New generations of stable quarks and leptons

Lecture from course

“Introduction to Cosmoparticle Physics”

Outlines

- Physical reasons for new stable quarks and/or leptons
- Inevitable overproduction of anomalous isotopes in Glashow’s tera-particle scenario
- Models, predicting stable -2 charged species

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 cosnservation 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.

New stable quarks and leptons:

- *Tera-fermions E and U of S.L.Glashow's*
- *Stable U-quark of 4-th family*
- *AC leptons from almost commutative geometry*
- *Technibaryons and technileptons in Walking Technicolor model*

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

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

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

m~3 TeV, (meta)stable

m~5 TeV, D → U +…

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

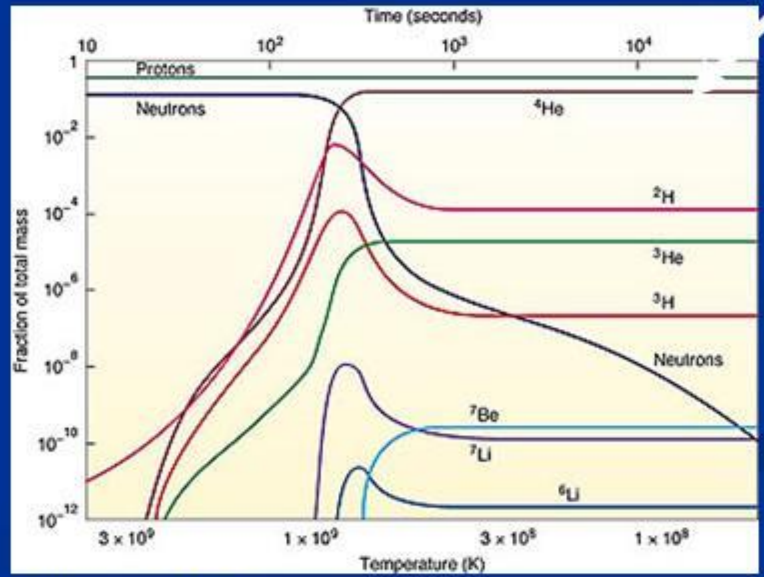
to attract and capture,

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.*

Example 1. 4-th family

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

m~50 GeV, (quasi)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 **ANti-U-Tripple-Ions of Unknown Matter** (anutium).*

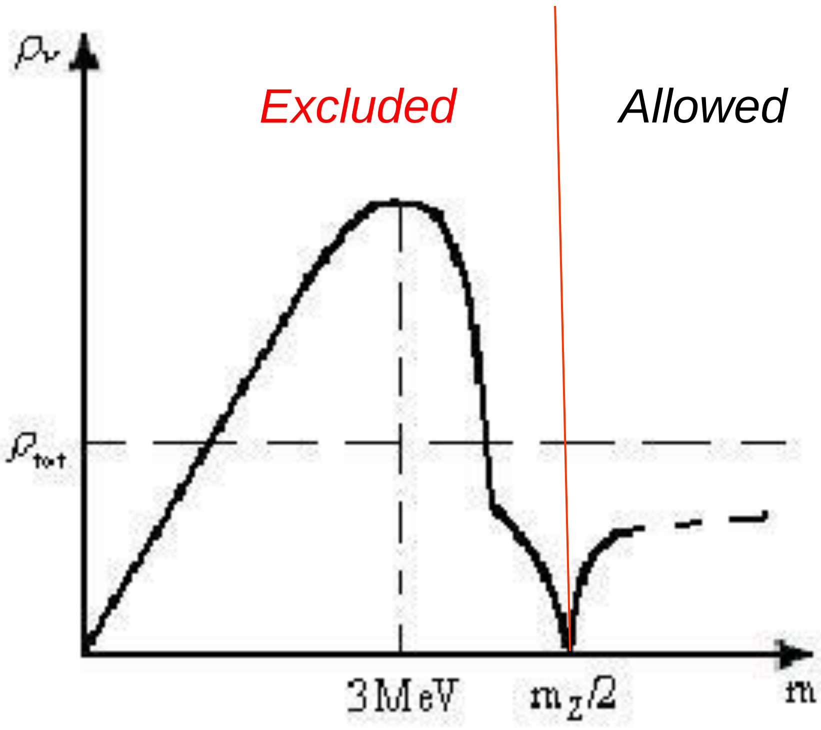
$\Delta^{--}_{\bar{U}\bar{U}\bar{U}} \equiv (\bar{U}\bar{U}\bar{U})$ *can become a -2 charge constituent of composite dark matter*

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.

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.

Stable neutrino of 4th generation



- For $m > 3MeV$ frozen out concentration of massive stable neutrinos decreases as $n_\nu / n_\gamma \propto m^{-3}$ and reaches minimum at $m = m_Z / 2$.
- Measurement of the Z-boson width constrains the mass of 4th neutrino by $m > m_Z / 2$.
- For the allowed range of mass for 4th neutrino, it can not be the dominant form of DM.

