Julius-Maximilians-
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GRK 1147

Theoretical Astrophysics and
particle Physics

On the vacuum stability of Supersymmetric models

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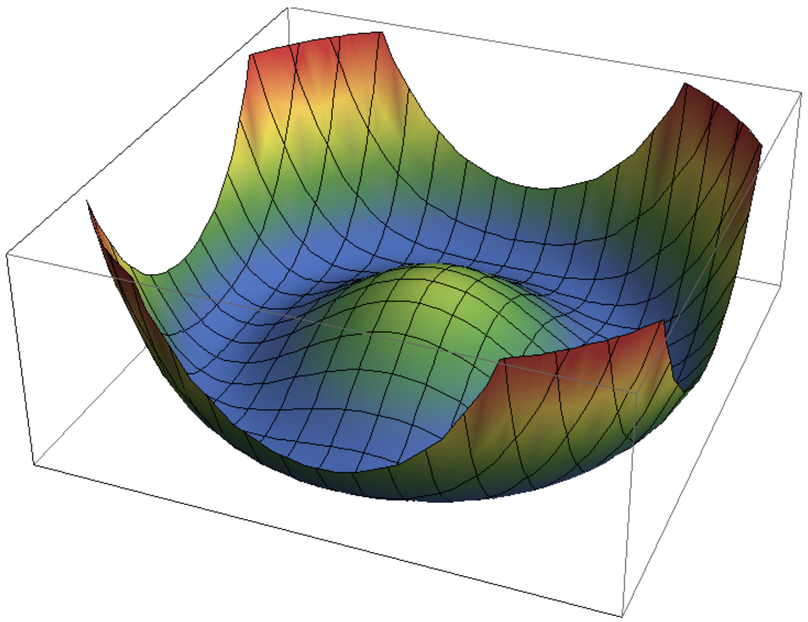
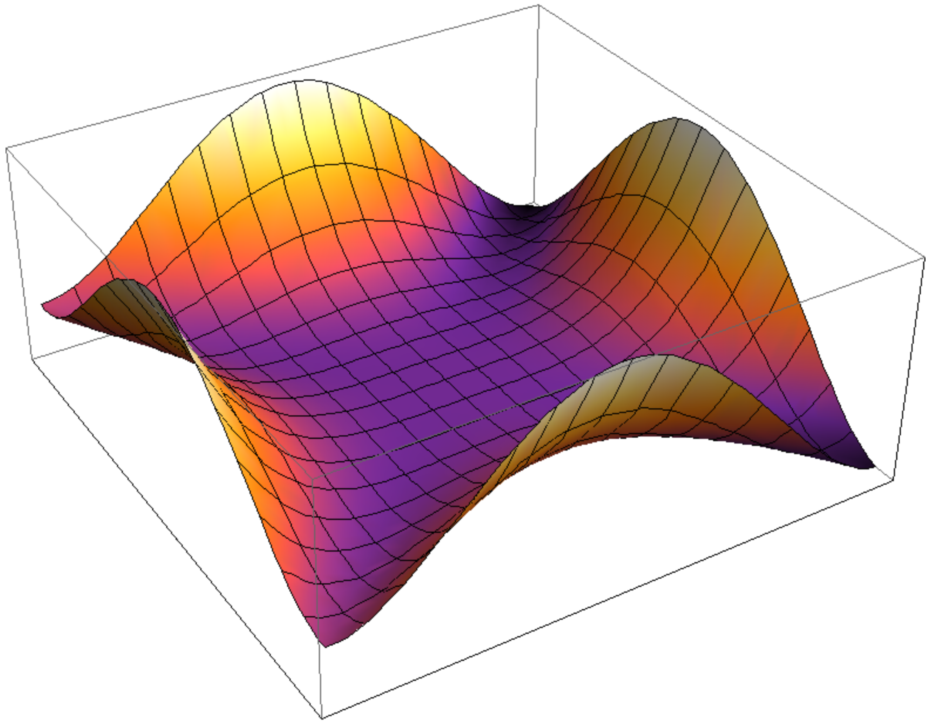
Vacuum stability



Easy

$$V(\phi^\dagger\phi) = m^2\phi^\dagger\phi + \frac{\lambda}{2}(\phi^\dagger\phi)^2$$



Not so easy *

$$V = \lambda_{ijkl}\phi_i\phi_j\phi_k\phi_l + A_{ijk}\phi_i\phi_j\phi_k + \mu^2_{ij}\phi_i\phi_j$$

* Min. conditions are degree 3 polynomials with many extrema.

