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SCHOOL ON
NON-ACCELERATOR PHYSICS
25 April - 6 May 1988

SUPERSTRINGS IMPLICATIONS TO PARTICLE PHYSICS & COSMOLOGY

by

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SUPERSTRING IMPLICATIONS TO PARTICLE PHYSICS/COSMOLOGY

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ICTP

3-5/5/88

SCHOOL ON NON-ACCEL. PHYSICS.

• Superstrings: i) Why (?)

ii) What (?) structure...

•• S_{tr} Phenomenology:

General Characteristics

New gauge Inter/particle

New "observables"

FCNC

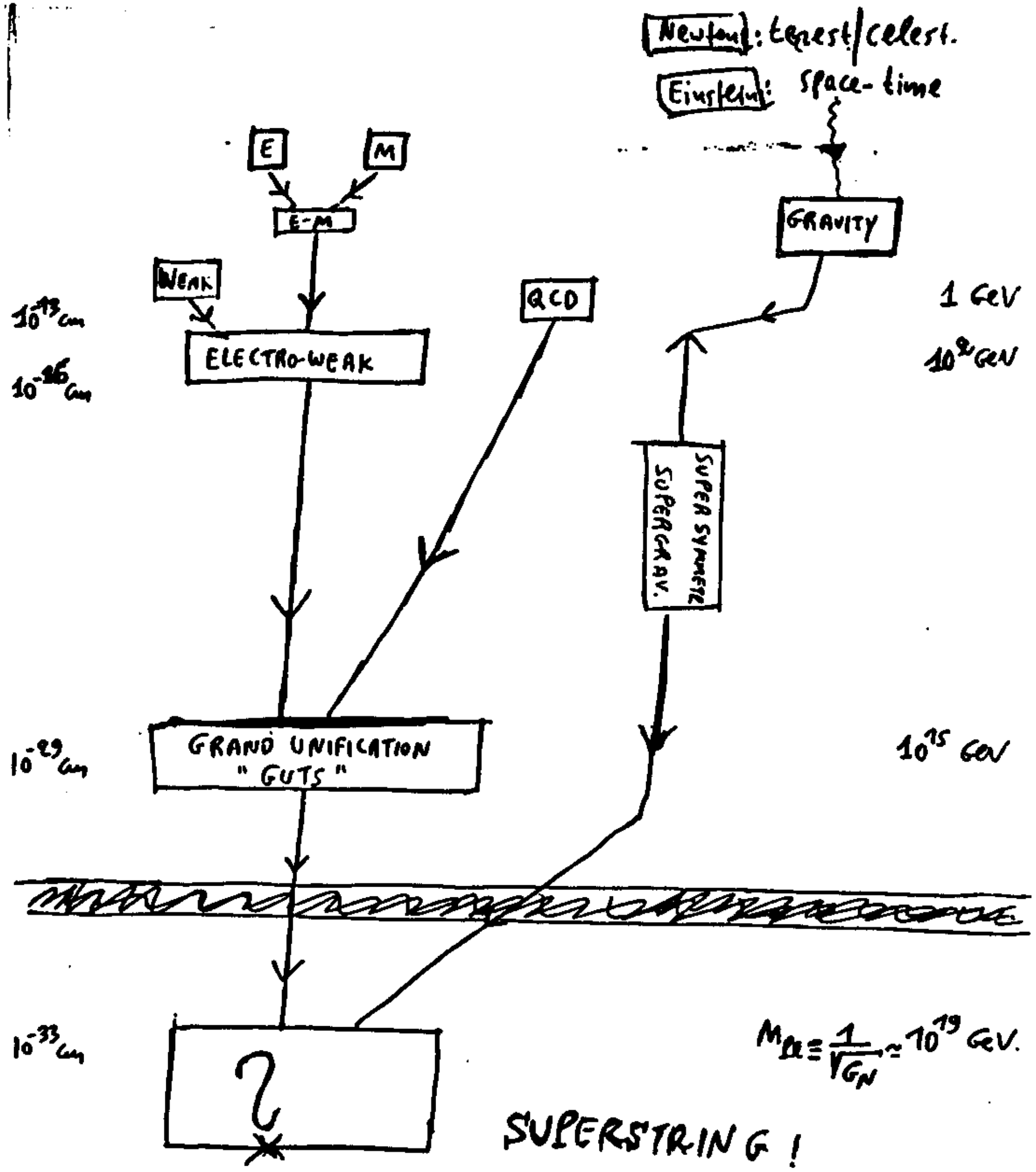
Proton decay

neutrino masses

"Photinos" as Dark matter

••• "FLIPPED" PHYSICS

...



