Dark atom solution for the puzzles of dark matter searches?

Lecture from course

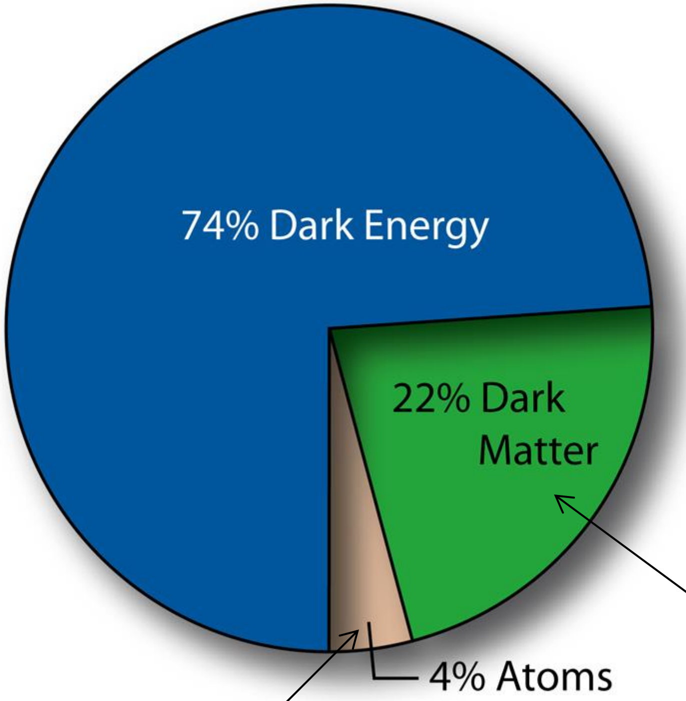
"Cosmoparticle Physics"

DARK MATTER FROM CHARGED PARTCILES?

Outline

- Dark atoms of composite dark matter, their cosmological evolution and effects.
- Dark atoms interaction with the matter of underground detectors
- Cosmic-ray and accelerator search for charged components of composite dark matter
- Conclusions

Composition of the Universe



$$\Omega \equiv \frac{\rho}{\rho_{cr}}$$

$$\Omega_b \approx 0.044 \qquad \Omega_{CMB} \approx 0.5 \cdot 10^{-4}$$

$$\Omega_{DM} \approx 0.20$$

$$\Omega_\Lambda \approx 0.7$$

$$\boxed{\Omega_{tot} \approx 1.0}$$

Baryonic matter consists of atoms

Can dark Matter consist of Dark atoms?

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 PARTCILES?

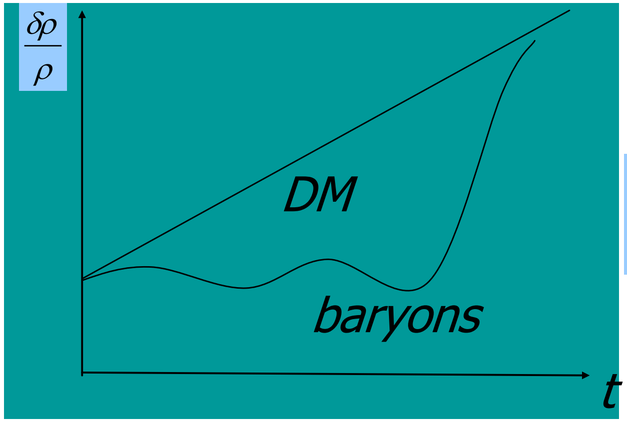
Cosmological Dark Matter

Cosmological Dark Matter explains:

- ***virial paradox in galaxy clusters,***
- ***rotation curves of galaxies***
- ***dark halos of galaxies***
- ***effects of macro-lensing***

But first of all it should provide formation of galaxies from small density fluctuations, corresponding to the observed fluctuations of CMB, and it should be nonbaryonic.

Nonbaryonic Dark Matter



$$\frac{\delta\rho}{\rho} \Rightarrow \frac{\delta T}{T}$$

Cosmological Dark Matter should provide formation of galaxies from small density fluctuations, corresponding to the observed fluctuations of CMB. Growth of these density fluctuations should not be prevented by the radiation pressure, which converts before recombination baryon density fluctuations in sound waves

To fulfil these duties Dark Matter should interact sufficiently weakly with baryonic matter and radiation and it should be sufficiently stable on cosmological timescale.
Usually Weakly Interacting Massive Particles are considered.

We draw attention to a possibility of stable charged particles, bound in atom-like states (Dark Atoms), which can play the role of dark matter.

Dark Matter – Cosmological Reflection of Microworld Structure

Dark Matter should be present in the modern Universe, and thus is stable on cosmological scale.

This stabilty reflects some Conservation Law, which prohibits DM decay.

Following Noether's theorem this conservation law should correspond to a (nearly) strict symmetry of microworld.

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.

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.

Abstract

- *The role of Sinister Heavy Fermions in recent Glashow's SU(3)*SU(2)*SU(2)'*U(1) model is to offer in a unique frame relic Helium-like products (an ingenious candidate to the dark matter puzzle), a solution to the See-Saw mechanism for light neutrino masses as well as to strong CP violation problem in QCD. Their mass are million times larger than common ones*
- *The Sinister model requires a three additional families of leptons and quarks, but only the lightest of them Heavy U-quark and E-"electron" are stable.*

Quarks	u up	c charm	t top
	d down	s strange	b bottom
Leptonen	ν_e e neutrino	ν_μ μ neutrino	ν_τ τ neutrino
	e electron	μ muon	τ tau

U

E

Quarks	u up	c charm	t top
	d down	s strange	b bottom
Leptonen	ν_e e neutrino	ν_μ μ neutrino	ν_τ τ neutrino
	e electron	μ muon	τ tau

Glashow's tera-fermions

SU(3)xSU(2)xSU(2)xU(1)

Tera-fermions (N,E,U,D) ⇔ W', Z', H', γ and g

+ problem of CP-violation in QCD

+ problem of neutrino mass

*+ (?) DM as [(UUU)EE] tera-helium **(NO!)***

$\begin{pmatrix} N \\ E \end{pmatrix}$ *Very heavy and unstable*

m~500 GeV, stable

$\begin{pmatrix} U \\ D \end{pmatrix}$ *m~3 TeV, (meta)stable*

m~5 TeV, D → U +…

$$\frac{m_E}{m_e} = \frac{m_U}{m_u} = \frac{m_D}{m_d} = \frac{\text{vev}'}{\text{vev}} = S_6 \quad 10^6$$

Why Tera-helium is a good Dark Matter gas?

- Teraparticles do not have normal W and Z interactions and do not contribute into SM parameters, so they can not be excluded by precision measurements of SM parameters
- CP' symmetry of Glashow's model helps to solve strong CP violation problem in QCD.
- Tera-neutrino is unstable, because it gives Dirac see-saw mass to normal neutrino.
- UUU as the new form of hadron - bound by ChromoCoulomb forces. It's size is about 1/alpha_QCD m_U about 10^-16 cm and it weakly interacts with hadrons.

