Title: CPT-Symmetric Universe

Speakers: Latham Boyle

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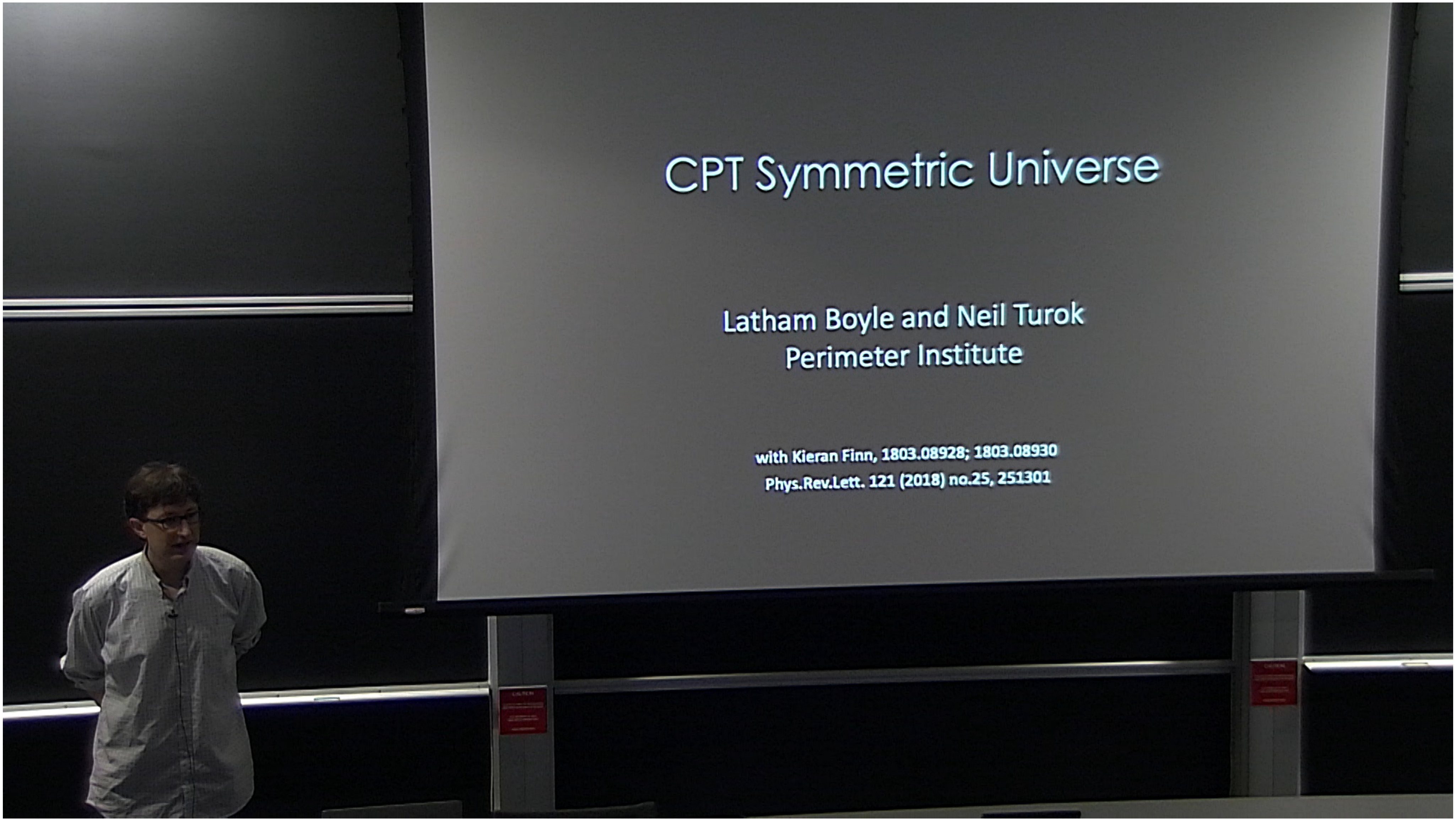
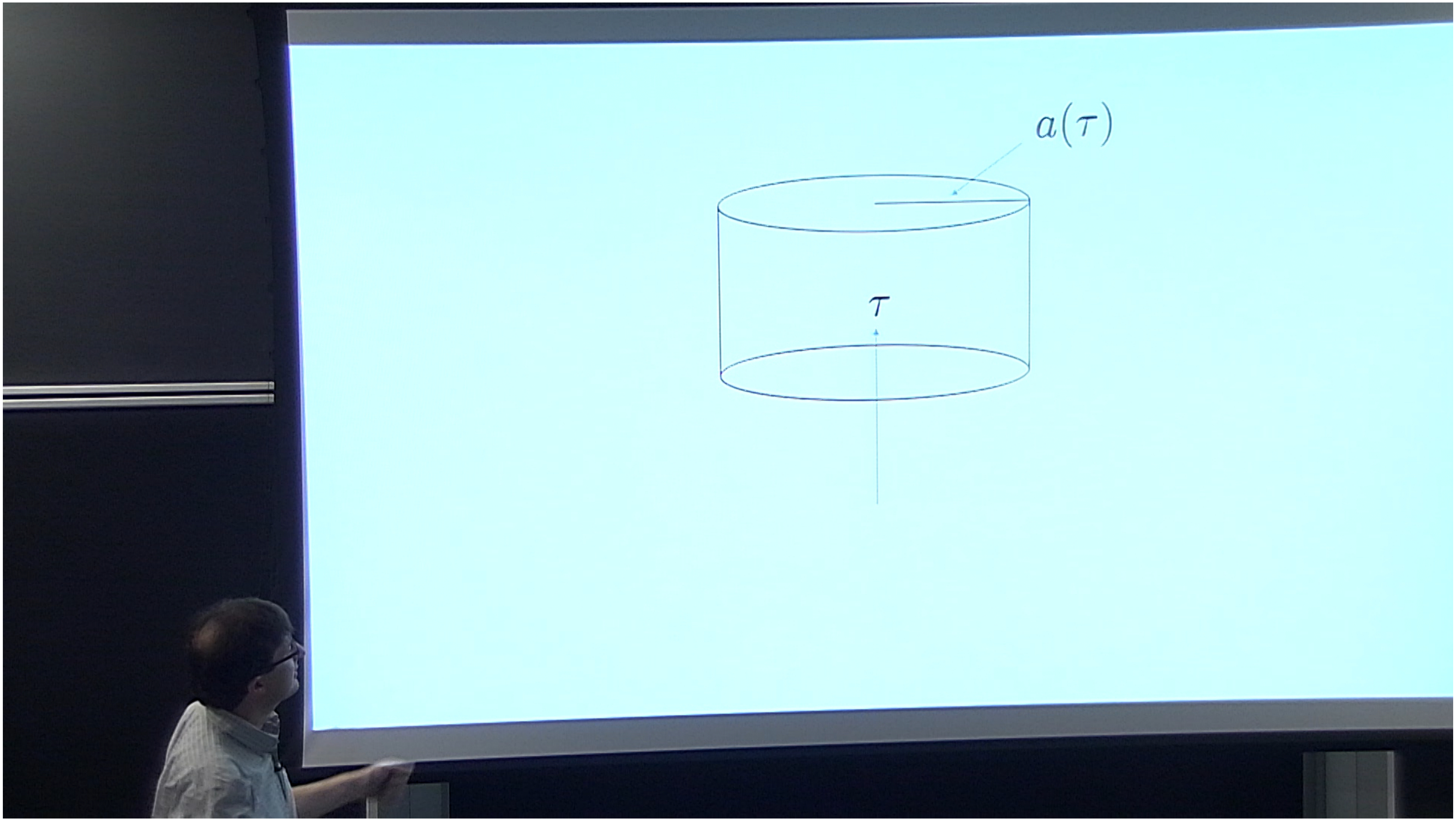
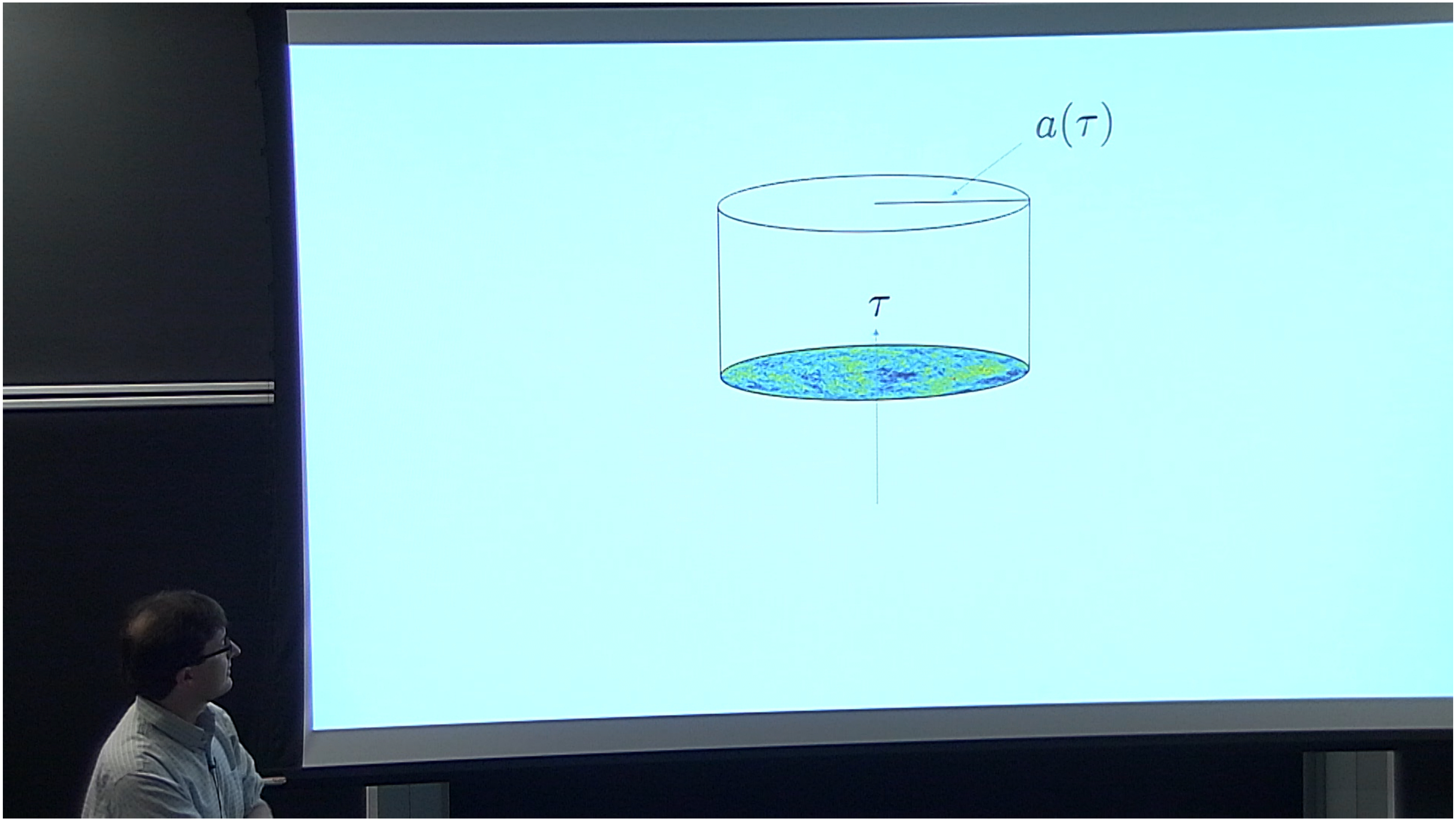
Abstract: I will introduce our recent proposal that the state of the universe does *not* spontaneously violate CPT. Instead, the universe after the big bang is the CPT image of the universe before it, both classically and quantum mechanically. The pre- and post-bang epochs comprise a universe/anti-universe pair, emerging from nothing directly into a hot, radiation-dominated era. CPT symmetry selects the QFT vacuum state on such a spacetime, providing a new interpretation of the cosmological baryon asymmetry, as well as a particularly economical explanation for the cosmological dark matter. Requiring only the standard three-generation model of particle physics (with right-handed neutrinos), a Z_2 symmetry suffices to render one of the right-handed neutrinos stable. We calculate its abundance from first principles: matching the observed dark matter density requires its mass to be 4.8 x 10^{8} GeV. Several other testable predictions immediately follow: e.g. (i) the lightest neutrino is massless; (ii) neutrinoless double beta decay occurs at a specific rate; and (iii) there are no primordial long-wavelength gravitational waves. The proposal also has interesting things to say about the strong CP problem, the observed electrodynamic arrow of time, cosmological boundary conditions, and the wave-function of the universe. (Based on arXiv:1803.08928, arXiv:1803.08930, and forthcoming work.)


