Saddle point MSSM-inflation

Anja, Dirk, G., Gilles, Laurent, Vincent, Richard, Sophie

APC, IJCLab, ITP, L2C,...

(Gilbert Moultaka)

IEA-Inflating-Heidelberg meeting, PhilosophenZoom, 2-3 Dec '21

Outline

- Introductory motivations
- SUSY flat directions
- The saddle point MSSM-Inflation model
- The Effective Potential
- The Renormalization Group Equations
- Implementation in SUSPECT3
- Conclusion

Introductory motivations

Where is –Is there– (TeV) New Physics ??

message from (the) BSM at the LHC (?)

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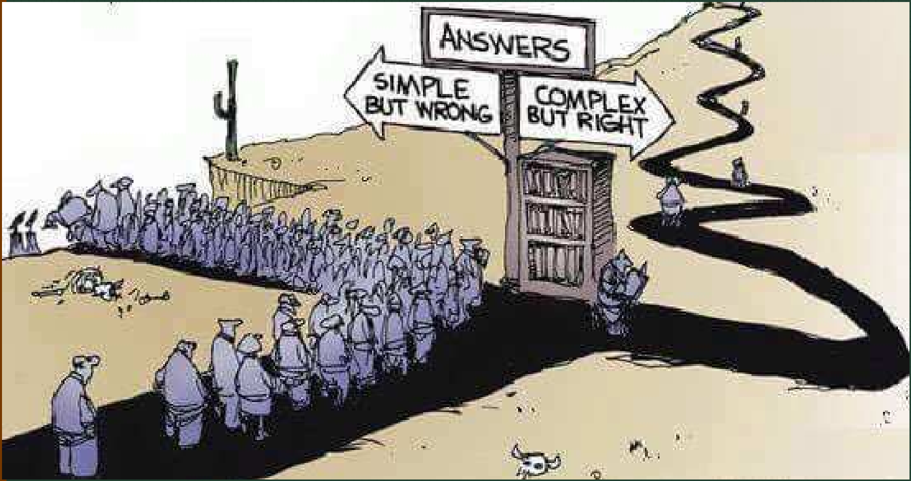
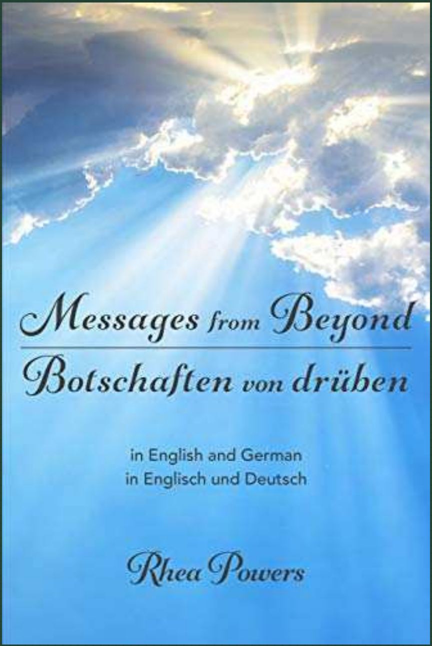


message from beyond the LHC?


Messages from Beyond
Botschaften von drüben
in English and German
in Englisch und Deutsch
Rhea Powers

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$\rightarrow$ ubiquity of flat directions of the scalar potential $\rightarrow$ inflationary sectors.

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→ deep connection between internal and space-time symmetries

→ unification with Gravity...

→ ubiquity of flat directions of the scalar potential → inflationary sectors.

→ In its (next-to-)minimal versions, (N)MSSM, possible relations between constraints from inflation (prediction of the scalar spectral index, the power spectrum normalization, etc.), and constraints from particle physics searches ?

SUSY flat directions

SUSY flat directions

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$$F_{\phi_k} := \frac{\partial W}{\partial \phi_k}, \quad \vec{D}^A := \Phi^\dagger \vec{T}^A \Phi, \quad (\Phi \text{ multiplet of } \phi_k{}'s)$$

