QUANTIC

DEVELOPMENT OF A MEMS GRAVIMETER

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UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

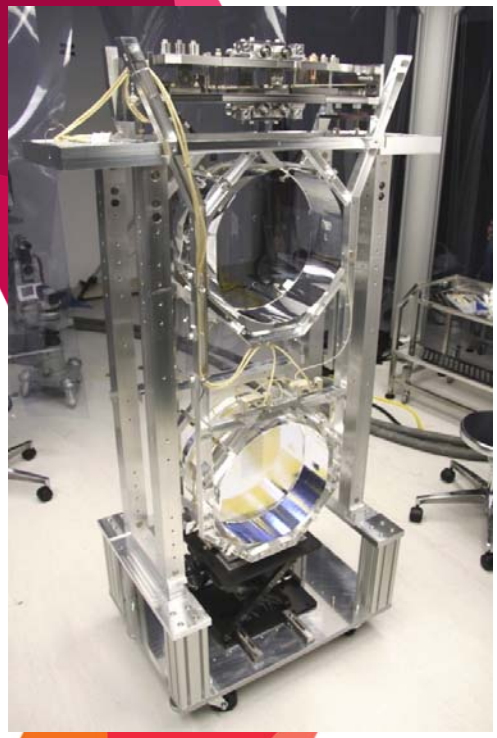
EPSRC Pioneering research and skills

Scottish Funding Council
Promoting further and higher education

Overview

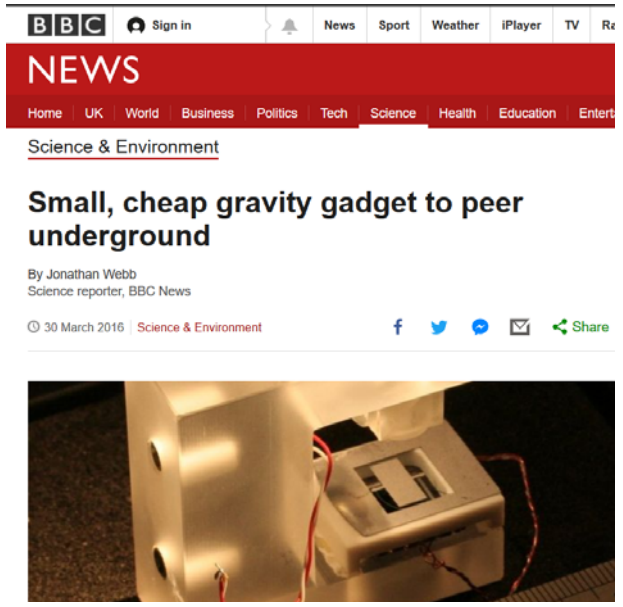
- Gravitational wave and Quantum Technologies
- Gravity applications
- Current tools in gravimetry
- Wee-g MEMS gravimeter and gradiometer
- Future opportunities

Gravitational Waves / Quantum Technologies



Fundamental research

Applied research



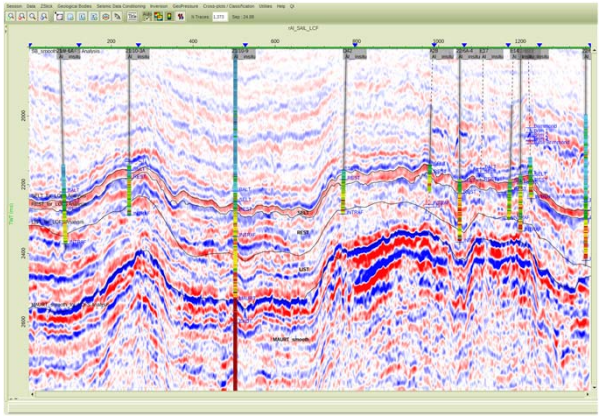
https://quantic.ac.uk

Gravity Imaging Applications

Oil & gas prospecting

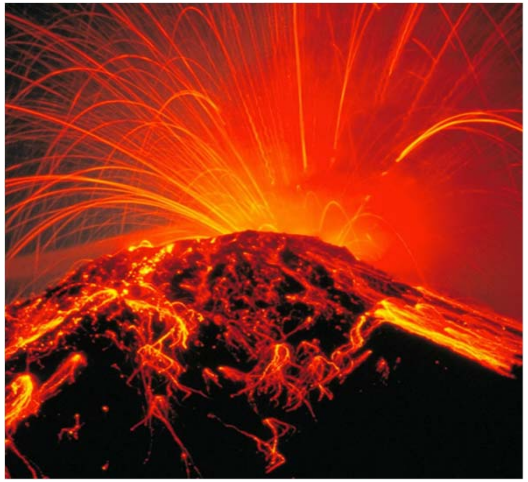
Navigation

Seismic surveys

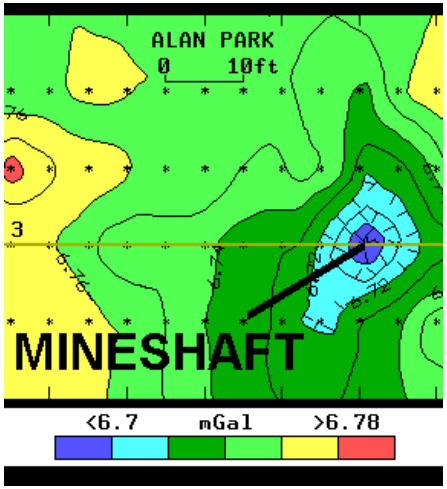


Security & Defence

Environmental monitoring



Sink hole detection



Current Tools in Gravimetry

- Relative gravimeter: compares gravity to the extension of a spring
- Mass 6kg
- 5uGal standard deviation
- Costs around £70k

- Absolute gravimeter: thrown corner cube
- Mass 250kg
- 10uGal standard deviation
- Costs around £200k
- Less portable

SCINTREX
A DIVISION OF LRS

No current gravimeter well suited to array-based gravimetry due to cost/form factor

MICROG LACOSTE
A DIVISION OF LRS

Glasgow MEMS Technology

Gravimeter (Wee-g)

Measure acceleration

$\propto 1/R^2$ for point mass

More sensitive to inertial (platform acceleration)

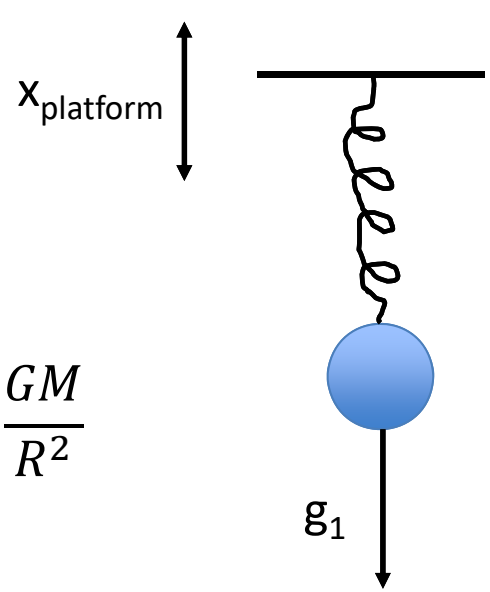
Gradiometer (Wee-grad)

