Сагитовские чтения, 4-5 февраля 2008

Подготовка нового эксперимента по определению Ньютоновской гравитационной постоянной

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Difficulties in determining G

- Extreme weakness of gravitation
- Gravitational effect can not be screened out
- Independent of other fundamental constants
- Absolute measurements increase the difficulties

For two protons, $\dfrac{\text{Gravitational force}}{\text{Electrostatic force}} \approx \dfrac{1}{10^{38}}$

Progress on experimental determination of G

1798, H. Cavendish:

$G=(6.67 \pm 0.07)\times10^{-11}\ m^3kg^{-1}s^{-2}$

First G value!

Uncertainty ~ 10000 ppm

2007, CODATA value:

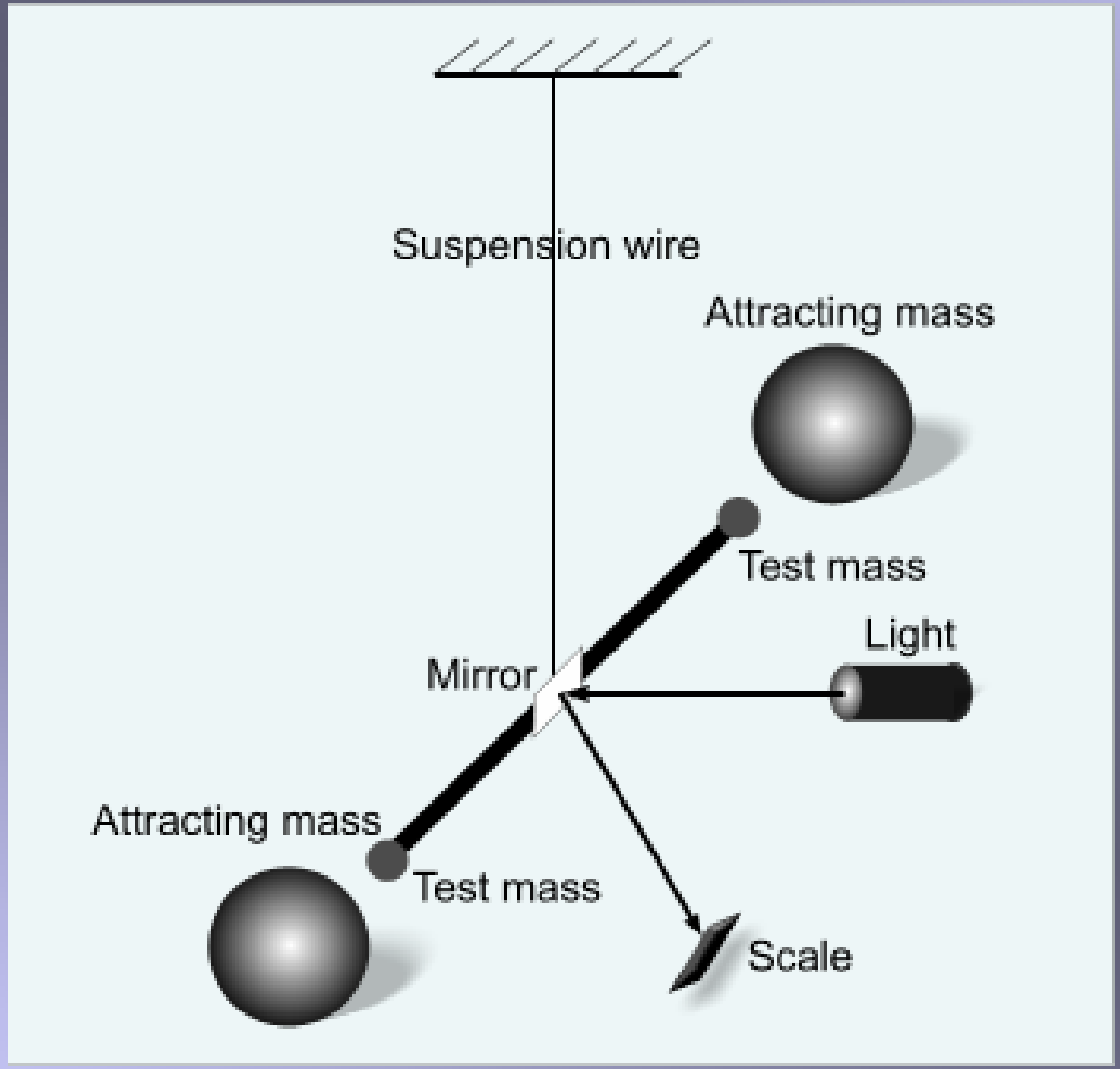
$G=(6.67428 \pm 0.00067)\times10^{-11}\ m^3kg^{-1}s^{-2}$

Uncertainty ~ 100 ppm

Величина ошибки уменьшалась примерно в 10 раз за столетие!

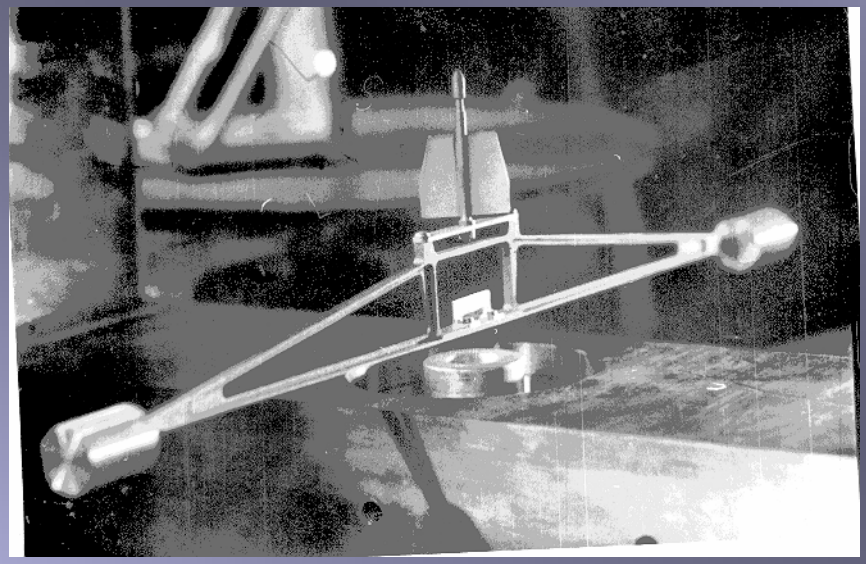
Это очень медленно!

