Title: Testing the isotropy of the universe and the axis of evil

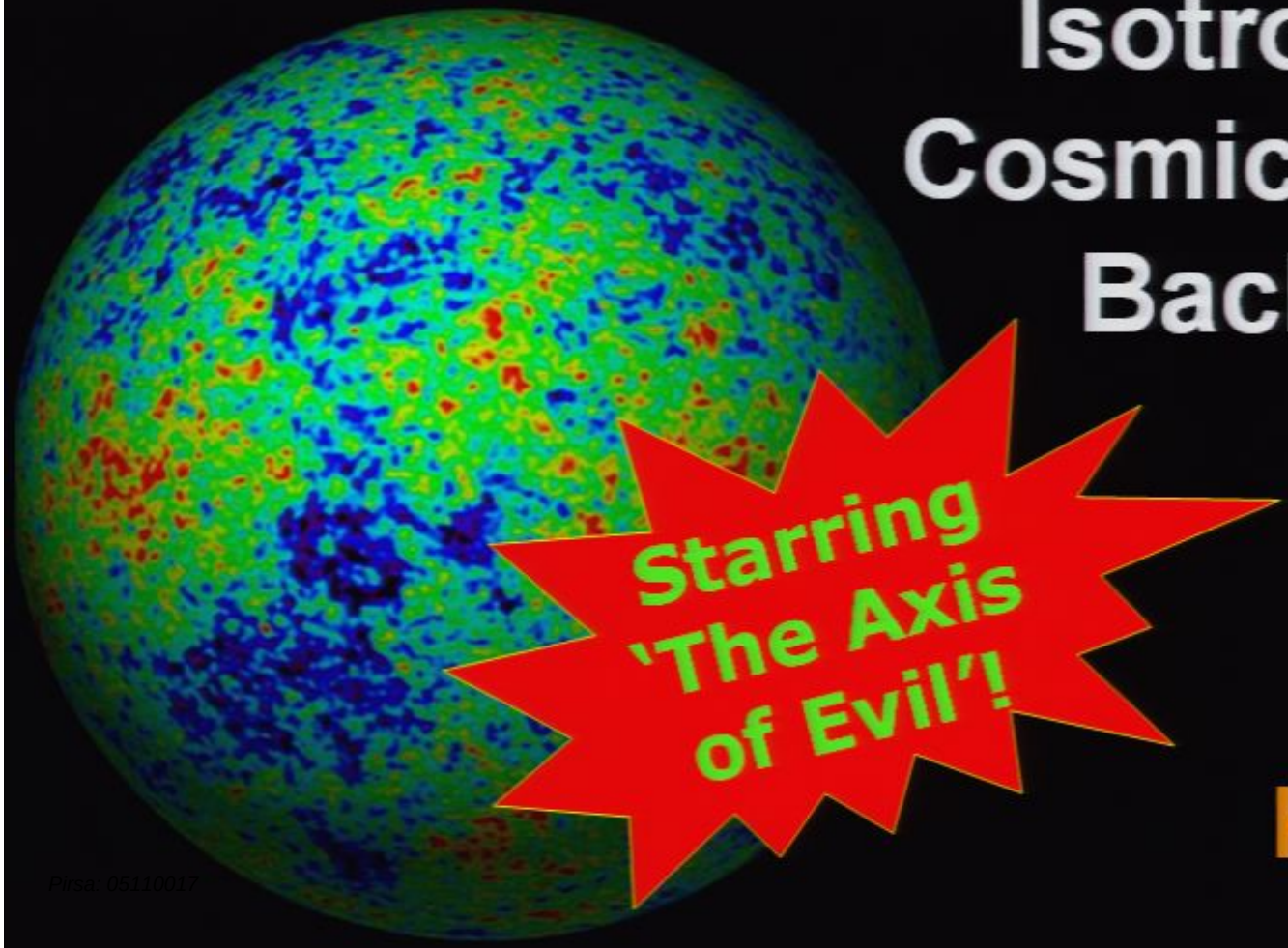
Date: Nov 22, 2005 11:00 AM

URL: http://pirsa.org/05110017

Abstract: I will review some recent claims of anomalous signatures in the WMAP data of the CMB - specifically those that indicate a departure from Statistical Isotropy. This will include an outline of various methods of analysis and the issues involved in testing the Gaussianity and Statistical Isotropy of the CMB. I will then discuss the various implications of the observations - the most exciting of which is that our Universe is not Isotropic and more complicated cosmological models need to be considered.

Imperial College London

Testing the Isotropy of the Cosmic Microwave Background



Kate Land

CONTENTS

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  - Results (Axis of Evil)
  - Further observations (Asymmetries, low power)

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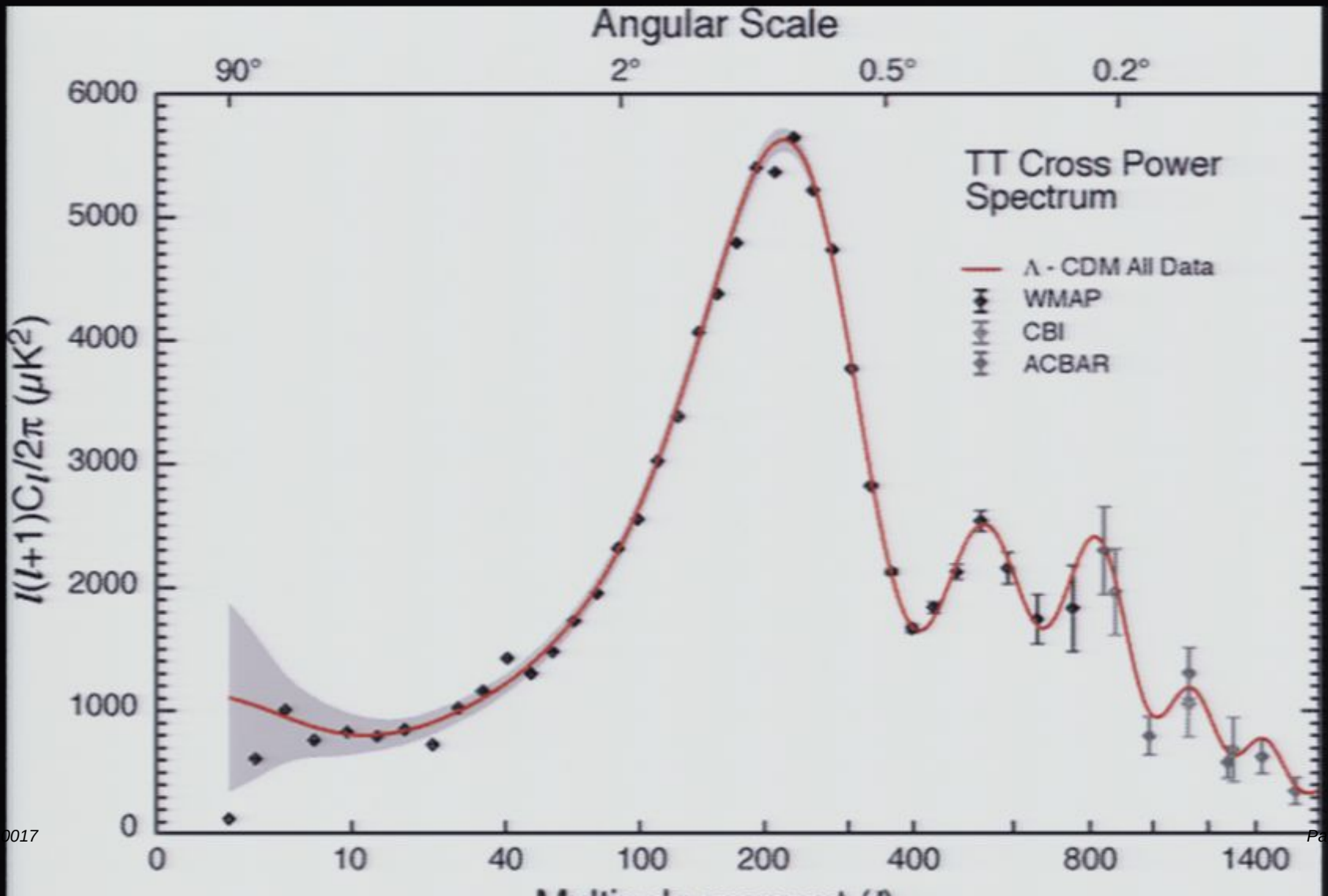
- Conclusions so far…

POWER SPECTRUM FROM WMAP



MOTIVATION: Common Assumptions

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  The universe is Homogeneous and Isotropic, on large scales.

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  ➔ **Statistical Isotropy**

- **Gaussianity** - as predicted by simple inflationary models

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These issues are often mixed

MULTIPOLES

$$T(\mathbf{n}) = \sum_{l} \sum_{\mathrm{m}} a_{lm} Y_{lm}(\mathbf{n})$$

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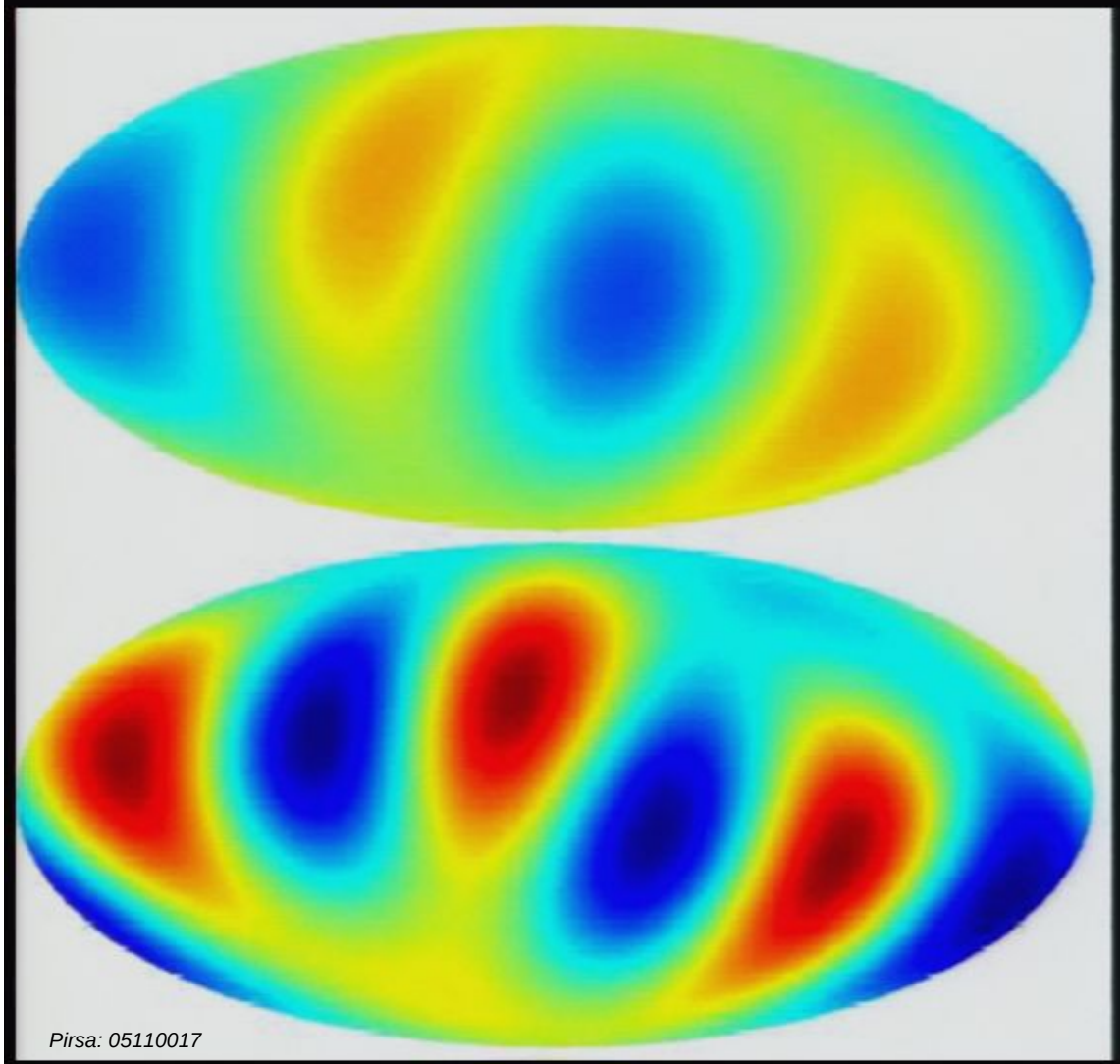
Degrees of freedom

$(2l+1)$ = 3 *rotational* & $(2l-2)$ *invariants*

MULTIPOLE FRAMES



Pirsa: 05110017

"Intriguingly, both the quadrupole and the octopole are seen to have power suppressed along a particular spatial axis, which lines up between the two, roughly towards

(l, b) ~ (-110, 60)

in Virgo."

PLANARITY

Oliveira et al. 0307282

$$\max_{\hat{\mathbf{n}}} \left\{ \sum_m m^2 |a_{\ell m}(\hat{\mathbf{n}})|^2 \right\}$$

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$$\text{MAX}_{\hat{\mathbf{n}}} \left\{ \sum_m m^2 |a_{\ell m}(\hat{\mathbf{n}})|^2 \right\}$$

Axis of maximum planarity

$$\begin{aligned} \hat{\mathbf{n}}_2 &= (-0.1145, -0.5265, 0.8424), \\ \hat{\mathbf{n}}_3 &= (-0.2578, -0.4207, 0.8698), \end{aligned} \qquad (2)$$

i.e., both roughly in the direction of $(l, b) \sim (-110°, 60°)$ in Virgo.

MULTIPOLE FRAMES II

When does a multipole look most like a pure m-mode?

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$$r_l = \max_{m\mathbf{n}} \frac{C_{lm}}{(2l+1)\hat{C}_l}$$

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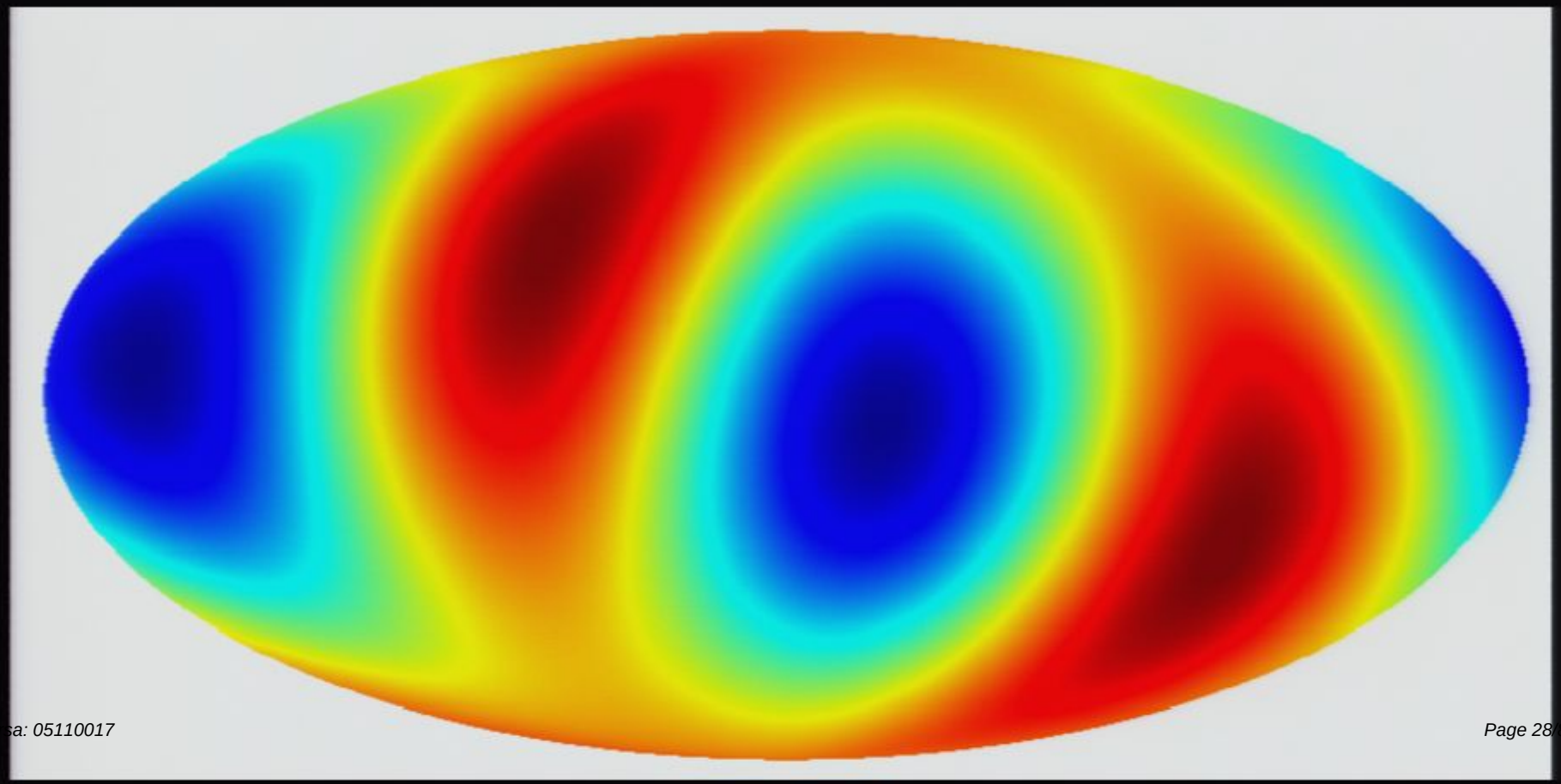
DIRECTION

$l = 2$ (Quadrupole)



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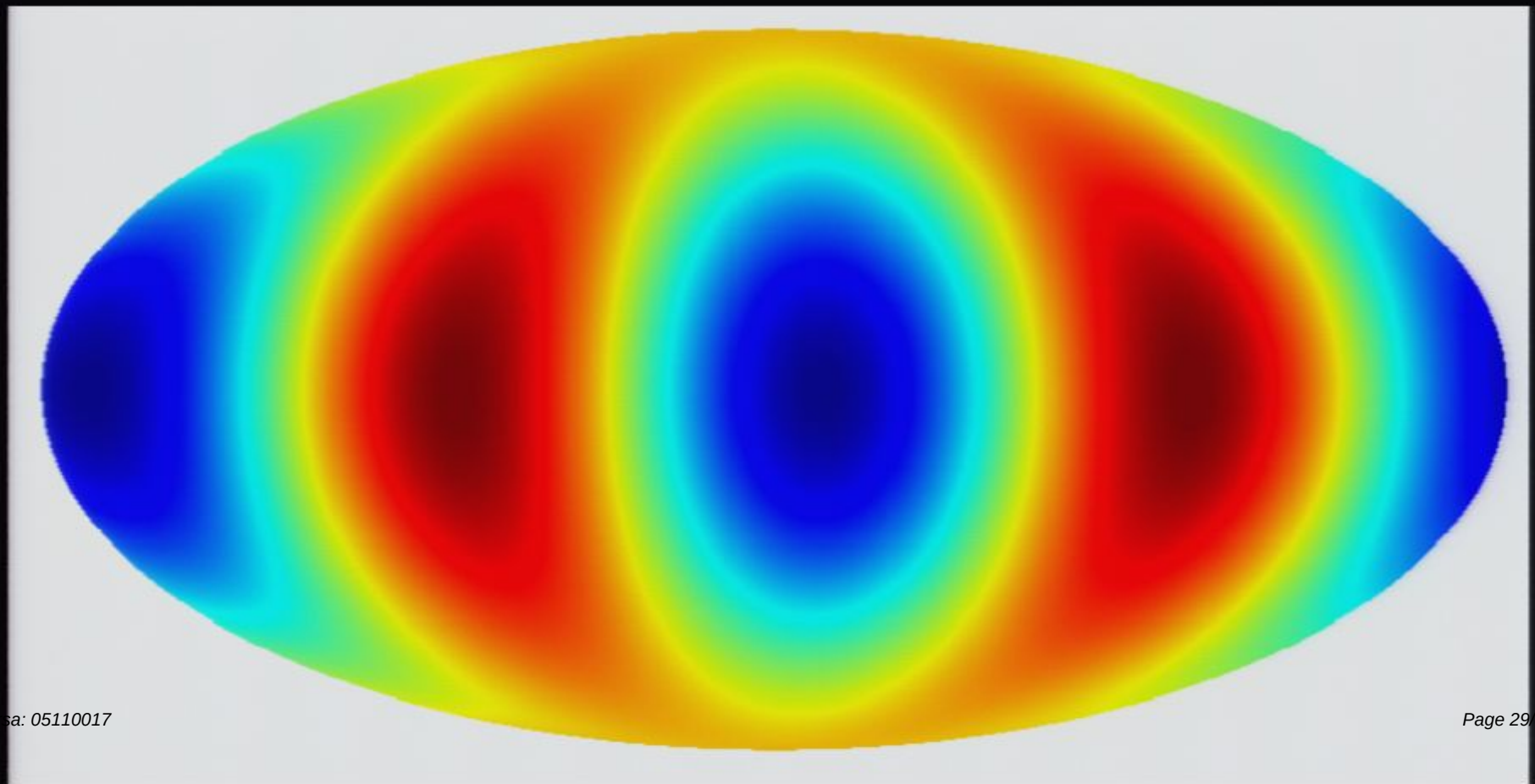
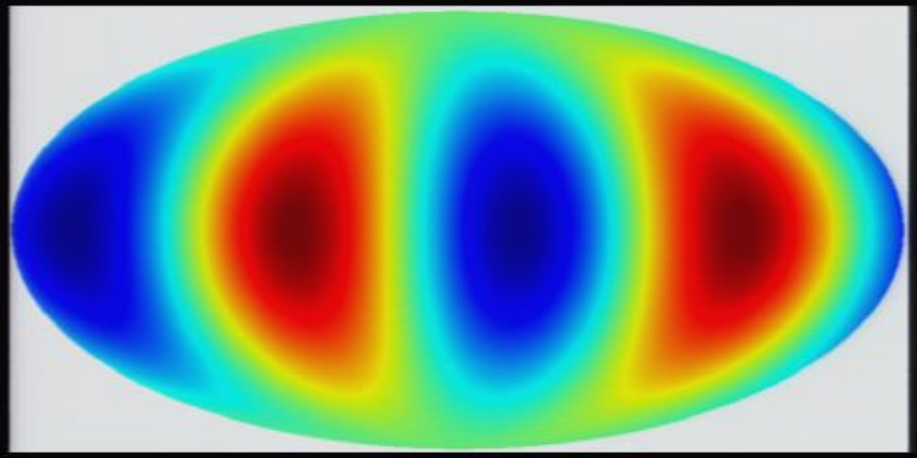
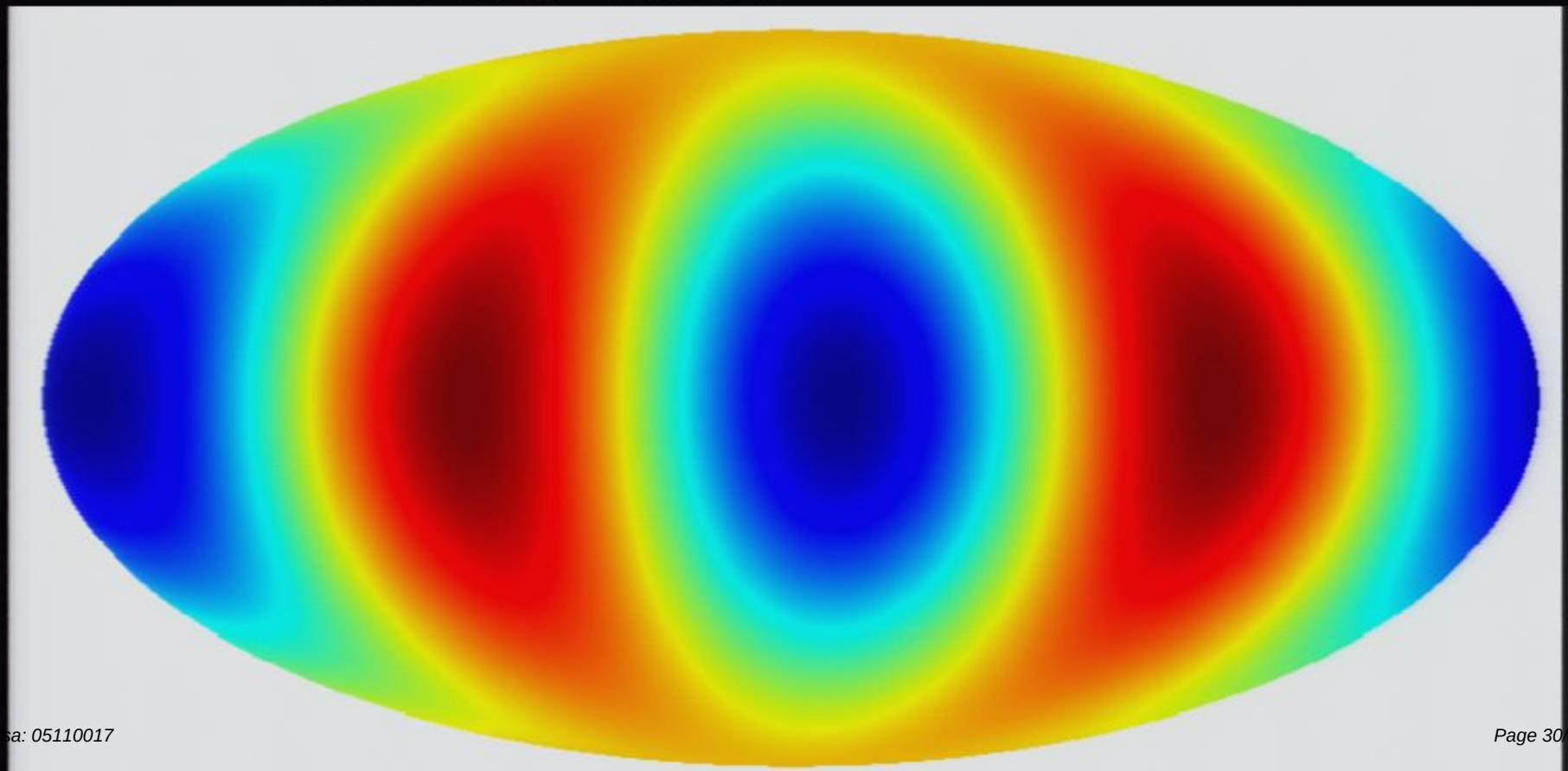


