A New Window into Stochastic Gravity Waves

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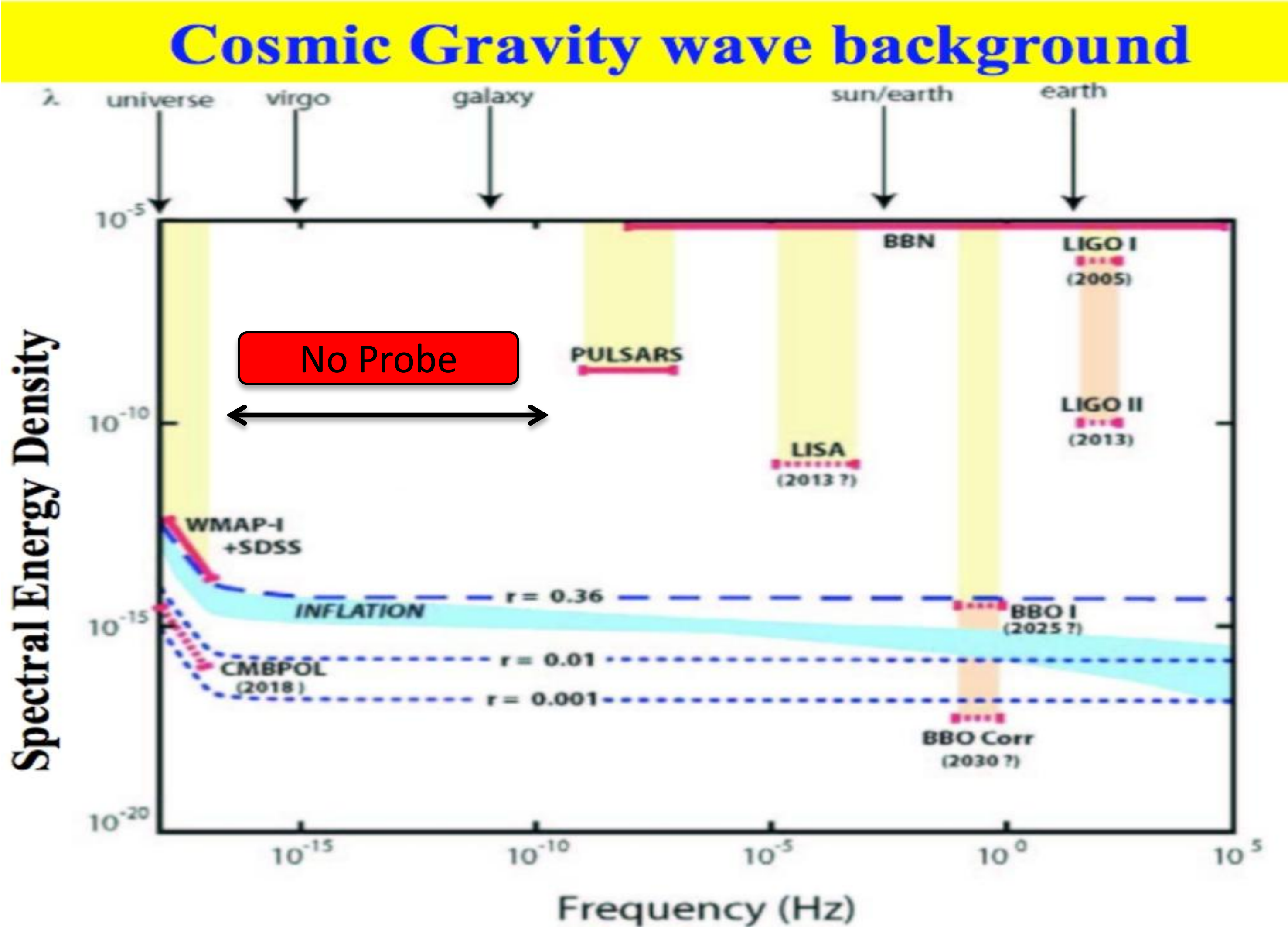
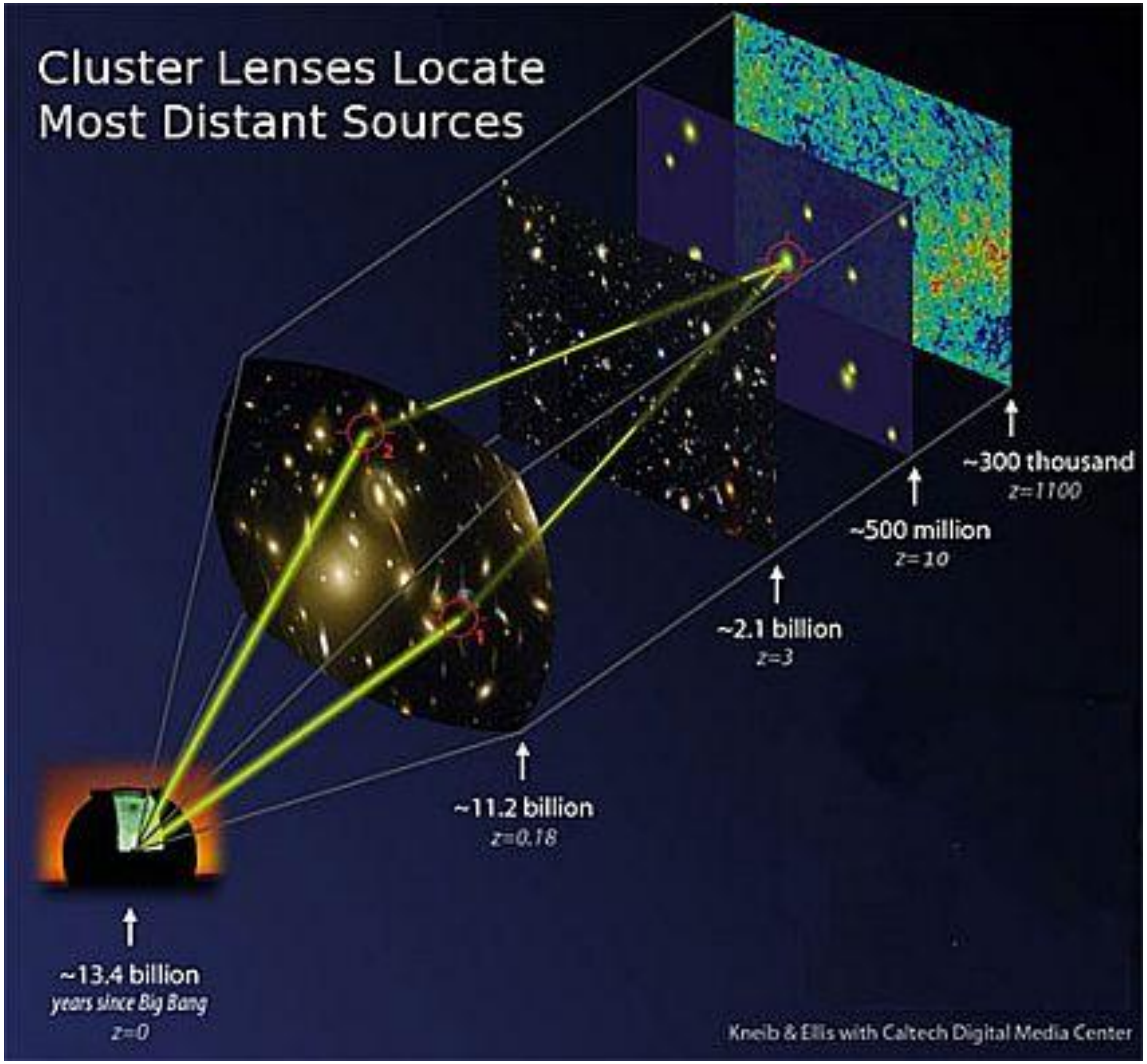
The Current Landscape



