

Clockwork at lepton colliders, beam dumps, supernovae, and neutron stars

- Clockwork mechanism generates hierarchical couplings and mass scales without introducing fine-tuning by utilizing asymmetric nearest-neighbor interactions. “Clockworking” fields with $s \neq 0$ requires a warped XD.
- Such models have some attractive properties from both theoretical and phenomenological aspects.
 - They i) can solve the EW hierarchy problem (Linear Dilaton), ii) have UV completion within string theory, and iii) possess distinctive signatures in both short-lived and long-lived lifetime regime - necessary combining searches employed to hunt flat LED (potentially related to the dark dimension) and the RS model.
- We found that future colliders like CLIC and FCC-ee will cover most of the natural region of the parameter space remaining for RS and LD.

Clockwork-inspired extra dimension with general warping

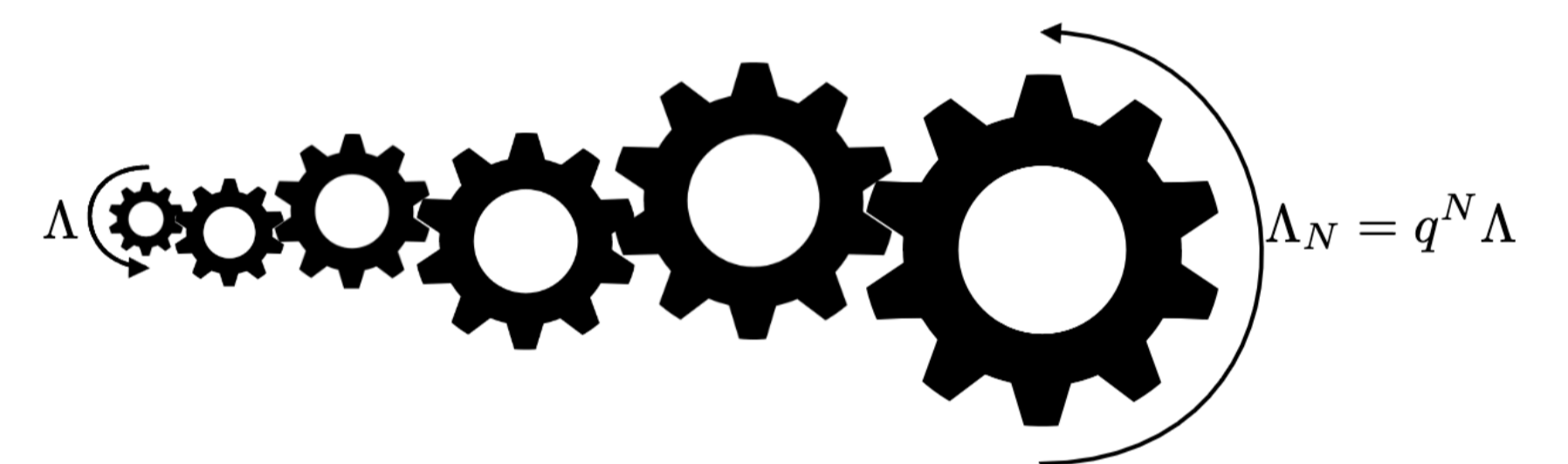
$$\int d^5x \sqrt{-g} \frac{1}{2} \partial_\alpha \pi \partial^\alpha \pi: \text{ field (spin } s) \text{ in the warped background } ds^2 = e^{2k_1 y} dx^2 + e^{2k_2 y} dy^2, \quad c^2 = \frac{k_2}{k_1}.$$

gravity + dilaton + cosmological constant on 5D orbifold $M_4 \times S^1/Z_2$

Complementary view: bulk and mass terms.

UV completions

- $c = 0$ (throats within IIB flux compactifications) Brummer, Hebecker, Trincherin 0510113
- $c = 1$ SUGRA Kehagias, Riotto 1710.04175, Antoniadis, Delgado, Markou, Pokorski 1710.05568
- $c \geq \sqrt{6}$ Heterotic M-theory S. H. Im, H. Nilles, M. Olechowski 1811.11838



Heterotic M-theory setup realizes Clockwork for $c \geq \sqrt{6} \gg 1$, which recovers LED and provides an UV completion of the Dark Dimension solving the cosmological constant problem inspired by swampland conjecture (the AdS/dS distance conjecture).

Clockwork can also solve the EW hierarchy problem with different stringy UV completion - the Linear Dilaton background ($c = 1$). Both regimes of clockwork include rich phenomenology: colliders, beam dumps, BBN, CMB, supernovae, neutron stars, etc.

