Gaugino mass from tree level R-symmetry breaking in gauge mediation models

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USTC-ICTS, 25 December 2014

Outline

SUSY and SUSY breaking

Gaugino mass in gauge mediation models

Gaugino mass from tree level R-breaking

No-go and bypass

- 0810.0477 (ZS)
- 1209.1059 (Zhaofeng Kang, Tianjun Li, ZS)
- 1412.0183 (Feihu Liu, Muyang Liu, ZS)
- Works in progress.

Outline

Supersymmetry (SUSY)

What is SUSY? (Martin, [hep-ph/9709356], and books)

- Supersymmetry: bosons $\leftrightarrow$ fermions. e.g.:

$$\begin{aligned} \text{the scalar boson: } \phi, \quad & \delta_\xi \phi = \sqrt{2}\xi\psi, \\ \text{the fermion: } \psi, \quad & \delta_\xi \psi = -i\sqrt{2}\sigma^\mu \bar{\xi}\partial_\mu \phi - \sqrt{2}\xi F, \\ \text{the auxiliary field: } F, \quad & \delta_\xi F = -i\sqrt{2}\partial_\mu \psi \sigma^\mu \bar{\xi}. \end{aligned}$$

- Organized in a superfield with fermionic coordinates θ, $\bar{\theta}$, e.g. chiral fields and vector fields (vector bosons $\leftrightarrow$ fermions):

$$\Phi = \phi + \sqrt{2}\theta\psi + \theta\theta F + \cdots,$$
$$V_{\mathrm{WZ}} = \bar{\theta}\bar{\sigma}^\mu\theta A_\mu + \bar{\theta}\bar{\theta}\theta\lambda + \theta\theta\bar{\theta}\bar{\lambda} + (1/2)\theta\theta\bar{\theta}\bar{\theta}D.$$

- The SUSY Lagrangian (using $\int \mathrm{d}\theta\theta = \int \mathrm{d}\bar{\theta}\bar{\theta} = 1$):

$$L = [\Phi^\dagger e^{2T^a V^a}\Phi]_D + ([(1/4)W^{a\alpha}W^a_\alpha]_F + [W(\Phi_i)]_F + \text{c.c.})$$

Why and Where

Why SUSY?

- A consistent extension of the Poincaré symmetry.
- An ingredient for fundamental theories, e.g., string theory.
- Phenomenology, e.g. solve (partially) the hierarchy of GUT $\rightarrow$ EW, Higgs mass, c.c. problem, etc..

Where is SUSY?

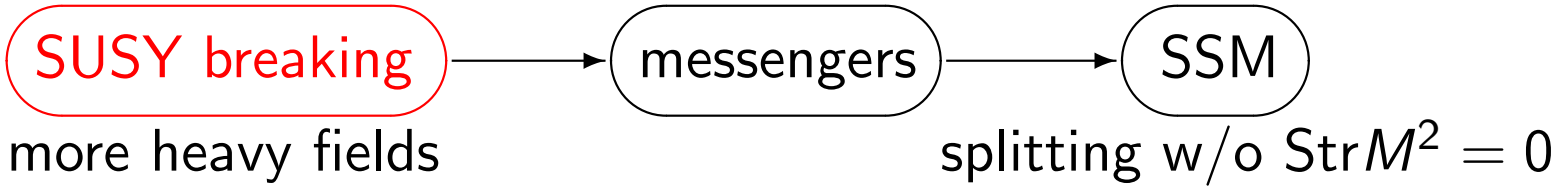
- The Standard Model (SM) is extended to SSM.
- No superpartner has been found $\Rightarrow$ superpartners are heavy (or weakly coupled) $\Rightarrow$ SUSY must be (spontaneously) broken.
- SUSY breaking by SSM fields has difficulties, e.g. light fields.
- To avoid difficulties, Spontaneous SUSY breaking in a hidden sector $\rightarrow$ messenger (mediation) $\rightarrow$ SSM mass splitting.

SUSY breaking in the hidden sector

General pictures

- $\mathrm{Str}M^2 = 0$ (≥ 0 for bosons and ≤ 0 for fermions).

- SUSY breaking in the hidden sector.



- F-type (by chiral fields) and D-type (by vector fields) SUSY breaking.
- Messenger sector models: Gravity mediation, gauge mediation, anomaly mediation.

