



# Open Problems.



## WMAP data anomalies.

- ♡ Low Quadrupole. WMAP showed that is not due to galactic contamination.
- ♡ Quadrupole-Octopole Alignment.
- ♡ North-South hemispherical assymetry.
- ♡ Cold-Spot.



## Multipole Alignment.

- Let us define a coordinate system where the  $Z$ -axis is in a given direction  $\hat{n}$ . Let us compute the quantity:

$$\left\langle \frac{\delta T}{T_o}(\hat{n}) \right| (\hat{n} \vec{L})^2 \left| \frac{\delta T}{T_o}(\hat{n}) \right\rangle = \sum_m m^2 |a_{lm}(\hat{n})|^2$$

and maximize it for all possible directions  $\hat{n}$ . The preferred directions for  $l = 2, 3$  are:

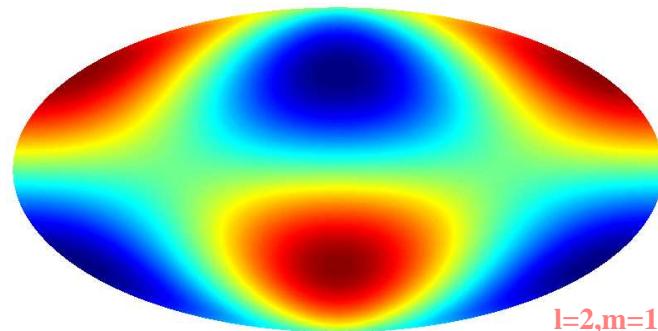
$$\hat{n}_2 = (-0.1145, -0.5265, 0.8424),$$

$$\hat{n}_3 = (-0.2578, -0.4207, 0.8698).$$

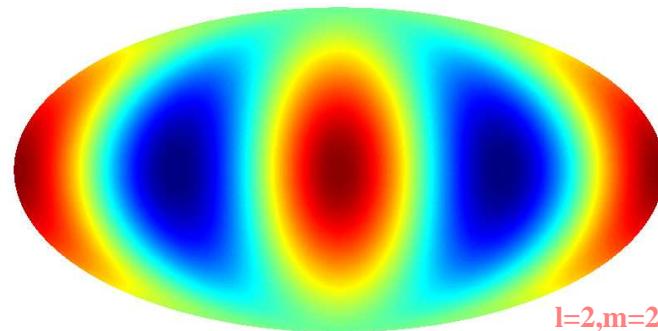
- The probability that 2 random vectors  $\hat{n}_2$  and  $\hat{n}_3$  are within  $10^\circ$  of each other is  $1/62$ , the fraction of area occupied by a patch of  $10^\circ$  radius over half the sky.



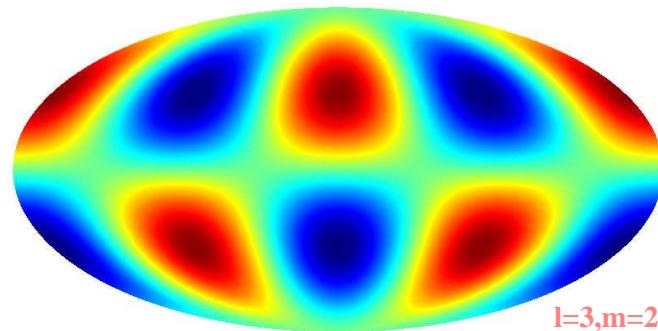
## Multipole Alignment.



