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Egyesült Nemzetek Nevelésügyi, Tudományos és Kulturális Szervezete

100th anniversary of Roland Eötvös (1848-1919), physicist, geophysicist, and innovator of higher education

Commemorated in association with UNESCO

Eötvös Loránd (1848-1919) fizikus, geofizikus és a felsőoktatás megújítójának 100. évfordulója

Az UNESCO-val közösen emlékezve

Lajos Völgyesi

György Szondy, Gyula Tóth, Bálint Kiss, Edit Fenyvesi, Gábor Péter, László Somlai, Csaba Égető, László Deák, Gergely Barnaföldi, Gyula Gróf, Péter Harangozó, Péter Lévai, Péter Ván

Experiences of the repeated Eötvös experiment

EÖTVÖS-100

Gbely, Slovakia, October 17. 2019.

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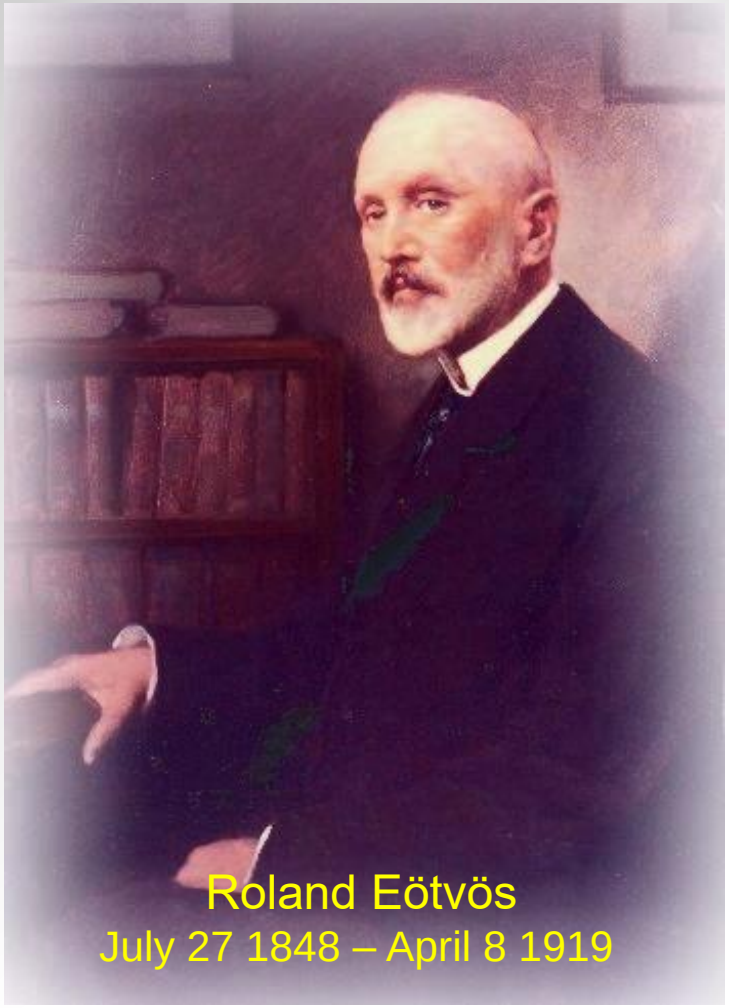
- In 2017 we decided to celebrate the Eötvös anniversary by re-measuring the Eötvös experiment for validating the equivalence of gravitational and inertial mass.
- When we started to study descriptions of the previous measurements, we found a possible explanation for the known systematic error and from this moment our plan of re-measurement became strongly motivated.
- Eötvös became a world famous physicist by his torsion balance. In the next we will discuss the base principle of the torsion balance and then the preparations and present status of our new equivalence experiment.



Roland Eötvös
July 27 1848 – April 8 1919

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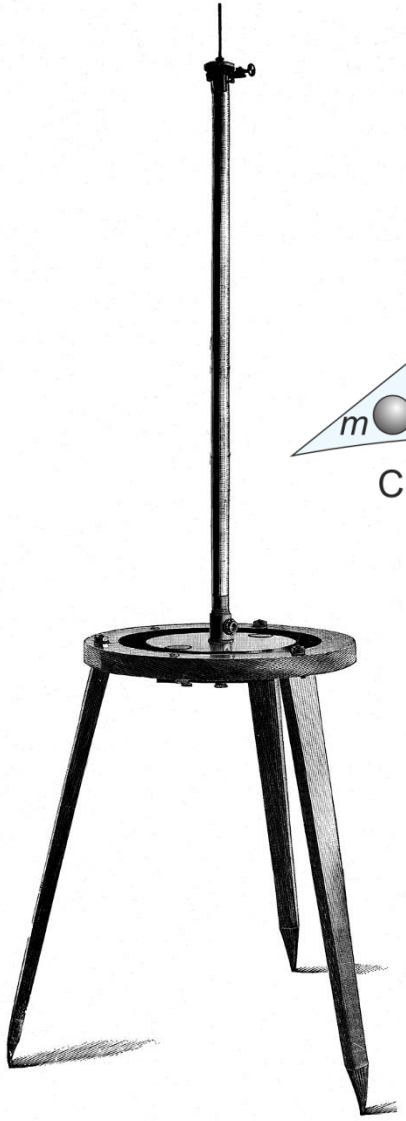
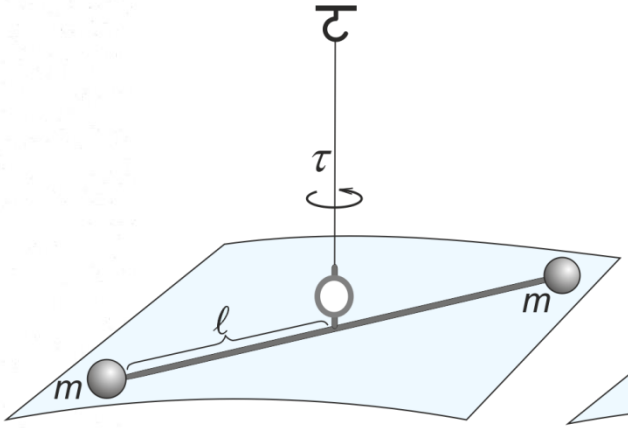
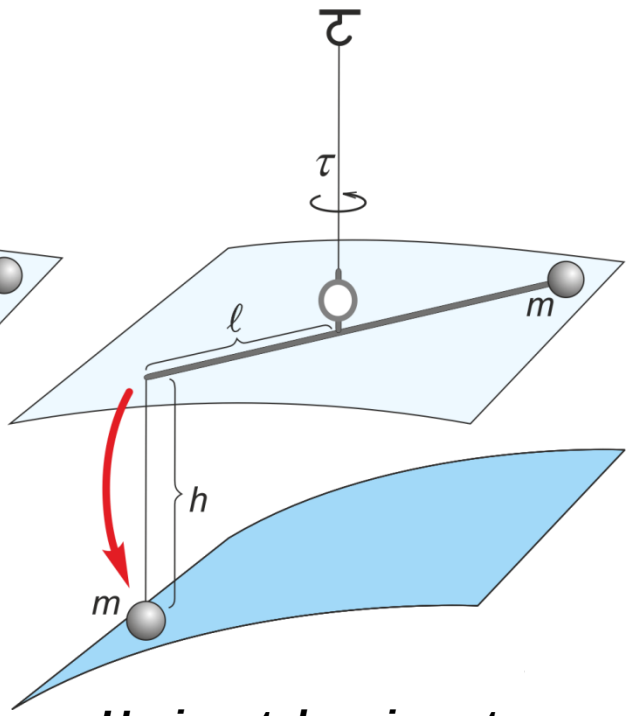
Curvature variometer Eötvös (1890) was a classic Coulomb (Cavendish) balance, comprising a horizontal beam with two identical masses at each end, suspended on a torsion wire.

