

# UK National Quantum Technology Hub in Sensors and Metrology

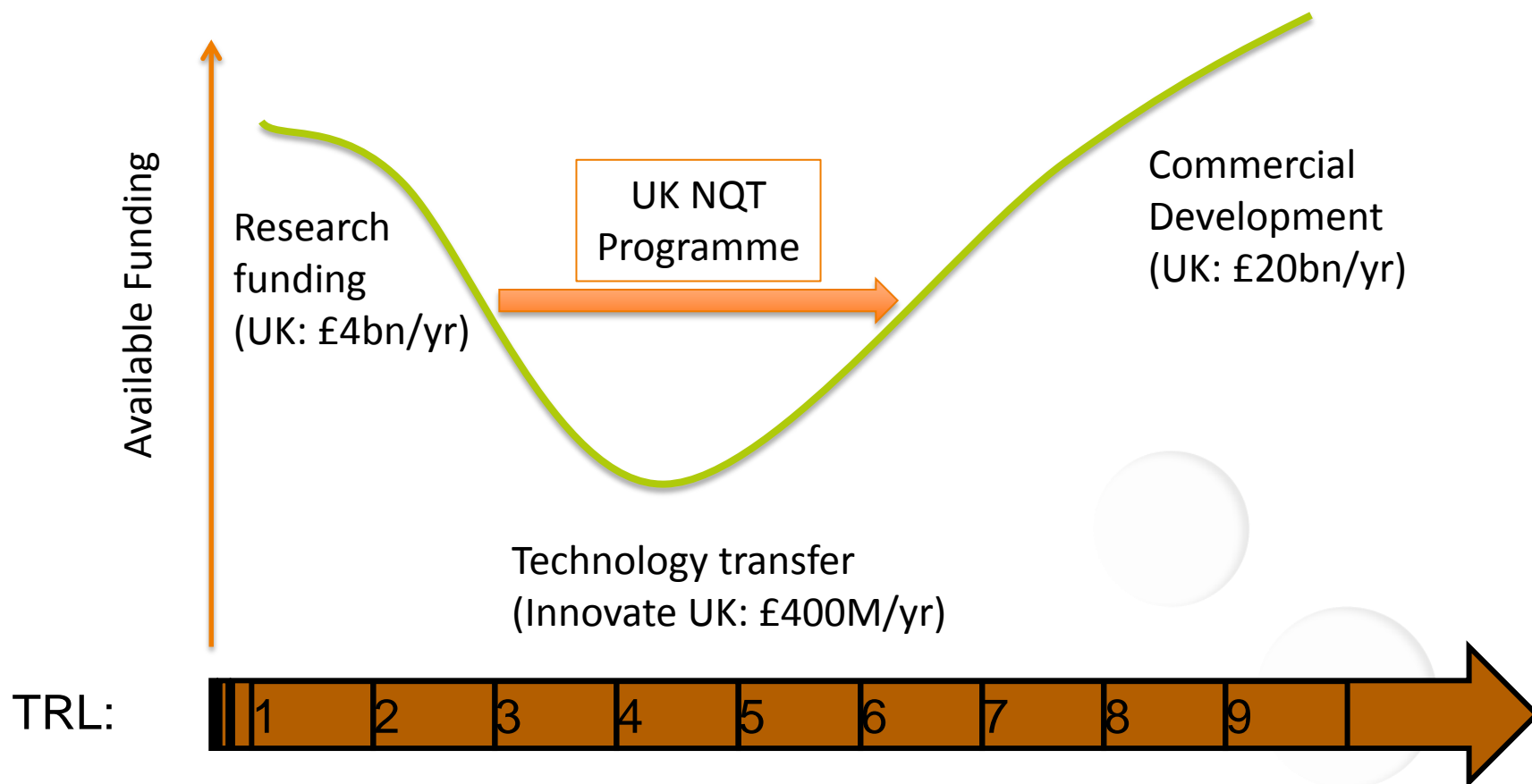
Prof. Kai Bongs, University of Birmingham  
Blue Sky Workshop


IEA Committee on Energy Research and Technology  
15 June 2017

# UK National Quantum Technologies Programme

- A **five-year £270M programme** announced by the UK government in the 2013 Autumn statement.
- Programme started October 2014.
- To exploit the potential of quantum science and develop a **portfolio of emerging technologies** with the potential to benefit the UK.
- Industry, government and academia working together to create opportunities for **UK wealth creation.**

# The “Valley of Death”



The logo features a large white letter 'Q' centered within three concentric, semi-circular arcs in shades of purple and blue.

# UK National Quantum Technology Hub

## Sensors and Metrology



UNIVERSITY OF  
BIRMINGHAM



University  
of Glasgow



The University of  
Nottingham  
UNITED KINGDOM - CHINA - MALAYSIA

UNIVERSITY OF  
Southampton

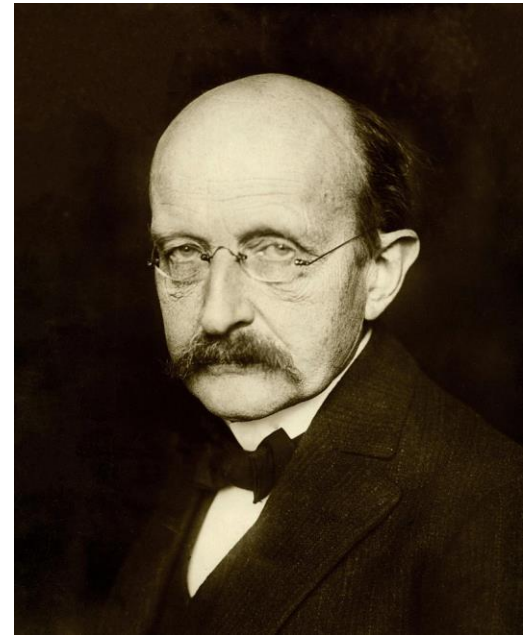
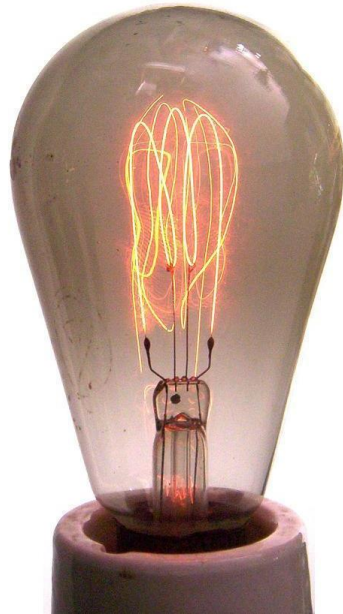


