Orologi e interferometri atomici

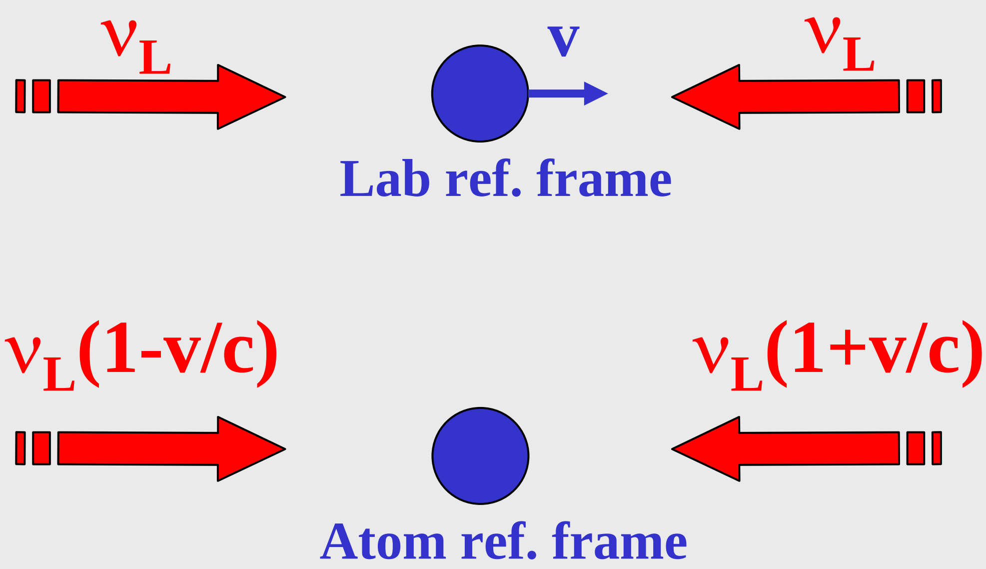
nuovi sensori ad atomi ultrafreddi per esperimenti di fisica fondamentale e applicazioni in laboratori terrestri e nello spazio

Guglielmo M. Tino

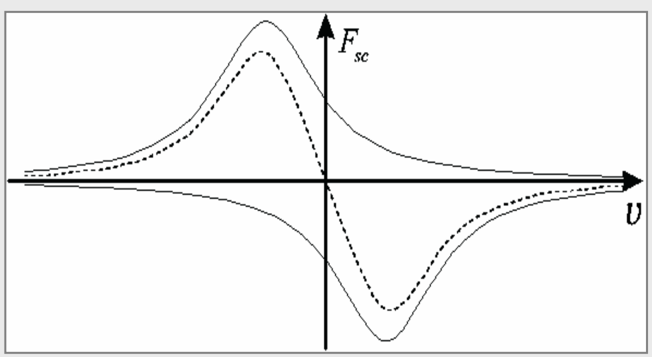
Dipartimento di Fisica, LENS - Università degli Studi di Firenze

INFN, Sezione di Firenze

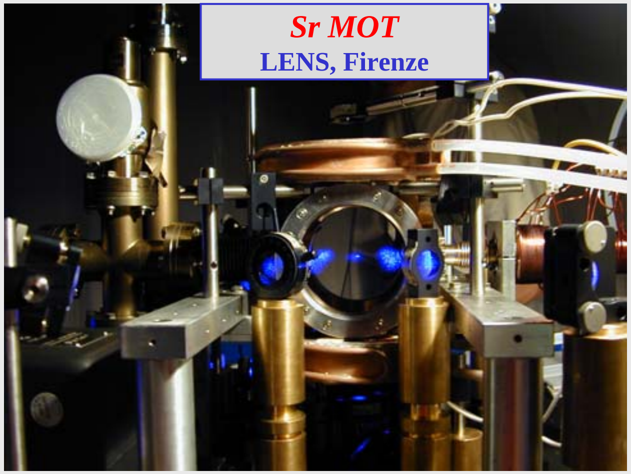
Laser cooling of atoms



Idea:
T.W. Hänsch, A. Schawlow, 1975
Exp. demonstration:
S. Chu et al., 1985



$$F(\mathrm{v}) \simeq \frac{h}{4\pi^2}\frac{\omega_L^2}{c^2}\frac{8\delta}{\Gamma}\frac{I/I_0}{[1+(\frac{2\delta}{\Gamma})^2]^2}\mathrm{v} = -\alpha\mathrm{v}$$



The Nobel Prize in Physics 1997

HOME SITE HELP ABOUT SEARCH

NOBEL e-MUSEUM

NOBEL | PHYSICS | CHEMISTRY | MEDICINE | LITERATURE | PEACE | ECONOMICS

LAUREATES ARTICLES EDUCATIONAL

Web Adapted Version of the Nobel Poster from the Royal Swedish Academy of Sciences

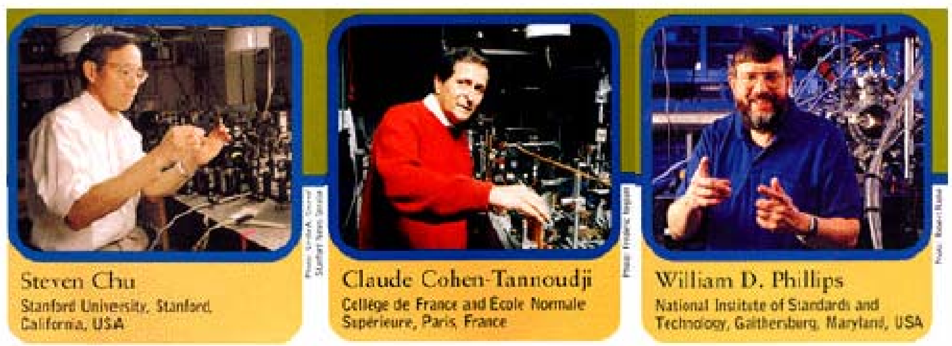
BACK

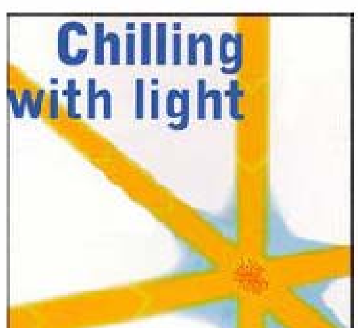
The Nobel Prize in Physics 1997

The Royal Swedish Academy of Sciences has awarded the 1997 Nobel Prize in Physics jointly to

Steven Chu, Claude Cohen-Tannoudji and **William D. Phillips**

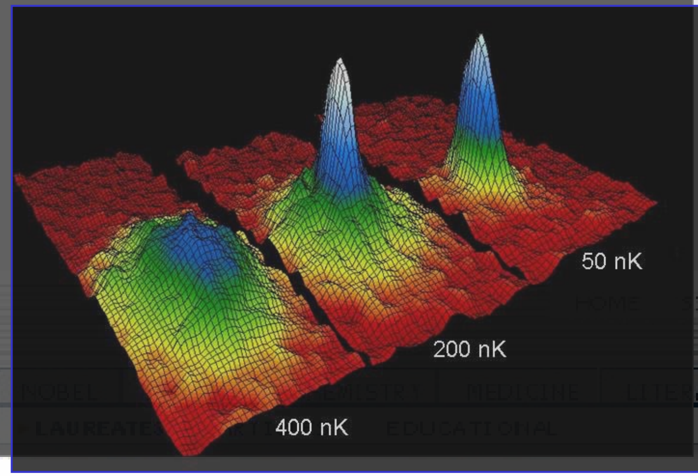
for their developments of methods to cool and trap atoms with laser light.





This year's Nobel laureates in physics have developed methods of cooling and trapping atoms by using laser light. Their research is helping us to study fundamental phenomena and measure important physical quantities with unprecedented precision.

The Nobel Prize in Physics 2001



NOBEL e-MUSEUM

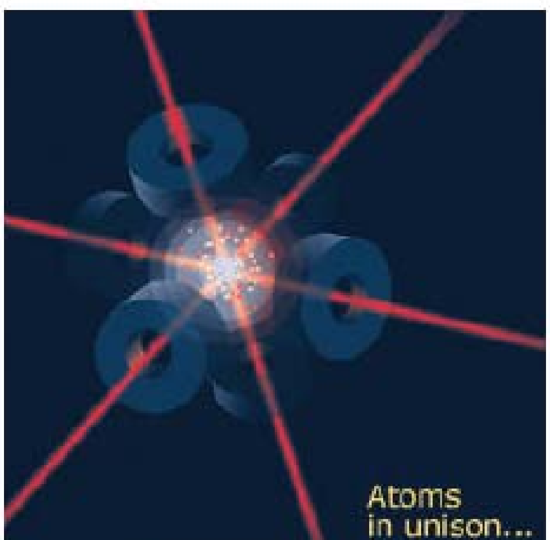
ITE HELP ABOUT SEARCH

TURE PEACE ECONOMICS

The Nobel Prize in Physics 2001

The Royal Swedish Academy of Sciences has awarded the Nobel Prize in Physics for 2001 jointly to Eric A. Cornell, Wolfgang Ketterle and Carl E. Wieman "for the achievement of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the condensates".

