Motivation

- The Baryonic Acoustic Feature has been detected to a significance of $5\sigma$ (WiggleZ+SDSS-II+6dFGRS; Blake et al. 2011c)
- So far the feature has been mostly used to measure the degenerate combination: $D_A^2/H$
- The ultimate holy grail is measuring $H(z)$ independently in order to examine the nature of the accelerating Universe
Discussion

- Within redshift clustering - *going under the hood*

- With various data sets (SNe, photometric clustering and other distance measures)
The Baryonic Acoustic Feature as a Standard Ruler

\( r_s \rightarrow D_A \left( z_{\text{dec}} \right) \)

Surface of last scattering \( z \sim 1100 \)

\( D_A^2 / H \left( \langle z \rangle \right) \)

Larson et al. (2010)

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Doing better than $D_A^2/H$

- For S/N reasons, most observational studies focus on angle averaged $\xi_0$ signals.
- Due to geometric arguments, the information in $\xi_0$ is degenerate: $D_A^2/H$.
- Anisotropic clustering constrains $D_AH$:
  - 2D plane ("$\pi-r_p$"), 1D statistics ($\xi_2$ or $\xi(\Delta\mu)$)
Disentangling $H-D_A$ Degeneracy
(simulated results)

$\xi_0 \xi_2$ (BLUE):
$H/H_{\text{TRUE}}^{(1D)} = 1.00080$  $H/H_{\text{TRUE}}^{(2D)} = 1.00111$
$\Delta H/H = -0.422\% +0.437\%$
$D_m/D_m^{\text{TRUE}}^{(2D)} = 0.99904$  $D_m/D_m^{\text{TRUE}}^{(2D)} = 0.99930$
$\Delta D_m/D_m = -0.356\% +0.357\%$

Kazin, Sanchez and Blanton (2012)

monopole only
$\sim D_A^2/H$

monopole & quadrupole

distorted cosmology (AP effect)
Redshift Distortions: Dynamical vs. Geometrical

Dynamical: squashing (Kaiser 1987), Finger of God

Geometrical: AP effect (Alcock & Paczynski 1979)

\[ \chi(z) = c \int_{0}^{z_{\text{obs}}} \frac{dz'}{H(z', \Omega)} \]
The Alcock Paczynski effect

Template (here I use mock true signal)

``data” (here I use mock signal affected by AP)

fit (here I fit Template to ``data” varying $H$ and $D_A$)
Disentangling $H$-$D_A$ Degeneracy (mock galaxy results)

Hexadecapole $\xi_4$ improves $H$ constraints (See also Taruya et al. 2011)
Redshift distortions arise due to two factors: geometric and dynamic.

**THEORY**

The solid contour lines, following the color scheme, correspond to the true distance. The dashed lines show the geometric distortions of the clustering signal along the line of sight. The right-hand panel illustrates the equivalent measure in real space.

**Figure 1.**

Clustering 2D plane $\xi(\mu,s)$

**Kazin, Sanchez & Blanton (2011)**

Mean two-dimensional correlation functions $\xi$ of the observed distribution of galaxies are shown. The solid contour lines correspond to the true distance, and the dashed lines show the geometric distortions. These distortions are more noticeable at large scales, though they are also present on small scales.

One way of overcoming these effects is to recalculate the clustering statistics for every set of parameters when determining cosmological constraints. However, that approach is currently not practical. Instead, we calculate the clustering signal along the line of sight, and the dashed lines show the effects.

The right-hand panel illustrates the equivalent measure in real space. Meaning, the solid lines correspond to the true distance. These distortions are more noticeable at large scales, though they are also present on small scales.
Clustering
2D plane
$\xi(\mu,s)$
Clustering Wedges $\xi_{\parallel}, \xi_{\perp}$ are complementary to multipoles
We use COSMOMC (Lewis & Bridle 2002) to combine the WMAP7 data (Komatsu et al. 2011) to derive constraints on cosmological parameters.

For BAO measurements from the various galaxy surveys with low.

We are including our best fit on selective parameters that are derived using COSMOMC (i.e., a larger BAO at a smaller scale than the concordance cosmology), in-
cluding our result for the whole ensemble of spectra by Mehta et al. 2011), which has not been accounted in this paper is shown with the black horizontal line. The gray shade represents 1σ constraints on cosmological parameters. For BAO measurements from the various galaxy surveys with low.

The derived cosmological parameters.

The BAO feature we measured, we shift the wavenumbers of the data beyond the redshifts of the data. One sees that the data beyond the BAO at a slightly smaller scale (i.e., a larger distance than the concordance cosmology), in-
We converted our Alcock-Paczynski measurements of the 4 DETERMINATION OF THE COSMIC are necessary to produce these fits. Our results are therefore insensitive to the model adopted much lower than the statistical error in the measurement. Alcock-Paczynski distortion fits.

al. 2011). In order to show that this does not introduce any acoustic oscillations (which do not appear in a smooth polynomial model) are not contributing any information to the inclusion of the supernovae systematics covariance matrix (compared to uncorrelated errors excluding systematic). This Figure displays our measurement of the evolution of the cosmic expansion rate using Alcock-Paczynski and supernovae data. The expansion rate is displayed using the value of the cosmic distance-redshift relation. We used the "Union-2" compilation by Amanullah et al. (2010) as our supernovae dataset, obtained from the website http://supernova.lbl.gov/Union.

