Review of
Dicke’s WEP Measurements

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ETTE – Gravitációs Teadélután

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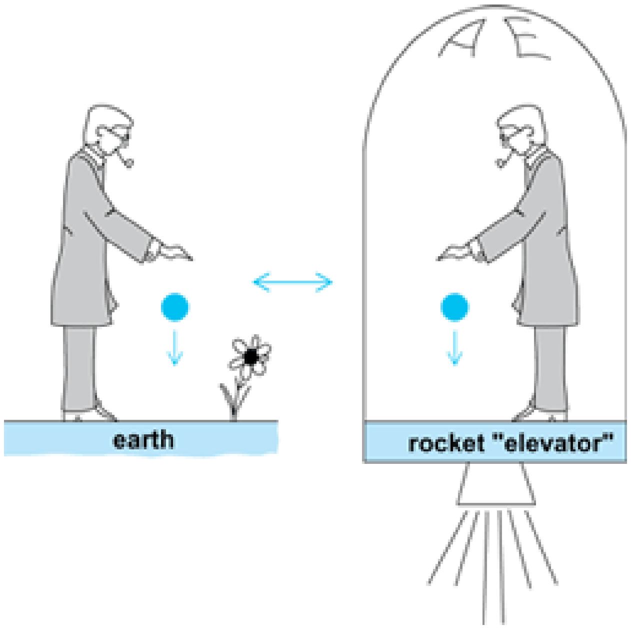
WEP measurements
„test the universality of free fall”



Torsion balance

- 1590 Galilei 10^{-2}
- 1686 Newton 10^{-3}
- 1832 Bessel 10^{-5}
- 1889 Eötvös 5×10^{-8}
- 1909 Eötvös (EPF) 2×10^{-9}
- 1964 Dicke et al. 10^{-11}
- 1971 Braginski et al. 10^{-12}
- 1976 Lunar Laser Ranging 10^{-12}
- 1990 Eöt-Wash group 10^{-13}
- ~~2014 STEP 10^{-18}~~

Basics of WEP measurements

Earth

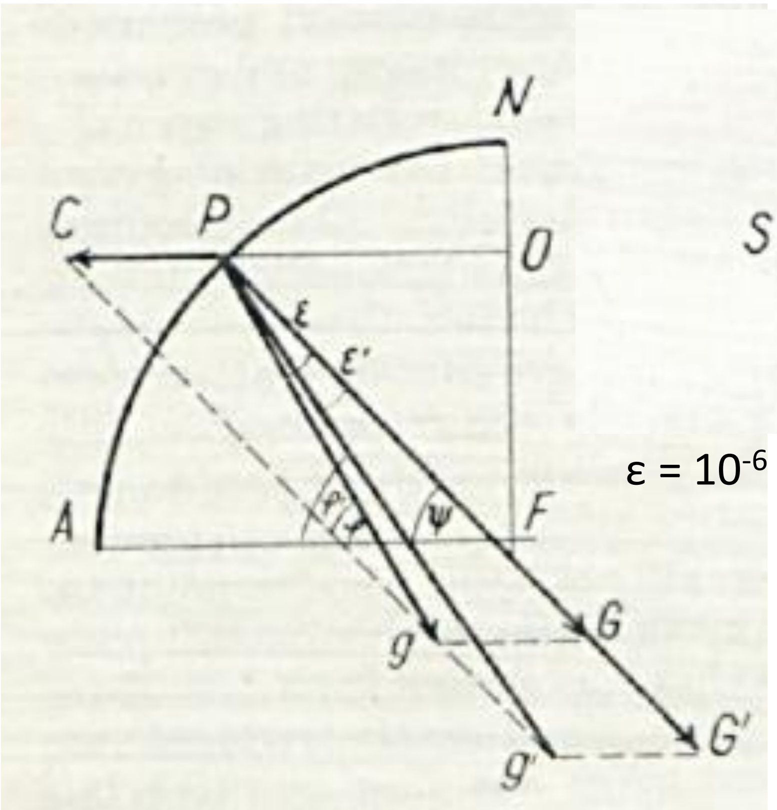


Fig. 1.

Sun

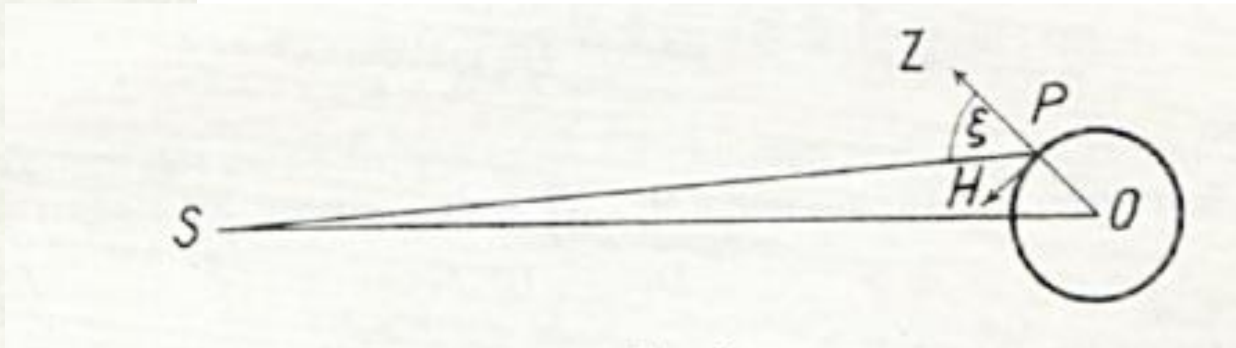
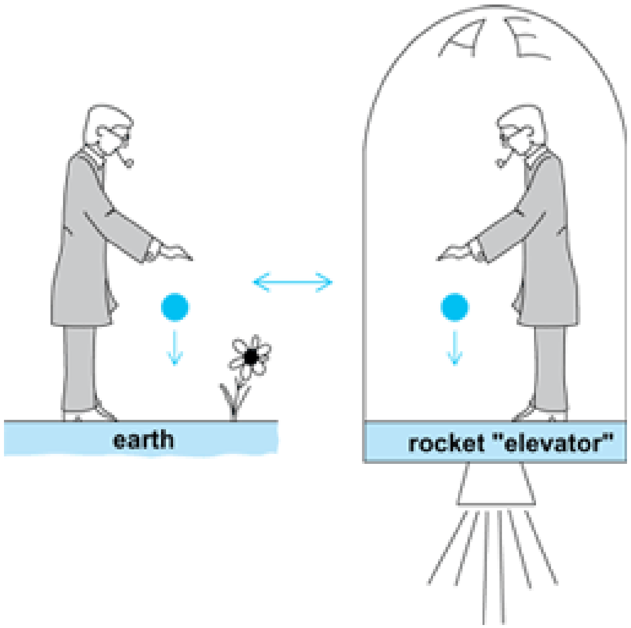


Fig. 5.