BACK



Eric A. Cornell
JILA and National Institute of Standards and Technology (NIST), Boulder, Colorado, USA.

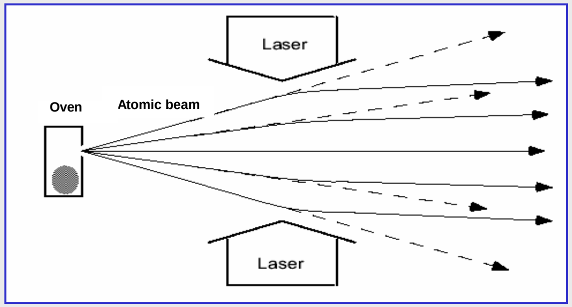
Carl E. Wieman
JILA and University of Colorado, Boulder, Colorado, USA.

Wolfgang Ketterle
Massachusetts Institute of Technology (MIT), Cambridge, Massachusetts, USA.

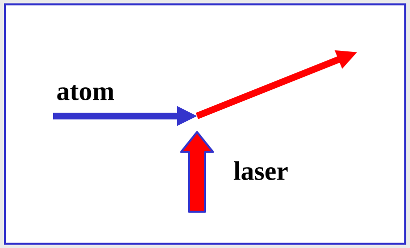
Contents:

Atom optics

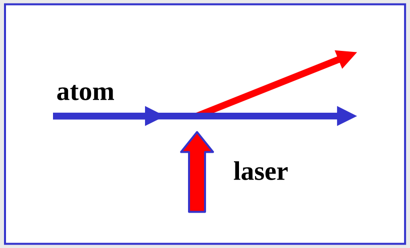
lenses



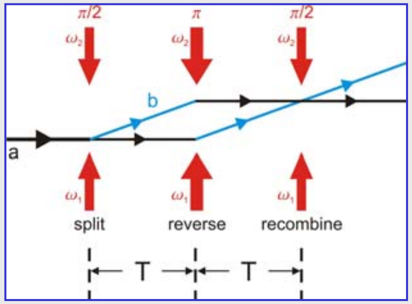
mirrors



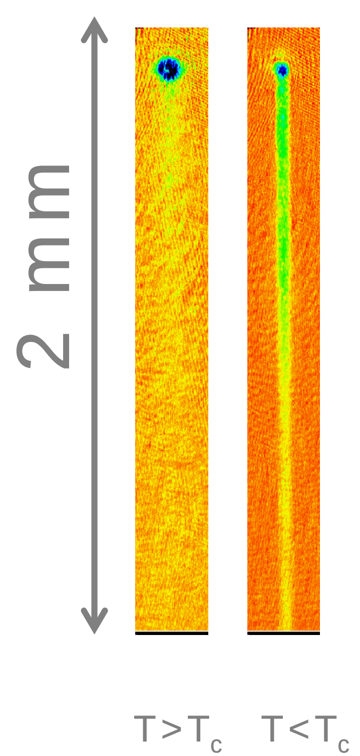
beam-splitters



interferometers



Atom Laser



μ-traps

Laser Cooling and loading: (<10 s)

Single MOT system (need <50 mW of light)

$\approx 10^8$ atoms at $T \approx 50\ \mu K$ and $n \approx 10^{10}\ cm^{-3}$

Evaporative cooling: (<1 s)

Static magnetic trap (Ioffe-type)

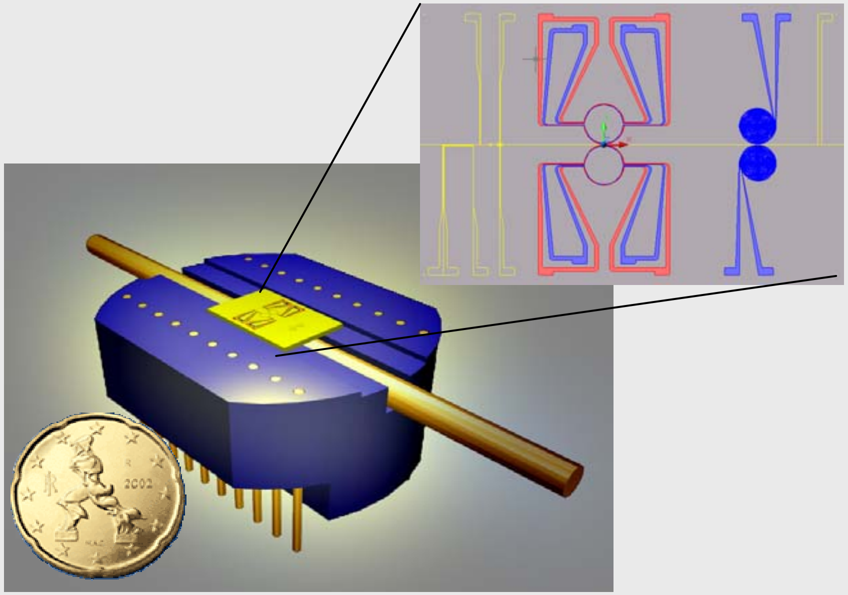
(need < 10 W)

