iSense: a portable ultracold-atom-based gravimeter

V. Boyer, T. Valenzuela and K. Bongs
for the iSense Consortium
School of Physics & Astronomy, University of Birmingham, Edgbaston, B15 2TT Birmingham UK

iSENSE Integrated Quantum Sensors
SEVENTH FRAMEWORK PROGRAMME

FET Open project 250072

Participants

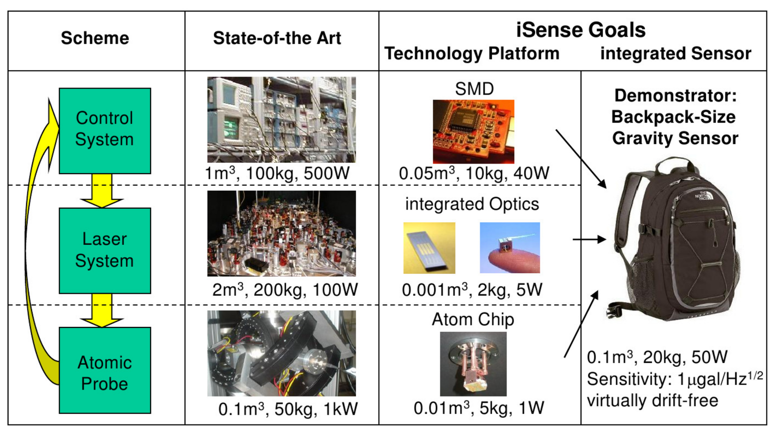
Participant no.	Orinisation name	Short name	Country
1 (Coordinator)	The University of Birmingham	Bham	UK
2	University of Nottingham	Nham	UK
3	University of Hamburg	UHH	D
4	Centre National de la Recherche Scientifique[1]	CNRS	F
5	University of Florence	UNIFI	I
6	Leibniz University Hannover	LUH	D
7	Insitute for Quantum Optics and Quantum Information - Austrian Academy of Sciences	IQOQI-OEAW	A
8	Ferdinand-Braun-Institut für Höchstfrequenztechnik im Forschungsverbund Berlin e.V.	FBH	D
9	QinetiQ	QinetiQ	UK

Idea

Quantum sensors based on ultracold atoms reach precision records for gravity, gravity gradients and time, but this revolutionaryquantum technology has remained confined to the lab. The iSense (an FP7, ICT FETopen collaborative project) vision is a modular, scalable and portable quantumtechnology family based on cold atoms in optical lattices. The goals are two-fold:

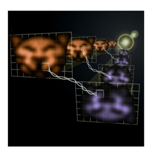
1. The miniaturisation and integration of the components of typical cold atom apparatuses using ICT

2. The construction of a state of the art **gravimeter** using the integrated technology.



Some potential applications

Quantum ICT



It is anticipated that future quantum ICT will be based on a split approach using photons for quantum communication and different systems for storage and processing of quantum information. iSense will benefit both parts, as it will provide robust and compact diode laser technology for coherent free-space telecommunication as well as an easy way to realize quantum gases as one of the most promising resources for quantum ICT research.

Space geodesy

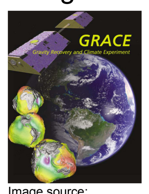
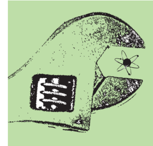


Image source: http://www.csr.utexas.edu/grace/gallery/other/misc/GRACE_Brochure_Cover.JPG

Earth observation using gravitational signals like in the GRACE and GOCE missions is a powerful source of information for the earth's gravity field and water circulation. The latter provides input for climate models and has significant impact on scenarios for securing future water and food supply. However, the current resolution is sensitivity-limited to large areas, such as the Amazon rainforest. iSense technology might allow cold atom satellite sensors, have the potential to boost the sensitivity of such missions by several orders of magnitude and thus allow resolution of much smaller features, such as river deltas.

Metrology/fundamental research



Laser sensors and atom interferometers have emerged as the most sensitive devices for measurements of distance, time, gravity, gravity gradients and rotations. They are thus valuable tools for the definition of SI units like the second, but can also be used to provide fundamental tests on the laws of physics, e.g. testing the constancy of "constants" like the fine structure constant. iSense will provide both laser as well as cold atom technology to further and accelerate this field.

