Co-baryogenesis of Dark and Visible matter: *mixing of ordinary and mirror particles*

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Contents

Bright & Dark Sides of the Universe

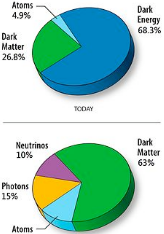
Todays Universe: flat $\Omega_{\rm tot} \approx 1$ *(inflation)* ... and multi-component:

- $\Omega_B \simeq 0.05$ observable matter: electron, proton, neutron !
- $\Omega_D \simeq 0.25$ dark matter: WIMP? axion? sterile ν? ...
- $\Omega_\Lambda \simeq 0.70$ dark energy: Λ-term? Quintessence? ....
- $\Omega_R < 10^{-3}$ relativistic fraction: relic photons and neutrinos

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

Antrophic 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?*

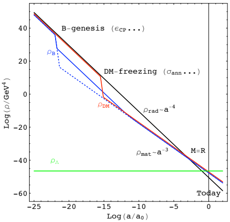


Baryogenesis requires BSM Physics:
(GUT-B, Lepto-B, Affleck-Dine, EW B ...)
Dark matter requires BSM Physics:
(Wimp, Wimpzilla, sterile ν, axion, ...)

Different physics for B-genesis and DM?
Not very appealing: looks as Fine Tuning

How these Fine Tunings look ...

B-genesis + WIMP



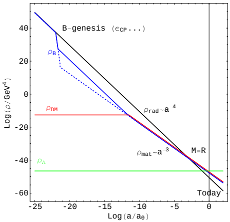
$m_X n_X \sim m_B n_B$

$m_X \sim 10^3 m_B$

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

Fine Tuning?

B-genesis + axion



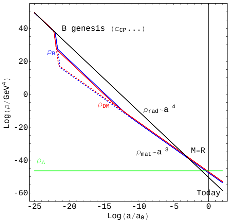
$m_a n_a \sim m_B n_B$

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

$n_a \sim 10^{13} n_B$

Fine Tuning?

B-cogenesis



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

$m_{B'} \sim m_B$

$n_{B'} \sim n_B$

Natural ?

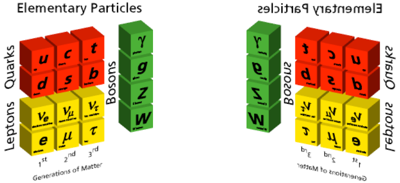
Two different New Physics for B-genesis and DM ?

Or co-genesis by the same Physics explaining why $\Omega_{DM} \sim \Omega_B$?

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

$G \times G'$

Regular world Mirror world



- Two identical gauge factors, e.g. SM $\times$ SM$'$ or $SU(5) \times SU(5)'$, with identical field contents and Lagrangians: $\mathcal{L}_{\rm tot} = \mathcal{L} + \mathcal{L}' + \mathcal{L}_{\rm mix}$
- Exact parity $G \to G'$: 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 $\mathcal{L}_{mix}$
- 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. $SU(3)' \times SU(2)' \times U(1)'$

Two parities

Fermions and anti-fermions :

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

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

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

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

Twin Fermions and anti-fermions :

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

B′=1/3 L′=1 B′=1/3 L′=1

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

B′=-1/3 L′=-1 B′=-1/3 L′=-1

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

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

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

All you need is ... M world colder than ours !

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}He.
Cosmological limits are more severe, requiring $T'/T < 0.2$ os so.
In turn, for M world this implies helium domination: 25% H$'$ + 75% ^{4}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)

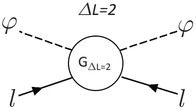
Because of $T' < T$, in mirror photons decouple much earlier than ordinary photons, and after that M matter behaves for the structure formation and CMB anisotropies essentially as CDM. This concords M matter with WMAP/Planck, BAO, Ly-α etc. if $T'/T < 0.25$ or so.

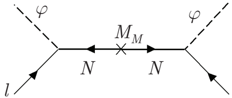
Halo problem – if $\Omega'_B \simeq \Omega_B$, M matter makes ~ 20 % of DM, forming dark disk, while ~ 80 % may come from other type of CDM (WIMP?)
But perhaps 100 % ? if $\Omega'_B \simeq 5\Omega_B$: – M world is helium dominated, and the star formation and evolution can be much faster. Halos could be viewed as mirror elliptical galaxies, with our matter inside forming disks.

