

Oscillations in the CMB angular power spectra at $\ell \ell \ell -120$

Kouichirou Horiguchi¹, Kiyotomo Ichiki¹, Jun'ichi Yokoyama²

¹ Nagoya University, ² University of Tokyo

20161128 COSPA@SYDNEY, AUSTRALIA

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Introduction

Previous studies : oscillations in WMAP data at multipole ell ~ 120

Method

Parameterization of the oscillations, MCMC analysis of Planck data

Result & discussion

Distributions of parameters, effects on cosmological parameters

Summary

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INTRODUCTION

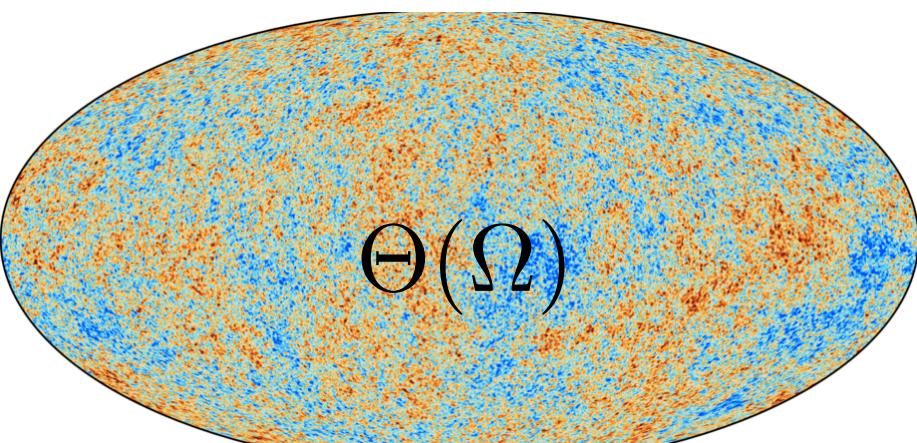
Cosmic Microwave Background (CMB)

Black body radiation : $T = 2.725 \text{ K}$, $\Theta(\Omega) = \Delta T/T \sim 10^{-5}$

Angular power spectrum

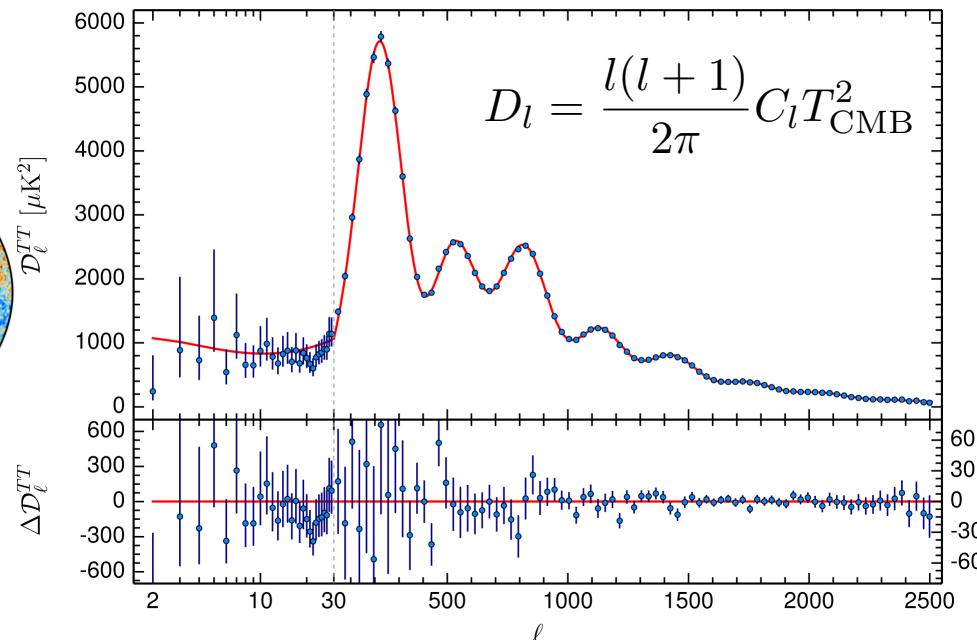
Fluctuations

$$a_{lm} = \int d\Omega \Theta(\Omega) Y_{lm}^*(\Omega) \rightarrow \langle a_{lm} a_{l'm'}^* \rangle = \delta_{mm'} \delta_{ll'} C_l$$



