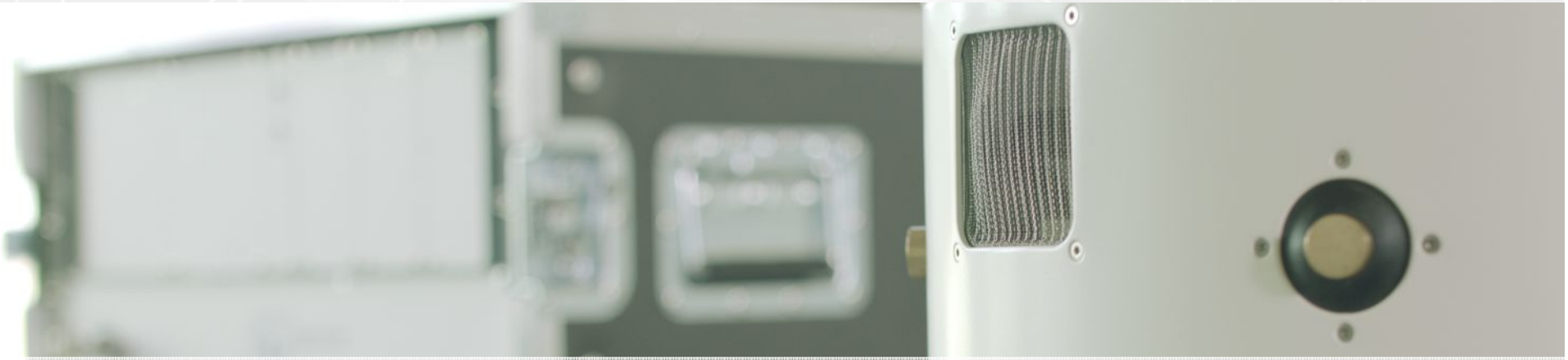


Operating the Absolute Quantum Gravimeter outside the laboratory

Pierre Vermeulen[1], Laura Antoni-Micollier[1], Tommaso Mazzoni[1], Gabriel Condon[1], Vincent Ménoret[1], Camille Janvier[1], Bruno Desruelle[1], Arnaud Landragin[2], Jean Lautier-Gaud[1], and Philippe Bouyer[3]

1. Muquans, Talence, France
2. LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, Paris, France
3. LP2N, Institut d'Optique, Université de Bordeaux, CNRS

μQUANS

MUQUANS: QUANTUM SENSORS & LASER SYSTEMS FOR SENSING AND METROLOGY

- ✓ **Company created in 2011**
- ✓ **30 employees**
- ✓ **Technology transfer from LNE-SYRTE and LP2N laboratories**

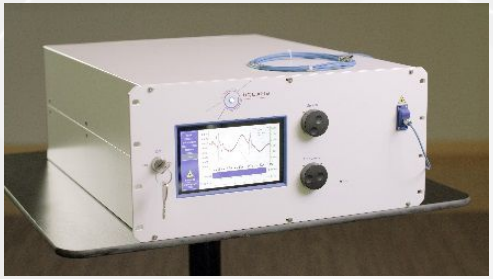
l'Observatoire de Paris – SYRTE

INSTITUT d'OPTIQUE GRADUATE SCHOOL

Cold atom gravity meters ($\Delta g/g \approx 10^{-9}$)

Cold atom atomic clock for VLBI ($\Delta f/f \approx 10^{-15}$)

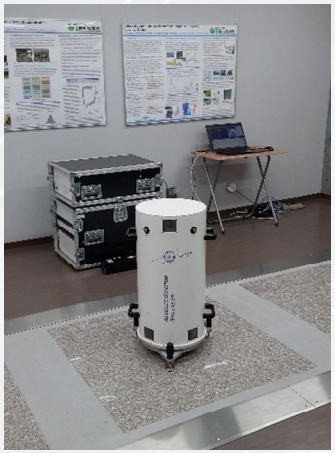
Laser solutions for optical and fiber sensing ($\Delta \lambda/\lambda \approx 10^{-10}$)

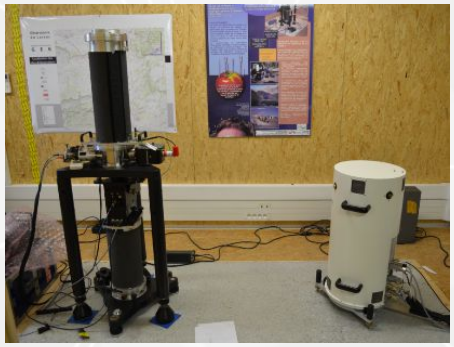


Optical frequency transfer for chronometric geodesy ($\Delta f/f \approx 10^{-20}$)

