History and Philosophy of Physics

NEWSLETTER

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US Airforce Support of General Relativity: Chapel Hill 1957 and Beyond[2]

By Joshua N. Goldberg (deceased), Syracuse University [1]

This memoir is a somewhat enlarged version of a talk given at the annual meeting of the APS in Columbus, Ohio on April 17, 2018. The session was devoted to celebrating the Chapel Hill Conference on **The Role of Gravitation in Physics** which was organized by Cecile and Bryce DeWitt of the Institute of Field Physics. The conference took place at Chapel Hill from January 18–23, 1957. At the time, I had just arrived at the Aeronautical Research Laboratories (ARL) at Wright Patterson Air Force Base to begin an in house program along with external support of research on gravitation—in particular, Einstein's theory of gravity. I took the invitation to speak as an opportunity to describe the brief period of seventeen years that the Air Force supported research in general relativity at ARL (Aerospace Research Laboratories after sputnik).

I arrived at the ARL, in September, 1956. There I found a group in solid state physics primarily engaged in growing CdS crystals and studying their electrical properties. Another group had a 4 Mev van de Graaf generator and was measuring nuclear energy levels. Although there were civilian physicists engaged in the work, both groups were mainly staffed by graduates from ROTC programs who were assigned to ARL for a two year tour of duty. There were also PhD physicists so assigned. Two that I remember were Lee Pondrom, in particle physics, who went to the University of Wisconsin in Madison and Paul Derain, in solid state physics, who went to Brandeis University. In addition to the local research programs, they monitored research contracts at universities and other institutions. Separated from the physicists, there was a group of German mathematicians who were brought over in Operation Paperclip. We were separated by a glass wall. We each knew the other was present, but we did not interact and I did not know what they were working on.

Max Scherberg, a mathematician, was the Senior Scientist at ARL. It was he who decided that it was important to initiate support for general relativity at the Laboratory. I was hired through the recommendation of Peter Bergmann. As noted earlier, my position was to do research in gravitational theory, in particular Einstein's theory of general relativity, and to grant support to individuals and institutions who were engaged in such research. The first thing I did was to visit Peter Bergmann at Syracuse University and John Wheeler at Princeton. The purpose was to let them know that support was available from this new office at ARL. At the

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In This Issue

The Indian contribution to the physics of black holes: 2020 Nobel Prize [1]

By Naresh Dadhich, Jamia Millia Islania, New Delhi, India

'If I have seen further than others, it is by standing on the shoulders of Giants'; thus spoke the great Newton in 1675. If Newton needed the shoulders to stand on, so would everyone else. No discovery in science is made in vacuum, it is always anchored in the background which serves as a conducive platform for creative and imaginative minds to see further than others and make new discoveries. In this note I will discuss some seminal Indian works that could be taken as 'the shoulders' on which Roger Penrose might have been riding on to see further and deeper into a collapsing star turning into a black hole.

The 2020 Nobel prize in physics has been awarded to Penrose[2] for proving the powerful mathematical theorems that established rigorously that a massive star collapsing under its own gravity ultimately ends up in singularity (Stephen Hawking had collaborated with Penrose in proving the famous singularity theorems, and he could have perhaps shared the Prize had he been alive), where its size goes to zero and energy density to infinity. Not only that, on the way to singularity it would turn into a black hole. This is the robust prediction of Einstein's theory of gravitation—general relativity. The other half of the Prize is shared by two astronomers, American Andrea Ghez and German Reinhard Genzel for detecting independently a supermassive star, believed to be a black hole, at the centre of our galaxy, the Milky Way. It should be noted that it is this remarkable observation that has lent the observational verification of the Hawking and Penrose prediction—a critical requirement for a Nobel Prize.

Black holes two centuries ago

The Indian connection to the term 'black hole' is the infamous incident that dates back to 1756, when Nawab Siraj-ud- Daulah squeezed 146 British soldiers into a dungeon, 14 18 sq ft, overnight in Fort William—which was known as the Black Hole of Kolkata. The message to be taken from and which is relevant for visualizing a physical black hole is that very large mass being confined to a very small volume with diverging density.

It is interesting that the first conception of the black hole as a scientific possibility was to follow pretty soon after by the British clergyman and scientist John Michell in 1784 and the great

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In Memoriam: Joshua N. Goldberg

By Donald Salisbury, Austin College

Joshua N. Goldberg was one of the leading general relativists of the twentieth century. He made major contributions in the development of the theory describing the generation and propagation of gravitational waves, and in his capacity as an administrator of US Air Force funding he was largely responsible for the financial support of research in general relativity in the late 1950's and early 1960's, a period now recognized as a Renaissance era of general relativity. The Goldberg name had been assigned to his Russian emigrant father at Ellis Island. The original Jewish name was Sclaroff[1]. Josh was born in Chicago on May 30, 1925. He passed away on October 5, 2020.

Art Komar, Peter Bergmann, and Joshua Goldberg at the 1962 Warsaw relativity meeting. Paul Dirac in the foreground.
(Photo courtesy of Joanna Robinson)

I was privileged to have known Josh both as a teacher and a friend, beginning when I entered the graduate physics program at Syracuse University in the Fall of 1968. I will include here some of my personal reminiscences, supplemented with a series of interviews that I recorded with him over the years. A broader overview of his work can be found in an upcoming book[2]. I still recall the gracious invitation to visit his home that he and his wife Gloria made to us incoming graduate students that Fall. Josh had returned to Syracuse in 1963, having left after obtaining his PhD in relativity under the direction of Peter G. Bergmann in 1952. He was in fact one of Peter's first students. I was fortunate to have been introduced to relativity in a two semester graduate course taught by Josh in the academic year 1972–73. It played a major role in my decision to complete my thesis in this field under Bergmann's supervision.

The central focus of Josh's thesis was the explicit demonstration of the link between the general covariance of general relativity and the iterative approximation procedure that had been introduced by Einstein, Infeld, and Hoffmann to deduce particle equations of motion. The EIH procedure was based on what they called 'the lemma', a consequence of the fact that the field equations contained an anti-symmetric contribution. Bergmann made the first step in 1949 in tracing the origin of this contribution to general covariance. Josh exploited the fact that general covariance leads to a strongly conserved pseudo stress-energy tensor. Strong conservation means that its divergence vanishes whether the field equations are satisfied or not. It follows that this pseudo tensor can in turn be written as an antisymmetric superpotential, and this antisymmetry was precisely what he had sought to find.

In 1952 he went to work at the Armour Research Foundation in Chicago. He was able to find time while working on applied physics problems to continue with his thesis focus. Much came to fruition after securing his position at the Aerospace Research Laboratories (ARL) in 1954. Major innovations included a focus on the role of the Riemann tensor in identifying gravitational radiation and a correct tracking of coordinate conditions in *v*/*c* expansions in work on source equations of motion[3]. 1954 was the year in which he had the opportunity to discuss his work with Einstein. "And I explained to him the issue of strong conservation, which he probably knew, but had never expressed it. But nonetheless, I thought I was telling him something new. I've always afterward been a little embarrassed by that thought. But, so it goes. Anyway, he did seem interested. But he was not really interested in equations of motion. If I come to him and show him a plane wave solution, any wave solution, he would have been ecstatic, but he was not interested in radiation from moving particles."[4] At ARL he worked in 1962 with Peter Havas on a `fast motion` approximation, with a pioneering treatment of Green function divergences. This same year he obtained a leave to work as a National Science Foundation Fellow at the University of London. There he joined forces with another former Bergmann student, Ray Sachs, to achieve his likely best known theoretical result, the Goldberg-Sachs theorem[5]. Prior to 1962

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Review of *Proving Einstein Right*

Reviewed by Dwight E. Neuenschwander

Proving Einstein Right: The Daring Expeditions that Changed How We Look at the Universe

by Sylvester James Gates, Jr. and Cathi Pelletier

(Public Affairs, New York, 2019), illustrated, 325 pages

Every physics major knows that the 1919 British solar eclipse expeditions supported Albert Einstein's prediction of starlight deflection by the Sun. But the backstories behind great discoveries are seldom told in textbooks; little beyond essential headline facts are well known.

History told through the intimate personal experiences of others acquires an immediacy that can only be improved by having been there ourselves. Anne Frank's diary, and Charles Darwin's diary from the Beagle's expedition, illustrate the point.

By sifting through letters, articles, and other primary source accounts, Sylvester James Gates, Jr. and Cathie Pelletier have written such a comprehensive "diary" for the personalities and events of the solar eclipse expeditions that culminated in the great 1919 result. "Over the course of a decade" they write, "several esteemed astronomers in four countries would take on the 'Einstein problem' in what would become an epic tale of frustration, faith, and ultimate victory."(p. 4) The book takes us through the epic tale in colorful detail, enabling the reader to *be there*.

Doing astronomy today by sitting before a computer screen linked to a distant telescope is another world compared to Victorian-era astronomy. We have greater security, but they had more adventure. Gates' and Pelletier's offer this preview:

> "From the mid-1800s into the first two decades of the 1900s, [astronomers]… planned for months and even years before journeying to exotic parts of the world. Travel by boat, train, wagons, and pack animals was always rigorous and often dangerous. And yet, their best-laid plans could be obliterated in seconds by rain or clouds. The outbreak of regional or national conflict could entirely undo a well-planned expedition. Gone from their families for months at time to foreign lands and unforgiving climates, these astronomers faced illness and possible death from bubonic plague, malaria, yellow fever, and the Spanish flu. They protected themselves as best they could from wild animals, poisonous stakes, venomous insects, floods, forest fires, food poisoning, and local superstitions. But through it all, their mission remained clear…"(3)

While becoming closely acquainted with the principal actors and their families, the reader is witness to and becomes a participant in the travel hassles, insects, torrential rains, local superstitions, and other joys of solar eclipse expeditions from before 1900 through 1919. The wealth of details in *Proving Einstein Right*, especially details not essential to the ultimate outcome, make visualizable in living color the motivations and logistics of those ambitious expeditions in a bygone era.

During the solar eclipses of the early 1900s the research priorities were solar corona studies and searches for the hypothetical planet Vulcan that was supposed to account for the anomalous precession of Mercury's orbit. When Einstein made his preliminary calculation of starlight deflection, he "needed two things: a total believer, and a total eclipse of the sun."(31) He got the first by seeking advice from colleagues at the University of Prague who contacted the Berlin Observatory, producing a response from Erwin Finlay-Freundlich, a former student of Felix Klein and Karl Schwarzschild. Freundlich was the first astronomer to show "spirited interest" in the light deflection prediction of general relativity.(34) He was advised to contact Charles Perrine of Lick Observatory about existing photographs. Having recently been made Director of the Argentina National Observatory, Perrine's Brazilian expedition for the 1912 eclipse was the first attempt to explicitly test Einstein's light deflection prediction.

