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Cosmological pattern of fundamental physical constants

Presented at **Conference on Precision Physics and Fundamental Physical Constants**

14 September 2012

My presentation at this meeting is possible thanks to

International Virtual Institute of Astroparticle Physics (CosmoVIA)

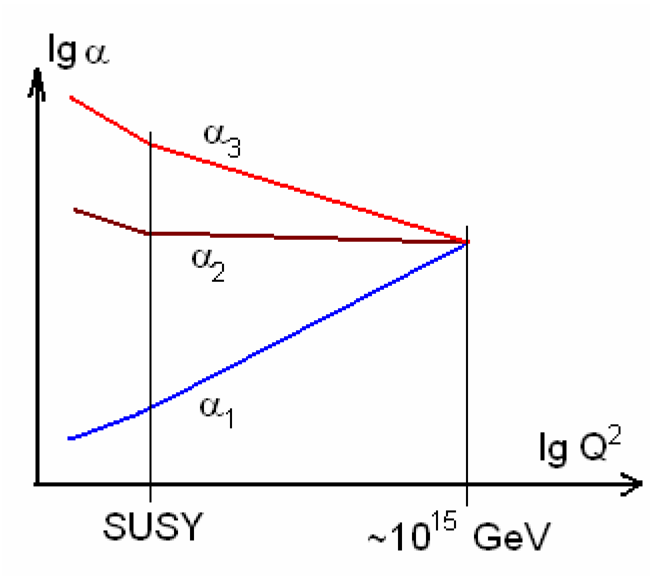
An unique Scientific-Educational complex, a e-science and e-learning tool, supporting regular interactive forms of collaboration in cross-disciplinary study of fundamental relationship between micro- and macro-worlds. Now incorporated in the structure of APC Laboratory, Paris, France

Outlines

- « Ecology » of fundamental physical constants
- Primordial macroscopic objects and structures as cosmological reflection of the fundamental scales of the microworld
- Formation of Cosmological Large Scale structure by Dark Matter. Dark atoms of composite dark matter – a solution for puzzles of dark matter searches?
- Cosmoparticle physics as cross disciplinary study of fundamental relationship of micro- and macro- worlds.

« Ecology » of fundamental physical constants

- **« Running constants » of microworld**



Relativistic effects and quantum corrections change the value of particle « constants » pending on physical conditions and scales (mass defect, renormalization etc).

Owing to particle identity their macroscopic statistical ensembles reflect parameters of individual particles and simulataneously create environment that influences the parameters of particles and fields - QFT at high temperatures and densities.

- **Variation of fundamental constants with time and in space.**

It may reflect cosmological phase transitions or existence of (large?) extra dimensions – branes, RS, ADD…

- **Fundametal constants of microworld determine the patterns of cosmological evolution**

The bedrocks of modern cosmology

Our current understanding of structure and evolution of the Universe implies three necessary elements of Big Bang cosmology that can not find physical grounds in the standard model of electroweak and strong interactions. They are:

- Inflation
- Baryosynthesis
- Dark matter/energy

All these phenomena imply extension of the Standard Model of Strong (QCD) and Electroweak Interactions. On the other hand, studies of physics Beyond the Standard Model involve Cosmology for their probe. It links the global properties of the Universe to fundamental parameters of the new physics.

Cosmological Reflections of Microworld Structure

- In the early Universe at high temperature particle symmetry was restored. Transition to phase of broken symmetry in the course of expansion is the source of topological defects (monopoles, strings, walls…).
- Dark Matter should be present in the modern Universe, and thus be stable on cosmological scale. This stability reflects some Conservation Law, which prohibits DM decay. Following Noether's theorem this Conservation Law should correspond to a (nearly) strict symmetry of microworld. Indeed, all the particles - candidates for DM reflect the extension of particle symmetry beyond the Standard Model.
- These model dependent features make possible to probe the physical basis of the modern cosmology.

PRIMORDIAL OBJECTS AND STRUCTURES FROM EARLY UNIVERSE

Cosmological Phase transitions 1.

- At high temperature $T > T_{cr}$ spontaneously broken symmetry is restored, owing to thermal corrections to Higgs potential

$$V(\varphi, T=0) = -\frac{m^2}{2}\varphi^2 + \frac{\lambda}{4}\varphi^4 \Rightarrow V(\varphi, T) = \left(C\lambda T^2 - \frac{m^2}{2}\right)\varphi^2 + \frac{\lambda}{4}\varphi^4$$

- When temperature falls down below

$$T = T_{cr} \cong \langle \varphi \rangle = \frac{m}{\sqrt{\lambda}}$$

transition to phase with broken symmetry takes place.

Cosmological Phase transitions 2.

- Spontaneously broken symmetry can be restored on chaotic inflationary stage, owing to corrections in Higgs potential due to interaction of Higgs field with inflaton

$$V(\varphi, \psi = 0) = -\frac{m^2}{2}\varphi^2 + \frac{\lambda}{4}\varphi^4 \Rightarrow V(\varphi, \psi) = \left(\varepsilon\psi^2 - \frac{m^2}{2}\right)\varphi^2 + \frac{\lambda}{4}\varphi^4$$

- When inflaton field rolls down below

$$\psi = \psi_{cr} \cong \frac{m}{\sqrt{\varepsilon}}$$

transition to phase with broken symmetry takes place.

Topological defects

- In cosmological phase transition false (symmetric) vacuum goes to true vacuum with broken symmetry. Degeneracy of true vacuum states results in formation of topological defects.
- Discrete symmetry of true vacuum $\langle \varphi \rangle = \pm f$ leads to domains of true vacuum with +*f* and -*f* and false vacuum wall on the border.
- Continuous degeneracy $\langle \varphi \rangle = f \exp(i\theta)$ results in succession of singular points surrounded by closed paths with $\Delta\theta = 2\pi$. Geometrical place of these points is line – cosmic string.
- SU(2) degeneracy results in isolated singular points – in GUTs they have properties of magnetic monopoles.

