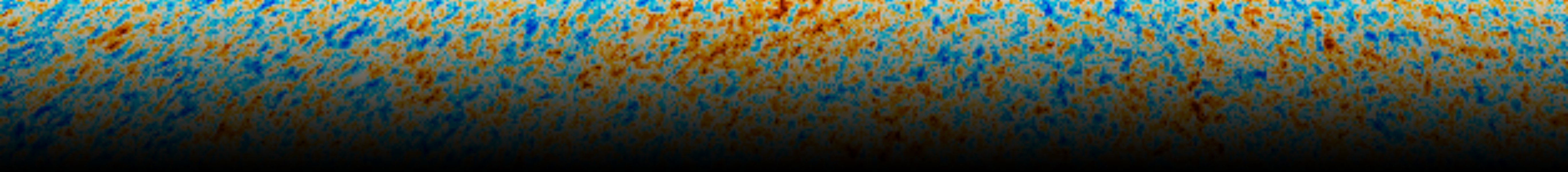


Gravitational Waves

Plenary Introduction

Raphael Flauger

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

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

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

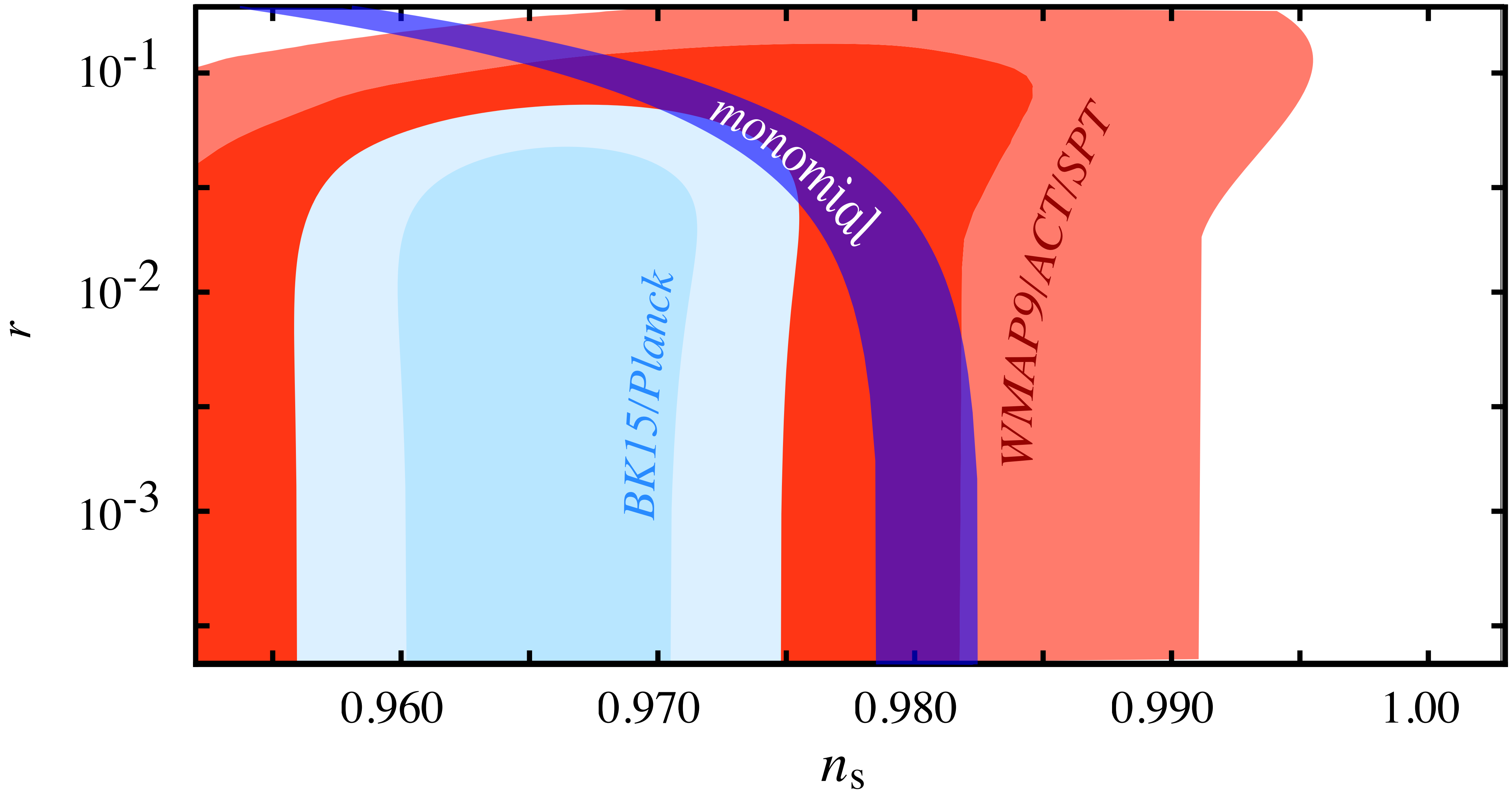
Plateau and hilltop models

$$r(\mathcal{N}) = \frac{8p}{\mathcal{N}}\left(\frac{\mathcal{N}_{\rm eq}}{\mathcal{N}}\right)^{p}$$

