How to constrain Dark Energy with Baryon Acoustic Oscillations

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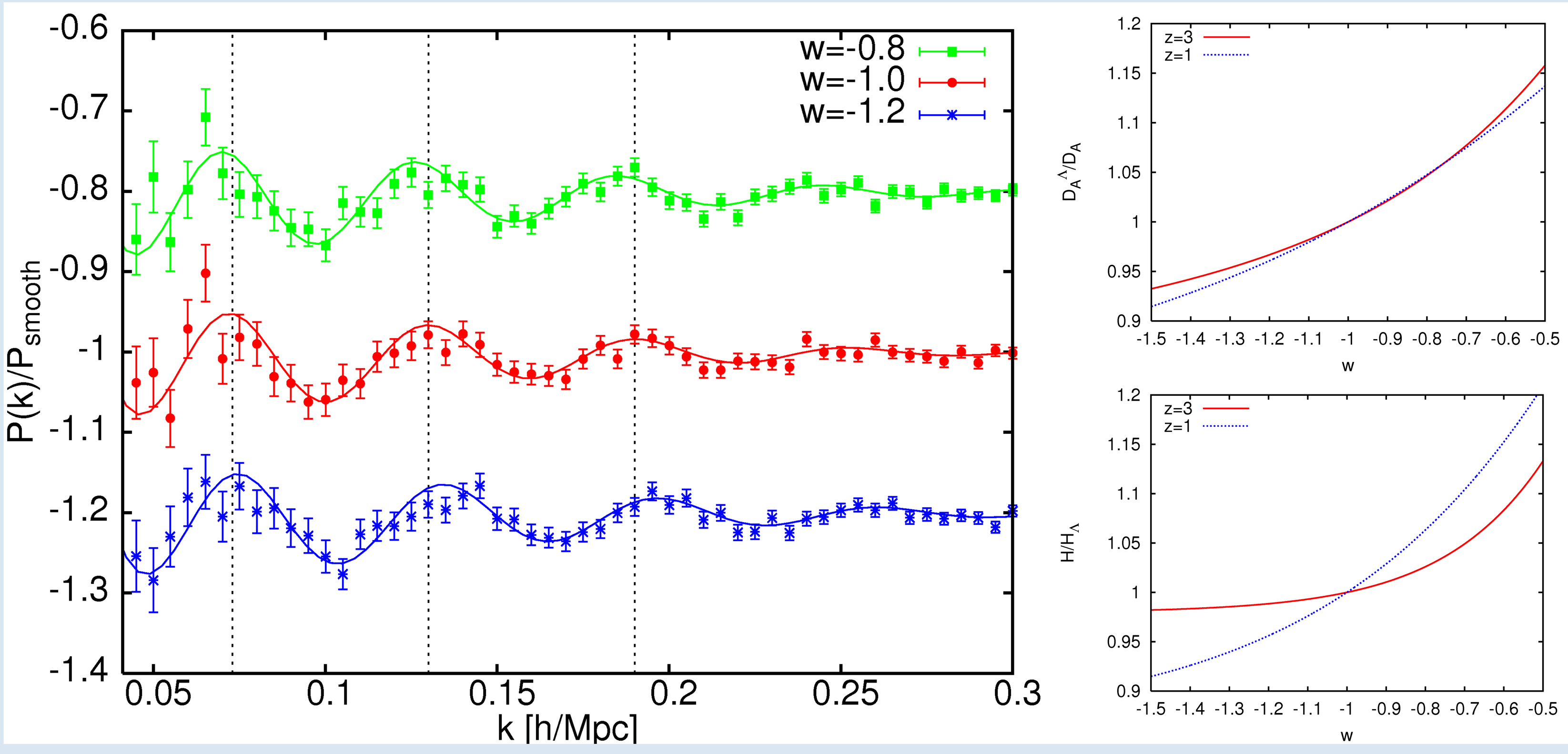
Baryon Acoustic Oscillations