Principle of Cavendish type experiment



The torsion balances and time of swing method

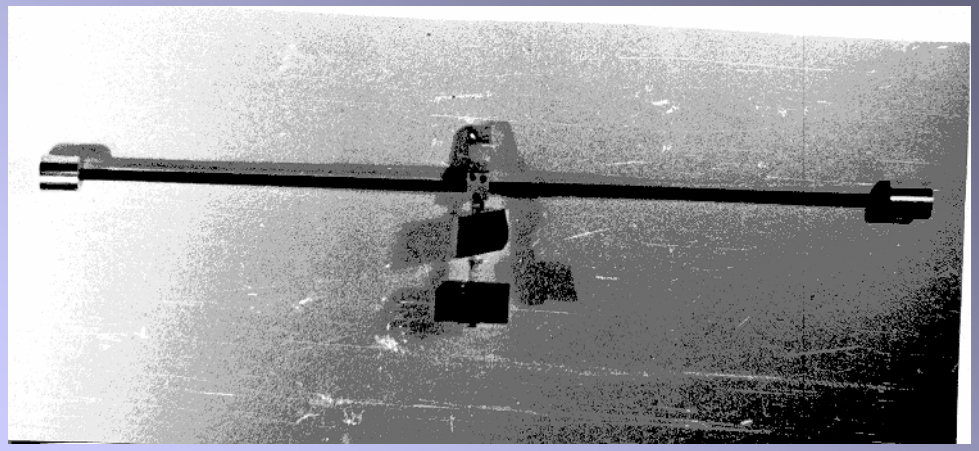
No 1

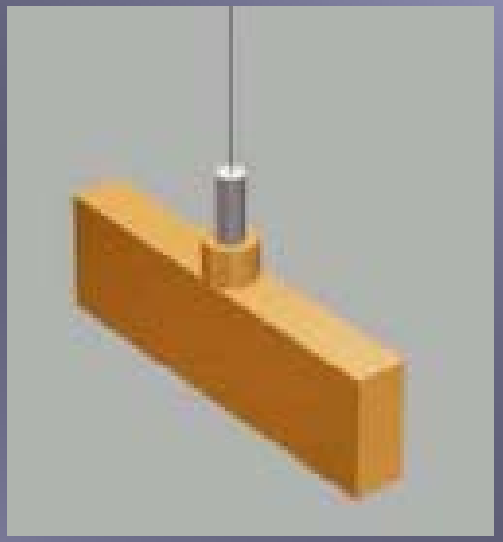


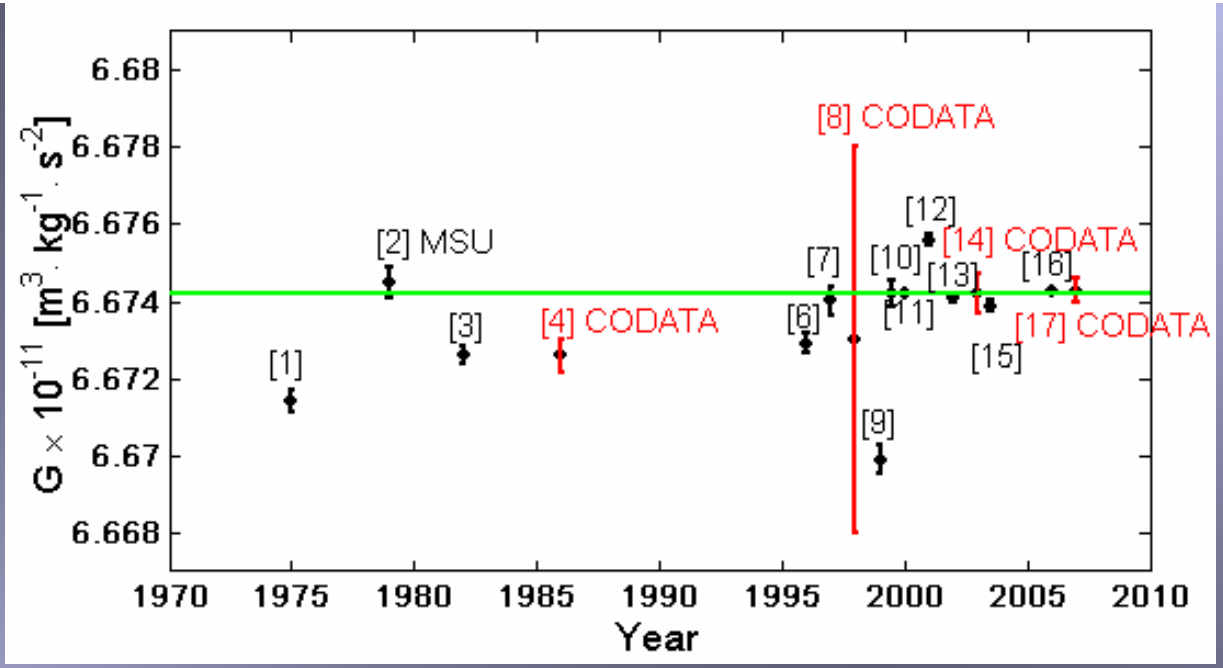
$$\omega^2 = \frac{D + G(\partial\Gamma/\partial\varphi)}{J}$$

$$G = \frac{J\left[(\omega^2)_1 - (\omega^2)_2\right]}{(\partial\Gamma/\partial\varphi)_1 - (\partial\Gamma/\partial\varphi)_2}$$

