GW anisotropies as a probe of primordial non-Gaussianity

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Outline

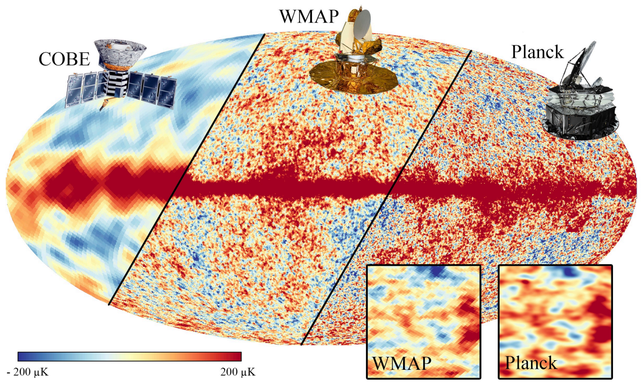
Tensor modes from Inflation

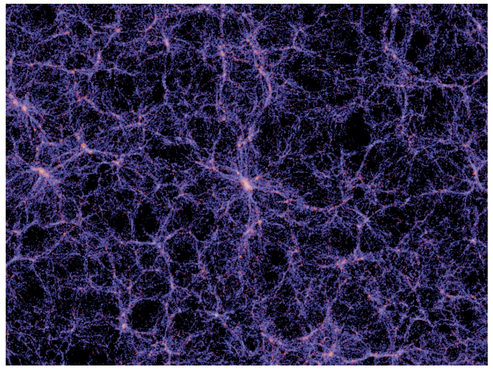
What kind of tensor nG signatures are observable at interferometers?

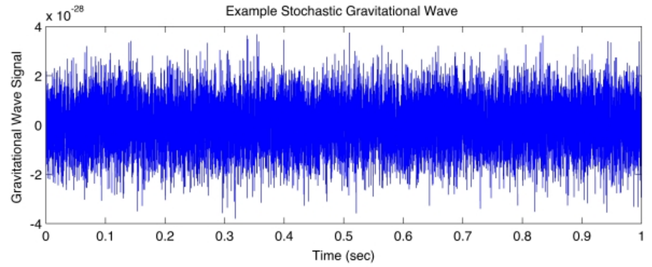
Detection prospects and forecasts

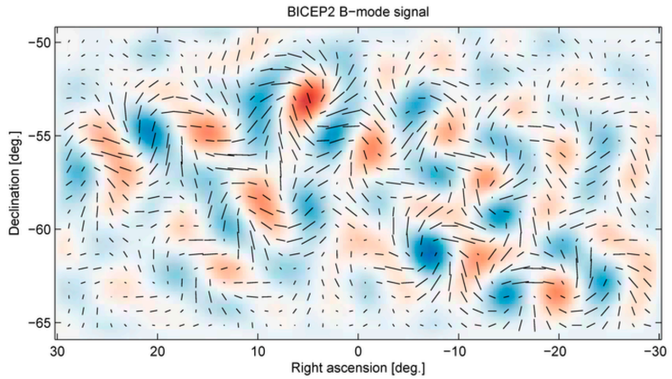
Inflationary perturbations

$$ds^2 = a^2(\eta)\left[-d\eta^2 + \left(e^{2\zeta}\delta_{ij} + h_{ij}\right)dx^i dx^j\right]$$









