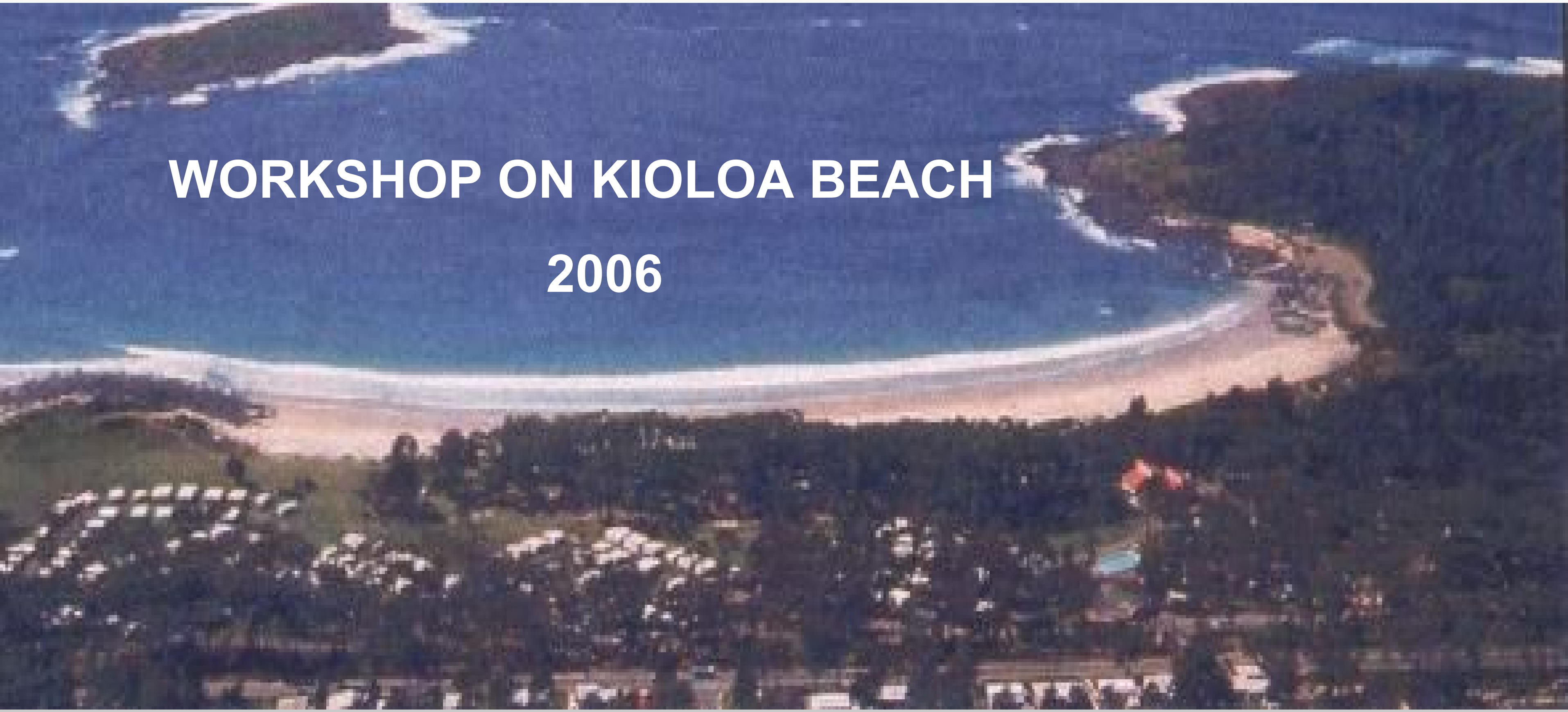
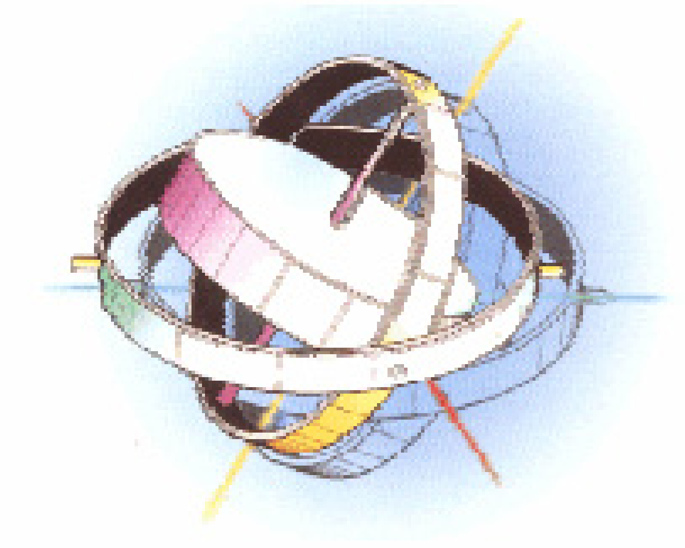
WORKSHOP ON KIOLOA BEACH

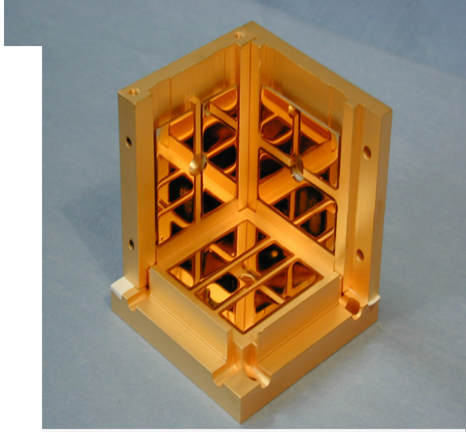
2006





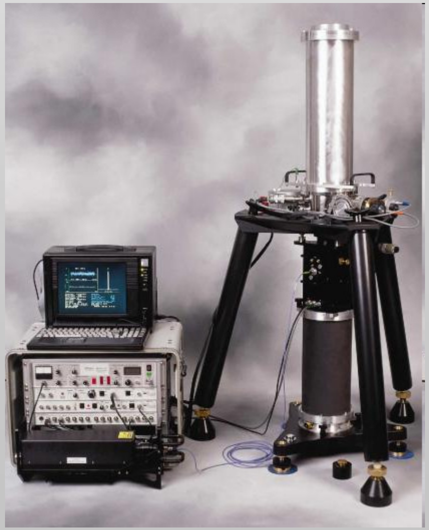
Inertial

Atomic Sensors

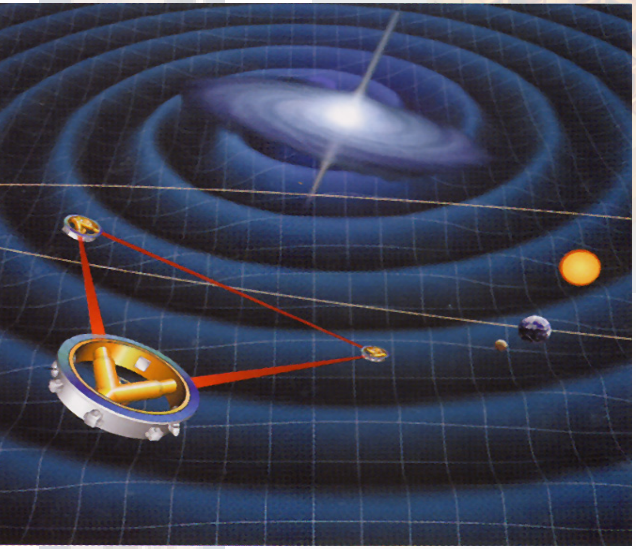


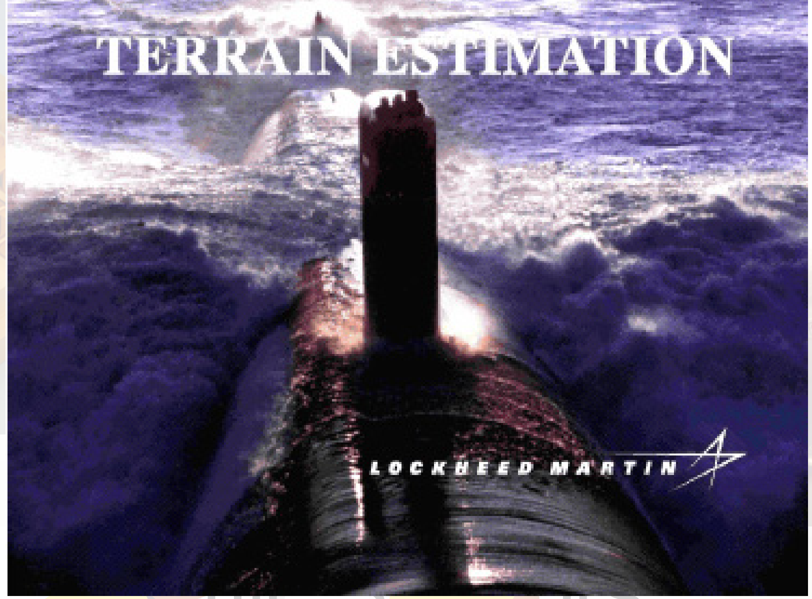
Atomic Sensors

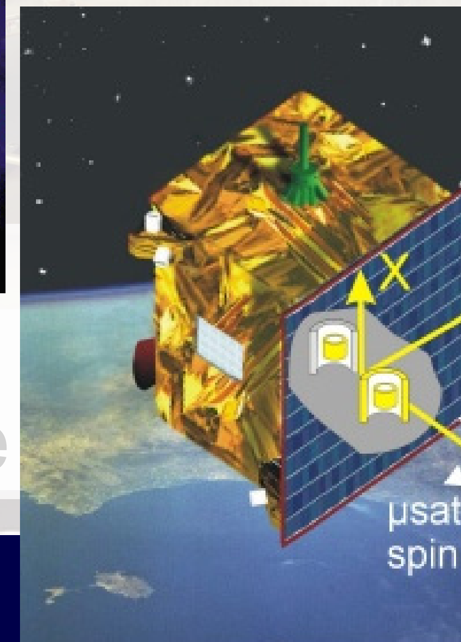
-an alternative technique ?