Primordial Black Holes

- Any object of mass M can form Black hole, if contracted within its gravitational radius.

$$r \le r_g = \frac{2GM}{c^2}$$

- It naturally happens in the result of evolution of massive stars (and, possibly, dense star clusters).
- In the early Universe Black hole can be formed, if expansion can stop within cosmological horizon [Zeldovich, Novikov, 1966]. It corresponds to strong nonhomogeneity in early Universe

$$\delta \equiv \frac{\delta\rho}{\rho} \sim 1$$

PBHs as indicator of early dust-like stages

- In homogeneous and isotropic Universe ($\delta_0 << 1$) with equation of state $p = k\varepsilon$ probability of strong nonhomogeneity $\delta \sim 1$ is exponentially suppressed

$$P(\delta) = A(\delta, \delta_0) \exp\left(-\frac{k^2 \delta^2}{2\delta_0^2} \right)$$

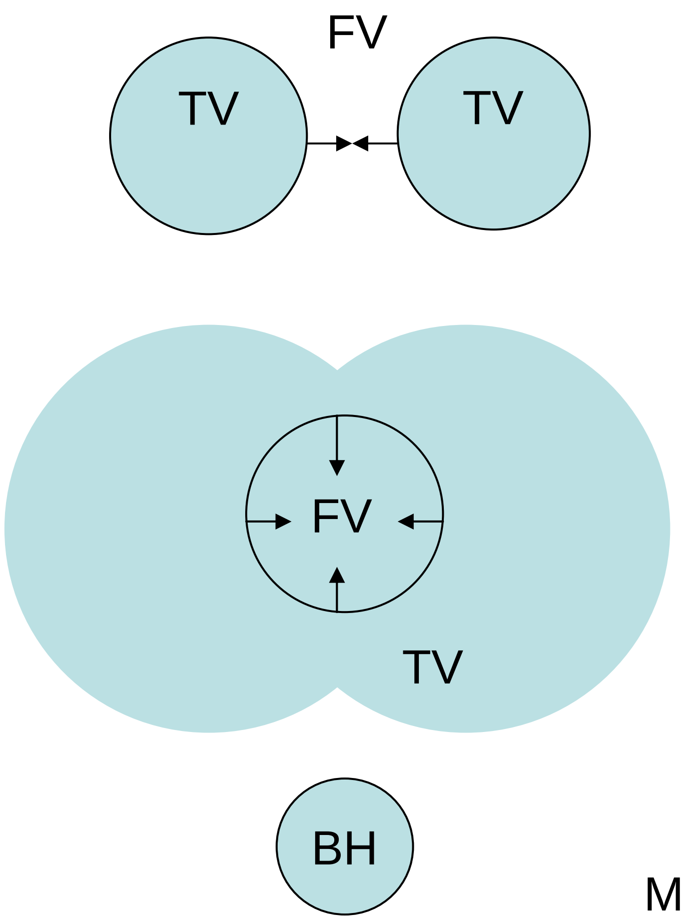
- At *k=0* on dust-like stage exponential suppression is absent. The minimal estimation is determined by direct production of BHs

$$A(\delta, \delta_0) \geq \left(\frac{\delta_0}{\delta} \right)^5 \left(\frac{\delta_0}{\delta} \right)^{3/2} = \left(\frac{\delta_0}{\delta} \right)^{13/2}$$

Dominance of superheavy particles

- Superheavy particles with mass *m* and relative concentration $r = n / n_{\gamma}$ dominate in the Universe at *T<r m.*
- Coherent oscillations of massive scalar field also behave as medium with *p*=0.
- They form BHs either directly from collapse of symmetric and homogeneous configurations, or in the result of evolution of their gravitationally bound systems (pending on particle properties they are like « stars » or « galaxies »).
- PBH spectrum is determined by parameters of particles and/or fields that form PBHs

PBHs as indicator of first order phase transitions



- Collision of bubbles with True Vacuum (TV) state during the first-order phase transition results in formation of False Vacuum (FV) bags, which contract and collapse in Black Holes (BH).

Mass of such PBHs is sharply peaked at the mass within horizon in the period of phase transition

Effects of Primordial Black Holes

- PBHs behave like a specific form of Dark Matter
- Since in the early Universe the total mass within horizon is small, it seems natural to expect that such Primordial Black holes should have very small mass (much smaller, than the mass of stars). PBHs with mass $M < 10^{15}\,g$ evaporate and their astrophysical effects are similar to effects of unstable particles.
- However, cosmological consequences of particle theory can lead to mechanisms of intermediate and even supermassive BH formation.

Strong nonhomogeneities in nearly homogeneous and isotropic Universe

- The standard approach is to consider homogeneous and isotropic world and to explain development of nonhomogeneous structures by gravitational instability, arising from small initial

$$\delta \equiv \delta\rho / \rho << 1$$

- However, if there is a tiny component, giving small contribution to total density,

$\rho_i << \rho$ its strong nonhomogeneity $\delta_i \equiv (\delta\rho / \rho)_i > 1$

is compatible with small nonhomogeneity of the total density

$$\delta = (\delta\rho_i + \delta\rho)/\rho \approx (\delta\rho_i / \rho_i)(\rho_i / \rho) << 1$$

Such components naturally arise as consequences of particle theory, shedding new light on galaxy formation and reflecting in cosmic structures the fundamental structure of microworld.

Strong Primordial nonhomogeneities from the early Universe

- Cosmological **phase transitions** in inflationary Universe can give rise to unstable cosmological defects, retaining a replica in the form of primordial **nonlinear** structures (like massive PBH clusters).
- Strong nonhomogeneities are severely constrained by CMB data at large scales.
- However, their existence at smaller scales is possible.
- Such model dependent consequences provide a sensitive tool to probe physics of very early Universe

U(1) model

$$V(\psi) = \frac{\lambda}{2}\left(\psi^2 - f^2\right)^2$$

After spontaneous symmetry breaking infinitely degenerated vacuum

$$\psi = f e^{i\varphi/f}$$

experiences second phase transition due to the presence (or generation by instanton effects)

