Mirror particles and mirror matter: 50 years of speculation and search

L.B. Okun
ITEP, Moscow, Russia

Abstract

This review describes the history of discovery of violation of spatial parity $P$, charge conjugation parity $C$, combined parity $CP$. The hypothesis of existence of mirror particles was called upon by its authors to restore the symmetry between left and right. The review presents the emergence and evolution of the concepts “mirror particles” and “mirror matter”. It could serve as a concise guide to the “mirror-land”. An important part of the review is the list of about 250 references with their titles.

1 Introduction

The terms “mirror particles”, “mirror matter” and “mirror world” refer at present to the hypothetical hidden sector of particles and interactions which compensate the mirror asymmetry of the weak interactions of ordinary particles. Mirror particles are considered to be a possible component of the invisible dark matter. The history of mirror particles is a history of intertwining of parity violation and parity degeneracy, strict and broken mirror symmetry, dark matter in the universe, atomic, nuclear and high energy physics, cosmology and astrophysics.
2 1950’s. Violation of P and C.
Conservation of PC.

In the middle of the 1950’s the so called θτ puzzle became the most challenging problem of elementary particle physics. At that time the decays $K^+ \rightarrow 2\pi$ and $K^+ \rightarrow 3\pi$ were assigned to two different mesons $\theta^+$ and $\tau^+$, having opposite P-parities. But the masses as well as lifetimes of $\theta^+$ and $\tau^+$ were suspiciously close. Therefore Lee and Yang put forward the idea of parity degeneracy \[1.\] However, in April of 1956 at the Rochester conference Feynman referring to Block asked the crucial question: could it be that parity is not conserved?

Here are a few excerpts from the Proceedings \[2\]:

“J.R. Oppenheimer presiding:

There are the five objects $K_{\pi 3}$, $K_{\pi 2}$, $K_{\mu 2}$, $K_{\mu 3}$, $K_{e 3}$. They have equal, or nearly equal, masses, and, identical, or apparently identical, lifetimes. One tries to discover whether in fact one is dealing with five, four, three, two, or one particle ...”.

“Yang’s introductory talk followed:

... the situation is that Dalitz’s argument strongly suggests that it is not likely that $K^+_{\pi 3} (\equiv \tau^+)$ and $K^+_{\pi 2} (\equiv \theta^+)$ are the same particles”.

“Dalitz discussed the $\tau$-$\theta$ problem ... 600 events ... when plotted on the “Dalitz diagram”, give a remarkably uniform distribution ... This would point to a $\tau$-meson of spin-parity $0^-$ ...”.

“... Feynman brought up a question of Block’s:

Could it be that the $\theta$ and $\tau$ are different parity states of the same particle which has no definite parity, i.e. that parity is not conserved ...”

“Yang stated that he and Lee looked into this matter without arriving at any definite conclusions.”

Presumably Feynman meant a special mechanism of parity violation through the mixing of degenerate scalar and pseudoscalar mesons.

It is interesting that neither Dalitz, nor Michel, who also participated in the discussion, mentioned the possibility of parity violation.

A few months later Lee and Yang suggested that parity is not conserved in weak decays and proposed experiments to search for pseudoscalar correlations of spin and momentum \[3\]. (Their famous paper was received by Physical Review on June 22, circulated as a preprint, and appeared in the journal on October 1, 1956.) At the end of this paper, in order to save the left-right
symmetry in a more general sense, the existence of hypothetical right-handed protons, \( p_R \), was considered, though the term “mirror particles” was not used and \( p_R \) and \( p_L \) were assumed to interact “with the same electromagnetic field and perhaps the same pion field”.

(Much later I learned that already in 1952 Michel \[4\] had considered parity violating interactions and pseudoscalar correlations between momenta of several particles in multiparticle processes. Wick, Wightman and Wigner considered pseudoscalar amplitudes \[5\]. Purcell and Ramsey suggested \[6\] to test experimentally parity conservation by measuring the electric dipole moment of the neutron. However, they did not realize (as Landau did realize subsequently) that electric dipole moment violates the time-reversal invariance as well. Berestetsky and Pomeranchuk published a note \[7\] on the beta-decay of the neutron, in which they mentioned a remark by Landau that there exists actually ten four-fermion couplings “if one allows, in addition to spinors for pseudo-spinors”.)

As is well known, the experiments proposed by Lee and Yang were performed half a year later and found large left-right asymmetries in the \( \beta \)-decay of \( ^{60}\text{Co} \) \[8\] and in \( \pi \rightarrow \mu \rightarrow e \) decays \[9, 10\].

Before the results of these experiments were published, Ioffe and Rudik had submitted to ZhETF a manuscript in which they argued that the existence of short-lived C-even \( K^0 \) meson and long-lived C-odd \( K^0 \) meson proved that C-parity was conserved and hence violation of P-parity would mean (due to CPT-theorem) violation of T-parity (time reversal invariance). This led them to the conclusion that P-odd, but T-even \( sp \) asymmetries are impossible (\( s – \) spin, \( p – \) momentum).

I vividly recall how ITEP theorists discussed these arguments with Landau after one of the traditional Wednesday ITEP seminars in November 1956. (At that time the name ITEP did not exist; it was called TTL – Thermo-Technical Laboratory.) The discussion took place in room No.9, where at that time young theorists worked and where my desk was.

Landau was absolutely against parity violation because space is mirror symmetric. This is analogous to conservation of momentum and angular momentum, because space is homogeneous and isotropic. Of course the analogy is not complete, because shifts and rotations are continuous, while reflections are discrete.

[Half a year earlier the Lebedev Institute hosted the first Moscow conference on elementary particles in which American physicists participated \[11, 12\]. I recall that Landau laughed at Gell-Mann (the youngest of the
Americans, but already very famous), when the latter during his seminar at
the Institute of Physical Problems mentioned that parity violation could be
one of the solutions of $\theta \tau$-problem.

Roughly at the same time Landau reacted similarly at an unpublished
note by Shapiro. In this note a Wu-type experiment was suggested. I learned
about it three years later, when Shapiro moved from the Moscow university
to ITEP and showed me his unpublished note. I remember that there was
a wrong statement in this note: the value of energy is different in left- and
right-handed coordinates, if $P$ is violated. Later Shapiro gave this note
to the director of ITEP Alikhanov, and it was lost. There was no copying
machine at ITEP.

But let us return to the discussion in room No.9. During the discussion
I pointed out that the short- and long-lived kaons might exist not due to
C-invariance, as was originally proposed by Gell-Mann and Pais [16], but
due to even approximate T-invariance. In that case $S$ asymmetries would
be allowed as well as the decay of long-lived neutral kaon into $3\pi^0$. As
a consequence of this discussion, Ioffe and Rudik urged me to become a
coauthor of their paper with my radical amendments. At first I refused,
but conceded after Ioffe literally went down on one knee in front of me. Our
article [18] was noticed by Yang and Lee, who together with Oehme [19]
independently but later came to the same conclusions (see references to [18]
in their Nobel lectures [20, 21]).

Another consequence of the discussion was that Landau suddenly changed
his mind and put forward the idea of strict CP-conservation [22]. At the end
of this paper he wrote: “I would like to express my deep appreciation to
L. Okun, B. Ioffe and A. Rudik for discussions from which the idea of this
paper emerged”. According to his idea, reflection in a mirror of a process

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1Gell-Mann repeated the talk he gave at Landau seminar, also in the office of Tamm. I was taking notes of both of them. He stopped for a moment and asked me with a smile: “What happens if you find at home that the two records contradict each other?”

In the 1980’s Telegdi published very interesting reports on the history of parity violation [14][15]. In [15] he wrote: “Murray Gell-Mann emphasized to me ..., that I.S. Shapiro most strenuously objected to the parity violation idea when M.G.M. presented the latter in 1956 in the Landau seminar as one of the possible solutions to the $\tau-\theta$ puzzle.”

As I have already mentioned, I remember the objections by Landau, but I don’t recall that they were raised also by Shapiro at the same seminar.

2Further exposition of this statement is contained in [13].

3The scheme in which $P$ and $T$ are violated, but $C$ is conserved, was at length discussed in [17] even after it was falsified by experiment.
with particles shows us a non-existent process which becomes physical only after changing particles into corresponding antiparticles.

An excellent example of CP-conjugated particles was presented by Landau [25] in his theory of massless longitudinally polarized neutrinos: the spin of \( \nu \) is oriented opposite to its momentum, while spin of \( \bar{\nu} \) is oriented along its momentum; in other words \( \nu \) is left-handed, \( \bar{\nu} \) is right-handed. Both articles [22] and [25] were published as one article in Nuclear Physics [26]. Longitudinal neutrinos were independently considered by Salam [27] and by Lee and Yang [28]. The longitudinal neutrinos lighted up the road to the \( V - A \) theory [29, 30]. According to this theory, in the relativistic limit \( (v/c \rightarrow 1) \) all elementary fermions become left-handed in weak interactions of charged currents, while their antiparticles become right-handed. Only a few years ago the discovery of neutrino oscillations made it clear that neutrinos are not massless and hence the theory of longitudinal neutrinos is valid only approximately, although in many cases with extremely high accuracy.