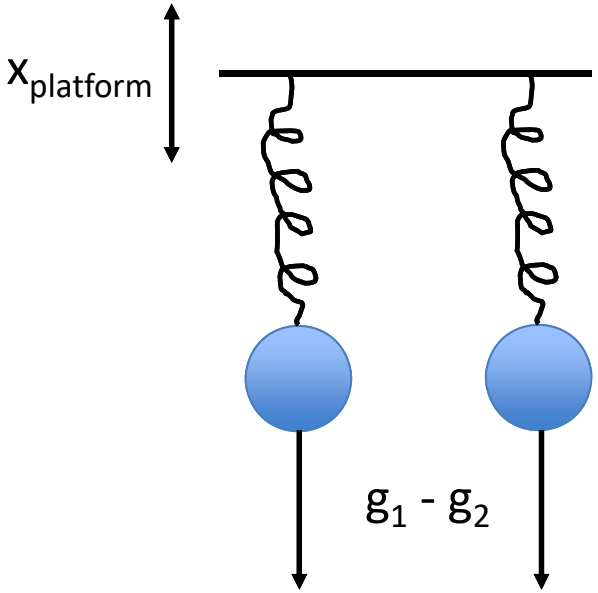
Measure differential acceleration

$\propto 1/R^3$ for point mass

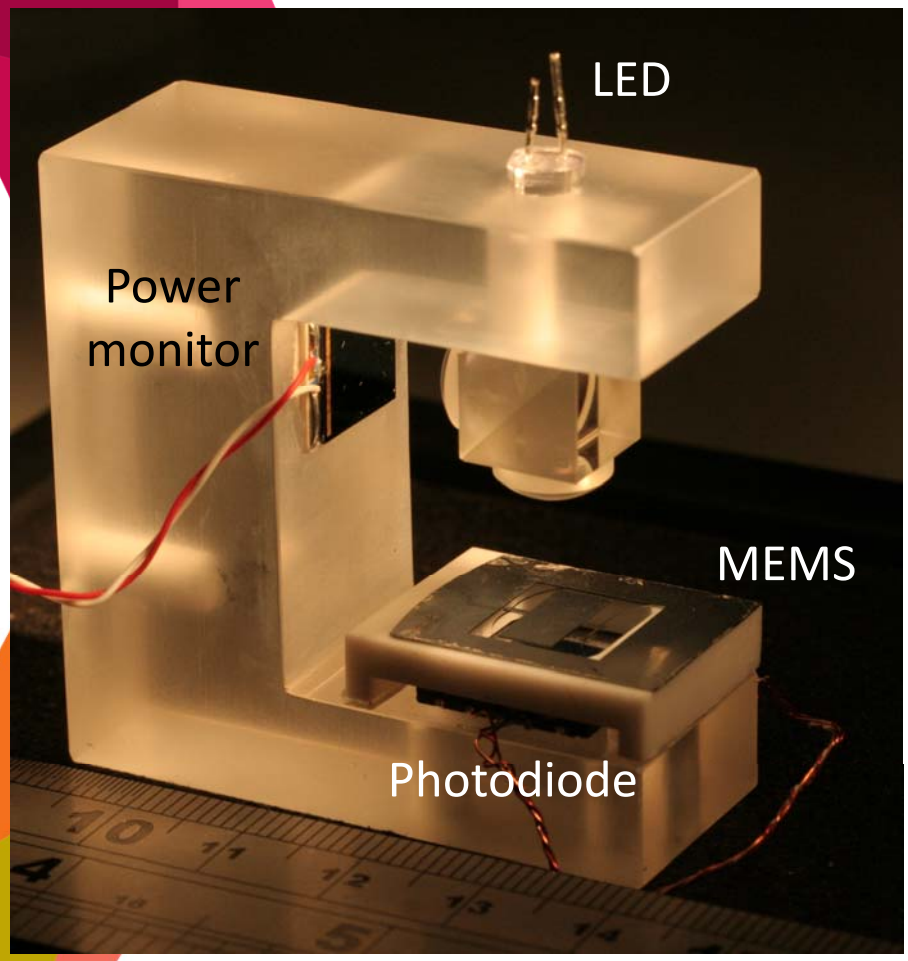
Less sensitive to inertial (platform acceleration)

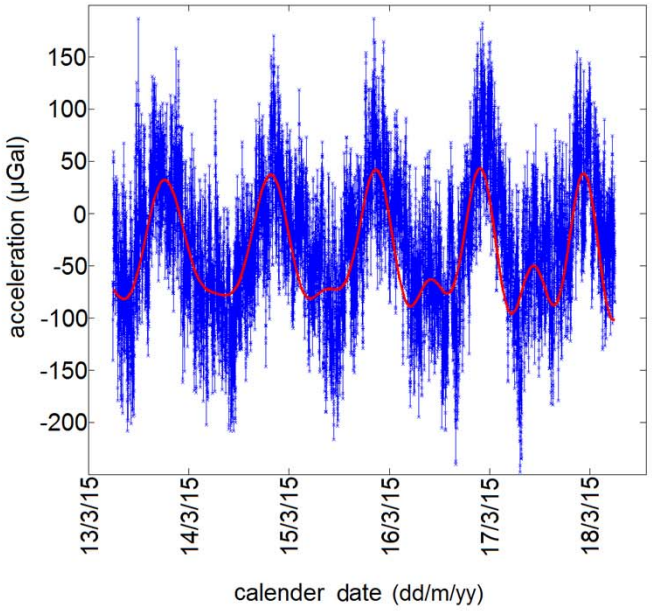
$$g = \frac{GM}{R^2}$$



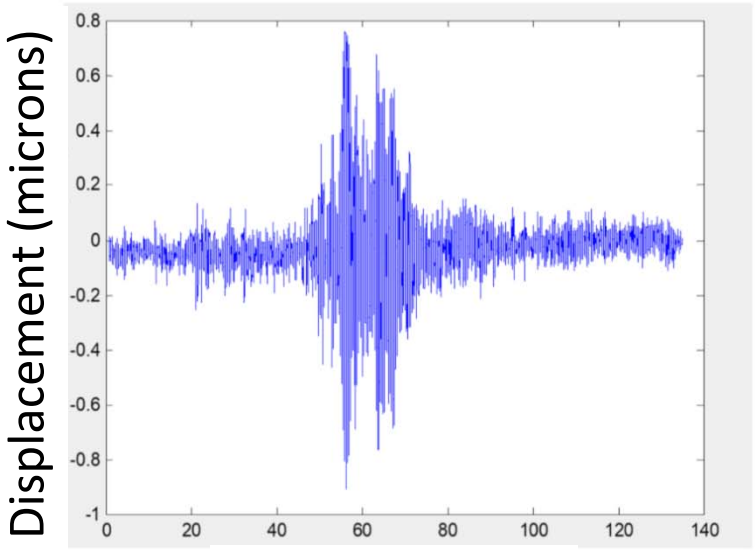


Glasgow MEMS Device (Wee-g)





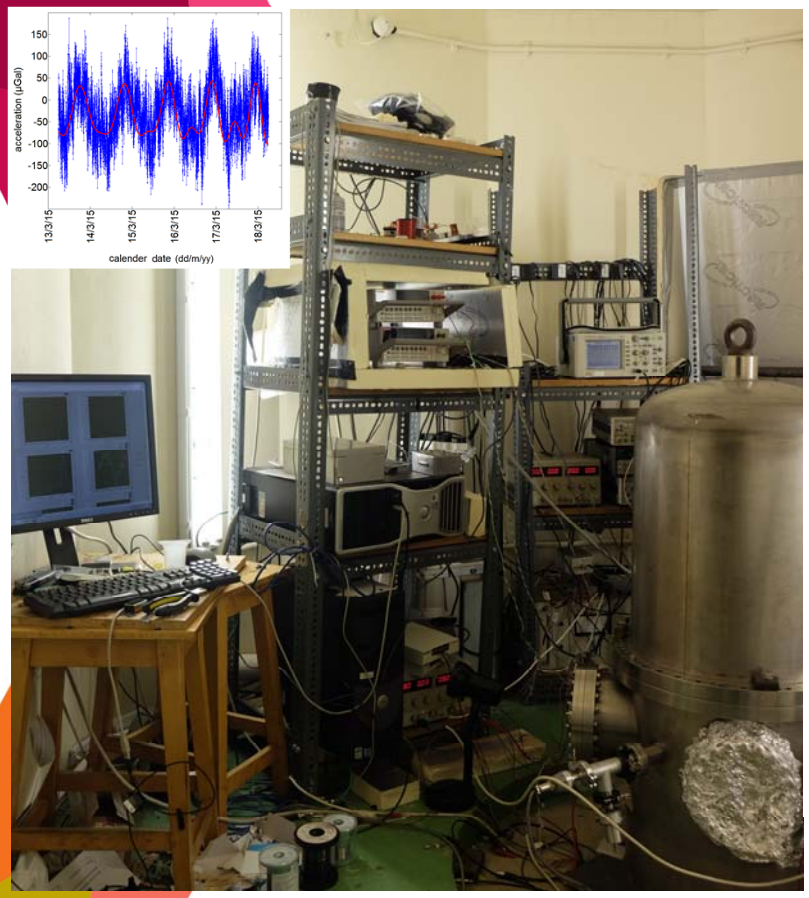
- Earth tides



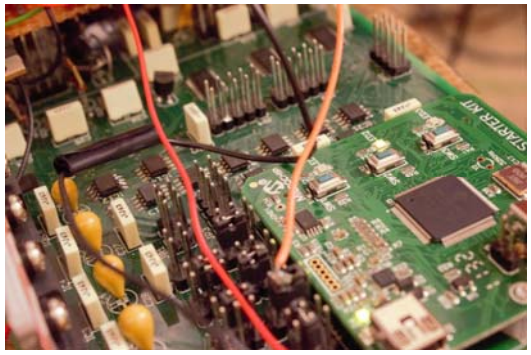
- Seismic noise (earthquakes)