Electronics

Complex electronics is required to run the experimental sequence and control the various conponents: laser stabilisation and locking to atomic lines, frequency shifting of the lasers, laser amplitude, magnetic trapping, readout of the atom interferometer,data processing and high precision frequency chain.
iSense electronics consists of a PC104-format computer controlling a series of of custom designed boards driving the variouscomponents and reading out the instruments.The lasers will be tightly integrated with their current driver and frequency controllers.

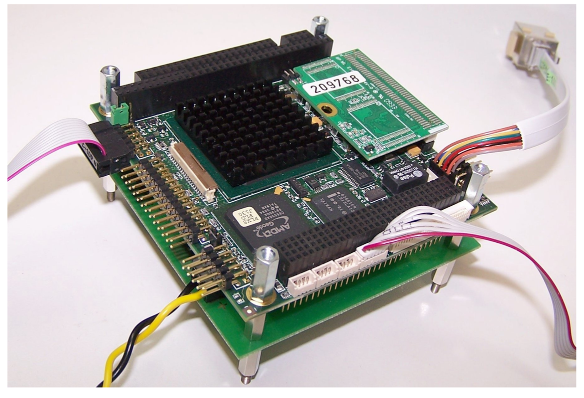
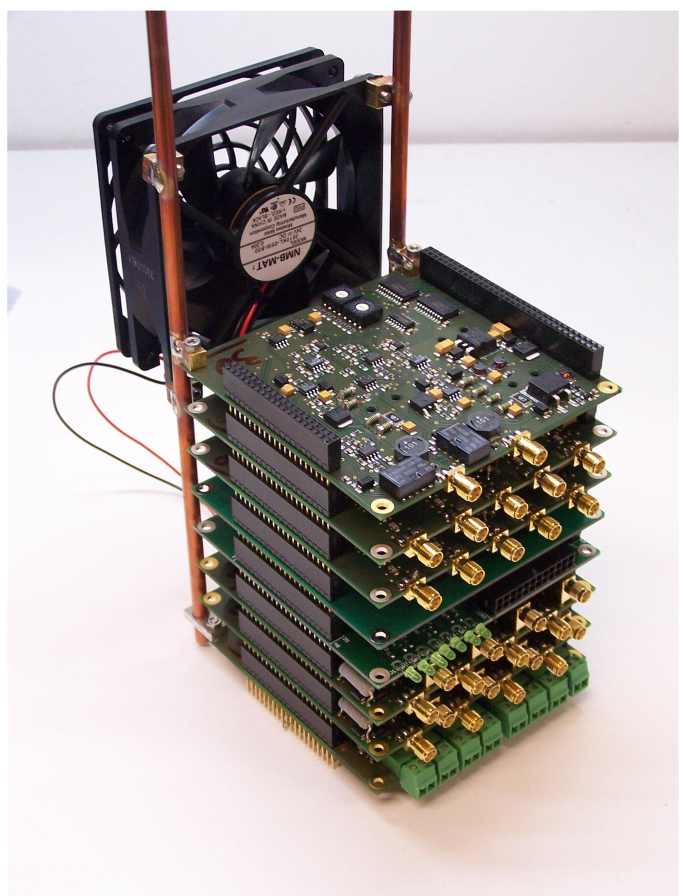
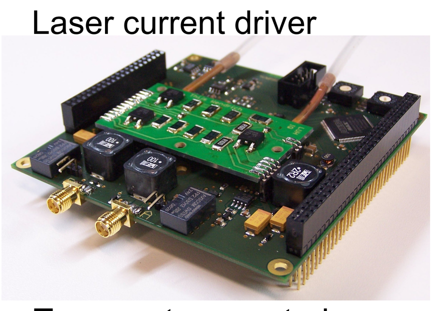


Image left:
PC104 computer. 500MHz AMD Geode, able to run NI LabVIEW Real-Time ETS.

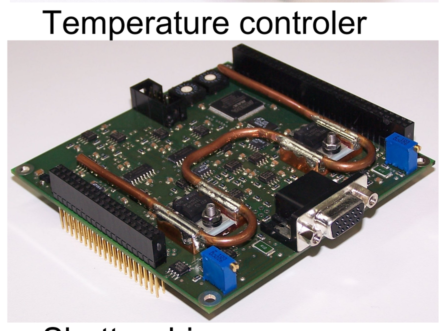
Image right:
Stack of various electronic modules. Including radio frequency generators and controllers, power supplies, analog and digital input/ output cards.



