SNS-Pisa
18/10/2019

Effective theories for high scale SUSY breaking

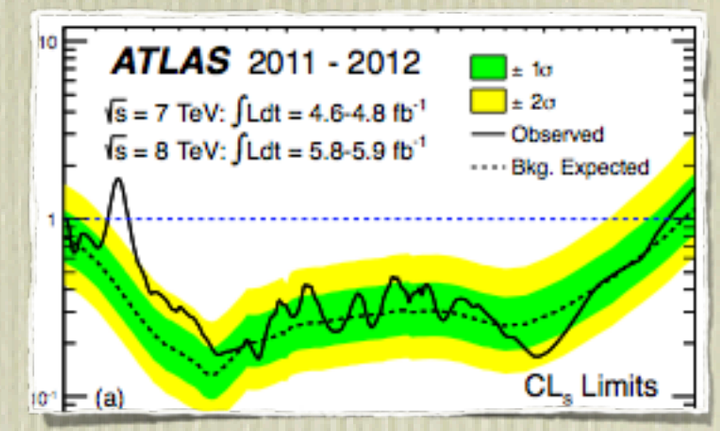
Gianguido Dall'Agata

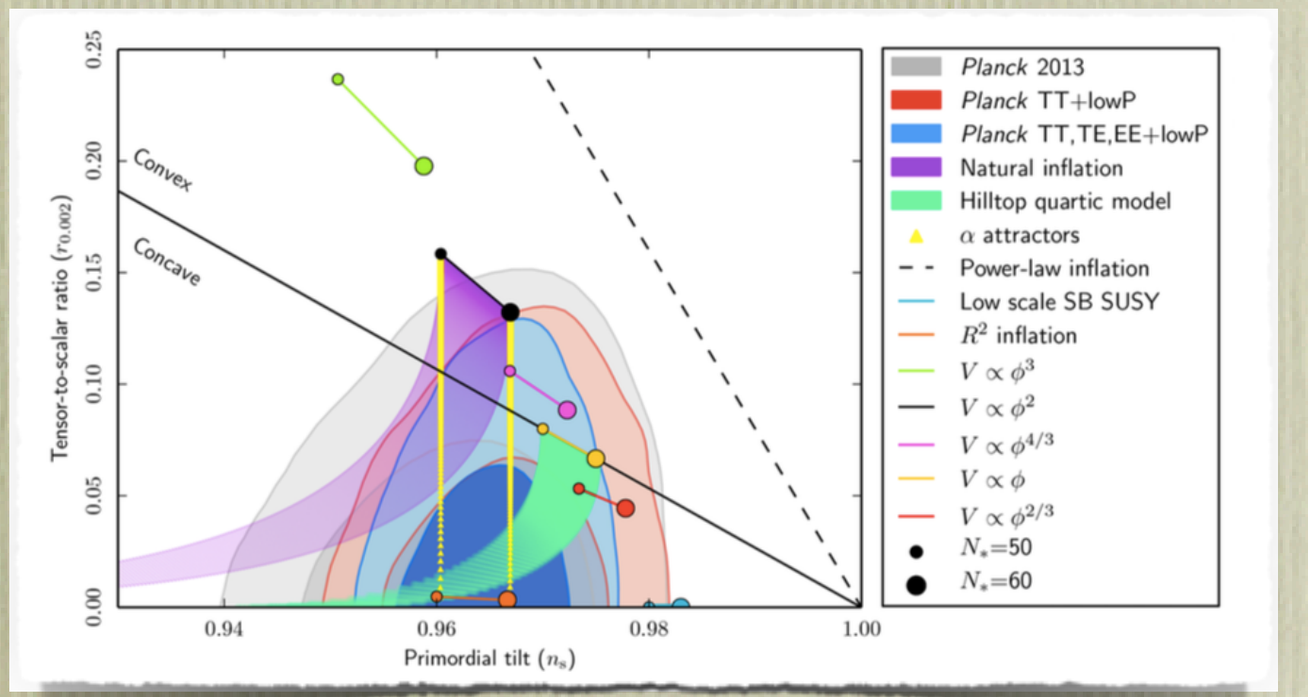
together with:

S. Ferrara, F. Zwirner, E. Dudas, N. Cribiori, F. Farakos and M. Porrati

Standard Models: great successes, no surprises (so far)

New impressive ***experimental progress*** gives new ***constraints*** on theoretical models describing the origin & evolution of our Universe





Quantum Gravity *necessary to UV complete inflationary models (but we may never see tensor modes)*

Old & New Hierarchy problems

HUGE
(vacuum energy)

$$\langle V \rangle^{1/4} \sim 10^{-30} M_P$$

Large
(gauge hierarchy)

$$G_F^{-1/2} \sim 10^{-16} M_P$$

little

$$m^2_{W,Z,h} \lesssim 10^{-2} m^2_{spart}$$

LHC constrains SM-like scalar ***h*** *at 125 GeV, new bounds on* ***H, A, H***$^{\pm}$ *and sparticles*

What about Susy?

Supergravity relevant ***iff*** *some superpartners (gravitino, MSSM sparticles...) are* ***light*** *with respect to KK/string/ Planck cutoff scale*

a. ***Not necessarily all*** *superpartners*

b. *Not necessarily at the* ***TeV/LHC scale***

Well motivated, but not granted.

If realized, challenges and opportunities for realistic supergravity models are related to BSM physics and inflation

What about Susy?

Supergravity relevant ***iff*** *some superpartners (gravitino, MSSM sparticles...) are* ***light*** *with respect to KK/string/ Planck cutoff scale*

a. ***Not necessarily all*** *superpartners*

b. *Not necessarily at the* ***TeV/LHC scale***

If Supersymmetry is broken at ***high scales*** *we can still use it to* ***constrain*** *and* ***parameterize*** *effective theories and provide low-energy theorems*

Non-linear symmetries

Broken symmetries useful to organize irrelevant operators using their non-linear action on the fields

Constraints on operators of different dimensions connected by (non-linearly realized) symmetry

E.g.: Higgs potential still unknown; non-linear $SU(2) \times U(1)$ *action constraints possible couplings at different order in the SMEFT expansion.*

Non-Linear Supersymmetry

From non-linear SUSY to constrained superfields

Casalbuoni-De Curtis-Dominici-Feruglio-Gatto

Simple example (global susy): $X = x + \sqrt{2}\,\theta\chi + \theta^2\, F^x$

$$K = |X|^2 - \frac{1}{\Lambda^2}|X|^4 \qquad\qquad W = f\,X$$

Linear susy in the region $\sqrt{f} \ll E \ll \Lambda$

Susy spontaneously broken at $x = 0$*, with susy breaking scale* $\sqrt{f}$

Spectrum: massless goldstino + massive scalar $m = 4\dfrac{f}{\Lambda}$

At scales below m we can build an ***effective Lagrangian*** *for the goldstino*

From non-linear SUSY to constrained superfields

Casalbuoni-De Curtis-Dominici-Feruglio-Gatto

Simple example (global susy): $X = x + \sqrt{2}\,\theta\chi + \theta^2\, F^x$

$$K = |X|^2 - \frac{1}{\Lambda^2}|X|^4 \qquad\qquad W = f\,X$$

At zero momentum:

$$\mathcal{L} = -f^2 + |F^X + f|^2 - \frac{1}{\Lambda^2}|2x\,F^x - \bar{\chi}\chi|^2$$

Minimized for

$$x = \frac{\bar{\chi}\chi}{2F^x}$$

Low-energy: ***constrained chiral superfield*** $X^2 = 0$

Chiral goldstino superfield

1972 Volkov-Akulov
1978 Rocek; Ivanov-Kapustnikov;
1979 Lindstrom-Rocek;
1983 Samuel-Wess
1989 Casalbuoni-DeCurtis-Dominici-Feruglio-Gatto;
2009 Komargodski-Seiberg;
2011 Kuzenko-Tyler;

Various actions, all equivalent to ***Volkov-Akulov*** *via non-linear field redefinitions*

- *Non-linear realizations of supersymmetry:*
  - *Effective theories*
    some field particularly heavy and hence integrated out
  - *Brane susy breaking models*
    (high-scale induced by mutually non-susy branes)