MUQUANS AQG: TWO VERSIONS OF A UNIQUE QUANTUM SENSOR

- **Indoor version**

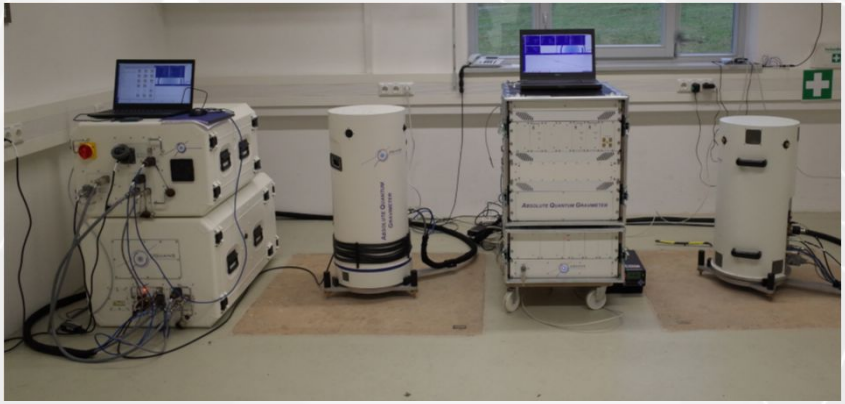




Courtesy of (Japan)

Courtesy of RESIF (France)

- **Outdoor version**

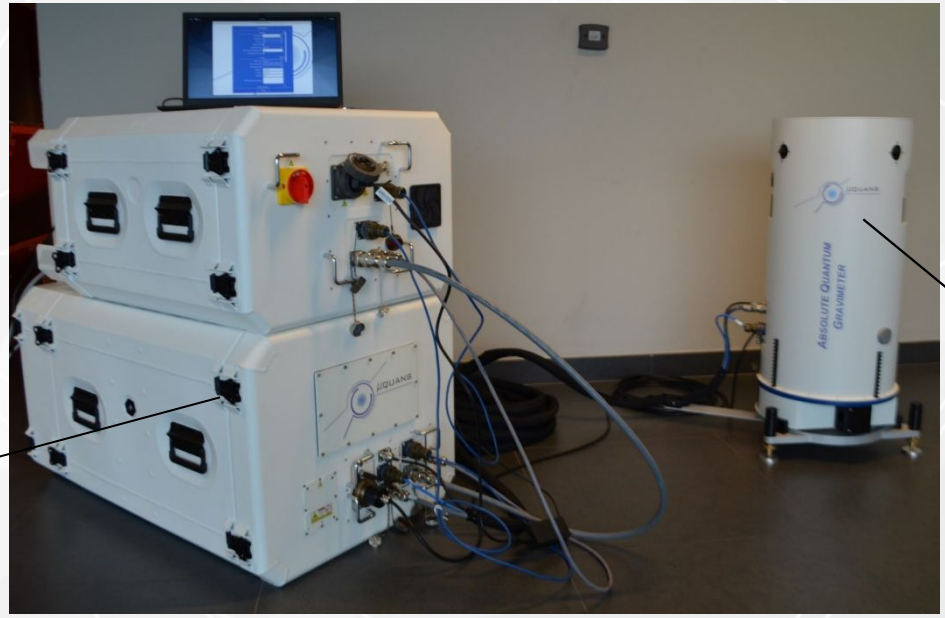


Courtesy of GFZ Helmholtz-Zentrum Potsdam, Federal Agency for Cartography and Geodesy (Germany)