R.P. Middlemiss et al. Nature 531, 614, 2016
Toninelli et al. Optics Express 25 (18), 2017
Bramsiepe et al. IEEE Sensors 18 (10), 2018
R.P. Middlemiss et al. MDPI Sensors, *17*(11), 2571, 2017

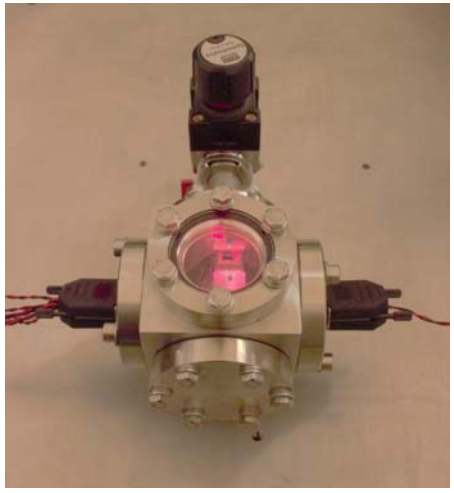
Development of a Field Unit



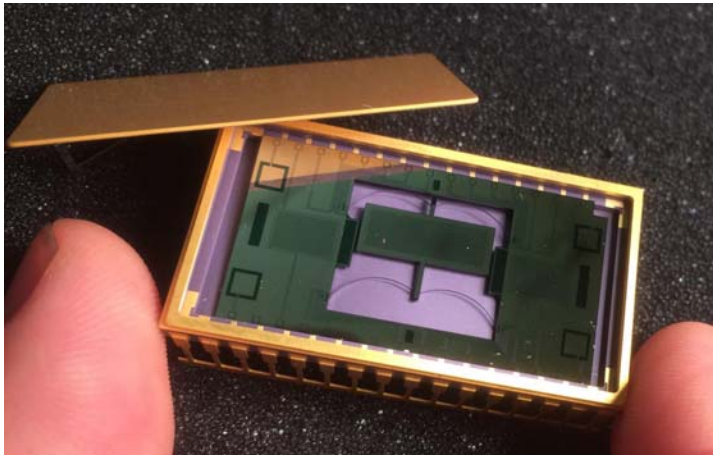
2015: lab based system with mains power, rack mount electronics

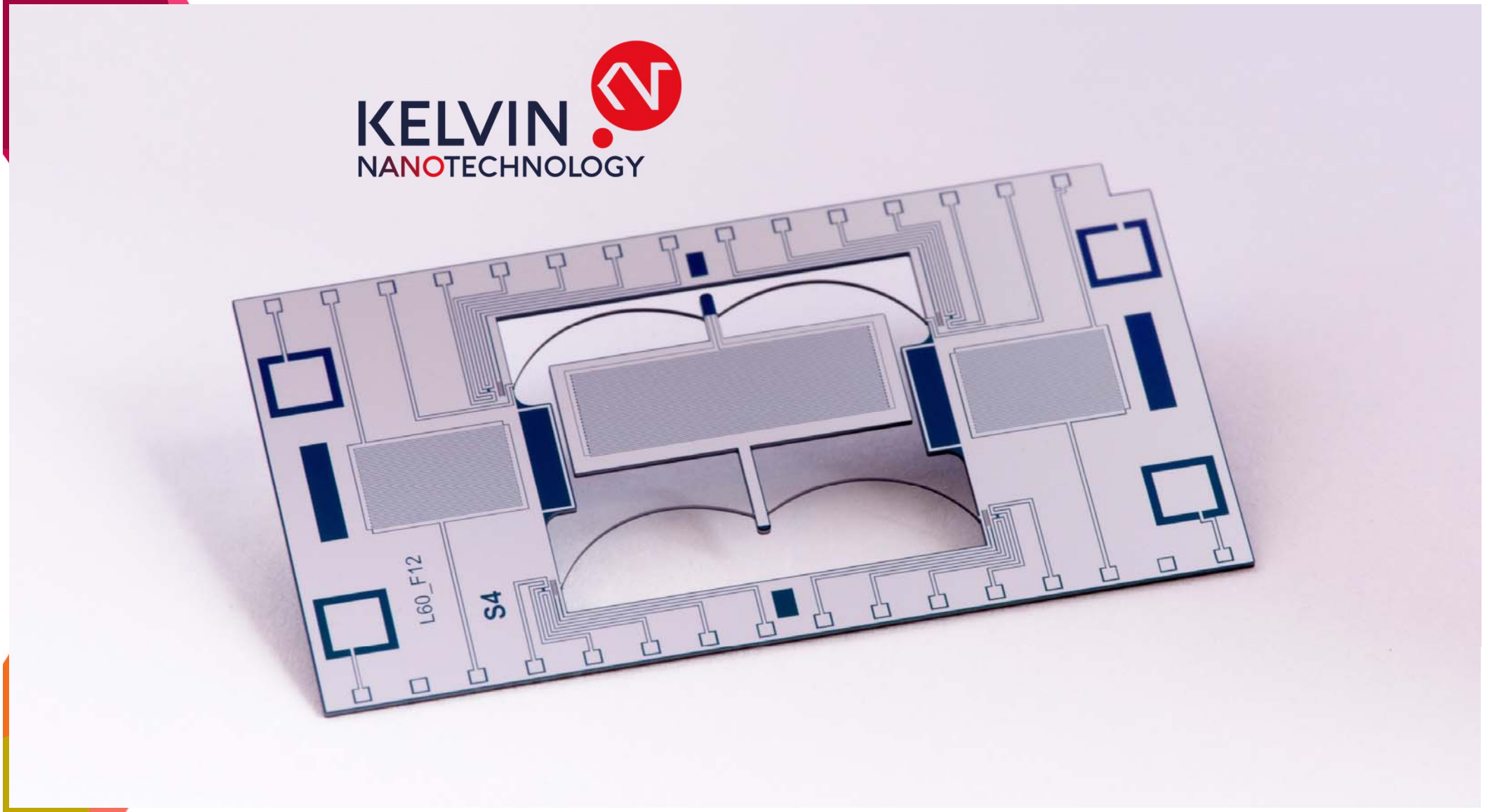


2016: shoebox sized field demonstrator, battery power



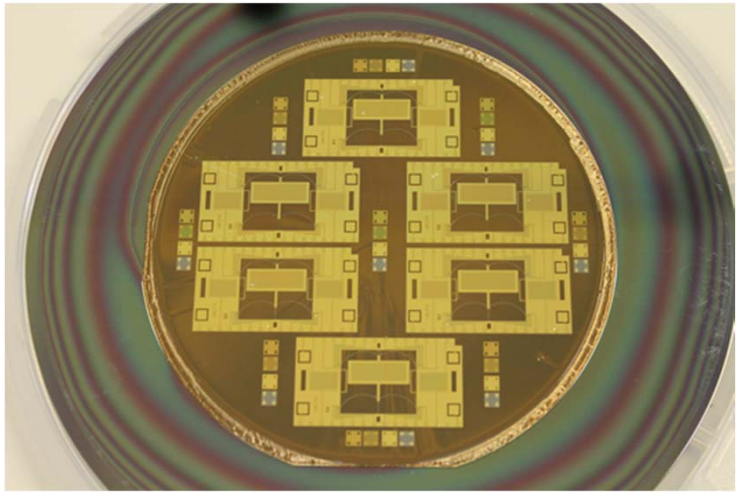
2018/19: packaged device with FPGA readout

