# Flavored Gauge Mediation

YS, Szabo 1103.0922 : general setup, sleptons

Abdullah, Galon, YS, Shirman 1209.4904: Higgs mass

Galon, Perez, YS 1306.6631: squarks

# overview

*LHC: no supersymmetry*

*? because there`s no supersymmetry*

*? because the spectrum is different from what we imagined*

*here: **FLAVOR***

*LHC: Higgs mass: around 125 GeV*

*? because there`s no supersymmetry*

*? because it`s not the MSSM, eg NMSSM*

*here:* ***large stop A-terms***

***heavy Higgs with superpartners within LHC reach***

***Flavored Gauge Mediation models:***

*GMSB +*

*messenger-matter couplings*

*(generation dependent)*

*→ new (generation dependent) contributions to soft terms*

*FLAVOR stuff to bear in mind (theory and exp):*

- *we do not understand the SM Yukawa couplings*

- ***assumption in most/all SUSY searches***

  *flavor blind soft terms → Minimal Flavor Violation (MFV): 1st, 2nd generation scalars degenerate*

*FLAVOR stuff to bear in mind (theory and exp):*

- *we do not understand the SM Yukawa couplings*

- ***assumption in most/all SUSY searches***

  *flavor blind soft terms → Minimal Flavor Violation (MFV): 1st, 2nd generation scalars degenerate*

  *motivated by constraints on FV*

*but this isn`t the only way to satisfy flavor constraints:*

*roughly: constrained quantity:*

$$\delta_{ij} = \frac{\Delta m_{ij}^2 \, K_{ij}}{m^2}$$

**scalar mass splittings**

**gaugino-scalar-fermion mixing**

**``average" soft mass**

** LHC searches: want to work in mass basis for both fermions scalars*

$$\delta_{ij} = \frac{\Delta m^2_{ij} \; K_{ij}}{m^2}$$

or combination

***degeneracy:***
***scalar mass matrix proportional to identity***

***alignment:***
***scalar mass matrix "aligned" with fermion mass matrix: approximately diagonal together → mixings small***

Nir Seiberg

***large scalar masses:***
***Effective SUSY aka Natural SUSY, Focus Point SUSY, Split SUSY***

***Flavored Gauge Mediation models:***

*GMSB +*

*messenger-matter couplings (generation-dep)*

*some FV constraints satisfied by degeneracy*

*(GMSB contributions dominant)*

*other FV constraints satisfied by alignment*

*(new contributions important)*

*or combination of degeneracy + alignment*

## ***Flavored Gauge Mediation models:***

*GMSB +*

*messenger-matter couplings (generation-dep)*

*some FV constraints satisfied by degeneracy*

*(GMSB contributions dominant)*

*other FV constraints satisfied by alignment*

*(new contributions important)*

*supersymmetric alignment:*

***low scale** too → little running → large splittings*

***Flavored Gauge Mediation models:***

*GMSB +*

*messenger-matter couplings (generation-dep)*

↓

*A-terms at messenger scale*

*→ large stop mixing*

*→ 125 GeV Higgs*

# flavor: LHC

*models:*

- *non-degenerate selectron, smuon*
- *non-degenerate up, down squarks*
- *light charm, strange*
- *mixings*

- *production:*
  - *dominated by u, d*

    *don't have 8 degenerate u, d squark*

    *(assumption in all jets + missing ET searches)*
- *detection:*
  - *efficiency goes up with mass*

Mahbubani Papucci Perez Ruderman Weiler 1212.3328:

** single charm squark at 400 GeV **

- *event shapes: distorted too: different scales*
  - *``Flavor Subtraction" (e-mu) doesn't work*
  - *kinematic edges: split and ``mixed"*

Galon YS

# THEORY

*the prime example of flavor-blind SUSY:*

***GAUGE MEDIATION***

*beautiful:* *nothing swept under $M_{\textbf{Planck}}$ carpet*

*calculable (in principle) from SUSY QFT*

*but is it really (automatically) flavor blind?*

*minimal GMSB : messengers :* $5 = T + D$ $\bar{5} = \bar{T} + \bar{D}$

$H_D$ $H_U$

*in principle:*

$$W = H_U qu + H_D qd + H_D le$$

$$+ \bar{D}qu \; + \; Dqd \; + \; Dle$$

*messenger-matter couplings*

(D, H same R-parity)

