Experiments in Mátra Gravitational and Geophysical Laboratory

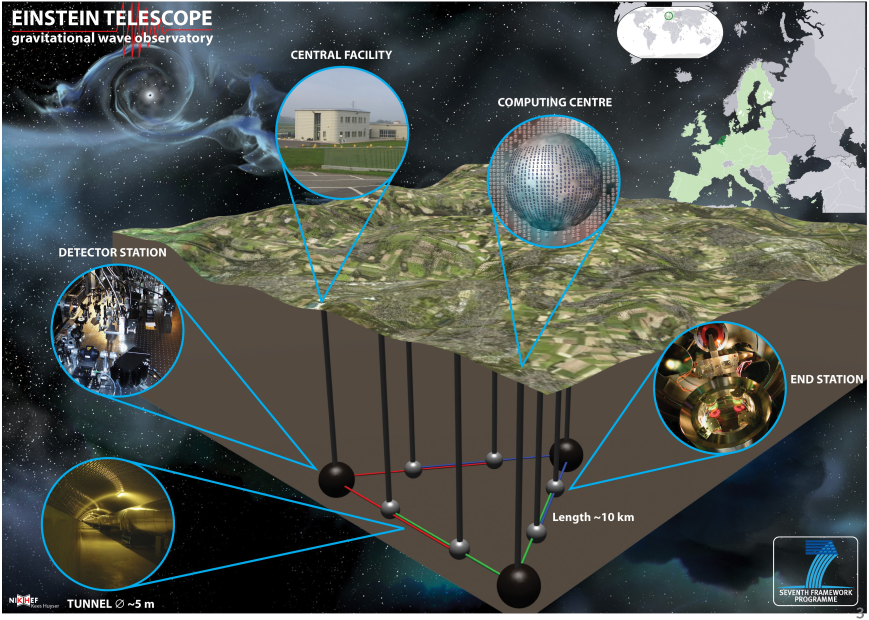
Péter Ván

Wigner Research Centre for Physics
Budapest, Hungary

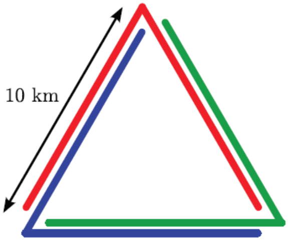
Orosei, 02/05/2019

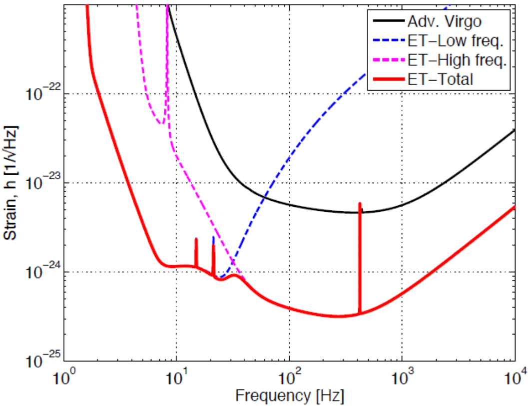
Content

Einstein Telescope



Einstein Telescope

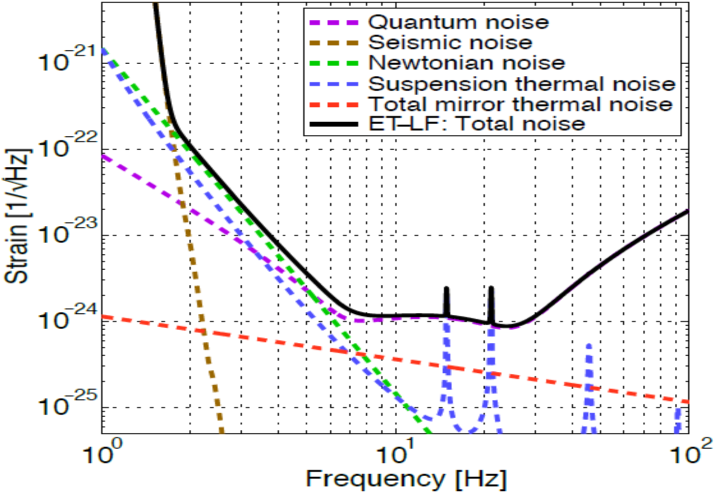




Six detectors, direction and polarisation sensitive.

