Can we see inflationary tensor non-Gaussianities?

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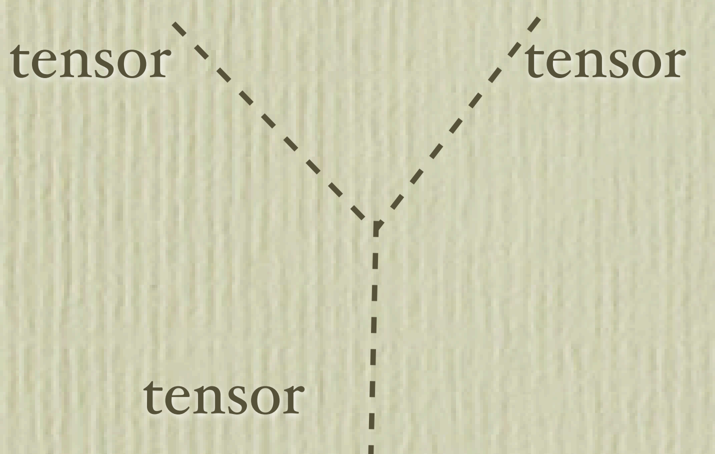
No.

The End.

What are 3-pt correlations?

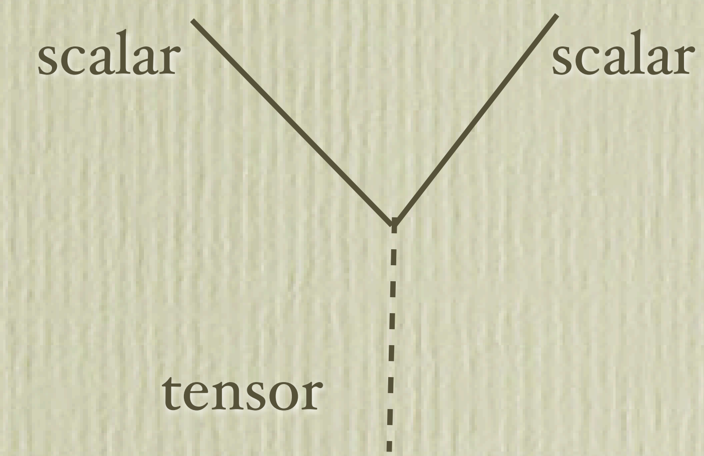
Part I



$\langle hhh \rangle$

Tensor Non-Gaussianities

Part II

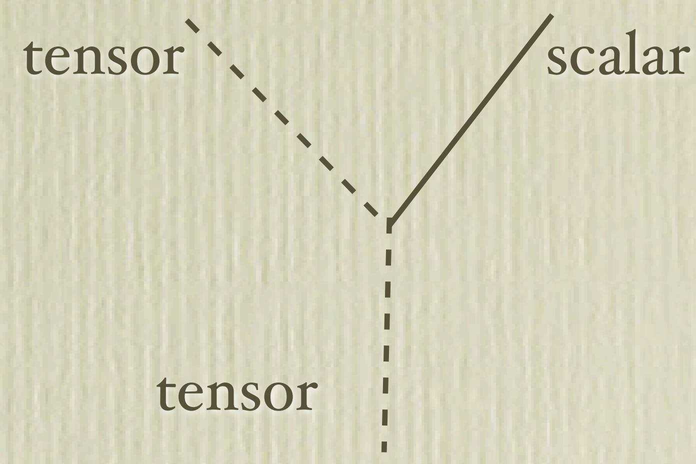


Gravitational Bremsstrahlung

$\langle \zeta\zeta h \rangle$

Preheating, Textures/
Global Phase transitions

Part III



$\langle \zeta hh \rangle$