On these expeditions we board ships for two-week voyages and climb aboard railroad cars for 13-hour train rides. Upon our arrival we are met by local dignitaries, welcomed as VIPs and made the talk of the town. We help choose the local observing site, renting a patch of someone's estate or the local jockey club. We help manhandle equipment from the train station to the viewing site, then build sturdy platforms for telescopes and cameras. That done, we tag along on sightseeing excursions to tropical jungles, mountain vistas, art museums, and quaint towns, all the while anxiously watching the cloud patterns, fervently hoping for clear skies during the upcoming big day's few minutes of totality.

"If you read only scientific papers in academic journals, you would think that these Victorian astronomers were concerned only with hard work. But private letters and accounts sometimes suggest otherwise."(40) Work hard they did—but we also see a case of fine wine being smuggled out of *Portugal* following the 1900 eclipse, the bottles deftly packed in instrument crates. The inquiring customs officer is cooly informed that the crate in question contains "a special instrument used to study double stars."(40) Enroute to Príncipe aboard the small steamer Portugal, Arthur Eddington lacks sufficient room for his daily workout, so he and Edwin Cottingham "took part in improvised games that were played by the passengers. It's comical to imagine the Plumian Professor of Astronomy and the director of the Cambridge Observatory engaged in Boots without Shoes, Rings without Strings, egg-and-spoon races, and Threading the Needle."(179) For the 1912 eclipse in France, helpful amateur John Atkinson ships his Gobron-Brillié roadster across the Channel so he and Sir Frank Dyson can tour the countryside afterwards. "They

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Change of Forum name and modification of by-laws

The FHP membership voted at the start of the year 2021 to change the name of the Forum to The Forum on the History and Philosophy of Physics (FHPP). Some changes in the unit by-laws were also ratified. They are available here: https://engage.aps.org/fhpp/governance/bylaws

The Quantum Century Project and World Quantum Day

The Quantum Century Project, which aims to mark the centennial of the birth of quantum mechanics in 2025 with a global celebration and public outreach campaign, has continued to develop along multiple fronts. The Project, initiated by the FHPP and other Forums and subsequently taken up by the APS as a whole, has a growing cadre of working groups and international partners focusing on different topics and geographical regions. A particularly useful partnership has been with members of the European Commission's Quantum Flagship initiative who have spearheaded an inaugural World Quantum Day that was announced on April 14 of this year. Serving both as an annual occasion to build up to and to echo the year-long 2025 events, this Day has also already allowed a useful platform for testing different modes of quantum outreach.

Summaries from several sectors are below. Those FHPP members interested in helping to contribute to the early stage planning of the Project should contact Quantum Century Working Group Chair, and former FHPP Chair, Paul Cadden-Zimansky

History Working Group

The History Working Group is co-chaired by Alexander Blum from the Max Planck Institute for the History of Science in Berlin and current FHPP Chair Michel Janssen of the University of Minnesota. It includes historians of science from Australia, Brazil, Canada, China, Denmark, France, Israel, Japan, Mexico, Spain, and Sweden. There are currently five project subgroups:

1. Women in Quantum Physics. One immediate goal is to organize invited sessions at the March and April 2022 APS meetings with FHPP sponsorship.
2. Genealogy of quantum textbooks. The initial focus is on tracking English language texts, but the intention is to branch out to other languages and regions. The group is preparing a questionnaire asking physicists from which textbooks they learned quantum mechanics as students and which books they have been using to teach their own students.
3. Archives. Various archives around the world are directly represented. Copyrights will be sought, and an effort will be made to make archival resources available to a wider public.
4. History of understanding of quantum mechanics. Olival Freire of the Universidade Federal da Bahia is the chair. An effort will be undertaken that transcends traditional disciplinary boundaries.
5. Institutional Geography and Individual Trajectories. The Chair is Kristian Camilleri from the School of Historical and Philosophical Studies of the University of Melbourne, Australia. The above topics will be tracked on a website map.

U.S./Canada Outreach Working Group

The quantum century U.S/Canada Outreach Group is responsible for developing the communication and outreach infrastructure of the project in these regions. The current focus is on developing a webpage branding and design strategy. In this effort the group is assisted by GitHub Design Director Sam Oshin. One aim of the group is to organize workshops in which a diverse cohort of physicists will receive training in communication from media professionals and to create networks that can connect scientists, outreach professionals, and those in media interested in promoting quantum understanding and enthusiasm. To this end Group members Spyridon Michalakis, Manager of Outreach for the Institute for Quantum Information and Matter at Cal Tech, and former FHPP Chair Paul Cadden-Zimansky partnered with the National Academy of Science's Science & Entertainment Exchange for a World Quantum Day event where Hollywood screenwriter Kieran Fitzgerald interviewed physicist Carlo Rovelli in front of a virtual audience of over 600 people.

"Quantum Century" Project in China

By Jinyan Liu, Institute for the History of Natural Science, Beijing, China

For the April 14th World Quantum Day the launching ceremony of "Quantum Century" Project in China was held under the organization of the International Centre for Theoretical Physics Asia-Pacific (ICTP-AP), Institute of Theoretical Physics, Chinese Academy of Sciences (ITP-CAS) and the Institute for the History of Natural Sciences, Chinese Academy of Sciences (IHNS-CAS). This meeting attracted an audience of nearly three thousand both on-site and online.

Prof. Yueliang Wu, academician of the CAS, academic vice president of the University of CAS, director of the ICTP-AP, gave a lecture on "Embracing the New Quantum Century and Igniting a New Scientific Revolution". He reviewed the important achievements in the development of quantum theory in the past 100 years, and emphasized the background and mentorship of scientists such as M. Planck, N. Bohr, M. Born, W. Heisenberg and E. Schrödinger when they

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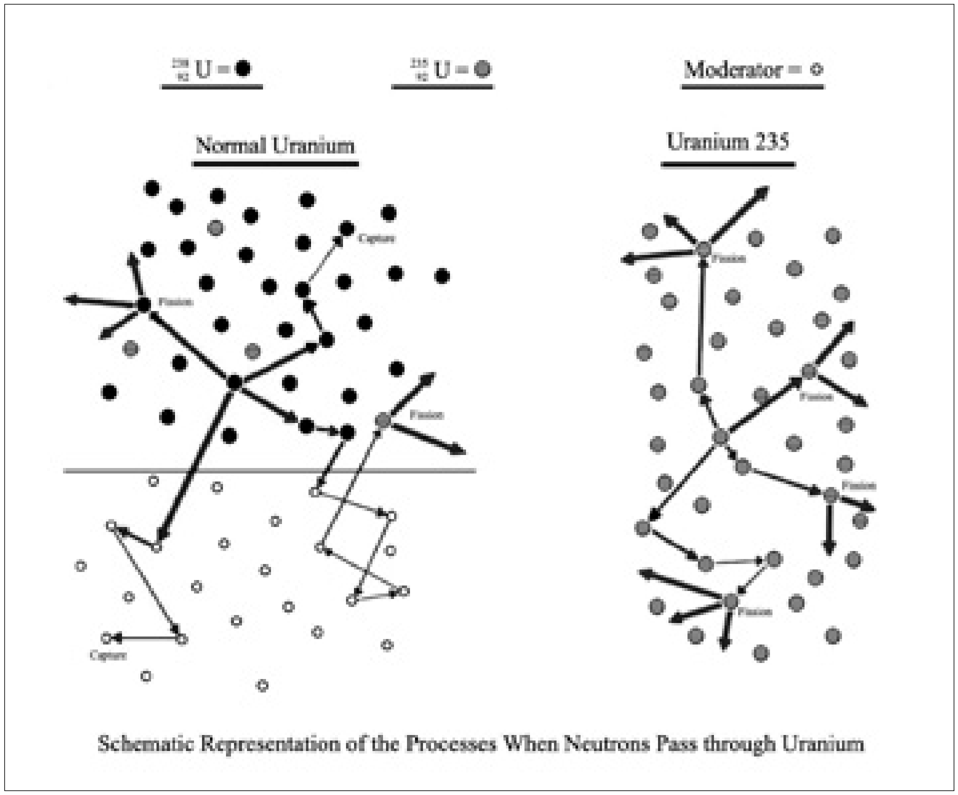
March Session Report: "Farm Hall Revisited"

By Mark Walker



A diagram used by Werner Heisenberg in a February, 1942 lecture. Mark Walker, German National Socialism and the Quest for Nuclear Power, 1939-1949 (Cambridge: Cambridge University Press, 1989), 56.

At the March 15th, 2021 meeting of the American Physical Society, a history of physics panel was held on "Farm Hall Revisited." This session was inspired by the award of the 2020 Abraham Pais Prize for History of Physics to Dieter Hoffmann "for insightful, determined, often courageous biographical and institutional studies of the history of German physics and technology, from Weimar through the Nazi and East German regimes." Dieter requested that, instead of him giving a talk, he participate in a panel discussion of an important topic of interest to a wide audience. The subject chosen was "Farm Hall": after the Second World war, ten German scientists, most of whom had worked on the German wartime uranium project, were interned in an English country house called "Farm Hall," where their conversations were overheard and recorded, including their reactions to the news of Hiroshima. Since the April, 2020 APS meeting was cancelled due to the COVID pandemic, the session, which was chaired by Michel Janssen from the School of Physics and Astronomy at the University of Minnesota, was included this year.

The first talk was given by David Cassidy, Professor emeritus at Hofstra University and the author of the definitive biography of Werner Heisenberg, a book on J. Robert Oppenheimer, and other publications. Most recently David has become a playwright and published the play: *Farm Hall and the German Atomic Project of World War II: A Dramatic History* (Cham: Springer, 2017). This drama highlights several incidents that bring the story to life, including the Germans' confused response to the news of the atomic bomb and the surprise announcement of Otto Hahn's Nobel Prize. Farm Hall thereby comes alive, with all the important contradictions and conflicts it embodies. His book should be of special interest to physicists and physics students and is a valuable addition to our understanding of this ambiguous chapter in the history of modern physics. David's talk, "The Drama of Farm Hall," described how he turned the drama of Farm Hall into a play, exploring the captured German scientists' struggles with their past, their reaction to Hiroshima, and their concern about their uncertain futures in order to open new perspectives on a crucial turning point in physics. However, the talk went beyond Farm Hall to a discussion of playwriting in general, especially drama designed to educate the audience about science as well.