AQG: ABSOLUTE QUANTUM GRAVIMETER

Power supply:
. Power supply
. Temperature control

Control Unit :
. Lasers
. Drive electronics
. On-board computer



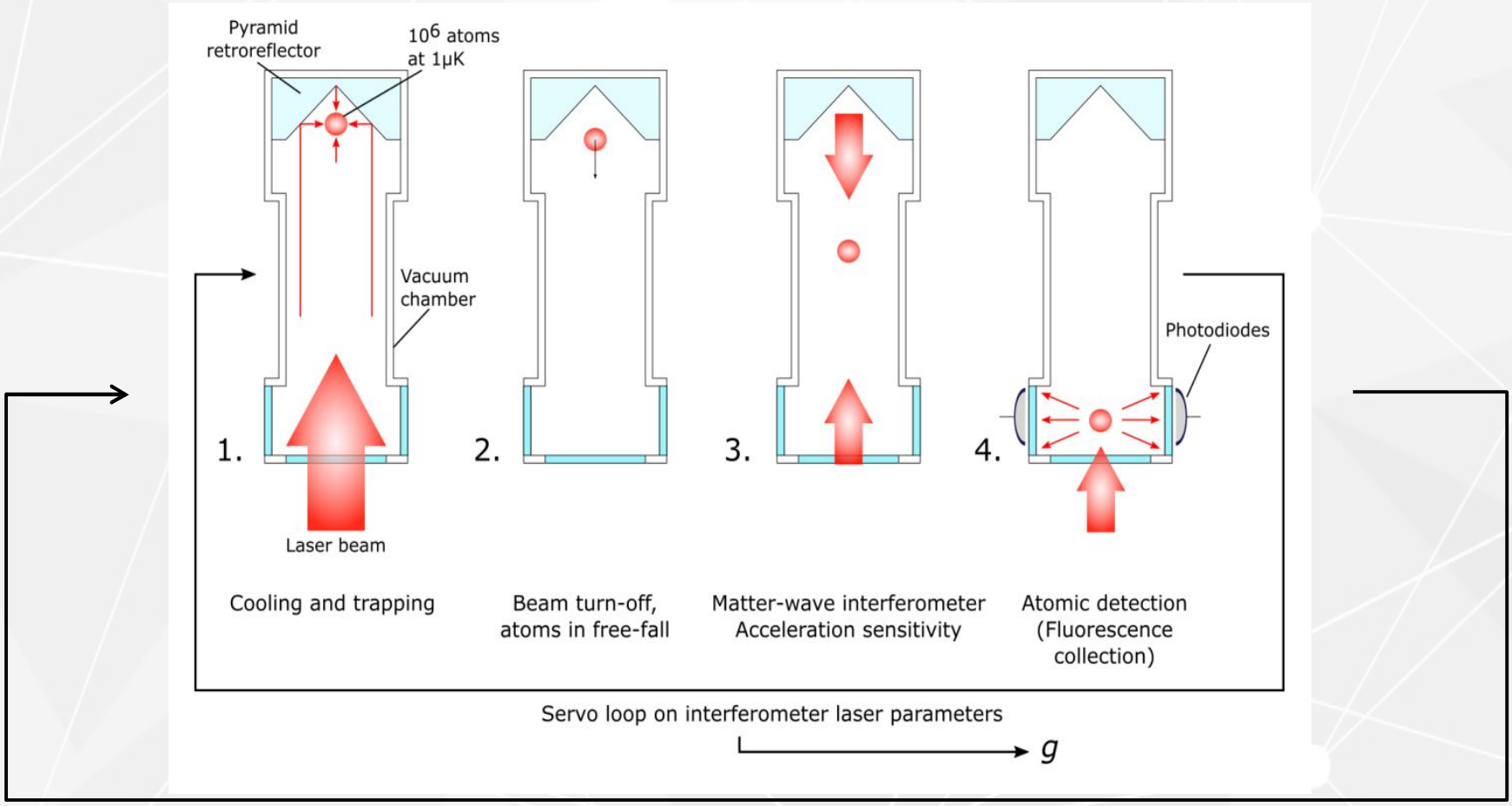
(picture of the outdoor version)
courtesy of RESIF

Sensor head :
. Dropping chamber
. Tilt-meters
. Accelerometer
. Pressure Gauge
. GPS receiver

- ✓ Strong robustness w.r.t ground vibrations even in urban environment
- ✓ Installation time < 20 minutes

V. Ménoret et al., Nature Scientific Reports, vol. 8, 12300 (2018)

AQG: A FREE FALL GRAVITY METER WITH ON-DEMAND TEST MASS



2 Hz cycling rate

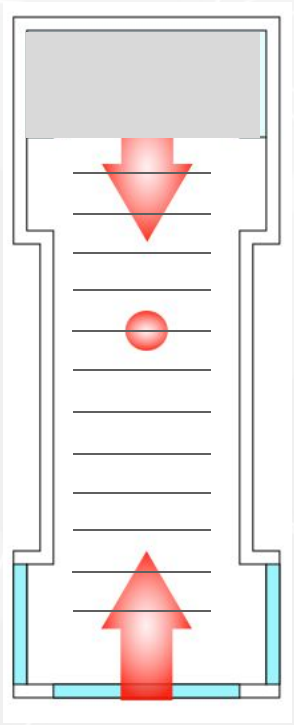
No moving parts:
once a set of atoms has fallen,
a new test mass is built up with new atoms for the next drop, etc…

