Mysteries of the large-angle microwave sky

Dragan Huterer

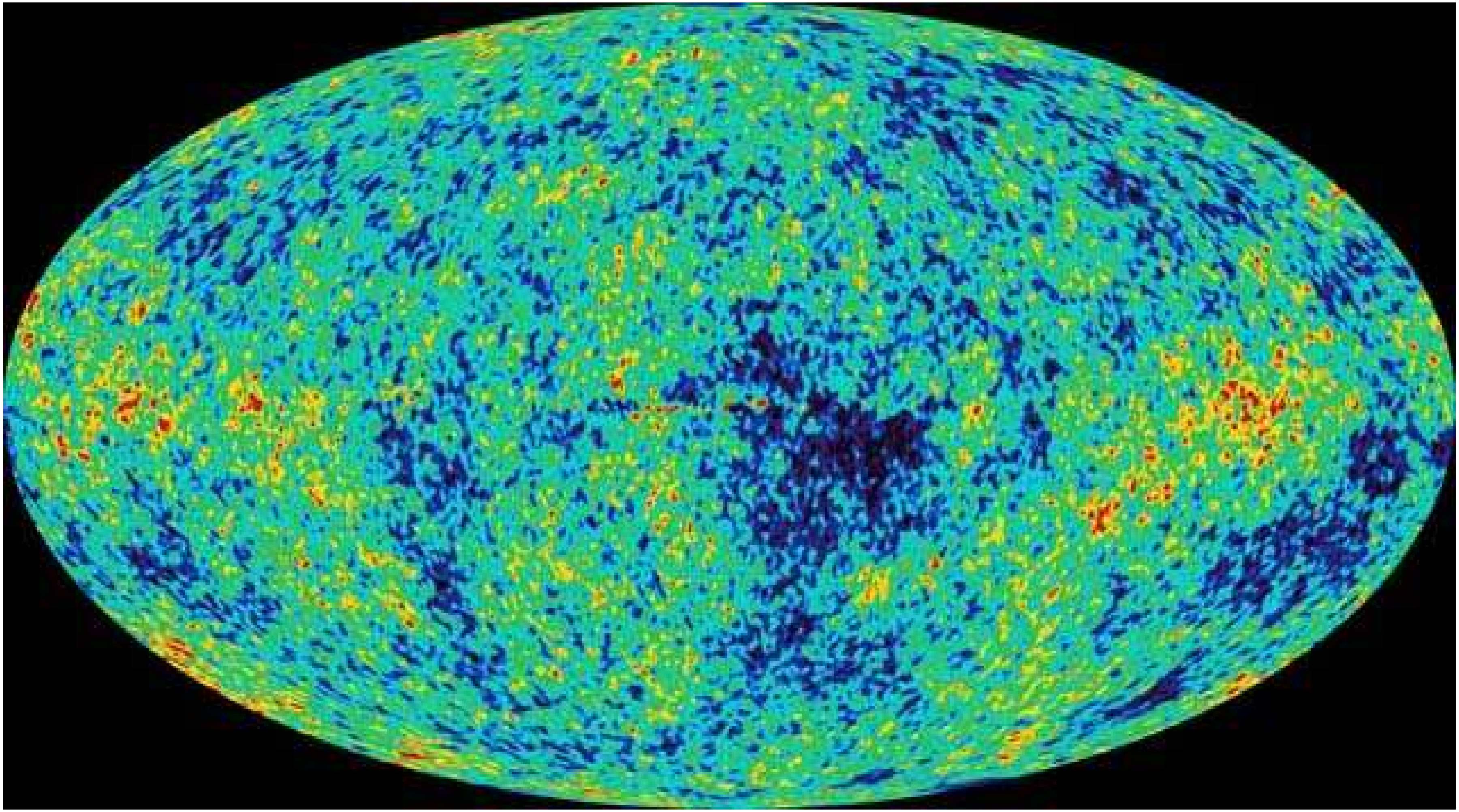
University of Chicago

Collaborators:

Craig Copi, Glenn Starkman (CWRU), Dominik Schwarz (Bielefeld)

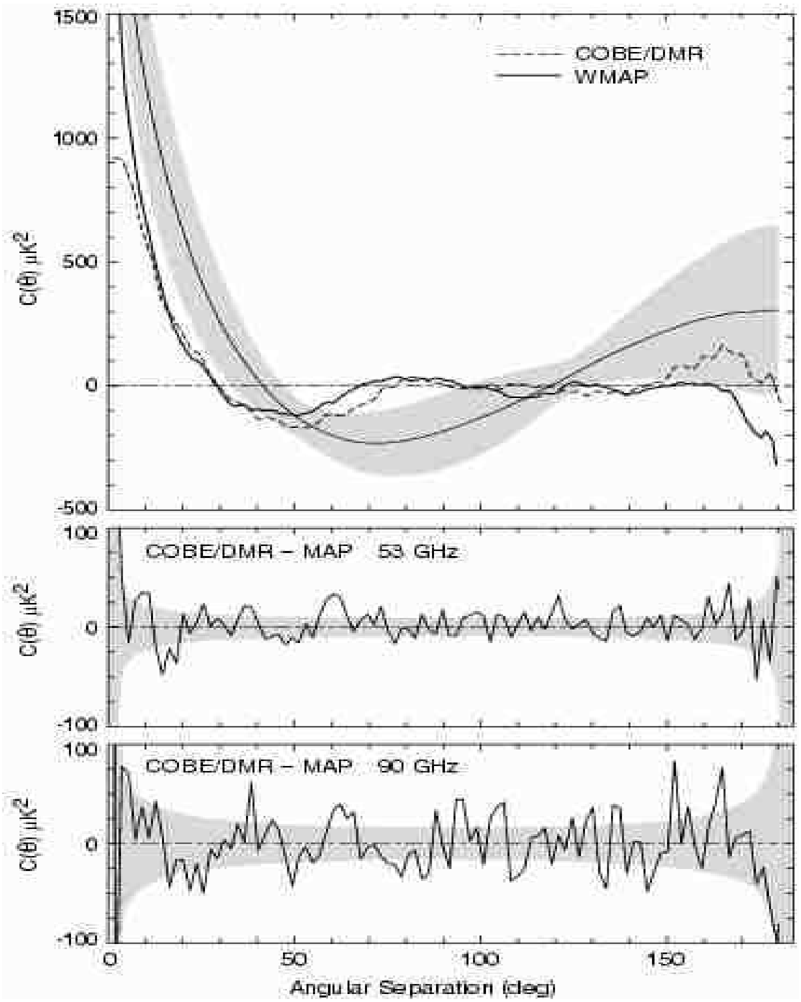
Chris Gordon, Wayne Hu, Tom Crawford (Chicago)

