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UNESCO

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

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# Remeasurement of the Eötvös equivalence experiment

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- Roland Eötvös died 100 years ago so we celebrate the 100th anniversary of his death this year.
- United Nations Educational, Scientific and Cultural Organization (UNESCO) declared the year 2019 as “Eötvös year”.
- In 2017 we decided to celebrate this anniversary, by re-measure 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 realy serious.
- 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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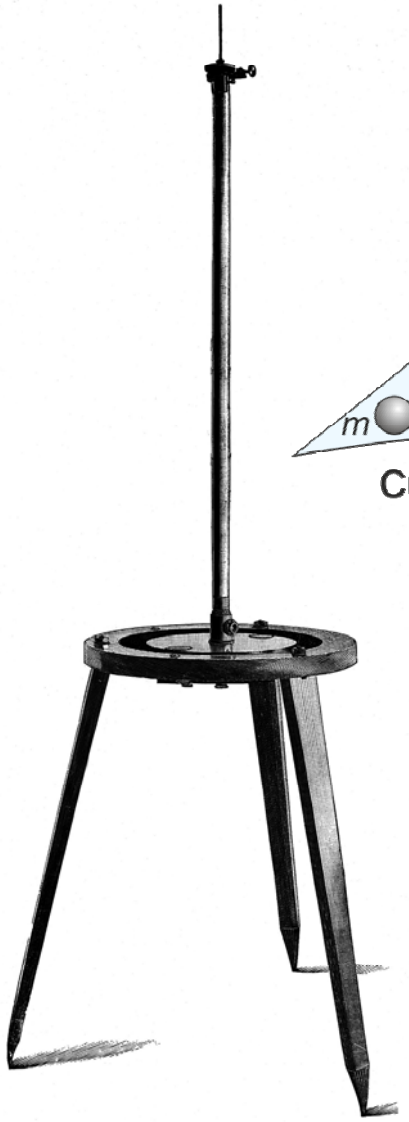
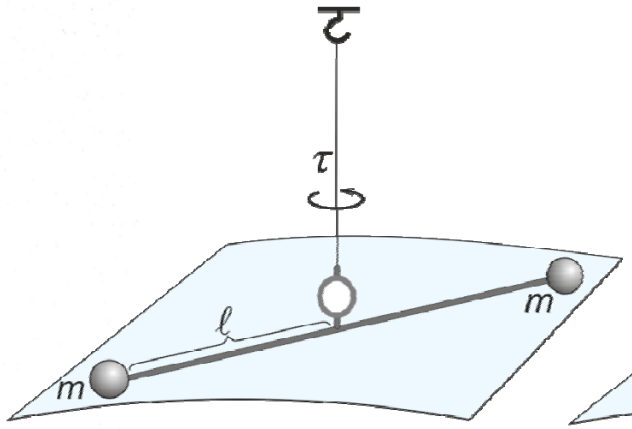
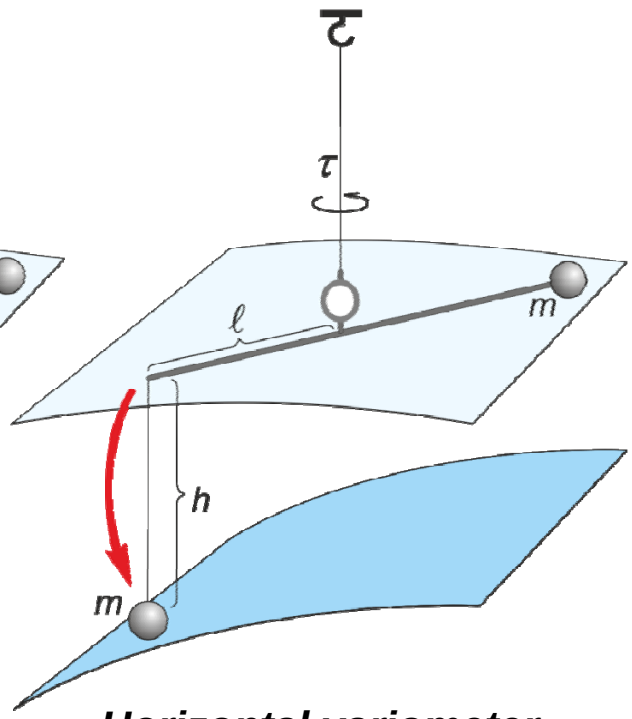
***Curvature variometer*** Eötvös (1890) was the classic Coulomb (Cavendish) balance, comprising a horizontal beam with two identical masses at each end, suspended on a torsion wire.

