Synthetic GW's and the Scale of Inflation

Ogan Ozsoy

Syracuse University

Work done with **Scott Watson**, **Kuver Sinha**
[arXiv:1410.0016]

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Motivation

New Sources of Gravitational Waves during Inflation

Leonardo Senatore[1], Eva Silverstein[1], and Matias Zaldarriaga[2]

[1] *Department of Physics and SLAC*
Stanford University, Stanford, CA 94305, USA

[2] *Institute for Advanced Study*
Einstein Drive
Princeton, NJ 08540

Abstract

We point out that detectable inflationary tensor modes can be generated by particle or string sources produced during inflation, consistently with the requirements for inflation and constraints from scalar fluctuations. We show via examples that this effect can dominate over the contribution from quantum fluctuations of the metric, occurring even when the inflationary potential energy is too low to produce a comparable signal. Thus a detection of tensor modes from inflation does not automatically constitute a determination of the inflationary Hubble scale.

- **Claims of missing factors of pi ? (Peloso, Barnaby, Shiu, Sorbo)**
- **Careful look at back-reaction constraints / Stronger constraints on Non-gaussianity from Planck**
- **Potentially observable effects and important to establish scale of inflation**

GW sources during Inflation

$$\bar{h}''_{ij} + \left(k^2 - \frac{a''}{a}\right)\bar{h}_{ij} = \frac{2}{m_p^2}\, a\, T^{TT}_{ij}$$

Canonical graviton e.o.m

quasi dS vacuum production

$$T^{TT}_{ij} = 0$$

$$\Delta_t^2(k) = \frac{2}{\pi^2}\left(\frac{H}{m_p}\right)^2$$

$$r \equiv \frac{\Delta_t^2}{\Delta_s^2}$$

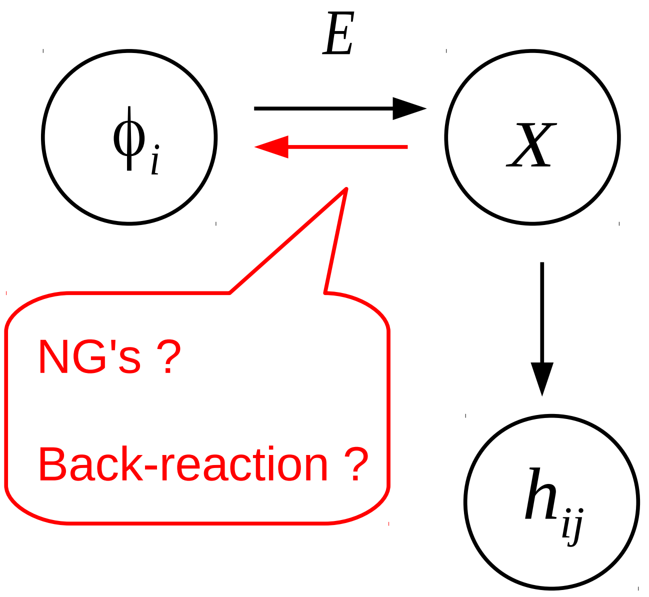
$$H_I \simeq 3 \times 10^{-5}\left(\frac{r}{0.08}\right)^{1/2} m_p$$

Additional Sources

$$T^{TT}_{ij} \neq 0$$

~~$$H_I \simeq 3 \times 10^{-5}\left(\frac{r}{0.08}\right)^{1/2} m_p$$~~

Additional Sources of GW's



- Idea behind secondary mechanisms: A sector X that absorbs energy via coupling to the inflaton (or spectator sector) and emits GW's