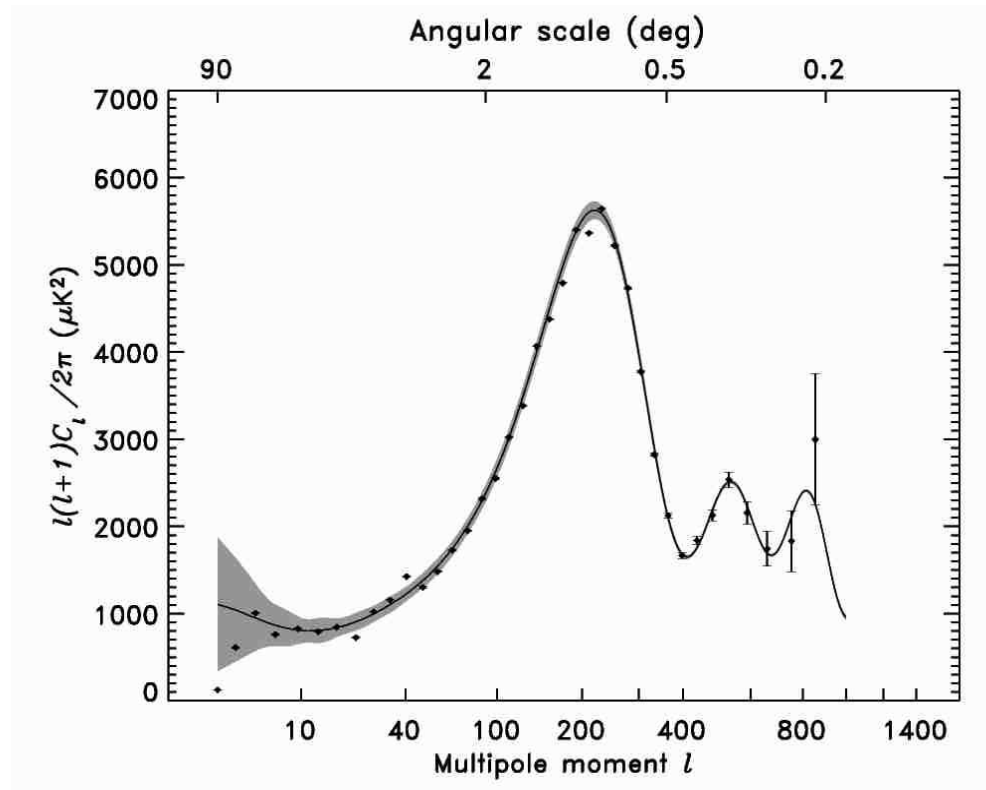
WMAP ILC map



Bennett et al. 2003

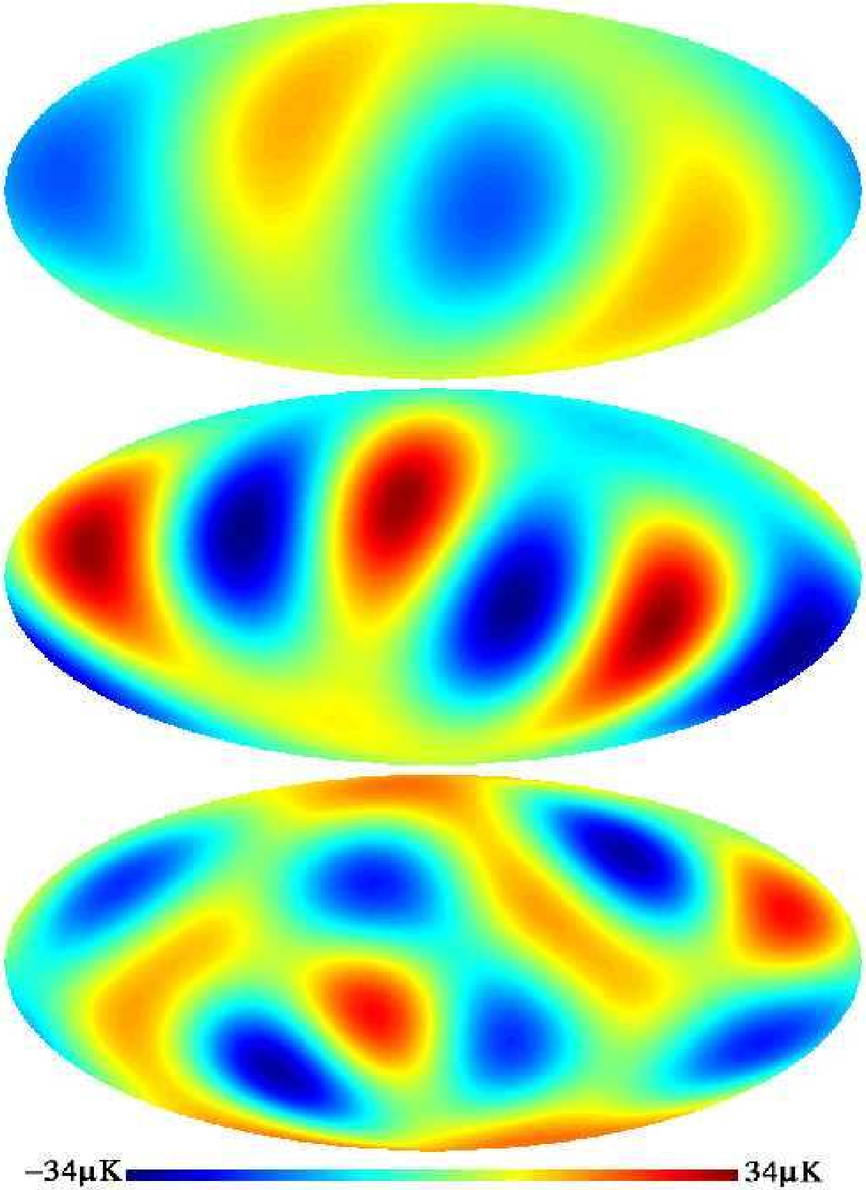
Lack of power at $\theta > 60$ deg





Bennett et al. 2003

$\ell = 2, 3$ are aligned and planar



Tegmark et al. 2003

Multipole Vectors

Spherical Harmonics:

$$\frac{\delta T}{T}(\theta,\phi) = \sum_{l,m} a_{lm} Y_{lm}(\theta,\phi), \qquad C_\ell \equiv \frac{1}{2\ell+1}\sum_{m=-\ell}^{\ell} |a_{\ell m}|^2$$