Cosmological tera-fermion asymmetry

$$\Omega_{(UUUEE)} \equiv \Omega_{CDM} = 0.224$$

$$\Omega_b = 0.044$$

- To saturate the observed dark matter of the Universe Glashow assumed tera-U-quark and tera-electron excess generated in the early Universe.
- The model assumes tera-fermion asymmetry of the Universe, which should be generated together with the observed baryon (and lepton) asymmetry

However, this asymmetry can not suppress primordial antiparticles, as it is the case for antibaryons due to baryon asymmetry

(Ep) catalyzer

- In the expanding Universe no binding or annihilation is complete. Significant fraction of products of incomplete burning remains. In Sinister model they are: (UUU), (UUu), (Uud), [(UUU)E], [(UUu)E], [(Uud)E], as well as tera-positrons and tera-antibaryons
- Glashow's hope was that at T<25keV all free E bind with protons and (Ep) « atom » plays the role of catalyzer, eliminating all these free species, in reactions like

$$[(UUU)E] + (Ep) \rightarrow [(UUU)EE] + p$$

$$E^{+} + (Ep) \rightarrow (E^{+}E) + p$$

But this hope can not be realized, since much earlier all the free E are trapped by He

Tera Leptons in Glashow's Sinister Universe

- Moreover, in opposition to almost effective pair Tera-Quark U annihilations (like common proton-anti-proton), there is no such an early or late Tera-Lepton pairs suppressions, because:
- a) electromagnetic interactions are "weaker" than nuclear ones because their coupling is smaller and mainly because the cross sections is proportional to inverse square Tera-Lepton Mass
- b) helium ion 4He++ is able

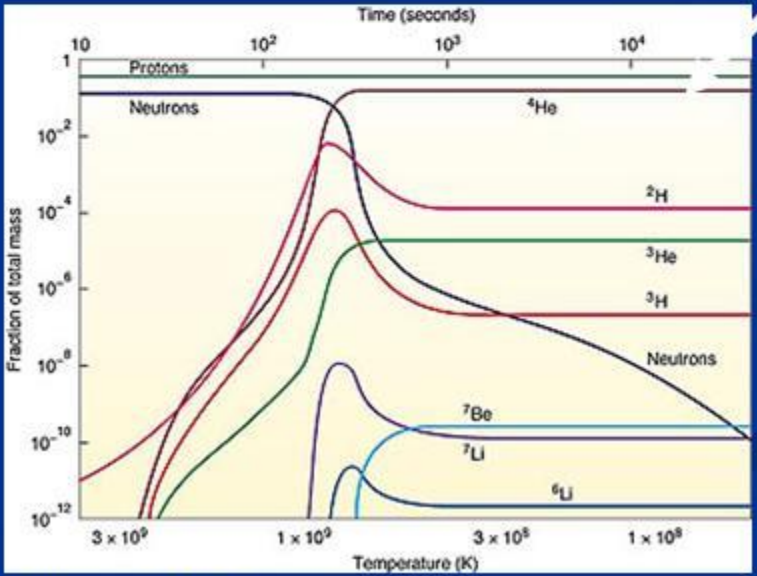
to attract and capture,

E-, fixing it into a hybrid

tera helium "ion" trap.

This takes place during the first

few minutes of the Universe



Why Grave Shadows over the Sinister universe?

- The helium ion $4He^{++}$ capture of E^- leads to a pile up of relic $(4HeE)^+$ traces, a lethal compound for any Sinister Universe.
- This capture leaves no Tera-Lepton frozen in Ep relic (otherwise an ideal catalyzer to achieve effective late E^+E^- annihilations possibly saving the model).
- The $(4HeE)^+$ Coulomb screening is also avoiding the synthesis of the desired UUUEE hidden dark matter gas. The $e(4HeE)^+$ behave chemically like an anomalous hydrogen isotope.
- Also tera-positronium (eE^+) relics are over-abundant and they behave like an anomalous hydrogen atom:

« 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.*

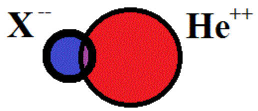
Nuclear-interacting composite dark matter: O-helium « atoms »

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:

^{4}He 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.

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]

-2n charged particles

- Such particles, if produced in excess over their +2n charged partners, can capture n primordial helium nuclei.
- Such bound states are not like Bohr atom, but look like Thomson atom with negatively charged core and nuclear droplet oscillating around it.

Constituents of composite dark matter

Few possible candidates for -2 charges:

Stable doubly charged "leptons" with mass >100 GeV (~1 TeV range):

- *AC « leptons » from almost commutative geometry*

D. Fargion, M.Khlopov, C.Stephan, Class. Quantum Grav. 23 (206) 7305

- *Technibaryons and technileptons from Walking Technicolor (WTC)*

M. Y. Khlopov and C. Kouvaris, Phys. Rev. D 77 (2008) 065002; M. Y. Khlopov and C. Kouvaris, Phys. Rev. D 78 (2008) 065040

Hadron-like bound states of:

- *Stable U-quark of 4-th family in Heterotic string phenomenology*

M.Yu. Khlopov, *JETP Lett.* 83 (2006) 1

- *Stable U-quarks of 5th family in the approach, unifying spins and charges*

N.S. Mankoc Borstnik, Mod. Phys. Lett. A 10 (1995) 587

M.Yu.Khlopov, A.G.Mayorov, E.Yu.Soldatov (2010), arXiv:1003.1144

WTC-model

*The ideas of Technicolor (TC) are revived with the use of SU(2) group for "walking" (not running) TC gauge constant *.*

1. *U and D techniquarks bound by Technicolor give mass to W and the Z bosons.*
2. *UU, UD, DD and their corresponding antiparticles are technibaryons and corresponding anti-technibaryons.*
3. *The electric charges of UU, UD, and DD are in general* ***y+1, y*** *and* ***y-1*** *respectively, where* ***y*** *is an arbitrary real number.*
4. *In order to cancel the* ***Witten global anomaly*** *the model requires in addition an existence of a fourth family of leptons.*
5. *Their electric charges are in terms of* ***y*** *respectively* ***(1 - 3y)/2*** *and* ***(-1 - 3y)/2.***
   If ***y=1****, both* ***stable doubly charged*** *technibaryons and technileptons are possible**.*

All these stable AC and techniparticles will look like stable doubly charged leptons at LHC

References

*

F. Sannino and K. Tuominen, *Phys. Rev.* D 71 (2005) 051901 ;
D. K. Hong *et al*.,*Phys. Lett.* B 597 (2004) 89 ;
D. D. Dietrich *et al*., *Phys. Rev.* D 72 (2005) 055001 ;
S. B. Gudnason *et al*., *Phys. Rev.* D 73 (2006) 115003 ;
S. B. Gudnason *et al*, *Phys. Rev.* D 74 (2006) 095008]

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M. Y. Khlopov and C. Kouvaris, Phys. Rev. D 77 (2008) 065002;

Even charged techniparticles

q	$\mathbf{UU}(q+1)$	$\mathbf{UD}(q)$	$\mathbf{DD}(q-1)$	$\nu'(\frac{1-3q}{2}$	$\zeta(\frac{-1-3q}{2}$
1	**2**	1	0	-1	**-2**
3	**4**	3	**2**	**-4**	-5
5	**6**	5	4	-7	**-8**
7	**8**	7	**6**	**-10**	-11

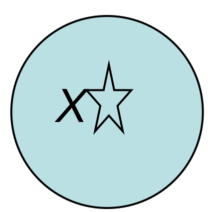
X-nuclearites – bound states of -2n charged particles with n He nuclei.

Stable multiple charged particles

WTC can lead to techniparticles with multiple charge

q	$UU(q+1)$	$UD(q)$	$DD(q-1)$	$\nu'(\frac{1-3q}{2})$	$\zeta(\frac{-1-3q}{2})$
1	**2**	1	0	-1	**−2**
3	**4**	3	**2**	**−4**	-5
5	**6**	5	**4**	-7	**−8**
7	**8**	7	**6**	**−10**	-11

-2n charged particles in WTC bound with n nuclei of primoridal He form Thomson atoms of Xhe - X-nuclearites – bound states of -2n charged particles with n He nuclei.



nHe

Techniparticle excess

- The advantage of WTC framework is that it provides definite relationship between baryon asymmetry and techniparticle excess.