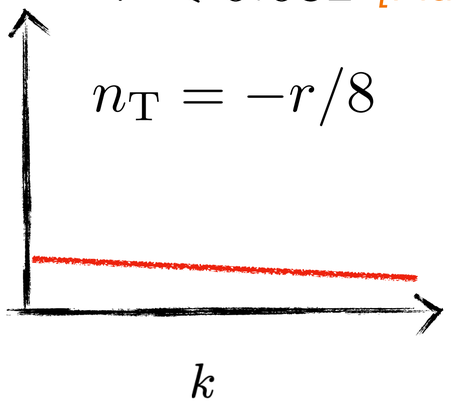
Tensor modes in SFSR

Amplitude + spectral tilt

$r < 0.032$ *[Planck+BK18]*

$\mathcal{P}_h(k)$

$n_{\rm T} = -r/8$



Unpolarised

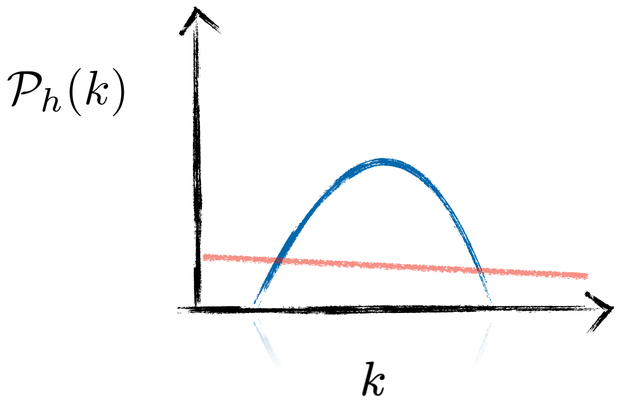
$\mathcal{P}_h^R = \mathcal{P}_h^L$

Gaussian

$\langle h_k h_k^* \rangle$

Tensor modes beyond SFSR

Amplitude + spectral tilt



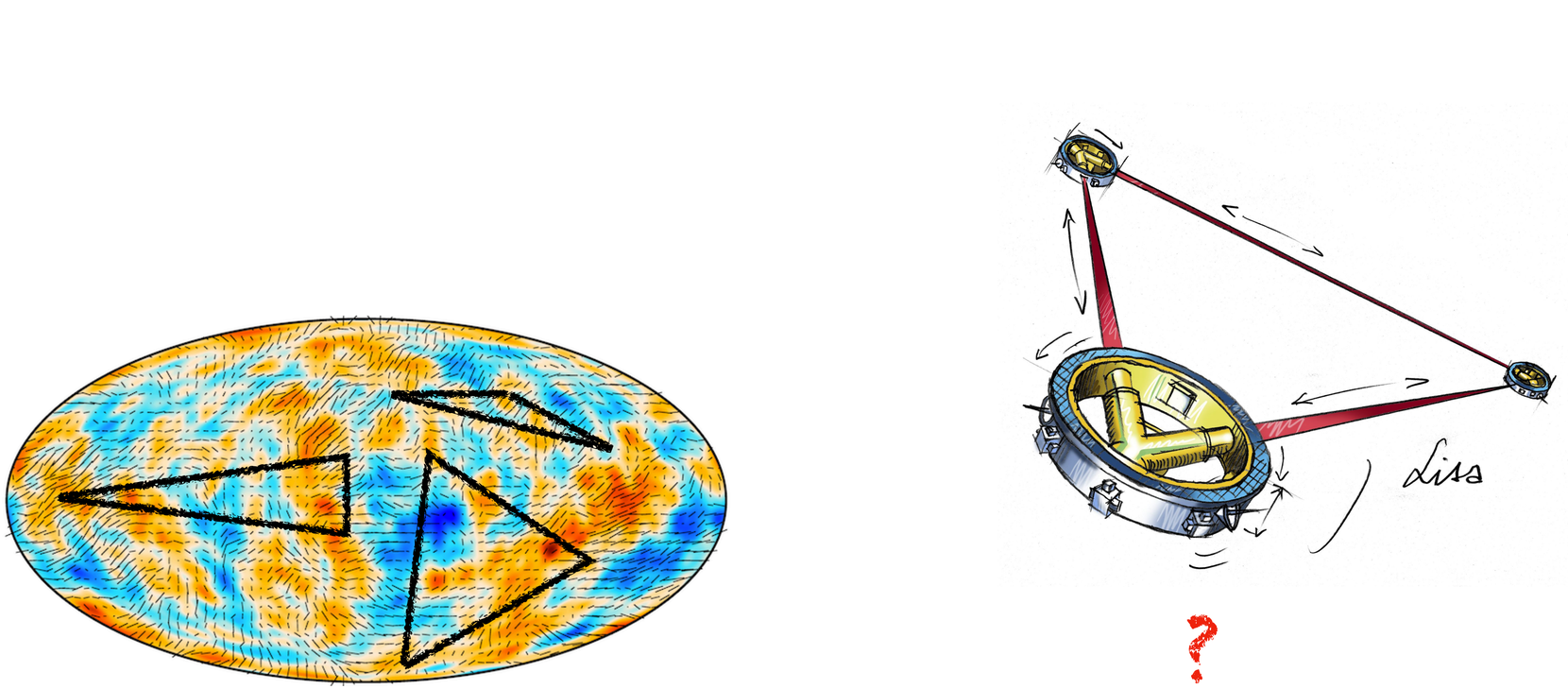
Polarisation

$$\mathcal{P}_h^R \neq \mathcal{P}_h^L$$

non-Gaussianity

$$\langle h_{k_1} h_{k_2} h_{k_3} \rangle$$
$$\langle \zeta_{k_1} h_{k_2} h_{k_3} \rangle$$
$$\langle h_{k_1} \zeta_{k_2} \zeta_{k_3} \rangle \ldots$$