University of  
Strathclyde  
Glasgow

US

University of Sussex

# What is “Quantum”

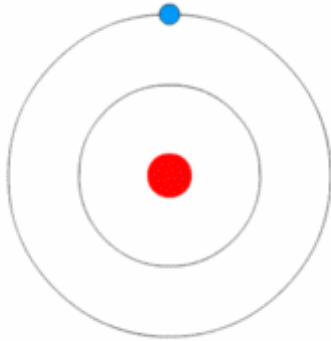


[https://en.wikipedia.org/wiki/Max\\_Planck#/media/File:Max\\_Planck\\_1933.jpg](https://en.wikipedia.org/wiki/Max_Planck#/media/File:Max_Planck_1933.jpg)

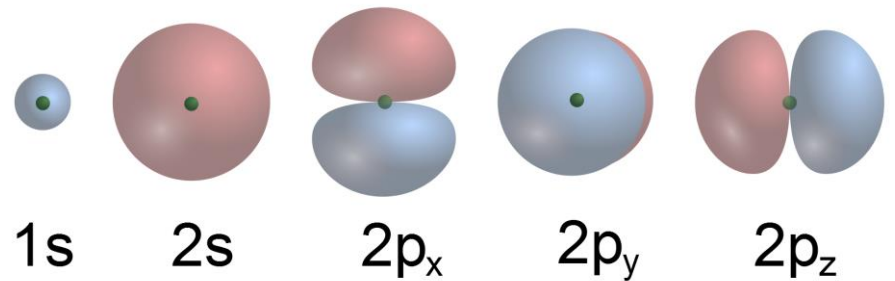
Planck postulate: electromagnetic energy could be emitted only in quantized form

$$E = h \nu$$

# Quantum Waves

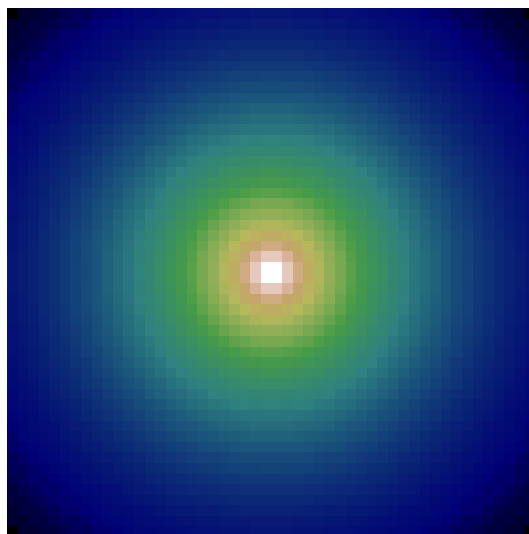


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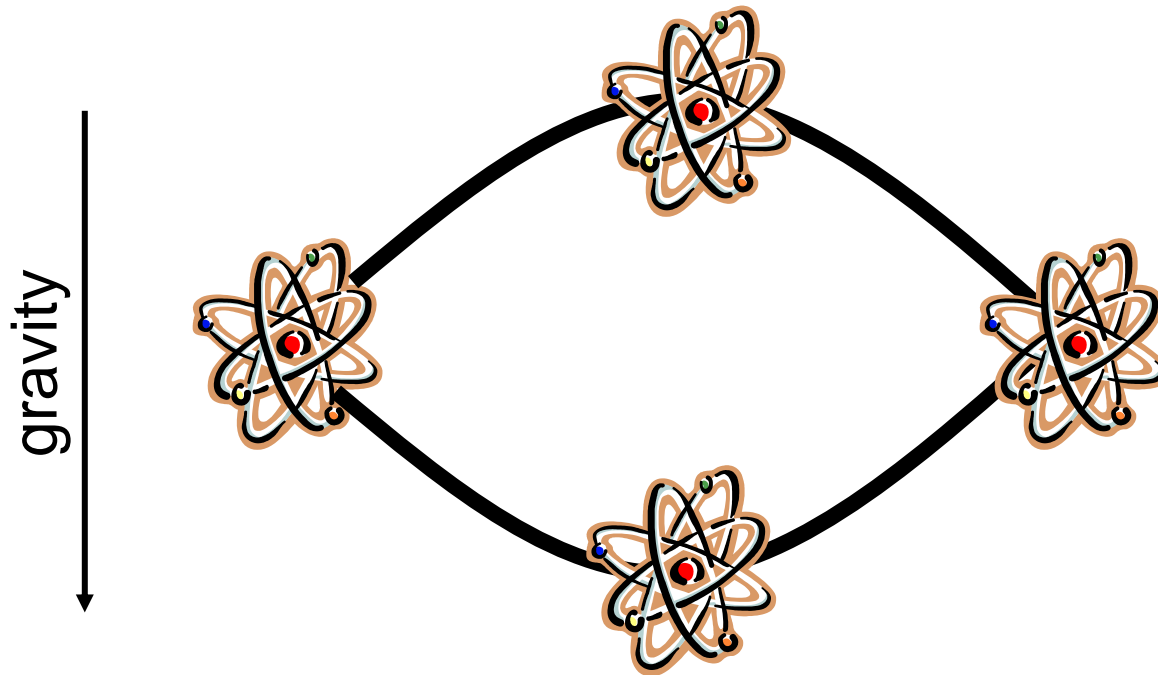
By This file was made by User:Sven  
(<http://creativecommons.org/licenses/by-sa/3.0/>), CC BY-SA 2.5-2.0-1.0

