



Thoughts on  
Dark Matter:

*windows to dark  
world ?*

Zurab Berezhiani

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Mirror Matter

B-L violating  
processes and  
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# Thoughts on Dark Matter: *windows to dark world ?*

Zurab Berezhiani

University of L'Aquila and LNGS

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# Some epochal discoveries after 30's of XIX ...

## Anti-matter, 1931-32



$$\left( \hbar \nabla^2 + \sum_{\alpha=1}^3 \alpha_{\alpha} p_{\alpha} c \right) \psi(\mathbf{x}, t) = i \hbar \frac{\partial \psi(\mathbf{x}, t)}{\partial t}$$

## Dark matter , 1932-33



## Neutron, 1932-33



## Parity Violation, 1956-57



## CP Violation, 1964



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## ...and a prophetic idea on the origin of matter

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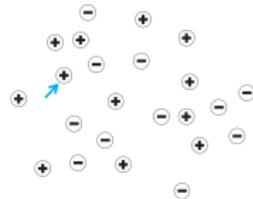
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*A dreamer ... Andrey Sakharov, 1967*

Matter (Baryon asymmetry) in the early universe can be originated (from zero) by processes that

- Violate  $B$  (better  $B - L$ )
- Violate CP
- and go out-of-equilibrium at some early epoch



I want to pose a question in this way:

Can the issues of the antimatter, dark matter, neutron, parity, CP-violation, baryon violation and some other issues of Standard Model more intimately related ?



# Standard Model on T-shirts

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$$\begin{aligned}\mathcal{L} = & -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \\ & + i \bar{\Psi} \not{D} \Psi + h.c. \\ & + \bar{\Psi}_i y_{ij} \Psi_j \phi + h.c. \\ & + \frac{1}{2} \partial_\mu \phi^2 - V(\phi)\end{aligned}$$

Fermions (= matter): quarks and leptons, *3 generations*

Bosons (= interactions): gauge fields + **God's particle** – Higgs



# Standard Model vs. P, C, T and B & L

*Fermions:*

$$q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix}, \quad l_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}; \quad u_R, d_R, e_R$$

$B=1/3$ 
 $L=1$ 
 $B=1/3$ 
 $L=1$



*Anti-Fermions:*

$$\bar{q}_R = \begin{pmatrix} \bar{u}_R \\ \bar{d}_R \end{pmatrix}, \quad \bar{l}_R = \begin{pmatrix} \bar{\nu}_R \\ \bar{e}_R \end{pmatrix}; \quad \bar{u}_L, \bar{d}_L, \bar{e}_L$$

$B=-1/3$ 
 $L=-1$ 
 $B=-1/3$ 
 $L=-1$



$$\mathcal{L}_{SM} = \mathcal{L}_{Gauge} + \mathcal{L}_{Higgs} + \mathcal{L}_{Yuk} \quad \text{CPT is OK (Local Lagrangian)}$$

$P (\Psi_L \rightarrow \Psi_R)$  &  $C (\Psi_L \rightarrow \bar{\Psi}_L)$  broken by gauge interactions

$CP (\Psi_L \rightarrow \bar{\Psi}_R)$  broken by complex Yukawas  $Y = Y_{ij}^{u,d,e}$

$$(\bar{u}_L Y_u q_L \bar{\phi} + \bar{d}_L Y_d q_L \bar{\phi} + \bar{e}_L Y_e l_L \bar{\phi}) + (u_R Y_u^* \bar{q}_R \phi + d_R Y_d^* \bar{q}_R \phi + e_R Y_e^* \bar{l}_R \phi)$$

There are no renormalizable interactions which can break B and L !

Good for our stability, Bad for baryogenesis

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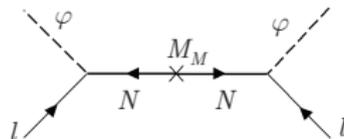
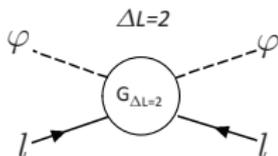
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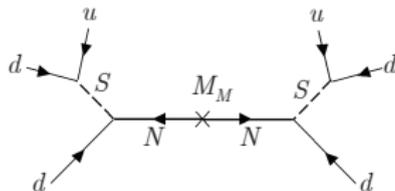
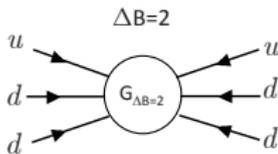
# Baryogenesis requires new physics:

B & L can be violated only in higher order (non-renormalizable) terms

- $\frac{1}{M}(l\bar{\phi})(l\bar{\phi})$  ( $\Delta L = 2$ ) – neutrino (seesaw) masses  $m_\nu \sim v^2/M$



- $\frac{1}{M^5}(udd)(udd)$  ( $\Delta B = 2$ ) – neutron-antineutron oscillation  $n \rightarrow \bar{n}$



can originate from new physics related to scale  $M \gg v_{EW}$  via seesaw



# Dark matter requires new physics

Standard Model has no candidate for dark matter

*massive neutrino ( $\sim 20$  eV) was a natural “standard” candidate of “hot” dark matter (HDM) forming cosmological structures (Pencakes) – but it was excluded by astrophysical observations in 80’s, and later on by the neutrino experiments! – RIP*

*In about the same period the BBN limits excluded dark matter in the form of invisible baryons (dim stars, etc.) – RIP*

Then a new *Strada Maestra* was opened – *SUSY*  
– well-motivated theoretical concept promising to be a highway for solving many fundamental problems, brought a natural and almost “Standard” candidate WIMP – **undead, but looks useless**

*Another well-motivated candidate, Axion, emerged from Peccei-Quinn symmetry for solving strong CP problem – alive, but seems confused*

All other candidates in the literature are *ad hoc* !

Apart one exception –

*which may answer to tantalizing question: do baryogenesis and dark matter require two different new physics, or just one can be enough?*

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# Cosmic Concordance and Dark Side of the Universe

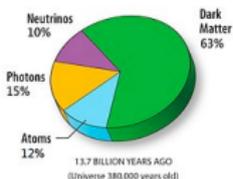
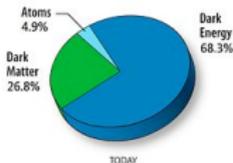
Today's Universe: flat  $\Omega_{\text{tot}} \approx 1$  (*inflation*) and multi-component:

- $\Omega_B \simeq 0.05$     observable matter: **electron, proton, neutron**
- $\Omega_D \simeq 0.25$     dark matter:    **WIMP? axion? sterile  $\nu$ ? ...**
- $\Omega_\Lambda \simeq 0.70$     dark energy:     **$\Lambda$ -term? Quintessence? ....**

**Matter – dark energy coincidence:**  $\Omega_M/\Omega_\Lambda \simeq 0.45$ , ( $\Omega_M = \Omega_D + \Omega_B$ )  
 $\rho_\Lambda \sim \text{Const.}$ ,  $\rho_M \sim a^{-3}$ ;    *why*  $\rho_M/\rho_\Lambda \sim 1$  – *just Today?*

Anthropic explanation: if not *Today*, then *Yesterday* or *Tomorrow*.

**Baryon and dark matter Fine Tuning:**  $\Omega_B/\Omega_D \simeq 0.2$   
 $\rho_B \sim a^{-3}$ ,  $\rho_D \sim a^{-3}$ : *why*  $\rho_B/\rho_D \sim 1$  - *Yesterday Today & Tomorrow?*



– How Baryogenesis could know about Dark Matter? popular models for primordial Baryogenesis (**GUT-B, Lepto-B, Affleck-Dine B, EW B ...**) have no relation to popular DM candidates (**Wimp, Wimpzilla, sterile  $\nu$ , axion, gravitino ...**)

– Anthropic? Another Fine Tuning in Particle Physics and Cosmology?

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Coincidence of luminous and dark matter fractions: why  $\Omega_D/\Omega_B \sim 1$  ? or why  $m_B \rho_B \sim m_X \rho_X$  ?

Visible matter from Baryogenesis ( Sakharov)

$B$  ( $B - L$ ) & CP violation, Out-of-Equilibrium

$$\rho_B = m_B n_B, \quad m_B \simeq 1 \text{ GeV}, \quad \eta = n_B/n_\gamma \sim 10^{-9}$$

$\eta$  is model dependent on several factors:

coupling constants and CP-phases, particle degrees of freedom, mass scales and out-of-equilibrium conditions, etc.

Dark matter:  $\rho_D = m_X n_X$ , but  $m_X = ?$ ,  $n_X = ?$

$n_X$  is model dependent: DM particle mass and interaction strength (production and annihilation cross sections), freezing conditions, etc.

- |                  |                                   |                                     |
|------------------|-----------------------------------|-------------------------------------|
| ● Axion          | ● $m_a \sim 10^{-5} \text{ eV}$   | $n_a \sim 10^4 n_\gamma$ - CDM      |
| ● Neutrinos      | ● $m_\nu \sim 10^{-1} \text{ eV}$ | $n_\nu \sim n_\gamma$ - HDM (×)     |
| ● Sterile $\nu'$ | ● $m_{\nu'} \sim 10 \text{ keV}$  | $n_{\nu'} \sim 10^{-3} n_\nu$ - WDM |
| ● Para-baryons   | ● $m_{B'} \simeq 1 \text{ GeV}$   | $n_{B'} \sim n_B$ - SIDDM           |
| ● WIMP           | ● $m_X \sim 1 \text{ TeV}$        | $n_X \sim 10^{-3} n_B$ - CDM        |
| ● WimpZilla      | ● $m_X \sim 10^{14} \text{ GeV}$  | $n_X \sim 10^{-14} n_B$ - CDM       |

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# How these Fine Tunings look ...

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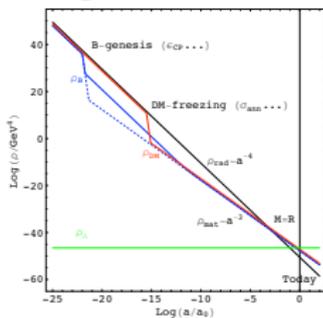
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## B-genesis + WIMP



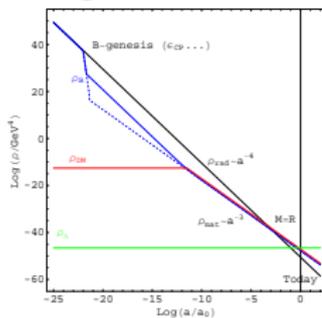
$$m_X n_X \sim m_B n_B$$

$$m_X \sim 10^3 m_B$$

$$n_X \sim 10^{-3} n_B$$

Fine Tuning?

