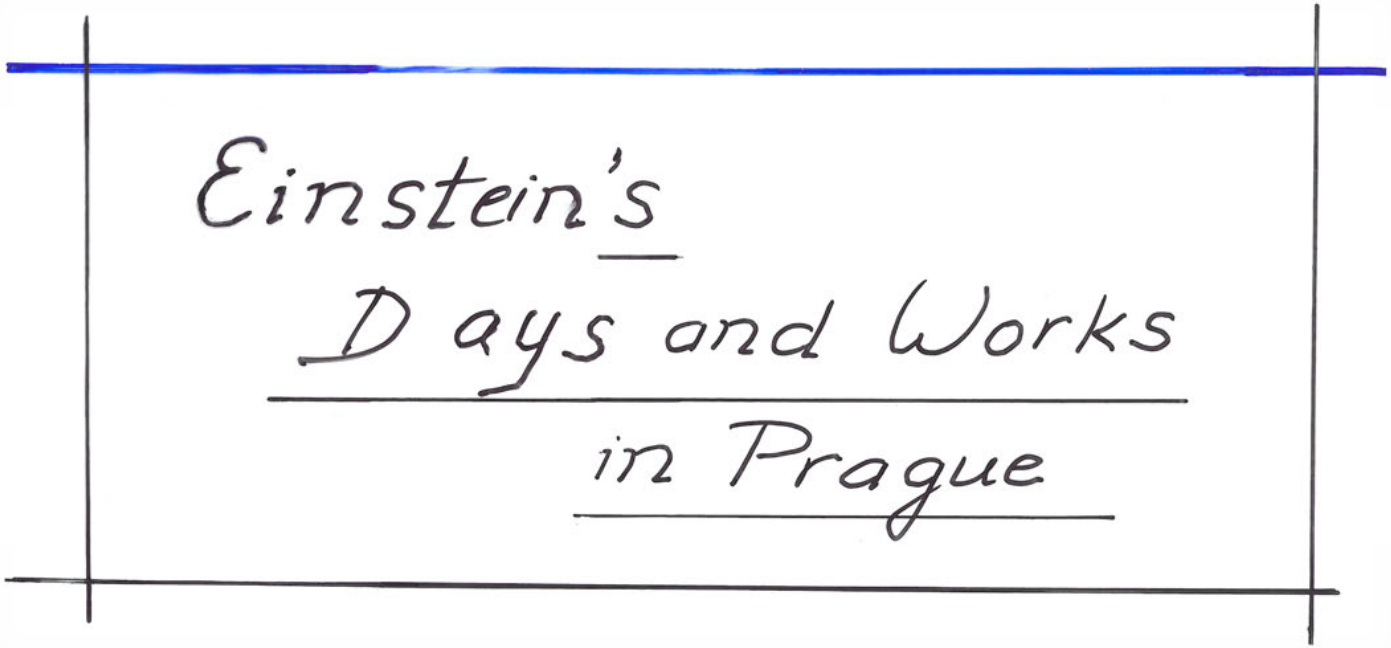
The city of Prague is very fine, so beautiful that it is worth a long journey for itself.

AE to his friend M. Besso, 13th May 1911

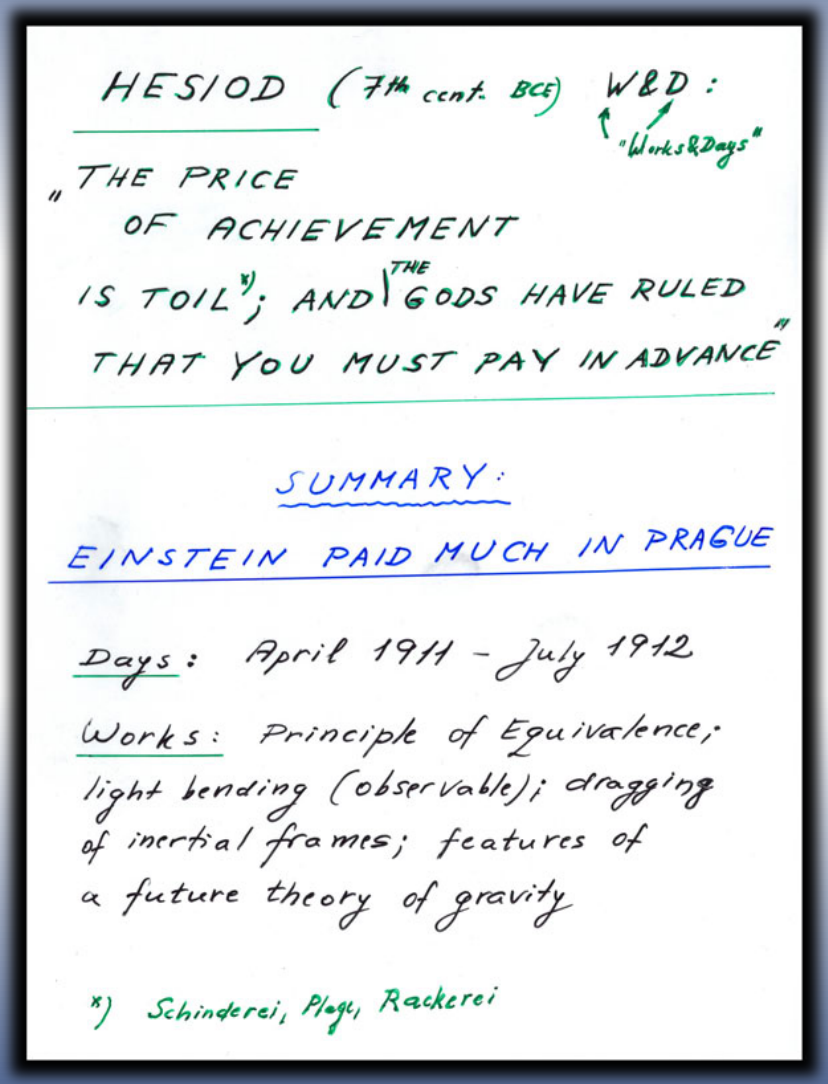
I have a magnificent institute here in which I work very comfortably.
Otherwise it is less homey (Czech language, bedbugs, awful water, etc.).
By the way, **Czechs are more harmless than one thinks.**

AE to M. Grossmann, 27th April 1911

Einstein's Days and Works in Prague: Relativity Then and Now



Einstein's Days and Works in Prague: Relativity Then and Now


HESIOD (7th cent. BCE) W&D: "Works & Days"

"THE PRICE OF ACHIEVEMENT IS TOIL*); AND THE GODS HAVE RULED THAT YOU MUST PAY IN ADVANCE"

SUMMARY:

EINSTEIN PAID MUCH IN PRAGUE

Days: April 1911 – July 1912

Works: Principle of Equivalence; light bending (observable); dragging of inertial frames; features of a future theory of gravity

*) Schinderei, Plage, Rackerei

"The price of achievment is toil†; and the gods have ruled that you must pay in advance"

Hesiod (7th cent. BC)
Works & Days

† Schinderei, Plage, Rackerei

Einstein paid much in Prague

Days: April 1911 – July 1912

Works:

- Principle of Equivalence
- light bending (observable)
- dragging of inertial frames
- features of a future theory of gravity

The building of Philosophical Faculty of the German University in Prague, Viničná

University

Philipp Frank: Einstein, His Life and Times
(A. Knopf, New York 1947)

The building of Philosophical Faculty of the German University in Prague, Viničná

University

psychiatric asylum

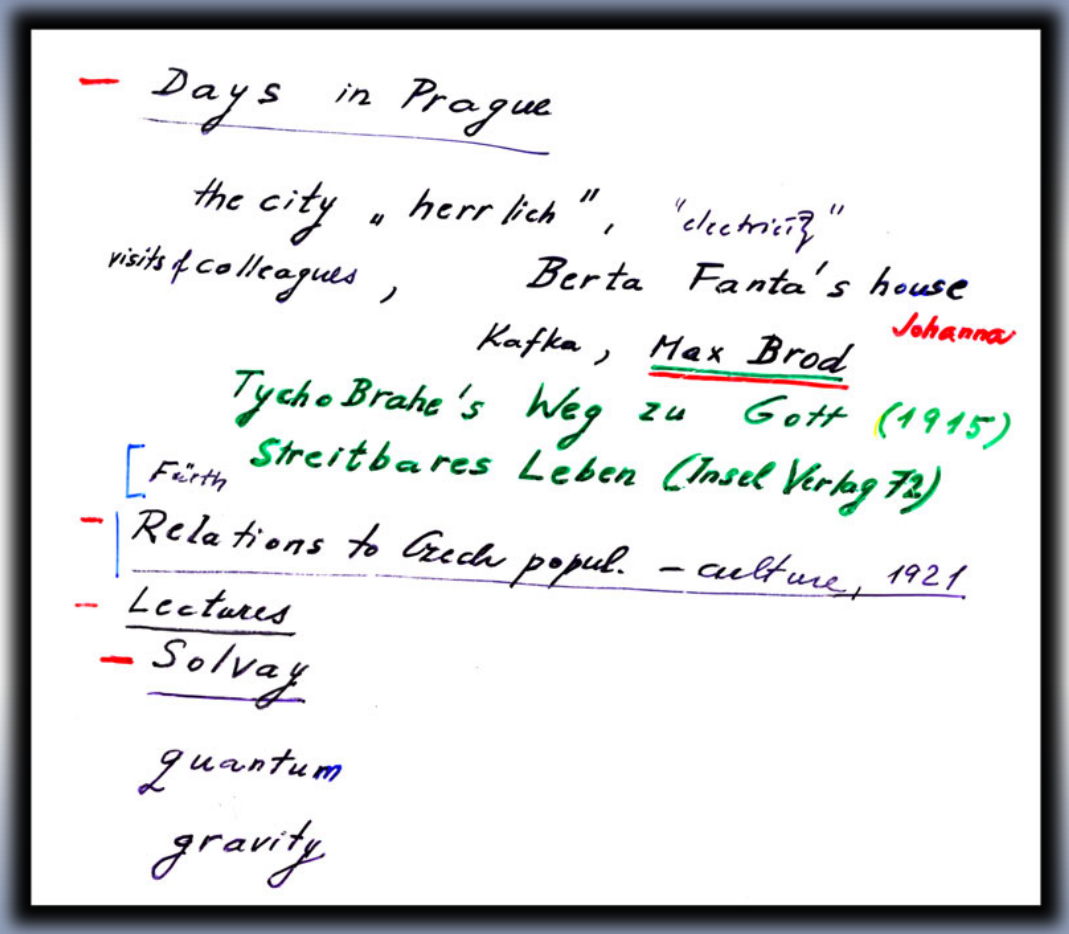
Philipp Frank: Einstein, His Life and Times
(A. Knopf, New York 1947)

Participants at the Einstein centenary celebrations in 1979 at the Charles University in Prague:

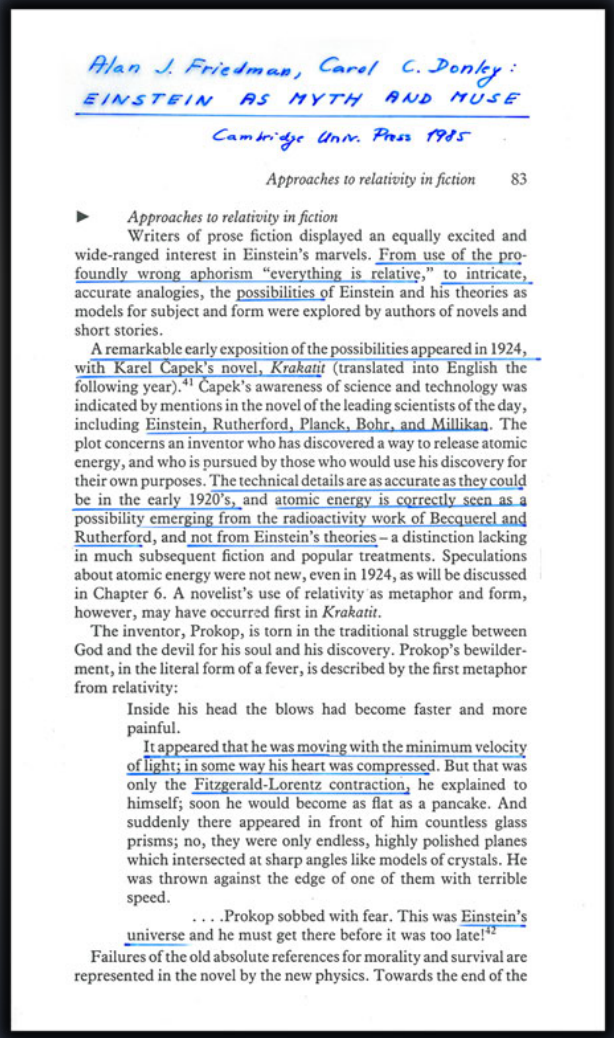
J.A. Wheeler, A. Trautmann, Mrs. Melcher, E. Schmutzer, J. Langer, M. Bergmann, P. Bergmann, H. Melcher (from left to right)

Why and how invited do Prague

- Charles University from 1348 – one educational centre for Czechs, Germans, Poles...
- In 1882 divided into the Czech and German parts; in 1911 4432:1844 students.
- In German part – F. Lippich math $\rightsquigarrow$ theor. physics A.Lampa ("Machian"), G. Pick ($g_{\mu\nu}$).
- Planck's letter, confession, library



Impact on Czech culture: Karel Čapek (1890-1938)



Alan J. Friedman, Carol C. Donley: EINSTEIN AS MYTH AND MUSE
Cambridge Univ. Press 1985

Approaches to relativity in fiction 83

▶ *Approaches to relativity in fiction*

Writers of prose fiction displayed an equally excited and wide-ranged interest in Einstein's marvels. From use of the profoundly wrong aphorism "everything is relative," to intricate, accurate analogies, the possibilities of Einstein and his theories as models for subject and form were explored by authors of novels and short stories.

A remarkable early exposition of the possibilities appeared in 1924, with Karel Čapek's novel, *Krakatit* (translated into English the following year).[41] Čapek's awareness of science and technology was indicated by mentions in the novel of the leading scientists of the day, including Einstein, Rutherford, Planck, Bohr, and Millikan. The plot concerns an inventor who has discovered a way to release atomic energy, and who is pursued by those who would use his discovery for their own purposes. The technical details are as accurate as they could be in the early 1920's, and atomic energy is correctly seen as a possibility emerging from the radioactivity work of Becquerel and Rutherford, and not from Einstein's theories – a distinction lacking in much subsequent fiction and popular treatments. Speculations about atomic energy were not new, even in 1924, as will be discussed in Chapter 6. A novelist's use of relativity as metaphor and form, however, may have occurred first in *Krakatit*.

The inventor, Prokop, is torn in the traditional struggle between God and the devil for his soul and his discovery. Prokop's bewilderment, in the literal form of a fever, is described by the first metaphor from relativity:

> Inside his head the blows had become faster and more painful.
>
> It appeared that he was moving with the minimum velocity of light; in some way his heart was compressed. But that was only the Fitzgerald-Lorentz contraction, he explained to himself; soon he would become as flat as a pancake. And suddenly there appeared in front of him countless glass prisms; no, they were only endless, highly polished planes which intersected at sharp angles like models of crystals. He was thrown against the edge of one of them with terrible speed.
>
> . . . .Prokop sobbed with fear. This was Einstein's universe and he must get there before it was too late![42]

Failures of the old absolute references for morality and survival are represented in the novel by the new physics. Towards the end of the

Alan J. Friedman, Carol C. Donley: Einstein as myth and muse Cambridge University Press 1985

From use of the profoundly wrong aphorism "everything is relative", to intricate. . . the possibilities of Einsteins. . .

