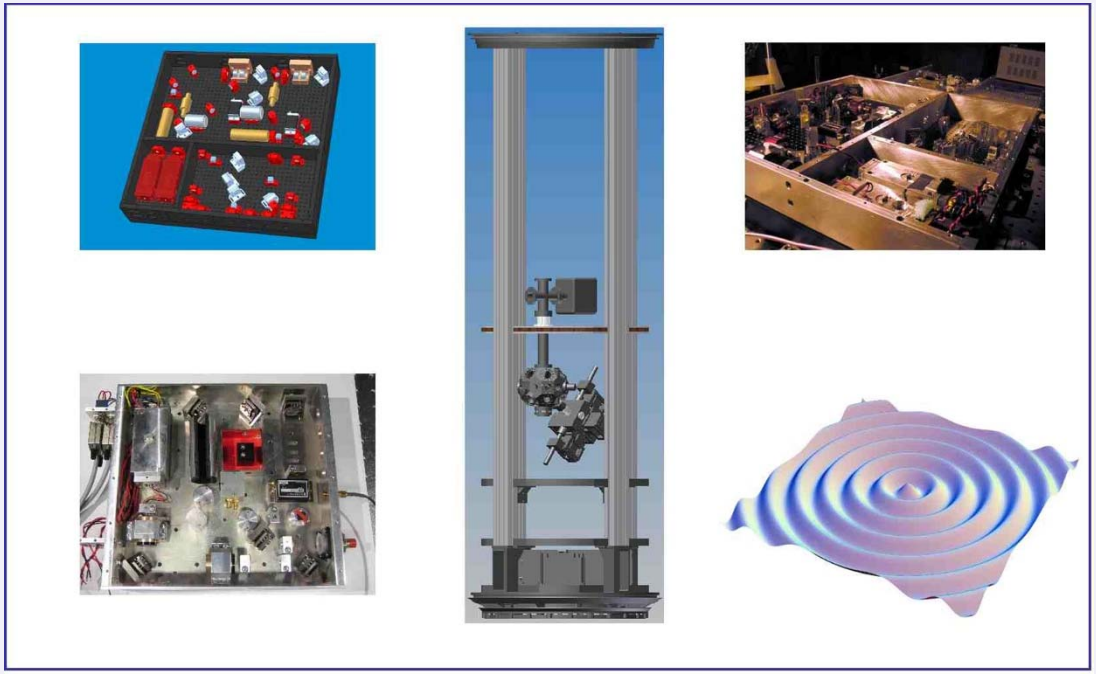
The Space Atom Interferometer (SAI) project: Status and perspectives



***Guglielmo M. Tino* (SAI *Project Coordinator*)**

Dipartimento di Fisica e Astronomia and LENS

Università di Firenze, Italy

for the SAI Team

Space Atom Interferometer - SAI

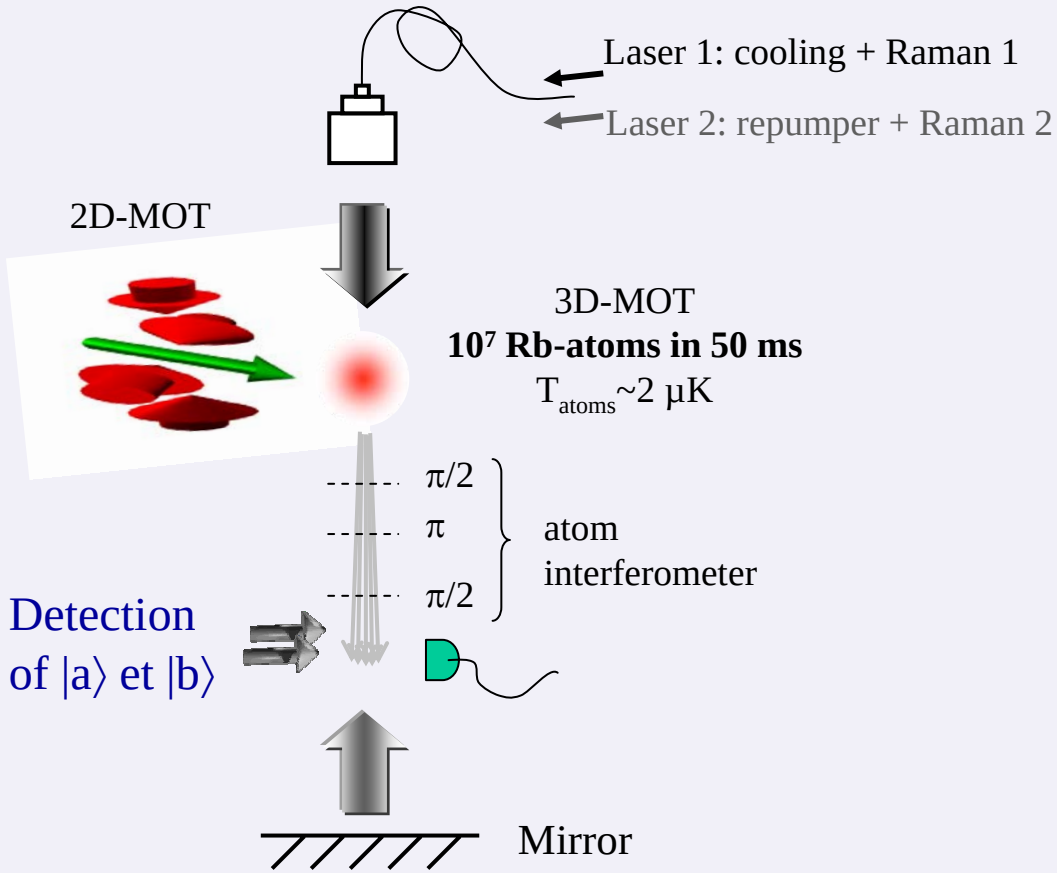
Space Atom Interferometer: **Pre-phase A study of a space instrument based on matter-wave interferometry for inertial sensing in space**

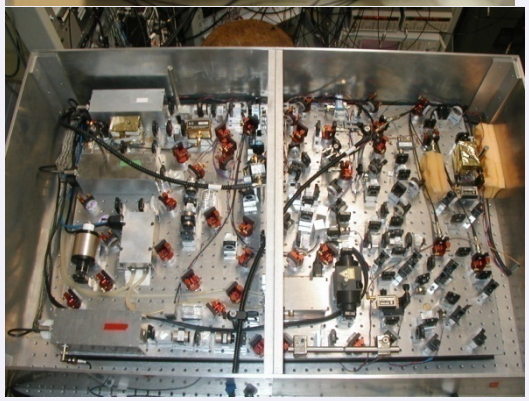
Team: **Firenze Univ. (I), IOTA (F), IQO (D), Hamburg Univ. (D), HU Berlin (D), SYRTE (F), LENS (I), Ulm Univ. (D), ZARM (D)**

Objective: **Ground based prototype of an atom interferometer for precision measurements**

Duration: **2007- 2010, funded within the ELIPS-2 Programme**

SYRTE transportable gravimeter





Small Optical bench: 60x90 cm

To be moved to Trappe (watt balance site)

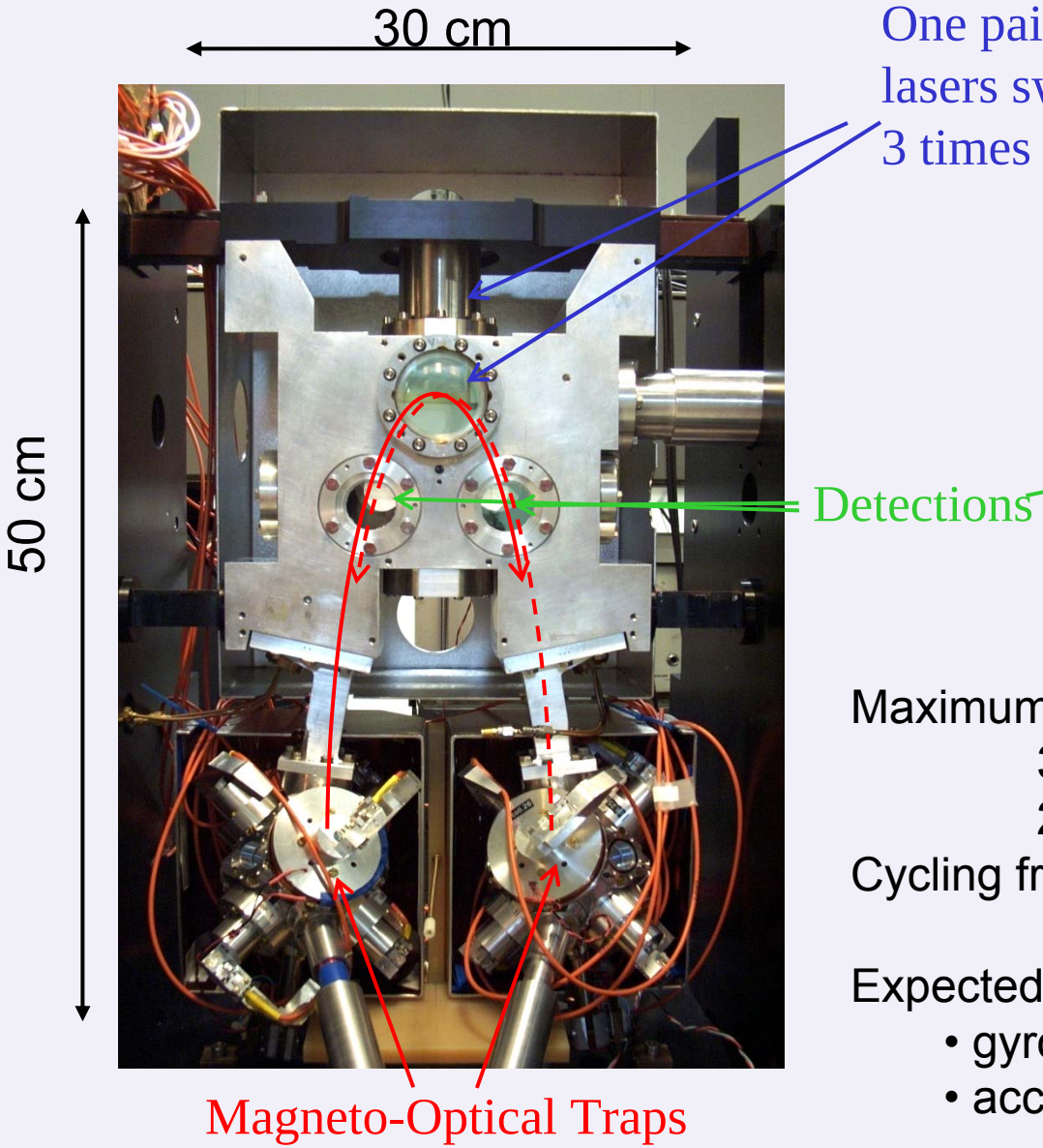
- 4 Hz repetition rate
- Accuracy goal < 10^{-9} g
- Present limits:

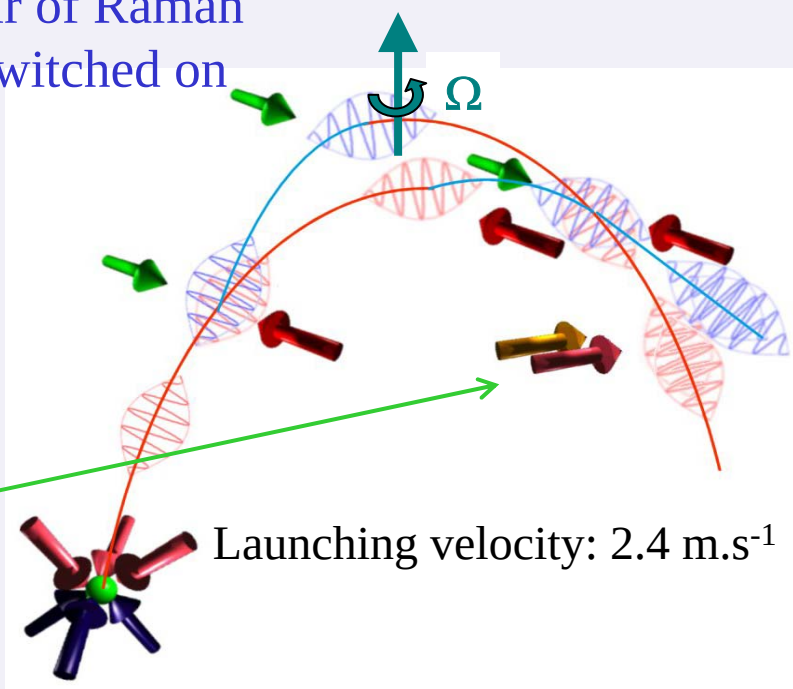
Sensitivity : **2 10^{-8}** g/√Hz (limited by residual vibrations)

Accuracy: comparison ~ 10^{-8} g

From A. Landragin, 2007

SYRTE cold atom gyroscope





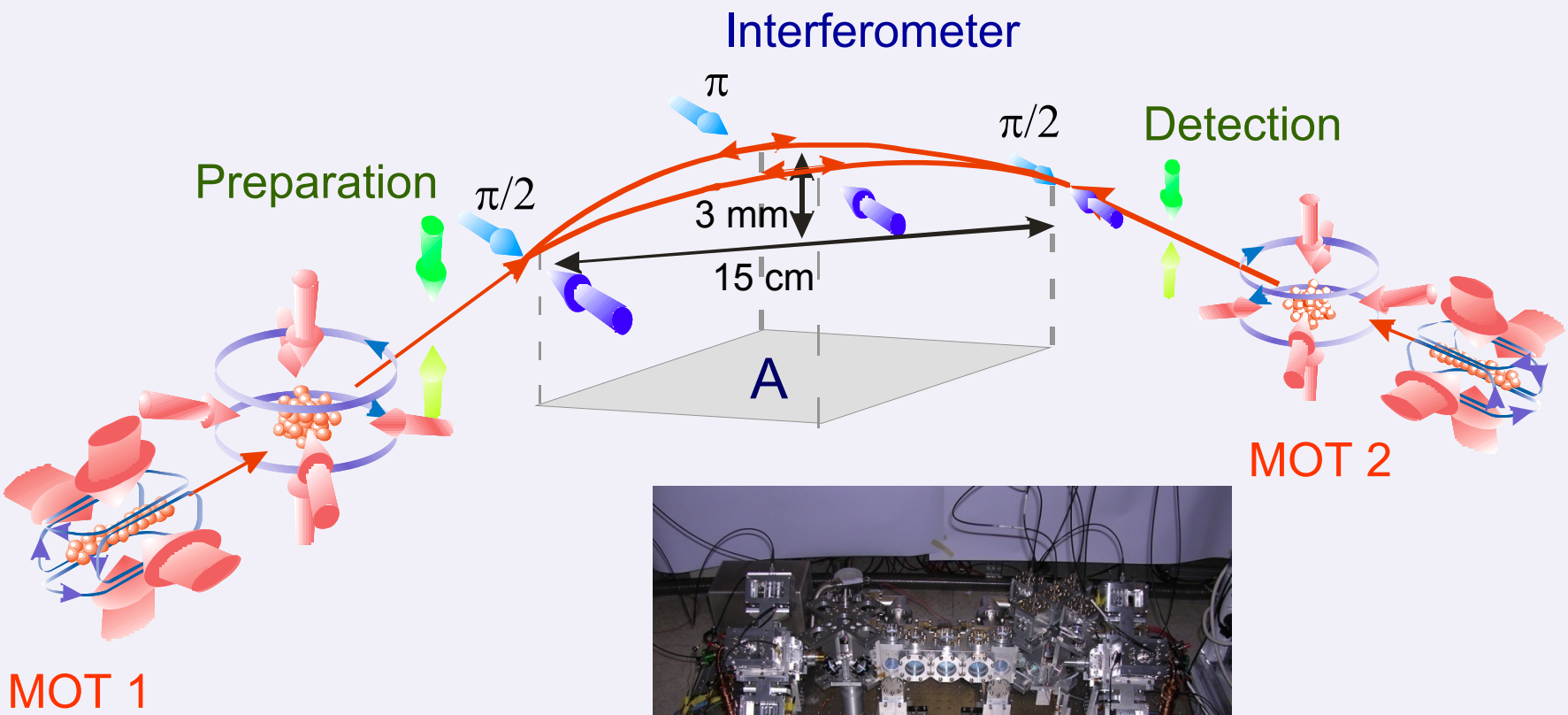
Maximum interaction time : 90 ms
3 rotation axes
2 acceleration axes
Cycling frequency 2Hz

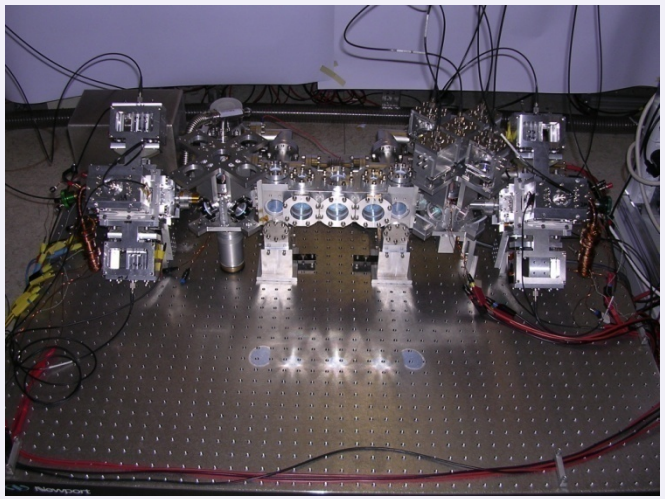
Expected sensitivity (10^6 at):

- gyroscope : $4\ 10^{-8}$ rad.s^{-1}.Hz$^{-1/2}$
- accelerometer : $3\ 10^{-8}$ m.s^{-2}.Hz$^{-1/2}$

B. Canuel et al., *Six-Axis Inertial Sensor Using Cold-Atom Interferometry*, PRL **97,** 010402 (2006)

IQO Cold Atom Sagnac Interferometer

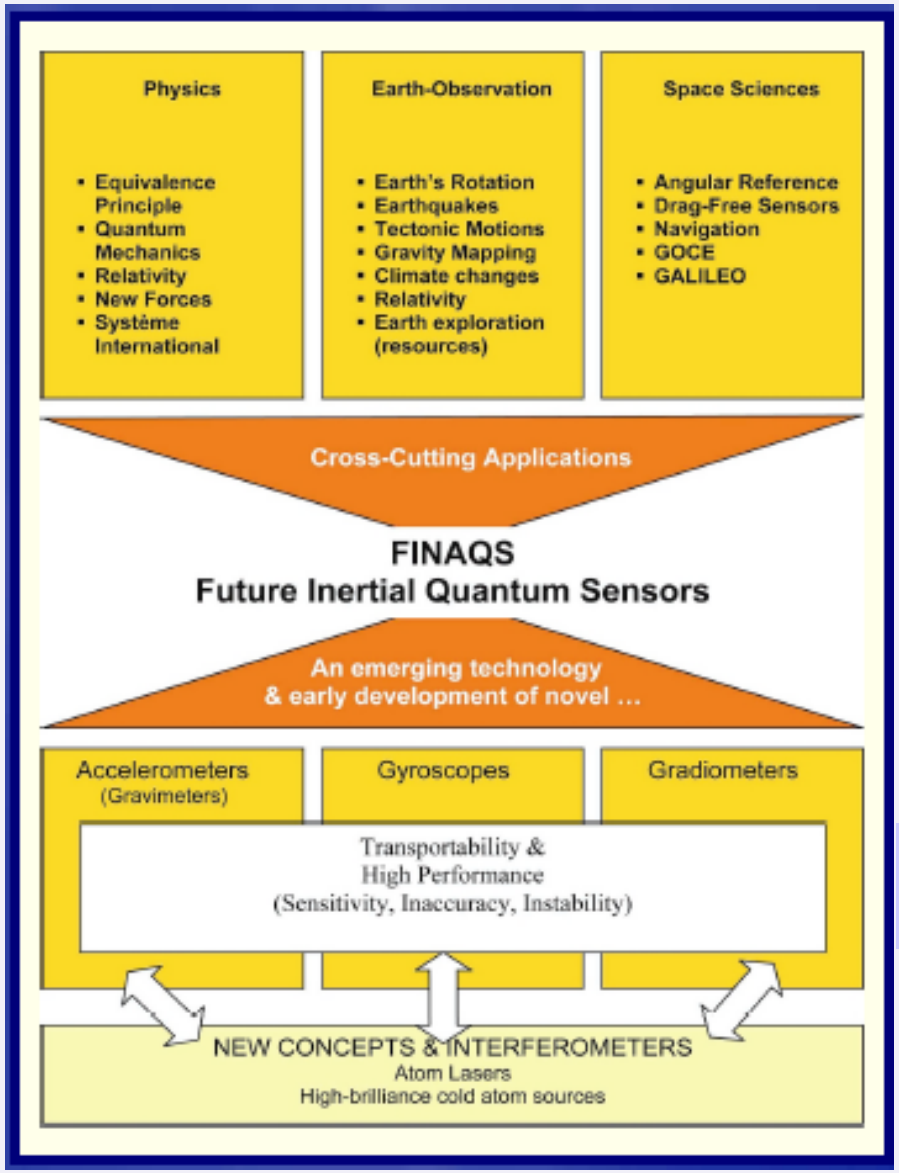




C. Jentsch, T. Müller, E. Rasel, and W. Ertmer, Gen. Rel. Grav, 36, 2197 (2004)

FINAQS – Future Inertial Atomic Quantum Sensors

6th Framework Programme/New Emerging Science Technology



M. Schmidt, M. Prevedelli, A. Giorgini, Guglielmo M. Tino, Achim Peters
A portable laser system for high precision atom interferometry experiments,
Applied Physics B (2010), to be published

www.finaqs.uni-hannover.de/

EUROPEAN COMMISSION

Information Society and Media Directorate-General

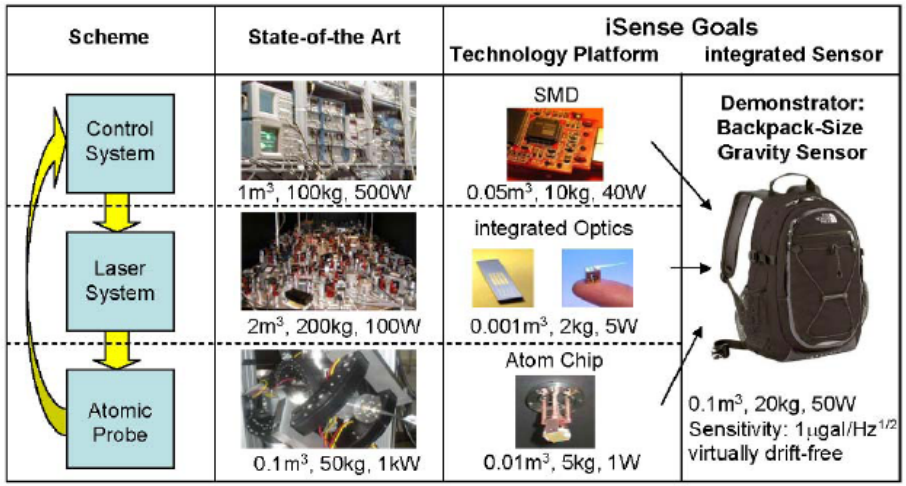
Emerging Technologies and Infrastructures

Future and Emerging Technologies (FET) - Open

iSense – Integrated Quantum Sensors

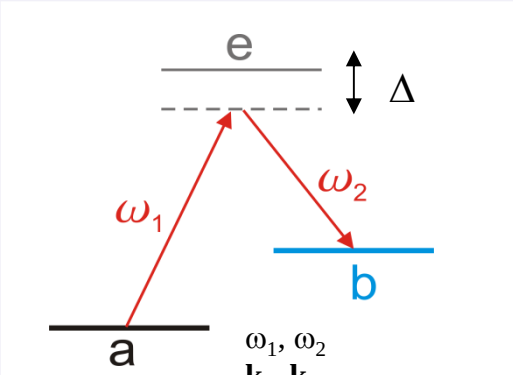
7th Framework Programme - Theme 3 "Information and Communication Technologies"

