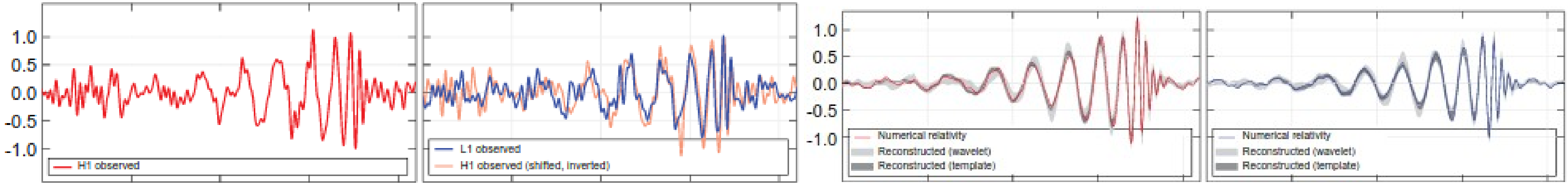
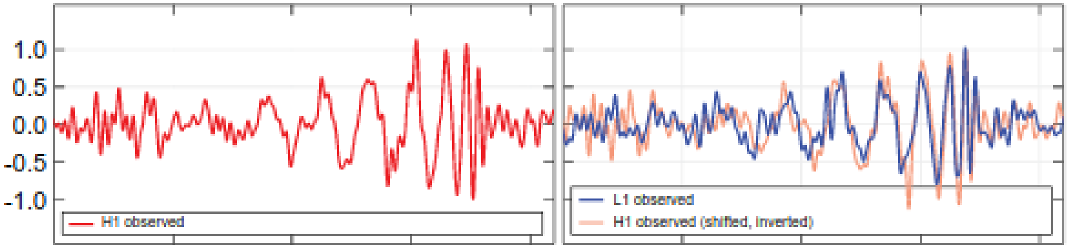


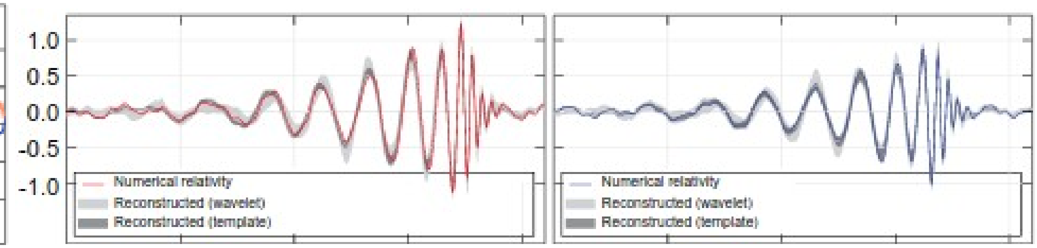

# Viajando à velocidade do pensamento

## breve história das ondas gravitacionais

Alberto Saa

(UNICAMP)

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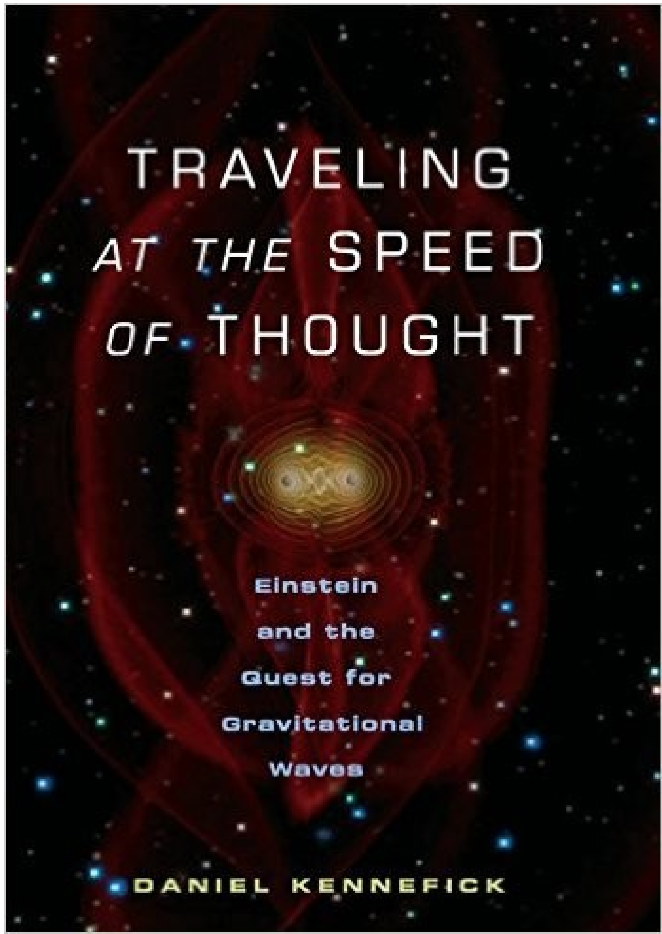

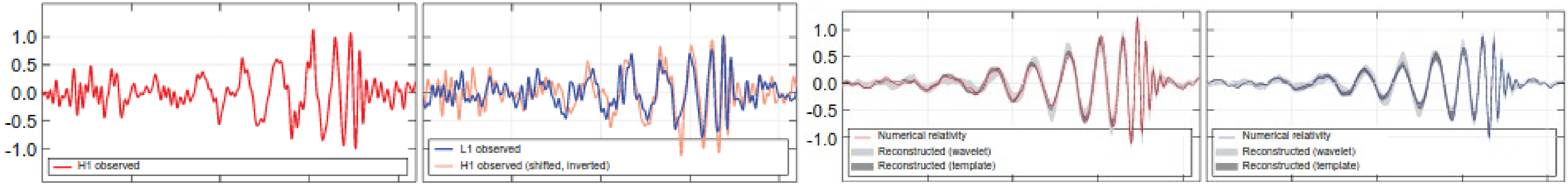


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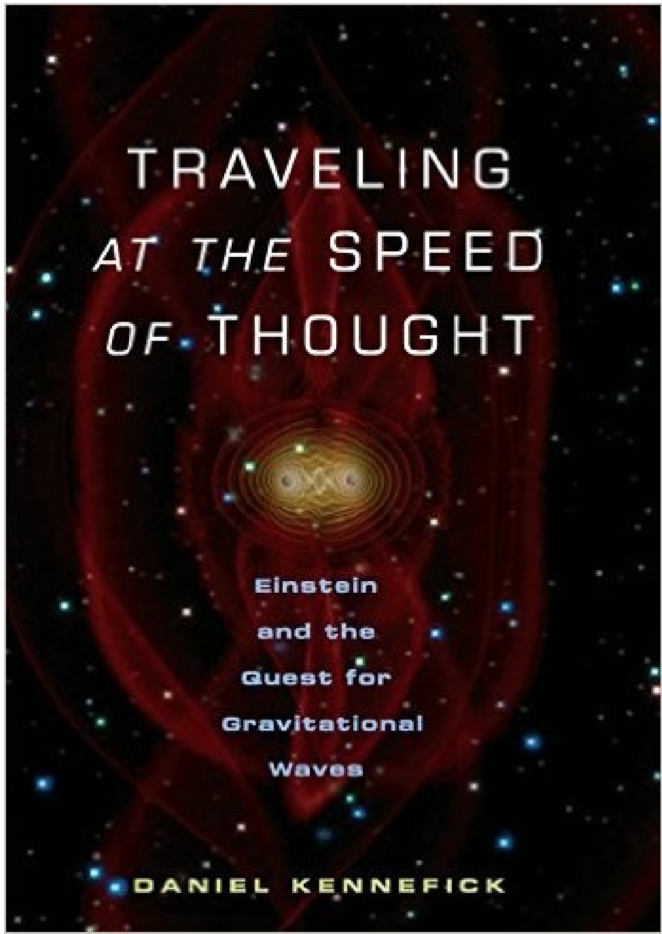


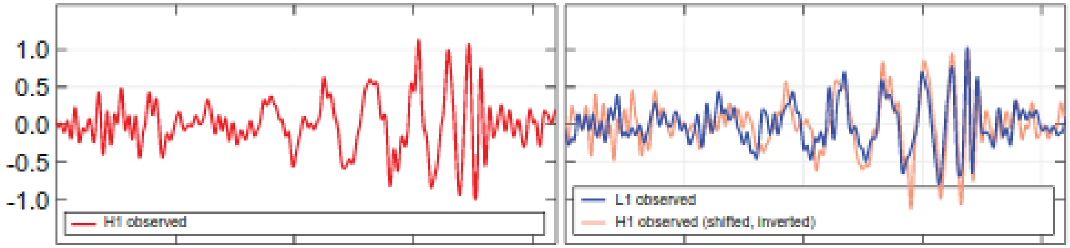

**Controversies in the History of the Radiation Reaction problem in General Relativity**

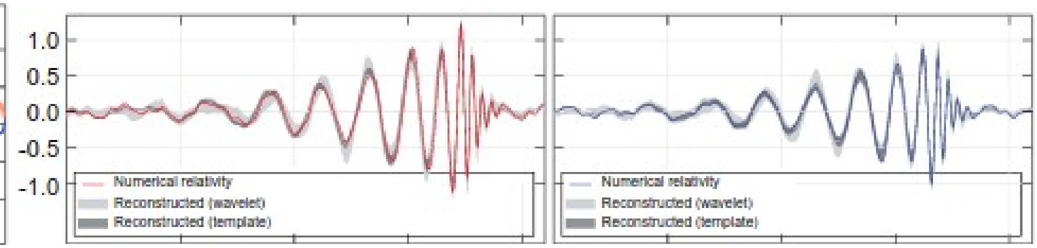
Daniel Kennefick

*(Submitted on 1 Apr 1997)*

This paper examines the historical controversy over whether gravitationally bound systems, such as binary stars, experienced orbital damping due to the emission of gravitational radiation, focusing especially on the period of the 1950s, but also discussing the work of Einstein and Rosen in the 1930s on cylindrical gravitational waves and the later quadrupole formula controversy.

Comments: 33 pages, Latex
Subjects: **General Relativity and Quantum Cosmology (gr-qc)**
Cite as: **arXiv:gr-qc/9704002**
(or **arXiv:gr-qc/9704002v1** for this version)

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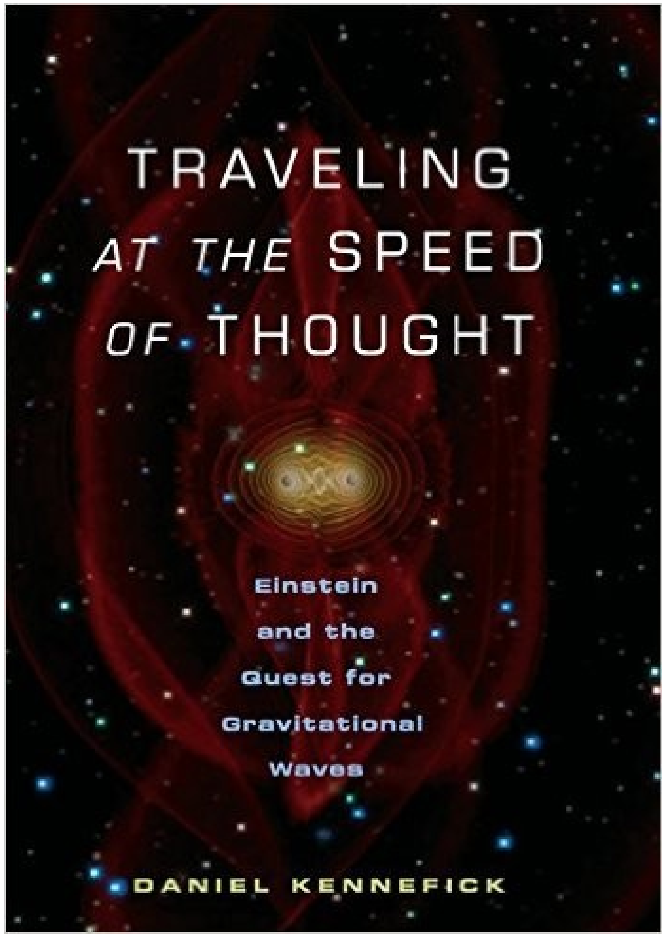


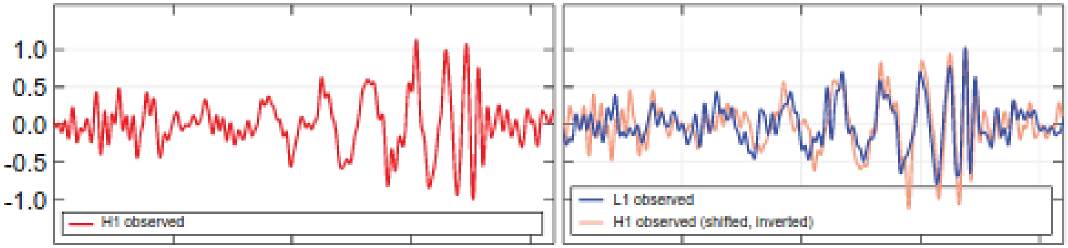

REVISTA BRASILEIRA DE ENSINO DE FÍSICA

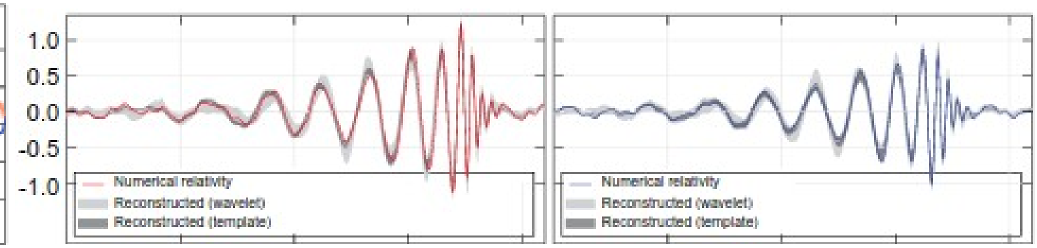
Rev. Bras. Ensino Fís. vol.38 no.4 São Paulo 2016 Epub Oct 10, 2016

http://dx.doi.org/10.1590/1806-9126-RBEF-2016-0191

SEÇÃO ESPECIAL - ONDAS GRAVITACIONAIS

**Cem anos de buracos negros: o centenário da solução de Schwarzschild**




Selected for a Viewpoint in *Physics*

PRL **116,** 061102 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

# Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.*[*]

(LIGO Scientific Collaboration and Virgo Collaboration)

(Received 21 January 2016; published 11 February 2016)

On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal. The signal sweeps upwards in frequency from 35 to 250 Hz with a peak gravitational-wave strain of $1.0 \times 10^{-21}$. It matches the waveform predicted by general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. The signal was observed with a matched-filter signal-to-noise ratio of 24 and a false alarm rate estimated to be less than 1 event per 203 000 years, equivalent to a significance greater than $5.1\sigma$. The source lies at a luminosity distance of $410^{+160}_{-180}$ Mpc corresponding to a redshift $z = 0.09^{+0.03}_{-0.04}$. In the source frame, the initial black hole masses are $36^{+5}_{-4} M_{\odot}$ and $29^{+4}_{-4} M_{\odot}$, and the final black hole mass is $62^{+4}_{-4} M_{\odot}$, with $3.0^{+0.5}_{-0.5} M_{\odot} c^2$ radiated in gravitational waves. All uncertainties define 90% credible intervals.



# Viewpoint: The First Sounds of Merging Black Holes

**Emanuele Berti**, Department of Physics and Astronomy, The University of Mississippi, University, Mississippi 38677, USA and CENTRA, Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Avenida Rovisco Pais 1, 1049 Lisboa, Portugal

February 11, 2016 • *Physics* 9, 17

**Gravitational waves emitted by the merger of two black holes have been detected, setting the course for a new era of observational astrophysics.**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Physics ABOUT BROWSE JOURNALISTS

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1916. № 7.

ANNALEN DER PHYSIK.

VIERTE FOLGE. BAND 49.

## 1. *Die Grundlage der allgemeinen Relativitätstheorie;*

*von A. Einstein.*


# LIGO

Laser Interferometer Gravitational-Wave Observatory
Supported by the National Science Foundation
Operated by Caltech and MIT

## LIGO Catches its Third Gravitational Wave!

**News Release • June 1, 2017**

LIGO detects a third gravitational wave emanating from coalescing black holes.


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WIKIPEDIA
The Free Encyclopedia

Main page
Contents

# List of gravitational wave observations

From Wikipedia, the free encyclopedia

This is a list of observed gravitational wave events. Observation of gravitational waves constitutes part of gravitational wave astronomy.


# New Scientist

DAILY NEWS 23 August 2017, updated 23 August 2017

# Exclusive: We may have detected a new kind of gravitational wave

Nobelprize.org
The Official Web Site of the Nobel Prize

# Announcements of the 2017 Nobel Prizes

The prize committees are currently working carefully and independently to select the recipients of the 2017 Nobel Prize and the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel. The Laureates will be announced starting on 2 October, revealing the scientists, writers and peace workers who - in keeping with the vision of Alfred Nobel - have conferred the greatest benefit to mankind.

All the announcements will be broadcast live on Nobelprize.org.