Lensing

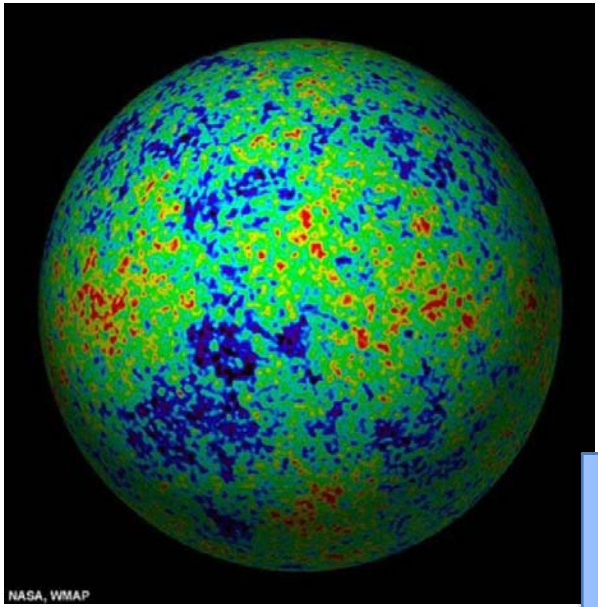


Cluster Lenses Locate
Most Distant Sources
~300 thousand
z=1100
~500 million
z=10
~2.1 billion
z=3
~11.2 billion
z=0.18
~13.4 billion
years since Big Bang
z=0
Kneib & Ellis with Caltech Digital Media Center

Lensing

Direction of photon arrival changed

$$(\theta_{\mathbf{0}}, \phi_{\mathbf{0}}) \rightarrow (\theta_{\mathbf{0}} + \delta\theta, \phi_{\mathbf{0}} + \delta\phi)$$



Let $\triangle$ denote the displacement on the sphere.

$$\mathbf{\Delta_a} = -\sum_{\mathbf{lm}} (\mathbf{h^{\oplus}_{lm} Y_{lm:a}} + \mathbf{h^{\otimes}_{lm} Y_{lm:b} \epsilon^{b}{}_{a}})$$

Angular power spectrum of photon displacements

$$C_l^{h^{\oplus}} = \frac{1}{2l+1} \sum_{m=-1}^{m=+l} \langle h^{\oplus}_{lm} h^{\oplus *}_{lm} \rangle \qquad \textit{Gradient spectrum}$$

$$C_l^{h^{\otimes}} = \frac{1}{2l+1} \sum_{m=-1}^{m=+l} \langle h^{\otimes}_{lm} h^{\otimes *}_{lm} \rangle \qquad \textit{Curl spectrum}$$

