Science & Technology Facilities Council

Gravity Measurements with Cold Atoms

RAL Space

Tristan Valenzuela

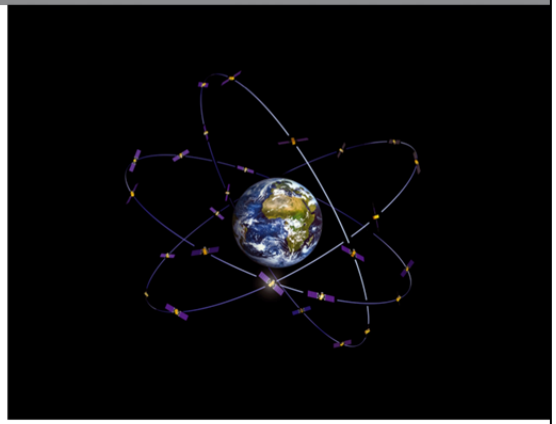
RAL Space

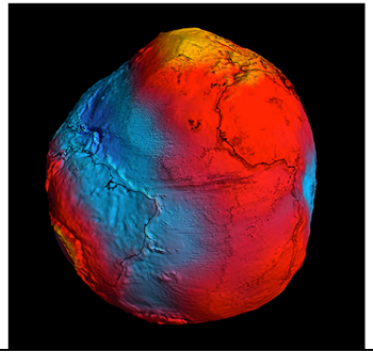
From B. Leone's presentation

Cold Atom Interferometry — Applications

esa

- Inertial Navigation
- Attitude Monitoring
- Accelerometers for Drag-Free Systems
- Deep Space Accelerometers
- Gravity Mapping
- Fundamental Physics:
  - Testing General Relativity
  - Short-Range Forces
  - Atom-Surface Interactions
  - Fundamental Constants
  - Electron Electric Dipole Moment
  - Spin-Gravity Coupling
  - Quantum Fluctuations
  - Decoherence



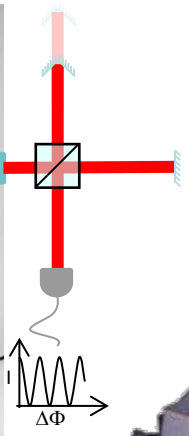


European Space Agency

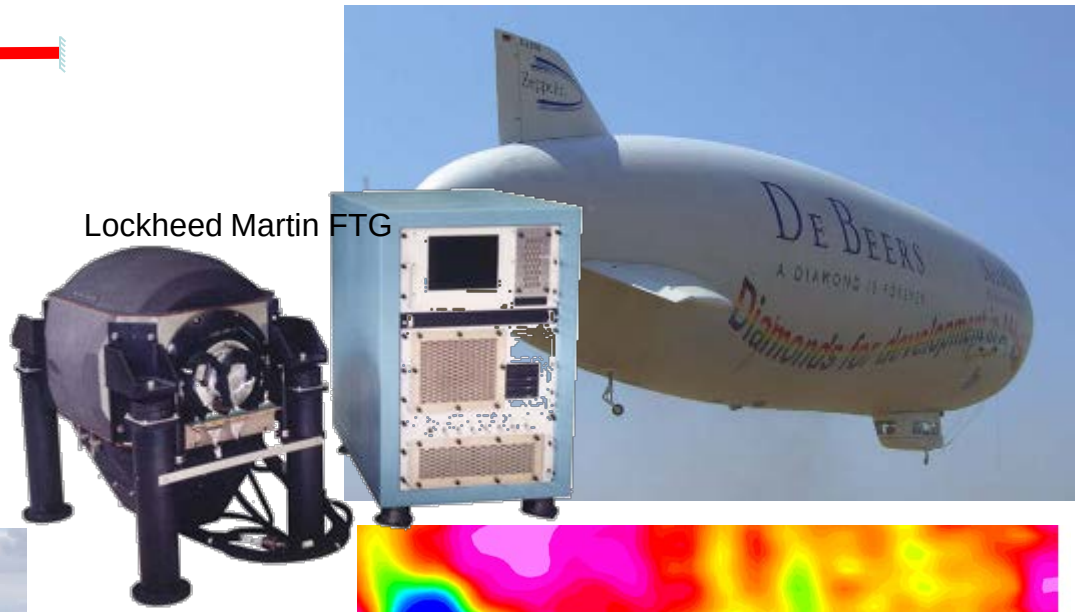
Outline

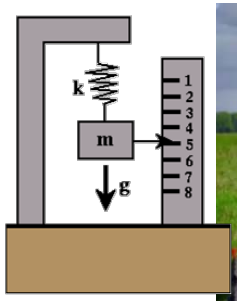
- Current Gravity Mapping
- Cold Atom Interferometry: How it works
- AI out of the lab in the UK and Overseas
- Quantum Technologies UK strategy
- QT at RALSpace

