United Nations
Educational, Scientific and
Cultural Organization

**100th anniversary of Roland Eötvös (1848-1919), physicist, geophysicist, and innovator of higher education**
Commemorated in association with UNESCO

# Roland Eötvös

## physicist, geophysicist and innovator of teacher’s training

# Curriculum vitae

| Year | Age | Family/Private | Scientific&Academic | Public&Social |
|---|---|---|---|---|
| 1848 | | Born in *Buda* | | |
| 1866-67 | 18-19 | Jura studies at University of *Pest* | | |
| 1868-70 | 20-22 | Studies at University of *Heidelberg*<br>Semester in *Königsberg* | | |
| 1870 | 22 | **PhD in Physics from U.-Heidelberg** | | |
| 1871 | 23 | | **Habilitation at University of *Pest*** | |
| 1873 | 25 | | Corresponding member of Hungarian Academy of Sciences | **Editor of the science popularization monthly Communications in Natural Sciences** |

# Curriculum vitae

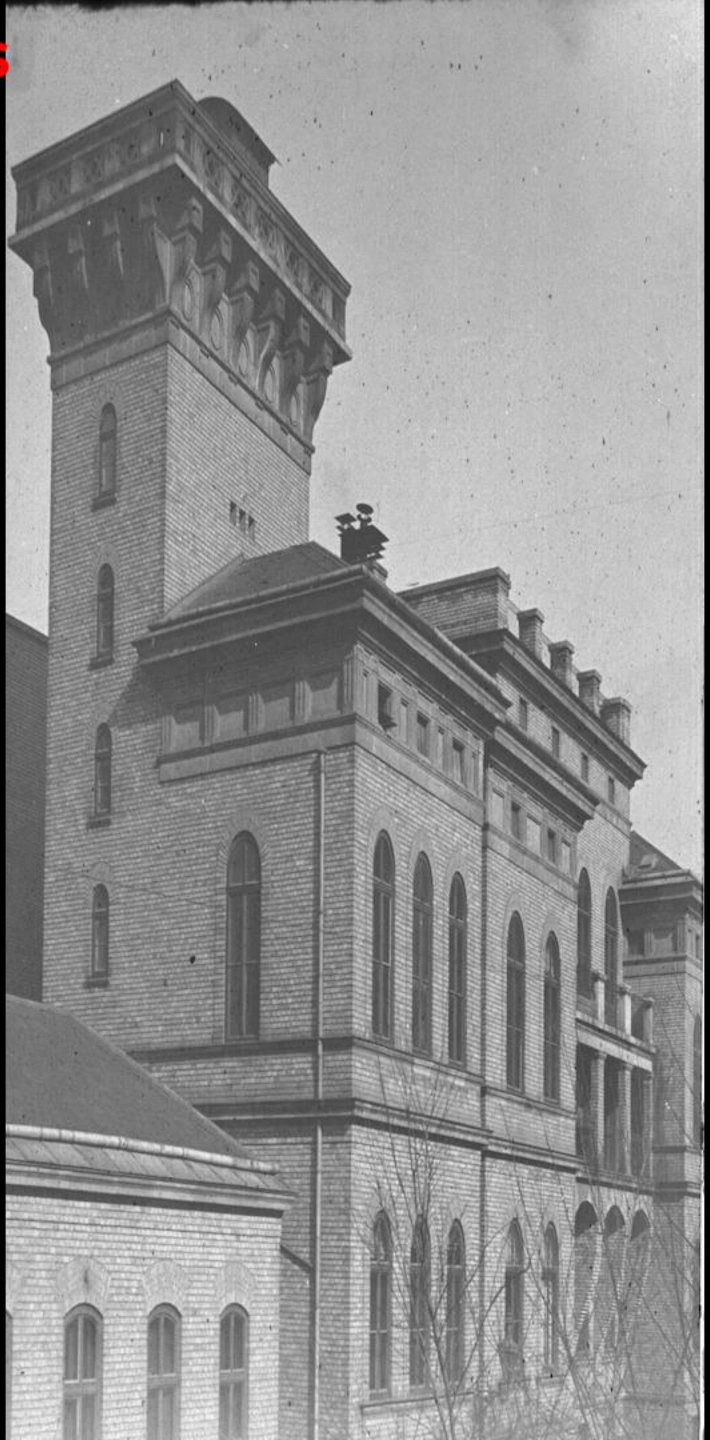
| | | | | |
|---|---|---|---|---|
| 1876 | 28 | Married on Gizella Horvát (2 daughters)<br>Summer mountaineering in Schluderbach (South Tirol) till 1914 | **New method for the experimental determination of the *capillary constant*** | |
| 1878 | 30 | | Head of the Department for Experimental Nature Studies<br>at University of *Budapest* | |
| 1880 | 32 | | | Vice-President of the Society for Advancement of Natural Sciences (till 1919) |
| 1885 | 37 | | | Foundation of the Table Meetings of Mathematicians |
| 1886 | 38 | | **Eötvös-rule of the *temperature dependence* of the capillary constant** | |

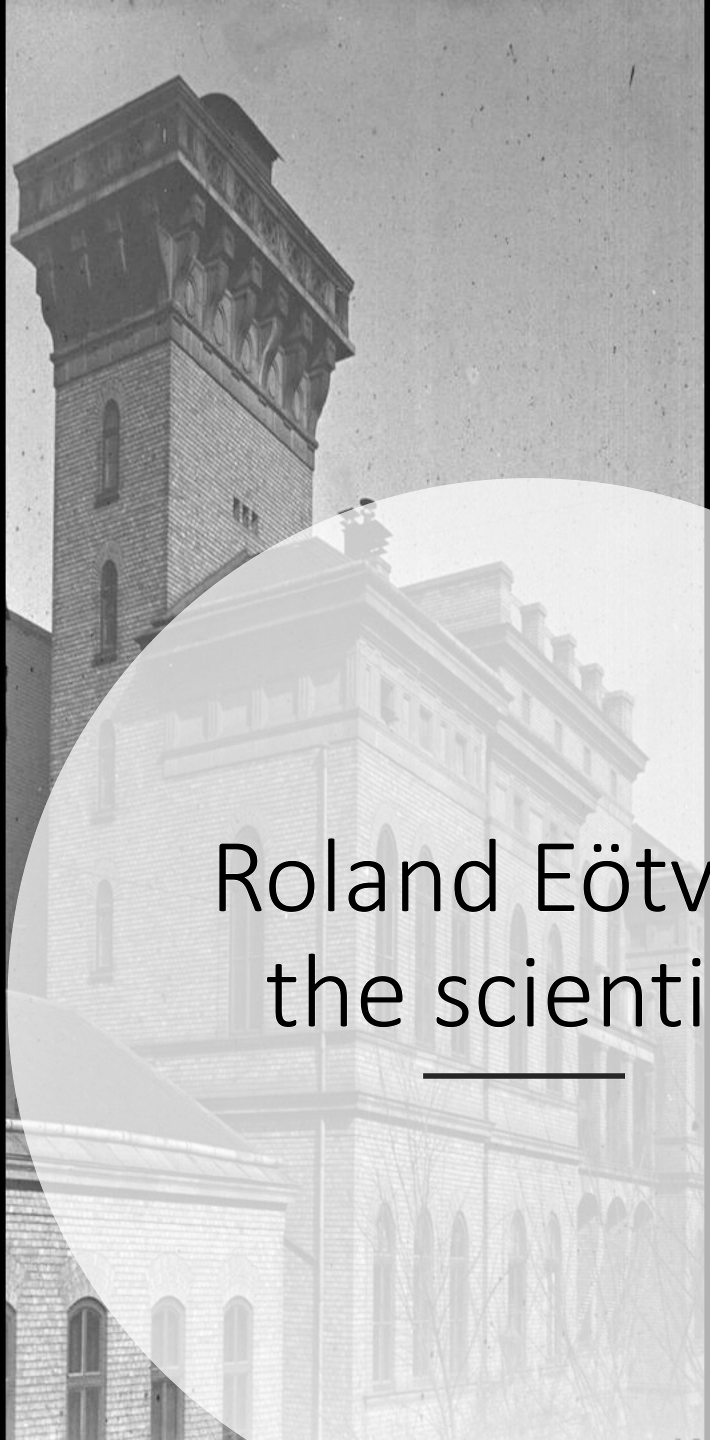
# Curriculum vitae

| | | | | |
|---|---|---|---|---|
| 1887 | 39 | | | Open letter to the Minister of Education and Cults on higher education |
| 1888-90 | 40-42 | | **New method for testing the law of Universal Free Fall** | |
| 1889 | 41 | | | President of the Hungarian Academy of Sciences (till 1905) |
| 1891 | 43 | | **Construction of the Eötvös-balance**<br>**Field tests in Western Hungary** | **Foundation of the Mathematical and Physical Society (president till 1919)** |
| 1892-93 | 44-45 | | Rector of the University of Budapest | |
| 1894-95 | 46-47 | | | **Minister of Education and Cults (7 months)** |
| 1895 | 47 | | | **Foundation of the József Eötvös Collegium (curator till 1919)** |

# Curriculum vitae

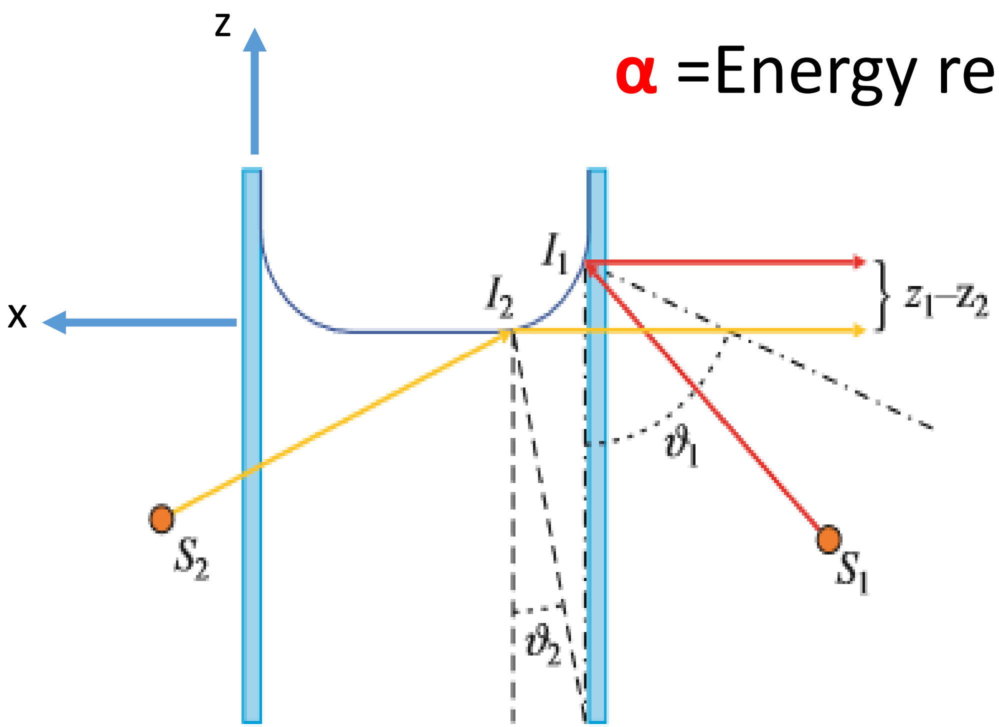
| | | | | |
|---|---|---|---|---|
| 1900 | 52 | | Report on field experiments with Eötvös-balance to the Paris Conference of Geodesy | |
| 1902 | 54 | Eötvös-peak in the Dolomites | | |
| 1906 | 58 | | Report on field experiments with Eötvös-balance to the Budapest Conference of Geodesy | |
| 1906-1909 | 58-61 | | **Improved bound on the validity of Universal Free Fall (Beneke Prize, University of Göttingen)** | |
| 1912 | 64 | | Report on field experiments with Eötvös-balance to the Hamburg Conference of Geodesy | |
| 1913 | 65 | | **Instrument for laboratory demonstration of the Eötvös-effect** | |
| 1891-1916 | | | Gravitational and magnetic anomaly mapping of the Austro-Hungarian Monarchy → **"Founding father" of applied geophysics** | |
| 1919 | 71 | Died in *Budapest* | | |





# Roland Eötvös, the scientist

# The Eötvös-rule for surface tension (1876-86)




**α** =Energy required for unit increase of the liquid layer surface

**R** curvature radius at height **z** along an infinite wall follows the geometric relation proposed by Gauss, Laplace, Poisson:

$$\frac{1}{R} = \frac{2z}{a^2}, \quad a = \frac{2\alpha}{g\rho}, \quad \frac{d\varepsilon}{dF} = \alpha,$$

ρ density
g grav. acc.