CONSISTENT QUANTUM FIELD THEORY THAT UNIFIES ALL INTERACTIONS.

WHY S'um. ?

Standard model:

$SU(3) \times SU(2) \times U(1)$ $[(3,2,1)]$

Great but:

UNIFICATION
GAUGE HIERARCHY ?
FLAVOUR
Q. GRAVITY

GUTS :

$G \supset (3,2,1)$

grand but:

GAUGE HIER. ?
FLAVOUR
Q. GRAVITY

SUSY/ SUGRA GUTS:

$N=1 \otimes G$

Supergrand but:

FLAVOUR ?
Q. GRAVITY

$N > 1 \cdots 8$ → CHIRALITY PROBLEMS

K-K : $D > 4$ →

\# space-time dimen.

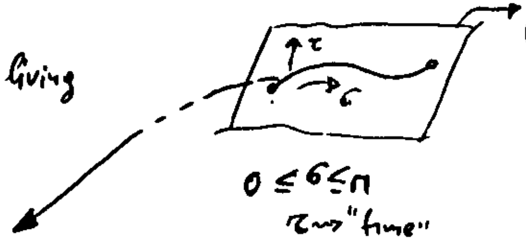
⊕ QUANTUM PROBLEMS

DESPERATELY ~~[illegible]~~ SEEKING FOR ...

Superstrings $\longrightarrow$ CONSISTENT "QUANTUM" THEORY OF GRAVITY / UNIFICATION

$\Downarrow$

1-D extended objects living in D-dimensions



WORLD SHEET (WS)

$0 \le \sigma \le \pi$

$\tau \rightsquigarrow$ "time"

$X^\mu(\sigma,\tau)$ $\quad \mu = \underbrace{1, 2, \ldots, D-2}_{\text{transverse}}, (D-1, D)$

World-Sheet physics $\rightsquigarrow$ 2-dimens. physics !

- Reparametrization Invariance (GCT): $g_{\alpha\beta}(\sigma)$ $(\alpha,\beta = 1,2)\ldots$

•• "Matter" fields : $X^\mu(\sigma)$, $\psi^A(\sigma), \ldots$

two-dimens. X^μ: Real bosons; ψ^A: fermions

$\longrightarrow$ INFINITE # 2-d THEORIES !

SYMMETRIES

1) $X^\mu(\vec\sigma) \longrightarrow X^\mu(\sigma) + a^\mu$; $g_{\alpha\beta}(\sigma) = g_{\alpha\beta}(\sigma)$ TRANSLAT. INVAR.

2) $g_{\alpha\beta}(\sigma) \longrightarrow f(\sigma)\, g_{\alpha\beta}(\sigma)$; $X'^\mu(\sigma) = X^\mu(\sigma)$ WEYL INVAR.

World Sheet Particle Content:

Bosons $\rightsquigarrow$ i) tachyons. ii) $\nexists$ fermions (space-time)

$\oplus$ Fermions $\rightsquigarrow$ i) $\nexists$ tachyons ii) $\exists$ fermions (space-time) $\oplus$ SUSY

$\rightsquigarrow$ 2-d SUPERCONFORMAL THEORY

$$S = -\frac{1}{2}\int d^2\sigma \left[\partial_\alpha X^\mu \partial^\alpha X_\mu - i\,\bar\psi^\mu \rho^\alpha \partial_\alpha \psi_\mu\right]$$

ψ^μ $\hookrightarrow$ vector repres. of $SO(D-1,1)$

$\rho^0 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$; $\rho^1 = \begin{pmatrix} 0 & i \\ i & 0 \end{pmatrix}$ $\rightsquigarrow$ $i\rho^\alpha\partial_\alpha$: real $\rightsquigarrow$ $\psi^\mu = \begin{pmatrix} \psi^\mu_- \\ \psi^\mu_+ \end{pmatrix}$ real $\to$ Majorana Spinor

$\{\rho^\alpha, \rho^\beta\} = -2\eta^{\alpha\beta}$

$\partial_\pm \equiv \frac{1}{2}(\partial_\tau \pm \partial_\sigma)$

$$\rightsquigarrow \quad S = -\frac{1}{2}\int d^2\sigma \left[\partial_\alpha X^\mu \partial^\alpha X_\mu - \psi^\mu_- \partial_+ \psi^\mu_- + \psi^\mu_+ \partial_- \psi^\mu_+\right]$$

ψ_-^μ: Major-Weyl, R-mov; ψ_+^μ: M-W, L-mov $\quad \boxed{\text{Decoupled}}$

- World Sheet $N=1$ SUSY !

•• Easy " $N=1$ SUPERGRAVITY $\begin{cases} \text{"graviton" (Non-propagating...)} \\ \text{"gravitino"} \end{cases}$ $\hookrightarrow \int e R\, d^2\sigma$: topol invar. [Euler charact.]

