Early Dark Energy and Planck's SZ cluster sample - Clusters as cosmological probes

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Motivation - Why Clusters?

- The physics is “relatively simple”
- Clusters trace the history of structure formation
- They are present during Dark Energy domination
- Future surveys promise large samples

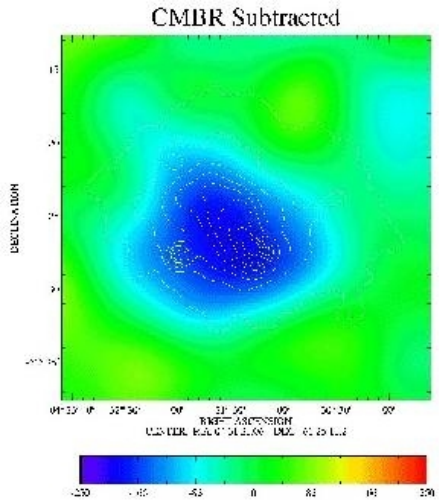
Lensing/Optical

Abell 1689 HST

X-Ray

Abell 1689 CHANDRA

SZ

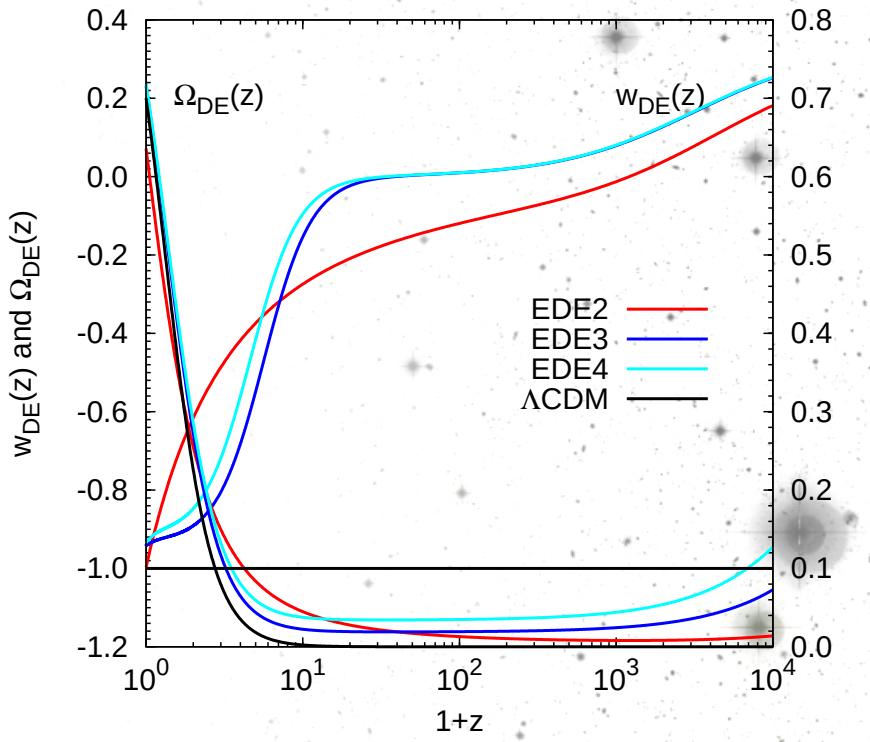


Abell 3266 ACBAR

Early Dark Energy

Concept and features

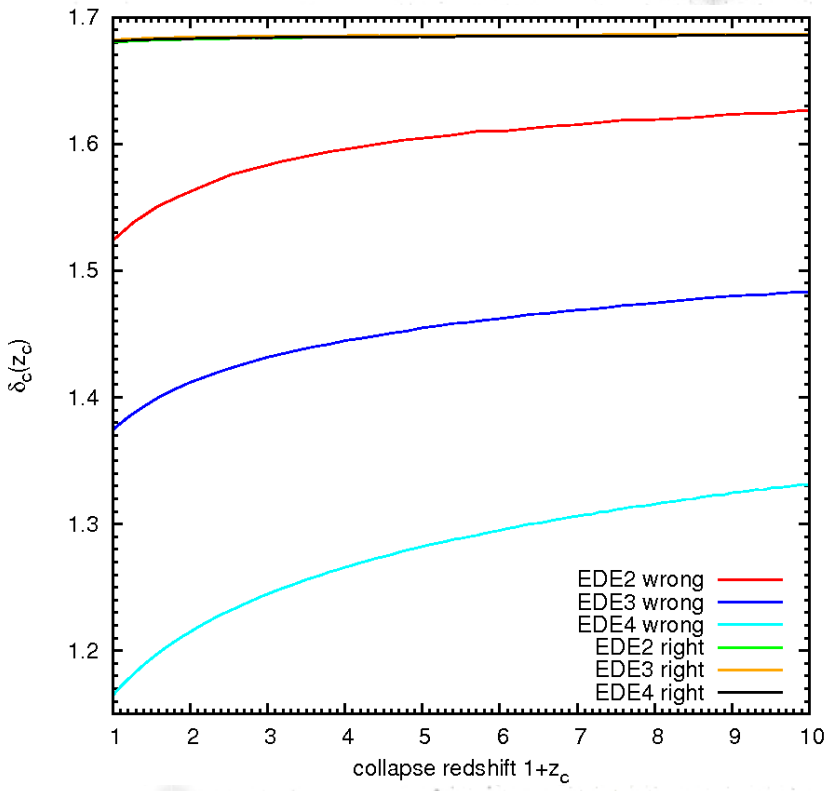
- Non-negligible DE contribution at higher redshifts



Early Dark Energy - Beware!

Concept and features

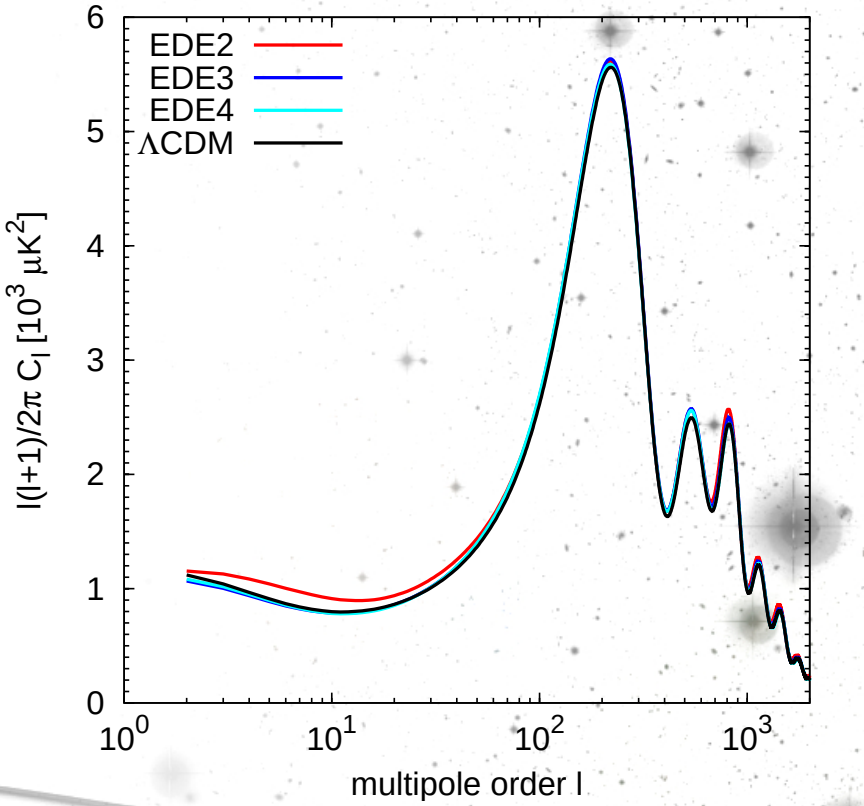
- Non-negligible DE contribution at higher redshifts
- **Linear density contrast δ_c NOT lowered by EDE**
  (Bartelmann et al. 2006, Francis et al. 2009)



