Hidden Sector Baryogenesis

Jason Kumar (Texas A&M University)
w/ Bhaskar Dutta (hep-th/0608188)
and w/ B.D and Louis Leblond (hep-th/0703278)

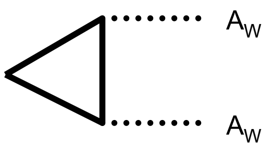
Basic Issue

- low-energy interactions seem to preserve baryon number
  - but world has more baryons than anti-baryons
  - how can we generate this asymmetry?
    - baryogenesis
  - Sakharov conditions
    - B violation (obvious)
    - C and CP violation (otherwise, create baryon/anti-baryons at same rate)
    - out-of-equilibrium (can't generate asymmetry in thermal equilibrium)

A few major models

- some major ideas
  - GUT baryogenesis
  - Affleck-Dine
  - leptogenesis
- electroweak baryogenesis
  - treat $U(1)_B$ as a global symmetry
  - left-handed quarks have weak interactions, but not right-handed
    - mixed anomaly $U(1)_B - SU(2)_L^2$
    - anomaly provides B violation via sphalerons (1 negative eigenval.)
      - sphaleron processes transition between different electroweak vacua, which changes baryon number

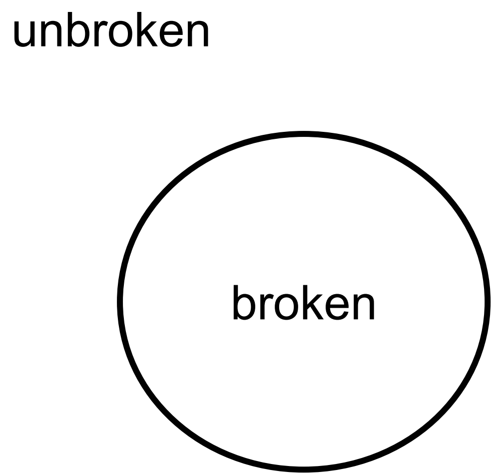
$$\partial_\mu J_B^\mu \propto Tr\left[F_W \wedge F_W\right] = \partial_\mu n_{CS}^\mu \left(A_W\right)$$



So, what happens?

- need EWPT to be 1st order
- need C and CP violation
  - CKM not enough
  - need complex Higgs phase
- as universe cools, T drops below T_c
  - bubbles nucleate
- at bubble walls
  - out of equilibrium
  - CP and B violation
  - end up with net baryon flow into broken region
- technical details depend on details of electroweak parameters

Bubble nucleation



Constraints on EWBG

- need sphalerons to shut down after transition
  - otherwise "washout"
  - need $\langle\phi\rangle \gg T_C$
- electroweak data
  - need EWPT - 1st order
  - need sphalerons to shut down
    - constraint on m_H
  - need large enough CP violation
    - leads to EDM constraints
- status of EWBG
  - EWBG in SM
    - need $m_H < 70$ GeV to get first order phase trans.
    - ruled out
  - in MSSM
    - need $m_H < 120$ GeV
      - 120 GeV $< m_{stop} < m_{top}$
    - LEP – $m_H > 114$ GeV
    - tight squeeze
  - in NMSSM
    - extra degrees of freedom
    - easier constraints

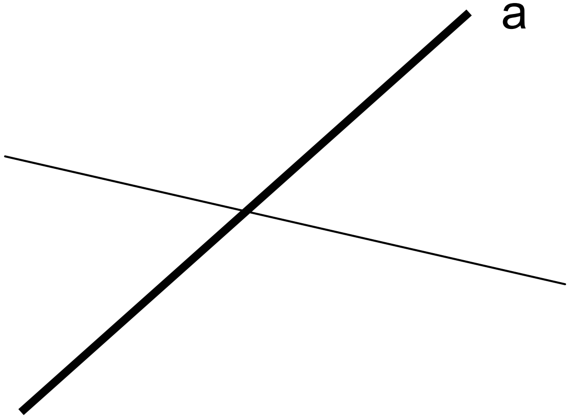
Our angle → Top down

- start from a string construction of SM-like effective field theory (we'll use intersecting brane models)
  - is there a "natural" way to get baryogenesis in this class of models?
  - Start with IBM motivation, but not tied down to a specific model→ "IBM motivated" but an EFT model
- IBM set-up → IIA compactified on orientifolded CY-3-fold – N=1 SUSY
  - D6-branes fill space-time, wrap 3-cycle
  - SM gauge theory on branes
    - $SU(3) \times SU(2)_L \times U(1)_Y$ [× hidden]

Branes and Matter

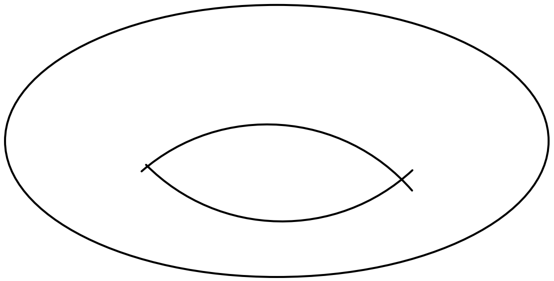
- chiral matter arises from strings living at topological intersection of branes
- divide up branes into two classes
  - "visible" sector branes → SM particles arise from strings which begin and end on these branes
  - "hidden" sector branes → the rest
- hidden sector branes are generic
  - we need them to cancel space-filling charges (RR tadpoles must vanish)

- I_{ab} chiral multiplets in the bifundamental of $G_a \times G_b$



Generic anomalies

- but net chiral multiplets in bifund. of $G_a \times G_b$ gives a mixed anomaly $U(1)_a$-G_b^2
- is this generic? yes
- take $T^6/Z_2 \times Z_2$
  - generically, $I_{ab} \neq 0$
- also non-zero for more generic CY compactification
  - cycles α_i, β_i → say a wraps α_1
  - I_{ab}=0 only if b_1=0



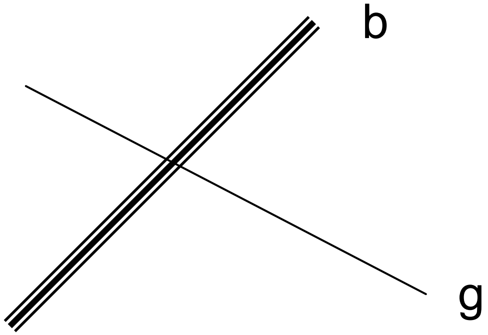
$$(n_1, m_1)(n_2, m_2)(n_3, m_3)$$

$$I_{ab} = \prod_{i=1}^{3} \left(n_i^a m_i^b - m_i^a n_i^b \right)$$

$$\int_{\alpha_i} \int_{\beta^j} \Omega \wedge \overline{\Omega} = \delta_i^j \qquad \sum_i a^i \alpha_i + b_j \beta^j$$

So what's the upshot?

- have brane stack "b" where $SU(3)_{qcd}$ lives
  - $U(1)_B$ is the diagonal subgroup of $U(3)_{qcd}$
- hidden sector group G lives on brane stack "g"
  - generically, I_{bg} is non-zero
  - chiral matter transforming under $U(1)_B$ and G
  - $U(1)_B$-G^2 mixed anomaly
  - G-sphaleron/instanton processes violate baryon number
- can use this to get baryogenesis in IBM



$$\partial_\mu J_B^\mu \propto Tr\left[F_G \wedge F_G\right]$$

What do we need?

- all cubic anomalies must cancel
  - automatic in IBM (RR-tadpole cancelation)
- non-vanishing $U(1)_B$-G^2 anomaly
- vanishing $U(1)_Y$ anomaly
  - easy to arrange – $U(1)_Y$ arises a lin. comb. of several U(1)'s – can find a set which is non-anomalous
  - needed for viable IBM
- Yukawa coupling permitting exotic baryon decay to SM baryons
  - can also arrange in IBM – fields with appropriate charge arise from generic intersections
    - worldsheet instantons generate coupling

Specific Model

- 4 stacks
  - a – $U(3)_{qcd}$
  - b – $U(1)_{T3R}$
  - c – $U(1)_L$
  - g – hidden group G
- more hidden sectors to cancel RR-tadpoles
- exotic chiral mults. are q, λ, η, ξ
- $I_{ag}=2$, $I_{gb}=4$, $I_{gb'}=1$, $I_{cg}=1$
- no $U(1)_Y$ anomaly
- but $U(1)_B$, $U(1)_{B-L}$ anomaly

$$U(1)_Y = \frac{1}{2}\left(U(1)_B - U(1)_L + U(1)_{T3R} - U(1)_G\right)$$

	Q_B	Q_G	Q_{T3R}	Q_L	Q_Y
$2\times q_i$	1/3	-1	0	0	2/3
$4\times \lambda_j$	0	1	-1	0	-1
η	0	1	1	0	0
ξ	0	-1	0	1	0

So what happens…?

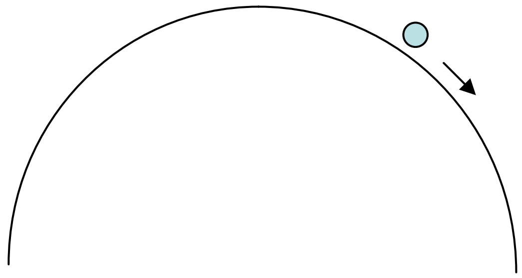
- like in EWBG, T drops as universe expands
  - at $T=T_C$, we have a phase transition where G either breaks or confines
    - needed for viable IBM, else chiral exotic fermions
- if transition is 1st order, nucleate bubbles of broken symmetry vacuum
  - at bubble walls, out of equilibrium
  - can have C and CP violation generically in G sector
  - G-sphalerons/instantons violate B
  - all Sakharov conditions satisfied
- so in this IBM scenario, baryon asymmetry can be generated

Points to note

- this is "natural" in IBMs
  - many hidden sectors
  - each generically has anomaly with $U(1)_B$
  - each must break/confine to avoid exotics (good IBM)
  - if even one has 1st order transition→ it can work
- generic $U(1)_{B\text{-}L}$–G^2 anomaly
  - EW sphalerons cannot wash out asymmetry even if generated above weak scale
  - avoids trouble with GUT baryogenesis
  - B-L anomaly could vanish (say Pati-Salam), but still works if G breaks at or below EW scale – gravity mediation
- details (like strength of transition, transport mech., local or non-local, etc.) are model dependent
  - not boxed in the way EWBG is

Can also realize HSB at inflation's end

- Louis discussed an inflation scenario in IBMs → inflaton and waterfall fields are bi-fundamentals
- when waterfall field condenses, energy dumped into long-wavelength modes
  - tachyonic preheating (FGGKLT)
  - can excite sphaleron
- during tachyon condensation, out of equilibrium
- if $I_{bg} \neq 0$ → $U(1)_B G^2$ mixed anomaly
  - baryon violation
  - with C and CP violation, can get baryogenesis



- Tranberg & Smit showed (numerically) that one can generate baryons in EWBG with tachyonic preheating
  - problem → low inflation scale
- since HSB has $U(1)_{B-L} G^2$ mixed anomaly, can work at higher scale
- whether numerics work out is model specific….