

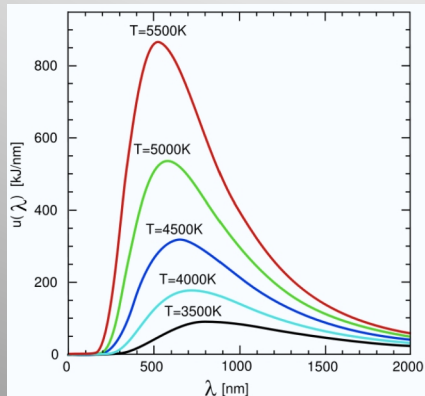
Black hole mysteries

- black holes and quantum information
- where did the supermassive black holes come from?

Black holes and information

- area of the event horizon measures the entropy of a black hole (related to the amount or order or information)
 - application of quantum mechanics to black holes shows they must evaporate:
Hawking radiation
- ...poses a conflict with quantum mechanics

Hawking radiation



Hawking radiation is predicted to be “thermal” or “black body” radiation

- spectrum described by temperature alone
- T proportional to $1 / M$
- individual photons are emitted independently

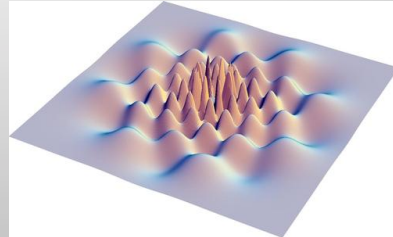
Hawking radiation

If this is true, even given perfect measurements of the radiation from an evaporating black hole (i.e. captured every single photon) we would learn nothing about the interior or how the black hole was made

Seems like an extension of the “No Hair” theorem, not only the exterior space time of a classical black hole but also the evaporation of a black hole due to quantum mechanics are same for all black holes

Quantum mechanics

Quantum mechanical systems are described by a *wave function* ψ



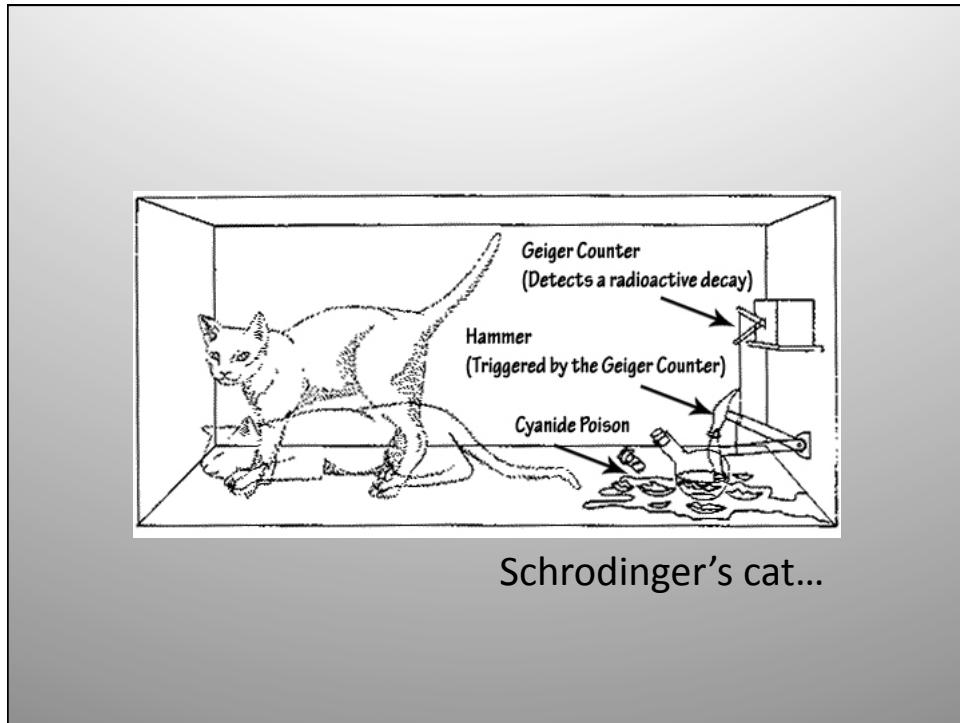
- wave function evolves in space and time in a *predictable* way (the Schrodinger equation for non-relativistic systems)
- when we make a measurement, the *probability* of getting an answer is given by $|\psi|^2$