Tensor nG probes

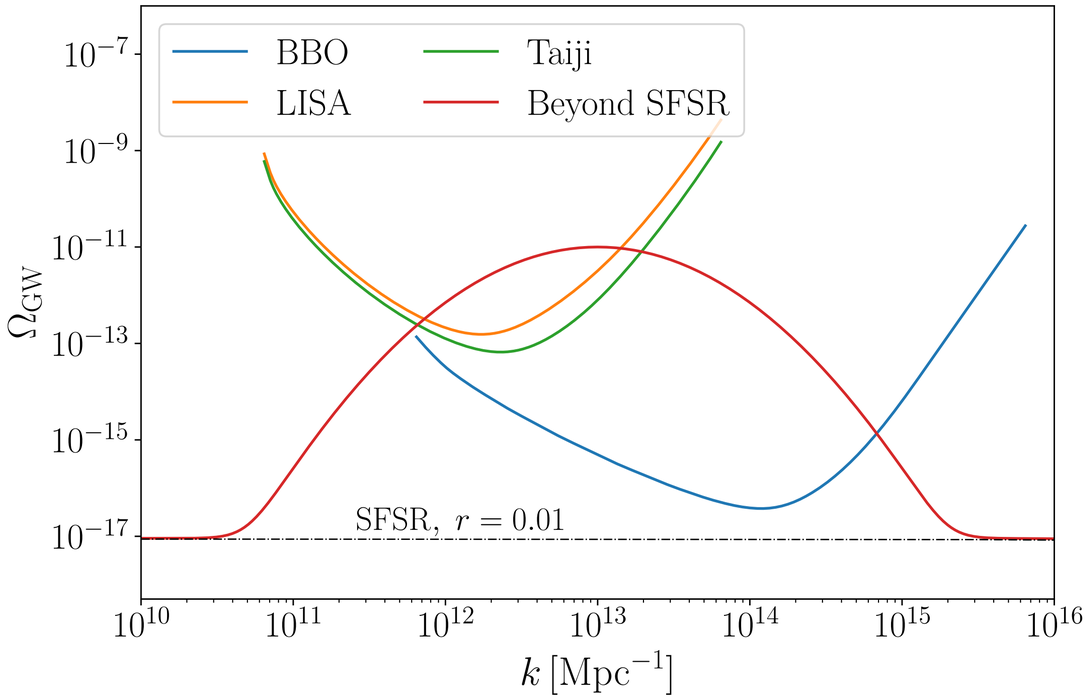


$k_{\rm CMB} \sim 10^{-3}{\rm Mpc}^{-1}$

$k_{\rm GW} \sim 10^{12}{\rm Mpc}^{-1}$

$\Delta N \sim 30$

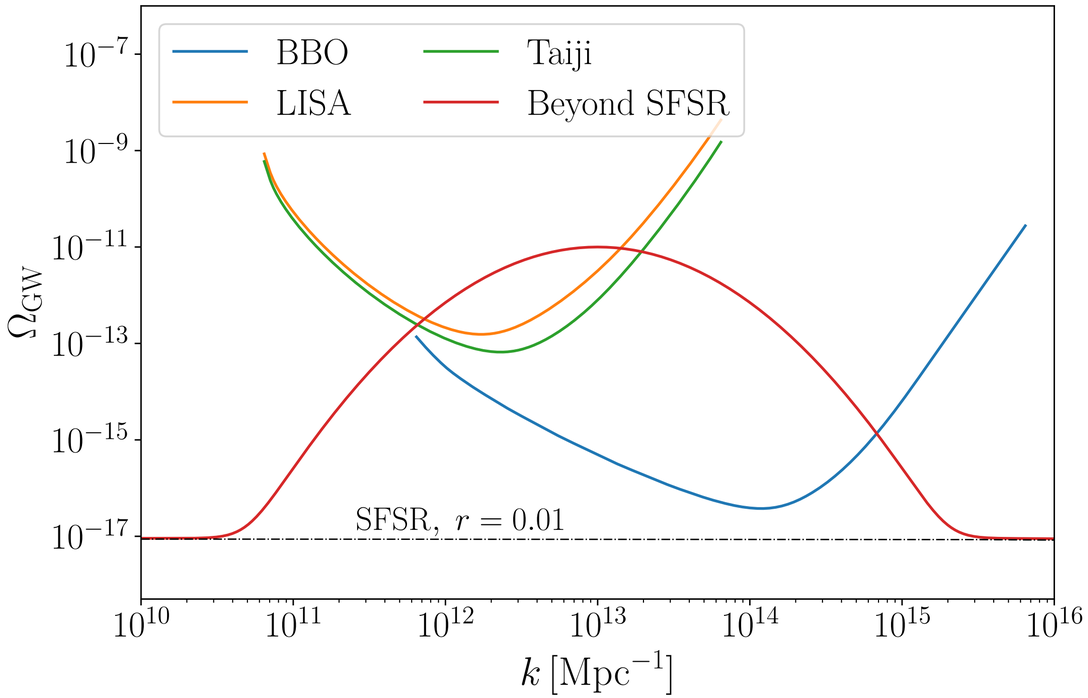
Can interferometers probe tensor non-Gaussianity?



GWB needs to be observable…

unlikely in SFSR Inflation

Can interferometers probe tensor non-Gaussianity?

