The MESSM

The Minimal Exceptional Supersymmetric Standard Model

Richard Howl

University of Southampton

UK BSM 2007

The MESSM

- **MESSM** = **M**inimal **E**xceptional **S**upersymmetric **S**tandard **M**odel
- An ∂_7 SUSY Grand Unified Theory based on the $\partial_7 \epsilon\ \epsilon\ t$
- Like the $\partial_7 \epsilon\ \epsilon\ t$, **MESSM** attempts to solve the a - problem of the MSSM
- But without the theoretical difficulties caused by incomplete ∂_7 multiplets that are introduced in the $\partial_7 \epsilon\ \epsilon\ t$ for gauge coupling unification

The a - Problem

- MSSM superpotential contains $ab_v b_e$ which gives mass to the Higgsinos
- Important for determining the Higgs scalar potential and the pattern of Electro-weak Symmetry Breaking (EWSB)
- From phenomenology we require a ¸ SUSY breaking (or EW) scale
- a is a free parameter, term is SUSY invariant, can be present before SUSY is broken " why a ¸ SUSY breaking (not e.g. t_q) ?

A popular solution is to introduce a SM singlet ϵ and a superpotential term: $\epsilon\, b_v b_e$ " $\psi\ \epsilon\ \Pi\, b_v b_e$ " $ab_v b_e$ (dynamically produced)

However, this term creates a global $v\ )2^*$ (PQ) symmetry which will produce a Goldstone boson when ϵ gets its VEV

One way to avoid this Goldstone boson is to embed the global $v\ )2^*$ Inside a local $v\ )2^{*1}$ " The would-be Goldstone boson gets ‘eaten’

The bilinear a - term $ab_v b_e$ is forbidden by this local $v\ )2^{*1}$ symmetry

The a - Problem in SUSY GUTs

- Gauge coupling unification for MSSM suggests can embed it within some Supersymmetric Grand Unified Theory
- If assume GUT exists and wish to solve the a - problem with a ϵ and v)2*[1], then both of these must be derived from the Grand Unified Theory
- ϵ VEV could then be determined from a radiative mechanism from GUT
- However:

SUSY GUTs * colour triplet particles: i >)4κ2*$_{\text{ç}\ \frac{2}{4}}$, $\overline{i}$ ±)$\overline{4}$κ2*$_{\frac{2}{4}}$ when we embed $b_{\text{v}}\kappa b_{\text{e}}$ into complete GUT multiplets

- Can cause rapid proton decay and can destroy gauge coupling unification
- Most popular solution is to give large (GUT scale) mass to i κ$\overline{i}$ via a doublet-triplet splitting mechanism
- * don't participate in low energy theory and proton decay suppressed

The a - Problem in SUSY GUTs

Problem:

Since $b_{\nu}\kappa b_{e}$ and $i\ \kappa\bar{i}$ come from the same representations:

To generate the $\epsilon\, b_{\nu} b_{e}$ term, we generally also get a $\epsilon\ i\ \bar{i}$ term

With a large effective $i\ \bar{i}$ mass term, ϵ could generally acquire a large effective VEV from $\epsilon\ i\ \bar{i}$ (one-loop tadpole diagrams) destroying EWSB

Whereas if $i\ \kappa\ \bar{i}$ have small masses (EW scale) then they can affect the RGEs to help drive the soft square mass of ϵ large and negative

Also, light $i\ \kappa\ \bar{i}$ could be used to cancel any anomalies for the $v\ )2^{*1}$

" **Suggests should try to keep $i\ \kappa\ \bar{i}$ 'light'**

(to solve a – problem)

Suppressing Proton Decay

- $i\ \kappa\ \overline{i}$ generally interact with quarks and leptons in GUTs via these terms:

1 $Q_{qr}\ U R R \kappa Q_{qr}\ \overline{U} e^{d} v^{d}_{r}$ 2 $Q_{m}\ f^{d} U v^{d} \kappa Q_{qm}\ R M \overline{U}$

  * Induce proton decay via d = 6 operators suppressed by $2\mu t\ \frac{3}{U}$

- Therefore if $i\ \kappa\ \overline{i}$ are light we must suppress proton decay by making Yukawa constants Q sufficiently small

  * Must only suppress the terms that induce proton decay and not the terms that allow the triplets to decay

However, we cannot have all Q small since then $i\ \kappa\ \overline{i}$ would become stable particles.

e.g. apply a discrete symmetry ϱ_3 on the leptons or the leptons and triplets

Then 1 or 2 are allowed but the other is forbidden

" proton decay sufficiently suppressed and $i\ \kappa\ \overline{i}$ are no longer stable

