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Is it possible to save heavy stable neutrinos?

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Recombination of heavy neutrinos

Effects of new long-range interaction: Recombination of relic Heavy neutrinos and antineutrinos

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Abstract

If stable Heavy neutrinos of 4th generation possess their own Coulomb-like interaction, recombination of pairs of Heavy neutrinos and antineutrinos can play important role in their cosmological evolution and lead to observable consequences. In particular, effect of this new interaction in the annihilation of neutrino-antineutrino pairs can account for γ-flux observed by EGRET.

1 Introduction

This work begins systematic study of model of subdominant component of dark matter in form of Heavy neutrinos [1] in the special case when this component possesses its own long range interaction. It is supposed that new interaction is Coulomb-like, being described with unbroken $U(1)$-gauge group. We call it y-interaction. Its massless gauge boson and charge are called y-photon and y-charge, respectively. The

Sinister model solving Sea saw and Dark Matter Problems

A Sinister Extension of the Standard Model to $SU(3) \times SU(2) \times SU(2) \times U(1)$

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This paper describes work done in collaboration with Andy Cohen. In our model, ordinary fermions are accompanied by an equal number 'terafermions.' These particles are linked to ordinary quarks and leptons by an unconventional CP' operation, whose soft breaking in the Higgs mass sector results in their acquiring large masses. The model leads to no detectable strong CP violating effects, produces small Dirac masses for neutrinos, and offers a novel alternative for dark matter as electromagnetically bound systems made of terafermions.

Outlines

- Problems of heavy stable neutrino of 4th generation : Higgs boson decay modes, and direct DM searches
- 4th generation with new U(1) gauge charge (charge symmetric case): neutrino binding and annihilation
- Charge asymmetric case (stable N and U) OHe scenario and neutrino-OHe binding

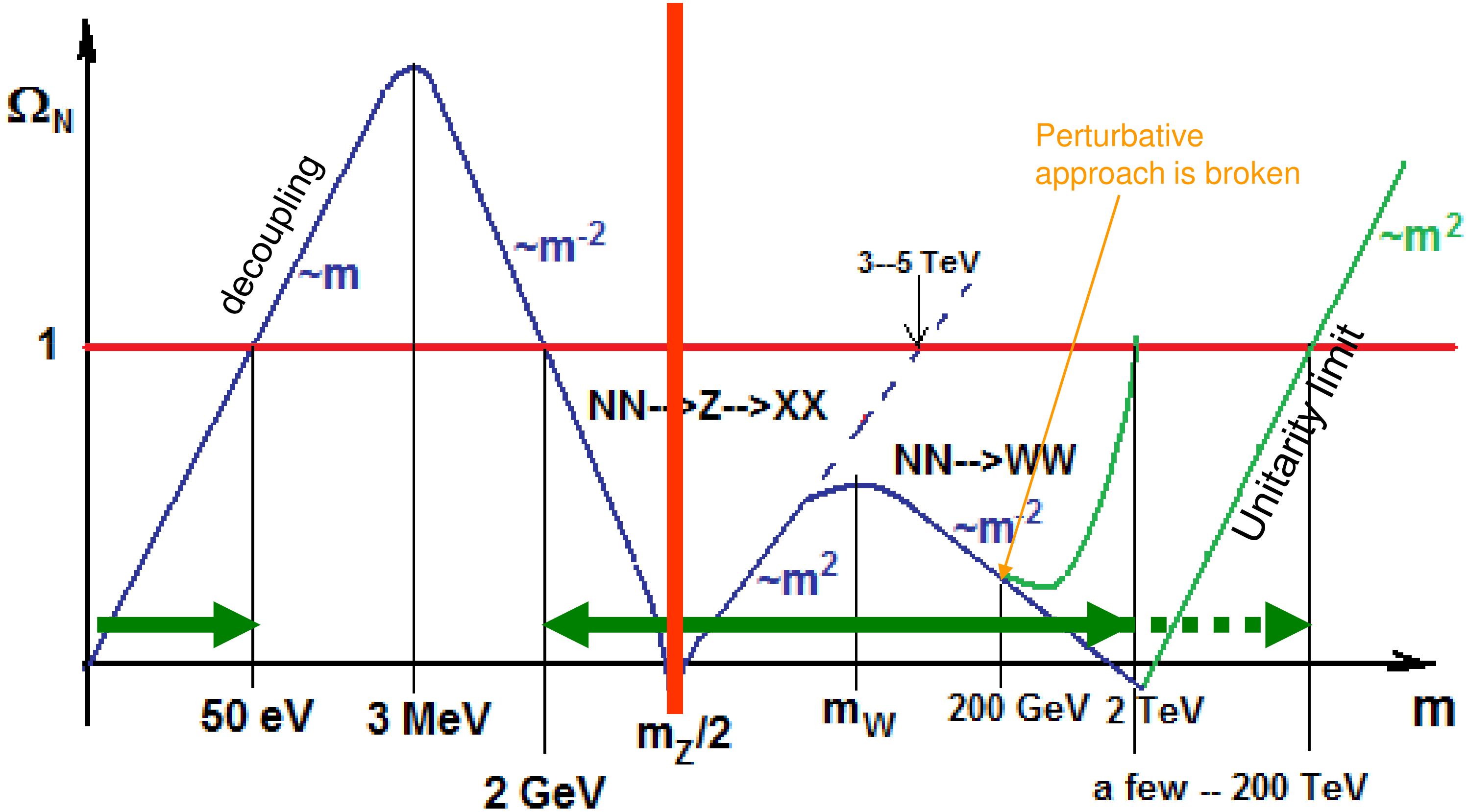
Mass of neutrino and physics beyond SM

- Majorana mass of neutrino – lepton number violation
- Dirac mass – new state of right handed neutrino

Physics of neutrino mass goes beyond the Standard Model

Constraint on the mass of neutrino

$$\Omega_N \sim \begin{cases} \dfrac{m_Z^4}{m_{Pl} m^2}, & m << \dfrac{m_Z}{2} \\ \dfrac{m^2}{m_{Pl}}, & \dfrac{m_Z}{2} << m < m_W \\ \dfrac{m_Z^4}{m_{Pl} m^2}, & m >> m_W \end{cases}$$



Thus 2 GeV < *m* < a few÷200 TeV is cosmologically allowable.

However *m* < 45 GeV is forbidden by accelerator data.