$\approx 10^5$ atoms in condensate

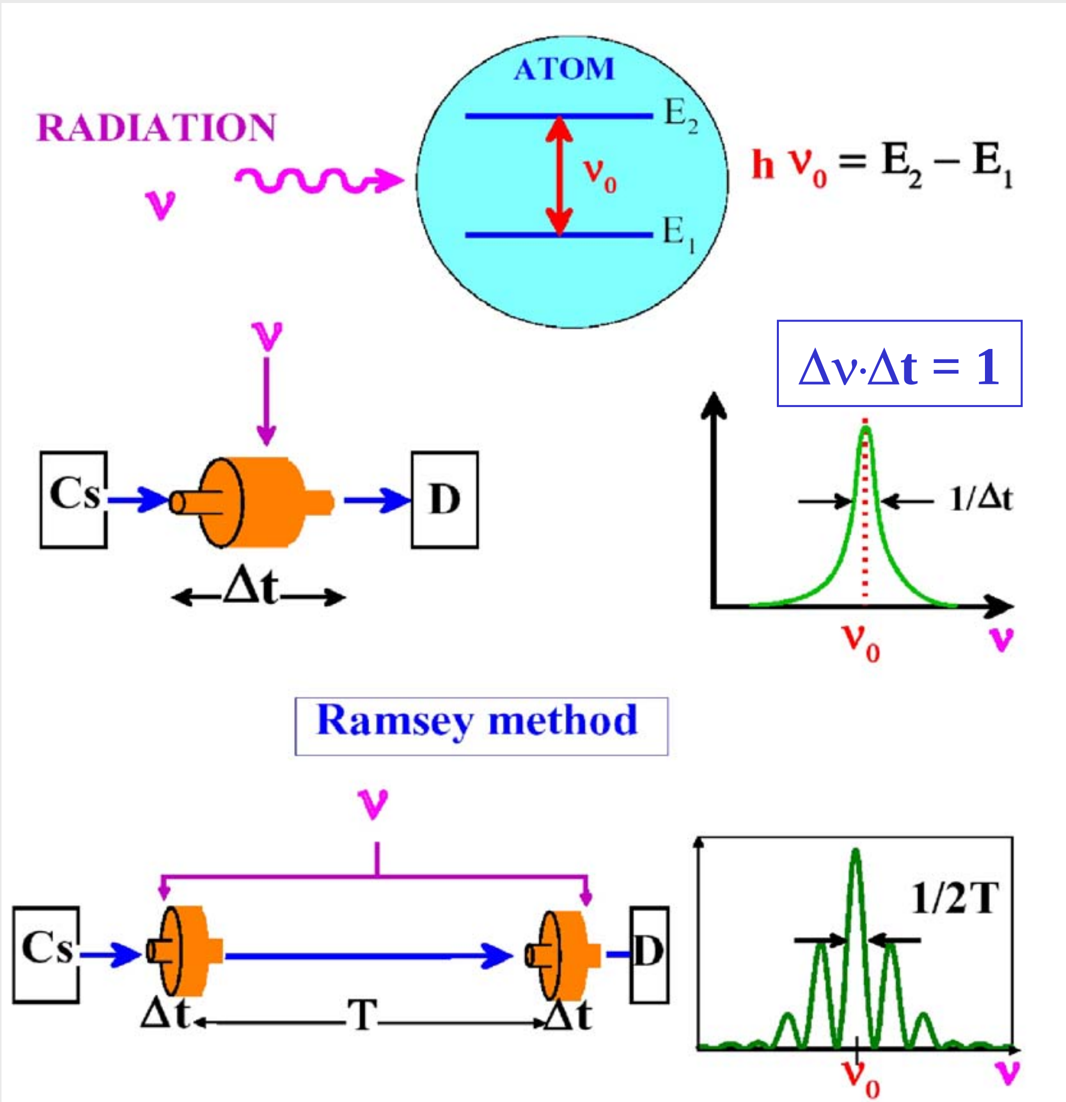
$\nu_a = 1$ kHz

$\nu_r = 10$ kHz

BEC production time < 10 s



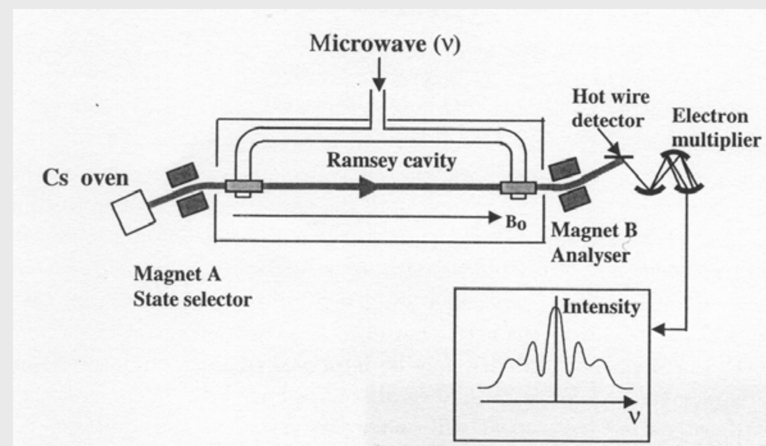
Atomic clocks



The definition of the second

The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the ^{133}Cs atom

(13th CGPM, 1967)

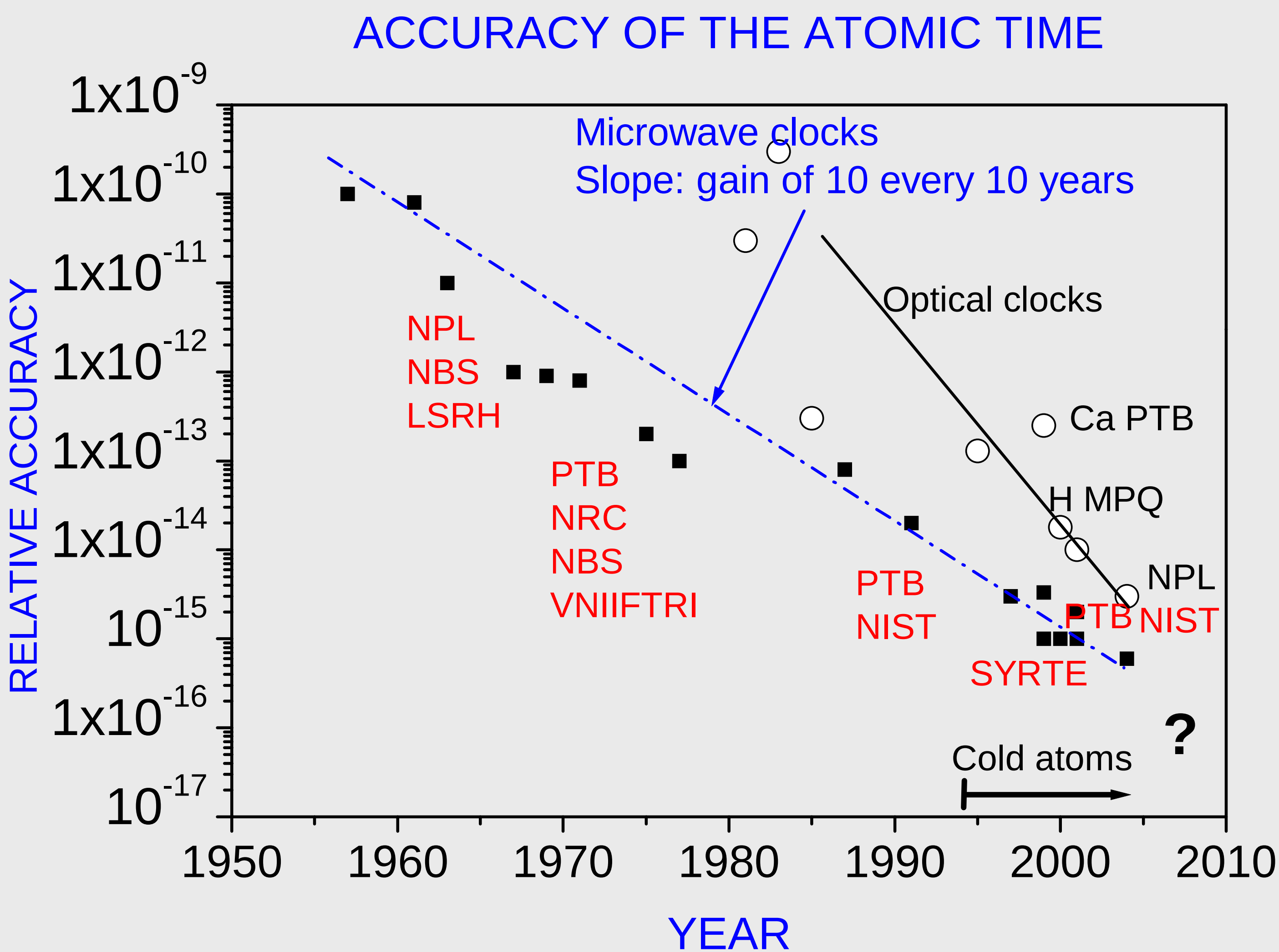


Atomic clocks

- Location finding
- Precision navigation and navigation in outer space
- Variability of Earth's rotation rate and other periodic phenomena
- Earth's crustal dynamics
- Secure telecommunications

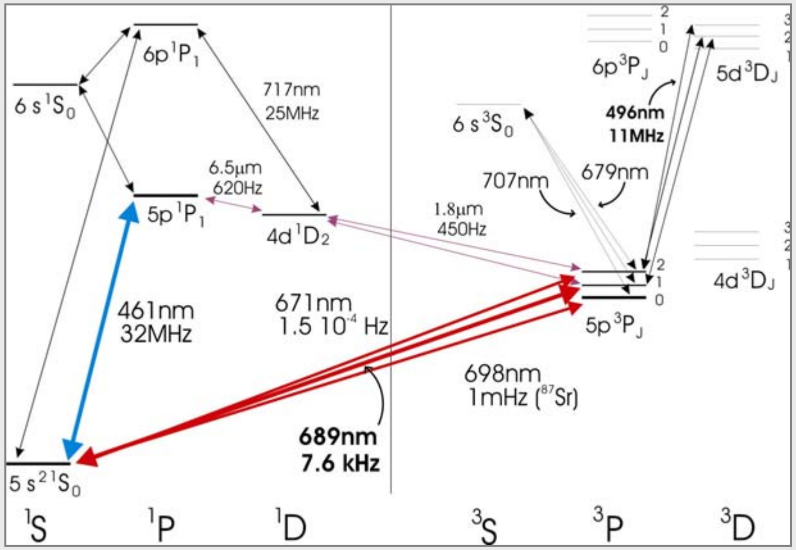
- Very Long Baseline Interferometry (VLBI)
- Spectroscopy
- Expression of other physical quantities in terms of time
- Tests of constancy of fundamental constants
- Tests of the special and general theories of relativity

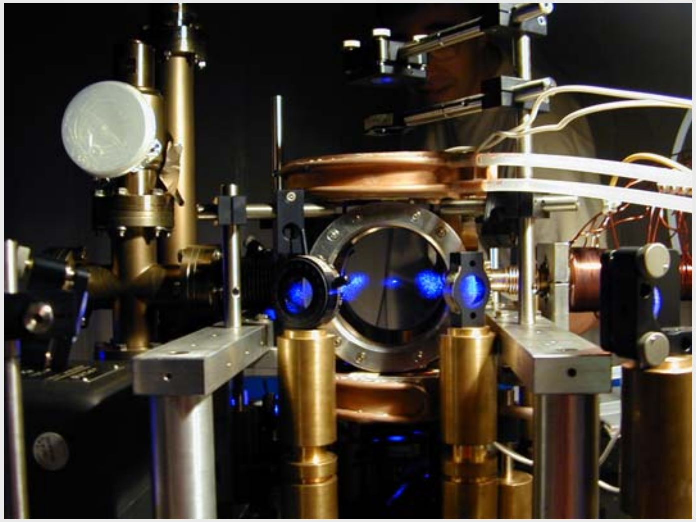
Accuracy of the atomic time



from C. Salomon

Towards a Sr clock – The experiment in Firenze





Firenze 2003, Magneto-optical trapping of all Sr isotopes

- Optical clocks using visible intercombination lines

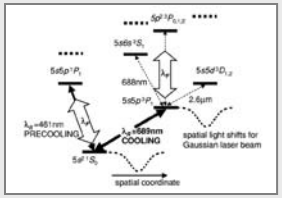
$^1S_0$ - $^3P_1$ (7.5 kHz)