Another possibility could be to apply a family symmetry and / or generate 1 or 2 via higher dimensional operators "

more work needed

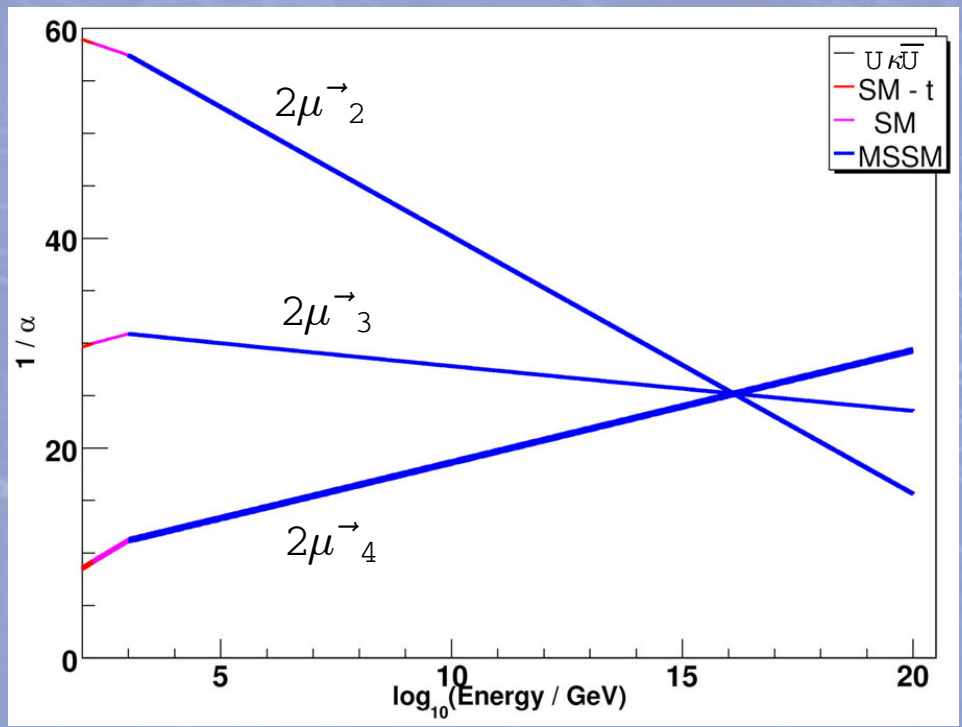
Must only suppress the terms that induce proton decay and not
the terms that allow the triplets to decay
Must try to suppress the terms that induce proton decay but not
the terms that allow the triplets to decay

Repairing Guage Coupling Unification

Proton decay now suppressed

but keeping $i\ \kappa\ \overline{i}$ light spoils the unification of the MSSM:

(2 – loop)

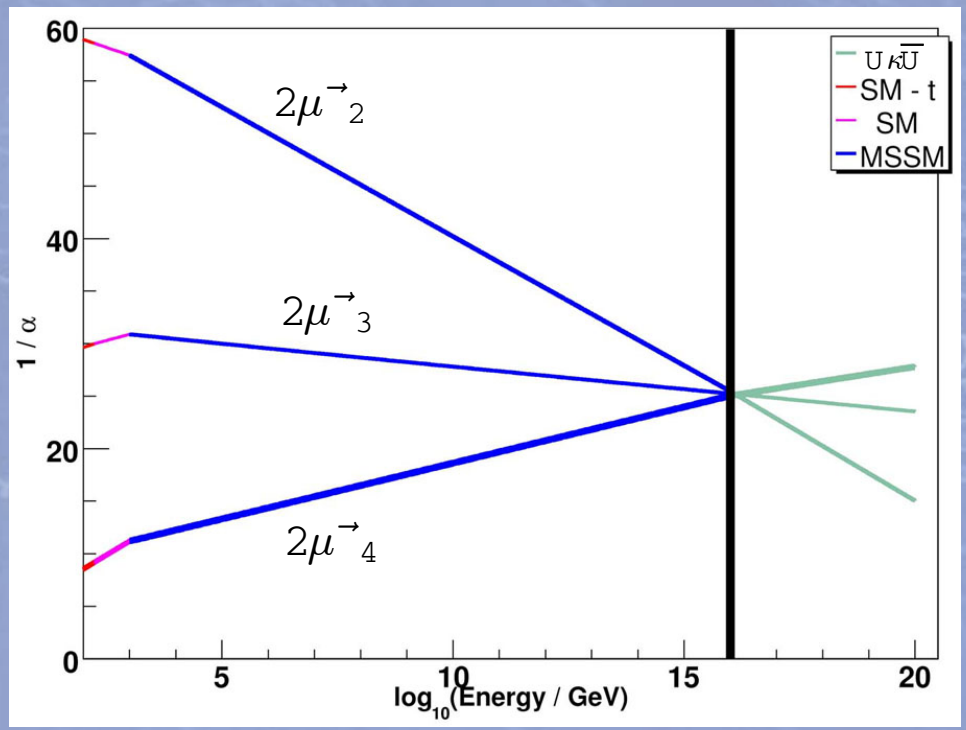


Repairing Guage Coupling Unification

- Proton decay now suppressed

but keeping $i\ \kappa\ \overline{i}$ light spoils the unification of the MSSM:

(2 – loop)



