Measuring Dark Energy with Galaxy Cluster Surveys

Christian Wagner [1], Stefan Gottlöber [1], Anatoly Klypin [2], Steffen Knollmann [1]

[1] Astrophysikalisches Institut Potsdam, [2] New Mexico State University

AIP

Galaxy Clusters and Dark Energy

Galaxy cluster surveys probe dark energy in two complementary ways. First, as the underlying dark matter also the spatial distribution of galaxy clusters show an excess of pairs at the scale of the baryon acoustic oscillations (BAO). This standard ruler can be used to measure the expansion history of the Universe.

Second, dark energy affects the growth rate of structures and therefore the abundance of galaxy clusters. When normalized to produce the same local cluster abundance, models with more dark energy in the past (e.g. w = -0.8) than ΛCDM (w = -1) have more clusters at higher redshifts per unit comoving volume (see bottom).

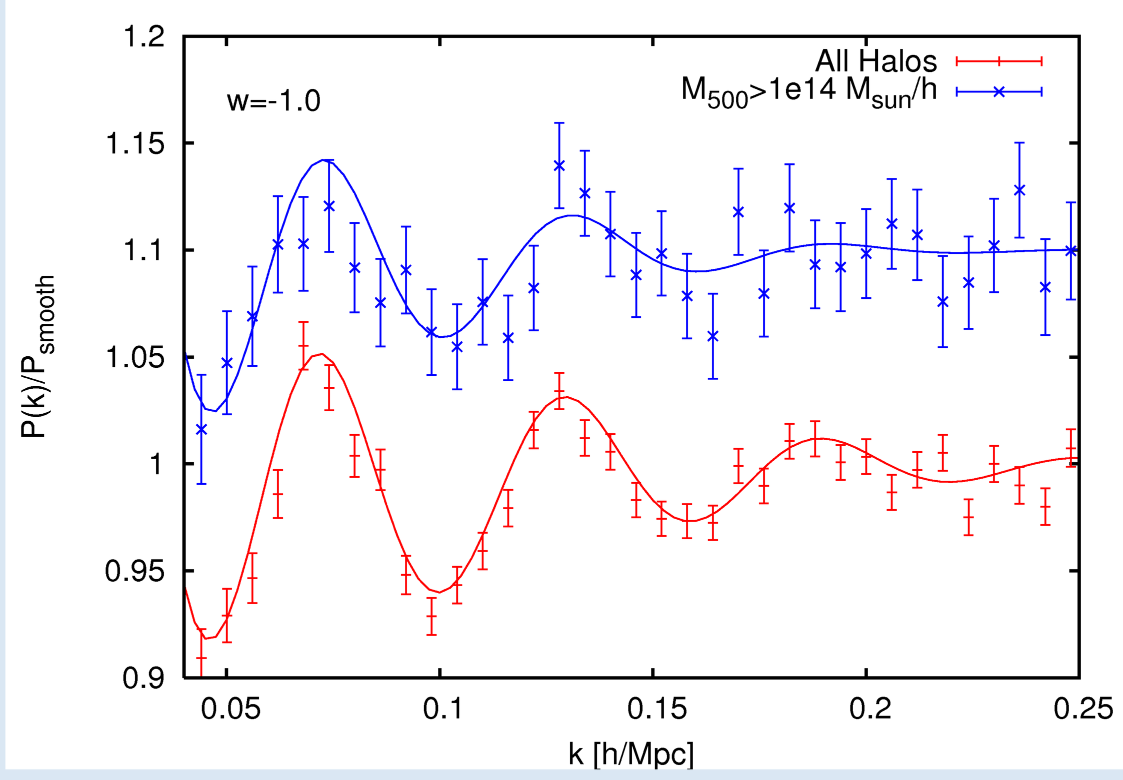
The X-ray space telescope eRosita will observe about 50,000 galaxy clusters of masses above 3.5×10^{14} M_{sun}/h with redshifts $z < 1.5$.