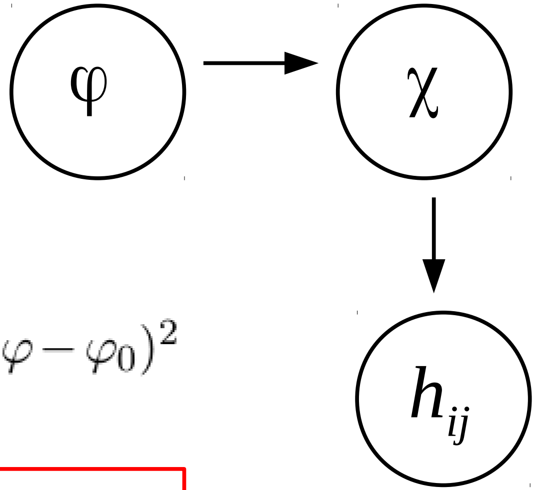
2 Types of Interaction

$$\mathcal{L}^{(1)}_{int} = -g^2(\varphi - \varphi_0)^2\chi^2$$

$$\mathcal{L}^{(2)}_{int} = -\frac{1}{4f}\phi_i F^{\mu\nu}\tilde{F}_{\mu\nu}$$

0902.1006: Green, D. Horn, B., Senatore, L., Silverstein, E.
1109.0022: Cook, J., Sorbo, L.
1206.6117: Barnaby, N., Moxon, J., Namba, Ryo., Peloso, Marco., Shiu, G., Zhou, Peng.
1307.7077: Cook, J. , Sorbo, L.
1412.0665: Mirbabayi, M. Senatore, L. Silverstein, E. Zaldarriaga, M.

$$\mathcal{L}_{int}^{(1)} = -g^2(\varphi - \varphi_0)^2\chi^2$$



$$\chi'' + \omega^2(\tau)\chi = 0$$

$$\langle\chi\rangle \neq 0 \longrightarrow \frac{\omega'}{\omega^2} \sim \frac{m'_{eff}}{m^2_{eff}} \gtrsim \mathcal{O}(1) \longrightarrow m^2_{eff}(\tau) = g^2(\varphi - \varphi_0)^2$$

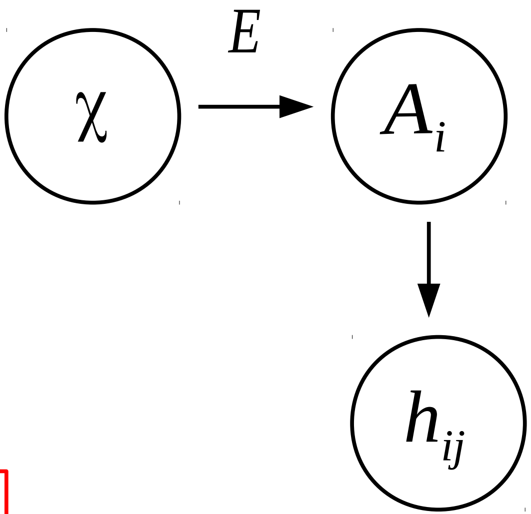
$$\bar{h}''_{ij} + \left(k^2 - \frac{a''}{a}\right)\bar{h}_{ij} = \frac{2}{m_p^2}\, a\, T^{TT}_{ij} \longleftarrow T_{ij} = \partial_i\chi\partial_j\chi + \delta_{ij}(\ldots)$$

$$\langle hh\rangle \sim \frac{n_\chi}{H^3}\left(\frac{H}{m_p}\right)^2\left(\frac{H}{m_p}\right)^2 \times \text{ Red Shifting}$$ ← Signal estimate

Some facts:

- **Red Shifting factor : Max signal when** $k\tau_* \simeq 1$
- **Multiple production events,** N_{events} **for scale invariance** $\mathcal{L}_{int}^{(1)} = \sum_i -g_i^2(\varphi - \varphi_i)^2\chi^2$
- **NG associated with** $\mathcal{L}_{int}^{(1)}$ **is of equilateral type** → $f_{\rm NL}^{\rm equil}$

$$\mathcal{L}_{int}^{(2)} = -\frac{1}{4f}\chi F^{\mu\nu}\tilde{F}_{\mu\nu}$$



$$A_\pm'' + \omega^2(\tau)A_\pm = 0 \qquad \omega^2(\tau) = k^2 \mp m^2(\tau, k)$$

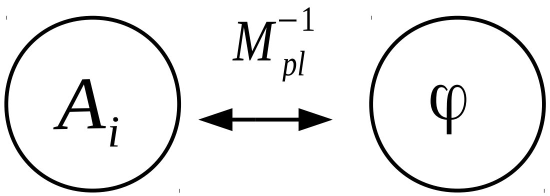
$$\bar{h}_{ij}'' + \left(k^2 - \frac{a''}{a}\right)\bar{h}_{ij} = \frac{2}{m_p^2}\, a\, T_{ij}^{TT} \quad \leftarrow \quad T_{ij} = \dot{A}_i\dot{A}_j + (\dots)$$

$$\langle hh\rangle \sim \left(\frac{H}{m_p}\right)^2\left(\frac{H}{m_p}\right)^2\frac{e^{4\pi\xi}}{\xi^6}$$

