Gravitational interaction of neutrinos in models with large extra dimensions

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[hep-ph/0012227]
[hep-ph/0103249]

Neutrinos and gravity

The effect of gravity on neutrino oscillation is tiny because of the equivalence principle

- spin-coupling effects
- violation of equivalence principle

[M. Gasperini, PRD 38 (1988) 2635; A. Halprin, C.N. Leung and J. Pantaleone, PRD 53 (1996) 5365]

Recent new angles

assume extra space-time dimensions

⇓

make them large enough to be observable

⇓

space-time geometry

⇓ ⇓

factorized non-compact

⇓

$M_{Planck} \rightarrow M_f$

⇓

M_f can be as small as 1 TeV

A long history

[D.W. Joseph, PR 126 (1962) 319
K. Akama, arXiv:hep-th/0001113
V.A. Rubakov and M.E. Shaposhnikov, PLB 125 (1983) 136
M. Visser, PLB 159 (1985) 22
E.J. Squires, PLB 167 (1986) 286
P. Horava and E. Witten, NPB 475 (1996) 94
L. Randall and R. Sundrum, PRL 83 (1999) 3370 and 4690
A. Brandhuber and K. Sfetsos, JHEP 9910 (1999) 013
...]

[J.D. Lykken, PRD 54 (1996) 3693
N. Arkani-Hamed, S. Dimopoulos and G. Dvali, PLB 429 (1998) 263
I. Antoniadis et al., PLB 436 (1998) 257
N. Arkani-Hamed, S. Dimopoulos and G. Dvali, PRD 59 (1999) 086004
...]

Sterile neutrino in the bulk

[G. Dvali and A. Yu. Smirnov, NPB 563 (1999) 63]

- standard model fields localized within 4-dimensional space-time
- fermion singlet allowed to propagate in the bulk with gravity

D=4+1+2

$$(2\pi)^3 M_f^5 R\,\rho^2 = M_{\mathrm{P}}^2 \equiv (4\,\pi\,G_N)^{-1}$$

Higgs mechanism in $D = 5$

$$m_D = h\,v\,M_f/M_{\mathrm{P}}$$

Oscillations

$$\tan 2\,\theta_m^{(n)} = \frac{\sin 2\,\theta_0^{(n)}}{\cos 2\,\theta_0^{(n)} - 2\,p\,V_m\,(R/n)^2}$$

