Stephan Schlamminger

Activities of Working Group 13 "Newtonian Constant of Gravitation, G"

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1 Introduction

The goal of the working group is to understand the discrepancy between different measurements of the gravitational constant G. Figure 1.1 shows the results of measurements of G published in the last 42 years. As can be seen from the figure, the relative spread of the results is on the order of 100 parts in 10^6, while the best experiments show relative uncertainties of 12 parts in 10^6.

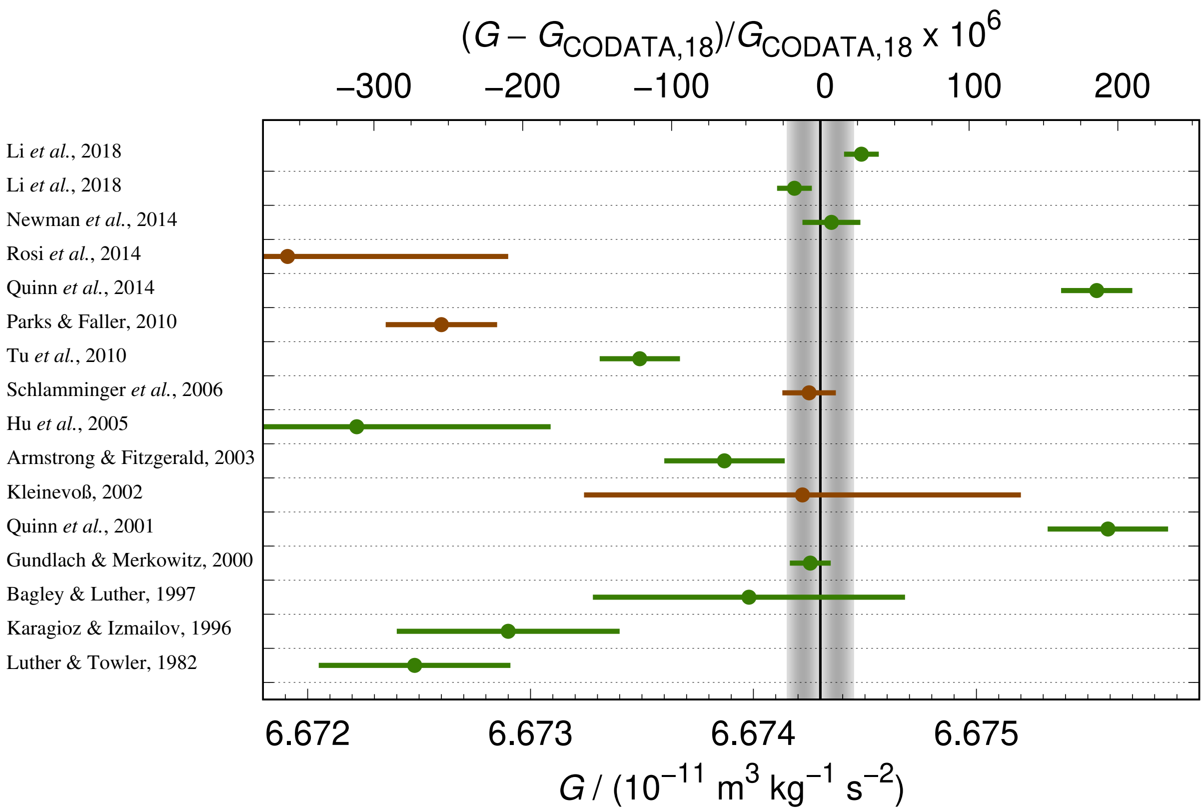

Figure 1.1: Sixteen measurements of the gravitational constant carried out over the last 42 years. The smallest relative uncertainty was reached in 2018 by a group at Huazhong University of Science and Technology in China. Their measurement had a relative standard uncertainty of 12×10^{-6}. Note how the difference between the smallest and largest measured value of G differ relatively by more than 500×10^{-6}.

2 Activities of the Working Group

COVID-19 has significantly restricted the work of the working group in recent years. Since 2019, no meeting of the working group has been held. A meeting is planned at the Bureau International des Poids et Mesures (BIPM), near Paris, in 2025. Part of the group will meet at the Conference on Precision Electromagnetic Measurements (CPEM) 2024 in Denver, USA, to plan the meeting at the BIPM. Myself and the cochair Christian Rothleitner from PTB in Germany are working on a publication about the technical details and principles of G experiments in the Living Reviews. The article is expected to be completed in late 2024.