Call identifier: FP7-ICT-2009- C FET-Open

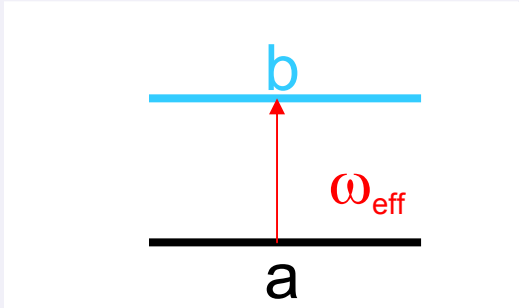


Participant no. *	Participant organisation name	Part. short name	Country
1 (Coordinator)	The University of Birmingham	Bham	UK
2	QinetiQ	QinetiQ	UK
3	University of Hamburg	UHH	D
4	Centre National de la Recherche Scientifique[1]	CNRS	F
5	University of Florence	UNIFI	I
6	Leibniz University Hannover	LUH	D
7	Institute 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	University of Nottingham	Nham	UK

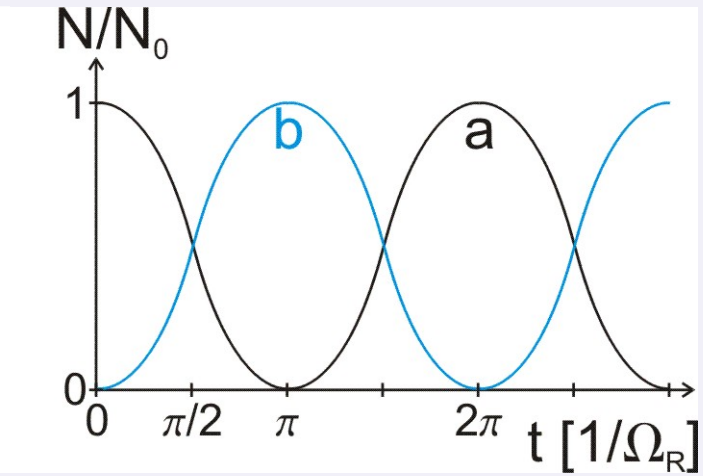
Raman pulse interferometer

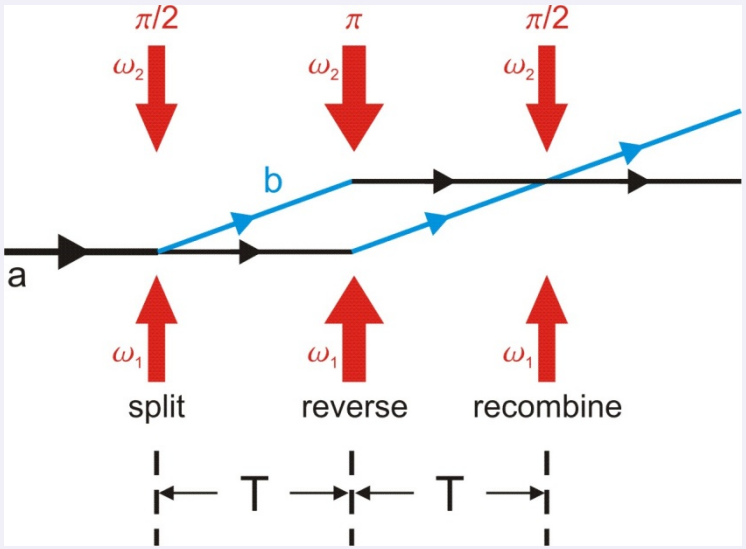


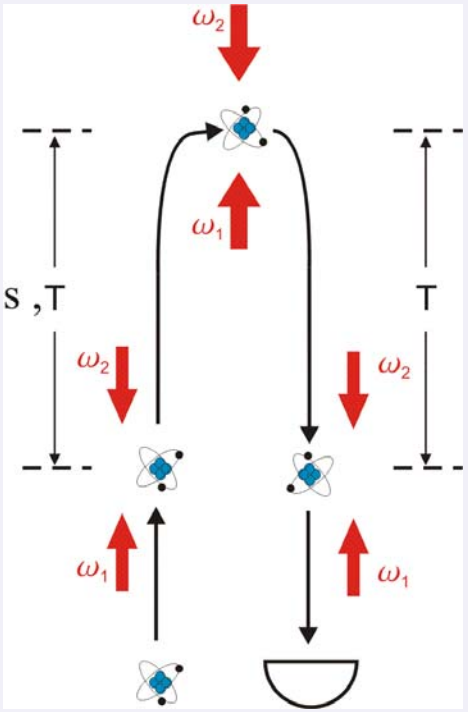
ω_1, ω_2
$\mathbf{k}_1$, $\mathbf{k}_2$
Ω_1, Ω_2
ϕ_1 , ϕ_2



$\omega_{eff} = \omega_1 - \omega_2$
$\mathbf{k}_{eff} = \mathbf{k}_1 - \mathbf{k}_2$
$\Omega_{eff} = \Omega_1\Omega_2/\Delta$
$\phi_{eff} = \phi_1 - \phi_2$

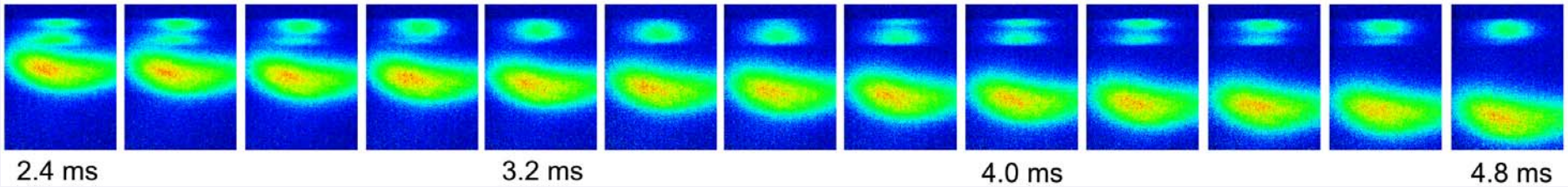


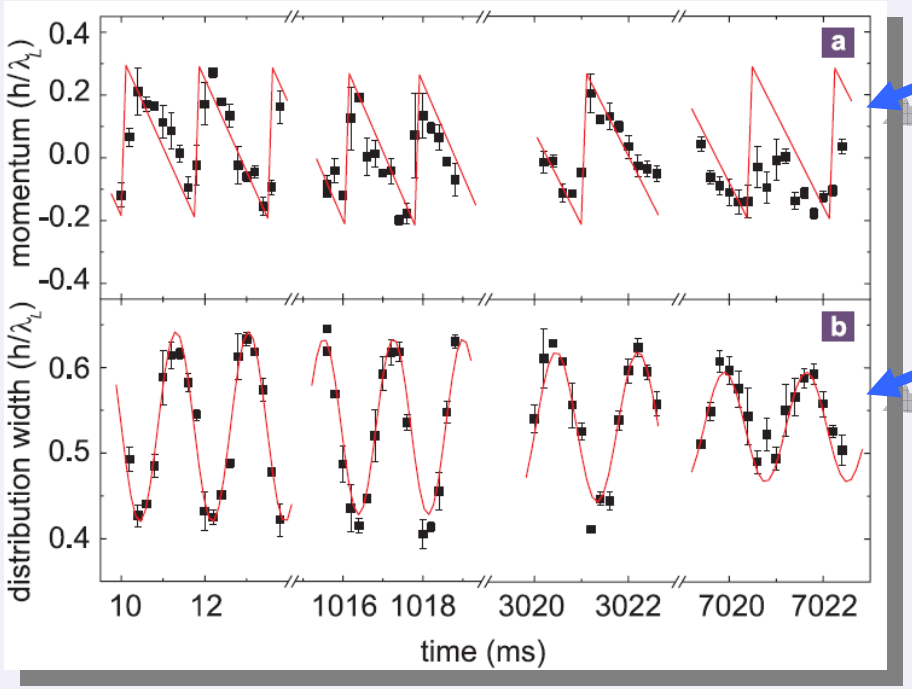




M. Kasevich, S. Chu, Appl. Phys. B 54, 321 (1992)
A. Peters, K.Y. Chung and S. Chu, Nature 400, 849 (1999)

Persistent Bloch oscillations





average vertical momentum of the lower peak

width of the atomic momentum distribution

Bloch frequency $\nu_B = 574.568(3)$ Hz

damping time $\tau = 12$ s

8000 photon recoils in 7s

$g_{meas} = 9.80012(5)\ ms^{-2}$

G. Ferrari, N. Poli, F. Sorrentino, G. M. Tino, *Long-Lived Bloch Oscillations with Bosonic Sr Atoms and Application to Gravity Measurement at the Micrometer Scale*, **Phys. Rev. Lett. 97, 060402 (2006)**

PRL **102,** 240403 (2009) PHYSICAL REVIEW LETTERS week ending 19 JUNE 2009

Atom Interferometers with Scalable Enclosed Area

Holger Müller,[1,2,*] Sheng-wey Chiow,[3] Sven Herrmann,[3] and Steven Chu[1,2]

[1]*Department of Physics, 366 Le Conte Hall, University of California, Berkeley, California 94720-7300, USA*
[2]*Lawrence Berkeley National Laboratory, One Cyclotron Road, Berkeley, California 94720, USA*
[3]*Physics Department, Stanford University, 382 Via Pueblo Mall, Stanford, California 94305, USA*
(Received 24 March 2009; published 18 June 2009)

Bloch oscillations (i.e., coherent acceleration of matter waves by an optical lattice) and Bragg diffraction are integrated into light-pulse atom interferometers with large momentum splitting between the interferometer arms, and hence enhanced sensitivity. Simultaneous acceleration of both arms in the same internal states suppresses systematic effects, and simultaneously running a pair of interferometers suppresses the effect of vibrations. Ramsey-Bordé interferometers using four such Bloch-Bragg-Bloch beam splitters exhibit 15% contrast at $24\hbar k$ splitting, the largest so far ($\hbar k$ is the photon momentum); single beam splitters achieve $88\hbar k$. The prospects for reaching 100 s of $\hbar k$ and applications such as gravitational wave sensors are discussed.

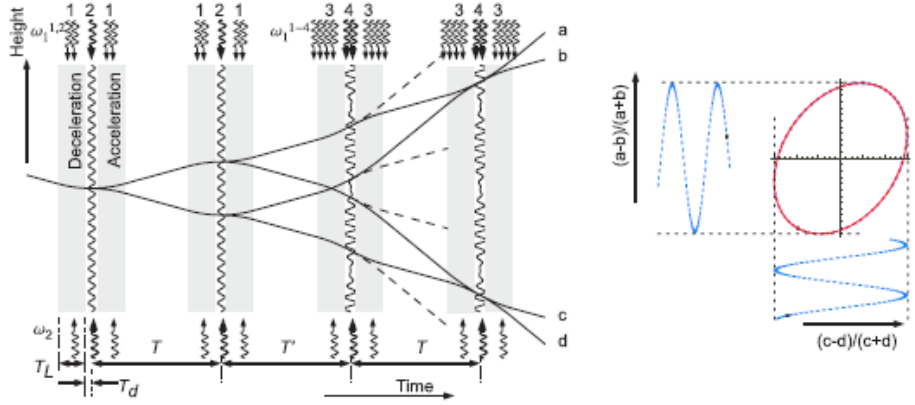
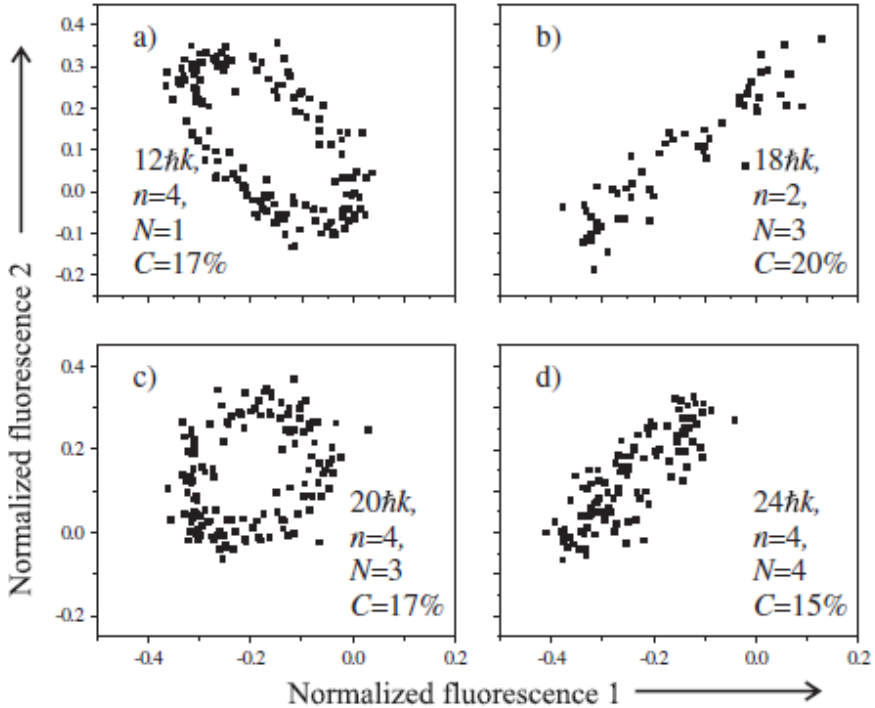
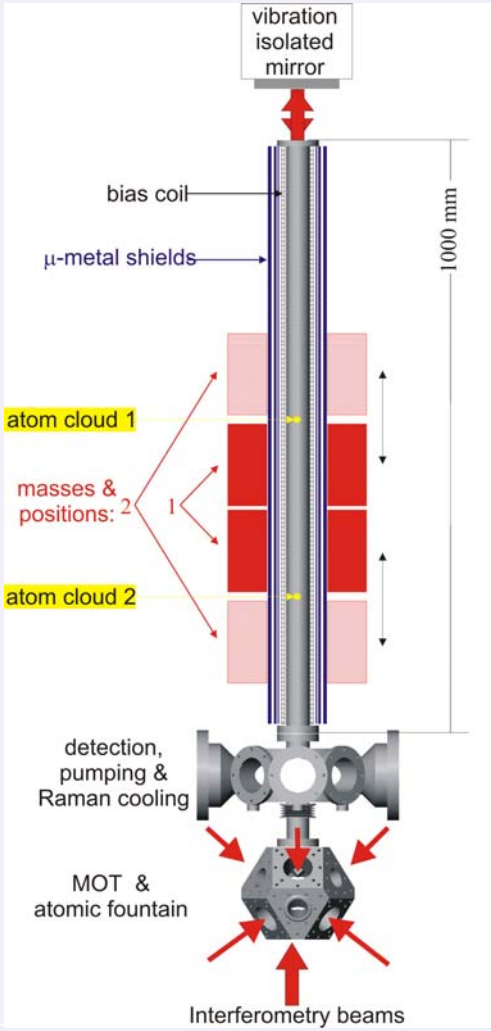
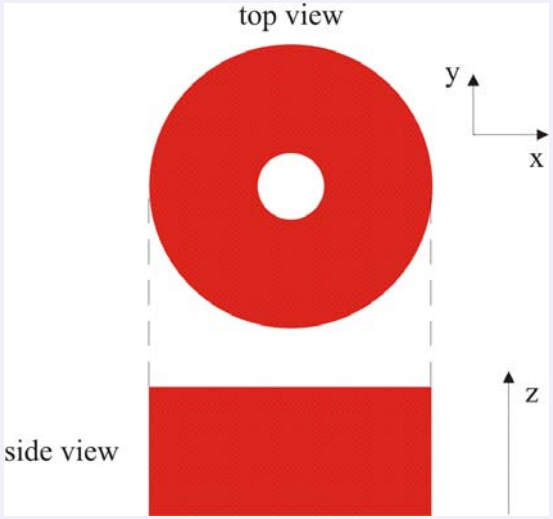


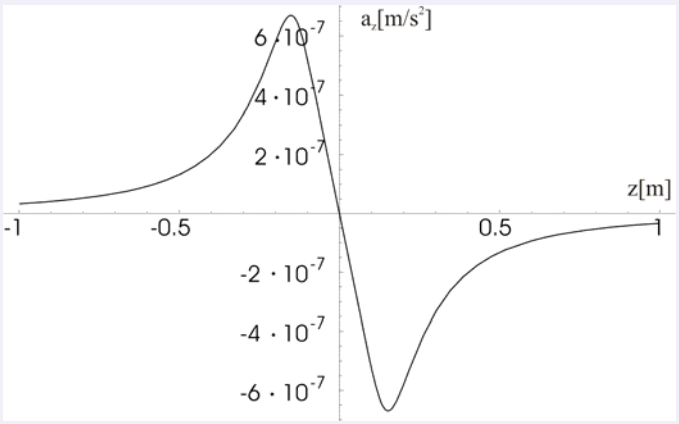
FIG. 1 (color online). Left: space-time diagram of simultaneous conjugate Ramsey-Bordé BBB-interferometers. 1: Dual optical lattice; 2: single Bragg beam splitter; 3: quadruple optical lattice; 4: dual Bragg beam splitter; (a)–(d): outputs. The dashed lines indicate trajectories that do not interfere. Right: plotting the outputs of the interferometers versus one another draws an ellipse.



MAGIA: Raman atom gravimeter + source mass







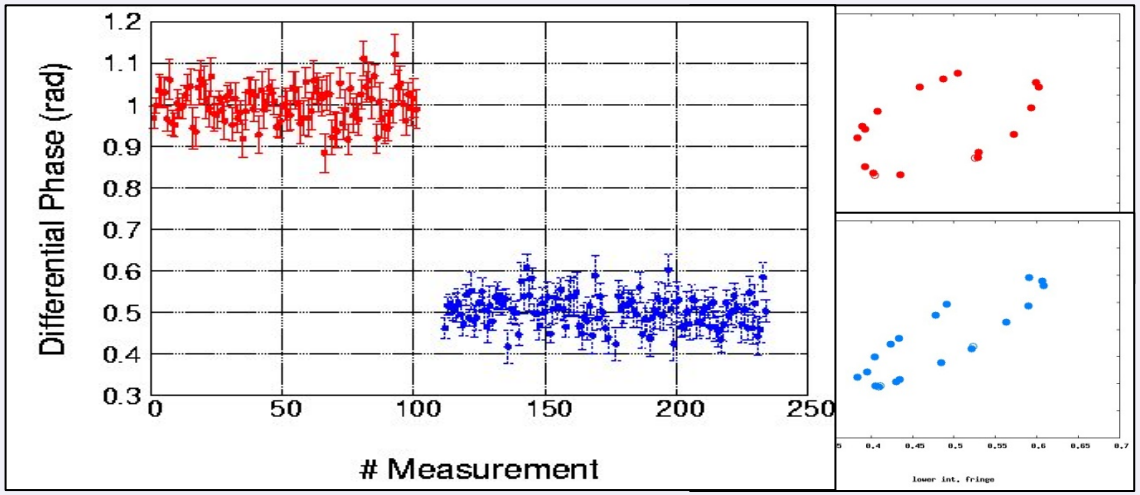
500 kg tungsten mass

Sensitivity 10^{-9}g/shot

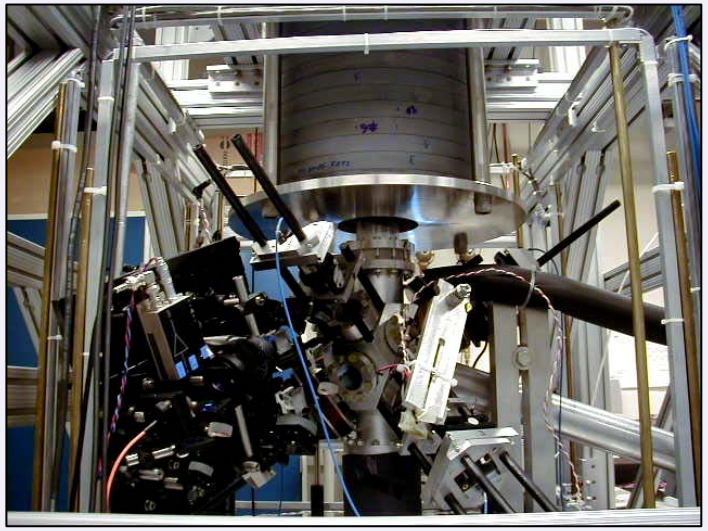
one shot $\Rightarrow \Delta G/G \approx 10^{-2}$

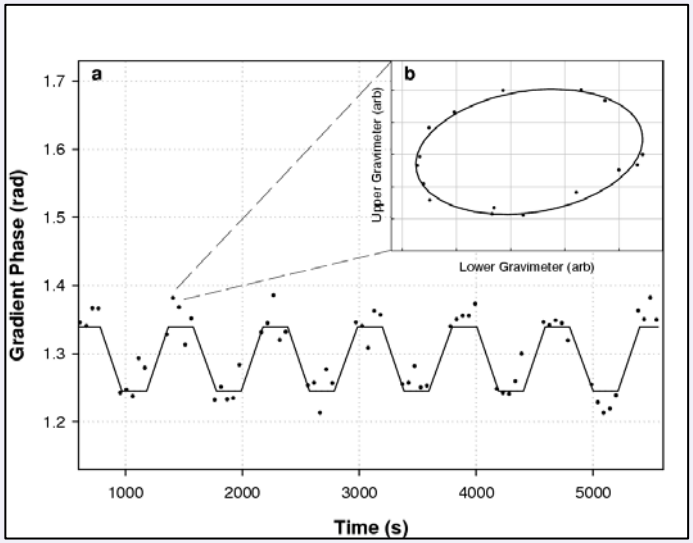
Peak mass acceleration $a_G \approx 10^{-7}$g

10000 shots $\Rightarrow$ **$\Delta G/G \approx 10^{-4}$**

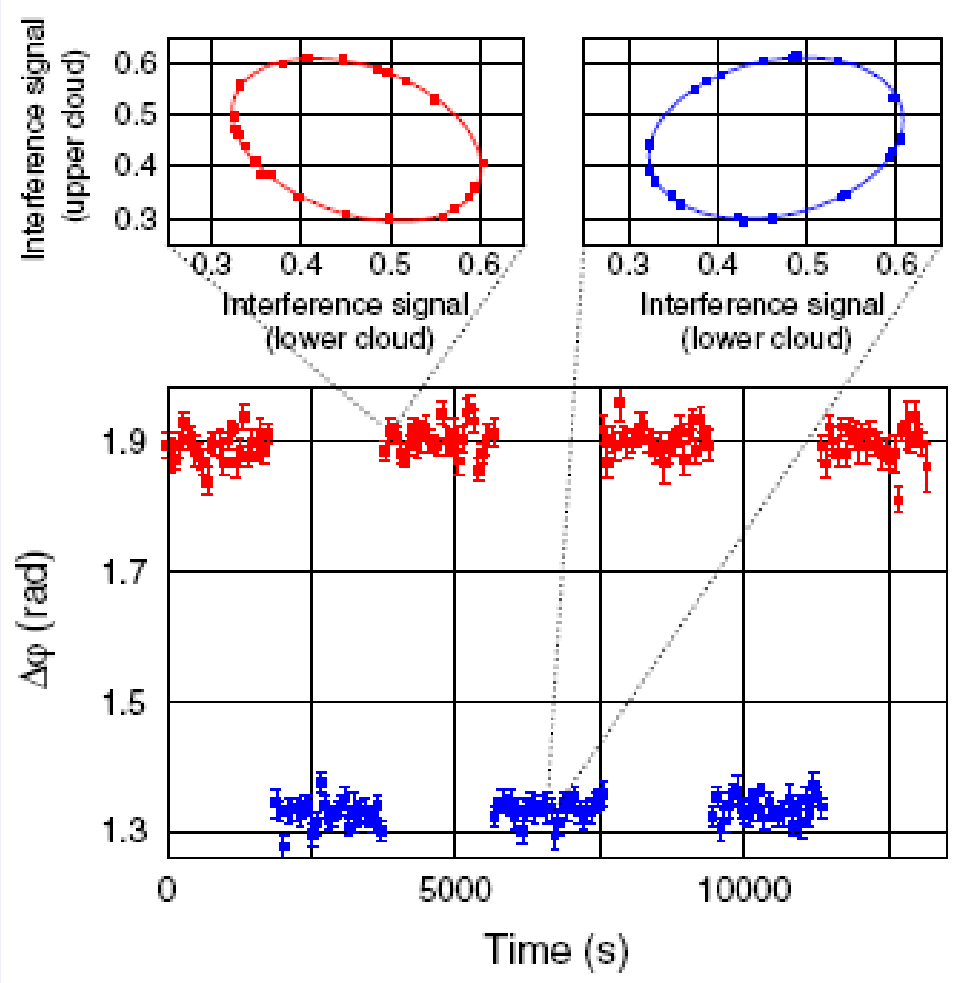


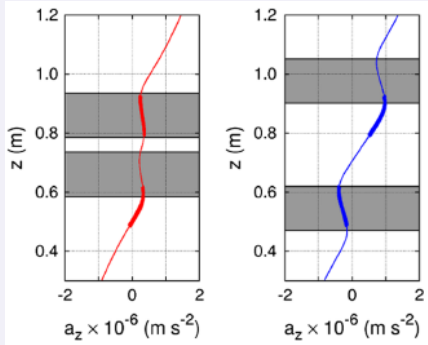
A. Bertoldi G.Lamporesi , L. Cacciapuoti, M. deAngelis, M.Fattori, T.Petelski, A. Peters, M. Prevedelli, J. Stuhler, G.M. Tino,
Atom interferometry gravity-gradiometer for the determination of the Newtonian gravitational constant G,
Eur. Phys. J. D 40, 271 (2006)





