# Probes of Pre-Inflationary Relics: From Theory to Data Analysis

Ely D. Kovetz
University of Texas at Austin
Cook's Branch 2012, March 23rd

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Based on:

Theory

N. Itzhaki and EDK, "Inflection Point Inflation and Time Dependent Potentials in String Theory", JHEP 2007
A. Fialkov, N. Itzhaki and EDK, "Cosmological Imprints of Pre-Inflationary Particles", JCAP 2010, arXiv:0911.2100

Data Analysis

EDK, A. Ben-David and N. Itzhaki, "Giant Rings in the CMB Sky", ApJ 724, 2010, arXiv:1005.3923
A. Ben-David, EDK and N. Itzhaki, "Parity in the CMB: Space Oddity", ApJ 748, 2012, arXiv:1108:1702

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- Motivation (Theory): Inflation Onset

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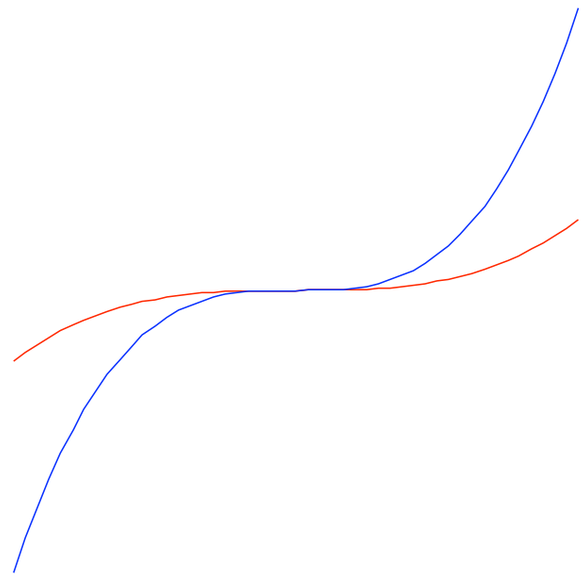

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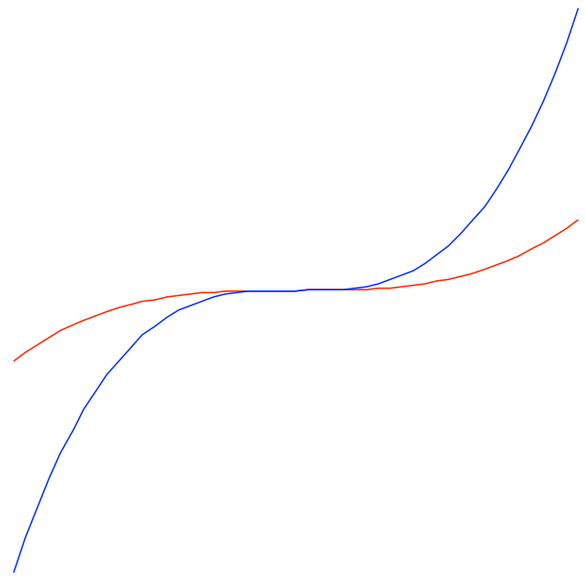

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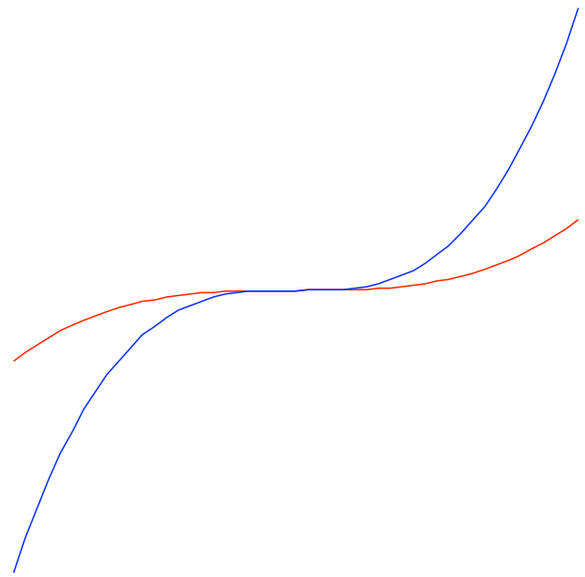

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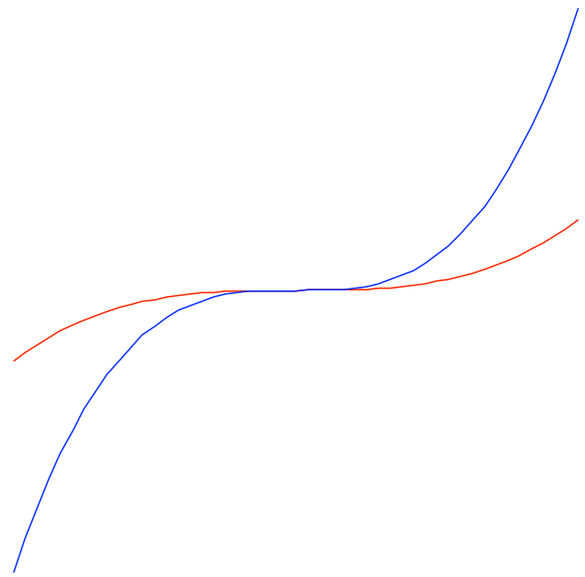

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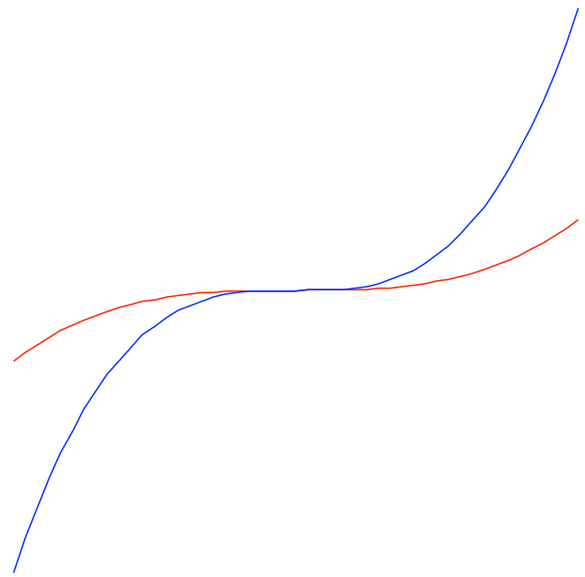

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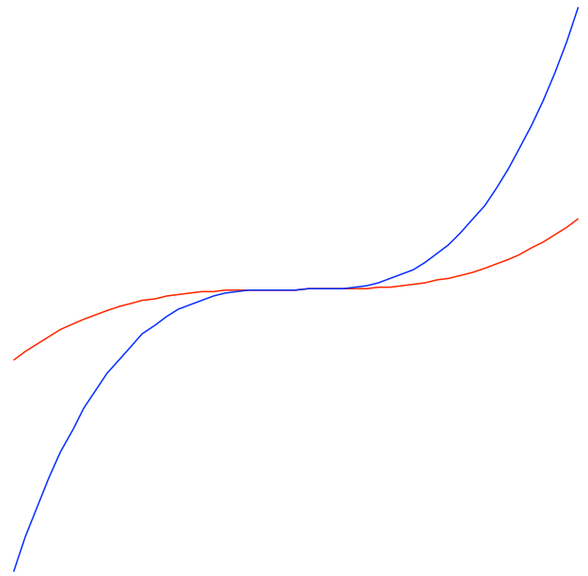

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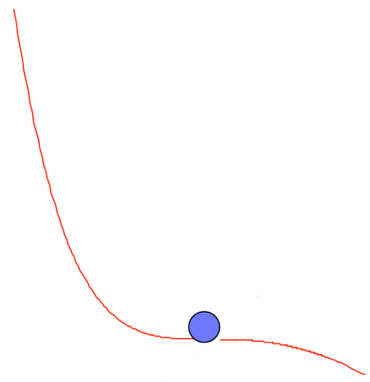

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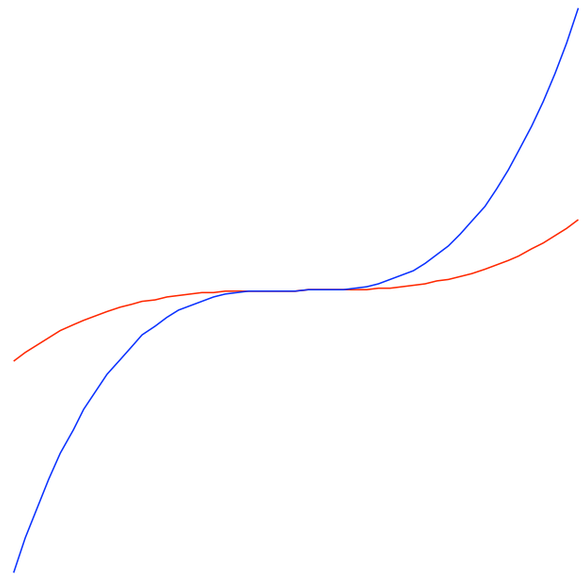

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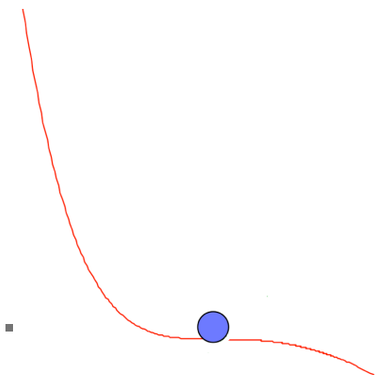

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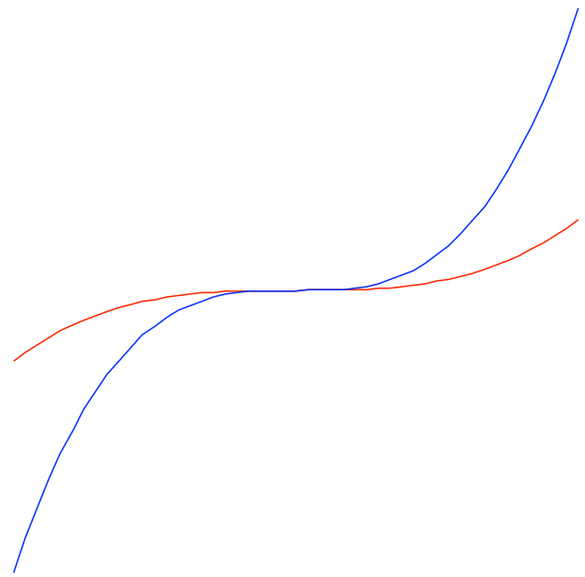

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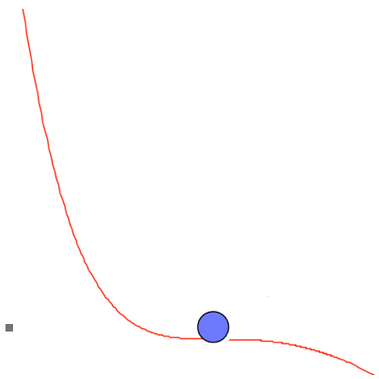

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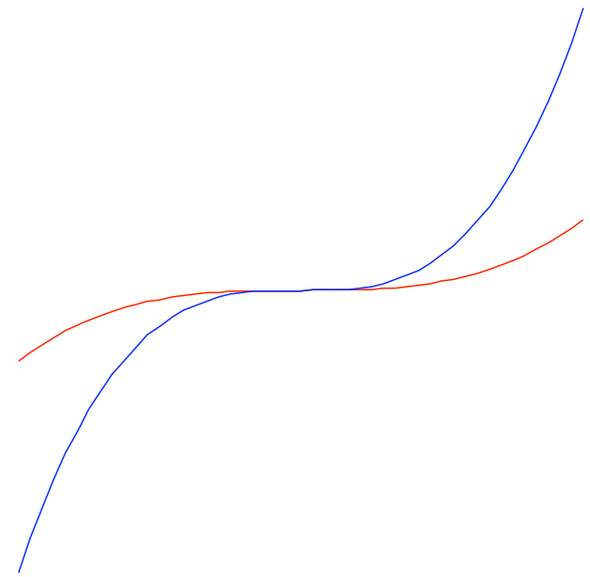

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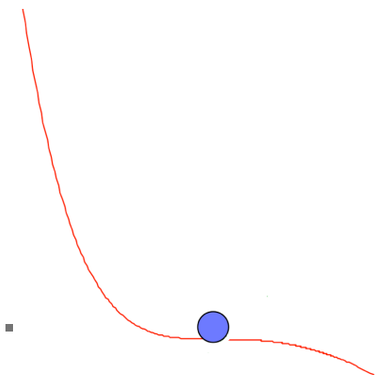

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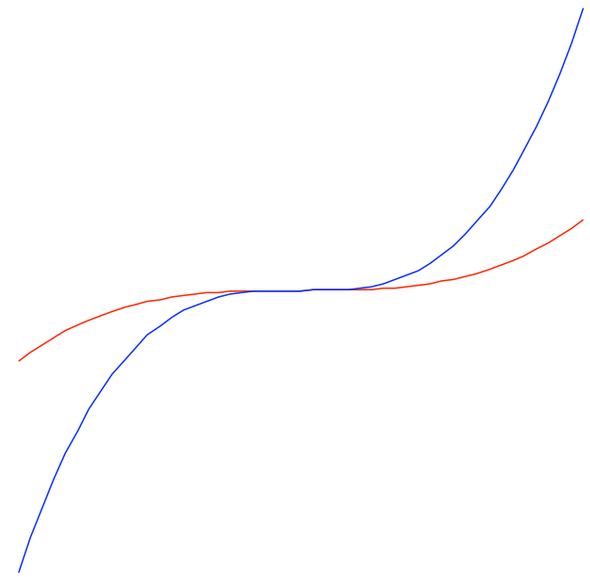

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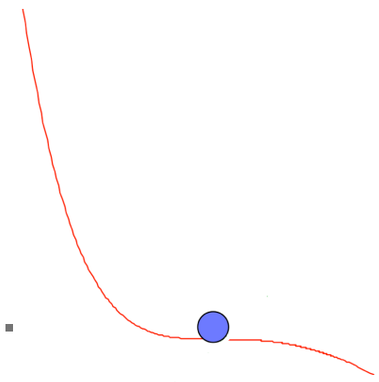

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  - Unless the initial conditions are fine-tuned, inflaton will **overshoot** and not enough inflation will be produced.

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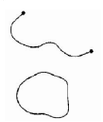

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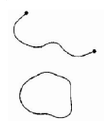

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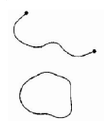

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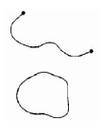

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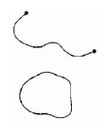

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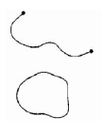
example 

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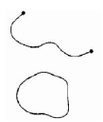
example 

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$$\begin{aligned} 3H^2 &= \frac{1}{2}\dot{\phi}^2 + V_{static} + V_{dynamic}, \\ \dot{n} &= -3Hn, \\ \ddot{\phi} + 3H\dot{\phi} &= -\frac{d}{d\phi}\left(V_{static} + V_{dynamic}\right) \end{aligned}$$

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Assuming a compactification on a manifold M with $\mathrm{Vol}_M \propto L^d$, $L$ is the inflaton.

example

- **(3+p)-branes**: wrap regular 4D + p cycles in M.
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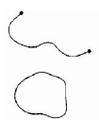

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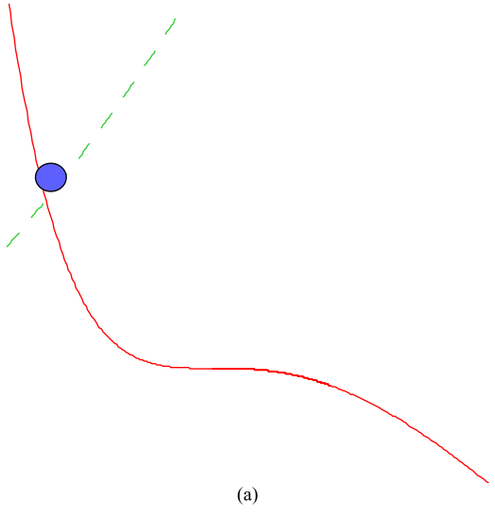

(a)

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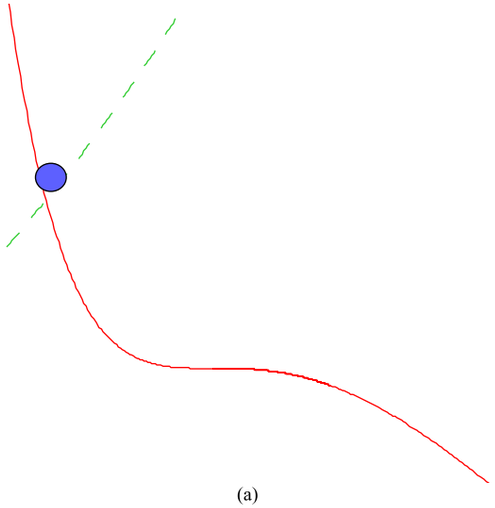

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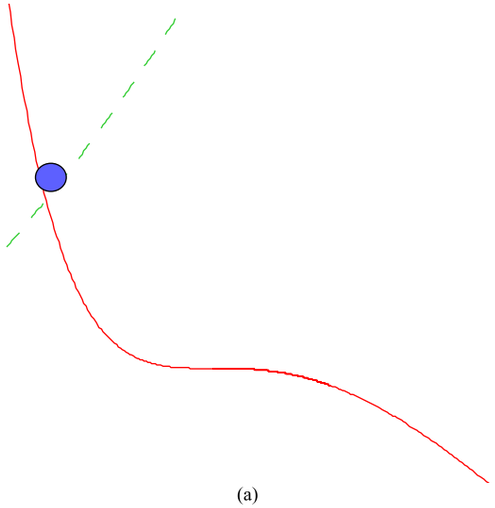


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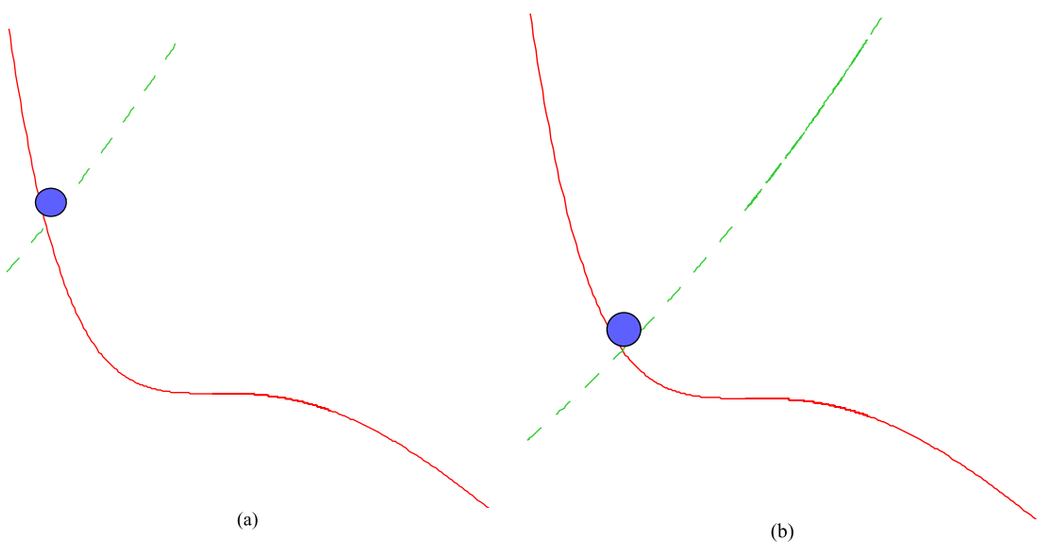


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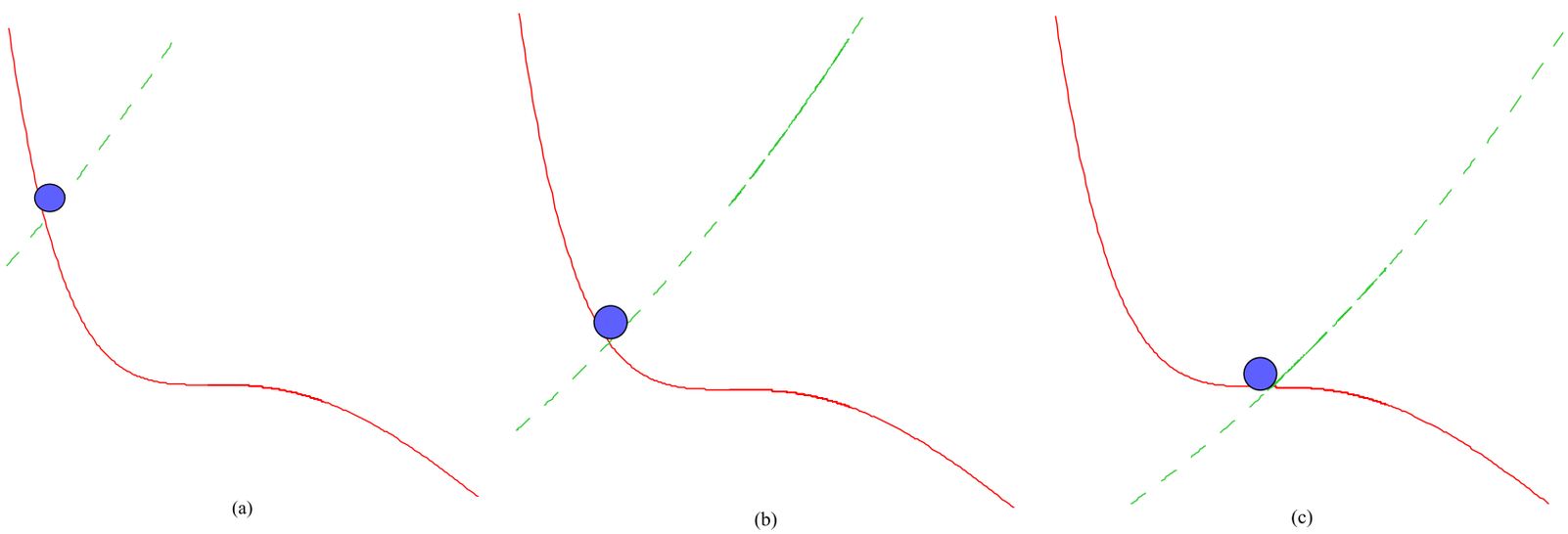


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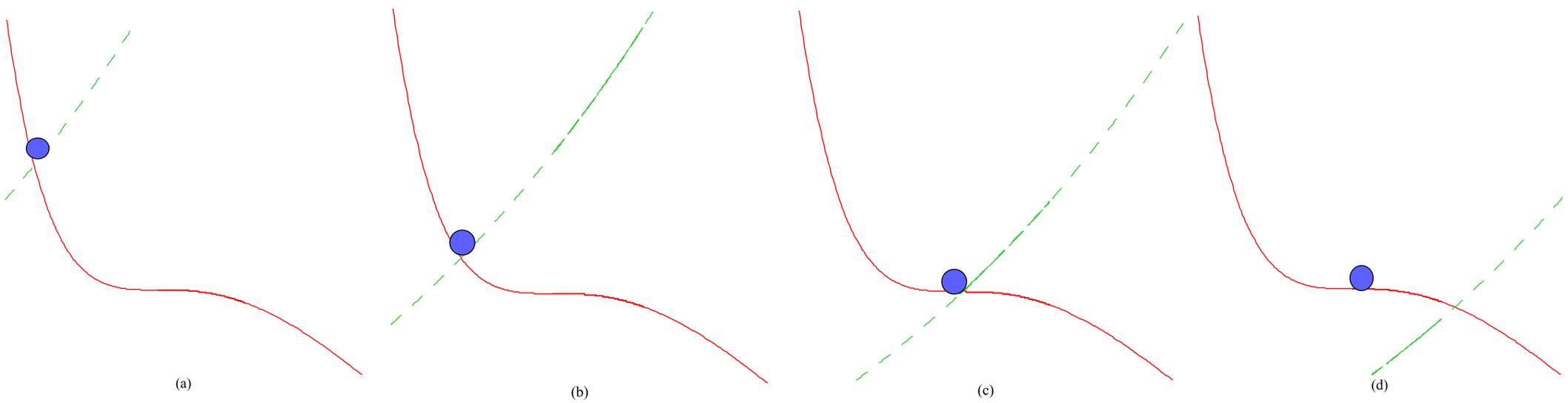


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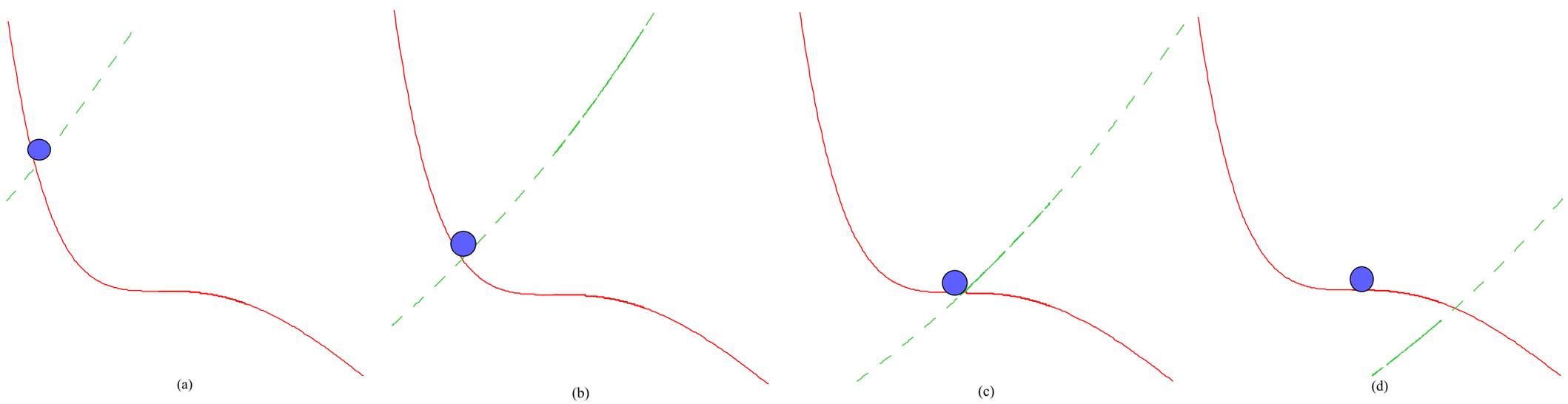


● Inflaton rolling ● $V_{\rm static}(L) = \sum_i \frac{a_i}{L^{p_i}}$ ● ~~$V_{\rm dynamic}(L) \propto n(t) L^q$~~

- Sounds good! Inflation occurs in the first place thanks to the PIP(s), a small field model suffices, inflation is hence short (and the CMB quadrupole (oct?) is low!)

# Outline

Ely D. Kovetz
Cook's Branch 2012

- Simplest Relic: Pre-Inflationary Particle

# Outline

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Cook's Branch 2012

- Motivation (Theory): Inflation Onset
- Simplest Relic: Pre-Inflationary Particle

# Pre-Inflationary Particle - Model

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Ely D. Kovetz
Cook's Branch 2012

- Pre-inflationary Particle Signatures

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- Motivation (Theory): Inflation Onset
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- Pre-Inflationary Particle - Signatures

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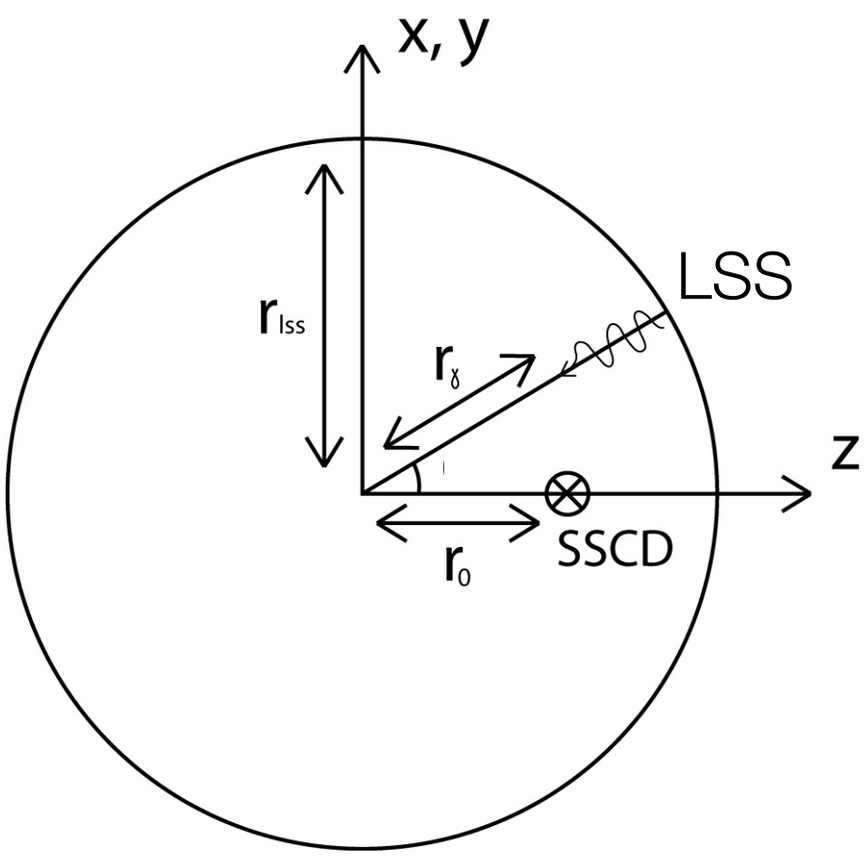

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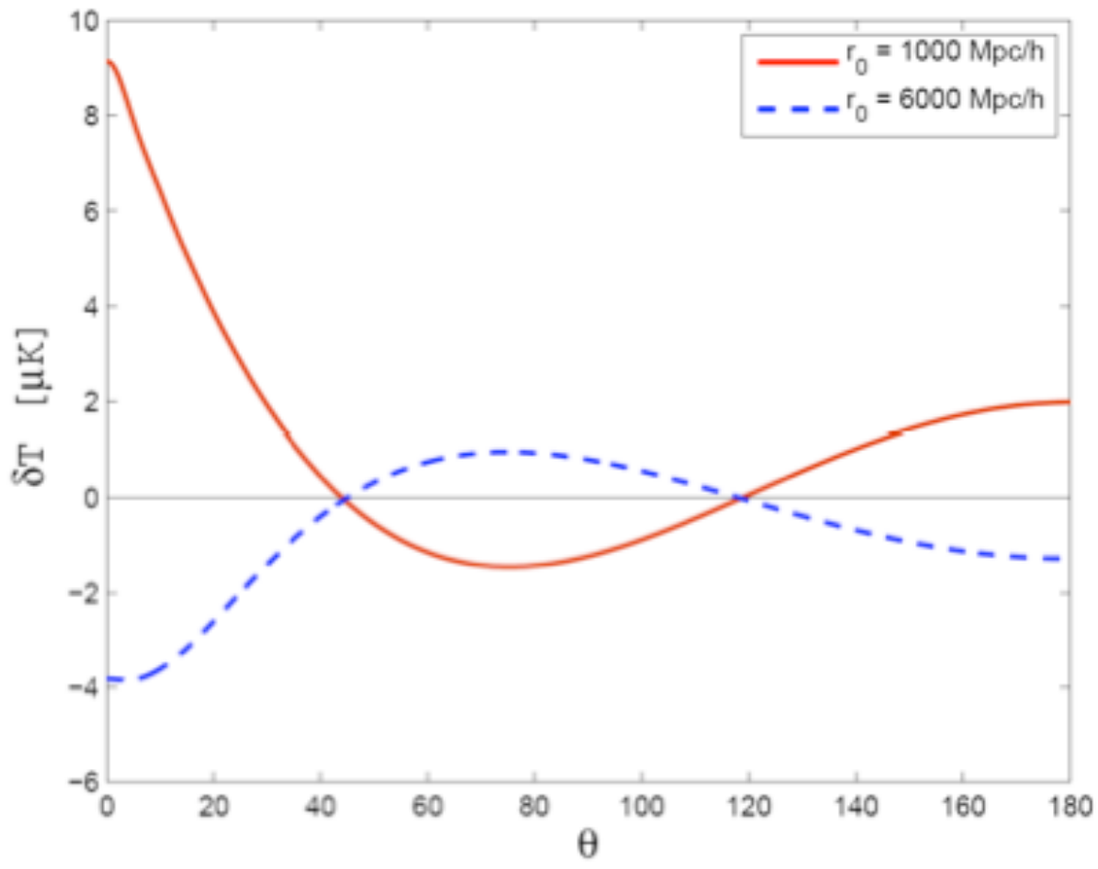


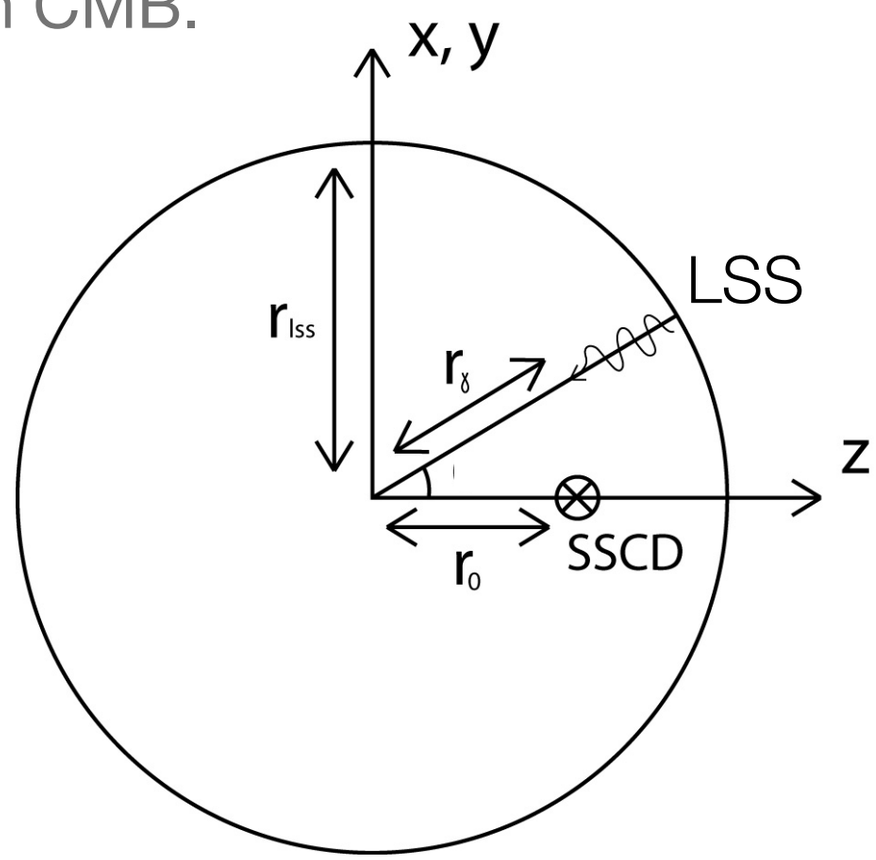

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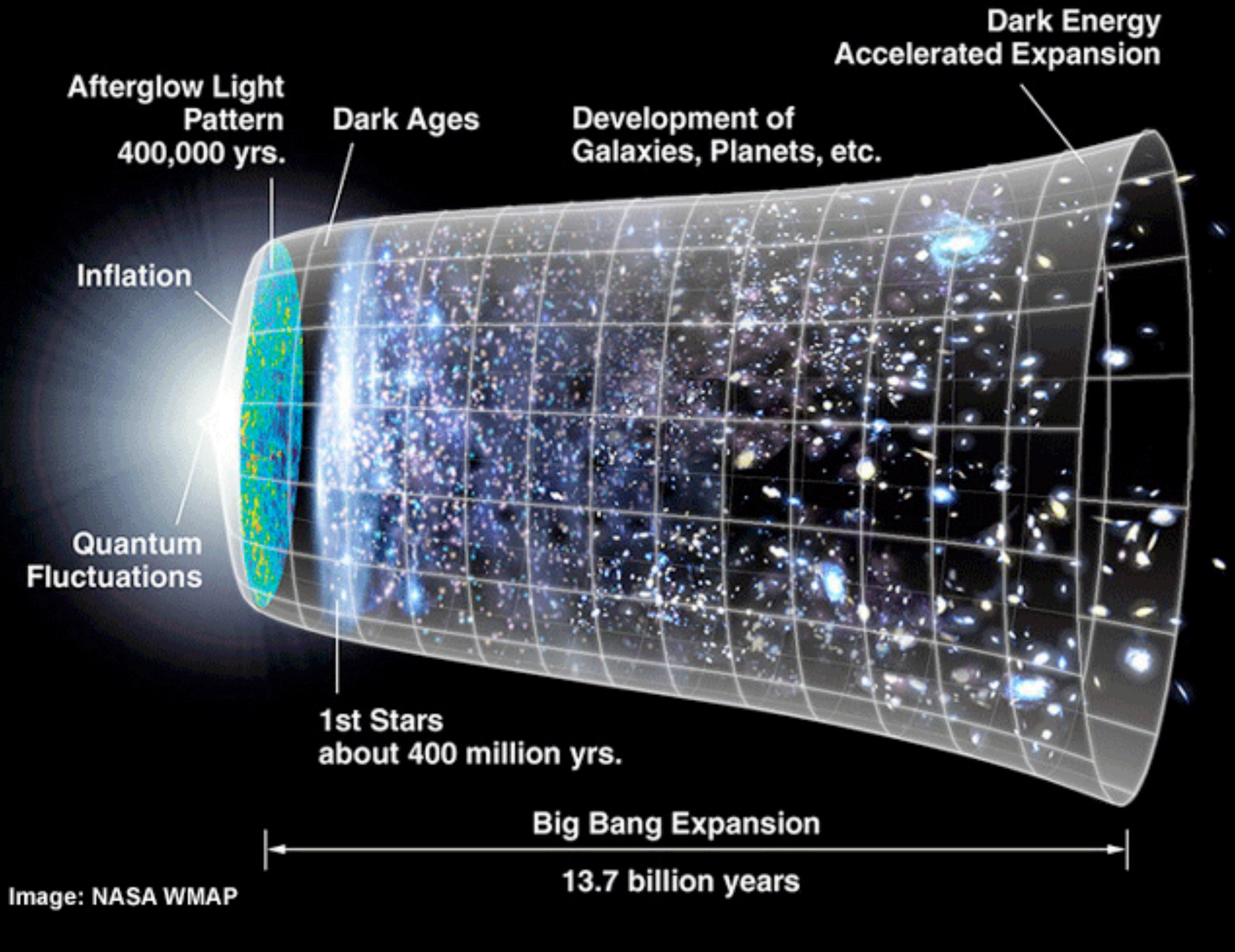

# ΛCDM + Pre-Inflationary Particle (PIP)

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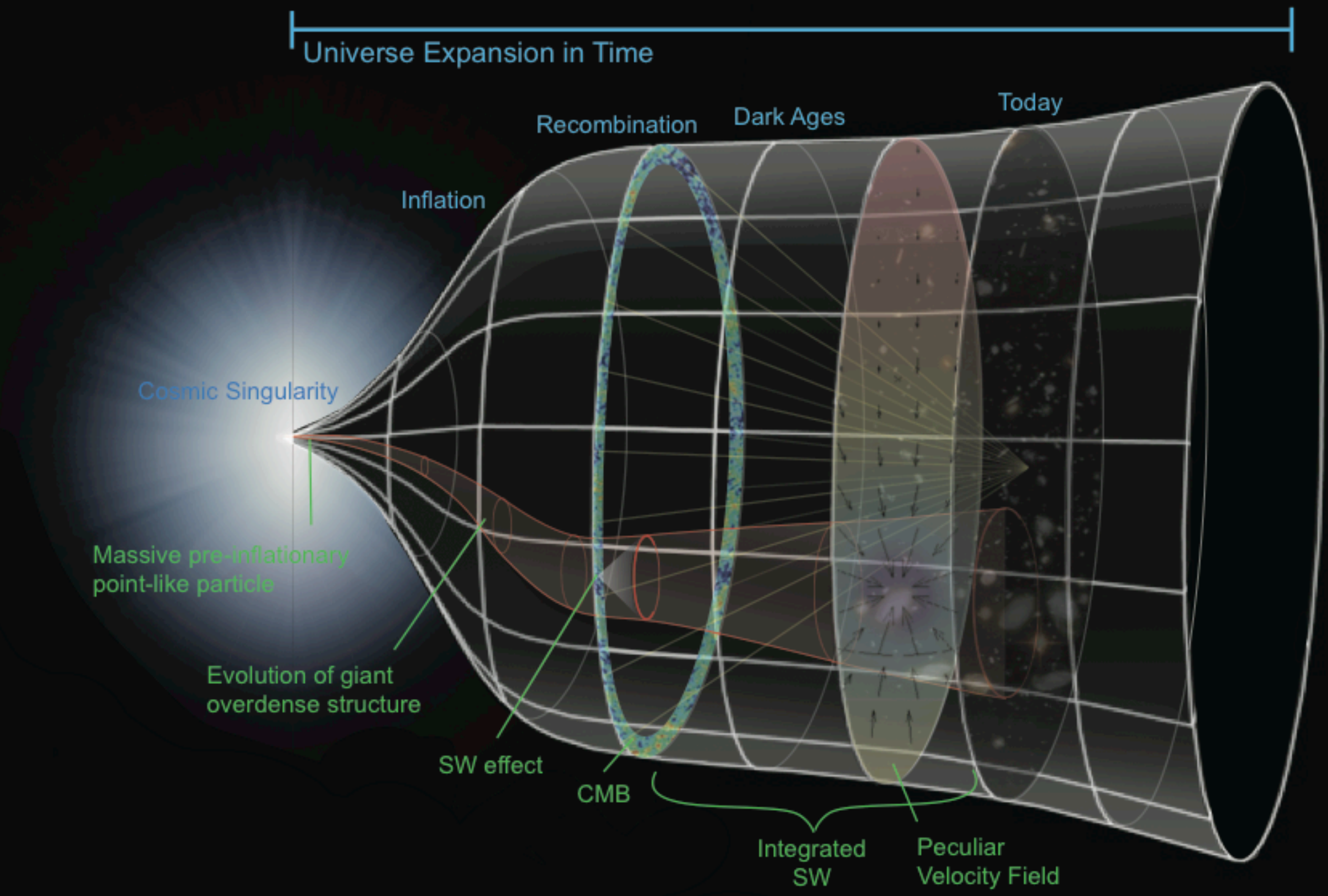

# Outline

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- Motivation (Data): Anomalies

