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Supersymmetry and its breaking

Hidden sector SUSY breaking II: Gravity mediation

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1 Introduction

In this report, we are presenting the main concepts of supergravity and how gravity mediates the Supersymmetry breaking, in the frame of multiple talks about different topics of Supersymmetry and its breaking. As we have learnt in the previous talks, supersymmetry must be broken softly, namely without introducing quadratic divergences. This is possible in multiple ways, one possibility is to consider an altogether non-renormalizable theory. The best-motivated example is given by gravity, since any sort of particle couples universally to it.
Indeed, the most general supergravity Lagrangian, in the presence of supersymmetry breaking, leads to an effective theory for the low-energy modes containing the desired soft terms.

From a particle physics perspective, the unique low-energy effective theory of gravity is General Relativity. Its consistency requires that gravity couples to matter through the stress-energy tensor, which is the origin of the equivalence principle. Because gravity couples to all forms of energy, it necessarily couples the SUSY breaking sector with the so-called "observable sector", even if there are no other interactions between the two sectors. In this case, we refer to the SUSY breaking sector as the "hidden sector".

Thus, we will treat the spontaneously broken $N = 1$ supergravity theory in which we highlight the transmission of supersymmetry breaking from the hidden to the observable sector via gravitational interactions.

In order to do that, we firstly need to recall some notions from General Relativity (GR), explaining the main concepts of Supergravity (SUGRA) and how can play a role in this context. Then it will be possible to study how the supersymmetry is broken in the hidden sector and and how this breaking is linked to the observable sector.

Of course this is not the only approach, as it has some problems, since the generated soft masses violate flavours. This problem can be avoided considering other approach, such as gauge mediation of SUSY breaking, that is the topic of the previous talk.

2 General Relativity

Our purpose, here, is to summarize the main concepts of General Relativity, and re-elaborate those results that are taken into account for the formulation of Supergravity, the basic element of gravity mediation for SUSY. Further details of these concepts can be found in other books [1, 2, 3].
The main feature of GR is that the space time is no more flat, this fact forces us to consider a non-trivial metric. We were used to the $\eta_{\mu\nu} = \mathrm{diag}(+1, -1, -1, -1)$ Minkowsky metric. In GR the metric isn't globally trivial, and we can replace η with a more general:

$$\eta_{\mu\nu} \to g_{\mu\nu}$$

Also the usual derivative has to adapt to this new concept, therefore, in order to take derivative in curved spacetime we need to 'evolve' it to the so-called covariant derivative:

$$\partial_\mu \to \nabla_\mu A^\nu = \partial_\mu A^\nu + \Gamma^\nu{}_{\mu\lambda} A^\lambda$$

where we defined the affine connection:

$$\Gamma^\mu{}_{\rho\sigma} = \frac{g^{\mu\lambda}}{2} \left(\partial_\rho g_{\sigma\lambda} + \partial_\sigma g_{\rho\lambda} - \partial_\lambda g_{\rho\sigma}\right)$$

In this context, the usual concept of "straight line" in flat spacetime, changes, so the geodesic equation that describe the shortest path of a free particle, becomes:

$$\frac{d^2 x^\mu}{dt^2} = 0 \to \frac{d^2 x^\mu}{dt^2} + \Gamma^\mu{}_{\rho\sigma} \frac{dx^\rho}{dt} \frac{d^2 x^\sigma}{dt} = 0$$

We can notice that all this quantities can go back to the previous one, i.e. in the flat space time limit, just imposing $g_{\mu\nu} = \eta_{\mu\nu}$ that implies: $\Gamma^{\mu}{}_{\rho\sigma} = 0$.
Furthermore, one important assumption can be made, and we will see that it will be broken in Supergravity, namely, we impose a torsion free theory:

$$T^{\lambda}{}_{\mu\nu} = \frac{1}{2}\left(\Gamma^{\lambda}{}_{\mu\nu} - \Gamma^{\lambda}{}_{\nu\mu}\right) = 0$$

At the end, we need to remark the natural coordinate basis we choose to impose in this structure. So, basically, it turns out, that the preferred coordinate choice for the tangent space T_P in one point P is given by the derivative basis in that point: $\frac{\partial}{\partial x^{\mu}} := \partial_{\mu}$. For its dual part: T^*_P, we want the differential dx^{μ}, so we have:

$$\left\{T_P, T^*_P\right\} = \left\{\hat{e}_{(\mu)}, \hat{\theta}^{(\mu)}\right\} = \left\{\partial_{\mu}, dx^{\mu}\right\}$$