SUSY breaking and R-symmetries

F-term SUSY breaking (Wess-Zumino or O'Raifeartaigh)

- Superpotential $W(\Phi_i)$, Kähler potential $K(\bar{\Phi}_i, \Phi_j)$.
- $L_{\text{W-Z}} = \int \mathrm{d}^2\,\theta W + \text{c.c.} \Rightarrow$ the scalar potential $V = K^{\bar{i}j}\bar{F}_i F_j$.
- Spontaneous SUSY breaking $\Leftrightarrow V > 0$ at the vacuum $\Leftrightarrow$ $F_i = \partial_i W = 0$ unsatisfied at the vacuum.

The Nelson-Seiberg theorem (revised) ([1209.1059])

- An R-symmetry: $\theta \to e^{i\alpha}\theta$, $z_i \to e^{i\alpha r_i} z_i$, $W \to e^{2i\alpha} W$.
- R-charges: $\mathrm{R}(z_i) = r_i$, $\mathrm{R}(W) = 2$, $\mathrm{R}(\theta) = 1$, $\mathrm{R}(\int \mathrm{d}\theta) = -1$.
- Generically, F-type SUSY breaking at the global minimum "$\Leftarrow$" W has an R-symmetry and $N_Y < N_X$ ($r_X = 2$, $r_Y = 0$).
- "Generic": A small change of parameters does not destroy the vacuum, so no fine-tuning is needed.

Outline

R-symmetry breaking and gaugino masses

R-symmetry breaking

- From Nelson-Seiberg, SUSY breaking needs R-symmetries.
- In SSM, Majorana gaugino masses need R-breaking.
- Loop level and tree level R-breaking.

Gauge mediation (with loop level R-breaking)

- SUSY breaking sector $\rightarrow$ spurion X (usually $r_X = 2$).
- X breaks both SUSY and R-symmetry: $X = \langle X \rangle + \theta\theta F_X$.
- Yukawa coupling to the messenger sector $W = X\tilde{\Phi}\Phi$:

$$[X\tilde{\Phi}\Phi]_F + \text{c.c.} = \langle X \rangle \tilde{\psi}\psi + F_X \tilde{\phi}\phi + \text{c.c.}.$$

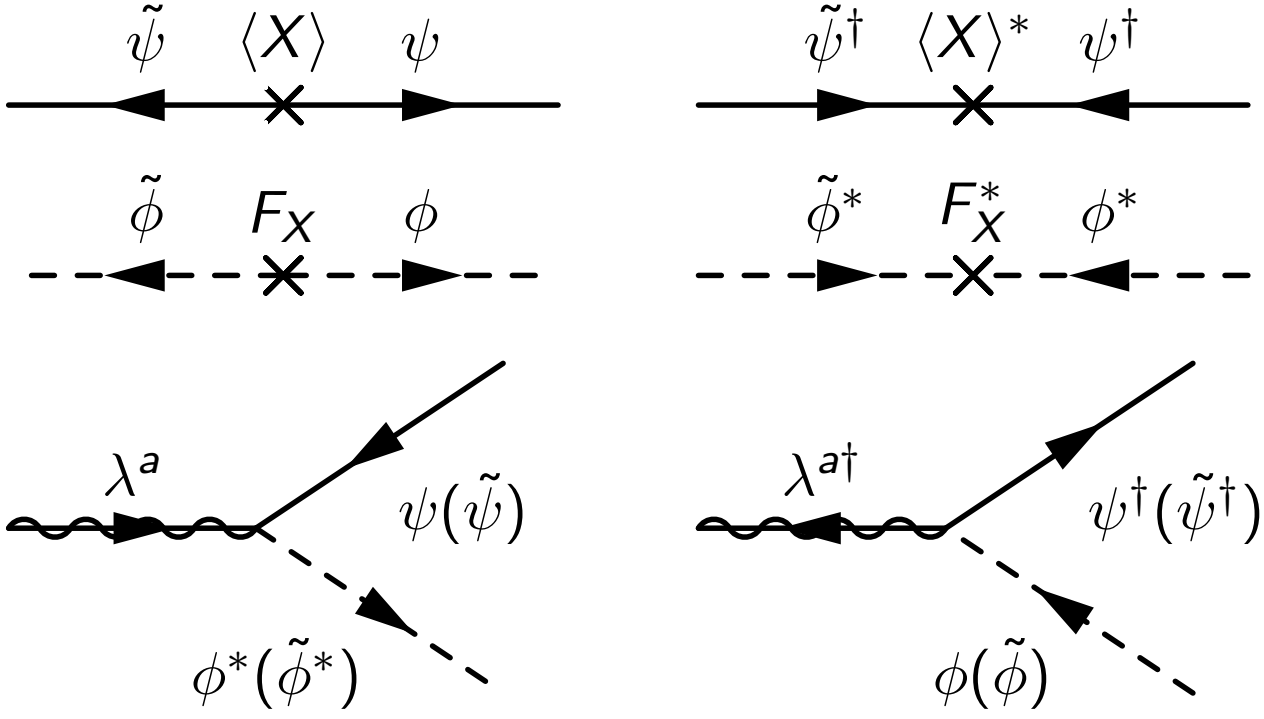
- Messengers are charged under SM gauge symmetry:

$$[\Phi^\dagger (e^{2T^a V^a})\Phi]_D = -\sqrt{2}(\phi^* T^a \psi)\lambda^a + \text{c.c.} + \cdots .$$

R-symmetry breaking and gaugino masses (2)

Vertexes related to gaugino masses

- $\langle X \rangle \tilde{\psi}\psi + F_X \tilde{\phi}\phi + \text{c.c.}$, $-\sqrt{2}(\phi^* T^a \psi)\lambda^a + \text{c.c.}$.

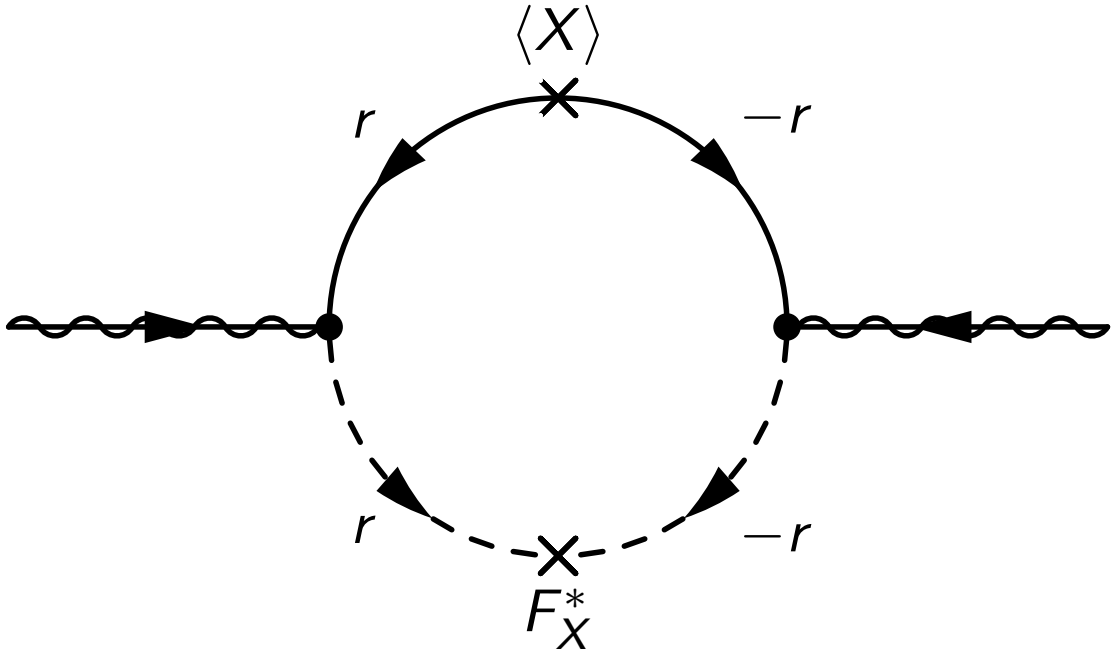


- λ^a corresponds to gauginos $\tilde{g}$.

R-symmetry breaking and gaugino masses (3)

One loop gaugino masses

- The loop diagram.



- R-charges of corresponding superfields has been labeled.
- The resulting gaugino mass: $M_{\tilde{g}} \sim \dfrac{\alpha}{4\pi} \dfrac{F_X}{\langle X \rangle}$.