Given that the normalization of the supernova Hubble parameter, the supernovae data yields the relative luminosity distance proportional to:

\[ D_L(z) = \frac{c}{H_0} \int_0^z \frac{dz}{H(z)} \]

\[ H(z)D_A(z) \]

We conclude from these tests that the systematic error induced from modelling redshift-space distortions is zero, and that the accuracy of the distance is measured by a statistic of 486 degrees of freedom.

The supernovae data is treated as an unknown parameter, the supernovae data yields the relative luminosity distance proportional to:

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This Figure displays the best-fitting 3rd-order polynomial fit to the observational data.

\[ F(z) = H_0 D_L(z) = H(z)D_A(z) \]

Blake et al. (2011)
### What methods & data are out there?

<table>
<thead>
<tr>
<th>data type</th>
<th>measures</th>
<th>survey, z</th>
</tr>
</thead>
<tbody>
<tr>
<td>z clustering</td>
<td>((D_A^2/H(z))/r_s^3, H(z)D_A, D_A/r_s, H*r_s)</td>
<td>SDSS-II &lt;0.5, SDSS-III &lt;0.7, &lt;3.5, WiggleZ&lt;0.8, HetDex 1.9&lt;z&lt;3.5</td>
</tr>
<tr>
<td>other Alcock Paczynski: stacking voids, pair count orientation</td>
<td>(H(z)D_A)</td>
<td>SDSS-III&lt;0.7</td>
</tr>
<tr>
<td>photometric clustering</td>
<td>(D_A / r_s)</td>
<td>SDSS-III&lt;0.7, DES, Panstarrs</td>
</tr>
<tr>
<td>CMB DT/T</td>
<td>(r_s \propto 1/\sqrt{\Omega_M H_0^2}, D_A(z^*))</td>
<td>WMAP, Planck etc z~1100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SNe</th>
<th>low z: (H_0), high z: (D_L^*H_0)</th>
<th>HST, Union 2 etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>other low z: Cepheid Variables, Masers, Tully-Fisher, Surface brightness fluctuations</td>
<td>(H_0)</td>
<td></td>
</tr>
<tr>
<td>(f_{\text{gas}}) (assumed constant in z)</td>
<td>(D_L^* \sqrt{D_A})</td>
<td>XEUS</td>
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<tr>
<td>Active Galactic Nuclei „reverberation”</td>
<td>(D_L = (1+z)^2D_A)</td>
<td></td>
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<tr>
<td>Radio galaxies accretion disks</td>
<td></td>
<td></td>
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<tr>
<td>futuristic: lensed CMB</td>
<td>(D_A(z)/D_A(z^*))</td>
<td></td>
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<tr>
<td>futuristic: gravitational waves as standard sirens</td>
<td>(D_L)</td>
<td></td>
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</tbody>
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Combinations

- z-clustering at high z + CMB -> $D_A^2/H(z)$, $D_A(z)$, $H(z)$
- z-clustering at low z + CMB -> $H_0$ (Beutler et al. 2011)
- z-clustering + S/N: $H(z)/H_0 \sim \bar{\alpha}/\bar{\alpha}_0$ (Blake et al. 2011)
- tests of $D_L(z)=(1+z)^2 D_A$? Learn about dust, photon decay to axion?
- $H(z,R.A,Dec)$? Back-reaction?
The figure clearly shows that at (cosmologically) low redshifts there is a large degeneracy between the parameters. This is relaxed at higher redshift.

In this study we examine AP effects when varying \( w_0 \) and \( \Omega_m \). The 'false' values are given in fractions in increments of \( w_0.33, 0.44 \) as indicated by thick boxes in the panels we highlight 5, 10 per cent deviations in the parameter.

Figure 2. The figure demonstrates that our results are consistent with \( M_0 \) and \( T \) for a number of redshifts. In each panel (each redshift) we hold \( M_0 \) and \( T \) fixed and see that there is a large degeneracy in the parameter space.

DE Parameter Degeneracy

Kazin, Sanchez and Blanton (2012)
Geometric Redshift Distortions

Real Space

\[ \frac{\Delta z}{\alpha z} = 1 \]

\[ \alpha \]

\[ H(z + \Delta z) \]

\[ H(z) \]

\[ H(z - \Delta z) \]

Redshift Space

\[ \frac{\Delta z}{\alpha z} < 1 \]

\[ \alpha \]

\[ \frac{\Delta z}{\alpha z} > 1 \]

\[ \alpha \]
Dynamical vs. Geometrical:
Testing LasDamas mock LRGs

Real Space

Dynamical z - distortions

\[ s \quad [h^{-1}\text{Mpc}] \]

\[ \theta \quad [\text{deg from LOS}] \]

\[ \xi(\text{Real Space}) \]

\[ \xi(\text{Velocity Space}) \]

true signal

geometrically distorted signal \[(\omega_{DE}=-1.1, \text{ instead of } \omega_{DE}=-1)\]

Eyal Kazin, Swinburne GEM December 7th 2011
Dynamical vs. Geometrical: Testing LasDamas mock LRGs

Dynamical $z$ - distortions

Real Space

Dynamical vs. Geometrical:
Testing LasDamas mock LRGs

Geometrically distorted signal ($w_{DE} = -1.1$; instead of $w_{DE} = -1$)

True signal

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