A remarkable early exposition of the possibilities appeared in 1924, with Karel Čapek's novel, **Krakatit**

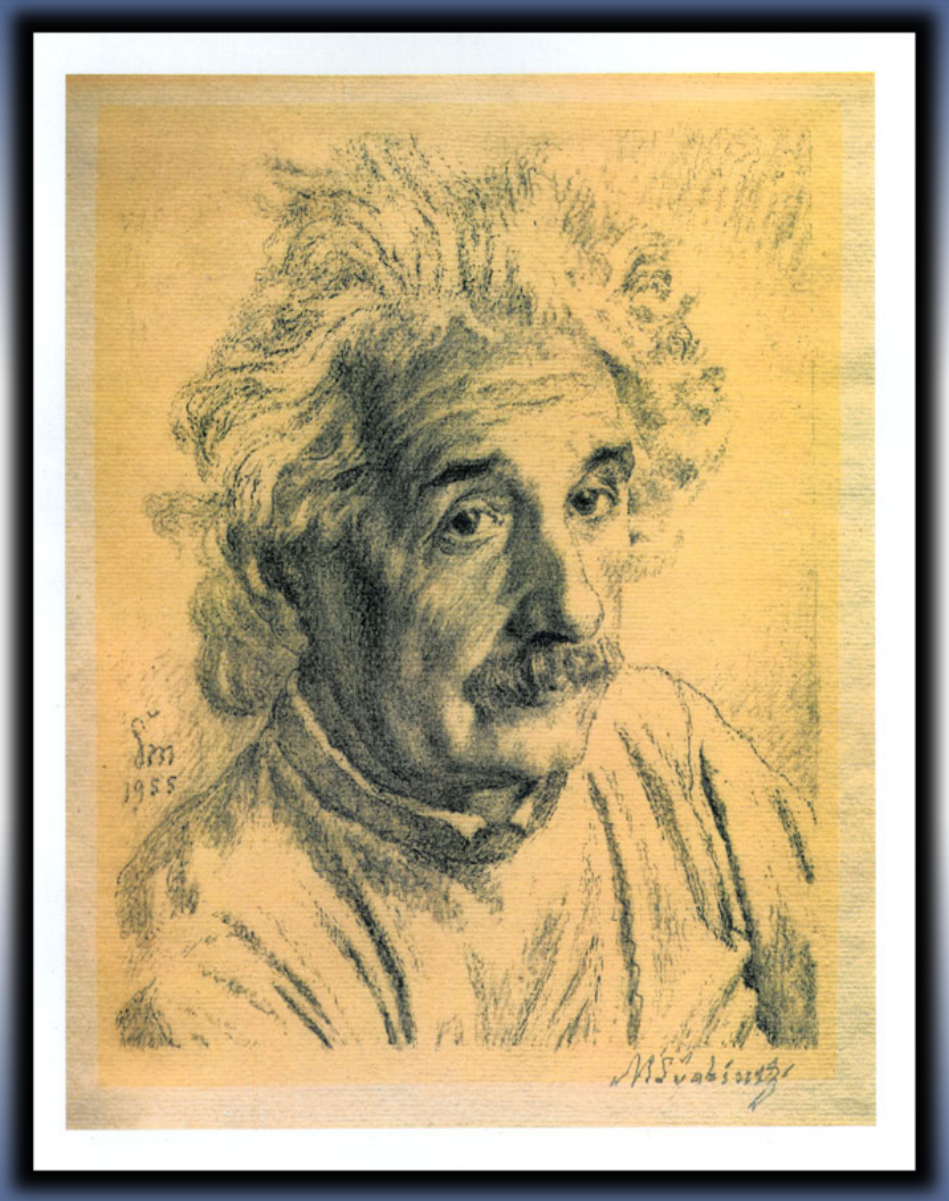
Einstein, Rutherford, Planck, Borh and Millikan

The technical details are as accurate as they could be in the early 1920's, and atomic energy is correctly seen as as a possibility emerging from the radioactivity work of Becquerel and Rutherford, and not from Einstein's theories

It appeared that he was moving with the minimum velocity of light; in some way his heart was compressed. . . Fitzgerald – Lorentz contraction

Einstein's universe

Max Šabinský (1873-1962)



Impact on Czech Physics & Astronomy

- A. Dittrich, A. Žáček — popular texts on special relativity 1912 (in Czech)
- K. Nachtikal: Principle of Relativity 1922 (in Czech)
- F. Záviška: Einstein's principle of relativity and theory of gravity 1925
- F. Link – astronomer – in Comptus Rendus in March 1936
  on gravitational lenses (AE in Science December 4, 1936)
- V. Hlavatý (Louny 1894 - Bloomington 1969) – differential geometry, unified theory
- M. Brdička (1912-2007): "On gravitational waves", Proc. Roy. Irish Acad (1951)
  see G. Gibbons, C. Rugina: Coryacher-Chaplygin, Kovalevskaya, and Brdička-Eardley-Nappi-Witten pp-waves spacetimes with higher rank Stäckel-Killing tensor, J. Math. Phys **52**, 122901 (2011)
- K. Kuchař, Canonical gravity $\rightsquigarrow$ 1968 $\rightsquigarrow$ Princeton, SLC
- Today:
  - Faculty of Mathematics and Physics (Theoretical Physics, Astronomy)
  - Academy of Science (Institute of Astronomy, Mathematical Institute)
  - Silesian University
  - Masaryk University

Lectures and seminars of Albert Einstein in Prague

	Title	No. of students
20.4.1911 – end of July 1911	Mechanik diskreter Massenpunkte (3h)	13
	Thermodynamik (2h)	12
	Seminar	6
19.10.1911 – Wednesday before Palm Sunday 1912	Mechanik diskreter Massenpunkte (3h)	12
	Wärmelehre (2h)	13
	Seminar	7
12.4.1912 – end of July 1912	Mechanik der Kontinua (2h)	10
	Molekulartheorie der Wärme (3h)	11
	Seminar	7

Prague's work of Albert Einstein

On thermodynamics, radiation theory and quantum theory

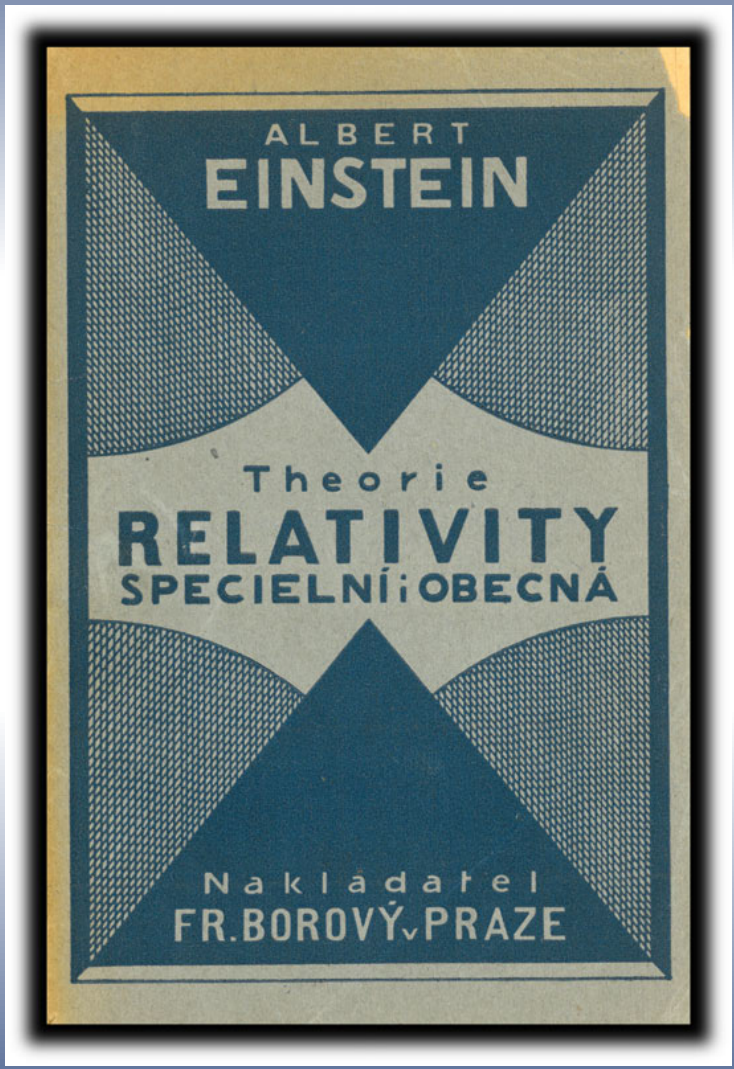
1. Elementare Betrachungen über die thermische Molekularbewegung in festen Körpern
   Ann. d. Phys. **35** (1911), 679-694.
2. État actuel du problème des chaleurs spécifiques
   Insituts Solvay, Conseil de Physique, Rapport et discussions de la Réunion Solvay, 1911; Paris, Gauthiers 1912, 407-435.
   Zum gegenwärtigen Stande des Problems der spezifischen Wärme, Deutsche Bunsengesellschaft, Abhandlungen, Nr. **7** (1914), 330-364.
3. Thermodynamische Begründung des photochemischen Äquivalentgesetzes,
   Ann. d. Phys. **37** (1912), 832-838.
4. Nachtrag zu meiner Arbeit: "Thermodynamische Begründung des photochemischen Äquivalentgesetzes",
   Ann. d. Phys. **38** (1912), 881-884.
5. Antwort auf eine Bemerkung von J. Stark: "Über eine Anwendung des Planckschen Alementargesetzes",
   Ann. d. Phys. **38** (1912), 888.

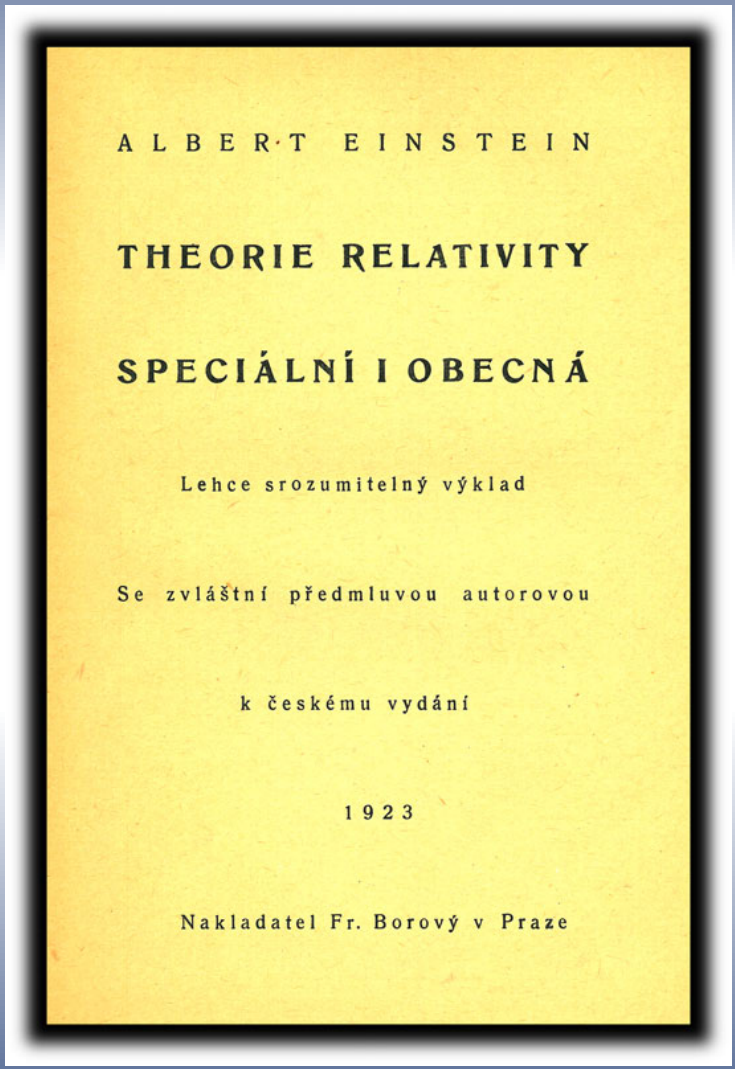
Prague's work of Albert Einstein

On the theory of relativity and gravitation

1. Die Relativitäts-Theorie,
   Vierteljahr. d. Naturf. Ges. Zürich **56** 1911, 1-14.
2. Zum Ehrenfestschen Paradoxon,
   Phys. Z. **12** (1911), 509-510.
3. **Über den Einfluss der Schwerkraft auf die Ausbreitung des Lichtes,**
   Ann. d. Phys. 35 (1911), 898-908.
4. Lichtgeschwindigkeit und Statik des Gravitationsfeldes,
   Ann. d. Phys. **38** (1912), 355-369.
5. **Zur theorie des statischen Gravitationslfeldes,**
   Ann. d. Phys. 38 (1912), 443-458.
6. **Gibt es eine Gravitationswirkung, die der elektrodynamischen Induktionswirkung analog ist?**
   Vierteljahrsschrift für gerichtliche Medizin 44 (1912), 37-40.
7. **Relativität und Gravitation: Erwiderung auf eine Bemerkung von M. Abraham,**
   Ann. d. Phys. 38 (1912), 1059-1064.

About the special and general theory of relativity in plain terms (Czech translation)





About the special and general theory of relativity in plain terms (Czech translation)

VORWORT
DES AUTORS ZUR TSCHECHISCHEN AUSGABE.

Es freut mich, daß das kleine Büchlein, in dem die Hauptgedanken der Relativitätstheorie ohne die mathematische Durchführung dargestellt sind, nun in der Nationalsprache desjenigen Landes erscheint, in dem ich die nötige Sammlung fand, um dem schon seit 1908 gefaßten Grundgedanken der allgemeinen Relativitätstheorie allmählich eine bestimmtere Form zu geben. In den stillen Räumen des Theoretisch-Physikalischen Instituts der Prager Deutschen Universität in der Viničná ulice kam ich 1911 auf die Entdeckung, daß das Äquivalenzprinzip eine Ablenkung der Lichtstrahlen an der Sonne von beobachtbarem Betrage verlangt, ohne zu wissen, daß mehr als hundert Jahre vorher eine ähnliche Konsequenz aus der Newtonschen Mechanik in Verbindung mit Newtons Emissionstheorie des Lichtes gezogen worden war. Auch die immer noch nicht einwandfrei bestätigte Konsequenz von der Rotverschiebung der Spektrallinien entdeckte ich in Prag. Den entscheidenden Gedanken von der Analogie des mit der Theorie verbundenen mathematischen Problems mit der Gaußschen Flächentheorie hatte ich allerdings erst 1912 nach meiner Rückkehr nach Zürich, ohne zunächst Riemanns und Riccis, sowie Levi-Civitàs Forschungen zu kennen. Auf diese wurde ich erst durch meinen Freund Großmann in Zürich aufmerksam, als ich ihm das Problem stellte, allgemein kovariante Tensoren aufzusuchen, deren Komponenten nur von Ableitungen der Koeffizienten der quadratischen Fundamentalinvariante abhängen. Heute scheinen sich Leistungen und Leistungs-

7

grenzen der Theorie schon klar übersehen zu lassen. Sie liefert tiefe Erkenntnisse über die physikalische Natur von Raum, Zeit, Masse, Gravitation, aber kein hinreichendes Mittel zur Lösung des Problems der Quanten und der atomistischen Konstitution der elektrischen Elementargebilde, aus denen die Materie besteht.