••• Extended SUSY: $N = 2; 4$ possible

→ UNIQUE THEORY : 2-d CONFORMAL THEORY ...

$$S[g,X] = -\tfrac{1}{2}\int d^2\sigma \underbrace{\sqrt{\det g_{\alpha\beta}}\, g^{\alpha\beta}}_{\text{Weyl invarian. [only in 2-d]}}\underbrace{[\partial_\alpha X^\mu \partial_\beta X^\nu \eta_{\mu\nu} + (\dots)]}_{\text{Transl. Invar.}}$$

SYMMETRIES COMPLETELY DETERMINE DYNAMICS ⟵ Weyl invarian. [only in 2-d]

Reparamete. invar.: $g_{\alpha\beta} = \varphi(\sigma,\tau)\cdot \eta_{\alpha\beta}$

decouples by Conform. Invar. ⟶ $\boxed{g_{\alpha\beta} = \eta_{\alpha\beta} = \begin{pmatrix} 1 & \\ & -1\end{pmatrix}}$

$\eta_{\mu\nu}$: Const. symmetr. real matrix ⟶ $\eta_{\mu\nu} = \begin{bmatrix} 1 & & \\ & 1 & \\ & & \ddots \\ & & & \pm 1\end{bmatrix}$

Lorentz invariance COME OUT OF TRANS. INVAR.!!!

QUANTUM THEORY :

$$\langle F[X,g]\rangle = \int \underbrace{[dX]}_{\text{"easy"}}\underbrace{[dg]}_{\text{"Complicated"}}\ \overset{\text{"any operator"}}{F[X,g]}\ \exp S[X,g]$$

"easy" free field theory: quadratic...

"Complicated"

Simplified: Wick rotation $\sigma \to i\sigma$ → Euclidean...

⟶ 2-d RIEMANN SURFACES

⟶ Classified:

(g = genus)

		# coupl. paramet.
$g=0$	sphere	0
$g=1$	torus	1
$g=$ # handles		$3g-3$ $\boxed{g \geq 2}$

$3g-3$ → Teichmüller Parameters

$$\text{"}\sum_g \int d\tau_g\text{"}$$

"Physics" in space-time ?

• $X^\mu(\sigma) \to X^\mu(\sigma) + a^\mu$ ⟶ action invar.: $X^\mu \to \Lambda^\mu_\nu X^\nu$

Lorentz-group

•• $V[X,g;\, p_i^\mu; \overset{\text{spin}}{\theta_i}] = \int d^2\sigma \sqrt{\det g_{\alpha\beta}}\; e^{i p_i X(\sigma)} (W_\Lambda(\sigma,\tau))$

Vertex operator ≅ "particle" Λ

moment.

$W_\Lambda(\sigma,\tau)$ → 2-d scalar → Lorentz-Q.N. Λ

$W_\Lambda = W_\Lambda(X_\mu, \partial_\alpha X_\mu \dots)$

Usual S-matrix in $(X^\mu \dots)$

$$\boxed{S'_{12\dots \to 34\dots} = \langle V_1 V_2 \dots V_3 V_4 \dots \rangle}$$

WE NEED THEM

• Lorentz Invariant ⟷ Lorentz Invar. $\{X^\mu \to X^\mu + a^\mu\}$

• Unitary ⟷ Reparam. Invar. ⊕ Weyl Invar. $\left\{\begin{array}{l} \exists\, g_{\alpha\beta} \\ g_{\alpha\beta} \to g_{\alpha\beta}\cdot f(\sigma)\end{array}\right\}$

∴ Reparametriz. Invariance (2-d) ⊕ Weyl Invar.

$\boxed{\text{CRUCIAL}}$ {Keep: $g_{\alpha\beta}=\eta_{\alpha\beta}$!!!}

1) Reparam. Invar.

→ Local

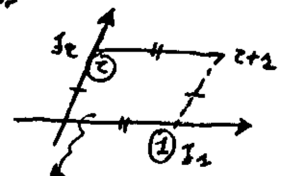
→ Global [transfor. not connect. to $\mathbb{1}$] $(g\geq 1)$

Modul. transform → Modular group

We need also: $\boxed{\text{MODULAR INVARIANCE}}$

Example: $g=1$ TORUS

~>



glue together: $\frac{//}{//}$ $-/-$

"flat" $g_{\alpha\beta}=\delta_{\alpha\beta}$

Complex plane z: identify $z \sim z+1 \sim z+\tau$

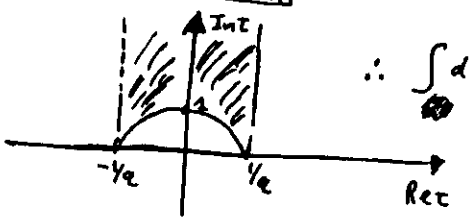
τ ≡ complex number: Teichmüller param.