J. B. Fixler, G. T. Foster, J. M. McGuirk and M. A. Kasevich,
Atom Interferometer Measurement of the Newtonian Constant of Gravity,
Science 315, 74 (2007)



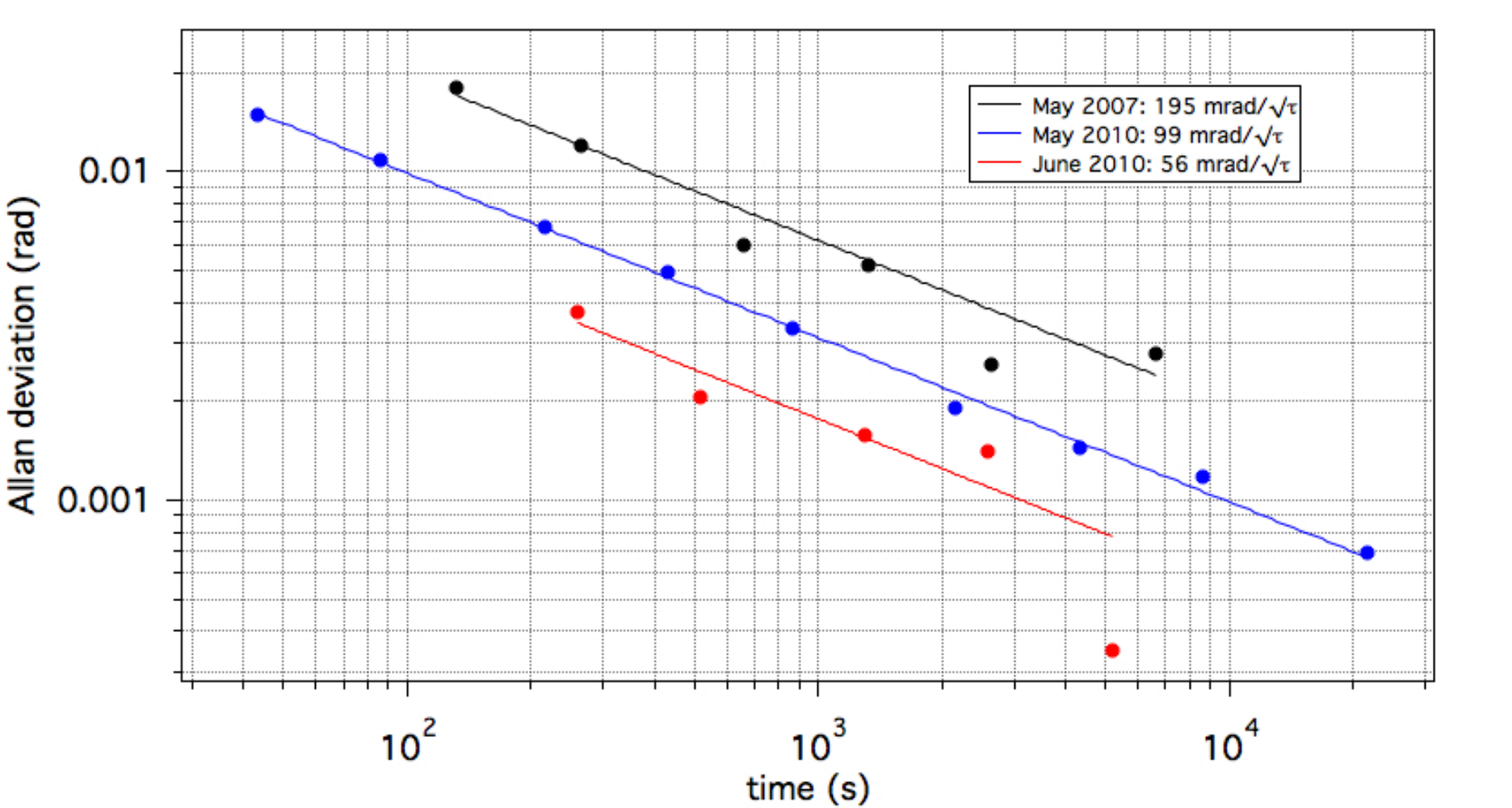


New results from MAGIA

$G = 6.667\ (11)\ (3)\ m^3\ kg^{-1}\ s^{-2}$

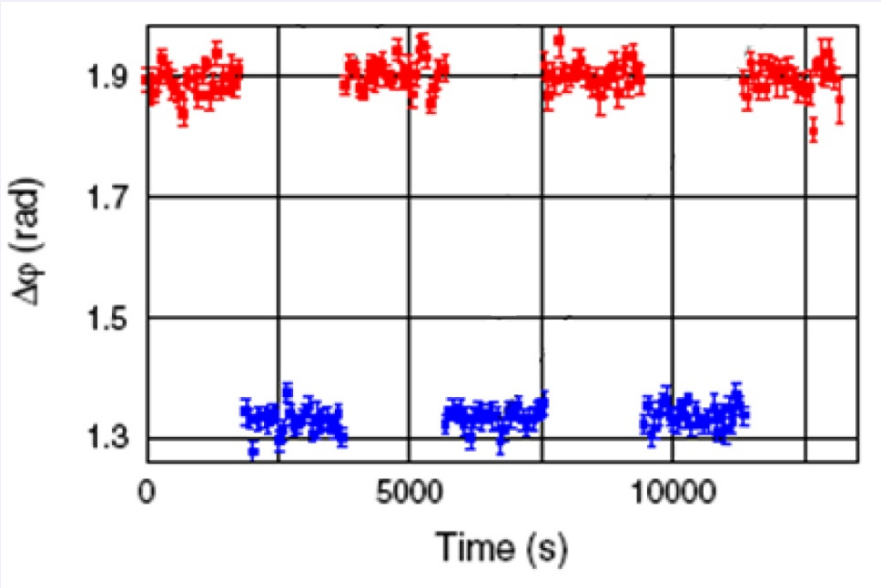
G. Lamporesi, A. Bertoldi, L. Cacciapuoti, M. Prevedelli, G. M. Tino
Determination of the Newtonian Gravitational Constant Using Atom Interferometry
Phys. Rev. Lett. 100, 050801 (2008)

MAGIA atom interferometer sensitivity



MAGIA: Recent results

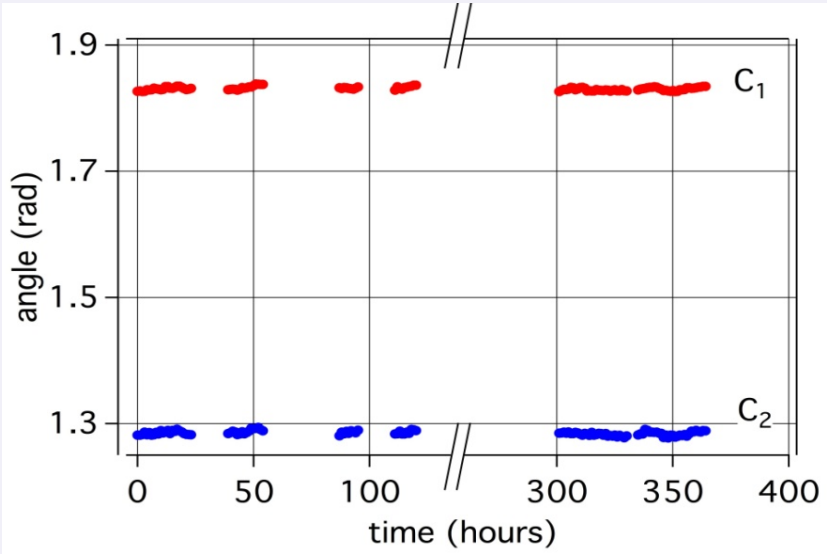
2008



statistical uncertainty : 1.6 x 10^{-3}

G. Lamporesi, A. Bertoldi, L. Cacciapuoti, M. Prevedelli, G. M. Tino, **Phys. Rev. Lett. 100, 050801 (2008)**

2010



statistical uncertainty : 4 x 10^{-4}

F. Sorrentino, Y.H. Lien, G. Rosi, L. Cacciapuoti, M.Prevedelli, G.M. Tino, **New J. Physics 12, 095009 (2010)**

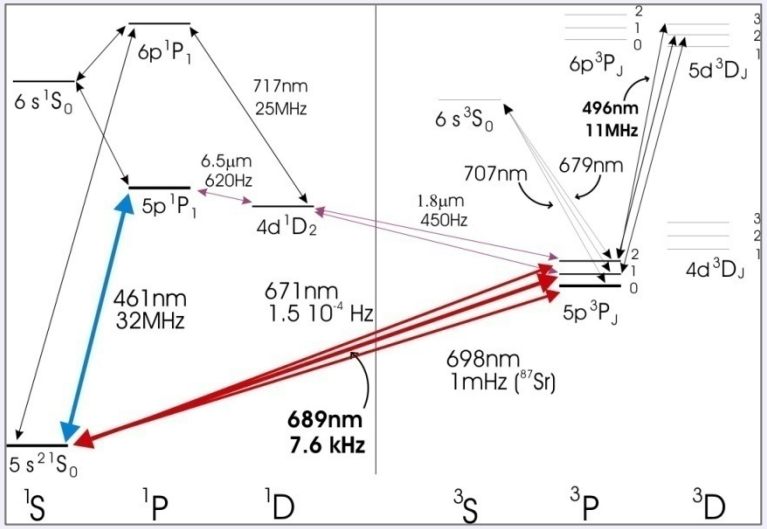
MAGIA – Relevant numbers

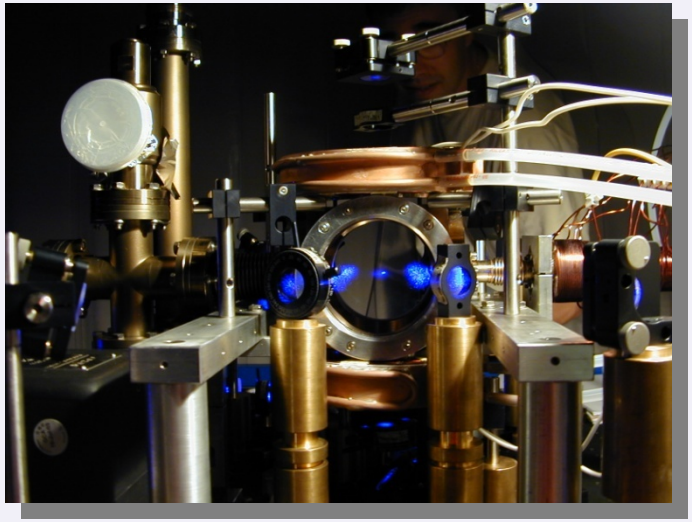
- time separation between pulses T=150 ms
- 10^6 atoms
- shot noise limited detection
- launch accuracy: 1 mm e $\Delta v \sim 5$ mm/s
- knowledge of the masses dimensions and relative positions: 10 μm
- 10000 measurements

$$\Downarrow$$

$$\Delta G/G \leq 10^{-4}$$

Ultracold Sr – The experiment in Firenze



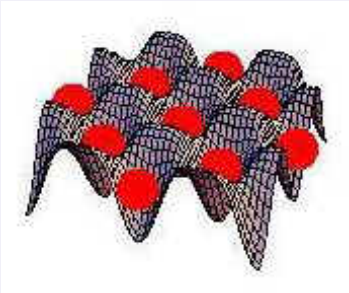


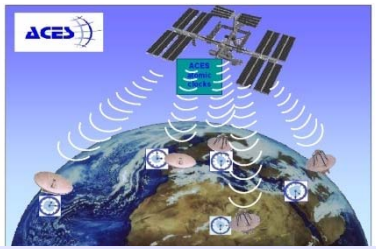
- Optical clocks using visible intercombination lines

- New atomic sensors for fundamental physics tests

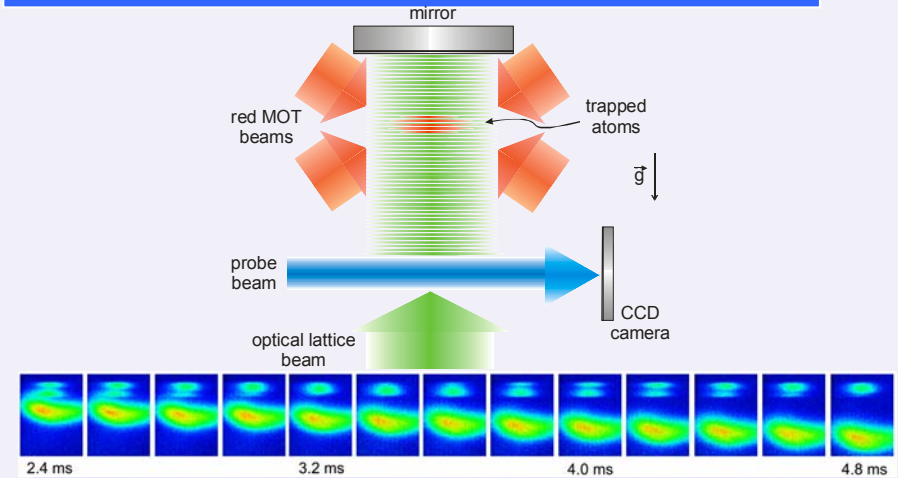
Optical clocks using visible intercombination lines

- $^1S_0$ - $^3P_1$ (7.5 kHz)
- $^1S_0$ - $^3P_0$ (1 mHz, ^{87}Sr)
- $^1S_0$ - $^3P_2$ (0.15 mHz)
- Optical trapping in Lamb-Dicke regime with negligible change of clock frequency
- Comparison with different ultra-stable clocks



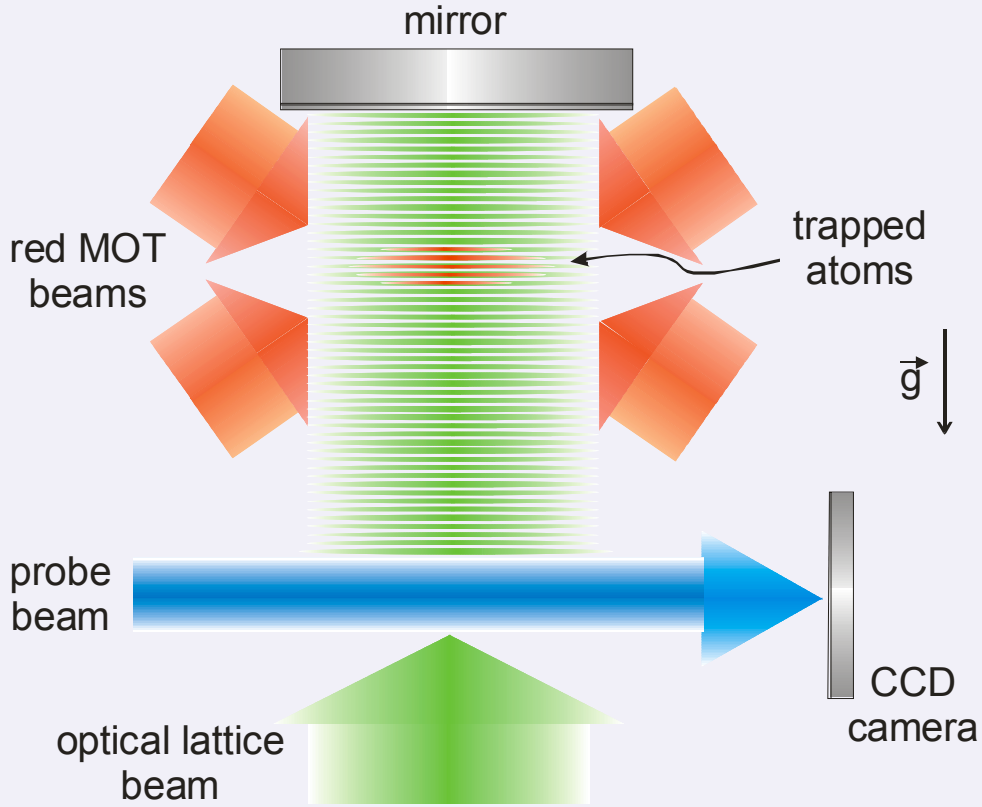


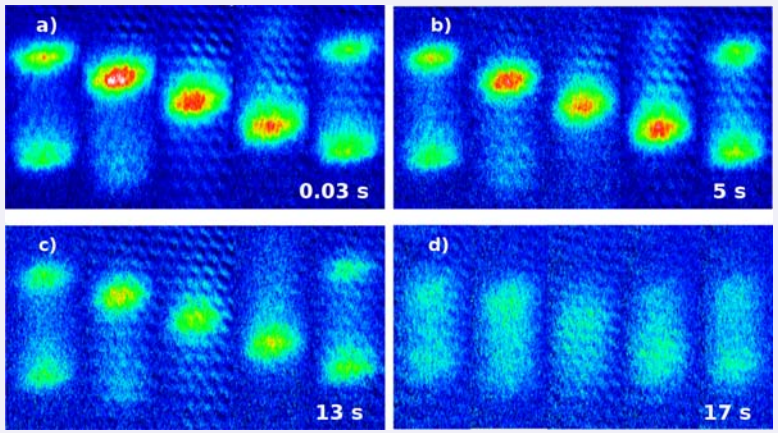
G. Ferrari, P.Cancio, R. Drullinger, G. Giusfredi, N. Poli, M. Prevedelli, C. Toninelli, G.M. Tino, *Precision Frequency Measurement of Visible Intercombination Lines of Strontium*, Phys. Rev. Lett. 91, 243002 (2003)



G. Ferrari, N. Poli, F. Sorrentino, and G. M. Tino, *Long-lived Bloch oscillations with bosonic Sr atoms and application to gravity measurement at micrometer scale*, Phys. Rev. Lett. 97, 060402 (2006)

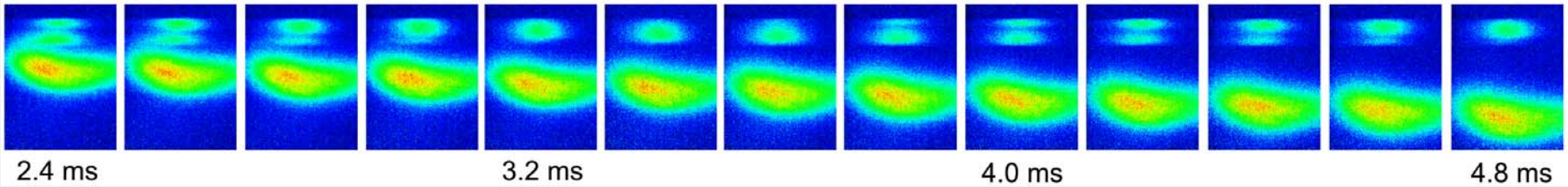
Precision gravity measurement at μm scale with Bloch oscillations of Sr atoms in an optical lattice

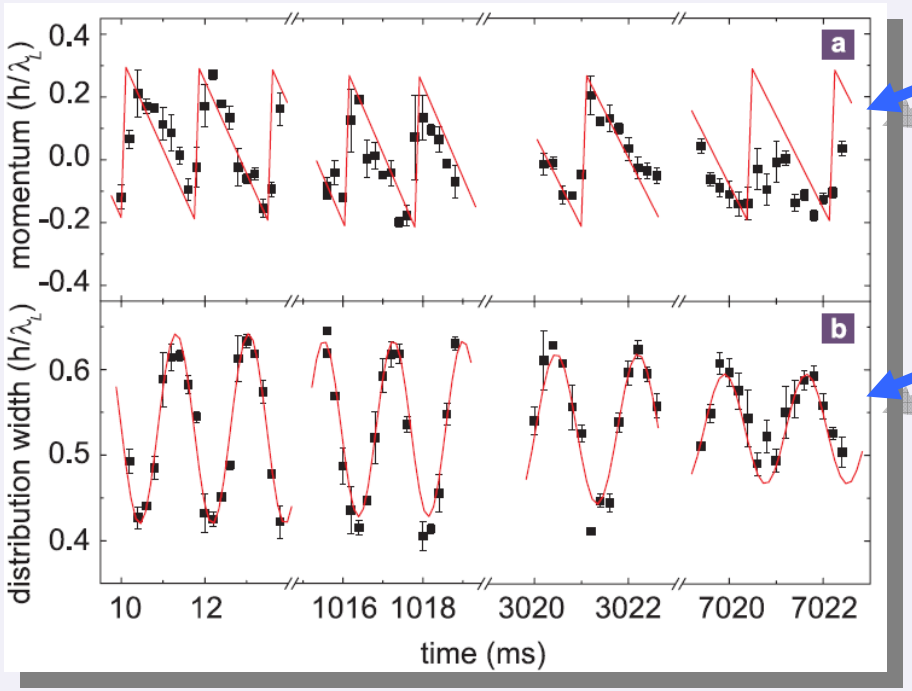




$$\nu = m\, g\, \lambda / 2\, h$$

Persistent Bloch oscillations





average vertical momentum of the lower peak

width of the atomic momentum distribution

Bloch frequency $\nu_B = 574.568(3)$ Hz

damping time $\tau = 12$ s

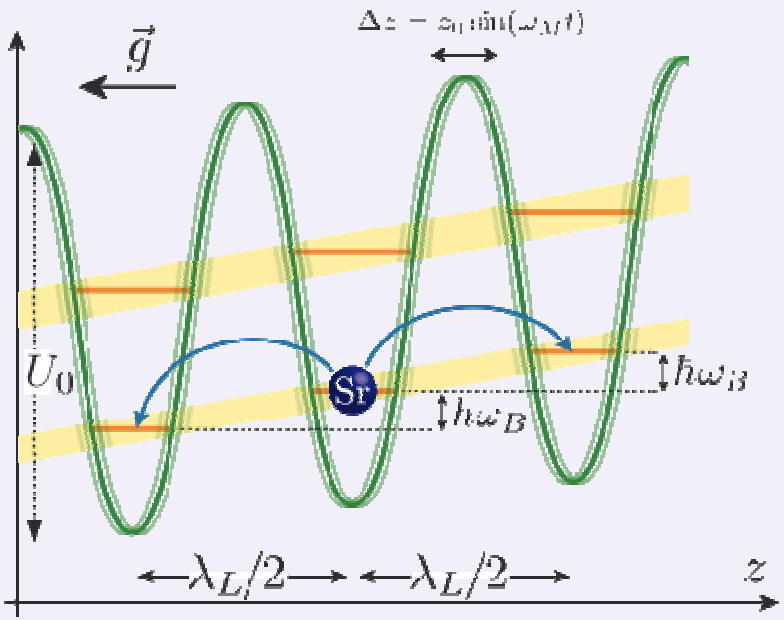
8000 photon recoils in 7s

$g_{meas} = 9.80012(5)\ ms^{-2}$

G. Ferrari, N. Poli, F. Sorrentino, G. M. Tino, *Long-Lived Bloch Oscillations with Bosonic Sr Atoms and Application to Gravity Measurement at the Micrometer Scale*, **Phys. Rev. Lett. 97, 060402 (2006)**

