Detecting parity violation from axion inflation with third generation detectors

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Parity Violation in the SGWB

- A stochastic gravitational wave background (SGWB) created from the overlap of gravitational wave (GW) sources.
- Some sources are expected to have uneven circular polarisations, called a Parity Violation (PV). Can be quantified with polarisation parameter $|\Pi| \leq 1$, where $\Pi = 0$ is an unpolarised spectrum and $\Pi > 0$ is right polarised.
- Such parity violating sources are expected to come from cosmologically sourced GWs – namely those coming from Axion Inflation.
- We anticipate to detect such GWs with the upcoming 3rd generation (3g) detectors, Einstein Telescope (ET) and Cosmic Explorer (CE).

<u>How well can we detect PV in the SGWB using 3g detectors?</u>

Axion Inflation

- A pseudoscalar inflaton field ϕ coupled to U(1) gauge fields can generate potentially detectable GWs.

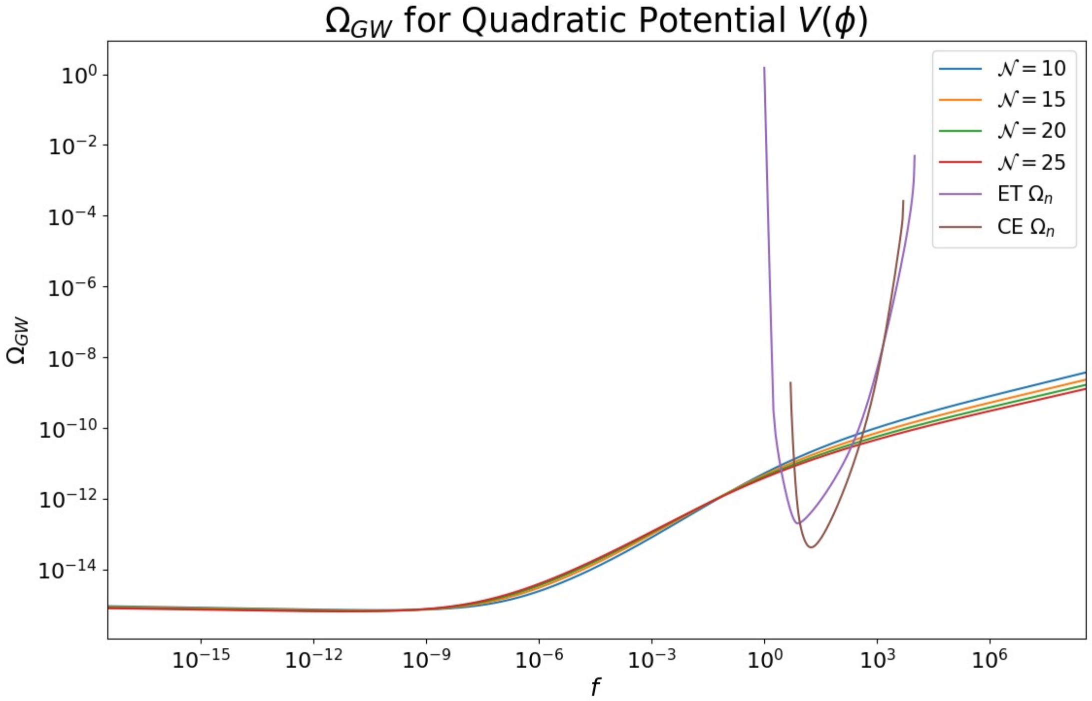
- Can be characterized primarily with $\xi(N_{CMB}) = \xi_{CMB} \equiv \alpha\left|\dot{\phi}\right|/2\Lambda H$, total e-folds N_{CMB}, and a choice scalar potential $V(\phi)$.

- However, we are constrained by an upper bound on scalar perturbation $\Delta_s^2(f)$ from the non-observation of primordial black holes. We can evade this by considering more than one gauge field coupling ($\mathcal{N} > 1$).

- GW energy density $\Omega_{GW}(f)$ spectra for quadratic potential $V(\phi) \sim \phi^2,\ N_{CMB} = 60,\ \xi_{CMB} = 2.5$ for $\mathcal{N} > 1$ gauge fields can be seen on right.