No 2





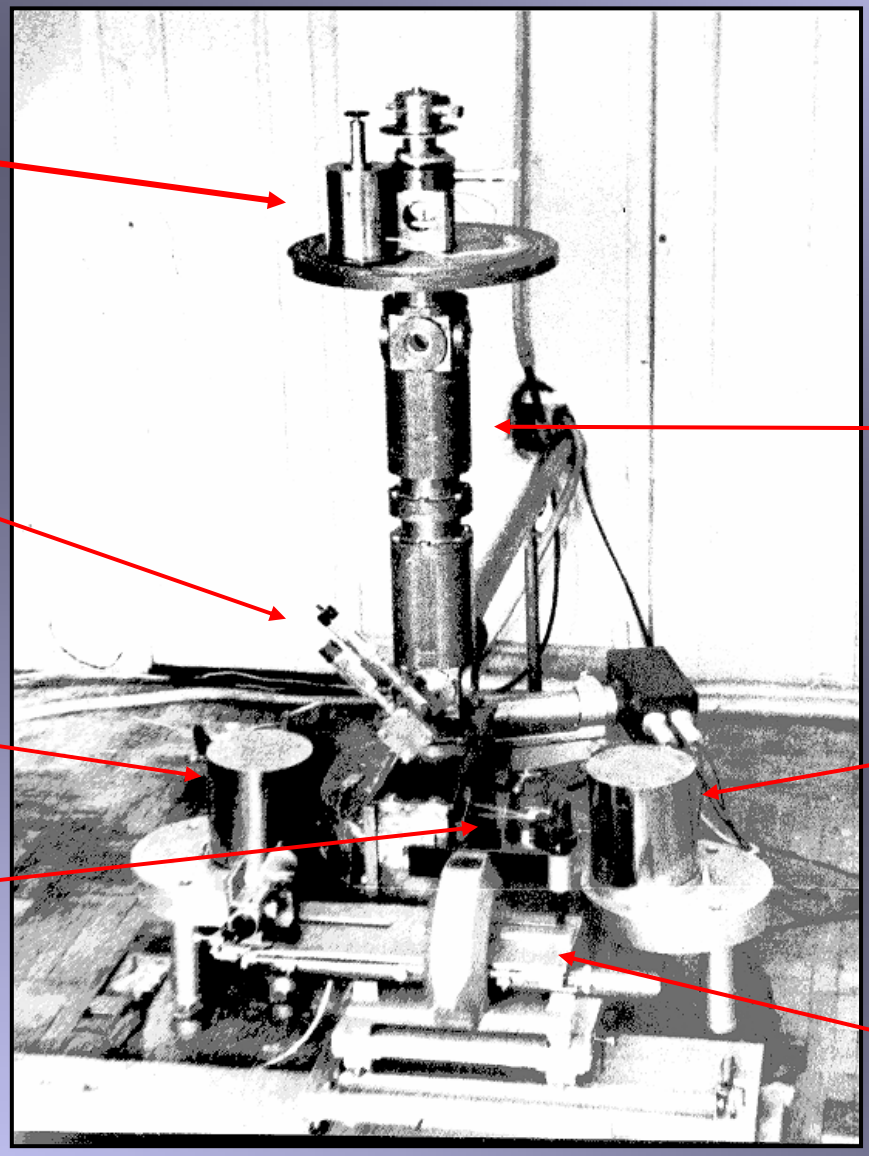


Authors, year of publication		Value of $G \times 10^{-11}$ $м^3 kg^{-1} s^{-2}$	STD $\times 10^{-11}$ $m^3 kg^{-1} s^{-}$	ppm
[1] *Facy and Ponticis*	1972	6.6714	0.0006	90
[2] *Sagitov, Milyukov, et al.*	1979	6.6745	0.0008	120
[3] *Luther and Towler,*	1982	6.6726	0.0005	75
[4] CODATA	**1986**	**6.67259**	**0.00085**	**128**
[5] *Michaelis, et al.*	1995	6.7154	0.0006	90
[6] *Karagioz, Izmailov,*	1996	6.6729	0.0005	75
[7] *Bagley and Luther,*	1997	6.6740	0.0007	105
[8] CODATA	**1998**	**6.673**	**0.010**	**1500**
[9] *Jun Luo, et al.,*	1999	6.6699	0.0007	105
[10] *Fitzgerald and Armstrong*	1999	6.6742	0.0007	105
[11] *Gundlach and Merkowich,*	2000	6.674215	0.000092	14
[12] *Quinn, Speake et all.*	2001	6.67559	0.00027	41
[13] *Schlamminger et all.*	2002	6.67407	0.00022	33
[14] CODATA	**2003**	**6.6742**	**0.0010**	**150**
[15] *Armstrong and Fitzgerald*	2003	6.67387	0.00027	40
[16] *Schlamminger et all*	2006	6.67425	0.00010	16
[17] CODATA	**2007**	**6.67428**	**0.00067**	**100**

Наилучшие эксперименты в мире по измерению G и CODATA величины.