The prize-awarding institutions have decided to announce their 2017 prize decisions as follows:

**Monday 2 October, 11:30 a.m. at the earliest - The Nobel Prize in Physiology or Medicine**
The Nobel Assembly at Karolinska Institutet, Wallenbergsalen, Nobel Forum, Nobels väg 1, Solna
More information: http://www.nobelprizemedicine.org/
E-mail: nobelforum@nobel.se

**Tuesday 3 October, 11:45 a.m. at the earliest - The Nobel Prize in Physics**
The Royal Swedish Academy of Sciences (Kungl. Vetenskapsakademien, KVA), Sessionssalen, Lilla Frescativägen 4A, Stockholm
More information: http://www.kva.se/en/pressroom/
E-mail: jessica.balksjo@kva.se

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DAILY NEWS 23 August 2017, updated 23 August 2017

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Russell A. Hulse
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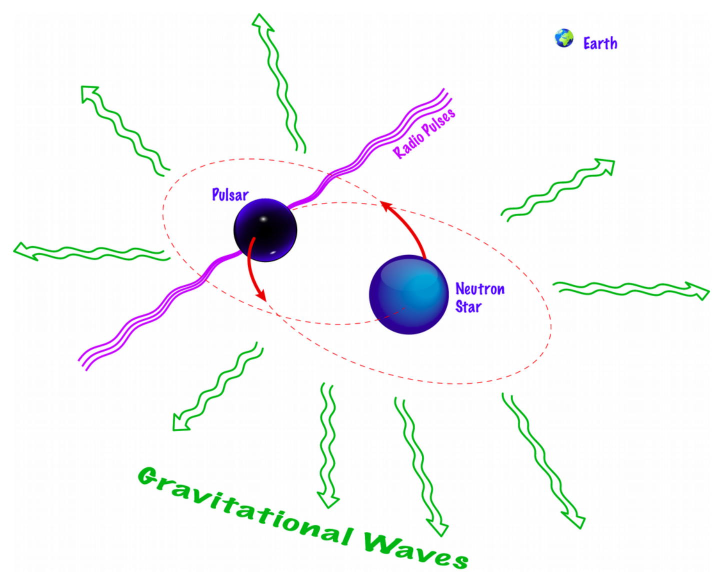

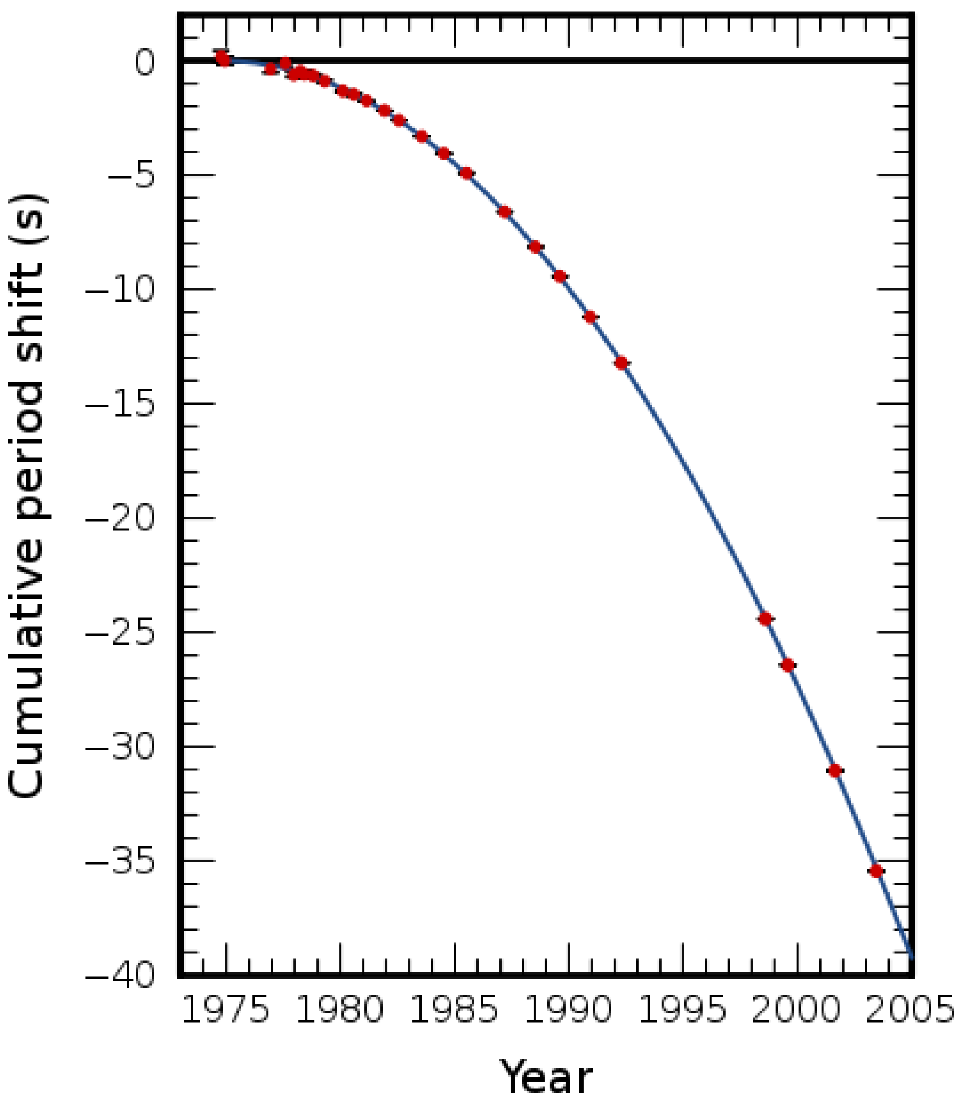


Nobelprize.org
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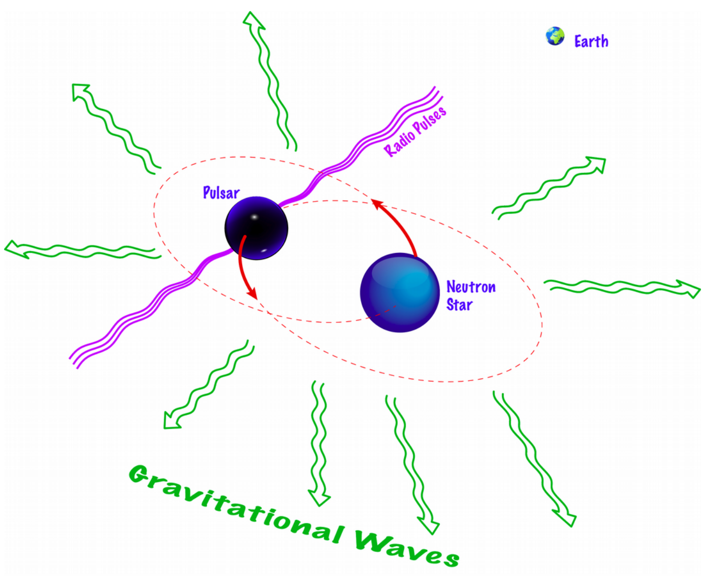

# Ondas gravitacionais

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- Ondas

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- Ondas
- Gravitação

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- Ondas
- Gravitação
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# Pierre-Simon Laplace

(1748-1827)

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TRAITÉ

DE

MÉCANIQUE CÉLESTE,

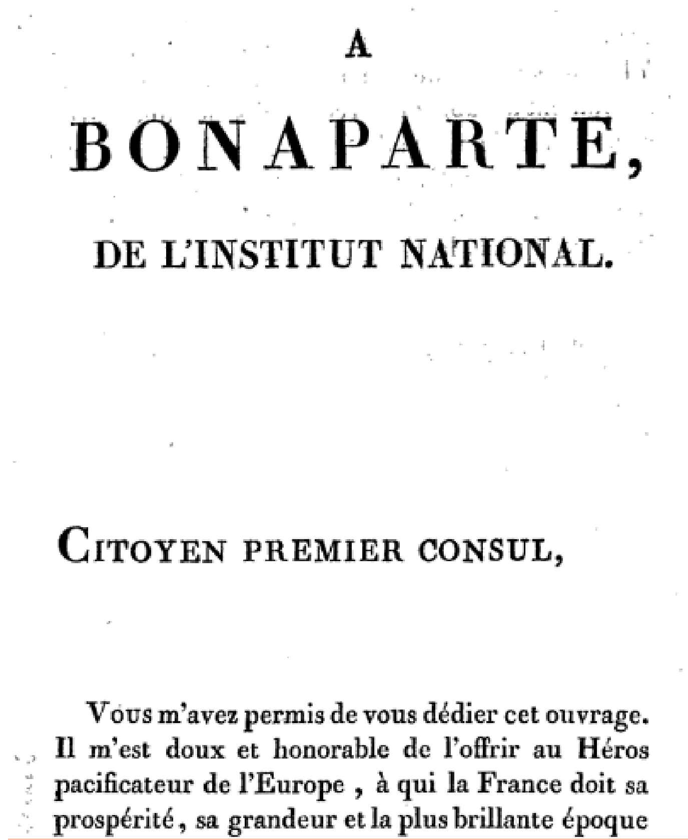
PAR P. S. LAPLACE,

TOME TROISIÈME

DE L'IMPRIMERIE DE CRAPELET

A PARIS,

# Pierre-Simon Laplace
(1748-1827)


A

BONAPARTE,

DE L'INSTITUT NATIONAL.

CITOYEN PREMIER CONSUL,

Vous m'avez permis de vous dédier cet ouvrage. Il m'est doux et honorable de l'offrir au Héros pacificateur de l'Europe, à qui la France doit sa prospérité, sa grandeur et la plus brillante époque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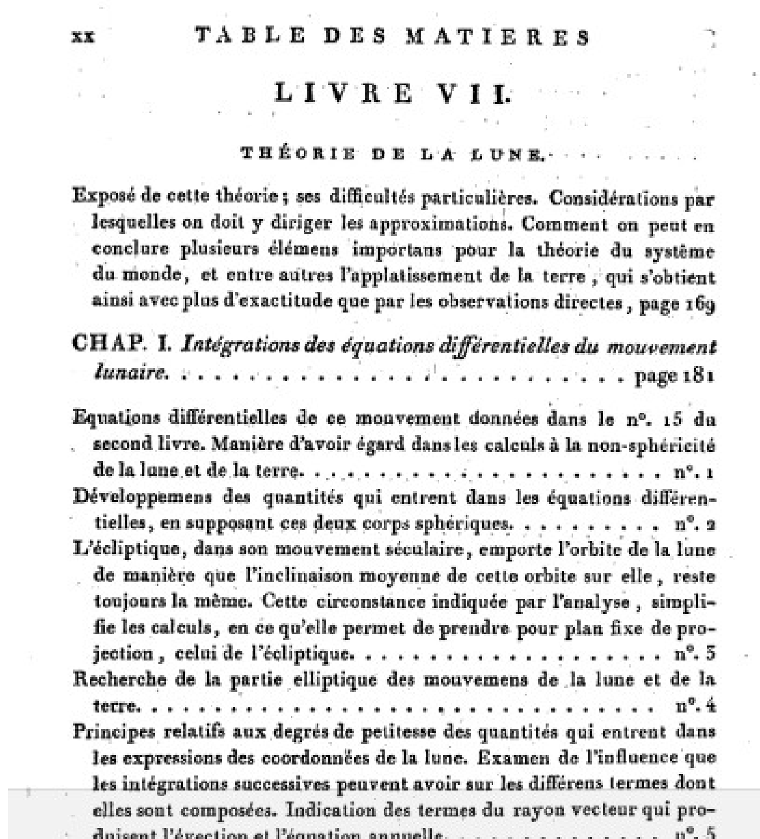



LIVRE VII.

THÉORIE DE LA LUNE.

Exposé de cette théorie; ses difficultés particulières. Considérations par lesquelles on doit y diriger les approximations. Comment on peut en conclure plusieurs élémens importans pour la théorie du système du monde, et entre autres l'applatissement de la terre, qui s'obtient ainsi avec plus d'exactitude que par les observations directes, page 169

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Développemens des quantités qui entrent dans les équations différentielles, en supposant ces deux corps sphériques. . . . . . . . . . . n°. 2

L'écliptique, dans son mouvement séculaire, emporte l'orbite de la lune de manière que l'inclinaison moyenne de cette orbite sur elle, reste toujours la même. Cette circonstance indiquée par l'analyse, simplifie les calculs, en ce qu'elle permet de prendre pour plan fixe de projection, celui de l'écliptique. . . . . . . . . . . . . . . . . . . . n°. 3

Recherche de la partie elliptique des mouvemens de la lune et de la terre. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . n°. 4

Principes relatifs aux degrés de petitesse des quantités qui entrent dans les expressions des coordonnées de la lune. Examen de l'influence que les intégrations successives peuvent avoir sur les différens termes dont elles sont composées. Indication des termes du rayon vecteur qui produisent l'évection et l'équation annuelle. . . . . . . . . . . . . . n°. 5

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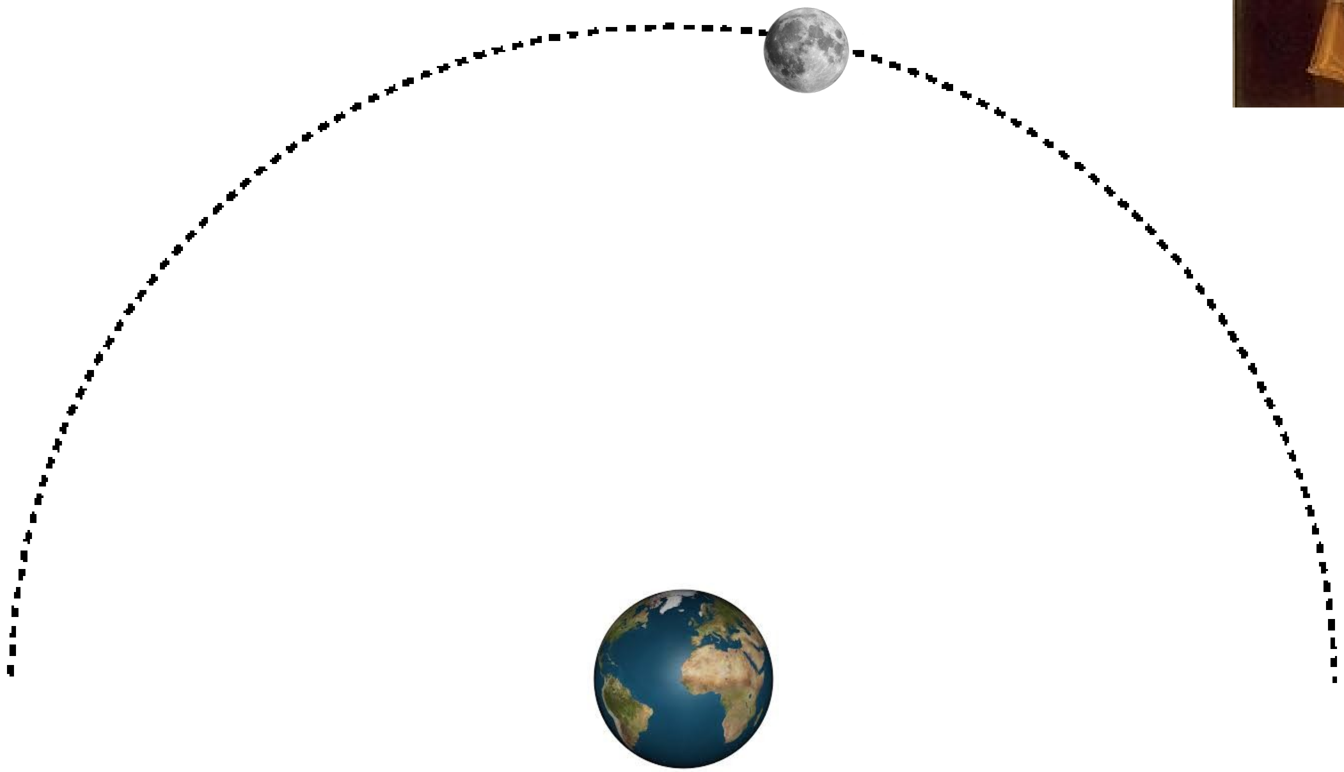

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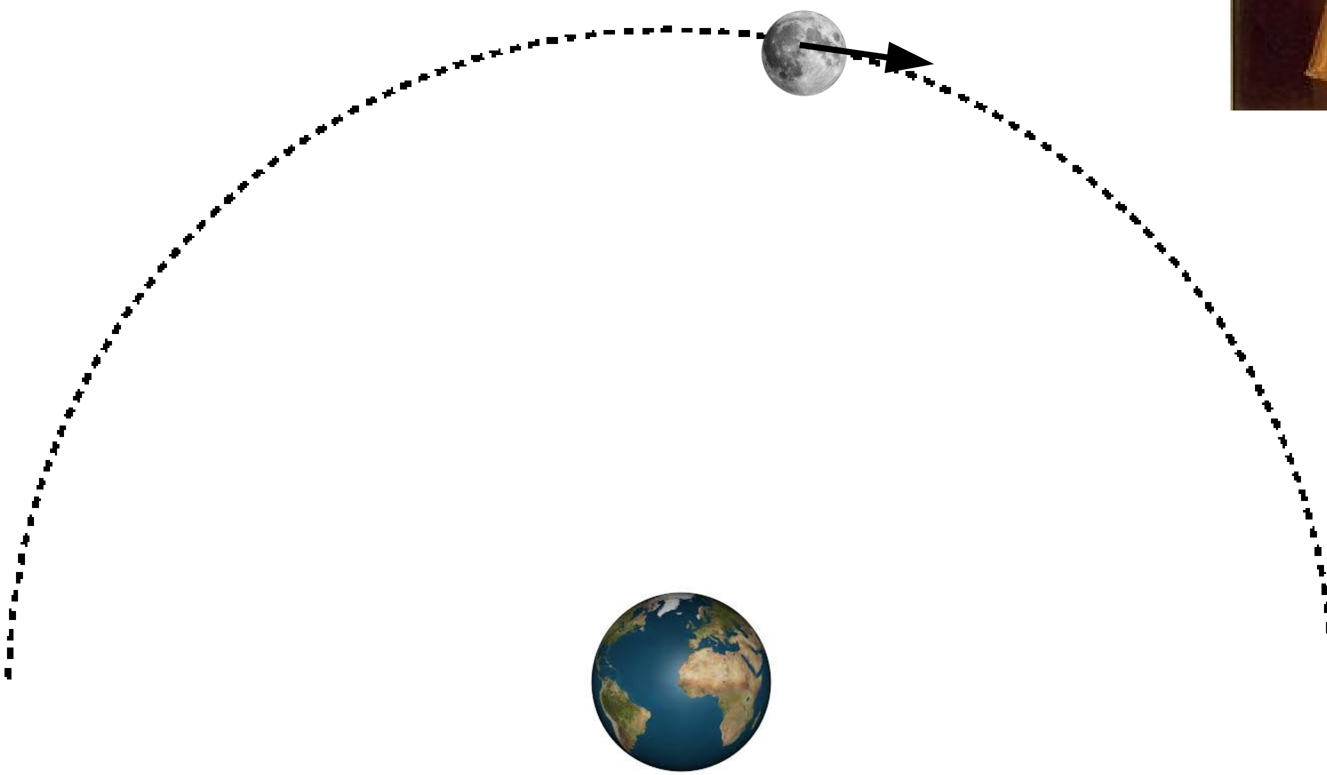