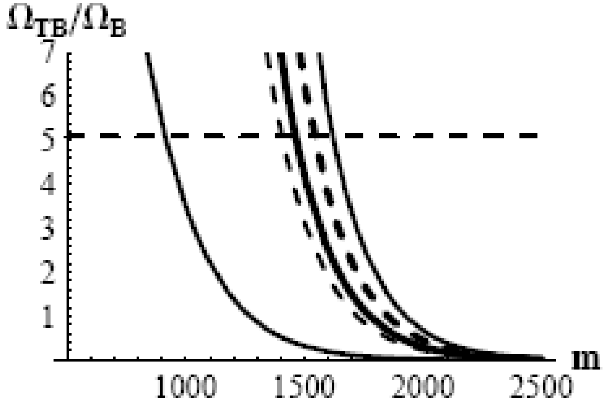
$$\frac{TB}{B} = -\sigma_{UU}\left(\frac{L'}{B}\frac{1}{3\sigma_\zeta} + 1 + \frac{L}{3B}\right)$$

Here $\sigma_i\ (i = UU, \zeta)$ are statistical factors in equilibrium relationship between, TB, B, L and L’

The equilibrium is maintained by electroweak SU(2) sphalerons and similar relationship can hold true for any SU(2) doublets (like U quarks of 4th family or stable quarks of 5th family)

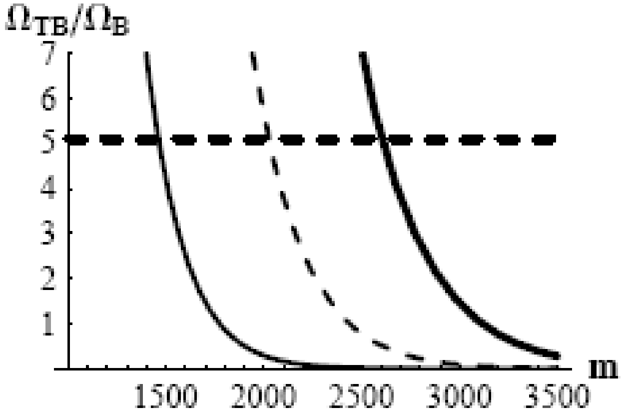
Relationship between TB and B

$$\xi = \frac{L'}{3B\sigma_\zeta} + 1 + \frac{L}{3B}$$



- L'=0, T*=150 GeV

ξ =0.1; 1; 4/3; 2; 3

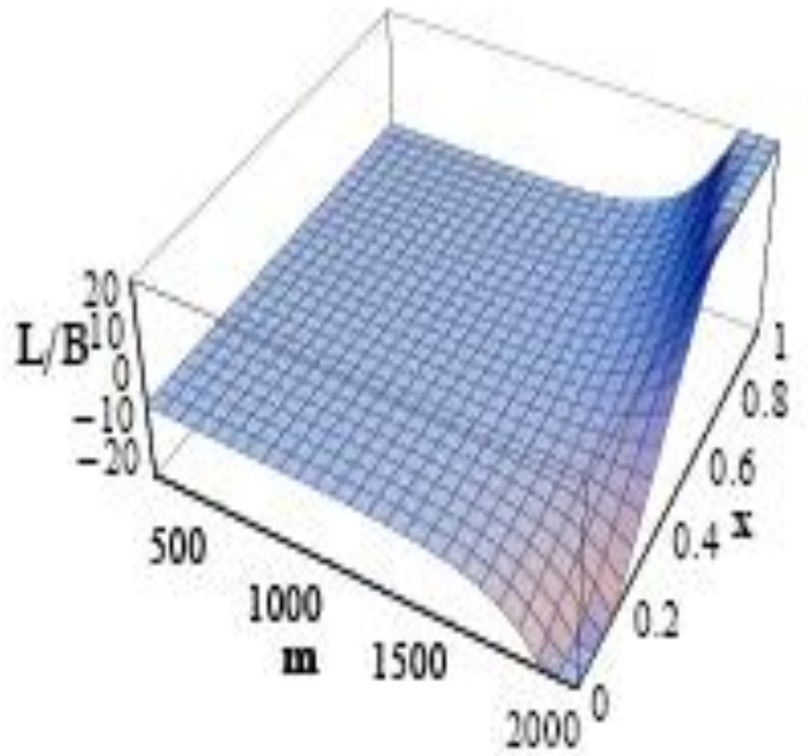


$\xi = 4/3$

- L'=0,

T*=150, 200, 250 GeV

Relationship between TB, L' and B



- x denotes the fraction of dark matter given by the technibaryon
- TB<0, L'>0 – two types of -2 charged techniparticles.

The case TB>0, L'>0 (TB<0, L'<0) gives an interesting possibility of (-2 +2) atom-like WIMPs, similar to AC model. For TB>>L' (TB<<L') no problem of free +2 charges

O-HELIUM DARK MATTER

O-helium dark matter

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

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

$$T_{RM} = 1eV$$

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

- 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

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

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 $g = 980$ 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.

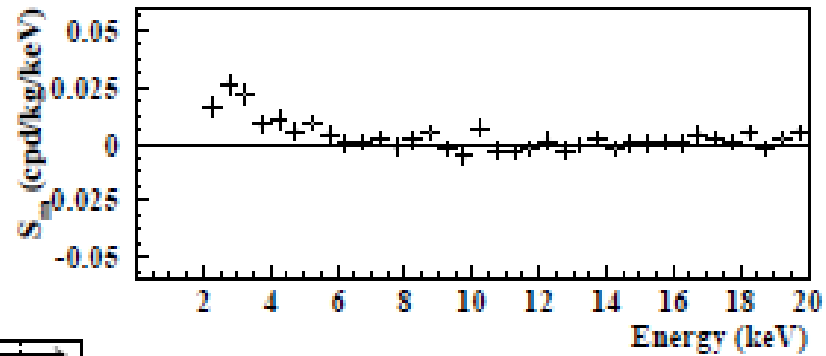
It implies development of specific strategy for direct experimental search for O-helium.

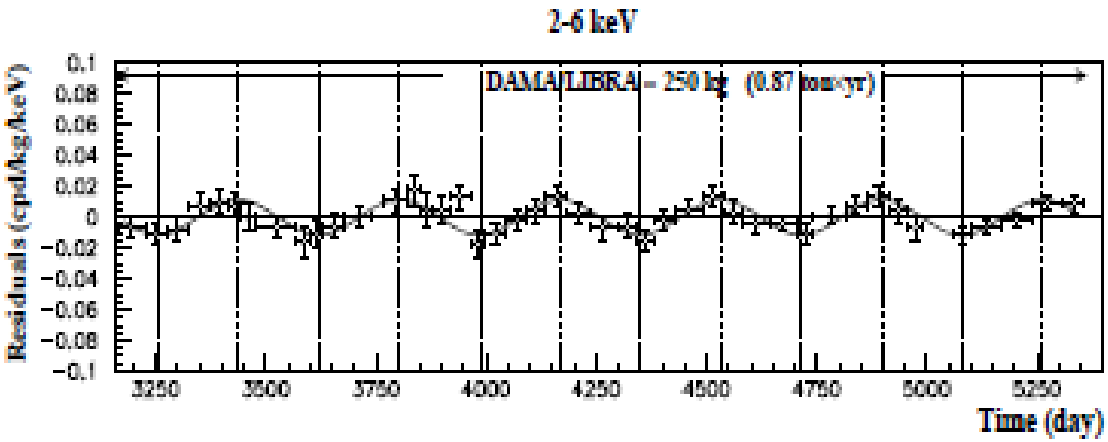
THE PUZZLES
OF DARK MATTER SEARCH

Direct search for DM (WIMPs)