← Signal estimate

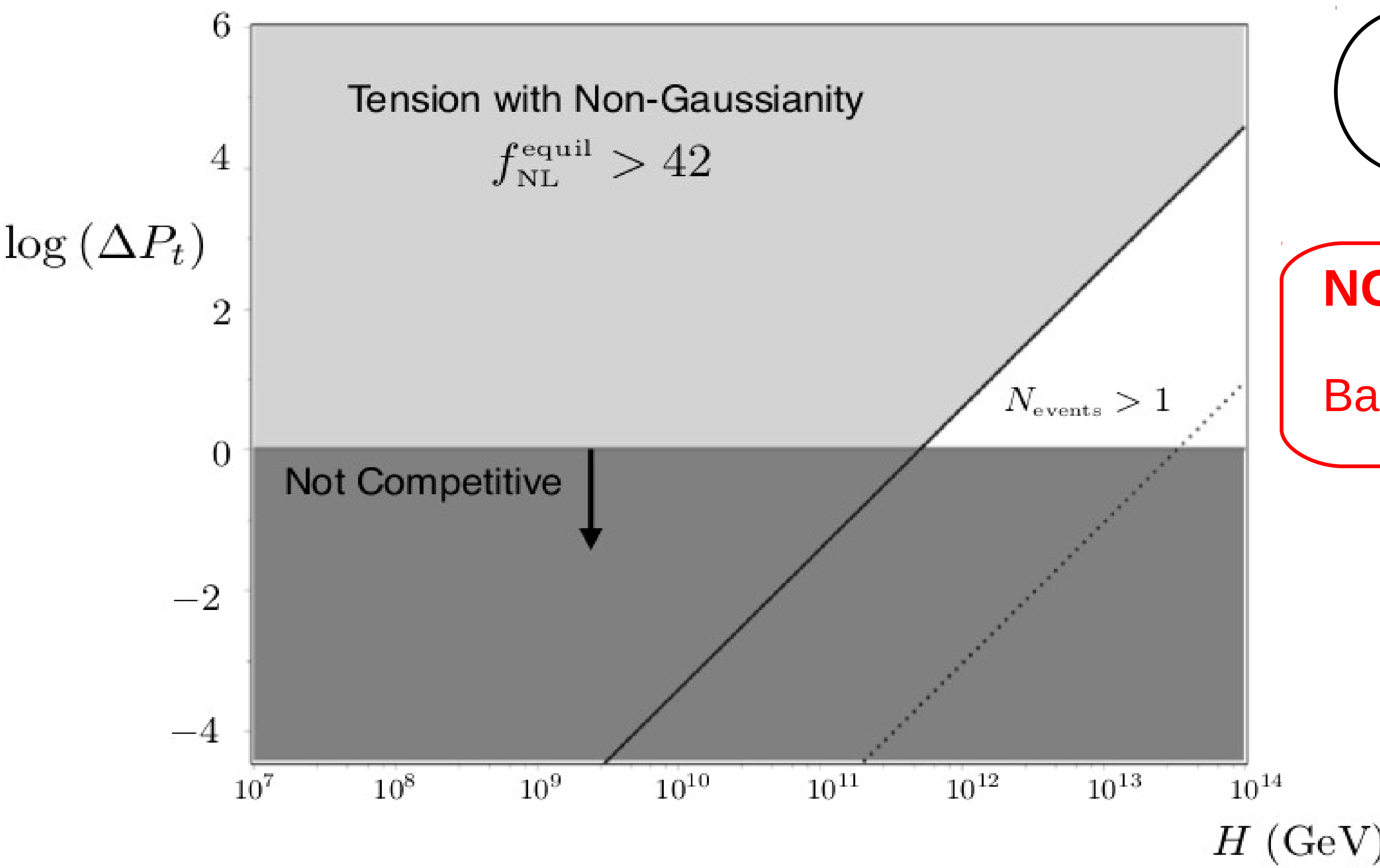
Some facts:

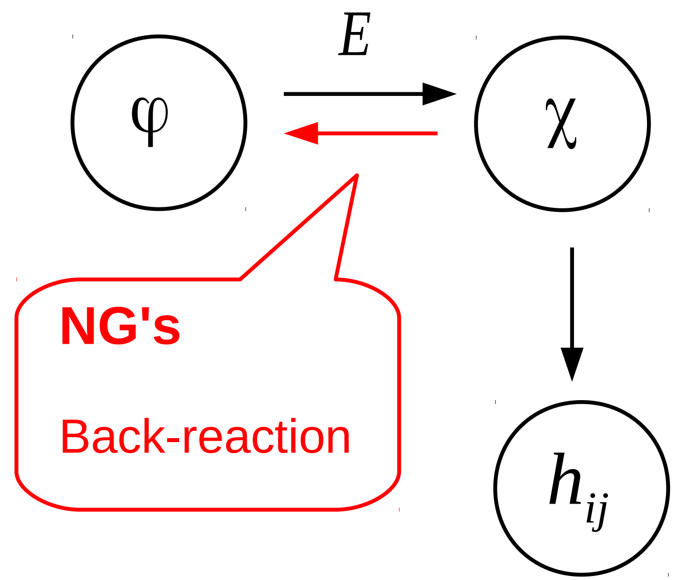
- **NG associated with** $\mathcal{L}_{int}^{(2)}$ **is LESS emphasized as**



- **Back-reaction constraints :** $\dot{\chi}^2 \ll \dot{\varphi}^2$ $\quad \dot{\chi}^2 \gg \langle \vec{E}^2 + \vec{B}^2\rangle$

