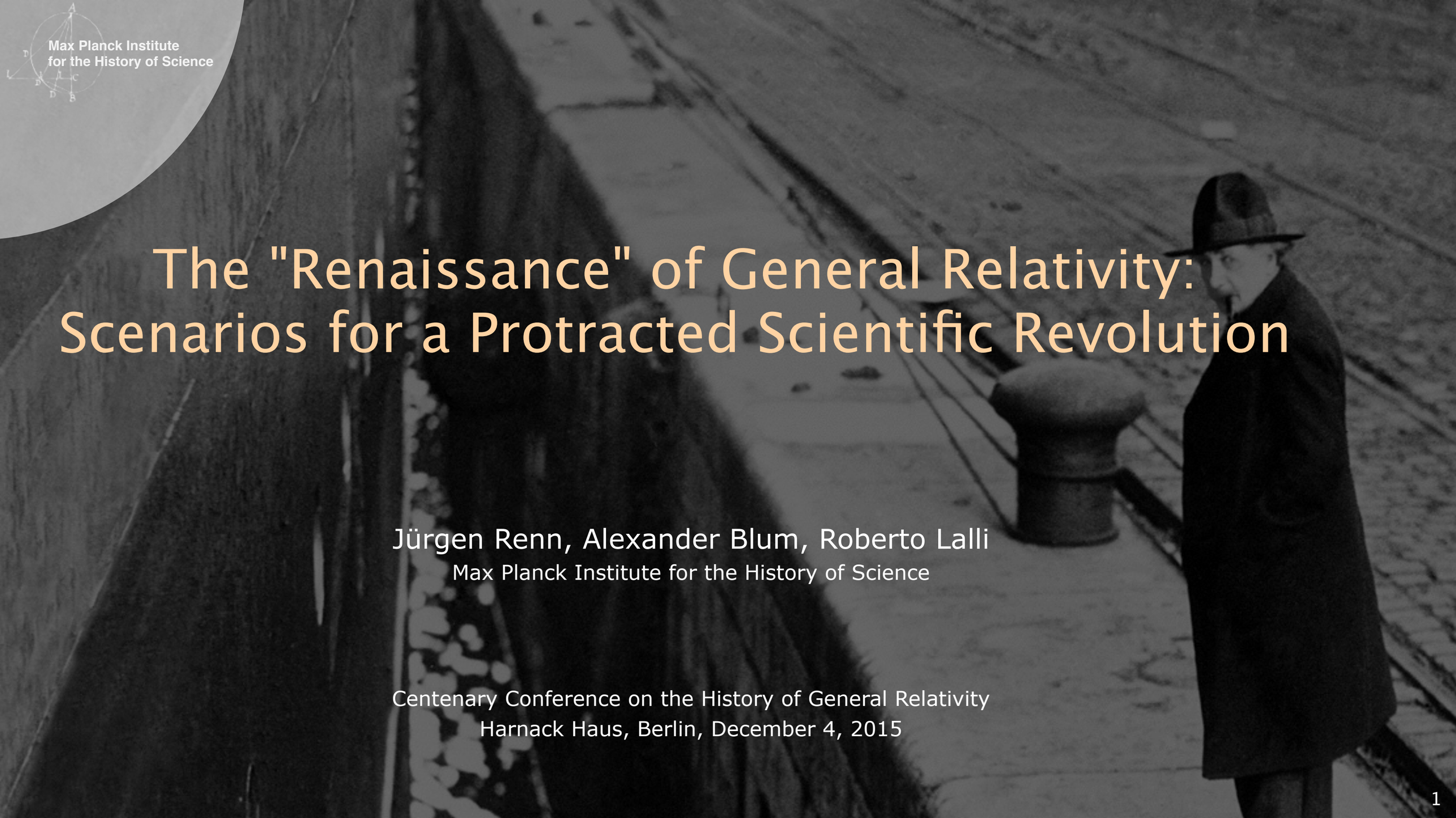
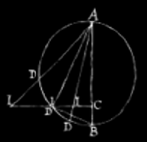


Max Planck Institute
for the History of Science

The "Renaissance" of General Relativity: Scenarios for a Protracted Scientific Revolution

Jürgen Renn, Alexander Blum, Roberto Lalli
Max Planck Institute for the History of Science

Centenary Conference on the History of General Relativity
Harnack Haus, Berlin, December 4, 2015



Epistemic and Social Factors in the Renaissance

- The recognition of the untapped potential of GR, together with
- an explicit effort at community building

allowed this formerly disparate and dispersed field to benefit from the postwar changes in the scientific landscape.