A. Stebbins, arXiv:astro-ph/p609149

Lensing Modifications to CMB

Lensing induces power transfer between the two polarization spectra

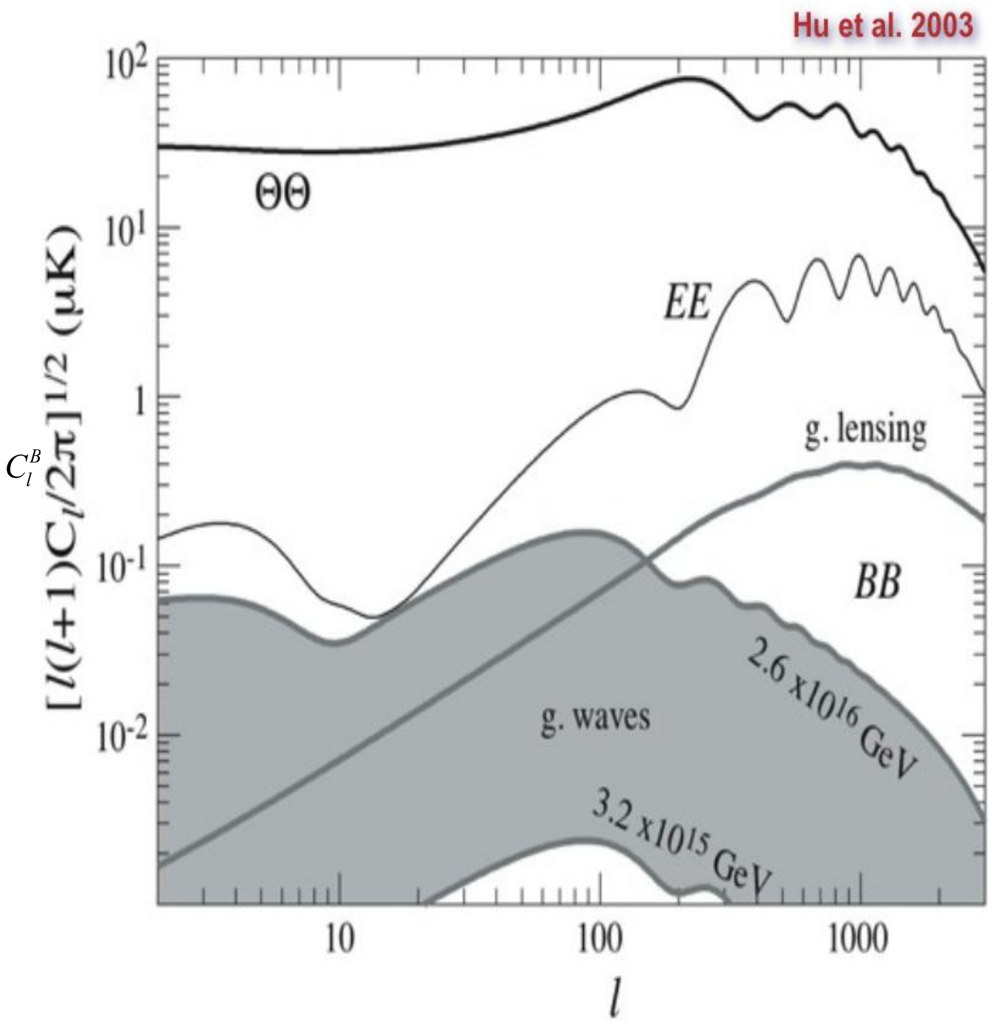
$$\begin{pmatrix} \tilde{C}_l^{EE} \\ \tilde{C}_l^{BB} \end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{pmatrix} \begin{pmatrix} C_l^{EE} \\ C_l^{BB} \end{pmatrix}$$

Lensing Kernel

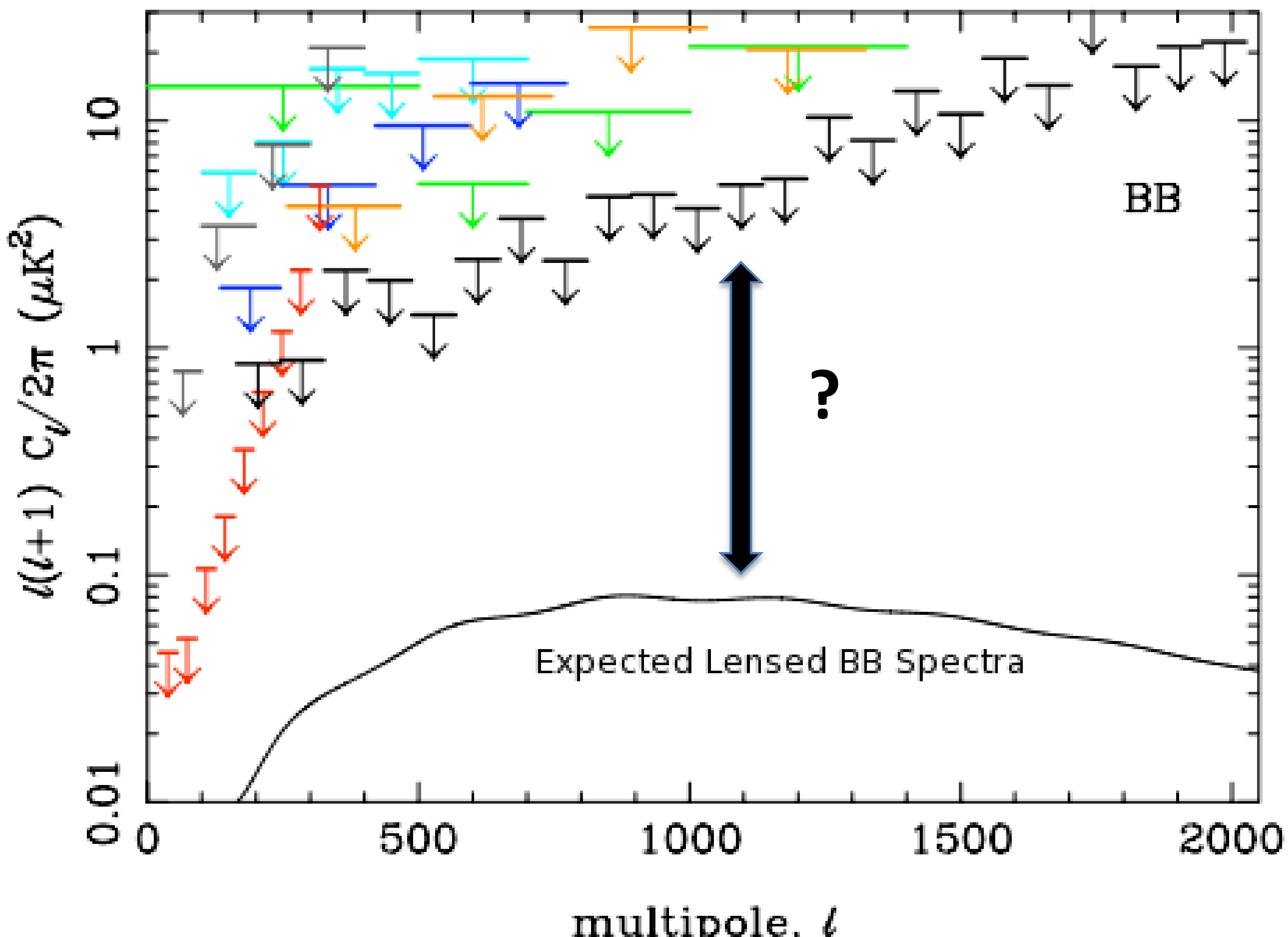
$$\begin{aligned} C_l^{\tilde{E}} &= C_l^E - (l^2 + l - 4) R C_l^E + \frac{1}{2(2l+1)} \\ &\times \sum_{l_1 l_2} \left[C_{l_1}^{h^{\oplus}} ({}_2F_{l l_1 l_2}^{\oplus})^2 + C_{l_1}^{h^{\otimes}} ({}_2F_{l l_1 l_2}^{\otimes})^2 \right] \left[(C_{l_2}^E + C_{l_2}^B) + (-1)^L (C_{l_2}^E - C_{l_2}^B) \right] \\ C_l^{\tilde{B}} &= C_l^B - (l^2 + l - 4) R C_l^B + \frac{1}{2(2l+1)} \\ &\times \sum_{l_1 l_2} \left[C_{l_1}^{h^{\oplus}} ({}_2F_{l l_1 l_2}^{\oplus})^2 + C_{l_1}^{h^{\otimes}} ({}_2F_{l l_1 l_2}^{\otimes})^2 \right] \left[(C_{l_2}^E + C_{l_2}^B) - (-1)^L (C_{l_2}^E - C_{l_2}^B) \right] \end{aligned}$$