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

Primordial gravitational waves

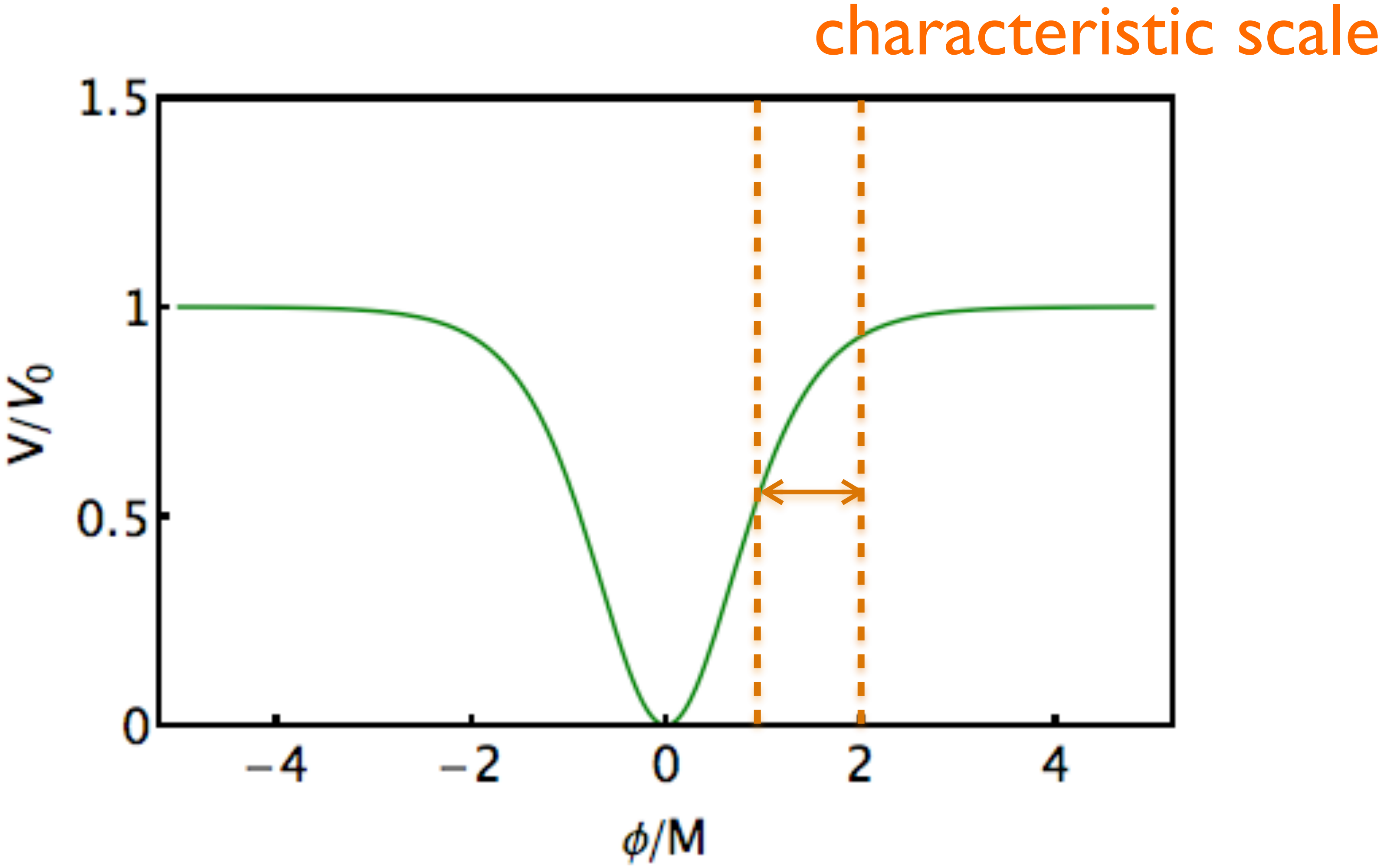
Monomial models



are about to be excluded by current data.