Baryogenesis requires new physics: B–L violation

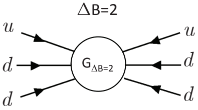
B & L can be violated only in higher order terms – but which ?

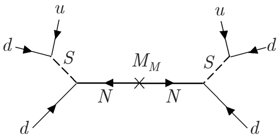
- $\frac{1}{M}(l\bar{\phi})(l\bar{\phi})$ $(\Delta L = 2)$ – neutrino (seesaw) masses $m_\nu \sim v^2/M$





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

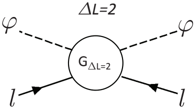


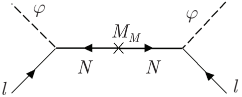


can originate from new physics related to scale $M \gg v_{\rm EW}$ via seesaw

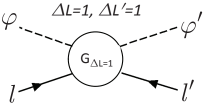
L-violation in O and M sectors: Active-sterile neutrino mixing

- $\frac{1}{M}(l\bar{\phi})(l\bar{\phi})$ $(\Delta L = 2)$ – neutrino (seesaw) masses $m_\nu \sim v^2/M$
M is the (seesaw) scale of new physics beyond EW scale.



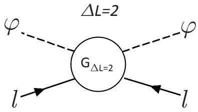


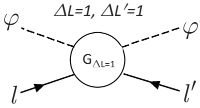
- Neutrino -mirror neutrino mixing – (active - sterile mixing)
L and L' violation: $\frac{1}{M}(l\bar{\phi})(l\bar{\phi})$, $\frac{1}{M}(l'\bar{\phi}')(l'\bar{\phi}')$ and $\frac{1}{M}(l\bar{\phi})(l'\bar{\phi}')$



Mirror neutrinos are natural candidates for sterile neutrinos

L and L' violating operators $\frac{1}{M}(l\bar{\phi})(l\bar{\phi})$ and $\frac{1}{M}(l\bar{\phi})(l'\bar{\phi}')$ lead to processes $l\phi \to \bar{l}\bar{\phi}$ $(\Delta L = 2)$ and $l\phi \to \bar{l}'\bar{\phi}'$ $(\Delta L = 1,\ \Delta L' = 1)$





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

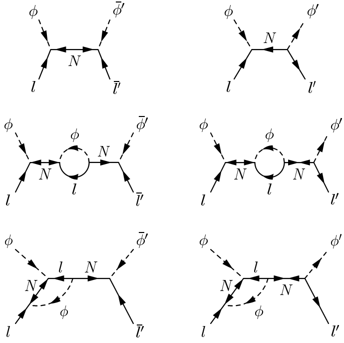
- These processes should be out-of-equilibrium
- Violate baryon numbers in both worlds, $B - L$ and $B' - L'$
- Violate also CP, given complex couplings

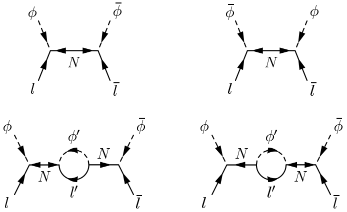
Green light to celebrated conditions of Sakharov

Co-leptogenesis:

Z.B. and Bento, PRL 87, 231304 (2001)

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 $\frac{1}{2}Mg_{jk}N_jN_k + \mathrm{h.c.}$



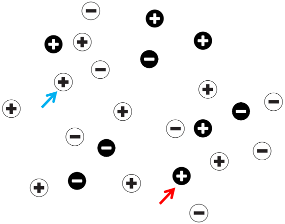


Complex Yukawa couplings $Y_{ij}l_iN_j\bar{\phi} + Y'_{ij}l'_iN_j\bar{\phi}' + \mathrm{h.c.}$

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

Co-leptogenesis: Mirror Matter as hidden Anti-Matter   Z.B., arXiv:1602.08599

Hot O World $\longrightarrow$ *Cold M World*



$$\frac{dn_{\rm BL}}{dt} + (3H+\Gamma)n_{\rm BL} = \Delta\sigma\, n_{\rm eq}^2$$

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

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

$$\sigma(l\phi \to \bar{l}'\bar{\phi}') - \sigma(\bar{l}\,\bar{\phi} \to l'\phi') = -(\Delta\sigma + \Delta\sigma')/2 \quad \to \quad 0 \quad (\Delta\sigma = 0)$$

$$\sigma(l\phi \to l'\phi') - \sigma(\bar{l}\,\bar{\phi} \to \bar{l}'\bar{\phi}') = -(\Delta\sigma - \Delta\sigma')/2 \quad \to \quad \Delta\sigma \quad (0)$$