Tree level SUSY breaking and R-breaking

No-go for tree level SUSY breaking (Komargodski, Shih, [0902.0030])

- Tree level SUSY breaking: Metastable for any $\langle X \rangle$.
- (Extra)ordinary gauge mediation: $W = (\lambda_{ij} X + m_{ij}) \tilde{\Phi}_i \Phi_j$.
- If there is an R-symmetry, then $\det(\lambda X + m) = X^n G(m, \lambda)$, where $n = r_X^{-1} \sum_i (2 - R(\tilde{\Phi}_i) - R(\Phi_i))$.
- Gaugino mass: $M_{\tilde{g}} \sim \frac{\alpha}{4\pi} F_X \partial_X \log \det(\lambda X + m) \sim \frac{\alpha}{4\pi} \frac{n F_X}{\langle X \rangle}$.
- Metastable for any $\langle X \rangle \Rightarrow n = 0 \Rightarrow M_{\tilde{g}} = 0$.
- $X = \langle X \rangle + \theta\theta F_X$, so the model is not tree-level R-breaking.

Tree level R-symmetry breaking ([0810.0477])

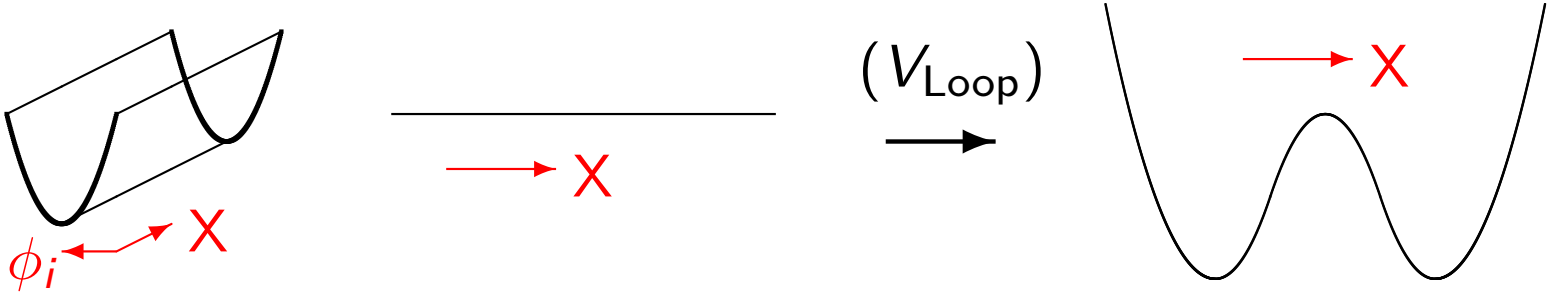
- SUSY breaking and R-breaking by different fields.
- Very complicated model, but still possible.

Outline

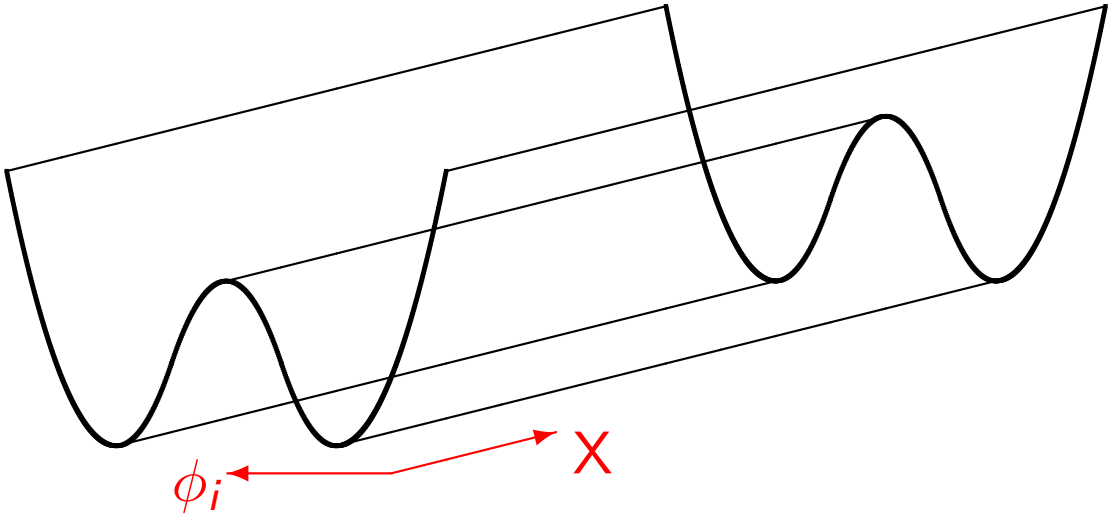
Loop level and tree level R-breaking

Plots of the scalar potential

- Loop level R-breaking:



- Tree level R-breaking



R-breaking everywhere on the pseudomoduli space.