3 Scientific News

In recent years, there have been no relevant publications providing new data for the CODATA value. However, there have been two publications showing other approaches to determining the gravitational constant. Reference [1] describes an experiment measuring the gravitational coupling between two gold spheres with masses under 100 mg, see Fig. 3.1. The physical distances between the mass centers are on the order of 2.5 mm. In the experiment, the position of the field-generating mass is harmonically varied relative to the test mass, which is attached to a miniature torsion balance. Since the masses are coupled by gravitational interaction, the variation of the source mass induces a harmonic oscillation in the torsion balance. The most important result of the experiment is the observation of the induced harmonic oscillation of the test mass, visible in the amplitude spectrum as a peak with the excitation frequency, along with a first higher harmonic peak, i.e., a frequency of twice the fundamental frequency of 12.7 mHz. The authors explain the emerging second peak with the nonlinear form of the gravitational field strength along the motion range. The authors provide a value for the gravitational constant determined from the observed data. This number is about 9% lower than the CODATA recommended value. However, the assigned statistical uncertainty fully covers the deviation. By gradually changing the mean distance between the masses, the Newtonian gravitational law could also be verified, as the observed dependence of the gravitational force within the measurement uncertainty agreed well with the $1/r^2$ law.
A recent article [2] describes an experiment measuring the dynamic gravitational coupling between two metal rods with masses of 1 kg and 3.8 kg, see Fig. 3.2. The heavier rod serves as the source mass, while the lighter rod represents the test mass. The novelty of this experiment is that it is conducted dynamically, unlike most G experiments that are static or quasi-static. The source mass is set into harmonic oscillations at the resonance frequency of about 42 Hz of the test mass rod. At a distance of 6 cm to 12 cm, the test mass rod was excited by the purely temporally varying gravitational field of the source mass rod. As an experimental result, the authors demonstrate the inverse square law of gravitational interaction, measure the gravitational constant G, and estimate the gravitational energy flow from the source mass to the test mass. A detailed theoretical description is provided. The value of the gravitational constant determined in the experiment deviates by 2.3% from the CODATA 2016 recommended value. This difference is higher than the estimated combined experimental standard uncertainty. However, the authors mention several possible reasons that could explain an overlooked systematic bias and suggest that further investigations are necessary. The described experiment can be considered a "proof-of-principle," which in itself represents an impressive result.
Currently, colleagues and I at the National Institute of Standards and Technology (NIST) are working on a G experiment. This involves an experimental setup already used by a group at BIPM (see Quinn et al. in the upper graph) over 10 years ago. The BIPM group conducted the experiment twice with a slightly modified setup. Both experiments yielded consistent values for G, but these values deviated from the CODATA value by multiples of the determined standard deviation. In a study soon to be published by the NIST group, it is shown that the value for G can vary depending on the air pressure (see the graph below). According to the study, this is due to a temperature gradient in the residual