A. Einstein.

8

About the special and general theory of relativity in plain terms (Czech translation)

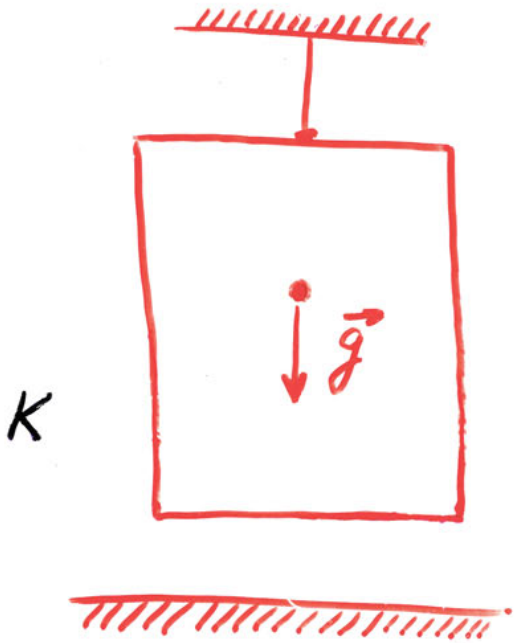
Prague stage of his journey to the general theory of relativity? First of all, there is a precious document — Einstein's foreword to the Czech edition of 1923 of his famous little popular book "About the Special and General Theory of Relativity in Plain Terms" (see the opposite page for the original German text): "*I am pleased that this small book, in which the main ideas of the theory of relativity are explained without mathematical elaboration, should now appear in the native language of the country in which I found the necessary concentration for developing the basic idea of the general theory of relativity which I had already conceived in 1908. In the quiet rooms of the Institute of Theoretical Physics of Prague's German University in Viničná Street, I discovered that the principle of equivalence implies the deflection of light rays near the Sun by an observable amount, without at that time knowing that a similar result had been derived from Newton's mechanics and his corpuscular theory of light. In Prague I also discovered the shift of spectral lines towards the red which is not yet completely confirmed. However, the decisive idea of the analogy between the mathematical formulation of the theory and the Gaussian theory of surfaces came to me only in 1912 after my return to Zürich, without being aware at*

that time of the work of Riemann, Ricci, and Levi-Civita. This was first brought to my attention by my friend Grossmann when I posed to him the problem of looking for generally covariant tensors whose components depend only on derivatives of the coefficients of the quadratic fundamental invariant. It now appears that it is already possible to evaluate the achievements and limitations of the whole theory. It gives a deep knowledge of the physical nature of space, time, matter and gravity; however, it does not provide sufficient means for solving the problems of quanta and of the atomic constitution of the elementary electric units of which matter is composed."

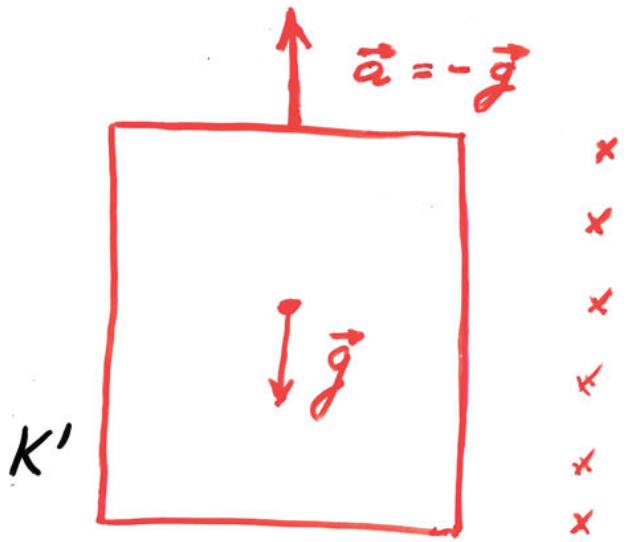
Einstein's foreword to the Czech edition of 1923 of his famous little popular book **"About the Special and General Theory of Relativity in Plain Terms"**

The principle of equivalence

EINSTEIN : Gravitation is universal

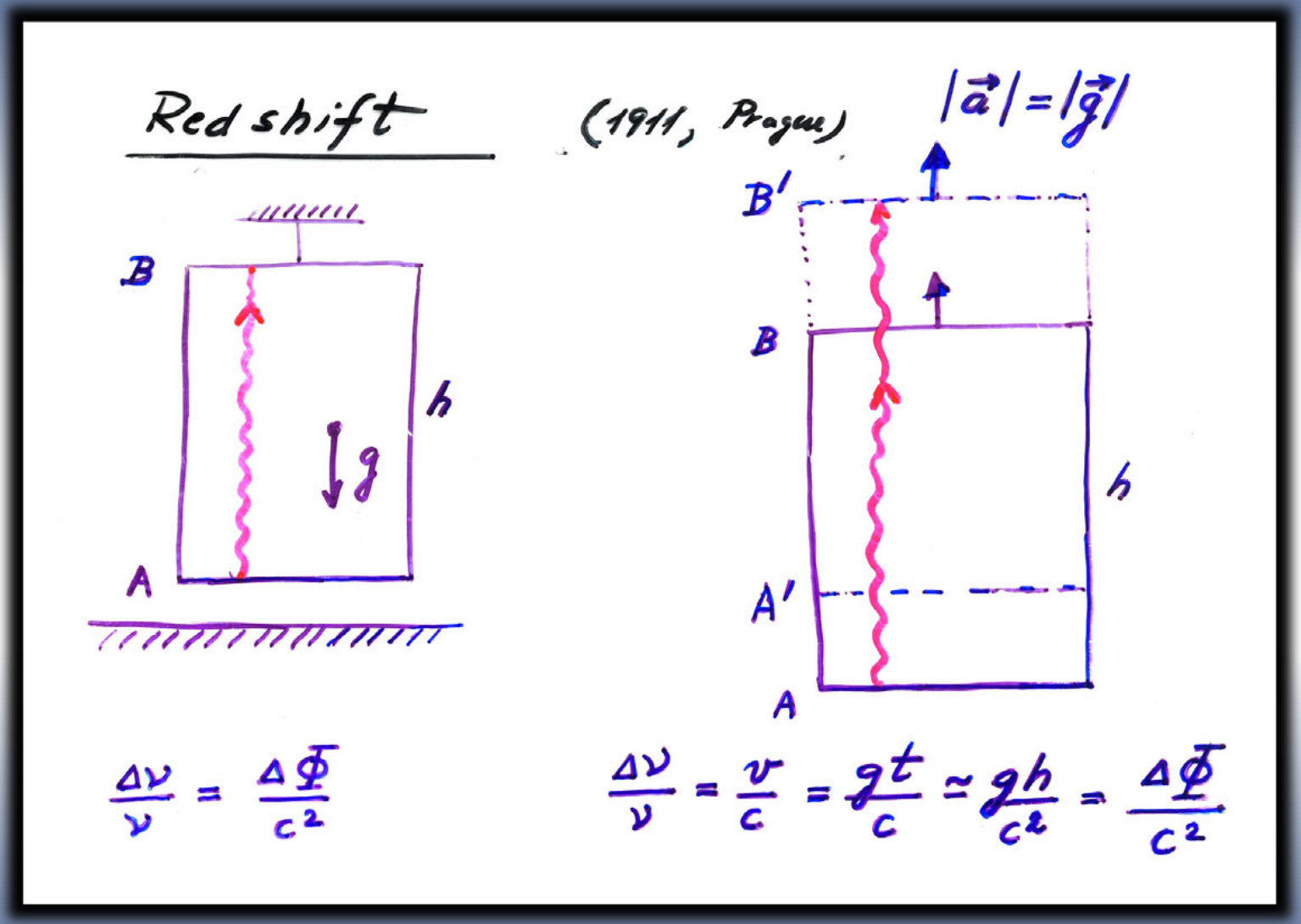


at rest in homogeneous gravitational field



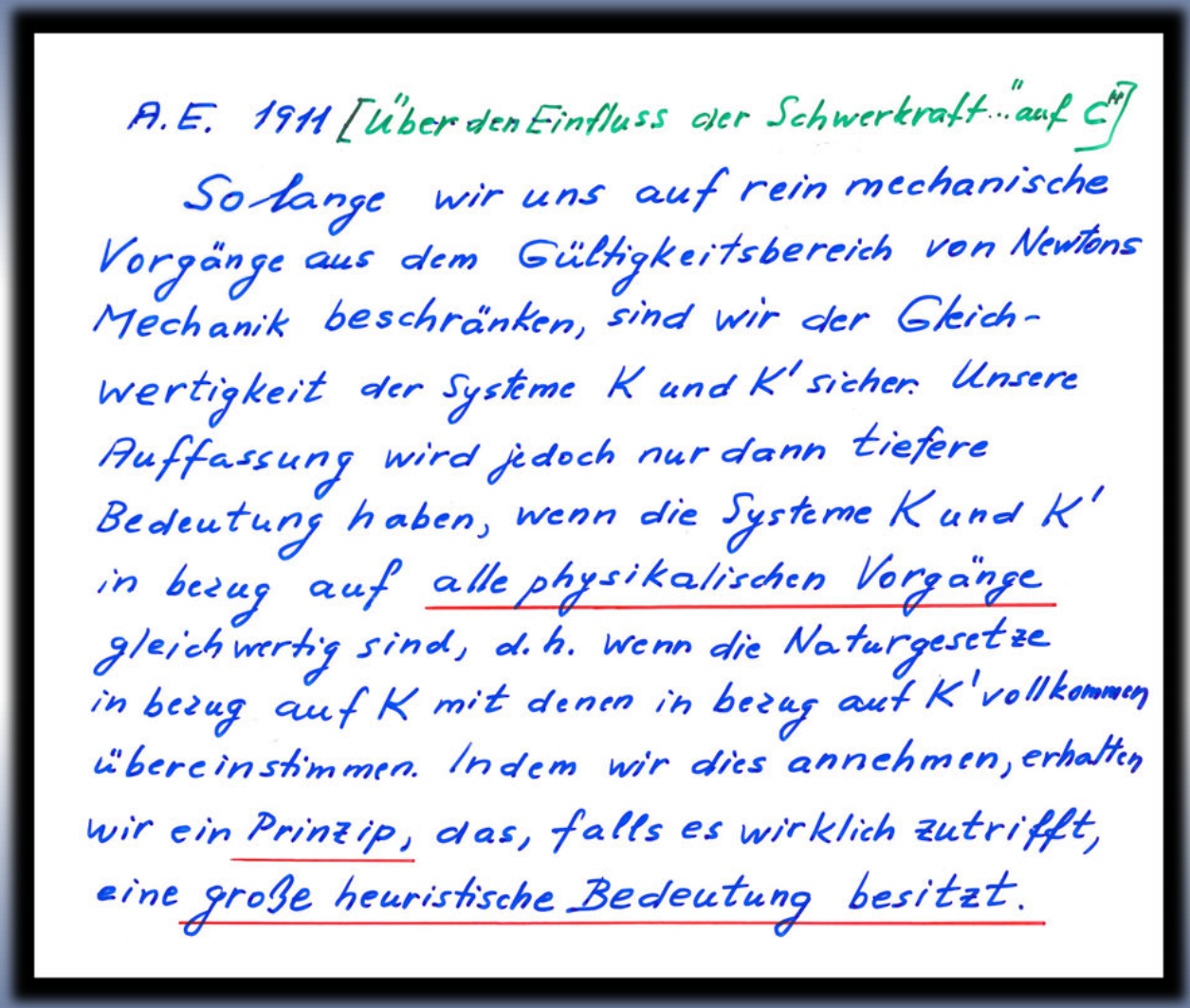
in uniformly accelerated motion in „empty space" (in inertial frame)

Redshift


Redshift
(1911, Prague)
$|\vec{a}| = |\vec{g}|$
B
h
g
A
B′
B
h
A′
A
$\frac{\Delta\nu}{\nu} = \frac{\Delta\Phi}{c^2}$
$\frac{\Delta\nu}{\nu} = \frac{v}{c} = \frac{gt}{c} \simeq \frac{gh}{c^2} = \frac{\Delta\Phi}{c^2}$

A. Einstein: Creator & Rebel (Banesh Hoffmann)

In the paper of 1907. . . Einstein had already begun his attack on the problem of acceleration, and he returned to it in his Prague paper of 1911. His arguments, particularly in its 1911 form, must rank as one of the most remarkable in the history of science.


A.E. 1911 [Über den Einfluss der Schwerkraft... auf C]

So lange wir uns auf rein mechanische Vorgänge aus dem Gültigkeitsbereich von Newtons Mechanik beschränken, sind wir der Gleichwertigkeit der Systeme K und K' sicher. Unsere Auffassung wird jedoch nur dann tiefere Bedeutung haben, wenn die Systeme K und K' in bezug auf alle physikalischen Vorgänge gleichwertig sind, d.h. wenn die Naturgesetze in bezug auf K mit denen in bezug auf K' vollkommen übereinstimmen. Indem wir dies annehmen, erhalten wir ein Prinzip, das, falls es wirklich zutrifft, eine große heuristische Bedeutung besitzt.

Mark Twain

Mark Twain (Life on Mississipi):

„The nice thing about Science is that one gets such wholesale returns of conjecture from such a trifling investment of fact"

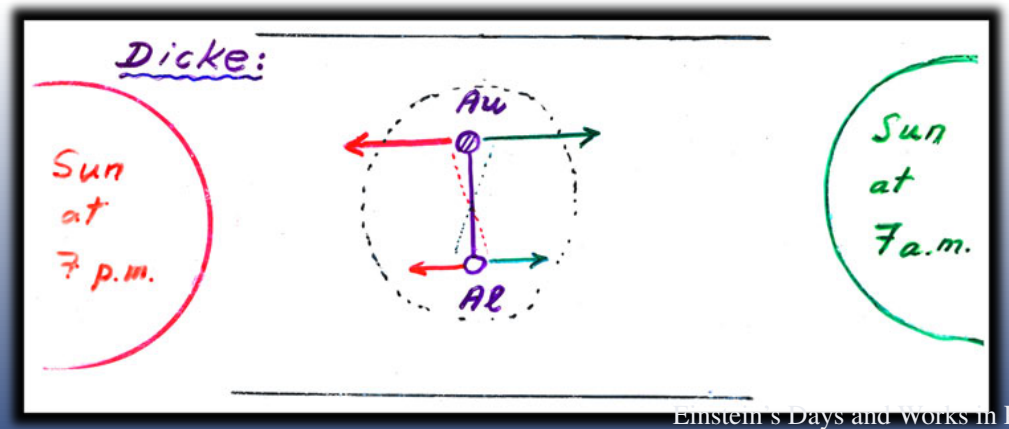
The principle of equivalence – present day formulation

- test bodies fall with the same acceleration independently of their structure or composition (WEP)
- the outcome of any local non-gravitational experiment is independent of:
  - the velocity of the local inertial frame in which it is performed (LLI)
  - of where and when in the universe is performed (LPI)

