The imprint of superstructures on the Cosmic Microwave Background through the ISW effect

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Plan

1. Introduction to the ISW effect

2. The imprint of superstructures

3. ISW modelling with LTB formalism
The ISW effect in one picture

Energy gain (or loss) for the CMB photons when crossing **large, evolving**, matter over-(under-)densities

**Direct signal of dark energy in a flat universe**
How to (classically) exploit the ISW Effect

Impact on CMB power spectrum

- Only visible at low multipoles $\ell$
  - $\Rightarrow$ severely limited by cosmic variance

- CMB spectrum alone is not enough

Cross-correlation with tracers of matter distribution

- **Idea**: use the link between **gravitational potentials** and the **underlying structures**
- **How-to**: cross-correlate CMB map with galaxy surveys
- **Up to now**: contradictory results, ranges from “null” to $4.5\sigma$, current surveys limited in depth and coverage
Recent and future (ISW) developments

Future large surveys

- LSST, Pan-STARRS, Euclid ...
- see Douspis et al., 2008, A&A, for associated performance forecasts

Use of other tracers of matter

Prediction of the cross-correlation with the Cosmic Infrared Background

See Ilic et al., 2011, MNRAS, for the complete study
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Alternative method by Granett et al. (2008)

50 most significant supervoids and 50 superclusters in SDSS DR6 LRG
Granett et al. (2008)

“Stacking” of CMB patches (WMAP 5) at the superstructures locations

<table>
<thead>
<tr>
<th>Voids</th>
<th>Clusters</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-11.3 \pm 3.1 \mu K (2.55\sigma)$</td>
<td>$7.9 \pm 3.1 \mu K (3.65\sigma)$</td>
<td>$9.6 \pm 2.2 \mu K (4.36\sigma)$</td>
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</tbody>
</table>

$\Lambda$CDM “predicts”:

- $4.2 \mu K$ from Millenium simulations (cf. Granett)
- Around $1-2 \mu K$ from perturbation theory
  (see for example Nadathur et al, 2011, arxiv :1109.4126)
Going further:
⇒ testing a few of our intuitions about ISW on these results

- The largest structures should contribute the most
- The “nearest/most recent” structures (therefore most DE-dominated) too

We focus here on the study of **voids**:

- Less likely to be contaminated by other signals
- Locally more DE-dominated (since $\Omega_m^{\text{local}} < \Omega_m^{\text{background}}$)
Analysis of Granett’s voids

Individual study of Granett’s objects impossible due to background noise (CMB !)

- We adopt a ”Jackknife” approach
- We randomly select sets of \( n \) voids (from the 50) in the Granett sample
- We compute their stacking and associated ISW flux, mean radius and redshift
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Predict the ISW effect

Objectives:

- Compute the full exact evolution of an over/underdensity (from $z = 1100$ to 0)
- Make a photon go through the structure at some chosen time in the history of the structure
- Keep track of its energy and compare it to that of a photon travelling in the background

Can be done exactly with the use of the LTB metric for spherically symmetric structures
The LTB metric

Most general spherically symmetric metric

\[ ds^2 = dt^2 - \frac{R_r^2}{1+2E(r)} dr^2 - R(r,t)^2 d\Omega^2 \]

\[ \Downarrow \]

\[ R_t^2 = 2E(r) + \frac{2M(r)}{R} - \frac{1}{3} \Lambda R^2 \]

- Two free functions, \( M(r) \) (“mass profile”) and \( E(r) \) (“curvature profile”)
- Determined by supplying an initial density profile (+ junction conditions)
- We work here with **compensated structures** embedded in an FLRW background
Computations

Typical evolution of a compensated void

![Graph showing the evolution of a compensated void](image)

Computation of the path of a travelling photon

Geodesic equations for a radial photon:

- **Motion**:\[
\frac{dr}{dt} = \pm \sqrt{1 + 2E}\frac{1}{R_r}.
\]
- **Energy**:\[
\frac{d\epsilon}{dt} = -\frac{R_{r,t}}{R_r} \epsilon.
\]
LTB exploration

Many degrees of freedom:
- Cosmological parameters → $\Lambda$-CDM
- Epoch of photon crossing → $z = 0.52$, mean redshift of Granett’s voids
- Initial profile → Compensated voids

Obtainable ISW levels

Granett’s signal ($\sim -11 \mu K$)
“theoretically” possible
Reproducing Granett’s voids

Granett’s structures:
- We have access to $R$, $z$, $\delta_{\text{min}}$, $\delta_{\text{mean}}$
- We can reproduce these with LTB, and compute the expected ISW effect

Predicted mean ISW effect weaker than observed (...again)
- A few large voids contribute the most
- If we remove them from Granett’s stacking: no difference!
Conclusions and perspectives

Discrepancy not solved (yet) but many explorations left:

- Full $\Delta T/T$ profile of the ISW effect
- Consequences of void overlaps and alignments?
- Testing other cosmological models

Data related:

- Same stacking with Planck data
- What is really the significance of 50 structures?
- $\Rightarrow$ Analysis of other independent catalogs
Thanks for your attention!