Ryan Dahn completed his Ph.D. in 2019 at the University of Chicago on "The Forgotten Founder of Quantum Mechanics: The Science and Politics of Physicist Pascual Jordan, 1902–1980," and held a postdoctoral position at the Consortium for the History of Science, Technology, and Medicine in Philadelphia, and is now the Books Editor at *Physics Today*. Dahn spoke on "The Use and Abuse of Nuclear History: Farm Hall in Historical Memory." As a rare primary document that quite literally reproduces real-time conversations, one might expect the Farm Hall transcripts to be the definitive source on wartime German nuclear intentions. Yet since 1945, these recordings have been used to make radically different arguments about the abortive program. Allied scientists like Samuel Goudsmit used them in an attempt to prove that Heisenberg and the Germans got their physics wrong when trying to construct a bomb—but that the Germans would have willingly provided Hitler with a nuke if only they could. Others, like the journalist Thomas Powers, have used them to spin a fanciful narrative of scientific resistance inside the Nazi regime. The former internees themselves, particularly Heisenberg and von

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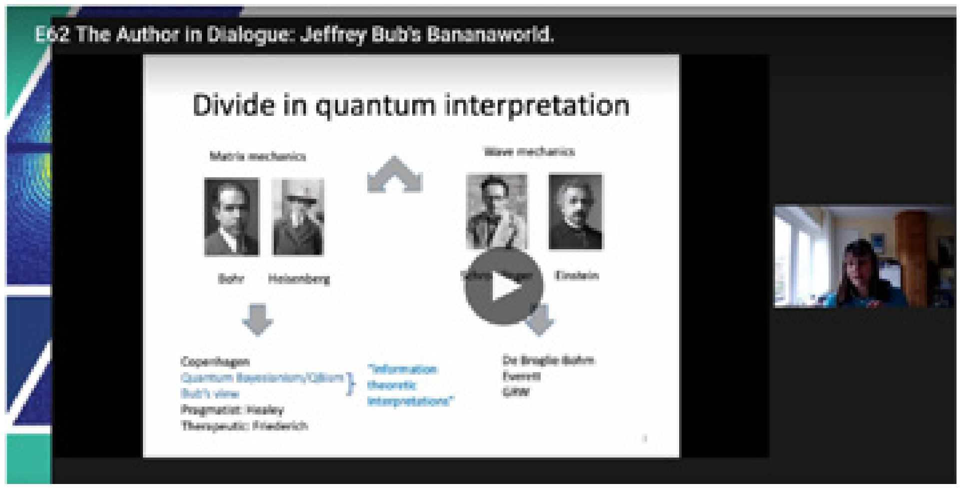
March Session Report: "The Author in Dialogue: Jeffrey Bub's Bananaworld"

By Michael Cuffaro

This session, dedicated to the book *Bananaworld: Quantum Mechanics for Primates* and to the information-theoretic interpretation of quantum mechanics defended within it, had talks by four speakers: Leah Henderson (University of Groningen), Michael Janas (University of Minnesota), Michael Cuffaro (LMU Munich), and Jeffrey Bub (University of Maryland). The titles of the talks were: *Pragmatism: a natural home for information-theoretic interpretations of quantum theory?* (Henderson), *Elliptopes and polyhedra: quantum correlations and their classical simulations* (Janas), *Interpreting quantum mechanics* (Cuffaro), and *Bananaworld: quantum mechanics for primates* (Bub). The session was chaired by Michel Janssen (University of Minnesota). It had 62 unique viewers, and as of March 17, 16 unique further viewers have watched it on demand (source: Hunter Clemens, APS director of meetings).



Leah Henderson screenshot

Henderson began the session by discussing the roots of the information-theoretic interpretation in the ideas defended by the circle of thinkers associated with Niels Bohr and Werner Heisenberg, on the one hand, and in contemporary re-axiomatization programs, on the other. She then discussed what the core commitments of an information-theoretic interpretation of quantum mechanics are: That the quantum state is a book-keeping device for keeping track of probabilities, that there are objective constraints on these probabilities, that the projection postulate is a quantum version of the classical Bayesian updating rule, and that the measurement problem is thereby dissolved, with the realization of a particular measurement outcome understood as a truly random event. Henderson considered the question of whether information-theoretic interpretations are realist, and she discussed some ways to make sense of the ontological commitments of information-theoretic interpretations. She asked, in particular, whether the philosophical view called American Pragmatism might function as a suitable philosophical foundation. Pragmatists are realists but resist the ideal of the "detached observer" and emphasize the centrality of the agent, clarifying meaning by tracing out the practical consequences of action. Henderson suggested using American Pragmatism's alternative understanding of realism as a rhetorical counter to some of the criticisms of information-theoretic interpretations that equate it with instrumentalism. In the question period, Bub commented that part of the point of the information-theoretic interpretation is that quantum mechanics (if we take it seriously) limits the ways that we can conceive of reality, effectively ruling out (via its non-Boolean algebra of observables) the detached-observer conception. Bub noted that associating the view too closely with a particular philosophical position from the outset may obscure this point. In response, Henderson clarified that appealing to pragmatism should not be thought of as a justification for the view but instead as a rhetorical counter to those who accuse the information-theoretic interpretation of instrumentalism. The point of this rhetorical counter is that the detached-observer conception of reality is not the only possible option and that there are alternatives.

In the second talk of the session, Michael Janas presented a number of results regarding elliptopes, polyhedra, quantum correlations and their classical simulations. He began by introducing an analogy between spin measurements and "peeling and tasting bananas", a pedagogical device used both in *Bananaworld* and in the take on the information-theoretic interpretation, inspired by Bananaworld, laid out in the book by Janas, Cuffaro and Janssen: *Understanding Quantum Raffles: Quantum Mechanics on an Information-Theoretic Approach: Structure and Interpretation. In Understanding Quantum Raffles*, bananas are identified with spin-1/2 particles, peelings with measurements of components of their spin, and tastes with the outcomes of such measurements. Janas then introduced the experimental "Mermin-setup" (inspired by an example of N. David Mermin's) used in *Understanding Quantum Raffles*, its associated correlation array, and the correlation coefficients that can be used to parameterize such arrays. He then introduced the concept of a "raffle", i.e., a toy model, with local hidden-variables modelled as raffle tickets, to reproduce the correlations

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March Session Report: Pais Prize

By Hasok Chang

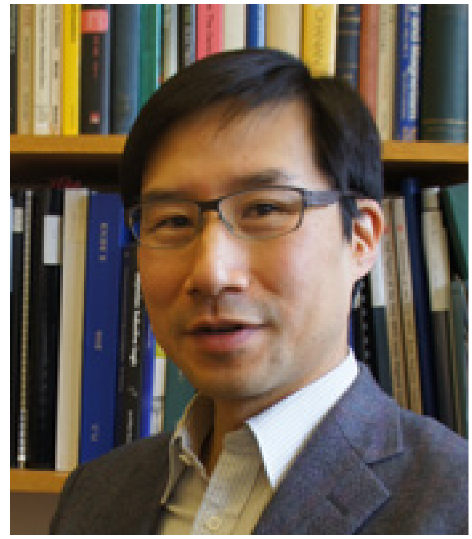
I was extremely honored and pleased to deliver the Abraham Pais Prize Lecture at the APS March Meeting (online) on 18 March 2021. There have been a great number of highly respected historians of physics in our time, and there is injustice in my receiving the Pais Prize before many of them. But I believe that my work is at least distinctive and unusual, and in the lecture I tried to convey the spirit and purpose of my research.

My historical work is strongly and explicitly motivated by philosophical concerns, focused on the question of how we know what we know. And I like to dig into the justification of the most basic items of scientific knowledge that we all take for granted and rely on. My first two books were on the question of how physicists and chemists learned to make thermometers (*Inventing Temperature*, 2004), and how they learned the basic atomic–molecular composition of matter (Is Water H_2O?, 2012). For example, it took chemists about half a century to agree on the H_2O formula for water, starting with Dalton's view that it must be HO since that was the simplest possibility. Avogadro's original proposal of the H_2O formula was sensibly inspired by the observed 2:1 gas-volume ratio in the combination of hydrogen and oxygen gases, but making the whole story coherent required Avogadro's hypothesis (equal number of molecules in equal volumes of all gases), and the assumption that hydrogen and oxygen gases consisted in diatomic molecules H_2 and O_2. These assumptions were rejected as *ad hoc* and physically unfounded. (Why would two oxygen or hydrogen atoms stick together, and if two of them will, why not more?) The eventual agreement on molecular formulas came only around 1860, through the establishment of the idea of valency after a great deal of work in organic chemistry.

Through learning this kind of history we learn why we have come to believe what we now take as basic truths in science, and what the points of contention were along the way. With the critical awareness gained in such a learning process, the quality of our knowledge is enhanced. It is also helpful to look at the history with full respect for the past scientists, and recognize that the scientific common sense of today was once the subject of controversy and exciting cutting-edge research. Going back to early periods of science with this kind of historical perspective can also help us regain a sense of fascination in the familiar aspects of nature. Making the science of everyday phenomena come alive can help us instill a love of science in students and the general public.

Another key feature of my historical work is giving attention to past scientific knowledge that scientists themselves tend to disregard as misguided or not worth remembering. In the discarded past of science we can often find something valuable. The history of science presented in science textbooks tends to be a picture of past heroes who anticipated modern knowledge, such as Galileo, Newton, Maxwell and Einstein. That has its purpose, but as a professional historian I make it my job to pay more attention to the "losers" of past science. Through such historical work we can recover forgotten ideas and phenomena. A further examination of such recovered knowledge can even lead to new scientific knowledge.

A memorable case of such recovery of neglected knowledge occurred in the course of my work on the history of temperature and thermometers. I was asking myself how people knew how to make thermometers, without having the kind of knowledge of thermal physics that they could have only got by already having thermometers they could trust. For example, how did they know that the "fixed points" of thermometers were actually fixed in temperature? I quickly learned that there had actually been plenty of doubts and disputes about the various proposed fixed points, the most famous of which was the boiling point of water. I read many reports of strange and hard-to-believe variations in the boiling temperature of pure (distilled) water under standard pressure. For example,



Hasok Chang

Gay-Lussac reported in 1812 that water boiled at exactly 100°C in a metallic vessel, but at around 101.2°C in a glass vessel. Biot repeated this claim in his textbook of physics.

