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SUGRA 30-JOURNÉE JOËL SCHERK
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— SUPERSYMMETRY (SUSY) AND SUPERGRAVITY (SUGRA)

WHAT ARE THEY? WHY ARE WE INTERESTED?

— THE HIERARCHY PROBLEM AND THE

MINIMAL SUPERSYMMETRIC STANDARD

MODEL (MSSM). THE "LITTLE HIERARCHY"

PROBLEM, EXTENSIONS OF THE MSSM

(NMSSM etc.)

— THE CERN LARGE HADRON COLLIDER (LHC).

AMAZING ENGINEERING FEAT!

WILL SUSY BE "FOUND" AT THE LHC AND

WHEN? MUCH HARDER THEN MOST THINK.

— THEORY: ALTERNATIVE SOLUTIONS OF THE

HIERARCHY PROBLEM (EXTRA DIMENSIONS)

WHICH WILL GIVE SIGNALS HARD TO

DISTINGUISH FROM SUSY

— EXPERIMENT: THE ABUNDANCE OF SIGNALS

AND BACKGROUND

(LHC OLYMPICS ETC.)

RESULT: MANY THEORISTS, INSTEAD OF MAKING NEW

MODELS, ARE BECOMING "HAUSTHEORETIKER,"

3 THE MINIMAL SUPERSYMMETRIC
STANDARD MODEL (MSSM)

SYMMETRIES SUCH AS

$SU(3) \otimes SU(2) \otimes U(1)$ OF THE STANDARD

MODEL OF ELEMENTARY PARTICLES
ARRANGE PARTICLES INTO

MULTIPLETS OF DIFFERENT

INTERNAL QUANTUM NUMBERS

BUT OF THE SAME TOTAL SPIN

SUPERSYMMETRY INTO SUPERMULTIPL.
OF DIFFERENT SPINS, AND STATISTICS

{ GLUON, SPIN 1, BOSON

{ GLUINO, SPIN $\frac{1}{2}$, FERMION

{ QUARK, SPIN $\frac{1}{2}$, FERMION

{ SQUARK, SPIN 0, BOSON

selectron e , selecton \tilde{e} ; W meson, Wino \tilde{W}

SM PARTICLES

Leptons: $L_i = \begin{pmatrix} \nu \\ e \end{pmatrix}_{L_i} = (1, 2, -\frac{1}{2})$

$e_{R_i} = (1, 1, -1)$

Quarks: $Q_i = \begin{pmatrix} u \\ d \end{pmatrix}_{L_i} = (3, 2, \frac{1}{6})$

$u_{R_i} = (3, 1, \frac{2}{3})$

$d_{R_i} = (3, 1, -\frac{1}{3})$
Higgs: $H = \begin{pmatrix} H_+ \\ H_0 \end{pmatrix} = (1, 2, \frac{1}{2})$

$i = 1, 2, 3$ family index

L left-handed

R right-handed

Numbers in parenthesis are the $SU(3) \otimes SU(2) \otimes U(1)$ quantum numbers.

SUPERPARTNER \rightarrow SUPERPARTNER

PARTICLE \leftarrow PARTICLE

EXAMPLE: R PARITY

MANY NEW PARTICLES, WHICH ALLOW
 MANY NEW INTERACTIONS, SOME
 KNOWN TO BE ABSENT IN PHYSICS,
 LIKE BARYON AND LEPTON NUMBER
 VIOLATION. NEED NEW SYMMETRIES.

H_2	1	1	2	0	0
H_1	1	1	2	0	0
\bar{D}_i	3	1	1	$-\frac{1}{3}$	0
\bar{U}_i	3	1	1	$-\frac{2}{3}$	0
\bar{Q}_i	3	2	1	$\frac{6}{3}$	0
\bar{E}_i	1	1	1	0	-1
L_i	1	2	1	$-\frac{2}{3}$	0
$SU(3)$					
$SU(2)$					
$U(1)$					
B					
L					

SUSY QUANTUM FIELD THEORIES
HAVE DESIRABLE FEATURES

- FEWER RENORMALIZATION CONSTANTS
 $N=4$ SUSY IS FINITE! UVP

- IN THE MSSM THE COUPLIN CONSTANTS
CONVERGE BETTER THEN IN THE SM,

AT $\sim 10^{16}$ GEV (SM AT 10^{15} GEV)
UNIFICATION WITH GRAVITY?

- IN EXACTLY SUSY QFT THE VACUUM
ENERGY VANISHES

HELP FOR THE COSM. CONSTANT
PROBLEM?

SUSY BREAKING (the hidden sector)
NOT TOO VIOLENTLY TO KEEP THE
DESIRABLE FEATURES

SPONTANEOUSLY? **X** (MASS SUM RULES)
SOFTLY, BUT HOW?

