Two (too) Big Problems

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at：YITP Lunch meeting

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Two Big Problems (too)

- Tiny cosmological constant
- Why 3 generations ?

Cosmological constant Λ, or vacuum energy

- Present value

$$\Lambda_0 \approx 10^{-29} \mathrm{gr/cm^3} \approx (2.5 \times 10^{-12}\ \mathrm{GeV})^4$$

$$\approx 10^{-56} \times \langle \mathrm{Higgs} \rangle^4$$

$$\approx 10^{-120} \times (M_{\mathrm{Planck}})^4$$

Reduced Planck scale $M_{\mathrm{Planck}} = 10^{18}$ GeV

Particle Physicists: static view

- Why is it so tiny?

  $\Longleftrightarrow$ huge zero-point vacuum energies of fields
- Global SUSY guarantees $\Lambda = 0$

  But it is (spontaneously) broken at

  $M_{SUSY} \approx$ 1 TeV so that we expect

  $\Lambda = (M_{SUSY})^4 \approx 10^{60} \times \Lambda_0$
- Moreover,

SUGRA (local SUSY) does not guarantees $\Lambda = 0$,
but requires fine tuning of 10^{-120} order

Particle cosmologists: historical view

- Why is it so tiny at present?
- We know that several spontaneous symmetry breakings occured in the past, which must have been accompanied by vacuum condensation.

(in collaboration with

Makoto Kobayashi, Naoshi Sugiyama and his student)

Particle cosmologists: historical view

- In the order going back history,

1. QCD chiral sym breaking: $-\Lambda_{QCD} \approx -(200\ \text{MeV})^4$
2. Electroweak symmetry breaking:

   $-\Lambda_{EW} \approx -(200\ \text{GeV})^4$
3. GUT symmetry breaking:

   $-\Lambda_{GUT} \approx -(10^{-2} M_{Planck})^4$

So that the initial cosmological constant should be

$$\Lambda_{initial} = \Lambda_0 + \Lambda_{QCD} + \Lambda_{EW} + \Lambda_{GUT} + ?$$

where $\Lambda_0 \ll \Lambda_{QCD} \ll \Lambda_{EW} \ll \Lambda_{GUT}$

Particle cosmologists: historical view

- There must be huge cosmological constant at the beginning of our universe:

$$\Lambda_{initial} = \Lambda_0 + \Lambda_{QCD} + \Lambda_{EW} + \Lambda_{GUT} + ?$$

nearly 10^{120-8} times larger than Λ_0

.

- Explain this initial value
- Possibility of observation of this history

Why 3 generations ?

- CY compactification of String

  Explains

  $3 = \text{big}\ \# - \text{big}\ \#$,

  big# : Hodge numbers of CY mfd

- SU(1,1) symmetry model

  $3 = \infty - \infty$

Quasi-NG-fermions

- If spontaneous breaking of a global symmetry: $G \rightarrow H$, then
  Nambu-Goldstone bosons appear for
  broken generators G/H at around M_{Planck}
- If ∃SUSY, NG bosons are accompanied by massless spin ½ fermions, called Quasi-NG-fermions
  (Buchmüller-Peccei-Yanagida'87, Ong'83)
- Kugo-Yanagida'84
  three generations from $E_7/SU(5) \times SU(3) \times U(1)$

Exceptional Groups: E_n

E_8 248

$\downarrow$

E_7 133

$\downarrow$

E_6 78

$\downarrow$

$E_5 = SO(10)$ 45

$\downarrow$

$E_4 = SU(5)$ 24 $\rightarrow$ $E_3 = SU(3) \times SU(2)$

Exceptional Groups: E_n

E_8 248 Maximal: a priori ***Raison d'être*** superstring, …

$\downarrow$

E_7 133 N=8 SUGRA $E_{7(7)}$

$\downarrow$

E_6 78

$\downarrow$

$E_5 = SO(10)$ 45

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$E_4 = SU(5)$ 24 $\rightarrow$ $E_3 = SU(3) \times SU(2)$

Suppose $\exists E_8$ or $E_7 \to E_4 \times U(1)^n$

$E_8 \to E_4 \times U(1)^4$

$$\frac{E_8}{E_4 \times U(1)^4} = \frac{E_8}{E_7 \times U(1)} \times \frac{E_7}{E_4 \times U(1)^3}$$

$E_7 \to E_4 \times U(1)^3$

$$\frac{E_7}{E_4 \times U(1)^3} = \frac{E_7}{E_6 \times U(1)} \times \frac{E_6}{E_5 \times U(1)} \times \frac{E_5}{E_4 \times U(1)}$$

$E_5 = SO(10)$, $E_4 = SU(5)$

Exceptional Groups: E_n

E_8 248 $\supset E_7$

$\downarrow$ 248-(133+1) = 56 +1 + h.c.

$\rightarrow$ NG chiral multiplet 56 of E_7

but any reprs of E_7 are real

56 = 27+1+27*+1* $\rightarrow$ 0 generations

E_7 133

$\downarrow$ 133-(78+1) = 27 + h.c. $\rightarrow$

Sequential Symmetry Breaking: E_n

E_7 133 $\supset E_6$

$\downarrow$ 133-(78+1) = 27 + h.c. $\rightarrow$ E_6 27

E_6 78 $\supset E_5$

$\downarrow$ 78-(45+1) = 16 +h.c. $\rightarrow$ E_5 16

E_5 = SO(10) 45 $\supset E_4$

$\downarrow$ 45-(24+1) = 10 +h.c. $\rightarrow$ E_4 10

E_4 = SU(5) 24

Appearing NG chiral multiplets

$E_7 \supset E_5$

$\downarrow \rightarrow E_6\ 27 = 16 + 10 + 1$

$= (10+5^*+1)+(5+5^*)+1$

$E_6 \supset E_4$

$\downarrow \rightarrow E_5\ 16 = 10+5^*+1$

$E_5 = SO(10) \supset E_4$

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Three generations $3 \times (10+5^*) + 5$ + singlets !

To do

- Introduce Higgs field as a matter field
- Introduce superpotential terms for the NG superfields as explicit breaking of G,

  to produce Higgs-matter Yukawa interaction terms

Sequential breaking pattern might explain the mass hierarchy and CKM and MNS mixing pattern. → This is now under investigation

(with Yanagida)