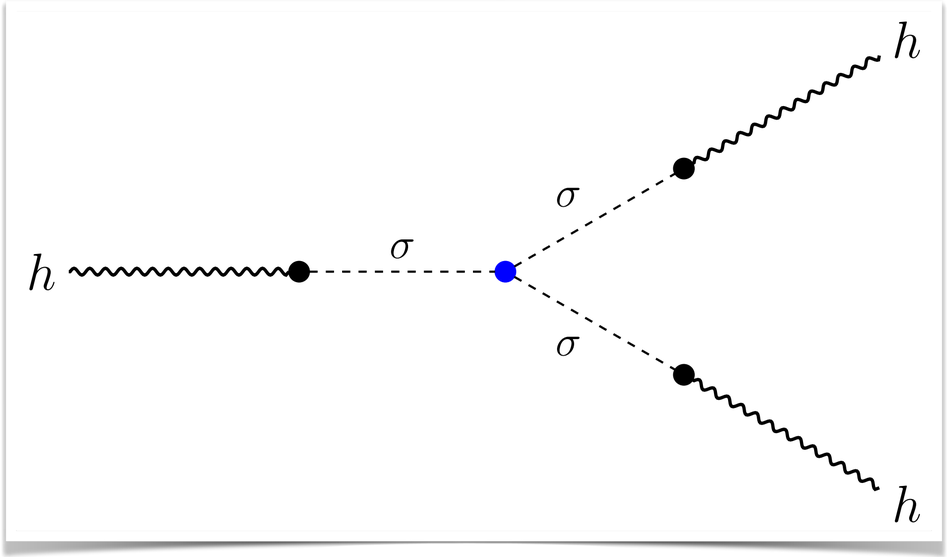


GWB needs to be observable…

$$h''_{ij} + 2\mathcal{H}h'_{ij} + k^2 h_{ij} = 16\pi a^2 \Pi_{ij}^{\rm TT}$$

Sourced by additional fields

Additional fields can source GW and also contribute to tensor nG



Could we then just measure $\langle h^3 \rangle$ and extract information about these fields?

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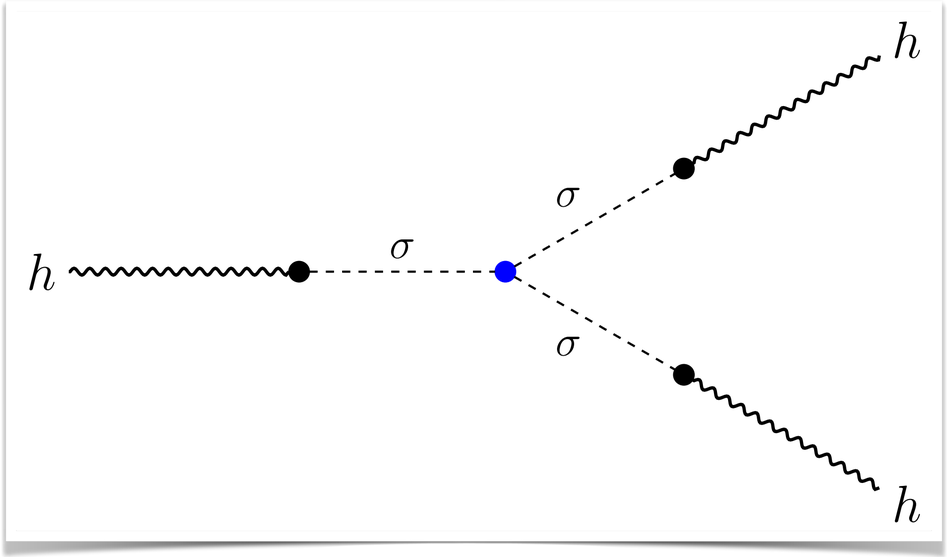


Could we then just measure $\langle h^3 \rangle$ and extract information about these fields?

Unfortunately, things are not so simple…

Can interferometers probe tensor non-Gaussianity?