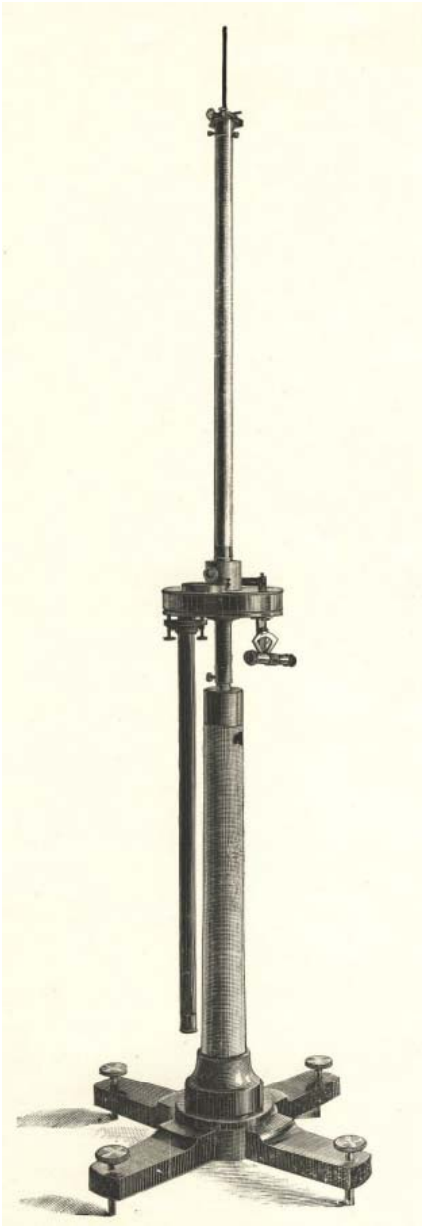





Curvature variometer

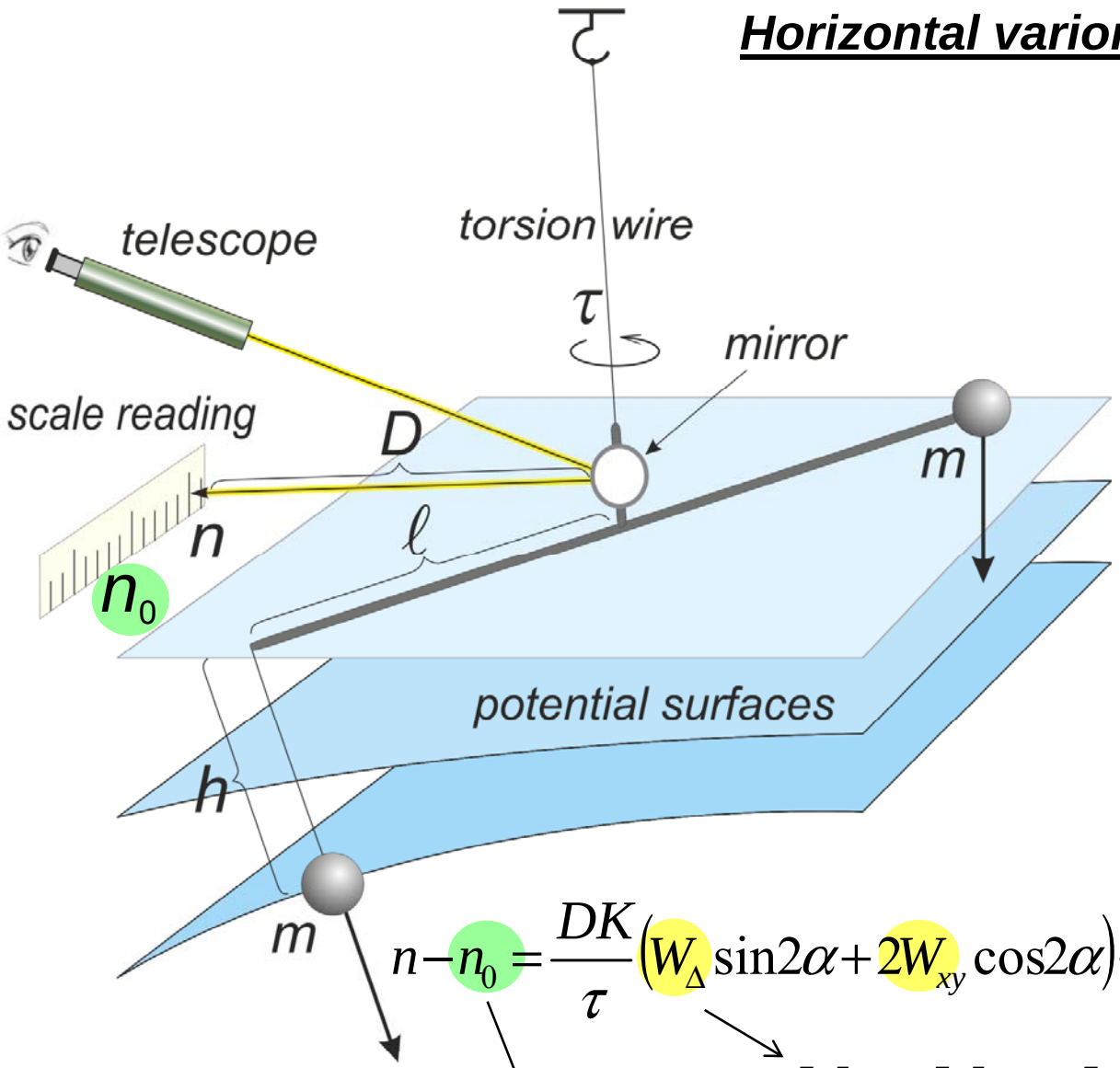



***Horizontal variometer***
Eötvös (1890)



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



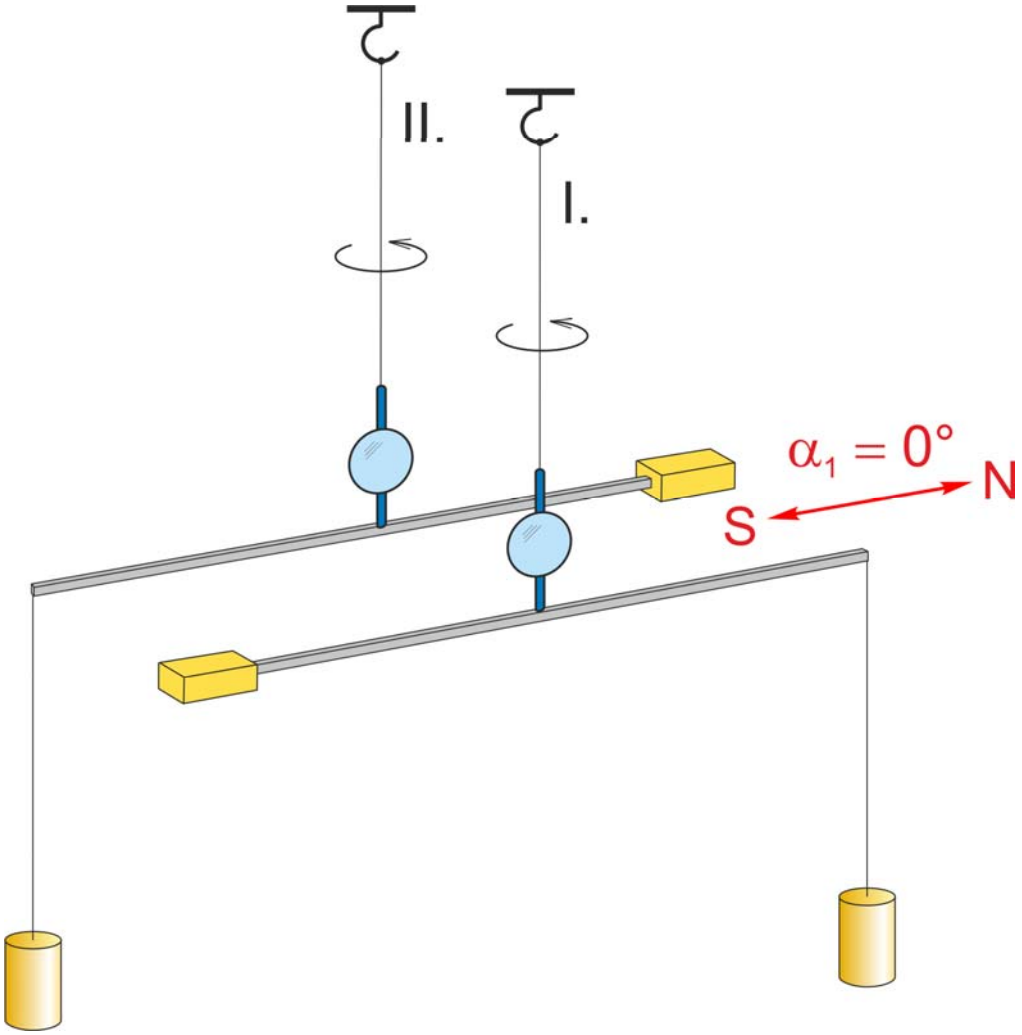

$$\mathbf{E} = \begin{bmatrix} W_{xx} & W_{xy} & W_{xz} \\ W_{yx} & W_{yy} & W_{yz} \\ W_{zx} & W_{zy} & \cancel{W_{zz}} \end{bmatrix}$$

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