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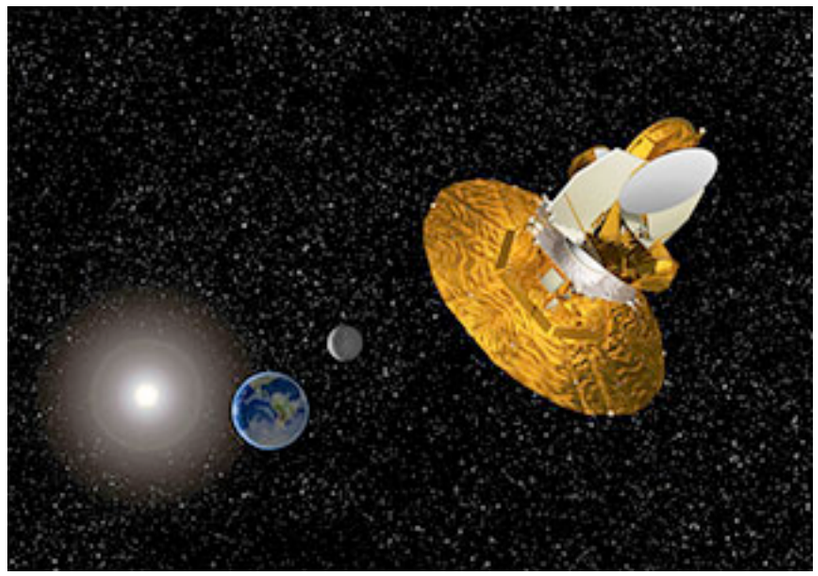

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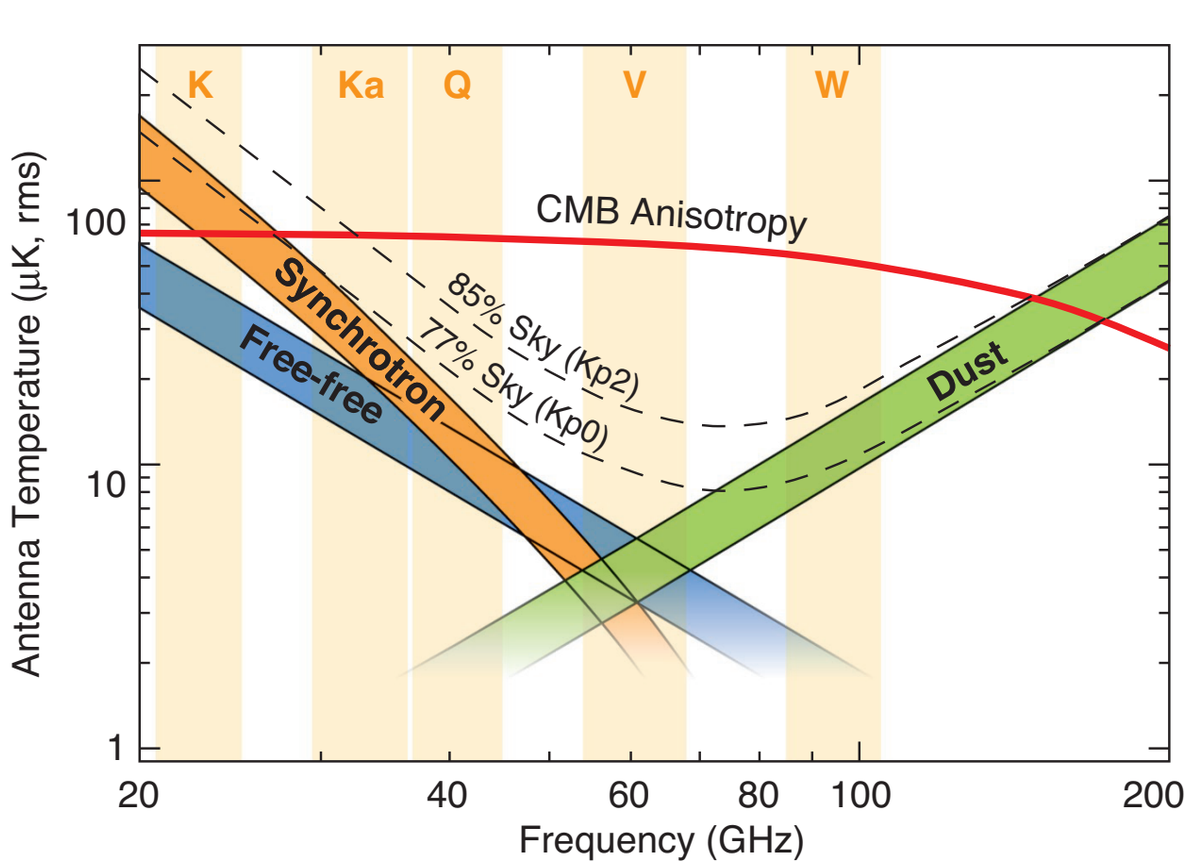
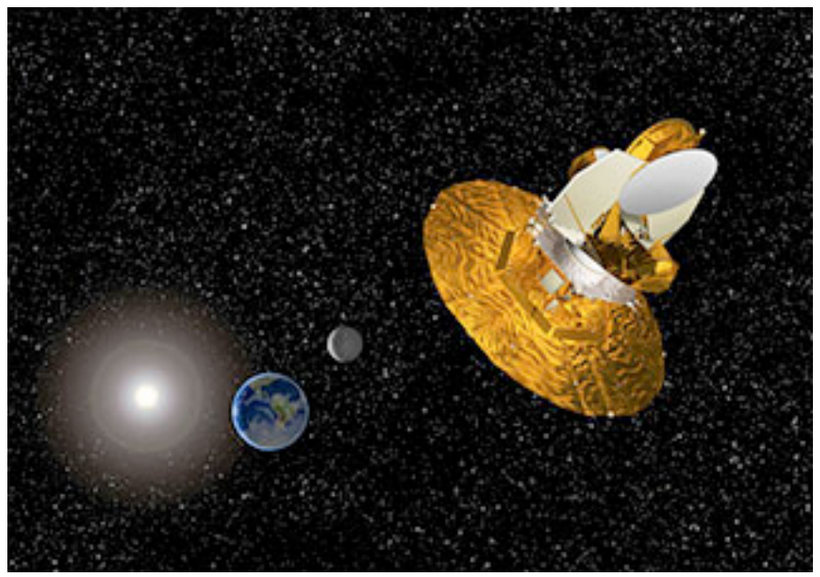
- WMAP Galactic noise budget:



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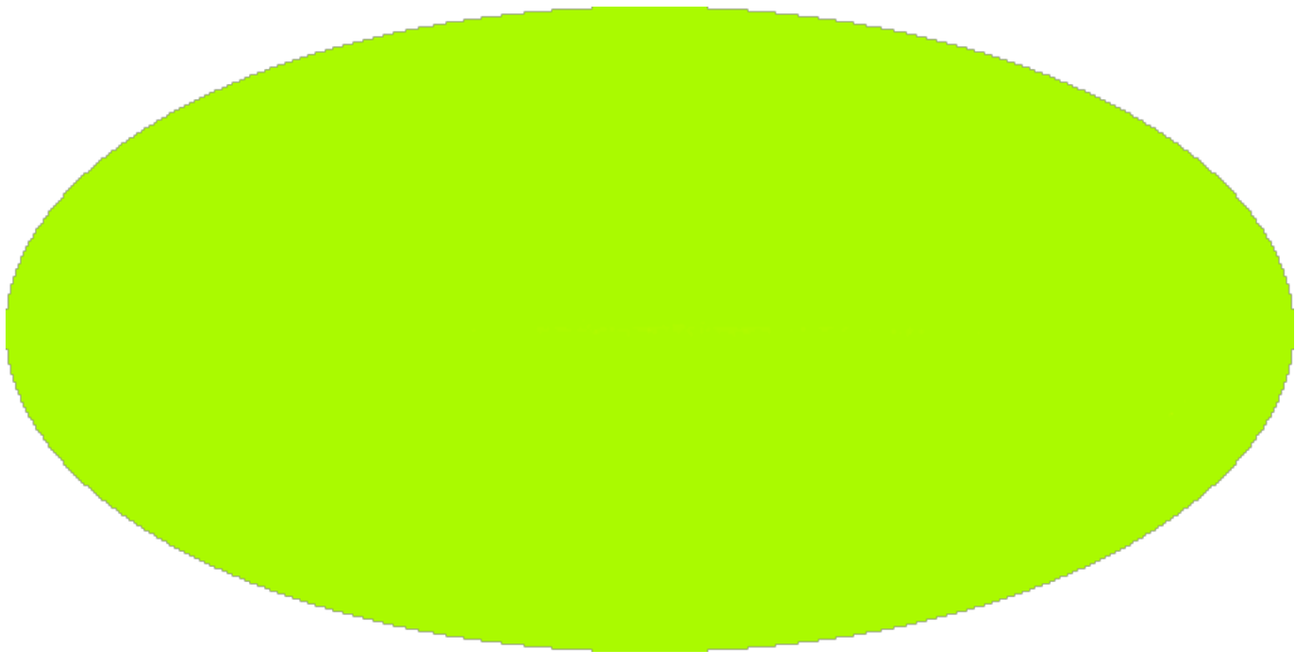

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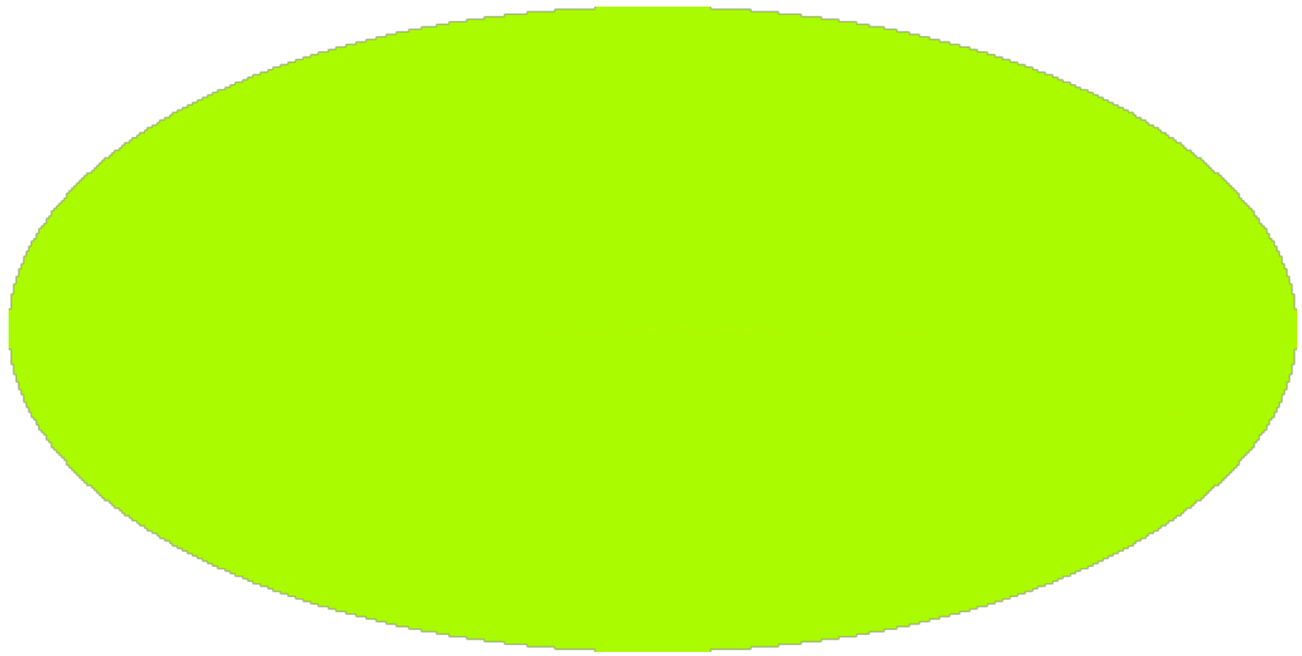
T= 2.726°K



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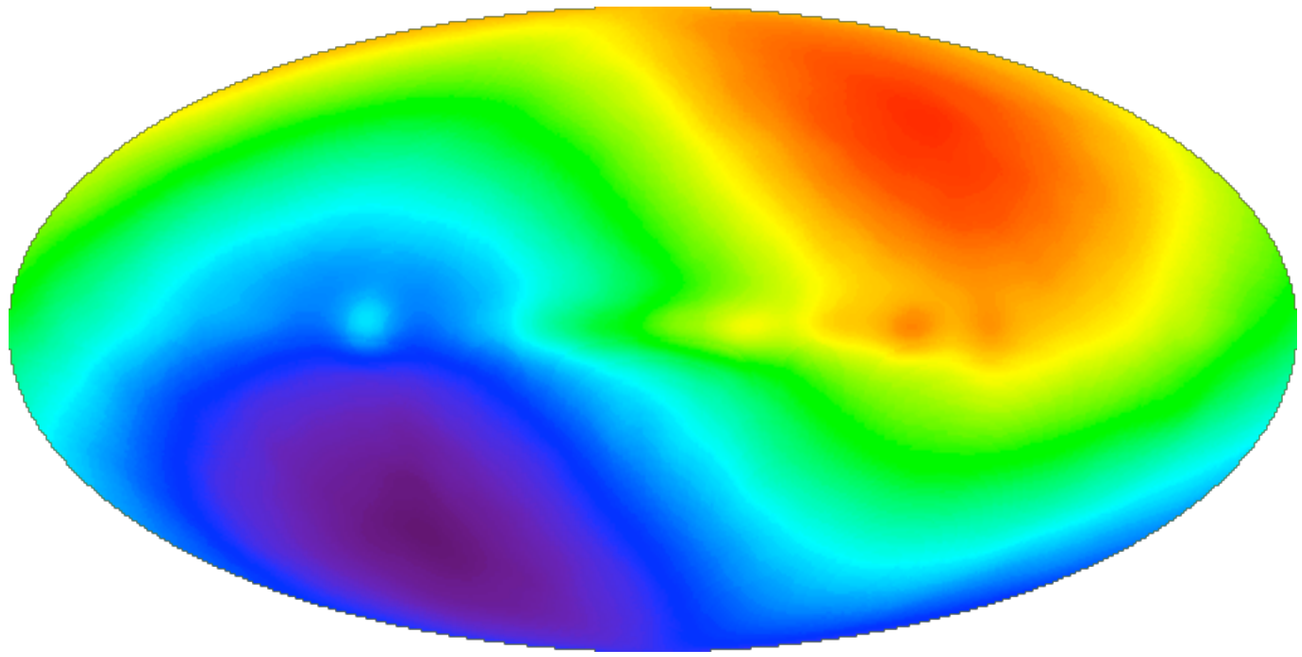
- Monopole



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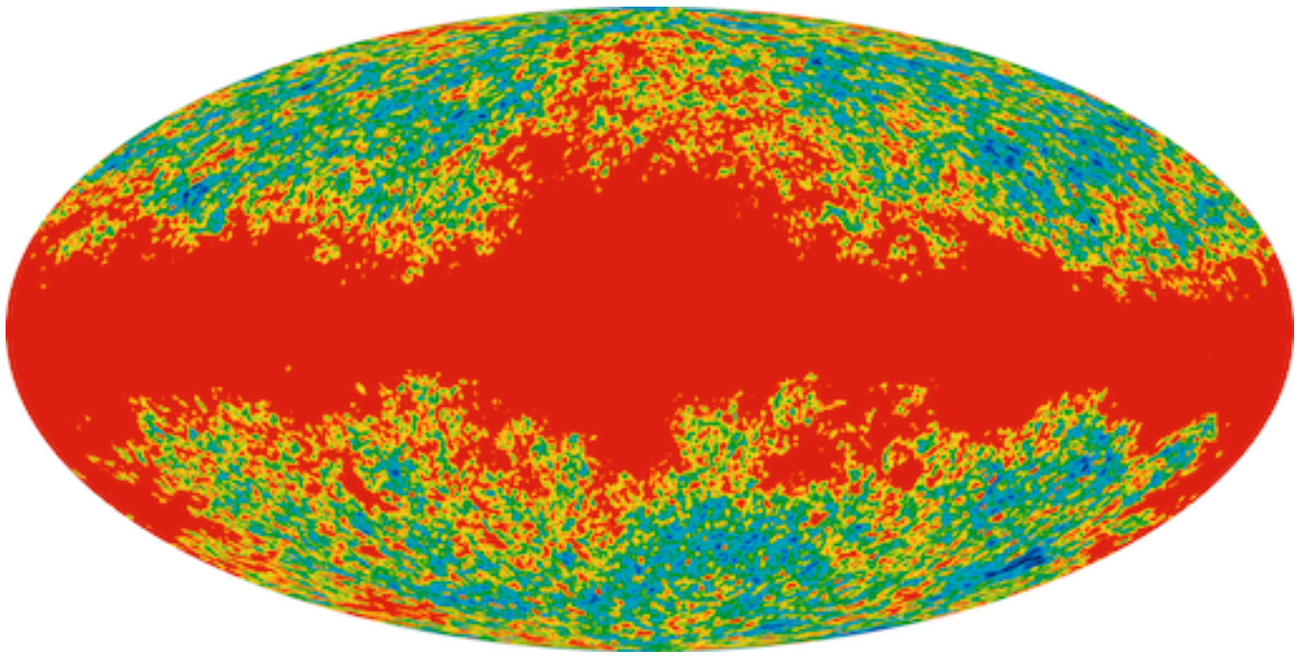
- Dipole



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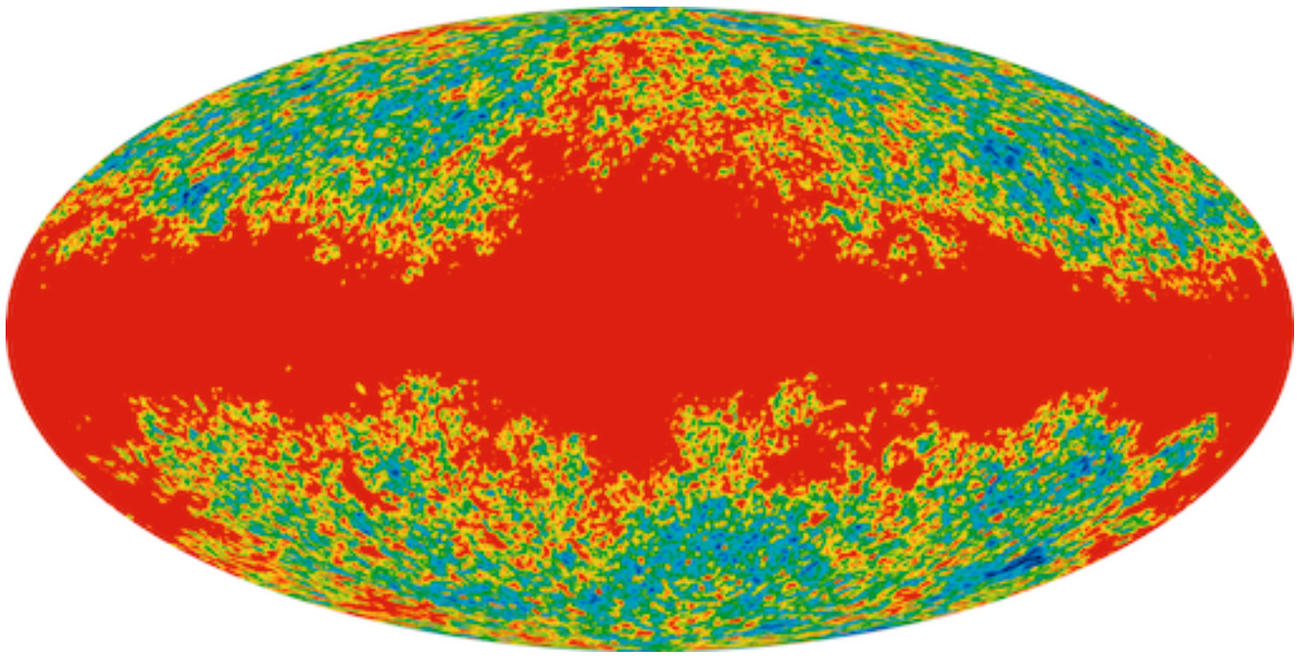
- Dipole

+ Combining all frequencies: K = 23 GHz



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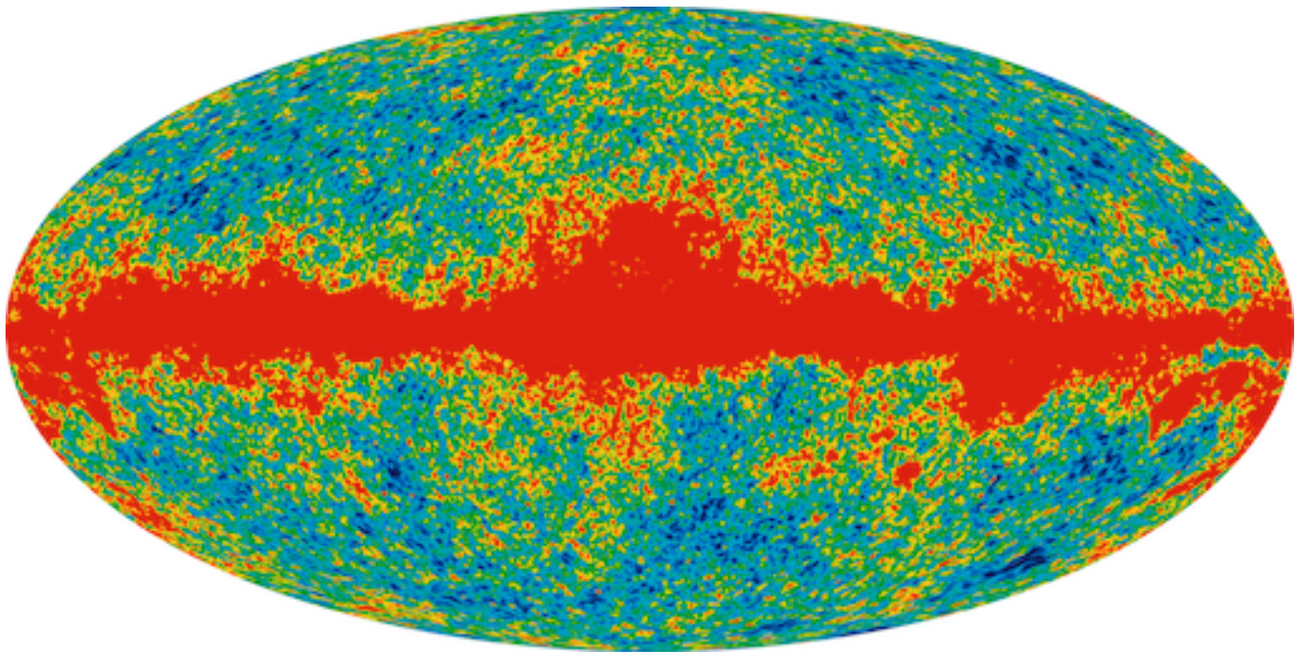

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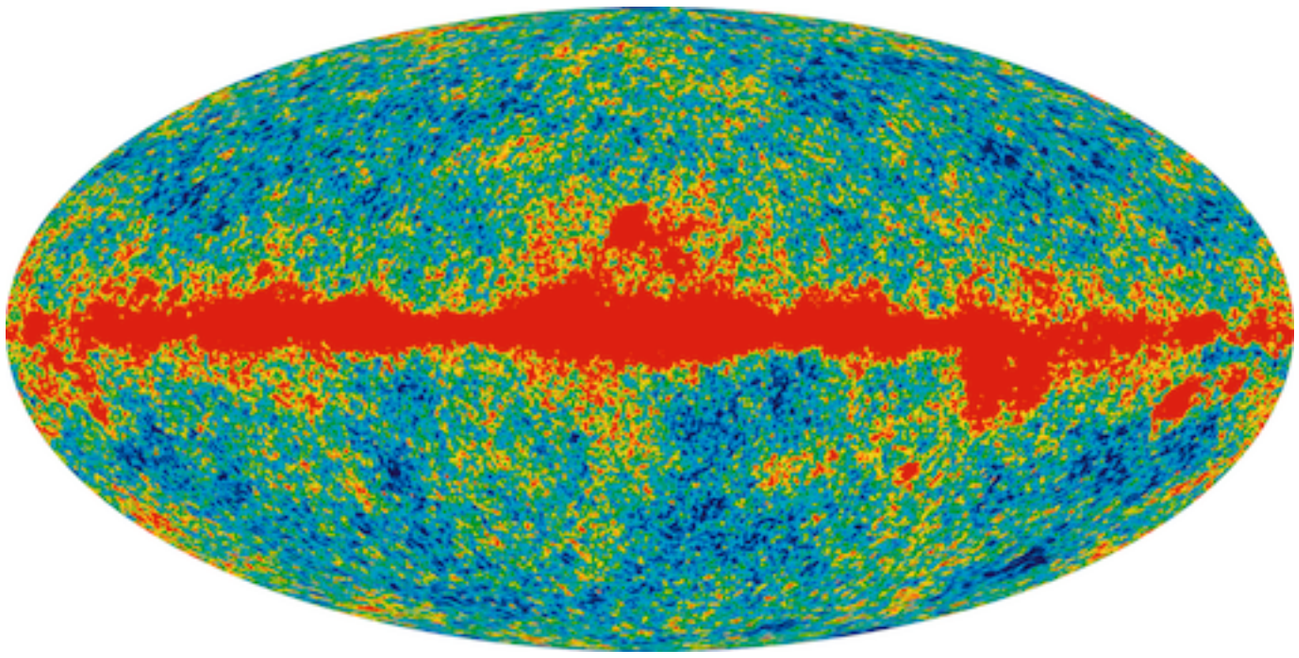

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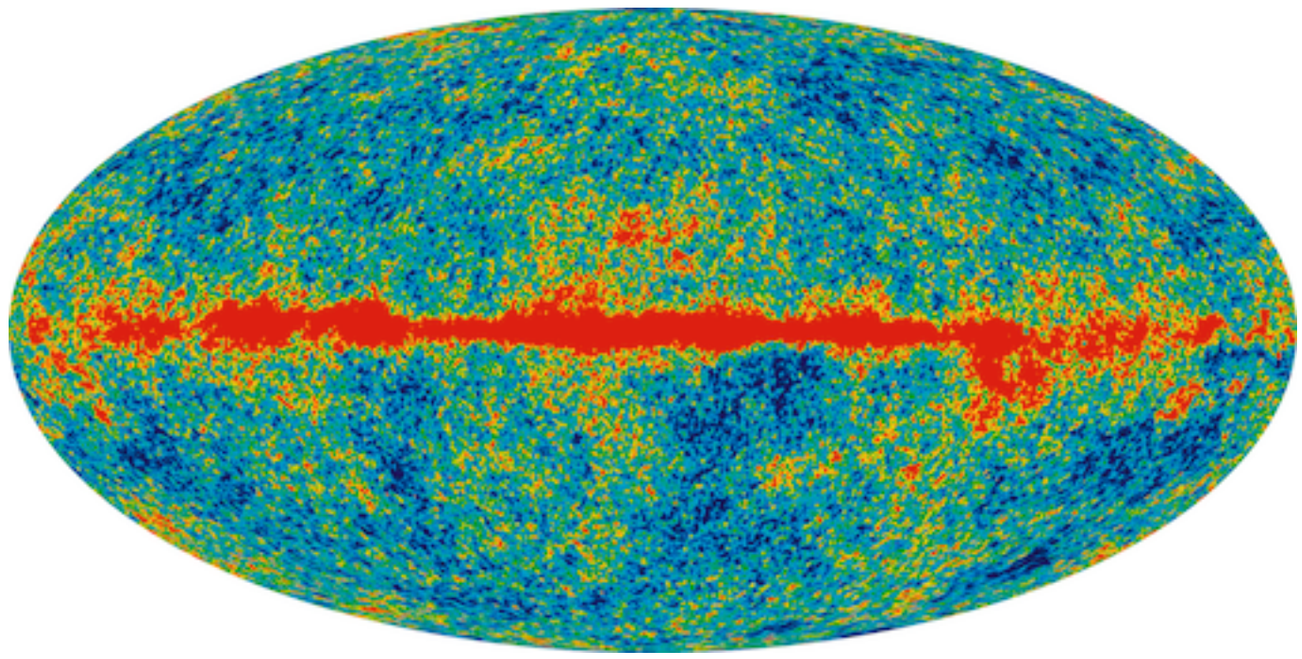
+ Combining all frequencies: V = 61 GHz



# Motivation: Data Anomalies

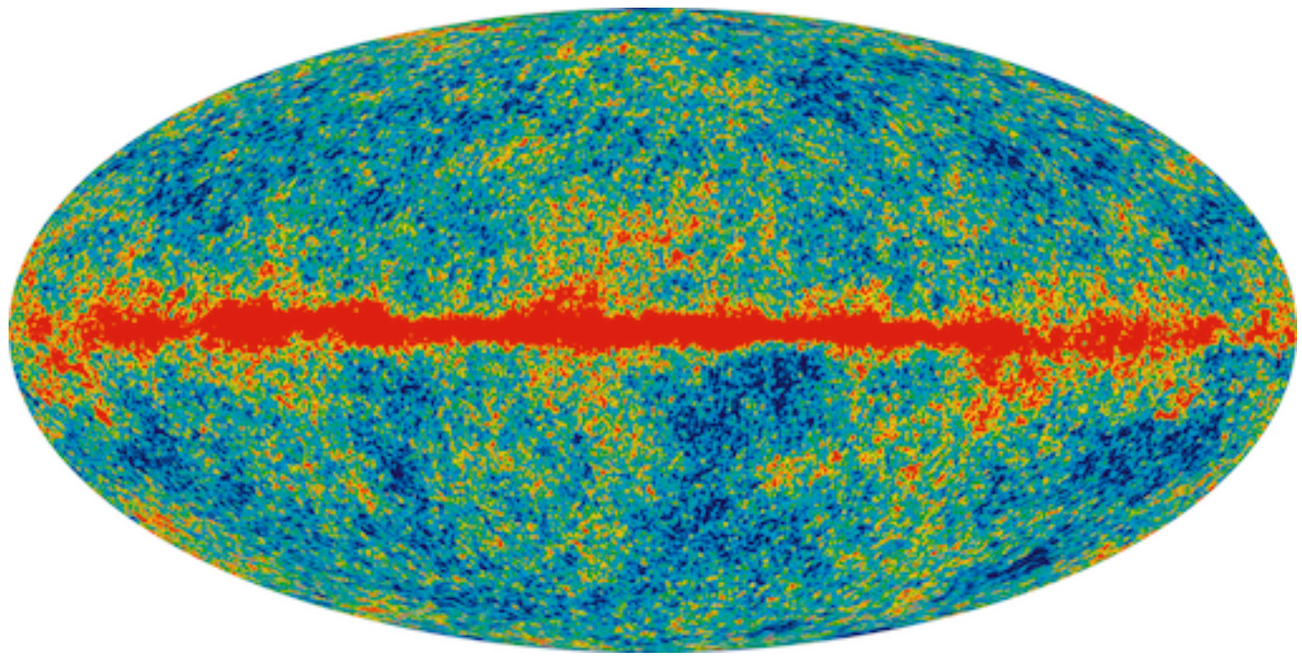
Ely D. Kovetz
Cook's Branch 2012

T= 2.726°K

- Monopole

- Dipole

+ Combining all frequencies: W = 94 GHz



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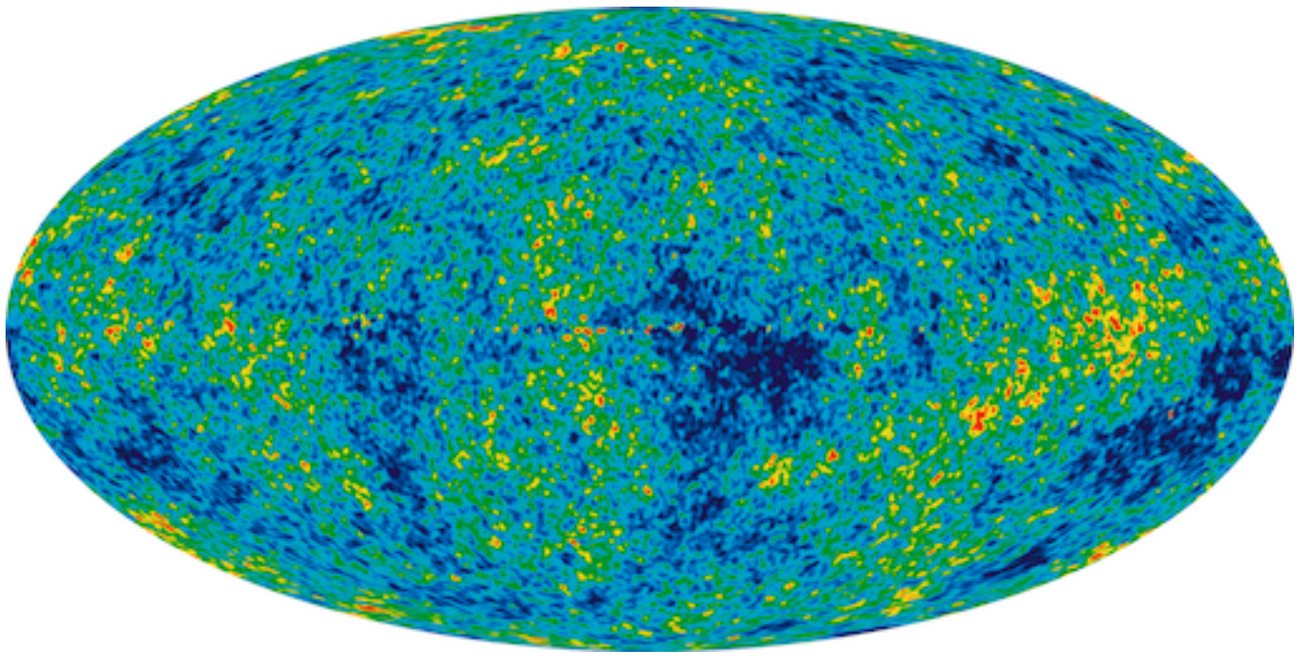

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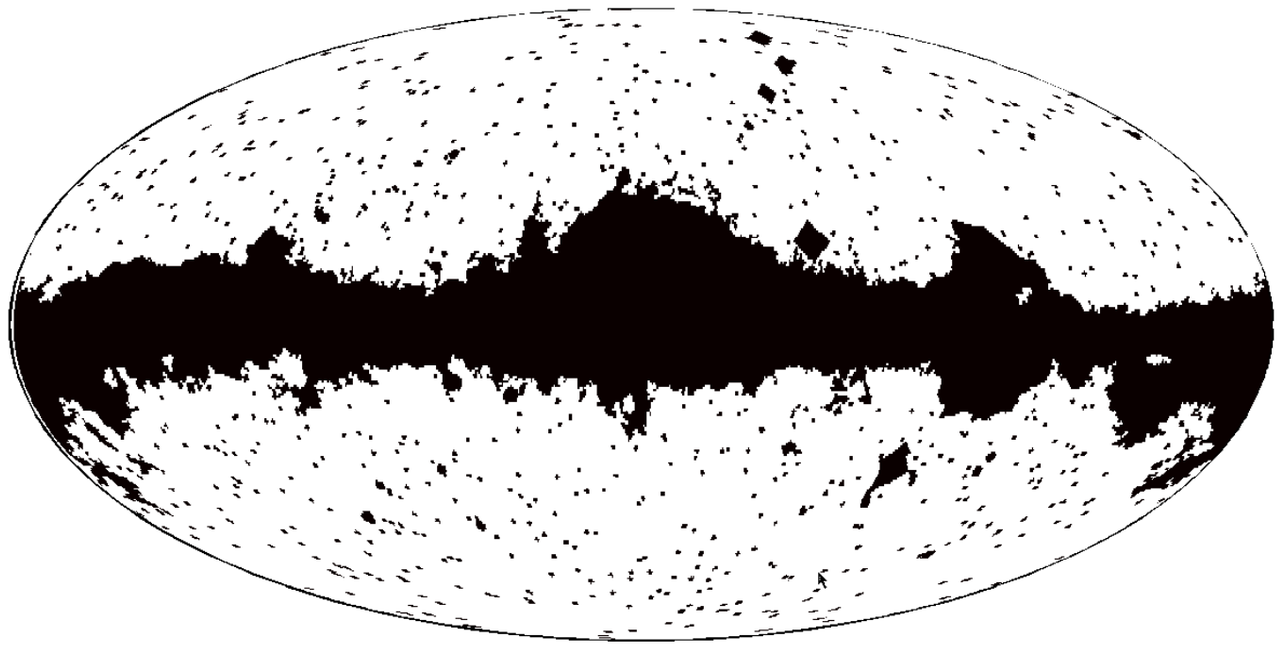

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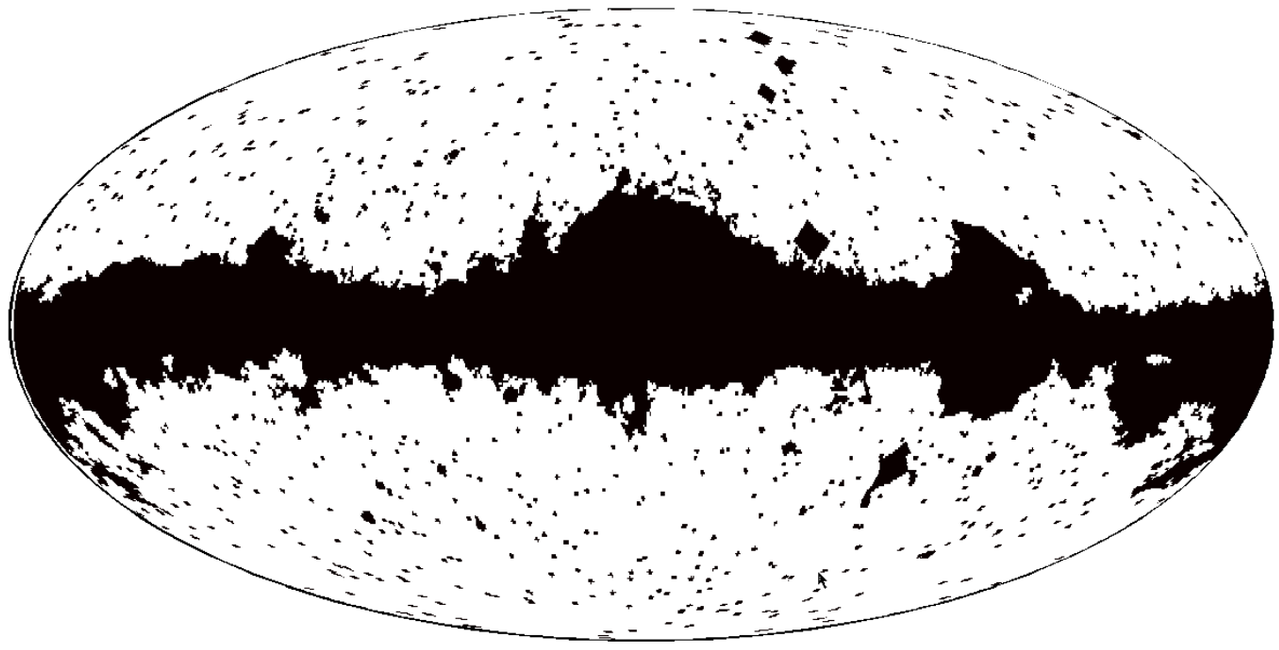

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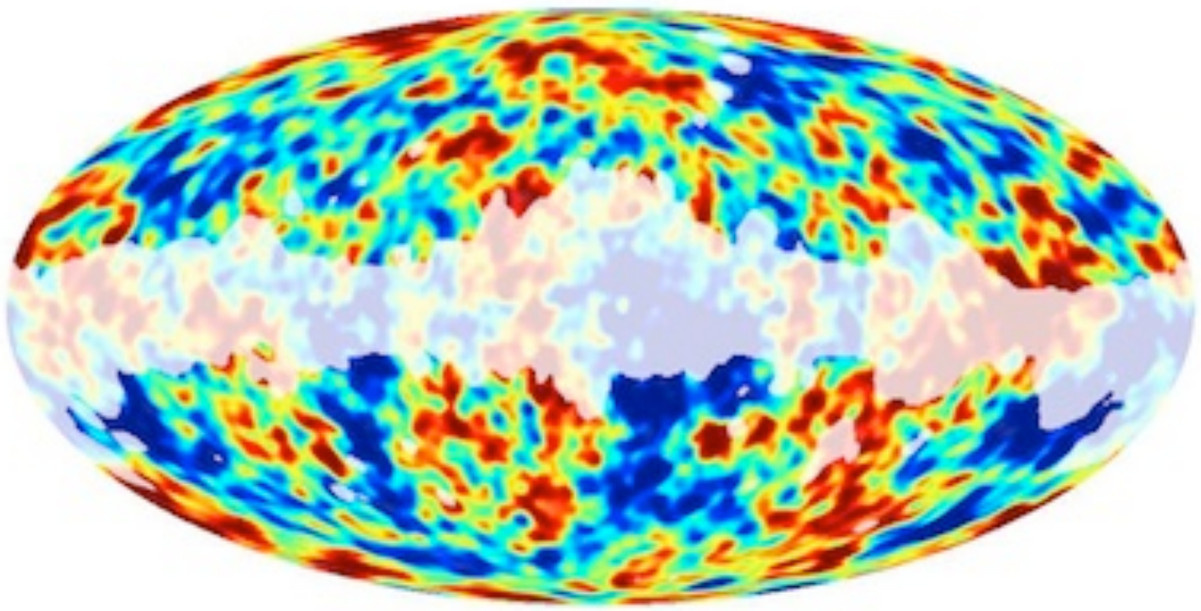

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= Masked ILC (Colorbar is $\pm 2\sigma$)

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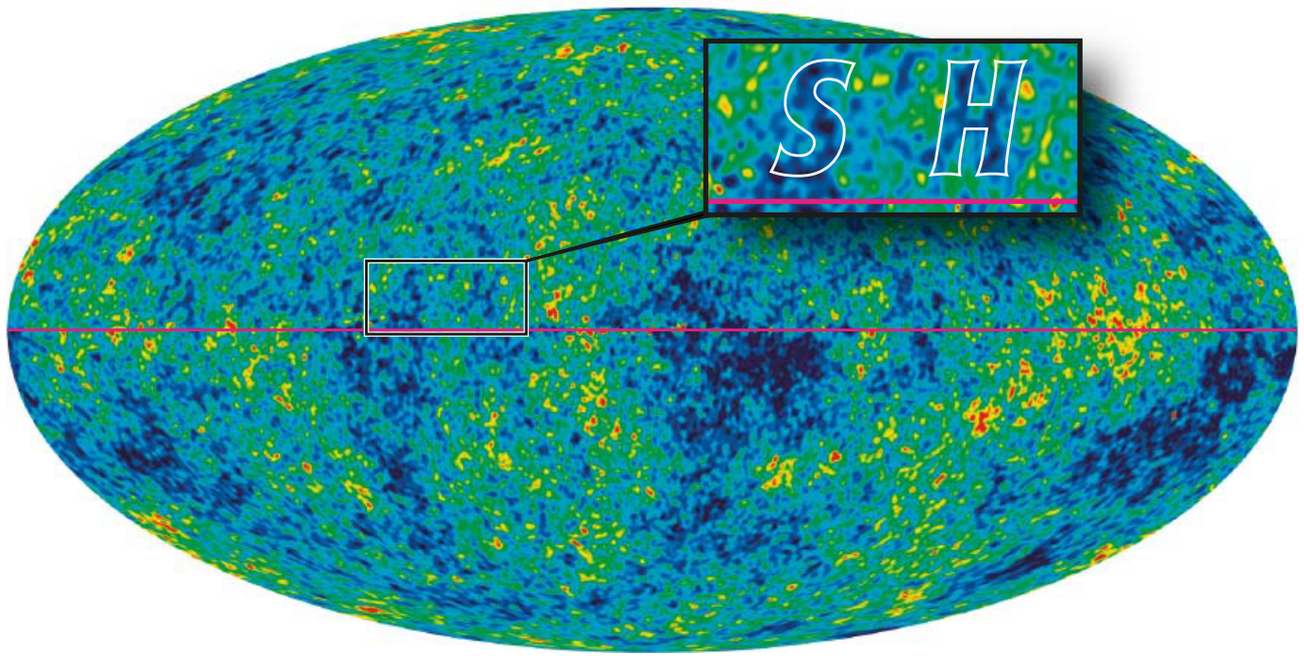