4th family and 125 GeV Higgs boson

SM Higgs production

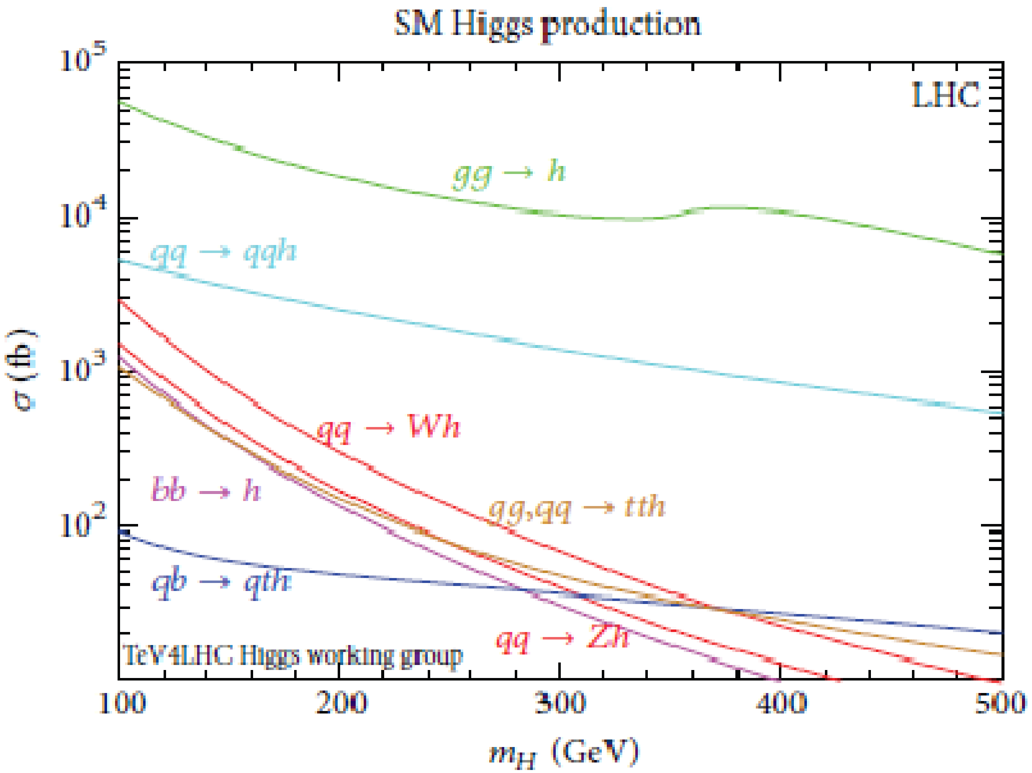
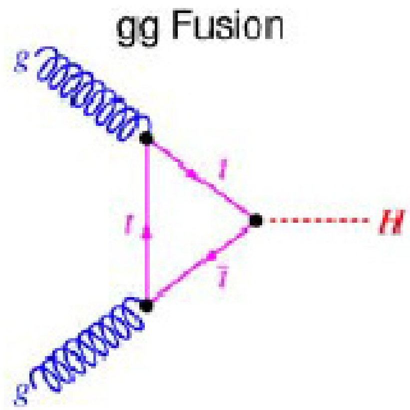
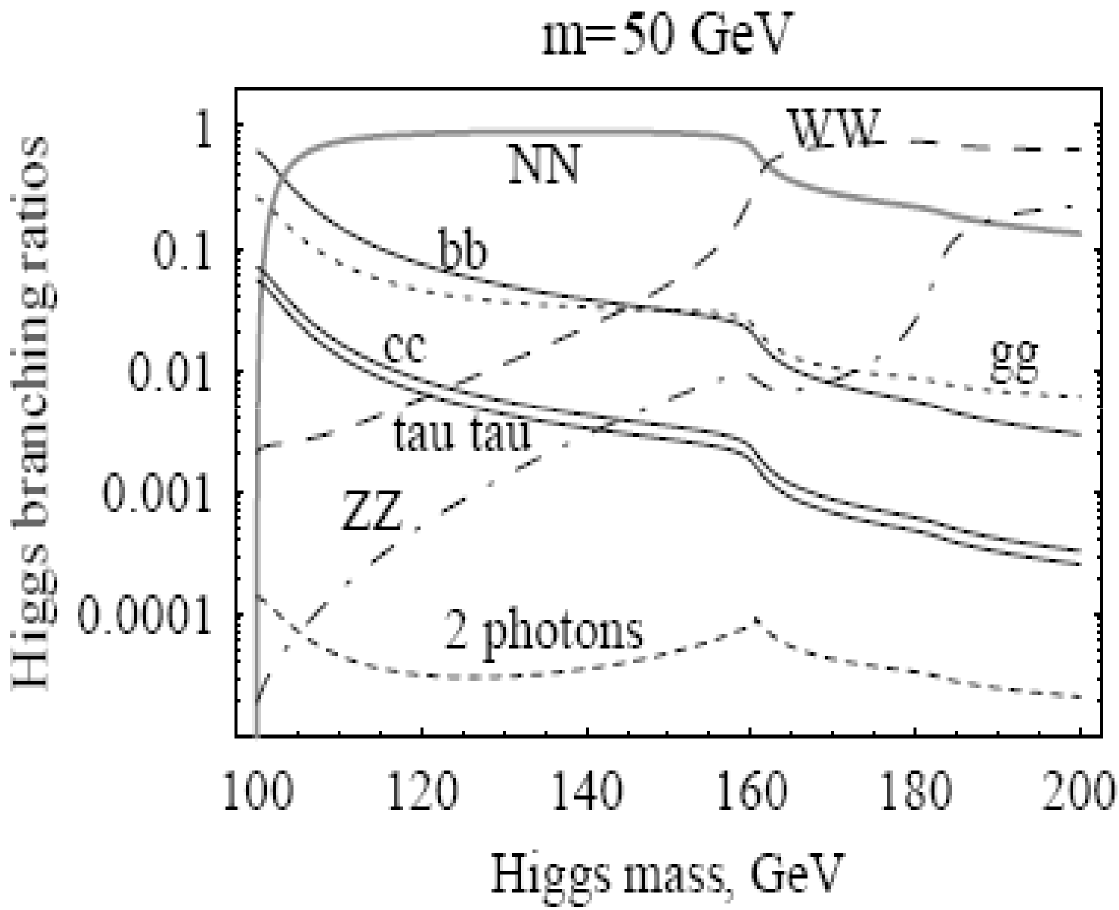
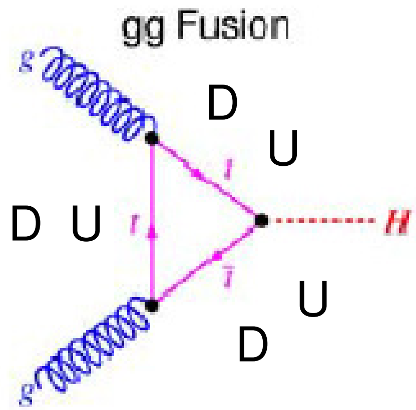


FIGURE 2: The cross section of the main processes of Higgs boson production in pp collisions at LHC (from [50]).