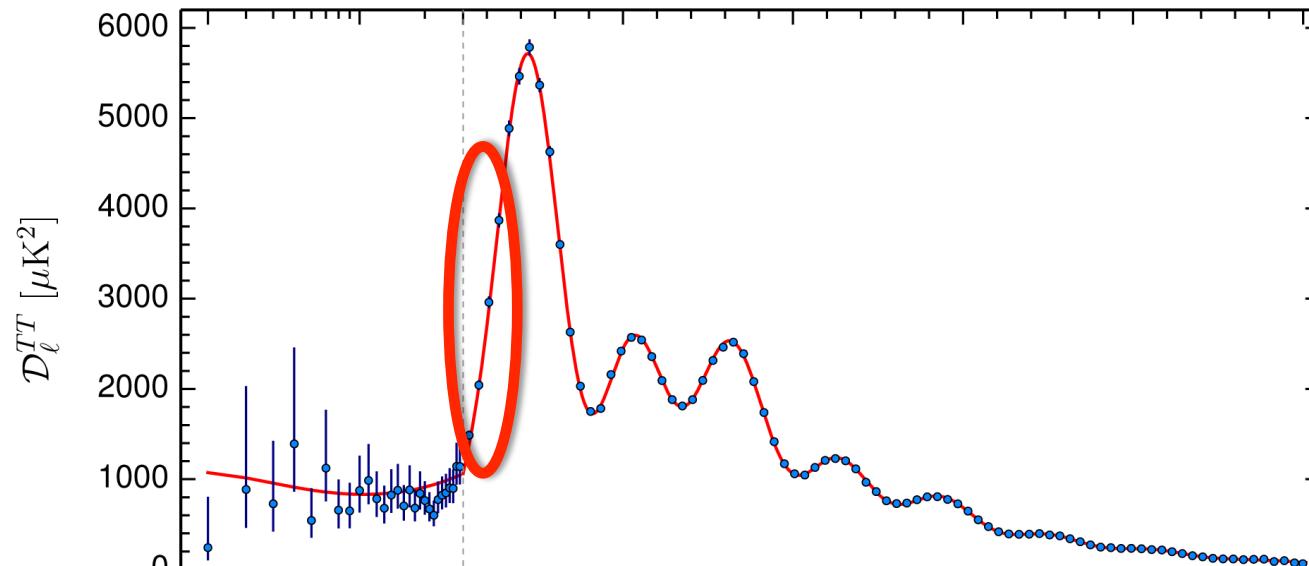
<http://www.cosmos.esa.int>

Planck 2015



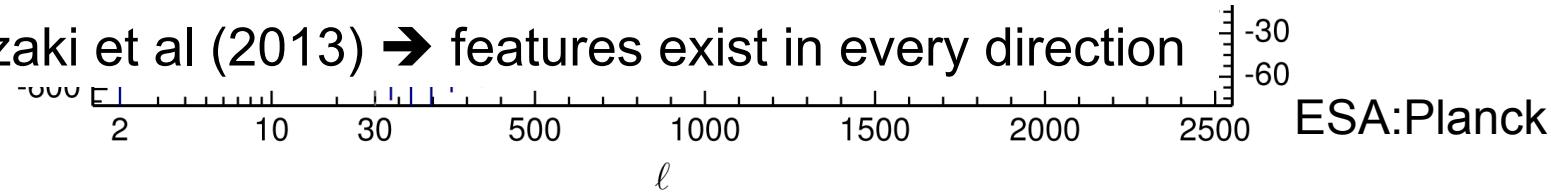
INTRODUCTION

Oscillations at $\ell \sim 120$



R.Nagata and J.Yokoyama (2008, 2009) → $\ell \sim 120$ in WMAP5 data
: using the cosmic inversion and the maximum-likelihood method

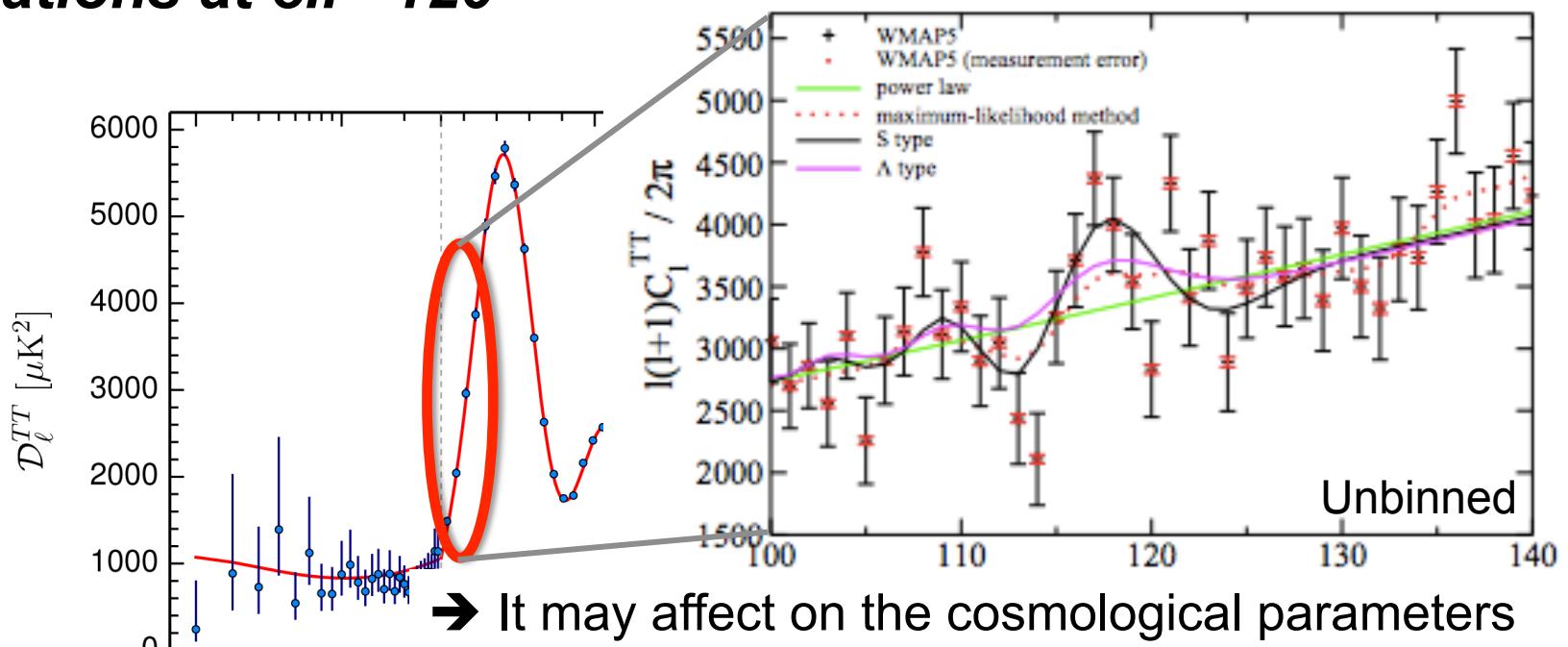
K.Kumazaki et al (2013) → features exist in every direction



INTRODUCTION

Oscillations at $\ell \sim 120$

K.Ichiki, R.Nagata, J.Yokoyama
PRD81,083010(2010)



