Spacetime Theories: Historical and Philosophical Contexts

Jerusalem, January 5-8 2015

Monday January 5, 2015

News from the editorial desk of The Collected Papers of Albert Einstein
Diana Kormos-Buchwald, Einstein Papers Project, Caltech

The story of Einstein's 'popular booklet' and the reception of relativity
Hanoch Gutfreund, The Hebrew University of Jerusalem

After submitting and publishing the final version of his general theory of relativity, Einstein completed the booklet ('buechlein' - as he referred to it) *Relativity: the Special and the General Theory (A Popular Account)* that was published in the spring of 1917. It had a tremendous success and within five years it appeared in fourteen German editions. After the confirmation of the predicted deflection of light by the gravitational field of the sun, it also appeared in about a dozen foreign languages. In the lecture, I shall describe the structure and contents of the booklet, and Einstein's unique method of presentation of his relativity revolution and its relevance to cosmology. I shall also highlight a long appendix, which he added in the 50's, constituting a concise summary of the development of his thinking on the concept of space, which may be perceived as his epistemological legacy. The story of the foreign language editions will be discussed in the context of the debates on relativity in the respective countries that accompanied the process of the reception of Einstein's revolutionary theory.

Einstein's 1913 Vienna Lecture: Modeling Gravitational theory on Electrodynamics.
Jürgen Renn (with Michel Janssen), The Max Planck Institute for the History of Science, Berlin

In his search for gravitational field equations from late 1912 to late 1915, Einstein vacillated between two different strategies. Following a "mathematical strategy," he extracted candidate field equations from the Riemann curvature tensor and checked whether these equations were compatible with energy-momentum conservation and reproduced Newton's theory of gravity in the appropriate limit. Following a "physical strategy," he constructed field equations for the gravitational field in close analogy with those for the electromagnetic field. In his later years, Einstein routinely claimed that he brought his search for gravitational field equations to a successful conclusion in November 1915 by switching to the mathematical strategy at the eleventh hour. Most commentators have accepted this later assessment but Jürgen Renn and I have argued that Einstein achieved his breakthrough of November 1915 by doggedly pursuing the physical strategy. In a lecture that Einstein gave at the annual meeting of the Society for German Scientists and Physicians in Vienna in September 1913, he clearly laid out this physical strategy. As long as one took the older Einstein's word for it that the mathematical strategy was responsible for the success of November 1915, one could quickly pass over the Vienna lecture. But if it was really the physical strategy that was responsible for this success, as Renn and I believe, the Vienna lecture deserves a much more prominent place in the account of the genesis of general relativity than it has been given so far.

A virtuous theorist's theoretical virtues: Einstein on physics vs. math and experience vs. unification

Jeroen van Dongen, University of Amsterdam/Utrecht University

When Albert Einstein formulated the general theory of relativity, he combined a physical and mathematical approach, as Renn *c.s.* have shown. He retained and explicitly referred to these categories also in his later work in unified field theory, but emphasized their usefulness differently, just as his later recollections of how he found general relativity gradually changed. These altered recollections were not only the consequence of his new, highly mathematical unification program, but also served as an advertisement for that program: Einstein enlisted idealizations of his self as justification for his highly controversial work.

Geometry, experience, and general relativity: On the ineffective reasonableness of mathematics

Robert DiSalle, University of Western Ontario

The relation between geometry and experience was the subject of some of Einstein's explicit philosophical reflections, in particular on the relation between abstract axiomatic structures and empirical measurement; it was also, according to Einstein, at the core of the motivating arguments for the general theory of relativity. These arguments were largely epistemological, and they included not only the familiar arguments about generalizing the relativity of motion, but also the more complicated argument about the empirical content of space-time geometry. On this matter, Einstein's views, broadly speaking, reflected the influence and insight of Poincare and Hilbert regarding the empirical interpretation of formal structures. More specifically, however, Einstein offered a reductive analysis of the empirical foundation of geometry, that is, the argument reducing geometrical measurements to observations of "point-coincidences". This reductive argument, whatever its intrinsic merit, does not account for the empirical character of general relativity—it does not account for the way in which the theory determines its characteristic theoretical magnitudes, such as the curvature of space-time. Thus the argument ultimately obscured the empirical significance of general relativity as a novel theory of space-time structure, and the nature of the evidentiary basis for this dramatic conceptual shift. I outline an alternative account of how general relativity connects with spatial and temporal measurement, by extending Poincaré's analysis of spatial measurement, and of the empirical character of non-Euclidean geometry, to the analysis of curved space-time. This account suggests, more generally, an account of scientific representation, and of the "coordination" between empirical descriptions and mathematical structures, that avoids the characteristic difficulties of standard recent approaches. By clarifying the effectiveness of geometrical structures in representing experience, this account also offers a clearer understanding of the ways in which the application of such a structure can fail, and thus prepare the way for a new theoretical framework.