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$$W_{MSSM} = \sum_{i,j=gen} Y_{ij}^u \,\hat{u}_{Ri}\hat{Q}_j.\hat{H}_u + Y_{ij}^d \,\hat{d}_{Ri}\hat{Q}_j.\hat{H}_d + Y_{ij}^l \,\hat{l}_{Ri}\hat{L}_j.\hat{H}_d + \mu\hat{H}_u.\hat{H}_d$$

$$\vec{D}^1 = \sum_{i=gen} \left(\tfrac{1}{6}\tilde{Q}_i^\dagger \tilde{Q}_i - \tfrac{1}{2}\tilde{L}_i^\dagger \tilde{L}_i - \tfrac{2}{3}\tilde{u}_{R_i}^\dagger \tilde{u}_{R_i} + \tfrac{1}{3}\tilde{d}_{R_i}^\dagger \tilde{d}_{R_i} + \tilde{l}_{R_i}^\dagger \tilde{l}_{R_i}\right) + \tfrac{1}{2}H_u^\dagger H_u - \tfrac{1}{2}H_d^\dagger H_d$$

$$\vec{D}^2 = \sum_{i=gen} \left(\tilde{Q}_i^\dagger \tfrac{\vec{\sigma}}{2}\tilde{Q}_i + \tilde{L}_i^\dagger \tfrac{\vec{\sigma}}{2}\tilde{L}_i\right) + H_u^\dagger \tfrac{\vec{\sigma}}{2} H_u + H_d^\dagger \tfrac{\vec{\sigma}}{2} H_d$$

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A DAUNTING TASK

SUSY flat directions

$\rightarrow$ a key correspondence between flat directions and gauge invariant monomials (in the '80 - '90) $\rightarrow$ a very powerful tool.

e.g. $\mathcal{O}$ gauge invariant $\Rightarrow \delta\mathcal{O} = 0 = \frac{\partial}{\partial\Phi}\mathcal{O}\vec{T}^A\Phi$

if $\frac{\partial}{\partial\Phi}\mathcal{O}_{|\Phi=\Phi_0} = \underset{(\neq 0)}{cte} \times \Phi_0^\dagger \Rightarrow$ D-flat in the Φ_0 direction

In fact also *necessary*

$\rightarrow$ classify all gauge invariant, independent monomials

$\rightarrow$ The (R_p-conserving)MSSM potential has ≈ 300 flat directions

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a flat direction:

- ○ has to be lifted...
- ○ and by not too much $\rightarrow$ slow-roll/enough e-folding to fit observations

$\rightarrow$ three main lifting sources:

- • renormalizable superpotential (MSSM)
- • soft SUSY breaking masses (MSSM)
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The basic idea:

if $F_\phi^{\mathcal{O}} \equiv \partial_\phi W^{\mathcal{O}} = 0 \Rightarrow \mathcal{O} = 0$ then the flat direction associated with $\mathcal{O}$ is lifted by $W^{\mathcal{O}}$

complete MSSM classification, Gherghetta,Kolda,Martin, '96

The saddle point MSSM-Inflation model

- $\epsilon_{\alpha\beta}\, L_i^\alpha L_j^\beta\, e_k$ $[SU(3)_c \times SU(2) \times U(1)_Y$ gauge inv.$]$ $\rightarrow$ 'LLe' D-flat direction

$$L_i = \begin{pmatrix} \varphi \\ 0 \end{pmatrix}, \; L_j = \begin{pmatrix} 0 \\ \varphi \end{pmatrix}, \; e_k = \varphi, \; \varphi \text{ complex-valued}$$

$$i \neq j, \; \alpha \neq \beta$$

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[but if R_p-violation is allowed $\rightarrow$ lifted by the renormalizable operators, $W \sim LLe$ resp. udd]

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Inflation along these directions (Enqvist & collab. '06 +)

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$\rightarrow$ Redefine $V_{inflation}$?

The saddle point MSSM-Inflation model

$$V_{inflation}^{tree} = \frac{1}{2}m_\phi^2\phi^2 - |A|\lambda\frac{\phi^6}{6M^3} + \lambda^2\frac{\phi^{10}}{M^6}, \ (\lambda > 0)$$

$V_{inflation}^{tree}$ has now a non-trivial minimum at $\phi = \phi_0 \neq 0$.
$\rightarrow$ Adjust the parameters to make this minimum as shallow as possible
$+$ initial condition for the inflaton field ϕ to get slow-roll.
$\rightarrow$ exact saddle-point at $\phi_0 = \left(\frac{M^3 m_\phi}{\lambda\sqrt{10}}\right)^{1/4}$ with $A = \sqrt{40}m_\phi$.