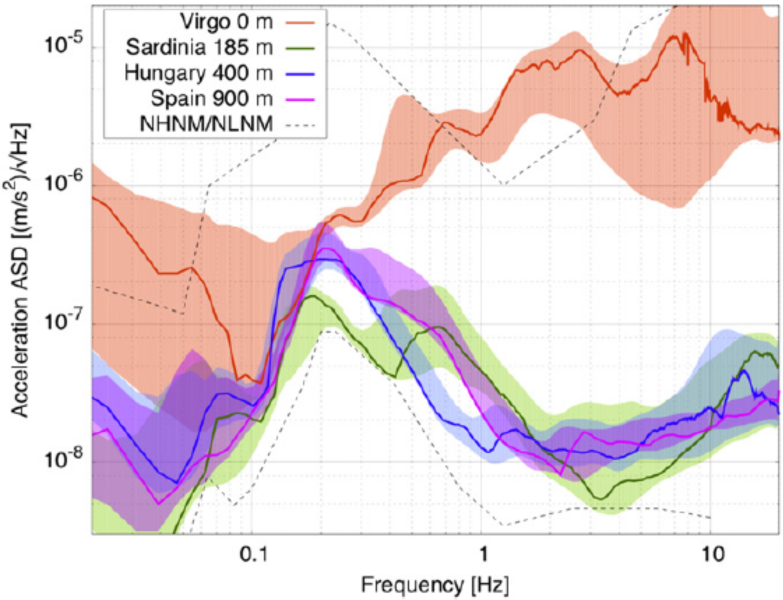
Low frequencies: seismic and newtonian

- Active damping for newtonian noise and for seismic noise below 4 Hz
- Maximum passive damping: 10 Hz, $10^{15}\times$



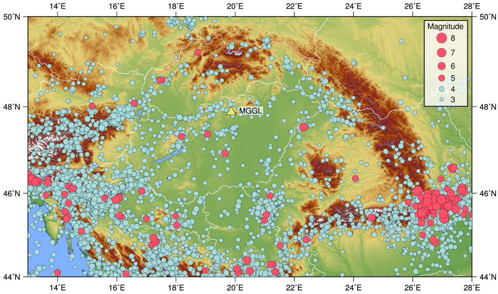
Mátra Gravitational and Geophysical Laboratory MGGL

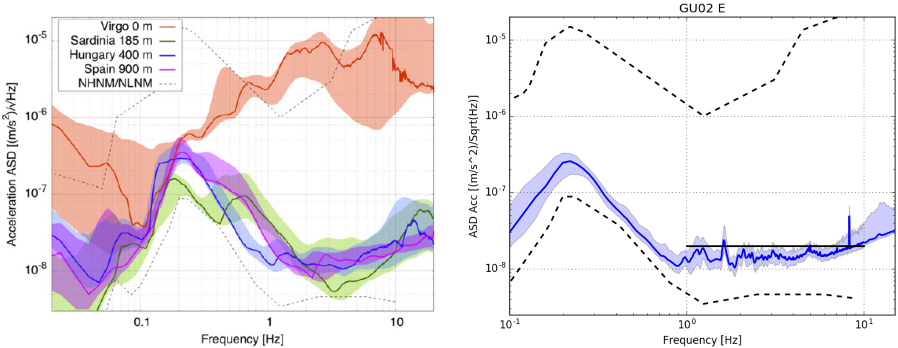
ET site selection survey



Mátra Gravitational and Geophysical Laboratory

- long term seismic noise
- former copper mine, reclamation works
- remote access
- 1280m inside
- depth: -88m, -404m



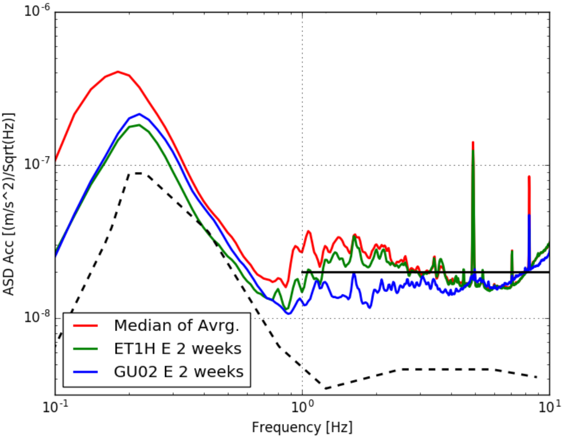


Left: Beker et al 2015, short term. Right: Somlai et al 2018, two weeks. Blue stripe: -404m, acceleration ASD, 10-90 percentiles. Blue line: the mode.

Cumulative characteristics rms_{2Hz}:

- Beker at al. (2011): 0.082nm (5 days)
- Somlai et al. (2018): 0.083nm (14 days) [arXiv:1811.05198]

Characteristic seismic noise

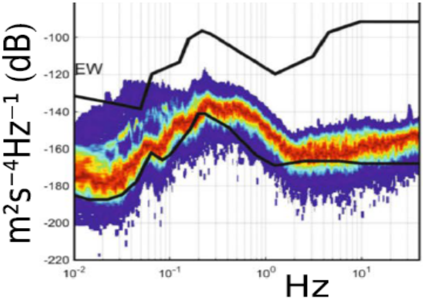


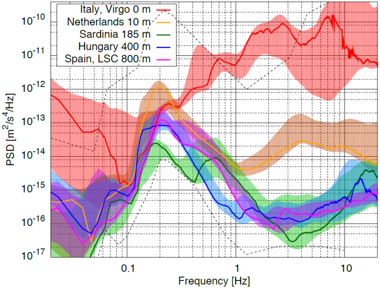
- Blue: -404m two weeks, $rms_{2Hz} = 0.083nm$,
- Green: -88m two weeks, $rms_{2Hz} = 0.133nm$,
- Red: -88m 547 days, $rms_{2Hz} = 0.148nm$.