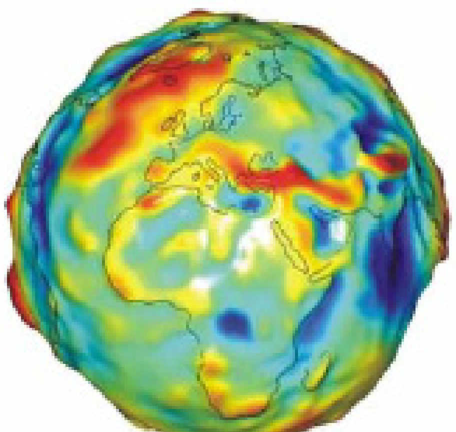
Bell Geospace

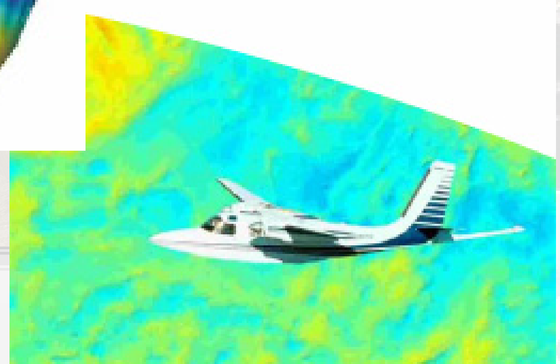


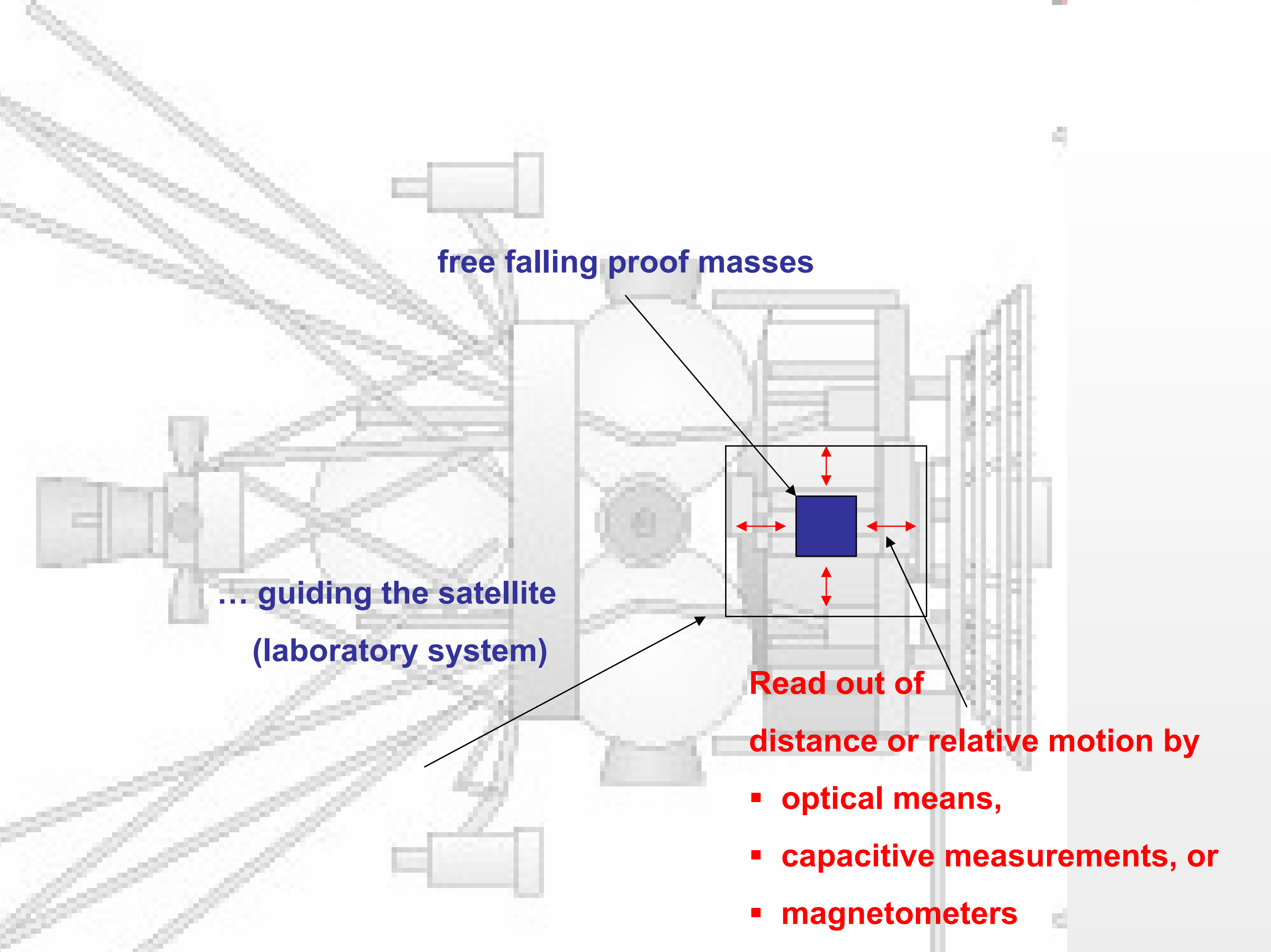


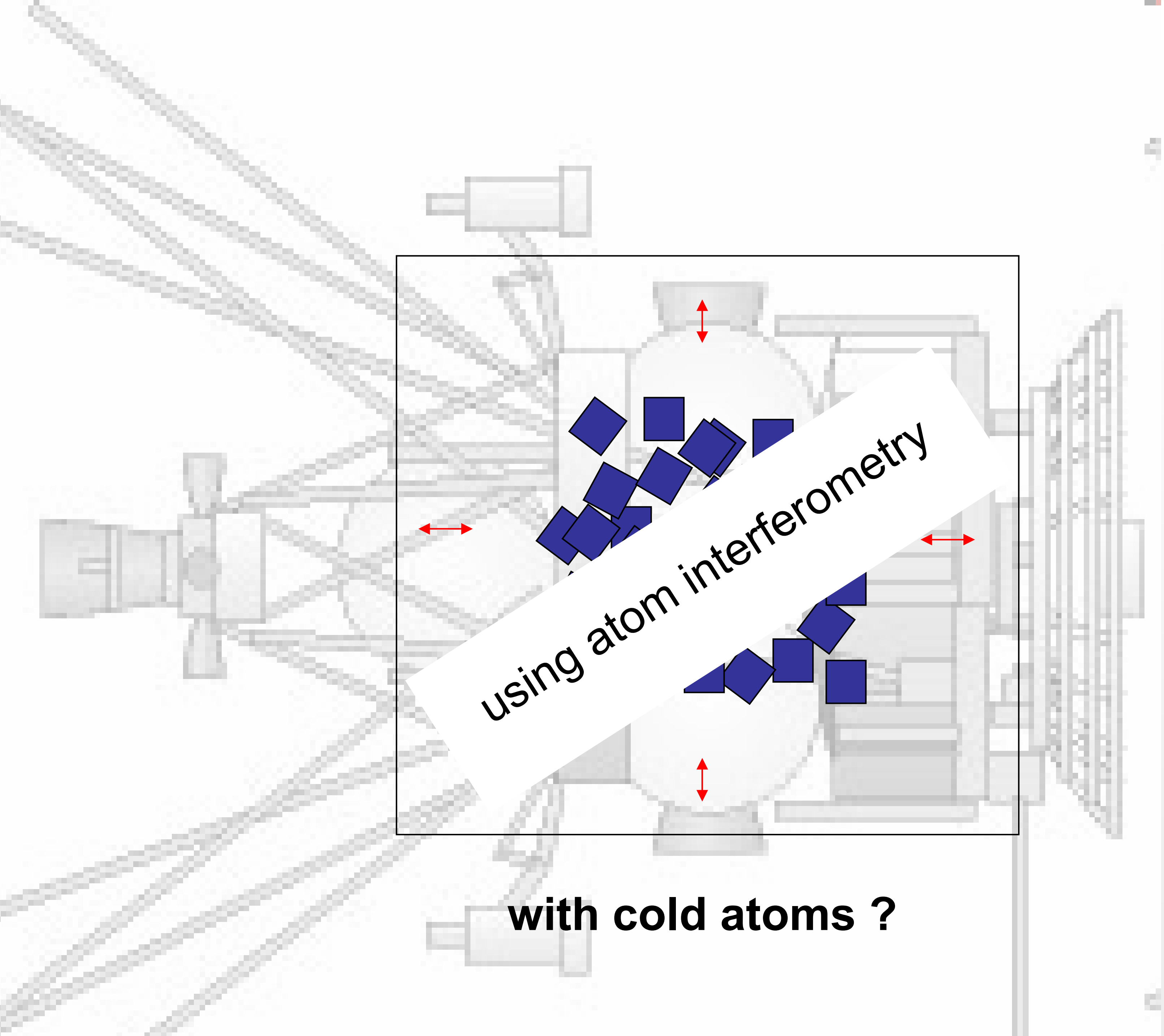


-an alte ative technique





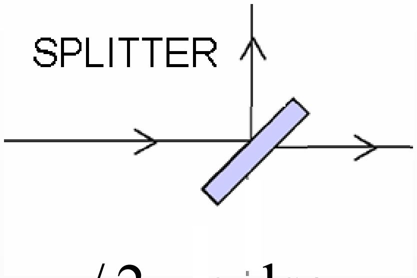

free falling proof masses
… guiding the satellite
(laboratory system)
Read out of
distance or relative motion by
optical means,
capacitive measurements, or
magnetometers



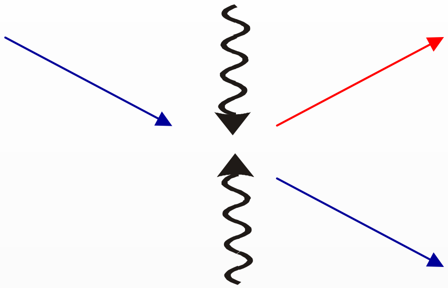
with cold atoms ?