V. Ménoret et al., Nature Scientific Reports, vol. 8, 12300 (2018)

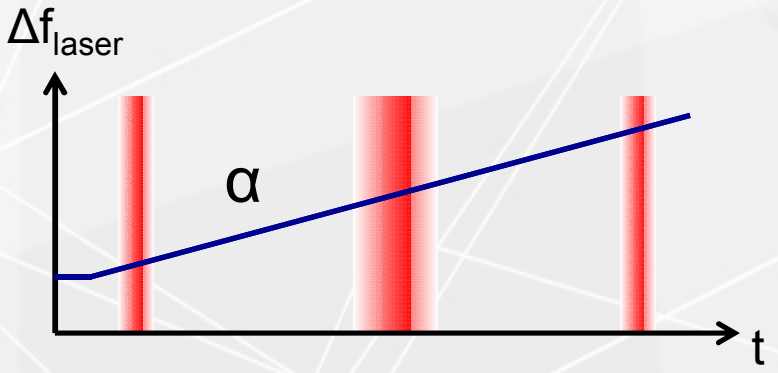
THE MEASUREMENT OF *g* WITH COLD-ATOM GRAVIMETRY

- Measurement of *g*: atom interferometry with laser-cooled atoms

  V. Ménoret et al., Nature Scientific Reports, vol. 8, 12300 (2018)



→ A chirp α is applied on the reference laser frequency to preserve the atom/laser resonance during the fall



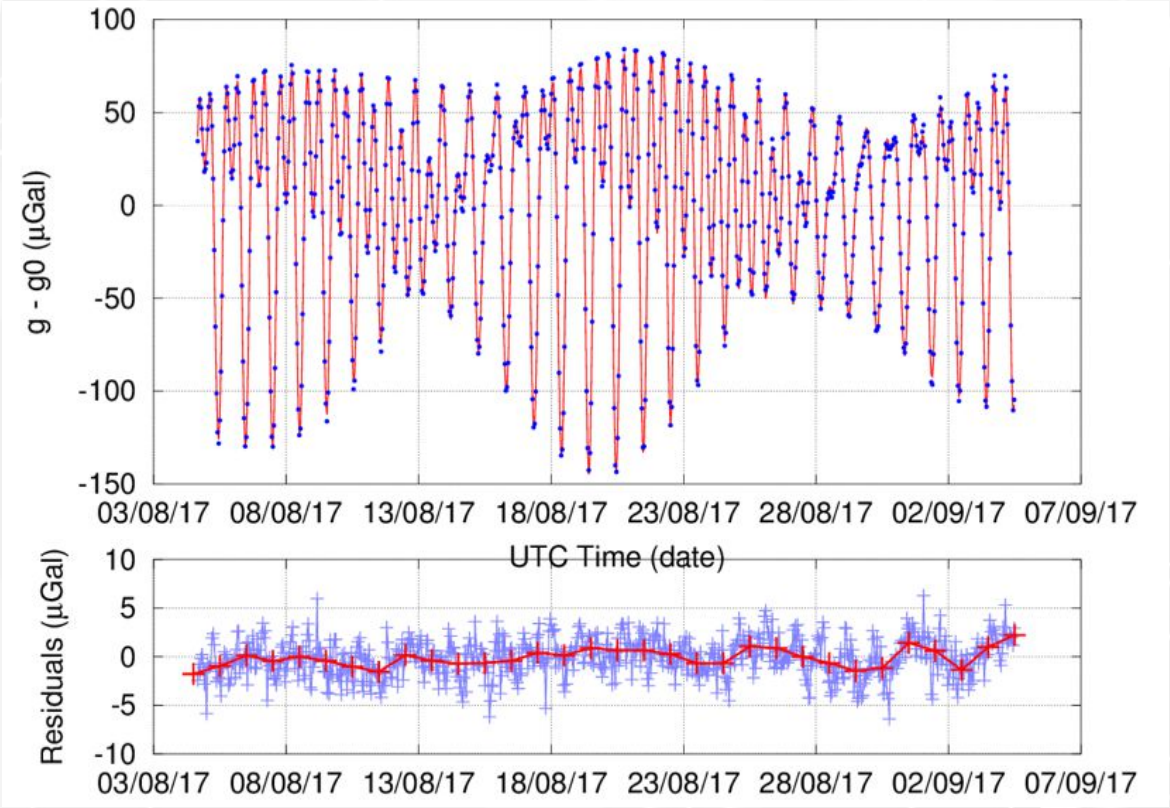
→ *g* comes from the measurement of the frequency chirp