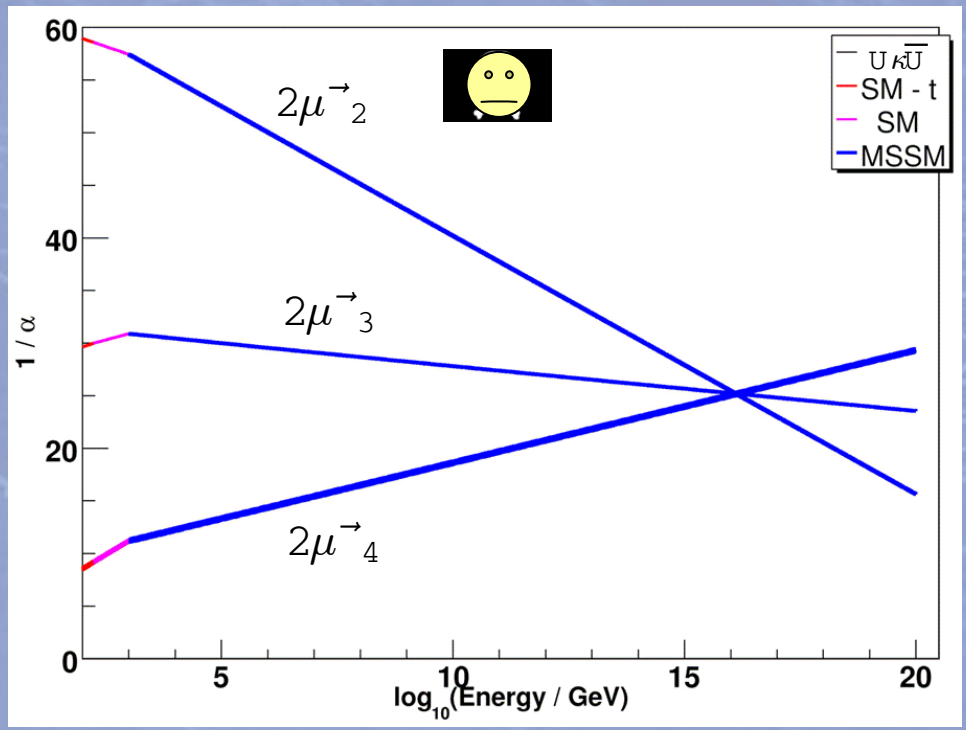
- The Black line indicates mass of $i\ \kappa\ \overline{i}$
- The **green lines** show their effect on the RGEs

Repairing Guage Coupling Unification

- Proton decay now suppressed

but keeping $i\ \kappa\ \overline{i}$ light spoils the unification of the MSSM:

(2 – loop)



(No Unification)

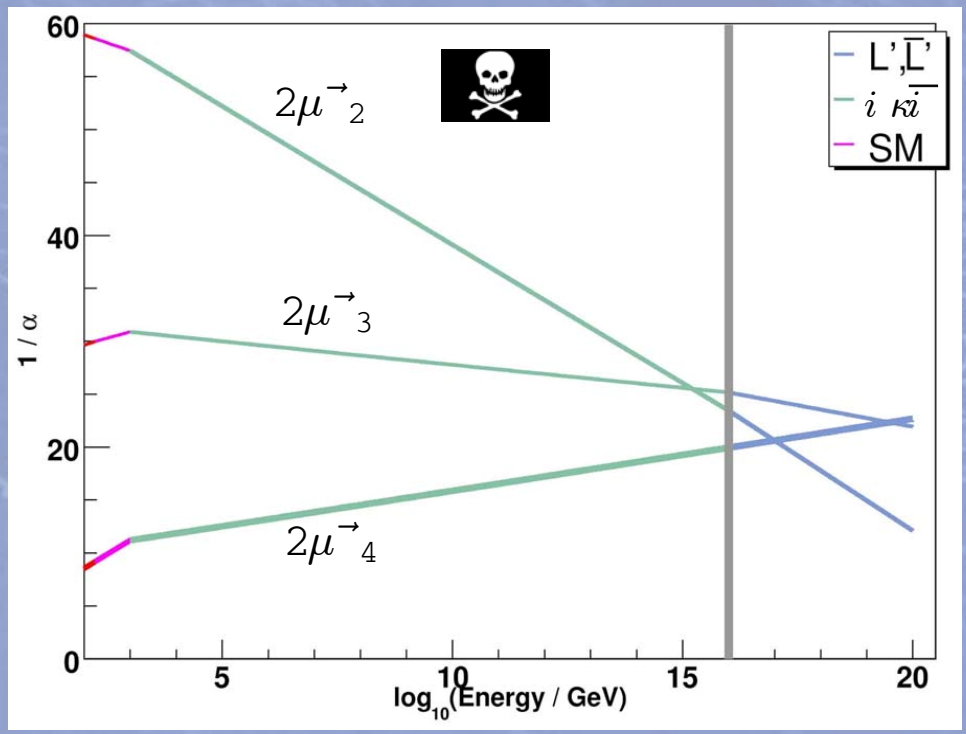
- The Black line indicates mass of $i\ \kappa\ \overline{i}$
- The **green lines** show their effect on the RGEs

Repairing Guage Coupling Unification

Proton decay now suppressed

but keeping $i\ \kappa\ \overline{i}$ light spoils the unification of the MSSM:

(2 – loop)