Simulation of a Galaxy Clusters Surveys

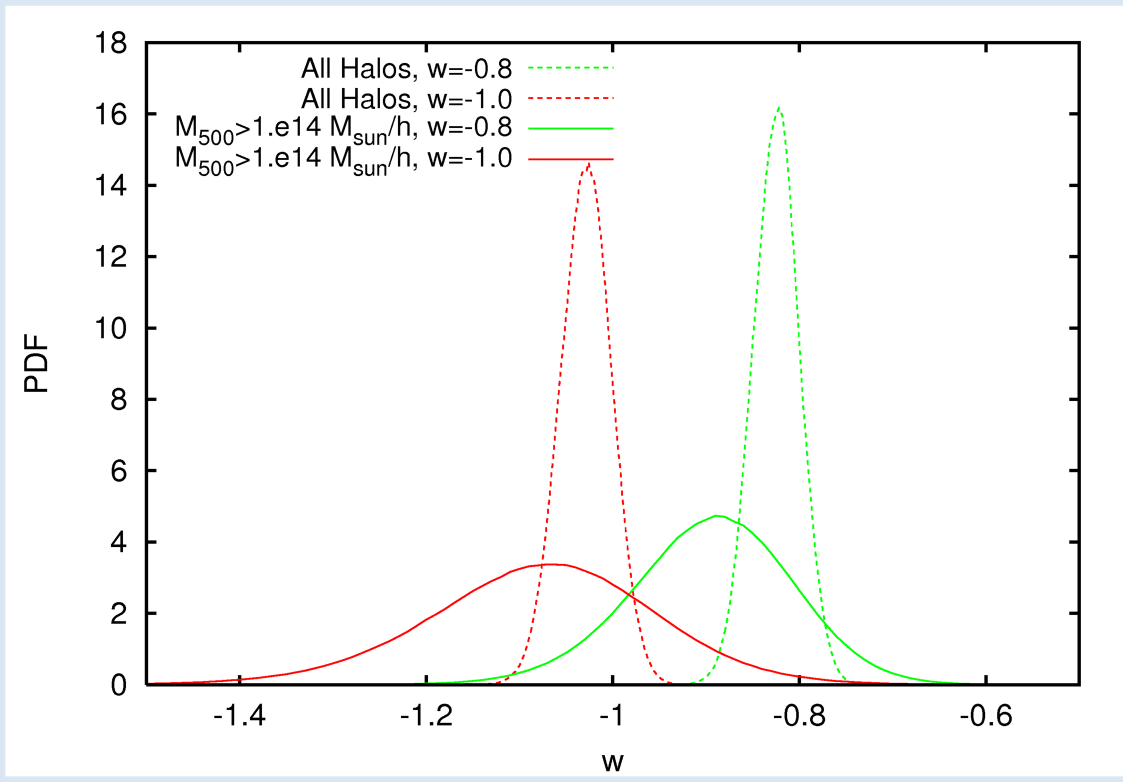
Using the N-Body codes ART and Gadget-2 we simulate the evolution of the dark matter density in a 3 Gpc/h and 1 Gpc/h computational box with 1024^3 particles for two different dark energy equation of state parameters w = -0.8 and w = -1.0. With the parallelized halo finder AHF we build cluster catalogs and calculate from the halo profiles the M_{500} cluster mass.

BAO in Galaxy Clusters Surveys

On the right we show the extracted BAO of about 70 thousand clusters in the 3 Gpc/h box at z = 0.5. The derived constraints on w reproduce the input values of the simulations. Large shot noise for the cluster sample degrades the measurement, though.



Extracted BAO at z = 0.5 derived from all halos (>20 particles, red) and cluster-sized halos (shifted by +0.1 along the y-axis, blue) together with the best fit.