Primordial gravitational waves

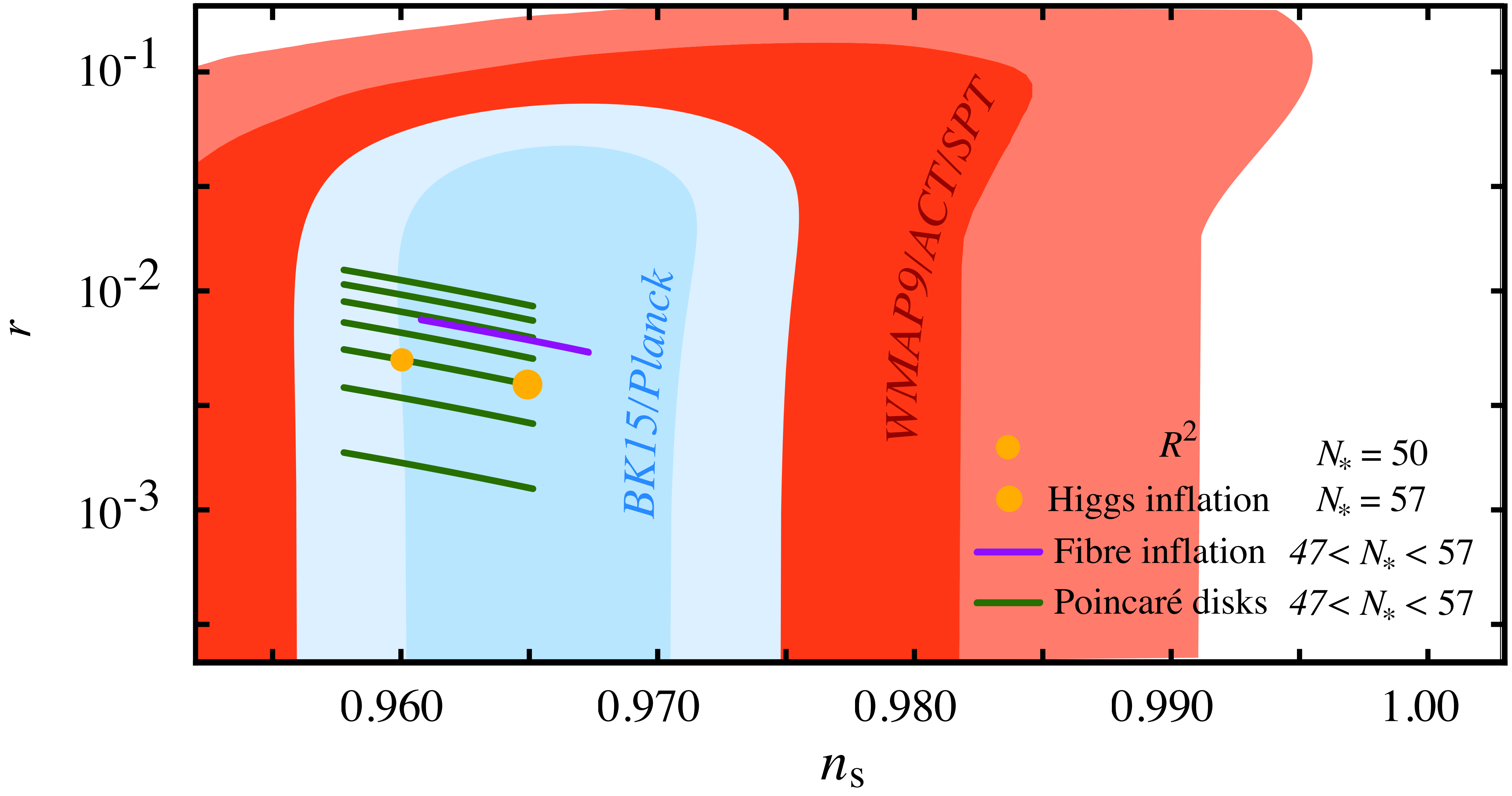
The plateau and hilltop models come with a characteristic scale over which the potential departs from a constant