Gravity measurements

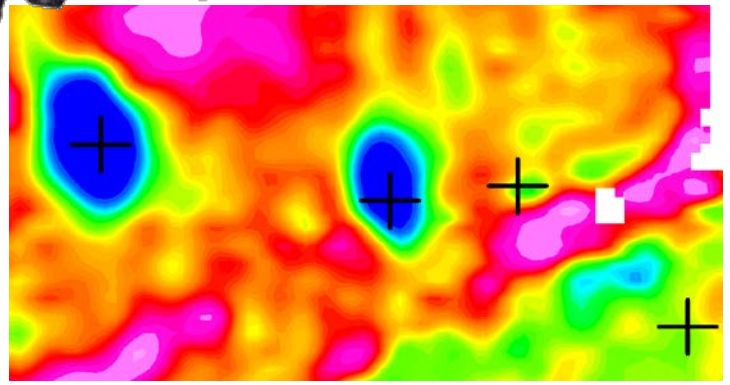


Lockheed Martin FTG

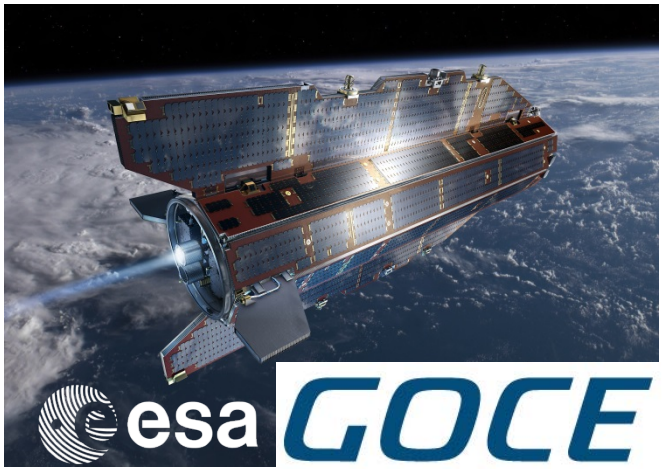


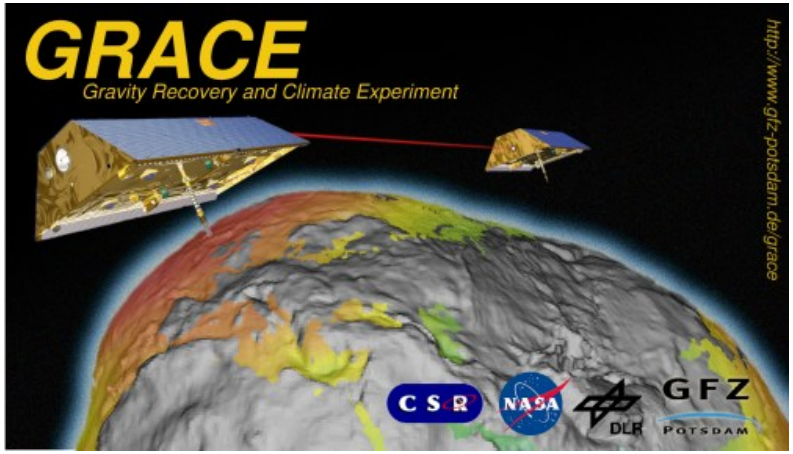


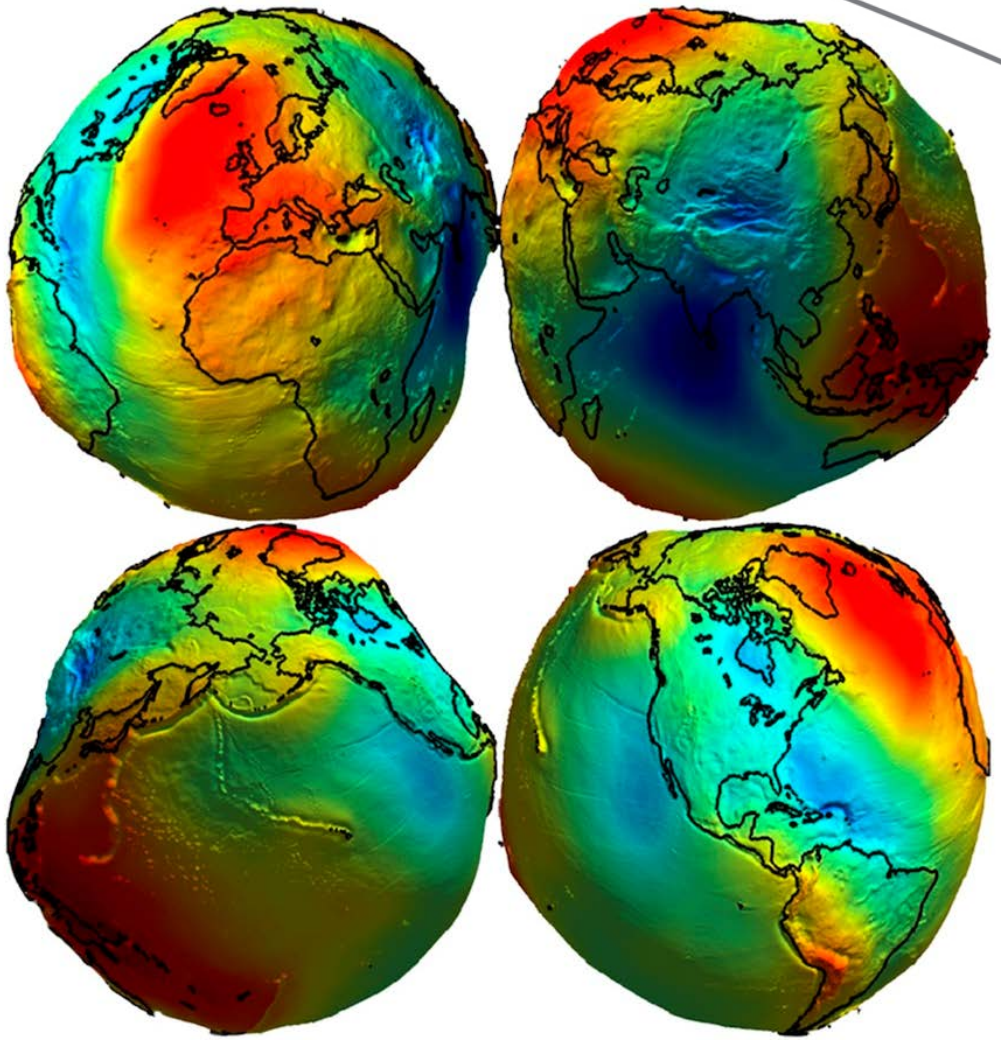
Scintrex CG5



Gravity measurements



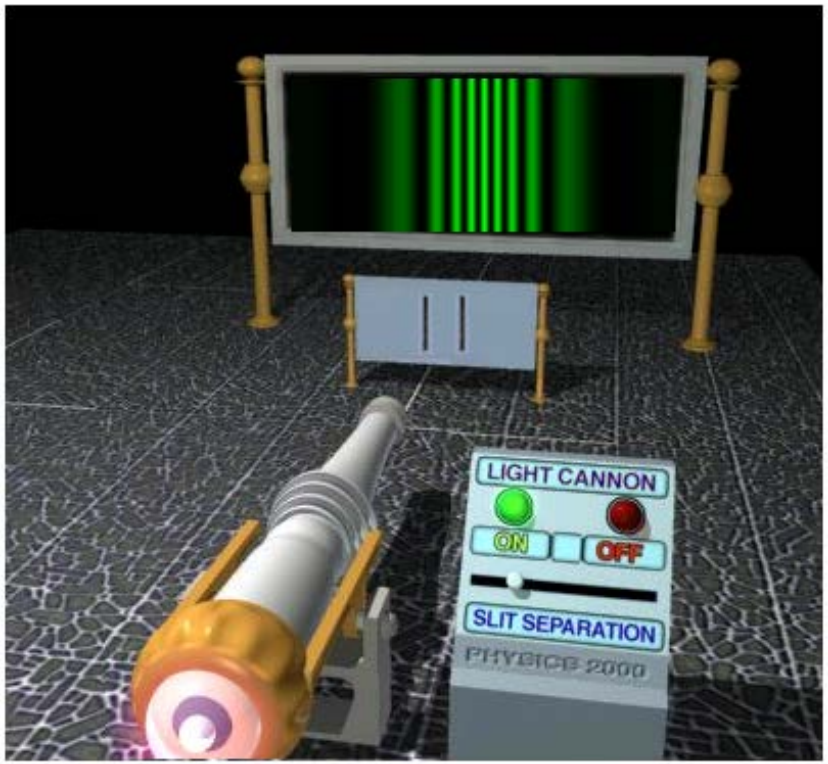




Interferences with Light

Young's double slit

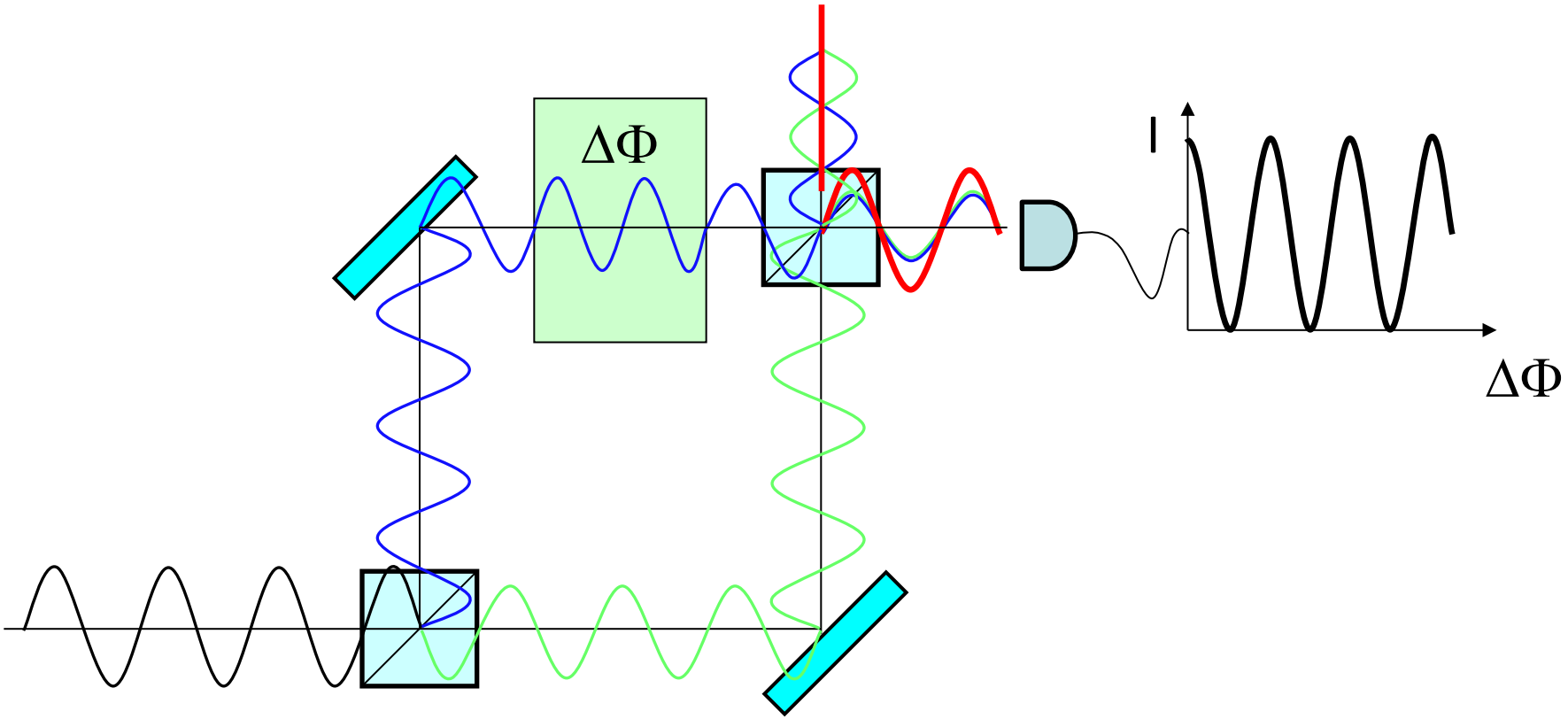
Phil. Trans. Roy. Soc. **92**, 387 (1802)
DOI:10.1098/rstl.1802.0016



http://www.colorado.edu/physics/2000/schroedinger/two-slit2.html

Interferences with Light

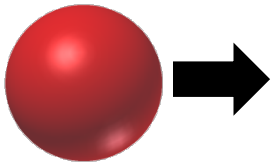
Mach-Zehnder Interferometer

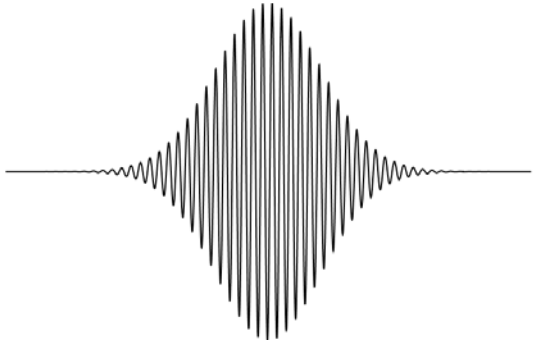


Wave-Particle Duality

- de Broglie, Ann. Phys. **3**, 32 (1925)
  $\lambda = \mathbf{h/p} = \mathbf{h/mv}$ de Broglie wavelength

- Electron diffraction by Davisson and Germer, Phys. Rev. **30**, 705 (1927)





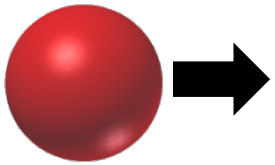
Wave-Particle Duality

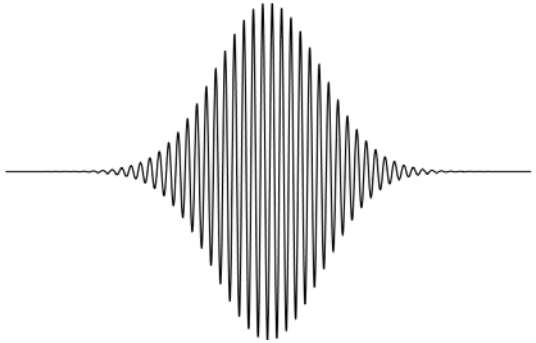
de Broglie wavelength of an Atom

$$\lambda = h/p$$

$$p = (3\, m\, k_B T)^{1/2}$$

eg. ^{87}Rb $m = 1.4 \times 10^{-25}$kg, $T = 10\mu K$ $\Rightarrow$ $\lambda \sim 100$nm



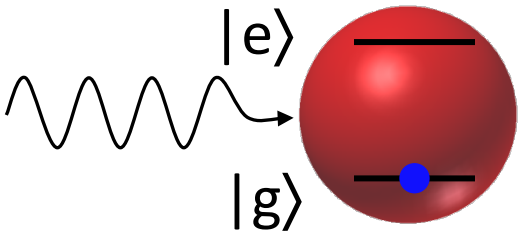


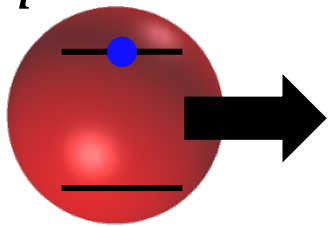
Momentum Conservation

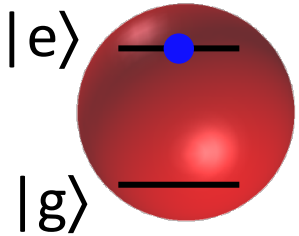
Two level atom

$E = \hbar\omega$

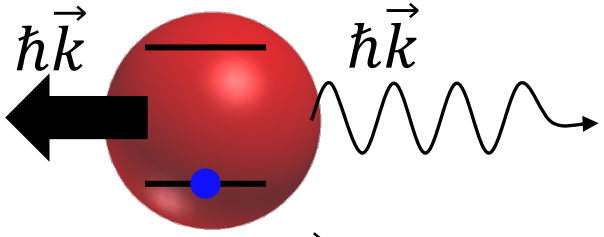
$\vec{p} = \hbar\vec{k}$







$\vec{p} = 0$



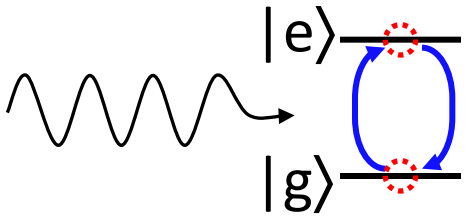
$\vec{p} = -\hbar\vec{k}$

$$|\vec{p}| = \frac{E}{c}$$

$$|\vec{k}| = \frac{\omega}{c} = \frac{2\pi}{\lambda}$$

Rabbi Oscillation

Two level atom



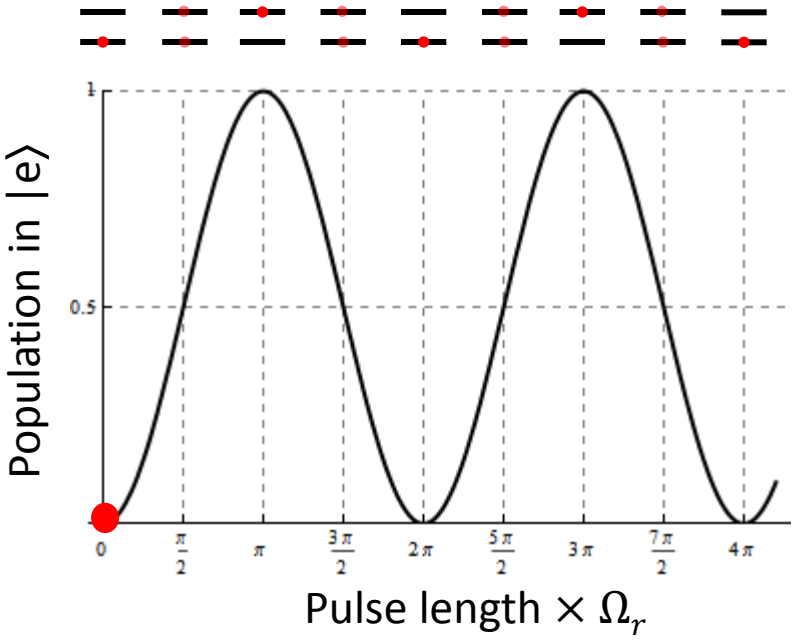
Population in $|e\rangle \sim \cos^2(\Omega_r t)$

Rabi frequency $\rightarrow \Omega_r = \sqrt{{\Omega_{eg}}^2 + \delta^2}$

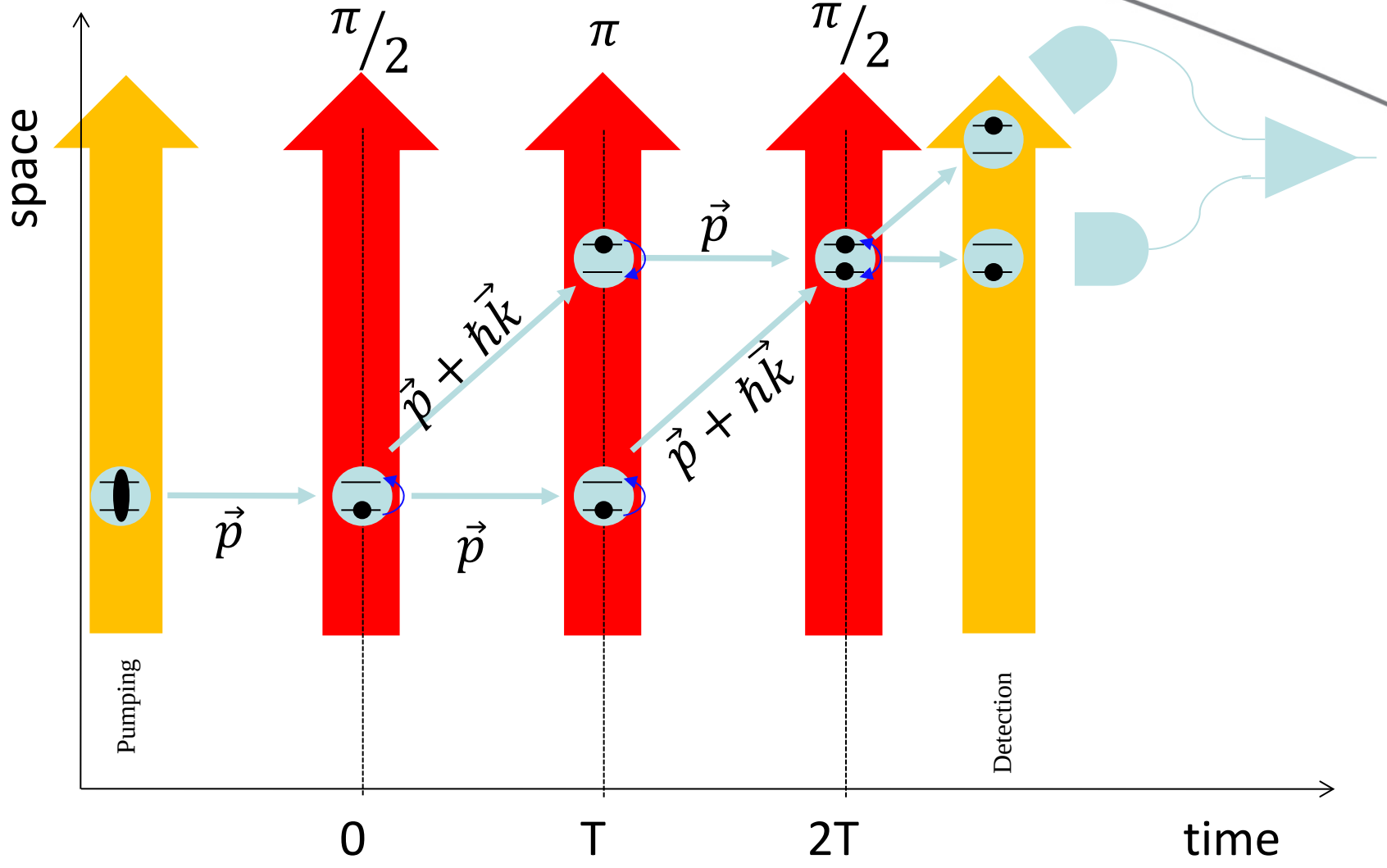
$$\Omega_{eg} = \frac{\langle e|\vec{d} \cdot \overrightarrow{E_0}|g\rangle}{\hbar}$$