Cross-correlating tensor
with scalars

Question : how do we measure these things?s

This talk : *Direct Detection of SGW* with interferometers

Unresolved Sources = Stochastic GW

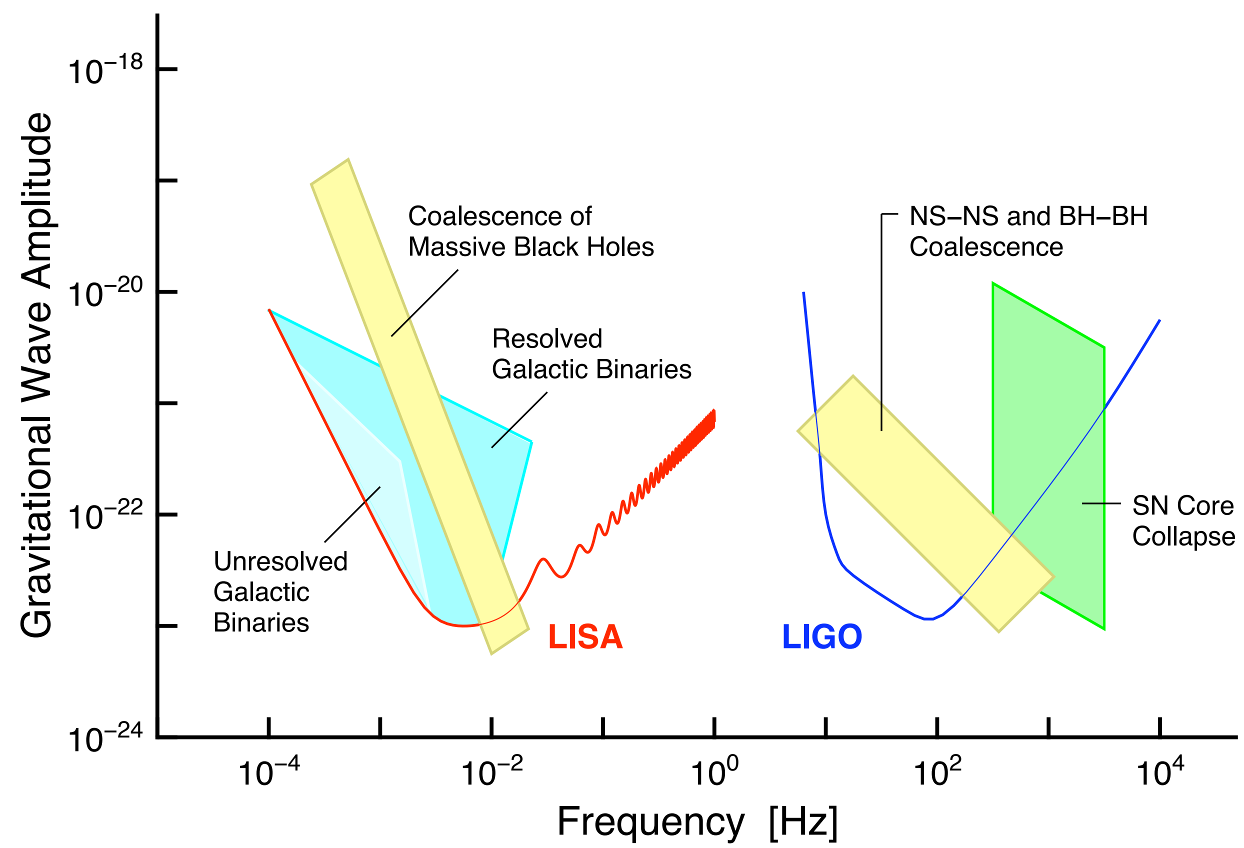
Stochastic : they "look" just like noise

Characterize them via *correlation functions*

Power Spectrum : $\langle h(f)h(f)\rangle$

Convention : *energy density* $\Omega_{gw} = \frac{\rho_{gw}}{\rho_g}$ $\rho_{gw} = \frac{M_p^2}{32\pi}\langle \dot{h}_{ij}\dot{h}^{ij}\rangle$