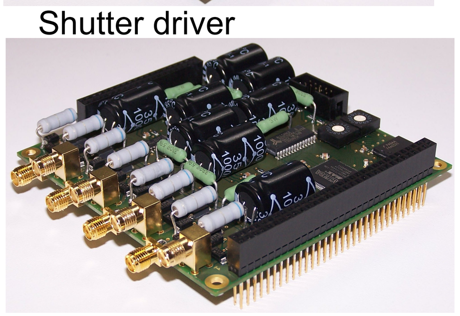
Laser current driver



Temperature controler



Shutter driver

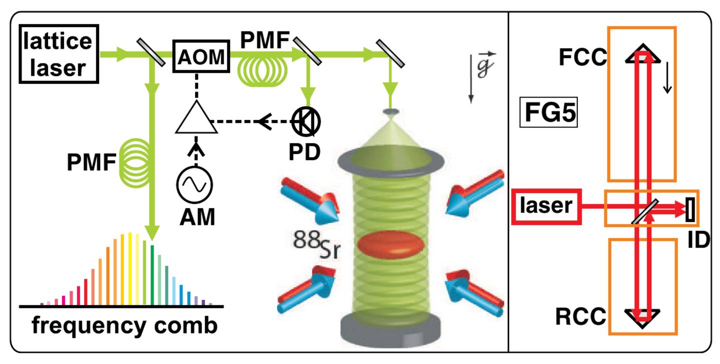


Sensor schemes

Today's sensors are almost entirely based on classical working principles, e.g. falling corner cube for gravity measurements. The precision is limited by manufacturing tolerances. **Atoms** used as probes are more reproducible and consistent. For the iSense gravimeter, several sensing schemes are investigated.

Bloch oscillations

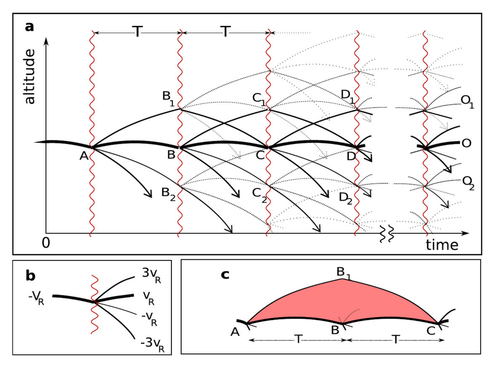
Atoms help in a vertical periodic potential are subject to the acceleration of gravity g and oscillate vertically. The measurement of the oscillation frequency gives the value of **g**.



Scheeme uncertainty ~2 x 10^{-7}

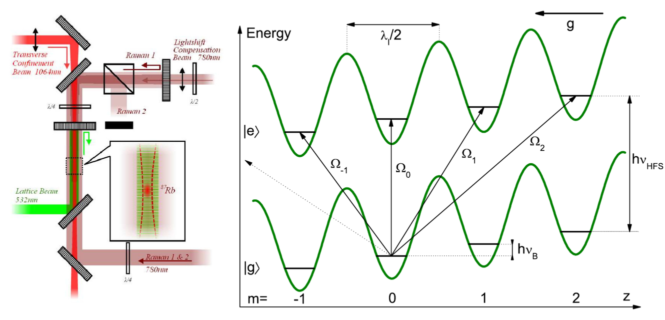
Atom trampoline

Ultracold atoms are levitated using a series of Bragg light pulses. By choosing the propper time interval between pulses the number of atoms levitated can be optimised. In order to levitate an atom the momentum transfered from the light should be equal to the momentum gained during free fall. This allows to extract the value of the acceleration of gravity g from the optimal time interval and the known moment kick received by the atoms from every Bragg pulse.



Scheeme uncertainty ~4 x 10^{-4}

Wannier-Stark ladder

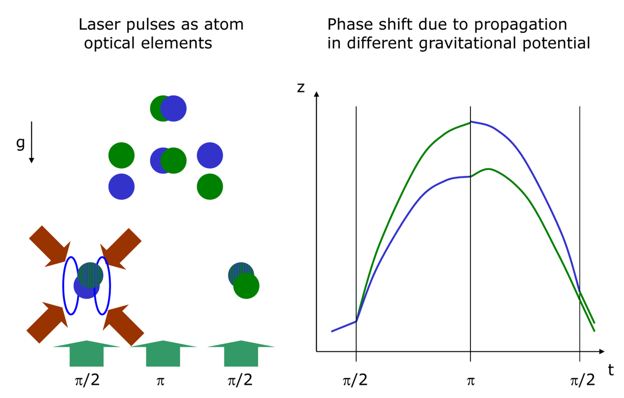


The atoms are placed in a vertical optical lattice. An atom interferometer relying on the atoms transitting through wells located at different heights. It measures the difference of gravitational potential energy between these wells and allows the interferometric measurement of g.