Invisble decay of Higgs boson H -> NN





Suppression of Higgs couplings

4th family is more massive, what appeals to its mass generation different from the one for the three known families.

So its coupling to 125 GeV Higgs boson should be suppressed.

The example of a two photon decay channel shows, that with such suppression the SM prediction can be reproduced.

$$R = \frac{\sigma_{SM4}(gg \to H)\,\Gamma_{SM4}(H \to \gamma\gamma)}{\sigma_{SM}(gg \to H)\,\Gamma_{SM}(H \to \gamma\gamma)}$$

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SM prediction can be reproduced

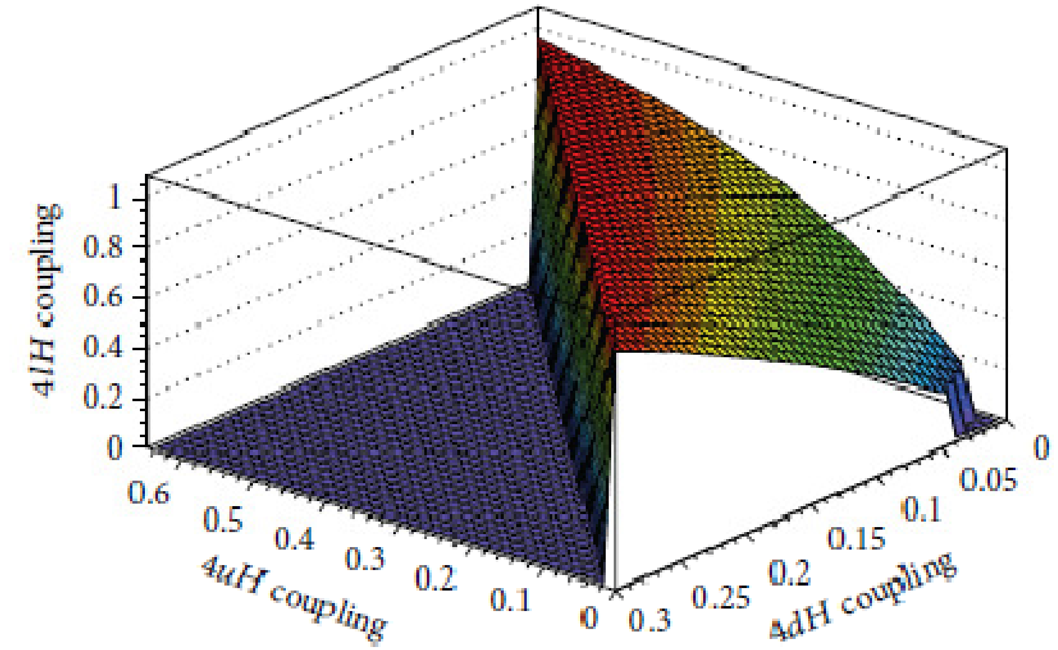

FIGURE 10: The surface in the space of parameters of the suppression factors 4dH, 4uH, and 4lH in the Higgs coupling to the quarks and leptons of the 4th generation, at which the value of ratio $R = 1$, corresponding to the Standard model prediction, is reproduced.

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4th family with new U(1) gauge charge

4th family from heterotic string phenomenology

- 4th family can follow from heterotic string phenomenology as naturally as SUSY.
- GUT group E_6 has rank (number of conserved quantities) 6, while SM, which it must embed, has rank 4. This difference means that new conserved quantities can exist.
- Euler characterics of compact manifold (or orbifold) defines the number of fermion families. This number can be 3, but it also can be 4.
- The difference of the 4th family from the 3 known light generations can be explained by the new conserved quantity, which 4th generation fermions possess.
- If this new quantum number is strictly conserved, the lightest fermion of the 4th generation (4th neutrino, N) should be absolutely stable.
- The next-to-lightest fermion (which is assumed to be U-quark) can decay to N owing to GUT interaction and can have life time, exceeding the age of the Universe.
- If baryon asymmetry in 4th family has negative sign and the excess of anti-U quarks with charge -2/3 is generated in early Universe, composite dark matter from 4th generation can exist and dominate in large scale structure formation.

RECOMBINATION AND ANNIHILATION OF U(1) CHARGED NEUTRINOS

Recombination

- In charge symmetric case at $T<T_{rec}$ neutrino and antineutrino recombine and annihilate.
- The rate of recombination exceeds the rate of expansion due to strong temperature dependence of classical dipole radiative capture, proposed in [Zeldovich, Khlopov,1978] for free monopole-antimonopole capture.
- It results in strong suppression of relic U(1) charged heavy neutrino density