Hints !!

- Current lensing considerations are only due to scalar perturbations.
- The scalar power spectrum is already well measured.
- A huge difference between current upper limits on the BB spectra and the expected signal.



Hints !! QUAD/BICEP



arXiv:0903-1003v3

Just a Reminder

Δ → $C_\ell^{h^{\oplus}}$ → Scalar Perturbations (LSS)

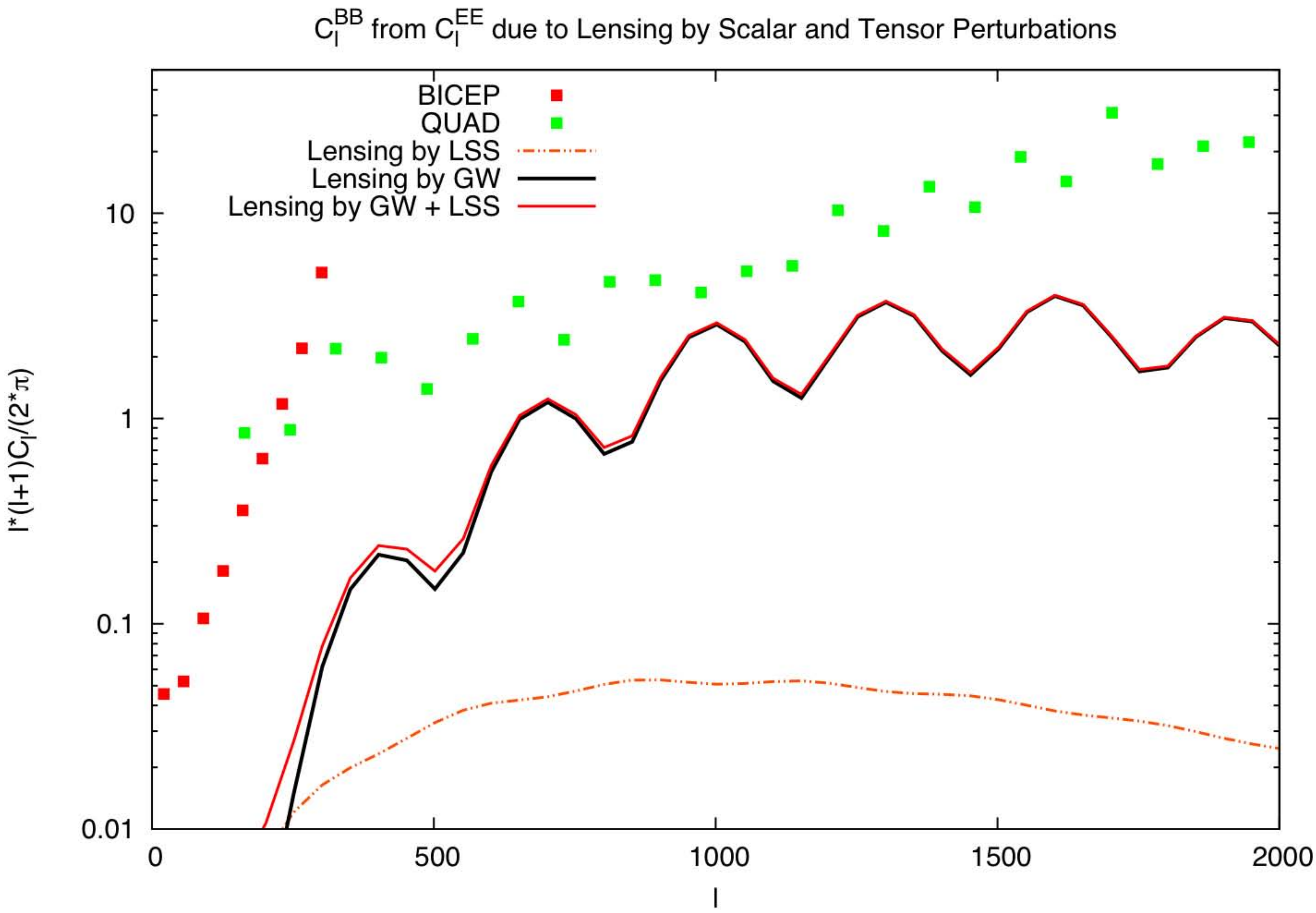
Δ → $C_\ell^{h^{\otimes}}$ → Tensor Perturbations (Gravity Waves)