It is worth mentioning here the idea of the baryonic photon coupled to baryonic charge [31]. This article became an inspiration for further search of leptonic photons, paraphotons and mirror photons (see below).

3 1960's. CP-violation

I liked very much the idea of the strict CP-conservation. But, on the other hand, I could not understand why the coefficients in the Lagrangian cannot be complex. Thus, in the lectures at ITEP [32] weak interactions of hadrons were described on the basis of a composite model assuming CP-conservation. In lectures in Dubna [33] and in the book [34] I insisted that the experimental test of CP-invariance is one of the highest priorities.

A group of Dubna experimentalists led by Okonov searched for CP-violating decay \( K_2^0 \rightarrow \pi^+ \pi^- \). They have not found two-body decays among 600 three-body decays [35]. Unfortunately at this stage they were stopped by their lab. director. The group was unlucky. Two years later a few dozens of these decays with the value of the branching ratio almost reached in [35] were discovered by the Princeton group [36].

The discovery of the decay \( K_2 \rightarrow 2\pi \) by Christenson et al. [36] put an end to Landau’s idea of strict CP-conservation according to which antiparticles look exactly like mirror images of particles. To avoid this conclusion

\[ \text{\footnotesize See also } [24]. \]
Nishijima and Saffouri \cite{37} put forward the hypothesis of “shadow universe” to explain the two pion decays without CP-violation. According to \cite{37}, the decays to two pions observed in 1964 were decays not of CP-odd $K_2^0$ but of a new hypothetical long-lived CP-even “shadow” $K_1^{0\prime}$-meson through its transition into ordinary $K_0^0$. However, as was shown in \cite{38}, this mechanism contradicts the results of the neutrino experiment, because shadow $K_1^{0\prime}$-mesons would penetrate through the shielding and decay into two pions in the neutrino detector, while such events were not observed.

In the next paper \cite{39} Kobzarev, Pomeranchuk, and myself postulated CPA-symmetry (A – from Alice) and the existence of hypothetical mirror particles and of a mirror world. (The modern terminology, in which mirror matter refers only to duplication of all our particles (not some of them) was \textit{in statu nascendi}, therefore the “mirror world” and “mirror particles” were used in \cite{39} practically as synonyms. Note that the Standard Model did not exist at that time.) According to \cite{39}, mirror particles cannot participate in ordinary strong and electromagnetic interactions with ordinary particles. In this respect they differ from the right-handed protons considered by Lee and Yang \cite{3}. The hidden mirror sector must have its own strong and electromagnetic interactions. This means that mirror particles, like ordinary ones, must form mirror atoms, molecules and, under favorable conditions, invisible mirror stars, planets and even mirror life. Moreover, this invisible mirror world can coexist with our world in the same space.

I recall a weekend hike with Igor Kobzarev in a forest near Moscow, when I suddenly “saw” an invisible mirror train silently crossing a clearing. It was argued in our paper \cite{39} that such a situation is impossible. A mirror train needs a mirror globe, but a mirror globe would gravitationally perturb the trajectory of our globe. Gravitational coupling between two worlds seemed indispensable.\footnote{We did not know the pioneering articles on dark matter by Oort \cite{40} and Zwicky \cite{41,42}.} The coupling of the two worlds via neutral kaons was considered in \cite{43}.

Mirror particles were discussed at the fourth European conference on elementary particles (Heidelberg, September 1967) \cite{44} and at the Moscow conference on CP-violation (January 1968) (see \cite{45}).

Perhaps it is worth mentioning a few papers which at first sight have no direct relation to mirror matter. In \cite{46} the muonic photon was considered and the transitions between it and ordinary photon through a muonic loop.
This gives a coupling $\epsilon F_{\alpha\beta} F'_{\alpha'\beta'}$, where $F$ is our field, $F'$ – the new one, while $\epsilon$ is a dimensionless constant. Because of this coupling, which is at present called “kinetic mixing”, muonic neutrino acquires a tiny electric charge $\epsilon e$ (see also [66], [86]-[89], [147]-[153], [231]-[236]).

In [47] the gravitational dipole moment of the proton was discussed and was shown to be forbidden in the framework of general relativity. Gravitational interaction of the so called sterile neutrino was considered in [48].

As is well known, in the mainstream of particle physics, the quarks and the electroweak theory with spontaneous symmetry breaking were suggested in the 1960s. An important note by Sakharov [49] was published, which connected CP-violation with the baryon asymmetry of the universe and hence with our existence.

4 1970’s. “Minimum”. Exotic vacua

In the 1970’s charm, beauty and $\tau$-lepton were discovered and QCD was formulated, but there was a minimum of publications on mirror particles. I know only one paper, by Pavšić [50]. A relation between mirror symmetry and the structure of a particle was attempted in it: mirror nucleons are unconditionally necessary, while mirror leptons are necessary only if they have internal structure. This differs from the standard concept of the mirror matter. In 2001 the paper [50] was posted on electronic archive with a note: “An early proposal of ‘mirror matter’ published in 1974” [51].

Also in the 1970’s spontaneous breaking of gauge symmetries was brought to the cosmological model of hot universe [52]-[54] and the first articles were published on spontaneous breaking of CP-symmetry [55], on domain structure of vacuum [56, 57] and on metastable vacuum [58]. Vacuum domains are a consequence of spontaneous breaking of discrete symmetry. They appear during cooling of the universe after the big bang. Thus space itself could be not mirror symmetric (recall Landau’s arguments). Metastable vacuum was dubbed false vacuum three years later, see [59]-[61].

5 1980’s. Revival

A revival of interest in mirror particles occurred in the 1980’s. In papers [62]-[70] various aspects of hidden sector of particles and interactions were
considered. In [62] the existence of new long range forces and of $x$- and $y$-particles was suggested. According to [62], $y$-particles have no direct interactions with ordinary ones, while $x$-particles serve as connectors: they have interactions with both ordinary and $y$-particles. In [63, 64] the existence of gluon-like $\theta$-bosons was proposed. The role of $\theta$-bosons in the early universe was discussed in [65]. They have large confinement radius and can form unbreakable strings with length measured in kilometers. In [66] mirror hadrons and neutral meson connectors were discussed. The existence of hidden paraphotons was suggested in [67]. The mixing of paraphotons leads to photon oscillations discussed in [67]. Tiny charges of particles which are usually considered to be neutral (such as atoms and neutrinos) were discussed in [68]. A review of hypothetical phenomena was presented in the rapporteur talk “Beyond the Standard Model” [69]. It contained, among other subjects, photon oscillations and left-right symmetric models, but no mirror particles.

In 1986 Ellis visited ITEP and suggested to write a review about “nothing”. Together with Voloshin we wrote the review [70], a part of which was dedicated to mirror particles. However at the last moment I decided not to submit it to Soviet review journal Uspekhi Fiz. Nauk as a too speculative one, therefore it was published only as an ITEP preprint.

Voloshin continued the quest for mirror particles. He induced the ARGUS collaboration at DESY to search for decays $\Upsilon(2S) \to \pi^+ \pi^- \Upsilon(1S)$, in which $\Upsilon(1S)$ due to transitions to its mirror counterpart decays into “nothing”. The upper limit for the branching ratio of this invisible channel was established: 2.3% at the 90% CL [71, 72]. The search for invisible decay products of $\phi$-meson was carried out in [73].

An experimental group at ITEP measured the spectrum of electrons in the tritium $\beta$-decay and announced that the mass of the electron neutrino is 30 eV. This prompted Zeldovich and Khlopov to publish their review [74]. Alongside with other scenarios they discussed mirror neutrinos and their implications for cosmology and astrophysics. The neutrino mass was considered by them as a bridge to the mirror world, the transitions between our left-handed neutrino and mirror right-handed neutrino being responsible for $m_\nu$.

A model in which connectors between the two worlds are the so called hybrids (particles with electroweak quantum numbers of ordinary quarks, and mirror QCD quantum numbers of mirror quarks and their mirror counterparts) was considered in [75]. This model contains bound states with fractional charges – fractons.
Schwarz and Tyupkin [76] suggested unification of mirror and ordinary particles within an SO(20)-symmetry. In this model, mirror cosmic strings appeared. After circling such an “Alice string” an ordinary particle is transformed into a mirror particle and vice versa (see also [77] and [78]).

