Ultracold atoms for quantum devices and quantum simulations

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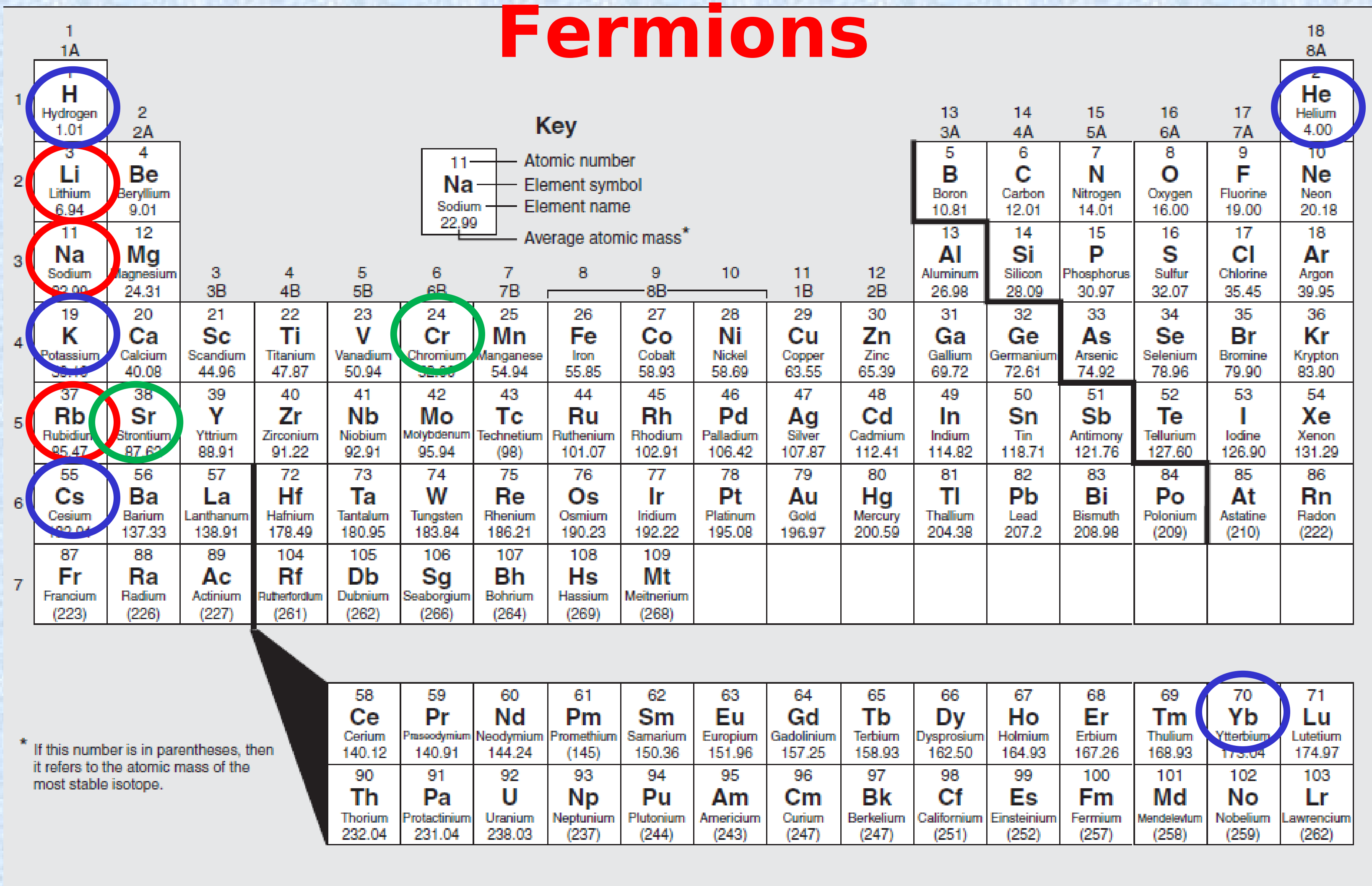
Three Minutes seminars, 19 November 2021