Shadmi Szabo

*new **generation dependent** contributions to soft masses from messenger loops* *minimal GMSB : messengers :* $5 = T + D$ $\bar{5} = \bar{T} + \bar{D}$

$H_D$ $H_U$

*in principle:*

$$W = H_U qu + H_D qd + H_D le$$

$$+ \bar{D}qu \; + \; Dqd \; + \; Dle$$

originally:
Chacko-Ponton:
MFV couplings
from 5d setup

*usually **forbid** messenger-matter couplings by*

***imposing** some global symmetry*

*overkill:*

- *we are ignorant about Yukawas:*

*we are at least as ignorant about the new couplings*

- *non-trivial Yukawas hint at some flavor theory*

*same flavor theory would necessarily control the new couplings*

# simplest example:
# MFV-like models

YS Szabo

Abdullah Galon YS Shirman

Calibbi Paradisi Ziegler (squark flavor)

$$W = Y_U H_U qu + \ldots$$
$$+\, y_U \bar{D} qu \;+\; \ldots$$

*if* $H_U,\ \bar{D}:$ *same properties under flavor theory*

$$\longrightarrow \boxed{(y_U)_{ij} \approx (Y_U)_{ij}}$$

*mass splittings MFV-like:*

*1st, 2nd generation sfermions nearly degenerate*

✓ *flavor constraints obeyed*

*at LHC:*

*1st, 2nd generations nearly degenerate*

*-- nothing new**

** mixings can be large:*

*two $SU(3)_q x SU(3)_u$ spurions:* $Y_U \quad y_U$

*and:*

$$\boxed{(y_U)_{33} \approx (Y_U)_{33} \sim 1}$$

→ *important implications for Higgs mass* non-degenerate spectra:

$H_U, \ \bar{D}$: *different properties under flavor theory* *simple realization: flavor symmetries*

*flavor symmetry controls*

*a. fermion masses*

*b. messenger-matter couplings*

***general setup:***

*need:*

- *no Higgs couplings to X*
- *Higgs, messenger couplings to matter*
- *for both up-type messenger couplings and down-type couplings: at least two messenger pairs*

*different choices of symmetries that give this*

$$W = XD_i\bar{D}_i + XT_i\bar{T}_i \qquad i = 1,2$$

$$+ Y_U H_U qu + Y_D H_D qd + Y_L H_D le$$

$$+ y_U \bar{D}_1 qu + y_D D_2 qd + y_L D_2 le$$

up squarks:
focus on these today

Abdullah Galon YS Shirman
Galon Perez YS

down squarks, sleptons

Shadmi Szabo

here: consider just N=1 with up type couplings

*U(1)xU(1) flavor symmetry*

*spurions of charge (-1), size* $\lambda \sim 0.2$

$$[\ H_U, H_D \sim (0,0)\ ]$$

*large charges → small entries*

## *fermion masses:*

*choose charges for matter fields to get eg:*

*(borrowed from Leurer Nir Seiberg alignment model)*

$$Y_U \sim \begin{pmatrix} \lambda^6 & \lambda^4 & 0 \\ 0 & \lambda^3 & \lambda^2 \\ 0 & 0 & 1 \end{pmatrix} \qquad Y_D \sim \begin{pmatrix} \lambda^6 & 0 & 0 \\ 0 & \lambda^4 & \lambda^4 \\ 0 & \lambda^2 & \lambda^2 \end{pmatrix}$$

*what about new coupling y?*

*U(1)xU(1) flavor symmetry*

*spurions of charge (-1) size* $\lambda \sim 0.2$

$[\ H_U,\ H_D \sim (0,0)\ ]$

*large charges → small entries*

→ *to get large entries of new coupling in 1st, 2nd generation : negative messenger charges*

