Inflating the MSSM...work in progress

Anja Butter, Laurent Duflot, Sophie Henrot-Versille, G.M., Vincent Vennin, Gilles Weymann-Despres, Dirk Zerwas

APC, IJCLab, ITP, L2C &... DMLab ☺

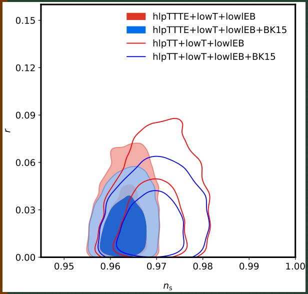
(Gilbert Moultaka)

CosPT meeting, IJCLab, May 10, 2022

Outline

- Introductory motivations
- SUSY flat directions
- The saddle point MSSM-Inflation model
- The Effective Potential & RGEs
- Towards the CMB constraints
- Implementation in SUSPECT3
- Conclusion

Is there a relation between...?



M. Tristram *et al*, A&A 647, A128 (2021)

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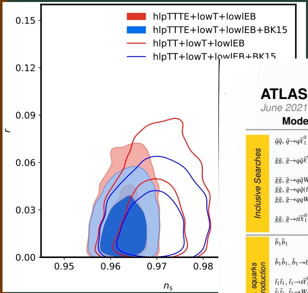

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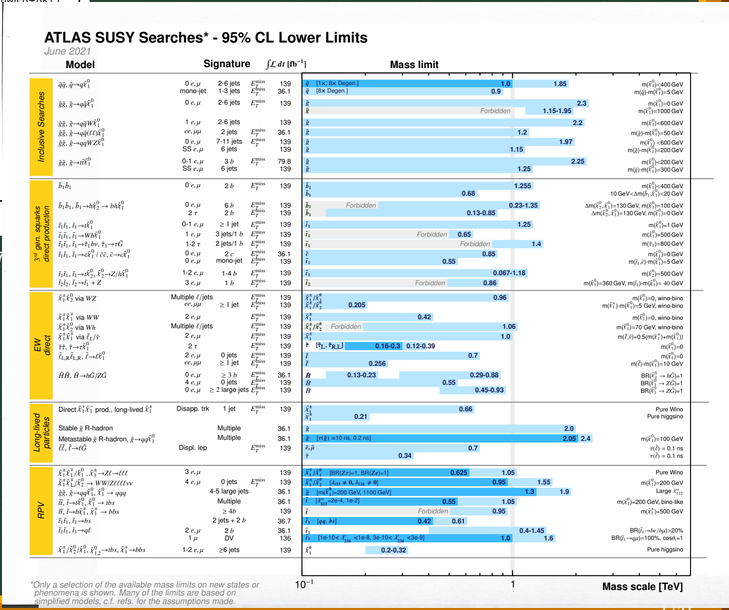
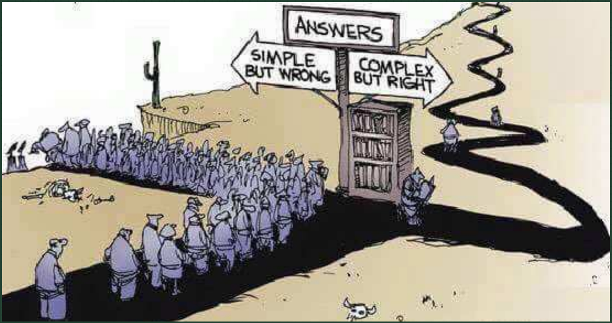
and this →



Introductory motivations

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

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



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→ deep connection between internal and space-time symmetries

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→ 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 DM candidates still viable, even for (relatively) light LSP, despite direct / indirect search limits and LHC constraints.

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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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a flat direction:

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

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- renormalizable superpotential (MSSM)
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e.g. $\rightarrow$ LLe or udd flat directions lifted by

$$W^{LLe} = \frac{\lambda}{M_p^3}(LLe)(LLe) \text{ resp. } W^{udd} = \frac{\lambda}{M_p^3}(udd)(udd)$$

SUSY flat directions

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

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

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

The saddle point MSSM-Inflation model

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

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$\to$ Adjust the parameters to make this minimum as shallow as possible + initial condition for the inflaton field ϕ to get slow-roll.

$\to$ exact saddle-point at $\phi_0 = \left(\frac{M_p^3 m_\phi}{\lambda\sqrt{10}}\right)^{1/4}$ with $|A| = \sqrt{40} m_\phi$.

