Darkness in the edge of physics

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In the effective field theory view discussed above, GR is adequate for describing scattering at sub-Planckian energies, but appears to be definitely invalidated when we try to go to $E \gg M_{Planck}$. At these scales, the conventional story goes, the outcome of the scattering is totally incalculable without using the more fundamental microscopic theory. This is in fact what is often meant by saying that "we don't know anything about quantum gravity".

Black hole formation in trans-Planckian collisions. Let us reconsider the scattering of two particles in the regime where $s \sim |t| \gg M_{Planck}^2$. There are two different length scales that characterize this problem: one is the classical gravitational radius[40]

$$R_G \sim G\sqrt{s} \tag{3.3.1}$$

and the other is the quantum uncertainty scale

$$b \sim \frac{\hbar}{\sqrt{|t|}}. \tag{3.3.2}$$

They correspond, respectively, to the Schwarzschild radius of a black hole of mass $\sqrt{s}$, and to the impact parameter of the collision. In the trans-Planckian regime where $s \sim |t| \gg \hbar/G$,

$$R_G \gg b. \tag{3.3.3}$$

The picture is this: we are trying to concentrate a large amount of energy into a small region of size $\sim b$. Classical GR tells us that gravitational collapse will occur, with the formation of a black hole of size $\sim R_G$. The black hole horizon cloaks the physics in the region of size b that we were expecting to investigate in our hard-scattering experiment. This horizon effects the *causal disconnection* of the outside observer from the region of infra-Planckian distances. Thus, the result of the experiment will be insensitive to this physics.

Black hole decay. In a quantum theory, the black hole will not be the absolute stable endpoint of this scattering event. The black hole will decay by Hawking emission of quanta with energies

$$\omega \sim T_H \sim \frac{1}{R_G}. \tag{3.3.4}$$

These will have large multiplicities

$$N \sim \frac{M}{\omega} \sim \frac{M}{T_H} \sim S_{BH} \sim \left(\frac{M}{M_{Planck}}\right)^2 \sim \frac{s}{M_{Planck}^2} \gg 1. \tag{3.3.5}$$

Thus, the experimenter will not be realizing a hard '2 → 2' scattering: this involves a huge reduction in entropy and the amplitude is suppressed by a factor $e^{-S_{BH}}$. Instead, one gets a soft '2 →many' scattering in which only distances of order R_G are probed. Note that the problems with perturbative unitarity disappear, since the unitarity-violating hard scattering amplitudes have been exponentially suppressed.