DAMA/NaI (7 years) + DAMA/LIBRA (6 years) *total exposure: 1.17 ton×yr*

$$R(t) = S_0 + S_m \cos[\omega(t - t_0)]$$



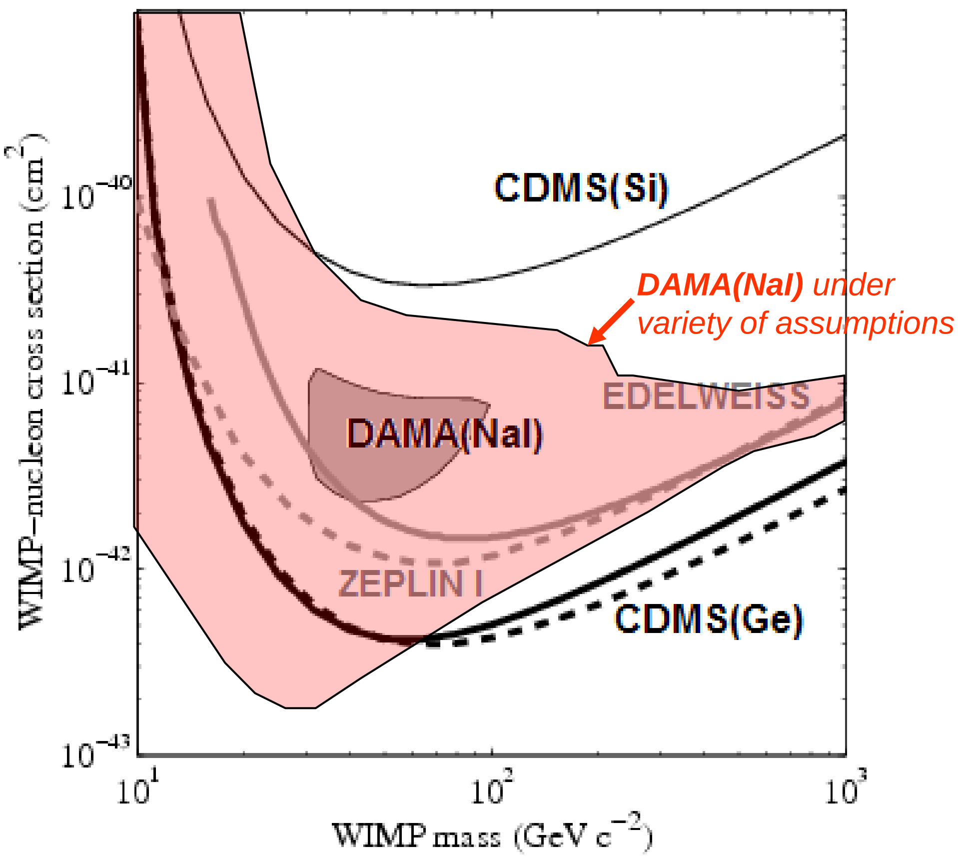


Confidence level 8.9

R.Bernabei et al, arXiv: 1007.0595, 4 July 2010

Direct search for WIMPs

<u>Experiment DAMA (*NaI*) vs other underground experiments:</u>
<u>Interpretation in terms of ***scalar*** *AX*-interaction.</u>



Analysis depends essentially on assumption about distribution of DM in vicinity of Solar system. On this picture a quite simplified assumption was adopted.

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 $\boldsymbol{V_h}$ is velocity of Solar System relative to DM halo (220 km/s), $\boldsymbol{V_E}$ 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 ***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

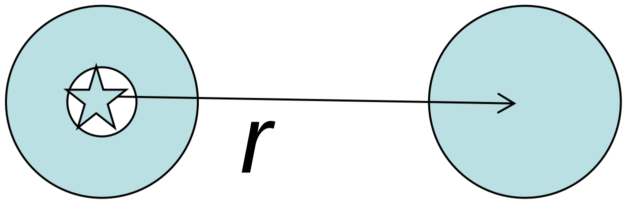
- OHe equilibrium concentration in the matter of DAMA detector is maintained for less than an hour
- The process

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

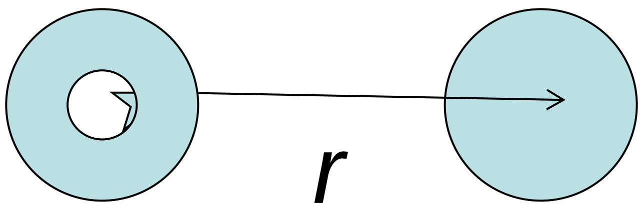
is possible, in which only a few keV energy is released. Other inelastic processes are suppressed

- 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

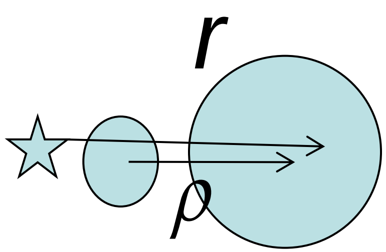
Potential of OHe-nucleus interaction



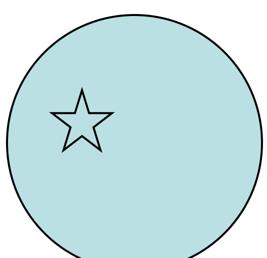
$$U_{Xnuc} = -2Z\alpha\left(\frac{1}{r}+\frac{1}{r_o}\right)\exp\left(-2r/r_o\right)$$



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

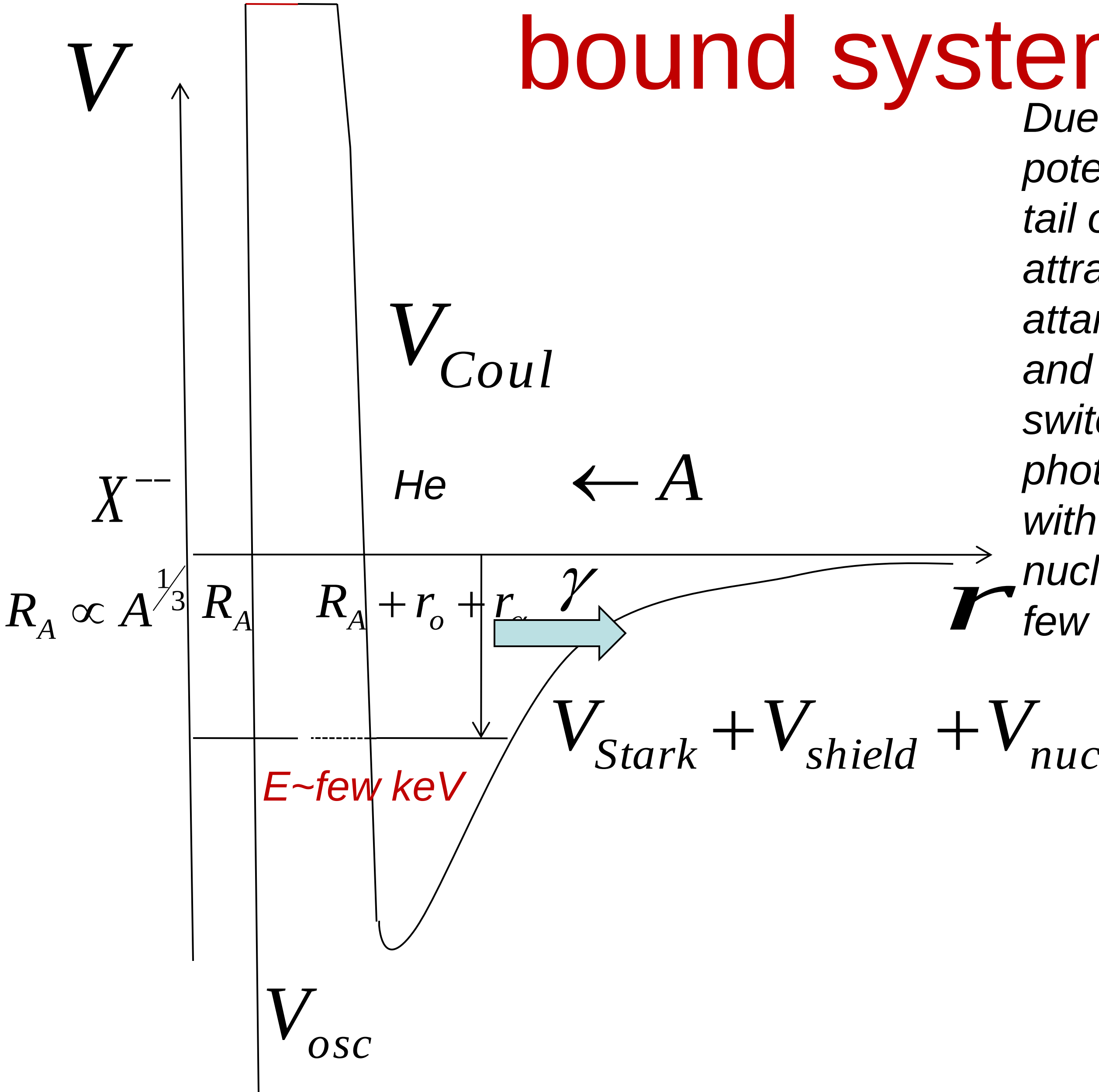


$$U_{Coul} = +\frac{2\alpha Z}{\rho} - \frac{2\alpha Z}{r}$$



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

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

$$E_{Na} = 3keV$$

Absence of signal in DAMA detector above 6 keV

The the results of DAMA experiment exhibit also absence of annual modulations at the energy above 6 keV. In our approach they can come from:

- Radiative capture to E>6keV levels in OHe-Tl system .
- Radiative capture of OHe by Na and I to deep internuclear ~tens MeV energy levels.
- Rapid decay of low energy levels of OHe-Na and OHe-I systems to deep inter-nuclear ~tens MeV levels in these systems.

