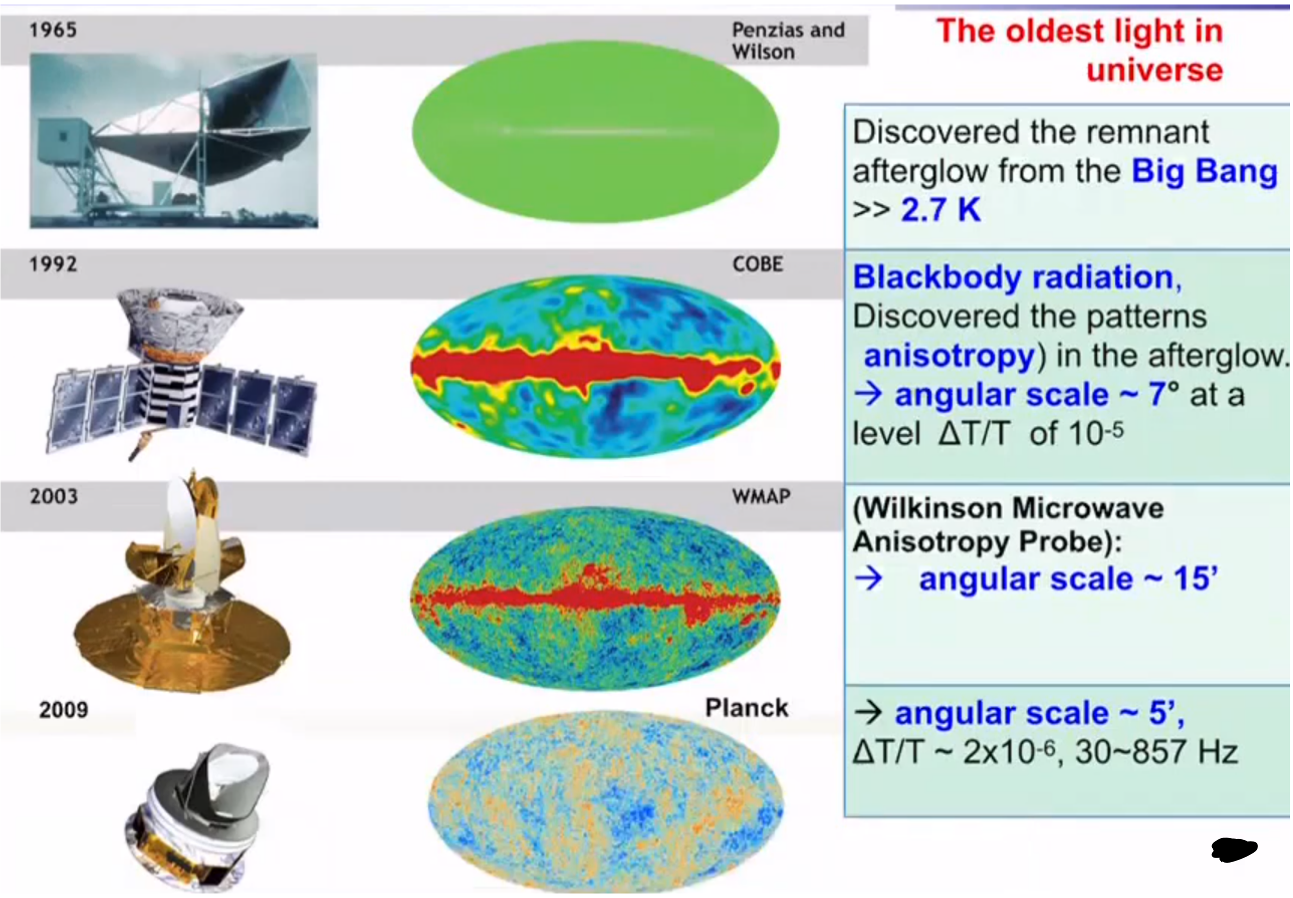
CMB



→ Red region are galaxies radiation. This represents galactic plane.

→ Foreground contribution → Galaxy radiation, dust, etc.

→ For purely background radiation, we use statistical information which is outside foreground & fill up in galactic plane. (our galaxy)

