Mirror and Shadow Worlds

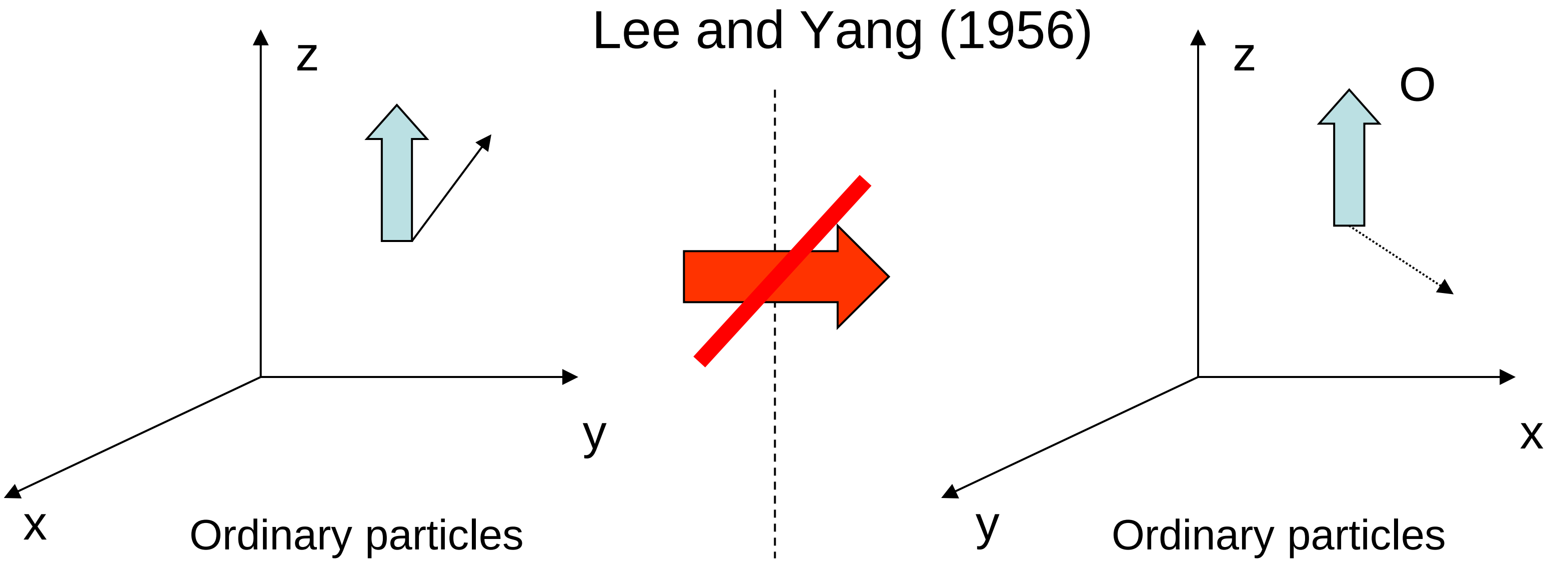
Lecture from course

“Introduction to Cosmoparticle Physics”