Low-Water-Mark Period

- Non-existence of a GR domain
  - "Neo-newtonian interpretation"
  - The model role of electromagnetism persisted
- Non-existence of a community
  - The interaction between astronomers, physicists and mathematicians remained limited
  - No community structures or building efforts
- Attempts to modify and replace GR with more encompassing theories
  - GR continued to meet with competitor theories
  - The attraction of the mathematical strategy persisted

John Lighton Synge: Les Houches, 1963

"...in those fifty years the progress that has been made is less than one might expect... Another reason is perhaps to be found in the scientific unrest of the twentieth century. Old theories have been broken up, and the infection of this destructive zeal has incited many to try to modify the new theories. Einstein himself devoted many years to the modification of his 1916 theory…"

John L. Synge in Warsaw 1962

General Relativity as a Stepping-Stone for Unified Field Theories

- The appeal of the Einstein-Hilbert program to the mathematicians
- Weak connections between practitioners
- Conduit to transmit GR to the next generation through research projects
- Cascade of transformations of GR

Einstein's success set an appealing example for pursuing a purely mathematical strategy. In particular, the use of modified notions of space and time in constructing a new physical theory turned out to be an immensely successful, and thus attractive, heuristic tool.

Hermann Weyl (1885–1955) and Theodor Kaluza (1885–1954)

Just Another Field Theory to be Quantized

- Formal exercise within QFT
- After the war “daring conservatism“ in the US
- Conduit to transmit GR to the next generation through research projects
- Cascade of transformations of GR

Linearized general relativity was quantized by Bronstein in 1936 and updated to the covariant, renormalized framework by DeWitt in 1950.

Techniques for dealing with the constraints: pioneering work by Rosenfeld in 1930, elaborate framework of constrained Hamiltonian dynamics by Dirac and Bergmann in the late 1940s.

Spin 1/2 particles integrated into the theory by Weyl and Fock in 1929 using the tetrad formulation originally developed by Einstein for his unified field theory of teleparallelism.

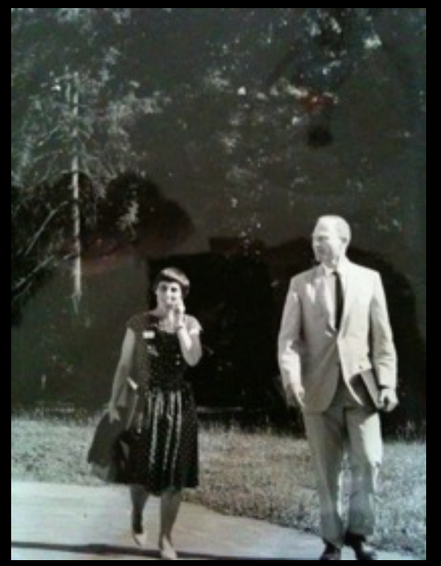
Matwei Petrowitsch Bronstein (1906–1938), Léon Rosenfeld (1904–1974)
and Vladimir Aleksandrovich Fock (1898–1974)

The hope was that the quantization of general relativity would deliver a better quantum field theory.

Wheeler's invention of geons was attempt at bringing the geometrical insights of general relativity to bear on problems in quantum field theory.

The goal of Bergmann's first studies of constrained Hamiltonian dynamics was to find the equations of motion of point singularities in a quantized gravitational field.

Quantizing gravity as a massless spin-2 field in the framework of Pauli and Fierz by DeWitt in 1950



John Archibald Wheeler (1911–2008), Peter Bergmann (1915–2002), Cécile DeWitt-Morette (*1922) and Bryce DeWitt (1923–2004)

A Contender in the Emerging Field of Physical Cosmology

- Early interpretational debates
- Creation of a kinematical canon independent from the GR framework (FL-RW metric)
- In the post-war period contender theories (steady-state) used GR as a starting point in the UK
- Conduit to transmit GR to the next generation through research projects
- Cascade of transformations of GR

In the beginning, the establishment of first ties between general relativity and astronomy involved only a small number of bridge builders with weak contact with the empirical research until the late 1920s when more solid connections could be built, especially in regard to the work of Edwin Hubble.

