The impact of hidden sector renormalisation on estimates of fine tuning

arXiv:1311.2944

JHEP 1403 (2014) 069

Ed Hardy,

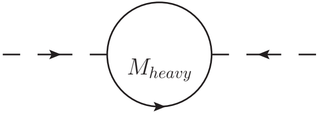
Oxford University,

e.hardy12@physics.ox.ac.uk

The Hierarchy Problem

Scalar masses are sensitive to any new scales in the theory (that they interact strongly enough with).

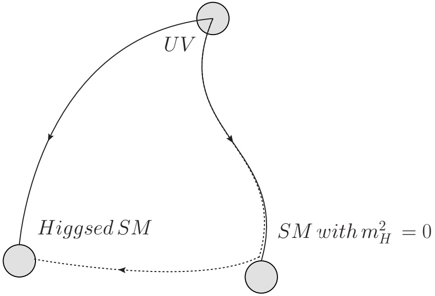
Often this understood as couplings to new states,



$$\Delta m_H^2 \sim M_{heavy}^2 \log\left(\frac{M_{heavy}}{m_Z}\right) \tag{1}$$

M_{heavy} may be the string scale, Plank scale, scale flavour structure is generated, etc.

Not just a perturbative effect



Without a new symmetry, there is nothing special about such a trajectory, c.f. tuning to a critical point in condensed matter.

Fine tuning

Fine tuning with respect to the parameter i, is defined as

$$Z_i = \frac{\partial \log m_Z^2}{\partial \log i}. \tag{2}$$

Important to measure from the scale at which the underlying theory is defined, and w.r.t. parameters that are independent in the fundamental theory (or at least try to).

Current collider limits mean tuning typically dominated by gluino and stops, enter m_Z at loop level

Much worse for high scale mediation, bigger logs. (Unless e.g. Dirac gauginos)

One way to reduce apparent tuning is more complex models with more parameters, X-MSSM's, XX-MSSM's. Is fine tuning actually reduced?

Alternatively, what assumptions can be relaxed?

1. Correlations between high scale parameters, due to underlying fundamental model. E.g. focus points, other regions of theory space [many]
2. Modify the running

Hidden Sector Renormalisation

[Nelson, Strassler, 2000][Dine, et al., 2004][Cohen, Roy, Schmaltz, 2006]

Naively expect the effects of hidden sector renormalisation to be very boring, but they don't have to be!

$$\mathcal{L} \supset \int d^4\theta a_i \frac{X^\dagger X}{M_*^2} \Phi_i^\dagger \Phi_i + \int d^2\theta c_n \frac{X}{M_*} W_{n\alpha} W_n^\alpha + \mathrm{h.c.}, \qquad (3)$$

where X is a SUSY breaking spurion, Φ_i visible sector chiral multiplets, W visible gauge field strength.

Wavefunction renormalisation of superfield X accounted for by defining

$$F(\mu) = \frac{F_0}{Z_X^{1/2}(\mu)}. \qquad (4)$$

If hidden sector is approximately SUSY, gaugino mass is given by

$$M_n(\mu) = g_n^2(\mu)\, c_n \frac{F(\mu)}{M_*}. \tag{5}$$

Where the gauge coupling running is given by

$$\beta(g) = -\frac{g^3}{16\pi^2} \frac{3T(Ad) - \sum_i T(R_i)(1-\gamma_i)}{1 - \frac{g^2}{8\pi^2} T(Ad)}. \tag{6}$$

Holomorphy $\implies$ gauge coupling running (1-loop + part from anomalies), and wavefunction renormalisation of X

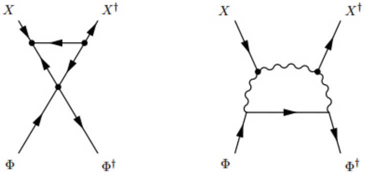
Scalar soft masses are more interesting

$$m_i^2 = a_i\left(\mu\right)\frac{F\left(\mu\right)^2}{M_*^2}. \tag{7}$$

$a_i\left(\mu\right)$ is the renormalised coupling, runs

$$\frac{da_i}{dt} = \gamma_i a_i - \frac{1}{16\pi^2}\sum_n 8C_n\left(R_i\right)g_n^6 c_n^2 + \ldots, \tag{8}$$

2nd term from visible sector, three ellipses = more suppressed effects from visible sector.



[From Cohen et al]

γ_i is the contribution to the anomalous dimension of the operator from hidden sector effects.

Reducing Fine Tuning

Large anomalous dimension, for an extended energy region can change the running of the sfermion soft masses dramatically, but doesn't change the gaugino masses.

How can this help fine tuning?

If the Higgs soft mass operator gains a large anomalous dimension, γ (assumed constant) in a strong coupling region between energy scales Λ_1 and Λ_2. Then

$$m_{Hu}^2(\Lambda_1) \approx m_{Hu}^2(\Lambda_2)\left(\frac{\Lambda_1}{\Lambda_2}\right)^{\gamma}. \tag{9}$$

Any feed in to the Higgs mass from superparticles above, or during, the strong coupling region is strongly suppressed

Model building challenges

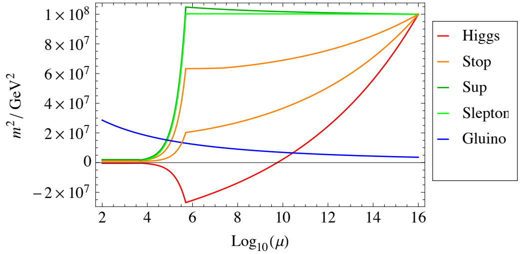
What is needed?