Outlines

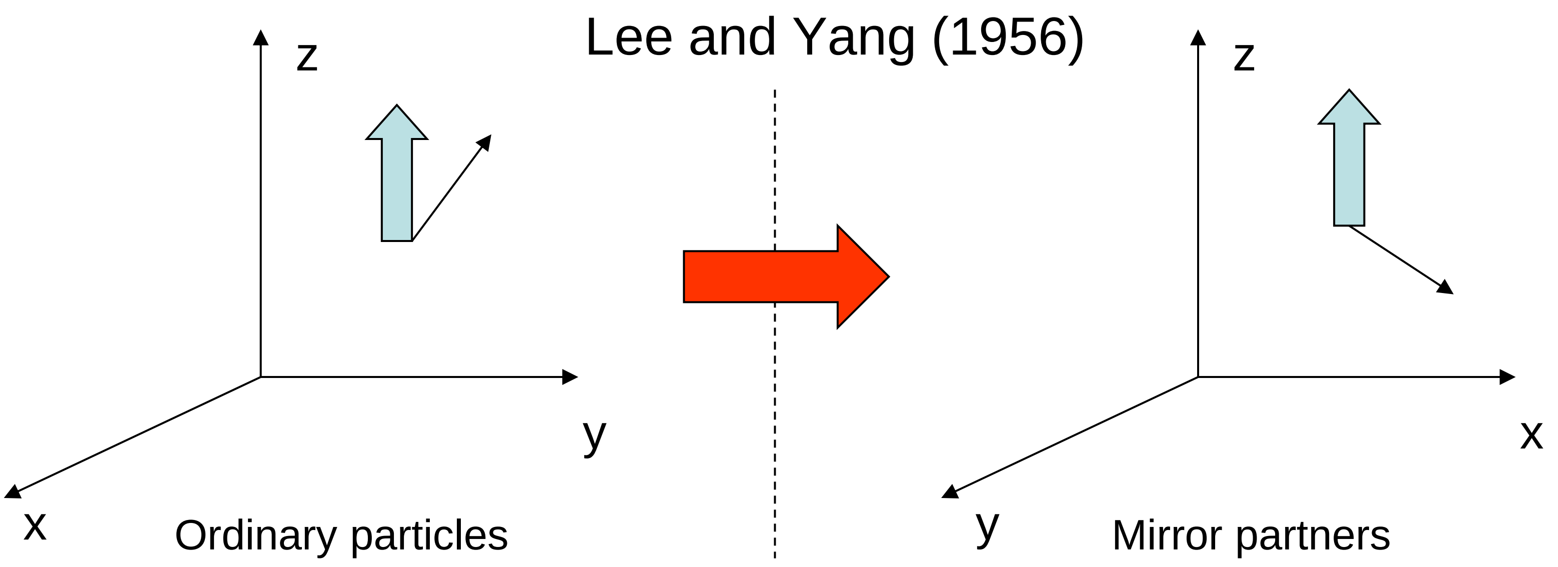
- Mirror matter
- Problems of strictly symmetric mirror world
- Shadow matter
- « Play Universe »
- Conclusions

P-violation



Parity (P) violation means that the process, reflected in mirror does not exist in Nature. It means non-equivalence of left- and right-handed coordinate systems. Beta decay of polarized nucleus, reflected in mirror, does not exist. To restore the equivalence of left- and right-handed coordinate systems P-transformation should be generalized. Together with mirror reflections particles should be changed by their mirror partners.

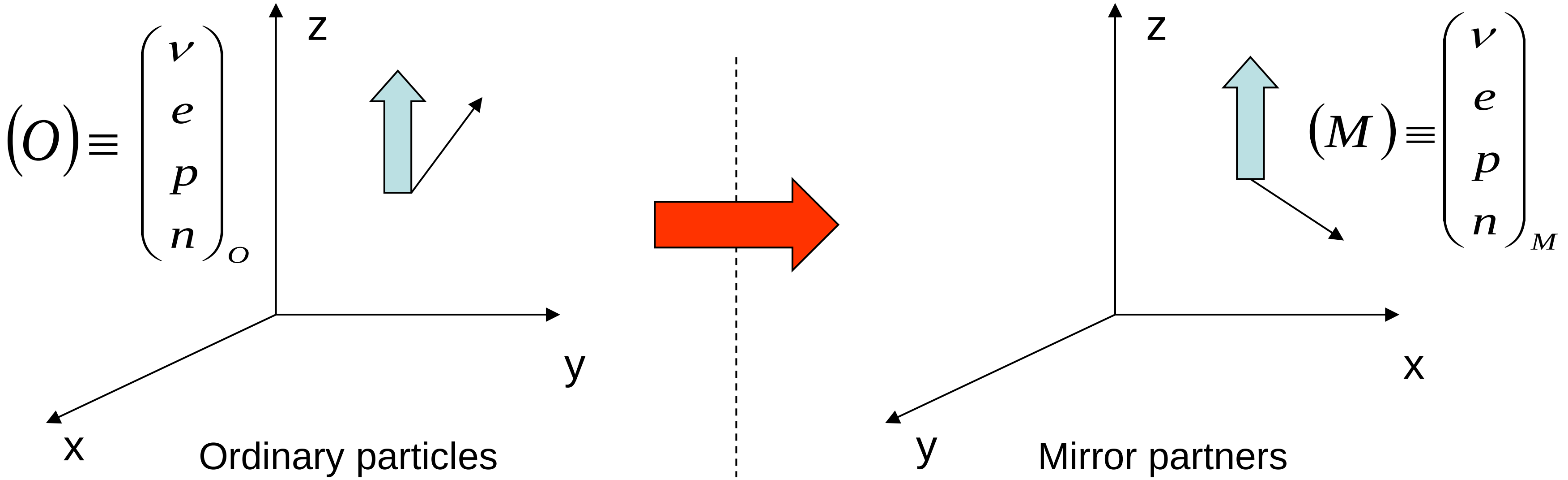
Mirror partners?