Tree level R-breaking models

Misaligned SUSY breaking and R-breaking fields ([1209.0183])

- $X = \theta^2 F_X$ breaks SUSY, $Y = \langle Y \rangle$ breaks R-symmetry.
- Including tree level R-breaking models and more.

Gauge mediation (with tree level R-breaking)

- Both spurions couple to messengers: $W = X\tilde{\Phi}_i\Phi_j + Y\tilde{\Phi}_i\Phi_j$

$$[X\tilde{\Phi}_i\Phi_j]_F + \text{c.c.} = F_X\tilde{\phi}_i\phi_j + \text{c.c.},$$
$$[Y\tilde{\Phi}_i\Phi_j]_F + \text{c.c.} = \langle Y\rangle\tilde{\psi}_i\psi_j + \text{c.c.}.$$

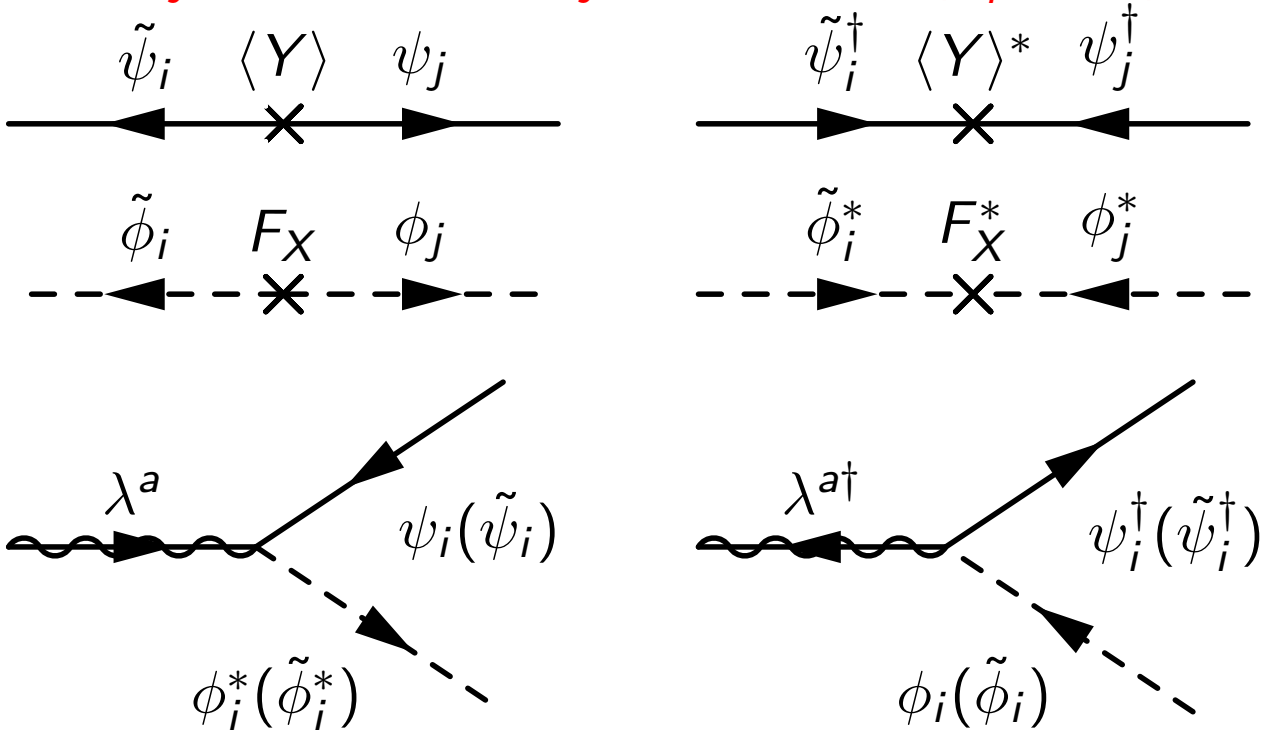
- Messengers are charged under SM gauge symmetry:

$$[\Phi_i^\dagger(e^{2T^aV^a})\Phi_i]_D = -\sqrt{2}(\phi_i^* T^a\psi_i)\lambda^a + \text{c.c.} + \cdots .$$