Further cosmological and astrophysical manifestations of mirror particles were discussed in [79]-[85]. In particular Alice strings were considered in [79, 82].

Glashow and his coworkers became interested in the mirror universe and photon oscillations [86, 87, 90]. In [87] he suggested to explain experimental anomaly in orthopositronium decays, observed at that time, by transitions between orthopositronium and mirror orthopositronium. (For later developments of this suggestion see [105], [148] - [153].)

Tiny ordinary electric charges of mirror particles which otherwise have no ordinary charge, but have a mirror electric charge, appear due to mixing of ordinary and mirror photons [88, 89] (see also [240]).

6 1991–2006. “Maximum”. From cosmology and astrophysics to LHC

A flood of mirror particle articles occurred after 1990.

The Australian physicist Foot became a great enthusiast of mirror particles and published dozens of articles on this subject. One can appreciate the range of his interests by looking at the titles of references [91] - [132] and of his book [133]. In [91] mirror symmetrical version of the standard gauge model was considered, in particular renormalizable mixing interaction of ordinary and mirror higgses was analyzed. Let us note that in this renormalizable model the strong transitions of three quarks into three mirror quarks or of two gluons into two mirror gluons are forbidden because such interactions are non-renormalizable. Therefore the discovery of a transition of neutron into a mirror neutron $n \leftrightarrow n'$ or of $\Upsilon \leftrightarrow \Upsilon'$ would falsify this theoretical model.

Let us also mention the new fantastic idea of grains of mirror matter embedded in the ordinary matter due to the interaction caused by mixing of ordinary and mirror photons [114, 118, 121]. Many coauthors of Foot – Volkas, Ignatiev, Mitra, Gninenko, Silagadze – published also their own papers on mirror particles [134]-[159] (see also [151]). A few of these papers
were also devoted to mirror grains [145, 147], [156]–[159].

An impressive contribution to the field of mirror particles belongs to Berezhiani, who together with his coauthors published over 15 papers on various subjects in mirror physics, mirror astrophysics and mirror cosmology [160]–[176]; (see also [177]–[182]).

Most of the papers cited in this section are based on strict mirror symmetry. They ascribe the observed macroscopic disparity between mirror and ordinary particles to the inflation stage of the universe (see [166, 143]).

Mohapatra published about 15 papers (many of them with coauthors) on various aspects of mirror astrophysics [183]–[196] in the framework of broken mirror symmetry.

The search [197]–[201] for gravitational microlenses produced by separate stars in the halos of galaxies – the so-called MACHOS (MASSive Compact Halo Objects) – has led to the discovery of an excess of machos in the direction of the Large Magellanic Cloud [200, 201]. Even before this discovery, theorists had indicated [202] [154]–[162] that some of the machos could be mirror stars. This interpretation was developed further in [203, 204]. Though the discovery of machos [200, 201] was questioned [205, 206] (see the discussion [207, 208]), many astrophysicists believe that the stellar dark matter cannot consist of ordinary baryons [209, 210].

Since the times of Oort [40] and Zwicky [41, 42] there existed two alternative explanations of anomalously high velocities of stars and galaxies (the so-called “virial paradox”): 1) invisible dark matter, 2) anomalously strong gravitational force at large distances. Recent observations [211, 212] of colliding clusters of galaxies seem to settle the ambiguity in favor of dark matter. The dark matter which manifests itself through the effect of gravitational lensing, is definitely segregated from the luminous parts of the clusters. If this dark matter is mirror matter the mirror stars in it must be more prominent compared to mirror gas than ordinary stars compared to ordinary gas (Blinnikov, Silagadze, private communications).

The correlation of gamma ray bursts with the distribution of dark matter in the galaxies might suggest that these bursts are produced by mirror stars either via mirror neutrinos [213]–[215], or via mirror axions [165] [167] [181] (see also [182]).

For Supernova constraints on sterile neutrino production see [216].

Cosmic mirror strings as sources of cosmic rays of ultra-high energies were considered in [217] (see also [218]–[220]). Various aspects of mirror astrophysics were discussed in articles [221] [222] and books [223] [224].
gauge mirror-type symmetry SU(2) was proposed in [225] and analyzed in [226]-[230]. For discussions of leptonic (muonic) photons in the 1990’s see [231]-[236]. Upper limits on invisible decays of $B^0$-meson, $\eta$- and $\eta'$-mesons were established in [237]-[238]. With the Belle detector the upper limit $2.5 \cdot 10^{-3}$ for the branching fraction $B(\Upsilon(1S) \rightarrow \text{invisible})$ was established [239].

For sundry “mirror matters” see [240]-[245]; for proposed searches of dark matter see [246]-[249].

The first physical run of a special position accumulator ring LEPTA was conducted in 2004 in Dubna. One of the aims of this ring is the search for mirror orthopositronium [250]-[255].

A very interesting discussion of invisible decay channels of higgses, which can be searched for at Large Hadron Collider, can be found in [141], [256]-[258] (see also [259]). The invisible decays appear due to the mixing of the ordinary and mirror higgses. The higgs could be discovered in the near future.

7 Concluding remarks

One might introduce an acronym for mirror symmetry: mirsy, analogous to susy for supersymmetry. Compare mirsy with susy. Mirsy cannot compete with susy in the depth of its concepts and mathematics. But I believe it can compete in the breadth and diversity of its phenomenological predictions. Certainly, mirror matter is richer than the dark matter of susy.

The preliminary version of this review was prepared for the talk at the ITEP Meeting on the Future of Heavy Flavor Physics, July 24-25, 2006 (http://www.itep.ru/eng/bellemeeeting) and published on June 19 as hep-ph/0606202 v.1. The final version (v.2) was prepared for the Russian review journal Uspekhi Fiz. Nauk during the summer of 2006.

As a result the number of references has doubled. It could have risen even higher. If you type in Google “mirror particles” (do not forget quotation marks!), you get a thousand entries (sites). (If you type “mirror world”, or “mirror universe”, you get about 200000 entries devoted mainly to Star Trek television episodes.) A search in Wikipedia is suggested in some of the entries. But the Wikipedia articles on mirror matter are rather misleading. Instead of Google it is better to use Google Scholar, where the number of entries for “mirror universe” is about a hundred, while for “mirror particle” – a few hundred. The extra articles in Google Scholar do not deal with those mirror particles that are the subject of this review. They are “mirror”
in a different sense. For instance, the terms “mirror families” or “mirror fermions” refer to hypothetical families of very heavy fermions with reversed isotopic quantum numbers, which are presumed to interact with ordinary photons and gluons.

8 Acknowledgements

I am grateful to M.V. Danilov for inviting me to give a talk on mirror matter at the ITEP meeting. I would like to thank Z.G. Berezhiani, S.I. Blin-nikov, O.D. Dalkarov, A.D. Dolgov, S.N. Gninenko, A.Yu. Ignatiev, M.Yu. Khlopov, Z.K. Silagadze, R.R. Volkas and M.B. Voloshin for very valuable suggestions, as well as T. Basaglia, E.A. Ilyina and O.V. Milyaeva for their help in preparing this review. This work was partly supported by grant NSh-5603.2006.2.

References

[1] T.D. Lee, C.N. Yang. Mass degeneracy of the heavy mesons. Phys. Rev. 102 (1956) 290.
[2] Proc. Rochester Conf., 1956, session VIII. Theoretical interpretation of new particles.
[3] T.D. Lee, C.N. Yang. Question of parity conservation in weak interactions. Phys. Rev. 104 (1956) 254.
[4] L. Michel. Interactions of elementary particles. in “Progress in cosmic ray physics”, v. 1, ed. J.G. Wilson. Amsterdam, 1952. Russian translation: Vzaimodeistviya elementarnyh chastit. v “Fizika kosmicheskih luchei”. Izd. IL. Moskva, 1954.
[5] G.C. Wick, A.S. Wightman, E.P. Wigner. The intrinsic parity of elementary particles. Phys. Rev. 88 (1952) 101.
[6] E.M. Purcell, N.F. Ramsey. On the possibility of electric dipole moments for elementary particles and nuclei. Phys. Rev. 78 (1950) 807(L).
[7] V.B. Berestetsky, I.Ya. Pomeranchuk. On the $\beta$-decay of neutron. ZhETF 19 (1949) 75 (in Russian).
[8] E. Ambler, R.W. Hayward, D.D. Hopes, R.R. Hudson, C.S. Wu. Experimental test of parity conservation in beta decay. Phys. Rev. 105 (1957) 1413.

[9] R.L. Garwin, L.M. Lederman, M. Weinrich. Observations of the failure of conservation of parity and charge conjugation in meson decays: The magnetic moment of the free muon. Phys. Rev. 105 (1957) 1415.