~> Continuous ~> $\int d\tau$ → NO !!!

preserved by $\tau \to \frac{n\tau+\ell}{m\tau+k}$ $\boxed{\text{Modul. transf}}$

$\begin{pmatrix} nk-\ell m=1 \\ n,k,\ell,m\in Z\end{pmatrix}$ ~> $SL(2,Z)$ ~> $\boxed{\text{Modul group}}$

$G\begin{pmatrix} n & \ell \\ k & m\end{pmatrix}$ with det=1

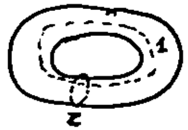


∴ $\int d\tau$ [illegible]

Furthermore: WS fermions present

→ we should determine $\boxed{\text{SPIN-STRUCTURE}}$

e.g.: $\boxed{g=1}$



$a_i \to (1) \to \begin{cases} 1 & + & P \\ 0 & - & A \end{cases}$

$b_i \to (\tau) \to \begin{cases} 1 & + & P \\ 0 & - & A \end{cases}$

$\begin{pmatrix} P\equiv R \\ A\equiv NS \end{pmatrix}$

$i=1,2,\dots$ fermions [Real]

∴ $\forall g=1,2\dots$ ---→ $\boxed{\text{STRING THEORY}}$

BUT: Imagine we fixed our Spin-Structure

e.g.: $g=1$ 1 fermion: $\alpha=1$, $\beta=0$

then $\xrightarrow{\text{MODUL TRANSF}}$ $\tau \to -\frac{1}{\tau}$ $(n=k=0;\ -\ell=m=1)$: $\alpha=0$, $\beta=1$?

MODUL. INVAR !!!

∴ SPIN-STRUCTURE NOT SINGLETS OF MODUL. GROUP

MODUL. INVAR. $\xRightarrow{\text{ENTAILS}}$ SUM OVER ALL SPIN-STRUCTURES WITH WELL-DEFINED COEFFICIENTS !!!

∴ STRING THEORY SHOULD BE: ① MULTILOOP-MODUL. INVARIA[NCE] ② FACTORIZABLE

2) Conformal Invariance

Classical level ✓ Quant. level (?) $\boxed{\text{ANOMALIES}}$!

$$\left((\tau,\sigma) \xrightarrow{\text{Wick}} \begin{matrix} z = \tau + i\sigma \\ \bar z = \tau - i\sigma \end{matrix} \right)$$

Energy-Mom. tensor: $T_{\alpha\beta} \to$ $T_{z\bar z} = 0$ ⇝ Scale Invariance

$T_{zz}(z) \equiv T(z)$

$T_{\bar z \bar z}(\bar z) \equiv \bar T(\bar z)$

generates Conform. transf:

$z \to z + f(z)$ (infinitesimal) by $T_f = \oint \frac{dz}{2\pi i} f(z) T_{zz}(z) \; \ldots$

A 2-d field: $\varphi(z) \to \left(\frac{\partial z'}{\partial z}\right)^{h} \varphi(z')$ when $z' = z'(z)$ (Conf.-Transf) $\boxed{\text{conf. dim}}$

OPE: $T(z)\varphi(w) \sim \frac{h\,\varphi(w)}{(z-w)^2} + \frac{\partial_w \varphi(w)}{z-w}$ + finite.

$(\varphi \equiv T)$ ⇝ $T(z)T(w) \sim \frac{\boxed{c}}{2(z-w)^4} + \frac{2\,T(w)}{(z-w)^2} + \frac{\partial_w T(w)}{z-w}$ + finite

O.K

$\boxed{\text{BAD: ANOMALY !!!}}$

In another way: $T(z) = \sum_{-\infty}^{\infty} \frac{L_n}{z^{n+2}}$

$$[L_m, L_n] = (m-n)L_{m+n} + \frac{\boxed{c}}{12}(m^3 - m)\,\delta_{m+n} \qquad \delta_{m+n} = \begin{cases} \delta_0 = 1 \\ 0 \text{ otherwise} \end{cases}$$

VIRASORO ALGEBRA
c: central charge

Keep Conformal Invariance at quantum level:

$\boxed{C_{tot} = 0}$

Contribution of anything that is on WS :

1) Scalars φ: $(h=0)$ $\quad -\frac{1}{2}\partial_z\varphi\partial_z\varphi \to T(z) \to c = 1$