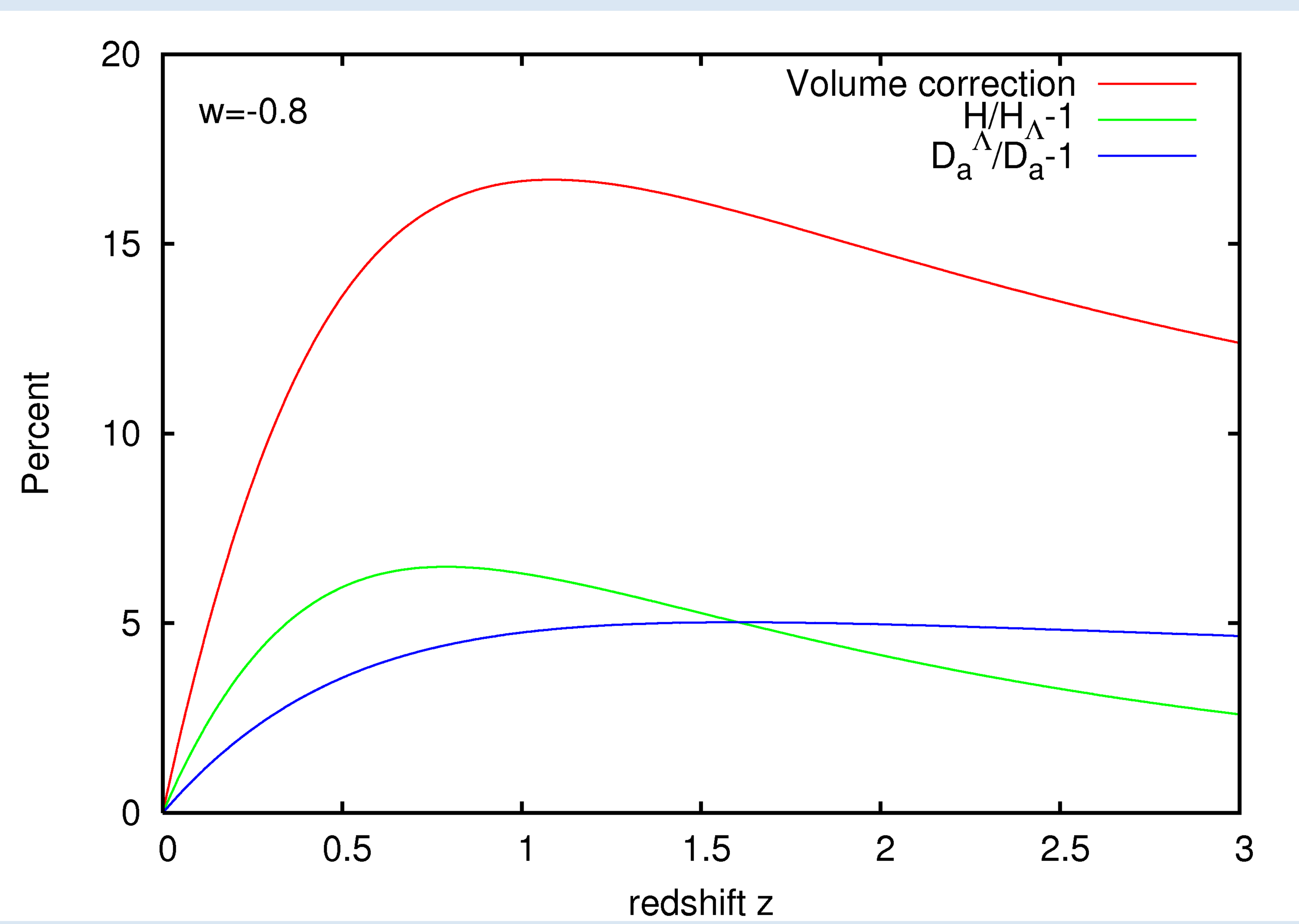


Measured probability distribution function of a constant w from the BAO shown above and, in addition, from the BAO of the w = -0.8 simulation.

