Emergent Potentials in Consistent Higher Derivative N=1 Supergravity

based on arXiv: 1207.4767

Fotis Farakos(in collaboration with A. Kehagias)

Department of Physics
National Technical University of Athens

Corfu Summer Institute, 2012

Outline

1. Potential with Superpotential
2. Potential without Superpotential and Safe Higher Derivatives
3. Gauged Chiral Models Coupled to SUGRA

SUSY

- The simplest supersymmetric Lagrangian

$$\mathcal{L}_0 = -\partial_\mu A \partial^\mu \bar{A} + i\partial_\mu \bar{\psi} \sigma^\mu \psi + \bar{F} F$$

- Invariant under:

$$\begin{aligned} \delta_\xi A &= \sqrt{2}\xi\psi \\ \delta_\xi \psi &= i\sqrt{2}\sigma^\mu \bar{\xi} \partial_\mu A + 2\xi F \\ \delta_\xi F &= i\sqrt{2}\bar{\xi}\bar{\sigma}^\mu \partial_\mu \psi \end{aligned}$$

SUSY in Superspace

- Chiral superfield in chiral co-ordinates

$$\Phi = A + \theta\psi + \theta\theta F$$

- Superspace Lagrangians

$$\mathcal{L}_0 = \int d^2\theta d^2\bar{\theta}\bar{\Phi}\Phi = -\partial_\mu A \partial^\mu \bar{A} + \bar{F}F$$

$$\mathcal{L}_m = \frac{m}{2}\int d^2\theta \Phi^2 + hc = mAF + m\bar{A}\bar{F}$$

By constuction supersymmetric!

Elimination of F

- Total Lagrangian

$$\mathcal{L}_0 + \mathcal{L}_m = -\partial_\mu A \partial^\mu \bar{A} + \bar{F} F + mAF + m\bar{A}\bar{F}$$

- F equations of motion

$$\bar{F} = -mA$$

which leads to the on-shell theory:

$$\mathcal{L}_{on-shell} = -\partial_\mu A \partial^\mu \bar{A} - m^2 \bar{A} A$$

Superpotential

- From a holomorphic function of the chiral superfields we have

$$\mathcal{L}_P = \int d^2\theta P(\Phi) + hc$$

- and after superintegration and elimination of F it leads to the on-shell theory:

$$\mathcal{L}_{on-shell} = -\partial_\mu A \partial^\mu \bar{A} - \bar{P}'(\bar{A}) P'(A)$$

Superpotential

- In rigid ungauged chiral models, the most general scalar potential is:

$$\mathcal{V} = K^{i\bar{j}}(D_i P)(D_{\bar{j}}\bar{P})$$

- In ungauged chiral models,coupled to supergravity, the most general scalar potential is:

$$\mathcal{V} = e^K[K^{i\bar{j}}(D_i P)(D_{\bar{j}}\bar{P}) - 3P\bar{P}]$$

This standard structure of the scalar potential breaks down when higher derivatives are introduced!

Cecotti, Ferrara, Girardello (1987)

Here we will explicitly consider a realization...

Higher Derivatives

- Consider the superspace Lagrangian:

$$\mathcal{L}_{HD} = \int d^2\theta d^2\bar{\theta}\Lambda\left[\bar{\mathcal{D}}_{\dot{\alpha}}\bar{\Phi}\mathcal{D}_{\alpha}\Phi\bar{\mathcal{D}}^{\dot{\alpha}}\bar{\Phi}\mathcal{D}^{\alpha}\Phi\right] + hc$$

Khoury, Lehners, Ovrut (2012)

- After superintegration:

$$\mathcal{L}_{\mathcal{HD}} = 16U\left\{\left(F\bar{F}\right)^2 + \partial_a A\partial^a A\partial_b\bar{A}\partial^b\bar{A} - 2F\bar{F}\partial_a A\partial^a\bar{A}\right\}$$

Where $\Lambda(\Phi,\bar{\Phi})| = U(A,\bar{A})$ is a hermitian function.

