Unification with mirror fermions

G. Triantaphyllou

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Outline

1. Introduction
   - The hierarchy problem
   - Inspiration
2. Symmetry breaking, unification and spinor gravity
   - Symmetry-breaking chain
   - Coupling convergence
   - Spinor gravity
3. Critical behaviour and emergence of symmetry
   - Estimating the unification coupling
   - Emergence of symmetry
   - Cosmological implications (**speculative**)
4. Summary

Why is the weak scale so small?

- Why are particles so much lighter than a small grain of sand?
- Weak scale $\sim 10^{-17} M_{Planck}$
- Higgs (/ Guralnik, Hagen, Kibble / Englert, Brout) (1964) mechanism successful but unstable

Stabilization symmetry needed

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Previous work

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- J.C. Pati and A. Salam (1973): Coupling unification
- F. Gursey and P. Sikivie (1976): E_7 GUT (W. Killing 1888)
  N.S. Baaklini; I. Bars and M. Gunaydin (1980): E_8 GUT
- S. Weinberg (1976), L. Susskind (1979):
  Dynamical Higgs mechanism
  Universe: a "superconductor", $Higgs \sim < \bar{\Psi}\Psi >$
- F. Wilczek and A. Zee (1982):
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Top quark A_{FB}: New Physics?

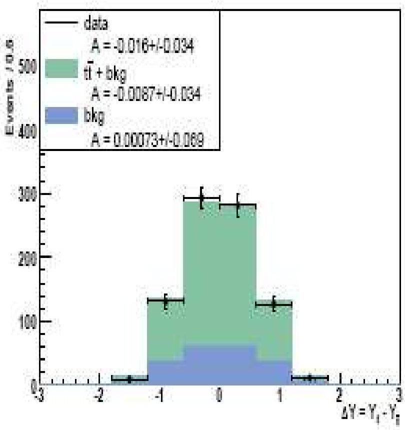

FIG. 12: Top: The distribution of Δy at low mass (left) and high mass (right).

> 3 σ effect: CDF Collaboration, PRD 83: 112003 (2011)

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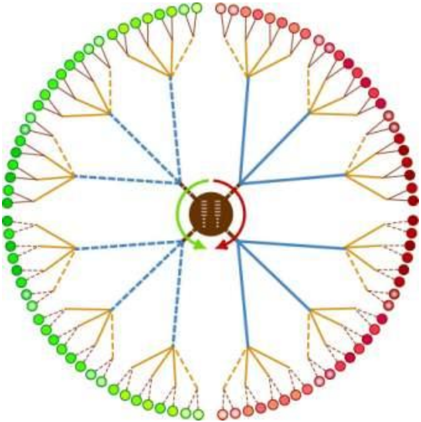
The model (1998 - present)



Breaking chain (Z_2 factors omitted)

$$E_8 \times E_8' \text{ (at } \Lambda_{GUT} \sim M_{Planck}) \rightarrow$$

$$SU(5) \times U(1)_X \times SU(5)' \times U(1)_X' \times SU(3)_K \text{ (at } \Lambda_{23}) \rightarrow$$

$$SU(3)_C \times SU(2)_L \times U(1)_1 \times U(1)_1' \times SU(3)_K \text{ (at 1 TeV)} \rightarrow$$

$$SU(3)_C \times U(1)_{em}$$

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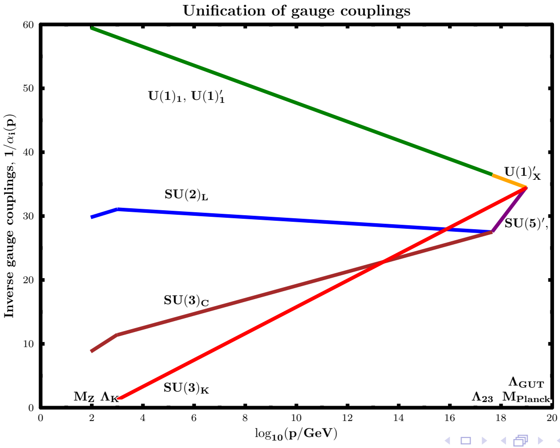
$1\ \mathrm{TeV} \sim M_{\mathrm{Planck}} \exp\left(-\frac{6\pi}{17\alpha(M_{Planck})}\right)$ (G.T. 2011)



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Metric: inherently quantum-mechanical