Reflection method of Eötvös

$$z_1 - z_2 = \sqrt{2}a(\sin\frac{\vartheta_1}{2} - \sin\frac{\vartheta_2}{2})$$

$$R = \frac{(1 + z'^2)^{\frac{3}{2}}}{z''}, \quad z' = \frac{dz}{dx} \qquad \frac{z^2}{a^2} = 2\,(\sin\frac{\vartheta}{2})^2$$

# The Eötvös—(Ramsay) rule

Eötvös' data on mercury (in *cm*)

| | | |
|---|---|---|
| 2,415 | 2,411 | 2,468 |
| 2,407 | 2,468 | 2,476 |
| 2,498 | 2,420 | 2,420 |

Középérték $a = 2{,}442$

Previous data of others

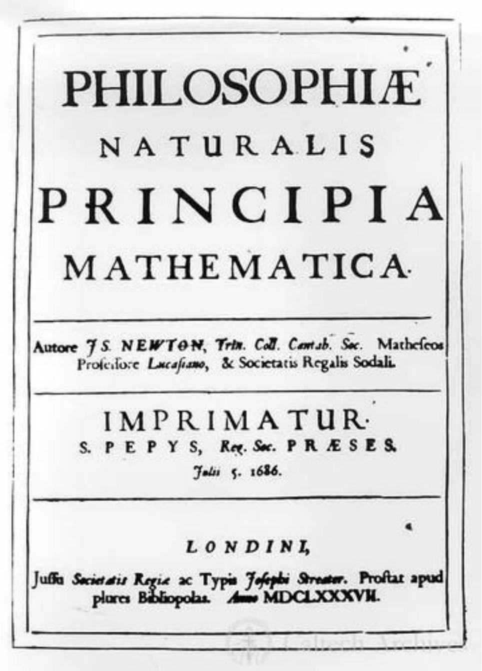
| | | | |
|---|---|---|---|
| LAPLACE | 2,55 | POISSON | 2,55 |
| HAGEN | 2,62—2,68 | BÉDE | 2,66 |
| DANGER | 2,59 | DESAINS | 2,62—2,65 |
| QUINCKE | 2,861—2,941. | | |

Equation of state of ideal gas

$pV$= RT, R= Regnault constant

Equation for surface layers

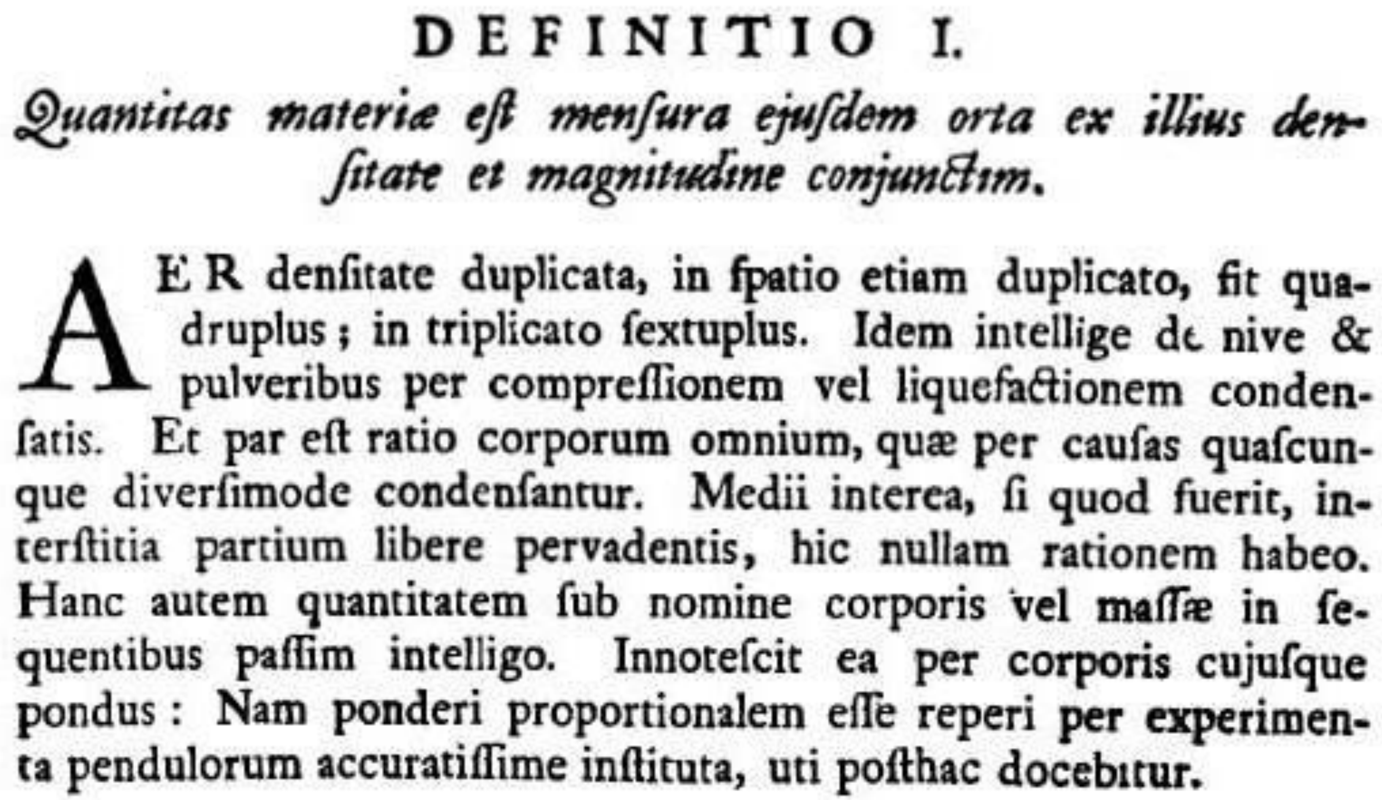
$\alpha V^{2/3} = E\ddot{o}\,(T_* - T)$ Eö = Eötvös constant


PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA

Autore J S. NEWTON, Trin. Coll. Cantab. Soc. Matheſeos Profeſſore Lucaſiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

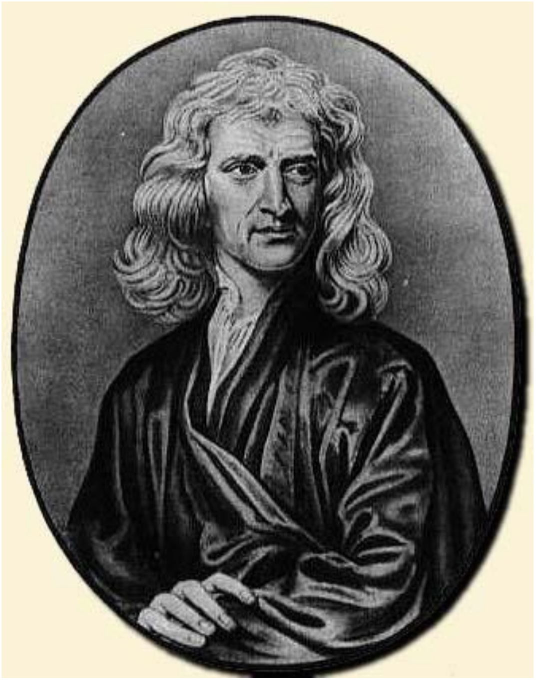
LONDINI,
Juſſu Societatis Regiæ ac Typis Joſephi Streater. Proſtat apud plures Bibliopolas. Anno MDCLXXXVII.


DEFINITIO I.

*Quantitas materiæ eſt menſura ejuſdem orta ex illius denſitate et magnitudine conjunctim.*

AER denſitate duplicata, in ſpatio etiam duplicato, fit quadruplus; in triplicato ſextuplus. Idem intellige de nive & pulveribus per compreſſionem vel liquefactionem condenſatis. Et par eſt ratio corporum omnium, quæ per cauſas quaſcunque diverſimode condenſantur. Medii interea, ſi quod fuerit, interſtitia partium libere pervadentis, hic nullam rationem habeo. Hanc autem quantitatem ſub nomine corporis vel maſſæ in ſequentibus paſſim intelligo. Innoteſcit ea per corporis cujuſque pondus: Nam ponderi proportionalem eſſe reperi per experimenta pendulorum accuratiſſime inſtituta, uti poſthac docebitur.

# A true challenge: Checking a fundamental concept of Newton's mechanics



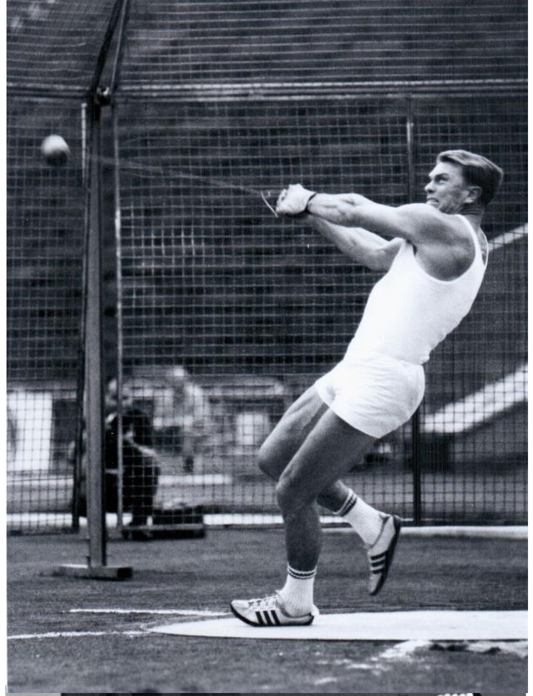
# In modern terms

$$\frac{\textcolor{red}{Inertial\ mass\ (}Zsivótzky-mass\textcolor{red}{)}}{\textcolor{red}{Gravitating\ mass\ (}Földi-mass\textcolor{red}{)}} =$$

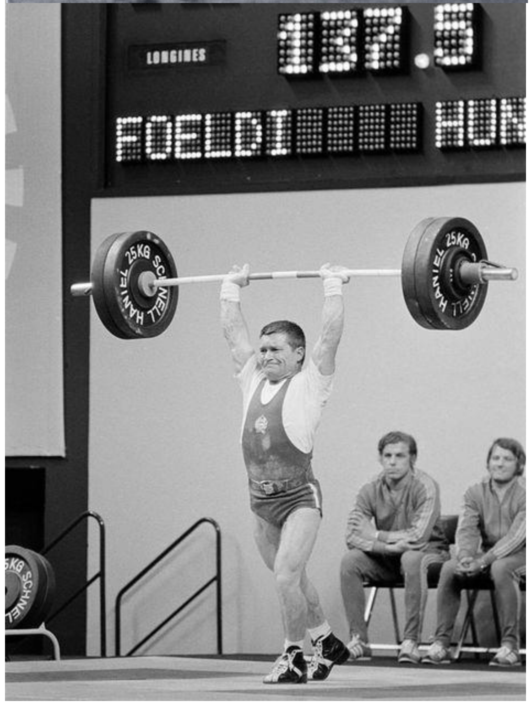
$$\textcolor{red}{\mathbf{Universal}}, independent\ of\ the\ kind\ of\ matter$$