Early Dark Energy

Concept and features

- Non-negligible DE contribution at higher redshifts
- Linear density contrast δ_c lowered by EDE
- Current observations (SN,LSS,CMB) give $\Omega_{\rm EDE} \lesssim 4\%$



Getting the right δ_c for EDE

(Pace, Waizmann & Bartelmann in prep.)

$$\begin{aligned} \frac{\partial \rho}{\partial t} + \vec{\nabla}_{\vec{r}} \cdot (\rho \vec{v}) &= 0 \\ \frac{\partial \vec{v}}{\partial t} + (\vec{v} \cdot \vec{\nabla}_{\vec{r}})\vec{v} &= -\vec{\nabla}_{\vec{r}}\phi \\ \vec{\nabla}^2_{\vec{r}}\phi &= 4\pi G\rho \end{aligned} \tag{1}$$

Procedure: combine continuity, Euler and Poisson equations, perturb them and keep all terms.

Getting the right δ_c for EDE

(Pace, Waizmann & Bartelmann in prep.)

Use $\rho = \bar{\rho}(1+\delta)$, $\vec{x} = a\vec{r}$ and $\vec{v} = (a\dot{\vec{x}}) = aH(a)\vec{x} + a\vec{u}$ to obtain:

$$\delta'' + \left(\frac{3}{a} + \frac{E'(a)}{E(a)}\right)\delta' - \frac{4}{3}\frac{\delta'^2}{1+\delta} - \frac{3}{2}\frac{\Omega_{m,0}}{a^5 E^2(a)}\delta(1+\delta) = 0$$

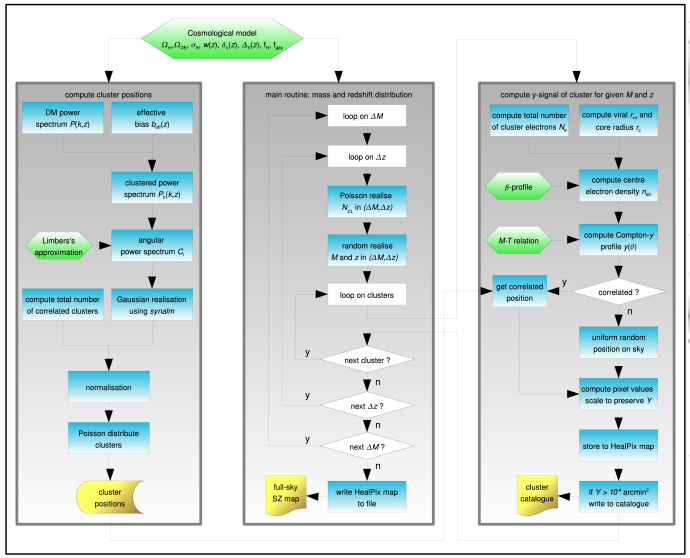
$$\delta'' + \left(\frac{3}{a} + \frac{E'(a)}{E(a)}\right)\delta' - \frac{3}{2}\frac{\Omega_{m,0}}{a^5 E^2(a)}\delta = 0 \tag{2}$$

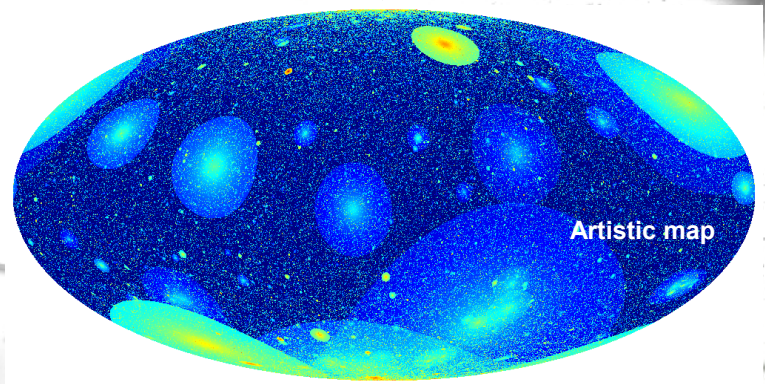
IC:$a_i = 5 \times 10^{-5}$, $\delta' = a_i$, δ_i to be searched.