Modulation of optical lattices

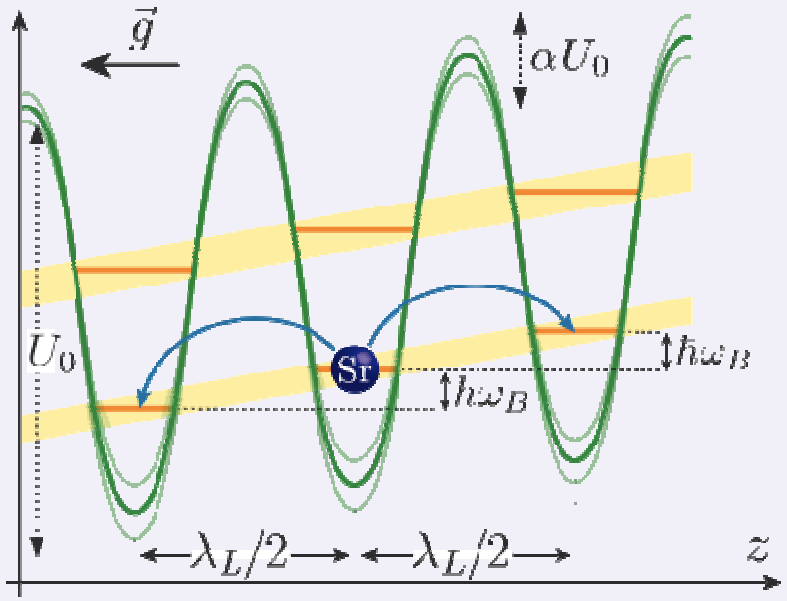
Phase modulation



$$\mathcal{H}_0 = \frac{p^2}{2m} - \frac{U_0}{2}\cos\left\{2k_L[z - z_0\sin(\omega_M t)]\right\} + mgz$$

V.V. Ivanov, A. Alberti, M. Schioppo, G. Ferrari, M. Artoni, M. L. Chiofalo, G. M. Tino, *Coherent Delocalization of Atomic Wave Packets in Driven Lattice Potentials*, **Phys. Rev. Lett. 100, 043602 (2008)**

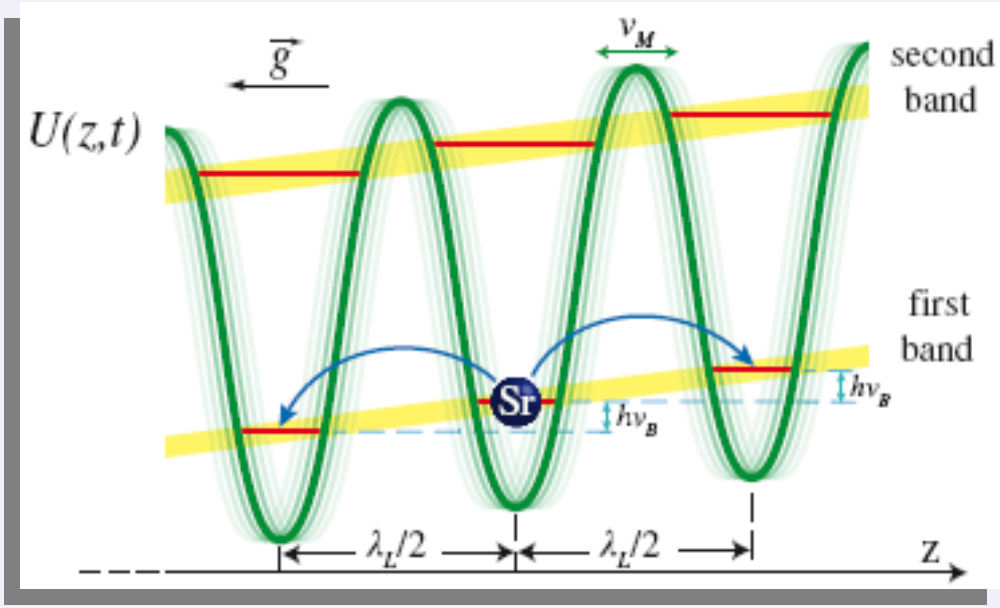
Amplitude modulation

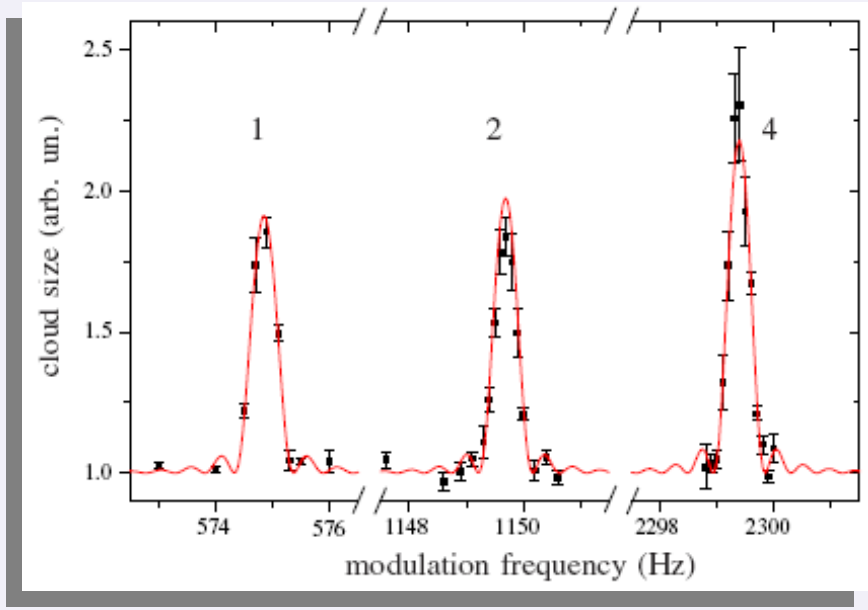


$$\mathcal{H}_0 = \frac{p^2}{2m} - \frac{U_0}{2}\cos(2k_L z)[1 + \alpha\,\sin(\omega_M t)] + mgz$$

A. Alberti, G. Ferrari, V.V. Ivanov, M. L. Chiofalo, G. M. Tino, *Atomic wave packets in amplitude-modulated vertical optical lattices*, **New Journal of Physics 12, 065037 (2010)**

Coherent Delocalization of Atomic Wave Packets in Driven Lattice Potentials





ν_B = (574.8459 +/- 0.0015) Hz,

g = (9.805301 +/- 0.000026) m/s^2

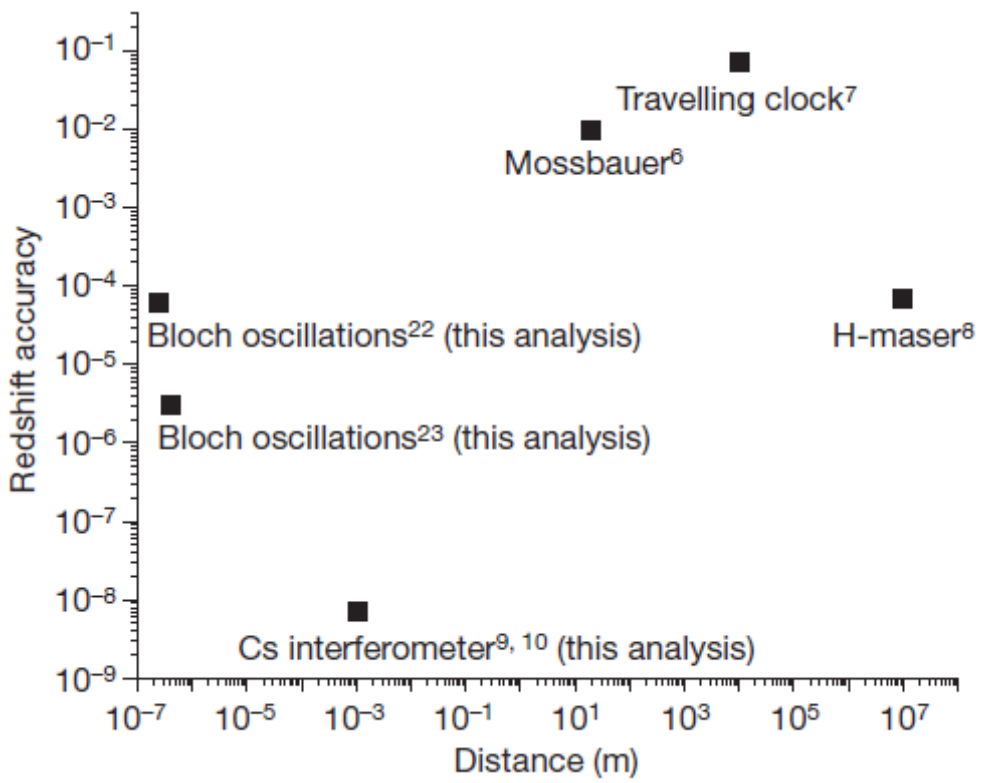
V.V. Ivanov, A. Alberti, M. Schioppo, G. Ferrari, M. Artoni, M. L. Chiofalo, G. M. Tino, *Coherent Delocalization of Atomic Wave Packets in Driven Lattice Potentials*, **Phys. Rev. Lett. 100, 043602 (2008)**

nature Vol 463|18 February 2010|doi:10.1038/nature08776

LETTERS

A precision measurement of the gravitational redshift by the interference of matter waves

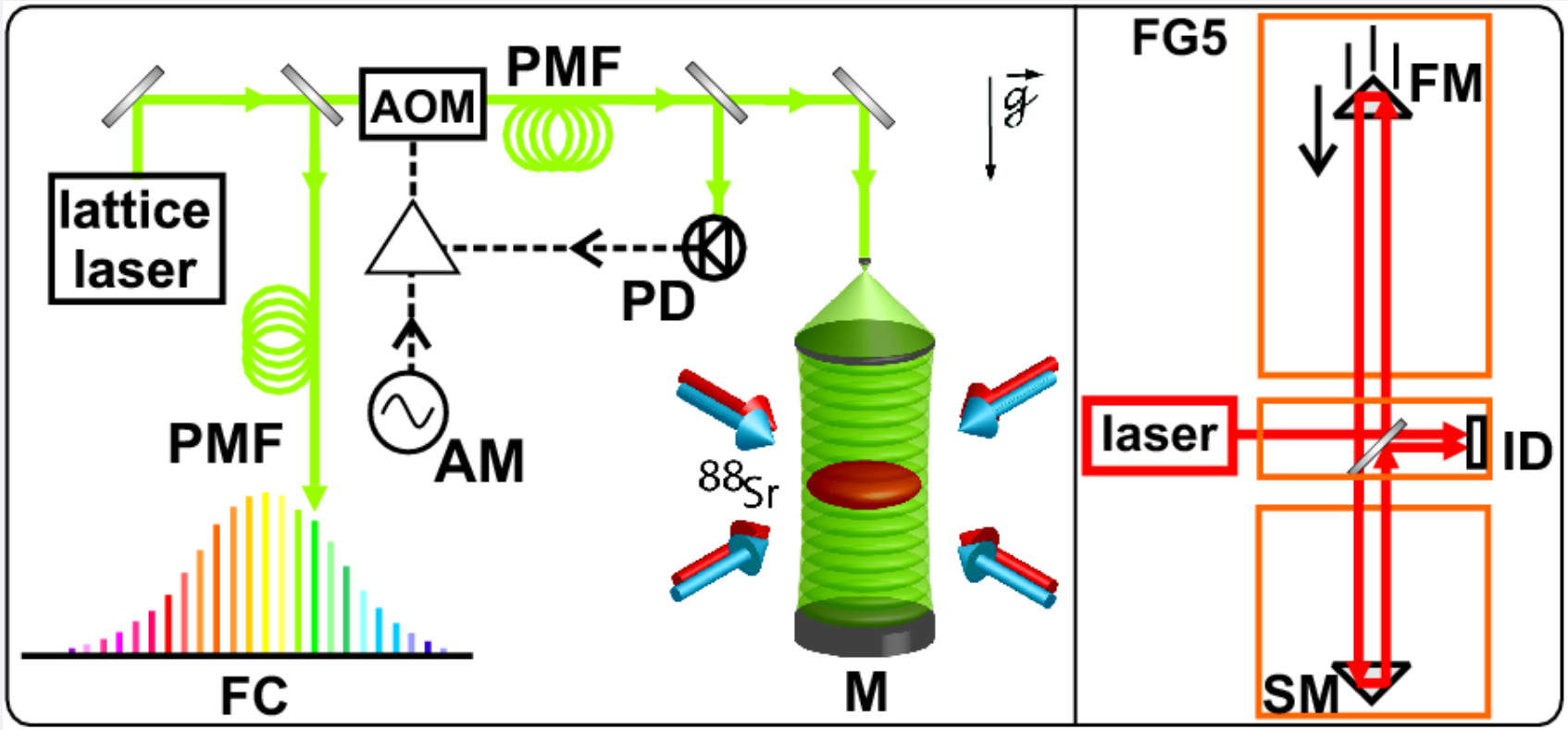
Holger Müller[1,2], Achim Peters[3] & Steven Chu[1,2,4]



6. Pound, R. V. & Snider, J. L. Effect of gravity on gamma radiation. *Phys. Rev.* **140**, B788–B803 (1965).
7. Hafele, J. C. & Keating, R. E. Around-the-world atomic clocks: observed relativistic time gains. *Science* **177**, 168–170 (1972).
8. Vessot, R. F. C. *et al.* Test of relativistic gravitation with a space-borne hydrogen maser. *Phys. Rev. Lett.* **45**, 2081–2084 (1980).
9. Peters, A., Chung, K. Y. & Chu, S. A measurement of gravitational acceleration by dropping atoms. *Nature* **400**, 849–852 (1999).
10. Peters, A., Chung, K.-Y. & Chu, S. High-precision gravity measurements using atom interferometry. *Metrologia* **38**, 25–61 (2001).

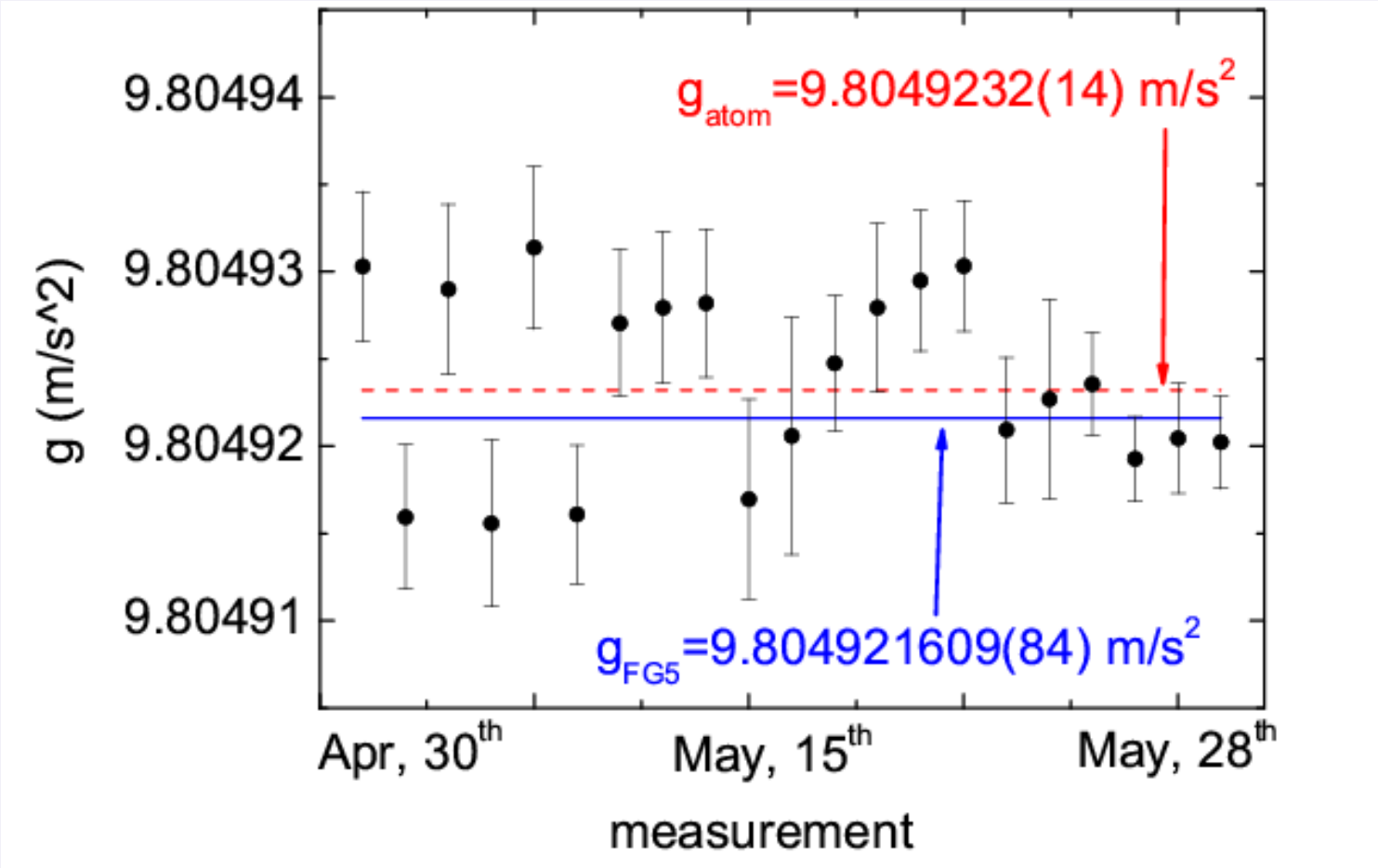
22. Ivanov, V. V. *et al.* Coherent delocalization of atomic wave packets in driven lattice potentials. *Phys. Rev. Lett.* **100**, 043602 (2008).
23. Cladé, P. *et al.* A promising method for the measurement of the local acceleration of gravity using Bloch oscillations of ultracold atoms in a vertical standing wave. *Europhys. Lett.* **71**, 730–736 (2005).

Precision measurement of gravity with cold atoms in an optical lattice and comparison with a classical gravimeter



N. Poli, F.Y. Wang, M.G. Tarallo, A. Alberti, M. Prevedelli, G.M. Tino, **(2010)**, **submitted**
http://arxiv.org/abs/1010.2033

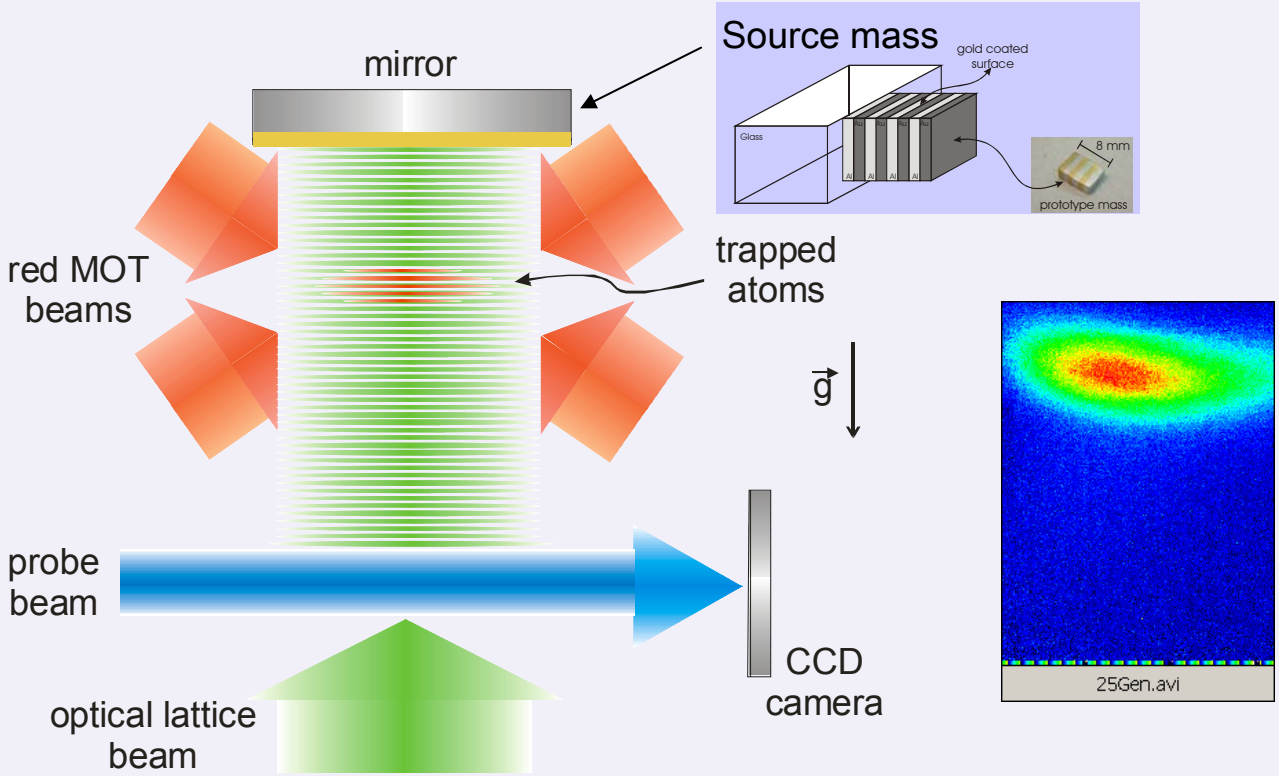
Precision measurement of gravity with cold atoms in an optical lattice and comparison with a classical gravimeter



140 ppb relative uncertainty

N. Poli, F.Y. Wang, M.G. Tarallo, A. Alberti, M. Prevedelli, G.M. Tino, **(2010)**, **submitted**
http://arxiv.org/abs/1010.2033

Scheme for the measurement of small distance forces



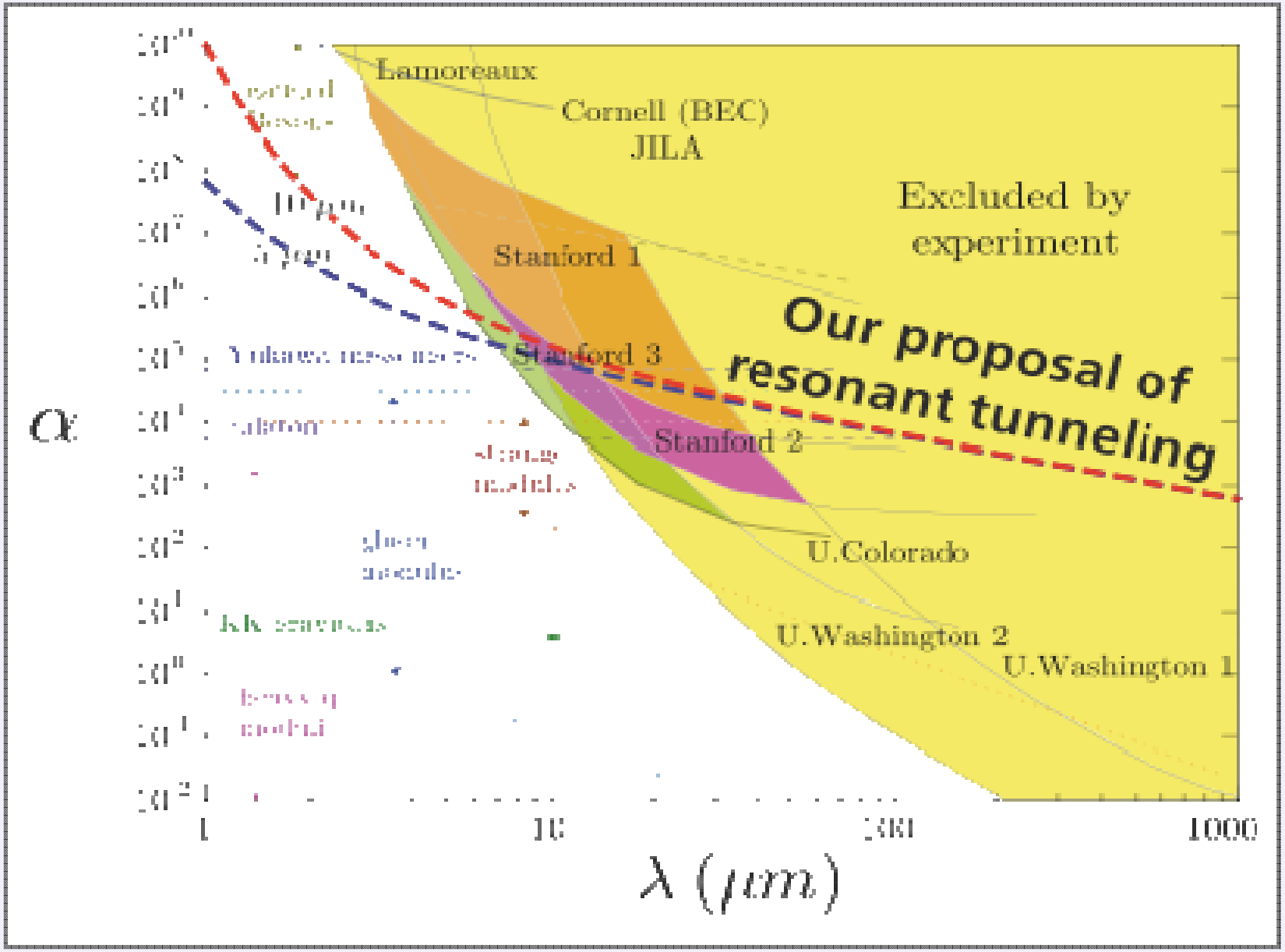
$$\nu = m\, a\, \lambda / 2\, h$$

$$\nu = m\, g\, \lambda / 2\, h$$

Objective: $\lambda = 1\text{-}10\ \mu m$, $\alpha = 10^3\text{-}10^4$

F. Sorrentino, A. Alberti, G. Ferrari, V. V. Ivanov, N. Poli, M. Schioppo, and G. M. Tino, *Quantum sensor for atom-surface interactions below 10 μm*, **Phys. Rev. A 79, 013409 (2009)**

