Parity in the CMB: Space Oddity

Assaf Ben-David
Tel-Aviv University

Recontres de Moriond
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Based on work with E. D. Kovetz and N. Itzhaki
Outline

- Motivation
- Searching for parity in the CMB
  - in pixel space
  - in harmonic space
- Masking the galactic plane
- Results
Motivation
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Assumption:

On large enough scales the universe is homogeneous and isotropic.
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Inflation:

$V(\phi)$

- Pre-inflationary physics
- Slow roll region
- Larger scales exit the horizon
- Smaller scales exit the horizon

$\Lambda$CDM
Motivation

Assumption:
On large enough scales the universe is homogeneous and isotropic.

- In small field models, inflation is short.
- Pre-inflationary physics affect largest scales.
- Test the assumption of isotropy on largest scales.
- Indeed, there are several large scale anomalies ($\sim 3\sigma$).
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• Parity with respect to reflections through a plane:

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• “S” statistic:

\[ S(\hat{n}) = \int d^2\hat{n}' [T(\hat{n}') - T(\mathcal{P}_\hat{n}(\hat{n}'))]^2 \]


de Oliveira-Costa, Tegmark, Zaldarriaga, Hamilton (PRD, 2004)]
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- “S” Map

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- There are 2-point correlations $C(\theta) \equiv \langle T(\hat{n})T(\hat{n}') \rangle \bigg|_{\hat{n} \cdot \hat{n}' = \cos \theta}$

Copi et al. (MNRAS 2009)
The Problems with Pixel-Space

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- Masking the galactic plane results in strong bias.

Copi et al. (MNRAS 2009)
Harmonic Space Score

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\[ S(\hat{n}) = \sum_{\ell=2}^{\ell_{\text{max}}} \left[ \sum_{m=-\ell}^{\ell} (-1)^{\ell + m} \frac{|a_{\ell m}(\hat{n})|^2}{\hat{C}_\ell} - 1 \right] \]

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- Standard \( \Lambda \)CDM signal should give \( \langle S \rangle = 0 \).
Parity Score - Full Sky Results
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- Results for WMAP 7-year ILC map, taking $\ell_{\text{max}} = 5$: 
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- A maximum at \((l, b) \approx (260^\circ, 60^\circ)\), the direction of the “Axis of Evil”.
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- A minimum at $(l, b) \simeq (266^\circ, -19^\circ)$. 
Masking Galactic Noise
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KQ75
Masking Galactic Noise

Naively, \( a_{\ell m} = \int_M d^2\hat{n} Y^*_{\ell m}(\hat{n}) T(\hat{n}). \)
Masking Galactic Noise

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• Spherical harmonics are not orthogonal on masked sky!

• Introduces correlations between coefficients.
Covariance Inversion Method
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- Use higher-$\ell$ correlations to reconstruct data on masked sky.

[Box]
de Oliveira-Costa, Tegmark (PRD, 2006)
Efstathiou, Ma, Hanson (arXiv:0911.5399)
Aurich, Lustig (MNRAS, 2011)
Covariance Inversion Method

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• For the discrete CMB data

$$\mathbf{x} = \mathbf{Y} \mathbf{a} + \mathbf{n}$$

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\[ x = Ya + n \]

\[ Y_{ij} = Y_{\ell j} m_j (\hat{r}_i) \]

- An unbiased ($\langle \hat{a} \rangle = a$) estimator

\[ \hat{a} = \left( Y^\dagger C^{-1} Y \right)^{-1} Y^\dagger C^{-1} x \]

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  \[ \hat{\mathbf{a}} = \left( \mathbf{Y}^\dagger \mathbf{C}^{-1} \mathbf{Y} \right)^{-1} \mathbf{Y}^\dagger \mathbf{C}^{-1} \mathbf{x} \]

- Use power spectrum to construct the covariance matrix

  \[ C_{ij} = \sum_{\ell=\ell_{\text{max}}+1}^{L} \frac{2\ell + 1}{4\pi} P_{\ell} (\hat{r}_i \cdot \hat{r}_j) C_{\ell} \]

References:
- de Oliveira-Costa, Tegmark (PRD, 2006)
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- Does not appear significant.
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- Does not move, for all masks.
Parity Score - Masked Sky Results

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- Appears much more significant.
Parity Score - Masked Sky Results

- At $A \sim 7\%$ jumps by almost $40^\circ$.
- Does not appear significant.
- Peaks are $90^\circ \pm 1^\circ$ apart.
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- Appears much more significant.
Significance of the Results
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• Normalize score:

\[ S_+(A) = \max_{\hat{n}} S(\hat{n}, A) \]

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\[ \ell_{\text{max}} = 6 \]

\[ 4.3\sigma \]
Future
Future

- Data from Planck.
Future

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- A model for a pre-inflationary effect which is parity odd?
Thank You!
Separate Frequency Bands

Masked with KQ85
Testing for Bias

- Bias due to masking?
- Bias due to degradation?
Motivation for Masking Scheme

Bennett et al. (ApJS 2011)