IPM Physics Colloquium

Tribute to Stephen Hawking

A great and inspiring physicist

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- Stephen W. Hawking was born on 8 January 1942 and passed away on 14 March 2018.

- He was an English theoretical physicist and mainly exploring General Relativity.

- Hawking has a long list of scientific achievements and a long lasting scientific influence.

- In this talk I review
  - his main scientific results, in a timeline.
  - his health conditions again as time passed by.
  - I'll provide an overview of general relativity uncovered through his works and the school-of-thought he had a significant role in its development.

On Hawking's Scientific and Health timeline

■ The 1960's, Singularity formation in GR

- Hawking entered university college, Oxford in fall 1959 and began his graduate school in Trinity Hall, Cambridge in 1962.

- He became student of Denis Sciama and in the first year he was diagnosed with the motor neurone disease when he was 21. Doctors gave him only two more years....

- It was encouragements of Sciama that brought him back to life and physics.

- Hawking received his PhD from Cambridge 1966, his thesis was "Singularities and the Geometry of Space-Time". In his thesis he studied cosmological and black hole singularities.

- In his thesis and the year after he expanded Roger Penrose's ideas on black hole singularities to cosmological spacetimes and in series of papers studied causality and singularity in cosmology.

- In 1966, he published a paper which set the basis of what is now known as cosmic perturbation theory.

- After his PhD, while a postdoc at DAMTP, Cambridge, he continued working on spacetime singularity together with Penrose.

- In the late 1960s, Hawking's physical abilities declined and could no longer give lectures regularly. He also gradually lost the ability to write.

- His main paper on this topic is what is known as Hawking-Penrose theorem and was published in 1970:

  If the universe obeys the general theory of relativity and fits any of the models of Friedmann cosmology, then it must have begun as a singularity.

- Since 1970 he became a tenured (distinguished) physicist at Cambridge and stayed there active until his last days.

- In the same year 1970, he was Distinguished visiting professorship at Caltech, which he kept until 1975. There he worked and betted with Kip Thorne.

- The bet was on nonexistence of black holes in real world, which of course he lost!.

■ The 1970's, Birth of black hole thermodynamics

- In 1970-1975 he focused more on black holes.

- He studied black hole collision and gravitational radiation. These studies and the results of other physicists at the time, guided him to the notion of second law of black hole dynamics and the area law.

- In 1973 in a paper coauthored by Bardeen and Carter they introduced four laws of black hole mechanics, in analogy with usual thermodynamics.

- In 1973 he and George Ellis published their very famous book entitled "The Large Structure of the Universe".

- During 1973-75 he was trying to understand black hole horizon which led him to

Hawking radiation: Particle Creation by Black Holes

- A few weeks after the announcement of Hawking radiation in 1974, Hawking was elected a Fellow of the Royal Society and was one of the youngest scientists to become a Fellow.

- By 1976, through works of Hawking, collaborators and others (mainly students of John Wheeler) at Princeton, the notion of black hole thermodynamics was established.

- His two students in this period Gary Gibbons and Jame Hartle also contributed to these developments.

- During 1975-78 years, Hawking tried to explore physical implications of Hawking-radiation and black hole evaporation.

- This led him to a deep inconsistency of Quantum Theory in presence of black hole horizons, what is known as information paradox.

- In the next 6-7 years Hawking explored the idea whether Quantum Gravity can resolve the information paradox.

- To this end, together with his students, they developed formulations and techniques of path integral quantization of general relativity.

- Although these studies did not lead to a resolution of information paradox and unitarity problem, they led to technicalities which were used in (quantum) cosmology.

- Notions like gravitational instantons, space-time foam, Euclidean Quantum Gravity was developed through these works.

- By late 1970's Hawking's speech deteriorated, and to communicate with others he relied on the help of close friends and family.

- In 70's Cambridge was not a disable-friendly place. Hawking had to fight the university to get a wheelchair access to his workplace.

- He had a dispute with the university over who would pay for the wheelchair ramp. Hawking and his wife campaigned for improved access and support for those with disabilities in Cambridge, including adapted student housing at the university.

- In general, Hawking had ambivalent feelings about his role as a disability rights champion. While he wanted to help others, he also sought to detach himself from his illness and its challenges.

■ The 1980's, Focus on (quantum) cosmology

- Hawking was very much puzzled with black holes and information loss. Unable to find resolution, he thought perhaps black holes do not exist in real world.

- So, he decided to work on something more real, cosmology.

- The main issue, to Hawking, in cosmology was how to resolve Big Bang singularity.