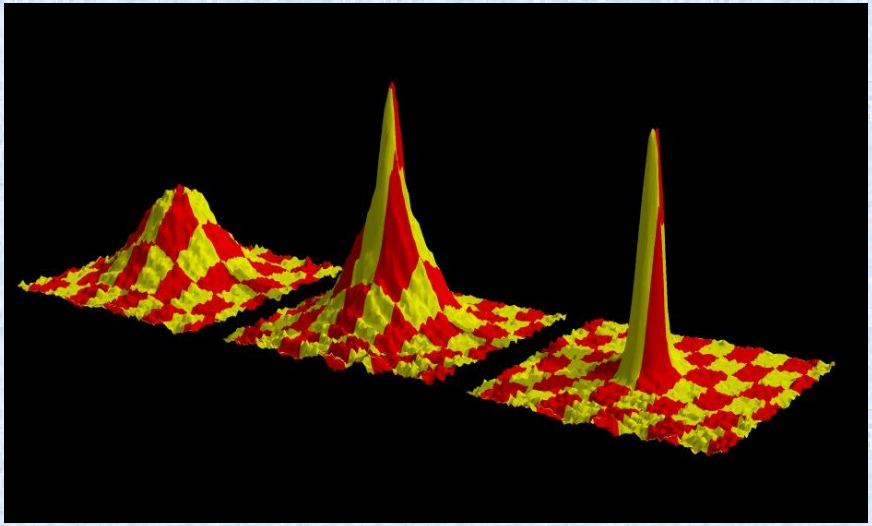
The ultracold family: Bosons & Fermions



Typical values:

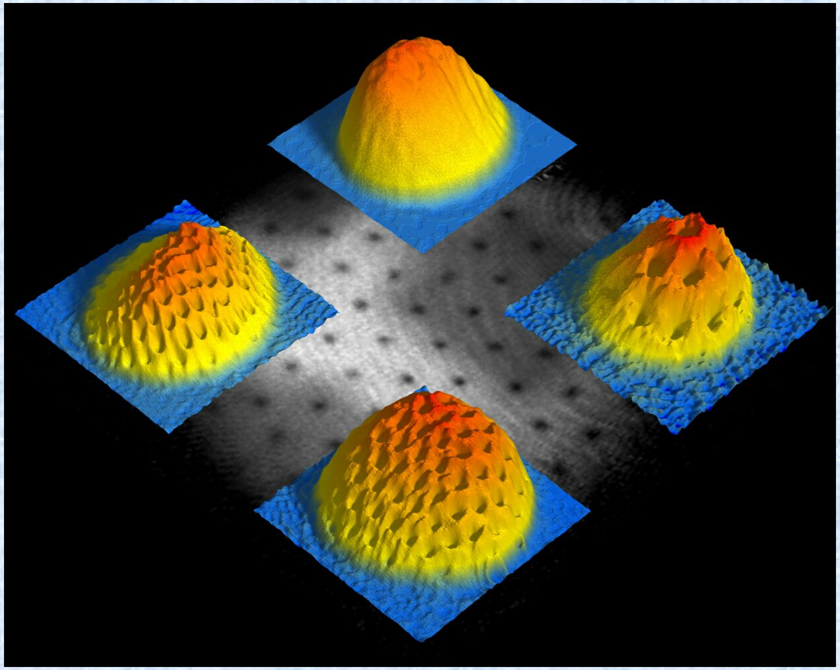
$$\begin{cases} numbers:\ 10^3 - 10^6\ atoms \\ temperatures: 10 - 100\ nanoKelvin \\ sizes:\ 1 - 50\ micrometers \end{cases}$$

Trapped Ultracold Atoms: Bosons



Bose-Einstein condensation (at temperature ~ 100nK)