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

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

Mirror (LR): $Y' = Y^* \quad \to \quad \Delta\sigma' = -\Delta\sigma \quad \to \quad B, B' > 0$

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

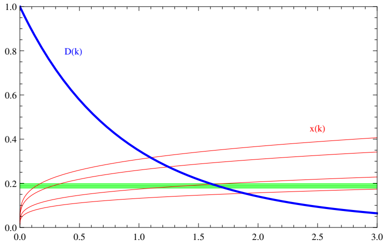
If $k = \left(\frac{\Gamma}{H}\right)_{T=T_R} \ll 1$, neglecting Γ in eqs $\quad \to \quad n_{BL} = n'_{BL}$

$$\Omega'_B = \Omega_B \simeq 10^3 \frac{J M_{Pl} T_R^3}{M^4} \simeq 10^3 J \left(\frac{T_R}{10^{11}\ {\rm GeV}}\right)^3 \left(\frac{10^{13}\ {\rm GeV}}{M}\right)^4$$

If $k = \left(\frac{\Gamma_2}{H}\right)_{T=T_R} \sim 1$, Boltzmann Eqs.

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

should be solved with Γ:



$D(k) = \Omega_B/\Omega'_B$, $\quad x(k) = T'/T$ for different $g_*(T_R)$ and Γ_1/Γ_2.

So we obtain $\Omega'_B = 5\Omega_B$ when $m'_B = m_B$ but $n'_B = 5n_B$

– the reason: mirror world is colder

Experimental and observational manifestations of mirror matter

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.

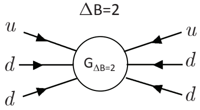
- Mirror baryons as asymmetric/collisional/dissipative/atomic dark matter: M hydrogen recombination and M baryon acoustic oscillations?
- Easier formation and faster evolution of stars: Dark matter disk? Galaxy halo as mirror elliptical galaxy? Microlensing ? Neutron stars? Black Holes? Binary Black 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 $\mathcal{L}_{\rm mix}$ 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 $\Omega'_B/\Omega_B = 1 \div 5$.

Neutron– antineutron oscillation

The Mass Mixing $\epsilon(n^T C n + \bar{n}^T C \bar{n})$ (Majorana mass of neutron) violating B by two units comes from six-fermions effective operator $\frac{1}{M^5}(udd)(u'd'd')$, M is the scale of new physics



$$\epsilon = \langle n|(udd)(udd)|\bar{n}\rangle \sim \frac{\Lambda^6_{\rm QCD}}{M^5} \sim \left(\frac{100 \text{ TeV}}{M}\right)^5 \times 10^{-25} \text{ eV}$$

free $n - \bar{n}$ oscillation time $\tau = \epsilon^{-1}$

Key observation: *$n - \bar{n}$ oscillation destabilizes nuclei:*
$(A, Z) \to (A-1, \bar{n}, Z) \to (A-2, Z/Z-1) + \pi\text{'s}$

Present bounds on ϵ from nuclear stability

$\epsilon < 1.2 \times 10^{-24}$ eV $\to$ $\tau > 1.3 \times 10^8$ s Fe, Soudan 2002

$\epsilon < 2.5 \times 10^{-24}$ eV $\to$ $\tau > 2.7 \times 10^8$ s O, SK 2015

Neutron– antineutron oscillation and magnetic field

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

Oscillation probability $P_{n\bar{n}}(t) = \frac{\epsilon^2}{\epsilon^2+\omega_B^2} \sin^2\left(t\sqrt{\epsilon^2+\omega_B^2}\right)$ where $\omega_B = \mu_n B$

If $\Omega_B t < 1$, then $P_{n\bar{n}}(t) = (t/\tau)^2 = (\epsilon t)^2$

If $\Omega_B t \gg 1$, then $P_{n\bar{n}}(t) = (\epsilon/\omega_B)^2$

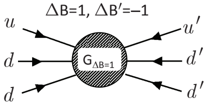
"Quasi-free" regime: for a given free flight time t, magnetic field should be properly suppressed to achieve $\omega_B t < 1$.
More suppression makes no sense !