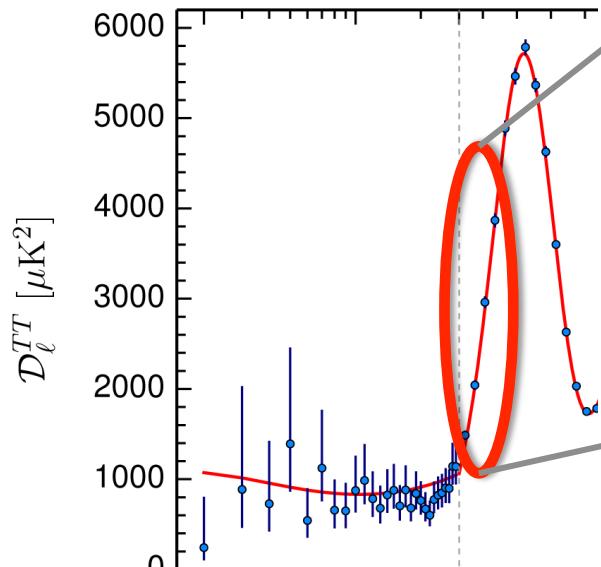
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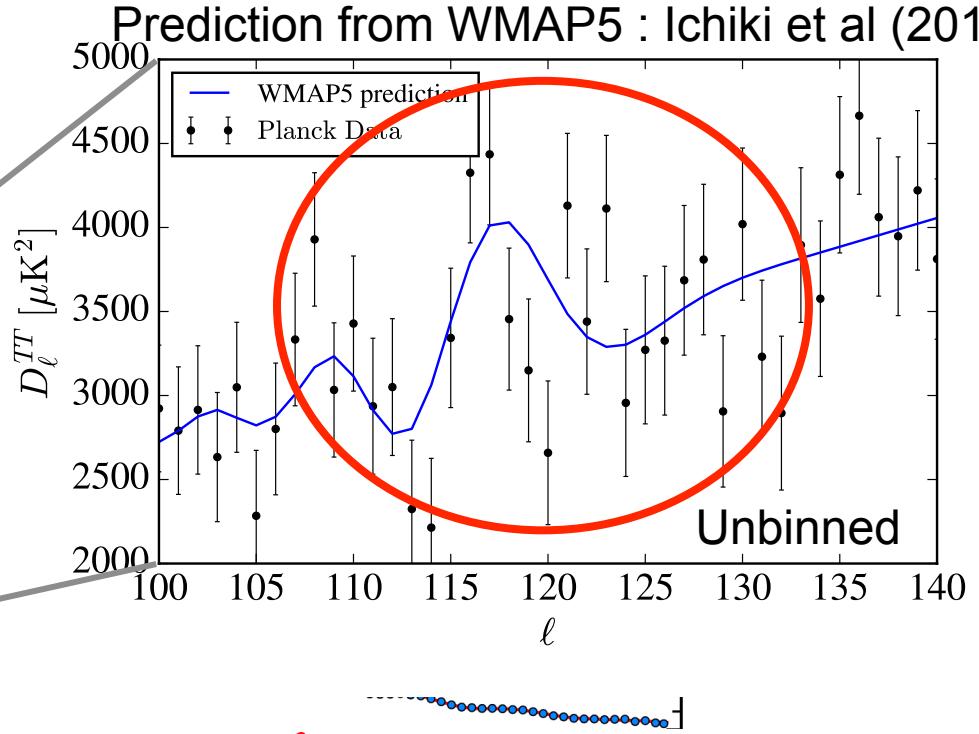


INTRODUCTION

Oscillations at $\ell \sim 120$



Planck 2015 unbinned data &
Prediction from WMAP5 : Ichiki et al (2010)



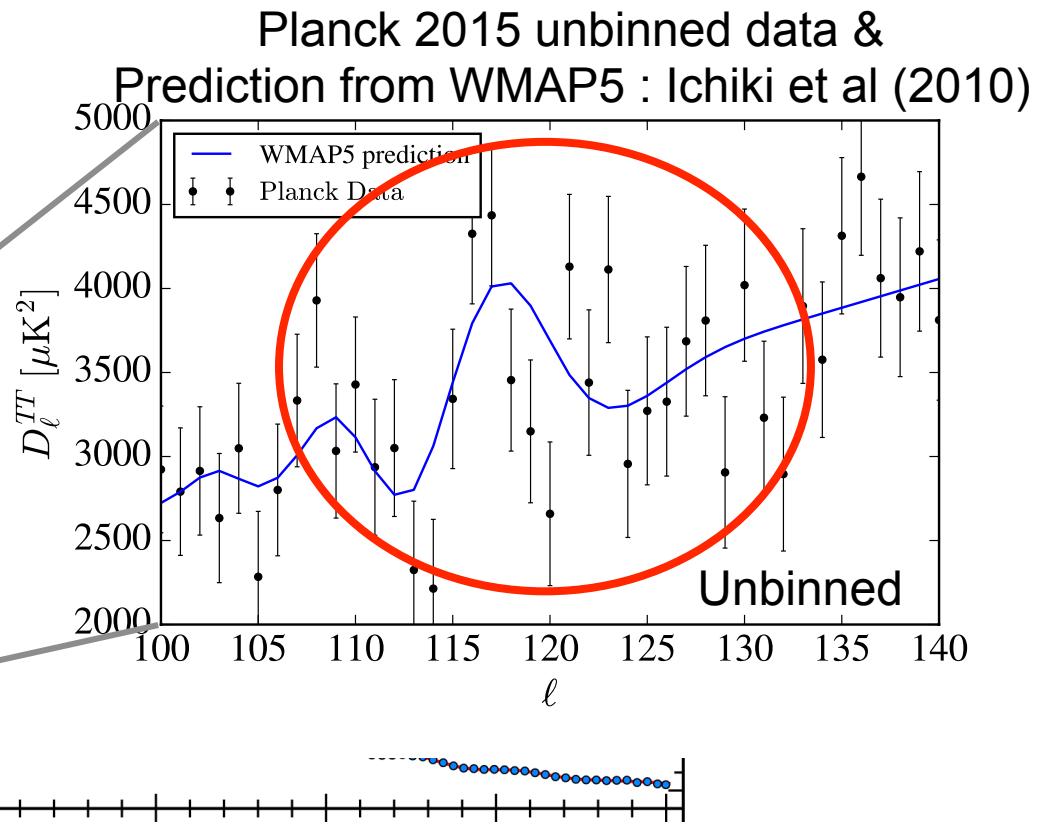
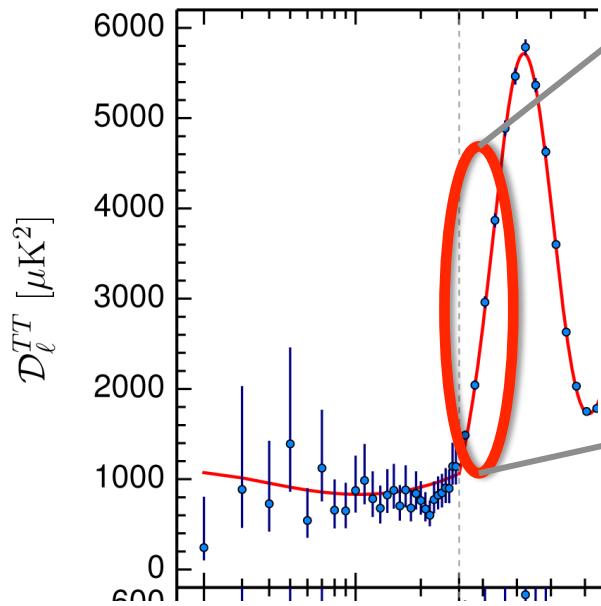
R.Nagata and J.Yokoyama (2008, 2009) $\rightarrow \ell \sim 120$ in WMAP5 data
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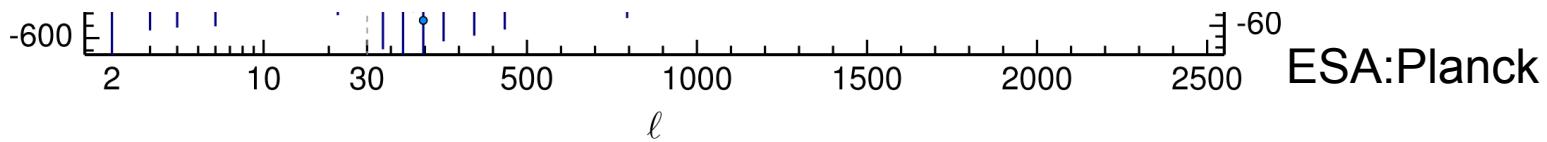