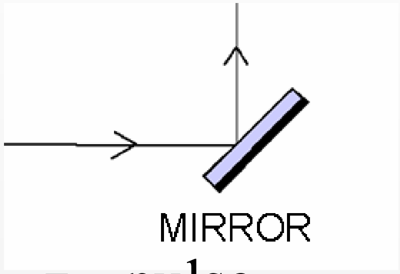
Atom Optics Components

… made out of Light

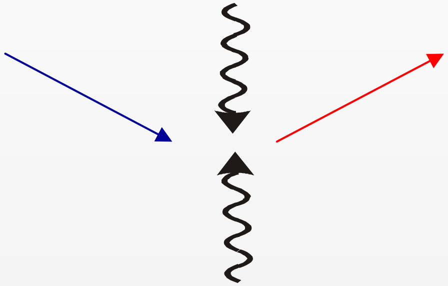


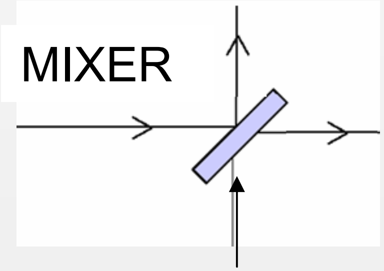
$\pi / 2 - \text{pulse}$



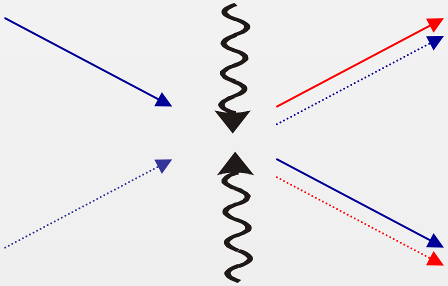


$\pi - \text{pulse}$

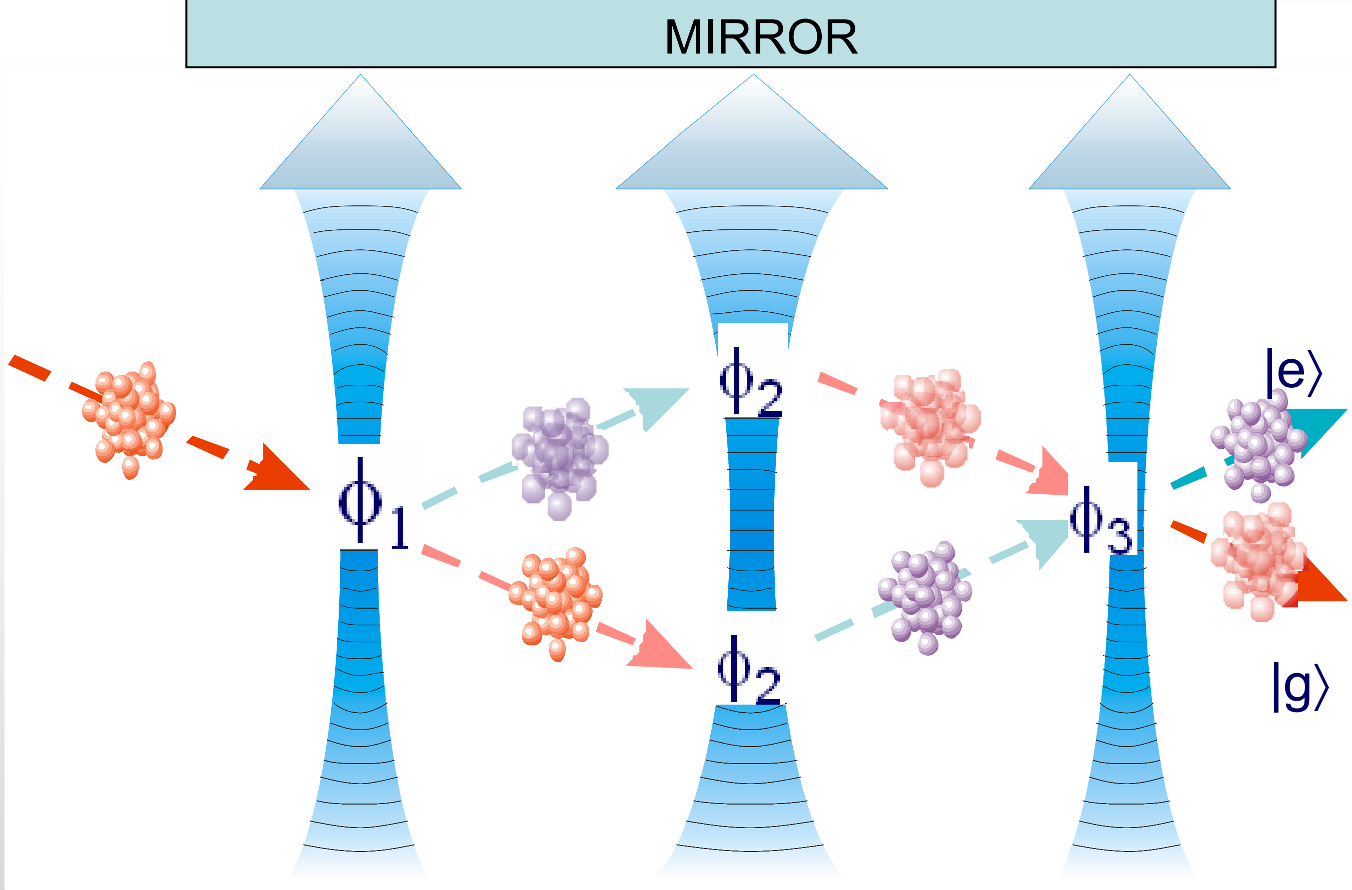




$\pi / 2 - \text{pulse}$



Atom-Light Interferometer

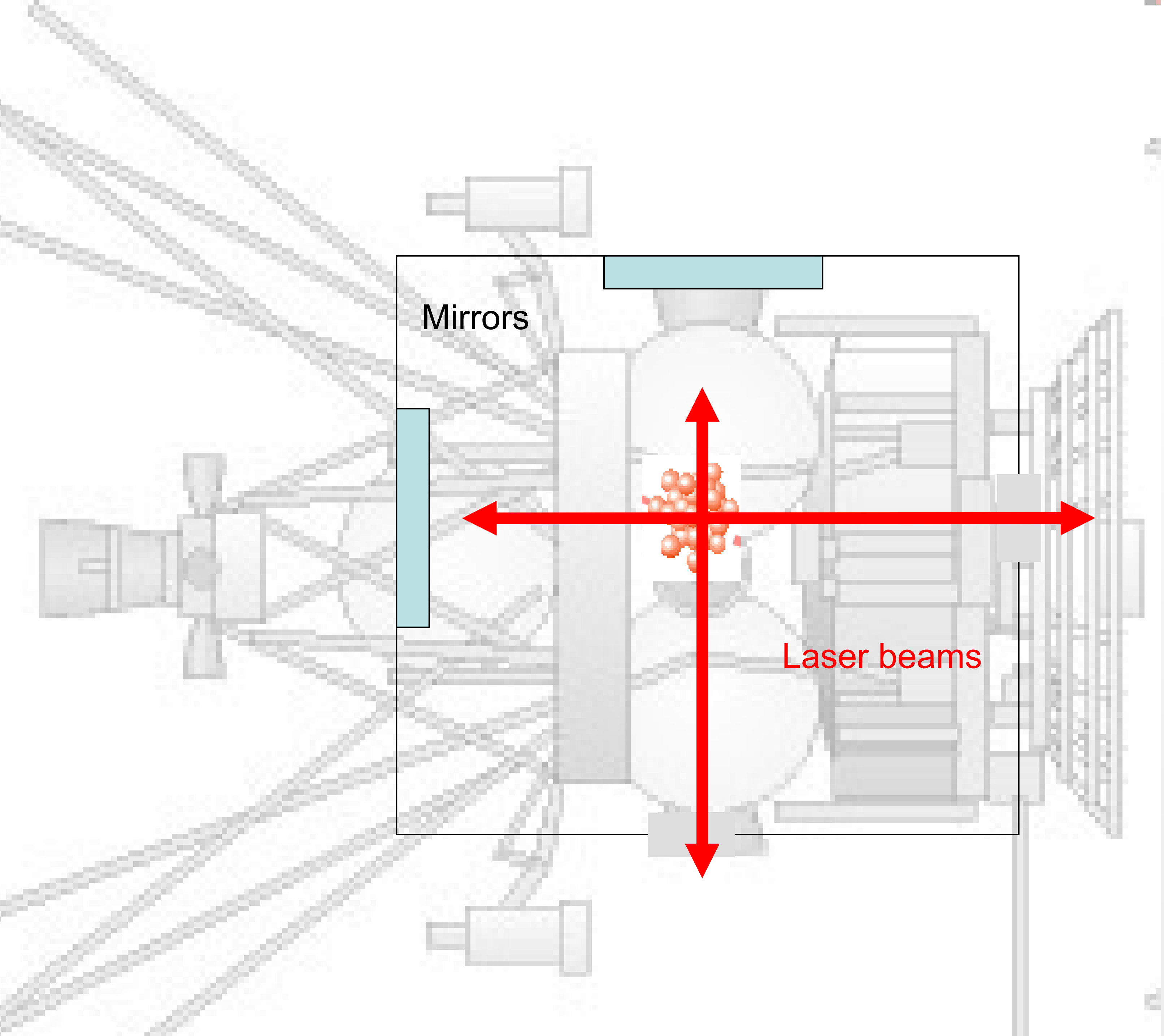


position

Signal at the output ports *time*

$$S \sim \cos[(\phi_3 - \phi_2)-(\phi_2 - \phi_1)]$$

C. Antoine, C. Bordé


Mirrors
Laser beams

Accelerometer

$$\Delta\varphi = [\varphi_3(2T+t_0) - \varphi_2(T+t_0)] - [\varphi_2(T+t_0) - \varphi_1(t_0)]$$

$$\Delta\varphi_{acc} = T^2 \vec{k} \cdot \vec{a}$$

Accelerational Sensitivity with 10^8 ats:

On ground 10^{-10} g/√Hz @ Expansion Time 0.2 s

*R. Colella, A.W. Overhauser, and S.A. Werner, "**Observation of Gravitationally Induced Quantum Interference**", Phys. Rev. Lett. 34, 1472 (1975).*

*A., Peters, C. Keng Yeow, and S. Chu "**Measurement of gravitational acceleration by dropping atoms**" Nature 400, 849 (1999).*

Gyroscope

$$\Delta\varphi = [\varphi_3(2T+t_0) - \varphi_2(T+t_0)] - [\varphi_2(T+t_0) - \varphi_1(t_0)]$$

$$\Delta\varphi_{rot} = \frac{2m_{Atom}}{\hbar}\vec{A}\cdot\vec{\Omega}$$

Rotational Sensitivity with 10^{8} ats:

On ground 10^{-9} rad/√Hz @ Expansion Time 0.025 s

Earth rotation rate:7.2 10^{-5} rad/s

*S.A.Werner, J.-L. Staudemann, and R. Colella," **Effect of Earth's Rotation on the Quantum Mechanical Phase of the Neutron**", Phys. Rev. Lett. 42, 1103 (1979).*

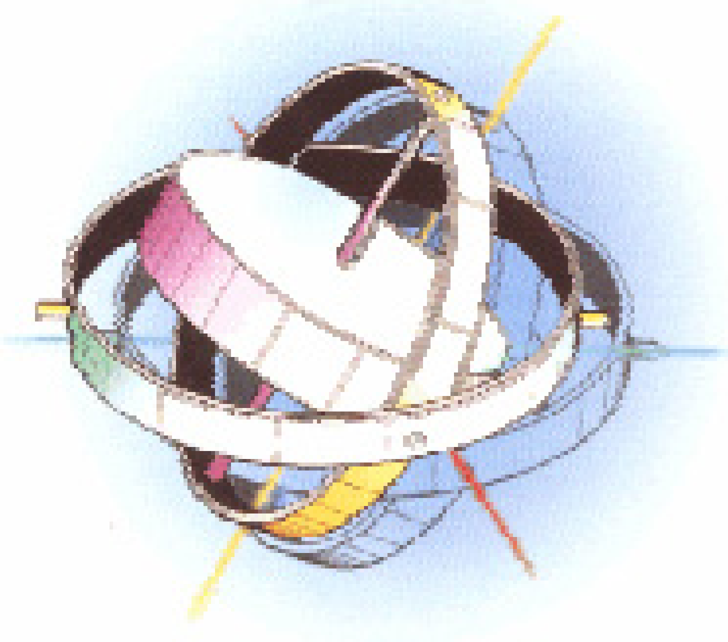
*F. Riehle, Th. Kister,A. Witte, J. Helmcke, and Ch. Bordé, "**Optical Ramsey spectroscopy in a rotating frame: Sagnac effect in a matter-wave interferometer**", Phys. Rev. Lett. 67, 177, (1991).*

*T. L. Gustavson, P. Bouyer and M. A. Kasevich, **A dual atomic beam matterwave gyroscope," in Methods for Ultrasensitive Detection**, edited by B. L. Fearey (1998), volume 3270 of Proceedings of SPIE, pp. 62{9.*