## B-genesis + axion



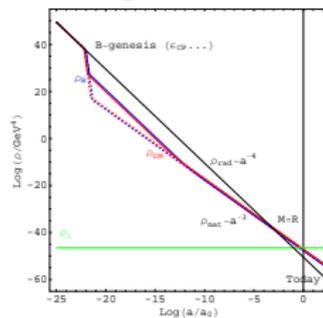
$$m_a n_a \sim m_B n_B$$

$$m_a \sim 10^{-13} m_B$$

$$n_a \sim 10^{13} n_B$$

Fine Tuning?

## B-cogenesis



$$m_{B'} n_{B'} \sim m_B n_B$$

$$m_{B'} \sim m_B$$

$$n_{B'} \sim n_B$$

Natural ?



# $SU(3) \times SU(2) \times U(1)$ & $SU(3)' \times SU(2)' \times U(1)'$

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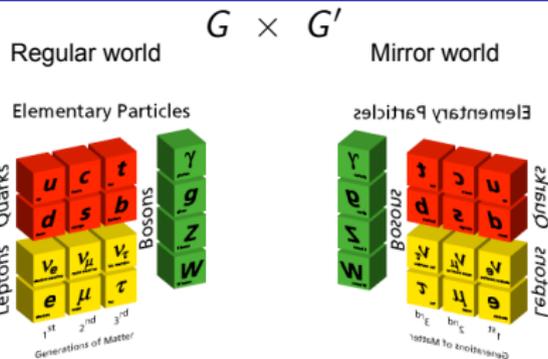
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- Two identical gauge factors, e.g.  $SU(5) \times SU(5)'$ , with identical field contents and Lagrangians:  $\mathcal{L}_{\text{tot}} = \mathcal{L} + \mathcal{L}' + \mathcal{L}_{\text{mix}}$
- Exact parity  $G \rightarrow G'$ : no new parameters in dark Lagrangian  $\mathcal{L}'$
- M sector is dark (for us) and the gravity is a common force (with us)
- M matter looks as non-standard for dark matter but it is truly standard in direct sense, just as our matter (self-interacting/dissipative/asymmetric)
- New interactions are possible between O & M particles  $\mathcal{L}_{\text{mix}}$
- Natural in string/brane theory: O & M matters localized on two parallel branes and gravity propagating in bulk: e.g.  $E_8 \times E_8'$



$SU(3) \times SU(2) \times U(1)$  vs.  $SU(3)' \times SU(2)' \times U(1)'$

generalized P and C parities

*Fermions and anti-fermions :*

$$q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix}, \quad l_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}; \quad u_R, d_R, e_R$$

**B=1/3**                      **L=1**                      **B=1/3**      **L=1**



$$\bar{q}_R = \begin{pmatrix} \bar{u}_R \\ \bar{d}_R \end{pmatrix}, \quad \bar{l}_R = \begin{pmatrix} \bar{\nu}_R \\ \bar{e}_R \end{pmatrix}; \quad \bar{u}_L, \bar{d}_L, \bar{e}_L$$

**B=-1/3**                      **L=-1**                      **B=-1/3**      **L=-1**



*Twin Fermions and anti-fermions :*

$$q'_L = \begin{pmatrix} u'_L \\ d'_L \end{pmatrix}, \quad l'_L = \begin{pmatrix} \nu'_L \\ e'_L \end{pmatrix}; \quad u'_R, d'_R, e'_R$$

**B=1/3**                      **L=1**                      **B=1/3**      **L=1**



$$\bar{q}'_R = \begin{pmatrix} \bar{u}'_R \\ \bar{d}'_R \end{pmatrix}, \quad \bar{l}'_R = \begin{pmatrix} \bar{\nu}'_R \\ \bar{e}'_R \end{pmatrix}; \quad \bar{u}'_L, \bar{d}'_L, \bar{e}'_L$$

**B=-1/3**                      **L=-1**                      **B=-1/3**      **L=-1**



$$(\bar{u}_L Y_u q_L \bar{\phi} + \bar{d}_L Y_d q_L \bar{\phi} + \bar{e}_L Y_e l_L \bar{\phi}) + (u_R Y_u^* \bar{q}_R \phi + d_R Y_d^* \bar{q}_R \phi + e_R Y_e^* \bar{l}_R \phi) \\ (\bar{u}'_L Y'_u q'_L \bar{\phi}' + \bar{d}'_L Y'_d q'_L \bar{\phi}' + \bar{e}'_L Y'_e l'_L \bar{\phi}') + (u'_R Y'^*_u \bar{q}'_R \phi' + d'_R Y'^*_d \bar{q}'_R \phi' + e'_R Y'^*_e \bar{l}'_R \phi')$$

Doubling symmetry ( $L, R \rightarrow L, R$  parity):  $Y' = Y \quad B - B' \rightarrow -(B - B')$

Mirror symmetry ( $L, R \rightarrow R, L$  parity):  $Y' = Y^* \quad B - B' \rightarrow B - B'$

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# Yin-Yang Theory: Dark sector ... similar to our luminous sector?

For observable particles .... *very complex physics !!*

$$G = SU(3) \times SU(2) \times U(1) \quad ( + \text{SUSY ? GUT ? Seesaw ? } )$$

photon, electron, nucleons (quarks), neutrinos, gluons,  $W^\pm - Z$ , Higgs ...

long range EM forces, confinement scale  $\Lambda_{\text{QCD}}$ , weak scale  $M_W$

... matter vs. antimatter (B-conservation, CP ... )

... existence of nuclei, atoms, molecules .... life.... Homo Sapiens !

If dark matter comes from extra gauge sector ... it is as *complex*:

$$G' = SU(3)' \times SU(2)' \times U(1)' ? \quad ( + \text{SUSY ? GUT ' ? Seesaw ? } )$$

photon', electron', nucleons' (quarks'),  $W' - Z'$ , gluons' ?

... long range EM forces, confinement at  $\Lambda'_{\text{QCD}}$ , weak scale  $M'_W$  ?

... asymmetric dark matter (B'-conservation, CP ... ) ?

... existence of dark nuclei, atoms, molecules ... life ... Homo Aliens ?

## Let us call it Yin-Yang Theory

in chinese, Yin-Yang means **dark-bright** duality

describes a philosophy how opposite forces are actually complementary, interconnected and interdependent in the natural world, and how they give rise to each other as they interrelate to one another.



$$E_8 \times E'_8$$

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# Can mirror matter be dark matter ?

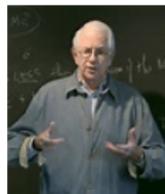
In spite of evident beauty of Yin-Yang dual picture, for a long while mirror matter was not taken as a real candidate for dark matter. There were real reasons for that: if O and M sectors have exactly identical microphysics and also exactly identical cosmologies, then one expected:

- Equal temperatures,  $T' = T$ ,  $g'_* = g_*$   $\rightarrow \Delta_\nu^{\text{eff}} = 6.15$  against BBN limits
- equal baryon asymmetries,  $\eta' = \eta$  ( $n'_B/n'_\gamma = n_B/n_\gamma$ ) and so  $\Omega'_B = \Omega_B$  while  $\Omega'_B/\Omega_B \simeq 5$  is needed for dark matter

If  $T' \ll T$  ? BBN is OK  
but  $\eta' = \eta$  implies  $\Omega'_B \simeq (T'/T)^3 \Omega_B \ll \Omega_B$

Such a mirror universe “can have no influence on the Earth and therefore would be useless and therefore does not exist”

S. Glashow, citing Francesco Sizzi



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# Always the same difficult story ...

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Understanding of astronomy, optics, and physics, a rumor about the four planets seen by the very celebrated mathematician Galileo Galilei with his telescope, shown to be unfounded.

Francesco Sizzi, criticism of Galileo's discovery of the Jupiter's moons

The microphysics of the postulated mirror matter should be exactly the same as that of the usual matter. However, we know that the spatial distribution of the dark matter is very different from that of the ordinary (baryonic) matter. On the face of it this makes mirror matter an implausible candidate for dark matter.

Anonimous Referee, a typical reviewer report on Mirror Matter



M baryons can be dark matter. If parallel world is colder than ours, all problems can be settled Z.B., Comelli, Villante, 2000

It is enough to accept a simple paradigm: at the Big Bang the M world was born with smaller temperature than O world; then over the universe expansion their temperature ratio  $T'/T$  remains constant.

$T'/T < 0.5$  is enough to concord with the BBN limits and do not affect standard primordial mass fractions: 75% H + 25%  $^4\text{He}$ .

Cosmological limits are more severe, requiring  $T'/T < 0.2$  or so.

In turn, for M world this implies helium domination: 25% H' + 75%  $^4\text{He}'$ .

Because of  $T' < T$ , the situation  $\Omega'_B > \Omega_B$  becomes plausible in baryogenesis. So, M matter can be dark matter (as we show below)

Because of  $T' < T$ , in mirror photons decouple much earlier than ordinary photons, and after that M matter behaves for the structure formation and CMB anisotropies essentially as CDM. This concordes M matter with WMAP/Planck, BAO, Ly- $\alpha$  etc. if  $T'/T < 0.25$  or so.

**Halo problem** – Mirror matter can be  $\sim 20\%$  of dark matter, forming dark disk, while  $\sim 80\%$  may come from other type of CDM (WIMP?)

**But perhaps 100% ?** – M world is helium dominated, and the star formation and evolution should be much faster. Halos could be viewed as mirror elliptical galaxies, with our matter inside forming disks.

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# Experimental and observational manifestations

**A. Cosmological implications.**  $T'/T < 0.2$  or so,  $\Omega'_B/\Omega_B = 1 \div 5$ .

Mass fraction: H' – 25%, He' – 75%, and few % of heavier C', N', O' etc.

- Mirror baryons as **asymmetric/collisional/dissipative/atomic** dark matter:

M hydrogen recombination and M baryon acoustic oscillations?

- Easier formation and faster evolution of stars: Dark matter disk? Galaxy halo as mirror elliptical galaxy? Microlensing ? Neutron stars? Black Holes? Binary Black Holes? Central Black Holes?

**B. Direct detection.** M matter can interact with ordinary matter e.g. via kinetic mixing  $\epsilon F^{\mu\nu} F'_{\mu\nu}$ , etc. Mirror helium as most abundant mirror matter particles (the region of DM masses below 5 GeV is practically unexplored). Possible signals from heavier nuclei C,N,O etc.