For the two latter processes dipole Coulomb barrier provides suppression of their rates beyond the experimental upper limits.

OHe in other experiments

In the absence of detailed quantitative description of OHe-nucleus interaction the following qualitative arguments can be given:

- OHe-nucleus binding takes place only for intermediate mass nuclei and it is absent in heavy nuclei, like Xe. It may explain severe constraints of XENON100 searches.
- Radiative capture rate is proportional to the square of OHe-nucleus relative velocity and should be suppressed in cryogenic detectors. It may explain the difference in results of CDMS and CoGeNT.
- Positive effects in CRESST (if any) can be explained by radiative capture by O and C.

EFFECTS OF O-HELIUM IN COSMIC RAYS

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:

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

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

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

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.

Gamma lines from bulge

- If OHe levels with nonzero orbital momentum are excited, gamma lines should be observed from the transitions

$$(n > m)\; E_{nm} = 1.598\,\mathrm{MeV}\,(1/m^2 - 1/n^2)$$

at the level

$$3 \cdot 10^{-4} S_o^{-2} (\mathrm{cm}^2\,\mathrm{s}\,\mathrm{MeV}\,ster)^{-1}$$

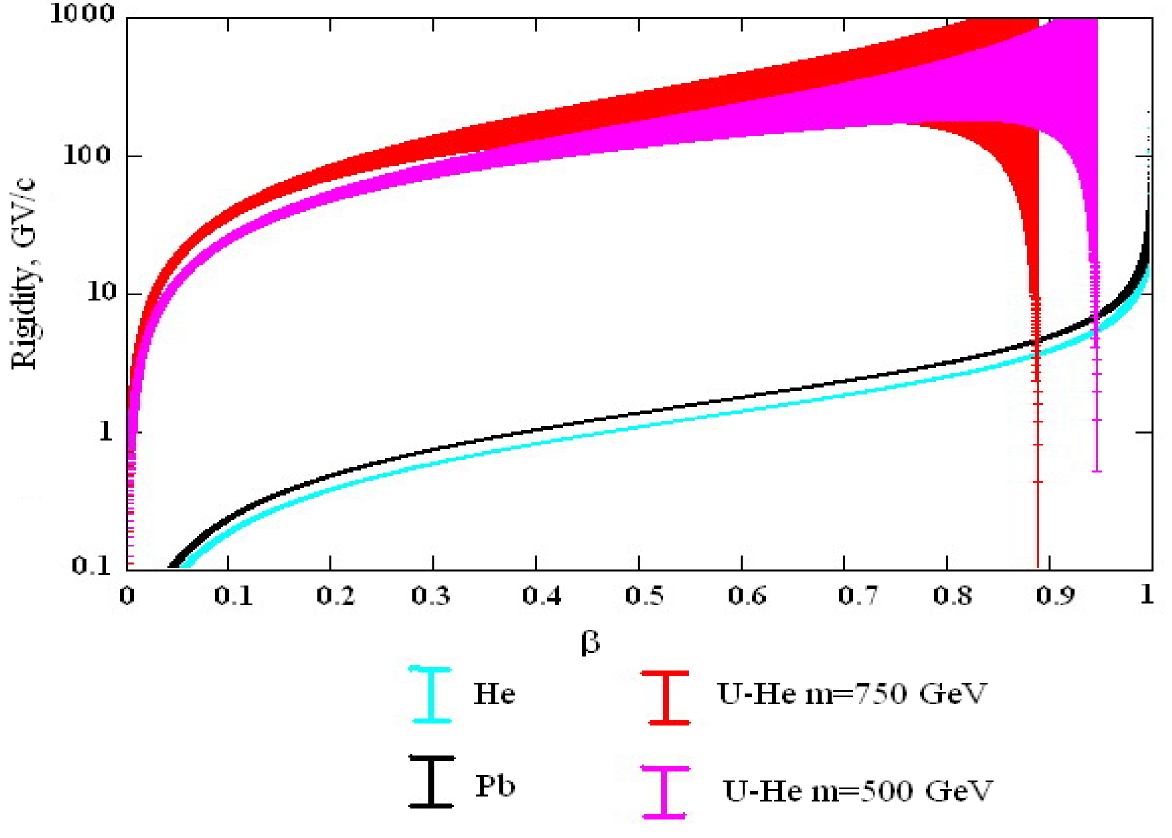
X component of cosmic rays

$$\frac{X^{--}}{^{4}He} \leq 10^{-7}$$

- Galactic cosmic rays destroy O-helium. This can lead to appearance of a free anutium component in cosmic rays.
- OHe captured on the stage of red giants and supergiants can be destroyed in the shock wave of successive supenova explosion and accelerated as normal cosmic rays.

Such flux can be accessible to PAMELA and AMS-02 experiments

Rigidity of X component



Difference in rigidity provides discrimination of X and nuclear component

A solution for cosmic positron excess?

- In WTC: if both technibaryons UU and technileptons ζ are present, CDMS, LUX results constrain WIMP-like (UUζ) component to contribute no more than 0,0001% of total DM density.
- Decays of positively charged UU->$l^+ l^+$ with a lifetime of about $10^{20} s$ and mass 700-1000 GeV can explain the excess of cosmic positrons, observed by PAMELA and AMS02

Cosmic positron excess from DM?

