Ministry of Science and Higher Education of the Russian Federation

National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)

ESSAY

Mirror world $m_n < m_p - m_e$

Student: V. V. Verzakova
Group: M21-115
Professor: M. Yu. Khlopov

Moscow 2023

Contents

1 Introduction

The standard model of electrically weak and strong interactions of elementary particles does not meet any experimental contradictions, but there are a number of reasons to consider it incomplete and to refer to its extensions. To explain hidden mass and dark energy, as well as baryonic asymmetry in the Universe, the existence of more new particles and fields is necessary. For this purpose, the concept of a "hidden sector"is introduced. The term "mirror world"denotes a hypothetical hidden sector of particles and interactions, which compensates the asymmetry of ordinary particles.

The first reasons for the existence of mirror partners were first given by Lee and Yang [1], in which they questioned the conservation of spatial parity in weak interactions. Previously, it was assumed that P parity is conserved in all fundamental interactions of elementary particles. This means that the inversion of coordinate axes leads to a transformation of the field of some particle into another field describing particles that also exist in nature.

Later, the parity violation was detected in the experiment of β-decay of cobalt [2]. Failure to preserve the P-count leads to the non-equivalence of left- and right-oriented coordinate systems. To restore left-right equivalence, Lee and Young suggested that P-inversion must be accompanied by mutual replacement of ordinary particles and their mirror partners.

For this reason, Landau and many others put forward theories of combined parity (CP-symmetry), in which hypothetical mirror particles are antiparticles. However, after the discovery of CP parity violation in 1964, it became clear that mirror partners cannot be antiparticles [3].

Kobzarev, Pomeranchuk and Okun in 1966 [4] showed that mirror particles cannot have electromagnetic and strong interactions of ordinary particles, since this would lead to an increase in the number of electron states in the atom and other effects contrary to experimental observations. Also, based on the fact that the width of W- and Z-bosons is consistent with the predictions of the Standard Model (i.e., there is no contribution of mirror particles), the assumption is made that there is no weak interaction between mirror and ordinary particles. Consequently, the mirror partners should be not only at particles of matter, but also at gauge bosons carrying out their interaction.

Thus, the mirror particles have their strong, weak and electromagnetic interactions, and gravitation is the main way of interaction for ordinary and mirror particles.

In models of mirror worlds different from ours, some mirror particles [5] and even astronomical objects from mirror particles can play the role of hidden.

This paper considers a mirror world model in which $m_n < m_p - m_e$.

2 Mirror world $m_n < m_p - m_e$

The model considers one generation of particles. The masses of mirror leptons and antileptons in this model are similar to the masses in the real world. The masses of neutrinos are much smaller than the masses of leptons and quarks. The Higgs mechanism is responsible for the presence of particle masses. Mirror particles can interact with ordinary particles through gravitational interaction. The only difference in the mirror model is the difference of quark masses.

2.1 Neutron and proton stability

In the real world, the masses of the neutron, proton, and electron are known from numerous experiments:

$$m_n = 939,272\,\mathrm{MeV}, \;\; m_p = 938,272\,\mathrm{MeV}, \;\; m_e = 0,511\,\mathrm{MeV}$$

The mass of the neutron is less than the mass of the proton, so the difference of neutron and proton masses is positive $\Delta m_{n-p} > m_e$. Thus, the proton is a stable particle, while the neutron is unstable. It decays by spontaneous β-decay: $n \to p + e^- + \widetilde{\nu}_e$.

In the case of a mirror world, under the condition $m_n < m_p - m_e$, the difference of masses of the proton and neutron must be greater than the mass of the electron: $\Delta m_{p-n} > m_e$. Since the mass of the proton is greater than the sum of the masses of the neutron and electron, this determines the possibility of its spontaneous decay. The neutron is a stable particle, the proton is unstable and in the free state: $p \to n + e^+ + \nu_e$. The proton lifetime can be estimated by the formula:

$$\tau_p \sim \frac{1}{G_F^2 \Delta m_{p-n}^5} \approx 900\,c \tag{1}$$

2.2 Early Universe evolution

It is believed that the mirror world in question involves the same mechanisms of inflation and baryosynthesis as ours.