**C. Oscillation phenomena between ordinary and mirror particles.**

The most interesting interaction terms in  $\mathcal{L}_{\text{mix}}$  are the ones which violate  $B$  and  $L$  of both sectors. **Neutral particles, elementary (as e.g. neutrino) or composite (as the neutron or hydrogen atom) can mix with their mass degenerate (sterile) twins:** matter disappearance (or appearance) phenomena can be observable in laboratories.

In the Early Universe, these  $B$  and/or  $L$  violating interactions can give primordial baryogenesis and dark matter genesis, with  $\Omega'_B/\Omega_B = 1 \div 5$ .

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# CMB and LSS power spectra

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Zurab Berezhiani

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Mirror Matter

B-L violating  
processes and  
origin of  
observable and  
dark matter

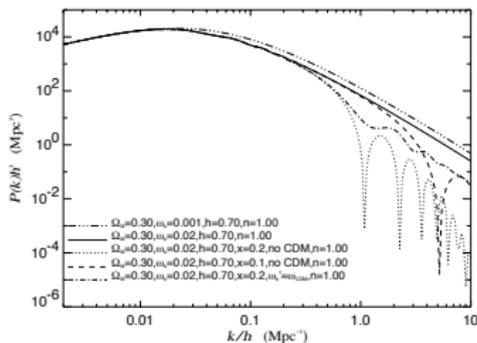
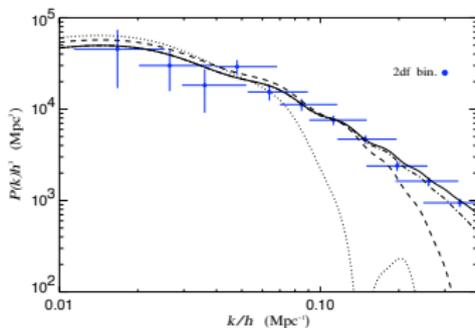
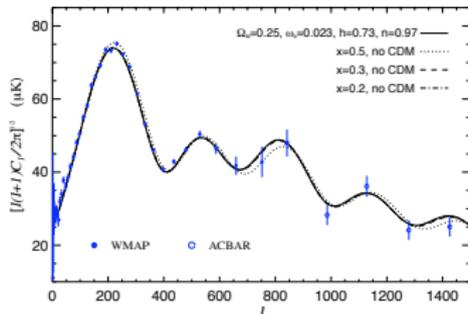
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*Acoustic oscillations and Silk damping  
at short scales:  $x = T'/T < 0.2$*



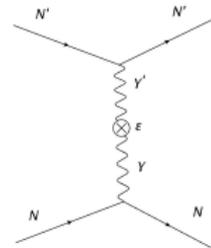
# Discussing $\mathcal{L}_{\text{mix}}$ : possible portal between O and M particles

- Photon-mirror photon kinetic mixing  $\epsilon F^{\mu\nu} F'_{\mu\nu}$

Experimental limit  $\epsilon < 4 \times 10^{-7}$

Cosmological limit  $\epsilon < 5 \times 10^{-9}$

Makes mirror matter nanocharged ( $q \sim \epsilon$ ) and is a promising interaction for dark matter direct detection

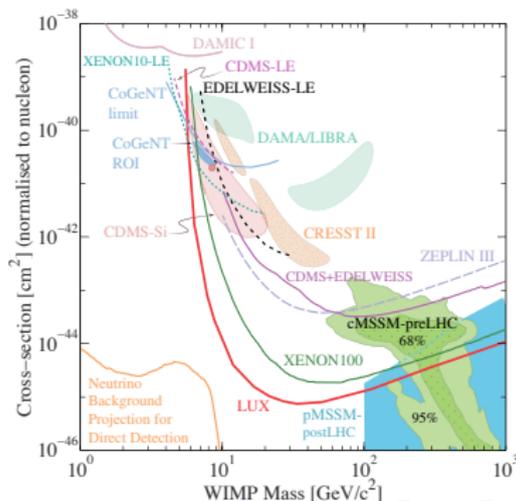


Mirror atoms: He' - 75 %,  
C', N', O' etc. few %  
Rutherford-like scattering

$$\frac{d\sigma_{AA'}}{d\Omega} = \frac{(\epsilon\alpha ZZ')^2}{4\mu_{AA'}^2 v^4 \sin^4(\theta/2)}$$

or

$$\frac{d\sigma_{AA'}}{dE_R} = \frac{2\pi(\epsilon\alpha ZZ')^2}{M_{AV}^2 E_R^2}$$

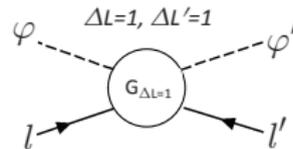
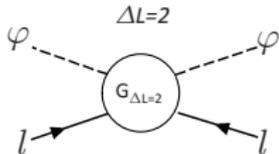


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# $\mathcal{L}_{\text{mix}}$ : $L$ and $B$ violating operators

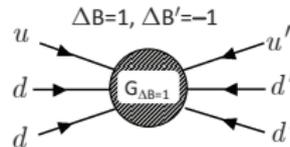
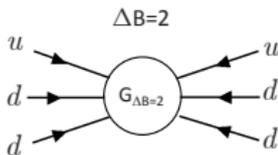
- **Neutrino -mirror neutrino mixing** – (Active - sterile mixing)  
 $L$  and  $L'$  violating operators:  $\frac{1}{M}(l\bar{\phi})(l\bar{\phi})$  and  $\frac{1}{M}(l\bar{\phi})(l'\bar{\phi}')$



$M$  is the (seesaw) scale of new physics beyond EW scale.

**Mirror neutrinos are most natural candidates for sterile neutrinos**

- **Neutron -mirror neutron mixing** – (Active - sterile neutrons)  $B$  and  $B'$  violating operators:  $\frac{1}{M^5}(udd)(udd)$  and  $\frac{1}{M^5}(udd)(u'd'd')$



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# Seesaw between ordinary and mirror neutrons

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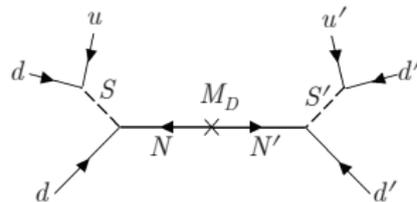
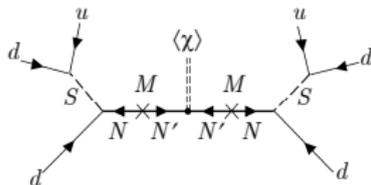
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$$Sud + S^\dagger d\mathcal{N} + M_D\mathcal{N}\mathcal{N}' + \chi\mathcal{N}^2 + \chi^\dagger\mathcal{N}'^2$$

$$g_n(\chi n^T Cn + \chi^\dagger n'^T Cn' + \text{h.c.})$$

$$\epsilon_{n\bar{n}} \sim \frac{\Lambda_{\text{QCD}}^6 V}{M_D^2 M_S^4} \sim \left(\frac{10^8 \text{ GeV}}{M_D}\right)^2 \left(\frac{1 \text{ TeV}}{M_S}\right)^4 \left(\frac{V}{1 \text{ MeV}}\right) \times 10^{-24} \text{ eV}$$

$$\tau_{n\bar{n}} > 10^8 \text{ s}$$

$$n - n' \text{ oscillation with } \tau_{nn'} \sim 1 \text{ s} \quad \tau_{nn'} \sim \frac{V}{M_D} \tau_{n\bar{n}}$$

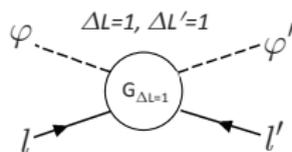
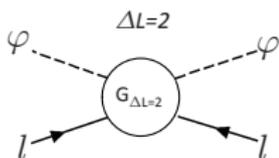
$$\epsilon_{nn'} \sim \frac{\Lambda_{\text{QCD}}^6}{M_D M_S^4} \sim \left(\frac{10^8 \text{ GeV}}{M_D}\right) \left(\frac{1 \text{ TeV}}{M_S}\right)^4 \times 10^{-15} \text{ eV}$$

$$M_D M_S^4 \sim (10 \text{ TeV})^5$$



# Theory of cogeneses: B/L violating interactions between O and M worlds

L and  $L'$  violating operators:  $\frac{1}{M}(l\bar{\phi})(l\bar{\phi})$  and  $\frac{1}{M}(l\bar{\phi})(l'\bar{\phi}')$



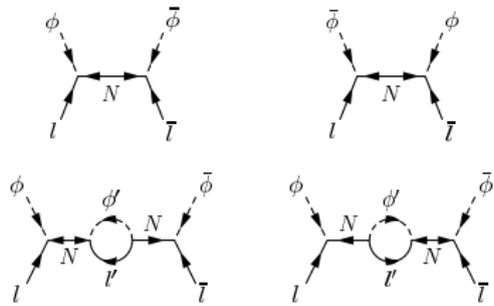
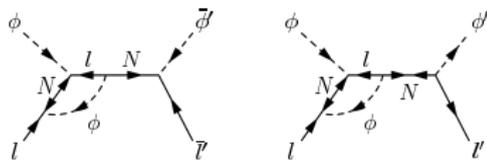
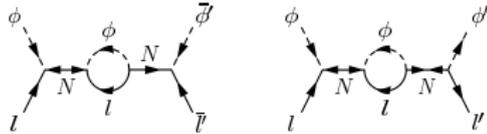
After inflation, our world is heated and mirror world is empty: but ordinary particle scatterings transform them into mirror particles, heating also mirror world.

