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ЭЛЕМЕНТАРНЫЕ ЧАСТИЦЫ И ПОЛЯ

NEUTRINO MASS AND THE MIRROR UNIVERSE

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The existence of the mirror world, with the same microphysics as our own one but with opposite P-asymmetry, not only restores an exact equivalence between left and right, but provides a natural explanation via see-saw-like mechanism why neutrino is ultralight.

It is well known, P-noninvariance of the weak interactions does not necessarily mean that there is an absolute difference between left and right in nature. Any P-asymmetry in matter (for example, the absence of right-handed neutrino) can be accompanied by the opposite P-asymmetry in anti-matter (for example, the absence of left-handed antineutrino), so that the overall situation can still be left-right symmetric. It is CP, not P, which represents the symmetry between left and right [1]. Less formally, although our world looks quite asymmetric when looking through P-mirror, it can still appear symmetric when looking through CP-mirror. But now we know that it is not either! In fact, it is the common belief, that the left-right symmetry is connected with CP, which makes CP-noninvariance so strange, otherwise a natural question we should to ask is why CP-violation is so tiny (and we really have to answer this question in QCD [2]).

But, contrary to this common belief, the left-right symmetry is not necessarily connected with CP-invariance. Space inversion (and any other geometric symmetry from the Poincare group) is represented not by one quantum-mechanical operator P, but by a whole class of operators $\{IP\}$, where $\{I\}$ forms an internal symmetry group of the system [3]. So we can use MP, instead of CP, as a quantum-mechanical parity operator relating left and right, where M is any internal symmetry operator. But can we find some good enough internal symmetry for which MP is exactly conserved?

In fact such an internal symmetry was suggested by Lee and Yang in their famous paper [4], about the possibility of parity nonconservation, and it involves a drastic duplication of the world. For any ordinary particle an existence of the corresponding "mirror" particle is postulated, so that there are two kinds of electrons, two kinds of photons and so on. The mirror world completely resembles the ordinary one at the microphysics level, except that it reveals an opposite P-asymmetry. In such an extended universe MP is an exact symmetry, where M interchanges ordinary and mirror particles, and there is no absolute difference between left and right: this universe looks symmetric when looking through MP-mirror.

Of course the mirror particles should interact with the ordinary ones only extremely weakly to escape detection [5], but they should interact at least gravitationally [5], and the big enough clusters of mirror matter can cause observable gravitational effects [6]. Even it is possible that such effects were already observed, if we adopt the dark matter interpretation as a mirror matter [7]. Then the recent observation of the possible gravitational microlensing events [8] can appear to be nothing but the observation of mirror stars [9]!

If there exist particles which carry both ordinary and mirror electric charges (a connector), then they can cause a significant mixing between ordinary and mirror photons even for a very heavy connector, and as a result mirror charged particles from the mirror world acquire a small ordinary electric charge [7, 10]. Such milli-charged particles had been searched but never found [11]. Another consequence of the above mentioned photon mixing would be a possibility for positronium to "disappear" in vacuum (to oscillate into mirror positronium) [12]. It follows from available orthopositronium experimental data that photon–mirror photon mixing, if present, is very small [13] and most probably the mixed form of matter carrying both ordinary and mirror electric charges does not exist [12].

The ordinary and mirror universes can be grand unified either with $G \times G$ type gauge group [14] or even more tightly with $SO(n)$ type groups [15]. In the latter case the existence of such queer objects as Alica strings is possible [15, 16]. The ordinary particle encircling around this string transforms into the mirror particle. So the standard particles might go through the looking-glass by means of such strings, as Alica did [17]. This can lead to the observable astronomical effects. For example, if Alica string passes between the Earth and a galaxy, the galaxy becomes invisible for a terrestrial observer [16].

The most serious test for the mirror world scenarium can come from cosmology [18, 19], because the new degrees of freedom introduced can affect the big bang nucleosynthesis [20] and overproduce the primordial ^{4}He. But contrary to the previous claims [18, 19], it appears that there are enough dodges for mirror world to pass this examination [9, 21].