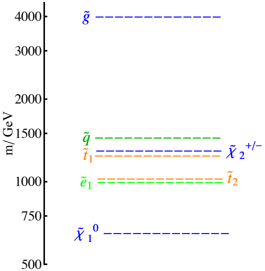
- some sector of the theory has to run close to a SCFT, in which operators gain large anomalous dimensions
- this strong coupling region needs to end not too far from the weak scale
- analysis assumes approximately SUSY, actually even without this it is not so unreasonable that gaugino mass operators behave very differently to scalar mass operators

Actual calculation for a specific model is hard, instead parameterise the hidden sector by taking

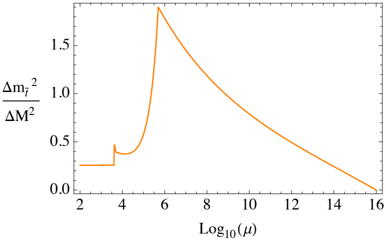
$$\gamma_i(\mu) = \begin{cases} 1 & \text{if } \Lambda_1 < \mu < \Lambda_2 \\ 0 & \text{otherwise} \end{cases}, \tag{10}$$

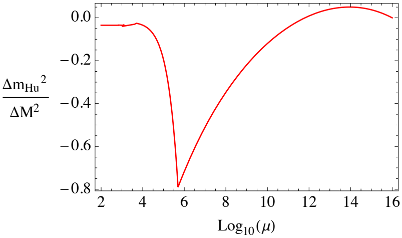
Simplest models, all scalars suppressed





Perturbation in the stop and Higgs mass squared from the Gluino, as a function of energy





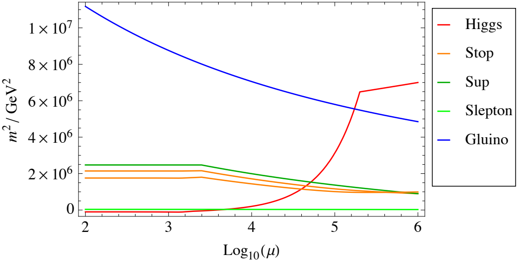
Gluino fine tuning

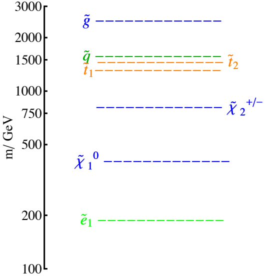
$$Z_{M3} \sim 15 \tag{11}$$

For comparison a 4 TeV gluino run from GUT scale normally means tuning ~ 600

Sfermion, stop, μ tunings about 50, slight improvement.

Need a more complicated structure to reduce sfermion fine tuning as well, suppose only Higgs mass squared operator gains large anomalous dimension.





Overall tuning about 15 in each parameter.

Without strong coupling, would be $\mathcal{O}(100)$

Low scale model

SUSY breaking sector is also the strong coupling sector.

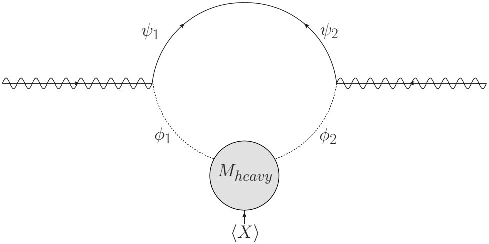
Theoretically reasonable, spontaneous SUSY breaking is often associated with running to strong coupling

Potential advantage- spontaneous SUSY breaking needs (approximate) R-symmetry, hard to get heavy enough gauginos normally.
Possible example: ISS model close to edge of conformal window.

High Scale Mediation

SUSY breaking sector probably cannot remain dynamic until near the weak scale, but the messenger sector can be.

Two stage mediation with some heavy and some light messengers. The latter run into strong coupling



No complete model at present, it would be nice to build one.

Other Model Possibilities

Combine with Dirac gauginos, theoretically nice: Both sectors now have an R-symmetry, can calculate operator anomalous dimensions in the SCFT.

More complicated mediation mechanisms, sfermion mass operators gain opposite sign anomalous dimensions to the Higgs, enhanced.

Natural SUSY-like, stops mass behaves differently to the other generations.

Conclusions

- LHC results are putting severe pressure on models which allow a natural weak scale
- Worth seeing if relaxing standard assumptions can alleviate this, if not completely solve it
- Certainly not all theories are tuned to the large figures of MSUGRA etc.
- Hidden sector renormalisation is interesting and not so heavily studied.
- May help reduce fine tuning, and is even if not it can leave other calculations inaccurate.

ISS model is a reasonable candidate [Intriligator, Seiberg, Shih, 2006] .

SUSY breaking, $\sqrt{\sum F} \sim (N_f - N_c)^{1/2} h^{1/2} \mu$

Tree level masses $\sim h\mu$

Pseudomoduli (scalar components of the multiplets that obtain F-terms) loop masses $\sim h^2 \mu$