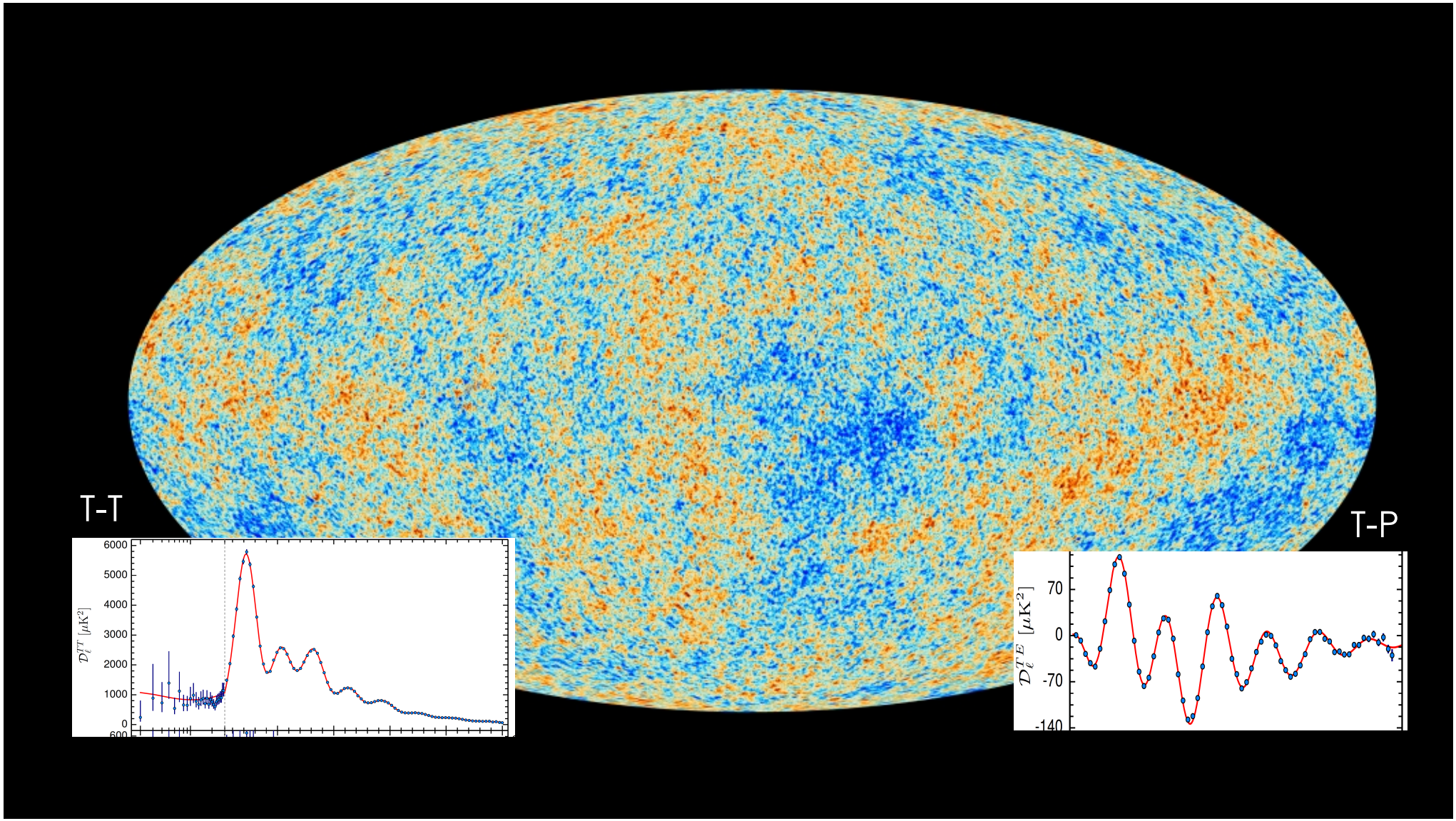
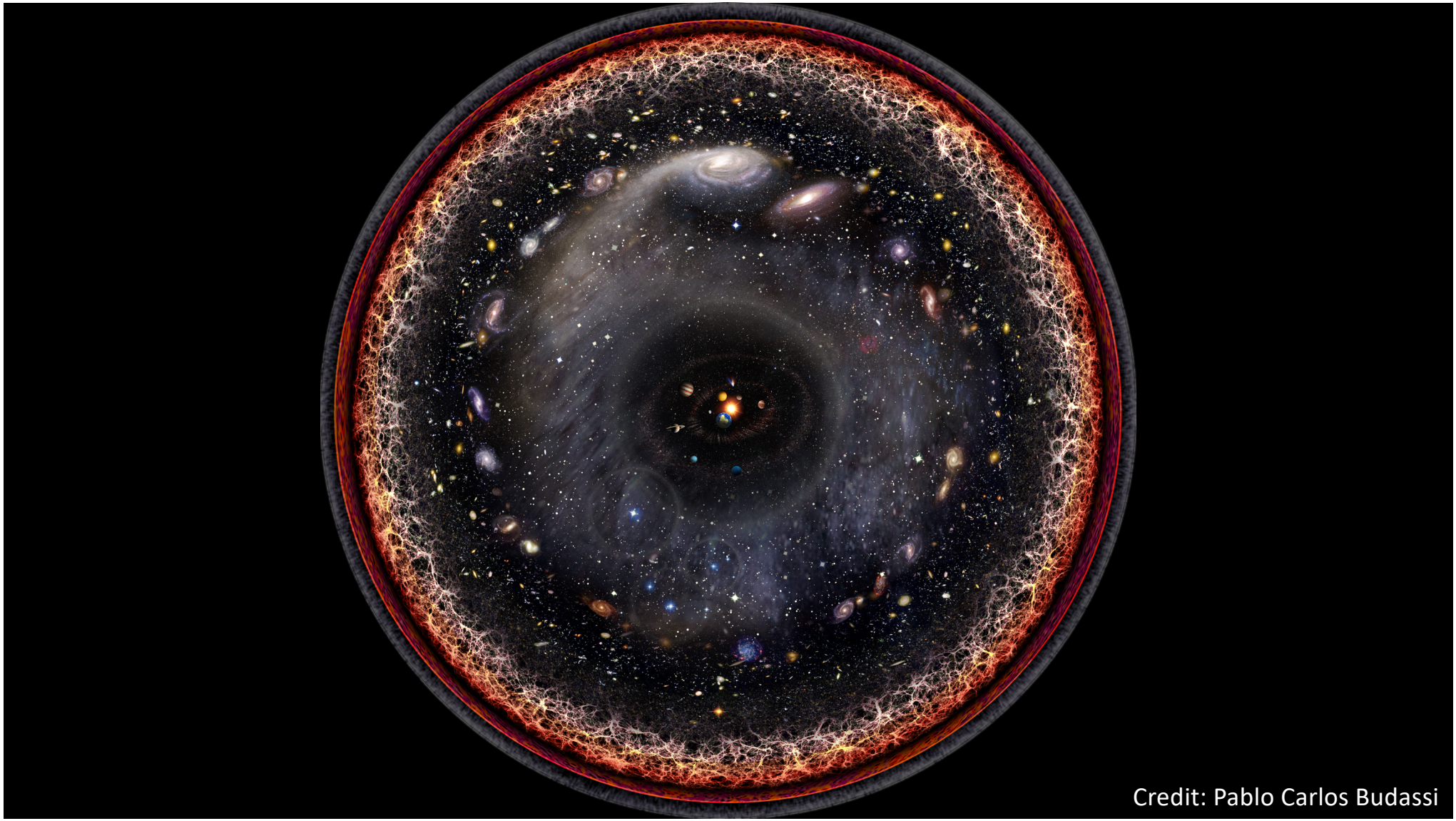
CPT Symmetric Universe