- He tried various ideas with the help of a crew of talented students, like, Malcom Perry, Don Page, Chris Pope, James Hartle, Ian Moss, Gary Horowitz, Jonathan Halliwell,

- He introduced the notion of Quantum Gravitational Bubbles and bubble nucleation and collision, as a way to avoid initial singularity and to formulate his notion of quantum cosmology.

- The "bubble cosmology" was then used by A. Guth to introduce inflation.

- He was really skeptical of "inflation" as it was later developed by many. He thought, as was argued in some papers together with D. Page in late 1980's, inflation was improbable. However, he worked on inflation later on.

- Disappointed from bubbles, he turned to another formulation of quantum cosmology:
  - Studied boundary condition of the Universe
  - Introduced wave-function of the Universe, the Hartle-Hawking wave function.

- Another idea he entertained was the cosmic thermal instanton, mediating the Hawking-Moss transition.

- In 1980's he thought "cosmological constant is probably zero".

- He understood that the key to some of the pressing questions in cosmology is cosmic arrow of time.

- Hawking thought Hartle-Hawking "no-boundary proposal" will yield an arrow of time: The universe first expands and then reaches a phase which stops and collapses back again, when the time runs backward.

- Of course he proved wrong by computations of two of his own students, Don Page and Ray Lafflame.

- He laid the basics of analysis of cosmic fluctuations during inflation (Hawking & Moss) which was later developed into a theory for origin of structure in the Universe (Halliwell & Hawking).

- He also entertained physical effects and impact of presence of wormholes in space-time, as they are allowed in reasonable models of quantum gravity in closed universe. Hartle-Hawking initial state leads to a closed universe.

- In 1985 during a visit to CERN Hawking contracted pneumonia in life-threatening conditions. He was so ill that his wife was asked if life support should be terminated. This finally led to losing his remainder of speech.

- The therapy and nursing at home was funded by an American foundation. Nurses were hired for the three shifts required to provide the round-the-clock support he required.

- For his communication, Hawking initially raised his eyebrows to choose letters on a spelling card. However, in 1986 he received a computer program which basically he used for the rest of his life, Hawking could now simply press a switch to select phrases from a bank of few thousand words.

- With this, Hawking commented that"I can communicate better now than before I lost my voice."

- The voice he used had an American accent and is no longer produced. Despite the later availability of other voices, Hawking retained this original voice, as he thought he is "identified with it."

- With this machine (and a bit more developed version) he prepared seminars and even lectures. He used this machine through 1990's.

■ The 1990's, Focus on black holes again

In 1990's Hawking, and his students, explored further and in more detail what he had proposed in the last two decades, e.g.

- continued working on no boundary proposal, initial conditions of the universe and the arrow of time;

- Time asymmetry: thermodynamical time arrow of Universe as a result of boundary conditions;

- They resorted to Weak Anthropic Principle to explain the observed agreement between Thermodynamic Arrow and Cosmological Arrow in an expanding universe.

- Black holes in the inflationary era;

- Chronology protection in general relativity dynamics.

- Most importantly, he focused on Black hole Evaporation phase, as he thought it may hold the key to information paradox.

- Elaborating on Entropy, Area, and Black Hole Pairs, they proposed extremal black hole have no entropy and tried to justify this considering extremal and non-extremal black hole pair production. These arguments proved to be wrong.

- Open inflation is natural and generic in no boundary proposal.

- In late 1997, early 1998 the AdS/CFT appeared. It fundamentally and profoundly changed the whole area of HEP-TH and gravity.

- Hawking, of course, understood the depth and significance of AdS/CFT. In some papers he wrote in late 1998 and 1999 he tried to keep up with the fast pace of the field and contribute to it.

- Hawking also tried to incorporate ideas appearing from string theory, like branes, into his models of cosmology.

■ 2000's, Era of inflationary cosmology & struggle with information paradox

- In 1998 the accelerated expansion of the Universe was observationally established and with it the dark energy and cosmological constant returned as major questions/problems.

- This highlighted again physics on de Sitter space, which has its own peculiar classical and quantum features. Hawking (together with Juan Maldacena and Andy Strominger) tried to address these using AdS/CFT.

- AdS/CFT provides a precise and unitary formulation of Quantum Gravity and it was then natural that Hawking tried to rethink information loss problem within this setup and for black holes in AdS background.

- Within Euclidean path integral formulation of QGr (through AdS/CFT), Hawking argued that elementary quantum gravity interactions do not lose information or quantum coherence.

- In early 2000's WMAP satellite provided a precise map of the CMB.

- WMAP results at large was viewed as a success for inflationary cosmology.

- Hawking hence tried to argue why and how inflation happened and "why inflation is natural".