There are no seasonal changes.

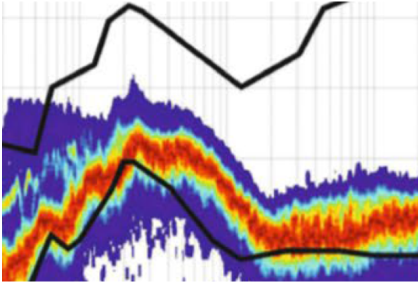
Site noise comparison

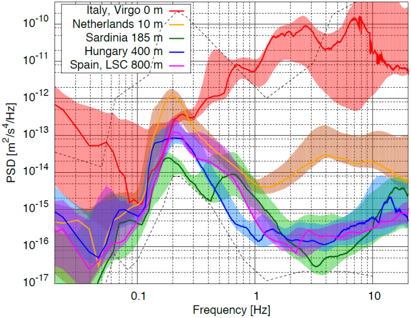
MGGL versus LSBB





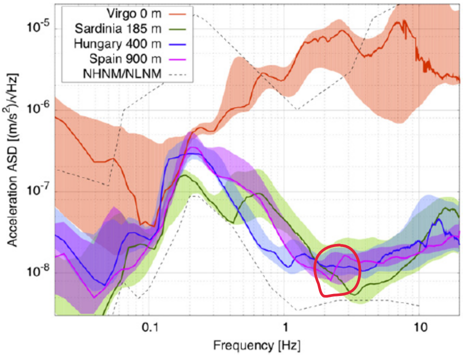
MGGL versus LSBB

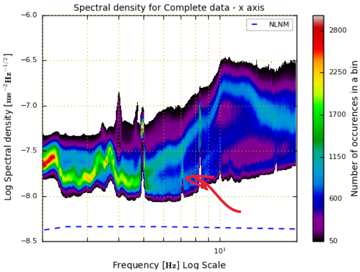




How to quantify? Long term? What really matters?

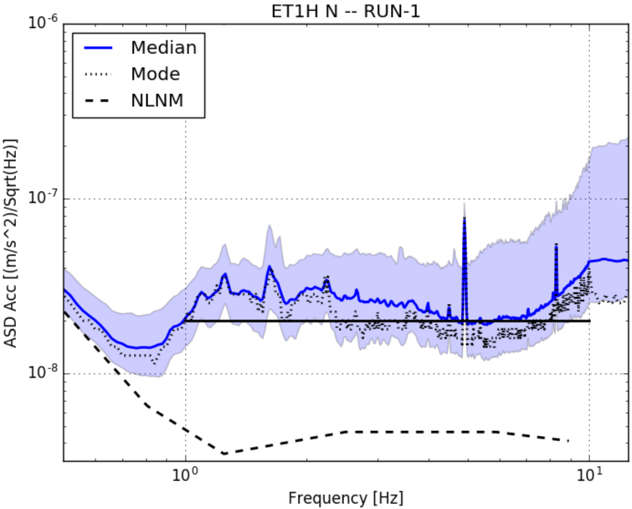
Methodological observations 1: Mode versus median





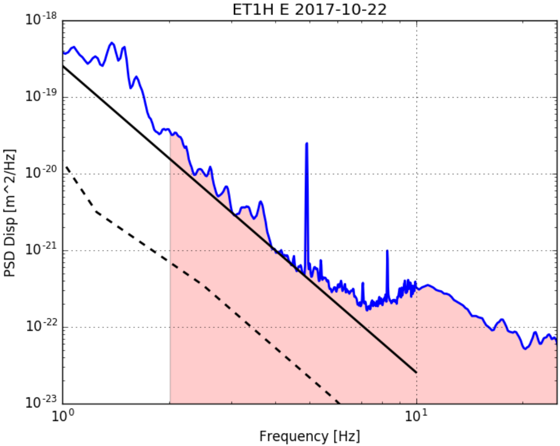
Left: Beker et al 2015, short term. Right: Van et al 2018, long term

Methodological observations 1 : Mode versus median



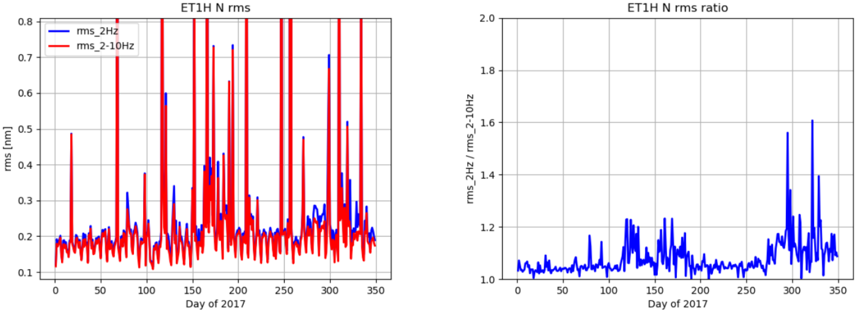
Data : -88m, 741 days, north direction, 10th and 90th percentiles, mode, median with Peterson's New Low Noise Model.