Eötvös:

“Logics requires to verify the fundamental concept with the accuracy one can achieve in measuring the weight of a body”



Gyula Zsivótzky, olympic champion (1968) **accelerates** the ***inertial mass*** of the hammer




Imre Földi, olympic champion (1972) **throws out** a **gravitating mass**

# Old method for investigating the fundamental concept of Principia

**I. Newton** (followed by **F. Bessel, 1830**):
Separate measurement of the $m_{inertial}/m_{gravitating}$ ratio for different samples A,B… with

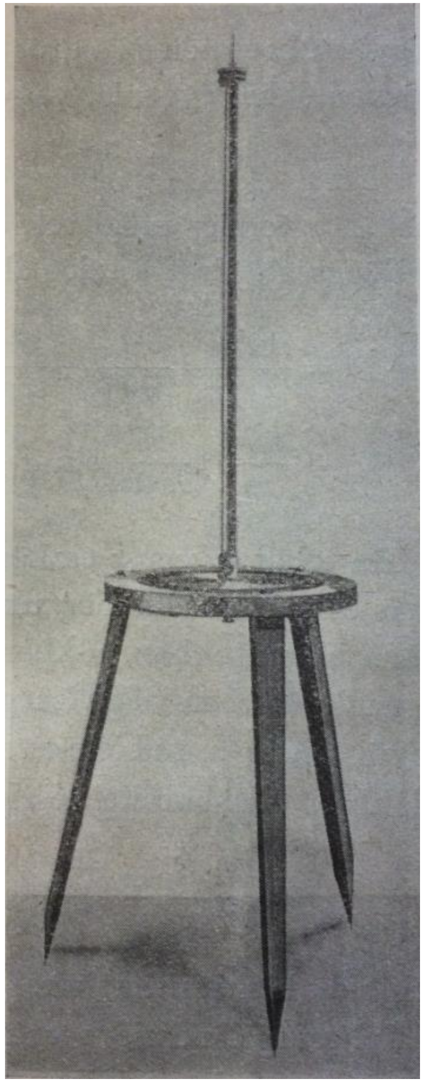
Kater's pendulum

and calculation of pairwise differences of the results

$$2\frac{\frac{m_{inertial,A}}{m_{gravitating,A}} - \frac{m_{inertial,B}}{m_{gravitating,B}}}{\frac{m_{inertial,A}}{m_{gravitating,A}} + \frac{m_{inertial,B}}{m_{gravitating,B}}} = \textbf{Eötvös} - \textbf{ratio}$$

Accuracy: $10^{-3} \rightarrow 10^{-5}$

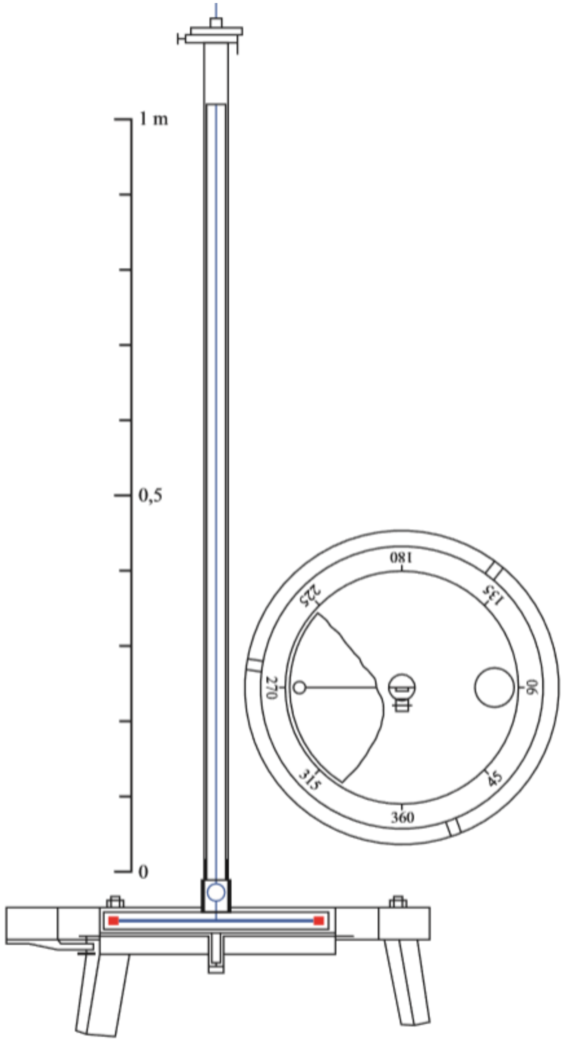
# NEW method for investigating the fundamental statement of Principia



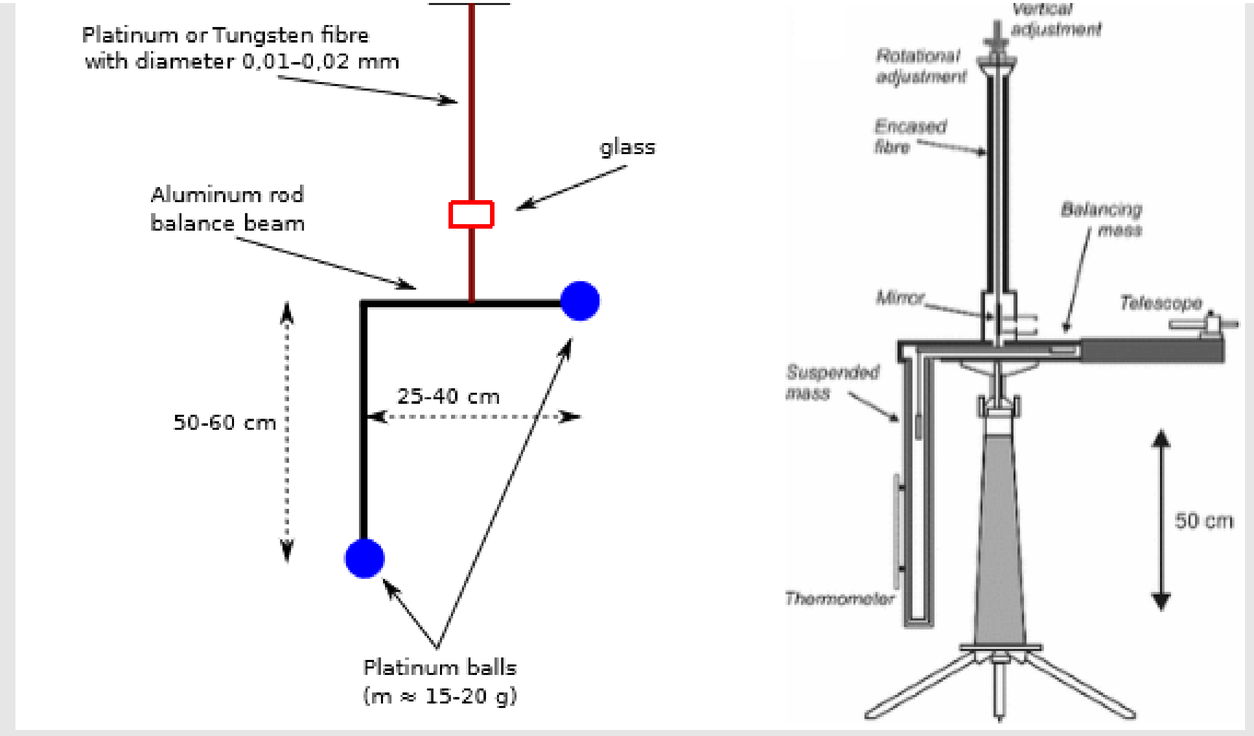
**Eötvös (1888-90)**:
Improved Cavendish-Coulomb type balance (***curvature variometer***) sensitive directly to the difference

$$m_{inertial}/m_{gravitating}\ \mathrm{A} - m_{inertial}/m_{gravitating}\ \mathrm{B}$$

Accuracy: 5 x $10^{-8}$



# The Eötvös-balance
# (***horizontal variometer***, 1891)




Complete characterization of the variations of the gravitational field in the horizontal plane

Order of magnitude improvement of the upper bound
on the Eötvös-parameter, 1906-09
Beneke Prize
from University of Göttingen

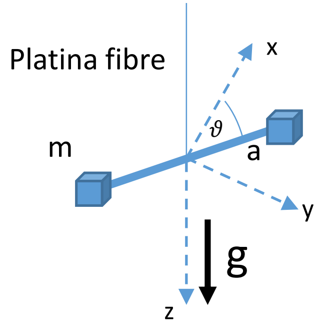
# The Cavendish—Coulomb-balance

- $V(\boldsymbol{x}) = \rho(\boldsymbol{x})U(\boldsymbol{x})$ Gravitational potential energy density

Orientation of the coordinate system of the balance:

- $\frac{\partial U}{\partial x} = \frac{\partial U}{\partial y} = 0, \; \frac{\partial U}{\partial z} = g$ at the centre of the beam, $\boldsymbol{x} = 0$
- Horizontal force components in inhomogeneous gravitational field
  $F_x = \rho(0)(U_{xx}(0)\Delta x + U_{xy}(0)\Delta y), \qquad F_y = \rho(0)(U_{yx}(0)\Delta x + U_{yy}(0)\Delta y)$
- Vertical torque expressed with components of the inertial moment

$$M_z = \int \left(\Delta x F_y - \Delta y F_x\right) = \left(\theta_{xx} - \theta_{yy}\right) \boldsymbol{U_{xy}(0)} + \theta_{xy}(\boldsymbol{U_{yy}(0)} - \boldsymbol{U_{xx}(0)})$$




Model of the balance:

two pointlike masses at the opposite ends of the beam at distance *a* from the centre

$$x = a\cos\vartheta\,,\ \ y = a\ \sin\vartheta$$

$$\theta_{xy} = m\,a^2\sin\vartheta\cos\vartheta\,, \qquad \theta_{xx} - \theta_{yy} = Ma^2(\cos\vartheta^2 - \sin\vartheta^2)$$

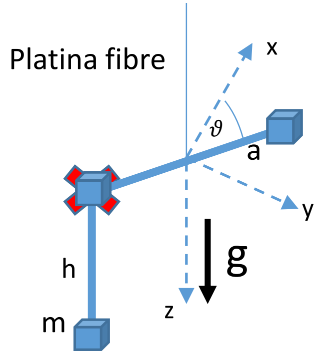
Determination of the equilibrium position of the balance

$$\boldsymbol{\tau(\varphi - \varphi_0) = K[U_{xy}(0)\cos 2\vartheta + (U_{yy}(0) - U_{xx}(0))\frac{\sin 2\vartheta}{2}]}$$

$\varphi_0$ = torquless position (unknown)