Bennet et al. (ApJ Sup. 2010)

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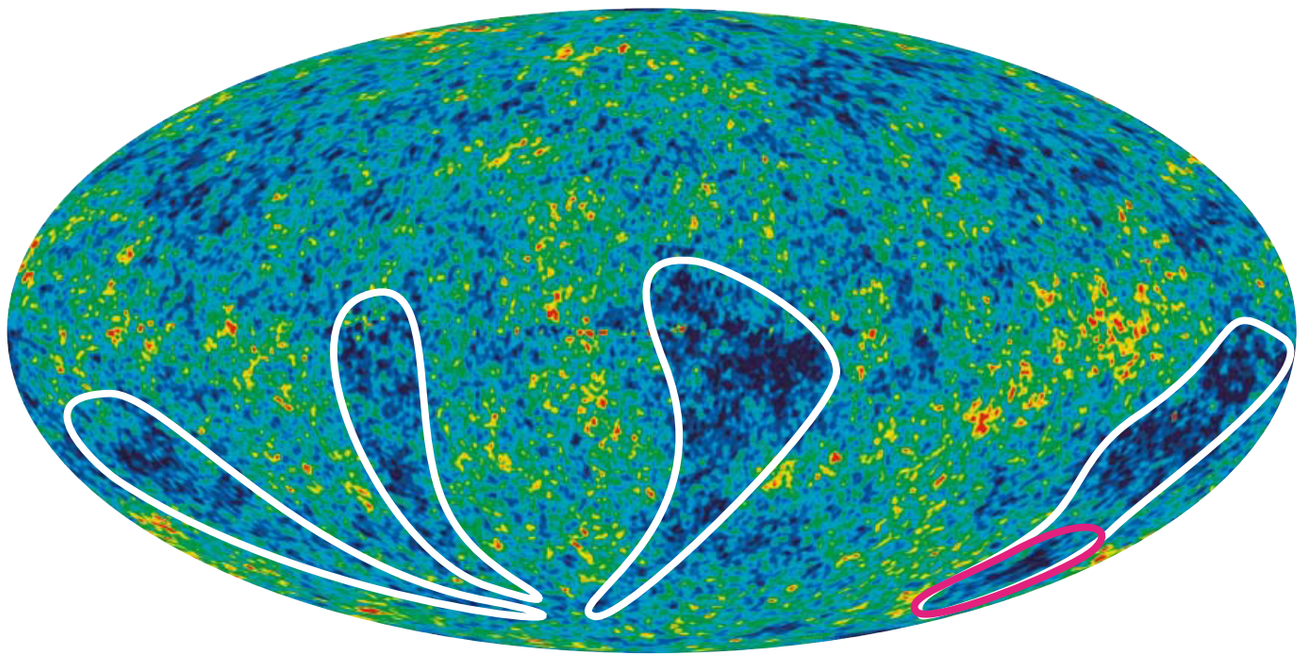

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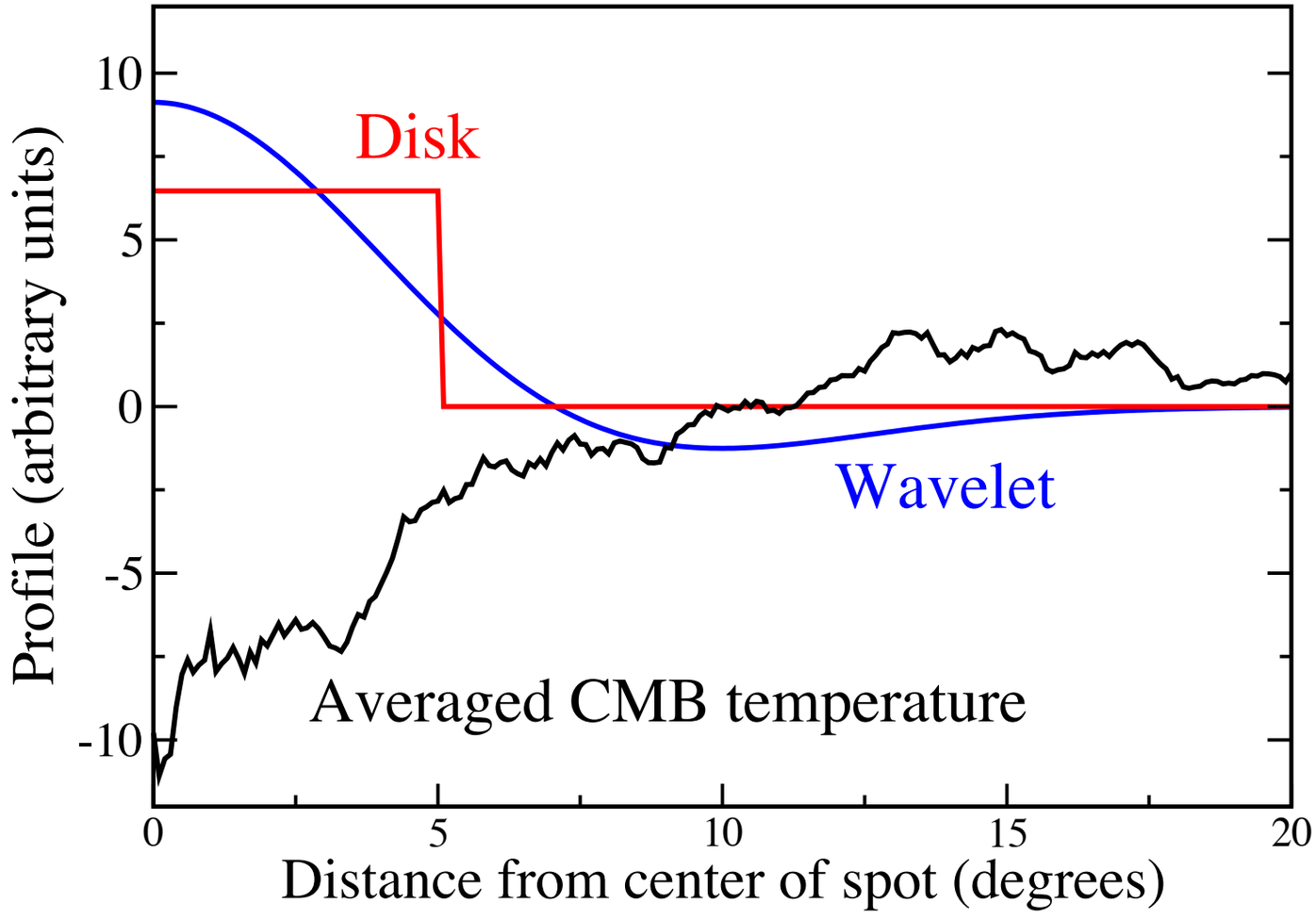

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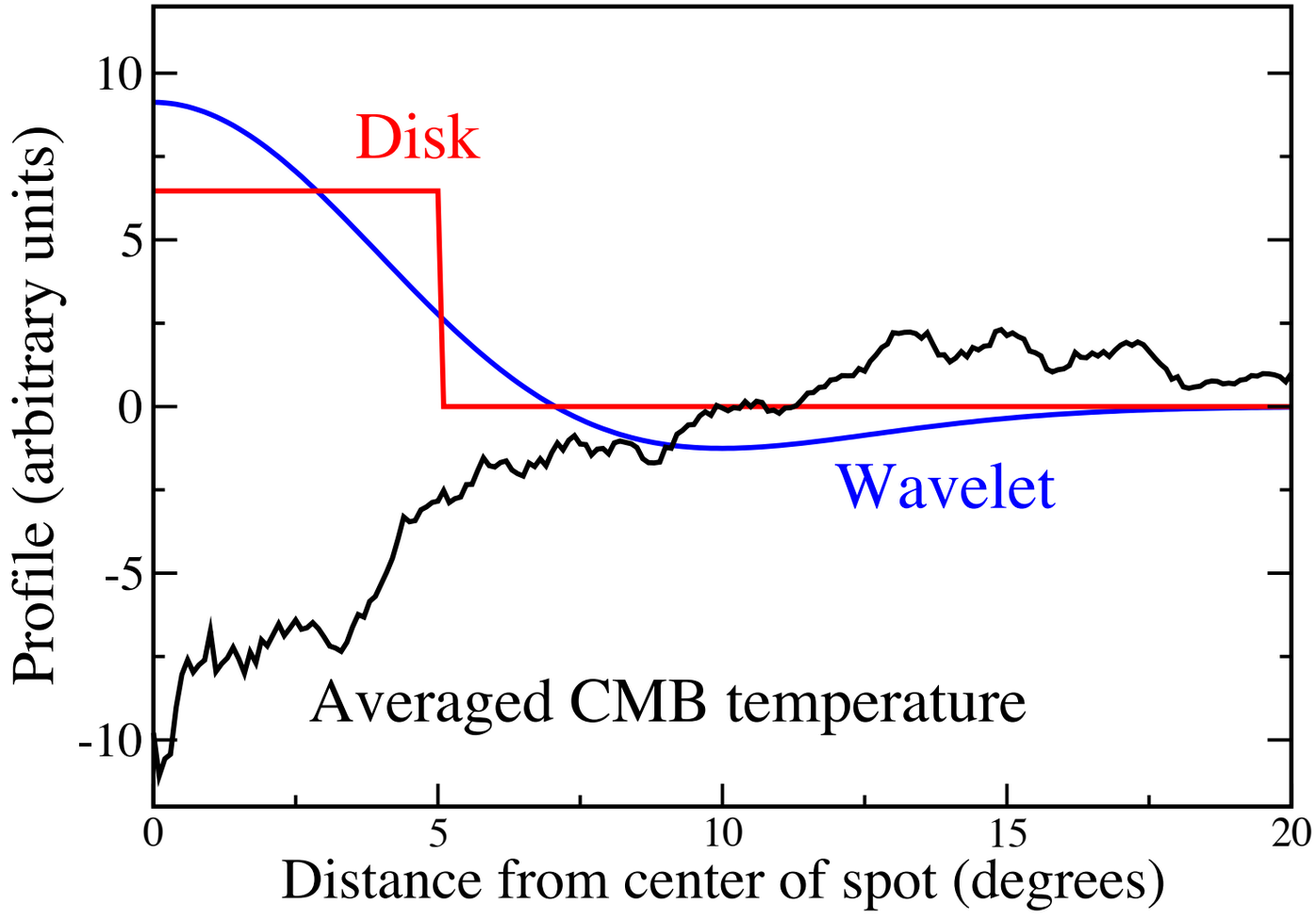
  Zhang & Huterer: No longer significant with a normal disk (p-value > 30%). (JCAP 2010)



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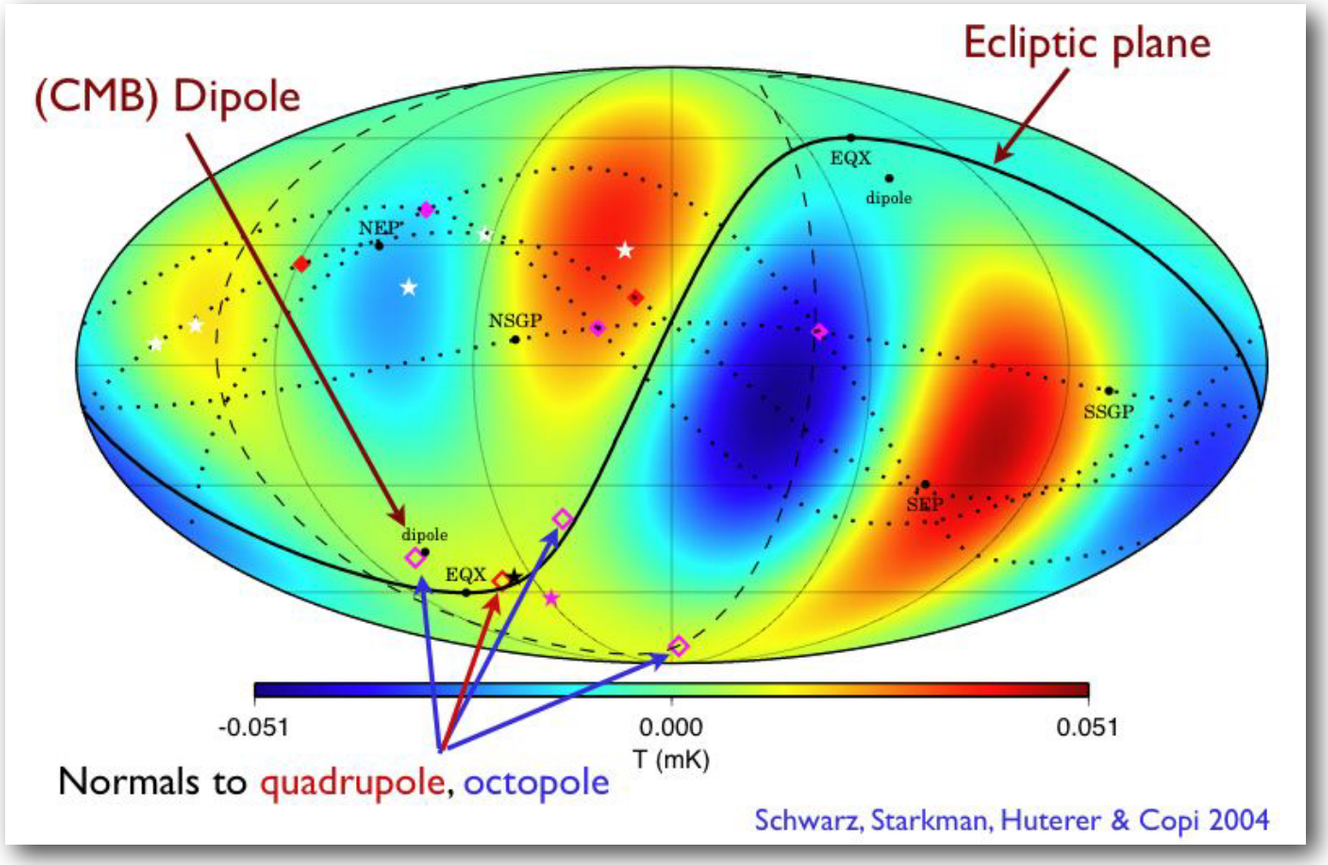

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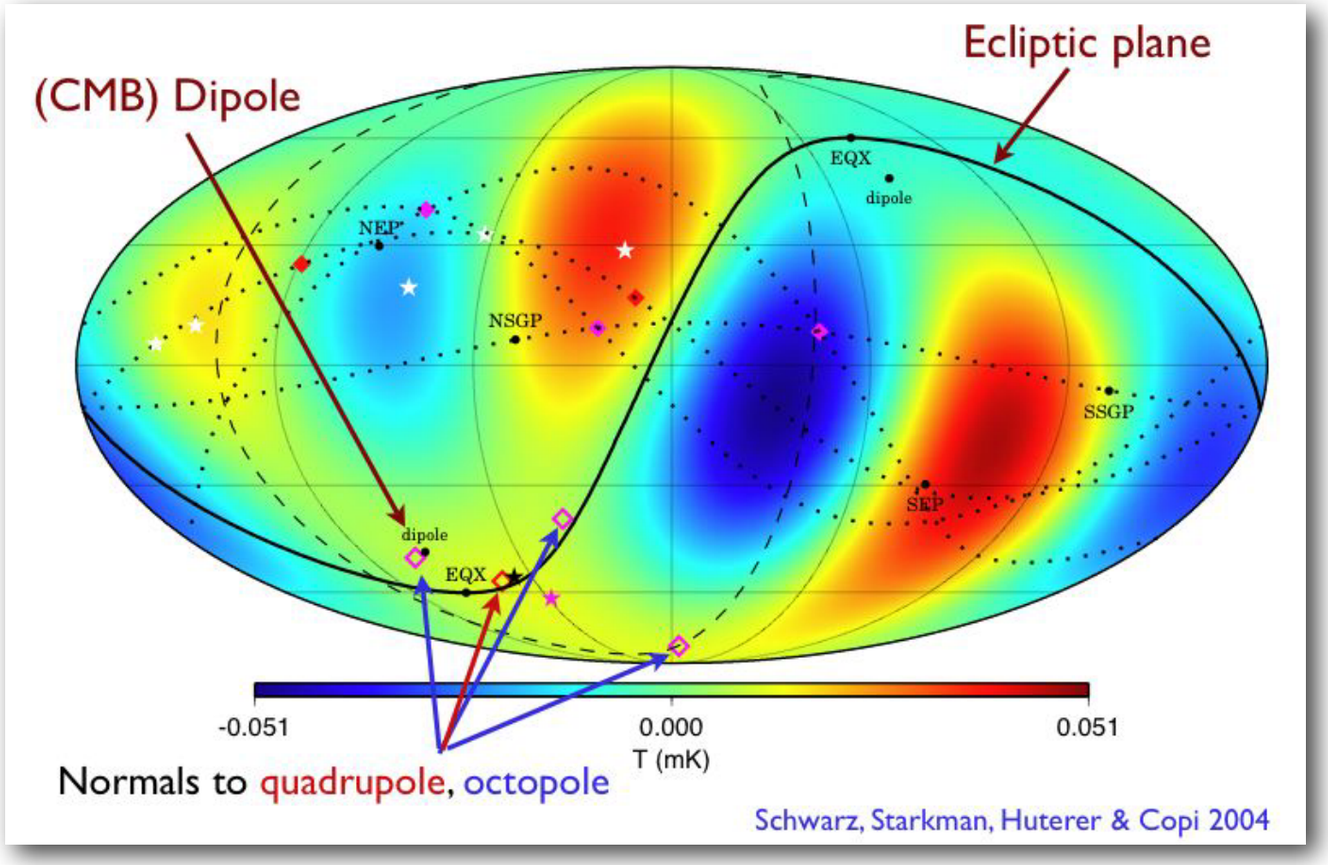

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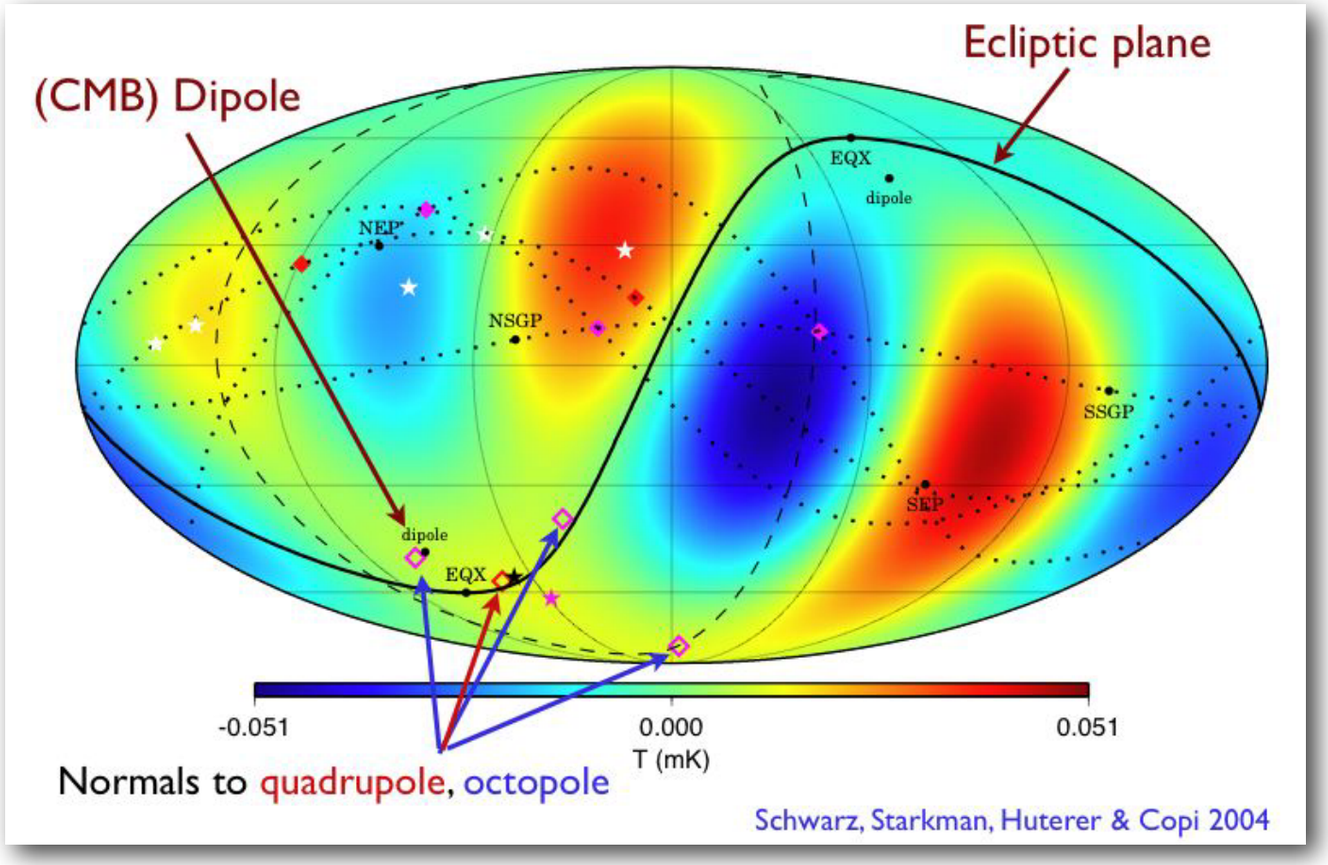

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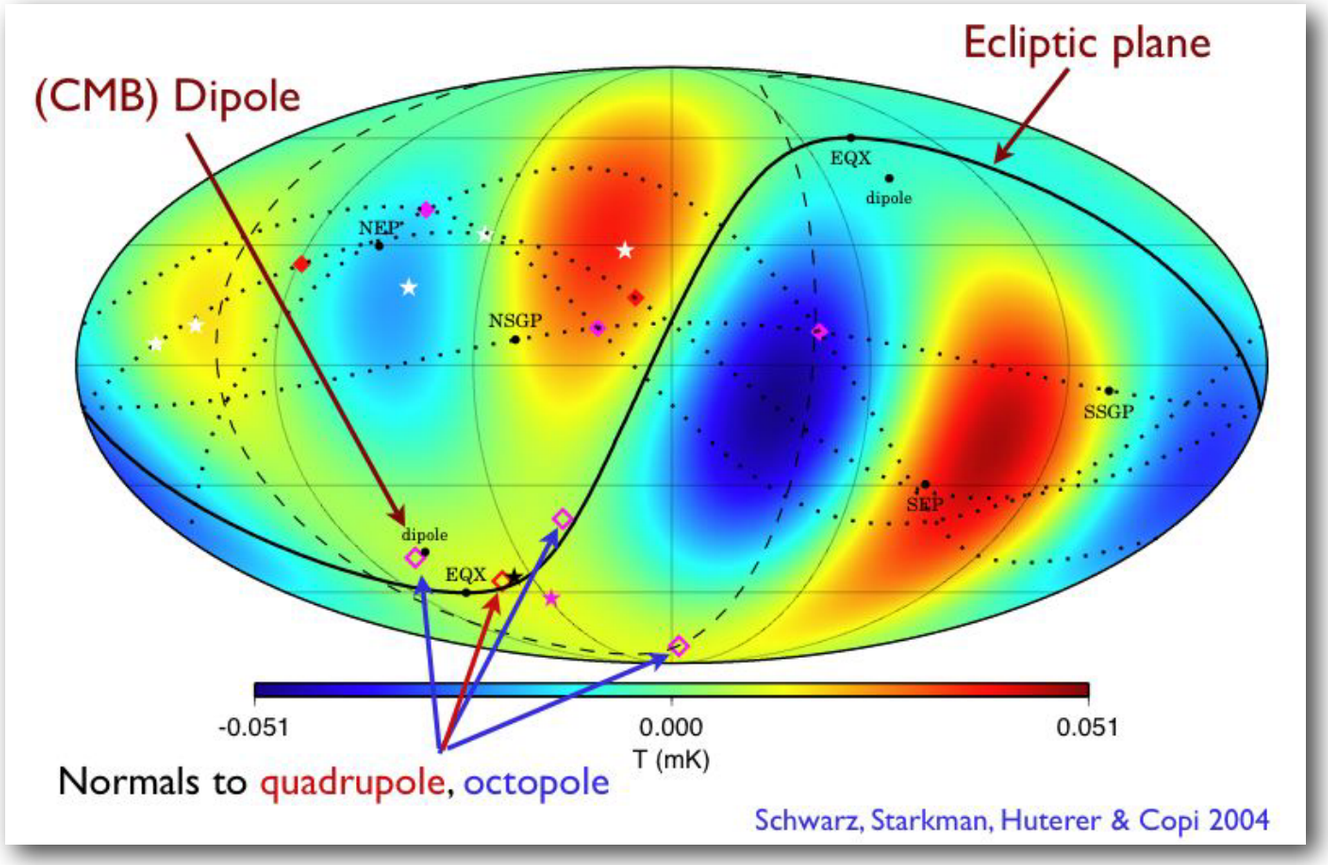

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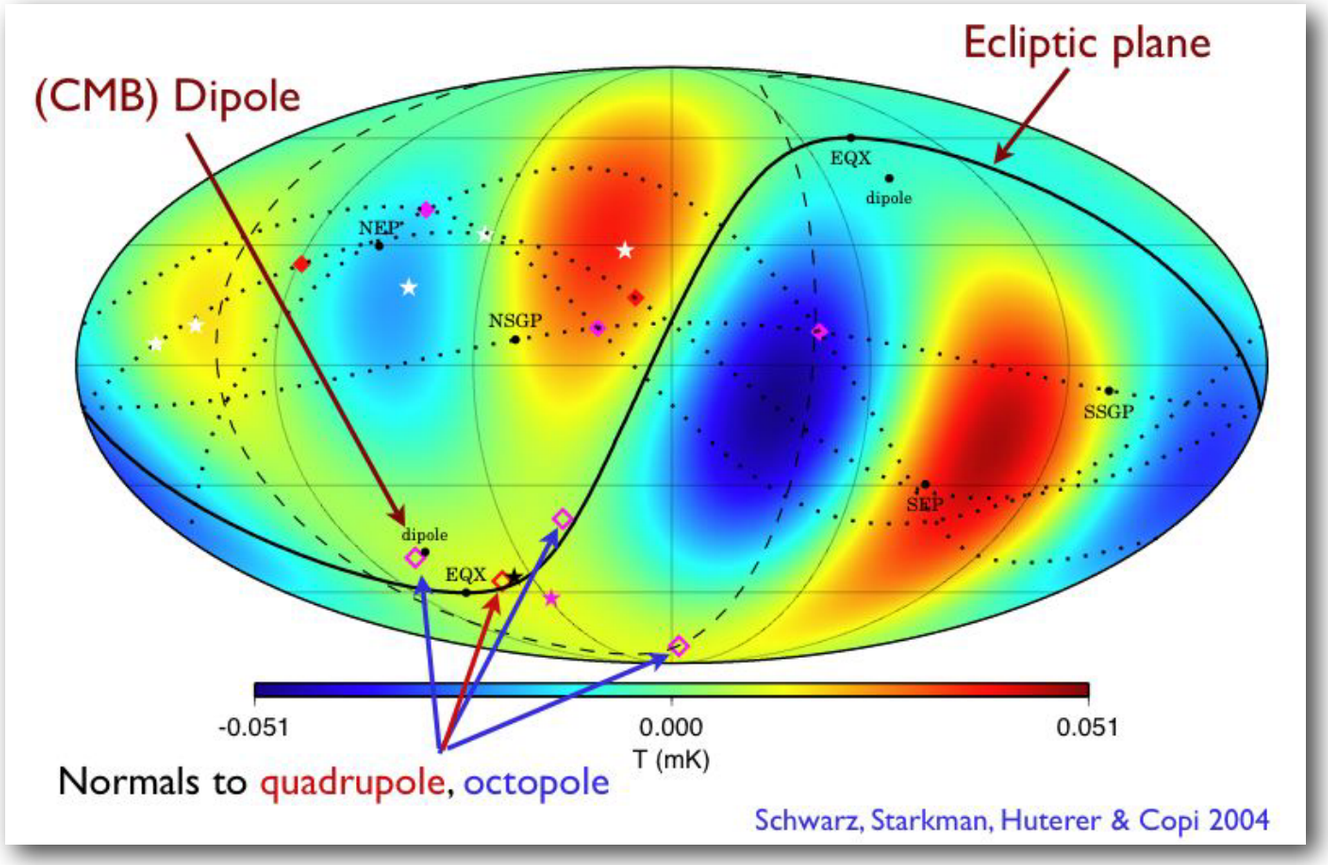

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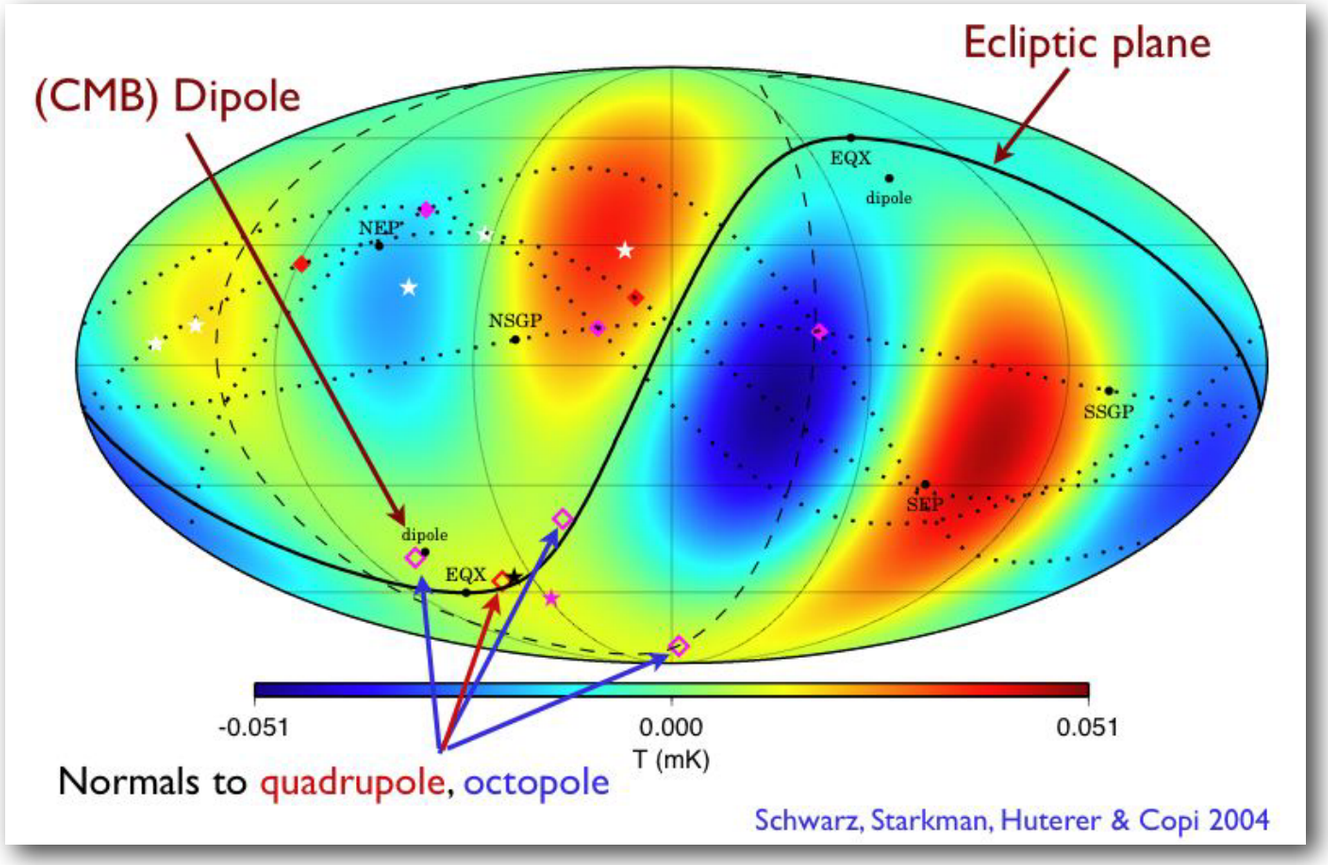

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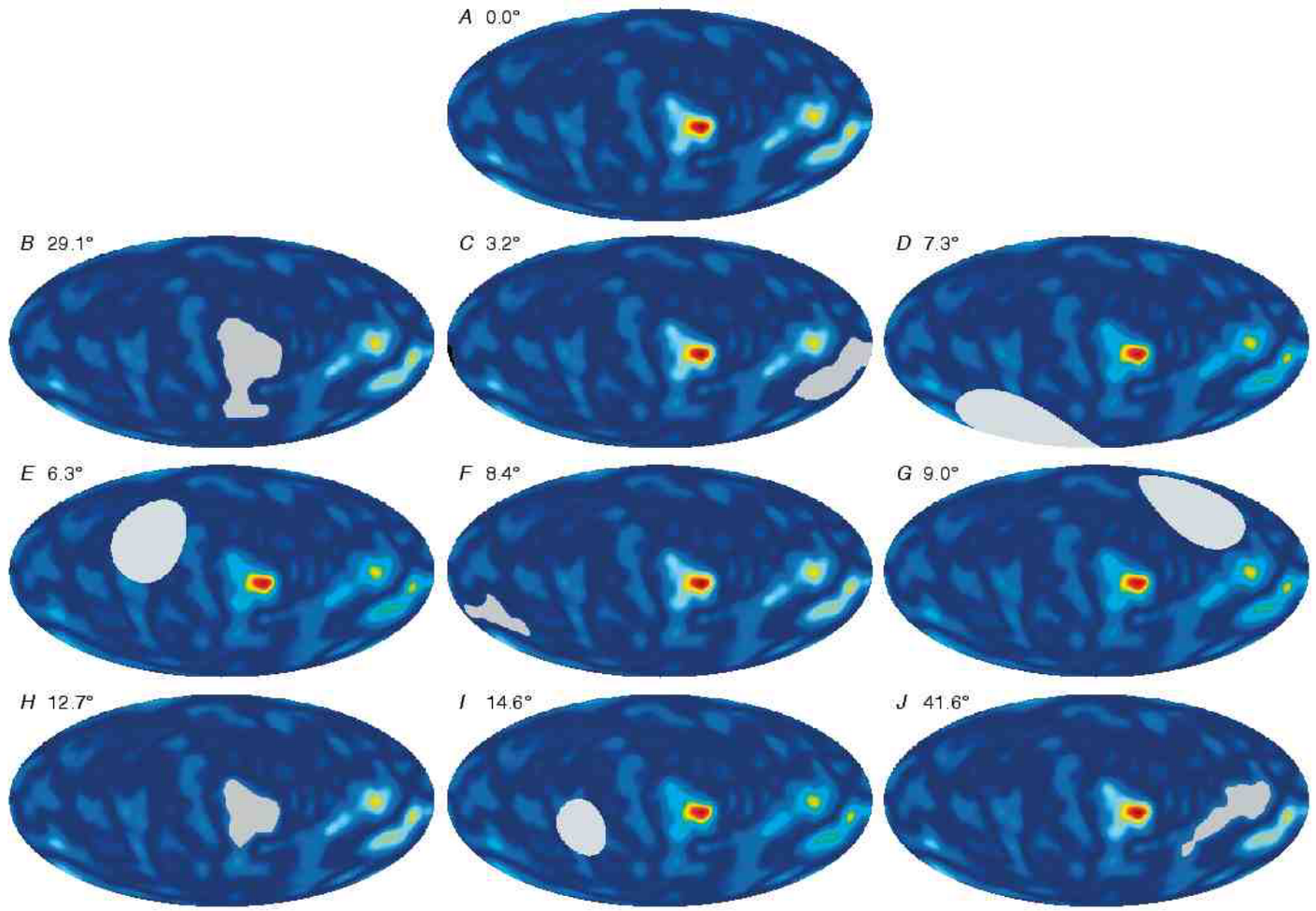


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# Outline

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- Motivation (Theory): Inflation Onset
- Simplest Relic: Pre-Inflationary Particle
- Pre-Inflationary Particle - Signatures
- Motivation (Data): Anomalies
- Where to look, what to look for?

# Where to look? Large Scales

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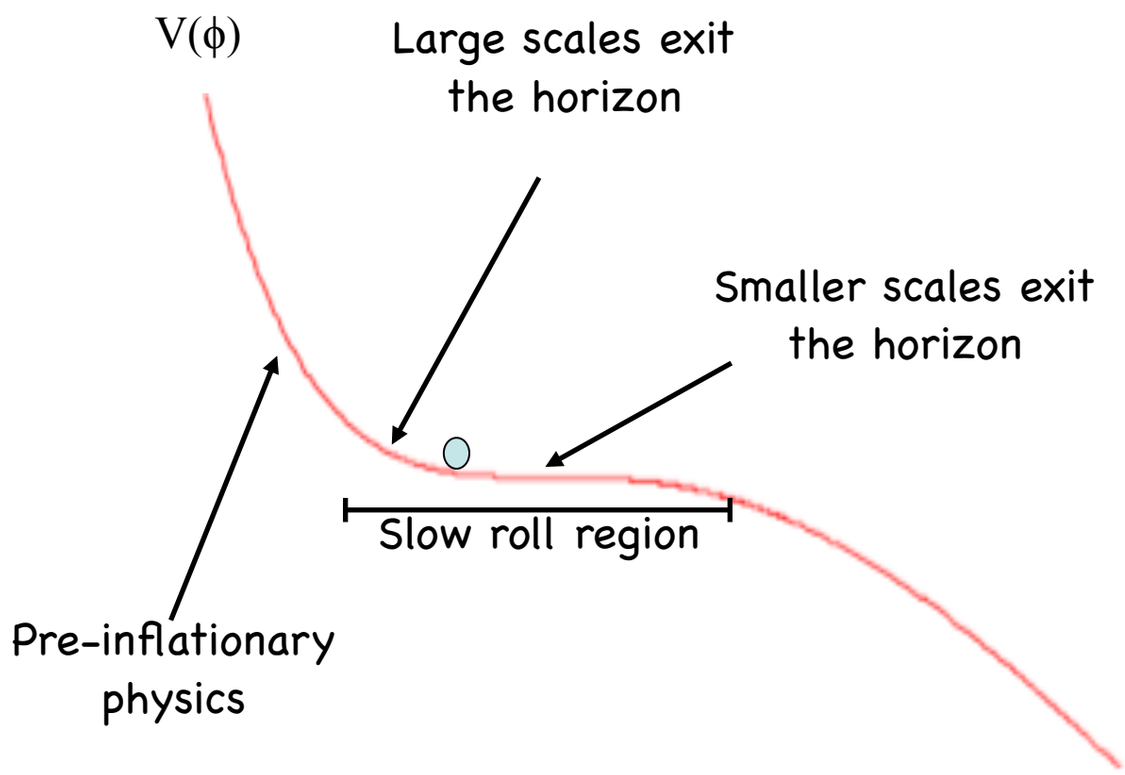


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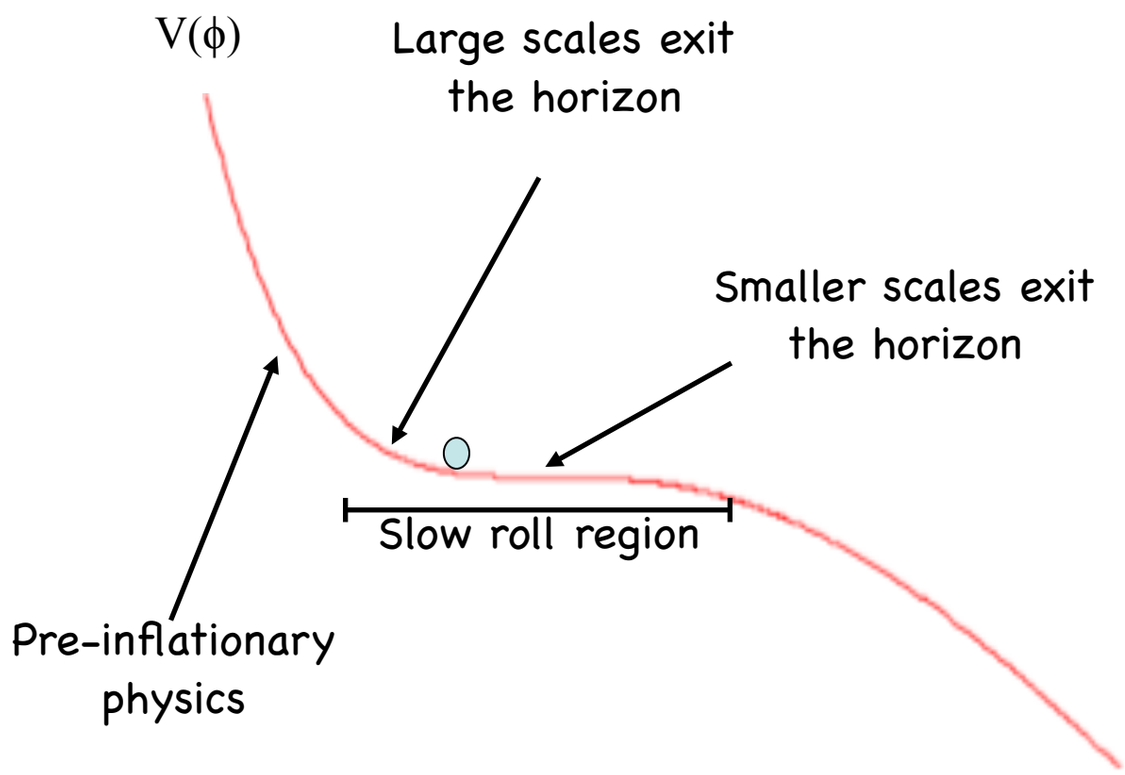


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- Logarithmic gravitational potential $\longrightarrow$ long-range effect.

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Cook's Branch 2012

- Pre-inflationary relics and their symmetries:

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- Overdense region with long-range gravitational potential:

  ▸ Test: Bulk flow (towards this "great attractor")!