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

torsion-free position

"*Large double balance*"
(1902)

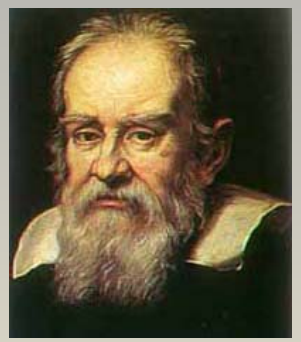



$$n_1 - n_0 = \frac{DK}{\tau}\left(W_\Delta \sin 2\alpha + 2W_{xy}\cos 2\alpha\right) + \frac{2Dhlm}{\tau}\left(W_{zy}\cos\alpha - W_{zx}\sin\alpha\right)$$

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

# Equivalence principle

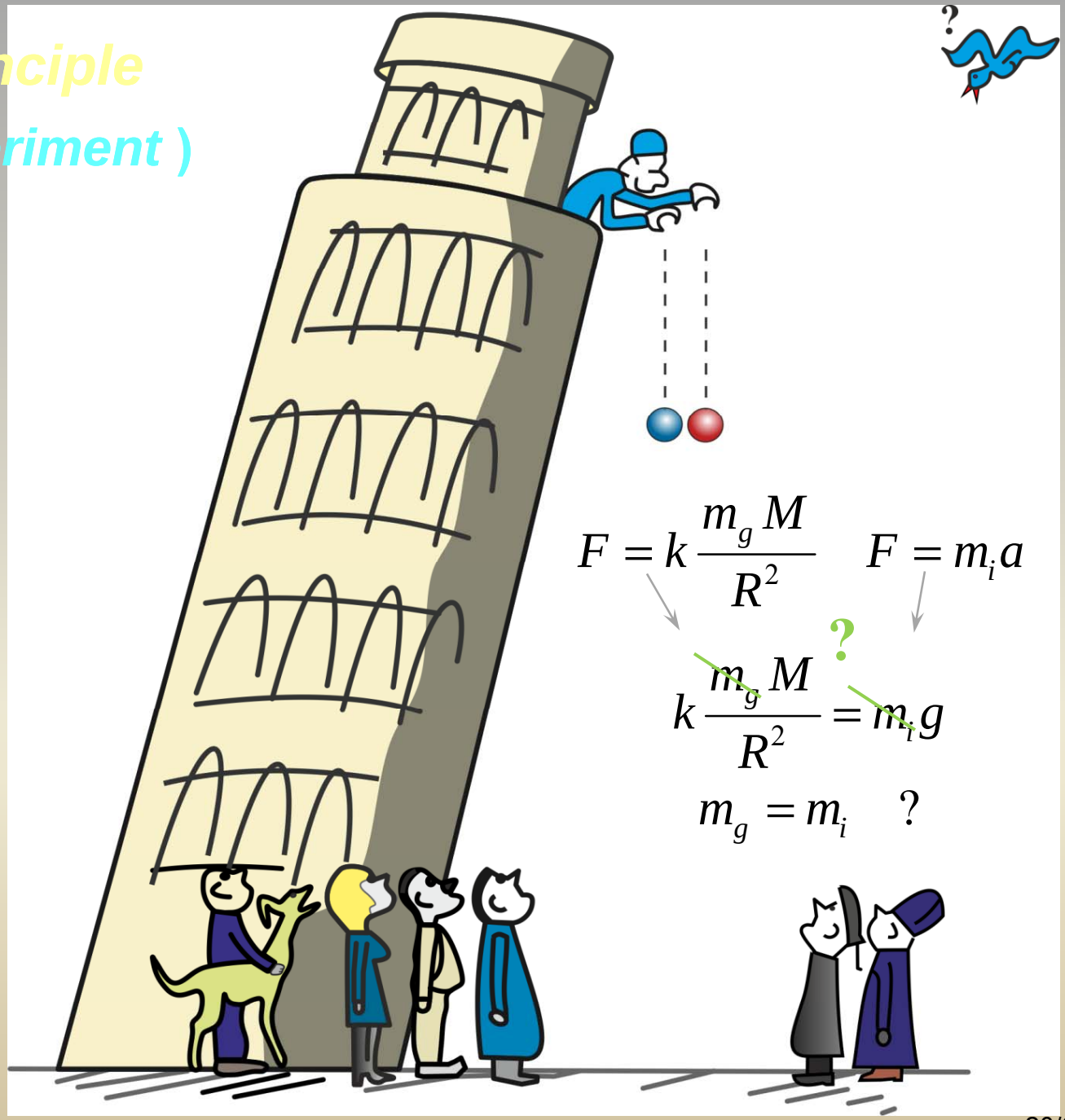
## (The first experiment )