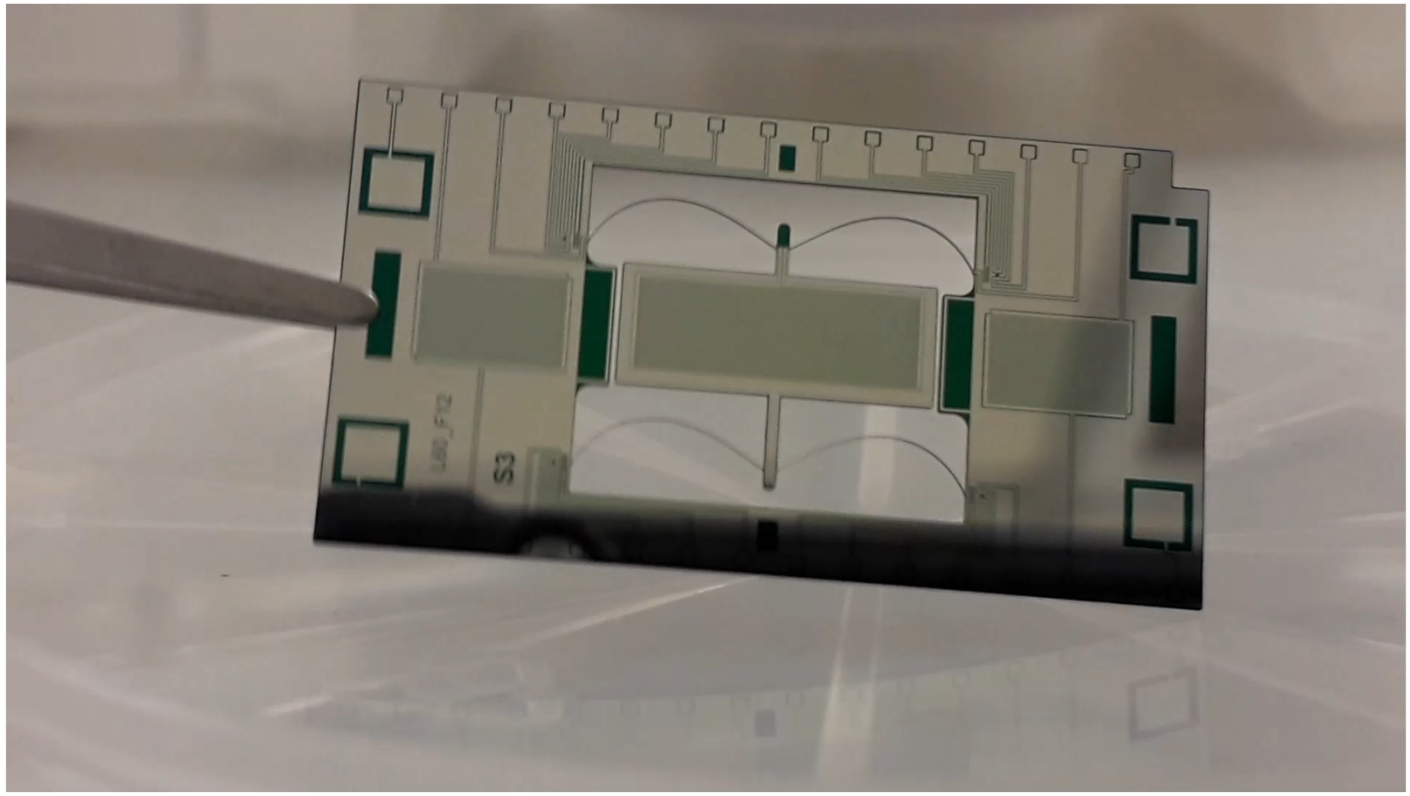




Wee-g sensor fabricated by KNT

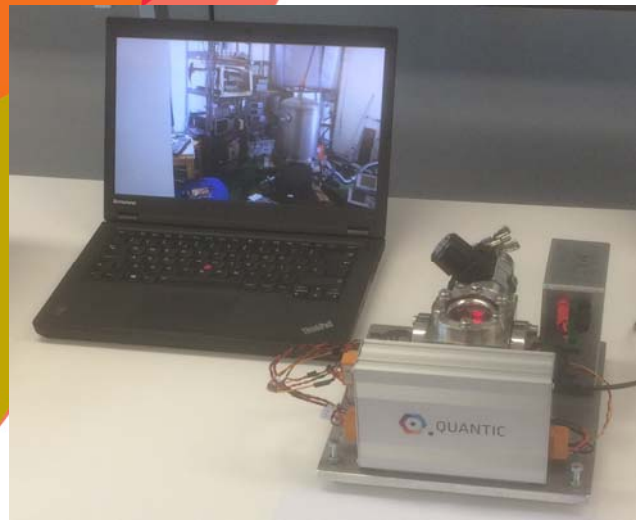
Wafer Scale Fabrication

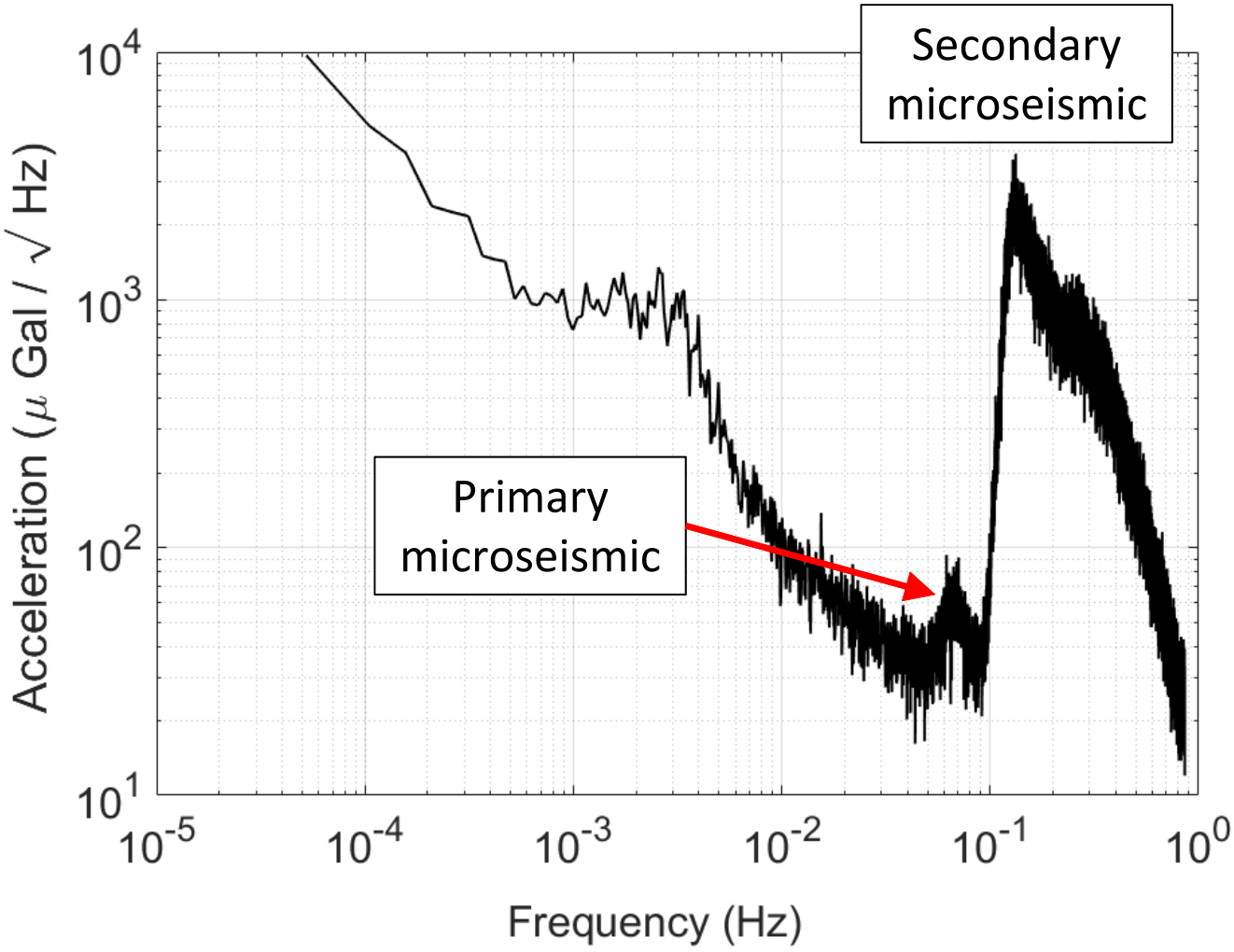




KELVIN NANOTECHNOLOGY

MEMS Field Prototype



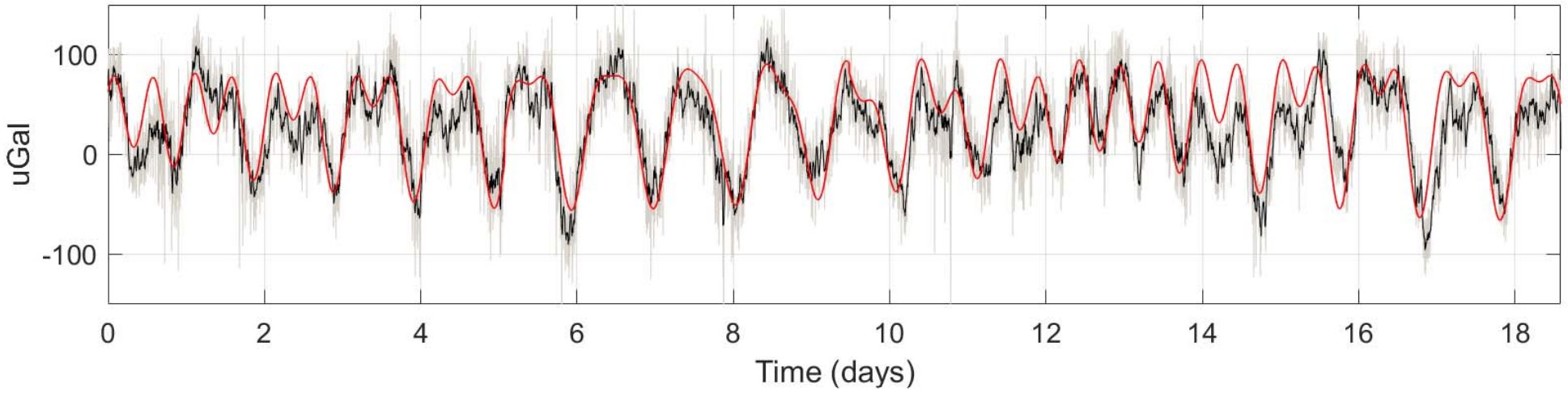


