BAO data analysis

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Overview

- history
- steps
- conclusions

History

- CMB: Sunyaev and Zeldovich 1970, Peebles and Yu 1970, Bond and Efstathiou 1984, Seljak and Zaldarriaga 1996, Lewis, etc
- Galaxies: Blake and Glazebrook 2003, Seo and Eisenstein 2003+, Chang et al 2008, Ngan et al 2011+
- first detections: 2dF, SDSS: Percival, Eisenstein et al 2005+
- mainstream Dark Energy Probe: WiggleZ, SDSS3/BOSS, DES, HETDEX, LSST, BigBOSS, WFIRST ...
- new approaches: CRT, Carpe, etc

Steps

- $E(t)^2 \longrightarrow T(x)$
- $T(x)^2 \longrightarrow P(x)$
- $P(x) \longrightarrow d(z)$
- $\Delta d \sim P(x)^2$
- Gaussianity from central limit theorem ...
- try to make estimator insensitive to galaxy properties

Cosmological Context

$$P = wc^2\rho \tag{1}$$

relating its pressure P and density ρ. A common parametrization of w is

$$w(z) = w_0 + \frac{w_1 z}{1+z} \tag{2}$$

where w_0 is the value in the present day. The Friedman equation now reads

$$H^2(z) = H_0^2 \left[\Omega_m(1+z)^3 + \Omega_r(1+z)^4 + \Omega_k(1+z)^2 + \Omega_\lambda \exp\left(3\int_0^z \frac{1+w(z)}{1+z}dz\right)\right] \tag{3}$$

Distance

For an object of a fixed co-moving size s, its projections across and along the line of sight are given by

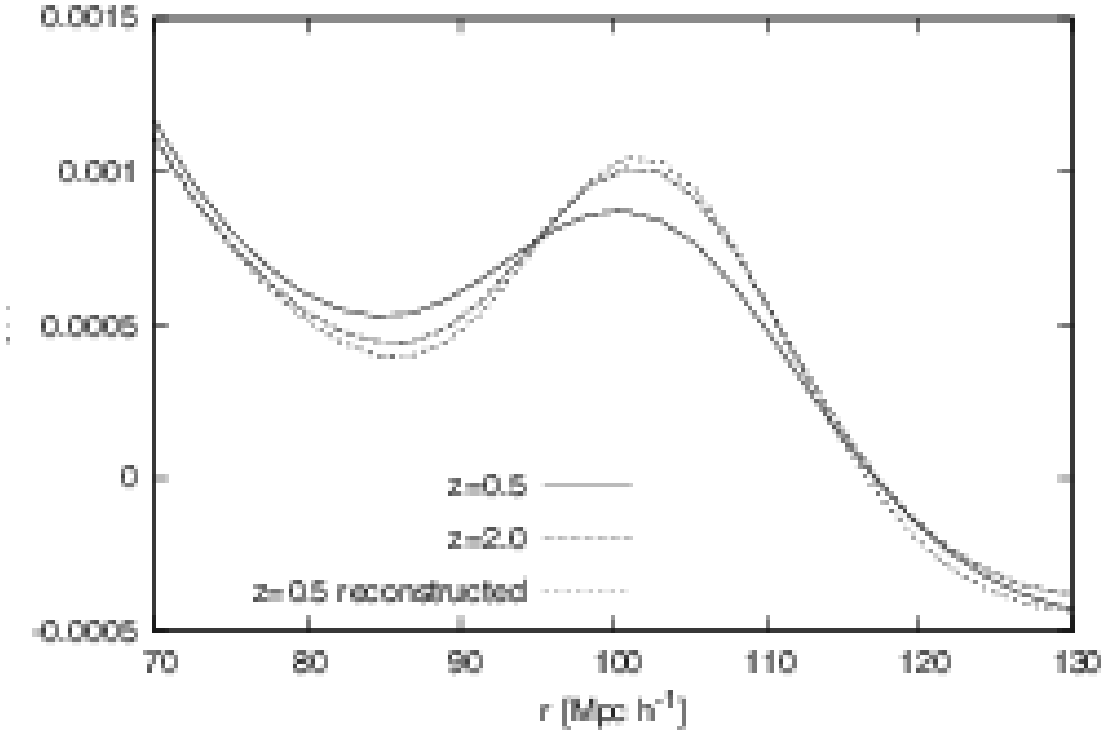
$$s_{||} = \frac{c\Delta z}{H(z)} \tag{4}$$

$$s_{\perp} = (1+z)D_A(z)\Delta\theta \tag{5}$$

respectively. Δz and $\Delta\theta$ are the redshift span and angular size of the object on the sky, and

