IAG Project - Novel Sensors and Quantum Technology for Geodesy (QuGe)

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QuGe website - https://geodesy.science/quge/

1 Structure

Working Groups

WG Q.1 Quantum gravimetry in space and on ground
Chair: Franck Pereira (France)
WG Q.2 Laser interferometry for gravity field missions
Chair: Samuel Francis (USA)
WG Q.3 Relativistic geodesy with clocks
Chair: Jakob Flury (Germany)

2 Activities during the reporting period 2023-2025

QuGe, with its fusion of quantum physics and geodesy expertise, bridges engineering prowess with fundamental research, propelling the boundaries of gravimetric Earth observation and reference system realization.

2.1 General

In the past two years, the QuGe has fostered and encouraged research in the areas of its working groups by facilitating the exchange of information and organizing workshops and sessions. QuGe has contributed to QuGe-related research activities and missions as studied and pushed forward by NASA, ESA, EU and national programs on the use of quantum technology. Examples are the missions MAGIC, CARIOQA, and ACES. The strengthening of the contact with industry has enabled good exchange with science, where the main focus of QuGe has remained on research. Also, many sessions at major conferences have been organized; see below.

Of the centrally organized events, we want to highlight:

- Co-organizing of the first Comparison campaign of six quantum gravimeters and related workshop, Hannover, Germany, January 2024;
- Contribution to measurement campaigns with transportable optical clocks and remote frequency transfer in Europe and Japan;
- Joint webinar with FIG WG 5.7 and IAG JSG 4.1.1 on "Advancing Geodesy and Navigation with Quantum Sensors“ (300 registrations, more than 160 participants), July 2024.

2.2 Dissemination activities

Contributions of QuGe members in the organization of sessions at conferences:

- EGU 2024 Vienna, Austria, April 2024, Session G4.2: Modern Concepts for Ground and Space Observations of the Earth Gravity Field. Convener: Marvin Reich, Co-conveners: Jürgen Müller, Daniele Carbone, Elske van Dalfsen, Sébastien Merlet
- CGU 2024, Ottawa, Ontario, May 26 - 29, 2024, Session G3. Quantum technology for Geodesy and Geophysics, Session Chairs: Marcelo Santos and Asif Iqbal
- 2024 IEEE International Geoscience and Remote Sensing Symposium, Athens, Greece, 7-12 July, 2024, CCS.86: Quantum Technology for Remote Sensing. Chairs: Upendra Singh, NASA, Olivier Carraz, ESA, Parminder Ghuman, NASA
- COSPAR 2024, Busan, Korea, 13-21 July 2024, Session H0.5: Advanced Methods for Geodesy, Metrology, Navigation and Fundamental Physics. Main Scientific Organizer: Roberto Peron, Deputy Organizer: Jürgen Müller
- GGHS 2024, Greece, 4-6 September 2024, Session 2 (Co-organized with the IAG QuGe Project): Novel technologies in terrestrial, airborne and satellite gravity field determination. Session chairs: Jürgen Müller, Derek van Westrum, Sylvain Bonvalot
- AGU 2024, Washington, USA, 9-13 December 2024, Session: Classical and Quantum Approaches to Gravity Field Determination: Acquisition, Analysis, and Applications of Terrestrial, Marine, Airborne, and Space Based Gravity Observations. Main convener: Derek van Westrum, Conveners: Marvin Reich, Vicki A Childers, Nan Yu, Thomas J Johnson, Ashton Flinders
- EGU 2025, Vienna, Austria, 27 April - 2 May 2025, Session G4.2: Modern Concepts for Ground and Space Observations of the Earth Gravity Field. Convener: Marvin Reich, Co-conveners: Jürgen Müller, Daniele Carbone, Elske van Dalfsen, Sébastien Merlet
- IAG SA 2025, Rimini, italy, 2-7 September 2025, Symposium G10: Modern Concepts and Quantum Technology for Geodesy. Convenors: Jürgen Müller, Jakob Flury, Öykü Koç, Marcelo Santos, Marvin Reich

2.3 WG Q.1 Quantum gravimetry in space and on ground

The goal of this WG is to elaborate the main benefit and most promising applications of atom interferometry for gravimetry and inertial sensing in space and on ground.
Two meetings took place in the period, one regular meeting of the WG Q.1 on December the 18th 2023 (5th meeting), and the second one on a different format on March the 21st of 2024. At the fifth meeting, general information was exchanged and updates on activities at national levels were presented by members of the working group. Reviews of relevant conferences and participation of our community were conducted. A review of companies involved in the development of quantum sensors was performed. It was proposed to organize meetings where these companies would be invited to present their activities, if they agree. Contacts have then been taken and several companies (Vector Atomic, Atomionics, NomadAtomic, Q-Ctrl and exail) have expressed their interest in contributing.
At the sixth meeting, we invited the company Vector Atomic to present their activities

on the development of quantum sensors based on atom interferometry. For that meeting, close collaborators of the members of WG Q.1 were invited to participate. Matt Cashen, CEO of the company, gave a very open presentation on their activities, titled "Progress towards Fieldable Quantum Gravimeters, Gradiometers, and Gyroscopes'. A 30-minute session of Q&A followed the presentation. More such meetings are to be organized.

WG members contributed to road maps, e.g., on using Quantum gravimetry on ground and in space.

2.4 WG Q.2 Laser interferometry for gravity field missions

WG Q.2 is in a transition phase to implement a new team of chairs and structure. The activities were related to collaborating and exchange with the teams of the ongoing satellite gravimetry missions like GRACE-FO as well as with the future concepts. The major activites were related to

- Discussing a workshop to brainstorm future laser interferometer architectures
- GRACE Follow On Laser Ranging Interferometer still disabled in-orbit
- GRACE Continuity Laser Ranging Interferometer Critical Design Review (CDR) early next year, testing of Engineering model hardware now
- ESA's NGGM satellite mission concept is being developed.

2.5 WG Q.3 Relativistic geodesy with clocks

WG Q.3 held an online meeting on 2025-03-18. Presentations focused on new chronometric leveling results in Europe, on the connection of height networks to chronometric leveling, on the status of measurements campaigns in Japan, and on the full general relativistic description of GRACE-like constellations.

The chronometric leveling results between NPL (London) and PTB (Braunschweig, Germany) are considered as a major breakthrough. The results were achieved using three 87Sr clocks, two of them transportable (RIKEN, PTB) and one stationary (PTB). The determination of frequency ratios combining both remote comparison and local comparison led to two independent results for the gravitational redshift, using the two independent transportable clocks, that agreed within $3 * 10^{-18}$ for the relative frequency deviation. A relativistic height difference was obtained that is considered more accurate than what can be achieved by other geodetic techniques on such continental distances [3].

The results will be further discussed at IAG SA 2025 in Rimini. The next online meeting of WG3 is planned for fall, after the IAG conference.

2.6 Selected publications of the QuGe members

The science addressed in the three QuGe WGs has led to several high-level publications. A selection of them [1–9, 12–22] is listed at the end.

3 Next steps

We will continue pushing the QuGe ideas and its successful activities such as contribution/link of QuGe research to satellite missions, quantum gravimetry and realizing chronometric levelling as well as the organization of sessions at major inter-disciplinary conferences, always with broad contribution from physics, geodesy and beyond.

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