- These GWs are expected to be almost entirely right-handed over 3g network frequency range ($5\ \mathrm{Hz} \leq f \leq 5000\ \mathrm{Hz}$), giving approximately constant $\Pi(f) \simeq 1$.

$$\mathcal{L} = -\frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{4}F^a_{\mu\nu}F_a^{\mu\nu} - V(\phi) - \frac{\alpha^a}{4\Lambda}\phi F^a_{\mu\nu}\tilde{F_a^{\mu\nu}}$$

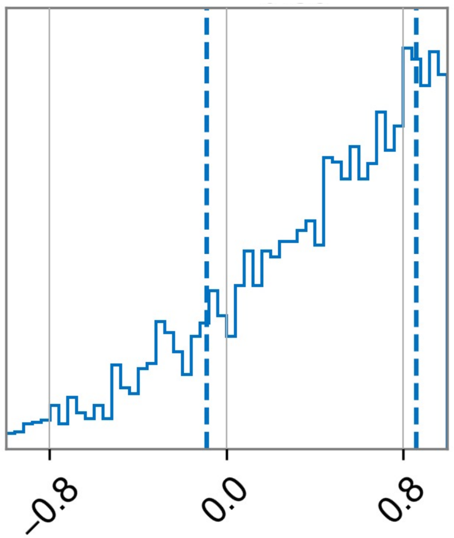


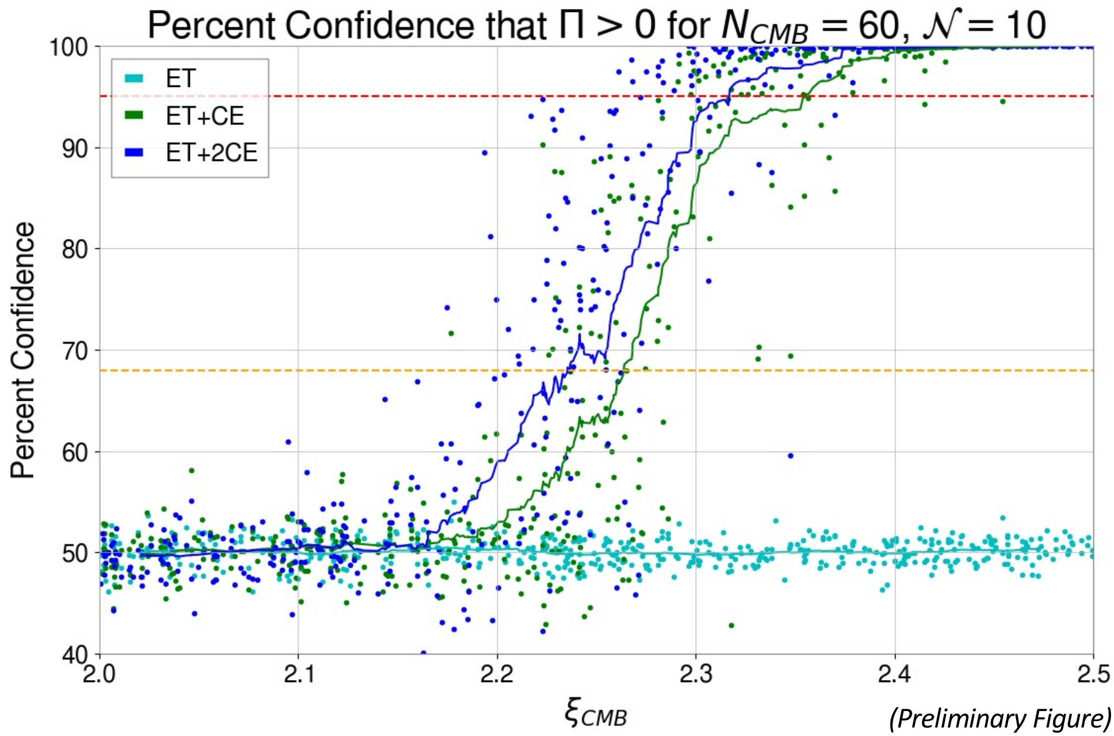
(Preliminary Figure)

Constraining PV in 3g detectors

- Assuming a quadratic model, parameter estimations are conducted on injected GW signals to understand how well we can detect PV.
- Different 3g detector networks were explored – we used ET alone, ET + CE, and ET + 2CE.
- Resulting estimations of Π can show a preference for positive values – so we base our results on percent of Π posterior distribution is greater than 0.
- Clear that additional detectors in network and increasing magnitude of ξ_{CMB} improve our ability to detect a parity violation

Π Posterior distribution for $\xi_{CMB} = 2.24$





(Preliminary Figure)

Conclusions

- Assuming an axion inflation quadratic scalar potential, we were able to find models that stay under $\Delta_s^2(f)$ constraint that may be detectable in upcoming 3g networks.

