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Supersymmetry, the Cosmological Constant, and a Theory of Quantum Gravity in Our Universe

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There are many theories of quantum gravity, depending on asymptotic boundary conditions, and the amount of supersymmetry. The cosmological constant is one of the fundamental parameters that characterizes different theories. If it is positive, supersymmetry must be broken. A heuristic calculation shows that a cosmological constant of the observed size predicts superpartners in the TeV range. This mechanism for SUSY breaking also puts important constraints on low energy particle physics models.

KEY WORDS: Quantum gravity; cosmology; supersymmetry.

Superstring Theory (ST) is our most successful attempt at constructing a quantum theory of gravitation. The advances of the Duality Revolution [1] gave us detailed mathematical evidence for the nonperturbative existence and consistency of the theory. Ironically, they also told us that its name is misleading because it emphasizes particular asymptotic regions of a collection of continuous moduli spaces of theories. A better name would be Supersymmetric Quantum Theories of Gravity (SQUIGITS).

Indeed, the most cogent statement of the results of the Duality Revolution is that the principles of supersymmetry (SUSY) and quantum mechanics imply the existence of these moduli spaces of theories and of certain extended objects in them, whose tension can be calculated exactly. One then sees that in certain

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limiting regions of moduli space, strings of tension much less than the Planck scale exist, and one is led to expect a perturbative theory of strings. The existing formalism of perturbative superstring theory is a brilliant confirmation of these general arguments. Almost all known perturbative string expansions can be derived from arguments of this sort. The perturbation expansions allow us to calculate many quantities whose value does not follow from SUSY. More remarkably, in many cases, they can be used to obtain a completely nonperturbative formulation of the theory. The latter examples go under the names of Matrix Theory [2] and the AdS/CFT correspondence [3].

Two points on a connected moduli space of such theories can be considered part of the same system because any physical observable of one can be recovered with arbitrary accuracy in terms of measurements done in the other. But this is no longer true if we try to compare theories on different moduli spaces [4]. We seem to be presented with a plethora of different consistent theories of quantum gravity, all of which are exactly supersymmetric and none of which describe the real world. It behooves us to search for criteria that would help us to understand how to construct a theory of the world, and to explain why our world is not described by a point on one of these moduli spaces of consistent theories.

An important general principle that emerges from our rigorous understanding of supersymmetric theories of quantum gravity is the principle of Asymptotic Darkness: The high energy spectrum of a theory of quantum gravity is dominated by black holes [5]. All scattering amplitudes at sufficiently large values of the kinematic invariants are dominated by black hole production [6]. The famed UV/IR connection [2] follows from this principle: high energy states take up large regions in space, and have low curvature external gravitational fields. This connection is the key to understanding that isolated vacuum states or theories with different values of the cosmological constant are not connected. The traditional notion of vacuum state in QFT is an infrared notion. Two vacua of the same QFT have identical high energy behavior, but this is false for states with different values of the cosmological constant.

For negative cosmological constant, the evidence for this statement comes from AdS/CFT. In these systems, the value of the cosmological constant in Planck units is determined by an integer $N$. $N$ determines the number of degrees of freedom of the conformal field theory whose boundary dynamics defines quantum gravity in the bulk of AdS space. For 5 dimensional AdS spaces the relevant

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4 This principle could have been declared earlier, on the basis of black hole physics. However, only the mathematically rigorous formulation of the SUSic theories, particularly the AdS/CFT correspondence, gives us confidence that it is correct.

5 as does the even more famous Holographic Principle. One can attempt to probe short distances in order to demonstrate the volume extensive density of states we expect from quantum field theory (QFT). The production of black holes prevents us from doing this, and instead presents us with an area extensive spectrum of states.