- These processes should be **out-of-equilibrium**
- **Violate** baryon numbers in both worlds,  $B - L$  and  $B' - L'$
- **Violate** also CP, given complex couplings

Green light to celebrated conditions of Sakharov



Operators  $\frac{1}{M}(l\bar{\phi})(l\bar{\phi})$  and  $\frac{1}{M}(l\bar{\phi})(l'\bar{\phi}')$  via seesaw mechanism – heavy RH neutrinos  $N_j$  with Majorana masses  $\frac{1}{2}Mg_{jk}N_jN_k + \text{h.c.}$



Complex Yukawa couplings  $Y_{ij}l_iN_j\bar{\phi} + Y'_{ij}l'_iN_j\bar{\phi}' + \text{h.c.}$

Xerox symmetry  $\rightarrow Y' = Y$ ,

Mirror symmetry  $\rightarrow Y' = Y^*$

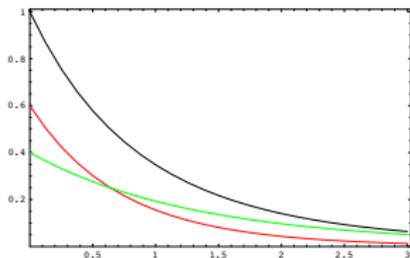
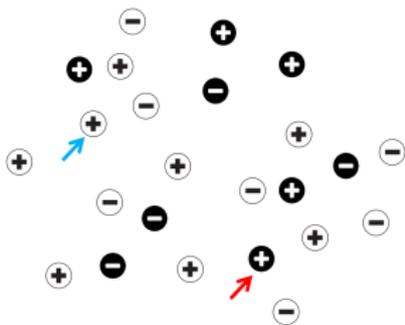
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# Theory of cogeneration: B/L violating interactions between O and M worlds

Hot World  $\longrightarrow$  Cold World

$$\Omega'_B/\Omega_B = 1 - 5 \quad \text{if } T'/T < 0.2$$



$$\frac{dn_{\text{BL}}}{dt} + (3H + \Gamma)n_{\text{BL}} = \Delta\sigma n_{\text{eq}}^2 \quad \frac{dn'_{\text{BL}}}{dt} + (3H + \Gamma')n'_{\text{BL}} = -\Delta\sigma' n_{\text{eq}}^2$$

$$\sigma(l\phi \rightarrow \bar{l}'\bar{\phi}') - \sigma(\bar{l}\bar{\phi} \rightarrow l'\phi') = (-\Delta\sigma - \Delta\sigma')/2$$

$$\sigma(l\phi \rightarrow l'\phi') - \sigma(\bar{l}\bar{\phi} \rightarrow \bar{l}'\bar{\phi}') = (-\Delta\sigma + \Delta\sigma')/2$$

$$\sigma(l\phi \rightarrow \bar{l}\bar{\phi}) - \sigma(\bar{l}\bar{\phi} \rightarrow l\phi) = \Delta\sigma$$

$$\Delta\sigma = \text{Im Tr}[g^{-1}(Y^\dagger Y)^* g^{-1}(Y'^\dagger Y') g^{-2}(Y^\dagger Y)] \times T^2/M^4$$

$$\Delta\sigma' = \Delta\sigma(Y \rightarrow Y')$$

Mirror (LR) symmetry:  $\Delta\sigma' = -\Delta\sigma \quad B, B' > 0$

Xerox (LL) symmetry:  $\Delta\sigma' = \Delta\sigma = 0 \quad B, B' = 0$

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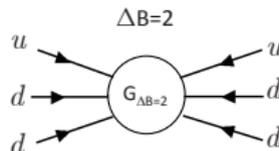
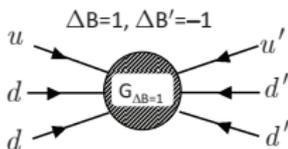
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The interactions able to make suchogenesis, should also lead to mixing of our neutral particles into their mass degenerate mirror twins.

The Mass Mixing  $\epsilon(\bar{n}n' + \bar{n}'n)$  comes from six-fermions effective operator  $\frac{1}{M^5}(udd)(u'd'd')$ ,  $M$  is the scale of new physics violating  $B$  and  $B'$  – but conserving  $B - B'$



$$\epsilon = \langle n | (udd)(u'd'd') | n' \rangle \sim \frac{\Lambda_{\text{QCD}}^6}{M^5} \sim \left( \frac{10 \text{ TeV}}{M} \right)^5 \times 10^{-15} \text{ eV}$$

Oscillations  $n \rightarrow \bar{n}'$  (regeneration  $n \rightarrow \bar{n}' \rightarrow n$ ) ... but  $n' \rightarrow \bar{n}$

$$H = \begin{pmatrix} m_n + \mu_n \mathbf{B} \sigma & \epsilon \\ \epsilon & m_n + \mu_n \mathbf{B}' \sigma \end{pmatrix}$$

Surprisingly,  $n - n'$  oscillation can be as fast as  $\epsilon^{-1} = \tau_{nn'} \sim 1 \text{ s}$ , without contradicting any experimental and astrophysical limits.

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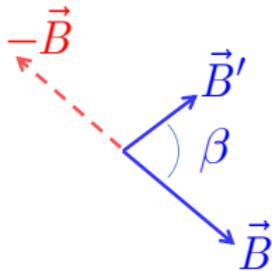
# Neutron – mirror neutron oscillation probability

The probability of n-n' transition depends on the relative orientation of magnetic and mirror-magnetic fields. The latter can exist if mirror matter is captured by the Earth

$$P_B(t) = p_B(t) + d_B(t) \cdot \cos \beta$$

$$p(t) = \frac{\sin^2 [(\omega - \omega')t]}{2\tau^2(\omega - \omega')^2} + \frac{\sin^2 [(\omega + \omega')t]}{2\tau^2(\omega + \omega')^2}$$

$$d(t) = \frac{\sin^2 [(\omega - \omega')t]}{2\tau^2(\omega - \omega')^2} - \frac{\sin^2 [(\omega + \omega')t]}{2\tau^2(\omega + \omega')^2}$$



where  $\omega = \frac{1}{2}|\mu B|$  and  $\omega' = \frac{1}{2}|\mu B'|$ ;  $\tau$  - oscillation time

$$A_B^{\text{det}}(t) = \frac{N_{-B}(t) - N_B(t)}{N_{-B}(t) + N_B(t)} = N_{\text{collis}} d_B(t) \cdot \cos \beta \leftarrow \text{assymetry}$$



# A and E are expected to depend on magnetic field

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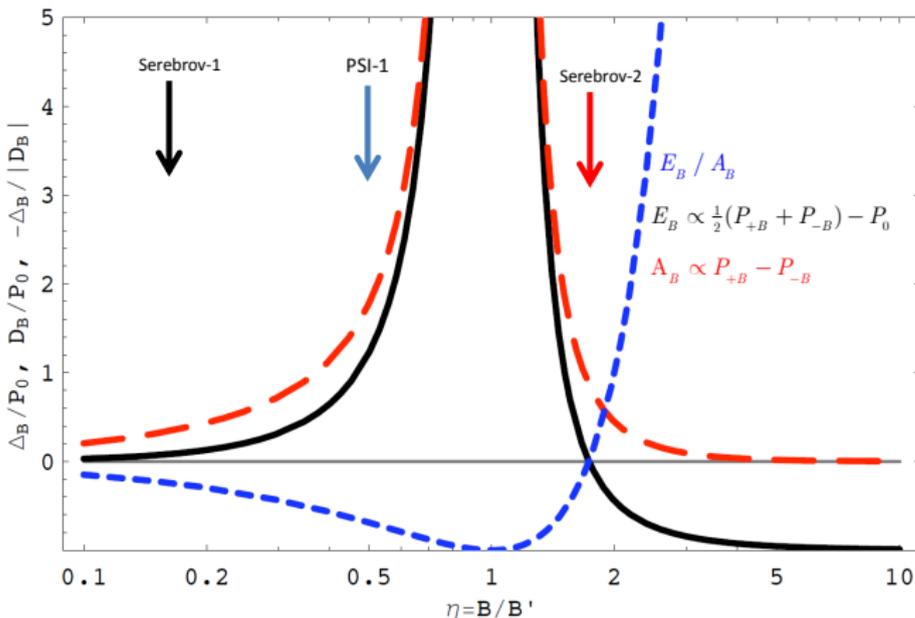
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E.g. assume  $B'=0.12$  Gauss





# Experiments

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Several experiments were done, most sensitive by the Serebrov's group at ILL, with  $^{190}\text{I}$  beryllium plated trap for UCN

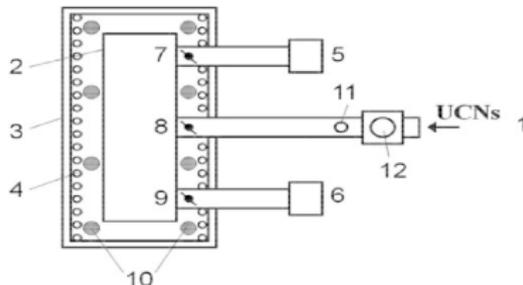




# Experimental Strategy

To store neutrons and to measure if the amount of the survived ones depends on the magnetic field applied.

- Fill the Trap with the UCN
- Close the valve
- Wait for  $T_S$  (300 s ...)
- Open the valve
- Count the survived Neutrons



Repeat this for different orientation and values of Magnetic field.

$$N_B(T_S) = N(0) \exp [ - (\Gamma + R + \bar{P}_B \nu) T_S ]$$

$$\frac{N_{B1}(T_S)}{N_{B2}(T_S)} = \exp [ (\bar{P}_{B2} - \bar{P}_{B1}) \nu T_S ]$$

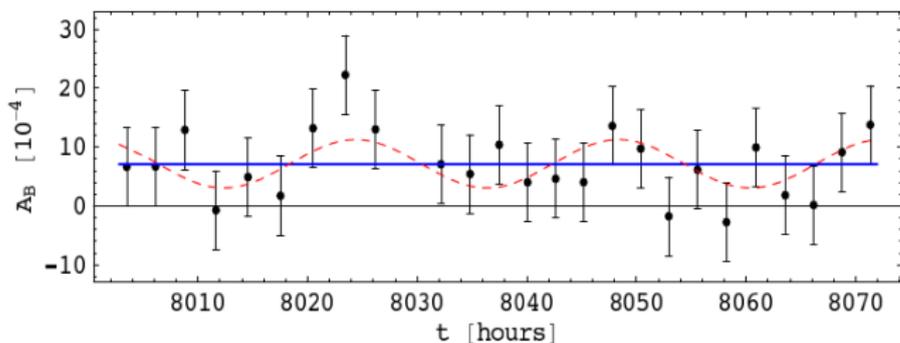
So if we find that:

$$A(B, T_S) = \frac{N_B(T_S) - N_{-B}(T_S)}{N_B(T_S) + N_{-B}(T_S)} \neq 0 \quad E(B, b, T_S) = \frac{N_B(T_S)}{N_b(T_S)} - 1 \neq 0$$



# Serebrov experiment 2007 – magnetic field vertical

Exp. sequence:  $\{B_-, B_+, B_+, B_-, B_+, B_-, B_-, B_+\}$ ,  $B = 0.2$  G



Analysis pointed out the presence of a signal:

$$A(B) = (7.0 \pm 1.3) \times 10^{-4} \quad \chi^2_{/dof} = 0.9 \longrightarrow 5.2\sigma$$

