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Stable multiple charged constituents of dark atoms

EoI Talk at

EF09 BSM-General: Various Topics

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"WIMP miracle"

- Freezing out of particles with mass of few hundred GeV and annihilation cross section of the order of weak interaction leads to their primordial abundance, which can explain dark matter.
- However direct search for such WIMPs doesn't give positive result, as well as no SUSY particles are detected at the LHC
- It can imply a much wider list of DM candidates and to non-SUSY solutions for SM problems.

From WIMP miracle to DM reality?

- The lack of positive evidence of SUSY particles at the TeV scale may reflect the super high energy SUSY scale.
- Composite Higgs boson is a possibility to solve the SM problems of the origin of EW energy scale and divergence of Higgs boson mass. This solution can be accompanied by the existence of stable multiple charged particles.

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.*

Constituents of composite dark matter

Few possible candidates for -2n charges:

Stable multiple 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

-2 charged Δ-like clusters of heavy (anti-) U quarks (n=1):

•*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

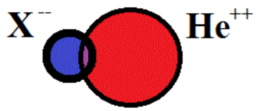
M.Yu.Khlopov, A.G.Mayorov, E.Yu.Soldatov (2010), arXiv:1003.1144

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*

$$T < I_o = 1.6 MeV$$

^{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



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

$$R_o = 2\ 10^{-13}\ cm$$

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]

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 techniparticles will look like stable multiple charged leptons at LHC

References

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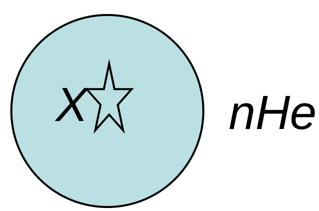
M. Y. Khlopov and C. Kouvaris, Phys. Rev. D 77 (2008) 065002;

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	$\mathbf{2}$	1	0	-1	$\mathbf{-2}$
3	$\mathbf{4}$	3	$\mathbf{2}$	$\mathbf{-4}$	-5
5	$\mathbf{6}$	5	$\mathbf{4}$	-7	$\mathbf{-8}$
7	$\mathbf{8}$	7	$\mathbf{6}$	$\mathbf{-10}$	-11

-2n charged particles in WTC bound with n nuclei of primoridal He form Thomson atoms of XHe



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) dublets (like U quarks of 4th family or stable quarks of 5th family)

O-helium dark matter

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

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

$$T_{RM} = 1eV$$

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

- 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 Warmer than Cold Dark Matter

New component of cosmic ray

- XHe atoms can be captured and ionized in stars and free multiple charged X particles can be accelerated in shocks at SN explosion.
- It leads to creation of a new exotic lepton-like multiple-charged component of cosmic rays.
- The advantage of cosmic ray search for X, as compared with their collider searches is that there is no suppression related with the energy threshold of their formation since they are of primordial origin.

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

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:
- $$M \simeq 1.25 \text{ TeV}$$

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

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

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 also explain some possible observed 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 experiments at the LHC.

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.

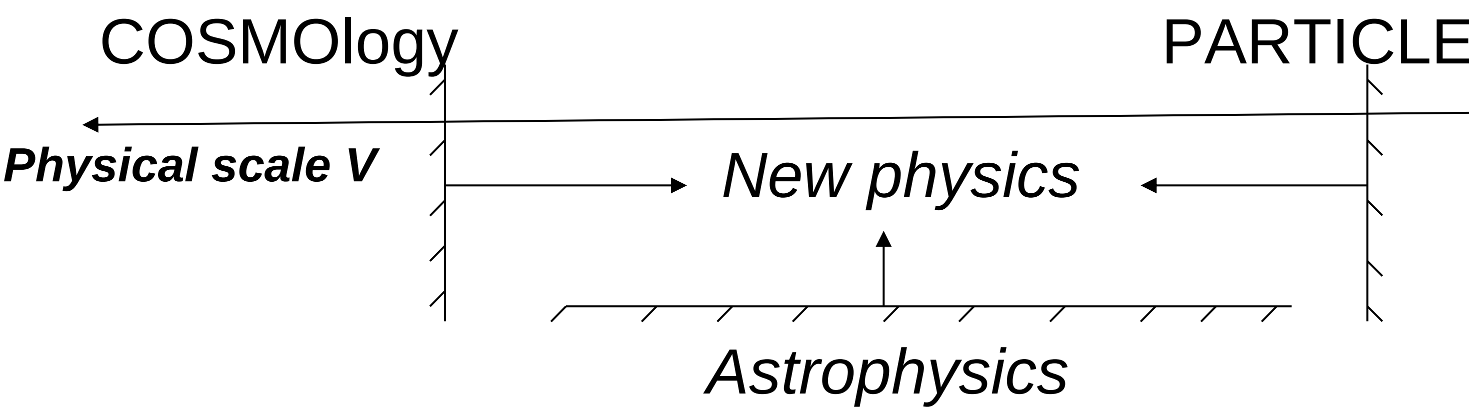
[ATLAS Collaboration, Search for heavy long-lived multi-charged particles in proton-proton collisions at √ s= 13 TeV using the ATLAS detector. Phys. Rev. D 99, 052003 (2019)

Conclusions

- **Dark atom hypothesis is based on non-SUSY solution for the SM problems and involves minimal number of BSM parameters – mass of stable multiple charged particles and their charge.**
- **Observational effects of dark atoms are dominantly determined by their helium shell. However, in the lack of usual approximations of atomic physics (EW interacting shell and small ratio of core/Bohr radii) the description of interaction of helium shell with nuclei involves complicated self-consistent treatment of nuclear attraction and Coulomb repulsion.**
- **The model can explain puzzles of direct dark matter searches and cosmic positron anomalies.**
- **It challenges direct probes at the LHC in search for stable multiple charged particles and in LHAASO experiment by search for EAS from high energy multiple charged leptons.**
- **These probes of new physics reflect the basic ideas of cosmoparticle physics, combining physical, astrophysical and cosmological probes.**

Basic ideas of cosmoparticle physics

- **Physics beyond the Standard model can be studied in combination of indirect physical, astrophysical and cosmological effects**
- **New symmetries imply new conserved charges. Strictly conserved charge implies stability of the lightest particle, possessing it.**
- **New stable particles should be present in the Universe. Breaking of new symmetries implies cosmological phase transitions. Cosmological and astrophysical constraints are supplementary to direct experimental search and probe the fundamental structure of particle theory at the scale V**
- **Combination of physical, cosmological and astrophysical effects provide an over-determined system of equations for parameters of particle theory**



Extremes of physical knowledge converge in the mystical Ouroboros vicious cycle of problems, which can be resolved by methods of Cosmoparticle physics

2021 – UN announced as the A.D.Sakharov’s year

- It may be a good occasion for us to celebrate 100th Anniversary of A.D.Sakharov by new achievements in studies of physics and cosmology beyond the Standard models