0.1 Gravitational Waves and Inflation

Measurements of the **CMB!** (**CMB!**) *BB* angular power spectrum are the only foreseeable way to detect inflationary gravitational waves. The strength of the signal, quantified by the tensor-to-scalar ratio r, is a direct measure of the expansion rate of the Universe during inflation, and together with the Friedmann equation, it reveals the energy scale of inflation. PICO will detect primordial gravitational waves at $5\,\sigma$ significance if inflation occurred at an energy scale of at least 5×10^{15} GeV, or equivalently $r = 5\times10^{-4}$. In a widely endorsed community white paper setting targets for measurements of inflationary gravitational waves in the next decade, **?**] quote two theoretically motivated r rejection targets: (1) $r < 0.01$, and (2) $r < 0.001$. The second threshold is motivated by the goal of rejecting all inflationary models that naturally explain the observed value of the spectral index n_s and having a characteristic scale in the potential that is larger than the Planck scale. Such models are shown in dashed lines in Figure **??**. They write "If these thresholds are passed without a detection, most textbook models of inflation will be ruled out; and ... the data would then force a significant change in our understanding of the primordial Universe." PICO is the only next-decade experiment with the raw sensitivity to reject both targets at high confidence; see Figure **??**.

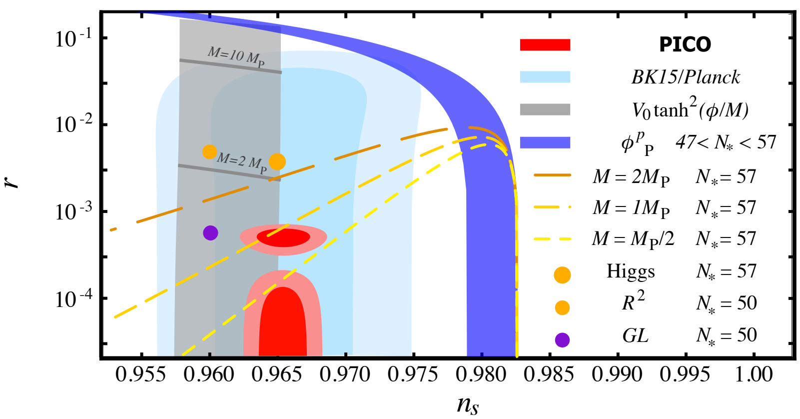

Figure 0.1: PICO will conclusively rule out all Inflation models for which the characteristic scale in the potential is M_p or higher, or will detect $r = 0.0005$ at $5\,\sigma$ (red 1 and $2\,\sigma$ limits and uncertainty ellipses). Current values of σ_r are a factor of 100 higher (cyan). The locus of classes of models and specific ones are shown with dots, solid, and dashed lines.

Uncertainty in the characterization of Galactic foregrounds already limits our ability to constrain r. These foregrounds are anticipated to be nearly 1000 times stronger than next-decade-targeted inflationary B-mode signals at low ℓ multipoles. 'Lensing' B-modes, created by gravitational lensing of E-modes, are an additional effective foreground for the higher multipoles. With sufficiently high resolution to remove at least 73% of the lensing effects, and 21 frequency bands to account for foregrounds, no other next-decade experiment is better equipped than PICO to overcome the challenges in robustly finding the faint inflationary signal, or in rejecting confusion due to foregrounds.

0.2 Fundamental Particles and Fields

• **Light Relics** The effective number of light relic particle species $N_{\rm eff}$ gives information about particle species that are predicted to have existed in the early Universe in extensions of the Standard Model. With three neutrino species $N_{\rm eff} = 3.046$. Additional light particles contribute a change $\Delta N_{\rm eff}$ that is a function only of the decoupling temperature of the additional species and the spin of the particle. PICO will provide a constraint $\Delta N_{\rm eff} < 0.06\,(95\%)$ and will either detect new particle species, or constrain the lowest temperature T_F at which any vector particle (spin 1) could have fallen out of equilibrium to a factor of 400 higher than today's constraint [**?**]. No next-decade experiment will provide a tighter constraint.

• **Neutrino Mass** The origin, structure, and values of the neutrino masses are among the outstanding questions about the nature of the Standard Model of particle physics. Cosmological measurements of $\sum m_\nu$ relate the amplitudes of the matter power spectrum and the primordial fluctuation power spectrum A_s. Both are limited by degeneracies with other parameters. PICO is the only instrument that will self consistently provide three of the four necessary ingredients [**? ?**]. In combination with ω_m coming from DESI and EUCLID data, PICO will give $\sigma(\sum m_\nu) = 14$ meV, giving a $4\,\sigma$ detection of the minimum sum of 58 meV. PICO will measure $\sum m_\nu$ in two additional ways, which will give equivalent constraints.

• **Dark Matter** **CMB!** experiments are effective in constraining dark matter candidates in the lower mass range, which is not available for terrestrial direct detection experiments [**? ? ? ? ? ?**]. For a spin- and velocity-independent contact interaction between dark matter and protons PICO will improve upon *Planck*'s dark matter cross-section constraints by a factor of 25 over a broad range of candidate dark matter masses. If 2% of the total dark content is made of axions in the mass range $10^{-30} < m_a < 10^{-26}$, PICO will detect this species at between 7 and $13\,\sigma$. These constraints are stronger than other proposed next-decade CMB experiments [**?**].

• **Primordial Magnetic Fields (PMFs)** PICO will probe PMFs as weak as 0.1 nG ($1\,\sigma$). Detection of PMFs would be a major discovery because it would signal new physics beyond the Standard Model, discriminate among different theories of the early Universe, and help explain the puzzling $1-10\ \mu$G fields observed in galaxies. Or it could conclusively rule out a purely primordial (i.e., no-dynamo-driven) origin of the largest galactic magnetic fields [**? ? ? ? ? ? ? ? ? ? ?**].

• **Cosmic Birefringence** A number of well-motivated extensions of the Standard Model involve fields with parity-violating coupling [**? ? ? ? ? ?**]. Their presence may cause cosmic birefringence – a rotation of the polarization of an electromagnetic wave as it propagates across cosmological distances [**? ? ?**]. PICO's constraints on cosmic birefringence are more stringent than any other next-decade experiment [**?**].