CPT Symmetric Universe
Latham Boyle and Neil Turok
Perimeter Institute
with Kieran Finn, 1803.08928; 1803.08930
Phys.Rev.Lett. 121 (2018) no.25, 251301


$a(\tau)$
τ



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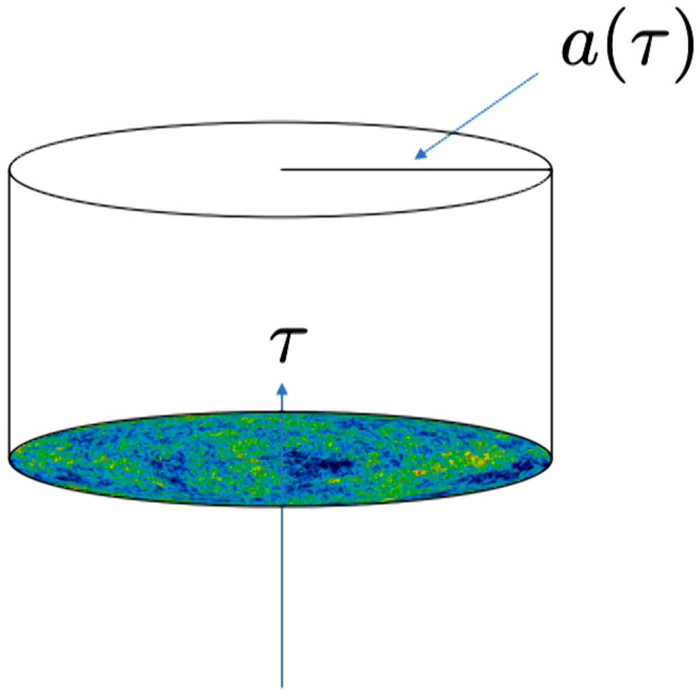
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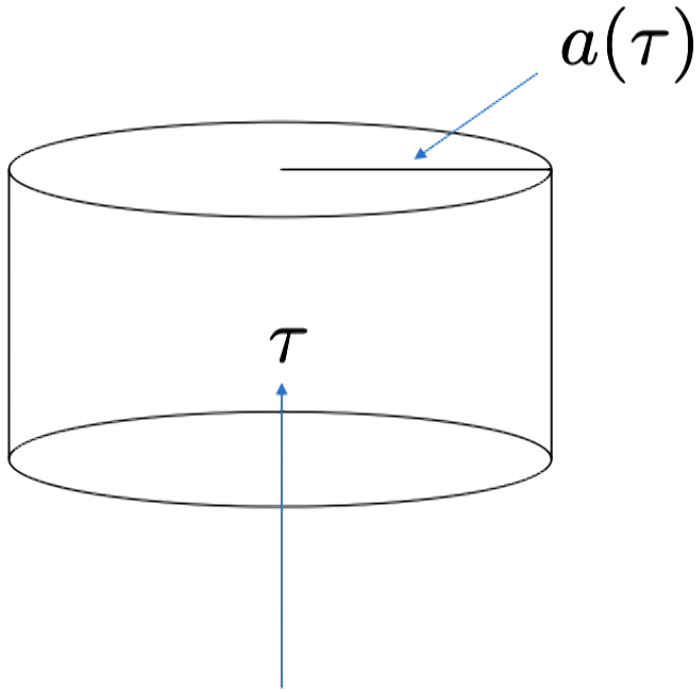