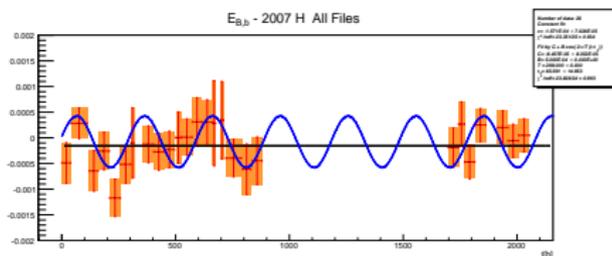
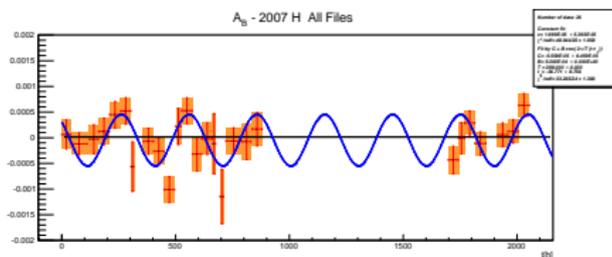
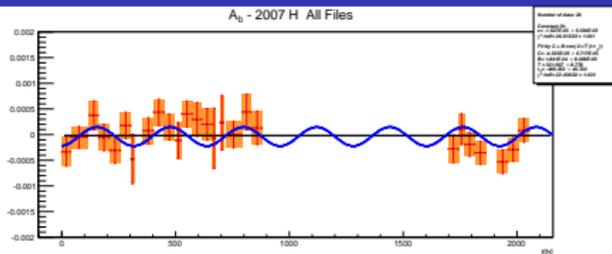
interpretable by  $n \rightarrow n'$  with  $\tau_{nn'} \sim 2 - 10s'$  and  $B' \sim 0.1G$

Z.B. and Nesti, 2012



# Serebrov 2007 – magnetic field Horizontal

$$\{b_-, B_-, B_+, b_+, b_+, B_+, B_-, b_-\}, B = 0.2 \text{ G}, b < 10^{-3} \text{ G}$$



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# Serebrov 2007 – magnetic field Horizontal

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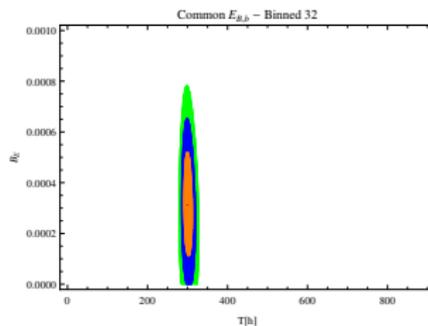
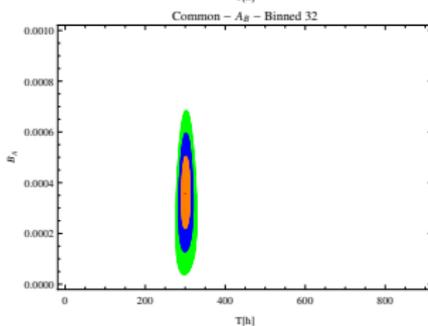
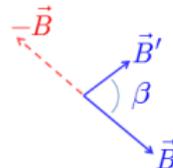
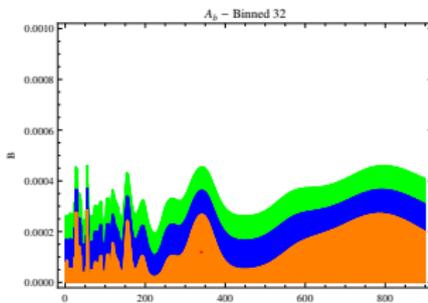
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# Earth mirror magnetic field via the electron drag mechanism

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Earth can accumulate some, even tiny amount of mirror matter due to Rutherford-like scattering of mirror matter due to photon-mirror photon kinetic mixing.

Rotation of the Earth drags mirror electrons but not mirror protons (ions) since the latter are much heavier.

Circular electric currents emerge which can generate magnetic field. Modifying mirror Maxwell equations by the source (drag) term, one gets  $B' \sim \epsilon^2 \times 10^{15}$  G before dynamo, and even larger after dynamo.



# The neutron enigma ...

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PARTICLE PHYSICS

# the neutron enigma

Two precision experiments disagree on how long neutrons live before decaying. Does the discrepancy reflect measurement errors or point to some deeper mystery?

By *Geoffrey L. Greene and Peter Geltenbort*

IN BRIEF

The best experiments in the world cannot agree on how long neutrons live before decaying into other particles.

Two main types of experiments are under way: bottle traps count the number of neutrons that survive after var-

ious intervals, and beam experiments look for the particles into which neutrons decay.

Resolving the discrepancy is vital to answering a number of fundamental questions about the universe.

**Geoffrey L. Greene** is a professor of physics at the University of Tennessee, with a joint appointment at the Oak Ridge National Laboratory's Spallation Neutron Source. He has been studying the properties of the neutron for more than 40 years.

**Peter Geltenbort** is a staff scientist at the Institut Laue-Langevin in Grenoble, France, where he uses one of the most intense neutron sources in the world to research the fundamental nature of this particle.





# Two methods to measure the neutron lifetime

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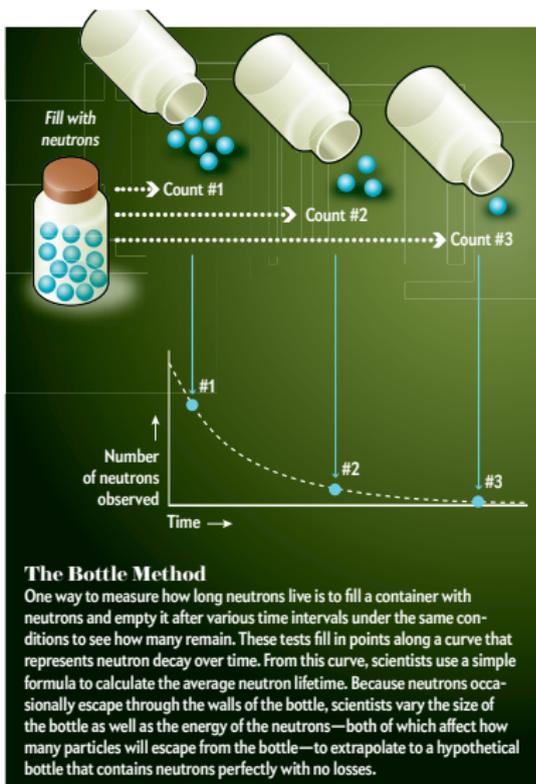
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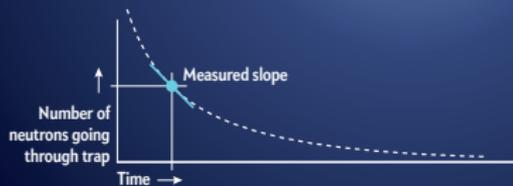
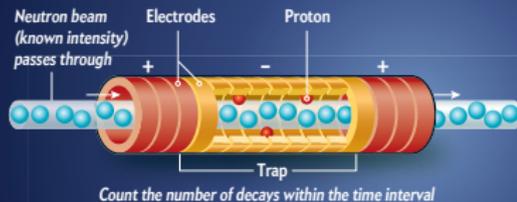
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## The Beam Method

In contrast to the bottle method, the beam technique looks not for neutrons but for one of their decay products, protons. Scientists direct a stream of neutrons through an electromagnetic "trap" made of a magnetic field and ring-shaped high-voltage electrodes. The neutral neutrons pass right through, but if one decays inside the trap, the resulting positively charged protons will get stuck. The researchers know how many neutrons were in the beam, and they know how long they spent passing through the trap, so by counting the protons in the trap they can measure the number of neutrons that decayed in that span of time. This measurement is the decay rate, which is the slope of the decay curve at a given point in time and which allows the scientists to calculate the average neutron lifetime.





# Problems to meet ...

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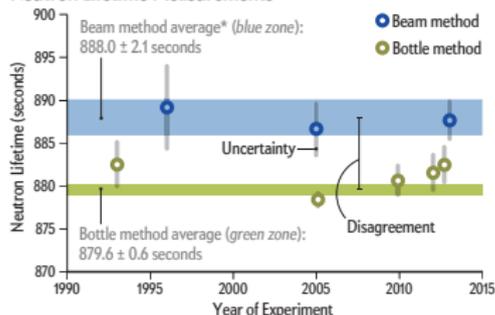
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Neutron Lifetime Measurements



A few theorists have taken this notion seriously. Zurab Berezhiani of the University of L'Aquila in Italy and his colleagues have suggested such a secondary process: a free neutron, they propose, might sometimes transform into a hypothesized “mirror neutron” that no longer interacts with normal matter and would thus seem to disappear. Such mirror matter could contribute to the total amount of dark matter in the universe. Although this idea is quite stimulating, it remains highly speculative. More definitive confirmation of the divergence between the bottle and beam methods of measuring the neutron lifetime is necessary before most physicists would accept a concept as radical as mirror matter.



# Mirror matter is a hidden antimatter ...

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why the neutron lifetime measured in UCN traps is smaller than that measured in beam method ?

I've taken my old calculations in the Yin-Yang dual cogenesis and finds out that, at least in simplest scenarios, the sign of mirror baryo asymmetry tells that mirror neutrons born in parallel world, oscillate into our antineutrons rather than in neutrons !

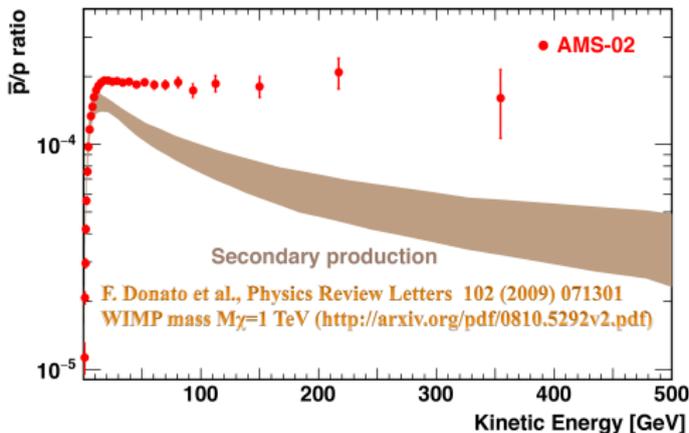
$n - \bar{n}'$  and  $n' - \bar{n}$  against  $n - n'$

This makes clear how discrepancy emerges – in traps our neutrons oscillate into mirror antineutrons and annihilate with the mirror gas with  $\langle \sigma v / c \rangle \simeq 50$  mb. These are continuous loses which cannot be distinguished from the UCN decay. The oscillation probability at the Earth magnetic field can be order  $10^{-6}$  which is sufficient for order second correction if the mirror gas density is about  $10^{-5}$  atm.