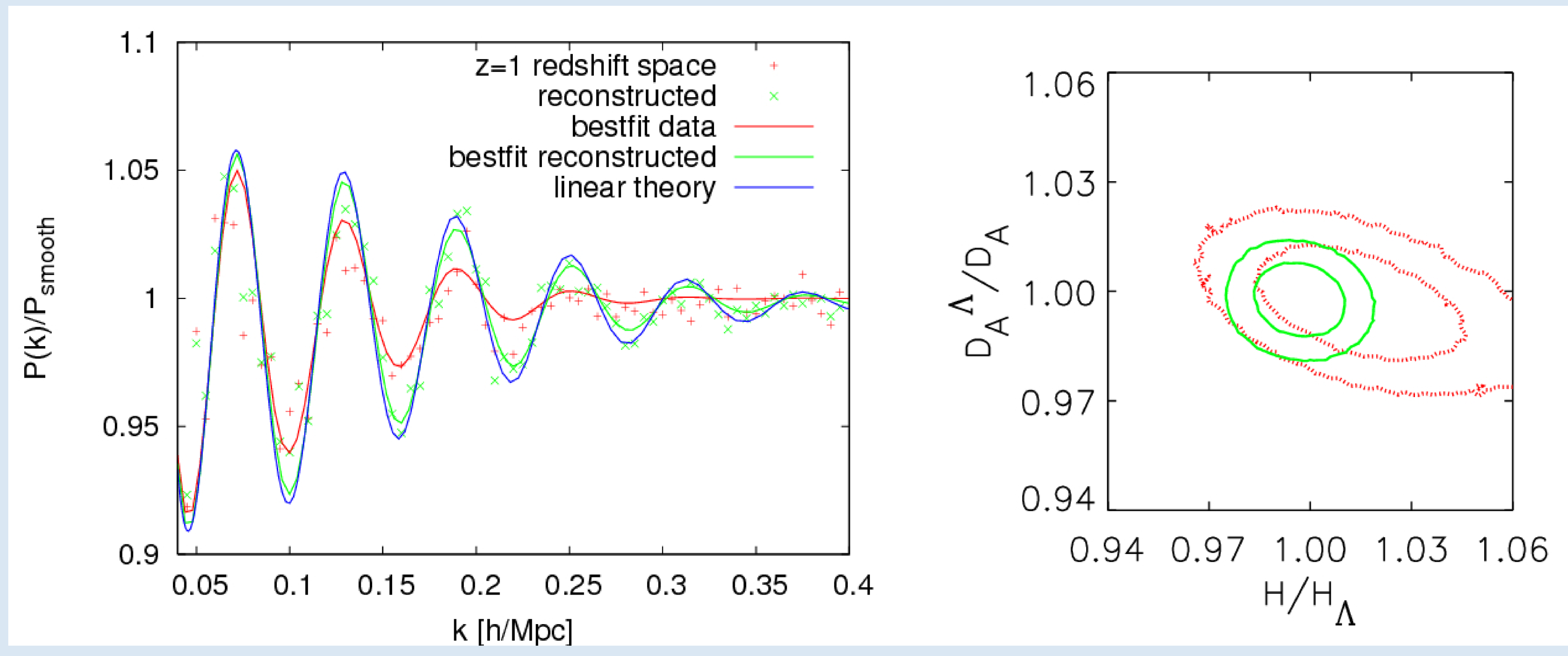
The baryon acoustic oscillations (BAO), imprinted on the matter power spectrum *P(k),* have the same origin as the acoustic anisotropies of the CMB. Therefore their physical scale is known to sufficient accuracy and they can be used as a standard ruler to measure the expansion history of the Universe, which depends on the dark energy equation of state parameter *w*. Using ΛCDM as reference cosmology the BAO are scaled by H/H_Λ and D_a^Λ/D_a along and transverse to the line of sight, respectively. On the right we show the extracted BAO for w = -0.8, -1.0, -1.2.



Left: The extracted BAO for w = -0.8, -1.0, -1.2 at z=3 (shifted by -0.8, -1.0, -1.2 along the y-axis, respectively). Right: Scaling factors as a function of *w*.

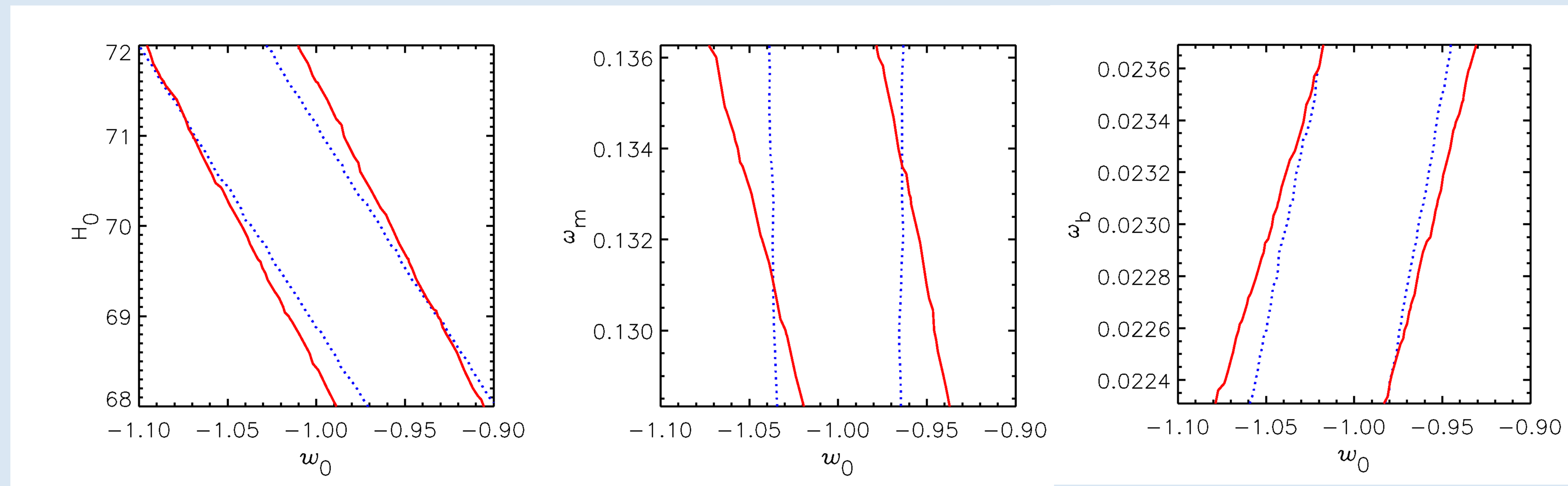
With N-Body simulations we are able to analyze nonlinear effects and can predict how well upcoming galaxy redshift surveys, like the Hobby-Eberly Telescope Dark Energy Experiment, HETDEX, can constrain dark energy.