Vortices & Superfluidity

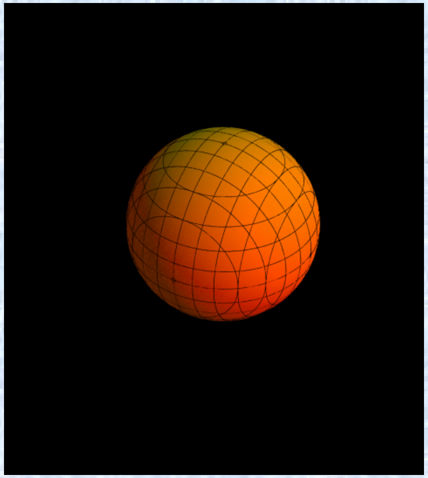


Geometry

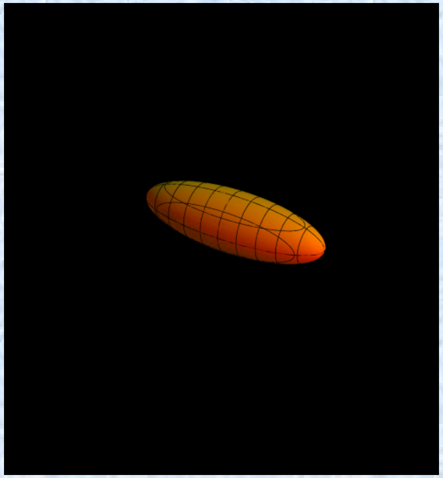
E.g. with a magnetic harmonic potential:

$$V(x,y,z)=\frac{1}{2}\,m\left(\omega_x^2\,x^2+\omega_y^2\,y^2+\omega_z^2\,z^2\right)$$

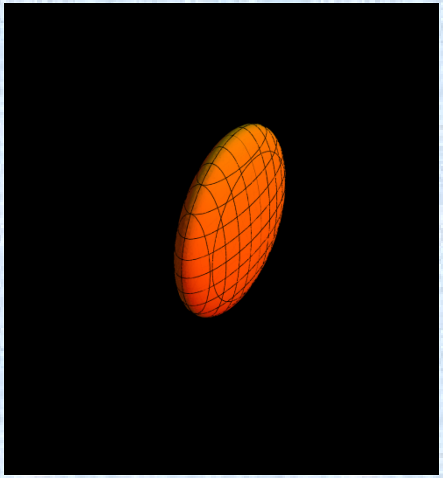
$\omega_x=\omega_y=\omega_z$



$\omega_x \ll \omega_y=\omega_z$



$\omega_x \gg \omega_y=\omega_z$



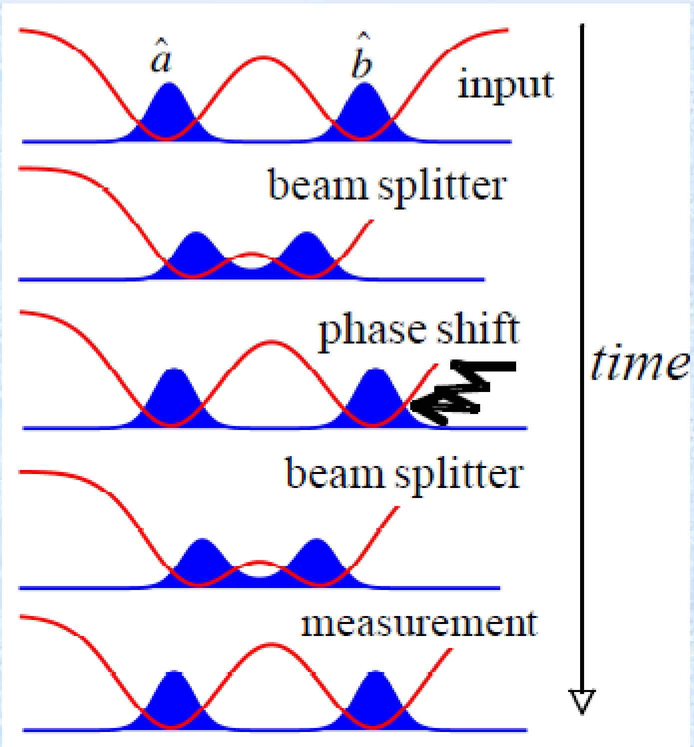
Main available “ingredients”