$$\delta = \omega_L - \omega_{eg}$$

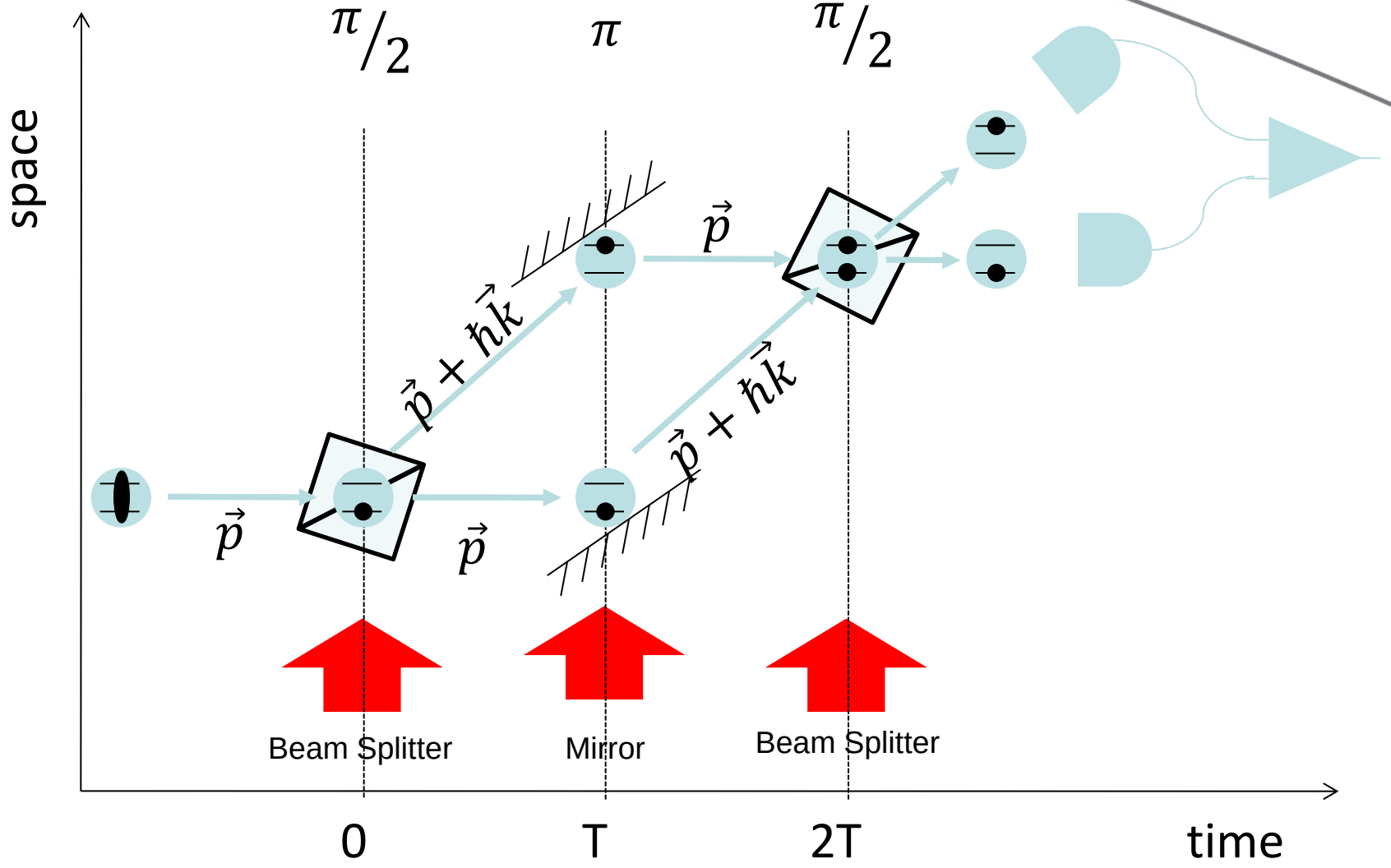
$$\omega_{eg} = Eeg \,/\, \hbar$$



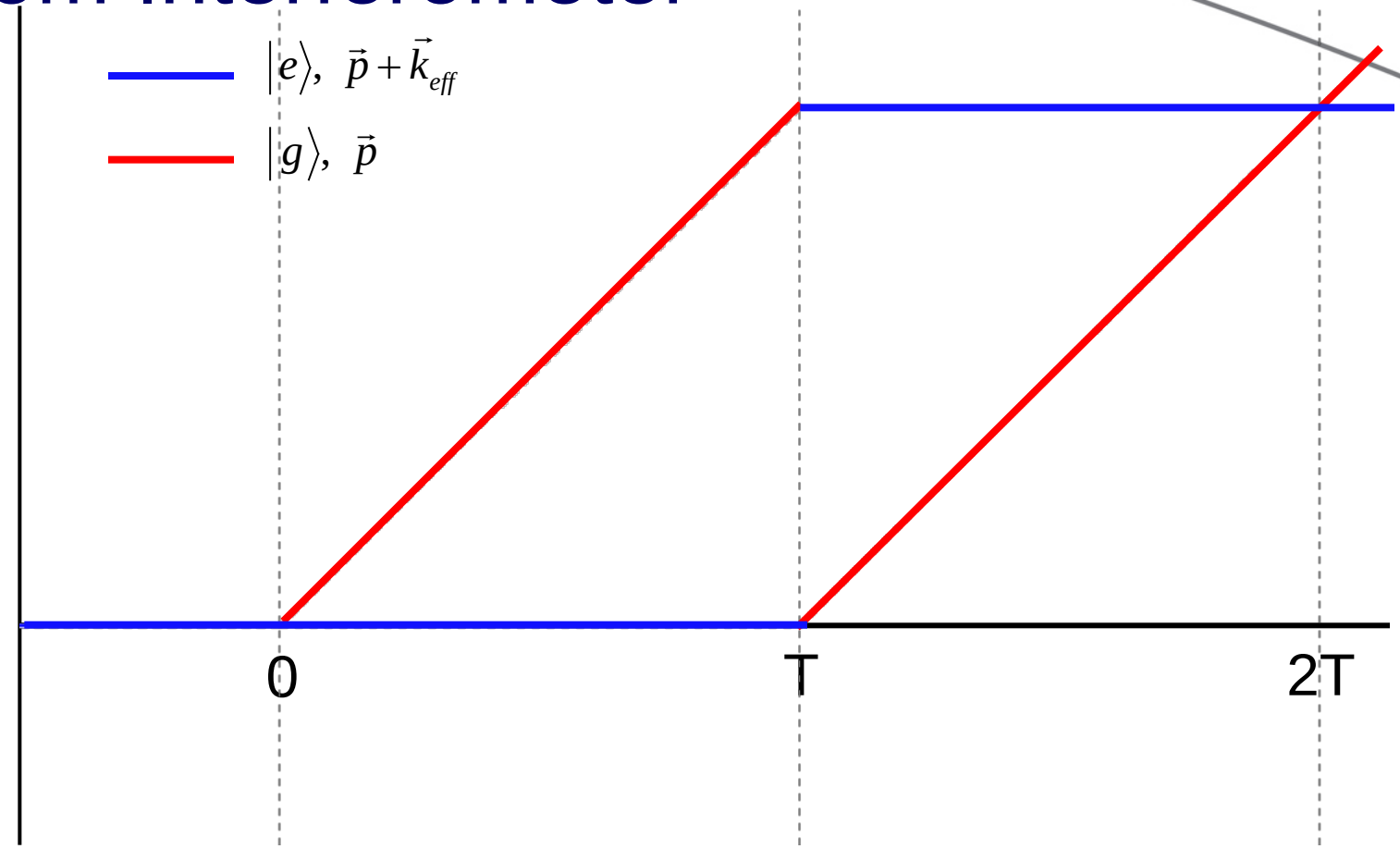
Atom Interferometer



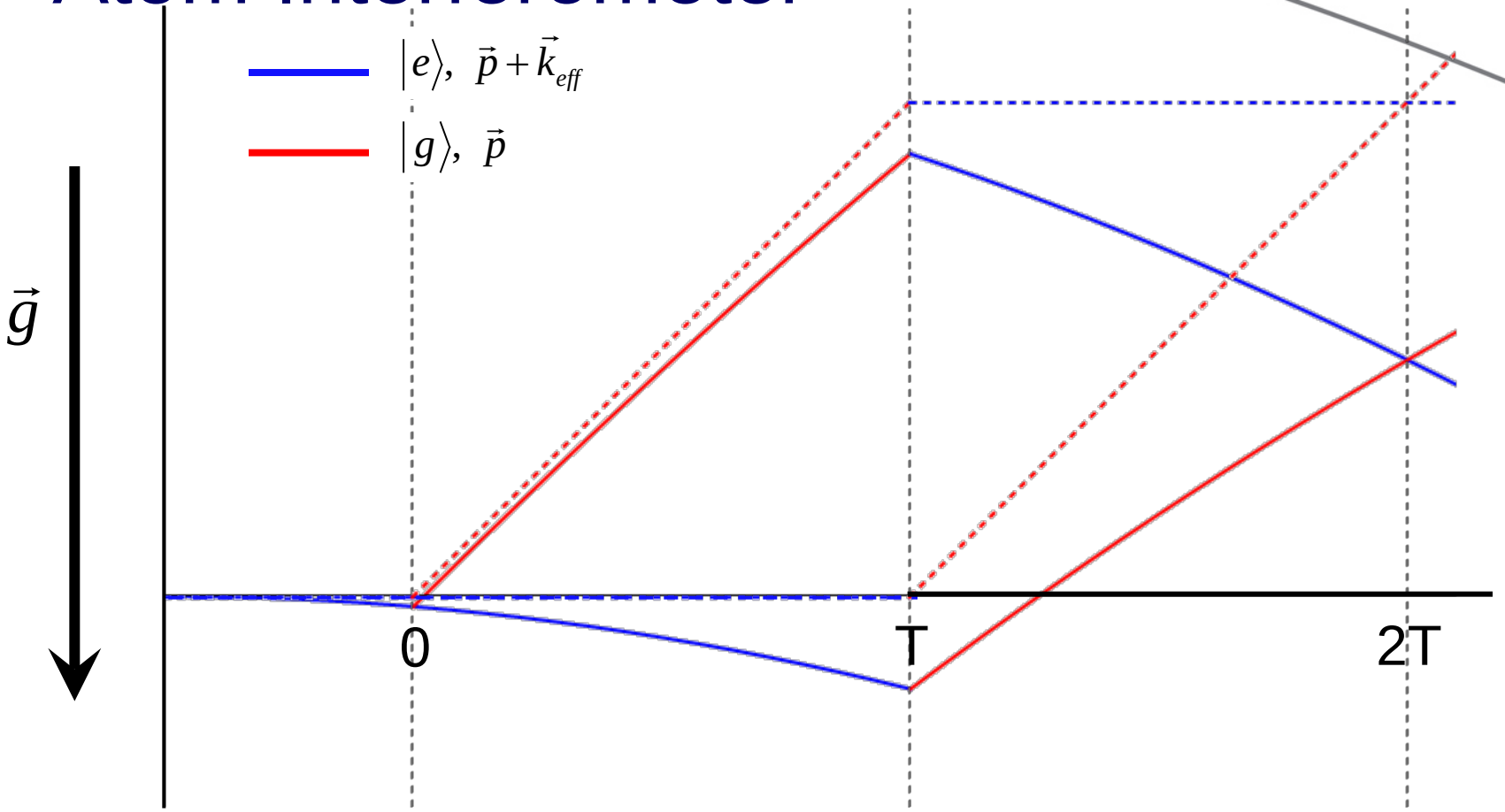
Atom Interferometer



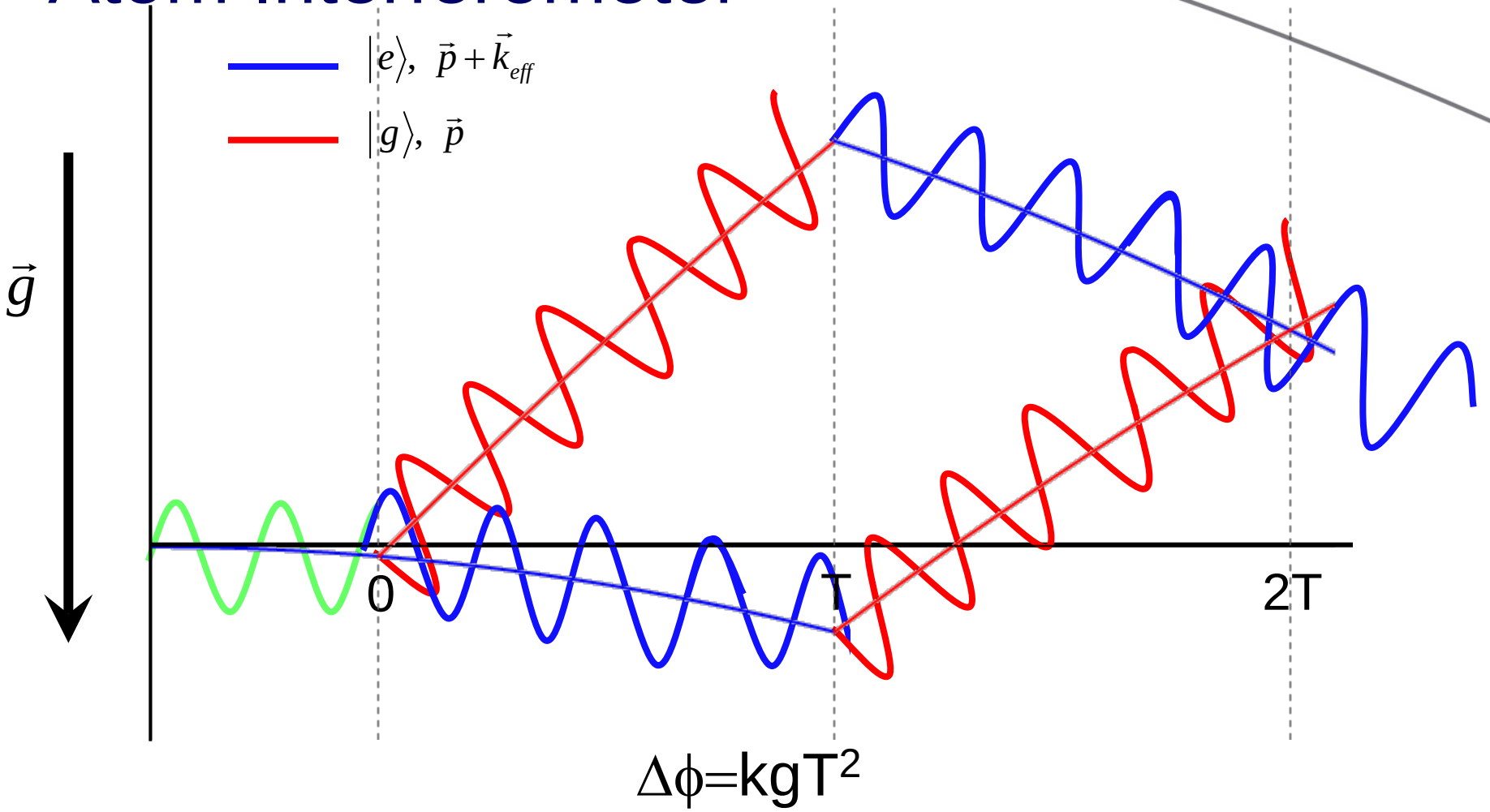