Toy model :

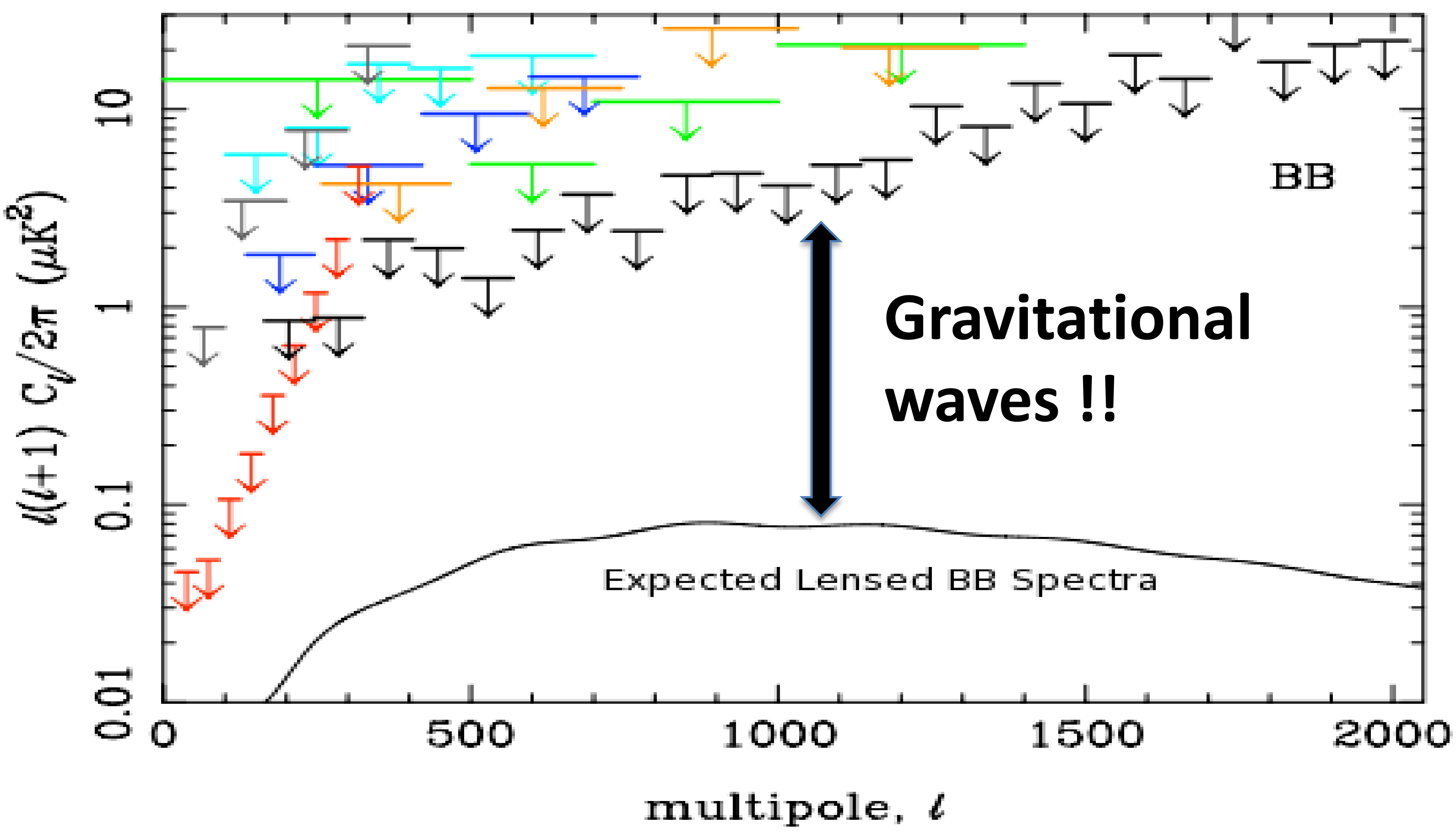
$$C_\ell^{h^{\otimes}} = C_\ell^{h^{\oplus}}$$

Power Spectrum of the projected lensing potential $C_\ell^{\psi\psi}$

A Comparison : GW more efficient !



Can we constrain Gravitational Waves Power Spectra ?