$$g_{\mu\nu} = a^2(\tau)\eta_{\mu\nu}$$

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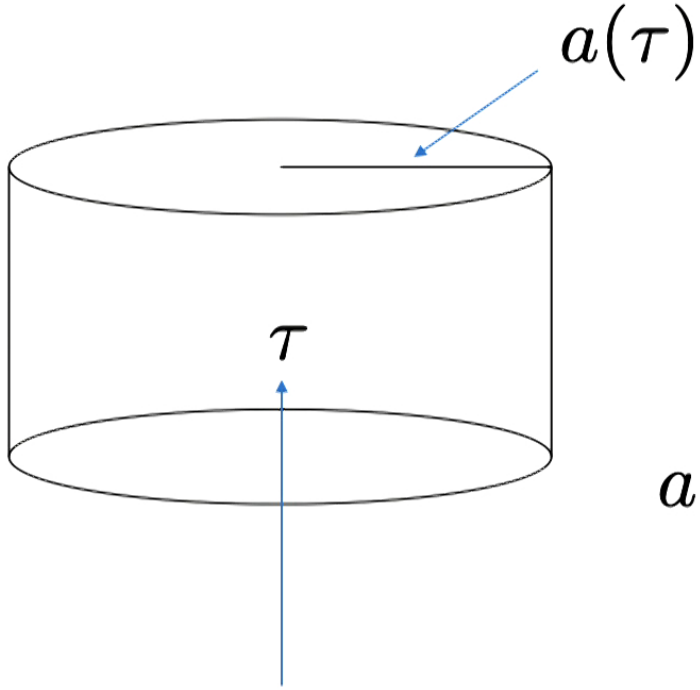

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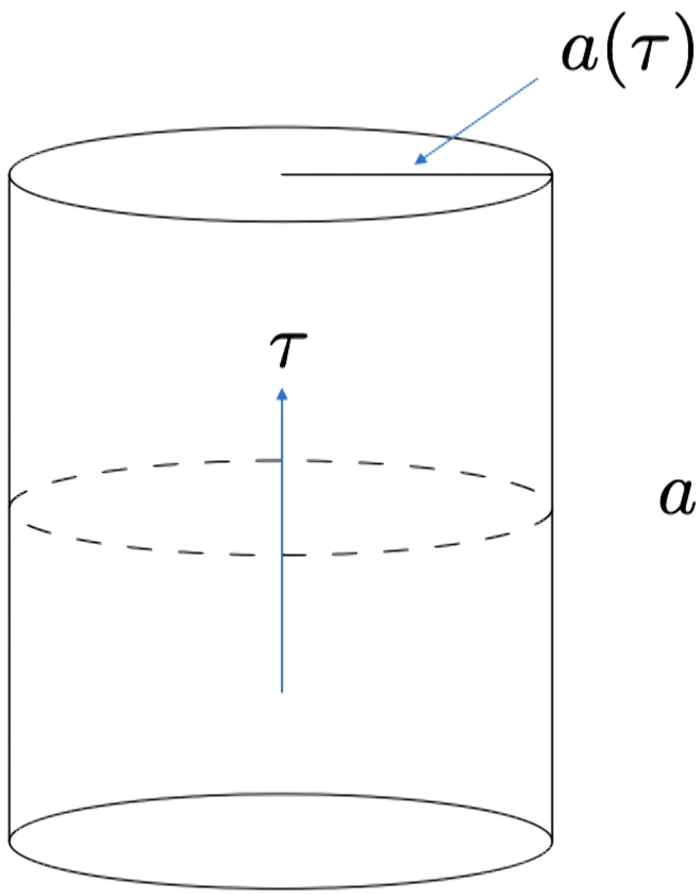