Latham Boyle and Neil Turok*
Perimeter Institute

with Kieran Finn, 1803.08928; 1803.08930
Phys.Rev.Lett. 121 (2018) no.25, 251301


T-T
T-P
6000
5000
4000
3000
2000
1000
0
$\mathcal{D}_\ell^{TT}$ [μK^2]
70
0
-70
-140
$\mathcal{D}_\ell^{TE}$ [μK^2]


Credit: Pablo Carlos Budassi

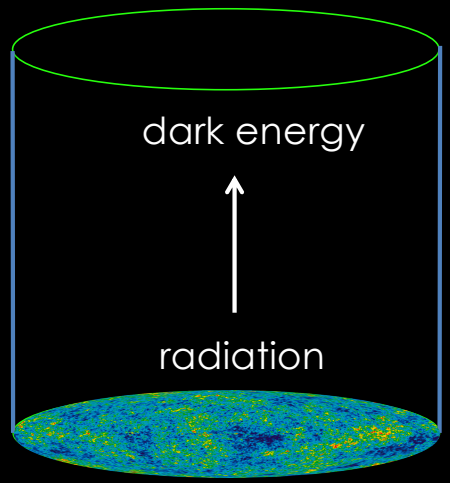
Just 4.5 numbers

energy content
- Nucleons per photon
- Dark matter/nuclear matter
- Dark energy density

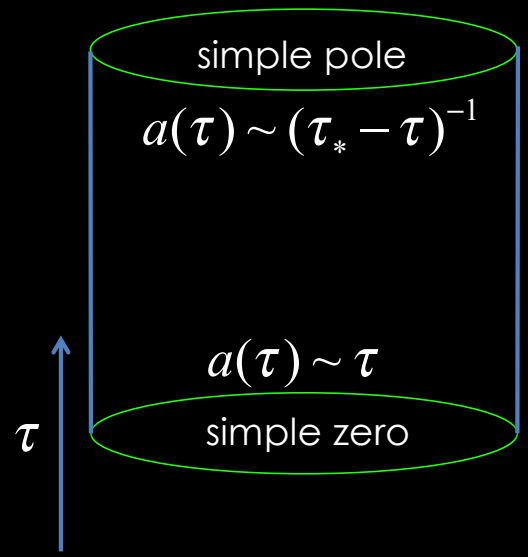
geometry
- Scalar amplitude
- Scalar tilt

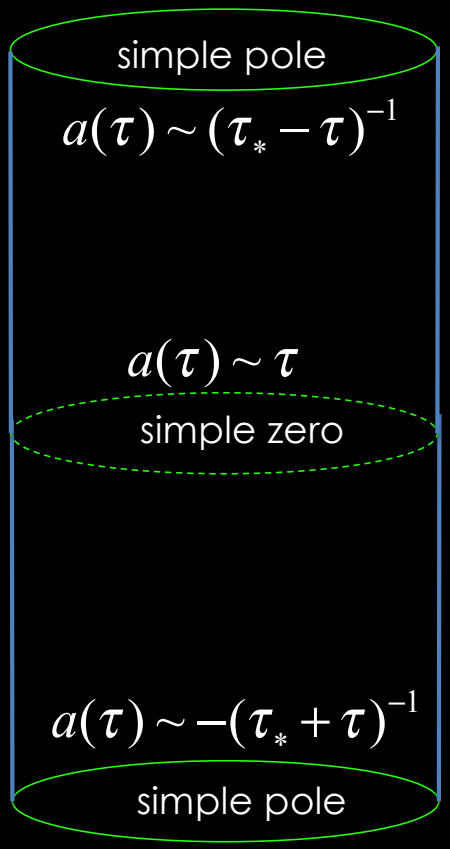
+ Standard Model including neutrino masses
  Many quantities so far observed to be consistent with zero

