Early Dark Energy and Planck's SZ cluster sample

Jean-Claude Waizmann and Matthias Bartelmann
Institute of Theoretical Astrophysics (ITA/ZAH), University of Heidelberg

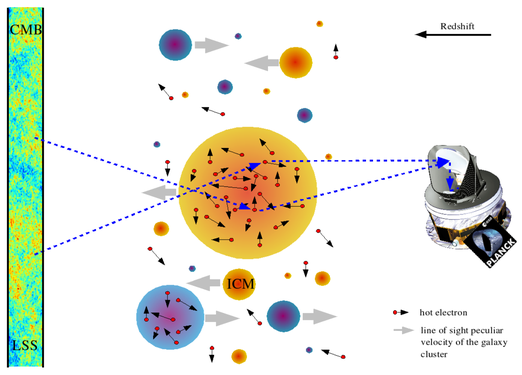
Abstract

We study the impact of Early Dark Energy (EDE) cosmologies, where the Dark Energy contribution is non-vanishing at early times, on the SZ cluster sample expected by the upcoming *Planck* mission. Since structures grow slower in the presence of EDE, one expects an enhancement of the number of galaxy clusters compared to ΛCDM at intermediate and high redshifts, which could explain the reported excess of the angular CMB power spectrum on cluster scales via an enhanced SZ contribution. We constructed four full-sky SZ maps for EDE and ΛCDM cosmologies, taking angular cluster correlation into account, to simulate *Planck* observations with and without Galactic foregrounds. After applying our filter pipeline we clearly find an enhancement in the detected number of clusters compared to the fiducial ΛCDM case. This shows that current filtering techniques are sufficiently sensitive for finding deviations from the ΛCDM sample, being caused by EDE. In addition we find an interesting effect of EDE on the completeness of the cluster sample, such that EDE helps to obtain cleaner samples.

Introduction

- BIMA, CBI and ACBAR report an excess in angular power at high multipoles $\ell > 2000$ with respect to the theoretically expected CMB power spectrum.
- If explained by the thermal SZ-effect within the framework of the ΛCDM cosmology, a rather high normalisation of the mass fluctuations $\sigma_8 \sim 1$ is required.
- The observed abundance of gravitational arcs and additionally their presence in high redshift galaxy clusters with $z \gtrsim 1$, gives rise to tension with the concordance model.
- EDE, belonging to the class of dynamical Dark Energy models, as well offers an explanation to the present observed cosmic acceleration.
- Models giving rise to attractor solutions naturally suggest that Dark Energy might be non-negligible during long periods of the evolution of the Universe.
- The presence of EDE alters the non-linear structure formation at the high mass end, such that it might be constrained by measuring the abundance of galaxy clusters at high redshifts.

Thermal SZ effect



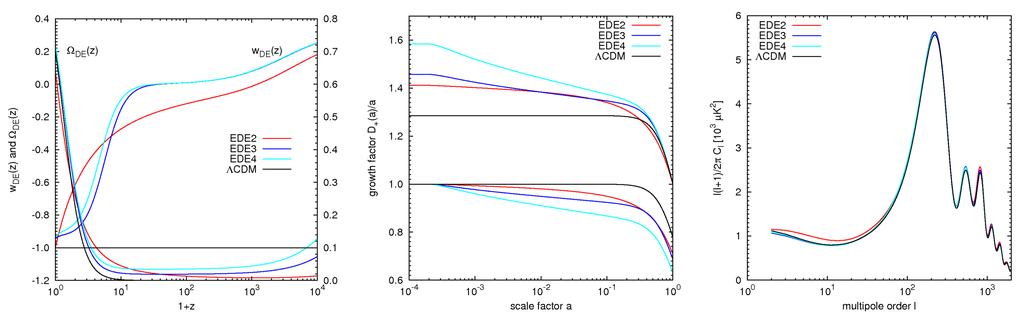
- Based on inverse Compton scattering of CMB photons off the hot electron gas in the gravitational potential of galaxy clusters.
- Identifiable by unique spectral shape of the distortion.
- Important quantity to model *Compton-y parameter*

$$y(\vec{\theta}) = \frac{k_\mathrm{B}\sigma_\mathrm{T}}{m_\mathrm{e}c^2}\int n_\mathrm{e}T_\mathrm{e}\mathrm{d}l.$$

- *Planck*'s HFI channel design optimised for SZ detection.