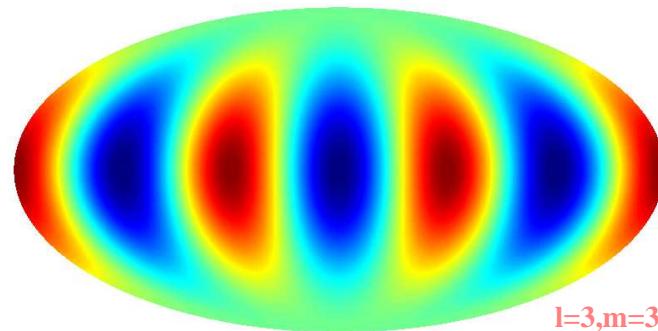
$l=2, m=1$



$l=2, m=2$



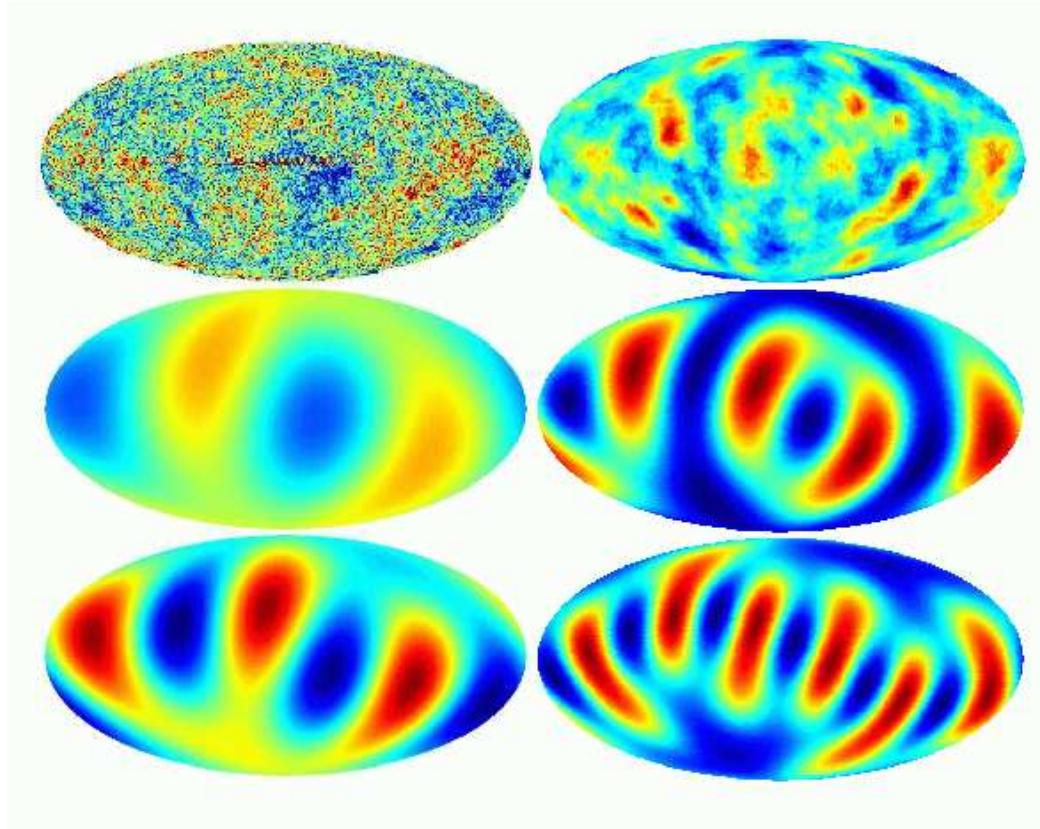
$l=3, m=2$



$l=3, m=3$

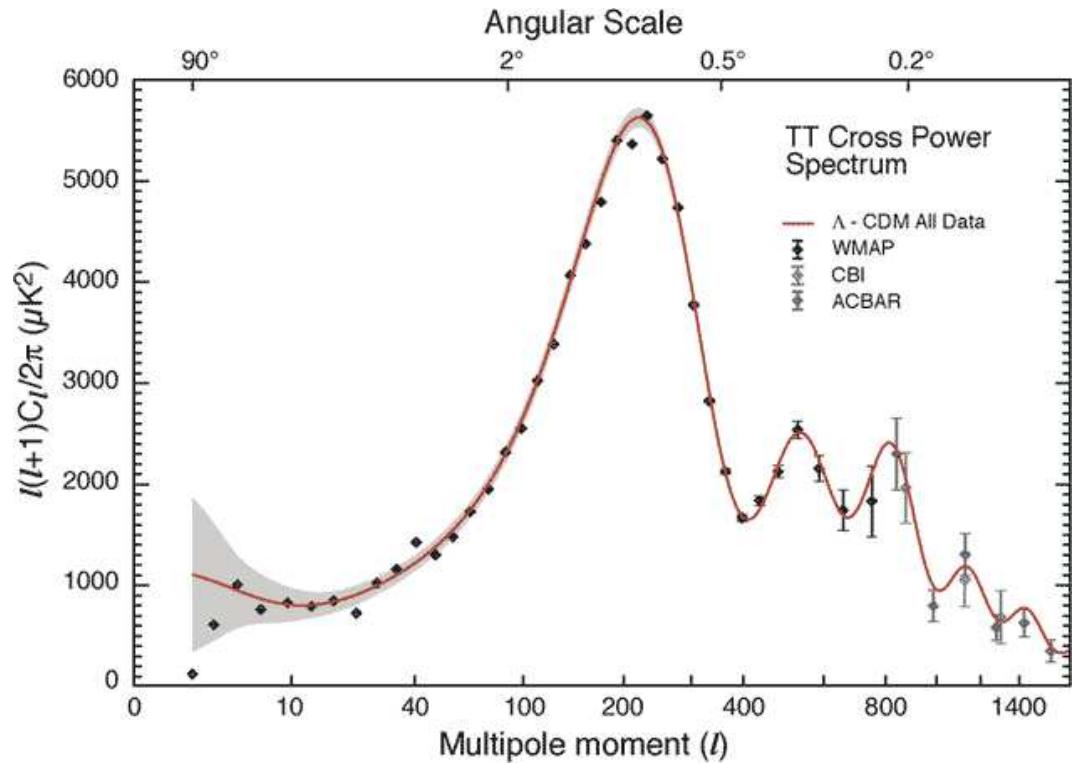


## Quadrupole-Octopole Alignment: Data.





## The low amplitude of the Quadrupole.



Radiation Power Spectrum from  
WMAP 1st year data.



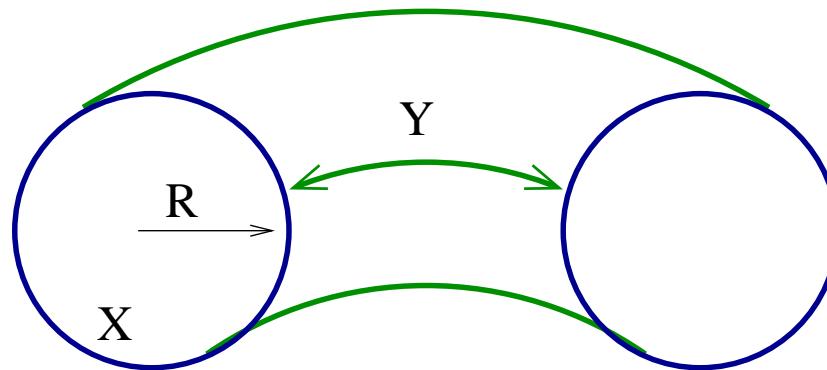
## A Topological Compact Universe?.

- The radiation Power Spectrum at low multipoles is dominated by the Sachs-Wolfe effect (with a small contribution coming from the ISW effect):

$$C_l = \frac{H_o^4}{2\pi} \int_o^\infty k^2 dk \frac{P(k)}{k^4} j_l^2(kR_H)$$

- The amplitude of  $C_2$  can be reduced introducing a cut-off scale in the power spectrum:

$$P(k) = \begin{cases} Ak^n & \text{if } k > k_{cut-off} \\ 0 & \text{if } k < k_{cut-off} \end{cases}$$



- A more elegant solution is to assume one -or more- dimensions are compact. If  $R$  is the size of the compact region, then:

$$P(k) = \begin{cases} A(k_x^2 + k_y^2 + k_z^2)^{n/2} & \text{if } k_x > 2\pi/R \\ A(k_y^2 + k_z^2)^{n/2} & \text{if } k_x < 2\pi/R \end{cases}$$