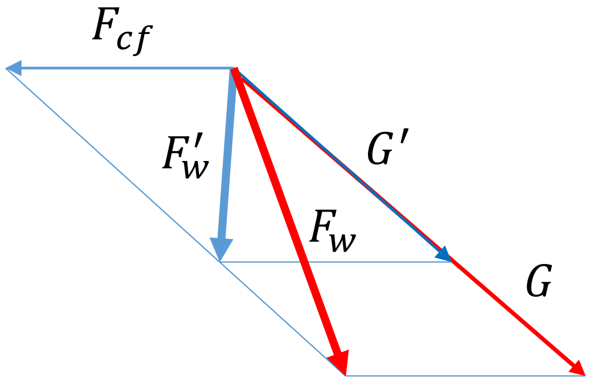
With 3 $\vartheta$ positions one finds $U_{xy}(0)$, $U_{yy}(0)$-$U_{xx}(0)$

# The Eötvös-balance




- $\Delta M_z = a\cos\vartheta\,\Delta F_y - a\sin\vartheta\,\Delta F_x \;= ma\left[h\left(\cos\vartheta\,\frac{\partial g}{\partial y} - \sin\vartheta\,\frac{\partial g}{\partial x}\right)\right]$

  $=mah(U_{zy}\cos\vartheta - U_{zx}\sin\vartheta)$
- **Consequence of different $m_{inertial}/m_{gravitational}$ ratios** for the two masses:



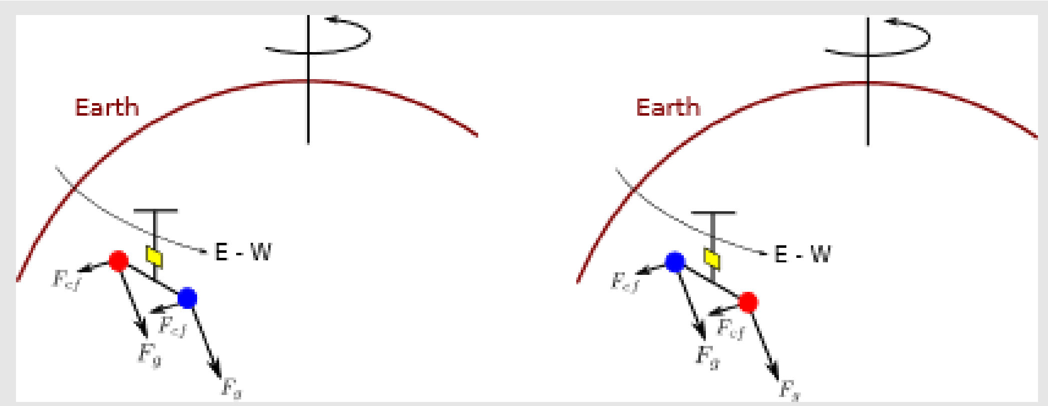

$$\varepsilon' - \varepsilon \approx \frac{G - G'}{F_w}\sin\varepsilon$$

$$\measuredangle F_w G = \varepsilon,$$
$$\measuredangle F'_w G' = \varepsilon'$$

$$\boldsymbol{G' = G_{ref}(1+\kappa_1)} \quad \boldsymbol{G = G_{ref}(1+\kappa_2)}$$

$$\boldsymbol{\tau(\varphi-\varphi_0)} = \mathrm{K}[U_{xy}(0)\cos 2\vartheta + (U_{yy}(0) - U_{xx}(0))\frac{\sin 2\vartheta}{2}]$$
$$+mah(U_{zy}\cos\vartheta - U_{zx}\sin\vartheta) - \boldsymbol{maG\sin\vartheta(\kappa_1-\kappa_2)\sin\varepsilon}$$

# Idealized determination




x-axis oriented along the main curvature (North)

East-West oriented beam, $\vartheta = \frac{\pi}{2}, \frac{3\pi}{2}$.

One pair of measurements with **Pt** — Reference-object,

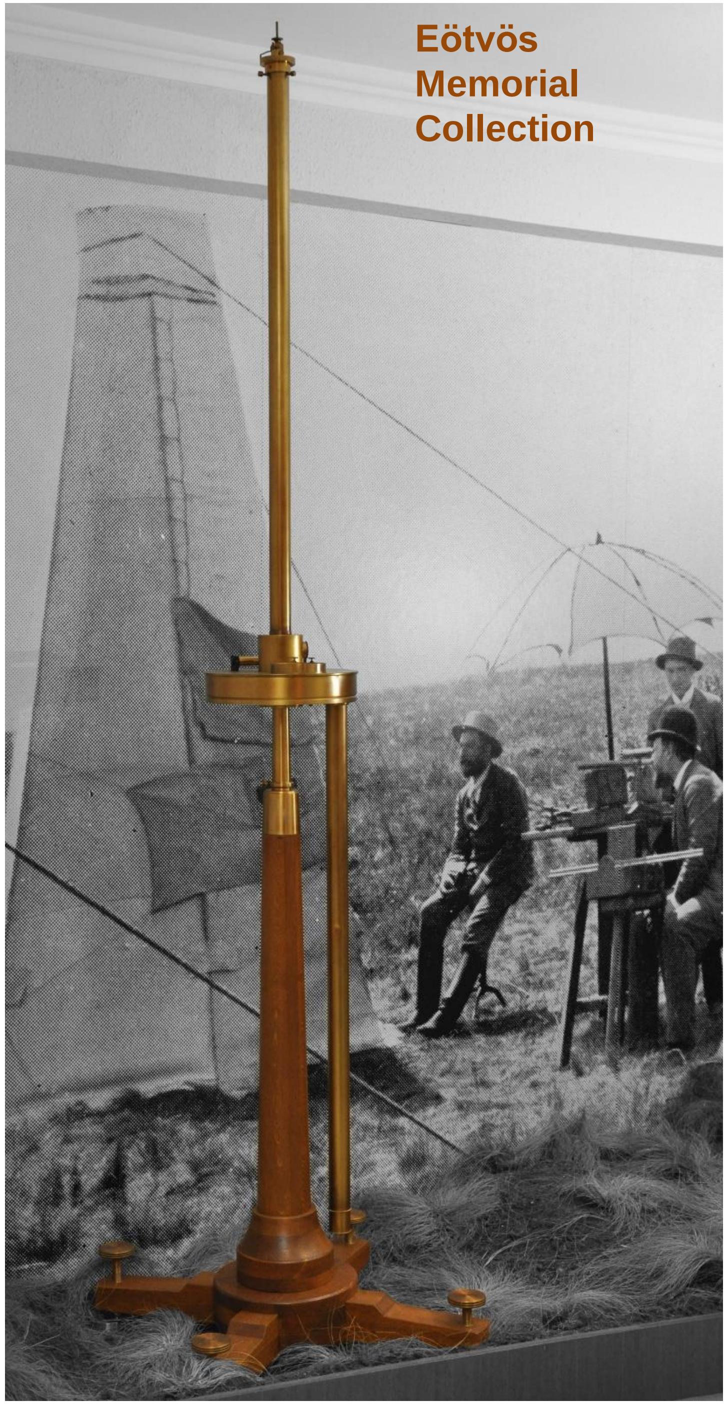
$$\tau\Delta\varphi_{\pi/2} = -KU_{xy} - mahU_{zx} + maG(\kappa_{Pt} - \kappa_{Ref}), \qquad \tau\Delta\varphi_{3\pi/2} = -KU_{xy} + mahU_{zx} - maG(\kappa_{Pt} - \kappa_{Ref})$$

Analogue measurement for the **Comparison object** – Reference-object:

$$\tau\Delta\varphi'_{\pi/2} = -KU_{xy} - mahU_{zx} + maG(\kappa_{Compare} - \kappa_{Ref}),$$

$$\tau\Delta\varphi'_{3\pi/2} = -KU_{xy} + mahU_{zx} - maG(\kappa_{Compare} - \kappa_{Ref})$$

$$\tau(\varphi_{\pi/2} - \varphi_{3\pi/2}) - \tau(\varphi'_{\pi/2} - \varphi'_{3\pi/2}) = 2\tau(\boldsymbol{\kappa_{Pt}} - \boldsymbol{\kappa_{Compare}})$$




# The Eötvös-balance
## (***horizontal variometer***, 1891)

Mapping  of gravitational anomalies

1901: Recognizing a tectonic line below the lake Balaton

1916: Identification of anticline dome formation containing natural gas/ oil at Egbell (Moravia)

# Worldwide success of the Eötvös-balance

- ≈100 “Original Eötvös Made in Hungary”

- Oil field explorations:
Texas, Louisiana (USA)
Egyiptom, Angola, Mexico, Venezuela
Punjab, Upper Assam (India)
Sarawak (Indonesia)

Eötvös Memorial Collection

Zeit eine unmittelbare physikalische Bedeutung. Ein Punktereignis hat die $X_1$-Koordinate $x_1$, bedeutet: Die nach den

1) Daß das Gravitationsfeld diese Eigenschaft mit großer Genauigkeit besitzt, hat Eötvös experimentell bewiesen.



Regeln der Euklidischen Geometrie mittels starrer Stäbe ermittelte Projektion des Punktereignisses auf die $X_1$-Achse

№ 7.

ANNALEN DER PHYSIK.

VIERTE FOLGE. BAND 49.

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

*von A. Einstein.*

Famous footnote in Einstein's extensive paper on the theory of General Relativity (1916)

W. Torge, *Geodesy*, de Gruyter, 2015 (p. 85)

$$\vartheta - \vartheta_0 = \frac{ml^2}{\tau}((W_{yy} - W_{xx}) \sin 2\alpha + 2W_{xy} \cos 2\alpha) + \frac{mlh}{\tau}(W_{xz} \sin \alpha - W_{yz} \cos \alpha). \tag{4.28}$$

The deflection $\vartheta$ is recorded photographically, and the instrumental constants $m$, $l$, $h$, $\tau$ are provided by the manufacturer. Hence, the field quantities $W_{yy} - W_{xx}$, $W_{xy}$, $W_{xz}$, $W_{yz}$, as well as $\vartheta_0$ can be determined by measuring $\vartheta$ for five different azimuths.

The development of a torsion balance suitable for field work was achieved around 1900 by the Hungarian physicist *R. v. Eötvös*; it was widely employed in applied geophysics between 1920 and 1940. An accuracy of $\pm 1$ to $\pm 5 \times 10^{-9}$ s$^{-2}$ can be attained for the field quantities (MUELLER et al. 1963). Due to the considerable effort that is required in making measurements and because of the large influence of nearby masses, the torsion balance has been superseded by the gravimeter.

*Spring gravimeters* can be used to approximate grad $g$ by measuring small gravity differences. With station separations of 10 to 100 m, the horizontal gravity gradient can be derived (HAMMER 1979). For the measurement of the vertical gradient, special tripods are used with heights of up to 3 m (RÖDER et al. 1985). A precision of $\pm 10^{-8}$s$^{-2}$ can be achieved with such measurements.