A possible solution is to add two additional EW doublets to light spectrum

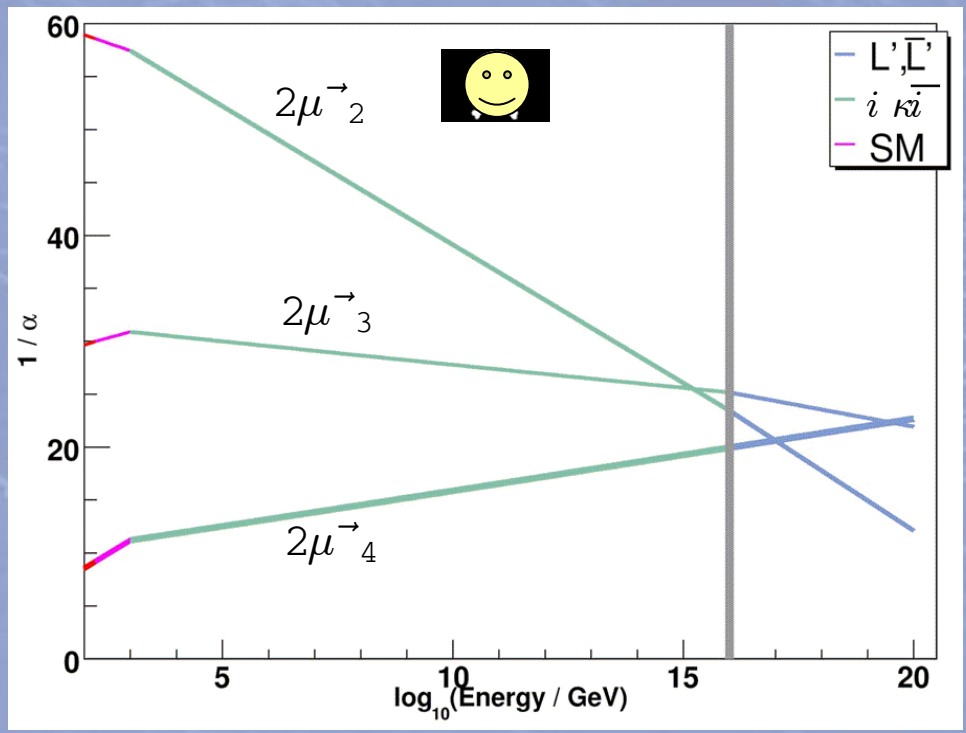
" have added two complete $\epsilon\ v\ )6^*$ multiplets (6 , $\overline{6}$) to the MSSM

Repairing Guage Coupling Unification

Proton decay now suppressed

but keeping $i\ \kappa\ \overline{i}$ light spoils the unification of the MSSM:

(2 – loop)



(higher unification coupling constant than for MSSM.)

However these new particles could introduce theoretical problems:

A possible solution is to add two additional EW doublets to light spectrum

e.g. How to keep the two extra doublets light but rest of GUT multiplet heavy.

