Thermal and nonthermal noises in the suspension
(recent results of MSU group)

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The promise (Aug. 1998): LIGO $\overline{\overline{II}}$ $\rightarrow$ $h \simeq 10^{-22}$, $\left(\frac{S}{N} = ? \; \Delta f = ? \; \tau_{AVER} = ?\right)$

The white papers (sept. 1999): LIGO $\overline{\overline{II}}$ $\rightarrow$ $h_f \simeq 7 \times 10^{-24} \frac{1}{\sqrt{Hz}}$

$$h \simeq 7 \times 10^{-23} \text{ for } \overline{f}_{grav} \simeq 10^{+2} Hz, \; \Delta f \simeq 10^{+2} Hz$$

$\uparrow$
Optimistic estimate based on the model of structural damping

?   LIGO $\overline{\overline{III}}$ $\rightarrow$ $h \simeq 10^{-23}$?

HOW SMALL THE DISSIPATION IN THE SUSPENSION HAS TO BE?

PESSIMISTIC model for pendulum mode ($H = const$)

$$F_{grav} = \frac{1}{2} h L \omega_{grav}^2 m \geq \frac{S}{N} \cdot \overbrace{\sqrt{4 k_B T H \frac{1}{\tau}}}^{FDT}$$

$h = 10^{-22}, \; L = 4 \times 10^5 cm$
$\omega_{gr} = 6 \times 10^2 s^{-1}, \; m \simeq 10^4 gram$

$\frac{S}{N} = 5, \; T = 300 k, \; m \simeq 10^{+4} gram$

$\tau = 10^{-2} sec$

$$\boxed{F_{grav} \simeq 8 \times 10^{-8} dyn}$$

$$\boxed{\tau_M^* = \frac{m}{H} \simeq 6 \times 10^{+8} sec \simeq 20 \text{ years}}$$

Quantum „remark"

$$h_{SQL} = \sqrt{\dfrac{2\hbar c}{\dfrac{m}{L^2}}} \simeq 7 \times 10^{-23} \quad \text{FOR } \tau = 5 \cdot 10^{-3} s, \; m = 10^4 \text{gram},$$
$$L = 4 \cdot 10^5 cm$$

TWO PIN TYPE
MEASUR. OF COORDINATE

> STANDARD QL
> NAIVE QL
> STUPID QL

There is no rigorouse formula for Δt

$$h_{SQL} \simeq \sqrt{\dfrac{4\hbar}{L^2 m \omega^2 c}} \simeq 2.5 \times 10^{-23} \quad \text{FOR } \tau\omega \simeq 1, \; \omega = 6 \cdot 10^{+2} \dfrac{rad}{sec}$$

IF $\omega\tau \gg 1$

$$\dfrac{2 R T \tau^2}{\tau_M^*} \Rightarrow \tau_M^* \simeq \dfrac{2 \cdot 4 \cdot 10^{-14} \cdot (5 \cdot 10^{-3})^2}{10^{-27}} \simeq 2 \times 10^9 sec \simeq 60 \, years$$

Brief „history" of MSU efforts ($t \geq 1991$)

INITIAL KNOWLEDGE: $\left(Q_{PURE \atop SiO_2}\right)_{INTRINSIC} \simeq 2 \times 10^{+7}$

I. Torsional mode

SiO_2

30cm

$1.5 \cdot 10^{-2} cm$

$m = 30$ gram
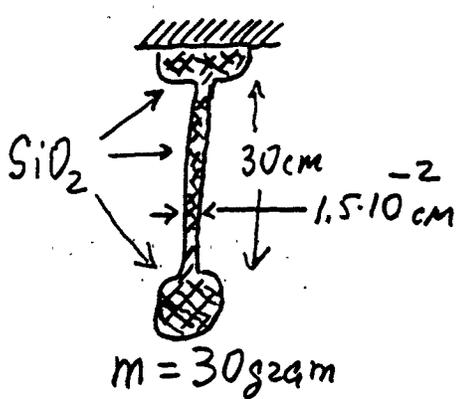
$$\omega_M \simeq 1.1 \dfrac{rad}{sec}$$
$$\tau_M^* \simeq (1.2 \pm 0.1) \times 10^7 sec$$
$$Q_M \simeq 7 \times 10^6$$