# Light-Atom Interactions



Source: <http://iff.physik.unibas.ch/~florian/rabi/rabi.html>

# What we do: Atoms manipulated by laser light

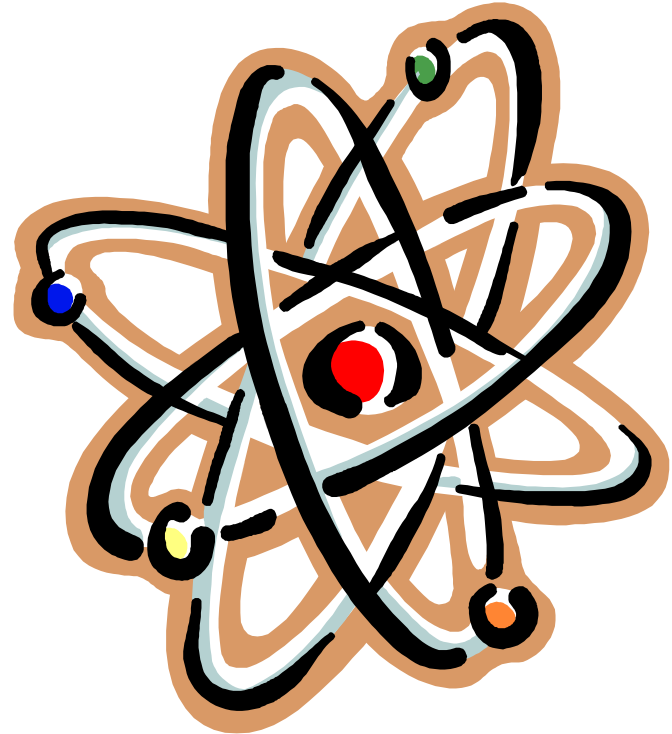


Also possible: rotation, time, magnetic fields,...



# The Atom: a Perfect Probe Particle?

- Always made the same by nature
- “Point-like”
- Well understood energy levels and interactions
- Can be precision manipulated by laser light
- ***But: need to be controlled, in order to allow interrogation***



# Laser cooling



## The Nobel Prize in Physics 1997

"for development of methods to cool and trap atoms with laser light"



S. Chu

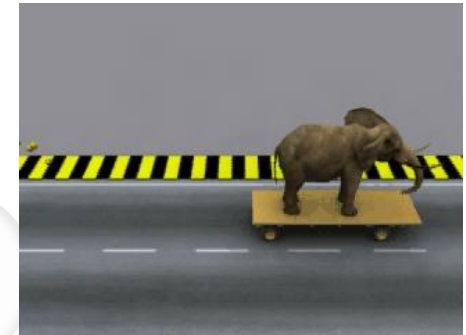
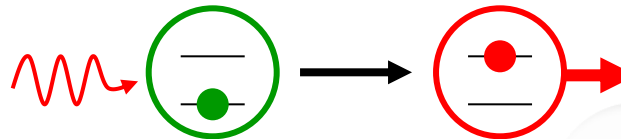


C. Cohen-Tannoudji

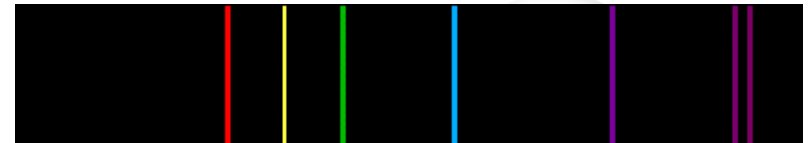


W.D. Phillips

1. photons have a momentum and transfer it to an atom upon excitation



2. Atoms absorb photons on narrow resonance lines



3. The Doppler effect causes a velocity dependence



# Laser cooling



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S. Chu

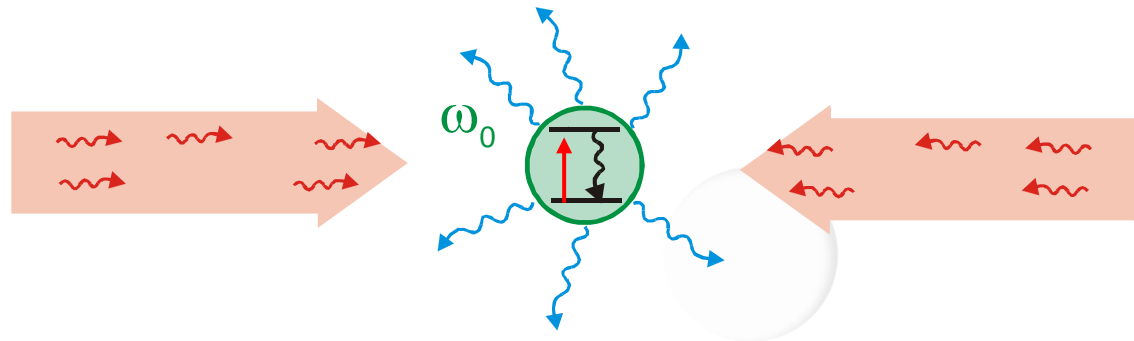


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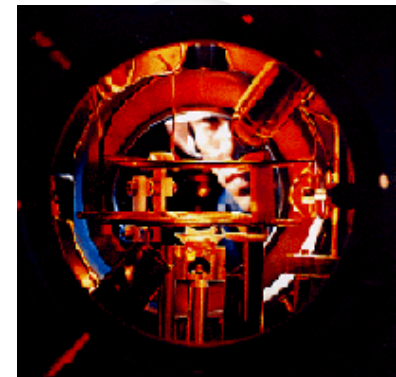
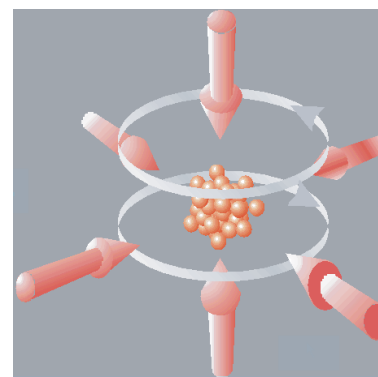