$$\Delta\Phi = \overrightarrow{k_{eff}}\,\vec{g}\,T^2 - \alpha\,T^2$$

AQG: LONG-TERM STABILITY OF AQG#A01 (INDOOR)
STABLE CONTINUOUS ABSOLUTE MEASUREMENTS

RESIF

1-month long continuous measurement, 2-Hz drop rate



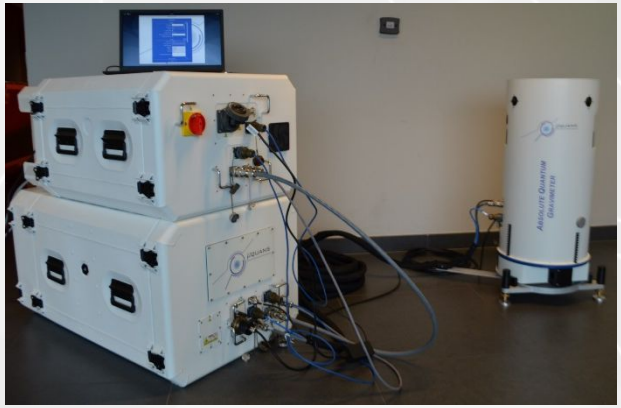
CNRS/RESIF
(S. Bonvalot &
N. Lemoigne)

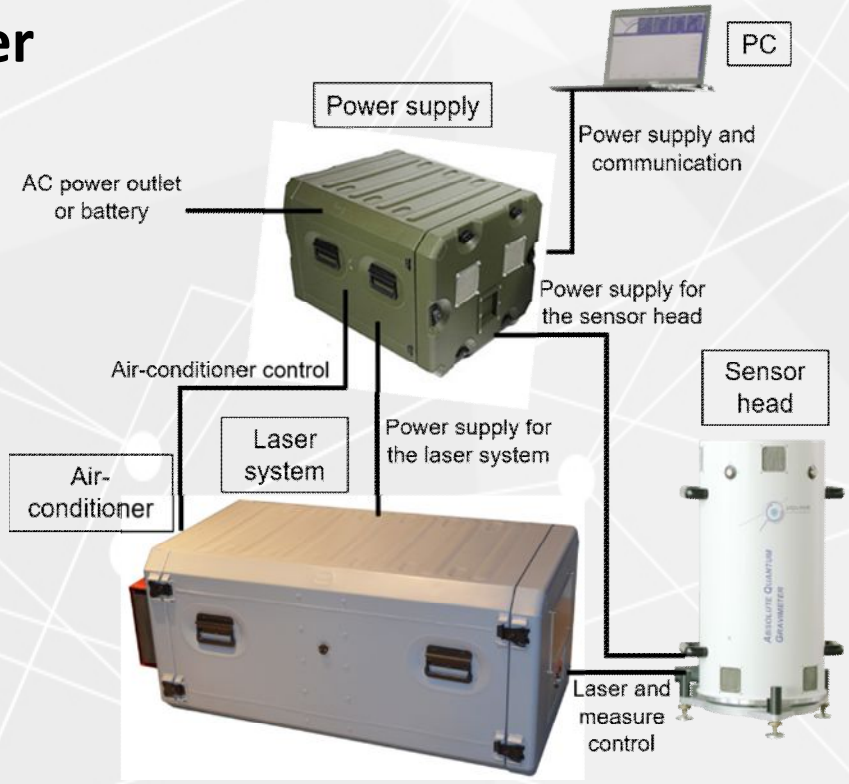
Blue: 1 h averaging time

Red: 1 day averaging time σ_g = 0.9 μGal

THE AQG FOR OUTDOOR OPERATION

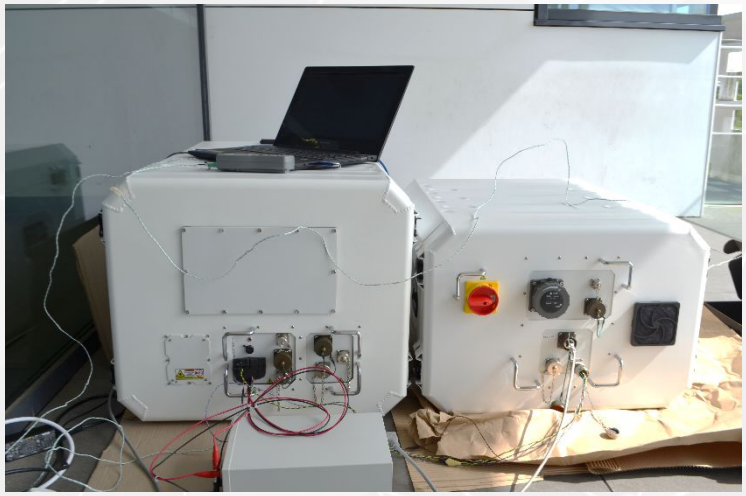
- **Full re-design of the instrument**
- **Same scientific specifications**
- **Operating temperature range [0°C ; 40 °C], up to 100% humidity**
- **Reduced size, weight and power**
- **Less cables and connectors**

