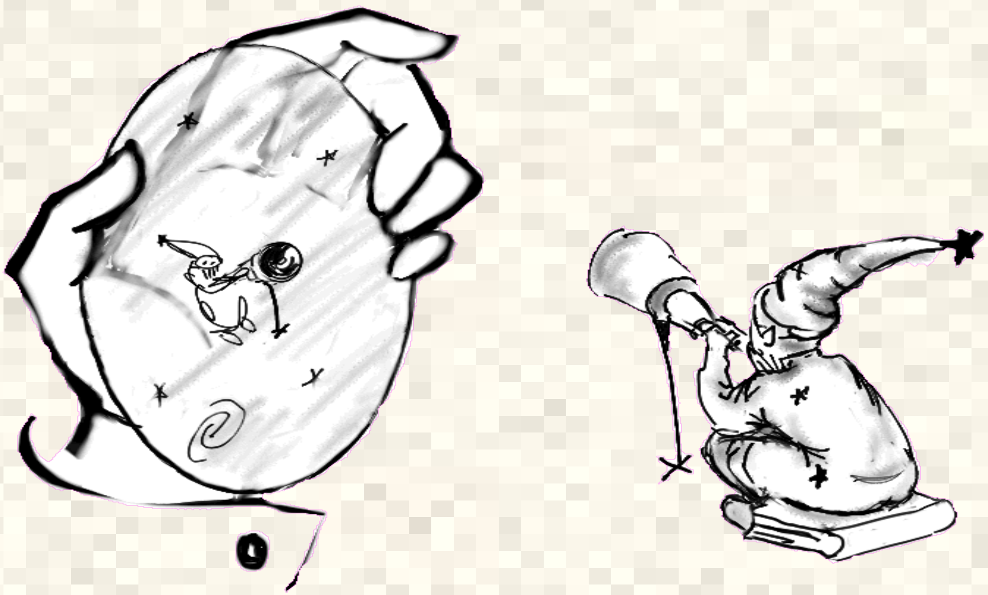
Lecture 3.

Non-gaussianity via local effects

Oleg Verkhodanov
Special astrophysical observatory, Russia



Cosmological tests with radio astronomy

- ***Cosmic microwave background***
  a) Angular power spectrum
  b) Statistical properties of the CMB signal (Gaussianity)
- ***Radio galaxies***
  a) “size – redshift” (standard rod)
  b) “flux density – redshift” (standard candle)
  c) “log N - log S” (“number of sources – flux density”)
  d) Gravitational lensing
  e) Large scale structure formation
  f) “Galaxy age – redshift“
  g) Dark matter with HI observations
- ***Pulsars***
  a) Double pulsars – gravitational wave emission
  б) Net of pulsars – gravitational wave propagation

Problem of non-Gaussianity

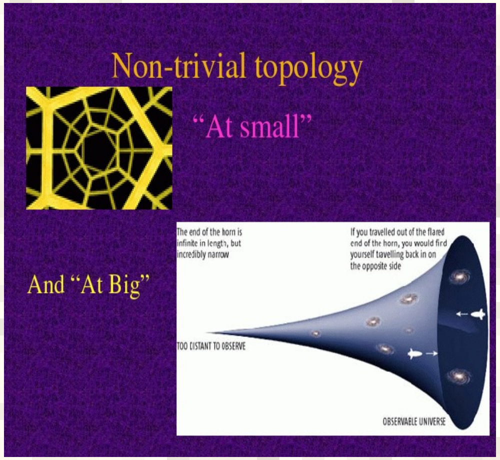
Are the data Gaussian ?
(*are the data good* ?)

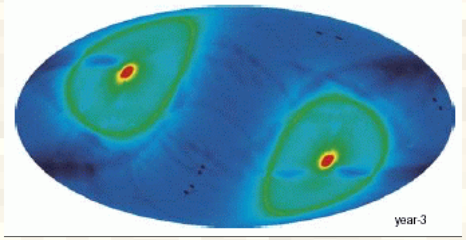
Why the Gaussianity is important ?

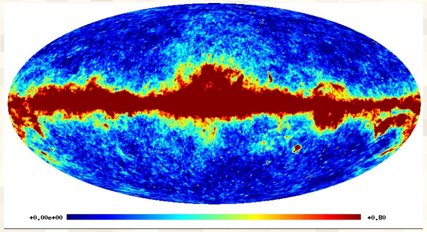
Test for standard (now) simple inflationary LCDM-cosmological model.

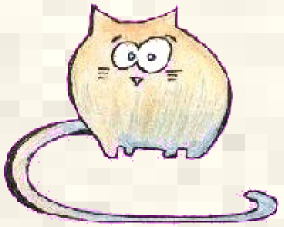
Non-Gaussianity:

1. Complex inflation
2. Anisotropic expansion
3. Topology:
   non-trivial,
   topological defects (strings, textures),
4. Systematics (observational and data analysis effects)
5. Contribution of foregrounds

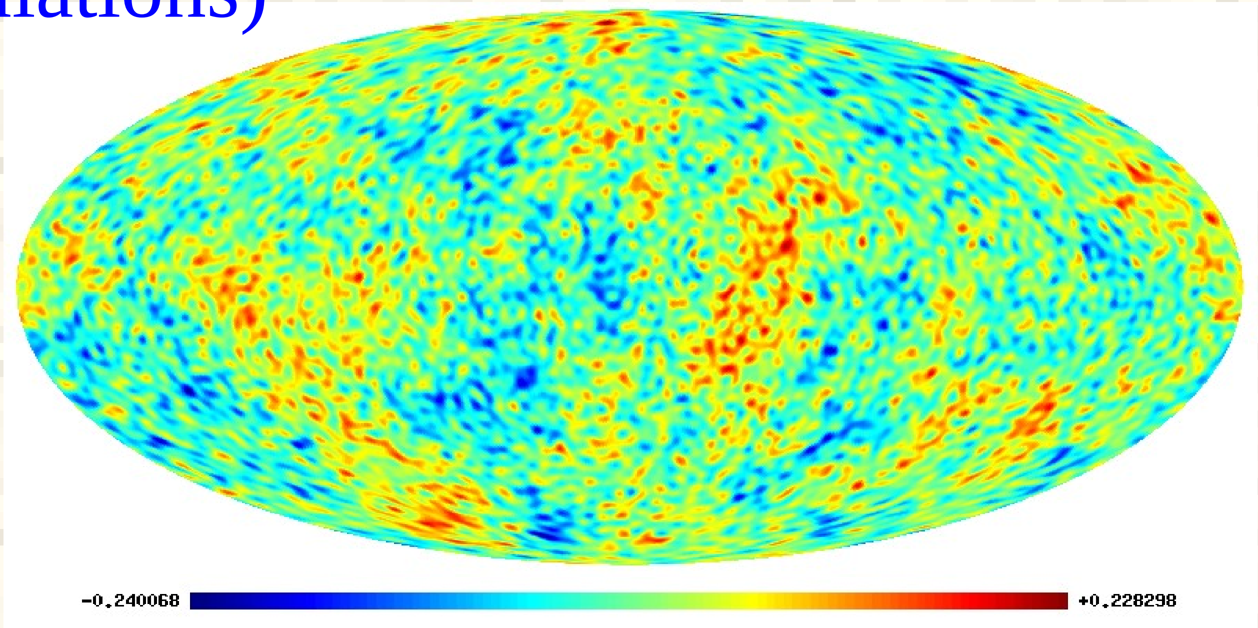




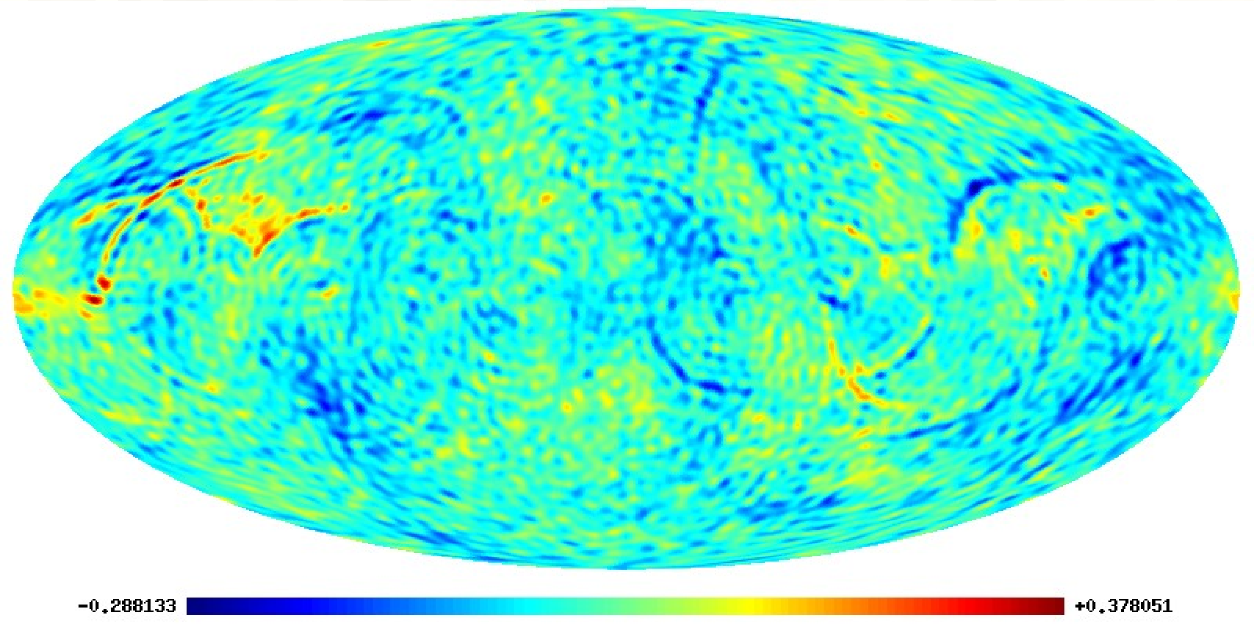




Non-Gaussianity and topological defects (simulations)



LCDM



Strings

Why Gaussianity is important ?

What else ? Angular power spectrum

$$C_\ell \equiv C_\ell(h, \Omega_b h^2, \Omega_{CDM} h^2, \Omega_\Lambda, \Omega_\nu, n, \ldots)$$

$$\Delta T(\theta, \phi) = \sum_{l=2}^{\infty} \sum_{m=-l}^{m=l} a_{l,m} Y_{l,m}(\theta, \phi)$$

$$C(l) = \frac{1}{2l+1}\left[|a_{\ell 0}|^2 + 2\sum_{m=1}^{l} |a_{l,m}|^2\right]$$

+

= ?

Methods of CMB Gaussianity control

- Phase analysis
- Multipole vectors
- Bipsectrum
- Minkowsky functionals
- Spherical wavelets (+needlets)
- Pixels correlational methods
- Angular power spectrum

For a simple inflationary model

Density perturbations -> CMB fluctuations:

$$a_{\ell m} = 4(-i)^\ell \int \frac{d^3\mathbf{k}}{(2\pi)^3} \Phi(\mathbf{k}) g_{T\ell}(\mathbf{k}) Y_\ell^* m(\hat{\mathbf{k}})$$

Primordial non-Gaussianity

$$\Phi(x) = \Phi_L(x) + f_{\rm NL}(\Phi^2(x) - \langle\Phi^2(x)\rangle)$$

Methods of CMB Gaussianity control

Goals and methods

Correlated signal of foreground component:

- Phase analysis
- Pixel correlational methods
- Angular power spectrum

Estimation of the NG parameter *f_NL*:

$$\Phi(x) = \Phi_L(x) + f_{\rm NL}(\Phi^2(x) - \langle\Phi^2(x)\rangle)$$

Bispecrum, Minkowski functional, wavelets

Problem:
simulation of a map containing non-Gaussian signal corresponding to a natural one

Phase analysis and non-Gaussianity

Phase analysis

$$\Delta T(\theta,\phi) = \sum_{l=2}^{\infty} \sum_{m=-l}^{m=l} a_{l,m} Y_{l,m}(\theta,\phi)$$

$$a_{\ell m} = |a_{\ell m}| \exp(i\psi_{\ell m})$$

Gaussian Random Fields

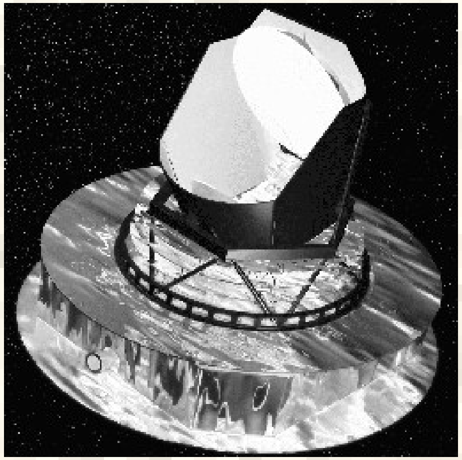
Strict definition of Gaussianity:

$$a_{\ell m} \equiv |a_{\ell m}| \exp(i\Phi_k) \equiv \Re[a_{\ell m}] + i\Im[a_{\ell m}]$$

They possess Fourier modes whose real and imaginary parts are independently distributed and both Gaussian,

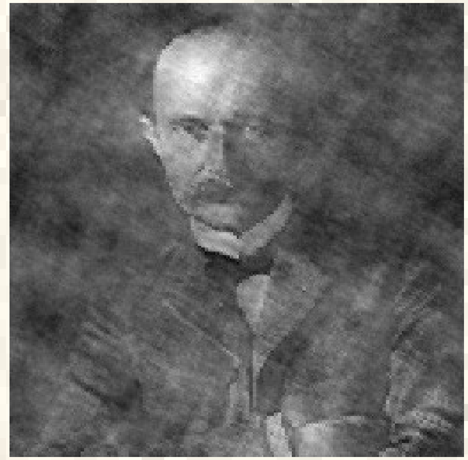
Weak definition of Gaussianity : random phase hypothesis

the Fourier phases are uniformly random between 0 and 2π (by Central Limit Theorem)



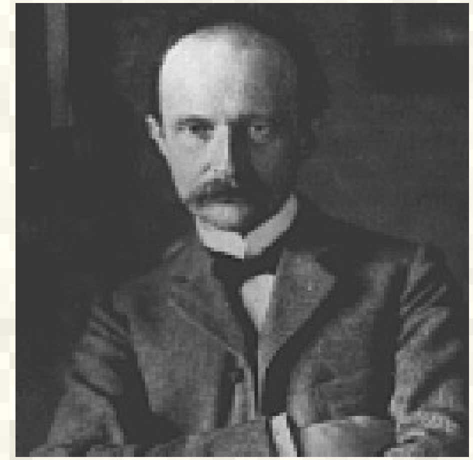
$|\delta k|\ \exp(i\Phi k)$

Planck satellite



$FT^{-1}[|\delta k|\ \exp(i\Phi k)]$

transformed Planck



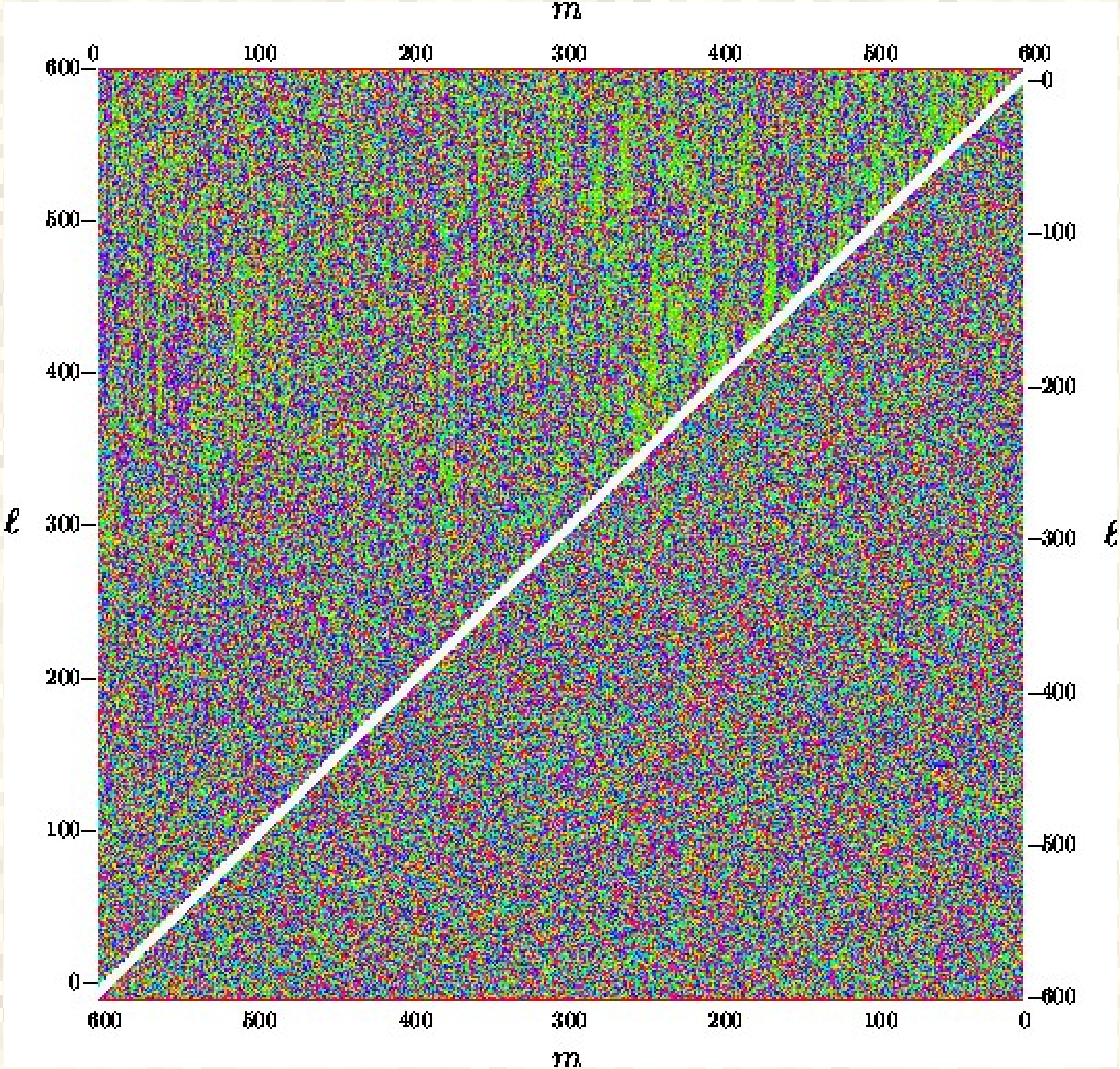
$|\delta k|\ \exp(i\Phi k)$

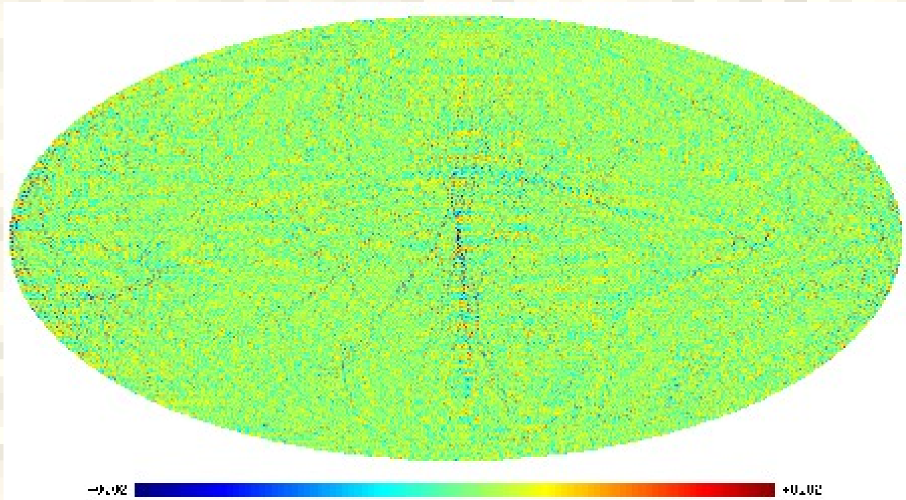
Max Planck

Planck satellite and transformed Planck have the same power spectrum (same $|\delta_k|$), they have different "faces" due to different phases:

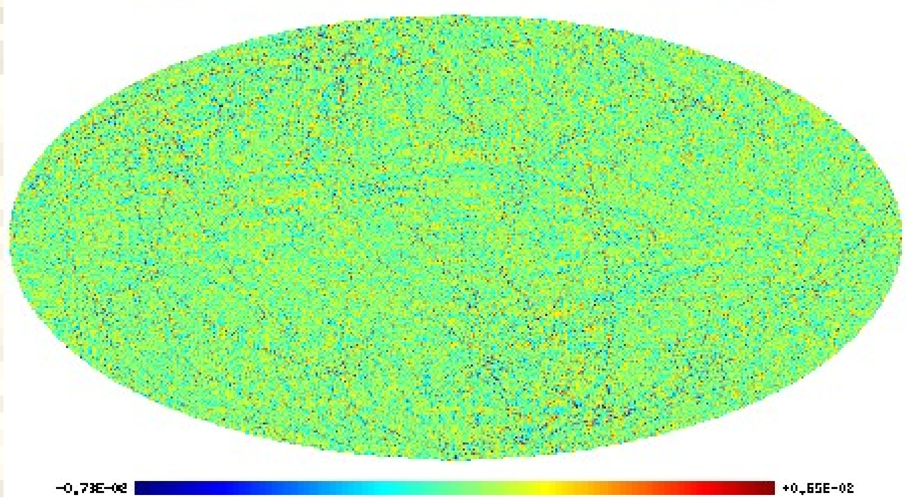
It is phase Φk that keep Max's face, not amplitude $|\delta_k|$!!

Non-Gaussianity: phase diagram for WMAP1





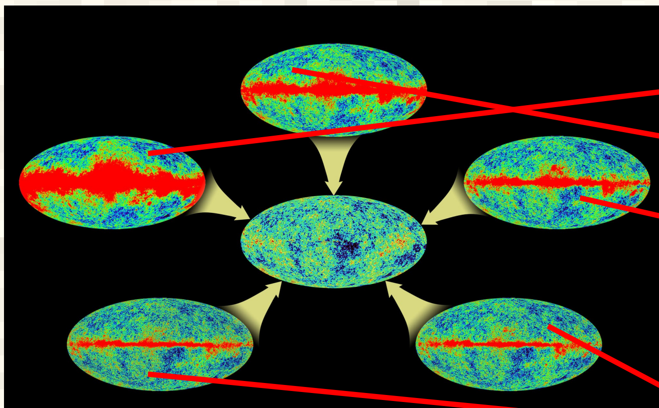
Non-Gaussian map, *l*=350-352

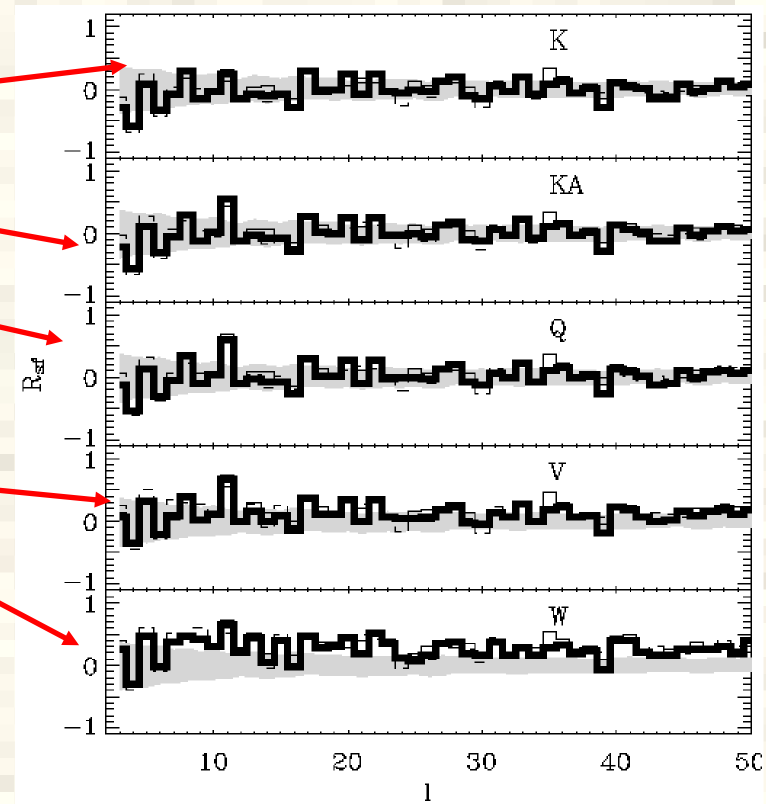


Gaussian map, *l*=350-352

• Phase cross-correlation between WMAP CMB signal and foregrounds.

P.Naselsky, A.Doroshkevich and O.Verkhodanov, 2003,ApJ.Lett,599,53
P.Naselsky, A.Doroshkevich , O.Verkhodanov, 2004,MNRAS,347,795

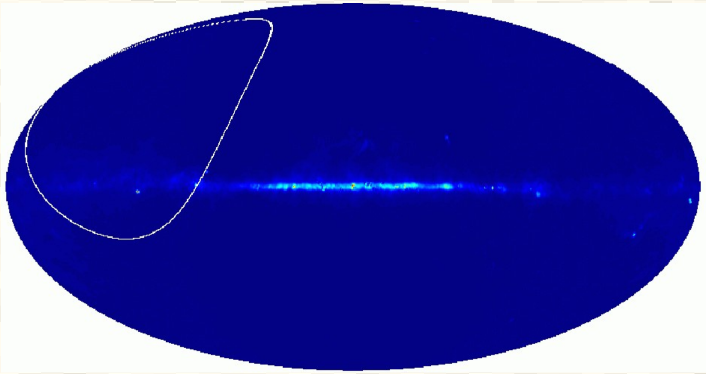




	K	KA	Q	V	W
$ILC^{(o)}$	-0.026	-0.031	-0.030	-0.033	-0.033
$ILC^{(d)}$	-0.017	0.018	0.022	0.112	0.262
FCM	0.031	0.051	0.071	0.157	0.320
PCM	-0.019	0.007	0.032	0.136	0.288

Mosaic correlation maps

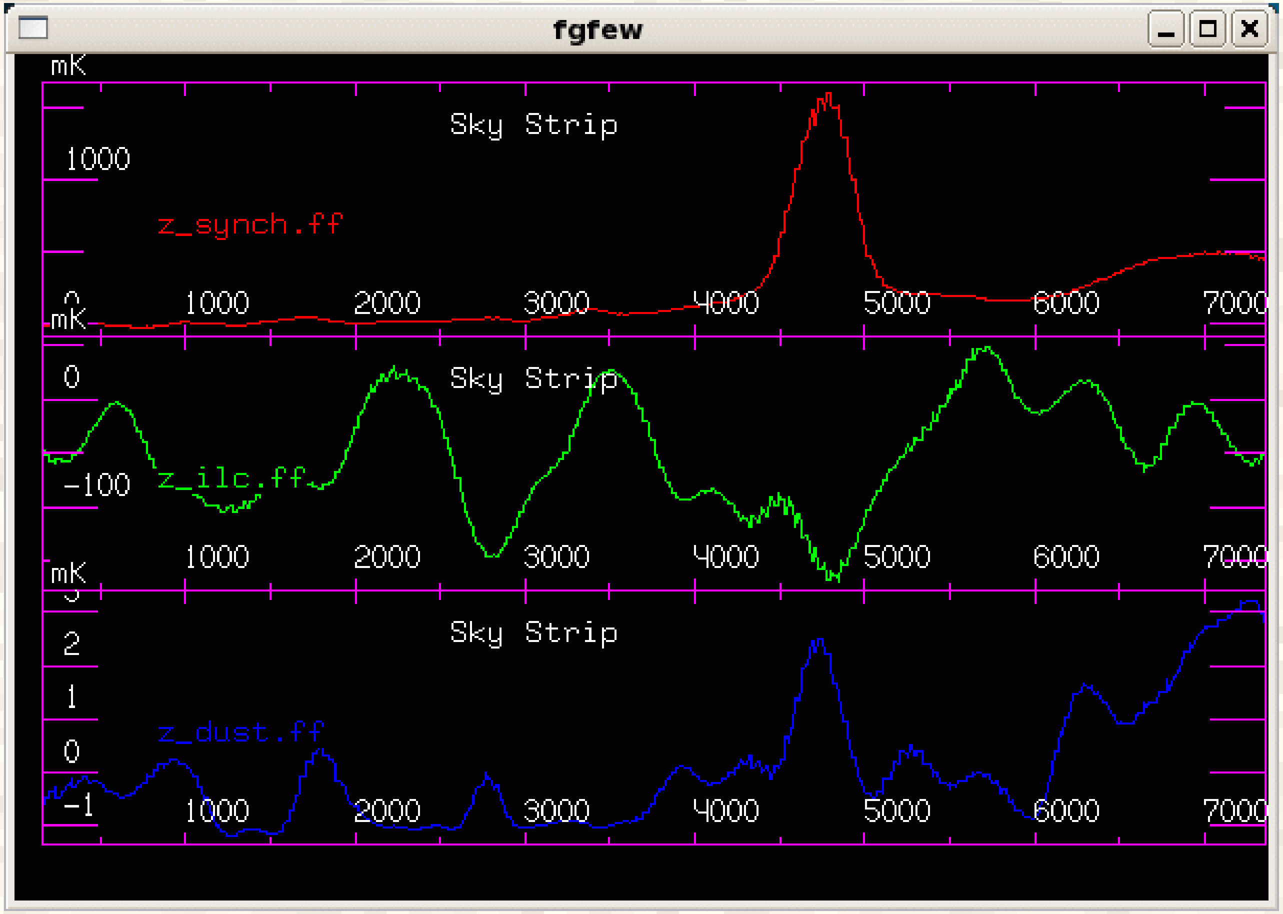
1-dimesional scan of WMAP maps at 41 deg by declination



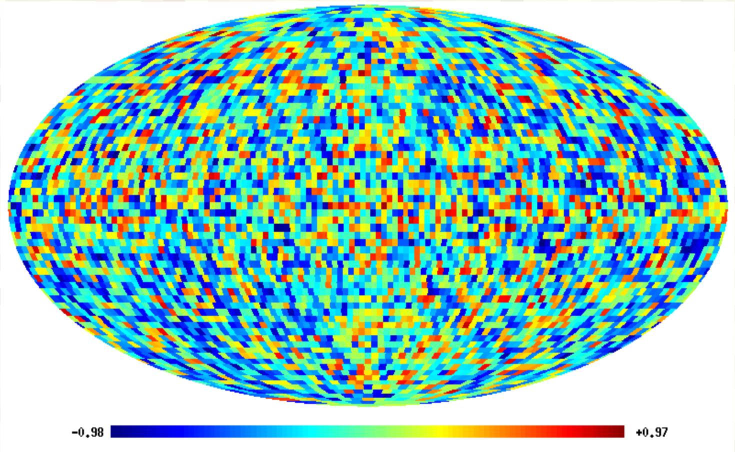
Sychrotron

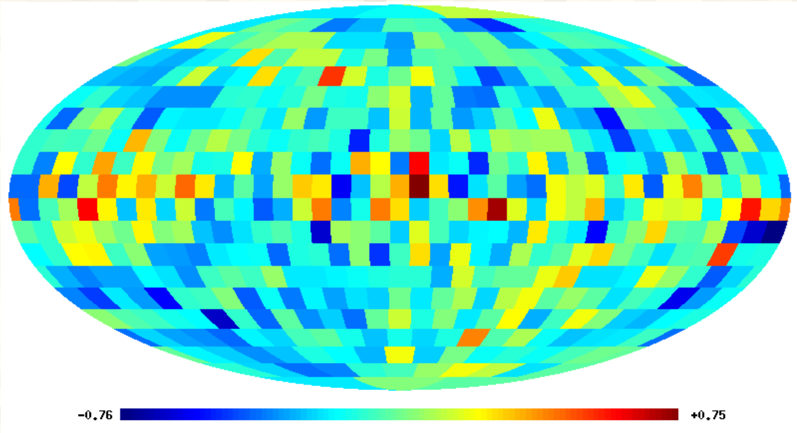
ILC

Dust



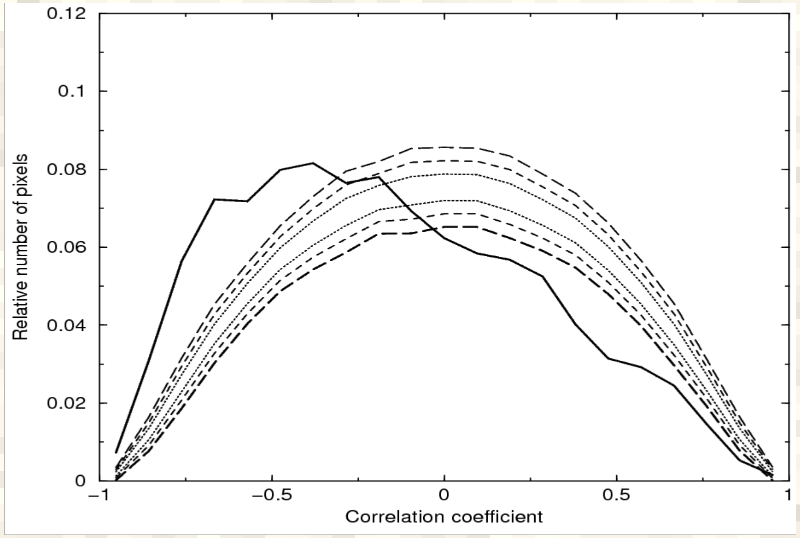
Mosaic correlation: ILC & dust

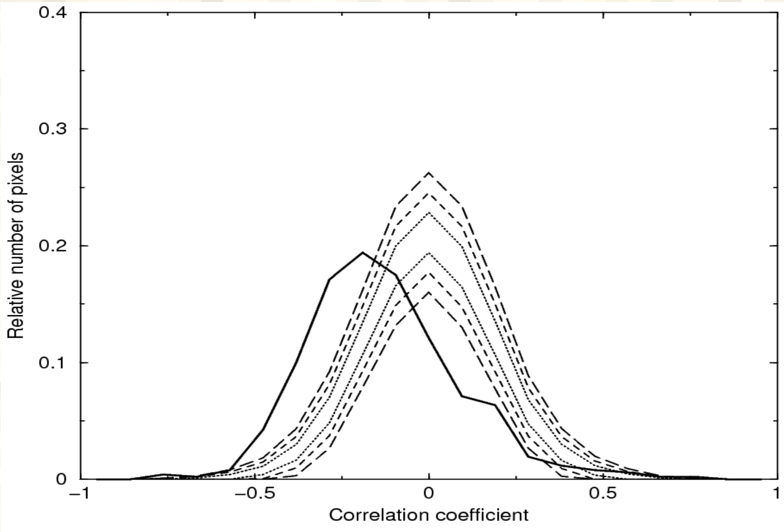




pixel=160'x160' (Lmax=33)

pixel=540'x540'(Lmax=9)