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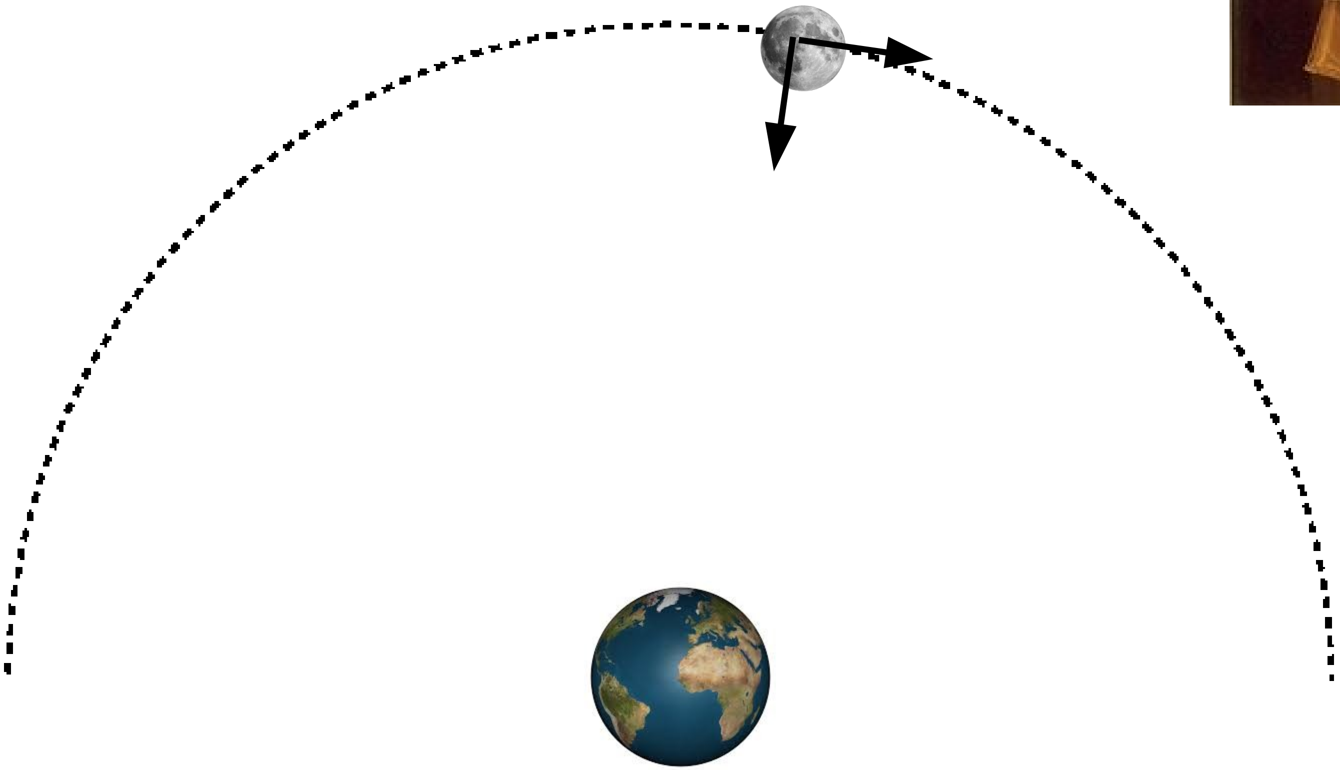

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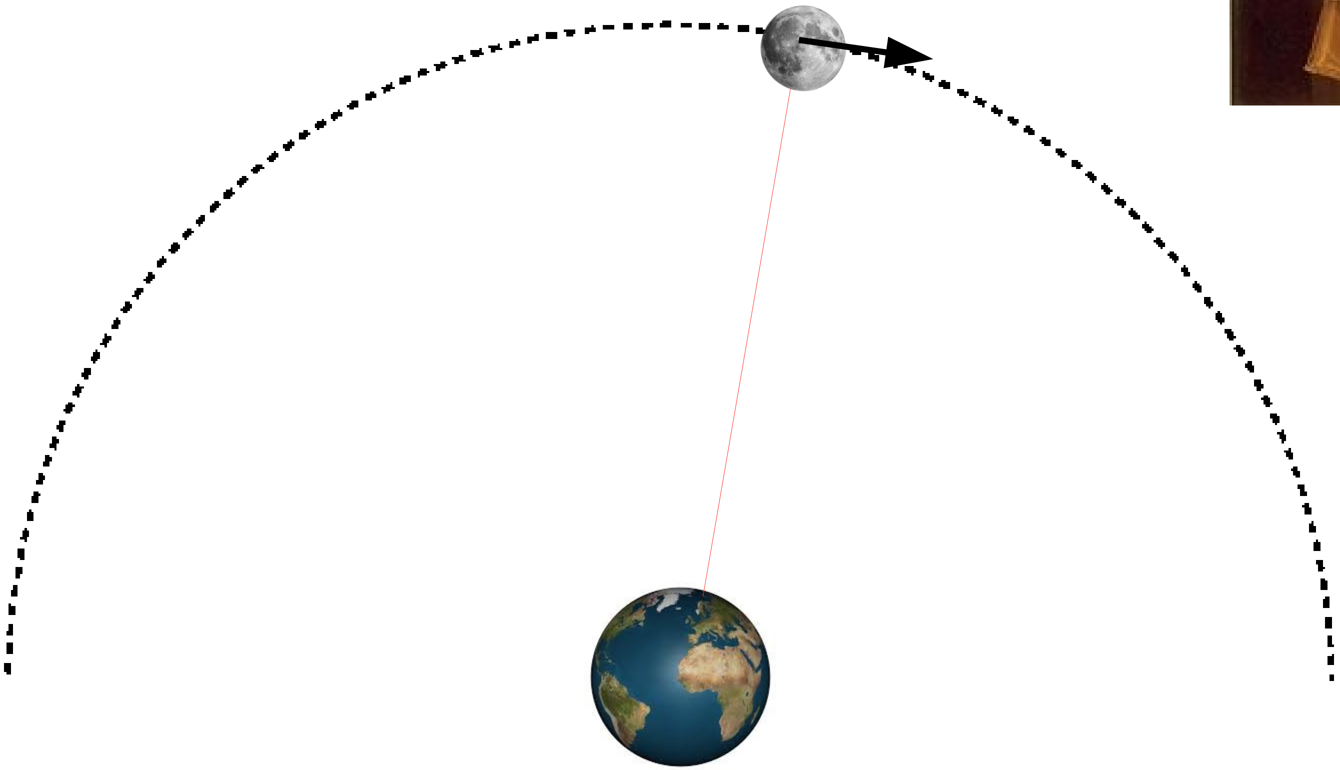

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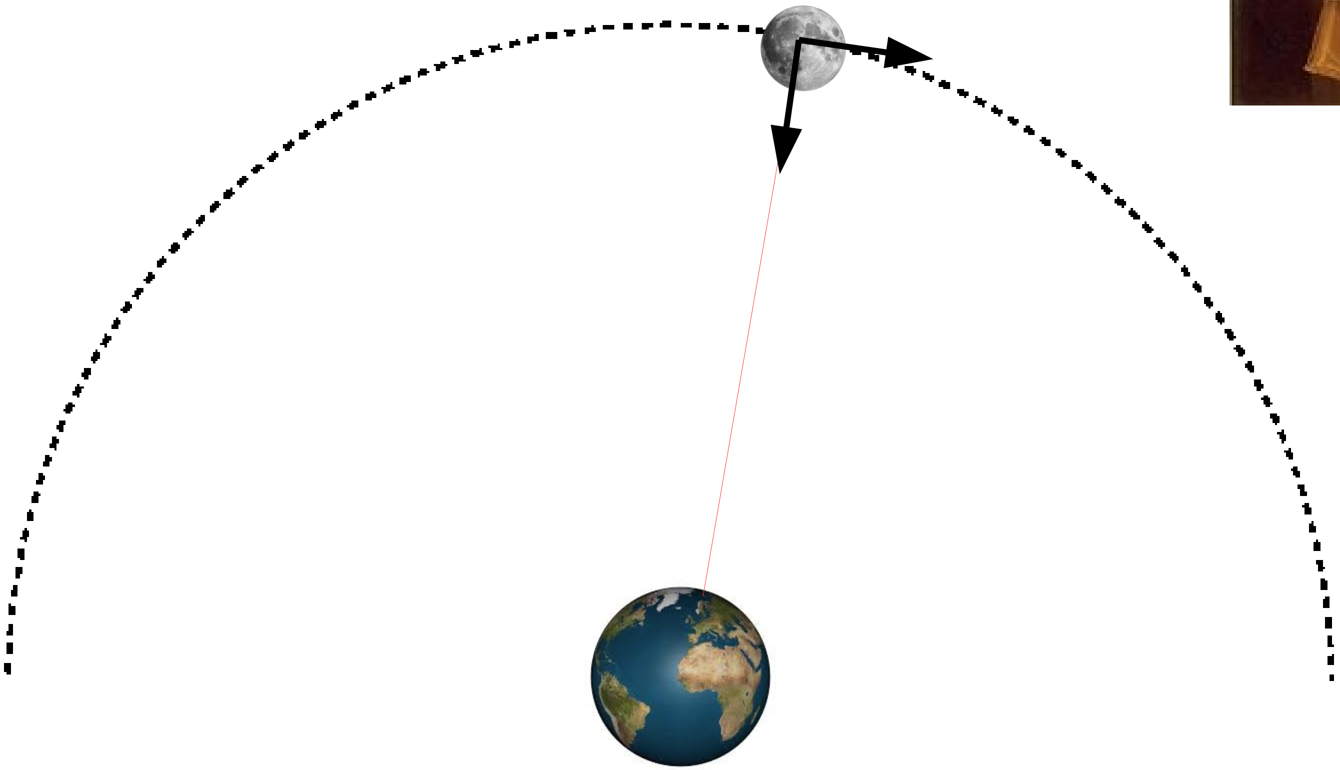

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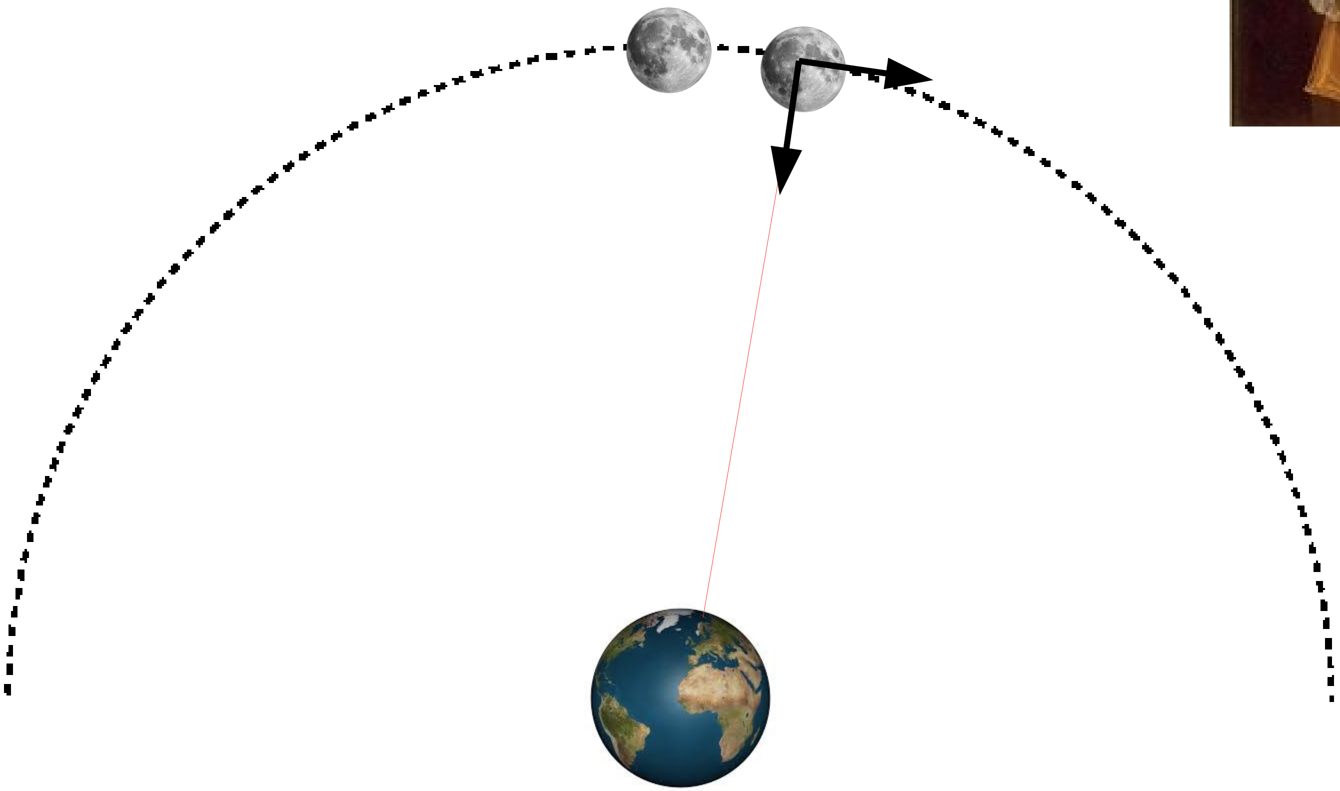

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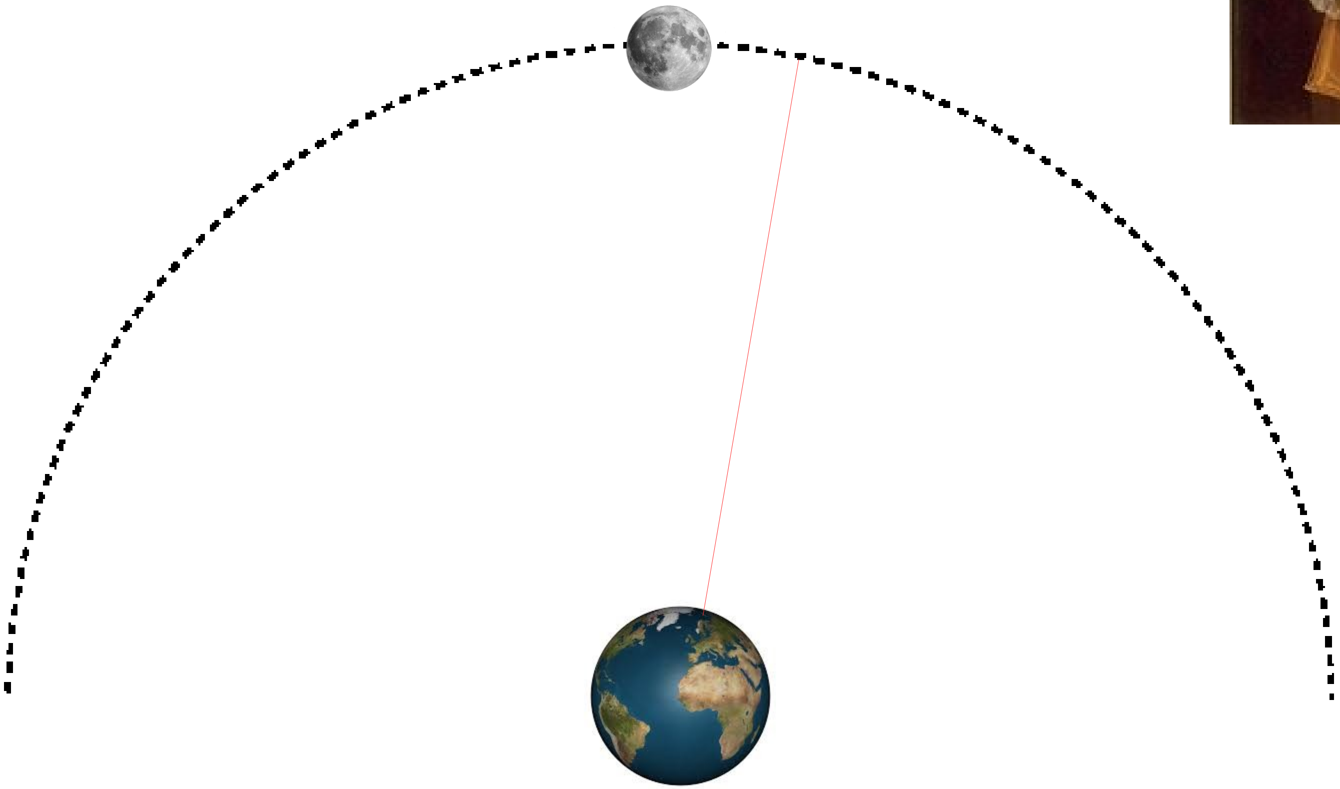