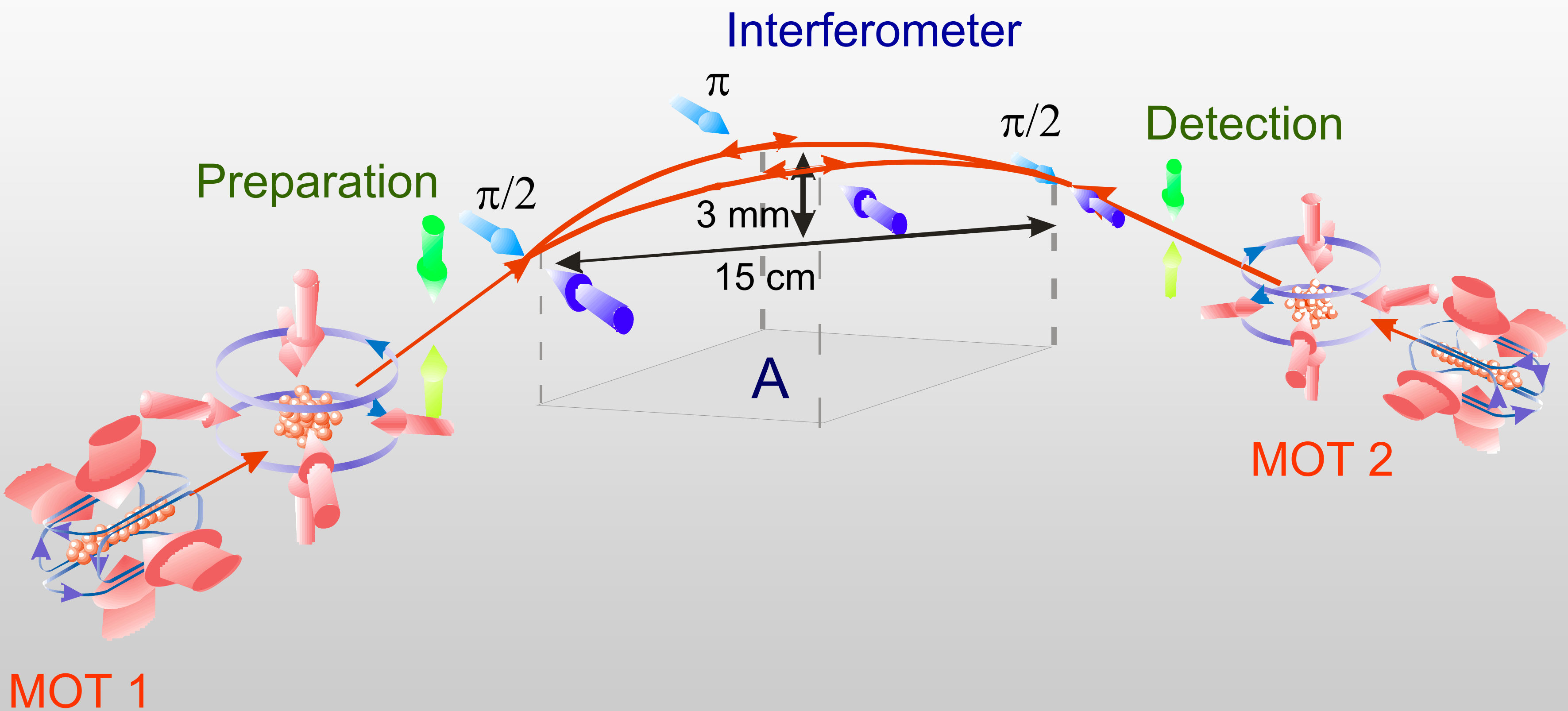
Concepts…

for

(ultra-)cold atomic inertial sensors

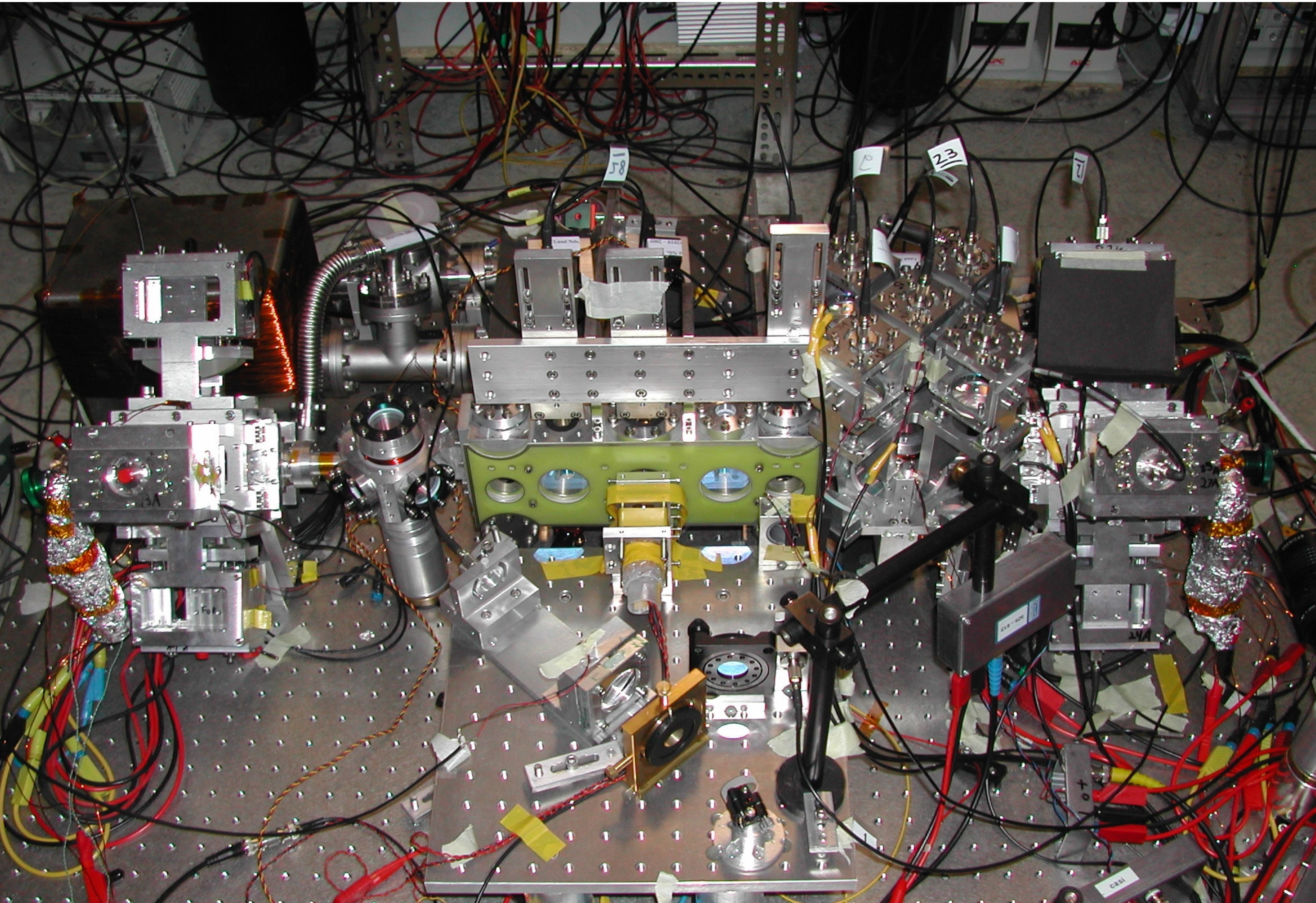


Cold Atom Sagnac Interferometer

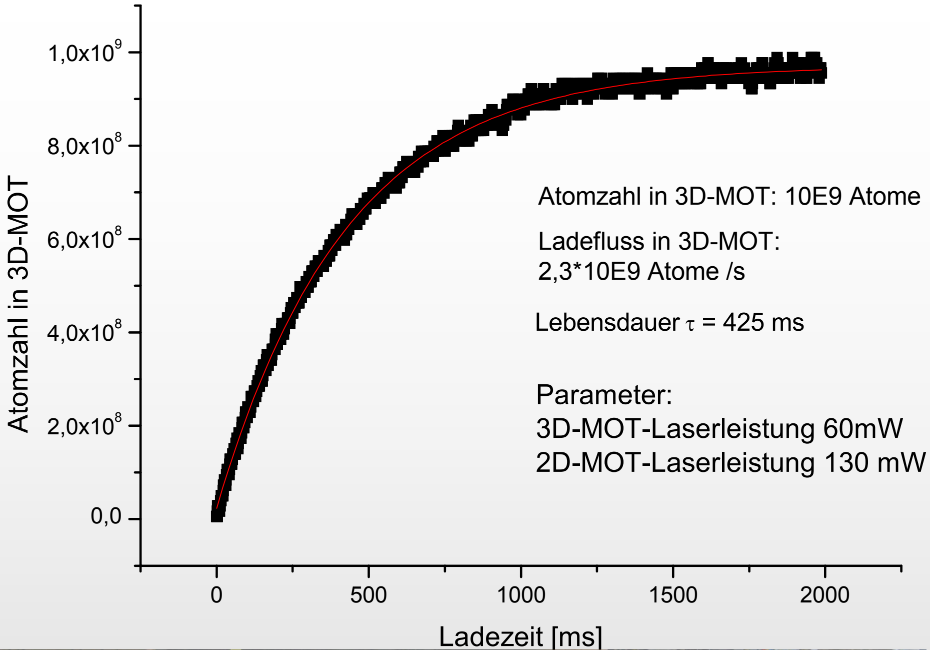


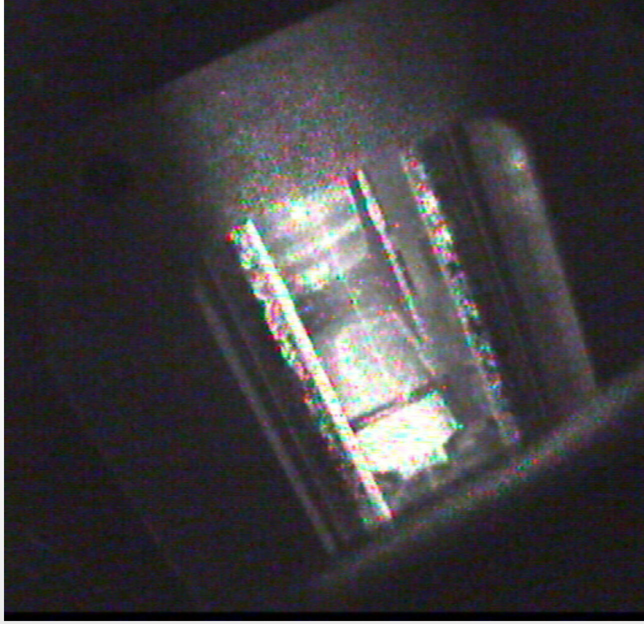
C. Jentsch, T. Müller, E. Rasel, and W. Ertmer, Gen. Rel. Grav, 36, 2197 (2004)
& Adv. At. Mol. Physics
PhD C. Jentsch, Diploma thesis T. Müller, S. Chelkowski