# Indirect detection: antimatter in the cosmos?

In mirror cosmic rays, disintegration of mirror nuclei by galactic UV background or in scatterings with mirror gas, frees out mirror neutrons which then oscillate into our antineutron,  $n' \rightarrow \bar{n}$ , which then decays as  $\bar{n} \rightarrow \bar{p} + \bar{e} + \nu_e$ .  
so we get antiprotons (positrons), with spectral index similar to that of protons in our cosmic rays ?



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# Mirror matter can be transformed into our antimatter !!!

Hence, in normal conditions  $n' \rightarrow n$  oscillation probabilities are tiny, mirror neutrons behave nicely and do not disturb us: everyone stays on his side of the mirror



However, under well-controlled vacuum and magnetic conditions, mirror neutrons can be transformed into our antineutrons with reasonable probabilities provided that the oscillation time  $n' \rightarrow \bar{n}$  is indeed small ... the resulting annihilations give energy, and we can use it



"It does not matter how beautiful your theory is, it does not matter how smart you are ... if it is not confirmed by experiment, it's wrong"

Now it is turn of experimentalists to turn this tale into reality .... or to exclude it – at least oscillation time  $\tau_{nn'} < 10^3$  s

If discovered – impact can be enormous ... One could get plenty of energy out of dark matter !

# Appendix

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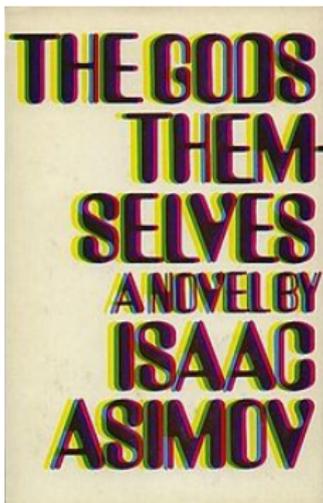
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**First Part:** *Against Stupidity ...*

**Second Part:** *...The Gods Themselves ...*

**Third Part:** *... Contend in Vain?*

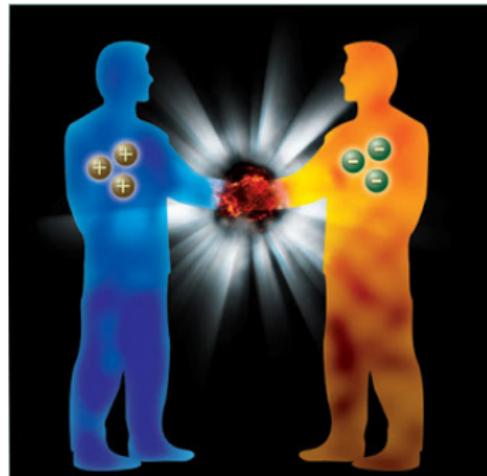
*"Mit der Dummheit kämpfen Götter  
selbst vergebens!"* – Friedrich Schiller



# Summary

Encounter of matter and antimatter leads to immediate (uncontrollable) annihilation which can be destructive

Annihilation can take place also between our matter and dark matter, but controllable by tuning of vacuum and magnetic conditions. Dark neutrons can be transformed into our antineutrons, or dark hydrogen atom into our anti-hydrogen atom, etc.



Two civilisations can agree to built scientific reactors and exchange neutrons ... and turn the energy produced by each reactor in 1000 times more energy for parallel world .. and all live happy and healthy

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# Fine

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Physics needs new ideas. But to have a new idea is a very difficult task: it does not mean to write a few lines in a paper. If you want to be the father of new idea, you should fully devote your intellectual energy to understand all details and to work out the best way in order to put the new idea under experimental test.

This can take years of work. You should not give up. Do not be afraid to encourage others to pursue your dream. If it becomes real, the community will never forget that you have been the first to open the field. – I.I. Rabi

*Thank You !*



# Once upon a time ....

Every epoch, starting from ancient times, had some fundamental(ist)) "understanding" of the Universe – other ideas were coined as heres, heretics were ignored, some even killed

First Standard Model was based on flat Earth carried on shoulders by three elephants ...

The idea of round Earth was not sustainable: the antipodes would fall down

The Earth was at rest, sun and planets moving around it ...

The idea of moving Earth was not sustainable – there had to be ever blowing wind

Matter was built of continuous media ...  
four elements: Earth, Water, Air, Fire

Someone courageously hypothesised existence of atoms ...

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# Some Beautiful Minds advanced the understanding of Cosmo and Microcosm

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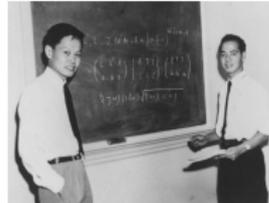
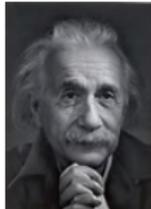
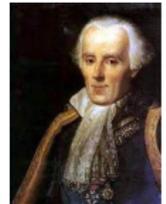
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# Standard Model: $SU(3) \times SU(2) \times U(1)$

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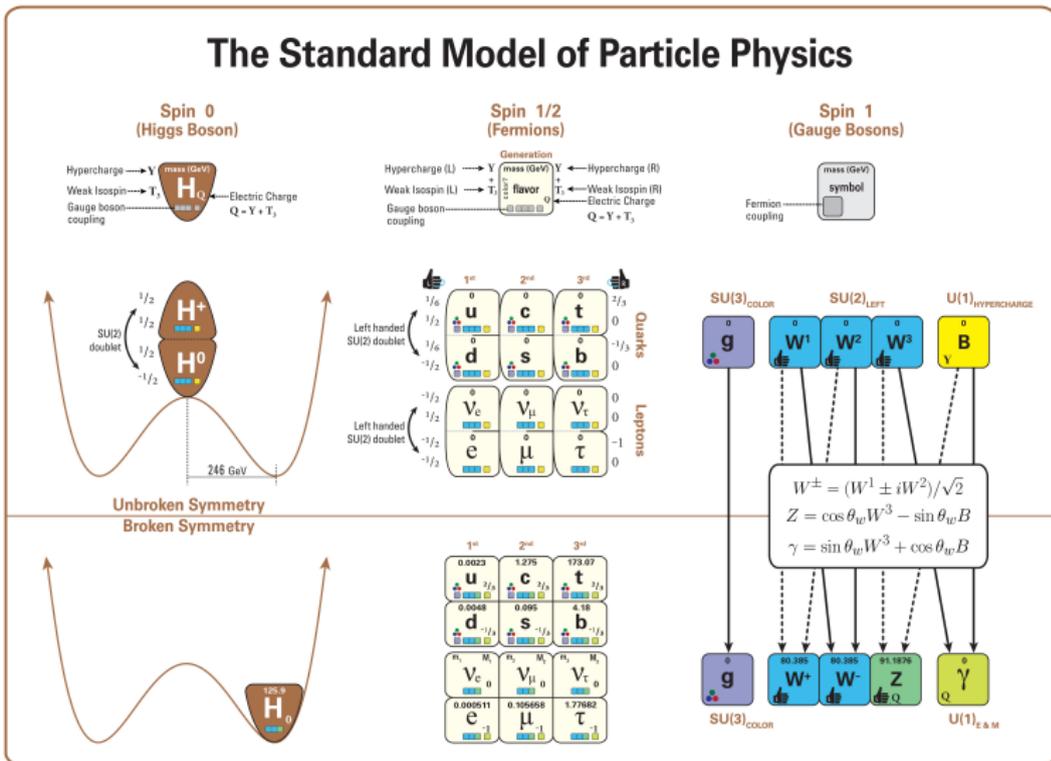
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## The Standard Model of Particle Physics





# Standard Model and Problems

- Hierarchy problem: origin of electroweak (Higgs) mass scale  $M_H \sim 100$  GeV (N.B. no problem with QCD scale  $\Lambda_{\text{QCD}} \sim 100$  MeV)
- Family problems: Why 3 fermion families? Why hierarchy of fermion masses and CKM mixing? CP-violation ?
- Strong CP-problem: Where ends up beautiful effect of CP-violation due to term  $\theta G_{\mu\nu} \tilde{G}^{\mu\nu}$  in non-perturbative QCD vacuum  $\theta \sim 1$  expected vs.  $\theta < 10^{-10}$  – exp. DEMON (EDM of neutron)
- Neutrino masses: Why they are so small? .... (and why they have large mixing?)
- Lepton and Baryon numbers: why and how are violated ? (deep connection to the origin of matter in the Universe)
- Dark matter: from where it comes ? can it be detectable ? (can it have interactions to normal matter or self-interactions ? Is it just one particle or multi-component ?
- Scalar fields in cosmology: Inflaton? Quintessence ?  
Dark energy: just cosmological constant or something time-variable ? (related: can be then also fundamental constants time variable ?)

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# Dunkle Materie

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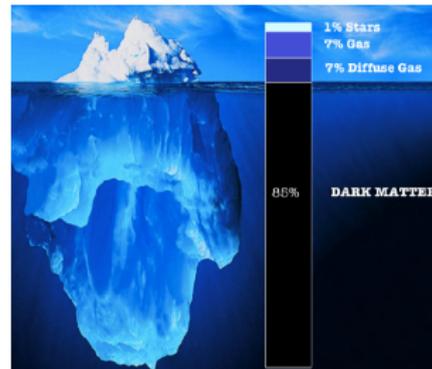
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*In 1933 Zwicky has hypothesised existence of  
dark matter in galaxies and in the universe ...  
applied virial theorem to Coma Cluster*



Later this was confirmed by several  
independent experimental Hints:

- Rotation Curves
- Clusters of Galaxies
- CMB and LSS
- Supernovae 1a
- Gravitational Lensing



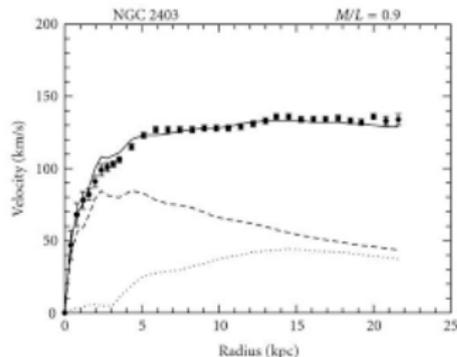
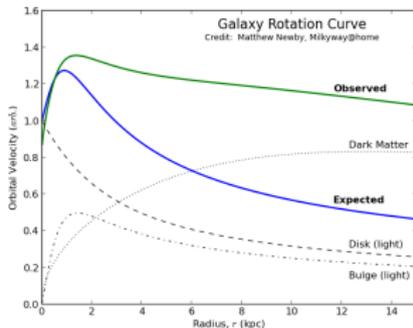