Methodological observations 2: rms_{2Hz} vs. rms_{2-10Hz}



rms: cumulative, integrated characteristics.

Methodological observations 2: rms_{2Hz} vs. rms_{2-10Hz}



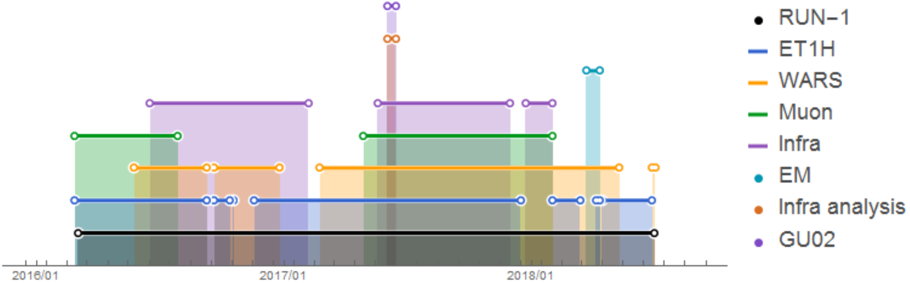
rms frequency range matters (arXiv:1810.06252)

- Spectrum: percentiles provide simple and natural filtering, are less fluctuating and more informative.
- *rms*: integration range matters.

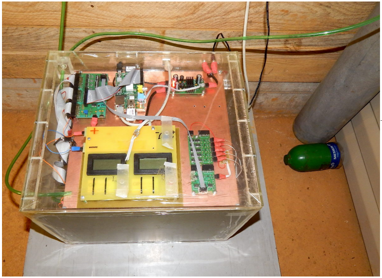
Role of noise: sensitivity is time dependent and event dependent. Estimation for BH mergers » L. Somlai.

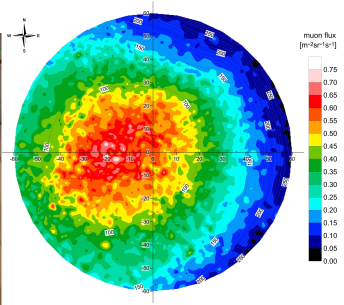
Further MGGL projects

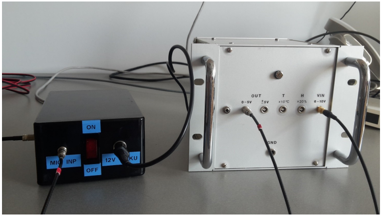
MGGL - timeline

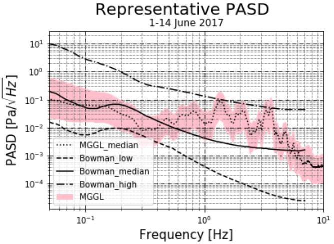


MGGL - muon, infrasound

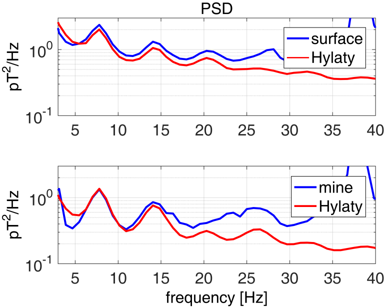








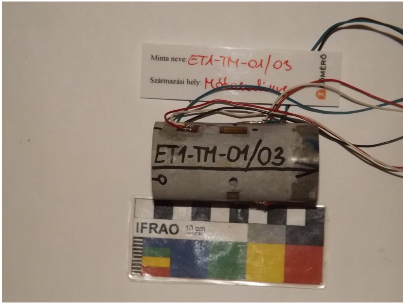
MGGL - electromagnetic

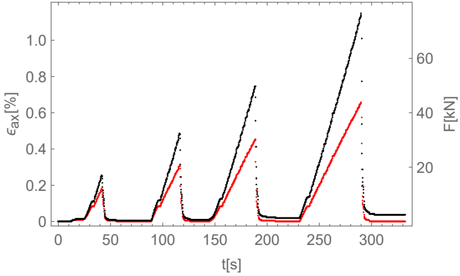


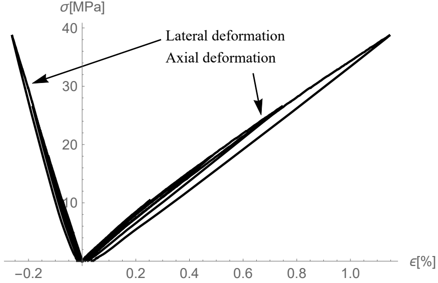
Triangulation : surface-mine-reference. Effective conductivity : $387\Omega m$, skin depth : $3520m$. Typical : $170 - 45000\Omega m$.

