaxy aligned with the LOS will have more light concentrated within a sky aperture.

GALAXIES ARE POINTING AT EARTH???

Lamman et al. (2023b) estimated the shape polarization of DESI LRGs from a parent sample without the aperture-magnitude cut. This was done by generating many 3D light profiles for each galaxy based on the expe... ...es from Padilla & Strauss (2008). These light profiles were assigned random orientations then put through an aperture-magnitude cut. The average ellipticity of the selected sh... ...LOS is the selection-induced shape polarization.

As this selection is done on aperture magnitudes from an image deconvolve... ...the shape selection bias is relatively independent of imaging quality. It matters more to model this effect with imaging that most closely reflects the intrinsic galaxy shape. The ... estimate for the entire sample was made using the portion of DESI's footprint with the highest quality imaging, the DES region. Although this results in a noisier measurement, only the average polarization of a sample affects the final RSD bias.

...well, not because we're special or anything. There's a VERY small tendency for galaxies to be pointing at us. And it's only in the sample of galaxies that DESI has chosen to observe.



You can read more about this in another paper I wrote.

To estimate the polarization of the LRG redshift samples, we averaged the polarization estimates from the parent sample in bins of color and ... LRGs in ... polarization based on the average in their corresponding bin, and their total average is the polarization estimate of that sample. This was not done for the ELG sample, which were only used as tracers. A demonstration of this mapping can be see in Figure 8 and the results are also displayed in Table 1. It is important to note that the polarization varies more across redshift bins than the IA signal, meaning that the redshift dependence of the final RSD bias is more dependent on survey selection than physical alignments.

We took the results of that paper and looked at how this effect changes in samples of galaxies that are different distances away from Earth.

HOW IT ALL COMES TOGETHER

5 FALSE RSD SIGNATURE IN DESI

To estimate the RSD bias created by the combination of IA and the selection-induced polarization, we use a nonlinear tidal model adopted from La...

This section connects everything talked about so far with the main thing we care about for this paper: how are the measurements of structure growth affected?

in this paper; we give only the results here. We have made minor notation changes for clarity.

The IA signal $\mathcal{E}$ is combined with the effective LOS-distance L, described in Section 3.1, and the nonlinear power spectrum P as τ:

$$\tau = \frac{2L(r_p)\mathcal{E}(r_p)}{r_p \frac{d}{dr_p}\left[\frac{1}{r_p}\Psi\right]}, \tag{9}$$

$$\Psi(R) = \int \frac{K\,dK}{2\pi}\frac{P(K)}{K}J_1(KR) \tag{10}$$

Here K is 2D Fourier Space and J_1 is the first Bessel function. τ is measured independently in each bin of transverse separation, r_p. The final variable used in our result, $\bar{\tau}$, is the average of these determinations with standard error. The transverse bins we used for determining τ were linear bins between $5-20h^{-1}$Mpc. Since these are relatively large scales, the change from a linear to nonlinear power spectrum had minimal effects on our final result, though it produced more consistent values of τ across the transverse bins.

The "false" signature this produces in the quadrupole of the correlation function, $\xi_{2,\,\mathrm{gI}}$, is

$$\xi_{2,\,\mathrm{gI}}(s) = \epsilon_{\mathrm{LOS}}\frac{\bar{\tau}}{2\sigma_{E1}^2}\int \frac{q^2dq}{2\pi^2}P(q)j_2(qs). \tag{11}$$

Here, ϵ_{LOS} is the selection-induced shape polarization, σ_{E1}^2 is the variance of the shape parameter ϵ_+ described in Section 2, j_2 is the second spherical Bessel function, and s is 3D separation. The relations most relevant for this study can be summarized as

$$\xi_{2,\,\mathrm{gI}} \propto \epsilon_{\mathrm{LRG}}\frac{\bar{\tau}}{\sigma_{E1}^2} \propto \epsilon_{\mathrm{LRG}}\frac{L\mathcal{E}}{\sigma_{E1}^2}. \tag{12}$$