FIRST EVIDENCE OF
THE SURFACE LOSSES

II Pendulum mode

$$m = 30\,g \simeq 4\,m$$
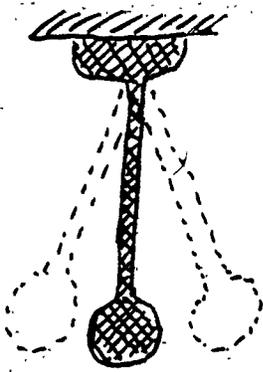
$$\omega_M \simeq 5.5 \;\frac{rad}{sec}$$

$$\tau_M^* \simeq 4.4 \times 10^{+7}\,sec \simeq 1.5\,year$$

$$Q \simeq 1.3 \times 10^{+8}$$

III VIOLIN MODES

WELDED

$\leftarrow 2 \times 10^{-2}\,cm \rightarrow$

SiO_2

SiO_2

$M = 1.6\,kg \simeq 4\,m$
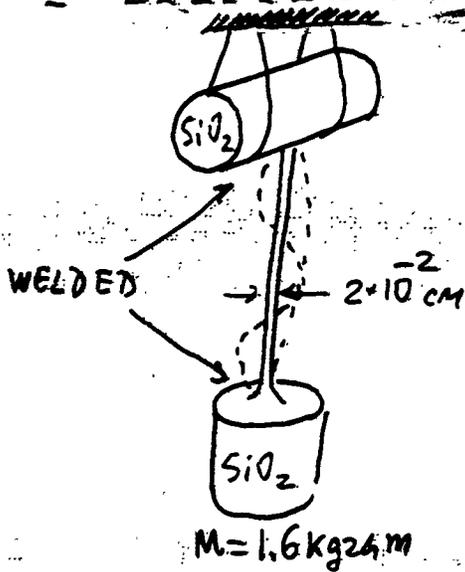
$$Q_{BENDING\ MODES} \simeq 10^6 - 5 \times 10^6$$
$$(NO\ 1.6\,kg\ mass)$$

ANOTHER EVIDENCE OF SURFACE LOSSES

$$\omega_{VIOLIN} \simeq 2\pi \left(1 \times 10^{+3} - 5 \times 10^{+3} \right) \frac{rad}{sec}$$

$$\underbrace{Q_{VIOLIN} \simeq 1 \times 10^{+7} - 1 \times 10^{+8}}$$

sufficient to reach
$$h < 10^{-22}$$

IV TORSIONAL-PENDULUM MODE (LOWER FREQUENCY ⟹ LOWER RECOIL LOSSES)

20 cm

25 cm

40 cm

PLATFORM OF VACUUM CHAMBER
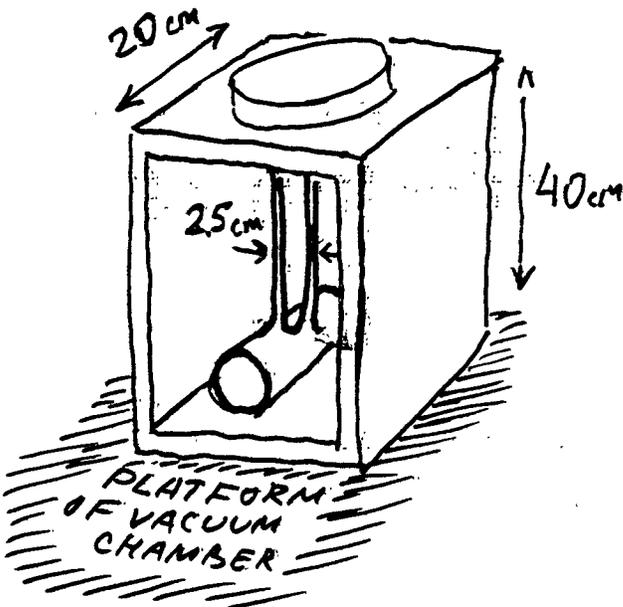
$$M = 2\,kg$$

$$\omega_M \simeq 2 \;\frac{rad}{sec}$$

$$\tau_M^* \simeq 1 \times 10^{+8} \pm 10\% \simeq 3\,YEARS$$

$$Q_{T-P} \simeq 1 \times 10^{+8}$$

$$Q_{expected} \simeq 10^{+9}$$
(SEE BELOW)

V TORSIOLAL-PENDULUM MODE (SECOND ATEMPT)

1) LOWER RECOIL LOSES
2) BETTER VACUUM
3) ENFORSED VENTILATION VIA DUST ABSORBER (1-2 orders less dust ?)