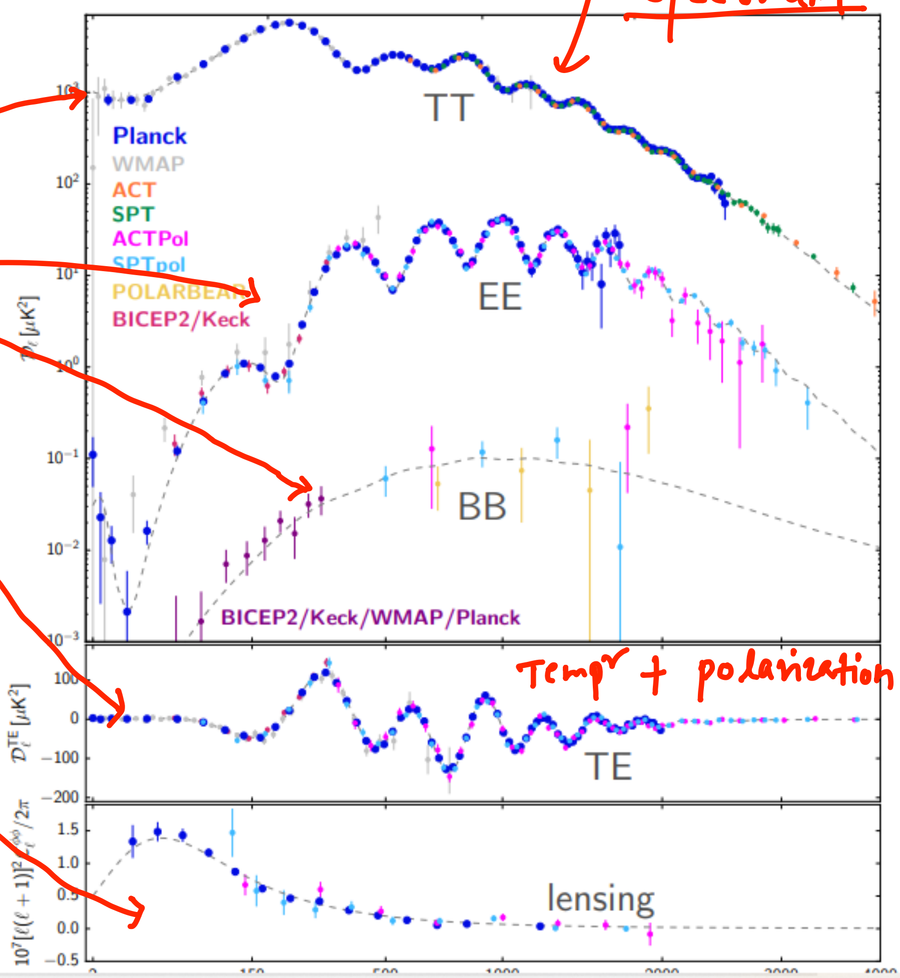
Why Temp^r Fluctuation ?

$\Rightarrow$ Initial Quantum Fluctuation leading to density perturbation. Then.

CMB Power Spectra

purely temp^r spectrum.

- Power spectra of CMB
  - temperature
  - polarization
  - lensing



Temp^r + polarization.