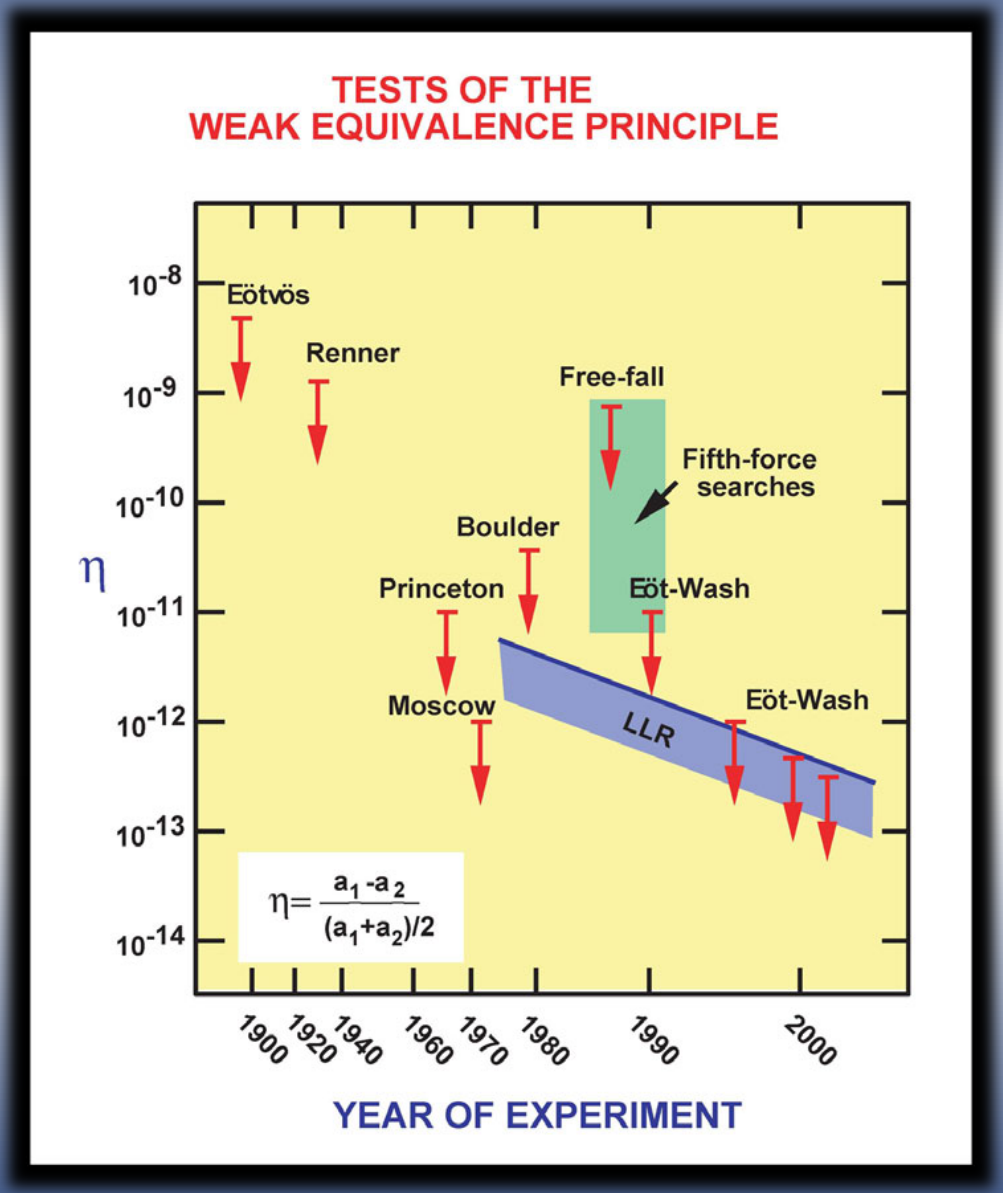
Cliff Will, Living Reviews

The present best limits on

$$\eta = \frac{a_A - a_B}{\frac{1}{2}\,(a_A + a_B)} \qquad \begin{cases} (0.3 \pm 1.8) \times 10^{-13}, & \text{Eöt-Wash} \\ (-1.0 \pm 1.4) \times 10^{-13}, & \text{LLR} \end{cases} \tag{1}$$

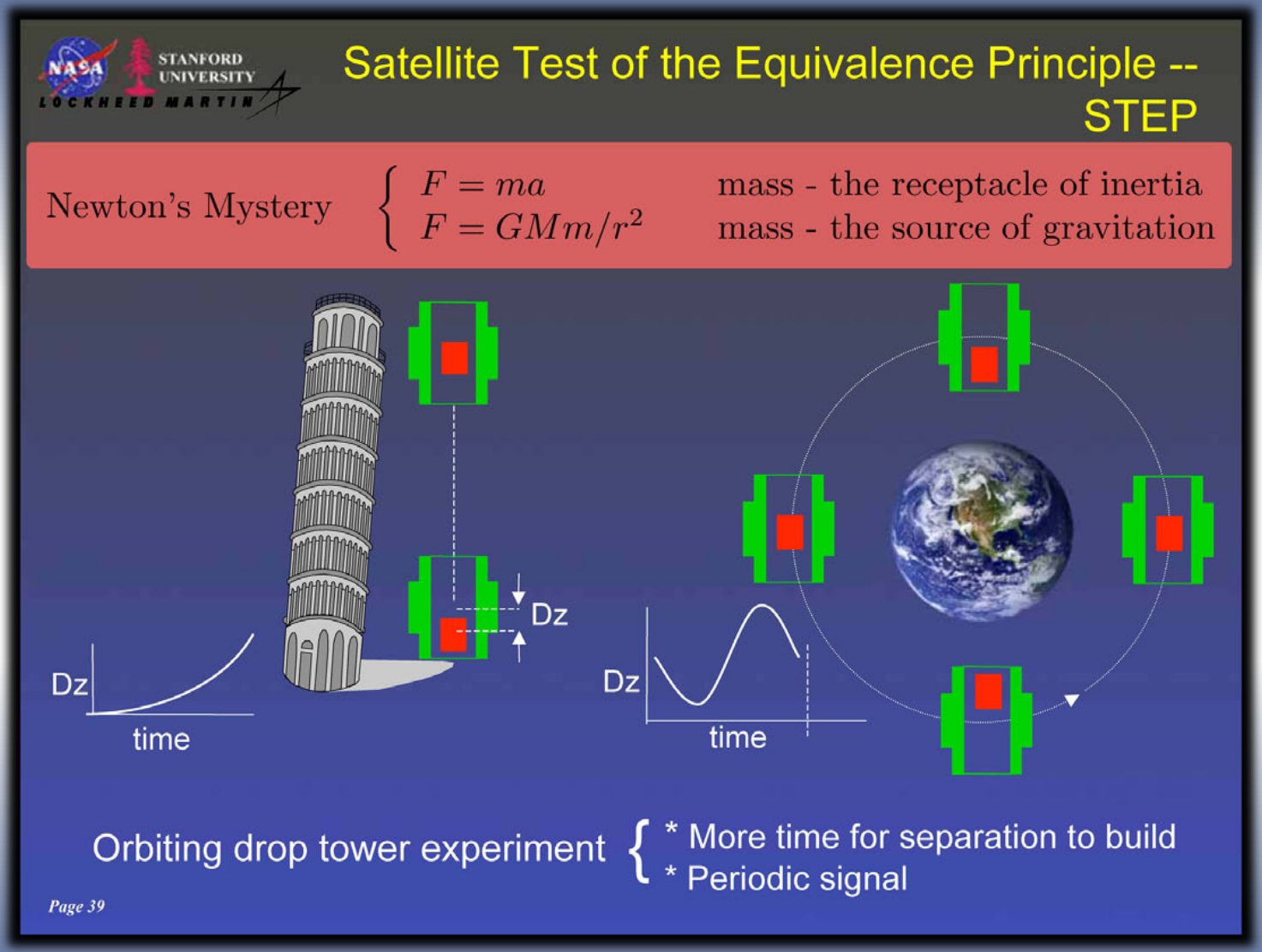


Test of weak equivalence principle

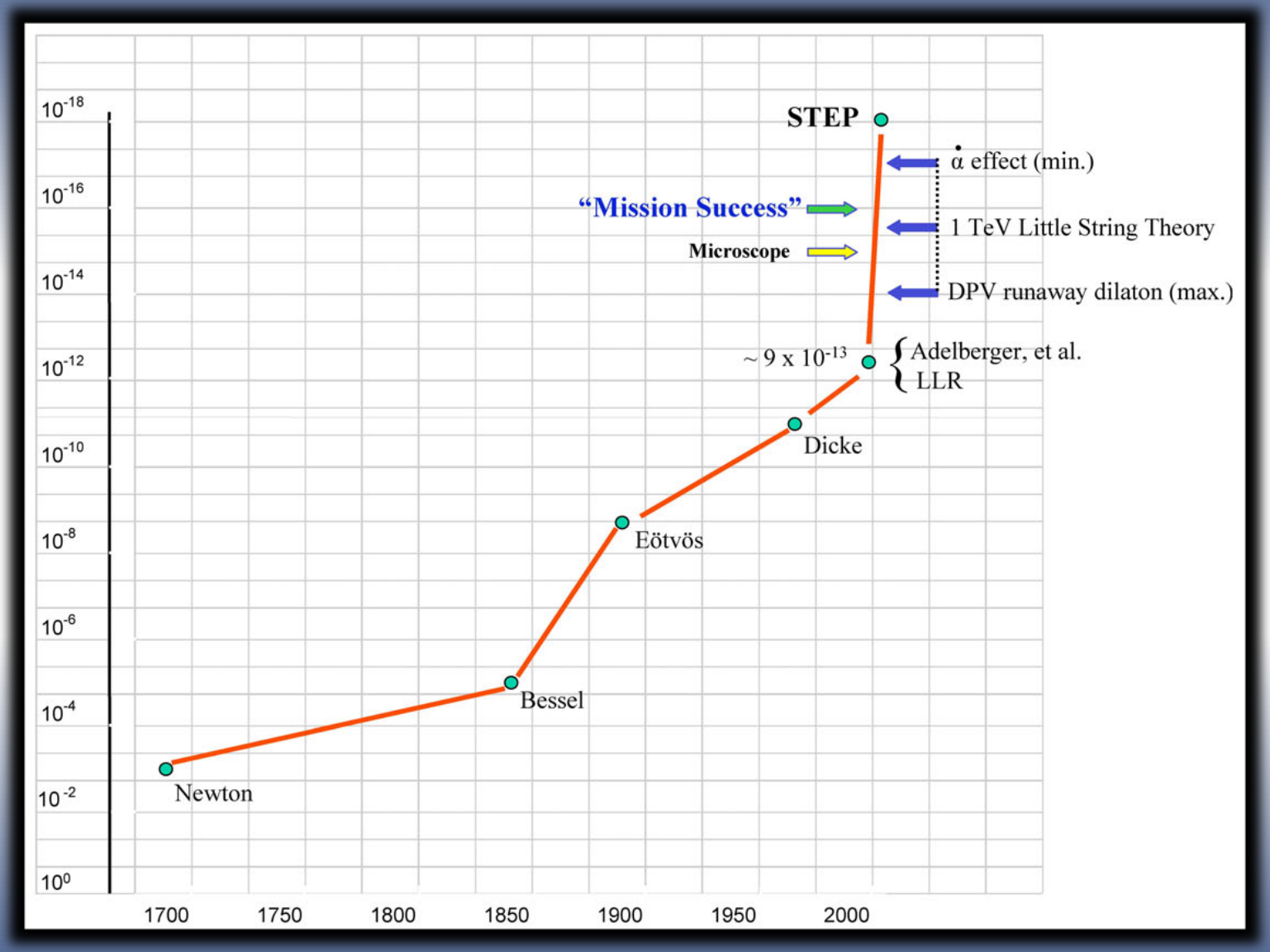


Test of weak equivalence principle
C. Will, Living reviews in general relativity (2006)

Satellite Test of Equivalence Principle



Space > 5 Orders of Magnitute Leap (Everitt)



Bending of light

4. *Über den Einfluß der Schwerkraft auf die Ausbreitung des Lichtes; von A. Einstein.*

Die Frage, ob die Ausbreitung des Lichtes durch die Schwere beeinflußt wird, habe ich schon an einer vor 3 Jahren erschienenen Abhandlung zu beantworten gesucht.[1]) Ich komme

Prag, Juni 1911.

(Eingegangen 21. Juni 1911.)

908 *A. Einstein. Einfluß der Schwerkraft usw.*

Nach Gleichung (4) erleidet ein an einem Himmelskörper vorbeigehender Lichtstrahl eine Ablenkung nach der Seite sinkenden Gravitationspotentials, also nach der dem Himmelskörper zugewandten Seite von der Größe

$$\alpha = \frac{1}{c^2}\int_{\vartheta=-\frac{\pi}{2}}^{\vartheta=+\frac{\pi}{2}} \frac{k\,M}{r^2}\cos\vartheta\cdot ds = \frac{2\,k\,M}{c^2\,\Delta},$$

wobei k die Gravitationskonstante, M die Masse des Himmelskörpers, Δ den Abstand des Lichtstrahles vom Mittelpunkt des Himmelskörpers bedeutet. *Ein an der Sonne vorbeigehender Lichtstrahl erlitte demnach eine Ablenkung vom Betrage* $4\cdot 10^{-6} = 0{,}83$ *Bogensekunden.* Um diesen Betrag erscheint die Winkeldistanz des Sternes vom Sonnenmittelpunkt durch die Krümmung des Strahles vergrößert. Da die Fixsterne der der Sonne zugewandten Himmelspartien bei totalen Sonnenfinsternissen sichtbar werden, ist diese Konsequenz der Theorie mit der Erfahrung vergleichbar. Beim Planeten Jupiter erreicht die zu erwartende Verschiebung etwa $^1/_{100}$ des angegebenen Betrages. Es wäre dringend zu wünschen, daß sich Astronomen der hier aufgerollten Frage annähmen, auch wenn die im vorigen gegebenen Überlegungen ungenügend fundiert oder gar abenteuerlich erscheinen sollten. Denn abgesehen von jeder Theorie muß man sich fragen, ob mit den heutigen Mitteln ein Einfluß der Gravitationsfelder auf die Ausbreitung des Lichtes sich konstatieren läßt.

[11]

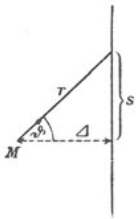


Fig. 3.

[12]

Prag, Juni 1911.

(Eingegangen 21. Juni 1911.)

