Adi and iso according to CMB and LSS

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GGI, Firenze, 23.10.2006

What?

We are considering events well after any process that generated the primordial perturbations.
• e.g., well after the end of inflation

In general there are the curvature perturbations $\mathcal{R}$ and the entropy perturbations $\mathcal{S}$ (can be several kinds of).

A general perturbation can be then divided into an adiabatic and an isocurvature mode
• adi: initially $\mathcal{R} \neq 0$ and $\mathcal{S} = 0$
• iso: initially $\mathcal{R} = 0$ and $\mathcal{S} \neq 0$

Adi and iso can be correlated since entropy perturbations can source curvature perturbations even on superhorizon scales.

Why?

We know that a simple adiabatic model is a very good fit to the data.

- Is isocurvature better constrained by the WMAP 3-year data?
  - revisit our earlier results

- How much isocurvature does the data allow?
  - it's not difficult to produce isocurvature
    - e.g., multi-field inflation

How?

- We consider a spatially flat universe
  - dark energy is the cosmological constant
  - CDM isocurvature
- We use the CMB data from WMAP-3 with additional small scale data and LSS data from SDSS

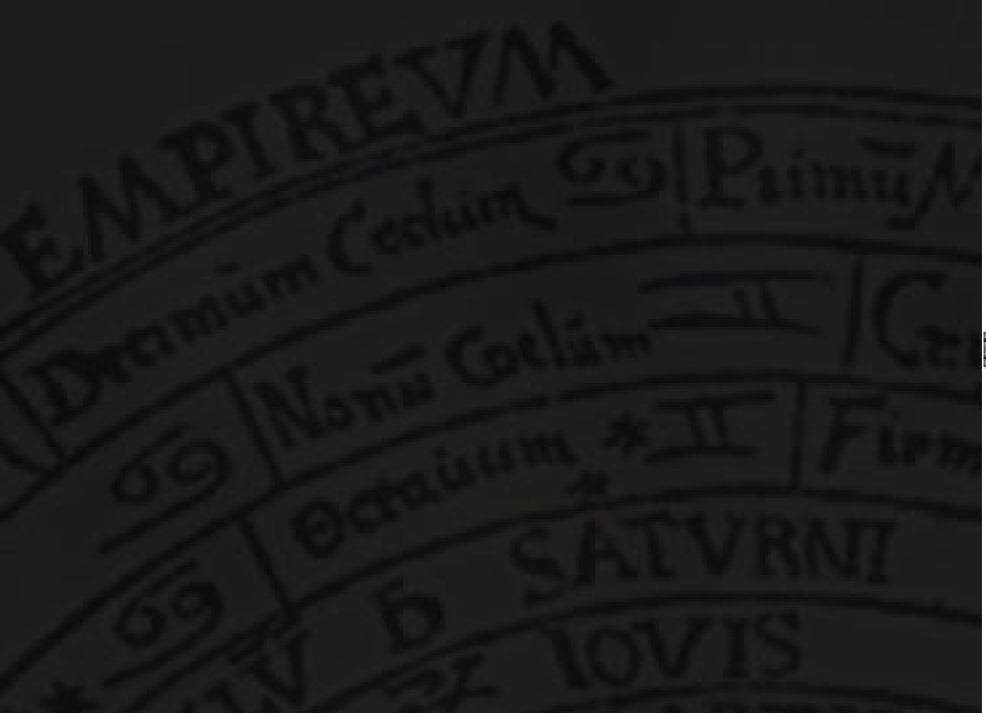
- The total C_l is a sum of four components