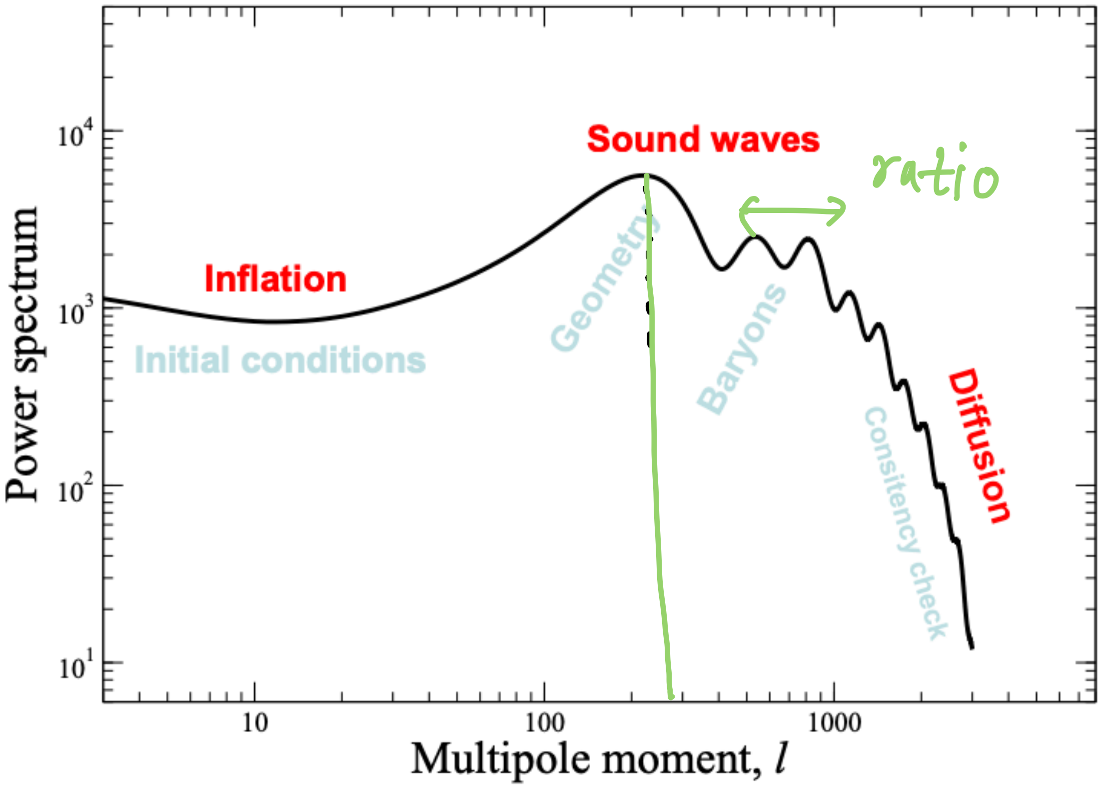
TE $\rightarrow$ sideways

EE $\rightarrow$ uptrend, sideway & down

CMB : Tool to understand the universe

(Cmb TT spectrum).

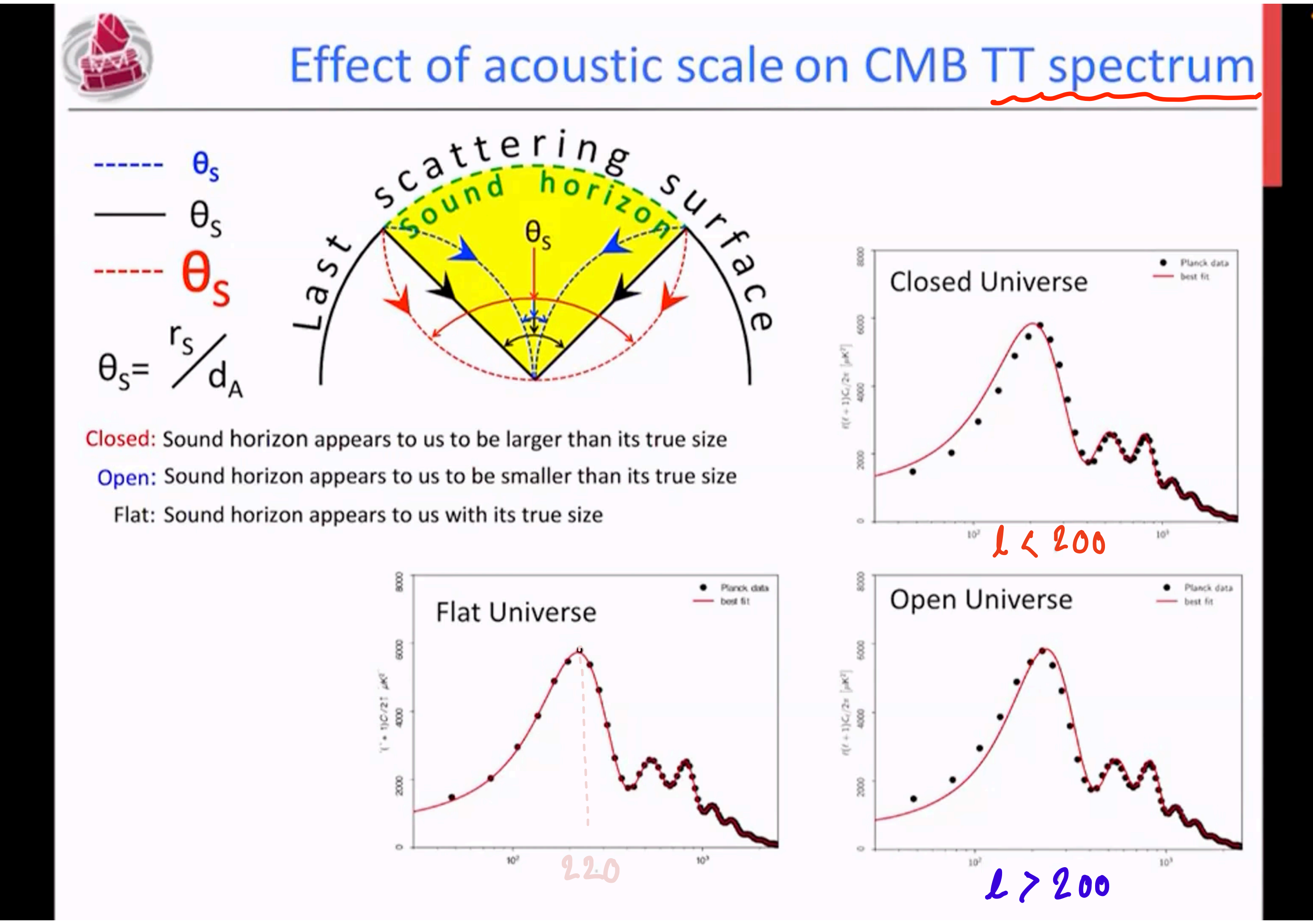
→ large l corresponds to smaller θ ↑ angular scale.



l increases

- TT spectrum = purely temp^r spectrum
- TE spectrum = Temp^r & E - mode
- EE spectrum = polarization spectrum.