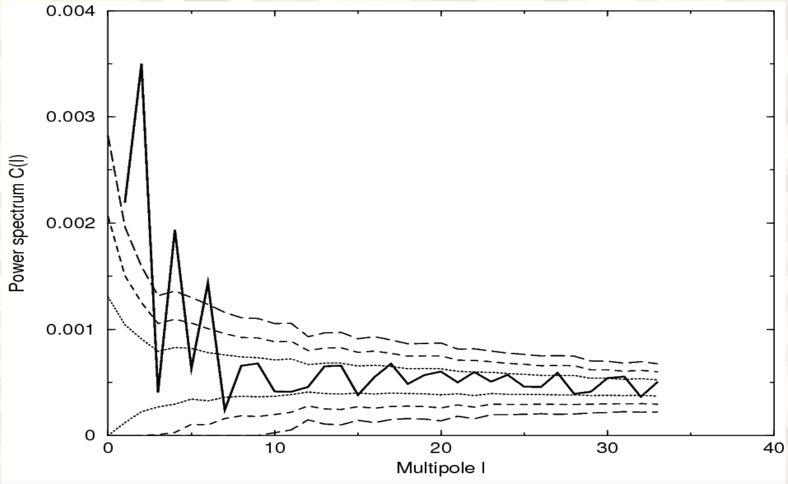




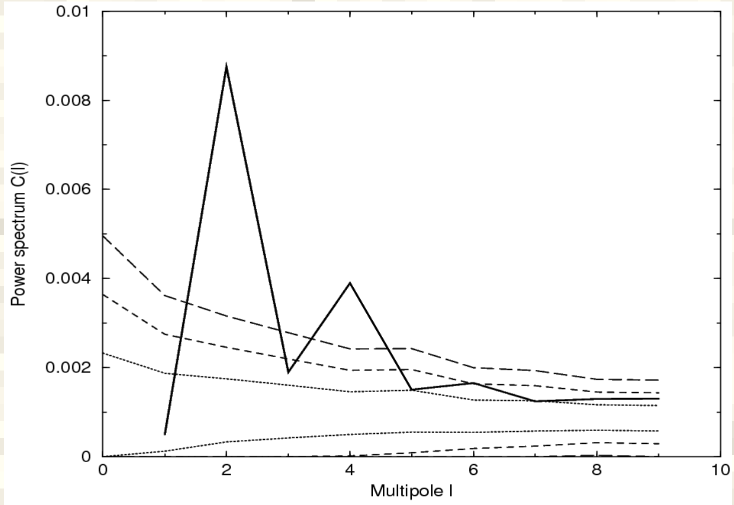
histogram for 160'

histogram for 540'

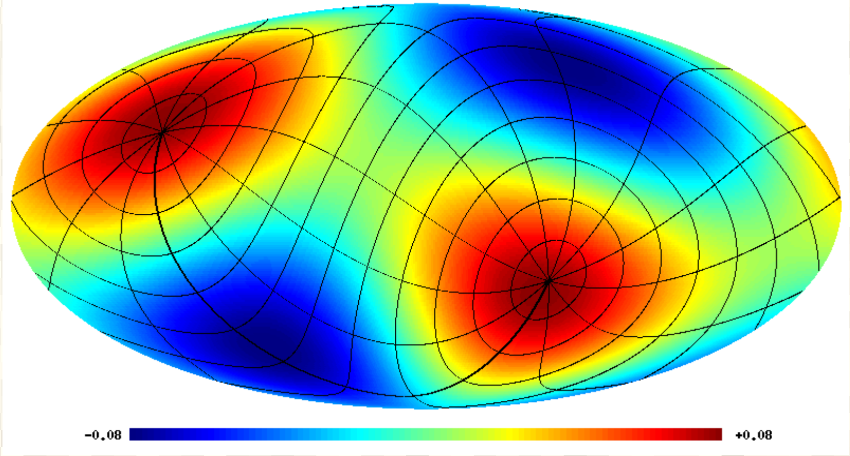
Mosaic correlation maps: strong mutlipoles and hidden coordinate systems



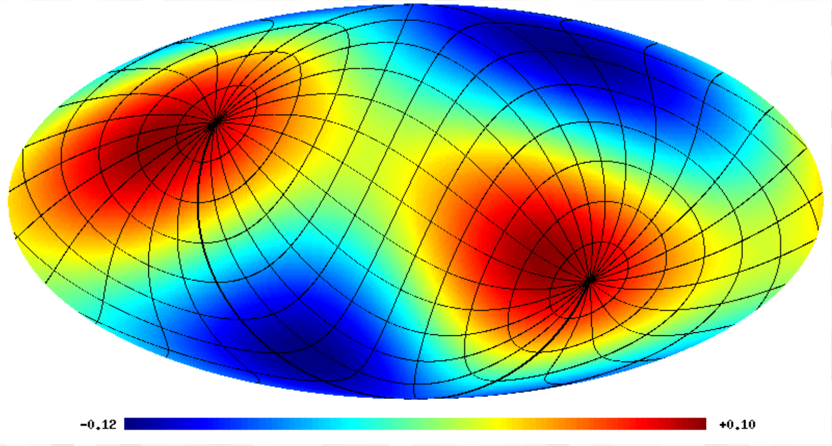
Power spectrum for 160'x160'



Power spectrum for 540'x540'



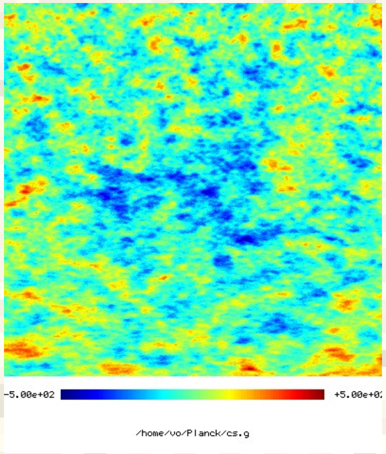
Quadrupole + equatorial system



Quadrupole + ecliptic system

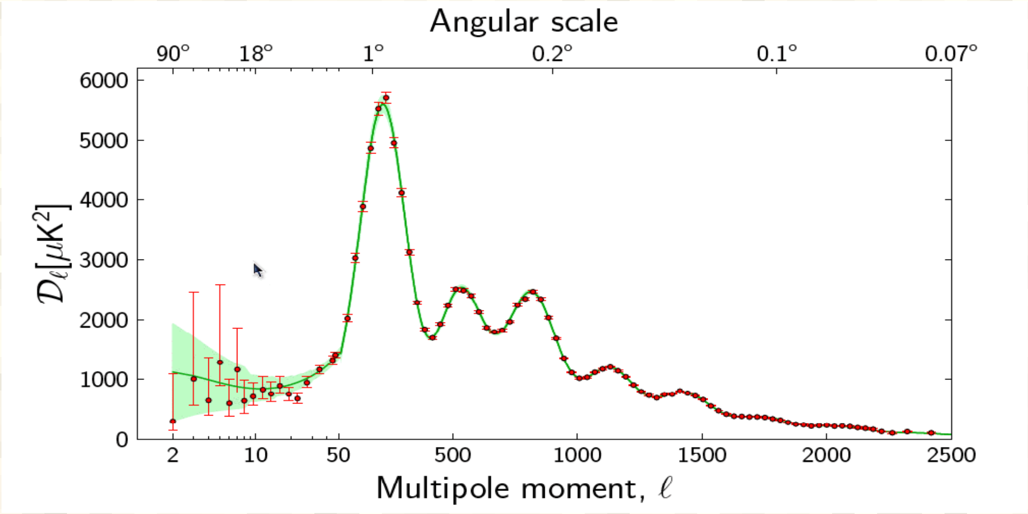
Let us look at some 'classic' anomalies...

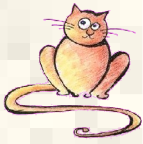
WMAP CMB anomalies



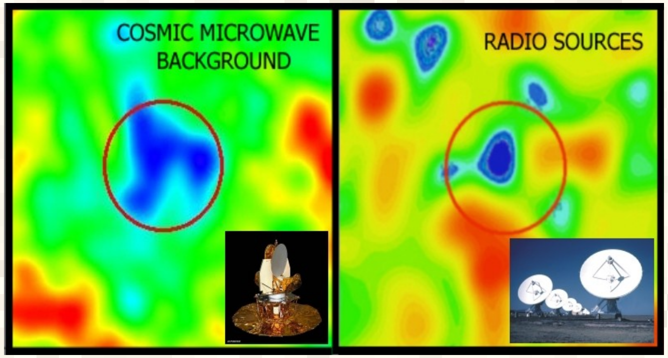
1) Cold Spot
2) Axis of Evil
3) Violation of the power spectrum parity
4) Asymmetry 'North — South' in galactic coordinate system

5) New anomaly: too low amplitude of low harmonics



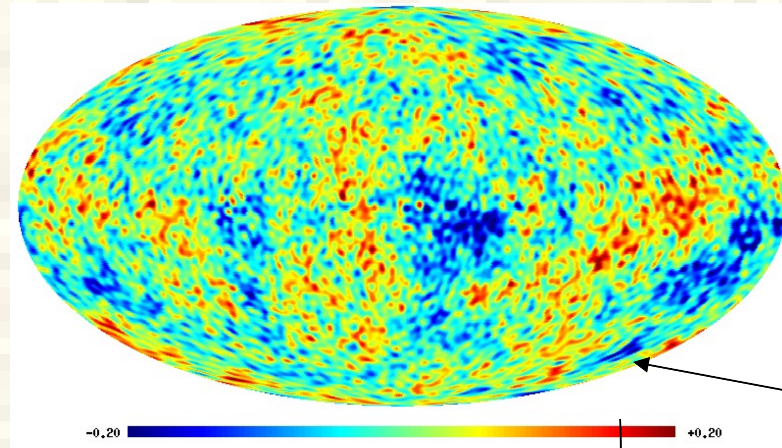


Cold Spot

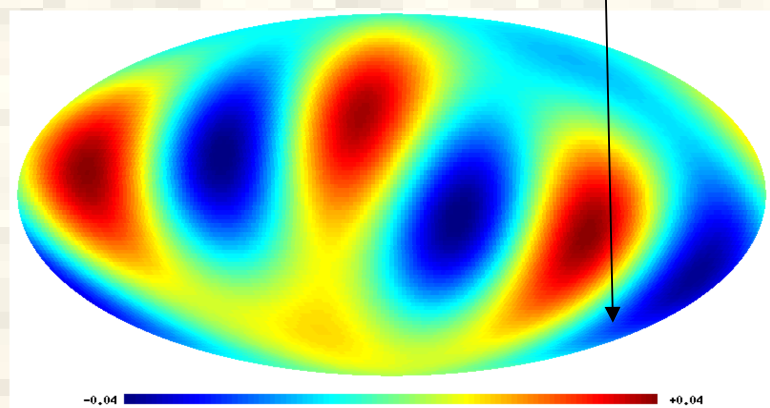


CMB NVSS Radio sources

(Rudnick et al., 2007)



Cold Spot
< -5sigma



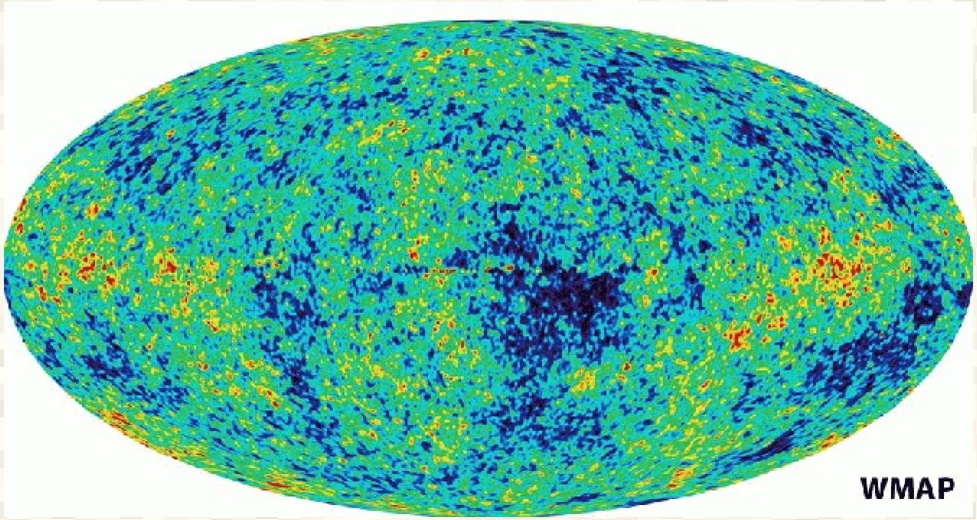
Part of octupole

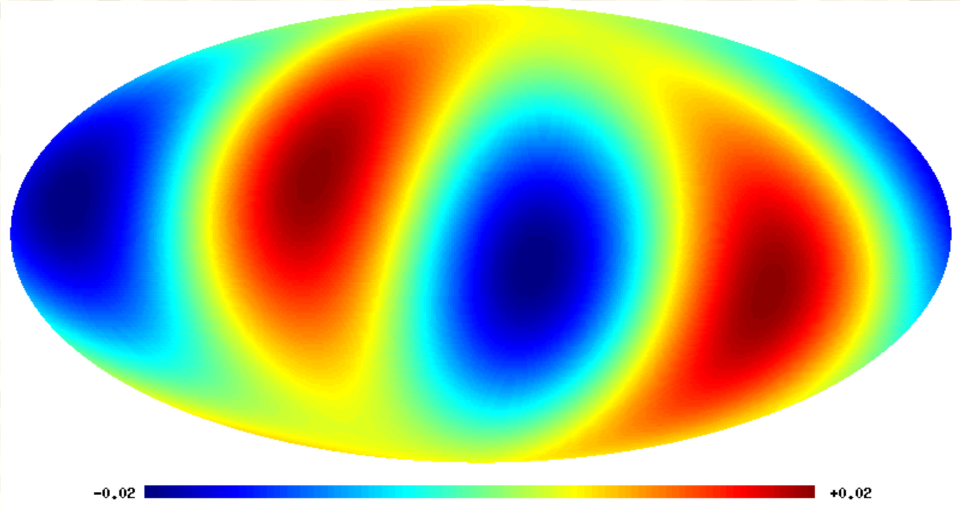
1) Huge Sachs-Wolfe effect *(Rudnick et al, 2007)*
2) Anistropic expansion *(Jaffe et al., 2005)*
3) Topological defect [texture] *(Cruz et al., 2007,2008, Planck 2013 ?)*
4) Artifact ?
5) Galactic phenomena (M.Hansen et al., 2012)