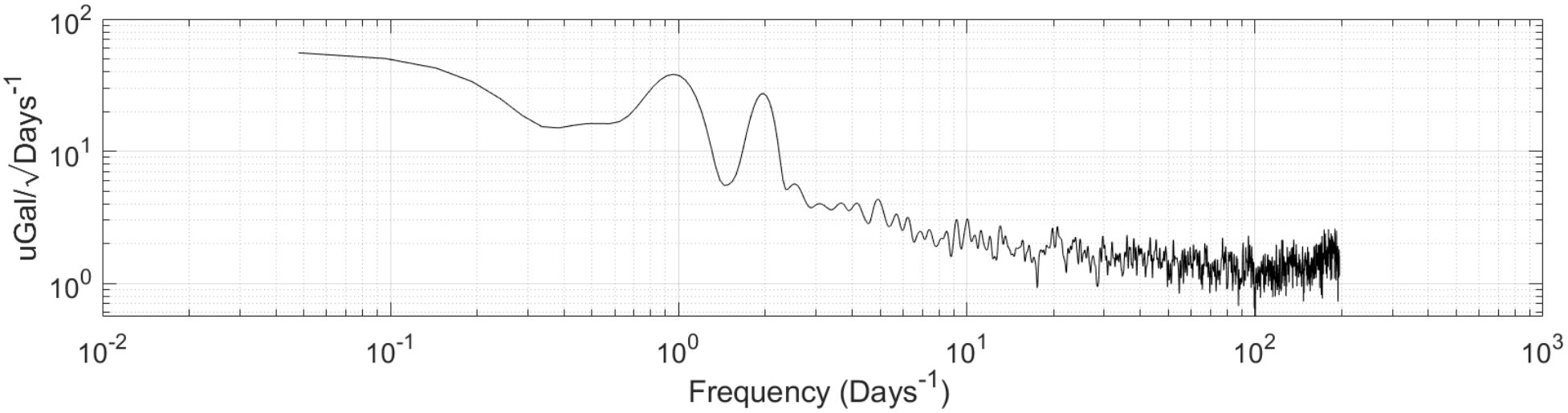
10 kg, 3.2 W, 15 hours battery

$\pm$ 2 mK temperature control

Long Term Gravity Monitoring

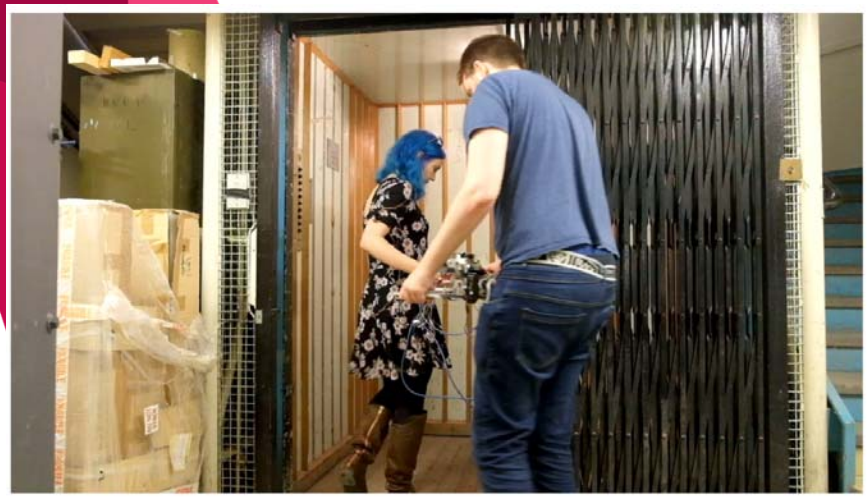
- Earth Tides detected last week with the new packaged Wee-g
- Long term monitoring over 19 days