Galilo Galilei
1564-1642

Galilei (?)
Simon Stevin, 1586

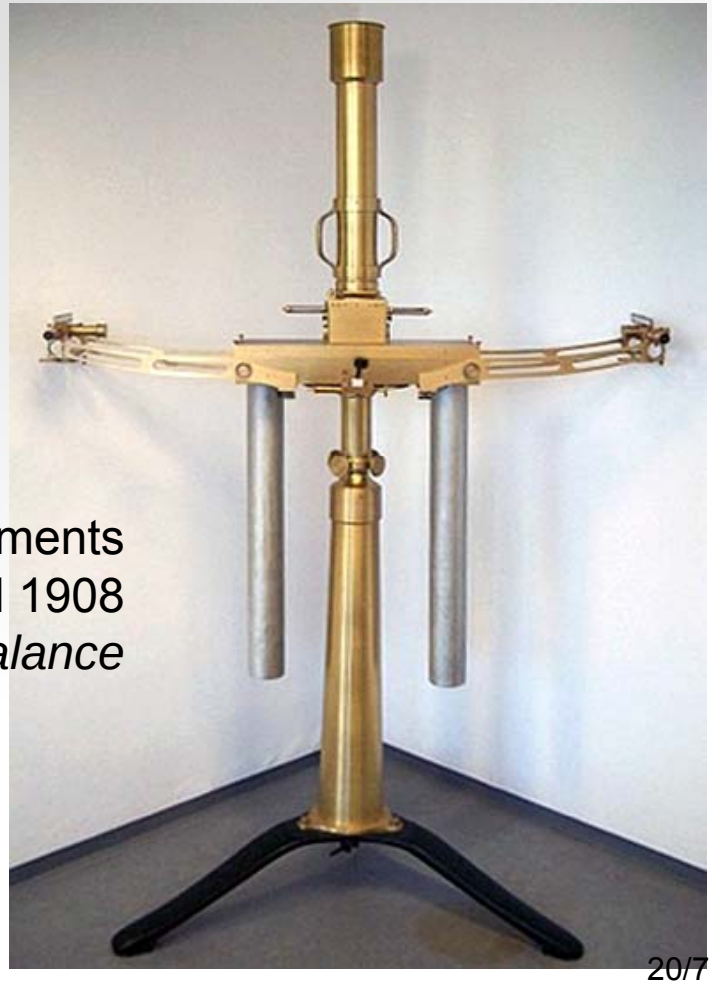
*Base question*:
Is the gravitation
depends on the material?