Rock rheology: thermodynamic time lag

- Dynamic and static elasticity
- $\tau\dot{\sigma} + \sigma = E_2\ddot{\epsilon} + E_1\dot{\epsilon} + E_0\epsilon$
- Relaxation times: $2 - 80s$
- Dynamic and static elastic moduli







Rock rheology : thermodynamic time lag

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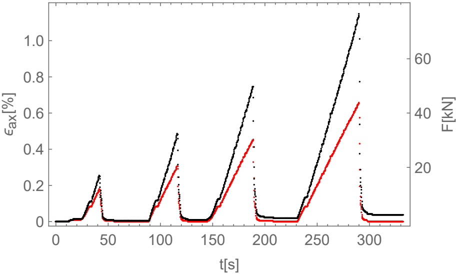
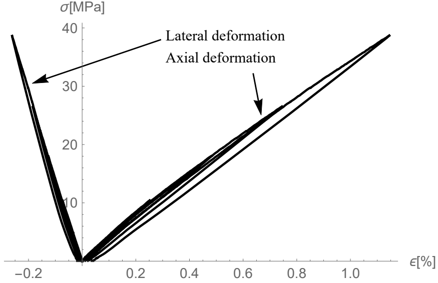
	E [GPa]	ν
static	25 ± 2	0.13 ± 0.03
rheodync	39 ± 4	0.23 ± 0.03
wavedyn	38.6 ± 2	0.18 ± 0.01





Orosz István:
Eötvös Loránd

Eötvös Loránd

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United Nations
Educational, Scientific and
Cultural Organization

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

Eötvös balance

Sensitivity: 10^{-9}. Improve to 10^{-11}.

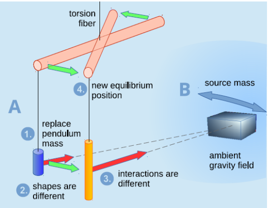
Eötvös balance: the 5th force mystery

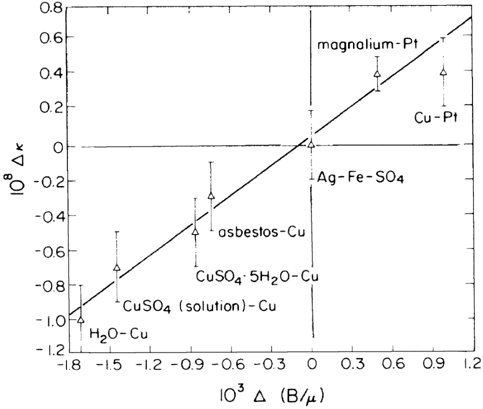
Eötvös ratio:

$$\eta = \Delta\kappa = 2\frac{|a_1 - a_2|}{|a_1 + a_2|} =$$

$$= \frac{m_{P1}}{m_{I1}} - \frac{m_{P2}}{m_{I2}} =$$

$$= C\Delta\left(\frac{B}{m}\right)$$





Fischbach et al. (1986)

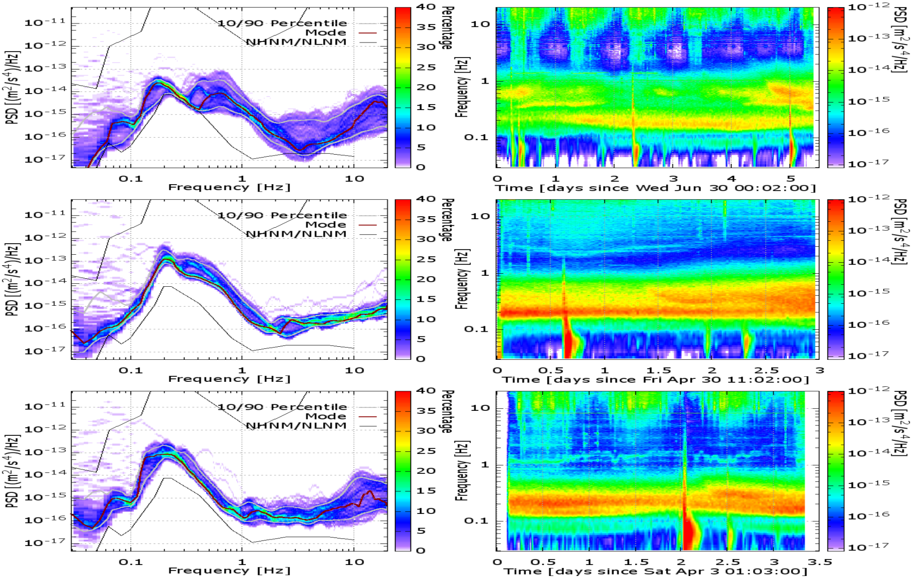
- ET site characterisation : seismic, EM, ... » L. Somlai, (arXiv:1810.06252,1811.05198)
- Rock mechanics and geophysics (NN? » R. Kovács)
- WEP measurement with Eötvös balance (arXiv:1803.04720)

Thank you for your attention !