[10] J.J. Friedman, V.L. Telegdi. Nuclear emulsion evidence for parity non-conservation in the decay chain $\pi^+ \mu^+ e^+$. Phys. Rev. 105 (1957) 1681.

[11] Abstracts of the talks at the All-Union conference on physics of high-energy particles. Publ. Academy of Sciences of the USSR. Moscow, 1956 (in Russian).

[12] E.M. Leikin, A.K. Burtsev, I.S. Danilkin, A.N. Lebedev, L.B. Okun. Sovehanie po fizike chastitz vysokih energii. Uspekhi Fiz. Nauk 61 (1957) 103 (in Russian).

[13] I.S. Shapiro. On parity non-conservation in beta-decay. Uspekhi Fiz. Nauk 61 (1957) 313 (in Russian).

[14] V.L. Telegdi. Parity violation. in Symmetries in Physics (1600–1980). Proceedings of the 1st International meeting on the history of scientific ideas, Sant Feliu de Guixols, Catalonia, Spain, September 1983, p. 433.

[15] V.L. Telegdi. The early experiments leading to the $V - A$ interactions. in Proceedings of the 1985 Fermilab conference on the history of particle physics.

[16] M. Gell-Mann, A. Pais. Behavior of neutral particles under charge conjugation. Phys. Rev. 97 (1955) 1387.

[17] B.L. Ioffe. Two possible schemes of non-conservation of parity in weak interactions. Sov. Phys. JETP 5 (1957) 1015; ZhETF 32 (1957) 1246 (in Russian).

[18] B.L. Ioffe, L.B. Okun, A.P. Rudik. The problem of parity non-conservation in weak interactions. Sov. Phys. JETP 5 (1957) 328 (ZhETF 32 (1957) 396, in Russian).
[19] T.D. Lee, R. Oehme, C.N. Yang. Remarks on possible noninvariance under time reversal and charge conjugation. Phys. Rev. **106** (1957) 340.

[20] T.D. Lee. Weak interaction and nonconservation of parity. Nobel lecture. December 11, 1957. Physics 1901 – 1995, p. 406, World Scientific.

[21] C.N. Yang. The law of parity conservation and other symmetry laws of physics. Nobel lecture. December 11, 1957. Physics 1901 – 1995, p. 393, World Scientific (CD-Rom).

[22] L.D. Landau. Conservation laws for weak interactions. Sov. Phys. JETP **5** (1957) 336 (ZhETF **32** (1957) 405 (in Russian)).

[23] Interview with L.D. Landau. News in nuclear physics. Pravda. 15.02.1957, No.46, page 4 (in Russian).

[24] E.P. Wigner. Relativistic invariance and quantum phenomena. Rev. Mod. Phys. **29** (1957) 255.

[25] L.D. Landau. Possible properties of the neutrino spin. Sov. Phys. JETP **5** (1957) 337 (ZhETF **32** (1957) 407 (in Russian)).

[26] L.D. Landau. On the conservation laws for weak interactions. Nucl. Phys. **3** (1957) 127.

[27] A. Salam. On parity conservation and neutrino mass. Nuovo Cimento **5** (1957) 299.

[28] T.D. Lee, C.N. Yang. Parity nonconservation and a two component theory of the neutrino. Phys. Rev. **105** (1957) 1671.

[29] R.P. Feynman, M. Gell-Mann. Theory of the Fermi interaction. Phys. Rev. **109** (1958) 193.

[30] R.E. Marshak, E.C.G. Sudarshan. Chirality invariance and the universal Fermi interaction. Phys. Rev. **109** (1958) 1860.

[31] T.D. Lee, C.N. Yang. Conservation of heavy particles and generalized gauge transformations. Phys. Rev. **98** (1955) 1501.
[32] L.B. Okun. Lectures on theory of weak interactions of elementary particles. 17 ITEP preprints, 1960-1961 (in Russian). English translation: Theory of weak interactions: Thirteen lectures, AEC-tr-5226. US Atomic Energy Commission. Oak Ridge, Tenn. Translation of lectures 14-16 and of contents: NP-10254, 10842, 10845, 10840.

[33] L.B. Okun. Lectures on the theory of weak interactions of elementary particles. JINR preprint P-833 (1961) (in Russian).

[34] L.B. Okun. Slaboe vzaimodeistvie elementarnykh chastits. Moskva, Fizmatgiz, 1963 (in Russian). English translation: Weak interaction of elementary particles. Pergamon Press, 1965.

[35] M. Anikina et al. Experimental study of some consequences of CP-invariance in the decays of $K^0_2$-mesons. Sov. Phys. JETP 15 (1962) 93; ZhETF 42 (1962) 130.

[36] J.H. Christenson, J.W. Cronin, V.L. Fitch, R. Turlay. Evidence for the 2 pi decay of the $K^0_2$ meson. Phys. Rev. Lett. 13 (1964) 138.

[37] K. Nishijima, M.H. Saffouri. CP invariance and the shadow universe. Phys. Rev. Lett. 14 (1965) 205.

[38] L.B. Okun, I.Ya. Pomeranchuk, “Shadow universe” and neutrino experiment, Phys. Lett. 16 (1965) 338; Pis’ma ZhETF 1, No.6 (1965) 28.

[39] I.Yu. Kobzarev, L.B. Okun, I.Ya. Pomeranchuk. On the possibility of observing mirror particles. Sov. J. Nucl. Phys. 3 (1966) 837 (Yad. Fiz. 3 (1966) 1154, in Russian).

[40] J. Oort. The force exerted by the stellar system in the direction perpendicular to the galactic plane and some related problems. Bull. Astron. Inst. Netherlands 6 (1932) 249.

[41] F. Zwicky. Die Rotverschiebung von extragalaktischen Nebeln. Helvetica Physica Acta 6 (1933) 110.

[42] F. Zwicky. On the masses of nebulae and of clusters of nebulae. ApJ 86 (1937) 217.

[43] N.N. Nikolaev, L.B. Okun, Possible experiments on search for mirror $K^0$ mesons, Phys. Lett. 27B (1968) 226.
[44] L.B. Okun, C. Rubbia. CP violation. Section 6. Mirror particles. in Proceedings of the Heidelberg International conference on Elementary Particles. Editor: H. Filthuth. North-Holland publishing Co. Amsterdam. 1968, p. 301.

[45] L.B. Okun. Violation of CP-invariance. Section V: Mirror symmetry and mirror particles. Sov. Phys. Uspekhi 11 (1968) 462; Usp. Fiz. Nauk 95 (1968) 402 (in Russian).

[46] L.B. Okun. On muonic charge and muonic photons. Sov. J. Nucl. Phys. 10, 206 (1970); Yad. Fiz. 10 (1969) 358 (in Russian).

[47] I.Yu. Kobzarev, L.B. Okun. On gravitational interaction of fermions. Sov. Phys. JETP 16 (1963) 1343; ZhETF 43 (1962) 1904 (in Russian).

[48] I.Yu. Kobzarev, L.B. Okun. On electromagnetic and gravitational interactions of Majorana particles. in Problems of Theoretical Physics. A memorial volume to Igor E. Tamm. Nauka, Moscow, 1972, p. 219 (in Russian).

[49] A.D. Sakharov. Violation of CP-invariance, C-asymmetry and the baryon asymmetry of the Universe. JETP Lett. 5 (1967) 24; Pisma v ZhETF 5 (1967) 32 (in Russian).

[50] M. Pavšič. External inversion, internal inversion, and reflection invariance. Int. J. Theor. Phys. 9 (1974) 229.

[51] M. Pavšič. External inversion, internal inversion, and reflection invariance. hep-ph/0105344

[52] D.A. Kirzhnits. Weinberg model in the hot universe. JETP Lett. 15 (1972) 529; Pisma ZhETF 15 (1972) 745.

[53] D.A. Kirzhnits, A.D. Linde. Macroscopic consequences of the Weinberg model. Phys. Lett. B 42 (1972) 471.

[54] A.D. Linde. Phase transitions in gauge theories and cosmology. Rept. Prog. Phys. 42 (1979) 389.

[55] T.D. Lee. CP nonconservation and spontaneous symmetry breaking. Phys. Rep. 9 (1974) 143.
[56] Ya.B. Zeldovich, I.Yu. Kobzarev, L.B. Okun. Spontaneous CP-violation and cosmology. Phys. Lett. B 50 (1974) 340.

[57] Ya.B. Zeldovich, I.Yu. Kobzarev, L.B. Okun. Cosmological consequences of the spontaneous breakdown of discrete symmetry. Sov. Phys. JETP 40 (1974) 1; ZhETF 67 (1974) 3.