Atom Interferometer



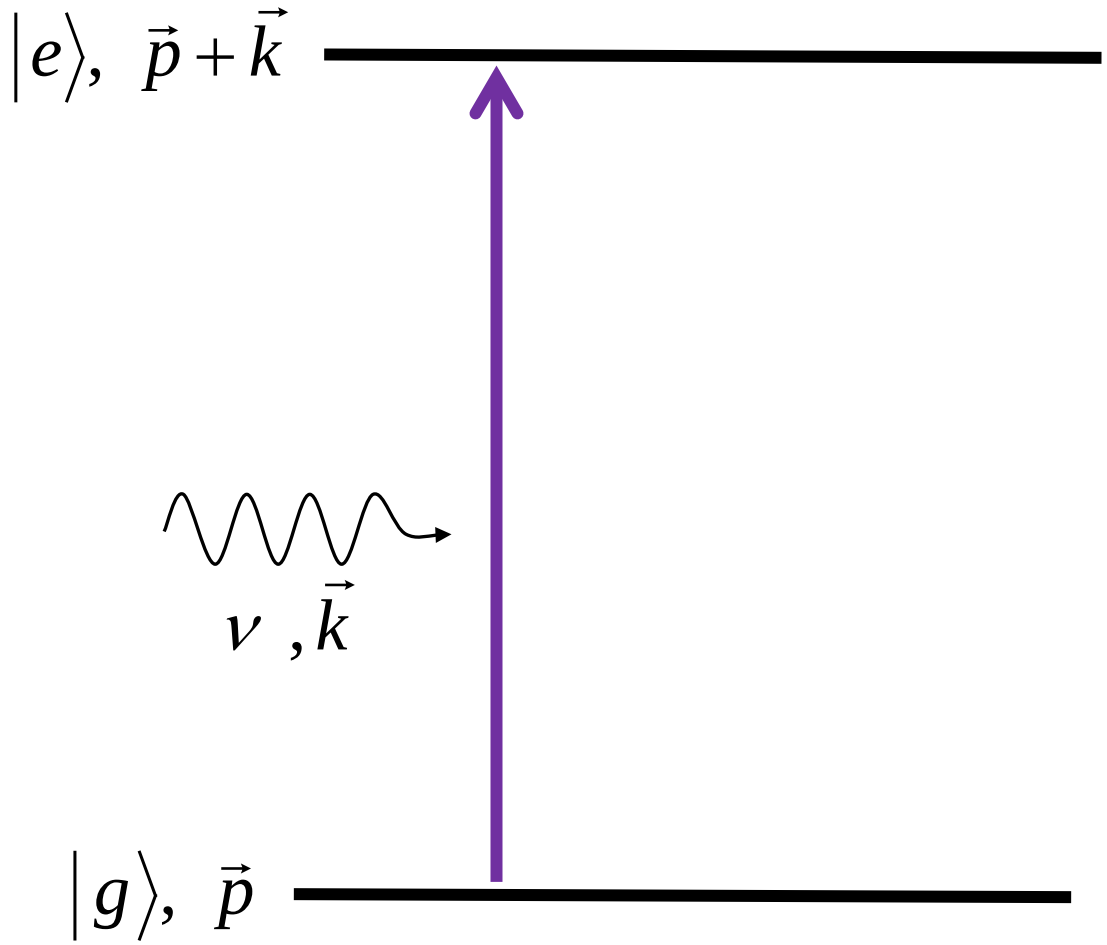
Atom Interferometer



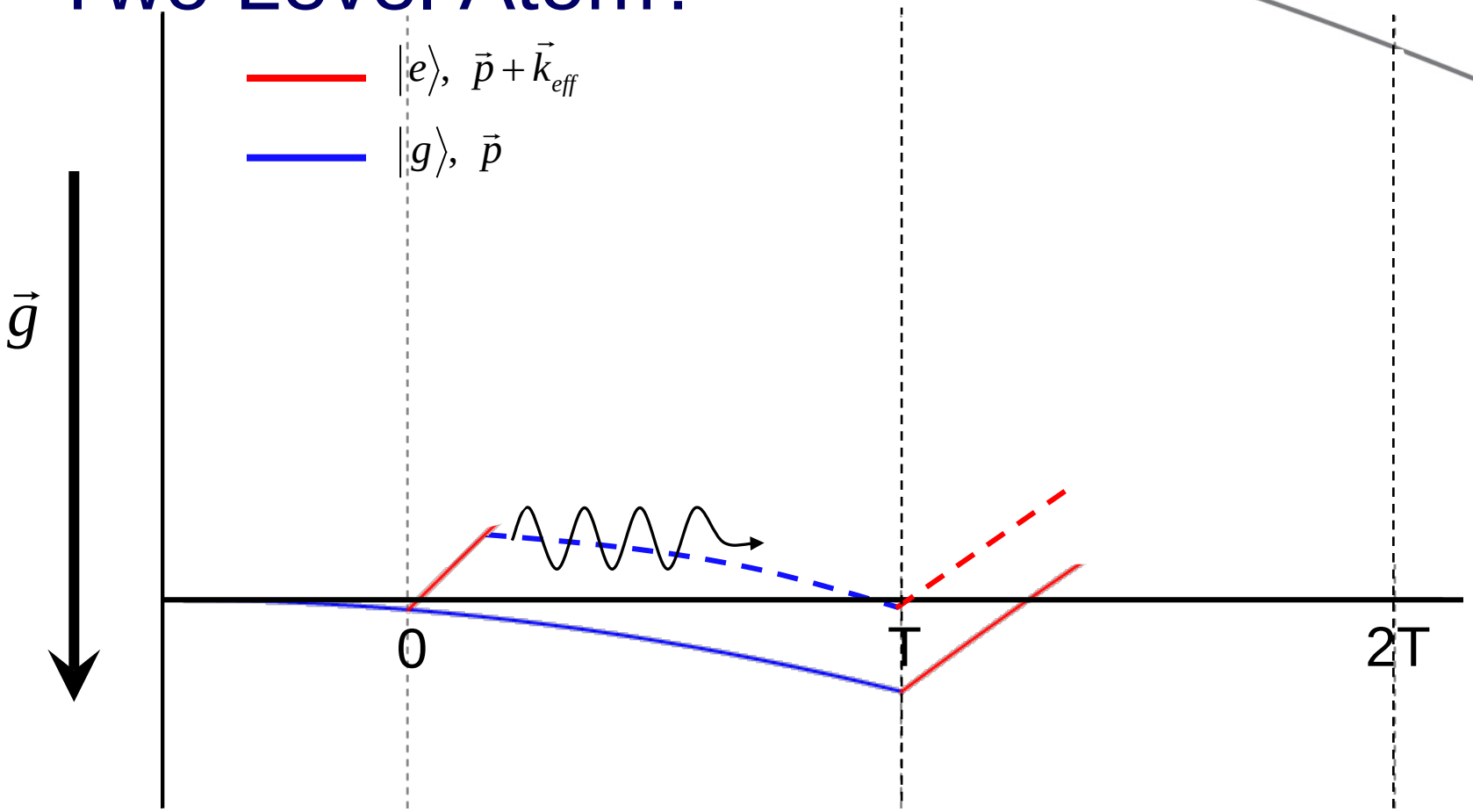
Atom Interferometer



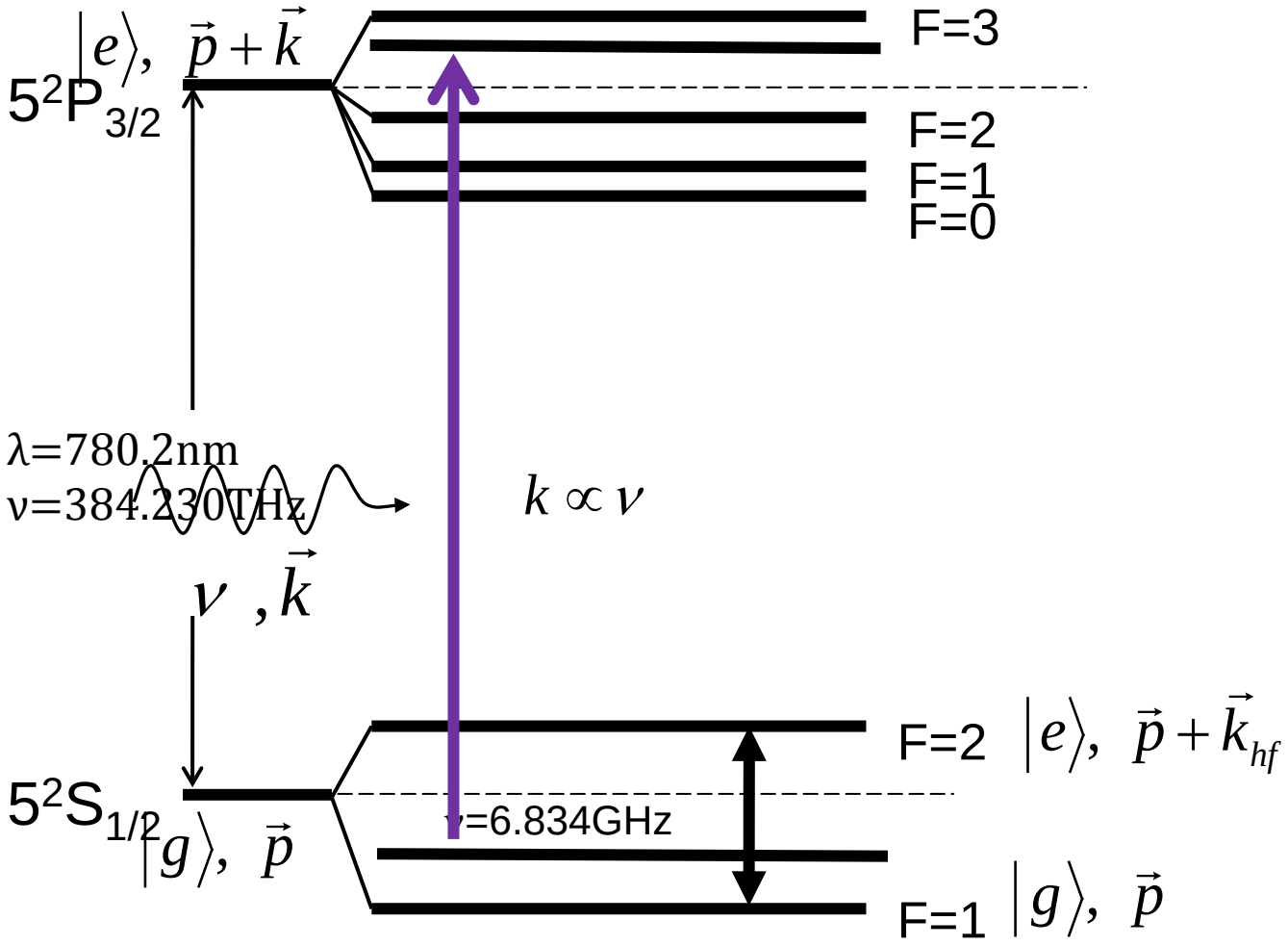
Two Level Atom?



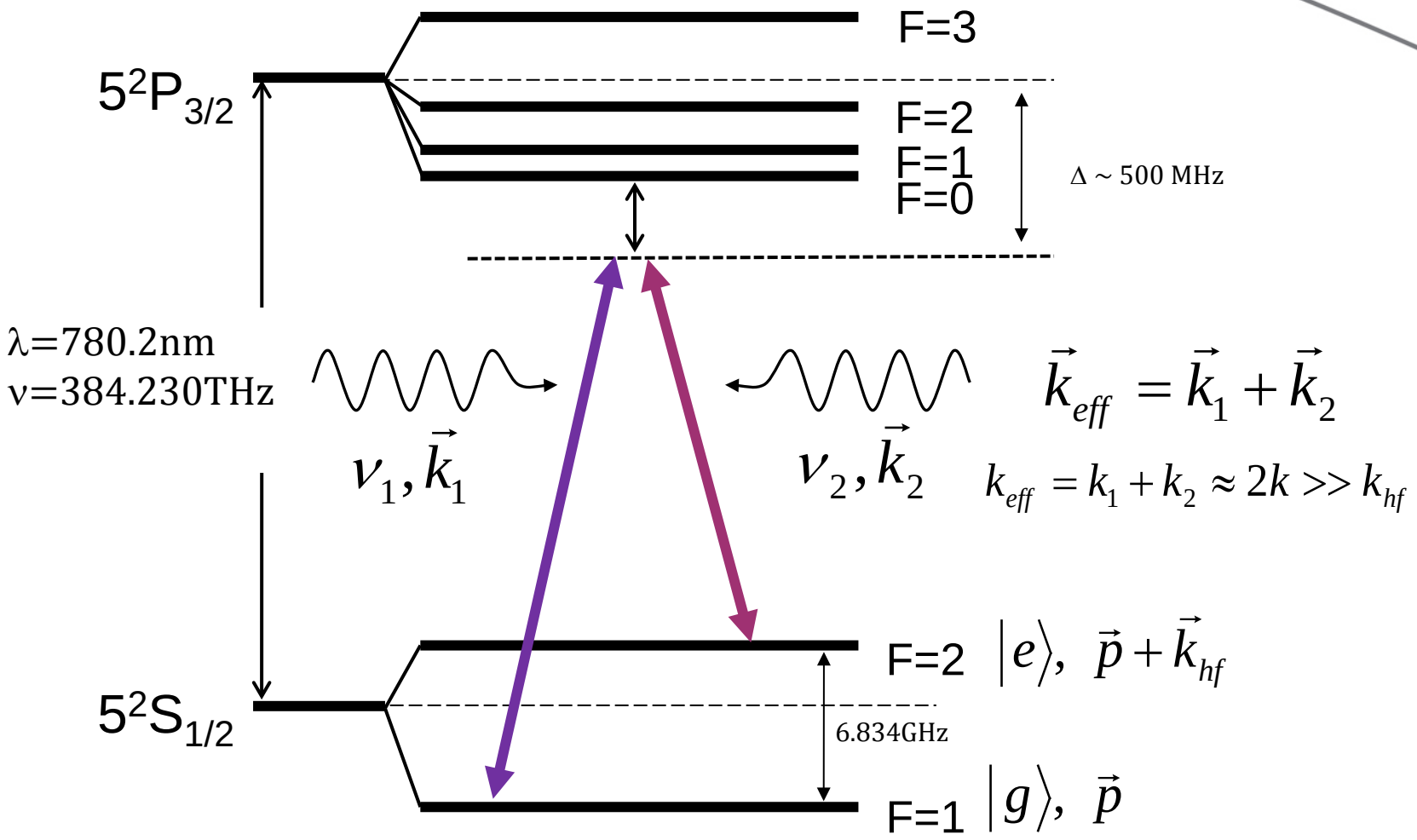
Two Level Atom?