Determination of G in SAI MSU (1975-1978)

General view on experimental device



Adjustment of torsion pendulum support

Vacuum pumps

Attractive mass

Torsion balance

Vacuum chamber

Attractive mass

Device for linear measurements

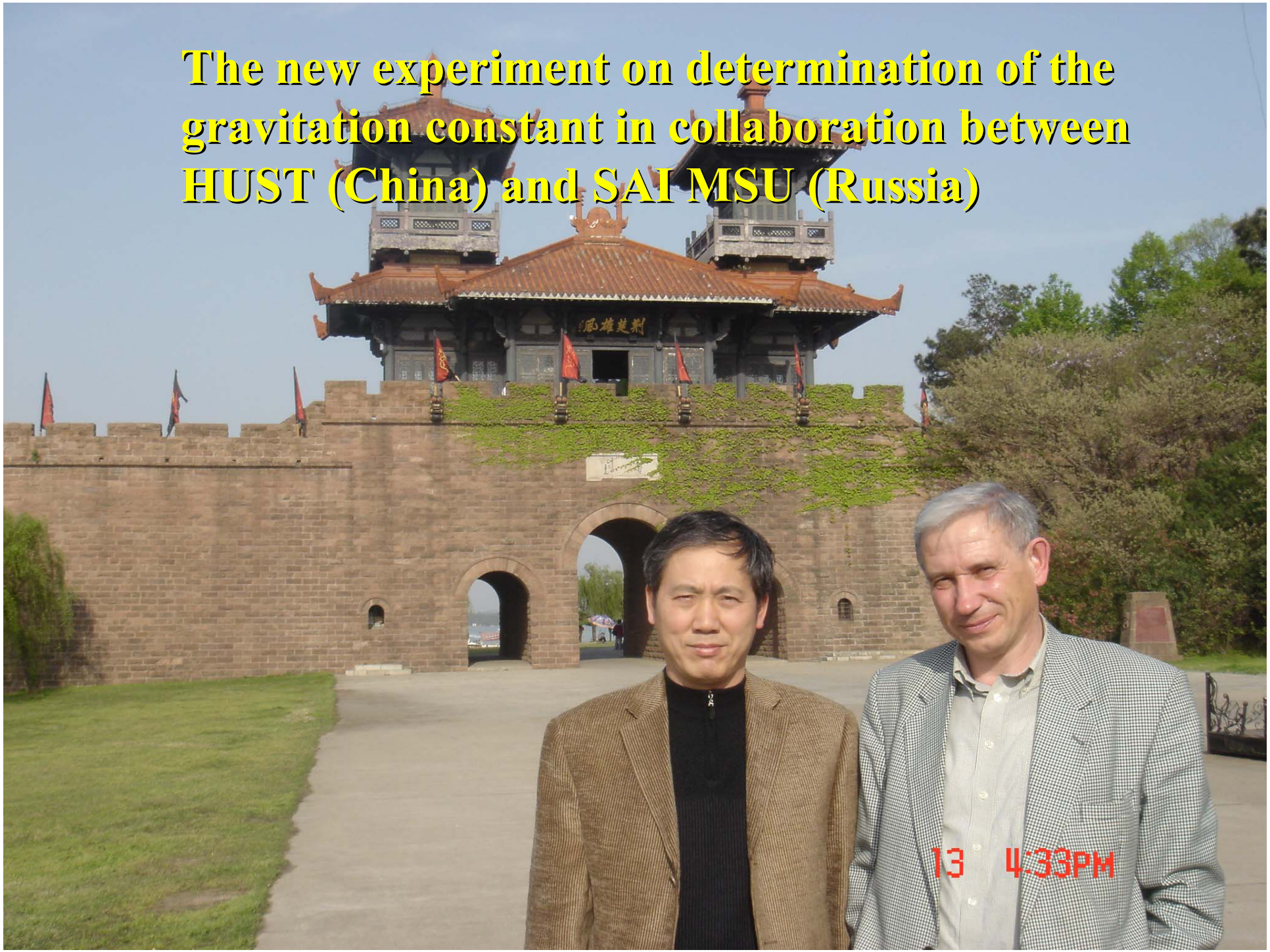
Results on measurement of Gravitational constant in SAI MSU in 1975-1978

Set No / Exp. No	$G \times 10^{-11} m^3 kg^{-1} s^{-2}$			
	I	II	III	IV
1	6.6739	6.6708	6.6686	6.6721
2	6.6741	6.6746	6.6795	6.6749
3	6.6746	6.6730	6.6800	6.6826
4		6.7612	6.6732	6.6719
5		6.6747	6.6755	6.6688
6				6.6779
7				6.6757
8				6.6715
9				6.6799
10				6.6774
Average value	6.6742 ± 0.002	6.6729 ±0.0009	6.6753 ±0.0020	6.6752 ±0.0013