$\bar{D}\ (n, -m) \qquad [D(-n, m)] \qquad n, m > 0$

*U(1)xU(1) flavor symmetry*

*spurions of charge (-1) size* $\lambda \sim 0.2$

$[\ H_U,\ H_D \ \sim \ (0,0)\ ]$

*large charges → small entries*

→ *to get large entries of new coupling in 1st, 2nd generation : negative messenger charges*

$\bar{D}\ (n, -m) \qquad [D(-n, m)] \qquad n, m > 0$

* *also forbids* $XH_U D$

# *example: light charm, strange squarks*

$$Y_U \sim \begin{pmatrix} \lambda^6 & \lambda^4 & 0 \\ 0 & \lambda^3 & \lambda^2 \\ 0 & 0 & 1 \end{pmatrix} \qquad Y_D \sim \begin{pmatrix} \lambda^6 & 0 & 0 \\ 0 & \lambda^4 & \lambda^4 \\ 0 & \lambda^2 & \lambda^2 \end{pmatrix}$$

*total charge (0,3)*

** zeros from holomorphy*

$$Y_U \sim \begin{pmatrix} \lambda^6 & \lambda^4 & 0 \\ 0 & \lambda^3 & \lambda^2 \\ 0 & 0 & 1 \end{pmatrix} \qquad Y_D \sim \begin{pmatrix} \lambda^6 & 0 & 0 \\ 0 & \lambda^4 & \lambda^4 \\ 0 & \lambda^2 & \lambda^2 \end{pmatrix}$$

*total charge (0,3)*

$$\bar{D}\ (1,-3) \longrightarrow y_U \sim \begin{pmatrix} \lambda^4 & 0 & 0 \\ 0 & \lambda & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

*only affects*
*2nd generation*

lower charm
strange masses

** zeros from holomorphy*

*new contributions to soft terms:*

- *A terms (one-loop) at messenger scale*
- *scalar masses-squared:*
  - *one loop: O(F^4/M^6)*  *[negative]*  ***low scales***
  - *two loop: O(F^2/M^4)*

    *y^4*

    *y^2 g^2*

    *y^2 Y^2*

    ***dominant for messenger scales above 10^7 GeV***

{ *can organize in spurion expansion:*

*3 flavor spurions:*

$$Y_U \sim y_U; \quad Y_D$$

$$\Delta m_q^2 \sim y_U y_U^+ + \ldots$$

$$\Delta m_u^2 \sim y_U^+ y_U + \ldots$$

}

*if only one entry in y:*

- *scalar masses-squared:*

  - *one loop: O(F^4/M^6)* *[negative]* ***low scales***

  - *two loop: O(F^2/M^4)*

    *y^4* *[positive]*

    *y^2 g^2* *[negative]*

    *y^2 Y^2* *[typically small for 1st 2nd generations]*

**dominant for messenger scales above 10^7 GeV**

*back to our example:*

$$Y_U \sim \begin{pmatrix} \lambda^6 & \lambda^4 & 0 \\ 0 & \lambda^3 & \lambda^2 \\ 0 & 0 & 1 \end{pmatrix} \qquad Y_D \sim \begin{pmatrix} \lambda^6 & 0 & 0 \\ 0 & \lambda^4 & \lambda^4 \\ 0 & \lambda^2 & \lambda^2 \end{pmatrix}$$