SUPPRESSION OF U(1) CHARGED NEUTRINOS

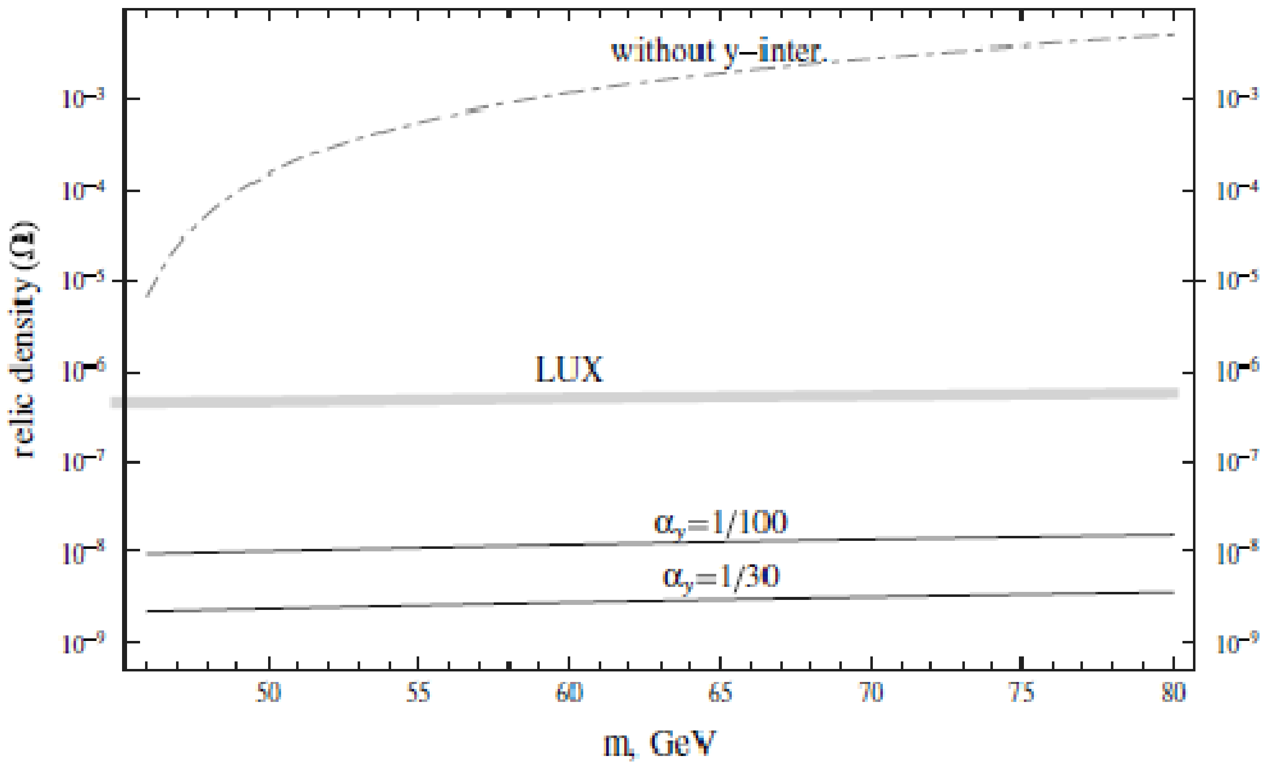


Fig. 1. Relic densities of fourth neutrinos in the galaxy in units of critical density for the cases without and with y-interaction. In the latter case, $\alpha_y = 1/30$ and $1/100$ were taken.

K.M. Belotsky, E. A. Esipova, M. Yu. Khlopov and M. N. Laletin. "Dark Coulomb Binding of Heavy Neutrinos of 4th family". IJMP D Vol. 24, No. 13 (2015) 1545008 (9 pages)

DARK MATTER FROM CHARGED PARTICLES OF 4TH FAMILY?

Baryonic Matter – atoms of stable quarks and charged lepton (electron)

- Ordinary matter consists of atoms
- Atoms consist of nuclei and electrons.
- Electrons are lightest charged particles – their stability is protected by the conservation of electric charge.
- Nuclei consist of nucleons, whose stability reflects baryon charge conservation.

In ordinary matter stable elementary particles are electrically charged, but bound in neutral atoms.

Dark Matter from Charged Particles?

By definition Dark Matter is non-luminous, while charged particles are the source of electromagnetic radiation. Therefore, neutral weakly interacting elementary particles are usually considered as Dark Matter candidates. If such neutral particles with mass m are stable, they freeze out in early Universe and form structure of inhomogeneities with the minimal characterstic scale

$$M = m_{Pl}\left(\frac{m_{Pl}}{m}\right)^2$$

- However, if charged particles are heavy, stable and bound within neutral « atomic » states they can play the role of composite Dark matter.
- Physical models, underlying such scenarios, their problems and nontrivial solutions as well as the possibilities for their test are the subject of the present talk.

« No go theorem » for -1 charge components

- *If composite dark matter particles are « atoms », binding positive P and negative E charges, all the free primordial negative charges E bind with He-4, as soon as helium is created in SBBN.*
- *Particles E with electric charge -1 form +1 ion [E He].*
- *This ion is a form of anomalous hydrogen.*
- Its Coulomb barrier prevents effective binding of positively charged particles P with E. These positively charged particles, bound with electrons, become atoms of anomalous istotopes
- *Positively charged ion is not formed, if negatively charged particles E have electric charge -2.*

Stable matter of 4-th generation

$\begin{pmatrix} N \\ E \end{pmatrix}$

m~50 GeV, stable

100 GeV <m<~1 TeV, E ->N lν,… unstable

$\begin{pmatrix} U \\ D \end{pmatrix}$

220 GeV <m<~1 TeV, U -> N + light fermions Long-living wihout mixing with light generations

220 GeV <m<~1 TeV, D -> U lν,… unstable

Precision measurements of SM parameters admit existence of 4th family, if 4th neutrino has mass around 50 GeV and masses of E, U and D are near their experimental bounds.

*If U-quark has lifetime, exceeding the age of the Universe, and in the early Universe excess of anti-U quarks is generated, primordial U-matter in the form of **AN**ti-**U**-**T**ripple-**I**ons of **U**nknown **M**atter (anutium).*

$\Delta^{--}_{\bar{U}\bar{U}\bar{U}} \equiv \left(\bar{U}\bar{U}\bar{U}\right)$ *can become a -2 charge constituent of composite dark matter*

4th neutrino with mass 50 GeV can not be dominant form of dark matter. But even its sparse dark matter component can help to resolve the puzzles of direct and indirect WIMP searches.

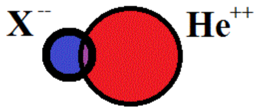
Nuclear-interacting composite dark matter: O-helium « atoms »

If we have a stable double charged particle X^{--} *in excess over its partner* X^{++} *it may create* Helium like neutral atom (O-helium) at temperature $T > I_o$

Where: $$I_o = Z_{He}^2 Z_\Delta^2 \alpha^2 m_{He} = 1.6 MeV$$

^4He is formed at T ~100 keV (t~100 s)
This means that it would rapidly create a neutral atom, in which all X^{--} are bound

$$X^{--} + {}^4He => (X\ He) + \gamma$$



The Bohr orbit of O-helium « atom » is of the order of radius of helium nucleus.

$$R_o = 1/\left(ZZ_{He}\alpha m_{He}\right) = 2 \cdot 10^{-13} cm$$

References

1. M.Yu. Khlopov, *JETP Lett.* 83 (2006) 1;
2. D. Fargion, M.Khlopov, C.Stephan, *Class. Quantum Grav.* 23 (2006) 7305;
2. M. Y. Khlopov and C. Kouvaris, *Phys. Rev.* D 77 (2008) 065002]