I *had* to check this out. And I was easily able to confirm Gay-Lussac's result, in about 20 minutes. But such a thing was never mentioned in all the physics I studied at Caltech as an undergraduate! Later I learned that there are boiling experts in engineering departments who know all about such things, but it is not general knowledge among physicists and chemists. Returning to the history: Gay-Lussac was in fact reporting nothing new. For example, De Luc had made elaborate investigations on the boiling of water 40 years earlier. One key discovery he made was that the amount of dissolved gases was a crucial variable in determining the boiling temperature and behavior of water. He made highly de-gassed water, which did not bubble up at all until it reached 112°C, and then exploded. Less dramatically, boiling water in a thin-necked flask with slow heating produces very interesting results; the process of boiling itself promotes degassing, and the small surface area

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time, I was unaware of the formation of the Institute Of Field Physics (IOFP) by Cecile and Bryce DeWitt at the University of North Carolina at Chapel Hill.

However, I soon became aware of the IOFP, when I received call from Bryce DeWitt to discuss his and Cecile's interest in organizing a conference on general relativity in January of 1957 to be held at Chapel Hill under the sponsorship of the Institute. I assured him of Air Force support and requested a formal proposal. The proposal came quickly with a request for $5000 in support of the conference. After a quick review, the Air Force wrote a contract with the University of North Carolina for a conference on general relativity to be held under the auspices of the Institute of Field Physics. In the course of a conversation, Peter Bergmann suggested that the Air Force be asked to transport people from abroad. I received Air Force support for the request and asked Bryce for names of those invited. In my memory, the travel request listed Hermann Bondi and Felix Pirani from Britain; André Lichnerowicz, Yvonne Choquet-Bruhat, and Mme Marie Anntoinette Tonnelat, from France; Nathan Rosen from Israel; and Jules Geheniau from Belgium. Ryoyu Utiyama from Japan and Behram Kursunoglu from Turkey were also present, but I don't remember whether they were among those transported. The Air Force approved transportation for all except Geheniau who was considered too far to the left to be brought to the United States by the Military Air Transport System. Except for Rosen, who did not come for personal reasons, the others did arrive and did participate in the conference.

The conference took place from January 18–23, 1957. Classical and quantum relativity as well as cosmological models were discussed and argued. The issue of gravitational waves (talks by Bondi and Pirani among others) took up much discussion with some remaining skepticism. Andre Lichnerowicz and Yvonne Choquet-Bruhat spoke on the initial value problem. There were long presentations by Peter Bergmann and Bryce DeWitt on the issues and methods of quantizing the Einstein theory. Tommy Gold discussed cosmological models, presented issues of measurement, and Robert Dicke discussed the observational data. The Air Force contract for the meeting required a report. That report could have been quite brief. However, Cecile and Bryce wanted a detailed description of the proceedings. There were recordings of the talks and discussions and individuals were requested to submit their comments as well. The result was the publication by the Air Force of the report *Conference on the Role of Gravitation in Physics* which was rather widely distributed. Cecile DeWitt and Dean Rickles have produced a reprint[2] with an historical preface and an additional remark by Feynman as an end paper.

This was not the end, however. As the conference was coming to an end, at the urging of the younger people, the senior participants, Peter Bergmann, John Wheeler, Hermann Bondi, and André Lichnerowicz had an informal discussion and decided that in the summer of 1959 there would be a follow up meeting in France and subsequent meetings in three year intervals. In time, a formal organization was formed, the International Committee on General Relativity and Gravitation (ICGRG). Roberto Lalli has written a detailed history of its formation and its transition to the ICGRG of today[3]

As we were leaving, Joe Weber told me that he was working on gravitational radiation, but did not say that he was planning to detect gravitational waves.

Two years earlier, in 1955, there was a meeting in Berne, Switzerland to celebrate the 50th anniversary of the 1905 publication of Einstein's paper introducing special relativity. Most of us in the new crop of physicists interested in general relativity were not even informed that the meeting in Berne was taking place and so did not attend although Stan Deser was there with Oscar Klein and Felix Pirani with Hermann Bondi. As a result, the meeting in Chapel Hill was the first time we younger colleagues had a chance to get together with the established physicists and mathematicians who had published work in the field. We were particularly grateful to Cecile and Bryce for organizing this meeting.

The end of the Chapel Hill Conference did not end US Air Force support of the subsequent meetings. Military Air Transport System support was available for US scientists to attend the meetings in France, Poland, and Britain. Travel to Poland was supported only as far as Paris, France, but not to Warsaw, Poland. In 1968, the Air Force refused to grant support for the GRG meeting in the Soviet Union and there was no further travel support for meetings through ARL as far as I know.

For the next year and a half, I mostly worked alone on research as well as monitoring contracts. In the course of time, the Air Force supported Peter Bergmann at Syracuse, Hermann Bondi at King's College London, Ted Newman and Allen Janis at Pittsburgh, Nathan Rosen at the Technion in Israel, Pascual Jordan in Hamburg, Oscar Klein in Stockholm, Peter Havas at Temple, and many others.

In the summer of 1957, I was able to arrange a two month appointment for Ted Newman who had just completed a year at the University of Pittsburgh. During this time we worked on the measurement of distance in cosmology. For this, we used the geodesic deviation of light. I attribute this work to Ted's continuing interest in the properties and applications of null rays.

The following year, 1958, I went to Europe to visit the Air Force office in Brussels and was able to visit with Jules Geheniau as well as Pascual Jordan in Hamburg and Andre Lichnerowicz in Paris. I apologized to Geheniau for not being able to bring him to the Chapel Hill Conference. He was very gracious, he gave me a copy of the report of the Berne conference, and invited me to come to a three day meeting in Brussels prior to the Royaumont meeting in 1959. Ted and I were able to present our work on the measurement of distance at this meeting.

The Air Force also allowed me to attend a workshop on quantum gravity in Neuchatel, Switzerland. The principal discussants were Richard Arnowitt, Stanley Deser, and Charles Misner with their then idiosyncratic approach and

Bergmann and Komar with what one could call a more conventional approach to quantum gravity. No middle ground was found, but field theorists preferred ADM to BK. Wolfgang Pauli, who was present for a couple of days, spoke briefly and suggested that the attempts at quantization were not crazy enough. Perhaps that is still true.

In the summer of 1958, while I was away, Max Scherberg had taken the privilege of hiring a student of Vaclav H'lavaty, Joseph Schell, who had just received his PhD. The Petrov classification of the conformal tensor was still relatively new. Joe made a classification using the infinitesimal holonomy group that is a refinement of the Petrov classification. This has not found much use as it is much too refined and therefore not easily applicable. In this time, Roy Kerr joined me and we found solutions using the end of the classification which is similar to the null case of the Petrov classification.

In the fall of 1960, the Air Force granted me a 16 month leave so I could go to King's College on an NSF Senior Post Doctoral Fellowship and could visit various institutions and summer schools during the summer months. At King's, I worked with Ray Sachs to prove that algebraically special spacetimes contain shear-free geodesic null congruences. I also constructed conservation laws based on the identities of the Riemann tensor using properties of the asymptotically flat spacetime. During the summer, I was able to visit Lichnerowicz in Paris and Jordan's group in Hamburg. In addition, I attended a summer school at Lake Como that was organized by Christian Moller who then invited Peter Havas and me to spend a month in Copenhagen. In the fall of '61, I returned to London to write up the paper on conservation laws which was sent to John Synge in Ireland as the referee.

While I was away, Roy was left in charge. Joe Schell left for a teaching position in Florida and Roy brought in Stuart Fickler who had worked with Dick Arnowitt on quantizing the Yang-Mills field. When I returned in January 1962, Roy and I demonstrated that the Maxwell field of an accelerating electric charge had the asymptotic behavior that exhibited the fall off of the algebraically special field. This was to exhibit a simple example of the Petrov classification for Synge who had not followed that development.

In the fall of '62, Roy left for a year with Alfred Schild in Austin. During that year, he wrote his paper on the rotating mass (rotating black hole). He listed both the University of Texas and ARL as his home. At some time in the following year, I suggested that ARL develop a program with temporary post-doctoral positions. This was discussed in conjunction with other laboratories at Wright Paterson Air Force Base and then went up the chain of command and was approved. The National Academy of Science was to select the candidates who applied. However, that program did not get under way until after I left for Syracuse and Roy left for Austin, Texas. Recently, I wrote to the NAS to inquire whether the program still exists and received the following reply from H. Ray Gamble, PhD, Director, Fellowships Office:

> *"The AFRL postdoctoral program, as administered by the NAS, began in 1965, with the first Research Associate beginning their tenure in March of 1966. Since then, we have awarded a total of 1212 fellowships at AFRL locations. This program has operated under the umbrella of the NRC Research Associateship Programs, which are funded, currently, by 23 federal sponsors and fund over 500 Research Associates each year. Among these, about 80 are at AFRL locations. More recently, AFRL has requested we rename the program to the AFRL Science and Technology Fellowship Program, although we still operate under the same processes. The web pages for these program can be found here: http://sites.nationalacademies.org/PGA/RAP/index.htm, http://sites.nationalacademies.org/PGA/Fellowships/AFRL/index.htm."*

Note that the program began in 1965, two years after I left ARL and involves all Air Force Research Laboratories.

In the spring of 1963, I was offered a position at Syracuse University and, as a result, Roy accepted a position in Austin with Alfred Schild. In the fall of 1963, Stu Fickler was left in charge and in 1965 he added Lou Tamburino, Jeff Winicour, as Air Force employees and, in 1967 Moshe Carmeli. I think it is worth quoting Jeff:

"It was Camelot as far as research atmosphere went…My only non-research duty was to monitor a few external grants and to evaluate occasional proposals, most of which were for things like perpetual motion machines. Money for travel and postdocs was abundant." Beginning in 1966, Richard Isaacson, David Robinson, Ed Glass, Lou Derry, Mike Russo, and others whose names I don't have were postdocs for two year periods.

At the end of two years, Isaacson went to IIT in Chicago and then to NSF as Director of the Gravity program where he vigorously supported the LIGO program. Robinson went to King's College London where he worked with Pirani – Bondi having left for the European Space Agency. Glass went to Windsor University in Canada and for 25 years was an Associate Editor of the Canadian Journal of Physics. I have not been able to find references to Derry and Russo.