- $g_{\mu\nu} =< \tilde{E}^m_\mu(x) >< \tilde{E}_{\nu m}(x) > \neq 0$ only for $m, \mu, \nu = 0, ..., 3$
- $\tilde{E}^m_\mu(x) \sim \bar{\Psi}(x)\gamma^m\partial_\mu\Psi(x)$, $m, \mu = 0, ..., d \geq 3$
  A. Hebecker and C. Wetterich (2003)
- Physical distances: induced by fermion correlat. functions; spacetime: dynamical, non-perturbat., not just background
- $S_f \sim \int d^d x \det(\tilde{E}^m_\mu) \rightarrow$
  $S_{<mean\ field>} \sim \int d^d x \det(< \tilde{E}^m_\mu >)(1 - < \tilde{E}^\mu_m > \tilde{E}^m_\mu + ...) \rightarrow$

  gravitational + gauge interactions:
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The value of $\alpha(M_{Planck})$

- Nambu-Jona-Lasinio (1961) inspired self-energy **m**

$$\frac{<\bar{\Psi}\Psi>}{M^2_{\rm Planck}} \equiv \mathbf{m} \sim \frac{\alpha C_2}{4} \int_0^{M^2_{\rm Planck}} \frac{\tilde{k}^2 d\tilde{k}^2}{max(k^2,\tilde{k}^2)} \frac{\mathbf{m}}{\tilde{k}^2+\mathbf{m}^2}$$

- $\alpha^{-1}(M_{Planck}) \sim C_2(E_8) = 30$ for $k \lesssim m$
- 1 TeV $\sim M_{\rm Planck} \exp(-1.23\, C_2)$ (G.T. 2011)
- Assume $\alpha(M_{Planck})$ = critical coupling for

$<\bar{\Psi}(x)\gamma^m\partial_\mu\Psi(x)> \neq 0$ leading to

  - Gauge-symmetry breaking via the $\mathbf{248}_a$ of E_8
  - Dynamical metric generation

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A toy lattice model (UV cut-off?)

- $S_{<mean\ field>} \to S_{lat} = \sum_{<i,j>} \mathcal{E}_{ij} \bar{\Psi}_i \Psi_j$

- Single-state Potts model (1952): percolation phenomena
  Local in sites
  $H_P = -J \sum_{<i,j>} \delta(S_i, S_j), \quad J > 0$ (ferrom.), $S_i = 0, 1$
  $\delta(S_i, S_j) = 1$ for $S_i = S_j = 1$, $\delta = 0$ otherwise

- Partition function (**non**-local in edges):
  $Z = \sum_{C_i} \left(e^{\beta J} - 1\right)^{E_i},$ $\qquad E_i$: # edges in cluster C_i

- Phase transition (large clusters) when
  $k_B T \leq k_B T_c = J/\ln 2 \sim 1.4 J$

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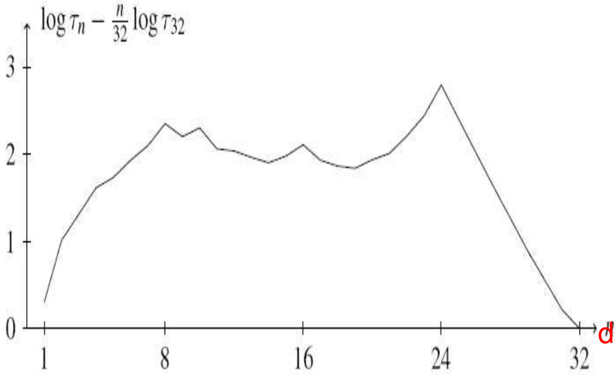
$\tau_d \equiv$ max(nearest-neighbor # in R^d) $\sim$ min(E_i): Cohn-Jiao-Kumar-Torquato (2011)

y-axis $\sim \log(\tau_d) - 0.17d$

Ostwald's rule (1897)



Self-organized criticality

Optimal lattices Γ: study via $\Theta_\Gamma(z) = \sum_{\lambda\in\Gamma} e^{i\pi z|\lambda|^2}$ (Im(z)>0),
modular form if Γ even & self-dual: $(-i)^{d/2} = 1 \Rightarrow d = 0$ mod(8)

- d=8: E_8 root lattice Γ_8, $\tau_8 = 240 =$
  $=$ max(τ_d of a Γ corresponding to roots of a Lie group);
  optimality of Γ_8: H. Cohn and A. Kumar (2007)

- d=16: Barnes-Wall Γ_{BW} (1959), $\tau_{16} = 4320$ (**not** self-dual)
- d=24: Leech lattice (1967), $\tau_{24} = 196,560$;
  largest of the 24 Niemeier lattices,
  related to largest sporadic finite simple group (Griess 1976)

- **Conjecture**: $E_8 \times E_8'$ emerging via Frenkel-Kac (1980)
  compactification on $T^{16}/(\pi\Gamma_8 \times \pi\Gamma_8)$: variant of d=8 case

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Do we find ourselves within a glass-crystal transition?