O-HELIUM DARK MATTER

O-helium dark matter

$$T < T_{od} = 1 keV$$

$$n_b \langle \sigma v \rangle \left(m_p / m_o \right) t < 1$$

$$T_{RM} = 1 eV$$

$$M_{od} = \frac{T_{RM}}{T_{od}} m_{Pl} \left(\frac{m_{Pl}}{T_{od}} \right)^2 = 10^9 M_{Sun}$$

- Energy and momentum transfer from baryons to O-helium is not effective and O-helium gas decouples from plasma and radiation
- O-helium dark matter starts to dominate
- On scales, smaller than this scale composite nature of O-helium results in suppression of density fluctuations, making O-helium gas more close to warm dark matter

O-helium in Earth

- Elastic scattering dominates in the (OHe)-nucleus interaction. After they fall down terrestrial surface the in-falling OHe particles are effectively slowed down due to elastic collisions with the matter. Then they drift, sinking down towards the center of the Earth with velocity

$$V = \frac{g}{n\sigma v} \approx 80 S_3 A_{med}^{1/2} \, \mathrm{cm/s}.$$

Here $A_{med} \sim 30$ is the average atomic weight in terrestrial surface matter, $n = 2.4 \cdot 10^{24}/A_{med}$ is the number of terrestrial atomic nuclei, σv is the rate of nuclear collisions and $g = 980 \ \mathrm{cm/s^2}$.

O-helium experimental search?

- In underground detectors, (OHe) “atoms” are slowed down to thermal energies far below the threshold for direct dark matter detection. However, (OHe) nuclear reactions can result in observable effects.
- O-helium gives rise to less than 0.1 of expected background events in XQC experiment, thus avoiding severe constraints on Strongly Interacting Massive Particles (SIMPs), obtained from the results of this experiment.

It implies development of specific strategy for direct experimental search for O-helium.

O-HELIUM DARK MATTER IN UNDERGROUND DETECTORS

O-helium concentration in Earth

The O-helium abundance the Earth is determined by the equilibrium between the in-falling and down-drifting fluxes.

The in-falling O-helium flux from dark matter halo is

$$F = \frac{n_0}{8\pi} \cdot |\overline{V_h} + \overline{V_E}|,$$

where ***V**_h_* is velocity of Solar System relative to DM halo (220 km/s), ***V**_E_* is velocity of orbital motion of Earth (29.5 km/s) and

$n_0 = 3 \cdot 10^{-4} S_3^{-1}\,\mathrm{cm}^{-3}$ is the local density of O-helium dark matter.

At a depth *L* below the Earth's surface, the drift timescale is ~*L/V.* It means that the change of the incoming flux, caused by the motion of the Earth along its orbit, should lead at the depth L ~ 10^5 cm to the corresponding change in the equilibrium underground concentration of OHe on the timescale

$$t_{dr} \approx 2.5 \cdot 10^2 S_3^{-1}\,\mathrm{s}$$

Annual modulation of O-helium concentration in Earth

The equilibrium concentration, which is established in the matter of underground detectors, is given by

$$n_{oE} = \frac{2\pi \cdot F}{V} = n_{oE}^{(1)} + n_{oE}^{(2)} \cdot sin(\omega(t - t_0)),$$

where $\omega = 2\pi/T$, T=1 yr and $\boldsymbol{t_o}$ is the phase. The averaged concentration is given by

$$n_{oE}^{(1)} = \frac{n_o}{320 S_3 A_{med}^{1/2}} V_h$$

and the annual modulation of OHe concentration is characterized by

$$n_{oE}^{(2)} = \frac{n_o}{640 S_3 A_{med}^{1/2}} V_E$$

The rate of nuclear reactions of OHe with nuclei is proportional to the local concentration and the energy release in these reactions leads to ionization signal containing both constant part and annual modulation.

OHe solution for puzzles of direct DM search

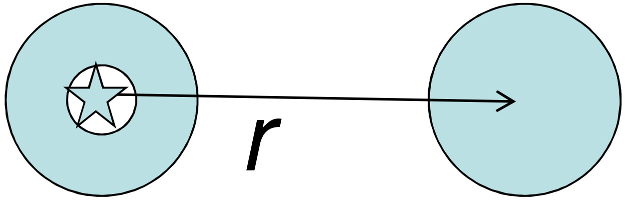
- OHe equilibrium concentration in the matter of DAMA detector is maintained for less than an hour
- The process

$$OHe + (A,Z) \Rightarrow [OHe(A,Z)] + \gamma$$

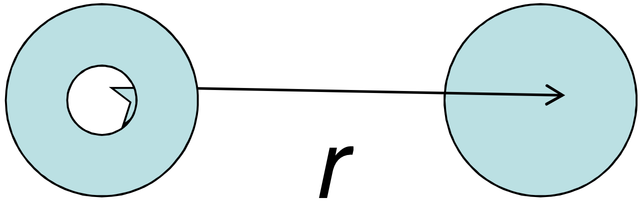
is possible, in which only a few keV energy is released. Other inelastic processes are suppressed

- Annual modulations in inelastic processes, induced by OHe in matter. No signal of WIMP-like recoil
- Signal in DAMA detector is not accompanied by processes with large energy release. This signal corresponds to a formation of anomalous isotopes with binding energy of few keV

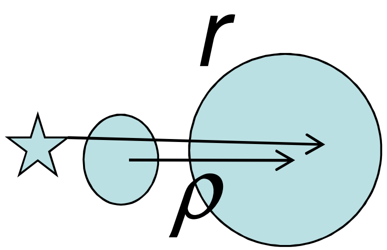
Potential of OHe-nucleus interaction



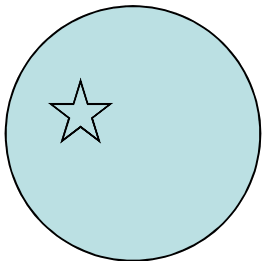
$$U_{Xnuc} = -2Z\alpha\left(\frac{1}{r} + \frac{1}{r_o}\right)\exp\left(-2r/r_o\right)$$