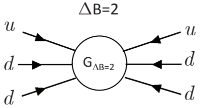
Exp. Baldo-Ceolin et al, 1994 (ILL, Grenoble) : $t \simeq 0.1$ s, $B < 100$ nT
$\tau > 0.9 \times 10^8 \quad \rightarrow \quad \epsilon < 7.7 \times 10^{-24}$ eV

but at ESS 2 orders of magnitude better sensitivity can be achieved, down to $\epsilon \sim 10^{-25}$ eV

Neutron – mirror neutron mixing

The Mass Mixing $\epsilon(nCn' + \mathrm{h.c.})$ 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 $B - B'$





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

Key observation: *$n - n'$ oscillation cannot destabilise nuclei: $(A, Z) \to (A-1, Z) + n'(p'e'\bar{\nu}')$ forbidden by energy conservation*

Surprisingly, $n - \bar{n}'$ oscillation can be as fast as $\epsilon^{-1} = \tau_{nn'} \sim 1$ s, without contradicting any experimental and astrophysical limits.
(c.f. $\tau_{n\bar{n}} > 2.5 \times 10^8$ s for neutron – antineutron oscillation)
Disappearance $n \to \bar{n}'$ (regeneration $n \to \bar{n}' \to n$) can be searched at small scale 'Table Top' experiments

Neutron – mirror neutron oscillation probability

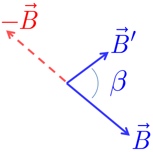
$$H = \begin{pmatrix} m_n + \mu_n \mathbf{B}\sigma & \epsilon \\ \epsilon & m_n + \mu_n \mathbf{B}'\sigma \end{pmatrix}$$

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

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

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

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



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

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

UHECR and GZK cutoff

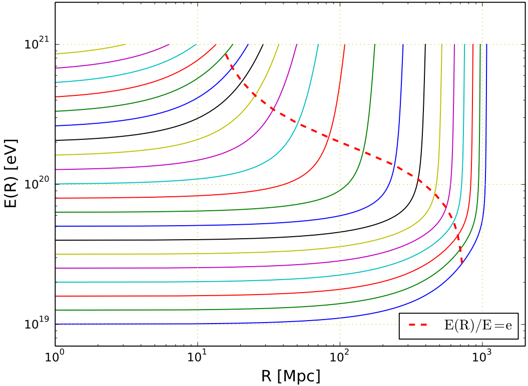
GZK cutoff:

Photo-pion production on the CMB if $E > E_{\rm GZK} \approx \frac{m_\pi m_p}{\varepsilon_{\rm CMB}} \approx 6 \times 10^{19}$ eV :

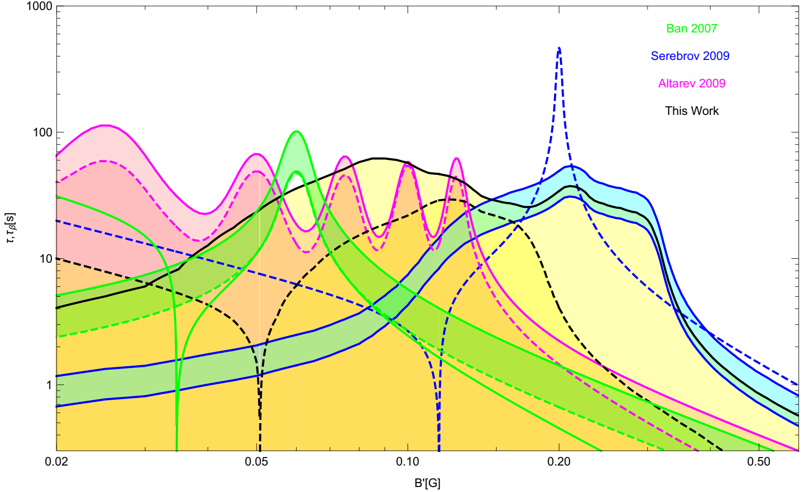
$p + \gamma \to p + \pi^0$ (or $n + \pi^+$), $\quad l_{\rm mfp} \sim 5$ Mpc for $E > 10^{20}$ eV $= 100$ EeV

Neutron decay: $n \to p + e + \bar{\nu}_e$, $\quad l_{\rm dec} = \left(\frac{E}{100~\rm EeV}\right)$ Mpc