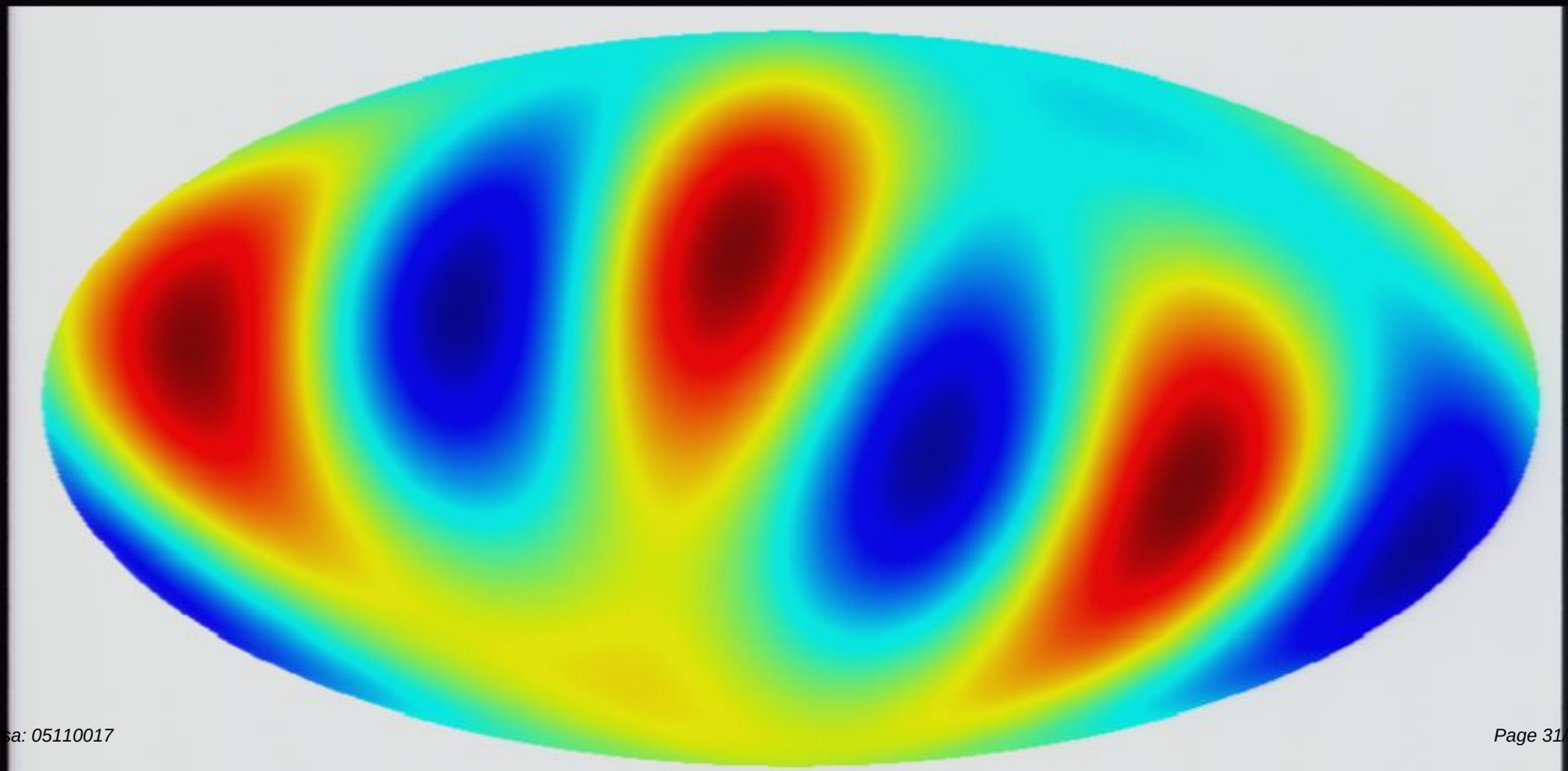
$l = 2$ (Quadrupole)

SHAPE $m = 2$
RATIO 0.957





$l = 3$ (Octopole)



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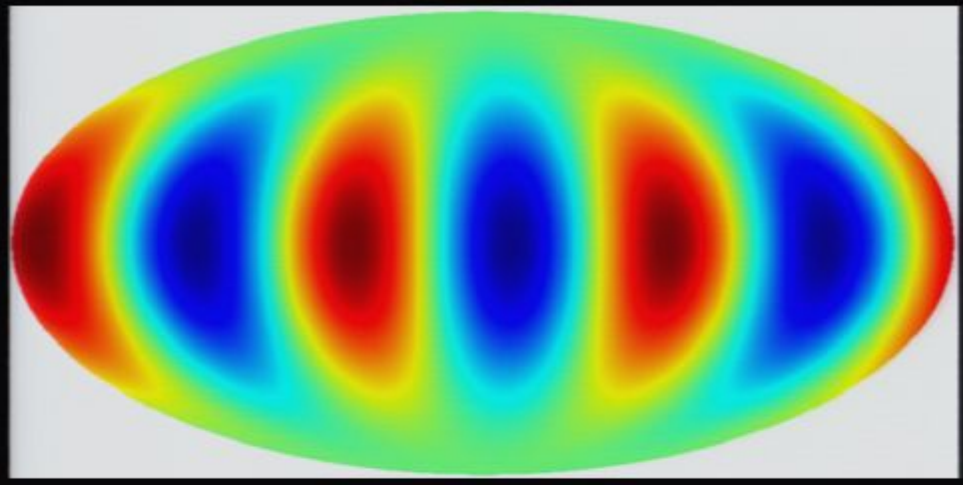

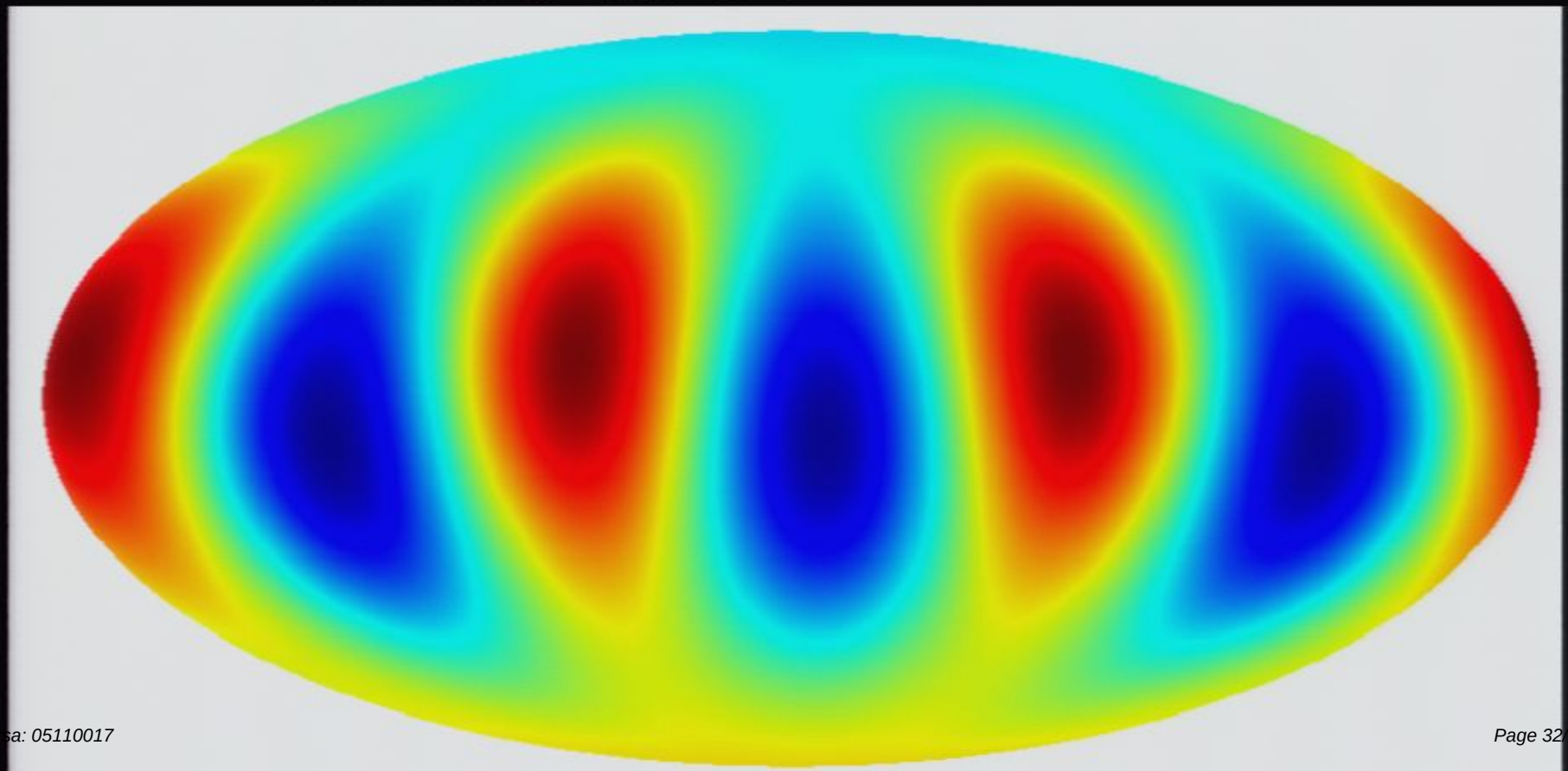

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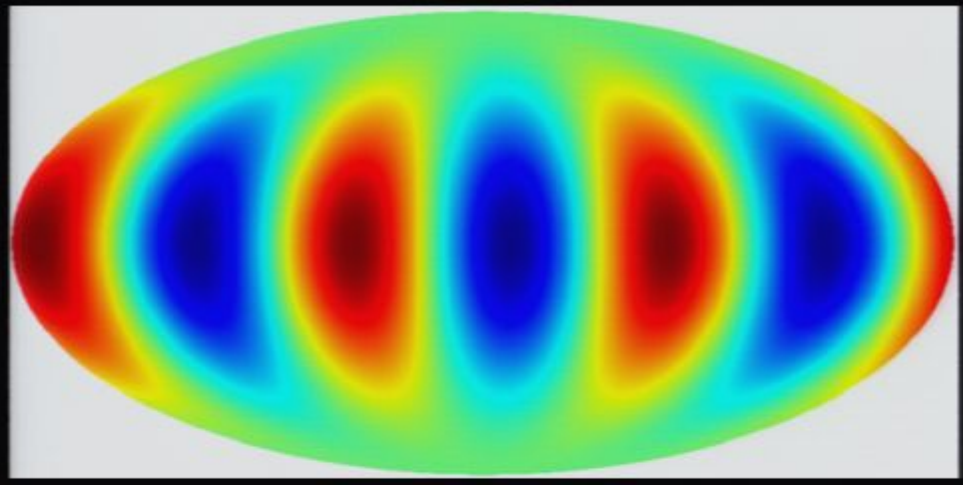
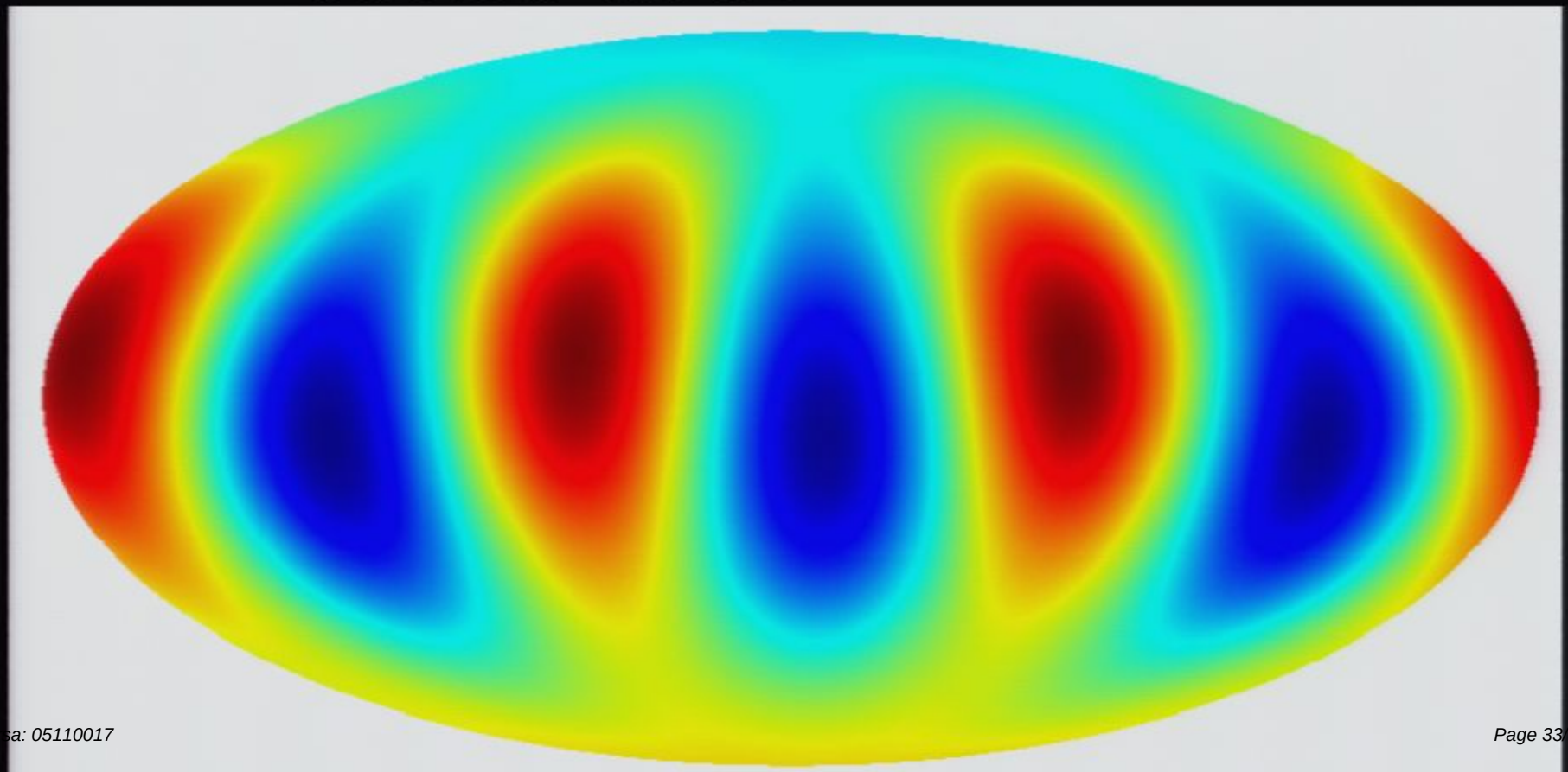
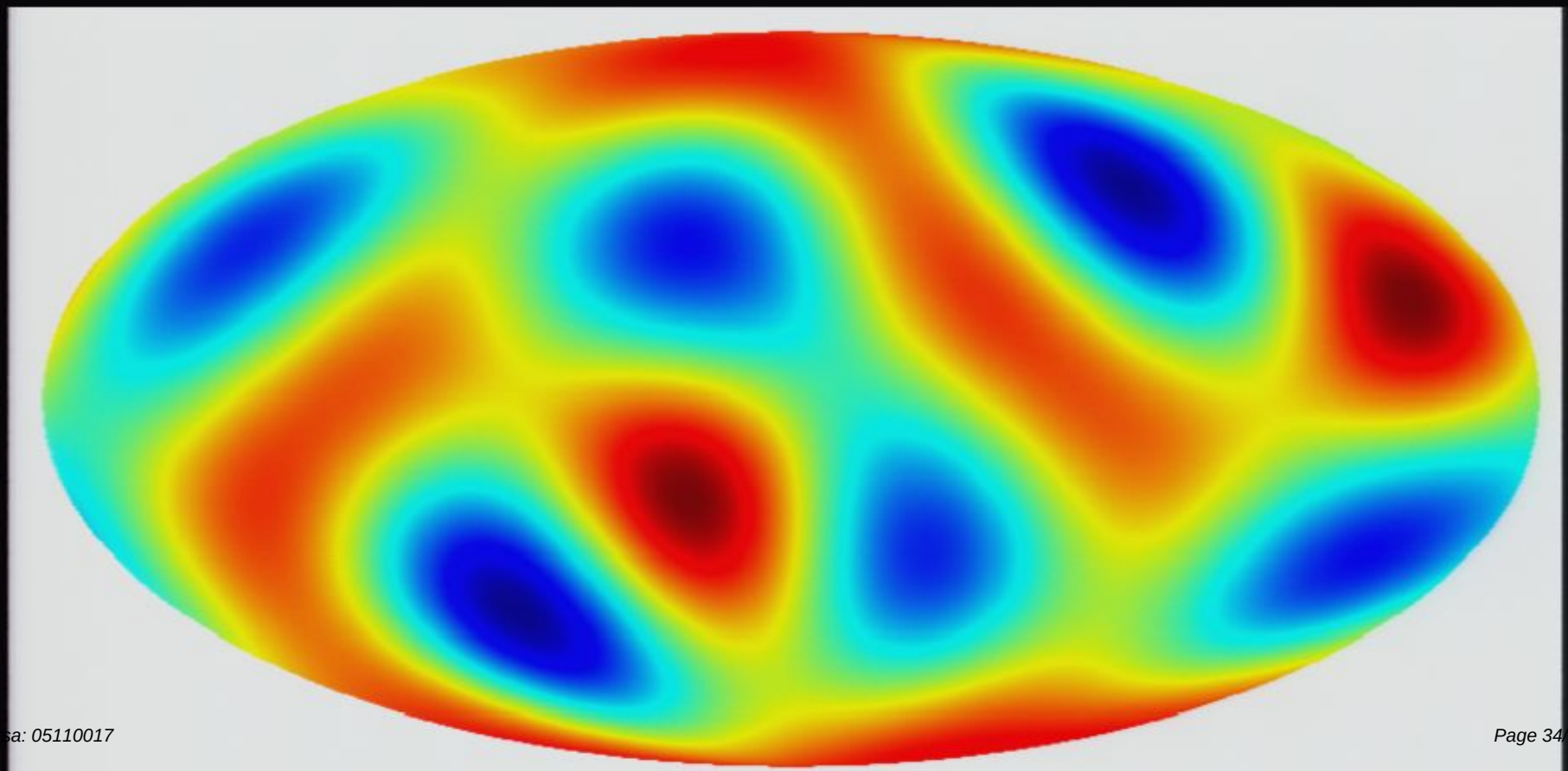