Arthur Stanley Eddington (1882–1944), Edwin Hubble (1889–1953), Willem de Sitter (1872–1934) and Albert Einstein (1879–1955)

Once the framework for a relativistic cosmic dynamics was established, it was separate enough from the full theory of general relativity to open an arena of cosmological debate in which the framework could be challenged and modified with consequences affecting only the cosmological sector.

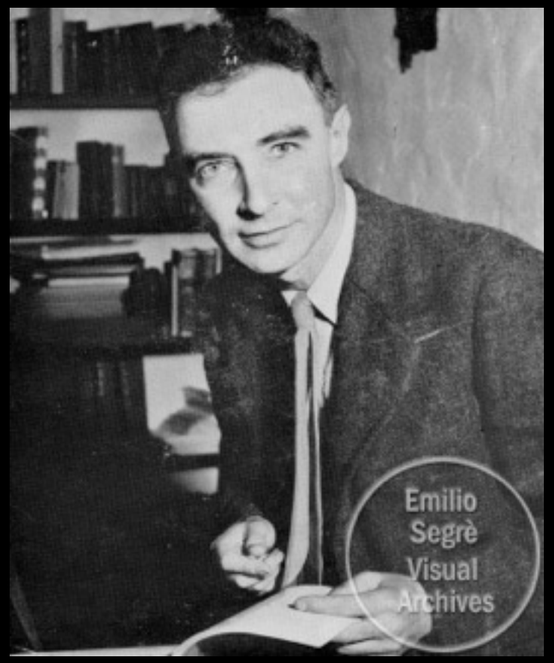
Howard P. Robertson (1903–1961), Georges Lemaître (1894–1966) and Arthur Geoffrey Walker (1909–2001)

In 1948, philosophical considerations led Hermann Bondi, Thomas Gold, and Fred Hoyle to propose the “steady-state” theory. It extended the cosmological principle by claiming that there is no privileged time, thus implying a constant matter density. To reconcile this with expansion, it was necessary to postulate the continuous creation of matter.

The“big bang” seemed to them a physically unacceptable extrapolation of relativistic cosmology.

Hermann Bondi (1919–2005), Dennis W. Sciama (1926-1999) and Fred Hoyle (1915–2001)

The first to use general relativity in treating a collapsing star were Oppenheimer and Snyder. Little emphasis was placed on the various singularities occurring in these calculations. Like early-universe cosmology, their approach was regarded as an unwarranted extrapolation of general relativity



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On Continued Gravitational Contraction

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University of California, Berkeley, California

(Received July 10, 1939)

When all thermonuclear sources of energy are exhausted a sufficiently heavy star will collapse. Unless fission due to rotation, the radiation of mass, or the blowing off of mass by radiation, reduce the star's mass to the order of that of the sun, this contraction will continue indefinitely. In the present paper we study the solutions of the gravitational field equations which describe this process. In I, general and qualitative arguments are given on the behavior of the metrical tensor as the contraction progresses: the radius of the star approaches asymptotically its gravitational radius; light from the surface of the star is progressively reddened, and can escape over a progressively narrower range of angles. In II, an analytic solution of the field equations confirming these general arguments is obtained for the case that the pressure within the star can be neglected. The total time of collapse for an observer comoving with the stellar matter is finite, and for this idealized case and typical stellar masses, of the order of a day; an external observer sees the star asymptotically shrinking to its gravitational radius.

I

RECENTLY it has been shown[1] that the general relativistic field equations do not possess any static solutions for a spherical distribution of cold neutrons if the total mass of the neutrons is greater than $\sim 0.7\odot$. It seems of interest to investigate the behavior of nonstatic solutions of the field equations.

In this work we will be concerned with stars which have large masses, $>0.7\odot$, and which have used up their nuclear sources of energy. A star under these circumstances would collapse under the influence of its gravitational field and release energy. This energy could be divided into four parts: (1) kinetic energy of motion of the particles in the star, (2) radiation, (3) potential and kinetic energy of the outer layers of the star which could be blown away by the radiation, (4) rotational energy which could divide the star into two or more parts. If the mass of the original star were sufficiently small, or if enough of the star could be blown from the surface by radiation, or lost directly in radiation, or if the angular momentum of the star were great enough to split it into small fragments, then the remaining matter could form a stable static distribution, a white dwarf star. We consider the case where this cannot happen.