Accessible region with atomic probes



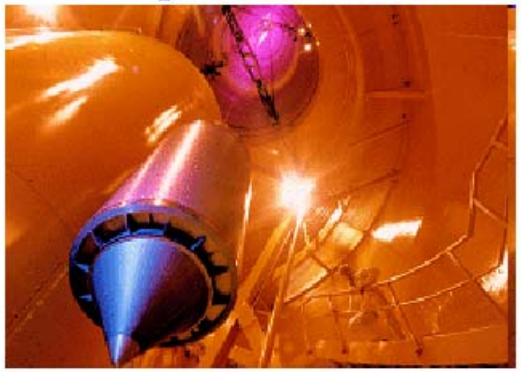
Need for space

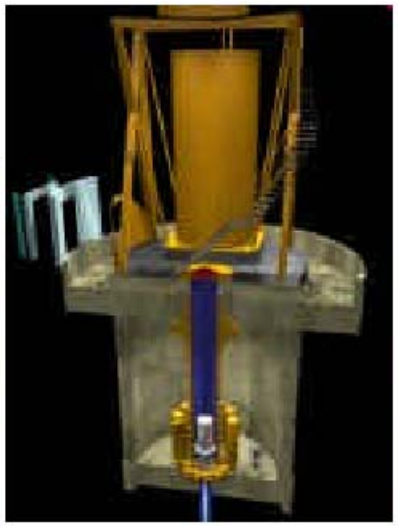
$$\Delta\Phi = k_e a T^2$$

In microgravity possible sensitivity ~ 10^{-13} m/s^2 @ 1 s achievable

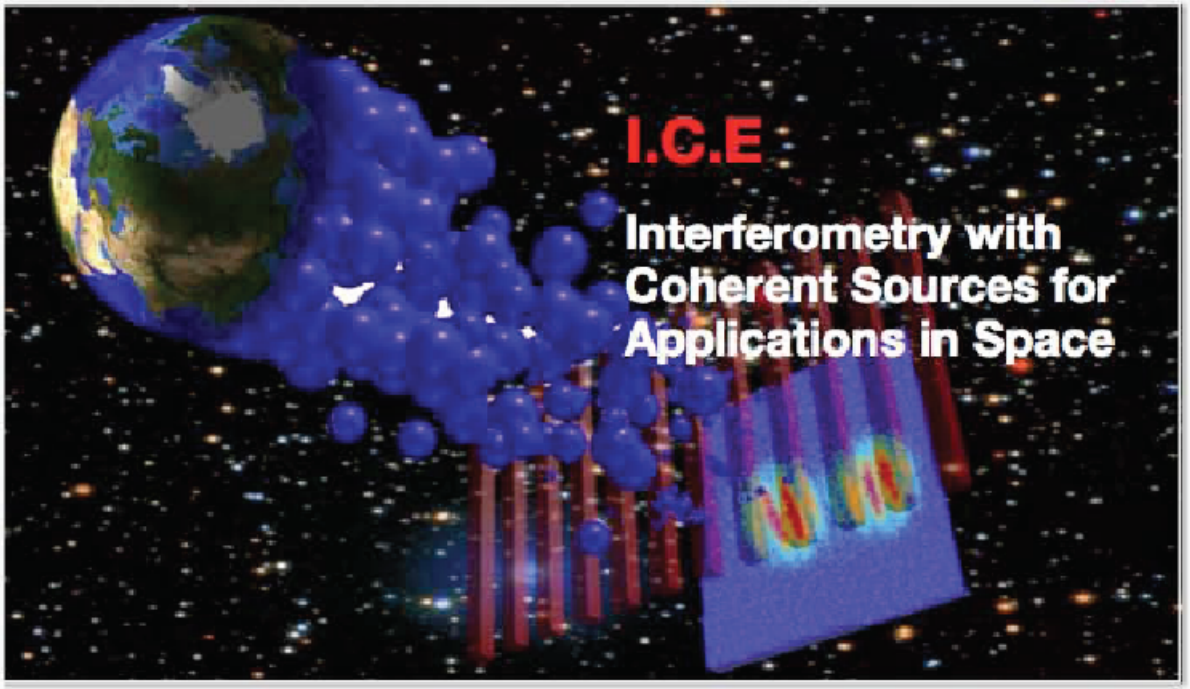
Implementation

- Free Fall: up to 9 sec
- Duration > 1 BEC-Experiment
- 3 flights per day
- Test of a robust BEC Facilities
  Dimensions < 0.6 ∅ x 1.5 m
  < 234 kg
- Height 110 m





ICE Concept ICE Cube The Lasers News



Project members

Philippe BOUYER
Robert NYMAN
Gaël VAROQUAUX
Jean-Francois CLEMENT
Jean-Philippe BRANTUT

Arnaud LANDRAGIN
Frank PEREIRA

Alexandre BRESSON
Yannick BIDEL
Pierre TOUBOUL

THE PROJECT

The objective of ICE is to produce an accelerometer for space with coherent atomic source. It uses a mixture of Bose-Einstein condensates with 2 species of atoms (Rb and K).

The major objective for 2007 is to carry out a first µg campaign, in parabolic flight for example, to test the various components together and to carry out a first comparison of accelerations measured by the 2 atomic species.

Partners

Institut d'Optique — OPTIQUE ATOMIQUE

ONERA — GROUPE ATOMES FROIDS

l'Observatoire de Paris — SYRTE — Systèmes de Référence Temps-Espace — GROUPE SENSEURS INERTIELS

cnes

Internal Pages

Space Atom Interferometer - SAI

Space Atom Interferometer: **Pre-phase A study of a space instrument based on matter-wave interferometry for inertial sensing in space**

Team: **Firenze Univ. (I), IOTA (F), IQO (D), Hamburg Univ. (D), HU Berlin (D), SYRTE (F), LENS (I), Ulm Univ. (D), ZARM (D)**

Objective: **Ground based prototype of an atom interferometer for precision measurements**

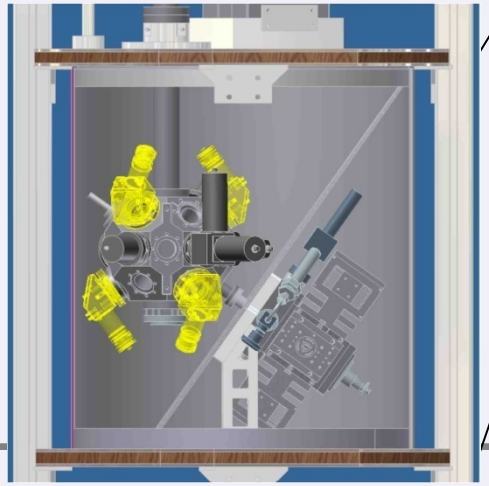
Duration: **2007- 2010, funded within the ELIPS-2 Programme**

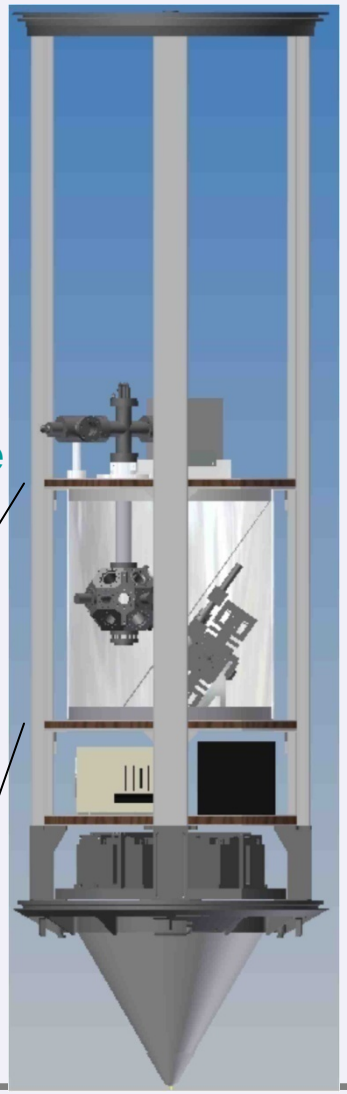
SAI - science goals

In three years, the project will: (1) demonstrate the possibility of construction of a space-compatible atom interferometry sensor and test it at system and subsystem level; (2) investigate new schemes, based for example on quantum degenerate gases as source for the interferometer. Additionally, it will investigate the realistically expected performance limits and potential scientific applications in a micro-gravity environment considering all aspects of quantum, relativistic and metrological sciences. For these purposes, the project will bring together European institutions which are leaders in this field, to share their mutual expertise.

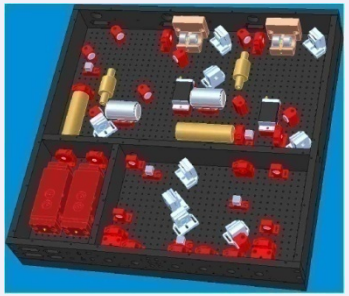
SAI - Space Atom Interferometer

- Single-axis accelerometer
- Sensitivity target 10^{-7} m/s^2 @1s
- Repetition rate ≈ 2 Hz
- Modular laser system + optical fibers
- MOT + atomic fountain
- Same chamber for MOT and detection
- Load from 2D-MOT
- **Compatible with drop-tower capsule**



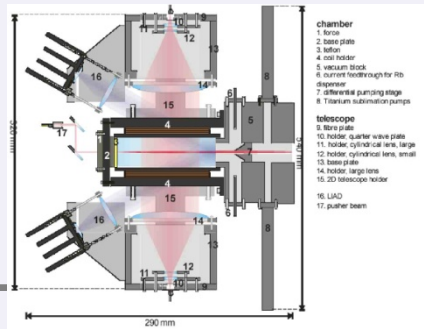


Raman laser system



Modular laser system

2D-MOT

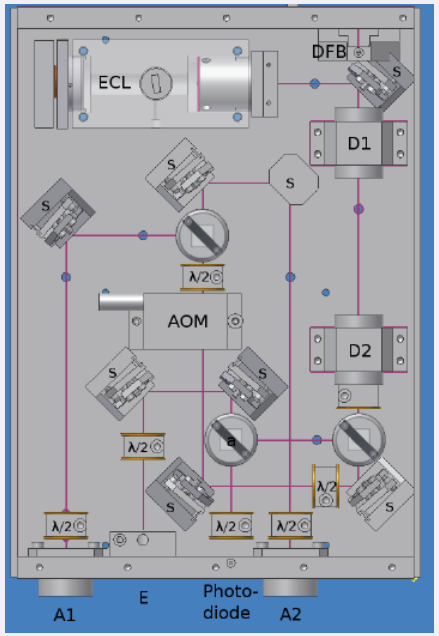


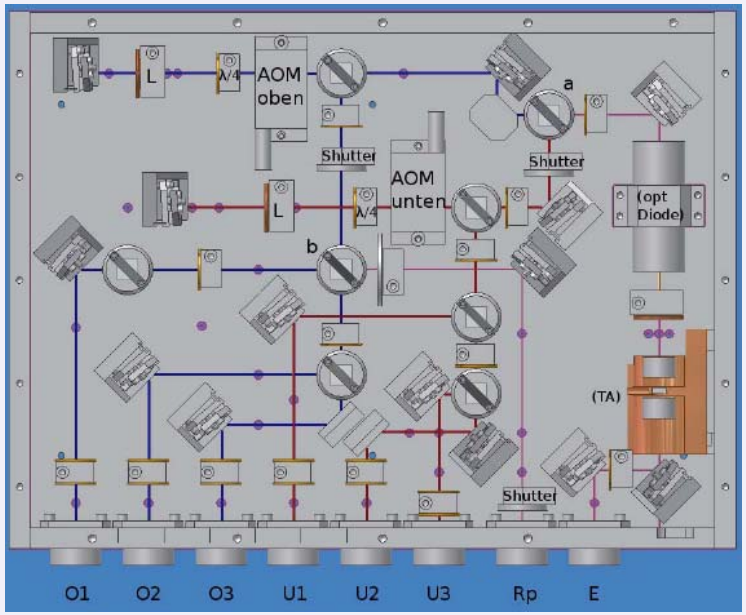
SAI: team roles

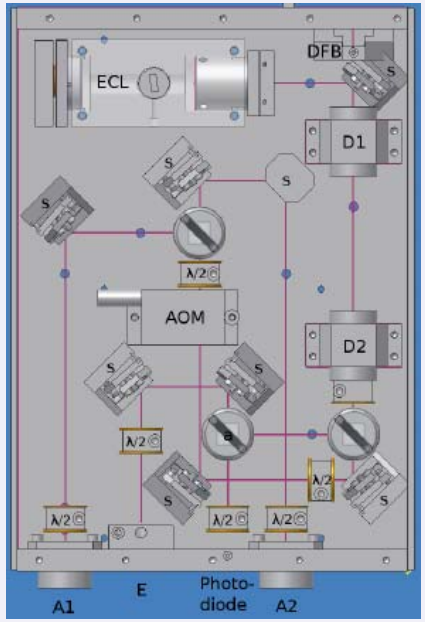
Team Roles

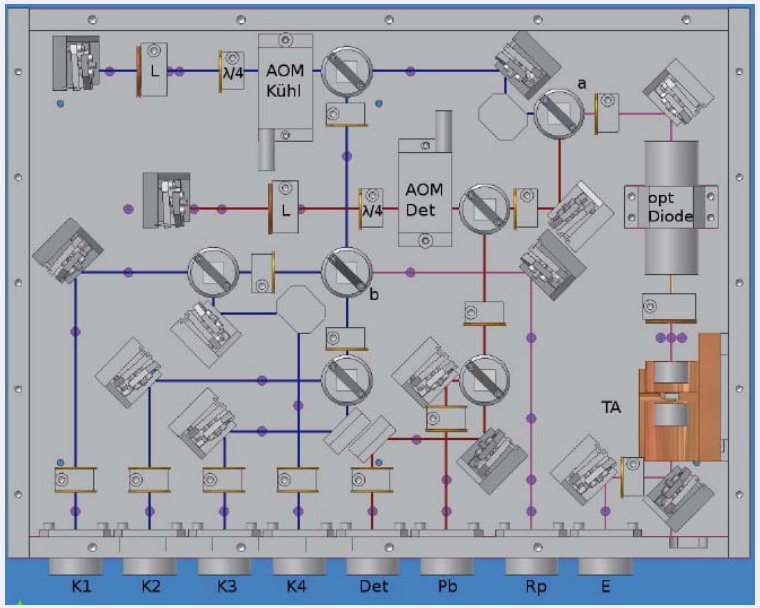
UNIFI	Prototype assembly + Raman lasers + Management
CNRS-IOTA	Transportable coherent atomic source design and test
IQO	Advanced atomic source + laser system
UH	Laser system + atomic source
HUB	Raman lasers systems and tests
SYRTE	Microwave source + Modelling and comparison of sensors
LENS	Transportable fermionic atomic source design and test
ULM	Theory
ZARM	Drop tower tests + theory

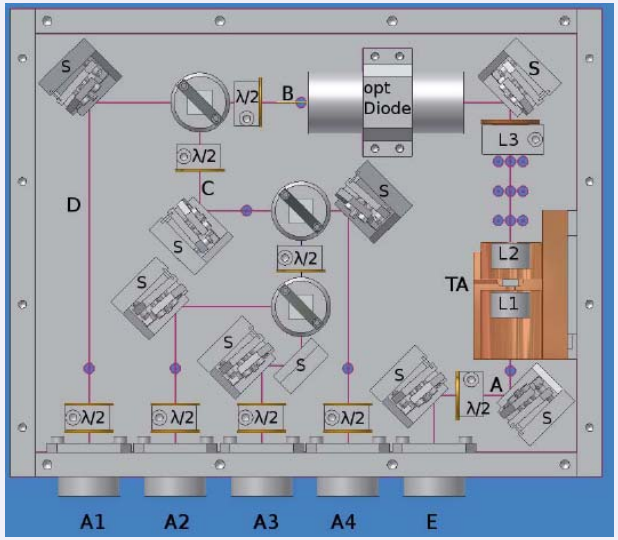
SAI Modular laser system [UH]



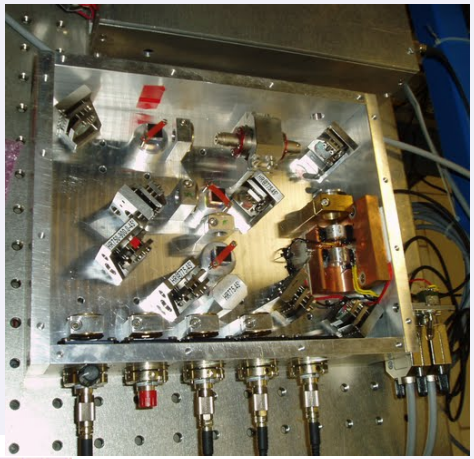


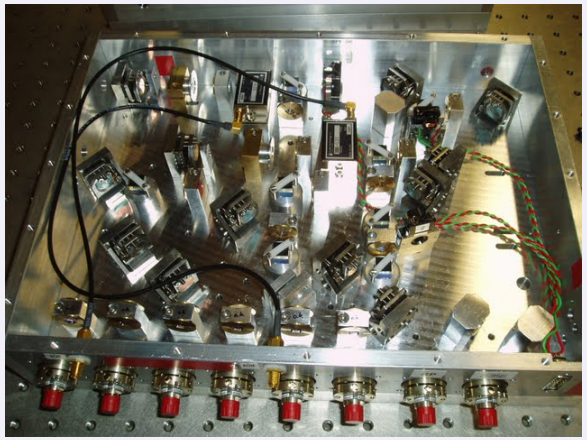


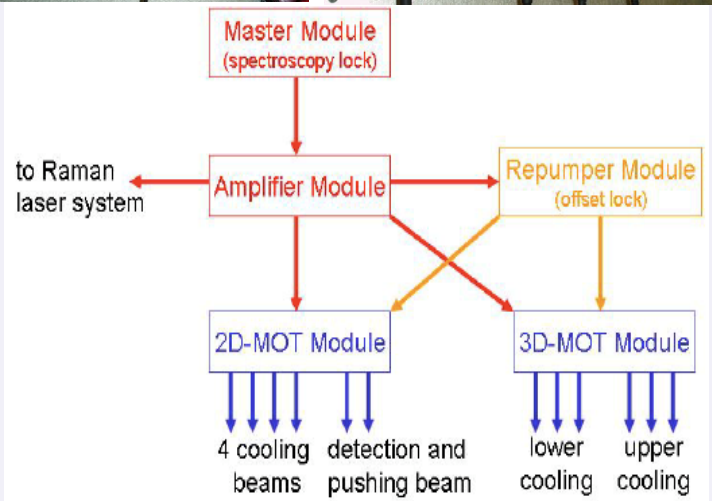


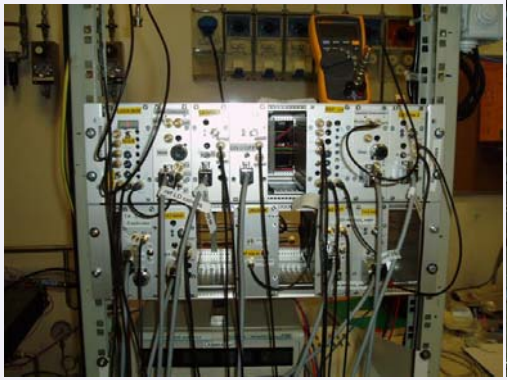


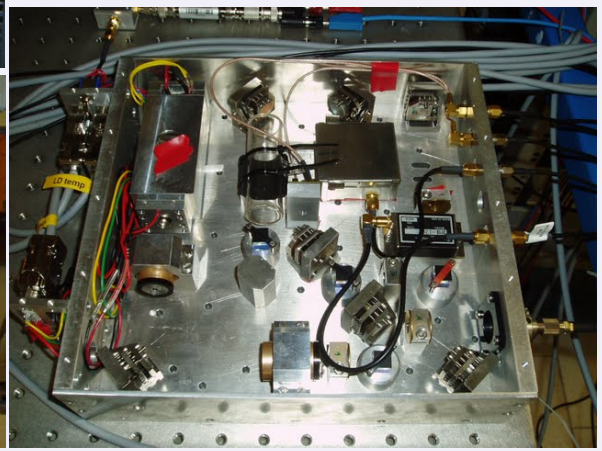
SAI compact laser modules and electronics (UH)





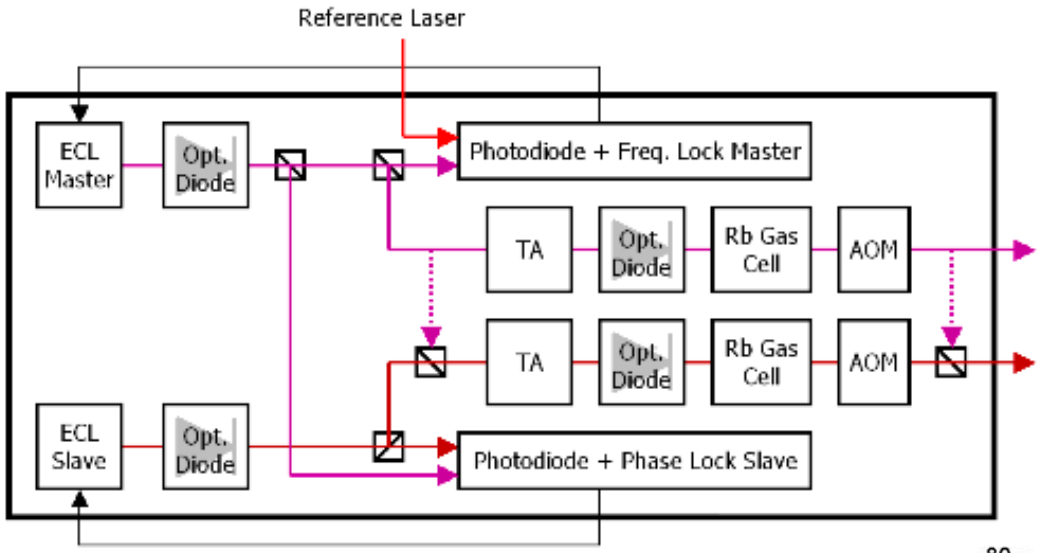


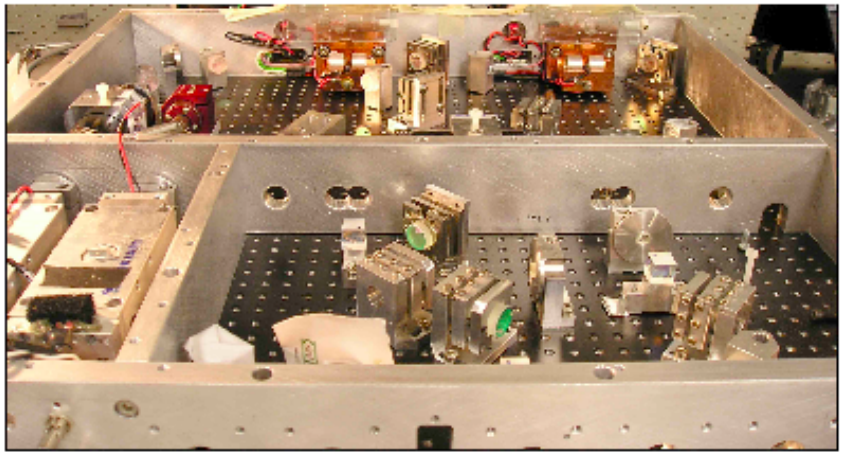




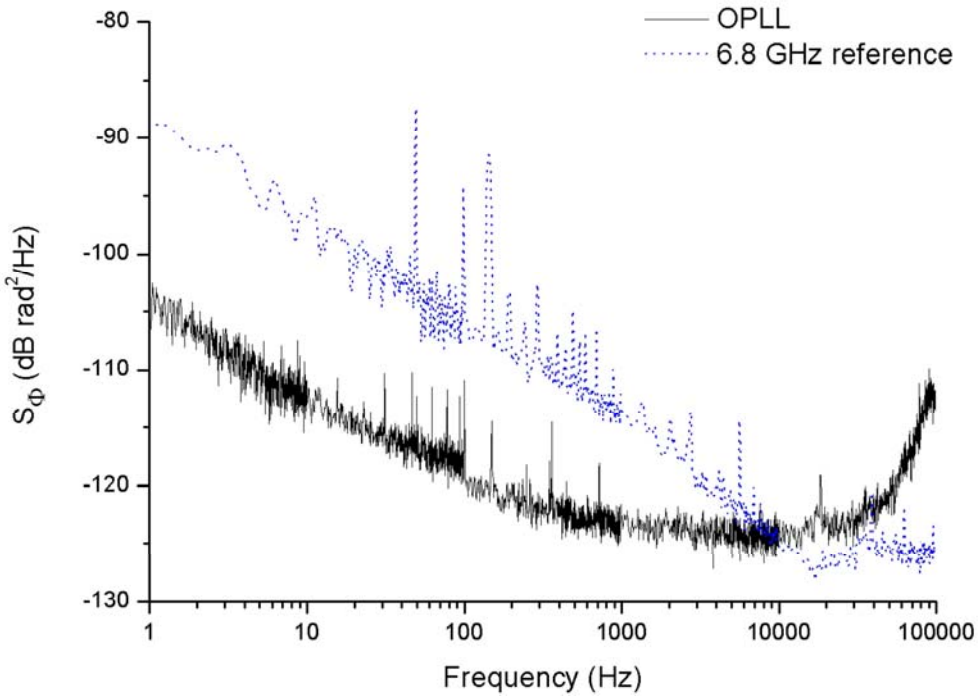
Module	Width [mm]	Depth [mm]	Height [mm]
Master Module	236	250+	63
Amplifier Module	240+	190+	66
Repumper Module	186	260+	63
2D-MOT Module	350+	260+	63
3D-MOT Module	350+	260+	73