2.2.1 Механизм инфляции

To implement the inflation mechanism, a scalar inflaton field is introduced. In the framework of the chaotic inflation model, the initial amplitudes of ordinary and mirror inflatons may be different, which leads to the formation of a domain structure in the distribution of ordinary and mirror matter.

In regions where the amplitude of ordinary inflatons is higher, ordinary particles should dominate after inflation, and the admixture of mirror particles should be small. Conversely, the dominance of mirror inflatons leads to a small density of ordinary particles after inflation [6].

If, however, the inflaton does not have a certain specularity and an equal number of specular and ordinary particles are born after inflation, the domain structure may be formed due to a random local asymmetry in the amplitudes of the ordinary and specular fields at different periods after the general inflation [7].

2.2.2 Mechanism of baryosynthesis

To implement the mechanism of baryosynthesis in our world can be used mechanism see-saw formation of a small Majorana neutrino mass, in which there is a heavy neutrino state, the processes involving which violate the lepton number. Subsequently, this lepton number is distributed between leptons and baryons due to sphaleron processes.

The same mechanism of baryosynthesis is assumed for the mirror particles. Since the temperature of the mirror world at baryosynthesis in the considered model is lower than in ours, the excess of mirror baryons may be different from the excess of ordinary baryons. Nevertheless, this will not affect significantly the further analysis, because, as it has been said above, the initial conditions are chosen so as to explain by the mirror matter the hidden mass, and the background of mirror gammas cannot be detected by experiment within this model, since the kinetic mixing of photons is not taken into account.

2.3 Proton-neutron ratio

As stated earlier, the proton in the mirror world with $m_n < m_p - m_e$ is an unstable particle with a lifetime of about 15 minutes. The fact that the proton is now heavier than the sum of the neutron and electron masses: $\Delta m_{p-n} \approx 1.3\text{MeV}$, will also affect the n/p concentration ratio at the moment of quenching ($T_F \sim 1\,\text{MeV}, t \sim 1\,\text{s}$ since the Big Bang) given by the ratio:

$$\frac{n}{p} = \exp\left(-\frac{\Delta m_{p-n}}{T_F}\right) \approx 6$$

2.4 Primary nucleosynthesis

Thus, by the time nucleosynthesis begins ($t \sim 1\,\mathrm{s}$), there is some concentration of protons, and 6 times the concentration of neutrons.

During nucleosynthesis ($\approx$ 3 min), about 10% of protons manage to decay, resulting in a $p/n \approx 1/7$.

Chains of thermonuclear reactions in the early Universe begin with formation of deuterium in the reaction:

$$n + p \to D + \gamma$$

Then, the deuterium nuclei produced by proton combustion serve as material for the formation of tritium and ^3He and then ^4He:

$$\begin{gathered} D + p \to T + \gamma, \\ D + D \to T + p, \\ D + p \to {}^3_2He + \gamma, \\ D + D \to {}^3_2He + n, \\ T + p \to {}^4_2He + \gamma, \\ {}^3_2He + n \to {}^4_2He + \gamma. \end{gathered}$$

It is possible to estimate the concentrations of ^4He and neutrons using the formula:

$$n_n = \frac{1 - p/n}{1 + p/n} \approx 0,75,$$

$$n_{^4He} = \frac{2p/n}{1 + p/n} \approx 0,25.$$

Thus, after the era of nucleosynthesis, the Universe is mainly composed of neutral stable neutrons and helium nuclei. Heavier nuclei are represented in much lower concentrations.