" have added two complete ϵ_6 multiplets (6 , $\overline{6}$) to the MSSM

Essentially a D-T (mass) splitting problem

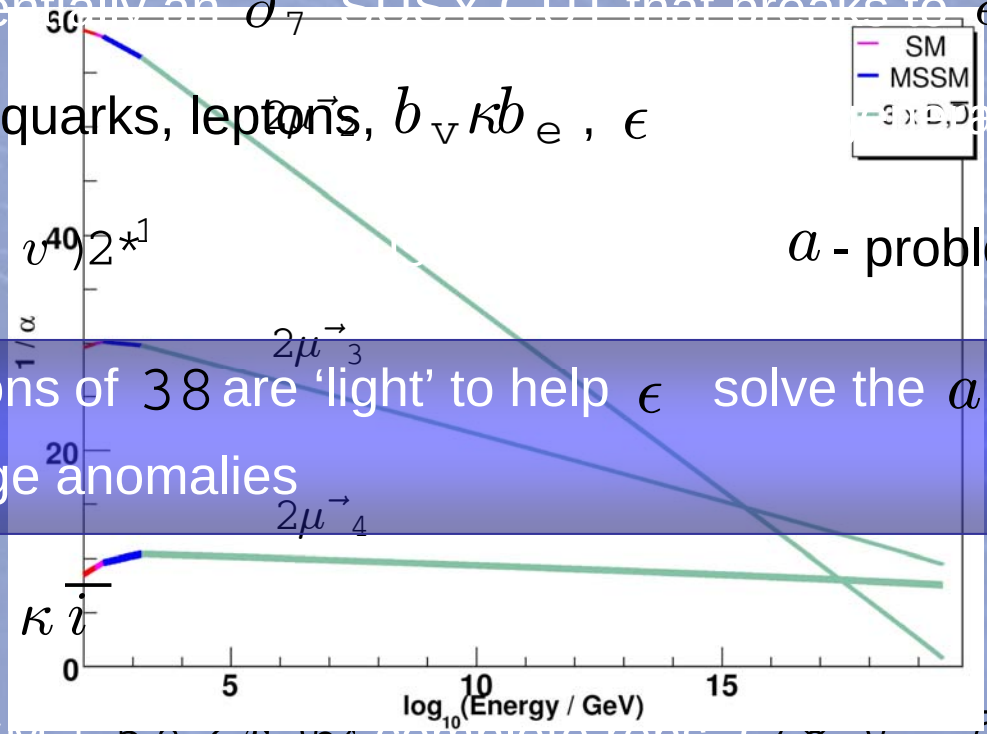
Unification in the ESSM

- An example of a SUSY GUT that requires two additional EW doublets for gauge coupling unification is the $\partial_{7}\epsilon\,\epsilon\,t$
- E_6SSM is essentially an ∂_{7} SUSY GUT that breaks to $\epsilon\, t$ ¤ v)2*1 and places the quarks, leptons, $b_{\mathrm{v}}\kappa b_{\mathrm{e}}$, ϵ into 3 generations of a 38
- ϵ from 38 and v)2*1 are both used to solve the a - problem of the MSSM
- All 3 generations of 38 are 'light' to help ϵ solve the a - problem and to cancel gauge anomalies
- 38 contains $i\ \kappa\ \overline{i}$
- * like MSSM + 5 ¤ $\epsilon\, v$)6* complete reps. (3 ¤)6 , $\overline{6}$*) + $i\ \kappa\ \overline{i}$

↑ spoil unification

Unification in the ESSM

- e.g. In $\partial_7 \epsilon t$ matter and Higgs are put into 3 generations of a $\partial_7 38$
- All 3 generations of 38 are 'light'
- An example of a SUSY GUT that requires two additional EW doublets for gauge coupling unification is the $\partial_7 \epsilon \epsilon t$
- E_6SSM is essentially an ∂_7 SUSY GUT that breaks to ϵt ¤ v)2*[1]
- and places the quarks, leptons, $b_{\nu} \kappa b_{e}$, ϵ ations of a 38
- ϵ from 38 and v)2*[1] a - problem of the MSSM



All 3 generations of 38 are 'light' to help ϵ solve the a - problem and to cancel gauge anomalies

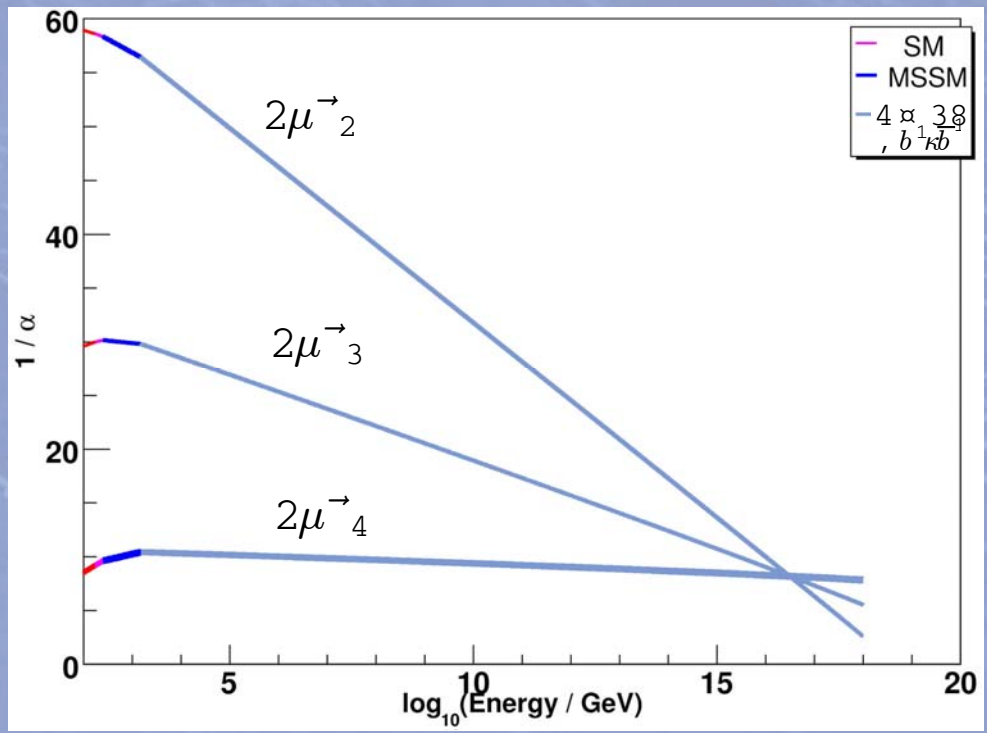
- 38 contains $i \kappa \overline{i}$
- * like MSSM + 5 ¤ ϵv)6* complete reps. (3 ¤)6 , 6*) + $i \kappa \overline{i}$

