The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2036-11

# International Workshop: Quantum Chromodynamics from Colliders to Super-High Energy Cosmic Rays

*25 - 29 May 2009*

**Black Holes, Low Scale Gravity.....**

A.D. Dolgov
*ITEP, Moscow, Russia & INFN*
*Ferrara*
*Italy*

# Black Holes, Low Scale Gravity, and Nonconservation of Global Quantum Numbers in Particle Physics and Cosmology


## A.D. Dolgov

*ITEP, 117218, Moscow, Russia*
*INFN, Ferrara 40100, Italy*
*University of Ferrara, Ferrara 40100, Italy*


## ICTP, Trieste

## May, 25-29

**Based on the works:**

C. Bambi, A.D. Dolgov, K. Freese, JCAP 0704, 005, 2007;
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**Evaporation of classical black holes (BHs) does not respect conservation of any global quantum number.**
**BH hairs: mass, angular momentum, and electric charge.** **All other quantum numbers are not observable and disappear at evaporation.**

**E.g. BH made of baryons decays into (almost) equal number of baryons and anti-baryons.**
**If C and CP are violated, small cosmological baryon asymmetry could be generated by BH evaporation (Ya.B. Zeldovich, AD) with conserved baryonic number in fundamental Lagrangian.**

**In massive electrodynamics electric field outside BH would disappear and charged BH would decay into electrically neutral state.**

**If photons are (a little) massive, the universe must be electrically charged, even if electric current is strictly conserved in microscopic theory.**

**Proton decay, Zeldovich (1975), due to formation of a virtual BH:**

$$\tau_p \sim \frac{M_{Pl}^4}{m_N^5} \approx 10^{45}\, years \left(\frac{M_{Pl}}{10^{19}\, GeV}\right)^4.$$

**If the fundamental gravity scale is TeV:**

$$\tau_p \sim 10^{-12}\, s.$$

**Does it kill TeV gravity or there are ways out?**

**Estimate, F. Adams et al:**

$$M_* > 10^{16} GeV.$$

**Possible solution: BHs with $Q \neq 0$ and $J \neq 0$ cannot be formed classically if $M_{BH} < M_{Pl}$. Postulate that it is true for quantum BHs.**

**Wild hypothesis but many interesting predictions. Proton life-time may be shifted above the experimental upper bound and non-conservation of $B$, $L_{tot}$, $L_a$ $(a = e, \mu, \tau)$ may be observable with mild increase of the existing experimental precision.**

## CONTENT

1. Baryogenesis in normal gravity and non-conservation of B by classical BHs.
Baryogenesis demands new physics beyond MSM, but is possible in MSM with TeV gravity.
2. Electrogenesis by classical BHs.
3. Rare processes in particle physics with TeV gravity, induced by virtual black holes.
4. Baryogenesis in TeV gravity with classical and quantum BHs.
5. Abundant antimatter in the Galaxy.

**What do we know about Q, L, and B nonconservation?**

**In the standard theory electric charge is most probably conserved.**

**If $m_\gamma = 0$, then $\partial J = 0$.**

**If $m_\gamma \neq 0$, then $\partial J \neq 0$ is possible but theory is infrared pathological.**

**No experiment in favour to Q nonconservation.**

**It is easy to break B and L conservation theoretically.**
**"Experimentally" established that neither baryonic nor individual leptonic numbers are conserved.**

**Neutrino oscillations mix electronic-muonic-tauonic neutrinos.**

**Astronomy proves that baryon number is not conserved.**

**Half a century ago: we exist, ergo baryons are conserved.**

**Now: we exist, so baryons are not forever.**

**The same fact but opposite conclusions - necessity of theory for interpretation of what we see.**

## Cosmological/astronomical data in favour of baryon nonconservation.

**I. Inflation is an "experimental" fact.**

**1. We do not know any other way to make the observed universe.**

**2. It explains the origin of expansion.**

**3. It solves the problems of homogeneity, isotropy, flatness and predicts $\Omega = 1$.**

**4. Makes density perturbations with the observed spectrum.**

**II. Inflation is impossible with conserved baryons.** Otherwise energy density could be constant at most during 4-5 Hubble times.
**We need at least 60.**

**OBSERVATIONS:**

**1. Baryon asymmetry is non-zero:**

$$\beta_B = N_B/N_\gamma = 6 \cdot 10^{-10}$$

**Large fluctuations of $\beta$ at small scales and even $\beta < 0$ (antimatter) are allowed theoretically and observationally.**

**2. Lepton asymmetry, not yet observed, may be non-zero and even large:**

$$\beta_L = N_L/N_\gamma \leq 0.1\,.$$

**This bound makes lepton asymmetry insignificant cosmologically, obtained from BBN because of LMA solution. If neutrinos are coupled to majoron, $\beta_L \sim 1$ is allowed.**
**Theoretically natural: $\beta_L \sim \beta_B$ but much larger one is possible.**

**3. Electric asymmetry is usually assumed to be identically zero.**

**Reasons for that:**

**1. Conservation of electric current.**

**2. Zero photon mass and long range Coulomb force.**

**Observational bounds are very strong but may be questionable.**

**Sakharov's conditions for generation of cosmological charge asymmetry:**

1. **Charge nonconservation.**
2. **C and CP violation.**
3. **No thermal equilibrium.**

**None is obligatory.**

## ELECTROGENESIS.

**If the photon mass is very small but non-vanishing, electric asymmetry of the universe MUST be generated, even if electric current is conserved,**

$$\partial J = 0$$

**Observational bounds are obtained for massless photons and may be invalid.**

**Standard Maxwell electrodynamics with massless photons:**

$$\partial_\mu F^\mu_\nu = 4\pi J_\nu$$

**Current $J_\nu$ is automatically conserved, because**

$$\partial_\mu \partial_\nu F^{\mu\nu} \equiv 0.$$

**Gauss law:**

$$div E = 4\pi\sigma$$

**If charge density $\sigma$ is homogeneous, E is a rising function of space point:**

$$E \sim x,$$

**kills isotropy and homogeneity.**
**Chaotic electric fields in causally non-connected parts!?**

**For an open universe the total electric charge $Q_{tot}$ might be non-zero, but $\sigma = 0$.**
**For a closed universe $Q_{tot} = 0$, due to the Gauss theorem.**
**Closed sections of DS must be electrically neutral.**

All change for non-zero photon mass. Current nonconservation is possible:

$$(D^2 + m_\gamma^2)A_\mu = 4\pi J_\mu \,,$$

leading to $D_\mu A^\mu \neq 0$ and longitudinal photons (if Proca equation is fulfilled).

**A very strong experimental upper bound on the photon mass,**

$$m_\gamma < 1/kpc$$

**leads to huge probability of charge non-conservation with emission of longitudinal photons,** $\sim (E/m_\gamma)^{2N}$.

**Same problem in gravity with non-conserved energy-momentum tensor.**

**From now on only conserved current is considered.**

**If cosmological electric asymmetry is somehow generated, then in homogeneous case the solution is**

$$A_t(t) = 4\pi J_t/m_\gamma^2 \equiv 4\pi\sigma/m_\gamma^2$$

**with zero electric field, $E = 0$.**

## The energy-momentum tensor:

$$\begin{aligned} T_{\mu\nu} = \ & F_{\mu\alpha}F^{\alpha}_{\nu} - g_{\mu\nu}F^{\alpha\beta}F_{\alpha\beta}/4 - \\ & m^2_{\gamma}A_{\mu}A_{\nu} + g_{\mu\nu}m^2_{\gamma}A^2 + A^2_{\alpha}/2 + \\ & (\partial_\mu + ieA_\mu)\phi^*(\partial_\nu - ieA_\nu)\phi + \\ & (\partial_\nu + ieA_\nu)\phi^*(\partial_\mu - ieA_\mu)\phi - \\ & g_{\mu\nu}[(\partial_\alpha + ieA_\alpha)\phi^*(\partial^\alpha - ieA^\alpha)\phi \\ & m^2_{\phi}|\phi|^2] + T^{matter}_{\mu\nu} \end{aligned}$$

**Energy density of uniformly charged universe with massive photons diverges for $m \longrightarrow 0$:**

$$\rho = \sigma^2/2m_\gamma^2 + ... \approx p$$

**Stiffest equation of state $w = +1$.**
**Expansion regime: $a \sim t^{1/3}$.**
**If charge density is inhomogeneous, then $E \neq 0$ and Coulomb repulsion may mimic anti-gravity of dark energy, (but many problems).**

**If photon mass is non-vanishing, no matter how small, cosmological electric asymmetry must be generated, even with conserved current:**

$$D_\mu J^\mu = 0$$

**Thus at least one of the Sakharov's conditions is not fulfilled.**
**C and CP violations are still necessary but deviations from thermal equilibrium may be not.**

## Capture of $Q$ by black holes.

In the standard theory black holes (BH) may have nonvanishing gravitational field related to their mass and rotation and Coulomb field created by their electric charge and nothing else.

Black holes do not have hairs if gauge boson is massive.

Electric charge would disappear inside BH without any trace if photon is massive with an arbitrary small mass.

**If $m_\gamma \neq 0$, in flat space-time Coulomb potential changes into Yukawa one:**

$$A_t = \frac{Q}{r} \rightarrow \frac{Q\, e^{-m_\gamma r}}{r}.$$

**Outside a charged BH:**

$$A_t = 0\,.$$

**Proca eq. in Schwarzschild metric:**

$$\frac{1}{r^2}\left(r^2 A_t'\right)' - \frac{m^2 r}{r - R_g} A_t = 0,$$

**prime is derivative with respect to $r$.**

**Effective charge $q = r\,A_r$ and the new variable $y = 2m(r - R_g)$, $\mu = mR_g$:**

$$\frac{d^2q}{dy^2} - \left(\frac{1}{4} + \frac{\mu}{2y}\right) q = 0,$$

**Whittaker equation with solution:**

$$\begin{aligned} q(y) &= C_i\, y\, e^{-y/2}\, \Phi(1 + \mu/2, 2, y) \\ &\quad + B_i\, y\, e^{-y/2}\, \Psi(1 + \mu/2, 2, y). \end{aligned}$$

**When radius of charged shell tends to the gravitational radius, $R_c \to R_g$,**

$$Q_{eff} \sim Q \frac{R_c - R_g}{R_g} \Gamma(1 + \mu/2).$$

**Electric field vanishes when the charged shell approaches $R_g$ and disappears completely when the charged shell is swallowed by the black hole**

**Effective charge nonconservation, despite formal current conservation.**

## Limiting transition to zero photon mass?

**For $m_\gamma = 0$:**

$$Q_{eff} = const,$$

**while for $m_\gamma = 0$:**

$$Q_{eff} \sim (R_c - R_g)/R_g.$$

**Characteristic time of vanishing of the Coulomb field is**

$$\tau \sim 1/m_\gamma.$$

**With $1/m_\gamma > 30000$ years the effects are non-zero but weak.**

**Electrogenesis could be significantly amplified if there exists the non-minimal coupling to gravity:**

$$\xi R A_\mu A^\mu$$

**In the early universe and near central galactic BH**

$$R \gg m_\gamma^2.$$

Some numerical values:

$$R \approx \rho / m_{Pl}^2$$

For cosmological energy density:

$$R^{-1/2} \sim t_U \approx 10^{10} \text{ years}$$

For galactic energy density:

$$R^{-1/2} \approx 10^7 \text{ years} \approx 3\,\text{Mpc}$$

## Galactic center (DM included):

$\rho \sim 10^{14} \rho_{gal}$(?) (Gondolo, Silk):

$$R^{-1/2} \approx 1 \text{ year}$$

$\rho \sim 10^{20} \rho_{gal}$(??) (Zakharov et al):

$$R^{-1/2} \approx 10^4 - 10^5 \text{ sec}$$

**Mechanisms of generation of cosmological electric asymmetry:**

1. **Evaporation (in the early universe).**
2. **Capture (recently and even today).**

**1. Evaporation.** Primordial BHs in the early universe create a neutral unstable particle which decays as

$$X^0 \rightarrow p + e \text{ or } t + \bar{u}$$

If C and CP are broken in X-decays, then $BR(X \rightarrow pe) \neq BR(X \rightarrow \bar{p}\bar{e})$.
Back-capture of p is more probable than e and electric charge may be accumulated inside BH, till gravity is stronger than electricity.
Effective time $\tau \sim 1/m_\gamma$. If $m_\gamma^2 \sim R$, then $\tau \sim t_U$.

**Black hole temperature:**

$$T_{BH} \sim R_g^{-1} \sim 1\, MeV\, \frac{10^{16}\, g}{M_{BH}}.$$

**Luminosity:**

$$L_{BH} \sim T^4 r_g^2 \sim m_{Pl}^4 / M_{BH}^2.$$

**Life-time:**

$$\tau_{BH} \sim M_{BH}^3 / m_{Pl}^4.$$

**For** $M_{BH} = 10^{15}$g, $\tau_{BH} \approx t_U$.

Example: $T_{BH} = 10^{10}$ GeV,
$M_{BH} = 10^9 m_{Pl} = 10^4$g,
$\tau_{BH} \sim 10^{-16}$ sec,
which corresponds to cosmological temperature $T \sim 10^5$ GeV and red-shift from the moment when horizon mass was equal to $M_{BH}$, was about $10^{10}$.

**If mass fraction of BH at production was $10^{-10}$ then at the moment of their evaporation they would dominate cosmological energy density and could create observed baryon asymmetry and by a similar mechanism, some electric asymmetry.**

**2. Capture.**

**More realistic mechanism in the present day or rather old universe:**

**A superheavy BH in galactic center (QSO) surrounded by electron-proton plasma. Mobility of protons in plasma is much larger than that of electrons. This leads to a constant capture rate of protons by BH, creation of negative charge in outer space, and repulsion of electrons out, generating radial electric currents.**

**The current is not spherically symmetric,**

$$J_r = J_r(r, \theta),$$

**because the propagation of electrons in the disk encounter more resistance; propagation in orthogonal directions could create jets of electrons accelerated by Coulomb repulsion which charge the universe.**

Maximum charge of BH at any given moment: equality of gravitational attraction of protons and the Coulomb repulsion of the accumulated charge of BH:

$$\epsilon = \frac{N_{charge}}{N_{total}} = \frac{m_p^3}{\alpha\, m_{Pl}^2} = 10^{-36}$$

The repulsion disappears during

$$\Delta t \sim 1/m_\gamma$$

and the process continues. (In fact one has to solve diffusion equation in Coulomb and gravitational fields.)

Estimated rate of charge accumulation:

$$\dot{Q} = \epsilon m_\gamma N_{BH}$$

**Generated current of electrons:** $\boldsymbol{J = \dot{Q}}$**.**
**Magnetic field:**

$$B \sim J/R_{gal} \sim 10^{-24}\text{Gauss}$$

**for** $R_{gal} = 1$ **kpc,** $M_{BH} = 10^6 M_\odot$**, and** $m_\gamma = 1/$**kpc.**

If $m_\gamma^2 = R$, and in the galactic center $\rho \approx 10^{-10}\mathrm{g/cm^3}$, then:

$$B \approx 10^{-20}\ \mathrm{Gauss}$$

The observed value (at galactic scale) $B \approx 10^{-6}$ Gauss. Dynamo about $10^{14}$ is necessary.
If $\rho \approx 10^{-5}\ \mathrm{g/cm^3}$, $B \approx 10^{-18}$ Gauss and milder dynamo about $10^{12}$ would be sufficient.

**May the magnetic fields in intergalactic space, $B \sim 10^{-6} - 10^{-9}$ G be explained by this mechanism?**

**Accumulated cosmic electric charge per galaxy:**

$$Q_{tot} = \dot{Q}\Delta t = 10^{34}$$

**during 3 Gyr. Total number of protons in galaxy $N_{gal} \approx 10^{69}$, i.e.**

$$Q/N_{gal} \approx 10^{-35} > 10^{-36}.$$

**Are electrons tightly bound in galaxies or free stream from them?**

## ELECTRO-CONCLUSION.

**If photon mass is nonvanishing then**

**1. The universe must be electrically charged.**

**2. Large scale magnetic fields may be explained by electric currents from central black holes.**

**3. Electric repulsion of galaxies before homogenisation of charge may create cosmic acceleration???**

## UNSOLVED PROBLEMS.

**1. Assume that $\sigma = const$, $E = 0$, and $\rho \sim 1/m^2$.**

**What if $m_\gamma \to 0$? Solution with $E \neq 0$ becomes more favourable?**

**Spontaneous electrization?**

**Possible way to regularise the limit $m_\gamma \to 0$?**

**2. $U(1)$ was spontaneously broken at high $T$ and electric asymmetry was generated.**

**When $U(1)$ is restored at low $T$, the asymmetry would disappear, by compensation of electric charge of particles and vacuum.**

**What happens if charge asymmetry was generated by black holes?**

**BARYOGENESIS = dynamical generation of charge (baryon) asymmetry of the universe.**

**Three Sakharov's conditions:**

**I. Non-conservation of baryons**
**II. Breaking of C,CP symmetry.**
**III. Deviation from thermal equilibrium.**

**Many models which explain one number. Impossible to distinguish.**

**I. Non-conservation of baryons.** Theory: GUT, SUSY, and even EW predicts

$$\Delta B \neq 0$$

No direct experimental confirmation. **The only "experimental piece of data" is our universe: inflation is impossible with conserved baryons.**

## II. C and CP violation:

discovered and confirmed by direct experiment.

History:

Before 1956, all conserved: P, C, T.

1956: discovery of parity non-conservation. Assumption of CP-invariance.

1964: CP-VIOLATION.

After this discovery life in the universe became possible.

**Only CPT survived destruction - the symmetry with solid theoretical justification: CPT-theorem:**

**1. Lorenz-invariance.**

**2. Canonical spin-statistics relation.**

**Still some models without CPT are considered, e.g. for explanation of some neutrino anomalies and just for fun.**

**NB: If CP is broken but CPT is not, T must be broken as well.**

**Baryon asymmetry with broken CPT**
**is possible in thermal equilibrium:**

$$\frac{N_B - N_{\bar{B}}}{N_B} = \int \frac{d^3p}{(2\pi)^3} \left[ f_B(p) - f_{\bar{B}}(p) \right],$$

where $f = 1/[\exp(E/T) + 1]$.

**The usual estimates for m > T:**

$$\frac{N_B - N_{\bar{B}}}{N_B} \approx \frac{\delta m}{T},$$

**and for m < T:**

$$\frac{N_B - N_{\bar{B}}}{N_B} \approx \frac{\delta m}{T} \frac{m}{T}.$$

Electric neutrality demands non-zero chemical potentials of quarks in equilibrium, $\mu \sim \delta m$, and:

$$\frac{N_B}{N_\gamma} = -0.126(m_d \delta m_d + 1.2 m_u \delta m_u)/T^2.$$

Normally in equilibrium: $\mu = 0$.

If $\delta m_q \sim \delta m_p < 2 \cdot 10^{-9}$ GeV, the mechanism is not efficient enough.

**NB. Estimates of asymmetry are true if the equilibrium distributions do not change because of CPT breaking - may be not so!**

**Validity of standard equilibrium kinetics with broken T-invariance?**

**Kinetic equation in FRW space-time:**

$$\frac{df_i}{dt} = (\partial_t - H\, p_i \partial_{p_i}) f_i = I_i^{coll}[f]$$

**Equilibrium distribution by definition is such that**

$$I_i^{coll}[f^{(eq)}] = 0$$

**COLLISION INTEGRAL** for the process $i + Y \leftrightarrow Z$:

$$I_i^{coll} = \frac{(2\pi)^4}{2E_i} \sum_{Z,Y} \int d\nu_Z \, d\nu_Y \delta^4(P_{in} - P_{fin})$$
$$[|A(Z \to i + Y)|^2 \prod_Z f \prod_{i+Y} (1 \pm f) -$$
$$|A(i + Y \to Z)|^2 f_i \prod_Y f \prod_Z (1 \pm f)]$$

$$d\nu_Y = \prod_Y \overline{dp} \equiv \prod_Y \frac{d^3 p}{(2\pi)^3 2E}$$

The signs '+' or '−' in $\prod(1 \pm f)$ are chosen for bosons and fermions respectively.

**In T-invariant theory $|A_{if}|^2 = |A_{fi}|^2$ (after some change of variables) and:**

$$\Pi f_{in} \Pi (1 \pm f_{fin}) - \Pi f_{fin} \Pi (1 \pm f_{in}) = 0,$$

**so $f^{(eq)}$ annihilate collision integrals due to conservation of energy**

$$\sum \mathrm{E_{in}} = \sum \mathrm{E_{fin}}$$

**and if chemical potentials satisfy:**

$$\sum \mu_{in} = \sum \mu_{fin},$$

**this condition is enforced by reactions.**

**If T-invariance is broken**

$$|A_{if}|^2 \neq |A_{fi}|^2.$$

**Do equilibrium distributions become different in T-noninvariant world?**

**Collision integral:**

$$I_{coll} = \frac{1}{2E_1} \int d\tau'_{in} d\tau_{fin}$$

$$\left[ |A_{if}|^2 \Pi f_{in} \Pi (1 \pm f_{fin}) \right.$$

$$\left. - |A_{fi}|^2 \Pi f_{fin} \Pi (1 \pm f_{in}) \right].$$

**For the usual equilibrium functions:**

$$\mathbf{I_{coll} \sim \Pi f_{in}(1 \pm f_{fin})\left(|A_{if}|^2 - |A_{fi}|^2\right)} \; .$$

**The last factor is non-vanishing.**

**T-violation is observable only if several processes contribute.**

**Instead of detailed balance, if T-invariance is broken, S-matrix unitarity leads to a new condition of cyclic balance:**

$$\sum_k \int d\tau_k \left( |A_{ki}|^2 - |A_{ik}|^2 \right) = 0\,.$$

**It ensures vanishing of $I_{coll}$ for $f = f_{eq}$.**

**Here $d\tau_k$ includes Bose/Fermi enhancement/suppression factors.**

COMMENTS:

1. In lowest order $\mathbf{A}^{*}_{\mathbf{if}} = \mathbf{A}_{\mathbf{fi}}$ and the effects of T-breaking are unobservable.

2. Full unitarity is not necessary.

Normalisation of probability

$$\sum_f w_{if} = 1$$

plus CPT invariance are sufficient.

Without CPT and unitarity the normal equilibrium statistics may be broken! Models with virtual BHs may break these sacred principles.

## Deviation from thermal equilibrium.

Number density with normal statistics:

$$n = (2\pi)^{-3} \int d^3p f(E, \mu, T)$$

$E = \sqrt{p^2 + m^2}$ is the same for particles and antiparticles, if $m = \bar{m}$ and in equilibrium $\mu = 0$, so $n = \bar{n}$.

Massive particles are always out of equilibrium:

$$\left(\partial_t - Hp\partial_p\right) f_{eq}\left(\frac{E-\mu(t)}{T(t)}\right) = \left[-\frac{\dot{T}}{T}\frac{E-\mu}{T} - \frac{\dot{\mu}}{T} - \frac{Hp}{T}\right] f'_{eq}$$

The factor in square brackets vanishes if $\dot{\mu} = \dot{T}/T = -H$ - TRUE;
$\mathrm{E}(\dot{\mathrm{T}}/\mathrm{T}) = -\mathrm{Hp}$ - can be and is true only for $\mathrm{m} = 0$ and so $\mathrm{E} = \mathrm{p}$.

Another way to break equilibrium: first order phase transition.

**For massive particles deviation from equilibrium is proportional to:**

$$\frac{H}{\Gamma} \sim \frac{mT}{m_{Pl}\Gamma},$$

$\Gamma \sim \alpha m$ **or** $\Gamma \sim \alpha^2 T$, **and** $T \sim m$.

**Deviation is very small if** $\mathrm{m_{Pl}} \gg \mathrm{T}$.

**At EW scale:** $H/\Gamma \sim 10^{-15}$.

**For massless particles equilibrium is usually unbroken. True for photons and somewhat wrong for neutrinos.**

## USUAL SCENARIOS OF BG.

Baryogenesis is possible in the standard model (but too weak) or in extended ones and may explain the observed asymmetry:

$$(n_B - n_{\bar{B}})/n_\gamma = 6 \cdot 10^{-10},$$

(found by two independent measurements: BBN and CMBR).

NB: If $n_B = n_{\bar{B}}$ locally then today

$$n_B/n_\gamma = n_{\bar{B}}/n_\gamma \approx 10^{-19}$$

**Great challenge:** is $\beta$ constant or $\beta = \beta(x)$?

What is characteristic scale $l_B$ of variation of baryonic number density?

Could the universe be **neutral** on average, $B_{tot} = 0$?

May there be astronomically **large domains of antimatter** nearby?

Answers to these questions depend upon the **mechanism of CP violation realised in cosmology.**

**Three possibilities for CP-breaking in cosmology:**

1. **Explicit**
2. **Spontaneous.**
3. **Stochastic or dynamical,**

**unobservable in particle physics.**

**Standard model:**
**explicit CP-violation leading to universal constant $\beta$, expressed through masses and couplings of fundamental particles.**

**Examples:**

**1. GUT baryogenesis.**

**2. Electroweak baryogenesis.**

**3. Baryo-thru-lepto-genesis.**

**But combined with other models of cosmological CP-violation may lead to more complicated pattern.**

## Mechanisms of CP-violation in cosmology.

I. Explicit. Complex constants in Lagrangian, in particular, complex Yukawa couplings transformed by the Higgs field $\langle\phi\rangle \neq 0$ into a non-vanishing phase in CKM-mixing matrix. However, in MSM the baryon asymmetry is too small, by 10 orders of magnitude.

An extension of MSM is necessary.

II. Spontaneous. A complex scalar field $\Phi$ acquiring different vacuum expectation values:

$$\langle \mathbf{\Phi} \rangle = \pm \mathbf{f}$$

Lagrangian is CP-invariant.
Locally indistinguishable from I.
Leads to globally charged symmetric universe, but $l_B \geq$ Gpc.
Domain wall problem (KOZ) demands $l_B \gg$ Gpc or a mechanism of wall destruction.

**III. Stochastic or dynamical.**
A complex scalar field $\chi$ displaced from its equilibrium point, e.g. by quantum fluctuations at inflation.
Infrared instability: $\chi^2 \sim H^3 t$. (What about the sign?)
After inflation $\chi$ relaxes down to zero.
No domain wall problem.
Could give rise to an inhomogeneous $\beta(x)$ with antimatter nearby.

## Electroweak baryogenesis in MSM.

**All the ingredients are present:**

**1. CP is known to be broken,**
**but very weakly, about $10^{-19}$, for the standard estimates, see below.**
**However, since $\theta$ is not relaxed down to zero, CP-violation may be much stronger.**

2. Baryonic charge is non-conserved because of nonabelian chiral anomaly. At zero T baryon nonconservation is exponentially suppressed as $\exp(-2\pi/\alpha)$ - barrier penetration between different vacua.
At high T it is possible to go over the barrier, but abundant formation of classical field configuration, sphalerons, is necessary.

**3. Thermal equilibrium is broken if phase transition is first order**
**- heavy Higgs made it improbable.**

**Deviation from equilibrium due to non-zero mass is weak:**

$$\sim m_{EW}/m_{Pl} \sim 10^{-16}.$$

**Could be large in TeV-gravity!**

## CP-violation in MSM

is absent for two quark families - can be rotated away. Three families are necessary - an anthropic explanation of number of flavours? (does not work).

If masses of different up or down quarks are equal, CP violation can be rotated away because unit matrix is invariant.

If mass matrix is diagonal in the same representation as flavour matrix CP-violation can also be rotated away.

Thus CP-breaking is proportional to the product of the mixing angles and to the mass differences of all down and all up quarks:

$$A_- \sim \sin\theta_{12} \sin\theta_{23} \sin\theta_{31} \sin\delta$$
$$(m_t^2 - m_u^2)(m_t^2 - m_c^2)(m_c^2 - m_u^2)$$
$$(m_b^2 - m_s^2)(m_b^2 - m_d^2)(m_s^2 - m_d^2)/M^{12}$$

At high T the characteristic mass $M \sim 100$ GeV and

$$A_- \sim 10^{-19}.$$

At T = 0 the mass in the denominator is the zero-temperature quark mass and the CP-odd amplitude is not such vanishingly small.

At high T quarks acquire QCD corrections to the "mass" of order T, while in the numerator there are still "Higgs masses" or, better to say, small Yukawa coupling constants.

Attempts to modify dispersion relation at high T, $E = E(p, T)$, were unsuccessful.

To explain cosmological C-asymmetry
physics beyond MSM is necessary.

POSSIBLE MODELS:

1. GUT baryogenesis.

Temperatures, T $\sim 10^{16}$ GeV, are needed, not reachable after inflation.
Still out-of-equilibrium heavy particles might be produced.
Gravitino problem.

## 2. Baryo-thru-leptogenesis

**Creation of lepton asymmetry by heavy ($m \sim 10^{10}$ GeV) Majorana $\nu$ decay, similar to GUT, and transformation of L into B by CP and $(B-L)$ conserving EW processes later.**

**L is naturally nonconserved.**

**Heavy particles to break thermal equilibrium are present.**

**Three CP-odd phases of order unity might be there.**

Common features of 1 and 2: baryogenesis in heavy particle decays.
Deviation from equilibrium:

$$Ha\frac{\partial f}{\partial a} = \Gamma\left(f_{eq} - f\right)$$

where $a \sim 1/T$ is cosmological scale factor. For small deviation from equilibrium $f = f_{eq} + \delta f$ and

$$\frac{\delta f}{f_{eq}} \approx \frac{Hm^2}{\Gamma E T} \approx \frac{10^2 m}{m_{pl}}$$

if $T \sim m$, $\Gamma \sim \alpha m$, and $\alpha \sim 10^{-2}$ .
Either heavy particles are needed or low decay rate, $\alpha \ll 10^{-2}$.

**More details.**

**Particles and antiparticles can have different decay rate into charge conjugated channels if C and CP are broken, while total widths are equal due to CPT invariance.**

**If only C is broken, but CP is OK, then partial widths, summed over spins, are the same:**

$$\Gamma\left(X \to f, \sigma\right) = \left(\bar{X} \to \bar{f}, -\sigma\right)$$

**If both C and CP are broken, partial widths are different.**

Example:

$$\mathbf{X} \to \mathbf{qq}, \quad \mathbf{X} \to \mathbf{q\bar{l}},$$
$$\bar{\mathbf{X}} \to \bar{\mathbf{q}}\bar{\mathbf{q}}, \quad \bar{\mathbf{X}} \to \bar{\mathbf{q}}\mathbf{l}\,.$$

**Width are different if re-scattering with baryonic charge non-conservation in the final state is taken into account:**

$$\Gamma_{X\to qq} = (1+\Delta_q)\Gamma_q, \quad \Gamma_{X\to q\bar{l}} = (1-\Delta_l)\Gamma_l,$$
$$\Gamma_{\bar{X}\to \bar{q}\bar{q}} = (1-\Delta_q)\Gamma_q, \quad \Gamma_{\bar{X}\to \bar{q}l} = (1+\Delta_l)\Gamma_l.$$

**Hence $B \sim (2/3)(2\Delta_q - \Delta_l)$.**
**$\Delta \sim \alpha$ and is small for weakly interacting X - potential problem for leptogenesis, solved by resonance transformation.**

**Rough estimate of the asymmetry:**

$$\beta \sim \frac{\delta f}{f}\frac{\Delta\Gamma}{\Gamma} \sim \frac{m}{m_{Pl}}$$

**Some small numerical coefficients make the result even smaller.**

**Subsequent entropy dilution by about 1/100 is not included.**

**For successful lepto/baryo-genesis the mass of the decaying particle should be larger than $10^{10}$ GeV (or $m_{Pl} \ll 10^{19}$ GeV).**

CP-violation in neutrino mass matrix:

$$\mathcal{L}_m = M \nu_R C \nu_R + m \nu_L C \nu_R.$$

Six CP odd phases, because $\nu\nu$ but not $\bar{\nu}\nu$: 3 phases in light $\nu$ sector and 3 phases in heavy $\nu$ sector.

Phases which may be measured in neutrino oscillations have nothing to do with phases in heavy $\nu$ decay, can be related in model dependent way only.

Number of phases, see next page.

**Number of CP-odd phases in mass matrix.** Dirac mass matrix:

$$\mathcal{L}_m = m_{ij}\bar{q}_i q_j$$

Diagonal terms $m_{ii}$ are real because of Hermicity. Off-diagonal $m_{ij}$ with $i \neq j$ can be complex.

Freedom because of phase rotation:

$$q_i \to e^{i\phi_i} q_i$$

One can change the phase of $m_{ij}$ by

$$m_{ij} \to e^{i(\phi_i - \phi_j)} m_{ij} \equiv e^{i\phi_{ij}} m_{ij}$$

Here $\phi_{12} + \phi_{23} + \phi_{31} = 0$.

Three phases in $m_{ij}$ and 2 conditions - one arbitrary phase remains.

**Majorana mass matrix:**

$$\mathcal{L}_M = M_{ij} \nu_i C \nu_j$$

**All $M_{ij}$ may be complex.**
**One can kill three phases in $M_{ii}$ by 3 phase rotations of $\nu_i$. No freedom left after that and three phases of $M_{12}, M_{23}, M_{31}$ remain arbitrary.**

**A problem: How many CP-odd phases are allowed in the case of both Dirac and Majorana mass matrices?**

## Comments.

### 1. Necessity of re-scattering with $\Delta B \neq 0$ or $\Delta L \neq 0$.

In lowest order $A = \bar{A}^*$ because of hermicity of Lagrangian.
The same would be true for higher order contributions if they were real.
Imaginary part is generated by re-scattering in the final state.
Why re-scattering with $\Delta B \neq 0$?

S-matrix unitarity:

$$\mathbf{i(T_{if} - T^{\dagger}_{if}) = -\sum_{n} T_{in} T^{\dagger}_{nf}}$$
$$\mathbf{= -\sum_{n} T^{\dagger}_{in} T_{nf}}$$

CPT: $\mathbf{T_{fi} = \tilde{T}_{\overline{fi}}}$, "tilde" means change of spin signs by PT-transformation. Since $\mathbf{T^{\dagger}_{if} = T^{*}_{fi}}$, total probabilities of any process with particles and antiparticles are equal in the lowest order (r.h.s. of unitarity relation is neglected).

If only two channels i and f are open, still $\Gamma = \bar{\Gamma}$. Indeed:

$$2\mathcal{I}m T_{ii}[\lambda] = \int d\tau_i |T_{if}|^2 + \int d\tau_f |T_{ff}|^2$$

By CPT:

$$T_{ii}[\lambda] = T_{\overline{ii}}[-\lambda]$$

and after summing over polarisation we find $\Gamma_{\mathrm{if}} = \Gamma_{\overline{\mathrm{if}}}$.

Hence to destroy the equality of partial widths $\Gamma_{\mathrm{if}} = \bar{\Gamma}_{\overline{\mathrm{if}}}$ at least three channels must be open:

$$\mathrm{i} \leftrightarrow \mathrm{f}, \;\; \mathrm{i} \leftrightarrow \mathrm{k}, \;\; \mathrm{k} \leftrightarrow \mathrm{f}.$$

**2. How charge asymmetry vanishes in equilibrium?** By inverse decay?
Using CPT, one finds:

$$\Gamma_{\bar{q}\bar{q}\to\bar{X}} = (1 + \Delta_q)\Gamma_q, \ \Gamma_{\bar{q}l\to\bar{X}} = (1 - \Delta_l)\Gamma_l,$$
$$\Gamma_{qq\to X} = (1 - \Delta_q)\Gamma_q, \ \Gamma_{q\bar{l}\to X} = (1 + \Delta_l)\Gamma_l.$$

Thus direct and inverse decays produce the same sign of baryon asymmetry!?

## SOME MORE MODELS.

3. **Primordial black hole evaporation.**
Energy density should be dominated by PBH at some early stage.
Heavy particles with
$m \sim 10^{10} - 10^{6}$ GeV are needed. Analogous to electrogenesis discussed above.

4. **Spontaneous baryogenesis**
May operate in thermal equilibrium.
Explicit CP-violation is not obligatory.

**5. SUSY B-condensate.**
**Somewhat similar to 4.**
**In a special version it could create astronomically interesting bubbles of antimatter in our neighbourhood, in particular heavy antinuclei: C, N, O and even Fe.**

3. PBH evaporation - does not demand B-nonconservation at particle physics level.

Thermal evaporation cannot create any charge asymmetry.

However the spectrum is not BLACK but GRAY due to propagation of the produced particles in gravitational field of BH. Moreover, an interaction among the produced particles is essential.

**A model:** **A-meson is created at the horizon and decays as:**

$$\mathbf{A} \rightarrow \mathbf{H} + \bar{\mathbf{L}} \text{ and } \mathbf{A} \rightarrow \bar{\mathbf{H}} + \mathbf{L}$$

**with different branching ratios.**
**Back-capture of H is larger than that of L. Net baryon asymmetry could be created.**
**If** $\rho_{BH}/\rho_{tot} = \epsilon$ **at the production, then at red-shift** $z = 1/\epsilon$ **BH would dominate. Their evaporation could provide baryon asymmetry and reheat the universe.**

Example: $T_{BH} = 10^{10}$ GeV,
$M_{BH} = 10^9 m_{Pl} = 10^4$g,
$\tau_{BH} \sim 10^{-16}$ sec,
which corresponds to cosmological temperature $T \sim 10^5$ GeV and red-shift from the moment when horizon mass was equal to $M_{BH}$, was about $10^{10}$.

If mass fraction of BH at production was $10^{-10}$ then at the moment of their evaporation they would dominate cosmological energy density and could create observed baryon asymmetry.
Planck mass remnants of PBH, if they are stable, could be cosmological DM.

One more model of baryogenesis with REAL $\Delta B = 0$ - similar to the one above but without BH. A sterile (w.r. to us) baryon is needed instead.
A toy model:

$$A \to q + \bar{Q}, \quad \text{and} \quad \bar{A} \to Q + \bar{q}$$

with different partial widths - leads to equal but opposite signs baryon asymmetries in our and in Q sectors.
Q-baryons could make dark matter if their mass is 5 times larger than $m_p$, a unique mechanism of baryogenesis and DM creation.

## 4. Spontaneous baryogenesis

Spontaneous breaking of U(1)

$$U(\phi) = \lambda(|\phi|^2 - \eta^2)^2,$$

related e.g. to baryonic charge, leads to massless, Goldstone boson, $\theta(x)$:

$$\phi = \eta\, exp(i\theta)$$

If the potential $V(\theta) \neq 0$ the boson would be massive but usually light. E.g. $\delta U(\phi) = m^2\left(\phi^2 + \phi^{*2}\right)$.

In the broken phase the Lagrangian can be written as:

$$\mathcal{L} = \eta^2(\partial\theta)^2 + \partial_\mu\theta j_\mu^B - V(\theta) + i\bar{Q}\gamma_\mu\partial_\mu Q + i\bar{L}\gamma_\mu\partial_\mu L + (g\eta\bar{Q}L + h.c.).$$

Red term looks like chemical potential, $\dot{\theta} n_N$ but in reality is not, because the coupling is derivative and $\mathcal{L} \neq \mathcal{H}$.

**If $V(\theta) = 0$, i.e. purely Goldstone case, we can integrate equation of motion:**

$$2\eta^2\partial^2\theta = -\partial_\mu j_\mu^B$$

**and obtain:**

$$\Delta n_B = -\eta^2\Delta\dot{\theta}$$

**i.e. non-zero baryon asymmetry in thermal equilibrium and without explicit CP-violation. The latter is created by initial $\dot{\theta} \neq 0$.**

**In realistic case $\dot{\theta}$ is small and pseudogoldstone case could be more efficient.**

**Equation of motion:**

$$\eta^2 \ddot{\theta} + 3H\dot{\theta} + V'(\theta) = \partial_\mu j^B_\mu .$$

**with** $V(\theta) \approx m^2 \eta^2 \left[ -1 + (\theta - \pi)^2 \right]$

**and** $j^B_\mu = \bar{\psi} \gamma_\mu \psi$.

**Initially $\theta$ is uniform in $[0, 2\pi]$ and after inflation it started to oscillate around minimum.**

Second equation for the quantum baryonic Dirac field:

$$(i\partial + m)\,\psi = -g\eta l + (\partial_\mu \theta)\gamma_\mu \psi$$

Find solution in one-loop approximation for $\psi(\theta)$ in external classical field $\theta$ and substitute $\bar{\psi}\psi = F(\theta)$ into equation of motion for $\theta$. The solution oscillates with alternating baryonic number. Net result:

$$n_B \sim \eta^2 \Gamma_{\Delta B} (\Delta\theta)^3.$$

# SUPERSYMMETRIC CONDENSATE

**SUSY predicts existence of scalars with $B \neq 0$.**
**Such bosons may condense along flat directions of the potential:**

$$U_\lambda(\chi) = \lambda|\chi|^4 (1 - \cos 4\theta) \,,$$

**where $\chi = |\chi| \exp(i\theta)$.**
**In GUT SUSY baryonic number is naturally non-conserved.**

**Due to infrared instability of massless (m $\ll$ H) fields $\chi$ travels away form zero:**

$$|\chi|^2 \sim H^3 t$$

**Mass term, $m^2\chi^2 + m^{*\,2}\chi^{*\,2}$, leads to:**

$$U_m(\chi) = m^2|\chi|^2[1 - \cos(2\theta + 2\alpha)]\,,$$

**where $m = |m|e^{\alpha}$.**
**If $\alpha \neq 0$, C and CP are explicitly broken.**

**“Initially” (after inflation) $\chi$ is away from origin and when inflation is over starts to evolve down to equilibrium point, $\chi = 0$, according to Newtonian mechanics:**

$$\ddot{\chi} + 3H\dot{\chi} + U'(\chi) = 0.$$

**Baryonic charge of $\chi$:**

$$B_\chi = \dot{\theta}|\chi|^2$$

**is analogous to mechanical angular momentum. When $\chi$ decays its baryonic charge is transferred to that of quarks in B-conserving process.**

**If $m = 0$ the B-charge of $\chi$ is in its "rotational" motion, induced by quantum fluctuations in orthogonal to valley direction. Leads to globally charge symmetric universe.**

**The domain size $l_B$ is determined by the size of the region with a definite sign of $\dot{\theta}$. Usually $l_B$ is too small if no special efforts are done.**

**If $m \neq 0$, the angular momentum, B, is generated by a different direction of the valley at low $\chi$.**
**If CP-odd phase $\alpha$ is small but non-vanishing, both baryonic and antibaryonic regions are possible with dominance of one of them.**
**Matter and antimatter domain may exist but globally $B \neq 0$.**

**With coupling to inflaton $\Phi$:**

$$\lambda|\chi|^2\,(\Phi-\Phi_1)^2$$

**the valley may be open only for a short time and $\chi$ would acquire a large baryonic charge condensate, giving $\beta \sim 1$ but in a tiny fraction of space.**
**The bulk of space has normally homogeneous baryon asymmetry $\beta = 6 \cdot 10^{-10}$, while hi-B regions are almost symmetric with respect to baryons and antibaryons.**

**Mass distribution of hi-B regions:**

$$\frac{dN}{dM} = C_0 \exp\left[-C_1 \ln^2 (M/M_0)\right]$$

**They could be primordial black holes, QSO's in particular, disperse clouds of antimatter, and unusual stars and anti-stars, all not too far from us.**

**Primordial nucleosynthesis in hi-B domains proceeded with large $n_B/n_\gamma$.**

**Hence primordial heavy anti-nuclei, up to anti-iron could be formed.**

**Evolved chemistry near hi-z QSO?**

## Baryogenesis (BG) conclusion.

1. Plethora of BG scenarios explaining observed asymmetry.

2. In the case of homogeneous BG only one number is to be explained.

3. Physics beyond the MSM is necessary.

4. There are models with inhomogeneous BG, with $\beta = \beta(x)$ and even with $\beta < 0$ - look for cosmic antimatter! Compact antimatter objects can be abundant even nearby, in the Galaxy.

## TEV GRAVITY

Antoniadis, Arkani-Hamed, Dimopoulos and Dvali, "geometric" solution to the hierarchy problem of particle physics: the Planck mass $M_{Pl}$ is an effective long-distance 4-dimensional parameter related to the fundamental gravity scale $M_*$ by

$$M_{Pl}^2 \sim M_*^{2+n} R^n,$$

where $R$ is the size of the extra dimensions.

For large extra dimensions, $R \gg M_{Pl}^{-1} \sim 10^{-33}$ cm the fundamental gravity scale can be as low as a few TeV i.e. of the same order of magnitude as $M_{EW}$. If $M_* \sim 1$ TeV:

$$R \sim 10^{(30/n)-17}\,cm$$

The hierarchy problem shifted from the hierarchy in energies to a hierarchy in the size of the extra dimensions which are much larger than 1/TeV $\sim 10^{-17}$ cm but much smaller than the 4-dimensional universe size.

The case $n = 1$ is excluded, since $R \sim 10^{13}$ cm and therefore strong deviations from Newtonian gravity at solar system distances would result. For $n \geq 2$, $R \lesssim 100\,\mu$m and nowadays we have no experimental evidence against a modification of gravitational forces in such a regime.

Theoretical problem: too strong violation of $B, L_{tot}, L_{e,\mu,\tau}$.

## Black holes and rare processes.

Position of horizon for charged and rotating BH (Kerr-Newmann):

$$R_{BH} M_{Pl} = \frac{M_{BH}}{M_{Pl}} + \sqrt{\left(\frac{M_{BH}}{M_{Pl}}\right)^2 - Q^2 - J^2 \left(\frac{M_{BH}}{M_{Pl}}\right)^{-2}},$$

Thus for BH formation is necessary:

$$\left(\frac{M_{BH}}{M_{Pl}}\right)^2 > \frac{Q^2}{2} + \sqrt{\frac{Q^4}{4} + J^2}.$$

**Theory of virtual BH creation is unknown.**
**Normal quantum field theory most likely does not work.**
**At this stage we can make only guesses, hopefully not too far from reality.**

Wild assumptions for set of rules, for formation of virtual BH:

1. Only $Q = J = 0$ virtual BH can be formed.

2. Only BH with $E_{tot} > 0$ can be formed. In particular, BH can be formed only in s-channel of virtual colliding particles.

3. BH can be formed only on mass shell. Probably old non-covariant formalism of QFT with broken Lorenz invariance should be used?!

## Particle coupling to BH

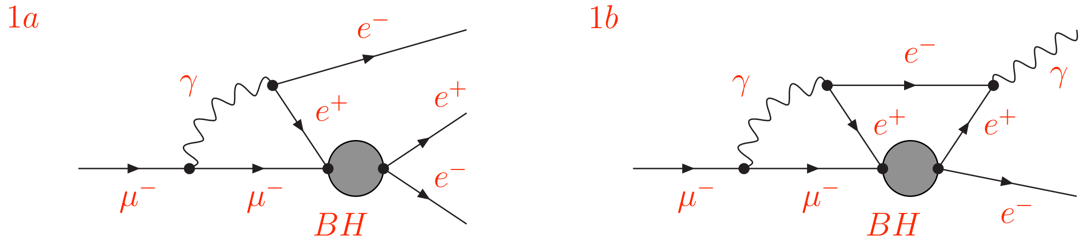
Dimensional estimate:

$$g_2 = M_{BH} R_S, \quad g_3 = R_S^2 M_{BH}, \quad g_4 = R_S^4 M_{BH}$$

for two fermions, two fermions and one scalar, and four fermions respectively.

**The $4+n$ Schwarzschild radius is**

$$R_S = \frac{1}{\sqrt{\pi} M_*} \left( \frac{M_{BH}}{M_*} \right)^{\frac{1}{n+1}} \left[ \frac{8\, \Gamma(\frac{n+3}{2})}{n+2} \right]^{\frac{1}{n+1}}.$$




# Muon decays with broken $L_\mu$: $\mu \to 3e$ and $\mu \to e\gamma$.

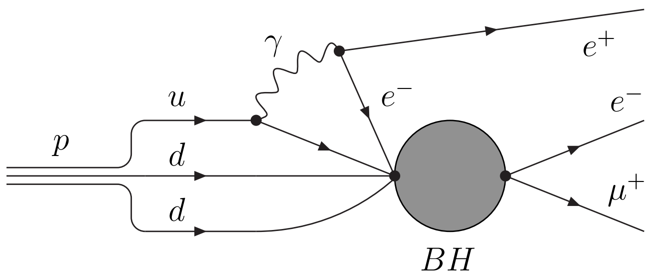
Decay width $\mu \to 3e$:

$$\Gamma \approx \frac{\alpha^2 m_\mu}{2^{11}\pi^5} \left( \ln \frac{M_*^2}{m_\mu^2} \right)^2 \left( \frac{m_\mu}{M_*} \right)^{4(1+\frac{1}{n+1})},$$

For $M_* = 1$ TeV and $n = 2$:
BR $= 2 \cdot 10^{-12}$. Experiment:

$$BR(\mu^- \to e^- e^+ e^-)\Big|_{Exp} < 1.0 \cdot 10^{-12}.$$

For $n > 2$ the disagreement with experiment is stronger. A minor increase of $M_*$ would help.
Decay width $\mu \to e\gamma$ is similar.




**Gravitationally induced proton decay. Since a 4-body collision is required in order to form a BH devoid of any quantum number, the process is strongly suppressed and experimental constraints can be compatible even with a gravity scale in the TeV range.**

**Correspondingly the lifetime of the proton with respect to the inclusive decay $p \longrightarrow \bar{q}ql^{+}$ is:**

$$\tau_p \approx 10^{29}\,\mathrm{years} \times \left(\frac{M_*}{\mathrm{TeV}}\right)^{10+\frac{10}{n+1}} \left(\frac{\mathrm{TeV}}{m_p}\right)^{\frac{10}{n+1}-\frac{10}{3}} \left(\frac{100\mathrm{MeV}}{\Lambda}\right)^{6} \ln^{-2}\left(\frac{M_*}{\mathrm{TeV}}\right) .$$

**Because parity is conserved by gravity the decays should be mostly 3-body ones.**

**The final state particles must always contain a positron, $e^+$, or a positive muon, $\mu^+$.**

**The branching ratio into three lepton channel is predicted to be larger than that into $e^+$ $(\mu^+)$ and two mesons.**

**Other processes.**

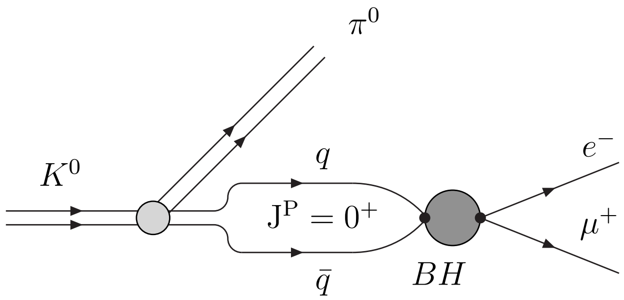
High energy reaction $e^+ + e^- \to \mu + e$ or similar ones with any other lepton or baryon in the final state.

$$\sigma(e^+e^- \to \mu e) \approx 7 \cdot 10^{-39}\,\mathrm{cm}^2$$

$$\left(\frac{M_{BH}}{100\,\mathrm{GeV}}\right)^{2+\frac{4}{n+1}} \left(\frac{\mathrm{TeV}}{M_*}\right)^{4+\frac{4}{n+1}},$$

quite close to the existing bound.

Helicity of colliding $e^+e^-$ should be zero in contrast to normal processes.



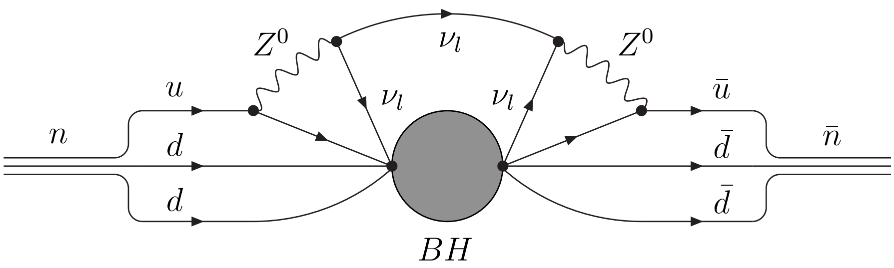

**Kaon decay $K^0 \longrightarrow \pi^0 e^- \mu^+$. $K$-meson probably cannot transform directly to a BH, because it is a pseudoscalar particle; instead, the emission of a $\pi^0$ leaves a scalar $q\bar{q}$ system.**

The decay $K \longrightarrow ll$ is suppressed because BH is a scalar.

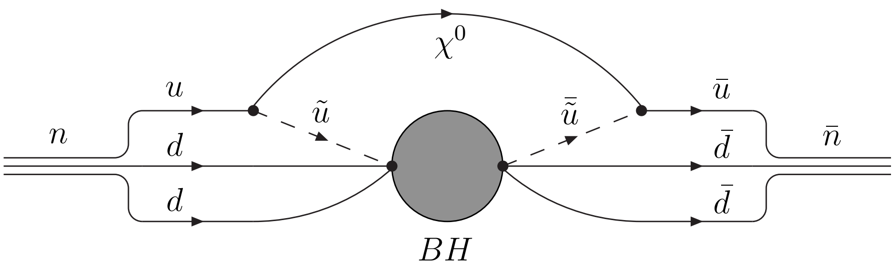
The life-time of $K \longrightarrow \pi ll$ is

$$\tau(K \longrightarrow \pi ll) = 0.85 \cdot 10^2\,\mathrm{s}\ (g_{K\pi S} m_\pi)^{-2} \left(\frac{M_*}{\mathrm{TeV}}\right)^{4+\frac{4}{n+1}} \left(\frac{\mathrm{TeV}}{m_K}\right)^{\frac{4}{n+1}-\frac{4}{3}} \left(\frac{300\,\mathrm{MeV}}{m_q}\right)^4 .$$

The bounds on the branching ratios of $K_L^0 \longrightarrow 2l\pi^0$ decays are $(3-5)\cdot 10^{-10}$. So for $n = 2$, $M_* = 1$ TeV, and such decays are on the verge of discovery. For larger $n$ a larger $M_*$ is needed.




**Neutron-antineutron oscillations mediated by a virtual BH. If we consider only Standard Model particles, the effect is negligible.**




**($n - \bar{n}$)-oscillation with supersymmetric particles. In this case the observation of the phenomenon may be accessible to future experiments.**

$$\tau_{n\bar{n}} \approx 3 \cdot 10^9\, sec \cdot 10^{\frac{12}{n+1}-4} \left(\frac{100\,\mathrm{MeV}}{\Lambda}\right)^6$$
$$\left(\frac{m_{SUSY}}{300GeV}\right) \left(\frac{GeV}{M_{BH}}\right)^{\frac{4}{n+1}} \left(\frac{M_*}{TeV}\right)^{\frac{4(n+2)}{n+1}}.$$

Experiment $\tau_{nn} > 10^8$ s.

If $M_* \sim TeV$ and $m_{SUSY} \sim 300$ GeV, the chances to see $n - \bar{n}$ transformations are high. According to our model the observation would be in favour of low scale gravity and low energy SUSY.

**Rare decay conclusion.**

**NB: no theory, only a toy model of the theory.**

**Predictions are unique and surprisingly very close to the present day bounds. The unwanted processes are suppressed.**

**Virtual BHs with negative mass or BH off-mass-shell probably do not exist. It is not an elementary particle and cannot be treated in normal field theory frameworks.**

**Baryogenesis with TeV gravity may be possible in MSM.**

**1. Easier out of equilibrium, $H \sim T^2/m_{Pl}$. Universe expands 16 orders of magnitude faster at $T \sim$ TeV.**
**2. Natural B-nonconservation by TeV BHs in heavy particle decays.**
**3. CP violation may be stronger due to lower $T$ below sphalerons or due to theta-term.**

**THE END**