Nevertheless, this kind of choice force us to obey to a certain coordinate system, and we want it to be the most general as possible, that's why we can introduce a change of coordinate in order to go from the canonical coordinate system to any other else, the so called vielbein:

$$\hat{e}_{(a)} = e_a{}^{\mu}\, \hat{e}_{(\mu)} = e_a{}^{\mu}\partial_{\mu}$$

Another object it is worth to introduce in order to take derivatives of spinor fields, is the spin connection, $\omega_{\mu}{}^{a}{}_{b}$, in can be expressed as a function of the vielbeins:

$$\omega_{\mu}{}^{a}{}_{b} = e_{\nu}{}^{a} e_{b}{}^{\lambda}\Gamma^{\nu}_{\mu\lambda} - e_{b}{}^{\lambda}\partial_{\mu} e_{\lambda}{}^{a}$$

At the end we can finally define the nonminimal covariant derivative, a mathematical tool necessary in order to take derivative of spinor fields. It will be useful later to define the Supergravity lagrangian:

$$\hat{\nabla}_{\mu} = \partial_{\mu} - \frac{i}{4}\omega^{ab}{}_{\mu}\sigma_{ab}$$

where:

$$\sigma_{ab} = \frac{1}{2}\left[\gamma_a, \gamma_b\right]$$

is proportional to the commutator of the usual Dirac matrices γ^{μ}.

At this point we are ready to transform the usual tensor of General relativity: Curvature tensor (Riemann) and Ricci tensor, from the usual coordinates basis, to a more general one, using the vielbeins and the spin connection.

$$R^{\sigma}{}_{\mu\varrho\nu}(\Gamma) = \partial_{\varrho}\Gamma^{\sigma}{}_{\nu\mu} - \partial_{\nu}\Gamma^{\sigma}{}_{\varrho\mu} + \Gamma^{\lambda}{}_{\nu\mu}\Gamma^{\sigma}{}_{\varrho\lambda} - \Gamma^{\lambda}{}_{\varrho\mu}\Gamma^{\sigma}{}_{\nu\lambda}$$

$$R^{ab}{}_{\mu\nu}(\omega) = \partial_{\mu}\omega^{ab}{}_{\nu} - \partial_{\nu}\omega^{ab}{}_{\mu} + \omega^{ac}{}_{\mu}\omega_{c}{}^{b}{}_{\nu} - \omega^{ac}{}_{\nu}\omega_{c}{}^{b}{}_{\mu}$$

And, defining the Ricci scalar: $R = g^{\mu\nu}R_{\mu\nu} = g^{\mu\nu}R^{\varrho}{}_{\mu\varrho\nu}$, it takes the form:

$$\begin{aligned} R &= \frac{1}{2}\left(e_a{}^{\mu}e_b{}^{\nu} - e_a{}^{\nu}e_b{}^{\mu}\right)R^{ab}{}_{\mu\nu}(\omega) \\ &= -\frac{1}{4e}e^{p}{}_{\lambda}e^{q}{}_{\varrho}\varepsilon_{pqab}\varepsilon^{\lambda\varrho\mu\nu}R^{ab}{}_{\mu\nu}(\omega) \end{aligned}$$

where we introduced the vielbein determinant:

$$e \equiv \det\left(e^{a}{}_{\mu}\right) = \frac{1}{\det\left(e_a{}^{\mu}\right)} = \sqrt{-\det\left(g_{\mu\nu}\right)}.$$

We are now ready to write our first GR Lagrangian, namely the Hilbert-Einstein Lagrangian:

$$\begin{aligned}\mathcal{L}_{\text{GR}} &= M_P^2\sqrt{-g}R(g,\Gamma)\\ &= -\frac{M_P^2}{2}eR(e,\omega)\end{aligned}$$

where in the second line it has been expressed in function of the vielbein basis. M_P is the Planck Mass: $M_P = (8\pi G)^{-1/2}$, in natural units.
The usual Einstein equations can be derived just variating the Lagrangian with respect to the vielbein.

$$e\left(R^a{}_\mu - \frac{1}{2}e^a{}_\mu R\right) = \frac{(T_M)^a{}_\mu}{M_P^2}$$

where we set:

$$R^a{}_\mu = R^{ab}{}_{\nu\mu}(\omega)e_b{}^\nu,$$

and where T_M is the energy momentum tensor coming from the matter action S_M: $S = S_0 + S_M$.