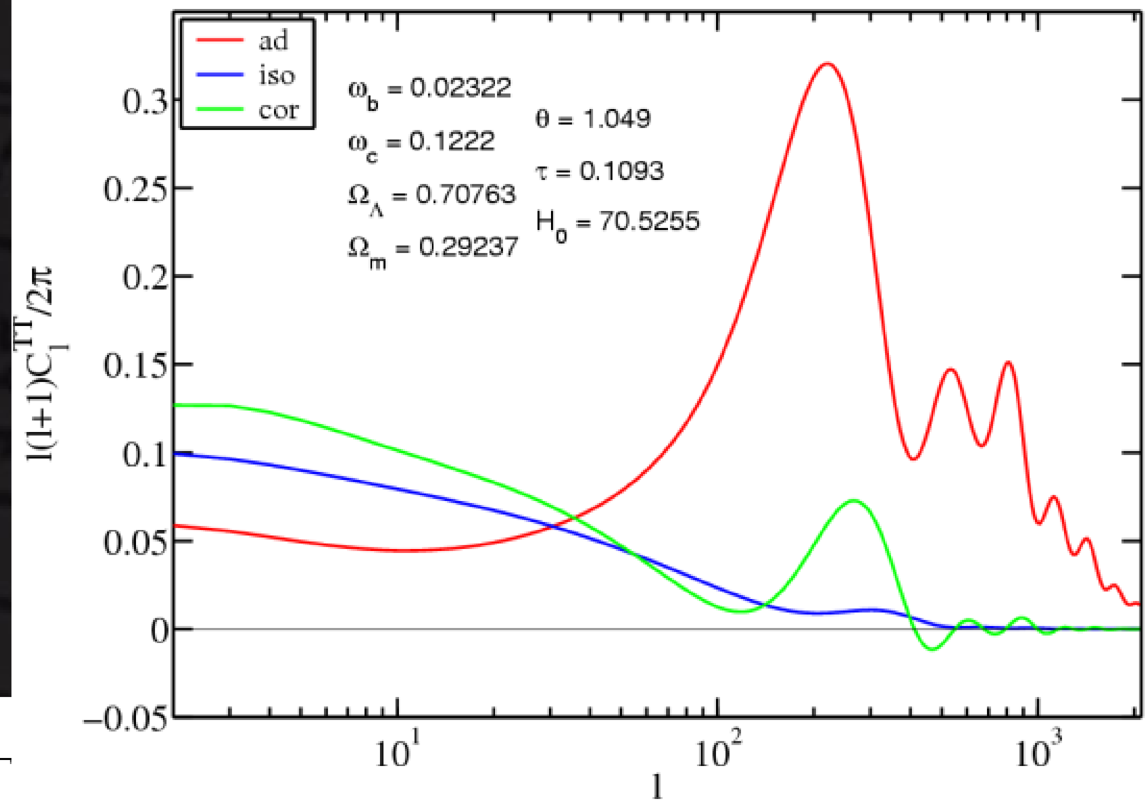
$$
\begin{aligned}
C_\ell = A^2 \big[&(1-\alpha)(1-|\gamma|)\hat{C}_\ell^{\rm ad1} + (1-\alpha)|\gamma|\hat{C}_\ell^{\rm ad2} \\
&+ \alpha \hat{C}_\ell^{\rm iso} + \mathrm{sign}(\gamma)\sqrt{\alpha(1-\alpha)|\gamma|}\hat{C}_\ell^{\rm cor}\big] \\
\equiv\ & C_\ell^{\rm ad1} + C_\ell^{\rm ad2} + C_\ell^{\rm iso} + C_\ell^{\rm cor},
\end{aligned}
$$