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new isometry:

$$\tau \rightarrow -\tau$$

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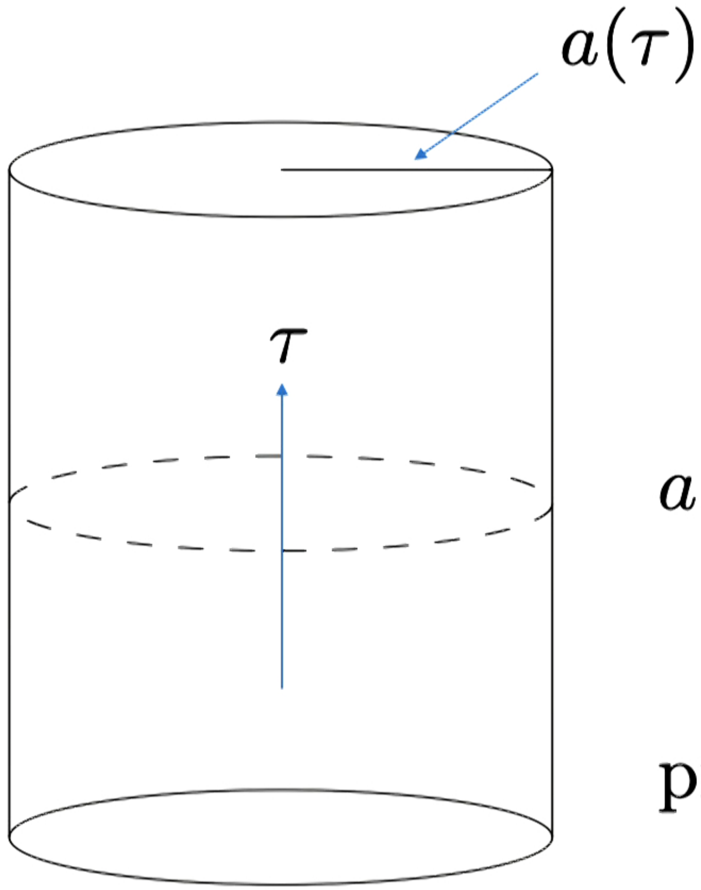

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preferred vacuum:

$$|0_{CPT}\rangle$$

$$\psi(x) = \sum_h \int \frac{d^3\mathbf{p}}{(2\pi)^{3/2}} \left[a(\mathbf{p},h)\psi(\mathbf{p},h,x) + b^\dagger(\mathbf{p},h)\psi^c(\mathbf{p},h,x) \right]$$

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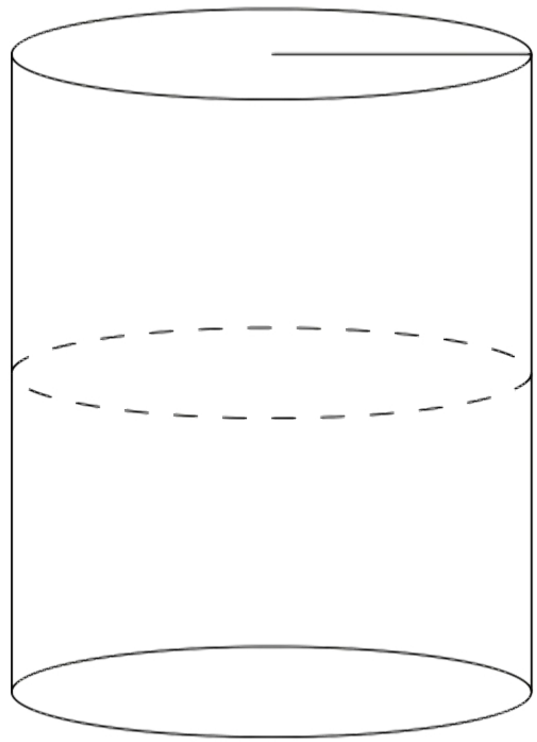

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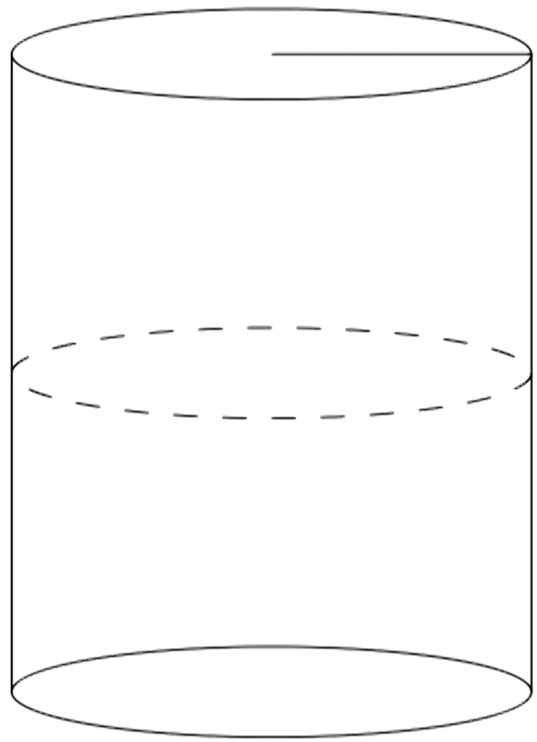
$\psi_+(\mathbf{p},h,x)$



$a_+, b_+ \;\Rightarrow\; |0_+\rangle$

$\psi_-(\mathbf{p},h,x)$

$a_-, b_- \;\Rightarrow\; |0_-\rangle$

$$\psi(x) = \sum_h \int \frac{d^3\mathbf{p}}{(2\pi)^{3/2}} \left[a(\mathbf{p},h)\psi(\mathbf{p},h,x) + b^\dagger(\mathbf{p},h)\psi^c(\mathbf{p},h,x)\right]$$