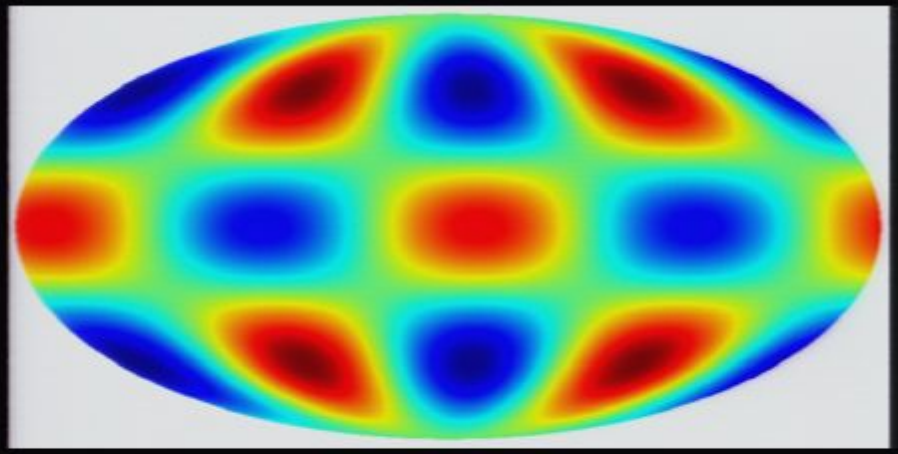


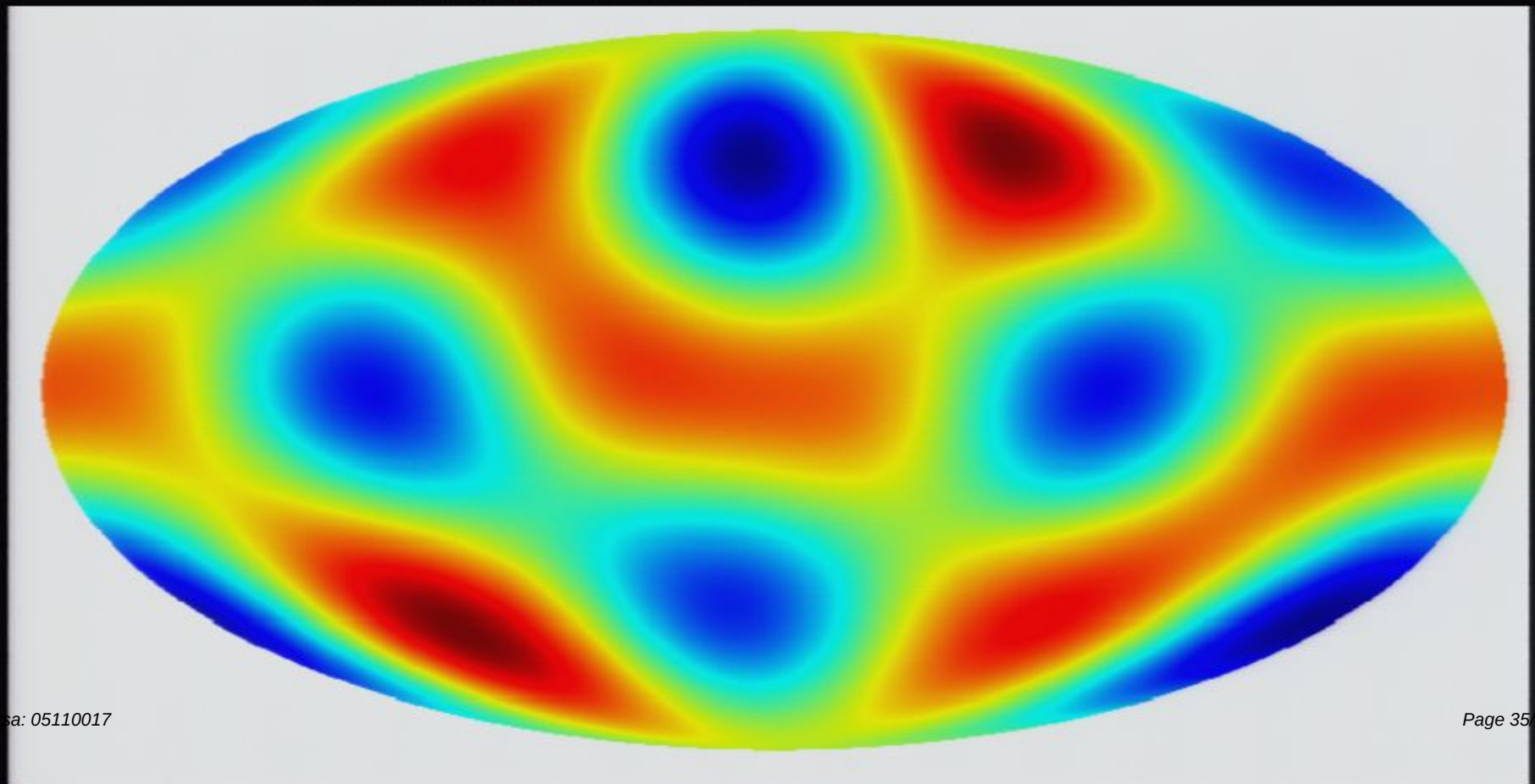
$l = 4$



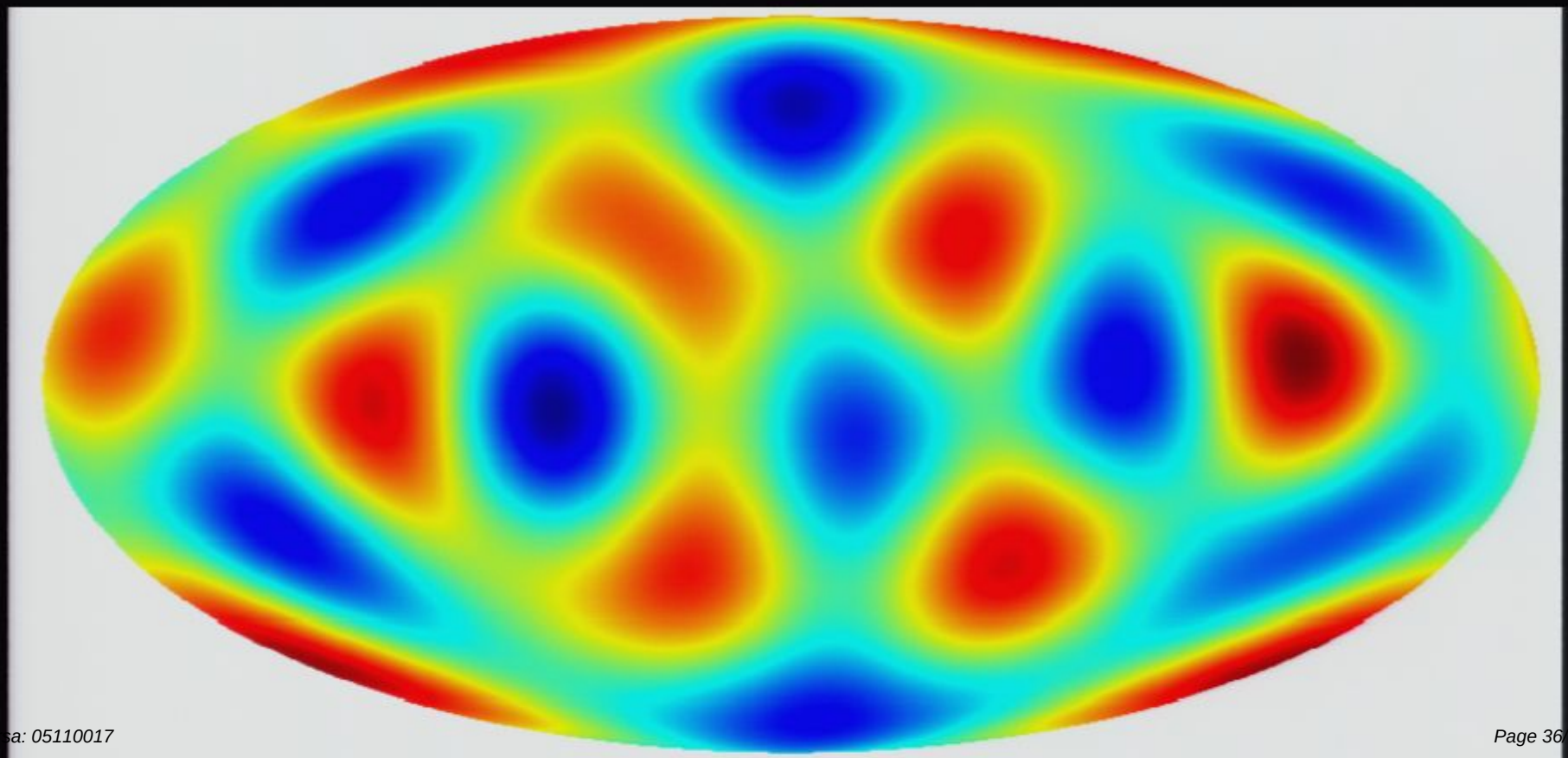
$l = 4$

SHAPE $m = 2$
RATIO 0.875





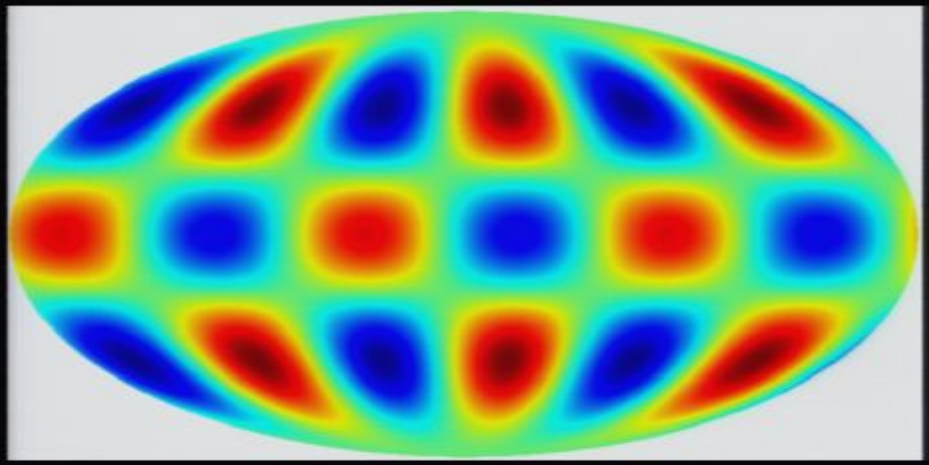
$l = 5$

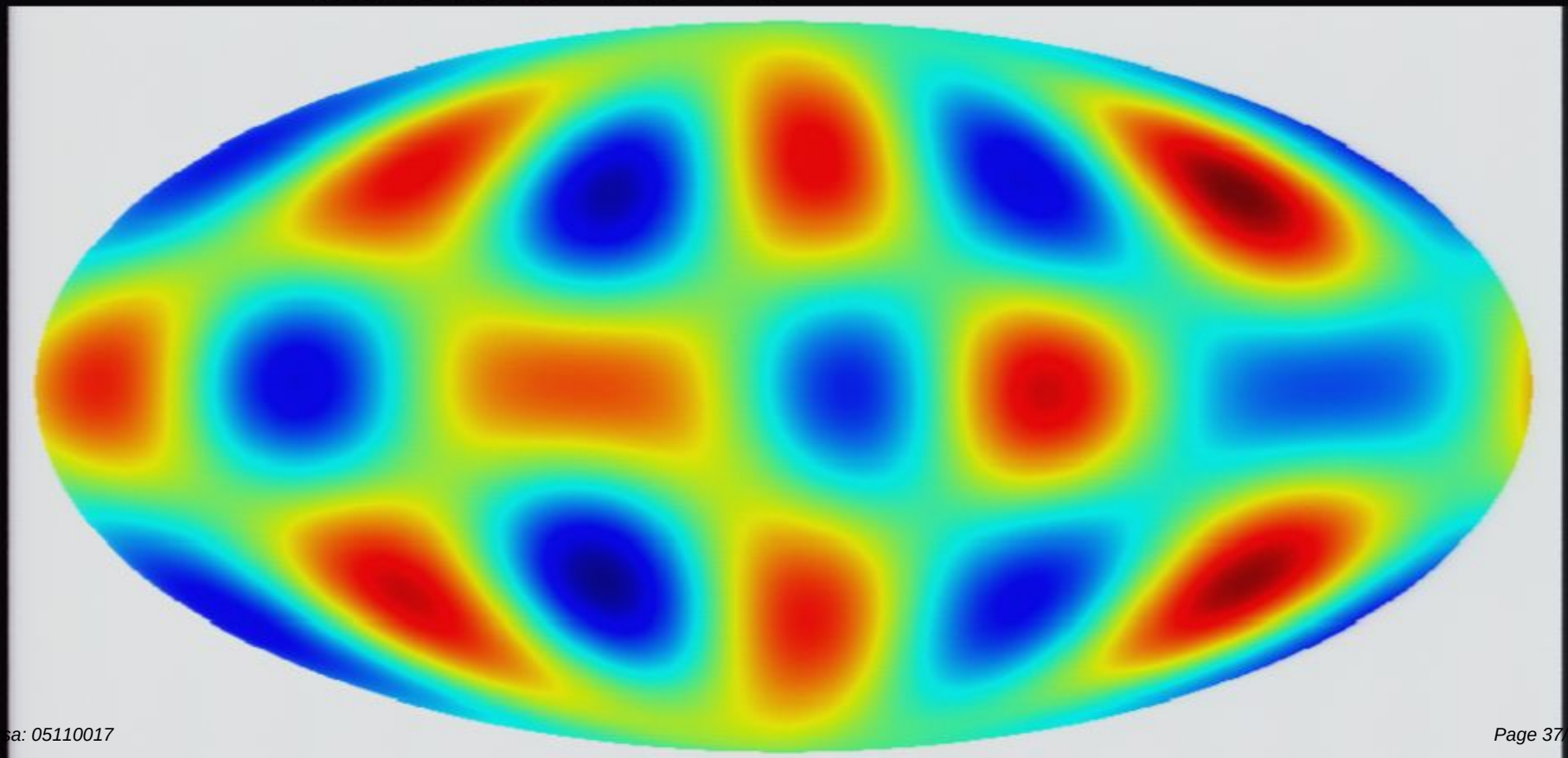


$l = 5$

SHAPE $m = 3$

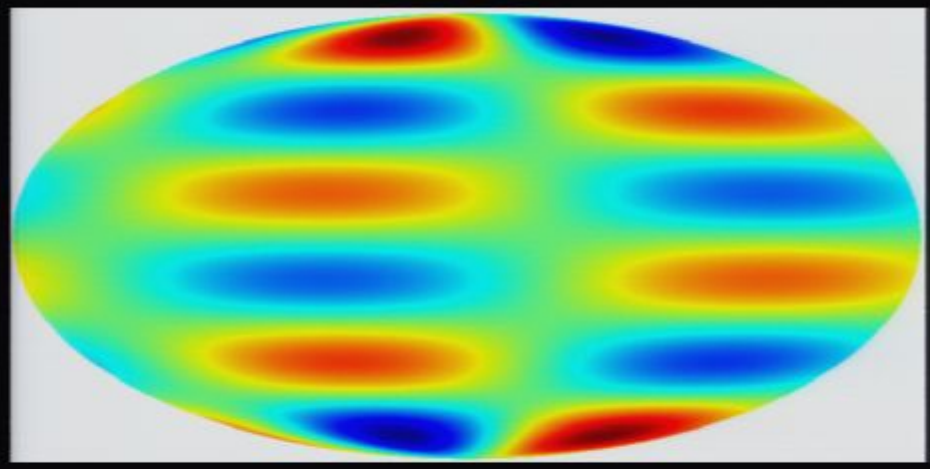
RATIO 0.895

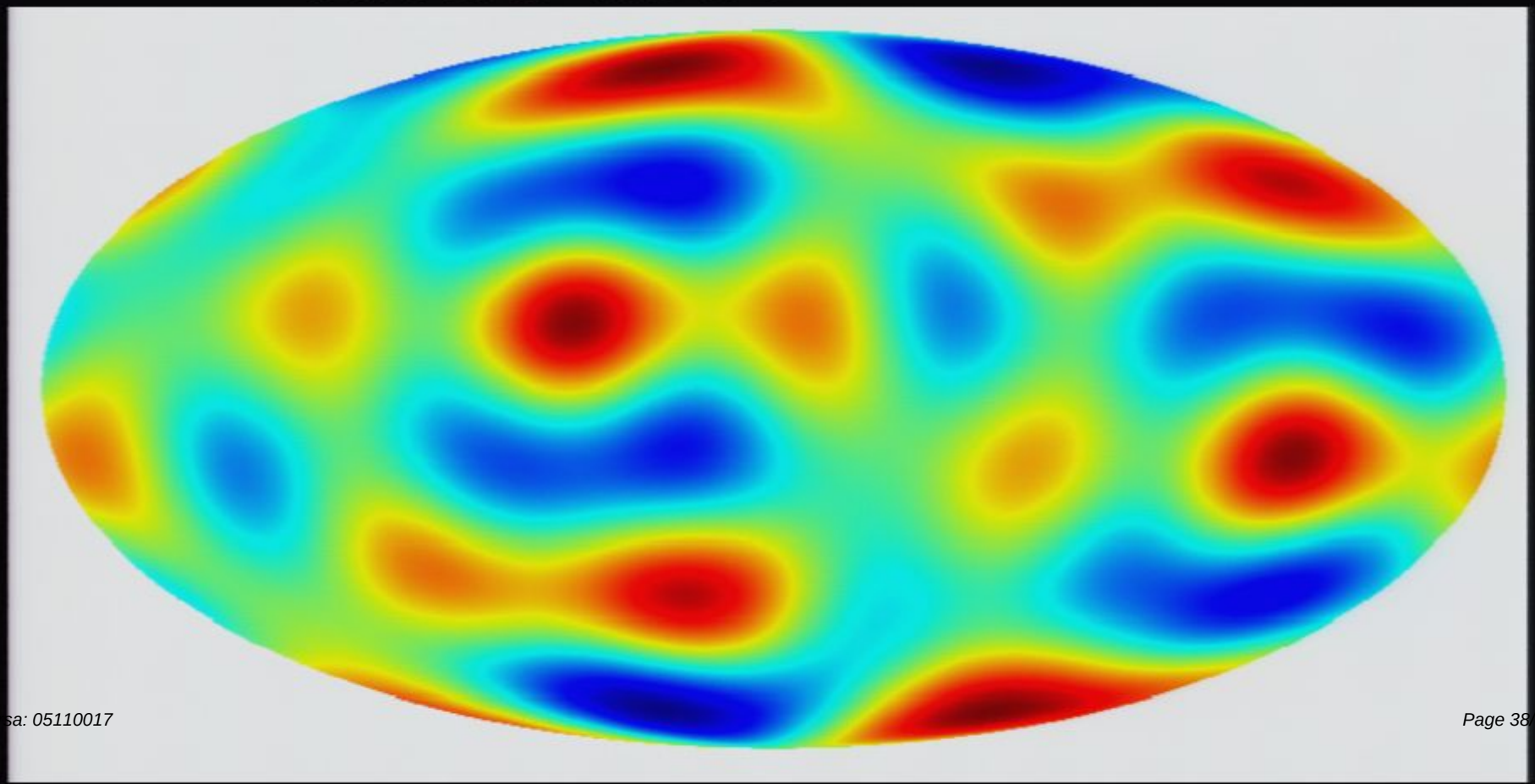




$l = 6$

SHAPE $m = 1$
RATIO 0.802





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Not just favouring one shape. Not always planar.

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Not significant – some ‘m preference’ is normal.

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'AXIS OF EVIL'

Land & Magueijo PRL(95)071301

- **SHAPES** m_l

Not just favouring one shape. Not always planar.

- **RATIOS** r_l

Not significant – some 'm preference' is normal.

- **DIRECTIONS** $\mathbf{n}_l$

Highly correlated for l = 2,3,4,5

All find direction $(l, b) \sim (-110, 60)$

Rejected by 99.9%

MULTIPOLE VECTORS

Copi, Huterer, Starkman PRD(70)043515. Copi &al. astro-ph/0508047

$$T_l(\mathbf{n}) = A_l\,(\mathbf{n}.\mathbf{v}_1)\ldots(\mathbf{n}.\mathbf{v}_l) + R_l(\mathbf{n})$$