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

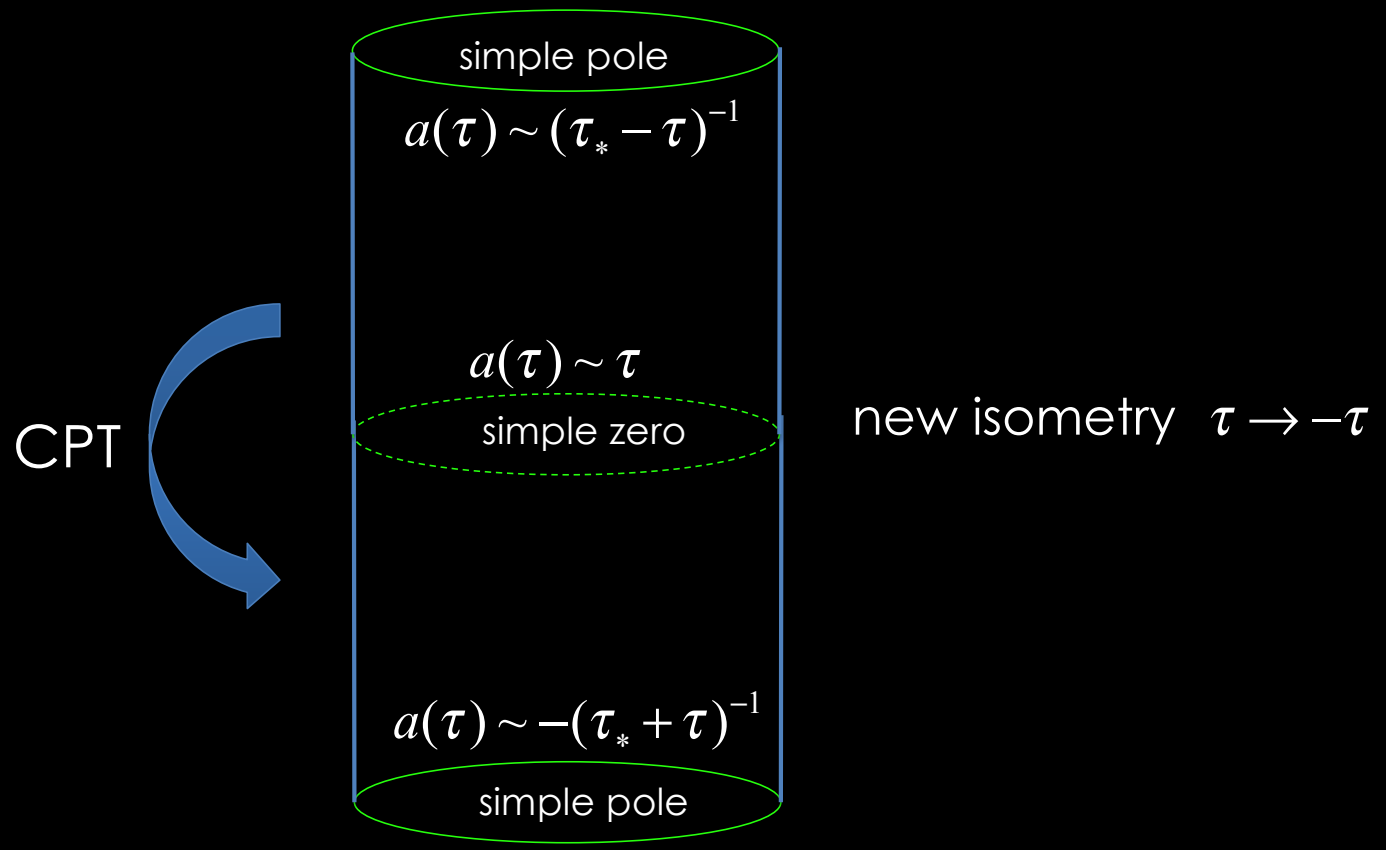


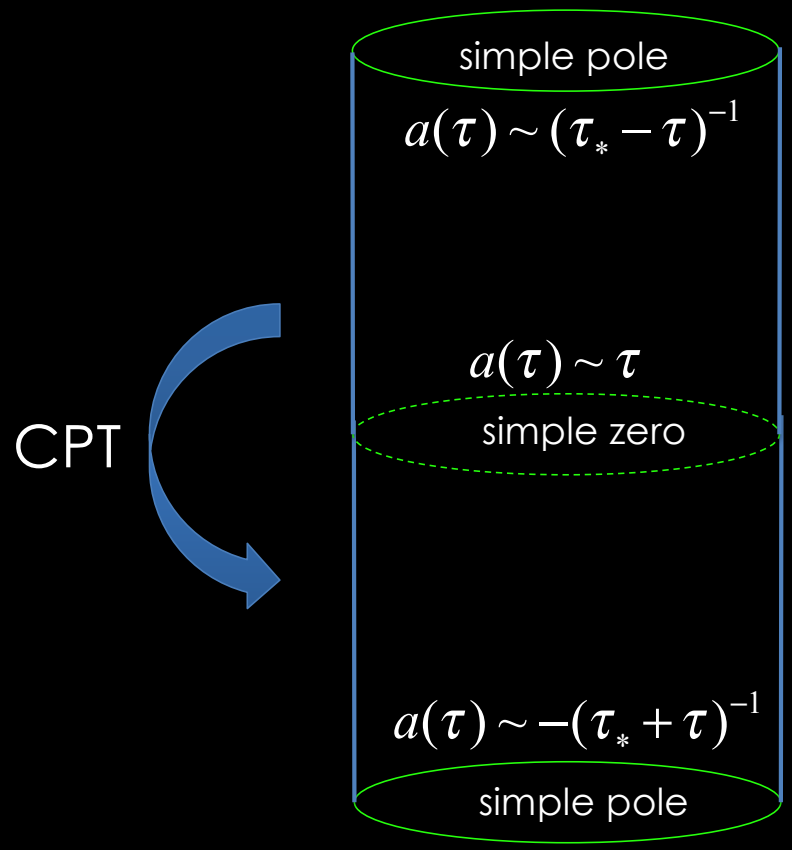
$$g_{\mu\nu} = a(\tau)^2 \eta_{\mu\nu}$$





new isometry $\tau \to -\tau$


simple pole
$a(\tau) \sim (\tau_* - \tau)^{-1}$
$a(\tau) \sim \tau$
simple zero
$a(\tau) \sim -(\tau_* + \tau)^{-1}$
simple pole
CPT
new isometry $\tau \to -\tau$