POSTULATE A "HIDDEN" SECTOR WHERE
SUSY IS BROKEN SPONTANEOUSLY AT
ENERGIES MUCH HIGHER THAN THE
WEAK SCALE. HIDDEN MEANS NO INTERACTIONS
WITH THE "VISIBLE" SM PARTICLES.

BY APPROPRIATE "MESSENGERS" THE
HIDDEN SECTOR COMMUNICATES SUSY
BREAKING TO THE VISIBLE SECTOR.

- GAUGE MEDIATION
- GRAVITY MEDIATION
- ANOMALY MEDIATION

SUGGESTED BY SUPERSTRING THEORY.

THE COLD DARK MATTER PROBLEM
MANY INDEPENDENT LINES OF
COSMOLOGICAL EVIDENCE (GALAXY
ROTATION, LENSING FROM GALAXY
CLUSTERS, ETC.) HAVE LED TO THE
CONCLUSION THAT THE VAST MAJORITY
OF MATTER IN THE UNIVERSE IS "DARK"
(EVADES OBSERVATION BASED ON
INTERACTION WITH ELECTROMAGNETIC
RADIATION), NONBARYONIC DARK
MATTER OUT-MASSSES ORDINARY MATTER
BY A FACTOR OF ABOUT 8. THE
DOMINANT CANDIDATES ARE
WEAKLY INTERACTING MASSIVE PARTICLES
"WIMPS",
THE BEST CANDIDATE SEEMS TO BE THE
TEV-SCALE SUSY "NEUTRALINO"
[OTHER SUGGESTION: THE "AXION"]

LIGHTEST SUPERPARTNER (LSP)
 [SNEUTRINOS? GRAVITINO?]

TO FOUR MASS EIGENSTATES $\chi_0^0, \chi_1^0, \chi_2^0, \chi_3^0, \chi_4^0$
 FOUR MAJORANA FERMIONS, MIXING

THE NEUTRAL WINO (\tilde{W}^0) AND THE
 BINO (\tilde{B}^0),
 NEUTRAL HIGGSINOS (\tilde{H}_u, \tilde{H}_d)
 CONSTRAINTS SATISFIED BY THE

AND COLORLESS.

ESCAPED DETECTION, ELECTRICALLY NEUTRAL
 - BE "WEAKLY INTERACTING" TO HAVE

FORMATION ("COLD" D.M.)

- BE NONRELATIVISTIC DURING STRUCTURE
- MECHANISM IN THE EARLY UNIVERSE
- HAVE AN EFFECTIVE PRODUCTION
- TO STRUCTURE FORMATION.

TO THE AGE OF THE UNIVERSE) TO CONTRIBUTE

- BE STABLE (LONG LIFE TIME COMPARED

A DARK MATTER CANDIDATE MUST:

THE COSMOLOGICAL CONSTANT, OR "DARK ENERGY", AND THE VACUUM

ENERGY PROBLEM.

DIMENSIONAL ARGUMENTS, AS WELL AS QFT CALCULATIONS WOULD GIVE IT A VALUE OF

$$\Lambda_P = \frac{\text{PLANCK MASS}^3}{(\text{PLANCK LENGTH})^3} \approx 10^{94} \frac{\text{grams}}{\text{cm}^3}$$

THE ACTUAL VALUE IS $\Lambda \sim 10^{-120} \Lambda_P$ BUT $\neq 0$. AS A CONSEQUENCE THE UNIVERSE'S

EXPANSION ACCELERATES (SUPERNOVAE)

SO Λ IS POSITIVE BUT VERY SMALL.

TODAY THIS IS ONE OF THE GREATEST

MISTRIES OF NATURE.

EXACT SUSY QFT WOULD GIVE $\Lambda = 0$

BUT SUSY IS BROKEN BY AN AMOUNT MUCH

TOO LARGE.

SUPERSTRING THEORY WITH SUSY BREAKING

GIVES ALSO A VALUE TOO LARGE FOR Λ .

A SINGLE CONSTANT Λ IN EINSTEIN'S

EQ'S WOULD AGREE WITH THE OBSERVED ACC.

CAN WE EXPLAIN ITS VALUE?

REMARKS ON SUPERSTRING THEORIES

CONSISTENCY REQUIRES 10 DIMENSIONAL SPACE-TIME.

FIVE THEORIES : TYPE IA TYPE IIB

TYPE I
HETEROTIC $E_8 \times E_8$
HETEROTIC $SO(32)$

RELATED BY TRANSFORMATIONS CALLED DUALITIES, CAN BE CONSIDERED A

SINGLE THEORY. THERE IS ALSO A HINT

OF A THEORY IN 11 DIMENSIONAL SPACE-TIME

WHICH TENDS TO ANY OF THE ABOVE FIVE

IN A SUITABLE LIMIT ("M" THEORY).

