Baryogenesis from symmetry principle

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4 indisputable evidences of new physics

- Cosmic baryon asymmetry: BBN, CMB
- Nonzero neutrino masses: neutrino oscillation
- Dark matter: gravitational effects
- Dark energy: accelerated cosmic expansion

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In this talk, I will focus on the issue of Cosmic baryon asymmetry from *symmetry* point of view

Outline

- Motivations (review)
- Early Universe effective theories
- U(1) symmetries and charges
- The Standard Model (SM)
- The Minimal Supersymmetric SM (MSSM)

Baryonic content of the Universe

- BBN: t ~ 1 seconds (T ~ MeV)
- CMB: t ~ 380000 years (T ~ eV)
- Both give $n_B/s \sim 10^{-10}$ to within 10% precision
- ~~Incredible~~ Impressive agreements between the two instill confidence in the *Standard Model of Cosmology* (SMC)
- *No evidence* of *primordial antimatter* on various scales:
  - Galaxy (antiproton flux consistent with secondary production)
  - Clusters of galaxies (no gamma ray from matter-antimatter annihilations)
  - Observable Universe (no distortion on CMB background) [Cohen, De Rujula & Glashow (1997)]

Is baryogenesis necessary?

- Starting with baryon-antibaryon symmetric Universe, the annihilations freeze out at t ~ 10^{-2} s (T ~ 20 MeV) with tiny $n_B/s = n_{\bar{B}}/s \sim 10^{-19}$ (but today $n_B/s \sim 10^{-10}$, $n_{\bar{B}}/s \sim 0$)
- Statistical fluctuation: at T > 1 GeV $\frac{1}{\sqrt{N_B}} \sim \frac{1}{\sqrt{N_{\bar{B}}}} \sim 10^{-40}$ [Riotto (1998)]
- Initial condition: **inflation** makes this very unlikely
- To explain this small $(n_B - n_{\bar{B}})/s \sim 10^{-10}$, a dynamical generation mechanism involving the interplay between *particle physics* and *cosmology* is called for

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T_{BBN} < Baryogenesis < T_{RH}

Ingredients for baryogenesis 1

- a.k.a. Sakharov's conditions (1967)
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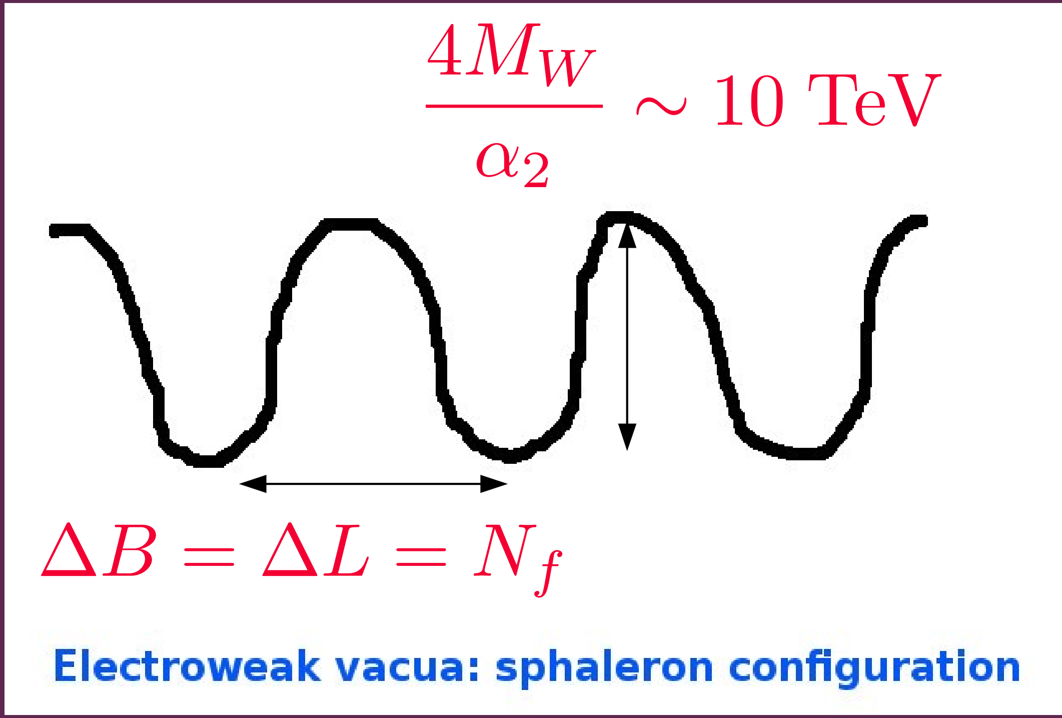