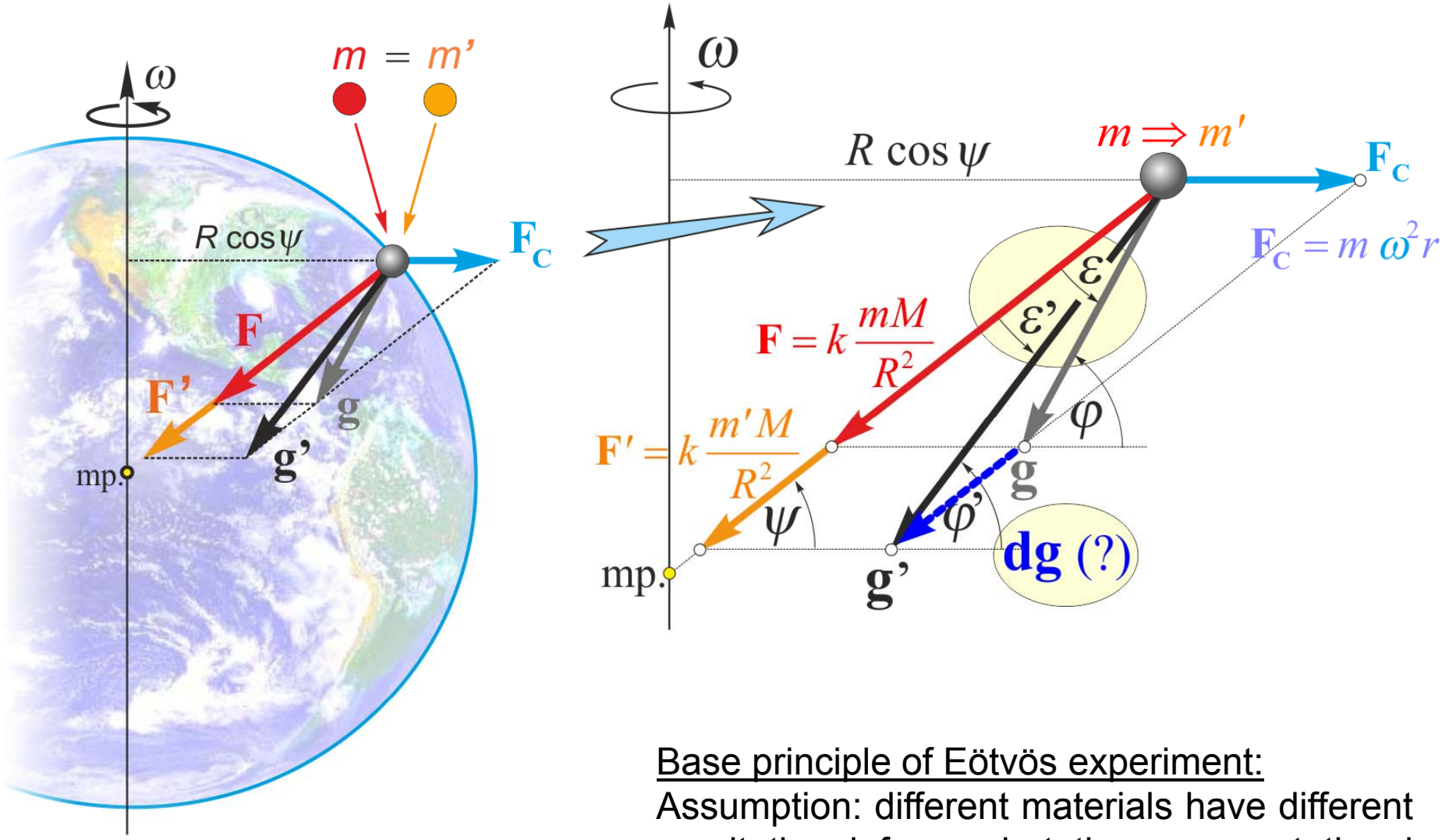
# *Equivalence principle*

## (*Eötvös experiment* )

First experiment in 1896
by *Curvature Variometer*

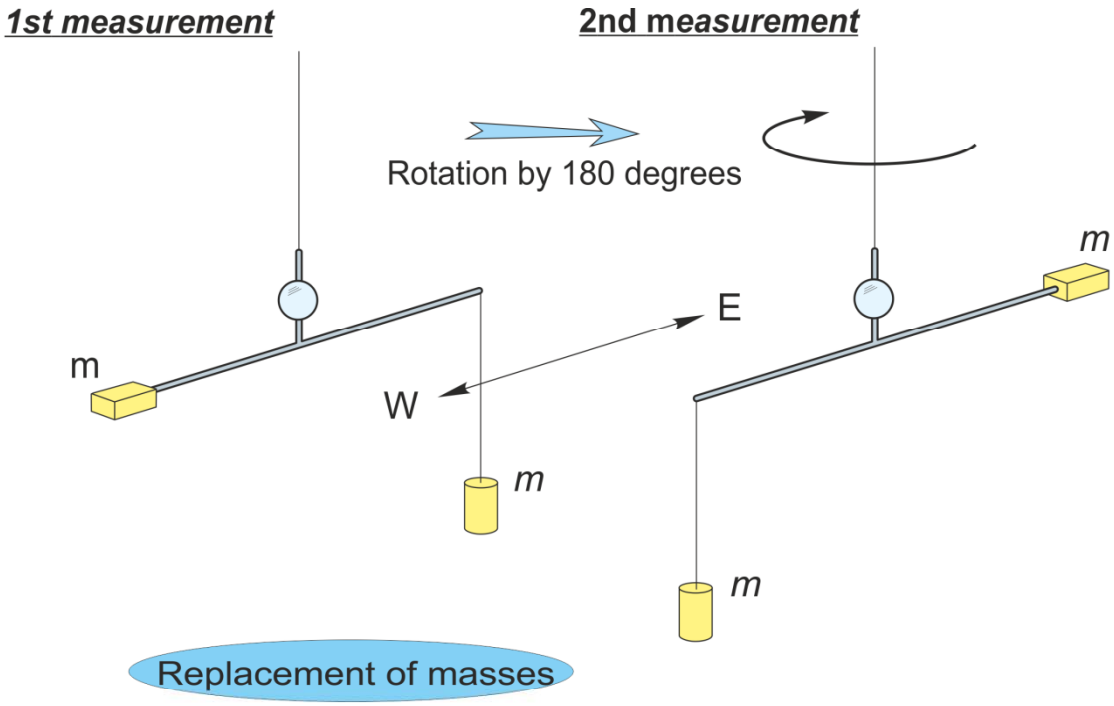


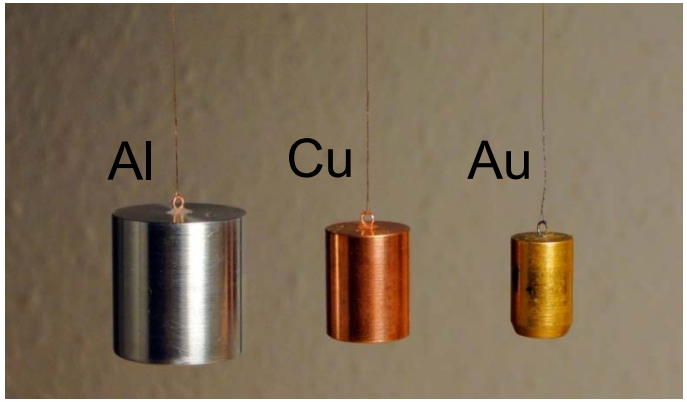
EPF measurements
between 1906 and 1908
by *Large Double Balance*



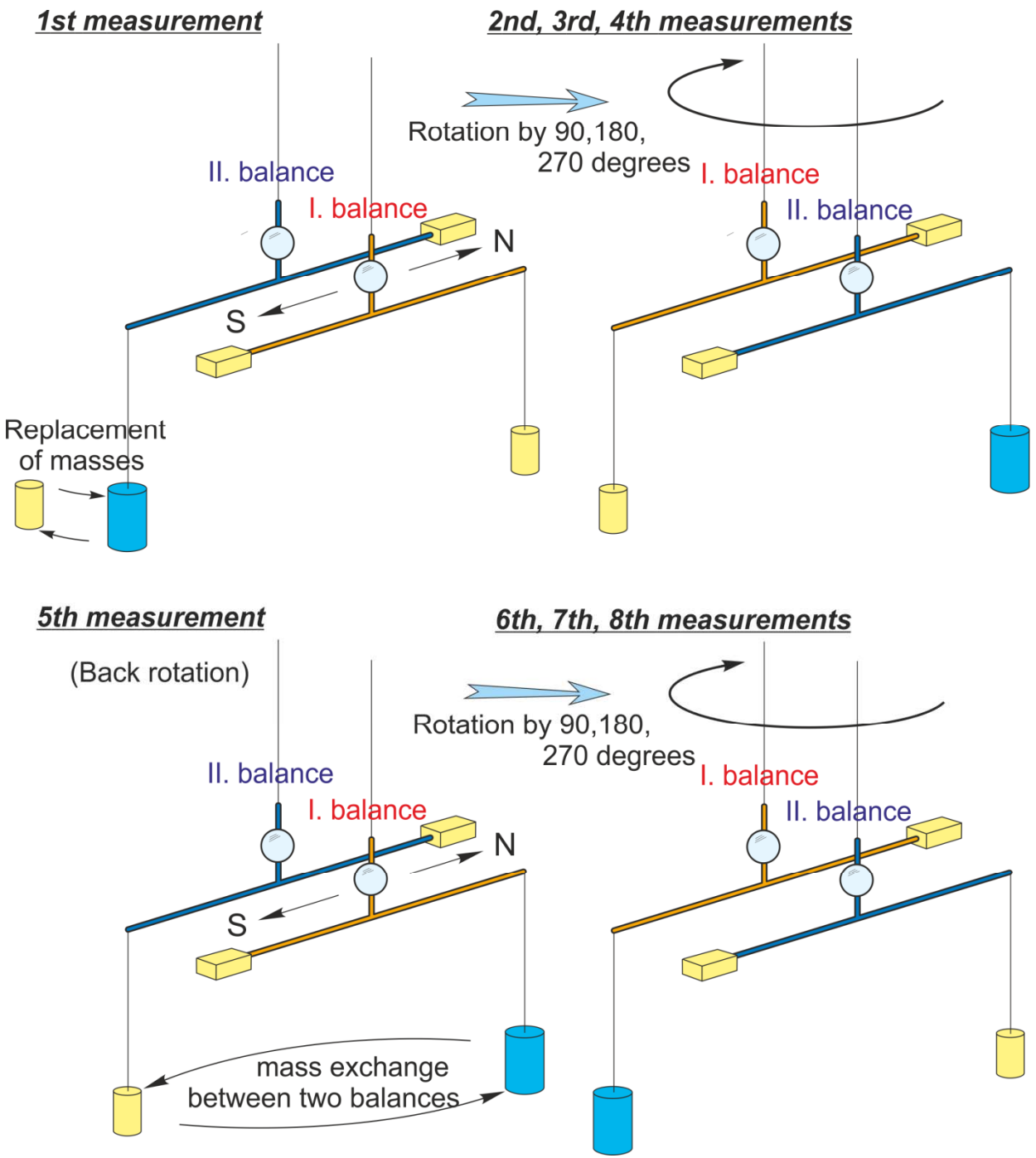

Base principle of Eötvös experiment:
Assumption: different materials have different gravitational forces but the same rotational centrifugal force.