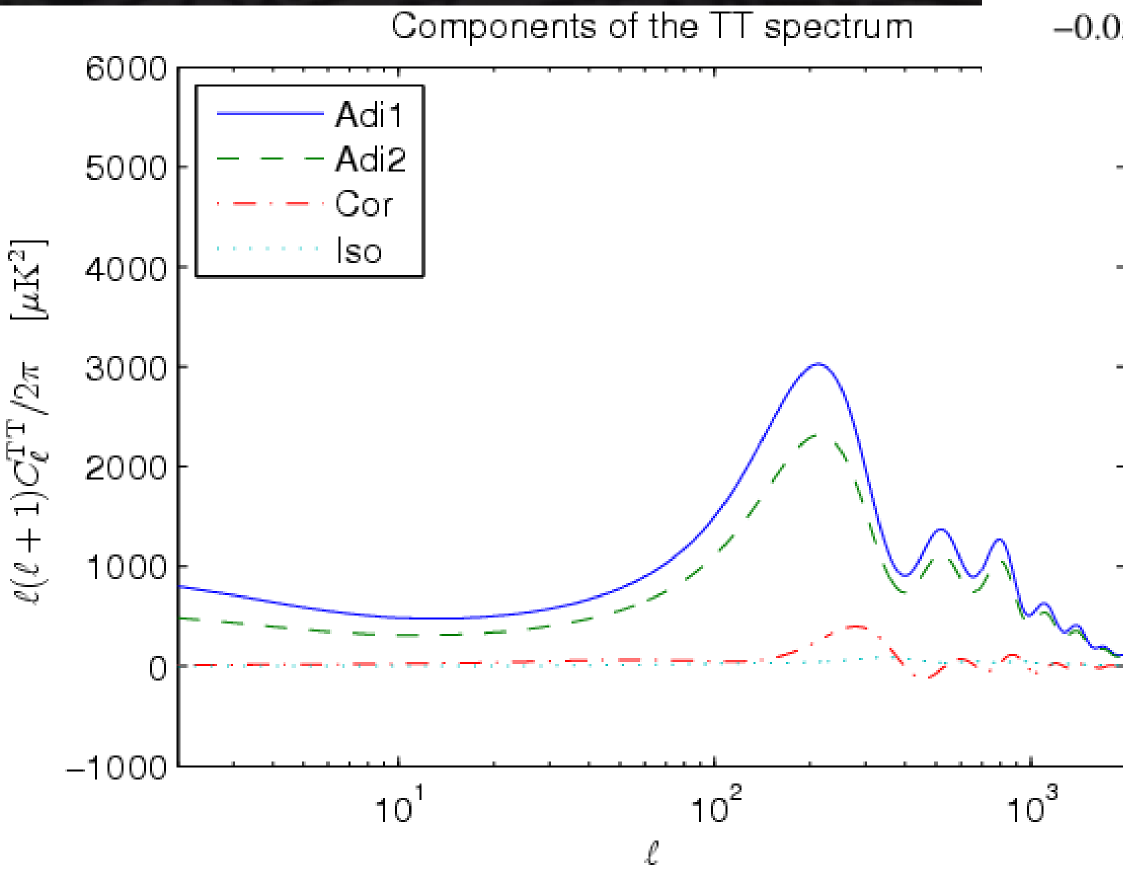
- In total there are 11 parameters

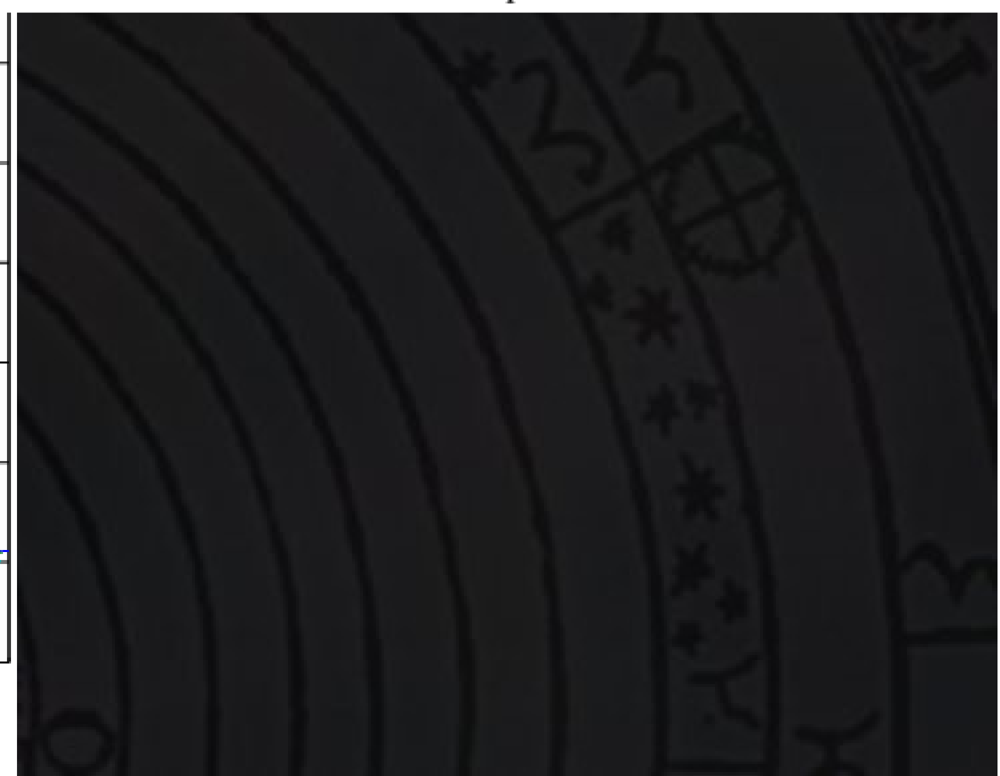
$$\omega_b, \omega_c, \theta, \tau, b, n_{ad1}, n_{ad2}, n_{iso}, \ln(10^{10}A^2), \alpha, \gamma$$