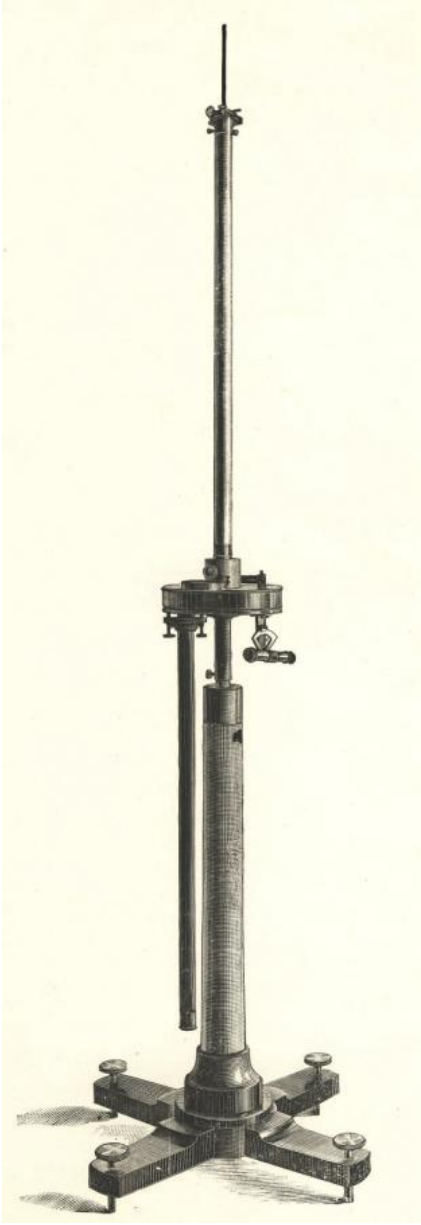




Curvature variometer

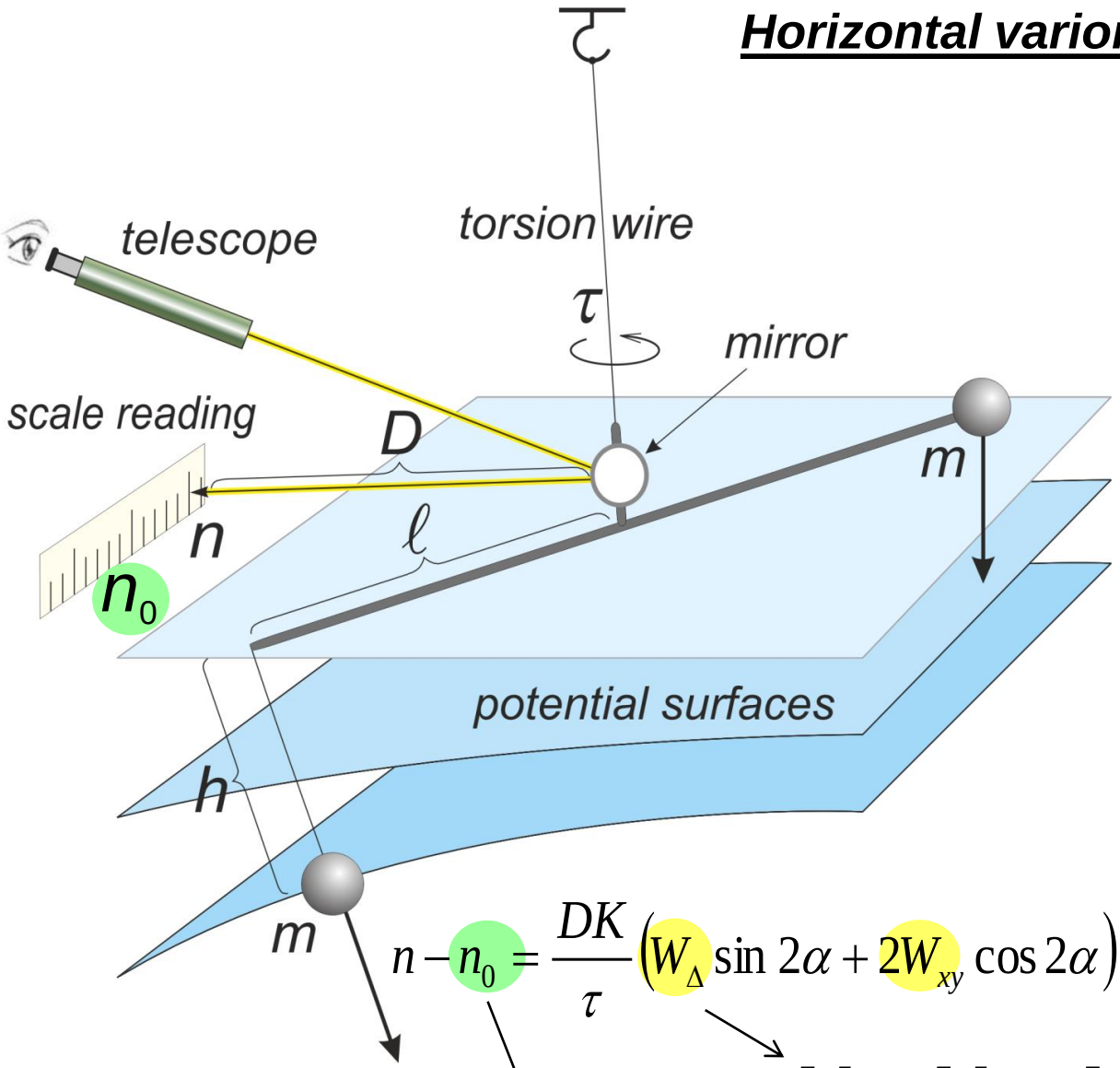


Horizontal variometer
Eötvös (1890)



The great invention of Eötvös was that he took one of the masses off the beam and suspended it with a thin wire in a deeper position.

Horizontal variometer



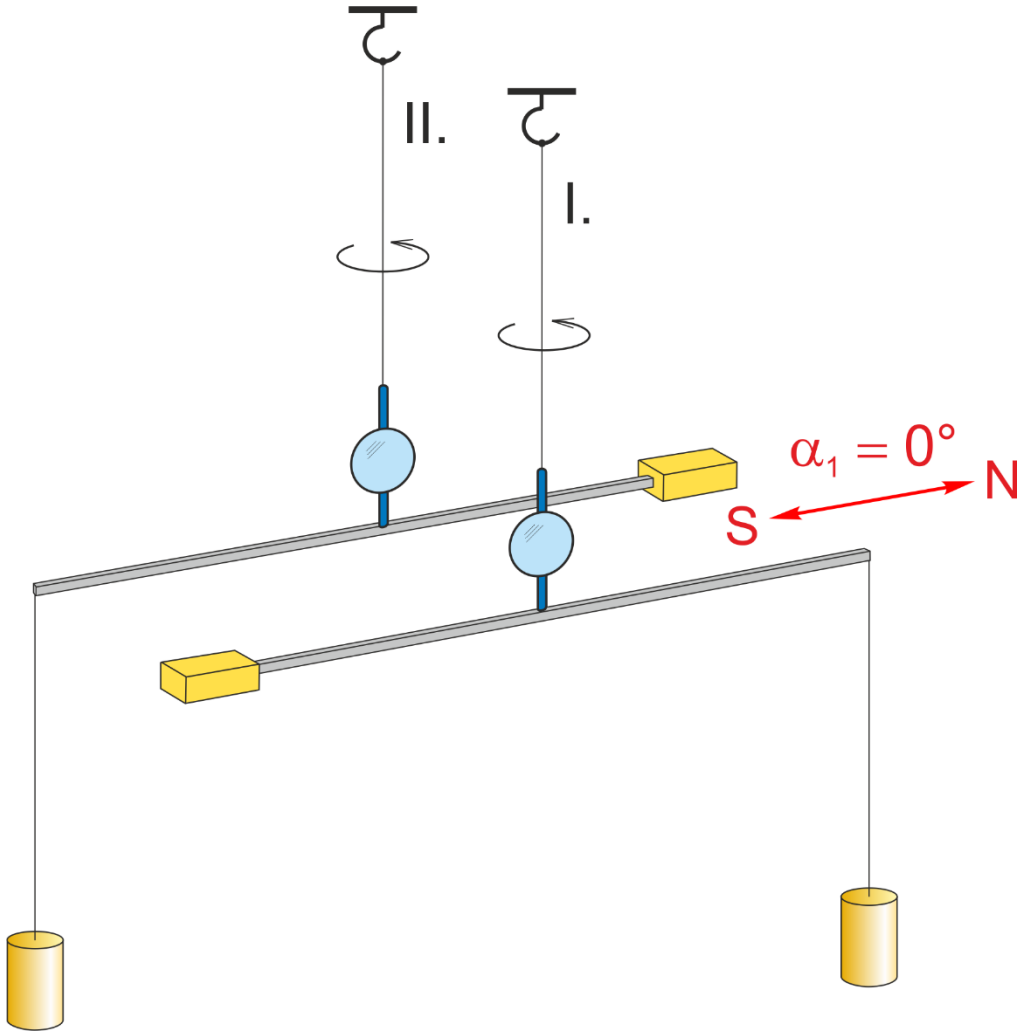
$$\mathbf{E} = \begin{bmatrix} W_{xx} & W_{xy} & W_{xz} \\ W_{yx} & W_{yy} & W_{yz} \\ W_{zx} & W_{zy} & \cancel{W_{zz}} \end{bmatrix}$$

$$n - n_0 = \frac{DK}{\tau}\left(W_\Delta \sin 2\alpha + 2W_{xy}\cos 2\alpha\right) + \frac{2Dhlm}{\tau}\left(W_{zy}\cos\alpha - W_{zx}\sin\alpha\right)$$

$$W_\Delta = W_{yy} - W_{xx}$$

torsion-free position

"*Large double balance*"
(1902)