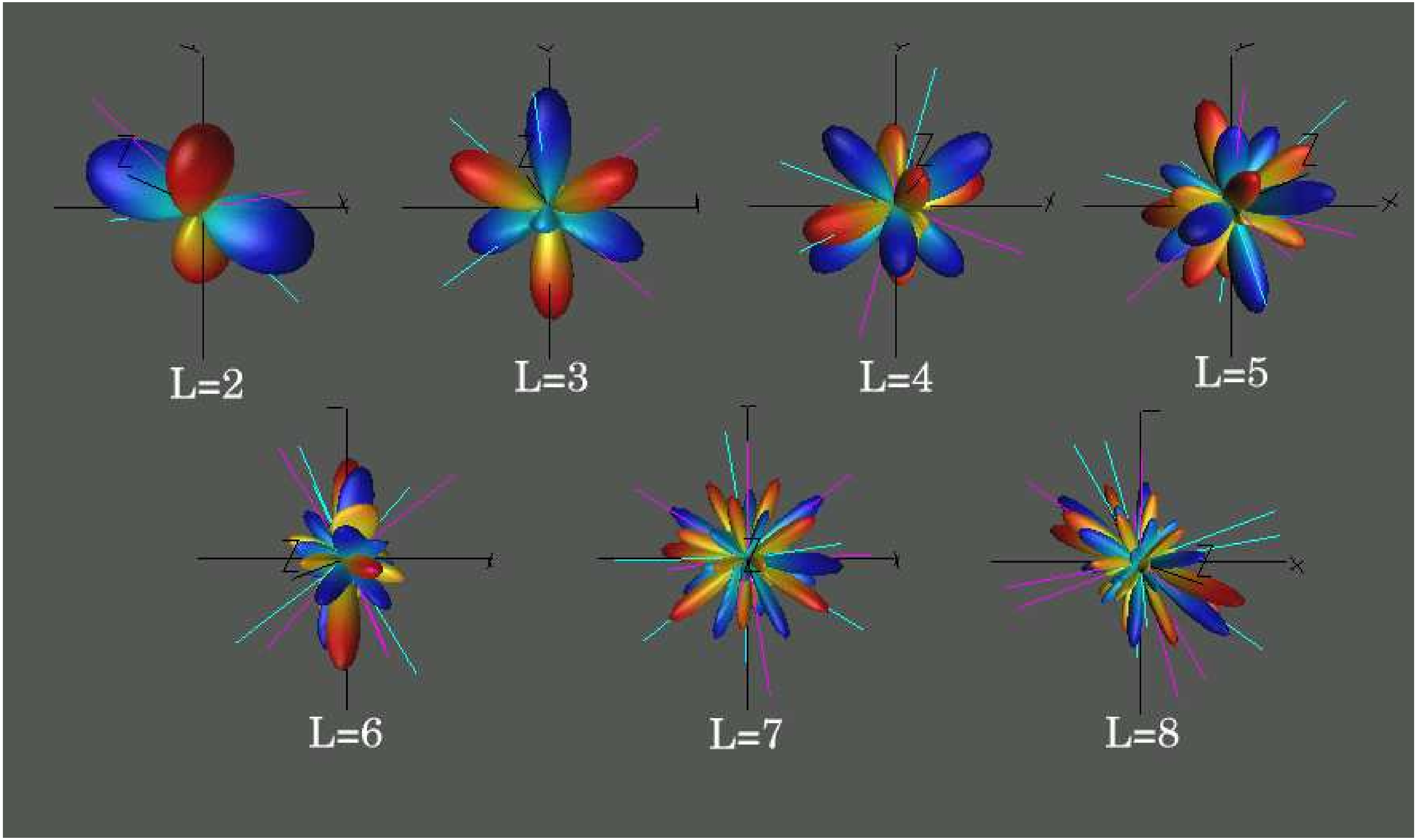
Multipole Vectors:

$$\sum_{m=-\ell}^{\ell} a_{lm} Y_{lm}(\theta,\phi) \quad = \quad A^{(\ell)} \left(\mathbf{v}_1^{(\ell)} \cdot \mathbf{e}\right) \cdots \left(\mathbf{v}_\ell^{(\ell)} \cdot \mathbf{e}\right)$$

$$\text{``} a^{(\ell)}_{i_1 \ldots i_l} \quad \leftrightarrow \quad A^{(l)} \left[\mathbf{v}_1^{(\ell)} \otimes \mathbf{v}_2^{(\ell)} \otimes \ldots \mathbf{v}_\ell^{(\ell)}\right]\text{''}$$

Copi, Huterer & Starkman, 2004

Multipole Vectors of our sky



Normals to multipole vectors

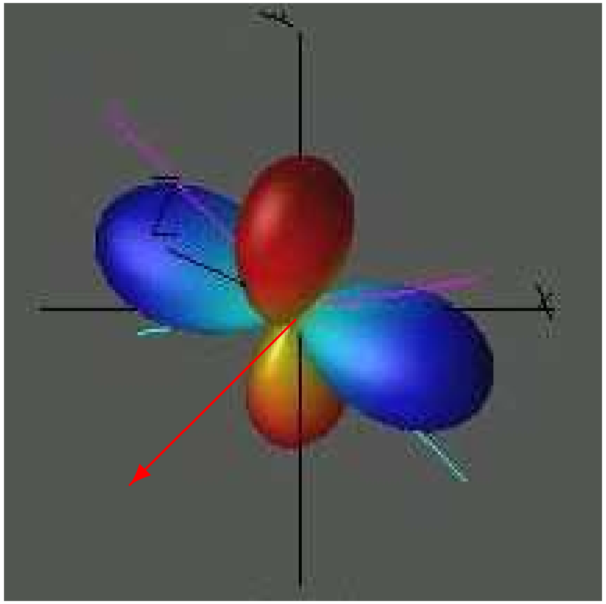
$$\mathbf{w}_{ij}^{(\ell)} \equiv \pm\left(\mathbf{v}_i^{(\ell)} \times \mathbf{v}_j^{(\ell)}\right)$$