Einstein, Cartan, Weyl, Jordan: The neighborhood of General Relativity in the space of spacetime theories

Dennis Lehmkuhl, IZWT, University of Wuppertal, and Einstein Papers Project, Caltech

Recent years have seen a renewed interest in Newton-Cartan theory (NCT), i.e. Newtonian gravitation theory reformulated in the language of differential geometry. The comparison of this theory with the general theory of relativity (GR) has been particularly interesting, among other reasons, because it allows us to ask how `special' GR really is, as compared to other theories of gravity. Indeed, the literature so far has focused on the similarities between the two theories, for example on the fact that both theories describe gravity in terms of curvature, and the paths of free particles as geodesics. However, the question of how `special' GR is can only be properly answered if we highlight differences as much as similarities, and there are plenty of differences between NCT and GR. Furthermore, I will argue that it is not enough to compare GR to simpler theories like NCT, we also have to compare it to more complicated theories; more complicated in terms of geometrical structure and gravitational degrees of freedom. While NCT is the most natural degenerative limit of GR, gravitational theory defined on a Weyl geometry (to be distinguished from a unified field theory based on Weyl geometry) and gravitational scalar-tensor theories (like Jordan-Brans-Dicke theory) are two of the most natural generalisations of GR. Thus, in this talk I will compare Newton-Cartan, GR, Weyl and Jordan-Brans-Dicke theory, to see how special GR really is as compared to its immediate neighborhood in the `space of spacetime theories'.

Peter G. Bergmann (1915 – 2002): A world point who will never fade

Donald Salisbury, Austin College Texas and the Max Planck Institute for the History of Science, Berlin

In celebration of Peter Bergmann's one hundredth birthday I will review insights on the geometry of spacetime that he attained in his pioneering effort to reconcile the underlying symmetry of general relativity with the technical and conceptual framework of quantum mechanics. But his impact on the development of relativity physics in the latter half of the twentieth century extends well beyond this theme. He oversaw theses of numerous distinguished relativists. His incisive intellect, infectious modesty, and personal warmth fostered an environment in which Syracuse emerged in the 50's and 60's as a relativity mecca. I will discuss some of the ideas that were spawned and cultivated within this globally connected community, and I will conclude with an account of Bergmann's instrumental role in the formation of the international General Relativity and Gravitation Society.

Tuesday January 6, 2015

Building the Relativity Community in Post-World War II Era: The Role of Communication Channels and Stabilization Processes in the Renaissance of General Relativity

Roberto Lalli, The Max Planck Institute for the History of Science, Berlin

The period lasting from the mid-1950s to the early 1970s experienced an explosive renewal of interest in general relativity after the theory had been considered little more than a mathematical curiosity in the previous three decades. One of the main outcomes of this process christened "renaissance of General Relativity" was the construction of a community of physicists with common goals and research agendas, which was later labeled "relativity community." By focusing on communication channels, publication strategies, and attempts to stabilize the consensus around the principal facts and tenets of general relativity, the present paper explores the dynamical process that led physicists belonging to different theoretical schools to cooperate in order to establish a social group, which was able to found its own international society as well as to launch its own journal in 1971.

The Schism - The Origins of Canonical and Covariant Quantum Gravity

Alexander Blum, The Max Planck Institute for the History of Science, Berlin

The split between covariant and canonical approaches to quantum gravity is today well established and manifests itself in the contemporary divide between the two main approaches, string theory and loop quantum gravity. I trace the origin of this divide to two attempts in the 1930s to go beyond the equal-time commutators, which were the standard quantization technique in the quantum electrodynamics of the day: On the one hand, the covariant commutation relations of Pauli Dirac's interaction representation, developed in 1932. On the other hand, the generalized commutation relations on space-like surfaces, developed by Paul Weiss in the years 1936-1938. I will further outline, how the former were adopted by the quantum community, because the split between kinematics and dynamics that they implied became conceptually important in renormalization theory, while the latter were adopted by the general relativity community, precisely because they allowed to avoid this split.