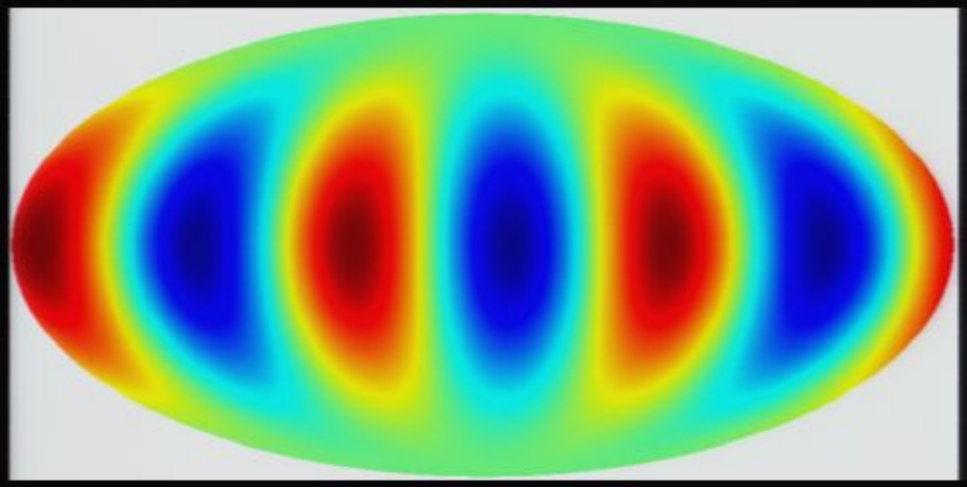
Will highlight directions

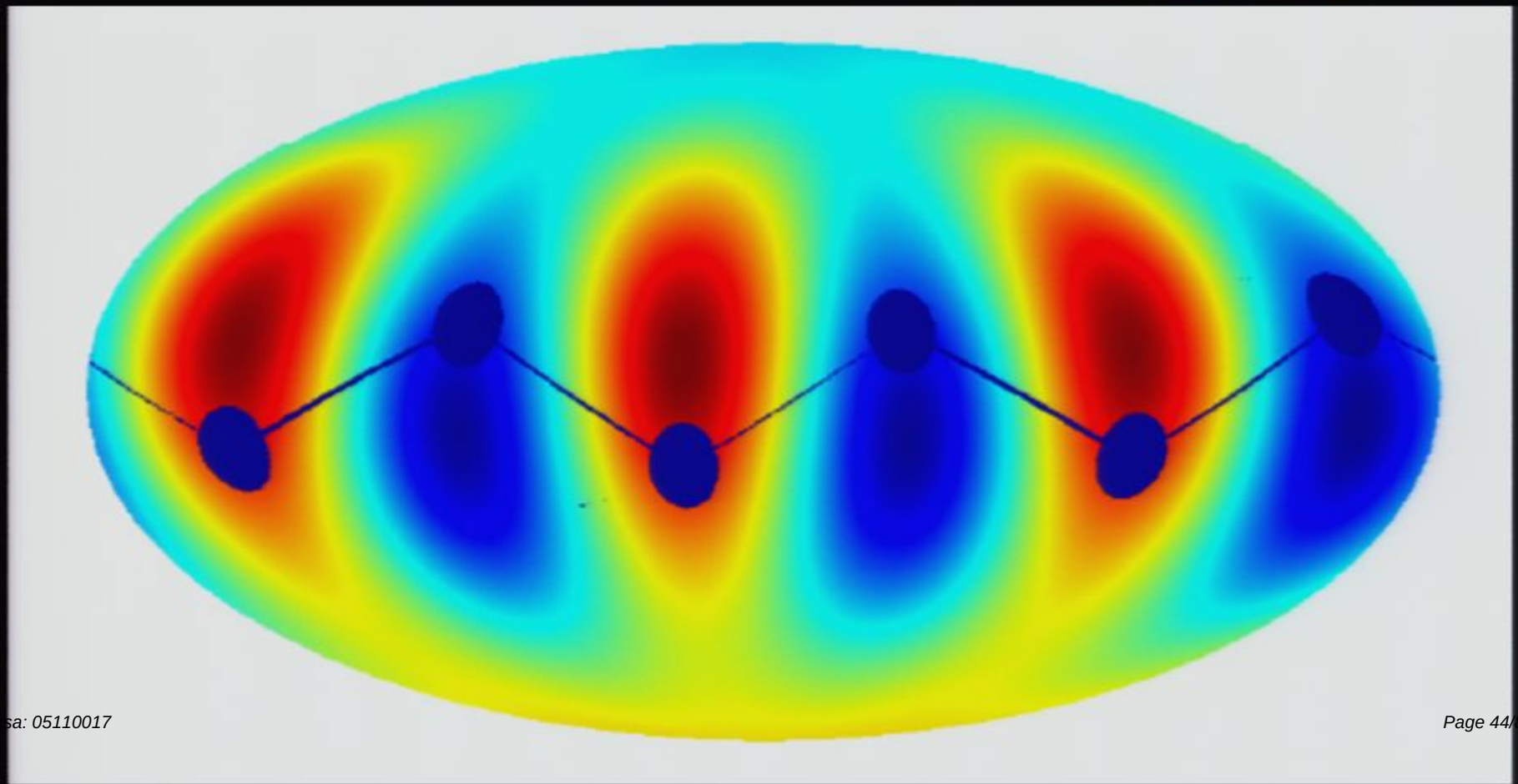
Simple form for pure m-mode

$$T_l = Y_{lm}(\mathbf{n})$$

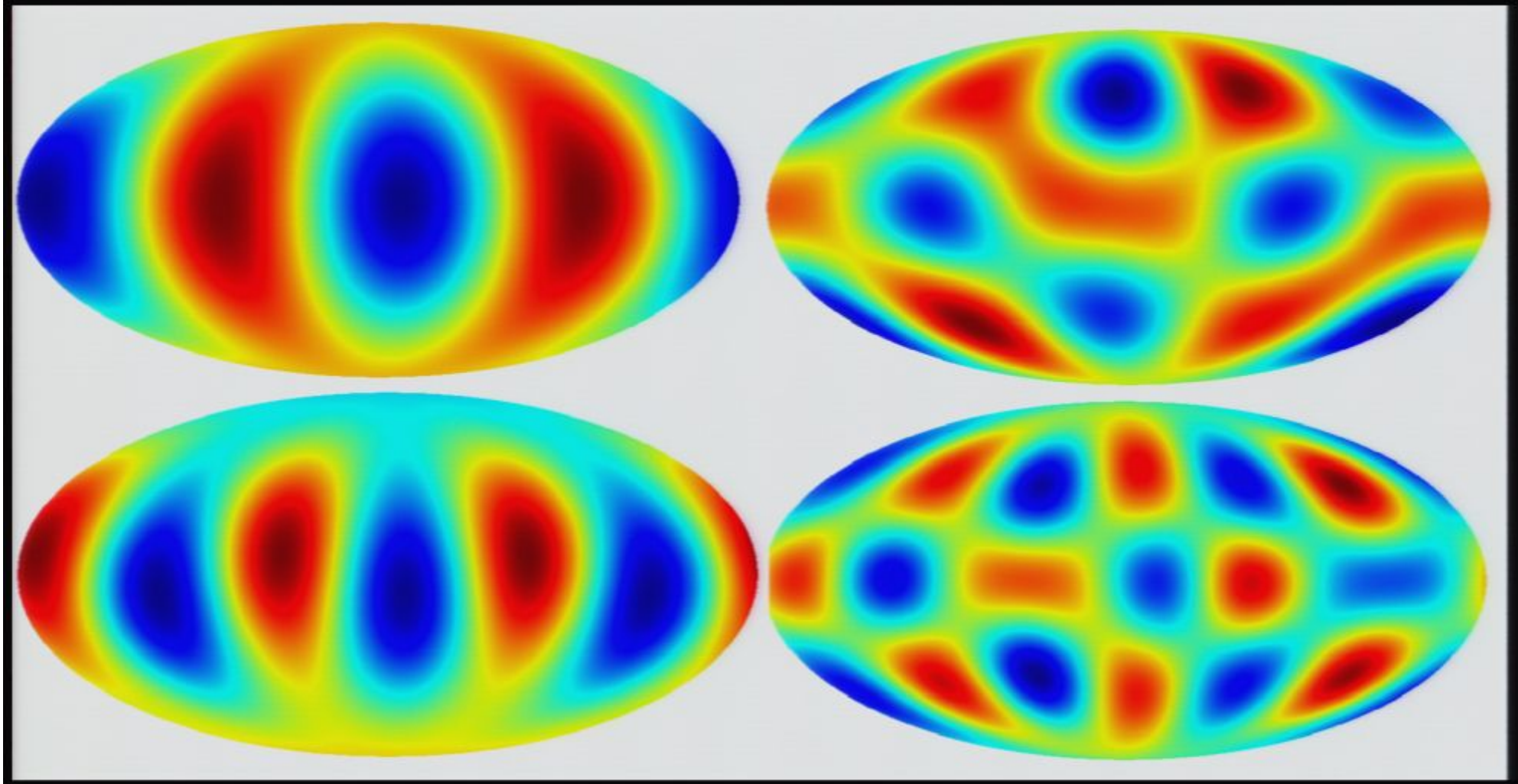
$l = 3$ (Octopole)

SHAPE $m = 3$

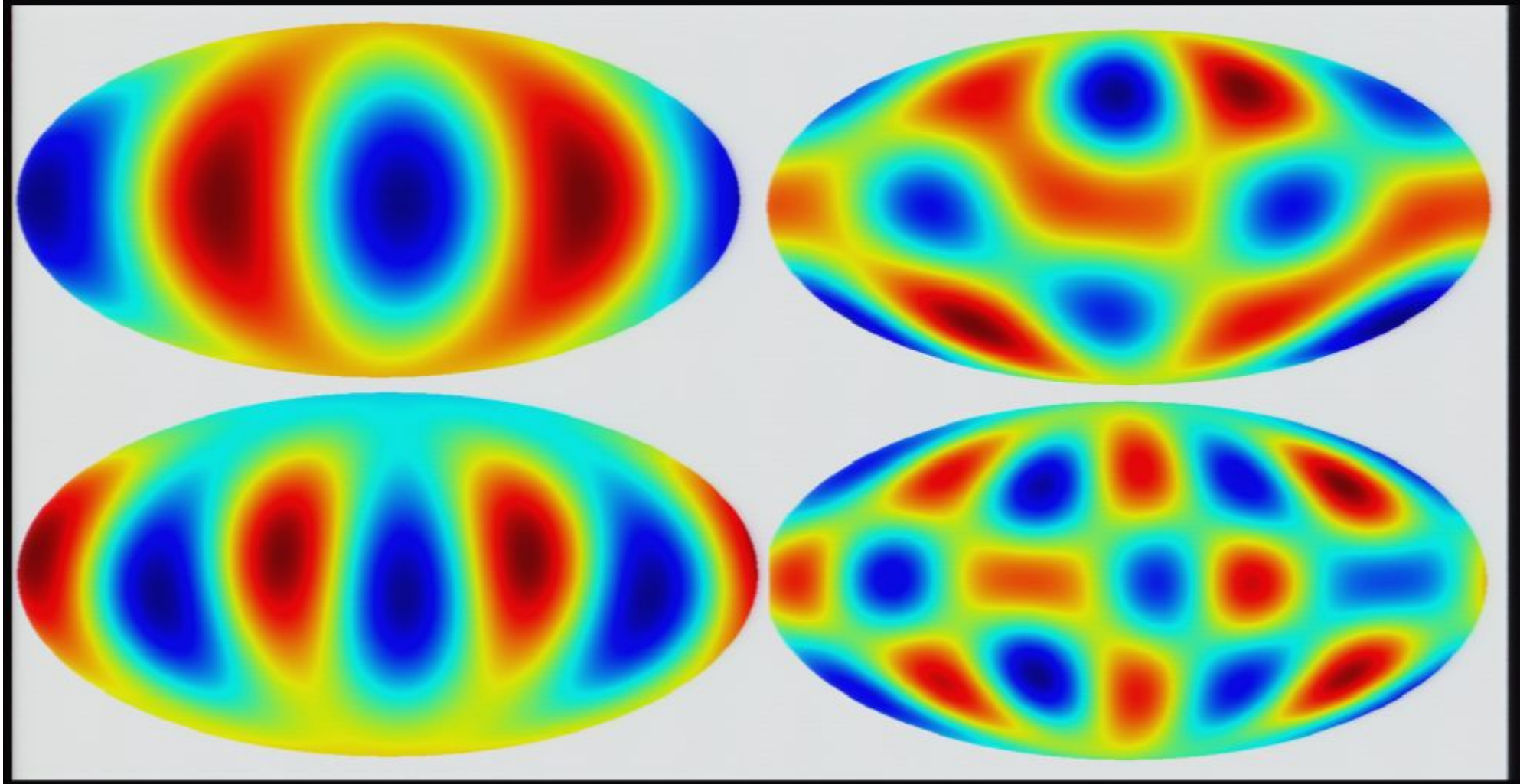




POSITIVE MIRROR PARITY: $(l + m)$ even



Preferred Axis 99.9% + Mirror Parity 90% = 99.99%



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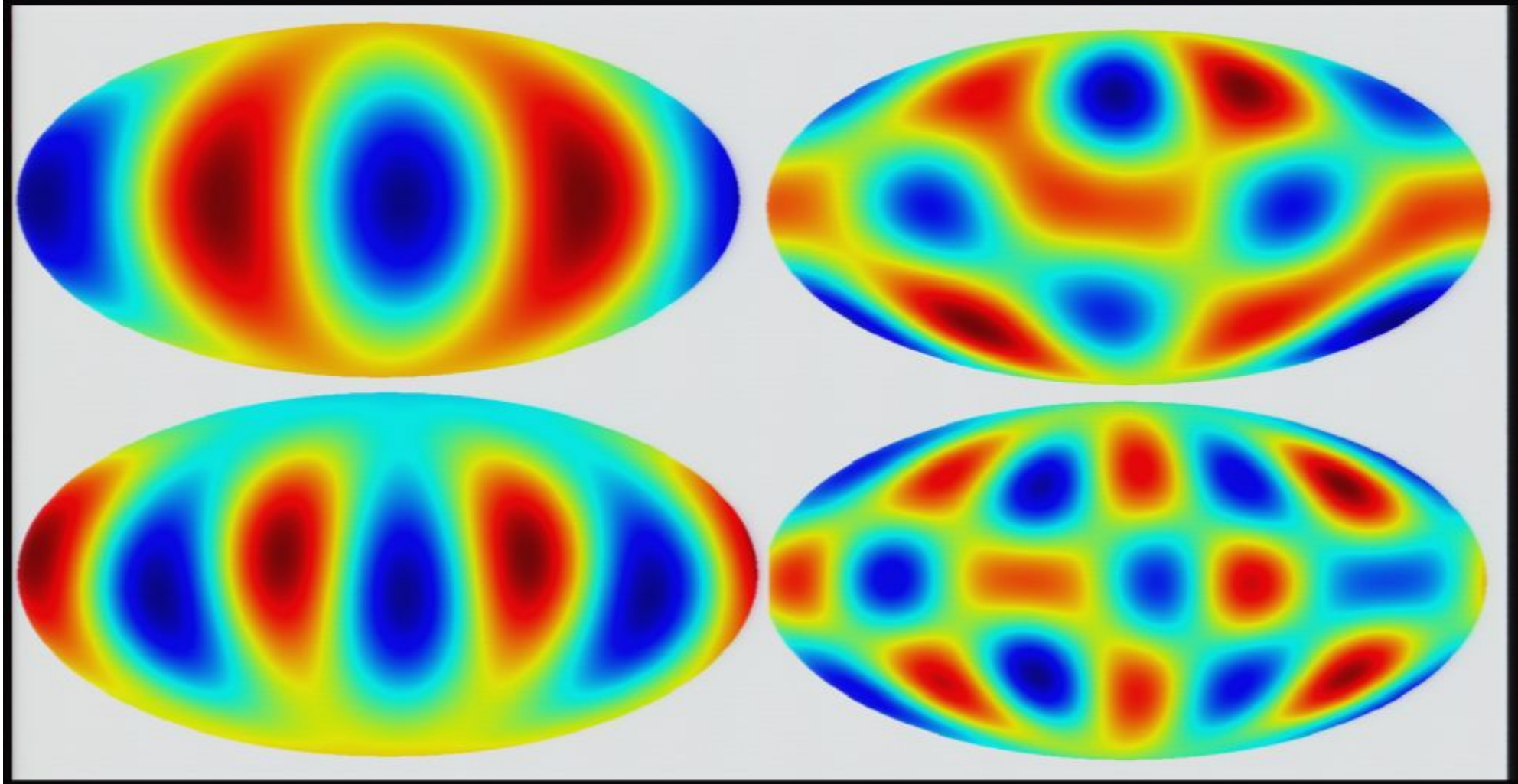

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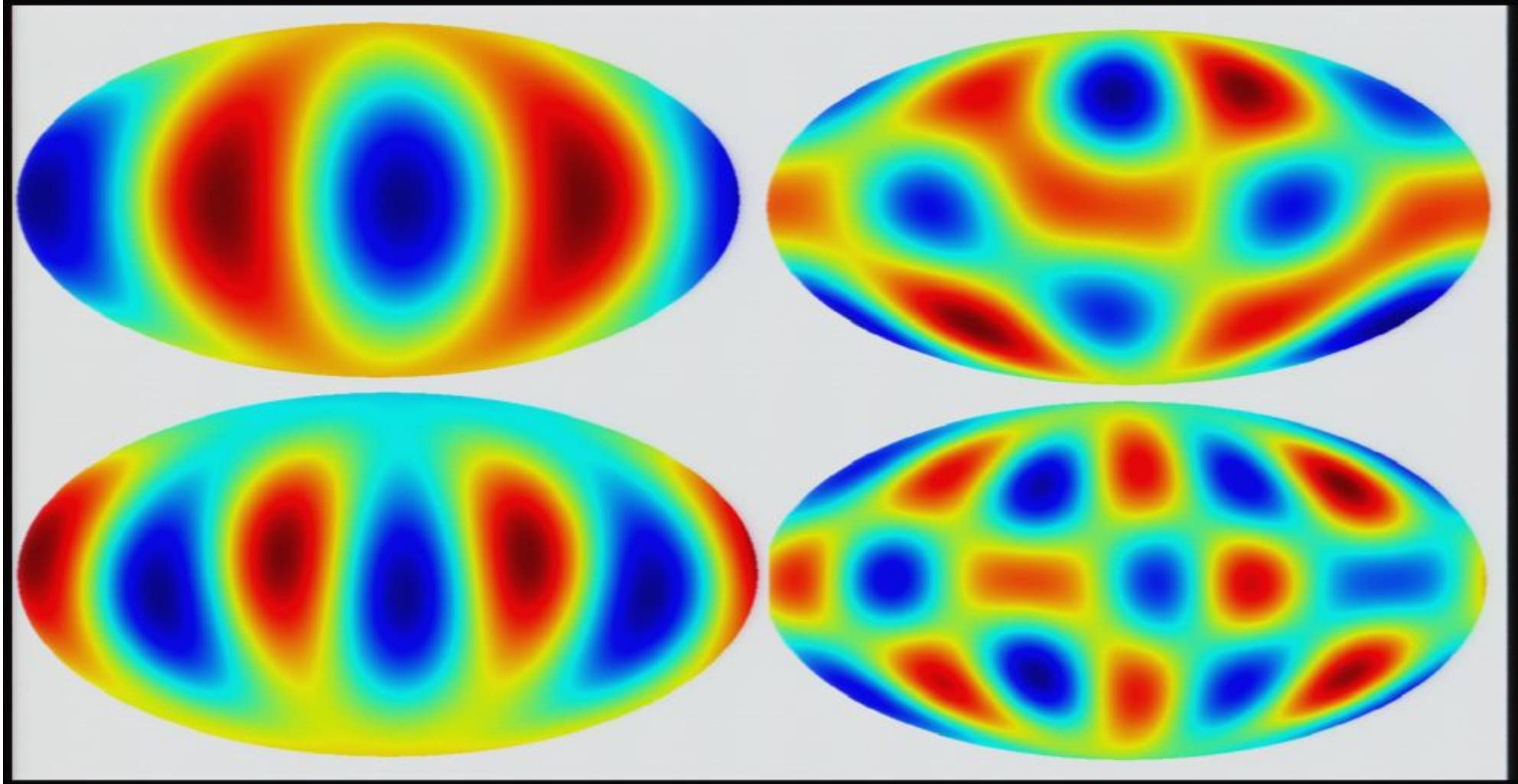

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ASYMMETRIES – POWER SPECTRUM

Eriksen & al. ApJ(605)14

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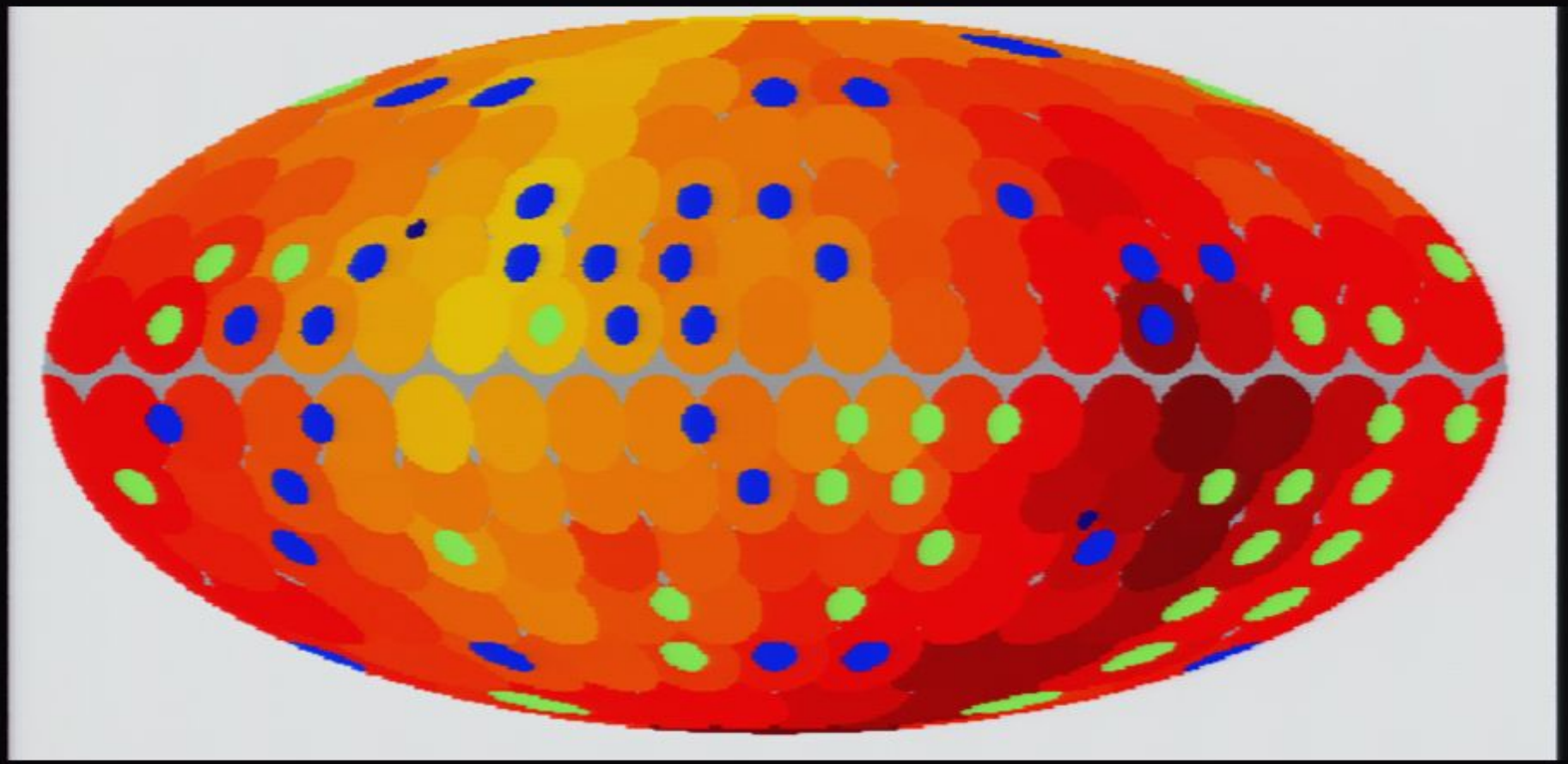
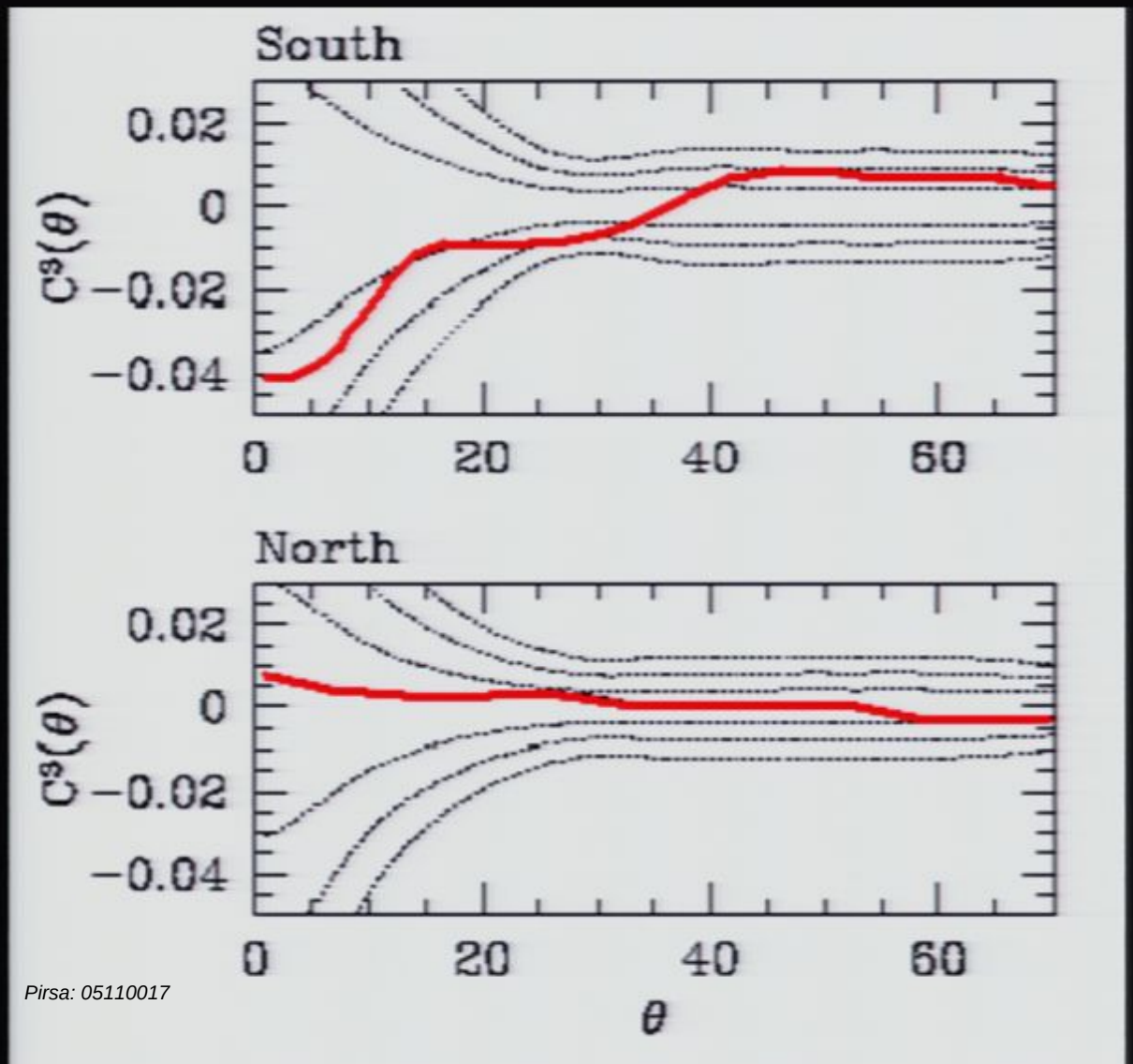