2) fermions ψ: $(h=1/2)$ $\quad \frac{1}{2}\psi\partial_z\psi \to T(z) \to c = 1/2$

3) "ghosts" : $\begin{pmatrix}\lambda = 2 \\ \lambda = 3/2\end{pmatrix}$ F-P analysis choise of (Super) Conform. gauge → pair of ghost fields on WS

$$c_{gh} = c_{gh}(\varepsilon, \lambda) = -2\varepsilon(6\lambda^2 - 6\lambda + 1)$$

$N=0$: $\varepsilon = 1$, $\lambda = 2$ ⇝ $\boxed{c_{gh} = -26}$ $(N=0)$

$N=1$: $\oplus$ $\varepsilon = -1$, $\lambda = 3/2$ → $\boxed{c_{gh} = -15}$ $(N=1)$

$\boxed{\text{ALWAYS THERE}}$

AND HERE STARTED A TWENTY-YEARS JOKE !!!

EXTRA DIMENSIONS !

$\boxed{\text{STRING THEORIES}}$

$\boxed{C_{tot}=0}$

$\boxed{N=0}$ (Bosonic String)

$c_{gh}=-26$; $\exists$ only bosons ($X^\mu \dots \mu=1,2,\dots D$)

each boson: $c=1$

$D\cdot 1-26=0 \rightsquigarrow \boxed{D_c=26}$

$\boxed{N=1}$ (Ferm. String)

$c_{gh}=-15$; $\exists$ bosons + fermions

$\underset{c=1}{\# X^\mu} = \underset{c=1/2}{\# \psi^\mu} \rightsquigarrow$ (SUSY)

$D+\frac{D}{2}-15=0 \rightsquigarrow \boxed{D_c=10}$

~~$\boxed{N=2} \to D_c=2$~~

~~$\boxed{N=4} \to D_c=-2$~~

$\Rightarrow$ AVAILABLE THEORIES: [∃ at least $N=1$ in L or R]

{L-R decoupled: L ⟲ R}

1) Open Strings: $\boxed{N=1}$; $D=10$ $N_{10}=1$ $\boxed{SO(32)}$

2) Closed Strings: L ⟲ R $\boxed{N_L=N_R=1}$; $D=10$; $N_{10}=2$ → ↑↓ IIA (non-chiral); ↑↑ IIB

{No gauge group}

dual

3) Heterotic String

Idea: i) L-R decoupled modes.

ii) $N^L_{(2)}$ or $N^R_{(2)}=1$ enough for {absence of tachyons; presence of fermions (D)}

L-sector: $(N_2)_L=1 \rightsquigarrow c_L=-15 \rightsquigarrow D=10: X^\mu; \psi^\mu_+$

R-sector: $(N_2)_R=0 \rightsquigarrow c_R=-26 \rightsquigarrow D=10 \oplus (26-10)\times 2$ Major. fermions

∴ $(c_{tot})_L=(c_{tot})_R=0$ ✓

32 fermions λ^A_-, $A=1,2,\dots 32$

$$S=-\frac{1}{2}\int d^2\sigma\Big(\underbrace{\sum_{\mu=0}^{9}\partial_\alpha X^\mu\partial^\alpha X_\mu-2\psi^\mu_+\partial_-\psi_{\mu+}}_{SO(9,1)\ \text{"vectors"; Inter. Symm. singlets}}-2\underbrace{\sum_{1}^{32}\lambda^A_-\partial_+\lambda^A_-}_{SO(9,1):\ \text{singlet}}\Big)$$

(Super) "space-time"

Carrier Intern. quant. numbers !!!! → "gauge" structure

λ^A: 1…32 same bound. condit. $\longrightarrow SO(32)$ gauge

$\lambda^A: \begin{cases}1\dots16 & (\pm)\\ 17\dots32 & (\mp)\end{cases} \longrightarrow E_8\times E_8 \oplus N_{10}=1$

$\rightsquigarrow (O(16)\times O(16) \oplus N_{10}=0)$

∴ ALWAYS START WITH $D=10$ FLAT DIMEN ⟶ COMPACTIFY….

Up to now: take for granted:

SUSY $\longleftrightarrow$ # bosons = # fermions $\boxed{\text{explicitely}}$

What about Non-linear realizations of SUSY (?)

