Thermal and nonthermal noises in the suspension

(recent results of MSU group)

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

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

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

↑ optimistic estimate based on the model of structural damping

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

HOW SMALL THE DISSIPATION IN THE SUSPENSION HAS TO BE?

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

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

$h=10^{-22}$, $L=4\times 10^5$ cm

$\omega_{gr}=6\times 10^2\ s^{-1}$, $m=10^{+4}_{gramm}$

$\frac{S}{N}=5$, $T=300$ K, $m \simeq 10^{+4}_{gramm}$

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

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

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

Quantum „remark"

$$h_{SQL} = \underbrace{\sqrt{\frac{2\hbar\tau}{m}\frac{1}{L^2}}}_{\text{TWO PIN TYPE MEASUR. OF COORDINATE}} \simeq 7\times10^{-23} \quad \text{FOR } \tau = 5\cdot10^{-3}\,s,\ m = 10^{4}\,g,\ L = 4\cdot10^{5}\,cm$$

STANDARD QL
NAIVE QL
STUPID QL

„There is no rigorous formula for Δ_t"

$$h_{SQL} \simeq \sqrt{\frac{4\hbar}{L^2 m\omega^2\tau}} \simeq 2.5\times10^{-23} \quad \text{FOR } \tau\omega = 1,\ \omega = 6\cdot10^{+2}\ \frac{rad}{sec}$$

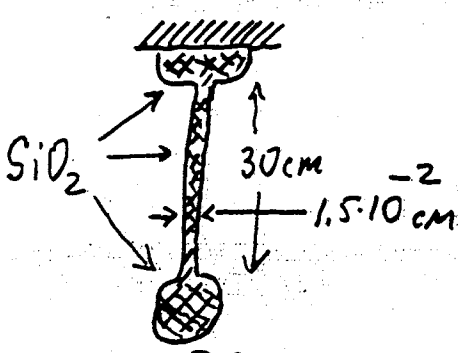
IF $\omega\tau \gg 1$

$$\frac{2kT\tau^2}{\tau_M^*} \Rightarrow \tau_M^* \simeq \frac{2\cdot4\cdot10^{-14}\cdot(5\cdot10^{-3})^2}{10^{-27}} \simeq 2\times10^{9}\,sec \simeq 60\ years$$

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

INITIAL KNOWLEDGE: $\left(Q_{\substack{PURE\\ SiO_2}}\right)_{INTRINSIC} \simeq 2\cdot10^{+7}$

I. Torsional mode



$$\omega_M \simeq 1.1\ \frac{rad}{sec}$$

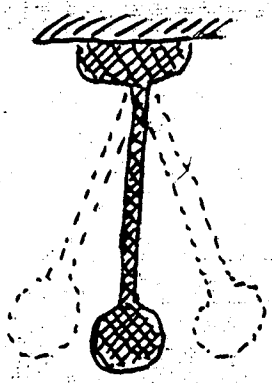
$$\tau_M^* \simeq (1.2 \pm 0.1)\times10^{7}\,sec$$

$$Q_M \simeq 7\times10^{6}$$

FIRST EVIDENCE OF THE SURFACE LOSSES

JETP LETT. v.55 (1992) 432

II Pendulum mode



$m = 30\,g\,24\,m$

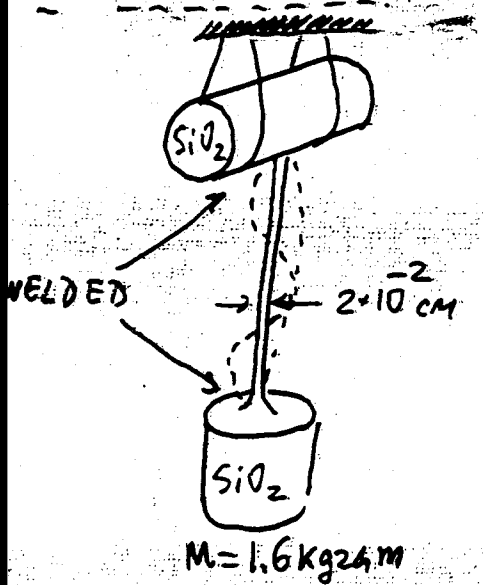
$\omega_M \simeq 5{,}5 \frac{2\,ad}{sec}$