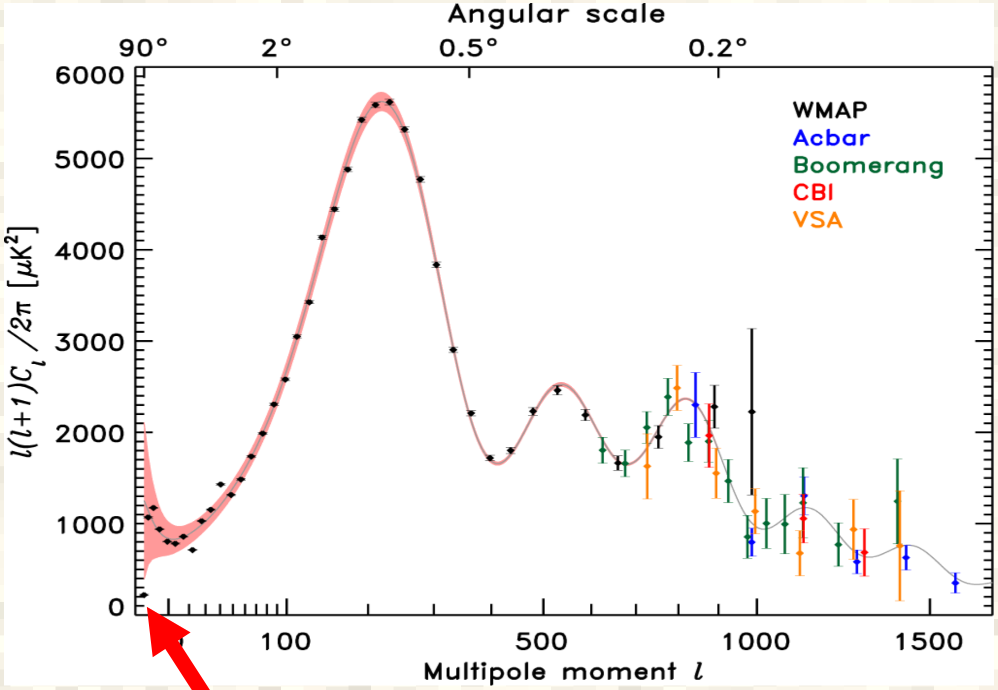
Axis of **Evil**

*(*Title: *Land & Magueijo, 2005)*

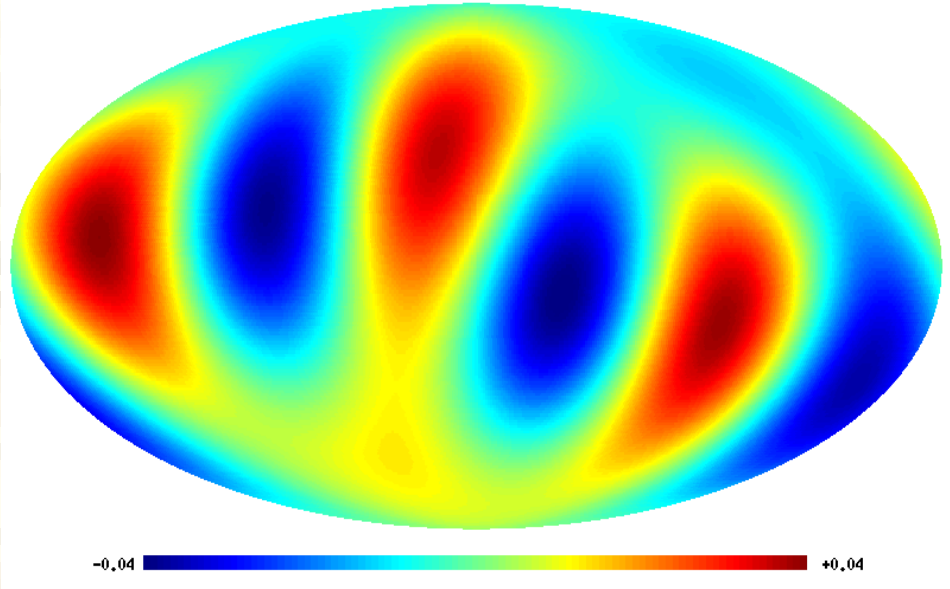
Problems of WMAP quadrupole



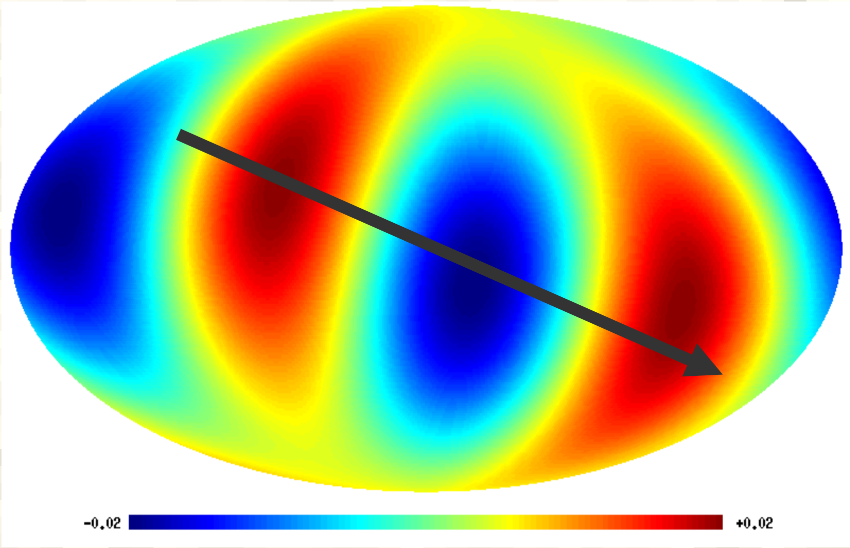




Amplitude

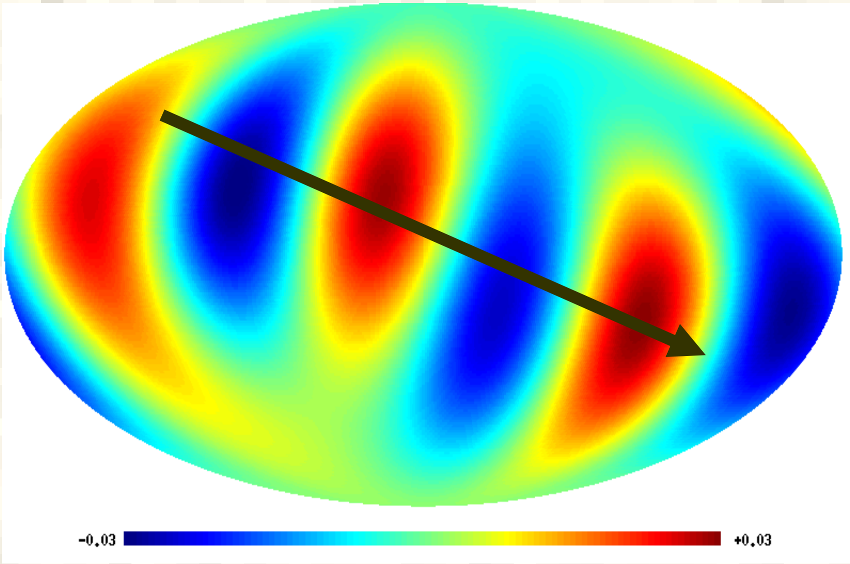


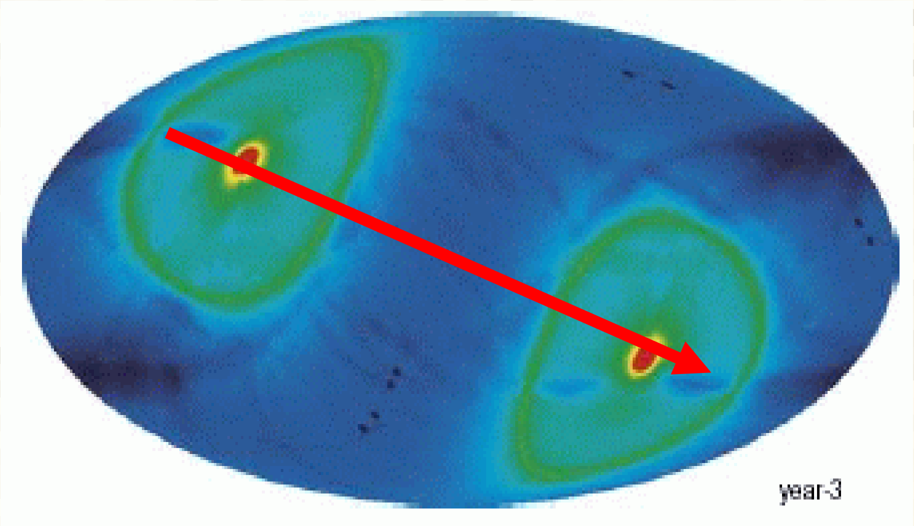
Axis of Evil: planarity + alignment
(Land & Magueijo, 2005)



What is the reason ?

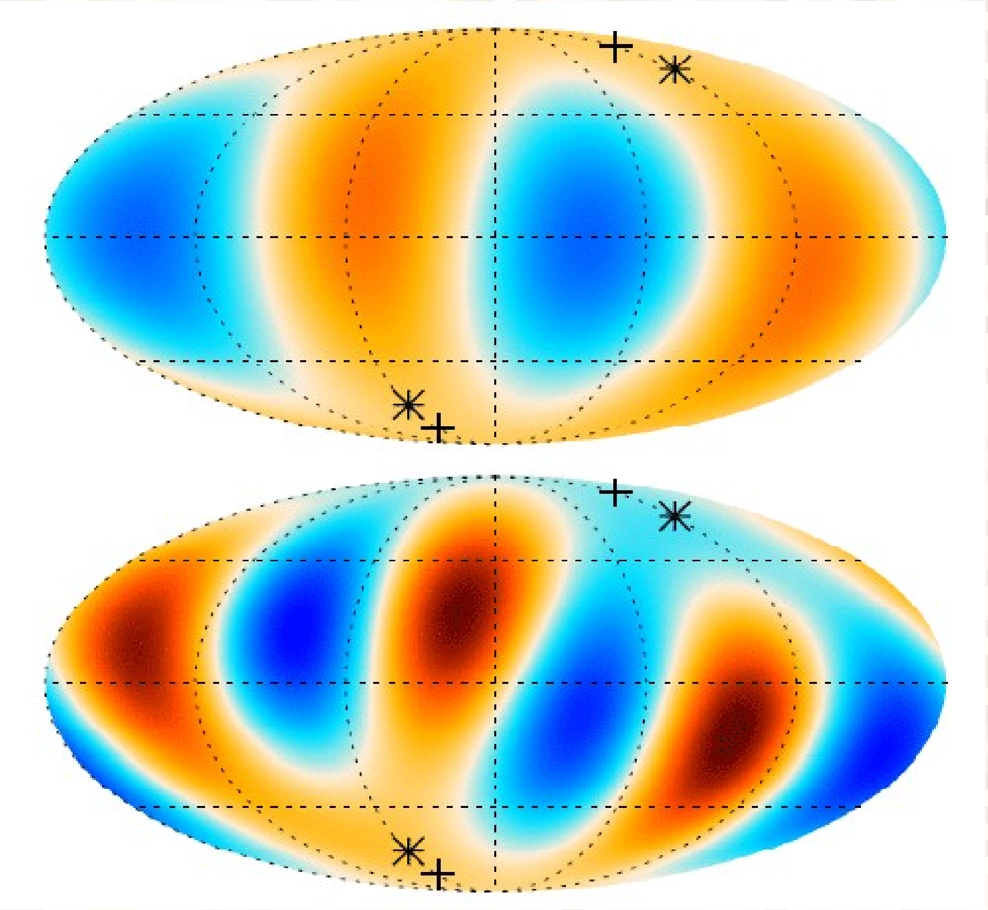
1) Component separation problem
(Doroshkevich, Verkhodanov, 2010)
2) Kouper Belt
(Hansen et al. 2011)
3) Moving in Local Group of galaxies?
(Tegmark et al., 2004)
4) Something else...
5) It is absent (random thing)





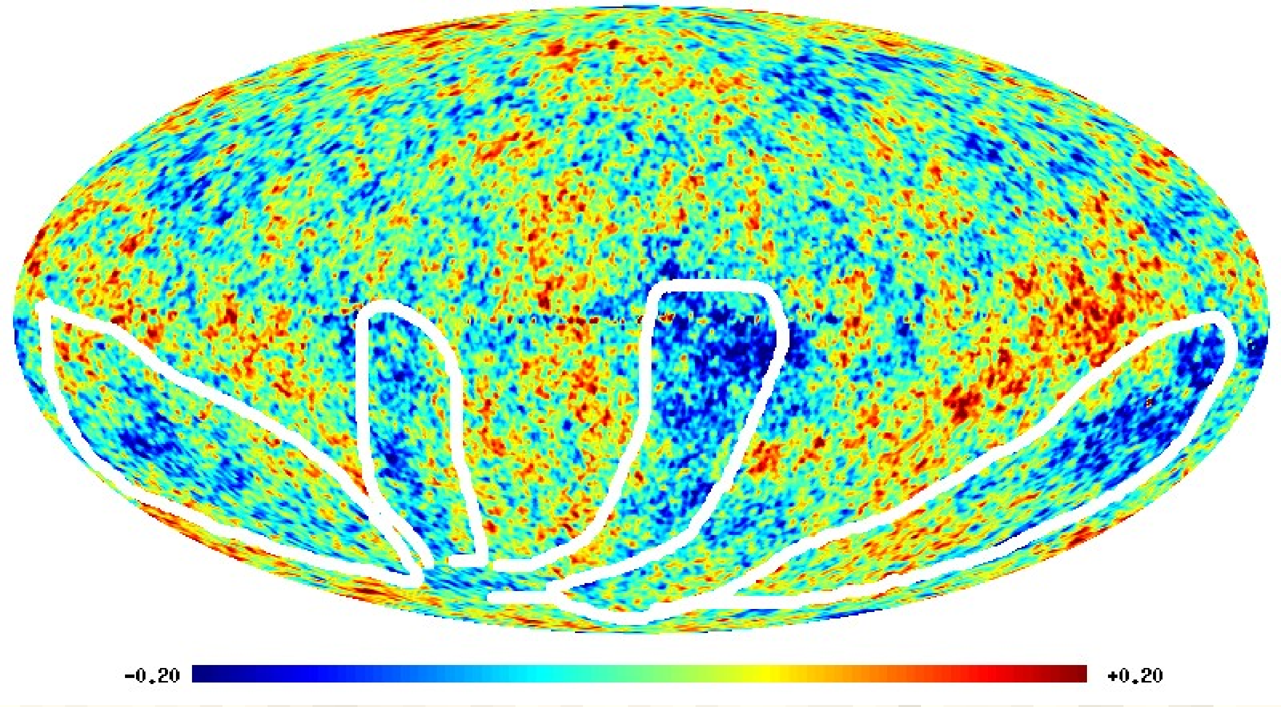
Axis of Evil

(Planck data)

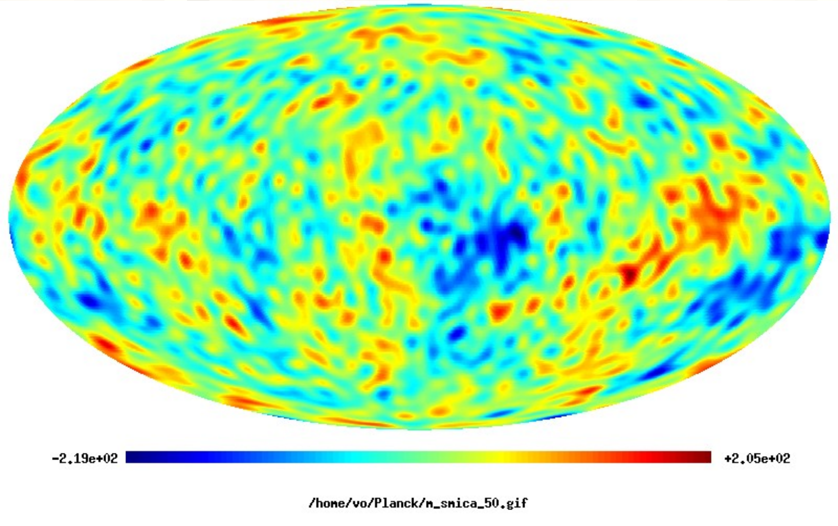


Copi et al., arXiv:1311.4562: direction of our motion exists

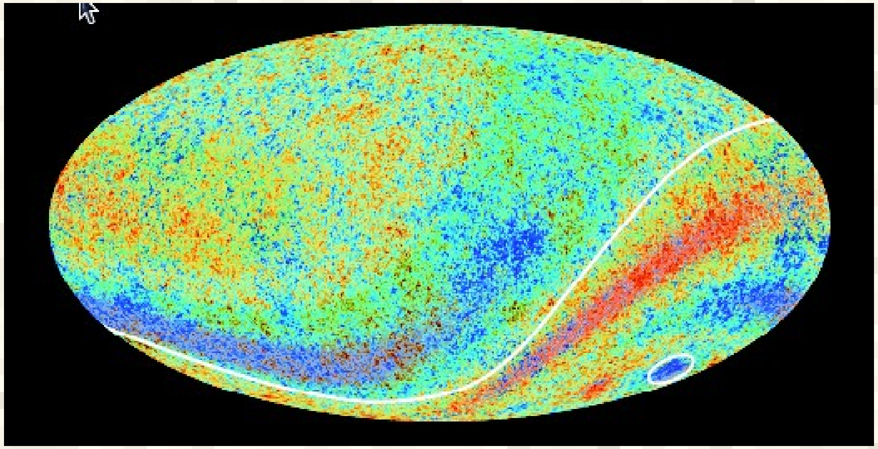
Asymmetry North-South: 4 WMAP fingers



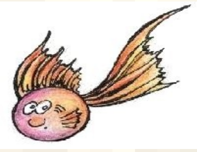
Asimmetry North-South
for both galactic and equatorial system



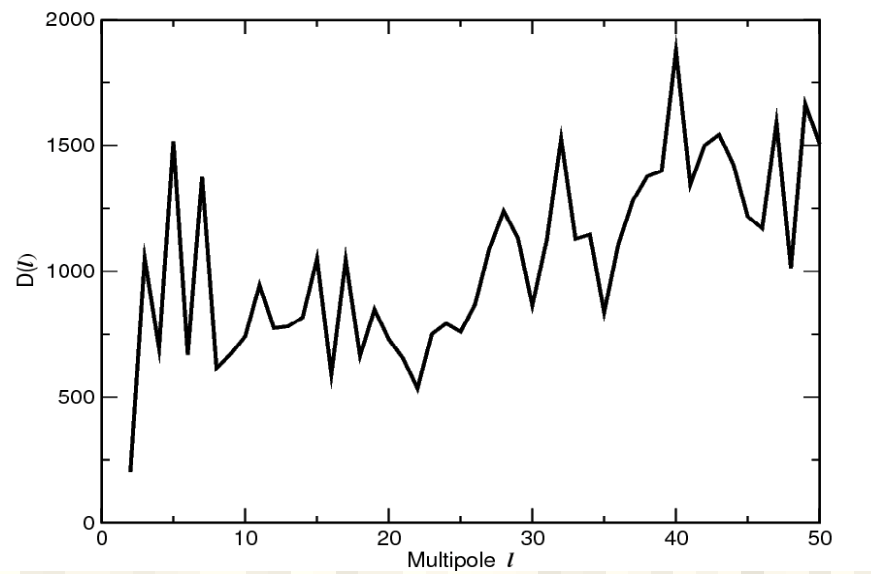
Planck CMB



CMB and Bianchi 7h anisotropy model ?