Max Pechstein:
Bildnis des Erwin Finlay Freundlich, 1919

Bending of light

Schwarzschild Metric

(Communicated Jan. 13, 1916)

(S) $ds^2 = -\left(1-\frac{2M}{r}\right)dt^2 + \frac{1}{1-\frac{2M}{r}}dr^2 + r^2\underbrace{(d\theta^2+\sin^2\theta d\varphi^2)}_{=d\Omega^2}$

Indep. J. Droste (student of H.A. Lorentz), May 1916

Impact on experimental relativity

Eddington, Robertson, ... Will PPN

parametrized post Newtonian

⇝ dimensionless parameters ↔ experiment

The simplest generalization of (S) (no dragging, oblateness, prof. frames)

$$ds^2 = -\left[1-\frac{2M}{r}+2\beta\frac{M^2}{r^2}\right]dt^2 + \left(1+2\gamma\frac{M}{r}\right)dr^2$$

(in general 10 PPN parameters)

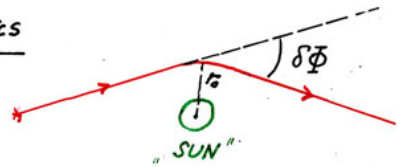
GR: $\beta=\gamma=1$

Advance of the pericentre

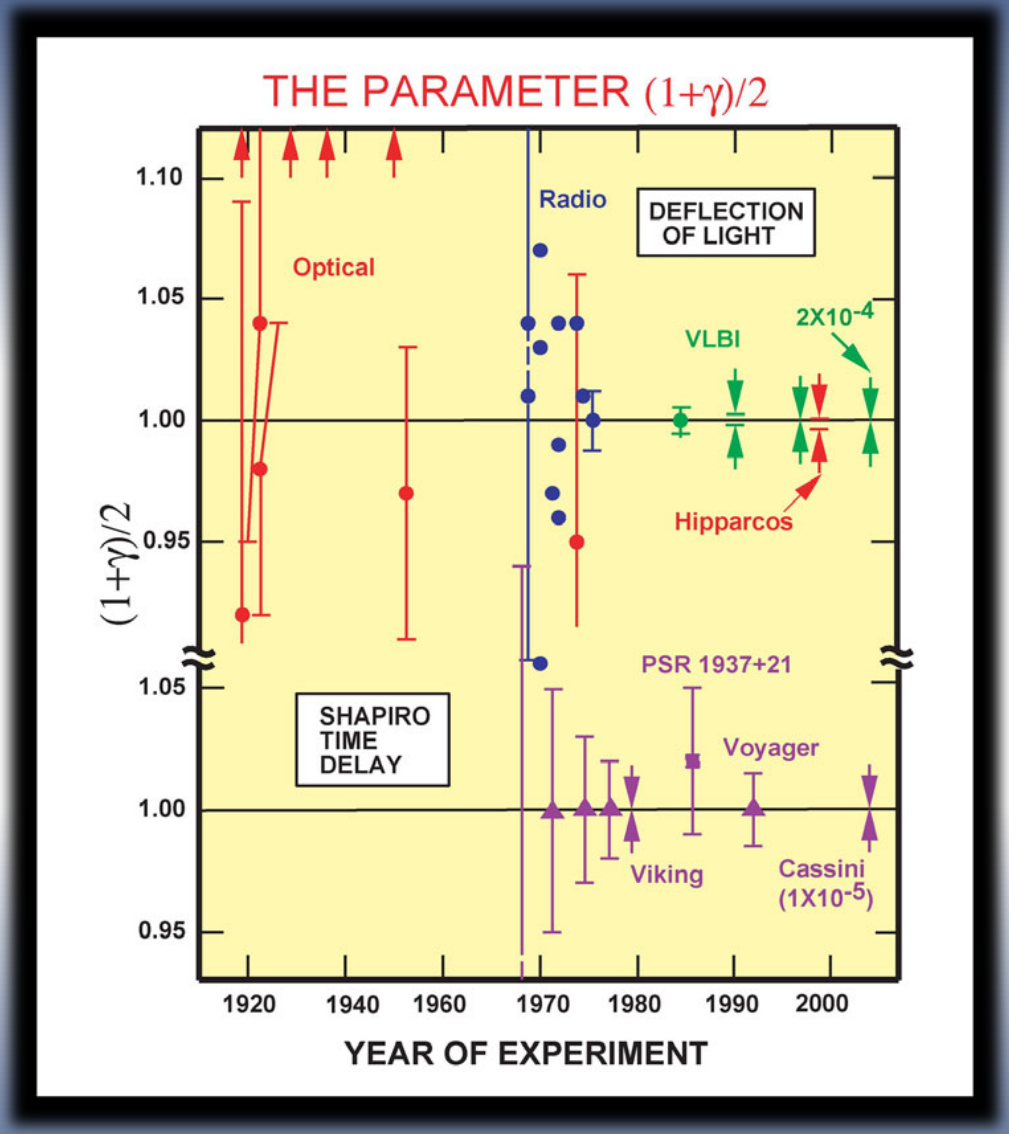
$\Delta\psi = \frac{1}{3}(2+2\gamma-\beta)\,6\pi M/a(1-e^2)$

Total deflection of waves

$$\delta\Phi = \frac{2(1+\gamma)M}{r_0}$$



The parameter γ



Cliff Will, Living Reviews (2006)

A 2004 analysis of ≈ 2 milion VLBI observations of 541 radio sources at 87 VLBI sites:

$$\gamma - 1 = (-1.7 \pm 4.5) \times 10^{-4}$$

Scalar-tensor theories must have

$$\omega > 40000$$

to be compatible

$$\gamma = \frac{1+\omega}{2+\omega}$$

Physics Today, March 2009

Physics Today; March 2009

feature article

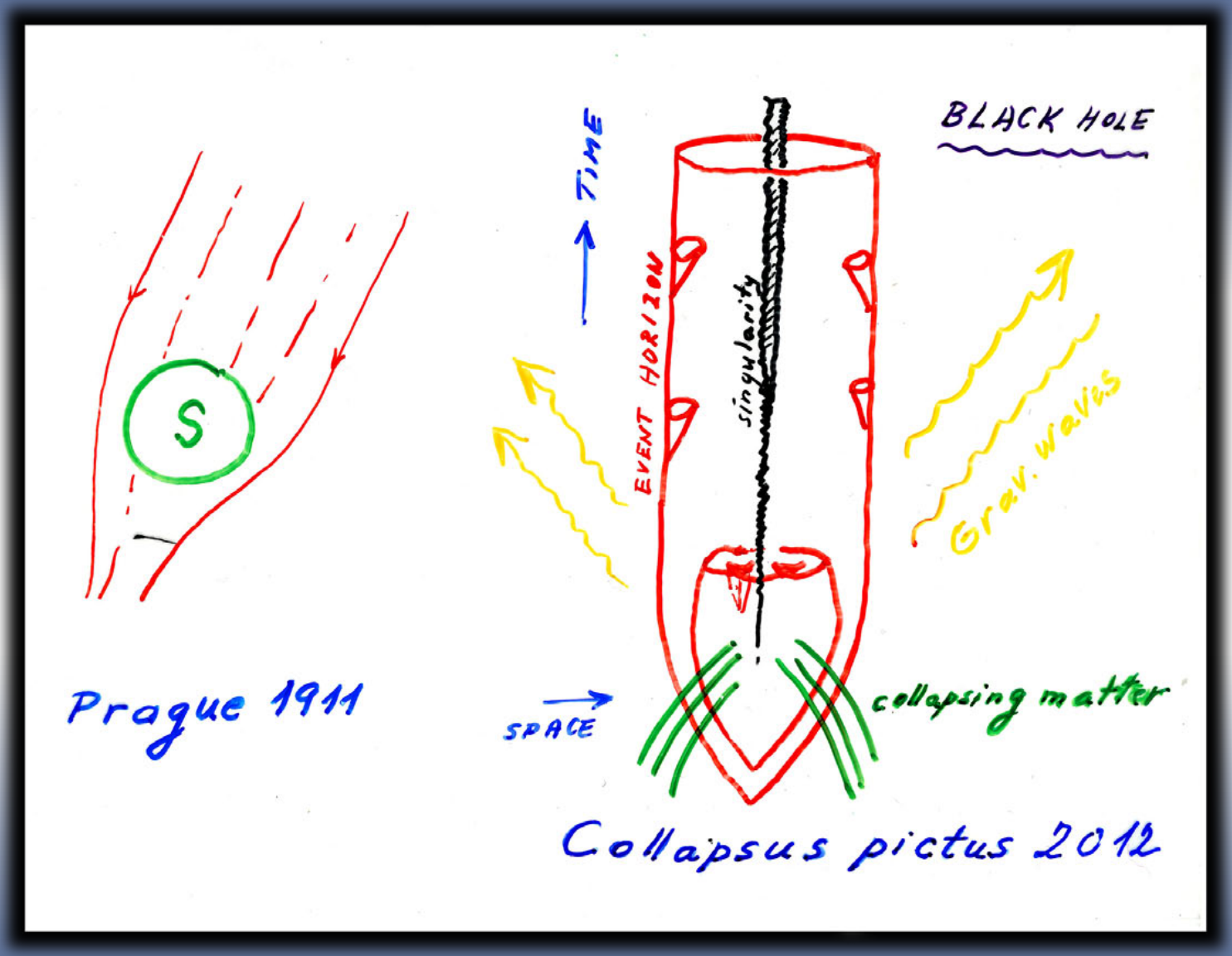
Testing relativity from the 1919 eclipse—a question of bias

Daniel Kennefick

When interpreting experimental results, context is everything. The researchers who took and analyzed the most important eclipse data had good reasons for judging the experiment a victory for Albert Einstein.

Daniel Kennefick is an assistant professor of physics at the University of Arkansas at Fayetteville.

Gravitational collapse



Einstein’s ring

ESA / Hubble & NASA

Collision of 2 galaxy clusters (1E0657-558)

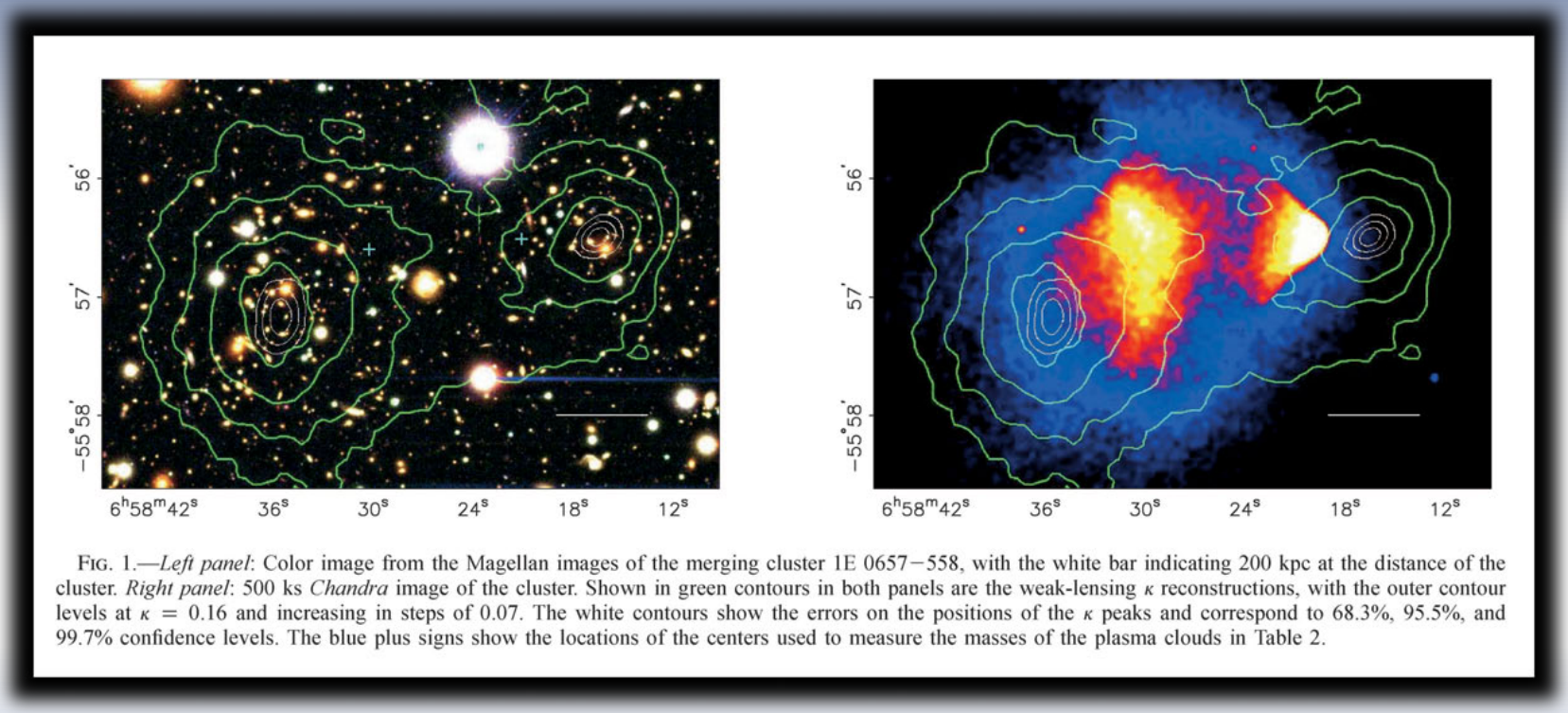


FIG. 1.—*Left panel*: Color image from the Magellan images of the merging cluster 1E 0657−558, with the white bar indicating 200 kpc at the distance of the cluster. *Right panel*: 500 ks *Chandra* image of the cluster. Shown in green contours in both panels are the weak-lensing κ reconstructions, with the outer contour levels at $\kappa = 0.16$ and increasing in steps of 0.07. The white contours show the errors on the positions of the κ peaks and correspond to 68.3%, 95.5%, and 99.7% confidence levels. The blue plus signs show the locations of the centers used to measure the masses of the plasma clouds in Table 2.

Cowley et al (2006)

On the history of gravitational lensing

- Einstein's Scratch Notebook 1912
- Notes by Eddington 1920,
  Chwolson Astron. Nacht. 1924
- Einstein, Science, December 4 1936
  "Lens-like Action of a Star by the Deviation of Light in the Graviatational Field" – interaction with a Czech amateur scientist Rudi Mandl
  J. Renn, T. Sauer, J. Stachel: On the Origin of Gravitational Lensing: A Postscript to Einstein's 1936 Science Paper, Science 1997

  Detailed account in
  J. Renn, T. Sauer: "Eclipses of the Stars – Mandl, Einstein, and the Early History of Gravitational Lensing" in "Revising the Foundations of Relativistic Physics – J. Stachel's Festschrift" Ed. A. Ashtekar *et al*, Kluwer (2003)

František Link

ASTROPHYSIQUE. — *Sur les conséquences photométriques de la déviation d'Einstein.* Note de M. **F. Link**, présentée par M. Charles Fabry.

Dès le début de la théorie de la relativité on a cherché de vérifier la déviation des rayons lumineux passant normalement au champ de gravitation d'un corps céleste. La déviation ω est

constant même très près de l'étoile occultée et à peine supérieur à sa valeur normale. Lorsque la distance apparente s'approche de la valeur

$$\rho_\infty \doteq \sqrt{\mathrm{K}k\alpha_1}.$$

L'intensité commence à augmenter pour atteindre à cette distance la valeur infinie, si l'étoile occultée était rigoureusement ponctuelle. Ce cas

$\rho_\infty = \sqrt{Kk\alpha_1}$ corresponds to angular size of Einstein ring Θ_E

Link F.: Comptus Rendus 202 (16 Mar 1936), 917-919

Sur les conséquences photométriques de la déviation d'Einstein

SUR LES CONSÉQUENCES PHOTOMÉTRIQUES
DE LA DÉVIATION D'EINSTEIN.

Par M. F. LINK.