## 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

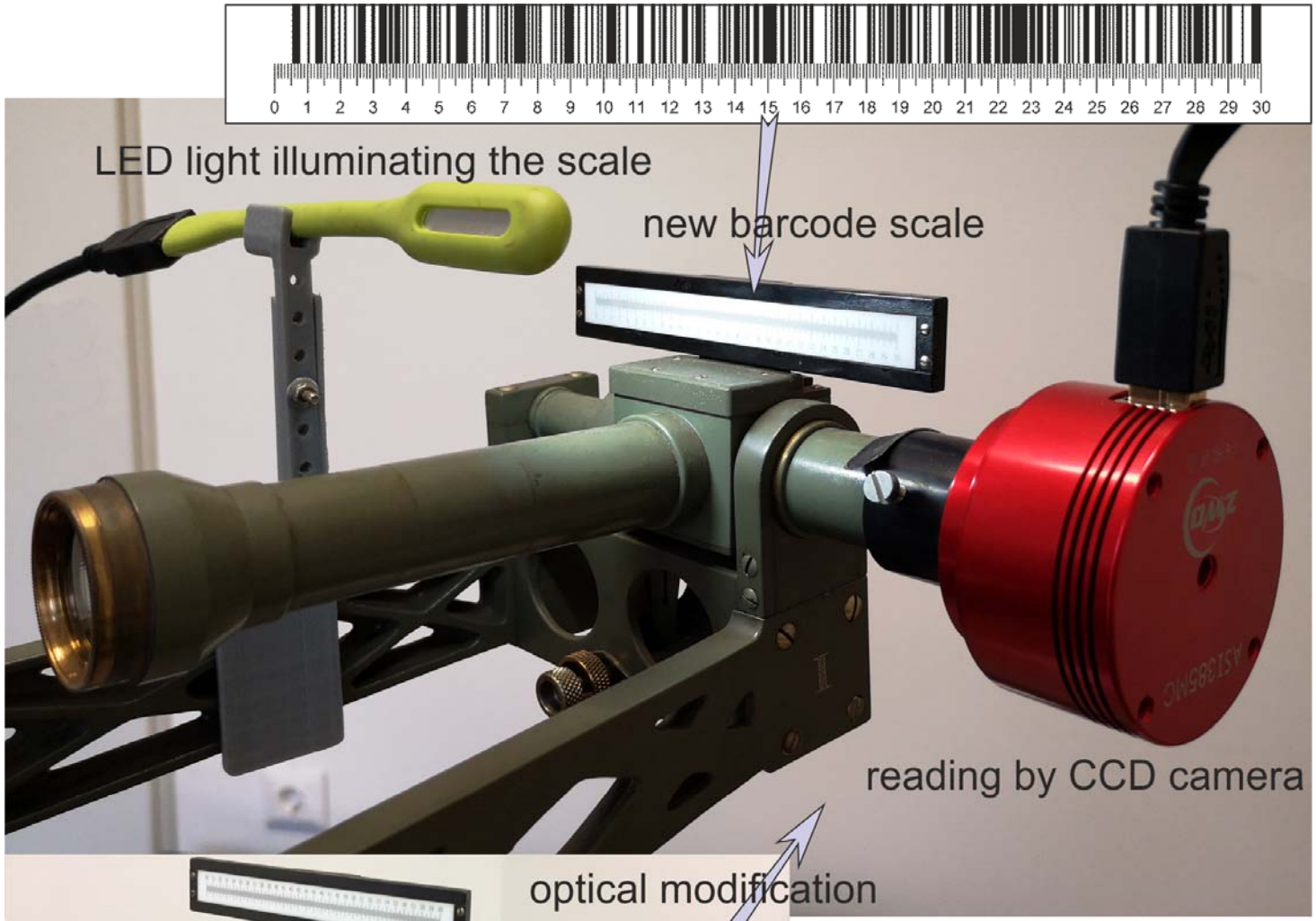
Best usable for equivalence measurements

*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.