CPT

new isometry $\tau \to -\tau$

preferred vacuum

$$|0\rangle_{CPT}$$

hypothesis:

the universe does not spontaneously violate CPT

the standard model

the standard model

$$G_\mu, W_\mu, B_\mu, h$$

the standard model

$$G_\mu, W_\mu, B_\mu, h$$

$$d_L, u_L, d_R, u_R$$
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$$e_L, \nu_L, e_R, \nu_R$$

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

$$\psi = \sum_h \int \frac{d^3\vec{p}}{(2\pi)^3} \left(a_{\vec{p},h} u(\vec{p},h,\vec{x}) + a^{\dagger}_{\vec{p},h} u^c(\vec{p},h,\vec{x}) \right)$$

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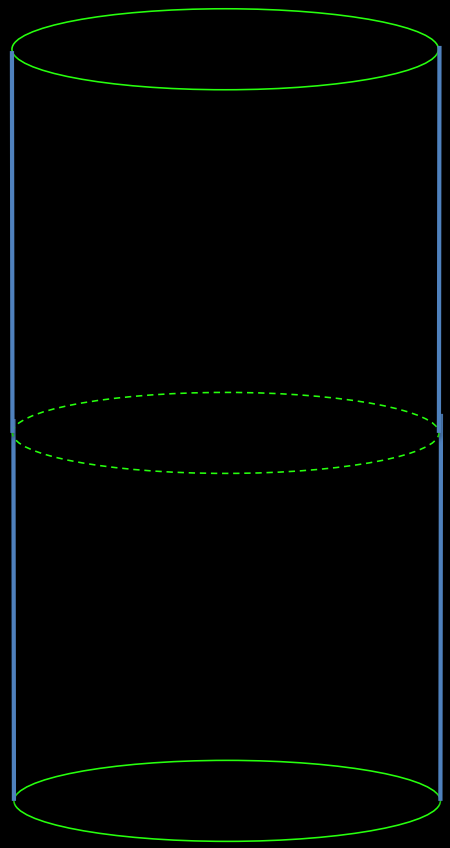

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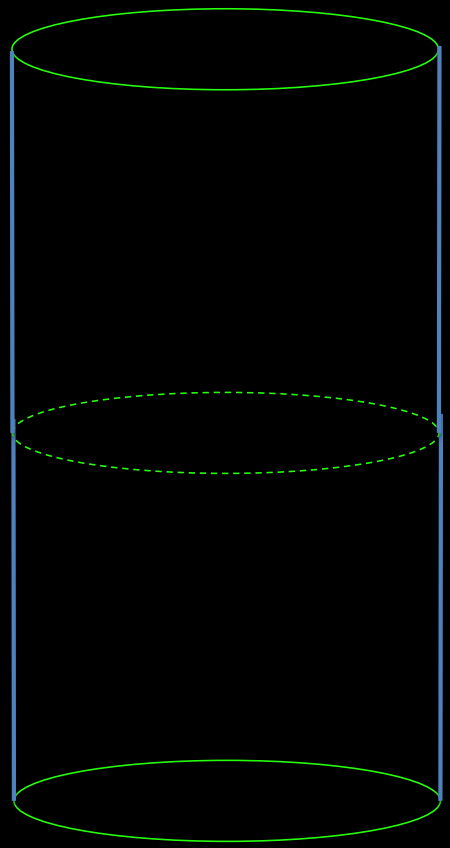
u_+



$a_+ \Rightarrow |0\rangle_+$

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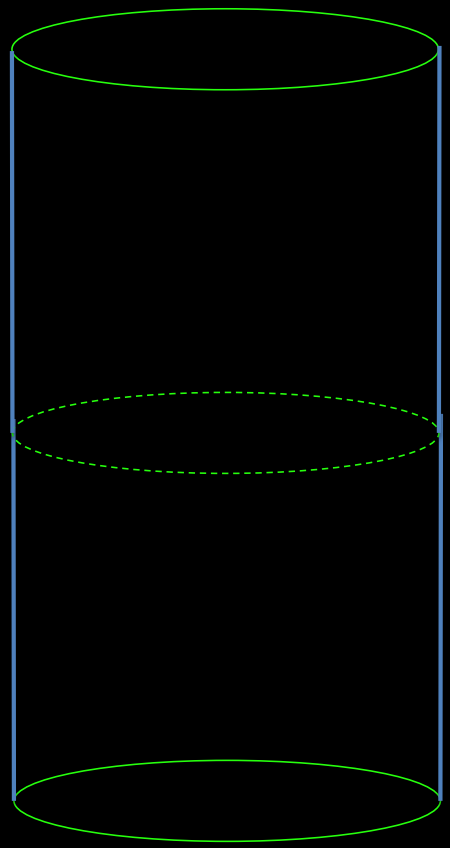