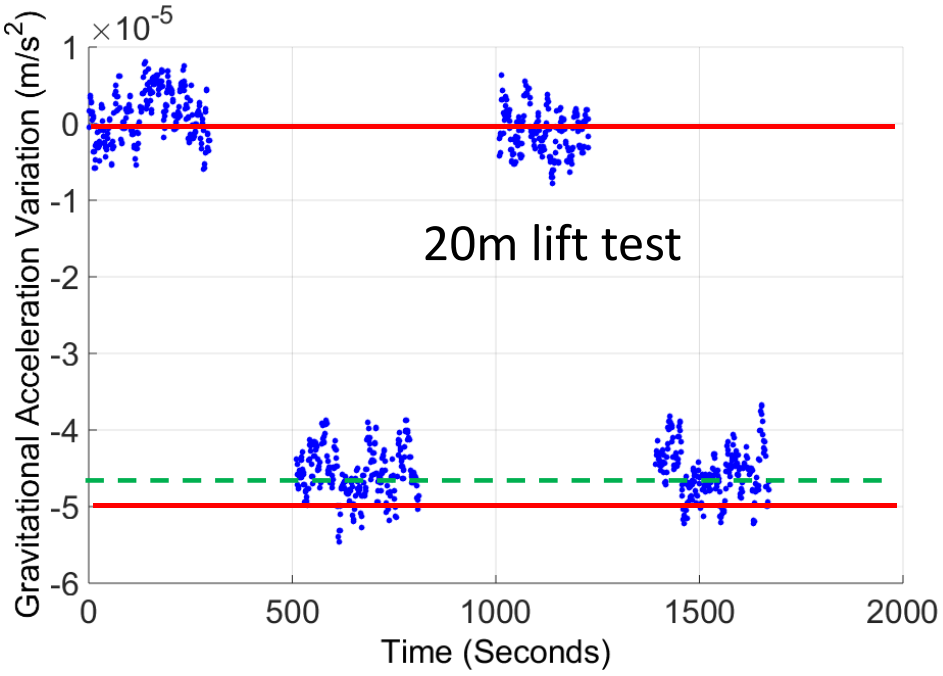




1µGal=10^{-8}m/s^2

Field Tests: In a Lift



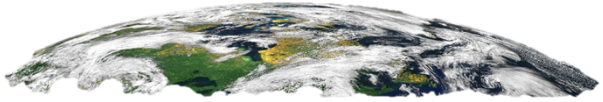


9.80994m/s²

20m

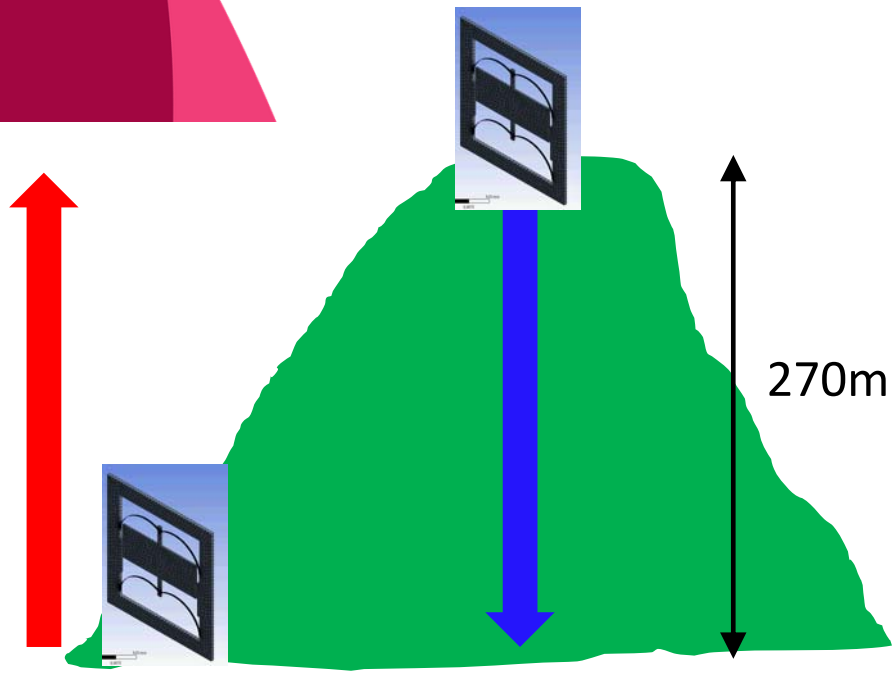
$$g = \frac{GM}{R_{Earth}^{\ 2}}$$

9.810000m/s²



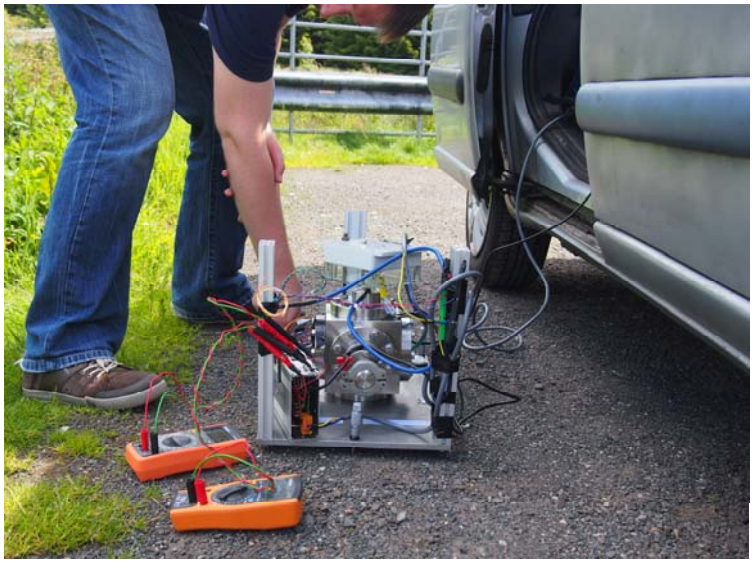
R. P. Middlemiss et al, Sensors **2017**, 17, 2571.

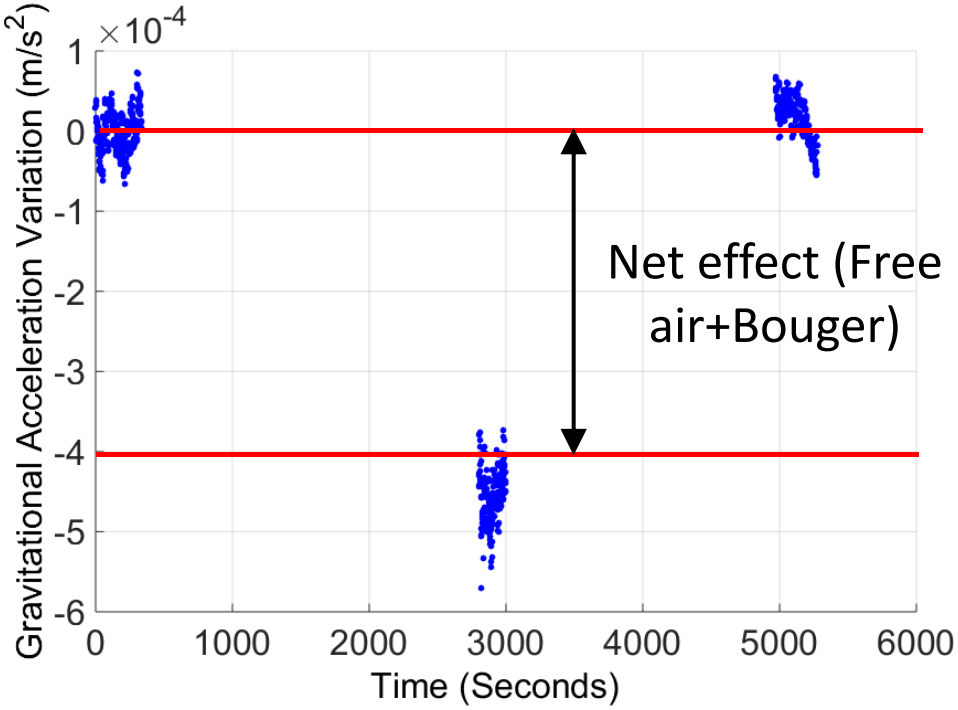
2017 Field Tests: Up a Hill



g reduces as moving away from earth (free air effect)

g increases as sitting on local rock (Bouger effect)

