Spontaneous Lorentz Symmetry Breaking and Horizons

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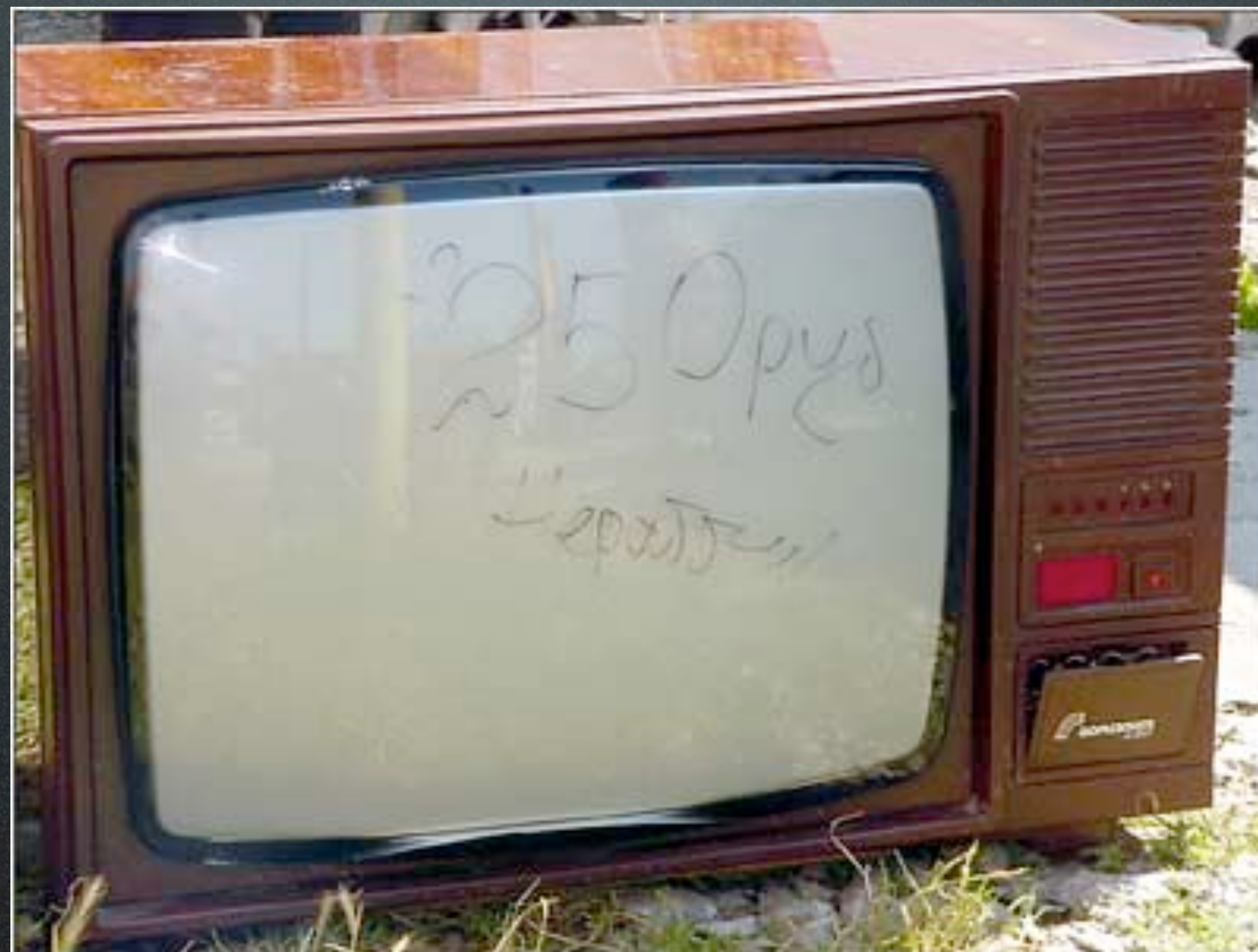
Lorentz symmetry gets broken even more frequently than the "Horizons" do



...and the breaking is spontaneous

Indeed all interesting solutions, including us, do break Lorentz symmetry.

In field theory, every solution

$$\Phi(x^\mu) : \partial_\mu \Phi \neq 0$$

breaks Lorentz symmetry

On the other hand in EFT there are kinetic couplings / non- canonical kinetic terms like:

$$(\partial_\mu \phi)^4, \quad (F^\mu \ \partial \ \phi)^2, \quad (A^\mu \partial_\mu \phi)^2, \mathrm{etc}$$

on Lorentz symmetry violating backgrounds these terms change the

front velocity

for the propagation of perturbations

Front velocity different form the speed of light

different Horizons for the perturbations of different fields

Troubles with Black Hole Thermodynamics???

It seems one can construct a perpetuum mobile

- different Horizons → different Hawking temperatures
  ↓
  violation of the II law of thermodynamics
  (Dubovsky & Sibiryakov (2006)):
- different Horizons → in between there is an analog of the ergoregion and an analog of a Penrose process. One can decrees the entropy of the BH.
  (Eling, Foster, Jacobson, Wall (2007))

Is the II Law always violated in theories with Lorentz symmetry breaking and different front velocities?

NO!

A counterexample:

$$S_\phi = \frac{1}{2}\int \mathrm{d}^4x\,\sqrt{-G}G^{\mu\nu}\partial_\mu\phi\partial_\nu\phi$$

where as usual

$$G = \det G^{-1}_{\mu\nu} \quad \text{and} \quad G^{\mu\lambda}G^{-1}_{\lambda\nu} = \delta^\mu_\nu$$

but

$$G_{\mu\nu} = g_{\mu\nu} + \lambda F_{\mu\alpha}F_{\nu\beta}g^{\alpha\beta}$$

EM field strength tensor

Now consider the a Reissner-Nordström Black Hole with electric charge Q

$$\mathrm{d}s^2 = g_{\mu\nu}\mathrm{d}x^\mu \mathrm{d}x^\nu = \Delta \mathrm{d}t^2 - \Delta^{-1}\mathrm{d}r^2 - r^2\mathrm{d}\Omega^2$$

$$\Delta(r) = 1 - \frac{2M}{r} + \frac{Q^2}{r^2}$$

$$E_r = F_{tr} = \frac{Q}{r^2}$$

Calculate the effective metric:

$$\begin{aligned} \mathrm{d}S_\phi^2 &= G^{-1}_{\mu\nu}\mathrm{d}x^\mu \mathrm{d}x^\nu = \\ &= \left(1 - \frac{Q^2}{r^4}\right)^{-1} \left(\Delta \mathrm{d}t^2 - \Delta^{-1}\mathrm{d}r^2\right) - r^2 \mathrm{d}\Omega^2 \end{aligned}$$

for all spherically symmetric metrics

$$\mathrm{d}s^2 = A\mathrm{d}t^2 - B\mathrm{d}r^2 - r^2\mathrm{d}\Omega^2$$

Hawking temperature:

$$T_H = \frac{\kappa}{2\pi} = \left(\frac{A'}{4\pi\sqrt{AB}}\right)_{r_H}$$

Horizons are the same!
and

$$T_{H\phi} = T_{H\gamma}$$

↓

No violation of the II Law