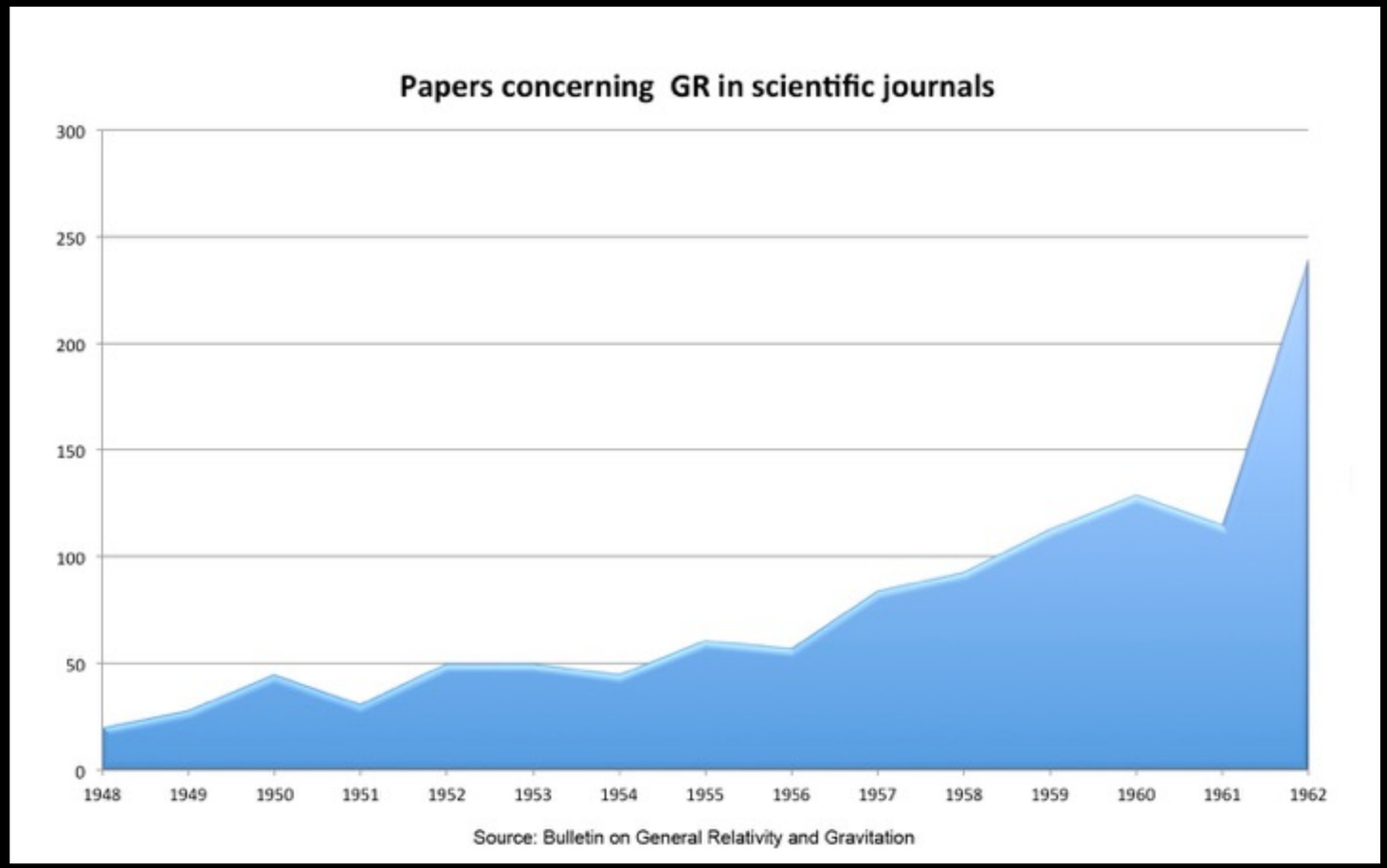
If then, for the late stages of contraction, we can neglect the gravitational effect of any escaping radiation or matter, and may still neglect the deviations from spherical symmetry

[1] J. R. Oppenheimer and G. M. Volkoff, Phys. Rev. **55**, 374 (1939).