$(l, b)=(57, 10)$ maximises asymm

ASYMMETRIES - 3 POINT CORRELATION F'NS



SOUTH ECLIPTIC

NORTH ECLIPTIC

Surprisingly Featureless

ASYMMETRIES - BISPECTRUM

$$B_{l_1 l_2 l_3} = \sum_{m_1 m_2 m_3} \begin{pmatrix} l_1 & l_2 & l_3 \\ m_1 & m_2 & m_3 \end{pmatrix} \langle a_{l_1 m_1} a_{l_2 m_2} a_{l_3 m_3} \rangle$$

$$\frac{B_{l_1 l_2 l_3}}{(\hat{C}_{\ell_1})^{1/2} (\hat{C}_{\ell_2})^{1/2} (\hat{C}_{\ell_3})^{1/2}}$$

Normalised Bispectrum

ASYMMETRIES - BISPECTRUM

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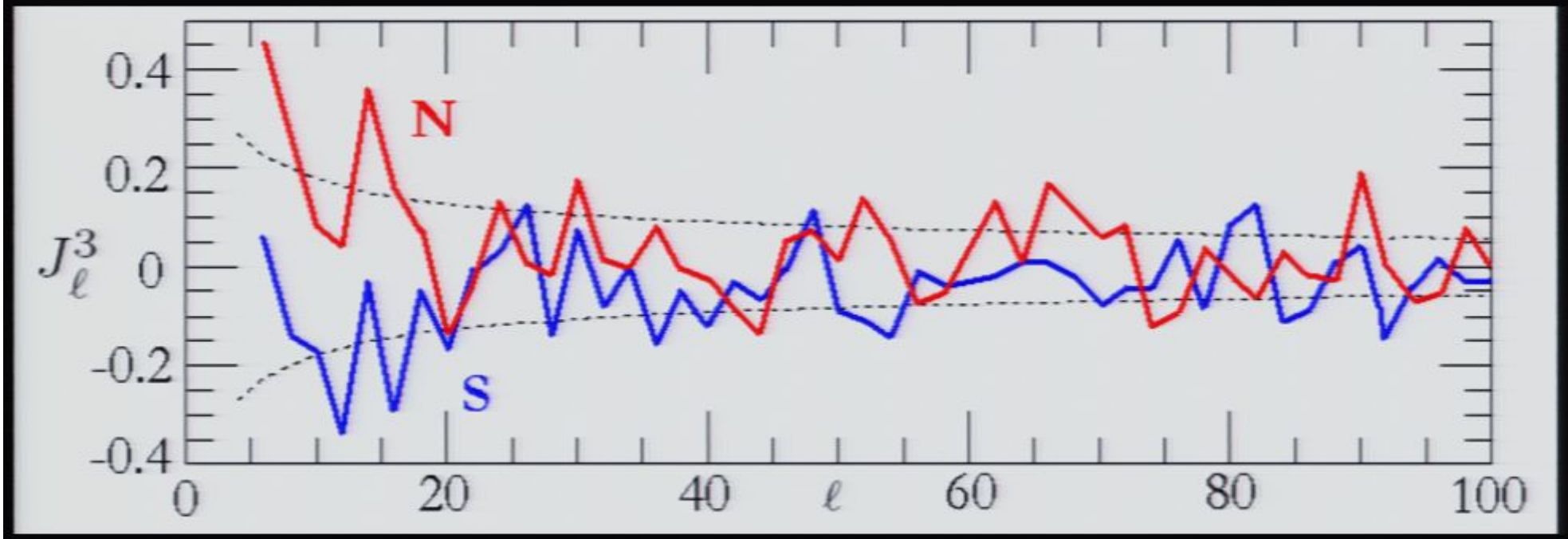
Normalised Bispectrum

- All-sky WMAP Bispectrum consistent with Guassianity, but…

ASYMMETRIES - BISPECTRUM

Land & Magueijo MNRAS(357)994



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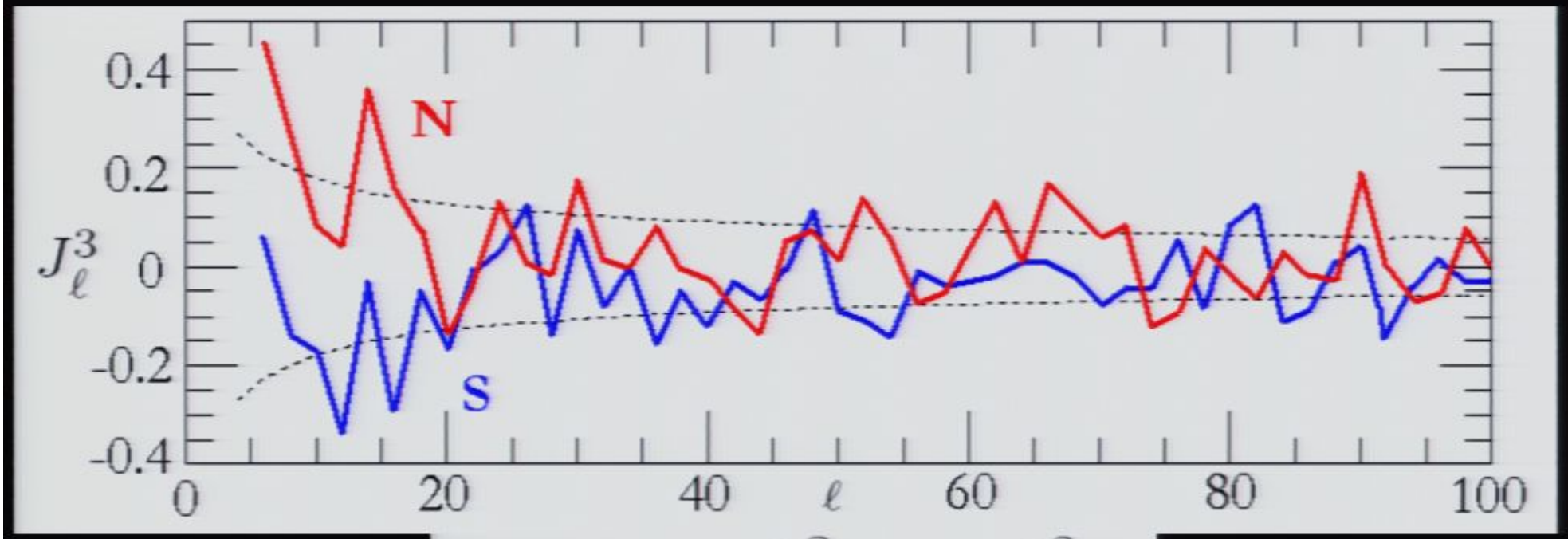
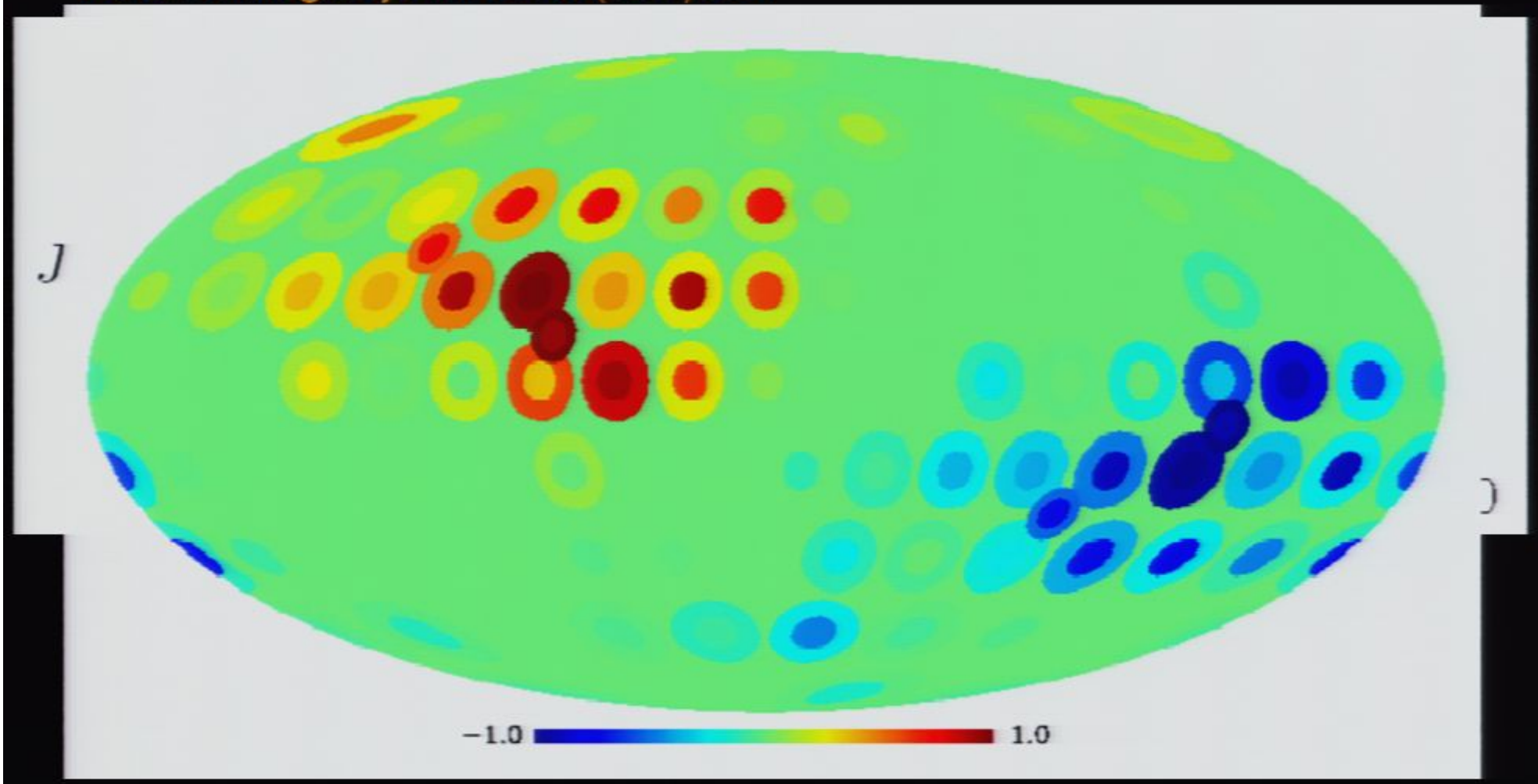


$$K = \sum_\ell \frac{J^3_{\ell,N} - J^3_{\ell,S}}{\sigma_\ell}$$

ASYMMETRIES - BISPECTRUM

Land & Magueijo MNRAS(357)994

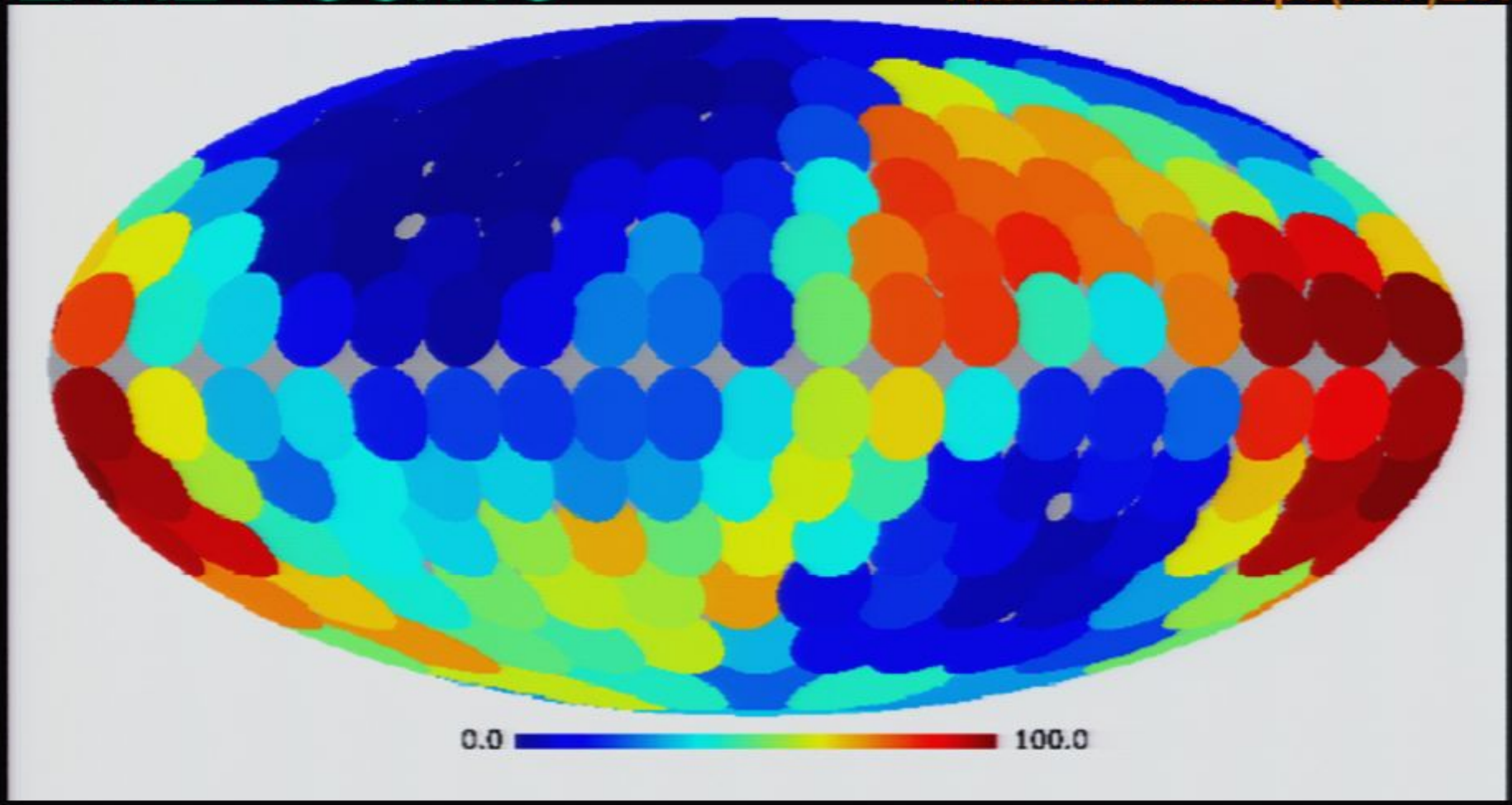


$(l,b)=(57,10)$ maximises asymm

ASYMMETRIES – LOCAL CURVATURE

LAKE COUNTS

Hansen & al. ApJ(607)L67



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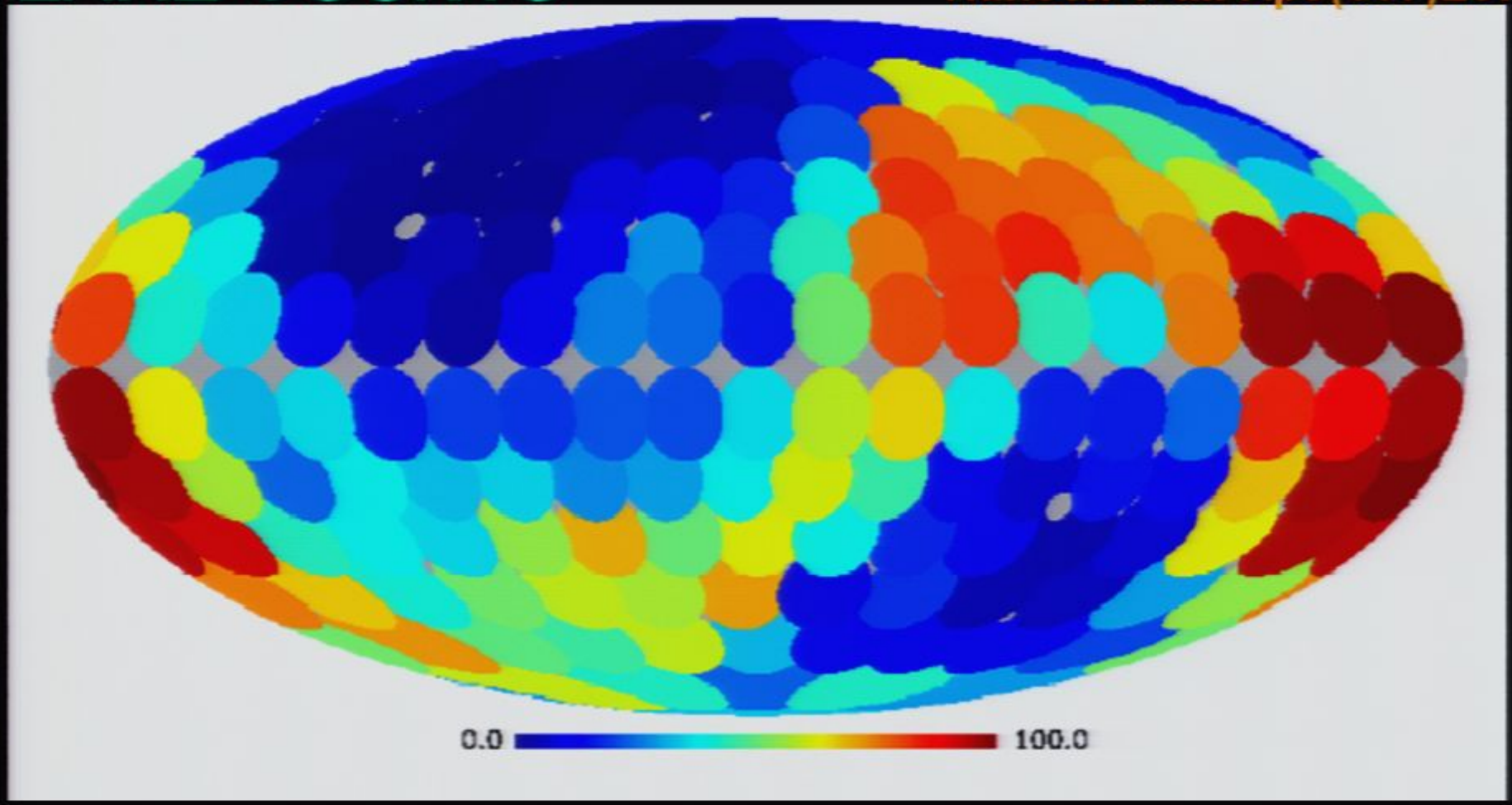

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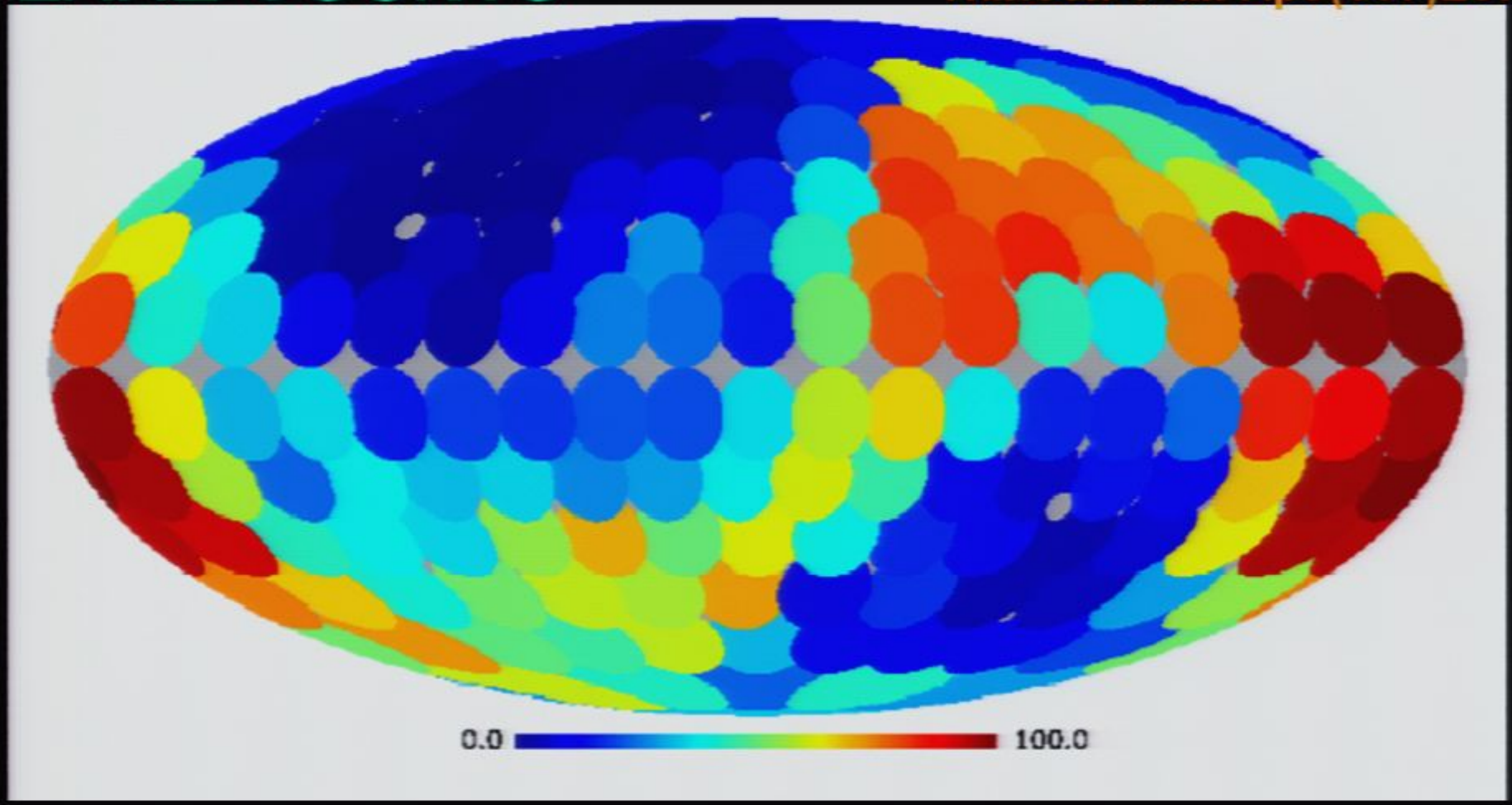