Nonlinear evolution diminishes the amplitude of the BAO (see right). Using reconstruction techniques for the density field we can almost completely reestablish the amplitude and by this improve the measurement of the apparent scale of the BAO, transverse (angular diameter distance D_A) and parallel (Hubble parameter *H*) to the line of sight. For surveys at lower redshifts, like BOSS, this effect is large and reconstruction becomes very important.



Left: The extracted BAO imprinted in the dark matter distribution. Right: Contour lines (68% and 95% c.l.) for the scaling factors derived from the BAO before and after the reconstruction of the density filed.

To get constraints on the dark energy parameter *w* one has to take other cosmological parameters, like the Hubble constant H_0, matter fraction ω_m and baryon fraction ω_b, into account. In particular, the uncertainty in the Hubble constant degrades the constraints on *w*.



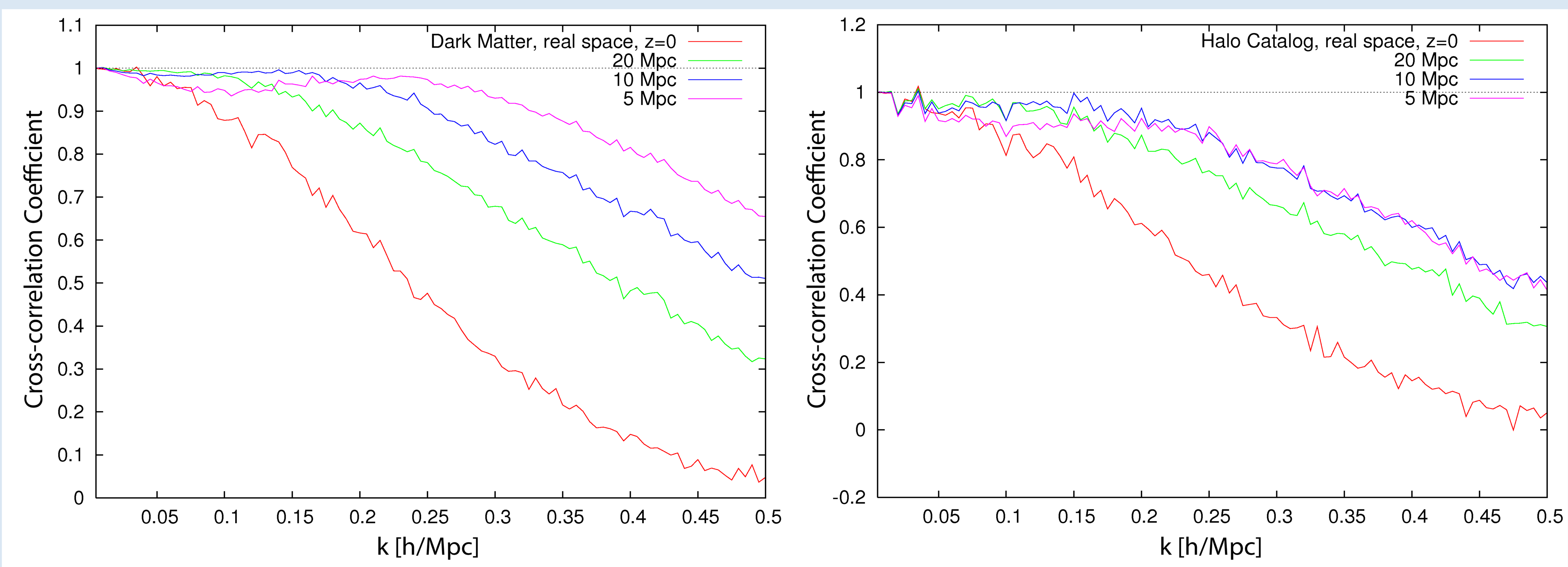
Degeneracies (95% c.l.) of the cosmological parameters H_0, ω_m, and ω_b with respect to a constant $w=w_0$ at redshift z = 1 (dotted) and 3 (solid) derived from the dark matter distribution in a 1.5 Gpc/h computational box.