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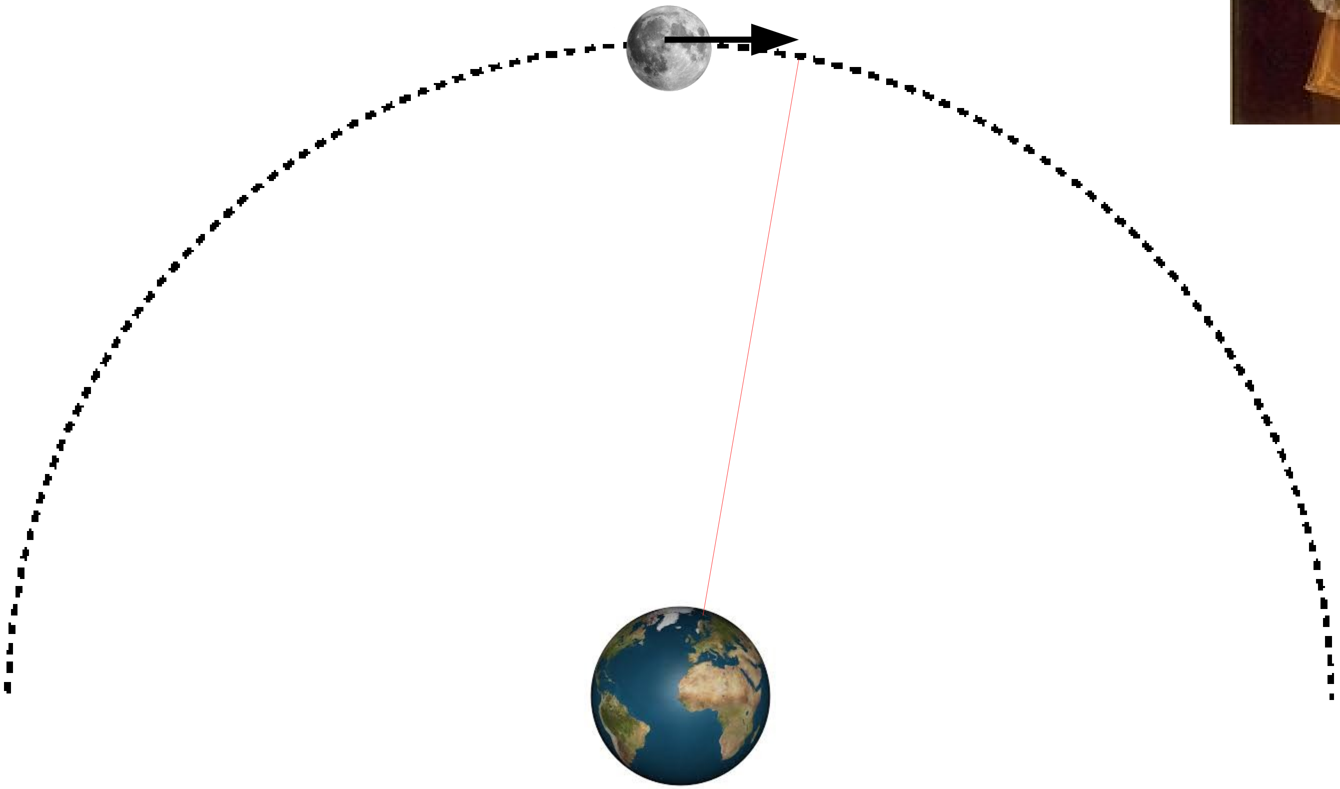

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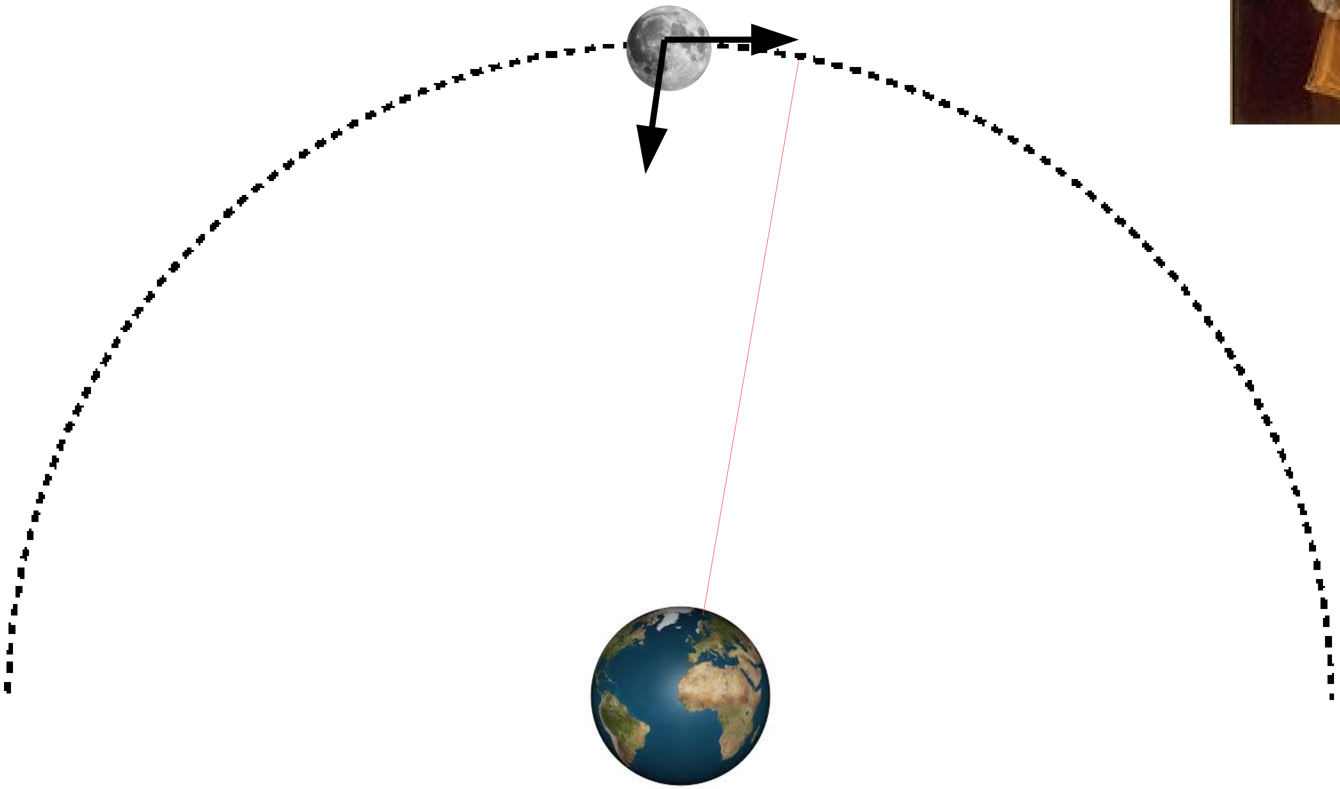

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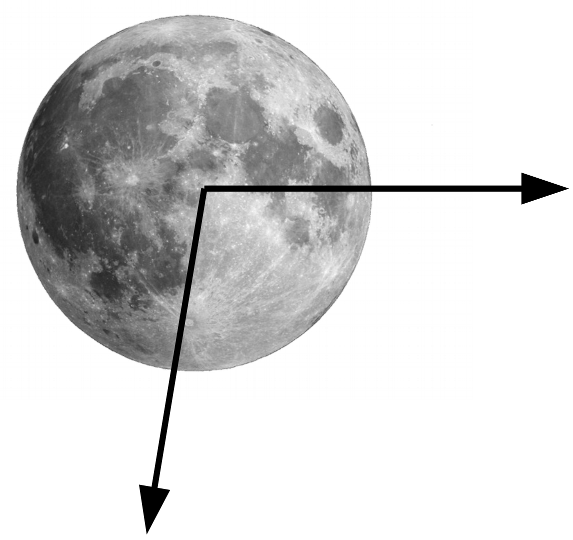

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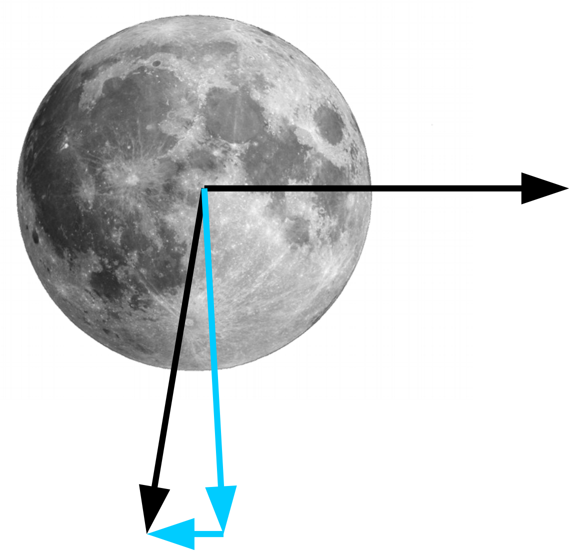

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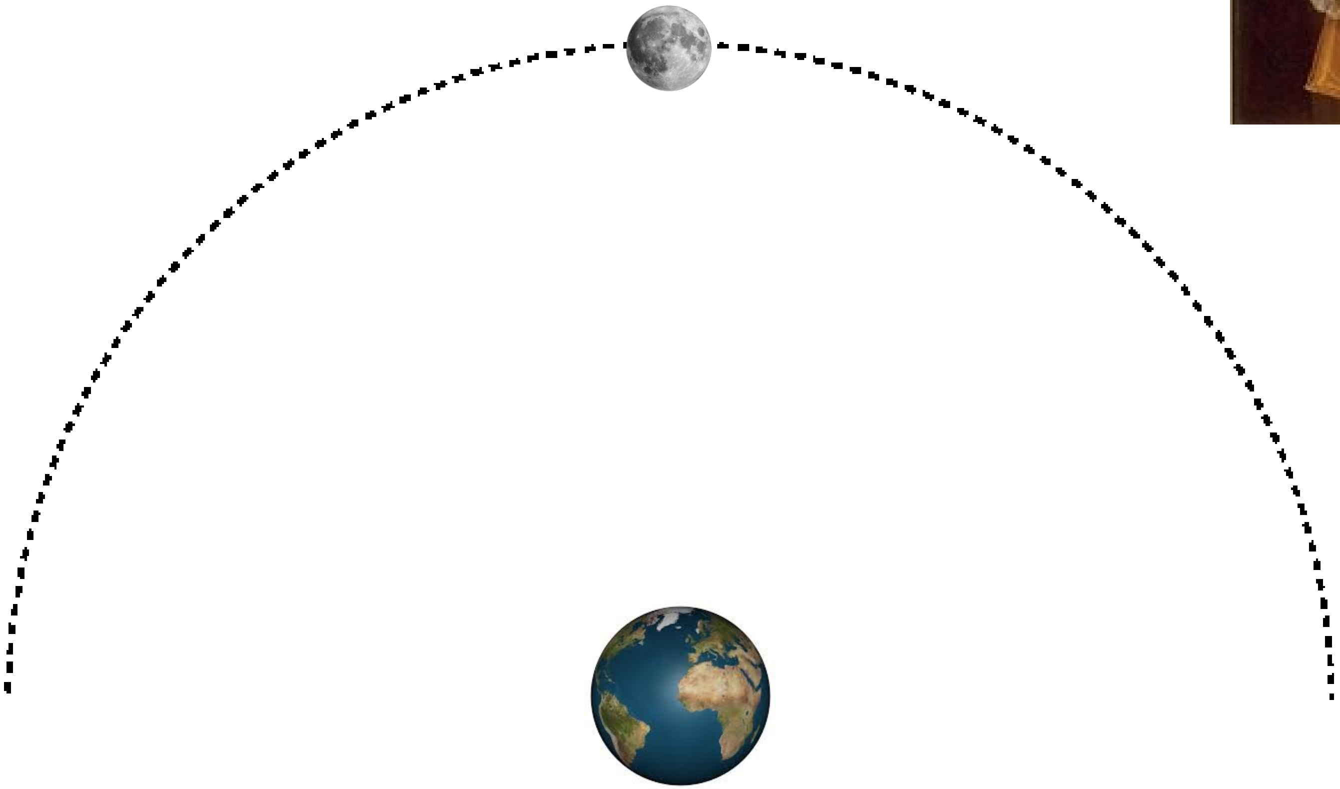

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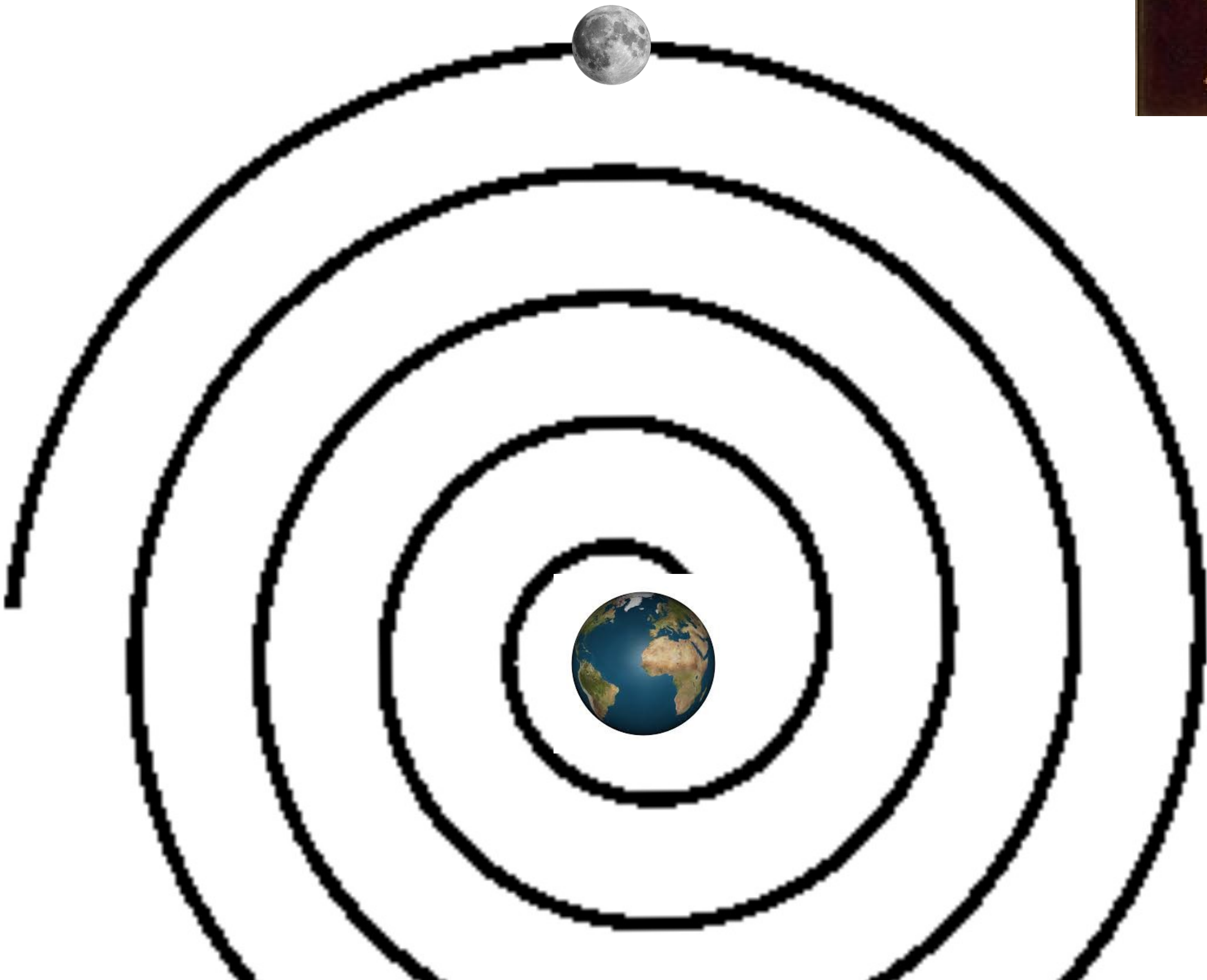

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**PERSPECTIVE** | PLANETARY SCIENCE

## Solving Laplace's Lunar Puzzle

**Kimmo Innanen***

+ See all authors and affiliations

*Science* 04 Aug 2006:
Vol. 313, Issue 5787, pp. 622-623
DOI: 10.1126/science.1131113

# Ondas gravitacionais

- Ondas
- Gravitação
  - Interações instantâneas

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- Ondas
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  - Analogia eletromagnética (Poincaré - 1908)

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- Relatividade Geral

# Relatividade Geral

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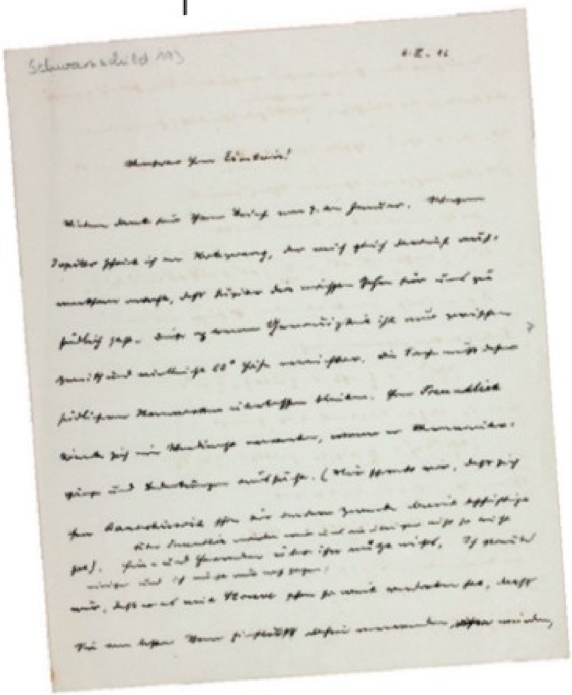
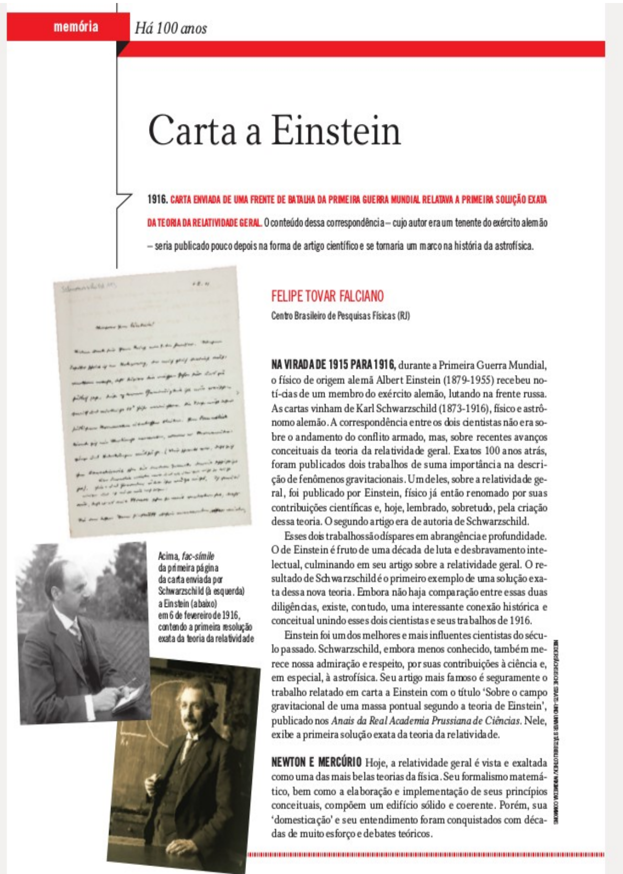


FELIPE TOVAR FALCIANO
Centro Brasileiro de Pesquisas Físicas (RJ)

**NA VIRADA DE 1915 PARA 1916,** durante a Primeira Guerra Mundial, o físico de origem alemã Albert Einstein (1879-1955) recebeu notí-cias de um membro do exército alemão, lutando na frente russa. As cartas vinham de Karl Schwarzschild (1873-1916), físico e astrônomo alemão. A correspondência entre os dois cientistas não era sobre o andamento do conflito armado, mas, sobre recentes avanços conceituais da teoria da relatividade geral. Exatos 100 anos atrás, foram publicados dois trabalhos de suma importância na descrição de fenômenos gravitacionais. Um deles, sobre a relatividade geral, foi publicado por Einstein, físico já então renomado por suas contribuições científicas e, hoje, lembrado, sobretudo, pela criação dessa teoria. O segundo artigo era de autoria de Schwarzschild.