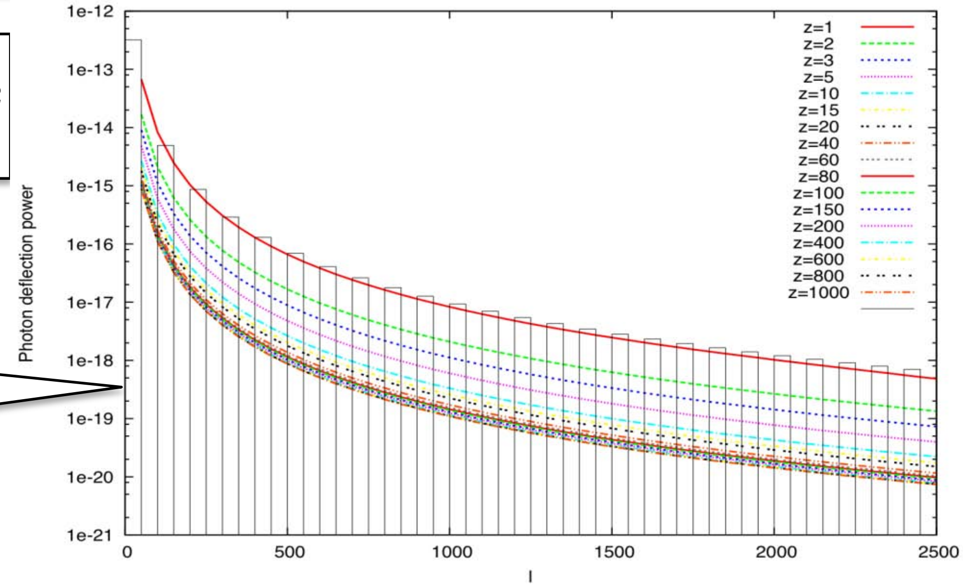


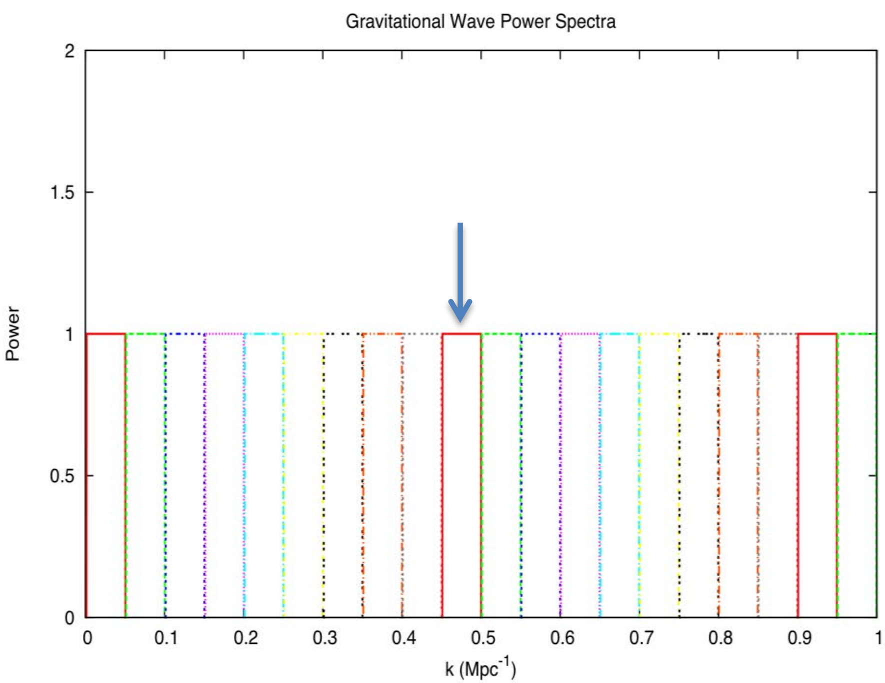
GW Power Spectra ⟷ Deflection Power Spectra

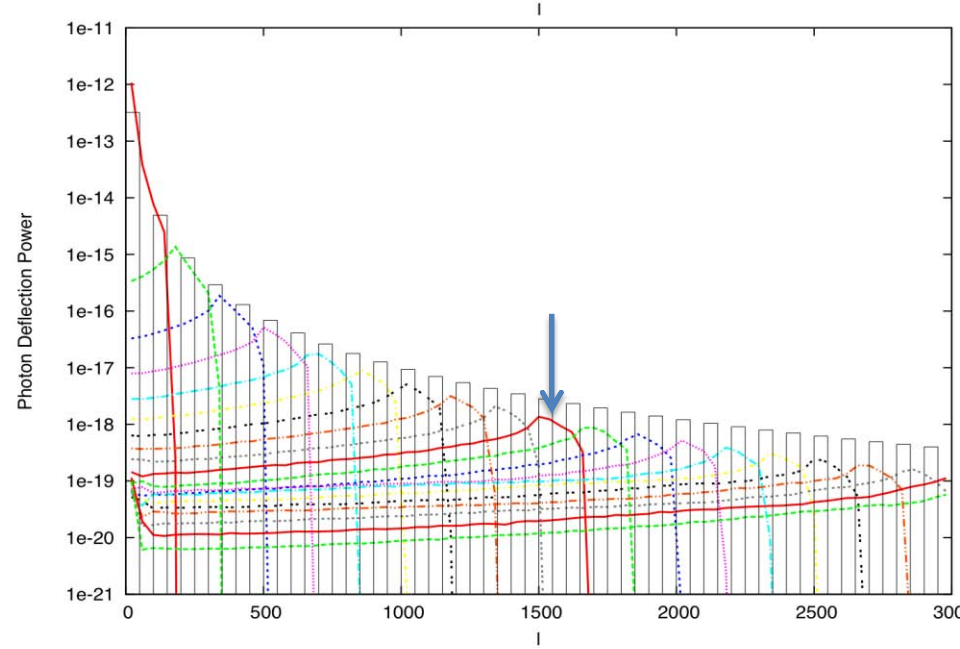
$$C_\ell^{h^\otimes} = \frac{\pi}{l^2(l+1)^2}\frac{(l+2)!}{(l-2)!}\int d^3\mathbf{k}P_T(k,z)|T_{eff}|^2$$