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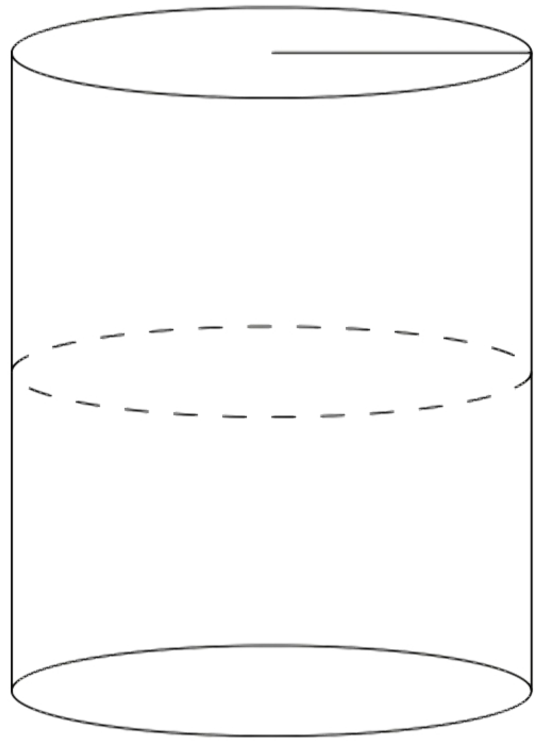

$\psi_0(\mathbf{p},h,x)$ $\qquad$ $a_0, b_0 \;\Rightarrow\; |0_0\rangle$

$\psi_-(\mathbf{p},h,x)$ $\qquad$ $a_-, b_- \;\Rightarrow\; |0_-\rangle$

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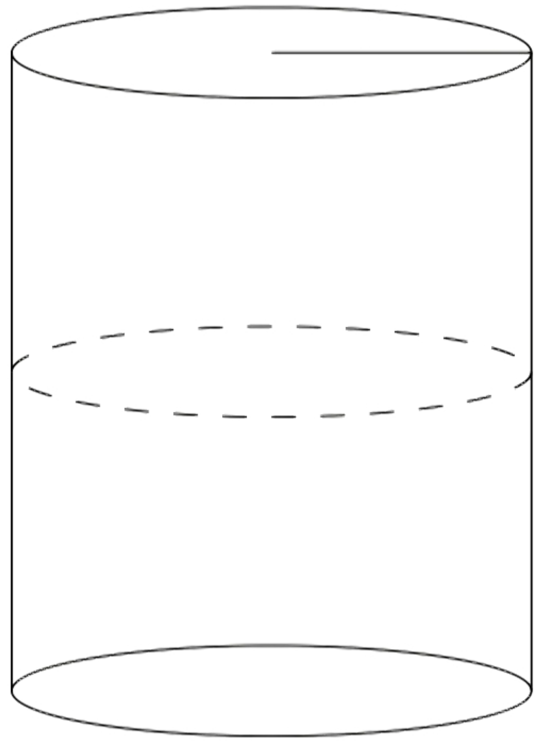

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$\psi_0(\mathbf{p},h,x)$ $\quad a_0, b_0 \;\Rightarrow\; |0_0\rangle$

$\Big(\, (\psi_0(\tau) \sim \psi_0^c(-\tau) \, \Big)$

$\psi_-(\mathbf{p},h,x)$ $\quad a_-, b_- \;\Rightarrow\; |0_-\rangle$

$$\psi_0(\mathbf{p},h,x) = \alpha(\mathbf{p})\psi_+(\mathbf{p},h,x) + \beta(\mathbf{p})\psi^c_+(-\mathbf{p},h,x)$$

$$\langle 0_0|a^\dagger_+(\mathbf{p},h)a_+(\mathbf{p},h)|0_0\rangle = |\beta(\mathbf{p})|^2 = e^{-\pi p^2 \frac{M_{\mathrm{pl}}}{m_{\mathrm{dm}}}\sqrt{\frac{3}{\rho_{\mathrm{rad}}}}}$$

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Like Hawking Radiation

the standard model

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$$e_L, \nu_L, e_R, \nu_R$$

the standard model

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$$\left.\begin{matrix} d_L, u_L, d_R, u_R \\ d_L, u_L, d_R, u_R \\ d_L, u_L, d_R, u_R \\ e_L, \nu_L, e_R, \nu_R \end{matrix}\right\} \times 3$$

dark matter

One stable neutrino: $\nu_R^{(1)}$ ($\mathbb{Z}_2$ symmetry: $\nu_R^{(1)} \to -\nu_R^{(1)}$)

$$\frac{n_{\rm dm}}{s_{\rm rad}} = C \left(\frac{m_{dm}}{M_{pl}} \right)^{3/2} \qquad (C = 0.003476\ldots)$$

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detection?