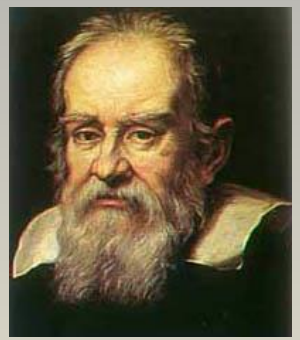


$$n_1 - n_0 = \frac{DK}{\tau}\left(W_\Delta \sin 2\alpha + 2W_{xy}\cos 2\alpha\right) + \frac{2Dhlm}{\tau}\left(W_{zy}\cos\alpha - W_{zx}\sin\alpha\right)$$

$$n_2 - n_0^* = \frac{DK}{\tau}\left(W_\Delta \sin 2\alpha + 2W_{xy}\cos 2\alpha\right) + \frac{2Dhlm}{\tau}\left(W_{zy}\cos\alpha - W_{zx}\sin\alpha\right)$$

Equivalence principle

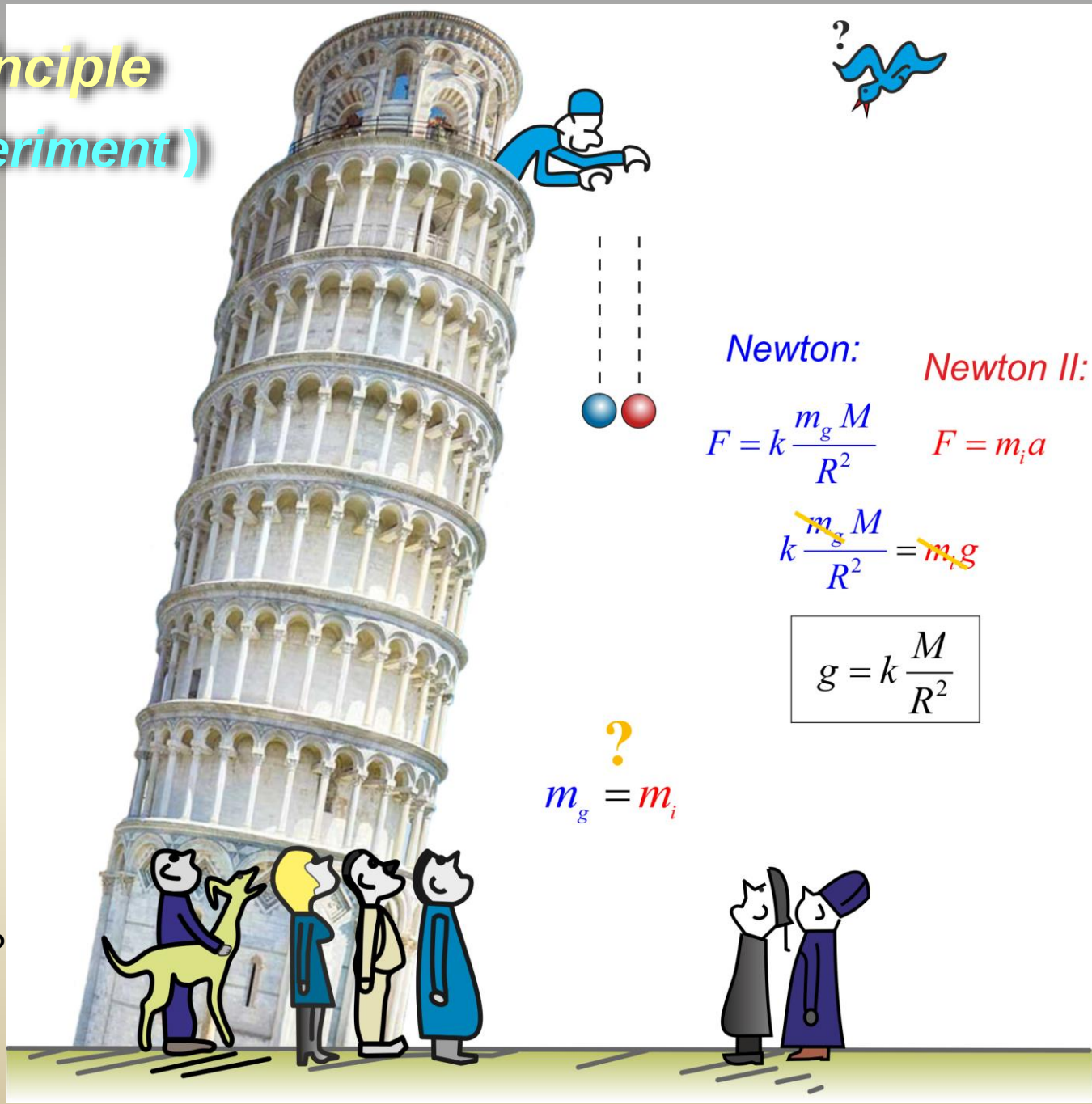
(The first experiment)