Anomalous symmetries

$$U(1)_B - SU(2)_L - SU(2)_L$$

$$U(1)_{L_\alpha} - SU(2)_L - SU(2)_L$$

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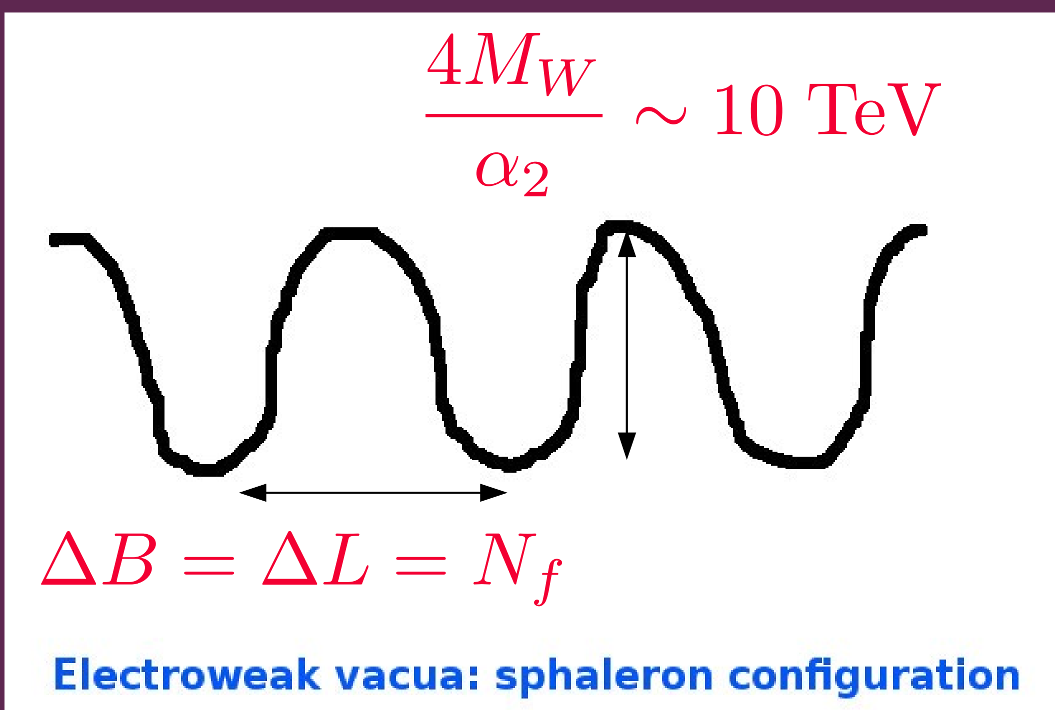

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T=0, quantum tunneling

$$\sim \exp\left(-\frac{4\pi}{\alpha_2}\right)$$ [t'Hooft (1976)]

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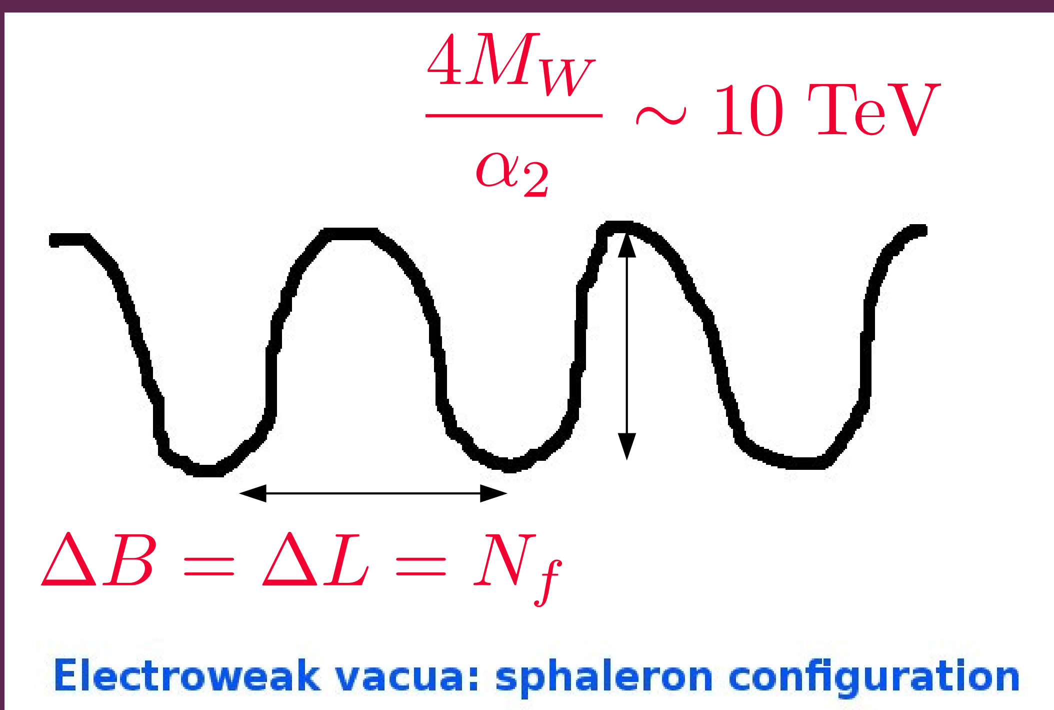

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$T>T_{EWPT}$, no suppression

$\Gamma_{\mathrm{EWsp}} \sim \alpha_2^4 T$ [Kuzmin, Rubakov & Shaposhnikov (1985)]

Ingredients for baryogenesis 1

- One can estimate when electroweak sphaleron (EWsp) are in thermal equilibrium by comparing with the rate of Cosmic expansion $H(T) = 1.66\sqrt{g_\star}T^2/M_{\rm Pl}$
  - $T_{EWsp-} \sim 100$ GeV < T < $T_{EWsp+} \sim 10^{12}$ GeV [Bento (2003)]
- For T > T_{EWsp-}, we have perfect source of B violation

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  - $T_{\rm EWsp-} \sim 100$ GeV < T < $T_{\rm EWsp+} \sim 10^{12}$ GeV [Bento (2003)]
- For T > $T_{\rm EWsp-}$, we have <u>perfect</u> source of B violation
- For T < $T_{\rm EWsp-}$, <u>new source</u> of B violation is required!
- Extensions to the SM with new source of B violation e.g.
  - SU(5) GUT [Georgi & Glashow (1974)]
  - dim-6 operators [Weinberg (1979)]
  - flat directions in the MSSM for baryogenesis [Affeck & Dine (1985)]

Ingredients for baryogenesis 2

- Both **C and CP violation**

$$\Gamma(X \to B_L B_L) + \Gamma(X \to B_R B_R) \neq \Gamma(X \to B_R^c B_R^c) + \Gamma(X \to B_L^c B_L^c)$$

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- Part of the SM
- In the SM, CP violation is not sufficient [Huet & Sather (1995)]

$$\frac{1}{T_c^{12}} J(m_t^2 - m_c^2)(m_c^2 - m_u^2)(m_u^2 - m_t^2)(m_b^2 - m_s^2)(m_s^2 - m_d^2)(m_d^2 - m_b^2) \sim 10^{-20}$$

- Extensions to the SM in general contains new sources of CP violation
- Interesting subject on its own

Ingredients for baryogenesis 3

- **Out-of-equilibrium condition**

$$n_B^{\mathrm{eq}}(\mu_B = 0) = n_{\bar{B}}^{\mathrm{eq}}(\mu_{\bar{B}} = 0) \qquad CPT : m_B = m_{\bar{B}}$$

- Part of the SM and SMC

(1) (Strong 1st order) phase transition: EW baryogenesis

- SM (requires $m_H < 70$ GeV) [Jansen (1995)]
- MSSM (ruled out?/difficult)
- MSSM + Georgi-Machacek (Mateo Garcia's talk)

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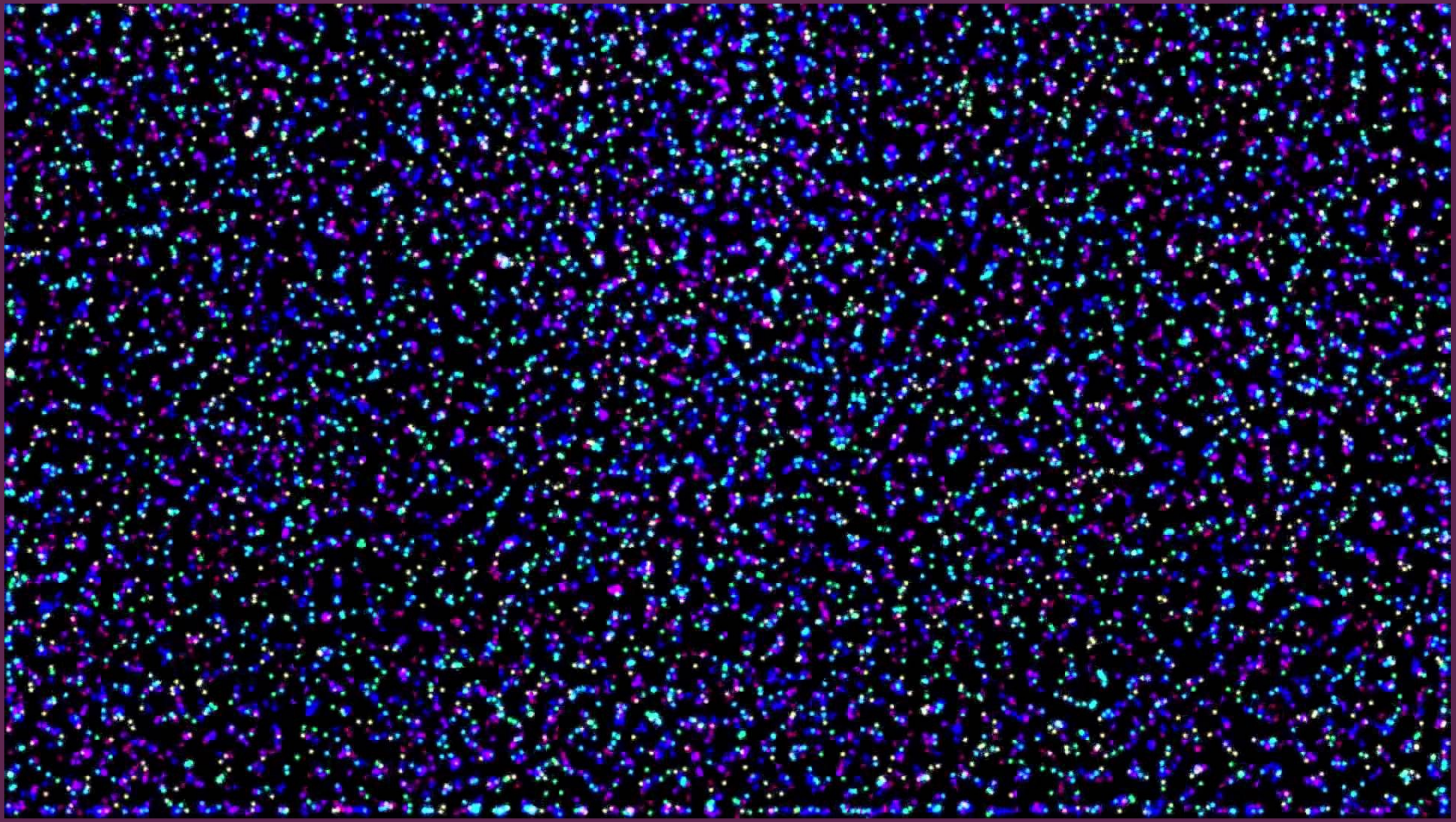
(2) *Cosmic expansion*

$$\Gamma(T) \lesssim H(T)$$

The early Universe is ...



Erza Anderson, Particle Soup

Early Universe effective theories

For the range of temperatures of interest T, reactions can be categorized into three types according to timescale:

(i) $\Gamma(T) >> H(T)$

- Achieve chemical equilibrium

$$\sum_I \mu_I = \sum_F \mu_F$$

Important assumption: fast gauge reactions $i + \bar{i} \rightarrow g$

$$\mu_g = 0 \implies \mu_i = \mu_{\bar{i}}$$

$$\sum_I \mu_I - \sum_F \mu_F = \sum_I \mu_I + \sum_F \mu_{\bar{F}} = 0 \implies \sum_i \mu_i = 0$$

- Can be "resummed" easily by identifying the *symmetries* of the system

Early Universe effective theories

For the range of temperatures of interest T, reactions can be categorized into three types according to <u>timescale</u>:

(ii) Γ(T) << H(T)

- Very slow due to small couplings, suppressions by temperature/mass scale (results in *effective symmetry*) e.g. electron Yukawa interactions

$$\Gamma_e(T) \sim 5 \times 10^{-3} y_e^2 T$$

$$T \gg 10^4 GeV \implies U(1)_e$$

[Cline, Kainulainen & Olive (1993)]

- Does no occur due to gauge symmetry (*exact symmetry*) e.g. hypercharge, electric charge

Early Universe effective theories

For the range of temperatures of interest T, reactions can be categorized into three types according to timescale:

(iii) $\Gamma(T) \sim H(T)$

- *Quasi/approximate symmetry*
- The evolution of the corresponding *Noether's charge* needs to be described by non-equilibrium dynamics like Boltzmann equation
- Essentially these are what we need to identify to obtain quantitative result

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Once we identity all the *U(1) symmetries* (exact/effective/approximate), the system can be described fully by the corresponding *Noether's charges*

U(1) symmetries and charges

- By symmetry, refer to U(1) symmetry which characterizes the *charge asymmetry* between particle & antiparticle (the diagonal generators of nonabelian group do not contribute)
- For each *complex* particle i (not real scalar or Majorana fermion), they can be assigned a chemical potential μ_i with charge q_i^x under $U(1)_x$
- For reactions of type (i), we have sets of linear equations

$$\sum_i \mu_i = 0$$

- By construction, if $U(1)_x$ is a symmetry of the system

$$\sum_i q_i^x = 0$$

- Hence the *most general solution* is $$\mu_i = \sum_x C_x q_i^x$$ Constants to be solved later

First introduced in [Antaramian, Hall & Rasin (1994)]

Some thermodynamics ...

- Particle i in *kinetic equilibrium* follows FD/BE distribution

$$f_i = \frac{1}{\exp(E_i - \mu_i)/T \pm 1}$$

Assumption: $i \to \bar{i}, \quad \mu_i \to -\mu_i$

- The number density is

$$n_i = g_i \int \frac{d^3p}{(2\pi)^3} f_i$$

- The number density *asymmetry* is

$$n_{\Delta i} \equiv n_i - n_{\bar{i}} = \frac{T^2}{6} g_i \zeta_i \mu_i$$

Assumption: $\mu_i/T \ll 1$

$$\zeta_i \to 1(2) \quad \text{for} \quad m_i \ll T; \quad \zeta_i \to 0 \quad \text{for} \quad m_i \gg T$$

- For each $U(1)_x$, the corresponding *Noether's charge*

$$n_{\Delta x} = \sum_i q_i^x n_{\Delta i}$$

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$$n_{\Delta x} = \sum_i q_i^x n_{\Delta i} \longrightarrow \frac{T^2}{6} \sum_i q_i^x g_i \zeta_i \mu_i \longrightarrow \frac{T^2}{6} \sum_y C_y \sum_i q_i^x g_i \zeta_i q_i^y$$

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J_{xy}

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Constants can be solved in terms of the *Noether's charge* and J_{xy}

Solutions

- The type (i) reactions are "resummed" in $J_{xy} \equiv \sum_i q_i^x g_i \zeta_i q_i^y$

$$C_y = \frac{6}{T^2} \sum_x J_{yx}^{-1} n_{\Delta x}$$

- The solutions in terms of only *Noether's charge*

$$n_{\Delta i} = g_i \zeta_i \sum_{x,y} q_i^y J_{yx}^{-1} n_{\Delta x}$$

- We can easily write down the *baryon asymmetry*

$$n_{\Delta B} = \sum_i q_i^B n_{\Delta i} = \sum_{x,y} J_{By} J_{yx}^{-1} n_{\Delta x}$$

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Detection of ("fast") B violation will not invalidate baryogensis due to fast washout but will be the source of B violation

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The roles of U(1) symmetries

- To clarify the roles of U(1) symmetries, let us single out the *exact symmetries* $U_0=\{U(1)_a, U(1)_b, \ldots\}$ and denote the rest of them as $\overline{U}=U-U_0=\{U(1)_m, U(1)_n, \ldots\}$. We can eliminate the U_0 charges using the following relation

$$n_{\Delta a}=0 \implies \sum_b J_{ab}C_b+\sum_m J_{am}C_m=0 \implies C_a=-\sum_{b,m} J^{-1}_{ab}J_{bm}C_m$$

- The number density asymmetry is

$$n_{\Delta i}=g_i\zeta_i\sum_{m,n}\bar{q}_i^m\bar{J}^{-1}_{mn}n_{\Delta n}$$

$$\bar{q}_i^m \equiv q_i^m-\sum_{a,b} q_i^a J^{-1}_{ab}J_{bm}$$

$$\bar{J}_{mn}\equiv J_{mn}-\sum_{a,b} J_{ma}J^{-1}_{ab}J_{bn}$$

Matrix with reduced dimension

Only nonexact symmetries

The roles of U(1) symmetries

- The baryon asymmetry is

$$n_{\Delta B} = \sum_{m,n} \left[J_{Bm} - \sum_{a,b} J_{Ba} J^{-1}_{ab} J_{bm} \right] \bar{J}^{-1}_{mn} n_{\Delta n} = \sum_{m,n} \bar{J}_{Bm} \bar{J}^{-1}_{mn} n_{\Delta n}$$

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Direct contributions

particles charged under $\overline{U}$ and carry B

Indirect contributions

particles charged under U_0 and $\overline{U}$ but do not carry B

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Generalization of the result of [Antaramian, Hall & Rasin (1994)] which states that a nonzero asymmetry in a preserved sector $\overline{U}$ that has nonzero hypercharge U_0 implies nonzero baryon asymmetry (a=b=Y).

The roles of U(1) symmetries

1. *Creator/destroyer*: type (iii) reaction of $\bar{U}$. The dynamical violation of $\bar{U}$ result in $n_{\Delta m} \neq 0$ from $n_{\Delta m} = 0$. The final $n_{\Delta m}$ depends on the rates of creation and washout.
2. *Preserver*: type (ii) reaction of $\bar{U}$ and nm neq 0. Prevent the asymmetry from being washout. The lightest electrically neutral particle in this sector (if stable) can be (asymmetric) dark matter.
3. *Messenger*: type (ii) reaction of U_0 and $n_{\Delta a}=0$. Some particles of $\bar{U}$ and some baryon needs to be charged under U_0 such that a nonzero asymmetry in $\bar{U}$ induces nonzero baryon asymmetry through U_0 conservation.

Example 1: The SM

- Let us define the U(1)$_x$– SU(N)-SU(N) mixed anomaly coefficient as $A_{xNN} \equiv \sum_i c_2(R) g_i q_i^x$

$$c_2(R) = \frac{1}{2} \quad \text{fundamental} \qquad\qquad c_2(R) = N \quad \text{adjoint}$$

$$\boxed{-\mathcal{L}_Y = (y_u)_{\alpha\beta}\,\overline{Q_\alpha}\epsilon H^* U_\beta + (y_d)_{\alpha\beta}\,\overline{Q_\alpha} H D_\beta + (y_e)_{\alpha\beta}\,\overline{\ell_\alpha} H E_\beta + \mathrm{H.c.}}$$

- We identify five U(1)'s: U(1)$_Y$, U(1)$_B$, U(1)$_{L\alpha}$

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- We identify five U(1)'s: $U(1)_Y$, ~~$U(1)_B$, $U(1)_{L\alpha}$~~
- The last four are anomalous: $A_{B22}=A_{L\alpha 22} = N_f/2$

$$\mathcal{O}_{\mathrm{EWsp}} = \sum_\alpha (QQQ\ell)_\alpha \longleftarrow$$ Type (i) reactions for T>100 GeV

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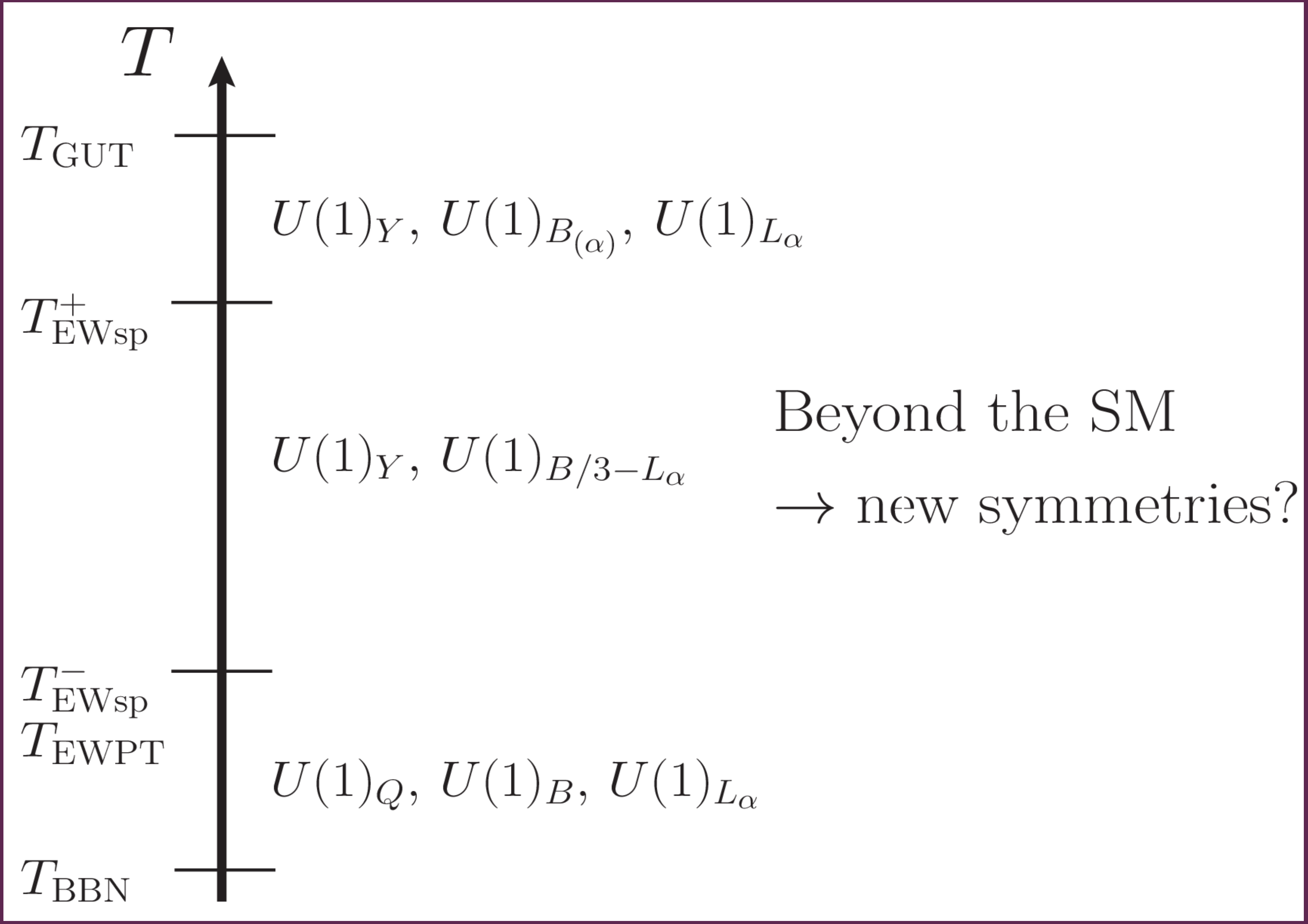
Due to quark mixing, $U(1)_{(B-L)\alpha} \rightarrow U(1)_{B/3-L\alpha}$

Example 1: The SM



Example 1: The SM

What we need ...

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What we need … a Table (& perhaps mathematica)

Table 1

The list of SM fields, their $U(1)$ charges q_i^x and gauge degrees of freedom g_i with fermion family index α. Here $N_H - 1$ is number of extra pairs of Higgses H' with the assumption that they maintain chemical equilibrium with the SM Higgs H.

$i =$	Q_α	U_α	D_α	ℓ_α	E_α	H	H'
$q_i^{\Delta_\alpha}$	$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$	-1	-1	0	0
q_i^Y	$\frac{1}{6}$	$\frac{2}{3}$	$-\frac{1}{3}$	$-\frac{1}{2}$	-1	$\frac{1}{2}$	$\frac{1}{2}$
q_i^B	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	0	0	0	0
$q_i^{L_\alpha}$	0	0	0	1	1	0	0
g_i	3×2	3	3	2	1	2	$2(N_H - 1)$

Example 1: The SM

Define the vectors: $q_i^T \equiv \left(q_i^{\Delta_\alpha}, q_i^Y\right), \quad n^T \equiv (n_{\Delta_\alpha}, n_{\Delta_Y})$

$$\Delta_\alpha \equiv B/3 - L_\alpha$$

At T ~ 10^4 GeV where all Yukawa interactions are in chemical eq.

Setting $n_{\Delta Y} = 0$, we obtain

$$J^{-1} = \frac{1}{3\,(198+39N_H)} \times \begin{pmatrix} 222+35N_H & 4\,(6-N_H) & 4\,(6-N_H) & -72 \\ 4\,(6-N_H) & 222+35N_H & 4\,(6-N_H) & -72 \\ 4\,(6-N_H) & 4\,(6-N_H) & 222+35N_H & -72 \\ -72 & -72 & -72 & 117 \end{pmatrix}$$

SM: $N_H = 1$

Equivalently, we can use the second formalism by constructing reduced matrix of 3 x 3 $\bar{J}$

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$\Delta_\alpha \equiv B/3 - L_\alpha$

At T ~ 10^9 GeV where 1st gen. Yukawa interactions are out of chemical eq.

Formally, $y_e, y_u, y_d \to 0$, we gain $U(1)_e$, $U(1)_u$, $U(1)_d$

Example 1: The SM

Define the vectors: $q_i^T \equiv \left(q_i^{\Delta_\alpha}, q_i^Y\right), \quad n^T \equiv (n_{\Delta_\alpha}, n_{\Delta_Y})$

$$\Delta_\alpha \equiv B/3 - L_\alpha$$

At T ~ 10^9 GeV where 1st gen. Yukawa interactions are out of chemical eq.

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- Formally, construct $n_{\Delta e}$ and set to zero (assuming initial $n_{\Delta e}=0$); in practice, set $g_e = 0$.
- u and d are indistiguisable under SU(3) (enter the same way in QCD sphalerons), set $Y_u = Y_d = 1/6$.

$$J^{-1} = \frac{1}{12\,(138+41N_H)} \times \begin{pmatrix} 807+210N_H & 12\,(5-2N_H) & 12\,(5-2N_H) & -222 \\ 12\,(5-2N_H) & 696+148N_H & 4\,(15-2N_H) & -312 \\ 12\,(5-2N_H) & 16\,(9-N_H) & 696+148N_H & -312 \\ -222 & -312 & -312 & 492 \end{pmatrix}$$

SM: $N_H = 1$

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Another important quantity: Relation between B and B-L

Define the vectors: $q_i^T \equiv \left(q_i^{B-L}, q_i^Y\right), \quad n^T \equiv (n_{B-L}, n_{\Delta_Y})$

- Assuming EW sphalerons decouple <u>before</u> EW phase transition (EWPT) i.e. consider the degrees of freedom in <u>unbroken</u> EW
- Consider all particles relativistic $\xi_i = 1(2)$, N_f fermion generations and N_H pairs of Higgs.

$$J^{-1} = \frac{1}{N_f\left(N_f + 13N_H\right)} \begin{pmatrix} 10N_f + 3N_H & -8N_f \\ -8N_f & 13N_f \end{pmatrix}$$

$$n_{\Delta B} = \frac{4\left(2N_f + N_H\right)}{22N_f + 13N_H} n_{\Delta(B-L)}$$

Result of [Harvey & Turner (1990)] but simpler derivation and easy to extend or generalize i.e. to consider mass threshold effects with ξ_i [Inui et al. (1994), Chung et al. (2008)])

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Table 2

Similar to Table 1 but for field components after EWPT where we use subscript 'L' to denote the left-handed fields which participate in weak interaction.

$i =$	$U_{\alpha,L}$	$D_{\alpha,L}$	U_α	D_α	$\nu_{\alpha,L}$	$E_{\alpha,L}$	E_α	W^+	H'^+
$q_i^{\Delta\alpha}$	$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$	-1	-1	-1	0	0
q_i^Q	$\frac{2}{3}$	$-\frac{1}{3}$	$\frac{2}{3}$	$-\frac{1}{3}$	0	-1	-1	1	1
q_i^B	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	0	0	0	0	0
q_i^L	0	0	0	0	1	1	1	0	0
g_i	3	3	3	3	1	1	1	3	$N_H - 1$

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$$J^{-1} = \frac{1}{2N_f\left[24N_f + 13\left(2+N_H\right)\right]} \begin{pmatrix} 2\left(6+8N_f+3N_H\right) & -8N_f \\ -8N_f & 13N_f \end{pmatrix}$$

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Example 2: The MSSM

- The superpotential

$$W = \mu_H H_u \epsilon H_d + (y_u)_{\alpha\beta} Q_\alpha \epsilon H_u U^c_\beta + (y_d)_{\alpha\beta} Q_\alpha \epsilon H_d D^c_\beta + (y_e)_{\alpha\beta} \ell_\alpha \epsilon H_d E^c_\beta$$

- Besides $U(1)_Y$, $U(1)_{(B-L)\alpha}$, we have an *R-symmetry* e.g.

$$q^R(H_d) = q^R(\ell_\alpha) = q^R(U^c_\alpha) = -q^R(E^c_\alpha) = 2$$

- This remains also with *R-parity violating* terms as well as *type-I seesaw* with $q^R(N_i^c) = 0$

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Contruct <u>*anomaly-free*</u> charge:

$$\bar{R} \equiv R + \frac{2}{3c_{BL}}(c_B B + c_L L), \quad c_{BL} \equiv c_B + c_L$$

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- Similarly at this temperatures, we can also set $\mu_H \to 0$ and we gain a *PQ symmetry (anomalous)* [Ibanez & Quevedo (1992)]

e.g. $-q^{PQ}(Q_\alpha) = q^{PQ}(\ell_\alpha) = q^{PQ}(H_u) = q^{PQ}(H_d) = 1,\ q^R(E_\alpha^c) = -2$

- Anomalies: $A_{PQ22} = -N_f + N_H$, $A_{PQ33} = -N_f$

With $N_f=3$, $N_H=1$, contruct A_{PQ22} *anomaly-free* charge:

$$\bar{P} \equiv \frac{3}{4} c_{BL} PQ + c_B B + c_L L, \quad c_{BL} \equiv c_B + c_L$$

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With $N_f=3$, $N_H=1$, contruct A_{PQ22} *anomaly-free* charge:

We still have to cancel A_{PQ33}!

$$\bar{P} \equiv \frac{3}{4} c_{BL} PQ + c_B B + c_L L, \quad c_{BL} \equiv c_B + c_L$$

Example 2: The MSSM

- We can make use of quark chiral symmetry discussed earlier. E.g. at T >> 10^6 GeV, up quark Yukawa interactions are out-of-equilibrium: $y_u \to 0$, gain anomalous $U(1)_u$
- Anomaly-free charge

$$\bar{\chi}_{u^c} \equiv \bar{P} + \frac{9}{2} c_{BL} u^c / q^{u^c}$$

$i =$	Q_a	U_a^c	D_a^c	ℓ_α	E_α^c	H_u	H_d
$q_i^{\Delta_\alpha}$	$\frac{1}{9}$	$-\frac{1}{9}$	$-\frac{1}{9}$	-1	1	0	0
q_i^{Y}	$\frac{1}{6}$	$-\frac{2}{3}$	$\frac{1}{3}$	$-\frac{1}{2}$	1	$\frac{1}{2}$	$-\frac{1}{2}$
$q_i^{\overline{R}}$	$\frac{2c_B}{9c_{BL}}$	$2 - \frac{2c_B}{9c_{BL}}$	$-\frac{2c_B}{9c_{BL}}$	$2 + \frac{2c_L}{3c_{BL}}$	$-2 - \frac{2c_L}{3c_{BL}}$	0	2
$q_i^{\overline{P}}$	$\frac{c_B}{3} - \frac{3c_{BL}}{4}$	$-\frac{c_B}{3}$	$-\frac{c_B}{3}$	$c_L + \frac{3c_{BL}}{4}$	$-c_L - \frac{3c_{BL}}{2}$	$\frac{3c_{BL}}{4}$	$\frac{3c_{BL}}{4}$
q_i^{B}	$\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0	0	0	0
q_i^{L}	0	0	0	1	-1	0	0
q_i^{PQ}	-1	0	0	1	-2	1	1
q_i^{R}	0	2	0	2	-2	0	2
g_i	3×2	3	3	2	1	2	2

Table 3: The $U(1)$ charges of left-handed chiral superfields. All gauginos $\widetilde{G}$, $\widetilde{W}$ and $\widetilde{B}$ have both R and $\overline{R}$ charges equal 1. Since all fermions in chiral superfields have R charges one less than that of bosons i.e. $R\,(\text{fermion}) = R\,(\text{boson}) - 1$, the differences between number density asymmetries of bosons and fermions are equal to that of gauginos.

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- Several comments:
  - c_B and c_L can be chosen at will as is convenient e.g. consider a model with $\mathcal{O}_B = U^c_\alpha D^c_\beta D^c_\delta$, choose c_B=0, $c_L \neq 0$ such that $\overline{R}$ and $\overline{P}$ are conserved by $\mathcal{O}_B$
  - Choosing $c_B = c_L$, the results are in *disagreement* with [Ibanez & Quevedo (1992)] due to sign error of gaugino chem. potential (could be avoided)
  - Effects of R-symmetry in supersymmetric leptogenesis (O(1) effect) [CSF, Gonzalez-Garcia, Nardi & Racker (2010)] and soft leptogenesis (O(100) effect) [CSF, Gonzalez-Garcia & Nardi (2011)]

Some takeaways

- The use of *symmetry formalism* makes it clear from the outset that the asymmetries of all particles will depend only on the *Noether's charges*
- All fast reactions i.e. type (i) are implicitly taken into account without having to be referred to explicitly. For e.g. we don't even have to know that EW and QCD sphaleron operators are modified in MSSM: $\mathcal{O}_{\text{EWsp}} = \tilde{H}_u \tilde{H}_d \tilde{W}^4 \prod_\alpha (QQQ\ell_\alpha)$
- The problem reduces to studying the dynamics of the *Noether's charges* (type (iii) reactions)
- Detection of ("fast") B violation will not invalidate baryogensis due to fast washout but will be the <u>source</u> of B violation and points to <u>new</u> U(1)'s as *creator/preserver*

Thank you for your attention