ARL did support another Conference on General Relativity. It was organized by Louis Witten at the University of Cincinnati and Stuart Fickler and Moshe Carmeli from ARL. It took place at the University of Cincinnati in July, 1969. The two things I remember about that conference were the incredibly beautiful lectures by Bob Geroch on singularities in the gravitational field and the surprising lecture by Joe Weber in which he announced the observation of Gravitational Radiation which was foreshadowed by his comment to me at the end of the Chapel Hill Conference. Joe's announcement opened up a scramble to verify his results and ultimately led to LIGO. For some reason the associated report was not an ARL report although Moshe Carmeli from ARL wrote the introduction and the three organizers are listed as editors. With regard to the organization of the conference, Moshe wrote:

> "The Relativity Conference in the Midwest was held in Cincinnati from June 2–6, 1969 and was sponsored jointly by the Aerospace Research Laboratories and the University of Cincinnati. During 1969, the Aerospace Research Laboratories celebrated the twentieth year of its existence and the University of Cincinnati celebrated its sesquicentennial year. Because of the extended interests of the Aerospace Research

Laboratories in the Theory of Relativity and the recent arrival at the University of Cincinnati of one of the conference organizers, it was felt that sponsoring a National Conference on Relativity designed primarily for participation by American scientists would represent a worthwhile contribution to the joint celebrations."

Among the most important things to come out of ARL are the publications of the reports that resulted from the research supported. These were widely distributed in gray covers and were freely available from the Armed Services Technical Information Agency (ASTIA). The largest report, 459 pages, came from the Bondi group in London. It covered the period from 1961-64. It contains the work of people who were at King's College London, who were visitors, or were passing through.

The gravitational program at ARL came to an end in 1972 due to an amendment to the bill that greatly increased the budget of the National Science Foundation. Senator Michael Mansfield added the amendment to the bill that required in-house research in science by the military to have specific relevance to its mission. At the time, general relativity was not considered relevant to the military. Not long later, GPS systems appeared and the military versions made use of GR. Perhaps some of the technology developed through gravitational astronomy will find application as well. And future space exploration will make use of GR as well. However, for many of us, the increase in our understanding of the universe is our reward for engaging in gravitational research.

When the gravitational program ended at ARL, Jeff Winicour went to Pittsburgh and Moshe Carmeli went to Beer Sheva University in Israel. Stuart Fickler and Lou Tamburino remained at the Wright Patterson Air Force Base, but at different laboratories. Unfortunately, Moshe, Stu, and Lou have died and could not contribute information about the last ten years of the existence of the program.

It has been a great pleasure for me to relive my connection with the Aerospace Research Laboratory. I benefited from comments about ARL not only from Jeff Winicour, but also from David Robinson for information about postdocs and both for critical remarks of a draft. Sadly, in the absence of the Mansfield amendment, the program at ARL could have existed happily alongside the NSF and other support programs. The end of this program was a loss to the Air Force of a particular skill as well as an entry to an important area of research.

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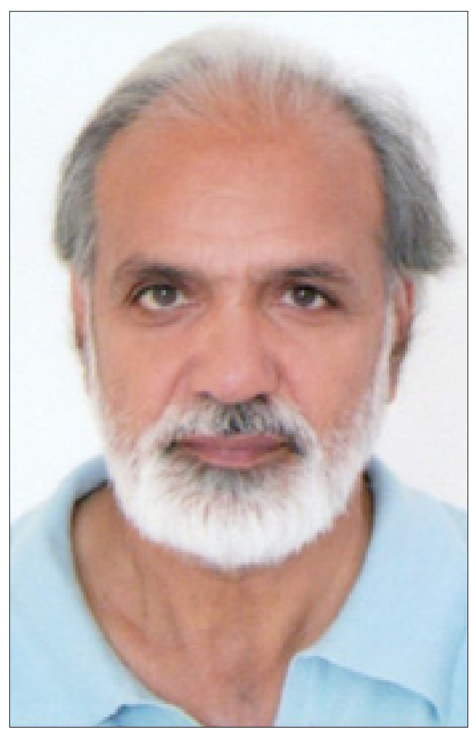
The Indian contribution to the physics of black holes: 2020 Nobel Prize

Continued from page 2

French mathematician Pierre Simon Laplace in 1796. They argued that if an object was very massive and dense, its gravity would be so strong that even light could not escape from it Such an object if it exists would be all dark and invisible, as no light can come from it. This follows from the very simple back of the envelope calculation in the Newtonian gravity. The escape velocity is given by equality of kinetic and potential energy of the escaping particle, $mv^2/2 = GmM/R$ giving $v^2 = 2GM/R$ in the usual notation. When it equals the velocity of light, then light will not be able to escape out. The radius of such an object would be, $R = 2GM/c^2$, which would trap all the light and turn absolutely black—a black hole. Just to set the scale, the escape velocity for Earth is 11 km/sec while the velocity of light is incredible 300,000 km/sec. If the Sun has to become a black hole, its entire mass has to be squeezed into as small a radius as 1.5 km.

Chandrasekhar mass limit

The modern story begins with Subrahmanya Chandrasekhar who, after finishing his B.Sc. in Madras in 1930, left for Cambridge, England for higher studies. On his voyage to Cambridge he did interesting calculations on white dwarfs. It was believed then that all stars would end their life by becoming a white dwarf—a final abode. This is a very enigmatic object which supports itself against the force of gravity because of the pressure exerted by electrons. In his mathematical investigation of such objects, the young Chandrasekhar combined Einstein's theory of special relativity and the then new theory of quantum mechanics. He made the startling discovery in 1931 that there is a maximum mass which a white dwarf can have. This is about 1.4 times the mass of our Sun. A white dwarf with mass greater than this value, now called the Chandrasekhar mass



Naresh Dadhich

limit, must necessarily collapse to a smaller size. This was an outstanding breakthrough discovery which had shattered the quiet, peaceful abode of eternal rest for a star at the end of its evolutionary journey.

Chandrasekhar's mentor and friend, Arthur Eddington from Cambridge, who was the most creative and influential astrophysicist of the day, did not for some strange unfathomable reason accept this brilliant discovery and criticized it strongly. The argument was more rhetoric than objective and rational when Eddington surmised that he believed that there would exist some law of Nature that would prevent this kind of catastrophe to occur. Even so, it does not take away anything from the new light the monumental discovery has shone on evolutionary track of a star. Chandrasekhar, however, had the last laugh when he was at long last awarded the Nobel Prize in 1983 a good half a century after the discovery.

Stars consume nuclear fuel to produce energy that they emit as light and heat. When all nuclear fuel is exhausted, i.e. temperature is no longer high enough for nuclear fusion to continue, the star collapses to a smaller size into a cold state of white dwarf, which is entirely supported against gravity by electron pressure. What Chandrasekhar had calculated was the limit on electron pressure—electron degeneracy, that could counter gravitational pull due to mass of a white dwarf. It turned out that according to the theories of relativity and quantum mechanics, electron pressure cannot sustain any mass greater than 1.4 solar mass. This is how the Chandrasekhar limit was discovered.

When electrons have given way, the next avenue of resistance could then come from neutrons.

Gravitational collapse

What happens when a star cannot end its life as white dwarf because it is too massive for that? It turns out that as a star continues its collapse, it eventually becomes so dense that almost all matter in it is converted into neutrons. These neutrons can likewise exert pressure to counter the gravitational collapse giving rise to a stable configuration, and the object so formed is called a neutron star. Such an object is so dense that just a spoonful of its matter would weigh the same as all of humanity. As mass further increases, like electron, neutron degeneracy could set in—neutron pressure is no longer sufficient to counter balance gravitational pull to retain stable configuration of the neutron star. It turns out that this happens when the star's mass exceeds about 3 solar mass. This limit is not as sharp as the Chandrasekhar limit because we do not understand interior of the neutron star well and definitive enough, in particular its equation of state which is a relation between pressure and density.

If a neutron star is more massive than this limit, it must collapse indefinitely as there is no other kind of pressure available in the present theory to resist it. It collapses right down to zero size and infinitely large density —singularity. Even before the object reaches this singular state, it would pass through a stage $R = 2GM/c^2$, where light gets trapped and cannot escape. The Michell–Laplace black hole would be formed.

Black holes in Einstein's theory

So far we have discussed this phenomenon in the Newtonian gravity. What happens in Einstein's theory of gravitation, where gravitation is beautifully synthesized into spacetime geometry? It is described by curvature of spacetime and hence is no longer an external force but an integral part of the geometry of spacetime.

In a simple intuitive way it could be understood as follows: Einstein's law of gravitation is the Newtonian inverse square law in curved space instead of flat space[3]. This makes a profound impact on our understanding of the phenomenon we are discussing.

Since the velocity of light is universally constant, hence it cannot change under any circumstance. The only way it could be trapped and confined is to make space curved so that it cannot propagate out. This is precisely what happens in general relativity. It is the space curvature that gives rise to the bizarre phenomenon of a black hole. This is a more profound and geometric object than what was conceived by Michell and Laplace.

In 1938, Bishveshwar Datt[4] of Kolkata, India, was to find an exact solution of Einstein's equation of expanding (the solution described an expanding cloud without boundary was therefore cosmological in character, rather than a collapsing cloud) (collapsing)[3] under its own gravity. Unfortunately he died soon after on the operation table, while being operated for hernia. A year later, Robert Oppenheimer and David Snyder[5] obtained the same solution as Datt did, and had also matched the interior solution with the exterior Schwarzschild vacuum solution at the collapsing boundary. It was truly a model of homogeneous gravitational collapse of a star-like object that proceeded uninterrupted down to the singularity, where spacetime curvatures and energy density diverge. It is famously known as the Oppenheimer–Snyder collapse in the literature.

Those were the Second World War years which had made the exchange of scientific information difficult in general, and more so from India. Due to this reason, and the sad and untimely demise of Datt, his contribution remained unsung until 1999, when the Journal of General Relativity and Gravitation[6] reprinted the original paper with an Editorial commentary in its series on 'Golden Oldies'. It would perhaps be appropriate to acknowledge Datt's contribution to the result that laid the foundation for a black hole formation in general relativity by naming it the Oppenheimer–Snyder–Datt (OSD) collapse.