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

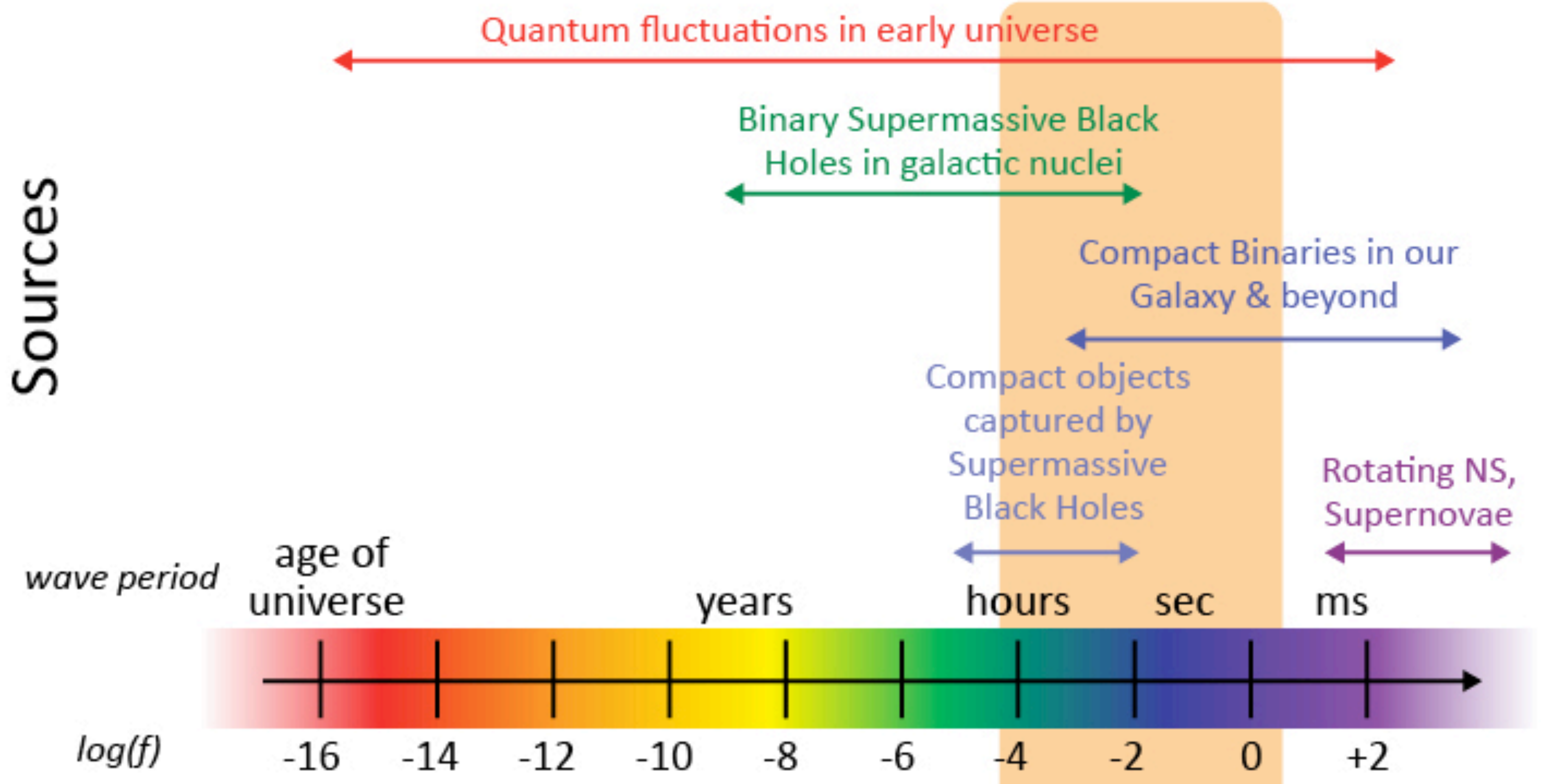
Primordial gravitational waves

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 $M \geq M_P$.