Constructing a full-sky tSZ-map (Waizmann & Bartelmann 2009)

In a nutshell

- Works also for $w(z)$ models
- Method is fast compared to numerical simulations
- Assume hydrostatic equilibrium M-T relation
- Model clusters as β-profiles
- Include spatial correlations (Limber approximation)
- Write to a HealPix map

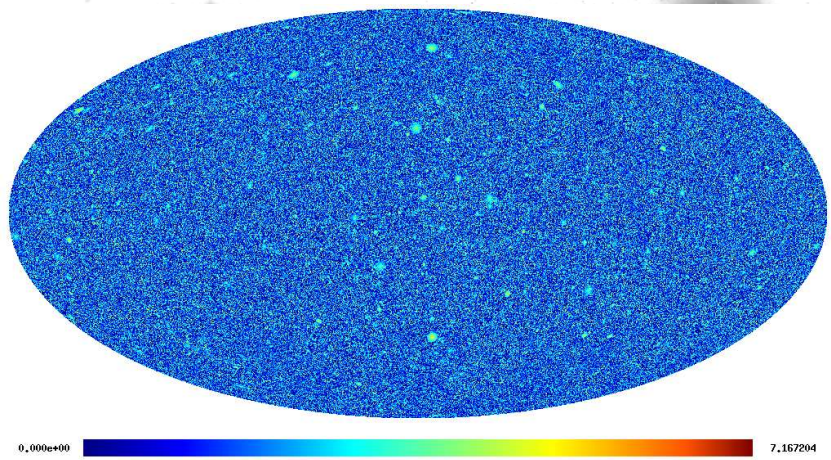


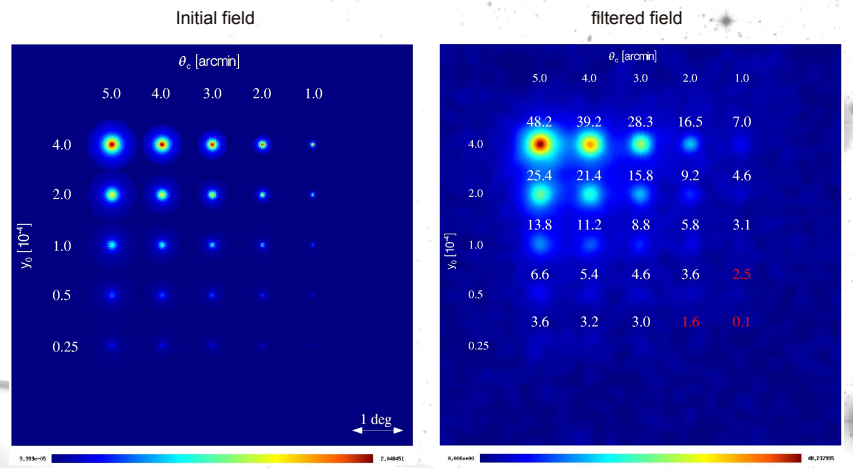


Impact of EDE on the *Planck* cluster sample

What we did

- We created a full-sky SZ map of 3 different EDE models
- Constructed observed sky maps including foregrounds and instrumental noise
- Fed observations into our filtering pipeline
- Cross-checked against cluster catalogue