Fourier space $\langle h(f)h(f')\rangle = \frac{3H_0^2}{20\pi^2} f^{-3}\Omega_{gw}(f)\delta(f-f')$



(1) Noise dominated

$n(t) \gg s(t)$

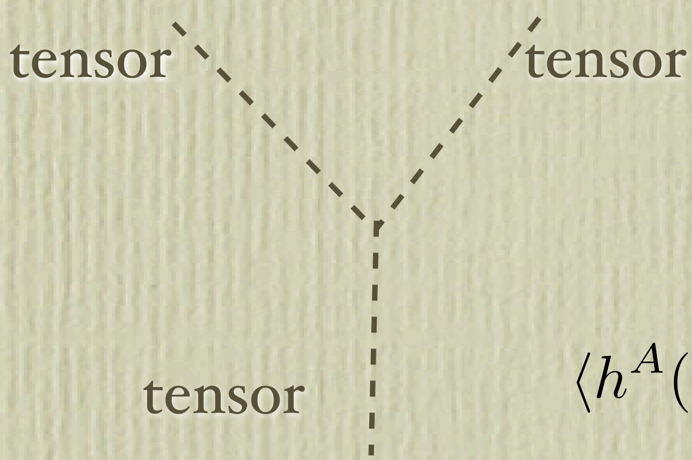
(2) Cannot see individual gravitons of SGW

(3) Only see *time-averaged* correlations

(4) Integrated over *all sky*

Part I : Inflationary Tensor 3-pt

Pure gravity tree-level self-interaction



$$\langle h^A(\mathbf{k}) h^{A'}(\mathbf{k}') h^{A''}(\mathbf{k}'') \rangle = \left(-K + \frac{kk' + k'k'' + kk''}{K} + \frac{kk'k''}{K} \right) (2\pi)^3 \delta(\sum \mathbf{k}$$

$$\times \frac{H^4}{M_p^4} \frac{-4}{8(kk'k'')} (e^A_{ii'}(\mathbf{k}) e^{A'}_{jj'}(\mathbf{k}') e^{A''}_{ll'}(\mathbf{k}'') t_{ijl} t_{i'j'l'})$$

$$\langle hhh \rangle$$

$$t_{ijk} \equiv k'^i \delta_{jl} + k''^j \delta_{il} + k^l \delta_{ij}$$

Tensor Non-Gaussianities

Maldacena (2002)
Maldacena + Pimentel (2011)

$$\langle hhh \rangle \propto \left(\frac{H}{M_p} \right)^4$$

3-pt GW Estimator

Adshead + Lim (2009)

Direct Detection with 3 Interferometers.

Peak Sensitivity Frequency f_*

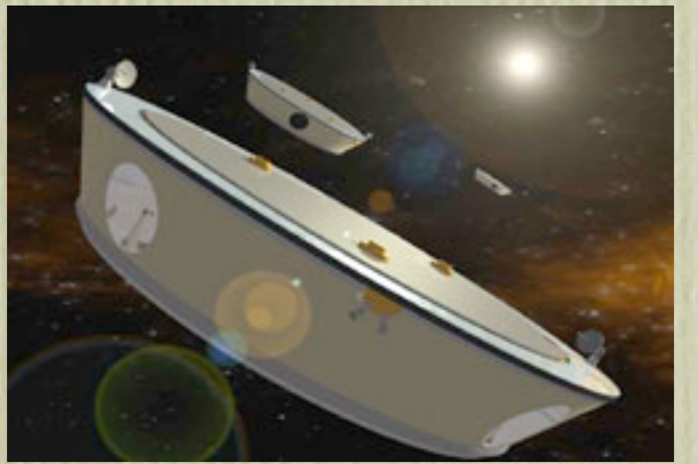
Sensitivity of Detectors to Triangles (Filtering)

$$\frac{\text{Signal}}{\text{Noise}} = \text{shape} \times \left(\frac{H_{\rm inf}}{M_{\rm pl}}\right)^4 \left(\frac{H_0}{2\pi}\right)^3 \left(\frac{1}{f_*}\frac{1}{z_{eq}^{1/2}}\right)^3 \left(\frac{1}{N_1^2(f_*)N_2^2(f_*)N_3^2(f_*)(\Delta f)^3}\right)^{1/2} \sqrt{\frac{T}{\Delta T}}.$$