Neutrino propagating in $D = 5$ space-time

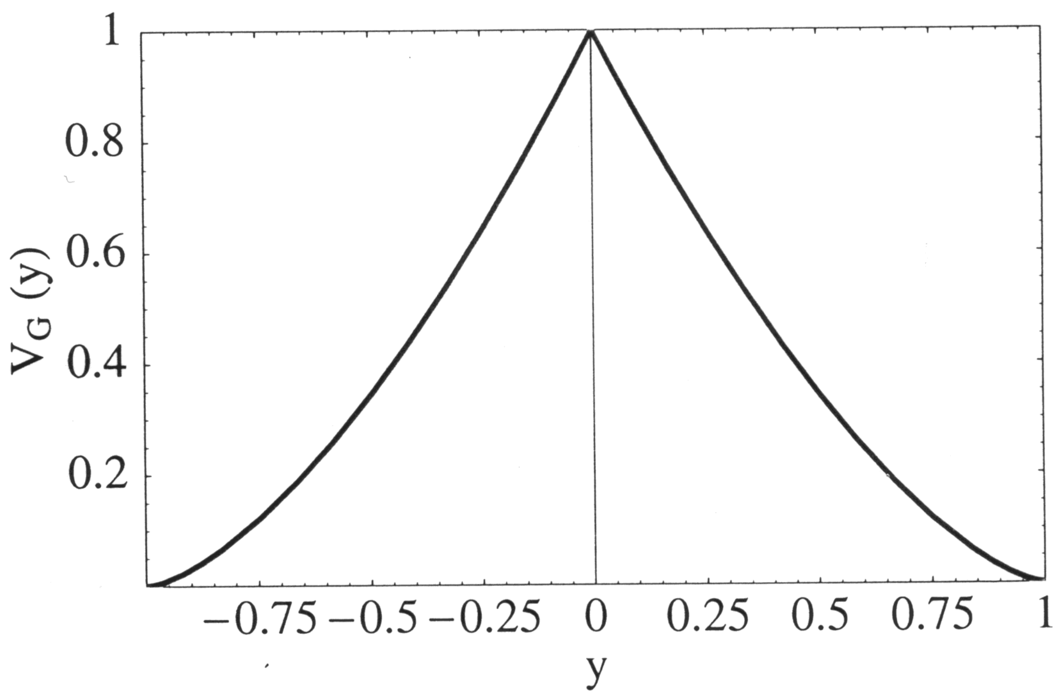
Enter gravity

the five-dimensional point of view

$$\begin{cases} [\partial_0 + \sigma^i \partial_i + i\, V_m + i\, V_G(y)]\nu_L & = & -i\, m^{(5)} N_R \\ [\partial_0 + \sigma^i \partial_i + i\, V_G(y)] N_L & = & -\partial_y N_R \\ [\partial_0 + \sigma^i \partial_i + i\, V_G(y)] N_R & = & \partial_y N_L + i\, m^{(5)} \nu \end{cases}$$

The potential energy

$$V_G(y) = -8\,\pi^2\,G^{(5)}\,\varepsilon_\nu\,\xi_N\,m_N\left\{\sqrt{R^2-y^2} - y\,\mathrm{arctan}\,\sqrt{R^2-y^2}/y\right\}$$



Bulk vs. standard neutrinos

potential energy $V_G(y)$

$\Downarrow$

bulk neutrinos feel a different potential wrt neutrinos constrained on the 4-dimensional world

$\Downarrow$

effective violation of the equivalence principle

$\Downarrow$

possibly large gravitational effects on neutrino physics

The effective Hamiltonian

$$i\frac{\mathrm{d}}{\mathrm{d}t}\begin{pmatrix} \nu_L \\ N_L^{(1)} \\ N_L^{(-1)} \\ \cdots \\ N_L^{(n)} \\ N_L^{(-n)} \end{pmatrix} = \mathcal{H}\begin{pmatrix} \nu_L \\ N_L^{(1)} \\ N_L^{(-1)} \\ \cdots \\ N_L^{(n)} \\ N_L^{(-n)} \end{pmatrix}$$

$$
2\,p\,\mathcal{H} = \begin{pmatrix}
m_D^2(n+1) - 2p(1-\Omega)V_m & m_D/R & -(m_D/R) & \cdots & n(m_D/R) & -n(m_D/R) \\
(m_D/R) & 1/R^2 & 2pV_G^{(2)} & \cdots & 2pV_G^{(n-1)} & 2pV_G^{(n+1)} \\
-(m_D/R) & 2pV_G^{(2)} & 1/R^2 & \cdots & \cdots & \cdots \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
n(m_D/R) & 2pV_G^{(n-1)} & \cdots & \cdots & n^2/R^2 & 2pV_G^{(2n)} \\
-n(m_D/R) & 2pV_G^{(n+1)} & \cdots & \cdots & 2pV_G^{(2n)} & n^2/R^2
\end{pmatrix}
$$

Oscillations

$$V_G(0) - V_G^{(0)} = -\Omega\, V_m$$

$$\Omega \simeq 10^5 \left(\frac{1\,\text{TeV}}{M_f}\right)^3 \left(\frac{R}{100\,\mu\text{m}}\right) \left(\frac{\varepsilon_\nu}{1\,\text{MeV}}\right) \frac{\xi_N}{\xi_e - \xi_N/2}$$

$$\boxed{\tan 2\,\theta^{(n)}_{(m+G)} = \frac{\sin 2\,\theta_0^{(n)}}{\cos 2\,\theta_0^{(n)} - 2\,(1-\Omega)\,p\,V_m\,(R/n)^2}}$$

Observable consequences

- change the values of the parameters used in fitting the experimental data and the possibility of a resonance solution itself;

- produce a peculiar distortion of the neutrino spectrum because of the extra energy dependence.

