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Small thesis on the topic:

# "MirRor world without weak interaction"

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**Introduction**

Before 1956 it wasassumed that mirror reflection of the process with any fundamental particle leads to the same process or other process which also does exist in nature. Discovery of parity violation inweak interaction initiated the study of the processes in which this fundamental rule is violated(for instance neutrinos in β- decay have only one polarization).

A P-transformation of coordinate system which describes the P-violating process corresponds to transitionfrom left to right coordinate system or mirror reflection of processes. Such transformation leads to a process that does not exist in nature. On the other hand, the existence of apreferred coordinate system means that the emptyspace-time itselfhas a preferred orientation.

To restore the equivalence of left and right Lee and Yang [1] supposed that all the known particles must have their mirror twins**.** Inthis case the P-inversion must be accompanied by change of ordinary particles by their mirror partners.

The simplest solutionwas to putantiparticle for the role of mirror particle. But due to discovery of CP-violation it was assumed in the paper [2] that ordinary particles have mirror partners which do not coincide with antiparticles.

The easiest way to include the set of mirror particles in our standard model is to add to the $SU\left(2\right)⊗U\left(1\right)⊗SU\left(3\right)\_{C}$ – gauge symmetry of standard model the same symmetry but corresponding to mirror particles.

Evolution of the Universe and the cosmological consequence of mirror world without weak interaction are presented inthis work.

There is considered the model of mirror world with $SU\_{M}\left(3\right)⊗U\_{M}\left(1\right)$ symmetries and only first family of fermions which have the same masses as the ordinary u- and d-quarks and $e$ which has also the same mass.In electroweak model, masses of quarks and leptons are generatedas result of interaction with Higgs field. This, in turn, is caused by a violation of the SU(2) symmetry.

However, in addition to a weak CP violation, there is a strong CP violation.

The additional symmetry $U\_{PQ}\left(1\right)$ is considered in R. Peccei and H. Quinn model [3].This symmetry is spontaneously broken by some complex scalar field $ϕ $on some energy scale. This field in mirror world may be the Higgs field which may give the mass to mirror particles.

Let’s check the Yukawa couplings for fermions on the example of an electron:

$m\_{e}=\frac{f\_{e}υ}{\sqrt{2}}, υ-$ Vacuum expectation value, $υ=246.2 GeV$

For electron $f\_{e}=\frac{16}{3}α\_{em}^{3}=2.07∙10^{-6}$ **[how does it explain the mass of electron in your case?**

But also $f\_{e}=\frac{m\_{e}\sqrt{2}}{υ}=2.87∙10^{-6}$

So the order of magnitude is kept. **[do you assume VEV for your PQ field equal to Electroweak scale, so that your axion is Weiberg-Wilczek axion?]**

We would have a doubling of some hadron states having a general strong interaction as well as a doubling of atomic states having a general electromagnetic interaction due to additional degrees of freedom. Thus, we have mirror electromagnetic and mirror strong interactions.

**Cosmological consequences**

Let‘s adopt the mirror world model with SU(3)⊗U(1) symmetry with the first generation of fermions. Now we are able to create mirror matter resistant to β - decay. In this case, the neutrons will become stable particles. The mesons $π^{\pm } $and protons will remain stable particles because they decay only by weak interaction. Electrons remain stable owing to conservation of electromagnetic charge as in our world.

Let‘s consider the complete model including mirror particles without weak interaction. The mirror world has the same kinds of interactions excluding the weak but they apply only to mirror particles

A possible interaction between the particles of our world and the particles of mirror world is gravity. Therefore, the mirror and ordinary gravitational interactions will be the same. In addition, kinetic mixing of ordinary and mirror particles is possible.

In the framework of Grand Unified Theory the gauge symmetry

$$[SU\left(2\right)⊗U\left(1\right)⊗SU\left(3\right)\_{C}]\_{O}⊗[U\left(1\right)⊗SU\left(3\right)\_{C}]\_{M}$$

of ordinary and mirror particles is included in a single symmetry group $G\_{OM}$.

Let us assume that in the mirror Universe there is charge symmetry for simplicity.

**Inflation**

To realization the inflation process, it is required to introduce an additional scalar inflaton field into the model which can interacting with particles of matter of the ordinary and mirror world and must decay so that in the post-inflationary period effectively generate the observed number of baryons and leptons of our world and suppress the number of mirror baryons and leptons.