$$U_{Stark} = -\frac{2Z\alpha}{r^4}\frac{9}{2}r_o^3$$

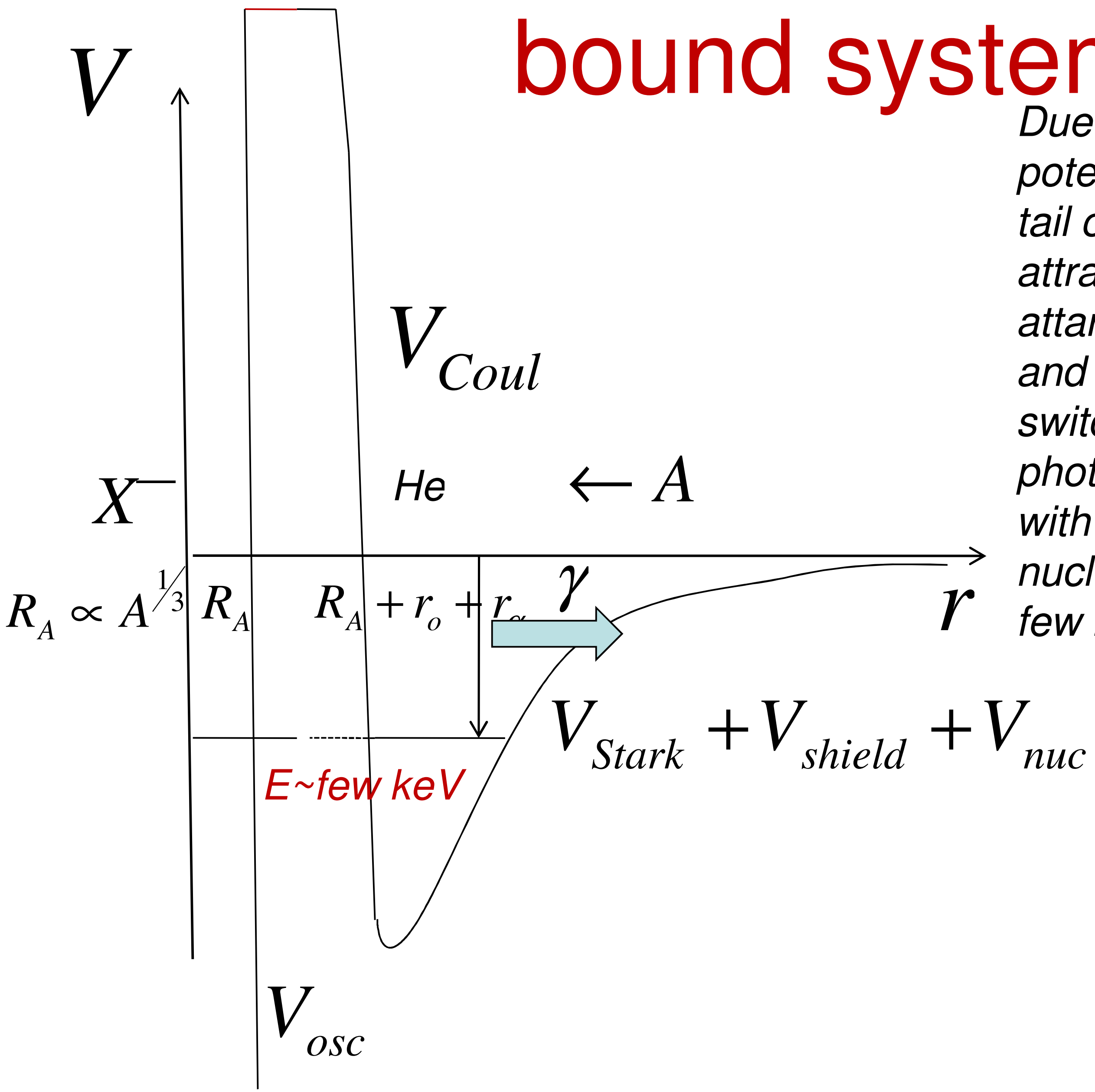


$$U_{Coul} = +\frac{2\alpha Z}{\rho} - \frac{2\alpha Z}{r}$$



$$U_{osc} = -\left[\frac{(Z+2)\alpha}{R}\left(1-\left(\frac{r}{R}\right)^2\right)\right]$$

Formation of OHe-nucleus bound system



*Due to shielded Coulomb potential of X, Stark effect and tail of nuclear Yukawa force OHe attracts the nucleus. Nuclear attarction causes OHe excitation and Coulomb repulsion is switched on. If the system emits a photon, OHe forms a bound state with nucleus but **beyond** the nucleus with binding energy of few keV.*

Few keV Level in OHe-nucleus system

- The problem is reduced to a quantum mechanical problem of energy level of OHe-nucleus bound state in the potential well, formed by shielded Coulomb, Stark effect and Yukawa tail attraction and dipole-like Coulomb barrier for the nucleus in vicinity of OHe. The internal well is determined by oscillatory potential of X in compound (Z+2) nucleus, in which He is aggregated.
- The numerical solution for this problem is simplified for rectangular wells and walls, giving a few keV level for Na.

Rate of OHe-nucleus radiative capture

As soon as the energy of level is found one can use the analogy with radiative capture of neutron by proton with the account for:

- Absence of M1 transition for OHe-nucleus system (which is dominant for n+p reaction)
- Suppression of E1 transition by factor $f \sim 10^{-3}$, corresponding to isospin symmetry breaking

(in the case of OHe only isoscalar transition is possible, while E1 goes due to isovector transition only)

Reproduction of DAMA/NaI and DAMA/LIBRA events

The rate of OHe radiative capture by nucleus with charge Z and atomic number A to the energy level E in the medium with temperature T is given by

$$\sigma v = \frac{f\pi\alpha}{m_p^2}\frac{3}{\sqrt{2}}\left(\frac{Z}{A}\right)^2\frac{T}{\sqrt{Am_pE}}.$$

Formation of OHe-nucleus bound system leads to energy release of its binding energy, detected as ionization signal. In the context of our approach the existence of annual modulations of this signal in the range 2-6 keV and absence of such effect at energies above 6 keV means that binding energy of Na-Ohe system in DAMA experiment should not exceed 6 keV, being in the range 2-4 keV.

Annual modulation of signals in DAMA/NaI and DAMA/LIBRA events

The amplitude of annual modulation of ionization signal (measured in counts per day per kg, cpd/kg) is given by

$$\zeta = \frac{3\pi\alpha \cdot n_o N_A V_E t Q}{640\sqrt{2} A_{med}^{1/2}(A_I + A_{Na})} \frac{f}{S_3 m_p^2} \left(\frac{Z_i}{A_i}\right)^2 \frac{T}{\sqrt{A_i m_p E_i}} = 4.3 \cdot 10^{10} \frac{f}{S_3^2} \left(\frac{Z_i}{A_i}\right)^2 \frac{T}{\sqrt{A_i m_p E_i}}.$$

This value should be compared with the integrated over energy bins signals in DAMA/NaI and DAMA/LIBRA experiments and the results of these experiments can be reproduced for

$$E_{Na} = 3keV$$

OPEN QUESTIONS OF THE OHE SCENARIO

Earth shadow effect

- OHe is nuclear interacting and thus should cause the Earth shadow effect.
- The studies, whether we can avoid recent DAMA constraints are under way.