The equivalence between left- and right-handed coordinate systems is restored, if reflection in mirror is accompanied by change of ordinary particles by their mirror partners. Lee, Landau,… (1957) offered an economic solution: CP invariance assumes that antiparticles play the role of mirror partners. Discovery of CP-violation in 1964 put again the question of proper choice for the set of mirror partners.

Mirror particles!

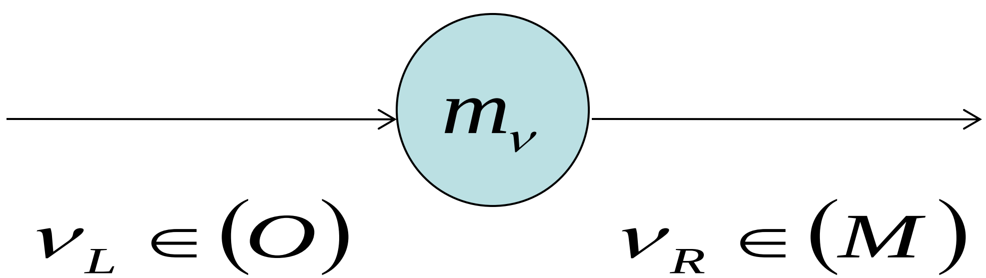
Kobzarev, Okun, Pomeranchuk (1966)



The equivalence between left- and right-handed coordinate systems is restored, if reflection in mirror is accompanied by change of ordinary particles by their mirror partners. Mirror partners are strictly symmetric to ordinary particles. Therefore they can not have ordinary electromagnetic and strong interactions (doubling of atomic levels, or pion states). Successive analysis have shown that (O) and (M) also can not share W and Z boson mediated weak interaction.