- 3g detectors are promising in detecting GWs sourced from such quadratic models.

- Our ability to detect a parity violating GW strongly depends on the 3g network of choice and parameter ξ_{CMB}. A multi-detector network is critical in detecting a parity violation in the SGWB.

- Our model assumed $N_{CMB} = 60$. Smaller assumed values of N_{CMB} would yield stronger GW signals, so our results are conservative in understanding PV detection outlook.

Thank you! Questions?

Spare slides – Methods

- To parameter estimate, use a hybrid frequentist-Bayesian approach using Gaussian log-likelihood:

$$\log p(\hat{C}(f)|\boldsymbol{\theta}) \propto \sum_{d_1 d_2} \sum_f \frac{\left[\hat{C}_{d_1 d_2}(f) - \Omega'_{\mathrm{GW}}(f,\boldsymbol{\theta})\right]^2}{\sigma^2_{d_1 d_2}(f)}$$

where

$$\Omega'_{\mathrm{GW}}(f) = \Omega_{\mathrm{GW}}(f)\left[1 + \Pi(f)\frac{\gamma_V^{d_1 d_2}(f)}{\gamma_I^{d_1 d_2}(f)}\right]$$

$$\gamma_I^{d_1 d_2}(f) = \frac{5}{8\pi}\int d\hat{\Omega}(F_{d_1}^{+} F_{d_2}^{+*} + F_{d_1}^{\times} F_{d_2}^{\times *})e^{2\pi i f \hat{\Omega}\cdot\Delta\vec{x}},$$

$$\gamma_V^{d_1 d_2}(f) = -\frac{5}{8\pi}\int d\hat{\Omega}(F_{d_1}^{+} F_{d_2}^{\times *} - F_{d_1}^{\times} F_{d_2}^{+*})e^{2\pi i f \hat{\Omega}\cdot\Delta\bar{x}}$$

for detectors d_1, d_2 and model parameters $\boldsymbol{\theta}$.

Spare slides – Axion Inflation Spectra

- From initial conditions ξ_{CMB}, N_{CMB}, can numerically calculate evolution of ϕ and ξ over frequency f using

$$-\phi_{,N} + M_{\rm Pl}^2 \frac{V_{,\phi}}{V} = \mathcal{N} \times \frac{2.4}{9M_{\rm Pl}^2} \times 10^{-4} \left(\frac{\alpha}{\Lambda}\right) \frac{V}{\xi^4} e^{2\pi\xi}$$

With these two sets of evolutions, can then compute $\Omega_{GW}(f)$ and $\Delta_s^2(f)$ spectra:

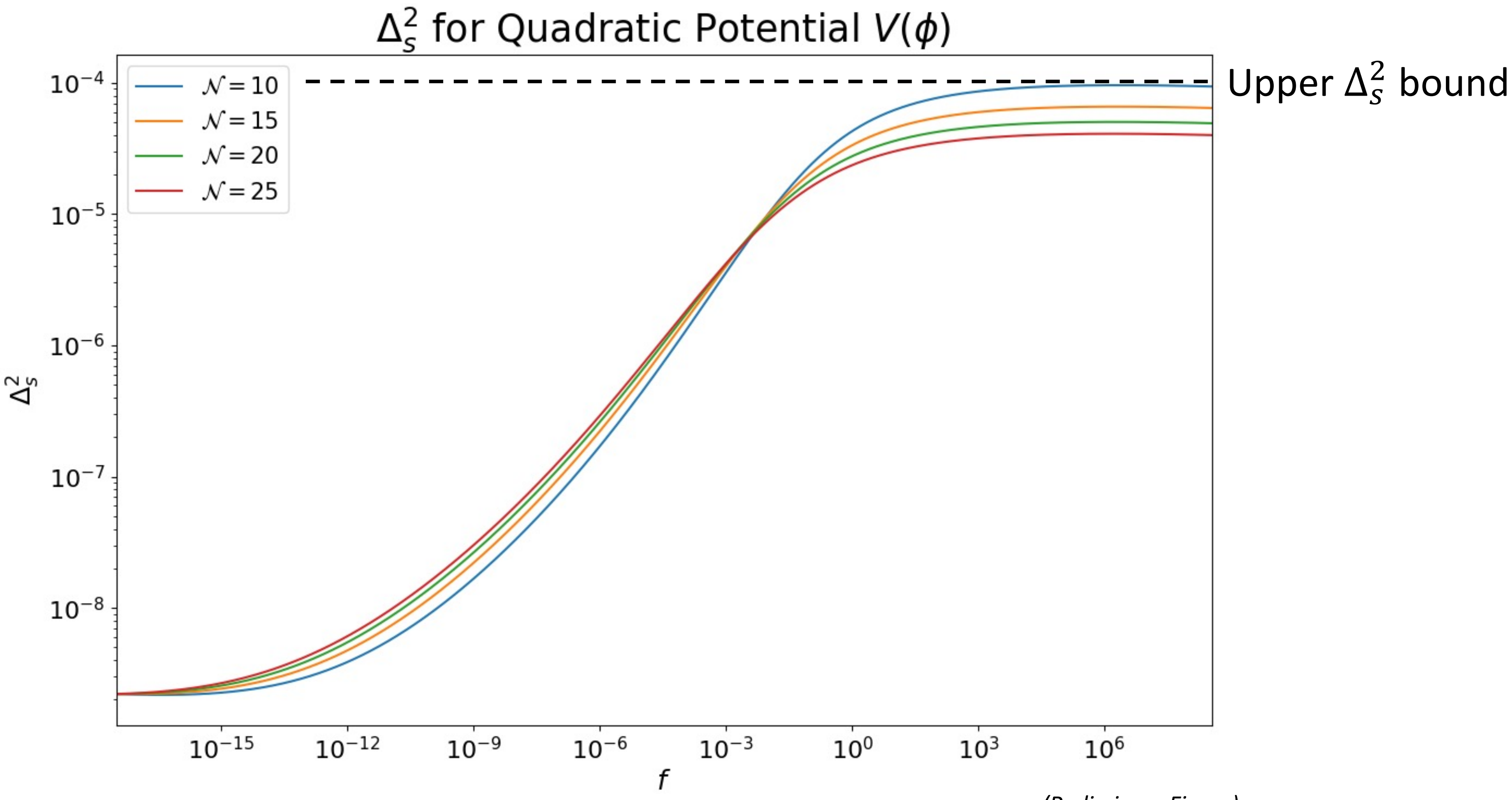
$$\Omega_{\rm GW} \simeq \frac{1}{12} \Omega_{R,0} \left(\frac{V}{3\pi^2 M_{\rm Pl}^4}\right) \left(1 + 4.3 \times 10^{-7} \mathcal{N} \frac{V}{3M_{\rm Pl}^4 \xi^6} e^{4\pi\xi}\right)$$

$$\Delta_s^2(k) = \Delta_s^2(k)_{\rm vac} + \Delta_s^2(k)_{\rm gauge} = \left(\frac{H^2}{2\pi|\dot{\phi}|}\right)^2 + \left(\frac{\alpha\langle \vec{E}\vec{B}\rangle/\sqrt{\mathcal{N}}}{3\Lambda\beta H\dot{\phi}}\right)^2$$ where $$\beta \equiv 1 - 2\pi\xi \frac{\alpha\langle \vec{E}\vec{B}\rangle}{\Lambda 3H\dot{\phi}}$$ and $$-\langle \vec{E}\vec{B}\rangle \simeq \mathcal{N} \cdot 2.4 \cdot 10^{-4} \frac{H^4}{\xi^4} e^{2\pi\xi}$$

and $\Omega_{R,0} = 8.6{\times}10^{-5}$ and M_{Pl} is the Planck mass (we set this to unity). For quadratic potential $V(\phi) \sim \phi^2$, we can calculate coupling constant $\frac{\alpha}{\Lambda} = 2\frac{\xi_{CMB}}{M_{Pl}}\sqrt{N_{CMB}}$. In addition, the parity violation parameter for the quadratic potential $V(\phi) = \lambda\phi^2$ can be written as:

$$\Pi \simeq \frac{4.3 \times 10^{-7} \frac{\lambda\phi^2}{3M_{\rm Pl}^4} \frac{e^{4\pi\xi}}{\xi^6}}{1 + 4.3 \times 10^{-7} \frac{\lambda\phi^2}{3M_{\rm Pl}^4} \frac{e^{4\pi\xi}}{\xi^6}}$$