$\tau^*_M \simeq 4.4 \times 10^{+7}\,sec \simeq 1.5\,y\,e\,a\,z$

$Q \simeq 1{,}3 \times 10^{+8}$

PHYS. LETT. A v. 175 (1993), 82

III VIOLIN MODES



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

ANOTHER EVIDENCE OF SURFACE LOSSES

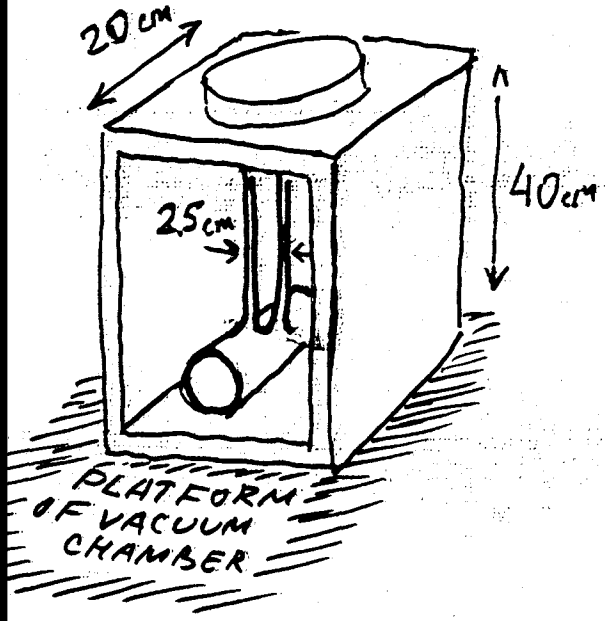
$\omega_{VIOLIN} \simeq 2\pi \left(1 \times 10^{+3} - 5 \times 10^{+3}\right) \frac{2\,ad}{sec}$

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

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

PHYSICS DOKLADY v. 345 (1995) 324

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



$m = 2\,kg$

$\omega_M \simeq 2 \frac{2\,ad}{sec}$

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

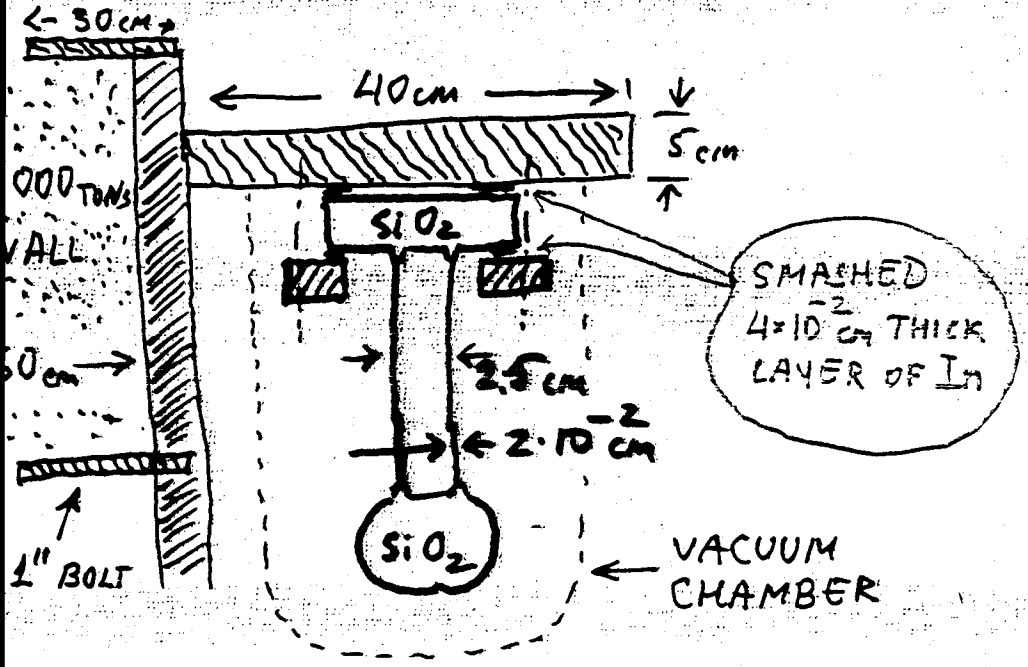
$Q_{T\text{-}P} \simeq 1 \times 10^{+8}$

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

PHYS. LETT. A v 218 (1996), 164.