Quantum mechanics

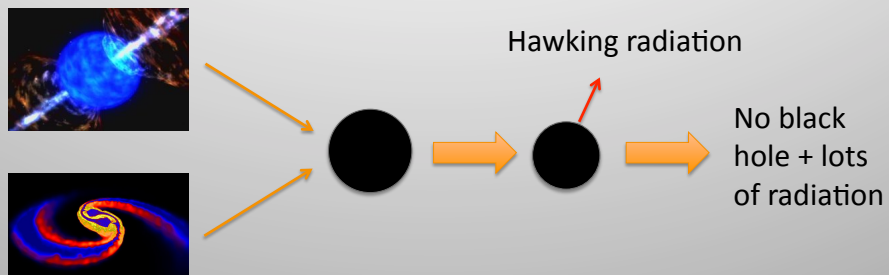
Probability / randomness *only* enters when we make measurements

An isolated quantum system (even a complex one) evolves predictably from initial to final state

No loss of information – we could reverse the evolution and go back from final to initial state just as in classical Newtonian mechanics



Information paradox



Limitless different ways to make a black hole

Exterior of the black hole says nothing about how it was made

Radiation encodes no information either

Final state violates quantum reversibility

Information paradox

Principles of quantum mechanics are extremely well tested – no-one knows how to modify QM to remove reversibility without violating known experimental results

Generally assumed: photons emitted as Hawking radiation are not completely random thermal radiation – return the “missing” information to the Universe when the black hole evaporates

Information paradox

But how?

- where is the information “stored” inside the black hole?
- is there a violation of locality?
- is the *classical* space time inside the hole different from simple GR predictions?

No clear answers to any of these questions...

Alice and Bob Meet the Wall of Fire

How a new black hole paradox has set the physics world ablaze.

by: Jennifer Ouellette

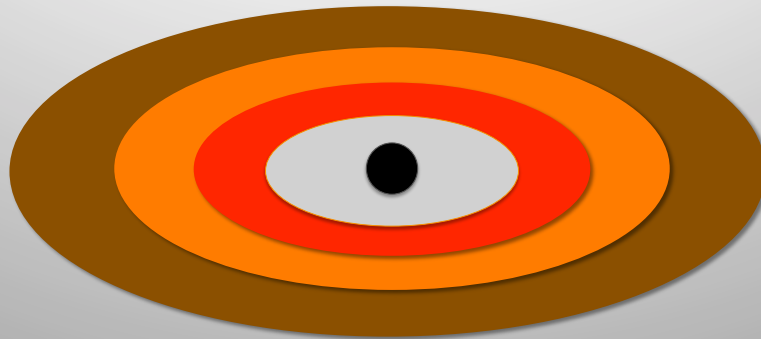
December 21, 2012



...for more, see the
article linked on D2L

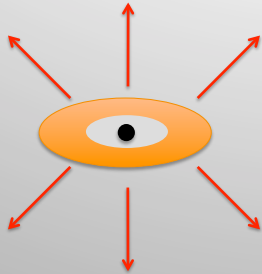
Perhaps these paradoxes will lead us to
the physical basis for quantum gravity

Supermassive black hole formation



Recall: disk accretion on to a black hole releases
~10% of the rest mass energy of the accreted
gas as radiation

Supermassive black hole formation



Radiation exerts an outward force on surrounding gas – if too strong stops gas from accreting

Predict that the fastest a black hole can double its mass from accretion is about 30 million years

The problem



The highest redshift quasar has $z = 7.1$

The age of the Universe at $z = 7.1$ is about 760 million years

The quasar probably has a supermassive black hole of about 10^9 Solar masses

The problem

Seed black hole: 10 Solar masses  Quasar black hole: 10^9 Solar masses

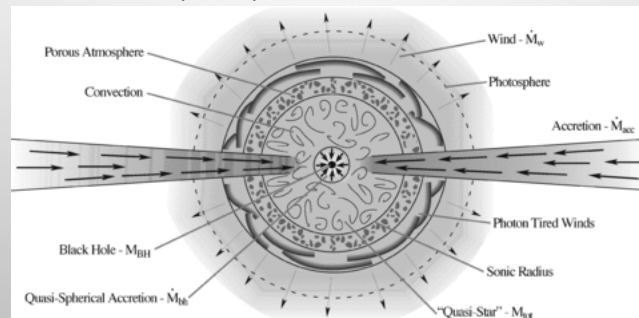
Need to double the mass 26 times

Each doubling takes 30 million years, we *need* at least 780 million years even if accretion is continuous – doubtful whether there is enough time available if the Universe is 760 million years old

How did supermassive black holes form?

- from stellar mass seeds formed in supernova explosions? (needs very efficient accretion)
- directly from the collapse of supermassive stars or gas clouds?

Dotan et al. (2011)



Perhaps a small black hole forms at the center of a supermassive gas cloud and consumes it from inside out?