The Gravitational Wave Spectrum



Sources

Quantum fluctuations in early universe

Binary Supermassive Black Holes in galactic nuclei

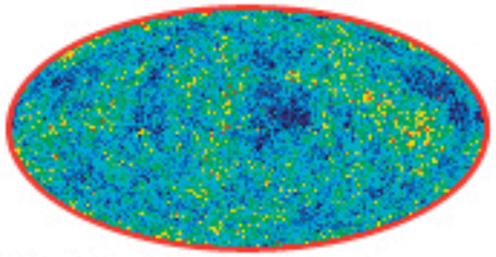
Compact Binaries in our Galaxy & beyond

Compact objects captured by Supermassive Black Holes

Rotating NS, Supernovae

Detectors

Cosmic Microwave Background Polarization

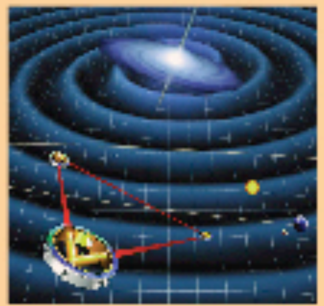


Credit: NASA / WMAP Science Team

Pulsar Timing

Credit: NRAO/AUI/NSF

Space Interferometers



Credit: NASA/ESA

Terrestrial Interferometers

