On Planck CMB Anomalies, Alignments and Calibration

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June 2015, Madrid, “Invisibles 2015”

[1] In collaboration with M.Quartin and earlier work with R.Catena, L.Amendola, I.Masina, C.Quercellini.
arXiv:1504.04897
JCAP 032P 0415
JCAP 1501 (2015) 01, 008
JCAP 1403 (2014) 019
JCAP 1202 (2012) 026
JCAP 1107 (2011) 027

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- What is the impact of our peculiar velocity?

CMB spectrum

More precisely

- $T(\hat{n}) \to a_{\ell m}$

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- Uncorrelated: NO preferred direction

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- **Doppler**:
  $T'(\hat{n}) = T(\hat{n})\gamma(1 + \beta\cos\theta) \qquad (\cos(\theta) = \hat{n}\cdot\hat{\beta})$
- **Aberration**:
  $T'(\hat{n}') = T(\hat{n})$
  with $\cos\theta - \cos\theta' = \beta\frac{\sin^2\theta}{1+\beta\cos\theta}$
  $\theta - \theta' \approx \beta\sin\theta$

Peebles & Wilkinson ’68, Challinor & van Leeuwen 2002, Burles & Rappaport 2006

In multipole space

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$$a'_{\ell m} \simeq a_{\ell m} + \beta(c^{-}_{\ell m} a_{\ell-1\,m} + c^{+}_{\ell m} a_{\ell+1\,m}) + \mathcal{O}((\beta\ell)^2 \cdot a_{\ell\pm 0,2})$$

- $c^{+}_{\ell m} = (\ell + 2 - 1)\sqrt{\frac{(\ell+1)^2 - m^2}{4(\ell+1)^2 - 1}}$

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- Doppler (constant), aberration grows with ℓ!
- For $\ell > 1/\beta \approx 800$ more neighbors are coupled

$$a'_{\ell m} = \sum_{\ell'} K_{\ell\ell' m} a_{\ell' m}$$

Testing Isotropy

- Given a map $T(\hat{n})$ we can mask a part of the sky: $\tilde{T}(\hat{n}) = M(\hat{n})T(\hat{n})$

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- And compare two opposite halves $\tilde{C}_\ell^N$ and $\tilde{C}_\ell^S$

Hemispherical asymmetry?

- Several papers significant (about 3σ) hemispherical asymmetry
  - at $\ell < \mathcal{O}(60)$

    Eriksen et al. '04, '07, Hansen et al. '04, '09, Hoftuft et al. '09, Bernui '08, Paci et al. '13

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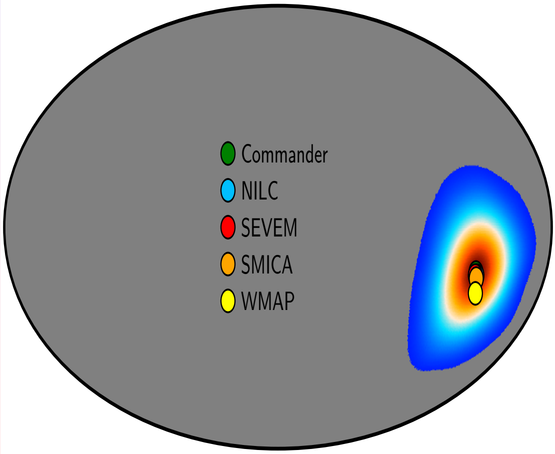
  - Also up to $\ell \leq 600$ (WMAP)
    Hansen et al. '09
  - And also to the Planck data! (Up to which ℓ?)
    Planck Collaboration 2013, XIII. Isotropy and Statistics.

Planck asymmetry

- 7% asymmetry
- Same as in WMAP



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- A correct analysis has to include Doppler and Aberration (important at high $\ell \simeq 1000$)

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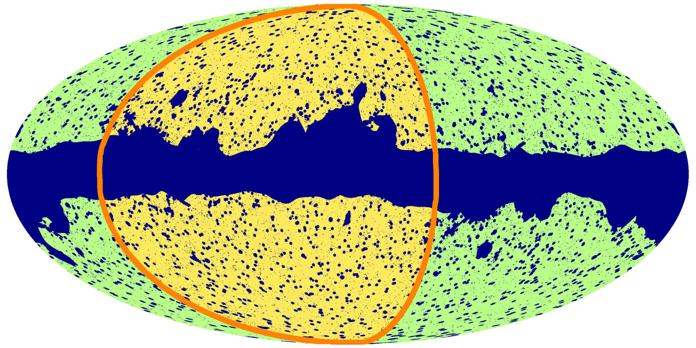
- We find between $2 - 3\sigma$ anomaly at $\ell \lesssim 600$ (A.N., M.Quartin & JCAP '14)