Gaugino masses from tree level R-breaking

Vertexes related to gaugino masses

- $F_X\tilde{\phi}_i\phi_j + \text{c.c.}$, $\langle Y\rangle\tilde{\psi}_i\psi_j + \text{c.c.}$, $-\sqrt{2}(\phi_i^* T^a\psi_i)\lambda^a + \text{c.c.}$.



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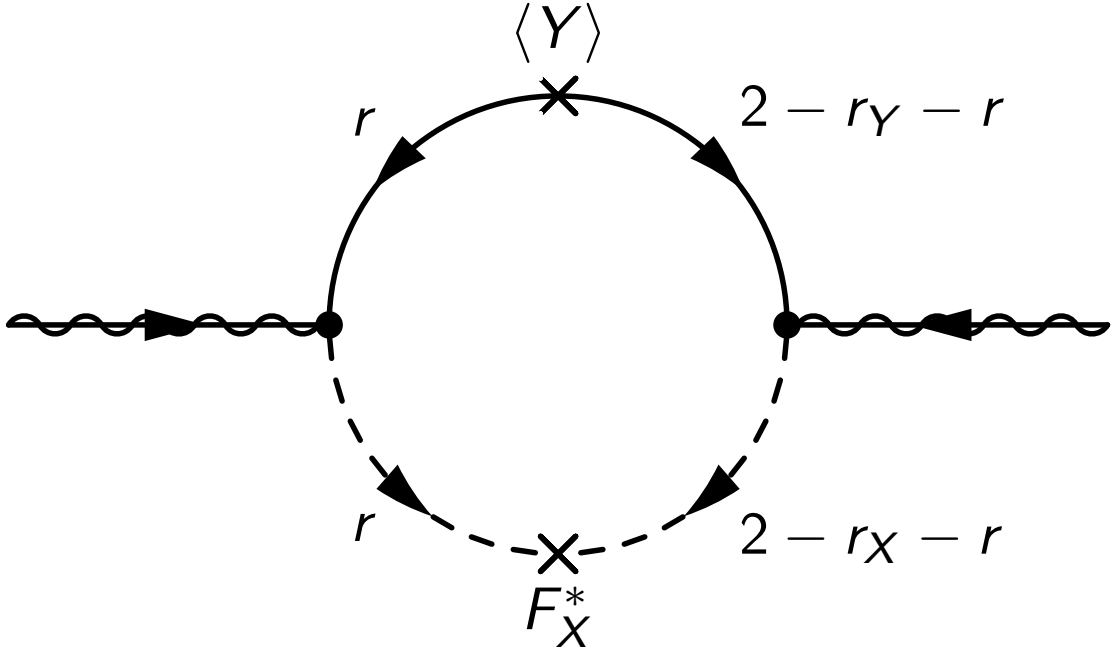


- The resulting gaugino mass: $M_{\tilde{g}} \sim \frac{\alpha}{4\pi}\frac{F_X}{\langle Y\rangle}$(?)
- R-charge conservation $\Rightarrow r_X = r_Y$.

Outline

No-go for tree level R-breaking

Concern of genericness

- $r_X \neq r_Y \Rightarrow$ vanishing $M_{\tilde{g}}$ at one loop $\Rightarrow$ no-go.
- $r_X = r_Y \Rightarrow X$ and Y are indistinguishable.
- $\Rightarrow$ generically $\langle X \rangle$, F_X, $\langle Y \rangle$, F_Y are non-zero and comparable.
- $\Rightarrow$ $M_{\tilde{g}}$ has loop level R-breaking contribution $\sim \dfrac{F_X}{\langle X \rangle}, \sim \dfrac{F_Y}{\langle Y \rangle}$
- $\Rightarrow$ tree level R-breaking is redundant and unnecessary.