3 Supergravity

Now, that we have all the instruments to understand General Relativity, we can move to Super Gravity. In particular we are interested in understanding which features are important for the gravity mediation of SUSY and why we do need gravity.
As shown in [4, 5], if we want our supersymmetric theory to be locally supersymmetric, we are forced to taking into account gravity. This is the main point of our discussion: that's why local supersymmetry is also called supergravity. The calculation are very simple and explain that any locally supersymmetric theory has to include gravity. In conclusion we can say that supergravity is a quantum theory of gravity. Promoting global supersymmetry to local supersymmetry, rigid superspace then becomes curved superspace, and from superspace vielbein and spin connection, we construct the superspace curvature and torsion. In particular we now have:

$$\begin{aligned}R^{ab}{}_{\mu\nu}(\omega) &= \partial_\mu\omega^{ab}{}_\nu - \partial_\nu\omega^{ab}{}_\mu + \omega^{ac}{}_\mu\omega_c{}^b{}_\nu - \omega^{ac}{}_\nu\omega_c{}^b{}_\mu\\ T^\lambda{}_{\mu\nu} &= \frac{1}{2}\left(\Gamma^\lambda{}_{\mu\nu} - \Gamma^\lambda{}_{\nu\mu}\right) \neq 0\end{aligned}$$

At this point, we can introduce a new concept: the supergravity multiplet. Up to now the other supermultiplet that has been introduced were the chiral and the vector supermultiplet, that have respectively a scalar boson plus a fermion partner, and a gauge boson plus a fermion partner for the vector supermultiplet. But now, in the presence of local supersymmetry we must include also the gravity supermultiplet, that reads:

$$\left\{e_\mu{}^a, \Psi_\mu{}^a, b_a, M\right\}$$

where:

- $e_\mu{}^a$ represents the graviton
- $\Psi_\mu{}^a$ is a Rarita Schwinger spin $3/2$ field for the gravitino (graviton superpartner)
- $\{M, b_a\}$ are the auxiliary terms

So, the Lagrangian density reads:

$$\mathcal{L}_{\text{SG}} = -\frac{1}{2}eR - \frac{1}{3}eM^*M + \frac{1}{3}eb^a b_a + \frac{1}{2}e\varepsilon^{\mu\nu\varrho\sigma}\bar{\Psi}_\mu\gamma_5\gamma_\nu\hat{\nabla}_\varrho\Psi_\sigma$$

that is invariant under:

- general coordinate transformations
- local Lorentz transformations
- local $N = 1$ supersimmetry

With these invariance, one can easilly infer the total degrees of freedon of every field: for example: in principle ${e_\mu}^a$ can be represented by a 4×4 matrix, with 16 d.o.f, but the invariance under coordinate transformation ($= -4$) and local Lorentz transformation($= -6$), leaves it with $16 - 6 - 4 = 6$ bosonic real components, that are the graviton components. The same logic can be applied to ${\Psi_\mu}^a$, with $16 - 4 = 12$, where 4 local SUSY symmetry d.o.f have been removed. For the auxiliary fields, we have a real, 4 components, vector b_α and a complex scalar M with 2 bosonic real components.

4 Soft SUSY breaking

Now that we have all the basic ingredients, it is possible to move to the interested topic of this report, that is the Gravity mediation of the SUSY breaking in the hidden sector. So we are going to present how it is possible and which consequences are related to this mechanism. Furthermore we will analyze the Super-Higgs mechanism, in order to give mass to gravitino.

4.1 Hidden and visible sector

As presented in the previous lectures of this seminar, we want to break the supersymmetry in a "hidden sector" of our theory, that is a sector of particles that has no direct couplings to the "visible sector" chiral supermultiplet, so what we can actually detect.
The two sectors share some interactions that are responsible for mediating supersymmetry breaking from the hidden sector to the visible sector, resulting in the Minimal Supersymmetric Standard Model (MSSM) soft terms.
A first rough calculation of the scale of our terms can be done. In the gravity mediated scenario, if SUSY is broken in the hidden sector by a vacuum expectation value (VEV): $\langle F \rangle \neq 0$, then the soft terms in the visible sector should be roughly, by dimensional analysis:

$$m_{\text{soft}} \sim \frac{\langle F \rangle}{M_P}$$

because m_{soft} must vanish:

- $\langle F \rangle \longrightarrow 0$ where supersymmetry is unbroken.
- $M_P \longrightarrow \infty$ ($G_{\text{Newton}} \longrightarrow 0$) in which gravity becomes irrelevant (flat limit).

