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Unbroken supersymmetry, without new particles

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We review Koide's equation for the standard model leptons jointly with previous hypotheses of the author, focusing on the possibility of studying it in a supersymmetric framework akin to the one of D=11 maximal supergravity.

I. KOIDE'S MODEL OF SUBQUARKS.

In 1981, Y. Koide [2] suggested some models where quarks and leptons were composed of more elementary bosons and fermions having global $SU(3)$ color and $SU(3)$ "generations" symmetry. With an adequate choosing of the representations for these subparticles, plus a relatively adhoc symmetry breaking scheme, it was possible to derive some parameters of the CKM matrix and, more interestingly, to predict the mass of the tau lepton which was measured years later. The prediction has today an astonishing precision within the current experimental error.

Koide's symmetry breaking scheme constrains the square root of the mass matrix M_l of charged leptons. When $M_l^{1/2}$ is decomposed in a central part U (a multiple of the identity) plus a traceless part V,

$$(U+V)^2 = M_l \tag{1}$$

the symmetry breaking scheme imposes a relationship between traces

$$Tr[U^2] - Tr[V^2] = 0 \tag{2}$$

And it works: with PDG 2009 data, the LHS is between -0.05 and 0.09 MeV. Or, if you prefer an adimensional quantity, the quotient $Tr[U^2]/Tr[V^2]$ is 1.00002 ± 0.00008.

Recently, Koide has produced some ways to the same formula without asking for compositeness, but we keep an eye on it because of the next section. It must be stressed that in 1981 the value of the mass of the tau lepton was far away from its current measurement.

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I want to do two observations here:

1) If we think of mass as a component of the momentum operator P_μ, the fact of having a condition in its square root smells to a condition on supersymmetry generators.

2) If supersymmetry were unbroken, the same condition should appear in the scalar partners of the charged fermions. Furthermore, we could think that the sfermions are composite. Even we could think that the sfermions are the only composites, where Koide's breaking scheme applies, and that Koide's formula in the leptons is only a reflection of the actual formula for sfermions.

II. SBOOTSTRAP

A motivation to pursue the above idea is that the masses of muon and tau, which are free parameters in the standard model, are very near of similarly charged (pseudo)scalar particles, the pion and the D meson. In fact the former case is so near than historically the muon was first interpreted, mistakenly, as a pion.

We advance one step over Koide's models of subquarks and do a bold suggestion: that the particles labeling the sfermions are really quarks themselves.

Astonishingly we exceed expectations when we notice that there are actually five "light" quarks, on the QCD-Chiral-Electromagnetic mass scales, and a massive quark, in the electroweak mass scale. And this quark is as massive as to be unable to bind into mesons. So the flavour global symmetry of our Standard Model quarks is SU(5). It can be labeled under SU(3)xSU(2) in order to separate the (d,s,b) and (u,c) kinds of charge.

The decomposition of SU(5) is well known. Take the 24 of $5 \otimes \bar{5} = 24 \oplus 1$ and the 15 of $\bar{5} \otimes \bar{5} = 15 \oplus 10$. Then under $SU(5) \supset SU(2) \times SU(3) \times U(1)$ we have

$$15 = (3,1)(6) + (2,3)(1) + (1,6)(-4) \tag{3}$$

$$24 = (1,1)(0) + (3,1)(0) + (2,3)(-5) + (2,\bar{3})(5) + (1,8)(0) \tag{4}$$

The $(2,3)(1)$ and $(1,6)(-4)$ are the partners of quarks down and up respectively. The antiparticles are provided in the $\bar{15}$ representation.

The $(2,3)(-5)$ and $(2,\bar{3})(5)$ are the partners of positron and electron. The other 12 particles of this multiplet are neutral.

So our [4] basic observation here is that

3) For three generations and a single ”massive” quark, the system closes on itself: the degrees of freedom generated in the product are the ones needed for the sfermions of a supersymmetric standard model, which in turn are transformed by susy into the original fermions we need to generate them.

It is not possible to do the same trick with any other number of generations, so in some sense the sBootstrap fixes the number of generations.

III. D=11 SUPERGRAVITY MULTIPLET

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There are some general motivations to look for susy in D=11 instead of down-to-earth in D=4. First, it is well known that the minumum number of extra dimensions to allow for SU(3)xSU(2)xU(1) symmetry is 7. It is known that superstring theory lives in D=10 and develops an extra dimension in some limits. It is less known that Connes' geometric version of the standard model lives in dimension 2 mod 8.

Superstring theory is a motivation for us from the point of view of our composites: we really would like to interpret each of our sfermions as quarks at the ends of a string. Really we know from Sagnotti and Marcus that the SO(32) symmetry of the quantised superstring is produced with only a set of 5 ”fermion flavour” in the worldsheet.

The puzzle with our view of superstring theory is that it seems to be the same thing that the usual QCD string. It seems we need a formulation where the bosonic states can be spatially extended in four dimensions, while the fermionic states -at least, the ones with lowest energy- are point like. It could be worth to remember (Susskind et al.) that the initial research in dual models run into problems when calculating the sizes of hadronic strings.