The MGGL group

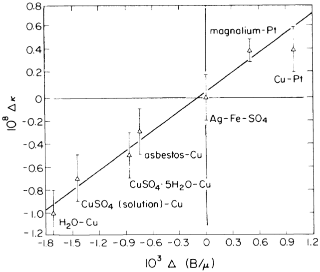
- Wigner Research Centre for Physics:
  P. Lévai, P. Ván, M. Vasúth, G.G. Barnaföldi, G. Huba (technical director), D. Barta*, R. Kovács, L. Somlai*, Z. Zimborás, P. Kicsiny*; E. Fenyvesi, D. Varga, G. Hamar, L. Oláh, P. Pázmándi*; E. Dávid, L. Deák,
- Research Centre for Astronomy and Earth Sciences:
  V. Wesztergom, I. Lemperger, Z. Gráczer, Z. Wéber, T. Cziffra, A. Novák*, B. Süle*;
- Other:
  M. Dobróka, P. Vass; T. Bulik, D. Gondek-Rosinska, M. Suchenek;T. Novák, Zs. Bernáth*, A. Molnár*; S. Lökös, L. Kovács, B. Vásárhelyi, J. Molnár, G. Surányi; L. Völgyesi, Gy. Tóth, G. Péter, B. Kiss, P. Harangozó, Gy. Szondy.

Sardegna (-189m) - Pirenei (-900m) - Mátra (-400m)

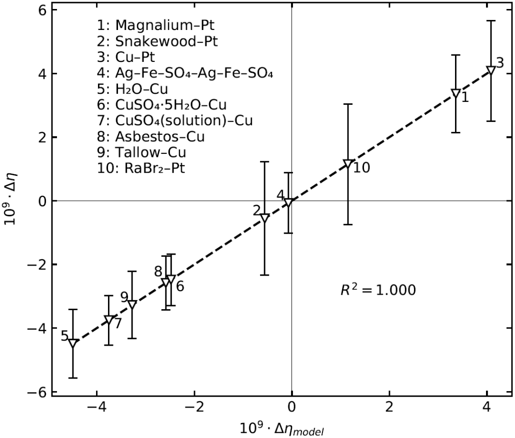


EPF 5th force: gravitational gradient effect

Careful analysis of available information and optimal calibration of the gradients from the environment.



Fischbach et al. (1986)



arXiv:1803.04720

Equivalence Principles: weak, strong, etc.

Einstein equivalence principle (EEP):

1. Weak Equivalence Principle (WEP) or Universality of Free Fall (UFF): "weight" is proportional to "mass". Strong Equivalence Principle (SEP): it is valid for self-gravitating bodies, too.
2. Local Lorentz invariance (LLI): The outcome of any local non-gravitational experiment is independent of the velocity of the freely-falling reference frame in which it is performed.
3. Local Position invariance (LPI): The outcome of any local non-gravitational experiment is independent of where and when in the universe it is performed.

If EEP is valid, then gravitation must be a curved spacetime phenomenon.

Survey: Will: Living Rev. Relativity, 2014

"Most of the ideas solving the big problems in physics predict effects that could show up in EP tests." (Adelberger)

WEP violations

Skalar, vector interactions, string theory, extra dimensions, supersymmetric theories, axions, generalized gravitation, (Horndeski, Brans-Dicke (?), MOND, etc.),...

$$m_P = m_I + \sum_A \frac{\eta^A E^A}{c^2}$$

m_P is passive gravitational mass, m_I inertial gravitational mass.
E^A internal energy, due to the interaction A, η^A coupling constant
E.g. for barionic interaction:

$$V(r) = -G_\infty \frac{m_1 m_2}{r}\left(1 + \alpha e^{-\frac{r}{\lambda}}\right), \qquad \alpha = -\xi_B \left(\frac{B_1}{m_1}\right)\left(\frac{B_2}{m_2}\right)$$

Restrictions for particular theories, including SEP and test of Newtonian gravitation depending on experimental setup.

SEP violations

Generalized gravitation, e.g. Horndeski, Brans-Dicke (?), MOND, ...