Esses dois trabalhos são díspares em abrangência e profundidade.



memória | *Há 100 anos*

## Carta a Einstein

**1916. CARTA ENVIADA DE UMA FRENTE DE BATALHA DA PRIMEIRA GUERRA MUNDIAL RELATAVA A PRIMEIRA SOLUÇÃO EXATA DA TEORIA DA RELATIVIDADE GERAL.** O conteúdo dessa correspondência – cujo autor era um tenente do exército alemão – seria publicado pouco depois na forma de artigo científico e se tornaria um marco na história da astrofísica.

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Esses dois trabalhos são díspares em abrangência e profundidade. O de Einstein é fruto de uma década de luta e desbravamento intelectual, culminando em seu artigo sobre a relatividade geral. O resultado de Schwarzschild é o primeiro exemplo de uma solução exata dessa nova teoria. Embora não haja comparação entre essas duas diligências, existe, contudo, uma interessante conexão histórica e conceitual unindo esses dois cientistas e seus trabalhos de 1916.

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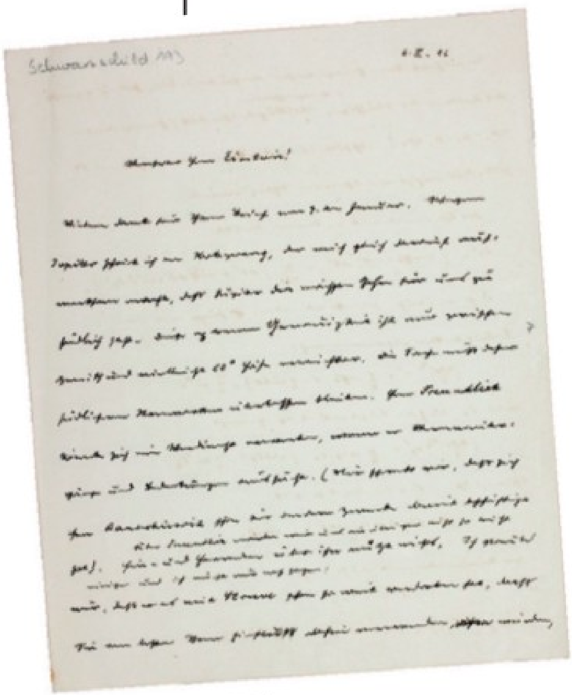
**NEWTON E MERCÚRIO** Hoje, a relatividade geral é vista e exaltada como uma das mais belas teorias da física. Seu formalismo matemático, bem como a elaboração e implementação de seus princípios conceituais, compõem um edifício sólido e coerente. Porém, sua 'domesticação' e seu entendimento foram conquistados com décadas de muito esforço e debates teóricos.

Acima, *fac-símile* da primeira página da carta enviada por Schwarzschild (à esquerda) a Einstein (abaixo) em 6 de fevereiro de 1916, contendo a primeira resolução exata da teoria da relatividade

# Relatividade Geral

*“Since then, I have handled Newton's case differently, of course, according to the final theory. - Thus there are no gravitational waves analogous to light waves. This probably is also related to the one-sidedness of the sign of scalar T, incidentally (Nonexistence of the 'dipole.')”*

Carta de A. Einstein a K. Schwarzschild, 19 Fev. 1916



FELIPE TOVAR FALCIANO
Centro Brasileiro de Pesquisas Físicas (RJ)

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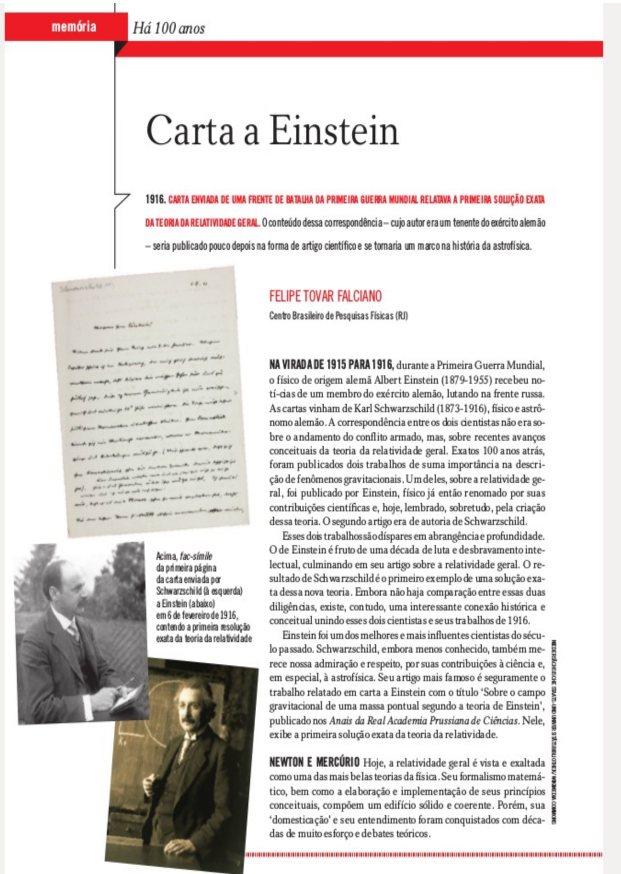



## Carta a Einstein

**1916. CARTA ENVIADA DE UMA FRENTE DE BATALHA DA PRIMEIRA GUERRA MUNDIAL RELATAVA A PRIMEIRA SOLUÇÃO EXATA DA TEORIA DA RELATIVIDADE GERAL.** O conteúdo dessa correspondência – cujo autor era um tenente do exército alemão – seria publicado pouco depois na forma de artigo científico e se tornaria um marco na história da astrofísica.

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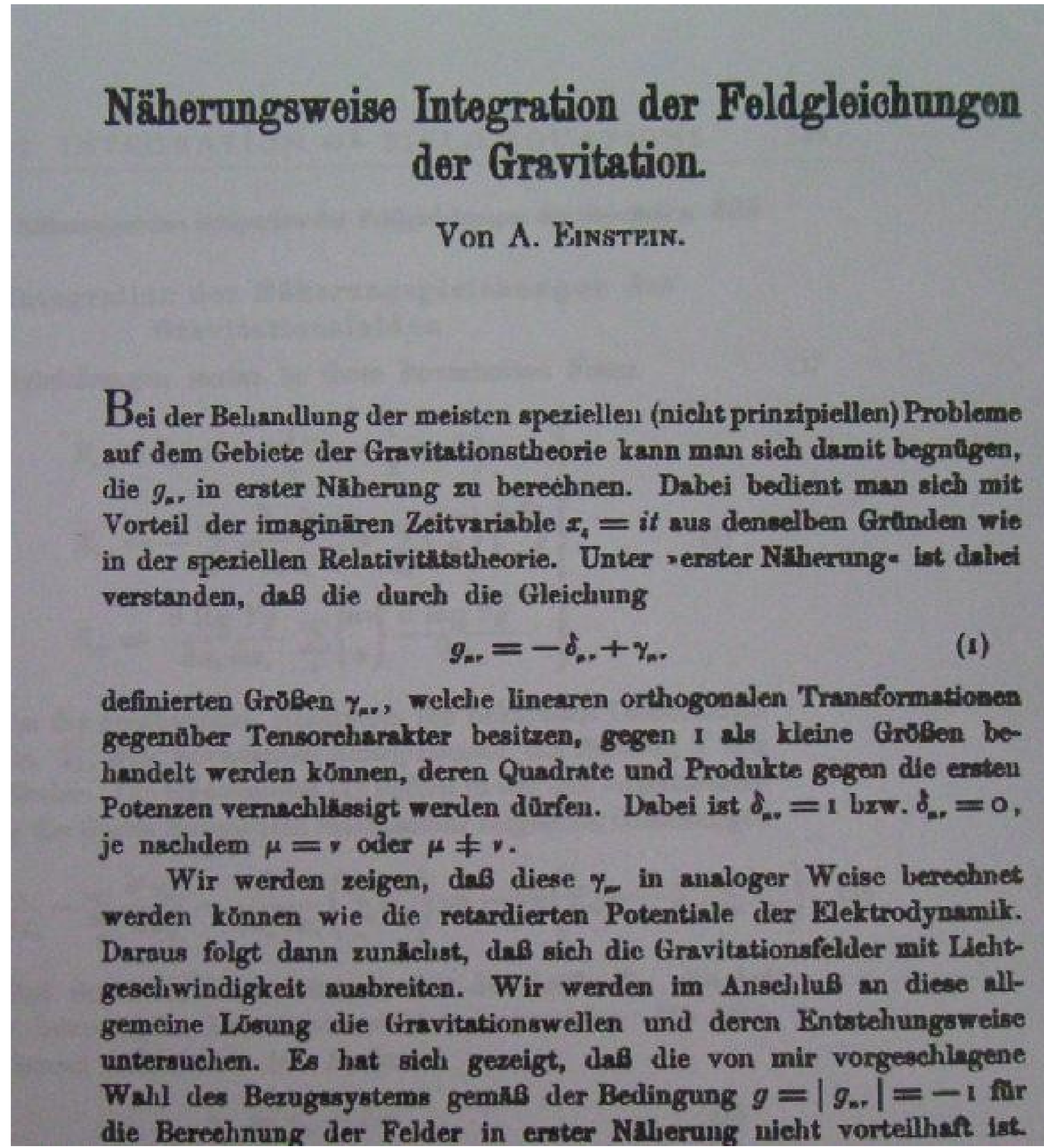
# Relatividade Geral



## Näherungsweise Integration der Feldgleichungen der Gravitation.

Von A. Einstein.

Bei der Behandlung der meisten speziellen (nicht prinzipiellen) Probleme auf dem Gebiete der Gravitationstheorie kann man sich damit begnügen, die $g_{\mu\nu}$ in erster Näherung zu berechnen. Dabei bedient man sich mit Vorteil der imaginären Zeitvariable $x_4 = it$ aus denselben Gründen wie in der speziellen Relativitätstheorie. Unter »erster Näherung« ist dabei verstanden, daß die durch die Gleichung

$$g_{\mu\nu} = -\delta_{\mu\nu} + \gamma_{\mu\nu} \qquad (1)$$

definierten Größen $\gamma_{\mu\nu}$, welche linearen orthogonalen Transformationen gegenüber Tensorcharakter besitzen, gegen 1 als kleine Größen behandelt werden können, deren Quadrate und Produkte gegen die ersten Potenzen vernachlässigt werden dürfen. Dabei ist $\delta_{\mu\nu} = 1$ bzw. $\delta_{\mu\nu} = 0$, je nachdem $\mu = \nu$ oder $\mu \neq \nu$.

Wir werden zeigen, daß diese $\gamma_{\mu\nu}$ in analoger Weise berechnet werden können wie die retardierten Potentiale der Elektrodynamik. Daraus folgt dann zunächst, daß sich die Gravitationsfelder mit Lichtgeschwindigkeit ausbreiten. Wir werden im Anschluß an diese allgemeine Lösung die Gravitationswellen und deren Entstehungsweise untersuchen. Es hat sich gezeigt, daß die von mir vorgeschlagene Wahl des Bezugssystems gemäß der Bedingung $g = |g_{\mu\nu}| = -1$ für die Berechnung der Felder in erster Näherung nicht vorteilhaft ist.

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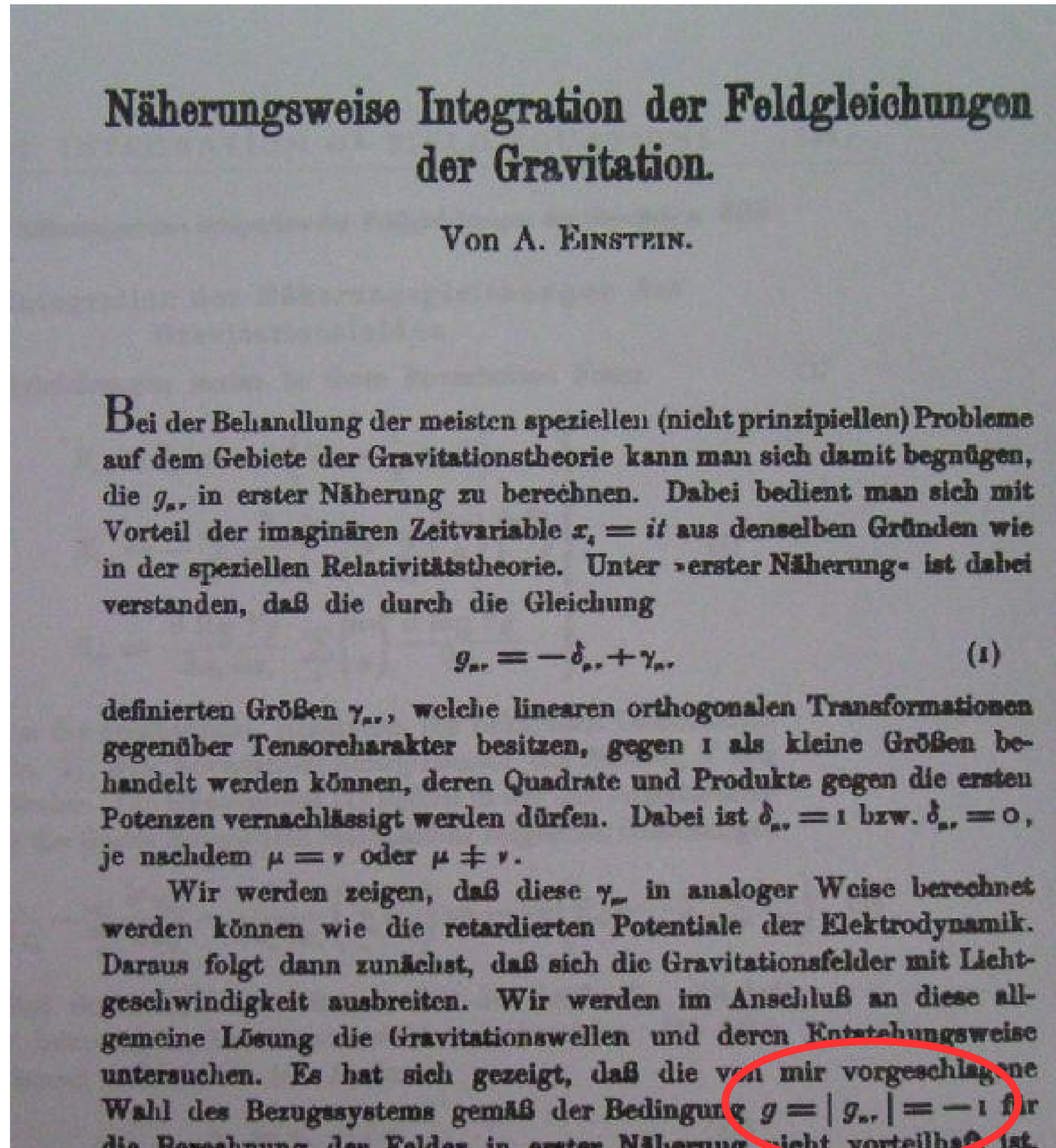