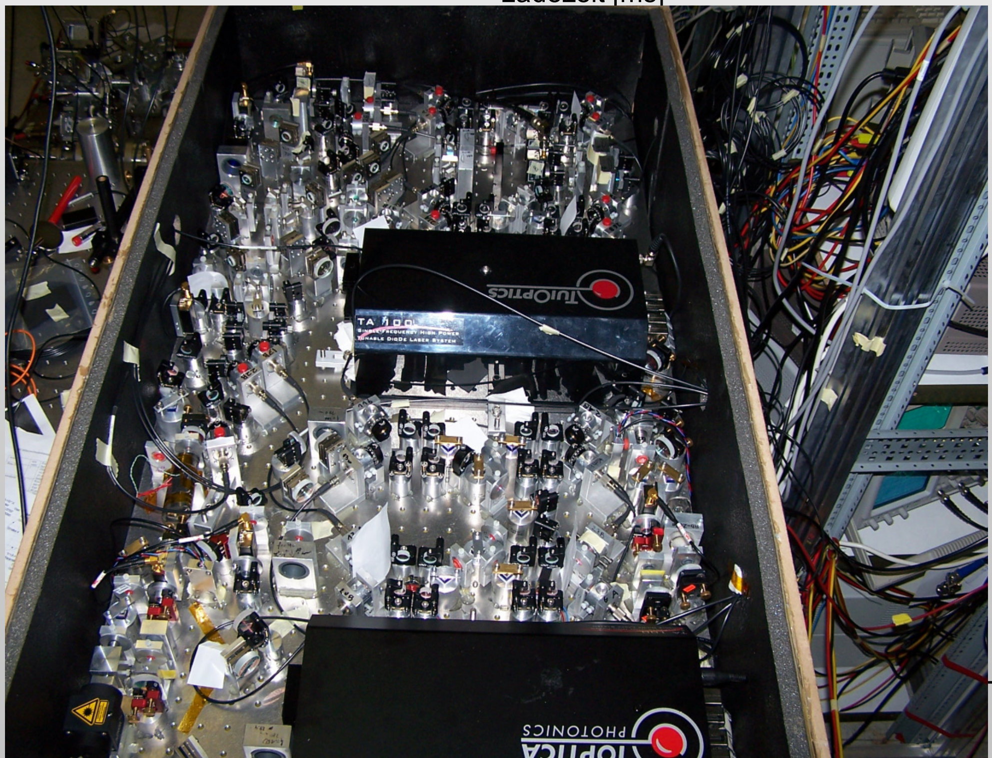
Technical Implementation



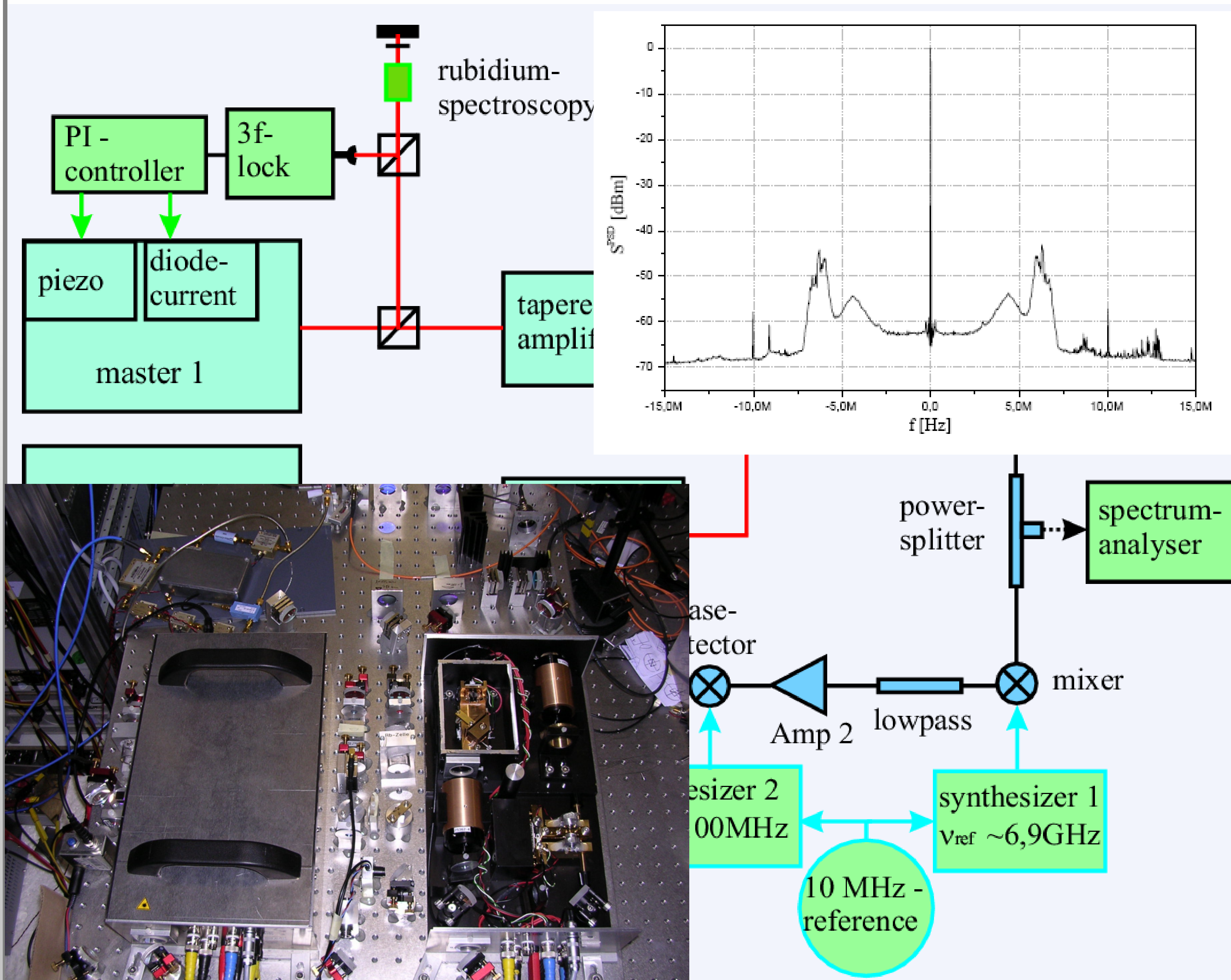
Atomic Source







Raman-Laser



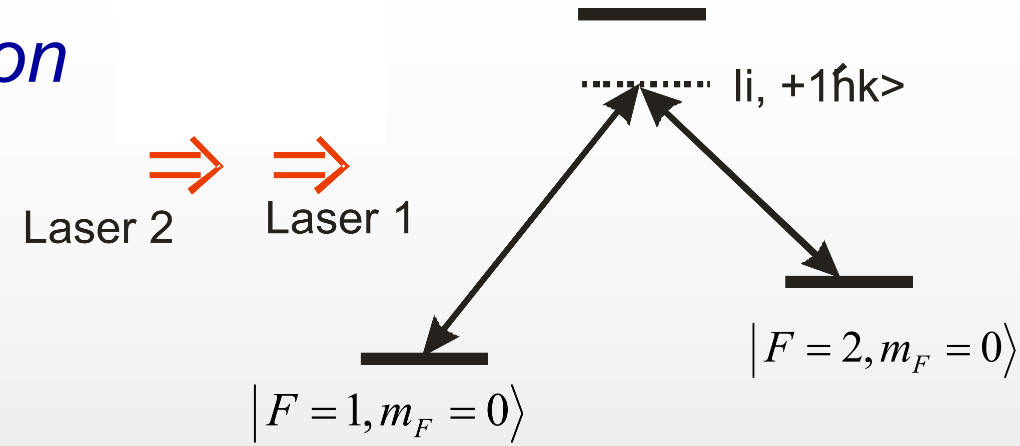
rubidium-
spectroscopy
PI -
controller
3f-
lock
piezo
diode-
current
master 1
power-
splitter
spectrum-
analyser
mixer
lowpass
Amp 2
synthesizer 1
νref ~6,9GHz
10 MHz -
reference
0
-10
-20
-30
-40
-50
-60
-70
S [dBm]
-15,0M
-10,0M
-5,0M
0,0
5,0M
10,0M
15,0M
f [Hz]

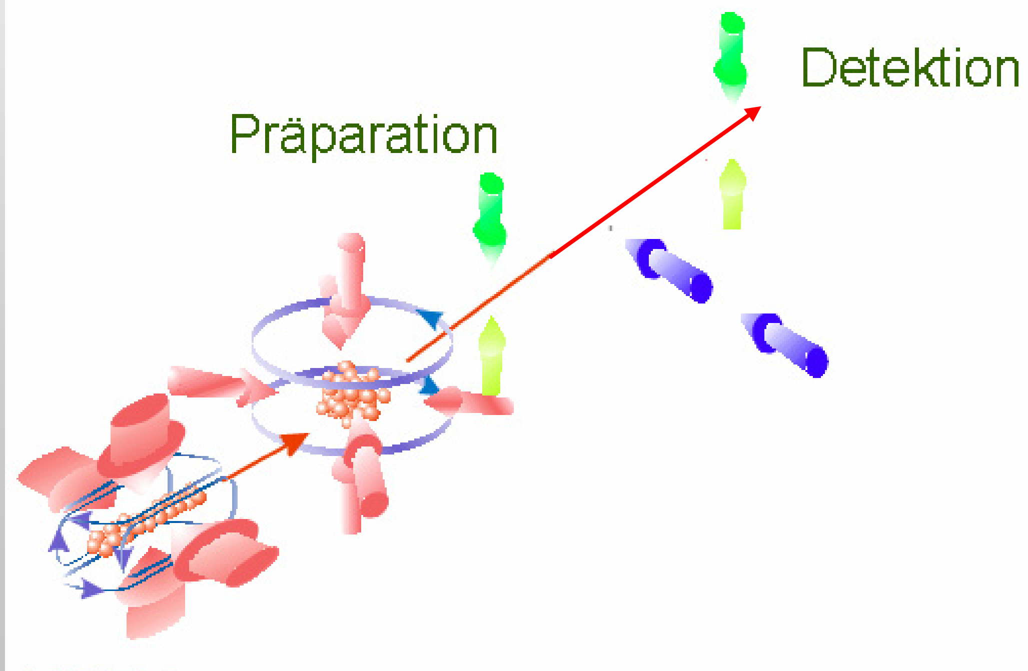
A Comparison

	Stanford U.	IQ
Element	Caesium	Rubidium
Atoms/s	10^9	$>10^8$
Length [cm]	200	15
Area [mm^2]	26	25
Sensitivity [$rad \cdot s^{-1} \sqrt{Hz^{-1}}$]	**$6 \cdot 10^{-10}$**	**$2 \cdot 10^{-9}$ @10^8**