Reconstruction

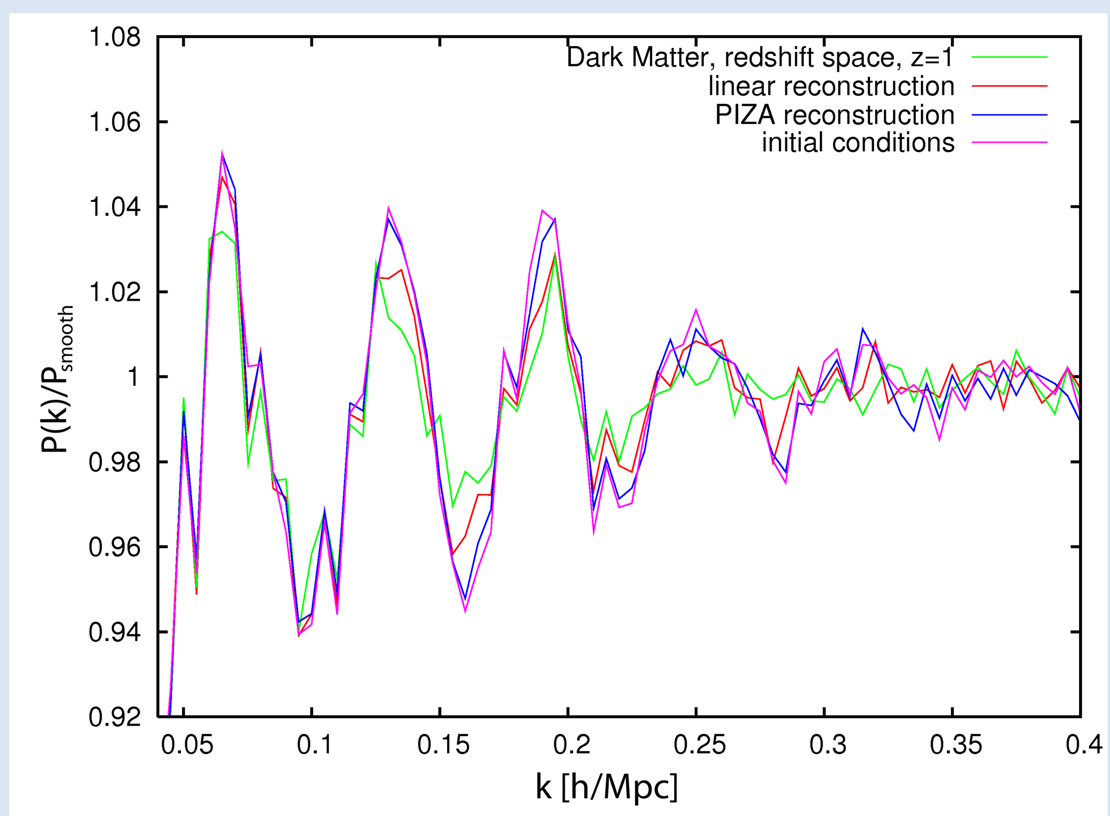
We implemented two different reconstruction techniques. PIZA (Path Interchange Zeldovich Approximation) is particle based and derives the displacement field by minimizing iteratively the sum of the displacements squared.

The linear reconstruction scheme uses the density field to determine the displacement field. It applies linear theory to the observed density field after smoothing it on a sufficiently large scale.

A measure how well the initial density field is reconstructed is the cross-correlation coefficient of the initial and the reconstructed density field $\langle \delta_{\rm in}(k)\delta^*_{\rm rec}(k)/(|\delta_{\rm in}(k)|^2 D)\rangle$, with $\delta(k)$ the Fourier mode of the density and *D* the growth function.



Cross-correlation coefficient of the initial and reconstructed density field at redshift z=0 for different smoothing lengths. The reconstruction was performed from the dark matter (left) and halo (right) distribution by applying the linear reconstruction scheme.



Reconstruction of the BAO in redshift space at z=0 using different reconstruction techniques.

For more details see: Wagner, Müller, and Steinmetz, *Astronomy & Astrophysics*, 487, 63-74 (2008)