Mass of neutrino

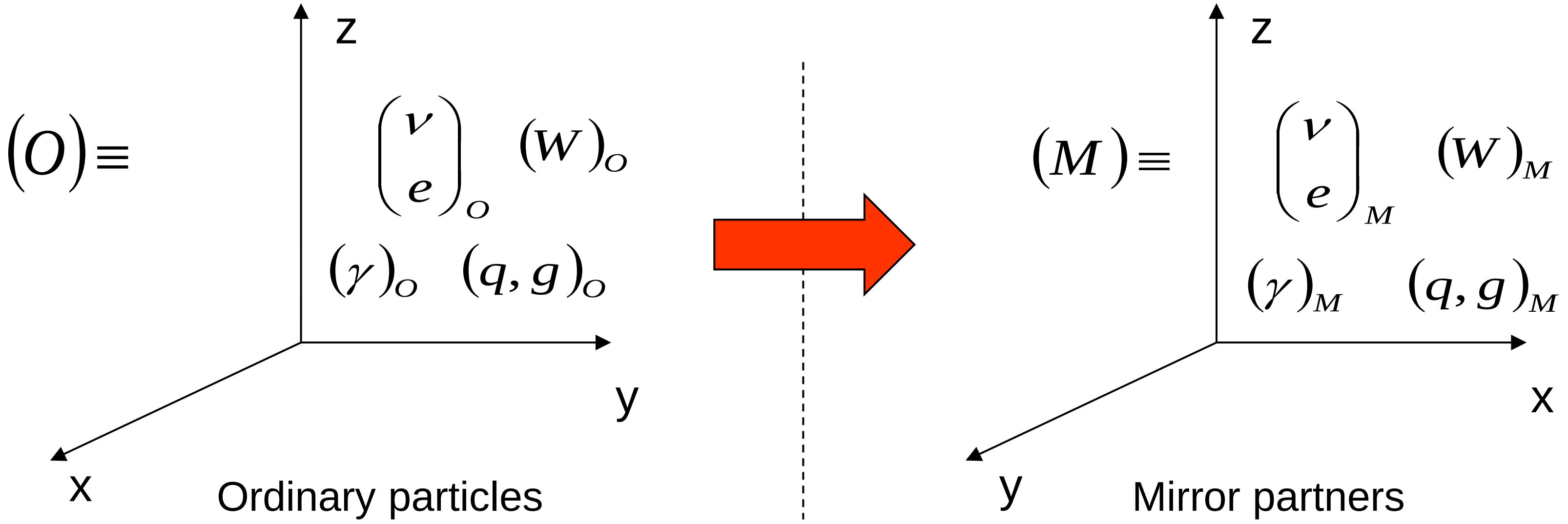
- If mass of ordinary neutrino $\nu_L \in (O)$ links it to mirror neutrino $\nu_M \in (M)$, mass of neutrino can play a role of the only narrow bridge to mirror world.



- How can we study particles, to which we can not apply usual methods of high energy physics?

Mirror world

Blinnikov,Khlopov(1980,1982,1984)



Assume that there is no common interaction between ordinary particles and their mirror partners, except for gravity. All the masses and coupling constants of mirror particles are strictly symmetric to the ordinary ones.The initial conditions are also assumed strictly symmetric.

Strictly symmetric evolution of mirror particles in the Universe

- Strict symmetry in physics and initial conditions leads to

$$n_O^i(x) = n_M^i(x)$$

for $i = \gamma, e, q, \ldots$ and to equality in the amount and spatial distribution for ordinary and mirror baryon excess

$$\Delta n_{B,O}^i(x) = \Delta n_{B,M}^i(x)$$

Primordial He and mirror particles

The frozen out n/p ratio is

$$\frac{n}{p} = \exp\left\{-\frac{\Delta m}{T_f}\right\}$$

and the freezing out temperature is

$$T_f \propto \left(\frac{\kappa}{\kappa_0}\right)^{1/6}$$

Any new species of relativistic particles increases the abundance of primordial He-4. Strict (but model dependent) constraints give

$$Y_{prim} = 0.25 \Rightarrow \Delta n_\nu < 1$$

Mirror particles double the number of relativistic species. It leads to

$$Y_{prim} \geq 0.28$$

which formally does not contradicts to the observed He abundance

$$Y_{obs} = 0.28\text{-}0.40$$

But it is only the first trouble of symmetric cosmology of mirror world

Separation of ordinary and mirror objects in Galaxy

- Strict symmetry in physics and initial conditions leads to symmetry in distributions

$$f_O^i(M) = f_M^i(M); \quad f_O^i(v) = f_M^i(v); \ \langle n_O^i(x) \rangle = \langle n_M^i(x) \rangle$$

but ordinary and mirror matter is separated on scales $M < M_{th} \sim 10^6 M_{sun}$ at which formation of objects involves development of thermal instability. Cold gas clouds are pressed by hot gas. It results in separate evolution of ordinary and mirror clouds, and formation of objects (e.g. stars) with definite mirrority.

Mirror objects in Galaxy

- Strict symmetry in physics should result in symmetry in forms of astronomical objects of mirror matter and their evolution. There should be mirror stars, planets and interstellar gas of mirror matter.
- Mirror stars in halo can play the role of MACHOs and observed by effect of microlensing.
- Mirror gas can be accreted by ordinary stars and ordinary gas can be accreted by mirror stars.
- Mirror gas accreted by Sun can form a mirror planet inside the Sun, giving rise to Solar surface oscillations with T=160min.
- Ordinary gas, accreted by mirror neutron star, can form a dense visible core $R_c \sim 100m$, giving rise to time variations $\tau \sim R_c / c$ more rapid, than in ordinary neutron stars and black holes.
- Galactic disc should contain equal amount of ordinary and mirror stars.