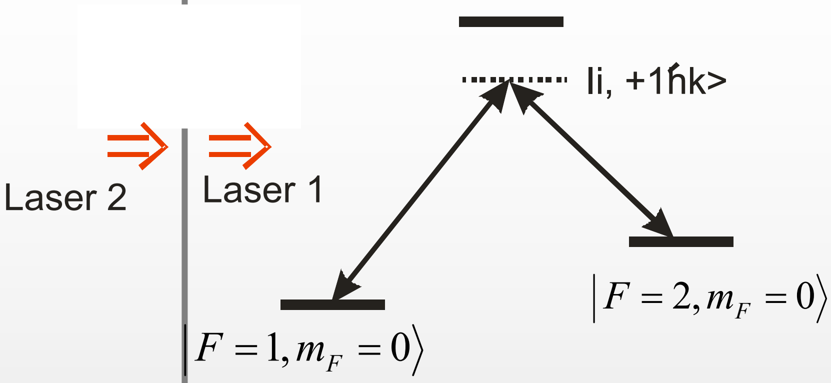
First Interference Experiments

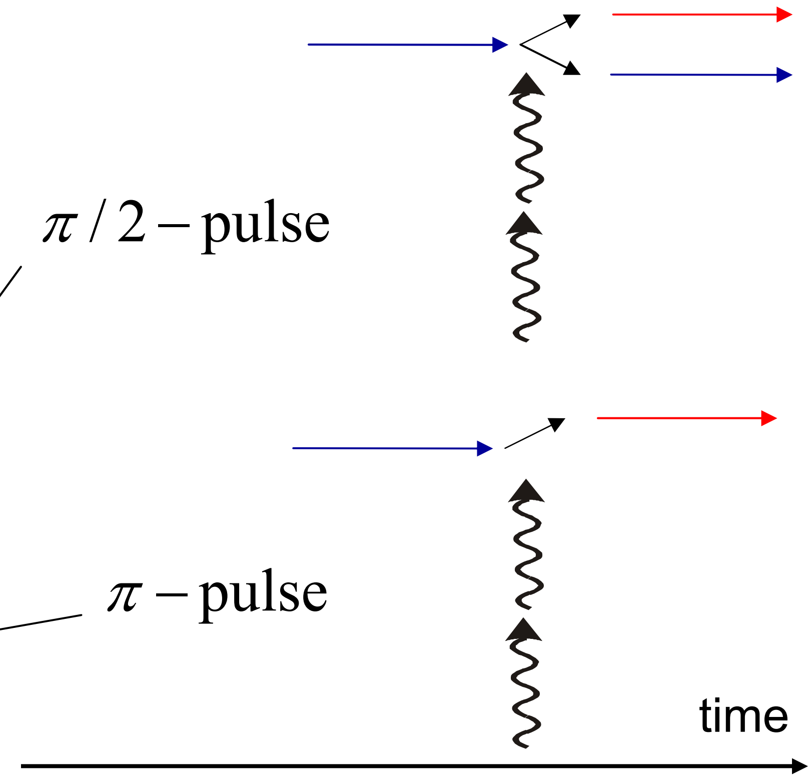
with a velocity-insensitve Raman-transition

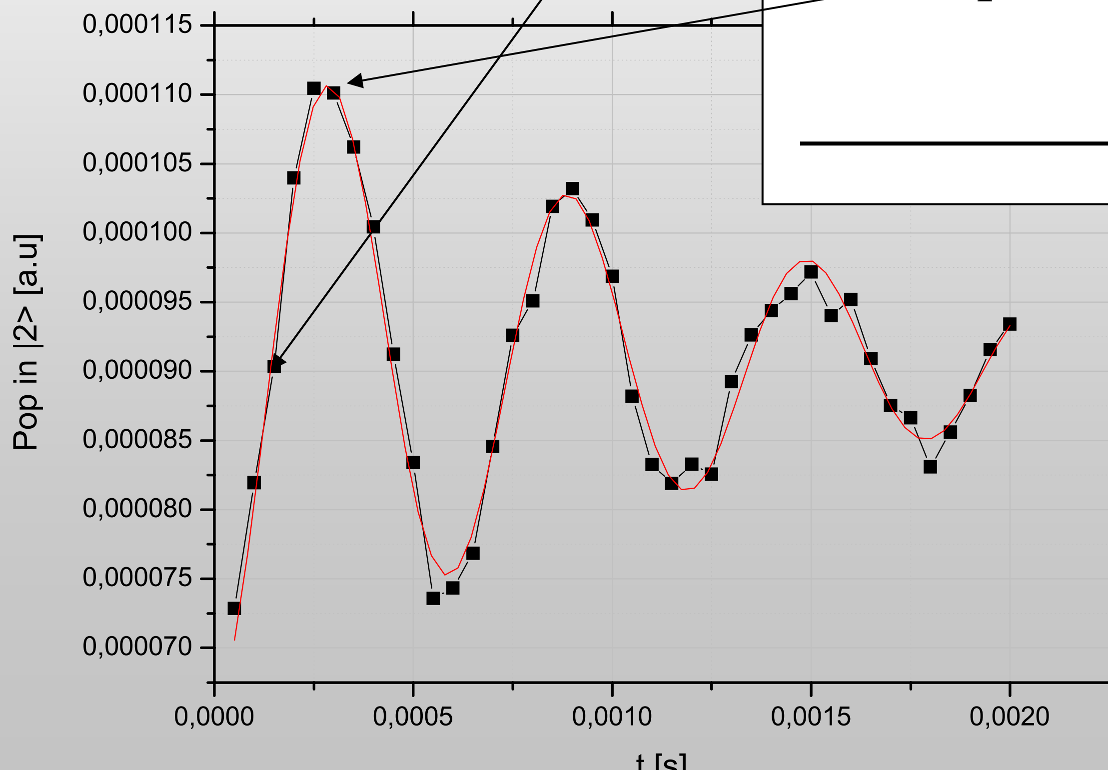




Rabi-Flop of a Raman-transition

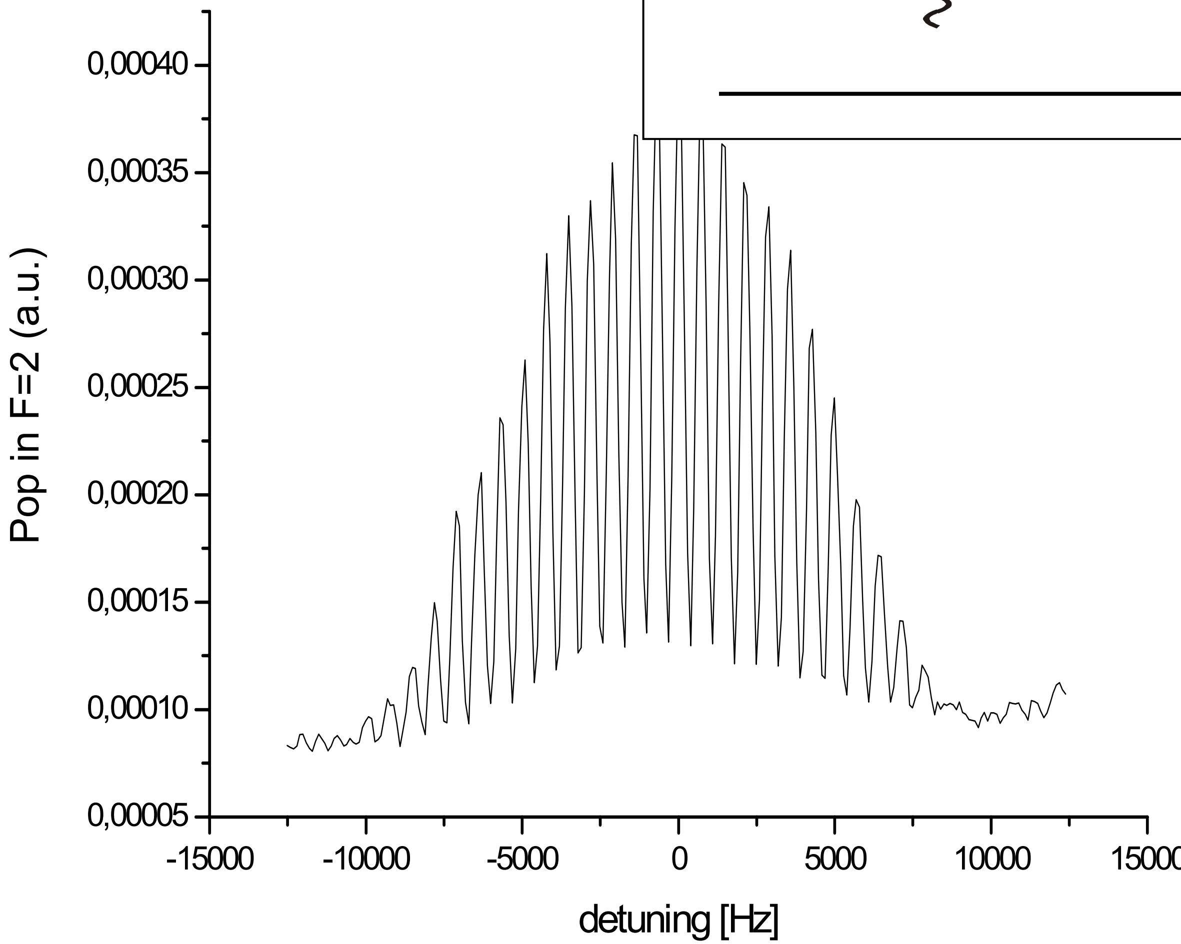


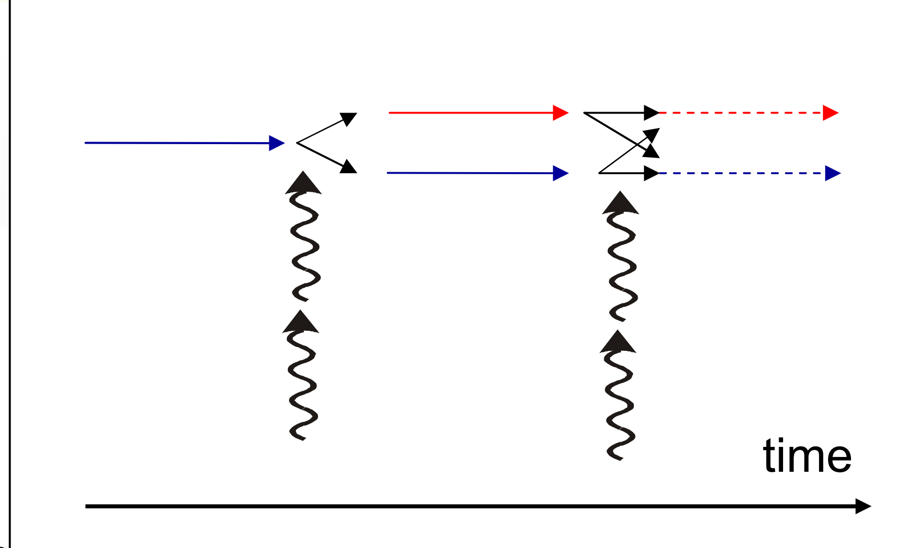




Fringes

of a Ramsey-type experiment





Aims

- Comparisson of distinct topolo
- Compact & Transp
- Non Atoms
- mic gyroscopes
- pe: Laser-Atom Gyroscope

Future Inertial Atomic Quantum Sensors
(FINAQS)

A proposal for a Specific Targeted Research Project (STREP) within
NEST-2003-1 ADVENTURE
"Harnessing atoms at their quantum limit"