- Then we do a normal MCMC analysis


EMPIREVM
SATVRNI
IOVIS

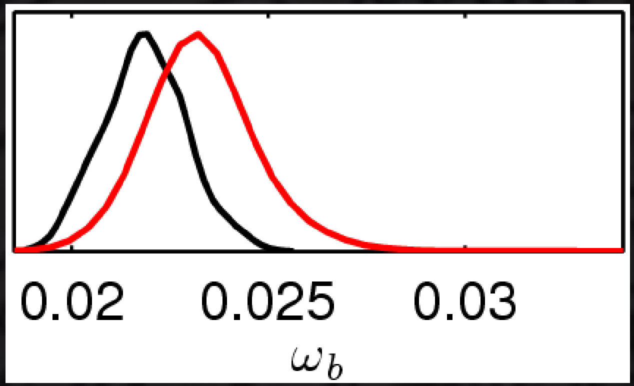

ad
iso
cor
$\omega_b = 0.02322$
$\omega_c = 0.1222$
$\Omega_\Lambda = 0.70763$
$\Omega_m = 0.29237$
$\theta = 1.049$
$\tau = 0.1093$
$H_0 = 70.5255$
$l(l+1)C_l^{TT}/2\pi$
l
0.3
0.25
0.2
0.15
0.1
0.05
0
−0.05
10^1
10^2
10^3


Components of the TT spectrum
Adi1
Adi2
Cor
Iso
$\ell(\ell+1)C_\ell^{TT}/2\pi \quad [\mu K^2]$
ℓ
6000
5000
4000
3000
2000
1000
0
−1000
10^1
10^2
10^3

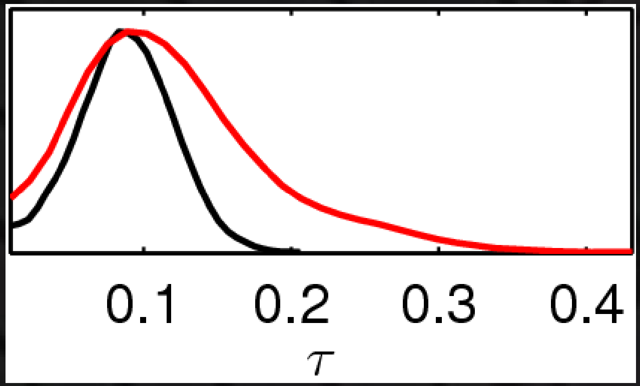


What do we find?

The isocurvature model is a slightly better fit to the data
• in terms of χ^2 the improvement is $\Delta\chi^2 \sim 10$