# Galactic rotation velocities

In disc galaxies (differential) rotation velocities, as a function of the distance from the center, indicate flat behaviour  $v \simeq \text{Const.}$  instead of Keplerian Fall ( $v \propto r^{-1/2}$ )

$$\text{Grav. force} = \text{Centr. force} \quad m \frac{v^2}{r} = m \frac{GM(r)}{r^2} \quad \rightarrow \quad v \simeq \sqrt{GM(r)/r}$$

Instead .... flat rotational curves were observed





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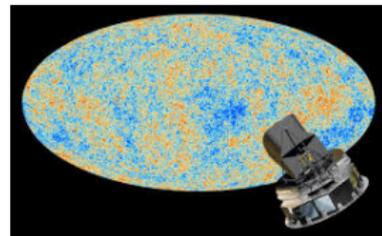
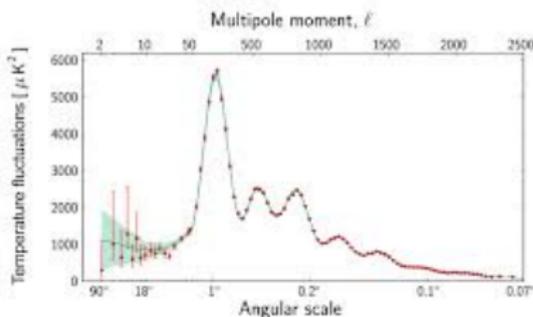
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$$\theta_* = (1.0415 \pm 0.0006) \times 10^{-2}$$

$$H_0 = (67.3 \pm 0.6) \text{ km/s} \cdot \text{Mpc}^{-1}, \quad \text{inflation } n_s = 0.960 \pm 0.005$$

$$\Omega_B = 0.0487 \pm 0.0006, \quad \Omega_D = 0.2647 \pm 0.0060 \quad \Omega_{\text{tot}} \approx 1$$

$$\Omega_M = \Omega_B + \Omega_D \simeq 0.31 \quad \rightarrow \quad \Omega_\Lambda \approx 0.69$$

It became clear that dark matter is not built of baryons !

*... but its identity remains unknown ...*



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## Supersymmetry:

symmetry between fermions and bosons

– extension of the Poincare symmetry:

space  $(x_\mu) \rightarrow$  superspace  $(x_\mu, \theta_\alpha, \bar{\theta}_{\dot{\alpha}})$ ,  
fields  $\Phi(x) \rightarrow$  superfields  $\Phi(x, \theta, \bar{\theta})$

spontaneously (softly) broken at weak scale

– medicine for the Higgs health (origin of the weak scale)

+ gauge coupling unification etc.



# SUSY and R-parity

SM  $\rightarrow$  MSSM: fields  $\rightarrow$  superfields:  $V = (g, \tilde{g}), Q = (q, \tilde{q}) \dots$

$$\mathcal{L}_{\text{SUSY}} = \mathcal{L}_{\text{gauge}} + \mathcal{L}_{\text{matter}} = \int d^2\theta G^2 + \int d^4\theta \Phi^\dagger e^V \Phi + \int d^2\theta W_{\text{matter}}$$

$$W_{\text{matter}} = QU^c H_2 + QD^c H_1 + LE^c H_1 + \mu H_1 H_2 \\ \sim \mathcal{L}_{\text{Yuk}} + \mu^2 H^\dagger H \text{ in SM}$$

$$\mathcal{L}_{\text{SSB}} = \mathcal{L}_{\text{gaugino}}^{\text{mass}} + \mathcal{L}_{\text{scalars}}^{\text{mass}} + \mathcal{L}_{\text{scalars}}^{\text{trilinear}} = \\ \int d^2\eta \theta G^2 + \int d^4\theta \eta \bar{\eta} \Phi^\dagger e^V \Phi + \int \eta d^2\theta W_{\text{matter}}$$

All superpartners get masses  $M_S \sim 1 \text{ TeV}$ , from  $\eta = M_S \theta^2$  but  $\mu$ -problem: why  $\mu \sim M_S$  ?

$$\dots W_{\text{R-viol}} = QD^c L + U^c D^c D^c + E^c LL + \mu' LH_2 \\ \text{problems for proton stability}$$

$$R = (-1)^{3B+L+2s} \quad (+ \text{ for SM particles, } - \text{ for superpartners})$$

or matter parity  $Z_2$ :  $F \rightarrow -F, H \rightarrow H$

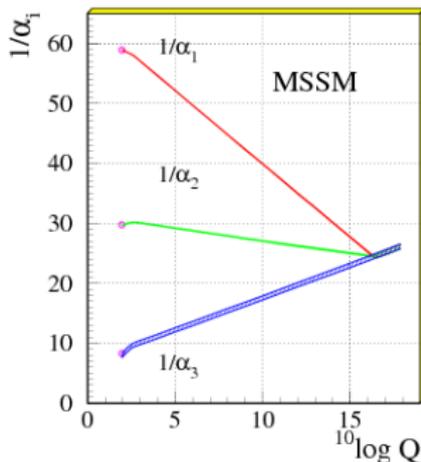
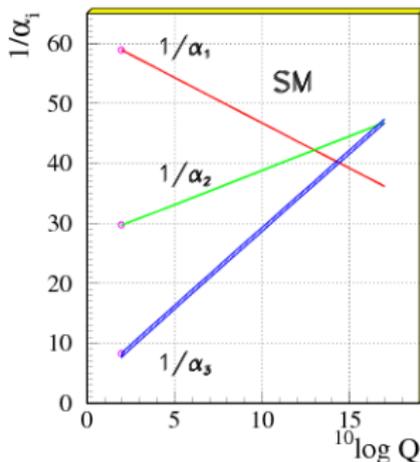
makes lightest SUSY partner (LSP) stable !



# SUSY + GUT = LOVE

- GUT:  $SU(3) \times SU(2) \times U(1) \rightarrow SU(5)$

## Unification of the Coupling Constants in the SM and the minimal MSSM



Hierarchy (and doublet-triplet splitting) problems – 28 orders –  
between  $M_{\text{Higgs}}^2 \sim (100 \text{ GeV})^2$  and  $M_{\text{GUT}}^2 \sim (10^{16} \text{ GeV})^2$



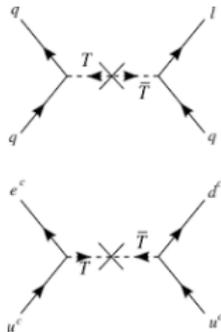
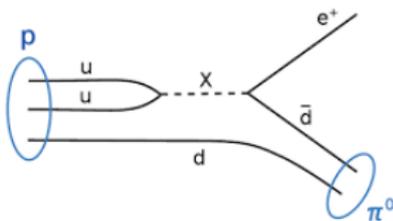
# Proton decay in $SU(5) \rightarrow SU(3) \times SU(2) \times U(1)$

Proton decay:  $p \rightarrow \pi^0 e^+$ ,  $p \rightarrow K^+ \nu$  etc.

- gauge mediated  $D = 6$ : new gauge bosons  $X, Y$  violating baryon and lepton numbers  $-\frac{1}{M_X^2} \bar{q} \gamma_\mu \tilde{u} l \gamma^\mu \tilde{d}$ , etc.

- Higgs mediated  $D = 6$ : color scalar triplets (leptoquarks)  $T$ , brothers of SM Higgs doublet  $\phi$ ,  $-\frac{1}{M_T^2} qqql$ , etc.

- Higgsino mediated ( $D = 5$ ): fermion superpartners of  $T$ ,  $-\frac{1}{M_T} qq\tilde{q}\tilde{l}$



proton stability limits  $\tau_p > 10^{34}$  yr require  $M_X, M_T > 10^{16}$  GeV.

D-T splitting:  $m_\phi \sim 100$  GeV,  $M_T > 10^{16}$  GeV – 14 orders!

**N.B. this B-violation not good for baryogenesis in the universe**



# SUSY + GUT = SU(6)

Z.B. and G. Dvali, 1989

SUSY can provide *technical solution* to the D-T splitting in SU(5) but **Fine Tuning** is unavoidable

Good solution (GIFT) with larger symmetry:

$$SU(3) \times SU(2) \times U(1) \rightarrow SU(5) \rightarrow SU(6) \quad (SU(6) \rightarrow E_6 ?)$$

Pseudo-Goldstone mechanism: gauge SU(6) breaking in 2 channels

$SU(6) \rightarrow SU(5)$ : fundamental reps  $H, \bar{H} \sim 6, \bar{6}$  ( $5, \bar{5}$  in SU(5))

$SU(6) \rightarrow SU(4) \times SU(2) \times U(1)$ : - adjoint  $\Sigma \sim 35$  (24 in SU(5))

while superpotential has double global symmetry  $SU(6)_H \times SU(6)_\Sigma$   
Fermions in  $2 \times \bar{6} + 15 = 27$  of  $E_6$

Higgs (super)fields remain as Goldstone modes **not eaten** by gauge (super)fields due to **accidental** global symmetry  $SU(6)_H \times SU(6)_\Sigma$  (just kill the term  $H\Sigma\bar{H}$  by a discrete symmetry)

Higgs gets mass  $\sim M_{\text{SUSY}} \sim 1$  TeV after SUSY breaking: **natural D-T splitting**. As a bonus, also many other problems are fixed: ( $\mu$ -problem:  $\mu \sim M_{\text{SUSY}}$ , top quark mass  $\sim 100$  GeV,  $y_t \sim 1$ , while other fermions are light but  $y_b \simeq y_\tau$ , etc.)

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# LHC – run II: can SUSY be just around the corner?

So called Natural SUSY (2 Higgses with  $m \sim 100$  GeV + Higgsinos) is dead ! *One* Higgs discovered by LHC perfectly fits the SM Higgs ... but already at LEP epoch many theorists understood (felt) that  $M_{SUSY} < 1$  TeV was problematic

- SUSY induced proton decays ( $D = 5$ ) require  $M_{SUSY} > 1$  TeV or so
- SUSY induced CP-violation: electron EDM,  $M_{SUSY} > 1$  TeV or so
- But gauge coupling crossing requires  $M_{SUSY} < 10$  TeV or so
- Generically, SUSY flavor limits in  $K - \bar{K}$  mixing,  $\mu \rightarrow e\gamma$  etc. require  $M_{SUSY} > 100$  TeV or so

But can be quark-squark mass alignment: universal relations like  $\tilde{m}_d^2 = m_0^2 + m_1^2(Y_d^\dagger Y_d) + m_2^2(Y_d^\dagger Y_d)^2$ , etc. Z.B. 1996

assuming the gauge symmetry  $SU(3)$  between 3 fermion families later on coined as Minimal Flavor Violation (MFV), Giudice et al., 2002

SUSY at scale of few TeV is still the best choice for BSM physics: maybe SUSY is indeed just around the corner?