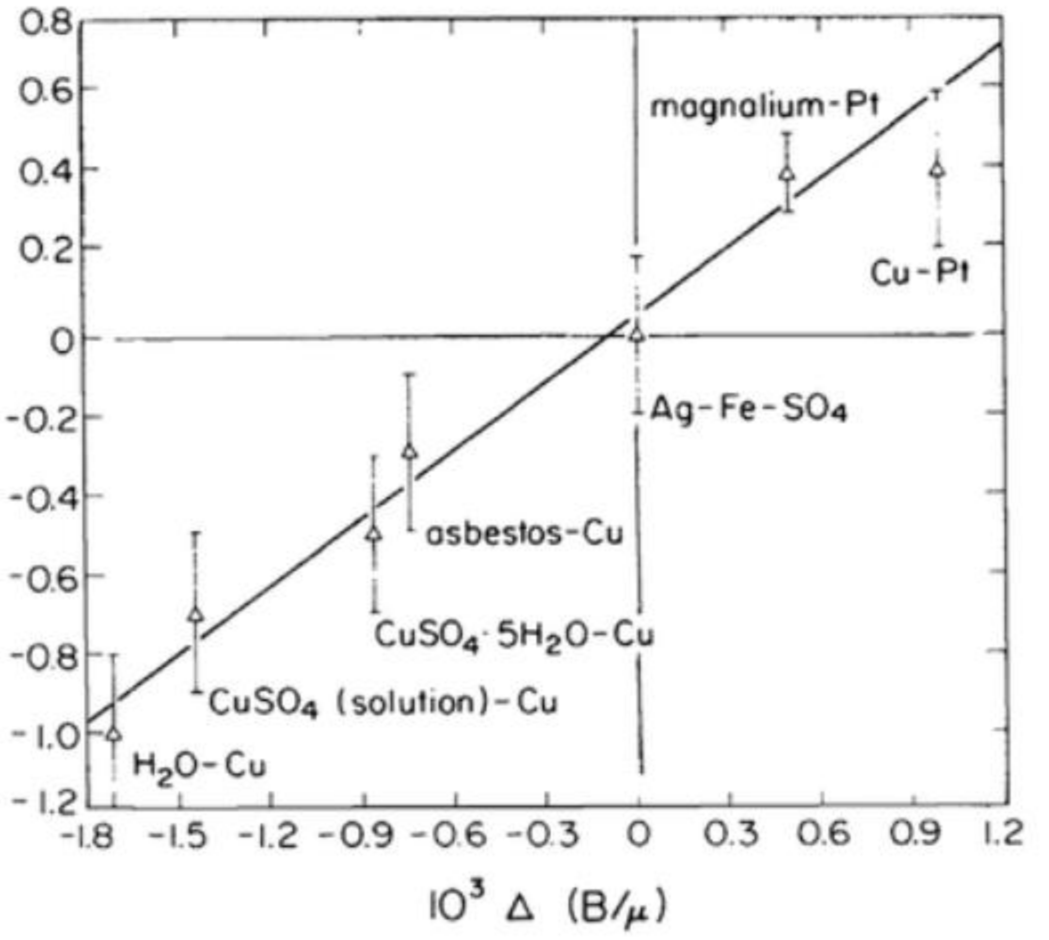
**Standard technological history reference in textbooks of geodesy and applied geophysics**

# The era of Eötvös-type experiments (1962-2008)

1957, Chapel Hill conference:
*The Role of Gravitation in Physics*
Robert Dicke, John Wheeler:
Exploration of the limitations of GR with high accuracy measurements

1963: Dicke, Roll, Krotkov
Comparison of the free fall of different samples towards the Sun
(3 orders of magnitude improvement)

1972: Braginsky, Panov
Further one order of magnitude improvement




1986: Ephraim Fischbach reanalyzes original data of Eötvös and collaborators from *1922*

# Fifth force?

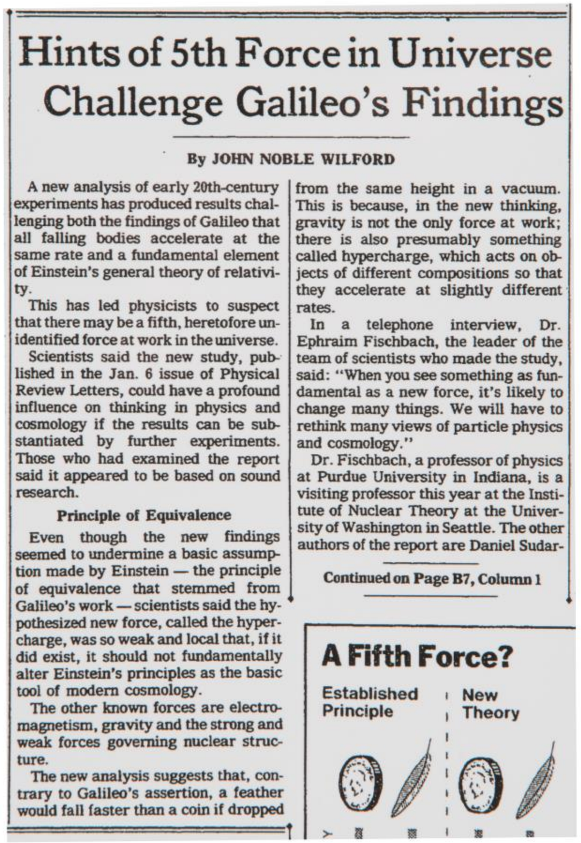
"All the News That's Fit to Print"

The New York Times

Late Edition

Weather: Mostly sunny and cold today, strong winds; clear and cold tonight. Partly sunny and warmer tomorrow. Temperatures: today 23-27, tonight 15-20; yesterday 18-27. Details, page C20.

VOL.CXXXV . . No. 46,648 — Copyright © 1986 The New York Times — NEW YORK, WEDNESDAY, JANUARY 8, 1986 — 50 cents beyond 75 miles from New York City, except on Long Island. — 30 CENTS



## Hints of 5th Force in Universe Challenge Galileo's Findings

By JOHN NOBLE WILFORD

A new analysis of early 20th-century experiments has produced results challenging both the findings of Galileo that all falling bodies accelerate at the same rate and a fundamental element of Einstein's general theory of relativity.

This has led physicists to suspect that there may be a fifth, heretofore unidentified force at work in the universe.

Scientists said the new study, published in the Jan. 6 issue of Physical Review Letters, could have a profound influence on thinking in physics and cosmology if the results can be substantiated by further experiments. Those who had examined the report said it appeared to be based on sound research.

**Principle of Equivalence**

Even though the new findings seemed to undermine a basic assumption made by Einstein — the principle of equivalence that stemmed from Galileo's work — scientists said the hypothesized new force, called the hypercharge, was so weak and local that, if it did exist, it should not fundamentally alter Einstein's principles as the basic tool of modern cosmology.

The other known forces are electromagnetism, gravity and the strong and weak forces governing nuclear structure.

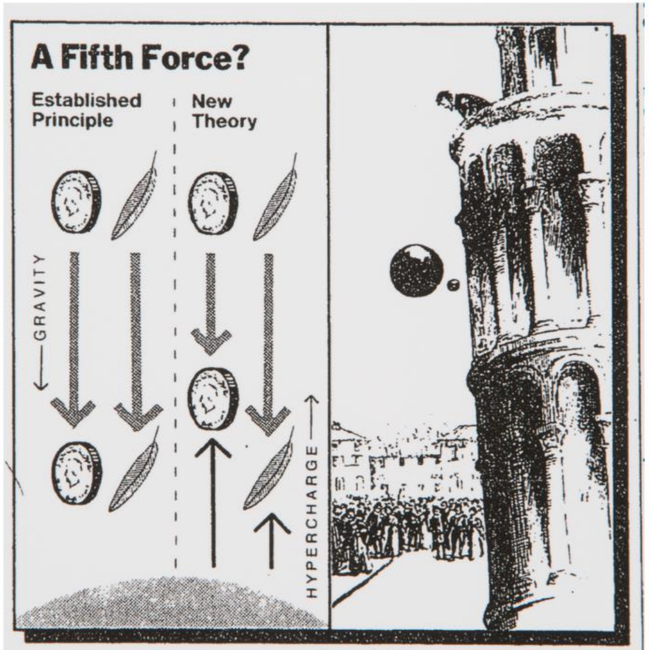
The new analysis suggests that, contrary to Galileo's assertion, a feather would fall faster than a coin if dropped from the same height in a vacuum. This is because, in the new thinking, gravity is not the only force at work; there is also presumably something called hypercharge, which acts on objects of different compositions so that they accelerate at slightly different rates.

In a telephone interview, Dr. Ephraim Fischbach, the leader of the team of scientists who made the study, said: "When you see something as fundamental as a new force, it's likely to change many things. We will have to rethink many views of particle physics and cosmology."

Dr. Fischbach, a professor of physics at Purdue University in Indiana, is a visiting professor this year at the Institute of Nuclear Theory at the University of Washington in Seattle. The other authors of the report are Daniel Sudar-

Continued on Page B7, Column 1

A Fifth Force?
Established Principle
New Theory



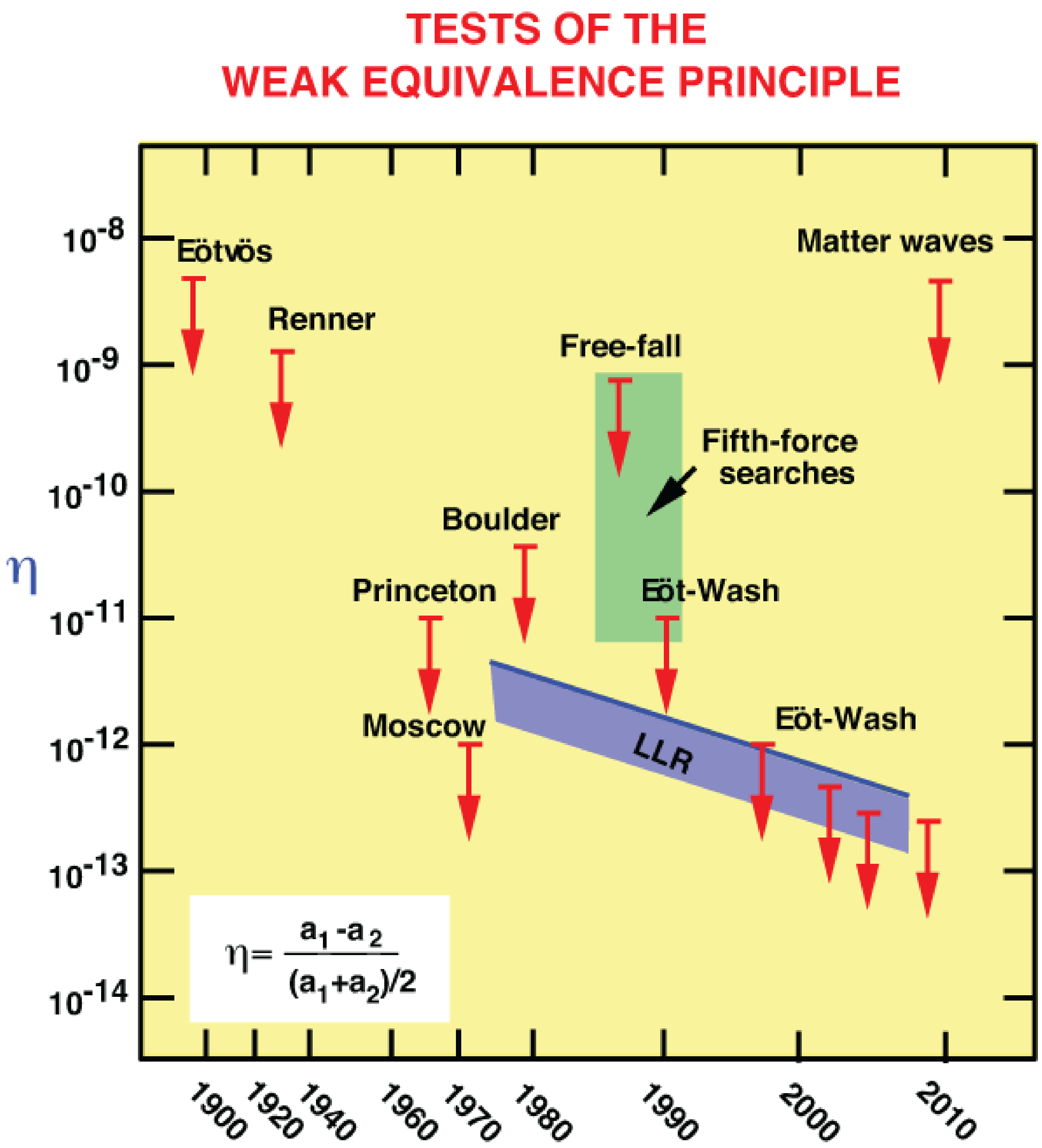

The new theory proposes that a fifth force called hypercharge pushes up against falling objects, working against the force of gravity. The force of the hypercharge is a function of the mass and the atomic composition of a given object; it is greater for a copper coin than for a feather. Thus, if a feather and a penny were dropped through a vacuum the feather would fall slightly faster than the coin. That contradicts established principle, shown by Galileo at Tower of Pisa, asserting that all objects fall at the same rate.