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) BAKING (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 YEAR

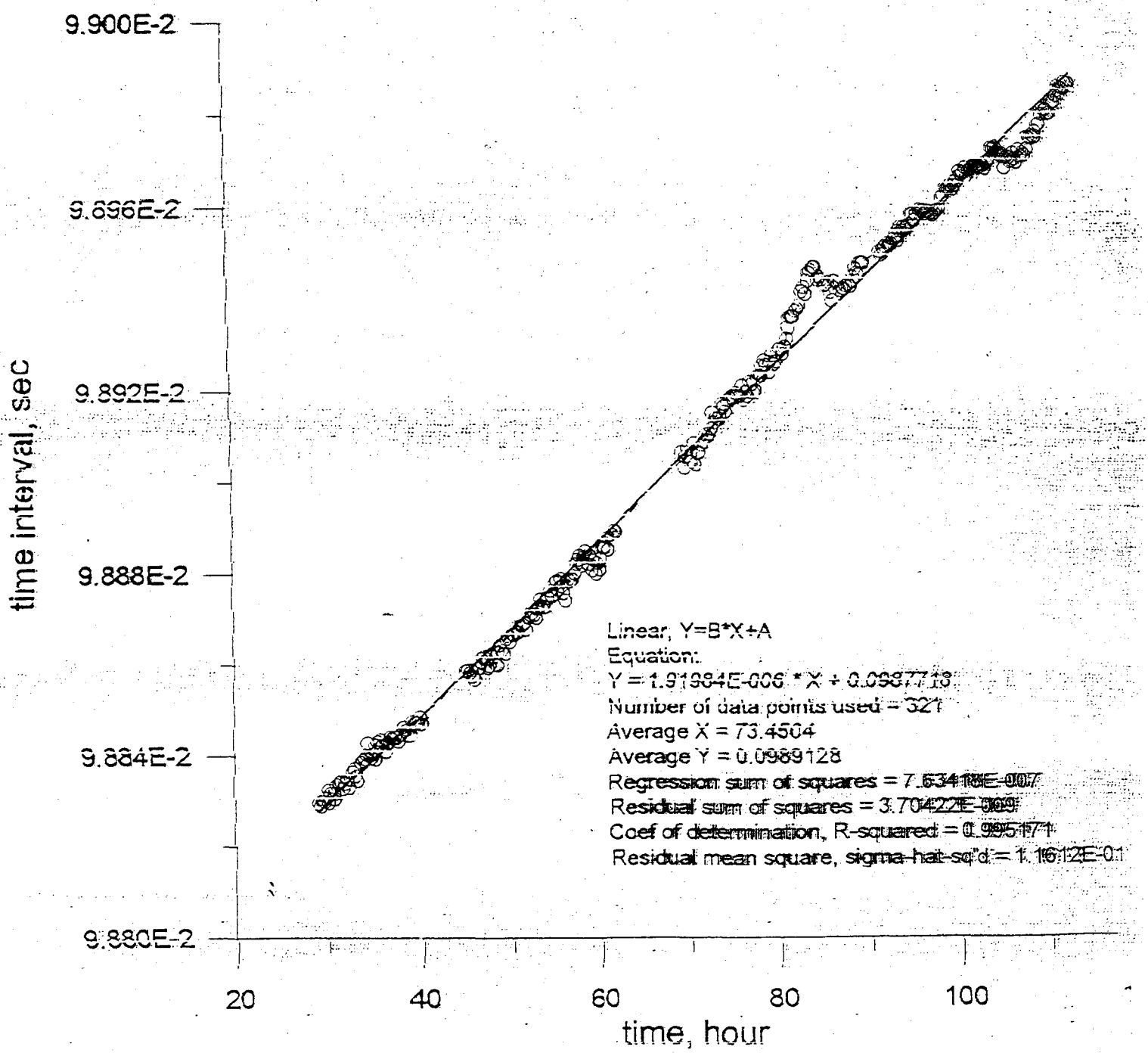
$Q_{T-P} \simeq 2 \times 10^{+8}$

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

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

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

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



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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, 1998

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

21. MAY, 1999

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$\tau^*_M = 6.3 \times 10^7$ sec, $Q_M \simeq 2.3 \times 10^8$

(JIM HOUGH GLUED SUSPENSION)