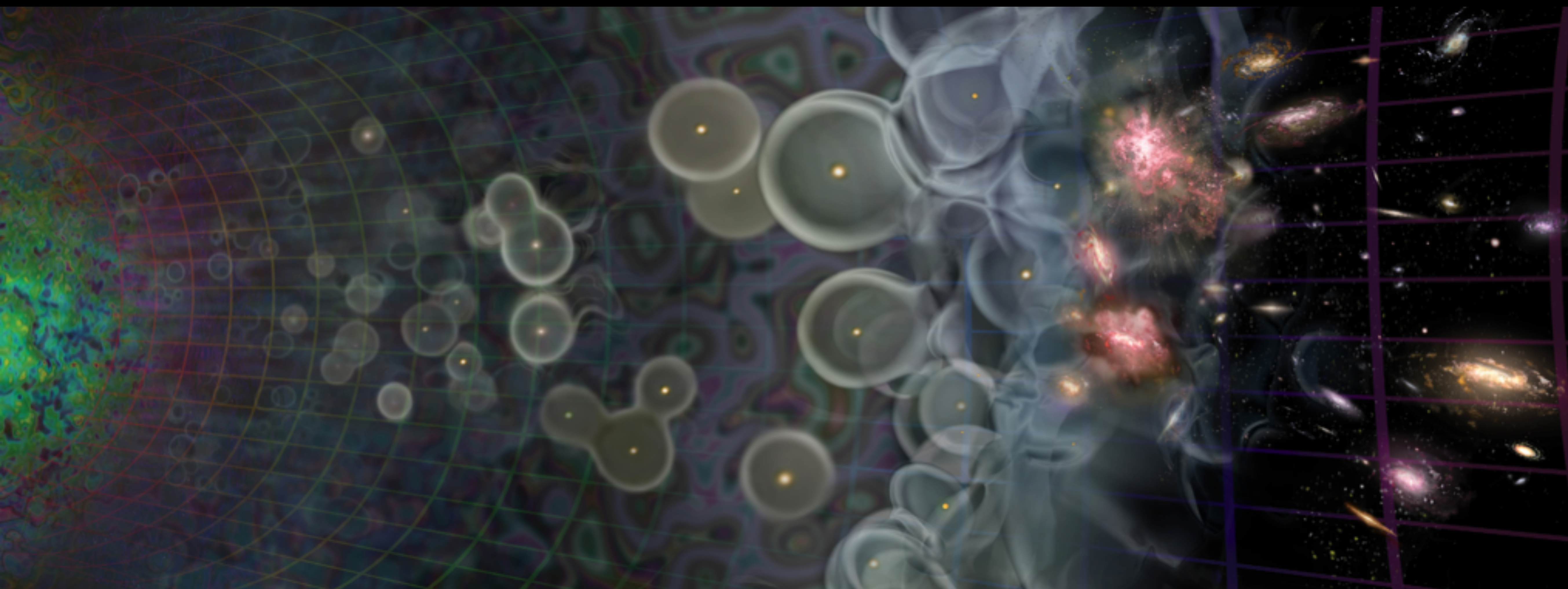
Introdução à Cosmologia Física

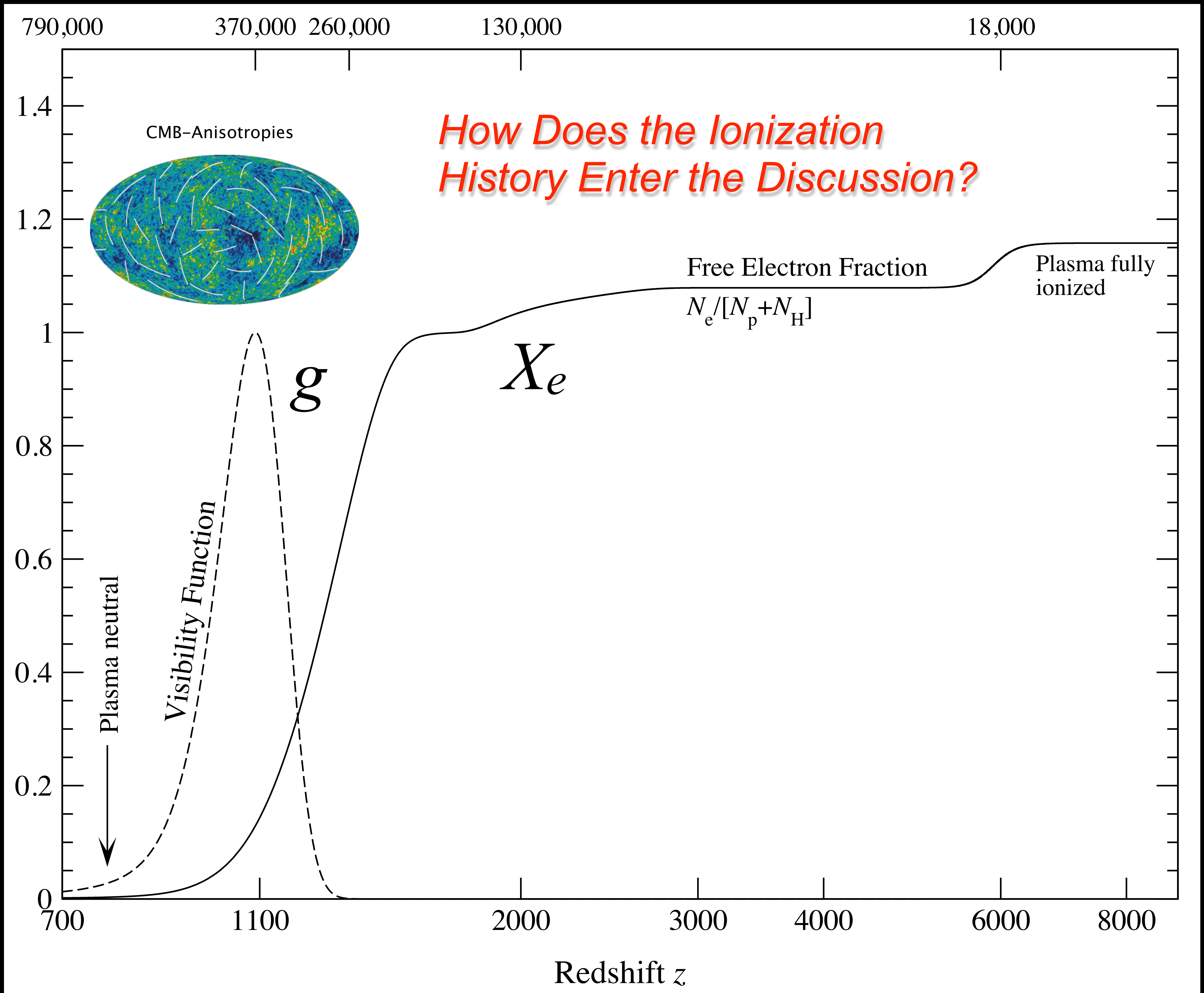


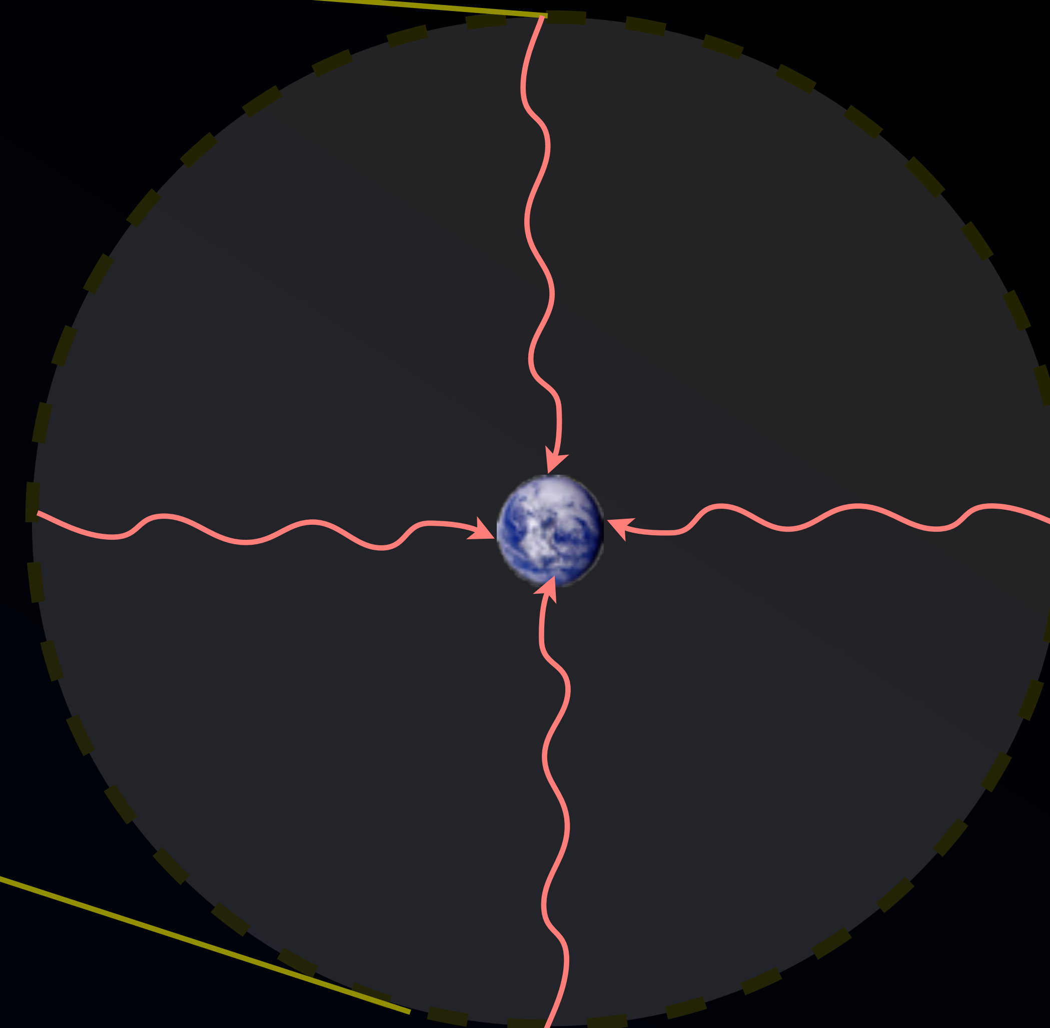
Hoje:

* Anisotropias da Radiação Cósmica de Fundo (RCF)
* O dipolo da RCF
* Como a RCF impões vinculos à **curvatura espacial**

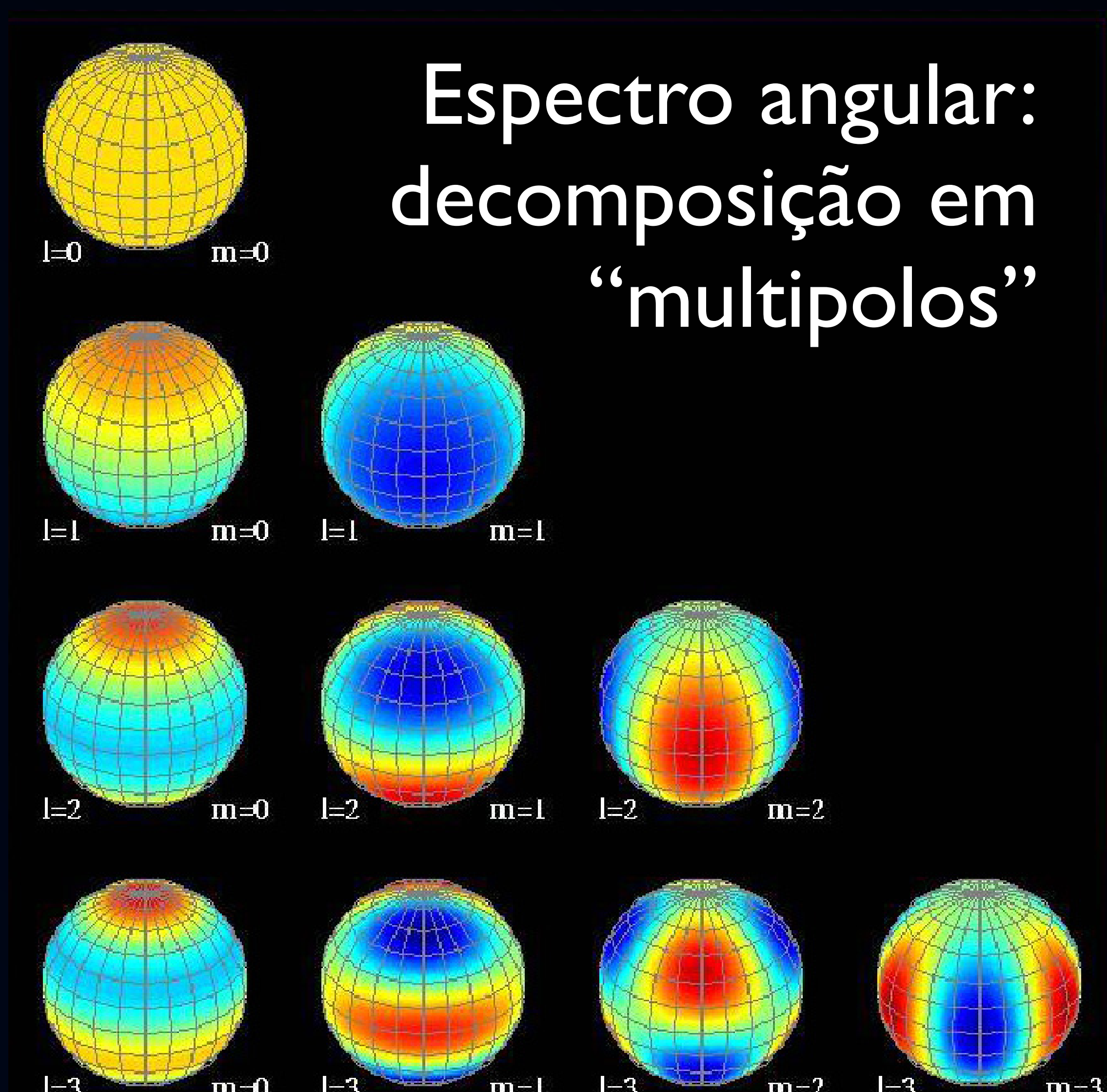
—> Ryder, Cap. 10

Função de visibilidade: $g(\eta) = \mu'(\eta) e^{-\mu(\eta)} \; = \; \sigma_T X_e(\eta) n_b(\eta) a(\eta) \times \exp\left[\int_0^{\eta} d\eta' \, \sigma_T X_e(\eta') n_b(\eta') a(\eta')\right]$



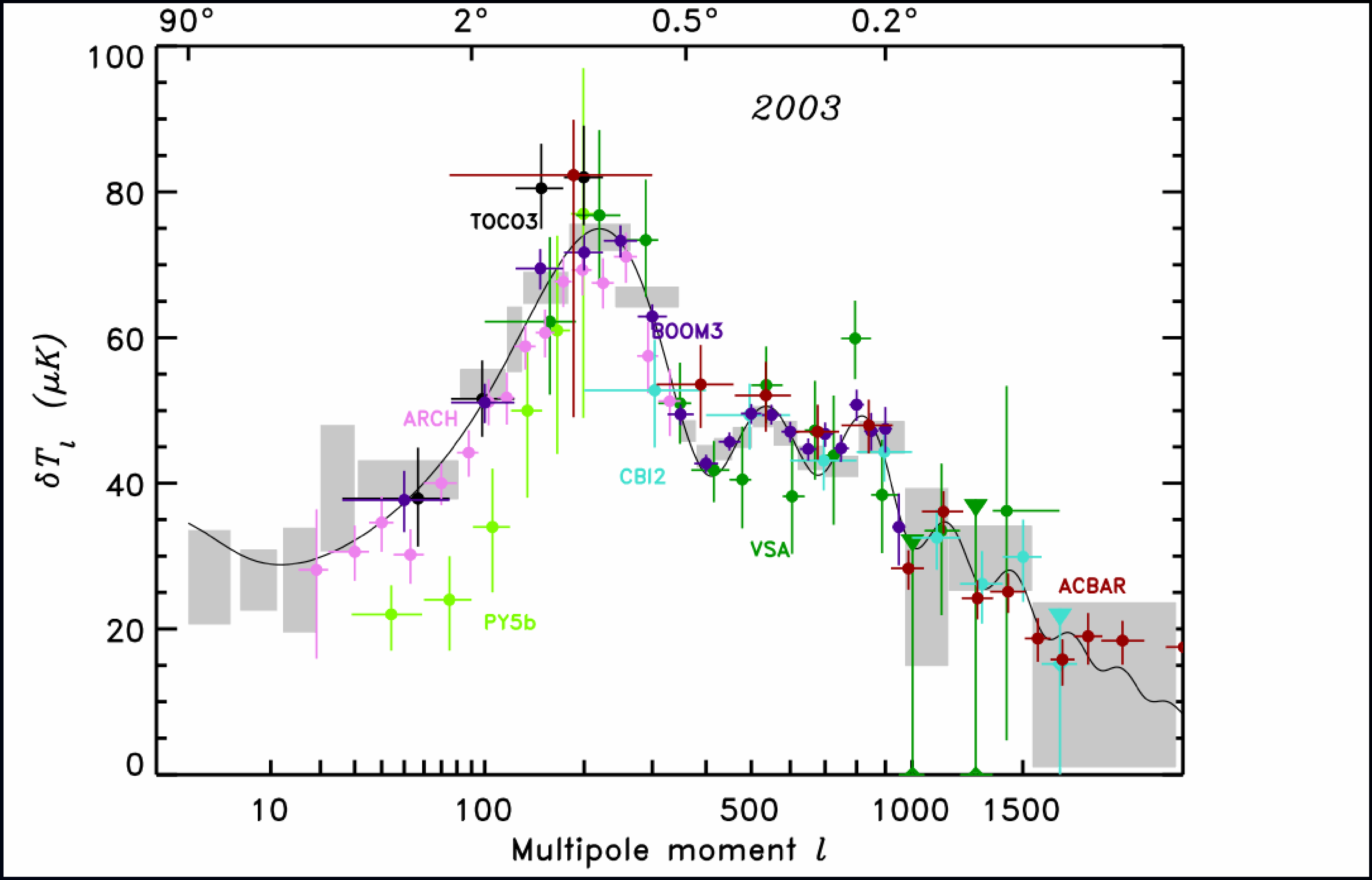


Espectro angular:
decomposição em
“multipolos”



