Breaking of Lorentz symmetry and thermodynamics of black holes

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Lorentz invariance: exact symmetry or just a good approximation?

Phenomenological approach

Leading effect of Lorentz symmetry breaking at small energies

different (maximal) propagation velocities for different particle species

What in a more comprehensive framework including General Relativity?

Black holes --- good low-energy probes of high-energy physics

In GR a black hole has temperature $T_H = (8\pi M)^{-1}$

and entropy $S_B = \mathcal{A}/4$

$G = 1$

area of horizon

- taking S_B into account the second law of thermodynamics holds: total entropy always grows

  non-trivial: entropy could just vanish beyond the horizon

- compatible with the possibility to embed GR in a unitary quantum theory with $S_B = \ln($number of microstates of black hole$)$

In case of broken Lorentz symmetry

→ different velocities for different particles

→ for each particle species its own horizon

What is the temperature & entropy of black hole?

A concrete model of ~~LS~~ is needed.

- Ghost condensate model

Arkani-Hamed et al., 2003

$\nabla_\mu \phi = (1, 0, 0, 0)$ in the vacuum

In the black hole background $\nabla_\mu \phi =$ four-velocity of a dust freely falling into the black hole

Important: GC flow does not carry energy

- Coupling of a test field to the ghost condensate

$$S_\psi = \int \left(\frac{(\nabla_\mu \psi)^2}{2} + \frac{\varepsilon (\nabla^\mu \phi \nabla_\mu \psi)^2}{2} \right) \sqrt{-g}\, d^4 x$$

temperature of the Hawking radiation in ψ-particles

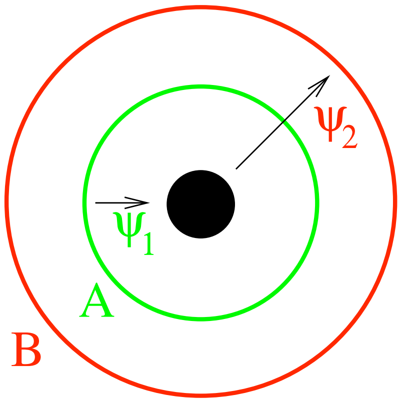
$$T_\psi = \frac{T_H}{(1+\varepsilon)^{3/2}}$$

$$v_\psi = \frac{1}{\sqrt{1+\varepsilon}}$$

depends on the particle species!

Second law of thermodynamics (textbook version): *a process, whose only result is transfer of energy from a cold body to a hot body, is impossible*

Perpetuum mobile of the 2nd kind



$\psi_1,\ \psi_2$

$v_1 < v_2$

$T_1 < T_A < T_B < T_2$

$F_1(T_A, T_1) > 0$ -- flux from *A* to black hole

$F_2(T_B, T_2) < 0$ -- flux from *B* to black hole

It is possible to choose T_A, T_B such that

$F_1(T_A, T_1) + F_2(T_B, T_2) = 0$

The state of the black hole does not change while the heat flows from *A* to *B*

Instead of conclusion

- The effect is generic: should be present in other Lorentz violating theories (*Einstein-aether, TeVeS, ...*)

- Three alternatives
  - *there is some subtle mechanism in the effective theory which prevents the process from going on forever*
  - *theories with ~~LS~~ are intrinsically inconsistent*
  - *UV completion of theories with ~~LS~~ is very unusual (non-unitary? non-local?)*

More work is needed