$$V(\varphi) = \Lambda^4\left(1 - \cos(\varphi/f)\right)$$

to vacuum states

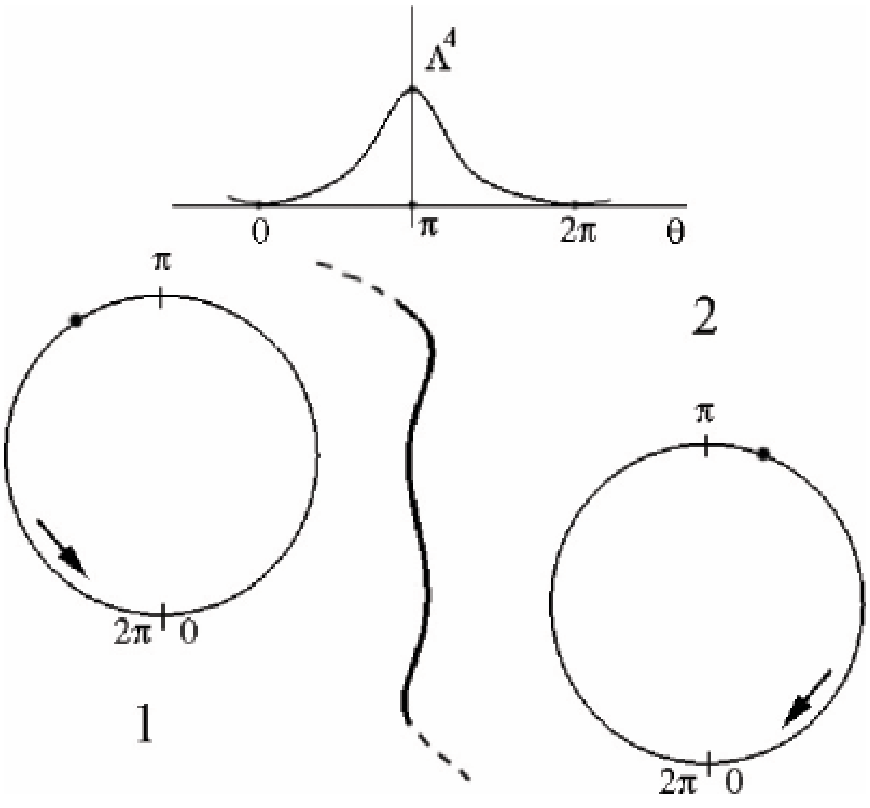
$$\theta \equiv \varphi/f = 0, 2\pi, \ldots$$

In particular, this succession of phase transitions takes place in axion models

Massive Primordial Black Holes

- Any object can form Black hole, if contracted within its gravitational radius. It naturally happens in the result of evolution of massive stars (possibly, star clusters).
- In the early Universe Black hole can be formed, if within cosmological horizon expansion can stop [Zeldovich, Novikov, 1966]. Since in the early Universe the total mass within horizon is small, it seems natural to expect that such Primordial Black holes should have very small mass (much smaller, than the mass of stars).
- However, cosmological consequences of particle theory can lead to mechanisms of intermediate and even supermassive BH formation.

Closed walls formation in Inflationary Universe



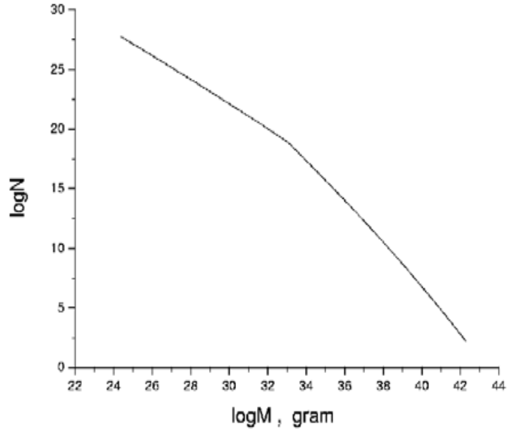
If the first U(1) phase transition takes place on inflationary stage, the value of phase θ , corresponding to e-folding N~60, fluctuates

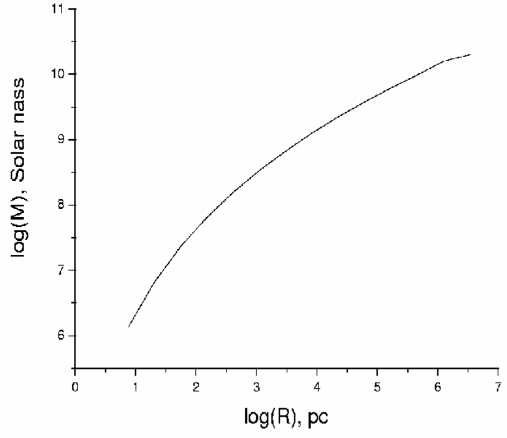
$$\Delta\theta \approx H_{\text{infl}} / (2\pi f)$$

Such fluctuations can cross π

and after coherent oscillations begin,regions with $\theta > \pi$ occupying relatively small fraction of total volume are surrounded by massive walls

Massive PBH clusters





Each massive closed wall is accompanied by a set of smaller walls.

As soon as wall enters horizon, it contracts and collapses in BH.

Each locally most massive BH is accompanied by a cloud of less massive BHs.

The structure of such massive PBH clouds can play the role of seeds for galaxies and their large scale distribution.

Spectrum of Massive BHs

- The minimal mass of BHs is given by the condition that its gravitational radius exceeds the width of wall ($d \approx 2f/\Lambda^2$)

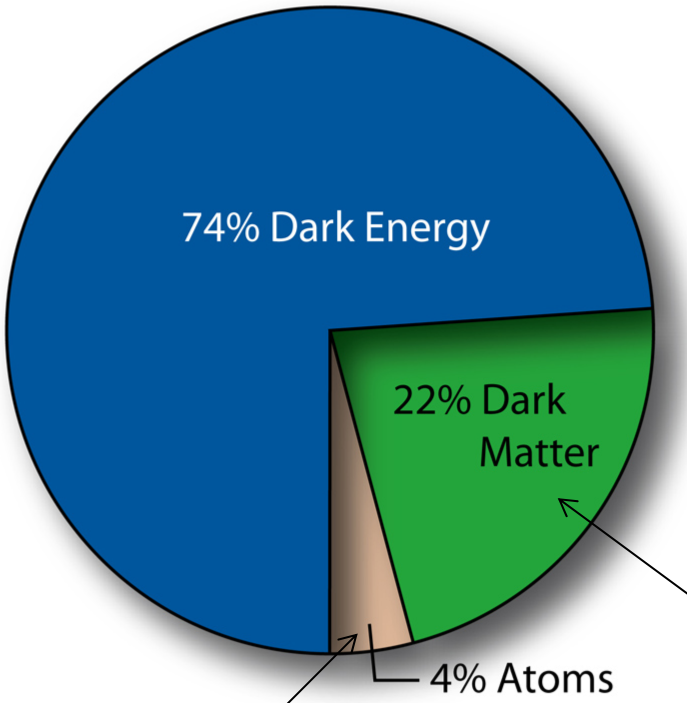
$$r_g = \frac{2M}{m_{Pl}^2} > d = \frac{2f}{\Lambda^2} \Rightarrow M_{\min} = f\left(\frac{m_{Pl}}{\Lambda}\right)^2$$