C. Li and A. Cooray, PRD 74, 023521(2006)

P(k)=Constant
GW sourced at different z



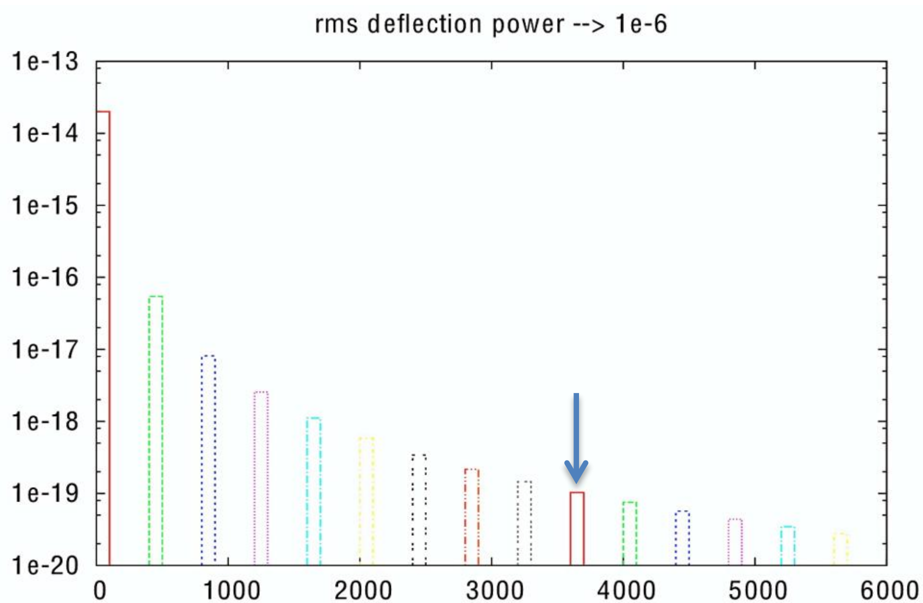




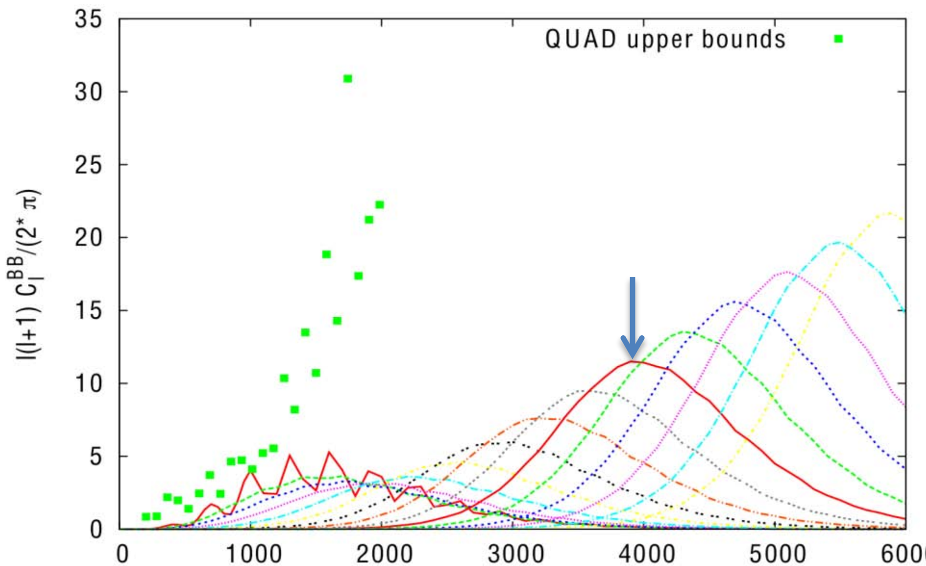
Constraining the deflection power spectra

Sensitivity of the lensed BB spectra to the deflection angular power spectra !!

The best constraints on the deflection power in the specific bins will come from the measurements of the $\mathrm{C}_\ell^{\mathrm{BB}}$ spectra at the location of the respective peaks.



$C_\ell^{h^\otimes}$



C_ℓ^{BB}

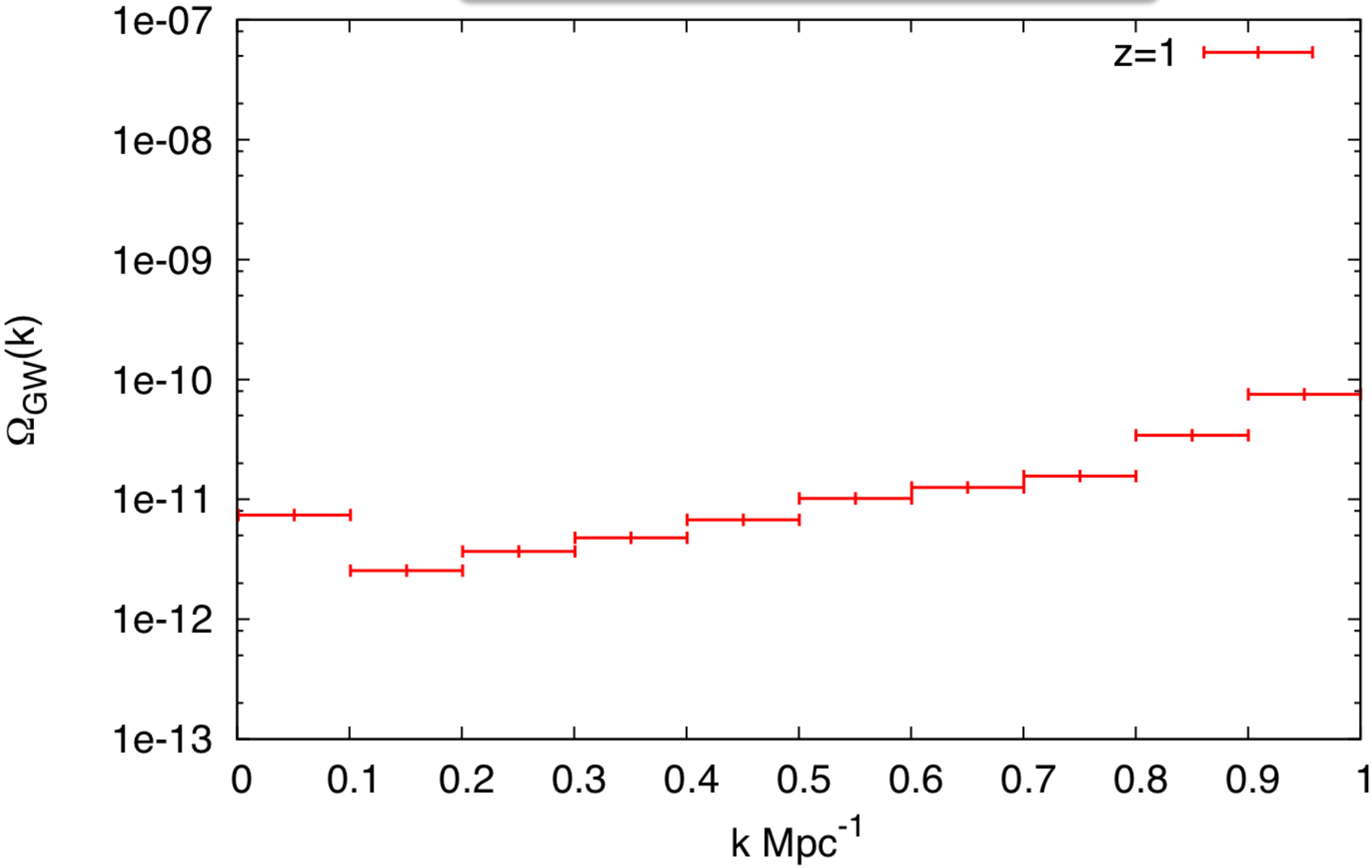
RMS deflection power is kept constant : $\langle \alpha^2 \rangle = \frac{1}{4\pi} \sum_l l(l+1)(2l+1) C_l^{h^\otimes}$