Signatures

- Effective 4D description:

$$\mathcal{L}_{int} \supset \frac{1}{\Lambda_n} G^{\mu\nu} (T_{\mu\nu}^{\text{gauge}} + T_{\mu\nu}^{\text{matter}})$$

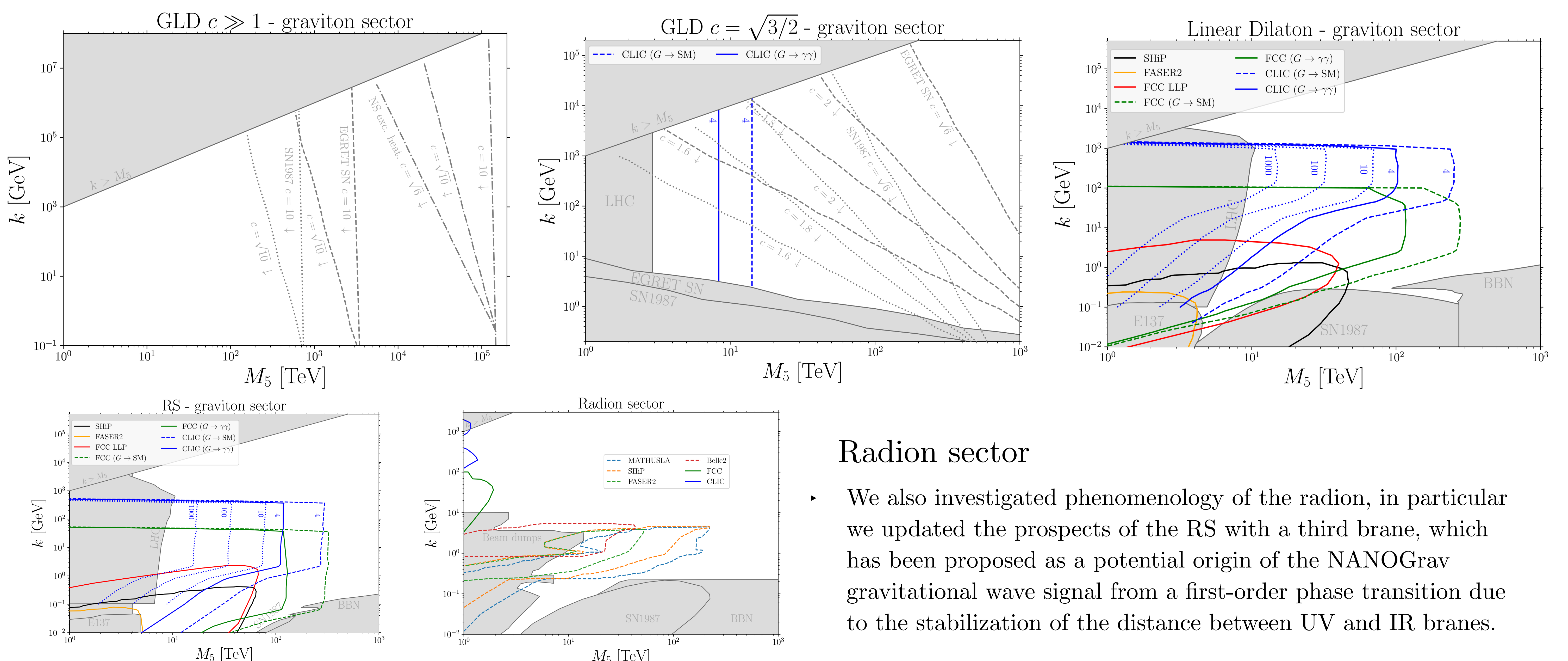
- Prompt and displaced KK gravitons decays

$$N = \mathcal{L} \times \sum \sigma_n \times \text{BR}(G_n \rightarrow \gamma\gamma),$$

- FCC-ee $\sigma(e^+e^- \rightarrow XG) = \int d\Omega \frac{d\sigma(e^+e^- \rightarrow GX)}{d\Omega} (1 - e^{-L_{\text{det}}/L_G^{\perp}(\theta)})$
- LHC $gg \rightarrow G$ Beam dumps: $\gamma + N \rightarrow G + N$

- Long-lived KK gravitons decays

- SN1987
- Neutron stars - monochromatic γ and basin bound



Radion sector

- We also investigated phenomenology of the radion, in particular we updated the prospects of the RS with a third brane, which has been proposed as a potential origin of the NANOGrav gravitational wave signal from a first-order phase transition due to the stabilization of the distance between UV and IR branes.