INTRODUCTION

Oscillations at $\ell \sim 120$



- Planck 2015 TT, TE, EE data : rich multipoles
- Effects on the estimation of the cosmological parameters



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Distributions of parameters, effects on cosmological parameters

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METHOD

Notation : angular power spectrum

$$C_l = \frac{2}{\pi} \int \frac{dk}{k} \underbrace{A(k)}_{\text{Initial power}} \underbrace{\left[T_l(k, \eta_0) \right]^2}_{\text{Transfer function}}$$

Parameterization

$$A(k) = A \left(\frac{k}{k_0} \right)^{n_s - 1} : \text{standard} \quad \left\{ \begin{array}{l} A \simeq 2.2 \times 10^{-9} \\ n_s \simeq 0.96 \\ k_0 = 0.05 \text{Mpc}^{-1} \end{array} \right.$$

METHOD

Notation : angular power spectrum

$$C_l = \frac{2}{\pi} \int \frac{dk}{k} \underbrace{A(k)}_{\text{Initial power}} \underbrace{|T_l(k, \eta_0)|^2}_{\text{Transfer function}}$$

Origin

Parameterization : Ichiki et al (2010)

$$A(k) = A \left(\frac{k}{k_0} \right)^{n_s - 1} \quad \text{: standard} \quad \begin{cases} A \simeq 2.2 \times 10^{-9} \\ n_s \simeq 0.96 \\ k_0 = 0.05 \text{Mpc}^{-1} \end{cases}$$

$$+ B \left(\frac{k}{k_0} \right)^{n_s - 1} \exp \left(-\frac{(k - k_*)^2}{\kappa^2} \right) \cos \left(\frac{\pi(k - k_*)}{\kappa} \right)$$

Oscillation term $\rightarrow B$: Amplitude / $\ell \simeq k_* d_{\text{ang}}$: Position / κ : Width [Mpc⁻¹]

d_{ang} : Angular diameter distance at the last scattering epoch

METHOD

Markov-Chain Monte-Carlo analysis

Cosmological parameters

$$A \quad n_s$$

$$\Omega_c h^2 \quad \Omega_b h^2$$

$$\tau \quad \Theta_{\text{MC}} \quad \text{etc...}$$



Oscillation parameters

Params : [range] (WMAP best fit)

$10^{10} B$: [0, 150] Ichiki et al (2010) ($\simeq 55.7$)

$10^4 \kappa$: [1, 30] ($\simeq 3.58$)

$k_* d_{\text{ang}}$: [100, 140] ($\simeq 124.5$)

 Planck 2015 (unbinned) data : TT, TT + TE + EE

COSMOMC

Best fit, Posterior distributions, Likelihoods, $\Delta\chi^2$

Check the existence of the features and
effects on the parameter estimation

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RESULT & DISCUSSION

Chi square and best fit parameters

Model data	Standard TT	with osc TT	Standard TTTEEE	with osc TTTEEE
χ^2	8431.9	8418.2	24190.9	24174.8
$\Delta\chi^2$	-	-13.7	-	-16.1
$10^{10} A$	21.6	21.6	21.2	21.3
n_s	0.969	0.970	0.965	0.967
τ	0.0719	0.0707	0.0613	0.0644
H_0	68.0	68.0	67.4	67.6
$\Omega_b h^2$	0.0223	0.0223	0.0222	0.0223
$\Omega_c h^2$	0.118	0.118	0.119	0.119
$10^{10} B$	-	46.3	-	37.4
$10^4 \kappa$	-	3.09	-	3.14
$k_* d_{\text{ang}}$	-	124.0	-	123.5