2.5 Galactic Structure Formation and Dark Matter

In the mirror world under consideration, neutrons will be the dominant matter. Since they are electrically neutral, they will almost not lose energy in the process of "friction"of the intergalactic gas, so they will not form disk structures like galaxies, but will form only spherically symmetric halos. This means that neutrons turn out to be close to the hidden mass by their properties. In this case, neutrons would be a colliding hidden mass with an interaction cross section of the order of the size of a neutron. As shown in [8], a noticeable deviation from the sphericity of the halo in the case of colliding hidden mass can be seen at $\frac{\sigma}{m} \sim 1\,\mathrm{cm}^2/\mathbf{g}$. For neutrons, this ratio is $\sim 0.01\,\mathrm{cm}^2/\mathbf{g}$, hence, no noticeable deviation of the shape of the halo of mirror neutrons from the spherically symmetric ones is expected.

Disk structures and galaxies will be formed from helium atoms, since the interaction cross section of atoms is much higher than the neutron collision cross section, so helium can lose energy and be deposited in the disk. The concentration of helium is 3 times less than the concentration of neutrons, in addition, the electromagnetic interaction cross section of helium atoms, approximately equal to the radius of the atom, is less than the interaction cross section of hydrogen atoms in our world (due to the helium nucleus charge, equal to 2 m). For this reason we can expect that by the present moment there will be few disk structures and galaxies.

After a long time of halo formation from mirror neutrons, the density of such clots may be sufficient to start thermonuclear reactions in them - neutron combustion similar to hydrogen combustion in our stars, that is, fusion of neutrons to form deuterium, electron and antineutrinos with the release of energy. Unlike hydrogen combustion, neutron combustion does not involve overcoming the potential barrier, so there is no need to reach the threshold temperature and no need to form a hot core.

In mirror galaxies the formation of stars is expected only from helium, which is known to start "burning"in thermonuclear reactions at much higher temperatures than hydrogen. Most clots in mirror galaxies will have insufficient mass to start burning helium and form helium dwarfs, in which electrons (which before ionization consisted of helium atoms) form degenerate gas, in which fully ionized helium nuclei with temperatures insufficient to overcome the potential barrier and start thermonuclear reactions are immersed. Some rare clots will have a large enough mass to form a star with helium burning in its center. Such stars will be similar to the stars in our world, with the difference that their number will be much smaller.

3 Conclusion

In this paper we considered a mirror world model under the condition: $m_n < m_p - m_e$. In this model, the universe will consist of helium as well as free stable neutrons.

It follows that only massive stars, in which the process of burning helium will take place, can exist. The formation of galactic structures in the mirror world will be different from the formation processes in our world.

Nevertheless, perhaps, the considered model of the mirror world is compatible with the available observational data, if we assume the neutrons of the mirror world as a candidate for the hidden mass.

References

1. *Lee T. D.*, *Yang C.-N.* Question of Parity Conservation in Weak Interactions // Phys. Rev. — 1956. — T. 104. — C. 254—258.
2. *Wu C. S.* [et al.]. Experimental Test of Parity Conservation in β Decay // Phys. Rev. — 1957. — Vol. 105. — P. 1413–1414.
3. *Christenson J. H.* [et al.]. Evidence for the 2π Decay of the K_2^0 Meson // Phys. Rev. Lett. — 1964. — Vol. 13. — P. 138–140.
4. *Kobzarev I. Y.*, *Okun L. B.*, *Pomeranchuk I. Y.* On the possibility of experimental observation of mirror particles // Sov. J. Nucl. Phys. — 1966. — Vol. 3, no. 6. — P. 837–841.
5. *Foot R.* Mirror dark matter: Cosmology, galaxy structure and direct detection // International Journal of Modern Physics A. — 2014. — T. 29. — C. 1430013.
6. *Хлопов М. Ю.* Основы космомикрофизики. — 2011.
7. *Дубрович В. К.*, *Хлопов М. Ю.* О доменной структуре теневой материи // Астрон. журн. — 1989. — Т. 66. — С. 232.
8. *Massey R.* [et al.]. The behaviour of dark matter associated with four bright cluster galaxies in the 10 kpc core of Abell 3827 // Monthly Notices of the Royal Astronomical Society. — 2015. — Vol. 449, no. 4. — P. 3393–3406.