4) SHORTER TIME BETWEEN THE MANUFACTERING OF THE
   FIBER AND THE INSTALLATION INTO THE CHAMBER

5) BACKING (100° - 120°C).
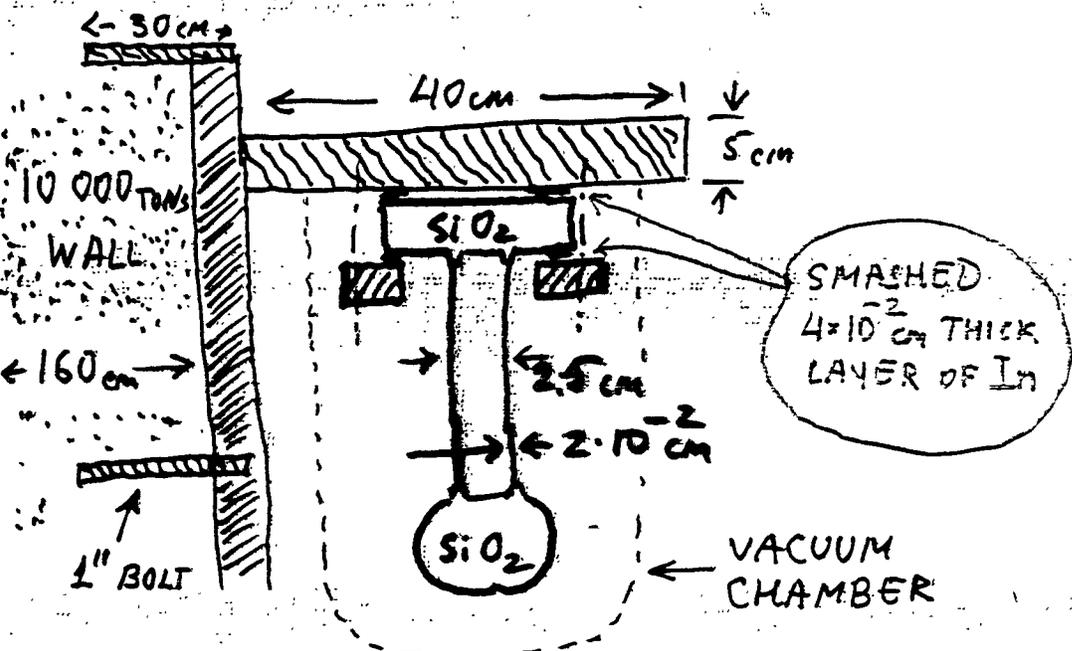
THE RESULTS!

$m = 2$ kg (ETHED PINS)

$\omega_M = 2\pi \times 0.34 \frac{rad}{sec}$

$\tau^*_{T-P} \simeq 1.86 \times 10^{+8} sec \simeq 6 \text{YEAR}$

$Q_{T-P} \simeq 2 \times 10^{+8}$

$m \simeq 0.5$ kg (J. HOUGH ET AL BONDED PINS)

$\omega_M \simeq 2\pi \times 1.17 \frac{rad}{sec}$

$\tau^*_{T-P} \simeq 6.3 \times 10^{+7} sec \simeq 2 \text{YEARS}$

$Q_{T-P} \simeq 2.3 \times 10^{+8}$

Linear, Y=B*X+A
Equation:
Y = 1.91984E-006 * X + 0.0987719
Number of data points used = 321
Average X = 73.4504
Average Y = 0.0989128
Regression sum of squares = 7.63418E-007
Residual sum of squares = 3.70422E-009
Coef of determination, R-squared = 0.995171
Residual mean square, sigma-hat-sq'd = 1.1612E-01