W.D. Phillips

the system:

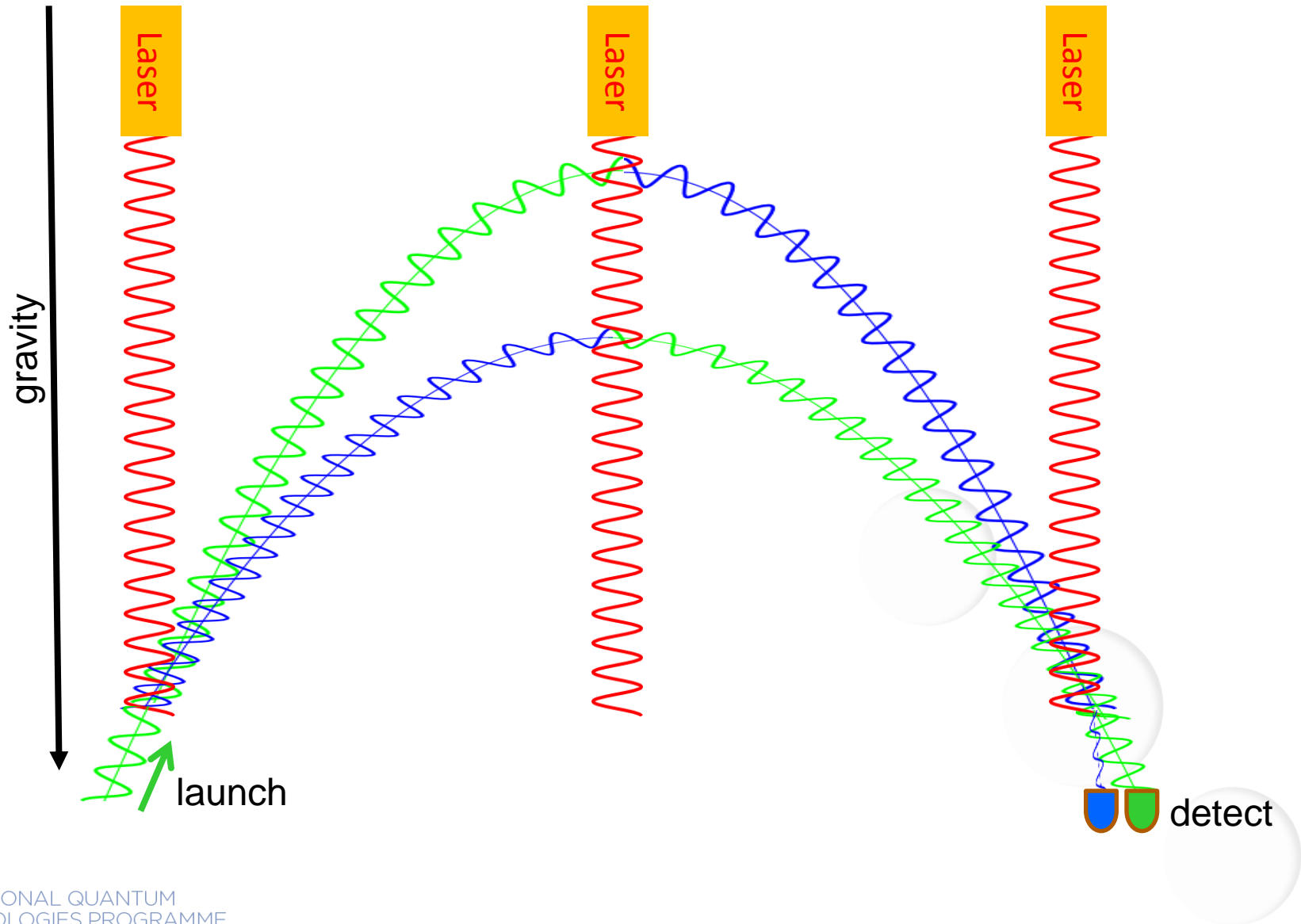


the result:



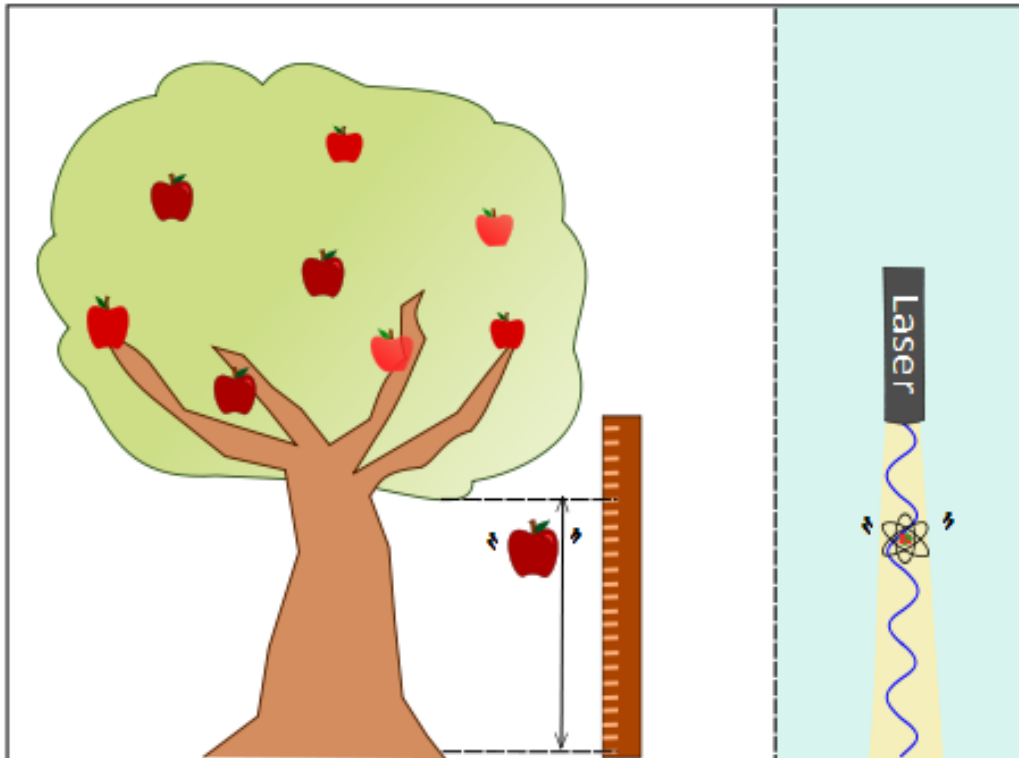
# Atom Interferometer Accelerometer

“Matter Wave Picture”



# Measuring Gravity

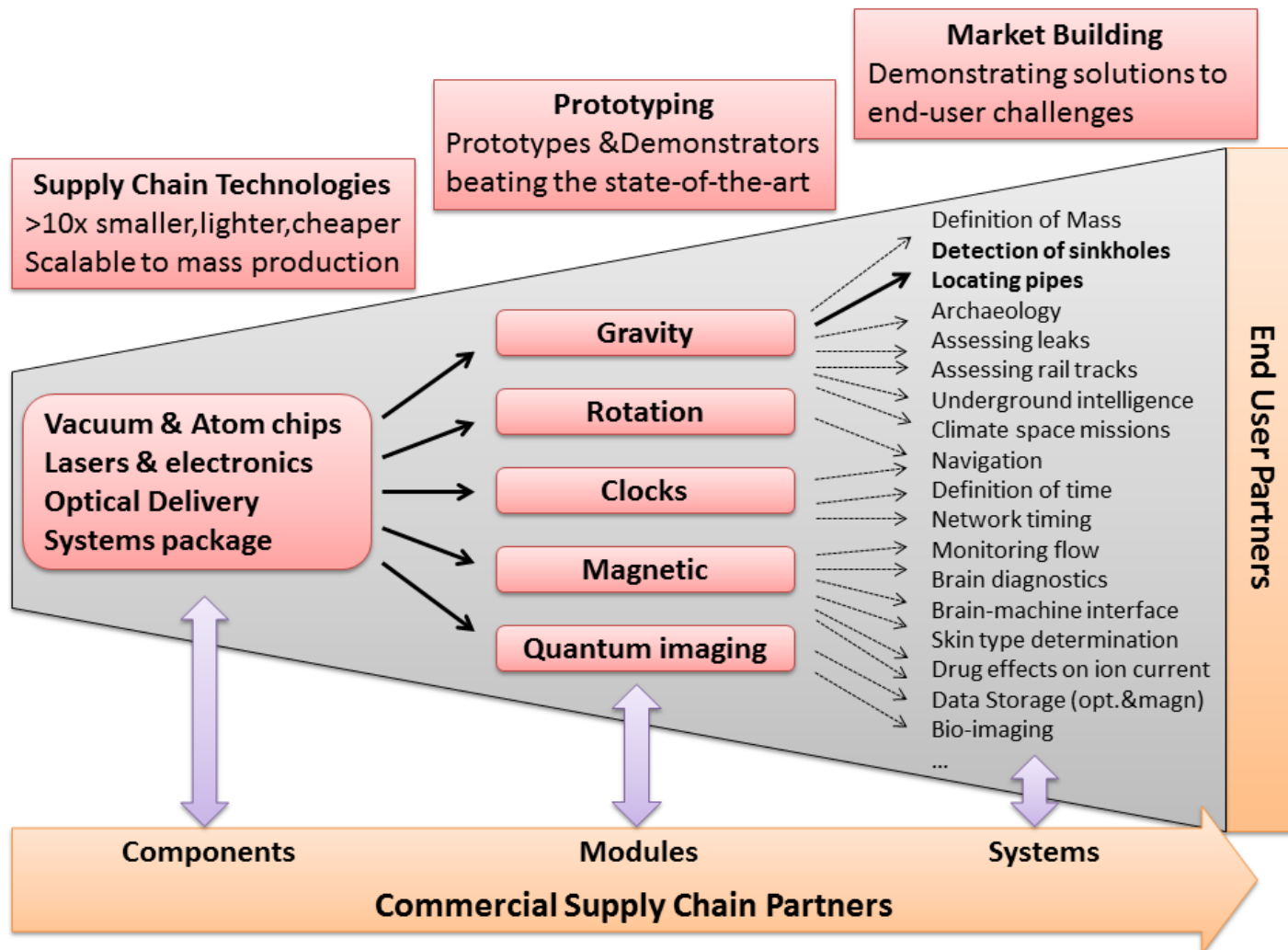
$$\Delta\Phi = k_z T^2 g_z = 2\pi \frac{\Delta z}{\lambda} \rightarrow \text{Dropping the atom next to a laser ruler}$$