Note that this result is independent of the amplitude of the power spectrum and galaxy bias, b. This is because $\xi_{2,\,\mathrm{gI}}$ arises from the correlation of the galaxy density field and the selection-induced shape polarization, the latter of which is independent of bias. It does depend on the projected correlation function w_p through L. Also, since the IA signal only affects $\xi_{2,\,\mathrm{gI}}$ through $\bar{\tau}$, which can be determined in transverse bins independently, we can forecast $\xi_{2,\,\mathrm{gI}}$ beyond the projected scales used to measure $\mathcal{E}$. ...variables measured for this estimate are listed in Table 1

Here's a summary of all the main measurements we need to put together for our result

Tracer	z_{min}	z_{max}	N	σ^2_{E1}	ϵ_{LOS}	$\bar{\mathcal{E}}(0 <$ [illegible]$)$	[illegible]	[illegible]$(5 < r_p < 18)$	$\bar{\xi}_{2,\,gI}(5 < s < 80)$
LRG	0.4	0.6	5298[illegible]2	0.046	2.3×10^{-3}	1.8×10^{-3}	[illegible] h^{-1}Mpc	$5.9 \pm 0.5 \times 10^{-3}$	0.044
LRG	0.6	0.8	80[illegible]	[illegible]	[illegible]7×10^{-3}	2.1×10^{-3}	$94.9\ h^{-1}$Mpc	$7.0 \pm 0.2 \times 10^{-2}$	0.22
LRG	0.8	1.1	896150	0.026	12.8×10^{-3}	1.8×10^{-2}	$92.9\ h^{-1}$Mpc	$5.6 \pm 0.2 \times 10^{-2}$	0.41
ELG	0.8	1.1	591687	0.026	12.8×10^{-3}	1.9×10^{-3}	$73.2\ h^{-1}$Mpc	$4.3 \pm 0.3 \times 10^{-2}$	0.34

Table 1. Samples and values used to estimate the RSD bias for three LRG redshift bins and the LRGxELG cross-correlation. r_p and s are given in units of h^{-1}Mpc. The tracer samples used in the top three rows were also used as the shape sample. The last row uses ELG tracers with LRG shapes. The table shows the redshift range and number N of tracers used, and properties of the shape sample: the variance of the real component of ellipticities σ^2_{E1} and the estimated selection-induced polarization of shapes along the LOS, ϵ_{LOS}. We do not include uncertainties for these columns as they have negligible statistical errors. The IA signal $\mathcal{E}(r_p)$ is measured as the ellipticity of shapes relative to the tracer sample. $L(r_p)$ is the effective LOS-distance that $\mathcal{E}(r_p)$ is averaged over. $\tau(r_p)$ is defined in Equation 9 and is a combination [illegible] transverse separation, r_p and are shown in this table as averages over the marked scales. The final column shows the average amplitude of the anisotropic clustering created by IA; the quadrupole of the correlation function without RSD effects. The full estimate of this final result along with the statistical error is shown in Figure 9.

...and this is the main plot showing that result!