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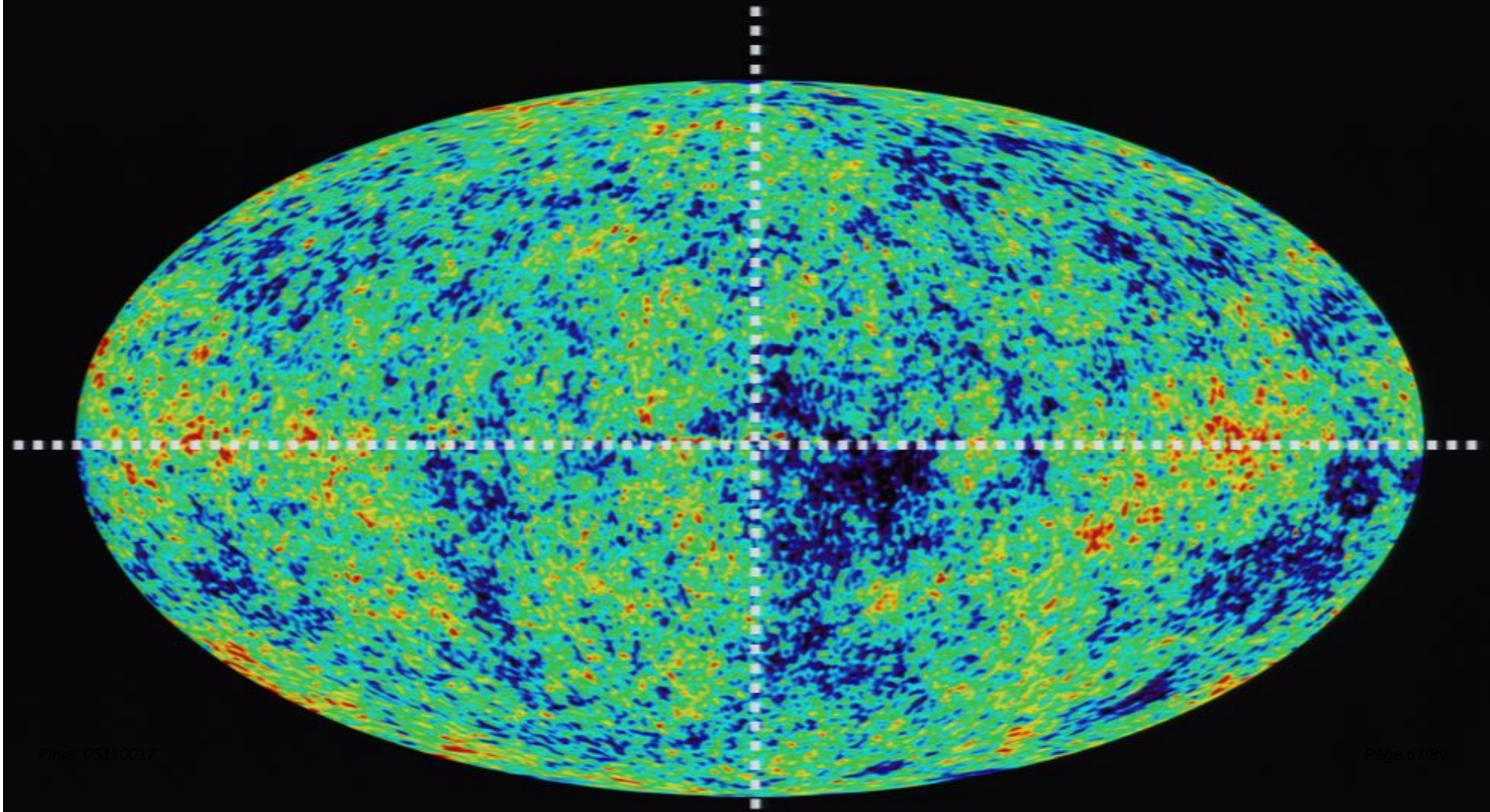
ANOMALIES SUMMARY



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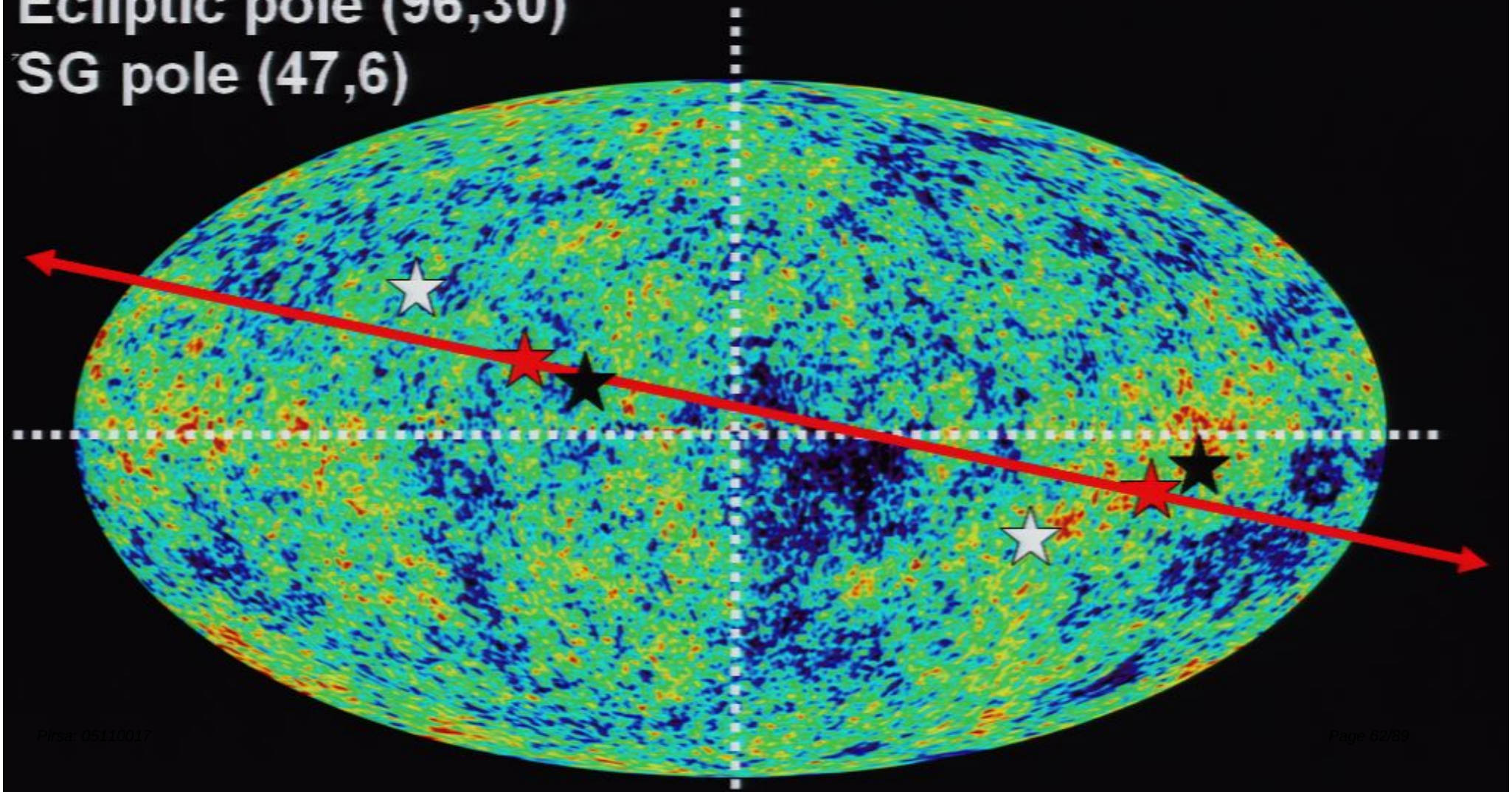
- Ecliptic pole (96,30)
- SG pole (47,6)



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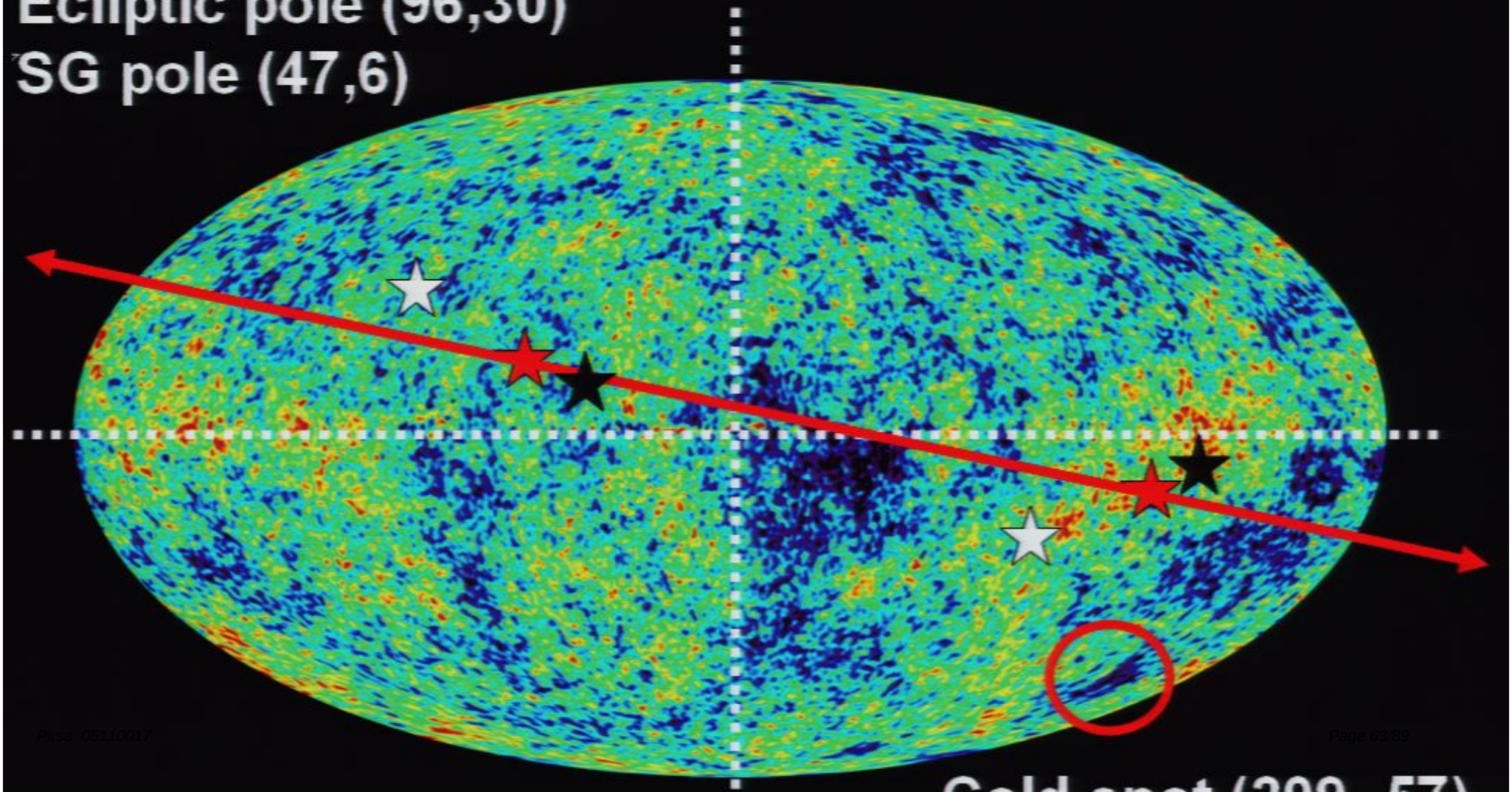

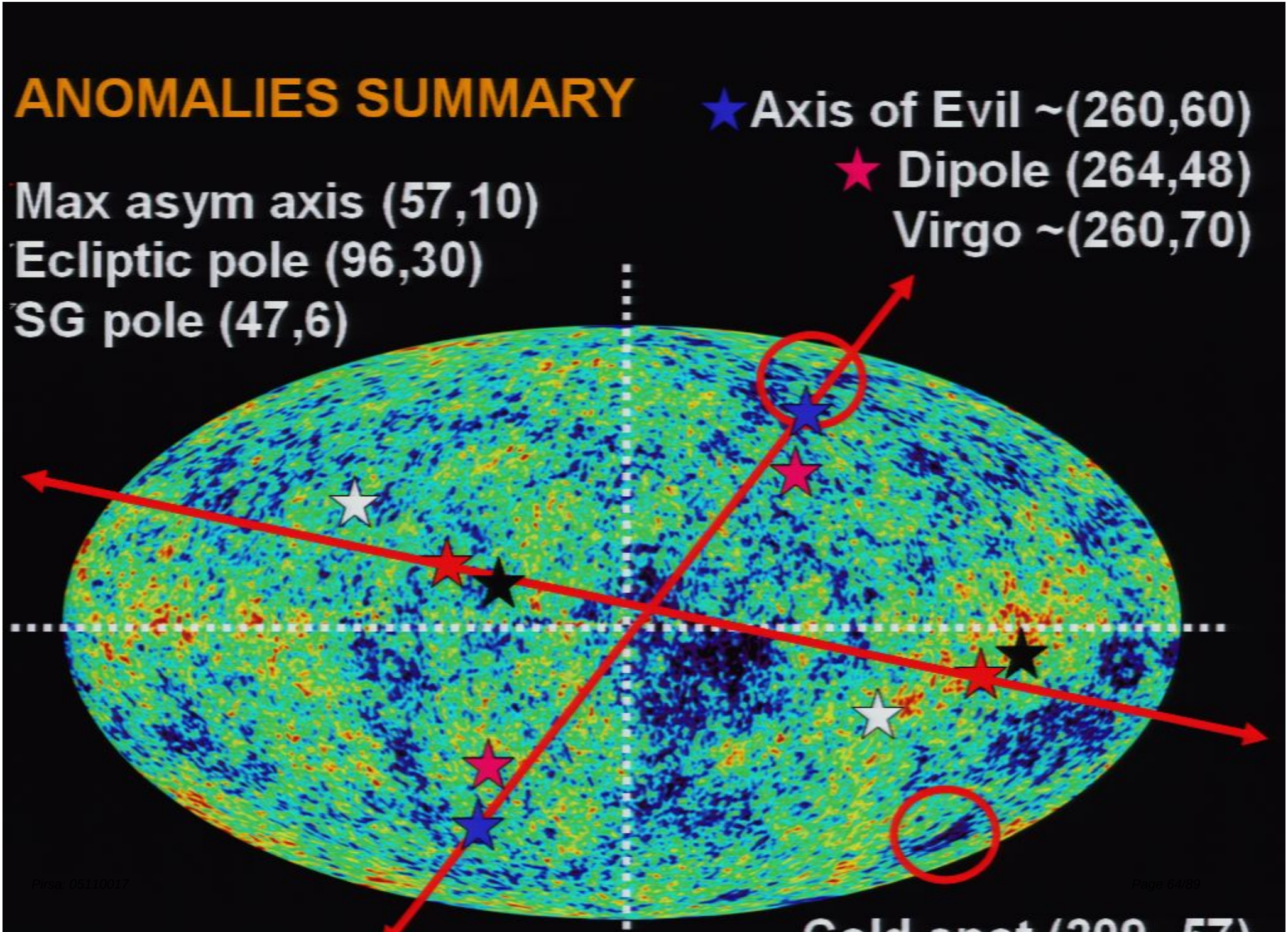
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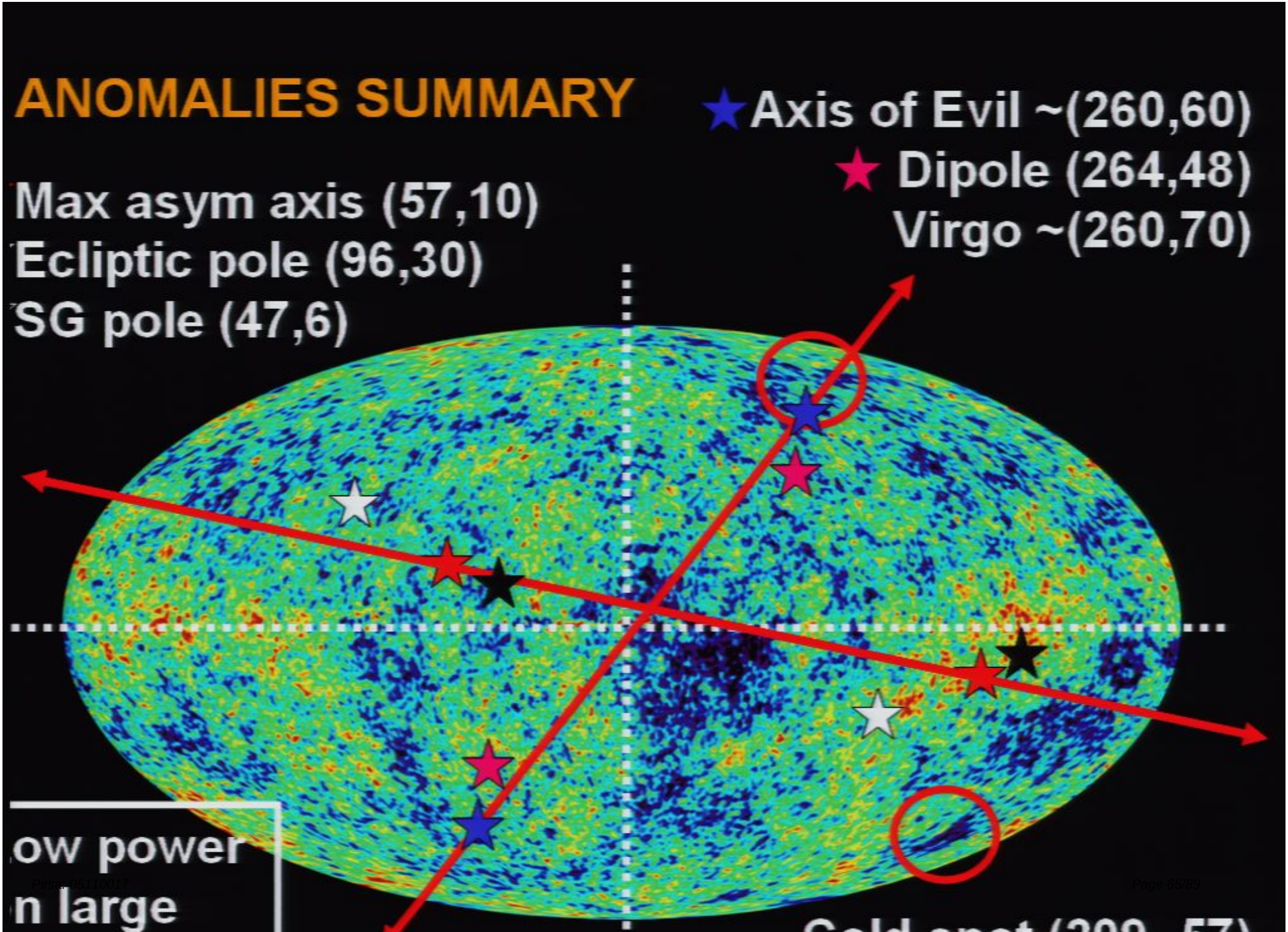
Axis of Evil ~(260,60)
Dipole (264,48)
Virgo ~(260,70)
Max asym axis (57,10)
Ecliptic pole (96,30)
SG pole (47,6)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HUNTING CULPRITS

- SYSTEMATICS

  Satellite, data pipeline, …

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  Foregrounds, local lensing, …

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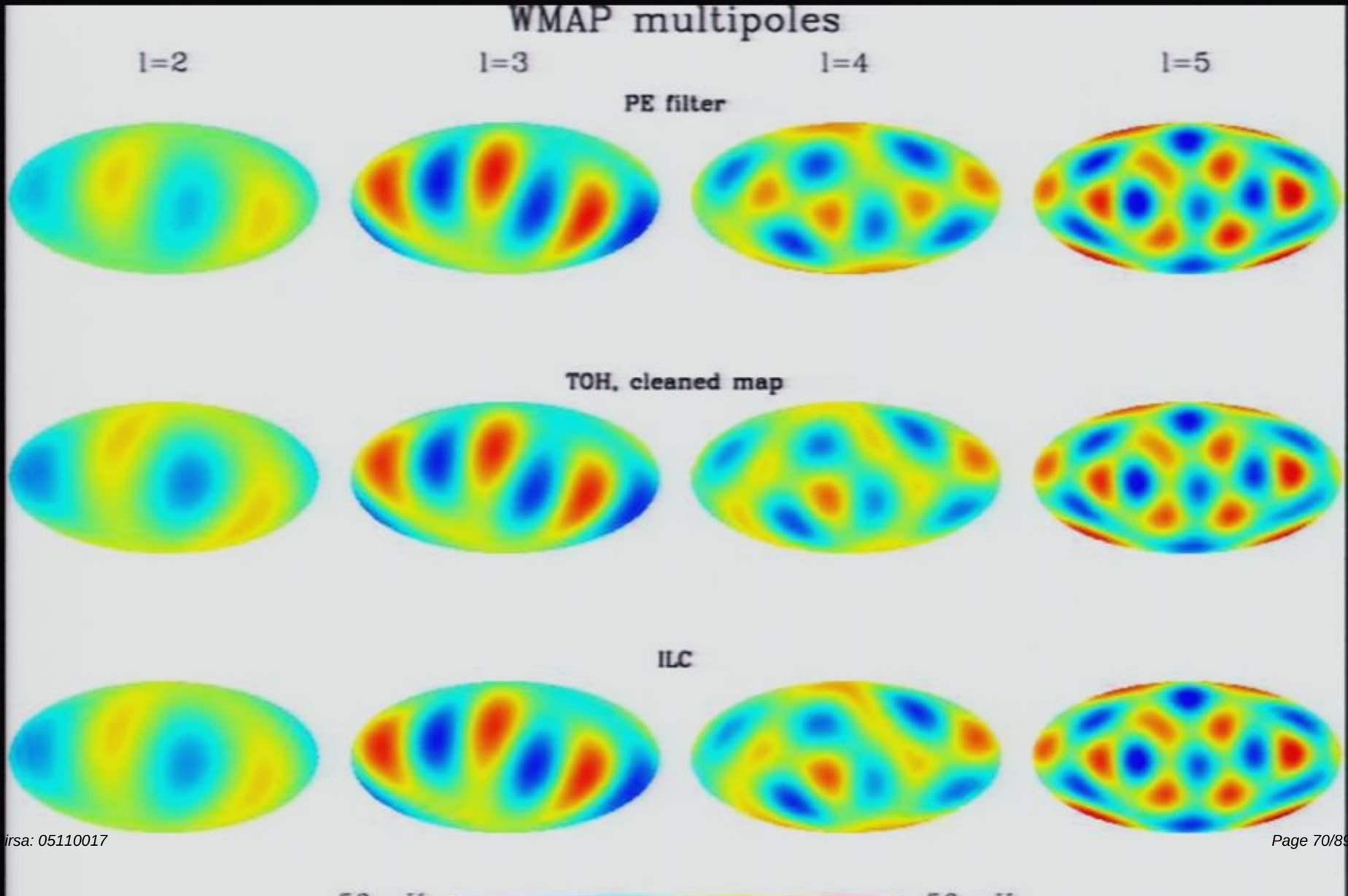
- IT JUST IS!
  Have we over-done the analysis?