Scale of Inflation H_{inf}

Noise of Instrument $N^2(f_*)$

Integration Time T



LISA (20$$)

LISA will take more than a billion years to detect GUT scale inflation *power spectrum* so is hopeless here.

3-pt GW Estimator

Adshead + Lim (2009)

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BBO (20??)

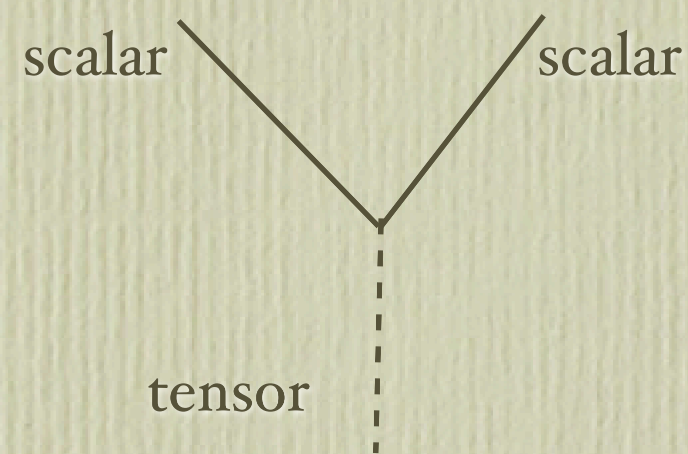
BBO : GUT Scale power spectrum ~ 5 years.

Tensor 3-pt : 10^6 years

$$T \propto (N(f_*))^6$$

"SuperBBO" : improve sensitivity $N(f_*) \rightarrow 10^{-1}N(f_*)$ means we can detect GUT scale tensor 3-pt in single digit years

Part II : 3-pt SGW from scalar sources



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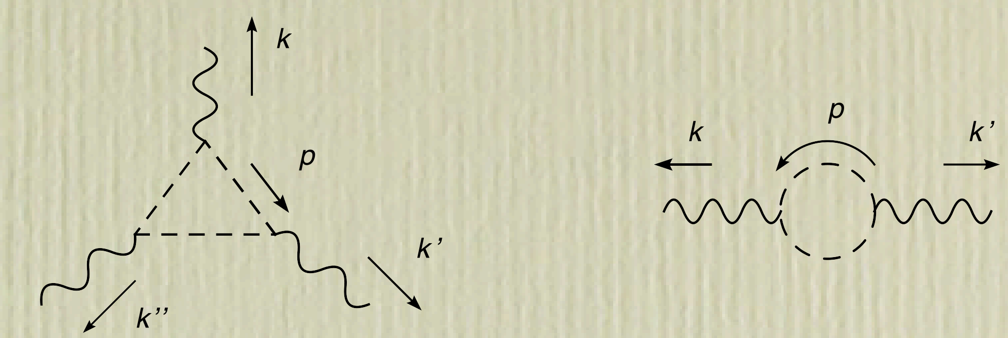

2-pt and 3-pt generated at 1-loop by *identical* interaction (Schematic!)

End of Inflation Preheating : *causal* process at length scale H_{end}^{-1}, highly correlated within this scale.

But our SGW sky is composed of $(H_{TeV}/H_0)^2 \sim 10^{80}$ uncorrelated patches!

Fun Fact : the preheating SGW sky is even more Gaussian than inflationary ones.