SOMMAIRE. — La déviation d'Einstein des rayons lumineux dans le champ de gravitation a pour conséquence une modification

il le frapperait en dS. Le rapport $\frac{dS'}{dS}$ donne la modification de l'éclairement en N. On l'obtient d'une façon analogue que nous avons traité l'affaiblissement par la réfraction dans les éclipses de Lune [5]:

$$(5) \qquad \frac{i}{\mathfrak{I}} = \frac{dS'}{dS} = s = \left[1 - \frac{\omega}{\alpha_1 + \alpha_2}\,\frac{a}{R'_0}\right]\left[1 - \frac{d\omega}{dR'_0}\,\frac{a}{\alpha_1 + \alpha_2}\right].$$

Link, F.: Bulletin Astronomique **10** (1937), 73-90

František Link

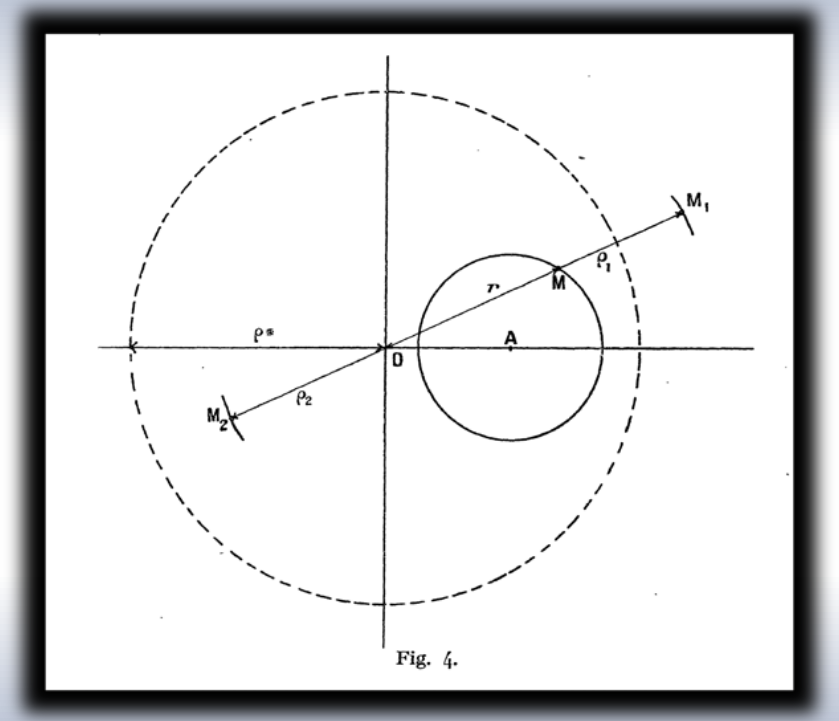
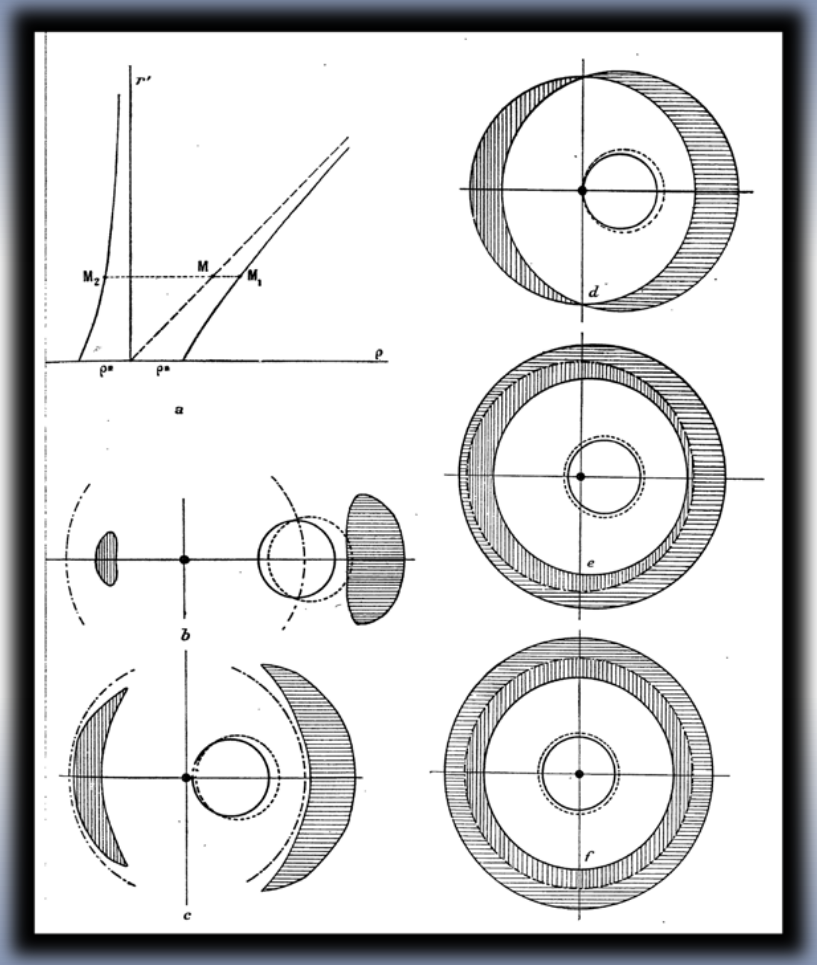


Fig. 4.

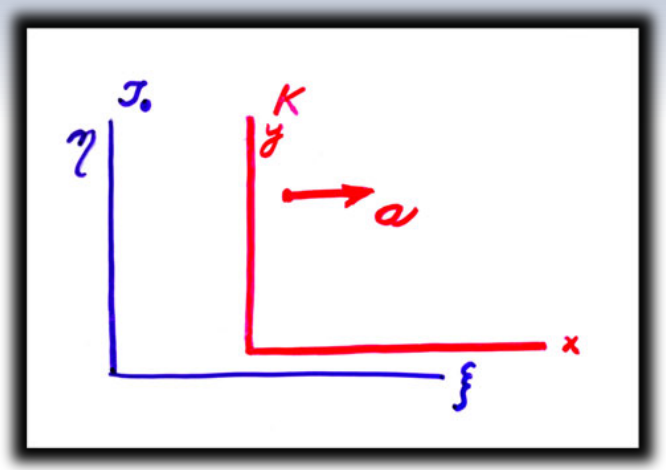


Prague works on gravitation 1912

- **"The speed of light and the statics of the Gravitational Field"** (received 25 Feb)
- On the Theory of the Static Gravitational Field and "Note added in Proof" (reviewed 23 March)
- Is There a Gravitational Effect which is Analogous to Electrodynamic Induction (published July)
- **Relativity and Gravitation**. Reply to a Comment by M. Abraham (received 4 July)

Prague works on gravitation 1912

$\mathcal{I}(\tau, \xi, \eta, \zeta)$
$\mathcal{K}(t, x, y, z)$



assume $\xi = \lambda(x) + \alpha(x)t^2 + \mathscr{O}\left(t^3\right)$
$\tau = \beta(x) + \gamma(x)t + \delta(x)t^2 + \mathscr{O}\left(t^3\right)$

$\eta = y, \quad \zeta = z$ At $t = 0$, $\xi = 0$, $x = 0$

$$\begin{aligned} \mathrm{d}s^2_{\mathcal{I}} &= -c_*^2\mathrm{d}\tau^2 + \mathrm{d}\xi^2 + \mathrm{d}\eta^2 + \mathrm{d}\zeta^2\,, \quad c_* = 1 \\ \mathrm{d}s^2_{\mathcal{K}} &= -c^2(x)\mathrm{d}t^2 + \mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2 \end{aligned}$$

from
$\mathrm{d}s^2_{\mathcal{I}} = 0 \Leftrightarrow \mathrm{d}s^2_{\mathcal{K}} = 0 \quad \Rightarrow \quad \xi = x + \frac{1}{2}\,act^2\,, \quad \tau = ct\,, \qquad c = c_0 + ax$

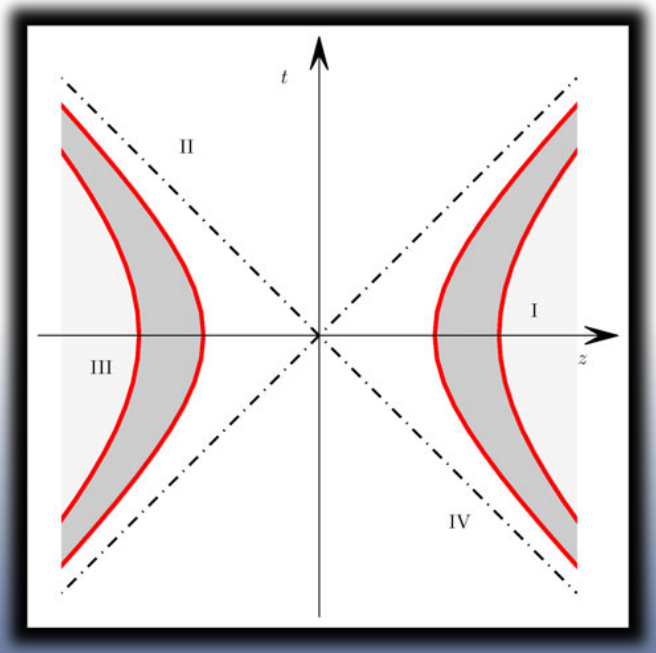
Today

Today transformation to the rigid uniformly accelerated ("Rindler") frame

$$\xi = \frac{1}{a}\left(\cosh at - 1\right) + x\cosh at \tag{2}$$

$$\tau = \frac{1}{a}\sinh at + x\sinh at \tag{3}$$

for small t (i.e. neglecting $\mathscr{O}\left(t^3\right)$) $\Rightarrow$ Einstein's Prague transformation



boost – rotation symmetric spacetimes

- radiative
- plausible Newtonian limit
- asymptotically flat
- C-metric
- etc.

Equations for static gravitational field

Equation for static gravitational field

$$\Delta c = 0 \ \text{(in vacuum)} \qquad \Delta c = kc\rho \ \text{(in matter)}$$

contradictions with conservation of energy and momentum ($\int \vec{f}\,\mathrm{d}V \neq 0$, where $\vec{f} = -\rho\,\mathrm{grad}\,c$)
$\Rightarrow$ modification of the field equation

$$\Delta c = k\left[c\rho + \frac{1}{2k}\frac{\mathrm{grad}^2 c}{c}\right]$$

$\Rightarrow$ **nonlinear field equation**
"local view" on the equivalence principle

$$\xi = x + \frac{1}{2}c\frac{\mathrm{d}c}{\mathrm{d}x}\,t^2, \quad c(x) \text{ arbitrary}$$

see D. Giulini's talk this afternoon

Dragging of intertial frames

The "first" dragging effect (really „quantified")

A. Einstein – 1 of 5 papers on gravitation from the Prague period:

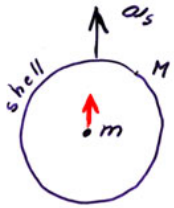
Gibt es eine Gravitationswirkung, die der elektrodynamischen Induktionswirkung analog ist?
[Vierteljahrsschrift für gerichtliche Medizin 44 (1912), 37.]

$$ds^2 = -c^2(x^i)\,dt^2 + dx^2 + dy^2 + dz^2$$

$$\Delta C = k c_g + \frac{1}{2}\frac{\mathrm{grad}^2 C}{c}$$

from PE → eqs. of motion of a test particle

$$\frac{d}{dt}\left[\frac{m\dot{x}}{\sqrt{c^2-\dot{\xi}^2}}\right] = -\frac{mc\,(\partial c/\partial x)}{\sqrt{c^2-\dot{\xi}^2}}$$



Force on m:

$$\frac{3}{2}\frac{GmM}{c^2R}\cdot a_s$$

Lense & Thirring $\omega_{drag} = \frac{4}{3}\frac{GM}{c^2R}\omega_s$

linear in M/R (Brill & Cohen, Pfister & Braun, ...)

DOC. 7 GRAVITATIONAL INDUCTION 175

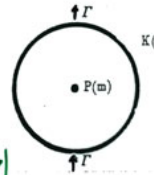
3.

Gibt es eine Gravitationswirkung, die der elektrodynamischen Induktionswirkung analog ist?

Von

Prof. Dr. Einstein-Prag.

Die in der Ueberschrift aufgeworfene Frage kann in Anlehnung an einen übersichtlichen Spezialfall in folgender Weise formuliert werden. Es werde ein System ponderabler Massen betrachtet, bestehend aus der Kugelschale K mit homogen über die Kugelfläche verteilter Masse M und dem im Mittelpunkt dieser Kugelschale angeordneten materiellen Punkt P mit der Masse m. Wirkt auf den festgehaltenen materiellen Punkt P eine Kraft, wenn ich die Schale K eine Beschleunigung Γ erteile? Die folgenden Ueberlegungen werden uns dazu führen, eine solche Kraftwirkung als tatsächlich vorhanden anzusehen und uns die Grösse derselben in erster Annäherung ergeben.



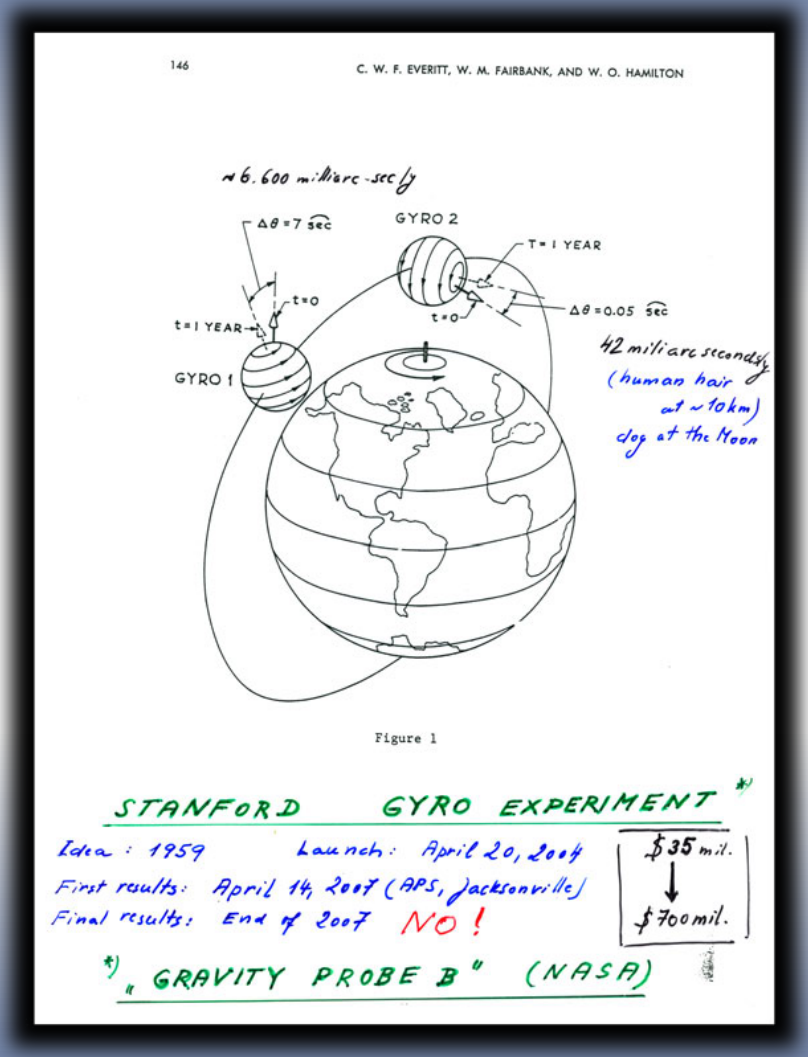
force to hold P: $\frac{3}{2}\frac{GmM\Gamma}{c^2R}$

