Very Low Energy Gauge Mediation

- Two motivations:
- Cosmological SUSY Breaking: $m_{3/2} = 10K\ \Lambda^{1/4} = K\ X10^{-43/4}$ GeV → $F = 18\ K\ (TeV)^2$
- (Factor of 10 From Witten explanation of M_{GUT}/M_{Planck} in terms of large extra dimensions. 8π??)
- Cosmology: $m_{3/2} < 30$ eV → $F < 6\ X\ 10^4\ (TeV)^2$

CSB Rules for Low Energy Lagrangian

- $\Lambda = 0$ limit is R symmetric and super-Poincare invariant.
- R breaking terms from "interaction with Horizon" including W_0 to tune c.c.
- Resulting field theory has (meta-stable) SUSY violating state.
- Decay is really Poincare recurrence:
- $P \sim e^{-A/4}$: A horizon area (Planck units)

Two Kinds of Models: I

- Goldstino Chiral Multiplet G Couples to Hidden sector via $W = G\, O_2$
- G has R charge 0
- R breaking terms $W_0 + F(G/M_P)$
- $F(0) = 0$; $F'(0)$ chosen to give gravitino mass $\sim \Lambda^{1/4}$ when G gets a VEV via
- $M^2 K(G/M, G^*/M)$; M confinement scale of hidden sector.

- If some hidden sector fields have SU(1,2,3) quantum numbers, then there will be couplings f_i (G/M) $(W_\alpha^{(i)})^2$ to std. model gauge multiplets: gaugino masses of order α_i / π F/M
- Chargino bound (m > 160 GeV) requires F/M > 3.5 TeV
- Coupling g_μG H_u H_d generates a μ term of order g_μ<G> and $B_\mu \sim g_\mu F$
- RH slepton mass harder to analyze a la "General Gauge Mediation". No cancellation of log divergence suggests it might be > neutralino → e^+e^- $\gamma\gamma$ + missing E_T

The Problem

- In all explicit models, the field O_2 appears in LEFT. $F_G = M\, O_2 + F$ and there is a nearby SUSIC vacuum with $\langle O_2 \rangle = - F/M$.
- Thus, no meta-stability (loophole: large N hidden sector, but causes problems with unification as in Pentagon model below).

The Pentagon Model

- Add $SU_P(5)$ Gauge Group With P_i^A P_B^j in $[5,5^*]+[5^*,5]$ of $SU_P(5)XSU(1,2,3)$ Plus Singlet S and Superpotential
- $g_S\, S\, P_i^A\, P_A^j\, X_j^i + g_\mu\, S\, H_u H_d + g_T S^3$
- Z_4 R symmetry protects d=4,5 B and L violating operators except neutrino seesaw term.
- Strong CP needs axion (might be dark matter).
- $\delta W = m_3\, P_i^A P_A^j\, (I_3)_j^i + m_2\, P_I^A\, P_A^j (I_2)_j^i + W_0$
- $m_3\, I_3 + m_2\, I_2$ lin. ind. of X

VEVs and the Higgs Sector

- VEV for meson M_i^j Breaks R symmetry and allows gaugino mass.
- Low energy (g_S small) :
- $V = K^{ab}(M/\Lambda, M^*/\Lambda)\, m_a\, m_b\, \Lambda^2$ a,b = 2,3. Λ Confinement scale. Valid as long as $m << 4\pi\Lambda$
- Assume nonzero minimum, can then calculate spectrum. Unknown parameters.

Breaking of SU(1,2)

- $H_u \sim H_d \sim (g_S / g_\mu)^{1/2} \Lambda \rightarrow g_S$ small ~ .1
- Little hierarchy problem ameliorated if g_μ "large"
- But <S> = 0, no mu term. F_S isn't zero, so B_μ ~ few 100 GeV
- Possible solution: 6th pentaquark with $m_6 \sim 4\pi\Lambda$ and coupling to S. Gives extra potential for S with minimum at – m_6

Sparticle Spectrum

- $m^i_{1/2} = 5X^i (\alpha^i / 4\pi) \mu$
- μ fcn of m_2 and m_3
- X's depend on unknowns in Kahler potential
- Squarks and sleptons have log divergent masses in low energy theory. Naively bigger by $\ln(\Lambda/\mu)$ (J. Jones)
- So probably neutralino is NLSP and there should be an $ee\gamma\gamma +$ missing energy signal

The PNGB of Penta-baryon number

- With H. Haber: strongest lab constraint K → π + b, easily satisfied, not accessible in reasonable upgrades
- Yukawa coupling to electron too large to satisfy stellar cooling bounds unless b too heavy to be produced → low (10^9 GeV) explicit breaking scale.
- This is also the range where b could be dark matter AND explain baryon asymmetry of the universe (w/ Echols and Jones)
- Must find symmetries to protect ordinary baryon number from d = 6 operators with this scale.

The Pentagon's Biggest Problem

- 1 loop unification works, but two loop beta fcns give Landau poles below the GUT scale (J Jones) → Theoretical error bar on unification prediction large
- Note: generic that 2 loop unification not as good as 1 loop. New thresholds? Interesting intermediate scale physics? Connection to neutrino see-saw scale?
- Could abandon CSB and have Pentagon at higher scale (m_a > 1000 TeV). Cosmologically problematic gravitino.
- Definite prediction of proton decay close to current bounds.

Other Models

- “Pentagon” or ISS like models with smaller hidden sector gauge groups don’t work.
- Baryonic branch of moduli space, where metastable vacua reside breaks SU(1,2,3), typically giving photon or gluon a mass
- Models with SU(1,2,3) singlet flavors in hidden sector still under exploration but some indications of a clash between unification, cosmological gravitino bounds, and dynamics of meta-stable SUSY breaking.

Conclusions

- Two kinds of models of VLGM consistent with CSB, but no explicit examples of first class
- Pentagon model attractive but problems with 2 loop unification – so far no attractive alternatives. General issue of gravitino bound vs. SUSY breaking dynamics and unification.
- Likely predictions: low scale superpartners, NLSP neutralino, $ee\gamma\gamma$ + missing E_T, light chargino, measureable proton decay.
- Dark matter: axion or PNGB b (in which case also explain baryon asymmetry). As yet no candidate for explanation of putative DM signals from PAMELA, ATIC, EGRET,DAMA/LIBRA etc. – PNGB in range consistent with stellar cooling bounds could(?) explain dark matter decays into only leptons but not annihilation signals of multi hundred GeV particle.

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