**Solution for these problems** ***two important enhancements:***

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

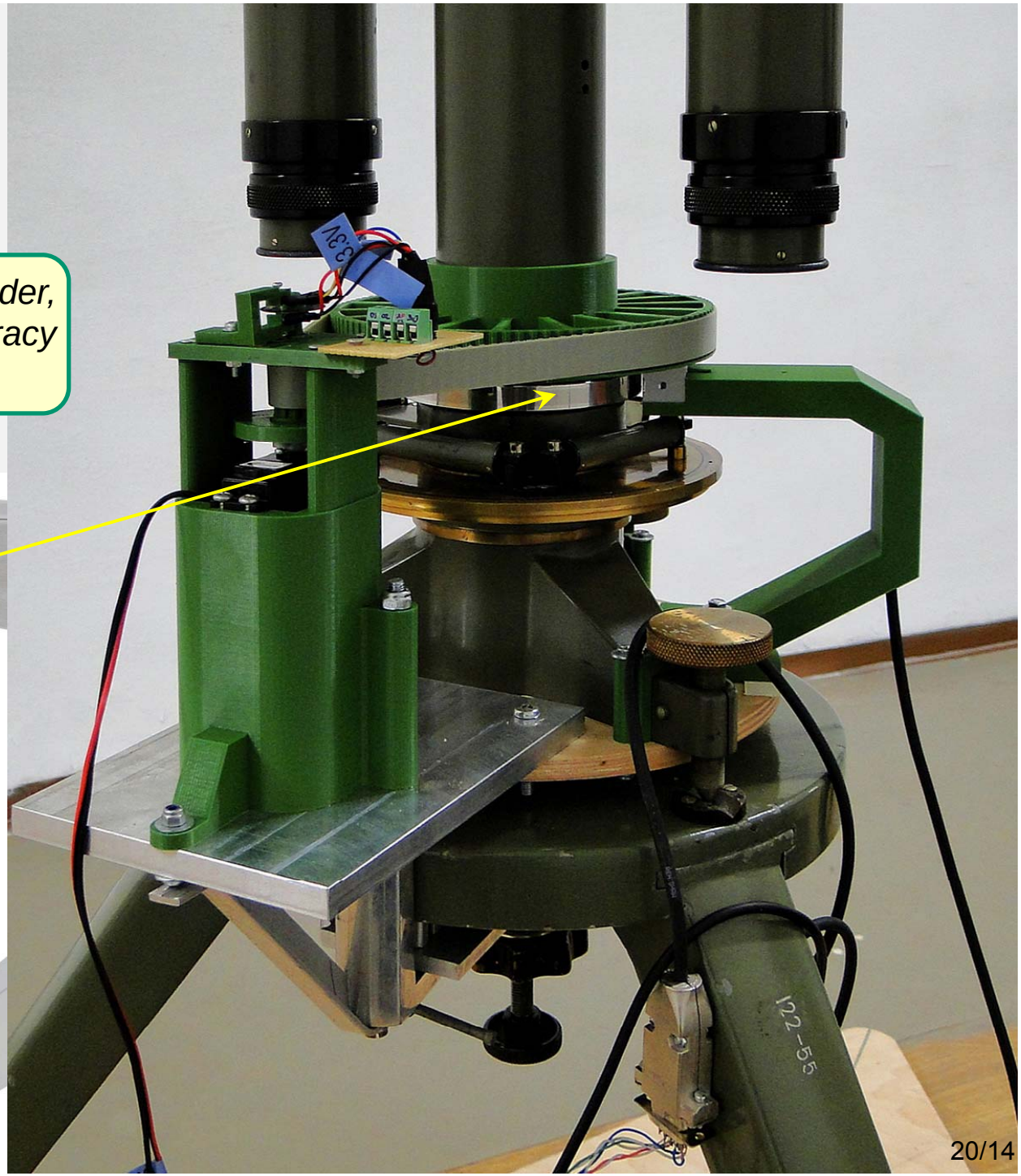


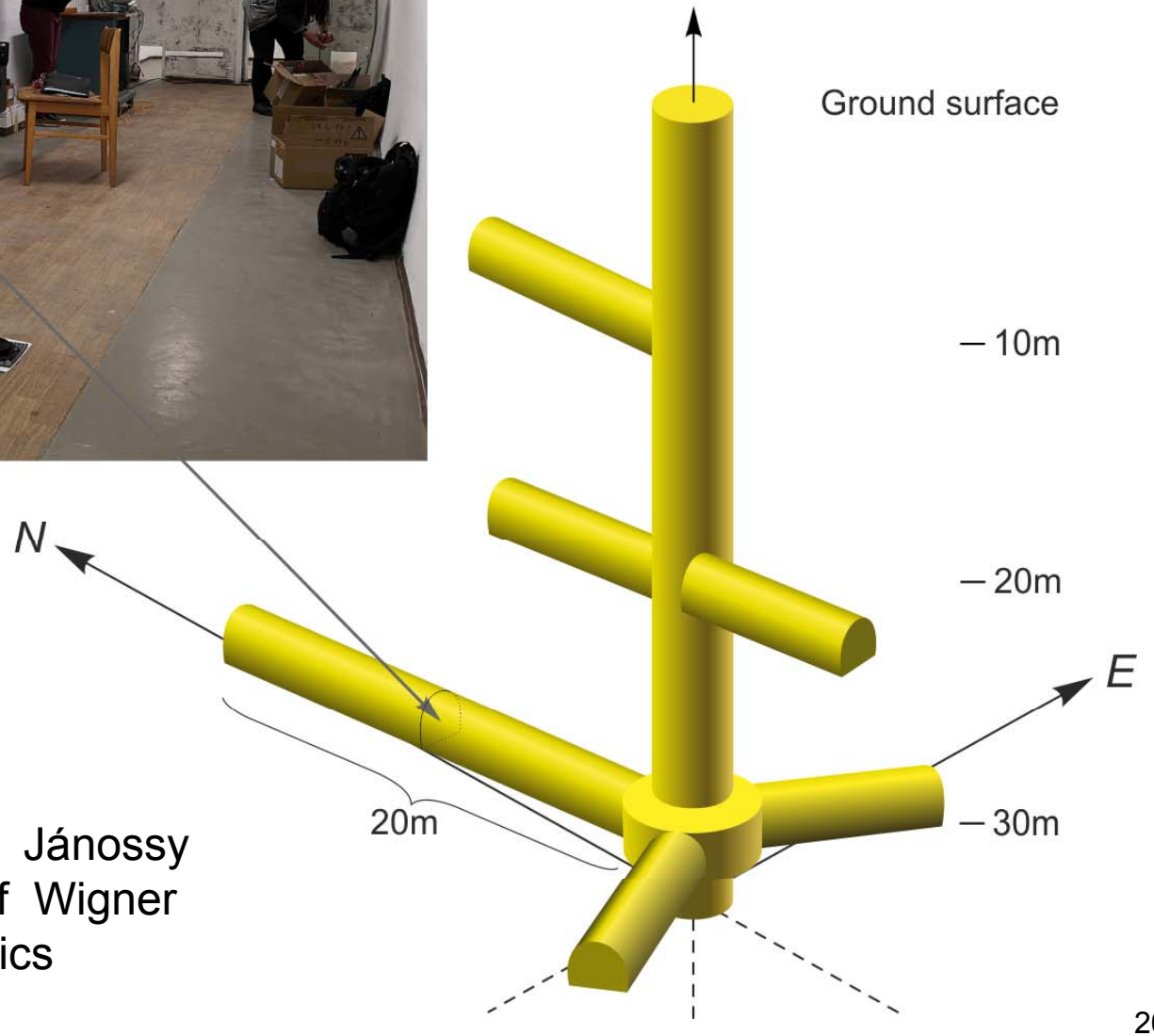

Originally: single reading after the damped position of the T.balance with accuracy of 0.1 scale division

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

## *Computer-controlled rotation mechanics*

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




*Location of measurements:* Jánossy Underground Laboratory of Wigner Researche Center for Physics