• 1^{st} peak $\longrightarrow$ Geometry.

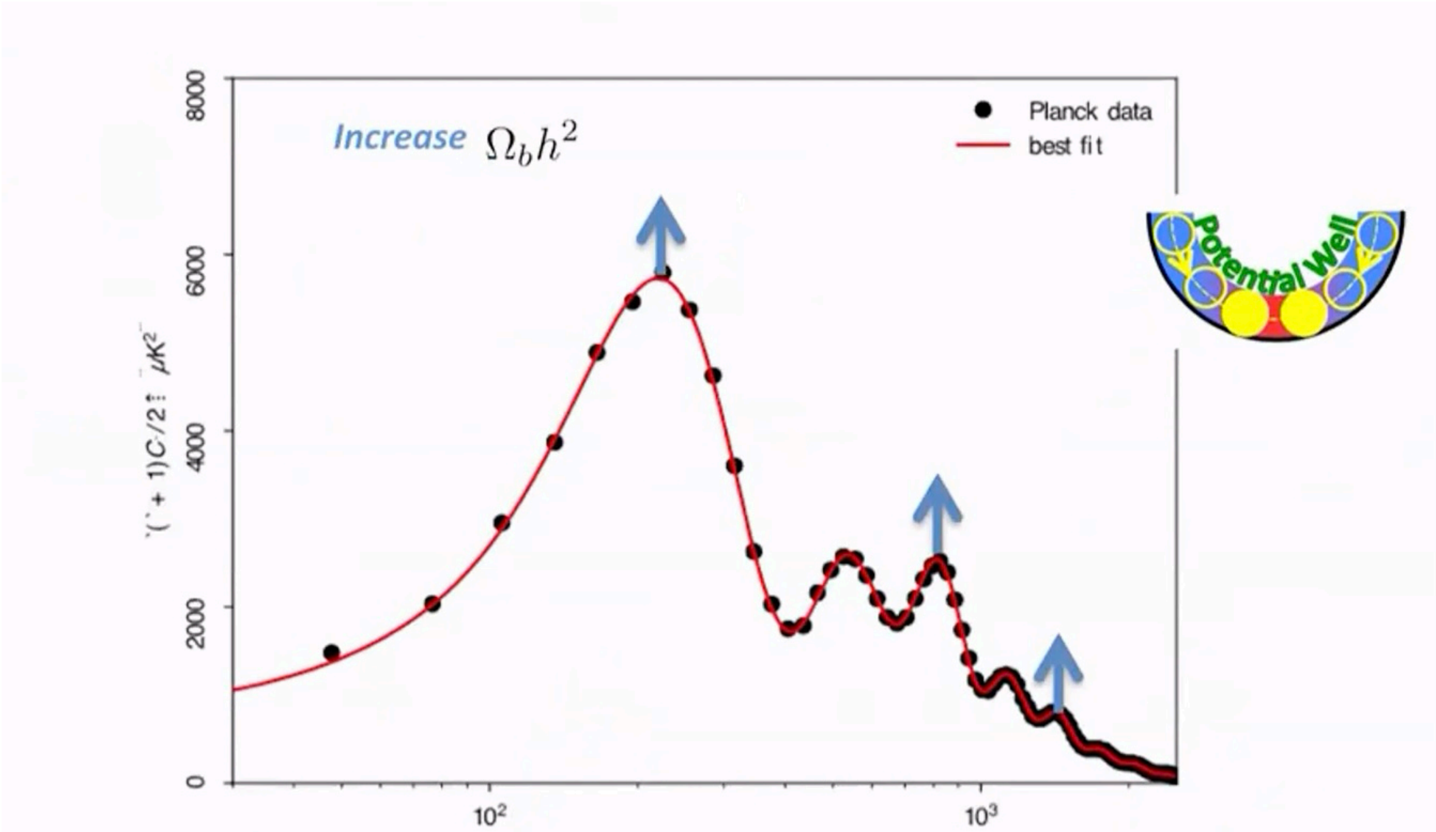


→ $l \approx 220$, universe is Flat.

→ $l > 220$, universe is open.