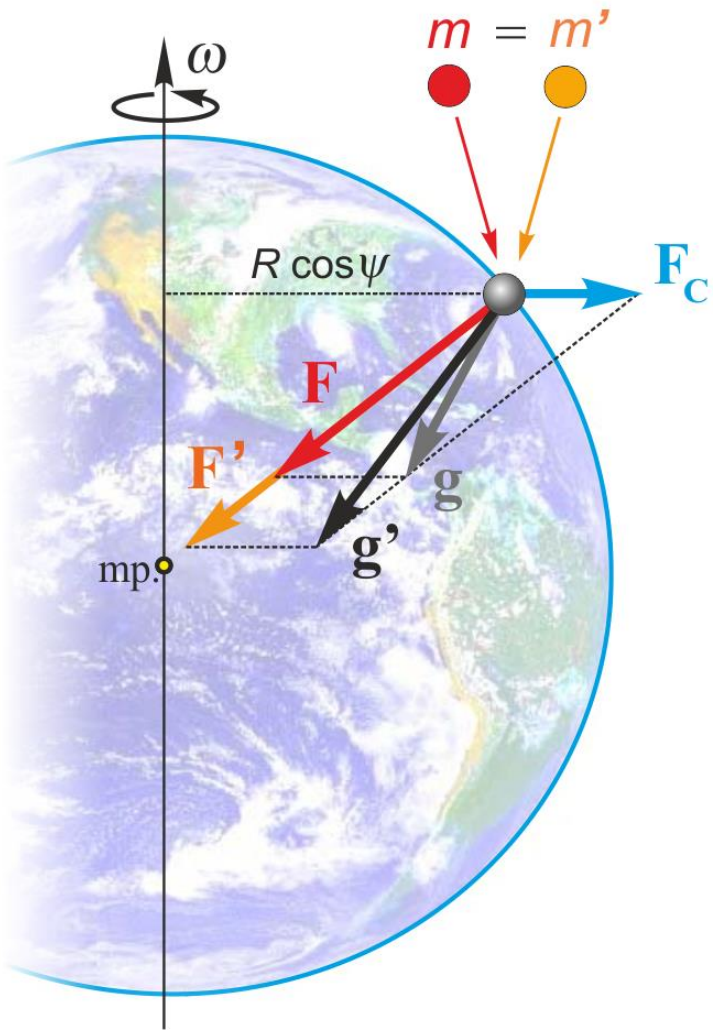


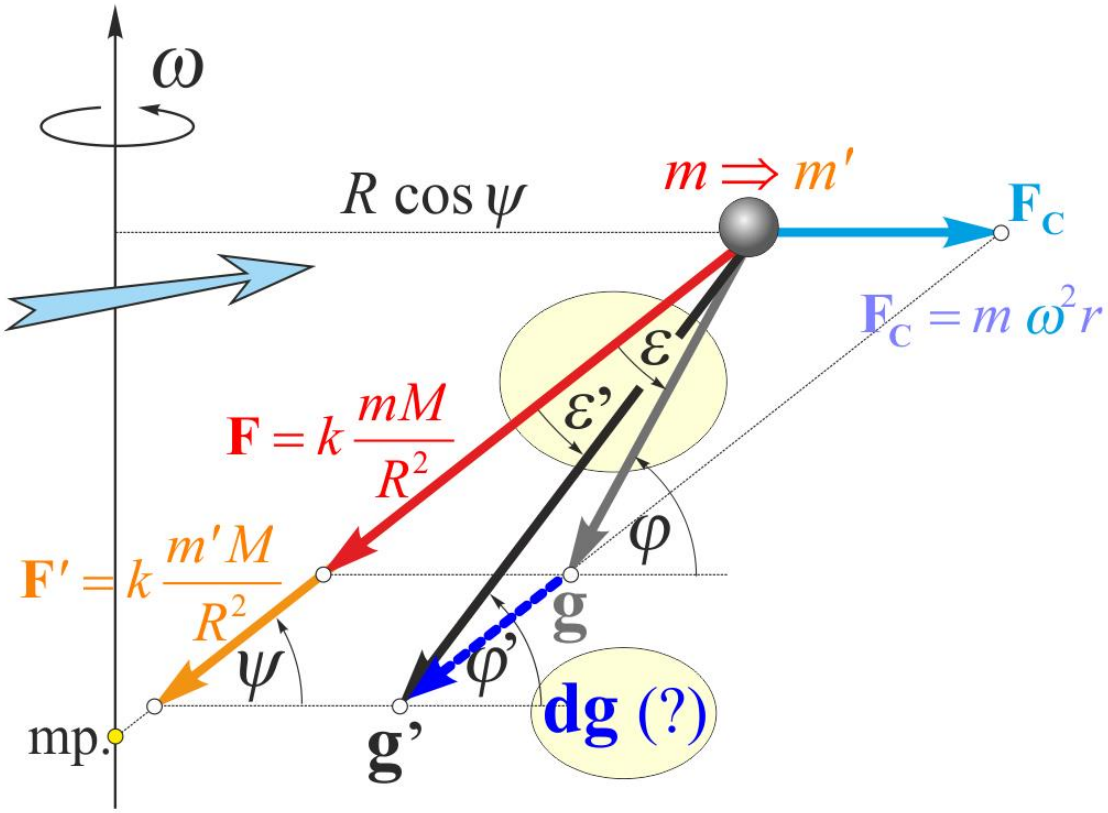
Galilo Galilei
1564-1642

Galilei (?)
Simon Stevin, 1586

Base question:
Is the gravitation
depends on the material?





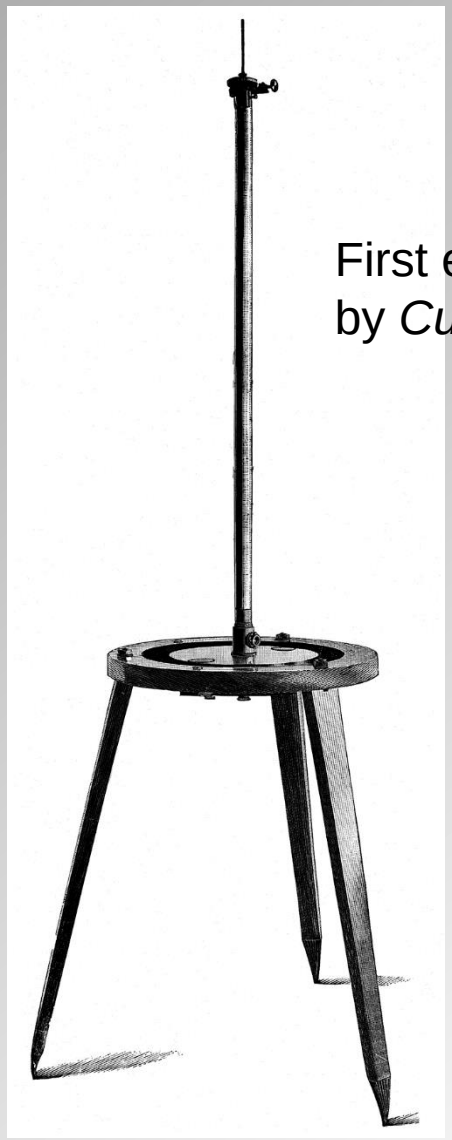


Base principle of Eötvös experiment:

Assumption: different materials have different gravitational forces but the same rotational centrifugal force.

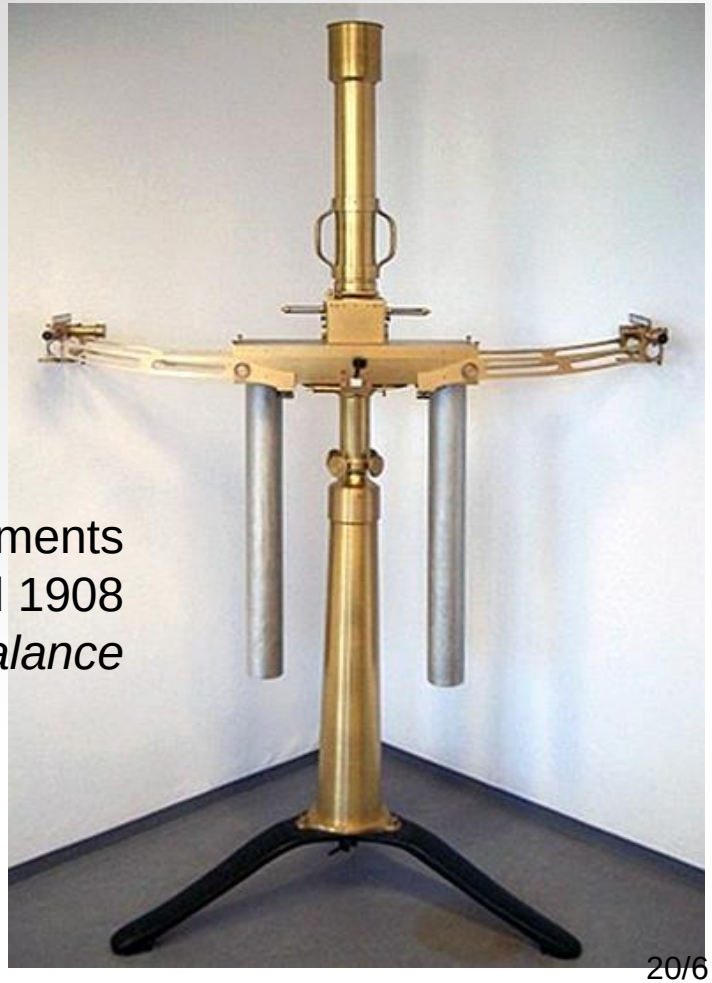
Equivalence principle

(The Eötvös experiment)