$a_+ \Rightarrow |0\rangle_+$

u_-

$a_- \Rightarrow |0\rangle_-$

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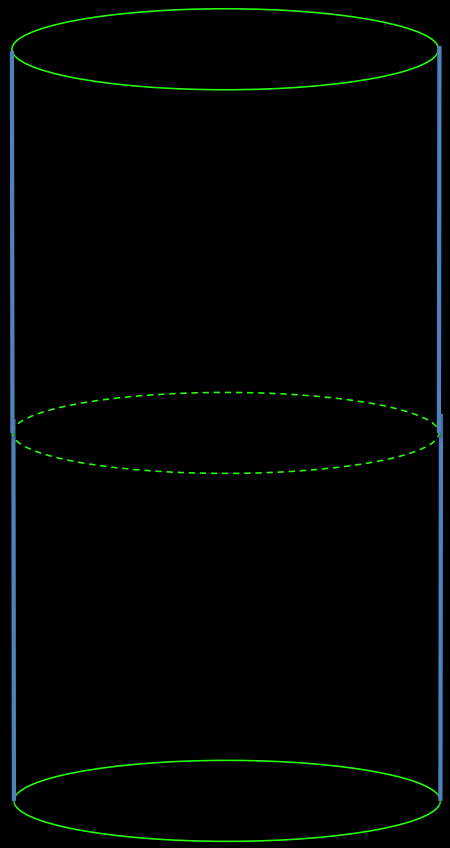
u_+

u_{CPT}

u_-



$a_+ \Rightarrow |0\rangle_+$

$a_{CPT} \Rightarrow |0\rangle_{CPT}$

$a_- \Rightarrow |0\rangle_-$

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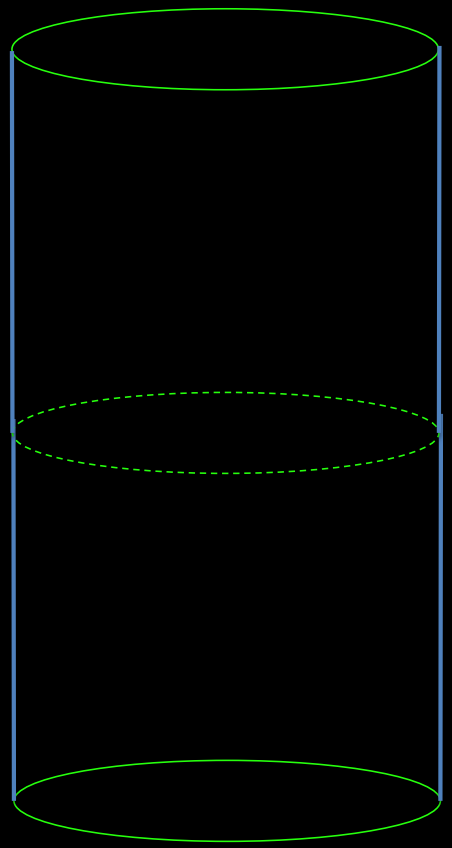
u_+ $\quad a_+ \Rightarrow |0\rangle_+$

$\left(u_{CPT}(\tau) \sim u^c_{CPT}(-\tau)\right)$ $\quad u_{CPT}$ $\quad a_{CPT} \Rightarrow |0\rangle_{CPT}$



u_- $\quad a_- \Rightarrow |0\rangle_-$

$$u_{CPT}(\vec{p},h,\vec{x}) = \alpha(\vec{p})u_{+}(\vec{p},h,\vec{x}) + \beta(\vec{p})u_{+}^{c}(\vec{p},h,\vec{x})$$

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Like Hawking Radiation

dark matter

One stable neutrino: $\nu_R^{(1)}$

dark matter

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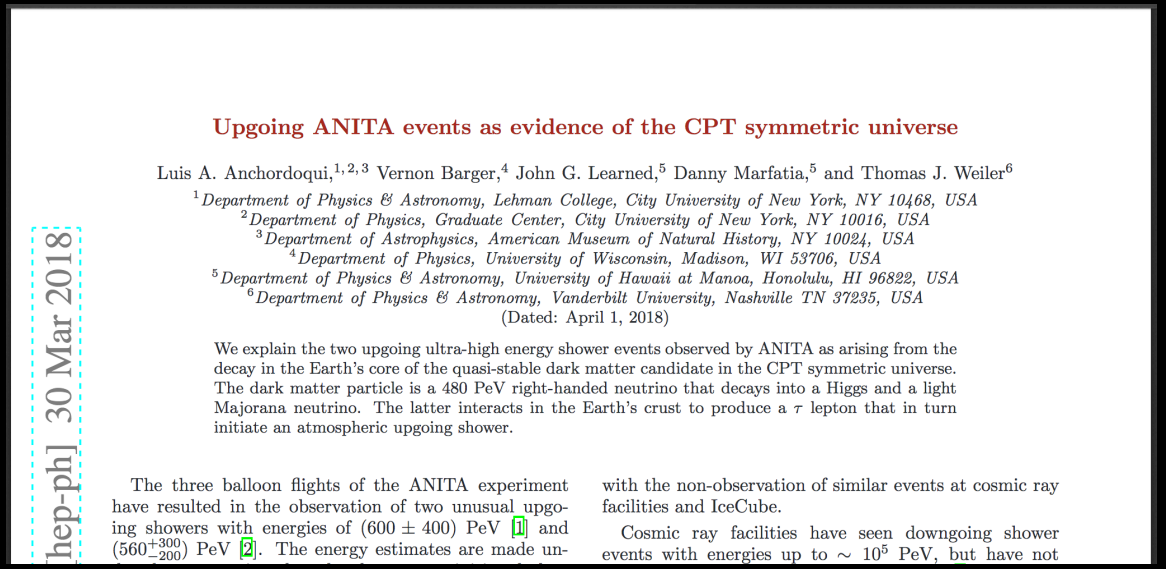
detection?