Observables consequences

- Ultra high-energy cosmic rays

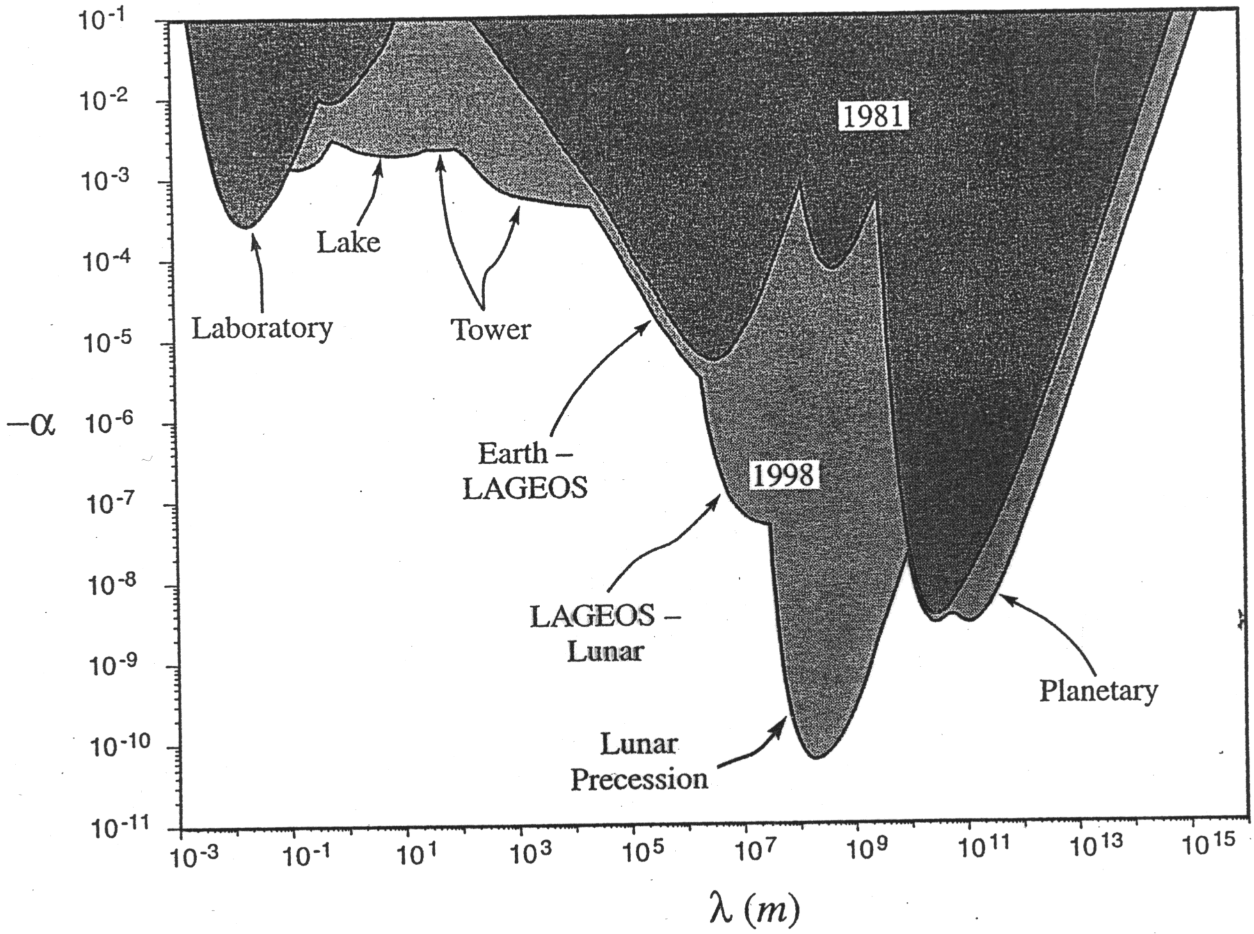
- Solar neutrinos: if only one extra large dimension and $M_f < 10$ TeV

Non-Newtonian gravity

How well do we know Newtonian gravity?

$$V(r)|_{r*} = \frac{G_N m_1 m_2}{r}\left[1 + \alpha_G \, e^{-r/\lambda}\right]\Big|_{r*}$$

Non-Newtonian gravity, II



There is planty of room at the bottom ($\lambda < 1$ mm)

Gravity in $4+\delta$ dimensions

$$V_\delta(r) = \frac{G_N m_1 m_2}{r}\left(\frac{a_\delta}{r}\right)^\delta$$

$$a_\delta = (G^{(\delta)}/G_N)^{1/\delta} = \frac{2\,\pi}{M_f}\left(\frac{4\,\pi}{\Omega_\delta}\frac{M_{\mathrm{P}}^2}{M_f^2}\right)^{1/\delta}$$

$$M_{\mathrm{P}} \equiv 1/\sqrt{G_N} = 1.22\times 10^{16}\ \mathrm{TeV}.$$

$$\Omega_\delta = 2\pi^{(3+\delta)/2}/\Gamma[(3+\delta)/2]$$

Non-Newtonian gravity

$$\alpha_G(\lambda) \leq \min_r \{[\left(\frac{a_\delta}{r}\right)^\delta - 1]e^{r/\lambda}\}$$

$$M_f = 1.2 \text{ TeV}$$