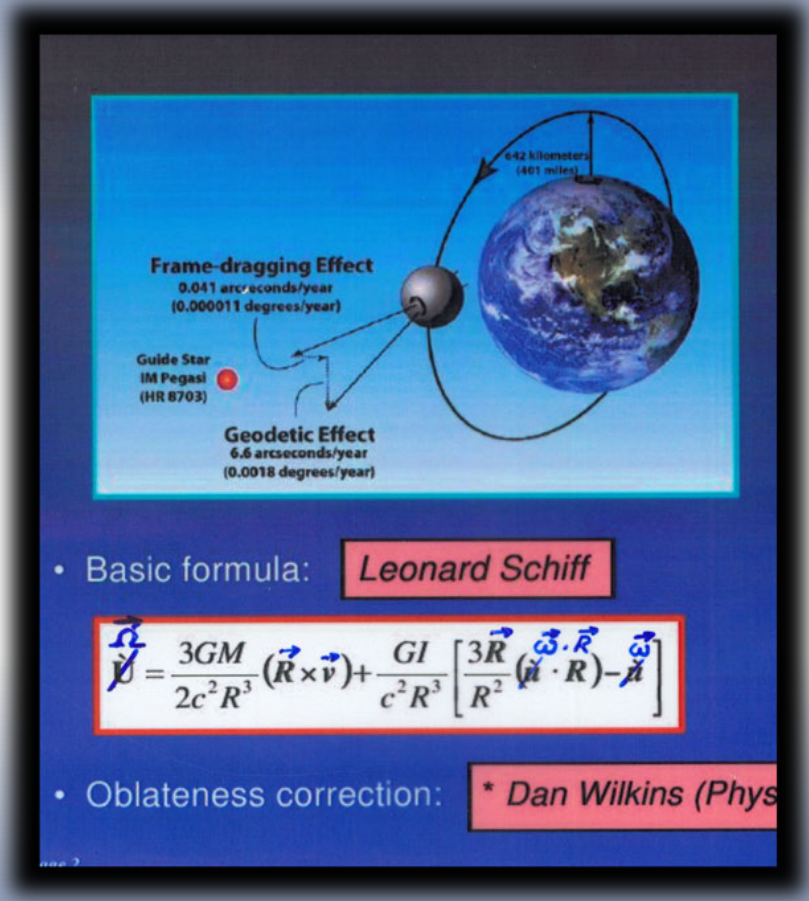
1. Nach der Relativitäts-Theorie ist die träge Masse eines abgeschlossenen physikalischen Systems von dessen Energieinhalt in solcher Weise abhängig, dass ein Energiezuwachs des Systems um E die träge Masse um $\frac{E}{c_0}$ vergrössert, wenn c die Vakuum-Lichtgeschwindigkeit bedeutet. Bezeichnet man also mit M die träge Masse von K bei Abwesenheit von P, und mit m die träge Masse von P bei Abwesenheit von K, oder mit anderen Worten mit M + m die träge Masse des aus P und K zusammen bestehenden Systems für den Fall, dass m sich in unendlicher Entfernung von K befindet, so folgt, dass die träge Masse des aus K und m bestehenden Systems, für den Fall, dass sich m im Mittelpunkt von K befindet, den Wert

$$M + m - \frac{kMm}{Rc^2} \quad \ldots . \quad (1)$$

See D. Lynden-Bell, H. Pfister, C. Schmid this afternoon

Gravity Probe B





Effects of rotating gravitational waves

Jiří Bičák, Joseph Katz, Tomáš Ledvinka, and Donald Lynden-Bell

Rev. D **85**(12), 124003 (2012)

$$\psi_{lm} = \frac{B_l 2^l l! N_l^m P_l^m(\cos\theta)\tilde{r}^l}{[((1+\tilde{r}^2-\tilde{t}^2)^2+4\tilde{t}^2]^{(l+1)/2}}\cos[m\varphi-\lambda(t,r)]$$

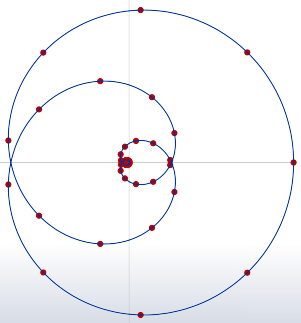
$$\lambda(t,r) = (l+1)\arctan\frac{2\tilde{t}}{1+\tilde{r}^2-\tilde{t}^2} \qquad \tilde{r}=\frac{r}{a},\ \tilde{t}=\frac{t}{a}$$

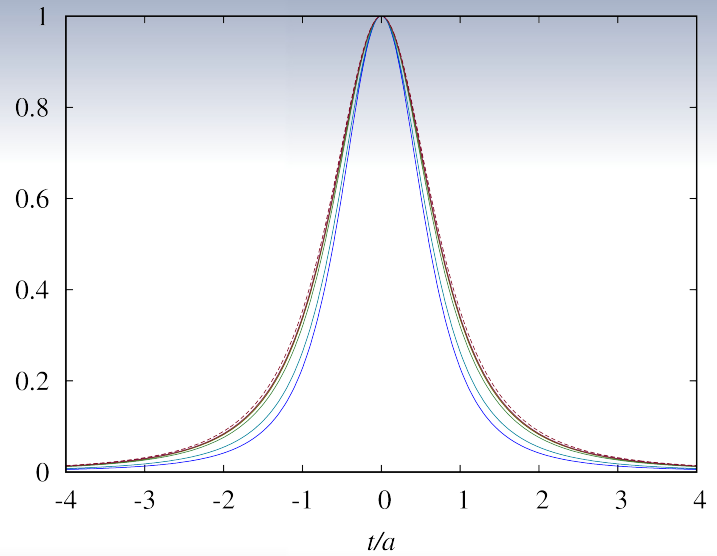
$$h^{(i)}_{\mu\nu} = \sum_{lm}\left[-\frac{\sqrt{2l(l+1)}}{r}h^{(i)}_{0lm}(t,r)c_{0lm\mu\nu} + i\frac{\sqrt{2l(l+1)}}{r}h^{(i)}_{1lm}(t,r)c_{lm\mu\nu}\right]$$

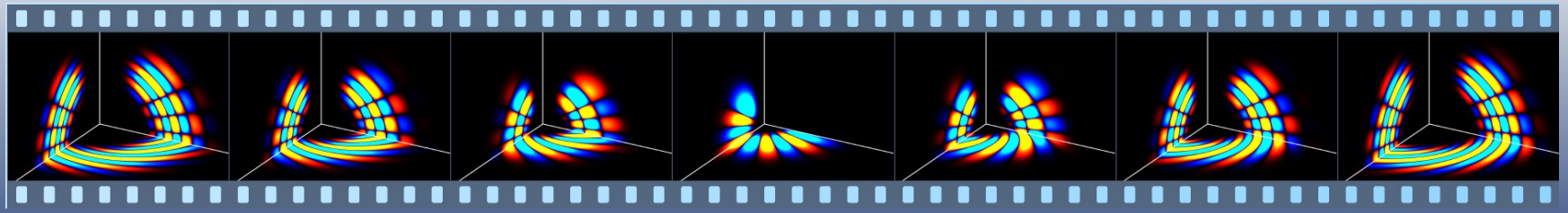
$$G^{(1)}_{\mu\nu}[h^{(2)}] = -G^{(2)}_{\mu\nu}[h^{(1)},h^{(1)}]$$

$$g^{(2)}_{t\varphi} = -\sqrt{\frac{3}{4\pi}}h^{(2)}_0(t,r)\sin^2\theta = -\omega_0 r^2\sin^2\theta$$

$$\omega_0 = \frac{1}{4\pi}\int_0^\infty\int R^{(2)}_{t\varphi}[h^{(1)},h^{(1)}]d\Omega\,\frac{dr}{r}$$







Relativität and Gravitation. Erwiderung…

12. ***Relativität und Gravitation.***
Erwiderung
auf eine Bemerkung von M. Abraham;
von A. Einstein.

In einer in diesen Annalen erscheinenden Notiz hat M. Abraham auf einige von mir geäußerte kritische Bedenken zu seinen Untersuchungen über Gravitation geantwortet, sowie

Allerding scheint der Weg zu diesem Ziele ein recht schwieriger zu sein. Man sieht schon aus dem bischer behandelten, höchst speziellen Falle der Gravitation ruhender Massen, daßdie Raum-Zeit-Koordinaten ihre einfache physikalische Deutung einbüßen werden, und es ist noch nicht abzusehen, welche Form die allgemeinen raumzeitlichen Transformationsgleichungen haben könnten. Ich möchte alle Fachgenossen bitten, sich an diesem wichtigen Problem zu versuchen.

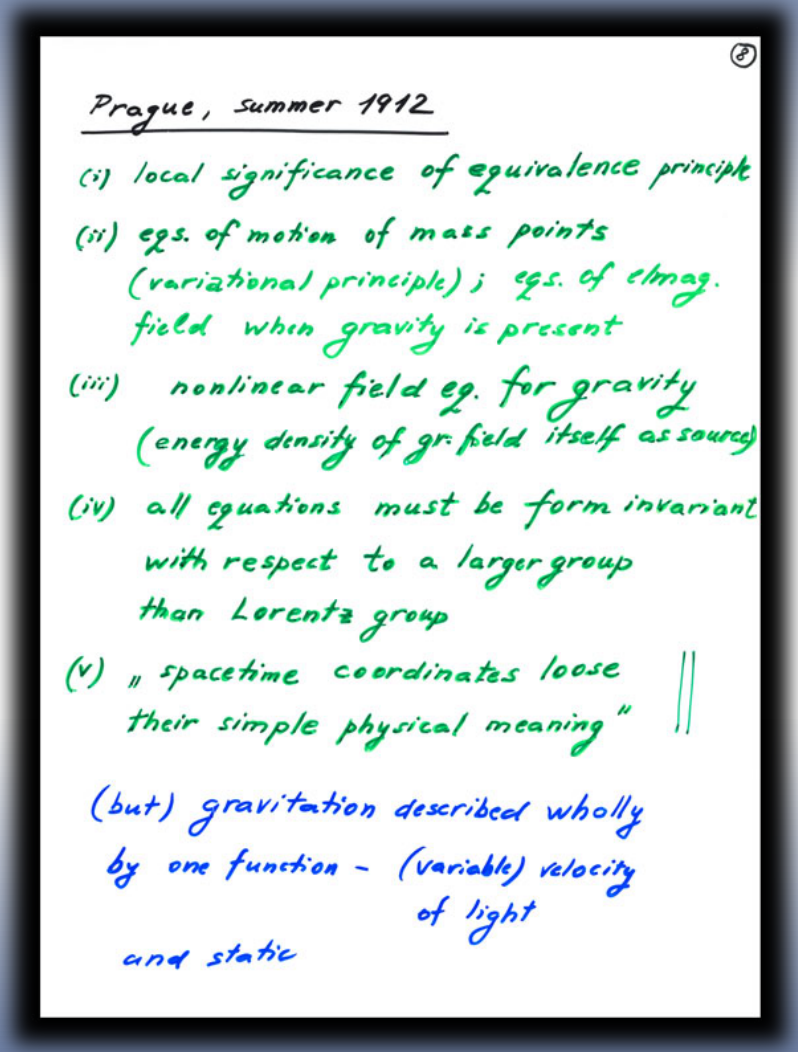
ist beispielsweise die Energiedichte im statischen Schwerefeld $\frac{c^2}{\gamma}\mathrm{grad}^2 c$, nach meiner Theorie $\frac{1}{2k}\frac{\mathrm{grad}^2 c}{c}$. Das Eingehen von c ist in beiden Theorien verschieden.

1) M. Abraham, Physik. Zeitschr. 13. Nr. 19. p. 2. 1912.

(Eingegangen 4. Juli 1912.)

Druck von Metzger & Wittig in Leipzig.

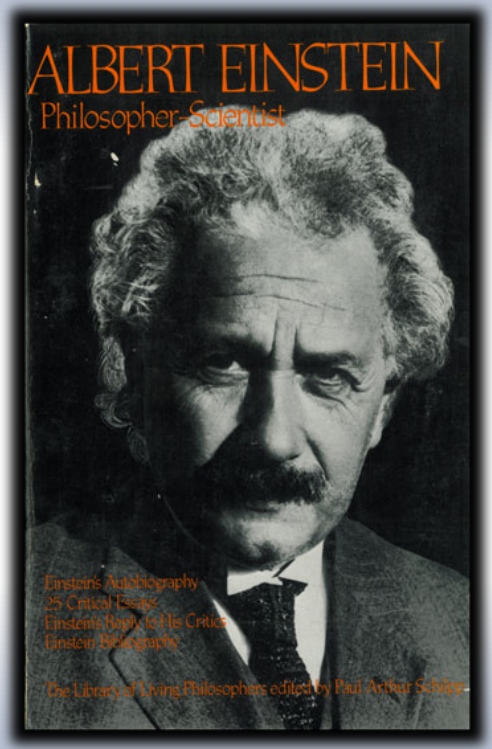
Prague, summer 1912

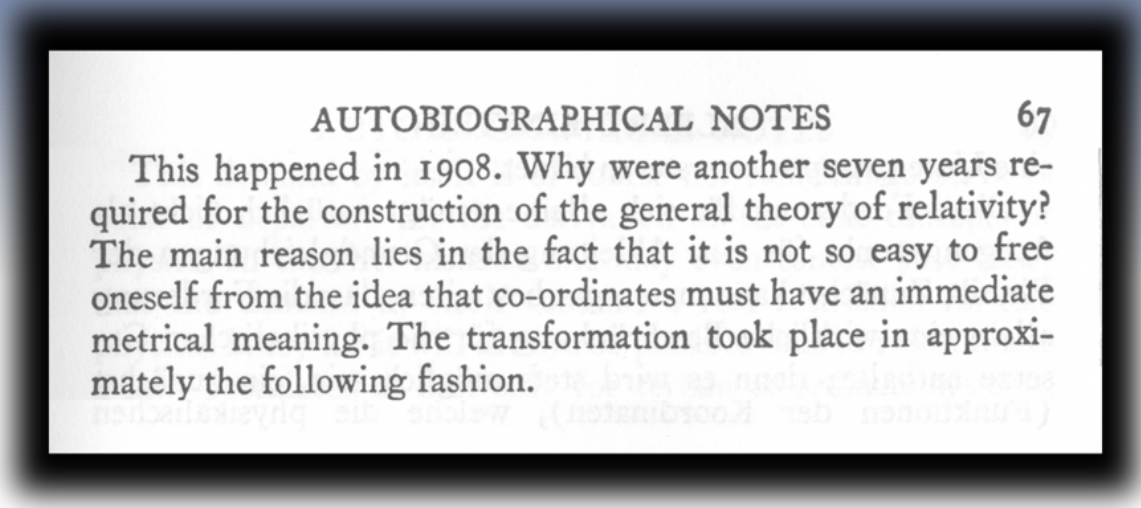


1. local significance of equivalence principle
2. eqs. of motion for mass points (variational principle),
   eqs. of elmag. field when gravity is present
3. nonlinear field eq. for gravity (energy density of gr. field itself as source)
4. all equations must be form invariant with respect to a larger group than Lorentz group
5. **spacetime coordinates loose their simple physical meaning**

(but) gravitation described wholly by one function — (variable) speed of light — and static (stationary)

Philosopher – Scientist



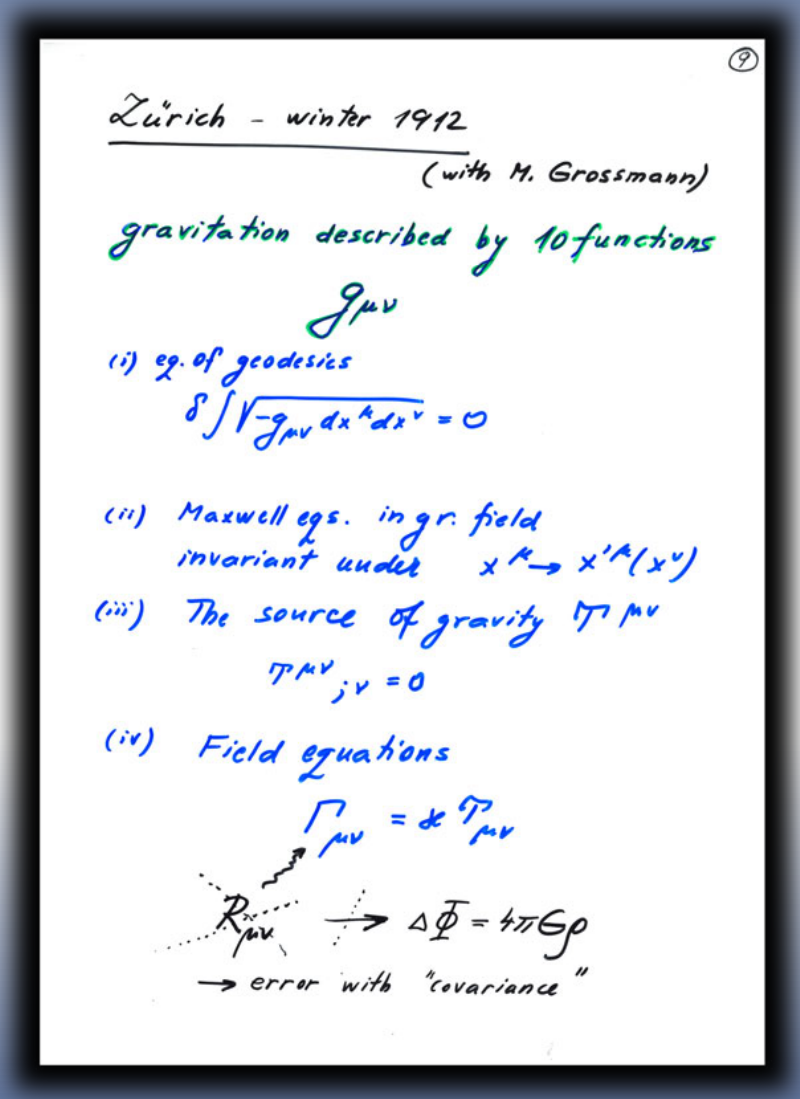


AUTOBIOGRAPHICAL NOTES 67

This happened in 1908. Why were another seven years required for the construction of the general theory of relativity? The main reason lies in the fact that it is not so easy to free oneself from the idea that co-ordinates must have an immediate metrical meaning. The transformation took place in approximately the following fashion.

