PRICE FOR NEUTRINO SUPERLUMINALITY

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This talk is based on

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in collaboration with

Gia Dvali
We are theoretical physicists, therefore we cannot and do not check this
OPERA:

\[ \frac{\nu - c}{c} = (2.48 \pm 0.28 \text{ (stat)} \pm 0.30 \text{ (sys)}) \times 10^{-5} \]

- Neutrino propagate in a metric \( g^{(\nu)}_{\alpha\beta} = g_{\alpha\beta} + \delta g_{\alpha\beta} \) different from gravitational \( g_{\mu\nu} \) by \( |\delta g_{\alpha\beta}| = \epsilon \sim 10^{-5} \)

\[
(\eta_{\alpha\beta} + \delta g_{\alpha\beta}) \overline{\nu} \gamma^\alpha \partial^\beta \nu
\]

- Only possible if the Lorentz symmetry is spontaneously broken by a background

- SN 1987A this background is *local*, sourced by the Earth?
Known Earth’s Backgrounds

* Magnetic Field \( B_\oplus \sim 0.1 \) Gauss

\[
\delta g_{\mu\nu} = \frac{c_1 F_{\mu\lambda} F^{\lambda}_\nu + c_2 F_{(\mu\lambda} F^{\lambda)}_{\nu)}}{M_B^4}
\]

\[
M_B \sim 1 \text{ eV}
\]

* Gravitational Field \( \delta g_{\mu\nu} = \frac{G_{\mu\nu}}{M_g^2} \)

\[
M_g \sim 10^{-16} \text{ eV}
\]

\[
\Lambda \sim \left( M_{Pl} M_g^2 \right)^{1/3} \sim 10^{-1} \text{ eV}
\]
Unknown Backgrounds?

*local* effect $\rightarrow$ general decomposition in *massive* degrees of freedom:

$$\delta g^{(\nu)}_{\mu\nu} = \frac{h_{\mu\nu}}{M_*} + \frac{\partial_{(\mu} A_{\nu)}}{M_1^2} + \frac{\eta_{\mu\nu}}{M_0} + \frac{\partial_\mu \partial_\nu \phi}{M'_0} + \ldots$$

Spin 2  Spin 1  Spin 0

$$\delta g_{\alpha\beta} \bar{\nu} \gamma^\alpha \partial^\beta \nu \simeq \delta g_{\alpha\beta} T^\alpha_\beta_{(\nu)} + \text{energy conservation} \quad \partial_\alpha T^\alpha_\beta_{(\nu)} \simeq 0$$

On this level only massive *spin 2 field* survives!
But other particles are not superluminal!

Pauli-Fierz Lagrangian:

\[ h^{\mu\nu} \mathcal{E} h_{\mu\nu} + m^2 (h_{\mu\nu} h^{\mu\nu} - h^\mu_\mu h^\nu_\nu) \]

Earth’s size

This massive spin 2 field is not universal!

\[ h_{\alpha\beta} T^{\alpha\beta}_{(\nu)} \]

\[ M_* \]

\[ h_{\alpha\beta} T^{\alpha\beta}_{(other \ particles)} \]

\[ M \]
Neutrino Metric Sourced by the Earth

\[ g^{(\nu)}_{00} = (\left(1 - \frac{1}{3}\epsilon\right) + \epsilon)\eta_{00}, \quad g^{(\nu)}_{ij} = \left(1 - \frac{1}{3}\epsilon\right)\eta_{ij}, \]

where \( \epsilon \equiv \frac{\mathcal{M}_\odot}{4\pi M_* M R_\odot} \)

superluminality \( \rightarrow \epsilon < 0 \rightarrow M_* M < 0 \)

Sign asymmetry! - Off Diagonal Antigravity...

\[ \text{OPERA} \rightarrow M_* M \sim 10^{-4} M_P^2 \]
Naive Constraints

* 5th force \( M > 10^2 \div 10^6 \, M_{Pl} \)

* Star cooling and BBN \( M_* > 10^8 \) GeV

\[ M_* \sim 10^{-6} \, M_{Pl} \quad \& \quad M \sim 10^2 \, M_{Pl} \]

one can choose

* Linear approximation works because for the Vainshtein radius

\[ R_V \sim ((M_{\oplus}/M^2)m^{-4})^{1/5} \sim 10^5 \, \text{cm} \ll R_{\oplus} \]
Strong coupling

For the “scalar part” of the graviton \( h_{\mu\nu}^{LL} = \varphi \eta_{\mu\nu} + \frac{\partial_\mu \partial_\nu \varphi}{m^2} \)

\( T_{(\nu)}^{\alpha\beta} \) is not conserved! There are weak and neutral currents!

\[
g \frac{\partial_\mu \varphi \partial_\mu \bar{\nu} \gamma^\alpha l_\nu W^+_{\alpha}}{m^2 M_*} \quad \text{and} \quad \frac{g}{\cos \theta_W} \frac{\partial_\mu \varphi \partial_\mu \bar{\nu} \gamma^\alpha \nu Z_\alpha}{m^2 M_*}
\]

very low strong coupling scale of the strength of Dark Energy!

\[
\Lambda = \left( m^2 M_* \right)^{1/3} \sim 10^{-3} \text{ eV}
\]
Conclusions:
no good theoretical model - always rather low strong coupling

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Superluminal Neutrinos. ................. ???