[58] M.B. Voloshin, I.Yu. Kobzarev, L.B. Okun. Bubbles in metastable vacuum. Sov. J. Nucl. Phys. 20 (1975) 65; Yad. Fiz. 20 (1974) 1229.

[59] P. Frampton. Consequences of vacuum instability in Quantum Field Theory. Phys. Rev. D 15 (1977) 2922.

[60] S. Coleman. The fate of the false vacuum. 1. Semiclassical theory. Phys. Rev. D 15 (1977) 2929; 16 (1977) 1248 (Erratum).

[61] C. Callan, S. Coleman. The fate of the false vacuum. 2. First quantum corrections. Phys. Rev. D 16 (1977) 1762.

[62] L.B. Okun. On the search for new long-range forces, Sov. Phys. JETP 52 (1980) 351 (ZhETF 79 (1980) 694).

[63] L.B. Okun, Theta particles, Nucl. Phys. B 173 (1980) 1.

[64] L.B. Okun, Thetons, JETP Lett. 31 (1980) 144 (Pisma Zh. Eksp. Teor. Fiz. 31 (1979) 156).

[65] A.D. Dolgov. On consentration of relict theta particles. Sov. J. Nucl. Phys. 31 (1980) 790; Yad. Fiz. 31 (1980) 1522 (in Russian).

[66] L.B. Okun, Limits of electrodynamics: paraphotons?, JETP 56 (1982) 502 (ZhETF 83 (1982) 892; preprint ITEP-48 (1982)).

[67] L.B. Okun. On a search for mirror particles, preprint ITEP-149 (1983); and Addendum to the preprint No.149 (1983).

[68] L.B. Okun, M.B. Voloshin, V.I. Zakharov. Electrical neutrality of atoms and Grand Unification Models. Phys. Lett. B 138 (1984) 115.

[69] L. Okun. Beyond the standard model. in Proceedings of the 25th Intern. Conf. on High Energy Phys., Singapore 1990, v. 1, p. 319.
[70] M.B. Voloshin, L.B. Okun, J. Ellis. On searches for new penetrating particles, preprint ITEP 86-189 (1986) (in Russian).

[71] The ARGUS collaboration. Search for exotic decay modes of the $\Upsilon(1s)$. Phys. Lett. B 179 (1986) 403.

[72] M.B. Voloshin, Yu.M. Zaitsev. Physics of $\Upsilon$-resonances: Ten years later. Sov. Phys. Uspekhi 30 (1987) 553; Usp. Fiz. Nauk 152 (1987) 361.

[73] V.P. Druzhinin et al. Search for rare radiative decays of phi meson at VEPP-2M. Z. Phys. C 37 (1988) 1.

[74] Ya.B. Zeldovich, M.Yu. Khlopov. The neutrino mass in elementary particle physics and in Big Bang cosmology. Sov. Phys. Uspekhi 24 (1981) 755 (Usp. Fiz. Nauk 135 (1981) 45 (in Russian)).

[75] M.Yu. Khlopov. Fractionally charged particles and confinement of quarks. Pisma JETP 33 (1981) 170.

[76] A.S. Schwarz, Yu.S. Tyupkin. Grand Unification and mirror particles. Nucl. Phys. B 209 (1982) 427.

[77] A.S. Schwarz. Field theories with no local conservation of the electric charge. Nucl. Phys. B 208 (1982) 141.

[78] A.S. Schwarz, Yu.S. Tyupkin. Grand unification, strings and mirror particles. in “Zvenigorod 1982, Proceedings, Group theoretical methods in physics. Vol.2”, pp. 279-289.

[79] S. Blinnikov, M. Khlopov. On possible effects of ‘mirror’ particles, Sov. J. Nucl. Phys. 36 (1982) 472 (Yad. Fiz. 36 (1982) 809 (in Russian)).

[80] S.I. Blinnikov, M. Khlopov. Excitation of the solar oscillations by objects consisting of y-matter. Solar Phys. 82 (1983) 383.

[81] S. Blinnikov, M. Khlopov. Possible astronomical effects of mirror particles. Sov. Astron. J. 27 (1983) 371 (Astron. Zh. Akad. Nauk SSSR 60 (1983) 632 (in Russian)).

[82] M.V. Sazhin, M.Yu. Khlopov. Cosmic strings and effects of gravitational lens. Sov. Astron. 33 (1989) 98 (Astron. Zh. Akad. Nauk SSSR 66 (1989) 191 (in Russian)).
[83] V.K. Dubrovich, M.Yu. Khlopov. On the domain structure of shadow matter. Sov. Astron. **33** (1989) 116 (Astron. Zh. Akad. Nauk SSSR **66** (1989) 232 (in Russian)).

[84] E.W. Kolb, D. Seckel, M.S. Turner. The shadow world. Nature **314** (1985) 415.

[85] H. Goldberg, L.J. Hall. A New Candidate For Dark Matter. Phys. Lett. B **174** (1986) 151.

[86] H. Georgi, P.H. Ginsparg, S.L. Glashow. Photon oscillations and the cosmic background radiation. Nature **306** (1983) 765.

[87] S.L. Glashow. Positronium versus the mirror universe. Phys. Lett. B **167** (1986) 35.

[88] B. Holdom, Two U(1)’s and epsilon charge shifts, Phys. Lett. B **166** (1986) 196.

[89] B. Holdom, Searching for epsilon charges and a new U(1), Phys. Lett. B **178** (1986) 65.

[90] E.D. Carlson, S.L. Glashow. Nucleosynthesis versus the mirror universe. Phys. Lett. B **193** (1987) 168.

[91] R. Foot, H. Lew, R.R. Volkas. A model with fundamental improper space-time symmetries. Phys. Lett. B **272** (1991) 67.

[92] R. Foot, X.-G. He. Comment on Z Z-prime mixing in extended gauge theories. Phys. Lett. B **267** (1991) 509.

[93] R. Foot, H. Lew, R.R. Volkas. Possible consequences of parity conservation. Mod. Phys. Lett. A **7** (1992) 2567.

[94] R. Foot. Neutrino oscillations and the exact parity model. Mod. Phys. Lett. A **9** (1994) 169; [hep-ph/9402241](https://arxiv.org/abs/hep-ph/9402241).

[95] R. Foot. A Parity invariant SU(3)(C) x SU(3)(L) x U(1) model. Mod. Phys. Lett. A **10** (1995) 159; [hep-ph/9402244](https://arxiv.org/abs/hep-ph/9402244).

[96] R. Foot, H. Lew. A Novel left-right symmetric model. [hep-ph/9411390](https://arxiv.org/abs/hep-ph/9411390).
[97] R. Foot. Experimental signatures of a massive mirror photon. hep-ph/9407331.

[98] R. Foot, R.R. Volkas. Neutrino physics and the mirror world: How exact parity symmetry explains the solar neutrino deficit, the atmospheric neutrino anomaly and the LSND experiment. Phys. Rev. D 52 (1995) 6595; hep-ph/9505359.

[99] S.P. Brumby, Robert Foot, R.R. Volkas. Quaternionic formulation of the exact parity model. hep-th/9602139.

[100] R. Foot, R.R. Volkas. The Exact parity symmetric model and big bang nucleosynthesis. Astropart. Phys. 7 (1997) 283; hep-ph/9612245.

[101] M. Collie, R. Foot. Neutrino masses in the SU(5) x SU(5)-prime mirror symmetric model. Phys. Lett. B 432 (1998) 134; hep-ph/9803261.

[102] R. Foot. Have mirror planets been observed? Phys. Lett. B 471 (1999) 191; astro-ph/9908276.

[103] R. Foot. Have mirror stars been observed? Phys. Lett. B 452 (1999) 83; astro-ph/9902065.

[104] R. Foot, R.R. Volkas. Implications of mirror neutrinos for early universe cosmology. Phys. Rev. D 61 (2000) 043507; hep-ph/9904336.

[105] R. Foot, S.N. Gninenko. Can the mirror world explain the ortho-positronium lifetime puzzle? Phys. Lett. B 480 (2000) 171; hep-ph/0003278.

[106] R. Foot, H. Lew, R.R. Volkas. Unbroken versus broken mirror world: A tale of two vacua. JHEP 0007 (2000) 032; hep-ph/0006027.

[107] R. Foot, A.Yu. Ignatiev, R.R. Volkas. Do 'isolated' planetary mass objects orbit invisible stellar mass companions? Astropart. Phys. 17 (2002) 195; astro-ph/0010502.

[108] R. Foot, A.Yu. Ignatiev, R.R. Volkas. Physics of mirror photons. Phys. Lett. B 503 (2001) 355; astro-ph/0011156.