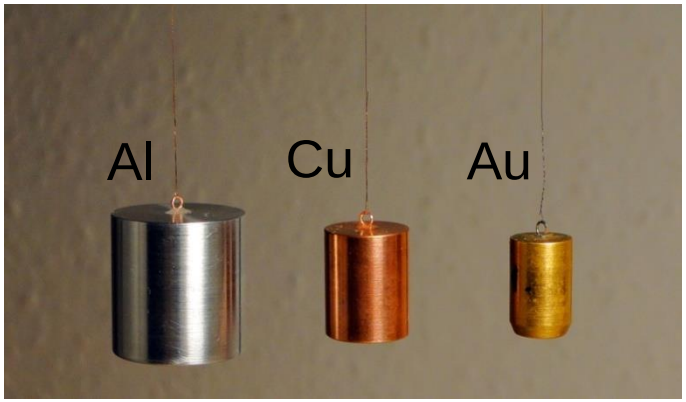


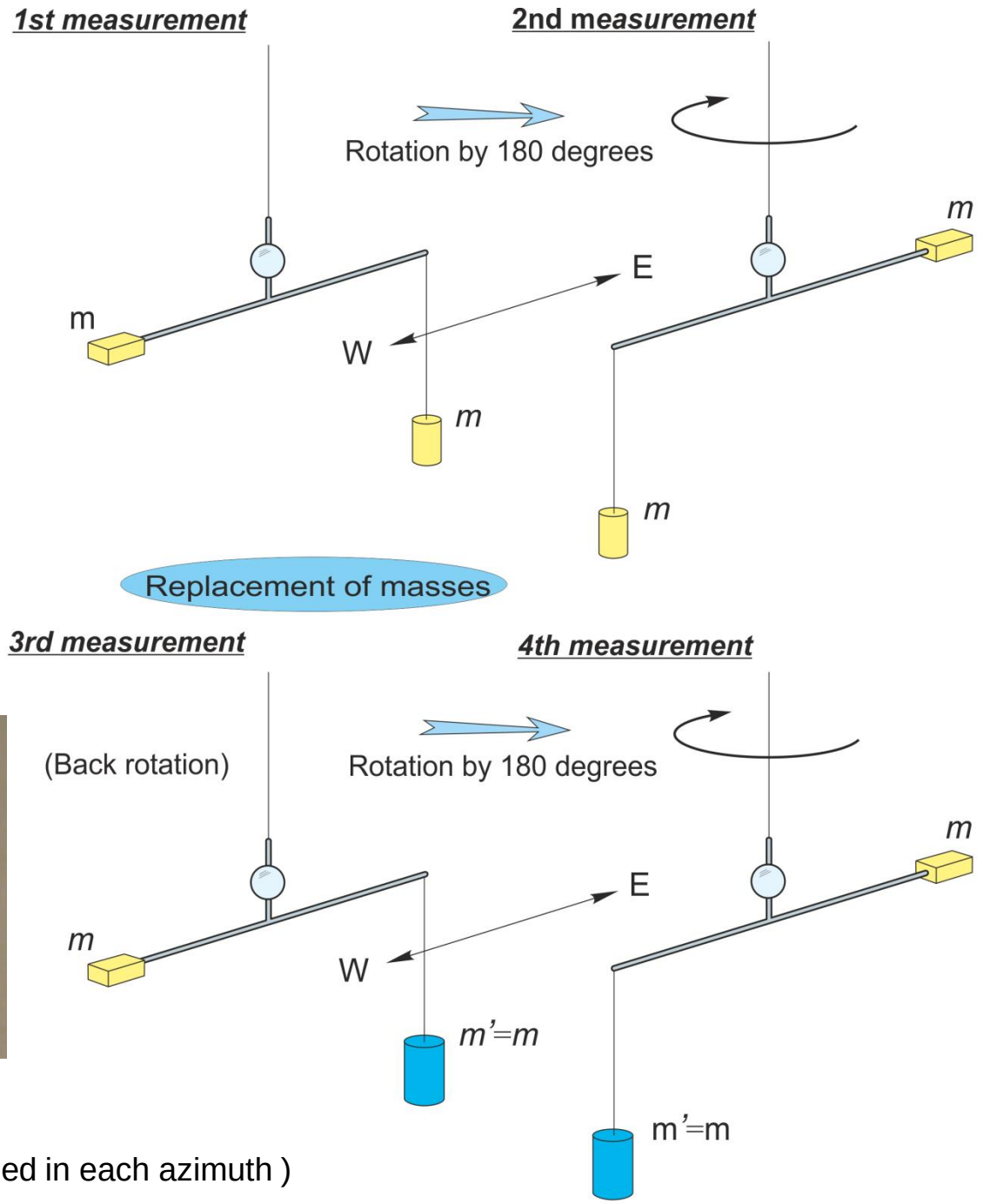
First experiment in 1896
by *Curvature Variometer*

EPF measurements
between 1906 and 1908
by *Large Double Balance*

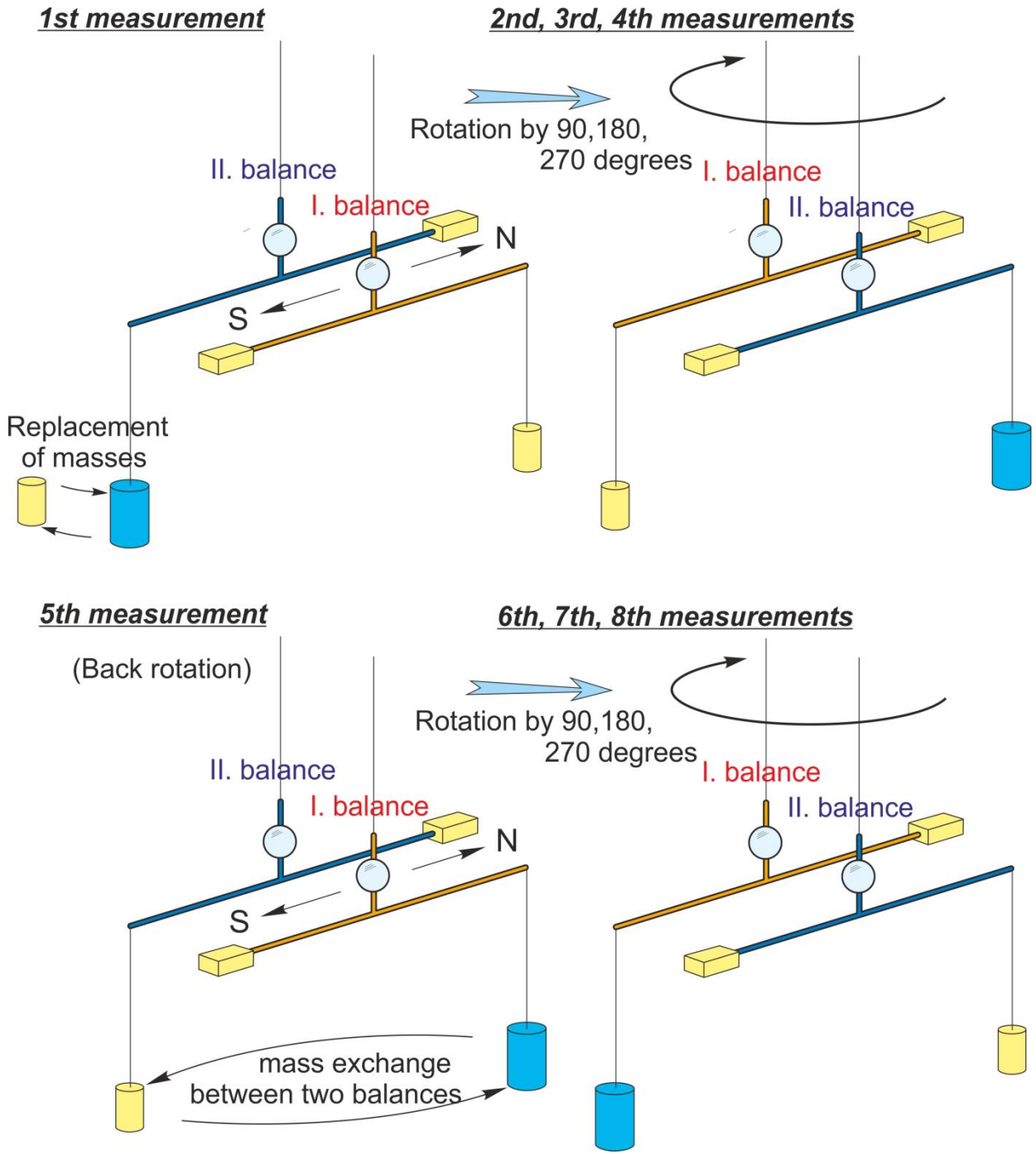


Mass exchanging measurement strategy





(The damped position should be recorded in each azimuth)


1st measurement
2nd, 3rd, 4th measurements
Rotation by 90,180,
270 degrees
II. balance
I. balance
N
S
Replacement
of masses
I. balance
II. balance
5th measurement
(Back rotation)
6th, 7th, 8th measurements
Rotation by 90,180,
270 degrees
II. balance
I. balance
N
S
mass exchange
between two balances
I. balance
II. balance

