AIRBORNE ATOM SENSORS: FROM GROUND TO SPACE

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ATOM-BASE INERTIAL SENSORS

Atom-based Inertial Sensors are based on the manipulation and the control at the "quantum level" of atoms using light or magnetic fields.

Atomic interferometry has demonstrated over the past 10 years that it can be more sensitive than other techniques (optical interferometry, vibrating system ...).

Starts to be many laboratory experiments in the world (in US, France, Germany, Italy): 3 leading laboratories in France and US (Stanford, Palaiseau, Paris) have demonstrated the feasibility of a transportable inertial base using atom interferometry.
We use an (optical) ruler to precisely measure the (atomic) test mass position.

Similar to falling corner cube gravimeter (FG5)

FG 5 : Laser phase is read by optical interferometry

Atom sensor : Laser phase is read by atom interferometry.

An Atom Interferometer “reads” the position of an atom proof mass using “atom/laser telemetry”
Interference fringes: $N_a \sim \cos(2\pi a T^2 / \lambda + \Phi)$

Extract acceleration from interference signal

Interference fringes: \( N_{at} \sim \cos\left(2\pi aT^2/\lambda + \Phi\right) \)

Extract acceleration from interference signal

\[
\Delta a_{\text{min}} = \frac{a}{\Delta\phi_{\text{acc}}} = \frac{1}{\sqrt{N}} \equiv \frac{1}{kT^2 \sqrt{N}}
\]

**ATOM-BASE GRAVIMETER**

- **2D-MOT**
- **87Rb**
- **3D-MOT**
  - $10^7$ atoms in 50 ms
  - $T_{\text{atoms}} = 2 \mu K$

EXPERIMENT MODEL

- **Bias fluctuations**: $\pm 10^{-6}$ g
- **Very robust experiment**

**2007, January 13 - 04:23 UTC**
- **Kuril Islands**
- **Magnitude 8.1**

**Signal in Paris**

**Period ~ 17 s**
HOW TO COPE WITH VIBRATIONS

Passive/Active

Sensitivity improved from 80 to 30 ng/√Hz

Sensitivity improved from 80 to 20 ng/√Hz
ULTIMATE SENSITIVITY: LONG BASELINE AND SPACE

- Gravitational waves
- Low temperature / EP test
- Tech.: Satellite for DARWIN / LISA
- Gravitational Sensor / EP test
- Earth gradiometry mission
- Sat to Sat Tracking for geodesy
- Mini satellite mission
- Micro gravity and vibration survey

Femto-g
Nano-g
Micro-g
Milli-g
ULTIMATE SENSITIVITY : LONG BASELINE AND SPACE
FROM GROUND TO AIRBORNE IN 0-G FLIGHT
DEVELOPMENT OF AIRBORNE COMPONENTS

Light Source

Fiber Optics

Atomic Physics Chamber: robust and flexible

Control Real-Time

Computing Man-machine ITF

Measurement: camera accelerometer...
First tests in March 2007: 500 parabolas since then.
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ATOM INTERFEROMETRY IN MICROGRAVITY

Env. 10 mg max = 1 s interrogation

- Performances: $10^{-10}$ m.s$^{-2}$ Hz$^{-1/2}$
- 100 measures $\Rightarrow 10^{-11}$ m.s$^{-2}$
- Need special isolation strategy
One frequency range needs to be cancelled (directly averaged in interference signal)
- Need to stabilize the retroreflecting mirror.
- Use of piezo-accelerometer readout and optical delay line (developed for LISA)
Vibrations in the plane

Atom interferometer fringes

Accelerometer Wilcoxon 728 A

1 ms interrogation: 1 mg/√Hz

With better reference accelerometer: 0.1 μg/√Hz
Towards compact airborne sensor

- Integrated telecoms technology (all integrated optics).
- Compact and simple sensor head (10 x 10 x 50 mm³).
- Scalable sensitivity/accuracy: 10 ng demonstrated.
TRANSPORTABLE SENSORS FOR GRAVITY MONITORING

- Sub micro-Gal precision
- Very low drift – less than 1 μGal/month
- Constant calibration factor
- More affordable price
- Consumes no liquid helium
- Lower power consumption
- Small size and weight
- Easily transportable
- Increased dynamic range
- Remote control
- Simplified initialization

Figure 1: Sections 31 and 39 corresponding to Pescin Spiaggi and University of Queensland.
De gauche à droite : G. Varoquaux (IO), N. Zahzam (Onera), L. Mondin (CNES), A. Bresson (Onera), P. Bouyer (IO) et A. Landragin (SYRTE).

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