Stephen Hawking and Quantum Gravity

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Abstract:

Through a combination of his extreme physical limitations, and the equally extreme nature of the subjects of his research, Stephen Hawking has captured a place in the popular imagination.

Quantum gravity in its various incarnations (for example, superstring theory) is now such a widely recognized enigma that many popular books are appearing, including Hawking's own "Brief History of Time".

Many of these books still leave non-experts in the dark.

Just what is involved?

Perceptions:

As is quite common with famous physicists, there is somewhat of a mismatch between the public perception of what he is famous for and the professional opinions of fellow physicists.

(Everyone agrees he's famous.)

Public perception:

- Brief history of time.
- Black holes.
- Baby universes/wormholes.
- Something quantum.

Perceptions:

Professional opinions:

- Singularity theorems (Classical).

- Hawking radiation (Semi-classical).
  - Black hole explosions.
  - Black hole thermodynamics.
  - Black hole geometric entropy.

- Quantum gravity? (Unfinished business).

Brief Biography:

- 1942: Born, Oxford, England.

- 1959: “went up to Oxford”;
University College (founded 1249).

- 1962: B.Sc. 1st class, U Oxford.

- 1963: Begins Ph.D. with Denis Sciama;
Diagnosis; meets Jane Wilde.

- 1965: Ph.D. U Cambridge;
Marriage (Jane Wilde);
Postdoc: Gonville and Caius [Keys].

- 1967-1970: Singularity theorems
(Classical).

- 1973: Large scale structure (Classical).
- 1974: Black hole explosions (Semi-classical).
- 1974: Inducted Royal Society.
- 1979: Lucasian Professor, Cambridge.
  (Inaugural Lecture: End of physics?)
- 1984: (Approx) Quantum gravity.
  (Fully quantum; still unfinished business).
- 1985: Trachectomy.
- 1988: Brief History of Time.
- 1990: Divorce (Jane Wilde);
  Re-marriage (Elaine Mason).

- 1990s: More quantum gravity.
- 1990s: More books.
- 1990s: String theory.
- 1999: AdS/CFT correspondence (string theory).
- 2000: Braneworld cosmologies.
- 2000: "Brane new world".
- 2000: Braneworld inflation.

Health:

Stephen Hawking has “atypical” ALS:

- Amyotrophic Lateral Sclerosis.
- Motor neuron disease.
- Motor neurone disease.
- Lou Gehring’s disease.

Stephen’s comments on ALS:

http://www.hawking.org.uk

The classical period:

- The singularity theorems.

Theorem A:
Assume:

1. Classical Einstein gravity.

2. "Energy is always positive".

3. "The universe is expanding right now".

Deduce:

1. There is a singularity in our past.
   (The Big Bang).

2. "Time had a beginning".

The classical period:

- The singularity theorems.

1. These are theorems of mathematics:

2. Assumptions in $\Rightarrow$ Conclusions out.

3. If you don't like the Conclusions, you must reject one (or more) of the Assumptions.

4. But these are pretty basic Assumptions.

5. Violating any of these Assumptions is almost as interesting as the singularity Theorem itself.

The classical period:

Theorem B:

Assume:

1. Classical Einstein gravity.
2. “Energy is always positive”.
3. “Stars can start to collapse”.

Deduce:

1. “If stars collapse too far, they can’t stop”.
2. Black holes are common, and they contain singularities inside them.

The semi-classical period:

- Black hole explosions?
- Black hole thermodynamics?
- Black hole geometric entropy?

Main points:

- Black holes are not completely black.
- There is a subtle quantum effect that lets energy leak out.
- Temperature proportional to surface gravity.

The semi-classical period:

- Temperature inversely proportional to mass.

- – As it loses mass it gets hotter;
  - it radiates more;
  - loses mass more quickly;
  - finally leading to an explosion?

- "Sorry Stephen, this is all rubbish."

The quantum period:

- Einstein: "God does not play dice with the universe".

- Hawking: "God not only plays dice; sometimes He throws them where they cannot be seen".

What comes out the back end of a black hole explosion?

- Naked singularity?

- Complete evaporation?

- Stable remnant?

The quantum period:

The issue of the final state?

(Of the Hawking evaporation process.)

To answer this question you need to go beyond semi-classical gravity.

You need a full-fledged quantum theory of gravity.

(Because the Hawking temperature has shot up to infinity.)

- Hawking: "Wrong again, Albert."

The quantum period:

Quantum gravity is an unfinished tapestry:

- Quantum mechanics good.
- General relativity good.
- Put them together: a right proper mess.

Two main candidates:

1. Quantum geometry
   [based in the relativity community].
2. M-theory
   [*aka* TOE, brane theory, string theory, *nee* dual resonance model].

The Planck scale:

Basic problem: Vacuum fluctuations.

Heisenberg says — (one version of the Uncertainty Principle) —

You can borrow energy from the vacuum provided you pay it back quickly enough:

$$\Delta E \, \Delta T \leq \hbar.$$

But the energy you borrow will be tightly localized:

$$\Delta L \leq c \, \Delta T.$$

(Speed of light limitation.)

The Planck scale:

If you borrow enough energy, quickly enough, the vacuum fluctuation will form a (virtual) black hole. This happens when:

$$\frac{G\,(\Delta E/c^2)}{\Delta L} \geq c^2.$$

Unwrap these equations:

Vacuum fluctuations with

$$\Delta E \geq \sqrt{\frac{G\,c^5}{\hbar}}$$

should form (virtual) black holes and curdle the vacuum...

This does not seem to happen in real life?

What is going on?

The Cosmological constant:

Problem:

(Just another way of looking at it.)

- The observational astronomers look out into the night sky and measure a (small) non-zero cosmological constant.

- The theorists try to calculate it.

- Oops:

$$(Theory) = 10^{123}\ (Observation).$$

- What is going on?

Conclusion:

- There is an ancient Chinese curse:
- "May you live in interesting times".
- The times are certainly interesting
- (though I don't think of this as a curse)
- Stephen Hawking is right
  in the thick of it.