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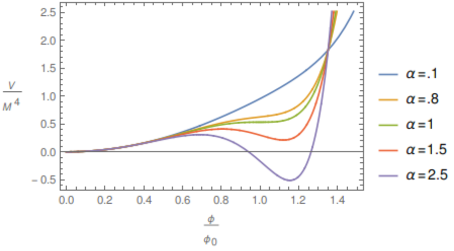

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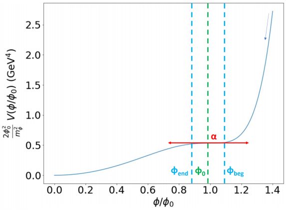
→ variance with the literature:

- $-|A| \to -2|A|$ ... $A\lambda\frac{\varphi^6}{6M_p^3} + h.c.$
- $|\varphi|$ kinetic term normalization, $\varphi \to \dfrac{\varphi}{\sqrt{6}}$.
- full RG improved effective potential, + yukawa sector.
- effects of the reheating era.

Towards the CMB constraints

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



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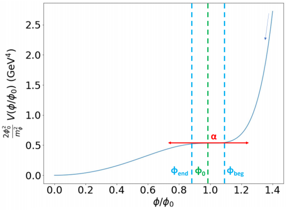

Slow-roll parameters

$$\varepsilon_1 \simeq \frac{M_p^2}{2} \left(\frac{V'(\phi)}{V(\phi)} \right)^2$$

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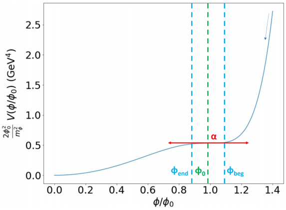

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Scalar perturbations power spectrum

$$\mathcal{P}_s(k) = A_s \left(\frac{k}{k*} \right)^{n_s - 1}$$

Planck:

$$n_s = 0.9665 \pm 0.0038,$$

$$A_s = (2.196 \pm 0.055) \times 10^{-9}$$

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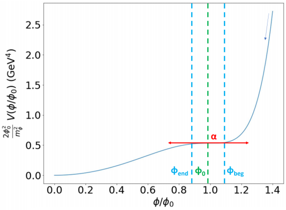

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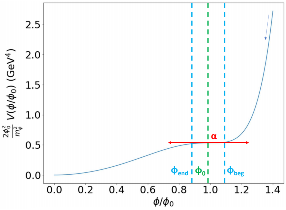

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$V'(\phi_0) \neq 0, V''(\phi_0) = 0 \rightarrow \alpha$ extremely fine-tuned: $\alpha \neq 1$ and $1 - \alpha < 10^{-8}$

Martin, Ringeval, Vennin '13

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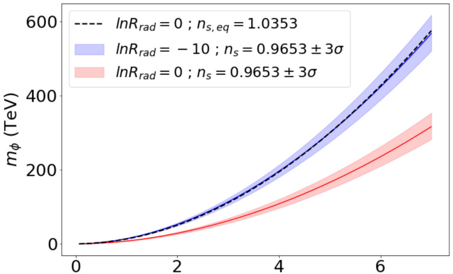

Gilles Weymann-Despres

$$\Delta N_* = -\frac{1}{M_{\rm Pl}^2}\int_{\phi_\star}^{\phi_{end}} \frac{V(\phi)}{V'(\phi)} d\phi$$

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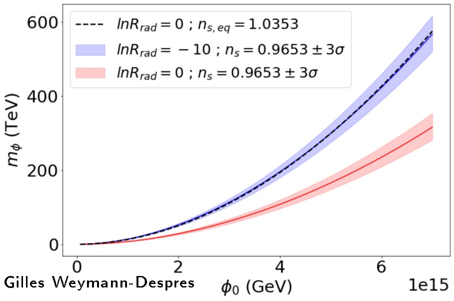

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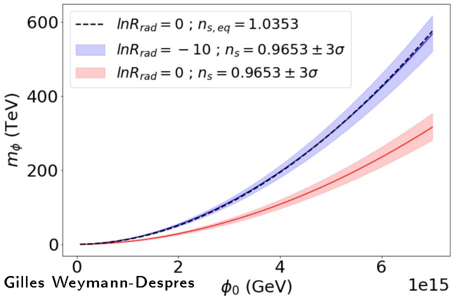

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$$V'(\phi_\star) = \sum c_n(\phi_0)(\phi_\star - \phi_0)^n + \mathcal{O}((\phi_\star - \phi_0)^9)$$

The Wall

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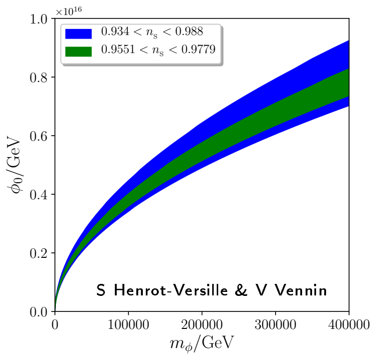
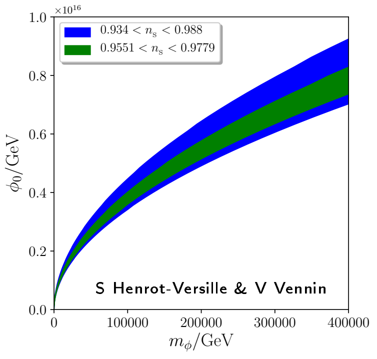