Local Dark Matter

- In vicinity of Solar system the density should be two times larger due to invisible mirror stars and gas:

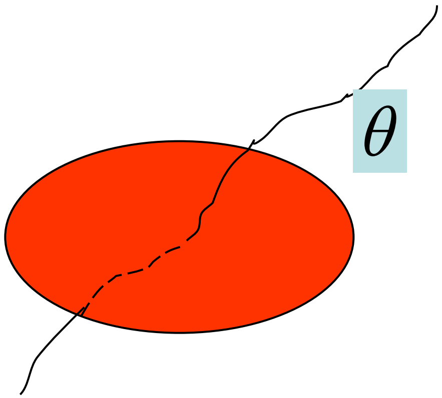
$$\rho_{dyn} \geq 2\rho_{vis}$$

- Such increase of local density can not be due to collisionless dark matter, and evidences for it could be considered as favoring mirror matter.
- HIPPARCOS data (1999) gave

$\rho_{dyn} = 0.098 \pm 0.011 \frac{M_{Sun}}{pc^3}$ for the estimated

$$\rho_{vis} = 0.095 \frac{M_{Sun}}{pc^3}$$

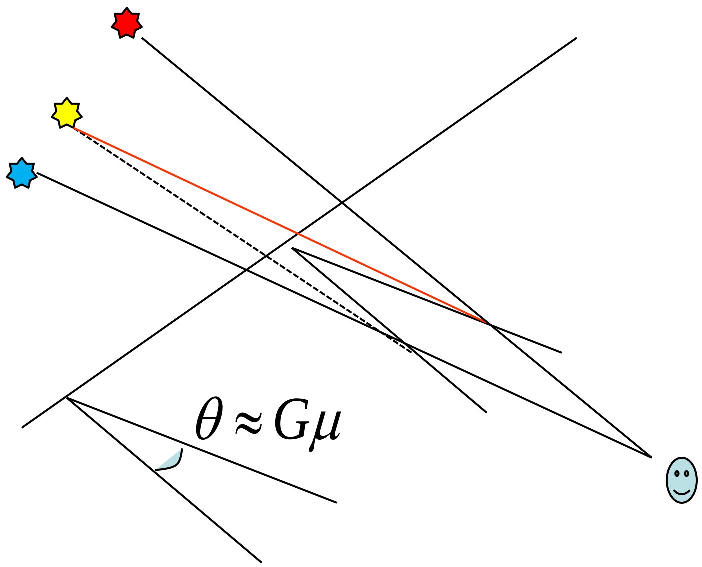
Alice strings



- If $GUT \supset M \otimes O$ due to strict symmetry $M \Leftrightarrow O$ multi-component Higgs fields play the role of imaginary and real parts of a single complex field. Corresponding cosmic string changes mirrority of particle circulating around it. Alice could go « Through the looking glass » around such Alice string.

- Spontaneous breaking of U(1) symmetry results in the continuous degeneracy of vacua. In the early Universe the transition to phase with broken symmetry leads to formation of cosmic string network.
- Alice string crossing a line of sight to a visible object changes its relative mirrority and makes it mirror and invisible. On the contrary, mirror object becomes visible, if Alice string crosses the line of sight to it.

Gravitational lens on Alice string



- If Alice string crosses the line of sight to QSO, it converts ordinary radiation into mirror radiation and vice versa. Rapid variation of QSO luminocity is then possible.

- Cosmic string cuts a piece of space along its line, and it leads to effect of gravitational lens. One sees two images instead of the lensed object.
- Alice string separates ordinary and mirror light. The light, which is ordinary to the left of the string is mirror to the right of the string.
- If the object is the source of ordinary and mirror light (as e.g. QSO) one sees its ordinary radiation in the left image, while the mirror radiation becomes ordinary and visible in the right image.