E-54 *Balance*
1954

Eötvös-Rybár Balance
(***AutERBal*** *Balance*)
1928

Eötvös-Pekár Balance
(*Small Double Balance*)
1930

Very accurate and reliable,
Easily replaceable masses

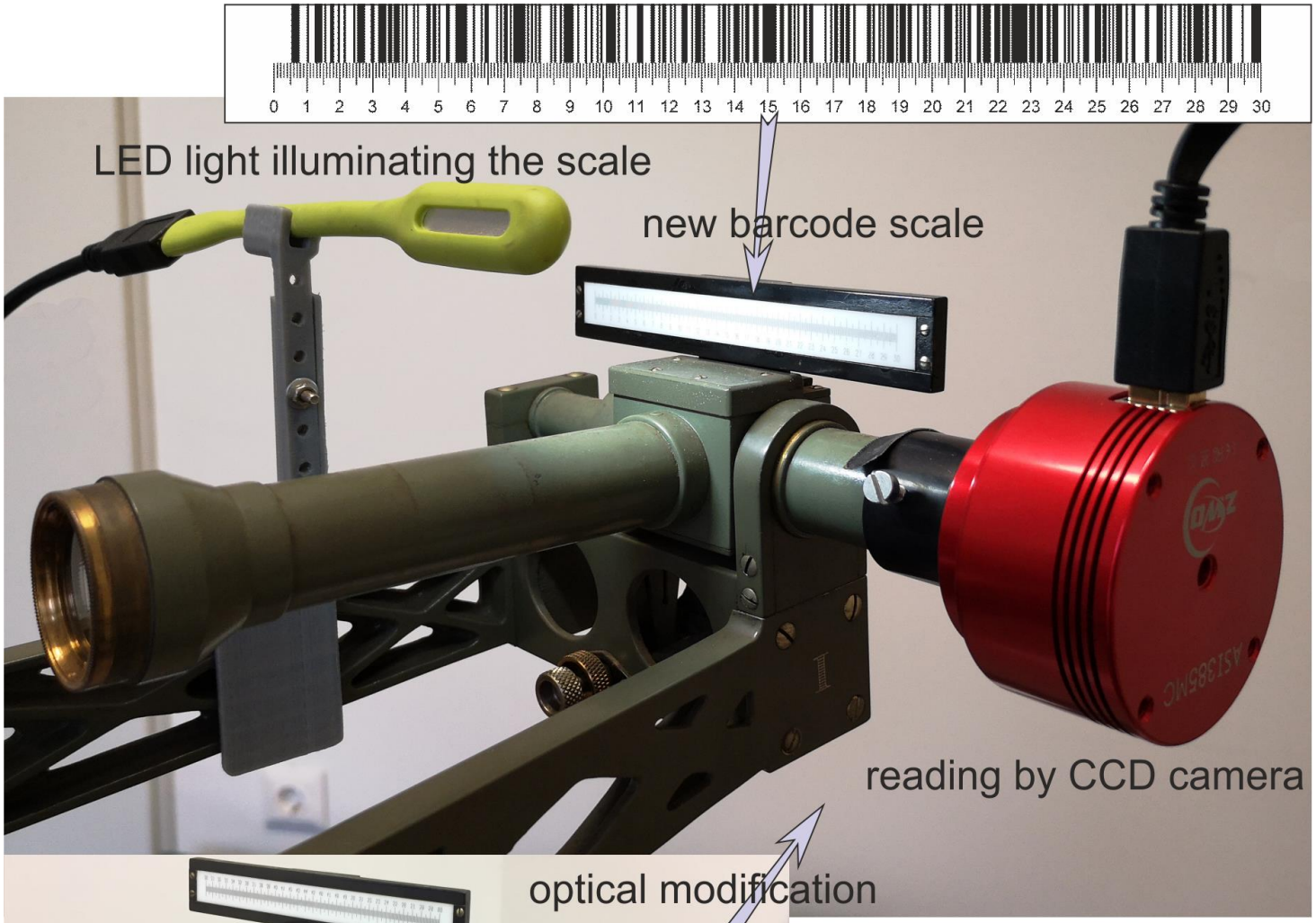
Best usable for equivalence measurements, so our further developments were focused on this instrument.

The biggest enemy of the torsion balance measurements is the man himself!

- The mass of the observer's body changes the damped position of the torsion balance,
- Going to instrument the noise of the observer's steps cause ground vibrations, which also disturbs the damped position of the torsion balance.

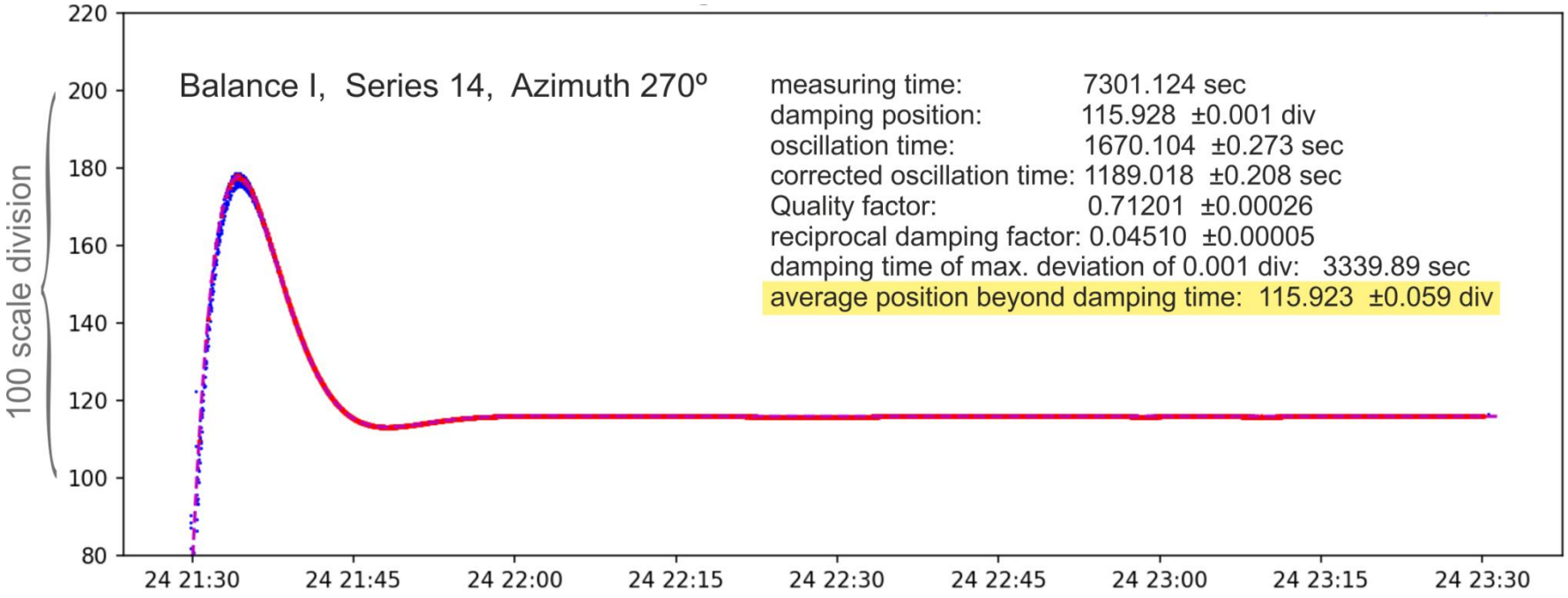
<u>Solution for these problems</u> ***two important enhancements:***

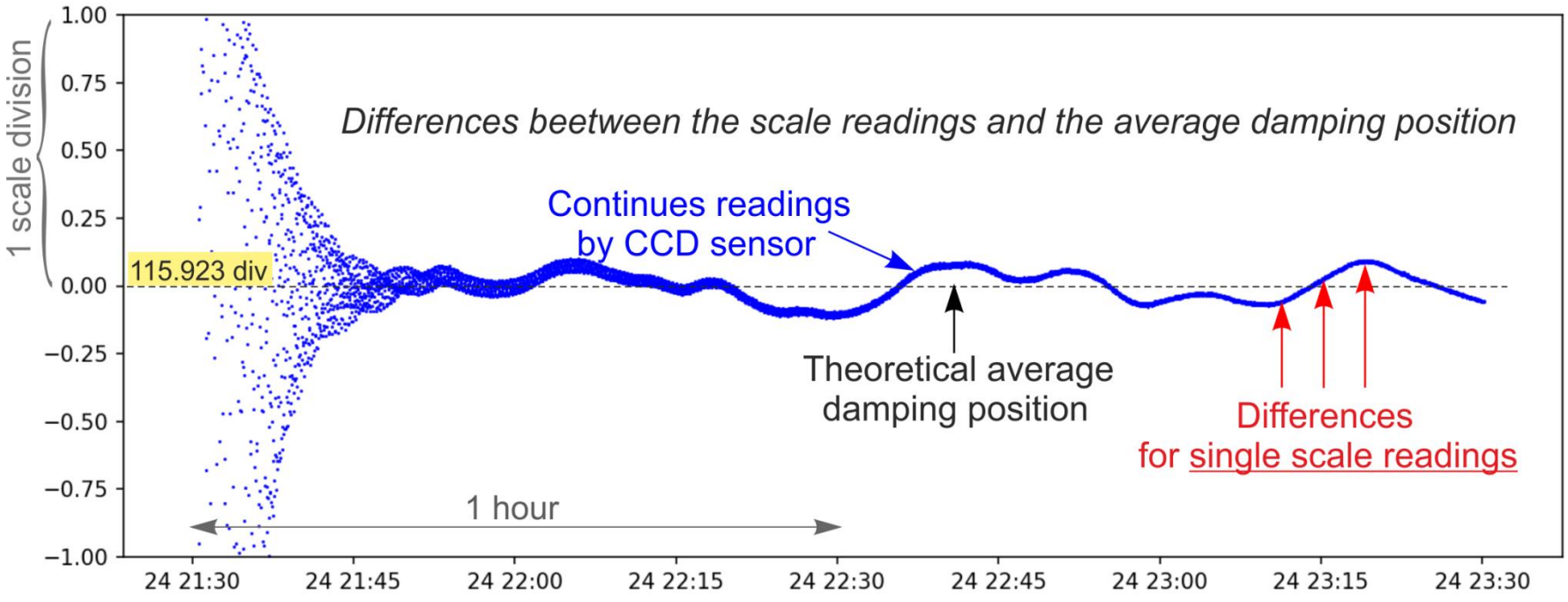
1. *Computer-controlled scan on a CCD sensor instead of visual reading*
2. *Using remote-controlled rotation mechanics*