Neutron on CMB scattering: $n + \gamma \to n + \pi^0$ (or $p + \pi^-$)



Experimental limits on $n - n'$ oscillation time

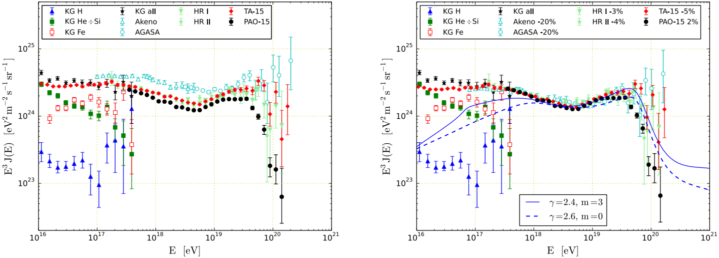


UHECR and GZK cutoff

Two giant detectors see UHECR spectra different at $E > E_{\rm GZK}$

Pierre Auger Observatory (PAO) – South hemisphere
Telescope Array (TA) – North hemisphere

At $E < E_{\rm GZK}$ two spectra are perfectly coincident
by relative energy shift ≈ 8 %



+ older detectors: AGASA, HiRes, etc. (all in north hemisphere)

Events with $E > 100$ EeV were observed
Cosmic Zevatrons exist in the Universe – but where is GZK cutoff?

But also other discrepancies are mounting ...

- Who are carriers of UHECR ?

PAO and TA see different chemical content: TA is compatible with protons at all energies, PAO insists UHECR become heavier nuclei above $E > 10$ EeV or so – perhaps new physics ?

- Different anistropies from North and South ?

TA excludes isotropic distribution at $E > 57$ EeV, observes hot spot for events $E > E_{\rm GZK}$ (which spot is cold for $E < E_{\rm GZK}$) . PAO anisotropies not so prominent: mild hot spot around Cen A, but observe dipole for $E > 10$ EeV – are two skies realy different ?

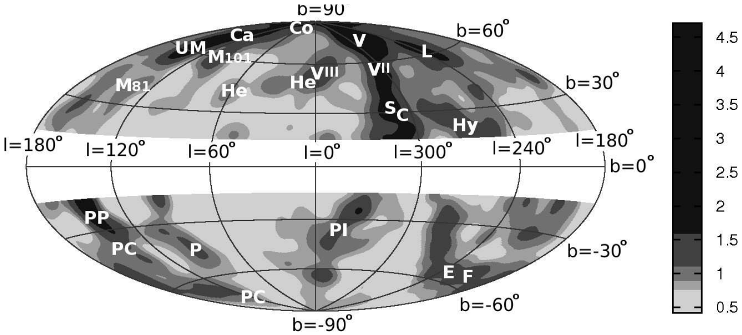
- From where come highest energy events?

$E > 100$ EeV are expected from local supercluster (Virgo, UM, PP etc.) and closeby structures. But they do not come from these directions. TA observes small angle correlation for $E > 100$ EeV events (2 doublets), which may indicate towards strong source – from where they come?

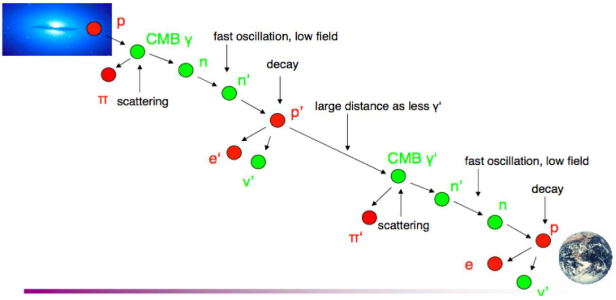
- Excess of cosmogenic photons ?

Standard GZK mechanism of UHECR produces too much cascades – contradicts to Fermi-LAT photon spectrum at $E \sim 1$ TeV – local Fog ?

From where highest energy CR are expected ?



$n - n'$ oscillation and UHECR propagation



Z. Berezhiani, L. Bento, Fast neutron – Mirror neutron oscillation and ultra high energy cosmic rays, Phys. Lett. B 635, 253 (2006).