[109] R. Foot. Are mirror worlds opaque? Phys. Lett. B 505 (2001) 1; astro-ph/0101055.
[110] R. Foot. Seven (and a half) reasons to believe in mirror matter: from neutrino puzzles to the inferred dark matter in the universe. Acta Phys. Polon. B 32 (2001) 2253; astro-ph/0102294.

[111] R. Foot, Z.K. Silagadze. Do mirror planets exist in our solar system? Acta Phys. Polon. B 32 (2001) 2271; astro-ph/0104251.

[112] R. Foot. The Mirror world interpretation of the 1908 Tunguska event and other more recent events. Acta Phys. Polon. B 32 (2001) 3133; hep-ph/0107132.

[113] R. Foot, R.R. Volkas. A Mirror world explanation for the Pioneer spacecraft anomalies? Phys. Lett. B 517 (2001) 13; hep-ph/0108051.

[114] R. Foot, T.L. Yoon. Exotic meteoritic phenomena: The Tunguska event and anomalous low altitude fireballs: Manifestations of the mirror world? Acta Phys. Polon. B 33 (2002) 1979; astro-ph/0203152.

[115] R. Foot, S. Mitra. Ordinary atom mirror atom bound states: A New window on the mirror world. Phys. Rev. D 66 (2002) 061301; hep-ph/0204256.

[116] R. Foot. Does mirror matter exist? hep-ph/0207175.

[117] R. Foot, S. Mitra. Mirror matter in the solar system: New evidence for mirror matter from EROS. Astropart. Phys. 19 (2003) 739; astro-ph/0211067.

[118] S. Mitra, R. Foot. Detecting dark matter using centrifuging techniques. Phys. Lett. B 558 (2003) 9; astro-ph/0301229.

[119] R. Foot, R.R. Volkas. Was ordinary matter synthesized from mirror matter? An Attempt to explain why Omega(Baryon) approximately equal to 0.2 Omega(Dark). Phys. Rev. D 68 (2003) 021304; hep-ph/0304261.

[120] R. Foot, S. Mitra. Have mirror micrometeorites been detected? Phys. Rev. D 68 (2003) 071901; hep-ph/0306228.

[121] R. Foot, S. Mitra. Detecting mirror matter on earth via its thermal imprint on ordinary matter. Phys. Lett. A 315 (2003) 178; cond-mat/0306561.
[122] R. Foot. Implications of the DAMA and CRESST experiments for mirror matter type dark matter. Phys. Rev. D 69 (2004) 036001; hep-ph/0308254.

[123] R. Foot. Experimental implications of mirror matter - type dark matter. Int. J. Mod. Phys. A 19 (2004) 3807; astro-ph/0309330.

[124] R. Foot, R.R. Volkas. Explaining Omega(Baryon) approximately 0.2 Omega(Dark) through the synthesis of ordinary matter from mirror matter: A More general analysis. Phys. Rev. D 69 (2004) 123510; hep-ph/0402267.

[125] R. Foot. Exploring the mirror matter interpretation of the DAMA experiment: Has the dark matter problem been solved? astro-ph/0403043.

[126] R. Foot, Z.K. Silagadze. Supernova explosions, 511-keV photons, gamma ray bursts and mirror matter. Int. J. Mod. Phys. D 14 (2005) 143; astro-ph/0404515.

[127] R. Foot. Reconciling the positive DAMA annual modulation signal with the negative results of the CDMS II experiment. Mod. Phys. Lett. A 19 (2004) 1841; astro-ph/0405362.

[128] R. Foot, R.R. Volkas. Spheroidal galactic halos and mirror dark matter. Phys. Rev. D 70 (2004) 123508; astro-ph/0407522.

[129] R. Foot. Testing the mirror world hypothesis for the close-in extrasolar planets. Acta Phys. Polon. B 35 (2004) 2473; astro-ph/0406257.

[130] R. Foot. Mirror matter-type dark matter. Int. J. Mod. Phys. D 13 (2004) 2161; astro-ph/0407623.

[131] R. Foot. Generalized mirror matter models. Phys. Lett. B 632 (2006) 467; hep-ph/0507294.

[132] R. Foot. Implications of the dama/nai and cdms experiments for mirror matter-type dark matter. astro-ph/0510705.

[133] R. Foot. Shadowlands: Quest for mirror matter in the universe. Parkland, USA: Universal Publ. (2002) 235 p.
[134] R.R. Volkas, Y.Y.Y. Wong. Energy dependent solar neutrino flux depletion in the exact parity model and implications for SNO, Super-Kamiokande and BOREXINO. Phys. Rev. D 58 (1998) 113001; hep-ph/9803456.

[135] N.F. Bell, R.R. Volkas, Y.Y.Y. Wong. Relic neutrino asymmetry evolution from first principles. Phys. Rev. D 59 (1999) 113001; hep-ph/9809363.

[136] N.F. Bell, R.R. Volkas. Mirror matter and primordial black holes. Phys. Rev. D 59 (1999) 107301; astro-ph/9812301.

[137] R.R. Volkas. Neutrino physics and the mirror world. Talk at 8th Intern. Workshop on Neutrino Telescopes. in Venice 1999, Neutrino telescopes, vol. 2, p. 13; hep-ph/9904437.

[138] R.R. Volkas, Y.Y.Y. Wong. Matter affected neutrino oscillations in ordinary and mirror stars and their implications for gamma-ray bursts. Astropart. Phys. 13 (2000) 21; astro-ph/9907161.

[139] R.R. Volkas. Mirror neutrinos and the early universe. Invited talk at COSMO 99: 3rd Intern. Conf. on Particle Physics and the Early Universe; hep-ph/0002002.

[140] N.F. Bell. Mirror matter and heavy singlet neutrino oscillations in the early universe. Phys. Lett. B 479 (2000) 257; hep-ph/0003072.

[141] A.Yu. Ignatiev, R.R. Volkas. Discovering mirror particles at the large hadron collider and the implied cold universe. Phys. Lett. B 487 (2000) 294; hep-ph/0005238.

[142] A.Yu. Ignatiev, R.R. Volkas. Geophysical constraints on mirror matter within the earth. Phys. Rev. D 62 (2000) 023508; hep-ph/0005125.

[143] A.Yu. Ignatiev, R.R. Volkas. Mirror dark matter and large scale structure. Phys. Rev. D 68 (2003) 023518; hep-ph/0304260.

[144] A.Yu. Ignatiev, R.R. Volkas. Mirror matter. Talk given at 15th Biennial Congress of the Australian Institute of Physics, Sydney, Australia, 8-11 Jul 2002; hep-ph/0306120.
[145] S. Mitra. Applications of mirror matter. http://people.zeelandnet.nl/smitra/applications.htm.

[146] S. Mitra. Has DAMA detected self-interacting dark matter? Phys. Rev. D 71 (2005) 121302; astro-ph/0409121.

[147] S. Mitra. Detecting dark matter in electromagnetic field penetration experiments. Phys. Rev. D 74 (2006) 043532; astro-ph/0605369.

[148] S.N. Gninenko. Limit on 'disappearance' of orthopositronium in vacuum. Phys. Lett. B 326 (1994) 317.

[149] S.N. Gninenko, N.V. Krasnikov, A. Rubbia. Invisible decay of orthopositronium versus extra dimensions. hep-ph/0205056.

[150] A. Badertscher et al. An Apparatus to search for mirror dark matter via the invisible decay of orthopositronium in vacuum. Int. J. Mod. Phys. A 19 (2004) 3833; hep-ex/0311031.

[151] A. Rubbia. Positronium as a probe for new physics beyond the standard model. Int. J. Mod. Phys. A 19 (2004) 3961; hep-ph/0402151.

[152] A. Badertscher et al. A New experiment to search for the invisible decay of the orthopositronium. hep-ex/0404037.

[153] S.N. Gninenko, N.V. Krasnikov, V.A. Matveev and A. Rubbia. Some aspects of positronium physics. Phys. Part. and Nucl. 37 (2006) 321.

[154] Z.K. Silagadze. Neutrino mass and the mirror universe. Phys. Atom. Nucl. 60 (1997) 272; Yad. Fiz. 60 (1997) 336; hep-ph/9503481.

[155] Z.K. Silagadze. Mirror world versus large extra dimensions. Mod. Phys. Lett. A 14 (1999) 2321; hep-ph/9908208.

[156] Z.K. Silagadze. TeV scale gravity, mirror universe, and ... dinosaurs. Extended version of the talk given at Gran Sasso Summer Institute on Massive Neutrinos in Physics and Astrophysics, Gran Sasso, Italy, 13-24 Sep 1999. Acta Phys. Polon. B 32 (2001) 99; hep-ph/0002255.