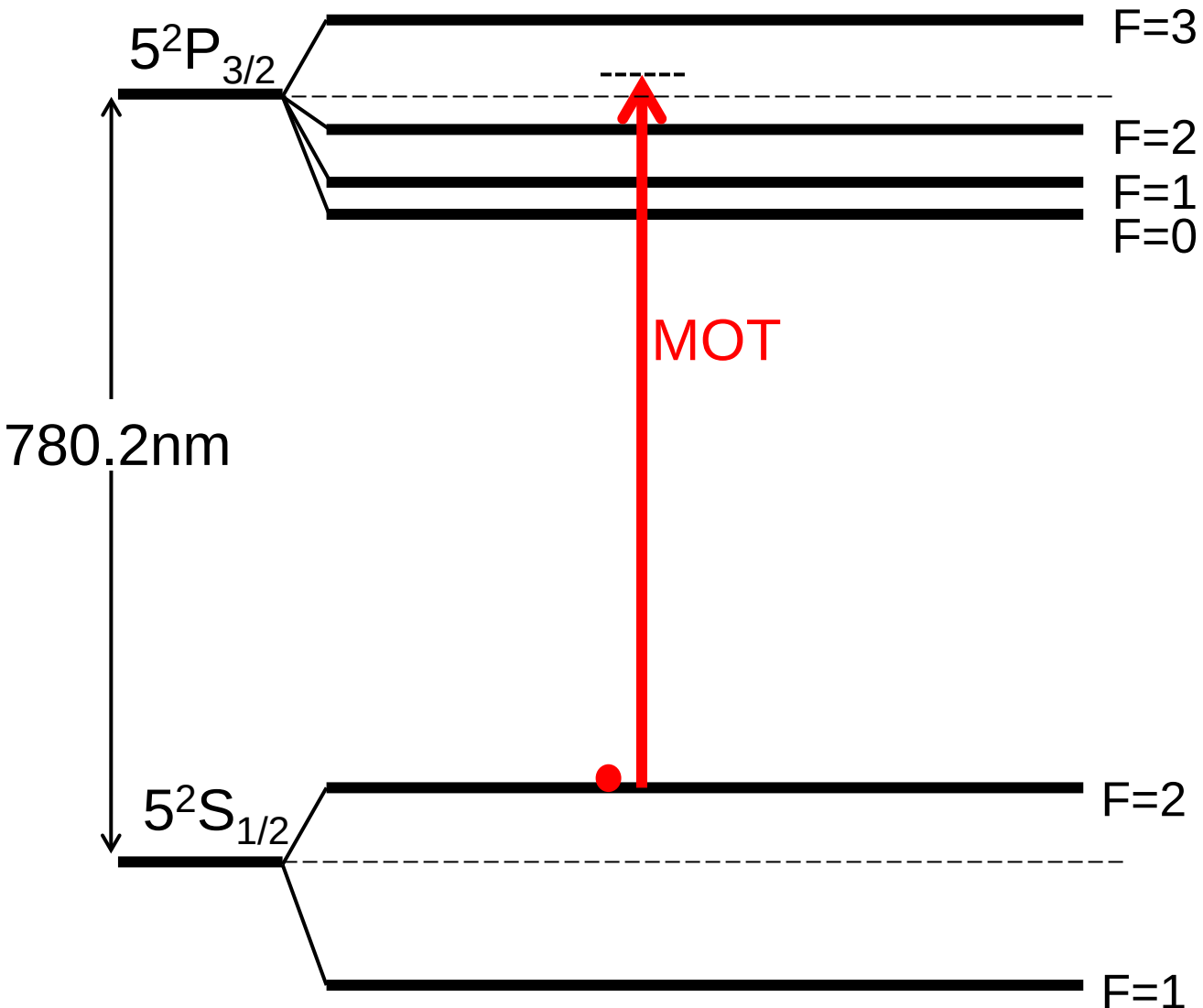
Rubidium Atom



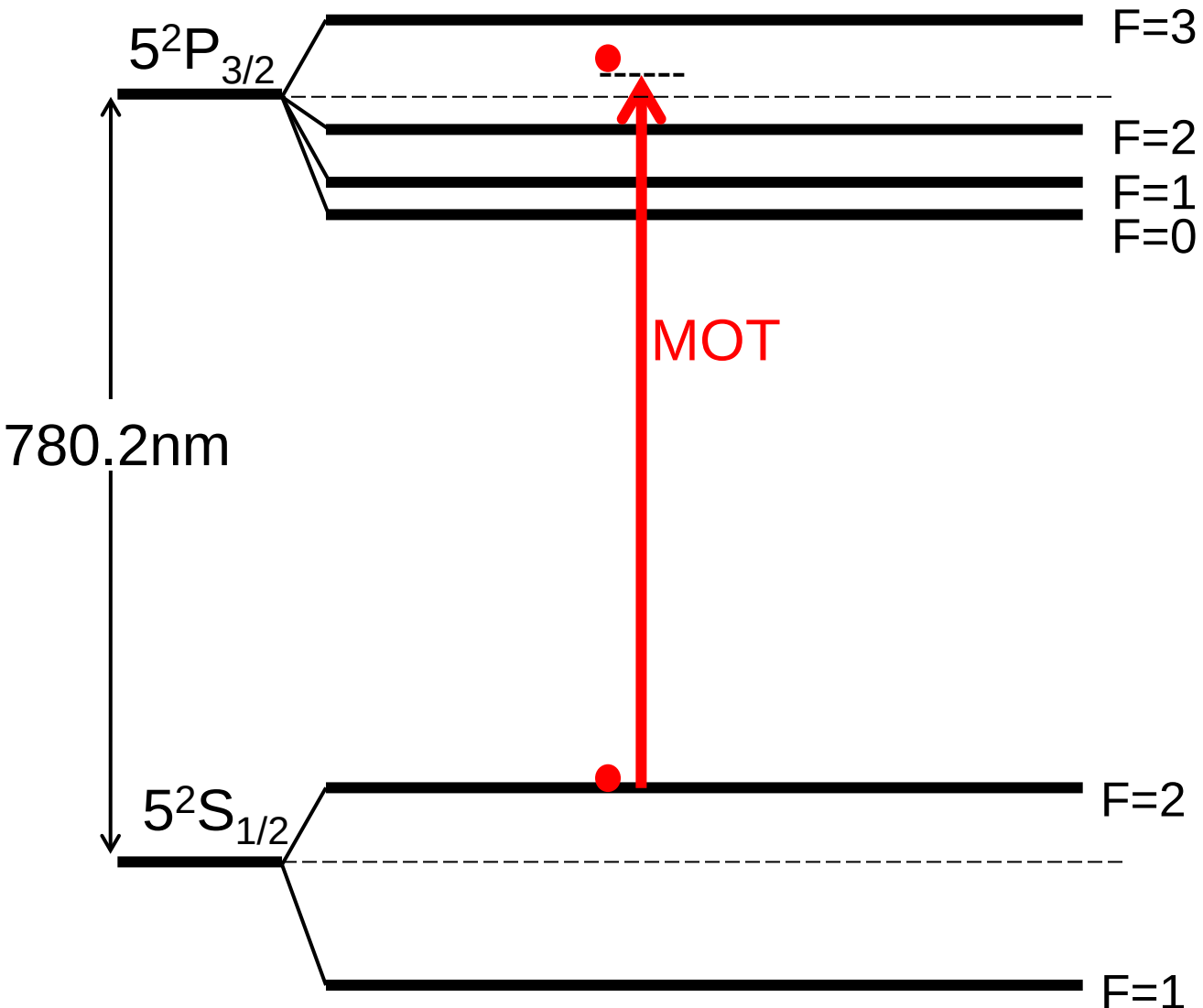
Rubidium Atom



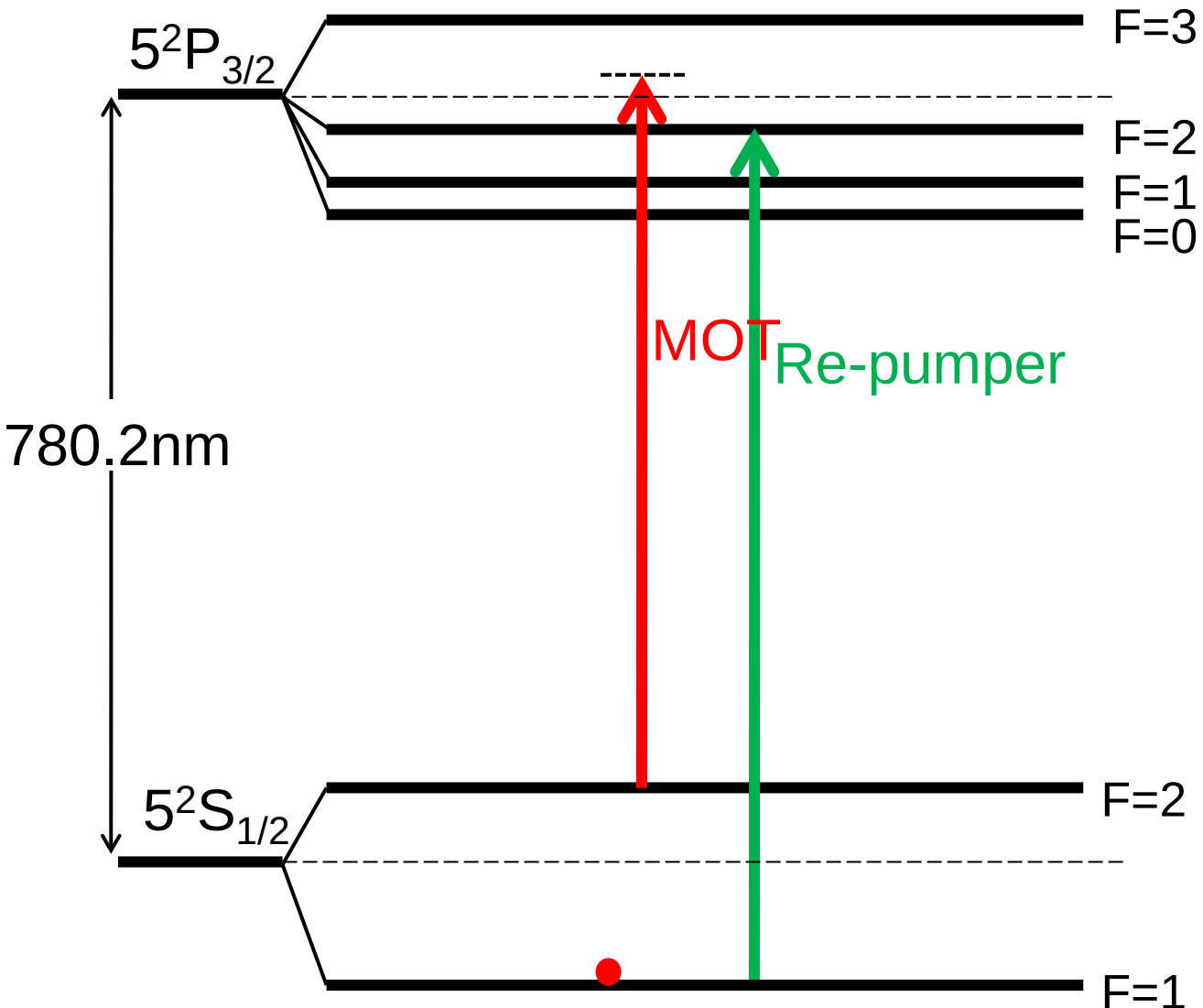
Measurement Cicle



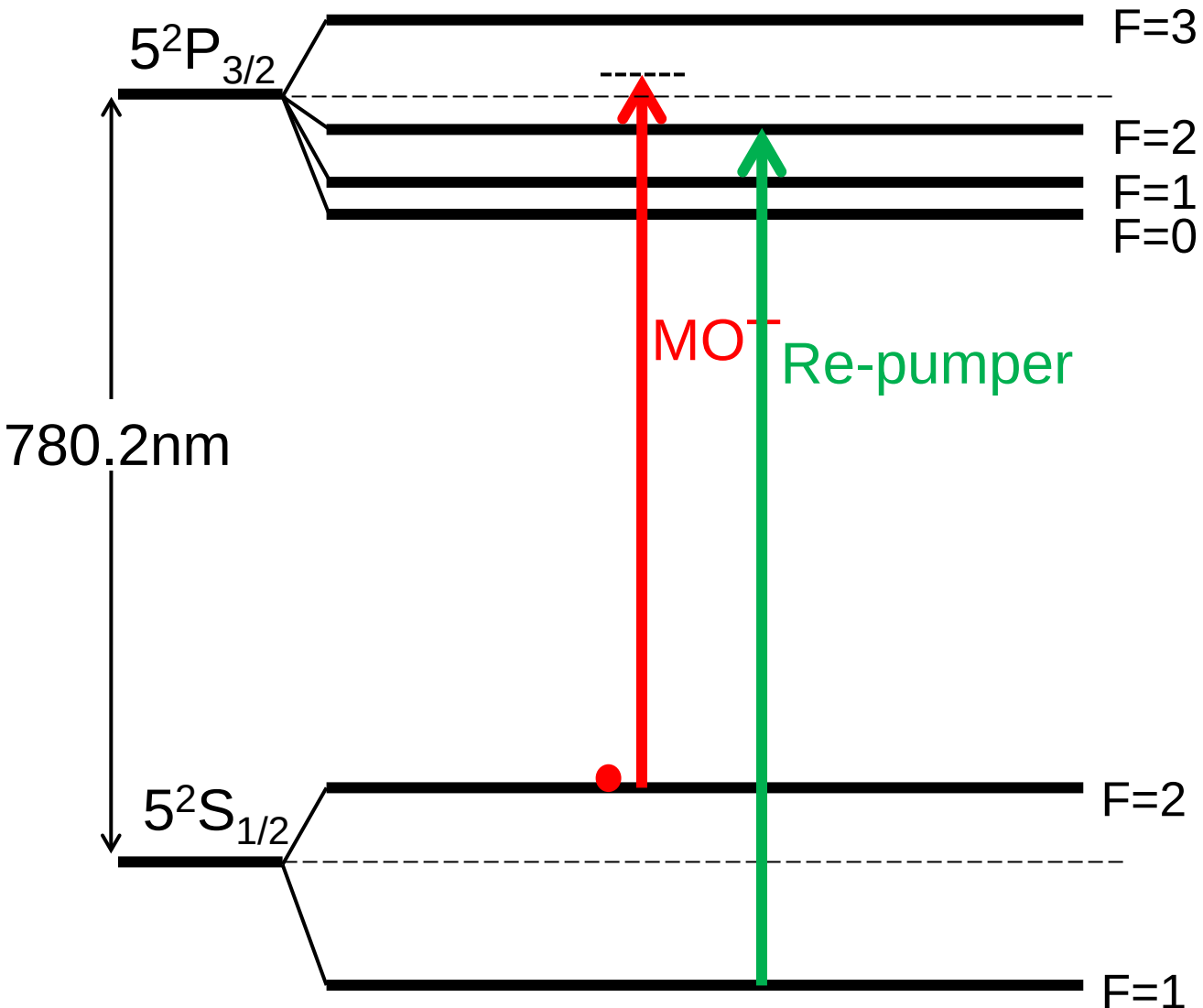
Measurement Cicle



Measurement Cicle



Measurement Cicle