Condensation of heavy neutrinos in Galaxy

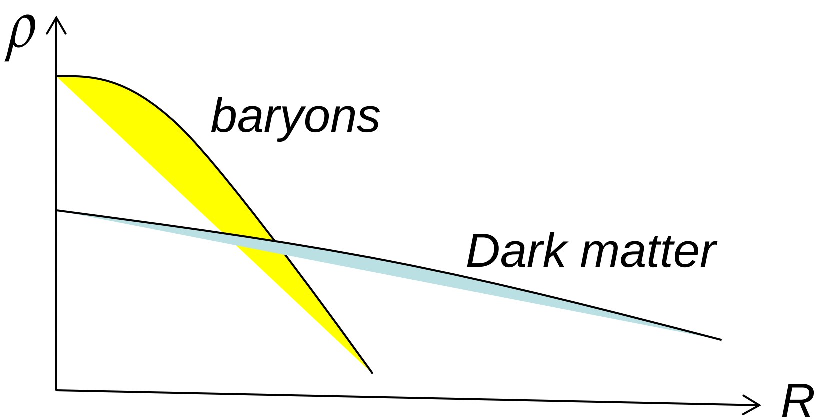
$$\ddot{R} + \omega^2 R = 0$$

$$\omega^2 = 4\pi G(\rho_\nu + \rho_b)$$

$$I = \frac{E(t)}{\omega(t)} = \frac{\omega^2 R^2}{2\omega} = const$$

$$\rho_\nu(t) \propto R^{-3} \propto \omega^{3/2} \propto [\rho_b(t)]^{3/4}$$

$$\rho_\nu(t) \propto [\rho_b(t)]^{3/4}$$



- Motion of collisionless gas in nonstationary field of baryonic matter, contracting owing to dissipation processes, provides effective dissipation and contraction of this gas.
- In result collisionless Dark Matter condences in Galaxy, but it is distributed more steeply, than baryonic matter.
- It gives qualitative explanation for formation of dark matter halo.
- Due to condensation effects of annihilation in Galaxy can be significant even for subdominant component as 4th neutrino.

Example 2: AC-model

Extension of Standard model by two new doubly charged « leptons » $(A^{--} \text{ and } C^{++})$

Form neutral atoms (AC, O-helium,….)-> composite dark matter candidates!

They are leptons, since they possess only γ and Z (and new, y-) interactions

+ follows from unification of General Relativity and gauge symmetries on the basis of almost commutative (AC) geometry (Alain Connes)

+ DM (AC) "atoms"

Mass of AC-leptons has « geometric origin ». Experimental constraint $m_A = m_C = m > 100GeV$

We take m=100GeV S_2

Their charge is not fixed and is chosen +-2 from the above cosmological arguments.

Their absolute stability can be protected by a strictly conserved new U(1) charge, which they possess.

In the early Universe formation of AC-atoms is inevitably accompanied by a fraction of charged leptons, remaining free.

Example 3: WTC-model

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

U and D techniquarks transform under the adjoint representation of an SU(2) technicolor gauge group.

The chiral condensate of the techniquarks breaks the electroweak symmetry.

There are nine Goldstone bosons emerging from the symmetry breaking. Three of them are eaten by the W and the Z bosons. The remaining six Goldstone bosons (UU, UD, DD and their corresponding antiparticles) are technibaryons and corresponding techniantibaryons.

The electric charges of UU, UD, and DD are given in general by y+1, y, and y-1 respectively, where y is an arbitrary real number. To cancel the Witten global anomaly model requires in addition the existence of a fourth family of leptons (ν' and ζ).

Their electric charges are in terms of y respectively (1 - 3y)/2 and (-1 - 3y)/2.

Techniparticle excess

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

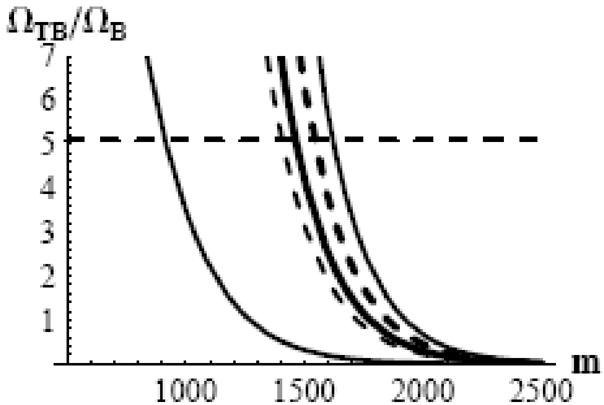
$$\frac{TB}{B} = -\sigma_{UU}\left(\frac{L'}{B}\frac{1}{3\sigma_{\zeta}} + 1 + \frac{L}{3B}\right)$$

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)