Finite range force field (cca. 10-100 m) disguised in the weight of the bodies?

# Eöt-Wash series of experiments

- 1989-2008: University of Washington, Eric Adelberger
- Sensitive to a force range not less than 1m
- No indication for the existence of 5th force

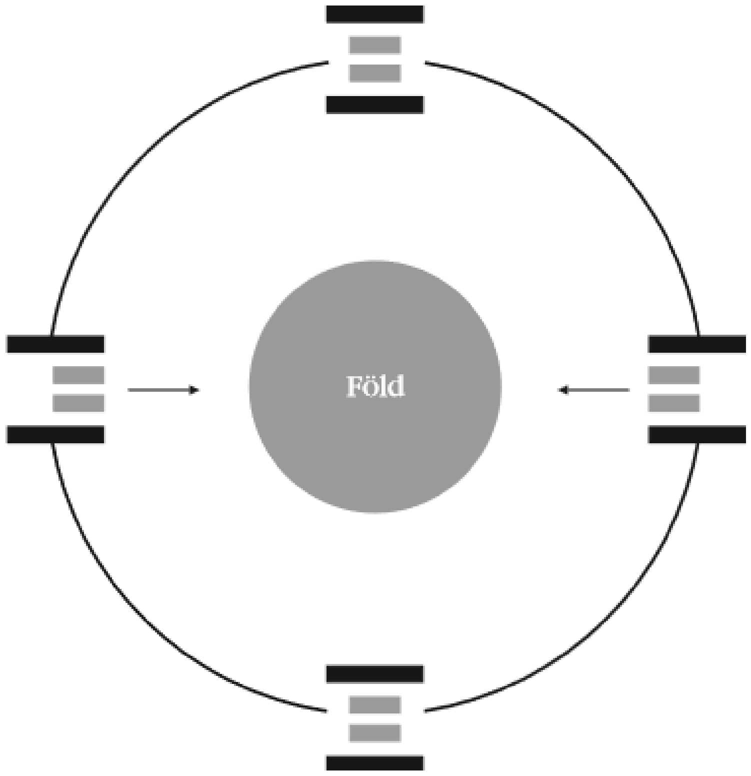
In 100 years 5 orders of magnitude improvement in the upper bound for the violation of Universal Free Fall



# Eötvös-parameter measurement in space (2017-19)

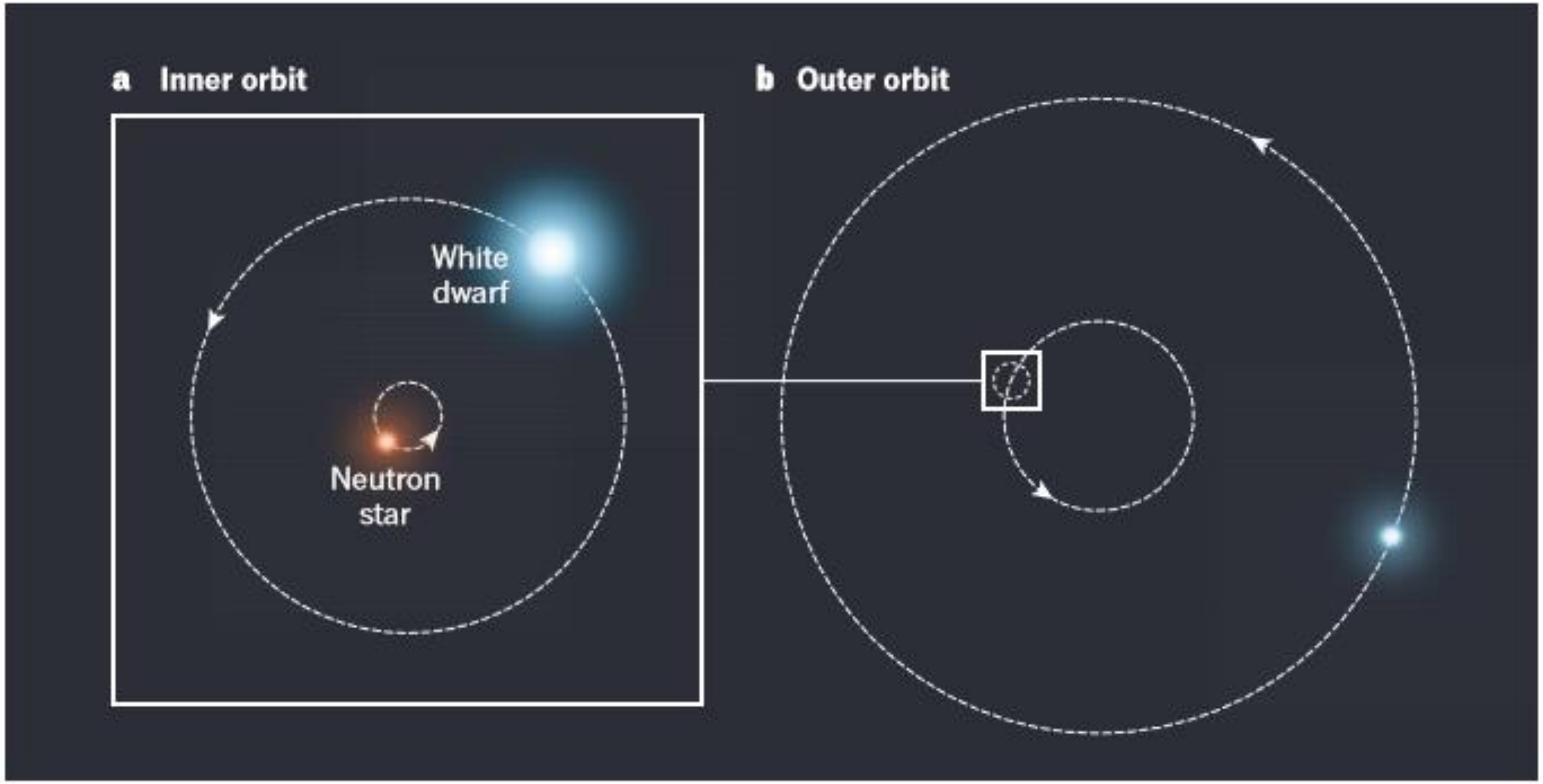
The MICROSCOPE mission: first results of a space test of the Equivalence Principle

Pierre Touboul, Gilles Métris, Manuel Rodrigues *et al.*




According to the Weak Equivalence Principle, all bodies should fall at the same rate in a gravitational field. The MICROSCOPE satellite, launched in April 2016, aims to test its validity at the $10^{-15}$ precision level, by measuring the force required to maintain two test masses (of titanium and platinum alloys) exactly in the same orbit. A non-vanishing result would correspond to a violation of the Equivalence Principle, or to the discovery of a new long-range force. Analysis of the first data gives $\delta(\mathrm{Ti},\mathrm{Pt}) = [-1 \pm 9(\mathrm{stat}) \pm 9(\mathrm{syst})] \times 10^{-15}$ ($1\sigma$ statistical uncertainty) for the titanium-platinum Eötvös parameter characterizing the relative difference in their free-fall accelerations.

# How does fall the gravitational field bound in binary neutron star – white dwarf system in the gravitational field of a third star?

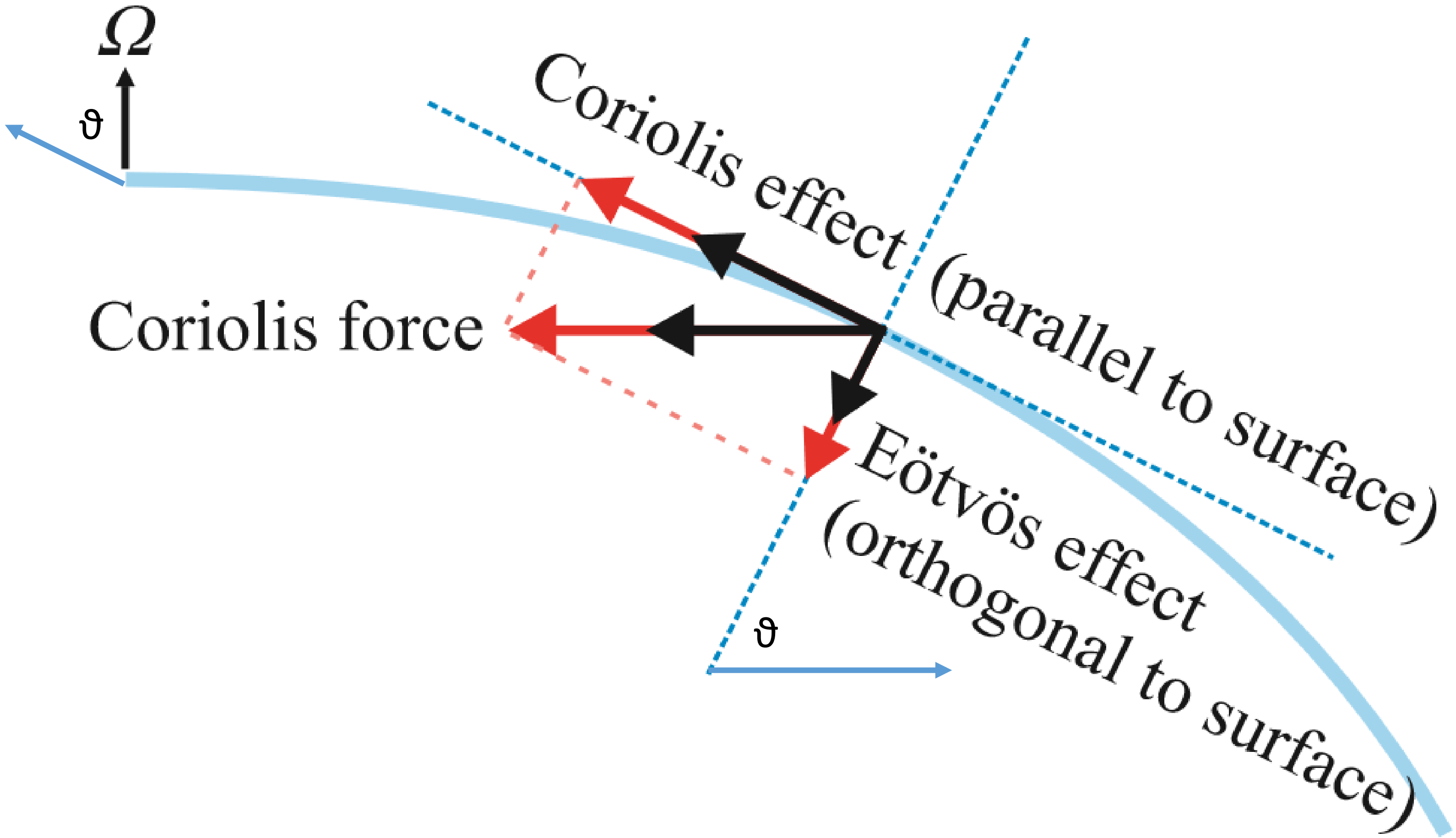



Triple star system discovered in 2014 (Ransom *et al.*)