$\mathbf{w}_{12}^{(\ell=2)}$

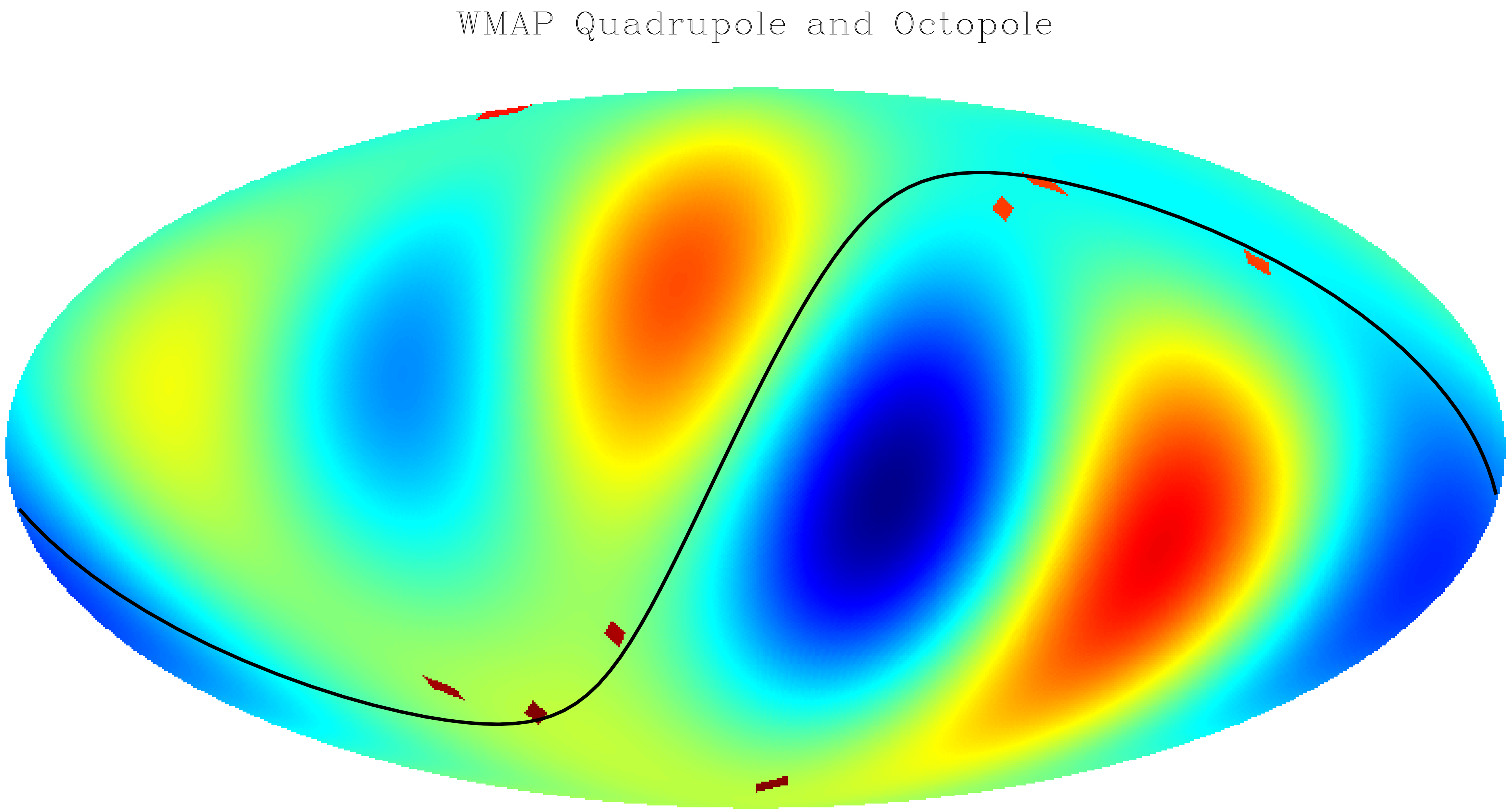
$\mathbf{w}_{12}^{(\ell=3)}$

$\mathbf{w}_{23}^{(\ell=3)}$

$\mathbf{w}_{31}^{(\ell=3)}$

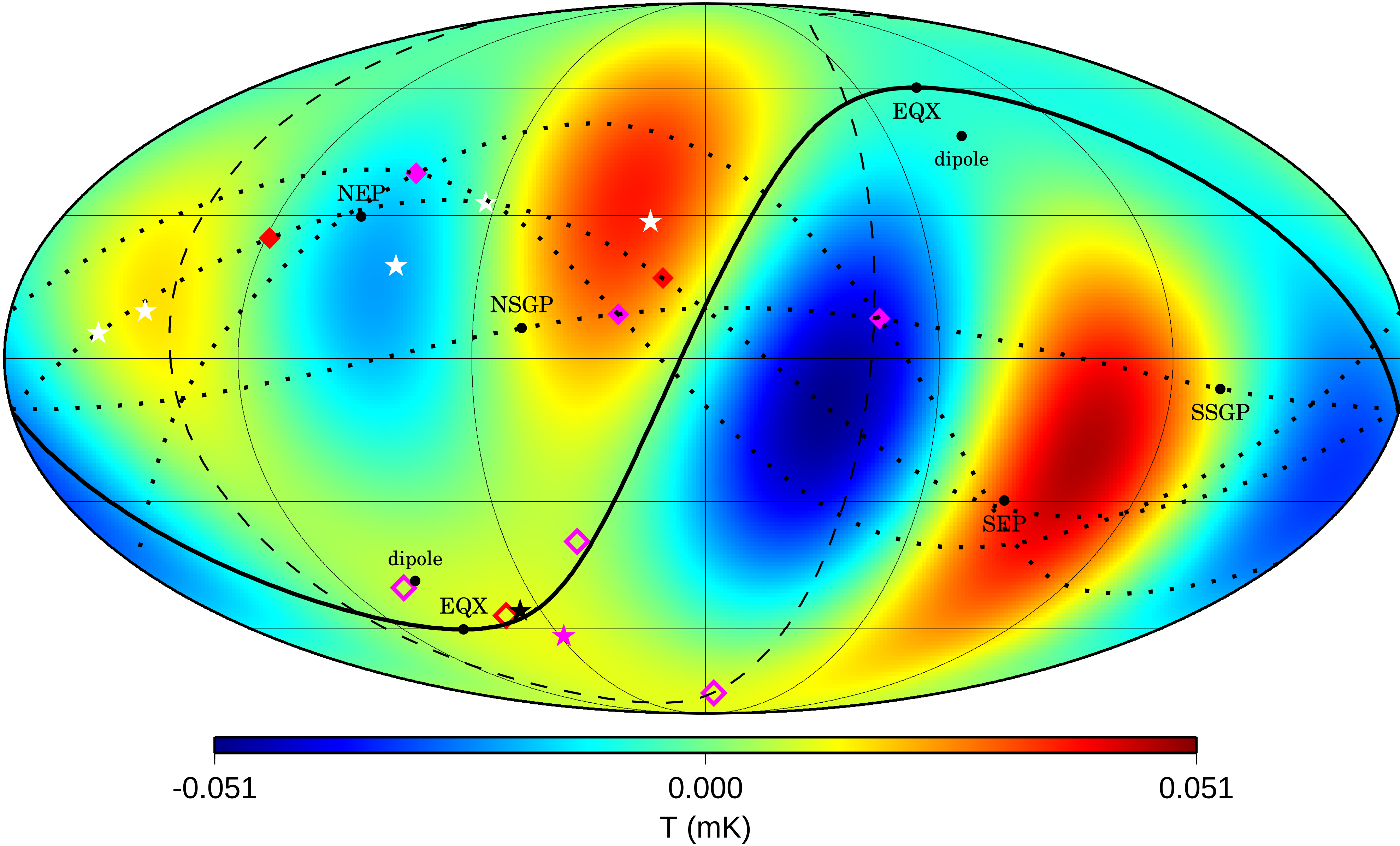


(Quad + Oct) map and the ecliptic plane



Schwarz, Starkman, Huterer and Copi, PRL 2005

(Quad + Oct) map and the ecliptic plane

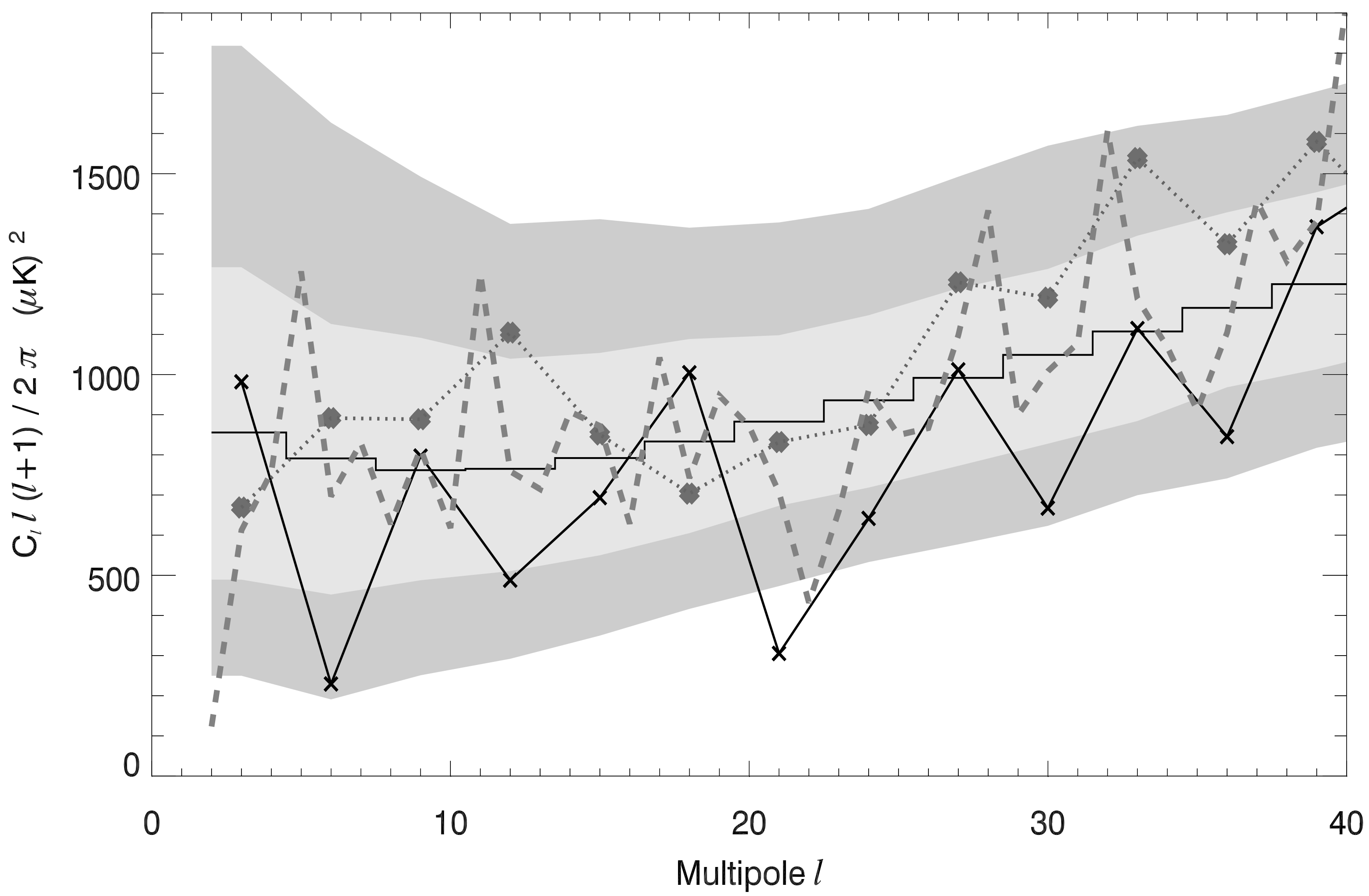


Found: unexpected alignments

- The four oriented area normals $\mathbf{w}_{ij}^{(\ell)} \equiv \pm \left(\mathbf{v}_i^{(\ell)} \times \mathbf{v}_j^{(\ell)}\right)$ for $\ell = 2, 3$ are mutually close (99.7-99.9% CL)
- $\mathbf{w}_{ij}^{(\ell)}$ lie close to the ecliptic plane (99% CL)
- $\mathbf{w}_{ij}^{(\ell)}$ are aligned to the dipole and to the equinoxes (99.9% CL)
- Ecliptic plane carefully separates stronger from weaker extrema, running between a maximum and a minimum over most of the sky (93% - 99.6% CL)