Güralp 3T compact three-component broadband seismometer

*Accuracy:*

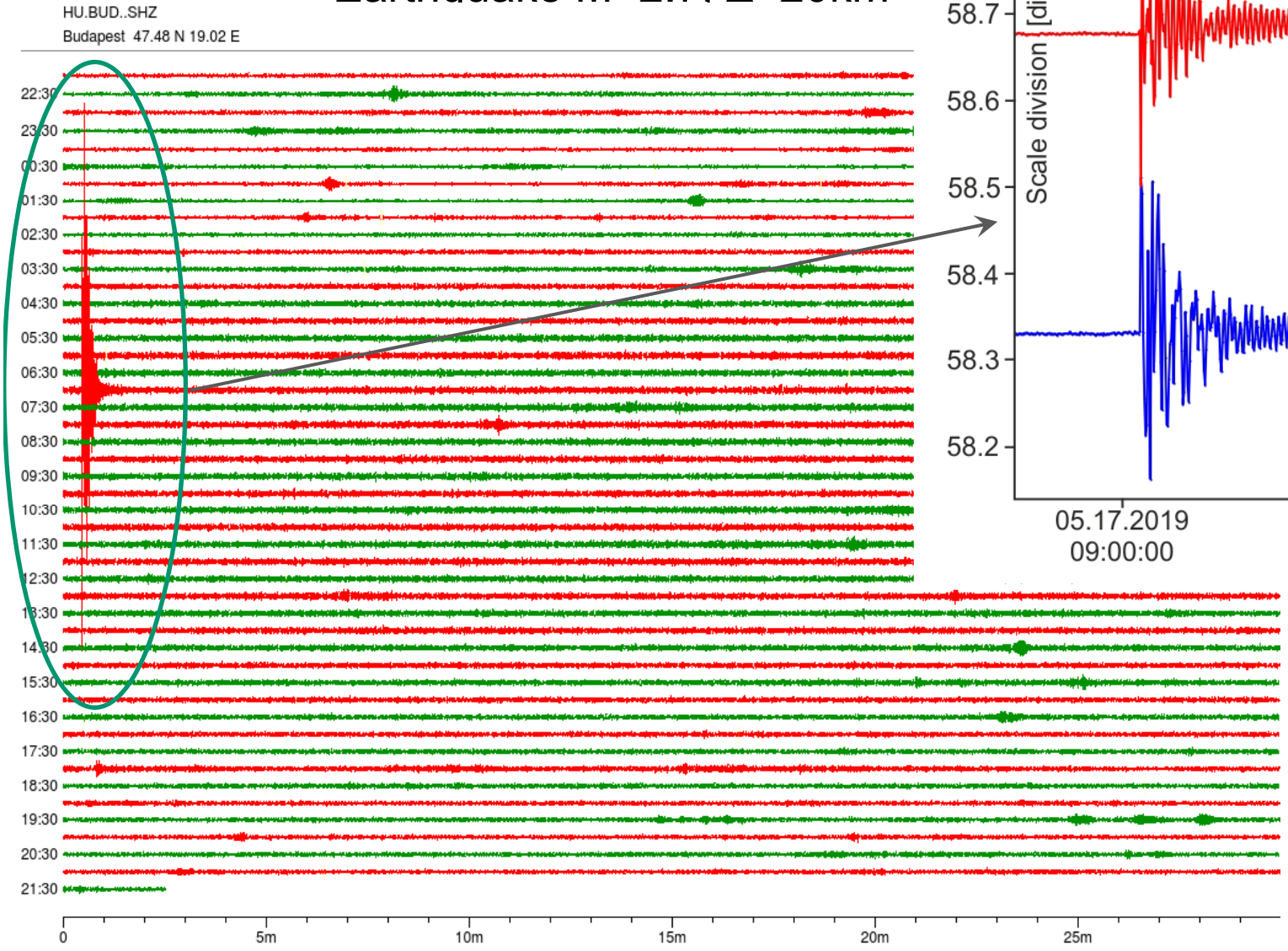
Eötvös: $10^{-9}$

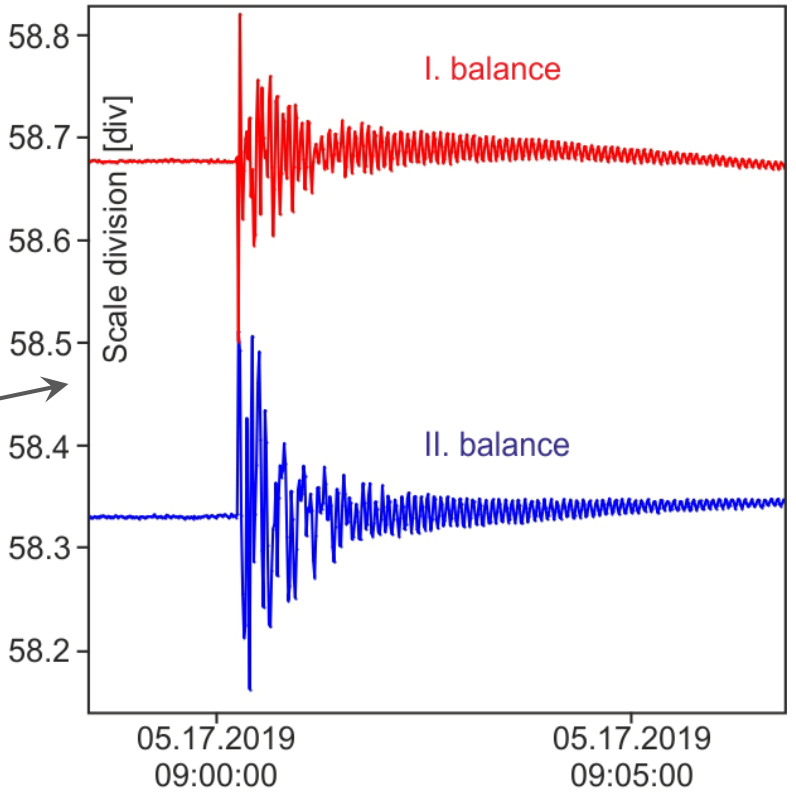
Now: $2 \cdot 10^{-11}$ *

* Recently our biggest problem is the elimination of the small microseismic ground vibrations and the infrasound pressure changes

*A curiosity example:*

May 17. 2019. 09:37
Earthquake M=2.7. Δ=20km

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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 2 moths ago, first results can be expcted at the end of this year.*

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# The staff of the experiment:

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Tóth Gy.

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