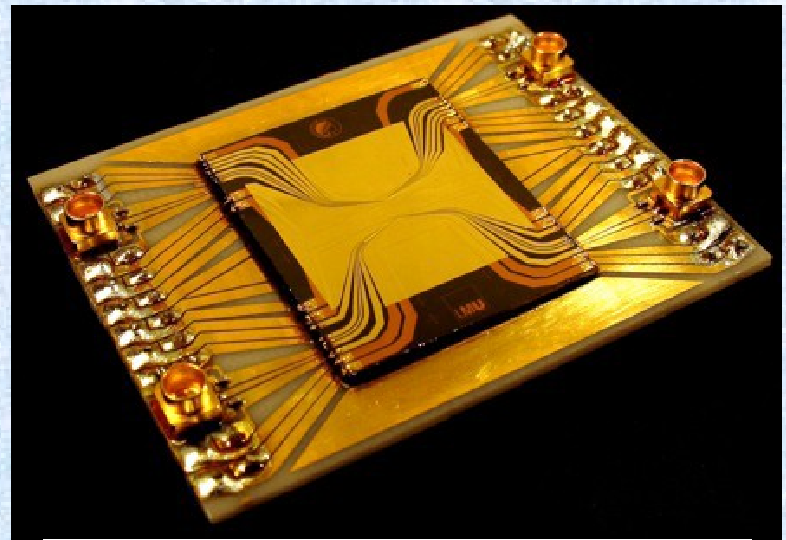
- **Bosons and/or Fermions**
- **Geometry (1D / 2D)**
- **Long-range interactions**
- **Add disorder**
- **Simulate a magnetic field through a rotation or with optical tools**
- **Time-dependence (and to a certain extent space-dependence) of the parameters of the Hamiltonian**
- **Explicit tuning of the interactions via Feshbach resonances**
- **Optical lattices**

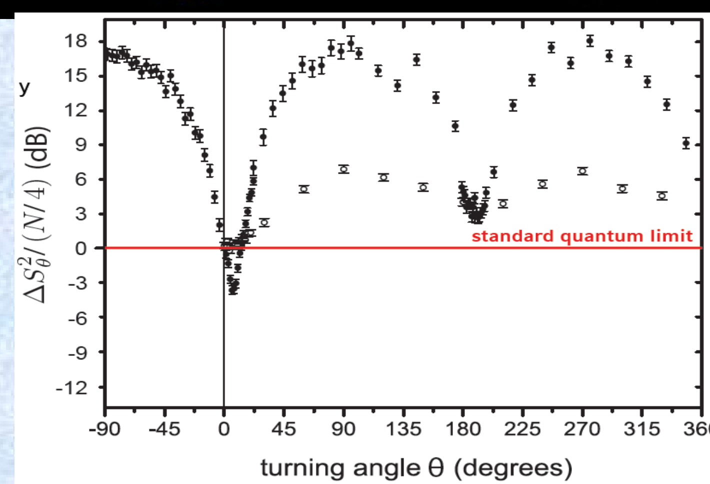
Outline

- Introduction on ultracold atoms
- **Ultracold atoms for quantum devices**
- Ultracold atoms for quantum simulations

Quantum interferometers with ultracold atoms







$$H = E_C(t)\,\hat{S}_z^2 - K(t)\,\hat{S}_x + \Delta E(t)\,\hat{S}_z$$

$$\hat{S}_x = \frac{1}{2}\left(a^+ b + b^+ a\right)$$

$$\hat{S}_z = \frac{1}{2}\left(a^+ a - b^+ b\right)$$

Riedel et al. & Gross et al. [Nature, 2010]

Outline

- Introduction on ultracold atoms
- Ultracold atoms for quantum devices
- **Ultracold atoms for quantum simulations**

Ultracold atoms as quantum simulators of:

- **<u>Interacting lattice systems</u>**
- **Disordered models**
- **Analogue models of gravity**
- **Relativistic field theories**
- **Low-dimensional & integrable systems**
- **Quantum Hall physics**

Thank you!