Schwarz, Starkman, Huterer and Copi, PRL 2005

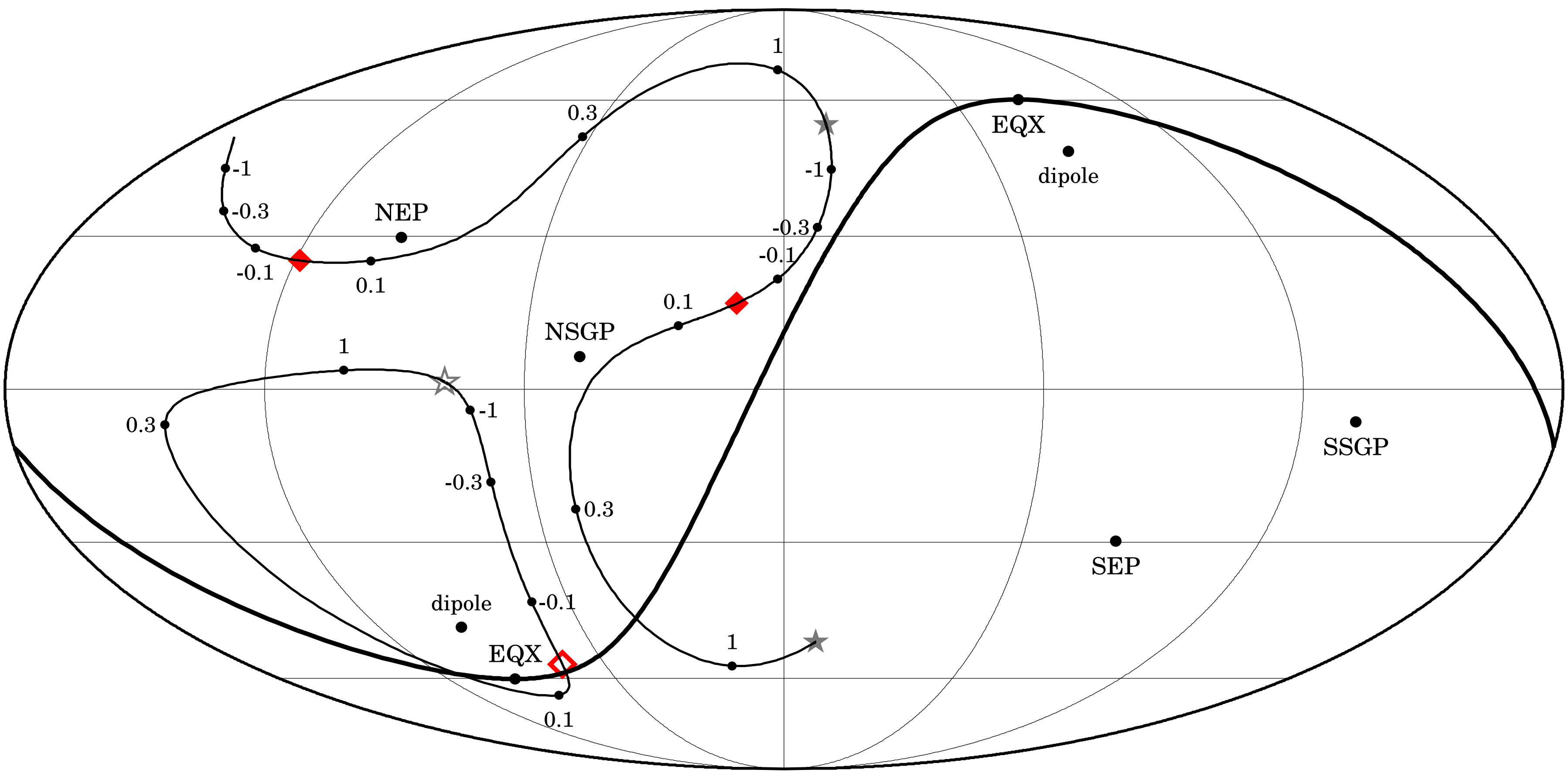
N/S power asymmetry



Eriksen et al. 2004; Hansen, Banday & Gorski, 2004

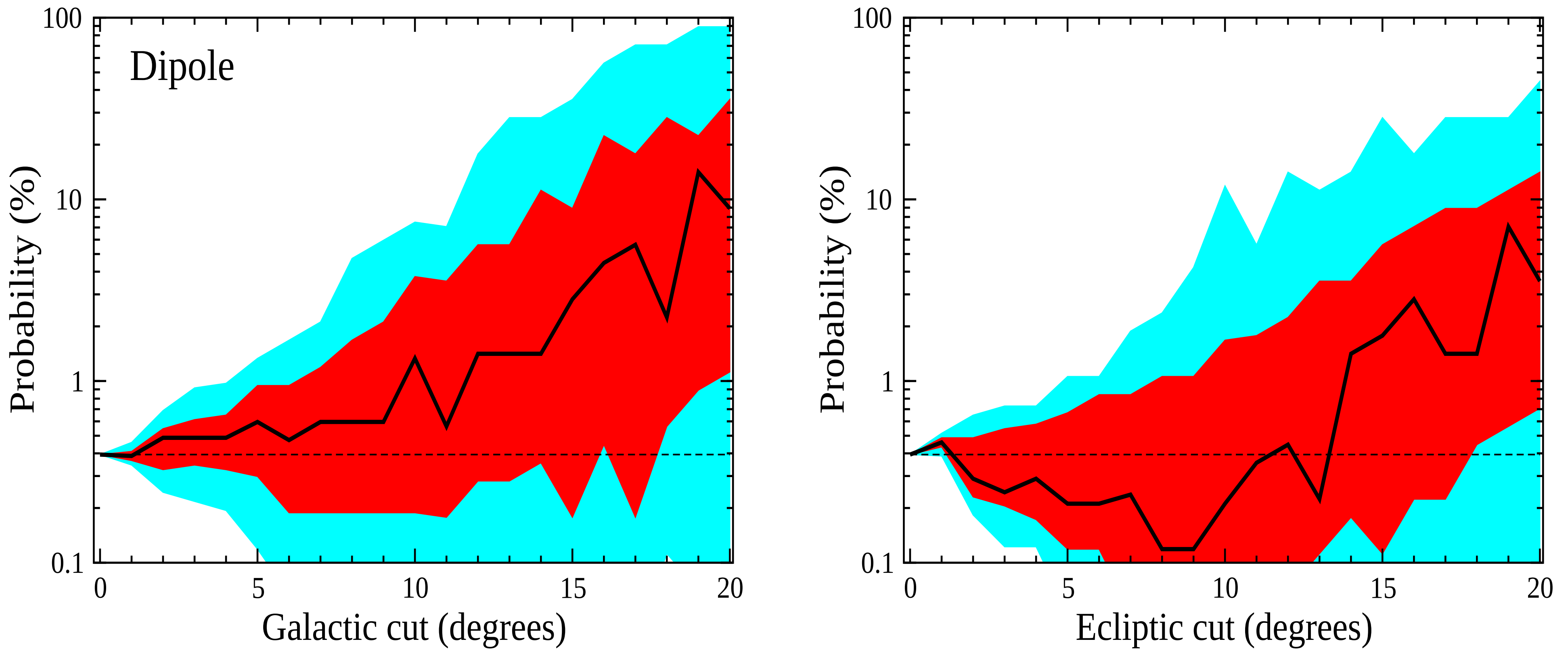
Systematic checks: foreground missubtraction

$$T_{\rm tot}(\theta) = T_{\rm CMB}(\theta) + c\,T_{\rm for}(\theta)\sqrt{\frac{{\rm Var}(T_{\rm CMB})}{{\rm Var}(T_{\rm for})}}$$