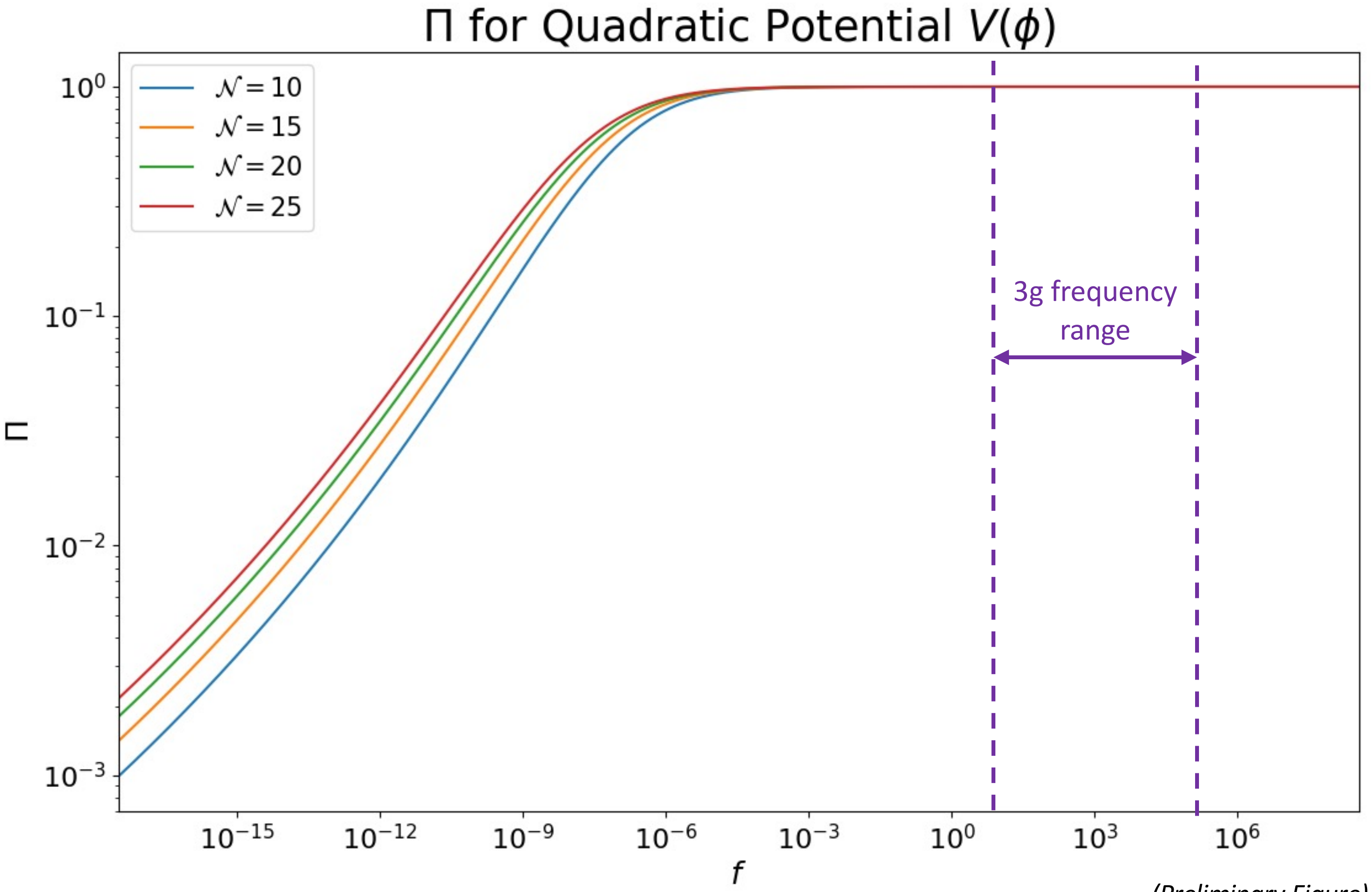
Spare slides – Axion Inflation Spectra



(Preliminary Figure)

$\Delta_s^2(f)$ for quadratic potential $V(\phi) \sim \phi^2$, $N_{CMB} = 60$, $\xi_{CMB} = 2.5$ for $\mathcal{N} > 1$ gauge fields. Note all spectra remain under upper bound

Spare slides – Parity Violation



(Preliminary Figure)

$\Pi(f)$ for quadratic potential $V(\phi) \sim \phi^2$, $N_{CMB} = 60$, $\xi_{CMB} = 2.5$ for $\mathcal{N} > 1$ gauge fields. Note all spectra are approximately equal to 1 in the 3g detector frequency range.