

The European Future Technologies Conference and Exhibition 2011

## iSense: A Portable Ultracold-Atom-Based Gravimeter<sup>☆</sup>

M. de Angelis<sup>a,b</sup>, M.C. Angonin<sup>c</sup>, Q. Beaufils<sup>c</sup>, Ch. Becker<sup>d</sup>, A. Bertoldi<sup>e</sup>, K. Bongs<sup>f</sup>,  
T. Bourdel<sup>e</sup>, P. Bouyer<sup>e</sup>, V. Boyer<sup>f</sup>, S. Dörscher<sup>d</sup>, H. Duncker<sup>d</sup>, W. Ertmer<sup>g</sup>,  
T. Fernholz<sup>h</sup>, T.M. Fromhold<sup>h</sup>, W. Herr<sup>g</sup>, P. Krüger<sup>h</sup>, Ch. Kürbis<sup>i</sup>, C.J. Mellor<sup>h</sup>,  
F. Pereira Dos Santos<sup>c</sup>, A. Peters<sup>j</sup>, N. Poli<sup>b</sup>, M. Popp<sup>g</sup>, M. Prevedelli<sup>k</sup>, E.M. Rasel<sup>g</sup>,  
J. Rudolph<sup>g</sup>, F. Schreck<sup>l</sup>, K. Sengstock<sup>d</sup>, F. Sorrentino<sup>b</sup>, S. Stellmer<sup>l</sup>, G.M. Tino<sup>b</sup>,  
T. Valenzuela<sup>f</sup>, T.J. Wendrich<sup>g</sup>, A. Wicht<sup>i</sup>, P. Windpassinger<sup>d</sup>, P. Wolf<sup>c</sup>

<sup>a</sup> Istituto di Fisica Applicata - CNR, via Madonna del Piano 10, 50019 Sesto Fiorentino, Italy

<sup>b</sup> Dipartimento di Fisica e Astronomia and LENS, Università di Firenze-INFN Sezione di Firenze, Via Sansone 1, 50019 Sesto Fiorentino, Italy

<sup>c</sup> LNE-SYRTE, UMR 8630 CNRS, UPMC, Observatoire de Paris, 61 avenue de l'Observatoire, 75014 Paris, France

<sup>d</sup> Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

<sup>e</sup> Laboratoire Charles Fabry de l'Institut d'Optique, CNRS and University Paris-Sud, Campus Polytechnique, RD 128,  
91127 Palaiseau cedex, France

<sup>f</sup> Midlands Ultracold Atom Research Centre, School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, United Kingdom

<sup>g</sup> Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

<sup>h</sup> Midlands Ultracold Atom Research Centre, School of Physics and Astronomy, University of Nottingham, Nottingham NG7 2RD, United Kingdom

<sup>i</sup> Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany

<sup>j</sup> Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany

<sup>k</sup> Dipartimento di Fisica, Università di Bologna-INFN Sezione di Bologna, Via Irnerio 46, 40127 Bologna, Italy

<sup>l</sup> Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, 6020 Innsbruck, Austria

### Abstract

We present *iSense*, a recently initiated FET project aiming to use Information and Communication Technologies (ICT) to develop a platform for portable quantum sensors based on cold atoms. A prototype of backpack-size highprecision force sensor will be built to demonstrate the concept.

© conference organizers and published by Elsevier B.V. Open access under [CC BY-NC-ND license](https://creativecommons.org/licenses/by-nc-nd/4.0/).

Selection and peer review under responsibility of FET11

### 1. Introduction

The long-term vision of *iSense* is a modular, scalable and portable quantum technology family based on the confinement of cold atoms using an optical lattice, adaptable to a wide variety of applications in diverse working environments. Today's sensors are almost entirely based on classical working principles, e.g. falling corner cubes for gravity measurements. Although hard to beat in terms of cost-benefit for standard applications, for step changes in precision these devices become impractical due to rapidly increasing requirements on material and manufacturing tolerances. In this realm quantum sensors based on atoms as probes are a superior choice, as the fundamental physical properties of the atoms themselves ensure reproducibility and consistency.