Rather unexpectedly, one more support for the mirror world hypothesis comes from the superstring theories. Namely, it was shown that some heterotic string models lead in the low energy limit to the promising $E_8 \times E_8$ effective gauge theory, with second E_8 acting in the "shadow" world of mirror particles [22].

A detailed analysis of observational physics of the mirror world and a broad program of searches for astronomical effects of mirror matter was given by Khlopov and his collaborators in [23].

Let us emphasize that for mirror world to restore an exact left-right symmetry, its principal existence, with the same microphysics as the ordinary world, is sufficient. The macrophysics can be quite different. But the left-right symmetry is a rather abstract concept. Can we point to some more material evidence in favor of the mirror world existence? We would like to remark in this note that such an evidence does really exist. Even if the arguments of [9] failed and the mirror world with different macrophysics is empty enough, Francesco Sizzi's opinion, cited in [18], that such a mirror universe, just like the moons of Jupiter discovered by Galileo, "can have no influence on the Earth and therefore would be useless and therefore does not exist", is still inapplicable, because even if the mirror matter is diluted away by inflation, it still leaves a very clear signal of its existence and this is very small mass of neutrino!

Actually a possible connection between the mirror world and neutrino mass was already hinted in [15] and [24]. We are going to argue that the suggestion of [24], that small neutrino mass maybe is a thin thread leading to the mirror world, is indeed correct.

Although plenty of models were suggested to explain the huge mass difference between neutrino and the corresponding charged lepton (see, for example, [25] and references therein), the most elegant explanation is given by the so called see-saw mechanism [26]. In its original form it gives a naturally small Majorana mass for left-handed neutrino, but after some modifications it is possible to produce small Dirac neutrino mass also [27, 28]. In the latter case an existence of other kinds of neutrinos, which are singlets under electroweak gauge group, is postulated. Let us however note that the universe with the mirror world is ideally suited for see-saw-like mechanism resembling the one described in [28]!

For simplicity, let us consider only one generation and suppose that the gauge group is $G_{WS} \times G_{WS}$ with conventional electroweak group $G_{WS} = SU(3) \times SU(2) \times U(1)$. Let us farther suppose that the known quarks and leptons together with their mirror partners transform as a $(f, 1) \oplus (1, f')$ representation of $G_{WS} \times G_{WS}$, where f is the usual quark-lepton family:

$$f = \begin{pmatrix} u \\ d \end{pmatrix}_L \begin{pmatrix} \nu \\ e \end{pmatrix}_L u_R d_R e_R,$$

and f' is the same for mirror particles except that left and right are interchanged, i.e., f' contains right doublets and left singlets with regard to the mirror weak isospin:

$$f' = \begin{pmatrix} u' \\ d' \end{pmatrix}_R \begin{pmatrix} \nu' \\ e' \end{pmatrix}_R u'_L d'_L e'_L.$$

Not to discriminate neutrino, let us also assume that there exist a right-handed neutrino ν_R and its left-handed mirror partner ν'_L, which are $G_{WS} \times G_{WS}$ singlets. Such particles naturally arise if, for example, $G_{WS} \times G_{WS}$ is a low-energy remnant of $SO(10) \times SO(10)$ grand unification.

If there exist some scalar field φ, which is singlet under $G_{WS} \times G_{WS}$, then the following Yukawa coupling is possible $\varphi(\bar{\nu}_R \nu'_L + \bar{\nu}'_L \nu_R)$, and if φ develops a nonzero vacuum expectation value, this will result in $\nu_R - \nu'_L$ mixing $M(\bar{\nu}_R \nu'_L + \bar{\nu}'_L \nu_R)$. Besides, ordinary electroweak Higgs mechanism and its mirror partner will lead to neutrino and mirror neutrino masses $m(\bar{\nu}_L \nu_R + \bar{\nu}_R \nu_L + \bar{\nu}'_R \nu'_L + \bar{\nu}'_L \nu'_R)$, where m is expected to be of the order of the charged lepton mass of the same generation. Note that *MP*-symmetry guarantees the presence of only one mass parameter.