The initial amplitudes of ordinary and mirror inflatons can be different which leads to the formation of a domain structure in the distribution of ordinary and mirror matter under the framework of the chaotic inflation model [5]. In areas where the amplitude of ordinary inflatons is higher after inflation ordinary particles should dominate and the admixture of mirror particles should be exponentially small. Conversely, the dominance of mirror inflatons leads to a low density of ordinary particles after inflation.[6]

**Baryosynthesis**

It is assumed that the baryon excess has been formed in the process of baryosynthesis (Sakharov, 1967; Kuzmin, 1970) [7-8] leading to the baryon asymmetry of the initially baryon-symmetric Universe. Baryon excess in this case occurs due to CP - violating effects at the out from the balance of processes with non-conservation of the baryon number.

However, in the mirror world, this effect of CP violation is not present without a weak interaction, for this reason the asymmetry of mirror matter and mirror antimatter on the mechanism of electroweak interaction is impossible. But if we assume that in the mirror world, as in ours, at high energies there is a merger **unification]** of strong and electromagnetic interaction and then the vertices in Fig.1 are possible:



Figure 1 The interaction of the vector boson with the quarks, antiquarks and antileptons [9]

both in our world and in the mirror world. In this case, there is a violation of the baryon number in the process (Fig. 2) that is required to create an excess of baryons over anti-baryons:



Figure 2 – The process with the exchange of a vector boson, leading to a violation of the baryon number [9].

The introduction of new supermassive mirror vector and scalar particles involved in mirror interactions with ordinary mirror particles will lead to asymmetry of mirror and ordinary baryons through the interactions presented in Fig. 1 by the decay of such particles.

Thus, the only way to get the asymmetry of mirror matter and antimatter is the introduction of new massive particles the decay of which will lead to baryon excess. At the same time, the lifetime of such particles should be less than 1 sec in order for them to completely disintegrate **[style]** to the stage of nucleosynthesis.

**Dark matter candidates**

The main properties dark matter particles must have are:

* Electroneutrality
* Stability (lifetime **[>>]** 14·109 years)
* Nonzero mass

Under these conditions, some mirror particles in the absence of weak interaction can be particles of dark matter, but only if the mass of the mirror substance is much larger than the mass of ordinary particles. This is possible if there was a freezing out of mirror particles.

In particular, mirror baryons can be candidates for the role of dark matter, they can form compact objects with stellar masses and sizes. [6]

**Evolution**

Let us consider how the further evolution of the model of the Universe with the mirror world took place without weak interaction.



Figure 3 – Thermal evolution of the Universe

The next phase of the Universe evolution after the inflation is the reheating. During this phase an active birth of high-energy particles and their thermalization occurred. [10]

The birth of particles in the mirror world occurs during this period, as in the case of particles of the ordinary world, due to rapid oscillations of the inflaton field near the minimum potential.

Let us consider the process of freezing out stable particles of the model. In this case, neutrons, protons, charged pions and electrons (positrons) remain stable.

Let’s calculate the equilibrium number density of nonrelativistic particle by formula [11]: **[it assumes charge symmetry, but you discussed above baryosynthesis and charge asymmetry]**

$$n=\left(\frac{2}{π^{3}}\right)^{^{1}/\_{2}}\frac{m^{^{3}/\_{2}}\left(kT\right)^{3/2}}{ℏ^{3}}exp\left(-\frac{mc^{2}}{kT}\right),$$

Let's estimate the freezing out temperature from the following considerations.

The freeze out condition is:

$$H=n\_{a}υ\_{ab}σ\_{ab}$$

Where $n\_{a}- $number density, $υ\_{ab}- $velocity of interaction **[relative velocity]**, $σ\_{ab}- $cross-section of interaction.

$$H\~\frac{\sqrt{k\_{ε}}T^{2}}{m\_{Pl}}$$

We can express the freeze out moment from equation of the Universe expansion law $ρ≈\frac{1}{Gt\_{1}^{2 }} $and the mass density expression$ ρ≈\frac{kT\_{1}}{c^{2}}\left(\frac{kT\_{1}}{cℏ}\right)^{3}$. At the freeze out time$kТ\leq mc^{2}$ then approximately$ [kТ=\frac{mc^{2}}{α}$, where $α≳1.$

$t\_{1}=α^{2}G^{-1/2}m^{-2}ℏ^{3/2}c^{-3/2}=\frac{m\_{Pl}}{m^{2}}\frac{ℏ}{c^{2}}$,

Where $G=\frac{ℏc}{m\_{Pl}^{2}}$, $m\_{Pl}=1.2∙10^{19}$ GeV.