(YES) ! ! | | | | |

ANTONIADIS-BACHAS-KOUNNAS - WINDEY Phys. Lett. 171 (1986) 51

$$S = \tfrac{1}{2} \int d^2\sigma \; \lambda^A_- \partial_+ \lambda^A \quad ; \quad \lambda^A: \text{2-d, M-W, free fermions}, \; A = 1, 2, \ldots, N$$

Invariant under $\delta \lambda^A = \eta^{ABC} \lambda^B \lambda^C \varepsilon$

(totall. antisymm. in its indices) — ε: infinits. Grassmann parameter

SUSY $\boxed{\longleftrightarrow}$ $\eta^{ABC} = [2\,c(G)]^{-1/2} f^{ABC}$ ✓

$$c(G) = \frac{f^{ABC} f^{ABC}}{\dim(G)}$$

$\boxed{\forall\; G\text{: semisimple group}}$ → $\boxed{\text{Complete classification}}$ ✓

$$T_F = \tfrac{1}{3} \eta^{ABC} \lambda^A \lambda^B \lambda^C$$

demand: $[T_F(z), T_F(w)]_+ = 2\, T_B(z)\, \delta(z-w) + \text{c-number}$

$$T_B(z) = \tfrac{1}{2} \lambda^A(z) \partial_z \lambda^A(z)$$

$\boxed{\text{OPENED THE WAY FOR 4-D STRINGS}}$

Idea:
i) L-R decoupled modes
ii) $N^L_{(2)}$ or $N^R_{(2)} = 1$ enough $\begin{cases} \nexists \text{ tachyons} \\ \exists \text{ fermions}_{(D)} \end{cases}$ HETEROTIC

$\oplus$ iii) Use $(N-1)$ SUSY fermions to reduce (space-time) dimensionality

(ABKW, ABK Nucl. Phys. B289 (1987)/87)

L-sector: $(N_2)_L = 1 \rightsquigarrow c_L = -15 \rightsquigarrow D = 4 \; (X^\mu, \psi^\mu)$, $\mu = 0 \to 3$

$\oplus$ 18 fermions: $\chi^I_+, y^I_+, \omega^I_+$

$\sim$ adjoint of semisimple group

only: $\boxed{SU(2)^6}$; ~~SU(2)~~×SU(4); ~~SU(3)~~×SO(5)

(for real fermions !)

$$c_L = -15 + (4+2) + \frac{18}{2} = 0 \quad ✓$$

R-sector: $(N_2)_R = 0 \rightsquigarrow c_R = -26 \rightsquigarrow D = 4$

$\oplus$ 44 fermions: λ^A_-, $A = 1 \cdots 44$

$$c_R = -26 + (4) + \frac{44}{2} = 0 \quad ✓$$

$\therefore \quad (c_{tot})_L = (c_{tot})_R = 0 \quad ✓$

After 20 years!

$$S_{4-D} = -\frac{1}{2}\int d^2\sigma \Big(\sum_{\mu=0}^{3} \partial_\alpha X^\mu \partial^\alpha X_\mu - 2\psi_+^\mu \partial_- \psi_{\mu+} - 2 (\chi_+^i \partial_- \chi_+^i) - 2 \sum_{1}^{44} \lambda_-^A \partial_+ \lambda_-^A \Big)$$

$i = 1, \dots 18$

- (X^μ, ψ^μ) : $SO(3,1)$ vectors; Intern. Symm. Singlets $\rightsquigarrow$ (SUPER) SPACE-TIME ✓

.. $\chi_+^i \equiv (\chi^I, y^I, \omega^I)$ with $(\chi^I, y^I, \omega^I) \sim \underline{3}$ of $SU(2)^I$ (i: 1…18; I: 1–6) ✓
λ_-^A; $A = 1 \dots 44$ $\rightsquigarrow$ Intern. Symmetries

$\therefore$ ALWAYS $\boxed{D=4}$!!!

(e.g: If all λ_-^A same B.C treatment $\rightsquigarrow SO(44) \longrightarrow \dots$)

- These "new" S'm theories consistent at the same level of the $D=10$ heterotic string ✓
.. "New" $\rightsquigarrow$ (?) still "very simple" ✓
... $D=4$ not unique (?) : same story: $\forall$ $D \leq 10$!

"PHYSICS" (?)

IV 4-D Superstrings: (ABK)

L ○ R

SUSY : $C_L = 15 = D + \frac{D}{2} + \frac{N_{F_L}}{2} \xrightarrow{D=4} N_{F_L} = 18$ (ABKW) Non-linear SUSY

NO SUSY : $C_R = 26 = D + \frac{N_{F_R}}{2} \xrightarrow{D=4} N_{F_R} = 44$ $\rightsquigarrow$ $\{ SO(44) \dots \}$

$\therefore$ $N=1$; $D=10$; $G = E_8 \times E_8$ or $SO(32)$; … ; $[N=4; \underline{D=4}; G = SO(44)]$

COMPACTIFICATION ON C-Y/ORBIFOLDS (CHWS') (W)

"AUTOMATIC" TRUNCATION (AEFNT)

(EFKN, ELNT, EKN (1983))