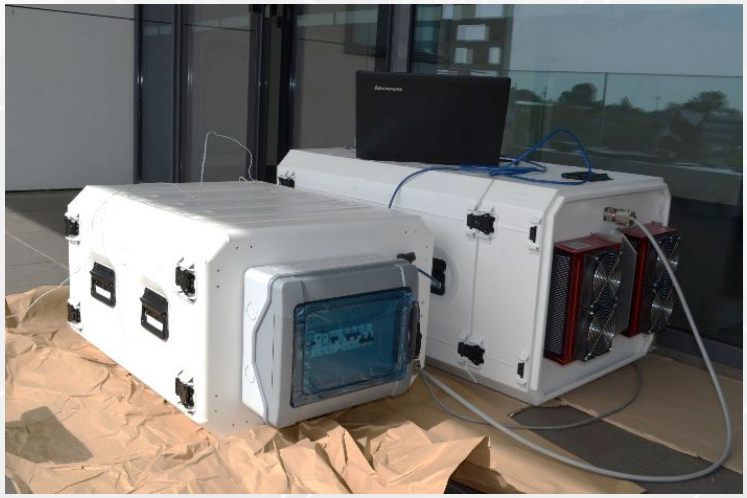




THE AQG FOR OUTDOOR OPERATION: TEMPERATURE CONTROL

The inner temperature of the control unit is actively stabilized





AQG laser system operating outdoor, at a temperature of 38°C

	Control unit case			Power supply case		
Typical Dimensions	height	width	length	height	width	length
	500 mm	620 mm	110 mm	410 mm	610 mm	900 mm
Weight	40 kg (without thermo-controller module) Thermo-controller module: 26kg			32 kg		

THE AQG FOR OUTDOOR OPERATION: TEMPERATURE CONTROL

The inside of the sensor head is heat-up. Additional insulation for cold environments

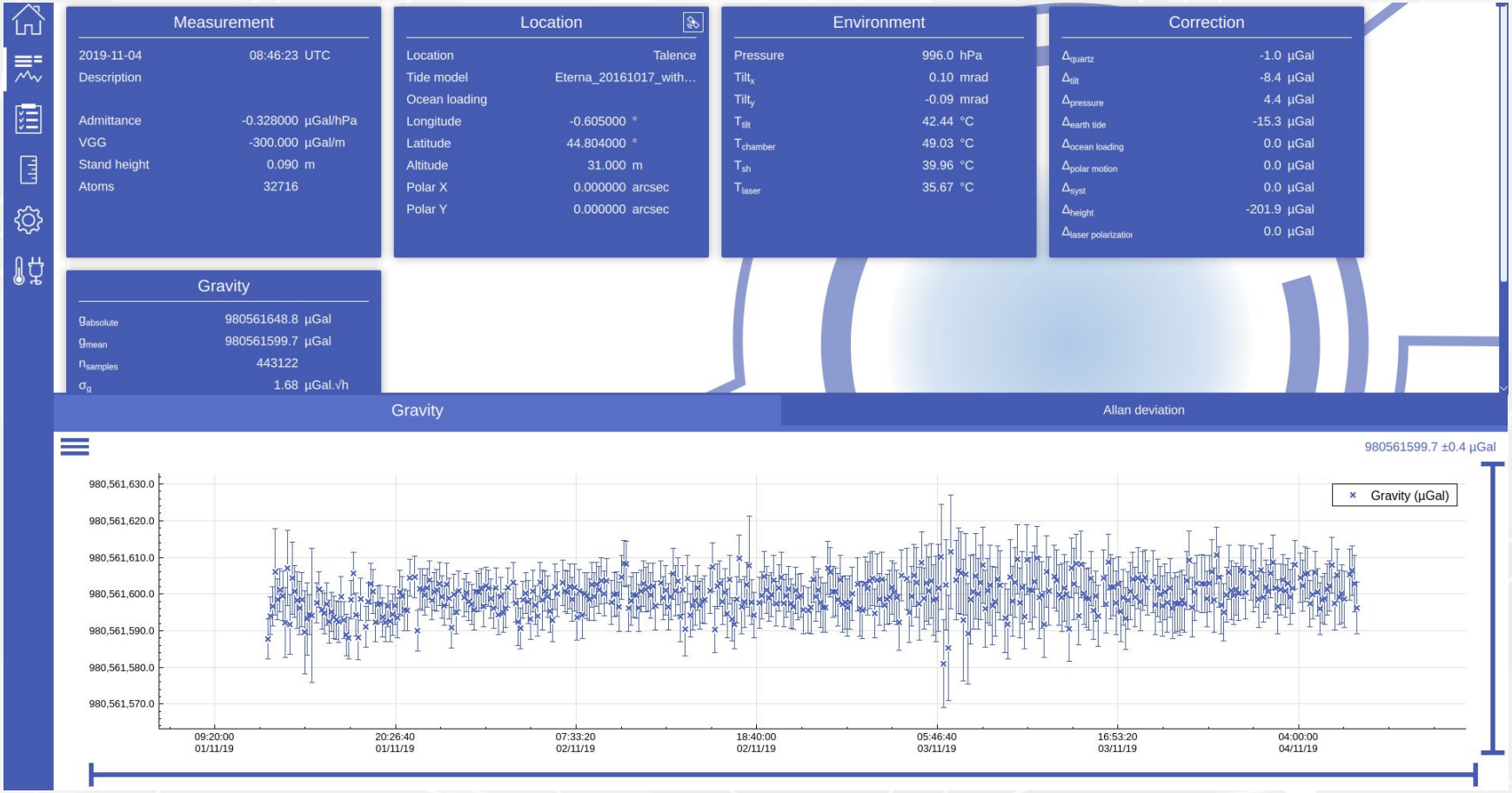
Dimensions: 840 mm (height) ; 380 mm (diameter)
Weight: 35 kg