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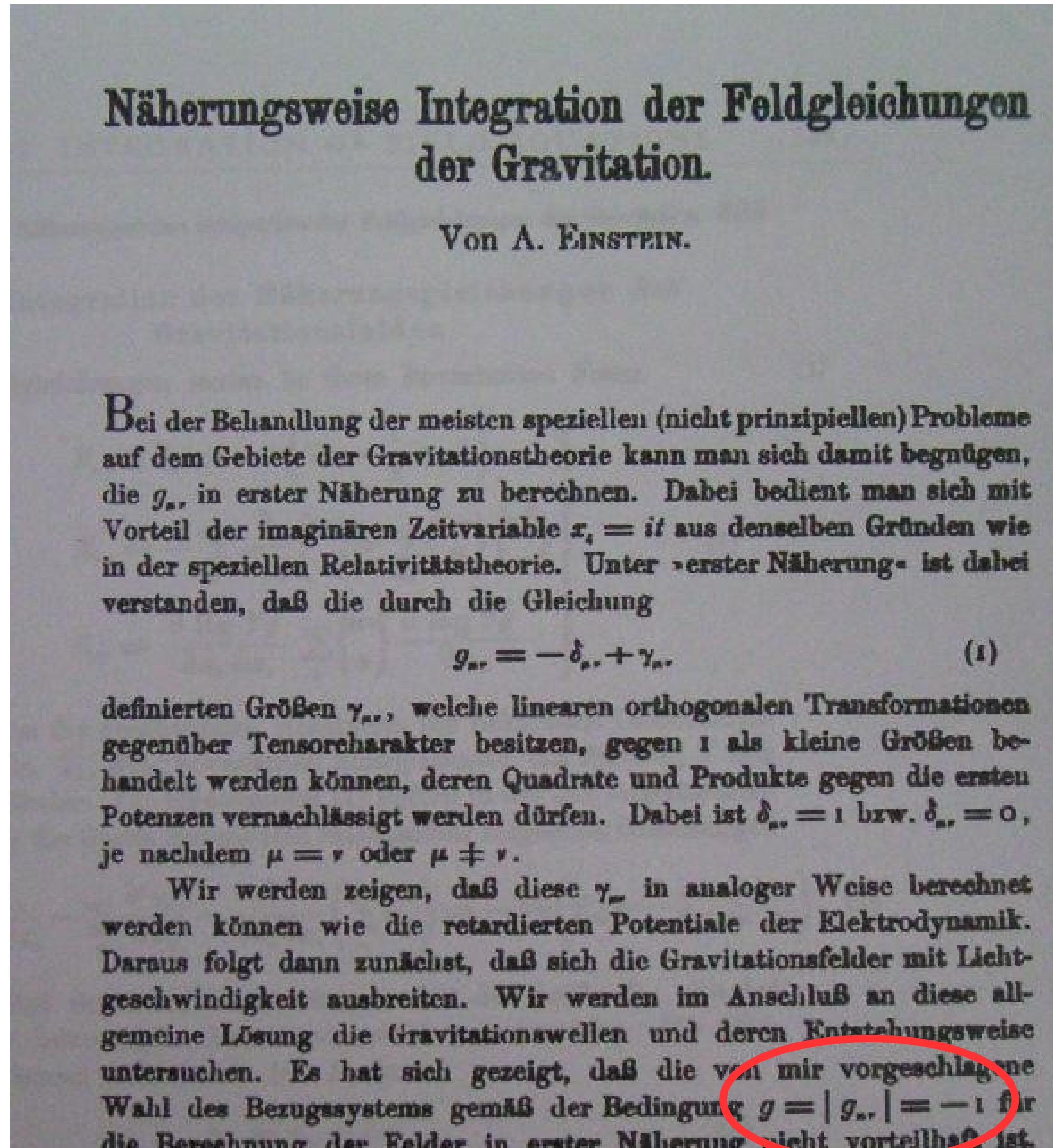

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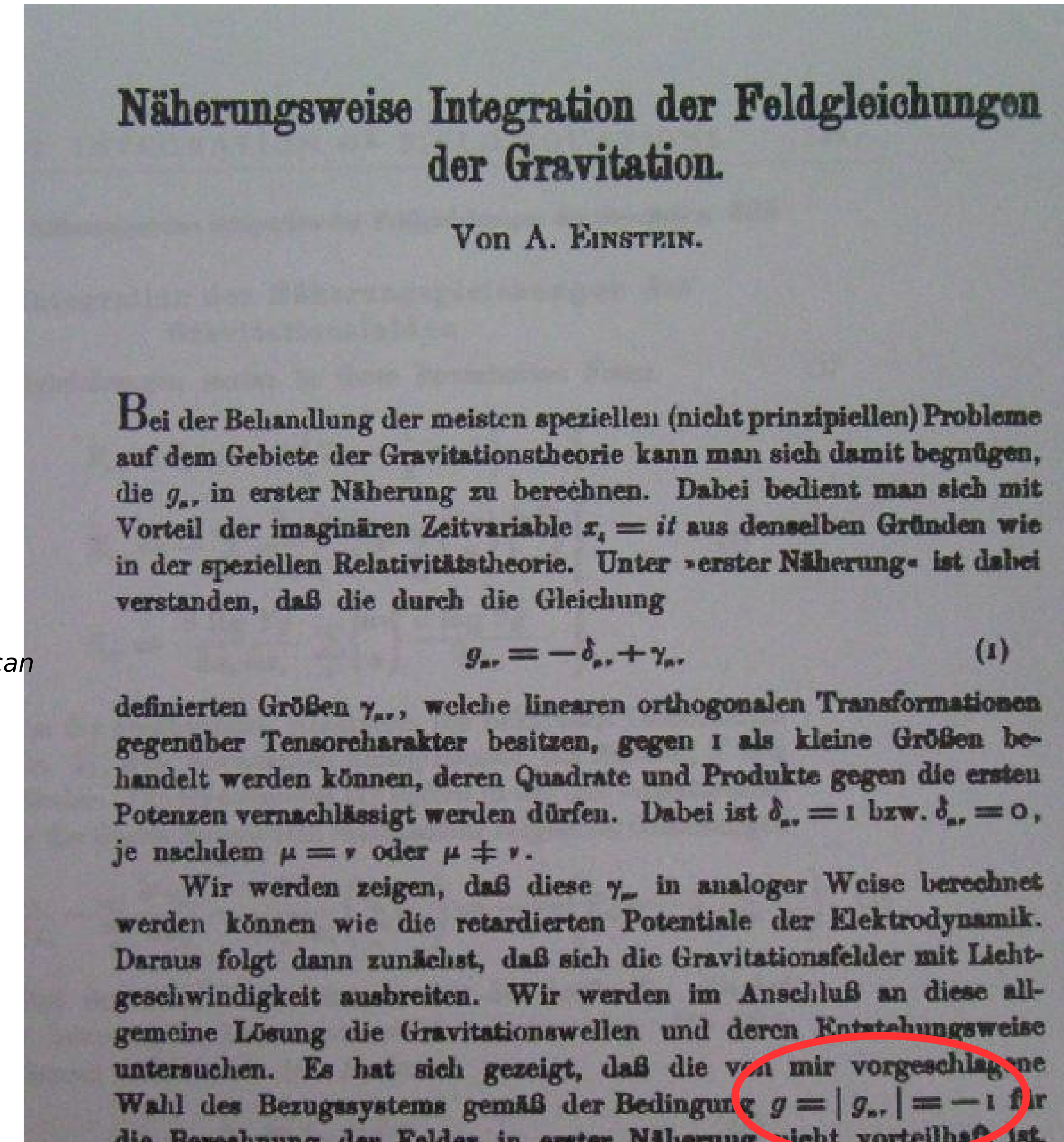
*“We shall show that these guv [the small perturbative quatities] can be calculated in a manner analogous to that of retarded potential in electrodynamics. From this it follows that gravitational fields propagate with the speed of light. Subsequent to this general solution we shall investigate gravitational waves and how they originate.”*



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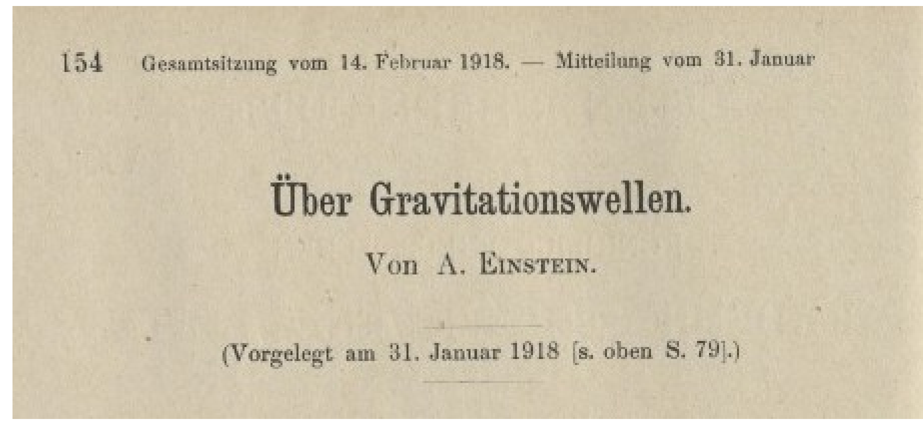

154 Gesamtsitzung vom 14. Februar 1918. — Mitteilung vom 31. Januar

**Über Gravitationswellen.**

Von A. Einstein.

(Vorgelegt am 31. Januar 1918 [s. oben S. 79].)

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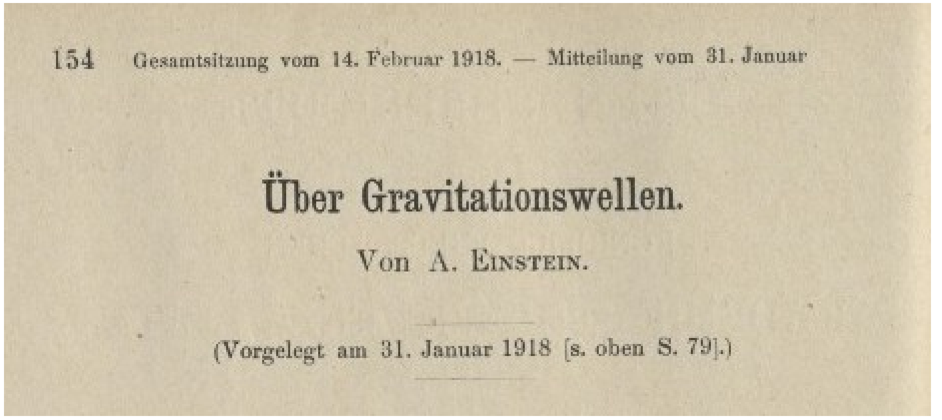
Condição relaxada





## Über Gravitationswellen.

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# Relatividade Geral

*The Propagation of Gravitational Waves.*

By A. S. Eddington, F.R.S.

(Received October 11, 1922.)

1. The problem of the propagation of disturbances of the gravitational field was investigated by Einstein in 1916, and again in 1918.* It has usually been inferred from his discussion that a change in the distribution of matter produces gravitational effects which are propagated with the speed of light; but I think that Einstein really left the question of the speed of propagation rather indefinite. His analysis shows how the co-ordinates must be chosen if it is desired to represent the gravitational potentials as propagated with the speed of light; but there is nothing to indicate that the speed of light appears in the problem, except as the result of this arbitrary choice. So far as I know, the propagation of the absolute physical condition—the altered curvature of space-time—has not hitherto been discussed.

Weyl† has classified plane gravitational waves into three types, viz.: (1) longitudinal-longitudinal; (2) longitudinal-transverse; (3) transverse-transverse. The present investigation leads to the conclusion that transverse-transverse waves are propagated with the speed of light *in all systems of co-ordinates*. Waves of the first and second types have no fixed velocity—a result which rouses suspicion as to their objective existence. Einstein had also become suspicious of these waves (in so far as they occur in his special co-ordinate-system) for another reason, because he found that they convey no energy.

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Subrahmanyan Chandrasekhar
(1910 - 1995)

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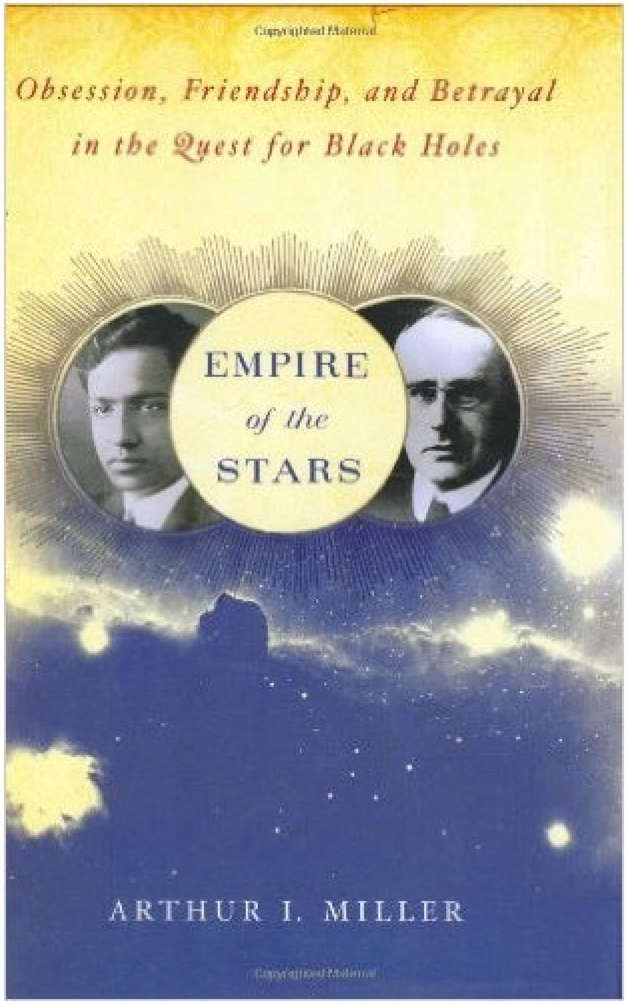


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# Relatividade Geral

Annals of Mathematics
Vol. 40, No. 4, October, 1939

**ON A STATIONARY SYSTEM WITH SPHERICAL SYMMETRY CONSISTING OF MANY GRAVITATING MASSES**

By Albert Einstein

(Received May 10, 1939)

If one considers Schwarzschild's solution of the static gravitational field of spherical symmetry

$$(1) \qquad ds^2 = -\left(1 + \frac{\mu}{2r}\right)^4 (dx_1^2 + dx_2^2 + dx_3^2) + \left(\frac{1 - \frac{\mu}{2r}}{1 + \frac{\mu}{2r}}\right)^2 dt^2$$

it is noted that

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The essential result of this investigation is a clear understanding as to why the "Schwarzschild singularities" do not exist in physical reality. Although the theory given here treats only clusters whose particles move along circular paths it does not seem to be subject to reasonable doubt that more general cases will have analogous results. The "Schwarzschild singularity" does not appear for the reason that matter cannot be concentrated arbitrarily. And this is due to the fact that otherwise the constituting particles would reach the velocity of light.

# Einstein Versus the *Physical Review*

**A great scientist can benefit from peer review, even while refusing to have anything to do with it.**

Daniel Kennefick

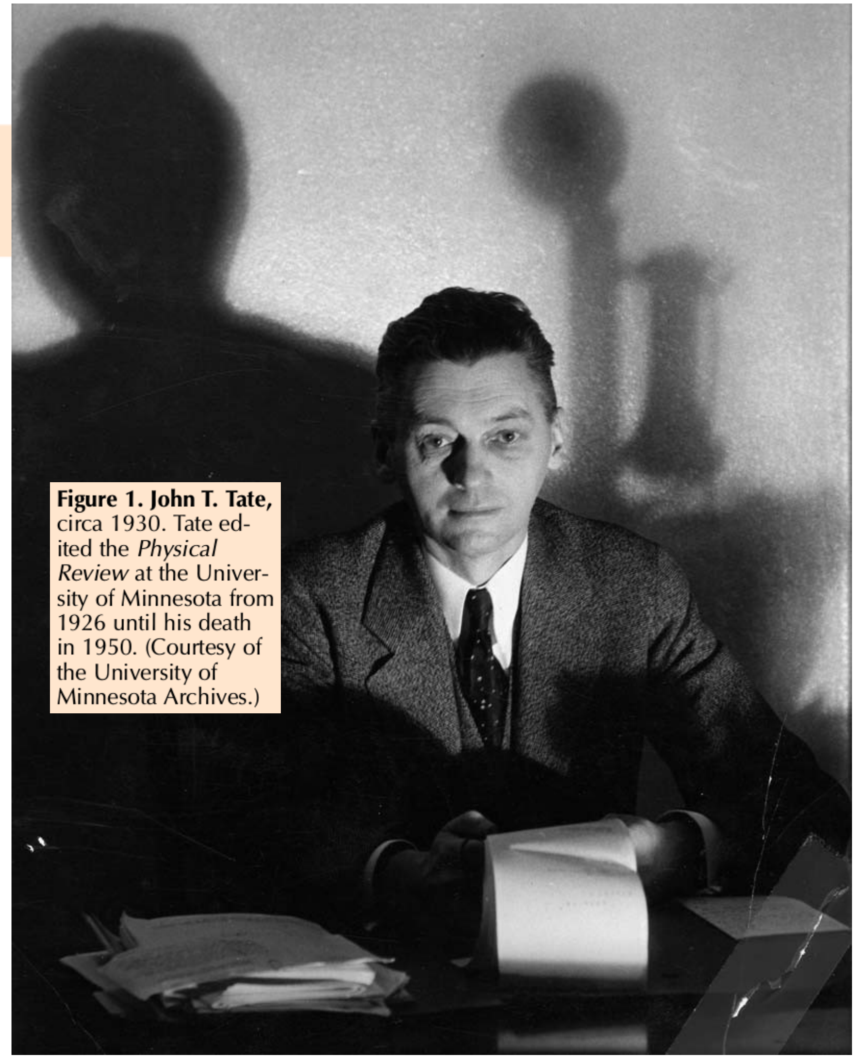

**Figure 1. John T. Tate,** circa 1930. Tate edited the *Physical Review* at the University of Minnesota from 1926 until his death in 1950. (Courtesy of the University of Minnesota Archives.)