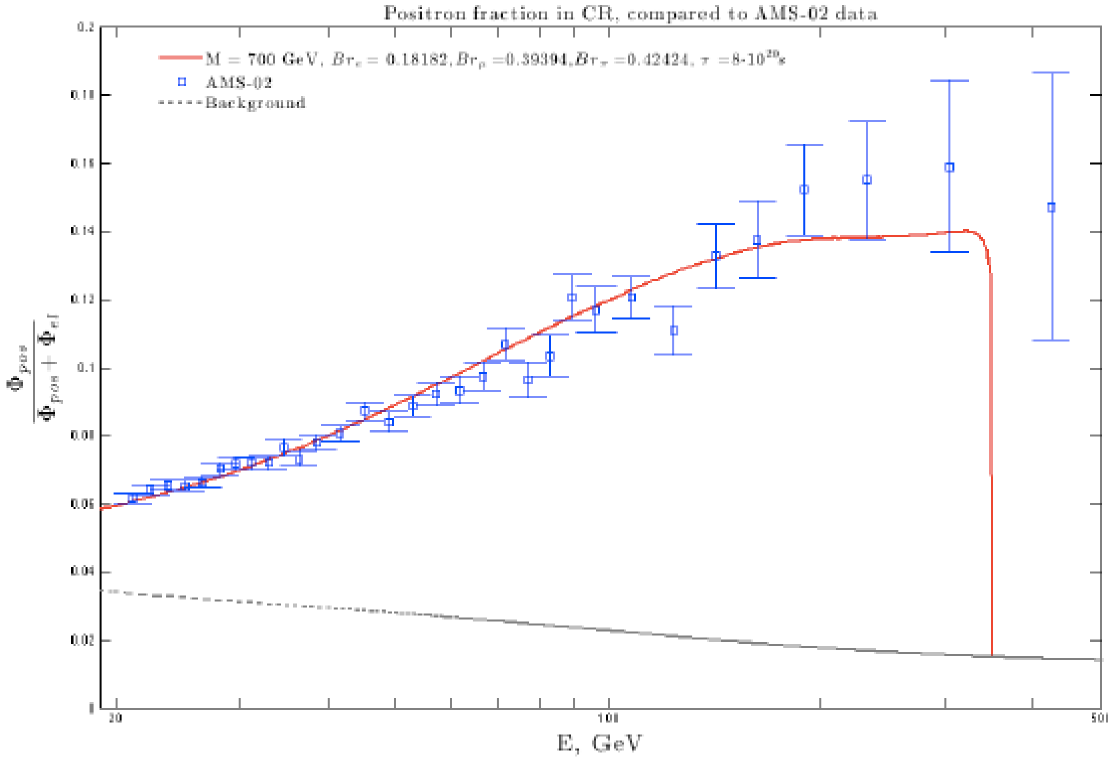
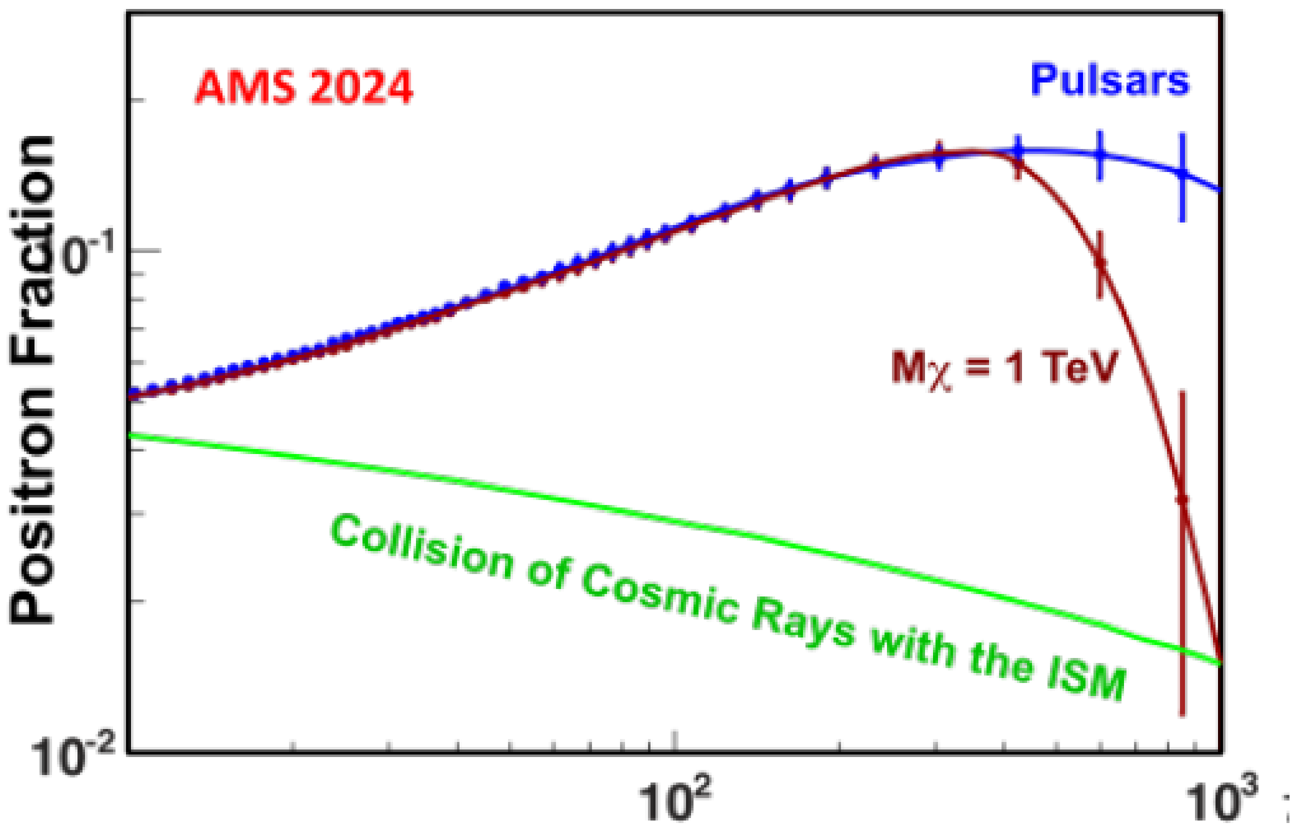


Figure 3: Positron fraction in the cosmic rays from decays of dark matter particles (red curve), corresponding to the best-fit values of model parameters ($M = 700\,\mathrm{GeV}, \tau = 8\cdot 10^{20}\,\mathrm{s}, Br_{ee} = 0.182, Br_{\mu\mu} = 0.394, Br_{\tau\tau} = 0.424$), and fraction of secondary positrons (gray line), compared to the latest AMS-02 data [34] (blue dots).

Probably such indirect effect is detected in the cosmic positron fluxes.

[figure from K.M.Belotsky et al. Int.J.Mod.Phys. D24 (2015) 1545004 arXiv:1508.02881]

AMS02 in the next decade



Presented in CERN on 08.12.2016 by Prof. S.Ting

OPEN PROBLEMS 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 PROBLEM OF POTENTIAL BARRIER

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.

SENSITIVITY OF INDIRECT EFFECTS OF COMPOSITE DARK MATTER TO THE MASS OF THEIR DOUBLE CHARGED CONSTITUENTS

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

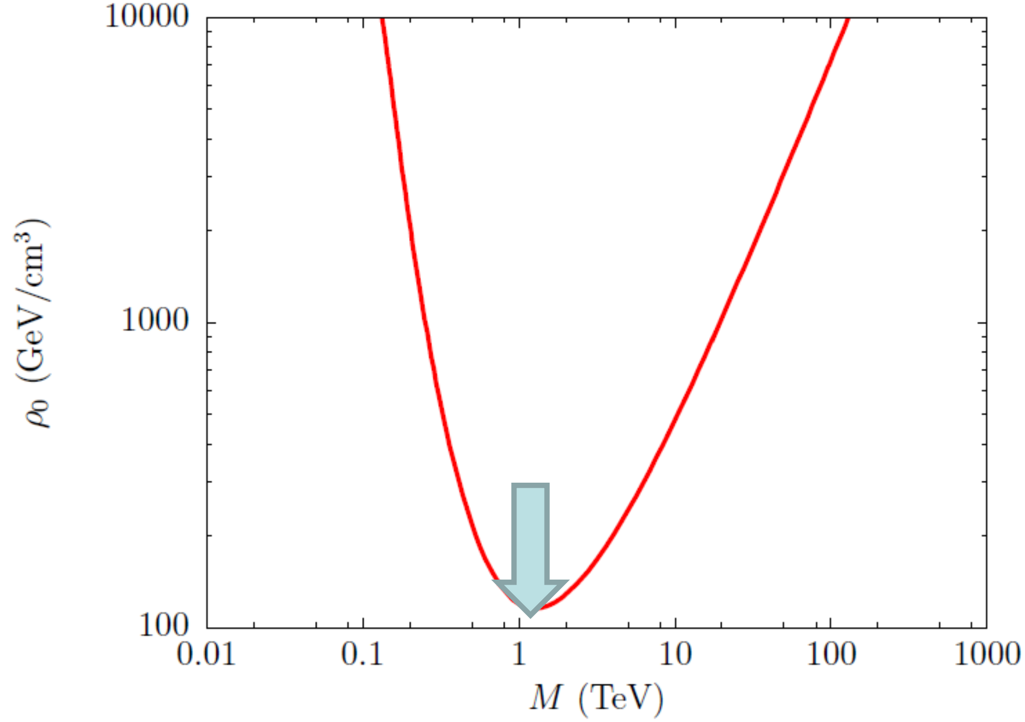


Figure 1: Values of the central dark matter density ρ_0 (GeV/cm^3) and of the OHe mas
M (TeV) reproducing the excess of e^+e^- pairs production in the galactic bulge. Belo
the red curve, the predicted rate is too low.