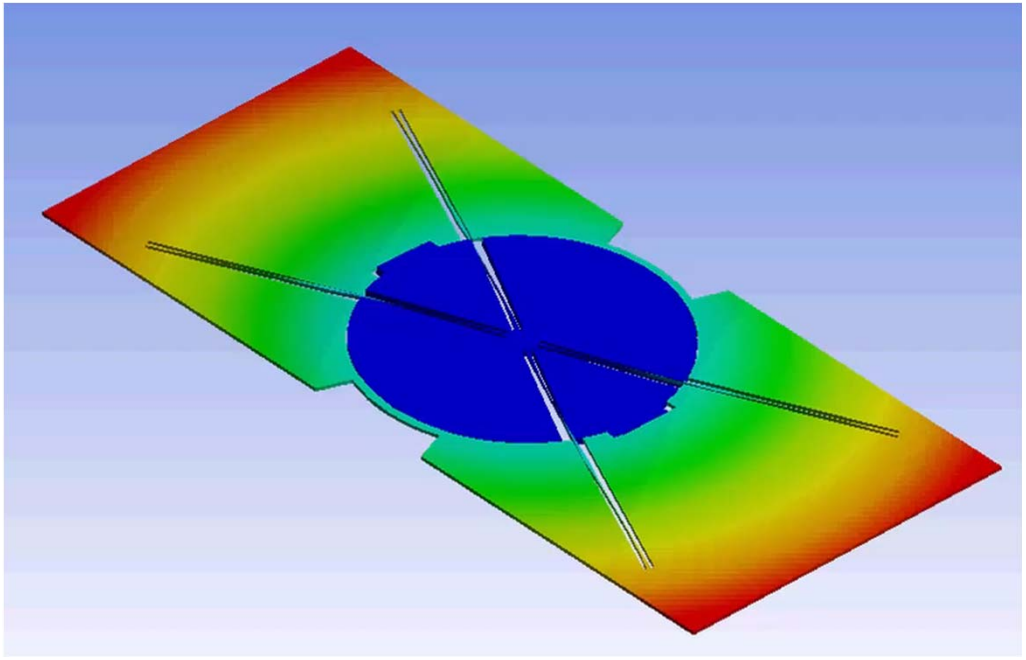




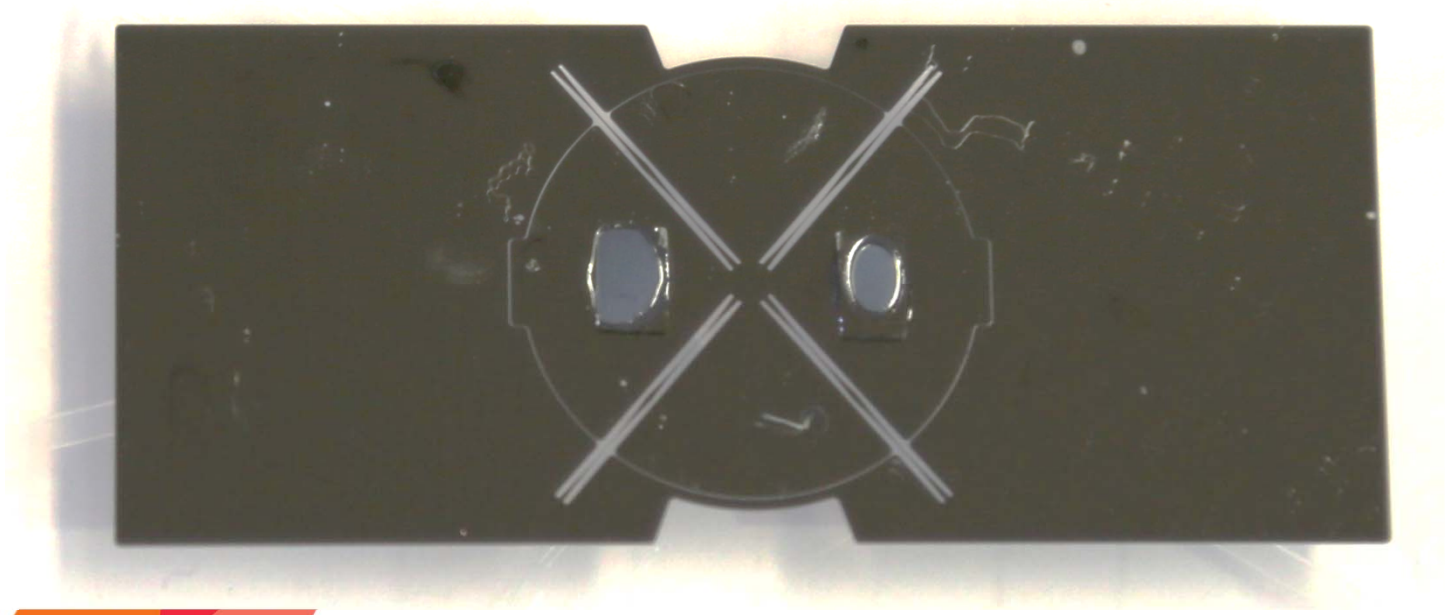
270m altitude change (Campsie Hills)

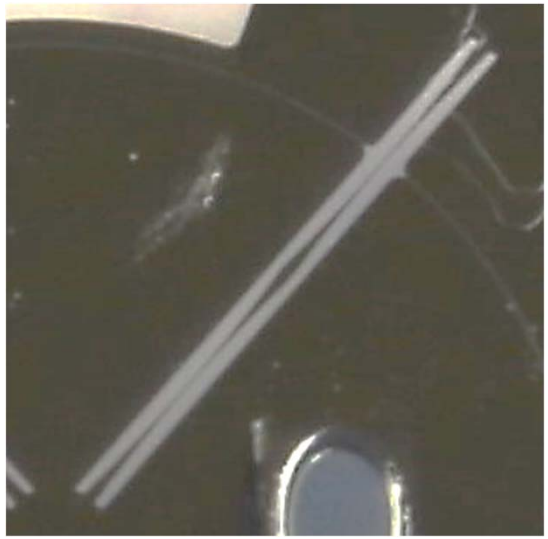
Wee-Grad

- Currently undertaking a 1 year field trial with BP
- Utilise torsion geometry to provide differential acceleration
- Target sensitivity 50 Eotvos/√Hz



Wee-Grad



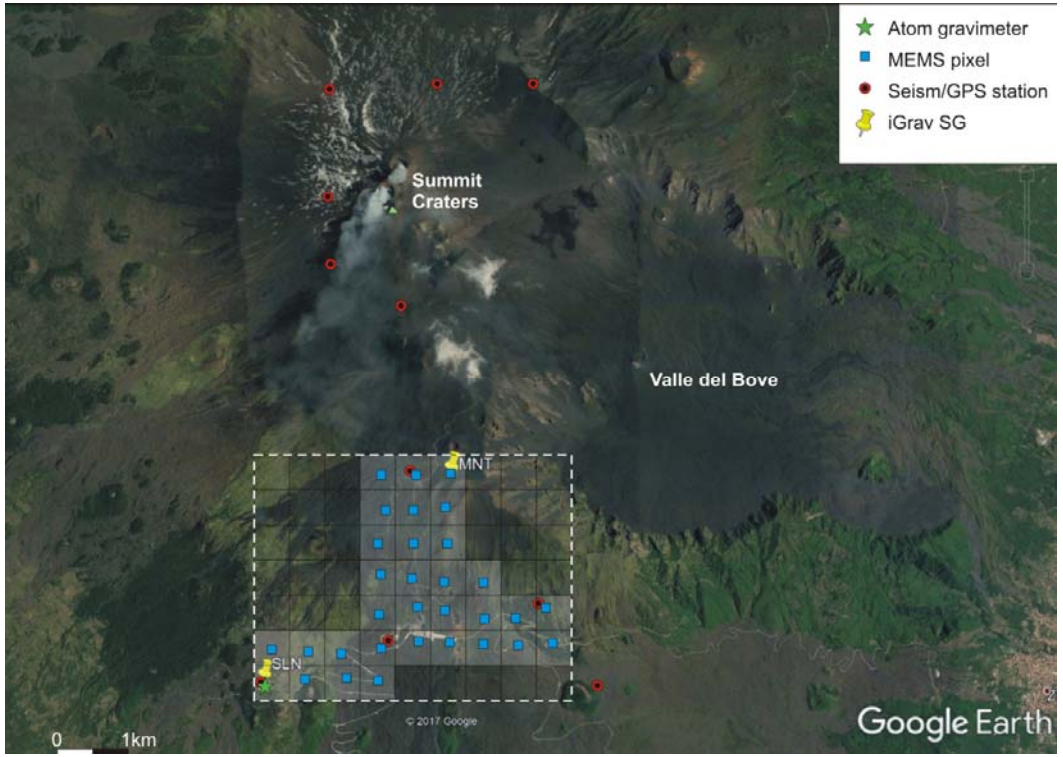


20μm thick flexures

- Devices currently being fabricated in Silicon
- Next steps:
  - Fabricate electrodes and integrate differential readout
  - Perform shake tests for robustness and common-mode rejection
  - Develop active/passive isolation systems