Part III : Gravity - Scalar Correlations

w/ P. Adshead + N. Ashfordi (WIP)

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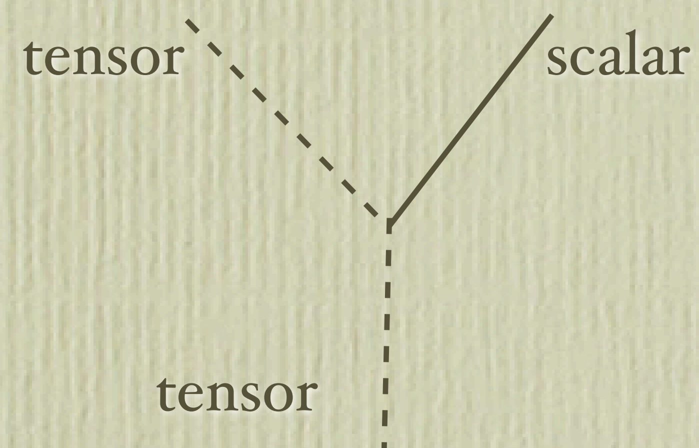


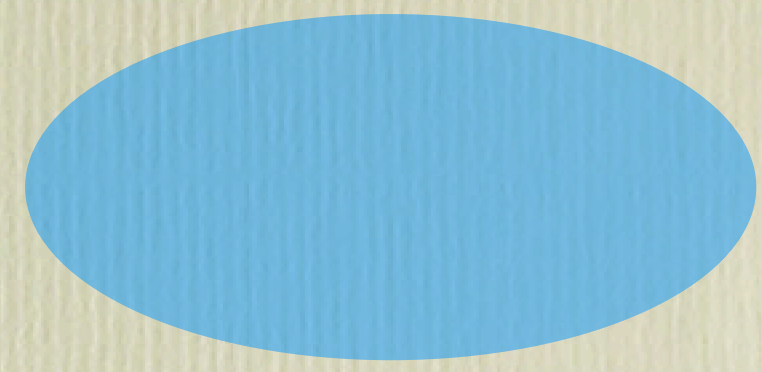
$$\langle \zeta h h \rangle$$

Cross-correlating tensors with scalar

See also Dimastrogiovanni et al (2007) for 1-loop corrections

CMB Anisotropy Map

SGW Anisotropy Map



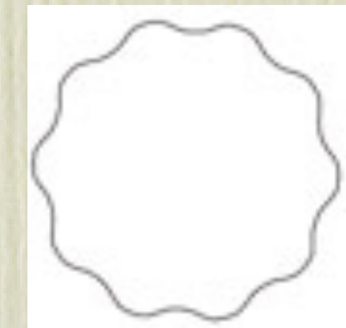
$$\delta_{GW,\hat{\Omega}}(f_*) \equiv \frac{\bar{P}(f_*) - P(f_*, \hat{\Omega})}{\bar{P}(f_*)}$$

$$C_{GW\times T}(f_*, l) \equiv \langle \delta_{GW,lm}(f_*)\delta_{T,lm} \rangle$$
$$\sim \langle \zeta h h \rangle$$

$$\delta P_{GW}(f_*; \mathbf{x}) = n_T(f_*)\bar{P}_{GW}(f_*)\zeta(\mathbf{x}) \sim 10^{-7}$$

Maldacena (2002)

Per frequency f_* one can think of a graviton emitting hypersurface, i.e. its horizon reentry at z_*, with coordinate $\mathbf{x}$



Due to scalar perturbation $\zeta(\mathbf{x}, \mathbf{z}_*)$, the crossing time is different resulting in SGW anisotropy.