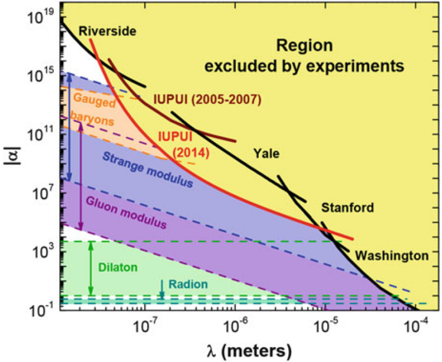
$$m_P = m_I + \eta_N E_g$$

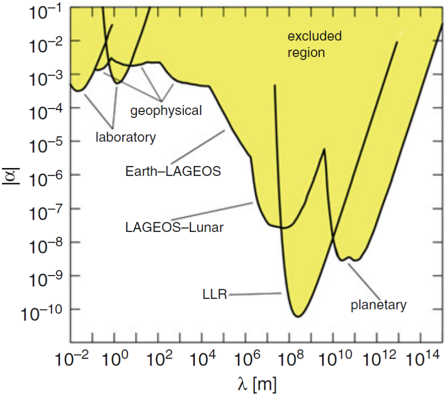
It is WEP for self-gravitating bodies, so called Nordtvedt effect. m_P passive gravitational mass, m_I inertial gravitational mass.
E_N is gravitational self-energy, η_N is the coupling constant.
With PPN parameters:

$$\eta_N = 4\beta - \gamma - 3 - \frac{10}{3}\xi - \alpha_1 + \frac{2}{3}\alpha_2 - \frac{2}{3}\zeta_1 - \frac{1}{3}\zeta_2.$$

γ, β, cuvature and superposition nonlinearity (Eddington-Robertson-Schiff); ξ preferred-location; $\alpha_{1,2,3}$ preferred-frame; α_3, $\zeta_{1,..,4}$ total momentum conservation.

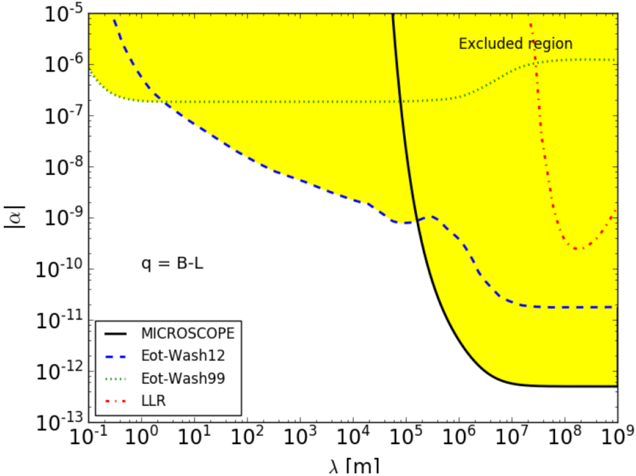
Status of WEP 1

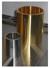




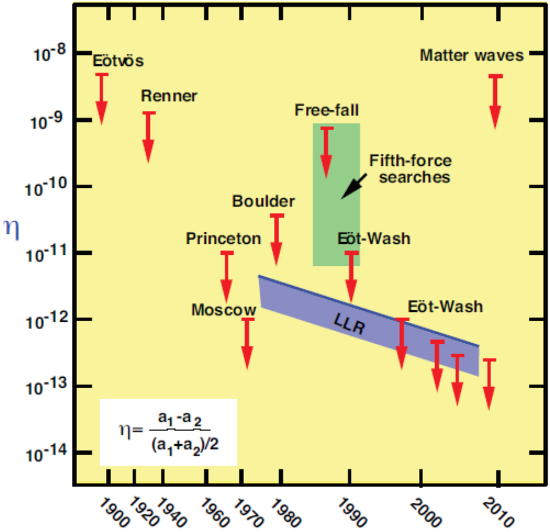
Franklin-Fischbach (2016), Adelberger et al. (2009).

MICROSCOPE



Platinum and titanium test masses. $\eta < 10^{-14}$. 

Status of WEP 2



Will (2014)

Improvement of Eötvös balance

Wigner: Jánossy UPL – Eötvös balance measurements

Wigner RCP and BME

Aim: WEP test

Motivation:

- Eötvös year
- EPF - 5th force test
- gravgrad hypothesis test
- Newtonian noise

Original Eötvös balance?

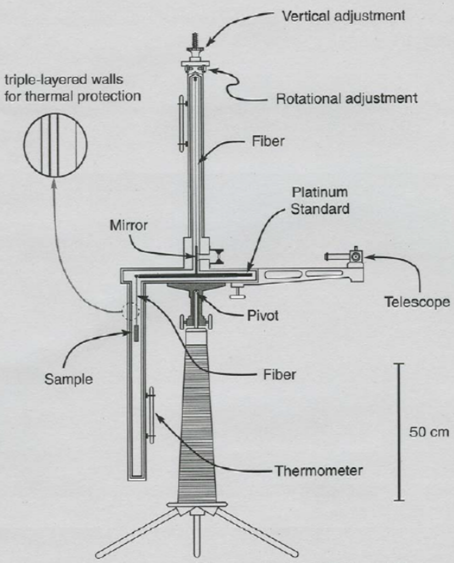


Figure 4.6: Single-arm torsion balance used by Eötvös, Pekár, and Fekete.