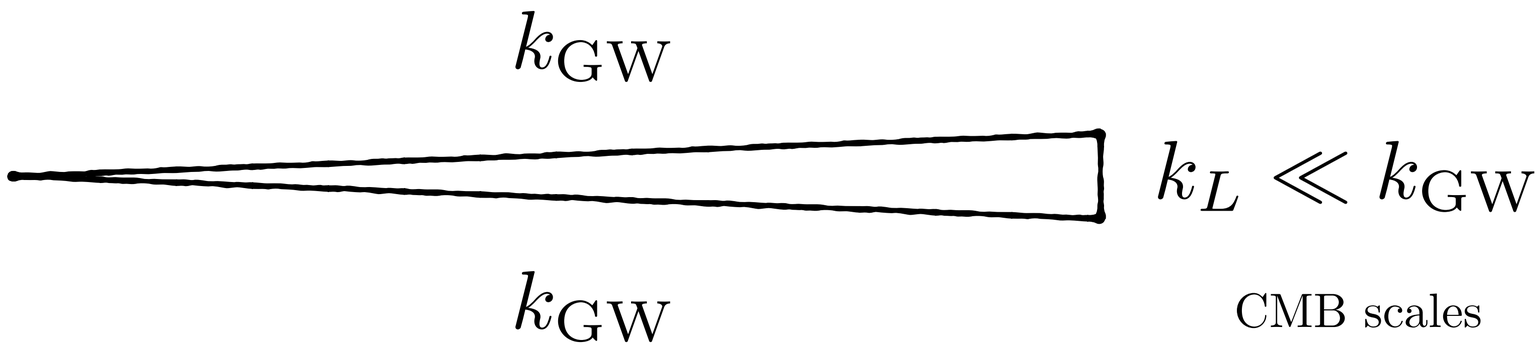
GW propagate in an inhomogeneous universe

→ GW incident from different directions get phase shifted by different amounts

Consequently observed $\langle h^{2n+1} \rangle$ vanishes *[Bartolo et al. 18, Margalit et al. 20]*

Indirect constraints of tensor nG with interferometers

Testing ultra-squeezed limit nG - our work *[2012.03498 and 2109.03077]*



Anisotropies from squeezed non-Gaussianity

Similar to ‘fossil’ effects in LSS *[Jeong, Kamionkowski (2012); Dai et al. (2013)]*

e.g from $\langle \zeta h h \rangle$ *[Adshead, Afshordi, Dimastrogiovanni, Fasiello, Lim, Tasinato (2020)]*

$$\mathcal{P}_h^{\rm mod}(\vec{k},\vec{x}) = \bar{\mathcal{P}}_h(k)\left[1+\int_{q\ll k}\frac{d^3q}{(2\pi)^3}\,e^{i\vec{q}\cdot\vec{x}}\,f_{\rm NL}(\vec{k},\vec{q})\,\zeta(\vec{q})\right]$$

$$f_{\rm NL} = \frac{B_{\zeta hh}(q,k)}{P_\zeta(q)P_h(k)}$$

Directional intensity flux of GW

$$\Omega_{\rm GW}(k,\hat{n}) = \bar{\Omega}_{\rm GW}(1+\delta_{\rm GW}(k,\hat{n}))$$

$$\delta_{\rm GW}(k,\hat{n}) = \int_{q\ll k} \frac{d^3q}{(2\pi)^3} e^{i\vec{q}\cdot\hat{n}(\eta_0-\eta_i)} f_{\rm NL}(\vec{k},\vec{q})\zeta(\vec{q})$$

Derivation via 'In-in' - see Lucas' talk

Anisotropies of V modes - see Giorgio's talk

Expand in spherical harmonics and get angular power spectra

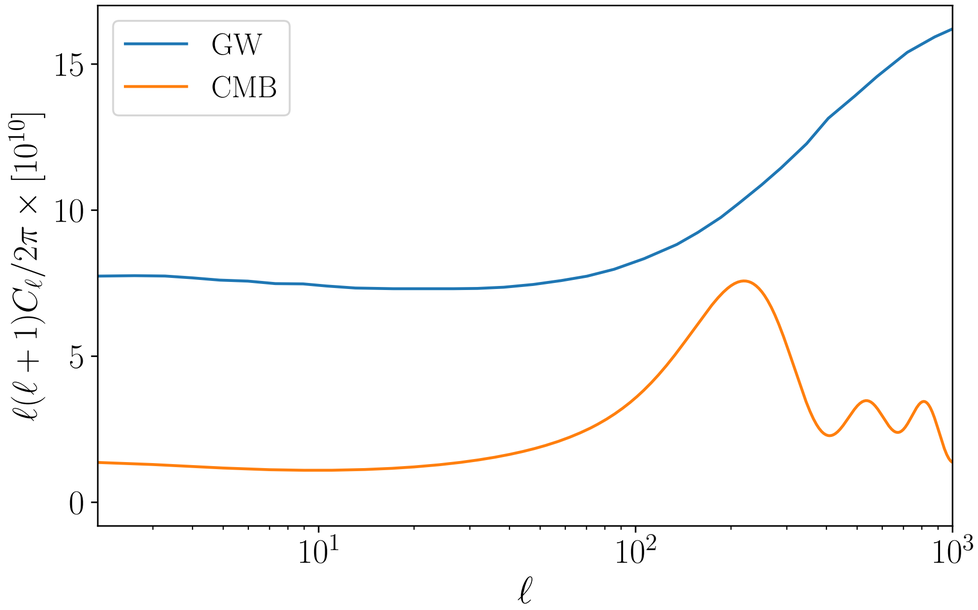
$$C_\ell^{\rm GW} \sim \frac{f_{\rm NL}^2 A_{\rm s}}{\ell(\ell+1)}$$