Here one may raise the question whether occurrence of singularity is the artefact of special properties of homogeneity and isotropy on the one hand and spherical symmetry on the other?

Raychaudhuri equation

In 1953, Amal Kumar Raychaudhuri[7], when he was a lecturer in Ashutosh College, Kolkata, obtained a remarkable equation, which bears his name, governing evolution of a system of particles according to Einstein's theory of gravitation. It is the Raychaudhuri equation that establishes in all generality the profound result that the occurrence of a singularity is inevitable in general relativity. It may be noted that the special conditions of homogeneity and isotropy, and of spherical symmetry of the OSD collapse have been lifted-off, and the Raychaudhuri equation makes no reference to any symmetry and nature of matter distribution, except of course positivity of matter energy. It was the key to what was to follow a decade later in terms of the singularity theorems.

In the mid 1960s, Penrose building on the Raychaudhuri equation and employing global analysis techniques of topology and differential geometry made the profound prediction that formation of a black hole with a singularity at its centre is inevitable in Einstein's theory of gravity. In collaboration with Stephen Hawking, he proved powerful theorems establishing the result mathematically and rigorously.

Though the Raychaudhuri equation leads to the conclusion that singularity is inevitable in gravitational collapse in general relativity, what the powerful theorems of Penrose and Hawking have shown is that as collapse proceeds, before singularity is reached, trapped surfaces would be formed from which nothing, including light, could escape out. From this state onwards we can receive no signal from the collapsing object. The surface marking this property is called 'event horizon', indicating complete blockade of all information and signals from external observer of what is happening inside. Thus a black hole is formed. It is this new perspective illuminating formation of the darkest object in the Universe, and its inevitability in Einstein's theory of gravitation, is what has won Penrose the 2020 Nobel Prize in Physics.

It is however worth speculating, had Raychaudhuri had the benefit of strong and sophisticated mathematical backup, could he have perhaps discovered the singularity theorems?

In essence, the theorems explain and demonstrate the process of black hole formation in terms of spacetime geometry. Though the black hole bizarre and exotic, yet it is, according to Chandrasekhar, the simplest object in Nature, because it is a purely geometric construct.

In addition to the work cited in the Nobel Prize, Penrose has several important and path-breaking contributions ranging from extraction of energy from a rotating black hole, to the transition from pre- to post-big bang state of the Universe. He has also worked extensively on the interface between science and philosophy, dwelling on the deep questions of physical reality and consciousness.

The order of profoundness in physics proceeds as follows: At the top is the discovery of a new law of physics. Then come the equations that govern the behaviour of various physical systems, like collapsing stars or the expanding Universe. And finally we have various important, useful and interesting results which follow from the equations. Einstein's theory of gravitation leads to the many profound and extraordinary results on black holes, the big bang and expanding Universe, and so forth. The role of the Raychaudhuri equation is clear in this hierarchy.

In 1966, Fred Hoyle and Jayant Narlikar[8] asked the question how massive a star must be so as to arrest cosmic expansion of surrounding matter to form a galaxy like structure? They found that it must have a mass about billion times the solar mass to form a galaxy of thousand billion solar mass. Thus they argued that the centre of the galaxy should harbour a supermassive star (The term 'black hole' was coined by John Wheeler a year later in 1967, in response to an audience question in a conference in New York, USA). This is purely an astrophysical argument for the existence of a supermassive object at the galactic centre.

Ghez and Genzel, have shared the Prize with Penrose for detecting a supermassive object, which is believed to be a black hole, at the centre of our galaxy. It is interesting that what Hoyle and Narlikar had predicted on astrophysical grounds over half a century ago has actually been observed. It should also be noted that they were the first to suggest that centres of galaxies should harbour supermassive objects—a profound prediction and foresight.

Black holes are the simplest objects as they could be fully characterized by three parameters, viz. mass, rotation and electric charge. Another young Indian graduate student, C. V. Vishveshwara in Maryland, USA, took fancy to this exotic object in 1970 and explored its various properties in a series of papers. The most remarkable and important among them[9,10] was the one that showed how a black hole, which is purely a geometric object, rings like any other object when struck by matter. It rings down before it settles down to its original state. This proves two important properties: one, stability of a black hole under perturbations and second, as and when collision of a black hole occurs with another black hole or star, gravitational waves would be produced and would be observed through the ringdown process.

In 2015, gravitational waves were detected in the LIGO observatory, winning the Nobel Prize in 1917 for Reiner Weiss, Kip Thorne and Barry Barish. The observed ring-down curve had uncanny and remarkable resemblance to the one obtained by Vishveshwara a good 45 years ago in the pre-sophisticated computer era.

In 1985, the Penrose process of energy extraction from a rotating black hole was generalized[11] to include the presence of magnetic fields around the rotating black hole turning it into magnetic Penrose process, by a young graduate student, Sanjay Wagh, a postdoc, Sanjeev Dhurabdhar and Naresh Dadhich, Pune University (now Savitribai Phule Pune University, India). They showed that inclusion of magnetic field made the process highly efficient and hence could serve as powering mechanism for the most luminous objects, quasars in the Universe[12]. It is gratifying that fully relativistic hydrodynamic flow simulations beautifully bear out the prediction made some 30 years ago[13]. It is considered as the most favoured powering mechanism for quasars, active galactic nuclei and ultra high energy cosmic rays[14,15].

Setting the stage

The 1960–70s were highly charged times for great discoveries in relativistic astrophysics and cosmology. Though the solution describing a black hole was obtained immediately after Einstein discovered his equation, yet it was not understood as a black hole until 1960s, a good 45 years later. As mentioned earlier, the term 'black hole' was invented by John Wheeler only in 1967.

Roy Kerr obtained astrophysically the most remarkable and interesting solution of Einstein's equation describing gravitational field around a rotating black hole. On the other hand was the observation of incredibly luminous objects, quasars that give out energy ten orders of magnitude of stellar luminosity.

The crowning glory was of course the momentous discovery of the cosmic microwave background radiation at temperature 3 K, which was the greatest prediction and the distinguishing feature of the big bang theory of the Universe. The Universe had a singular beginning in a hot big bang, and the observed microwave radiation is carrying that message and signature.

The stage was thus set for a great discovery and prediction that formation of a black hole and consequently, the central singularity are inevitable and distinguishing features of Einstein's general relativity.

It is gratifying to note that the two purely general relativity Nobel Prizes, one for detection of gravitational waves in 2017 and the present one for prediction of the formation of a black hole and its detection at the galactic centre, had a strong Indian trail in the seminal works of Datt and Raychaudhuri for the former, and Vishveshwara for the latter.

Acknowledgement

I thank Ajit Kembhavi and Abhay Ashtekar for useful discussions.

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March Session Report: "Farm Hall Revisited"

Continued from page 6

Weizsäcker, used them to demonstrate their apparent innocence on all counts. Dahn's talk explored how a seemingly authoritative text has been used to support such differing perspectives, investigating a phenomenon all too familiar in 2020: how apparently incontrovertible evidence can be spun to support a variety of viewpoints. The meaning and interpretation of the Farm Hall recordings have been contested since their creation in 1945.

Mark Walker is the John Bigelow Professor of History at Union College in Schenectady, NY and along with Christian Forstner is the co-editor of *Biographies in the History of Physics: Actors, Objects, Institutions* (Cham: Springer: 2020), including the chapter by Walker: "A Biography of the German Atomic Bomb." His talk, "Farm Hall: Did Heisenberg Understand How Atomic Bombs Worked?" examines the Nobel laureate, one of the founders of quantum mechanics, and one of the most important scientists in the German research project into nuclear energy and nuclear weapons during World War II. A controversy has raged since the end of this war over Heisenberg's understanding of how an atomic bomb would work, ranging from accusations of incompetence to claims of resistance against Hitler, with several other variants in between. Walker's talk explained what we do and do not know about this, including a suggestion as to what questions we should be asking.

The last talk was given by Dieter Hoffmann, researcher emeritus at the Max Planck Institute for History of Science in Berlin, and editor of the German version of the Farm Hall transcripts, *Operation Epsilon. Die Farm-Hall-Protokolle oder Die Angst der Alliierten vor der deutschen Atombombe* (Berlin: Rowohlt, 1993), which will appear soon in a new second edition. Hoffmann spoke on "Carl Friedrich von Weizsäcker and Farm Hall," discussing the central place of Farm Hall in the life and work of this student, colleague and friend of Werner Heisenberg, leading physicist of the German nuclear project during the Third Reich, and one of the ten German internees in Farm Hall. There Weizsäcker was not only one of the younger generation, but also someone who dominated the discussions, in particular those of political nature. Just after Hiroshima he argued that "the peaceful development of the uranium engine was made in Germany under the Hitler regime, whereas the Americans and the English developed the ghastly weapon of war." The time he spent in Farm Hall also became instrumental for his thinking about the political responsibility of scientists and in particular of physicists during the atomic age. It was no coincidence that he became one of the main initiators of the so called Göttingen declaration of 18 (West)German atomic physicists against the development of nuclear weapons in Germany in 1957, and his work as a pioneer of freedom- and conflict-research, which shaped the last decades of his academic life, was also rooted in the discussions and contemplations of Farm Hall.

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it had been known that all algebraically special solutions of Einstein's vacuum equations possessed shear-free null congruences. The theorem proved the converse.

New discoveries did of course not cease on his return to Syracuse. Disputes on the production and description of gravitational waves persisted. Null geodesics and null surfaces also remained a focus. Much was inspired by Sach's pioneering research in which Petrov types fall off along null rays with varying inverse powers of the radial coordinate. It was natural in this context to adapt the Newman-Penrose formalism to the investigation of the asymptotic behavior of fields, and this led to his most cited work[6]. In 1976 he co-authored an influential paper with Jürgen Ehlers, Havas and Arnold Rosenblum that summarized the inadequacies of all the current gravitational back reaction procedures[7]. Also, his familiarity with Ted Newman's asymptotic H- space and Penrose's twistor program led him to discover a new geometrical approach to Abhay Ashtekar's gravitational field variables. The outcome in 1988 was a new derivation of the Ashtekar constraint algebra and the associated symmetry transformations[8]. Abhay had first joined the relativity group at Syracuse in 1980, assuming a position as Assistant Professor that had been created with an NSF grant that Josh had marshaled through the system while serving as the Physics Department Chair. It was natural, given the long-standing emphasis on the Syracuse group on the canonical quantization of Einstein's theory, that in the late 1980's Josh would turn his attention, with collaborators David Robinson and Chrys Soteriou, to the canonical formalism on null surfaces[9]. Finally, as Abhay has testified[2], Josh produced in 1992 a landmark paper with Jerzy Lewandowski and Cosimo Stornailo dealing with the

D. Salisbury, Joshua Goldberg, and D. Rickles – Syracuse, March, 2011

self-dual gravitational connection that put the loop quantum gravity approach on a firm footing[10].