<sup>☆</sup> <http://www.isense-gravimeter.com>.

However, despite highly successful proof-of-principle demonstrators 10 years ago, e.g. reaching precision records for gravity and gravity gradients, this revolutionary quantum technology has essentially remained confined to a laboratory environment. The main reason lies in the bulkiness and fragility of the setup, which is dominated by a complex laser system necessary for state control and interrogation and a vacuum system which has to allow for a “free fall” period in which the sensing is taking place.

This project tackles both these fundamental barriers by simultaneously targeting two breakthroughs, one scientific and one technological. Scientifically it seeks to demonstrate novel schemes for guided precision sensors using optical lattices or quantum levitation, which would allow significant reductions in size of the vacuum system and remove precision limitations due to finite free fall periods. Technologically it utilises state-of-the-art methods of the information and communication sector, where integrated optics is enabling ubiquitous high-speed internet and communications infrastructure. Transferring ICT has the potential to reduce the form factor of atom-based quantum sensors by at least an order of magnitude which would enable a step change towards commercial applications.

Overall, this project aims at a general technology platform proven by the demonstration of a self-contained backpack-size, “turn-key” force sensor (gravimeter) based on atom interferometry. This would be the first in a line progressing from sensors to quantum computation, the latter being enabled by precision control of the optical lattice environment and control beams resulting from the transfer of ICT to this systems concept.

## 2. Applications

Gravity sensors are already used in geodesy, in the exploration of resources and archaeology. The improvements in precision and robustness offered by the quantum force sensor would not only make these applications more routine but offer completely new possibilities, e.g. the location and extraction of fragmented oil bubbles in current oil fields.

In the longer term we anticipate novel communications paradigms (e.g. wide-band network timing) using a quantum-based position-time grid that would not require GPS, and exceed its accuracy by orders of magnitude. Further applications would become apparent as the technology develops, e.g. atom-based quantum information technology including computing and secure communications for a range of purposes including global trade exchange.

## 3. Technology breakthroughs

Cold atom research relies on a large number of core technologies: ultra-high vacuum, high-performance laser systems, active optics (electro- and acousto-optics), fiber optics, electromagnets (magnetic trapping), detectors (photodiodes, cameras), precision electronics (frequency chains, computer control), etc. The novelty of this proposal lies in a consistent and thorough step change in the miniaturisation and integration of these technological components.

*Integrated optics.* iSense will for the first time create a set of integrated optics devices for cold atom applications at 780nm using GaAs technology and explore its further extension to the full visible range using GaN technology. For this crucial breakthrough for cold atom applications iSense will achieve a technology leap in optical systems similar to the replacement of discrete circuits by integrated circuits in electronics.

*Laser modules.* Up to now, when compact and robust diode laser systems are required for spectroscopy, distributed feedback (DFB) (or distributed Bragg reflector, DBR) lasers have to be used. However, these typically do not achieve the frequency stability required for all aspects of precision optical metrology, and the state of the art in cold atom research and its applications relies on extended cavity diode lasers and hence, up to now, on macroscopic optics.

Recognising the need for optics external to the diode lasers, iSense will develop microbench optical modules including all the non-integrable parts in the smallest possible form factor, a factor of 100-1000 volume size reduction as compared to the current state-of-the-art.

*Atom trap.* Atom chips are an example of one of the early attempts to make the production of cold atoms, in particular quantum gases easier, less power consuming and better controlled, with a lot of successes and a high state-of-the-art. iSense aims at the further completion of the atom chip revolution and realize novel ideas by designing low-power atom chips without external coils in particular for sensor applications, using transparent conductor technology.

*Vacuum.* iSense will realize novel compact and fully UHV compatible systems with full anti-reflection coating as necessary for ultra-precise sensor applications. The size of below  $0.001 \text{ m}^3$  will be more than 1 order of magnitude smaller than the current state-of-the-art.

*Electronics.* iSense will develop a SMD-based electronics platform with coherent computer control, such that fully autonomous operation of cold atom experiments will be possible for the first time. As a particular point, a compact precision radiofrequency reference source for application in atom sensors will be developed.