SAI Raman laser module (HUB+UNIFI) + 6.8 GHz reference (SYRTE)

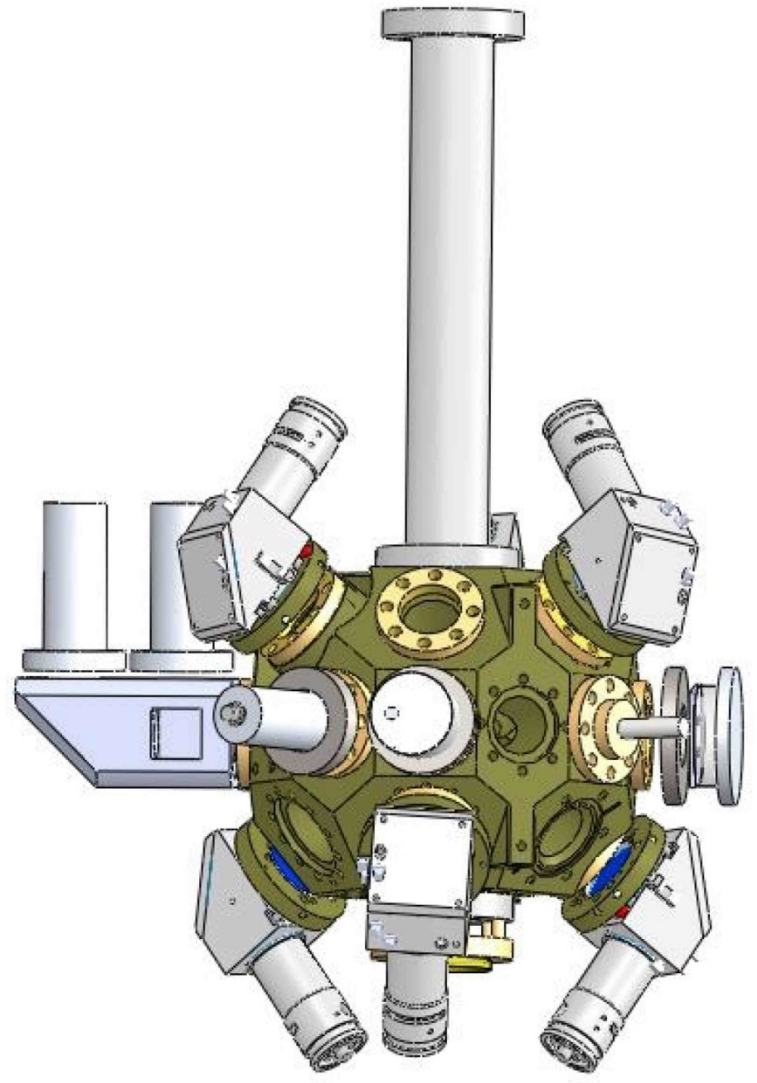


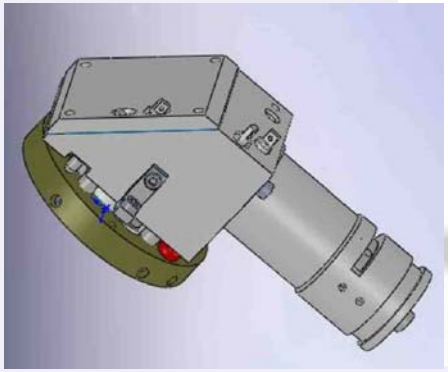


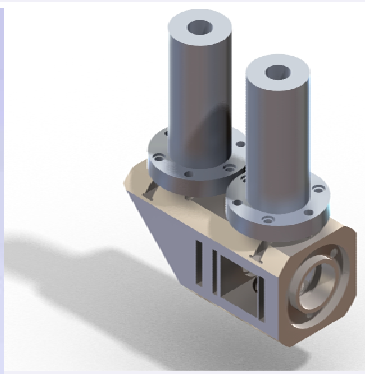
- Two independent TAs
  - 350 mW available on the atoms
- OPLL phase noise
  - < 1 µrad/√Hz between 100 Hz and 40 kHz
  - Among lowest noise OPLL ever reported
- Frequency chain optimized for T ≈ 1 s interferometer time



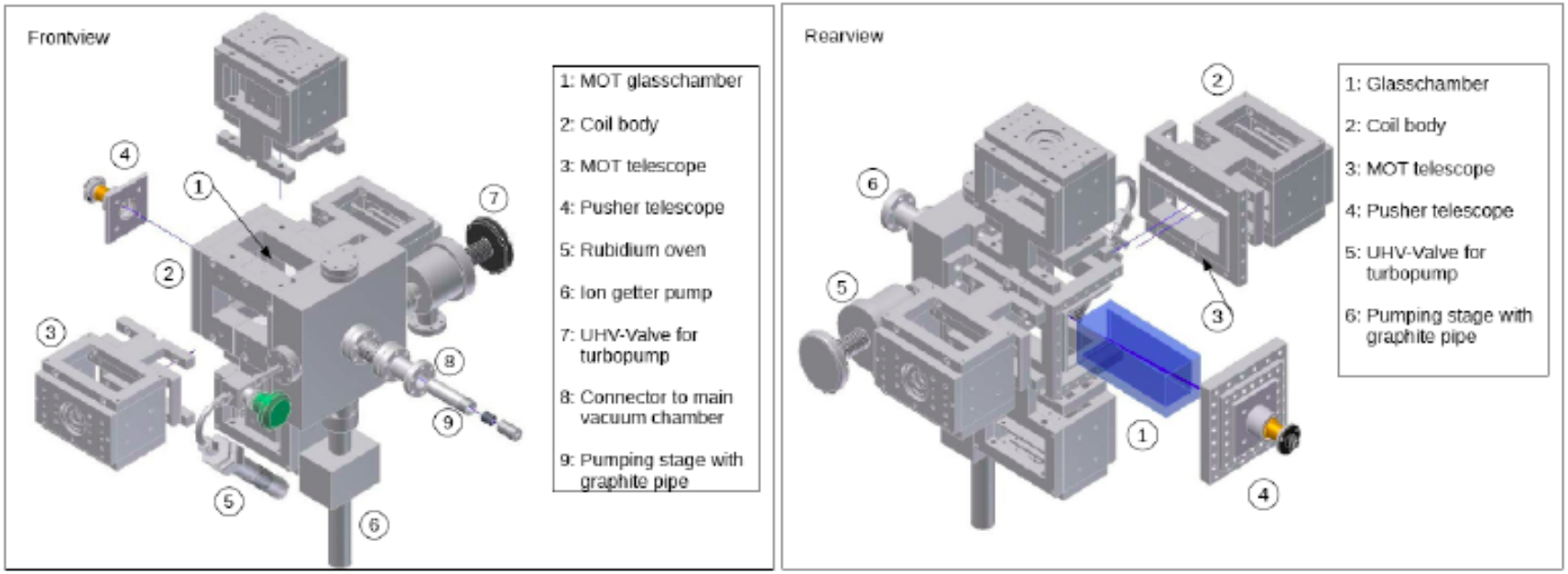
SAI Vacuum and Optics [ZARM+UNIFI+HUB]

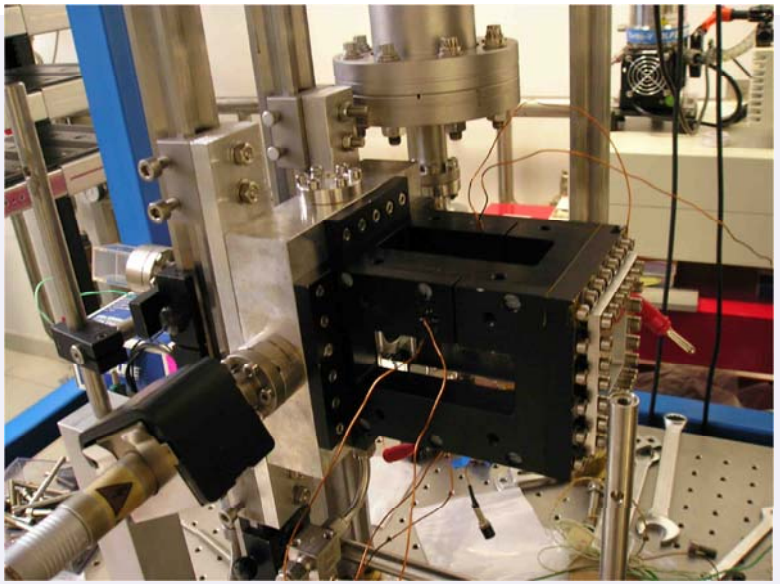






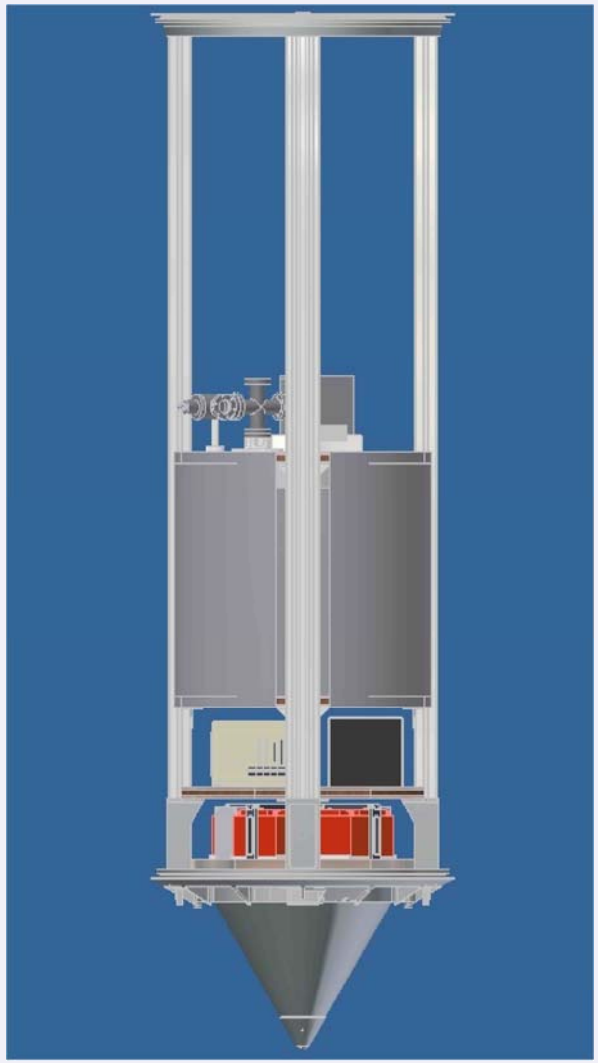
SAI - compact 2D-MOT (IQO)

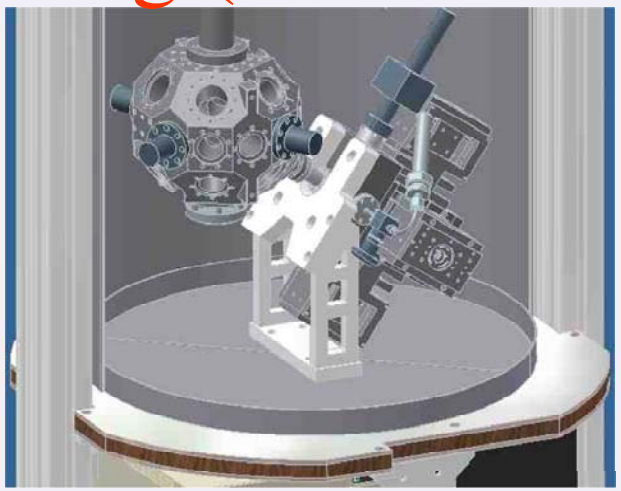




- Design similar to CASI and ATLAS
  - glass cell pressed to Al body with In seal
- Expected flux $>10^9$ at/s

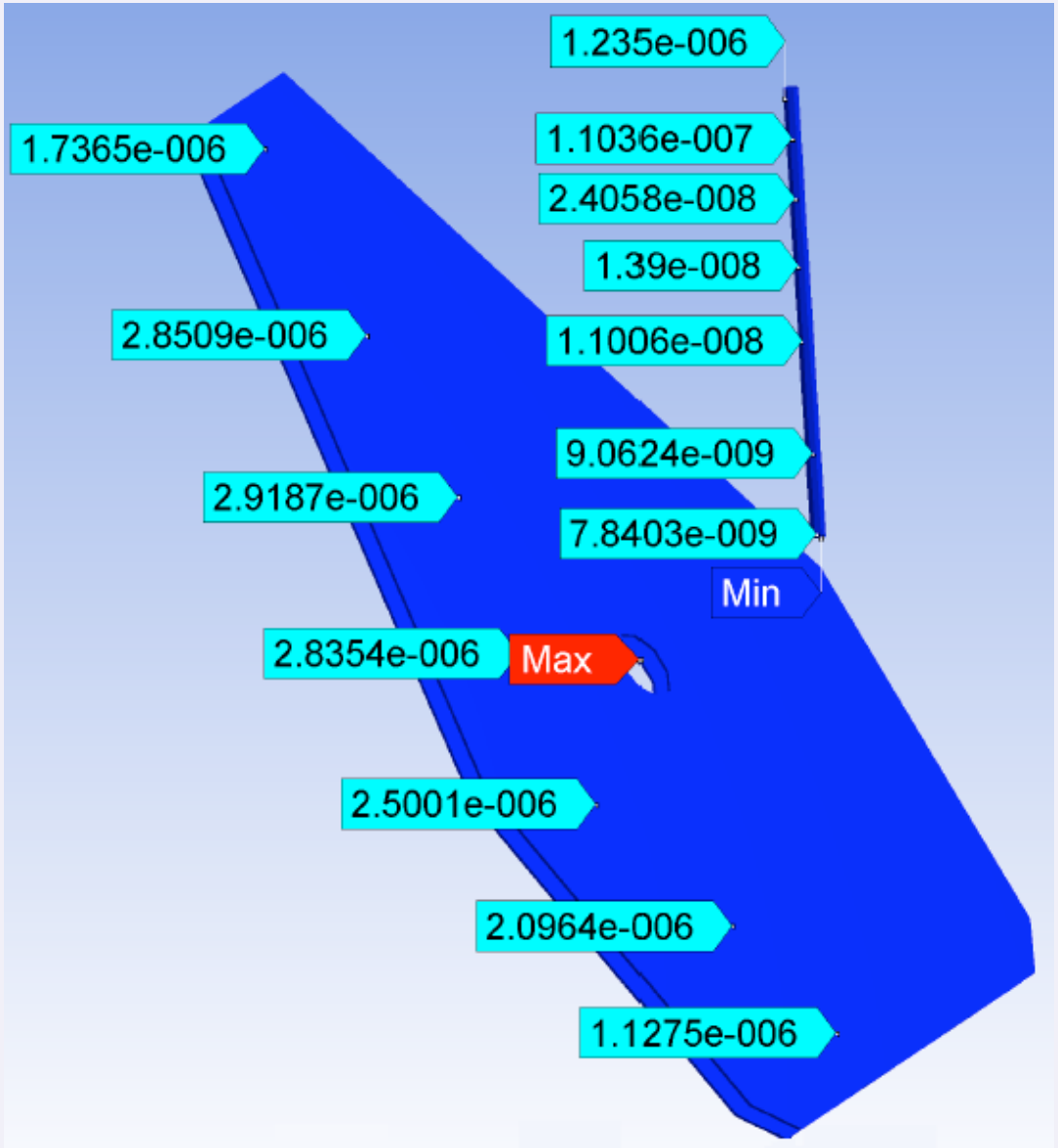
SAI mechanical structure and magnetic shielding (ZARM+UNIFI)





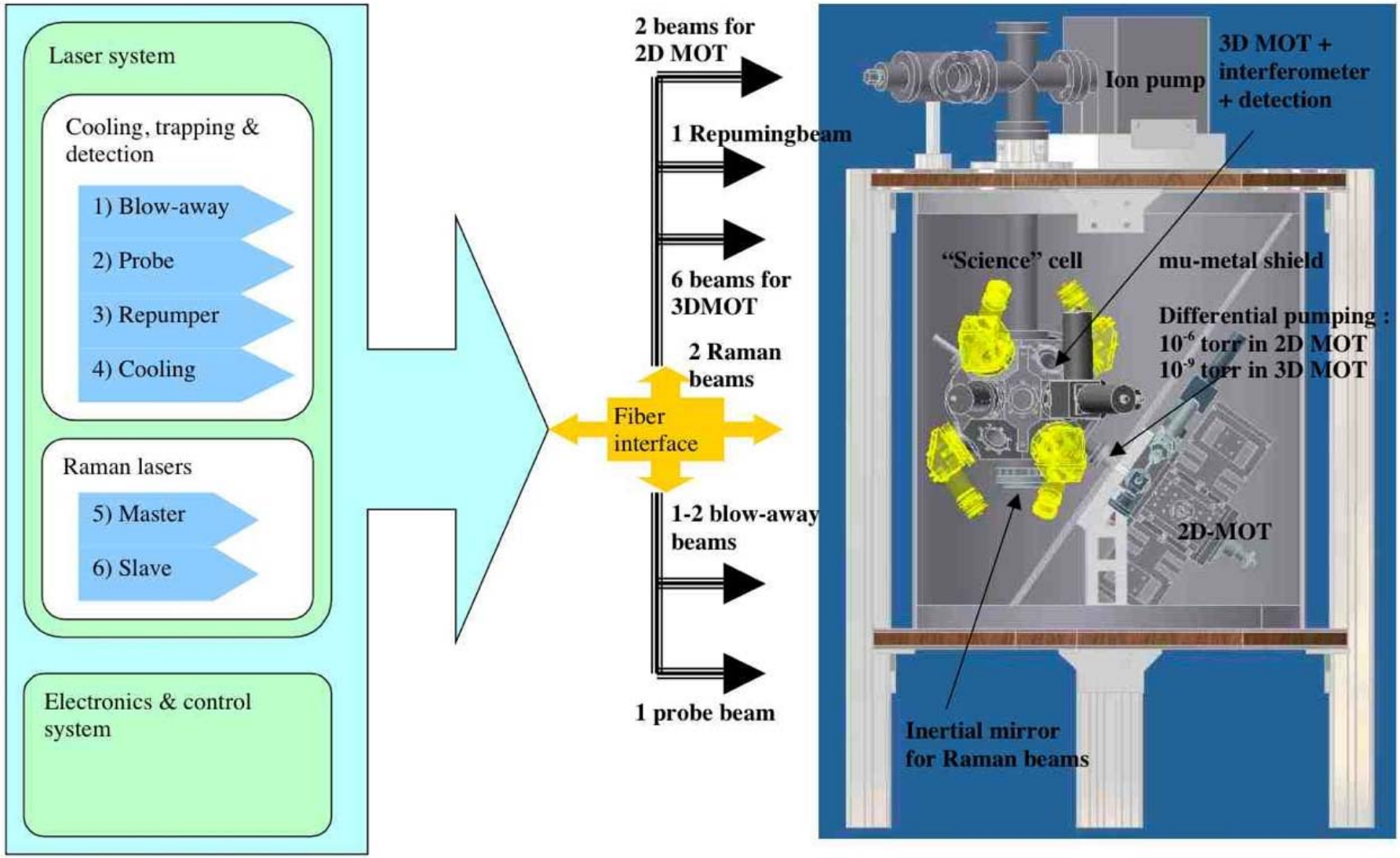
- Structure compatible with drop tower capsule
- Magnetic shield of the whole system
- Shielding factor better than 6000 from numerical simulation

Magnetic shield [ZARM+UNIFI]