- Cosmological constant?
- Crystal formation $\rightarrow$ inflation, initial entropy, arrow of time? Connection with spin glasses?
- Dark Matter & Energy, elementary particles: **topological**?

  Particle # density: $d_p \sim S_p/S_B \sim 10^{-33} \sim \exp(-H/k_B T_{eff})$
  (H: enthalpy cost of a vacancy defect)
- Connection with
  - Intergalactic voids (larger than simulations)?
  - Shape of spiral and scarcity of dwarf galaxies?
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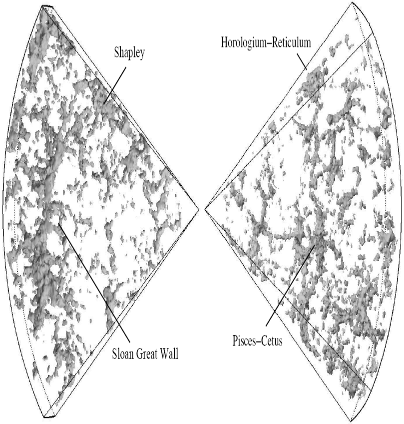
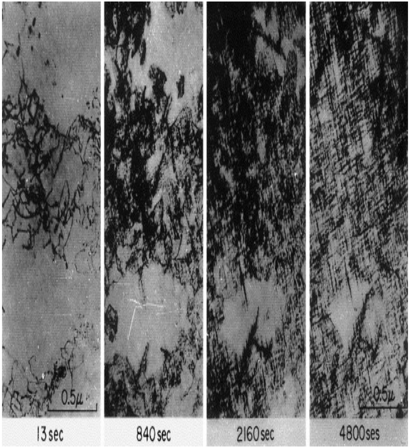
Solid state meets Particle Physics and Cosmology I: Free-energy minimization → clustering

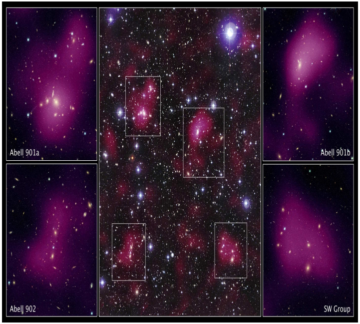


2dF Galaxy Redshift Survey, W. Schaap (2007)

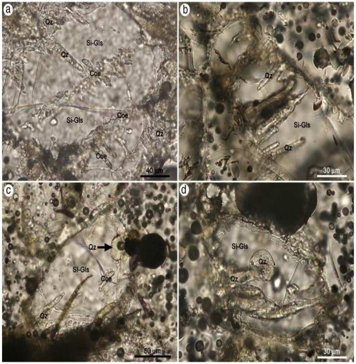


Vacancy clusters in Cu, M. Kiritani (J. Nucl. Mat. 2000)

Solid state meets Particle Physics and Cosmology II: Is Dark Matter topological?



DM inferred by gravitational lensing from Abell 901/902 galaxy superclusters Hubble, ESO et.al. (2008)



Qz within Si-Gls from Xiuyan crater, M. Chen, W. Xiao, X. Xie (E. Plan. Sci. Lett. 2010)

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- Emerging symmetry → family structure, spacetime dim.
- Topological nature of DM, DE, elementary particles?
- Optimal Connectivity Principle

- Check
  - Spinor gravity potentiality (UV cut-off, dynamic. spacetime); connection with non-commutat. geometry (Connes 1979)?
  - Γ_8 metastability, Potts model universality class
  - the S parameter, mass-dependent couplings, $|V_{tb}|$
  - the LHC for mirror particle signals (G.T. 2000); plans for a 3-4 TeV linear collider
  - **the structure of spacetime**

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- Optimal Connectivity Principle

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  - the S parameter, mass-dependent couplings, $|V_{tb}|$
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Only if question arises

Dimensional arithmetics

String theory:

d_0 = **24** (Leech)+ **2** (world-sheet) = **26** (spacetime: background)

$d_{c1} = d(E_8 \times E_8, \mathrm{R})$ = **16** (symmetry underutilization?)

d_{c2} = **6**

$d_{spacetime} = d_0 - d_{c1} - d_{c2} = \mathbf{4}$ (R)

Spinor gravity applied to Katoptron theory:

$d(E_8\ cluster) = \mathbf{8}\ (R) \longrightarrow d(E_8, C) = \mathbf{8}\ (C) \rightarrow$

crystalization: $d_0 = d(E_8 \times E_8', \mathrm{C})$ = $2d(E_8, C)$= **16** (C)

$d_c = d(E_7 \times E_7', \mathrm{C})$ = **14** (C)

$d_{spacetime} = d_0 - d_c = \mathbf{2}$ (C) = **4** (R) (spacetime: dynamical)

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String theory:
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