Observation of the orbital for 4 years: Archibald *et al.* (2018)

No distortion:
Accuracy: $10^{-5}$

# Weight variation of objects moving relative to the surface of the Earth (1913 – 1917 – 1919)



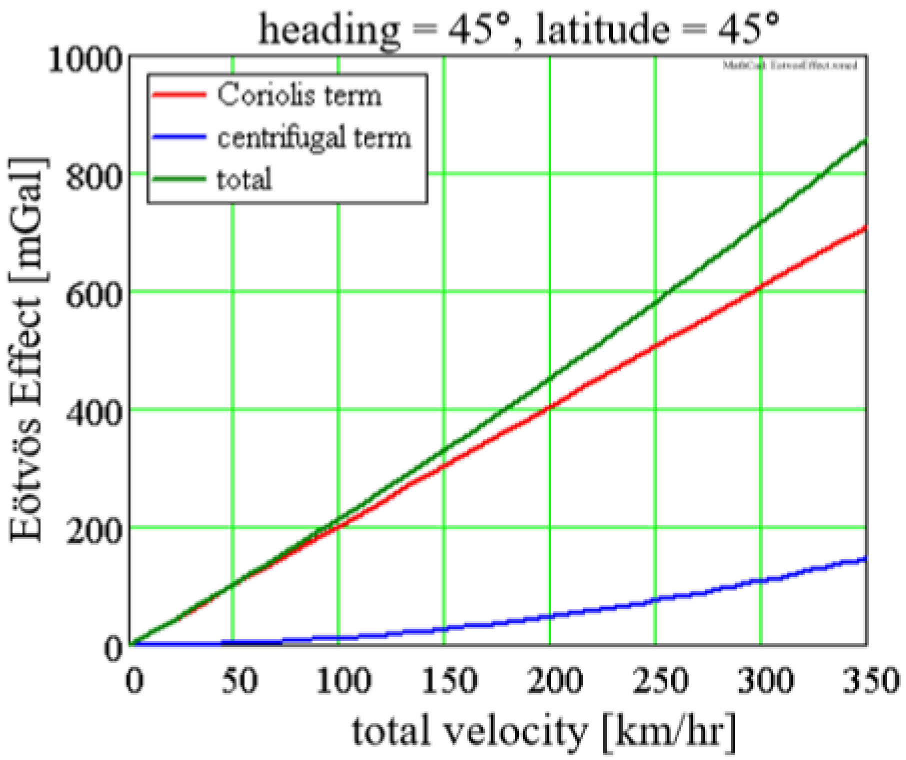

**Eötvös effect** = vertical component of Coriolis acceleration

$$\Delta g = -2\Omega \cos \vartheta v_{East}$$

# Rotating balance of Eötvös


More in the lecture by Prof. István Groma

# Eötvös correction




Important for interpreting data of airborne gravimetry

# Roland Eötvös, the public figure

**1871**

Initiates countrywide system supporting research of high-school teachers

**1887**

Open letter to the Minister of Education on problems of higher education

**1891-1919**

**Founding president of Mathematical and Physical Society**

**1894**

Minister of Education and Cults
Increased budget of education, sextuple financial support for elementary school teachers

**1895-1919**

**Founding curator of József Eötvös College**

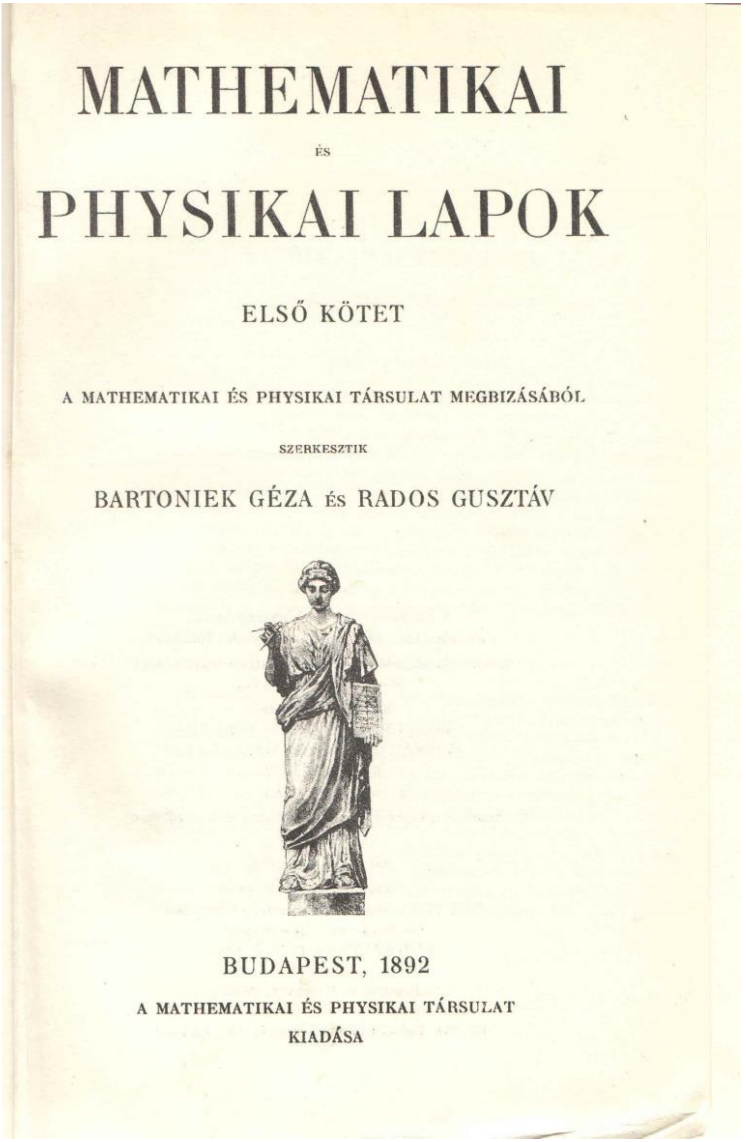
**1896-1919**

**Chair of the Teacher's Examination Committee of the Budapest University**

**1898**

President of the Budapest University Athletic Club

“The school needs a good school system and good teachers
You might ask which is more important. Myself, I would prefer the latter.”




“The quality of teaching depends in first place on the scientific preparedness of the teachers”

The idea of “teacher-scientist”

Vol. 1 of the monthly
Mathematical-Physical Journal

AZ EÖTVÖS-KOLLEGIUM ÚJ ÉPÜLETE.

Building of the
Eötvös College, 1910

# József Eötvös College

- Independent, self-governing teacher's training boarding-school (100 student/year, 30 stipends for students from poor families)
- High intensity educational program (best library of the country, foreign language courses) with strict performance requirements
- Students of the Eötvös College (1895-1950):

    1204 accepted members

    400 high-school teachers

    81 members of the Hung. Acad. of Sciences

Famous pupils:

*Zoltán Kodály* (composer)

*Tamás Varga* (math. teacher-innovator)

*Miklós Vermes* (physics teacher, organizer of the Eötvös problem solving competition in physics)

Living tradition under heavy disputes:

Elitist institution or a widely followed example?

In the democratic environment since 1990:

newly founded colleges follow the EC-tradition

Science Faculty of Eötvös University: **Bolyai College** (1992)

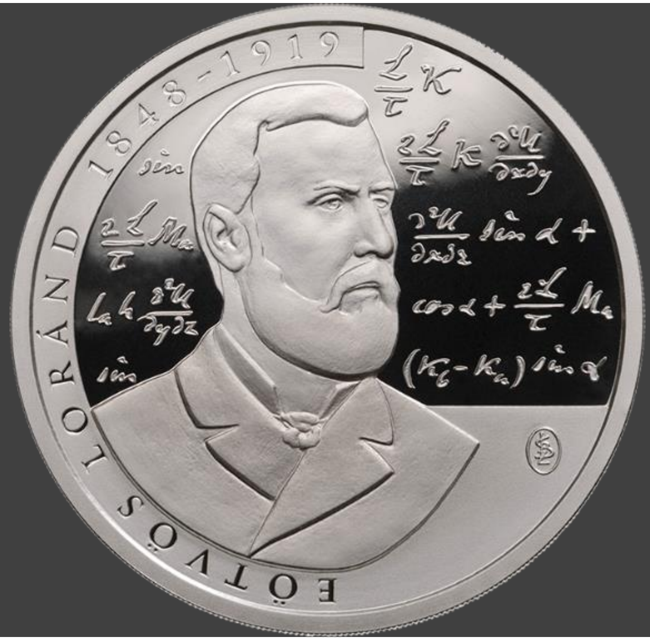
Adapting the meaning of “teacher-scientist” to the actual needs of public education:

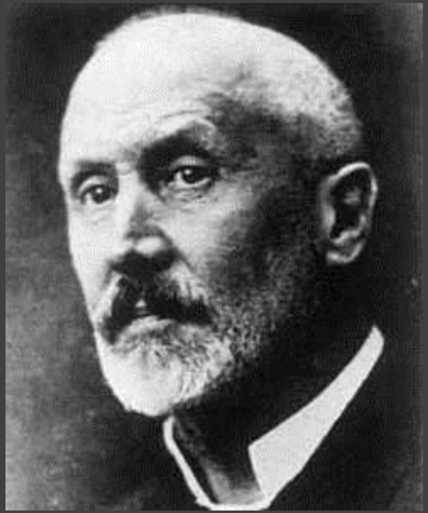
**Content pedagogy development research** initiated by the Hungarian Academy of Sciences:

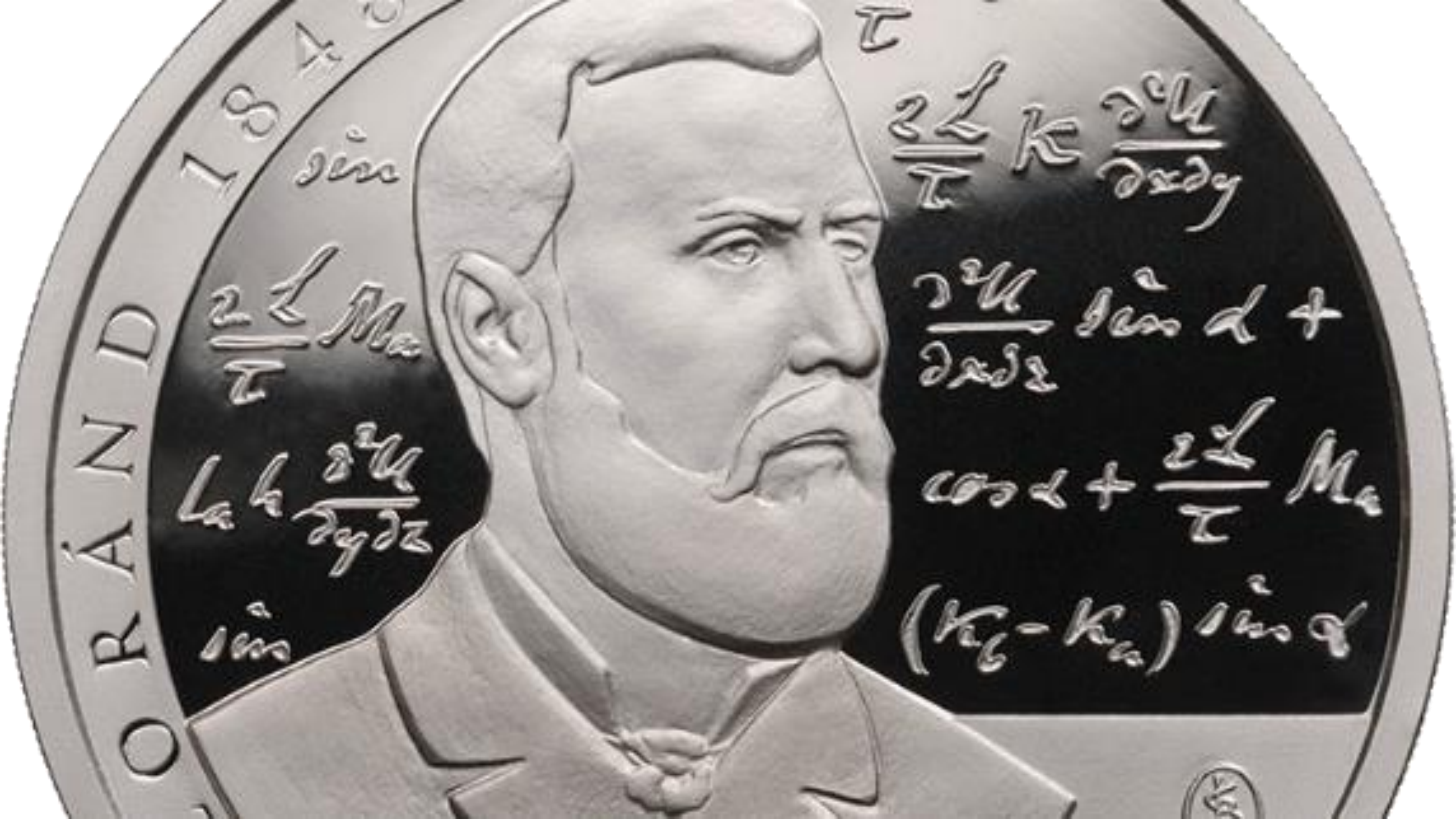
talks by teacher-members of the MTA-ELTE Physics Education Research Group at present conference