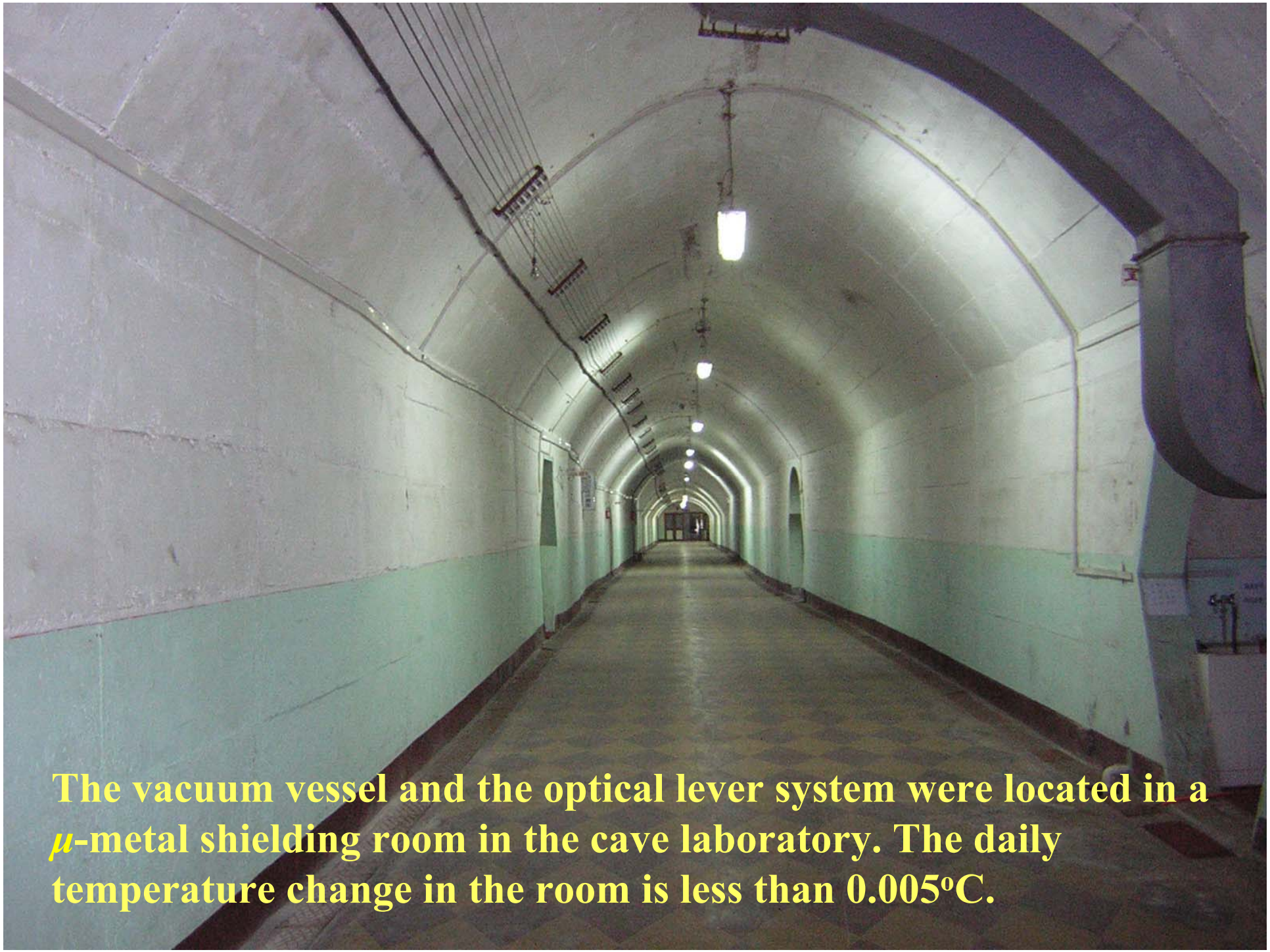
According to STUDENT criterion (t-criterion) all these four sets on the 0.95 confidence level are belong to one statistical ensemble with the average value of

$$G=(6.6745 \pm 0.0008) \times 10^{-11}\ m^3 kg^{-1} s^{-2}$$

The new experiment on determination of the gravitation constant in collaboration between HUST (China) and SAI MSU (Russia)



General view of the experimental setup of Huazhong University of Science and Thechnology



The vacuum vessel and the optical lever system were located in a μ-metal shielding room in the cave laboratory. The daily temperature change in the room is less than 0.005^{o}C.

New experiment design

Merits:

1. the structure is very simple.

2. the instruments are all placed in vacuum.

3. the operation is under remote control.

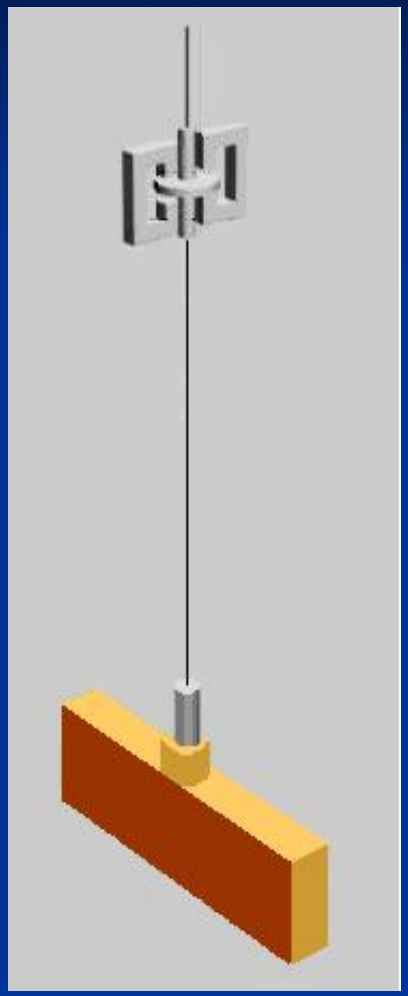
Dismerit:

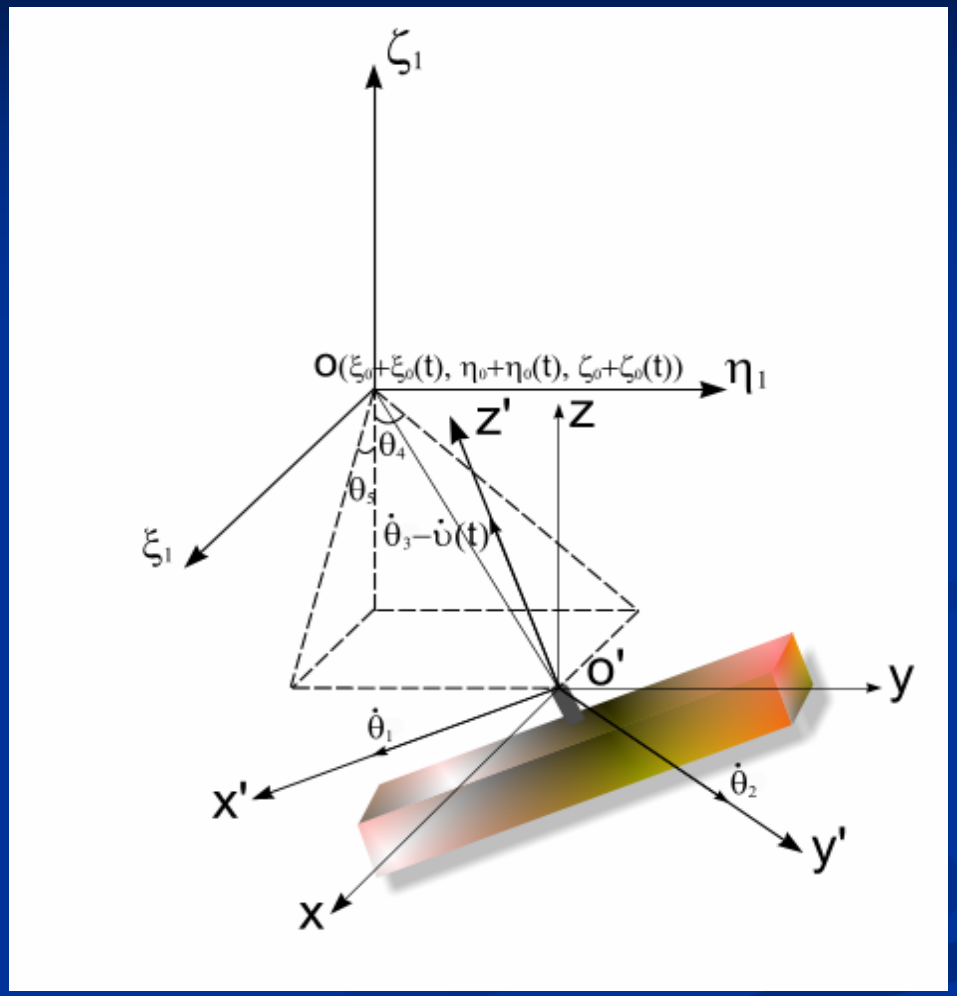
The period (587s) changes only about 0.8%