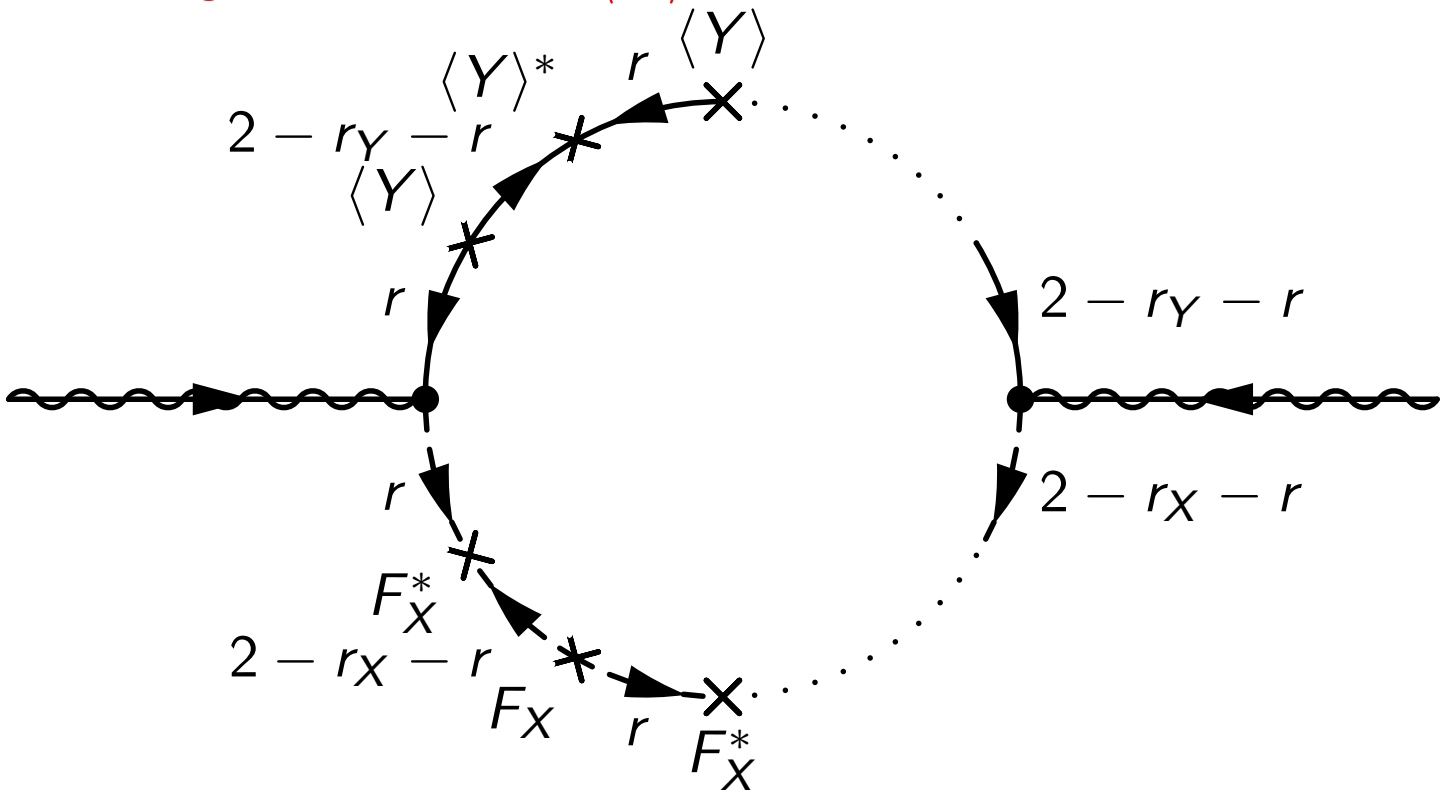
Conclusion

- Tree level R-symmetry breaking is either no-go, or redundant for phenomenology model building (if we concern simpleness, genericness, naturalness of the model).
- Forget about tree level R-breaking(?)

Bypassing the no-go

More vertexes

- Inserting more F_X and $\langle Y \rangle$:



- Both F_X and $\langle Y \rangle$ must be inserted odd number of times.
- R-charge conservation $\Rightarrow r_X = r_Y \Rightarrow$ no-go again.
- Multiple X or Y fields is plausible (works in progress).