Scheeme uncertainty ~6x10^{-5}

Free fall

An atom interferometer where the two paths have distinct heights will measure a dephasing associated with the difference in gravitational potential energy of the two paths. The measure of the dephasing and the knowledge of the height difference gives the value of g.

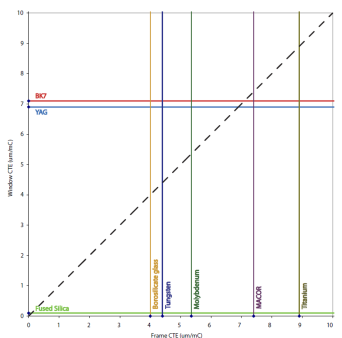


Scheeme uncertainty ~1x10^{-8} Hz$^{-1/2}$

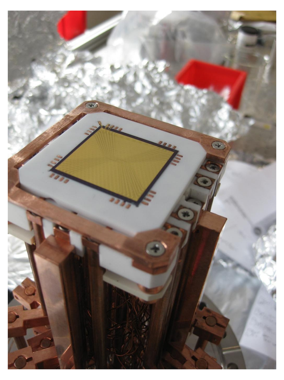
Vacuum chamber / atom trap

Vacuum technology is heavy and cumbersome. iSense is exploring new bonding technologies to create small glass ultra-high vacuum cells that can be integrated with small pumps.

Hydroxyde catalyzed silicate bonding test piece - CNRS-IOGS



Glued window vacuum chamber and analysis of material combinations - Bham
(developments by M. Holynski and J. Kronjaeger)

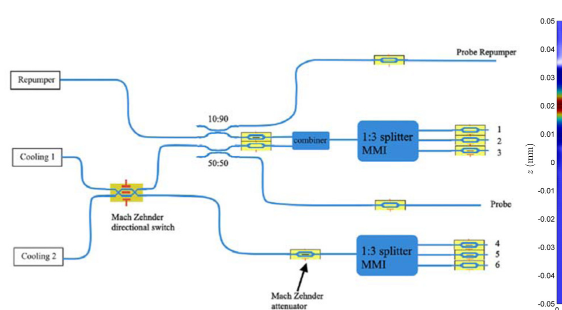


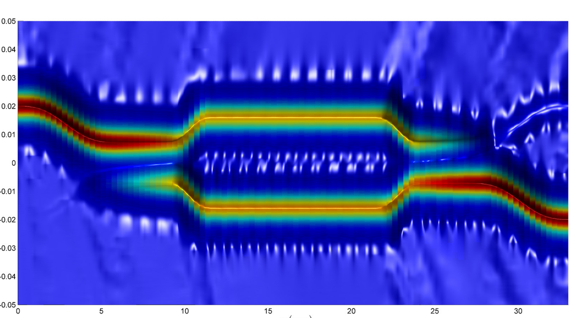
Magneto-optical trapping of the atoms will be done with state-of-the-art atom chip technology. It combines magnetic coils with a reflective surface and integrates the hardware required for laser cooling and trapping into a small package.

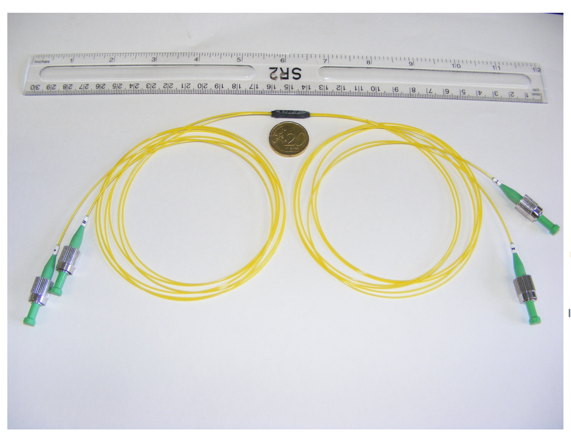
Image on the left:
Atom chip setup developed by UNott with a power consumption of just 5W.