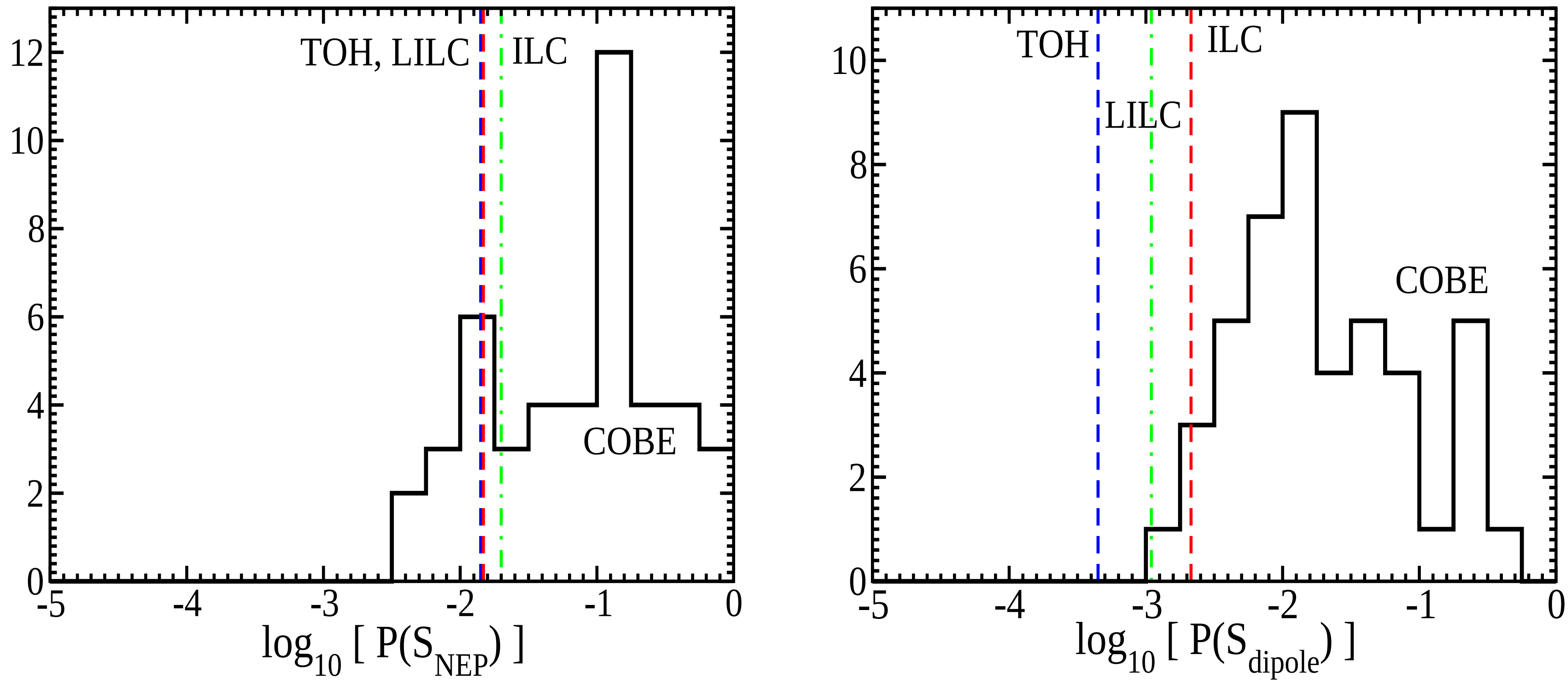
Copi, Huterer, Schwarz & Starkman, astro-ph/0508047

Systematic checks: sky cut



Copi, Huterer, Schwarz & Starkman, astro-ph/0508047

What about COBE?



Using the COBE MCMC maps from Wandelt, Larson & Lakshminarayanan (2004)

4 classes of explanations:

- Astrophysical (e.g. an object or other source of radiation in the Solar System)
  - BUT: we think we know the Solar System. It would need to be a large source *and* undetected in data cross-checks.
- Instrumental (e.g. there is something wrong with WMAP instrument measuring CMB at large scales)
  - BUT: the instruments have been extremely well calibrated and checked. Plus, why would they pick out the Ecliptic plane?
- Cosmological (e.g. some property of the universe – inflation or dark energy for example – that we do not understand)
  - This is the most exciting possibility. BUT: why would the new/unknown physics pick out the Ecliptic plane?
- These alignments are a pure fluke!
  - BUT: they are <0.1% likely!

What could be going on?

- Dipole subtraction?
- Scanning strategy?
- Solar system signal?

or perhaps...

- Anisotropic universe?

Any of the above would have implications for cosmological parameter determination.

Additive and multiplicative errors

Let $T(\hat{\mathbf{n}}), A(\hat{\mathbf{n}}), B(\hat{\mathbf{n}})$ be temperature fields

$$T(\hat{\mathbf{n}}) \equiv A(\hat{\mathbf{n}}) + f[1 + w(\hat{\mathbf{n}})]B(\hat{\mathbf{n}})$$

$$\Rightarrow t_{\ell m} = a_{\ell m} + f b_{\ell m} + f \sum_{\ell_1 \ell_2} R_{\ell m}^{\ell_1 \ell_2} b_{\ell_2 m}$$