[hep-ph] 30 Mar 2018

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]

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[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*
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(Dated: April 1, 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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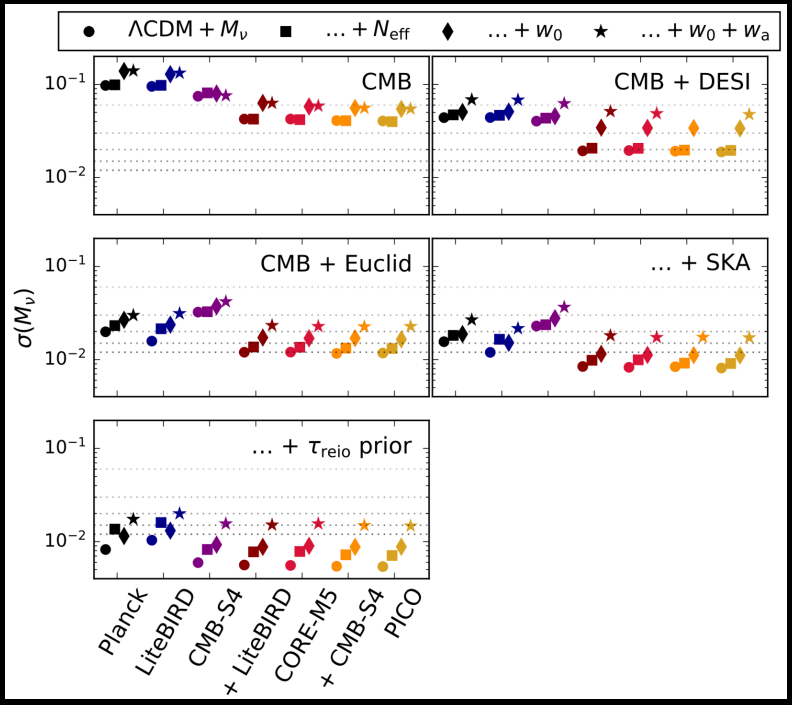

(Brinckmann et al, arXiv:1808.05955)

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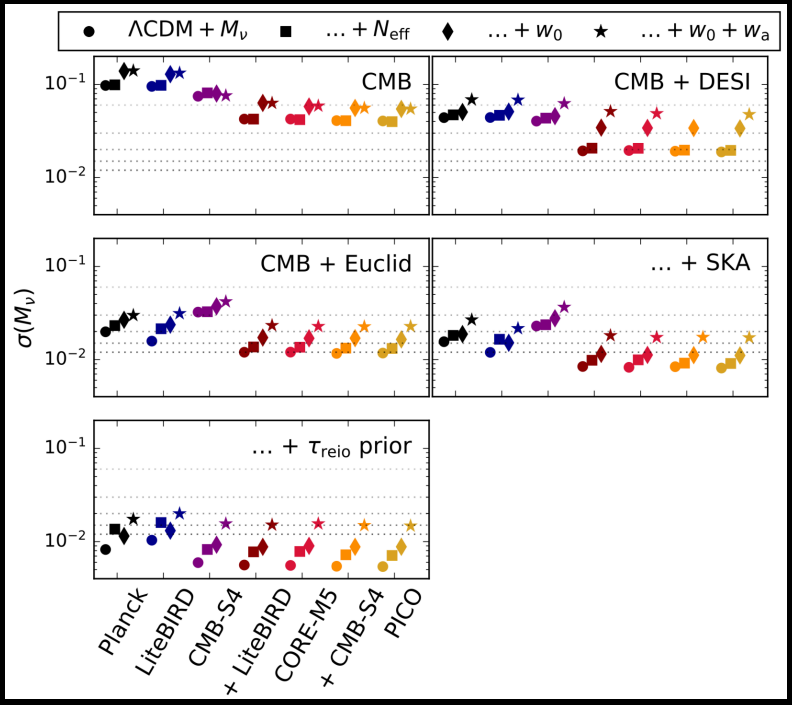
$0\nu\beta\beta$ decay:



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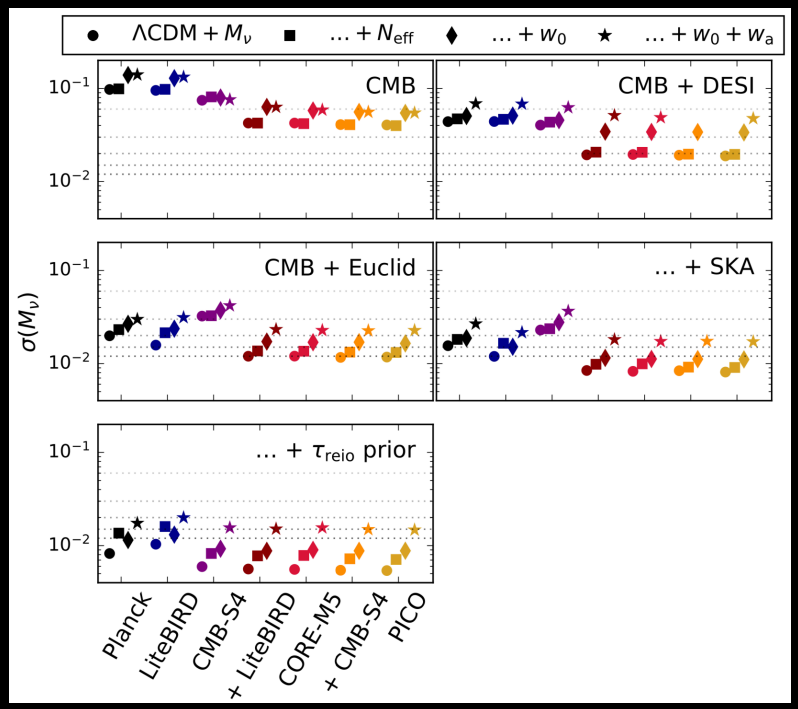

