THEORETICAL PERSPECTIVES ON EDM’S

-- A top-down, or underlying theory, view

Gordy Kane

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- Supersymmetry may, and arguably does, actually predict small EDMs not in disagreement with present bounds

- EDMs are among the most important things that can be measured to help us understand the most fundamental questions about the universe

Can say more than in past because of steady improvement in understanding of theory

The Standard Model predicts very small EDM's, so there is a window for new CPV physics

Two known examples of CPV physics:

- Quark CKM matrix has a phase – large
- CPV required for matter asymmetry in the universe
  - several possible ways to generate this – CPV phase in lepton equivalent of CKM matrix ("PMNS") can do that via "leptogenesis"

So no further CPV is required to understand any phenomena we know of today

ORIGIN OF QUARK, LEPTON MASSES AND CKM MATRIX

- Can have LH or RH quarks, up-type (u,c,t) or down-type (d,s,b)

  → four Yukawa coupling 3x3 matrices
- CKM matrix is $(Y_{uL})^{\dagger}(Y_{dL})$
- Up quark masses from diagonalizing $Y_{ij}(U_L)^{i\dagger}(D_R)^j$<h>, etc
- Higgs vev must be non-zero for non-zero mass, but all the variation in masses due to the Yukawas, phases in Yukawas
- Phase in CKM matrix can explain all CPV in kaon, b-quark system, all known laboratory CPV

Supersymmetry is a hypothetical, very well motivated, possible symmetry of nature that extends the Standard Model:

- Theory unchanged if bosons ↔ fermions
- Can do this in a relativistic quantum field theory
- If supersymmetry unbroken, NO new parameters – no EDMs
- Superpartner masses ≠ particle masses → expect symmetry spontaneously broken, so characterized by some new parameters – called softly broken Lagrangian
- IF breaking mechanism known, NO unknown new parameters – calculate all of them
- Parameters can be complex – new phases
- Actually need data to learn how supersymmetry broken, so historically parameterize breaking and try to measure parameters – make "effective theory" at low energies
- Calculate EDMs in terms of parameters, *assume* arbitrary phases → EDMs exceed limits

Some correct supersymmetry predictions or explanations – supersymmetry invented ~ 1974 – later realized

- Stable hierarchy between Planck scale and weak scale
- Calculation of EW mixing angle, or gauge coupling unification
- Light higgs boson

  -- general theory M(h) < about 2 M(Z)

  -- LEP experiment M(h) < 160 GeV
- Good DM candidate, explain relic density

  -- currently wino LSP gives good description of PAMELA satellite data
- Heavy top quark

There is a 3rd possible phase, the "strong CP phase", θ -- enters quark interactions since from the strong interaction

Neutron EDM implies $\theta < 10^{-16}$, $d_n \sim 10^{-16}\,\theta$

Allowed by QCD, in Standard Model – not yet understood or calculable

The parameters will in general have patterns, values characteristic of the underlying theory they come from – but we may not know it

Recently we calculated supersymmetry-breaking phases in a compactified string theory with definite supersymmetry breaking mechanism (M-theory compactified on 7D G_2 manifold)

[GK, Piyush Kumar, Jing Shao, arXiv:0905.2986,

based on Acharya, Bobkov, GK, Kumar, Shao, th/0701034]

Find *no phases in soft breaking parameters!*

This class of string theories predicts no sources of CPV beyond the quark and lepton CKM matrices and the strong CP phase!

We argue this result is more general in string theory

However, a practical problem – this is at the string scale ~ 10^{16} GeV

Must calculate at electroweak, nuclear scale ≤ 100 GeV – the "trilinear" soft breaking terms A^u, A^d acquire phases from the Yukawas and this "renormalization group running"

$$dA^u / d(\log energy) \approx A^u Y^{u\dagger} Y^u + \ldots$$

Non-zero trilinears lead to EDMs

Electroweak trilinears model dependent, but results for G_2 don't exceed experimental limits! – string-based supersymmetric theory does not predict too-large EDMs

So – supersymmetry "prediction" is no soft phases at string scale, some induced at weak scale – in this class of theories

EDMs probe string theory!

-- will be calculable as we understand the theory better

-- could interpret result as saying many string theories already ruled out by EDM data – remaining ones tested by future EDM data

Small EDMs may provide remarkable clue(s) – in G2 construction

- $d_n \sim 10^{-16}\,\theta$ + Yukawas effect
- $d_{Hg} \sim (d_d - d_u - 0.012\, d_s \sim 10^{-18}\,\theta)$ + Yukawas effect
- $d_e \sim$ Yukawas effect only $\sim 10^{-31}$

Most important priority experimentally after initial discovery is to separate strong CPV from Yukawas effect