Recollections of my work on mSUGRA with Pran Nath and Richard Arnowitt 
Circa 1981-85

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In the early 1975 when I was a graduate student of Abdus Salam at Imperial College, London, working on the topic of supersymmetry, Salam gave me a paper he had recently received from Dick Arnowitt and Pran Nath where the new idea of supergravity in superspace was introduced[1]. Salam asked me to study this paper and work on this topic if I found it interesting. I thought that this was a brilliant idea, and the topic became part of my thesis[2]. This was my first encounter with Pran and Dick although it was only through their work. It turned out that this was only a prelude to an extended interaction at the collaborative level that was soon to come. Thus in the Fall of 1980 I was a scientific associate at CERN when I met Pran there as he was spending his sabbatical leave at CERN. Soon after our first meeting he made me an offer to visit Northeastern University as a research associate for one year. At that time Lebanon was engulfed in a savage civil war, so I readily accepted his kind offer as it gave me and my family a safe shelter and a good environment to pursue my research. In January 1981 I joined Northeastern University, and at first I continued my work on $N = 1$ ten-dimensional supergravity[3] and I succeeded in constructing the coupling

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of supergravity to Yang-Mills gauge supersymmetry, and compactifying the system to four-dimensions\[^4\]. The problem I faced was that the compactified four-dimensional system has only $N = 4$, $N = 2$ or $N = 0$ supersymmetry and it appeared difficult to get an $N = 1$ compactified theory since at that time the Calabi-Yau compactification was not familiar to physicists\[^5\]. On the other hand unified models based on $N = 1$ supersymmetry appeared to resolve the problem of gauge hierarchy at least at the technical level\[^6\] and hence it was imperative that further work on model building utilize the framework of $N = 1$ supersymmetry.

After the analysis on the reduction of ten-dimensional supergravity was completed, I started interacting with Pran and Dick. At that time they were working on supergravity in superspace and on the $U(1)$ axial anomaly\[^7\]. However, as a consequence of our interactions our interests converged on model building based on $N = 1$ supergravity. This was a novel idea as there were no phenomenologically viable models of this type in the literature at that time. My discussions with Pran and Dick started in earnest in September 1981 on ways of obtaining realistic $N = 1$ supergravity interacting with $N = 1$ super Yang-Mills and chiral $N = 1$ multiplets. The first attempt was to realize such a construction from ten-dimensions. However, as explained already, at that time there was no known way of obtaining $N = 1$ supersymmetry from higher dimensions. Thus we decided to construct the general $N = 1$ supergravity interactions directly in four-dimensions. A Lagrangian with the most general coupling of one chiral multiplet had already been constructed in 1979 by Cremmer et al\[^8\] using the methods of superconformal tensor calculus\[^9\]. We used this method to construct the general $N = 1$ supergravity Lagrangian coupled to super Yang-Mills multiplets and an arbitrary number of chiral multiplets. This proved to be a rather complicated task which we were able to finish in early spring of 1982. The results were very interesting, and the form of the supergravity scalar potential which contained both positive and negative contributions implied that it was possible to break supersymmetry spontaneously and obtain a zero cosmological constant, which is essential to obtain a realistic model. The most general interactions involved an arbitrary function of the scalar fields, denoted by $G$ which can be split into a Kahler part and a superpotential part which was dictated by requiring that when the limit $M (\text{Planck}) \to \infty$ is taken the action reduces to that of global supersymmetry.

Although we had all the results on the $N = 1$ applied supergravity in early spring of 1982 we did not immediately publish them (they were later
published in Trieste Lectures Series\cite{10}) since there were some other weighty ideas we were after and these included the construction of a realistic model of particle interactions within the $\mathcal{N} = 1$ supergravity framework where supersymmetry was broken by a super Higgs mechanism. The main aim was to obtain soft breaking including mass growth for the sparticles which overcame the pitfalls of models based on global supersymmetry where, for example, spontaneous breaking of supersymmetry leads to a squark having mass less than that of a quark. Thus beginning in early Spring of 1982, our efforts over the next few months were focused in this direction. There were several hurdles to be overcome. The first was to break supersymmetry and adjust the vacuum energy to zero. This could be done by breaking supersymmetry by a super Higgs mechanism, and utilizing the fact that the scalar potential of the model was not positive definite, to fix the vacuum energy to zero. The second was to protect the low energy theory below the Planck scale from mass growth of the size of the Planck mass. Such a mass growth would arise naturally if the super Higgs mechanism occurred in the same sector where the quarks, leptons and other matter fields reside in the superpotential. To overcome this hurdle the superpotential was split into two different sectors, a (visible) sector where visible matter, i.e., quarks, leptons, and Higgs, reside and a (hidden) sector where the super Higgs mechanism operates. The key idea here was to have no direct interaction between these two sectors. Because of a lack of this direct interaction soft masses in the physical sector of the size of the Planck scale are avoided. On the other hand, the two sectors are coupled by gravitational interactions because of the supergravity structure of the scalar potential. An interesting question then arises, what is the implication of breaking of supersymmetry in the hidden sector on the visible sector? We addressed this issue by deducing the effective low energy theory in the visible sector. The result of the analysis was very interesting in that the scalar fields in the visible sector showed mass growths of size $O(m^2/M_{\text{Planck}})$ where $m$ is an effective intermediate scale that appears in the super Higgs effect. Thus with $m \sim 10^{10}$ GeV, soft masses of size $O(10^{2-3})$ GeV could be generated. Additionally we found that there were soft bilinear and trilinear couplings in the effective theory before the Planck scale. The nature of soft breaking depends on the nature of Kahler potential chosen and for the analysis we performed the Kahler potential was assumed to be flat. Consequently our analysis exhibited a universality of the soft parameters.

There are two further phenomena which need to be commented on in
this initial work on supergravity model building. The first one is that the model we were working with was a grand unified supergravity model. And in this model the breaking of supersymmetry and of grand unification was accomplished in one step. Quite remarkably the soft breaking was found to be independent of not just the Planck scale but also of the grand unification scale $M_G$. Second, in our analysis we showed that the soft breaking lead to the breaking of the electroweak symmetry from $SU(2)_L \times U(1)_Y$ to $U(1)_{em}$. Thus together these phenomena produced a supergravity grand unification with soft breaking of electroweak size and provided also for an explanation for the breaking of the electroweak symmetry. All these results are contained in our first paper Ref.[11]. After the submission of our work to Physical Review Letters[11] we became aware of the work of Cremmer et al on the couplings of $N = 1$ supergravity[12]. However, this paper did not contain formulation of a SUGRA model with hidden sector breaking. Immediately after, we received the work of Ref[13] which also achieved soft breaking of supersymmetry through the hidden sector mechanism. However, this work did not contain a grand unification nor an exhibition of the phenomenon that the low energy theory was independent of $M_G$.

I spent the next three years working hard in a very fruitful collaboration with Dick and Pran on different applications of $N = 1$ supergravity pushing the idea to its limits which resulted in many interesting additional works[14, 15, 16, 17, 18, 19, 20, 21, 22]. I learned from them how to work as part of a team, spending endless hours in discussions. They served for me an excellent example of how to dedicate oneself to science. With Pran I found the friend who was eager to help long after I left Northeastern. I am glad for having his friendship all these years.

References