Upgoing ANITA events as evidence of the CPT symmetric universe

Luis A. Anchordoqui,[1,2,3] Vernon Barger,[4] John G. Learned,[5] Danny Marfatia,[5] and Thomas J. Weiler[6]

[1] *Department of Physics & Astronomy, Lehman College, City University of New York, NY 10468, USA*
[2] *Department of Physics, Graduate Center, City University of New York, NY 10016, USA*
[3] *Department of Astrophysics, American Museum of Natural History, NY 10024, USA*
[4] *Department of Physics, University of Wisconsin, Madison, WI 53706, USA*
[5] *Department of Physics & Astronomy, University of Hawaii at Manoa, Honolulu, HI 96822, USA*
[6] *Department of Physics & Astronomy, Vanderbilt University, Nashville TN 37235, USA*

(Dated: April 1, 2018)

[hep-ph] 30 Mar 2018

We explain the two upgoing ultra-high energy shower events observed by ANITA as arising from the decay in the Earth's core of the quasi-stable dark matter candidate in the CPT symmetric universe. The dark matter particle is a 480 PeV right-handed neutrino that decays into a Higgs and a light Majorana neutrino. The latter interacts in the Earth's crust to produce a τ lepton that in turn initiate an atmospheric upgoing shower.

The three balloon flights of the ANITA experiment have resulted in the observation of two unusual upgoing showers with energies of (600 ± 400) PeV [1] and (560^{+300}_{-200}) PeV [2]. The energy estimates are made un-

with the non-observation of similar events at cosmic ray facilities and IceCube.

Cosmic ray facilities have seen downgoing shower events with energies up to $\sim 10^5$ PeV, but have not

Prediction: one neutrino is massless

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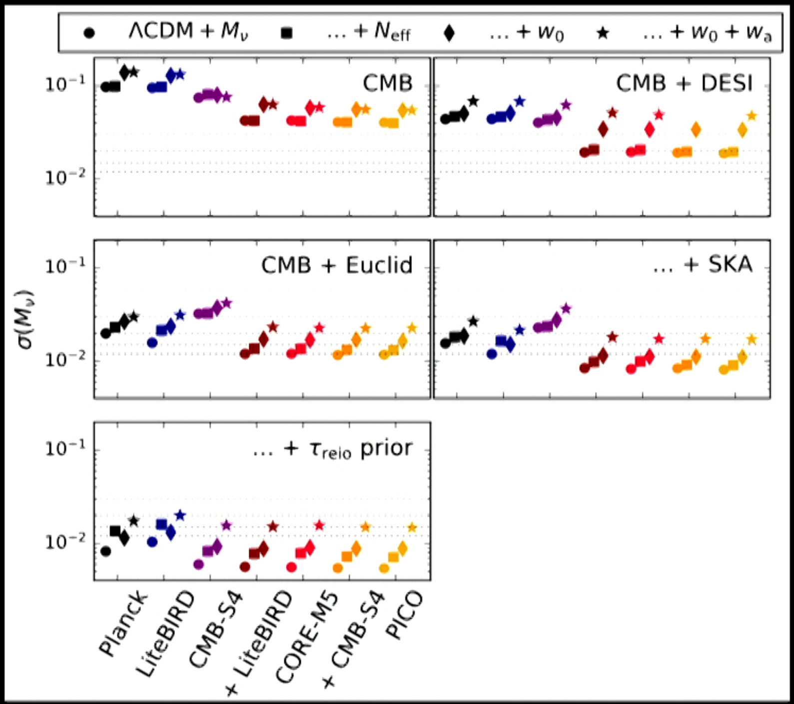
$$\sum m_\nu \approx .06eV(NH) \text{ or } .12eV(IH)$$



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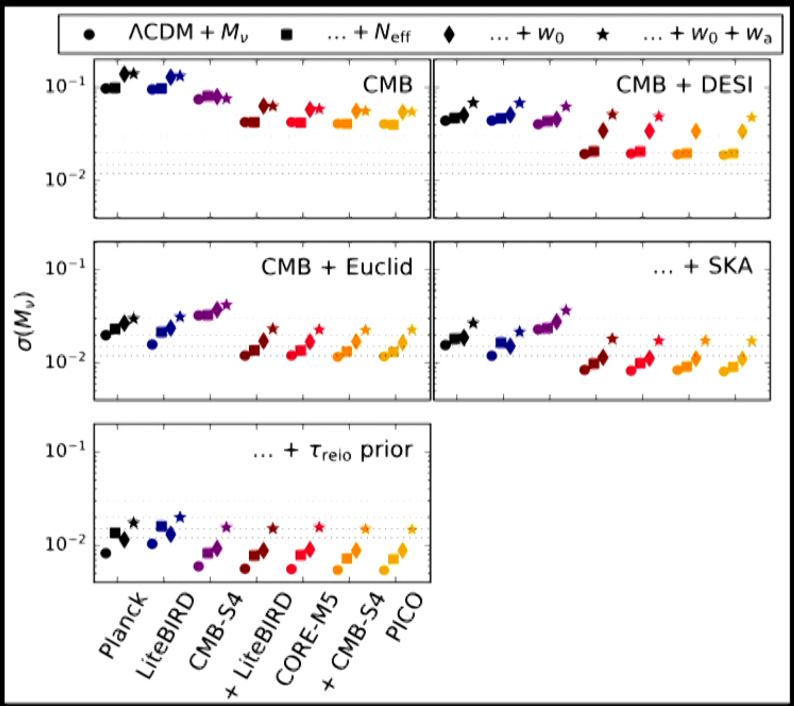