Part III : Gravity - Scalar Correlations

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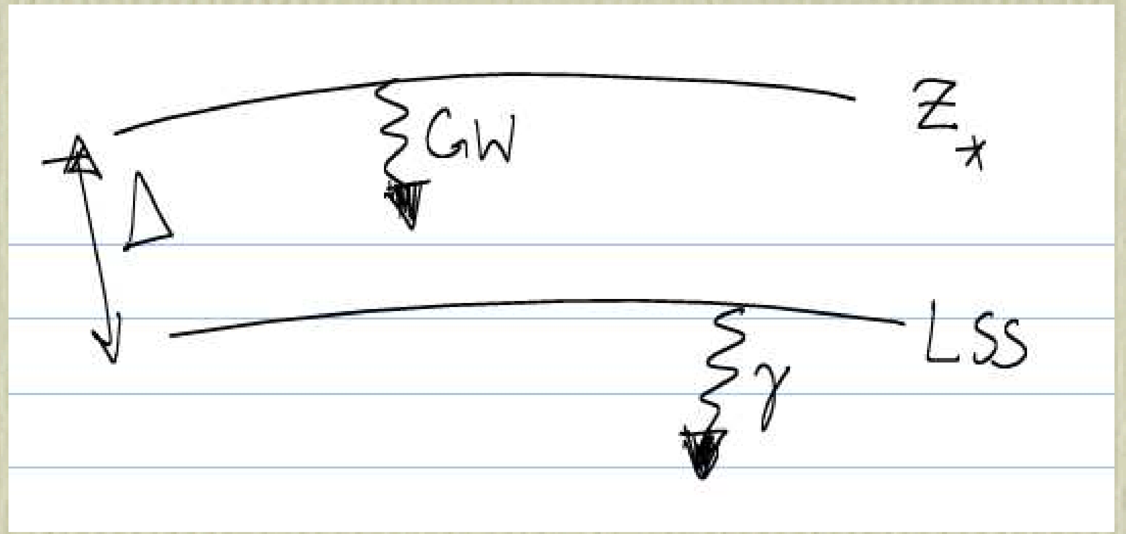

Think of high gravitons $f_* \sim \text{Hz}$ *frequency* as equivalent to CMB photon $\sim \text{GHz}$ freq in WMAP/PLANCK.

We want to correlate $\zeta(\mathbf{x})$ between the z_* surface and the z_{CMB} surface.

$$\Delta = \text{Comoving Distance from CMB to } z_* \approx \frac{(z_{eq}\Omega_m)^{1/2}}{z_{CMB}H_0} \sim 0.10\ H_0^{-1} \sim 0.031\ d_A(z_{CMB})$$

What scales are correlated between CMB and z_* surfaces?

Correlated around $l_* \leq \dfrac{d_A}{\Delta_*} = 33$

I.e. around 1 square degree scale on the CMB sky : requires SGW anisotropy map to this resolution.

Part III : Gravity - Scalar Correlations

w/ P. Adshead + N. Ashfordi (WIP)

Constructing SGW Anisotropy Map

Hard and Fast estimate : assume BBO-class detector needs 1 year to *detect* SGW.

$$\text{beam size} = \frac{4\pi^2}{\text{total patches}}$$

total patches $\sim$ 40000 for 1 sq deg

Chop up the sky into 1 square degree sized patches : use a beamed SGW interferometer.

$$\text{SNR}_{patch} \approx \frac{\text{SNR}_{sky}}{\sqrt{40000}}$$

$$\text{Time} \propto \text{SNR}^2 \sim 40000 \text{ years}$$

Need to know SGW power per patch to at least 10^{-5} or $5 \sim 6\sigma$ so need $\sim 10^7$ years.

posteriori Motivation aka *Why?? Eugene!?*

- Tests of non-Inflationary generators of SGW.

  e.g. Global Phase Transitions generation of SGW

Krauss (1992), Jones-Smith et al (2007), Fenu et al (2009)

$$k^6 \langle hhh \rangle_\Delta = \mathcal{C}_{NL} (k^3 \langle hh \rangle)^{3/2}$$

$$\mathcal{C}_{NL} \sim 1 \ vs \ \mathcal{C}_{NL} \sim H_{inf}/M_p \ \text{(inflation)}$$

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- Somebody gotta do it.