A. $p + \gamma \to p + \pi^0$ or $p + \gamma \to n + \pi^+$ $\quad P_{pp,pn} \approx 0.5 \quad l_{\rm mfp} \sim 5$ Mpc

B. $n \to n' \quad P_{nn'} \simeq 0.5 \quad l_{\rm osc} \sim \left(\frac{E}{100\ {\rm EeV}}\right)$ kpc

C. $n' \to p' + e' + \bar{\nu}'_e \quad l_{\rm dec} \approx \left(\frac{E}{100\ {\rm EeV}}\right)$ Mpc

D. $p' + \gamma' \to p' + \pi'^0$ or $p' + \gamma' \to n' + \pi'^+ \quad l'_{\rm mfp} \sim (T/T')^3\, l_{\rm mfp} \gg 5$ Mpc

$n - n'$ oscillation in the UHECR propagation

Baryon number is not conserved in propagation of the UHECR

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

In the intergalactic space magnetic fields are extremely small.

But for relativistic neutrons transverse component of B is enhanced by Lorentz factor: $B_{\rm tr} = \gamma B$ $\quad (\gamma \sim 10^{11}$ for $E \sim 100$ EeV)

Average oscillation probability: $P_{nn'} = \frac{1}{1+q(E)}$

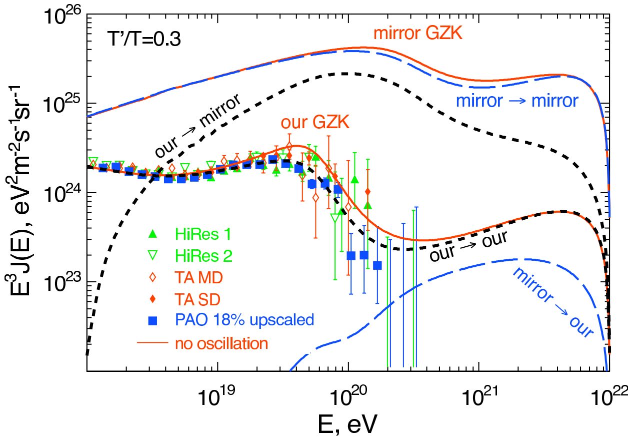
$$q = 0.45 \times \left(\frac{\tau_{nn'}}{1\ \rm s}\right)^2 \times \left(\frac{B_{\rm tr} - B'_{\rm tr}}{1\ \rm fG}\right)^2 \times \left(\frac{E}{100\ \rm EeV}\right)^2$$

If $q(E) < 1$, $n - n'$ oscillation becomes effective

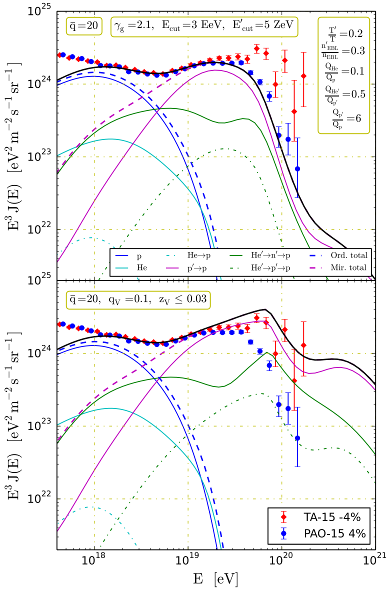
Earlier (than GZK) cutoff in cosmic rays

Z.B. and Gazizov, Neutron Oscillations to Parallel World: Earlier End to the Cosmic Ray Spectrum? Eur. Phys. J. C 72, 2111 (2012)

Baryon number is not conserved in propagation of the UHECR

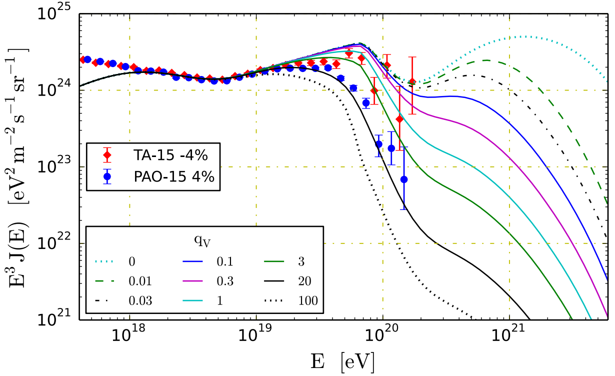


Ordinary and Mirror sources



Swiss Cheese Model

Mirror CRs are transformed into ordinaries in nearby Voids. $n - n'$ oscillation probability depends on the magnetic fields in the Voids.