ε = 10^{-6} → 10.2

ε = 10^{-6} → 3.5

WEP measurements
„test the universality of free fall"



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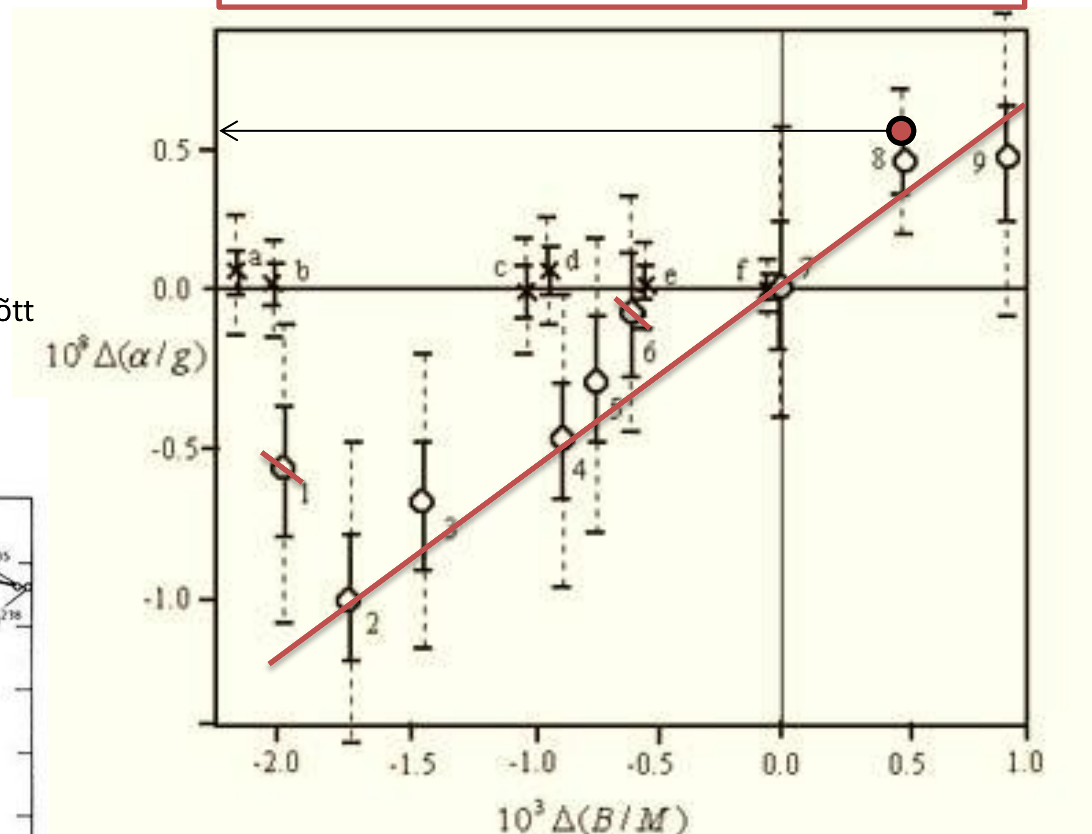
~~2014~~	~~STEP~~	~~10^{-18}~~