Anisotropies from propagation

SGWB also has CMB like anisotropies arising from propagation through large scale perturbations *[Bartolo et al. 2019, Dall'Armi et al. 2020]*

$$C_\ell^{\mathrm{GW,prop}} \propto \int d\ln k\, \mathcal{P}_\mathcal{R}(k) T_\ell^{\mathrm{GW}}(k)^2 \sim A_\mathrm{s}$$

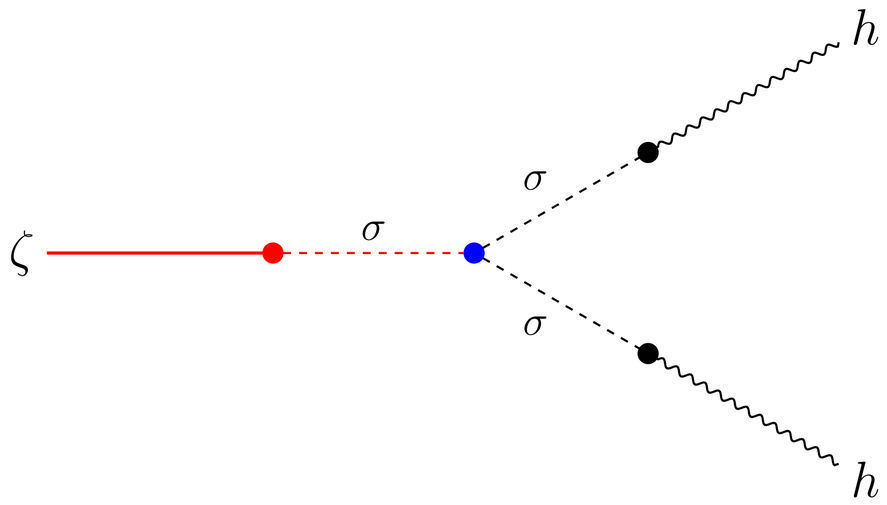
SW+ISW



For $f_{\mathrm{NL}} \gg 1$, the anisotropies from non-Gaussianity dominate

Example: additional Spin-2 field

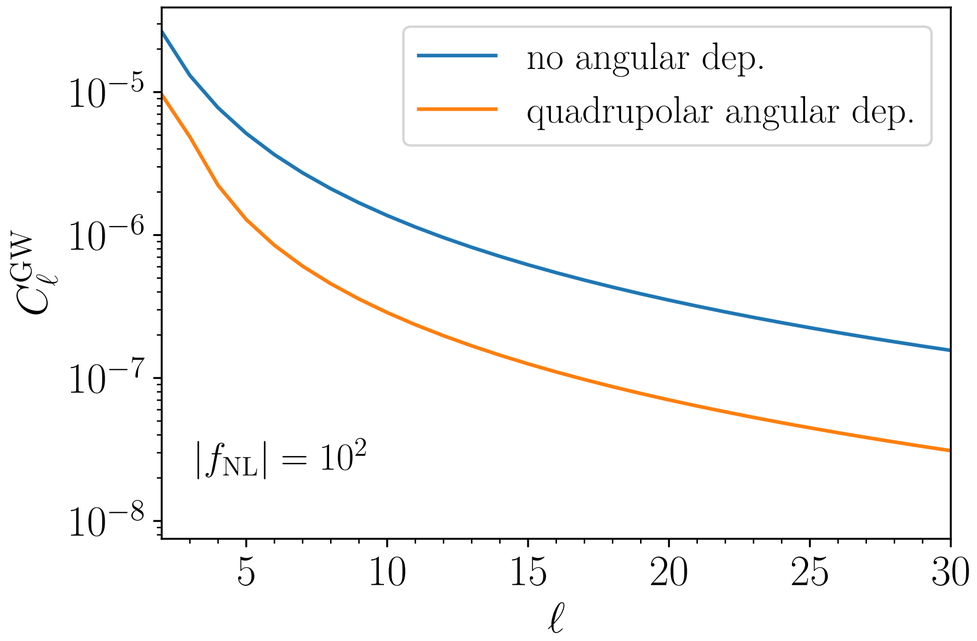
Can linearly source GW and contribute to NG *[Bordin et al. 2018, Iacconi et al. 2020a, 2020b]*