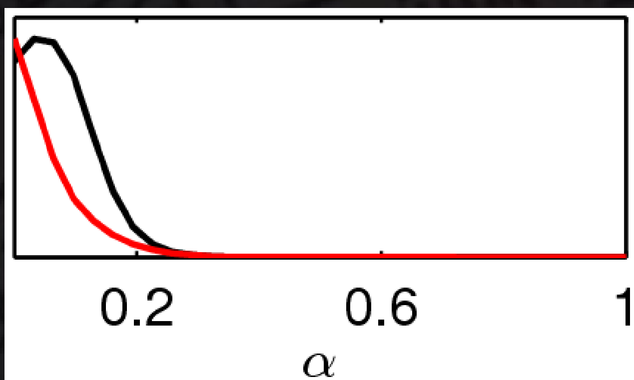


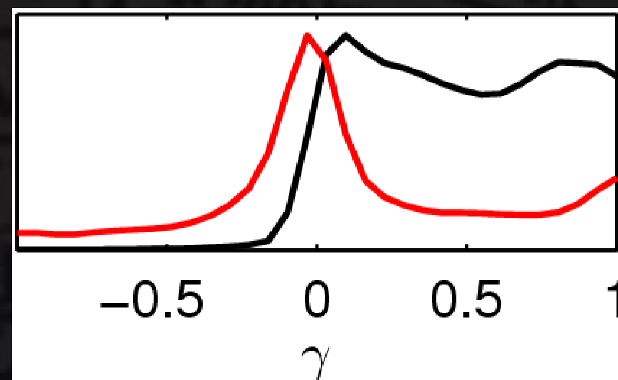
Slightly better fit to BBN values.

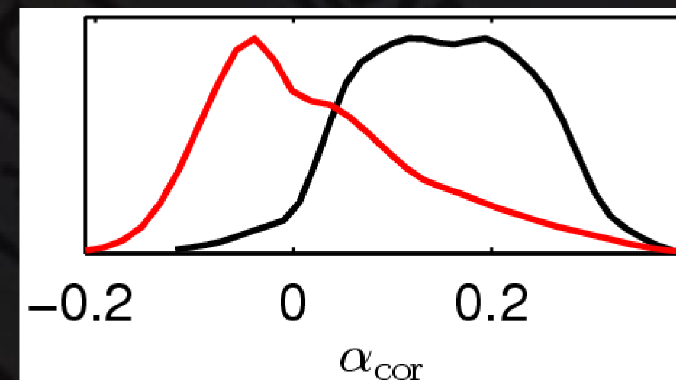


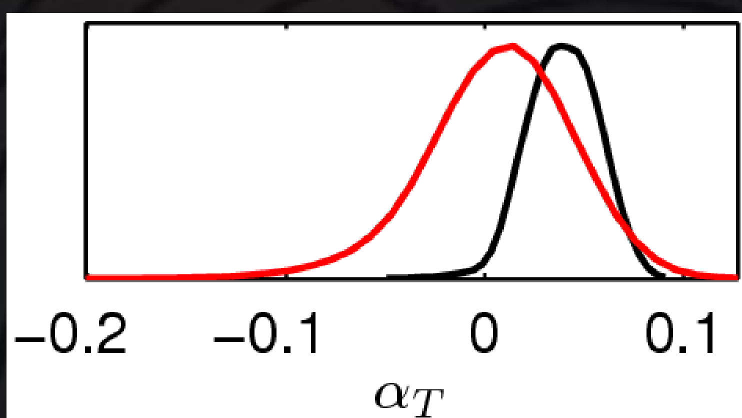
Better constrained due to WMAP polarization data.

Surprisingly, the WMAP 3-year data does not lead to tighter constraints on the isocurvature parameters.