And the temperature of freeze out estimated from the approximate expression:

$$T\_{freez out}≈0,86 MeV\sqrt{\frac{1 sec}{t\_{1}}}$$

Then get:

|  |  |  |  |
| --- | --- | --- | --- |
|  | $$t\_{1}, sec$$ | $T\_{freez out}$, MeV | $$n\_{freez out}, sm^{-3}$$ |
| $$π^{\pm }$$ | $$4,236⋅10^{-4}$$ | 41,785 | 1,384$∙10^{37}$ |
| $$n^{0}$$ | $$7,896⋅10^{-6}$$ | 305.9*7*4 | 1,667$⋅10^{39}$ |
| $$e^{\pm }$$ | 31.584 | 0.153 | 1.42$∙10^{28}$ |

For a proton, due to the almost equality of masses, we get the same values as for the neutron.

So the freeze out of the neutron to proton ratio in the mirror world occurs by the following reactions:

$$π^{+}n\rightarrow π^{0}p $$

$$π^{-}p\rightarrow π^{0}n $$

At the first second there is a freezing out of relativistic neutrinos in our world. This process is due to the fact that the neutrino gets out of balance **[decouple]** , since the reverse lifetime of the neutrino **[the rate of neutrino interaction]**

$τ\_{ν}^{-1}=σ\_{ann.}n\_{υ}\~T^{5}$ ,

And expansion rate $\~\frac{1}{T^{2}}$ . However, in a mirror world without weak interaction, a neutrino cannot be born in $e^{-}e^{+}$ reactions, as well as scattering on electrons and annihilate since such processes go through a weak interaction. Hence, we obtain that mirror neutrinos are not initially present in the equilibrium state, so the decoupling of mirror neutrinos does not occur.

A birth of relic mirror neutrinos and their further “cooling” as the Universe expands are occurring. In the mirror world, the birth of neutrinos occurs only in a gravitational way. Due to this their concentration should be extremely small and the mass should be of the order of ~kT (1 sec) since in the mirror world there is only the first generation of leptons, the oscillations between different flavors of mirror neutrinos does not exist, but we can assume that the oscillations occur between our world and the mirror with one generation. In this case, the mirror electron neutrino may be a candidate for the role of sterile neutrino.

The density of ordinary and mirror radiation is different at the RD stage due to different equilibrium temperatures.

The observed abundance of 4Не is

Уobs = (28 ±12)%

The freezing out the ratio of neutrons and protons number in the ordinary matter after the first second of expansion the contribution of mirror photons and mirror electron-positron pairs should be taken into account in the full density. However, given the assumption that the equilibrium temperature in the mirror world was lower the contribution of mirror photons is suppressed and the contribution of electron-positron pairs is significantly less than that of other stable particles.

At the matter dominant stage the Large Scale Structure of the Universe (LSS) is formed. The influence of mirror matter on LSS is possible only in the case of large scale mirror domains corresponding to the mass scale:

$$M>10^{16}M\_{⊙}$$

or large scale islands distribution of baryons. In this case the mirror baryon islands have to look like voids which have not Galaxies from ordinary matter.

The most of the matter is dark matter in our world, however, in the mirror world it may not be so. If the temperature in the mirror world is less but the baryon asymmetry is greater mirror matter can play the role of dark matter in our world.**[you assumed charge symmetry in freeze out]**

The pions are stable in the mirror world. They participate in charge exchangereactions which generating protons and neutrons. Thus, mirror nuclei can play the role of direct latent mass,**[???]** since such nuclei must remain stable.

$$π^{+}n\rightarrow π^{0}p $$

$$π^{-}p\rightarrow π^{0}n $$

Thus, $π^{0}$- component of matter prevails due to the effect of charge exchange reactions. **[??? Neutral pions are unstable, they have two-gamma decay]** But the mirror weakless Universe enters the nucleosynthesis phase with approximately equal numbers of protons and neutrons. If the visible baryon-to-photon ratio $\frac{n\_{b}}{n\_{γ}}$ were the same as in our Universe, then it is easy to estimate that nearly all protons and neutrons get absorbed into helium. [13]

In our case, the electron number density is much smaller then charged pion number density. This fact leads to pion atoms formation (negative charged pion is bound with nuclei).

**Conclusion**

Thus, in the model of the mirror world without weak interaction with the first generation of fermions, charged pions, all leptons, protons and neutrons remain stable. And also the process of annihilation of neutrinos by weak interaction is impossible, therefore their number becomes small.

Mirror baryons can be candidates for the role of the dark matter. But also it can be mirror nuclei consisting of negative charged pion bounding with nuclei because abundance of pions in primary plasma is high and much more then abundance of electrons and pion is bound with nuclei much earlier, than recombination with mirror electrons takes place.

Mirror neutrinos are not initially present in the equilibrium state, so the decoupling of mirror neutrinos does not occur.

The mirror world model does not affect the amount of primary helium concentration.

The influence of mirror matter on the Large Scale Structure of the Universe is possible in the case of large-scale mirror domains or Large Scale Island distribution of baryons.

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