Splitter

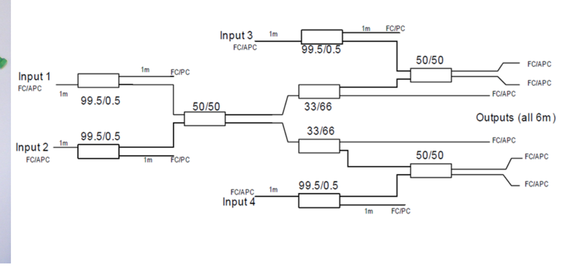
Cold atom experiments make extensive use of optical components to generate the cooling and trapping light beams. iSense will integrate these table-top set-ups into a small package using ICT. Guiding, splitting and switching will be implemented with







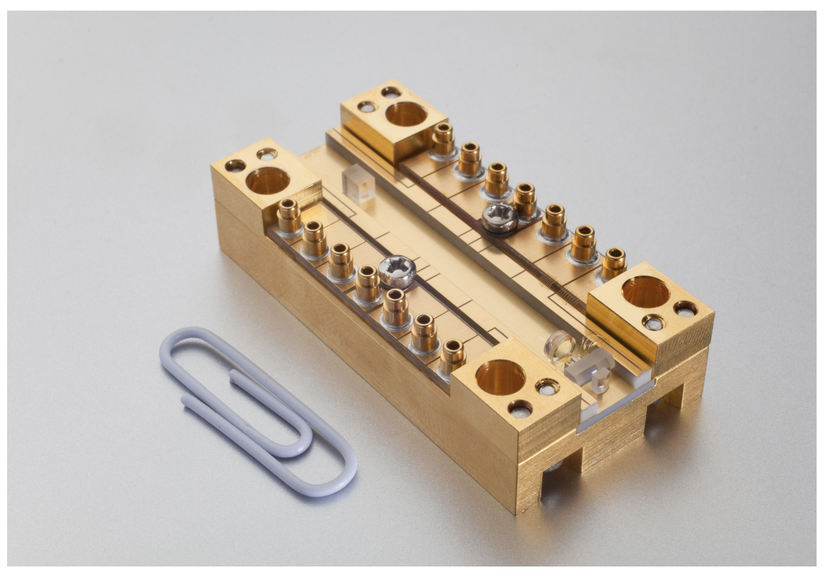
In a first stage, iSense will be using commercial fiber splitters and networks combined with standard acousto-optics switches.



Micro-integrated laser systems

Cold atom interferometers require a range of narrow-line lasers to trap, cool, manipulate and probe the atoms. Semiconductor lasers are small and powerful but require additional external optics to meet the linewidth requirements. iSense develops micro-bench optical modules that will reduce the volume of the lasers by a factor 100–1000.

Additional optical set-ups allowing the lasers to be locked to atomic lines or to each other will also be integrated on micro-benches.



This picture shows a micro-integrated ECDL for Rb spectroscopy at 780.24 nm. The output power exceeds 100 mW, the linewidth (FWHM, 10 μs) is < 100 kHz with an intrinsic linewidth below 10 kHz. The modul is integrated on a ceramic bench (50 mm x 10 mm footprint), which itself is mounted on a conductively cooled package made of copper with a 50 mm x 25 mm footprint.

Future extensions

- Blue laser sources

- Integrated waveguides for optical wavelengths (GaN, SiC, Polymer, ...)

- Integrated optical clocks with earth alkali atoms

- Further shrinkage by using ASIC electronics and micromachined vacuum systems

- ...

Publications:

[1] S. Stellmer, M. K. Tey, R. Grimm, and F. Schreck, Bose-Einstein condensation of 86Sr, Phys. Rev. A 82, 041602(R) (2010)

[2] R. Messina, S. Pelisson M.-Ch. Angonin and P. Wolf, Atomic states in optical traps near a planar surface, submitted, arXiv:1103.1581

[3] Q. Beaufils, G. Tackmann, X. Wang, B. Pelle, S. Pelisson, P. Wolf and F. Pereira dos Santos, Laser controlled tunneling in a vertical optical lattice, submitted, arXiv:1102.5326

Web page

www.isense-gravimeter.com

Acknowledgements

This research is carried on within the project iSense (Integrated Quantum Sensors), which acknowledges the financial support of the Future and Emerging Technologies (FET) programme within the Seventh Framework Programme for Research of the European Commission, under FET-Open grant number: 250072.