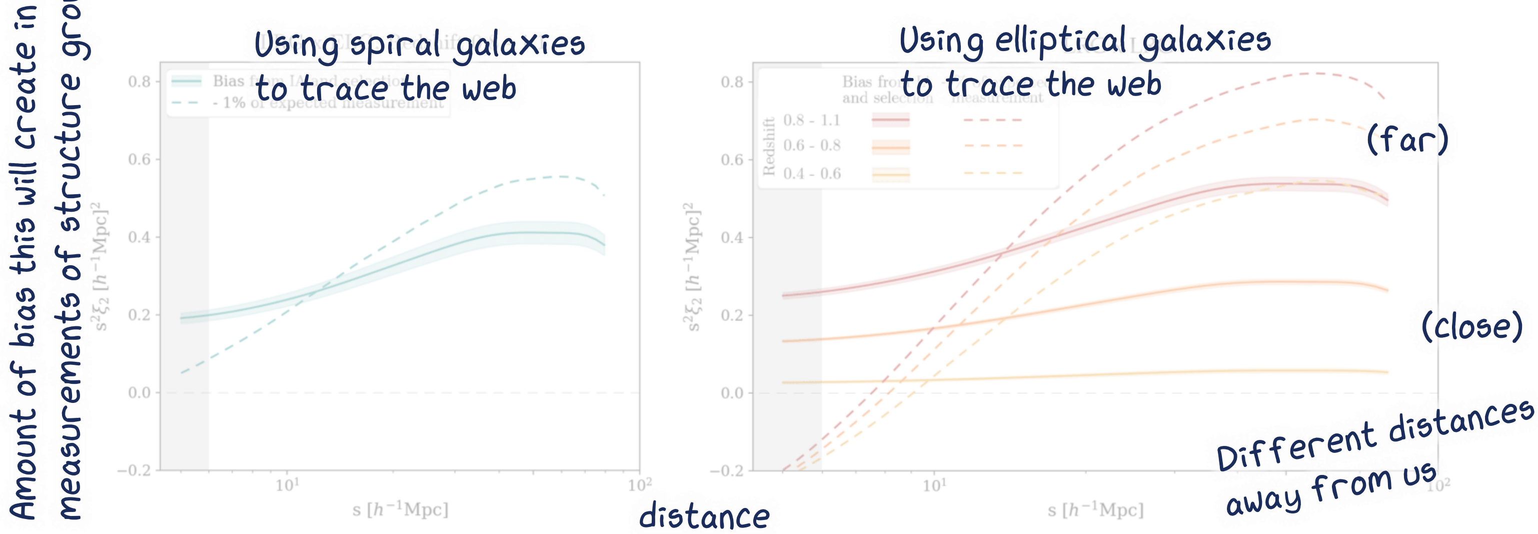


Figure 9. The anisotropic clustering signal arising from tidal alignment and a selection bias, $\xi_{2,\,gI}$. Statistical errors are shown in the shaded bands, although the total errors are dominated by systematic effects (Section 6). For context, we have also plotted 1% of the expected ξ_2 signal from RSD. This is well above DESI's error budget for measuring the growth rate of structure, which is 0.4-0.7% for LRGs and ELGs combined. Since the ξ_2 signal created by the growth of structure is opposite in sign to that created by IA, we have multiplied the RSD ξ_2 by -1 for an easier comparison. This plot demonstrates that IA will dampen DESI's RSD measurements to a degree that is a significant fraction of the error budget, particularly at higher redshifts. Incorporating these estimates into the ξ_2 measurement will mitigate this effect.

$\boxed{\text{The "fake" clustering pattern}} \propto \boxed{\text{How much the shapes of galaxies correlate with large-scale structure}} \times \boxed{\text{How much galaxies in the survey tend to be pointed towards Earth}}$

and the fin[illegible]ad[illegible]gnature for all our samples is shown in Figure 9. To provide context for this signal, we estimate the total quadrupole signatures ξ_2 expected for these galaxy samples. They are based on HOD [illegible] made with the AbacusSu[illegible] (Hadzhiyska et al. 2021; Maksimova et al. 2021; Yuan et al. in prep. 2024), and scaled with measurements from DESI's Survey Validation (DESI Collaboration et al. 2023b). Figure 9 shows 1% of these estimates, which is well above DESI's total error budget for measuring ξ_2. Since the ξ_2 signal created by the growth of structure is opp[illegible] line by -1 for a clear comparison. On the scales used to measure $f\sigma_8$ ($10 < s < 80\ h^{-1}$Mpc), ξ_2 for LRGs will be dampened by around 0.1[illegible] between redshifts 0.4-0.6, 0.53% between redshifts 0.6-0.8, and 0.80% between redshifts 0.8-1.1. ξ_2 as measured by LRG x ELG cross-correlations will be biased by around 0.83% between redshifts of 0.8-1.1.

Like I did in the real paper, here I'll copy and paste some of the information from my last paper for easy reference. The main idea is that the more galaxy correlation we see, and the more bias there is in galaxy shapes, the more DESI's measurements will be affected.

We used a Nonlinear Alignment model, which has shown to be valid down to 6 h^{-1}Mpc for LRGs (Singh et al. 2015). In principle our estimate can be extended down to the scales of the Fingers of God effect, where peculiar velocities of galaxies create a "smearing" along the LOS, as opposed to the "squashing" created by structure growth (Jackson 1972). Here, the sign of ξ_2 switches and this bias will result in an enhancement of the signal. However, as nonlinear effects become more apparent here and this effect is less relevant for DESI's main science goals, it is most valuable to interpret the [illegible] large scales.