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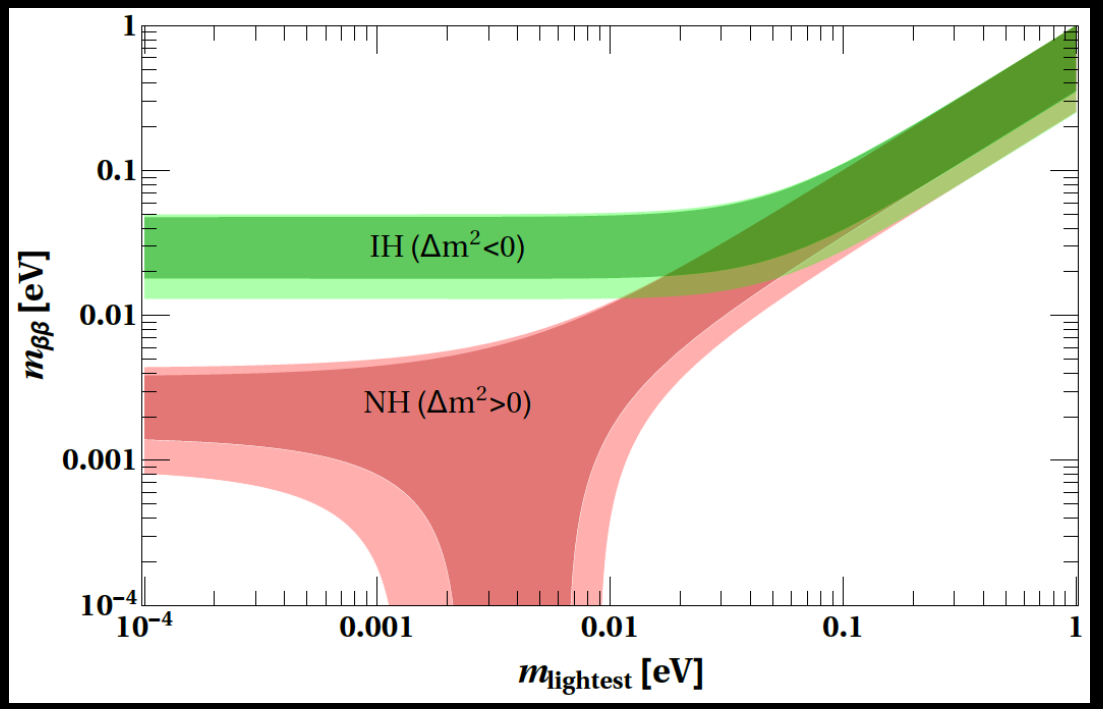

(Dell'Oro et al, arXiv:1601.07512)

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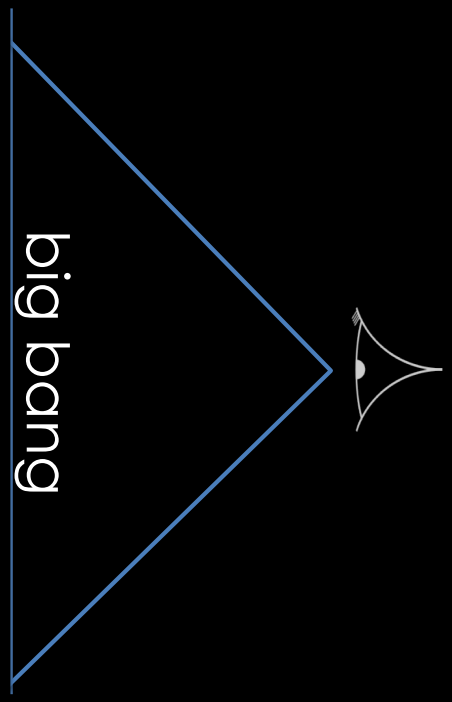
- Thank you!



most probable universe:

spatially flat, homogeneous and isotropic

space and time are emergent

CPT symmetry $\Longrightarrow$ matter-antimatter asymmetry

dark matter can consist of right handed neutrinos

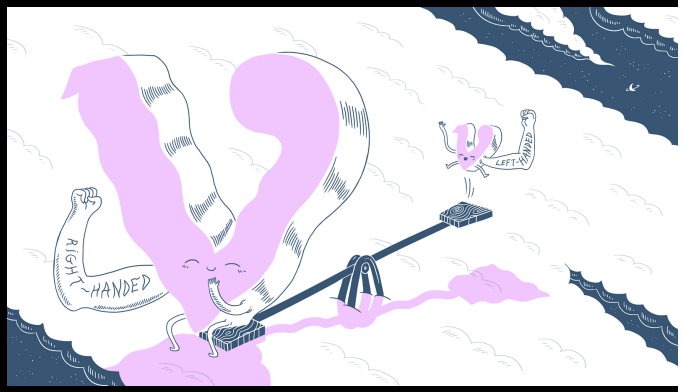
scale invariant perturbations from conformal anomaly
In the standard model (in progress)

$\Longrightarrow$ a new, simpler cosmology is in prospect

w/L. Boyle and K. Finn

The dark matter has been hiding in plain sight: its right handed neutrinos!

can impose discrete symmetry $\nu_{R,1} \to -\nu_{R,1}$
(*i.e. reduce* SM coupling space),
renders one rh neutrino stable



Couples only to gravity - in CPT symmetric vacuum, outgoing particle density nonzero

$$\Rightarrow m_{\nu_R} = 4.8 \times 10^8 \, GeV$$

Predict: - one of left handed neutrinos is massless (at tree level)

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

- testable via cosmic structure formation

- double beta decay rate

how will we know?

Forthcoming CMB+galaxy measurements (S4+DESI)

$$\Rightarrow \sigma(\sum m_\nu) \approx .02eV$$

a new experiment,10x size of CHIME, could set a much tighter bound

Experimental confirmation?