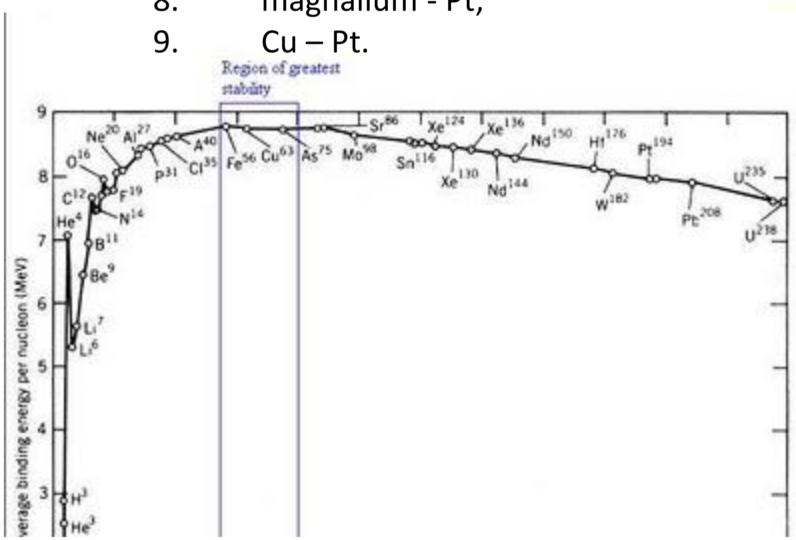
Everything seems to be OK

Fischbach 1986.01.06

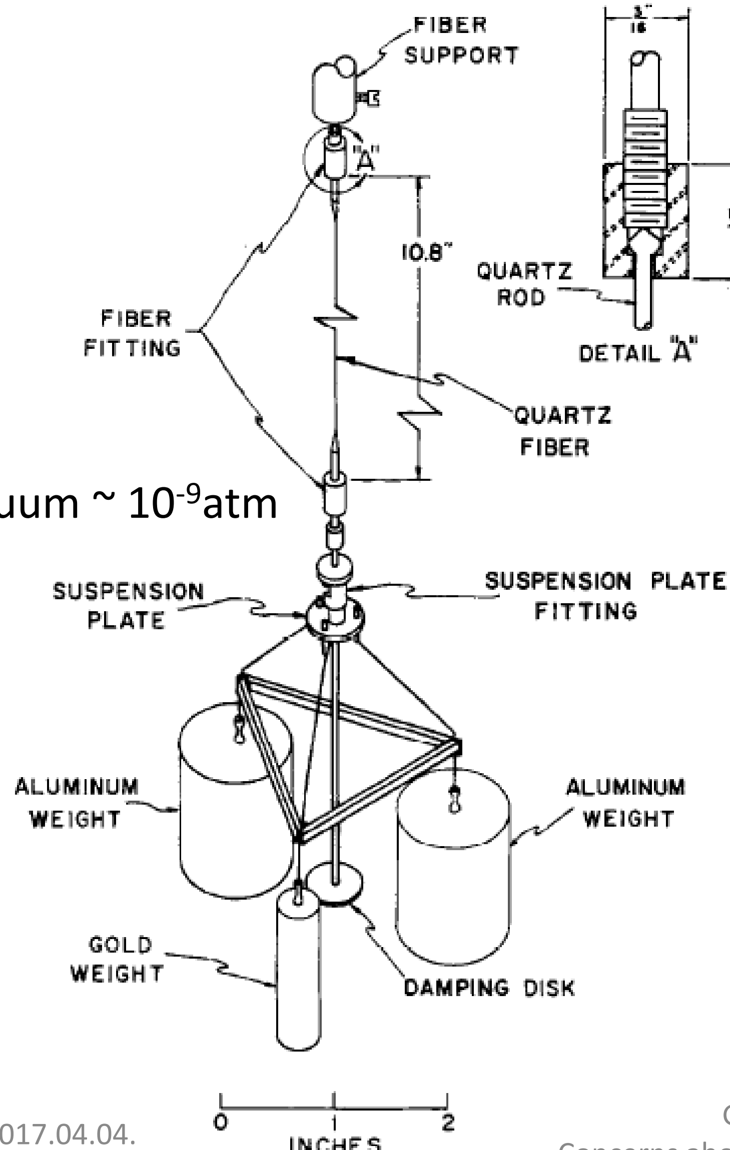
- EPF: „acceleration […] sensitive to the composition of the materials used.”
- Eötvösék (1-9) által mért dα/g értékek d(B/M) függvényében.
  1. ~~faggyú - Cu;~~
  2. víz - Cu;
  3. CuSO4 oldat - Cu;
  4. $CuSO_4$ kristályok - Cu;
  5. azbeszt - Cu;
  6. ~~fa - Pt;~~
  7. ezüstszulfát + vasszulfát (reakció elõtt és után);
  8. magnalium - Pt;
  9. Cu – Pt.