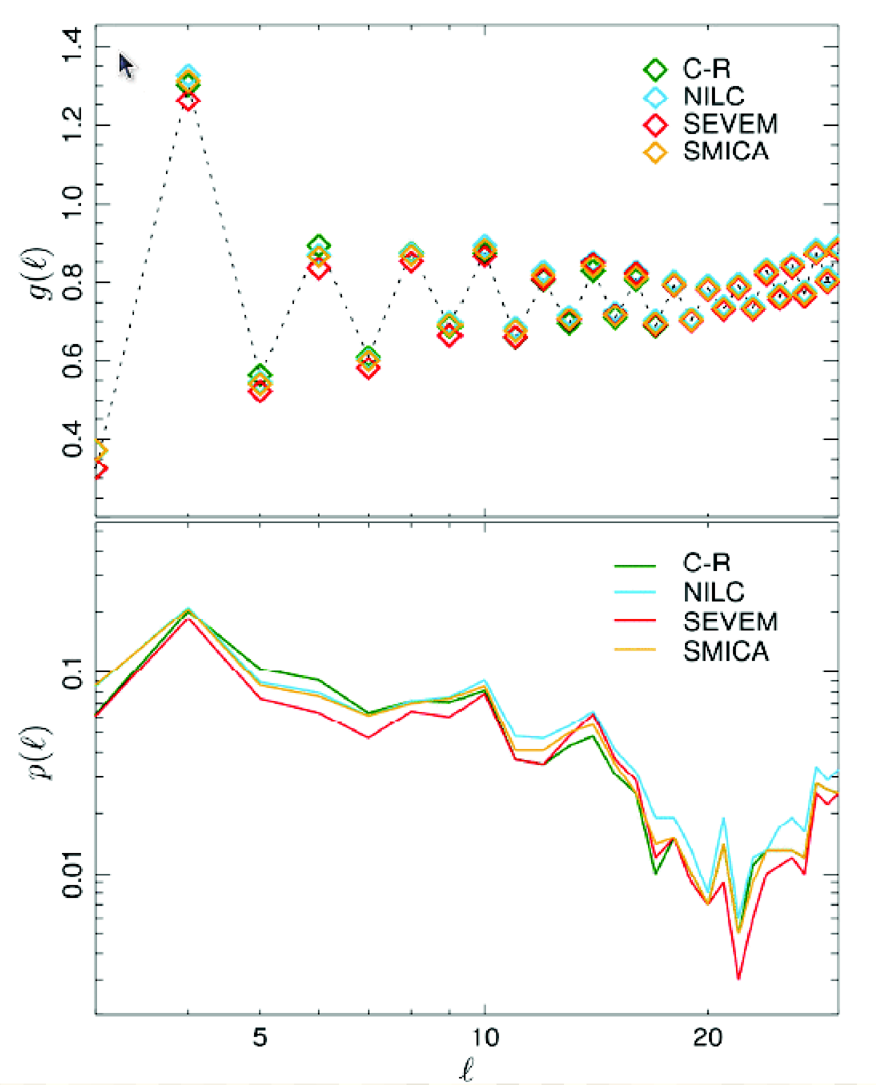
Violation of power spectrum parity



$$P^{+}(\ell) = \sum_{n=2}^{\ell} \Gamma^{+}(n) \frac{n(n+1)}{2\pi} C_n,$$

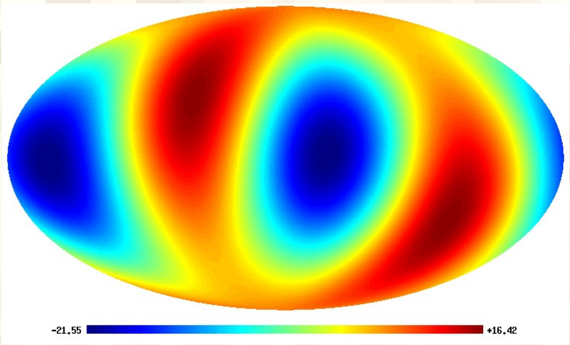
$$P^{-}(\ell) = \sum_{n=2}^{\ell} \Gamma^{-}(n) \frac{n(n+1)}{2\pi} C_n,$$

$$g(\ell) = \frac{P^{+}(\ell)}{P^{-}(\ell)}$$



Low multipoles of missions

Low multipoles in WMAP



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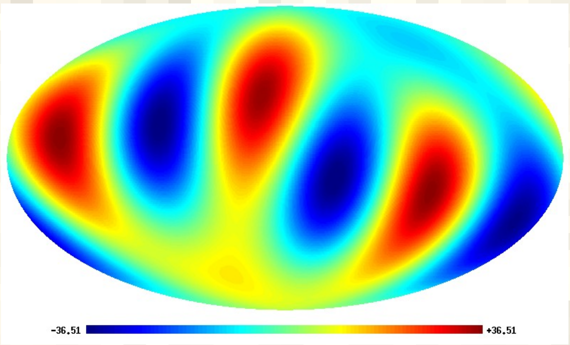

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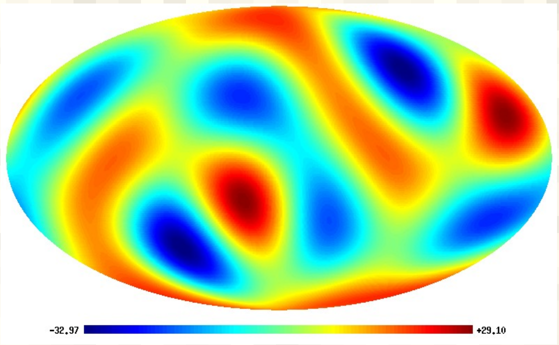

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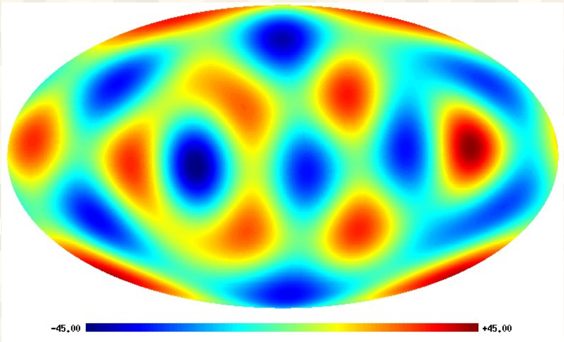

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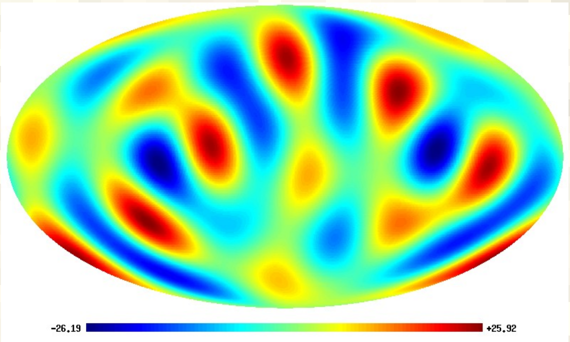

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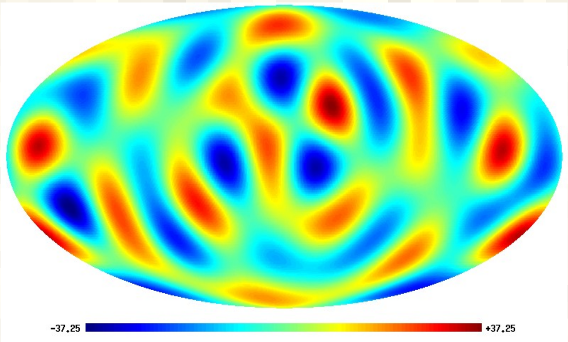

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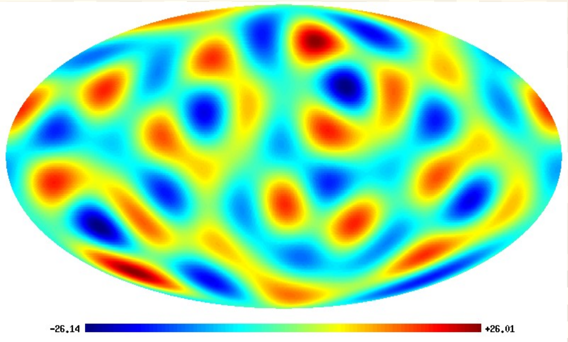

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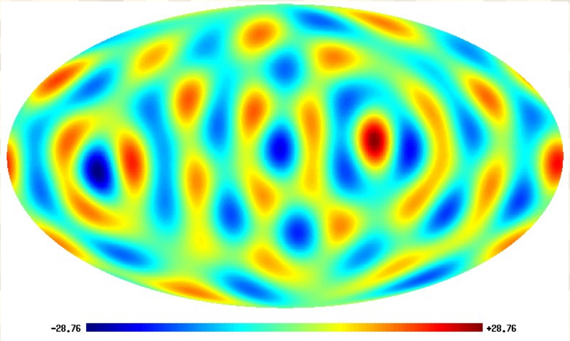

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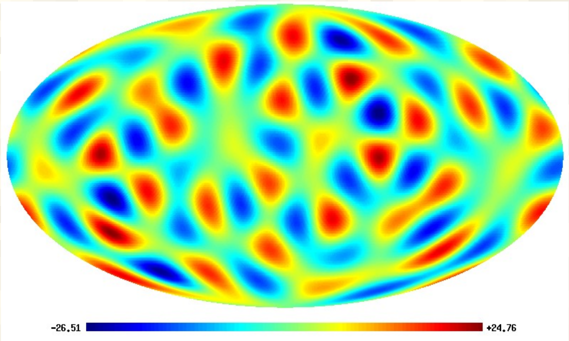

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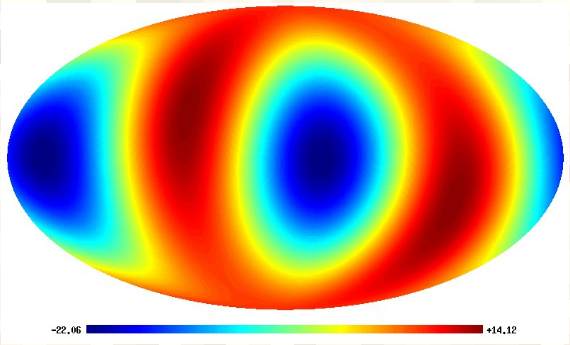
Low multipoles in Planck



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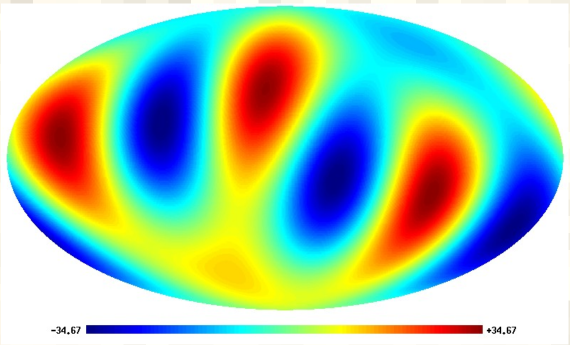

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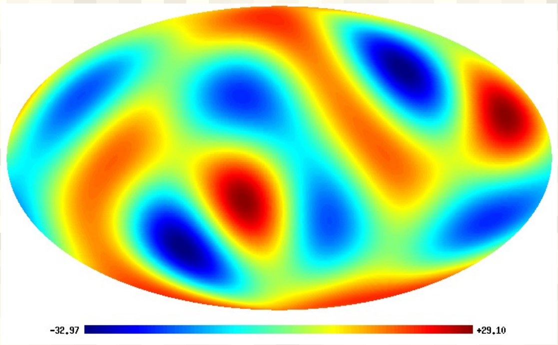

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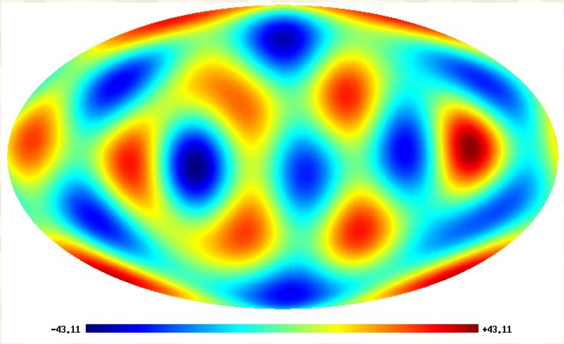

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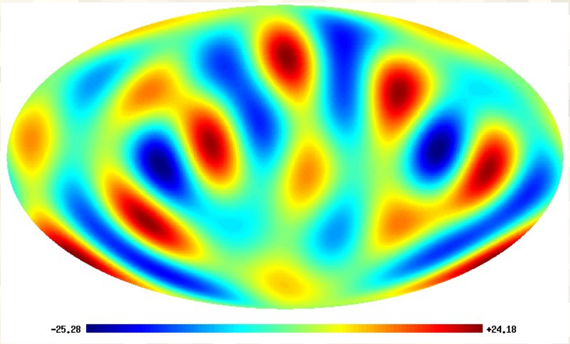

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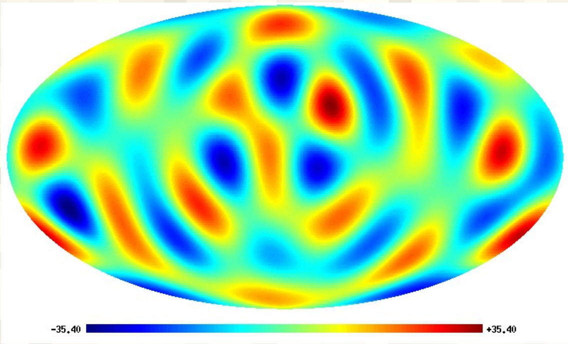

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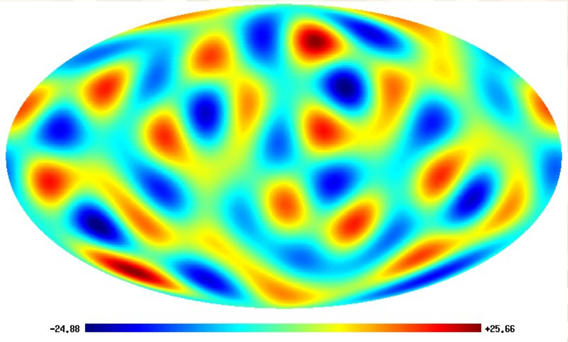

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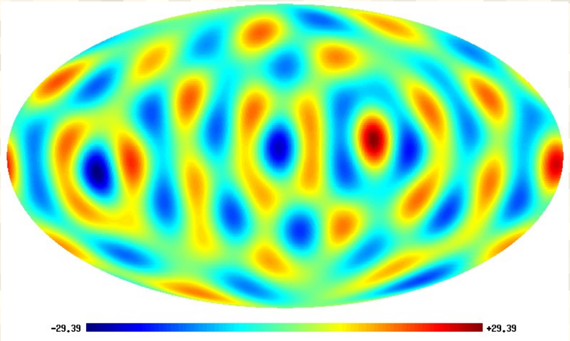

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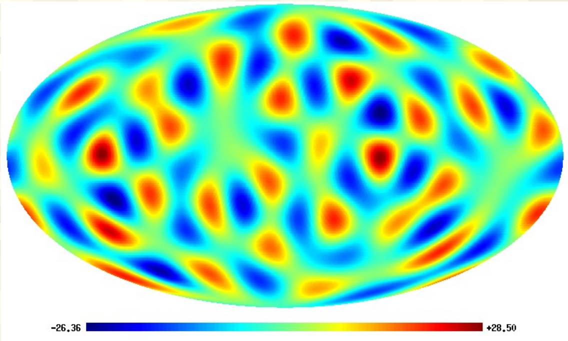
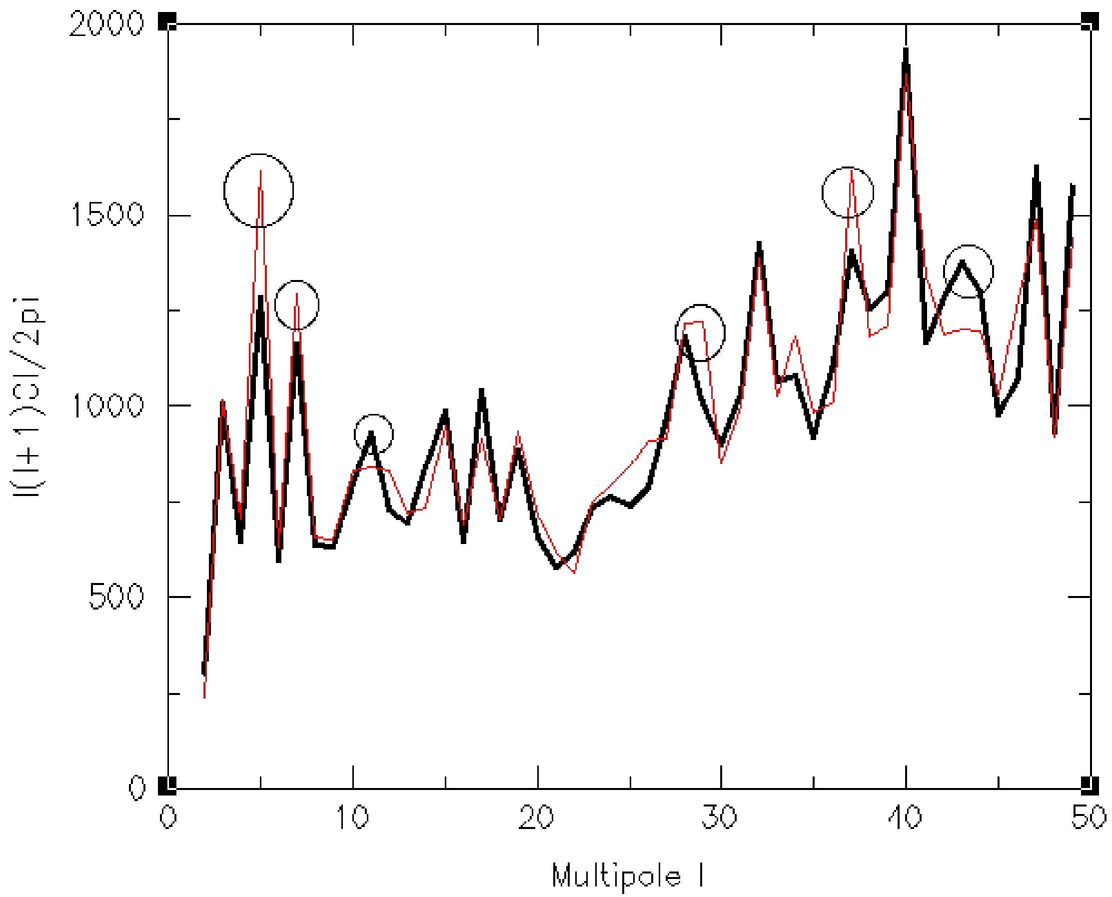