New experimental process

- Measurement of test mass
- Measurement of source masses
- Alignment of the masses
- Stability of pendulum period

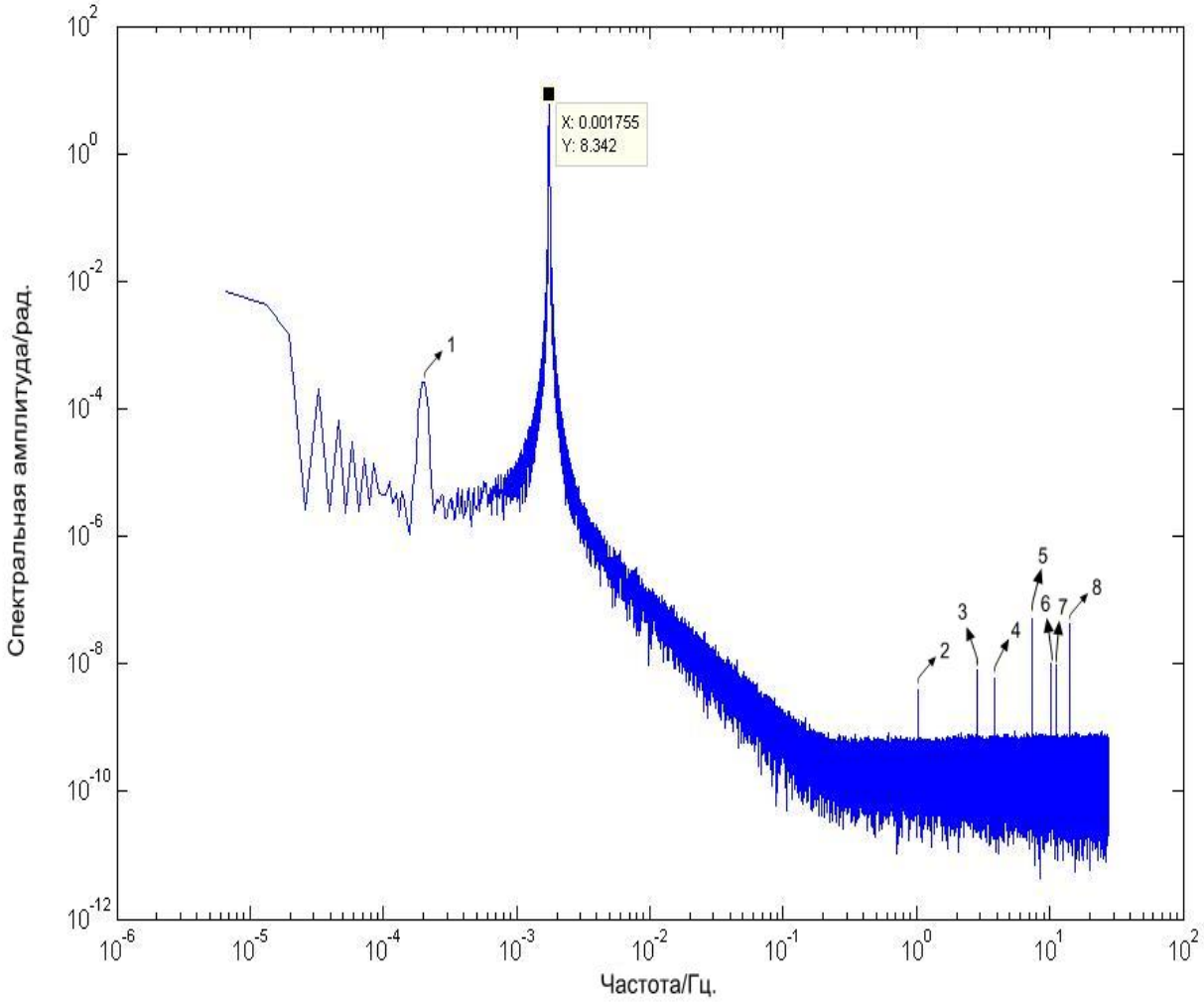
The torsion balance is the system with five degrees of freedom





Co-ordinats Θ_1 and Θ_4 is swing oscillations in the plate ZX,
Co-ordinats Θ_2 and Θ_5 is swing oscillations in the plate ZY.
Θ_3 is the torsion oscillations