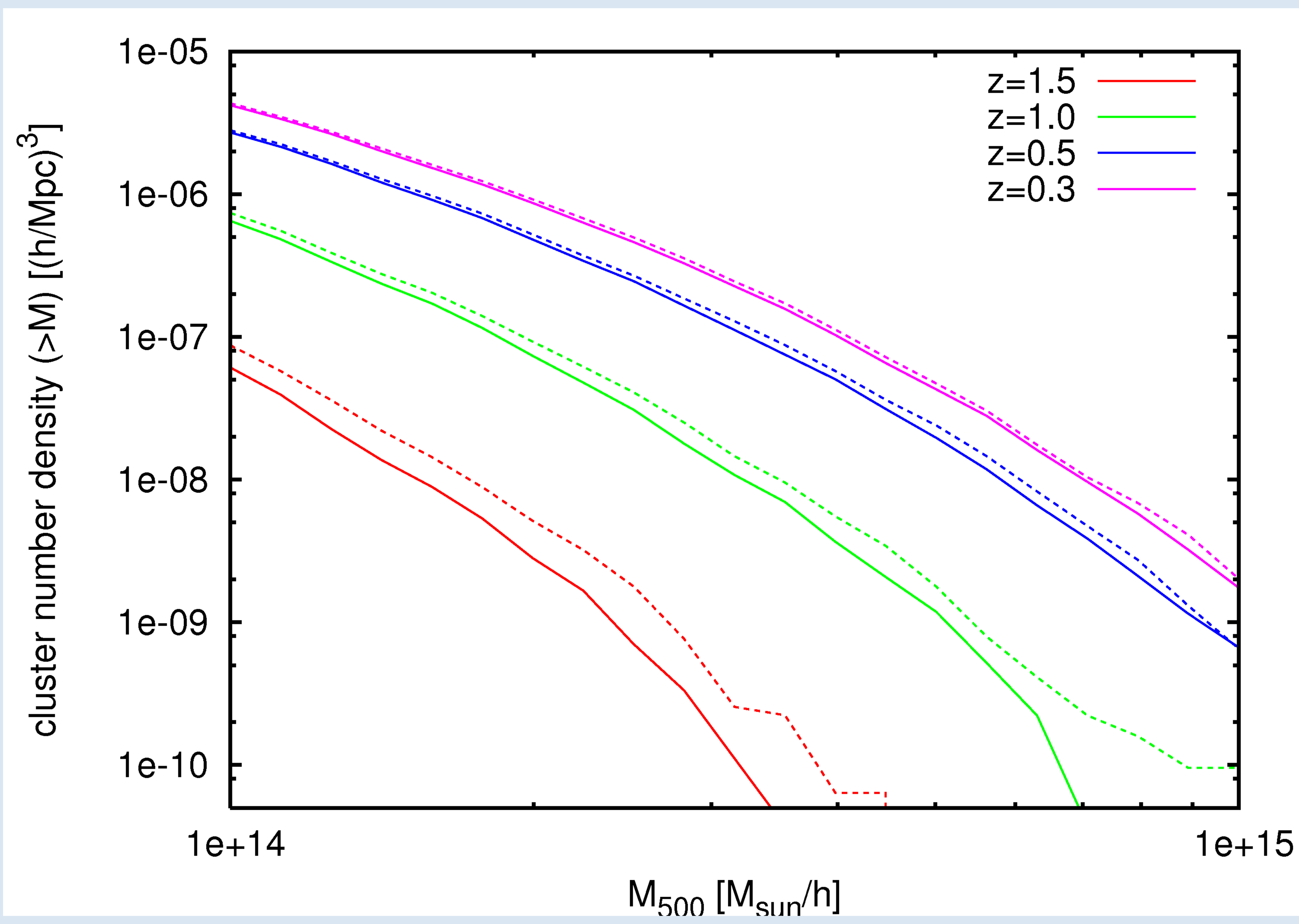
Galaxy Cluster Mass Function

The observed cluster mass function does not only depend on dark energy through the growth rate of structure but also through the scaling of the comoving volume element. Assuming ΛCDM as reference cosmology the correction for the observed volume is shown below on the left. This effect counteracts the effect of the dark energy on the cluster growth rate and both these effects are redshift dependent.

At the bottom right we present the derived cluster mass functions including the volume correction for several redshifts. The dashed lines belong to the w = -0.8 cosmology and the solid lines to the w = -1 cosmology (ΛCDM). The degeneracy between the dark energy (i.e. w) and the normalization of the initial perturbations (i.e. σ_8) in the cluster mass function can be broken by measuring the cluster mass function for several redshifts.



Scaling factors along (H/H_Λ) and transverse (D_a^Λ/D_a) to the line of sight, and the combined volume correction factor (H/H_Λ) $(D_a^\Lambda/D_a)^2$ in percent.



Cluster mass functions at several redshifts derived from the the 3 Gpc/h box of the two simulations with w = -1.0 (solid line) and w = -0.8 (dashed line).