Since, $M_P = \sqrt{8\pi G}^{-1} = 2.4 \times 10^{18}$ GeV, since we know $m_{\text{soft}} \sim 100$ GeV $- 1$ TeV, it must follow that: $\sqrt{\langle F \rangle} \sim 10^{10} - 10^{11}$ GeV

4.2 Super-Higgs mechanism

As long as supersymmetry is unbroken, the graviton and the gravitino are both massless, each with two spin helicity states. Once supersymmetry is spontaneously broken, the gravitino acquires a mass by absorbing the goldstino, which becomes its longitudinal (helicity ±1/2) components. The massive spin-3/2 gravitino now has four helicity states, of which two were originally assigned to the would-be goldstino. Its interactions will be of gravitational strength, that is very weak, so the gravitino will not play any role in collider physics, but it can be important in cosmology.

4.3 Soft breaking and mSUGRA

Let's analyze how actually the supersimmetry breaking is mediated by gravity and how particles acquire mass.

Of particular interest to us are operators that connect the fields in the hidden sector with those of the observable sector. We assume that SUSY is broken in the hidden sector by the F auxiliary component of a chiral superfield X, and without loss of generality we shift X so that:

$$\langle F \rangle \neq 0; \qquad \langle X \rangle = 0$$

Let's consider first a globally supersymmetric effective Lagrangian, with the Planck scale suppressed effects that communicate between the two sectors included as non-renormalizable terms. We can expand the superpotential W, the Kähler potential K and the gauge kinetic function f_{ab} for large M_P. In the minimal supergravity model (mSUGRA) framework, the superpotential and Kähler potential have terms coupling X to the MSSM fields as [6]:

$$\begin{aligned} W &= W_{\text{MSSM}} - \frac{1}{M_P}\left(\frac{\alpha}{6} y^{ijk} X\Phi_i\Phi_j\Phi_k + \frac{\beta}{2}\mu^{ij} X\Phi_i\Phi_j\right) + \dots, \\ K &= |\Phi^2| + \frac{n}{M_P}\left(X + X^*\right)|\Phi^2| - \frac{k}{M_P^2} XX^*|\Phi^2| + \dots, \\ f_{ab} &= \frac{\delta_{ab}}{g_a^2}\left(1 - \frac{2}{M_P} fX + \dots\right). \end{aligned}$$

Where Φ^i represent the chiral superfields of the MSSM, $\alpha, \beta, n, k \in \mathbb{R}$ and y^{ijk}, f are dimensionless coupling, while μ^{ij} has mass dimensions, W_{MSSM} is:

$$W_{\text{MSSM}} = \frac{1}{6} y^{ijk}\Phi_i\Phi_j\Phi_k + \frac{1}{2}\mu^{ij}\Phi_i\Phi_j$$

Effective field theory non-renormalizable Lagrangian (part of) that couples F to the MSSM scalar fields ϕ_i and gauginos λ^a [6]:

$$\begin{aligned} \mathcal{L}_{\text{GMSB}} = &-\left(\frac{F}{2M_P} f\lambda^a\lambda^a + \text{ c.c. }\right) - \frac{|F^2|}{M_P^2}(k+n^2)|\phi^2| \\ &-\left(\frac{F}{6M_P}\alpha y^{ijk}\phi_i\phi_j\phi_k + \frac{F}{2M_P}\beta\mu^{ij}\phi_i\phi_j + \text{ c.c. }\right) \end{aligned}$$

Our Lagrangian is non-renormalizable because Gaugino masses cannot arise in a renormalizable SUSY theory at tree-level. This is because SUSY does not contain any (gaugino)-(gaugino)-(scalar) coupling that could turn into a gaugino mass term when the scalar gets a VEV. Furthermore the low-energy modes are described by an effective Lagrangian, which has non-renormalizable kinetic terms at the quantum level, induced by known gauge interactions.