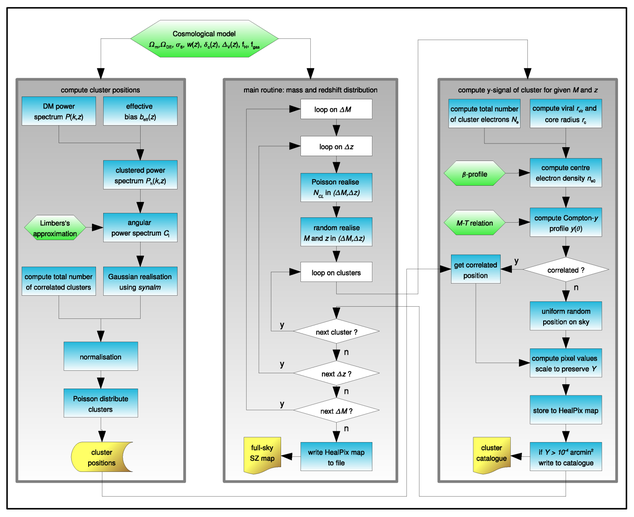
Early Dark Energy Cosmologies

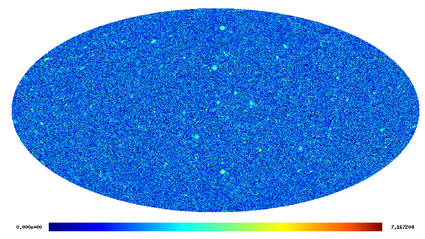
- EDE is a natural consequence of tracking quintessence, offering an explanation to the observed current accelerated expansion and the coincidence problem.
- Constraints form BBN and CMB limit the EDE fraction to be less than 4% [Doran & Robbers 2006].
- The presence of EDE lowers the linear collapse parameter δ_c in the spherical collapse model.
- The growth factor for EDE falls behind ΛCDM, such that structures have to grow earlier to reach the same level at present time.
- The mass function for massive clusters at $z = 1$ is, compared to ΛCDM, a factor of $\approx (5 - 10)$ higher.
- Merger activity at moderate and high redshifts is enhanced.



Left panel: Redshift evolution of the equation-of-state parameter $w(z)$ (left axis) and of the Dark Energy density $\Omega_\mathrm{DE}(z)$ (right axis).
Middle panel: Evolution of the growth function with scale factor a normalised to today (upper curves) and to early times (lower curves).
Right panel: CMB power spectra as calculated with CMBEASY [Doran 2005].

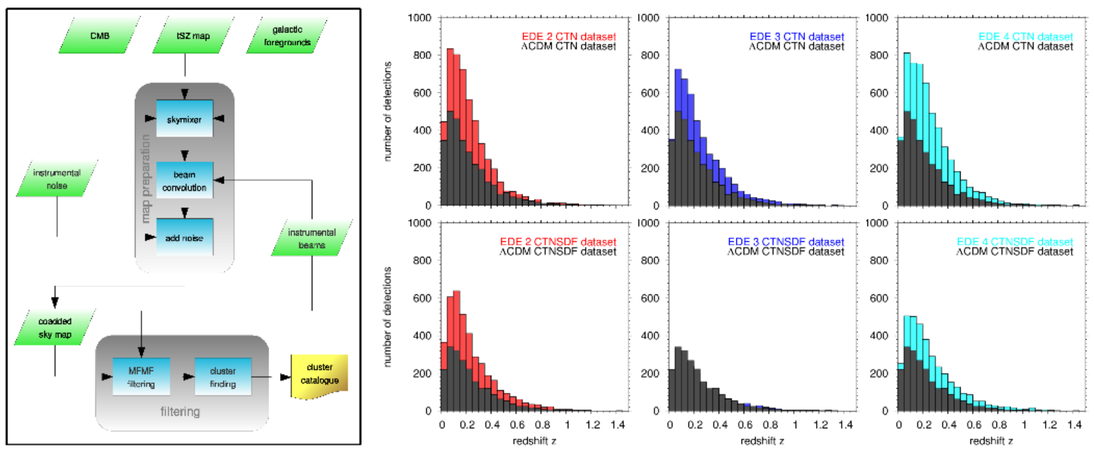
Creation of full-sky SZ maps





Left panel: Flowchart for the creation of full-sky Compton-y maps.
Upper panel: Simulated full-sky SZ map for an EDE cosmology, the shading is proportional to $\mathrm{arcsinh}(10^6 y)$.