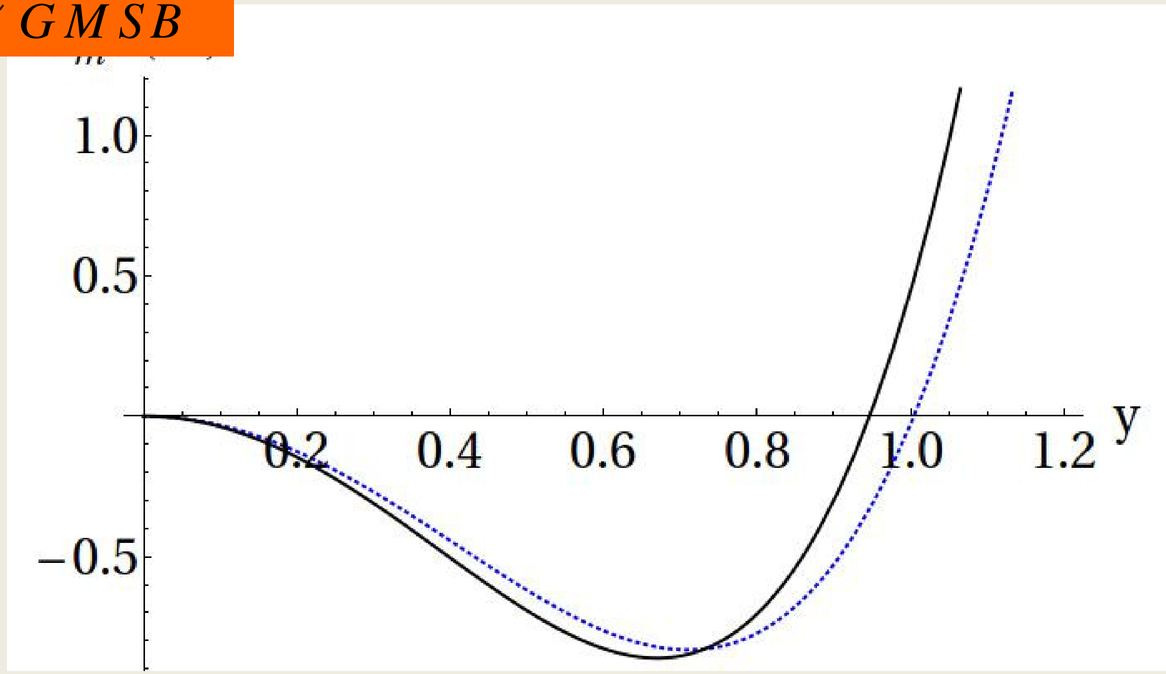
$$\bar{D}\ (1, -3) \longrightarrow \qquad y_U \sim \begin{pmatrix} \lambda^4 & 0 & 0 \\ 0 & \lambda & 0 \\ 0 & 0 & 0 \end{pmatrix} \approx \begin{pmatrix} 0 & 0 & 0 \\ 0 & \lambda & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

*L, R charm; L strange masses lowered*

*at messenger scale:* $\Delta m^2 \sim -m^2_{GMSB}$

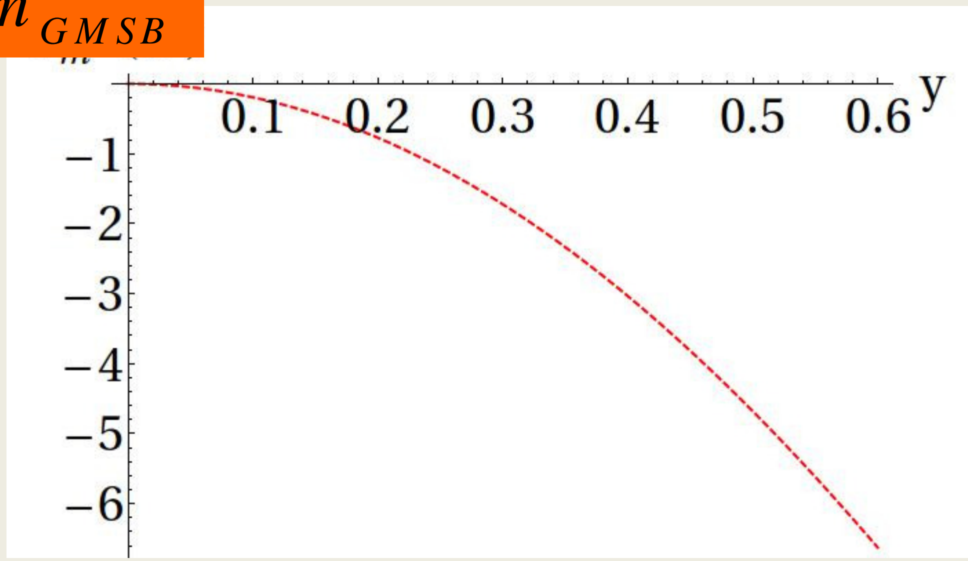
## *higher scales: mainly 2-loop contribution (N=1)*