$G_{WS} \times G_{WS}$ symmetry is not affected by $\langle \varphi \rangle \neq 0$, so it is natural to connect this vacuum expectation value to some early stages of symmetry breaking in more full theory (for example, $SO(10) \times SO(10) \longrightarrow SU(5) \times SU(5)$). Therefore the expected value of M is 10^{14}–10^{15} GeV, and m/M is really very small.

Thus we expect the following neutrino mass terms:

$$L_m = M(\bar{\nu}_R \nu'_L + \bar{\nu}'_L \nu_R) + \\ + m(\bar{\nu}_L \nu_R + \bar{\nu}_R \nu_L + \bar{\nu}'_R \nu'_L + \bar{\nu}'_L \nu'_R). \quad (1)$$

The mass eigenstates of (1) (physical neutrinos) are

$$\begin{aligned} \tilde{\nu}_L &= \cos\theta \nu_L + \sin\theta \nu'_L, \\ \tilde{\nu}'_R &= \cos\theta \nu'_R + \sin\theta \nu_R \equiv MP(\tilde{\nu}_L), \\ \tilde{\nu}'_L &= \cos\theta \nu'_L - \sin\theta \nu_L, \\ \tilde{\nu}_R &= \cos\theta \nu_R - \sin\theta \nu'_R \equiv MP(\tilde{\nu}'_L). \end{aligned} \quad (2)$$

Substituting (2) into (1), we immediately find that

$$\mathrm{tg}(2\theta) = -2r$$

and

$$L_m = M_+\left(\bar{\tilde{\nu}}_R\tilde{\nu}'_L + \bar{\tilde{\nu}}'_L\tilde{\nu}_R\right) + M_-\left(\bar{\tilde{\nu}}'_R\tilde{\nu}_L + \bar{\tilde{\nu}}_L\tilde{\nu}'_R\right), \quad (3)$$

where

$$r = \frac{m}{M}, \quad M_+ = \frac{M}{2}(1 + \sqrt{1+4r^2}),$$

$$M_- = \frac{M}{2}(1 - \sqrt{1+4r^2}).$$

So we have a superheavy Dirac neutrino ($\tilde{\nu}'_L$, $\tilde{\nu}_R$). Formulae (2) show that this is a rather bizarre object, its left-handed part mostly inhabiting in the mirror world, while right handed part prefers our ordinary world. Besides, we have a ultralight Dirac neutrino ($\tilde{\nu}_L$, $\tilde{\nu}'_R$). Its left-handed part $\tilde{\nu}_L$ is nearly our old nice neutrino from β-decay, and right-handed part $\tilde{\nu}'_R$, is probably more familiar for mirror physicists.

To summarize, the mirror world hypothesis of Lee and Yang is very attractive. It not only restores the full equivalence between left and right, but also can explain why neutrino has incredibly small mass. It should be mentioned that the idea of this work emerged while reading the book [29].

Note added:

After this work was completed, the author became aware of some relevant papers. The possibility of exact parity conservation was rediscovered by Foot, Lew, and Volkas in [30] and possible consequences, in particular for neutrino physics, were thoroughly investigated in the subsequent publications [31]. The effect of the mirror world on neutrino physics was also considered by Berezhiani and Mohapatra in their recent work [32].

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МАССА НЕЙТРИНО И ЗЕРКАЛЬНАЯ ВСЕЛЕННАЯ

З. К. Силагадзе

Существование зеркального мира с той же микрофизикой, как в нашем мире, но с противоположной *P*-асимметрией не только восстанавливает полную эквивалентность между левым и правым, но может предоставить естественное объяснение с помощью see-saw-механизма, почему масса нейтрино так мала.