J. Robert Oppenheimer (1904–1967) and Hartland Sweet Snyder (1913–1962)

The “Renaissance” Phenomenon

Within a few years all of this changed. GR became the uncontested theory of space and time, trusted all the way down to the Planck length. It became the physical basis of astrophysics. An international society was established, publications rapidly increased, and the leaders in the field, such as Hawking and Penrose, came to be counted among the most renowned scientists.



The beginnings of the renaissance that would place general relativity at the forefront of physics in the 1960s were rather unspectacular. A handful of physicists planned a conference to honor the fiftieth birthday of special relativity at its birthplace in Bern.

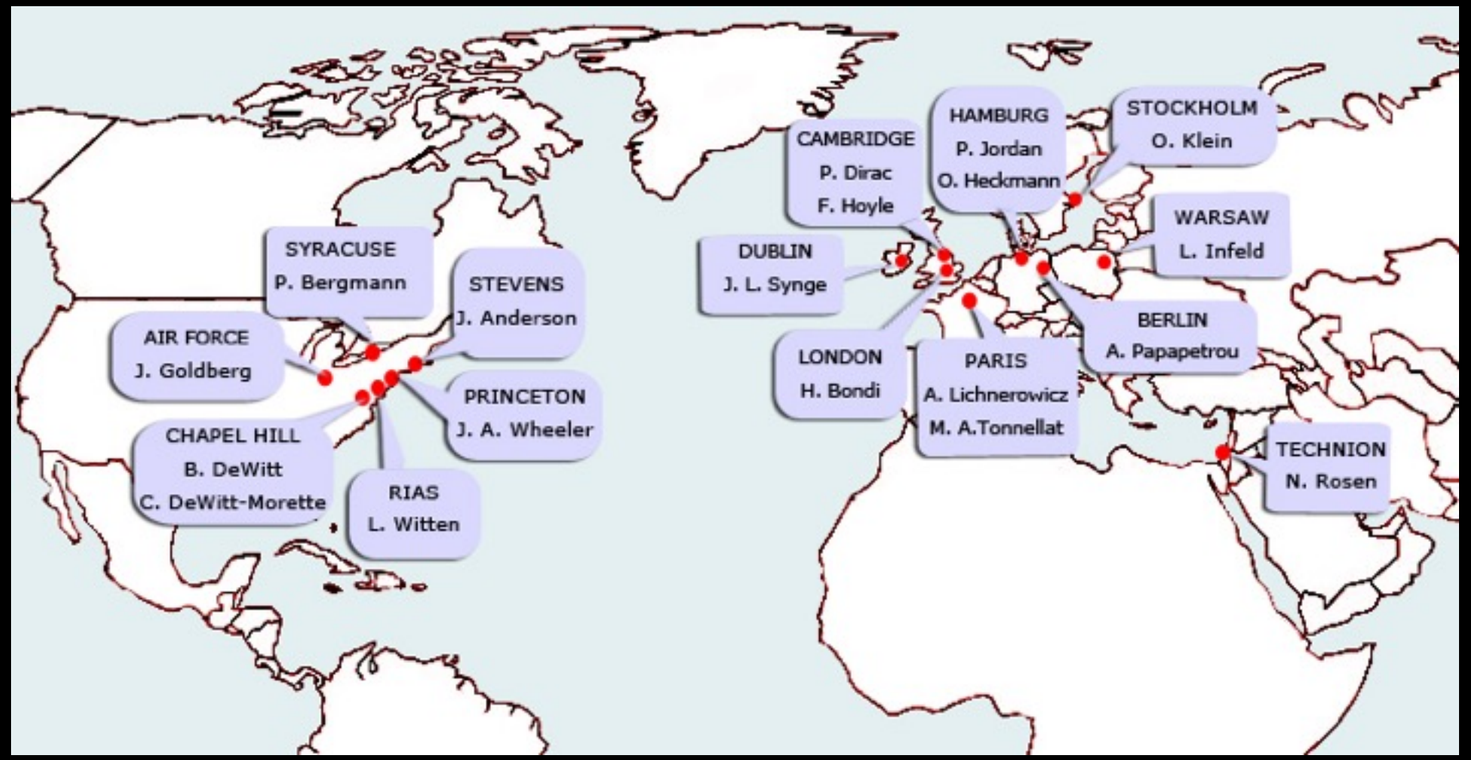
Wolfgang Pauli (1900–1958)

"In Spring 1955, we want to hold a congress on relativity theory and cosmology in Berne. Because of the 50th anniversary of Einstein's first work in Berne, there is actually a chance of getting money for this."