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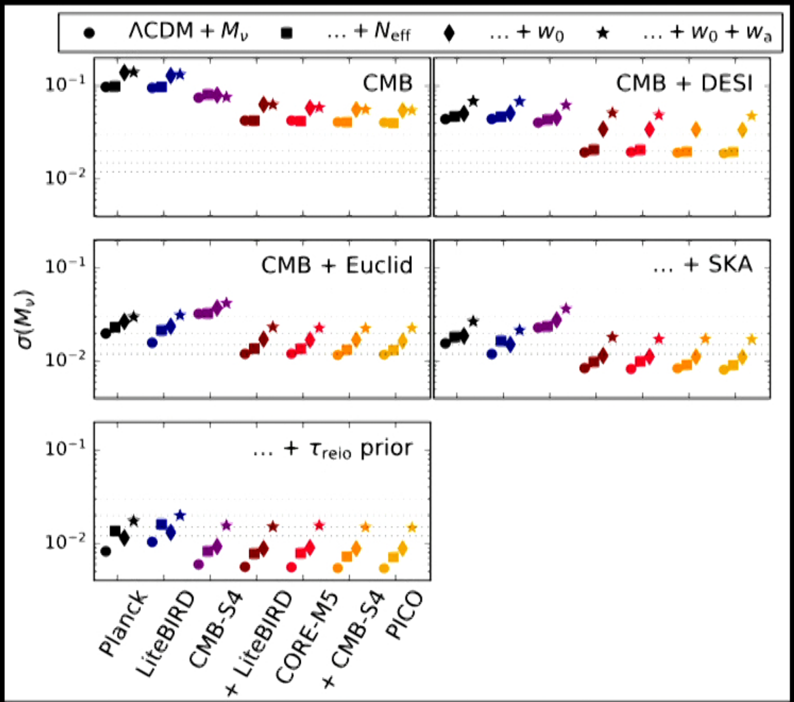

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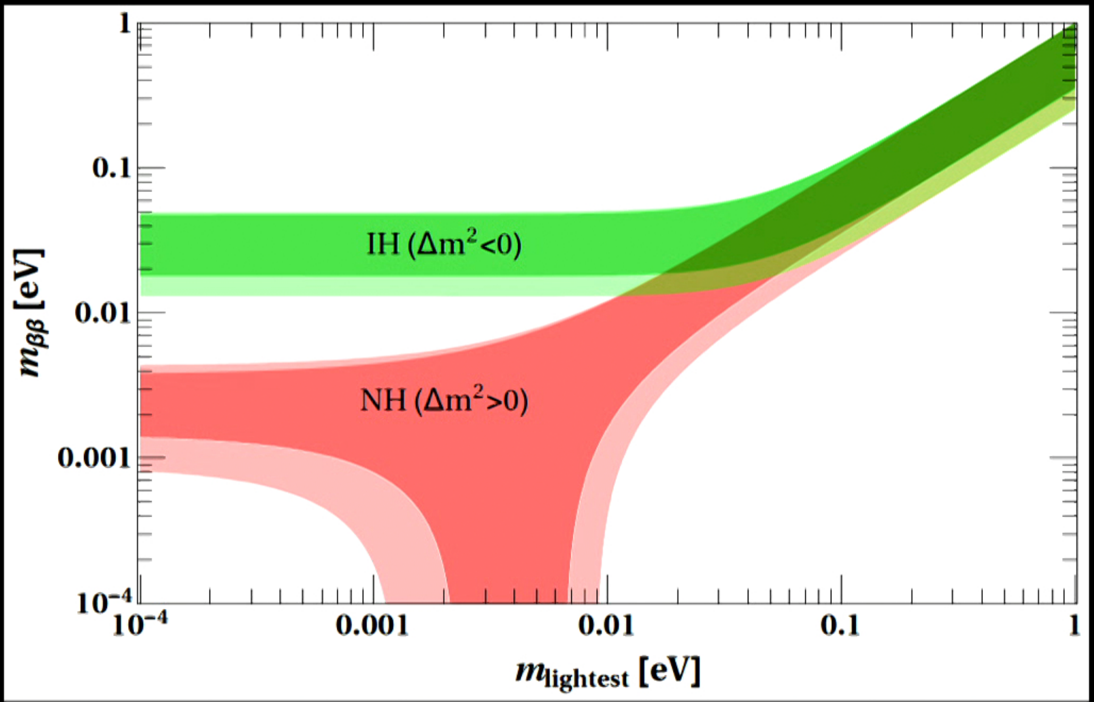

(Dell'Oro et al, arXiv:1601.07512)

AdS Boundary Conditions (as rephrased by Hawking '83)

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boundary conditions have been discussed by Breitenlohner and Freedman [6]. They formulated two sets of reflective boundary conditions which can be expressed as

$$2^s t^{AA'} t^{BB'} \ldots t^{LL'} \varphi_{AB\ldots L} = \pm \bar{\varphi}^{A'B'\ldots L'}. \tag{8}$$

In the case of spin zero, the boundary conditions were

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When applied to the Bang, correspond to our CPT condition!

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- Thank you!