- He tried to understand inflation within his no boundary proposal.

- On the theoretical front in 2000's it became clear that string theory has a landscape of vacuua, i.e.

  While in 10 or 11 dim. there are handful of string theories (all related via dualities), once compactified down to 4 dim. there are many many many solutions all allowed by string theory; we have a landscape of vacua.

- Moreover, it was proved that
  - inflation is not natural in string theory even given its landscape of vacua;
  - string landscape probably do not contain stable de Sitter vacuum solution.

- In some papers Hawking tried to explore and address issues and puzzles of string landscape; after all, AdS/CFT which was a fallout of string theory could address information loss (he thought).

- Hawking gradually lost the use of his hand, and in 2005 he began to control his communication device with movements of his cheek muscles, with a rate of about one word per minute.

- He was at risk of locked-in syndrome. Intel researchers worked on a machine to translate his brain patterns or facial expressions. It did not work out.....

- Finally the London-based startup SwiftKey, using a system similar to his original technology made an adaptive word predictor whose database included Hawking's papers and other written materials (a similar technology is now used on smartphone keyboards).

- By 2009 he could no longer move his neck and hence could not drive his wheelchair independently, despite all the efforts to develop a technology for that....

■ The 2010's, Return to black holes

- Hawking was not happy with his AdS/CFT based resolution to information paradox, as it had many loose ends.

- In 2012, evaporating black holes "diagnosed' with another controversy, the firewall.

- Hawking argued against existence of firewalls based on CPT symmetry. He then argued based on AdS/CFT and other ideas that

gravitational collapse produces apparent horizons but no event horizons behind which information is lost. The collapse to form a black hole is in general be chaotic and turbulent.

Thus, like weather forecasting on Earth, information will effectively be lost, although there would be no loss of unitarity.

- His later papers since 2015 showed he was not happy with his resolution of black hole information loss problem.

- He, Perry and Strominger published several papers trying to prompt the idea of black hole soft hairs.

- The soft hairs are zero energy excitations of a black hole which can play the role of black hole microstates and eventually resolve the information loss.

- The idea is still thriving but will probably not work exactly in the same way as he and his collaborators first put it.

- Hawking's last paper appeared few days after his death, two three weeks ago. It was with Gordon Kane on

Should China build the Great Collider?

- Near the end of his life, he was experiencing increased breathing difficulties, requiring a ventilator at times, and was hospitalised several times.

- I'll next show you a brief summary of Hawking's scientific records (Source:Inspire).

Citations summary

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Hawking, Stephen W.

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Personal Details (HepNames)

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Wikipedia	Stephen_Hawking
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1965 – 2018	SENIOR	Cambridge U., DAMTP
1962 – 1965	PHD	Cambridge U.
1959 – 1962	UG	Oxford U.

Update Details

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Santa Barbara, KITP (2)
Munich, Max Planck Inst. (1)
UC, Santa Barbara (1)
CAMBRIDGE U. (1)
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Collaborations

No Collaborations

Publications Datasets External

1. Should China build the Great Collider?
2. A Smooth Exit from Eternal Inflation?
3. The Conformal BMS Group
4. Superrotation Charge and Supertranslation Hair on Black Holes
5. Soft Hair on Black Holes
6. The Information Paradox for Black Holes
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Highlights of Hawking's Scientific Legacy

Hawking's works influenced a lot how we think about black holes, the notion of horizon, causal structure, closed timelike curves, singularity

- Singularity Theorem
- Topology Theorem
- Black holes as thermodynamical systems
- Hawking-radiation and black hole evaporation

Hawking deeply believed that a physical theory cannot allow for any kind of singularity and had special ideas on cosmology and inflation

- No boundary proposal

- Various techniques and concepts to deal with Quantum Gravity.

- He was ambivalent about inflation, whether it happened, was natural and whether it was necessary to resolve the initial singularity.

- On cosmological constant he initially thought it ought to be zero, but after discovery of accelerated expansion of the universe, he tried to understand physics on de Sitter space.

Hawking did not come in terms with the information loss, firewall and black hole microstates

- Despite of many attempts he did not come in terms with information paradox. While he initially thought this is a "feature" and one should live with it, he then tried to resolve it within a theory of QGr, which ought to be unitary.

- In later times he resorted to AdS/CFT to resolve it. Later on the proposed that formation of black holes is fundamentally unitary but turbulent and chaotic, so effectively information is lost.

Above all, despite all the odds, he never gave up his scientific endeavor.

Hawking is definitely a great, great scientist of the caliber of Newton, Maxwell or Einstein.

His scientific legacy will live on for years.

Thank You
For Your Attention