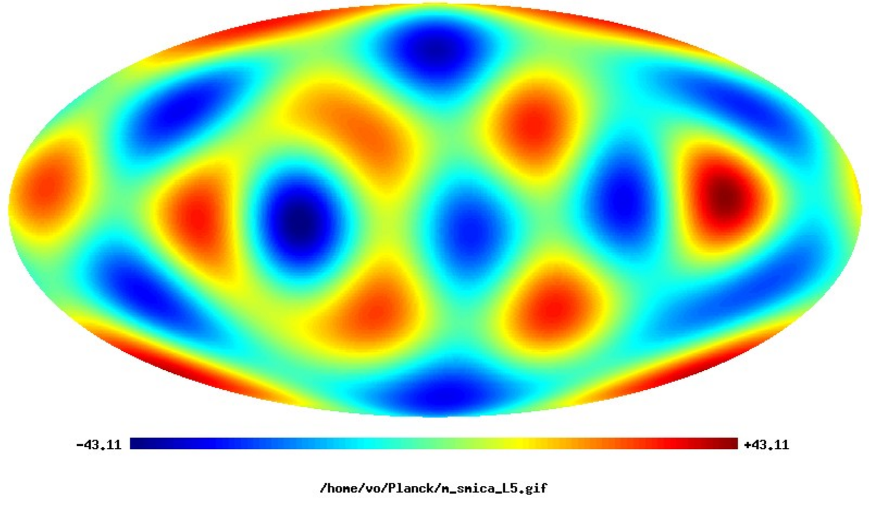
L=10

Power spectrum C(l), l<=50



Planck, WMAP

L=5



Planck, SMICA

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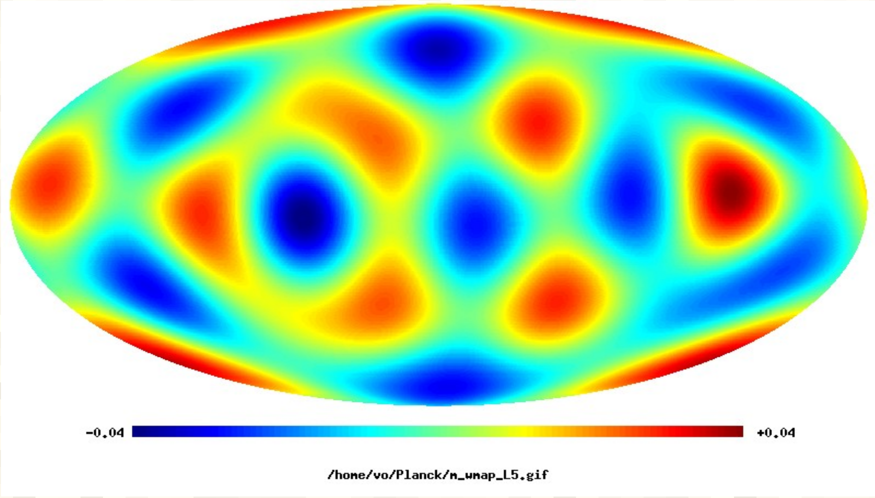

WMAP

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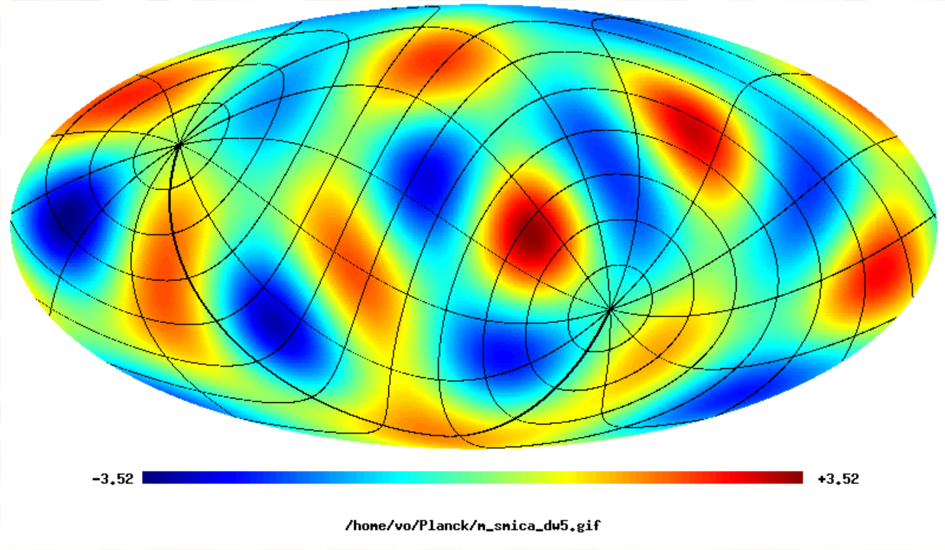

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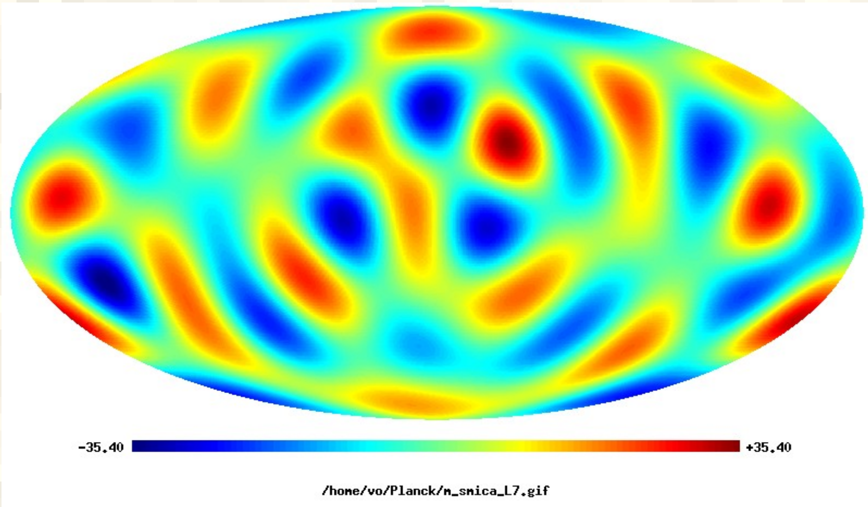

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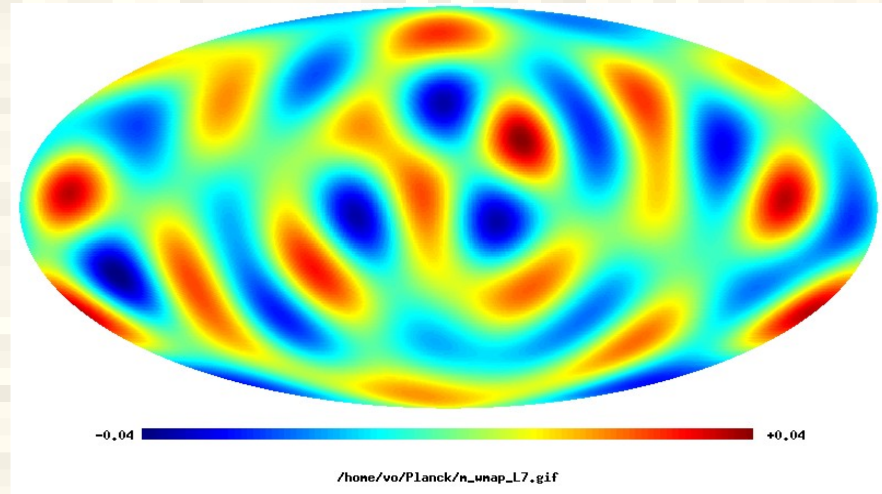

Planck, SMICA

WMAP

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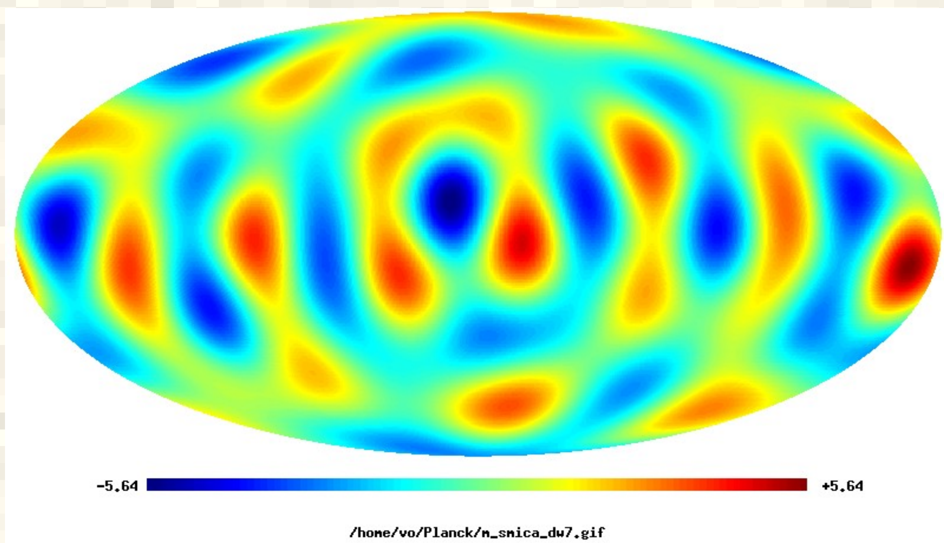

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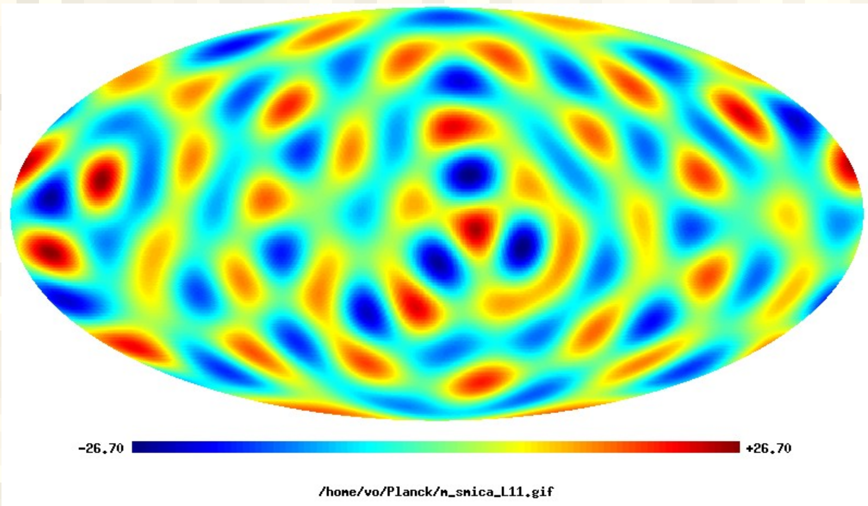

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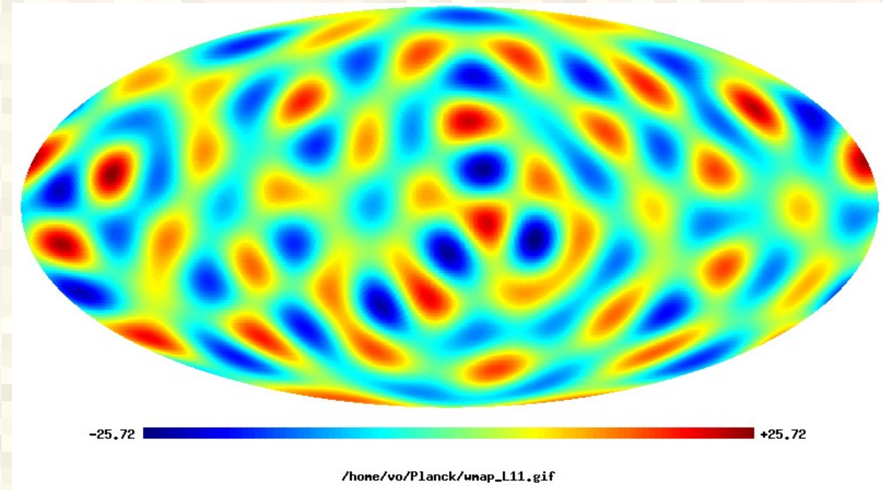

Planck, SMICA

WMAP

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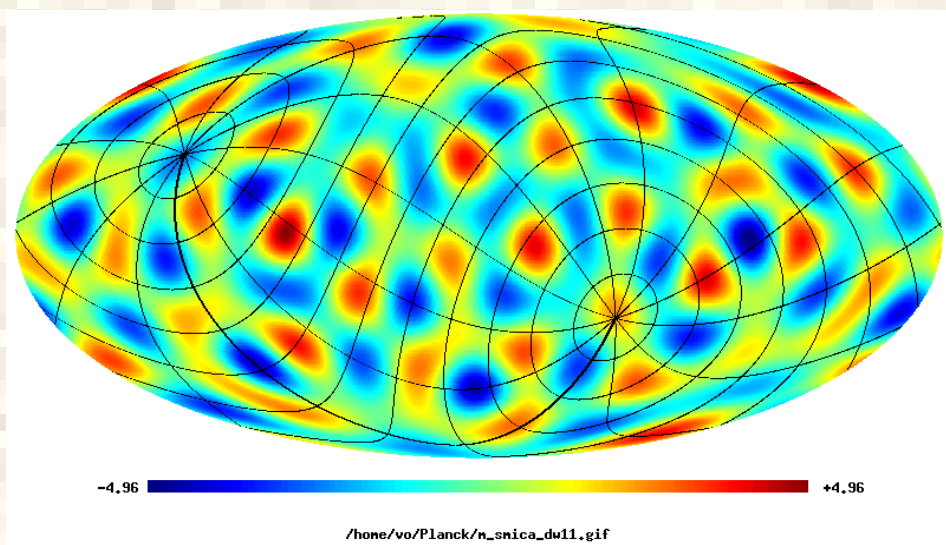

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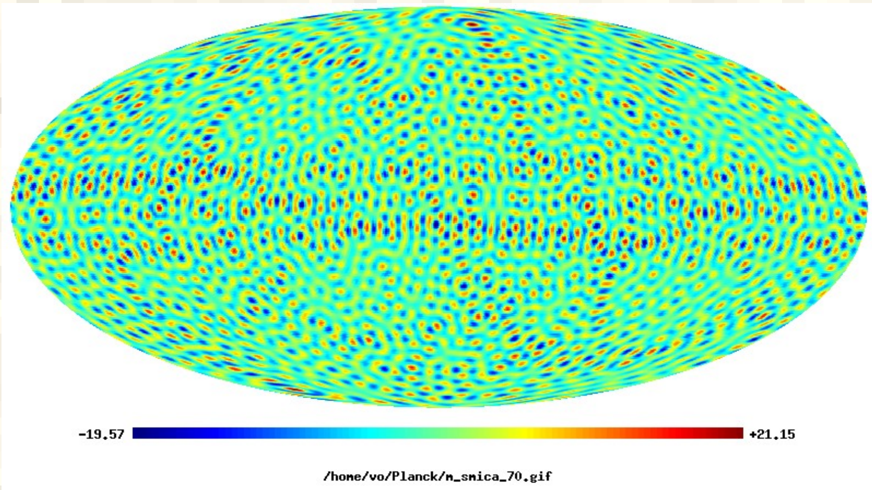
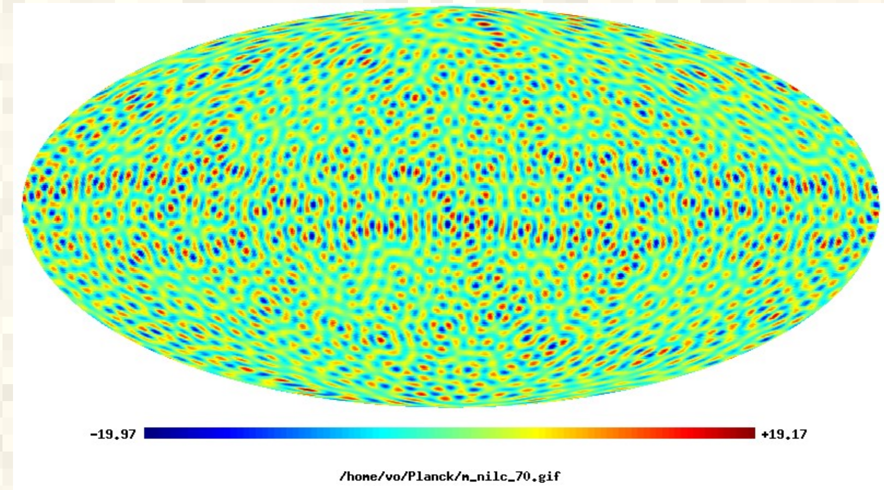
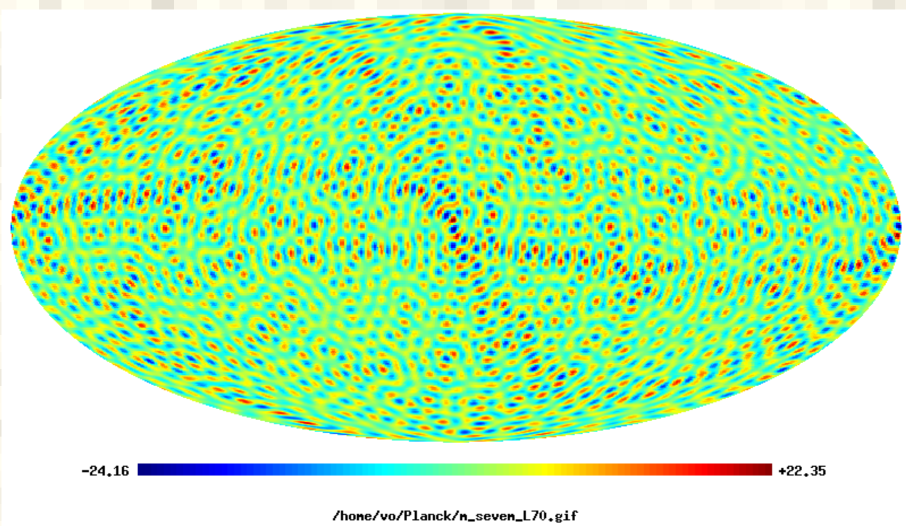