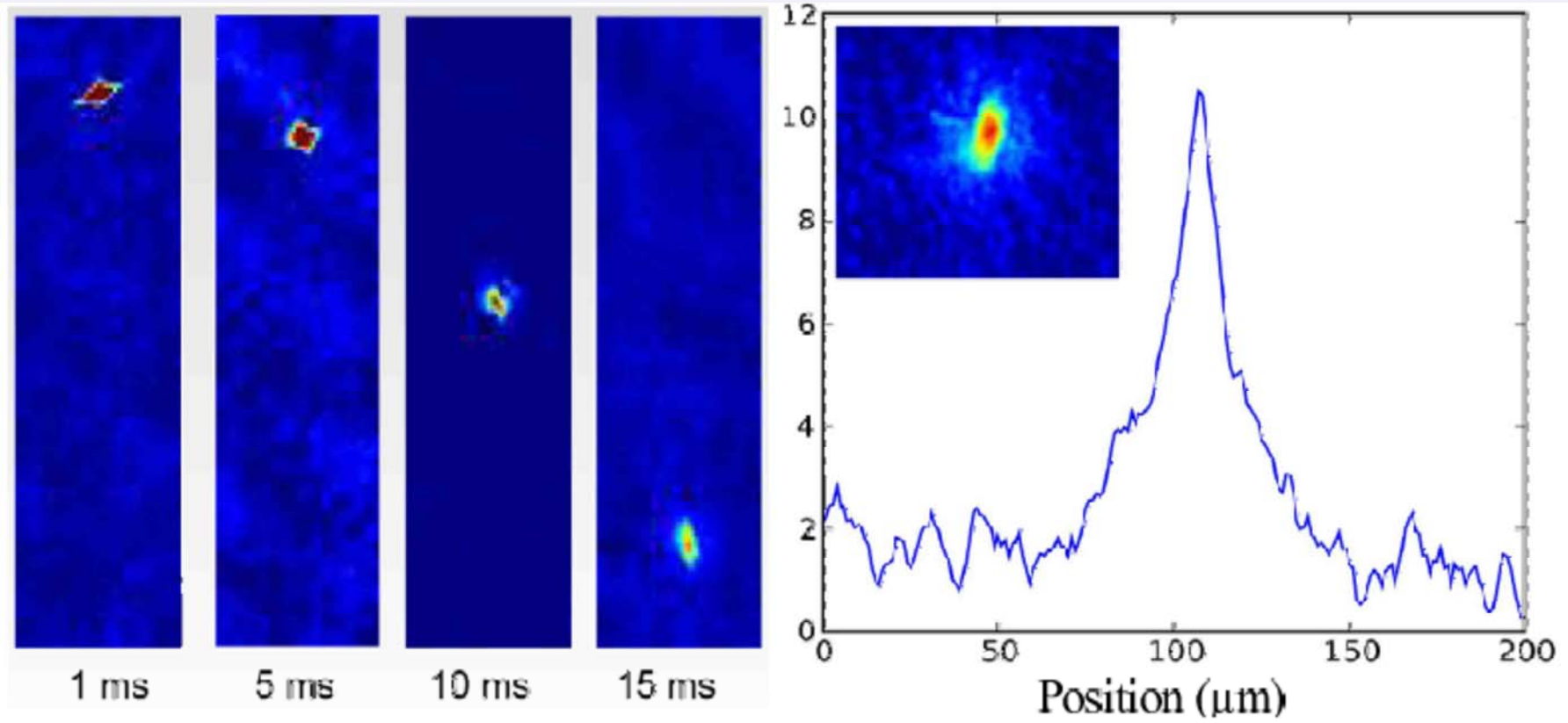
31
EUR

SAI: Basic structure of sensor



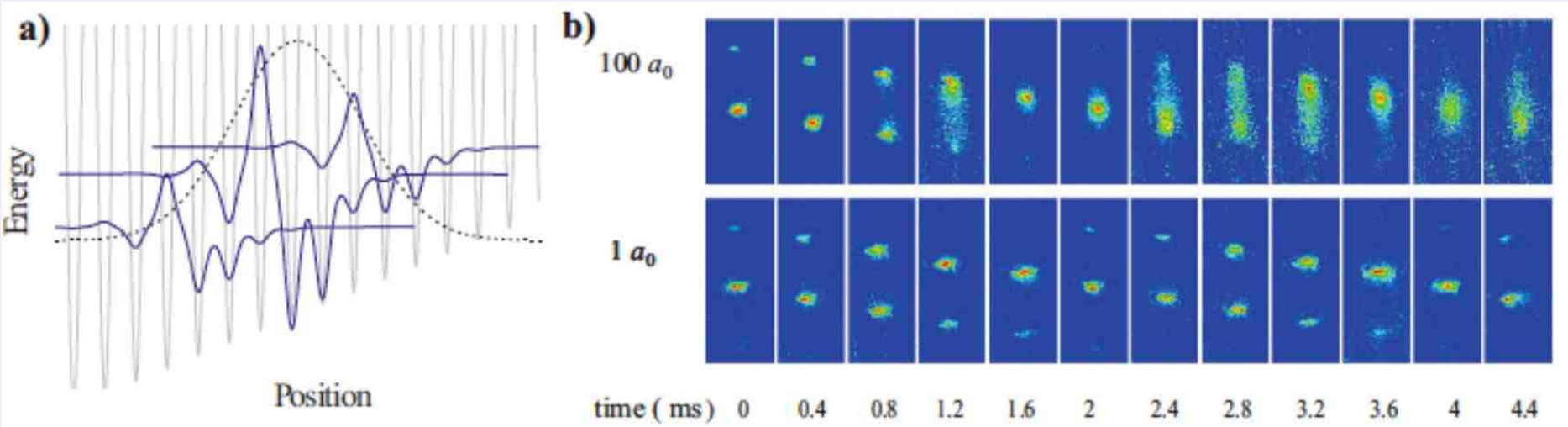
SAI coherent atomic source (CNRS-IOTA)

- SAI design compatible with all-optical evaporation to BEC



*Clément et al., PRA **79**, 061406 (2009)*

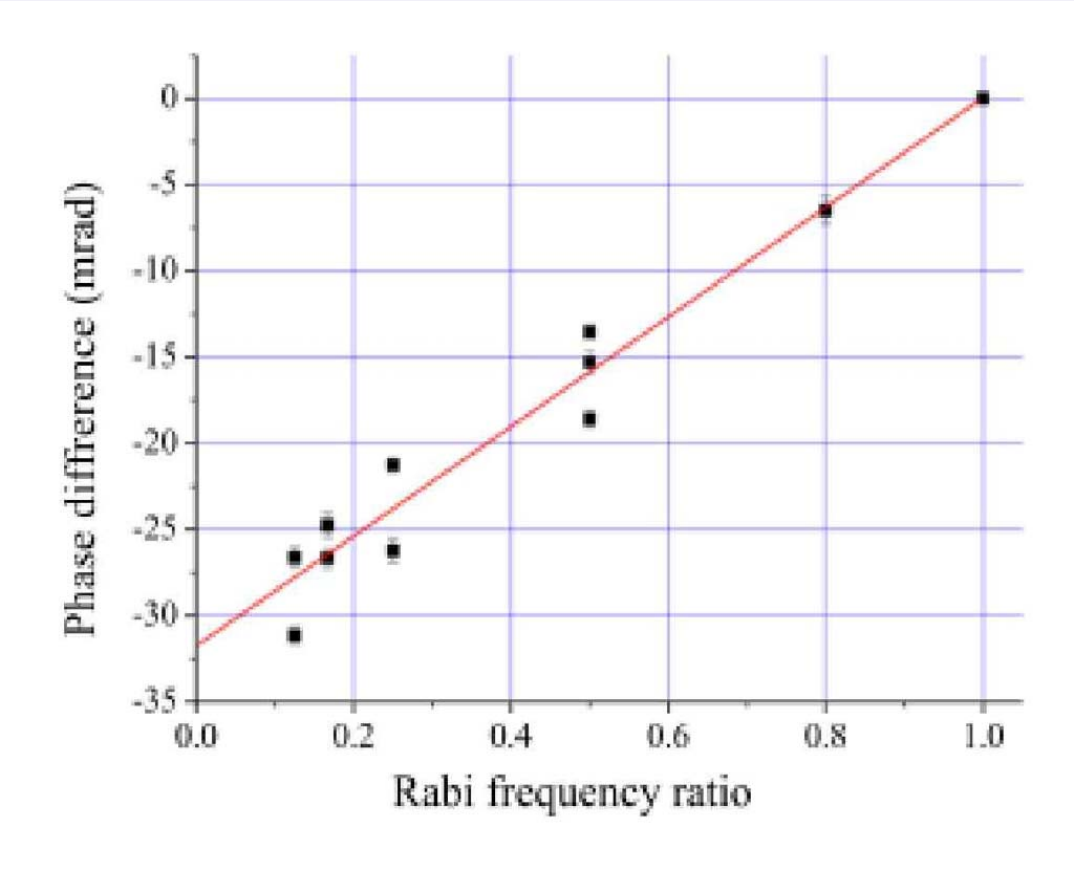
Advanced atomic sources (LENS)



SAI metrological model (SYRTE)

• Metrological model to study noise and systematic effects on interferometer phase

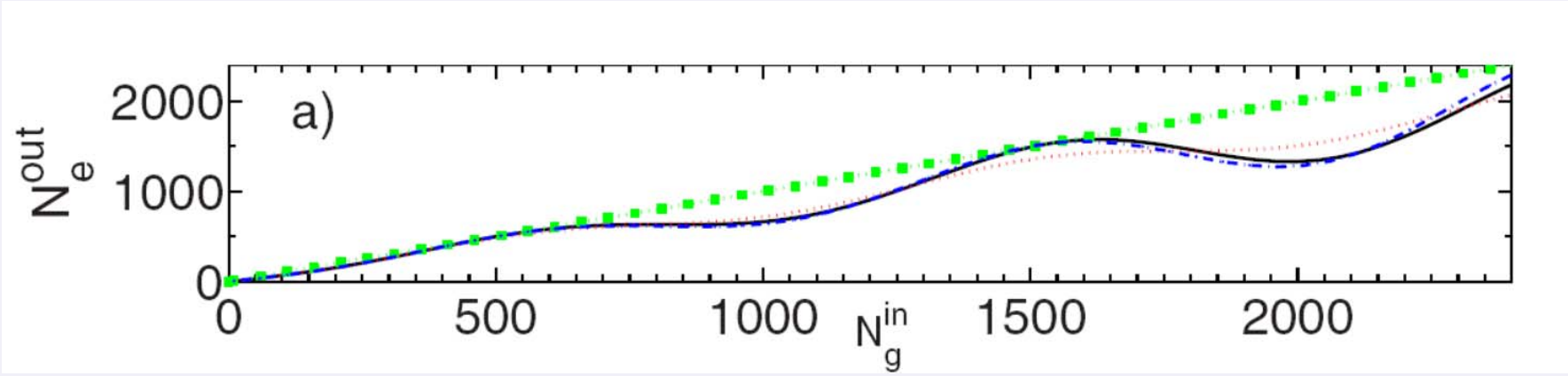
•Example: effect of two-photon light-shift on interferometer



A. Gauguet et al., Phys. Rev. A ***78,*** *043615 (2008)*

SAI theoretical investigations (ULM)

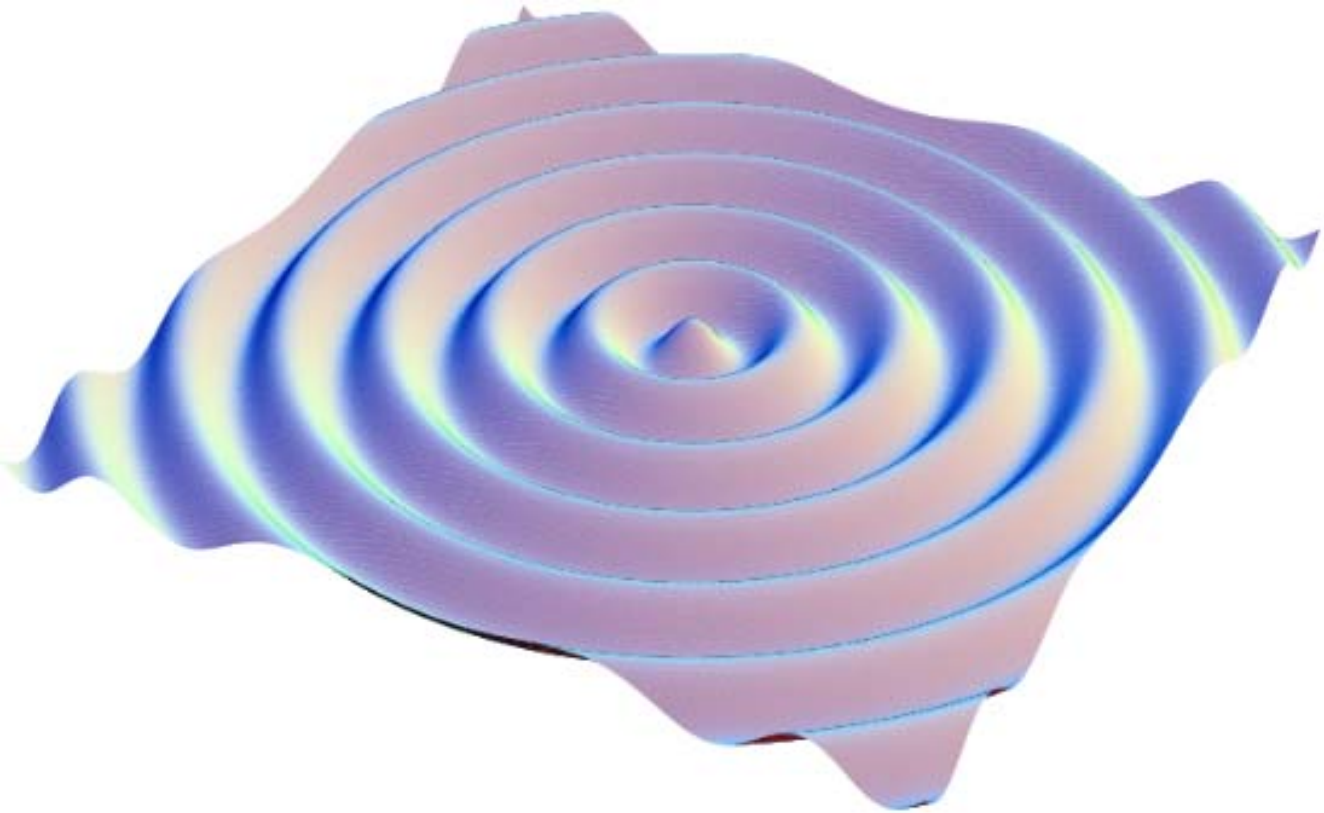
- Number filter for matter-waves interferometer
- Calculate the effect of mean field on atom number fluctuations



G. Nandi et al., Phys. Rev. A ***78****, 013605 (2008)*

SAI theoretical investigations (ZARM)

- Study possible effects of space-time fluctuations on atom interferometers
- connection with



E. Göklü and C. Lammerzahl, Class. Quantum Grav. ***25,*** *105012 (2008)*

SAI status

- Sensor hardware under final assembly
- Subcomponents finished and tested
  - Raman laser module
  - Modular laser system
  - 6.8 GHz source
  - High-flux atomic source (2D-MOT)
  - Vacuum system
  - Mechanical structure & magnetic shield
  - Electronic control system
- Theoretical investigations

SAI Mid-Term Report, June 2009
available online http://coldatoms.lens.unifi.it/files.html

Fiodor Sorrentino, Kai Bongs, Philippe Bouyer, Luigi Cacciapuoti and Marella de Angelis, et al.
A Compact Atom Interferometer for Future Space Missions
Microgravity Science and Technology, Online First, 23 September 2010

SAI: timeline

- **SAI project will end in December 2010**
  - Tests of vacuum system (October 2010)
  - Complete sensor assembly (November 2010)
  - Start tests (December 2010)

- **Roadmap towards a mission on ISS**
  - 2011-14 breadboard development “SAI 2”
  - 2011-14 Technology and Engineering Model development - Phase I
  - 2014-16 Breadboard development project “SAI-3”
  - 2014-16: Technology and Engineering Model development - Phase II
  - 2012-16 Tests and validation of breadboards and component EMs
  - 2016-18 Development of the flight model and ground facilities
  - 2018: Mission start - mission end in 2020

SAI: Key technologies and requirements

- **Laser sources for Rb cooling and manipulation**
  - **Overall optical power requirement ~ 1 W @ 780 nm out of optical fibres**
    - **Diode lasers and TA**
    - **telecom fibre lasers @ 1500 nm + SHG**
    - **Possible developments: integrated micro-optics**
  - **Ultra-low phase noise @ 6.8 GHz frequency difference for Raman wave-packet manipulation**
    - **OPLL**
    - **High frequency modulators (AOM or EOM)**
  - **High power FORT laser for optical BEC**
- **Vacuum system**
  - **UHV ($10^{-10} \div 10^{-11}$ torr)**
  - **Perfectly non-magnetic**
  - **viewports for 780 nm laser beams (also 1500 nm FORT)**
    - **Titanium body + glass viewports (PHARAO)**
    - **Glass cell with silicate bonding**
- **Magnetic shielding**
  - **B field on atom interferometry area uniform within 10 nT**
- **Electronics**
  - **6.8 GHz frequency reference**

Science Objectives

APPIA

Applications and Implementations of Atom-Based Inertial Quantum Sensors

Proposal in Response to ESA's ITT AO/1-5421/07/NL/HE

l'Observatoire de Paris – SYRTE – Systèmes de Référence Temps-Espace

EADS astrium

IQ – Institute of Quantum Optics, University of Hannover

Humboldt-Universität zu Berlin

LENS – European Laboratory for Non-linear Spectroscopy – Università degli Studi di Firenze

University of Birmingham

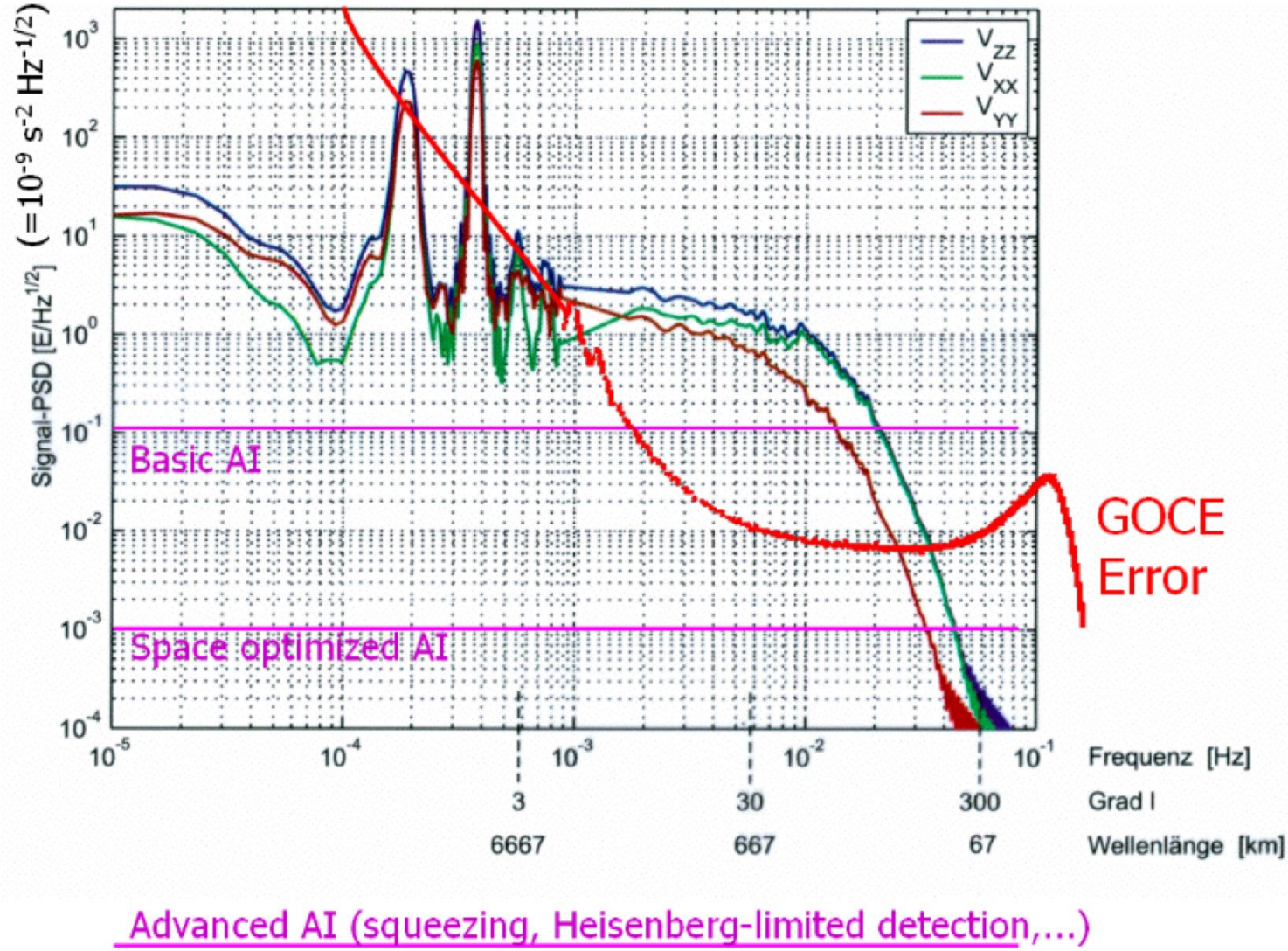
ZARM

Institut d'Optique Graduate School

THALES

Possible scientific objectives

Geoid mapping

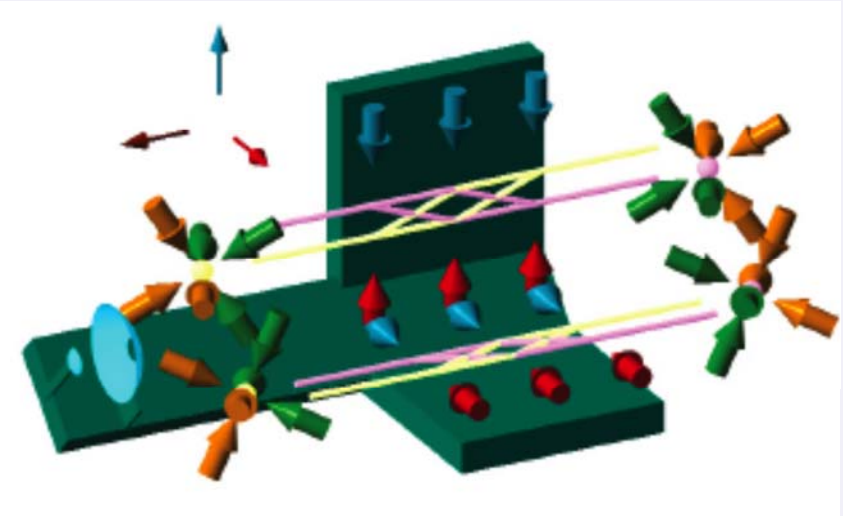


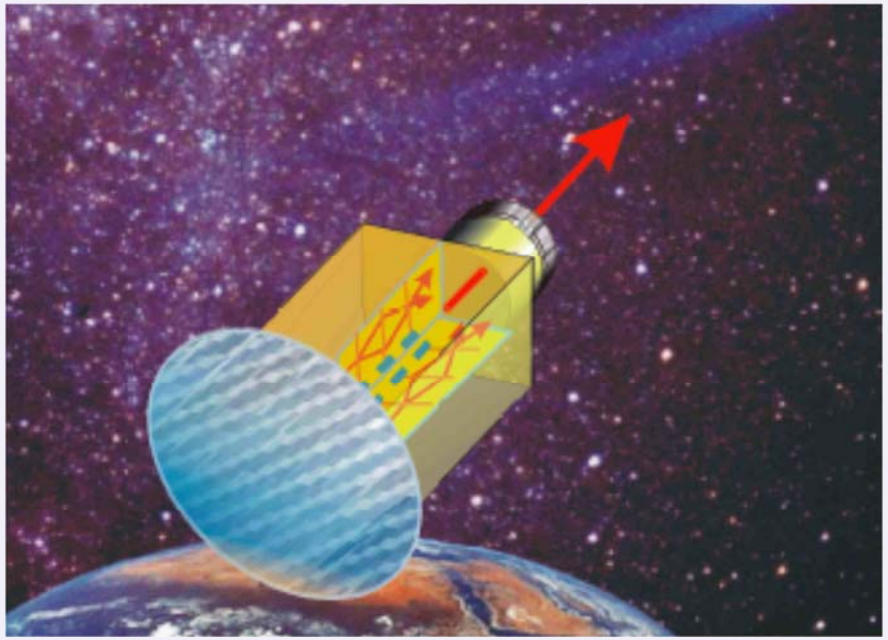
Advanced AI (squeezing, Heisenberg-limited detection,...)