Future Opportunities

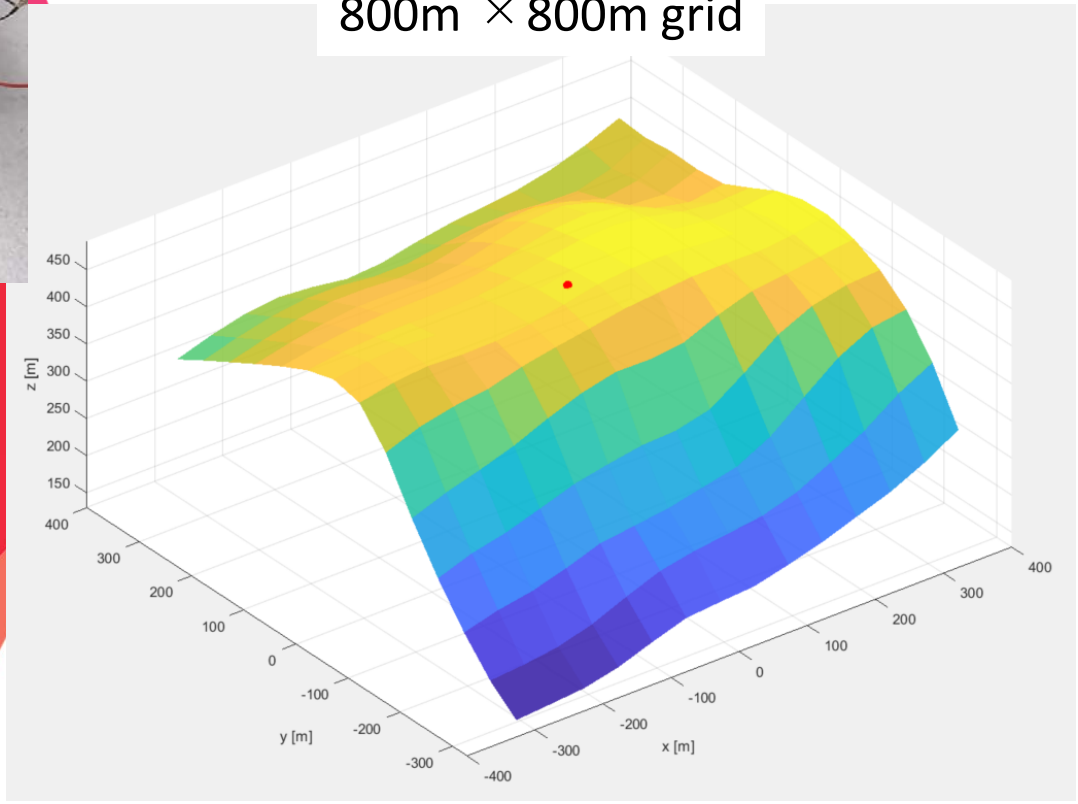
- FET-OPEN H2020 grant to deploy 70 MEMS onto Mt Etna by 2022 (www.newton-g.eu/)
- Combine a single absolute gravimeter and multiple MEMS “pixels” to image the lava plumbing system
- Sensitivity requirements around 50μGal

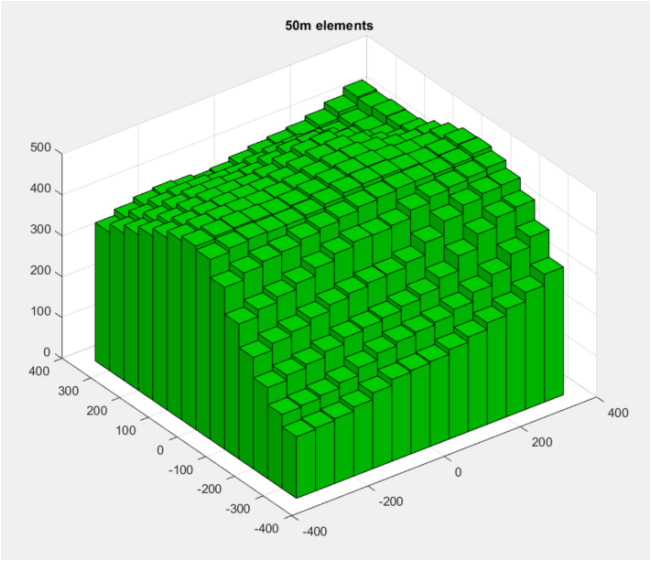


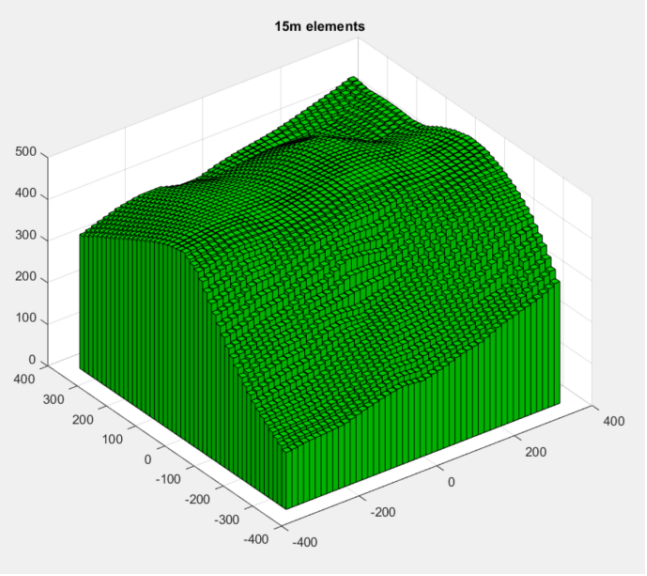
- Plan for a fully functional field prototype by Q3 of 2019
- Tests on the volcano in early 2020

Gravity Modelling for Land and Subsea Surveys

800m ×800m grid







- Developing tools for terrain/gravity modelling
- Hybrid meshing shows topology limits accuracy to few uGal

The Team

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R. Walker
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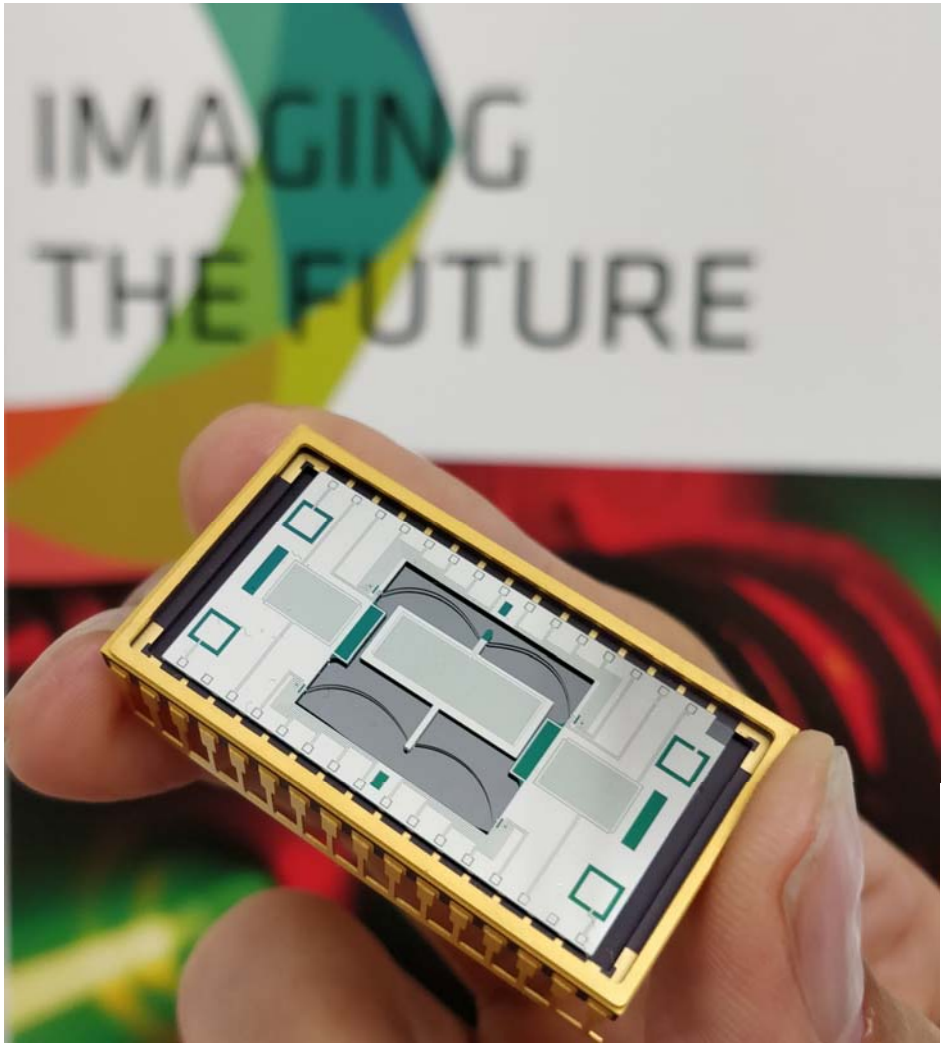
Conclusions



- > £4 million investment (industry/research council)
- Looking to spin-out company in 2019