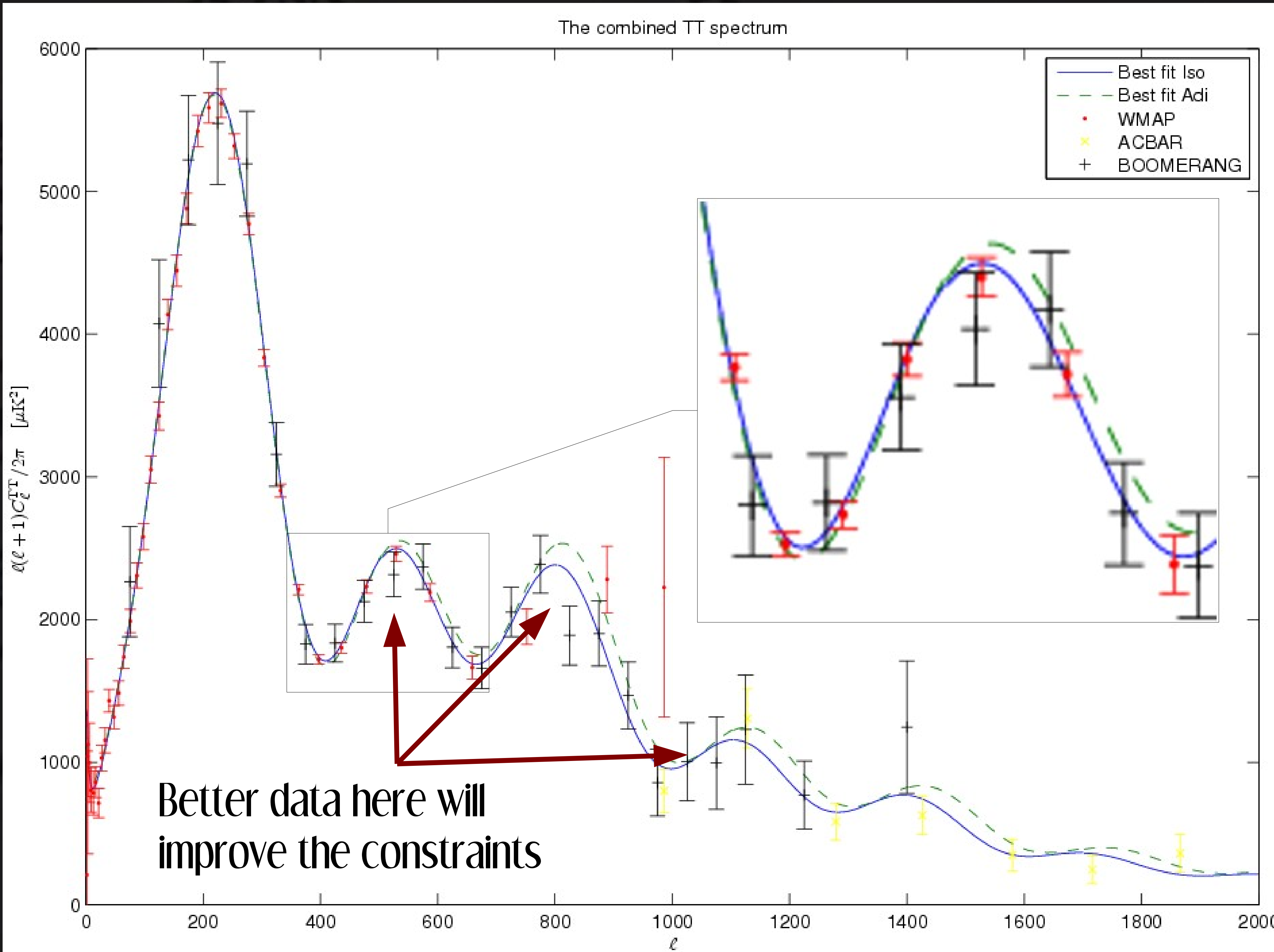






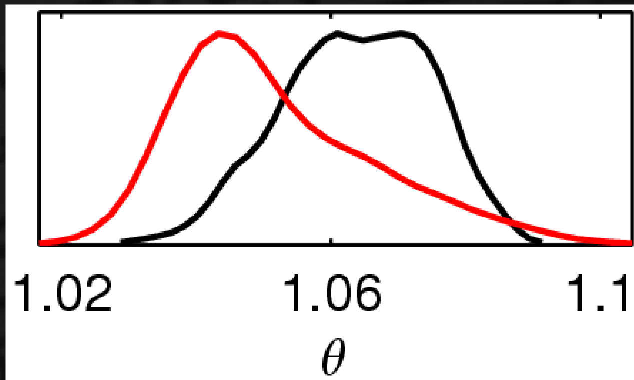
$$\alpha_T = \frac{\langle(\delta T^{\mathrm{non-ad}})^2\rangle}{\langle(\delta T^{\mathrm{total}})^2\rangle} = \frac{\sum_\ell (2\ell+1)\left(C_\ell^{\mathrm{TTiso}} + C_\ell^{\mathrm{TTcor}}\right)}{\sum_\ell (2\ell+1)\, C_\ell^{\mathrm{TT}}}$$