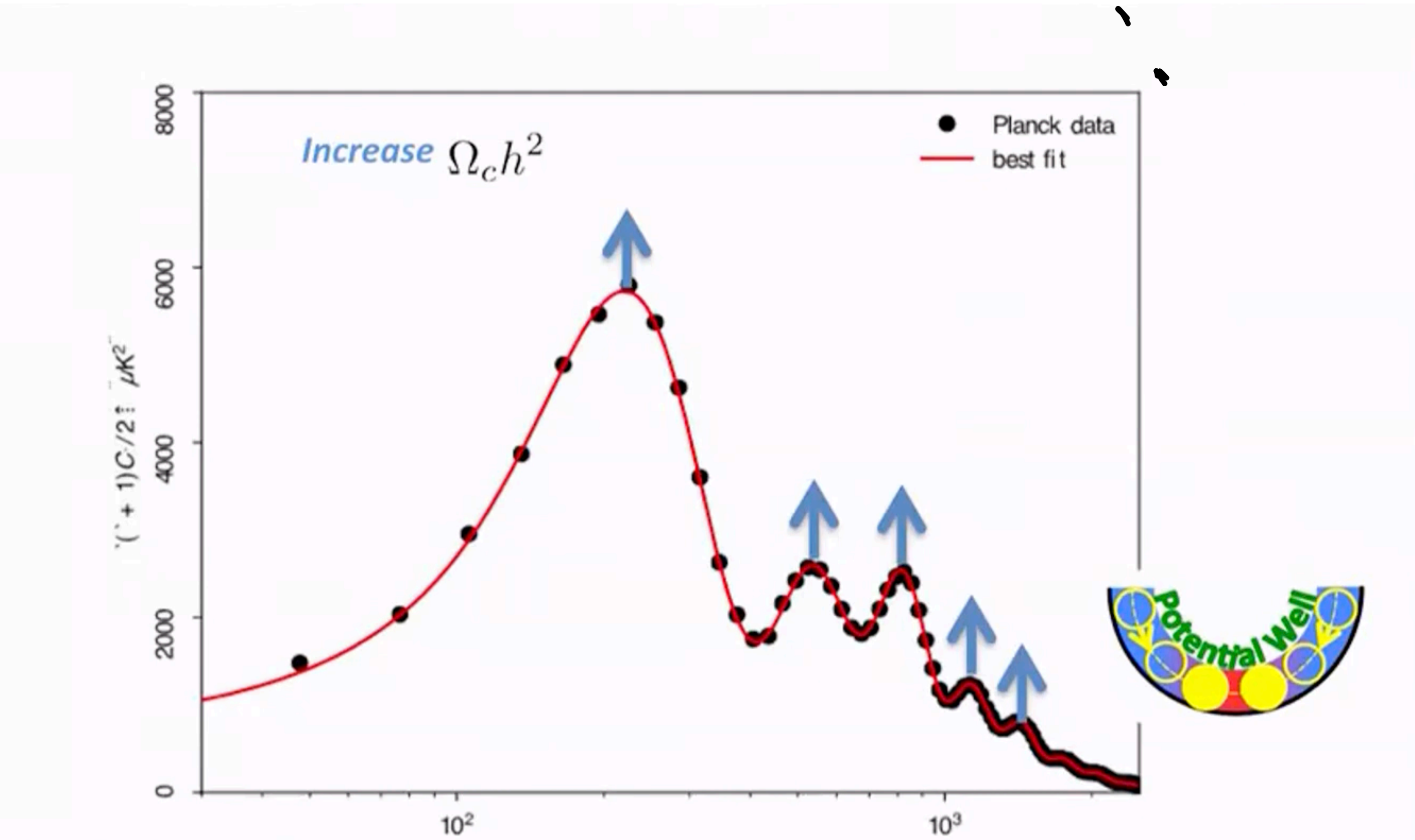
→ $l < 220$, universe is closed.

· odd peak enhancement $\longrightarrow$ Baryon density.



$\left\{ \begin{array}{l} \cdot \text{ If we increase } \Omega_b h^2 \text{, it will only effect odd peaks.} \\ \text{Eg : } 3^{rd} \text{ peak gets higher than } 2^{nd} \text{ peak.} \end{array} \right\}$

· Boost in all peaks ⟶ Increase in $\Omega_c h^2$.



→ Ratio of 2^{nd} to 3^{rd} peak determines the ratio of baryon to dark matter density.