Higher Derivatives, No Superpotential

- We now have the total Lagrangian:

$$\begin{aligned}\mathcal{L}_0 + \mathcal{L}_{HD} &= -\partial_\mu A \partial^\mu \bar{A} + \bar{F} F \\ &+ 16U \left\{ (F\bar{F})^2 + \partial_a A \partial^a A \partial_b \bar{A} \partial^b \bar{A} - 2F\bar{F}\partial_a A \partial^a \bar{A} \right\}\end{aligned}$$

- The equation of motion for F is:

$$\bar{F}(1 - 32UF\bar{F} + 32\partial_a A \partial^a \bar{A}) = 0$$

Two solutions!

1) SUSY preserving

- The first solution preserves supersymmetry, it is the standard solution one expects when there is no superpotential:

$$F = 0$$

- The *standard branch* on-shell theory is:

$$\mathcal{L}_0 + \mathcal{L}_{HD} = -\partial_\mu A \partial^\mu \bar{A} - 16 U(A, \bar{A})\, \partial_a A \partial^a A \partial_b \bar{A} \partial^b \bar{A}$$

More in J. -L. Lehners talk (with superpotential)

2) SUSY breaking

- The second solution is:

$$F\bar{F} = \frac{1}{32U(A,\bar{A})} + \partial_\mu A \partial^\mu \bar{A}$$

- This branch breaks SUSY spontaneously, the on-shell theory is:

$$\begin{aligned} \mathcal{L}_0 + \mathcal{L}_{HD} = -\frac{1}{32U(A,\bar{A})} &- 16U(A,\bar{A})\, \partial_a A \partial^a A \partial_b \bar{A} \partial^b \bar{A} \\ &+ 16U(A,\bar{A})\, \partial_a A \partial^a \bar{A} \partial_b \bar{A} \partial^b A \end{aligned}$$

Emerging Potential in SUSY

- A scalar potential emerges, even though there is no superpotential to start with:

$$\mathcal{V} = -\frac{1}{32U(A,\bar{A})}$$

Koehn. Lehners, Ovrut(2012)
FF, Kehagias(2012)

- This potential is negative definite and breaks SUSY spontaneously.

Coupling to Supergravity

- Now U is a Kähler space tensor,

$$e^{-1}\mathcal{L}_{\rm bos} = -\frac{1}{2}R - g_{A\bar{A}}\partial_a A\partial^a\bar{A} + g_{A\bar{A}}\, e^{\frac{K}{3}}F\bar{F}$$
$$-16U\,\left\{e^{\frac{2K}{3}}(F\bar{F})^2 + \partial_a A\partial^a A\partial_b\bar{A}\partial^b\bar{A} - 2e^{\frac{K}{3}}F\bar{F}\partial_a A\partial^a\bar{A}\right\}$$

- The on-shell theory thatspontaneously breaks SUSY is:

$$e^{-1}\mathcal{L}_{\rm bos} = -\frac{1}{2}R + \frac{(g_{A\bar{A}})^2}{64U}$$
$$-16L\partial_a A\partial^a A\partial_b\bar{A}\partial^b\bar{A} + 16L\partial_a A\partial^a\bar{A}\partial_b A\partial^b\bar{A}.$$

Gauged Chiral Models

- The most general Lagrangian in superspace is:

$$\begin{aligned}\mathcal{L}_{tot} &= \int d^2\Theta\; 2\mathcal{E}[\frac{3}{8}\left(\bar{\mathcal{D}}\bar{\mathcal{D}} - 8\mathcal{R}\right)e^{-\tilde{K}/3} \\ &+\frac{1}{16g^2}F_{ab}(\Phi)W^{(a)}W^{(b)} + P(\Phi) \\ &+\frac{1}{8}\left(\bar{\mathcal{D}}\bar{\mathcal{D}} - 8\mathcal{R}\right)\left[\tilde{\Lambda}^{\bar{r}i\bar{n}j}\;\bar{\mathcal{D}}_{\dot{\alpha}}\tilde{K}_i\mathcal{D}_\alpha\tilde{K}_{\bar{r}}\bar{\mathcal{D}}^{\dot{\alpha}}\tilde{K}_j\mathcal{D}^\alpha\tilde{K}_{\bar{n}}\right]] + hc\end{aligned}$$