spoil unification

Unification in the ESSM

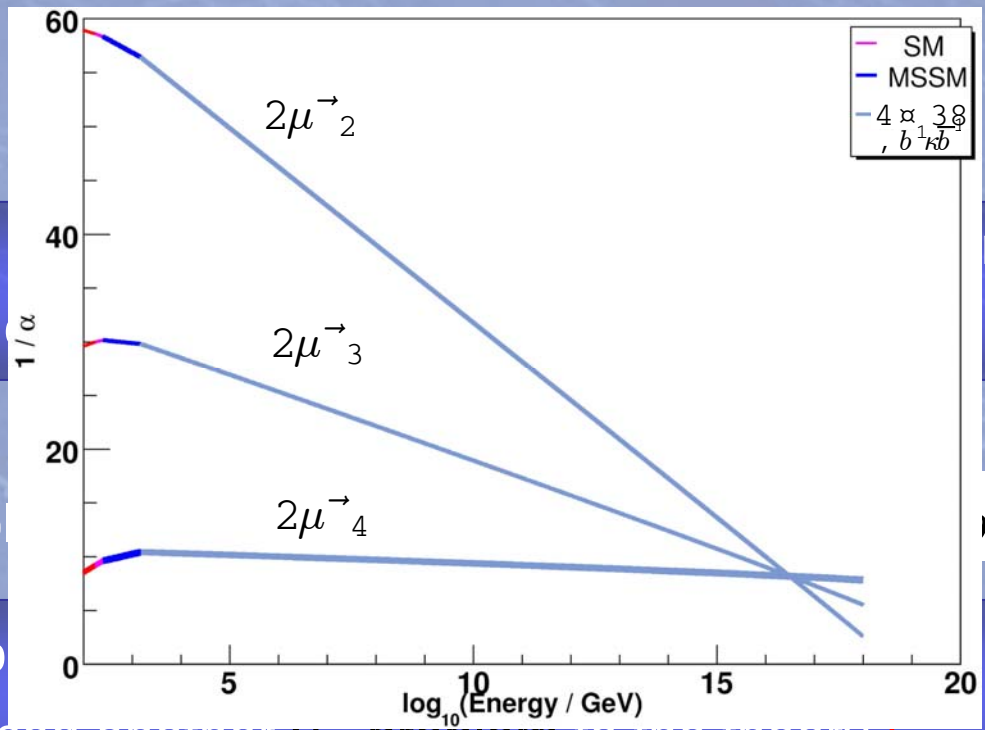
- e.g. In $\partial_7 \epsilon\, \epsilon\, t$ matter and Higgs are put into 3 generations of a $\partial_7\ 38$
- All 3 generations of 38 are 'light' + **two extra doublets** $b^{1}\kappa\bar{b}^{-1}$
- * like MSSM + $\exists\, \alpha\ \epsilon\ v\ )6^*$ complete reps. $(\exists\, \alpha\ )6\ ,\ \bar{6}^*)$ + $i\ \kappa\ \bar{i}$

spoil unification



Unification in the ESSM

- e.g. In $\partial_7 \epsilon\, \epsilon\, t$ matter and Higgs are put into 3 generations of a ∂_7 38
- All 3 generations of 38 are 'light' + **two extra doublets** $b^{1}\kappa\bar{b}^{1}$
  - * like MSSM + 7¤ $\epsilon\, v$)6* complete reps. (4¤)6 , $\bar{6}$*)



Problems:

No explanation … mplete
∂_7 representati… problem

The extra doubl… $^{1}\bar{b}^{1}$

→ Why do… e.g. t q) ?
→ Introduced another α - problem to the theory !

Unification with Intermediate Symmetries

A way of avoiding these new doublet particles could be to use an intermediate symmetry to 'repair' the unification instead

non-simple group , Grand Unified Group

gauge couplings no longer need to unify but instead turn into , gauge couplings (at the symmetry breaking scale) which do unify

e.g. in and we could use a left-right symmetric Pati-Salam:

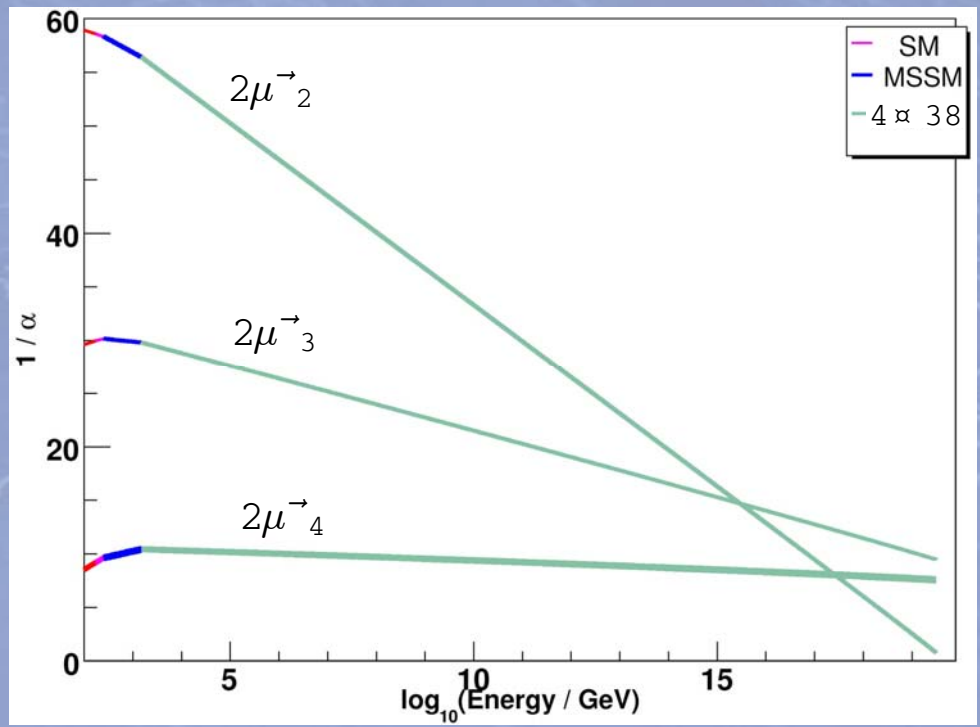
At the P-S symmetry breaking scale the SM gauge couplings must satisfy:

(When GUT normalized and with)

* P-S symmetry breaking scale determined from running gauge couplings with energy until they satisfy the above equation.

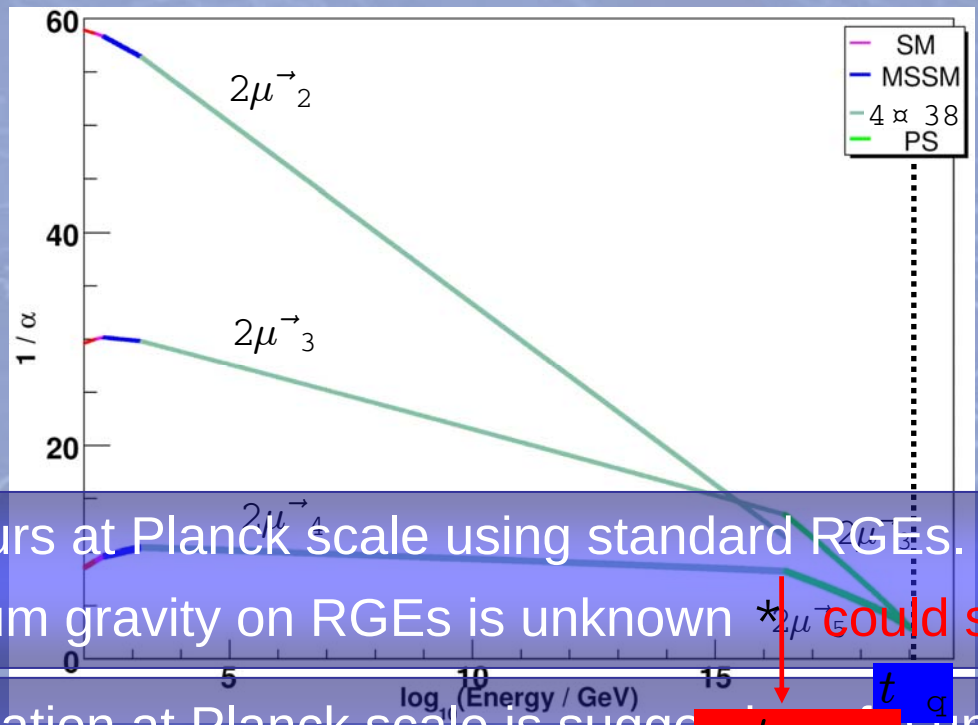
Unification with Intermediate Symmetries

- e.g. ∂_7 with quarks, leptons, $b_\nu \kappa\, b_e \kappa\, i\ \kappa\, \overline{i}\ \kappa\, \epsilon$ in a fundamental 38
- All 3 generations of 38 ‘light’.



Unification with Intermediate Symmetries

- e.g. ∂_7 with quarks, leptons, $b_{\nu}\kappa\, b_{e}\kappa\, i\ \kappa\, \overline{i}\ \kappa\, \epsilon$ in a fundamental 38
- All 3 generations of 38 'light'.
- Can now obtain unification if: $, > \epsilon\, \upsilon\ )5^{*} \neg\ \epsilon\, \upsilon\ )3^{*}_{M} \neg\ \epsilon\, \upsilon\ )3^{*}_{S} \neg\ \rho_{MS}$



Unification occurs at Planck scale using standard RGEs.

Effect of quantum gravity on RGEs is unknown * could spoil unification

However, unification at Planck scale is sugge[illegible] unification of the gauge fields with gravity.

Use Higgs multiplets from 38, $\overline{38}$ to break P-S symmetry.

Assumed 38, $\overline{38}$ have mass of order of the P-S breaking scale.

* assumed quantum gravity does not spoil this unification but instead could unify gravity with the gauge fields.