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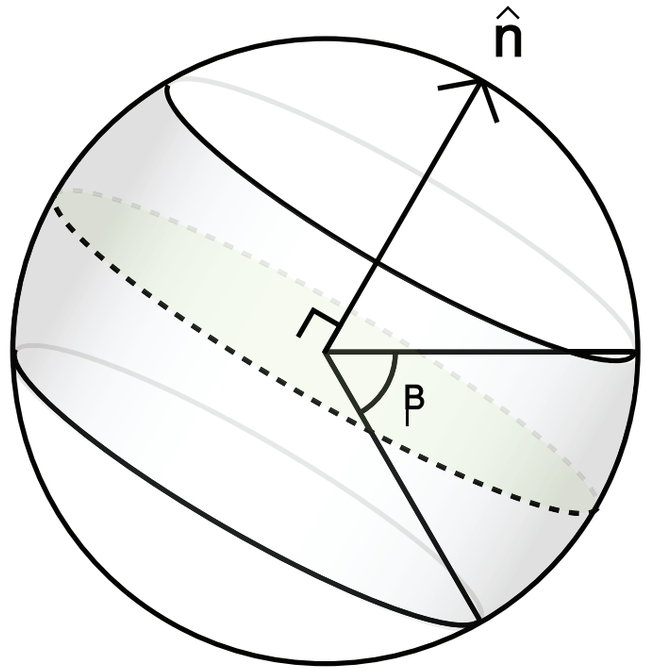

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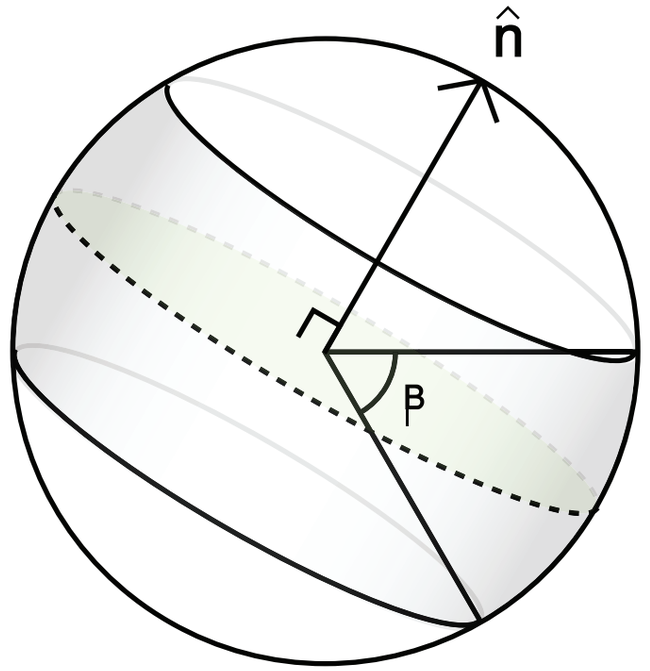

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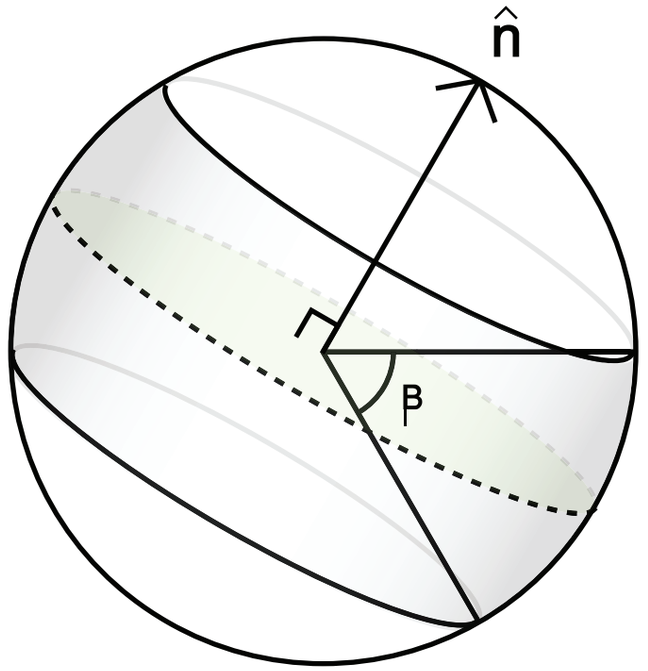

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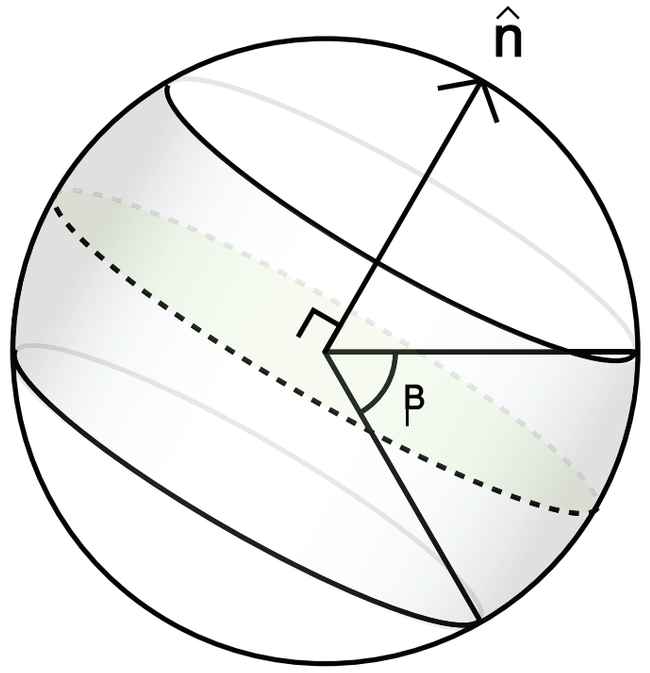

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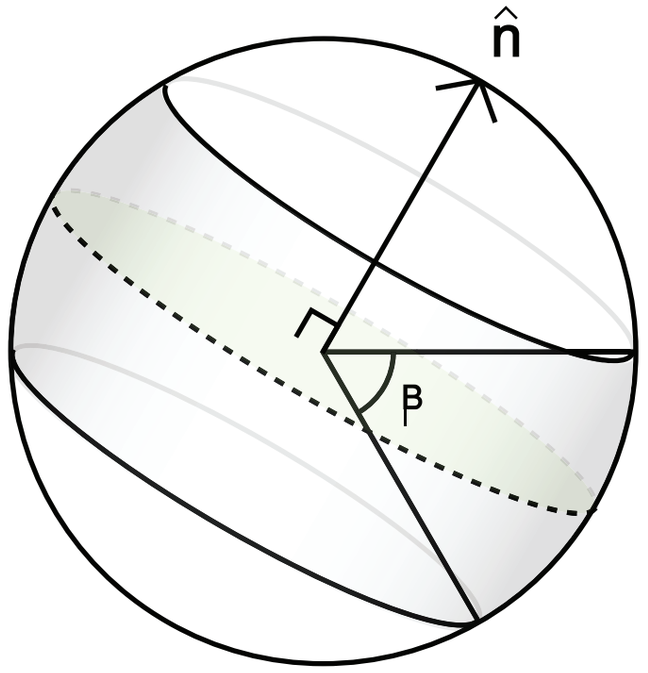

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- $T(\theta, \hat{n})$ = mean temperature of an infinitesimal ring
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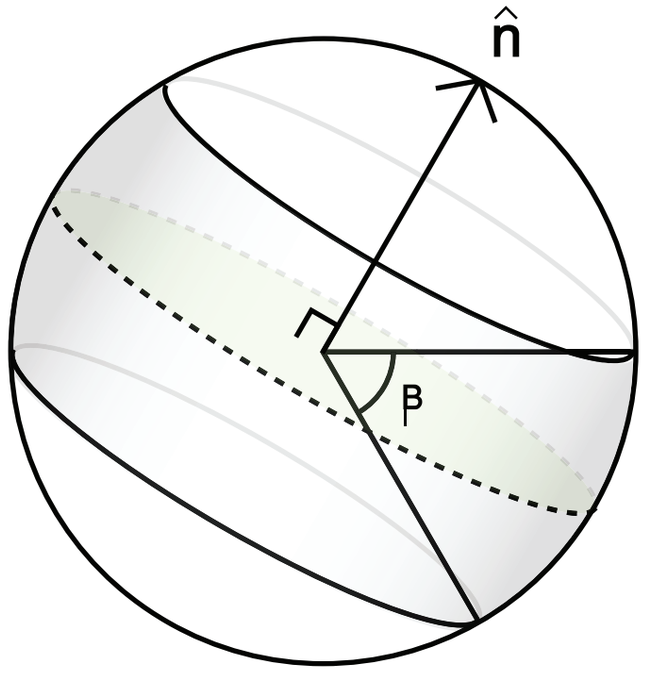
- Calculate the following:

$$R(\beta, \hat{n}) = \int_{\frac{\pi-\beta}{2}}^{\frac{\pi+\beta}{2}} d(\cos\theta)\ \tilde{T}^2(\theta, \hat{n}),$$

$$\tilde{T}(\theta, \hat{n}) = T(\theta, \hat{n}) - T_0$$



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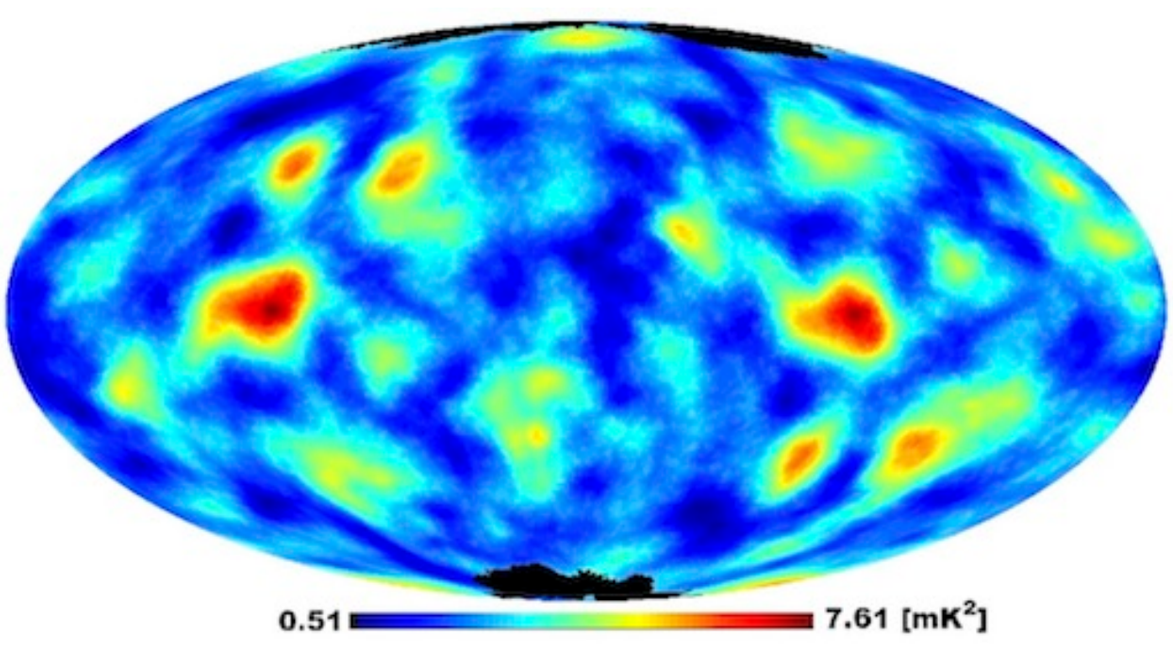


$$\beta = 90^\circ$$

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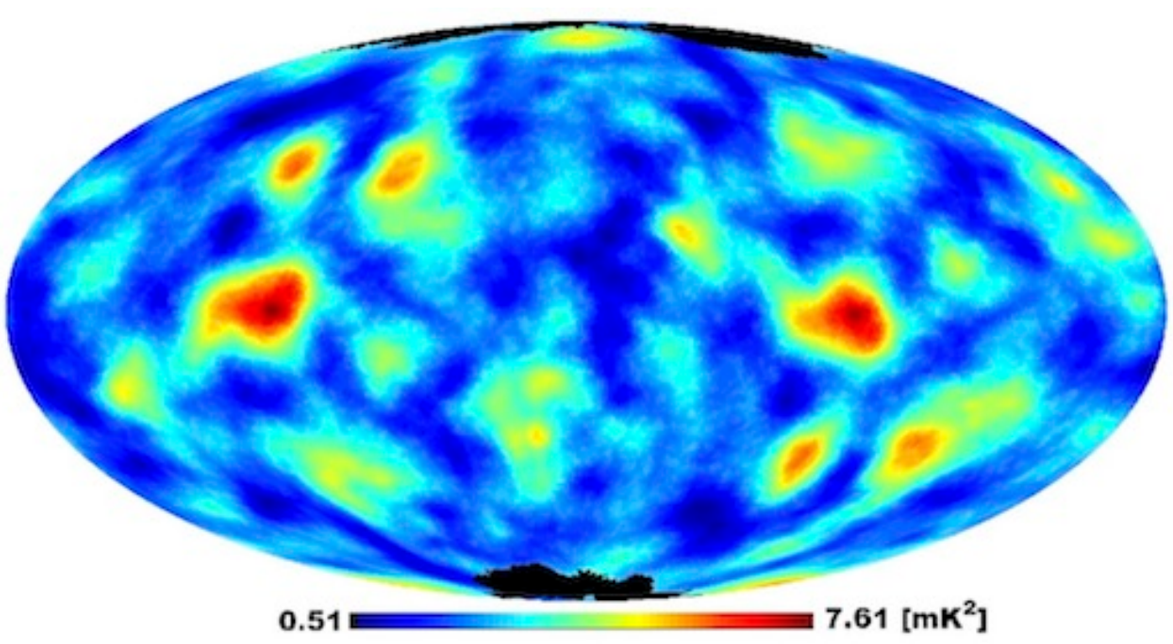


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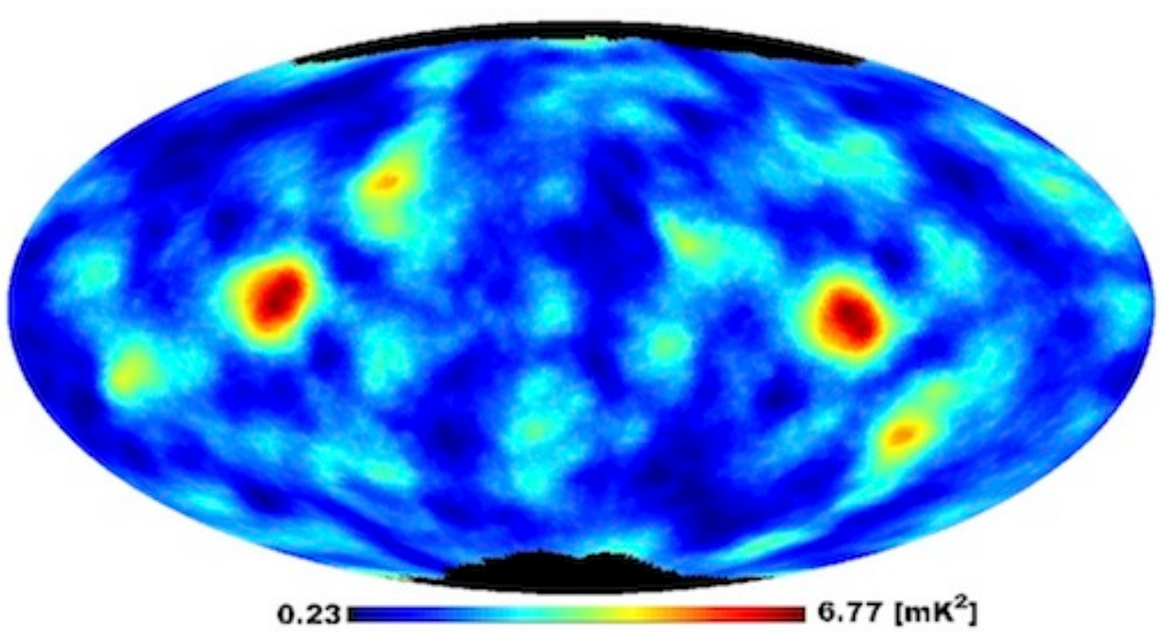


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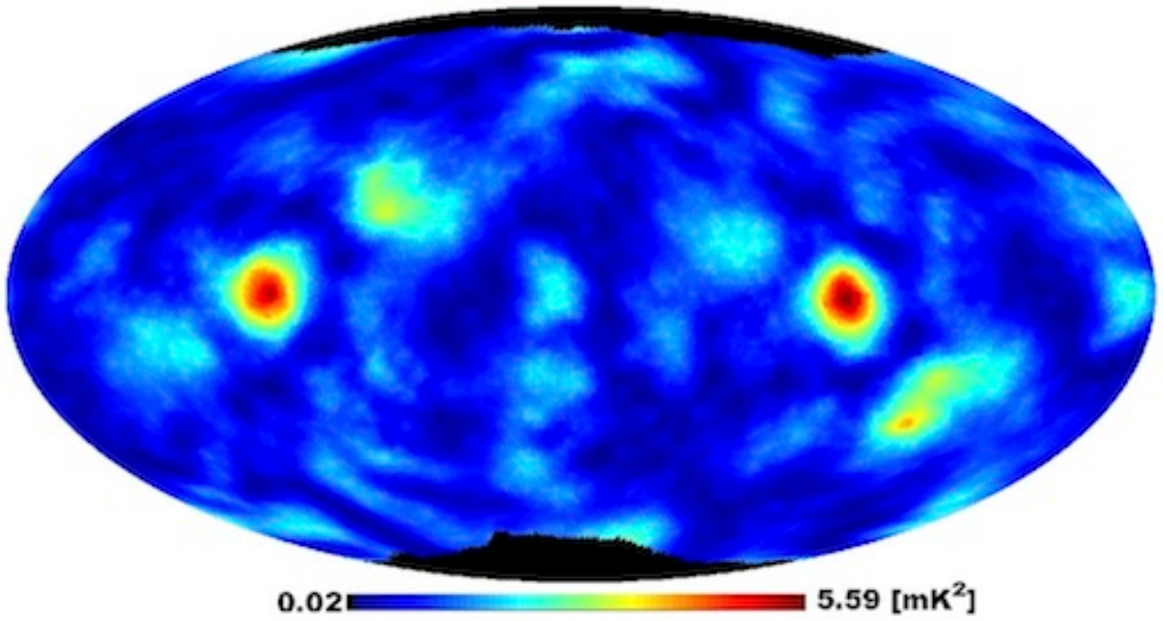


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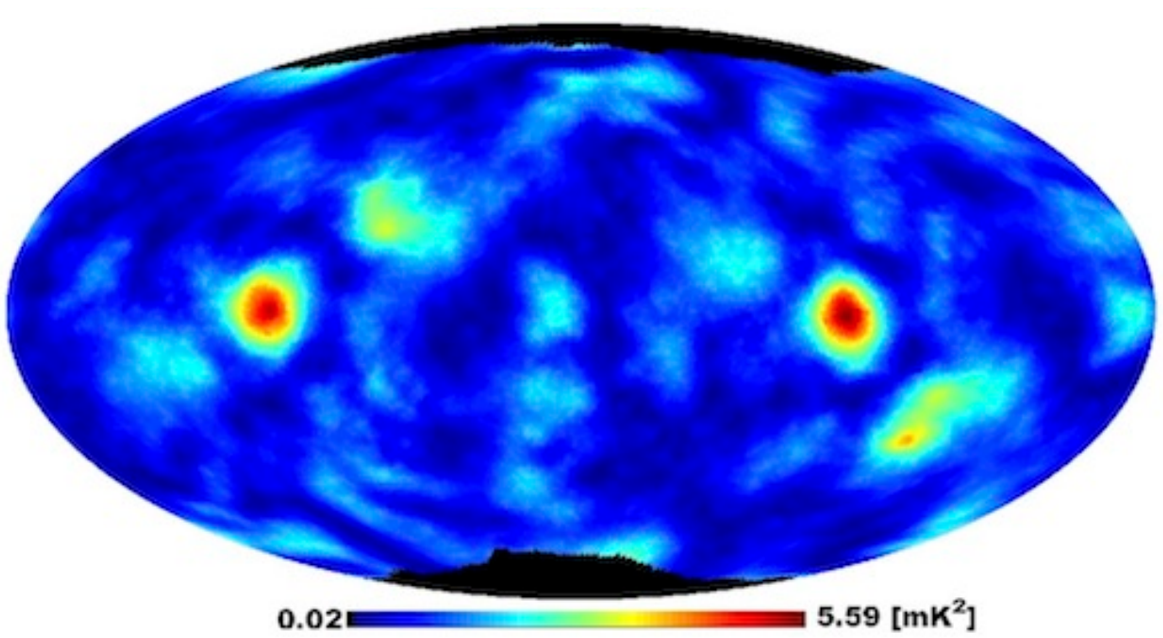


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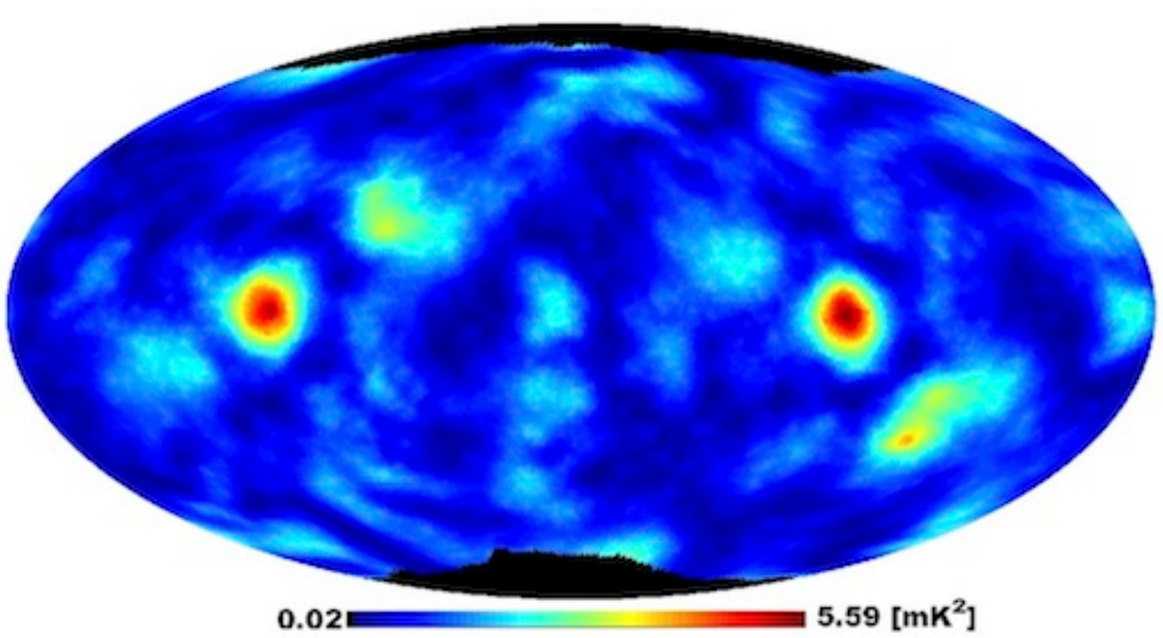


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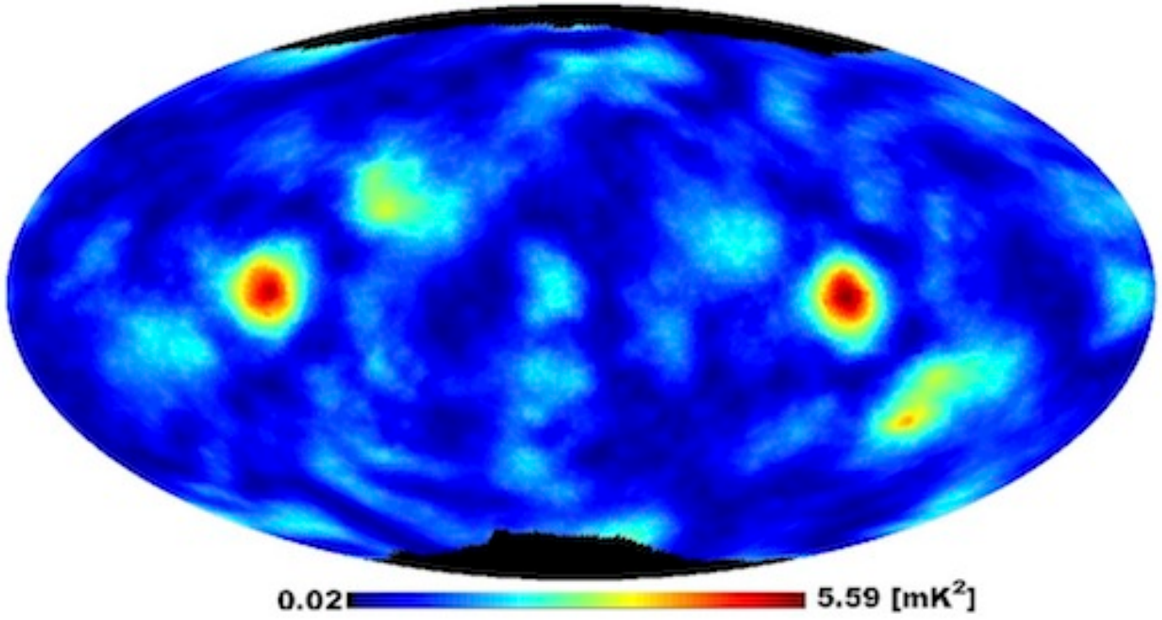


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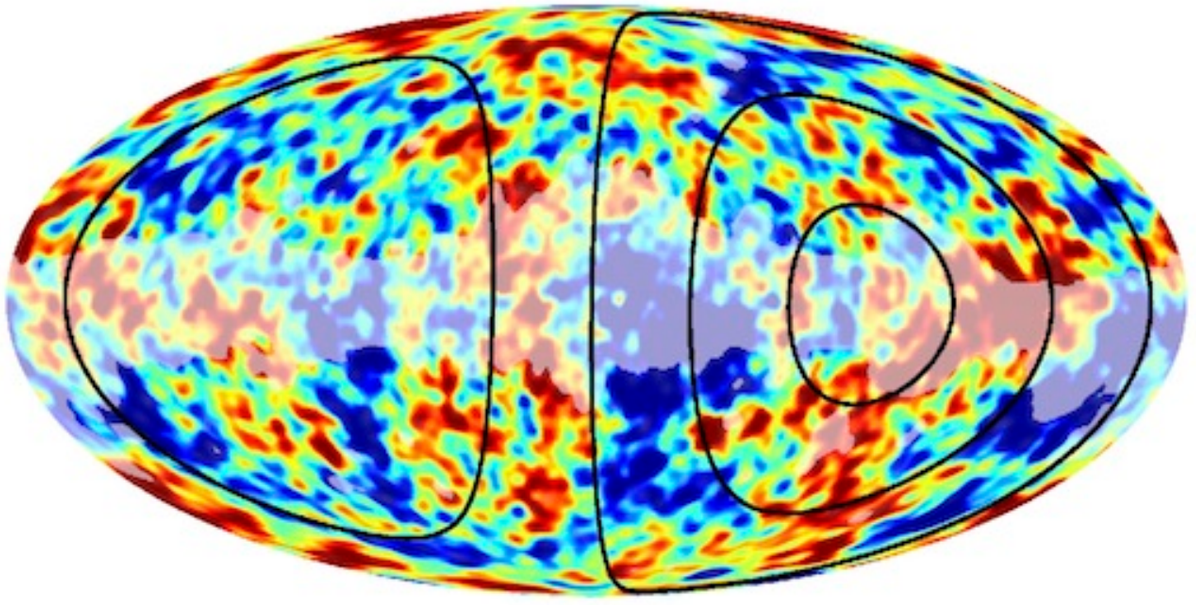

Rings in 7-year ILC map

# Rings Score - COBE-DMR

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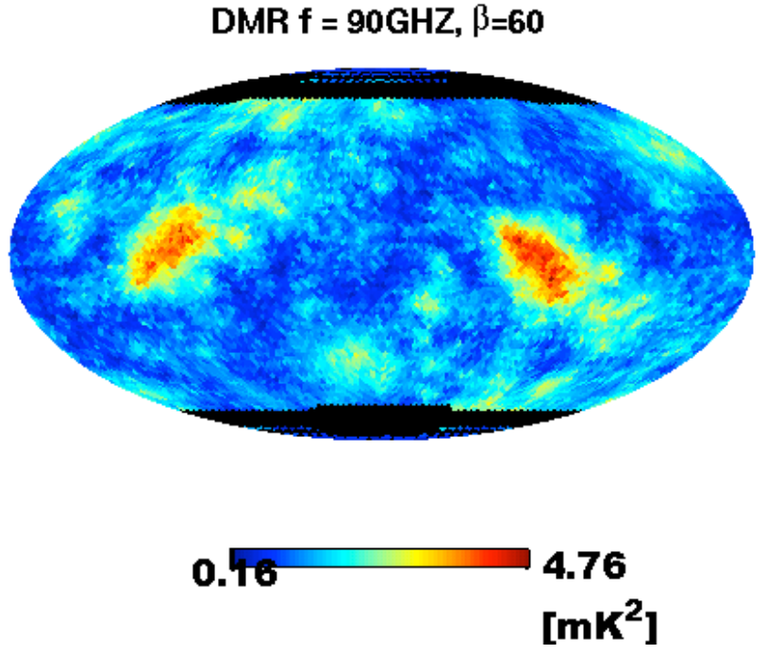
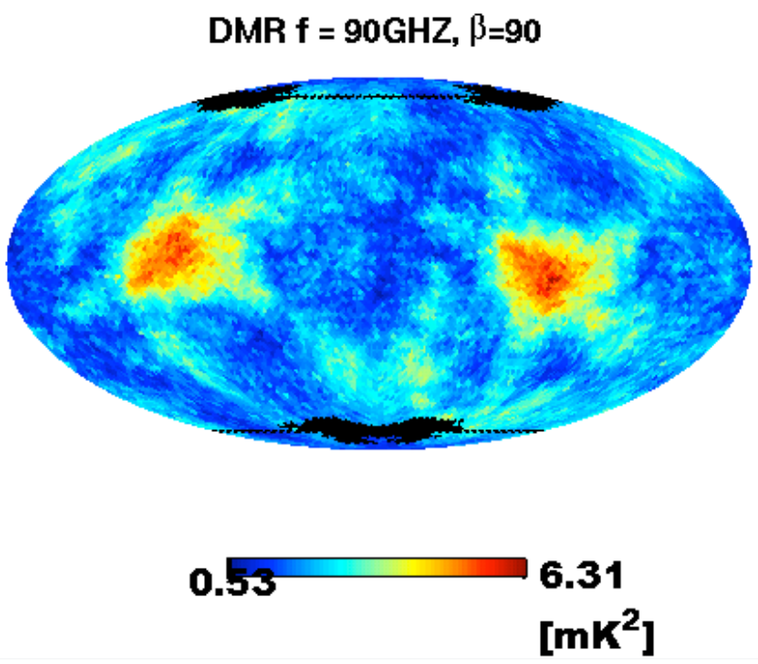
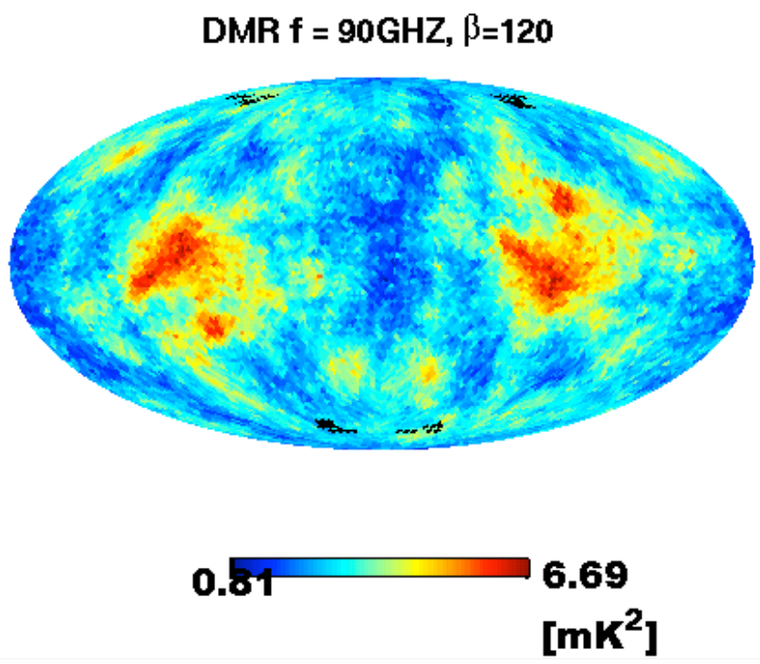
## Low Resolution...



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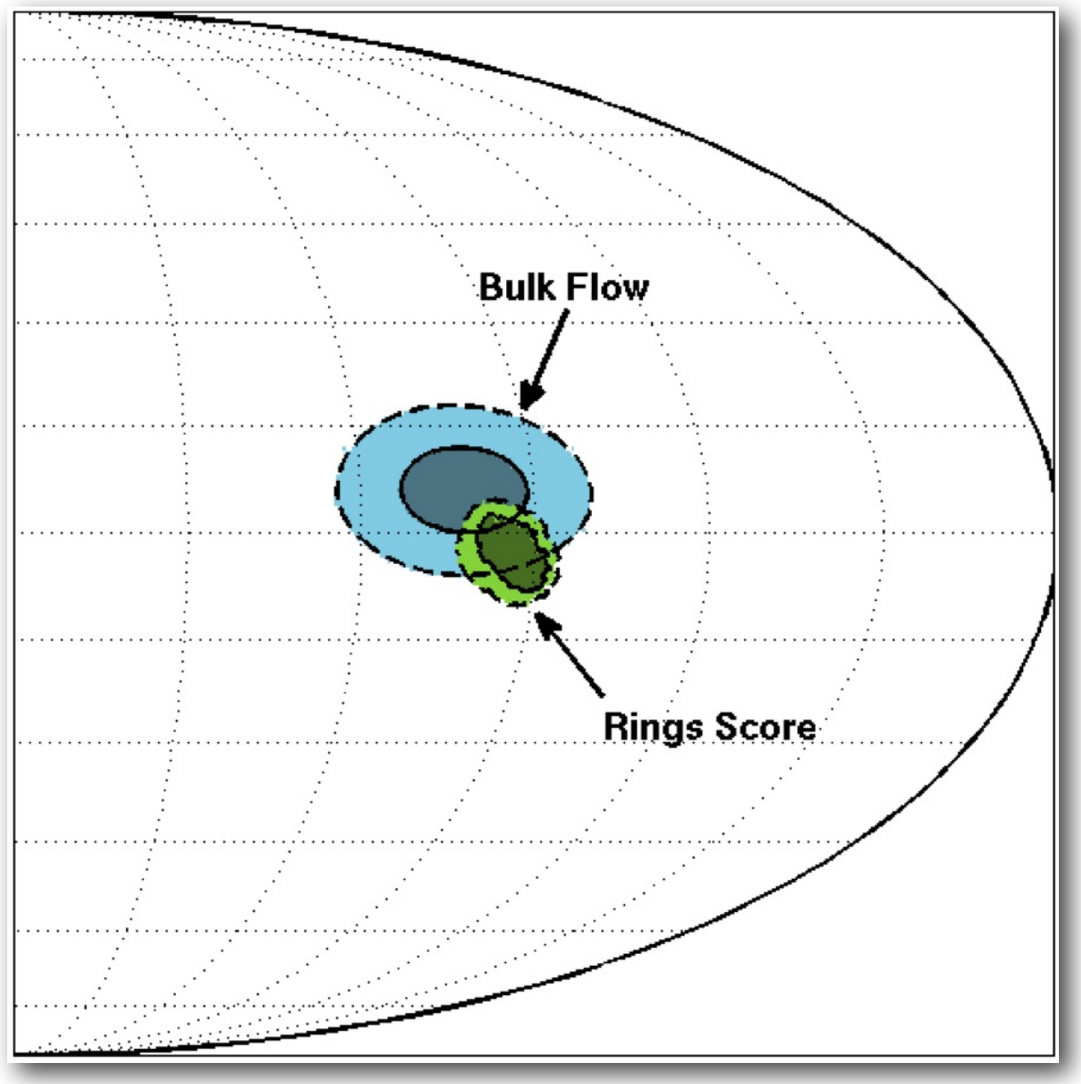

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~1% chance alignment

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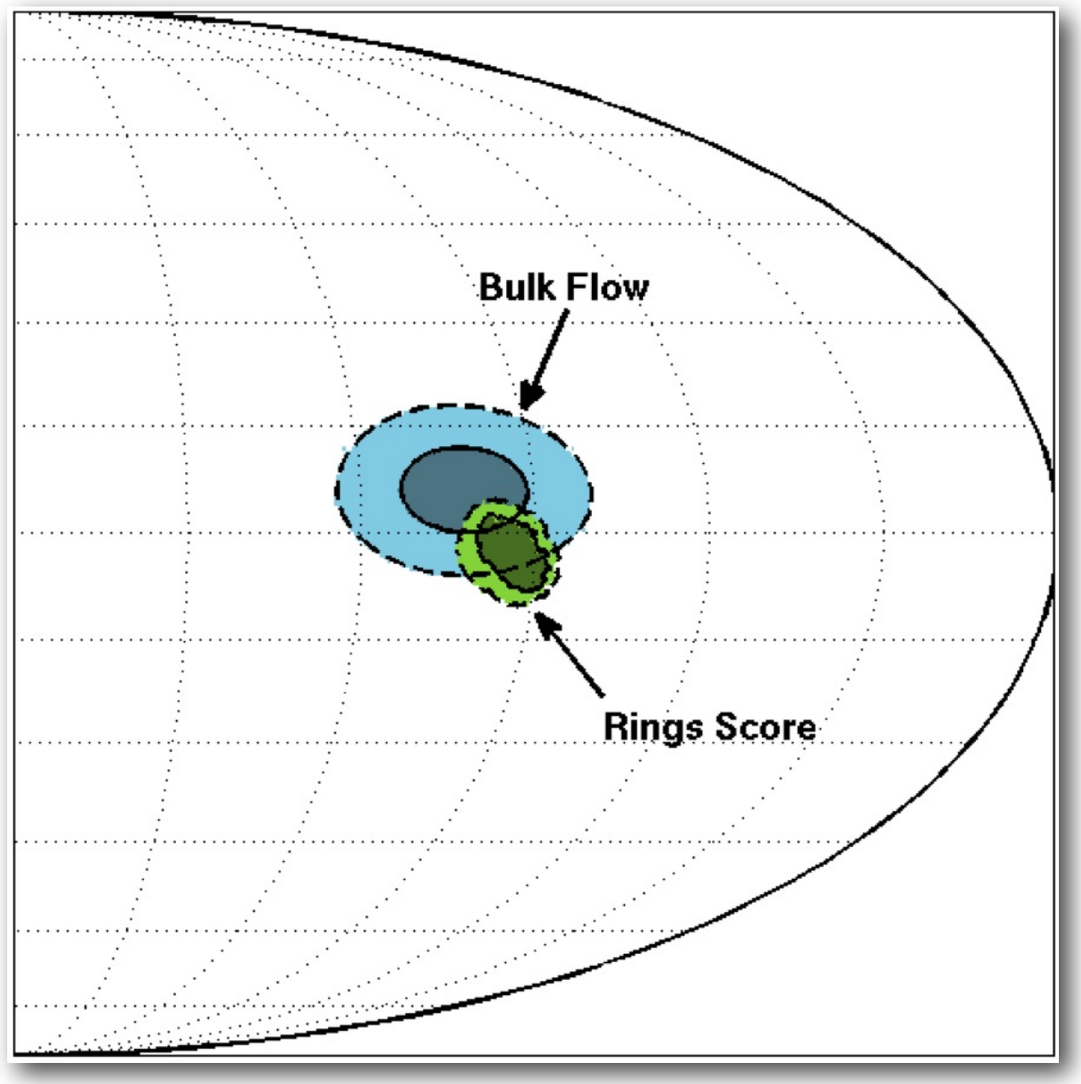

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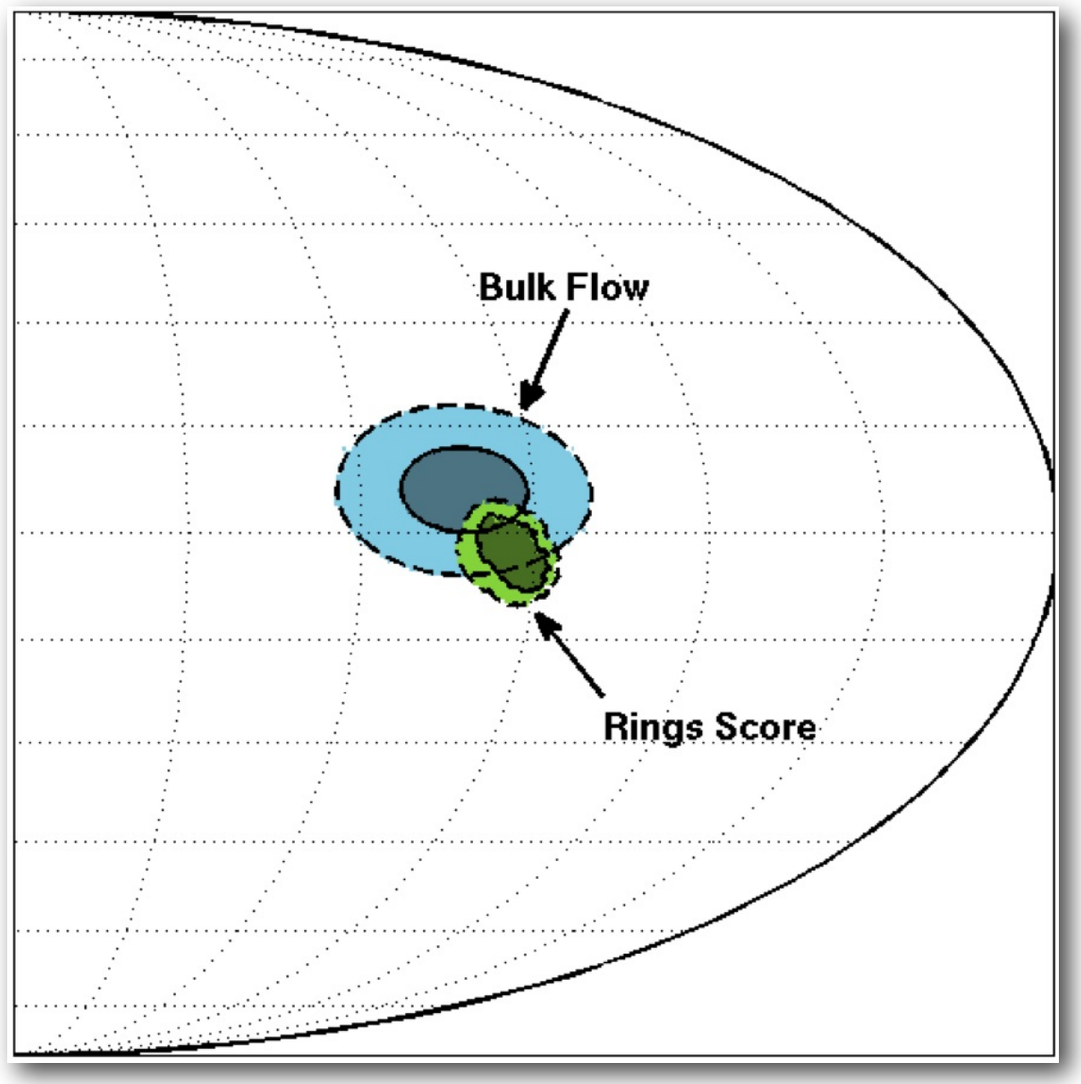