When we replace F by its VEV $\langle F \rangle$, we find that this generates all the soft SUSY breaking terms of the MSSM:

- Gaugino masses:

$$m_{1/2} = \langle M_a \rangle = \frac{\langle F \rangle}{M_P} f$$

- Scalar couplings:

$$A_0 = \langle a^{ijk} \rangle = \frac{\langle F \rangle}{M_P}(\alpha + 3n)$$

- Scalar squared mass:

$$B_0 = \langle b^{ij} \rangle = \frac{\langle F \rangle}{M_P}(\beta + 2n)$$

$$m_0^2 = \left\langle \left(m^2\right)^i_{\ j} \right\rangle = \frac{|\langle F \rangle|^2}{M_P}(k + n^2)$$

4.4 Gravitino mass

Now we want to give more details about the gravitino mass, and which terms of the lagrangian give it. Let's introduce the Kähler function:

$$G = M_P^2 \left[K\left(\frac{\phi_i}{M_P}, \frac{\bar{\phi}^{*i}}{M_P}\right) - \ln\left(\frac{W(\phi_i)W(\phi_i)^*}{M_P^6}\right) \right]$$

with:

- K : Kähler potential
- W : Superpotential

With the following derivatives:

$$G^i = \frac{\delta G}{\delta \phi_i};\ G_i = \frac{\delta G}{\delta \phi^{*i}};\ G^i_{\ j} = \frac{\delta^2 G}{\delta \phi_i \delta \phi^{*j}} = K^j_{\ i} M_P^2.$$

The interaction lagrangian terms, that give rise to renormalizable interactions at energies much lower than the Planck mass, are:

$$\mathcal{L}^I_{\text{SUGRA}} = 3M_P^4 e^{-G/M_P^2} + G^i_{\ j} F_i F^{*j} + \frac{1}{2} D_\alpha D^\alpha$$

with scalar potential:

$$V = V_F + V_D = \sum_i |F_i|^2 + \frac{1}{2}\sum_\alpha |D_\alpha|^2$$

and where F_i are order parameters for SUSY breaking in supergravity:

$$F_i = \frac{\partial W}{\partial \phi_i} = M_P e^{-G/(2M_P^2)} (G^{-1})^j_{\ i} G_j = e^{-G/(2M_P^2)} \left(W_j^* + W^* K_j\right)$$

and D_α are the D-term SUSY breaking, presented in the previous talks.
We also make the following ansatz:

- Minimal Kähler potential:

$$K = \varphi^{*i}\varphi_i + X^* X$$

- We divide the fields φ_i into a visible sector including the MSSM fields φ_i, and a hidden sector containing a field X that breaks supersymmetry:

$$W = W_{\text{vis}}(\varphi_i) + W_{\text{hid}}(X)$$

  thus, the total superpotential is assumed to be additively split between observable sector and hidden sector contributions

We can write the generalization of the F-term contribution to the scalar potential in ordinary renormalizable global supersymmetry [2, 6]:

$$V_F = -M_P^2 e^{-G/M_P^2} \left[G^i (G^{-1})^j{}_i G_j + 3M_P^2 \right] = G^j{}_i F_j F^{*i} - 3e^{-G/M_P^2} \frac{WW^*}{M_P^2}$$

Local Supersimmetry will be broken if one or more of the F_i obtain a VEV. Te gravitino then absorbs the would-be goldstino and obtains a mass:

$$m_{3/2}^2 = \frac{\langle F \rangle^2 + \langle D \rangle^2}{3M_P^2} = \frac{\langle F \rangle^2}{3M_P^2} = \frac{\langle G^i{}_j F_i F^{*j} \rangle}{3M_P^2}$$

Because we want fo follow the "F-term breaking models", where a $\langle F_i \rangle \neq 0$ for at least one i. Thus, if one impose the constraint: $\langle V \rangle = 0$, one obtain:

$$\langle G^i{}_j F_i F^{*j} \rangle = 3e^{-\langle G \rangle / M_P^2} \frac{|\langle W \rangle^2|}{M_P^2} = 3M_P^4 e^{-\langle G \rangle / M_P^2}$$

Giving the gravitino mass:

$$m_{3/2} = M_P e^{-\langle G \rangle / (2M_P^2)}$$

We don't know why the terms in the scalar potential conspire to produce V = 0, but at least we can fine tune them to obtain the value we want.