Pascual Jordan (1902–1980)

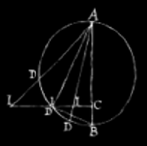
After World War II and in the context of the global arms race during the Cold War, substantial funding and talent were flowing into the field of theoretical physics.

Around 1955, several of the research centers that would shortly become hubs of the new relativity community were already active in all the various fields that had kept the tradition of general relativity alive:



Research centers active in subjects related to GR around 1955

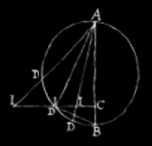
Untapped Potential of GR



- People working in different research agendas competent on GR – dispersion and lack of communication
- Insights into the structure of GR clouded by different perspectives and disciplinary divides

  (At the Bern conference, the commentators attempting to summarize the results reported at the meeting were unable to find a common way of categorizing the topics.)
- Lack of awareness of physical consequences of GR

Activation of the Potential



- Post-war environmental transformations for theoretical physics:

  The multitude of smaller local centers, rather than hindering the coordination of the research, was turned into an asset.

- Post-doc cascade:
  The structure of stable centers and highly mobile and well-trained specialists greatly increased the connectivity of the network of scholars working on general relativity-related problems at the interinstitutional and international level.

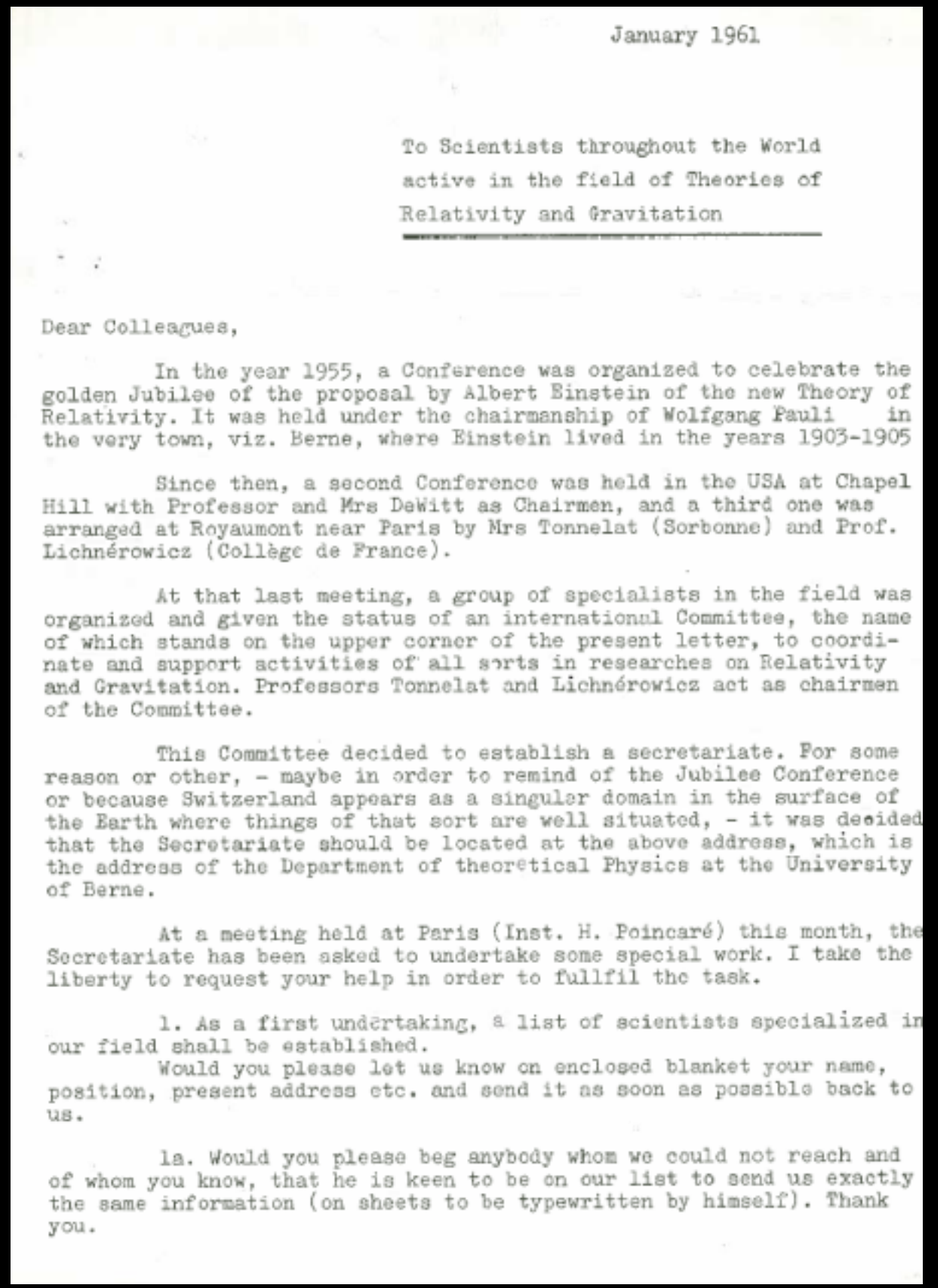
- Community building activity: Conferences, Committee, Bulletin, …