EPF - Sun: Magnalium - Pt

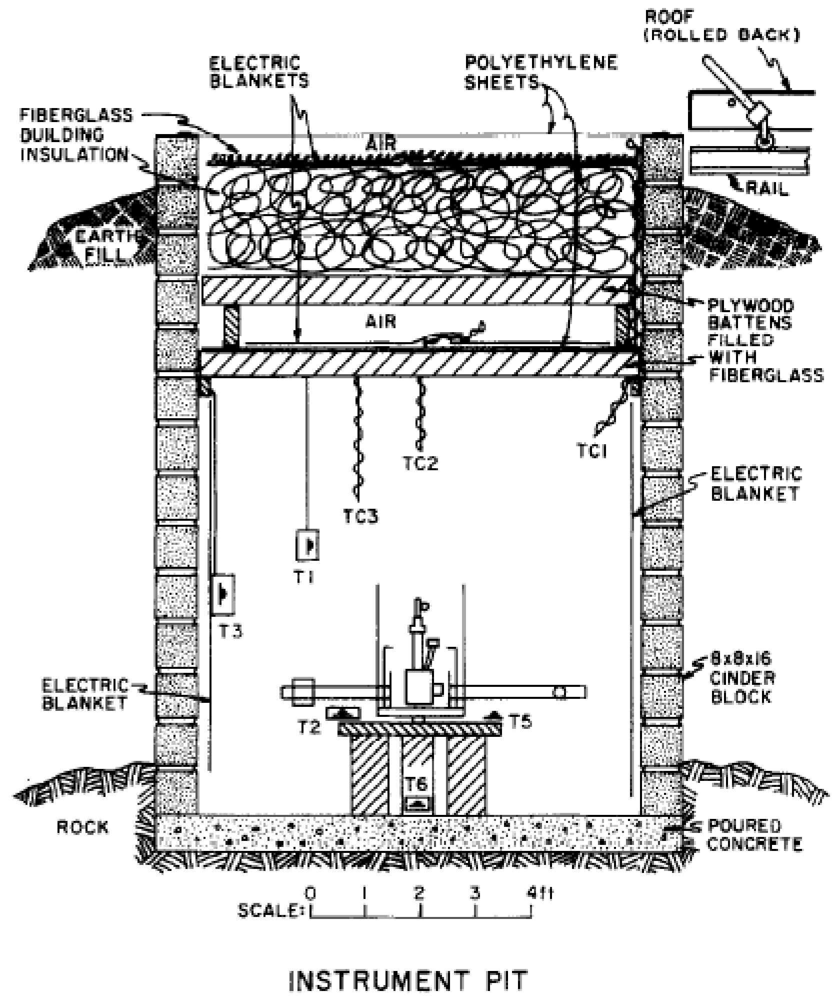




Dicke measurements



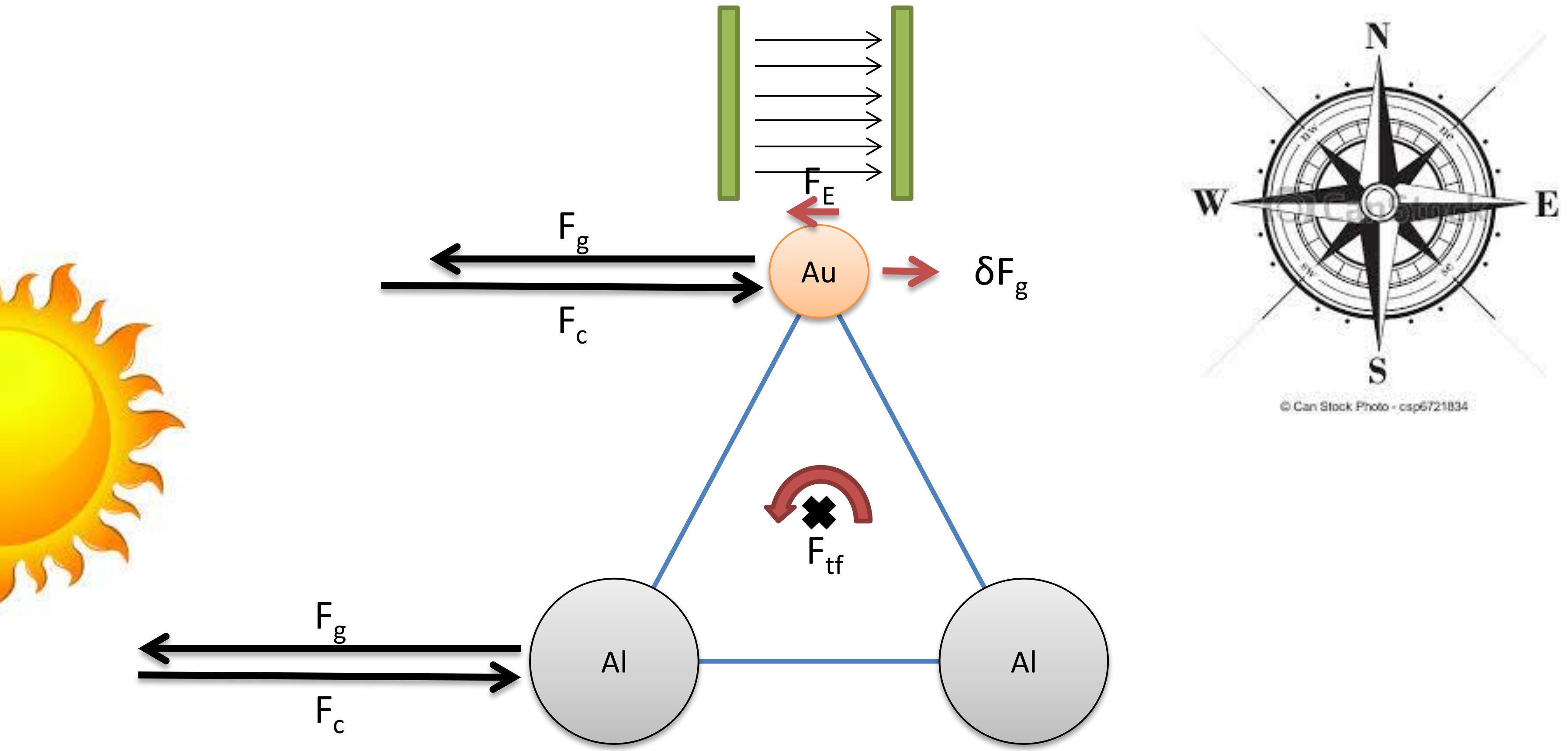
Vacuum ~ 10^{-9}atm



Gravitaional effect

Aspect	**Eötvös**	**Dicke**	**Difference**
Source	Earth	Sun	
Effect (d=10-6)	10.2 E	3.5 E	~0.34x
Materials:	H_2O-Cu	Au-Al	
Expected diff:	$10x10^{-9}$	$2.6x10^{-9}$	~0.26x
Mass	25g	30g	~1.2x
Moment arms	21.2 cm	3.3 cm	~0.16x
Overall effect (M) [dyn cm]	10^{-7}	$1.6x10^{-9}$	~0.016x
Precision: → $1,8x10^{-10}$ dyn → $3x10^{-9}$ rad	$2x10^{-9}$	10^{-11}	$\sim 0.5x10^{-2}$x