# Accelerometer Operation



# Activities and Links



# Gravity Imager Impact Potential

**>\$1 trillion investment in irrigation and water management to 2050**

<http://www.fao.org/docrep/017/i1688e/i1688e.pdf>

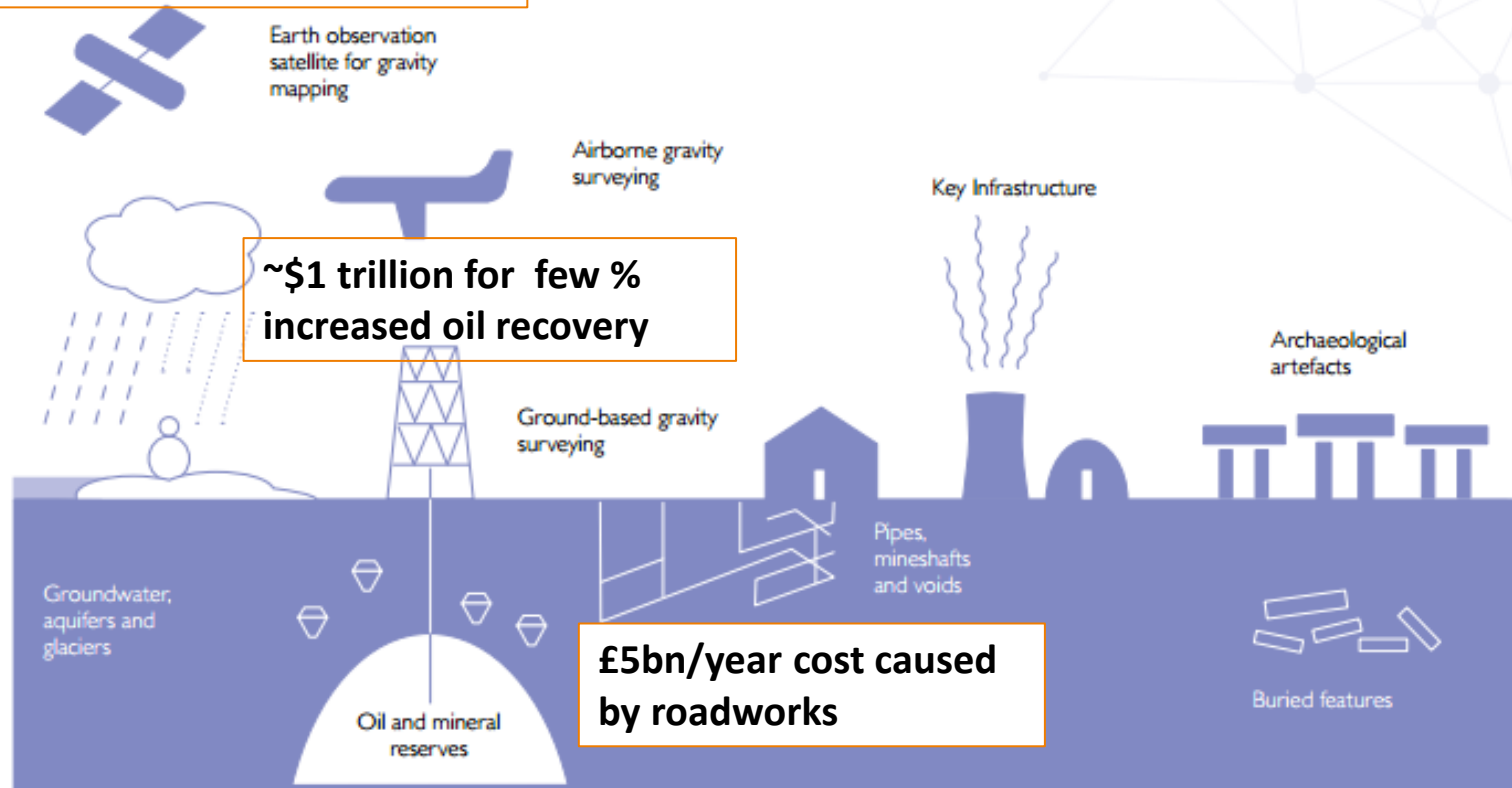


Image: Quantum Blackett Report:

[https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/564946/gs-16-18-quantum-technologies-report.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/564946/gs-16-18-quantum-technologies-report.pdf)



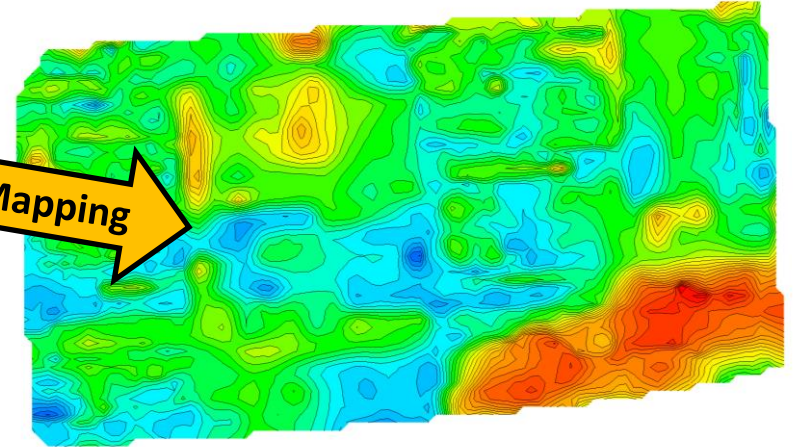
# Market Example WP11:

## QT Gravity Gradient Sensors for Underground Mapping

UNIVERSITY OF  
BIRMINGHAM



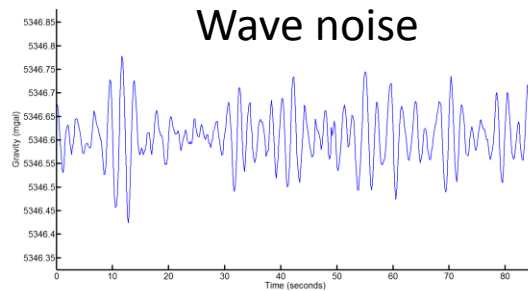
Gravity Mapping



**UK cost of digging up  
the roads : £5bn/yr**

# We don't really need better gravity sensors...

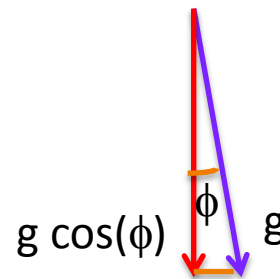
## • Acceleration vs gravity



Requirement to  
achieve 1 ng

Minutes / point

## • Tilt



0.001° alignment

# Gravity Gradiometer

- Acceleration vs gravity

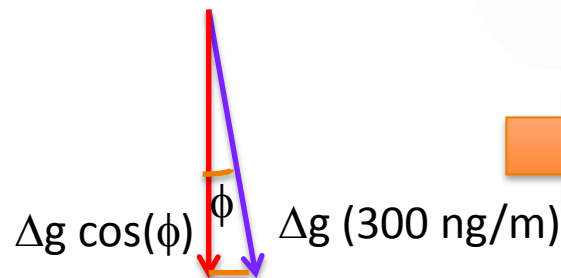
- suppression of accelerations

Requirement to  
achieve 1 ng/m



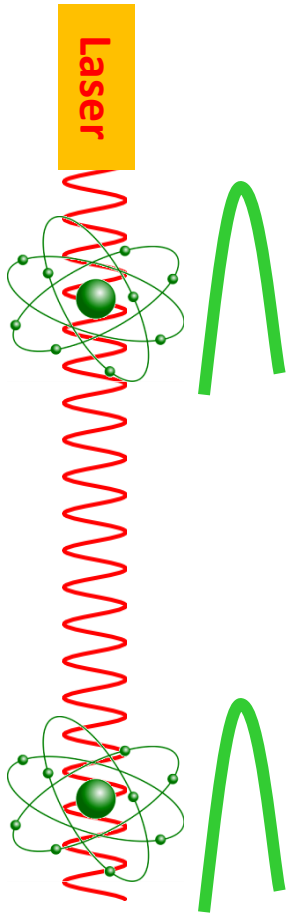
As fast as your  
instrument  
→ 1 s / point

- Tilt



3° alignment

# Cold Atom Gravity Gradiometer



## COLD ATOM TECHNOLOGY INTRINSICALLY REALISES THE PROMISES OF GRAVITY GRADIOMETERS

**Idea:** Simultaneously interrogate two atoms at different height using the same laser ruler

→ “perfect” suppression of acceleration due to “infinitely” rigid coupling  
(140dB demonstrated by Kasevich group)

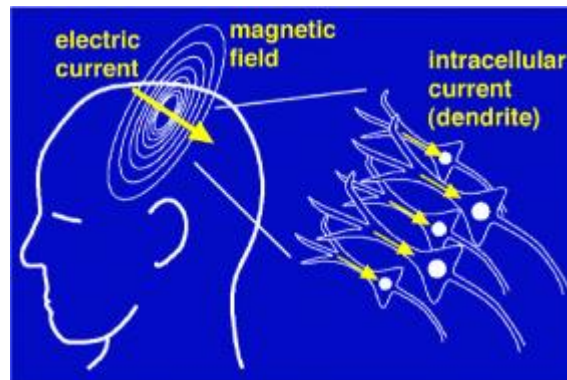
→ “perfect” alignment of gravimeter measurement axes  
(necessary for reduced tilt sensitivity)

# Does QT Work?



# QT Magnetic Sensors for Healthcare

- 10M cases of dementia each year worldwide
- Worldwide cost >£500bn/year (>1% GDP)
- QT for mobile monitoring and treatment





# Tests in MEG application



The University of  
Nottingham

UNITED KINGDOM • CHINA • MALAYSIA



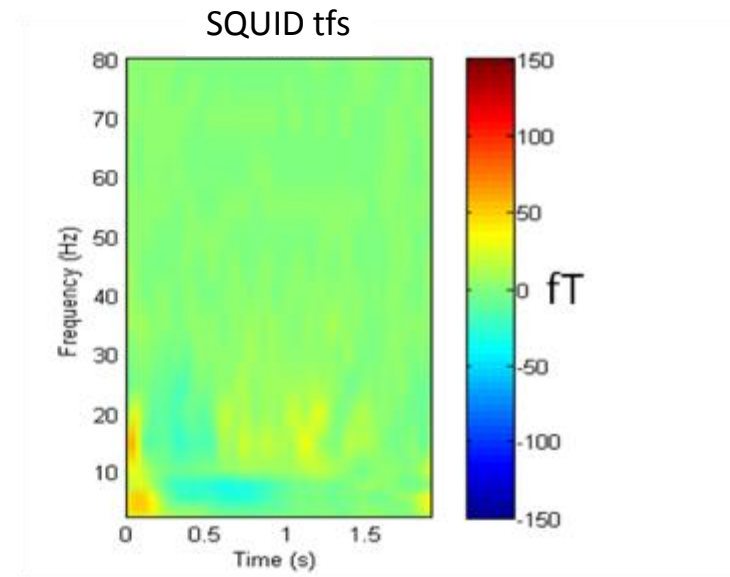
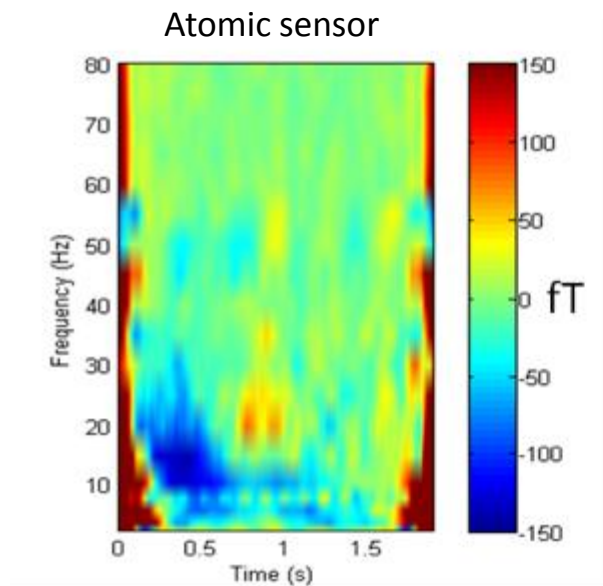
- 3d printed head cast enables fixed position direct comparison of OPMs to conventional SQUID sensors