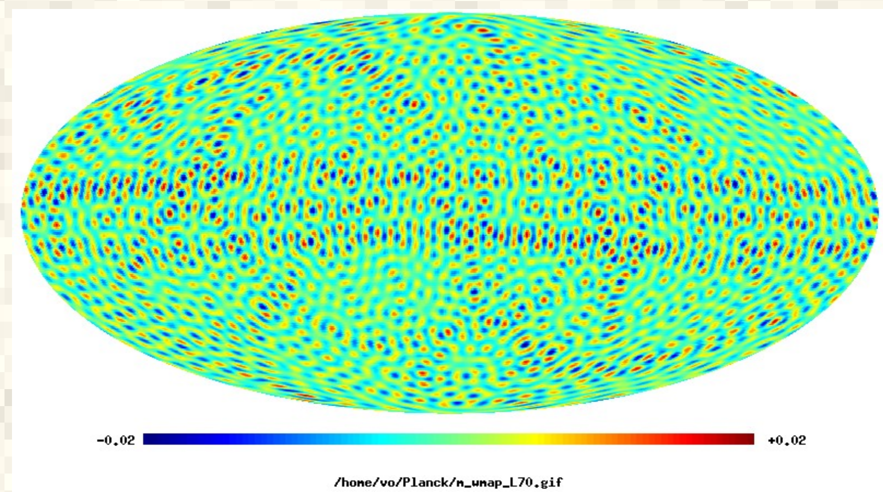
Planck, SMICA



NILC



SEVEM

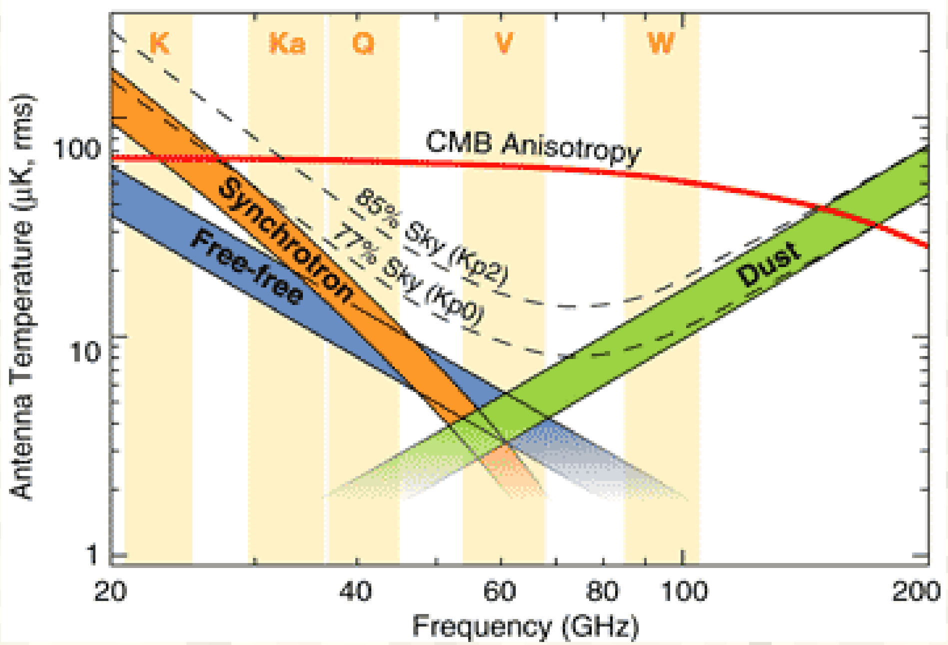


WMAP

Observational channel of **217** GHz:
what is unusual ?

Data of 217 GHz: what is unusual ?

1) Very close to CMB map outside the Galactic plane,
but let us remember WMAP bands:

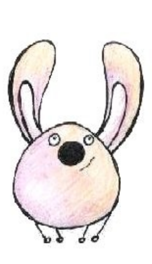


Data of 217 GHz: what is unusual ?

1) Close to the CMB map

2) Calibration problem ?
(Spergel et al., arXiv:1312.3313)

If one removes the 217 GHz channel, then it can be obtained good restoration of the WMAP cosmology

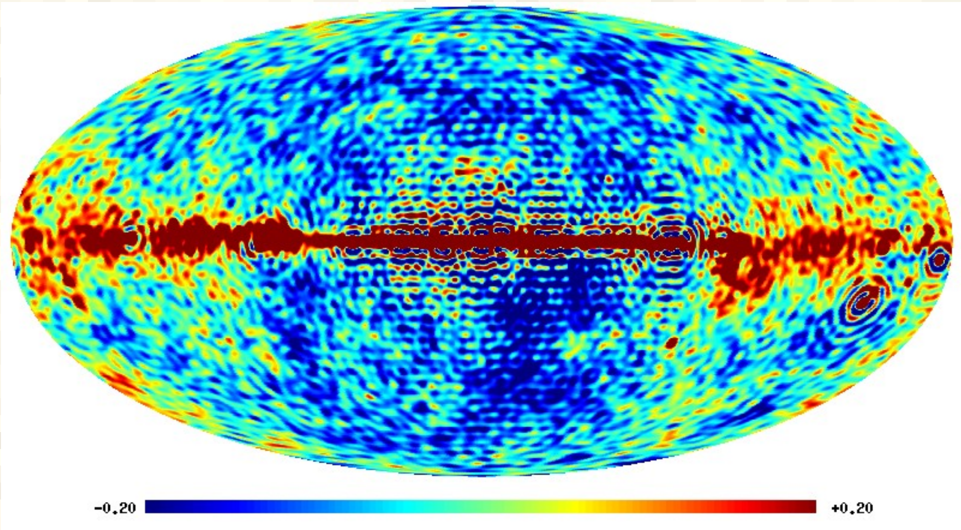


Is the Universe odd ?

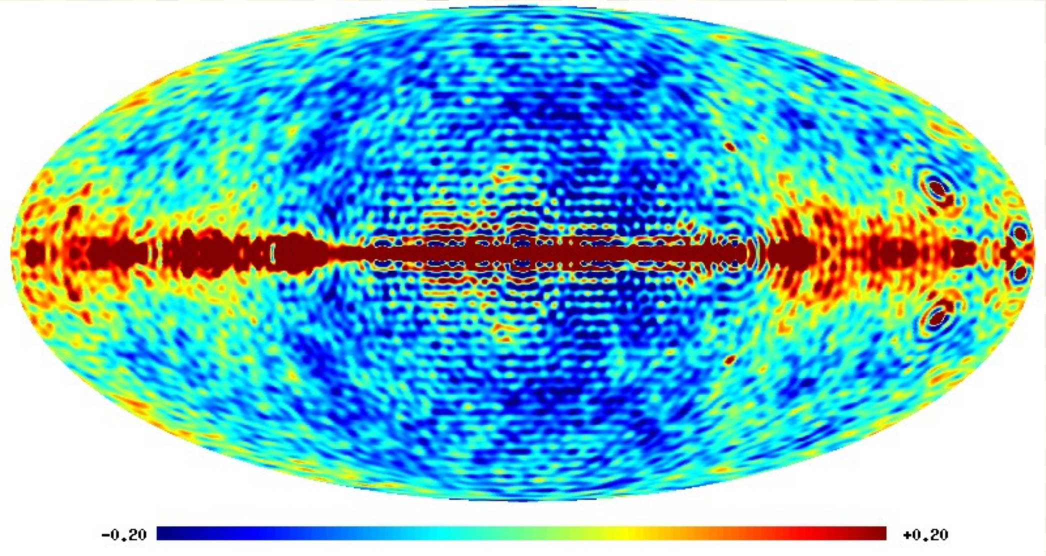
(Land & Magueijo, 2005)