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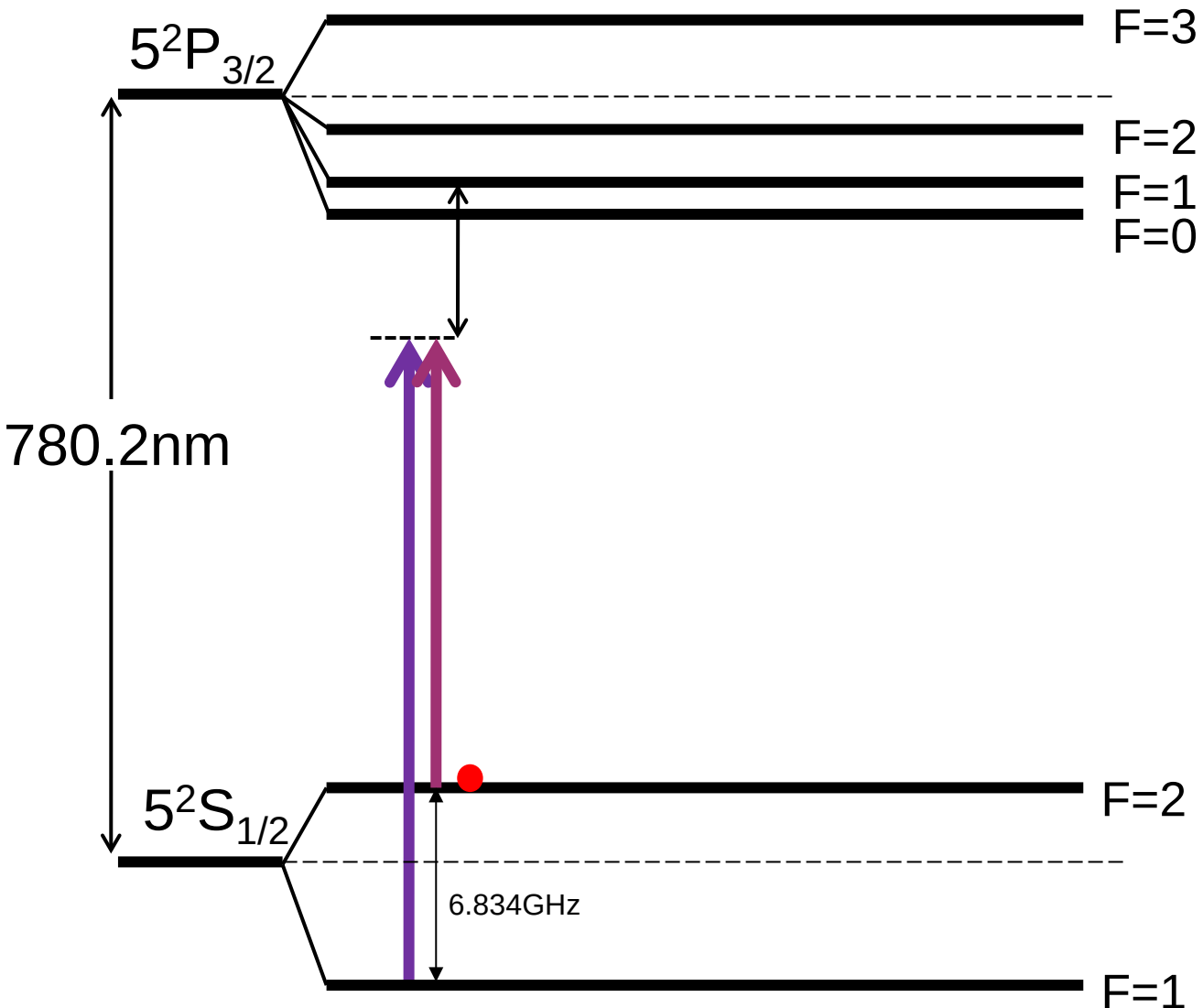

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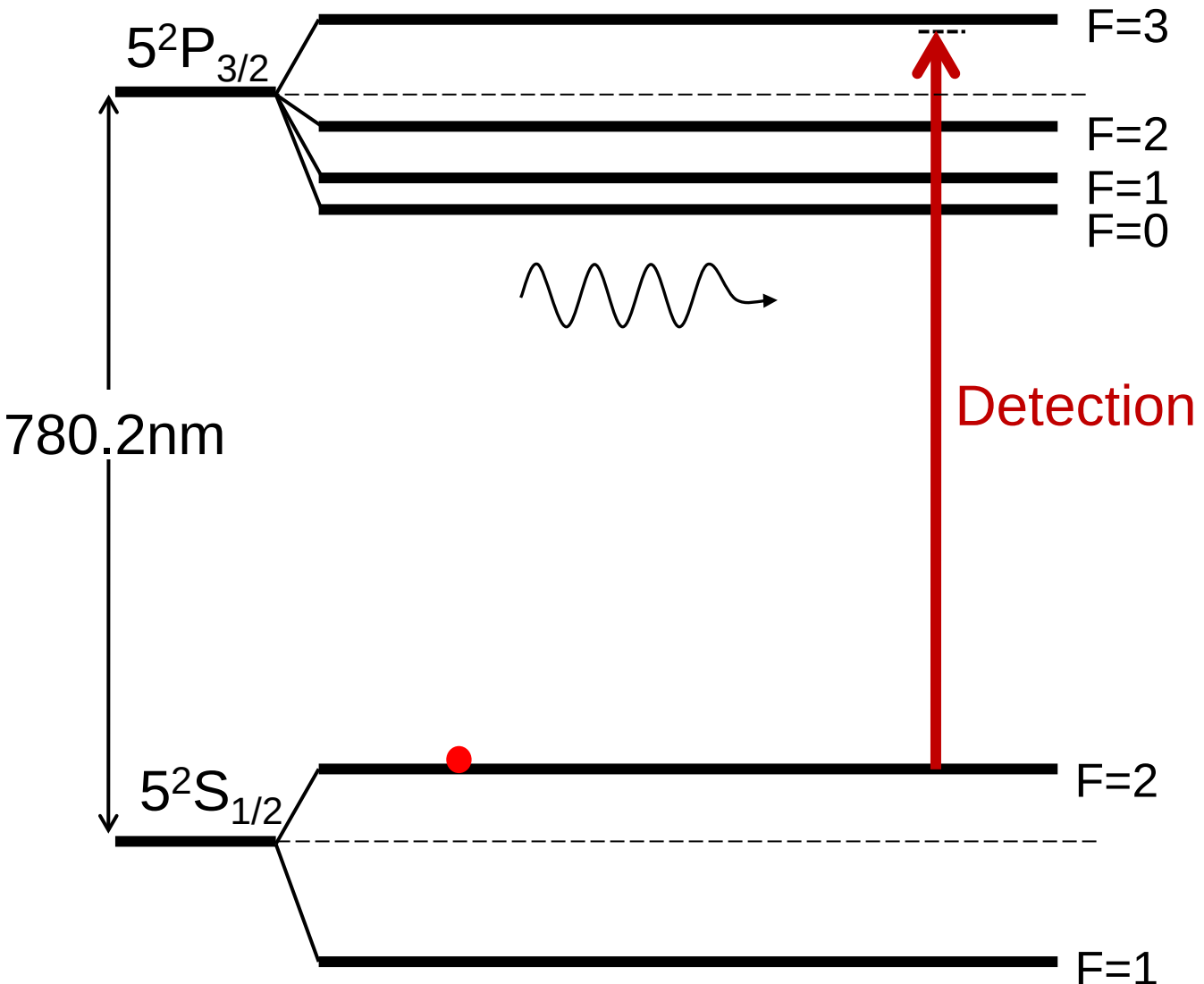
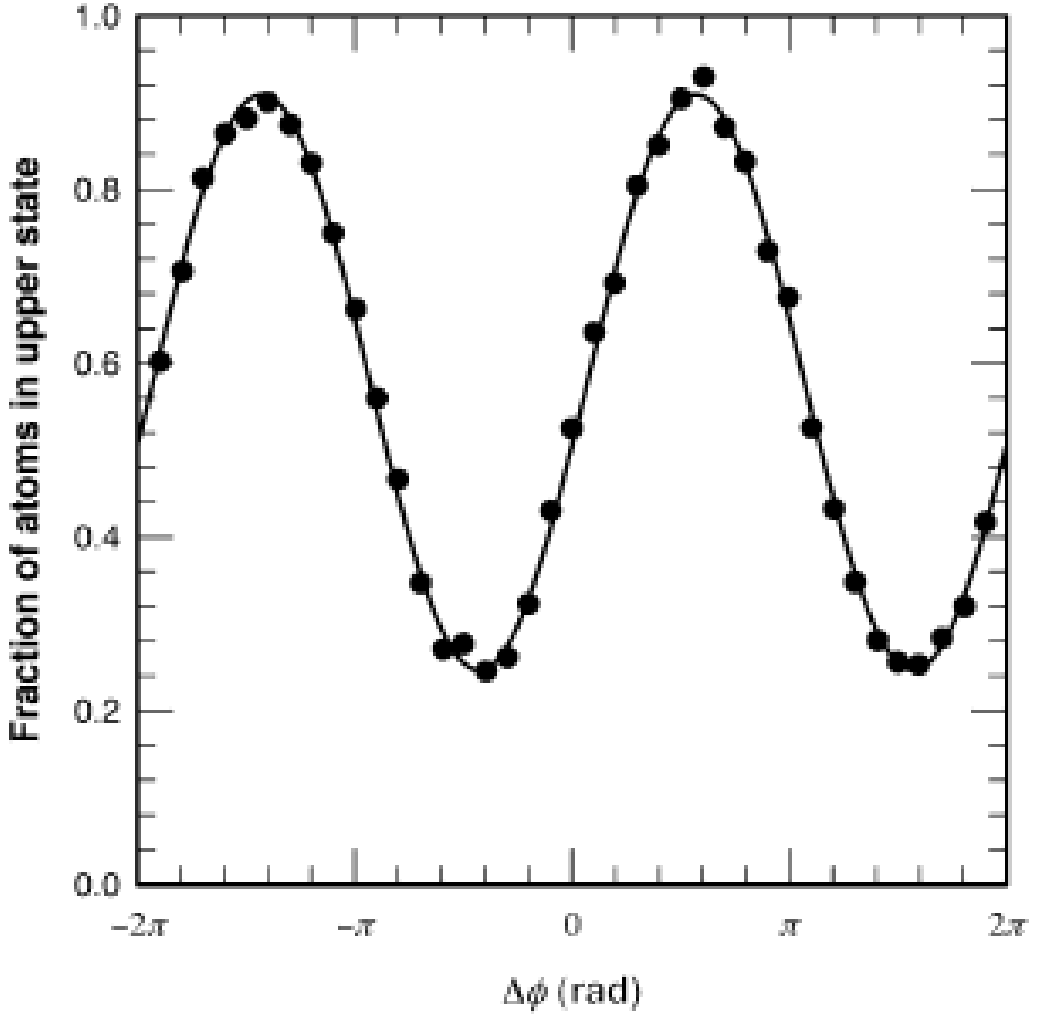
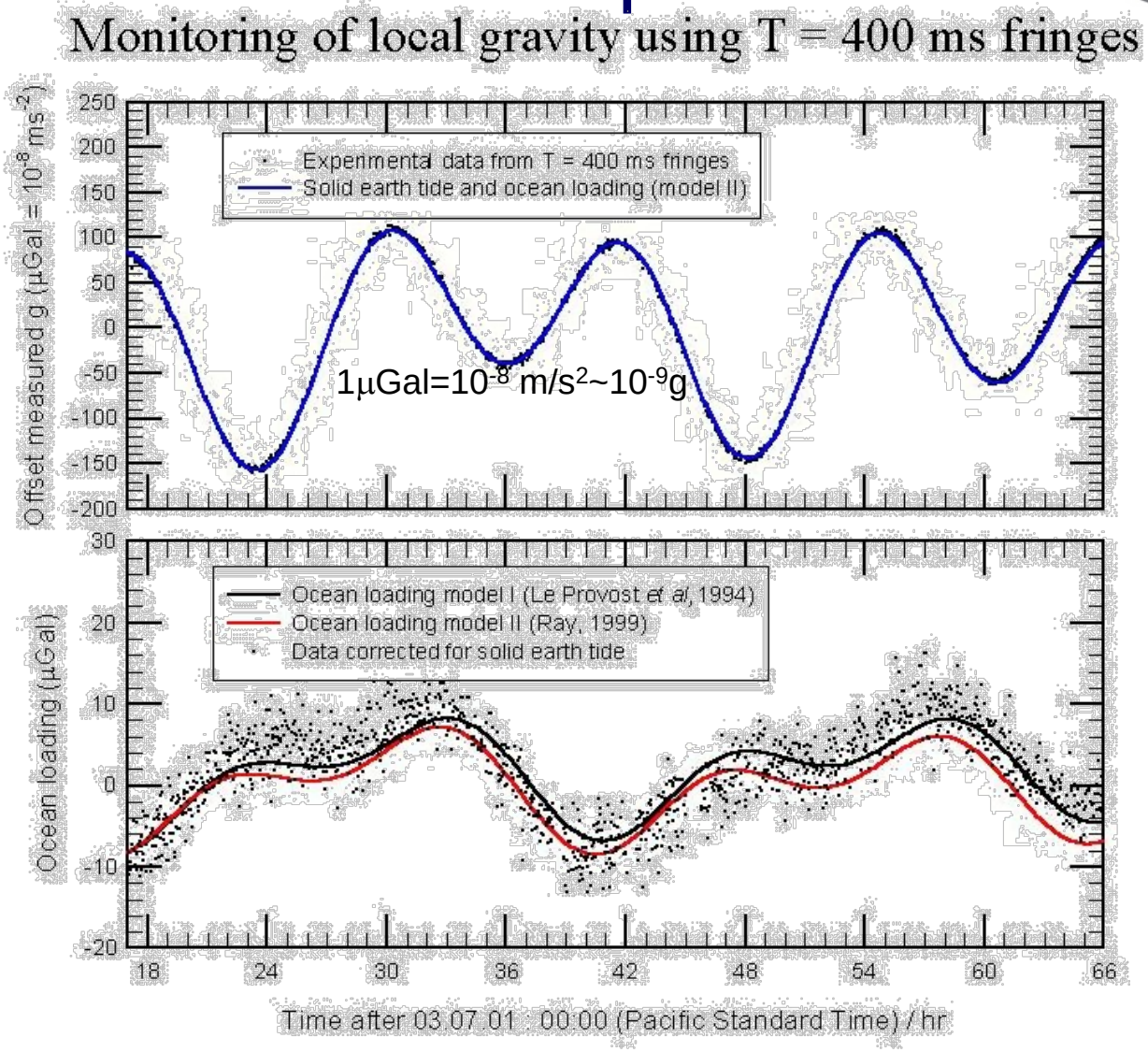