×10^16
1.0
0.8
0.6
0.4
0.2
0.0
$0.934 < n_s < 0.988$
$0.9551 < n_s < 0.9779$
ϕ_0/GeV
S Henrot-Versille & V Vennin
0
100000
200000
300000
400000
m_ϕ/GeV

The Wall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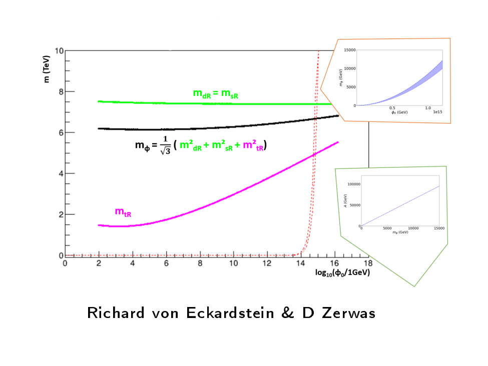
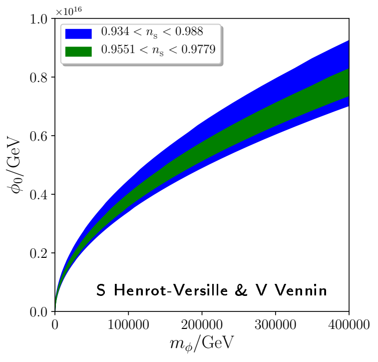
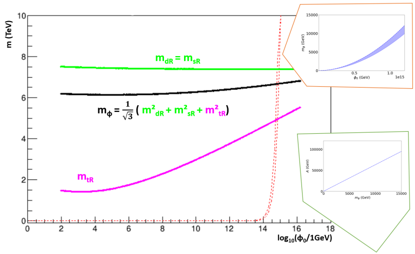

m (TeV)
10
8
6
4
2
0
$m_{dR} = m_{sR}$
$m_\phi = \frac{1}{\sqrt{3}} (m^2_{dR} + m^2_{sR} + m^2_{tR})$
m_{tR}
0 2 4 6 8 10 12 14 16 18
$\log_{10}(\phi_0/1GeV)$
15000
10000
5000
0
0.5
1.0
1e15
100000
50000
0
5000
10000
15000
Richard von Eckardstein & D Zerwas

The Wall





Richard von Eckardstein & D Zerwas

There is always a solution!

The Effective Potential & RGEs

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

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

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

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

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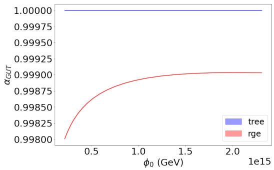

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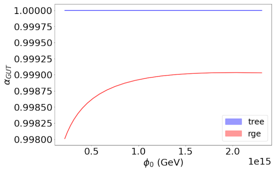

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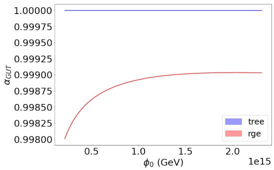

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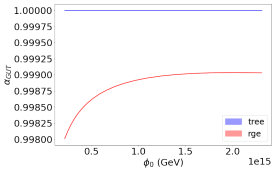

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In fact α should be redefined!

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:

tds:

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

tsb:

$$16\pi^2 \frac{d}{dt}(\mathbf{\Lambda}_{U3})_{23}=2\times\left(-\frac{4}{5}g_1^2-8g_3^2+2\sum_{i=2}^{3}(\mathbf{Y}_{D\,ii})^2+2(\mathbf{Y}_{U\,33})^2\right)(\mathbf{\Lambda}_{U3})_{23}$$

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Implemented in SUSPECT3

- Inflation scale
- High scale boundary conditions relating A to MSSM soft breaking couplings.
- RGEs for m_ϕ^2, A and λ for all LLe and udd directions, including 3rd generation Yukawa effects.

Ready for a full-fledged analysis:

Outlook

- Although (particularly) fine-tuned, the saddle-point MSSM inflation is an interesting set-up $\rightarrow$ relates high scale inflation to low scale susy particle physics.
- The on-going collaboration: brings together exp & theo/cosmo & particle, expertise and related analysis tools (private Python and Mathematica codes and ASPIC/SuSpect3/SFitter)
- Extension to other SUSY scenarios; comparison of theoretical predictions to future experimental HEP, cosmology and DM searches.

THANK YOU FOR YOUR ATTENTION

BACKUP SLIDES

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 !!

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

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