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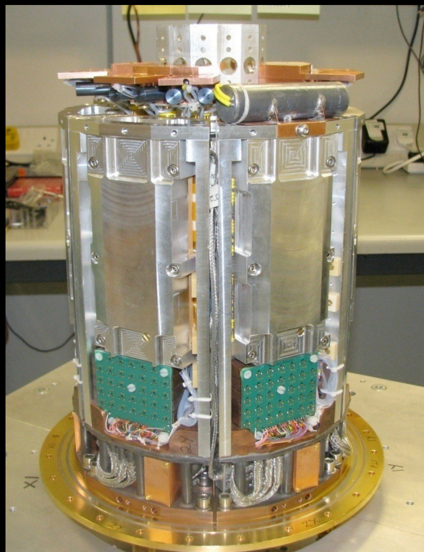
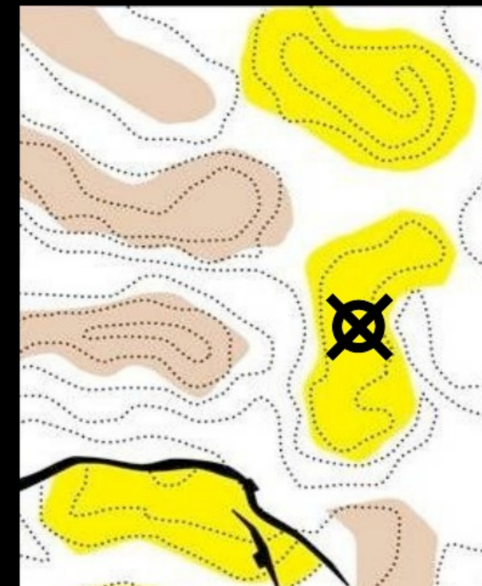
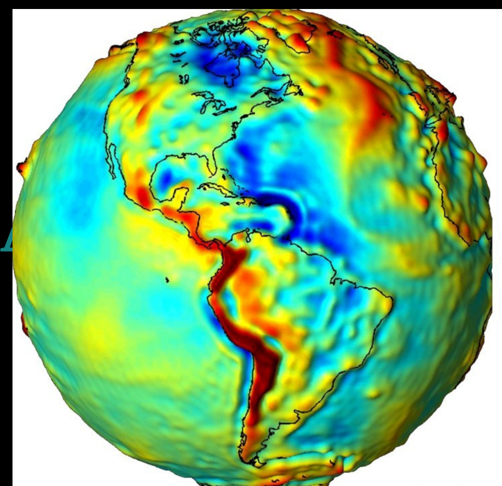