# Legacy of Roland Eötvös

- Pioneer of high precision physics experiments, always stretching the accuracy to the actual limits of the measuring equipment;
- Inventor of a method for the verification of the Weak Equivalence Principle, which for a century has determined the direction of research by its continuous adaptability to the progress of technology;
- Founder of institutions (Eötvös College) and organizations (Mathematical and Physical Society) of considerable social impact, and existing even today, thanks to their continuous adaptability to the changing social environment


1848-1919
EÖTVÖS LORÁND



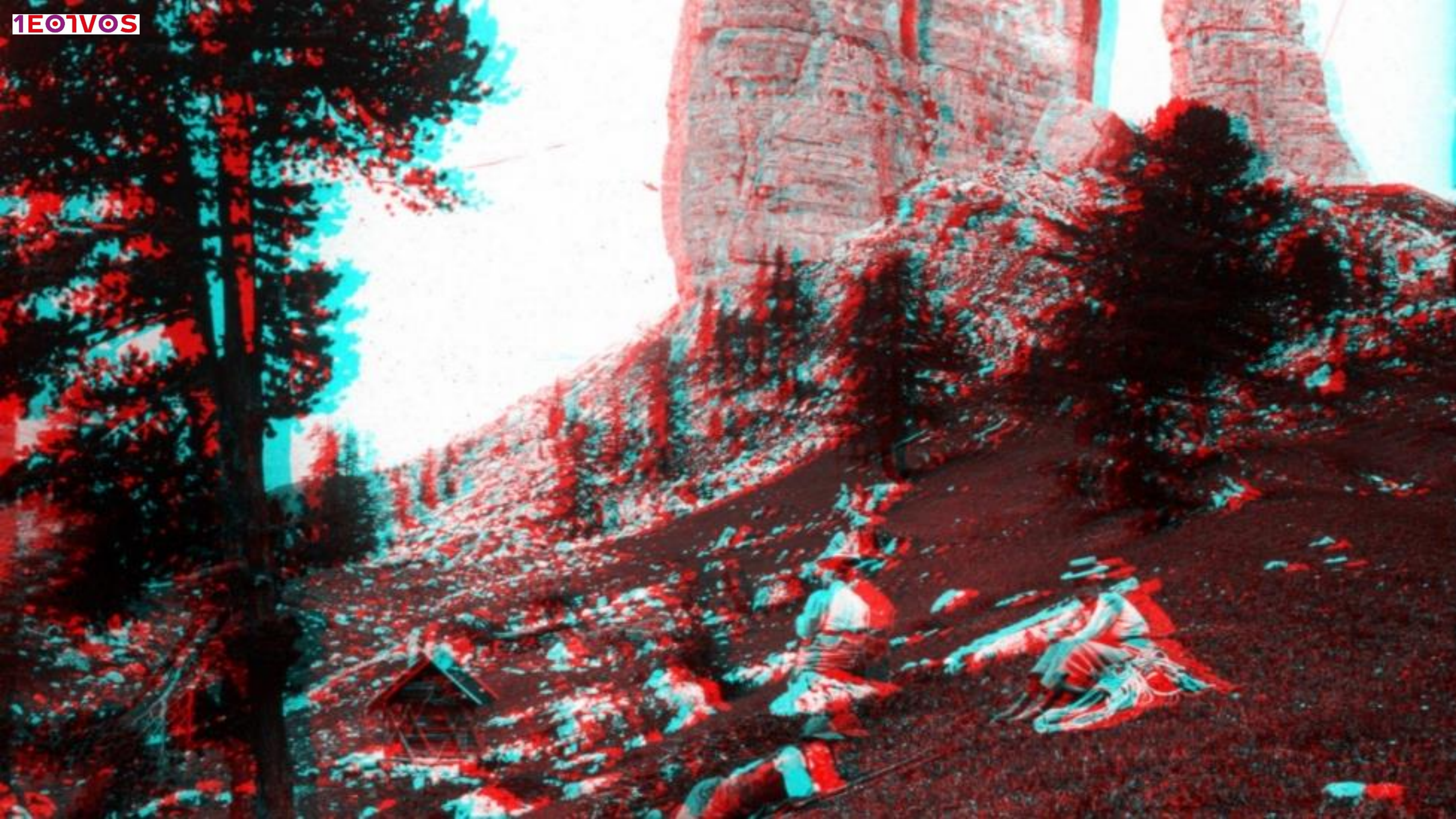

ORÁND 184

# Roland Eötvös, the sportsman

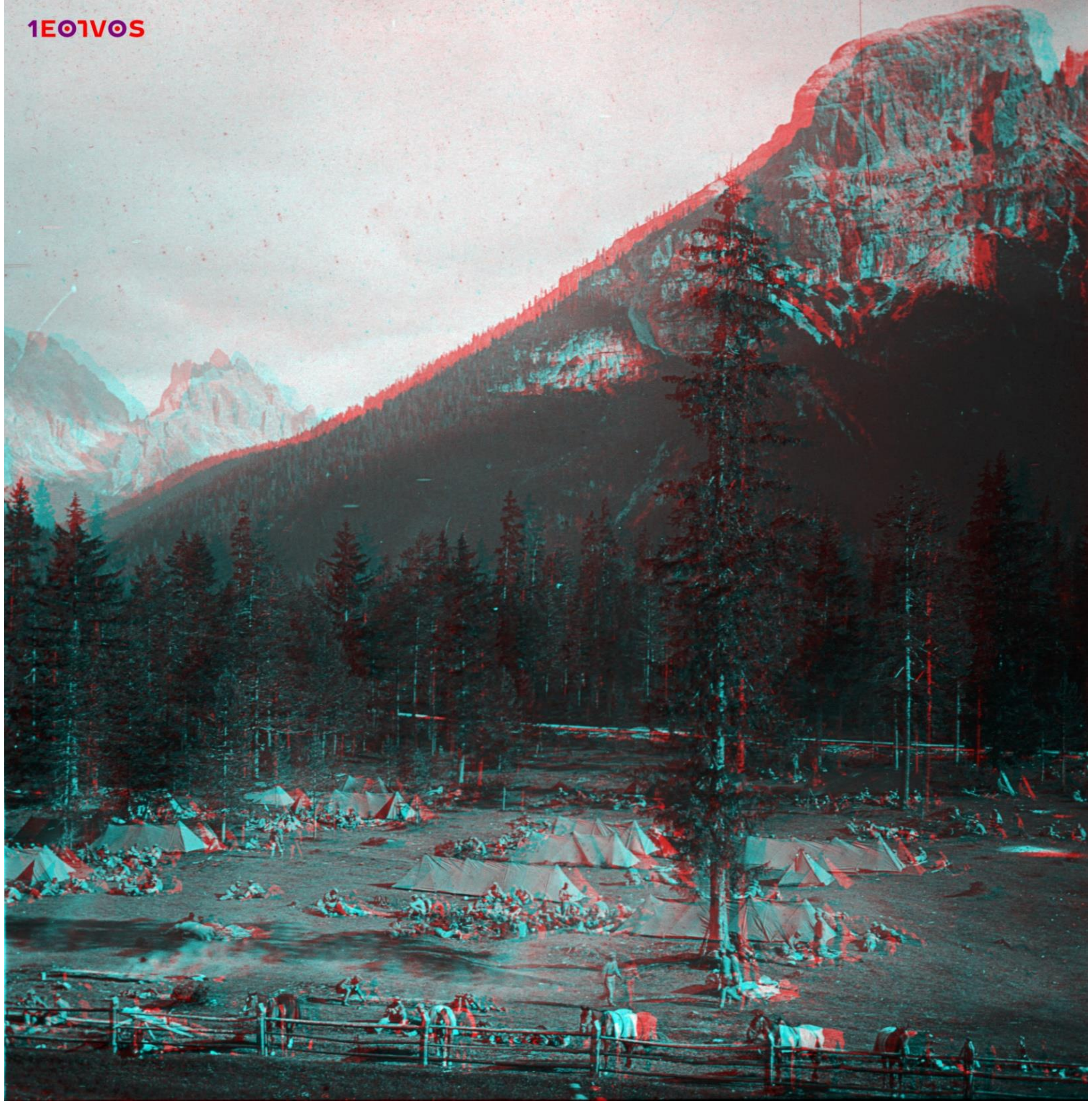
https://eotvos100.hu/en/page/tomorlatvany_kepek

Anagliph photos can be enjoyed with Cyan (right) - Red (left) glasses

# Stereoscopic photos of a mountaineer




ALBERGO MISURINA



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Italia

www.bibliothek-toblach.com

August 10 – September 21, 2019

# Method of Eötvös for measuring Newton’s constant


$$\Delta\, M_z = +\frac{1}{2} G\rho l^2 \sin 2\vartheta_l \;\cdot\; \Delta m \qquad\qquad \Delta\, M_z = -\frac{1}{2} G\rho l^2 \sin 2\vartheta_{tr} \;\cdot\; \Delta m$$

Equations of small oscillations around a torsion fibre

$$\boldsymbol{\Theta \ddot{\vartheta}_l = -(\tau - G\varrho\Theta)\vartheta_l} \qquad\qquad \boldsymbol{\Theta \ddot{\vartheta}_{tr} = -(\tau + G\varrho\Theta)\vartheta_{tr}}$$

Difference of the oscillation periods: $\boldsymbol{\frac{1}{T_{tr}^2} - \frac{1}{T_l^2} = \frac{1}{2\pi^2} G\varrho}$

# The idea of the “teacher-savant”

“Yes, we have to educate high-school teachers as scientists in order they could teach their subject on the highest level.
**But also to save them from disinterest and paralysis caused by the daily repetitive obligations.**
An activity full of enchantment will keep their ambitions awaken during a life career often lacking even the due recognition.”

Rector’s inaugural speech, 1892