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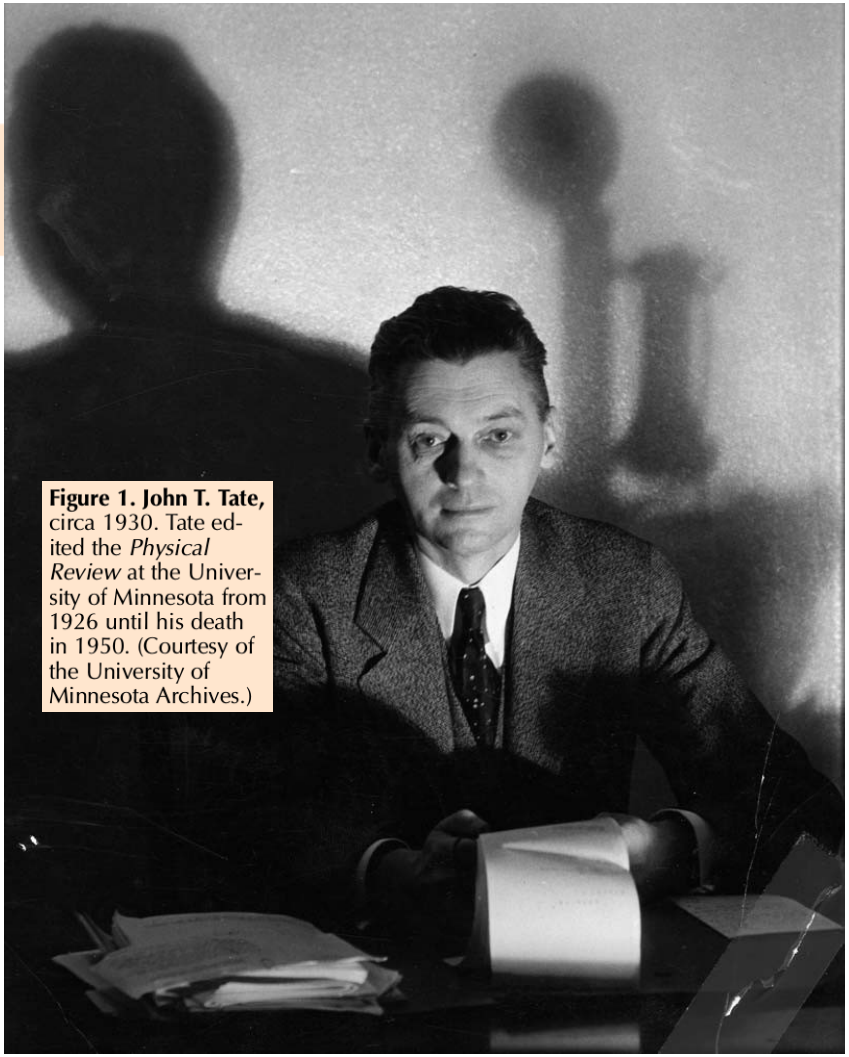

**Figure 1. John T. Tate,** circa 1930. Tate edited the *Physical Review* at the University of Minnesota from 1926 until his death in 1950. (Courtesy of the University of Minnesota Archives.)

**Figure 2. Albert Einstein** and Leopold Infeld in Einstein's Princeton, New Jersey, home in 1938. (Courtesy of the Lotte Jacobi Collection, University of New Hampshire.)

Dear Sir,

We (Mr. Rosen and I) had sent you our manuscript for publication and had not authorized you to show it to specialists before it is printed. I see no reason to address the—in any case erroneous—comments of your anonymous expert. On the basis of this incident I prefer to publish the paper elsewhere.

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**Referees and precedents**

Although it now bears Einstein and Rosen's names, the solution for cylindrical gravitational waves had been previously published by the Austrian physicist Guido Beck in 1925. But Beck's paper was completely unknown to relativists with the single exception of his student Peter Havas, who entered the field in the late 1950s. In a 1926 paper by the English mathematicians O. R. Baldwin and George B. Jeffery, and in the referee's report on Einstein's paper, there was discussion of the fact that singularities in the metric coefficients are unavoidable when describing plane waves with infinite wavefronts. But although such a wave shows some distortion, in the words of the referee, "the field itself is flat" at infinity.[9]

9. G. Beck, *Z. Phys.* **33**, 713 (1925); O. R. Baldwin, G. B. Jeffery, *Proc. Phys. Soc. London, Sect. A* **111**, 95 (1926).

# Guido Beck

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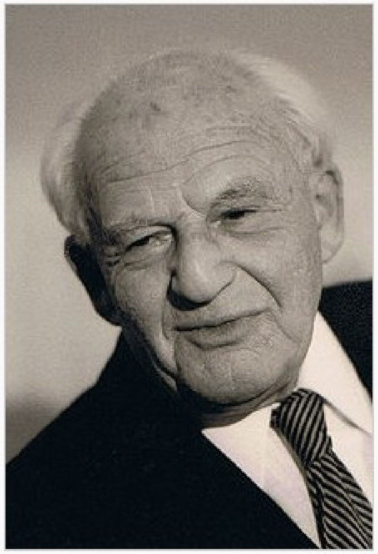
Guido Beck 1971/72

**Guido Beck** (August 29, 1903 – October 21, 1988) was a physicist born in what was then the town of Reichenberg in the Kingdom of Bohemia (Austria-Hungary), and is now Liberec in the Czech Republic. He studied physics in Vienna and received his doctorate in 1925, under Hans Thirring. He worked in Leipzig in 1928 as an assistant to Werner Heisenberg. A combination of the troubled political climate of Europe in the 1930s, his own restlessness, and the Nazi persecutions in Germany, made the Jewish-born Beck a traveler in those years. Until 1935 he worked in Cambridge with Ernest Rutherford, Copenhagen, Prague, United States and Japan.

In 1935, Beck was invited to work in the Soviet Union by Head of the Institute of Physics, Odessa University Yelpidifor Anempodistovich Kirillov. At the Odessa University Beck head of the Department of Theoretical Physics and gave a course of theoretical physics in German; lectures were simultaneously translated into Ukrainian by assistant Yu.G. Vekshtein. In 1936-1937 Beck head of the department of theoretical mechanics at the Institute of Water Transport Engineers in Odessa. Four of his Odessa students - VV Malyarov, MM Alperin, GV Skrotskii and PE Nemirovsky - became professors in Odessa and Moscow.

In 1937, Guido Beck moved to France, where he was imprisoned when World War II broke out. In 1941, he fled to Portugal, and in 1943 he emigrated to Argentina.

In Argentina, he was instrumental in training several Argentinian physicists, including José Antonio Balseiro, and had a profound impact in developing physics in Argentina. He moved once more, this time to Brazil, in 1951, where his influence in developing physics was also great.

He was called back to Argentina in 1962, after the death of Balseiro, and continued his work at the Instituto Balseiro.

In 1975, he returned to Brazil, and worked in the Centro Brasileiro de Pesquisas Físicas (CBPF).

Apart from his influence as a teacher in South America he contributed to a theory of beta-decay, which was later superseded by a more complete theory by Fermi. He was a friend of the famous writer Ernesto Sabato.

He died in a car accident in Rio de Janeiro in 1988.

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Dear Sir,

We (Mr. Rosen and I) had sent you our manuscript for publication and had not authorized you to show it to specialists before it is printed. I see no reason to address the—in any case erroneous—comments of your anonymous expert. On the basis of this incident I prefer to publish the paper elsewhere.

*Respectfully,*

P.S. Mr. Rosen, who has left for the Soviet Union, has authorized me to represent him in this matter.

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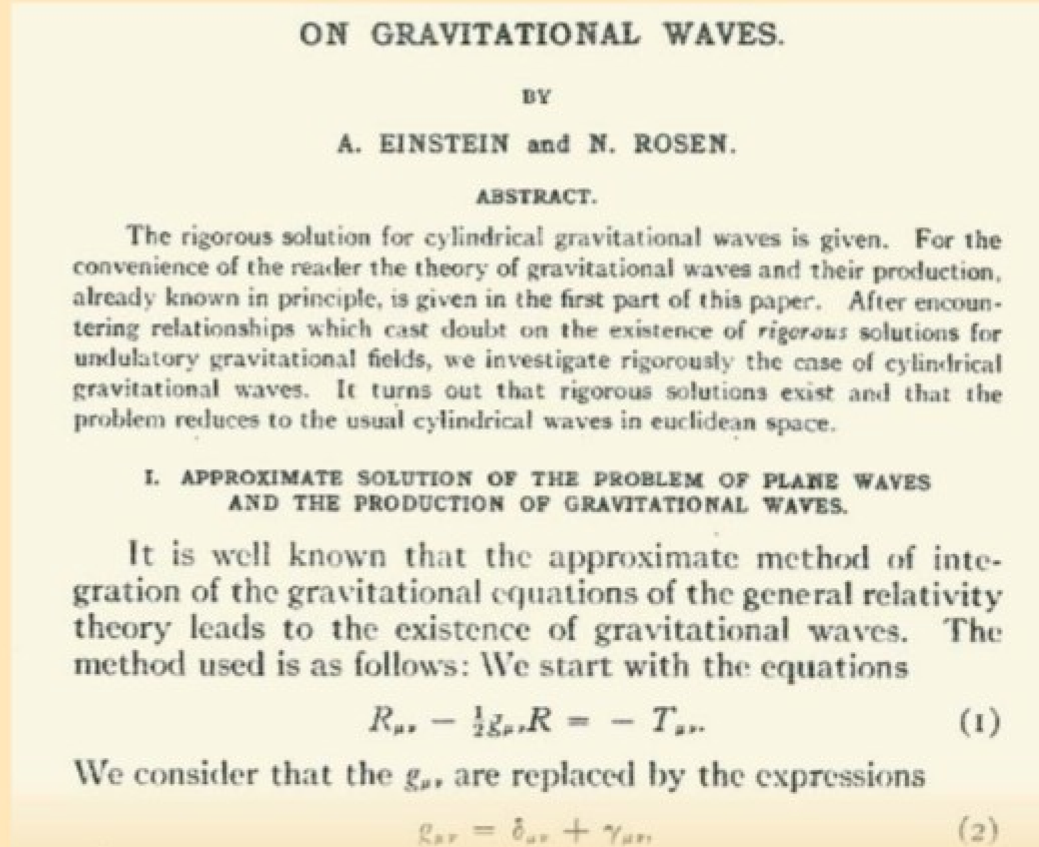


ON GRAVITATIONAL WAVES.

BY

A. EINSTEIN and N. ROSEN.

ABSTRACT.

The rigorous solution for cylindrical gravitational waves is given. For the convenience of the reader the theory of gravitational waves and their production, already known in principle, is given in the first part of this paper. After encountering relationships which cast doubt on the existence of *rigorous* solutions for undulatory gravitational fields, we investigate rigorously the case of cylindrical gravitational waves. It turns out that rigorous solutions exist and that the problem reduces to the usual cylindrical waves in euclidean space.

I. APPROXIMATE SOLUTION OF THE PROBLEM OF PLANE WAVES AND THE PRODUCTION OF GRAVITATIONAL WAVES.

It is well known that the approximate method of integration of the gravitational equations of the general relativity theory leads to the existence of gravitational waves. The method used is as follows: We start with the equations

$$R_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} R = - T_{\mu\nu}. \qquad (1)$$

We consider that the $g_{\mu\nu}$ are replaced by the expressions

$$g_{\mu\nu} = \delta_{\mu\nu} + \gamma_{\mu\nu}, \qquad (2)$$

**Figure 4. A revised account** of Albert Einstein and Nathan Rosen's solution for gravitational waves was published in the *Journal of the Franklin Institute.*[6]

**Figure 2. Albert Einstein** and Leopold Infeld in Einstein's Princeton, New Jersey, home in 1938. (Courtesy of the Lotte Jacobi Collection, University of New Hampshire.)

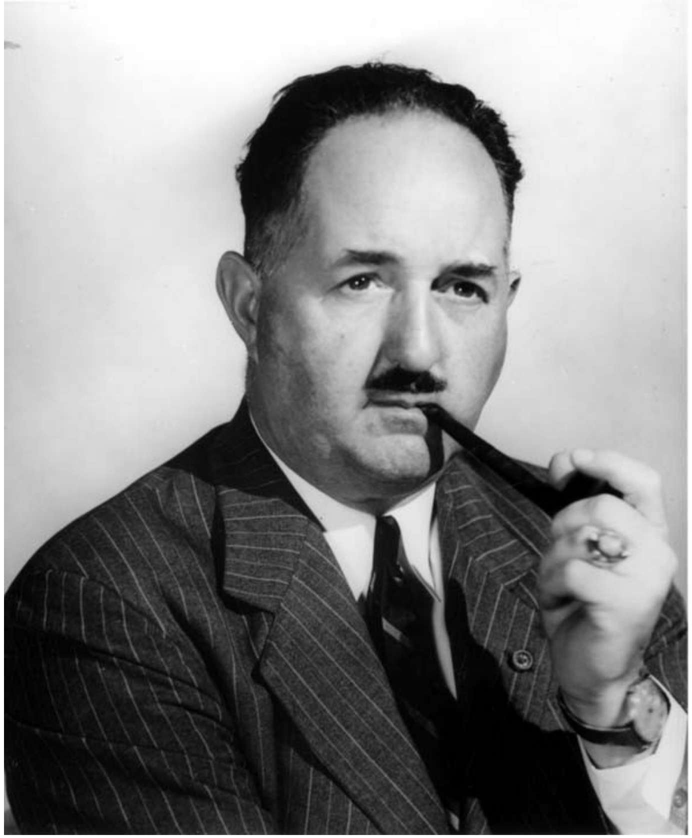
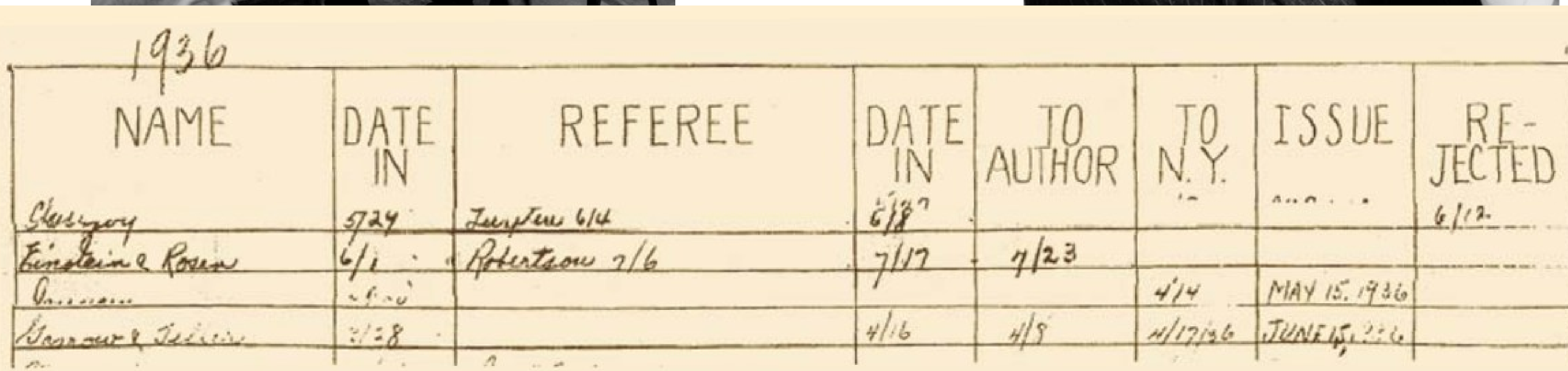


**Figure 3. Howard Percy Robertson** (1903–1961). (Courtesy of AIP Emilio Segrè Visual Archives, PHYSICS TODAY Collection.)

**Figure 2. Albert Einstein** and Leopold Infeld in Einstein's Princeton, New Jersey, home in 1938. (Courtesy of the Lotte Jacobi Collection, University of New Hampshire.)



1936

| NAME | DATE IN | REFEREE | DATE IN | TO AUTHOR | TO N.Y. | ISSUE | REJECTED |
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| [illegible] | 5/24 | [illegible] 6/4 | 6/8 | | | | 6/12 |
| Einstein & Rosen | 6/1 | Robertson 7/6 | 7/17 | 7/23 | | | |
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| [illegible] | 3/28 | | 4/16 | 4/8 | 4/17/36 | JUNE 15, [illegible] | |

**Figure 5. An early extract from the *Physical Review* logbook.** The Einstein–Rosen article was received by the journal on 1 June 1936. After a delay of more than a month, John Tate sent a referral to Howard Percy Robertson on 6 July, finding him in Moscow, Idaho, on vacation after a sabbatical at Caltech. Robertson returned the manuscript and his review to Tate on 17 July. Six days later the package was sent back to Einstein. (Courtesy of Martin Blume, American Physical Society.)

# Ondas gravitacionais

- Ondas
- Gravitação
  - Interações instantâneas
  - Analogia eletromagnética (Poincaré)
- Relatividade Geral

# Ondas gravitacionais

- Ondas
- Gravitação
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  - Analogia eletromagnética (Poincaré)
- Relatividade Geral
- Detecção

# Detecções

# Detecções

Joseph Weber
(1919-2000)

# Detecções

Joseph Weber
(1919-2000)

VOLUME 22, NUMBER 24 PHYSICAL REVIEW LETTERS 16 JUNE 1969

EVIDENCE FOR DISCOVERY OF GRAVITATIONAL RADIATION*

J. Weber
Department of Physics and Astronomy, University of Maryland, College Park, Maryland 20742
(Received 29 April 1969)

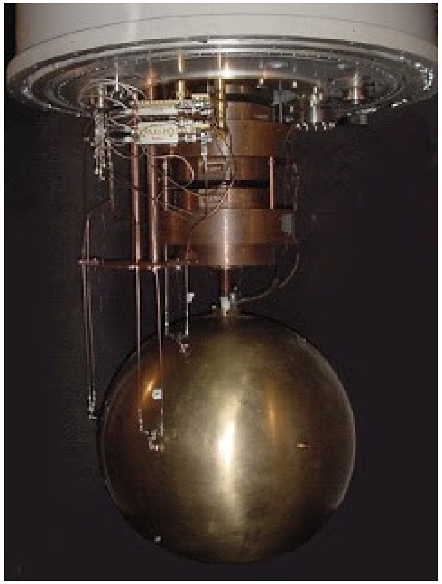
Coincidences have been observed on gravitational-radiation detectors over a base line of about 1000 km at Argonne National Laboratory and at the University of Maryland. The probability that all of these coincidences were accidental is incredibly small. Experiments imply that electromagnetic and seismic effects can be ruled out with a high level of confidence. These data are consistent with the conclusion that the detectors are being excited by gravitational radiation.

# Detecções

Joseph Weber
(1919-2000)

# Detecções

Joseph Weber
(1919-2000)



SHARE

The LIGO facility in Livingston, Louisiana, has a twin in Hanford, Washington. © ATMOSPHERE AERIAL

# ‘Woohoo!’ email stokes rumor that gravitational waves have been spotted

By Adrian Cho | Feb. 5, 2016 , 2:30 PM

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· Feb 3
Inside scoop ... Nobel prize is coming someone's way

Cliff Burgess
d-phys@mcmaster.ca
February 03, 2016, 10:48 AM

Hi all, the LIGO rumour seems real, and will apparently come out in Nature Feb 11 (no doubt with press release), so keep your eyes out for it.