Originally: single reading after the damped position of the T.balance with accuracy of 0.1 scale division

Now with CCD sensor: continuous reading (up to 10 readings/sec) with accuracy of 0.002 div


Balance I, Series 14, Azimuth 270°
measuring time: 7301.124 sec
damping position: 115.928 ±0.001 div
oscillation time: 1670.104 ±0.273 sec
corrected oscillation time: 1189.018 ±0.208 sec
Quality factor: 0.71201 ±0.00026
reciprocal damping factor: 0.04510 ±0.00005
damping time of max. deviation of 0.001 div: 3339.89 sec
average position beyond damping time: 115.923 ±0.059 div
100 scale division
220
200
180
160
140
120
100
80
24 21:30
24 21:45
24 22:00
24 22:15
24 22:30
24 22:45
24 23:00
24 23:15
24 23:30


Differences beetween the scale readings and the average damping position
1 scale division
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
115.923 div
Continues readings
by CCD sensor
Theoretical average
damping position
Differences
for single scale readings
1 hour
24 21:30
24 21:45
24 22:00
24 22:15
24 22:30
24 22:45
24 23:00
24 23:15
24 23:30

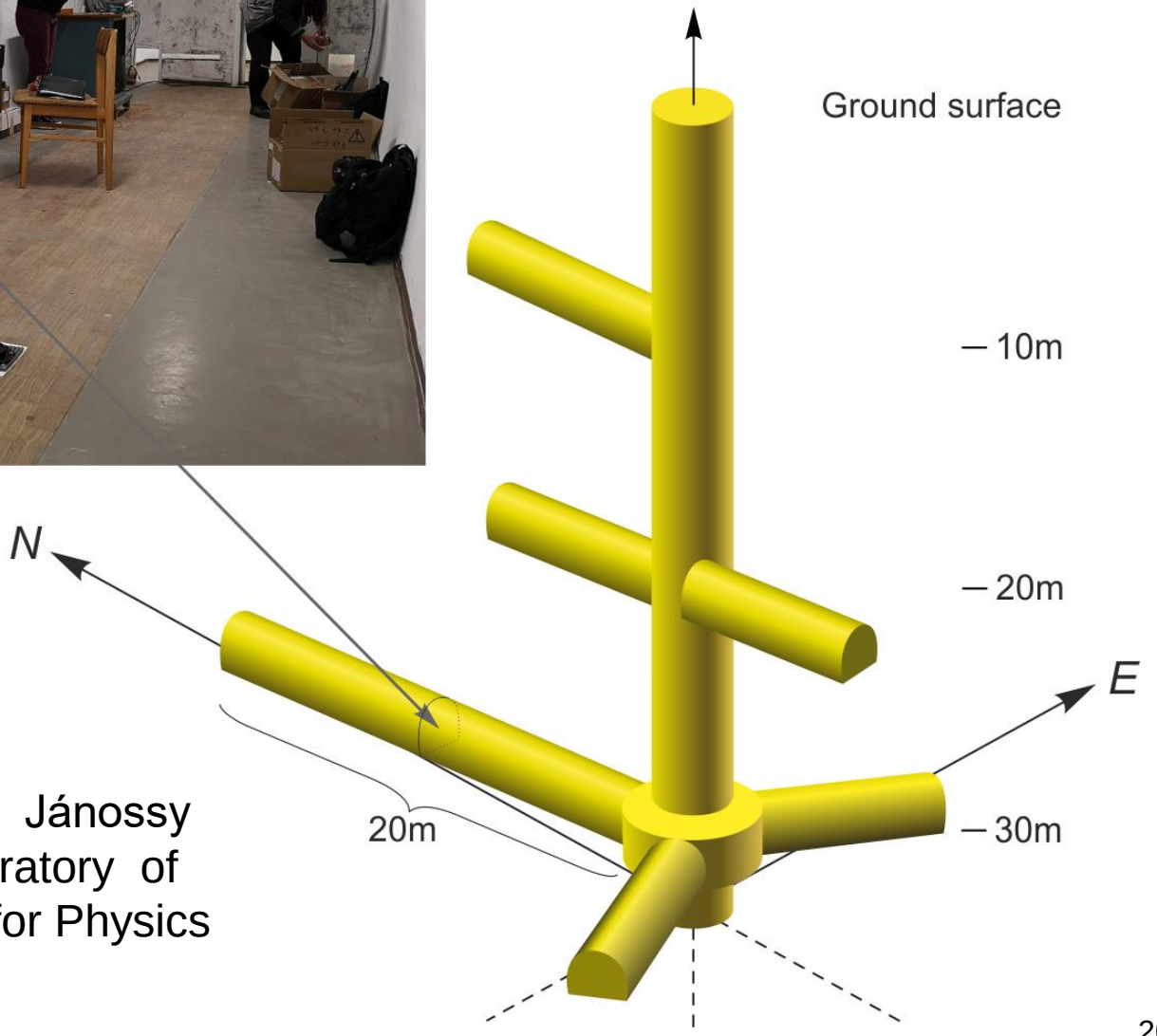
Computer-controlled rotation mechanics

Using RENISHAW optical encoder, position (azimuth) readout accuracy is under arcseconds

The modified rotational mechanics

The mechanism has low weight and low metallic content. We used 3D printing technology to produce most of the parts.

After a long preparatory work the instruments were taken to the final measuring site



Location of measurements: Jánossy Underground Physics Laboratory of Wigner Researche Center for Physics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Important milestone: after 2 years preparatory work
the actual equivqalence measurements started on May 14. 2019.
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Present state:

- Preparation of the measurement site is completed.
- Torsion balance has been restructured.
- Calibration measurements have been made.
- The new remote controlled rotation mechanism works well.
- CCD sensors, Led light illuminating and the scales are suitable for the measurements.
- The necessary control and evaluation software have been written and tested.
- Some of the test masses have been made, the replacement of masses is solved.
- *Equivalence measurements started 5 moths ago, curently our measurements are one order of magnitude more accurate than the original Eötvös experiment.*

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First results

Eötvös: 10^{-9}

Present state: $\mathbf{10^{-10}}$

Planned: $\mathbf{10^{-11}}$

Eötvös parameter: $$\eta = 2\frac{\left(m_g / m_i\right) - \left(m_g' / m_i'\right)}{\left(m_g / m_i\right) + \left(m_g' / m_i'\right)}$$

measurement period	*material*	η
05.15-05.20.	Au–Cu	0.02×10^{-10}
05.15-05.20.	Au–Au	0.12×10^{-10}
05.21-06.04.	Au–Cu	-0.76×10^{-10}
05.21-06.04.	Au–Au	0.15×10^{-10}
06.17-06.24.	Au–Al	1.74×10^{-10}
06.17-06.24.	Au–Au	-0.33×10^{-10}
06.26-07.03.	Au–Al	0.91×10^{-10}
06.26-07.03.	Au–Au	0.09×10^{-10}

Present state: Up to know we did not detect any deviation from the equivalence principle.

