Introduction

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One can often hear that "We don't know what quantum gravity is" (which is fair enough though rather vague) or some not-quite equivalent paraphrase of it, such as "We don't have a theory of quantum gravity" (worse), or "We don't know how to quantize gravity" (really bad). When I hear these statements I wonder if I'm talking to a "sleeping beauty", who went to sleep 30 years ago and just woke up without having an idea of the progress made since then.

In this lecture I present my attempt at explaining to the recently awaken (beauties or not) that, even if we certainly don't understand everything about quantum gravity, we do have a fairly good understanding of several general features of quantum gravity, and we even have a *complete formulation of a class of quantum theories of gravity*. These exist in several dimensions, including D=4, and have propagating degrees of freedom (gravitational waves and gravitons) and black holes. Even if there remain important open problems --foremost, we still don't know how to describe quantum gravity in a universe like ours-- this progress is remarkable, far-reaching, and sound, and contains deep lessons that no one interested in quantum gravity can afford to ignore.

The first that can be said about quantum gravity is that it has long been known how to quantize the theory of General Relativity. We have a calculationally well-defined theory, which is predictive and is based on conventional, well-understood principles of quantum field theory. But this theory is only approximately valid in a low-energy regime, and it clearly points to the need of a different full theory.

There's one caveat to make here: the black hole information problem seems to point to very subtle breakdowns of the quantum field theory of GR that are unexpected from the conventional view, and which involve the entanglement structure of large numbers of quanta produced over long times. Although very important, we willl have little to say about this issue.

Why does quantum GR break down? It is often said that Einstein's *classical* theory leads to its own demise since it predicts that singularities can form starting from smooth initial conditions. The breakdown of quantum GR can be regarded as the quantum counterpart of this phenomenon, since it happens for much the same reason: the unstoppable tendency of gravity to produce ever larger concentrations of energy. And, in both the classical and quantum cases, the physical consequences of the breakdown are dramatically altered from naive expectations, owing to the formation of black hole horizons.

Black holes will guide us on the way to take the theory beyond the point where qGR breaks down, and they will show us how to arrive at a complete theory, at least for spacetimes that are asymptotic to AdS. Following this path leads to a new, surprising *paradigm for quantum theories of gravity* (not "the theory of quantum gravity") that is totally unlike the Wilsonian paradigm of quantum field theory.

Remarkably, the formulations of quantum gravity that we obtain are complete, non-perturbative, and background independent, and as we said, include gravitons and black holes in D=4. But the nature of the fundamental degrees of freedom in these theories, and how spacetime emerges from them, is wholly unlike imagined in any previous approach.

The argumental line leading to these conclusions assumes what we believe are robust aspects of gravity, namely that

- Black holes form when we attempt to reach very high energy densities
- Black holes emit quantum thermal radiation
- Black holes show thermodynamic behavior, and have a large entropy given by the Bekenstein-Hawking formula S=A/(4G hbar)
- This entropy is a measure of the number of fundamental degrees of freedom in the quantum theory of gravity

We will proceed by explaining that

1. The *quantum theory of General Relativity is very effective* for studying physics at energy densities *below the Planck scale*. But this effectiveness breaks down when this scale is approached.
2. Nevertheless, *at superPlanckian scales we recover predictivity* (at least partially) due to a non-perturbative phenomenon of semiclassical physics: *black holes appear* in the spectrum and control the high-energy regime.
3. It follows that *gravity is not a Wilsonian theory*. These are formulated in terms of degrees of freedom defined at very short scales, independently of the large distance properties of states of the theory. The appearance of a large classical gravitational length scale at high energies implies that the degrees of freedom at high energies are sensitive to the long-distance properties (asymptotics) of the field. This goes against the decoupling of scales that is the organizing principle of Wilsonian QFT.
4. *Gravity is a holographic theory*. The growth with area of the maximum entropy contained within a region indicates that the fundamental degrees of freedom are localized at the boundary of spacetime. In the case of AdS asymptotics, the microscopic theory is a conformal field theory in one less dimension.

The remainder of the lecture consists of excerpts of the notes "The Black Hole Guide to the Quantum Theories of Gravity", which contain more details and further elaboration. I've also included illustrations from slides of a colloquium with the same title.