Gravitational Waves
Plenary Introduction

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CMB-S4 Collaboration Meeting, August 11, 2021
Primordial gravitational waves

Science goals for CMB-S4

- detect gravitational waves provided \( r > 3 \times 10^{-3} \)

or

- provide an upper limit of \( r < 10^{-3} \) at 95% CL otherwise

This excludes all models of inflation that naturally explain the observed value of the spectral index and have a super-Planckian characteristic scale.
Primordial gravitational waves

Models of inflation that naturally explain the observed value of the scalar spectral index fall into two classes

Monomial models

\[ r(\mathcal{N}) = \frac{8p}{N} \]

with (during inflation) \( V(\phi) = \mu^{4-2p} \phi^{2p} \)

Plateau and hilltop models

\[ r(\mathcal{N}) = \frac{8p}{N} \left( \frac{\mathcal{N}_{\text{eq}}}{\mathcal{N}} \right)^p \]

with (during inflation) \( V(\phi) \approx V_0 \left[ 1 - \left( \frac{\phi}{\Lambda} \right)^{\frac{2p}{p-1}} \right] \)
Primordial gravitational waves

Monomial models are about to be excluded by current data.
Primordial gravitational waves

The plateau and hilltop models come with a characteristic scale over which the potential departs from a constant

The integration given by \( \mathcal{N}_{eq} = \frac{p}{4} \left( \frac{M}{M_P} \right)^2 \)
Primordial gravitational waves

In many models, $M \approx M_P$ because they have common origin.

CMB-S4 is designed to detect gravitational waves or exclude all models that naturally explain the observed value of the spectral index with $M \geq M_P$. 
Primordial gravitational waves

Effect of expansion on gravitational waves

$$\ddot{h}_{ij} + 3H \dot{h}_{ij} - \frac{1}{a^2} \nabla^2 h_{ij} = 0$$

After creation or horizon entry, the evolution is described by

$$h_k(t) \propto \frac{1}{a(t)} \exp \left[ -ik \int_t^{t_0} \frac{dt'}{a(t')} \right]$$

So

\[ h_k(t_{\text{today}}) \approx \frac{h_k^0 a_k}{a_{\text{today}}} \]

strain at creation  \quad \text{scale factor at creation}

\[ a_k H(a_k) \approx k \]
Primordial gravitational waves

Radiation domination

\[ H(a_k) \propto \frac{1}{a_k^2} \quad a_k \propto \frac{1}{k} \]

Matter domination

\[ H(a_k) \propto \frac{1}{a_k^{3/2}} \quad a_k \propto \frac{1}{k^2} \]

Given current CMB constraints, a scale-invariant gravitational wave background is far out of reach of current or planned interferometers.
Synergies

Given current CMB constraints, a scale-invariant gravitational wave background is far out of reach of current or planned interferometers.

The CMB is not sensitive to astrophysical sources of gravitational waves.

We might detect a primordial signal that is not dominated by vacuum fluctuations in the metric (e.g. source by a gauge field with a tachyonic instability).

In this case, the signal is expected to have different statistical properties, e.g. parity violating spectra, large non-Gaussianity.

If this is how nature works, there would be interesting synergies, and provided we are able to characterize the CMB signal well enough.
# Parallel session

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<th>Time</th>
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<tr>
<td>11:00</td>
<td>The quest for the SGWB with terrestrial detectors</td>
<td>Tania Regimbau</td>
<td>11:10 - 11:28</td>
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<td></td>
<td>LISA and GW cosmology across 29 decades in frequency</td>
<td>Robert Caldwell</td>
<td>11:29 - 11:47</td>
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<td>Beyond a measurement of the tensor-to-scalar ratio</td>
<td>Daan Meerburg</td>
<td>11:48 - 12:06</td>
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<td>12:00</td>
<td>Towards precision measurements of the primordial GW background spectrum: the role of CMB and direct GW detectors</td>
<td>Paolo Campeti</td>
<td>12:25 - 12:45</td>
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<td>Mid-Parallel Break</td>
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<td>Measuring non-standard tensors with a BK-like experiment</td>
<td>Prof. Clem Pryke</td>
<td>12:45 - 13:03</td>
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<td>13:00</td>
<td>Measuring the B-mode bispectrum from BICEP/Keck Array</td>
<td>Toshiya Namikawa</td>
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<td>Discussion</td>
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<td>13:21 - 14:00</td>
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Thank you