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

Institut d'Optique

Polo Scientifico Universita' degli Studi di Firenze

Humboldt-Universität zu Berlin

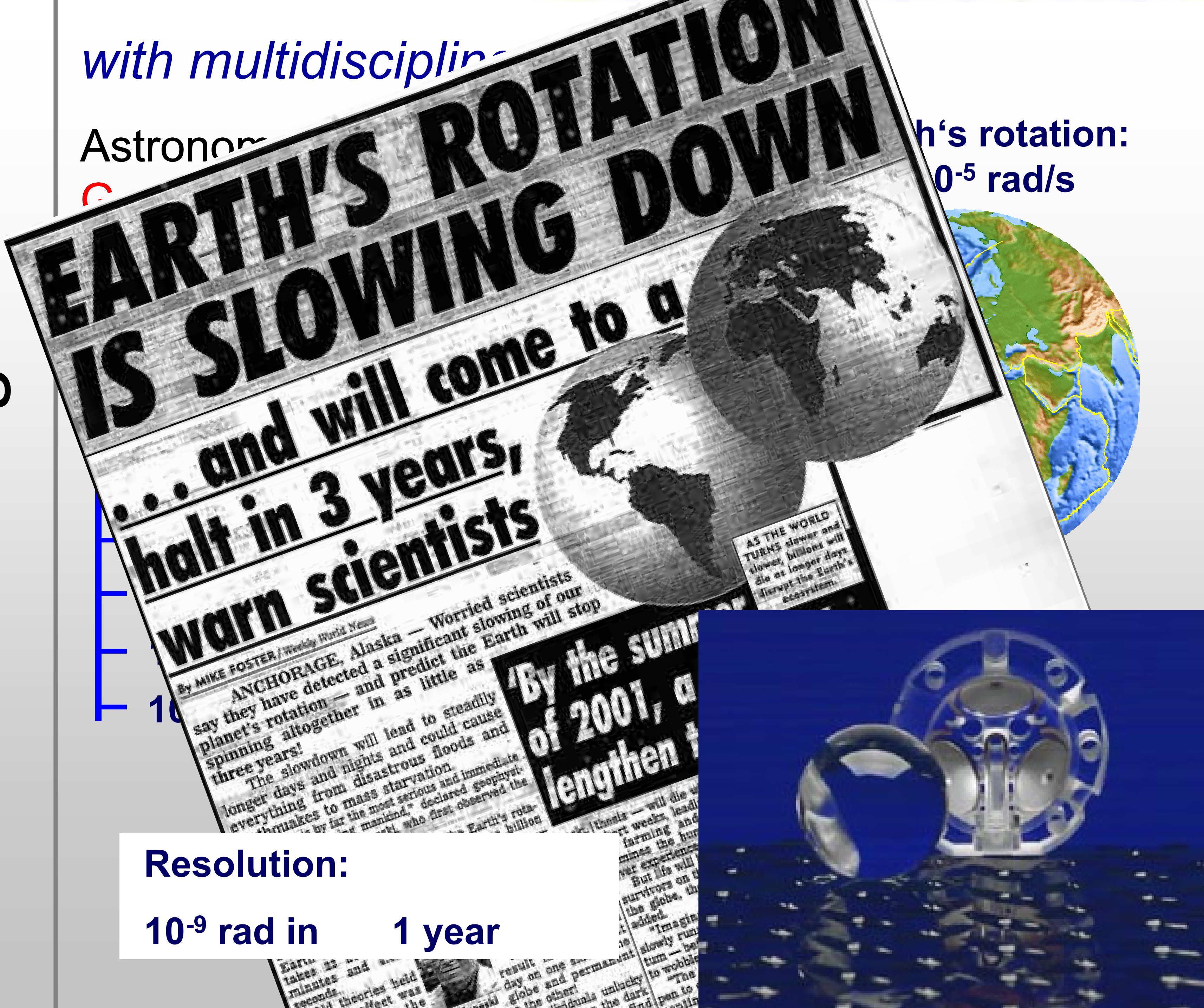
Rotation sensing

with multidisciplin

Astronom

h's rotation:

0^{-5} rad/s



EARTH'S ROTATION IS SLOWING DOWN

. . . and will come to a halt in 3 years, warn scientists

AS THE WORLD TURNS slower and slower, billions will die as longer days disrupt the Earth's ecosystem.

By MIKE FOSTER/Weekly World News

ANCHORAGE, Alaska — Worried scientists say they have detected a significant slowing of our planet's rotation — and predict the Earth will stop spinning altogether in as little as three years!

The slowdown will lead to steadily longer days and nights and could cause everything from disastrous floods and earthquakes to mass starvation

'By the summer of 2001, a lengthen t

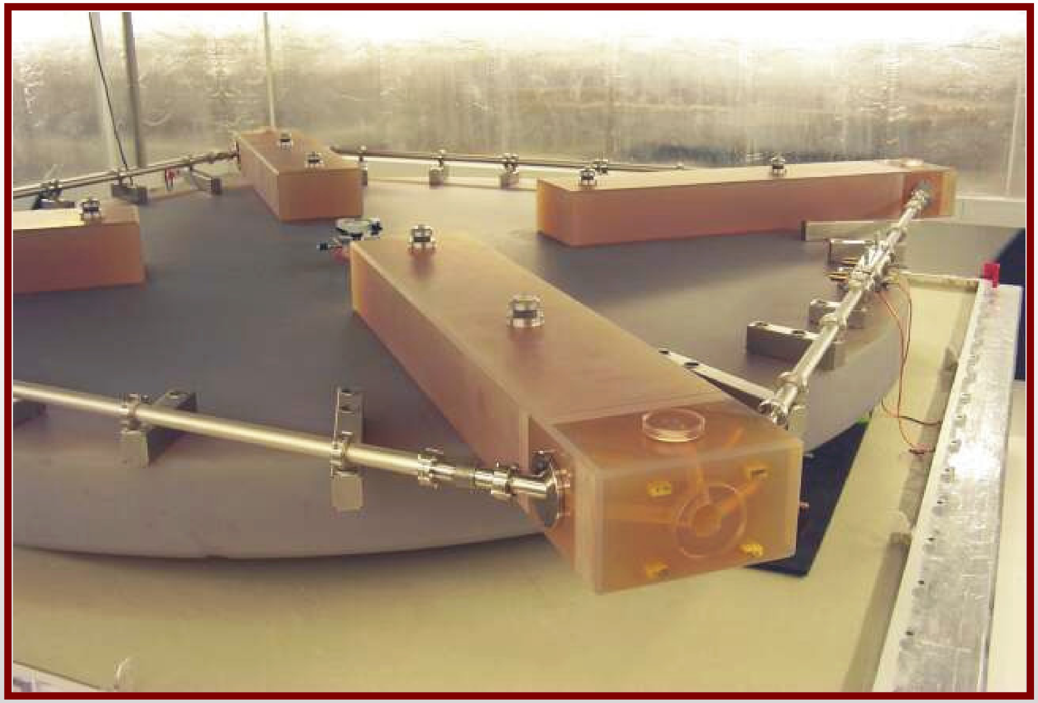
10

Resolution:

10^{-9} rad in 1 year

Lasergyroscope G

…at Fundamentalstation Wettzell



- comparison and calibration of Laser Ring Gyroscopes
- geophysical interest
- relativity (Lense-Thirring effect)

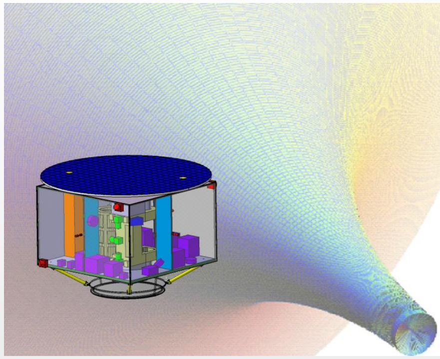
Ring Laser	Area, m^2	f_{Sagnac}, Hz	Gyroscope Sensitivity $\delta\Omega/\Omega$	DPM_{max} $\delta\Omega/\Omega$
C-II	1	79.4	1×10^{-7}	1×10^{-7}
G	16	348.6	1×10^{-8}	9.8×10^{-8}
UG1	367	1512.8	3×10^{-8}	1×10^{-7}

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 109, B06405, doi:10.1029/2003JB002803, 2004

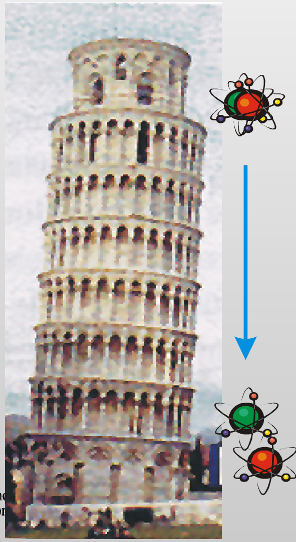
Atomic Quantum Sensors

Fields of Interest:

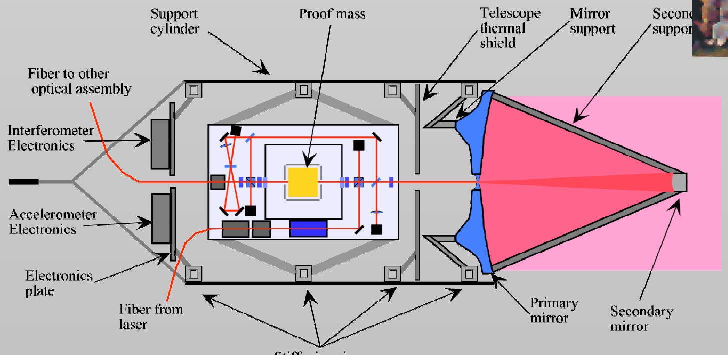
- Inertial standards/references

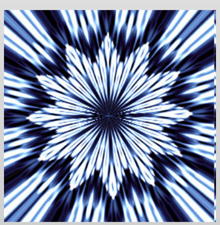


- Earth Observation
- Measurement of relativistic effects & gravity



- Testing the Weak Equivalence Principle
- Drag-free sensors
  perhaps in gravitational wave detectors ?

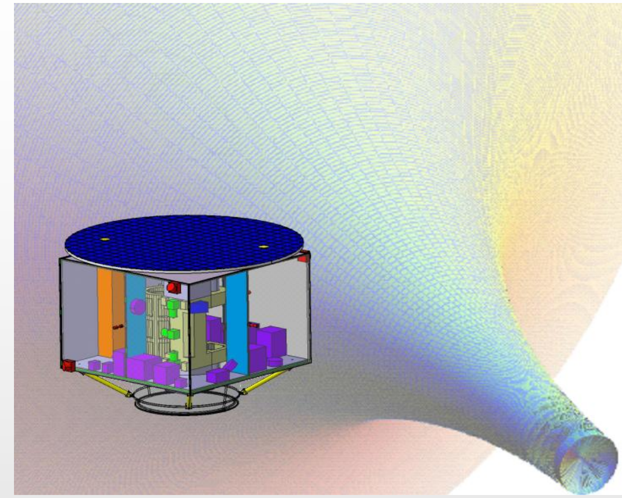




Towards the limits

Towards the limits

…with cold atoms



Accelerational Sensitivity with 10^{8} ats:

Space 10^{-12} g/√Hz @ Expansion Time 3 s

Rotational Sensitivity with 10^{8} ats:

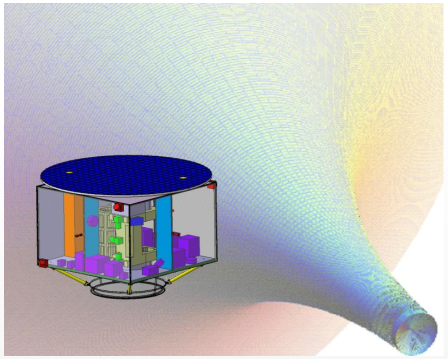
Space: $8\cdot10^{-12}$ rad/√Hz @ Expansion Time 3 s

Room for Improvements?