- Identification of common questions of relevance for all research agendas, e.g. the existence and properties of gravitational waves.

Explicit Community Building

Bulletin on GRG (Jan 1961)

- List of scientists specialized in the field
- Retrospective bibliography “especially indicating the domain of research”



January 1961

To Scientists throughout the World
active in the field of Theories of
Relativity and Gravitation

Dear Colleagues,

In the year 1955, a Conference was organized to celebrate the golden Jubilee of the proposal by Albert Einstein of the new Theory of Relativity. It was held under the chairmanship of Wolfgang Pauli in the very town, viz. Berne, where Einstein lived in the years 1903-1905

Since then, a second Conference was held in the USA at Chapel Hill with Professor and Mrs DeWitt as Chairmen, and a third one was arranged at Royaumont near Paris by Mrs Tonnelat (Sorbonne) and Prof. Lichnérowicz (Collège de France).

At that last meeting, a group of specialists in the field was organized and given the status of an international Committee, the name of which stands on the upper corner of the present letter, to coordinate and support activities of all sorts in researches on Relativity and Gravitation. Professors Tonnelat and Lichnérowicz act as chairmen of the Committee.

This Committee decided to establish a secretariate. For some reason or other, - maybe in order to remind of the Jubilee Conference or because Switzerland appears as a singular domain in the surface of the Earth where things of that sort are well situated, - it was decided that the Secretariate should be located at the above address, which is the address of the Department of theoretical Physics at the University of Berne.

At a meeting held at Paris (Inst. H. Poincaré) this month, the Secretariate has been asked to undertake some special work. I take the liberty to request your help in order to fullfil the task.

1. As a first undertaking, a list of scientists specialized in our field shall be established.
Would you please let us know on enclosed blanket your name, position, present address etc. and send it as soon as possible back to us.