RESULT & DISCUSSION

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Akaike's information criteria :			0.965	0.967

$-\Delta\chi^2 > n_p \times 2 \rightarrow$ more desirable model

$13.7, 16.1 > 6 \rightarrow$ oscillations are preferred

$\Omega_c h^2$	0.118	0.118	0.119	0.119
$10^{10} B$	-	46.3	-	37.4
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n_s		$10^{10} B \simeq 55.7 \rightarrow 37.4$		0.967
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H_0				67.6
$\Omega_b h^2$				0.0223
$\Omega_c h^2$		$k_* d_{\text{ang}} \simeq 124.5 \rightarrow 123.5$		0.119
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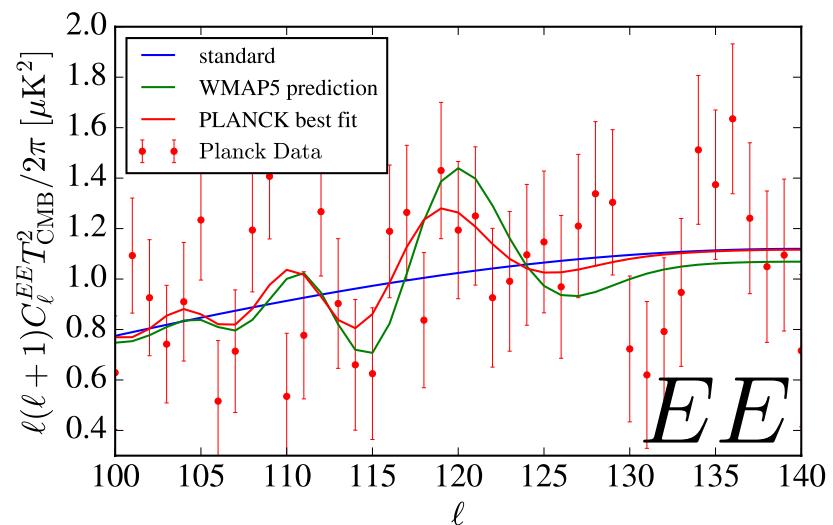
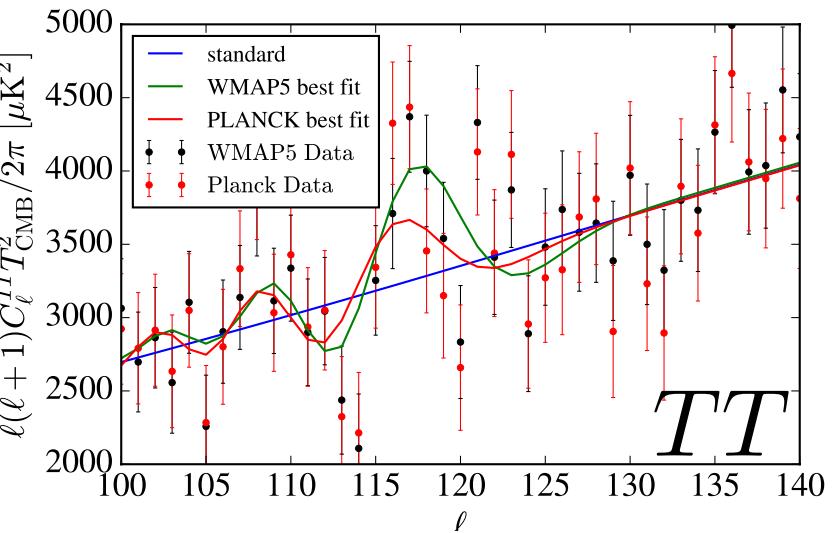
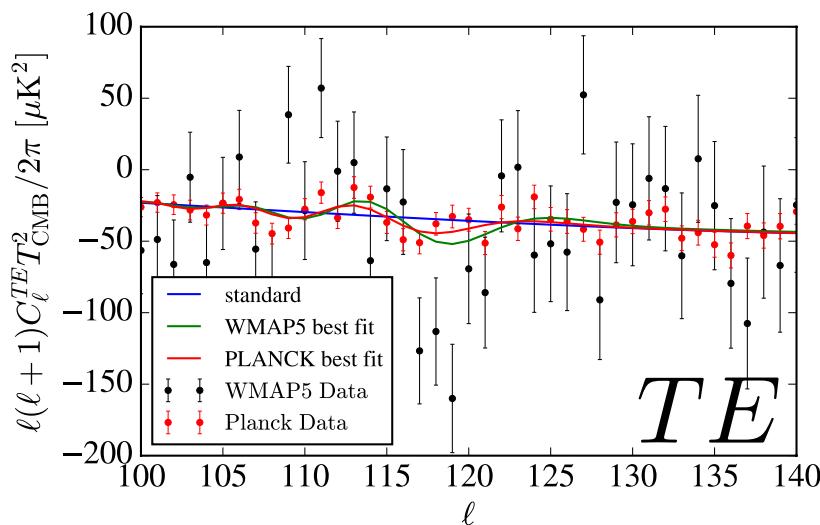
RESULT & DISCUSSION

Comparison with data

TT : Almost the same

TE : Lowered the amplitude

EE : Good prediction by WMAP



RESULT & DISCUSSION

Likelihoods of the oscillation parameters

Effects of polarized (TE,EE)
Data on the distribution of the
oscillation parameters