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

Composite dark matter explanation for low energy positron excess

- In spite of large uncertainty of DM distribution in galactic bulge, where baryonic matter dominates and DM dynamical effects are suppressed, realistic simulations favor lower value of DM central density around $\rho_0 \simeq 115$ GeV/cm^3. Then observed excess of positron annihilation line can be reproduced in OHe model only at the mass of its heavy double charged constituent:
- $$M \simeq 1.25 \text{ TeV}$$

Diffuse Gamma ray background

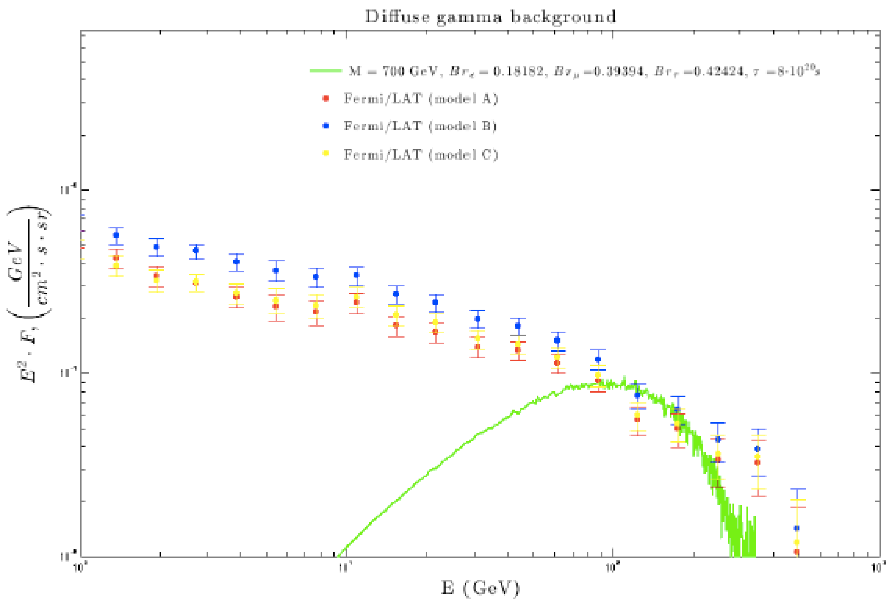


Figure 4: Gamma-ray flux multiplied by E^2 from decays of dark matter particles in the Galaxy and beyond (green curve), corresponding to the best-fit values of model parameters ($M = 700\,\mathrm{GeV}, \tau = 8 \cdot 10^{20}\,\mathrm{s}, Br_{ee} = 0.182, Br_{\mu\mu} = 0.394, Br_{\tau\tau} = 0.424$), compared to the latest FERMI/LAT data on isotropic diffuse gamma-ray background [42] ($|b| > 20°, 0° \leq l < 360°$ with point sources removed and without diffuse emission attributed to the interactions of Galactic cosmic rays with gas and radiation fields (foreground); here three different foreground models A (red dots), B (blue dots) and C (yellow dots) are shown). In our analysis we have used model B.

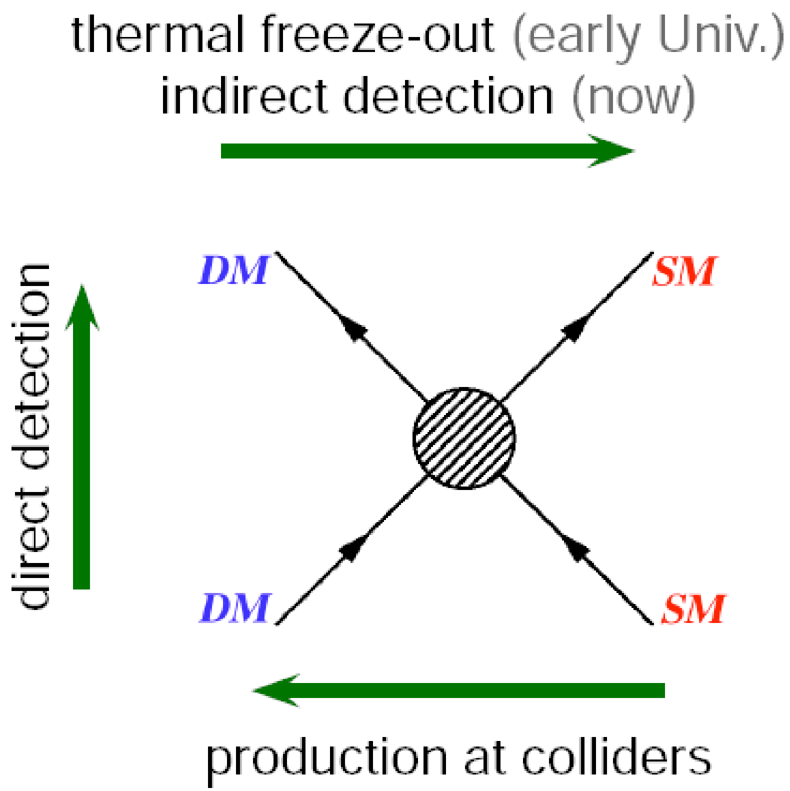
Composite dark matter explanation for high energy positron excess

- Any source of high energy positrons, distributed in galactic halo is simultaneously the source of gamma ray background, measured by FERMI/LAT.
- Not to exceed the measured gamma ray background the mass of decaying double charged particles should not exceed