Credit: LIGO Laboratory

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

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

So

strain at creation

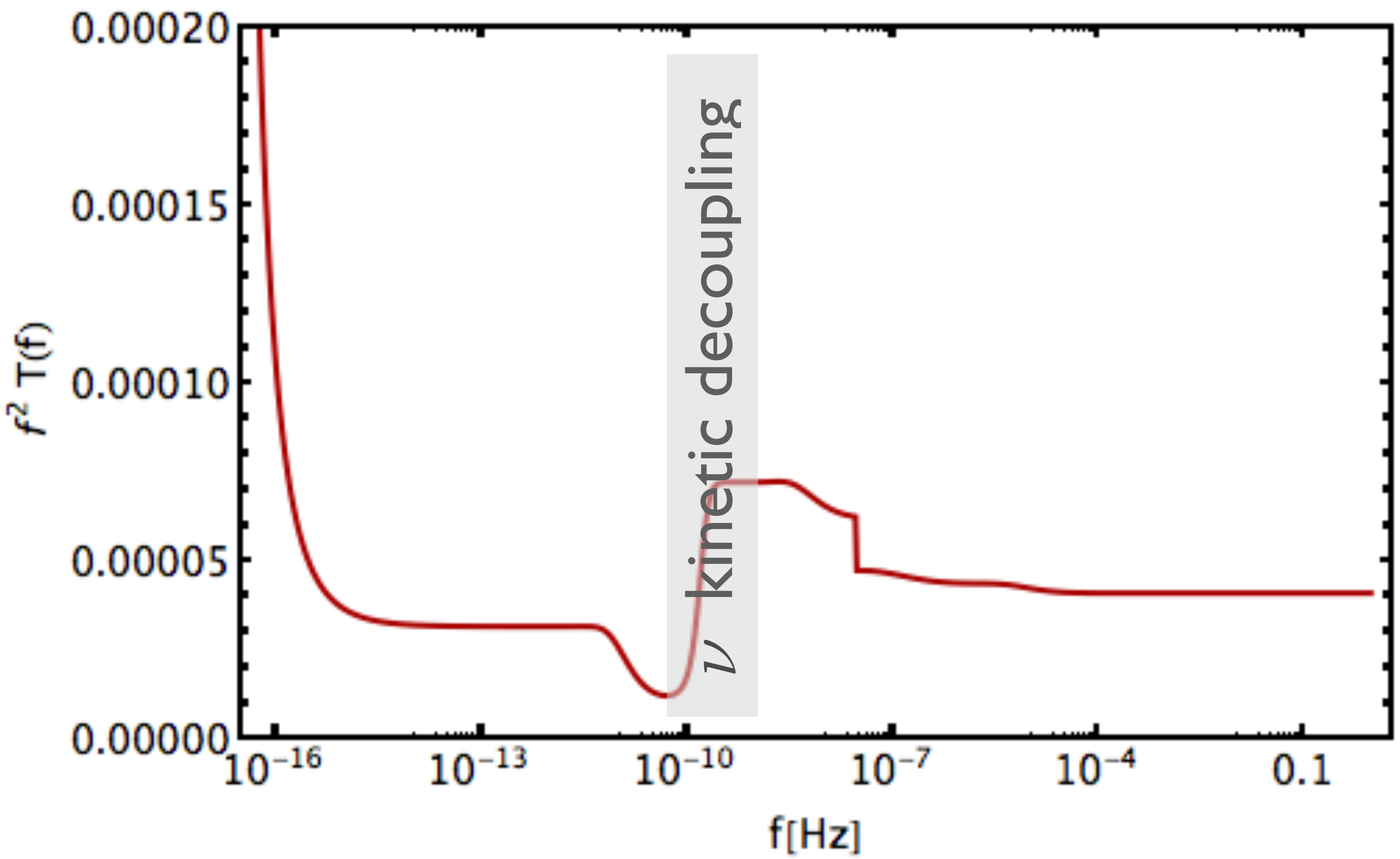
scale factor at creation

$$h_k(t_{\rm today}) \approx \frac{h_k^o a_k}{a_{\rm today}} \qquad a_k H(a_k) \approx k$$

Primordial gravitational waves

Radiation domination $H(a_k) \propto \frac{1}{a_k^2}$ $a_k \propto \frac{1}{k}$

Matter domination $H(a_k) \propto \frac{1}{a_k^{3/2}}$ $a_k \propto \frac{1}{k^2}$