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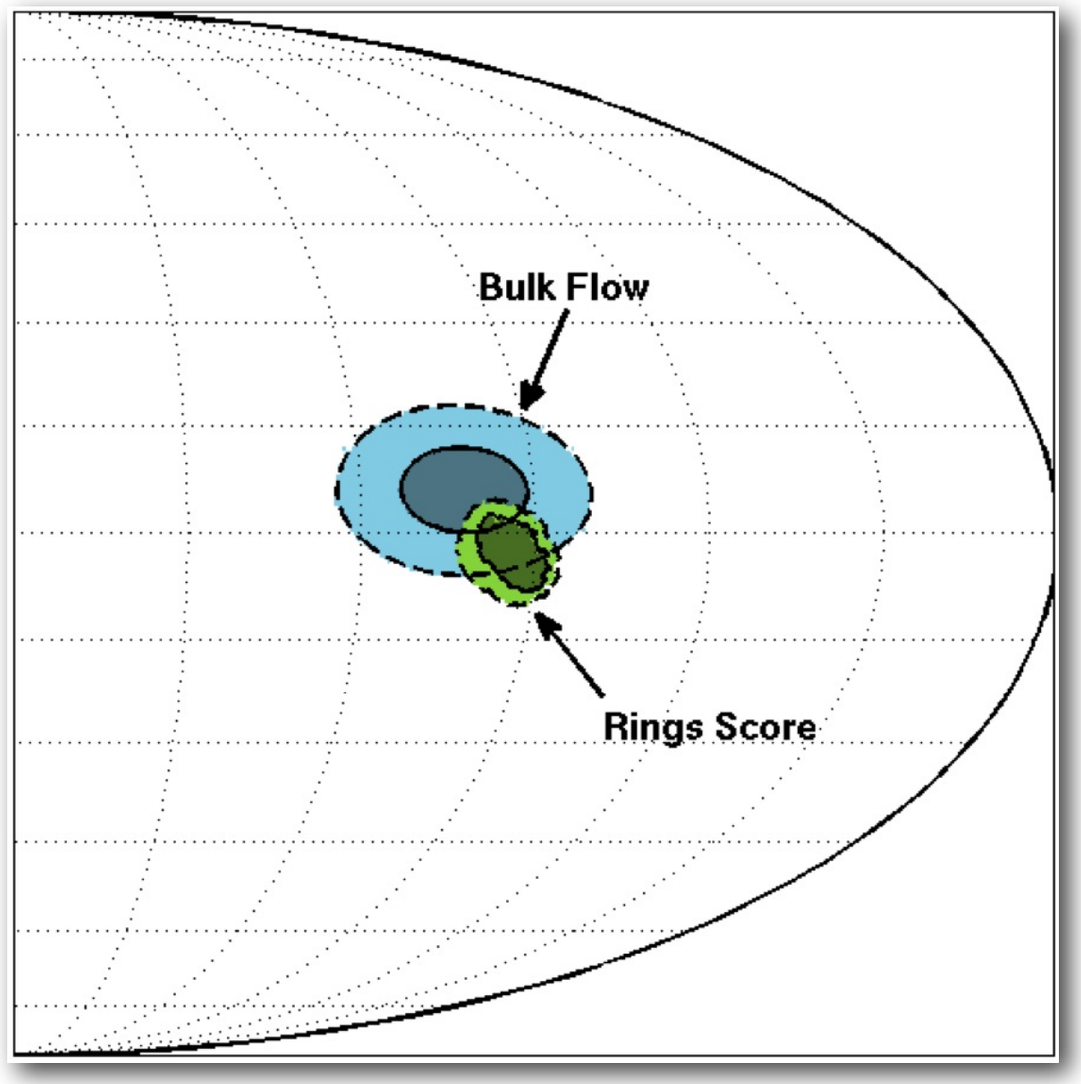

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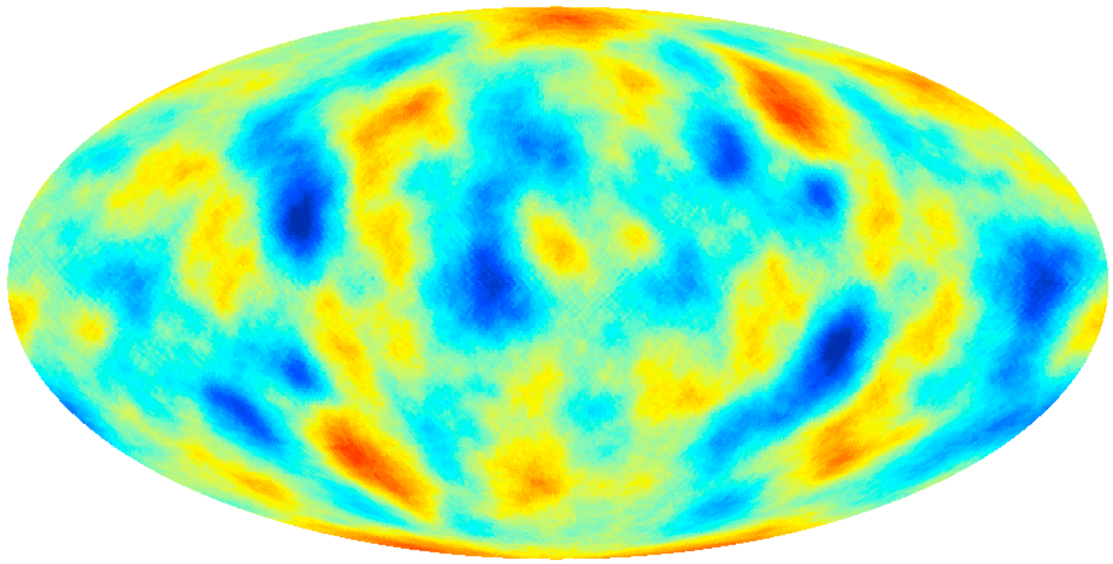

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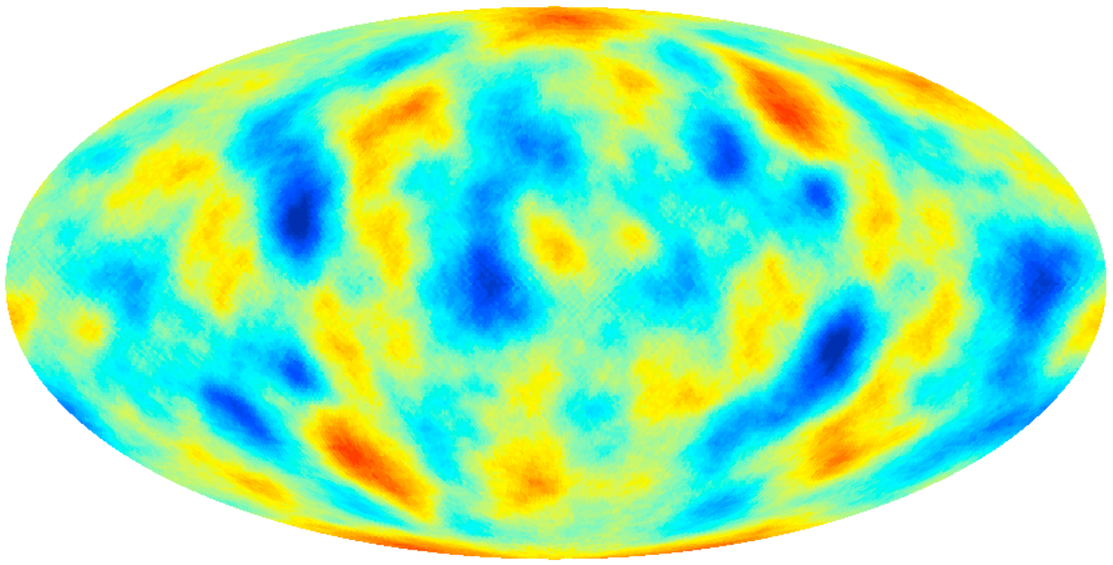

- Problems with this approach:

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Cook’s Branch 2012

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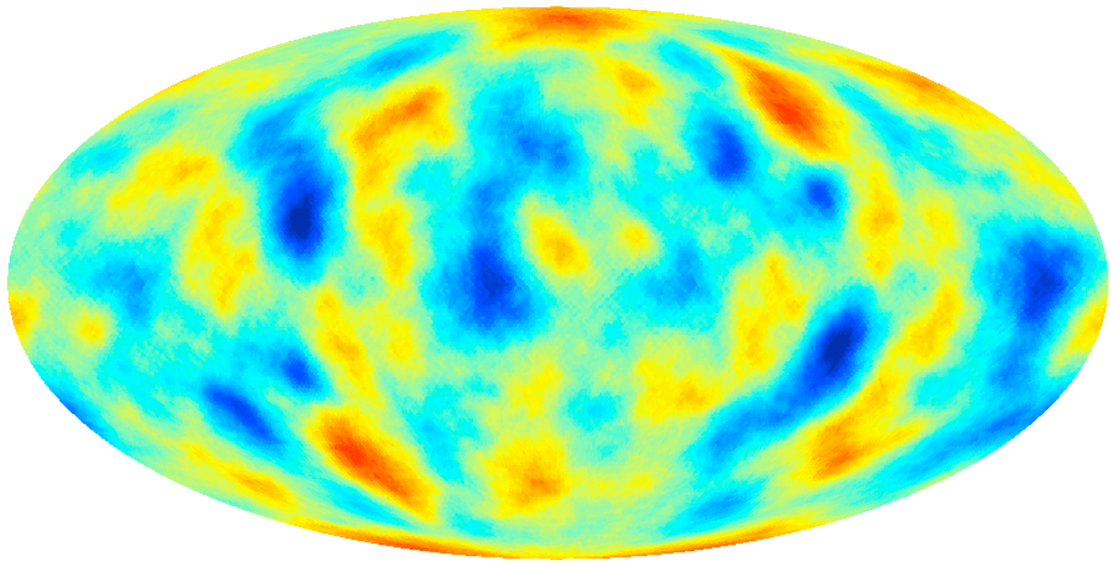

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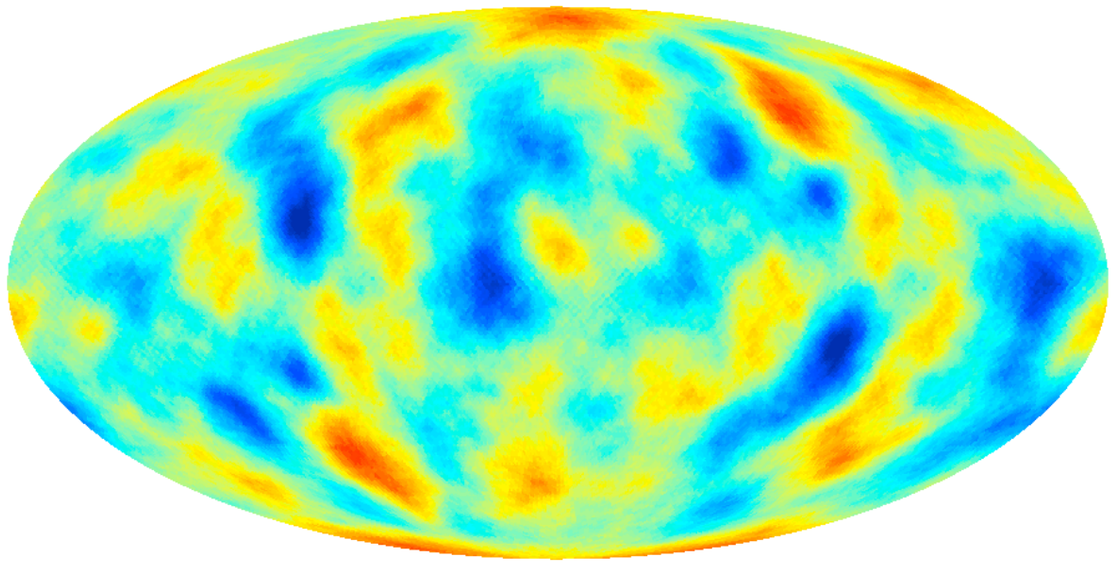

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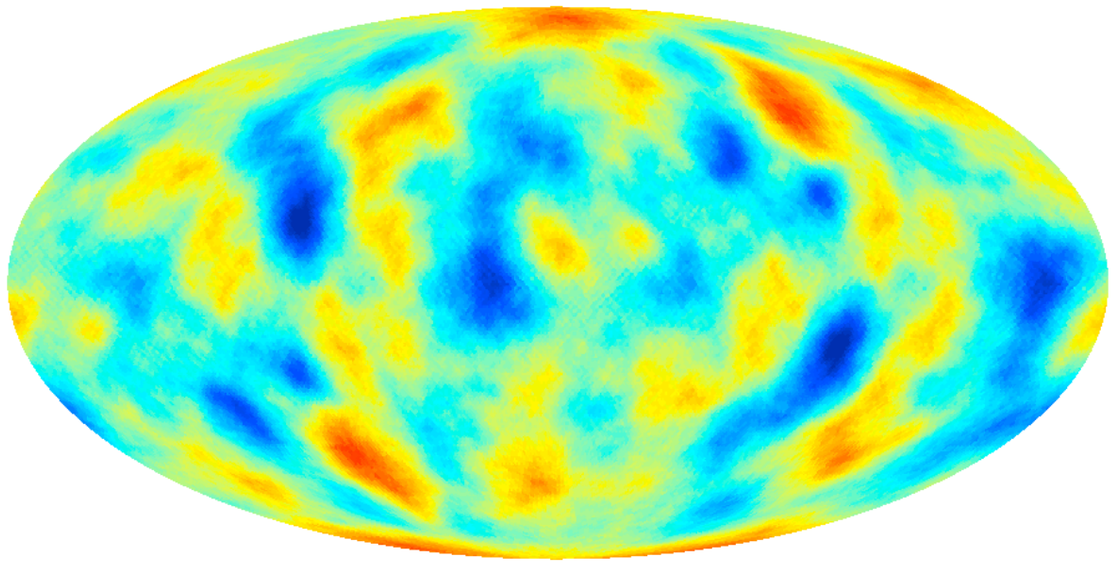

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# Parity - Even/Odd Multipoles

**(Ben-David, EDK and Itzhaki, ApJ 2012)**

Ely D. Kovetz
Cook's Branch 2012

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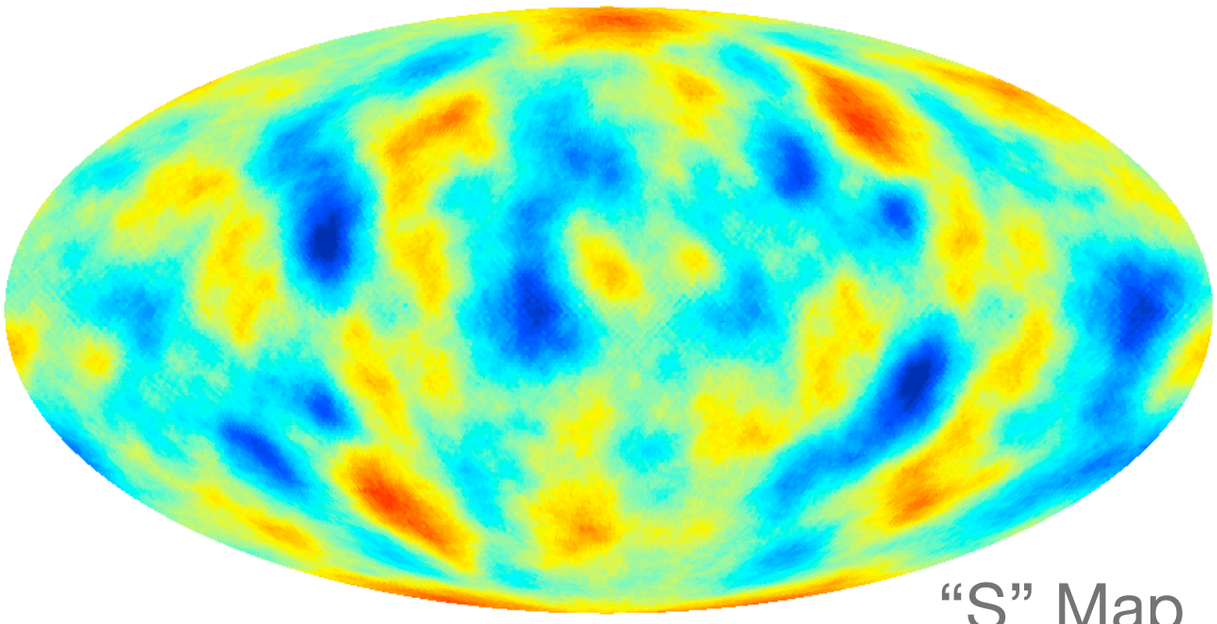

"S" Map

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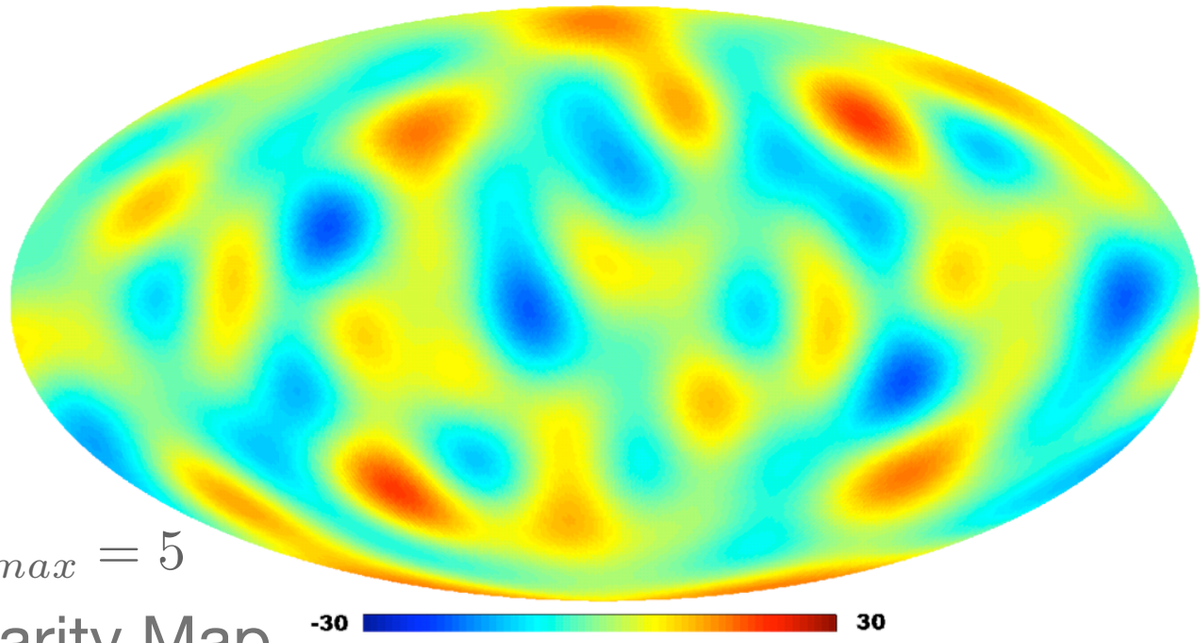
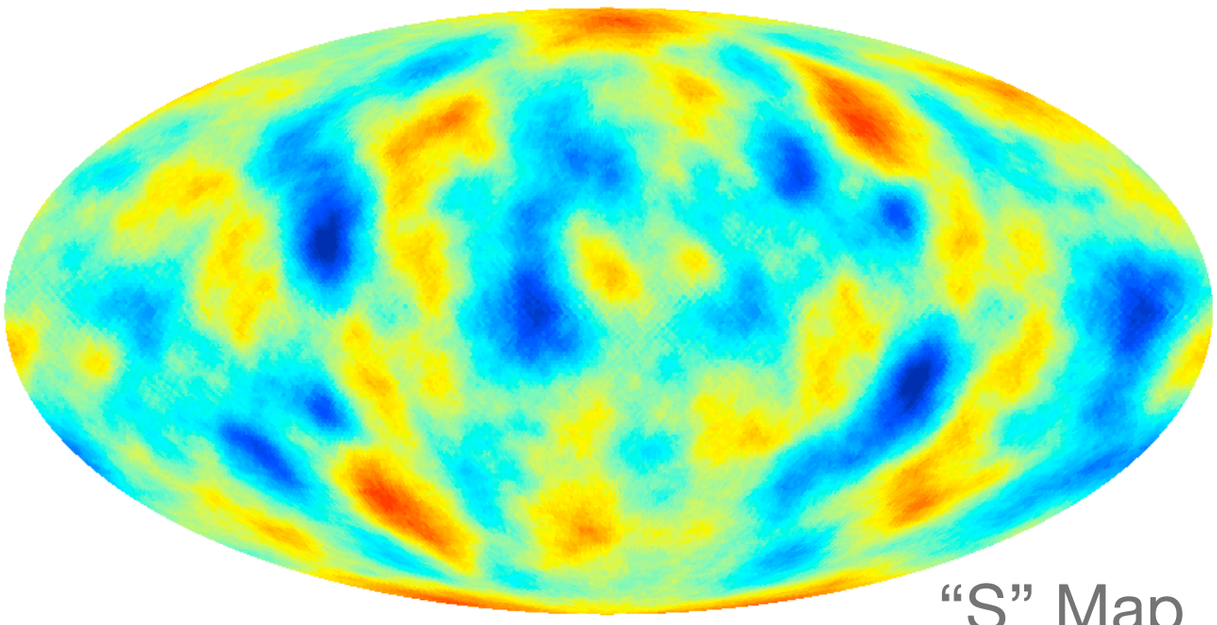



$\ell_{max} = 5$

Parity Map



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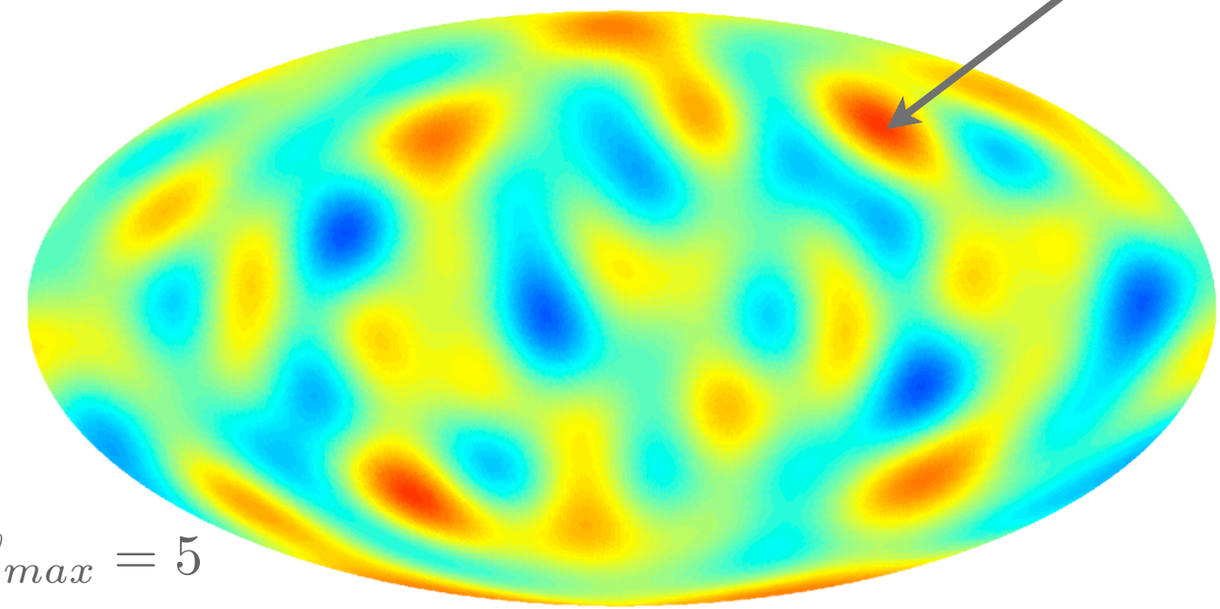


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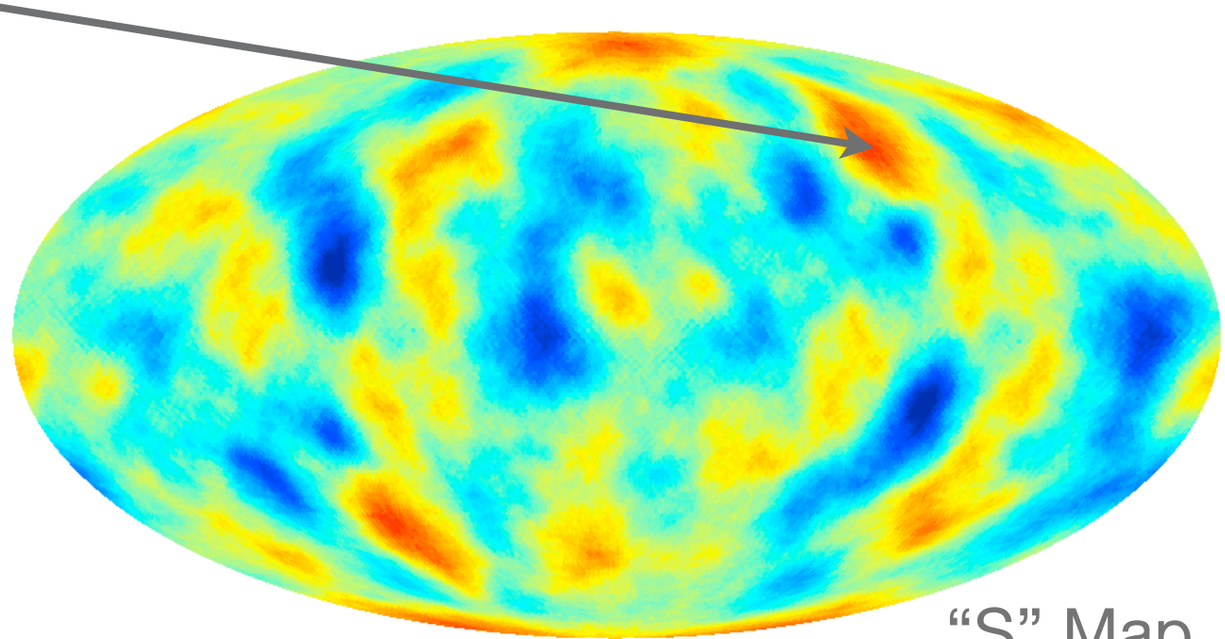

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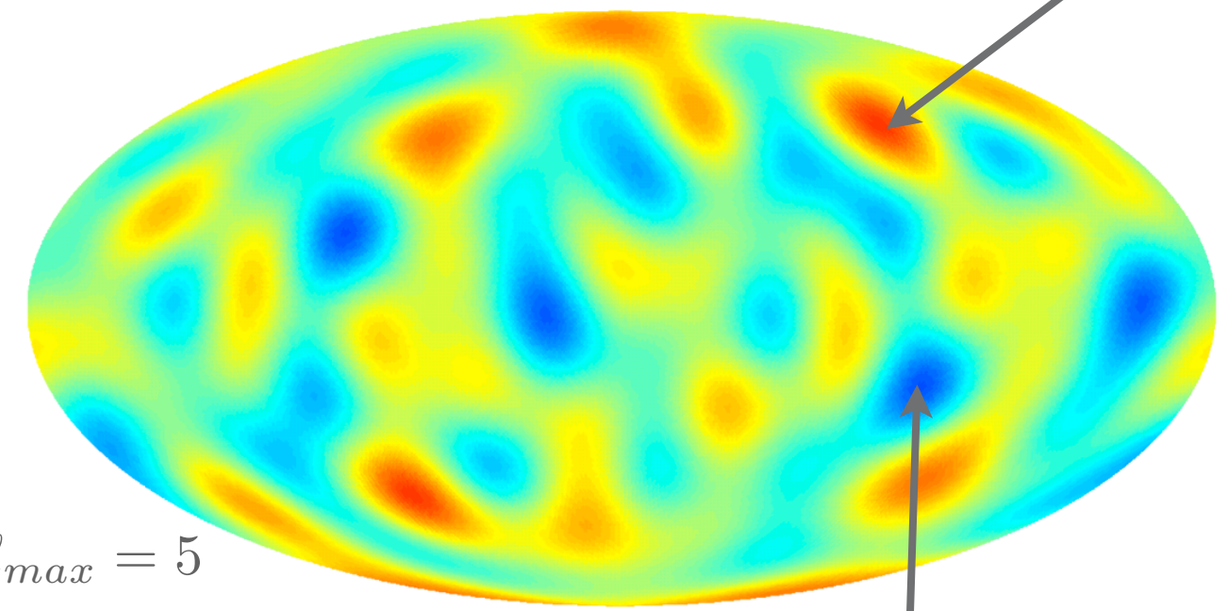


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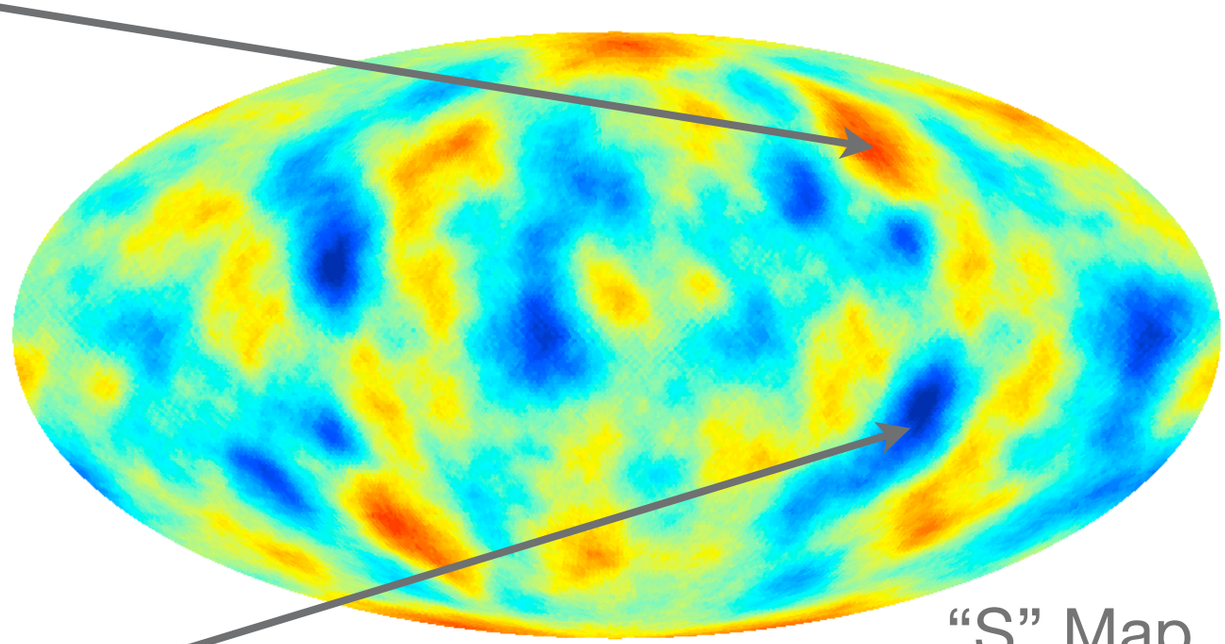

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- Minimum: $(l, b) \simeq (266^\circ, -19^\circ)$.

# Parity - Masking and Reconstruction

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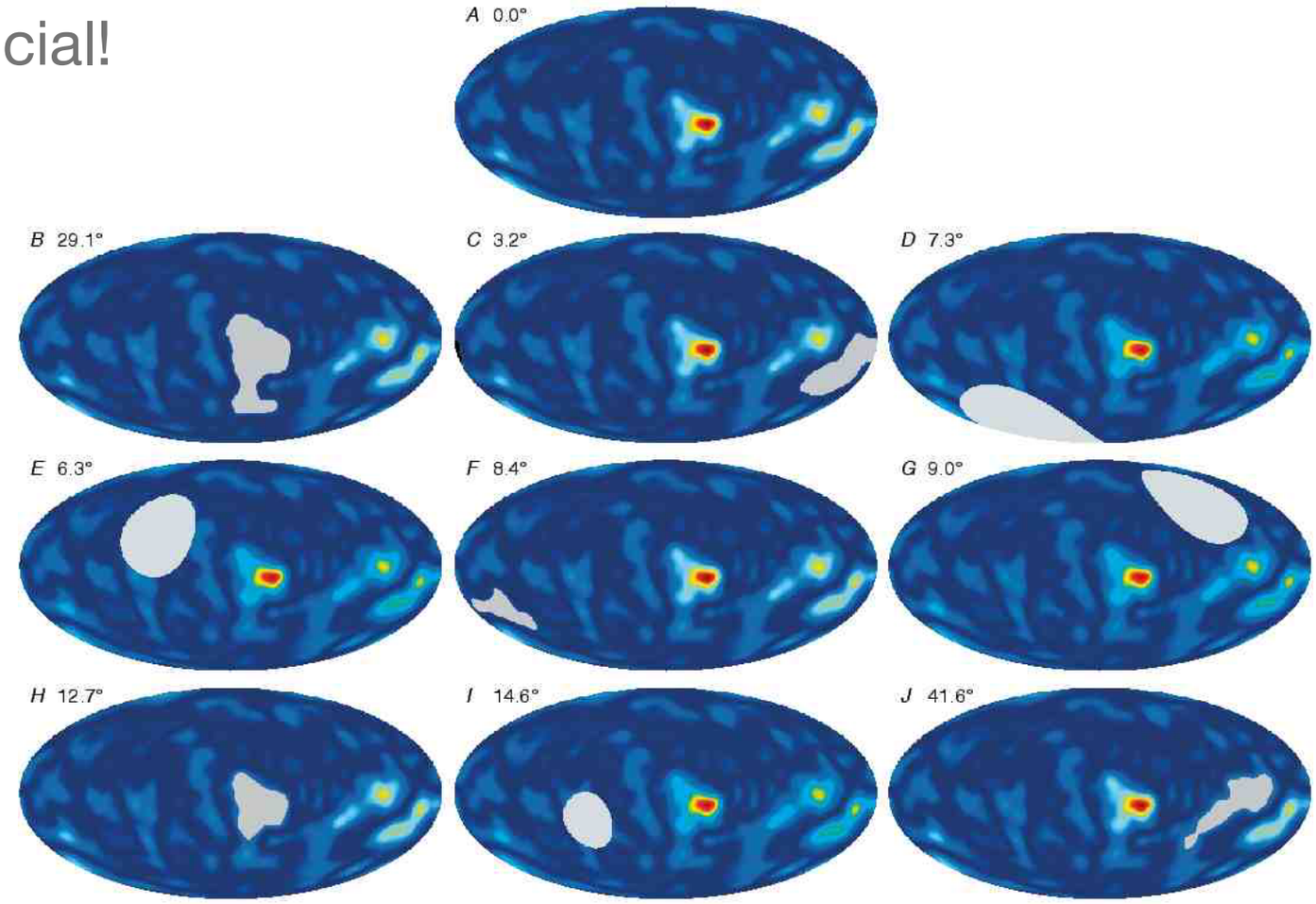

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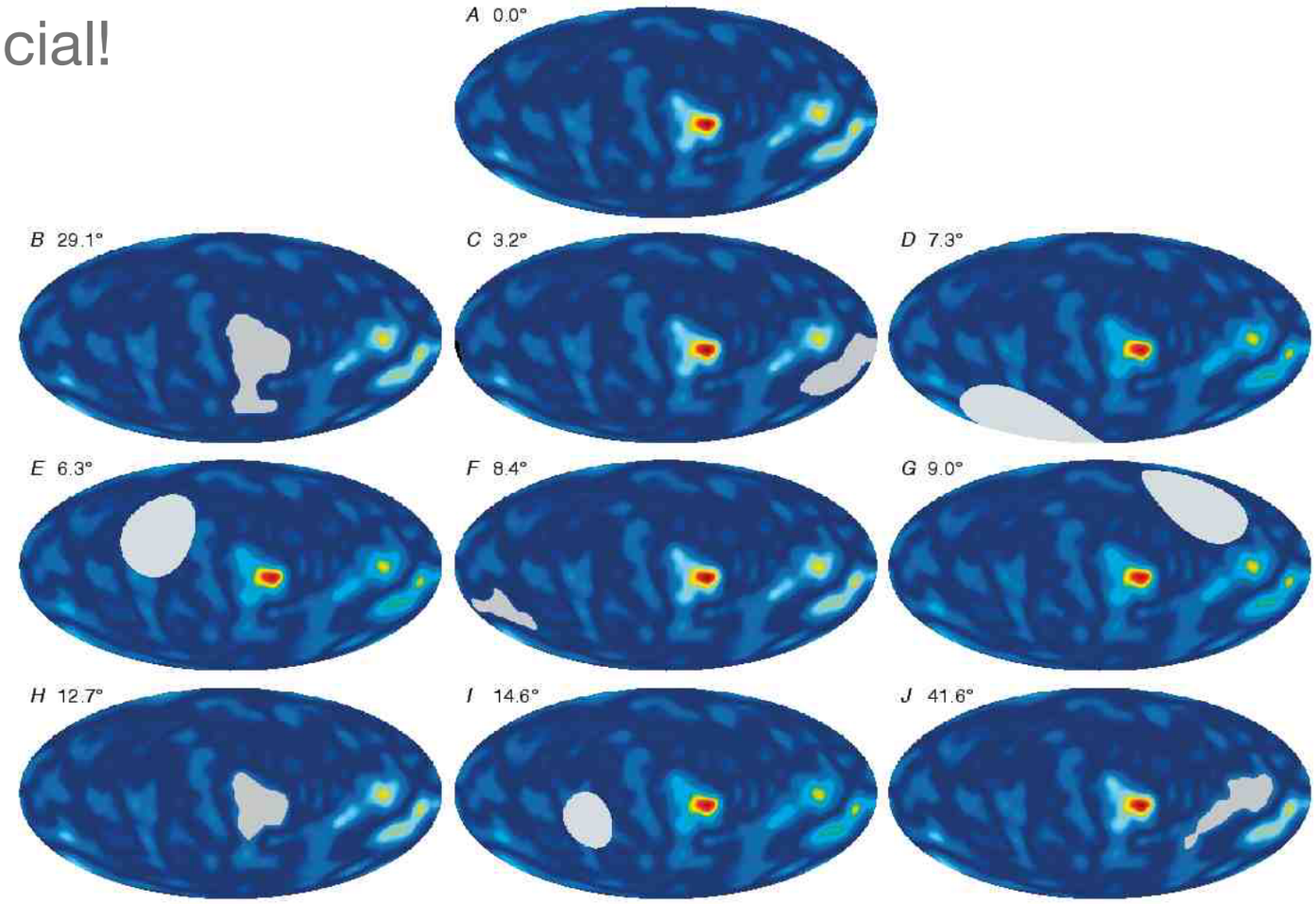


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- $a_{\ell m}$ Reconstruction:

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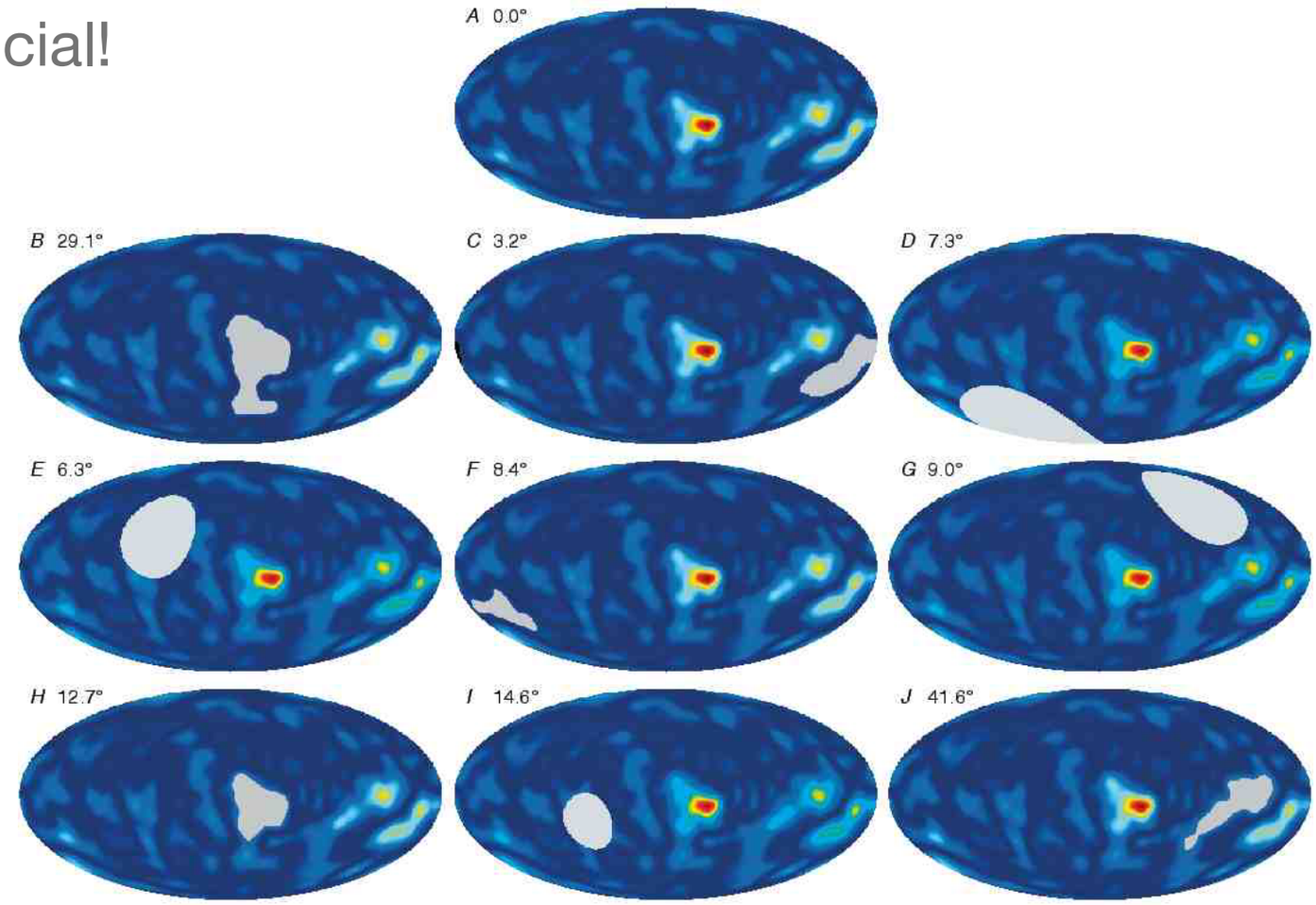