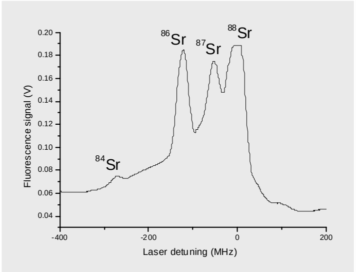
$^1S_0$ - $^3P_0$ (1 mHz, ^{87}Sr)

$^1S_0$ - $^3P_2$ (0.15 mHz)

Optical trapping in Lamb-Dicke regime with negligible change of clock frequency

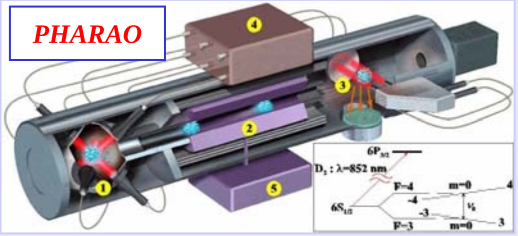
Comparison with different ultra-stable clocks (PHARAO/ACES)





	Abundance
^{88}Sr	82.6%
^{86}Sr	9.9%
^{87}Sr	7.0%
^{84}Sr	0.6%

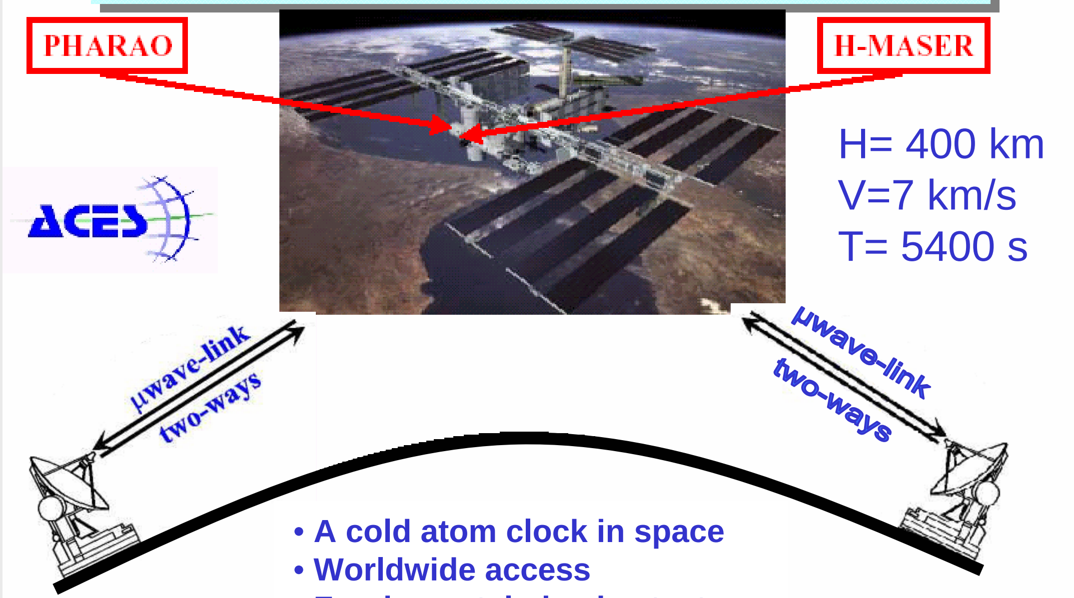
Isotope	I	transition	lifetime	λ	t_{int}	$\sigma_y\, t^{-1/2}$	abundance
^{88}Sr	0	$^1S_0$-$^3P_1$	20 μs	689 nm	10 μs	$2\ 10^{-13}$	83%
^{87}Sr	9/2	$^1S_0$-$^3P_0$	200 s	698 nm	0.5 s	10^{-17}	7%



http://www.lens.unifi.it/poli/

Atomic Clock Ensemble in Space

ACES : New clocks on board the ISS



- A cold atom clock in space
- Worldwide access
- Fundamental physics tests

PHARAO : Cold Atom Clock in Space. CNES (France)

A. Clairon, P. Laurent, P. Lemonde, M. Abgrall, S. Zhang, C. Mandache, F. Allard, M. Maximovic, F. Pereira, G. Santarelli, Y. Sortais, S. Bize, H. Marion, D. Calonico, (BNM-LPTF), N. Dimarcq (LHA), C. Salomon (ENS)

SHM : Space Hydrogen Maser. ON (Switzerland)

L. Jornod, D. Goujon, L.G. Bernier, P. Thomann, G. Busca

MWL : Microwave link. Kayser-Threde-Timetech (Germany)

W. Schaefer, S. Bedrich

ACES is open to any interested scientific user

W. Knabe, P. Wolf, L. Blanchet, P. Teyssandier, P. Uhrich, A. Spallici

New members :

2001: UWA (Australia), A. Luiten, M. Tobar, J. Hartnett, R. Kovacich

2002: LENS (Italy), G.M. Tino, G. Ferrari, L. Cacciapuoti

ESA: MSM

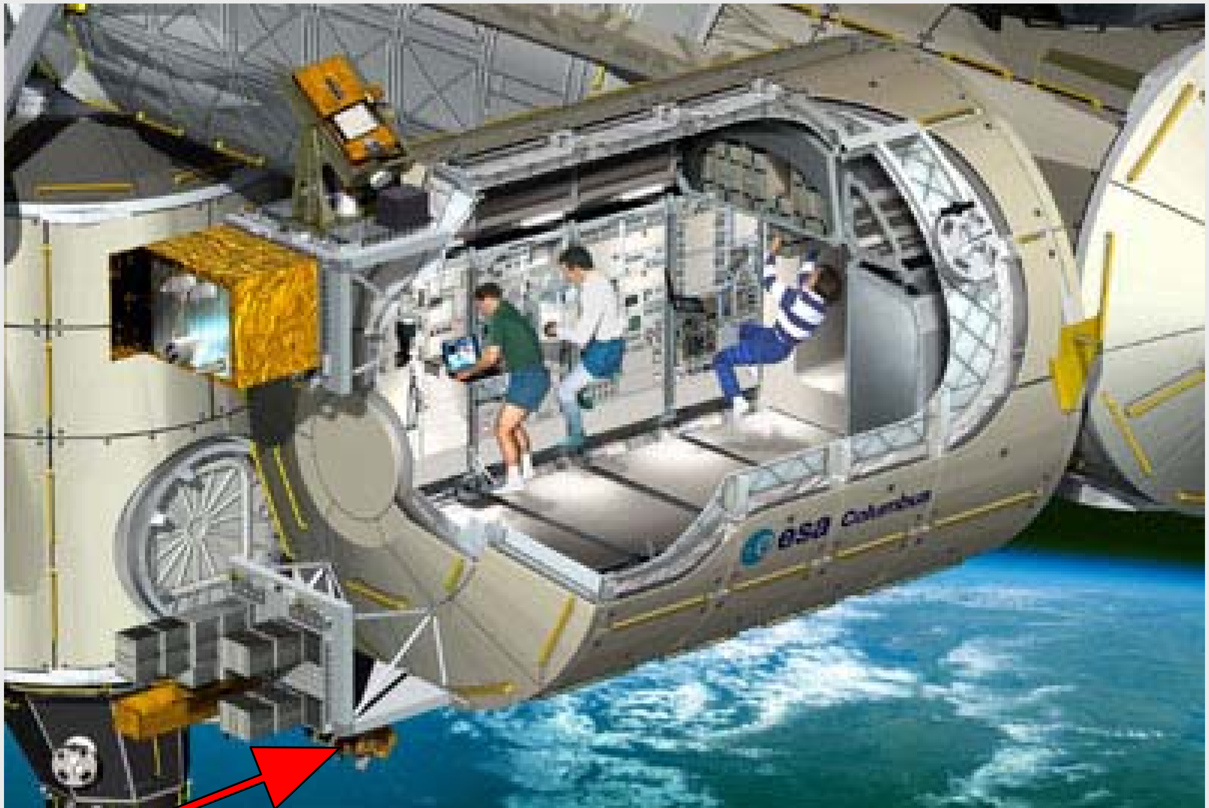
Stephen Feltham

CNES:

C. Sirmain + team of 20 engineers at CST, Toulouse

Support: ESA, CNES, BNM, CNRS

ACES ON COLUMBUS EXTERNAL PLATFORM



ACES

M = 227 kg **P = 450 W**

Launch date : end of 2008
Mission duration : 18 months

ACES objectives

ACES

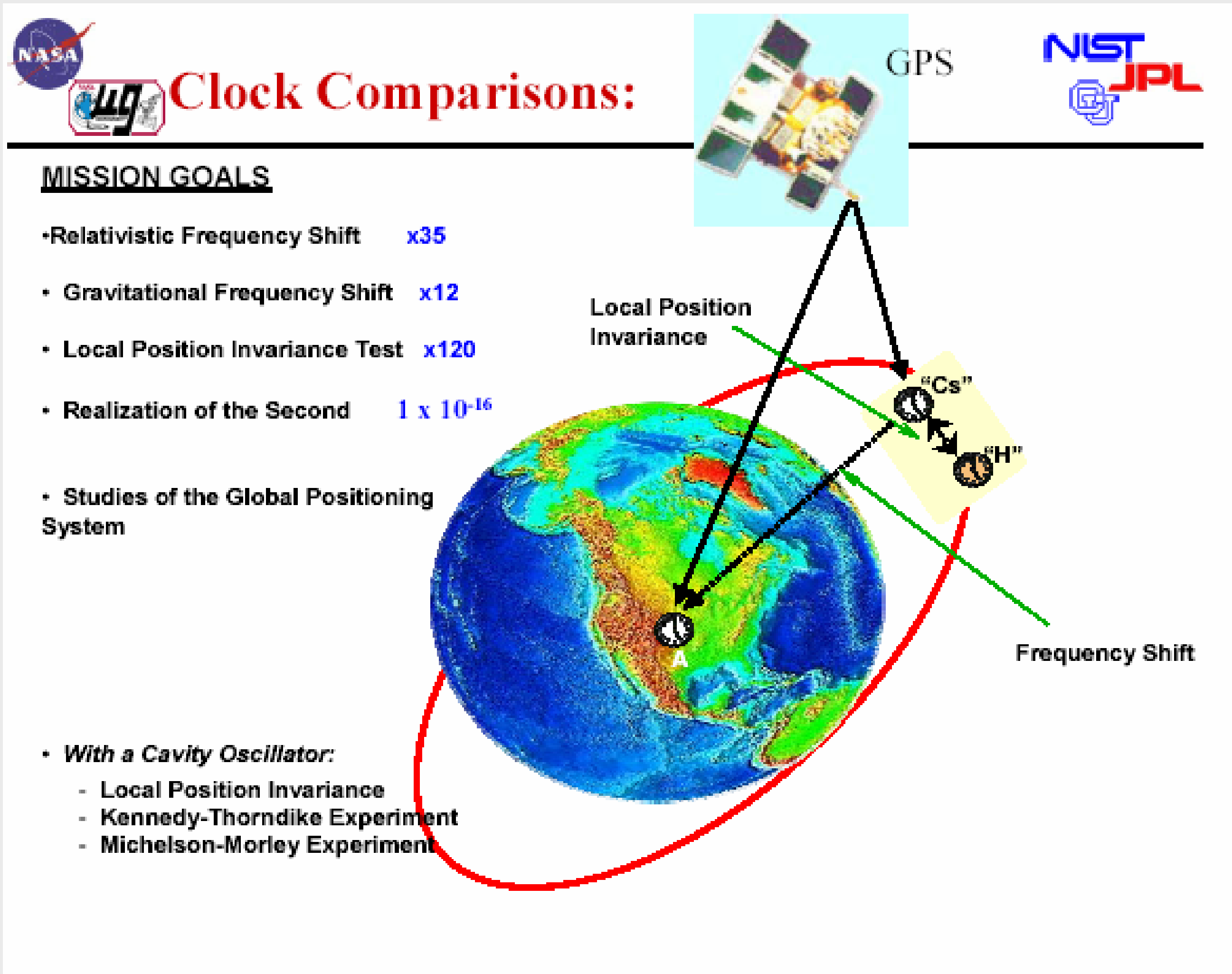
1. Operate a cold atom clock in microgravity :
   - A linewidth of 50 milliHertz
   - A frequency stability of : $\sigma_y(\tau)$ $< 10^{-13}\,\tau^{-1/2}$

     $< 3\ 10^{-16}$/day
2. Study the ultimate stability and accuracy in space :
   - Accuracy : $\sim 10^{-16}$
   - Compromise stability-accuracy
3. Ultra-stable time-scale comparisons on a worldwide basis :
   - 30 ps accuracy
   - Clock synchronisation (10^{-16} accuracy)
   - Contribution to TAI
4. Test General Relativity :
   - Red shift : x25 sensitivity improvement
   - Search for a possible drift of the fine structure constant

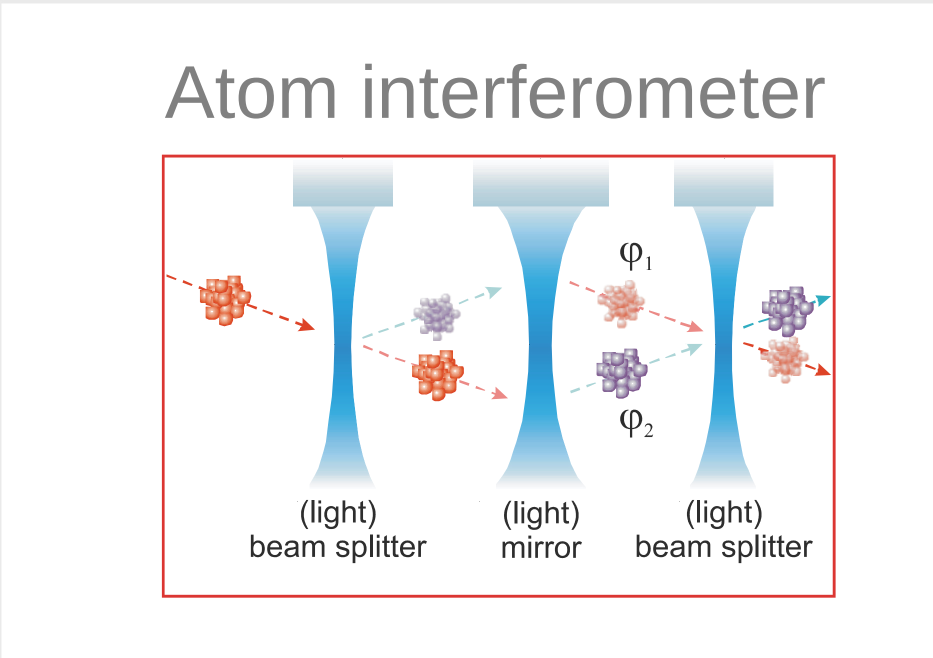
     α : 10^{-16} / year (x100)
   - Search for an anisotropy of speed of light (x10)

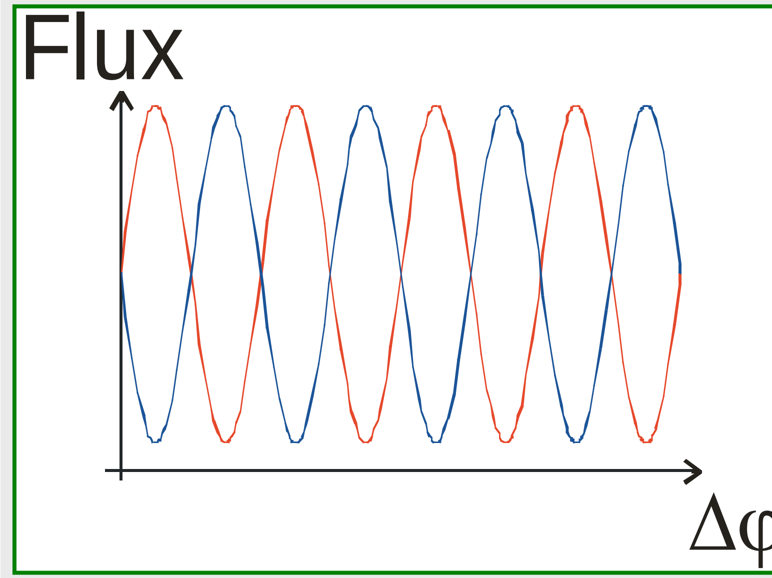
L. Blanchet, C. Salomon, P. Teyssandier, and P. Wolf, A&A 370, 320 (2001)

PARCS
Primary Atomic Reference Clock in Space



Atom Interferometry





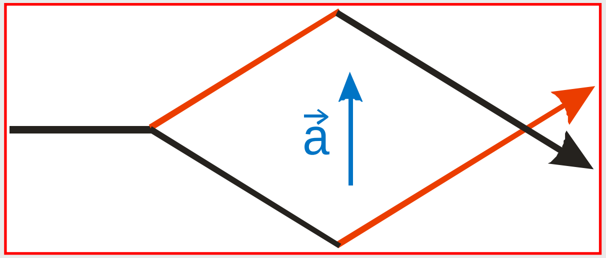
atomic flux at **exit** port **1**
at **exit** port **2**

Phase difference

$$\Delta\varphi = \varphi_1 - \varphi_2$$

Matter wave sensors

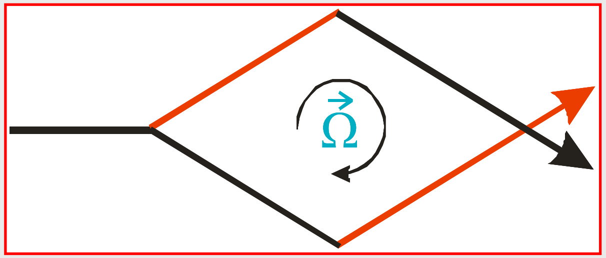
accelerations:



$$\Delta\Phi_{acc} = k\, T_{drift}^2 \cdot a$$

$$\frac{\Delta\varphi_{mat}}{\Delta\varphi_{ph}} \sim \left(\frac{c}{v_{at}}\right)^2 \approx 10^{11} - 10^{17}$$