Simulating and filtering of Planck observations

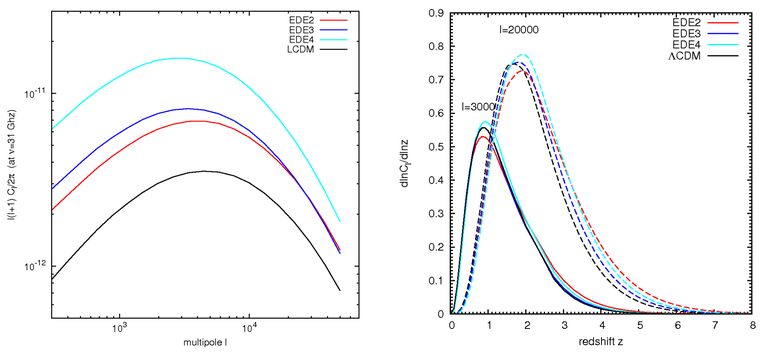


Left panel: Flowchart for the preparation of the coadded maps and subsequent filtering procedure, using the *Planck* LevelS pipeline and the spherical multi-frequency matched filters (sMFMF) [Schäfer et al. 2006].
Right panel: Number of detections in redshift bins of width $\Delta z = 0.05$ for $Y_\mathrm{threshold} = 2 \times 10^{-4}$ arcmin^2 and an association radius of $r_\mathrm{search} = 30$ arcmin comprising the EDE 2, EDE 3 and EDE 4 models from left to right for the clean case (CTN) in the upper row and for the galactic foreground dataset (CTNSDF) in the lower one.

Summary and Conclusions

- The enhanced presence of galaxy clusters in EDE cosmologies is also reflected in the detected cluster sample, using the sMFMF filtering technique.
- The possibility of detection depends on the strength of the EDE, such that it seems that a contribution of $\bar{\Omega}_\mathrm{DE,sf} \sim 0.04$ is required for significant detection with the considered filtering method.
- EDE also lowers the contamination of the detected cluster sample via the relative noise contribution compared to ΛCDM.
- The physical properties of galaxy clusters like the central and integrated comptonisation or the angular extent are only mildly affected by EDE.
- For the SZ power spectra we obtain the expected increase in power for the EDE cases, such that a lower σ_8 would give higher levels compared to ΛCDM.

SZ power spectra for EDE cosmologies



Left panel: SZ angular power spectra at $\nu = 31$ GHz for the EDE2, EDE3 and EDE4 as well as the fiducial ΛCDM model.
Right panel: Redshift distribution of C_ℓ plotted as $\mathrm{d}\ln C_\ell/\mathrm{d}\ln z$ for a given ℓ of 3000 and 20000.

Following [Komatsu & Seljak 2002], we computed the angular SZ power spectra for our set of EDE cosmologies and clearly find the expected boost in the levels of the spectra. In this way EDE could offer an explanation to the recent observations with ground based CMB experiments like BIMA, CBI and ACBAR of an excess in angular power at high multipoles $\ell > 2000$. If explained by the contribution of the thermal SZ effect within the framework of the ΛCDM cosmology, a rather high normalisation of the mass fluctuations $\sigma_8 \sim 1$ would be required. In the case of EDE cosmologies similar levels of the SZ power spectra could be achieved with much lower values of σ_8 that would be in agreement with constraints from other cosmological probes.

References

- Bartelmann, M., Doran, M., & Wetterich, C., 2006, *Non-linear Structure Formation in Cosmologies with Early Dark Energy*, A&A, 454, 27
- Doran, M., 2005, *CMBEASY: an object oriented code for the cosmic microwave background*, Journal of Cosmology and Astro-Particle Physics, 10, 11
- Doran, M., & Robbers, G., 2006, *Early Dark Energy Cosmologies*, Journal of Cosmology and Astro-Particle Physics, 6, 26
- Komatsu, E., & Seljak, U., 2002, *The Sunyaev-Zeldovich angular power spectrum as a probe of cosmological parameters*, MNRAS 336, 1256
- Ratra, B., & Peebles, P. J. M., 1988, *Cosmological consequences of a rolling homogeneous scalar field*, Phys. Rev. D, 59, 3406
- Sadeh, S., Rephaeli, Y., & Silk, J., 2007, *Cluster abundances and Sunyaev-Zel'dovich power spectra: effects of non-Gaussianity and early dark energy*, MNRAS, 380, 637
- Schäfer, B., Hell, R. M., Pfrommer, C., & Bartelmann, M., 2006, *Detecting Sunyaev-Zel'dovich clusters with Planck - II. Foreground components and optimized filtering schemes*, MNRAS, 370, 1713
- Waizmann, J.-C., & Bartelmann, M., 2008, *Impact of Early Dark Energy on the Planck SZ cluster sample*, astro-ph, 0804.2815
- Wetterich, C., 1988, *Cosmology and the fate of dilatation symmetry*, Nuclear Physics B, 302, 668

Institute of Theoretical Astrophysics - University of Heidelberg
Mail: waizmann@ita.uni-heidelberg.de