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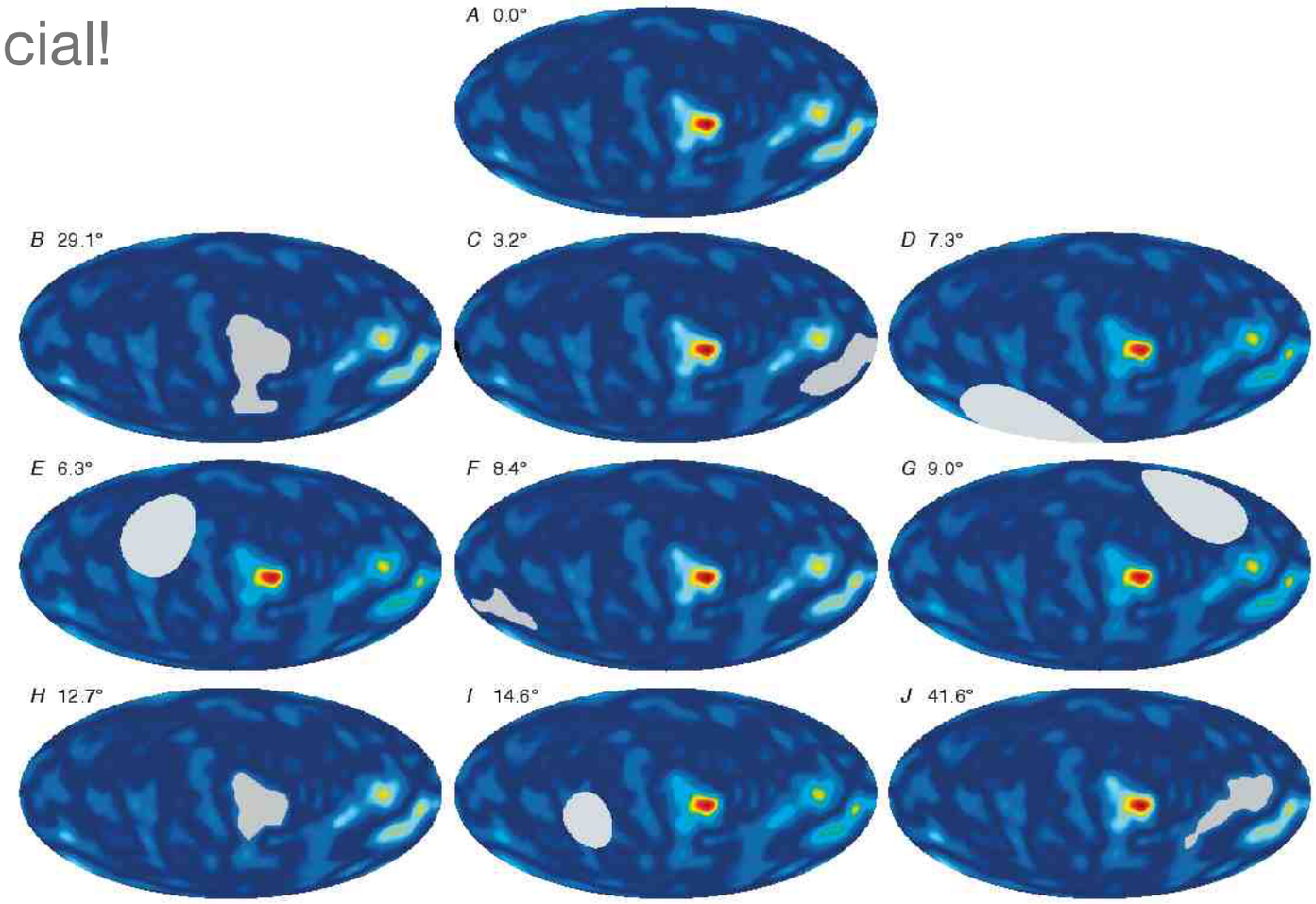


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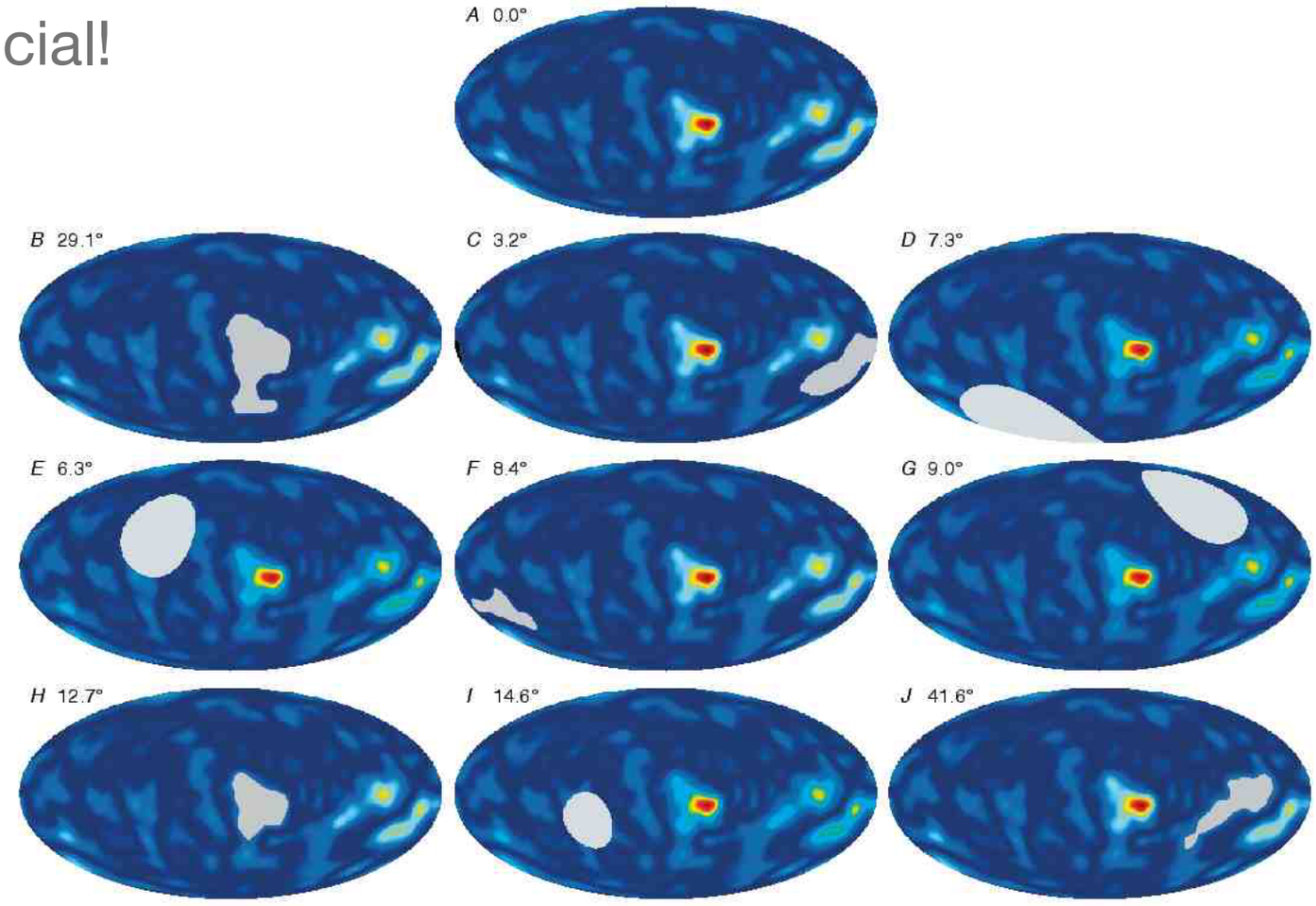


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# Parity - Cut-Sky Results

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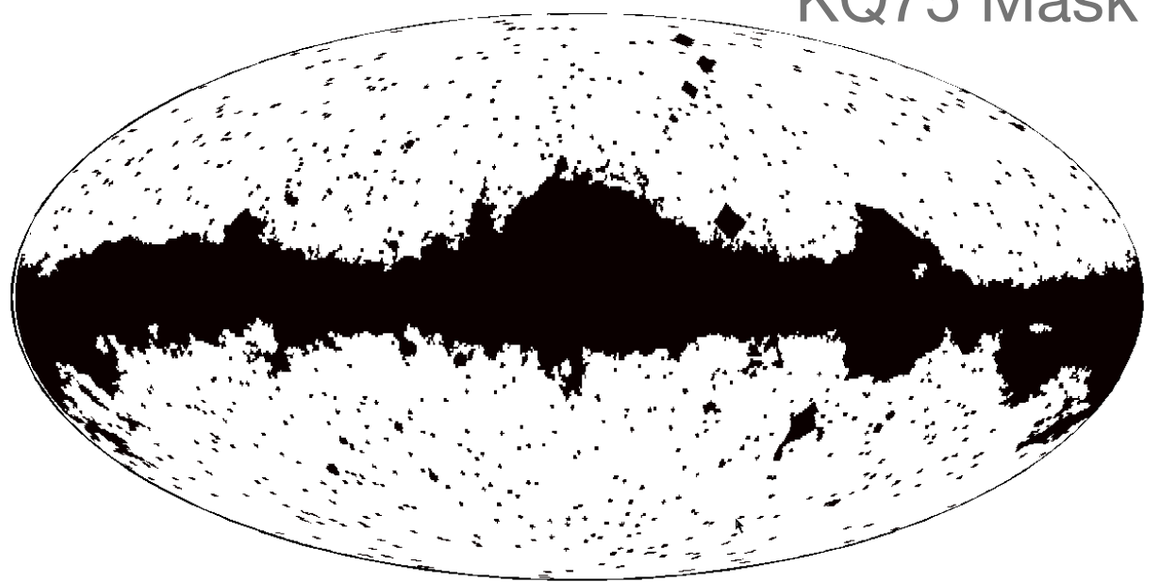
KQ75 Mask



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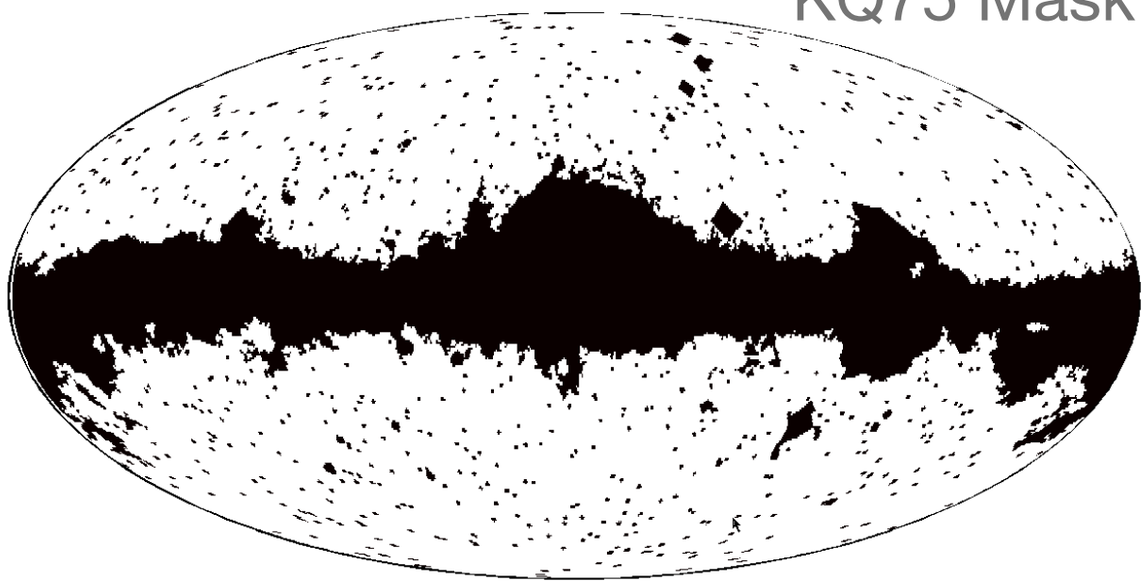

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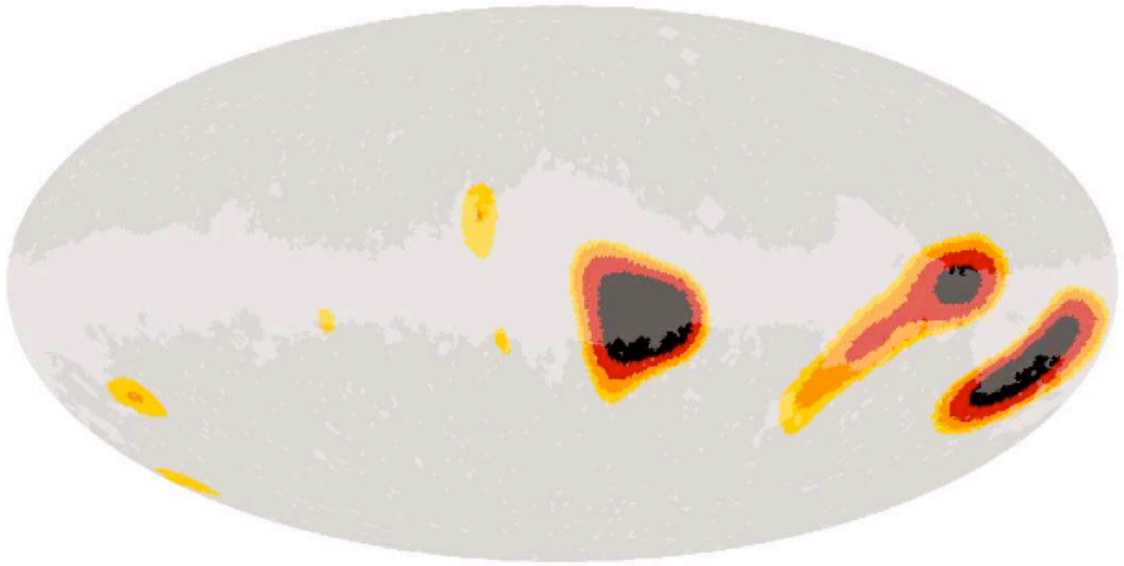

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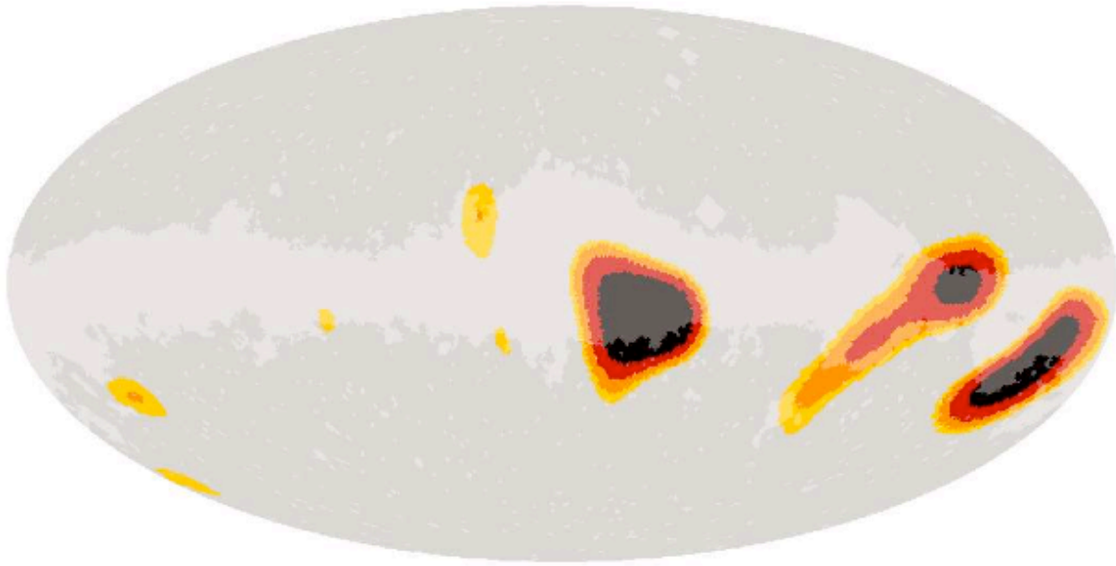

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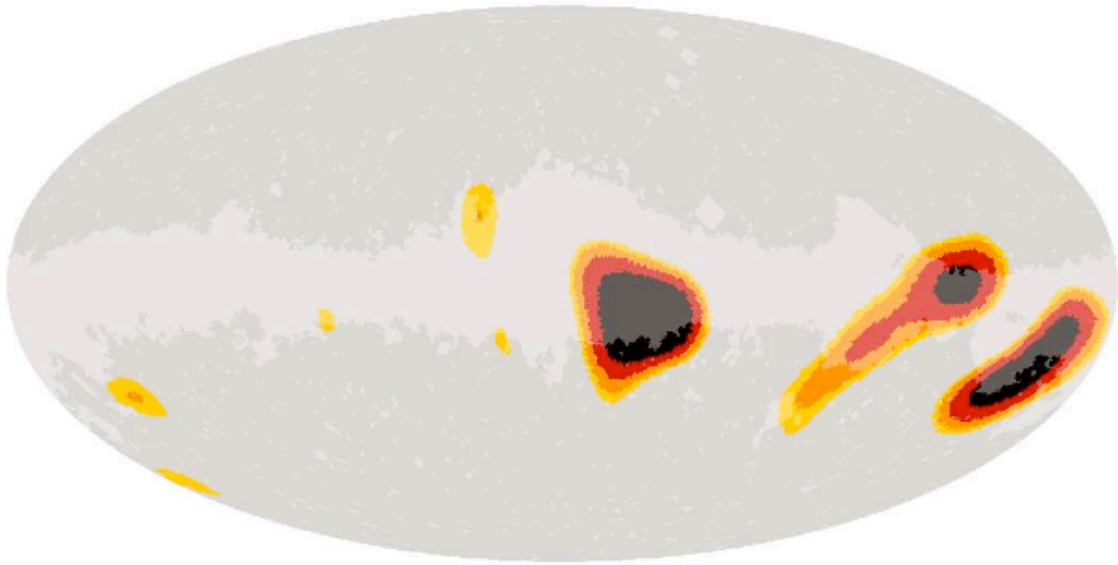

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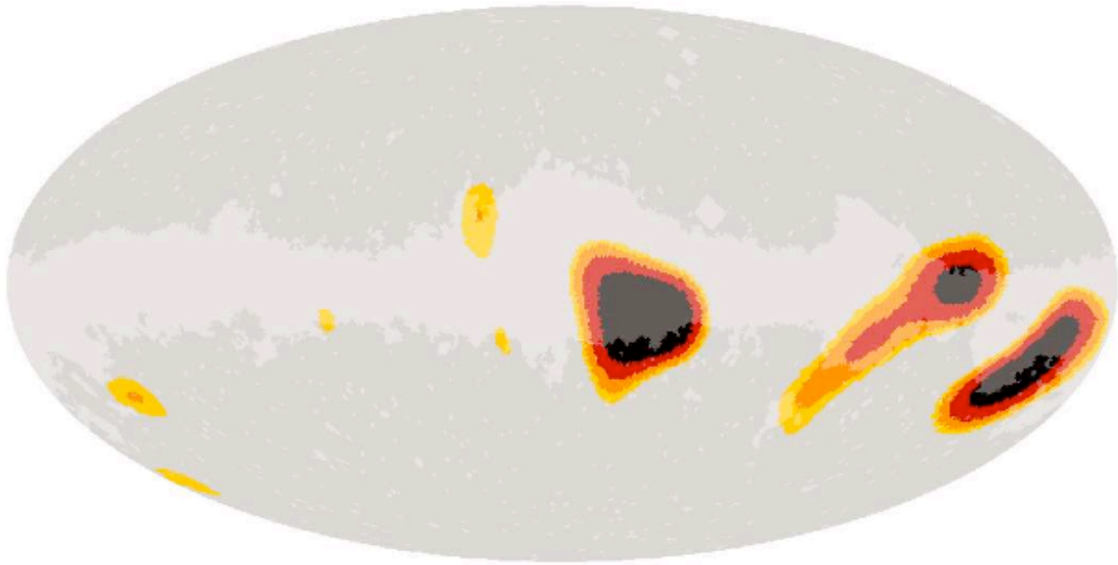

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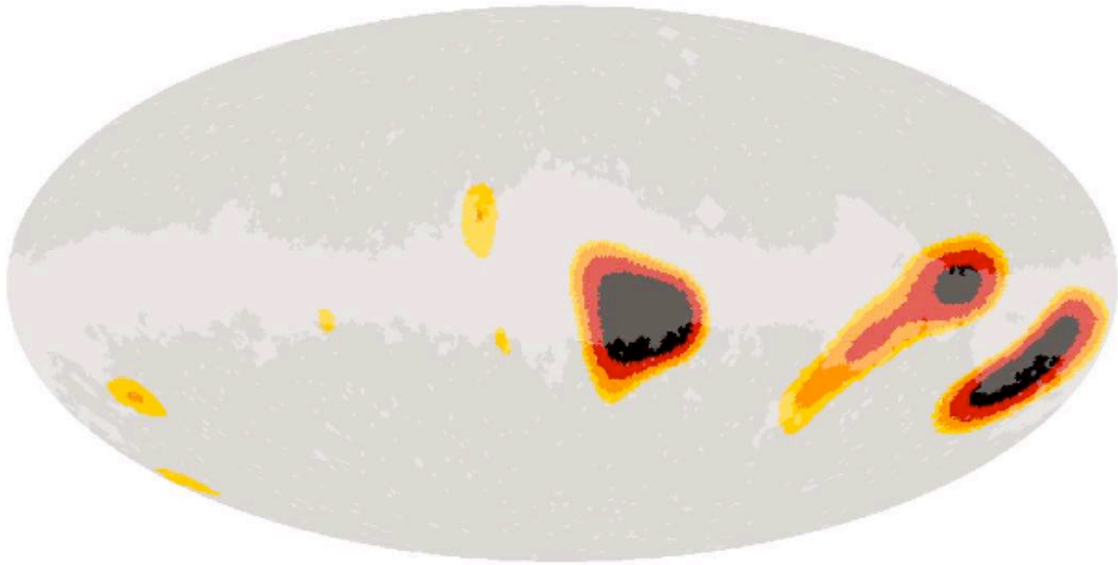

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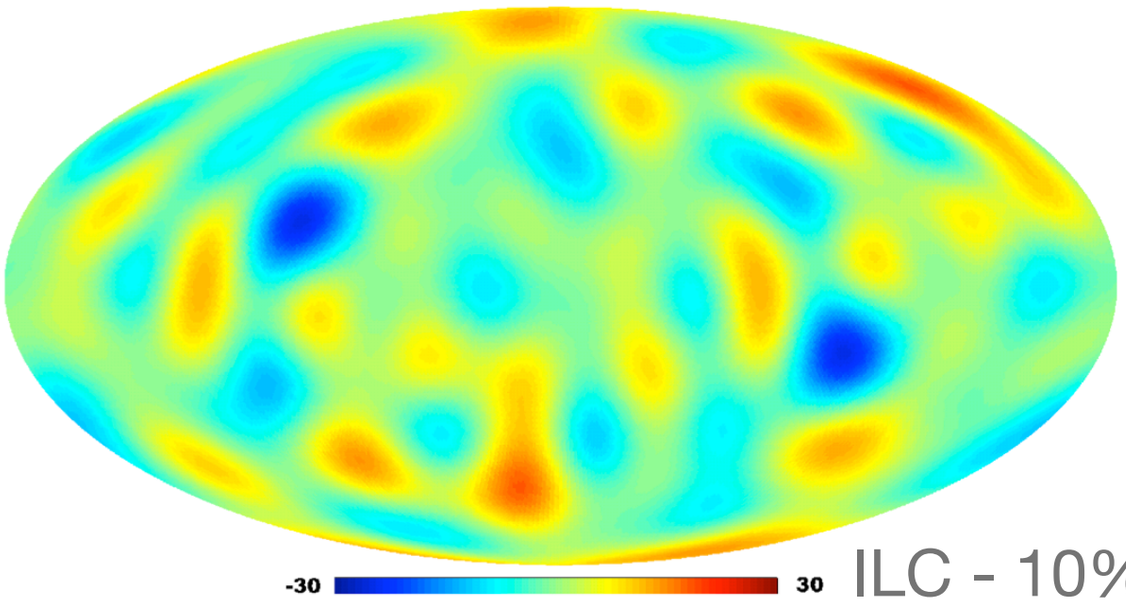


ILC - 10%

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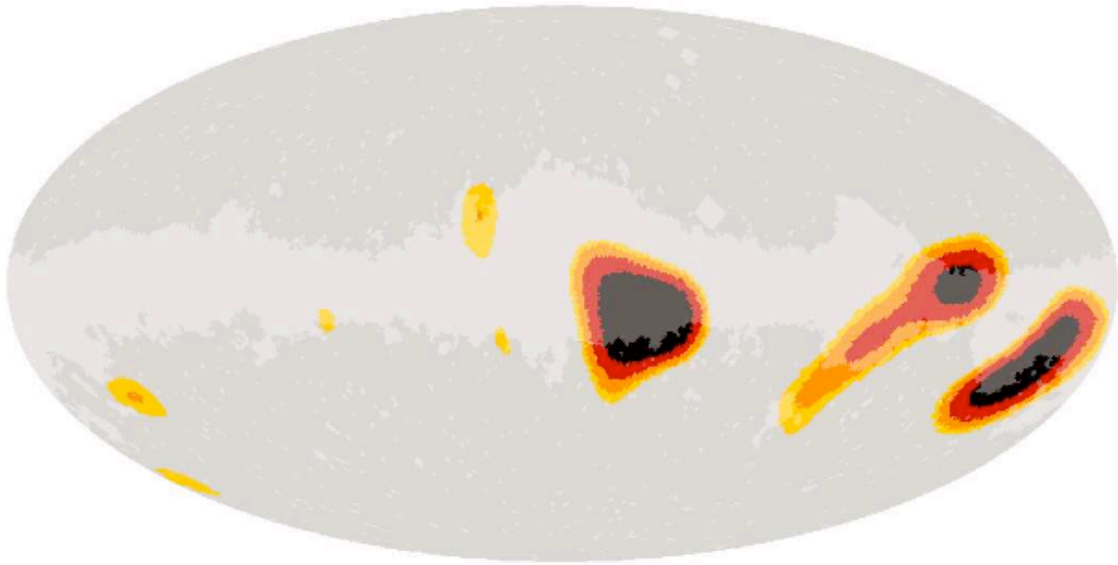

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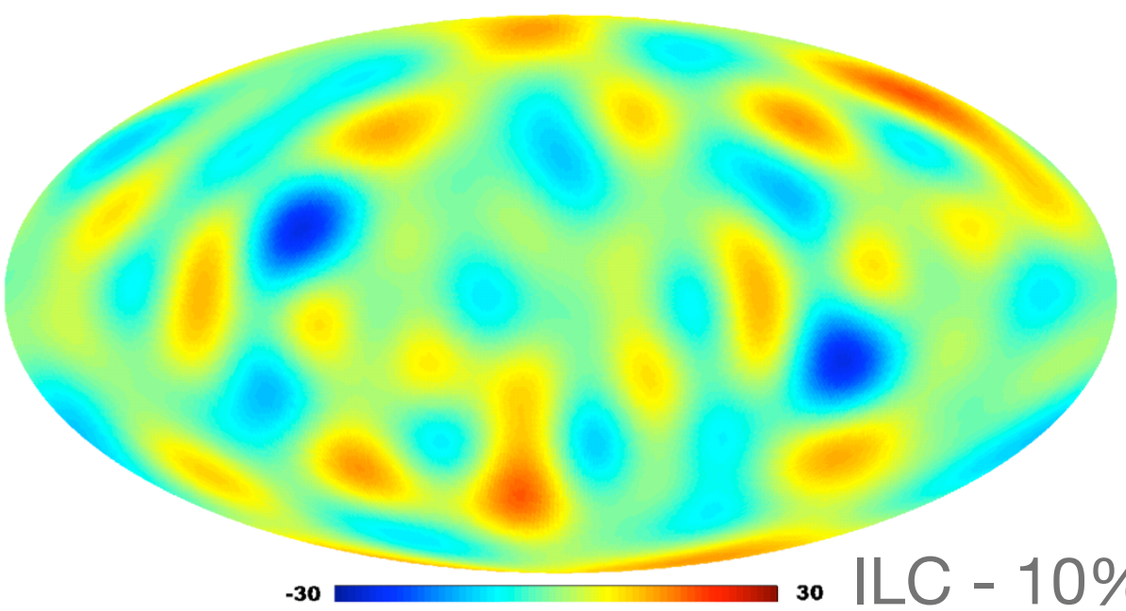


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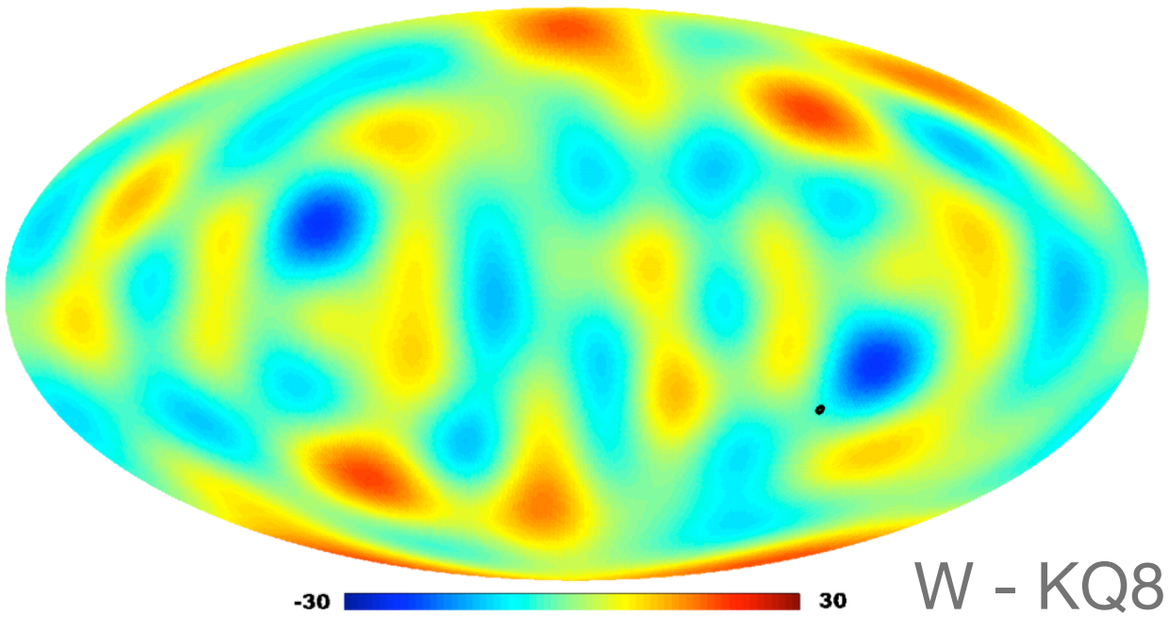


W - KQ85

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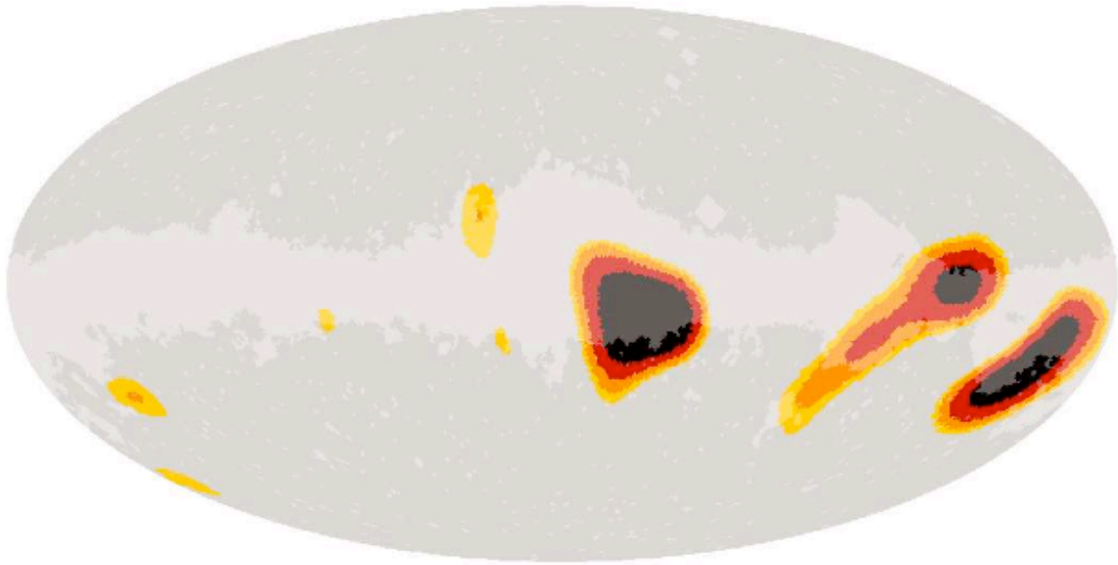

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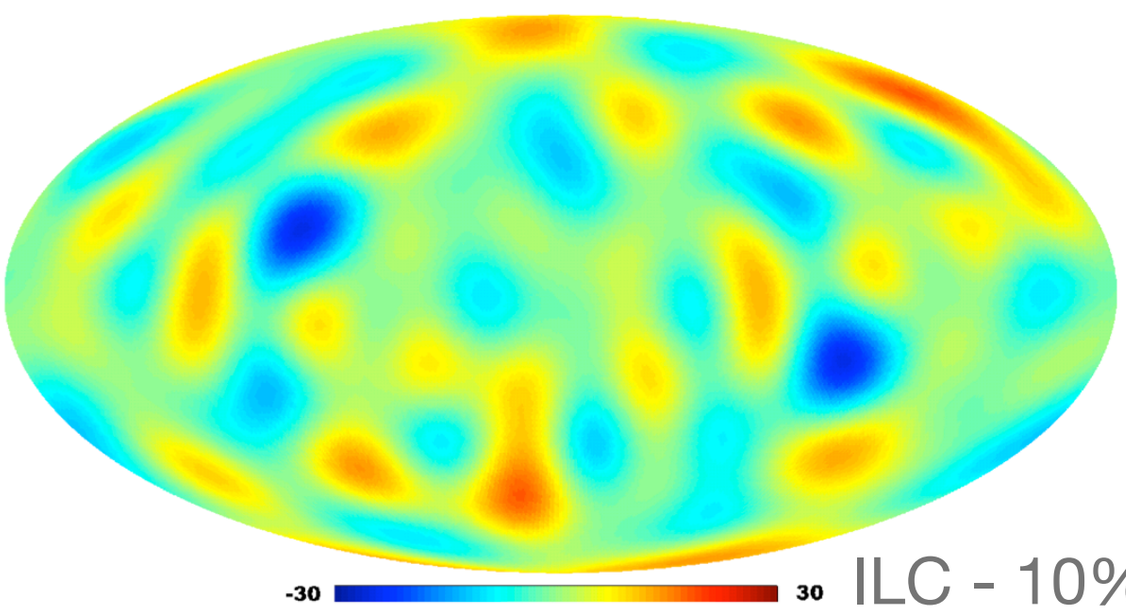


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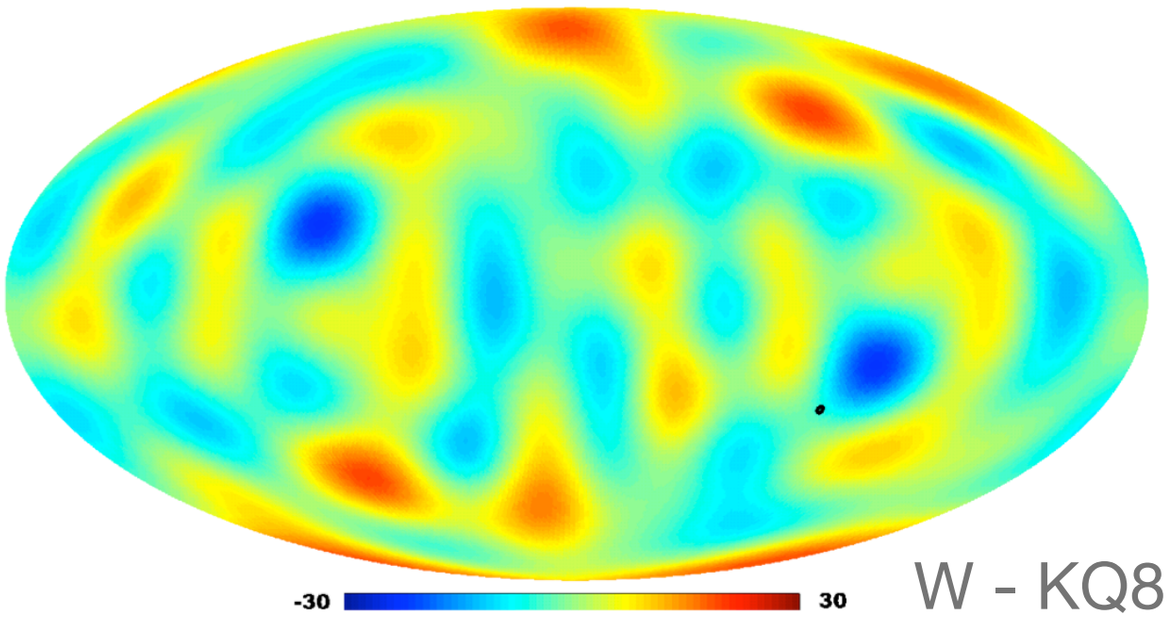


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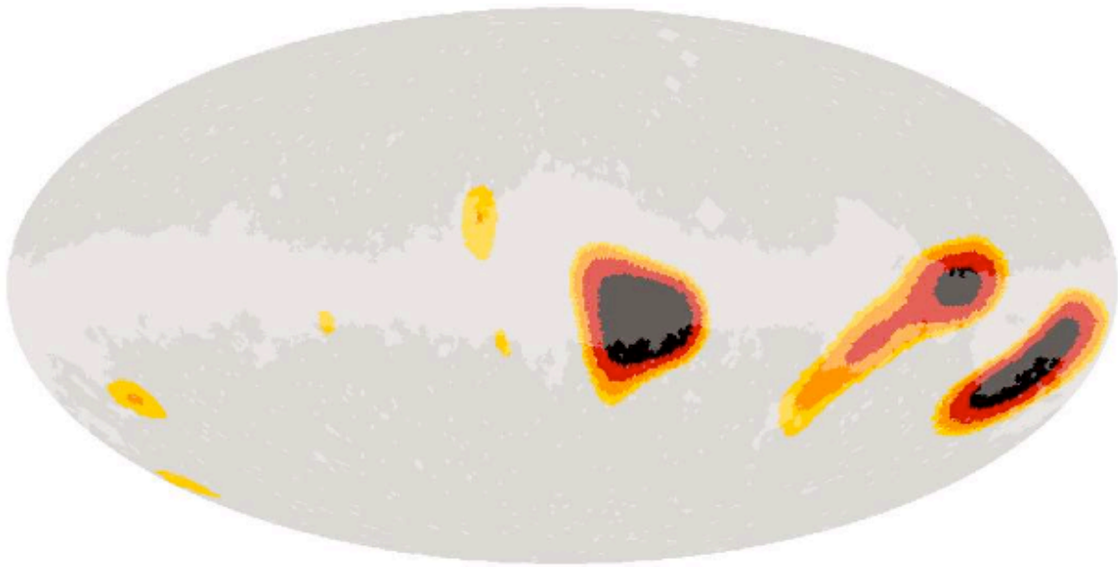

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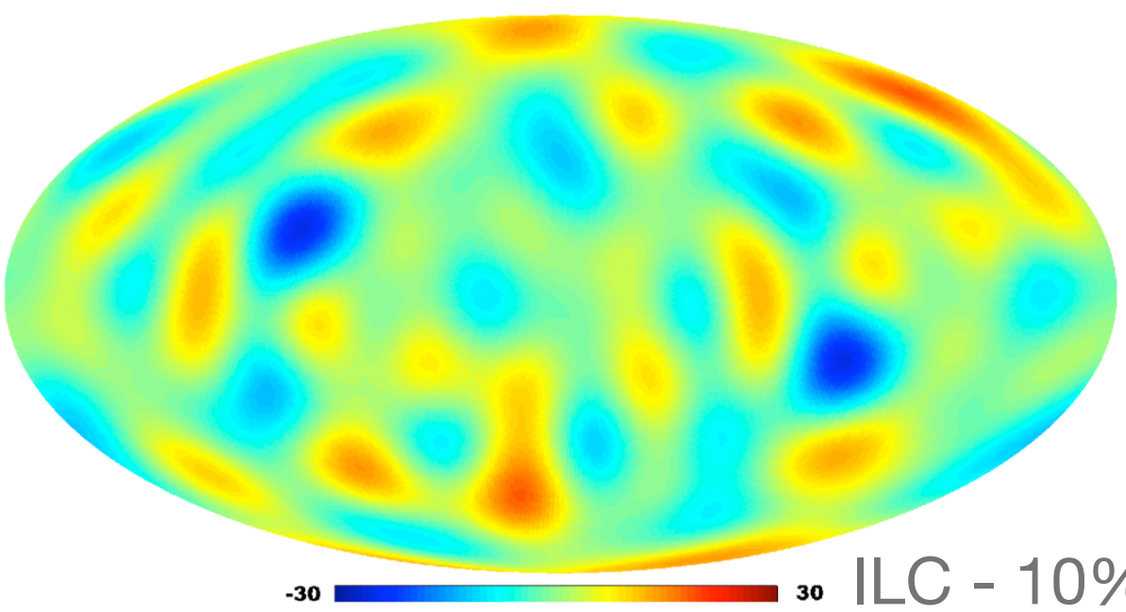


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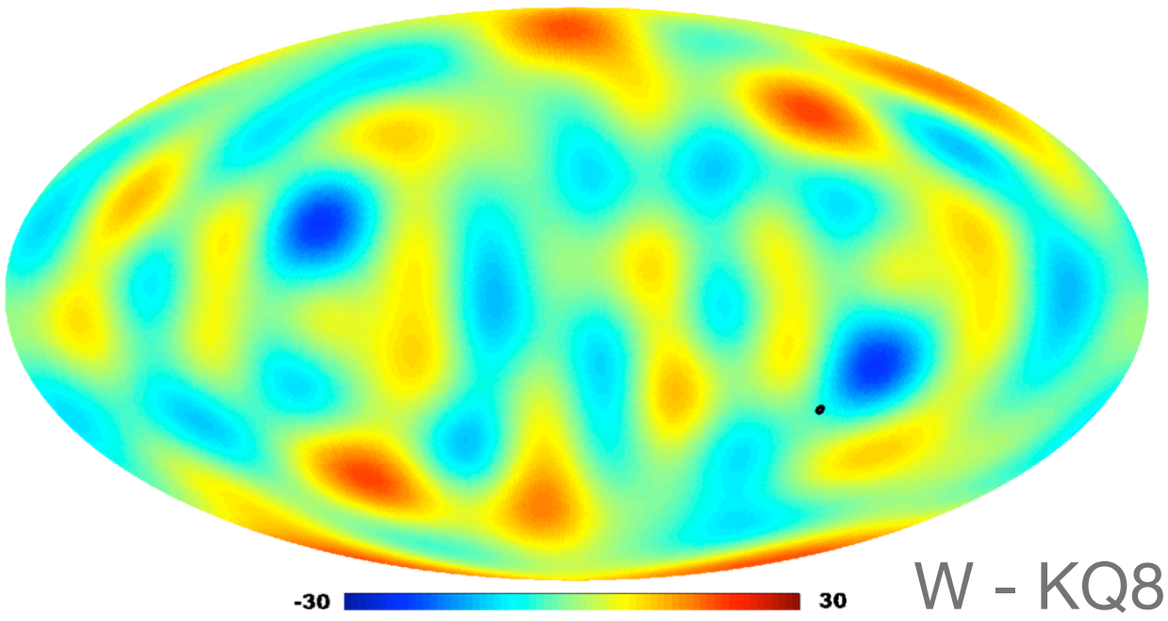


W - KQ85

- Odd parity at $(l, b) \simeq (264^\circ, -18^\circ)$ is significant: ~0.01% for $\ell_{max} = 5 - 7$.