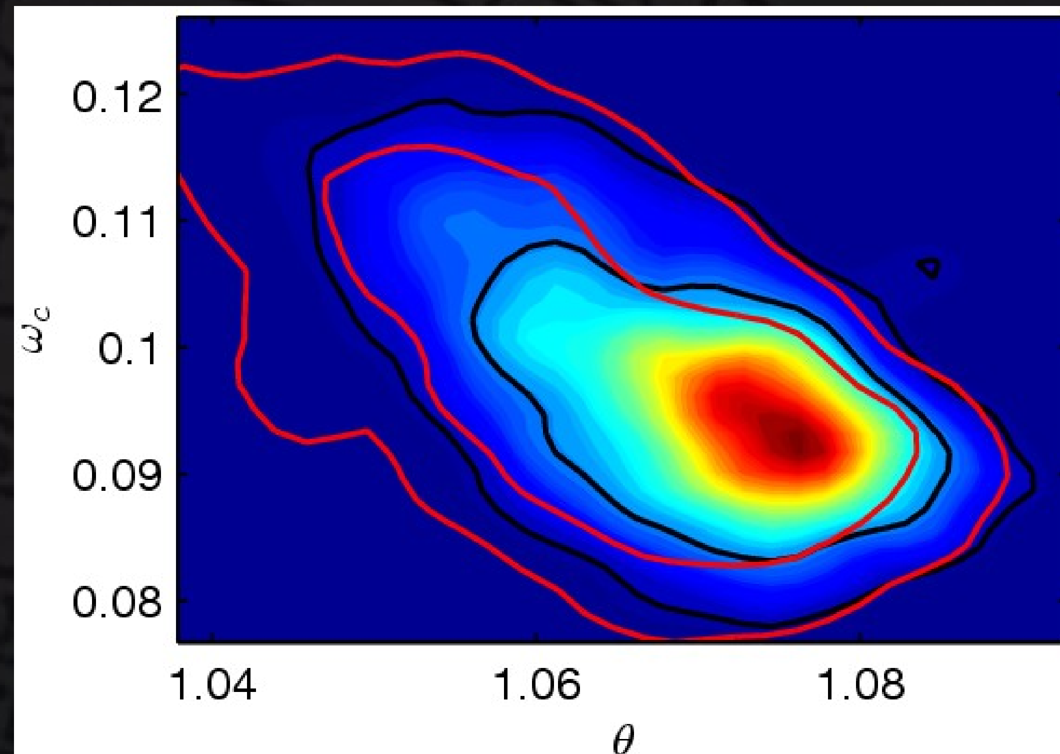
A non-adiabatic contribution ~5% is allowed by the data.

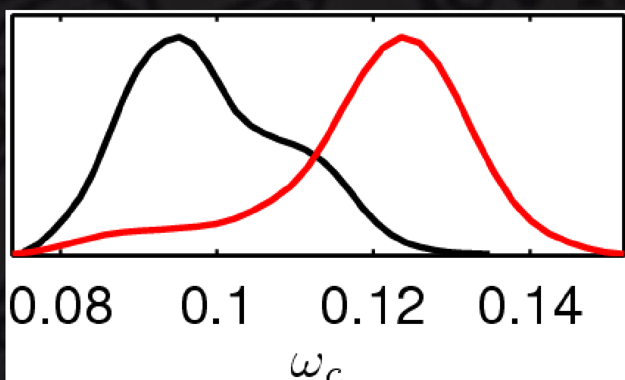


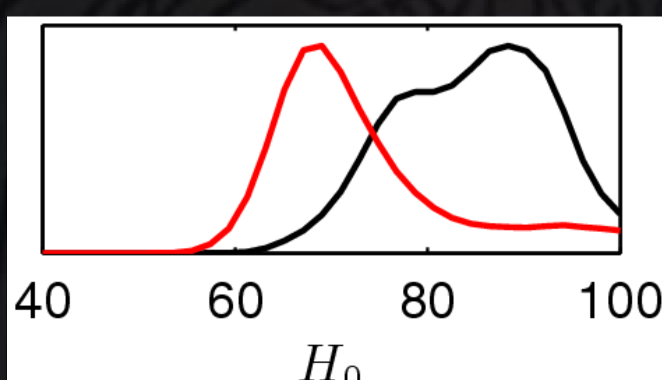
The combined TT spectrum
Best fit Iso
Best fit Adi
WMAP
ACBAR
BOOMERANG
$\ell(\ell+1)C_\ell^{TT}/2\pi$ [μK^2]
ℓ
0
1000
2000
3000
4000
5000
6000
200
400
600
800
1000
1200
1400
1600
1800
2000
Better data here will
improve the constraints