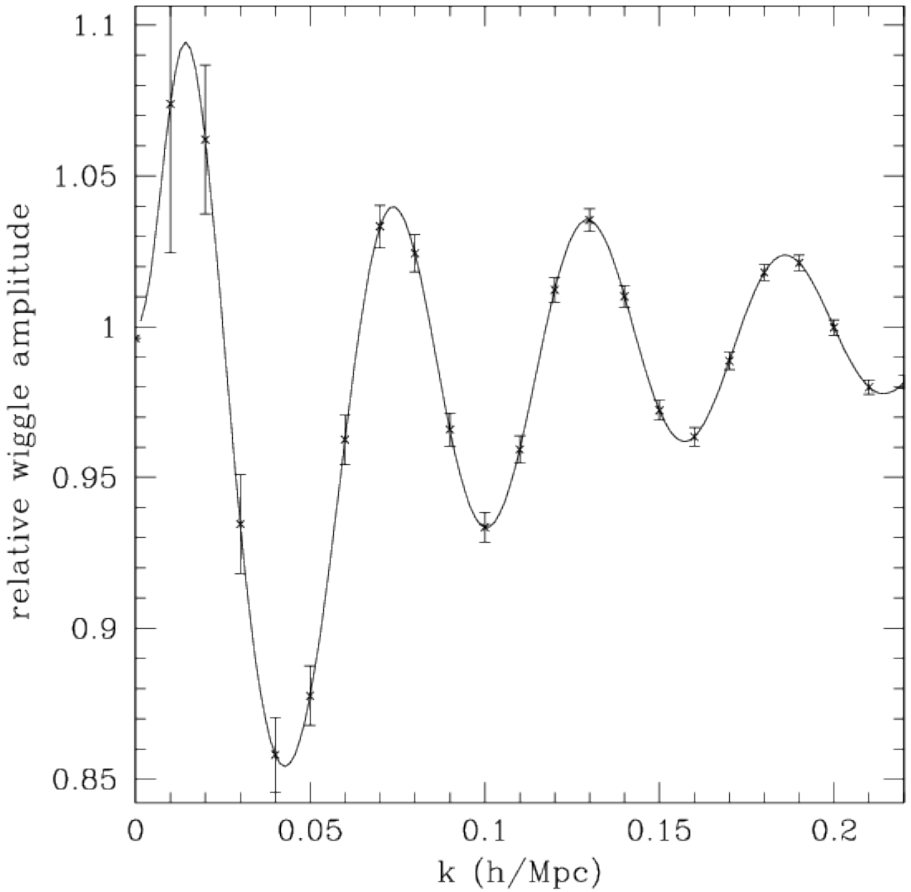
$$D_A(z) = \frac{c}{1+z}\int_0^z \frac{dz'}{H(z')} \tag{6}$$

Correlation Function



Correlation function $\xi(r)$ at redshifts $z = 0.5$ and $z = 2.0$, as well as reconstruction (smoothing scale $R = 10\ h^{-1}$Mpc) at $z = 0.5$. The functions are rescaled by the square of the growth factors so that the acoustic peak locations match the $z = 0.5$ case.

Relative Power Spectrum



Covariance

Covariance matrix between each data point as

$$C(k,k') = \frac{1}{n-1}\sum_{i=1}^{n}\left[P_i(k) - \langle P(k)\rangle\right]\left[P_i(k') - \langle P(k')\rangle\right] \qquad (7)$$

Least Squares

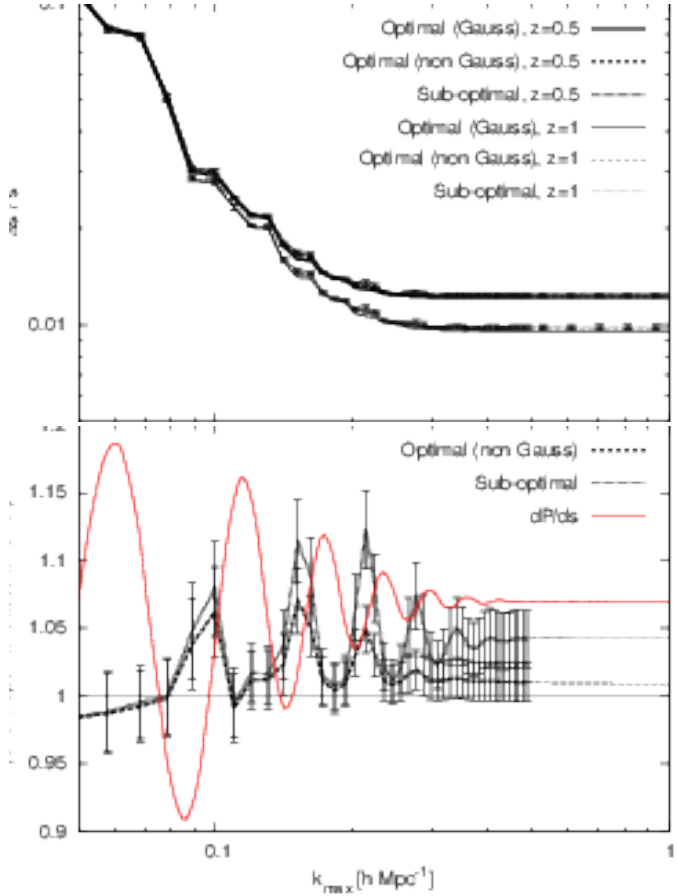
$$x = (A^T \tilde{C}^{-1} A)^{-1} A^T \tilde{C}^{-1} b. \quad (8)$$