The MESSM

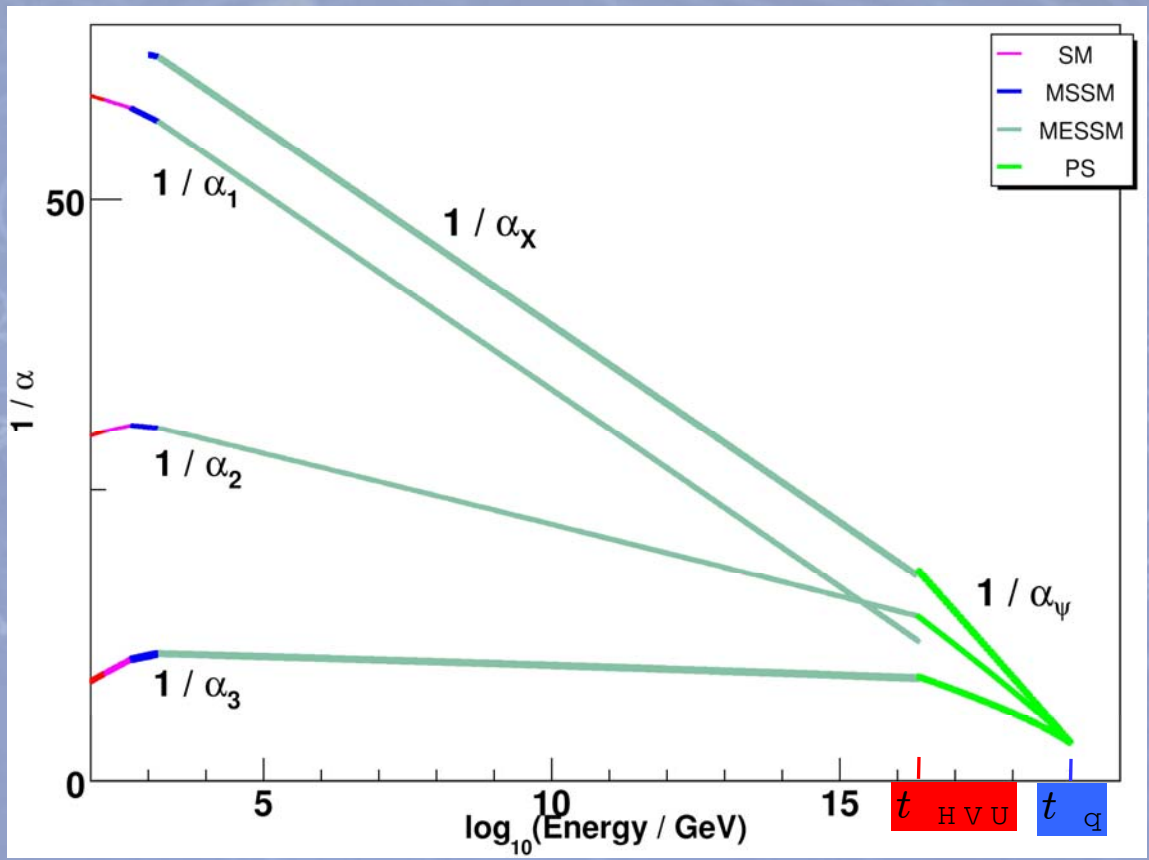
- If assume Planck scale unification then can use an intermediate symmetry rather than two EW doublets for gauge coupling unification.
  - " avoiding the theoretical difficulties they introduce.
- The **MESSM** is based on the E_6SSM but uses a Pati-Salam symmetry for gauge coupling unification instead of the E_6SSM EW doublets
  - " no need for a D-T splitting mechanism or the extra a^{1} term

$$\partial_7 \text{ " } \epsilon \sharp)21^* \neg v)2^*_4 \text{ " } \epsilon v)5^* \neg \epsilon v)3^*_M \neg \epsilon v)3^*_S \text{ ¤ } \rho_{MS} \neg v)2^*_4$$

- To break P-S ¤ $v)2^*_4$ to SM ¤ $v)2^{*1}$ we use Higgs bosons from 38 , $\overline{38}$: $\tau_S \pm)5\kappa 2\kappa 3^*_{¢\frac{2}{3}}$ $\kappa\overline{\tau}_S >)\overline{5}\kappa 2\kappa 3^*_{\frac{2}{3}}$ with VEVs in n_S direction
- ϵ from 38 and $v)2^{*1}$ are used to solve a - problem of MSSM
- n_S are singlets of the SM ¤ $v)2^{*1}$
  - * Can generate conventional see-saw mechanisms.

The MESSM

∂_7 " ϵv)5*¬ ϵv)3*$_M$ ¬ ϵv)3*$_S$ ¤ ρ_{MS} ¬ v)2*$_4$ " ϵt ¬ v)2*$_Y$ " ϵt



- Pati-Salam symmetry broken at ¸ $21^{27;5}$ ϕ ˆ2 ¸ t_{HVU}
- ∂_7 symmetry assumed to be broken at the Planck mass scale

Summary

- The **MESSM** attempts to solve the a - problem of the MSSM using a SM singlet particle ϵ and a local v)2* group from an ∂_7 GUT
- To help ϵ solve the a- problem and to cancel anomalies, all 3 generations of 38 light. (including the colour triplets)
- To 'repair' the gauge coupling unification an intermediate Pati-Salam symmetry is used.
- The P-S symmetry is broken at the **GUT** scale

  The ∂_7 symmetry is assumed to be broken at the **Planck** mass scale.
- The Higgs bosons used to break P-S come from 38 , $\overline{38}$ which can have the same (**GUT** scale) mass
- " No ∂_7 multiplet (mass) splitting.