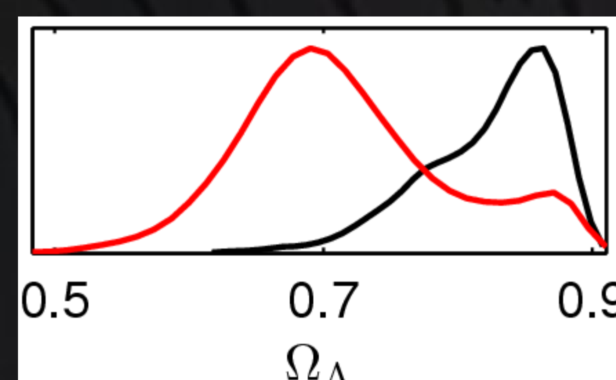
There are some effects, however, on the other parameters...











Conclusions

- The CMB is dominantly adiabatic, but a small isocurvature component is clearly allowed
  - this is true even with the latest more accurate data
  - there might be a small feature that can be explained with iso
  - more accurate data on the 2nd and 3rd peak will give further constraints
- In the observed CMB spectra there can be ~5% non-adiabatic contribution

To calculate the CMB power spectra, one needs the curvature and entropy perturbations given deep in the radiation dominated era.

$$\begin{bmatrix} \mathcal{R}(\mathbf{k}) \\ \mathcal{S}(\mathbf{k}) \end{bmatrix}_{\rm rad} = \begin{bmatrix} 1 & \mathcal{T}_{\mathcal{RS}}(k) \\ 0 & \mathcal{T}_{\mathcal{SS}}(k) \end{bmatrix} \begin{bmatrix} \mathcal{R}(\mathbf{k}) \\ \mathcal{S}(\mathbf{k}) \end{bmatrix}_*$$

A correlation between two random variables is given by:

$$\langle x(\mathbf{k}) y^*(\mathbf{k}') \rangle = \frac{2\pi^2}{k^3} \mathcal{C}_{xy}(k) \delta^{(3)}(\mathbf{k} - \mathbf{k}')$$

$$\begin{aligned} \mathcal{C}_{\mathcal{RR}}(t_{\rm rad}, k) &= \mathcal{P}_{\mathcal{R}}(t_*, k) + T_{\mathcal{RS}}(k)^2 \mathcal{P}_{\mathcal{S}}(t_*, k) \\ \mathcal{C}_{\mathcal{RS}}(t_{\rm rad}, k) &= T_{\mathcal{RS}}(k) T_{\mathcal{SS}}(k) \mathcal{P}_{\mathcal{S}}(t_*, k) \\ \mathcal{C}_{\mathcal{SS}}(t_{\rm rad}, k) &= T_{\mathcal{SS}}(k)^2 \mathcal{P}_{\mathcal{S}}(t_*, k) \,, \end{aligned}$$

Approximating the power spectra and the transfer functions by power laws leads to:

$$\mathcal{P}_{\mathcal{R}}(k) \equiv \mathcal{C}_{\mathcal{R}\mathcal{R}}(k) = A_r^2 \hat{k}^{n_{\mathrm{ad1}}-1} + A_s^2 \hat{k}^{n_{\mathrm{ad2}}-1}$$

$$\mathcal{P}_{\mathcal{S}}(k) \equiv \mathcal{C}_{\mathcal{S}\mathcal{S}}(k) = B^2 \hat{k}^{n_{\mathrm{iso}}-1}$$

$$\mathcal{C}_{\mathcal{R}\mathcal{S}}(k) = \mathcal{C}_{\mathcal{S}\mathcal{R}}(k) = A_s B \hat{k}^{n_{\mathrm{cor}}-1}$$

$$n_{\mathrm{cor}} = \frac{1}{2}(n_{\mathrm{iso}} + n_{\mathrm{ad2}})$$

The total CMB angular power spectrum is now:

$$C_\ell^{ab} = 4\pi \sum_{xy} \int \frac{dk}{k} \mathcal{C}_{xy}(k) g_{x\ell}^a(k) g_{y\ell}^b(k)$$