Крутильные колебания и комбинационные моды

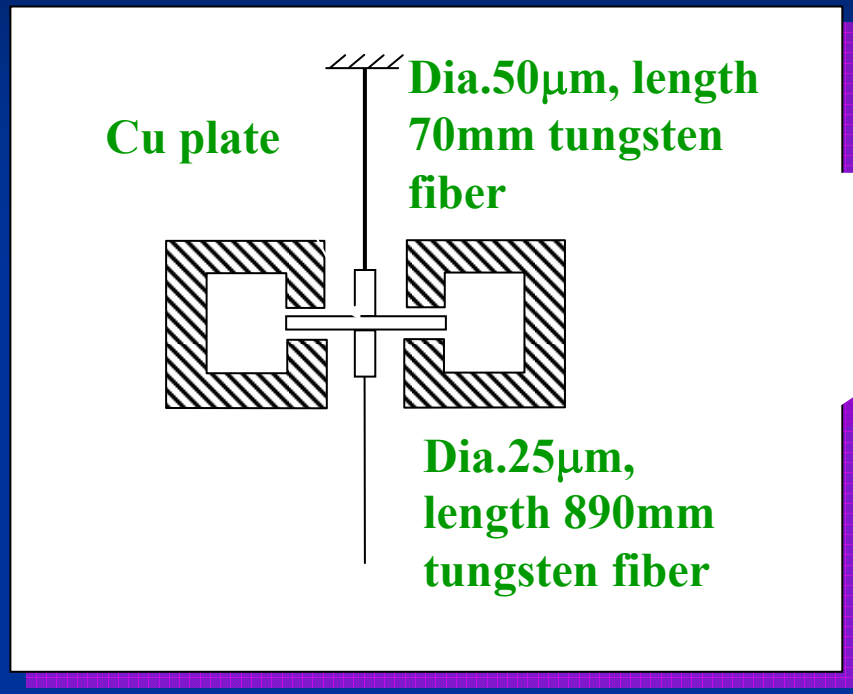


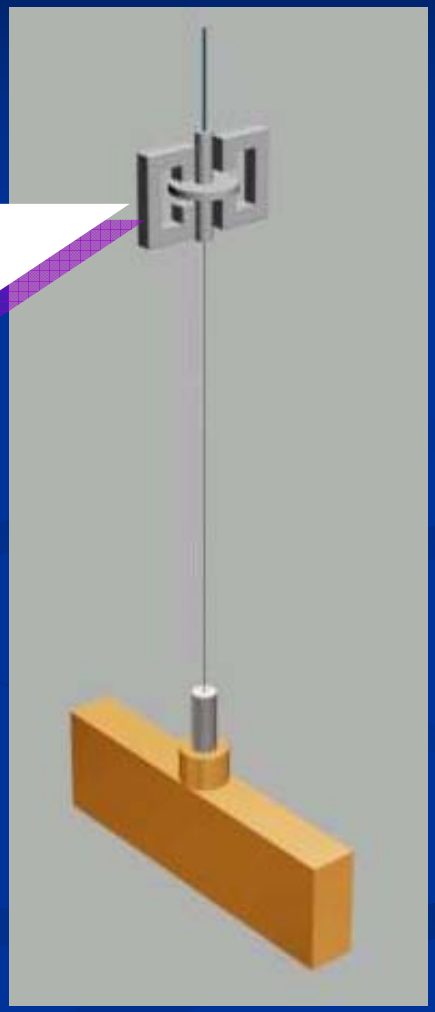
Частоты комбинационных мод определяются линейной комбинацией маятниковых частот.

No.	*Частота, Гц*
1	**0.0002**
2	**1.0372**
3	**2.8562**
4	**3.8936**
5	**7.3401**
6	**10.20**
7	**11.2335**
8	**14.0899**