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$\rightarrow$ correlation between the inflation requirements/constraints and the MSSM spectrum

The Effective Potential

Improve the Potential $\rightarrow$ loop corrections $\rightarrow$ $\log \frac{\phi}{\phi_0}$ resummation.

$$V^{tree}_{inflation} = \frac{1}{2} m_\phi^2 \phi^2 - |A|\lambda \frac{\phi^6}{6M^3} + \lambda^2 \frac{\phi^{10}}{M^6}$$

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$$V_{inflation}^{tree} = \frac{1}{2} m_\phi^2 \phi^2 - |A|\lambda \frac{\phi^6}{6M^3} + \lambda^2 \frac{\phi^{10}}{M^6}$$

$m_\phi^2 \rightarrow \overline{m}_\phi^2(\phi)$, $|A| \rightarrow \overline{|A|}(\phi)$, $\lambda \rightarrow \overline{\lambda}(\phi)$, $\phi \rightarrow \overline{\phi}(\phi)$

$$V_{inflation}^{tree} \rightarrow V_{inflation}^{loop} \leftarrow \text{'slight' shape modification}$$

BUT

$$V^{eff} \sim V^{tree} + \frac{1}{64\pi^2} Str \mathcal{M}^4 \log \mathcal{M}^2 + \cdots$$

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$\mathcal{M}^2 \supset \frac{\partial^2}{\partial \phi^2} V^{tree}_{inflation}$ induces ϕ^4, ϕ^8, ...not considered (?)

Relating A to the soft MSSM trilinear couplings

$\rightarrow$ Minimal SUGRA (minimal Kähler potential)
At the 'high' scale:

$$V = \sum_a |F_{\phi_a}|^2 + m_{3/2}^2 |\phi_a|^2 + m_{3/2} \left(\sum_a \phi_a F_{\phi_a} + (\mathcal{A} - 3) W + h.c. \right)$$

$\rightarrow$ soft terms in ϕ_b^3 and ϕ_c^6 are thus related

$$A_3 = \mathcal{A} m_{3/2}, \; A_6 = (3 + \mathcal{A}) m_{3/2}$$

$\rightarrow$ in the simplest calculable case (Polonyi superpotential)

$$\mathcal{A} = 3 - \sqrt{3} \Rightarrow A_6 = A_3 \frac{6 - \sqrt{3}}{3 - \sqrt{3}}$$ used in the study

CAUTION: valid only for universal soft terms @ GUT !!

The Renormalization Group Equations

Can be adapted from RPV results

(see e.g. Allanach, Dedes, Dreiner, Phys Rev D 69, 115002 (2004))

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udd:

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$$16\pi^2 \tfrac{d}{dt}(\mathbf{\Lambda}_{U3})_{12} = 2\times\left(-\tfrac{4}{5}g_1^2 - 8g_3^2 + 2\textstyle\sum_{i=1}^{2}(\mathbf{Y}_{D\,ii})^2 + 2(\mathbf{Y}_{U\,33})^2\right)(\mathbf{\Lambda}_{U3})_{12}$$

$$16\pi^2 \tfrac{d}{dt}(\mathbf{A}_{U3})_{12} = 2\times\left(\tfrac{8}{5}g_1^2 M_1 + 16 g_3^2 M_3 + 4\textstyle\sum_{i=1}^{2}\mathbf{A}_{D\,ii}(\mathbf{Y}_{D\,ii})^2 + 4\mathbf{A}_{U\,33}(\mathbf{Y}_{U\,33})^2\right)$$

tsb:

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The Renormalization Group Equations

LLe:

$L_e L_\mu \tau$:

$$16\pi^2 \tfrac{d}{dt}(\mathbf{\Lambda}_{E3})_{12}=2\times\left(-\tfrac{9}{5}g_1^2-3g_2^2+\textstyle\sum_{i=1}^{2}(\mathbf{Y}_{E\,ii})^2+2(\mathbf{Y}_{E\,33})^2\right)(\mathbf{\Lambda}_{E3})_{12}$$

$$16\pi^2 \tfrac{d}{dt}(\mathbf{A}_{E3})_{12}=2\times\left(\tfrac{18}{5}g_1^2M_1+6g_2^2M_2+2\textstyle\sum_{i=1}^{2}\mathbf{A}_{E\,ii}(\mathbf{Y}_{E\,ii})^2+4\mathbf{A}_{E\,33}(\mathbf{Y}_{E\,33})^2\right)$$

$L_\tau L_\mu \tau$:

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Implemented in SUSPECT3

Conclusion

- although (particularly) fine-tuned, the saddle-point MSSM inflation is an interesting set-up $\rightarrow$ relates high scale inflation to low scale particle physics.
- the on-going collaboration: brings together exp & theo/cosmo & particle, expertise and related analysis tools (ASPIC/SuSpect3/SFitter)
- new results (see Gilles talk)