y-axis: time interval, sec

x-axis: time, hour
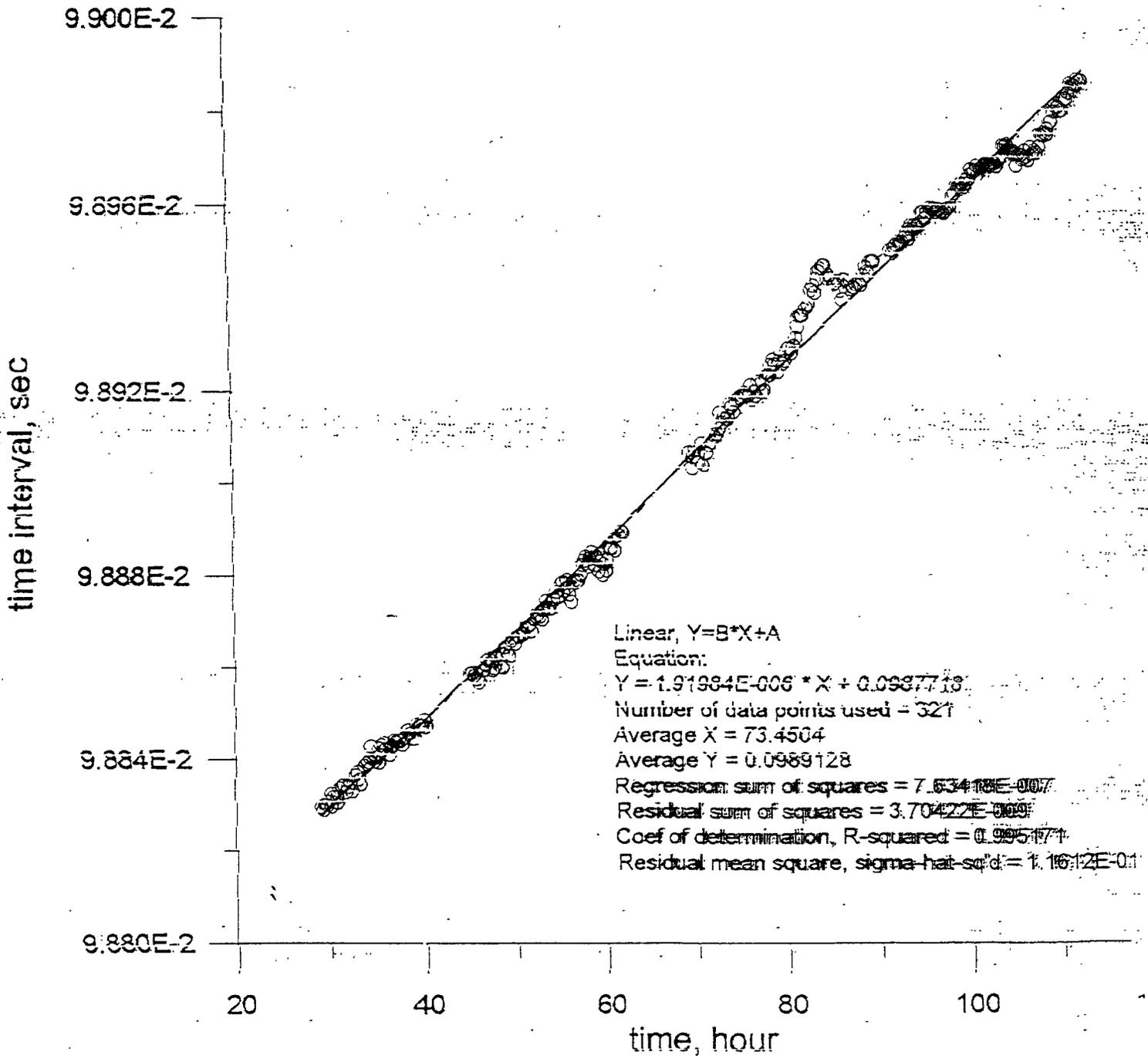
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$\tau_M^* \simeq 1.86 \times 10^{+8}$ sec $\simeq 6$ years, $Q_M \simeq 2 \times 10^{+8}$, MARCH 2nd, 1997

$$\tau^* = \frac{9.9 \cdot 10^{-2}}{1.92 \cdot 10^{-6}} \cdot 3600 = 1.86 \cdot 10^{8}$$