an example





Gabon

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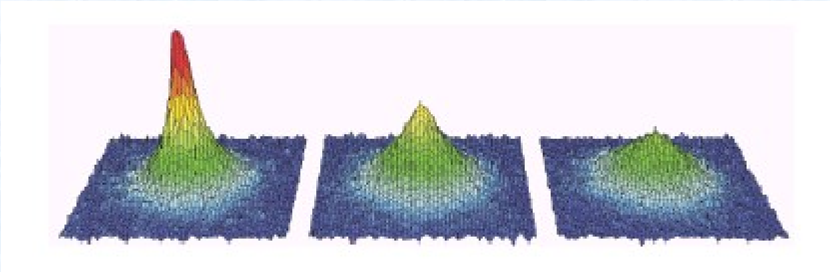
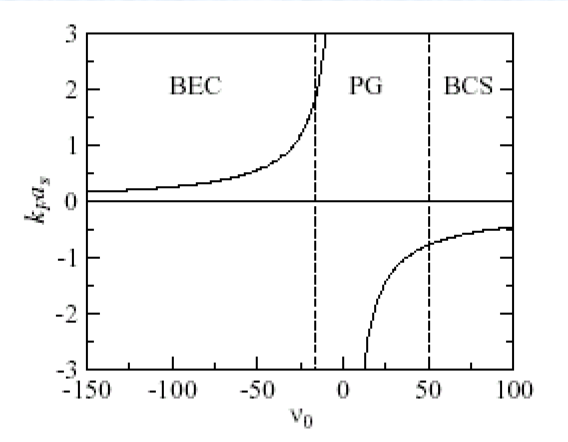
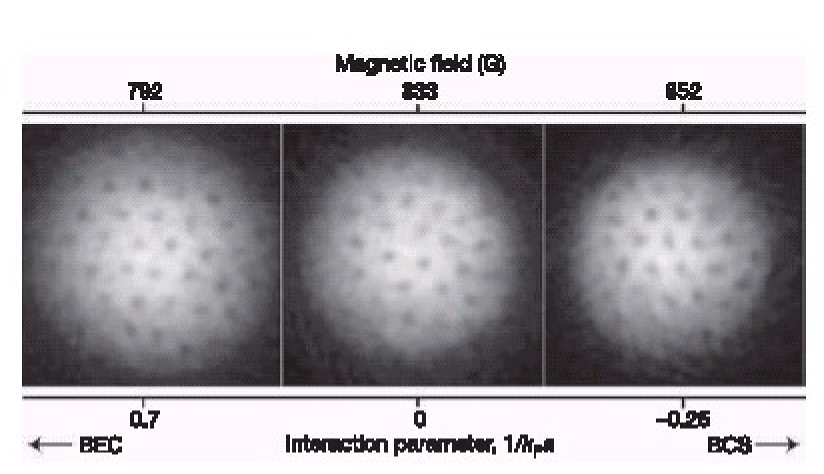
Trapped Ultracold Atoms: Fermions