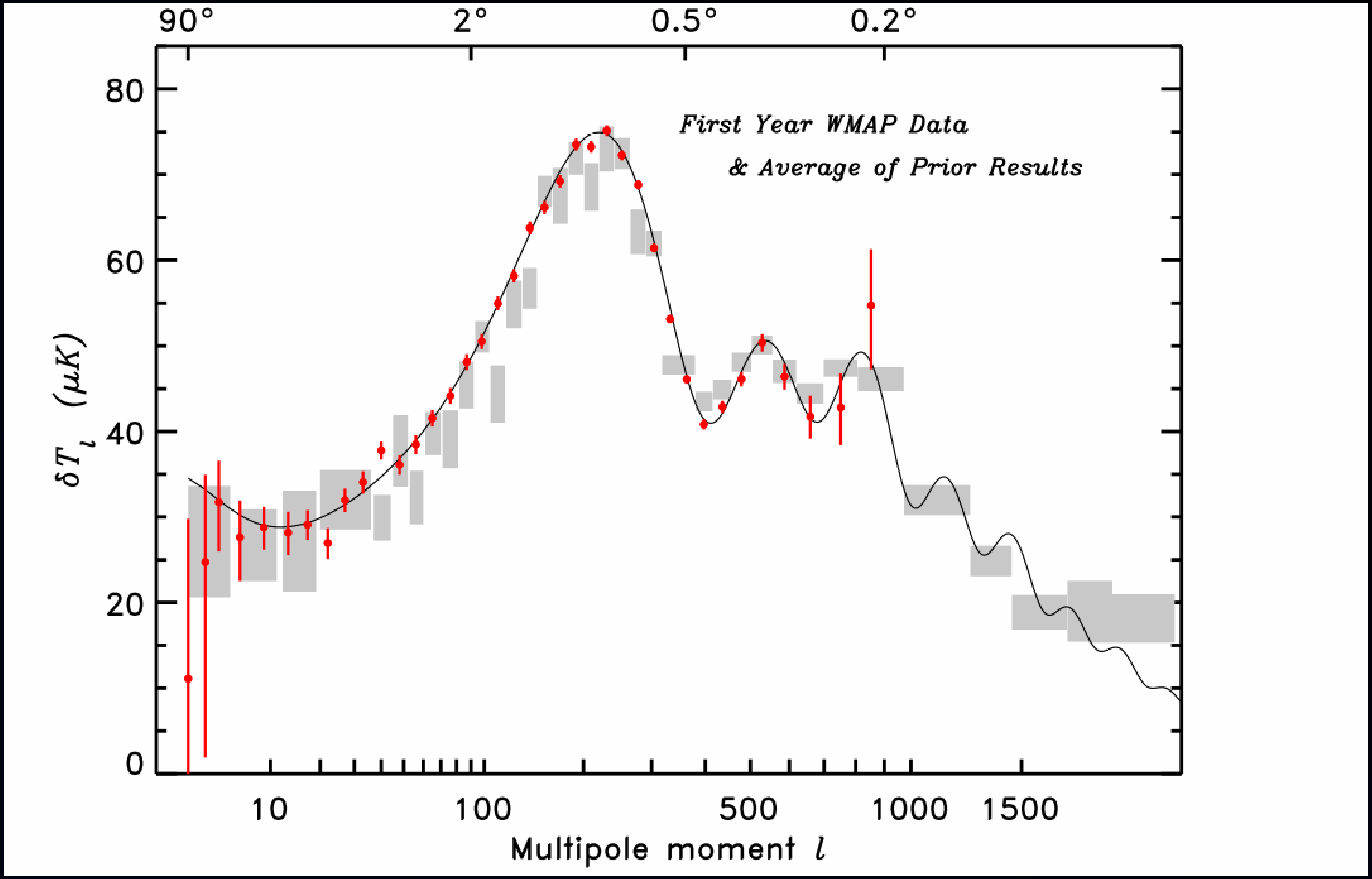
$$\delta T(\theta,\varphi) = \sum_{\ell,m} a_{\ell m} Y_\ell^m(\theta,\varphi)$$

$$C_\ell = \frac{1}{2\ell+1}\sum_{m=-\ell}^{\ell} \left|a_{\ell m}\right|^2$$



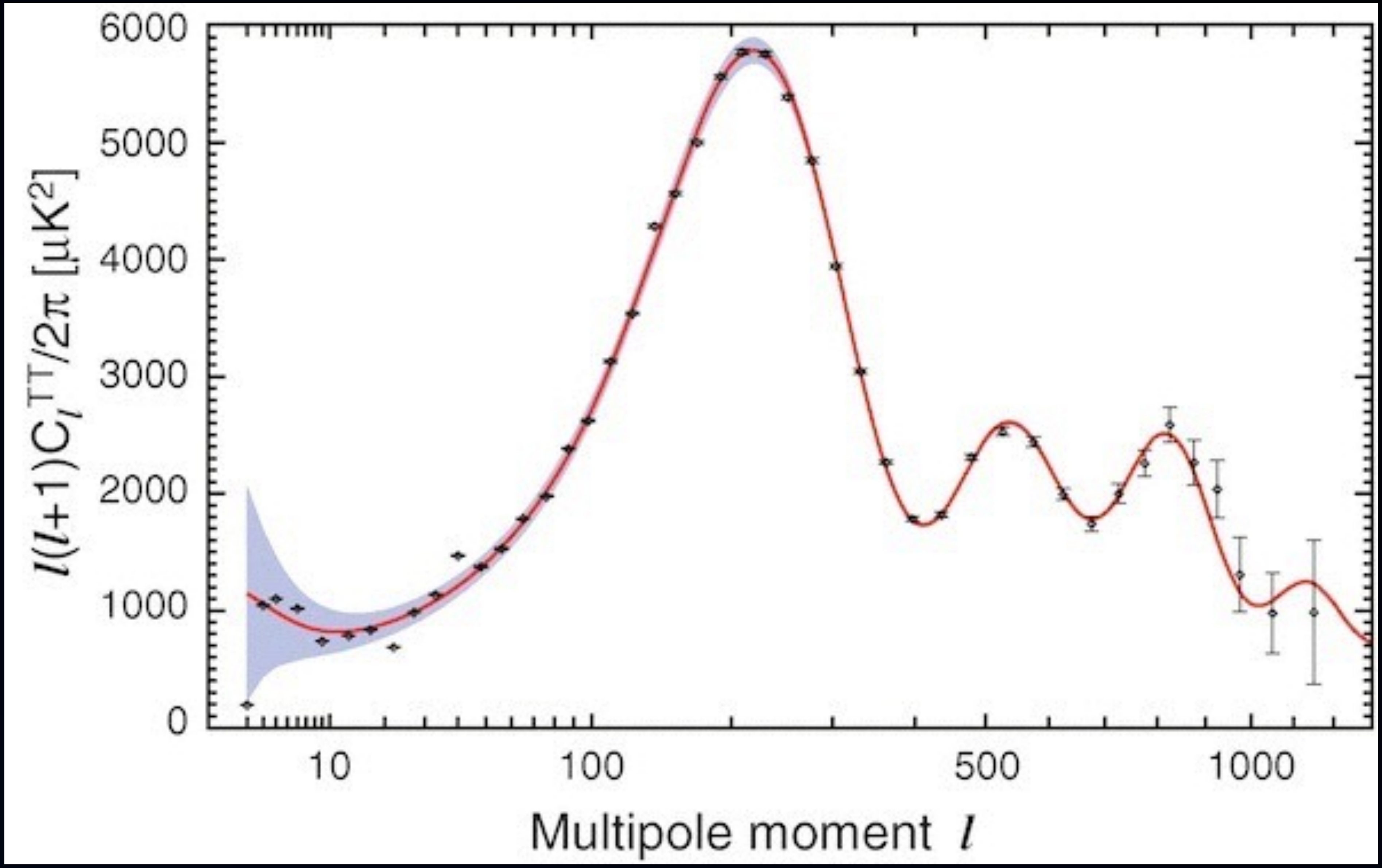
90°
2°
0.5°
0.2°
2003
TOCO3
BOOM3
ARCH
CBI2
VSA
ACBAR
PY5b
δT_l (μK)
Multipole moment l