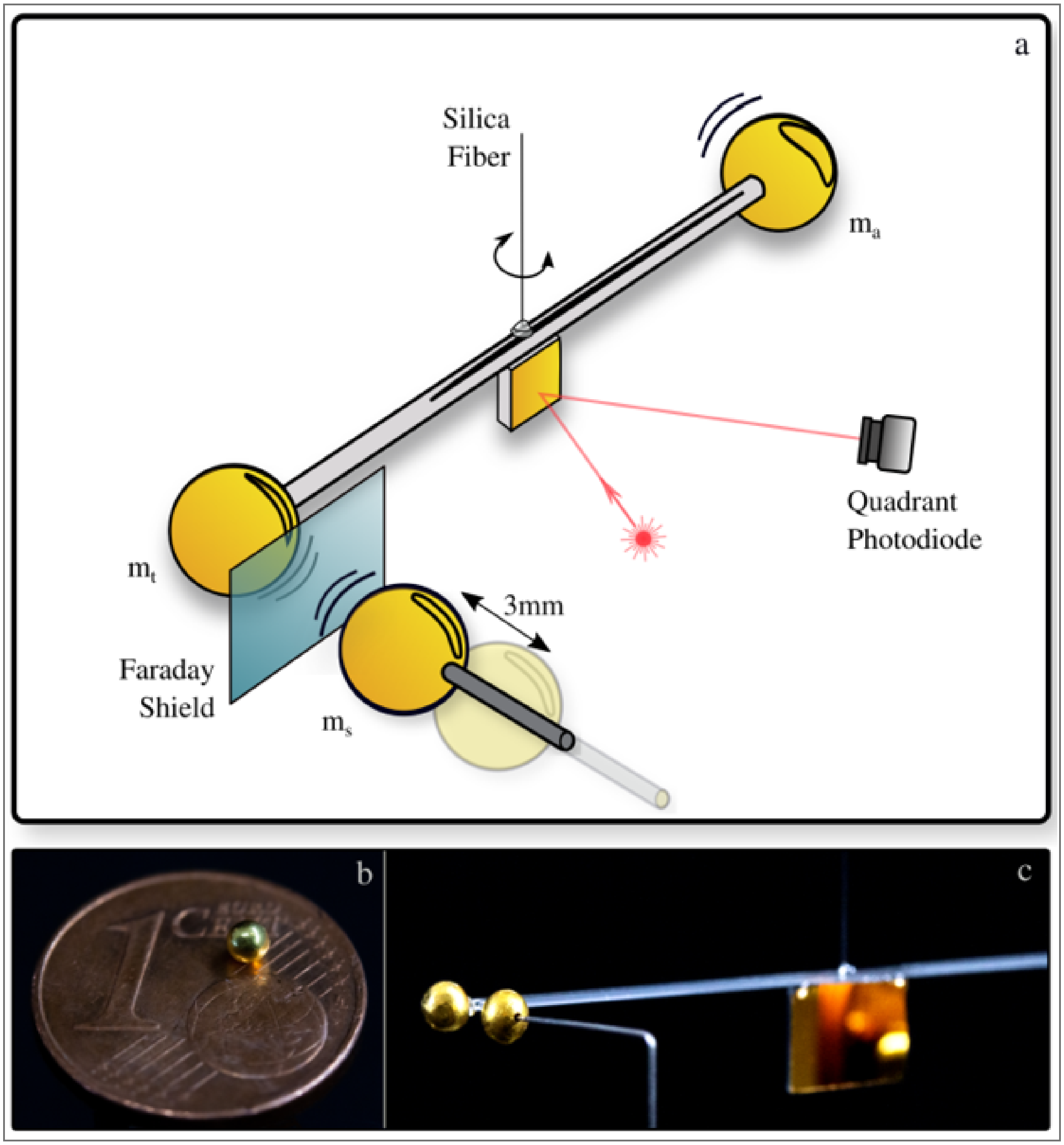

Figure 3.1: Experiment to measure the coupling between two very light masses. Figure from [1]. Copyright by Nature.

air surrounding the test masses.
Finally, it should be mentioned that a team led by Prof. Ricardo Decca at Indiana University-Purdue University Indianapolis (IUPUI) is also working on an experiment to measure G. This experiment is funded by the National Science Foundation (NSF).

Bibliography

[1] T. Westphal *et al.* Measurement of Gravitational Coupling between Millimeter-Sized Masses *Nature* **591** 225-228 (2021).