- The maximal mass is given by the condition that pieces of wall do not dominate within horizon, before the whole wall enters the horizon

$$R < \frac{3\sigma_w}{\rho_{tot}} \Rightarrow M_{\max} = f\left(\frac{m_{Pl}}{f}\right)^2\left(\frac{m_{Pl}}{\Lambda}\right)^2 \Rightarrow \frac{M_{\max}}{M_{\min}} = \left(\frac{m_{Pl}}{f}\right)^2$$

DARK MATTER and PUZZLES OF ITS SEARCHES

Composition of the Universe



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

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

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

$$\Omega_\Lambda \approx 0.7$$

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

Baryonic matter consists of atoms

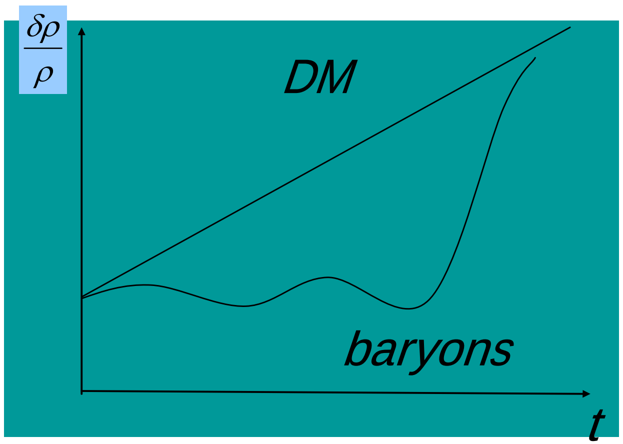
Can dark Matter consist of Dark atoms?

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.

Cosmological Dark Matter



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

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 provides formation of galaxies from small density fluctuations, corresponding to the observed fluctuations of CMB

To fulfil these duties Dark Matter should interact sufficiently weakly with baryonic matter and radiation and it should be sufficiently stable on cosmological timescale.
Scenario of Large Scale structure formation (Cold, Hot, or Warm) is determined by DM particle properties (by particle mass in the Case of Weakly Interacting Massive Particles (WIMPs)

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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Physics Department
Boston University
Boston, MA 02215

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.

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 ***<u>(NO!)</u>***

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

Very heavy and unstable

m~500 GeV, stable

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

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

m~3 TeV, (meta)stable

m~5 TeV, D → U +…

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

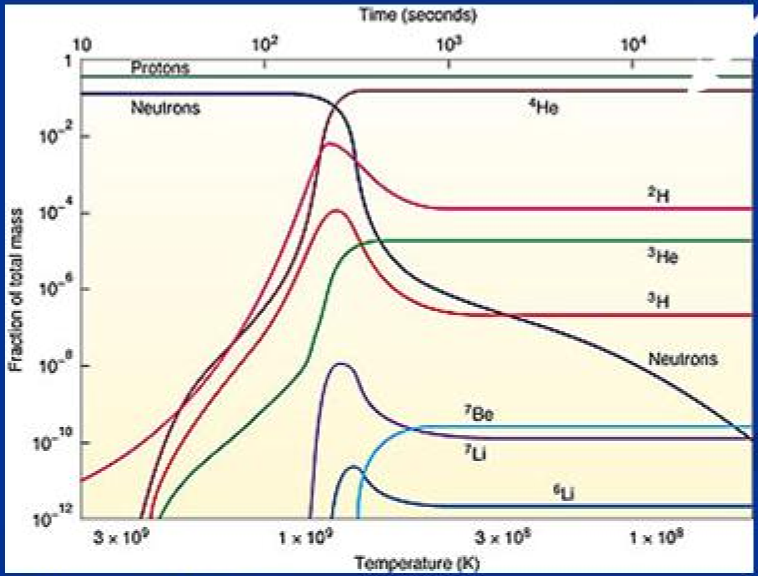
to attract and capture,

E-, fixing it into a hybrid

tera helium "ion" trap.

This takes place during the first

few minutes of the Universe



« 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 -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

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

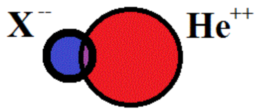
If we have a stable double charged particle X^{--} *in excess over its partner* X^{++} *it may create* *Helium like neutral atom (O-helium) at temperature* $T > I_o$

Where:

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

^{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.