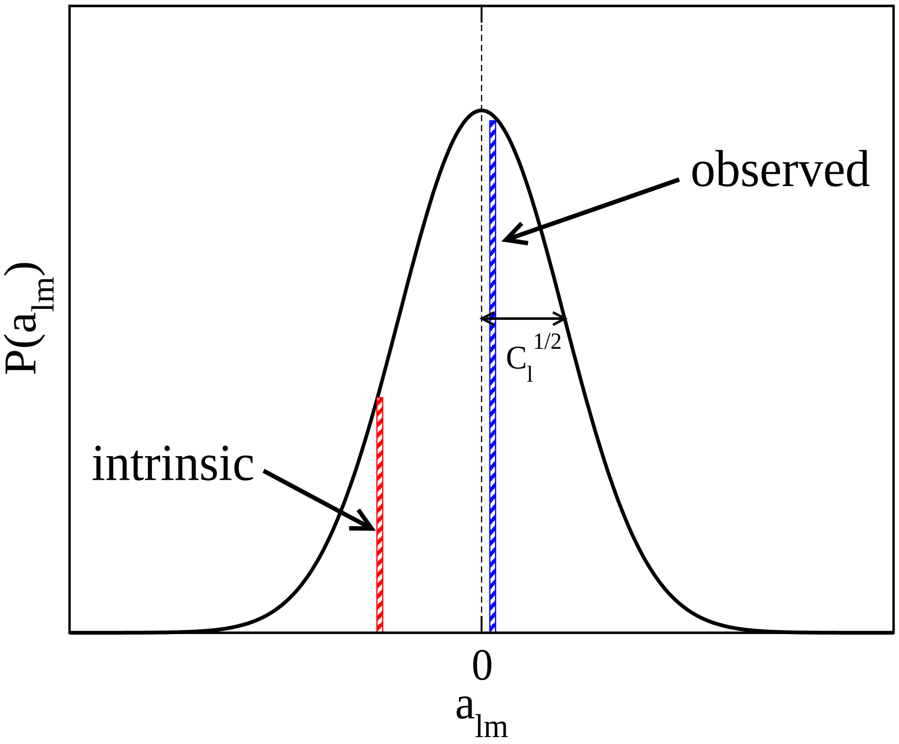
- $B(\hat{\mathbf{n}}) = 1 \Rightarrow \langle t^*_{\ell m} t_{\ell' m} \rangle = \delta_{\ell \ell'} C_\ell^{aa} + f^2 w_\ell w_{\ell'} \delta_{m0}$ (additive)
- $w(\hat{\mathbf{n}})$, $B(\hat{\mathbf{n}})$ depend on $\hat{\mathbf{n}}$
  $\Rightarrow$ coupling between ℓ, ℓ' (multiplicative)

Gordon, Hu, Huterer & Crawford, astro-ph/0509301

Additive schemes “don’t work”

Double (likelihood) penalty:

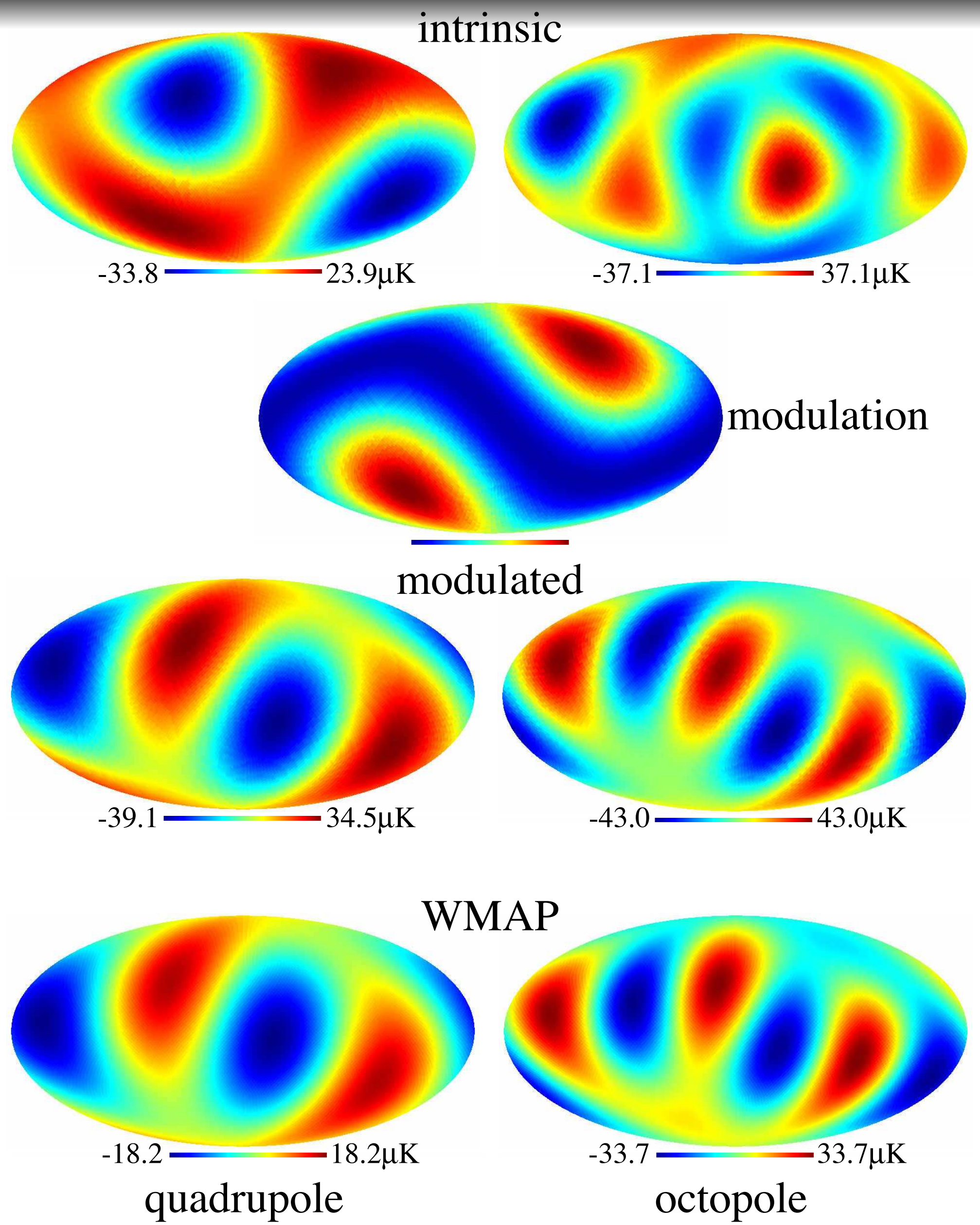
- Intrinsic sky is less likely than observed
- Requires a chance cancellation



Same true for all additive schemes: Bianchi templates, Solar System contamination, ...

Gordon, Hu, Huterer & Crawford, astro-ph/0509301

Multiplicative modulation: example



Gordon, Hu,
Huterer & Crawford,
astro-ph/0509301

Conclusions

- We (and others) observe a number of anomalies at large scales in WMAP, including correlations with the Ecliptic.
- Is dark energy or inflation doing something weird? Are there unaccounted-for local contaminants or foregrounds?
- No as-of-yet proposed mechanism works. Multiplicative modulations are promising, additive ones are not.
- Future data:
  - WMAP 2nd year etc temperature maps (but expected to be unchanged)
  - WMAP polarization maps (but expected to be systematics-dominated)
  - Planck