Bielewicz, Gorski, Banday MNRAS(355)1283



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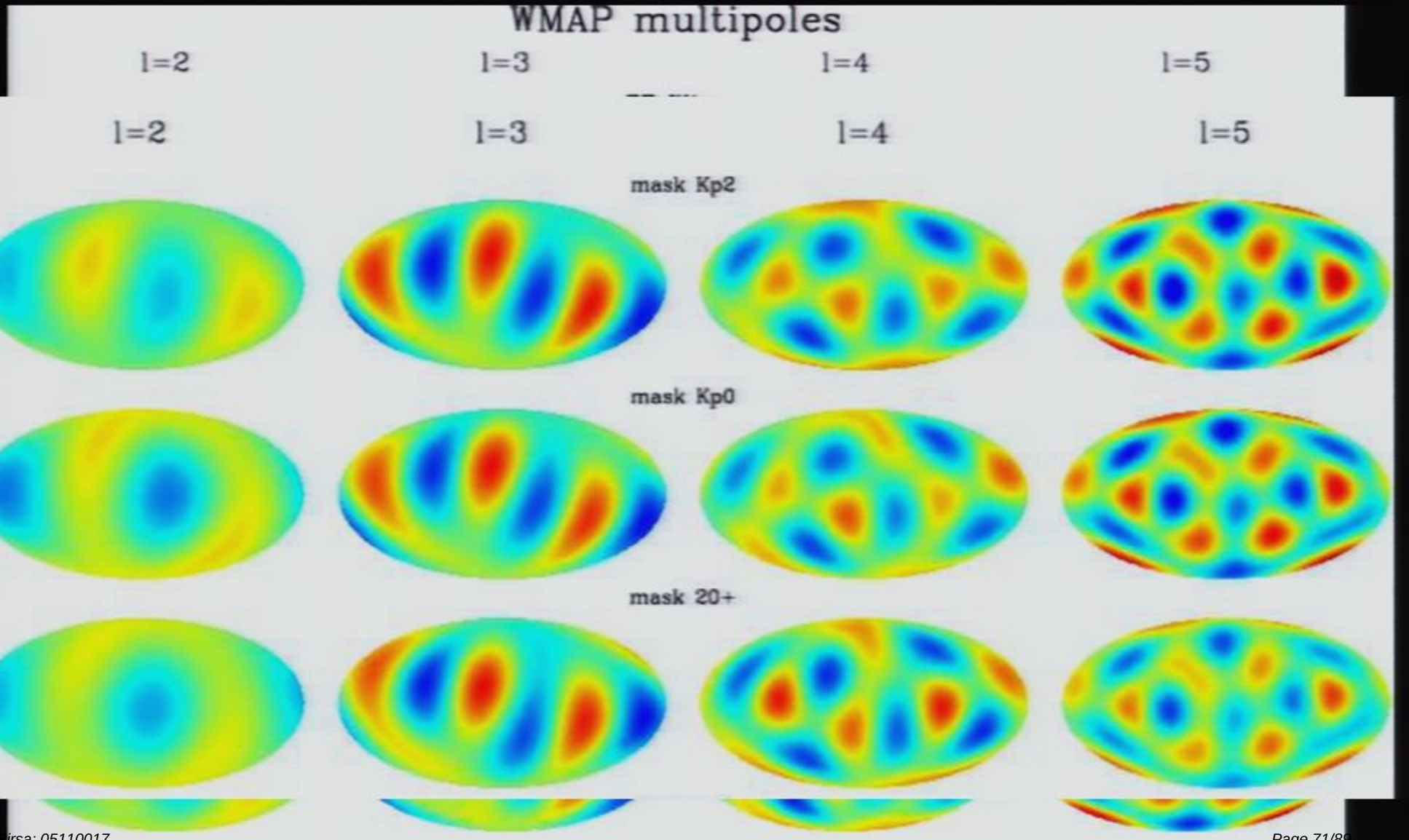

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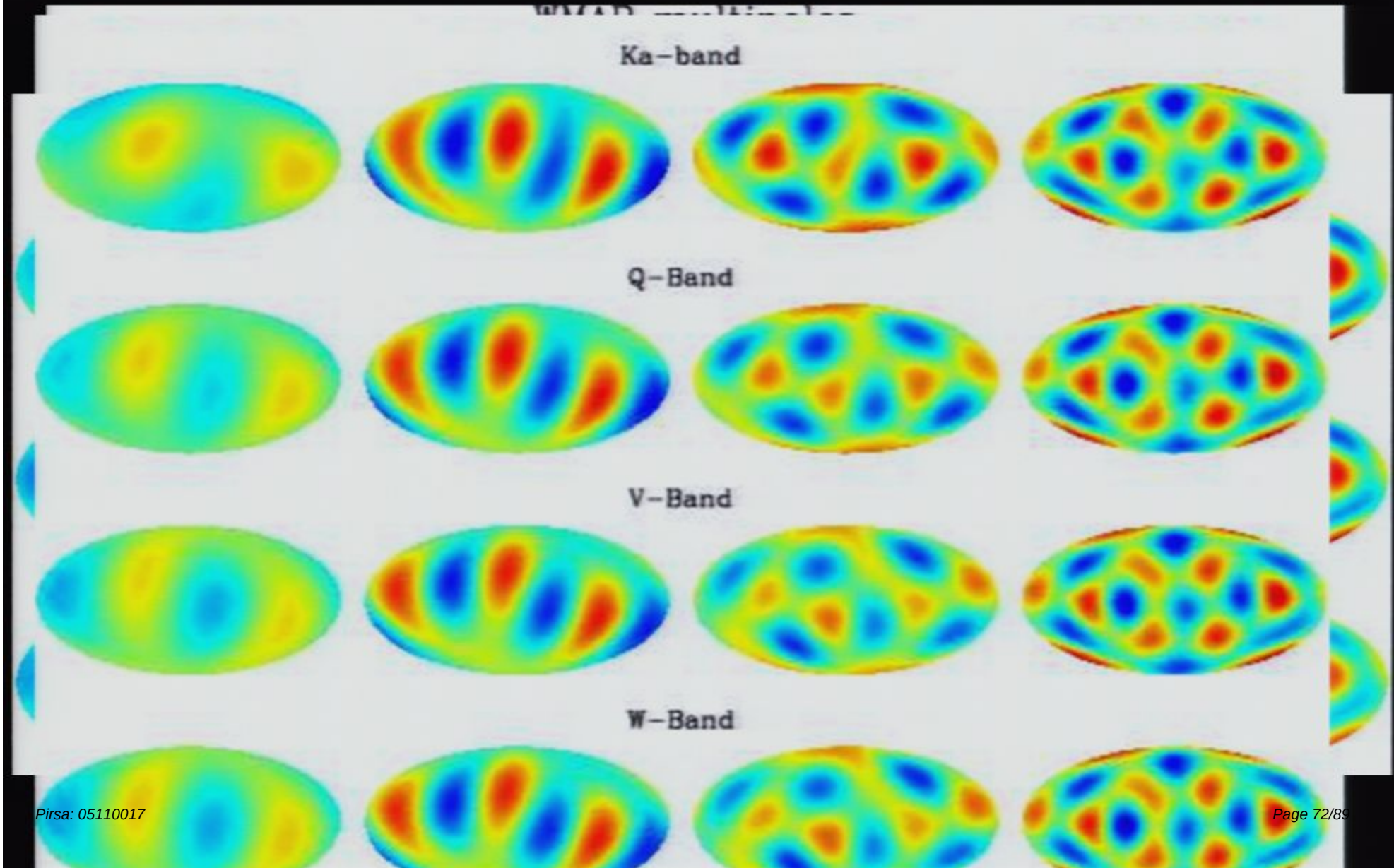
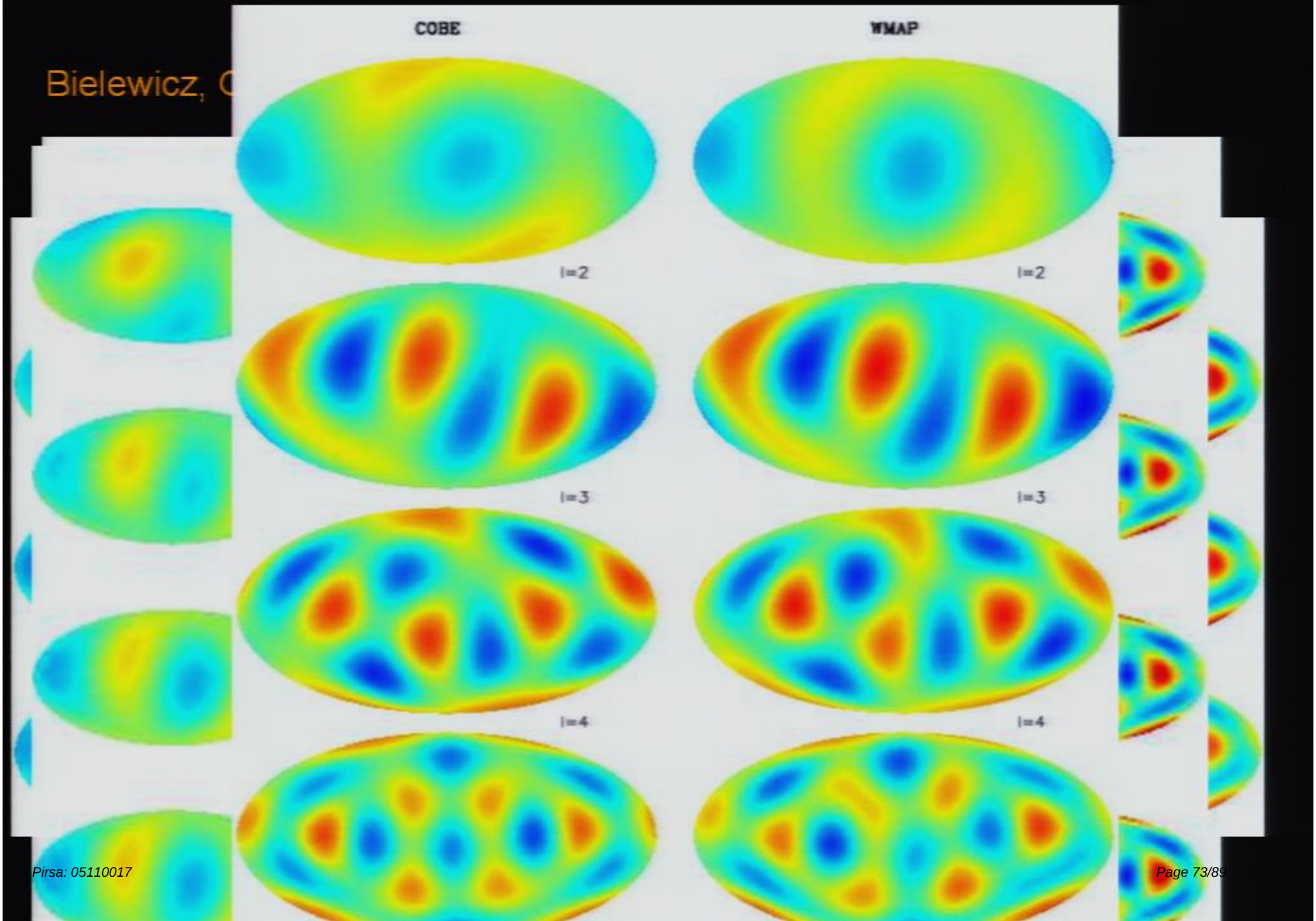
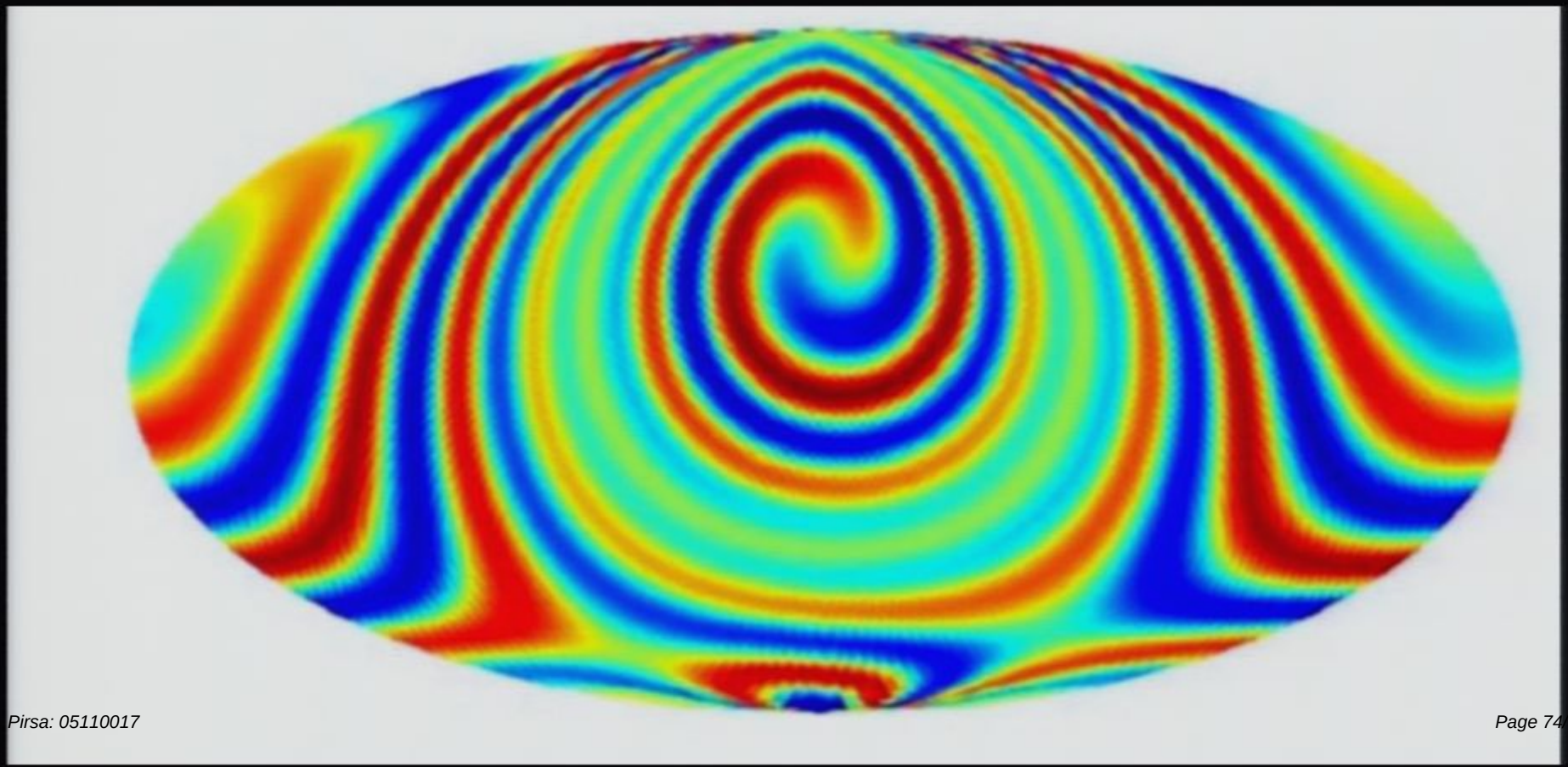


Bielewicz, C



BIANCHI VII_h MODELS

A class of anisotropic cosmological models.
Have shear and rotation about preferred axis.



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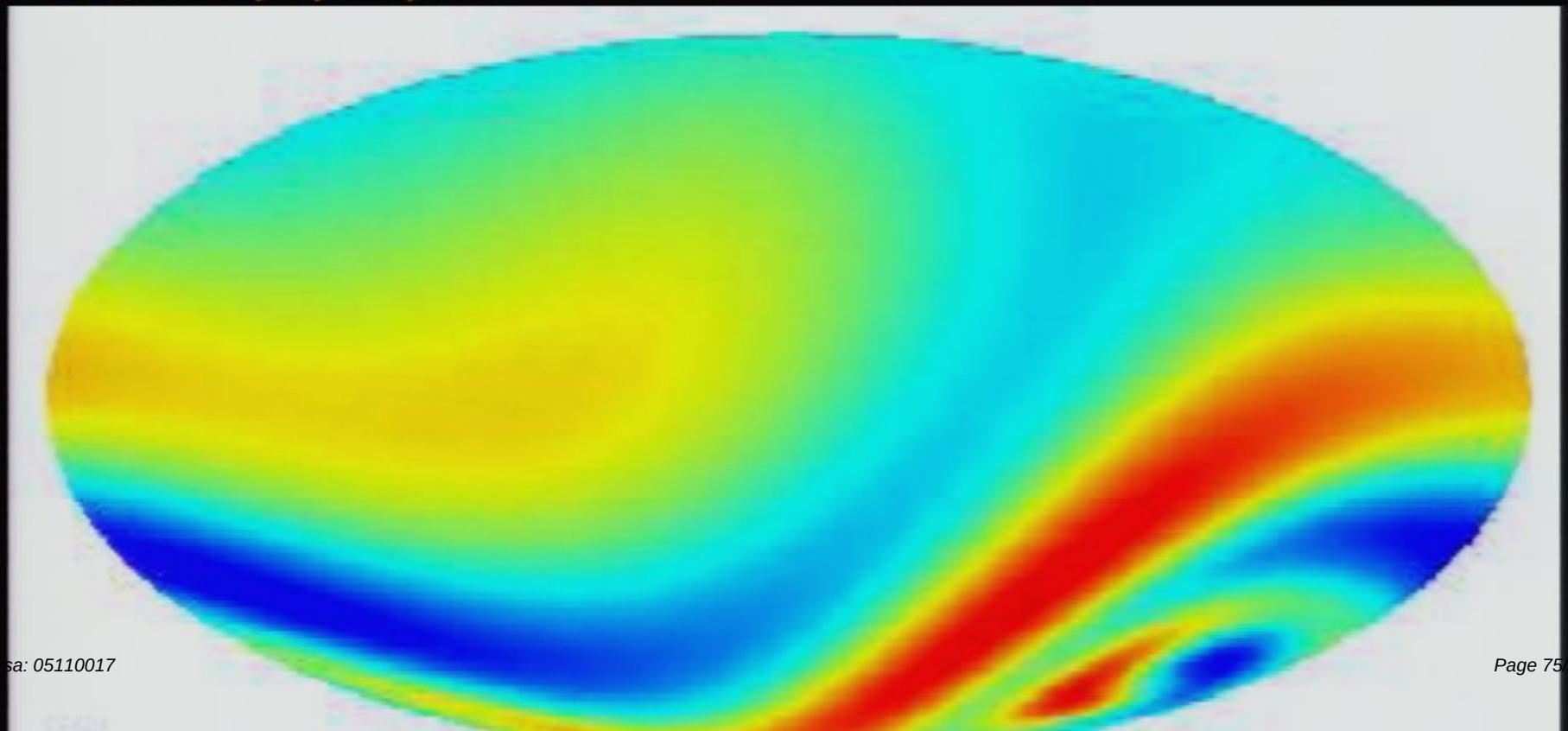
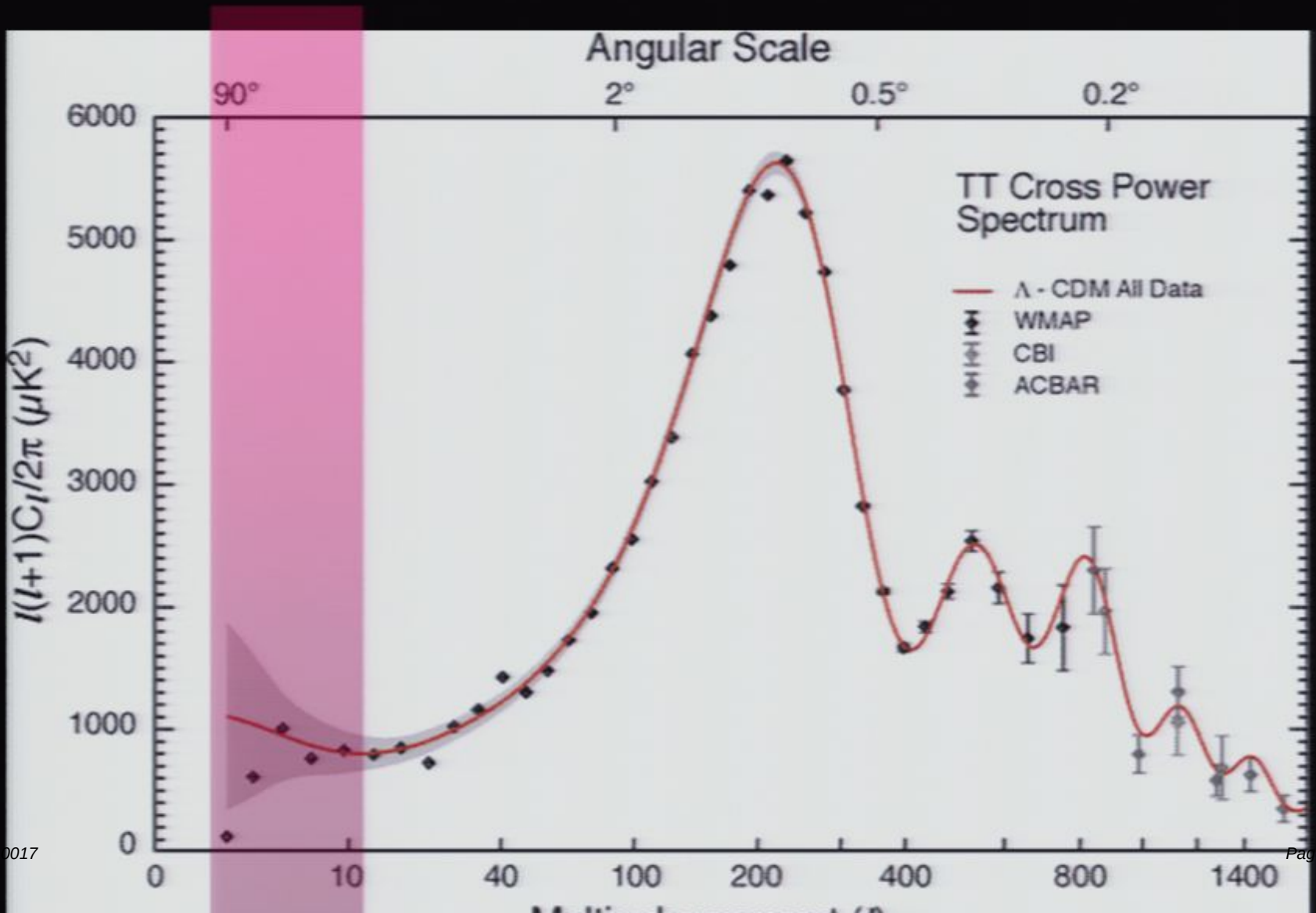
Jaffe & al. ApJ(629)L1