WMAP @ 2003



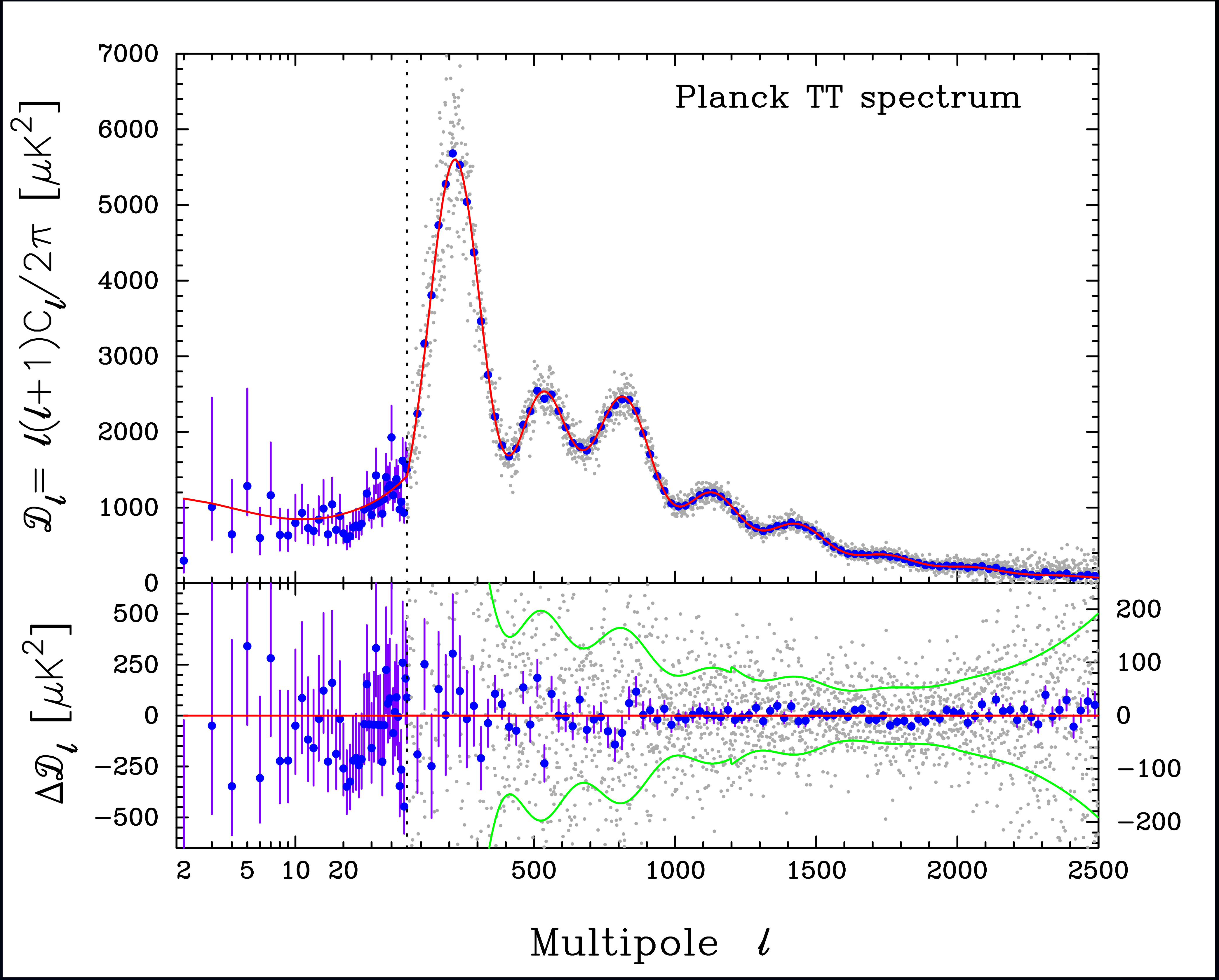
90°
2°
0.5°
0.2°
First Year WMAP Data
& Average of Prior Results
80
60
40
20
0
δT_l (μK)
10
100
500
1000
1500
Multipole moment l