Institute of Field Physics, Inc: Private Patronage and the Renaissance of Gravitational Physics

Dean Rickles, Sydney University

The Institute of Field Physics was established at the University of North Carolina, Chapel Hill, in 1955, primarily to study gravitational physics. It was, in no small way, behind the shift from what Jean Eisenstaedt has labeled "the low water mark of general relativity" (1925-1955) to what Clifford Will has labelled "the renaissance of general relativity". The Institute of Field Physics was the brainchild of Agnew Bahnson (closely guided by John Wheeler), a wealthy industrialist with a love physics (and physicists). It followed closely behind another such venture, the Gravity Research Foundation, established and underwritten by Roger Babson, again a wealthy businessman with a taste for physics (primarily all things Newtonian). Though seemingly unlikely, together these two businessmen transformed the research landscape of gravitational physics. In this talk I describe the evolution of gravity research (primarily *quantum* gravity) as driven by these and other forces, from 1947-1957. In so doing I aim to fill in what I take to be incompletenesses in other discussions of this important transition in the status of general relativity."

The Construction of the Asymptotic Structure of Spacetime.

Daniel Kennefick, University of Arkansas and the Einstein Papers Project, Caltech

During the 1950's debates over the existence of gravitational waves in General Relativity led to efforts to describe the structure of infinity, that is of the distant reaches of spacetime, to which radiation travels from a source. This paper examines the role played by such discoveries as the Petrov classification of spacetime, the peeling theorem and the compactification of spacetime in the emergence of a sophisticated theory of spacetime, which led to an understanding that it contained a number of different infinities.

Time and Law in a Cosmological Context

Lee Smolin, Perimeter Institute (Video)

Can Physics End Time?
Yuval Dolev, Bar-Ilan University

The block universe is in vogue, and its circle of devotees is growing. At the same time, new voices that call into question the removal of tense and passage from our scientific picture of the world are also emerging. I wish to critically assess both the arguments for and the arguments against the reality of tense and passage, as they appear in relation to physics. I will argue that at present neither holds. Tense and passage do not enter the scientific discourse at all, and so cannot be either defended or refuted scientifically. They are, however, presupposed by scientific praxis and experimentation. I will demonstrate this in the context of special relativity, focusing in particular on the notion of a global present.

Macroscopoic and Microscopic Arrows of Time
Meir Hemmo, Haifa University and
Orly Shenker, the Hebrew University of Jerusalem

Wednesday January 7, 2015

Morning session: TBA

Einstein Meets Hilbert on the Way to General Relativity: Who Arrives First?
Leo Corry, Tel Aviv University

On November 25, 1915, Albert Einstein presented to the Berlin Academy of Sciences the explicit, complete and correct, generally-covariant field equations of gravitation, lying at the heart of his General Theory of Relativity. This was the fourth consecutive week in which he presented, at the weekly meetings of the Academy, what he believed to be the culmination of many years of intense efforts to generalize his principle of relativity so as to cover cases of relatively moving reference systems more general than the inertial ones, and so as to apply to gravitation.

Five days earlier, on November 20, David Hilbert presented in Göttingen his own version of the equations that, in the published version that appeared in print several months later, contained the correct and explicit equations of the theory. According to a view that was commonly accepted for many years, Hilbert had anticipated Einstein in five days in correctly formulating this important part of the latter's work. Recent historical research, however, has shown that this was not really the case.

As this interesting episode involves two of the foremost scientists and one of the most momentous developments of the beginning of the twentieth century, it has aroused much interest and debate among historians of science as well as in broader circles.

Still, despite the intrinsic curiosity that it arises, priority disputes ("Who arrived first?") are not the kind of foremost questions that attract the interest and research efforts of historians of science. This is also the case in the story of Hilbert and Einstein.