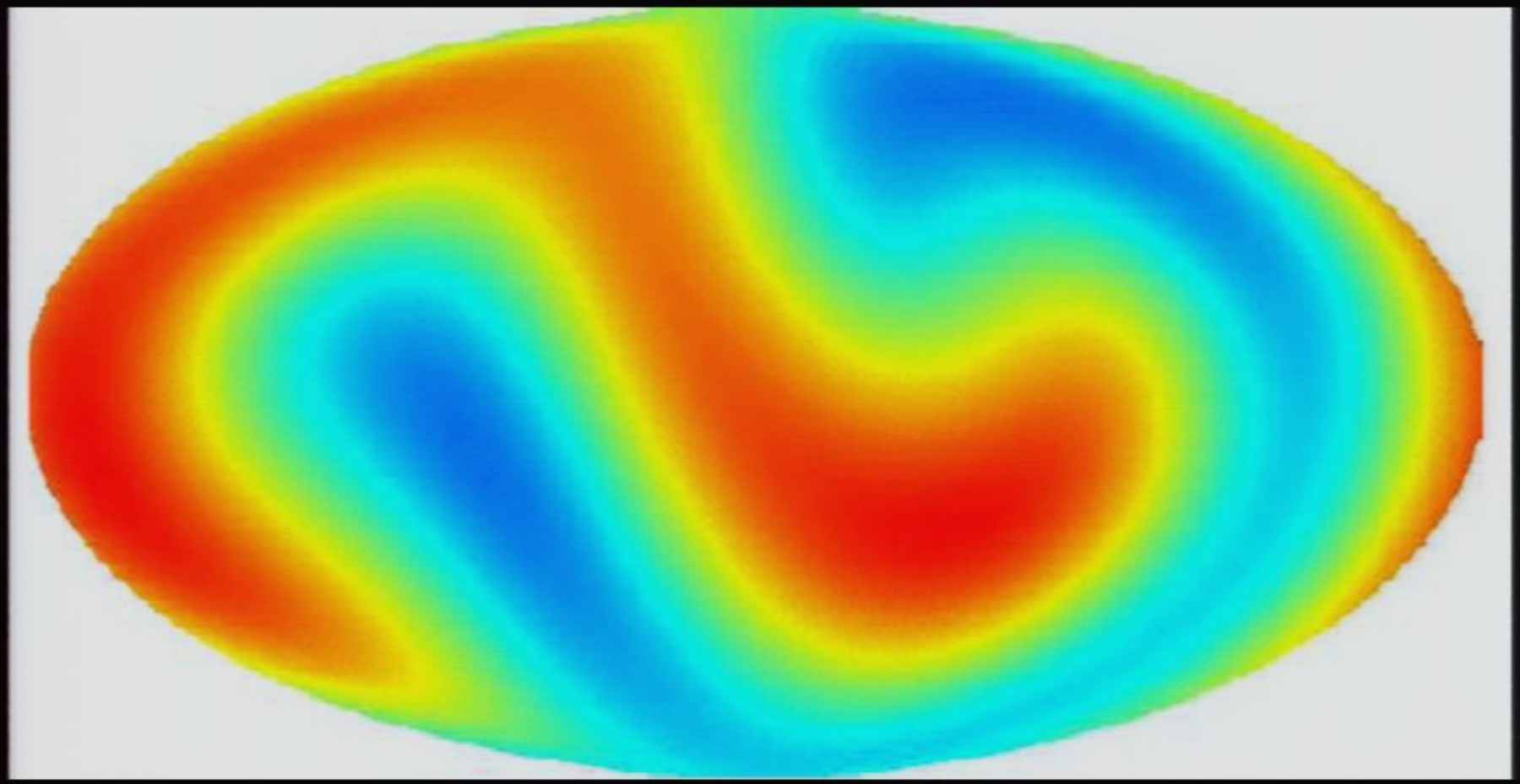


TEMPLATE FITTTING



BIANCHI VII_h MODELS

Land & Magueijo astro-ph/0509752



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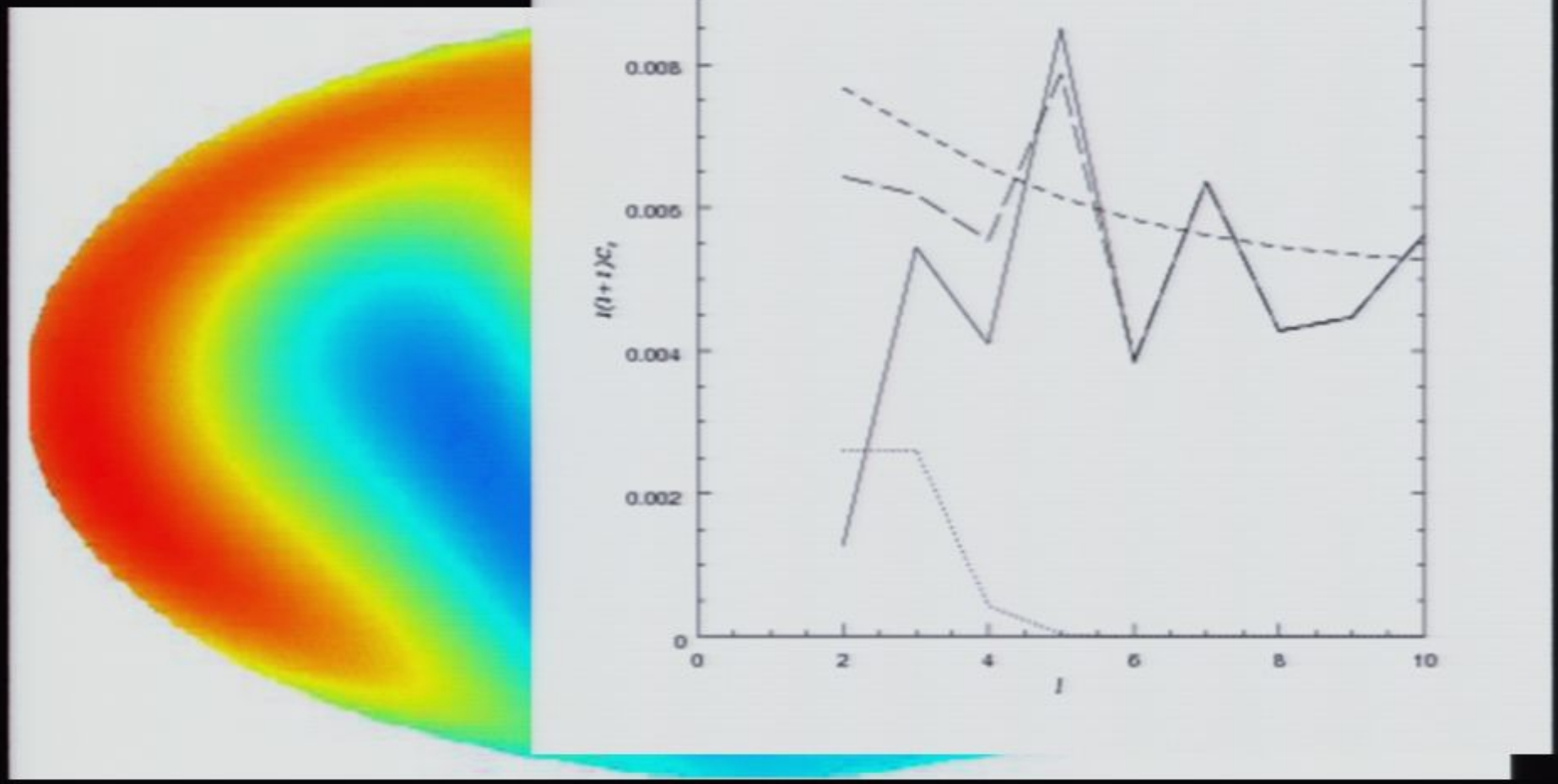

Axis of Evil removed + Low power restored

But chance alignment is needed

LENSING FROM LOCAL STRUCTURE

'Local Pancake Defeats Axis of Evil' Vale astro-ph/0509039

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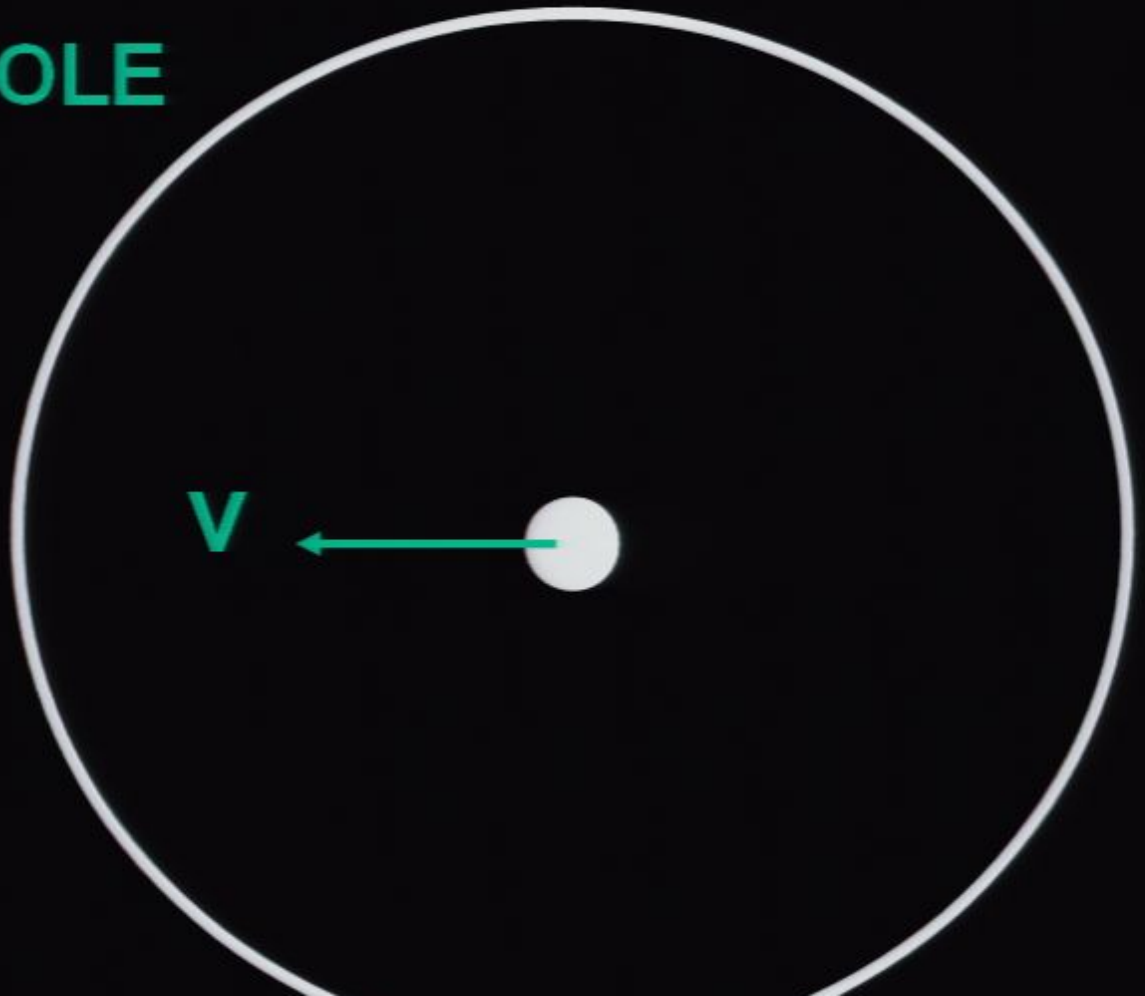
MONOPOLE



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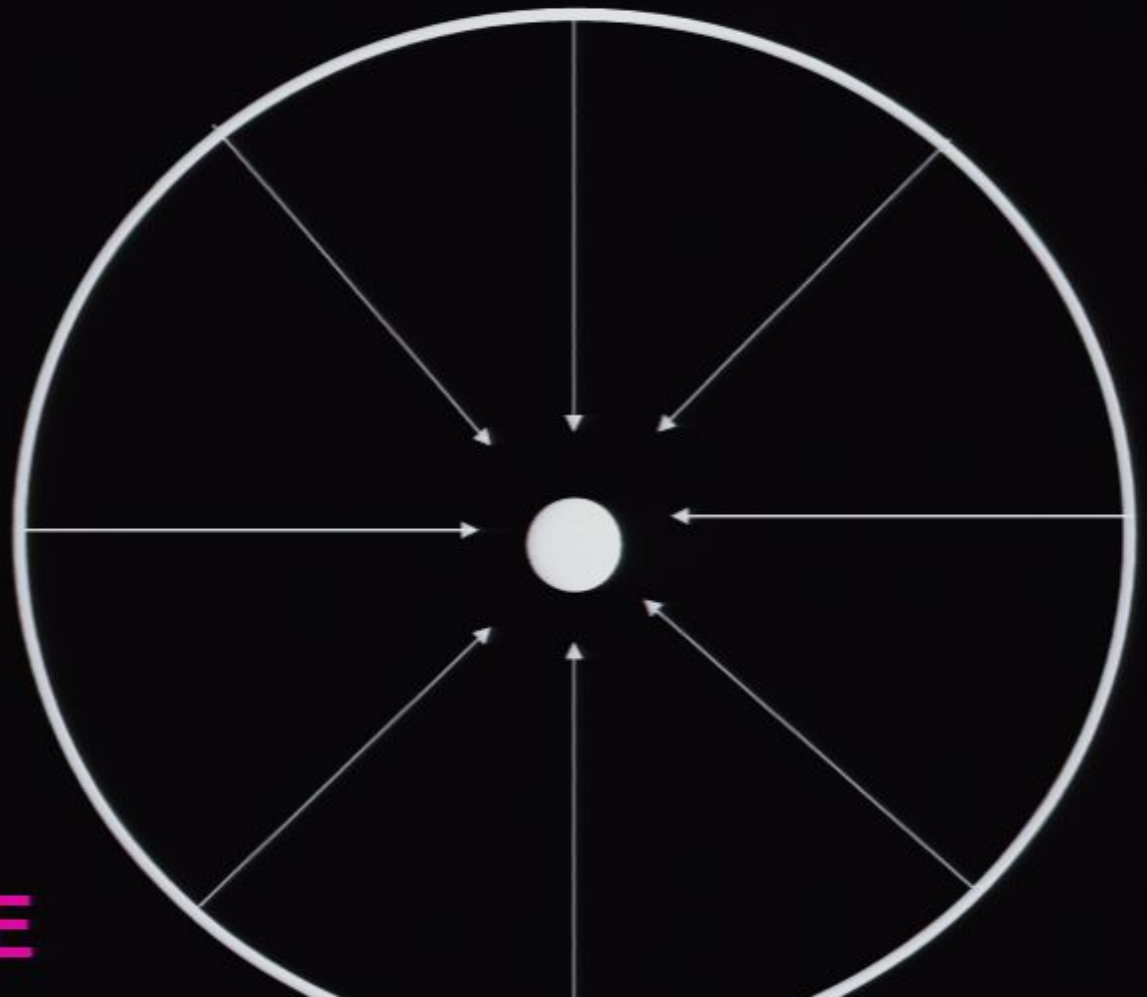

DIPOLE

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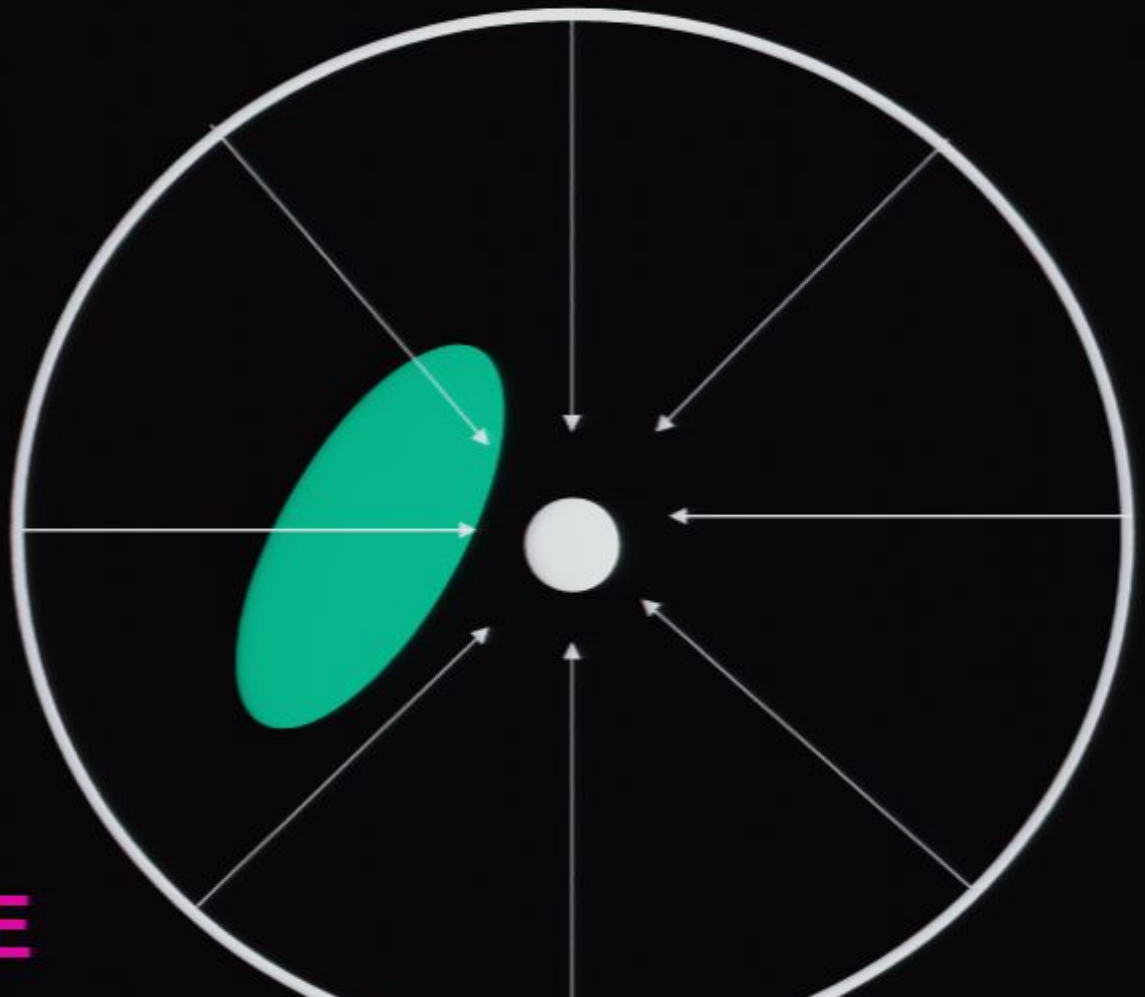

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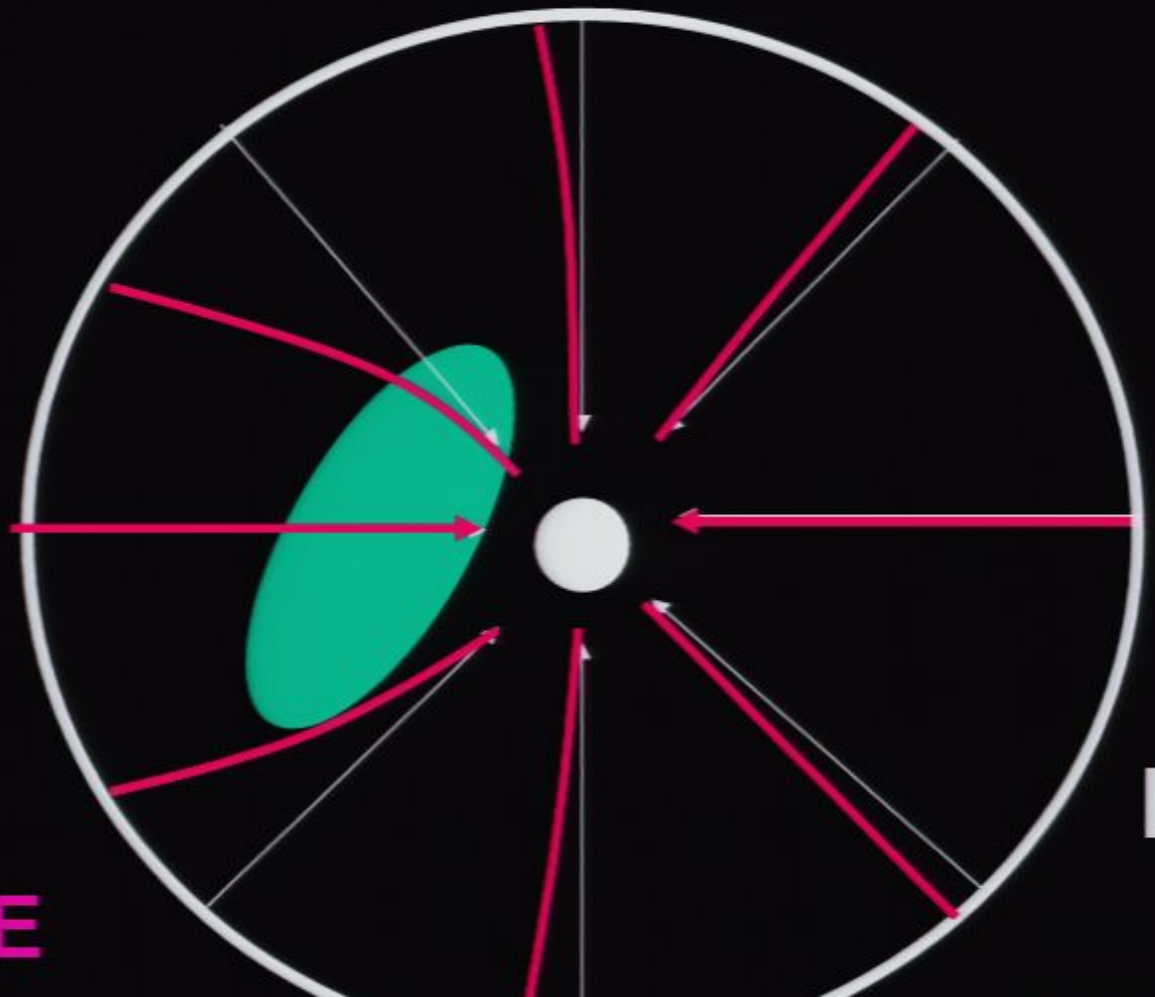

POWER LEAKS TO HIGHER

DIPOLE

OTHER IDEAS…

- Non-trivial topology
- Lemaitre-Tolman-Bondi model Moffat astro-ph/0502110
- Dominating long wavelength modes
- Eccentric universe Berera, Buniy, Kephart JCAP(0410)016
- Other Bianchi models
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AND THE MORE MUNDANE…

- Contamination
  - Look for correlations with local structure (work in progress)

SUMMARY

- It is important to test our assumptions of Isotropy and Gaussianity

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- It is important to test our assumptions of Isotropy and Gaussianity
- There is evidence of such deviations in first year WMAP data
- Culprit(s) not known

Work in progress…

Imperial College
London