Planned developments

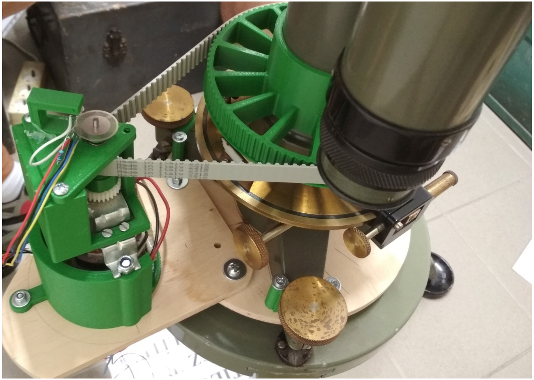
Improvements stage 1:

- Automatic rotation
- Automatic data acquisition and evaluation
- Silent, controlled environment

Expected sensitivity: 10^{-10}

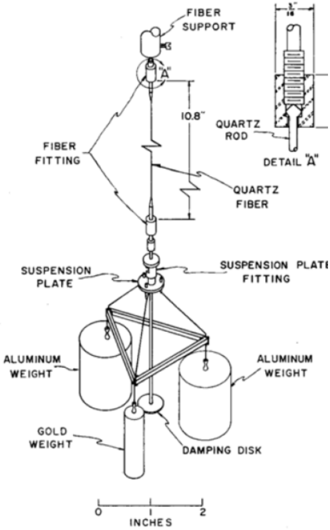
Possible future developments:

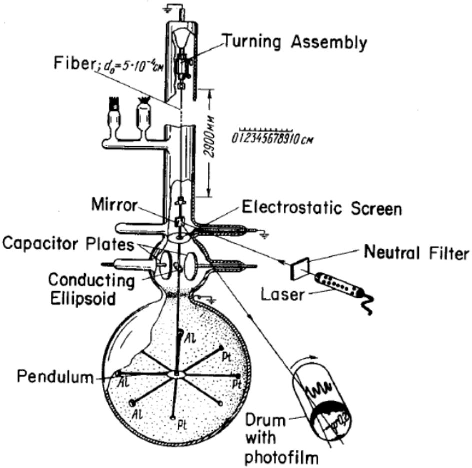
- Motion control
- Damping-motion modelling
- Interferrometric readout



Recovering the weights

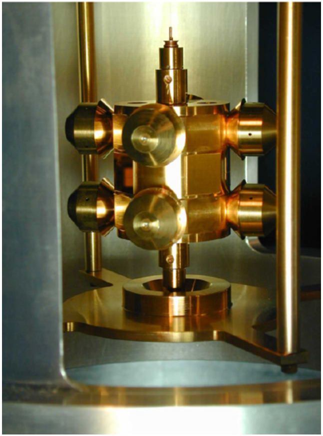
Roll-Krotkov-Dicke (1964); Panov-Braginskii (1972)

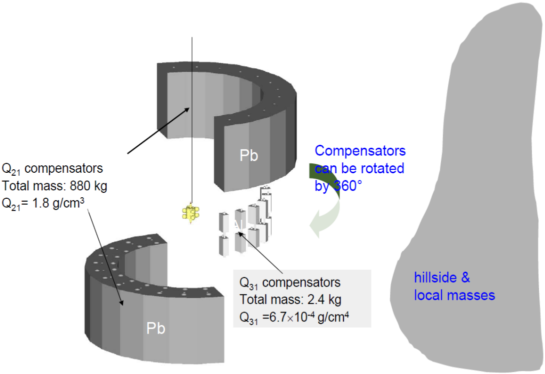




Sun related, 24h period (Eöt-Wash); torsion drift.

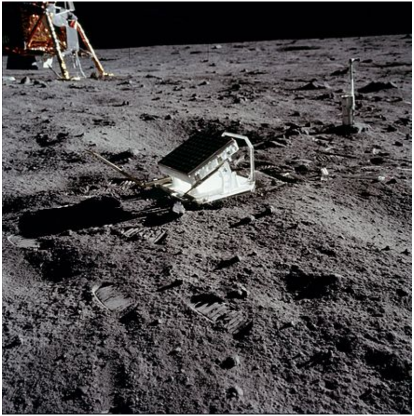
Eöt-Wash

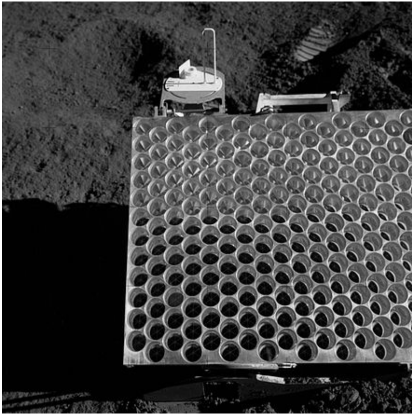




Huge gradients, compensated first moments, hollow test masses

Lunar Laser Range





Zoltán Bay, Apollo 11 and Apollo 15.
Assumes different material compositions of the Moon and the Earth. This is not the most accepted geophysical theory. SEP test.