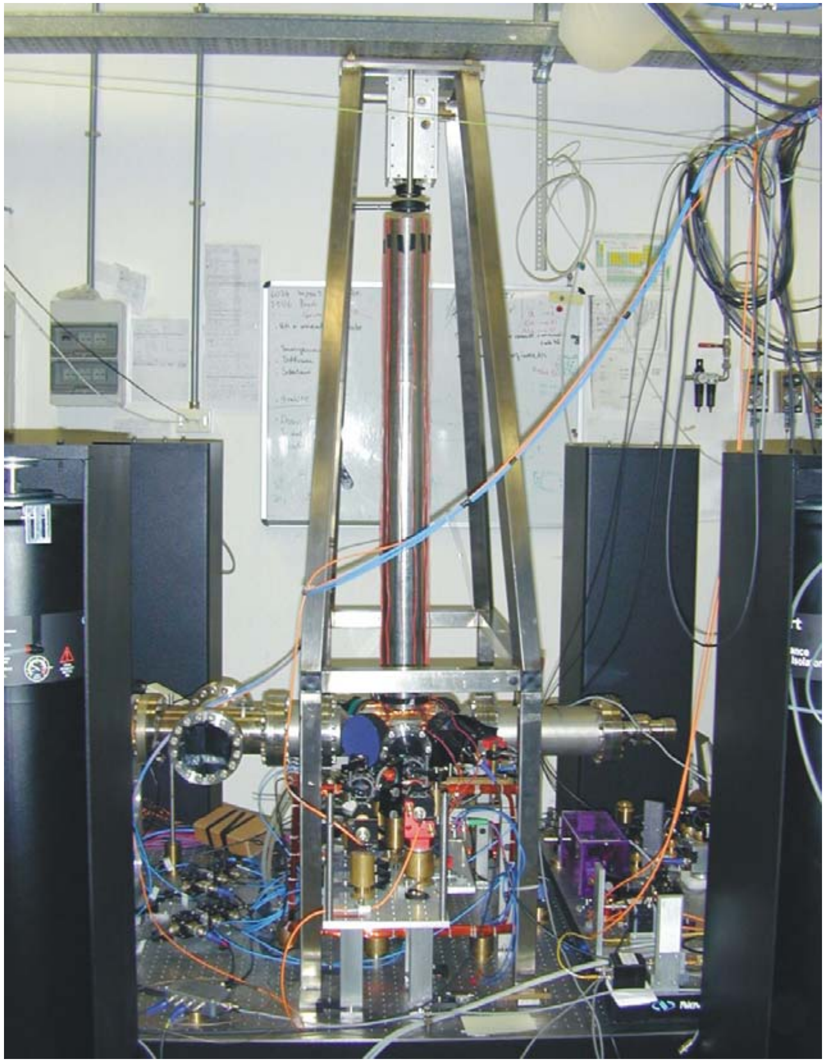
rotations:

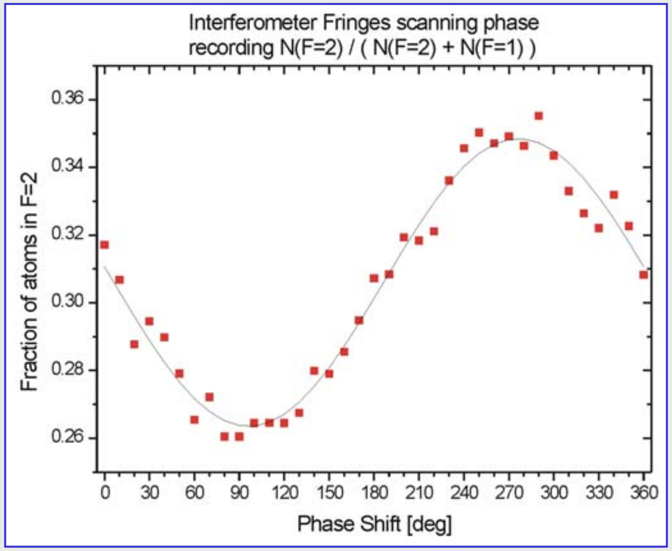


$$\Delta\Phi_{rot} = 2\pi \frac{2\, m_{at}}{h} A \cdot \Omega$$

$$\frac{\Delta\varphi_{mat}}{\Delta\varphi_{ph}} \sim \frac{m_{at} \cdot \lambda \cdot c}{h} \approx 5 \cdot 10^{10}$$

Atom gravimeter/gradiometer in Firenze

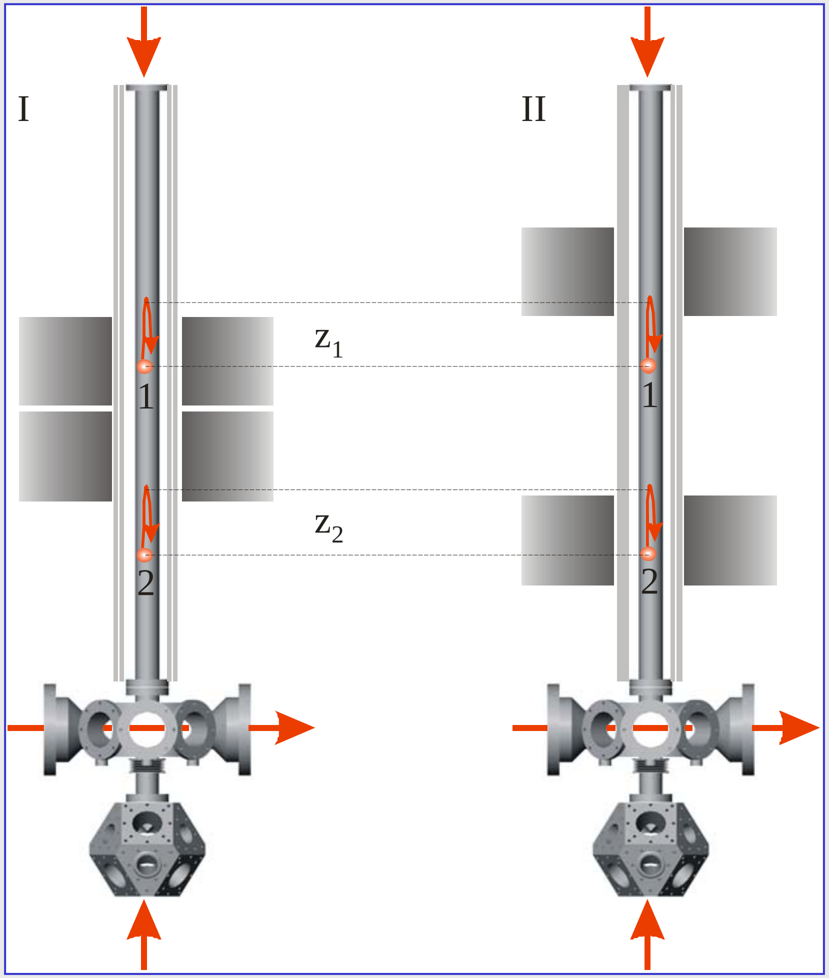


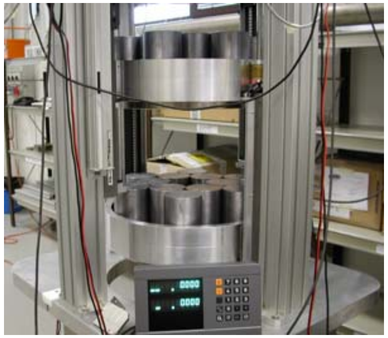


$$\Rightarrow \Delta g/g = 8.6 \cdot 10^{-6} \frac{1}{\sqrt{\text{Hz}}} = 9.1 \cdot 10^{-7} \text{ in } 90\text{ s}$$

MAGIA

Misura Accurata di G mediante Interferometria Atomica

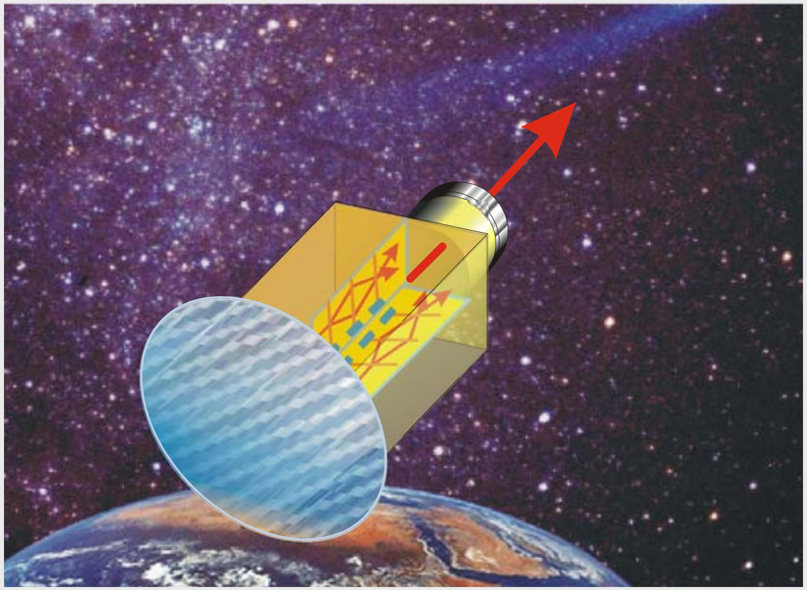




In collaboration with LNF, Frascati

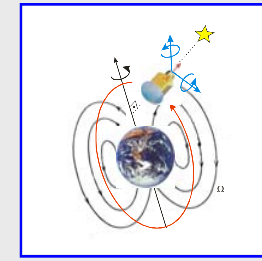
http://www.fi.infn.it/sezione/esperimenti/MAGIA/home.html