$$\frac{\Delta m^2}{m^2_{GMSB}}$$



## *low scales: mainly 1-loop contribution (N=1)*

$$\frac{\Delta m^2}{m^2_{GMSB}}$$



$$\frac{\Delta m^2}{m^2_{GMSB}} = -1$$

- *M=500 TeV: up, down squarks near 2 TeV*

  *gluino 1.5 TeV*

  *R charm 900 GeV*
- *M=400 TeV: up, down squarks near 1.5 TeV*

  *gluino 1.2 TeV*

  *R charm 670 GeV*

*huge mass differences:*
*flavor constraints?*

## *flavor constraints?*

*mixings are small: squark, quark matrices aligned*

$$Y_U \sim \begin{pmatrix} \lambda^6 & \lambda^4 & 0 \\ 0 & \lambda^3 & \lambda^2 \\ 0 & 0 & 1 \end{pmatrix} \qquad Y_D \sim \begin{pmatrix} \lambda^6 & 0 & 0 \\ 0 & \lambda^4 & \lambda^4 \\ 0 & \lambda^2 & \lambda^2 \end{pmatrix}$$

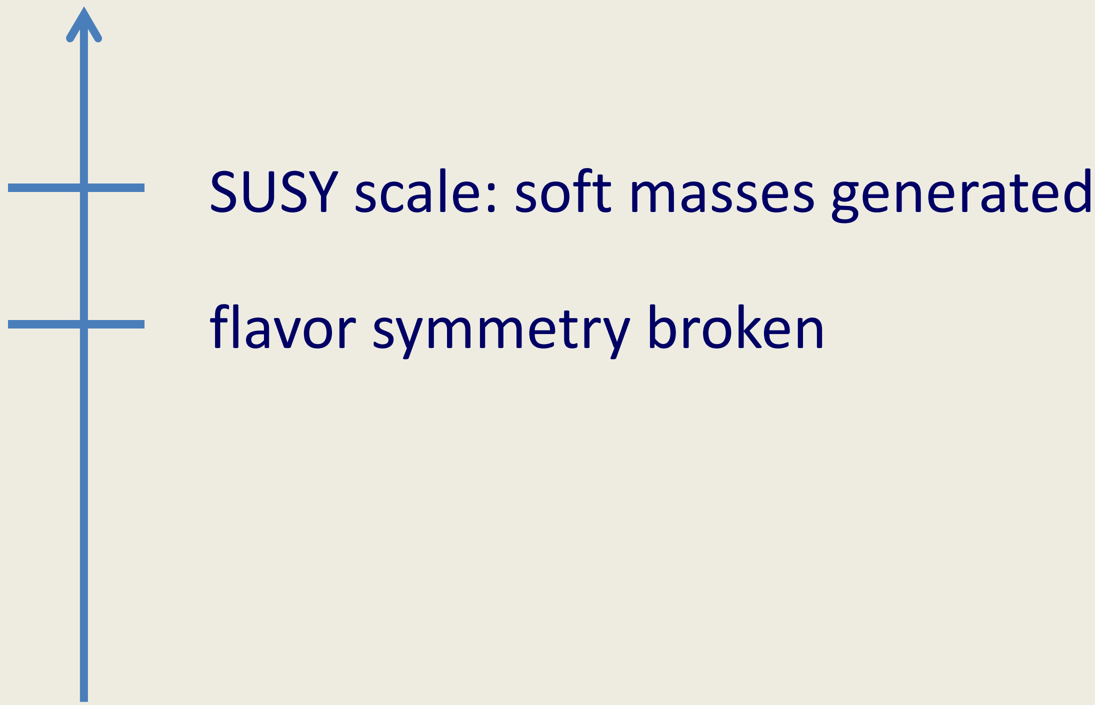
no down L
12 mixings

$$y_U \sim \begin{pmatrix} \lambda^4 & 0 & 0 \\ 0 & \lambda & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