FF, Kehagias(2012)

Where $\tilde{\Lambda}^{\bar{r}i\bar{n}j}$ is a gauge invariant Kähler space tensor and $\tilde{K} = K + \Gamma$.

Gauged Chiral Models

- In component form:

$$
\begin{aligned}
e^{-1}\mathcal{L}_{tot} = & -\frac{1}{2}R - g_{i\bar{r}}\tilde{D}_m A^i \tilde{D}^m \bar{A}^{\bar{r}} + e^{\frac{K}{3}} g_{i\bar{r}} F^i \bar{F}^{\bar{r}} \\
& - \frac{1}{16g^2} F_{ab}(A) F^{(a)}_{mn} F^{mn(b)} - \frac{1}{2} g^2 \left(\mathcal{D}^{(a)}\right)^2 \\
& - e^{\frac{2K}{3}} \left(F^i D_i P + \bar{F}^{\bar{r}} D_{\bar{r}} \bar{P} \right) + 3e^K P \bar{P} \\
& - 16\, \tilde{L}_{i\bar{r}j\bar{n}} \Big(e^{\frac{2K}{3}} F^i F^j \bar{F}^{\bar{r}} \bar{F}^{\bar{n}} + \tilde{D}_a A^i \tilde{D}^a A^j \tilde{D}_b \bar{A}^{\bar{r}} \tilde{D}^b \bar{A}^{\bar{n}} \\
& \qquad - e^{\frac{K}{3}} F^i \bar{F}^{\bar{r}} \tilde{D}_a A^j \tilde{D}^a \bar{A}^{\bar{n}} - e^{\frac{K}{3}} F^i \bar{F}^{\bar{n}} \tilde{D}_a A^j \tilde{D}^a \bar{A}^{\bar{r}} \Big)
\end{aligned}
$$

Single Chiral Superfield, Gauged U(1)

- The extended Kähler potential is:

$$\tilde{K} = \bar{\Phi}\Phi + d + V\bar{\Phi}\Phi + \frac{1}{2}V^2\bar{\Phi}\Phi + \xi V$$

- For a gauged U(1), the Killing potential is:

$$D^{(1)} = \bar{\Phi}\Phi + \xi$$

- No superpotential:

$$P = 0$$

Scalar Potential

- After the elimination, the scalar potential reads:

$$\mathcal{V} = \frac{1}{2} g^2 (\bar{A}A + \xi)^2 - \frac{1}{64 \tilde{U}(A, \bar{A})}$$

- Simple example

$$\tilde{U} = m g_{A\bar{A}} g_{A\bar{A}} = m$$

with scalar potential:

$$\mathcal{V} = \frac{1}{2} g^2 (\bar{A}A + \xi)^2 - \frac{1}{64 m}$$

can describe, DS, ADS, Minkowski vacua, all with spontaneously broken SUSY.