The crucial role of potential barrier in OHe-nucleus interaction

- Due to this barrier elastic OHe-nucleus scattering strongly dominates.
- If such barrier doesn't exist, overproduction of anomalous isotopes is inevitable.
- Its existence should be proved by proper quantum mechanical treatment

J.-R. Cudell, M.Yu;Khlopov and Q.Wallemacq

Some Potential Problems of OHe Composite Dark Matter,

Bled Workshops in Physics (2014) V.15, PP.66-74; e-Print: arXiv: 1412.6030.

INDIRECT PROBES OF O-HELIUM DARK MATTER MODELS

Excessive positrons in Integral

Taking into account that in the galactic bulge with radius ~ 1 kpc the number density of O-helium can reach the value

$$n_o \approx 3 \cdot 10^{-3}/S_3\,\mathrm{cm}^{-3}$$

one can estimate the collision rate of O-helium in this central region:

$$dN/dt = n_o^2 \sigma v_h 4\pi r_b^3/3 \approx 3 \cdot 10^{42} S_3^{-2}\,\mathrm{s}^{-1}$$

At the velocity of particules in halo, energy transfer in such collisions is E ~ 1MeV. These collisions can lead to excitation of O-helium. If 2S level is excited, pair production dominates over two-photon channel in the de-excitation by E0 transition and positron production with the rate

$$3 \cdot 10^{42} S_3^{-2}\,\mathrm{s}^{-1}$$

is not accompanied by strong gamma signal. This rate of positron production is sufficient to explain the excess of positron production in bulge, measured by Integral.

Excessive positrons in Integral from dark atoms– high sensitivity to DM distribution

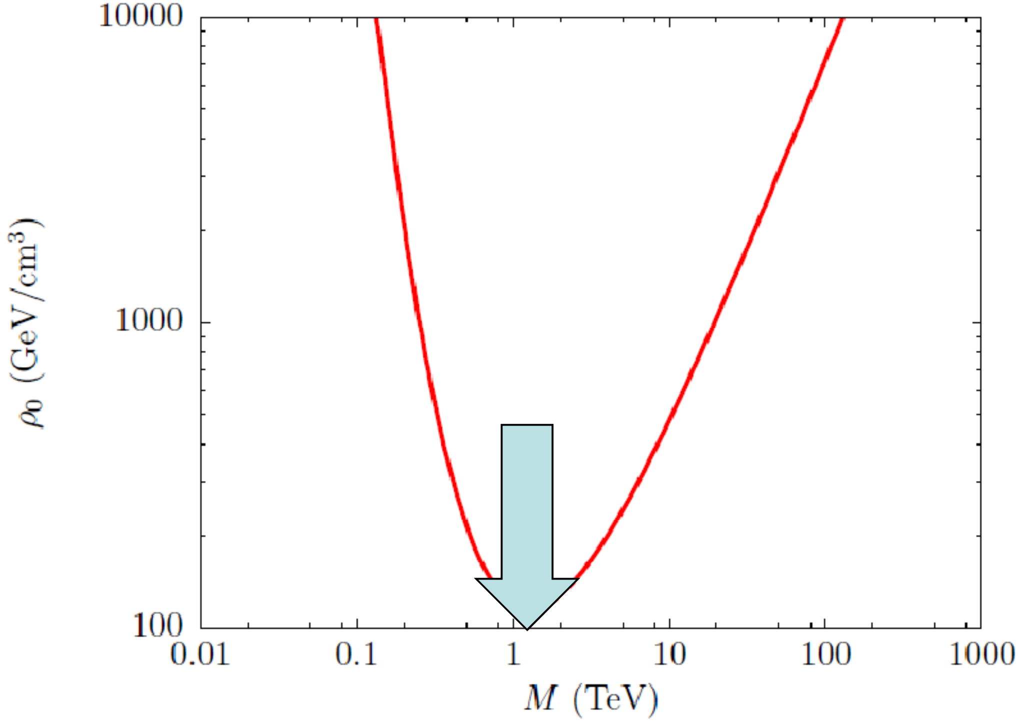
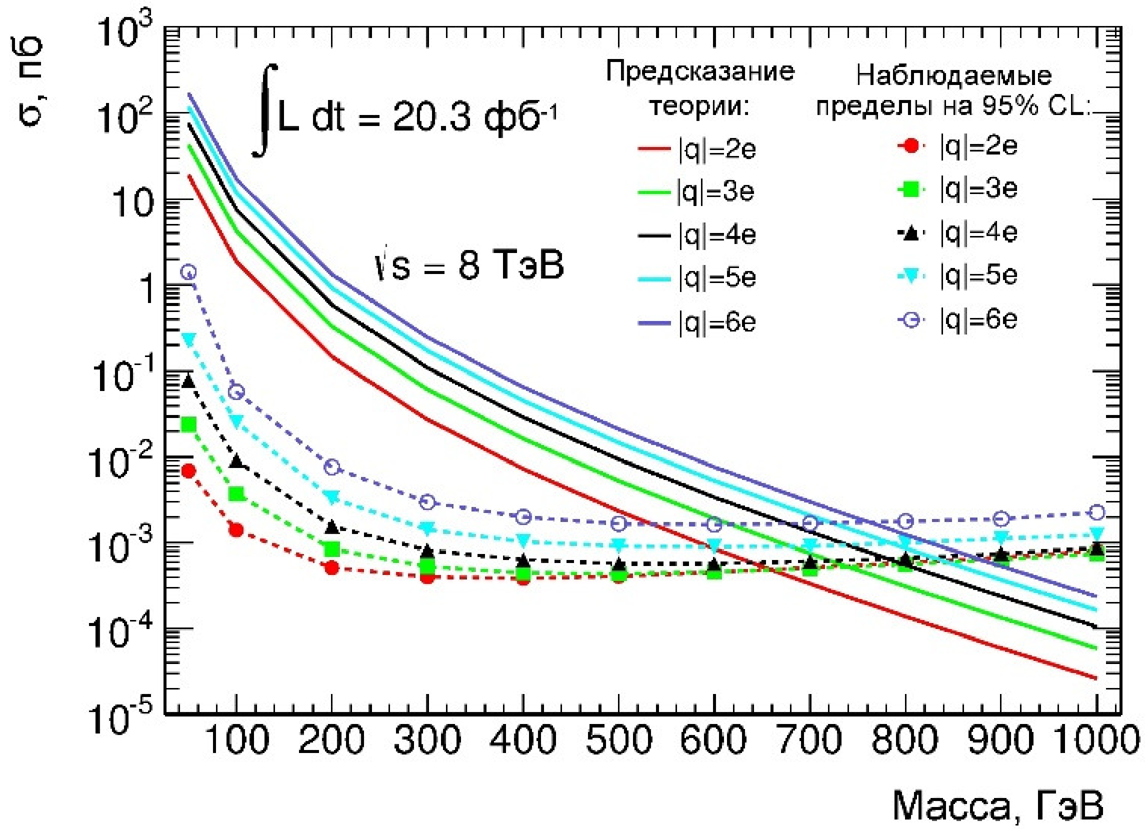