Basic forces



Dicke measurements for 10^{-11}

$1{,}8 \times 10^{-10}$ dyn

3×10^{-9} rad

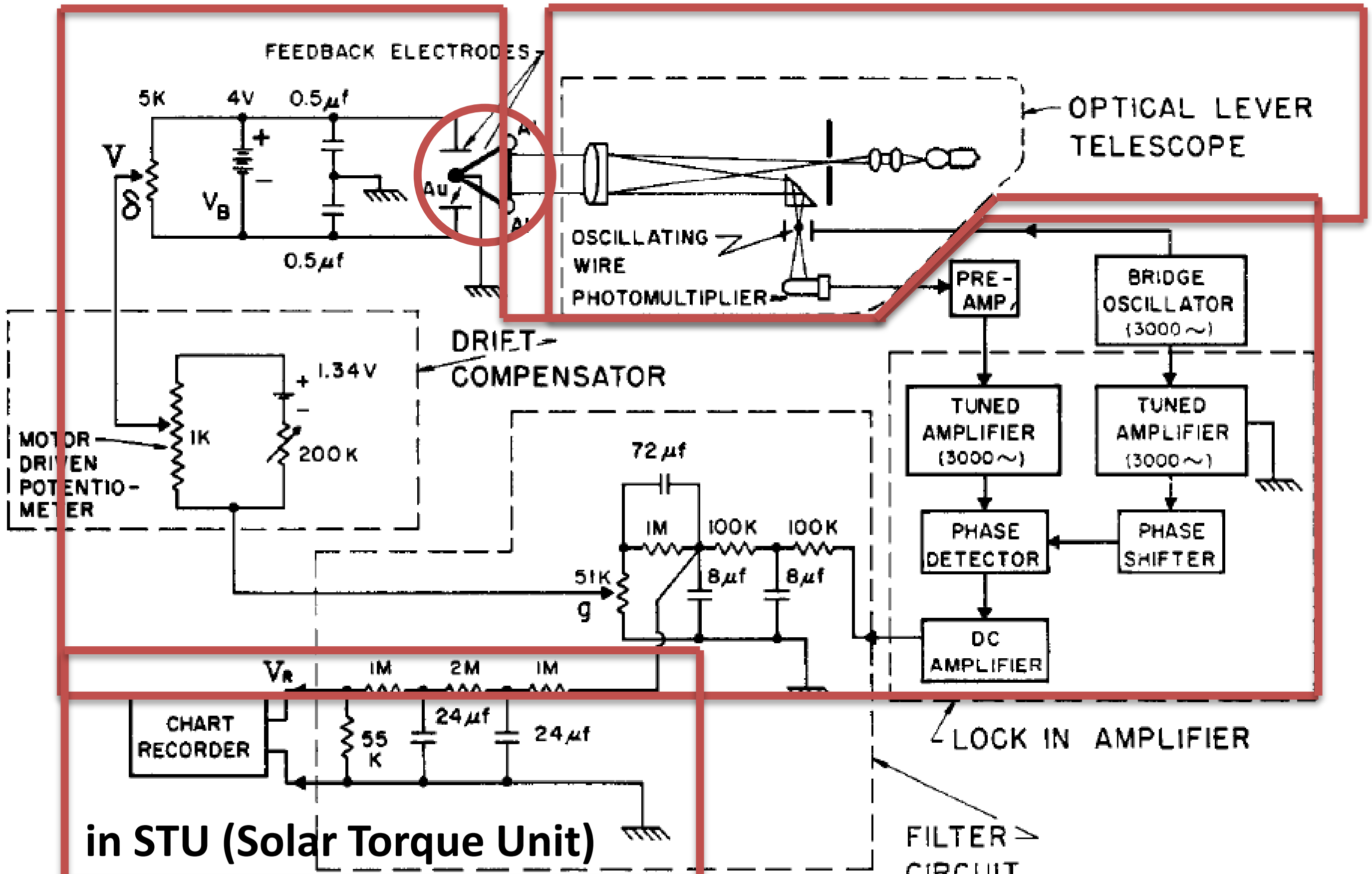
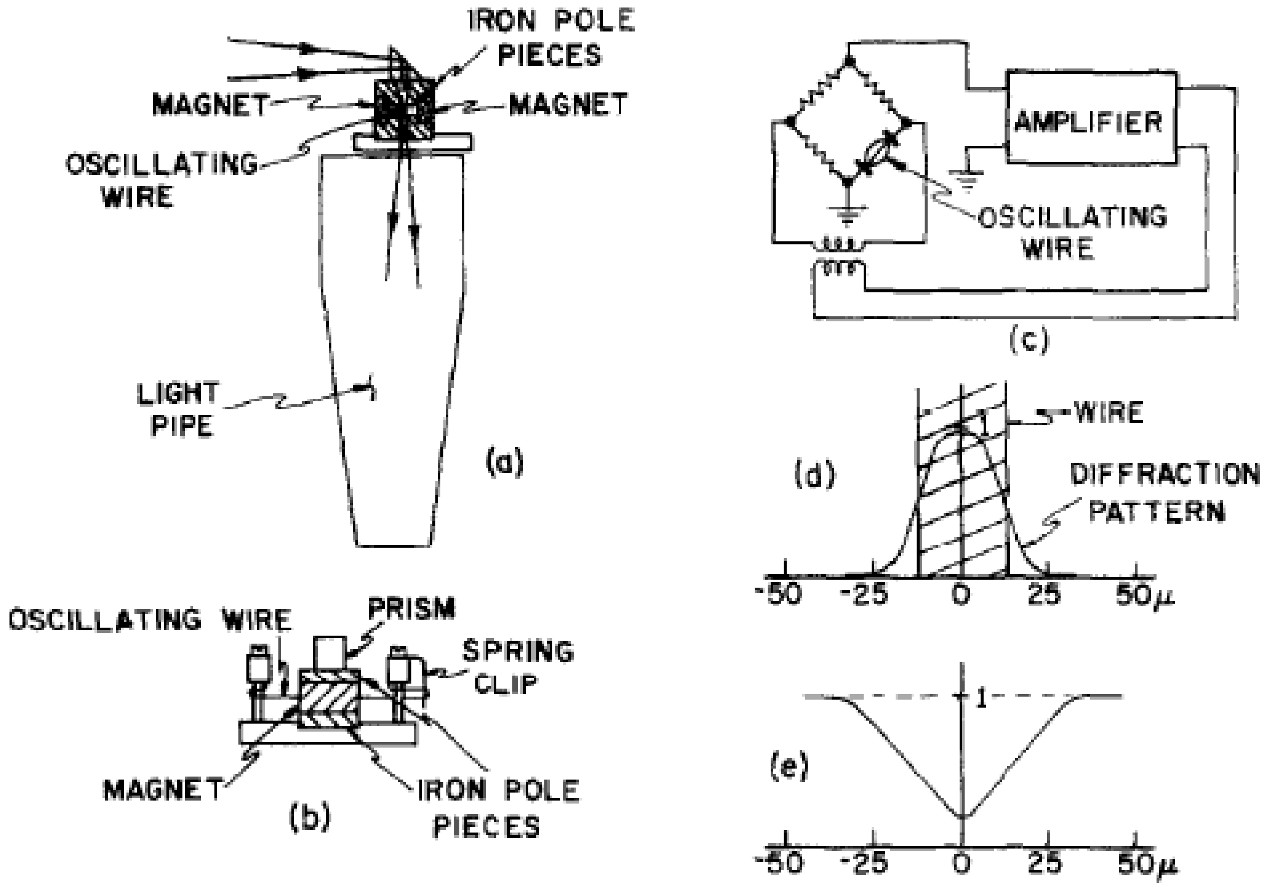