Supergravity is a motivation because its minimal multiplet has barely the number of degrees of freedom to store the information of the supersymmetric standard model, except for the Higgs. See [1]: after accounting for all the standard model, their gauge forces and their superparners, plus the 2 degrees of freedom of the 4-D gravitino, only 6 scalars, from the 128 of the full multiplet, are left. And we need 8 for the Higgs of the MSSM. Yet, the Higgs mechanism is still undiscovered. Or, the graviton could be exiled in favour of a 4D, $N = 4 \times N = 4$, superYangMils theory.

D=11 supergravity has a natural way to produce D=4 because of the structure of supersymmetry multiplets. Its 128-component fermion can not be matched with a 44 component graviton only, so an extra field is needed to hold the extant 84 bosons. This field happens to be a tensor with three indices and thus induces a 4D uncompactified sector in some models.

Amusingly, we could be interested on two numerological happenings of the number "84" in the standard model:

- the "charged fermions" of the standard model amount to 84 degrees of freedom (plus 12 neutrinos = 96)
- the "light fermions" of the standard model amount to 84 degrees of freedom (plus 3 colors of the top quark = 96)

A more than bold conjecture should be that both realisations are related by some duality. We do not need to pursue this idea, but it is noticeable that also the neutrino sector is expected to include are a huge mass term, in order to allow for seesaw.

IV. KOIDE'S RELATIONSHIP FOR MESONS

We can think that the supersymmetry in the bosonic part has got an extra contribution from the breaking of flavour symmetry. So lets see what happens if we restore some of this breaking.

If we set the masses of the bottom and strange quark to the same value that the mass of the down quark, we are left with only three mass levels: 1870 MeV, 139.5 MeV and 0. The zero level should be inhabited by the "η_1 singlet" combinations of π^-, K^-, B^- and D^-, D_s^-, B_c^-, while the other levels are inhabited by the "η_8, π_8" combinations.

SUSY, of course, is still slightly broken, if we compare with the lepton triple (0.511, 105.66, 1777 MeV). But Koide's relationship fares better, and the quotient $Tr[U^2]/Tr[V^2]$ is about 1.005. It seems that the breaking of SUSY aims to preserve Koide's, contrary to our initial expectation (or, again, exceeding it)

If instead restoring SU(3)-down flavour we restore SU(2)-up flavour (or none at all) we still have that the masses of Kaon and Upsilon, jointly with a zero mass, also form a Koide "triple". In fact there are no more triples with a zero mass. Some other triples in the meson and baryon sectors have been explored by Carl Brannen.

In the neutral case the fit is not so good because the Kaon is a highly mixed particle. The η_8 of the classical SU(3) "u,d,s" flavour group is a better candidate.

V. PUZZLES OF CHIRALITY

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We have not addressed the question of chirality, mostly because the sBootstrap aims to produce the missing scalars of the supersymmetric standard model, and the fermions are already the ones we know.

Of course, there are no chiral fermions in D=11, thus no way to implement SU(2) in the way it works in the standard model.

Note that the minumum number of extra dimensions for the $SU(3) \times U(1)_{EM}$ symmetry is 5, so it seems that the chiral part of the standard model, $SU(2) \times U(1)_{EW}$, interpolates, as we move the mass of W from zero to infinity, between two non-chiral theories in D=9 and D=11.

The neutrinos in the 24 of SU(5) appear in a very irregular way: a triplet, a singlet and an octuplet. We need to mix them if we want to recover a grouping in three generations. From the point of view of composites $D\bar{U}$, the charged leptons can contemplate two ways to decay to neutrinos: either a decay D to U, landing in the triplet, or a decay $\bar{U}$ to $\bar{D}$, landing in the combination of octet and singlet. So perhaps the (3,1) triplet of the 24 has some special role to build chiral interactions.

The (3,1) triplet from the 15, and its antitriplet from the $\bar{1}5$, are the only "predicted" particles not in the standard model. They should have electric charge 4/3 so it seems that we can not accomodate them as the partners of (three generations of) a two-component fermion. But we can not arrange them in Dirac fermions, as they amount to 6 degrees of freedom, or 18 if we consider that they should be coloured as the rest of the 15 multiplet. More, if they are coloured they overcrown the D=11 multiplet. So it seems that the (3,1) triplet in 15 asks for a chiral fermion in each family, but the sBootstrap, charge, and other considerations ask for this chiral fermion to dissapear.

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[1] L. J. Boya, "Supersymmetry and Polytopes," AIP Conf. Proc. **1093** (2009) 28 [arXiv:0808.3667 [hep-th]].

[2] Y. Koide, "A New Formula For The Cabibbo Angle And Composite Quarks And Leptons," Phys. Rev. Lett. **47** (1981) 1241.

[3] Y. Koide, "Quark And Lepton Masses Speculated From A Subquark Model," http://www-spires.slac.stanford.edu/spires/find/hep/www?r=SH-81-11

[4] A. Rivero, "Supersymmetry with composite bosons," arXiv:hep-ph/0512065.