OTHER FEATURES

- **Outside operation**
  - Field connectors and cables
  - Water and air tight enclosure for laser and sensor head
  - Industry-grade safety management
  - Battery operation (24 V, ~500 W)
  - 15 m cables between sensor head and control unit

- **Ease of use**
  - Small number of connectors
  - < 40 kg per module
  - Installation in a dedicated vehicle for survey
    - Battery for thermal stabilisation during transport
    - Fast installation and measurement on site.

THE AQG: USER INTERFACE



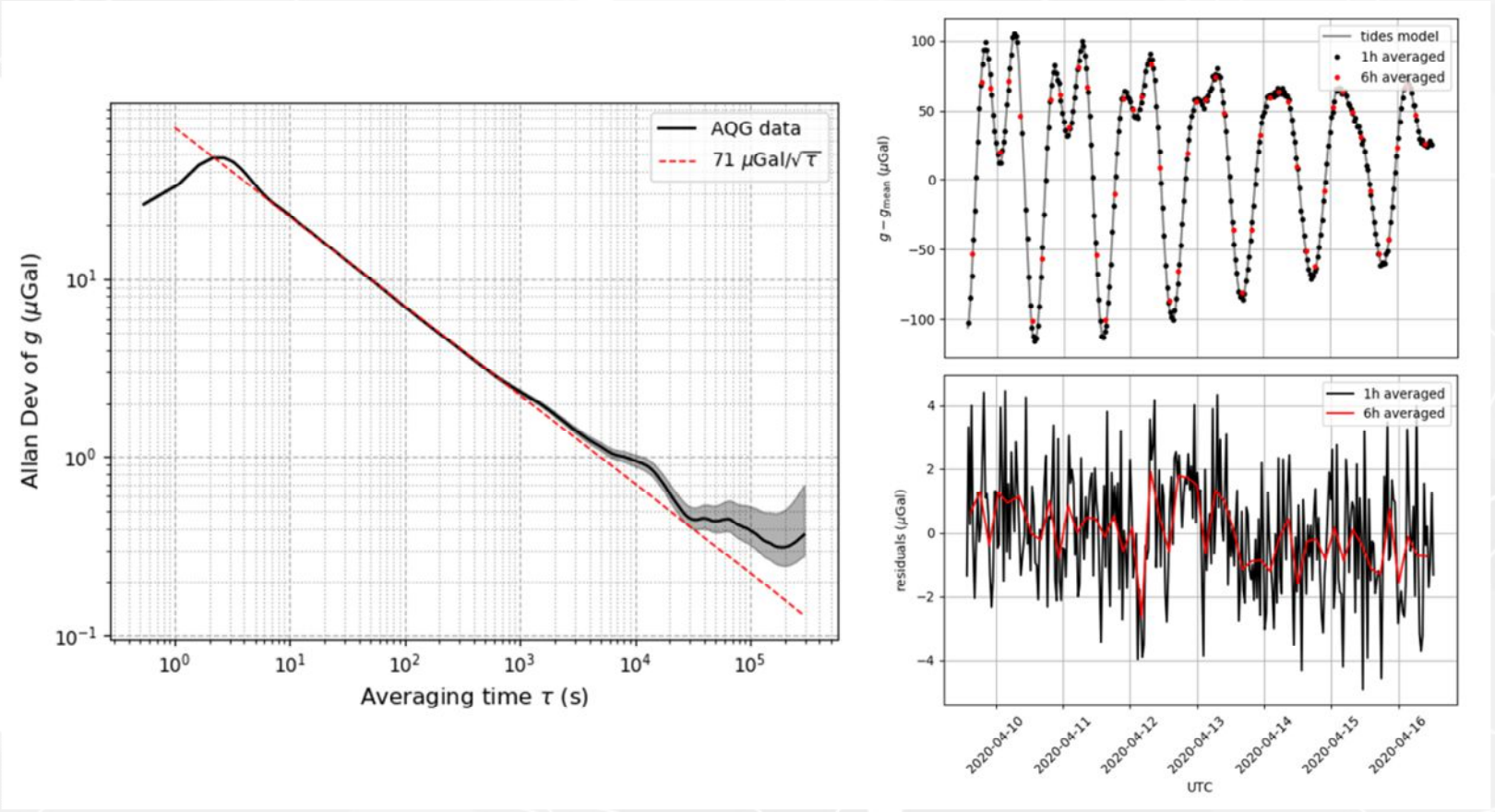
- File format
  - .info
  - .csv, _raw.csv
- Quick data processing