Amplitude

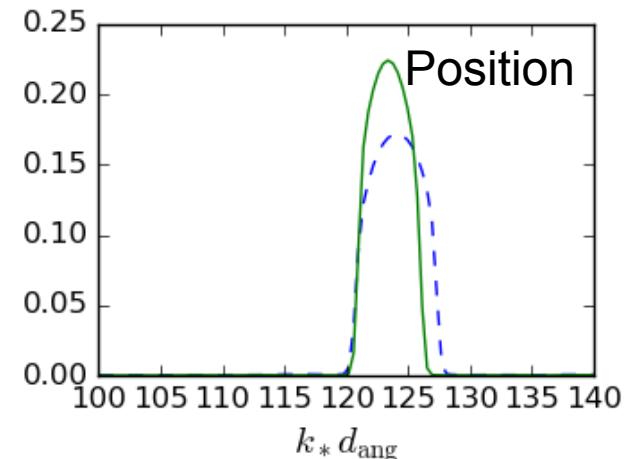
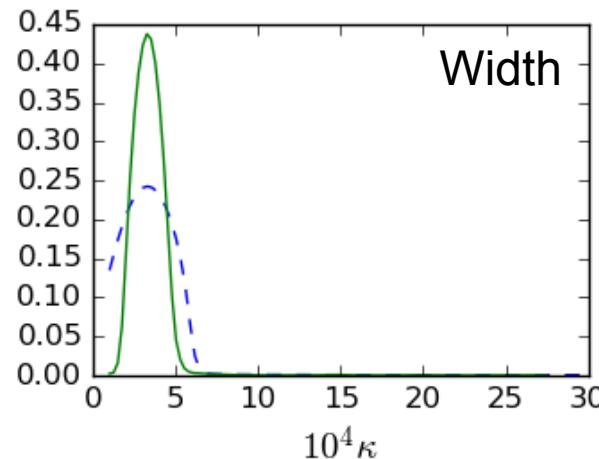
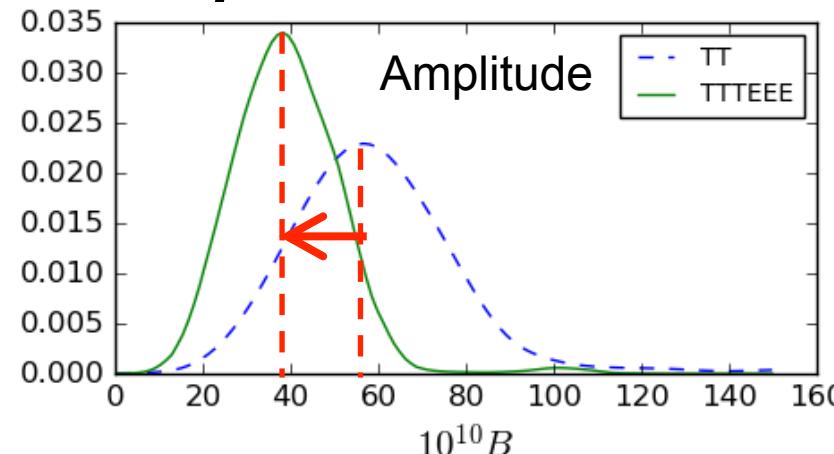
Sharpened & shifted

Width

Sharpened

Position

Sharpened



RESULT & DISCUSSION

Chi square and best fit parameters

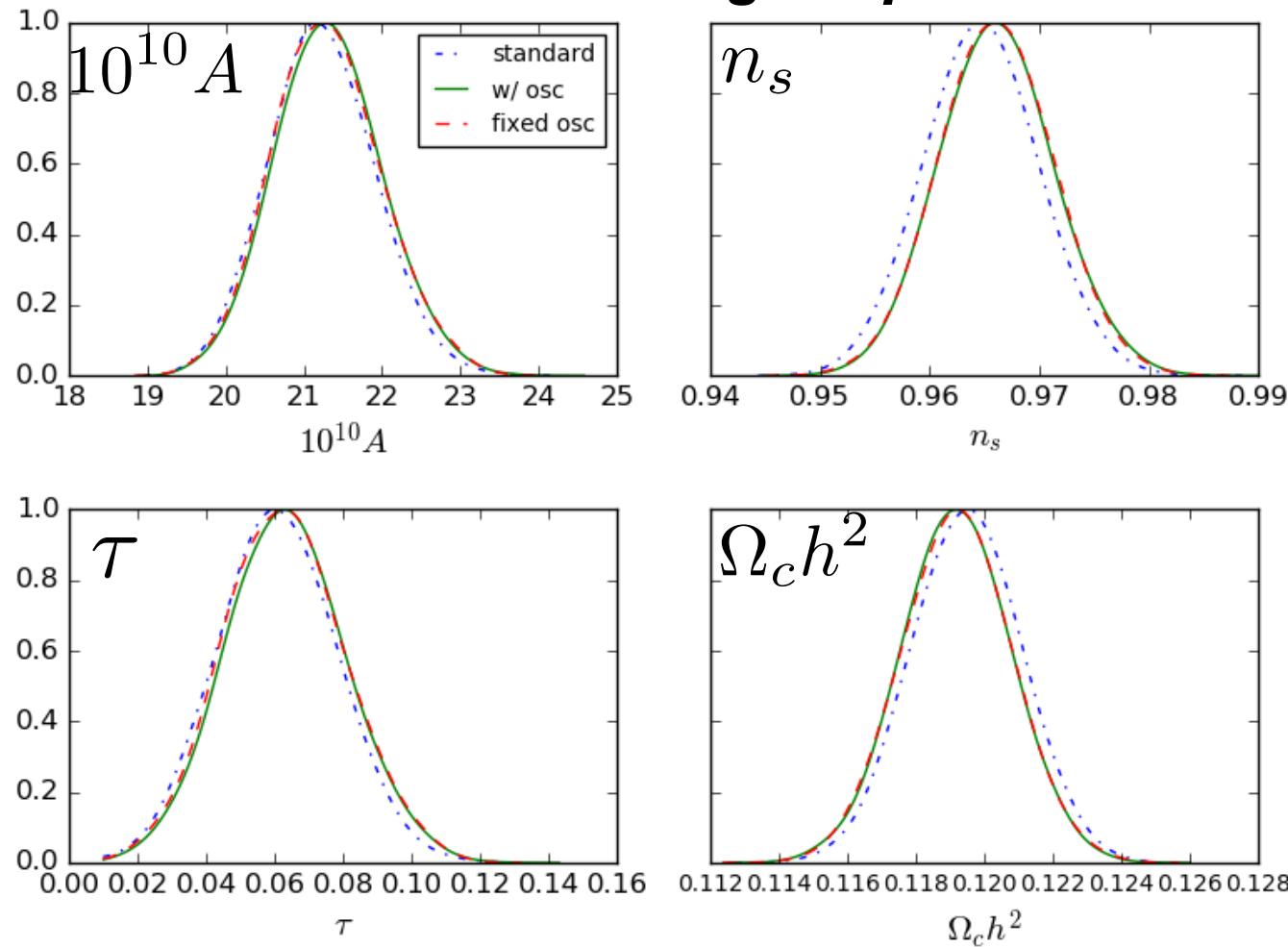
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$10^{10} B$	←	46.3	←	37.4 →

We should check the distributions of these parameters too.