WMAP @ 2009

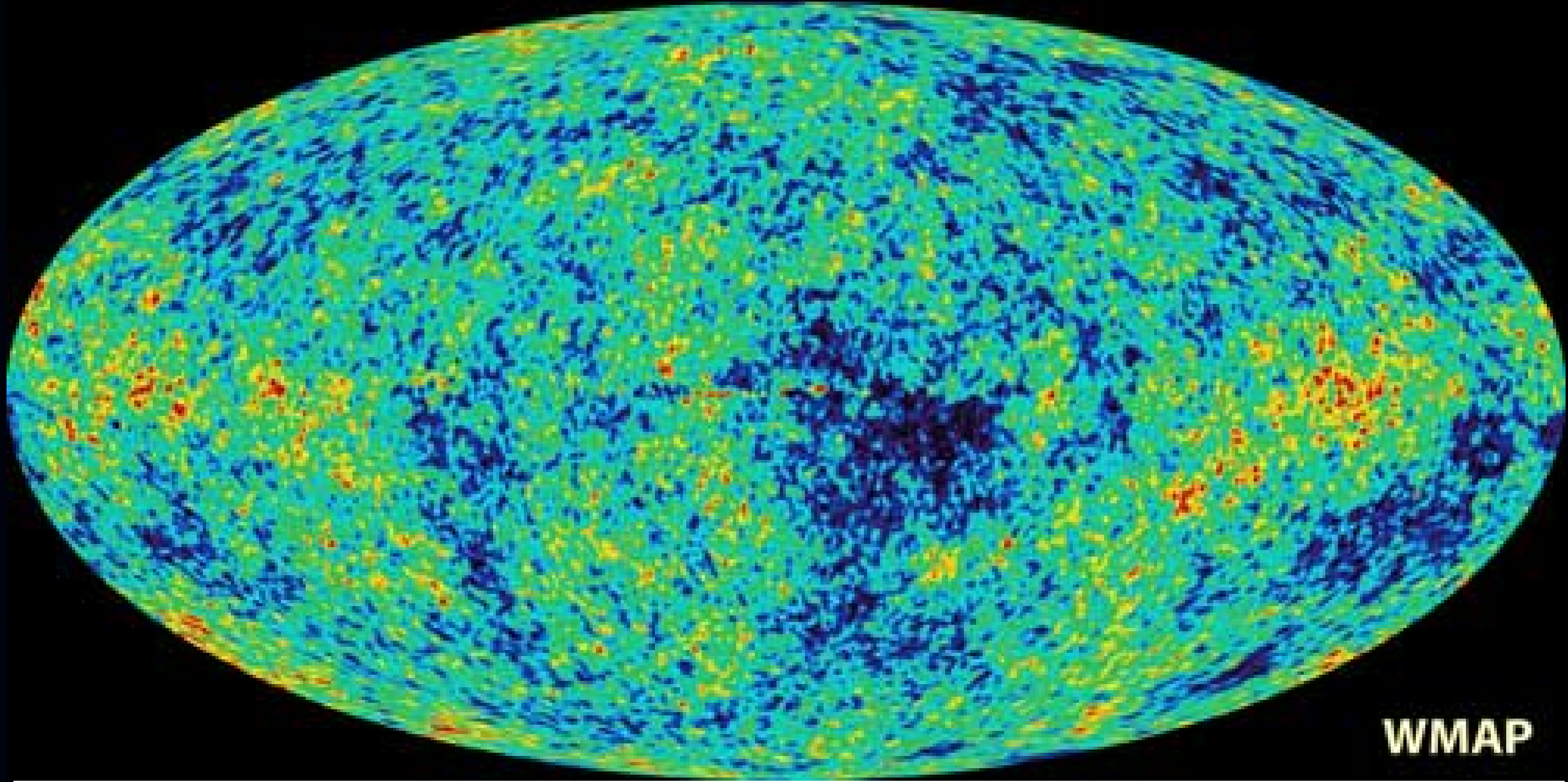


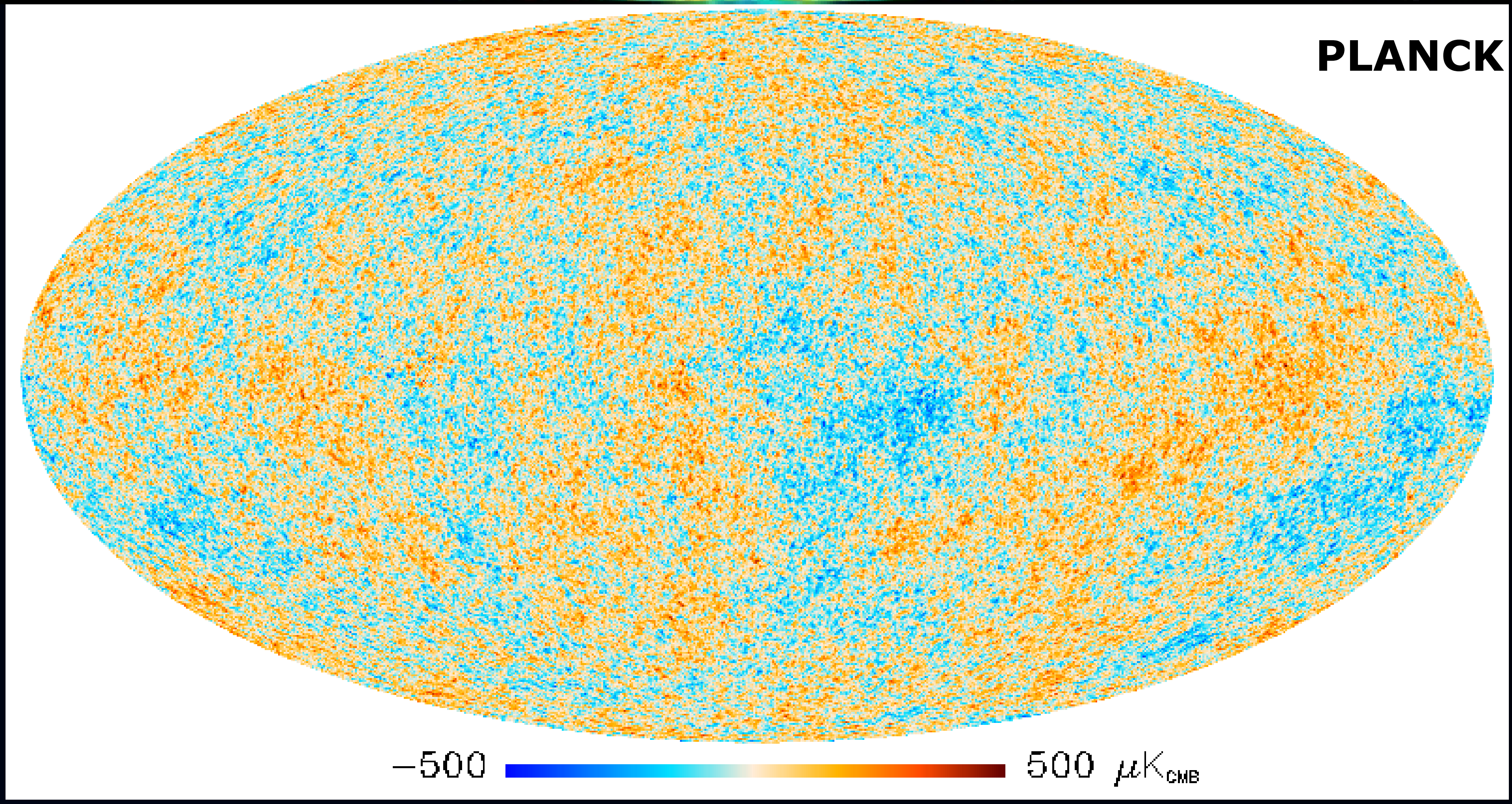
6000
5000
4000
3000
2000
1000
0
$l(l+1)C_l^{TT}/2\pi$ [μK^2]
10
100
500
1000
Multipole moment l

PLANCK @ 2013

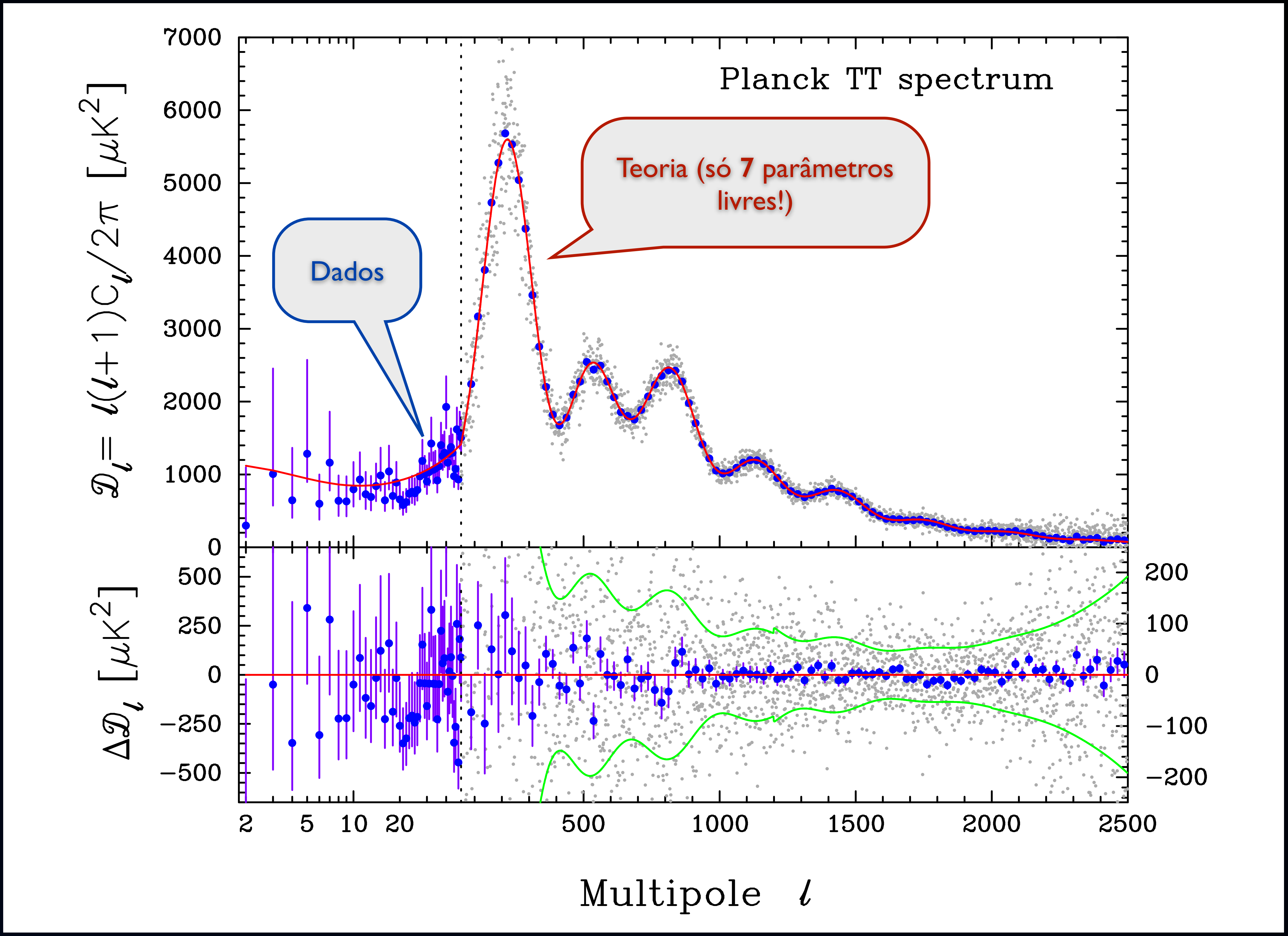


Planck TT spectrum
$\mathcal{D}_\ell = \ell(\ell+1)C_\ell/2\pi\ [\mu K^2]$
$\Delta\mathcal{D}_\ell\ [\mu K^2]$
Multipole ℓ
7000
6000
5000
4000
3000
2000
1000
0
500
250
0
−250
−500
200
100
0
−100
−200
2
5
10
20
500
1000
1500
2000
2500