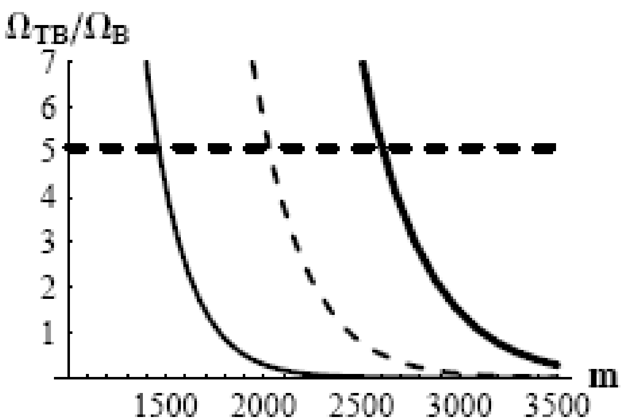
Relationship between TB and B

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



- L'=0, T*=150 GeV

ξ =0.1; 1; 4/3; 2; 3

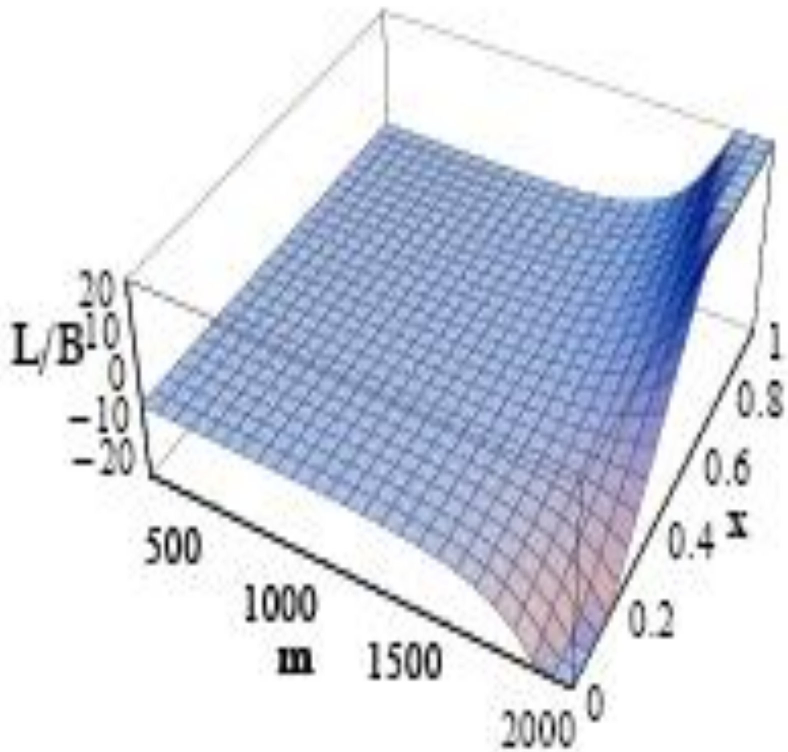


$\xi = 4/3$,

- 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

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

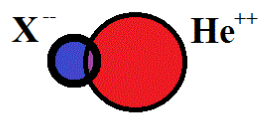
If we have a stable double charged particle *X^{--}* *in excess over its partner* *X^{++}*
it may create Helium like neutral atom (O-helium) at temperature $T > I_o$

Where:

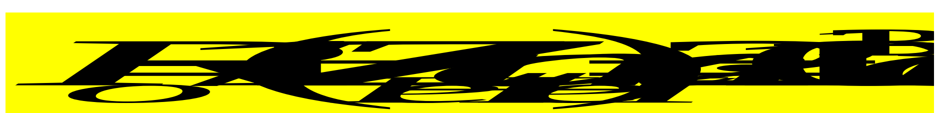
^4He is formed at $T \sim 100$ keV ($t \sim 100$ s)

This means that it would rapidly create a neutral atom, in which all X^{--} are bound

$$X^{--} + {}^4He \Rightarrow (X\,He) + \gamma$$



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



References

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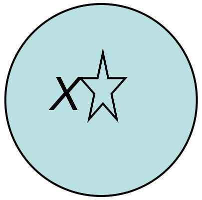
2. D. Fargion, M.Khlopov, C.Stephan, *Class. Quantum Grav.* 23 (2006) 7305;
2. M. Y. Khlopov and C. Kouvaris, *Phys. Rev.* D 77 (2008) 065002]

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



nHe

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.
- It can provide alternative ways to solve the SM problems, like HP, proposed by Andrea.
- Composite Higgs boson is another possibility to solve the SM problems, involving, in particular, stable multiple charged particles.

Conclusions

- New stable quarks and leptons can appear in various extensions of Standard Model.
- The necessary condition is that there should not be -1 charged stable species and positively charged species should be suppressed.
- Existence of -2n charged stable species can lead to their atom-like states with n nuclei of primordial helium – basic element of composite dark matter scenario.