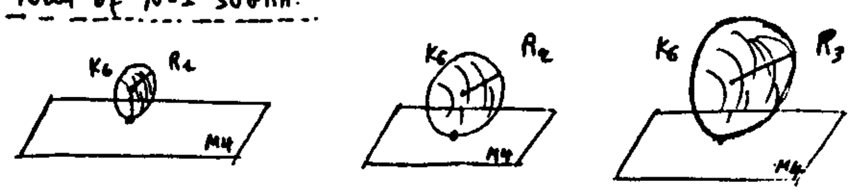
$\boxed{N=1 \ \text{NO-SCALE SUPERGRAVITY}; D=4; G' \subseteq G}$ At M_{Planck}

$\left\{ \begin{array}{l} \text{i) } \Lambda_{cosm} = 0 \text{ tree-level NATURALLY} \\ \text{ii) } M_W \sim \tilde{m}_{SUSY} \sim e^{-1/\alpha} M_{Pl} \end{array} \right\} \rightsquigarrow$ $N=1$ SUSY $SU(3) \times SU(2) \times U(1) \times \cdots$ At M_W.

∴ ∃ At least an extra $U(1)_E$ [gauge boson Z_E] at low energies ! (?)

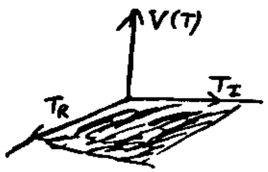
*Comment: Recent suggestions for $O(10)$ or $SU(5)$ (W) problematic (?) → (EENOQZ)

6) Form of $N=1$ SUGRA.



tree level: $V=0$ $V=0$ $V=0$

excitations of dim. of manifold → complex field T



$\begin{pmatrix} W \\ EEN \end{pmatrix}$ tree level: $V(T)=0$

for 1-field

UNIQUELY DETERMINES FORM OF $N=1$ SUGRA → $\boxed{\text{NO-SCALE TYPE}}$

$$V = e^G\left[G_i G_j (G_i^j)^{-1} - 3\right] \quad \text{with :} \quad \boxed{G = -3\ln(T+T^*)}$$

generalized to N-fields

$$\boxed{G = -3\ln(T+T^* - \varphi_i\varphi_i^*)}$$

(C-F-K-N, E-L-N-T, E-K-N, E-E-N) (1983)

Characteristics (EGN)

i) local susy : spontan. broken $\xrightarrow{\text{by}}$ gauge forces of $Q \subset G_E'$

$$\langle (\tilde{g}\tilde{g})_Q \rangle \neq 0$$

(like $\langle q\bar{q}\rangle_{QCD} \neq 0$ breaks $SU(2)\times SU(2) \to SU(2)_{ISOSPIN}$)

ii) global susy $\subset$ ($N=1$ SUGRA) : unbroken tree level: $m_b^2 = m_f^2$

$m_0 = 0$; $m_{3/2}$, $\varphi = 0$

$m_e = m_{\tilde{e}}$; $m_g = m_{\tilde{g}}$!!!

7) Dynamical determination of everything ! (CEGN, CEEN, EENZ)

i) Higher orders { grav., Sum, non-perturbative } fix values of T_i ← "gauge singlets"

→ $\langle T_i \rangle \sim M_{PL}$

M_{comp}; M_X; Λ_Q; $m_{3/2}$ $\propto f_i(T_i)$ → dynamically determined

ii) $\alpha_{GUT} \propto \frac{M_{PL}}{\langle T_i \rangle}$ → dynamically determined ✓

If α_{GUT}, M_X dynam. determ. → $\boxed{\alpha_{E.M}\ ;\ \Lambda_{QCD}\ ;\ \sin^2\theta_W}$

dynamically determined ✓

IN THE RIGHT BALLPARK !

iii) (Non) gravitat. Radiat. corrections

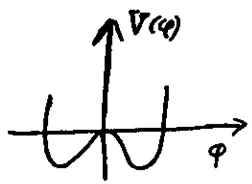
$$m_{1/2}\Big|_{\sim M_c} \neq 0 \quad (\gg m_0) \quad (?)$$

(dynamically)

$$\boxed{m_{1/2} \sim M_W \sim M_{Z^0} \sim e^{-1/\alpha} M_{Pl.}}$$

Let's elaborate a bit:

$$V(\varphi) = \ominus \frac{\mu^2(Q)}{2}\varphi^2 + \frac{\lambda(Q^2)\varphi^4}{4} \longrightarrow$$



$$\therefore \qquad \langle\varphi\rangle = \sqrt{\frac{\mu^2}{\lambda}}\,; \quad m_H^2 = 2\lambda^2\langle\varphi\rangle^2\,; \quad M_G^2 \sim g^2\langle\varphi\rangle^2$$

$\boxed{\text{BY HAND}}$!