Vacuum stability

HOW TO:

Tree level:

All tree-level extrema guaranteed by using homotopy continuation

Powerful way to find all the roots of a system of polynomial equations quickly. Continuously deforms a simple system of polynomial equations with known roots to the system one wants to solve.

One loop:

Numerical minimization of the one-loop effective potential

Tree-level minima are used as starting points for numerical minimization of the one-loop effective potential. Possible bifurcation of minima is taken into account and the lowest minimum is found. Calculating tunneling time between different minima is necessary, metastable vacua may appear.

Vevacious

A Tool For Finding The Global Minima
Of One-Loop Potentials

JECM,O'Leary, Porod, Staub.
arXiv:1307.1477
http://vevacious.hepforge.org/

Model + parameter point + set of VEVs. Are there other deeper minima?

- Finds all the tree level potential minima using the homotopy continuation method. ⇨ **HOM4PS2** Lee, T. L. et al., Computing, 83(2-3), 109-133
- Uses them as starting points for numerically minimizing the one-loop effective potential. ⇨ **PyMinuit** https://code.google.com/p/pyminuit/
- Calculates tunneling times between the "physical" input minimum and any other minima. ⇨ **CosmoTransitions** arXiv:1109.4189.
- **Classifies your input "physical" minimum as short-lived, long-lived or stable.**

MSSM
stop and stau VEVs
3 to 18 secs

Vevacious

JECM,O'Leary, Porod, Staub.
arXiv:1307.1477
http://vevacious.hepforge.org/

INPUTS

Choose the model:

Model file with one-loop potential and mass matrices

Can be generated with Mathematica package **SARAH** (arXiv:1207.0906).
A set of model files for popular models is included with Vevacious.

Choose a parameter point:

SLHA file for your parameter point

Can be generated with spectrum calculators like SPheno, SoftSusy or Suspect.

$$W = Y_u\,\hat{u}\,\hat{q}\,\hat{H}_u - Y_d\,\hat{d}\,\hat{q}\,\hat{H}_d - Y_e\,\hat{e}\,\hat{l}\,\hat{H}_d + \mu\,\hat{H}_u\,\hat{H}_d + Y_\nu\,\hat{l}\,\hat{H}_u\,\hat{\nu} - \mu_X\,\hat{\chi}_1\,\hat{\chi}_2 + Y_x\,\hat{\nu}\,\hat{\chi}_1\,\hat{\nu}$$

BLSSM

JECM,O'Leary, Porod, Staub.
arXiv:1212.4146 To appear in PRD

In general, we allow the 3 generations of $\tilde{\nu}_R$ to get VEVs and this creates R-parity violating terms.

$$W_{\mathrm{RPV}} \supset Y_x\,v_R\,\hat{\nu}\,\hat{\chi}_1 + Y_\nu\,v_R\,\hat{l}\,\hat{H}_u$$

Once we have a parameter point with a local minimum at a reasonable place:

How often does R-parity spontaneously break?

How often are other deeper minima appearing?