Remains *Little hierarchy problem* – 2 orders Fine Tuning – between  $M_{\text{Higgs}}^2 \sim (100 \text{ GeV})^2$  and  $M_{\text{SUSY}}^2 \sim (1 \text{ TeV})^2$

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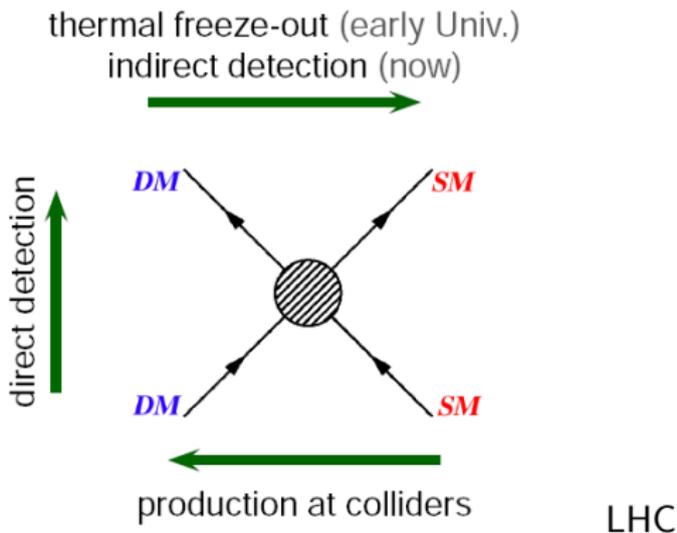
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# WIMP detection modes

Weak scale MSSM +  $R$ -parity: lightest spartner (LSP) is stable !  
A perfect candidate for CDM with mass  $M_\chi \sim 100$  GeV



Direct Detection @ LNGS: DAMA, CRESST, XENON, DARKSIDE



# WIMP miracle and optimism for direct detection

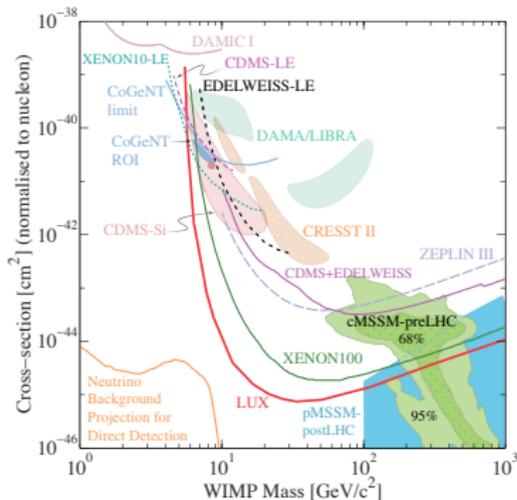
WIMP/LSP with mass  $M_X \sim 100$  GeV – perfect candidate for CDM

$$\Omega_D h^2 \simeq \frac{0.02 x_f}{g_f^{1/2}} \left( \frac{1 \text{ pb}}{v \sigma_{\text{ann}}} \right) \quad v \sigma_{\text{ann}} \sim 1 \text{ pb} \quad \rightarrow \quad \Omega_D h^2 \sim 0.1$$

$$\text{WIMP Miracle: } v \sigma_{\text{ann}} \sim \frac{\pi \alpha^2}{M_S^2} \sim \left( \frac{100 \text{ GeV}}{M_X} \right)^2 \times 10^{-36} \text{ cm}^2$$

But for elastic scattering  $X + N \rightarrow X + N$  one expects  $\sigma_{\text{scat}} \sim \sigma_{\text{ann}}$  which is important for direct detection

However ... no evidence at LHC and no evidence from DM direct search + many problems to natural SUSY



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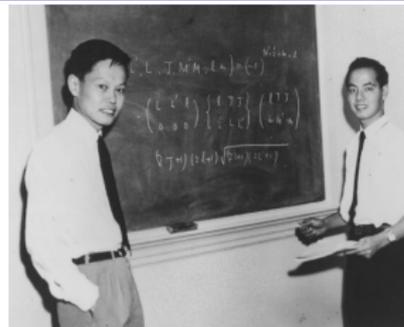
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# Parity Violation & Mirror Fermions – Lee and Yang, 1956

The conservation of parity is usually accepted without questions concerning its possible limit of validity being asked. There is actually no *a priori* reason why its violation is undesirable. Its violation implies the existence of right-left asymmetry and we have shown in the above some possible experimental tests of this asymmetry.



If such asymmetry is indeed found, *the question could still be raised whether there could not exist corresponding elementary particles exhibiting opposite asymmetry such that in the broader sense there will still be over-all right-left symmetry. If this is the case, there must exist two kinds of protons  $p_R$  and  $p_L$ , the right-handed one and the left-handed one.* At the present time the protons in the laboratory must be predominantly of one kind to produce the supposedly observed asymmetry. *This means that the free oscillation period between them must be longer than the age of the Universe. They could therefore both be regarded as stable particles. The numbers of  $p_R$  and  $p_L$  must be separately conserved.* Both  $p_R$  and  $p_L$  could interact with the same E-M field and perhaps the same pion field ...

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## Mirror Fermions as parallel sector – Kobzarev, Okun, Pomeranchuk, 1966

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In connection with the discovery of CP violation, we discuss the possibility that “mirror” ( $R$ ) particles exist in addition to the ordinary ( $L$ ) particles. The introduction of these particles reestablishes the equivalence of left and right. It is shown that *mirror particles cannot interact with ordinary particles strongly, semistrongly or electromagnetically.  $L$  and  $R$  particles must have the same gravitational interactions. The possibility of existence and detection of macroscopic bodies (stars) made up of  $R$ -matter is discussed.*



# Alice @ Mirror World – “Through the Looking-Glass” (1871)

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I'll tell you all my ideas about Looking-glass House. *The room you can see through the glass – that's just the same as our room ... the books there are something like our books, only the words go the wrong way ...* I can see all of it – all but the bit just behind the fireplace. *I want so to know whether they've a fire:* you never can tell, you know, unless *our fire smokes, and then smoke comes up in that room too ...* Oh, how nice it would be if we could get through into Looking-glass House! Let's pretend there's a way of getting through into it, somehow ... *It'll be easy enough to get through I declare!*



Lewis Carroll



# Always the same difficult story ...

In spite of evident beauty of Yin-Yang dual picture, for a long while mirror matter was not taken as a real candidate for dark matter. There were real reasons for that: if O and M sectors have exactly identical microphysics and also exactly identical cosmologies, then one expects:

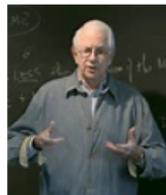
- Equal temperatures,  $T'_{CMB} = T_{CMB}$   $\Delta_\nu^{\text{eff}} = 6.15$  against BBN limits
- equal baryon asymmetries,  $\eta' (= n'_B/n'_\gamma) = \eta (= n_B/n_\gamma)$  and so  $\Omega'_B = \Omega_B$  while  $\Omega'_B \Omega_B \simeq 5$  is needed for dark matter

If  $T' \ll T$  ? BBN is OK

but  $\eta' = \eta$  implies  $\Omega'_B \simeq (T'/T)^3 \Omega_B \ll \Omega_B$

Such a mirror universe “can have no influence on the Earth and therefore would be useless and therefore does not exist”

S. Glashow, citing Francesco Sizzi



- Even if  $\Omega'_B > \Omega_B$ , Why M matter, as dissipative as O matter, would form galactic halos and not disks?

Thoughts on  
Dark Matter:

windows to dark  
world ?

Zurab Berezhiani

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# More parallel worlds ?

Imagine there are 4 worlds all described by Standard Model, related by mirror (LR) and xerox (LL) symmetries ...

This can be used for solving little hierarchy problem, invoking also SUSY

Consider superpotential

$$W = \lambda S_1 (H_1 H_2 + \Phi_1 \Phi_2 - \Lambda^2) + \lambda S_2 (H'_1 H'_2 + \Phi'_1 \Phi'_2 - \Lambda^2)$$

Xerox symmetry:  $H_{1,2} \rightarrow \Phi_{1,2}$ ,  $H'_{1,2} \rightarrow \Phi'_{1,2}$

Mirror symmetry:  $S_1 \rightarrow S_2$ ,  $H_{1,2} \rightarrow H'_{1,2}$ ,  $\Phi_{1,2} \rightarrow \Phi'_{1,2}$

Global symmetries  $SU(4)_H$  and  $SU(4)'_H$

Take  $\Lambda \sim 10$  TeV and assume that SUSY breaking spurion  $\eta = M_S \theta^2$  is odd against Xerox symmetry,  $\eta \rightarrow -\eta$ .

$\Phi$ 's get VEVs  $v' \sim 10$  TeV,  $H$ 's remain pseudo-Goldstone, then getting VEVs  $v \sim 100$  GeV

$\Phi$  sectors – Standard Models with  $m_E \sim (v'/v)m_e$  but  $m_{P,N} \simeq (2 \div 3)m_{p,n}$  ( $\Lambda_\Phi/\Lambda_{\text{QCD}}$  rescales softer with  $v'/v$ )

Dark matter can be very compact hydrogen atoms from  $\Phi$  sectors, or even neutrons if  $m_P > m_N$

Self-collisional DM with right amount  $\sigma/m_N \sim 1$  b/GeV – perfect candidate for Dark matter resolving many problems of halos

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## Technical solution ... some uncounted systematics ?

why the neutron lifetime measured in UCN traps is smaller than that measured in beam method ?

May some factor contribute to the UCN continuous loses in the bottle?

In 2013, making an experiment at the ILL, I observed that  $^3\text{He}$  detectors had different capacities (one was counting twice less than another).

I asked how this can occur? The answer:  $^3\text{He}$  is very volatile and it evaporates from the detector volume, typically during an year ...

But where  $^3\text{He}$  ends up? Clearly inside the UCN trap, since the aluminium folder covering the detector is not perfectly hermetic ... but then it would eat the UCN stored inside the bottle, with a huge cross section,  $\langle\sigma v/c\rangle \simeq 3 \text{ mb}$

Nesvizhevsky helped me in technical details. We calculated that these continuous loses could give  $\sim 1$  second correction to the neutron lifetime

He told me that this effect was never taken into account in the error budget of the bottle experiments

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