Spies who have seen the paper say they have seen gravitational waves from a binary black hole merger. they claim that the two detectors detected it consistent with it moving at speed c given the distance between them, and quote an equivalent 5.1 sigma detection. the bh masses were 36 and 29 solar masses initially and 62 at the end. Apparently the signal is spectacular and they even see the ring-down to kerr at the end.

Woohoo! (I hope)

SHARE

The LIGO facility in Livingston, Louisiana, has a twin in Hanford, Washington. © ATMOSPHERE AERIAL

# 'Woohoo!' email stokes rumor that gravitational waves have been spotted

By **Adrian Cho** | Feb. 5, 2016 , 2:30 PM

Selected for a Viewpoint in *Physics*
PRL **116,** 061102 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

# Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.*[*]
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 21 January 2016; published 11 February 2016)

On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal. The signal sweeps upwards in frequency from 35 to 250 Hz with a peak gravitational-wave strain of $1.0 \times 10^{-21}$. It matches the waveform predicted by general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. The signal was observed with a matched-filter signal-to-noise ratio of 24 and a false alarm rate estimated to be less than 1 event per 203 000 years, equivalent to a significance greater than $5.1\sigma$. The source lies at a luminosity distance of $410^{+160}_{-180}$ Mpc corresponding to a redshift $z = 0.09^{+0.03}_{-0.04}$. In the source frame, the initial black hole masses are $36^{+5}_{-4} M_\odot$ and $29^{+4}_{-4} M_\odot$, and the final black hole mass is $62^{+4}_{-4} M_\odot$, with $3.0^{+0.5}_{-0.5} M_\odot c^2$ radiated in gravitational waves. All uncertainties define 90% credible intervals. These observations demonstrate the existence of binary stellar-mass black hole systems. This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.

DOI: 10.1103/PhysRevLett.116.061102

| | |
|---|---|
| Primary black hole mass | $36^{+5}_{-4} M_\odot$ |
| Secondary black hole mass | $29^{+4}_{-4} M_\odot$ |
| Final black hole mass | $62^{+4}_{-4} M_\odot$ |
| Final black hole spin | $0.67^{+0.05}_{-0.07}$ |
| Luminosity distance | $410^{+160}_{-180}$ Mpc |
| Source redshift $z$ | $0.09^{+0.03}_{-0.04}$ |

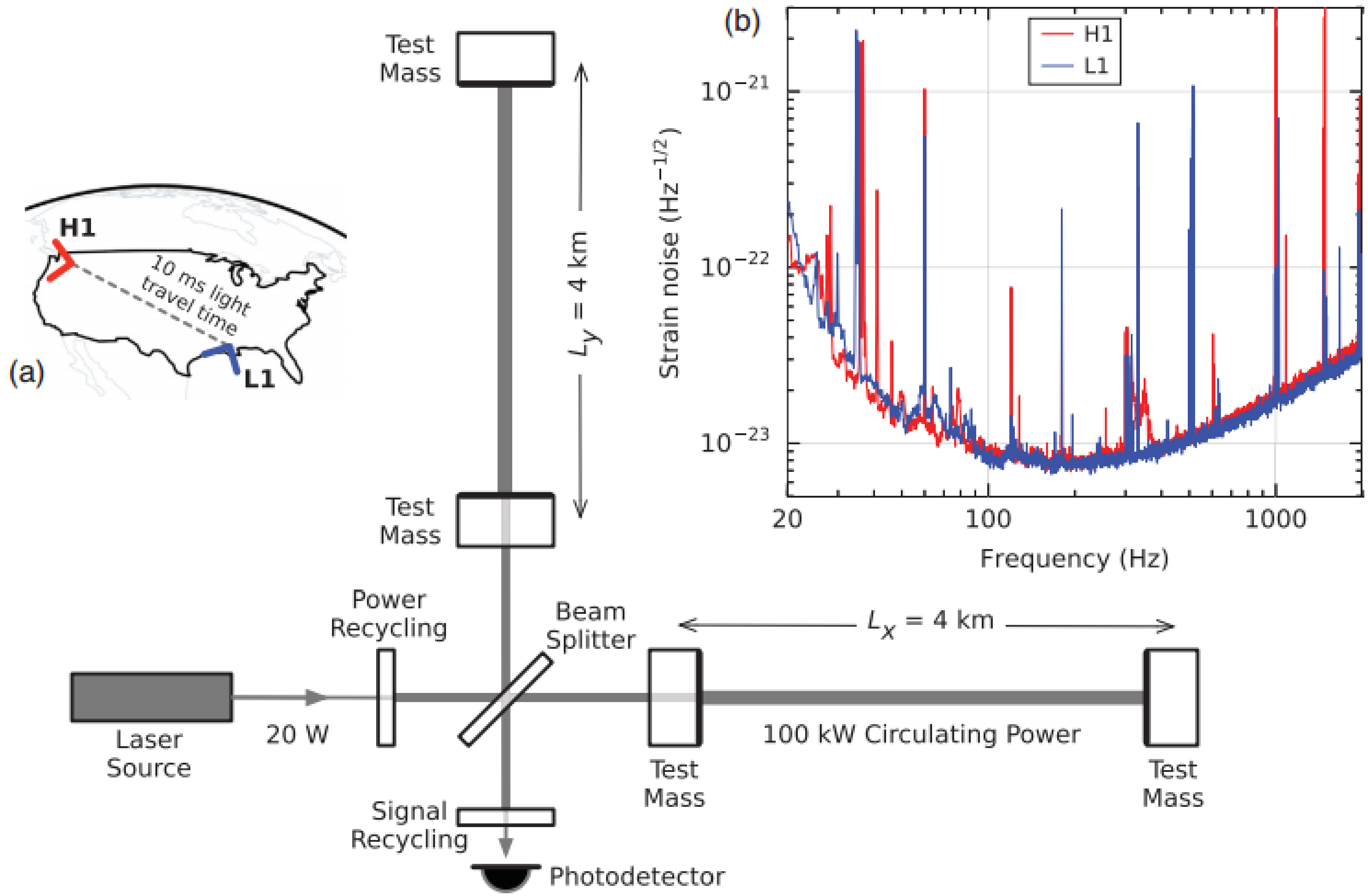



FIG. 3. Simplified diagram of an Advanced LIGO detector (not to scale). A gravitational wave propagating orthogonally to the detector plane and linearly polarized parallel to the 4-km optical cavities will have the effect of lengthening one 4-km arm and shortening the other during one half-cycle of the wave; these length changes are reversed during the other half-cycle. The output photodetector records these differential cavity length variations. While a detector's directional response is maximal for this case, it is still significant for most other angles of incidence or polarizations (gravitational waves propagate freely through the Earth). *Inset (a):* Location and orientation of the LIGO detectors at Hanford, WA (H1) and Livingston, LA (L1). *Inset (b):* The instrument noise for each detector near the time of the signal detection; this is an amplitude spectral density, expressed in terms of equivalent gravitational-wave strain amplitude. The sensitivity is limited by photon shot noise at frequencies above 150 Hz, and by a superposition of other noise sources at lower frequencies [47]. Narrow-band features include calibration lines (33–38, 330, and 1080 Hz), vibrational modes of suspension fibers (500 Hz and harmonics), and 60 Hz electric power grid harmonics.

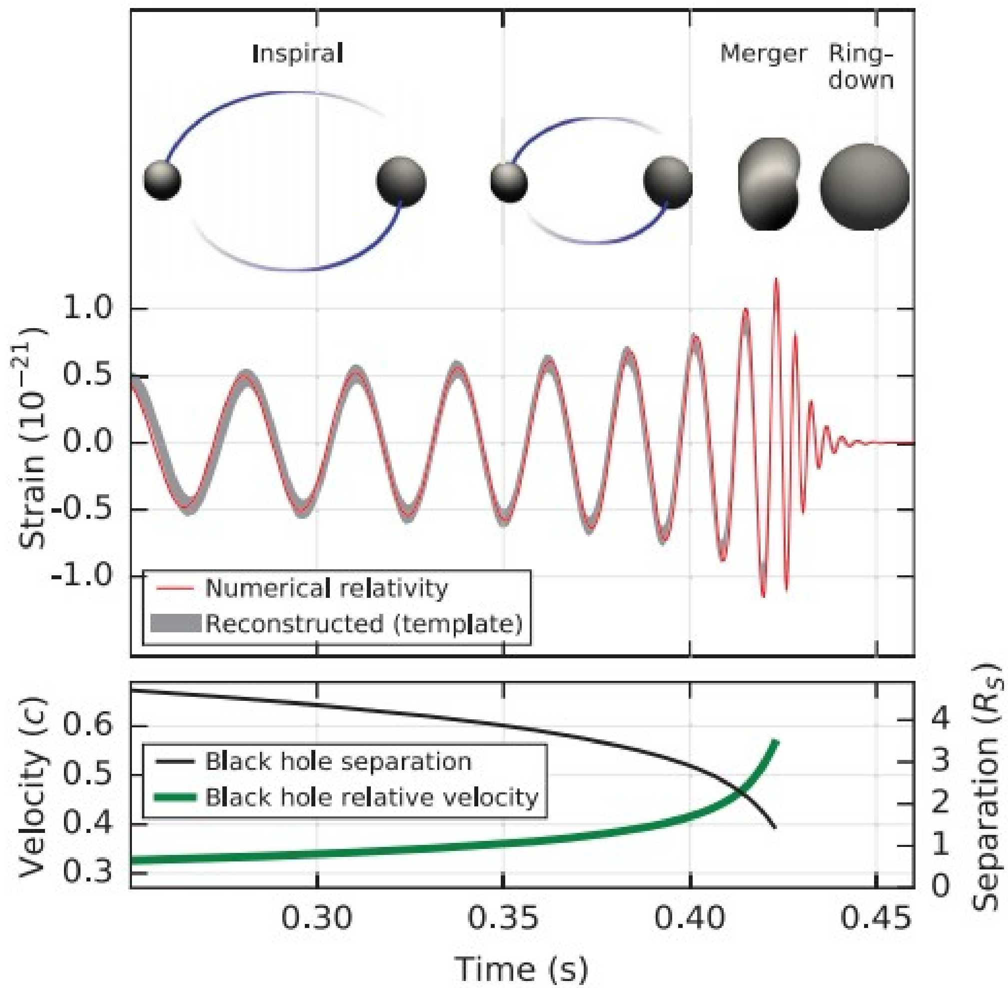
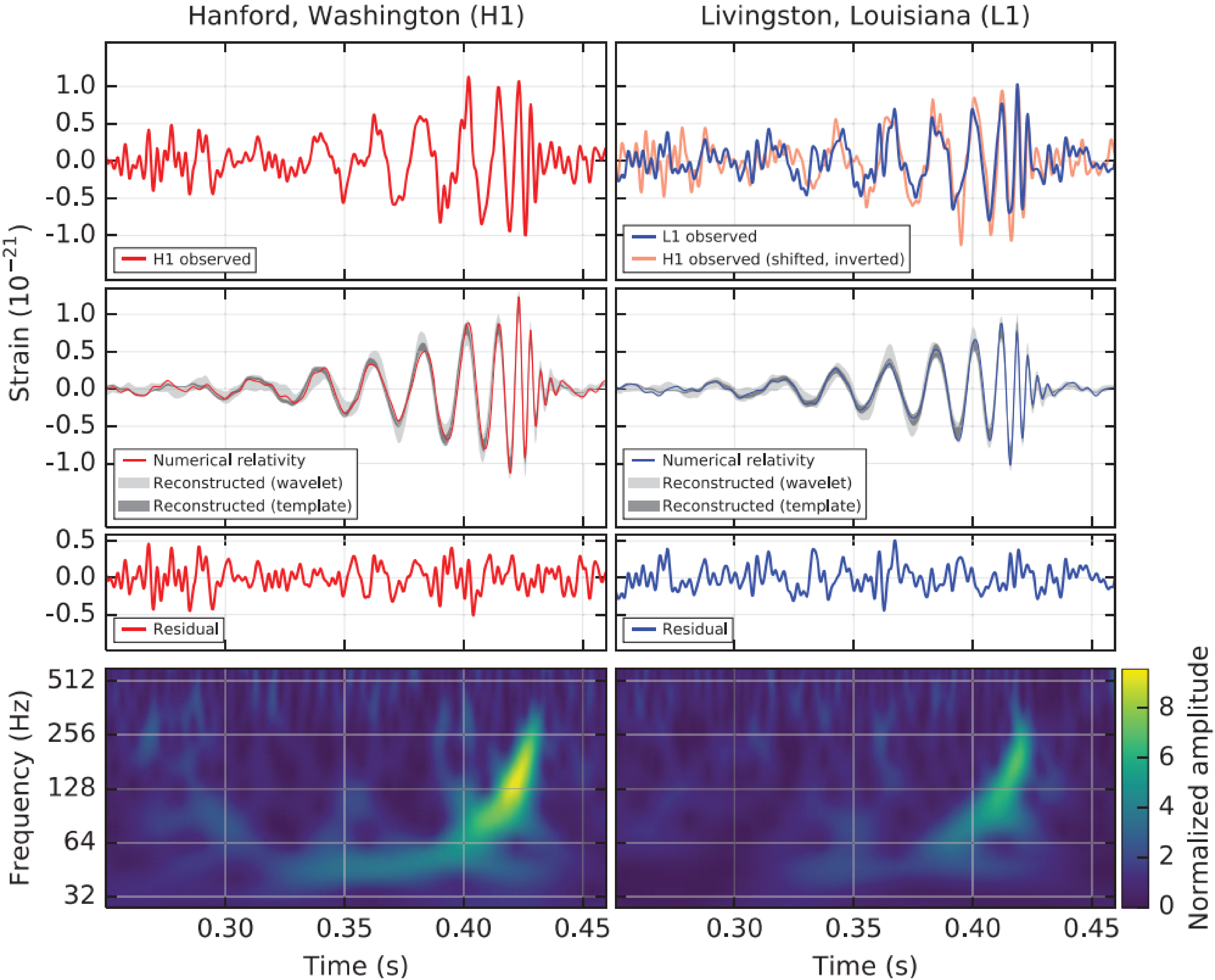



FIG. 2. *Top:* Estimated gravitational-wave strain amplitude from GW150914 projected onto H1. This shows the full bandwidth of the waveforms, without the filtering used for Fig. 1. The inset images show numerical relativity models of the black hole horizons as the black holes coalesce. *Bottom:* The Keplerian effective black hole separation in units of Schwarzschild radii ($R_S = 2GM/c^2$) and the effective relative velocity given by the post-Newtonian parameter $v/c = (GM\pi f/c^3)^{1/3}$, where $f$ is the gravitational-wave frequency calculated with numerical relativity and $M$ is the total mass (value from Table I).



Hanford, Washington (H1)
Livingston, Louisiana (L1)
Strain ($10^{-21}$)
H1 observed
L1 observed
H1 observed (shifted, inverted)
Numerical relativity
Reconstructed (wavelet)
Reconstructed (template)
Residual
Frequency (Hz)
512
256
128
64
32
0.30
0.35
0.40
0.45
Time (s)
Normalized amplitude

# Electromagnetic Counterparts to Black Hole Mergers Detected by LIGO

Abraham Loeb (Harvard)

*(Submitted on 15 Feb 2016)*

Mergers of stellar-mass black holes (BHs), such as GW150914 observed by LIGO, are not expected to have electromagnetic counterparts. However, the Fermi GBM detector identified of a gamma-ray transient 0.4 s after the gravitational wave (GW) signal GW150914 with consistent sky localization. I show that the two signals might be related if the BH binary detected by LIGO originated from two clumps in a dumbbell configuration that formed when the core of a rapidly rotating massive star collapsed. In that case, the BH binary merger was followed by a gamma-ray burst (GRB) from a jet that originated in the accretion flow around the remnant BH. A future detection of a GRB afterglow could be used to determine the redshift and precise localization of the source. A population of standard GW sirens with GRB redshifts would provide a new approach for precise measurements of cosmological distances as a function of redshift.

Comments: 3 pages, submitted to ApJL
Subjects: **High Energy Astrophysical Phenomena (astro-ph.HE)**; Cosmology and Nongalactic Astrophysics (astro-ph.CO); Solar and Stellar Astrophysics (astro-ph.SR); General Relativity and Quantum Cosmology (gr-qc); High Energy Physics - Phenomenology (hep-ph)
Cite as: **arXiv:1602.04735 [astro-ph.HE]**
(or **arXiv:1602.04735v1 [astro-ph.HE]** for this version)

**Submission history**

From: Avi Loeb [view email]

# Comments on Graviton Propagation in Light of GW150914

John Ellis, Nick E. Mavromatos, Dimitri V. Nanopoulos

*(Submitted on 15 Feb 2016)*

The observation of gravitational waves from the Laser Interferometer Gravitational-Wave Observatory (LIGO) event GW150914 may be used to constrain the possibility of Lorentz violation in graviton propagation, and the observation by the Fermi Gamma-Ray Burst Monitor of a transient source in apparent coincidence may be used to constrain the difference between the velocities of light and gravitational waves: $c_g - c_\gamma < 10^{-17}$.

Comments: 6 pages, no figures
Subjects: **General Relativity and Quantum Cosmology (gr-qc)**; Cosmology and Nongalactic Astrophysics (astro-ph.CO); High Energy Astrophysical Phenomena (astro-ph.HE); High Energy Physics - Phenomenology (hep-ph); High Energy Physics - Theory (hep-th)
Report number: KCL-PH-TH/2016-06, LCTS/2016-04, CERN-TH/2016-032, ACT-02-16, MI-TH-1608
Cite as: **arXiv:1602.04764 [gr-qc]**
(or **arXiv:1602.04764v1 [gr-qc]** for this version)

**Submission history**

From: John Ellis [view email]
**[v1]** Mon, 15 Feb 2016 18:52:37 GMT (7kb,D)

- https://phet.colorado.edu/sims/radiating-charge/radiating-charge_en.html