[157] Z.K. Silagadze. Mirror objects in the solar system? Prepared for Tunguska 2001: International Conference, Moscow, Russia, 30 Jun - 1 Jul 2001. Acta Phys. Polon. B 33 (2002) 1325; astro-ph/0110161.
[158] Z.K. Silagadze. Tunguska genetic anomaly and electrophonic meteors. Acta Phys. Polon. B 36 (2005) 935; astro-ph/0311337.

[159] Z.K. Silagadze. Maxwell’s demon through the looking glass. physics/0608114.

[160] E.Kh. Akhmedov, Z.G. Berezhiani and G. Senjanović. Planck scale physics and neutrino masses. Phys. Rev. Lett. 69 (1992) 3013; hep-ph/9205230.

[161] Z.G. Berezhiani and R.N. Mohapatra. Reconciling present neutrino puzzles: Sterile neutrinos as mirror neutrinos. Phys. Rev. D 52 (1995) 6607; hep-ph/9505385.

[162] Z.G. Berezhiani, A.D. Dolgov and R.N. Mohapatra. Asymmetric inflationary reheating and the nature of mirror universe. Phys. Lett. B 375 (1996) 26; hep-ph/9511221.

[163] Z. Berezhiani. Astrophysical implications of the mirror world with broken mirror parity. Acta Phys. Polon. B 27 (1996) 1503; hep-ph/9602326.

[164] Z. Berezhiani. Unified picture of the particle and sparticle masses in SUSY GUT. Phys. Lett. B 417 (1998) 287 (1998).

[165] Z. Berezhiani, A. Drago. Gamma-ray bursts via emission of axion-like particles. Phys. Lett. B 473 (2000) 681; hep-ph/9911333.

[166] Z. Berezhiani, D. Comelli, F. Villante. The Early mirror universe: Inflation, baryogenesis, nucleosynthesis and dark matter. Phys. Lett. B 503 (2001) 362; hep-ph/0008105.

[167] Z. Berezhiani, L. Gianfagna and M. Giannotti. Strong CP problem and mirror world: The Weinberg-Wilczek axion revisited. Phys. Lett. B 500 (2001) 286; hep-ph/0009290.

[168] L. Bento, Z. Berezhiani. Leptogenesis via collisions: The lepton number leaking to the hidden sector. Phys. Rev. Lett. 87 (2001) 231304; hep-ph/0107281.

[169] L. Bento, Z. Berezhiani. Baryon asymmetry, dark matter and the hidden sector. Fortsch. Phys. 50 (2002) 489
[170] L. Bento, Z. Berezhiani. Baryogenesis: The lepton leaking mechanism. hep-ph/0111116.

[171] Z. Berezhiani. Mirror world and its cosmological consequences. Int. J. Mod. Phys. A 19 (2004) 3775; hep-ph/0312335.

[172] Z. Berezhiani, P. Ciarcelluti, D. Comelli, F. Villante. Structure formation with mirror dark matter: CMB and LSS. Int. J. Mod. Phys. D 14 (2005) 107; astro-ph/0312605.

[173] Z. Berezhiani and L. Bento. Neutron - mirror neutron oscillations: How fast might they be? Phys. Rev. Lett. 96 (2006) 081801; hep-ph/0507031.

[174] Z. Berezhiani, S. Cassisi, P. Ciarcelluti, A. Pietrinferni. Evolutionary and structural properties of mirror star MACHOs. Astropart. Phys. 24 (2006) 495; astro-ph/0507153.

[175] Z. Berezhiani. Through the looking-glass: Alice’s adventures in mirror world. Published in Ian Kogan Memorial Collection ‘From Fields to Strings: Circumnavigating Theoretical Physics,’ Ed. M. Shifman et al., World Scientific, Singapore, vol.3, pp.2147-2195; hep-ph/0508233.

[176] Z. Berezhiani and L. Bento. Fast neutron - mirror neutron oscillation and ultra high energy cosmic rays. Phys. Lett. B 635 (2006) 253; hep-ph/0602227.

[177] P. Ciarcelluti. Cosmology of the mirror universe. Ph.D. Thesis. Advisor: Zurab Berezhiani. astro-ph/0312607.

[178] P. Ciarcelluti. Structure formation, CMB and LSS in a mirror dark matter scenario. Frascati Phys. Ser. 555 (2004) 1; astro-ph/0409629.

[179] P. Ciarcelluti. Cosmology with mirror dark matter. 1: Linear evolution of perturbations. Int. J. Mod. Phys. D 14 (2005) 187; astro-ph/0409630.

[180] P. Ciarcelluti. Cosmology with mirror dark matter. 2. Cosmic microwave background and large scale structure. Int. J. Mod. Phys. D 14 (2005) 223; astro-ph/0409633.

[181] L. Gianfagna, M. Giannotti, F. Nesti. Mirror world, supersymmetric axion and gamma ray bursts. JHEP 0410 (2004) 044; hep-ph/0409185.
[182] M. Giannotti. Mirror world and axion: Relaxing cosmological bounds. Int. J. Mod. Phys. **A20** (2005) 2454; astro-ph/0504636.

[183] R.N. Mohapatra, V.L. Teplitz. Structures in the mirror universe. Astrophys. J. **478** (1997) 29; astro-ph/9603049.

[184] B. Brahmachari, R.N. Mohapatra. Grand unification of the sterile neutrino. Phys. Lett. B **437** (1998) 100; hep-ph/9805429.

[185] R.N. Mohapatra. Sterile neutrinos: Phenomenology and theory. hep-ph/9808236.

[186] R.N. Mohapatra, D.W. Sciama. Diffuse ionization in the Milky Way and sterile neutrinos. hep-ph/9811446.

[187] R.N. Mohapatra, V.L. Teplitz. Mirror matter MACHOs. Phys. Lett. B **462** (1999) 302; astro-ph/9902085.

[188] R.N. Mohapatra. Sterile neutrinos. hep-ph/9903261.

[189] R.N. Mohapatra, S. Nussinov, V.L. Teplitz. TeV scale quantum gravity and mirror supernovae as sources of gamma-ray bursts. Astropart. Phys. **13** (2000) 295; astro-ph/9909376.

[190] R.N. Mohapatra. Theories of neutrino masses and mixings. hep-ph/9910365.

[191] R.N. Mohapatra, V.L. Teplitz. Mirror dark matter and galaxy core densities of galaxies. Phys. Rev. D **62** (2000) 063506; astro-ph/0001362.

[192] R.N. Mohapatra, V.L. Teplitz. Mirror dark matter. astro-ph/0004046.

[193] R.N. Mohapatra. Origin of neutrino masses and mixings. Nucl. Phys. Proc. Suppl. **91** (2001): 313; hep-ph/0008232.

[194] R.N. Mohapatra, S. Nussinov, V.L. Teplitz. Mirror matter as self-interacting dark matter. Phys. Rev. D **66** (2002) 063002; hep-ph/0111381.

[195] R.N. Mohapatra, S. Nasri. Avoiding BBN constraints on mirror models for sterile neutrinos. Phys. Rev. D **71** (2005) 053001; hep-ph/0407194.
[196] R.N. Mohapatra, S. Nasri, S. Nussinov. Some implications of neutron mirror neutron oscillation. Phys. Lett. B 627 (2005) 124; hep-ph/0508109.

[197] E. Aubourg et al. Microlensing optical depth of the Large Magellanic Cloud. Astronomy and Astrophysics 347 (1999) 850.

[198] T. Lasserre et al. Not enough stellar mass Machos in the Galactic halo. Astronomy and Astrophysics 355 (2000) L39.

[199] C. Alcock et al. Possible gravitational microlensing of a star in the Large Magellanic Cloud. Nature 365 (1993) 621.

[200] C. Alcock et al. The MACHO project Large Magellanic Cloud microlensing results from the first two years and the nature of the Galactic Dark Halo. ApJ 486 (1997) 697.

[201] C. Alcock et al. The MACHO project: Microlensing results from 5.7 years of Large Magellanic Cloud observations. ApJ 542 (2000) 281.

[202] H.M. Hodges. Mirror baryons as the dark matter. Phys. Rev. D 47 (1993) 456.

[203] S.I. Blinnikov. A quest for weak objects and for invisible stars. astro-ph/9801015

[204] R.N. Mohapatra, V.L. Teplitz. Mirror matter machos. Phys. Lett. B 462 (1999) 302; astro-ph/9902085

[205] V. Belokurov, N.W. Evans, Y.L. Du. Light-curve classification in massive variability surveys - I. Microlensing. Mon. Not. Roy. Astr. Soc. 341 (2003) 1373.

[206] V. Belokurov, N.W. Evans, Y.Le Du. Light-curve classification in massive variability surveys - II. Transients towards the Large Magellanic Cloud. Mon. Not. Roy. Astr. Soc. 352 (2004) 233.