Josh's role as an administrator of Air Force funding in general relativity is well known and much appreciated. Less well known are his achievements as the Chair of the Syracuse Physics Department where with some internal opposition he managed the installation of new laboratories within the physics building. And I personally thank him for having extended my teaching assistantship appointment beyond the usual six year limit!

He was also, of course, an active presence in weekly seminars and regular work sessions with relativity graduate students, resident post-docs, and frequent visitors. I recall many instances in which he pursued calculations at the relativity group blackboard. His demeanor was always calm, confident, and poised. He radiated a non-pretentious self-confidence and never hesitated to engage if he disagreed. There was never any doubt that he was simply seeking the truth.

We did indeed disagree on an issue that had occupied the Syracuse relativity school since Bergmann's arrival in 1947[11]. Josh believed that an overarching principle was still lacking, and in particular, "anything we find may be in conflict with general covariance and I'm not, and I hope that my friends are not die-hards so that they'll insist that general covariance is an ultimate requirement that they refuse to give up in any case"[12]. History will be the ultimate judge!

Notes and References

[1] Oral History interview of Joshua Goldberg by Dean Rickles and Donald Salisbury, March 21, 2011, https://www.aip.org/history-programs/niels-bohr-library/oral-histories/34461

[2] D. Salisbury, A. Ashtekar, and D. Robinson, "Joshua N. Goldberg" in D. Malafarina and S. Scott, eds., *The Golden Age of Space-time*, (2021)

[3] J. N. Goldberg, "Gravitational radiation", *Phys. Rev.*, **99**, 1873 (1955).

[4] Interview in Columbus, Ohio, April 2018

[5] J. N. Goldberg and R. K. Sachs. "A Theorem on Petrov types", *Acta Physica Polonica*, **22**, 13 (1962); reprinted in *Gen. Rel. Grav.*, **41**, 433 (2009).

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[7] J. Ehlers, A. Rosenblum, J. N. Goldberg and P. Havas, "Comments on gravitational radiation damping and energy loss in binary systems", *Astro. Phys. J.*, **208**, L77 (1976).

[8] J. N. Goldberg, "Triad approach to the Hamiltonian of general relativity", *Phys. Rev. D*, **37**, 2116 (1988).

[9] J. N. Goldberg, D. C. Robinson and C. Soteriou, "Null hypersurfaces and new variables", *Class. Quant. Grav.*, **9**, 1309 (1992).

[10] J. N. Goldberg and J. Lewandowski and C. Stornaiolo, "Degeneracy in loop variables", Comm. Math. Phys., **148**, 377 (1992).

[11] See D. Salisbury, "Toward a quantum theory of gravity: Syracuse 1949-1962", in A. Blum, R. Lalli, and J. Renn, eds., *The Renaissance of General Relativity in Context* (2020).

[12] Interview in Berlin, Germany, December 2015.

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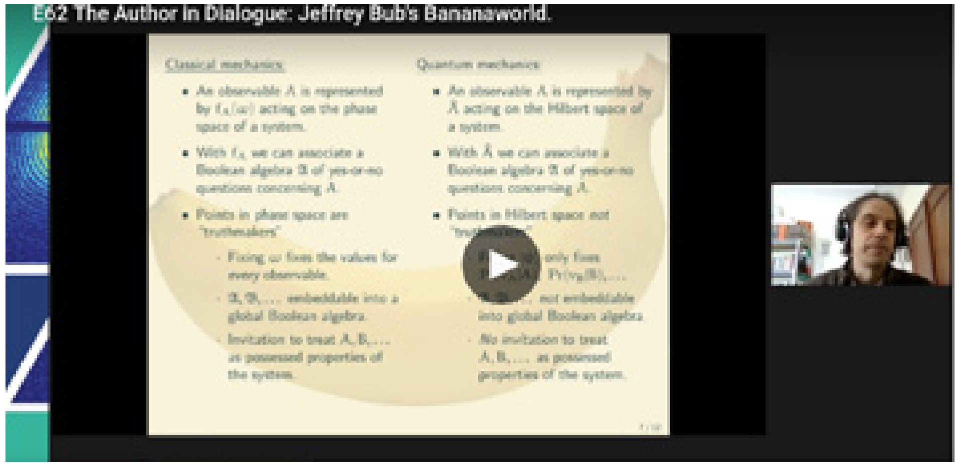
described by a given correlation array, and he discussed the polyhedra that the correlations associated with such raffles describe. He showed how the facets of these polyhedra more and more closely approximate an elliptope as the number of outcomes per variable increases, but do not achieve it except in the limit of the number of outcomes per variable. Janas then turned to quantum mechanics, as applied to banana peeling and tasting experiments, and introduced a formalism for describing banana peeling directions, the angles between them, and their associated (anti-)correlation coefficients. He then presented the Gram matrix describing the correlations between peeling angles, and derived an inequality constraining the values of the anti-correlation coefficients. The inequality describes an elliptope. Janas noted that in quantum mechanics the elliptope is achieved for any number of outcomes per variable (i.e., regardless of the value of spin). Janas then explained that the elliptope inequality is actually a generic constraint (first discovered in the 19th century) on the correlations between three arbitrary random variables. He then discussed how to apply the generic version of the inequality to quantum mechanics, noting that what the general ("from without") derivation and the derivation "from within" quantum mechanics have in common is an appeal to Hilbert space, a Hilbert space of random variables and a Hilbert space of observables, respectively. In the question period Janas was asked by a member of the general audience whether he had considered computing Hausdorf fractal dimensions and using them to clarify physical meaning. Janas answered that that doesn't seem to be applicable here.

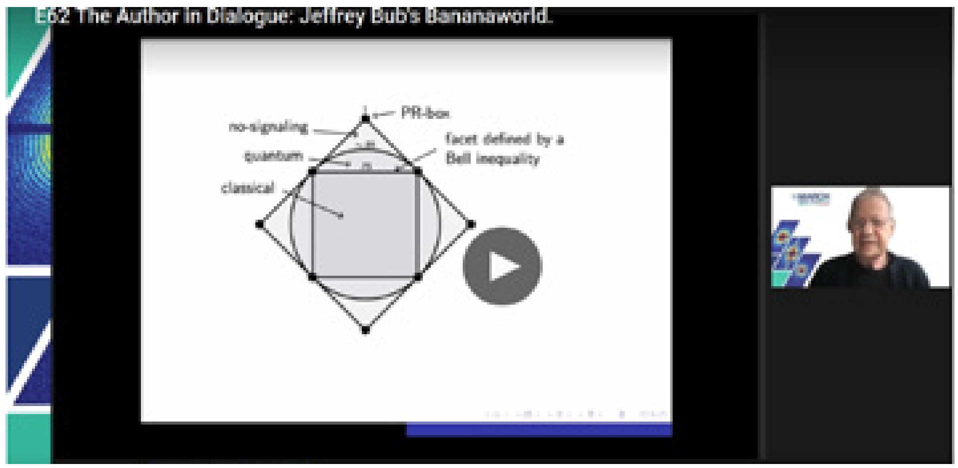
Michael Janas screenshot

In the third talk of the session, Cuffaro began his defence of the information-theoretic interpretation laid out in *Understanding Quantum Raffles* by noting that the reason quantum mechanical systems (unlike local hidden-variable models) in the Mermin setup saturate the elliptope, for any value of spin, is that in quantum mechanics we can assign a value to a sum without assigning values to the summands. He then clarified that the claim: "quantum mechanics is all about information" is properly understood as indicating where the conceptual novelty of the theory is located, i.e., in the kinematical constraints that the theory imposes on every specific system it describes, and illustrated this by comparing classical phase space with Hilbert space. Cuffaro then clarified that what is real, on the information-theoretic interpretation, are the values of observable quantities. This is also true in classical theory, but classical theory's kinematical constraints invite an interpretation of these values as originating in observer-independent properties, while quantum theory's kinematical constraints do not. He then discussed the "big" and the "small" measurement problems (arising from irreducible indeterminism and contextuality, respectively). Cuffaro explained that the labels (originally due to Bub and Itamar Pitowsky) are ironic, and that the "small" problem is the more interesting one as it illuminates the structure of the theory, but ultimately both it and the "big" problem are "not bugs but features". In the question period, Bub noted that the "big" label was indeed meant ironically but noted that "small" has both an ironic (because it is more important) and a non-ironic (because it is tractable) meaning. Bub also noted that the "big" problem is the more important one for the Everettian ("many worlds") interpretation, and that Everettians call the "small" problem the preferred basis problem. Cuffaro welcomed these comments and elaborated further on the relation between the view defended in *Understanding Quantum Raffles* and Everett, noting that Everett seems committed to reifying Hilbert space. Michel Janssen then mentioned historical work by Ofer Gal and Raz Chen-Morris on the conceptual history of optics, and asked for Cuffaro's thoughts on Henderson's discussion of pragmatism. Cuffaro commented that he endorsed appealing to pragmatism as a counter to criticism (in the way Henderson clarified in her response to Bub's question). He also mentioned Kantianism and other alternatives to the "representationalist" view besides pragmatism that could play the same role. Henderson then asked Cuffaro whether privileging values of observable quantities would invite the charge of instrumentalism. Cuffaro noted that values are not simply sense impressions, and that they include both dynamical and fixed quantities. He also denied that values of observable quantities exhaust what we can say about reality, even if they are primary. Bub then added that physics seems to be telling us that indeed we do have to be "a little bit" instrumentalist, and that he doesn't think that instrumentalism is a bad thing, *per se*; i.e., if quantum theory tells us that there are certain constraints on how we can represent reality then we should believe it.