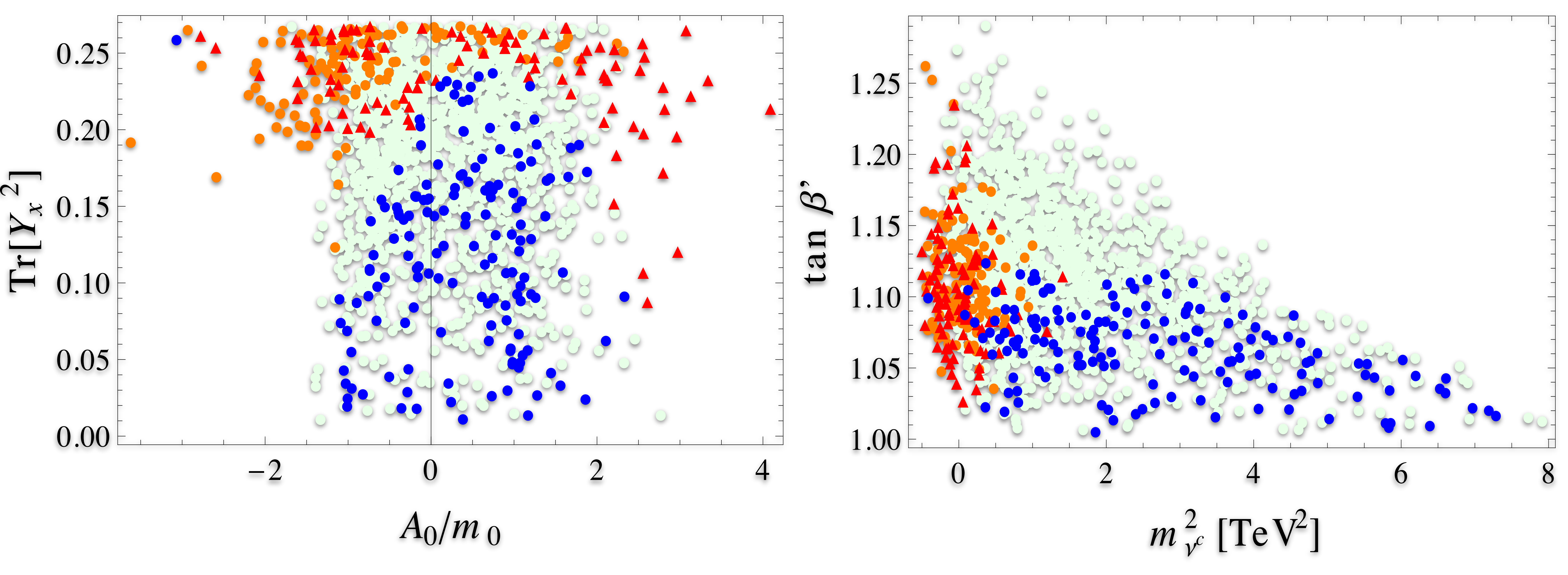
Categorization	Hierarchical scan		Democratic scan	
total	1640		2330	
	tree level	one-loop level	tree level	one-loop level
“RPC”	1422	1275	2236	2167
“RPV”	218	212	94	86
“unbroken”	0	153	0	77

RPC

Metastable RPC

RPV

Gauge conserving



CMSSM

JECM,O'Leary, Porod, Staub.