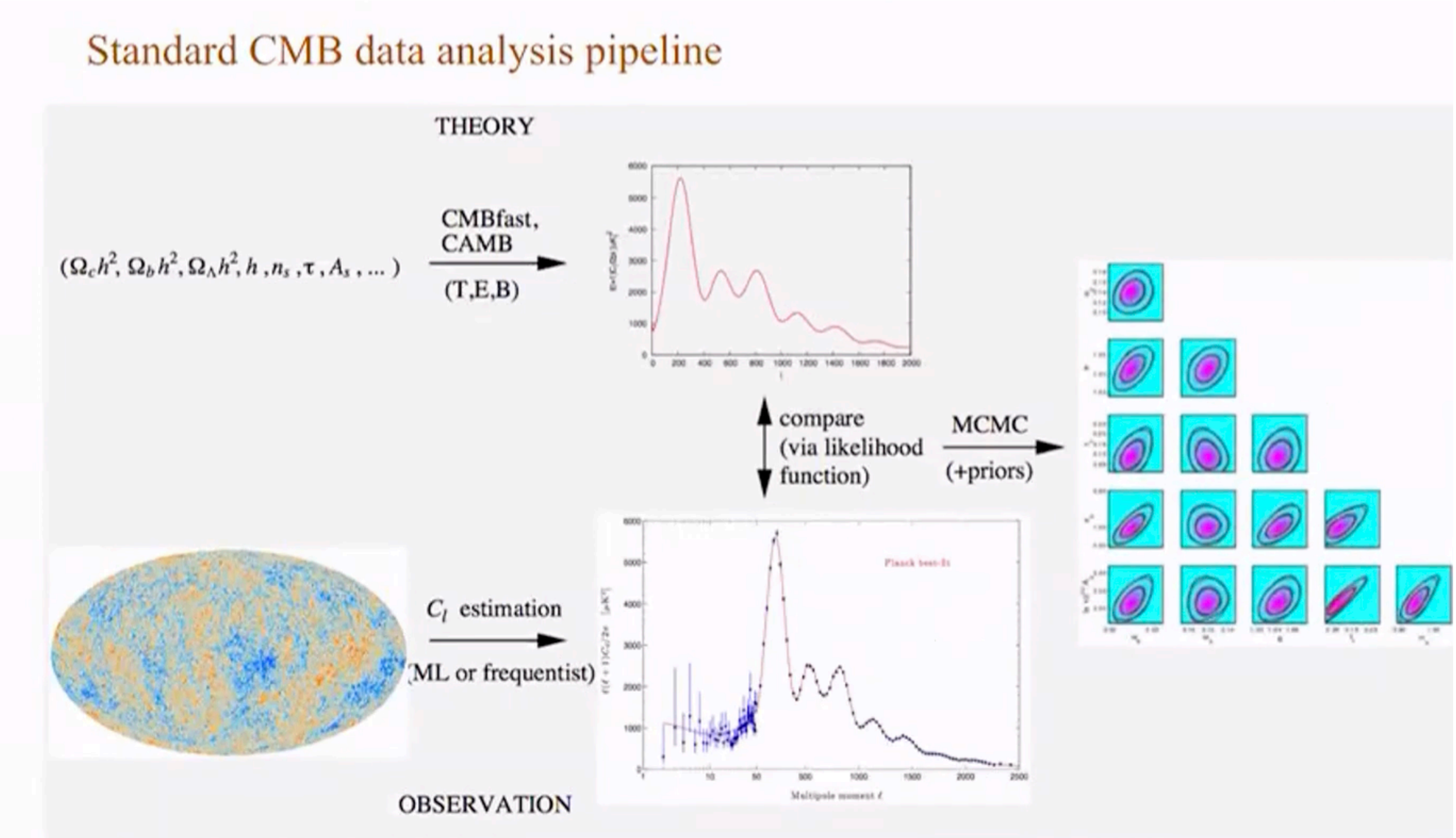
parameter Estimation.

Model

$\Downarrow$

Friedmann's equation

$$\frac{H^2}{H_0^2} = \Omega_R a^{-4} + \Omega_m a^{-3} + \Omega_k a^{-2} + \Omega_\Lambda$$