−5−

21. MAY, 1999

V. P. MITROFANOV, K. V. TOKMAKOV

$$\tau_M^* = 6.3 \times 10^7 \text{ sec}, \quad Q_M \simeq 2.3 \times 10^8$$

(JIM HOUGH GLUED SUSPENSION)

Y = 1.32258E-006 * X + 0.0228795
Number of data points used = 896
Average Y = 0.0229833
Coef of determination, R-squared = 0.994092

временной интервал, сек

время, часы
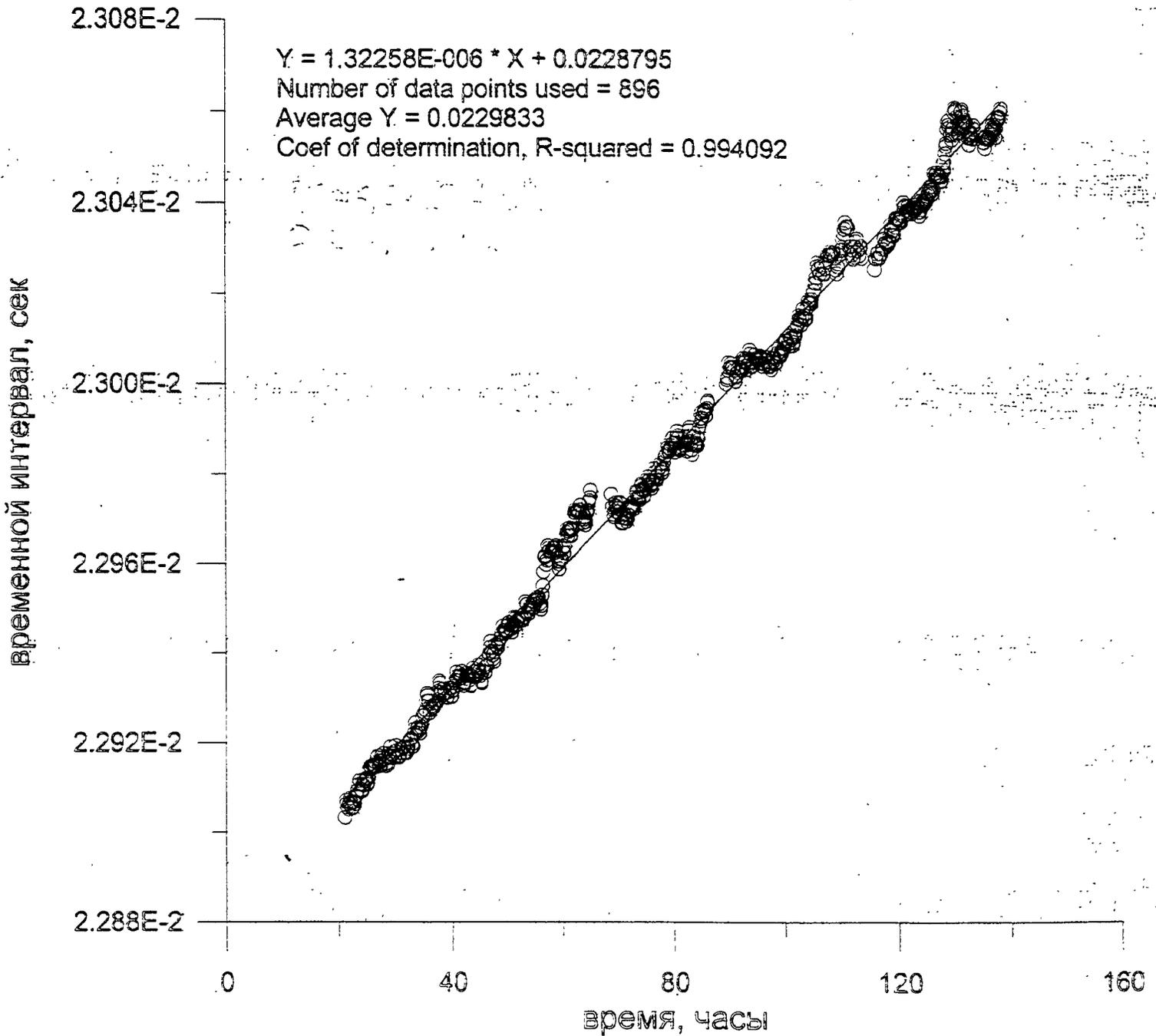
The comparison with the "theory"