Measurement Example



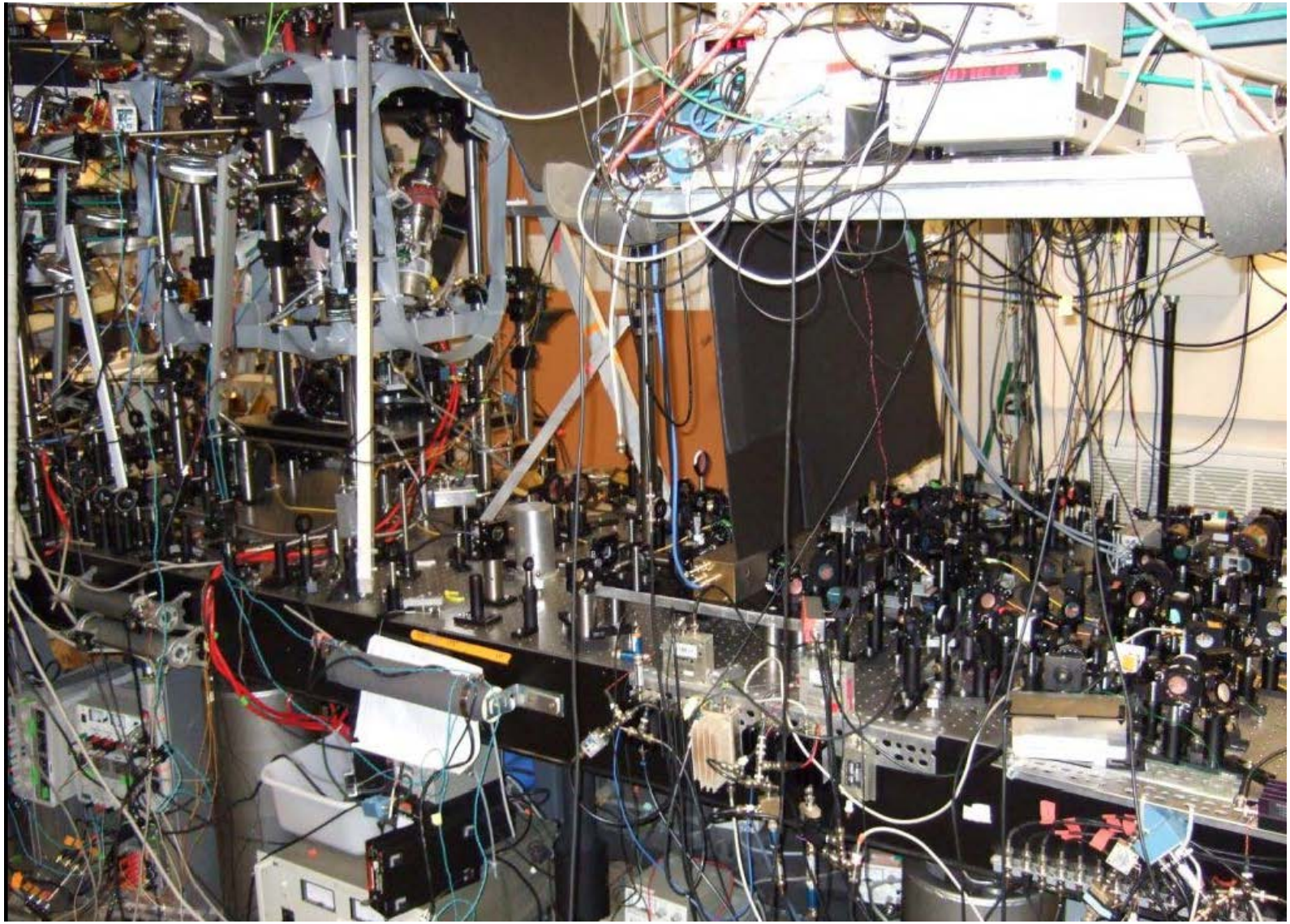
A. Peters, *et al.* Phil. Trans. R. Soc. Lond. A **355**, 2223 (1997).

Measurement Example



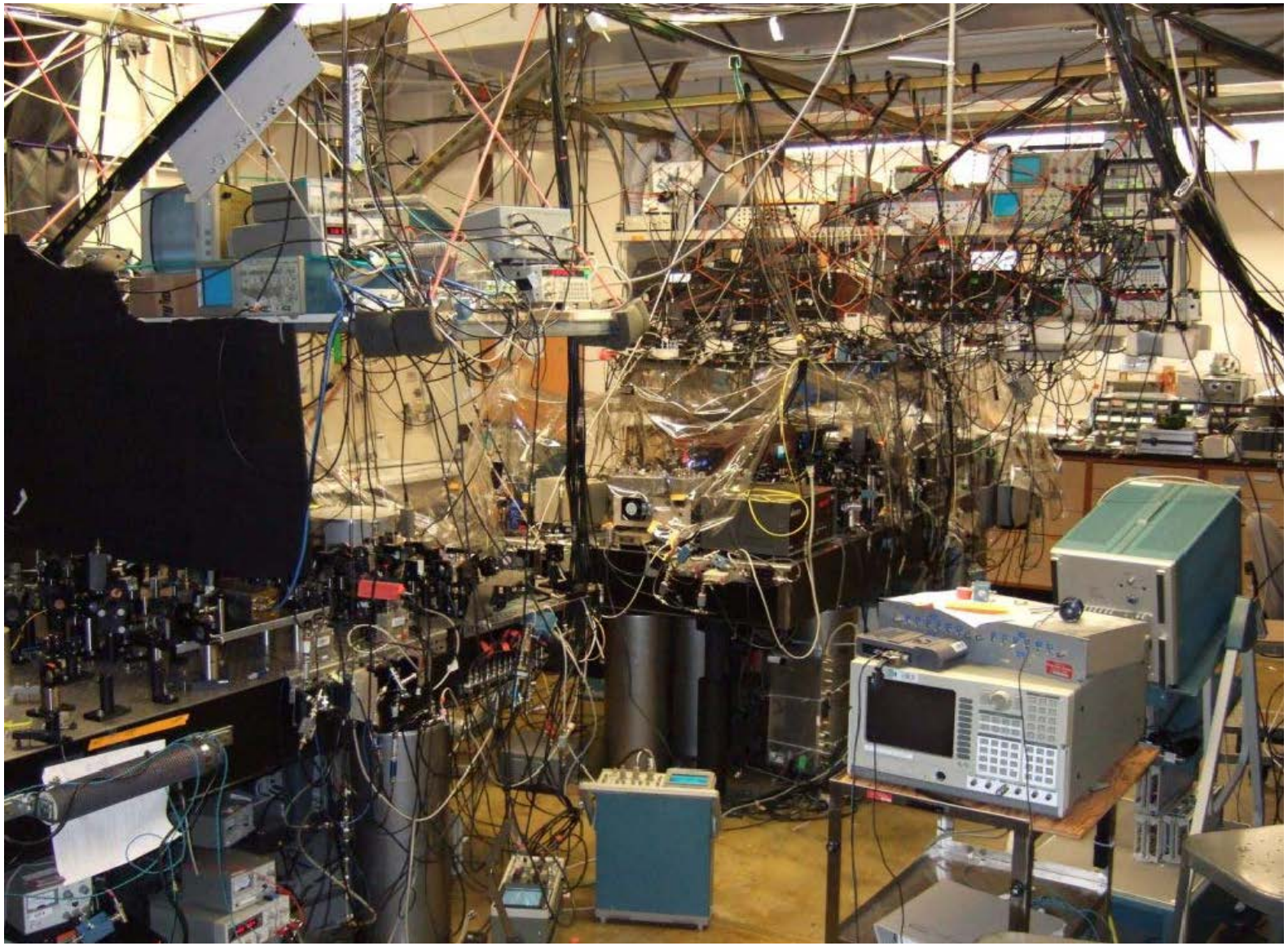
A. Peters, *et al.* Phil. Trans. R. Soc. Lond. A **355**, 2223 (1997).

Typical Lab Setting



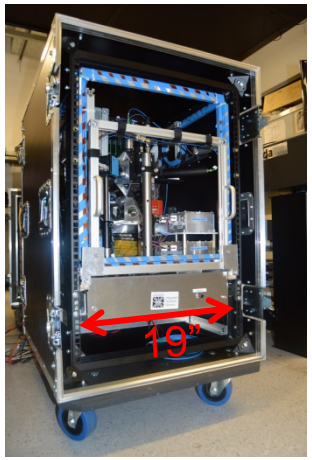
H. Müller lab @ Berkeley (http://matterwave.physics.berkeley.edu/)