The main point of historical interest in the story concerns the first half of the title of this talk: "Einstein meets Hilbert on the Way to General Relativity". Here we have these two prominent scientists working out their long-term research programs, each one with his specific aims in mind, working within different disciplines, using different methodologies, and based on different bodies of knowledge as their respective backgrounds. Their scientific and personal encounter raises important and difficult historical questions: What was the essence of their research programs? Where was each of them heading with their work? How did their programs meet and what kind of interaction ensued? How this influenced each of them and their programs? Where did the meeting ultimate lead to?
My talk will address all of these questions and will attempt to provide some of the answers that recent research has brought to light.

The Renaissance of General Relativity - A New Reading
Jürgen Renn (with Alexander Blum), The Max Planck Institute, Berlin

The paper will deal with the renewal of General Relativity after overcoming the "low-watermark period" (Eisenstaedt) of the theory in the early sixties. It is usually assumed that this period was mainly overcome in consequence of the new astronomical discoveries. This leaves it however open which were the intellectual and technical resources that enabled physicists and mathematicians at the time to develop new solutions and techniques, such as the Kerr solution or Kruskal coordinates, that helped to explain the newly discovered astrophysical discoveries but also to understand the topological structure and interpretation of the theory. We will outline a complementary explanation, where these resources are viewed as coming from a cohort of mathematically-minded relativists, who abandoned the more ambitious attempts of going beyond general relativity that their teachers had pursued (such as the quantization of gravity), and instead set themselves to unearth the untapped potential of general relativity itself.

Thursday January 8, 2015

Geometrodynamics: the Nonlinear Dynamics of Curved Spacetime
Kip Thorne, Caltech

I will describe, from a physicist's perspective, the history of efforts to understand how spacetime curvature behaves when it is highly dynamical and strongly nonlinear. My focus will be on the quest for physical insight, and it will cover the era from the 1930s to today. The principal arenas for geometrodynamics that I will discuss include gravitational collapse to form black holes and naked singularities, the dynamics of curved spacetime near generic singularities, and collisions of spinning black holes. I will describe the discovery and elucidation of structures made from curved spacetime (tidal tendexes and frame-drag vortexes), chaotic behaviors in curved spacetime, and phase-transition-like phenomena. And I will present a vision – a hope – that gravitational wave observations and numerical relativity simulations together will transform this subfield of relativity into one with rich interactions between observation and theory.

Quantum Spacetime
Carlo Rovelli, Aix-Marseille University

I review the recent progress in understanding the quantum structure of space and time, and the efforts towards confirming these ideas empirically.

A Philosophical Tour of de Sitter Spacetime
Gordon Belot, University of Michigan

De Sitter spacetime is among the most elegant and natural of relativistic spacetimes and was one of the first to be investigated by physicists. After a hundred years of thinking about relativity, it is time for philosophers to get better acquainted with it. Some scenic vistas we will take in: de Sitter spacetime and its near relatives; time and energy in de Sitter spacetime; asymptotic boundary conditions and the birth of de Sitter spacetime; asymptotically de Sitter spacetimes and the fate of our universe.

Retrocausality as an axiom

Daniel Rohrlich Ben-Gurion University of the Negev

Einstein derived the kinematics of spacetime from two simple axioms of clear physical content: the speed of light is a constant *c*; and physical law holds in all inertial reference frames. Aharonov and Shimony, independently, suggested an analogous derivation of quantum mechanics from the two axioms of *causality* (no superluminal signaling) and *nonlocality* (nonlocal equations of motion or nonlocal correlations). But an axiom of nonlocality, even if simple and of clear physical content, is not at all natural. Let us replace the axiom of nonlocality with an axiom of retrocausality, and ask, with Price, whether Einstein would have accepted retrocausality as a basis for quantum mechanics.

Spacetime and Nonlocality: Revisiting the Epistemic Interpretation of QM

Yemima Ben-Menahem, The Hebrew University of Jerusalem

According to a number of current interpretations of QM, the quantum correlations supposedly manifesting nonlocality can be derived from purely probabilistic and information-theoretic constraints. It is further claimed that as such, they do not constitute a spacetime phenomenon and have nothing to do with no-signaling or any other spatial-temporal constraint. I will compare these recent epistemic interpretations of QM with earlier epistemic interpretations and question the cogency of their understanding of non-locality.

Can There Be a New Metaphysics of Spacetime?

Gabriel Motzkin, The Jerusalem van Leer Institute