Fig. 6. Block diagram of the optical lever detection system

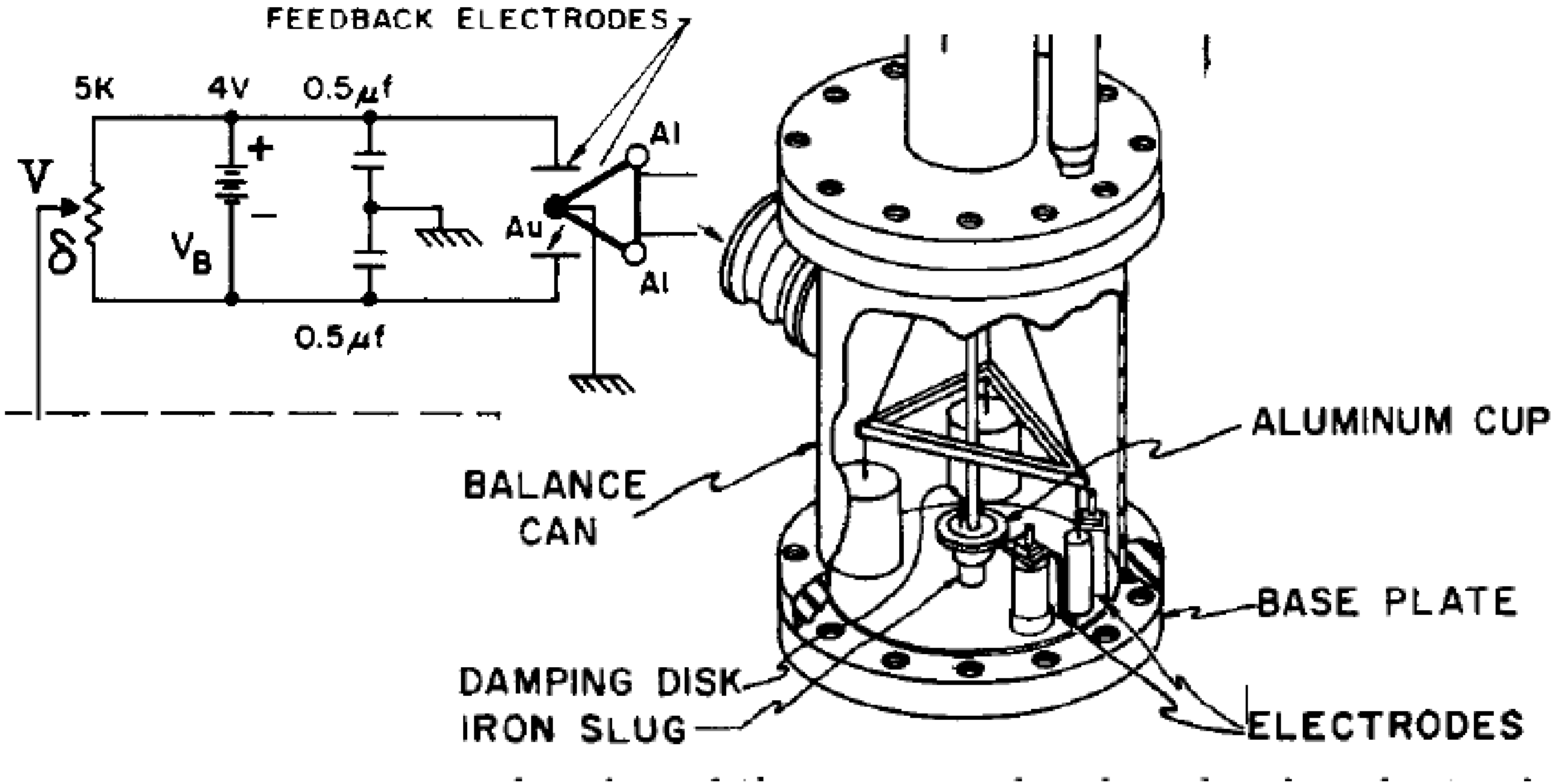
Torque turn detector - $3x10^{-9}$ rad

Oscillating wire light modulator: 10^{-5}rad → $3x10^{-9}$ rad



Feedback electrodes - 10^{-15}N

10^{-11}N → $\underline{10^{-15}\text{N}}$ → $\delta < 10^{-4}$

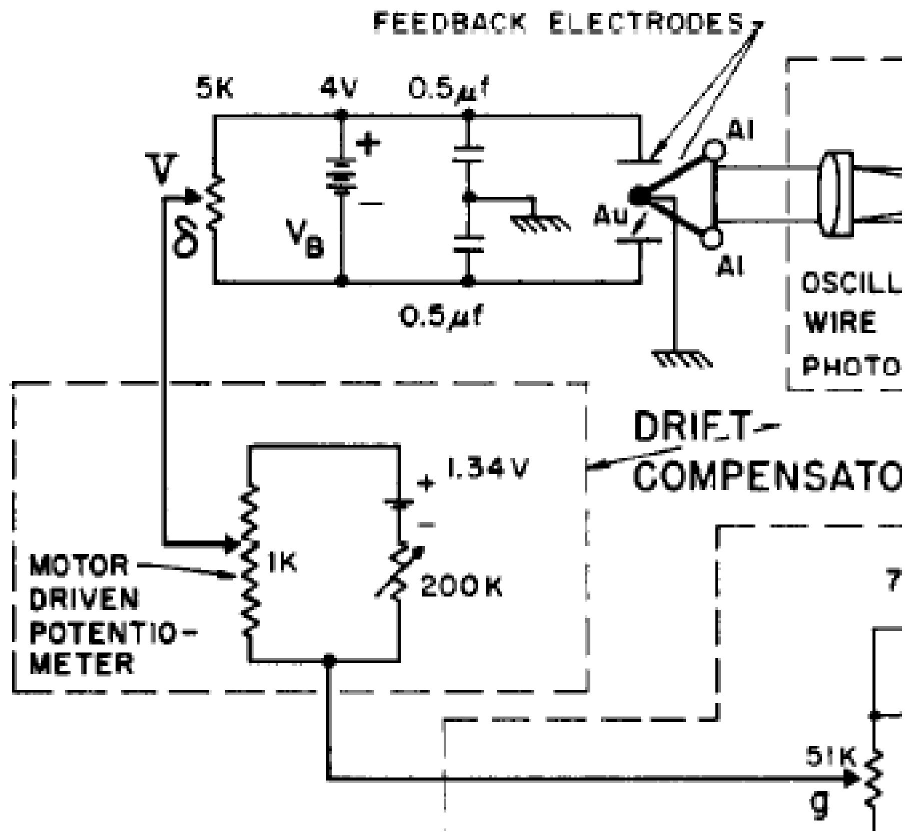


Torziós szál

- Platina-Iridium szál (Eötvös)
  - Stabil egyensúlyi helyzet
  - Mechanikai behatásokra nem érzékeny
- Wolfram szál (Dicke, Braginski, Eöt-Wash)
  - Dicke: lecserélte (mágnesesség, érzékenység növelés)
- Kvarc szál (Dicke)
  - Eötvös: egyáltalán nem rendelkezik a kívánatos tulajdonságokkal