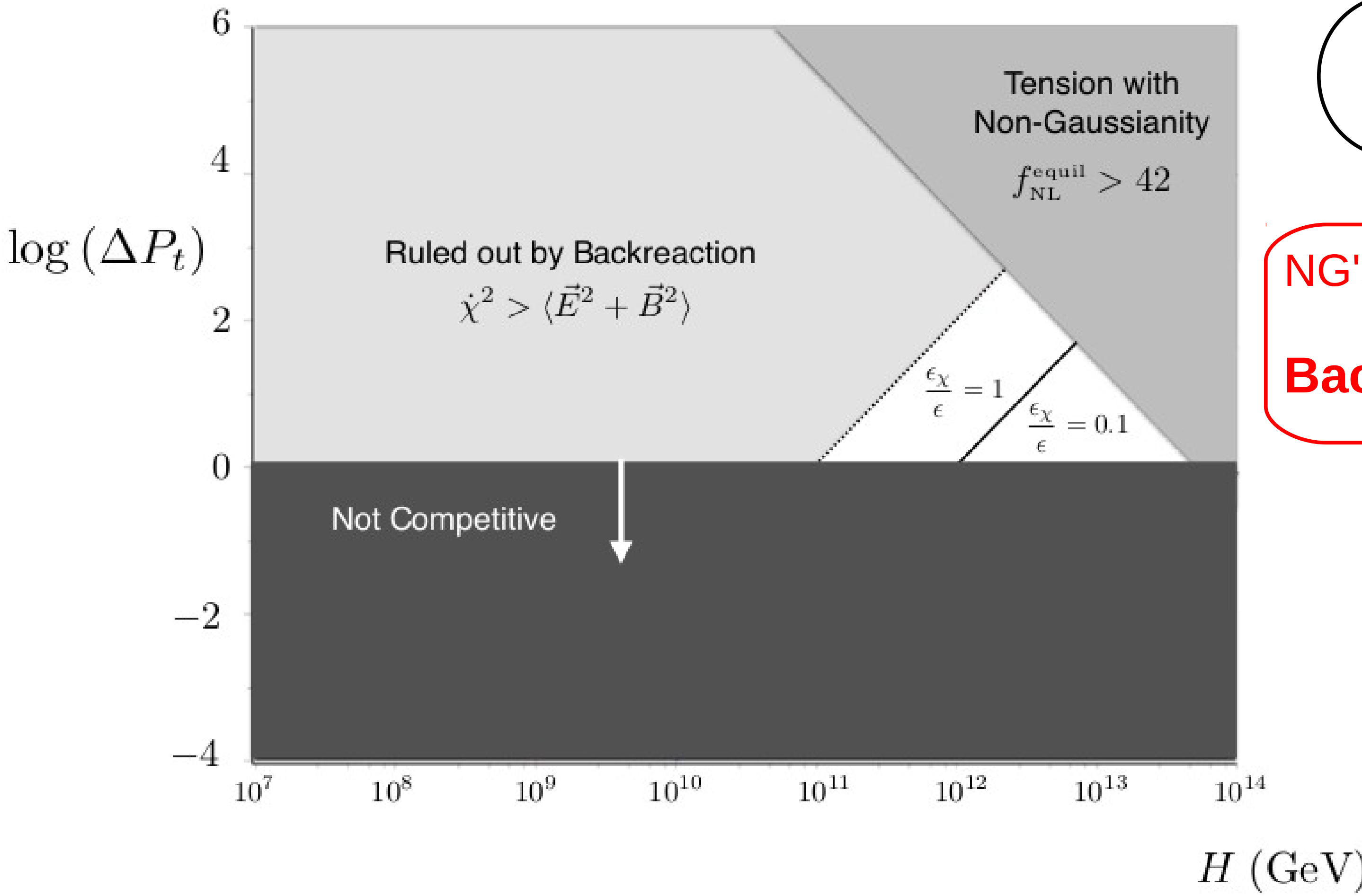
Excess Power in Tensors & Constraints

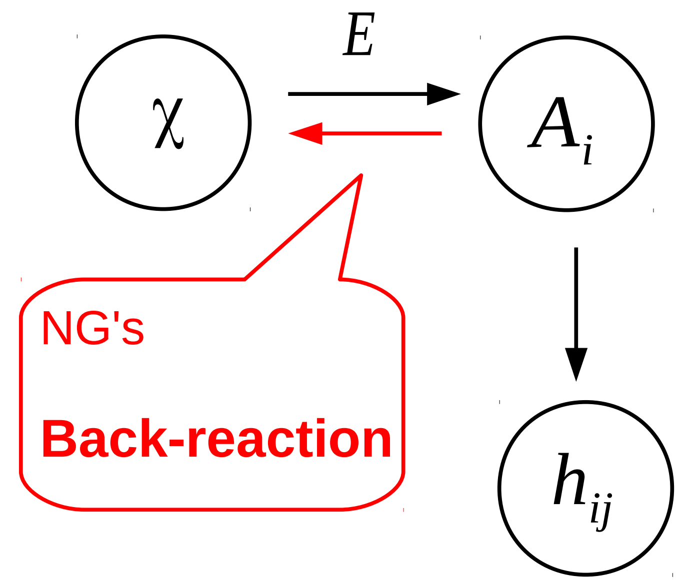




$$\mathcal{L}_{int}^{(1)} = \sum_i -g_i^2(\varphi - \varphi_i)^2\chi^2 \longrightarrow N_{events}$$

Excess Power in Tensors & Constraints





$$\mathcal{L}_{int}^{(2)} = -\frac{1}{4f}\chi F^{\mu\nu}\tilde{F}_{\mu\nu}$$

Conclusions

- **Answer regarding the question in beginning of this talk :**

  Even though there can be competitive sources to the vacuum fluctuations for the origin of primordial B-modes, it is challenging to separate the scale of inflation from that implied by CMB polarization measurements.

See also [arXiv:1410.0016] for UV completion in the context of String Theory flux compactifications with Axion Monodromy.

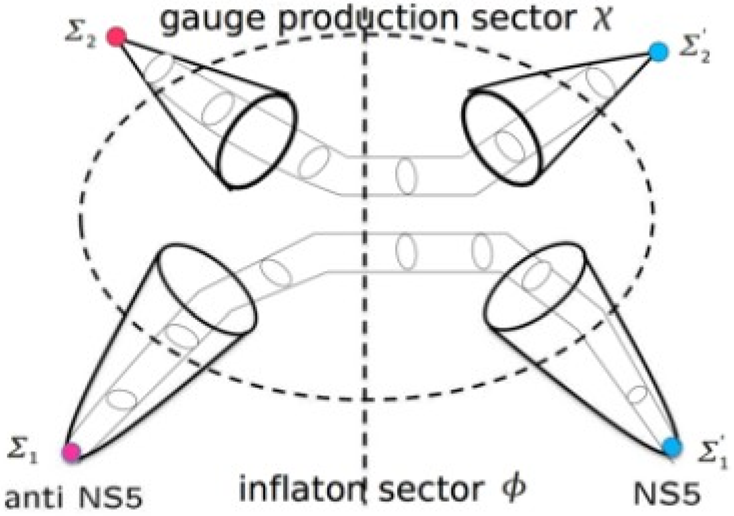
THANK YOU !

Cheat Sheet

UV Completion

A 5-brane carrying world volume flux generates the appropriate term

$$\mu_1 \int_{\Sigma_2} C_2 \wedge F \wedge F$$



$$\mathcal{L}_{hidden} = -\frac{1}{2}(\partial\chi)^2 - U(\chi) - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{\chi}{4f}F_{\mu\nu}\tilde{F}^{\mu\nu}$$