In the final talk of the session, Bub began by describing his initial motivation for writing Bananaworld, namely to highlight entanglement as the core feature of quantum theory that sets it apart from classical theory. But as he continued to develop the book, he found that the geometry of correlations began to emerge more prominently; i.e., the idea that classical correlations can be mathematically described as a subset of quantum correlations, which in turn can be described of as a subset of all possible no-signaling correlations, and so on. Bub's intention in the book was not so much to say but to show that non-classicality ultimately stems from non-commutativity / non-Booleanity, something that can be asserted in a precise mathematical sense. But noted that for George Boole, a Boolean algebra captures what Boole called "the conditions of possible experience," and that the shift from classical to quantum theory amounts to a shift from a Boolean algebra of subsets of a set (phase space) to a non-Boolean algebra of subspaces of a vector space (Hilbert space), where by a "non-Boolean algebra" we mean a family of intertwined Boolean algebras. Bub then noted that John von Neumann once wrote that quantum probabilities are *sui generis*, and "there from the start". Bub endorsed this, defending the view that quantum mechanics is about probability, in the sense of being a new framework for dealing with probability, one in which new sorts of nonlocal correlations associated with entanglement are possible. Bub then mentioned that he regrets attaching the label "information-theoretic" to his interpretation of quantum mechanics. Upon reflection, what he always really meant, and should have said, is that quantum mechanics is about probabilities in the same way that special relativity is about spacetime. Bub then moved on to the topic of visualisability, and mentioned how in a footnote in his 1926 paper on wave mechanics, Erwin Schrödinger wrote that he was "repelled" by matrix mechanics because of its lack of visualisability. He also noted that Heisenberg was "repulsed" with Schrödinger's theory and had a low opinion of his colleague's appeal to visualisability. Bub then asked what visualisability is, and why quantum mechanics is puzzling. He noted that what is puzzling from a Boolean perspective is that measurement in a non-Boolean theory is not passive but produces a change in the description of a phenomenon. Measurement represents a loss of information, a kind of Boolean "snapshot" of an underlying non-Boolean description. (Bub mentioned that Wolfgang Pauli once called observation an "irrational, unique actuality".) Bub then asserted that quantum probabilities do not represent ignorance in the normal sense, but a new sort of ignorance about something that doesn't yet have a truth value, that requires us to act and do something before nature supplies a truth value, and removes the truth values of incompatible propositions not belonging to the same Boolean algebra. Bub mentioned that Schrödinger called the measurement problem the most interesting and difficult part of the theory. He then raised the question, how does what we do when we measure select a basis in Hilbert space? Does this require a kinematical or a dynamical answer, or a combination of both? For Bub the dynamical answer amounts to a consistency proof. In the question period Bub elaborated on the history of *Bananaworld* as well as on the "serious comic about entanglement", *Totally Random*, that he co-authored with his daughter, Tanya Bub. According to Bub, *Bananaworld* was intended as a popular book but in the end the result was somewhere in between a popular book and a scholarly book. *Totally Random* was partly intended to remedy this, and is truly a popular book.



Michael Cuffaro screenshot



Jeffrey Bub screenshot

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attended a lavish lunch in Paris and then a birthday party for twelve-year-old Ruth Turner, daughter of astronomer H.H. Turner. They presented the girl with a box of chocolate bells….One can only imagine the astronomer royal and the comical 'Atky' poring over the candies at some tiny boutique, the Gobron-Briellié parked out front."(41)

Embarking on the 1919 expedition, we see the astronomers grow anxious as their precious instrument crates have yet to arrive at the Liverpool dock as the time for departure aboard the 400-foot steamer *Anslem* draws near. In the field, we see distinguished astronomers commuting between their lodging and the observing site on a locomotive cow catcher. With the observing camp in readiness, while awaiting eclipse day we accompany our heroes on a mountain excursion in a Studebaker provided by the host national government—but after the chauffer's aggressive hard driving overheats the engine and blows out two tires, the astronomers elect to hike back to camp.(213)

As in all great adventures, difficulties and disappointments occur. Under what were initially perfect conditions, we share the discouragement when an eclipse is rained out. While enroute to 1914 eclipse sites, World War I breaks out. Hoping for the best, as the country mobilizes all around us we press on deep into Russia, only to be taken into custody and our instruments confiscated. For the June 1918 eclipse William Campbell of the Lick Observatory is obliged to make do with borrowed equipment as his best instruments languish somewhere on their slow journey back from Russia—then on eclipse eve Campbell learns that his son Douglas, a WW I flying ace, has been shot down, his fate then unknown. Hours after the 1919 eclipse, we appreciate the difficulties of developing fragile, cumbersome photographic glass plates in the field. We sample the expedition's costs to families due to long absences, such as missing a child's birthday party back home far away. We learn the histories of landscapes darkened by the eclipse—including histories darkened in deeper ways such as human enslavement on the cocoa plantations of Príncipe and the rubber plantations of Sobral.

Finally in 1919 the weather, equipment, and eclipse align to yield good images at last. Some plates come out better than others, but the results are consistent with Einstein's predicted deflection and rule out Newton's. Back in London, we see the reactions of participants at the joint meeting of the Royal Society and the Royal Astronomical society where, under a portrait of Newton, the expedition's results are officially announced and discussed. Not all listeners are thrilled—Sir Oliver Lodge, a "committed 'ether man'…rose and left the meeting" —but we cannot help feeling some pity for the grieving Sir Lodge when we learn the reason for his persistent commitment to the ether.(241)

One day while teaching a general-education science class, I found it helpful to borrow a passage from *Proving Einstein Right* to illustrate the distinction between *laws* of nature and *theories*. Illustrating the distinction by metaphor, Gates and Pelletier imagine a "Law of Sunrise"(238), articulating the observed pattern, for which a "Theory of Sunrise" *explains* the Sunrise Law in terms of Earth's spin. *Proving Einstein Right* contains passages that assist pedagogical discussions on philosophy of science, in addition to shining an engaging light on the history of physics and astronomy.

Reader-friendly features include several photographs and a wealth of detailed endnotes that connect the main narrative to interesting sidebar stories. A map of paths of totality for the solar eclipses of 1900-1922 is appreciated. Gates and Pelletier bring this epic tale to closure by relating the 1919 expedition's aftermaths and how the principal actors spent the rest of their days. In *Proving Einstein Right* the reader comes to care about them as human beings. That is a gracious accomplishment for any historical narrative.

As in any large story, besides the principal actors we meet many others whose roles range from family members and government officials to professional colleagues and volunteer assistants. If a second printing is ever considered, I suggest including an annotated list of main and secondary characters, perhaps as an appendix. Such a list appears in Walter Isaacson's recent biography of Albert Einstein, where it is fitting to see Gates included in the acknowledgments.

While reading *Proving Einstein Right*, the reader will have no trouble translating the words on the pages into vivid mental pictures, feeling like he or she tags along on these eclipse expeditions as a companion of Eddington and Dyson, Perrine and Campbell and all the rest, including sharing in Einstein's hopes and troubles as he offers encouragement from Germany. We see from behind the scenes what it took to bring everything together in making possible the proud announcement of 1919. *Proving Einstein Right* offers an illuminating and enjoyable journey—or rather a collection of journeys. Indeed, I immediately read it a second time so I could experience the adventures and intellectual companionships all over again.

March Session Report: Pais Prize

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prevents the re-introduction of air. In such a setup the water produces fewer and larger bubbles as it goes on boiling, its temperature reaching around 104°C. It then continues indefinitely in a quiescent state with occasional explosive large bubbles bringing the temperature down slightly but not down to 100°C. I spent a whole summer boiling water, reproducing De Luc's results from 1772 and devising my own experiments to resolve various follow-up questions, and learning from the modern specialist work as well. The main results from this work are summarized in an online paper with some video clips of experiments (http://www.sites.hps.cam.ac.uk/boiling/).

The kind of historical (and philosophical) work that I have illustrated here can be done about almost any item of scientific knowledge. The subject matter of my work has ranged from early quantum physics and relativity to Count Rumford's "frigorific rays." Currently I am completing a book titled *How Does a Battery Work?*, following the development of electrical science that followed Volta's invention of the battery. I call my brand of research "complementary science": historical and philosophical investigations that address scientific questions neglected in current specialist science. I regard this as one of the functions of the history and philosophy of science. There are clear implications of such work for science education and the public understanding of science. I think it is very important that people have an opportunity to experience the *doing* of science, rather than just learning knowledge created by others. Looking to the history of the most basic items of scientific knowledge gives us a body of manageable science that any interested people can experience and enjoy.

FHPP News

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made distinguished achievements. Prof. Shenghua Hu (deputy editor-in-chief of Science Press and director of the Journal Publishing Center) and Prof. Baichun Zhang (former director of the IHNS-CAS) gave a presentation on "Shoujing Wang and Early Quantum Mechanics Research". Shoujing Wang's work on solving hydrogen molecules was one of the earliest PhD theses on quantum mechanics in the United States.

In addition, associate professor Jinyan Liu from the IHNS-CAS gave a shout introduction of the "Quantum Century (2025)" Project and its forthcoming activities in China, which includes a series of public lecture on quantum science and technology in 2021, an international symposium on the "History of Quantum Mechanics" in 2023, and a symposium on the 70th anniversary of the Yang-Mills gauge theory in 2024. In 2025, the Quantum century, which coincides with the 110th anniversary of the birth of the founding director of the ITP-CAS, Huanwu Peng, a number of academic activities will be held.

World Quantum Day

By Yasser Omar, University of Lisbon

The World Quantum Day is an initiative from quantum scientists from 65+ countries, launched on 14 April 2021 as the countdown towards the first global celebration on 14 April 2022. The World Quantum Day aims at engaging the general public in the understanding and discussion of Quantum Science and Technology, namely how it helps us understand Nature at its most fundamental level, how it helped us develop technologies that are crucial for our life today, and how it can lead to future scientific and technological revolutions and how these can impact our society. It is a decentralized and bottom-up initiative, inviting all quantum scientists, engineers, educators, historians, philosophers, communicators, entrepreneurs, technologists, and their institutions, to organize their own activities, such as outreach talks, lab tours, debates, interviews, etc., to celebrate the World Quantum Day around the World. The World Quantum Day is celebrated on April 14, a reference to 4.14, the rounded first digits of Planck's constant: 4.135667696×10^−15 eV.s.

Even though this year only one symbolic launch event was planned, there was an overwhelming enthusiasm and, despite the short notice, events were organized in Asia, Europe, Africa, South America, and North America, and the World Quantum Day web site had visitors from 120+ countries.

Preparations for the 2022 celebration of the World Quantum Day are now ongoing. Furthermore, the World Quantum Day supports and collaborates closely with the Quantum Century project. Albeit an independent initiative, the World Quantum Day can act as a precursor, as well as a continuator of the Quantum Century celebrations.