Typical Lab Setting



H. Müller lab @ Berkeley (http://matterwave.physics.berkeley.edu/)

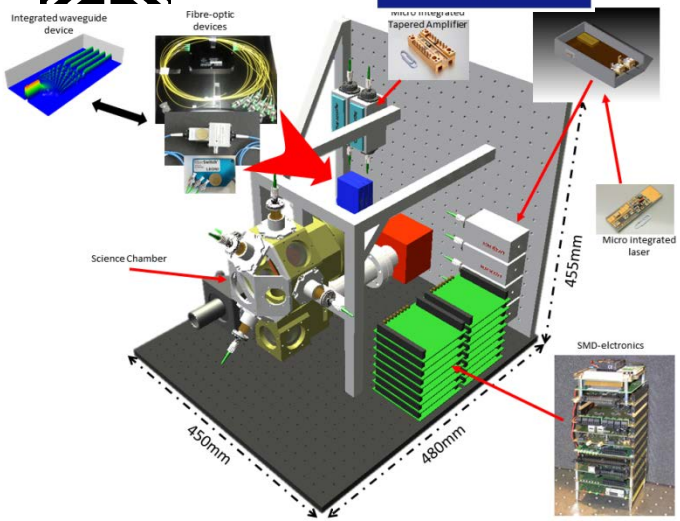
Projects outside of the Lab: UK



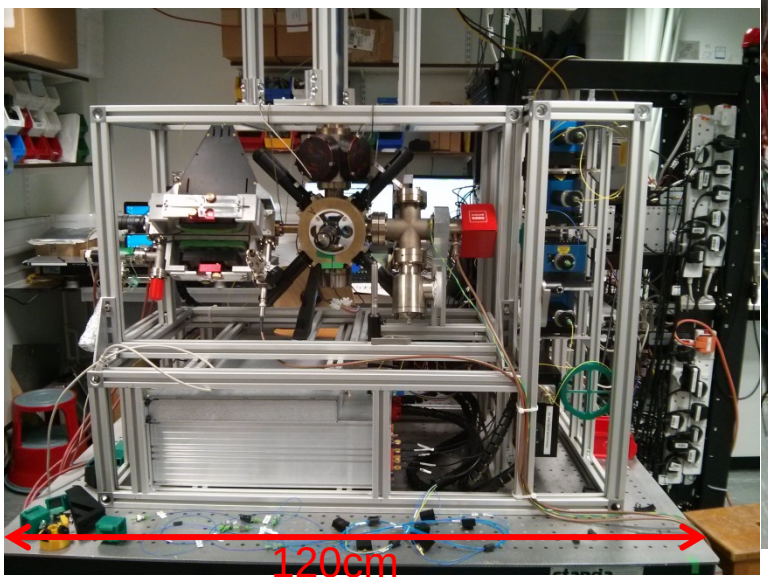
iSENSE Integrated Quantum Sensors

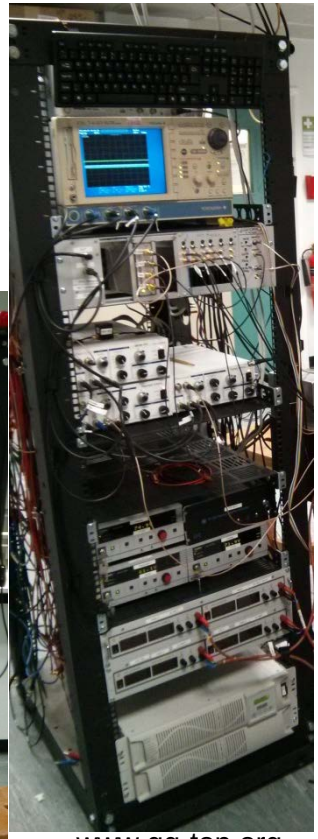
UNIVERSITY OF BIRMINGHAM

EPSRC GG top



www.isense-gravimeter.eu

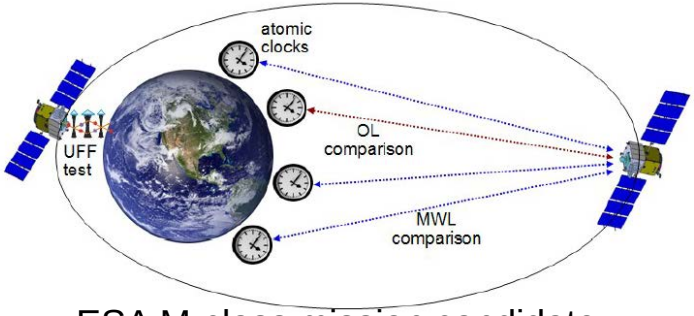




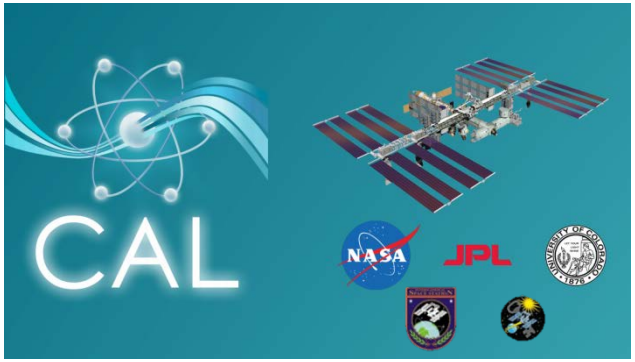
www.gg-top.org

Other Projects outside of the Lab

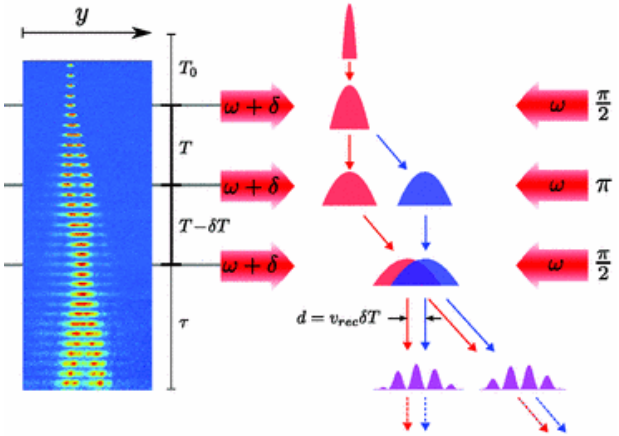
STE-QUEST



ESA M-class mission candidate



QUANTUS



Science **328**, 1540 & Phys. Rev. Lett. **110**, 093602

Scheduled 2015

UK National Quantum Technology Hub in Sensors and Metrology

UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

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UK Quantum Technology Hub for Sensors and Metrology

The mission of the UK Quantum Technology Hub for Sensors and Metrology is to translate state-of-the-art lab technology into deployable practical devices. Collaboration is at the heart of what we do, with academics and leading companies working together to translate research into marketable applications. We are an international centre of excellence bringing together world-leading physicists, engineers, industry and end-users.

Our Hub members are the universities of Birmingham, Glasgow, Nottingham, Southampton, Strathclyde and Sussex.

Find out more...

Events

- 20 April - QT Hub PhD Student Recruitment Event

View our calendar for more events.

Contact us

Interested in finding out more about Quantum Technology?

1 of 4 QT Hubs
Funding ~35m
Total Scheme ~120m

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 · EPSRC Pioneering research and skills

Quantum Technologies at RALSpace

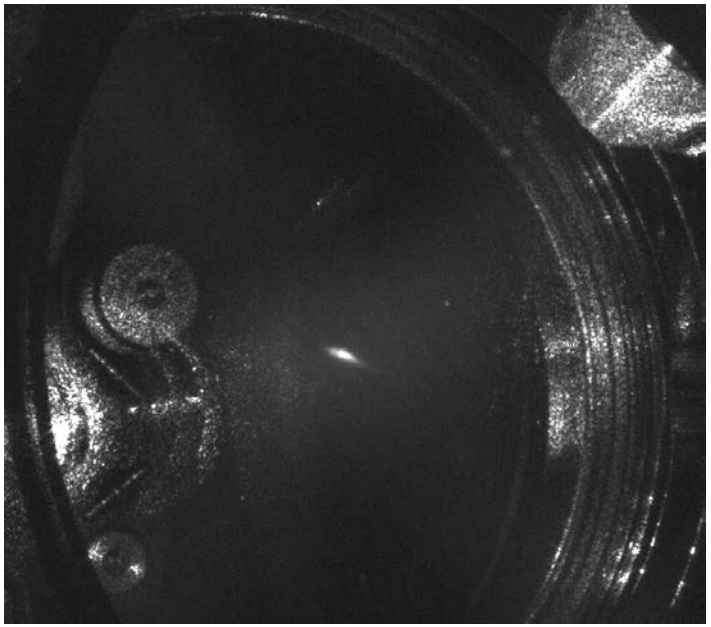
Leading an ESA TRP activity

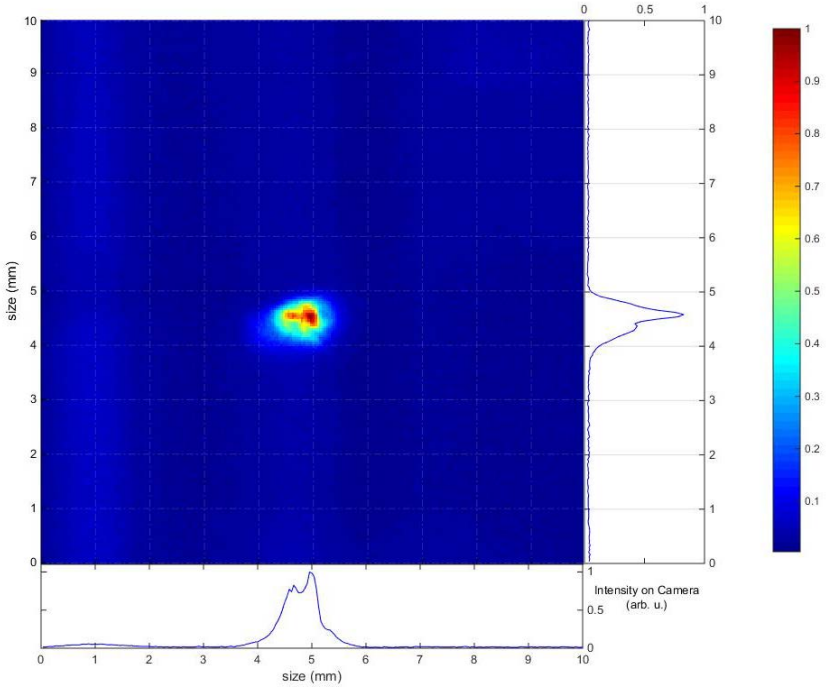
⇒ Design and characterize a vacuum chamber able to deliver an ultracold atomic clouds at a 1Hz rate

Research on Additive Manufacturing

⇒ Miniaturize physics package

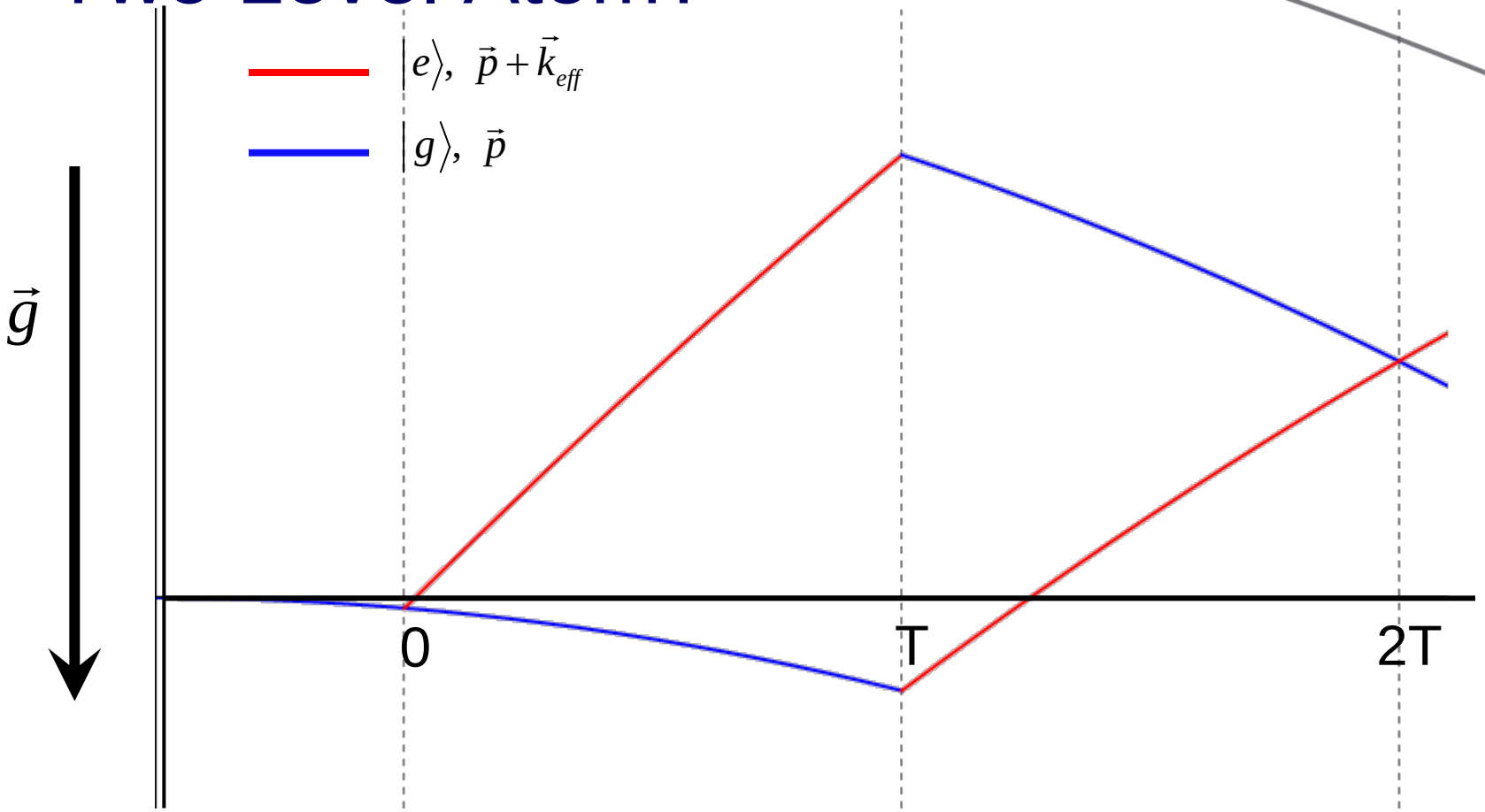
Develop own capabilities: 1st MOT @ RAL Space on 1st April 2015





Thank you!

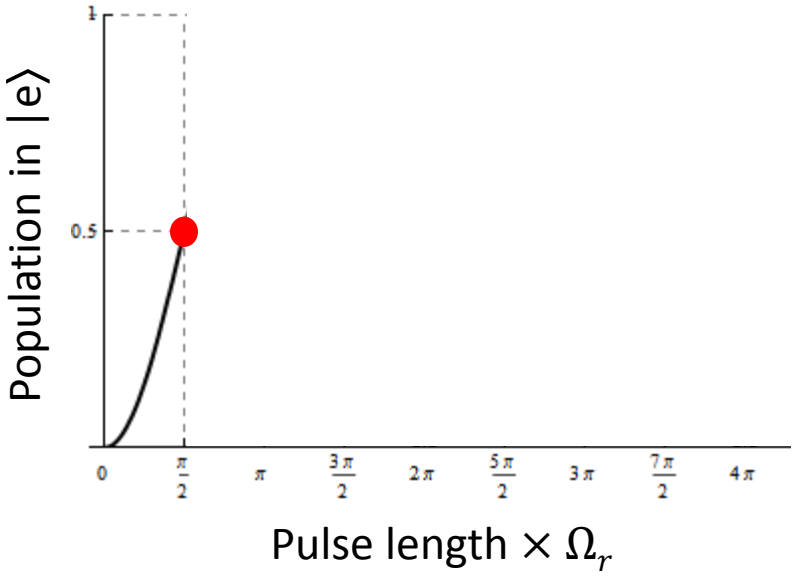
Two Level Atom?



Rabbi Oscillation

Pulse length = $\pi/2\ /\Omega_r$

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|g\rangle + |e\rangle\right) \qquad P_{|e\rangle} = 1/2$$



Rabbi Oscillation

Pulse length $=\pi/\Omega_r$

$|\psi\rangle = |e\rangle$

$P_{|e\rangle} = 1$