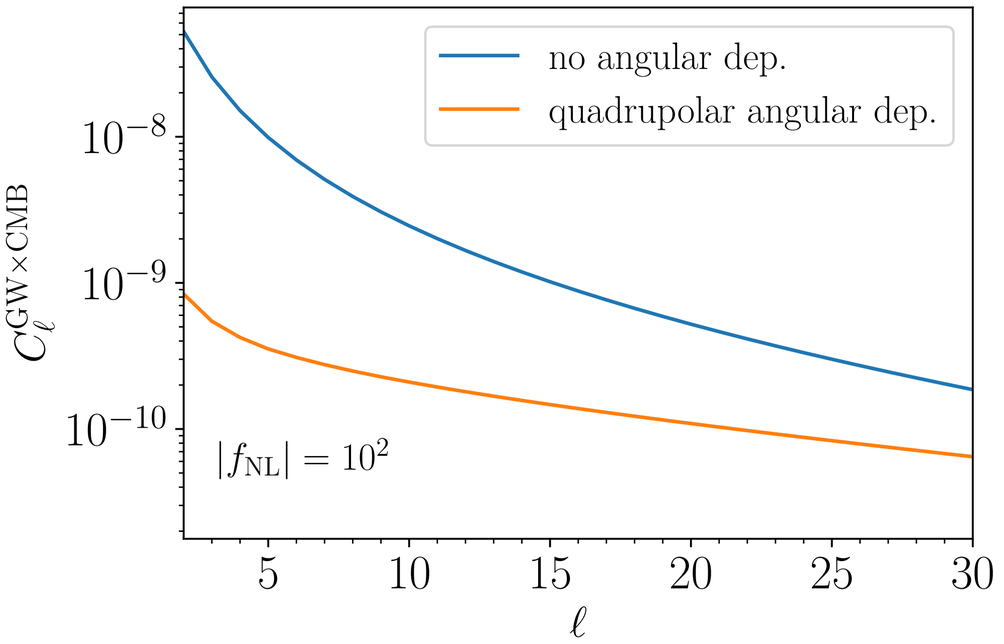


see Laura's talk for more on the spin-2 model and $\langle\gamma^3\rangle$

consequence of spin-2 $\rightarrow \langle\zeta_{k_L} h_k h_k\rangle \propto \mathcal{P}_2(\hat{k}_L \cdot k)$

Angular Power Spectrum - Spin 2 Model





On large angular scales cross-correlation scales differently with ℓ - GW quadrupole × CMB monopole

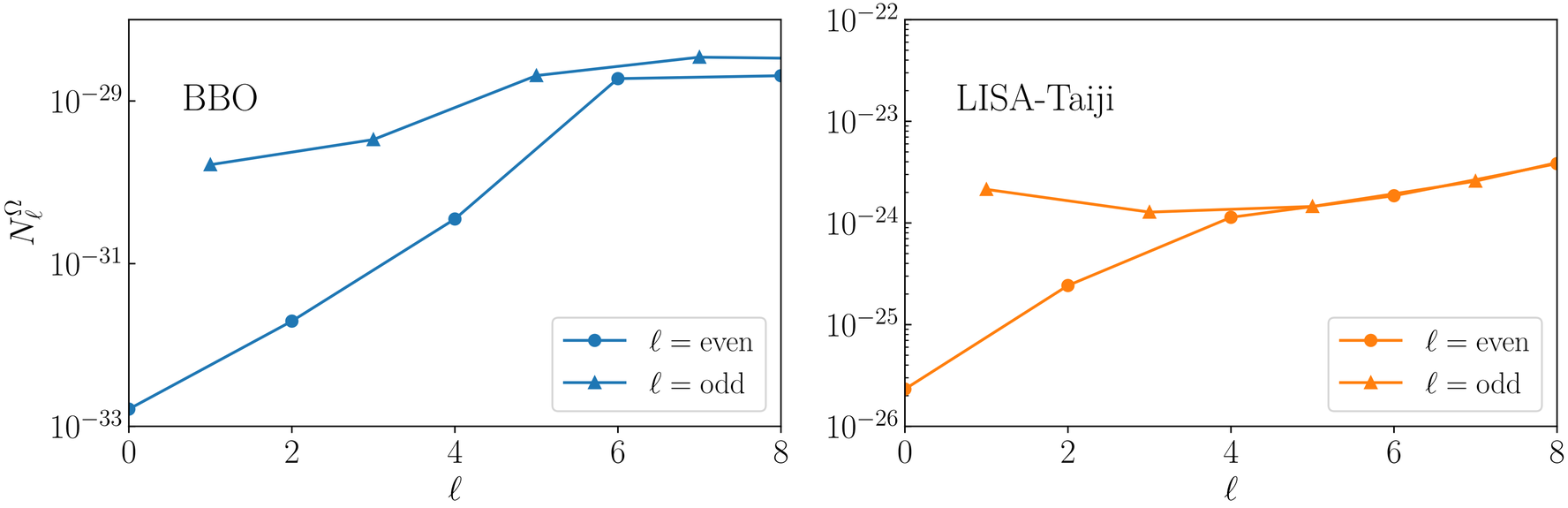
Detection prospects - Noise Angular Power Spectrum

$$N_\ell^{-1} \sim T_{\rm obs} \sum_{IJ} \int df \, \frac{\sum_m |\mathcal{A}^{IJ}_{\ell m}(f)|^2}{N_f^I N_f^J}$$