In preparation

With stop and stau VEVs

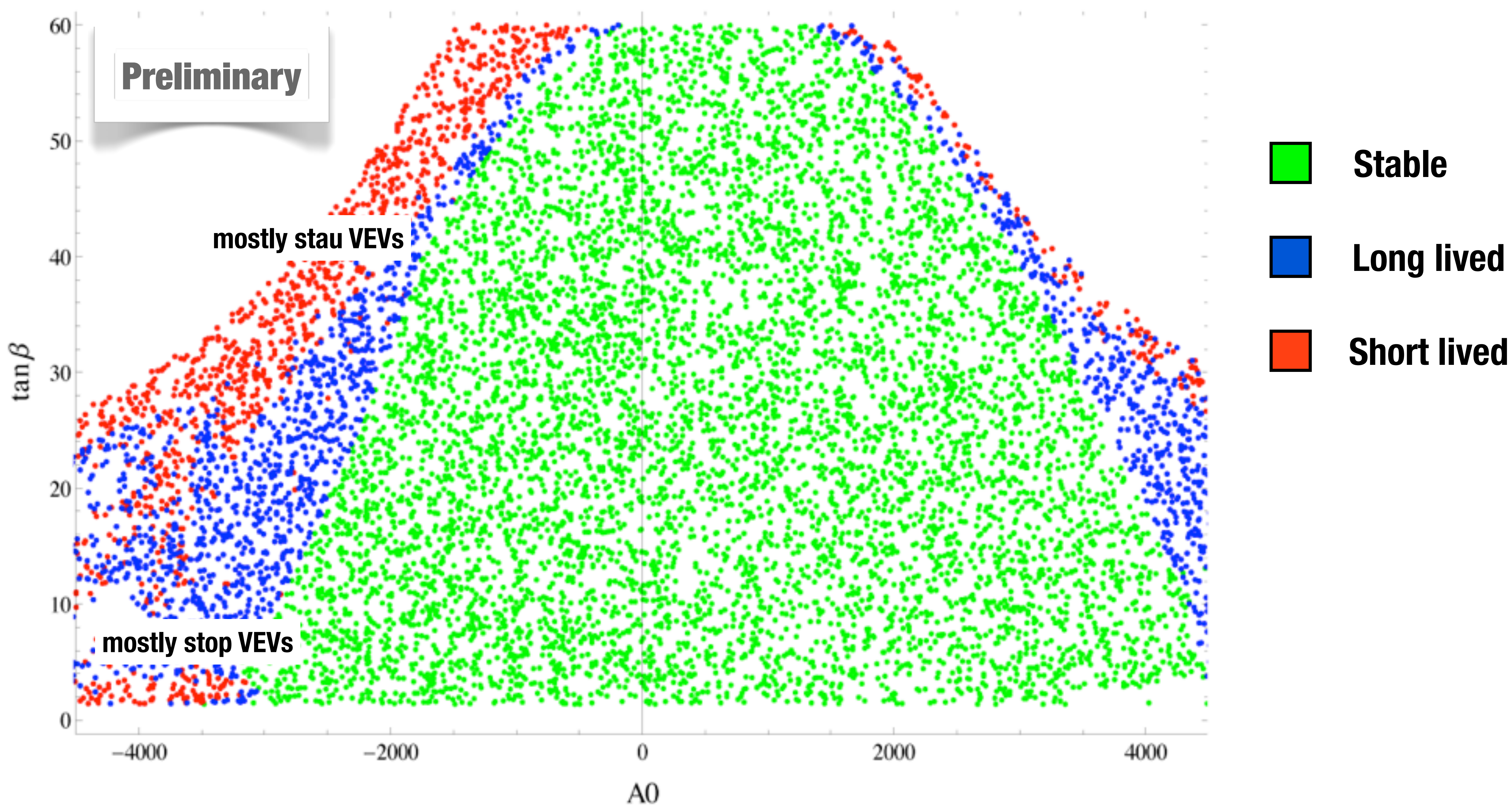
Stops and staus can have VEVs

Color and charge breaking minima might appear

When does this happen?

Can we have safe regions in allowed parameter space?

Can we exclude previously allowed regions?



$$V \supset |\mu\, h_u - y_\tau \tilde{\tau}_L \tilde{\tau}_R^*|^2 + \frac{g_2^2}{8}\left(|\tilde{\tau}_L|^2 + |h_u|^2\right)^2$$

Summary

- Vacuum stability is an important phenomenological issue in models with many scalars (SUSY)
- There is a systematic way of including this as a new constraint for pheno studies. We implemented it and released the public code Vevacious.
- We saw some examples of the application of Vevacious in two SUSY models.

BACKUP SLIDES

Just in case

One-loop Potential

$$V^{\text{1-loop}} = V^{\text{tree}} + V^{\text{counter}} + V^{\text{mass}}$$

$$V^{\text{mass}} = \frac{1}{64\pi^2} \sum_n (-1)^{(2s_n)} (2s_n + 1) (\bar{M}_n^2(\phi_i))^2 \left[\log(\bar{M}_n^2(\phi_i)/Q^2) - c_n \right]$$

Tunneling times

- $\Gamma/$ volume $= Ae^{-B/\hbar}(1+\mathcal{O}(\hbar))$
- A is solitonic solution, should be $\sim$ energy scale of potential
- $B \sim$ ([surface tension]/[energy density difference])^3