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

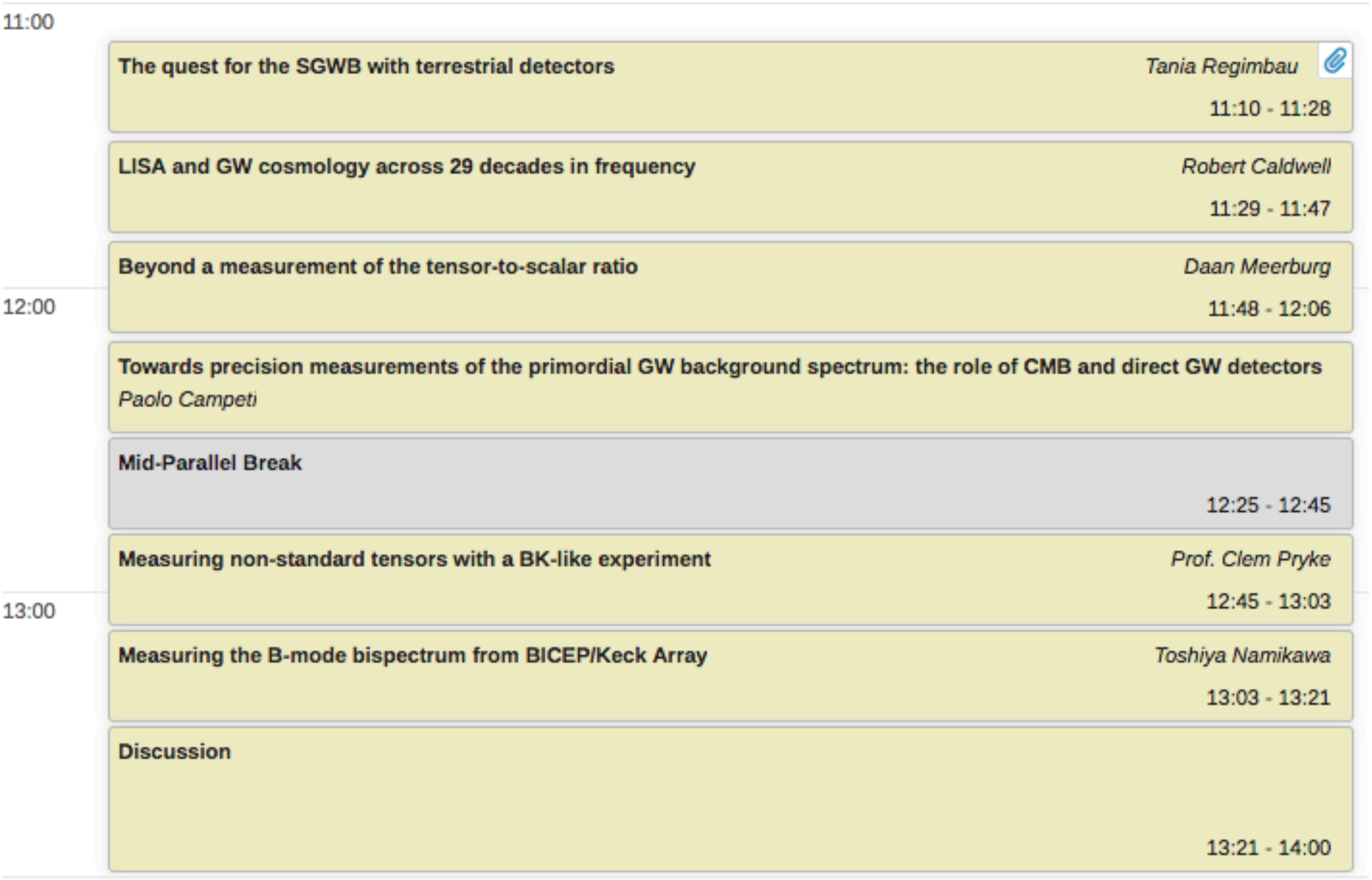
The CMB is not sensitive to astrophysical sources of gravitational waves

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



11:00

The quest for the SGWB with terrestrial detectors *Tania Regimbau* 11:10 - 11:28

LISA and GW cosmology across 29 decades in frequency *Robert Caldwell* 11:29 - 11:47

Beyond a measurement of the tensor-to-scalar ratio *Daan Meerburg* 11:48 - 12:06

12:00

Towards precision measurements of the primordial GW background spectrum: the role of CMB and direct GW detectors *Paolo Campeti*

Mid-Parallel Break 12:25 - 12:45

Measuring non-standard tensors with a BK-like experiment *Prof. Clem Pryke* 12:45 - 13:03

13:00

Measuring the B-mode bispectrum from BICEP/Keck Array *Toshiya Namikawa* 13:03 - 13:21

Discussion 13:21 - 14:00

Thank you