5 Problems

Let's now look at some of the problems of this approach. Firstly, we have to mention that in the gravity mediation approach the soft masses can violate flavour. Furthermore we analyze some implications of our approach with cosmology.

5.1 Flavour problem

In the gravity-mediated approach, the soft terms are generated at the Planck scale, and there is then no obvious reason why the supersymmetry-breaking masses for squarks and sleptons should be flavour-invariant. Unless there are flavor symmetries at the Planck scale, there appears no reason for these coefficients to be flavor-diagonal or universal. This is the flavor problem of hidden sector models of SUSY breaking. One way to avoid the flavor problem is to assume that there is a gauged flavor symmetry at the Planck scale.

5.2 Cosmology

In the Gravity mediated supersymmetry breaking case, the gravitino mass is comparable to the masses of the MSSM sparticles [7] . As we saw $m_{3/2} \sim 100$ GeV -1 TeV, and its lifetime is dictated by gravity to be $\tau \sim 10^6$ s (TeV/$m_{3/2}$)^3. Its interactions will be of gravitational strength, so the gravitino will not play any role in collider physics, but it can be important in cosmology.

If it is the lightest sparticle (LSP), then it is stable and its primordial density could easily exceed the critical density, causing the universe to become matter-dominated too early.

Even if it is not the LSP, the gravitino can cause problems unless its density is diluted by inflation at late times, or it decays sufficiently rapidly. The gravitino is (almost certainly) the LSP, and all the MSSM sparticles will eventually decay into final states that include it. Naively, one might expect that these decays are extremely slow. This, however, is not necessarily true, because the gravitino inherits the non-gravitational interactions of the goldstino it has absorbed. This means that the gravitino or, more precisely, its longitudinal (goldstino) components can play an important role in collider experiments. The mass of the gravitino can be ignored for kinematical purposes, as can its transverse (helicity ±3/2) components, which really do have only gravitational interactions.

6 Conclusion

In this report, we treated the spontaneously broken $N = 1$ supergravity theory in which we have highlighted the transmission of supersymmetry breaking from the hidden to the observable sector via gravitational interactions, giving mass to the soft terms. Furthermore we saw how gravity can play a fundamental role in electroweak physics, indeed, Standard Model does not include gravity at all. With this approach we have been able to include supergravity, a quantized gravity theory, that manage to join General relativity and quantum physics.

Of course supergravity cannot be the final theory of elementary particles since it is non-renormalizable. However, it might be the effective theory of the final theory (perhaps superstrings).

Furthermore our approach can not explain the flavour violation, problem that is naturally solved in the gauge mediation approach, since that approach is already flavour-blinded and SUSY is independent on flavour breaking terms.

At the end we saw some of the implications of our approach in cosmology, underlining the importance of the gravitino role in this case.

Unfortunately we couldn't present other advanced extension of the mSUGRA model, attempts made in order to solve the problem of the flavour invariance [2], and we didn't mentioned at all any phenomenology of the mSUGRA model. Also different models of gravity-mediated supersymmetry breaking exist [6, 4].

References

[1] Sean M Carroll. *Spacetime and geometry*. Cambridge University Press, 2019.

[2] Manuel Drees, Rohini Godbole, and Probir Roy. *Theory and phenomenology of sparticles: An account of four-dimensional N= 1 supersymmetry in high energy physics*. World Scientific, 2005.

[3] Julius Wess and Jonathan Bagger. *Supersymmetry and Supergravity: Revised Edition*, volume 103. Princeton university press, 2020.

[4] DG Cerdeno and C Munoz. An introduction to supergravity. In *Prepared for 6th Hellenic School and Workshop on Elementary Particle Physics:, Corfu, Greece*, pages 6–26. Citeseer, 1998.

[5] Joseph D Lykken. Introduction to supersymmetry. *arXiv preprint hep-th/9612114*, 1996.

[6] Stephen P. Martin. A SUPERSYMMETRY PRIMER. **Kane, G.L. (ed.): Perspectives on supersymmetry II**, pages 1–98, 1998. doi: 10.1142/9789812839657_0001.

[7] R. Rattazzi G. F. Giudice. Theories with gauge mediated supersymmetry breaking. *Phys. Rept.*, page 322, 1999.