Suppression of coupling modes

Magnetic damper

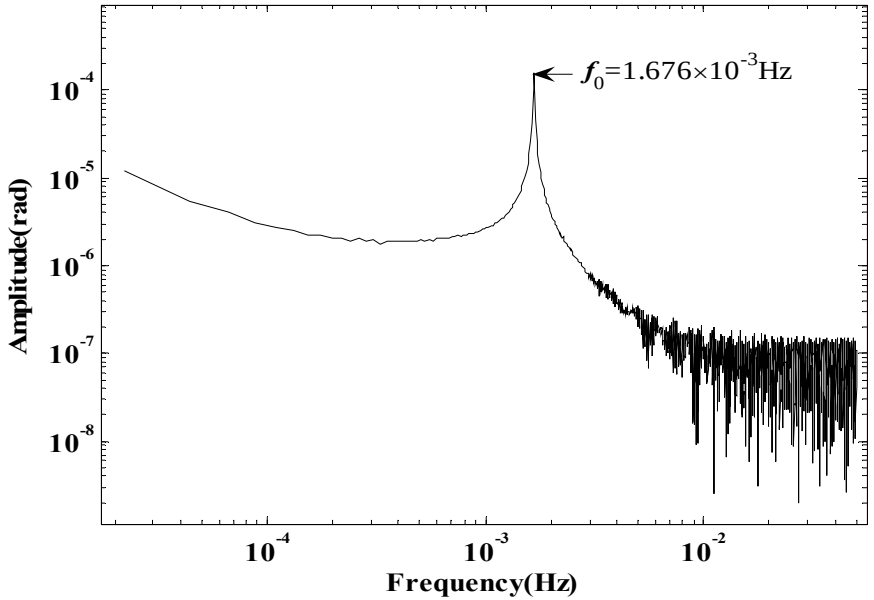


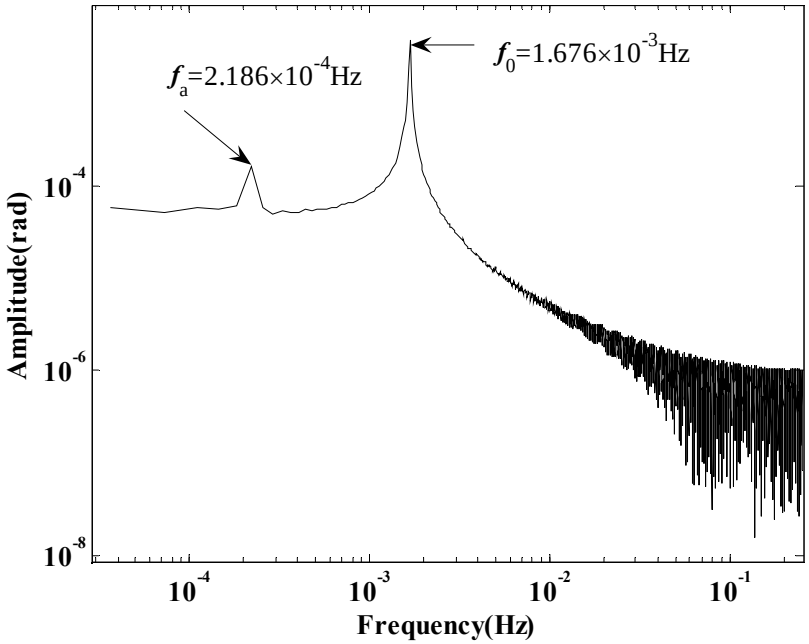


By eddy current loss of Al plate, the swing mode is suppressed effectively

Амплитудное подавление

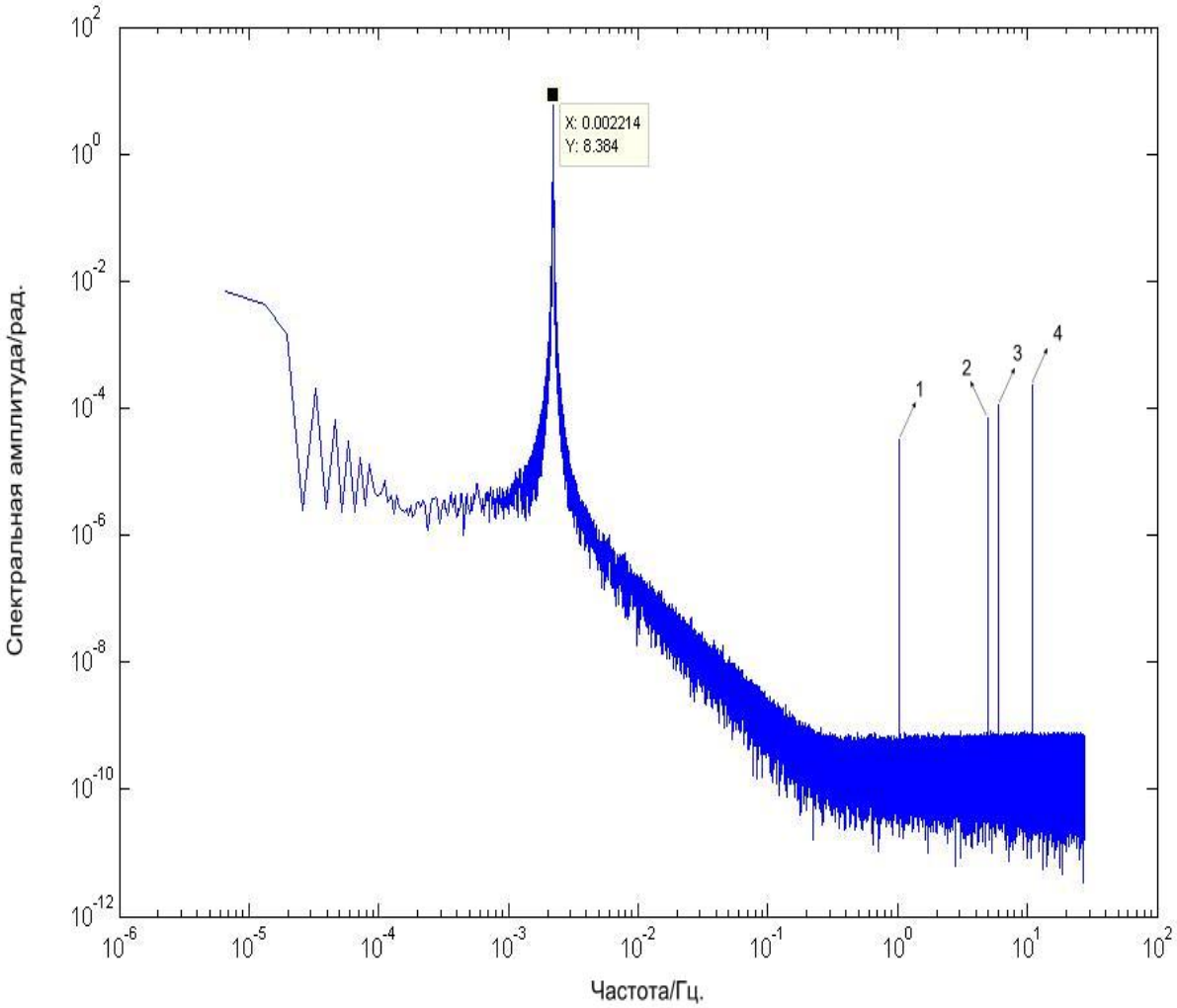
Весы без магнитного демпфера. Пик на частоте $1.676 \cdot 10^{-3}$ Гц представляет собственные колебания крутильной моды. Пик на частоте $2.186 \cdot 10^{-4}$ Гц – комбинационная мода.





Весы с магнитным демпфером. Комбинационная мода на частоте $2.186 \cdot 10^{-4}$ Гц эффективно подавлена.

Частотное подавление



Комбинационные моды остались лишь 4, и то только находится в верхней части спектра.

No.	*Частота, Гц*
1	1.0372
2	4.9790
3	6.0162
4	10.9952

Заключение

- В течение ближайшего времени мы можем ожидать получение нового значения Ньютоновской гравитационной постоянной на уровне точности 11-15 *ppm*.