Matter couplings using constrained superfields

Scalarless models
(orthogonal superfields)

$$X^2 = 0 = XY$$

Brignole-Feruglio-Zwirner

Seiberg-Komargodski models

$X W_\alpha = 0$ — *gaugino-less*

higgsino-less — $\overline{D}_{\dot\alpha}(X\bar{H}) = 0$

$X(B - \overline{B}) = 0$ — *real scalar models*

Lacks organizing principle *and derivation.*
Supergravity realizations may change results

Non-Linear Supersymmetry

Supergravity realizations through Lagrange multipliers

Ferrara-Kallosh-Van Proeyen

General actions with auxiliary fields

Ferrara-Kallosh-Van Proeyen-Wrase
Freedman-Roest-Van Proeyen

Unique organizing principle *and derivation from linear SUSY:*

G.D., dudas, Farakos

$$X\overline{X}\Phi = 0$$

Consistently removes ***only the lowest component*** *of* Φ

Includes all known cases

Consistency constraints on allowed Φ

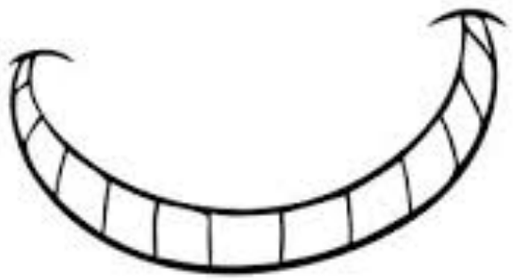
Rewriting susy lagrangian with constrained superfields

Proof that no matter the type of susy breaking (F or D term) the effective theory contains the goldstino constrained superfield X

Pure D-term breaking *can be described by* X *such that* $X^2 = 0$ *and vector field with*

$$XW_\alpha = 0 \qquad X\bar{X}W_\alpha = 0$$

The latter removes the auxiliary field D, because susy breaking is now captured by F^x



... Sgoldstino as Cheshire cat

The constraint implies that K and W can be expanded about X = 0:

$$K(X,\bar{X},z,\bar{z}) = h(z,\bar{z}) + X\bar{k}(z,\bar{z}) + \bar{X}k(z,\bar{z}) + |X|^2 g(z,\bar{z})$$

$$W(X,z) = W_0(z) + XW_1(z)$$

For the bosonic action, compute everything and set <x>=0 afterwards!

$$V = e^K(|DW|^2 - 3|W|^2)|_{x=0}$$

$$D_x W|_{x=0} = W_1(z) \neq 0$$

Nilpotent supergravity

Supergravity coupled to nilpotent field

Antoniadis-Dudas-Ferrara-Sagnotti; Bergshoeff-Freedman-Kallosh-Van Proeyen; Hasegawa-Yamada

Contains only the *graviton* and one *massive gravitino*

$$K = X\bar{X} \qquad\qquad W = m_{3/2} + fX$$

The cosmological constant is ***arbitrary***

$$\Lambda = |f|^2 - 3m_{3/2}^2$$

Matter couplings

- Susy matter spectrum $m_{sp} \leq E \ll \sqrt{f}$
  - *linear realizations = ordinary superfields*
- Non-susy matter spectrum $E \ll m_{sp}, \sqrt{f}$
  - *non-linear realizations = Constrained superfields*

General lagrangians using previous rules

- Constrained auxiliary fields give ***potentials*** that ***differ*** from ordinary supergravity

Constrained supergravity

Cribiori-G.D.-Farakos-Porrati

- (Old) Minimal supergravity multiplet in:
  - Chiral density $2\mathcal{E} = e\left\{1 + i\,\Theta\sigma^a\overline{\psi}_a - \Theta^2(m^* + \overline{\psi}_a\overline{\sigma}^{ab}\overline{\psi}_b)\right\}$
  - Curvature superfield

$$\mathcal{R} = \left\{m, 2\sigma^{ab}\psi_{ab} - i\sigma^a\overline{\psi}_a\, m + i\psi_a b^a, -\frac{1}{2}R + i\overline{\psi}^a\overline{\sigma}^b\psi_{ab} + \frac{2}{3}|m|^2 + \dots\right\}$$

  - Auxiliary vector $\mathcal{D}^\alpha B_{\alpha\dot{\alpha}} = \overline{\mathcal{D}}_{\dot{\alpha}}\overline{\mathcal{R}}$.