*reason why needed 2 U(1)s:*

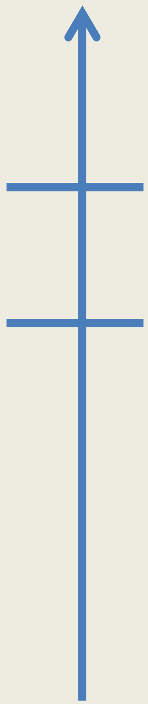
*with single U(1): just Cabibbo suppressed* *but this is not the ``old” alignment:*

*usual alignment models: flavor symmetry controls soft terms → high scale only*



*here: ``supersymmetric alignment”:*

*flavor symmetry controls superpotential coupling y*



flavor symmetry broken: y determined

SUSY scale=messenger scale:
soft masses generated

→ *messenger scale can be low*

→ *no large (universal) RGE gluino contribution:*

→ *much larger mass differences possible*

*(in high scale models only 10-20%)*

- *to get large mass splittings: $N_5$=1:*

$$\frac{\Delta m^2}{m^2_{GMSB}} \sim \frac{1}{N_5}$$

$$\frac{m_{gluino}}{m_{squark}} \sim \sqrt{N_5}$$

*larger gluino contribution in RGE*

- in large parts of parameter space (*$N_5$>1, large messenger scales): near-degeneracy*

# and 125 GeV Higgs

Abdullah Galon YS Shirman

MFV: Evans Ibe Yanagida
Kang Li Liu Tong Yang

+ different couplings: Craig Knapen Shih Zhao
Albaid Babu
Craig Knapen Shih
Evans Shih

$$m_h^2 \approx M_Z^2 \cos^2 2\beta + \frac{3}{4\pi^2}\frac{m_t^4}{v^2}\left[\log\frac{M_s^2}{m_t^2} + \frac{X_t^2}{M_s^2}\right]$$

$$X_t = A_t - \mu \cot\beta$$

*large for:*

- *large stop masses*
- *large mixings*

- *pure GMSB: no A terms*
- *large Higgs mass → large stop masses → large squark masses 8-10 GeV*

*but see Feng Kant Profumo Sanford: 3 loop*

*Flavored Gauge Mediation: A-terms at messenger scale*

*with* $(y_U)_{33} \sim 1$ *large stop A-term*

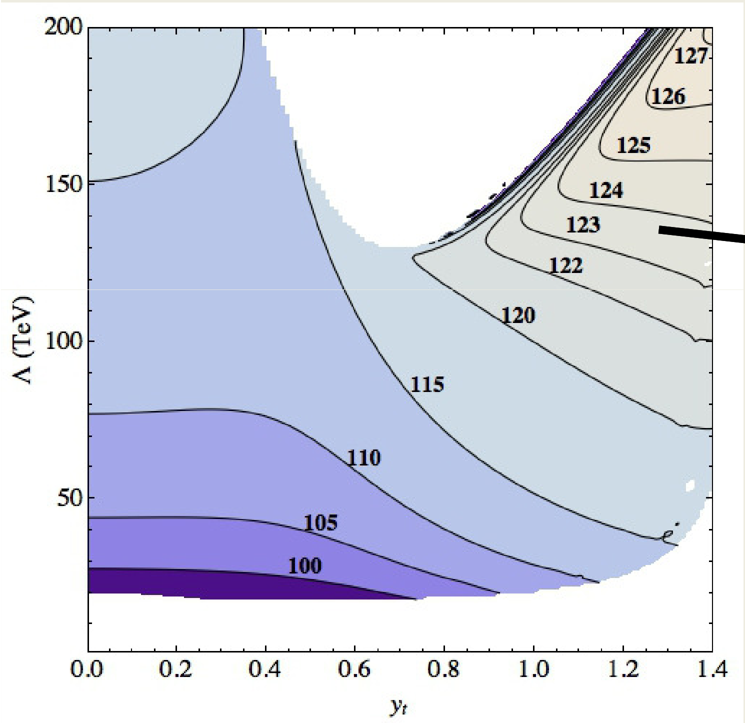
*+ new contributions to stop (only) masses*