Do some tricks

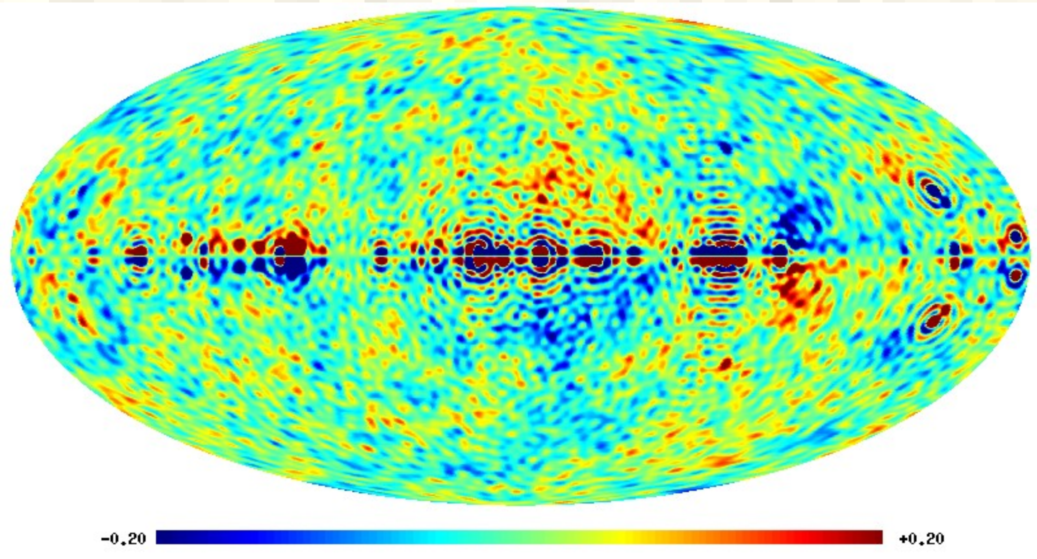
Do some tricks



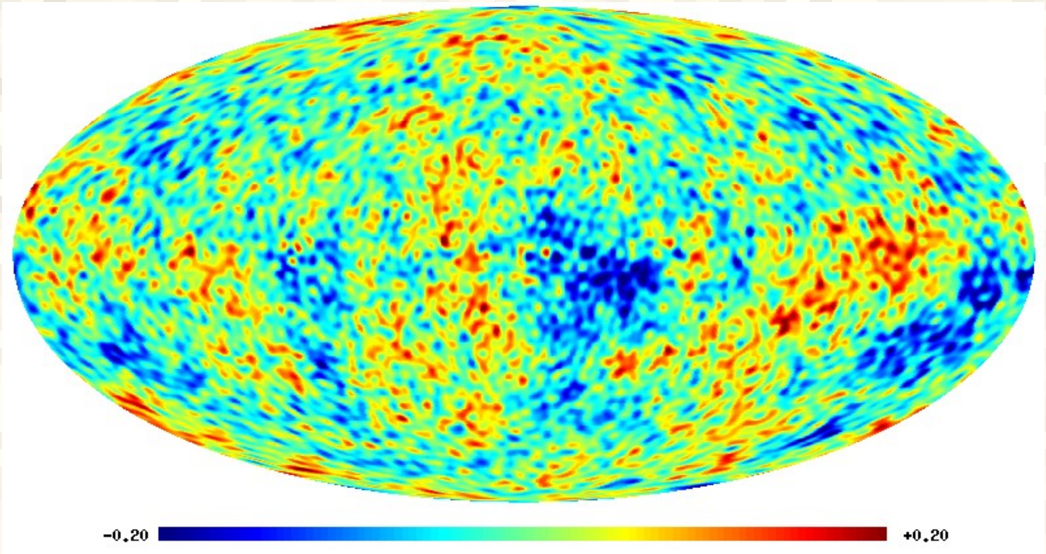
WMAP, V channel, L<100



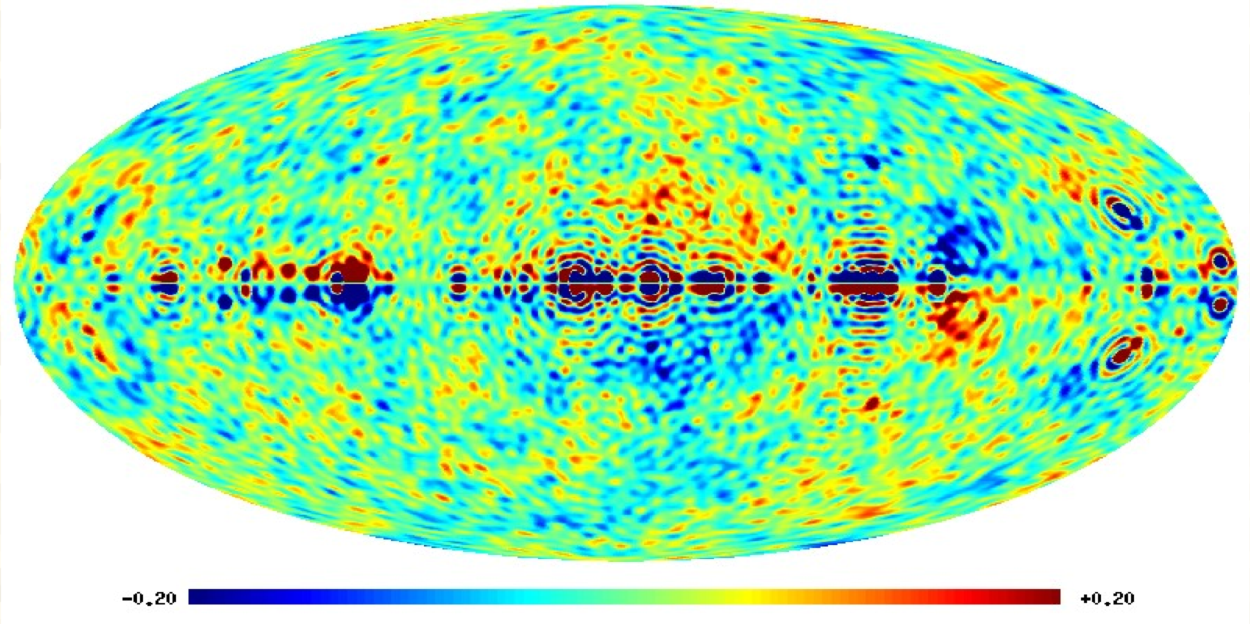
Even (*l*+*m*) harmonics



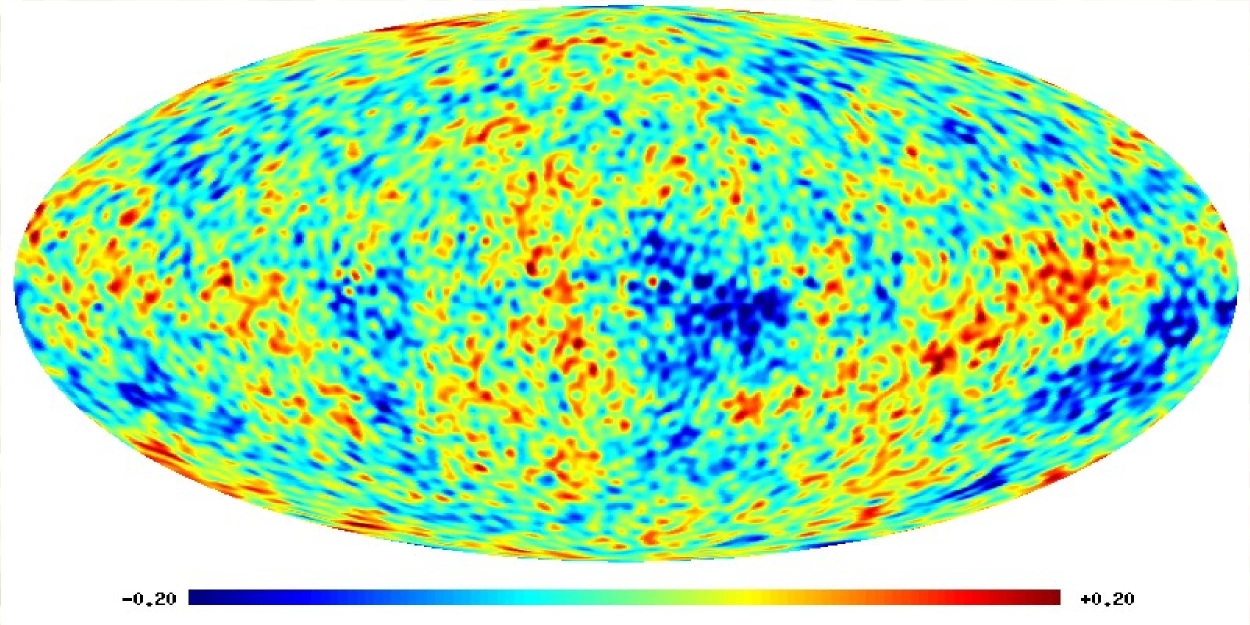
Odd (*l*+*m*) harmonics



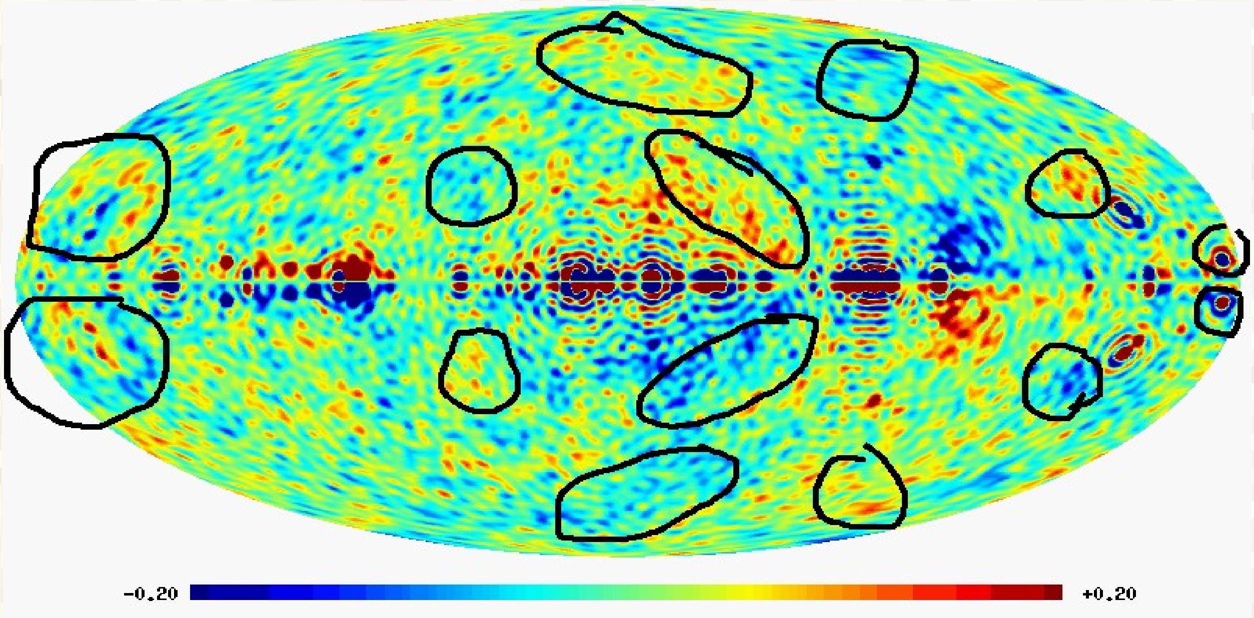
ILC map



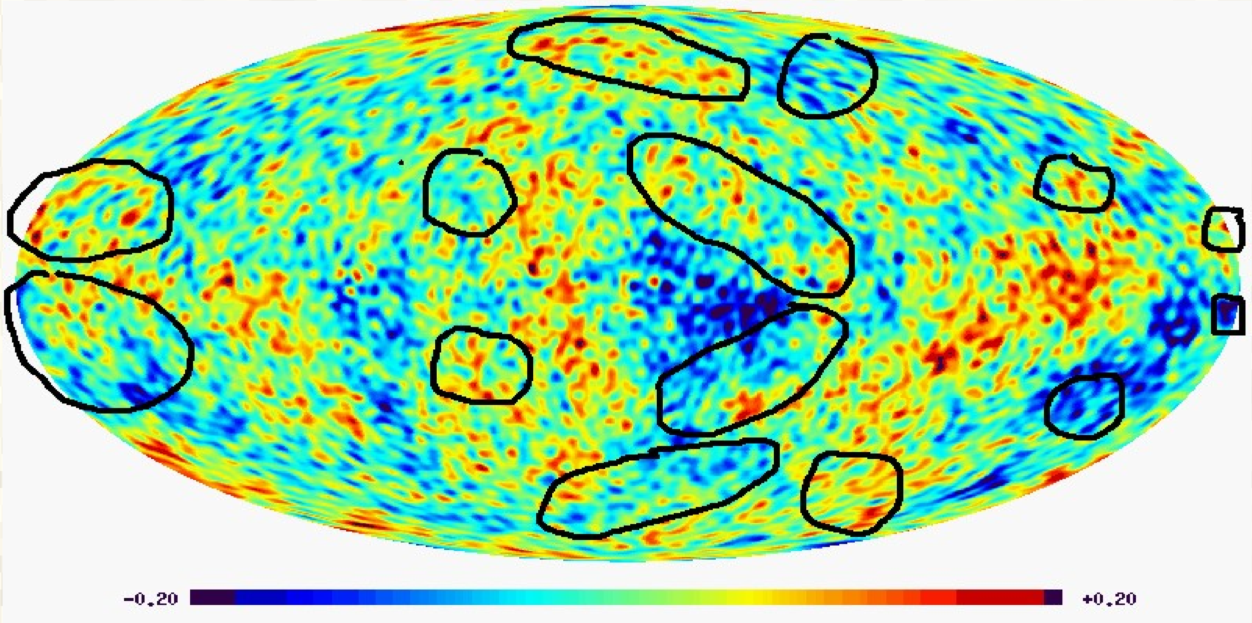
V channel,
odd ($l+m$)



ILC



V channel, odd (l+m)

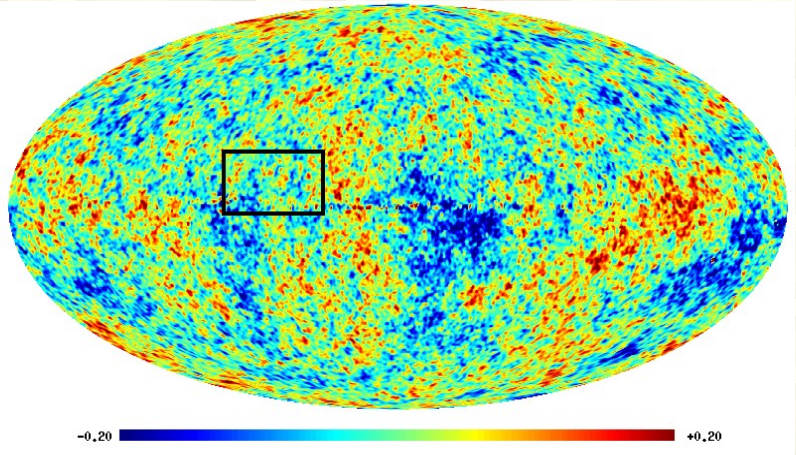


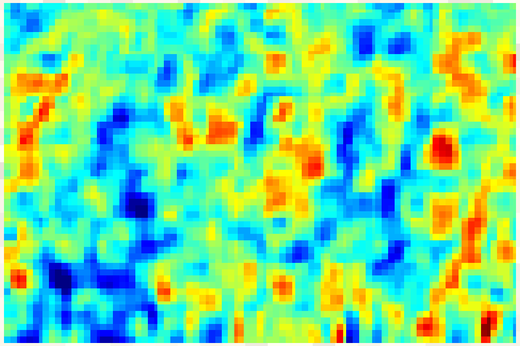
ILC

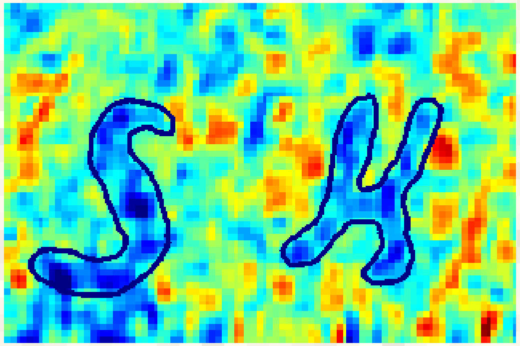
And in ecliptic too...

Stephen Hawking «stamp» :)

WMAP

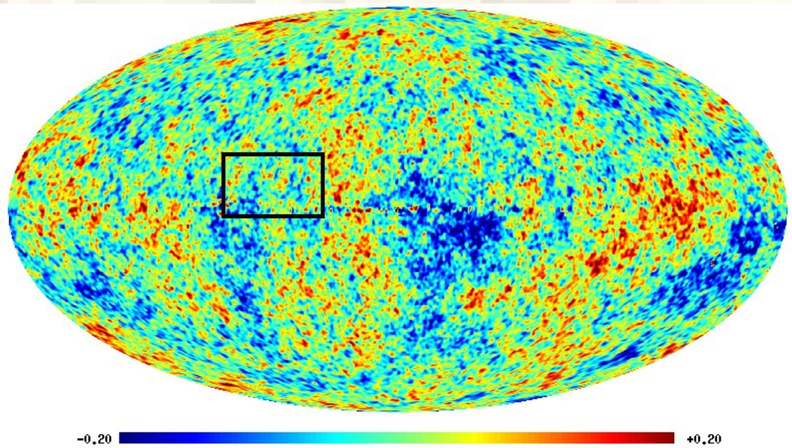


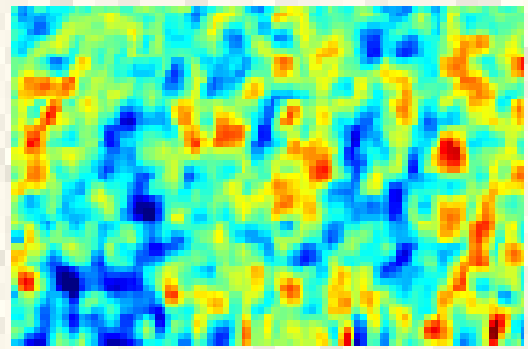


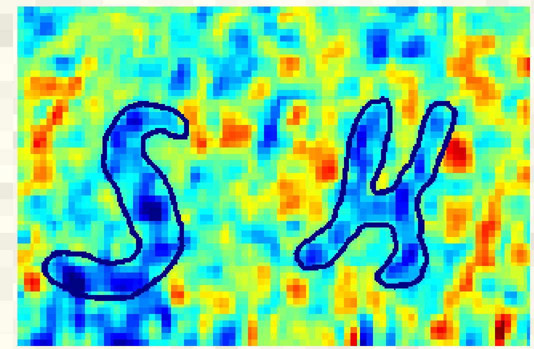


Stephen Hawking «stamp» :)

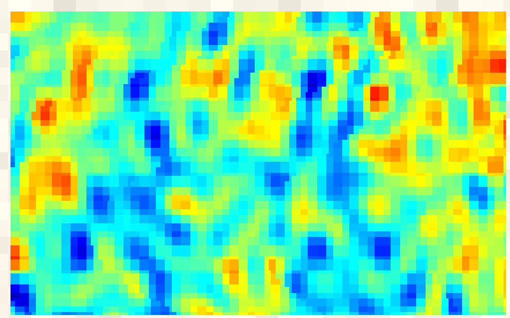
WMAP

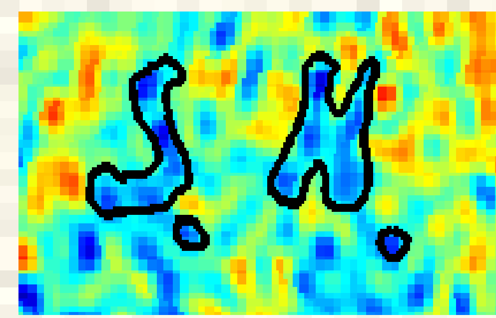






Planck,SMICA





Summary

What have we wait for ? and what to do ?

1) WMAP and Planck data have practically the same low multipole anomalies

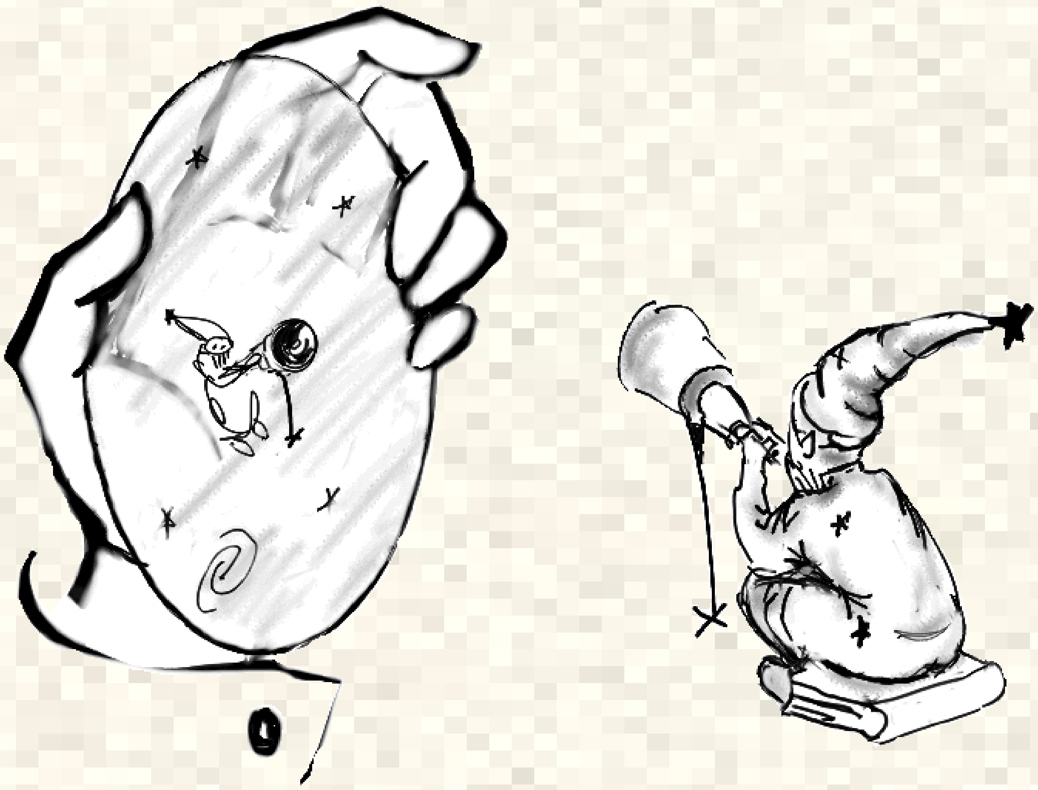
2) The difference of power spectra looks like one due to systematic effects of maps prepartion

3) We are waiting for a new release in summer 2014:
    Maps of temperature anisotropy and ***polarization***

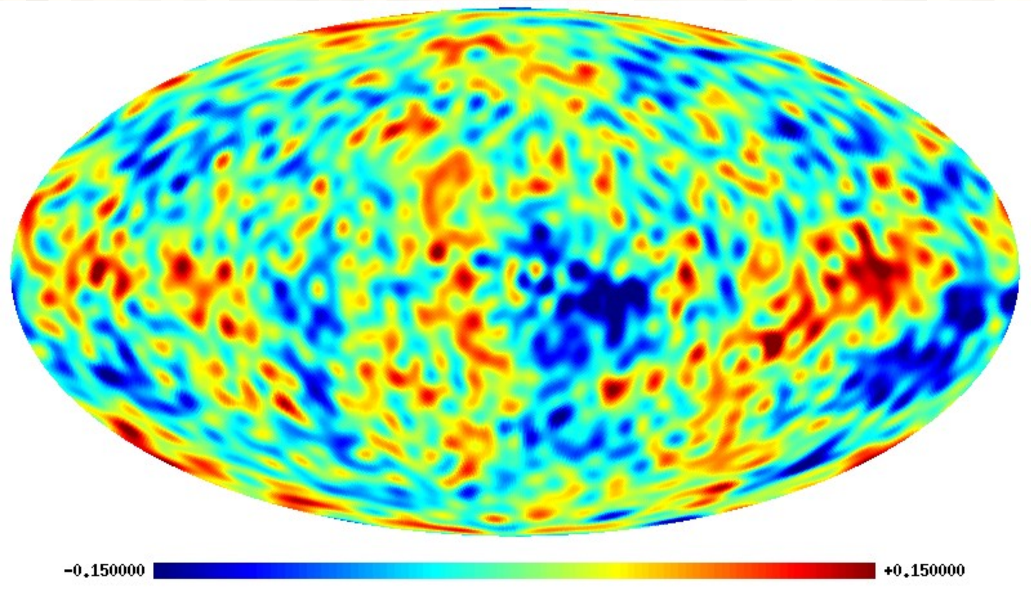
4) Data are comparatively good (in resolution and sensetivity) when we take into account strangeness

So, again: what do we observe ?

(what can we learm from life ?)

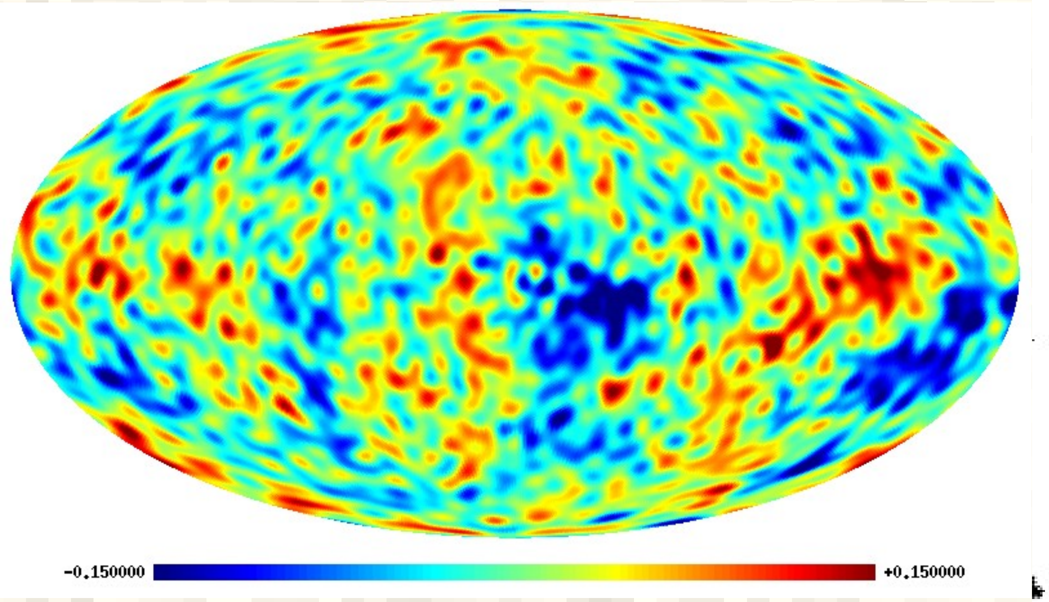


The only realization



And what is the real CMB ?

And non-Gaussianity of the only realization



What is in real CMB ?

This is still a rhetorical question...