This happened in 1908. Why were another seven years required for the construction of the general theory of relativity? The main reason lies in the fact that it is not so easy to free oneself from the idea that co-ordinates must have an immediate metrical meaning. The transformation took place in approximately the following fashion.

Zurich, winter 1912



cooperation with M. Grossmann
gravitation described by 10 functions

$$g_{\mu\nu}$$

1. eq. of geodesics

$$\delta \int \sqrt{-g_{\mu\nu} \mathrm{d}x^\mu \mathrm{d}x^\nu} = 0$$

2. Maxwell eqs. in gr. field invariant under $x^\mu \Rightarrow x'^\mu(x^\nu)$
3. the source of gravity $T^{\mu\nu}$

$$T^{\mu\nu}{}_{;\nu} = 0$$

4. field equations

$$\Gamma_{\mu\nu} = \kappa T_{\mu\nu}$$

Einstein Field Equations

25. 11. 1915, Berlin

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \varkappa T_{\mu\nu}$$

Einstein's field equations

"Belatet Decision in the Hilbert-Einstein Priority Dispute", L. Corry, J. Renn,... Science **278**, 14 Nov 1997

Lidové noviny, Saturday 15th May 2004

20 Sobota 15. května 2004 LIDOVÉ NOVINY

Zajímavosti týdne

Einstein očima Johanny z Čech

V těchto dnech by Princetonská univerzita měla začít plnit to, co před měsícem slíbila: odstartovat sérii článků o vztahu mezi Albertem Einsteinem a Johannou Fantovou. Jedním z podkladů jsou i nedávno objevené zápisky, které si fyzikova přítelkyně vedla v posledních dvou letech jeho života.

Marie Homolová

Ty zápisky se našly šťastnou náhodou. Princetonská univerzita se rozhodla připravit seriál o slavných párech, které se vyskytovaly v její historii. A protože se vědělo, že Einstein, který za amerického pobytu v Princetonu působil, a Fantová, která tam pracovala v knihovně, měli k sobě blízko, otevřeli autoři seriálu letos v únoru její dokumentaci. Kromě jiného tu ke svému překvapení našli i deník, obsahující na 62 stránkách více než dvě stovky záznamů.

„V 90. letech se mě řada lidí dotazovala, zda existuje," říká Don Skemer, kurátor zdejší sbírky rukopisů. „Odkazoval jsem je na experty a sbírky po celých Stá-

„Chtěla jsem k tomu, jak Einsteina chápeme, přidat nový pohled," napsala Fantová v úvodu. „Nezachytit ho jako žijící legendu ani jako věhlasného vědce, ale jako člověka."

Z Prahy do Princetonu

Johanna Fantová se narodila roku 1901 v severních Čechách jako Johanna Bobaschová. Její muž Otto byl synem manželů Fantových, kteří před první světovou válkou vedli v pražském domě U bílého jednorožce slavný salon, kde se scházel pražský kulturní svět. Mezi hosty se objevoval i Franz Kafka, Max Brod a... Albert Einstein, který tehdy v letech 1911 a 1912 přednášel v Praze na německé univerzitě fyziku.

Johanna, které tehdy bylo deset a běhala na zcela jiné adrese, se s Einsteinem sešla až v roce 1929 v Berlíně, kde jí nabídl, aby mu uspořádala jeho rozsáhlou, ale chaotickou knihovnu. Ačkoliv je dělilo dvaadvacet let věku, velmi se spřátelili, a nakonec ji přizval i ke své nejmilejší zábavě, jízdě na plachetnici. Když v roce 1939 odjela do Spojených států, znovu se k Einsteinovi, který tam už několik let žil v emigraci, přihlásila.

Einstein už měl za sebou dvě manželství. V roce 1902 se oženil se srbskou studentkou fyziky Milevou, měli spolu dva syny, ale časem se rozvedli. Druhá manželka, setřenice Elsa, ho doprovázela i do Ameriky, kam emigroval

UDÁLOST TÝDNE

Albert Einstein a Johanna Fantová spolu v Americe rádi jachtařili na Lake Carnegie Repro LN

týdně spolu dlouze telefonovali, ona mu stříhala vlasy, on jí psal básně, obnovili i příjemné chvíle na pla-

„Unavený z dlouhého ticha chci ti tímto jasně ukázat, jak silné myšlenky na tebe budou vždy sídlit v jedné

že všichni jsme malé Země, ale každý si myslí, že je jejich středem...

A tak dále.

mera, který vedl americký program vývoje atomové bomby. Když se Oppenheimer, kterého si Einstein velmi považoval, ocitl před McCarthyovým Výborem pro vyšetřování neamerické činnosti, Fantová si zaznamenala, že se to u nich stalo častým předmětem konverzace. „Politická perzekuce jeho přítele byla pro něj hořkým vystřízlivěním," zapsala si.

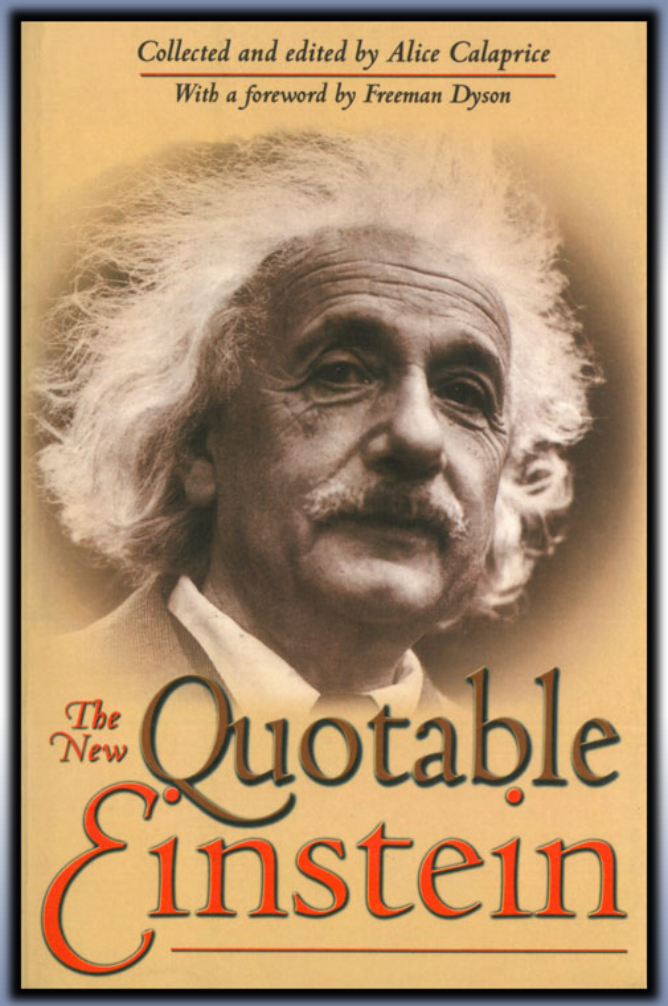
Soucítil s Oppenheimerovým zklamáním, ale o sobě říkal, že se „narodil se sloní kůží" a nikdo mu nemůže ublížit. „Každá kritika po mně steče jako voda."

Přesto si nikdy nepřestal vyčítat, že je svým způsobem odpovědný za tragédie způsobené atomovou bombou. Nejen proto, že k bombě dal jistý podnět svými vědeckými závěry, ale především za druhé světové války napsal prezidentu Rooseweltovi dopis, ve kterém ho varoval, že Němci jsou blízko k sestrojení a je důležité předběhnout je. Ten dopis byl jedním z impulsů, které způsobily, že se americký projekt opravdu rozjel na plné obrátky. Odpovědnost za to, co následovalo, „ho velmi stresovala", zapsala si Fantová.

Zápisy dosvědčují, jak se trápil vývojem světa i tím, že už ho nemůže ovlivnit. Sovětům vrátil mírovou cenu, nechtěl nést nálepku bolševika. A zároveň odmítl varovat před preventivní válkou s Čínou, protože věděl, že by jeho slova padla do prázdna. Zlobil se, že jméno Einstein „zna-

An article about Einstein in Lidové noviny

From: Day-by-Day Summary of Johanna Fantová's Journal

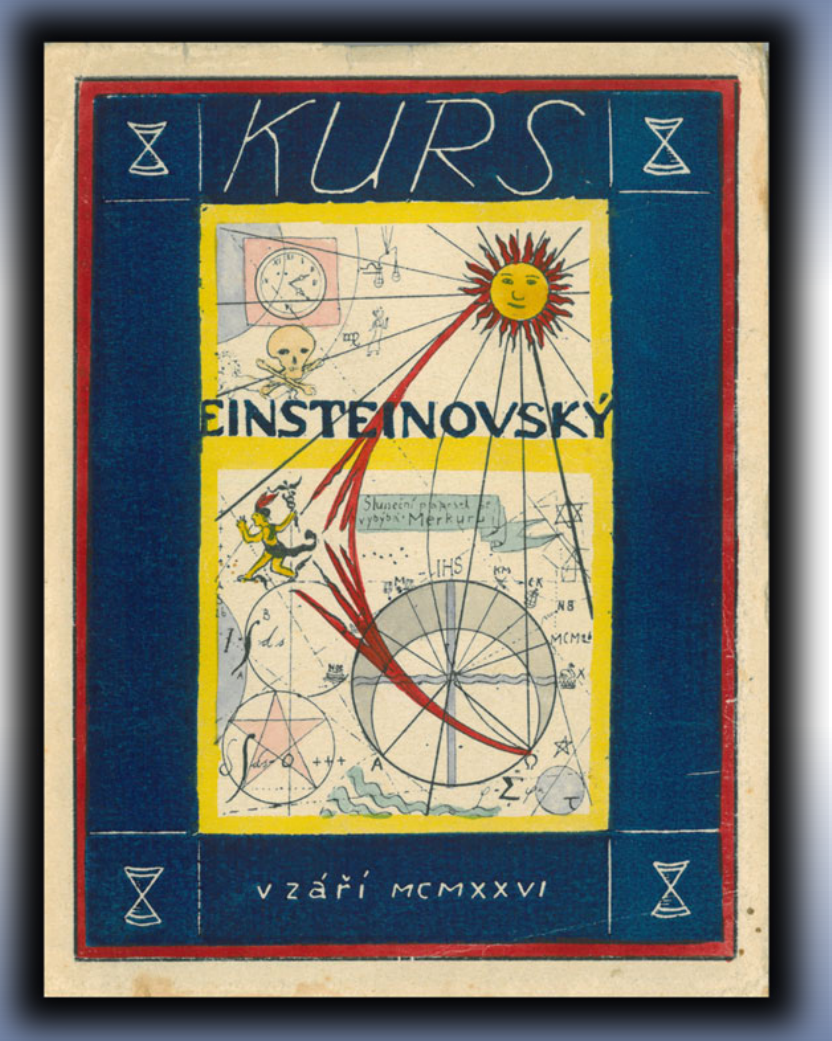


April 13, 1954 Expresses annoyance at Oppenheimer for letting the McCarthy and Atomic Energy Commission affairs bother him so much. Already told the press that he has great respect for Oppenheimer, both as a human being and as a scientist.

October 24, 1954 He calculated like crazy again today but accomplished nothing.

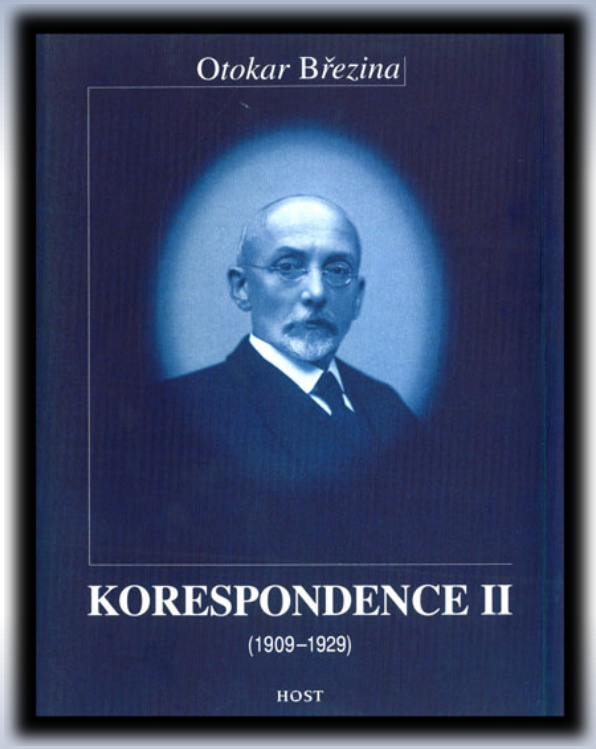
The last but one (AE died in the night, April 18, 1955): **April 10, 1955** He tried all day to compose a radio message on behalf of Israel and did not succeed in finishing it. He claims he is totally stupid – that he ha always thought so, and that only once in a while was he able to accomplish something.

Einstein's course, J. Florian Publisher



Einstein's course (Eddington,. . .),
Stará Říše, September 1926

Otokar Březina



There will always be minds who, by the united force of knowledge and dreams, science and poetry, will strive for a unified picture of the universal processes, an image that in equal measure corresponds both to the eternal longing of the human mind for harmony and beauty and to the thirst of the heart for justice.

Otokar Březina (in the letter to F. Novotný, February 7, 1920)

Einstein's Days and Works in Prague: Relativity Then and Now

Overture:	Biography & Culture
1st Movement:	Lectures & Papers
2nd Movement:	Principle of Equivalence
	Light bending
3th Movement:	Dragging of inertial frames
4th Movement:	Uniform acceleration & static fields
Finale:	Basic features of a theory of gravity
Coda	