With attractive interactions…



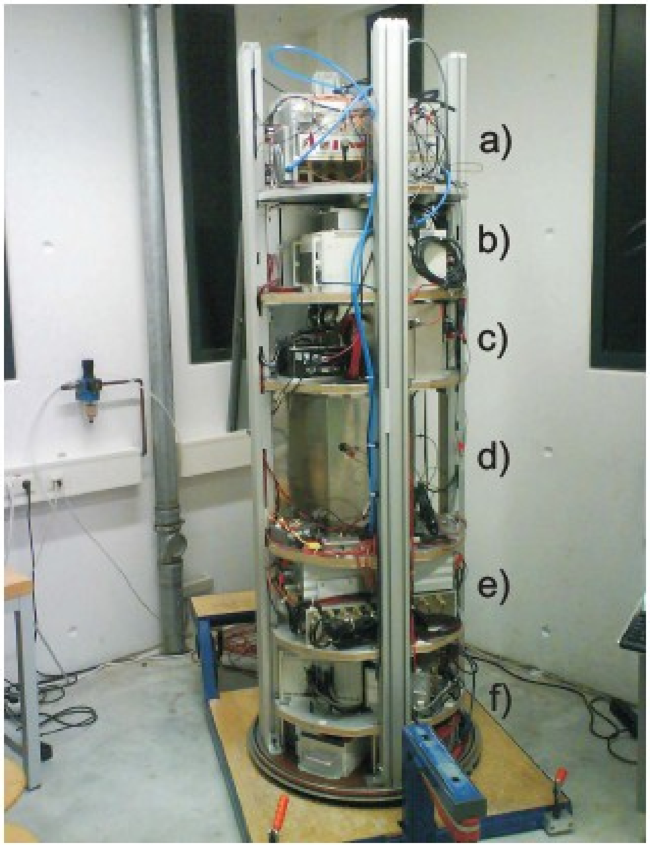


Vortices

Quantum technology

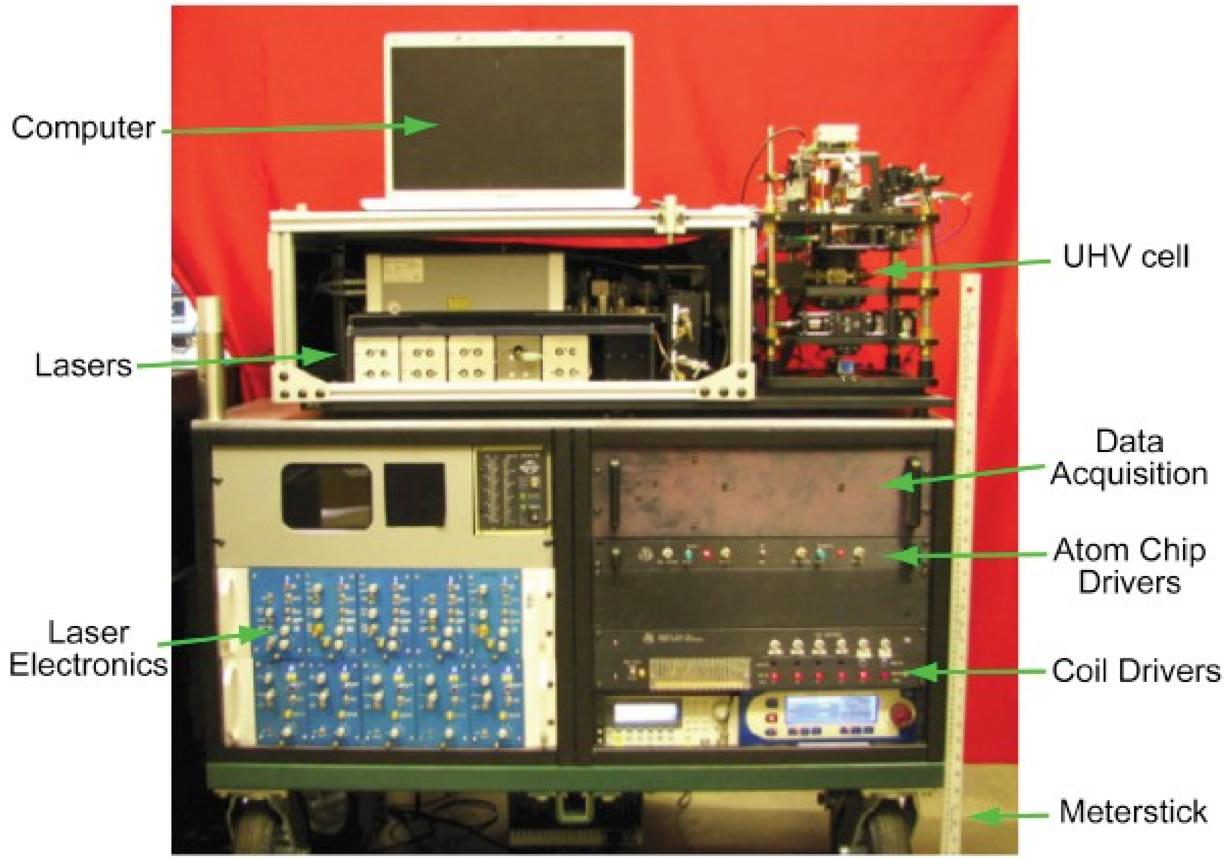
QUANTUS project

A. Vogel et al.,
Appl. Phys. B 84, 663 (2006).



D. Anderson's group, Boulder

D. M. Farkas et al., arXiv:0912.0533 (2009).



Key components commercially available: ColdQuanta www.coldquanta.com