HYPER

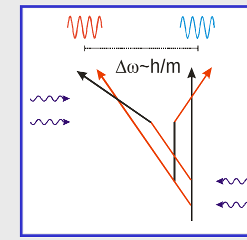


Differential measurement between two atom gyroscopes and a star tracker orbiting around the Earth

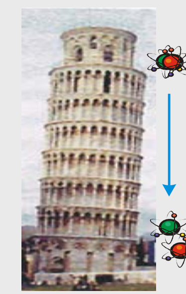
Mapping Lense-Thirring effect close to the Earth



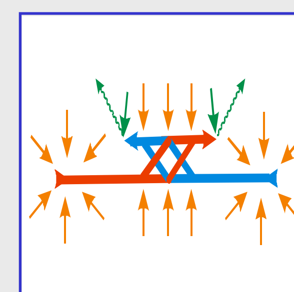
Improving knowledge of fine-structure constant



Testing EP with microscopic bodies



Atomic gyroscope control of a satellite

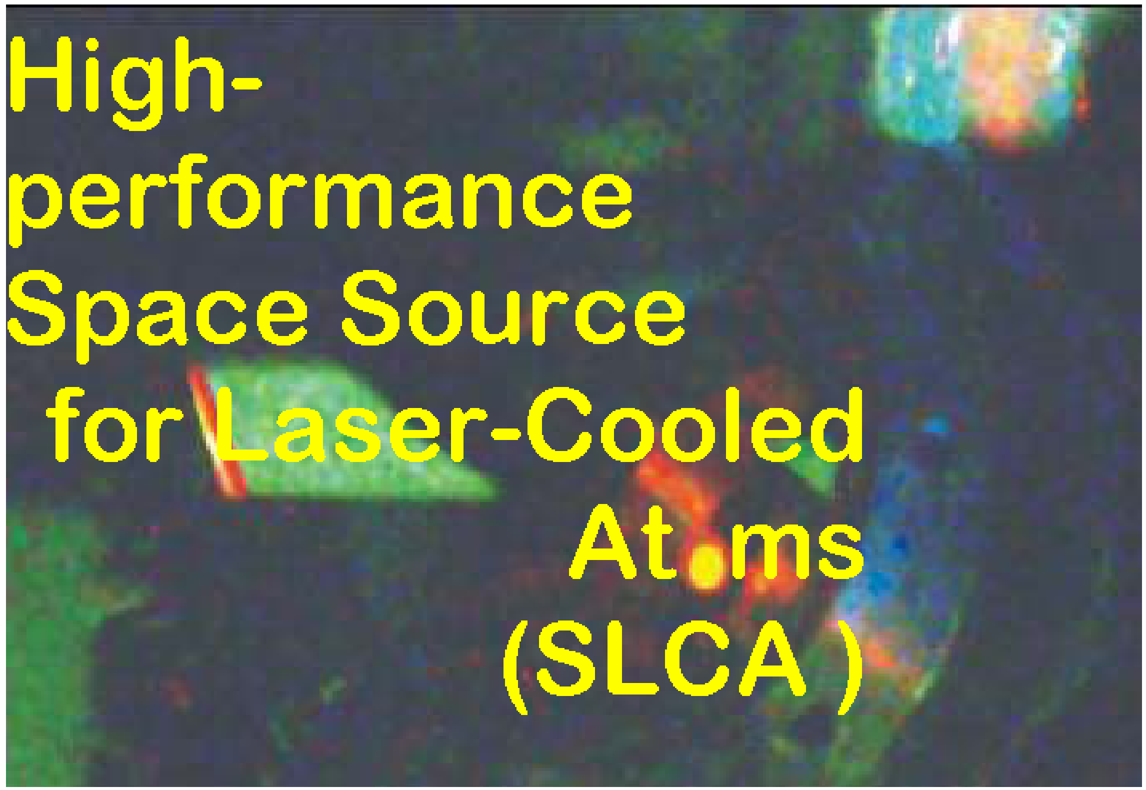


Laser Cooled Atom (LCA) Sensor

for Ultra-High-Accuracy Gravitational Acceleration

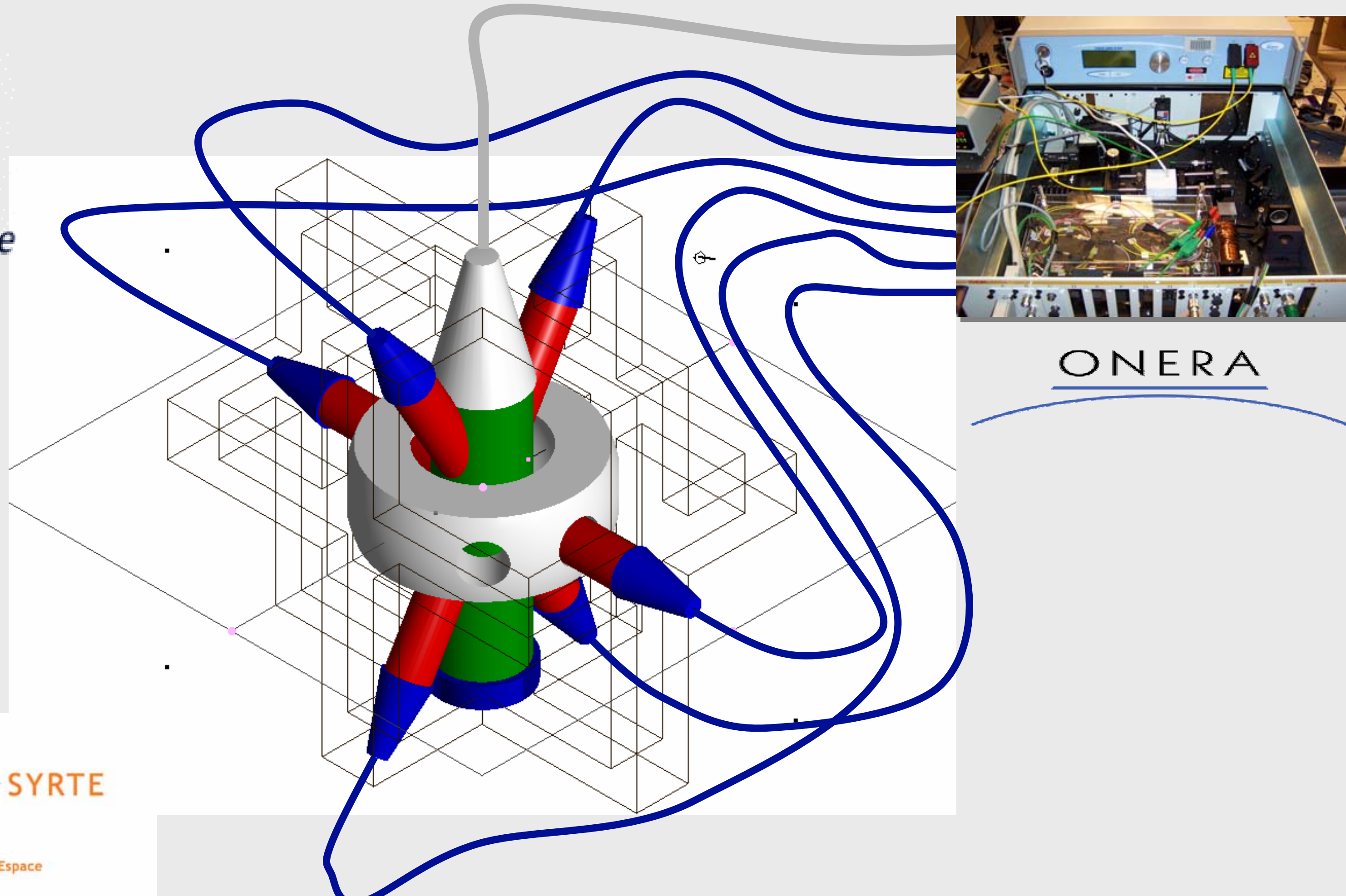
and Rotation Measurements

in response to ESA ITT No. AO-1-4477/03/NL/CH



ICE : interferometry in 0-g

Institut d'Optique



ONERA

l'Observatoire de Paris | SYRTE

Systèmes de Référence Temps-Espace

ω

OMEGA: Orologi in Microgravità E Giroscopi Atomici

Proposal application in response to ASI Call for Proposals ***Nuove idee di missioni spaziali (2000)***