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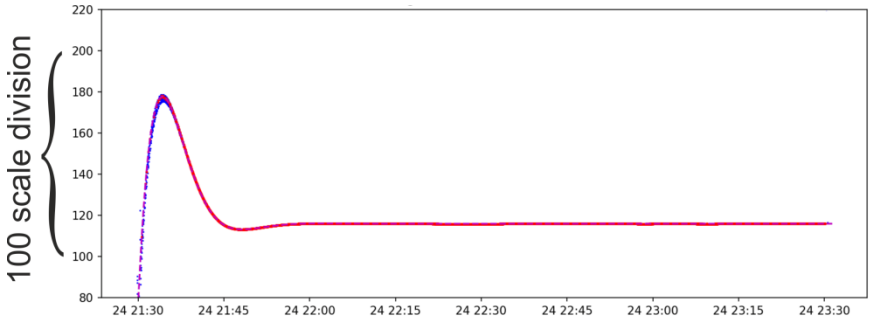
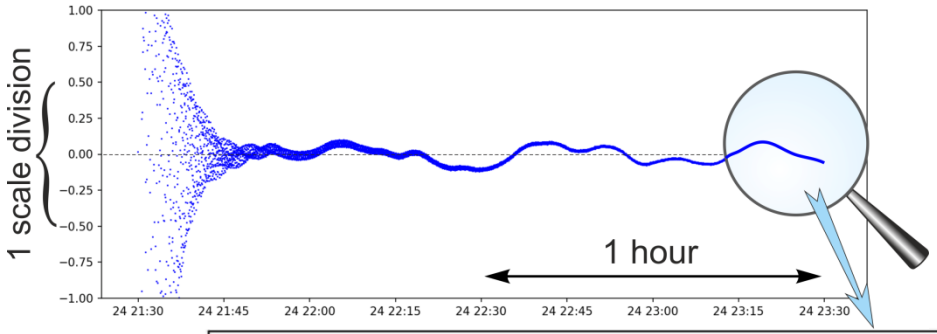


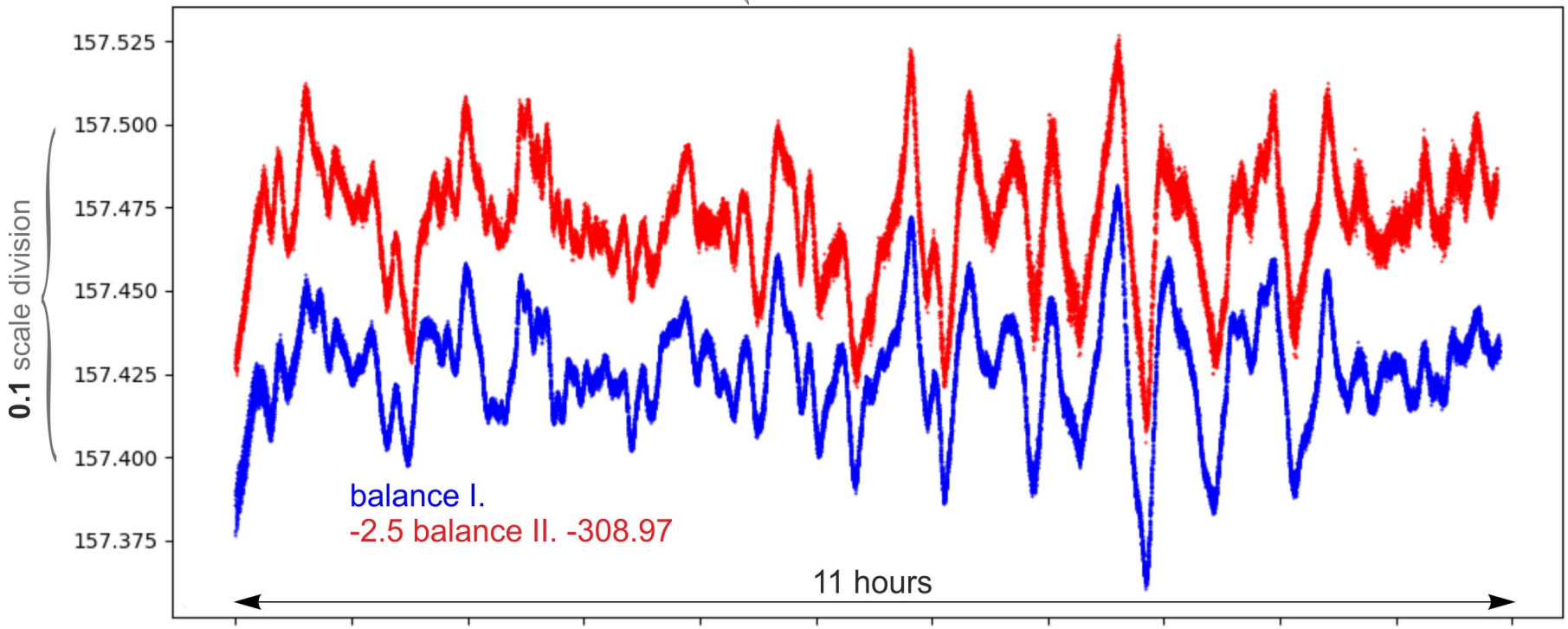


Microseismic ground vibrations

can be solved by Gürap 3T seismograph

Infrasound vibrations

our task in the next future



Güralp 3T compact three-component broadband seismometer

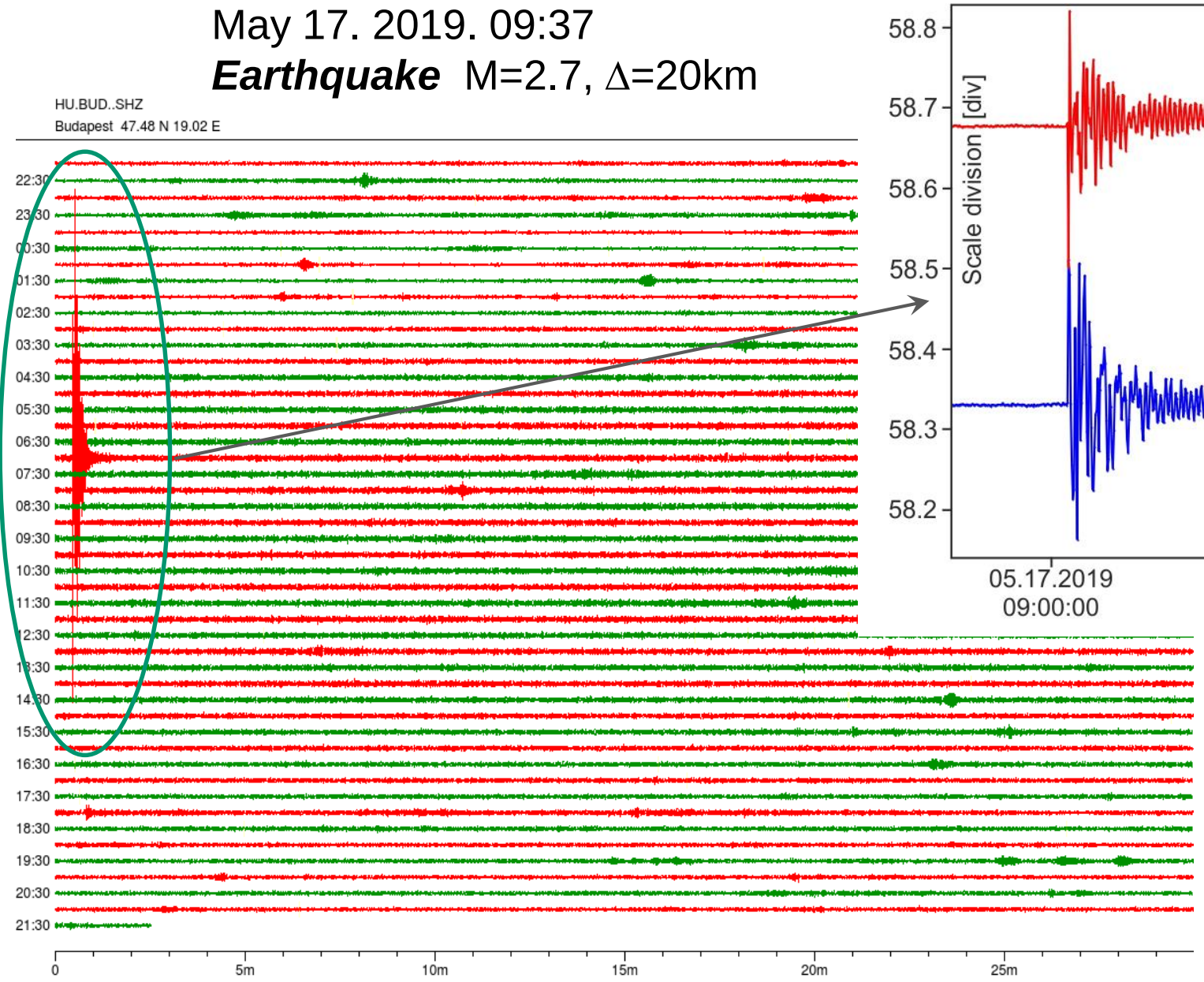
Recently our biggest task the elimination of the microseismic ground vibrations and the infrasound pressure changes

A curiosity example from our registrations:

Torsion balance can be used as a seismograph

May 17. 2019. 09:37

Earthquake M=2.7, Δ=20km



The staff of the experiment:


Völgyesi L.


Szondy Gy.


Tóth Gy.


Ván P.


Fenyvesi E.


Kiss B.


Péter G.


Harangozó P.


Gróf Gy.


Lévai P.


Barnaföldi G.


Deák L.


Égető Cs.


Somlai L.

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(*Physicists, geophysicist, geodesists, electrical engineers, mechanical engineers*)