Fractons

- Mixed states, having mirror and ordinary charges, have unusual properties.
- Mirror hadron, having ordinary electroweak charges, behaves as fractionally charged lepton.
- Ordinary quarks, having mirror electroweak charges, are neutral relative to ordinary electromagnetism and, bound with ordinary quarks, give rise to a colorless fractionally charged particles.
- While negatively charged « leptonic » fractons should be bound with nuclei and thus excape annihilation with their positively charged antiparticles, « hadronic » fractons possess mirror electromagnetic charges and owing to mirror Coulomb attraction diffuse to their antiparticles and annihilate in dense matter bodies.
- Recombination of hadronic fractons in matter makes their exitence compatible with stringent experimental upper limits on abundance of fractionally charged particles in terrestrial matter.

Asymmetric initial conditions

- Problems of strictly symmetrical cosmology of mirror matter can be avoided, if initial cosmological conditions were different for ordinary and mirror matter (Berezhiani et al).
- If temperature of mirror matter after reheating of Universe was few times smaller, than for ordinary matter, symmetric mechanism of baryogenesis should lead to mirror baryon excess, larger than for ordinary matter.
- Smaller temperature of relativistic mirror species in the period of SBBN reduces their influence on He abundance.
- Larger mirror baryon excess can provide mirror baryonic matter as the dominant form of Dark Matter.
- However, constraints on MACHOs and on Local Dark Matter put forward a question about the dominant form of mirror baryons in the Galaxy.

Shadow world

- Asymmetry in physics of ordinary and mirror matter (e.g. by a scale factor in their masses – Mohapatra, Senjanovich), Okun's y-matter, 248 fundamental particles and 248 fundamental interactions of E_8' symmetry in $E_8' \otimes E_6$ GUT model of $E_8' \otimes E_8$ heterotic string give examples of shadow world.
- As shadow deforms an image of the original, properties of shadow particles and their interactions may strongly differ from the ones of the ordinary matter, even if shadow world results from breaking of initially strict mirror symmetry.
- Qualitative features of shadow world can be analyzed with the use of methods of cosmoarcheology, while quantitative description of the Universe with shadow matter is strongly model dependent.
- This model dependence provides good example of relationship between cosmological scenarios and particle models, on which these scenarios are based.

« Play Universe »

- Any given set of particles and their interactions determines specific combination and succesion of physical processes in the Universe.
- Realistic physical model should include SM.
- Realistic cosmological scenario should contain physical mechanism for inflation, baryosynthesis and non-baryonic dark matter.
- Variety of possible models of shadow world leads to variety of realistic cosmological scenarios, which differ by the combination of their observational effects.

Cosmological Reflections of Microworld Structure

- **(Meta-)stability of new particles reflects some Conservation Law, which prohibits their rapid decay. Following Noether's theorem this Conservation Law should correspond to a (nearly) strict symmetry of microworld. Indeed, all the particles - candidates for DM reflect the extension of particle symmetry beyond the Standard Model.**
- **In the early Universe at high temperature particle symmetry was restored. Transition to phase of broken symmetry in the course of expansion is the source of topological defects (monopoles, strings, walls…).**
- **Structures, arising from dominance of superheavy metastable particles and phase transitions in early Universe, can give rise to Black Holes, retaining in the Universe after these structures decay.**

Conclusions

- Postulated symmetry between ordinary and mirror particles excludes the possibility of their common strong, weak and elecromagnetic interactions.
- Even decoupled from ordinary particles, symmetric mirror world by its very presence in the Universe causes effects, inconsistent with observational data.
- Existence of a « curved mirror » or shadow worlds leads to numerous cosmological scenarios, determined by underlying physics.
- The variety of these scenarios is an example of fundamental relationship between micro- and macro worlds, studied by cosmoparticle physics.

Scheme of referat

- Specify cosmologically significant consequences of physical model
- Physics of inflation, baryogenesis and candidates for dark matter
- Cosmological scenario: main stages of evolution and their physical reasons
- Conclusion about consistency of the scenario with observational data