Key points from Lecture 27 of ASTR 350

1. One of the axioms of quantum mechanics says that *in principle* (but definitely not in practice!) the wavefunction of an isolated system has a perfectly known evolution. Thus if you know it at one time, you know it forever before and after.
2. But we've seen that it follows from the axioms of general relativity that "a black hole has no hair", i.e., the only properties of a black hole are its mass, angular momentum, and electric charge. Hawking radiation, which we discovered causes black holes to evaporate, similarly depends only on the instantaneous mass, angular momentum, and electric charge.
3. These axioms contradict each other, because according to GR knowing only the final state (the black hole) we can't reconstruct the initial state (the star), in contradiction to QM. This is the *information paradox* because it is often phrased as "in QM information is preserved, but black holes appear not to preserve information".
4. As pointed out by Sabine Hossenfelder, the proposed solutions all involve giving up axiom(s)... but this is a physics problem, not a mathematics problem, so we need observations to tell. Since we haven't seen (and may never see) Hawking radiation from a black hole, we may not get the true solution. But it's fun to try anyway!
5. The amount of information that could in principle be stored on the boundary of a black hole (i.e., the event horizon; this is the *holographic principle*) is enormous, so we just need Hawking radiation to be ever so slightly non-blackbody to (again in principle!) retain all of the initial information.
6. Hawking radiation involves virtual pairs, which are *entangled*, so if both particles eventually get out there's a chance... but it's not obvious how this specifies the whole initial state of the matter/energy that fell in.
7. Some possible solutions: (a) information actually is lost, (b) near the horizon there are extra "degrees of freedom" that encode the information, (c) really the horizon is made of superstrings, so the information is there, (d) entanglement is broken near the horizon, which takes a lot of energy and forms a "firewall", (e) classical Hawking radiation breaks down when the remaining BH has close to the Planck mass, and that nugget retains the information, (f) mass that falls into a black hole emerges in a baby universe and all information is preserved. No solution is without problems or has the agreement of the community.
8. Besides intellectual fun, one reason to pursue the information paradox is that it might give us hints about quantum gravity or very early universe cosmology. Or it might not!