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## Two-brane structure and its manifestation

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We study the neutrino sector of an eight-dimensional two-brane model based on  $f(R)$  gravity. The metric is warped:

$$ds^2 = e^{2\gamma(u)} \eta_{\mu\nu} dx^\mu dx^\nu - du^2 - r^2(u) d\Omega_{n-1}^2.$$

Here  $u$  is the radial extra coordinate, and the remaining three coordinates parametrise a compact internal manifold. The classical field equations admit a countable family of solutions in which  $\gamma(u)$  and  $r(u)$  vanish at two endpoints  $u_1$  and  $u_2$ . Matter fields accumulate near these endpoints. A pair of four-dimensional branes therefore forms spontaneously, as a solution of the gravitational dynamics. Nothing is assumed about their existence, position or tension.

We then derive the consequences of this geometry for the matter sector. Massless bulk fermions obey

$$\left( \partial_u + \frac{\partial_u r(u)}{2r(u)} + 2\partial_u \gamma(u) \right) Y(u) = 0$$

along  $u$ . The solution is sharply peaked at  $u_1$  and  $u_2$ . On the compact factor, a normalisable chiral zero mode requires a suitable background gauge field. Each bulk fermion then has one chiral zero mode per brane, and the two sets of modes are effectively decoupled, because  $|Y(u)|^2$  is exponentially small between the branes. The Higgs vacuum expectation value differs on the two branes, so masses and couplings on brane-2 are free up to  $m_D$ . The gauge zero mode behaves differently: it is constant along  $u$ , so the  $Z$  boson is common to both branes.

Dimensional reduction of the neutral-current action reflects this structure. Besides the canonical on-brane vertices, it produces off-diagonal neutrino- $Z$  couplings weighted by the overlap of the two profile functions. Exponential localisation makes this overlap of order  $\exp[-m(u_2 - u_1)]$ , that is about  $10^{-35}$  for an interbrane distance  $u_2 - u_1 \approx 80 m_D^{-1}$  and  $m \sim 1$ . The geometry thus supplies an exponentially small parameter without fine-tuning. A seesaw with the brane-2 vacuum expectation value places a superheavy sterile neutrino on the hidden brane, and the off-diagonal vertex lets it decay at a rate suppressed by the squared overlap. The resulting lifetime is cosmological, so the particle is a dark-matter candidate.

The decay  $\nu^{(2)} \rightarrow \nu^{(1)} Z^* \rightarrow \nu^{(1)} \nu^{(1)} \bar{\nu}^{(1)}$  gives a quasi-monochromatic flux peaked at  $E_\nu \sim m_2$ . We estimate the diffuse rate and compare it with IceCube and KM3NeT data, including KM3-230213A at  $2.2 \times 10^8$  GeV. The competing annihilation channel  $\bar{\nu}^{(2)} \nu^{(2)} \rightarrow Z^* \rightarrow \bar{\nu}^{(1)} \nu^{(1)}$  falls about 18 orders of magnitude short, because its production rate scales as  $m_2^{-4}$ .

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