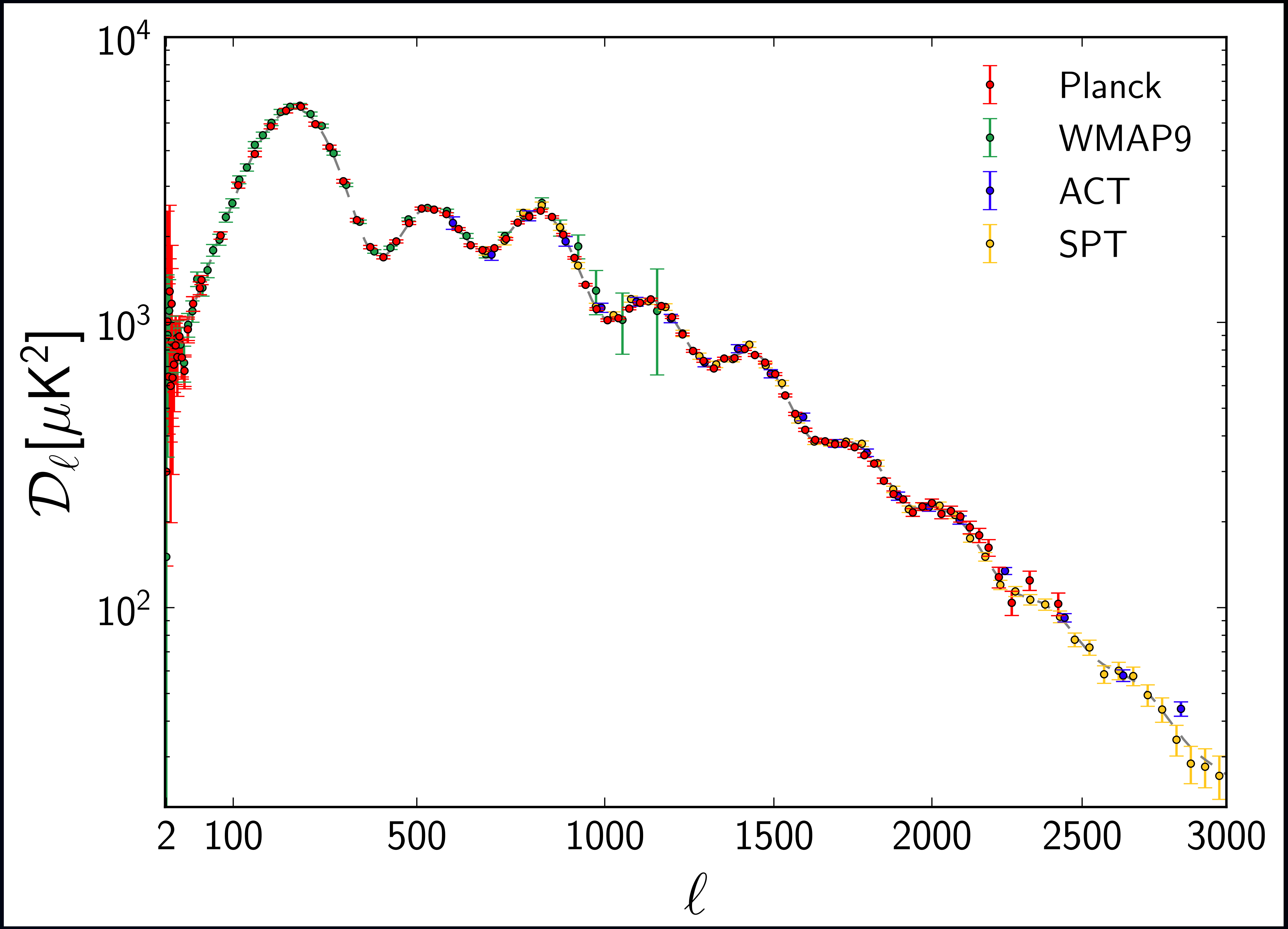

WMAP


PLANCK
−500
500 μK_CMB

Teoria *v.* dados (temperatura)



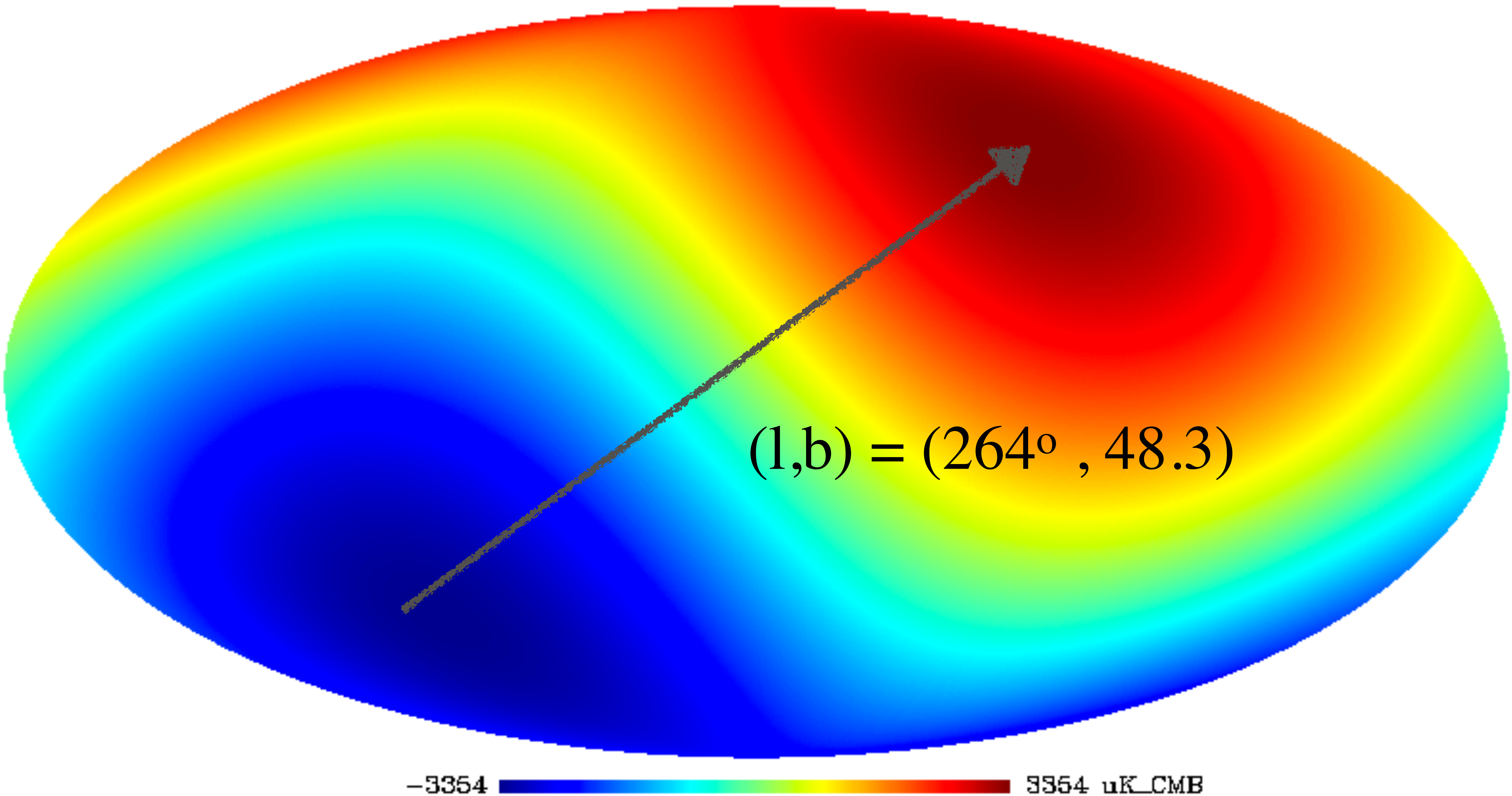
Estado-da-arte em 2014



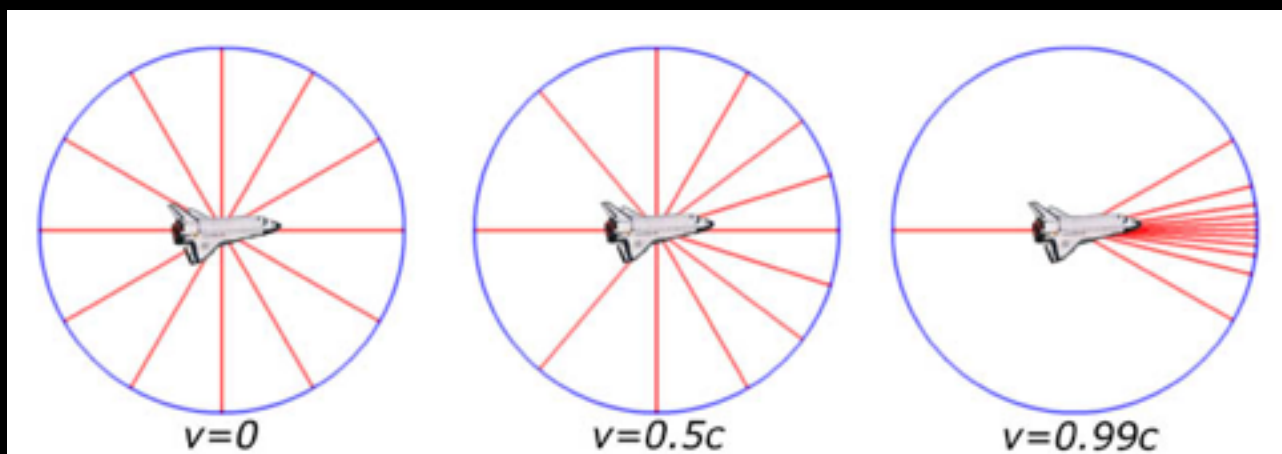
Radiação cósmica de fundo: "Cosmologia de precisão"