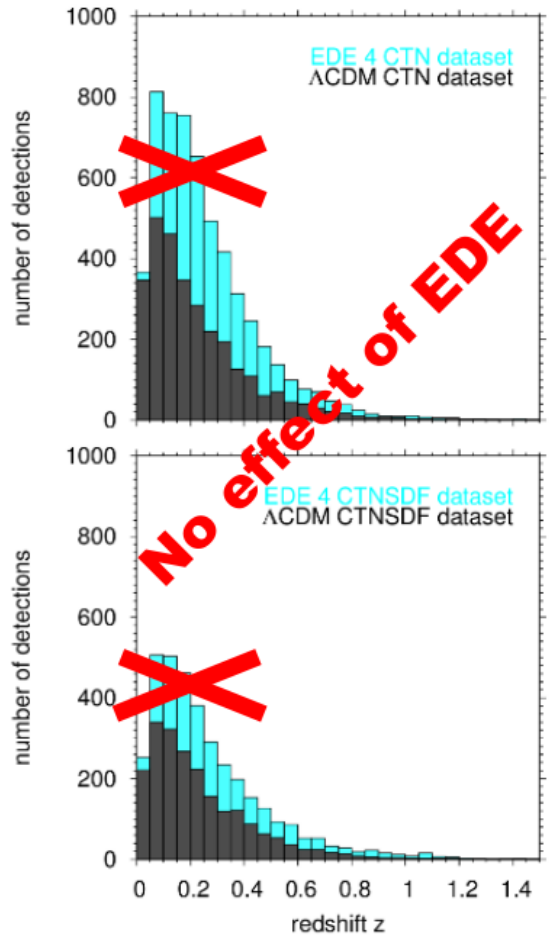
Results

What we found:

- Models with different history of structure formation change detected sample
- EDE models can not be detected, using number counts

What we omitted:

- point source contamination omitted
- complete follow-up for cluster redshift determination



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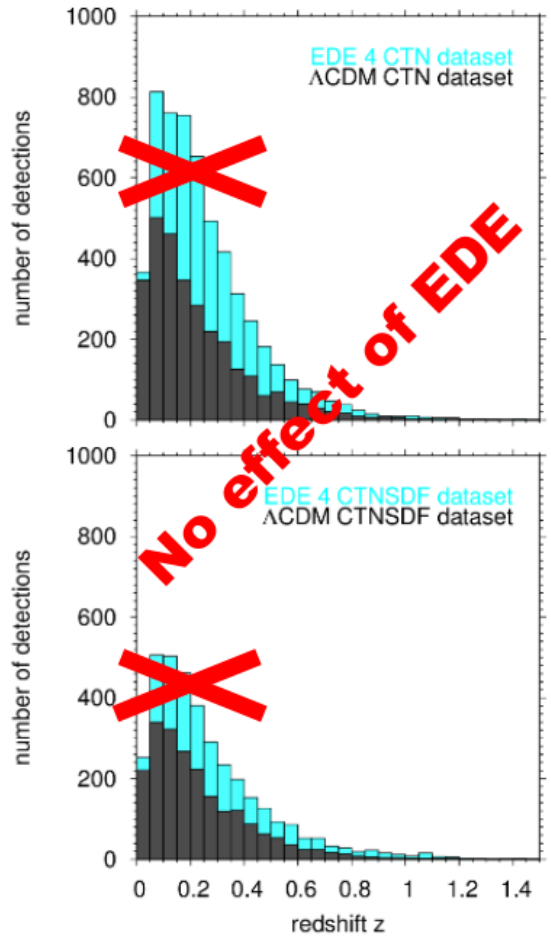

Summary & Conclusions

Early Dark Energy

- It is still a valid model
- δ_c is **not** lowered compared to ΛCDM
- Impact on non-linear structure formation is neglible

tSZ mapmaking

- Our method is applicable to different models
- Allows quick exploration of parameter space
- Foregrounds & Point Source contamination make life hard

Cluster Cosmology

- We need many clusters for Cosmology
- Future missions will probe high-redshift clusters
- Better understanding of high-z cluster evolution is needed

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