Figure 1: Values of the central dark matter density ρ_0 (GeV/cm^3) and of the OHe mas
M (TeV) reproducing the excess of e^+e^- pairs production in the galactic bulge. Belov
the red curve, the predicted rate is too low.

J.-R. Cudell, M.Yu.Khlopov and Q.Wallemacq
Dark atoms and the positron-annihilation-line excess in the galactic bulge.
Advances in High Energy Physics, vol. 2014, Article ID 869425, : arXiv: 1401.5228

Searches for multiple charged particles in ATLAS experiment



M>659 GeV for |q|=2e at 95% c.l. [Yu. Smirnov, PhD Thesis]

[ATLAS Collaboration, Search for heavy long-lived multi-charged particles in pp collisions at √s=8 TeV using the ATLAS detector, Eur. Phys. J. C 75 (2015) 362]

SAVING OF 4TH NEUTRINOS IN OHE COSMOLOGY

OHE – N recombination

- In charge asymmetric case, when dark matter is explained by excessive anti-U quarks, U(1) charge conservation implies the corresponding N excess.
- Then at $T<T_{rec}$ free N are captured by OHe and hidden in it under its helium nuclear shell. Such « molecule » has nuclear interaction with matter, and most of N are elusive for WIMP searches.

SUPPRESSION OF FREE U(1) CHARGED NEUTRINOS

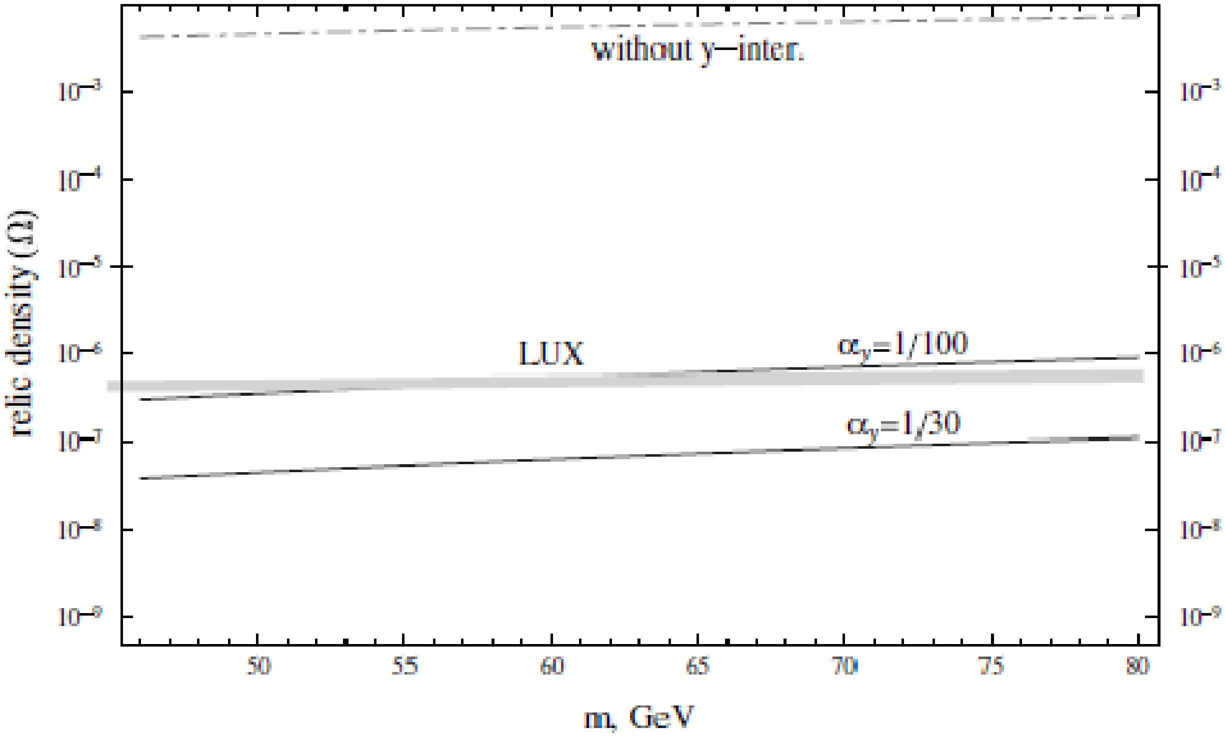


Fig. 2. The same as on Fig. 1 but for the cases of N-$\bar{U}\bar{U}\bar{U}$ charge asymmetric dark matter.

K.M. Belotsky, E. A. Esipova, M. Yu. Khlopov and M. N. Laletin. “Dark Coulomb Binding of Heavy Neutrinos of 4th family”. IJMP D Vol. 24, No. 13 (2015) 1545008 (9 pages)

Conclusions

• 4th family with stable heavy neutrino and stable U quark can manage to escape severe constraints from Higgs boson studies and direct dark matter searches, if it has reduced coupling with 125 GeV Higgs and possess a new strictly conserved U(1) charge.

•The dominant dark matter of 4th generation is in the form of nuclear interacting O-helium « atoms ». Their binding with nuclei in underground detectors possess annual modulation and can explain positive results of DAMA/NaI and DAMA/LIBRA experiments and controversial results of other groups. OHe model can also explain some puzzles of indirect dark matter searches, what is close to experimental verification at the LHC.

•Binding of most of free N with OHe hides them under its nuclear shell, making them elusive for direct WIMP searches

• The open problems of OHe scenario should be solved to prove or disprove this approach.