Arrival directions of $E > 100$ EeV events

All $E > 57$ EeV events $\quad (+$ AGASA etc.$)$

Is sky different from North and South ?

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 199:26 (22pp), 2012 April HUCHRA ET AL.

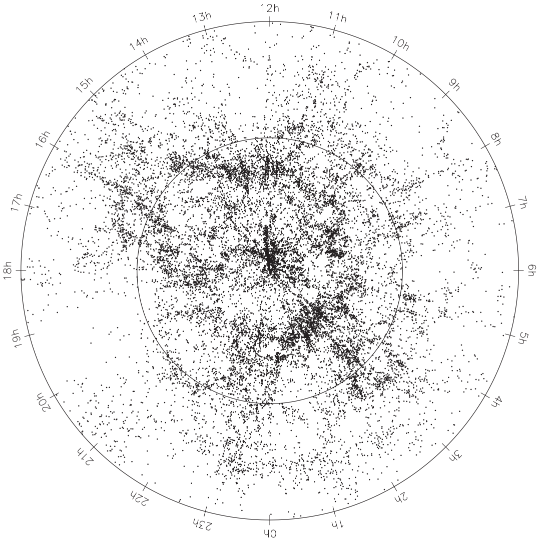


Figure 7. Hockey Puck plot—a full cylinder section—of 2MRS in the north celestial cap. The view is looking downward from the NCP, the thickness of the "puck" is 8000 km s^{-1}, and its radius is 15,000 km s^{-1}.

Is sky different from North and South ?

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 199:26 (22pp), 2012 April HUCHRA ET AL.

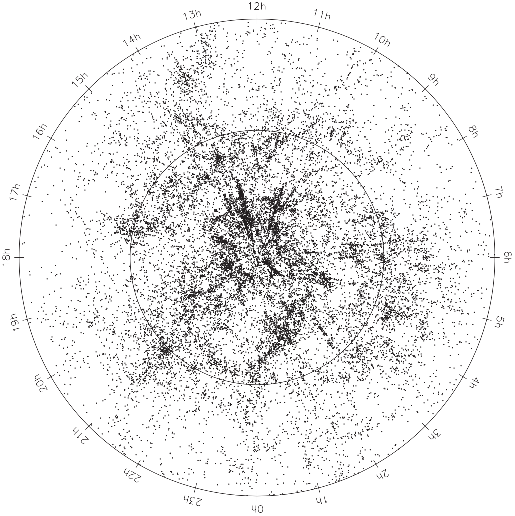
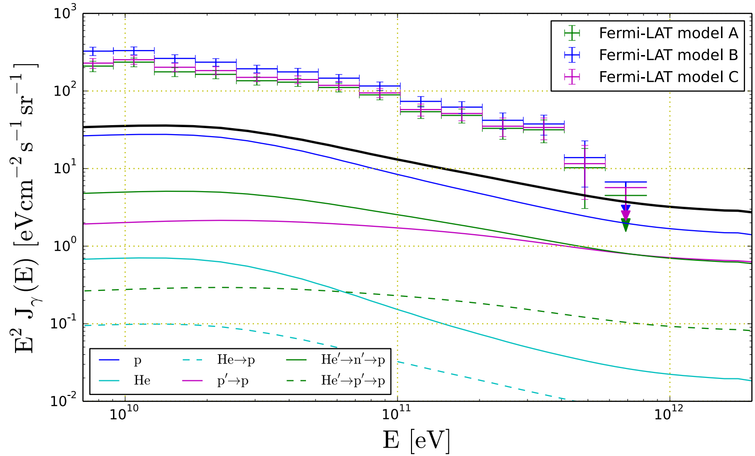


Figure 8. Same as Figure 7 but for the south celestial cap.

Cosmogenic gammas vs Fermi-LAT IGRB spectrum



Summary

But $n' \to \bar{n}$ produces appearance of our antimatter from dark mirror matter – with a lot of interesting cosmological implications for UHECR, AMS 2 and PAMELLA, INTEGRAL positron excess, Primordial Lithium problem, etc.

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, etc.

Two civilisations can agree to built scientific reactors and exchange neutrons ... and turn the energy produced by each reactor in 1000 times