$\kappa_* a_{\text{ang}}$	-	124.0	-	125.5
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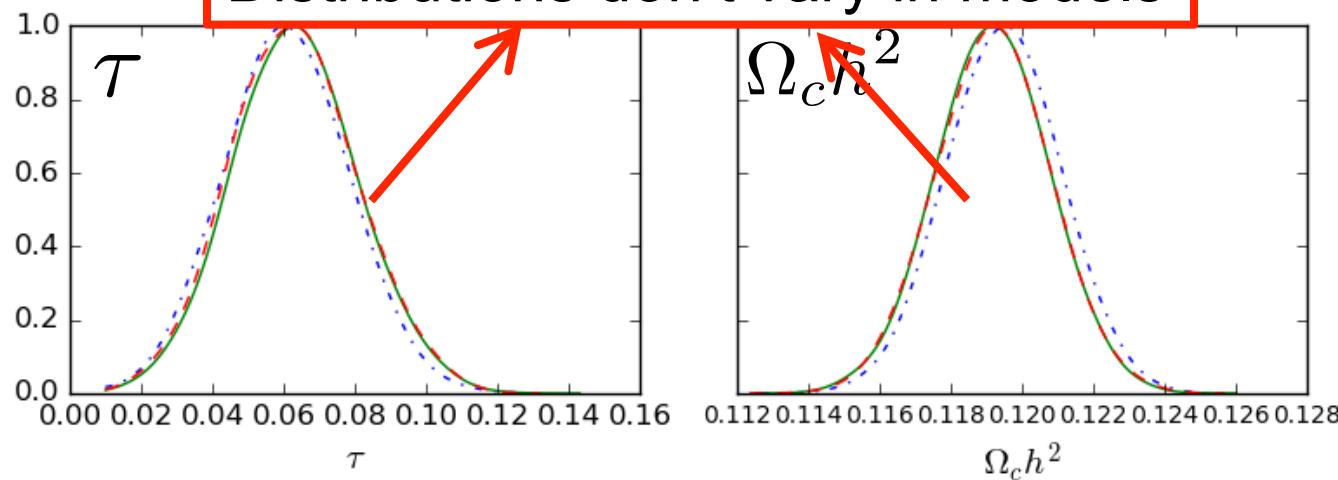
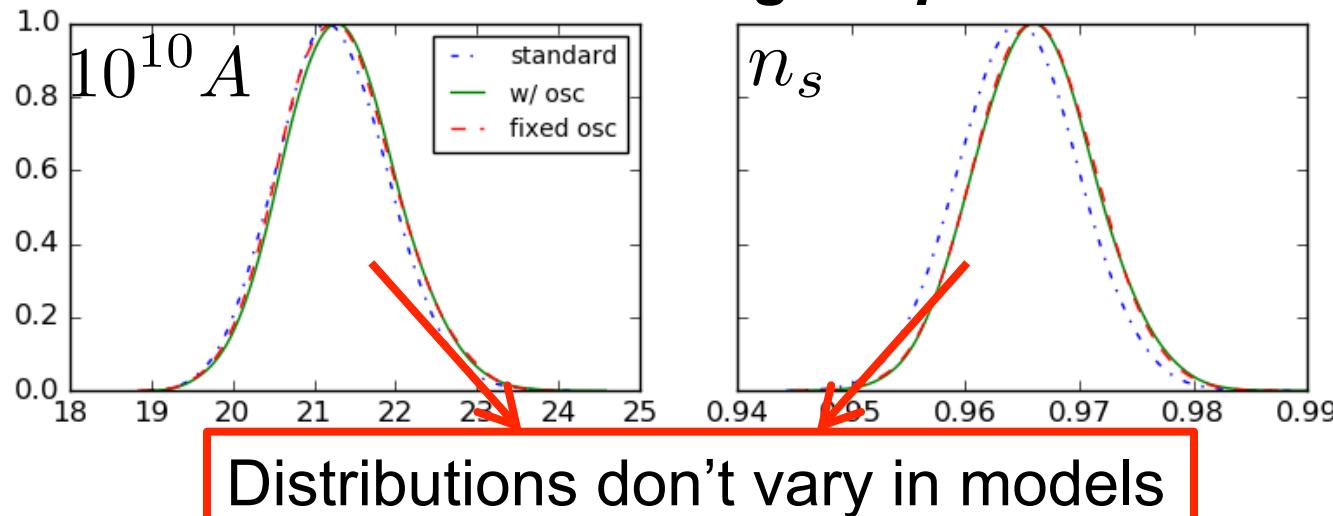
RESULT & DISCUSSION