Steady drift

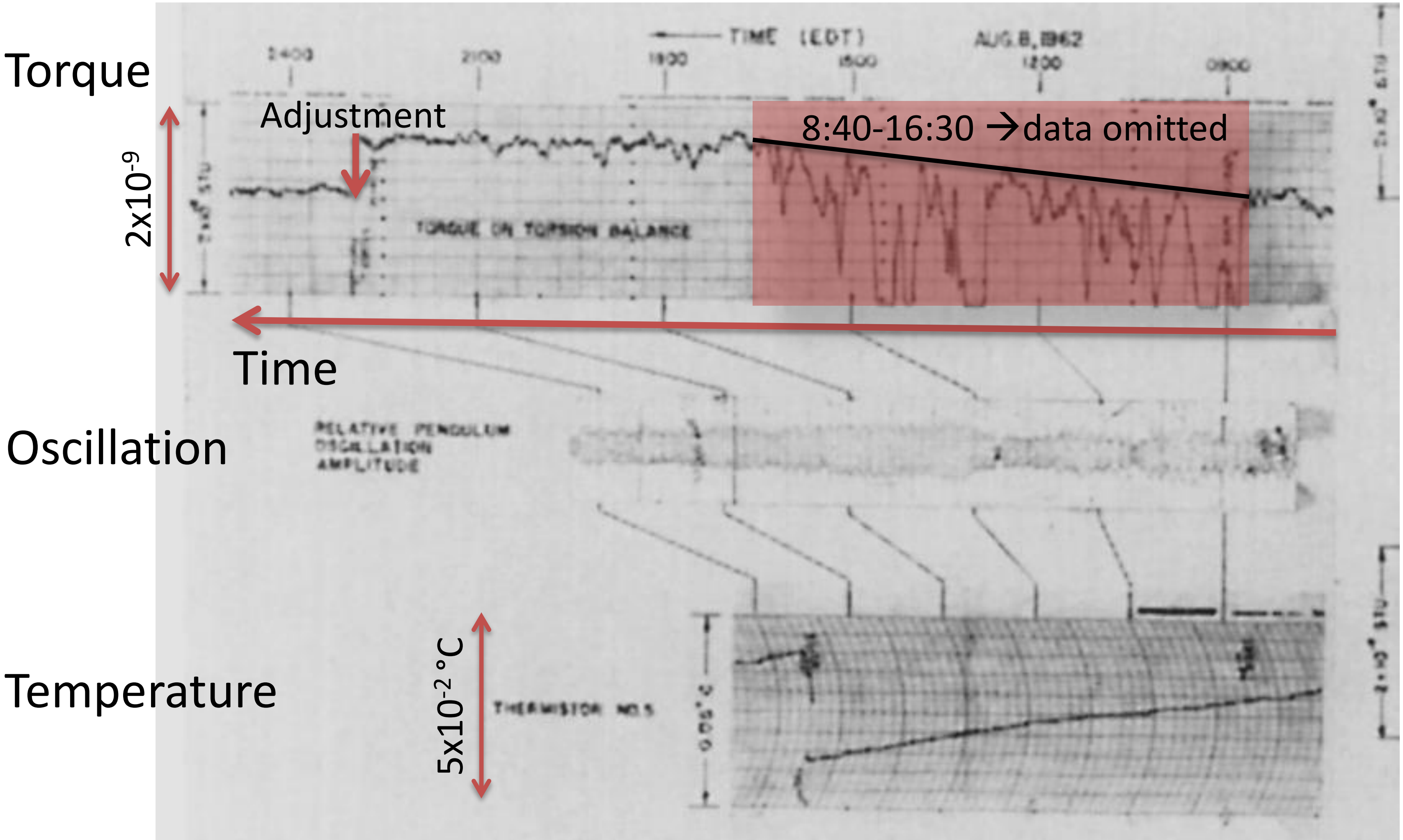
- Relaxation of strains in the torsion fiber?
- linear drift
- Drift compensator
- 2.5 to 7.5 mV per day
  - (5mV → 10x10^{-9} STU)
  - 4x expected diff



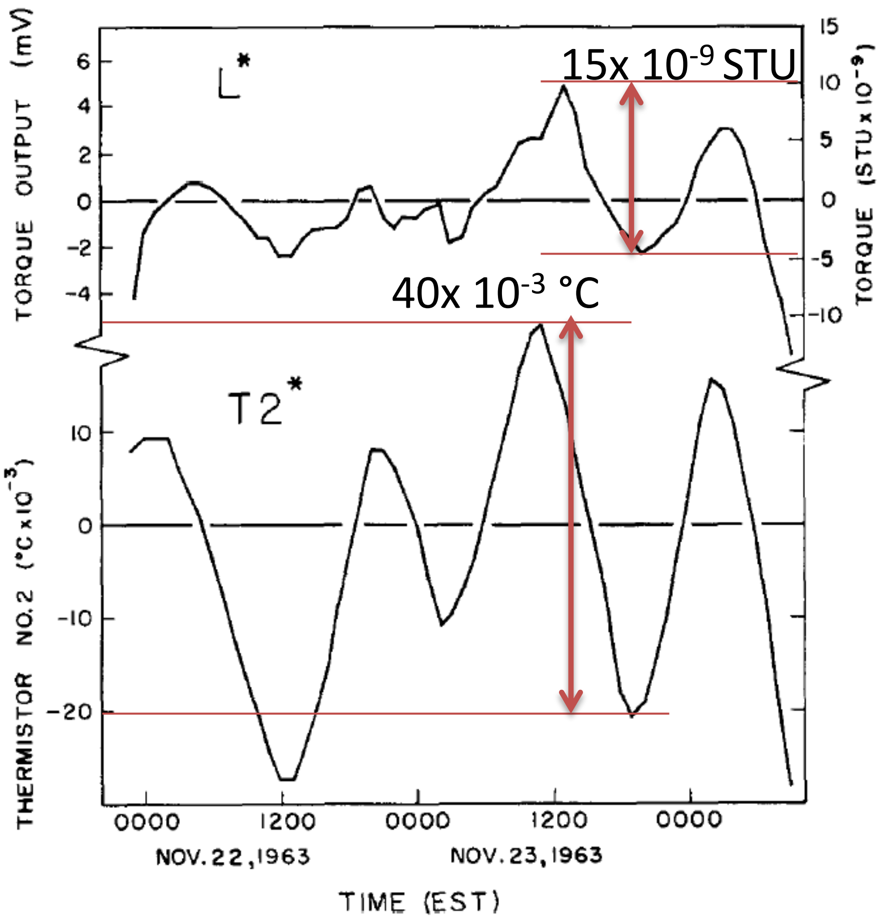
Comments of Eöt-Wash group: Problems with Dicke & Braginski

- The 24 hour signal period
- Most noise sources increase as the frequency decreases
  - 1/f for fibre damping
  - $1/f^2$ for several other sources
- Furthermore many possible systematic effects have a 24 h period
  - Temperature
  - Vibration
  - power fluctuations
  - etc.

Vibration - „typical run on a week day."