COMPLETE TITLE OF PROJECT

ULTRACOLD ATOMS IN MICROGRAVITY:
HIGH PRECISION ATOMIC CLOCKS AND ATOMIC INTERFEROMETERS

SHORT TITLE

OMEGA: OROLOGI IN MICROGRAVITÀ E GIROSCOPICI ATOMICI

PRINCIPAL INVESTIGATOR

Guglielmo M. Tino, PhD., Professor of Physics of Matter

COMPLETE ADDRESS

European Laboratory for Nonlinear Spectroscopy (LENS)
Largo E. Fermi, 2
I-50125 FIRENZE

Tel.: +39-081-676149
Fax: +39-081-676346
E-mail: tino@na.infn.it

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S. Leschiutta **A. Godone** **F. Cordara** **F. Levi** **L. Lorini** **P. Tavella**	**Istituto Elettrotecnico Nazionale "Galileo Ferraris" (IEN)** Strada delle Cacce, 91 – 10135 TORINO
F. Minardi	**Istituto Nazionale per la Fisica della Materia (INFM), Unità di Firenze** Largo E. Fermi, 2 – 50125 FIRENZE
P. De Natale **G. Giusfredi**	**Istituto Nazionale di Ottica Applicata (INOA)** Largo E. Fermi, 6 – 50125 FIRENZE

INTERNATIONAL COLLABORATIONS

C. Salomon	**Ecole Normale Superieure (ENS), Paris, F**
A. Clairon	**Bureau National de métrologie, LPTF /Observatoire de Paris, Paris, F**
C. Sirmain	**Centre National d'Etudes Spatiales (CNES), Paris, F**

DATE: 29/3/2001

SIGNATURE: *Prof. Guglielmo M. Tino*

Future Inertial Atomic Quantum Sensors

FINAQS

Date of preparation: 13.09.2004

A Specific Targeted Research Project (STREP)

FULL Proposal

for

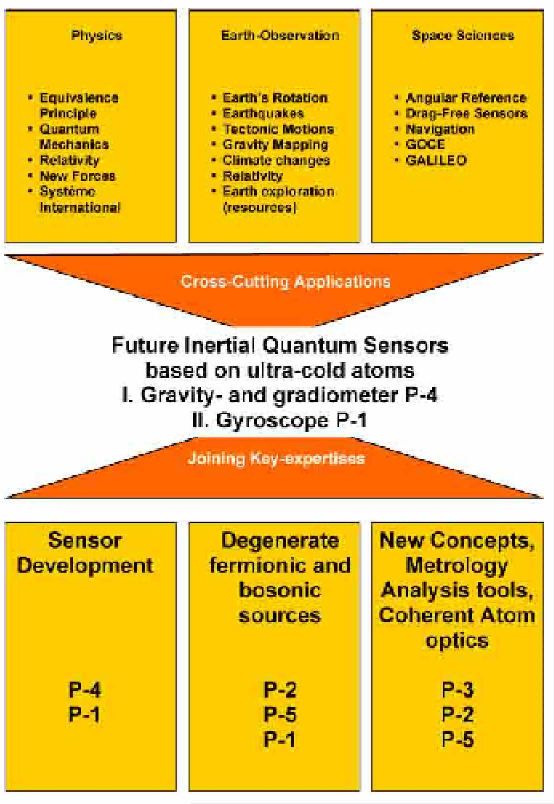
NEST-2003-1 ADVENTURE

Duration: 3 years

Co-ordinator: Prof. Dr. Wolfgang Ertmer
Contact: Email: ertmer@iqo.uni-hannover.de
Phone: +49 511 762-3242
Fax : +49 511 762-2211

Participants

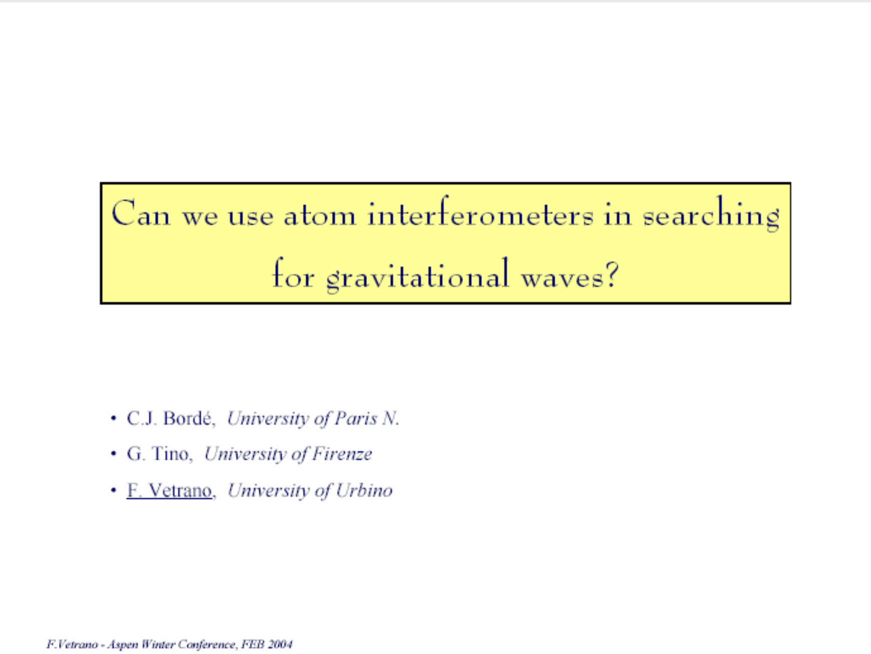
Nr	Organisation name	Abbrev.	Town	
1	Institut für Quantenoptik, Universität Hannover	IQ	HANNOVER	D
2	Laboratoire Charles Fabry de l'Institut d'Optique	IOTA	ORSAY	F
3	Système de Références Temps – Espace, Observatoire de Paris	BNM/SYRTE	PARIS	F
4	AG Optische Metrologie / Institut für Physik Humboldt-Universität zu Berlin	HUB	BERLIN	D
5	Dipartimento di Fisica, Università di Firenze	UNIFI	FIRENZE	I

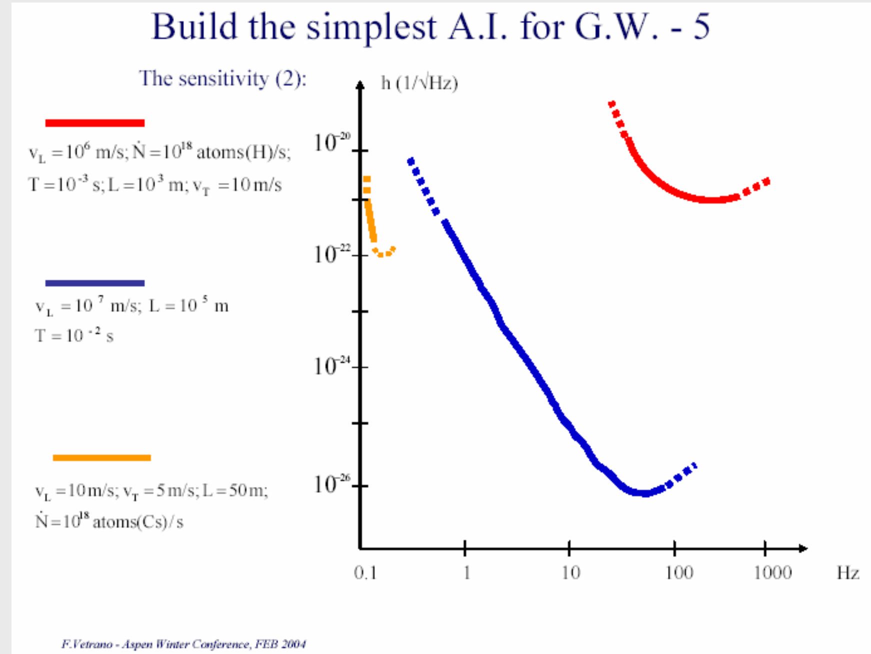


Future prospects: Atom interferometers

- Development of transportable atom interferometers → geophysics → space
  EC-STREP "FINAQS": BEC or Fermionic Source?
- Test of Newton's law at short distances
- Test of equivalence principle
- New definition of kg
- Accurate measurement of h/m and α
- Search for electron-proton charge inequality
- Test of equivalence principle for anti-matter (?)
- New detectors for gravitational waves (?)

Gravitational wave detection by atom interferometry





Presentation at 2004 Aspen Winter College on Gravitational Waves:
See http://www.ligo.caltech.edu/LIGO_web/Aspen2004/pdf/vetrano.pdf

See also:
Chiao RY, Speliotopoulos AD, J. Mod. Opt. 51, 861 (2004)
A. Roura, D.R. Brill, B.L. Hu, C.W. Misner, gr-qc/0409002

Fine