Posterior distribution of cosmological parameters



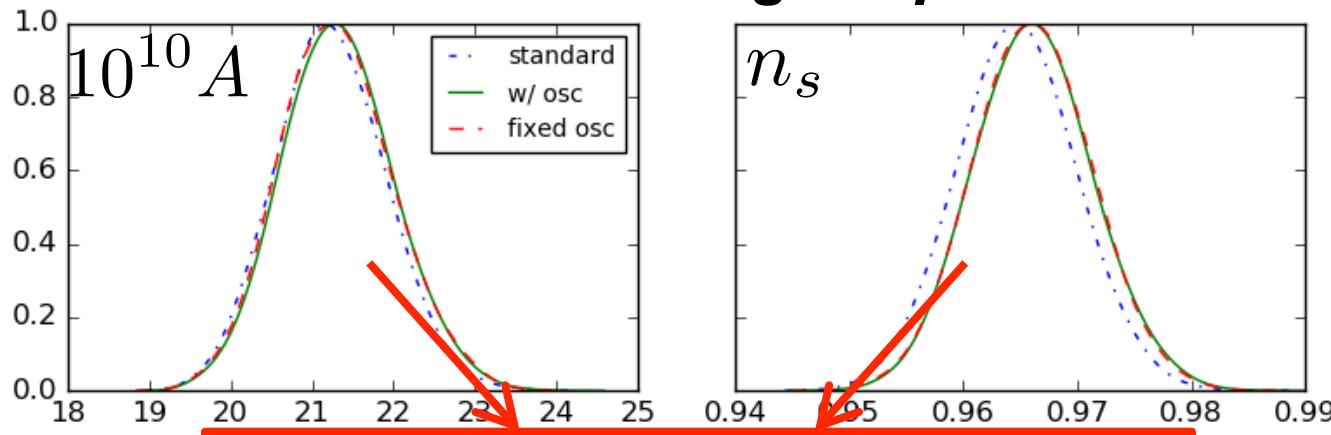
RESULT & DISCUSSION

Posterior distribution of cosmological parameters

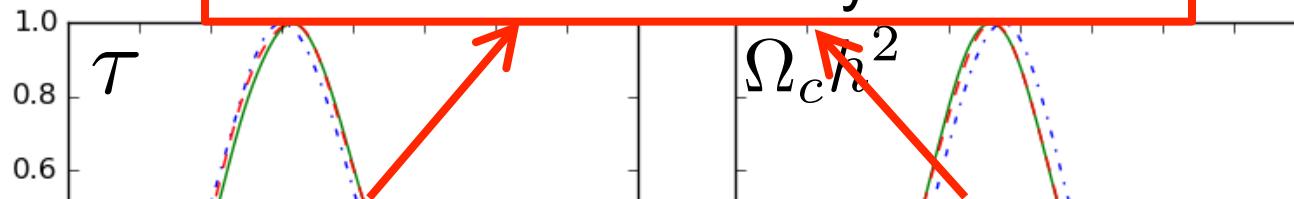


RESULT & DISCUSSION

Posterior distribution of cosmological parameters



Distributions don't vary in models



The existence of the oscillations dose not affect on the estimation of the cosmological parameters

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SUMMARY

Oscillations in Planck data at

$-\Delta\chi^2 = 16.1 > 3 \times 2 \rightarrow$ Oscillations are preferred
Polarization data \rightarrow Sharpened likelihoods

Best fit values $10^{10}B = 37.4$, $10^4\kappa = 3.14$, $k_*d_{\text{ang}} = 123.5$

Estimation of the cosmological parameters

Oscillations at $\ell \sim 120$ do not affect on

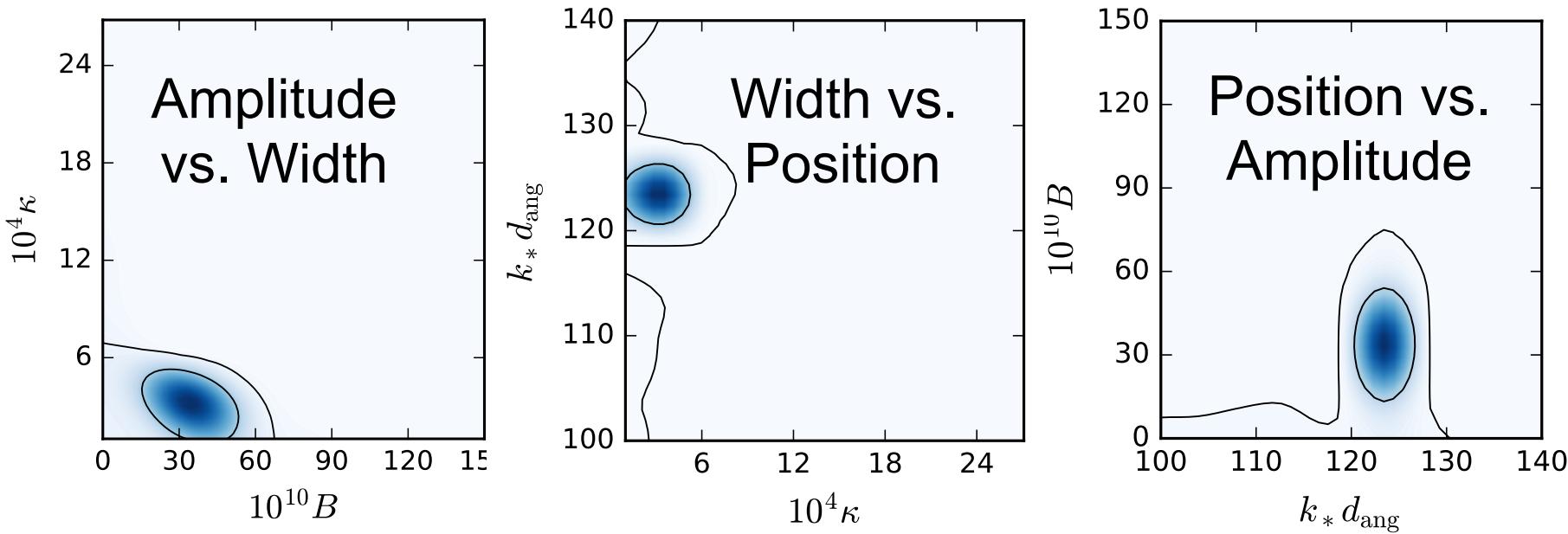
- 1. Best fit values
- 2. Distributions

Cosmological parameters can be determined precisely
using only higher multipoles data.

BACKUP

BACKUP

2d Posterior distribution of oscillation parameters



Contrast : Posterior distributions

Lines : 68% and 95% confidence lines