$$Q_{T-P}^{-1} \simeq \frac{\pi G \tau^4}{m g a^2} \phi_G + \frac{1}{\ell}\sqrt{\frac{\pi Y \tau^4}{2 m g}} \phi_Y$$

$$G = 3 \times 10^{11} \frac{dyn}{cm^2}$$
$$Y = 7 \times 10^{11} \frac{dyn}{cm^2}$$
$$m = 2 \times 10^{+3} gram$$

$$a = 2.5 \, cm$$
$$\tau = 1 \times 10^{-2} cm$$
$$\ell = 25 \, cm$$

$$+ \quad \phi_G = \phi_Y = 1.4 \cdot 10^{-7}$$
FROM EXPIMENT (ER)

$$(Q_{T-P}) \simeq 2 \times 10^{+9}$$
EXPECTED

POSSIBLE EXPLANATIONS $[(Q_{T-P})_{MEASUR} \simeq 2 \times 10^{+8}]$

1. Nonperfect isolation (recoil losses), In?

2. Nonsufficient backing (mud on surface: $H_2O + SiO_2$)

3 Additional losses on the pins (rough surface + sedimentation)

4 Dust particles (16 particles detected by a torch in "postmortal" examination of the fiber)

THE RESERVES (SEE THE FORMULA ABOVE)

1. $\frac{G_F}{Y} = 4 \times 10^{-3}$ IN THE MEASURMENTS, BUT "VIRGIN" FIBERS ACCEPT $G_F/Y \simeq (2-3) \times 10^{-2}$! (O.A. Okhrimenko)

2. $\tau^4 \to a b^3$ (ribbon) $\to$ may give factor 3-6 for Q

3. $\ell = 25 \, cm \Rightarrow \ell = 250 \, cm.$

$\Rightarrow \quad Q \simeq 10^{10}$ IS NOT A CRAZY NUMBER (IF ONE HAS ENOUGH MONEY AND PATIENCE)

STRATEGIC RESERVE : THE SUBSTRACTION OF BROWNIAN MOTION: "HOW TO REDUCE THE SUSPENSION THERMAL NOISE WHITHOUT IMPROVING THE Q's IN THE PENDULUM AND VIOLIN MODES": 2 orders (GR-QC/9805031)

The problem of the nonthermal noise (excess noise)
(FDT is a big illusion)

An assumption:

Probably (?) the main source of nonthermal noise is very stressed wire (fiber) in the suspension.

The results:

1) The tungsten wires are very noisy (strong excess noise above the thermal one) even when $\frac{\sigma_{Appl}}{\sigma_{Break}} \simeq 0.3$

(Phys. Lett. A 227 (1997), 159)

2) The steel wires are (5-8) times less noisy then the tungsten ones, but if $\frac{\sigma_{appl}}{\sigma_{Break}} \simeq 0.3$ this noise may mimic $h \simeq 5 \cdot 10^{-21}$

$$\sqrt{\Delta X^2_{THERM}} \simeq 2 \cdot 10^{-10} \, cm, \quad \Delta X_{METER} \simeq 2 \times 10^{-11} \frac{cm}{\sqrt{Hz}}$$

(Phys. Lett. A 246, (1998), 479)

NOISE IN SiO_2 FIBERS?

The goal is $\Delta X_{meter} \simeq 10^{-13} \frac{cm}{\sqrt{Hz}}$ and do not damage the VIRGINITY of the SiO_2 fiber ($t \simeq 1999, 2000$)
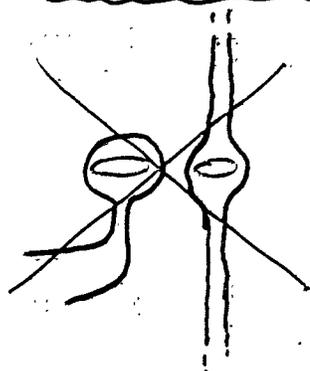
THIS VERSION OF
METER FAILED

new version of meter is in process of assembling.
If our calculations are correct then $\Delta X \simeq 1 \times 10^{-15} \frac{cm}{\sqrt{Hz}}$ and the VIRGINITY will not be damaged