THIS EFFECTIVE UNIQUENESS WAS GRATIFYING

FOR A NUMBER OF YEARS. HOWEVER.....

STRING THEORY MUST BE COMPACTIFIED ON

A 6 DIMENSIONAL MANIFOLD, DOWN TO

THE 4 DIMENSIONAL SPACE-TIME OF PHYSICS.

AMBIGUITIES; CHOICE OF MANIFOLD, SIZE,

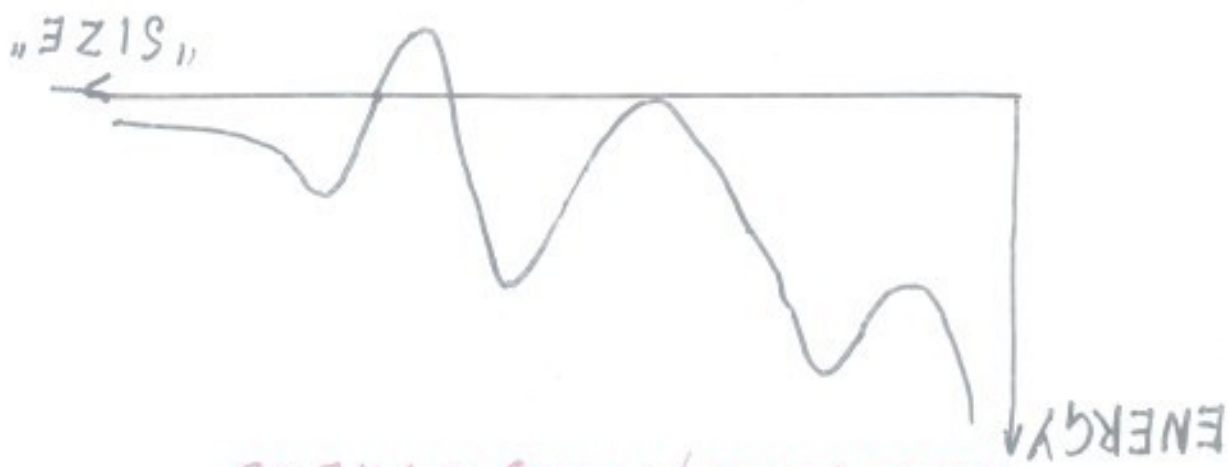
TOPOLOGY, FLUXES, ETC. THE 4-DIMENSIONAL

PHYSICS IS NOT UNIQUE. 10^{500} SOLUTIONS?

A "LANDSCAPE" OF SOLUTIONS.

SUPERSTRING THEORY LANDSCAPE

BOUSSO, POLCHINSKI, SUSSKIND,
DOUGLAS, MANY OTHERS



SCHEMATIC DESCRIPTION, ONLY THE SIZE
OF THE COMPACTIFYING MANIFOLD IS INDICATED.
SOME VACUA ARE STABLE, SOME METASTABLE,
SOME SUPERSYMMETRIC, SOME NOT.

THE VACUUM ENERGY CORRESPONDS TO THE
VALUE OF THE COSMOLOGICAL CONSTANT.

WHY IS IT POSITIVE AND VERY SMALL

BUT NOT ZERO? WEINBERG'S "WEAK"

ANTHROPIC PRINCIPLE!?

SHOULD WE ACCEPT THE ANTHROPIK
PRINCIPLE?

STRONG FEELINGS ON BOTH SIDES.

→ DAVID GROSS: I WOCULATE MYSELF
BY EMOTIONAL INTENSITY AGAINST IT
BECAUSE IT'S VERY CONTAGIOUS

→ BURT RICHTER: MUCH OF WHAT PASSES
FOR THEORY THESE DAYS IS MORE LIKE
THEOLOGICAL SPECULATION

→ JOE POLCHINSKI: IF ASTRONOMEKS
FOUND A NONVANISHING COSMOLOGICAL
CONSTANT, I WOULD GIVE UP PHYSICS,
BECAUSE IT WOULD REQUIRE TO INVOLVE
THE ANTHROPIK PRINCIPLE

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PROBABLY A THEORY ENCOMPASSING
THESE AND SUPERGRAVITY M-THEORY

SPIN FOAM QUANTUM GRAVITY HAWKING

LOOP QUANTUM GRAVITY
ROVELLI, SMOLIN
etc.

THEORIES OF GRAVITY:

ALTERNATIVE (MOSTLY NONSUPERSTRYMM)