$\Omega_{SNL} = 4 \cdot 10^{-12}$ rad/s/√Hz

$A_{SNL} = 10^{-12}$ g/√Hz

per shot, 0.3 Hz



Time: ***3s*** $\rightarrow$ *?* *+ Resolution:* $\sim T_{Drift}^{\ 2}$

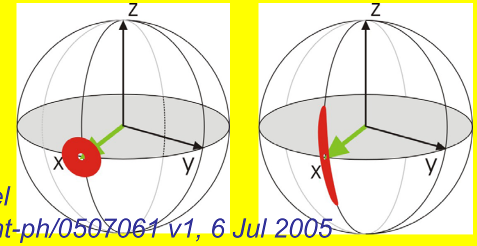
- $T_{at} <$ **1μK**

- Dynamic Range

Atoms: $\mathbf{10^8} \rightarrow$ *?* *+ Resolution:* $\mathbf{\sim 1/\sqrt{N}}$ $\rightarrow$ $\mathbf{1/N}$

- T_{at} *?*

- Laser- Phase Noise ?



K. Eckert, P. Hyllus, D. Bruß, U.V. Poulsen, M. Lewenstein, C. Jentsch, T. Müller, E.M. Rasel & W. Ertmer, Differential atom interferometry beyond the standard quantum limit, arXiv: quant-ph/0507061 v1, 6 Jul 2005

Beamsplitter: ***Multi-****Photon?*

- New Beam Splitters?

*„****All-Atomic****" Gravitational Wave Detector?*

The Teams

Mg- optical clock

A. Douillet

J. Keupp

T. Mehlstäubler

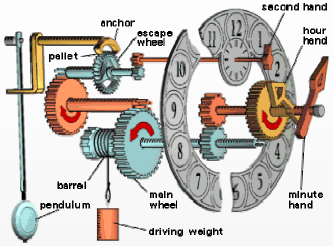
N. Rehbein

C. Moldenhauer

J. Friebe

M. Riedmann

SYRTE & PTB



QUANTUS

T.v. Zoest

MPQ/ENS

Univ. Berlin

Univ. Hamburg

Univ. Ulm

ZARM

CASI

C. Jentsch

T. Müller

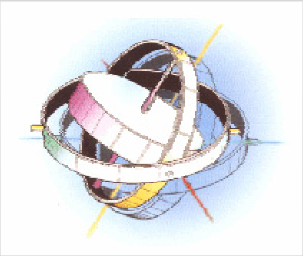
T. Wendrich

M. Golovski

SYRTE & PTB

K. Eckert, P. Hyllus,

D. Bruss, M.Lewenstein



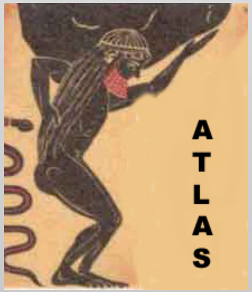
ATLAS

M. Zaiser

SYRTE & IOTA

Univ. Berlin

LENS



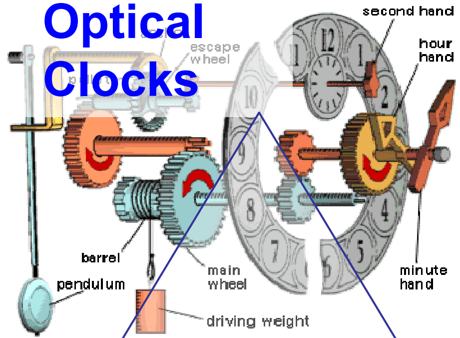
Open Positions !

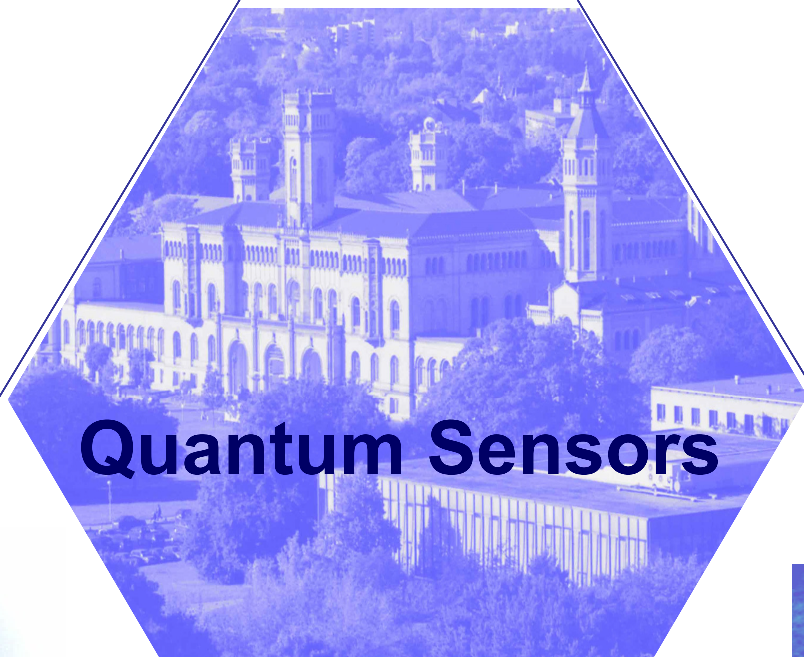
Visit us in Hannover Castle

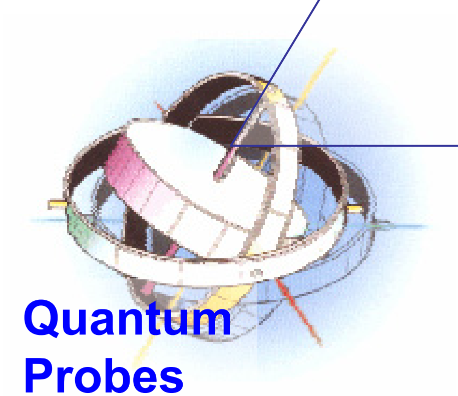
Open Post-Doc Positions

- **ATLAS/CASI**
- **LOW-NOISE & ULTRA STABLE SOURCES FOR SPACE**

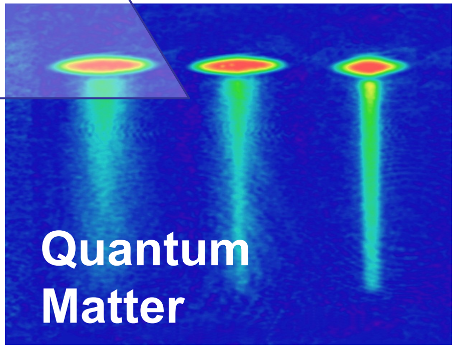
IQ



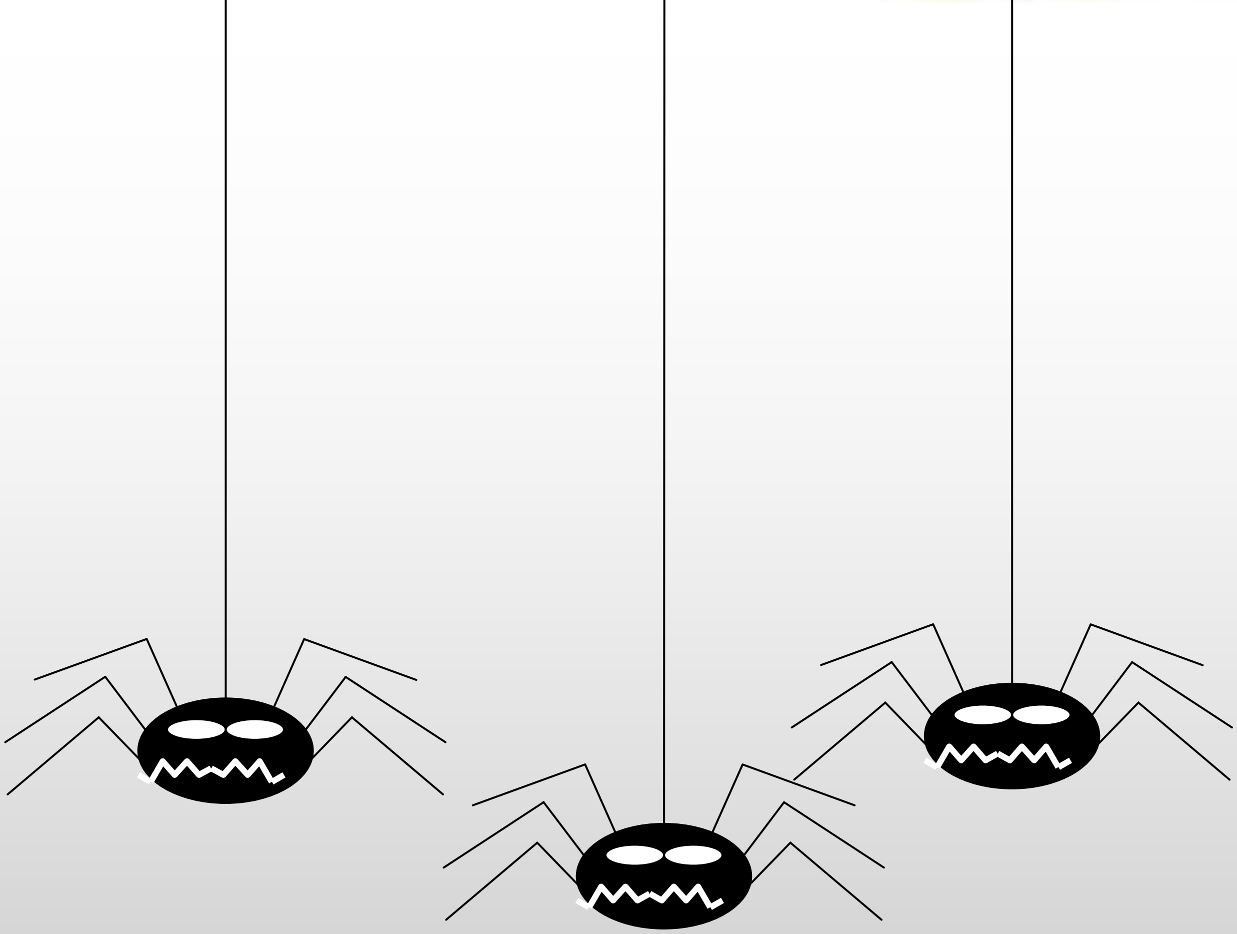




AG Ertmer –IQ/Hannover



SFB 407 esa DLR FINAQS



THE END