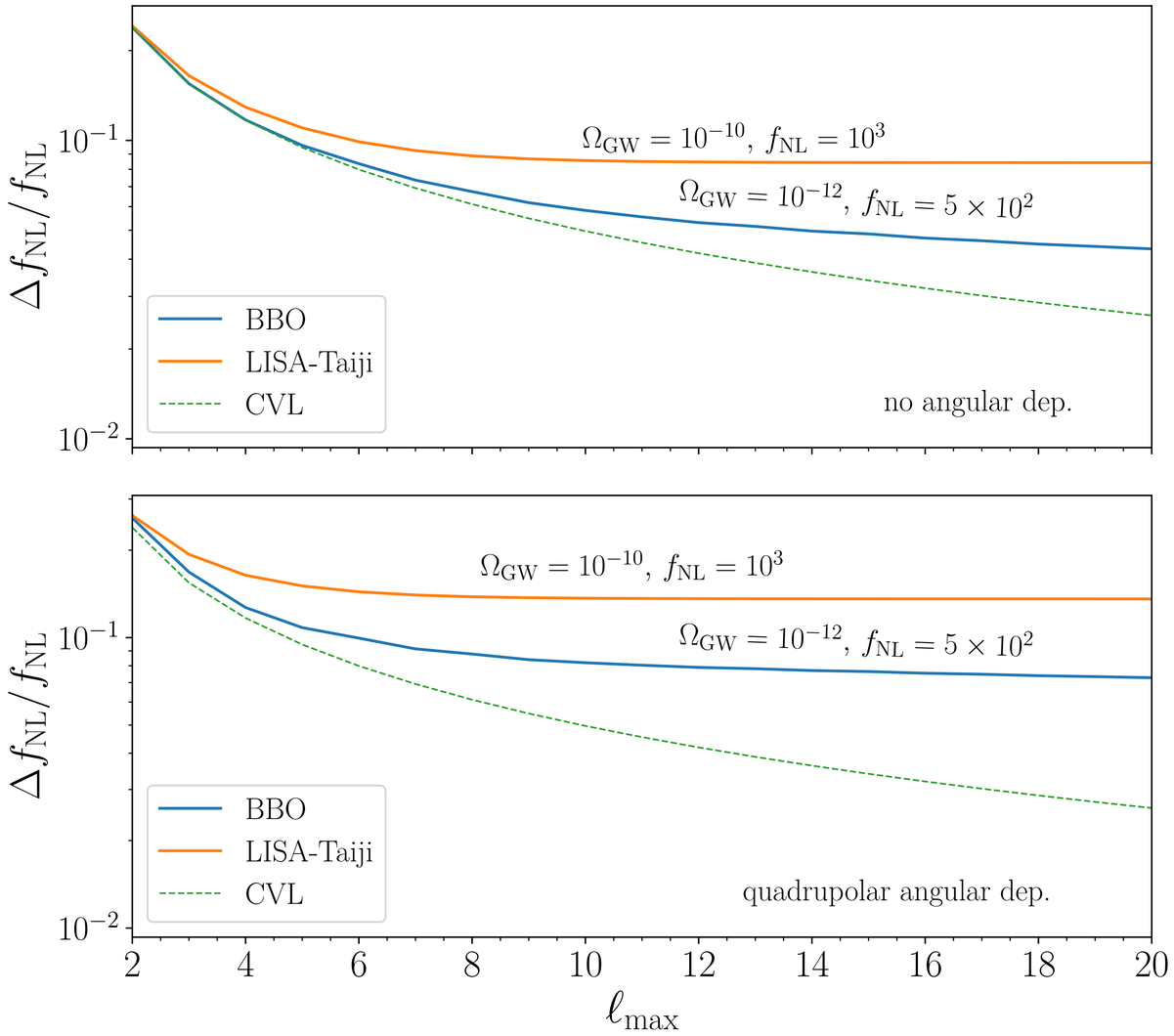
→ *[Alonso et al. (2020)]*

GW detectors have limited angular resolution

$\ell_{\rm max} \sim 15$



Forecasts for $f_{\rm NL}$



Error saturates quickly but $f_{\rm NL} \gg 1$ could still be probed with relative error* $\sim \mathcal{O}(0.1)$

Additional possibility

Can we see effects of scale dependent NG?

$$f_{\rm NL}(k,q)$$

Frequency dependence of induced anisotropies

Similar to n_s in CMB

Summary

Models with detectable SGWB can also have significant non-Gaussianity → hints to nature of inflationary interactions

Propagation effects in the inhomogeneous universe render $\langle h^3 \rangle$ unobservable at interferometers

However, indirect observations of squeezed limit $\langle \zeta hh \rangle$ and $\langle h^3 \rangle$ are still possible through the anisotropies of the SGWB

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Thank you!