[207] K. Griest, C.L. Thomas. Contamination in the MACHO dataset and the puzzle of LMC microlensing. Mon. Not. Roy. Astron. Soc. 359 (2005) 464; astro-ph/0412443
[208] N.W. Evans, V. Belokurov. Is there a microlensing puzzle? astro-ph/0505167

[209] K. Freese. Death of baryonic dark matter. Phys. Rep. 333-334 (2000) 183.

[210] K. Freese, B.D. Fields, D.S. Graff. Death of stellar baryonic dark matter. Proc. of MPA / ESO Workshop on the First Stars, Garching, Germany, 4-6 Aug 1999; astro-ph/0002058

[211] M. Bradač et al. Strong and weak lensing united III: Measuring the mass distribution of the merging galaxy cluster 1E0657-56. astro-ph/0608408

[212] D. Clowe et al. A direct empirical proof of the existence of dark matter. astro-ph/0608407

[213] S.I. Blinnikov. Gamma-ray bursts produced by mirror stars. astro-ph/9902305

[214] S.I. Blinnikov. Cosmic gamma-ray bursts. Surveys High-Energy Phys. 15 (2000) 37; astro-ph/9911138

[215] D.Yu. Tsvetkov, S.I. Blinnikov, N.N. Pavlyuk. Gamma-ray bursts, type Ib/c Supernovae and star-forming sites in hostgalaxies. astro-ph/0101362

[216] E.W. Kolb, R.N. Mohapatra, V.L. Teplitz. New Supernova constraints on sterile neutrino production. Phys. Rev. Lett. 77 (1996) 3066; hep-ph/9605350.

[217] V.S. Berezinsky, A. Vilenkin. Ultrahigh-energy neutrinos from hidden sector topological effects. Phys. Rev. D 62 (2000) 083512; hep-ph/9908257.

[218] V. Berezinsky, M. Narayan, F. Vissani. Mirror model for sterile neutrinos. Nucl. Phys. B 658 (2003) 254; hep-ph/0210204

[219] V. Berezinsky. SuperGZK neutrinos: Testing physics beyond the standard model. hep-ph/0303091

[220] V. Berezinsky. SuperGZK neutrinos. astro-ph/0509675.
[221] M.Yu.Khlopov, G.M.Beskin, N.G.Bochkarev, L.A.Pustilnik, S.A.Pustilnik. Observational physics of mirror world. Sov. Astron. 35 (1991) 21 (Astron. Zh. Akad. Nauk SSSR 68 (1991) 42 (in Russian)).

[222] V.L. Oknyanskij. QSO 0957+561 and other large-separated double quasars: Some new results and a future observational project. astro-ph/0502087.

[223] M.Yu.Khlopov, Cosmoparticle physics, World Scientific, 1999.

[224] M.Yu.Khlopov. Osnovy kosmomikrofiziki, URSS, Moscow, 2004 (in Russian).

[225] S.L. Glashow. A sinister extension of the standard model to SU(3) x SU(2) x SU(2) x U(1). 11th International Workshop on Neutrino Telescopes, Venice, Italy, 22-25 Feb 2005. Published in “Venice 2005, Neutrino telescopes” 539-547; hep-ph/0504287.

[226] M.Yu. Khlopov. New symmetries in microphysics, new stable forms of matter around us. Invited contribution to the special issue of honorary series of ”Annals of Louis de Broglie Foundations”, dedicated to E.Majorana; astro-ph/0607048.

[227] K.M. Belotsky, M.Yu. Khlopov, K.I.Shibaev. Composite dark matter and its charged constituents. astro-ph/0604518.

[228] M.Yu. Khlopov, C.A. Stephan. Composite dark matter with invisible light from almost-commutative geometry. astro-ph/0603187.

[229] D. Fargion, M. Khlopov, C. A. Stephan. Cold dark matter by heavy double charged leptons? astro-ph/0511789.

[230] D. Fargion, M. Khlopov. Tera-leptons shadows over sinister universe. hep-ph/0507087.

[231] A.K. Çiftçi, S. Sultansoi, Ş. Türköz. Lepton charge as possible source of new force. Ankara University preprint AU/94-03(HEP).

[232] S.I. Blinnikov, A.D. Dolgov, L.B. Okun, M.B. Voloshin. How strong can the coupling of leptonic photons be? Nucl. Phys. B 458 (1996) 52; hep-ph/9505444.
[233] L. Okun. Leptons and photons. Phys. Lett. B 382 (1996) 389; hep-ph/9512436.

[234] L.B. Okun. Leptonic photon and light element abundances. Mod. Phys. Lett. A 11 (1996) 3041; hep-ph/9611360.

[235] V.A. Ilyin, L.B. Okun, A.N. Rozanov. On the search for muonic photons in neutrino experiments. Nucl. Phys. B 525 (1998) 51; hep-ph/9707479.

[236] CHARM II Collaboration (P. Vilain et al.). Experimental search for muonic photons. Phys. Lett. B 484 (1998) 200.

[237] BABAR collaboration (B. Aubert et al.). Search for B0 decays to invisible final states and to nu anti-nu gamma. Phys. Rev. Lett. 93 (2004) 091802; hep-ex/0405071.

[238] BES collaboration. Search for Invisible Decays of eta and eta-prime in the Processes J/ psi → phi eta and phi eta-prime. hep-ex/0607006.

[239] The Belle collaboration. O.Tajima et al. Seach for the invisible decay of the Υ(1S). hep-ex/0611041.

[240] S. Davidson, B. Campbell, D.C. Bailey. Limits on particles of small electric charge. Phys. Rev. D 43 (1991) 2314.

[241] L.B. Okun. Spacetime and vacuum as seen from Moscow. in “2001: A Spacetime Odyssey”, p. 105. Editors M.J. Duff, J.T. Liu. World Sci.; Int. J. Mod. Phys. A 17S1 (2002) 105; hep-ph/0112031.

[242] S.L. Dubovsky, S.M. Sibiryakov. Domain walls in noncommutative gauge theories, folded D branes, and communication with mirror world. Nucl. Phys. B 691 (2004) 91; hep-th/0401046.

[243] J. Evslin, M. Fairbairn. Photon mixing in domain walls and the cosmic coincidence problem. JCAP 0602 (2006) 011; hep-ph/0507020.

[244] Yu.N. Pokotilovski. On the experimental search for neutron → mirror neutron oscillations. Phys. Lett. B 639 (2006) 214; nucl-ex/0601017.

[245] A.D. Dolgov. Cosmology and new physics. hep-ph/0606230.
[246] O. Maximenko. Search of mirror world. Vokrug Sveta **06** (2006) 29 (in Russian).

[247] J.L. Rosner. Dark matter in many forms. astro-ph/0509196.

[248] N. Seto, A. Cooray. Search for small-mass black hole dark matter with space-based gravitational wave detectors. Phys. Rev. D **70** (2004) 063512; astro-ph/0405216.

[249] A.W. Adams, J.S. Bloom. Direct detection of dark matter with space-based laser interferometers. astro-ph/0405266.

[250] I.N. Meshkov, A.N. Skrinsky. The antihydrogen and positronium generation and studies using storage rings. Nucl. Instr. and Methods in Phys. Research A **391** (1997) 205.

[251] I.N. Meshkov, A.O. Sidorin. Conceptual design of the low energy positron storage ring. Nucl. Instr. and Methods in Phys. Research A **391** (1997) 216.

[252] O.I. Kartavtsev, I.N. Meshkov. Method of in-flight production of exotic systems in charge-exchange reactions. Nucl. Instr. and Methods in Phys. Research A **391** (1997) 221.

[253] I.N. Meshkov. Experimental studies of anti-hydrogen and positronium physics: Problems and possibilities. Phys. Part. Nucl. **28** (1997) 198; Fiz. Elem. Chast. Atom. Yadra **28** (1997) 495 (in Russian).

[254] I.N. Meshkov. High-precision experiments with antihydrogen and positronium in-flight. Phys. Atom. Nucl. **61** (1998) 1679; Yad. Fiz. **61** (1998) 1796.

[255] E.V. Boltushkin et al. Physical run of the storage ring LEPTA. Atomnaya Enegriya **98** (2005) 225 (in Russian).

[256] Z. Chacko, H.-S. Goh, R. Harnik. The twin higgs: natural electroweak breaking from mirror symmetry. hep-ph/0506256.

[257] R. Barbieri, T. Gregoire, L. J. Hall. Mirror world at the large hadron collider. CERN-PH-TH-2005-162, UCB-PTH-05-25, LBNL-58803; hep-ph/0509242.
[258] B. Patt, F. Wilczek. Higgs-field portal into hidden sectors. hep-ph/0605188.

[259] M.J. Strassler. Possible effects of a hidden valley on supersymmetric phenomenology. hep-ph/0607160.