Constrained supergravity

Cribiori-G.D.-Farakos-Porrati

- (Old) Minimal supergravity action:

$$\mathcal{L} = \frac{3}{8}\int d^2\Theta\, 2\mathcal{E}\,(\overline{\mathcal{D}}^2 - 8\mathcal{R})e^{-\frac{1}{3}K(X,\overline{X})} + \int d^2\Theta\, 2\mathcal{E}\, W + h.c.,$$

- Constraints on the auxiliary fields:

$$X\left(\mathcal{R} + \frac{c}{6}\right) = 0$$

Constrains auxiliary scalar

$$X\overline{X}B_{\alpha\dot{\alpha}} = 0$$

Constrains auxiliary vector

No more Kæhler invariance!

Constrained supergravity

CRIBIORI-G.D.-FARAKOS-PORRATI

- Unitary gauge action:

$$
\begin{aligned}
e^{-1}\mathcal{L} &= -\frac{1}{2}R + \frac{1}{2}\epsilon^{klmn}(\overline{\psi}_k\overline{\sigma}_l\mathcal{D}_m\psi_n - \psi_k\sigma_l\mathcal{D}_m\overline{\psi}_n) \\
&- (m_{3/2}\,\overline{\psi}_a\overline{\sigma}^{ab}\overline{\psi}_b + \overline{m}_{3/2}\,\psi_a\sigma^{ab}\psi_b) - \Lambda,
\end{aligned}
$$

$$
\Lambda = \frac{1}{3}|c|^2 + |f|^2 + m_{3/2}\overline{c} + \overline{m}_{3/2}c = \Lambda_S - 3|m_{3/2}|^2
$$

- *Susy breaking scale:* $\Lambda_S = |f|^2 + \left|\frac{c}{\sqrt{3}} + \sqrt{3}\,m_{3/2}\right|^2$

Matter couplings different from "de Sitter" sugra

"Anything you want" supergravity

Delacretaz-Gorbenko-Senatore

CCWZ procedure to construct dressed fields

$$A = D_G \left[e^{\mathcal{G} Q} \right] \circ a$$

transforming linearly under h

$$A' = D_G \left[e^{\mathcal{G}' Q} \right] \circ a' = D_G \left[h(\mathcal{G}, \phi) \right] \circ A$$

Invariant lagrangian using ***dressed vielbein and gravitino***

No constraints on the parameters in the action:

- possible *violation of unitarity bounds*;
- consistency of the effective action

- **Brane origin of constrained superfields**
  - *Susy is non-linearly realized on antibranes* Dudas-Mourad
  - *For one anti-D3 on top of O3 the only dof is the goldstino*
  - The anti-D3 brane action can be written using the goldstino superfield Kallosh-Wrase, Bandos-Martucci-Sorokin-Tonin, Bandos-Kuzenko-Martucci-Sorokin
  - *anti-D3/O3 used in* ***KKLT****:* uplift written with manifest susy using nilpotent fields
    Kallosh-Linde, Bergshoeff-Dasgupta-Kallosh-VanProeyen-Wrase; Kallosh-Quevedo-Uranga, Aparicio-Quevedo-Valandro, Dasgupta-Emelin-McDonough
  - *More constrained multiplets* arise from *world volume fields* of the anti-D3 brane Kallosh-Vercnocke-Wrase, Bandos-Kuzenko-Martucci-Sorokin

Summarizing:

Supersymmetry may still be relevant for pheno and cosmo if broken at "high" scale, but split spectrum

Much below heavy sparticles mass scale we should consider nonlinear realizations

Recent developments provide ***techniques***, organizing principles, ***consistency conditions*** *and* UV completions *of nonlinear realizations in global and local supersymmetry*

The generation of generic EFTs with nonlinear susy from string theory and BSB is still sketchy