Planck Mask (Symmetrized)

- We cut the sky into two parts (N vs. S)



Hemispherical Asymmetry due to Velocity

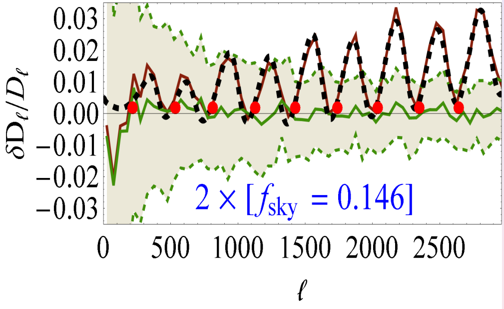
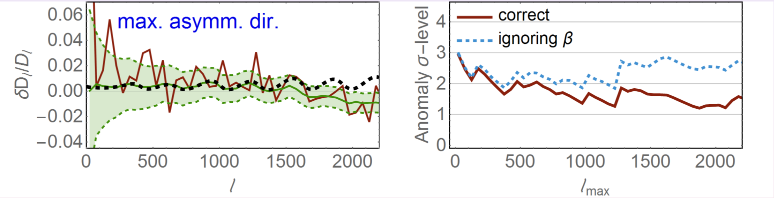


Figure : Discs along the Dipole direction

A.N., M.Quartin, R.Catena 2013

Significance: Results



Simulations include Noise and Doppler+Aberration.

(A.N., M.Quartin 2014)

“Dipolar modulation"?

- Several authors have studied the ansatz

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$$T = T_{\text{isotropic}} \left(1 + \boldsymbol{A}_{\text{mod}} \cdot n\right) ,$$

- 3-σ detections of $A_{mod} \approx 7\%$
  (For $\ell < 64$ or $\ell < 600$)

Our Results on A

CMB

CMB & Proper motion
Anomalies
Alignments
Planck Calibration

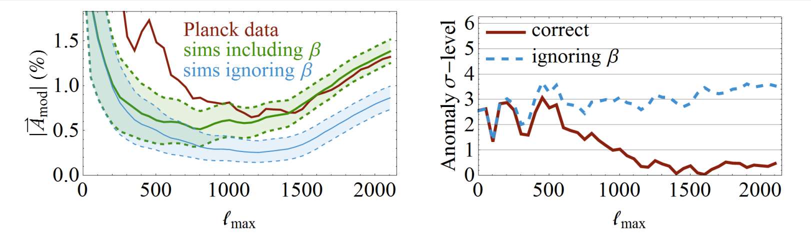

Figure : All simulations include Planck noise asymmetry.

A.N. & M.Quartin, 2014

WMAP/Planck Quadrupole-Octupole alignments

Another anomaly:

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- $\hat{n}_2 \cdot \hat{n}_3 \approx 0.99$ $\quad (p - value \approx 0.01)$
- And also Dipole-Quadrupole-Octupole $(\hat{n}_1, \hat{n}_2, \hat{n}_3)$ aligned (*e.g.*Copi et al. '13)

Removing Doppler quadrupole

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- After removing Doppler $\rightarrow 2.9\sigma$ (Copi et al. '13) (agreement with WMAP)

Frequency dependence!

- The Dopper Quadrupole is frequency dependent: (Sazonov & Sunyaev '99, Kamionkowski & L. Knox '04, Chluba & Sunyaev '04)

$$\delta I'(\nu') \propto \frac{\delta T(\hat{\boldsymbol{n}})}{T_0} + (\boldsymbol{\beta} \cdot \hat{\boldsymbol{n}}) + Q(\nu)(\boldsymbol{\beta} \cdot \hat{\boldsymbol{n}})^2 + \ldots, \qquad (1)$$

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- $Q(\nu)$ weighted average in the range $1 - 5$ (High ν channels)

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- WMAP calibrated using $\beta_{ORBITAL}$ ($\approx 10^{-4}$)
- Planck 2013 calibrated on β_{SUN} (using WMAP!)
- Planck 2015 calibrated on $\beta_{ORBITAL}$

Planck Calibration?

- Splitting $\beta_{TOT} = \beta_S + \beta_O$ (A.N. & M.Quartin '2015) :

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  - Systematics still not understood in Planck HFI and polarization still not used!