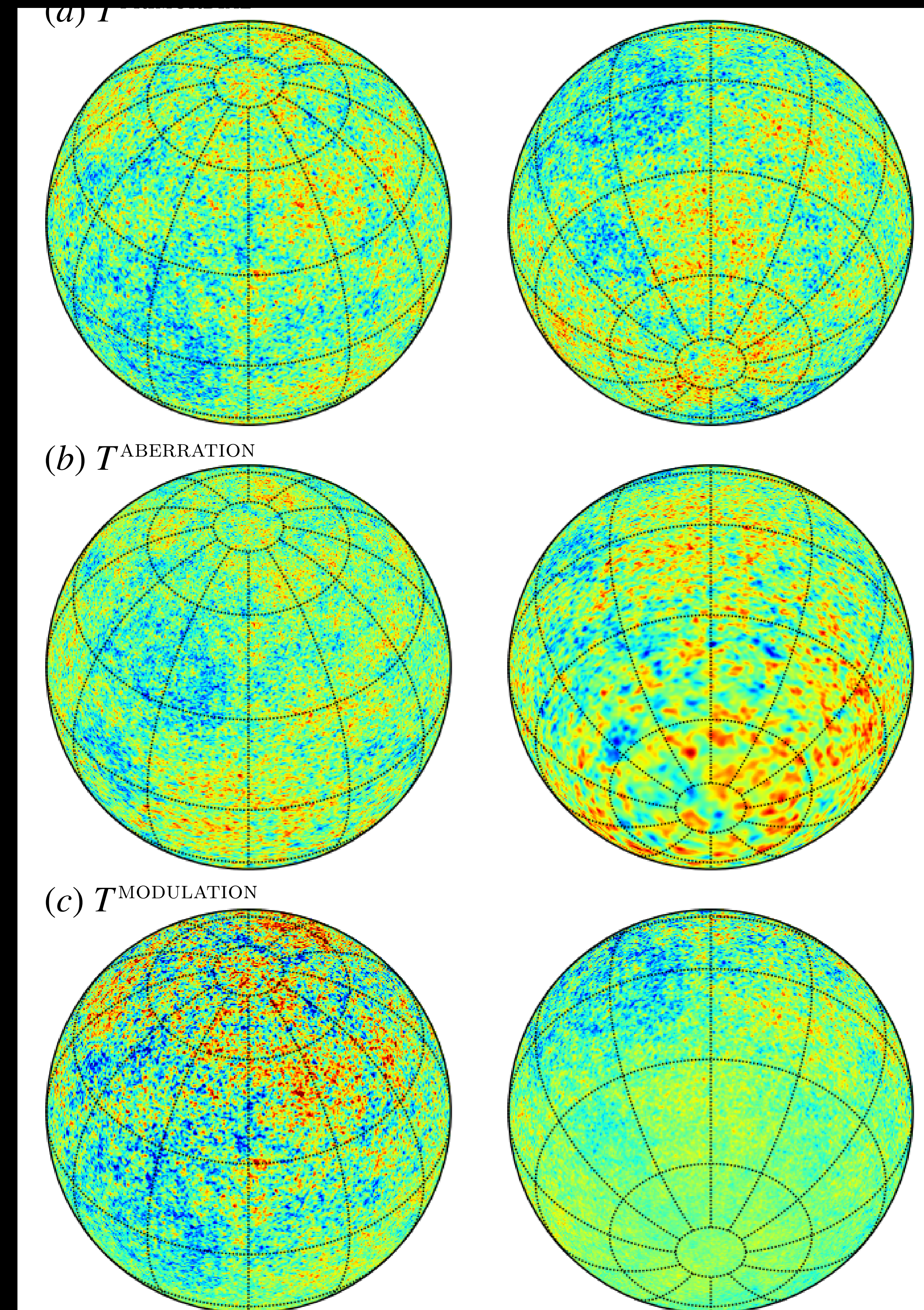
Parameter	*Planck* (CMB+lensing) Best fit	*Planck* (CMB+lensing) 68 % limits	*Planck*+WP+highL+BAO Best fit	*Planck*+WP+highL+BAO 68 % limits
$\Omega_b h^2$	0.022242	0.02217 ± 0.00033	0.022161	0.02214 ± 0.00024
$\Omega_c h^2$	0.11805	0.1186 ± 0.0031	0.11889	0.1187 ± 0.0017
$100\theta_{MC}$	1.04150	1.04141 ± 0.00067	1.04148	1.04147 ± 0.00056
τ	0.0949	0.089 ± 0.032	0.0952	0.092 ± 0.013
n_s	0.9675	0.9635 ± 0.0094	0.9611	0.9608 ± 0.0054
$\ln(10^{10} A_s)$	3.098	3.085 ± 0.057	3.0973	3.091 ± 0.025
Ω_Λ	0.6964	0.693 ± 0.019	0.6914	0.692 ± 0.010
σ_8	0.8285	0.823 ± 0.018	0.8288	0.826 ± 0.012
z_{re}	11.45	$10.8^{+3.1}_{-2.5}$	11.52	11.3 ± 1.1
H_0	68.14	67.9 ± 1.5	67.77	67.80 ± 0.77
Age/Gyr	13.784	13.796 ± 0.058	13.7965	13.798 ± 0.037
$100\theta_*$	1.04164	1.04156 ± 0.00066	1.04163	1.04162 ± 0.00056
r_{drag}	147.74	147.70 ± 0.63	147.611	147.68 ± 0.45
$r_{drag}/D_V(0.57)$	0.07207	0.0719 ± 0.0011		

1. Dipolo da RCF:



Efeito Doppler e Aberração:





$$T_{Obs}(\hat{n}) = \frac{T_R(\hat{n}_R)}{\gamma(1 - \hat{n} \cdot \vec{\beta})}$$

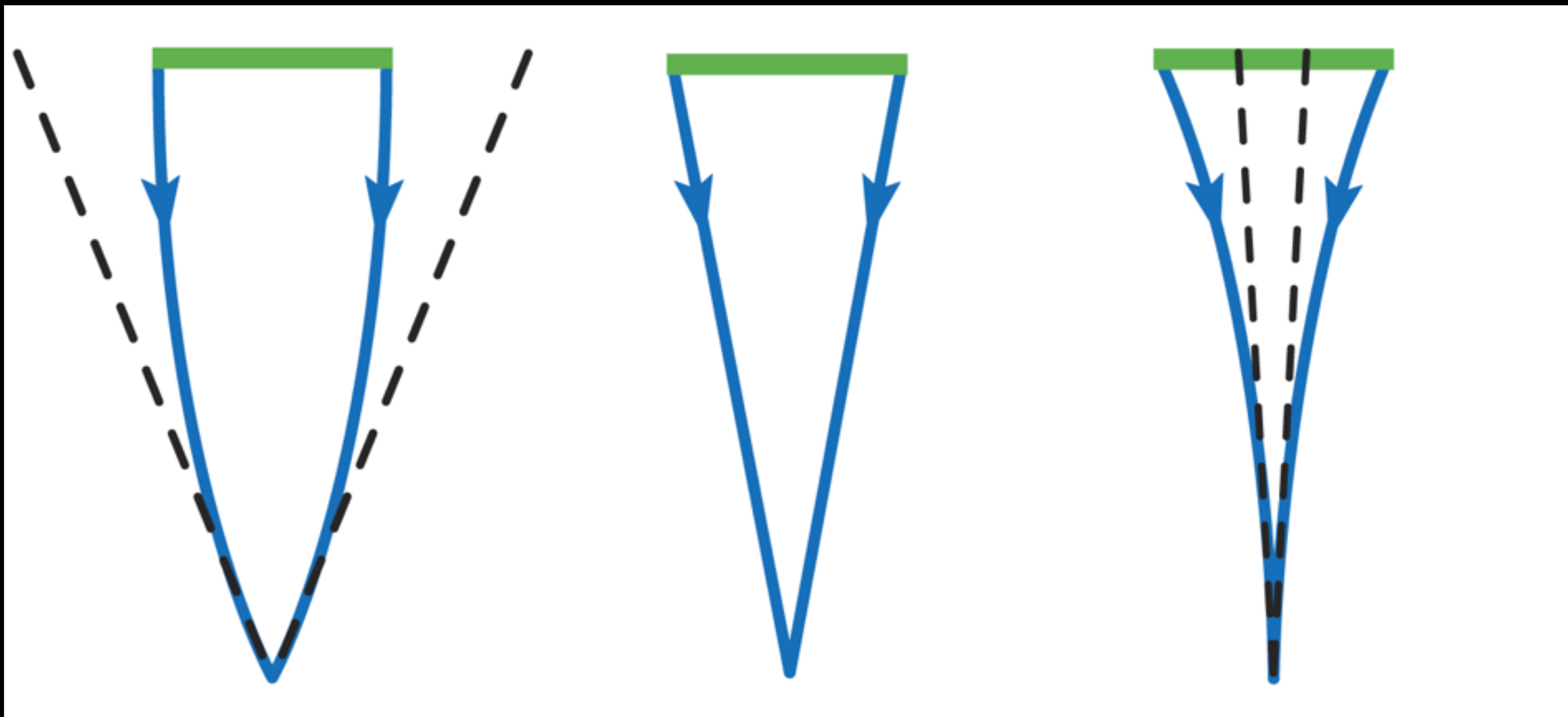
$$\hat{n} = \frac{\hat{n}_R + [(\gamma - 1)\hat{n}_R \cdot \hat{\beta} + \gamma\, \beta]\hat{\beta}}{\gamma(1 + \hat{n}_R \cdot \vec{\beta})}$$