6 CONCLUSION

We measure the tidal alignment of LRGs with DESI Year 1 red-shifts, using both LRG and ELG tracers. We also estimate a redshift-[illegible] arises from an aperture-based target selection. Using a nonlinear tidal model, we calculate the signal this will create in DESI's measurements of the quadrupole of the correlation function. It ranges from 0.2-1.1% of the quadrupole signal created by RSD, a significant fraction of DESI's full-survey error budget of around 0.4-0.7% for measuring the growth rate with LRGs and ELGs combined.

The RSD bias is over five times larger in the highest redshift sample, $0.8 < z < 1.1$, than the lowest, $0.4 < z < 0.6$. This is partially due to a stronger alignment signal, but mostly due to the selection effect. Galaxies at higher redshifts are redder and fainter, falling closer to the target selection cuts. Therefore their orientation has a stronger

CONCLUSION

Correlations between galaxy orientations and the cosmic web combine with a bias in galaxy orientations and mess with our measurements of how the cosmic web is growing.

This is not a new idea, but we are able to measure this effect with some of DESI's first data, allowing us to see how it changes with more distant galaxies. We find it's a bigger deal for more distant galaxies, mostly because they're fainter and more likely to have biased orientations.

Without the corrections in this paper, DESI could underestimate the growth rate of structure, therefore overestimating the effects of dark energy.

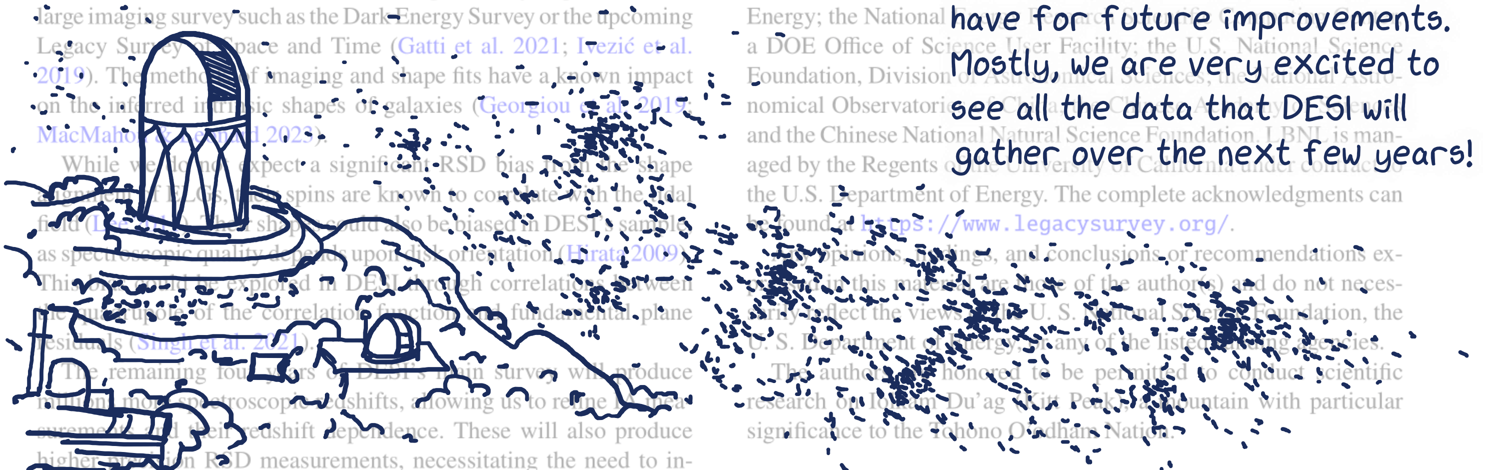
influence on whether or not they pass the aperture magnitude cut and the sample has a stronger orientation polarization. If uncorrected for, this redshift-dependent bias will suppress measurements of the growth rate ... will also bias determinations of how the growth rate evolves, a critical estimator for constraining cosmological models (Kazantzidis & Perivolaropoulos ...). ... created by IA presented here can be used to mitigate this bias.