IMAGINE:

At M_{Pl}: all scalars: Higgs, sl, sq, ...

DEMOCRATIC : $m_i^2\Big|_{M_{Pl}} = m_0^2 \geq 0$

LET DYNAMICS DECIDE

WHICH $m_i^2\Big|_{M_W} < 0 \rightsquigarrow$ Correspond symmetry broken

$\hat{m} \equiv \frac{m}{m_0}$

$$SU(3)_c \checkmark \longleftarrow \frac{\partial \hat{m}^2_{\tilde{q}}}{\partial \ln\mu} \propto -\underline{\alpha_3}\,\hat{m}_g^2 + \underline{\alpha_t}\,\hat{m}^2_{\tilde{q}} \qquad \alpha_3 \gg \alpha_t$$

$$U(1)_{E.M} \checkmark \longleftarrow \frac{\partial \hat{m}^2_{\tilde{\ell}}}{\partial \ln\mu} \propto -\underline{\alpha_2}\,\hat{m}_{\tilde{g}}^2 + \underline{\alpha_\tau}\,\hat{m}^2_{\tilde{\ell}} \qquad \alpha_2 \gg \alpha_\tau$$

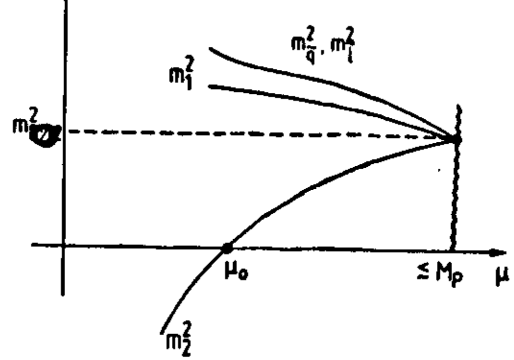


Fig. 12

$$\frac{\partial \hat{m}^2_{H_2}}{\partial \ln\mu} \propto -\underline{\alpha_2}\,\hat{m}^2_{H_2} + \underline{\alpha_t}\,\hat{m}^2_{\tilde{q}}$$

$\alpha_2 \sim \alpha_t$

$SU(2)\times U(1)$ broken for $m_t > O(40$ GeV$)$

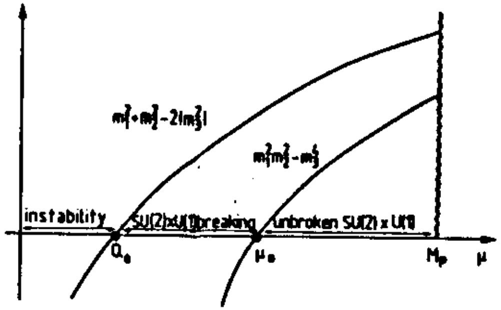
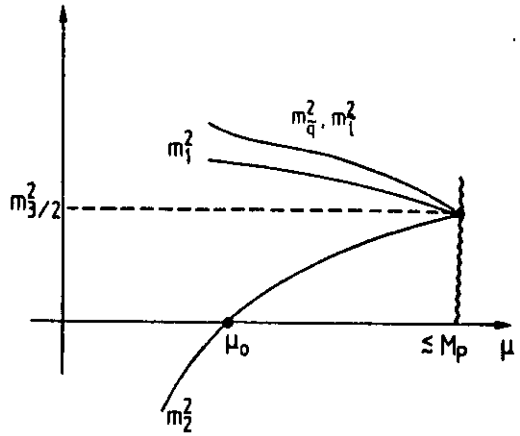
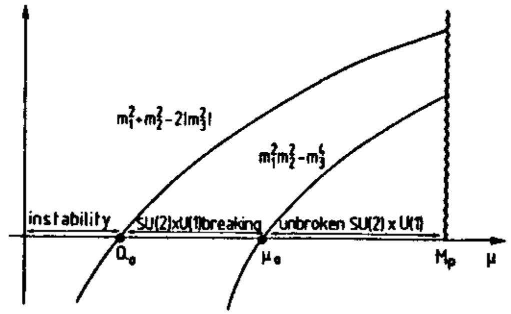


Fig. 13



$m_{\tilde q}^2, m_{\tilde l}^2$
m_1^2
$m_{3/2}^2$
μ_0
$\lesssim M_P$
μ
m_2^2

Fig. 12



$m_1^2+m_2^2-2|m_3^2|$
$m_1^2m_2^2-m_3^4$
instability
SU(2)xU(1)breaking
unbroken SU(2) x U(1)
Q_0
μ_0
M_P
μ

Fig. 13