*simplest example:* *Abdullah Galon YS Shirman*

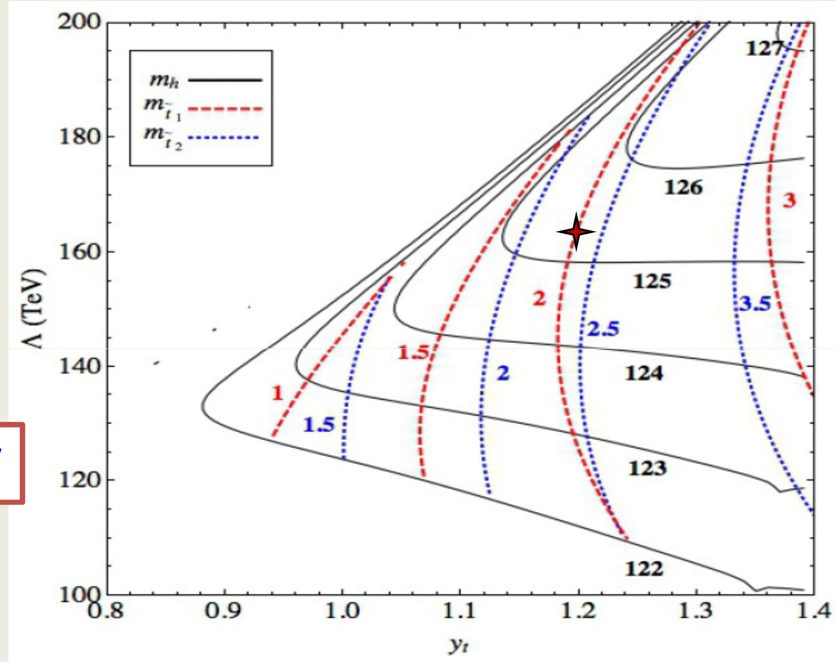
$H_U,\ \bar{D}$: *same flavor charges*

$$(y_U)_{ij} \approx (Y_U)_{ij} \sim \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

# → *Higgs heavy because of large stop mixing*




M=400 TeV




stops 2, 2.3 TeV

u, c squarks 1.7-1.8 TeV gluino 1.3 TeV

sleptons ~ 500 GeV LSP 230 GeV

*split up + heavy Higgs*
*with a single set of messengers*

$$Y_U \sim \begin{pmatrix} \lambda^6 & \lambda^4 & 0 \\ 0 & \lambda^3 & \lambda^2 \\ 0 & 0 & 1 \end{pmatrix} \qquad Y_D \sim \begin{pmatrix} \lambda^6 & 0 & 0 \\ 0 & \lambda^4 & \lambda^4 \\ 0 & \lambda^2 & \lambda^2 \end{pmatrix}$$

$$\bar{D}\ (6, -9) \longrightarrow \qquad y_U \sim \begin{pmatrix} 0 & 0 & 0 \\ \lambda^2 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}$$

- *R squarks:*

$$y_U^+ y_U \sim \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

→ *R up squark goes up for large range of O(1) coeffs*

- *L squarks:*

$$y_U y_U^+ \sim \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

→ *only stop is affected*

*( here y^2 Y^2 important too: different structure from models with only large* $y_{33}$*)*

*+ large stop A term*

→ *large stop mixing* → *large loop contributions to Higgs mass*

## *to conclude:*

*given the*

- *importance of flavor assumptions at LHC*
- *our ignorance about fermion masses*

*must think of flavor dependent soft terms*

*FGM: viable models, low-scale too:*

*supersymmetric alignment → large mass splittings*

- *generation dependent scalars*
- *A-terms: large contributions to Higgs mass with superpartners within LHC reach*