$$M < 1 \text{ TeV}$$

O-HELIUM CONSTITUENTS AT ACCELERATORS

Complementarity in searches for Dark Matter

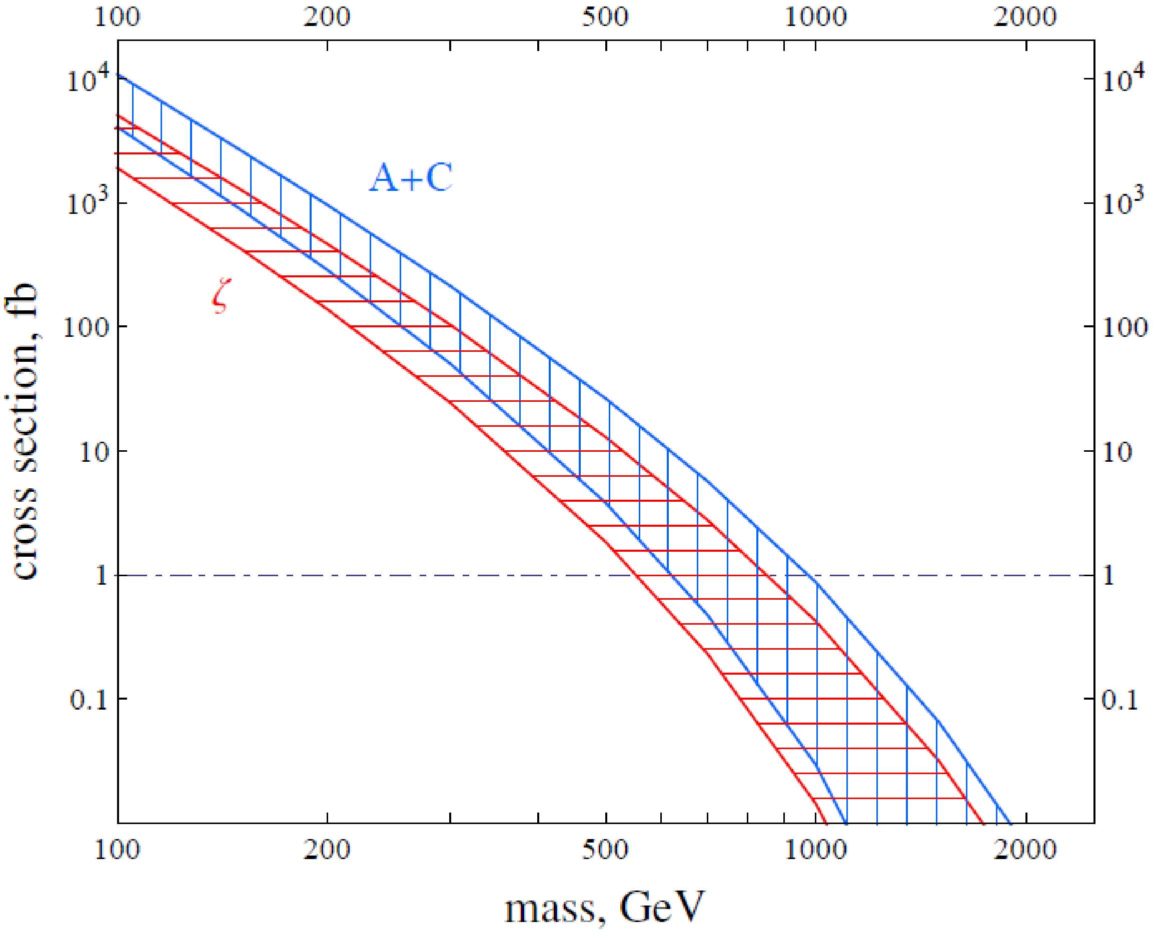


Usually, people use this illustration for complementarity in direct, indirect and accelerator searches for dark matter. However, we see that in the case of composite dark matter the situation is more nontrivial. We need charged particle searches to test dark atom model

Collider test for dark atoms

- Being the simplest dark atom model OHe scenario can not only explain the puzzles of direct dark matter searches, but either explain some possible indirect effects of dark matter. Such explanation implies a very narrow range of masses of (meta-) stable double charged particles in vicinity of 1 TeV, what is the challenge for their search at the current run of the LHC.

LHC discovery potential for charged components of composite dark matter



The shaded strips correspond to production cross sections of technileptons and A,C leptons with Q=2 at 7 teV < $\sqrt{s}$ < 14 TeV

Search for multi-charge particles in the ATLAS experiment

Work is done in a frame of Multi-Charge Analysis Group

Search for Multi-charge Objects in *pp* collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector

K.M. Belotsky[a], O. Bulekov[a], M. Jüngst[b], M.Yu.Khlopov[a,h], C. Marino[c], P. Mermod[d], H. Ogren[e], A. Romaniouk[a], Y. Smirnov[a], W. Taylor[f], B. Weinert[g], D. Zieminska[e], S. Zimmermann[g]

[a]*Moscow Engineering Physics Institute*
[b]*CERN*
[c]*University of Victoria*
[d]*Oxford University*
[e]*Indiana University*
[f]*York University*
[g]*University of Bonn*
[h]*University of Paris*

Our studies favor good chances for detection of multi-charge species in ATLAS detector

ATLAS results at 13 TeV

Phys. Rev. D 99 (2019) 052003
DOI: 10.1103/PhysRevD.99.052003

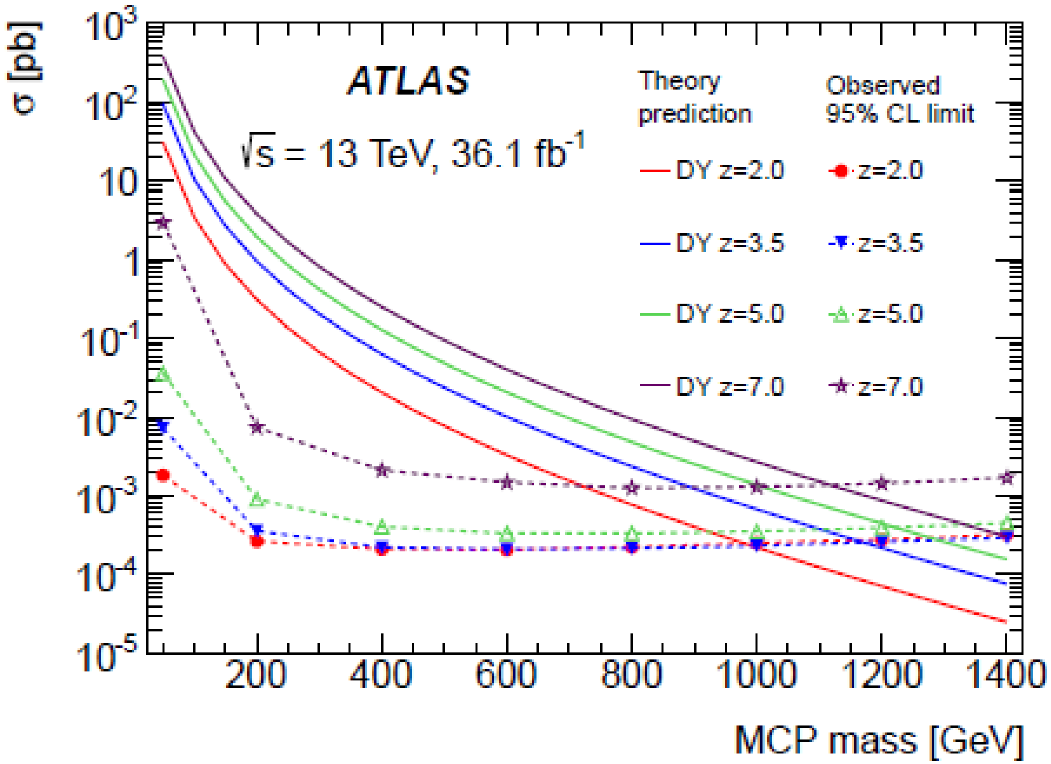
CERN-EP-2018-284
March 18, 2019

Search for heavy long-lived multi-charged particles in proton–proton collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector

The ATLAS Collaboration

A search for heavy long-lived multi-charged particles is performed using the ATLAS detector at the LHC. Data with an integrated luminosity of 36.1 fb^{-1} collected in 2015 and 2016 from proton–proton collisions at $\sqrt{s} = 13$ TeV are examined. Particles producing anomalously high ionization, consistent with long-lived massive particles with electric charges from $|q| = 2e$ to $|q| = 7e$, are searched for. No events are observed, and 95% confidence level cross-section upper limits are interpreted as lower mass limits for a Drell–Yan production model. Multi-charged particles with masses between 50 GeV and 980–1220 GeV (depending on their electric charge) are excluded.

Searches for multiple charged particles in ATLAS experiment



M>980 GeV
for |q|=2e
at 95% c.l.

[ATLAS Collaboration, Search for heavy long-lived multi-charged particles in proton-proton collisions at √ s= 13 TeV using the ATLAS detector. Phys. Rev. D 99, 052003 (2019)

Experimentum crucis for composite dark matter at the LHC

Coming analysis of results of double charged particle searches at the LHC can cover all the range of masses, at which composite dark matter can explain excess of positron annihilation line in Galactic bulge,

|q|/e	z										
	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
Lower mass limit [TeV]	0.98	1.06	1.13	1.17	1.20	1.22	1.22	1.21	1.19	1.16	1.12

Remind that composite dark matter can explain excess of low energy positrons at M=1.25 TeV and high energy positrons at M<1 TeV. The latter is already excluded for double charged constituents.

[ATLAS Collaboration, Search for heavy long-lived multi-charged particles in proton-proton collisions at $\sqrt{s}$= 13 TeV using the ATLAS detector. Phys. Rev. D 99, 052003 (2019)

Conclusions

- New stable quarks and leptons can appear in extensions of Standard Model and exist around us, bound within neutral « atomic » states.

- Composite dark matter can be 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.

- The test for composite dark matter and its constituents is possible in cosmoparticle physics analysis of its signatures and experimental search for stable charged particles in cosmic rays and at accelerators.