From APPIA (preliminary)

Test of Lense-Thirring effect: Hyper

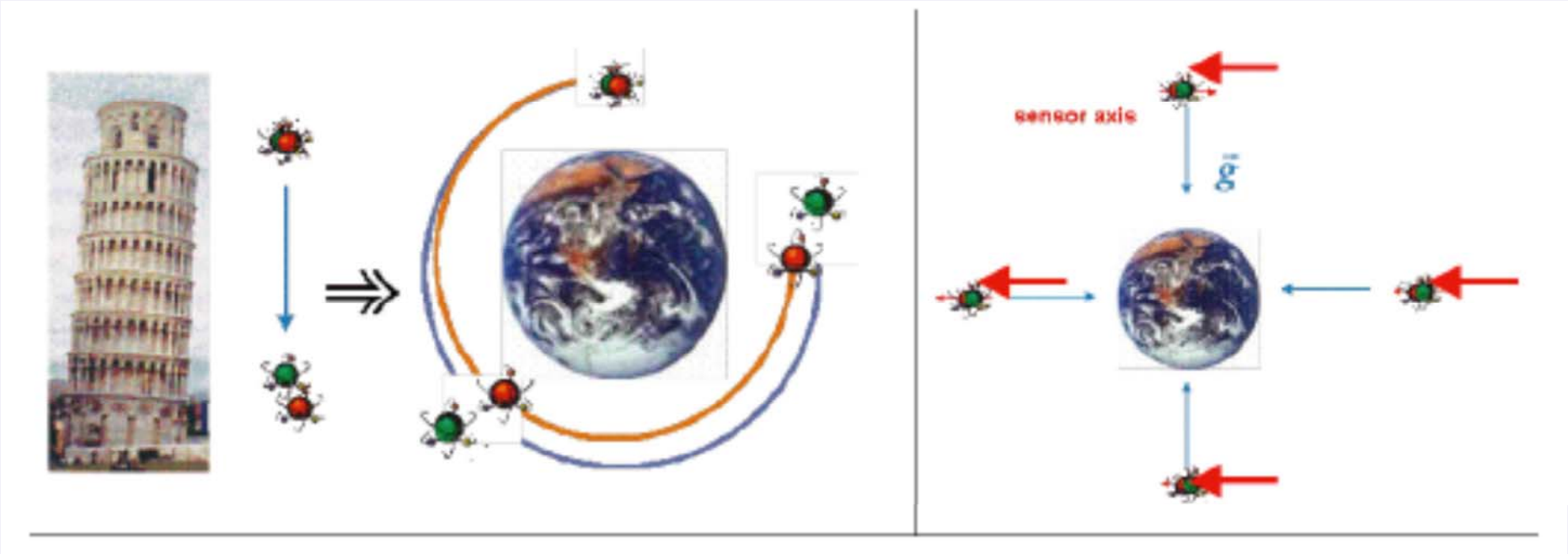
- Differential measurement between 2 atom gyroscopes and a telescope
- 4 atom interferometers
- Link between AI and telescope are Raman laser beams





From APPIA (preliminary)

Matter Wave eXplorer of Gravity



Compare free fall of two atomic species

Class-M mission proposal
for ESA COSMIC VISION 2015-2025

Ertmer W, Schubert C, Wendrich T, et al., *Matter wave explorer of gravity (MWXG)*, EXPERIMENTAL ASTRONOMY 23, 611-649 (2009)

MWXG

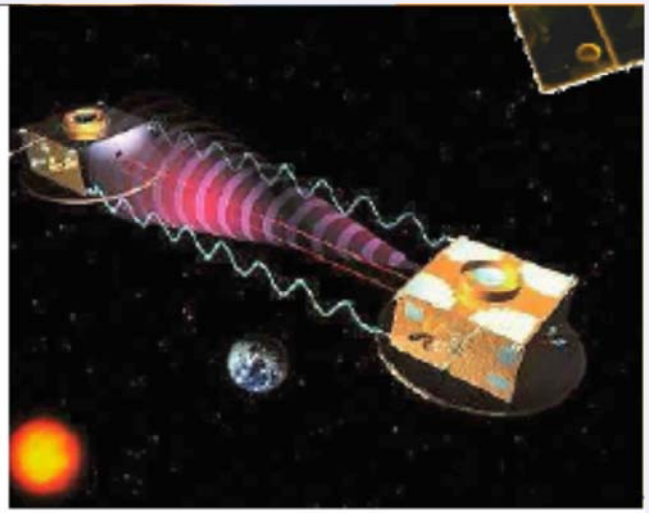
	mass [kg]	mass incl margin [kg]	power [W]	power incl margin [W]
physics package	45,1	54,1	23,0	27,6
cooling and detection laser system	32,0	38,4	52,0	62,4
Raman laser system	24,0	28,8	40,0	48,0
femtosecond comb reference	7,6	9,1	24,0	28,8
Optical fibers	1,6	1,9	0,0	0,0
Harness	2,0	2,4	0,0	0,0
Computer control and interface	11,0	13,2	22,2	26,6
Total:	123,3	**148,0**	161,2	**193,4**

From APPIA (preliminary)

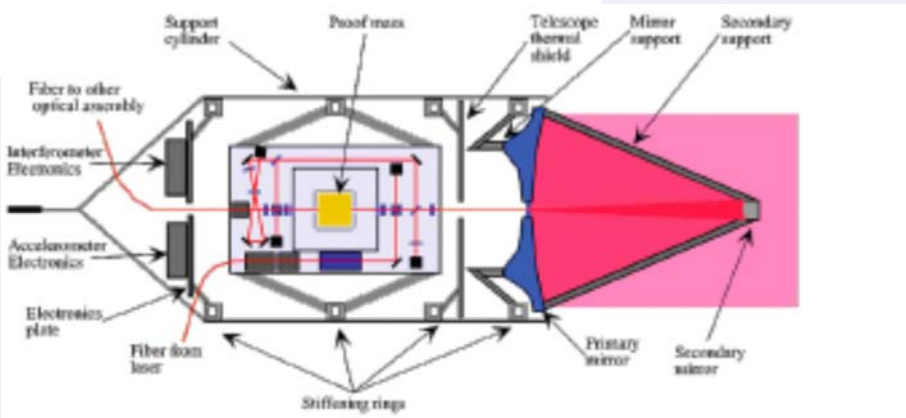
GW detection

Performance

Noise limited sensitivity

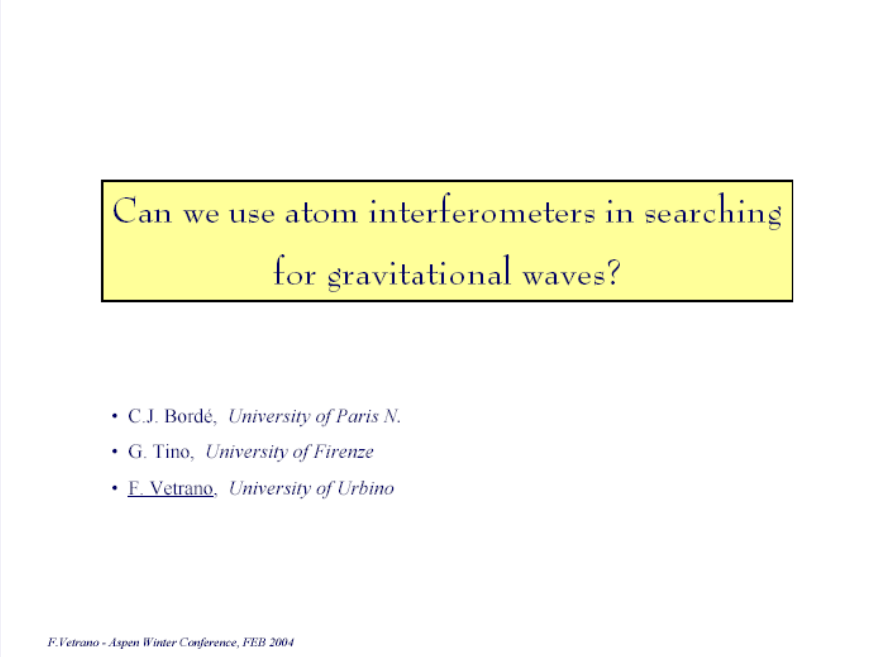


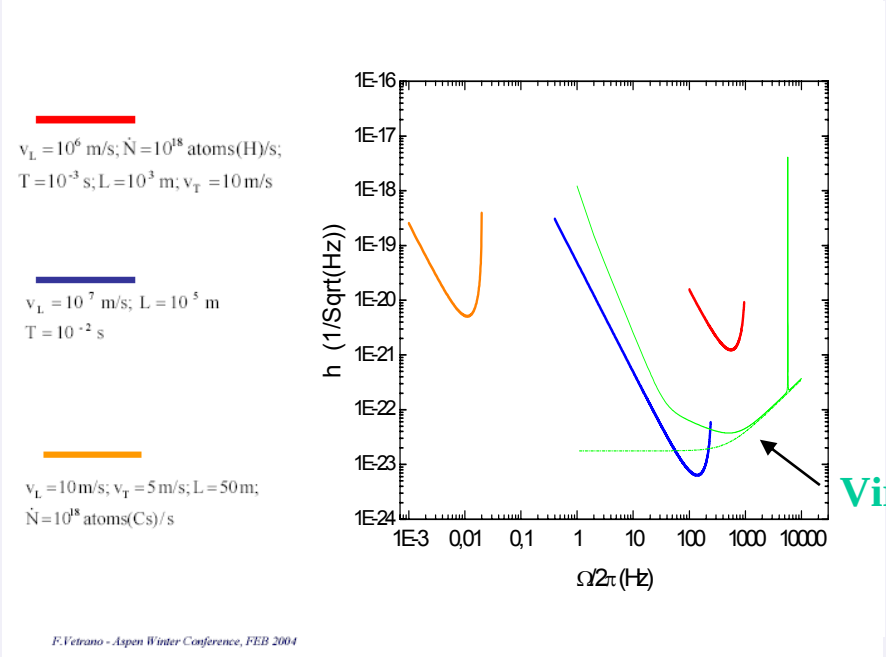
$$\sigma \approx 10^{-16} \frac{\mathrm{g}}{\sqrt{\mathrm{Hz}}} @ 10^{-3} - 10^{-4}\,\mathrm{Hz}$$



From APPIA (preliminary)

Gravitational wave detection by atom interferometry





• C. Bordè, G. M. Tino, F. Vetrano, "Can we use atom interferometers in searching for gravitational waves?", 2004 Aspen Winter College on Gravitational Waves. Available online at: http://www.ligo.caltech.edu/LIGO_web/Aspen2004/pdf/vetrano.pdf

• R.Y. Chiao, A. D. Speliotopoulos, "Towards MIGO, the matter-wave interferometric gravitational-wave observatory, and the intersection of quantum mechanics with general relativity", Journal of Modern Optics (2004), 51(6-7), 861-899

• A. Roura, D.R. Brill, B. L. Hu, C.W. Misner, W.D. Phillips, "Gravitational wave detectors based on matter wave interferometers (MIGO) are no better than laser interferometers (LIGO)", Physical Review D: Particles and Fields (2006), 73(8), 084018/1-084018/14

• G.M. Tino, F. Vetrano, "Is it possible to detect gravitational waves with atom interferometers?", Class. Quantum Grav. 24, 2167 (2007)

• S. Dimopoulos, P.W. Graham, J.M. Hogan, M. A. Kasevich, S. Rajendran, "Atomic gravitational wave interferometric sensor", Phys. Rev. D 78, 122002 (2008)

October 14, 2008

- home
- events
- calls
- opportunities
- visit info
- weekly participants
- staff
- computing

Gravitational Waves Detection with Atom Interferometry

Conference

Apply | Schedule

Organizers:

Guglielmo M. Tino, University of Firenze, Italy Flavio Vetrano, University of Urbino, Italy

Period: from 23-02-2009 to 24-02-2009

Deadline: 15-01-2009

Note: The number of participants is limited to 50 The participation fee for the Workshop is 150 Euros including registration, coffee-breaks, lunches and the social dinner. The fee should be paid cash on arrival at the registration desk

Abstract

The possibility of using atom interferometers to detect gravitational waves is attracting increasing interest as an alternative to other detectors. Several papers were published discussing theoretical and experimental aspects. Although the results show that dedicated technological developments are still needed to achieve the required sensitivity values which are beyond those presently available, new schemes for atom interferometers, beam splitters and high flux coherent atomic sources could lead to an increase in sensitivity and make atom interferometers competitive with other gravitational wave detectors. The Workshop on "Gravitational Waves Detection with Atom Interferometry" will bring together scientists interested in theoretical and experimental aspects, to discuss different points of view and possible experimental implementations in Earth laboratories and in space. The Workshop will consist of oral presentations and open discussions.

Special Issue on *Gravitational Waves Detection with Atom Interferometry*
G.M. Tino, F. Vetrano, and C. Laemmerzahl Eds.
To be published in *General Relativity and Gravitation*

If you want to submit **your abstract or reserve hotel**, please click
If don't have an account, please register

Home Favorite

- Introduction
- Committees
- Program

Co-Chairmen

Xuanhui Lu , Zhejiang University, China
Yuzhu Wang, Shanghai Institute of Optics, CAS, China
Guglielmo M. Tino, University of Firenze, Italy

Program Committee

Co-Chairmen
Jun Luo, Huazhong Un. of Science and Technology, China
Flavio Vetrano, University of Urbino, Italy

No.38 Zheda Road,
Yuquan Campus, Zhejang University,
Hangzhou City,
Zhejiang province, China
Zp Code: 310027

General Information

2010 International Workshop on Gravitational Waves Detection with Atom Interferometry will be held in the Yuquan Campus of Zhejiang University, Hangzhou, China, on Oct 20-22, 2010. The workshop is sponsored and organized by Zhejiang University, and co-sponsored by the Shanghai Institute of Optics and Fine Mechanics, CAS and Wuhan Institute of Physics and Mathematics, CAS and the ministry of education of China and the ministry of science and technology of China.

The possibility of using atom interferometers to detect gravitational waves is attracting increasing interest as an alternative to other detectors. First workshop on Gravitational Waves Detection with Atom Interferometry was held in Florence, Italy, in Feb. 2009. Several new schemes for atom interferometers, beam splitters and high flux coherent atomic sources were proposed and demonstrated. These make atom interferometers competitive with other gravitational wave detectors. This workshop will bring together scientists interested in theoretical and experimental aspects, to discuss different points of view and possible experimental implementations in Earth laboratories and in space and also provides an opportunity to develop or strengthen scientific exchanges and collaborations among researchers of different countries in this field.

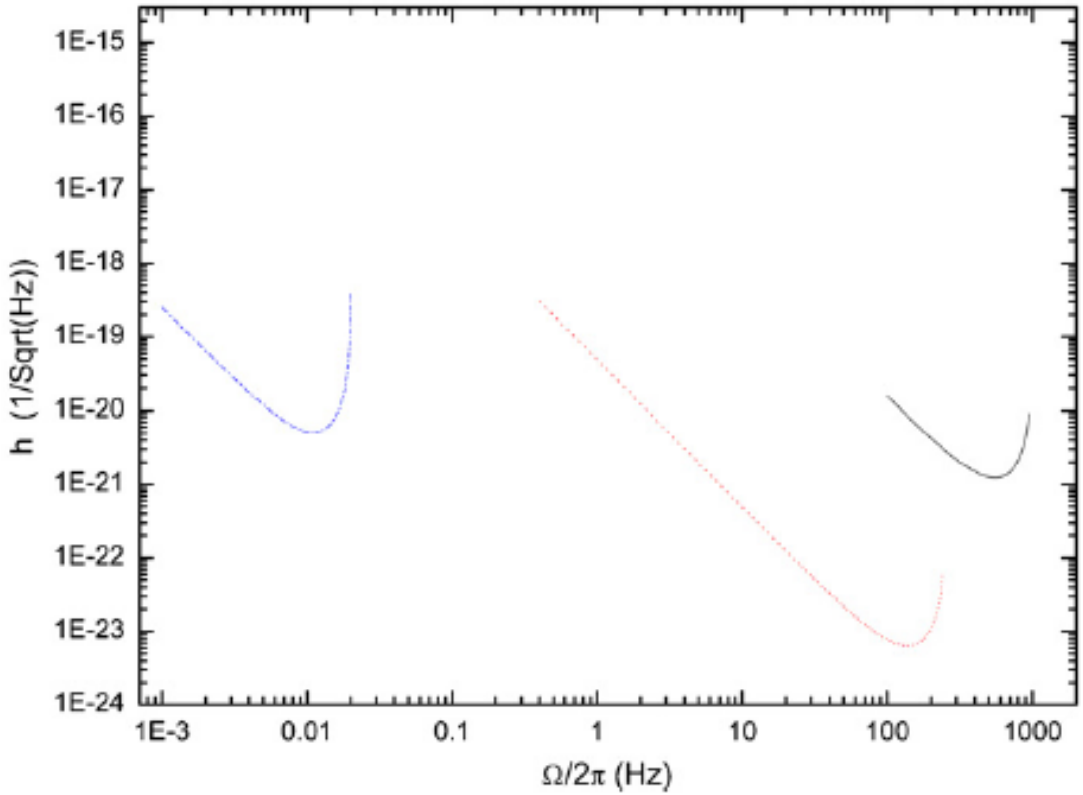


Figure 3. Sensitivity curves of GW detectors based on atom interferometry for the three parameter sets discussed in the text: $L = 10^3$ m, $v_L = 10^6$ m s^{-1} (continuous line); $L = 2 \times 10^5$ m, $v_L = 5 \times 10^7$ m s^{-1} (dotted line); $L = 50$ m, $v_L = 1$ m s^{-1} (dashed-dotted line).

G. M. Tino, F. Vetrano, *Is it possible to detect gravitational waves with atom interferometers?*, **Class. Quantum Grav. 24, 2167 (2007)**

An Atomic Gravitational Wave Interferometric Sensor in Low Earth Orbit (AGIS-LEO)

Jason M. Hogan, David M. S. Johnson, Susannah Dickerson, Tim Kovachy, Alex Sugarbaker, Sheng-wey Chiow, Peter W. Graham, and Mark A. Kasevich*
Department of Physics, Stanford University, Stanford, California 94305, USA

Babak Saif
Space Telescope Science Institute, Baltimore, Maryland 21218, USA

Surjeet Rajendran
Center for Theoretical Physics, Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA and Physics Department, Johns Hopkins University, Baltimore, Maryland 21218, USA

Philippe Bouyer
Laboratoire Charles Fabry de l'Institut d'Optique, Centre National de la Recherche Scientifique, Université Paris Sud 11, Institut d'Optique Graduate School, RD 128, 91127 Palaiseau Cedex, France

Bernard D. Seery, Lee Feinberg, and Ritva Keski-Kuha
NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, USA
(Dated: September 15, 2010)

We propose an atom interferometer gravitational wave detector in low Earth orbit (AGIS-LEO). Gravitational waves can be observed by comparing a pair of atom interferometers separated over a $\sim$ 30 km baseline. In the proposed configuration, one or three of these interferometer pairs are simultaneously operated through the use of two or three satellites in formation flight. The three satellite configuration allows for the increased suppression of multiple noise sources and for the detection of stochastic gravitational wave signals. The mission will offer a strain sensitivity of $< \frac{10^{-18}}{\sqrt{\mathrm{Hz}}}$ in the 50 mHz – 10 Hz frequency range, providing access to a rich scientific region with substantial discovery potential. This band is not currently addressed with the LIGO or LISA instruments. We analyze systematic backgrounds that are relevant to the mission and discuss how they can be mitigated at the required levels. Some of these effects do not appear to have been considered previously in the context of atom interferometry, and we therefore expect that our analysis will be broadly relevant to atom interferometric precision measurements. Finally, we present a brief conceptual overview of shorter-baseline ($\lesssim$ 100 m) atom interferometer configurations that could be deployed as proof-of-principle instruments on the International Space Station (AGIS-ISS) or an independent satellite.

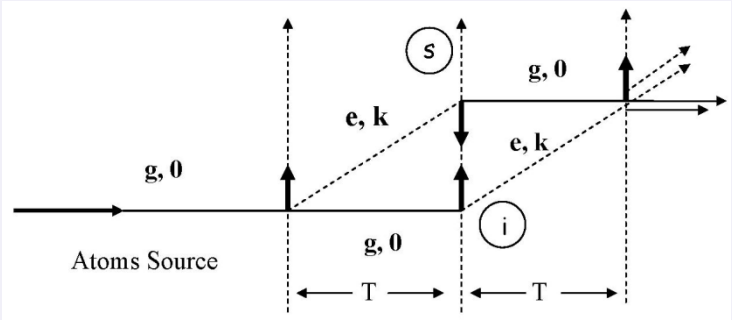
http://arxiv.org/abs/1009.2702

Main ideas

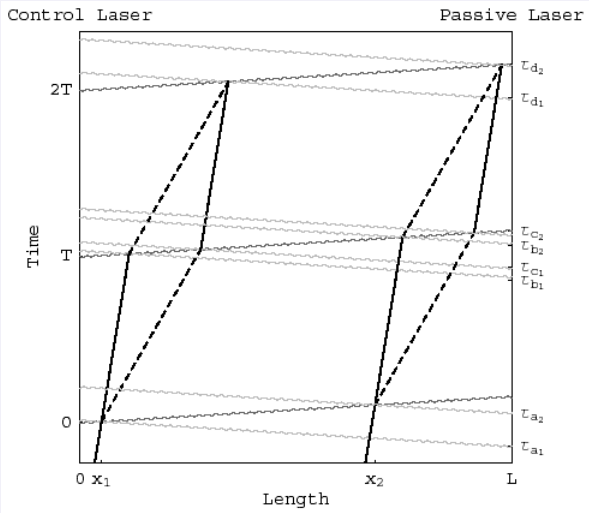
- Detection of GWs by matter waves
- Drastic reduction of critical noise sources
- Addressing new interesting frequency ranges

Two possible schemes

- *Single atom interferometer*



- *Differential scheme*



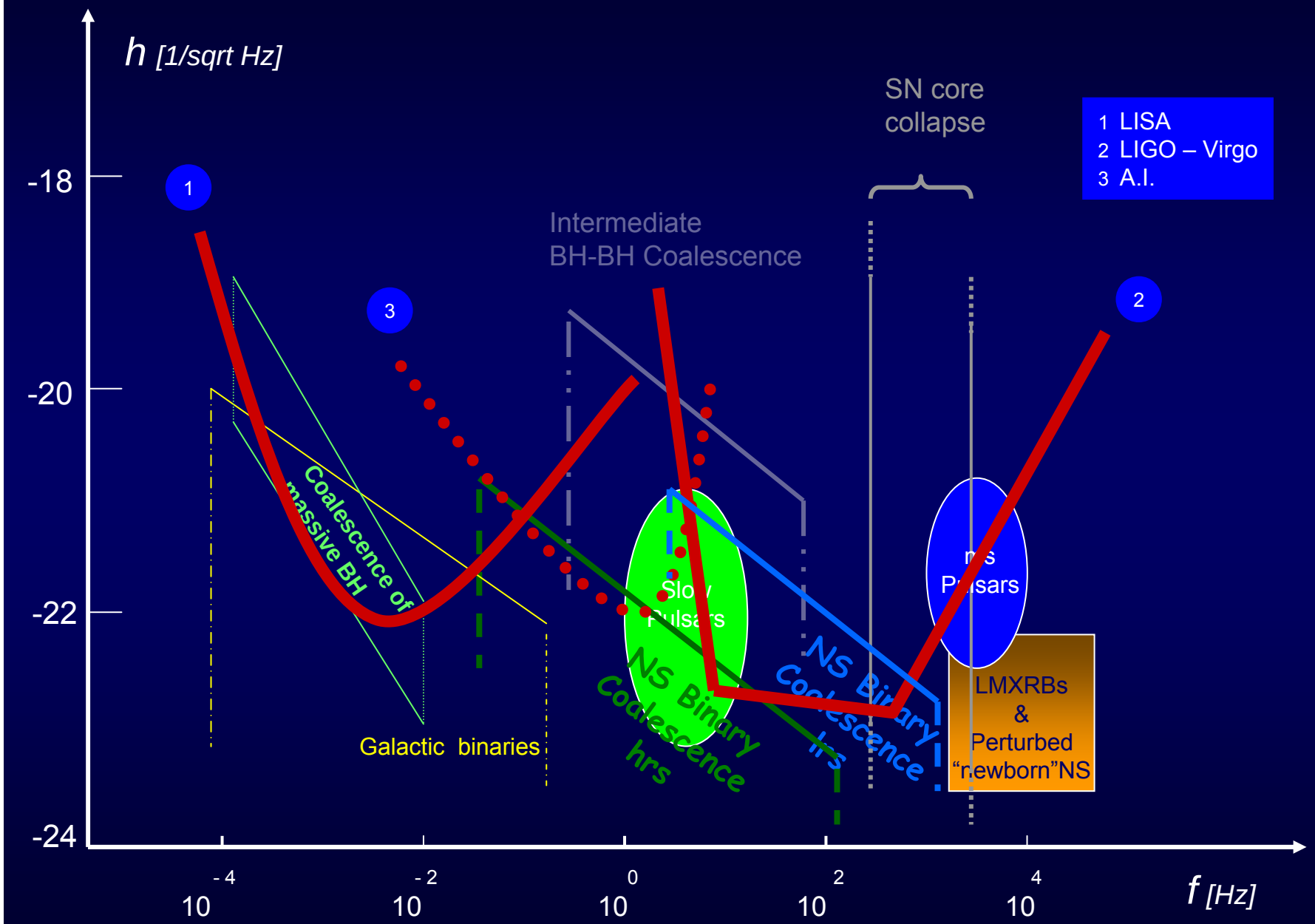
Why using atoms

- “Mirrors” are light wavefronts, linked by light cones
- Allows for common-mode rejection of vibrations
  - No vibration isolation necessary
- Distance measurement based on quantum mechanics
- Action of laser on atom inherent part of operation
  - No thermal noise
- Frequency response can be tuned
- Allows peak sensitivity around 1 Hz (mid way between LIGO/Virgo and LISA)
- New technology, at the beginning of a development

Technical challenges

- shot-noise limit to sensitivity ~ $\frac{1}{\sqrt{\dot{N}}}$
- max atom flux $\dot{N}$~10^{18} s^{-1} for H (~10^{11} for alkali)
- in a 1-kW laser the photon flux > 10^{22} s^{-1}
- much lower path difference than in optical interferometers (better beam splitters, optical cavities, …)

A rough picture of Sources & Detectors



Conclusions

- New atomic quantum devices can be developped with unprecedented sensitivity using ultracold atoms and atom optics
- Applications: Fundamental physics, Earth science, Space research
- Well developed laboratory prototypes
- Work in progress for transportable/space-compatible systems