# Parity - COBE-DMR

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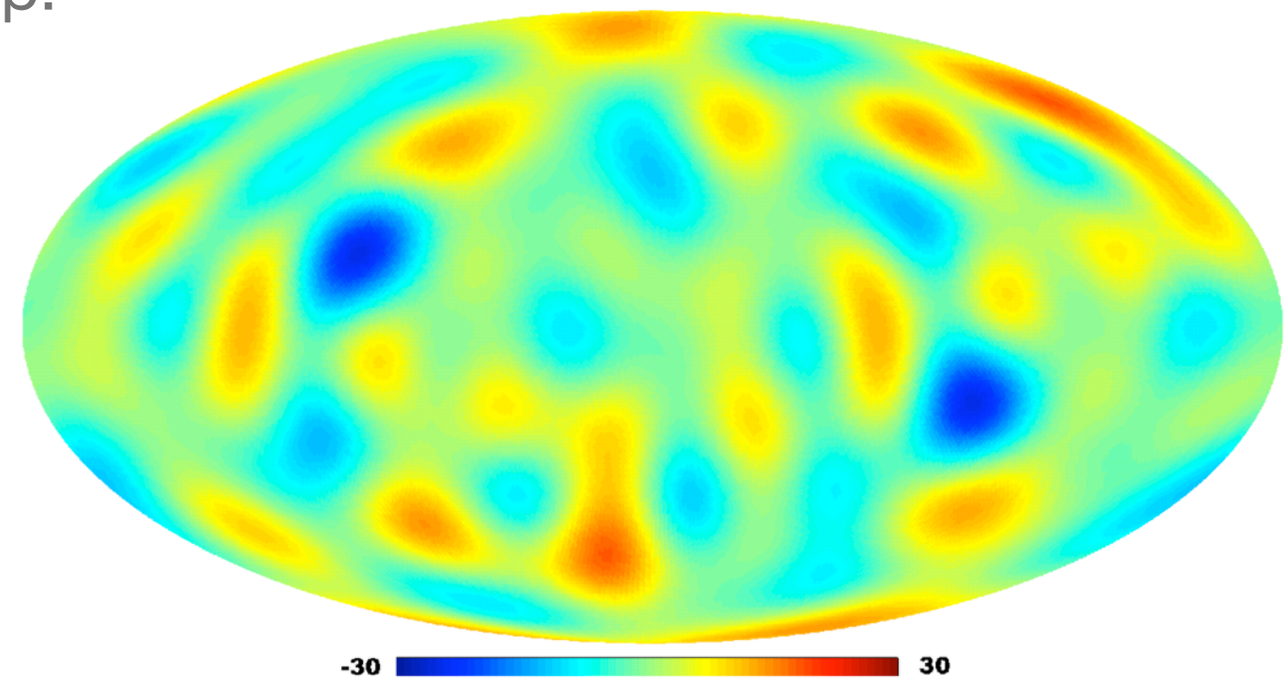
- WMAP parity map:



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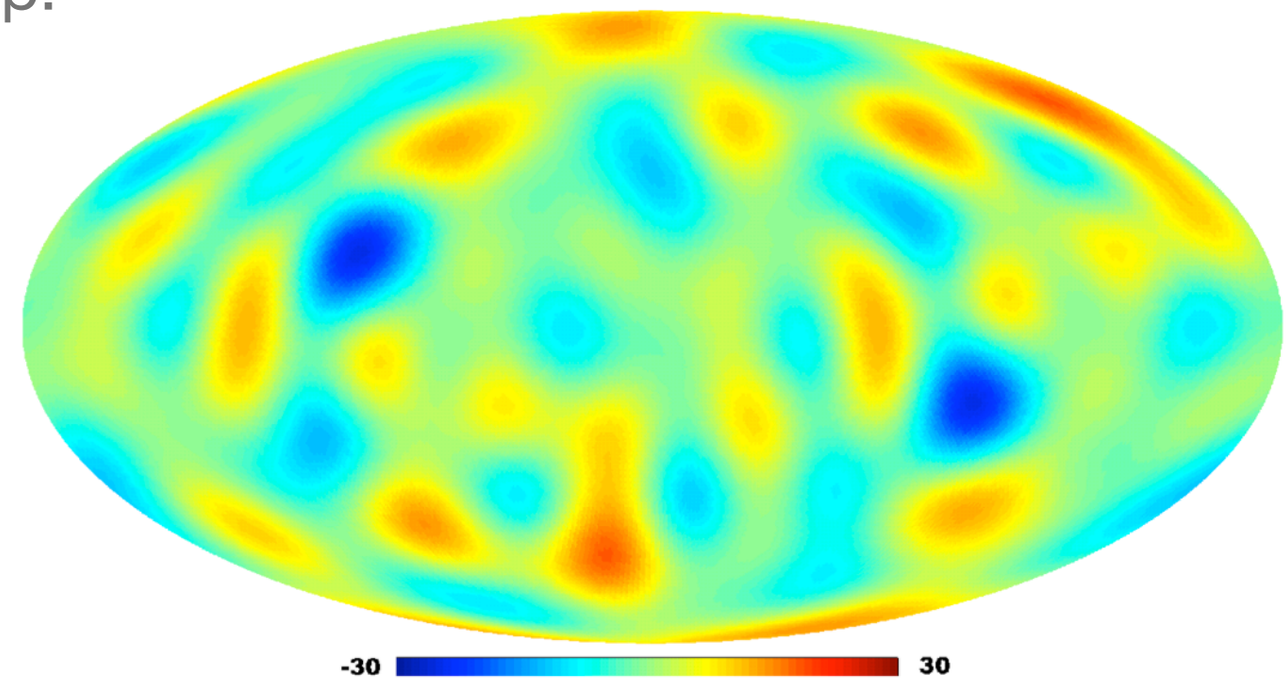


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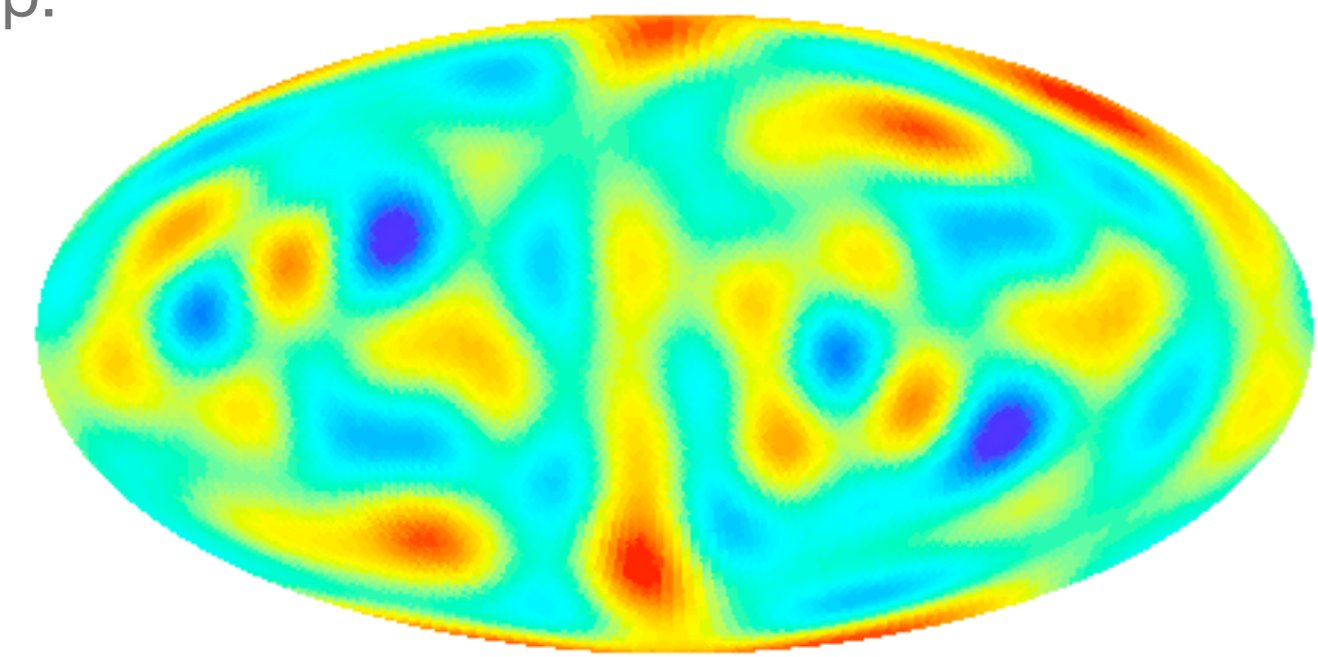

# Outline

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- Motivation (Theory): Inflation Onset
- Simplest Relic: Pre-Inflationary Particle
- Pre-Inflationary Particle - Signatures
- Motivation (Data): Anomalies
- Where to look, what to look for?
- Observational Tests: CMB Rings, Bulk Flow, Mirror Parity.
- Current work and Conclusions

# Moving PIP Model

**(Ben-David, EDK and Itzhaki, *in progress*)**

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- (Dipole structure could create both even and odd parity, $90^\circ$ apart.)

# Simulation vs. data: Moving PIP

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Simulating LCDM + a moving PIP (with fine-tuned location and velocity):

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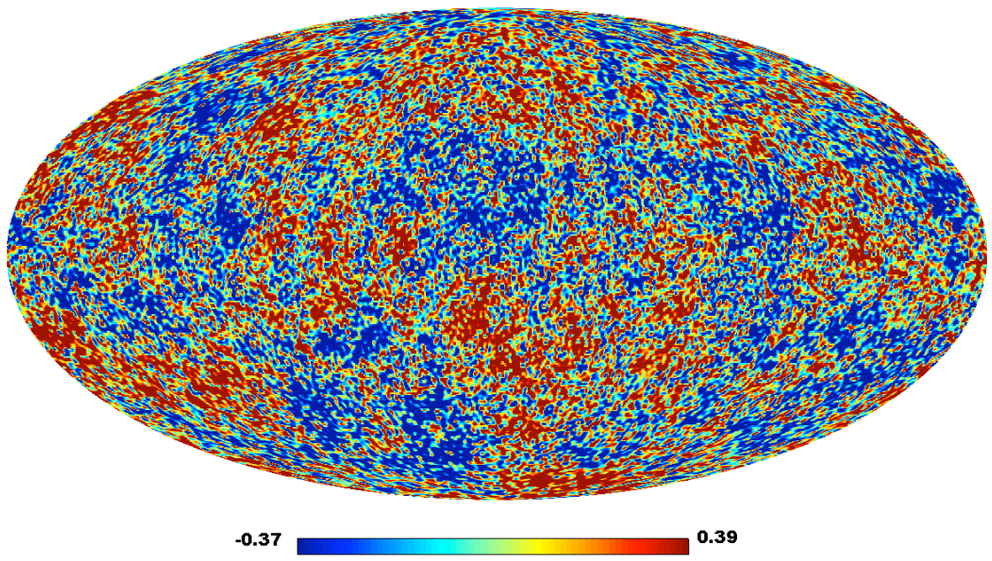

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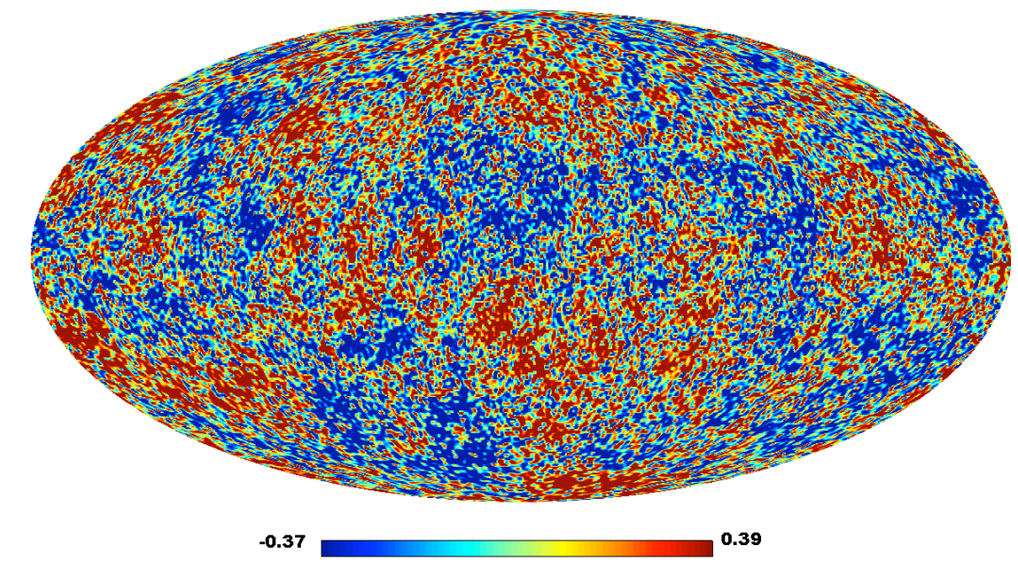


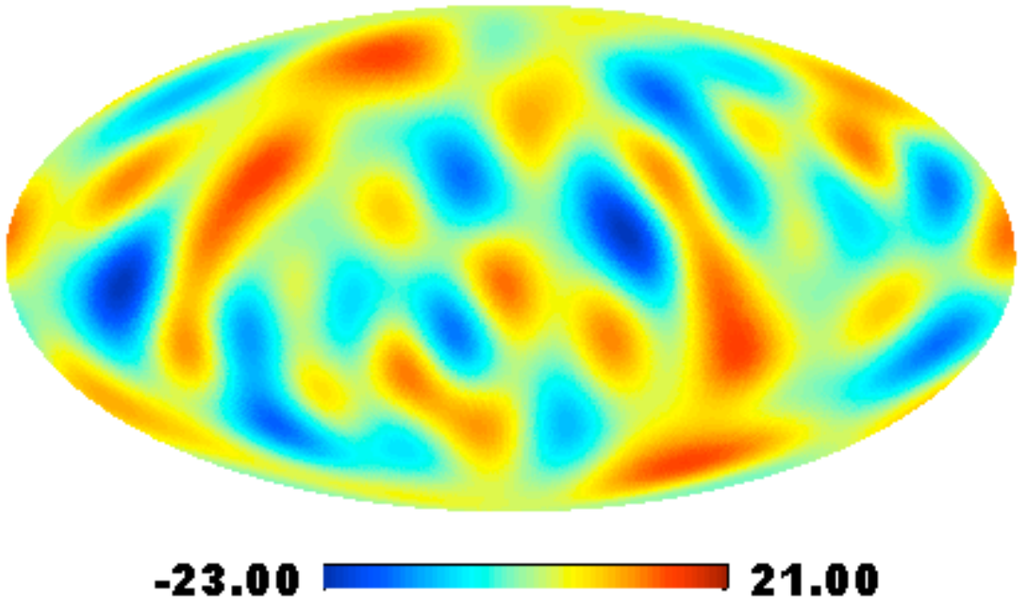

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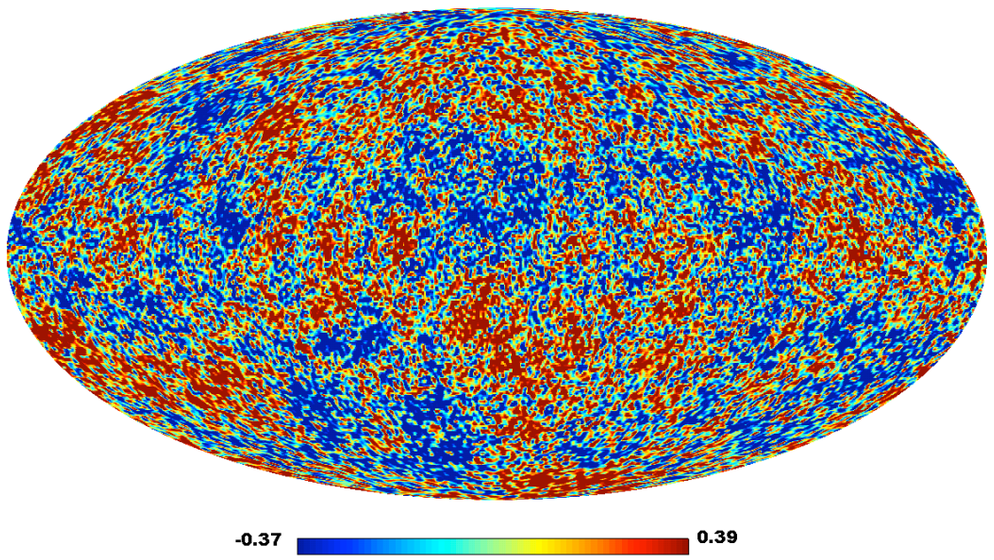


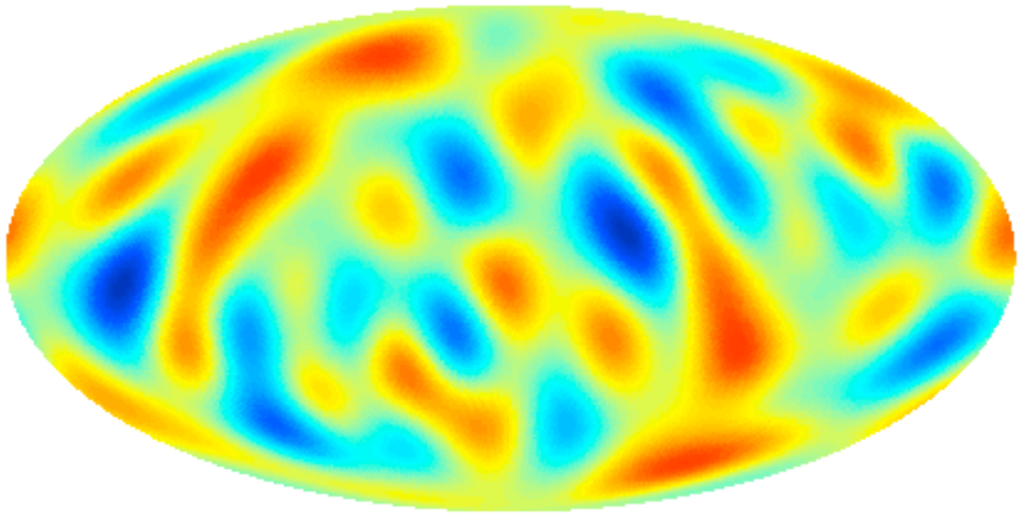


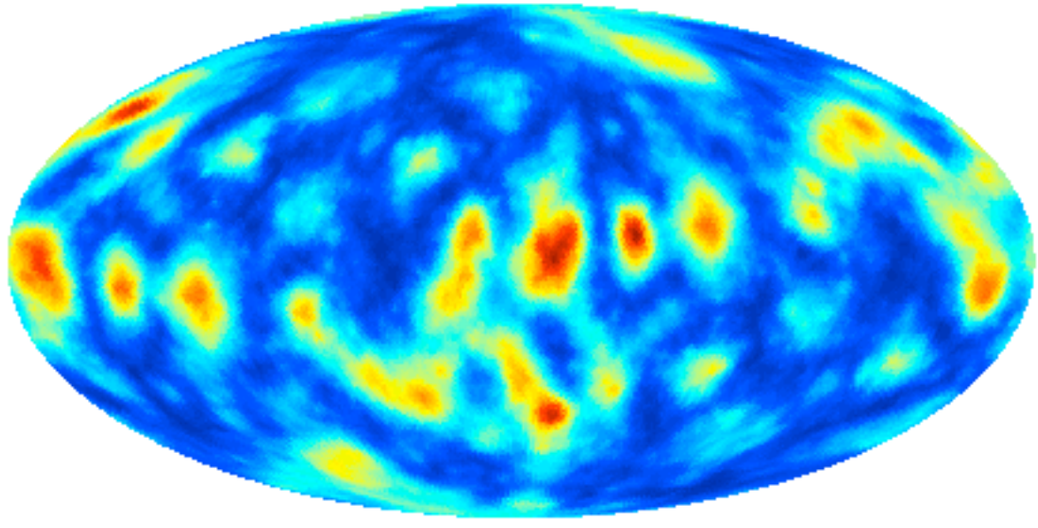

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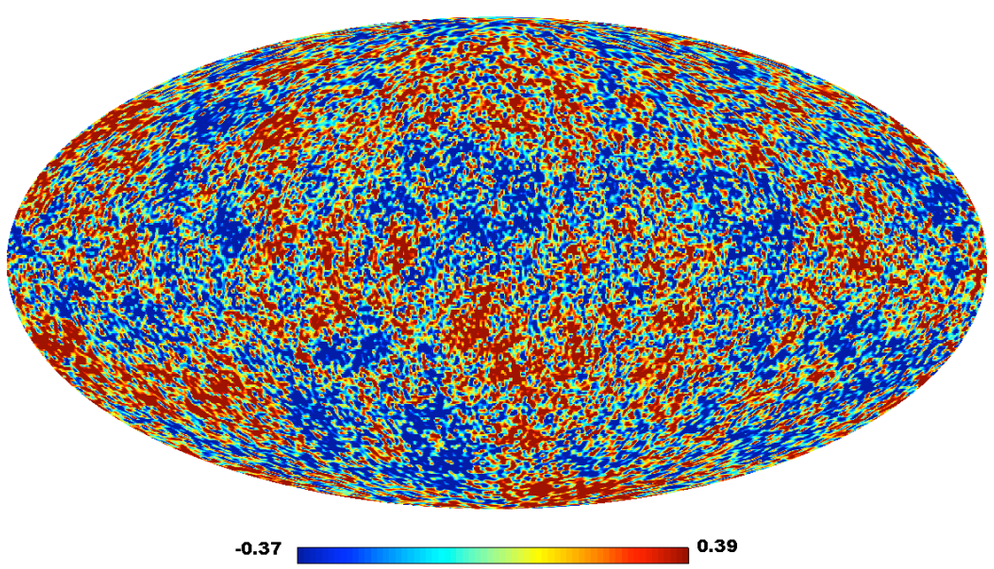


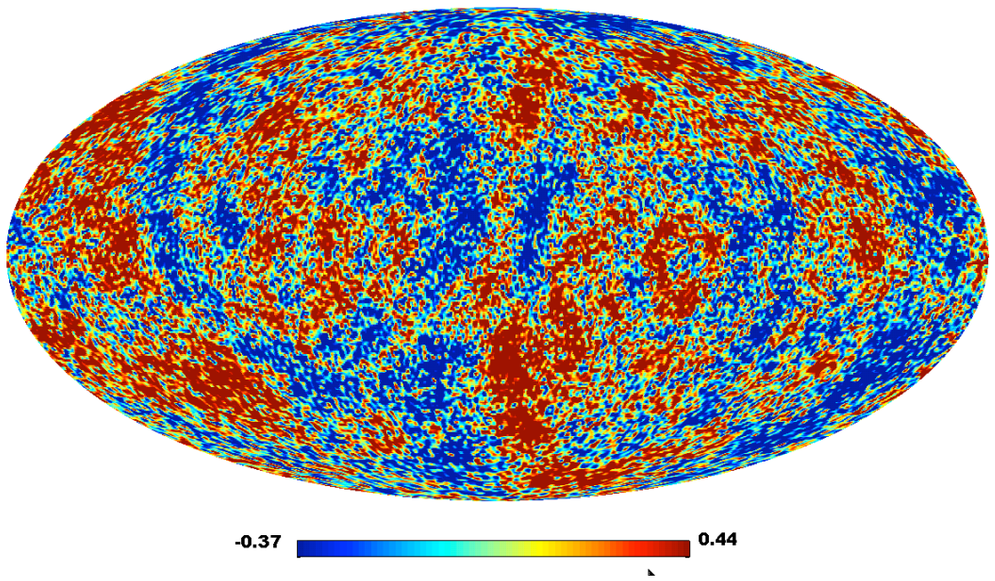


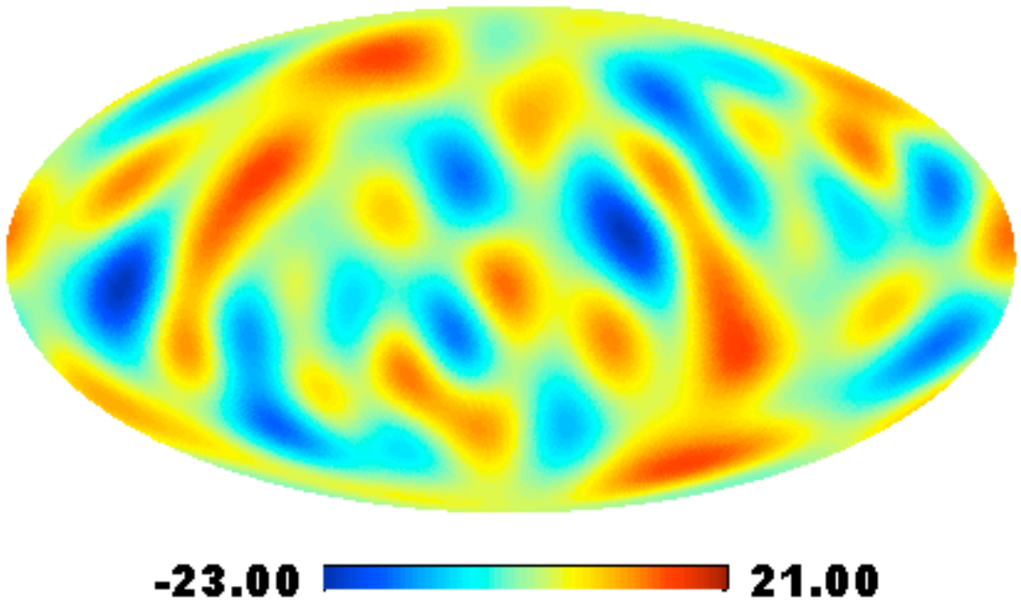


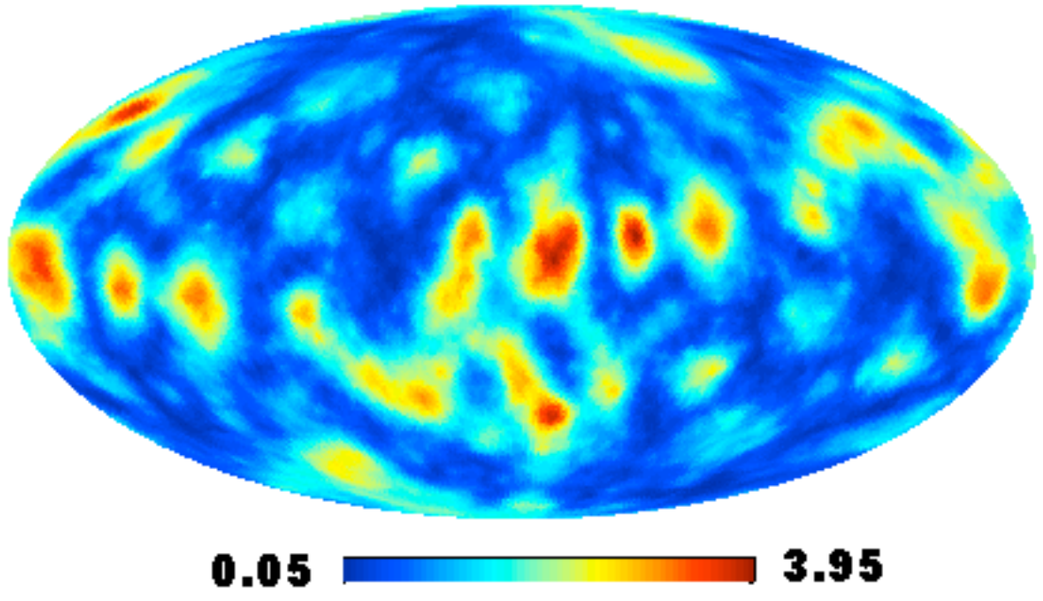

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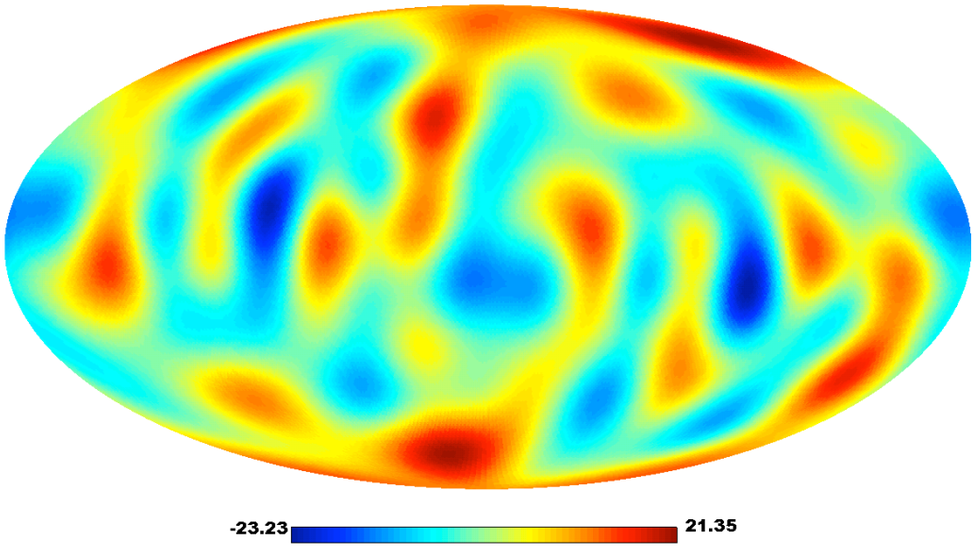


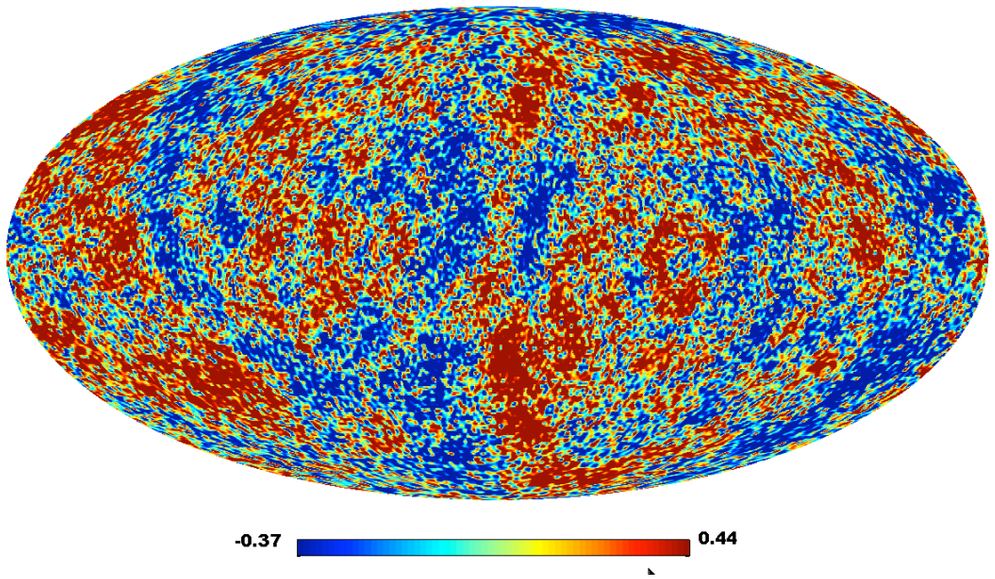


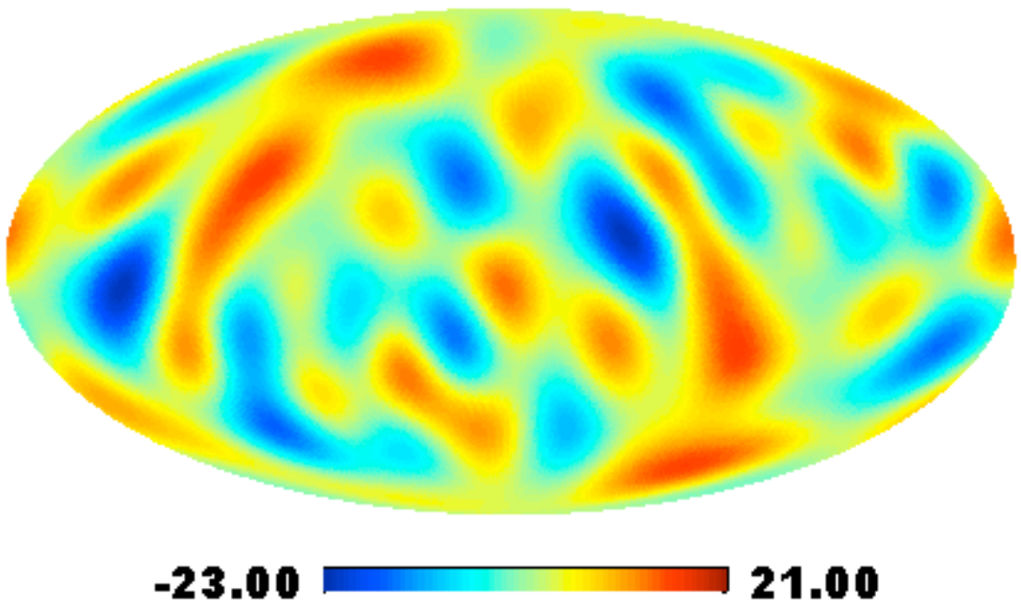


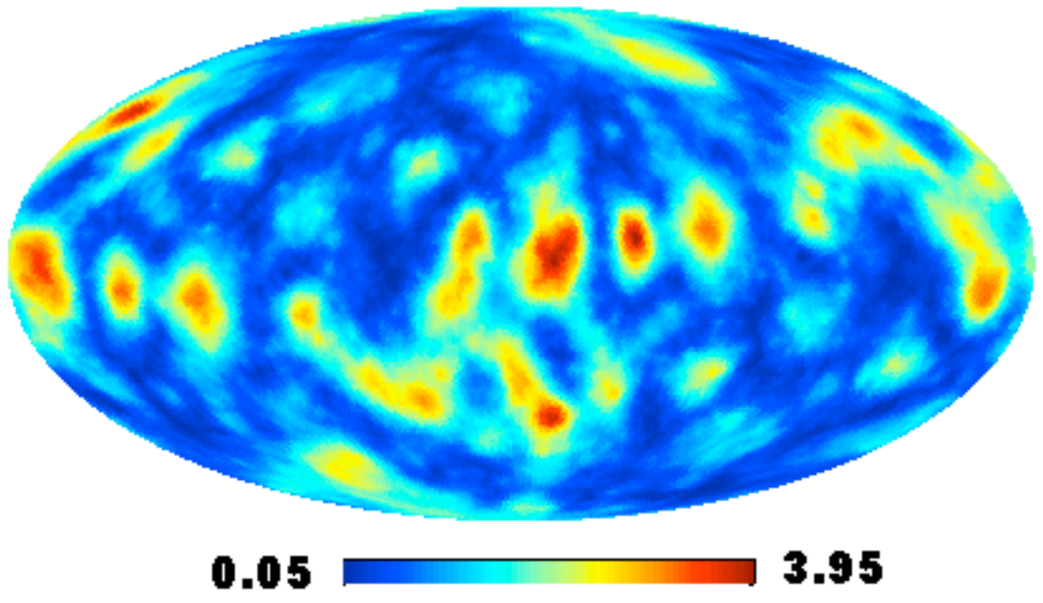

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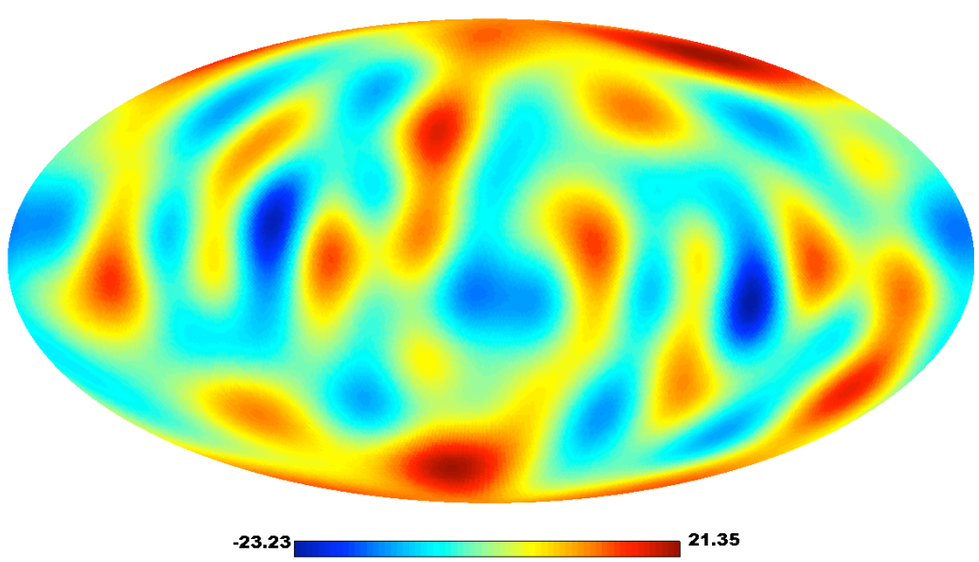


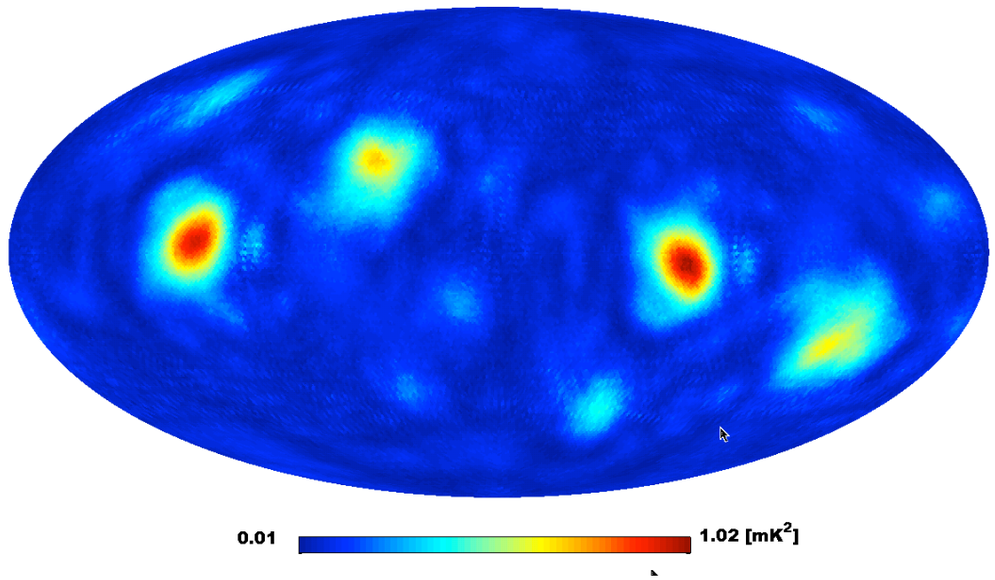


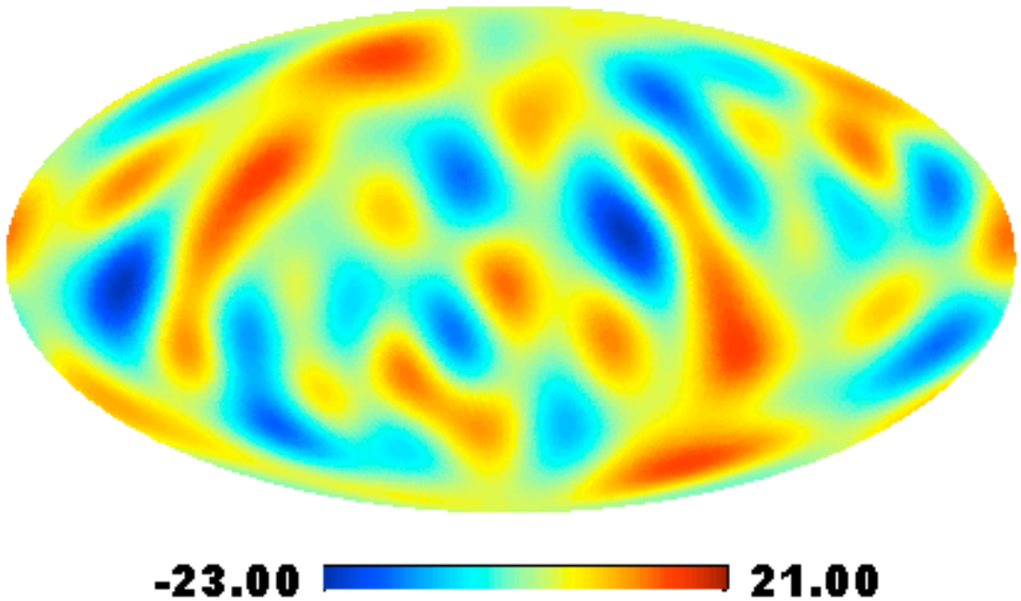


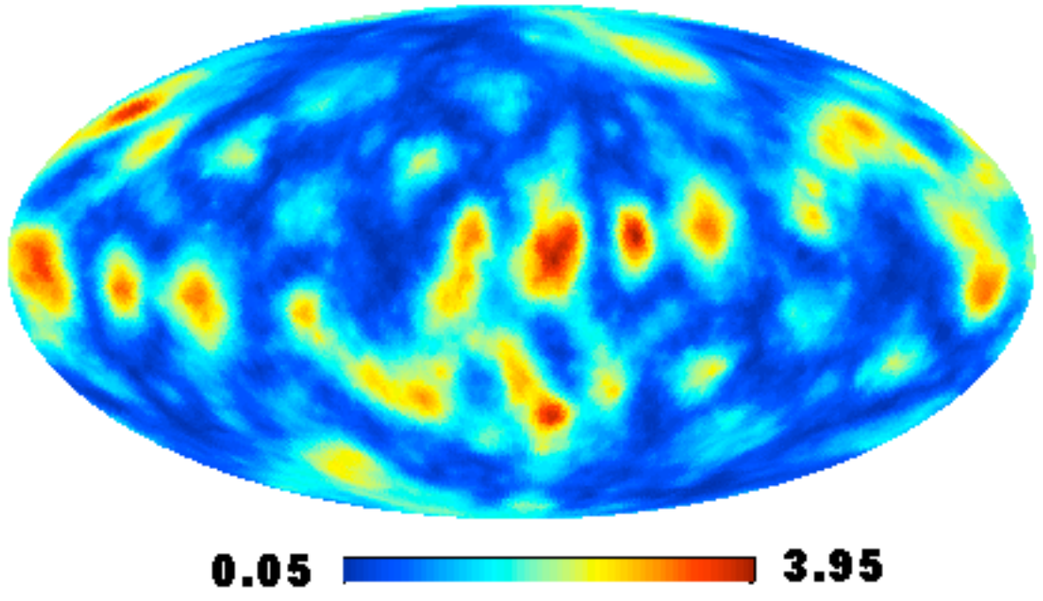

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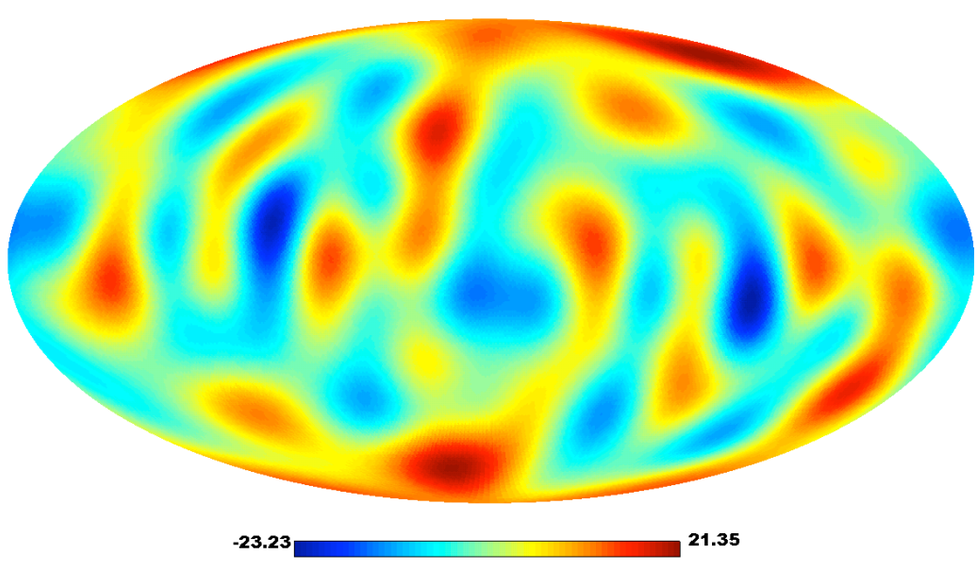