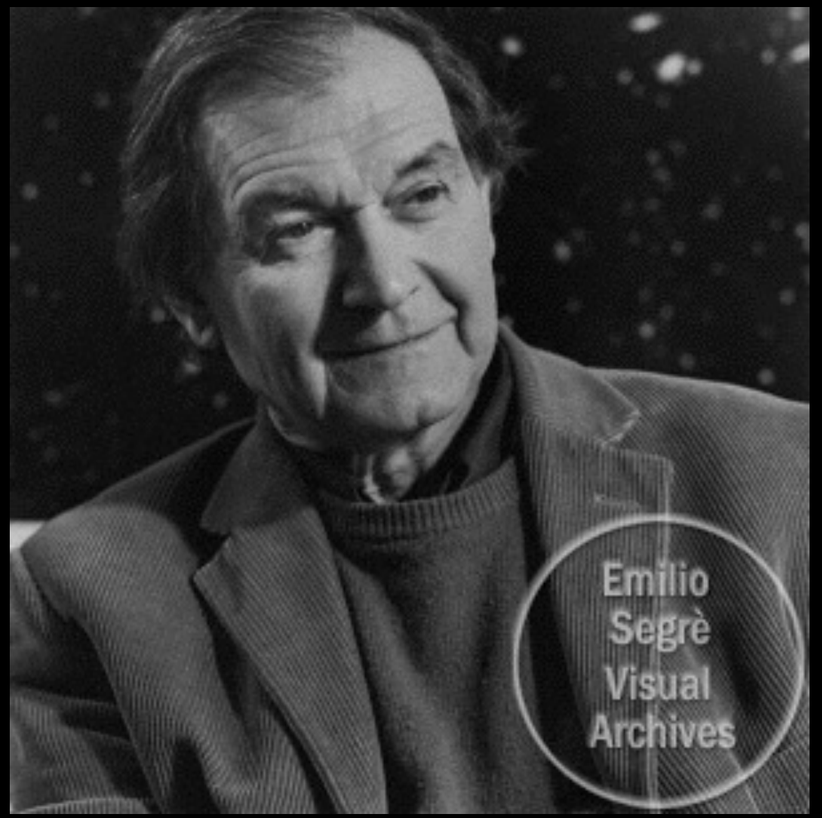
1a. Would you please beg anybody whom we could not reach and of whom you know, that he is keen to be on our list to send us exactly the same information (on sheets to be typewritten by himself). Thank you.

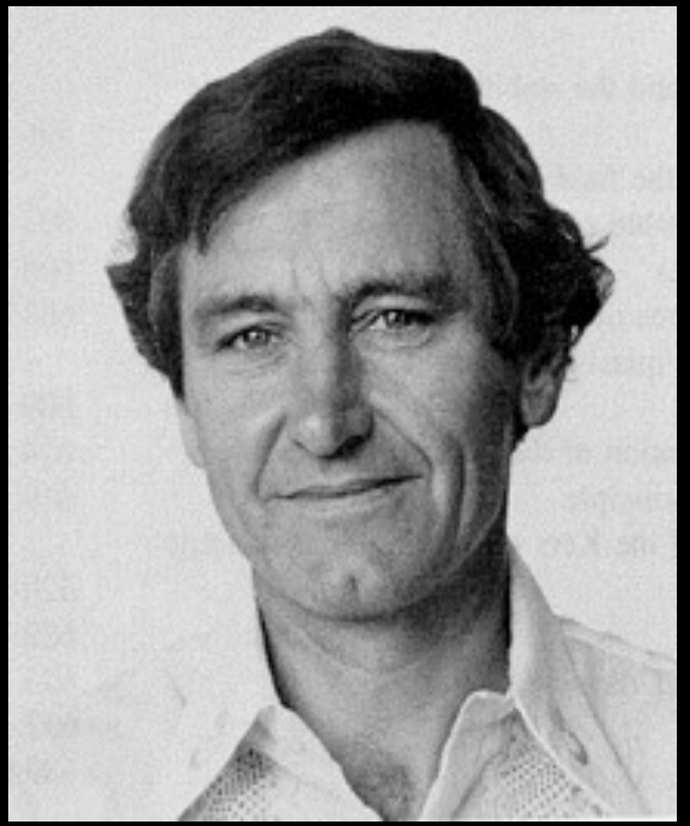
Edited Volumes (1962)

"[M]uch unpublished work was communicated by word of mouth to those few in the charmed circles of Princeton, Warsaw and London." (Kilmister 1963)

"The editorial committee thus succeeded in presenting several approaches in those areas in which opinions widely differ, rather than selecting "orthodox" views." (Bergmann 1962)

Charles Misner (*1932), Roger Penrose (*1931) and Roy Kerr (*1934)





Scenarios

- Sugar Daddy (Cold War):

  Neglect of epistemic changes

- Glorious Few:

  Neglect of the social network and community building

- Sleeping Beauty:

  Chronology is wrong

- Einstein's death:

  Generational change is not sufficient, neglects social changes

- Autocatalytic scenario:

  Combines social and epistemic factors and gives chronology

In the four decades following the creation of general relativity, people had been inspired by and tried to mimic Einstein's methodology rather than sticking to the theory of general relativity, which they tried to supersede. The "Renaissance" turned this around: general relativity now became central to research and the research community and attracted a wealth of new, post-Einsteinian tools and methodologies.

Thank you for your attention!