L. Anchordoqui et al.
1803.11554

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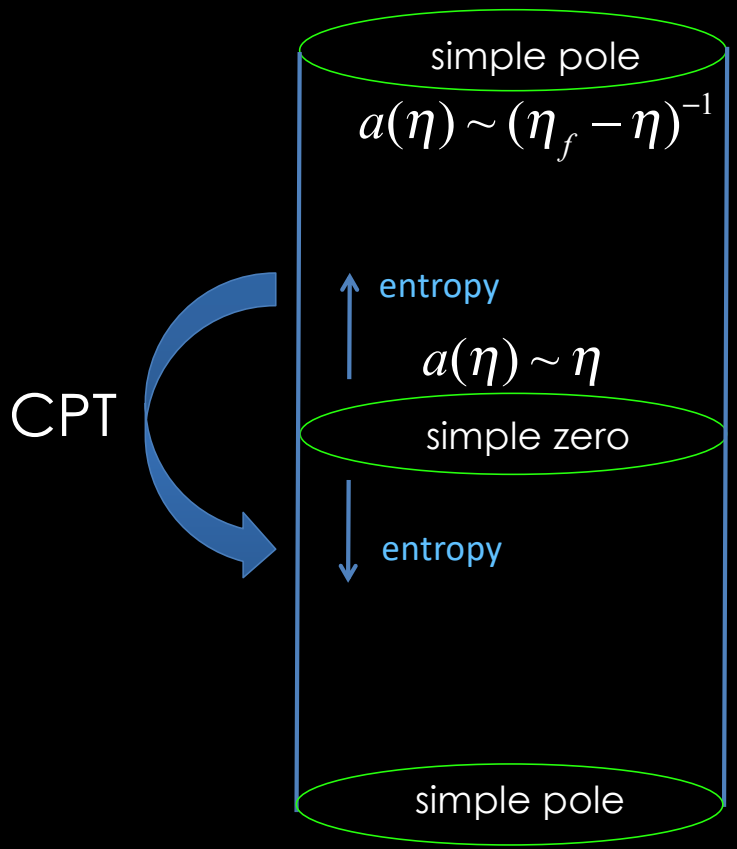
FLRW background in conformal coordinates

$$ds^2 = a(\eta)^2(-d\eta^2 + d\vec{x}^2),$$



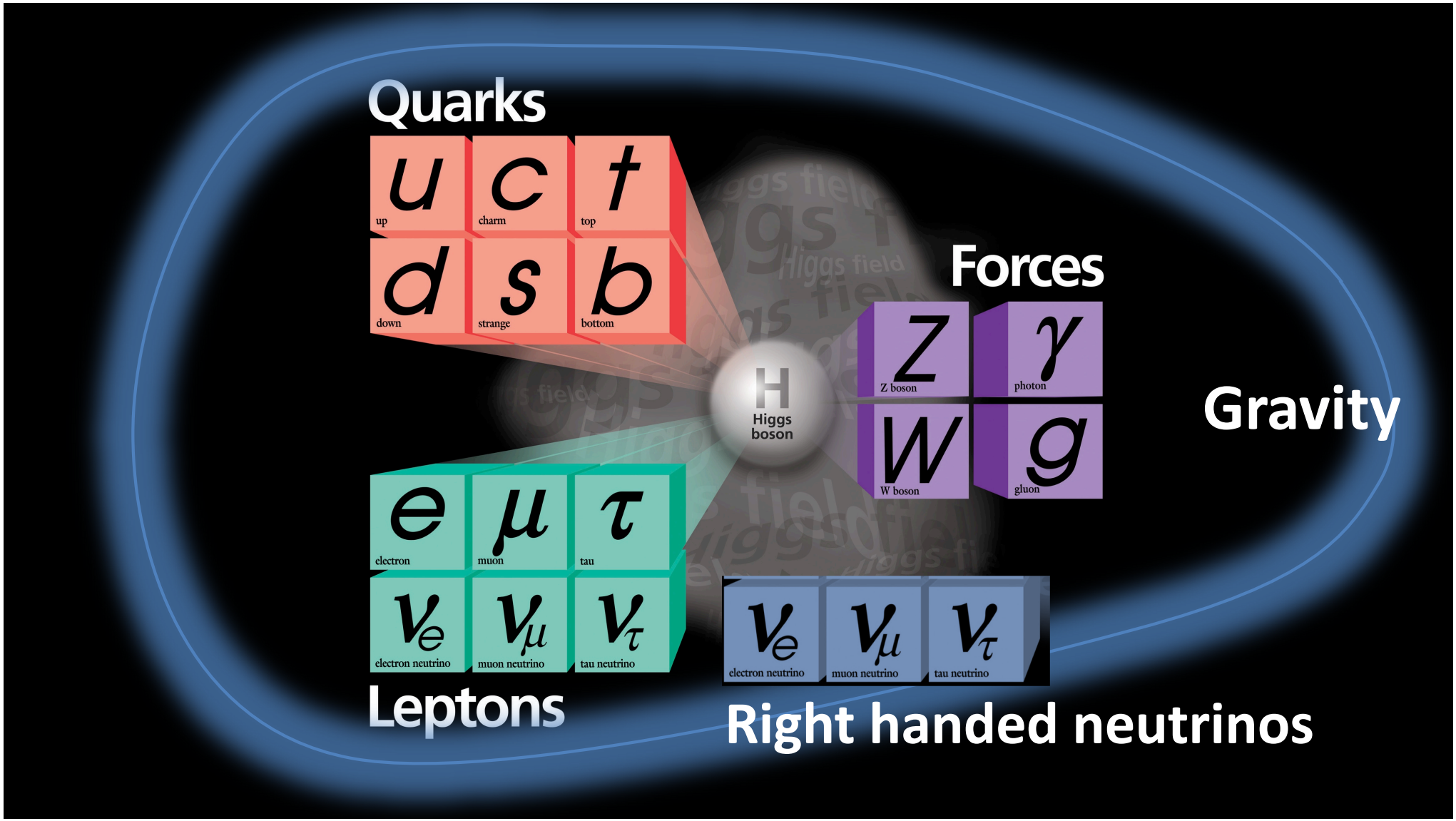
dark energy

natural continuation to $\eta < 0$

radiation

classical background invariant under time reversal symmetry $\eta \leftrightarrow -\eta$

dark energy


Quarks
u
up
c
charm
t
top
d
down
s
strange
b
bottom
Higgs field
H
Higgs boson
Forces
Z
Z boson
γ
photon
W
W boson
g
gluon
Gravity
e
electron
μ
muon
τ
tau
νe
electron neutrino
νμ
muon neutrino
ντ
tau neutrino
Leptons
νe
electron neutrino
νμ
muon neutrino
ντ
tau neutrino
Right handed neutrinos