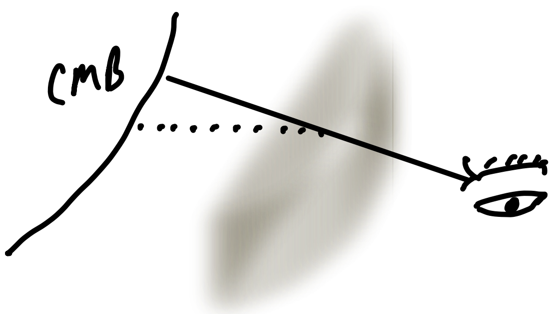


planck + ΛCDM

Parameter	TT+lowE 68% limits	TE+lowE 68% limits	EE+lowE 68% limits	TT,TE,EE+lowE 68% limits	TT,TE,EE+lowE+lensing 68% limits
$\Omega_b h^2$	0.02212 ± 0.00022	0.02249 ± 0.00025	0.0240 ± 0.0012	0.02236 ± 0.00015	0.02237 ± 0.00015
$\Omega_c h^2$	0.1206 ± 0.0021	0.1177 ± 0.0020	0.1158 ± 0.0046	0.1202 ± 0.0014	0.1200 ± 0.0012
$100\theta_{MC}$	1.04077 ± 0.00047	1.04139 ± 0.00049	1.03999 ± 0.00089	1.04090 ± 0.00031	1.04092 ± 0.00031
τ	0.0522 ± 0.0080	0.0496 ± 0.0085	0.0527 ± 0.0090	$0.0544^{+0.0070}_{-0.0081}$	0.0544 ± 0.0073
$\ln(10^{10} A_s)$	3.040 ± 0.016	$3.018^{+0.020}_{-0.018}$	3.052 ± 0.022	3.045 ± 0.016	3.044 ± 0.014
n_s	0.9626 ± 0.0057	0.967 ± 0.011	0.980 ± 0.015	0.9649 ± 0.0044	0.9649 ± 0.0042
H_0 [km s^{-1} Mpc^{-1}]	66.88 ± 0.92	68.44 ± 0.91	69.9 ± 2.7	67.27 ± 0.60	67.36 ± 0.54
Ω_Λ	0.679 ± 0.013	0.699 ± 0.012	$0.711^{+0.033}_{-0.026}$	0.6834 ± 0.0084	0.6847 ± 0.0073
Ω_m	0.321 ± 0.013	0.301 ± 0.012	$0.289^{+0.026}_{-0.033}$	0.3166 ± 0.0084	0.3153 ± 0.0073
$\Omega_m h^2$	0.1434 ± 0.0020	0.1408 ± 0.0019	$0.1404^{+0.0034}_{-0.0039}$	0.1432 ± 0.0013	0.1430 ± 0.0011
$\Omega_m h^3$	0.09589 ± 0.00046	0.09635 ± 0.00051	$0.0981^{+0.0016}_{-0.0018}$	0.09633 ± 0.00029	0.09633 ± 0.00030
σ_8	0.8118 ± 0.0089	0.793 ± 0.011	0.796 ± 0.018	0.8120 ± 0.0073	0.8111 ± 0.0060
$S_8 \equiv \sigma_8(\Omega_m/0.3)^{0.5}$	0.840 ± 0.024	0.794 ± 0.024	$0.781^{+0.052}_{-0.060}$	0.834 ± 0.016	0.832 ± 0.013
$\sigma_8 \Omega_m^{0.25}$	0.611 ± 0.012	0.587 ± 0.012	0.583 ± 0.027	0.6090 ± 0.0081	0.6078 ± 0.0064
z_{re}	7.50 ± 0.82	$7.11^{+0.91}_{-0.75}$	$7.10^{+0.87}_{-0.73}$	7.68 ± 0.79	7.67 ± 0.73
$10^9 A_s$	2.092 ± 0.034	2.045 ± 0.041	2.116 ± 0.047	$2.101^{+0.031}_{-0.034}$	2.100 ± 0.030

bend slightly (not huge affect)

- Weak lensing = Gravitation bending of CMB photons by matter.

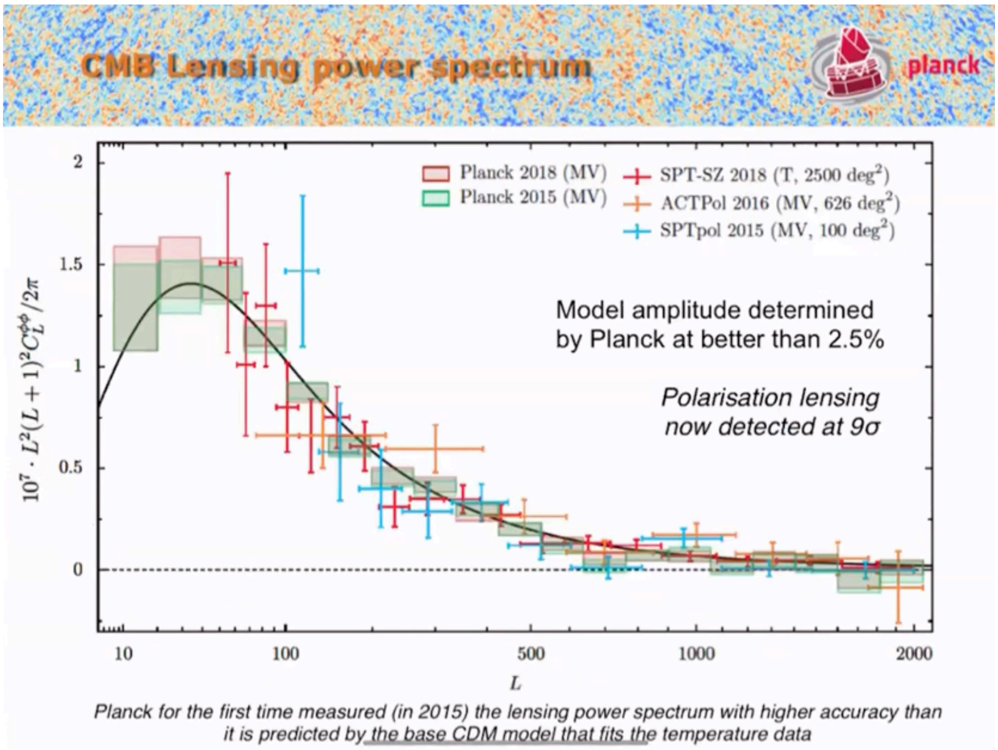


- CMB lensing can probe dark matter distribution.

• lensing power spectrum.

- lensing potential are telling distribution of matter that lens CMB photon.

$C^{\phi\phi} \Rightarrow$



• Data Analysis.