Torsion balance and teperature



Temperature coefficient

B(T2) $3{,}7 \times 10^{-10}$ [STU/10^{-3} °C]

B(T2) (stu/10^{-3} °C)[a]

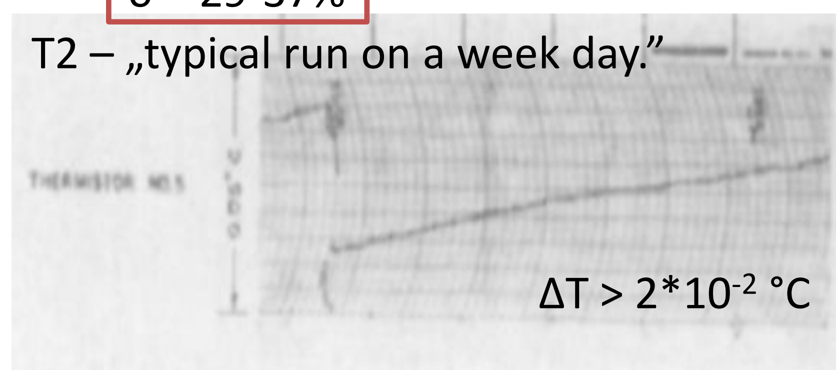
7.1×10^{-11}
5.6×10^{-11}
6.3×10^{-11}
4.5×10^{-11}

→ Reference runs (first three values)

→ Mean from normal runs (last value)

δ ~ 29-37%

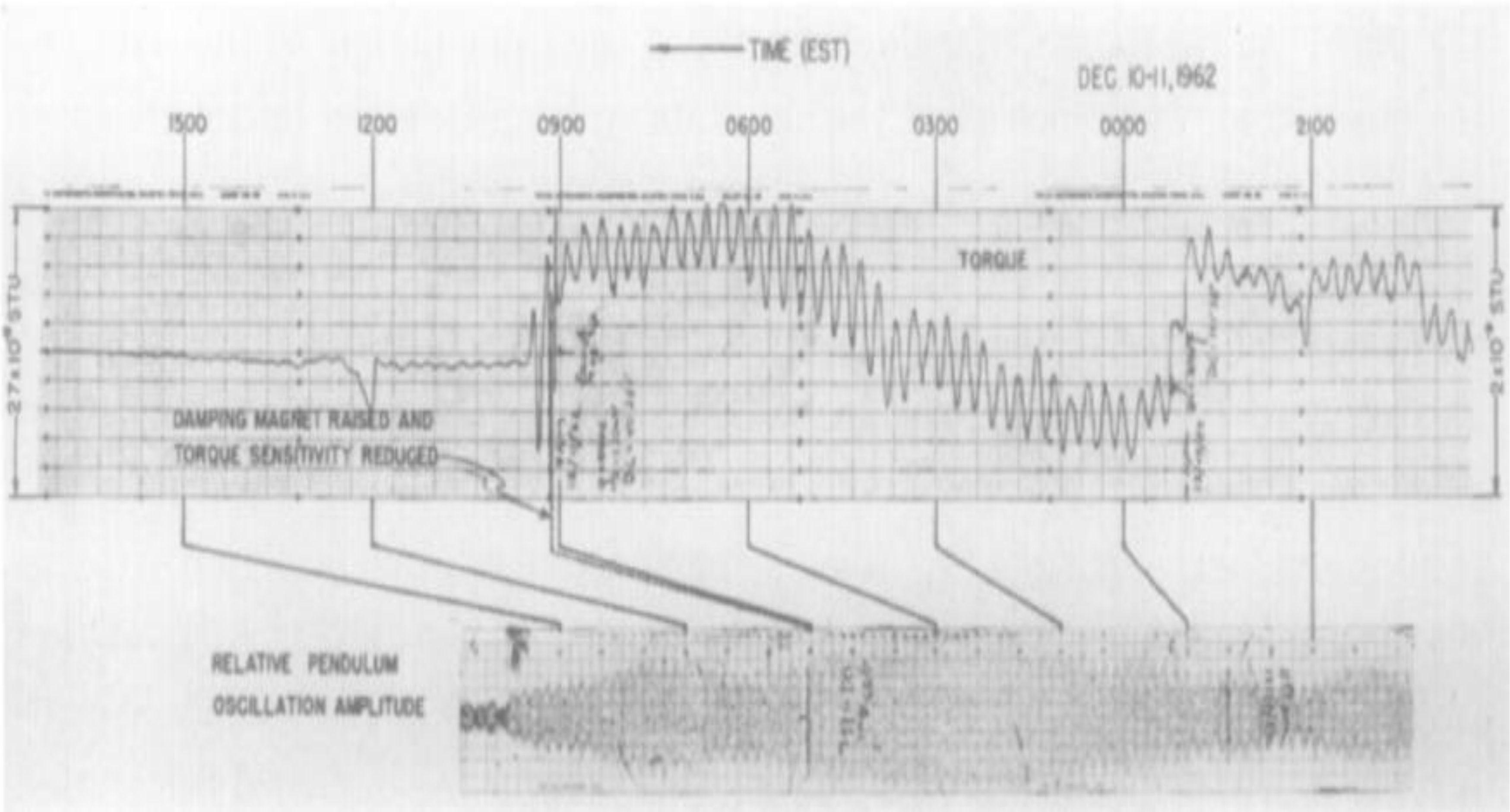
T2 – „typical run on a week day.”



B(T2)*ΔT ~ 7x 10^{-9} STU

ε ≈ δ *B(T2)*ΔT ~ 2.5x 10^{-9} STU

Measurement example



Summary

- Expected difference 2.6×10^{-9}
- Measured signal 1.6%, error 0.5×10^{-2} → s/n 10^{-4}
- Turn detection: 10^{-5} rad → 3×10^{-9} rad
- Needed feedback linearity: 10^{-4}
- Continuous 10^{-8} STU/day drift and manual jumps + omitted data between 8:40-16:30
- Temperature coefficient error ~2.5×10^{-9} (?)

- Other measurements? (Braginski, Eöt-Wash, LLR)
- New measurements?

Questions & Comments

Eöt- Wash

Figure 3. [Colour online] Torsion pendulum used in the recent Eöt-Wash WEP test. An Al frame holds 4 mirrors and supports 8 barrel-shaped test bodies, 4 of which are Be and 4 are Ti or Al. The structure underneath the pendulum allows the pendulum to be parked to prevent damage when the apparatus is serviced and catches the pendulum if a small earthquake should break the suspension fibre. The tungsten fibre is just visible at the top.