Scalar Potential

- Second example

$$\tilde{U} = \frac{k}{64} \frac{(A\bar{A})^2}{A\bar{A} + \xi}$$

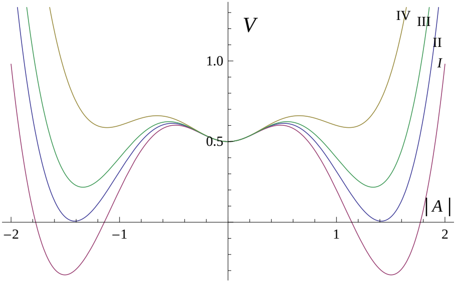

Figure : Uplifted Emergent Potential

Two U(1) Gauged Chiral Superfields

- For simplicity suppose:

$$K = K_1(\Phi_1, \bar{\Phi}_1) + K_2(\Phi_2, \bar{\Phi}_2) + d$$

- with Killing potential:

$$D^{(1)} = \bar{\Phi}_1 \Phi_1 + \bar{\Phi}_2 \Phi_2 + \xi$$

- and for the Kähler space gauge invariant tensor:

$$\tilde{\Lambda}_{i\bar{r}j\bar{n}} = m \tilde{K}_{i\bar{r}} \tilde{K}_{j\bar{n}}$$

A general system can be solved for any number of chiral multiplets, but it's very complex.

Two U(1) Gauged Chiral Superfields

$$
\begin{aligned}
e^{-1}\mathcal{L}_{tot} &= -\frac{1}{2}R - \frac{1}{4}g_{i\bar{r}}\tilde{D}_a A^i \tilde{D}^a \bar{A}^{\bar{r}} - \frac{1}{16g^2}F^{(a)}_{cd}F^{cd(a)} \\
&+ \frac{1}{64m} - \frac{1}{2}g^2\left(\bar{A}_1 A_1 + \bar{A}_2 A_2 + \xi\right)^2 \\
&+ 9m\left(g_{i\bar{r}}\tilde{D}_a A^i \tilde{D}^a \bar{A}^{\bar{r}}\right)^2 - 16 m g_{i\bar{r}} g_{j\bar{n}}\tilde{D}_a A^i \tilde{D}^a A^j \tilde{D}_b \bar{A}^{\bar{r}} \tilde{D}^b \bar{A}^{\bar{n}} \\
&+ 4m g_{1\bar{1}} g_{2\bar{2}} \tilde{D}_a A^2 \tilde{D}^a \bar{A}^{\bar{1}} \tilde{D}_b A^1 \tilde{D}^b \bar{A}^{\bar{2}} \\
&+ m\left(g_{1\bar{1}}\tilde{D}_a A^1 \tilde{D}^a \bar{A}^{\bar{1}} - g_{2\bar{2}}\tilde{D}_a A^2 \tilde{D}^a \bar{A}^{\bar{2}}\right)^2 \\
&\pm \left(\frac{1}{4} + 6m g_{i\bar{r}}\tilde{D}_a A^i \tilde{D}^a \bar{A}^{\bar{r}}\right)\Big\{\left(g_{1\bar{1}}\tilde{D}_a A^1 \tilde{D}^a \bar{A}^{\bar{1}} - g_{2\bar{2}}\tilde{D}_a A^2 \tilde{D}^a \bar{A}^{\bar{2}}\right)^2 \\
&\quad + 4 g_{1\bar{1}} g_{2\bar{2}} \tilde{D}_a A^2 \tilde{D}^a \bar{A}^{\bar{1}} \tilde{D}_b A^1 \tilde{D}^b \bar{A}^{\bar{2}}\Big\}^{\frac{1}{2}}
\end{aligned}
$$

Two U(1) Gauged Chiral Superfields

- We recover canonical kinetic terms
- DBI terms and safe higher derivatives
- Manifest higher derivative nature of this supersymmetric theory through 2 on-shell Lagrangians
- SUSY is spontaneously broken
- D-term uplifted emergent potential

$$\mathcal{V} = -\frac{1}{64m} + \frac{1}{2}g^2\left(\bar{A}_1 A_1 + \bar{A}_2 A_2 + \xi\right)^2$$

FF, Kehagias (2012)

Applications

- Cosmology in supergravity
  Sasaki, Yamaguchi, Yokoyama (2012)
  Koehn, Lehners, Ovrut (2012)
- Hidden sector SUSY breaking
- Theories with symmetries that forbid a superpotential
  (Potential without superpotential)