# Market Example WP6: Thermal atom sensors for MEG



Some initial tests using a commercially available optical atomic magnetometer

- 5-fold increase in Signal-to-noise
- Example of temporal response to median nerve stimulus





# QT Game Changers Healthcare



- MEG helmet operating in natural environment

- Cost ~£20k

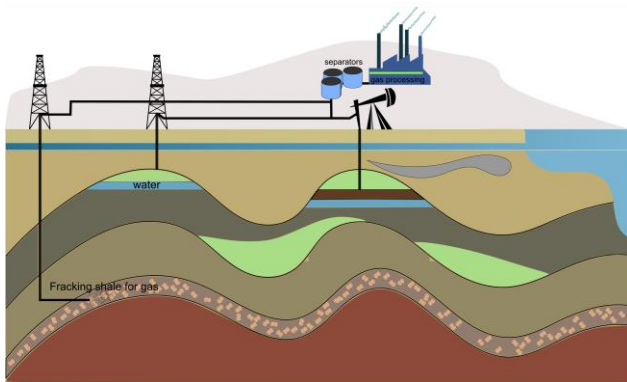


- **QT MEG could provide early diagnosis methods for dementia, opening up effective treatment**

# Potential Uses of QT in Energy?



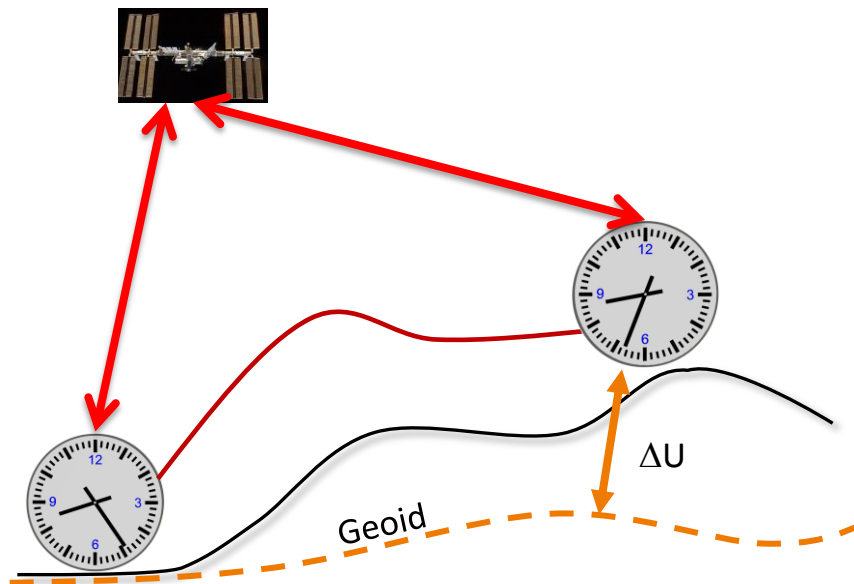
- Gravity for monitoring of geophysics changes:
  - carbon storage
  - Shale gas and oil
- Down borehole gravity gradiometers



# Potential Uses of QT in Energy?



- Cocks for height referenced to Earth potential  
“Relativistic Geodesy”



$$\frac{\Delta \nu}{\nu} = \frac{\Delta U}{c^2} = \frac{10^{-16}}{\text{m}}$$



European Vertical Reference Frame 2007 (EVRF2007)  
Source: <http://www.bkg.bund.de>

Vermeer, Rep. of the Finnish Geod. Inst. 83, 1 (1983)  
Bjerhammar, Bull. Geodesique 59, 207 (1985)

# Potential Uses of QT in Energy?

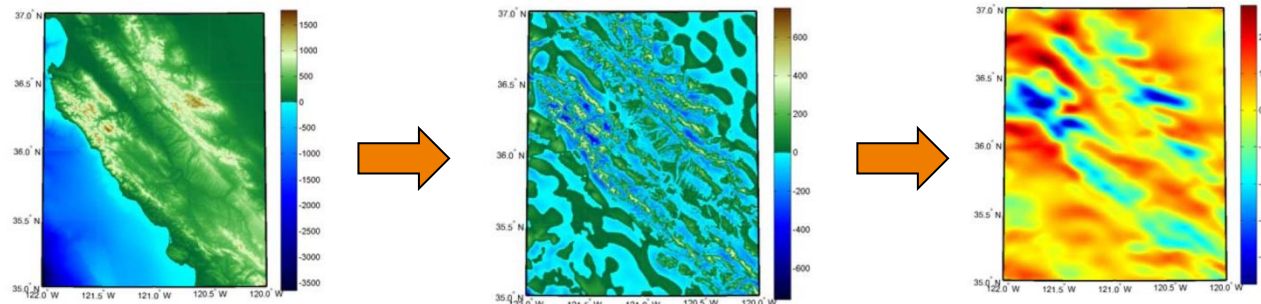


- Subsea navigation with Gravity Gradient map matching?

2013 American Control Conference (ACC)  
Washington, DC, USA, June 17-19, 2013

## Modeling Earth's Gravitational Gradients for GPS-Free Navigation<sup>†</sup>

Troy C. Welker,<sup>1</sup> Richard E. Huffman, Jr.,<sup>2</sup> and Meir Pachter<sup>3</sup>



- Simulate aircraft with 300m/s at 5km height and a 4mE sensor → below 10m deviations after 1hr.

# Thank you for listening