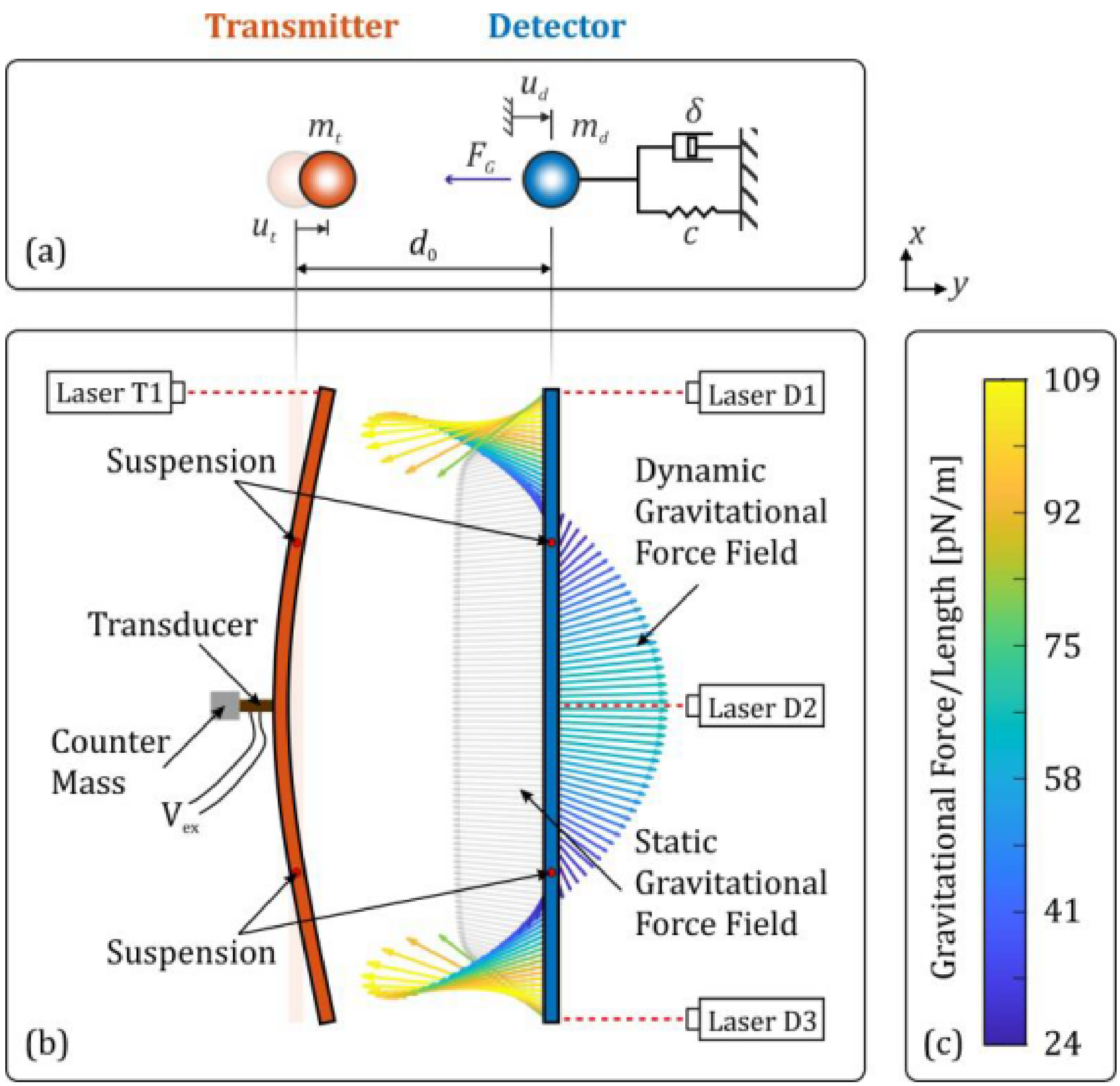

Figure 3.2: The Swiss experiment to measure dynamic gravitational coupling. Figure taken from [2]. Copyright by Nature physics.

[2] T. Brack *et al.* Measurement and Theory of Gravitational Coupling between Resonating Beams, *Nature Physics* **18.8** 952 -957 (2022).

[3] S. Schlamminger *et al.* Beware of Thermal Effects in Precision Measurements, *ASPE 2023 Proceedings* 52 (2023).

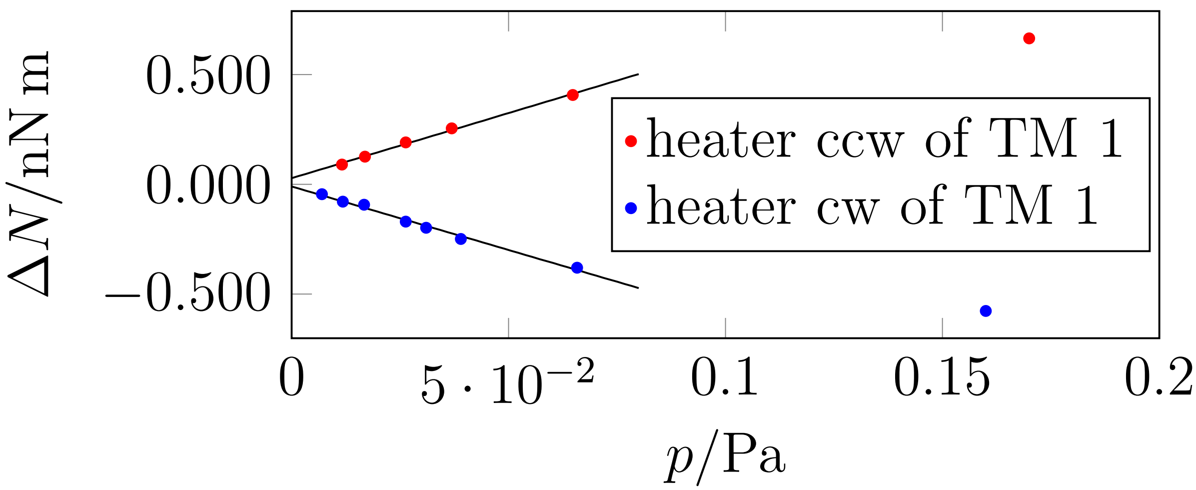

Figure 3.3: A torque mediated by thermal gradients and residual gas in the vacuum chamber could affect G experiments.