BAO :

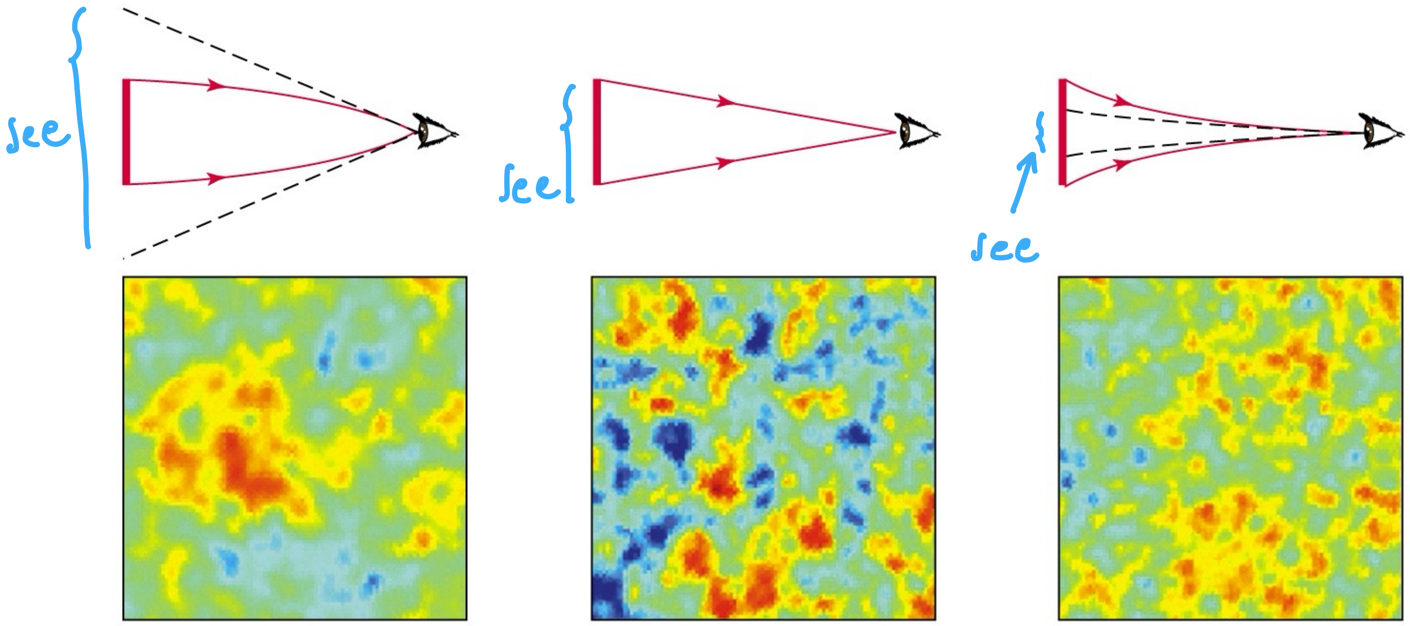
$$\frac{D_M}{r_d}, \quad \frac{D_V}{r_d}, \quad \frac{D_H}{r_d}$$

CMB :

power spectrum : $C^{TT}_{,\ell}$ $C^{TE}_{,\ell}$ $C^{EE}_{,\ell}$ $C^{BB}_{,\ell}$

lensing spectrum : $C^{\phi\phi}_{,\ell}$.

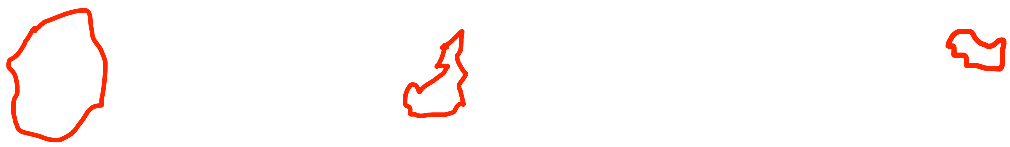
· CMB (Universe flat, closed or open)



a If universe is closed, “hot spots” appear larger than actual size

b If universe is flat, “hot spots” appear actual size

c If universe is open, “hot spots” appear smaller than actual size



→ If look at hot spots, in open universe you will see smaller & vice-versa in closed.

→ It's like seeing through lens where you see shift in position.

→ larger θ ⟹ small l

i.e shift in 1st peaks towards lower l.

Questions

1. Why are B modes polarisation not considered ?

→ Only consider in primordial GW (Tensor).

2. What actually COBE did ?

⇒ penzias and Wilson discoverd radiation in 1964. (CMB → 2.73)

⇒ Radiation be as of Blackbody Spectrum.

COBE

→ All sky survey, it measured deviation from the blackbody.

i.e temp^r fluction $\frac{\Delta T}{T} \sim 10^{-5}$

→ Almost blackbody (very small fluctuation)