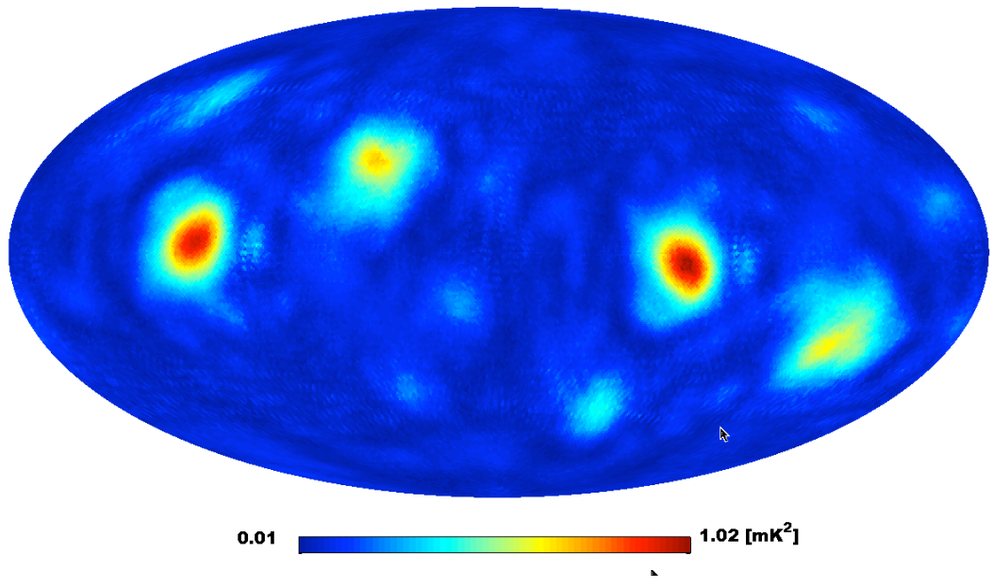


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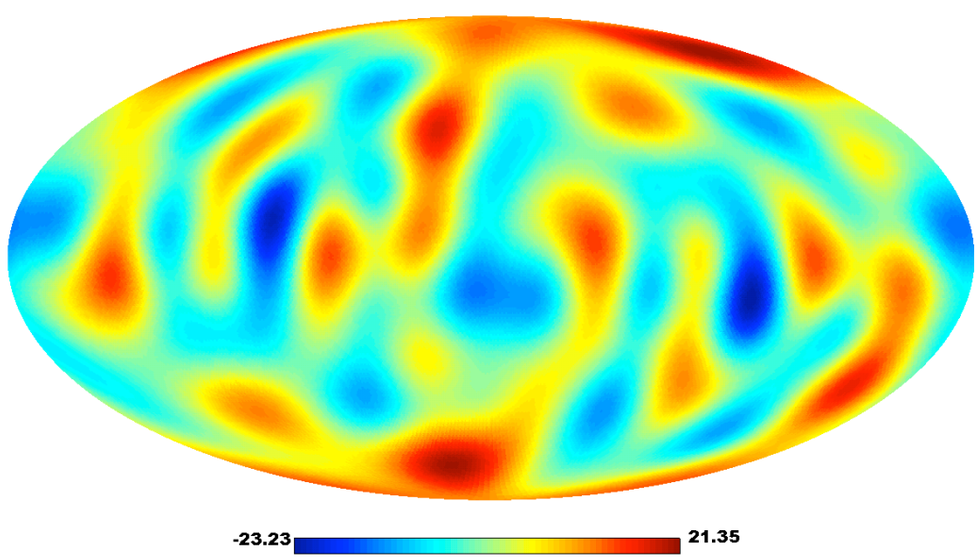


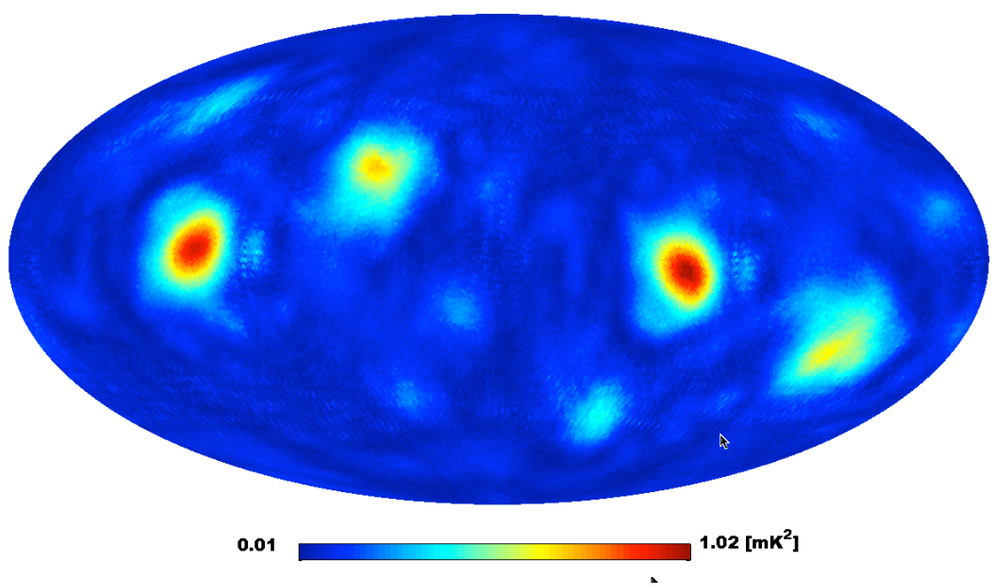


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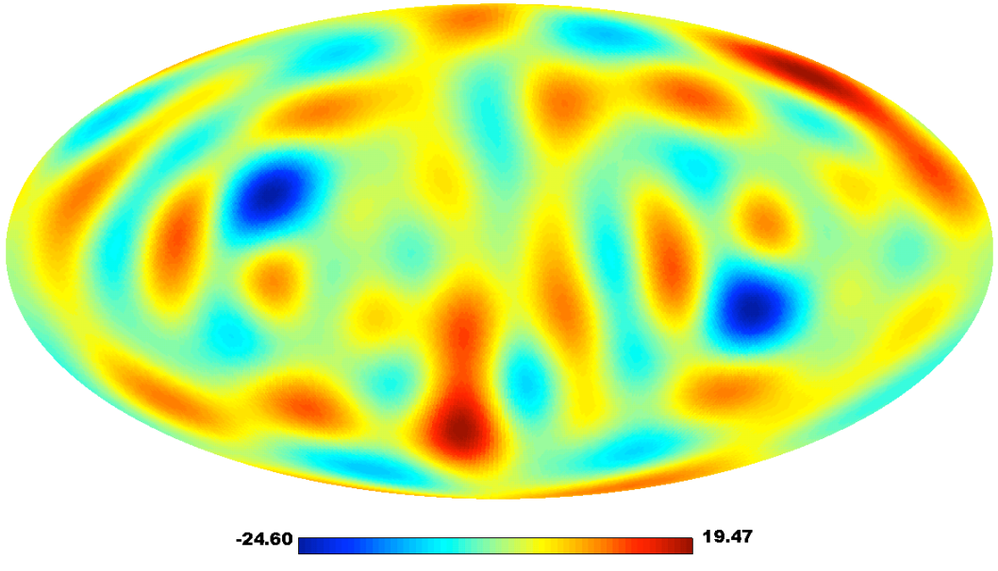

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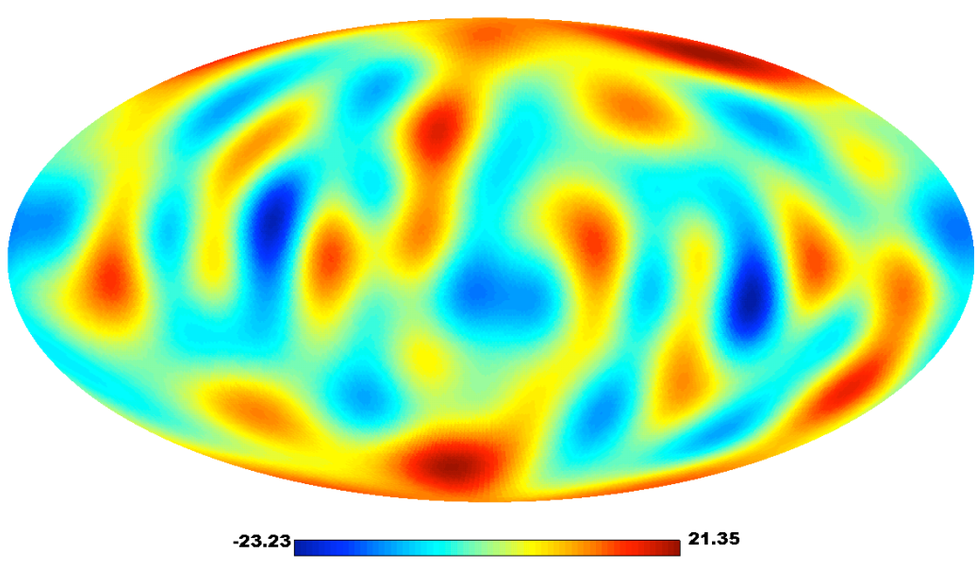


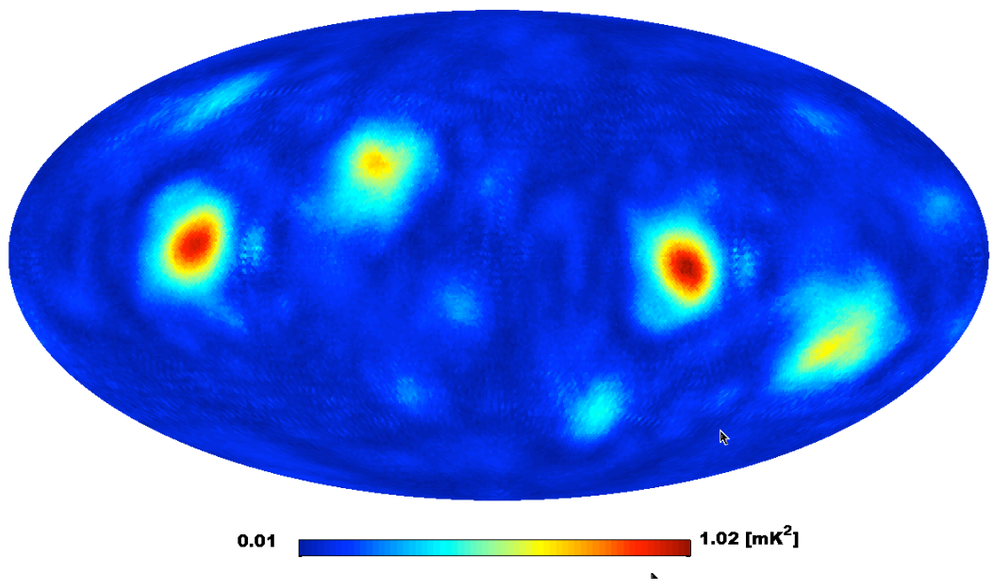


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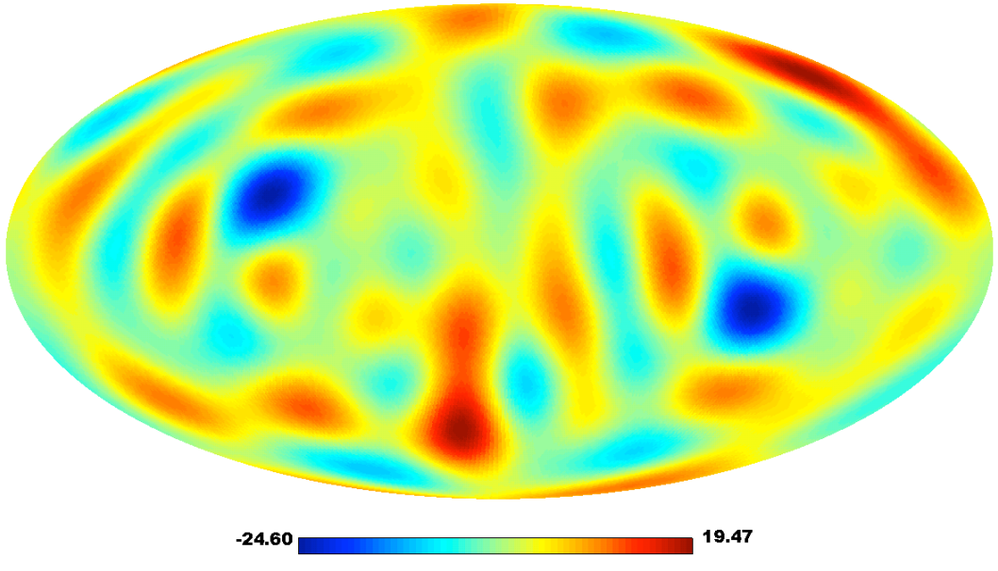


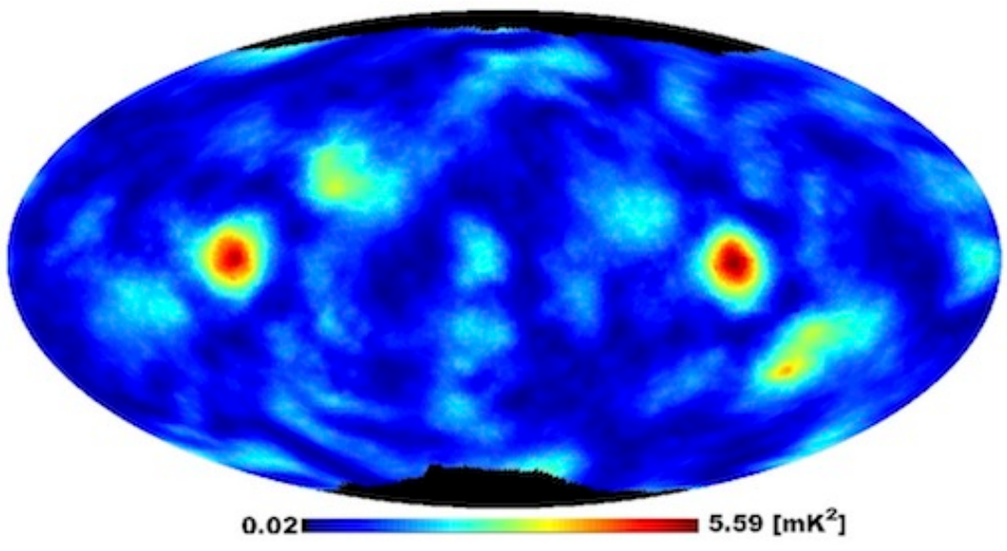

# Constraining Parameter Space

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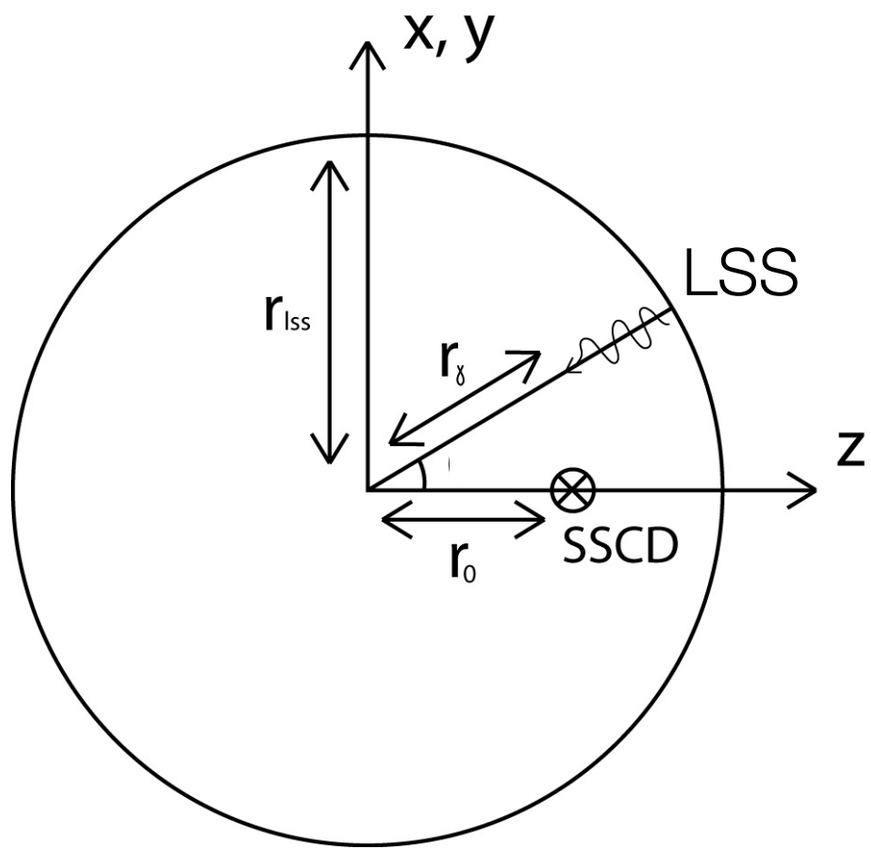

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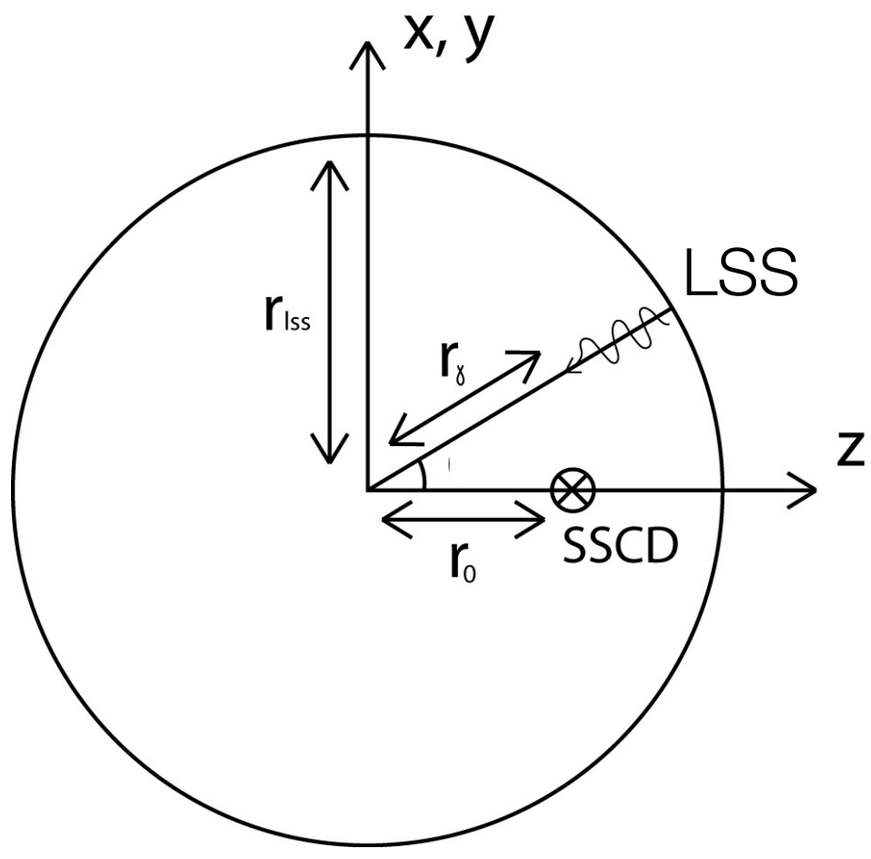

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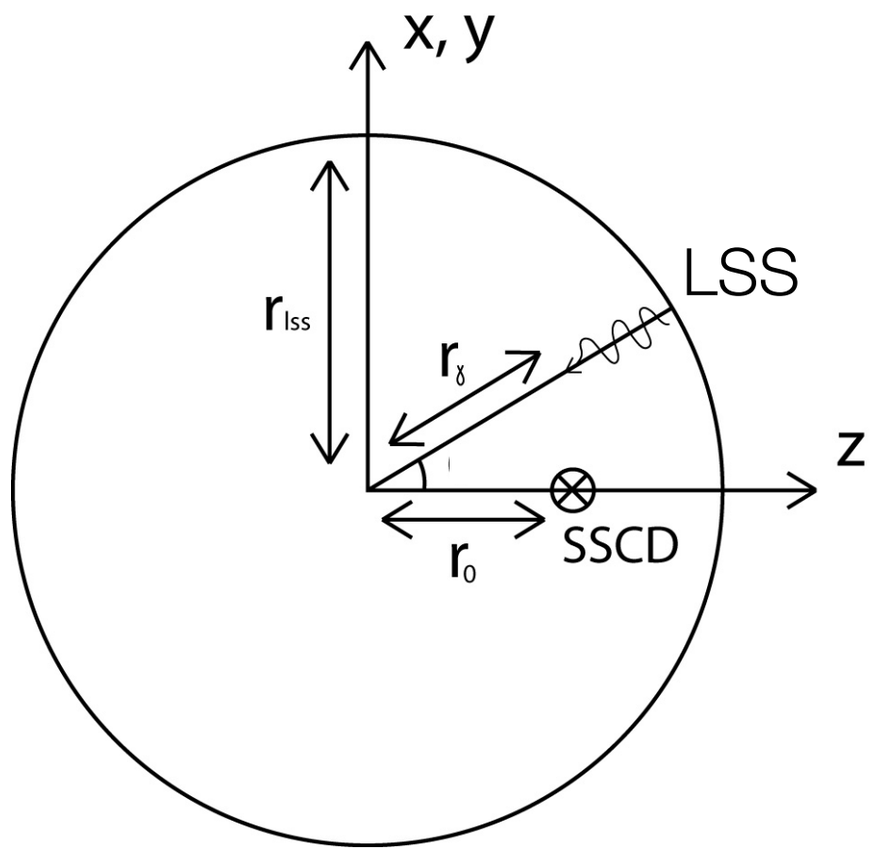

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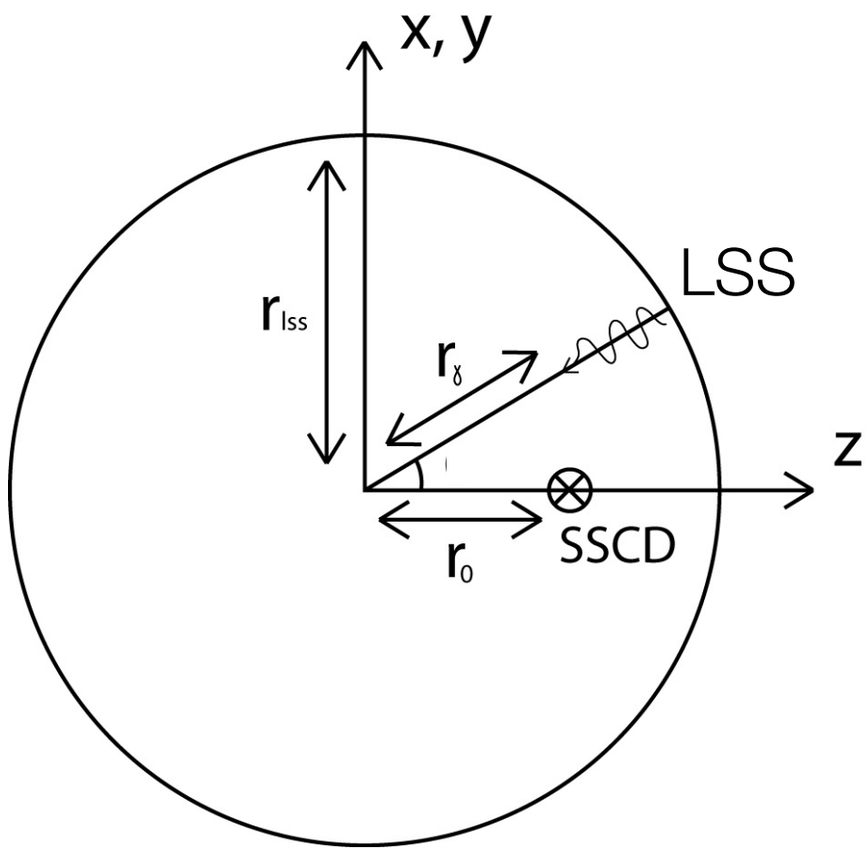

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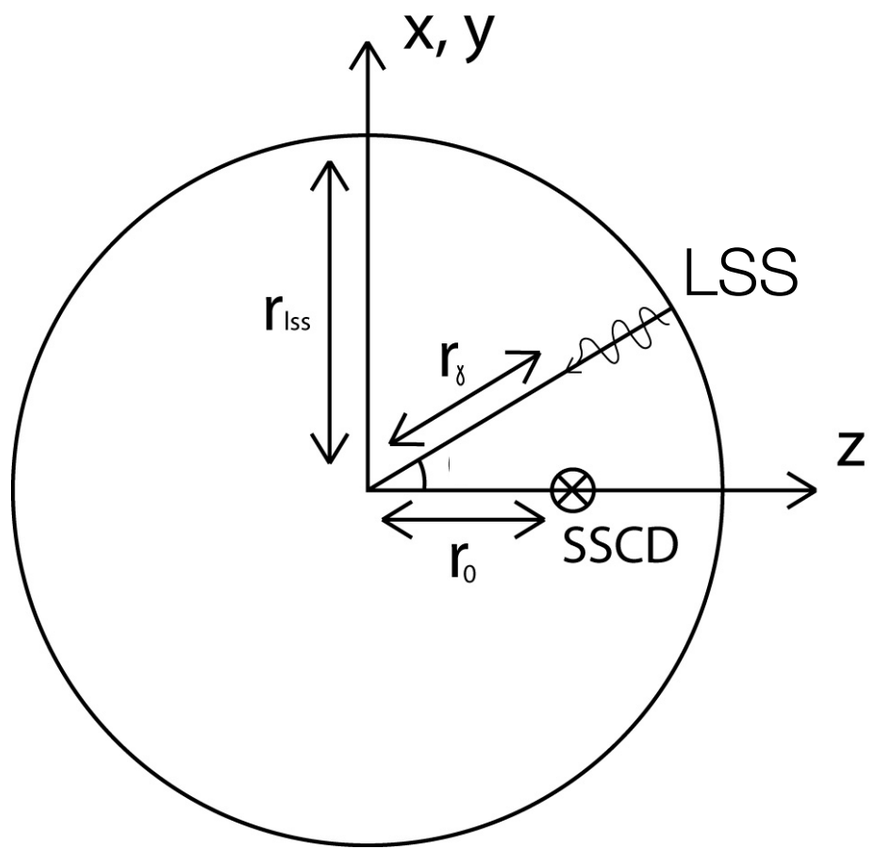

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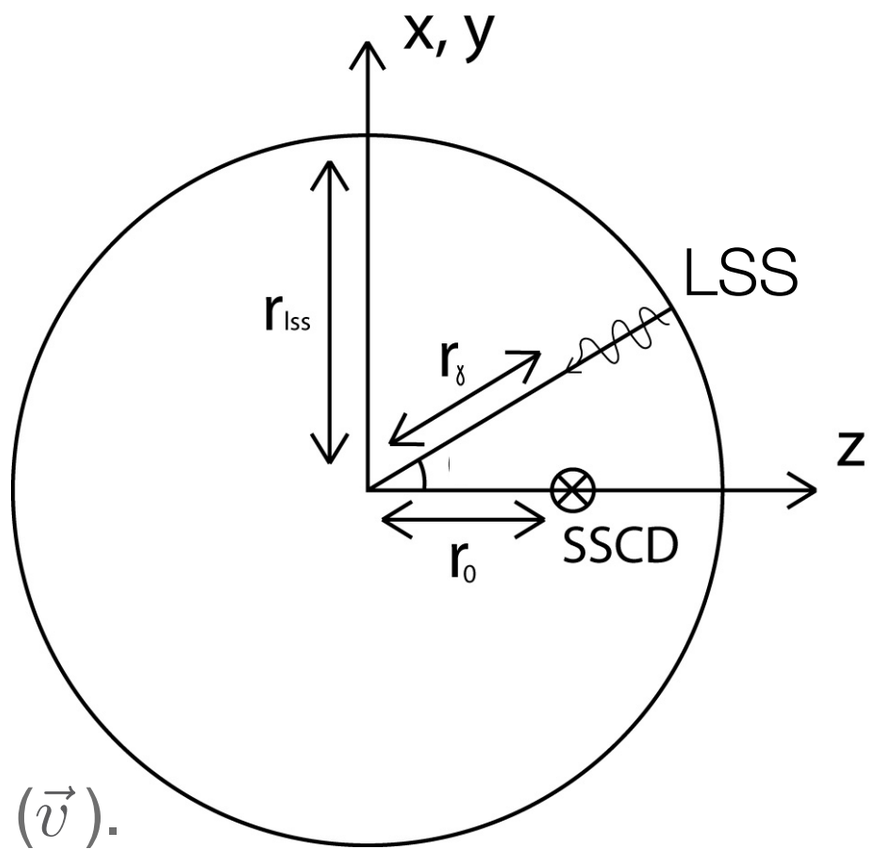

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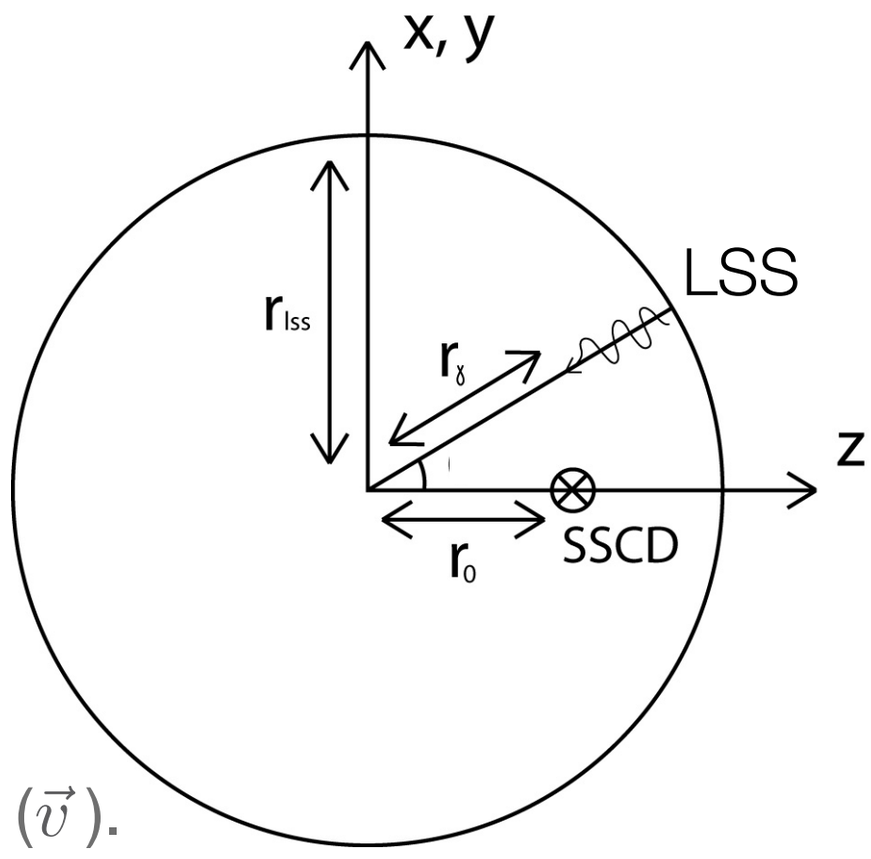

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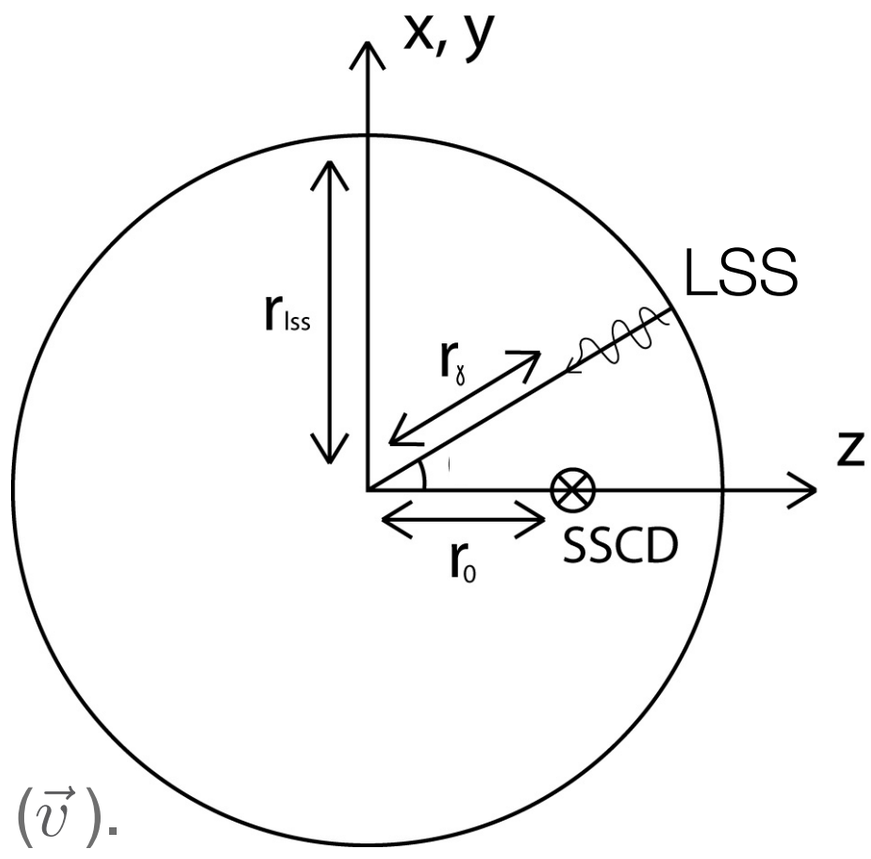
- Calculate SW + ISW for CMB, Peculiar Velocity for Local Group.
- Fit to data.



# Future

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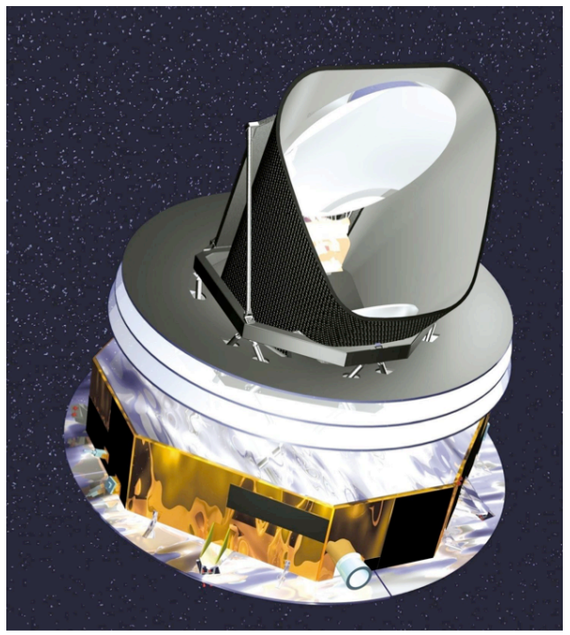
Using new observational data:



# Future

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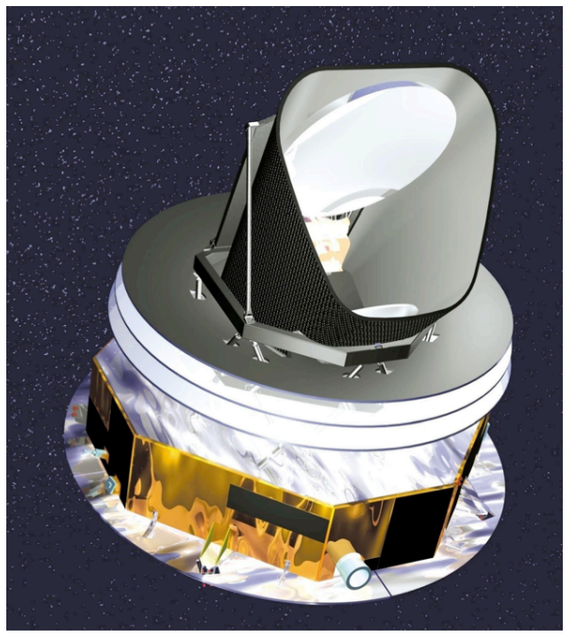
Using new observational data:

- Planck: $T_{CMB}$ Anomalies.



# Future

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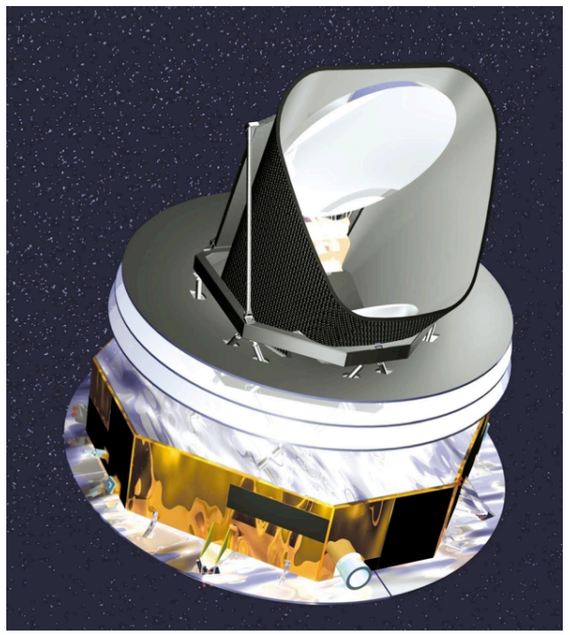
Cook's Branch 2012

Using new observational data:

- Planck: $T_{CMB}$ Anomalies.
- Planck: Weak Lensing.



# Future

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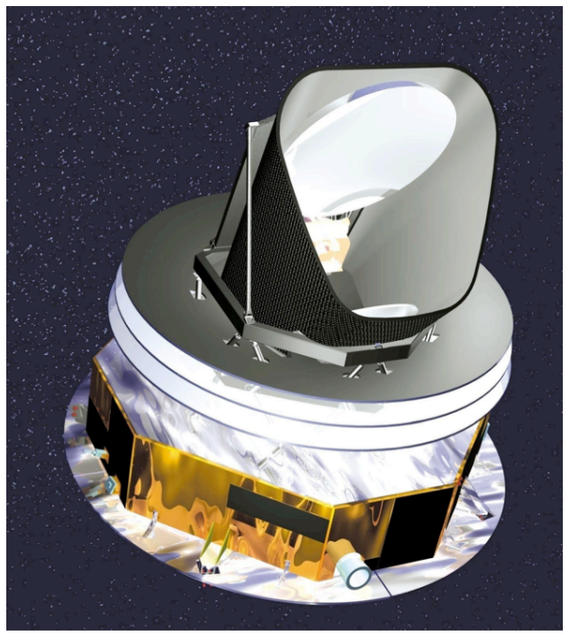

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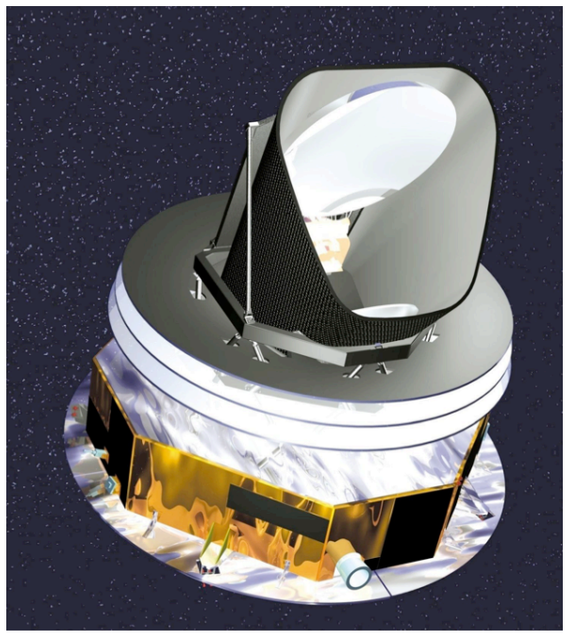
- Planck: Weak Lensing.
- Planck: BF from kSZ effect.



- SNIa: BF converges at high-z?

SCP Supernova Cosmology Project

# Conclusion

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  - Conformal Csyclic Cosmology (Penrose 2010)

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  - Finite universe topologies might induce odd-parity structure.

**Takeaway:** Phenomenology of any pre-inflationary physics might be strongly related to large scale anomalies

# *Thank You!*

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