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

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

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

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

$$T_{RM} = 1eV$$

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

- 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

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

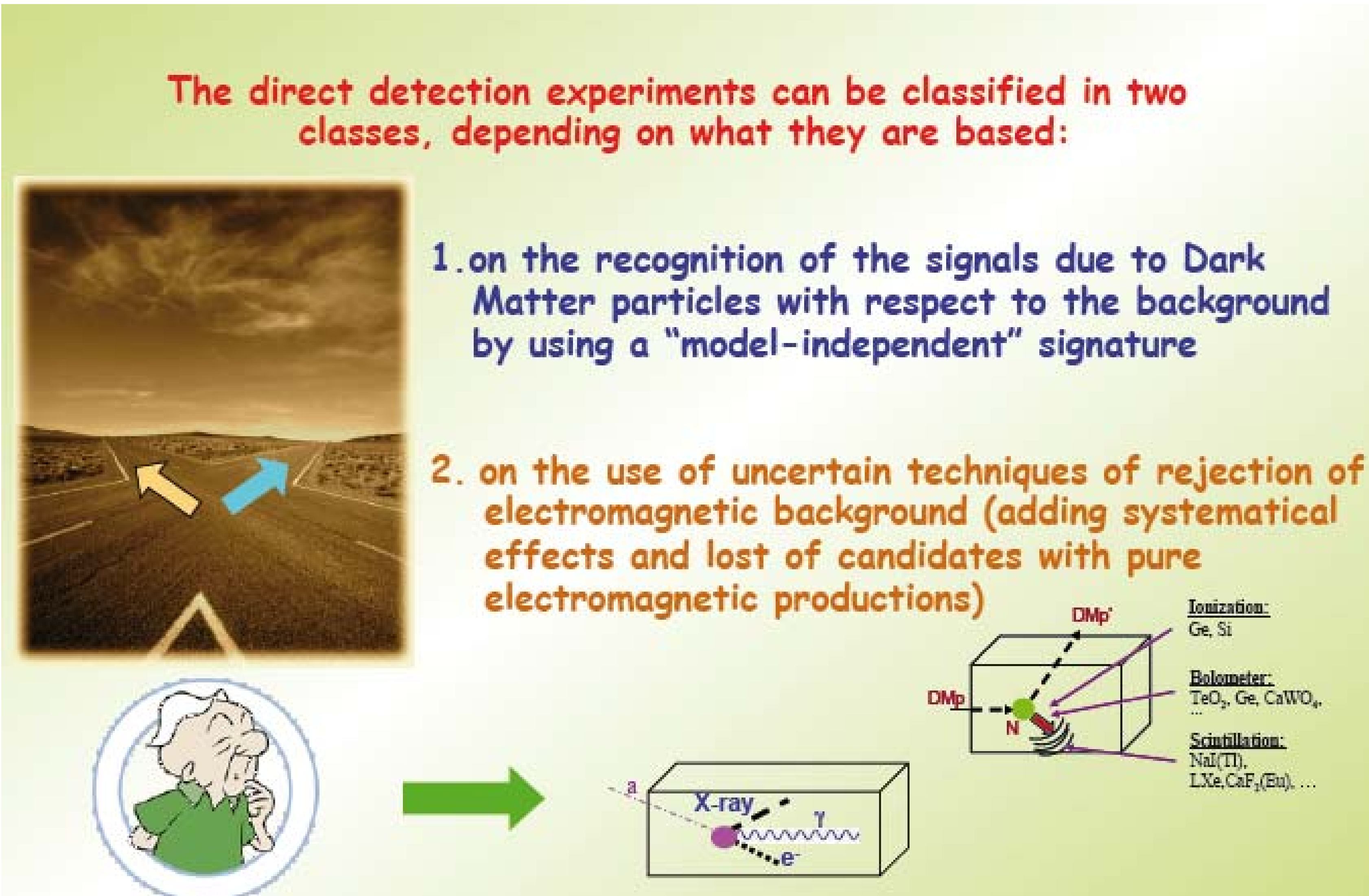
Here $A_{med} \sim 30$ is the average atomic weight in terrestrial surface matter, $n = 2.4 \cdot 10^{24}/A_{med}$ is the number of terrestrial atomic nuclei, σv is the rate of nuclear collisions and $g = 980 \text{ cm/ s}^2$.

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.

Direct Dark Matter search

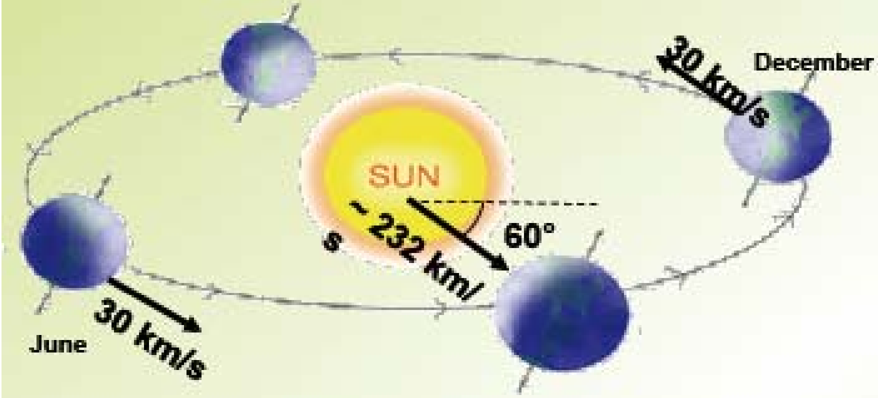


[P.Belli. Invited talk at XV Bled Workshop, 2012]

The annual modulation: a model independent signature for the investigation of Dark Matter particles component in the galactic halo

With the present technology, the annual modulation is the main model independent signature for the DM signal. Although the modulation effect is expected to be relatively small a suitable large-mass, low-radioactive set-up with an efficient control of the running conditions can point out its presence.

Drukier, Freese, Spergel PRD86
Freese et al. PRD88



- v_{sun} ~ 232 km/s (Sun velocity in the halo)
- v_{orb} = 30 km/s (Earth velocity around the Sun)
- $\gamma = \pi/3$, $\omega = 2\pi/T$, T = 1 year
- t_0 = 2nd June (when $v_\oplus$ is maximum)

$$v_\oplus(t) = v_{sun} + v_{orb} \cos\gamma \cos[\omega(t-t_0)]$$

$$S_k[\eta(t)] = \int_{\Delta E_k} \frac{dR}{dE_R} dE_R \cong S_{0,k} + S_{m,k} \cos[\omega(t-t_0)]$$

Expected rate in given energy bin changes because the revolution motion of the Earth around the Sun, which is moving in the Galaxy

Requirements of the annual modulation

1) Modulated rate according cosine
2) In a definite low energy range
3) With a proper period (1 year)
4) With proper phase (about 2 June)
5) Just for single hit events in a multi-detector set-up
6) With modulation amplitude in the region of maximal sensitivity must be <7% for usually adopted halo distributions, but it can be larger in case of some possible scenarios

To mimic this signature, spurious effects and side reactions must not only - obviously - be able to account for the whole observed modulation amplitude, but also to satisfy contemporaneously all the requirements

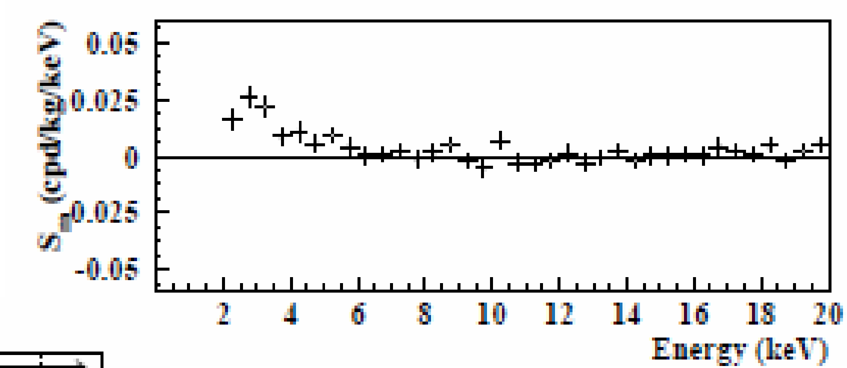
The DM annual modulation signature has a different origin and peculiarities (e.g. the phase) than those effects correlated with the seasons

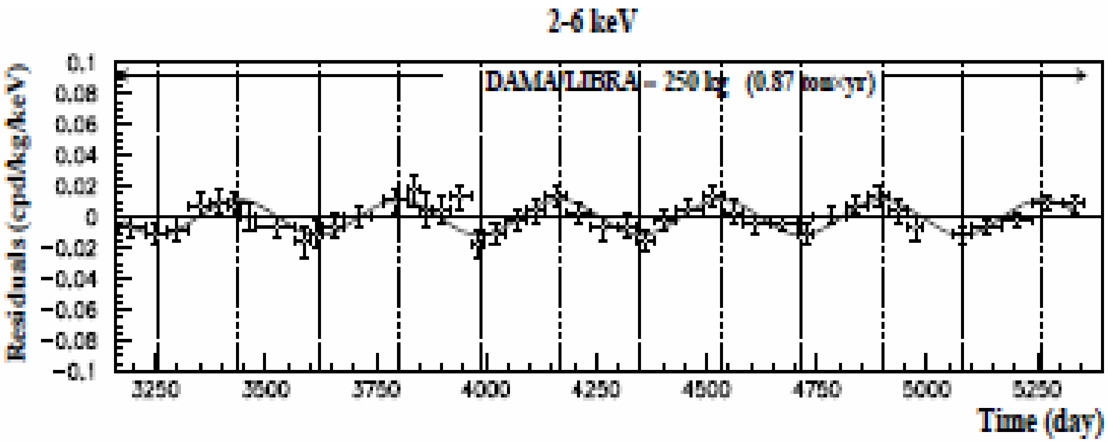
[P.Belli. Invited talk at XV Bled Workshop, 2012]

Direct search for DM (WIMPs)

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

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

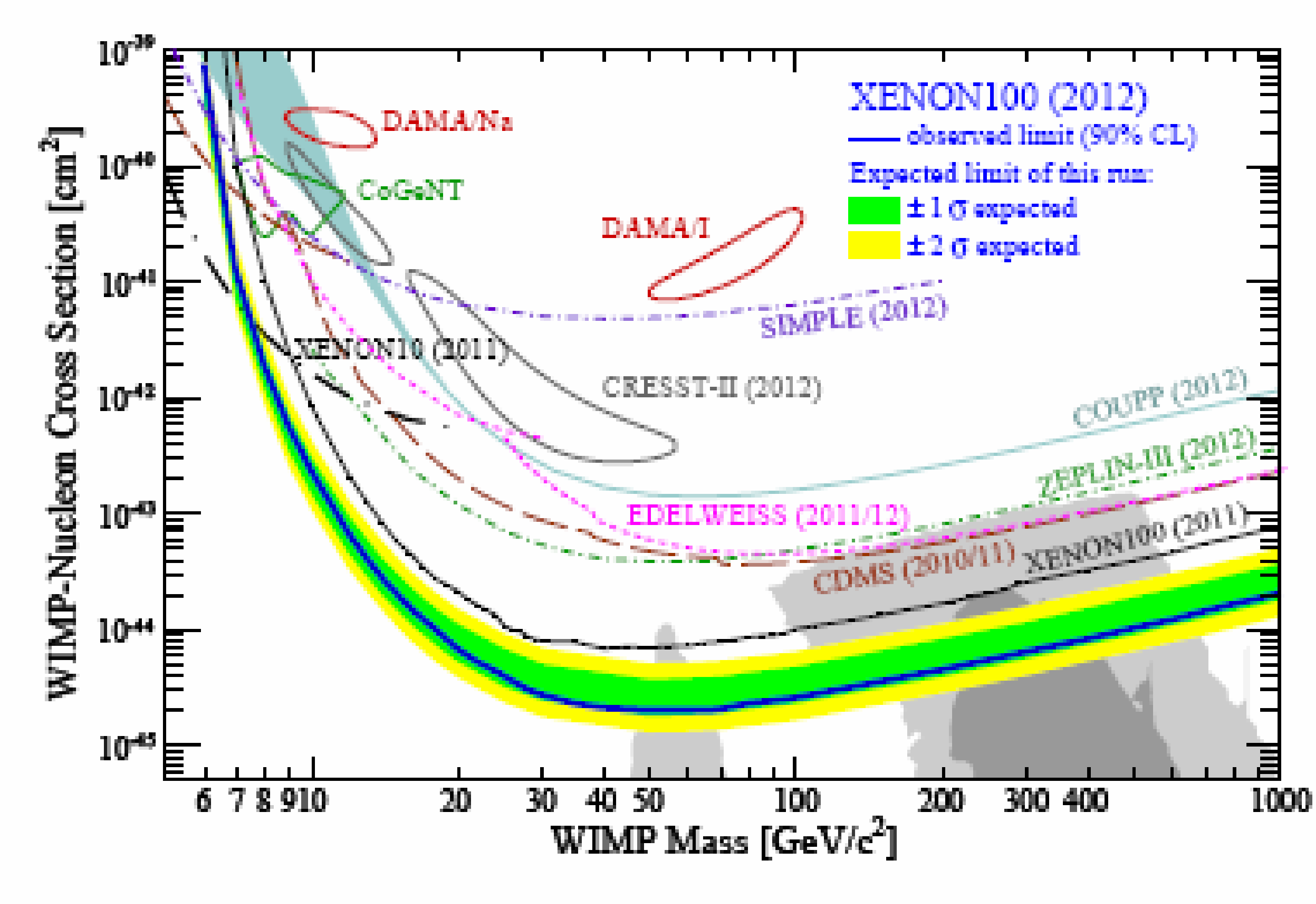




Confidence level 8.9

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

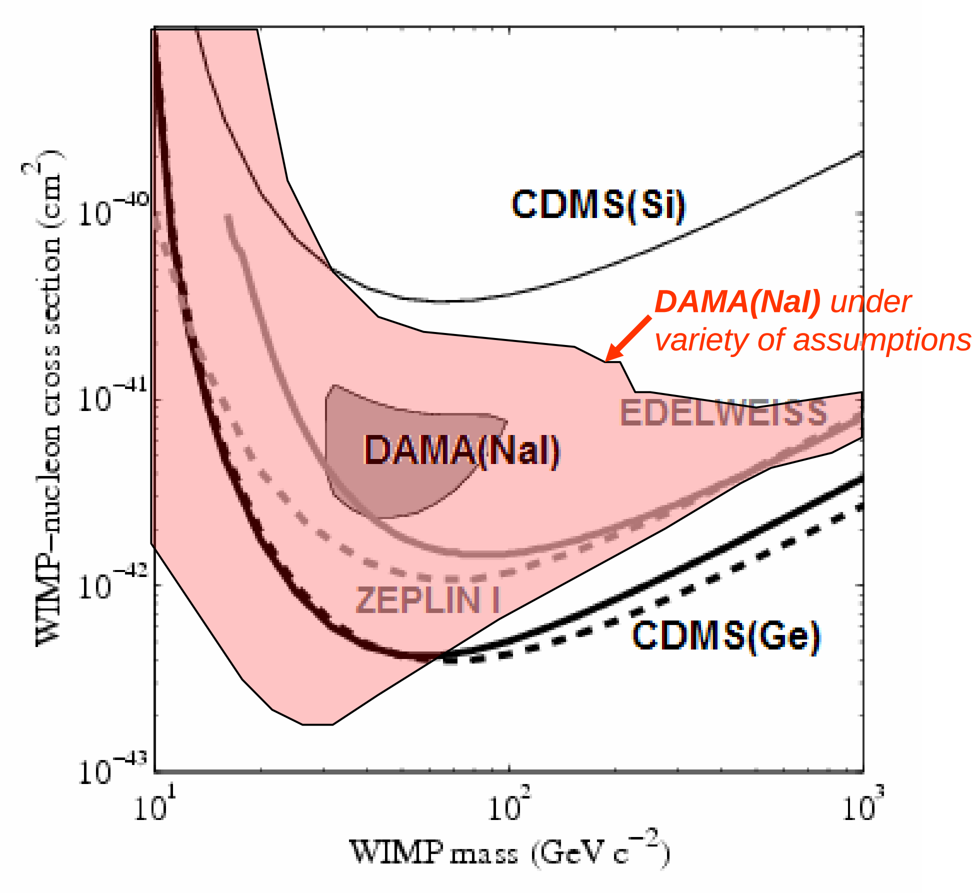
Direct searches for WIMPs



XENON100 Collaboration arXiv:1207.5988

Direct search for WIMPs

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



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 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 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

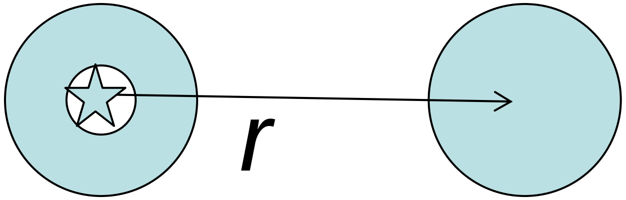
$$OHe + (A,Z) \Rightarrow [OHe(A,Z)] + \gamma$$

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

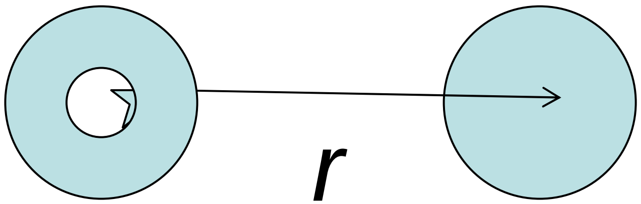
→

- 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

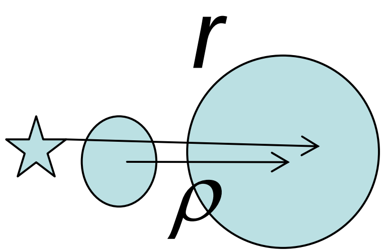
Potential of OHe-nucleus interaction



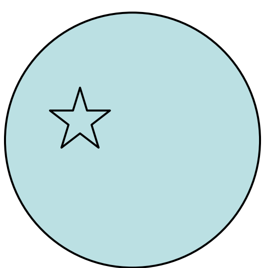
$$U_{Xnuc} = -2Z\alpha\left(\frac{1}{r} + \frac{1}{r_o}\right)\exp\left(-2r/r_o\right)$$



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

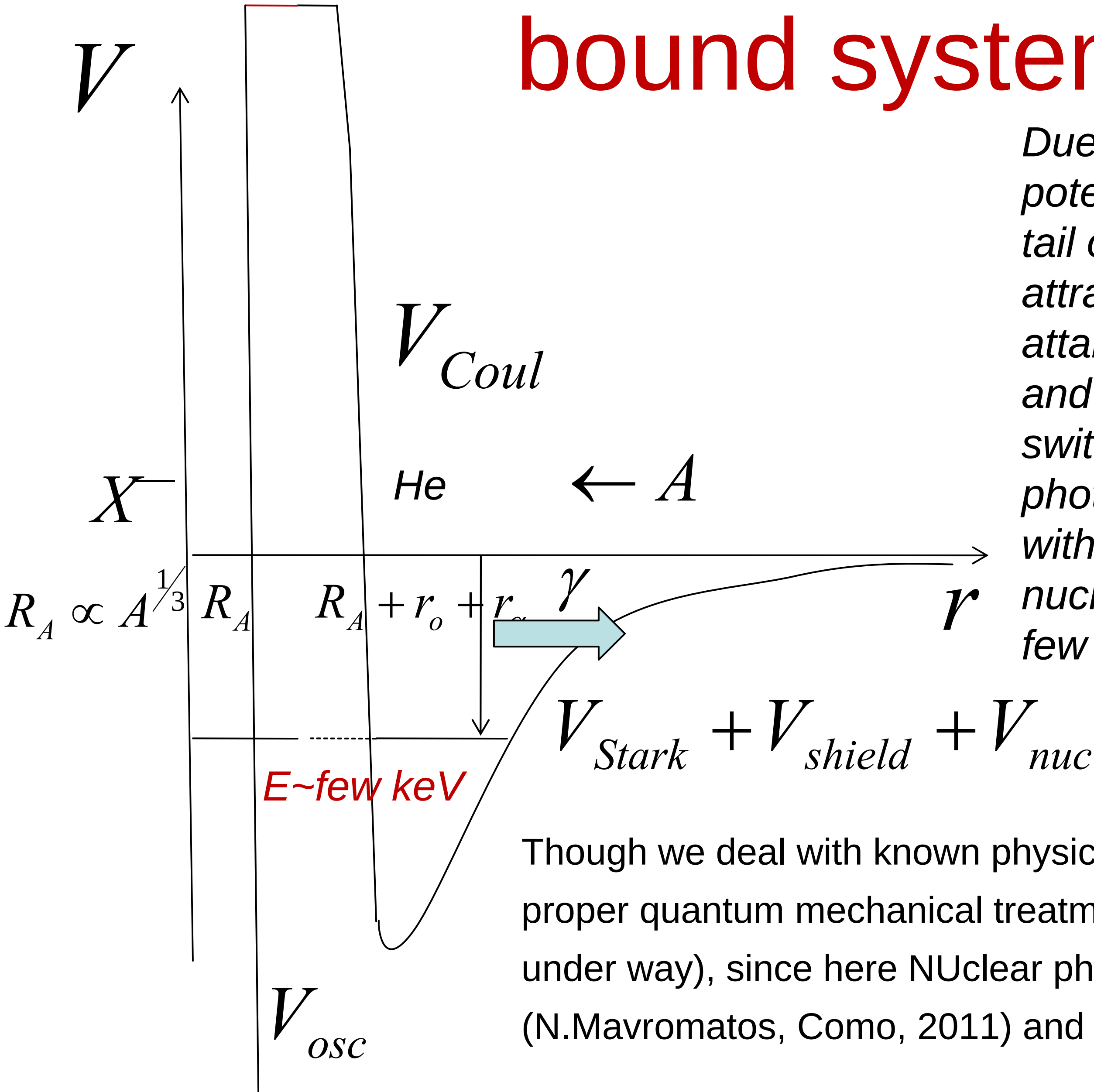


$$U_{Coul} = +\frac{2\alpha Z}{\rho} - \frac{2\alpha Z}{r}$$



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

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.*

Though we deal with known physics, it is not so easy to make proper quantum mechanical treatment of the problem (which is now under way), since here NUclear physics appears as UNclear physics (N.Mavromatos, Como, 2011) and needs clarifying.

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

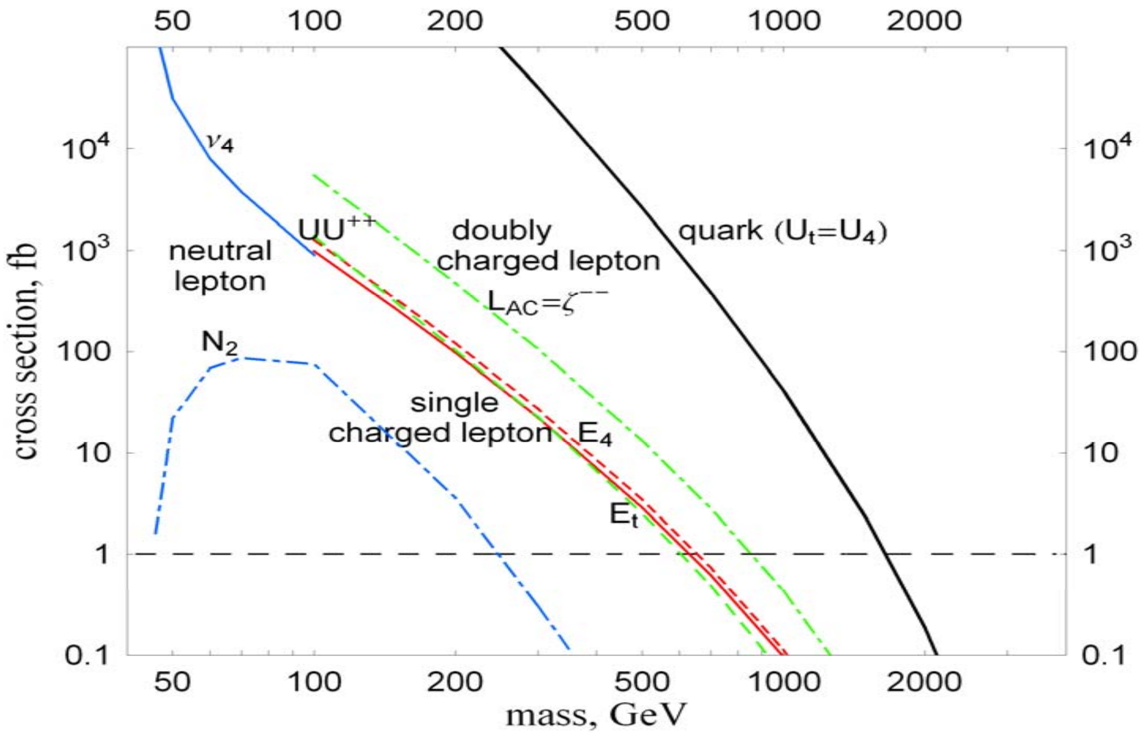
The amplitude of annual modulation of ionization signal (measured in counts per day per kg, cpd/kg) is given by

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

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

$$E_{Na} = 3keV$$

LHC discovery potential for components of composite dark matter



- In the context of composite dark matter search for new (meta)stable quarks and leptons acquires the meaning of crucial test for its basic constituents
- The dashed level of 1 fb corresponds to the LHC sensitivity during the next 2 years of operation

Conclusions

- The fundamental structure of microworld can be linked to cosmological structures reflecting the fundamental relationship between micro- and macro worlds.
- Primordial cosmic structures (cosmological defects, PBHs, massive PBH clouds) reflect the parameters of superhigh energy particles and fields and provide the sensitive tool to determine these parameters.
- Parameters of dark matter particles determine the fundamental scale of Large Scale structure formation.
- Dark matter can be in the form of nuclear interacting O-helium « atoms », which can explain the puzzles of direct dark matter searches.
- Determination of fundamental parameters of new physics is possible in cross disciplinary cosmoparticle physics analysis of their physical, cosmological and astrophysical effects.

Basic ideas of cosmoparticle physics in studies of New Physics, underlying Modern Cosmology

- 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
- Combination of physical, cosmological and astrophysical effects provide an over-determined system of equations for parameters of particle theory

COSMOlogy PARTICLE PHYSICS

Physical scale

→ *New physics* ←

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