errors of x are given by the diagonal components of the covariance matrix $\langle x^2 \rangle = x x^T$. Correspondence $x \equiv \Delta \ln s$, $b \equiv \Delta P$, $A \equiv \partial P / \partial \ln s$, Error in $\ln s$:

$$\langle (\Delta \ln s)^2 \rangle = (P_s^T \tilde{C}^{-1} P_s)^{-1} P_s^T \tilde{C}^{-1} C \tilde{C}^{-1} P_s (P_s^T \tilde{C}^{-1} P_s)^{-1} \quad (9)$$

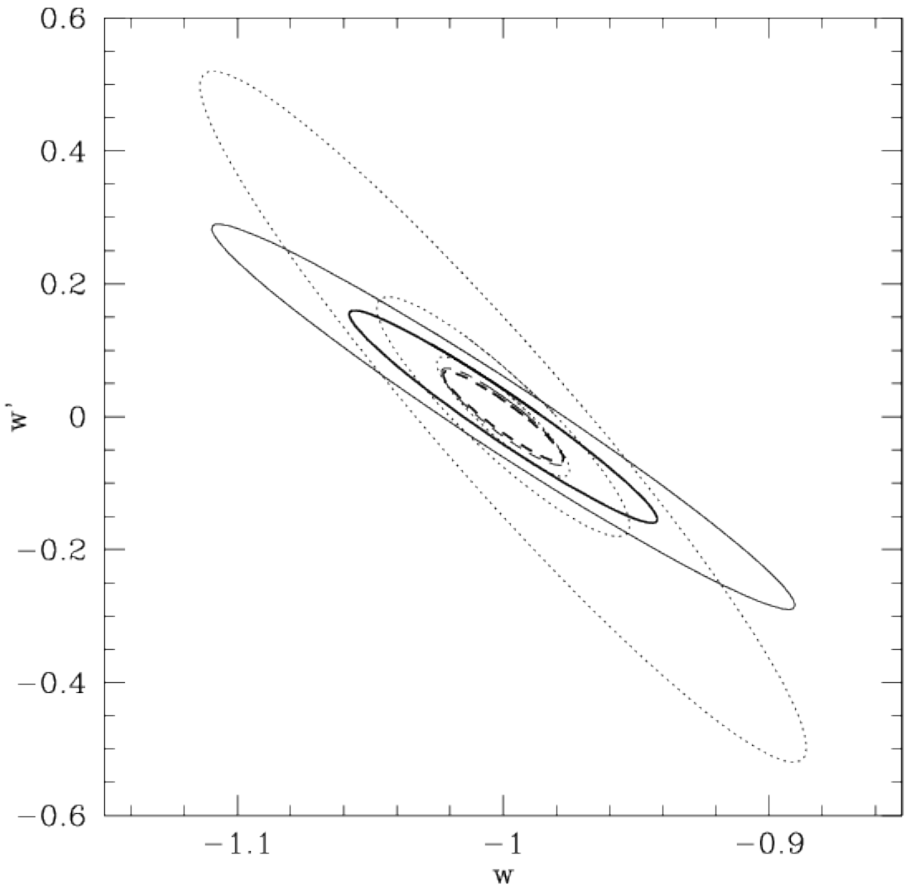
$P_s \equiv \partial P / \partial \ln s$, $P_s^T C P_s$ is a vector-matrix-vector product

Errors



Top panel: Fractional distance errors. *Bottom panel*: Optimal non-Gaussian and sub-optimal errors, each divided by the optimal Gaussian errors at $z = 0.5$.

Dark Energy



The 1-σ contour for IM combined with Planck (inner thick solid for baseline model, outer thin solid for worst case), the Dark Energy Task Force Stage II projects with Planck (outer dotted), the Stage II and III projects with Planck (intermediate dotted), the Stage II, III and IV projects with Planck (inner dotted), and all above experiments

Conclusions

- BAO measures angular diameter distance (transverse), expansion rate (radial)
- Linear operation on power spectrum
- Challenge to compute error bars