These results agree with the previous work in Lamman et al. (2023) ... and estimated that it will produce around a 0.5% decrease on measurements of $f\sigma_8$ with the full LRG sample. While large, upcoming photometric surveys can provide constraints on IA, for this effect it's most important to understand the IA of our particular sample. Additionally, redshifts are necessary to make clean distant cuts to explore redshift ...

The largest uncertainty in our final results comes from systematic effects in the estimate of the selection-induced shape polarization. This is sensitive to assumptions in the light profiles used for mock selection and the underlying triaxial distribution of shapes, which is based on SDSS imaging (Padilla & Strauss 2008) and not in clear agreement with comparable galaxies in hydrodynamic simulations (Bassett & Foster 2019). This could be significantly improved with a large imaging survey such as the Dark Energy Survey or the upcoming Legacy Survey of Space and Time (Gatti et al. 2021; Ivezić et al. 2019). The method of imaging and shape fits have a known impact on the inferred intrinsic shapes of galaxies (Georgiou et al. 2019; MacMahon & Joachimi 2023).

While we do not expect a significant RSD bias from the shape alignment of ELGs, their spins are known to correlate with the tidal field (...), so their shapes could also be biased in DESI's sample as spectroscopic quality depends upon disk orientation (Hirata 2009). This could be explored in DESI through correlations between the ... of the correlation function and fundamental plane residuals (Singh et al. 2021).

The remaining four years of DESI's main survey will produce millions more spectroscopic redshifts, allowing us to refine ... measurements and their redshift dependence. These will also produce higher precision RSD measurements, necessitating the need to incorporate the anisotropic clustering effect caused by IA.



Here we also discuss what we see as the biggest sources of error in our results and the ideas we have for future improvements. Mostly, we are very excited to see all the data that DESI will gather over the next few years!

WE DIDN'T DO IT ALONE

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The DESI Legacy Imaging Surveys consist of three individual and complementary projects: the Dark Energy Camera Legacy Survey (DECaLS), the Beijing-Arizona Sky Survey (BASS), and the Mayall z-band Legacy Survey (MzLS). DECaLS, BASS and MzLS together include data obtained, respectively, at the Blanco telescope, Cerro Tololo Inter-American Observatory, NSF's NOIRLab; the Bok telescope, Steward Observatory, University of Arizona; and the Mayall telescope, Kitt Peak National Observatory, NOIRLab. NOIRLab is operated by the Association of Universities for Research in Astronomy (AURA) under a cooperative agreement with the National Science Foundation. Pipeline processing and analyses of the data were supported by NOIRLab and the Lawrence Berkeley National Laboratory. Legacy Surveys also uses data products from the Near-Earth Object Wide-field Infrared Survey Explorer (NEOWISE), a project of the Jet Propulsion Laboratory/California Institute of Technology, funded by the National Aeronautics and Space Administration. Legacy Surveys was supported by: the Director, Office of Science, Office of High Energy Physics of the U.S. Department of Energy; the National Energy Research Scientific Computing Center, a DOE Office of Science User Facility; the U.S. National Science Foundation, Division of Astronomical Sciences; the National Astronomical Observatories of China, the Chinese Academy of Sciences and the Chinese National Natural Science Foundation. LBNL is managed by the Regents of the University of California under contract to the U.S. Department of Energy. The complete acknowledgments can be found at https://www.legacysurvey.org/.

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The authors are honored to be permitted to conduct scientific research on Iolkam Du'ag (Kitt Peak), a mountain with particular significance to the Tohono O'odham Nation.

SEE THE DATA YOURSELF

DATA AVAILABILITY

You can find the publicly available data we used here

The DESI Legacy Imaging Survey is publicly available at legacysurvey.org and DESI's Early Data Release is publicly available at data.desi.lbl.gov/doc/releases/edr. ... covers the DESI Year 1 sample and will be publicly released as part of DESI Data Release 1 (DR1). AbacusSummit ... abacusnbody.org. Code for projecting ellipsoids and generating light profiles can be found at github.com/cmlamman/ellipse_alignment.

Data plotted in this paper are available at zenodo.org/uploads/10162040.

WE DIDN'T START FROM SCRATCH

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This project is built upon the work and ideas of others, and is part of an ongoing scientific conversation

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