$R = 1.9 \times 10^{-4}$

Scalar Perturbations

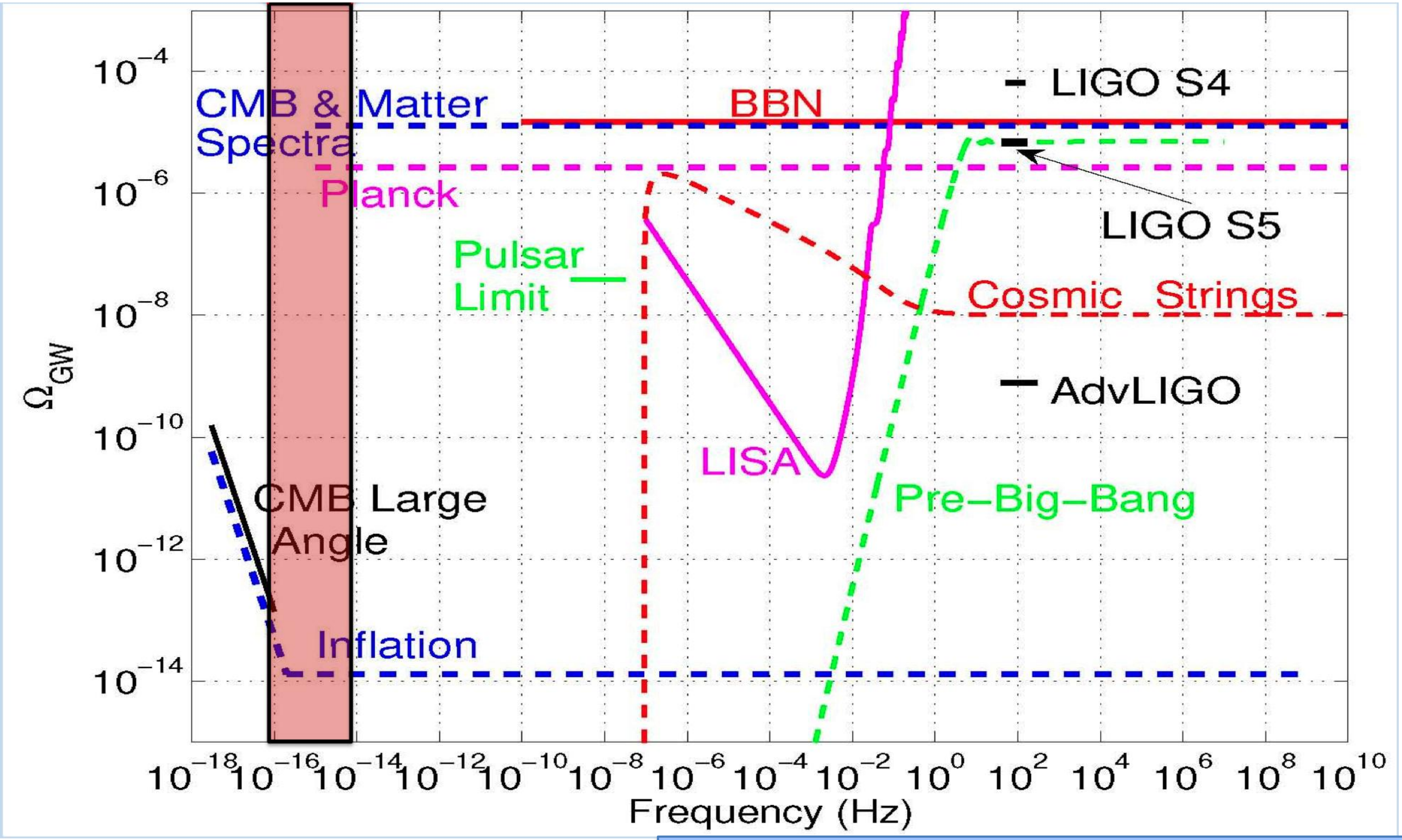
Constraints on the GW power spectra.

Preliminary Results



A New Window into Gravitational Waves !!

k = 0.001 – 1 Mpc^{-1} → $10^{-16} – 10^{-14}$ Hz



Vol 460 | 20 August 2009 | doi:10.1038/nature08278

Summary :

- Tensors are more efficient at transferring power from EE → BB spectra.
- From current and future experiments which will measure the CMB polarization spectra, it will be possible to put constraints on the Gravitational Waves spectra.
- This probe provides a new window into Gravitational Waves which has not been previously explored.

Thank you for your attention ☺