- Data
  2 Hz raw data
  10 min averaged data

- Recorded files:
  Version
  Location
  Corrections
  Tide model
  Results

PRELIMINARY EVALUATION

- 60 µGal/√t (the second level of a building, city center)
- 1 µGal long term stability (demonstrated at 20°C)



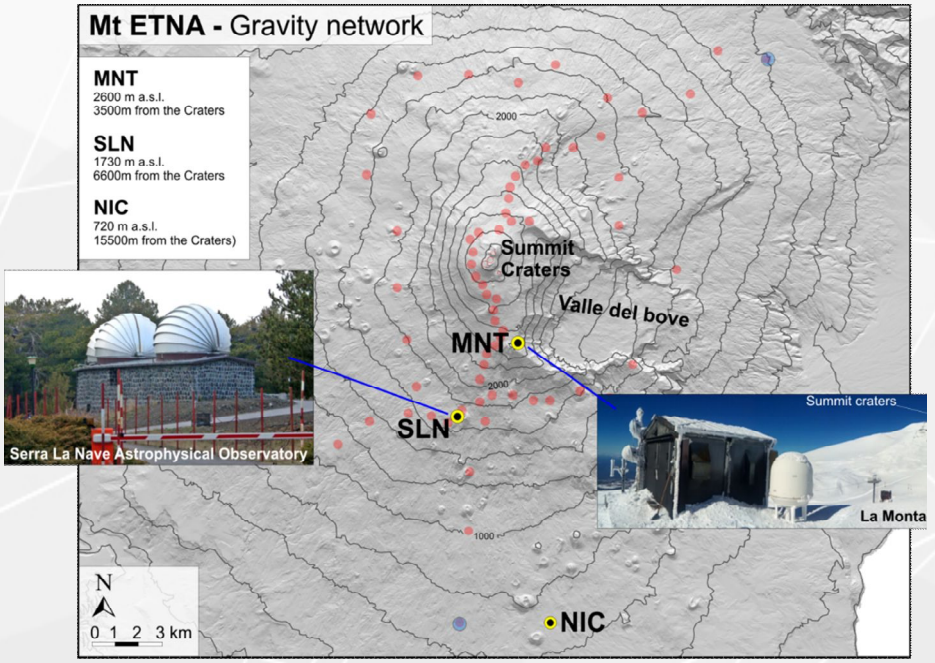
Results from a 1-week continuous measurement in Talence, in April 2020. Left: Allan deviation of gravity residuals. Sensitivity is 71 µGal/√t and long-term stability is below 1 µGal. Top right: raw measurements, averaged over 1 hour (black dots) 6 hours (red dots), with local tide model (solid line). Bottom right: gravity residuals after correction from tidal effects and atmospheric pressure. Standard deviation for a 1 hour (resp. 6 hour) averaging time is 1.9 µGal (resp. 1.0 µGal).

SPECIFIC FOCUS: THE AQG ON MOUNT ETNA (ITALY)

NEWTON-g

(New tools for terrain gravimetry)

http://www.newton-g.eu/



- **One special unit of the field AQG is being manufactured and will be deployed on Mt Etna in 2020**

CONCLUSIONS AND PERSPECTIVES

- **The first units of the field AQG have been delivered to customers**
- **First operation of a quantum gravimeter in Japan validated**
- **Extended temperature evaluation on-going**
- **Deployment on the field is on going (hydrology, volcanology, geodesy)**

See also:

EGU2020-9185 | Displays | G4.2

Operating an industry-grade quantum differential gravimeter

VISIT

www.muquans.com

https://www.muquans.com/product/absolute-quantum-gravimeter/

CONTACT

jean.lautier@muquans.com

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