Expandindo:

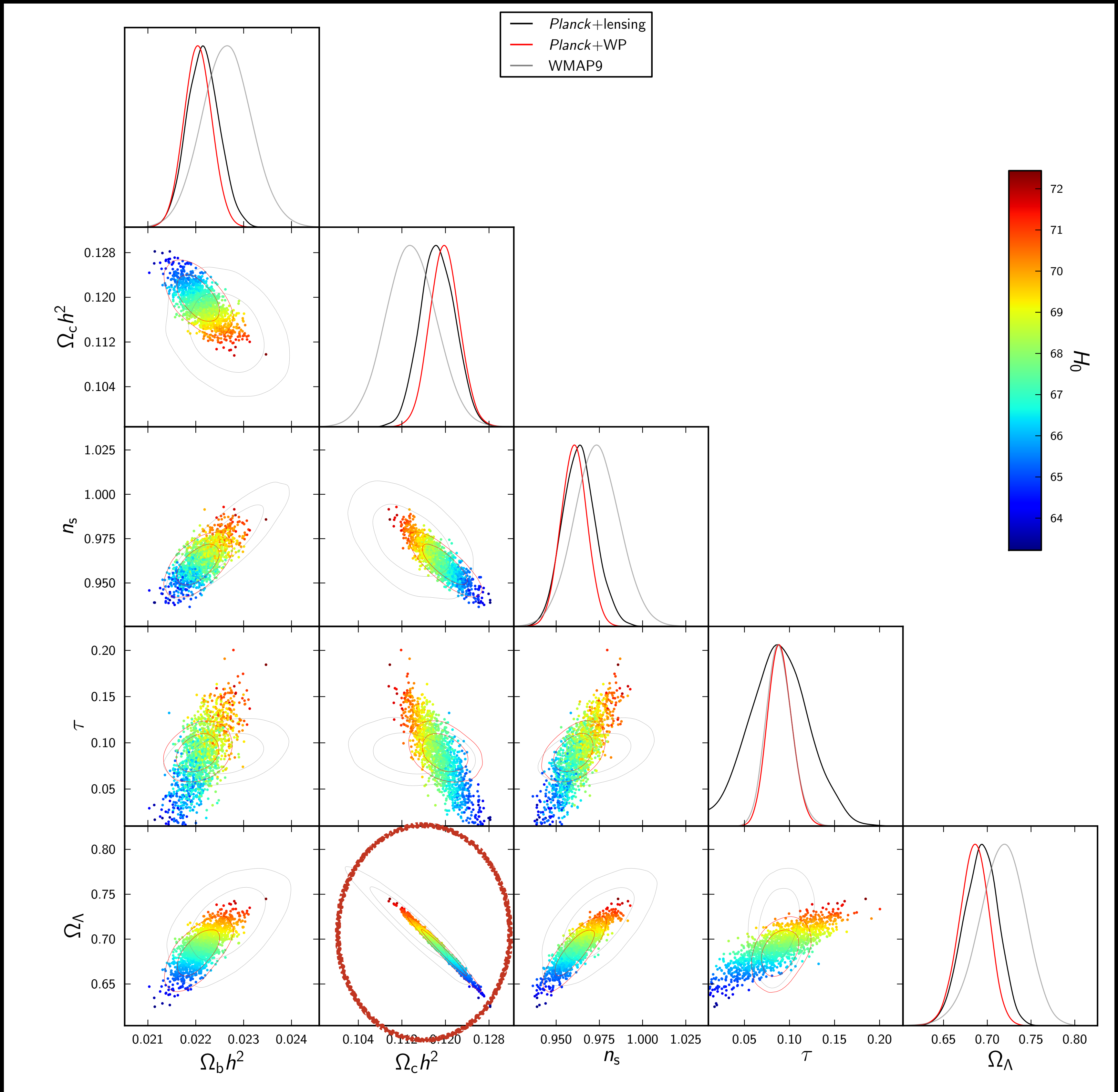
$$T_R(\hat{n}_R) \simeq T_R[\hat{n} - \vec{\nabla}(\hat{n} \cdot \vec{\beta})]$$

$$\Delta T_\beta(\hat{n}) \simeq T_0\, \hat{n} \cdot \vec{\beta} + \Delta T_{RCF}[\hat{n} - \vec{\nabla}(\hat{n} \cdot \vec{\beta})]\,(1 + \hat{n} \cdot \vec{\beta})$$

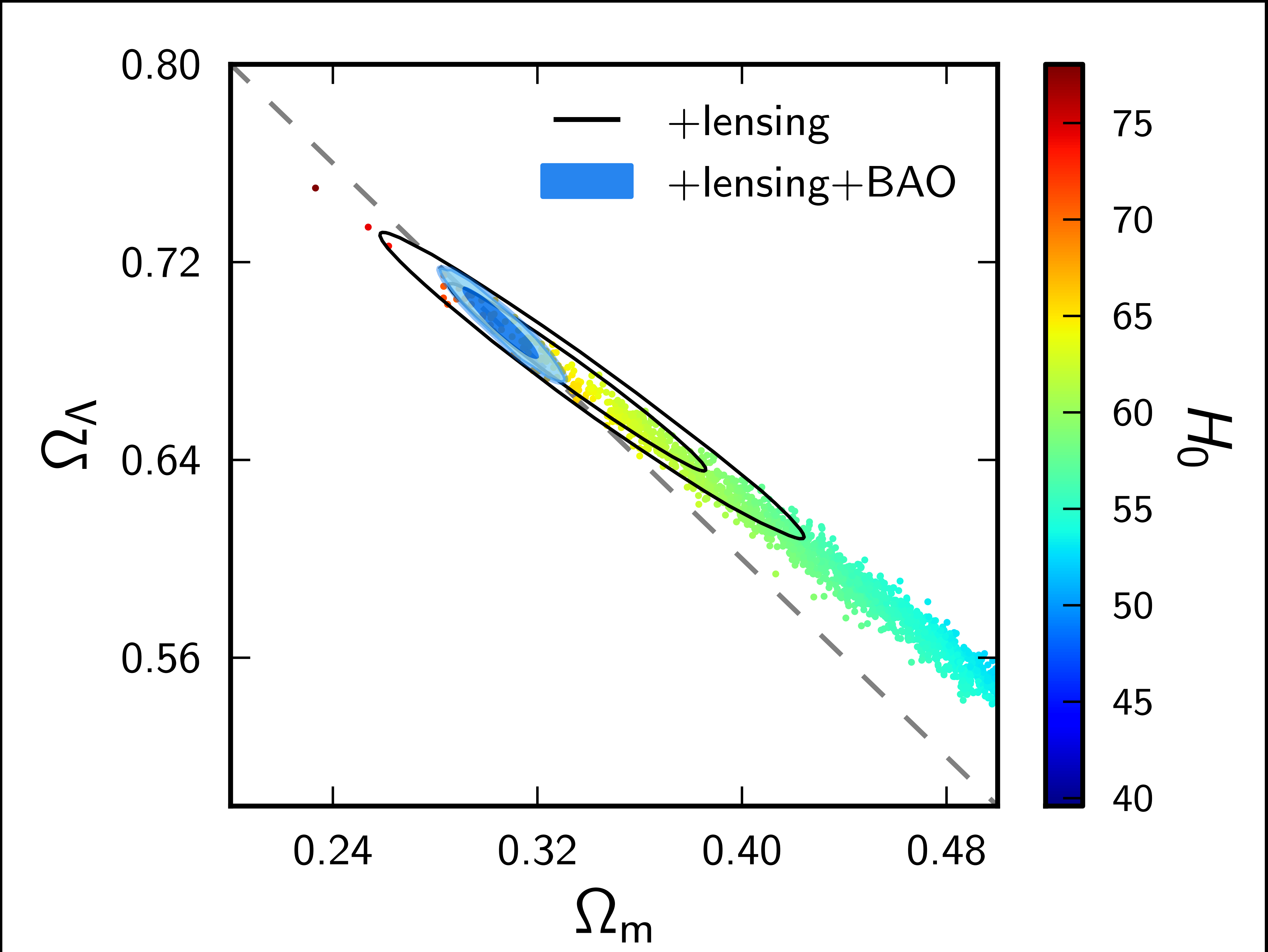
2. O horizonte sonoro (r_s) e a curvatura espacial



Resultados do Satélite Planck (2013):



Curvatura espacial muito bem limitada pela RCF...



Mas a RCF, sozinha, não dá conta do recado: