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In the Early Universe
And Early Generations
Quantum Transport Equations

(Santa Barbara)

Feb 90
ALWAYS "BEYOND THE SH" REQUIRED

Nucleo Syntheses

\[ \frac{N_R}{N_B} = 10^{-10} \text{ from WMAP} \]

Beyond Asymmetry

- Defeats
- Lensing
- Gravitational
- SuperNovae
- Large Redshifts
- Galaxies with
  (WHAP)
  CMB

Fascinating new observations

"Beyond Weierstrass, the three functions"

Astrophysics

Beyond Particle Physics

ELEVENTHARY PHYSICS

Cosmology GY
Barons: increase compression (odd) decrease rarefaction peaks
Phase Transition

Decay
Out of Equil.
Universe
Expanding

NON EQUILIBRIUM

SPINLESS BOSONS

PHASES IN NONSTATIONARY SYSTEM

CP

SKEIN THEORY

ELECTROMAGNETIC

CAUSALITY

PHYSICAL REALITY

3ARKO GEENSIS
Heavy Holography - Neutrino

• Lepton Number Violation BY

At the end of (hyperb) initialization.

• Creation of a Charge Asymmetry

• Coherent Baryogenesis

\[ \text{(phi)} \]

\[ \text{(phi)} \]

• sphaleron transition (SM)

\[ \text{(phi)} \]

\[ \text{(phi)} \]

\[ \text{(phi)} \]

\[ \text{(phi)} \]

\[ \text{(phi)} \]

Need 1st order phase transition.

• Electroweak Baryogenesis

Consider two models ≠ transport!
Du Ring - First Order Phase Transition
Electroweak and Baryogenesis

(But: Higgs Neutrino)

\( B - L = 0 \)

\( B', L = 0 \)

\( B, L \neq 0 \)

\( (B^2 + L) - \text{Volatility} \)

\( \text{Unsuppressed} \) in

\( \exp \left( -\frac{1}{\lambda} \right) \)

\( T \neq 0 : \text{Sphelepton} \)

The Ral Transition

\( T \neq 0 : \text{Sphelepton} \)
- CP violation on bubble walls
- CP violation in symmetric phase
- 
- Create chemical asymmetry
- Expanding bubbles of Higgs phase

**Charge Transport**

Electroweak baryogenesis at a strong first order transition
PHASE TRANSITION
GET STRONG 1. ORDER

Increase \( N_{\text{SSM}} \)

SUPER SYMMETRIC VARIANTS

FOR \( m \gg m_\text{EW} \) (Doublet\/Vector)

NO PHASE TRANSITION

\( S_1 \)

ELECTROWEAK BARYOGENESIS

KM - CP VERY SMALL
Does not exist in HSH

Does exist in NHSH

\[ \text{no restrictions by } \exp \text{ bounds on } \epsilon, \delta. \]

- No parameters at the PT
- Lower estimate near the critical
- Transitional CP-violation, part in the
- Potential (T-dependent)
- Spontaneous violation of CP in Higgs
- 

Restrictions by \( \exp \) bounds on \( \epsilon, \delta, \epsilon' \)
- In beat-frequency (via \( \epsilon', \delta' \))
- Matrix by complex \( N_2 \)

\[ \text{HSH: in Higgsino-Gaugino masses} \]

Explicit CP-violation
In front of Bubble Wall

by Hot, Spontaneous

Chiral Asymmetry

Dilatation Eqs. to Produce

Quantum Transport Eqs. for Chiral Anomalies

Boundary with CP Violating Effects

Transport in Presence of Holographic Phase

Our Subject Today

Deformation of SYM Phase

Viable

Higgs SYM Phase

Stationary Expansion

Yam .. ! Product

Temperature (One Bubble / Universe)

Super Cooling / Nucleation

Epsilon - Growth

Transition Probability

(Horizon) Higgs Field Critical Bubble

- A Very Concrete Step by Step Procedure

Electroweak Baryogenesis
Need first principle derivation.

\[ \text{Use this in classical transport (Boltzmann)} \]

Get split in part / amount.

Problem: Prin \neq \text{Prandtl in case of } \text{CP}.

\[ H = V \text{meas} \]

Later: Complex mass matrix.

Simplification: \[ \text{Ma} = \text{Im} \text{e} \]

\[ (c) e^{-\frac{c}{2}} \sqrt{\frac{2}{\pi t}} \]

Naive expectation: VK-B-Approximation

Dirac - Particles:

Need order \( \theta \) because of CP.

Derivative expansion.

Quasiclassical description.

\[ p \ll T \ll \text{thermalm} \]

\[ \text{Thick wall} \quad \alpha \ll \text{mean free path} \]

Diffusion in presence of having wall.
\[
\begin{align*}
\text{Wien-} & \text{Kramers} \\
\text{Central:} & \\
\text{Real Time / Keldysh Formalism} & \\
\text{Force (Kamalainen, Prokofe, Soh, Weinstock)} & \\
\text{First Principle Deriv of semiclassical} & \\
\end{align*}
\]
\[ c_{s} = c_{o} - s \sin \theta \left( \frac{1}{2}(c_{o} - 1) \right) \]

**Dispersion Relation**

\[ s = \frac{\omega}{c_{o}} = \frac{1}{\sqrt{1 - \frac{s^{2}}{c_{o}^{2}}}} \]

\[ \text{Sol.} \quad \frac{\omega_{0}}{c_{o}} = \sqrt{\frac{1}{\sqrt{2}} \left( \frac{c_{o}}{K_{o}^{2}} k_{0}^{2} \right)} \]

**Debye Exp.**

\[ \theta = \text{Angular } K_{o} \left( K_{o}^{2} > K_{o}^{2} \right)^{1/2} \]

\[ \theta_{s} = \frac{\omega_{0}}{c_{o}} \left( \omega_{0} \left( K_{o}^{2} \right) \right)^{1/2} \]

**First Order**

\[ \theta_{s} = \frac{\omega_{0}}{c_{o}} \left( \omega_{0} \left( K_{o}^{2} \right) \right)^{1/2} \]

\[ \text{CE - Eliminate} \rightarrow \theta_{s} \text{ Eq.} \]

**CE - Eliminate**

\[ \text{Transport Eq.} \]

**Imaginary Part**

\[ \text{Real Part of Dirac Eq.} \]

\[ \text{Conservation} \]

\[ \text{Conserved Spin} \]

\[ T \text{ Wall} \]

\[ -y = \frac{5}{4} x_{1} \times 8 \]

\[ \text{Wall} \]

\[ \text{Free Spin} \]
TE - USE CE AND ELIMINATE $\Rightarrow g_{00}^s$ EQ.

$$\left[ k_z \partial_z - \frac{1}{2} \text{Im} \omega \partial k_z - \frac{1}{2} \text{Im} \theta \partial k_z \right] g_{00}^s = 0$$

SECOND ORDER DERIV. EXP.

$\Rightarrow$ VLASOV EQ. FOR $f_s$

$$V_s \partial_z f_s + F_s \partial k_z f_s = 0$$

WITH $V_s = \frac{k_z}{\omega_s}$ GROUP VELOCITY

$F_s = -\frac{\text{Im} \omega}{2 \omega_s} + \frac{s(\text{Im} \theta)}{2\omega_s(\omega_s - k^2_{\perp})^{1/2}}$

CP VIOLATING SEMICLASSICAL FORCE

ROUGH AGREEMENT WITH WKB ($k_{\text{FIN}}$!)

CAN BOOST TO PLESHYA FRAME
\[ \text{Flavor Rotation} \]

\[ \left( \begin{array}{c} n_1 \\ n_2 \\ n_3 \end{array} \right) = \left( \begin{array}{c} m_1 \\ m_2 \\ m_3 \end{array} \right) \]

\[ \text{Higgsino: Gaugino- Higgsino Oscillations} \]

\[ H_{\text{Mass}} \]

\[ \text{Mass Matrix: Flavor Oscillations} \]
\[ \mathcal{L} = \mathcal{L}_{\text{matter}} + \mathcal{L}_{\text{force}} + \mathcal{L}_{\text{gravity}} \]

**CP Violation Sources**

- **CP Violating Sources**
- **Without Interacting Constraints (K-lobe)**
- **Obtain Kinetic Eq.** in stationary case
- **Nonlocal in higher derivative orders**
- **Separate Constraints/DISP. Eq.**
- **Construct Proce.**

\[ \varphi = \varphi_0 + \varphi_1 \]

\[ \varphi_0 = \varphi_1 \]

\[ \Gamma = \Gamma_0 + \Gamma_1 \]

\[ \Gamma_0 = \Gamma_1 \]

\[ \Theta = 0 \]

\[ \Theta = \Theta_0 \]

\[ \Theta_0 = \Theta_1 \]

**CP Neutrino**

**Flavor Rotation of Mass Matrix**
For comparison:

\[ T \equiv \text{Typical} : \sim \text{CP-violating currents (vector, axial)} \]

\[ \frac{1}{2} R^2 \text{C/P/E - Transformed EEs.} \]

\[ (\text{And } R \leftrightarrow \nu, \text{ s} \leftrightarrow \bar{\text{s}}) \]

\[ \begin{align*}
K^{\pm} & \rightarrow \text{CP-violating EEs,}
\end{align*} \]

\[ \begin{align*}
& \text{with } S_F = -S^{\bar{F}} \text{ for } \bar{F}.
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& \text{with } S_F = -S^{\bar{F}} \text{ for } \bar{F}.
\end{align*} \]
**Exercise:**

1. In lowest (no) derivative order:

\[ \nabla^a \rightarrow \nabla^a, \quad \nabla^a \rightarrow \nabla^a \]

2. In diagonal basis:

\[ \nabla^a = \{ \nabla^a e_1, \nabla^a e_2 \} \frac{1}{2} - \{ \nabla^a e_1, \nabla^a e_2 \} \frac{1}{2} + \nabla^a e_2 \nabla^a \]

3. Heelner + Antenna.


Bayh-Kadmon-Eo.

[Note: Non-Newtonian (Exercise)]
\[ n_\ell = 5n_\ell + 4n_r \]

\[ \frac{\gamma_{\text{em}}}{\gamma_{\text{em}}} \]

\[ n_\beta = -3 \sqrt{\text{Wek}} \text{ GeV} \]

Produce Baryon Asymmetry

AND CP - TRANSLATION

LEFT HANDED QUARKS + LEEPTONS

SPALATION TRANSITION:

\[ \Rightarrow \text{DIFFUSION EQUATIONS} \]

\[ \rightarrow \text{QUARKS + LEEPTONS} \]

\[ (\text{ASYMMETRIC}) \]

\[ \text{CHARGINO DECAY} \]

\[ \text{CHARGINO BARYOCENESIS} \]

\[ \text{IMPORTANT} \]

\[ \text{ALSO GENERATE CP - ASYMMETRY} \]

\[ \text{DRIVE SYSTEM BACK TO EQUILIBRIUM} \]

\[ \text{COLLISION TURNS} \]
The diffusion equations are derived from the Lagrangian for left-handed fermions and leptons in the presence of a magnetic field. The diffusion coefficients are given by

$$
\begin{align*}
\frac{d\Phi}{dt} &= \nabla \cdot \left( \tau \Phi \right) \\
\end{align*}
$$

where $\Phi$ denotes the density of the left-handed fermions and leptons. The diffusion equations are

$$
\begin{align*}
\frac{d\rho}{dt} &= \nabla \cdot \left( \tau \rho \right) \\
\end{align*}
$$

To determine how the CP-violating currents are transported from the charginos to the weak interaction and produce a net baryon number, we use a system of coupled diffusion equations derived in a vacuum. These diffusion equations are

$$
\begin{align*}
\frac{d\rho}{dt} &= \nabla \cdot \left( \tau \rho \right) \\
\end{align*}
$$

Using our formalism, we can deduce the CP-violating particle densities in the charging sector.
Restrictions for R.L. Greenberg

Maximal CP-Violation

The figure plots the region of $m_A = 400$ GeV. The black region denotes $\rho_0 < 1$, whereas the yellow region is viable. The right plot for $m_A = 400$ GeV is used, for $0 < \Gamma(0 \to 100 \text{ GeV}, 100 \text{ GeV}) < 1$ and the left plot the value for $m_A = 200$ GeV is used. For $\gamma_{\pi} H(\phi)$ parameter space from

Fig. 5: The baryon-to-entropy ratio $\rho_0 = 10^{-10}$ in the $(m_H^2, \phi^2)$ parameter space from

H. S. Eucen, H. L. Gefen, T. Prokopec, T. Constandin

HSS
MAXIMAL CP VIOLATION ASSIGNED

\( T = 0.25 \alpha T \)

C6V. The plot on the left shows the sources with the damping, \( T = \alpha T \), while on the right plot, \( V_{\text{eff}} = 200 \).

FIG. 2: This plot shows the first and second order sources as a function of \( \tau \) with \( V_{\text{eff}} = 200 \).

\[ 10 \left( \frac{\delta}{\delta \nu} \right) = 10 \left( \frac{\delta}{\delta \nu} \right) \]
The MSSM 2 loop Higgs contribution for electron EDM

\[ d_{\text{edm}}^e \sim 1 \times 10^{-32} \text{ cm} \]

The standard model (WSM) value

\[ d_{\text{edm}}^e \sim 1 \times 10^{-38} \text{ cm} \]

The current measurement bound on the electron electric dipole moment (EDM)

\[ |d_e| < 1.6 \times 10^{-27} \text{ cm} \]

Electric Dipole Moment From MSSM
Produced parity asymmetry in random MSSM models.
For Fermions / Bosons

Høyer & Eg. (Schrödinger-Keldysh CTP)

Consider "Quantum Boltzmann Equ.

Asymmetry \( \rightarrow \) Barvon Asym.

\( \leftrightarrow \) CP of Mass Matrix

Toled to E-L

Certain charge numbers twist -

of scalar cond.

by non-adimensional time dependence

Coherent Partile Production

Mass Matrix in Cosmology

Induces the dependent

Scalar field condensate

Coherent Barvogenesis
The Helicity Operator $\mathbf{A} = \mathbf{K} \cdot \mathbf{P}$

Simultaneously Remove

The phases cannot be

$\mathcal{M}(t) \text{ and } \mathcal{M}(t) \text{ CP-violating}$

$\mathcal{M} = \frac{2}{3} \mathcal{M} + \mathcal{M}^*$

Dirac-EO, with the dependent

Dirac-EO and EO. Species

$< G_x(x) = \int \rho_0 G_x >$

(Closest to classical phase space distributions)

Wigner Functions
2. a. \( \text{Gal}(k') \) Conicseven (Yukawa interaction)

- Helicity \( k' = \text{Gal}(k') \)
- Charge of hole with hole, and

\[
\text{for } f \rightarrow -\infty \quad \text{for } f \rightarrow \infty
\]

Initial cond.: No fermions

EXACT MTH

HEISEN.

\[
\text{coll.} \quad 10
\]

HAT RIX EAS

\[
\frac{d}{dt} f_{\text{coll}} + f_{H} = 0
\]

\[
\text{for } 2n \text{ even } f_{H} + f_{H} = 0 \quad [M_{H, f_{H}}] + f_{f_{H}} = 0
\]

\[
\text{for } 2n \text{ odd } f_{H} + f_{f_{H}} = 0 \quad [M_{f_{H}, f_{H}}] + f_{f_{H}} = 0
\]

\[
\text{for } 2 \text{ odd } f_{H} + f_{f_{H}} = 0 \quad [M_{f_{H}, f_{H}}] + f_{f_{H}} = 0
\]

\[
\frac{d}{dt} f_{\text{coll}} = \frac{d}{dt} f_{H} = \frac{1}{2} \sum_{k} \left( \text{Gal}_k + \text{Gal}_k \right) \otimes \left( \text{Gal}_k \right) \otimes \left( \text{Gal}_k \right)
\]

\[
\log n = \frac{1}{4} \left( \frac{1}{n} + \frac{1}{n} \right) \otimes \left( \frac{1}{n} \right)
\]

Decompose
A2450
A2456

Fgure 1: Hybrid Potential

(INFLATION)

HYBRID INFLATION
\[ F_c = \left( \frac{4}{\sqrt{3}}, 1, 2 \right) \text{ leptons } + (6, H) \text{ quarks} \]

- \( B - L \) asymmetry generated
- \( SU_2 \) Real Conly
- \( C = \text{Charge} \)
- For \( S \neq 0 \): Generate change \( Q_1 = -\frac{1}{2} \)

\[ \langle S \rangle = \frac{\langle S \rangle}{\langle S \rangle} = \frac{\langle S \rangle}{\langle S \rangle} \]

\[ m_c = \frac{4}{\sqrt{3}} \]

\[ \left[ \begin{array}{c} \chi_r \cr \chi_i \end{array} \right] = \left[ \begin{array}{c} \chi_r \cr \chi_i \end{array} \right] \]

\[ \text{Mass - Matrix} \]

\[ \left( \begin{array}{c} \chi_r \cr \chi_i \end{array} \right) = \left( \begin{array}{c} \frac{1}{2} \cr -\frac{1}{2} \end{array} \right) \]

\[ \chi \]

\[ \text{Dirac Fermions} \]
The produced charges of the Dirac fermions $\chi^f$, $\chi^c$ are summed over both helicities.

**Hybrid Inflation**

**Coherent Barocogenesis in**
\[ 3 \cdot \frac{3}{2} \cdot \frac{9}{4} = \frac{27}{8} \]

\[ B - L = - \frac{3}{2} q_2 + \frac{1}{3} q_1 = q_1 \]

**Vacuum Energy**

\[ S < 2/3 \times 10^{15} \] Easy

**Detailed Reheating**

**Estimate**

**After sphaleron processes**

\[ B = \frac{10}{3} (B - L) \]

**Couplings**

\[ x \rightarrow \frac{\Delta}{H} \]

\[ x \rightarrow \frac{\Delta}{H} \]

\[ \Delta \rightarrow d + \gamma \text{ Majorana} \]

No CP decay required in leptogenesis.

\[ \chi \rightarrow \ell e \text{ Higgs for } \ell \]

\[ H = \text{ Majorana} \]

\[ \chi \rightarrow \Delta \text{ Higgs} \]

Singlet scalar fermion (with tree one-loop interference)
\[ H_0^2 = \frac{\rho_{de}}{3 \rho_{m}} \]

Energy density after inflation:

\[ \rho = \frac{2 \pi \rho_{m}}{9} \]

Entropy density:

\[ S = \frac{2 \pi 8 \pi T_0^3}{9} \]

\[ T = \frac{\sqrt{\rho}}{\sqrt{S}} \]

\[ N_{\text{eh}} \sim 10^{63} \text{ GeV}^{2} \]

\[ N_{\text{eH}} \sim 10^{14} \text{ GeV} \]

Reheating temperature:

\[ T_{\text{reheat}} \sim 10^{5} \text{ GeV} \]

\[ T_{\text{reheat}} \sim 2 \times 10^{18} \text{ GeV} \]

\[ \frac{\rho_{\text{de}}}{\rho_{m}} \sim 1 \times 10^{-11} \]

\[ \frac{\rho_{\text{eH}}}{\rho_{m}} \sim 3 \times 10^{-17} \]
\[ \frac{S}{\sqrt{b}} \approx 8 \times 10^{-11} \]
\[ \approx \frac{10^5 \text{GeV}}{0.01 \text{TeV}} \]
\[ \frac{10^{-6} \text{TeV}}{1} \]
\[ \frac{10^5 \text{GeV}}{0.01 \text{TeV}} \]
\[ \frac{S}{\sqrt{b}} \geq 3 \times 10^{-11} \]

I - Loop Interference
Maximum Mixing And CP Violation Via

NonTheHali

\[ m_H = 2.7 \times 10^9 \text{GeV} \]

Lightest Higgs \( H^0 = 2.9 \times 10^7 \text{GeV} \)

\[ \psi \]

- Higgsinos Neutrino Mass After Preliminary

NonTheHali LeptoGeneS (in Same Model)
CONCLUSIONS

- Models for the generation of a baryon asymmetry have to combine detailed informations from elem. particle physics, cosmology, and quantum (at least to) transport theory

- Try to narrow down to models explaining also other features in cosmology (inflation...) and elem. particle physics (Gut's...)

- Most aspects: beyond the Sh!

- Common feature: B+L \Rightarrow 0 by hot sphaleron in equilibrium

- B-generation in (modified) electroweak theory at phase boundary

- At Gut/inflation energies by nonequilibrium and L-violating Majorana neutrinos

Exiting field at the borderline between cosmology and elem. particle physics