Measurements using Atom Free Fall

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Young's double slit with atoms

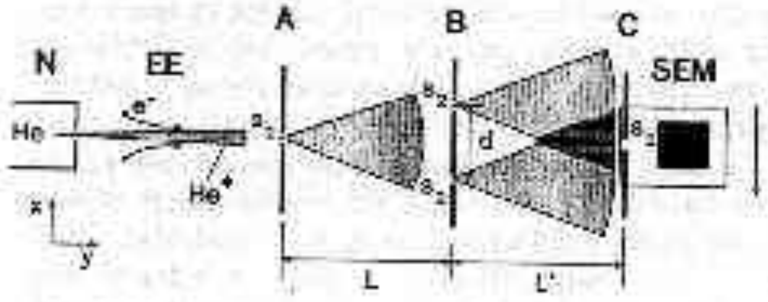


FIG. 2. Schematic representation of the experimental setup.

Young's 2 slit with Helium atoms

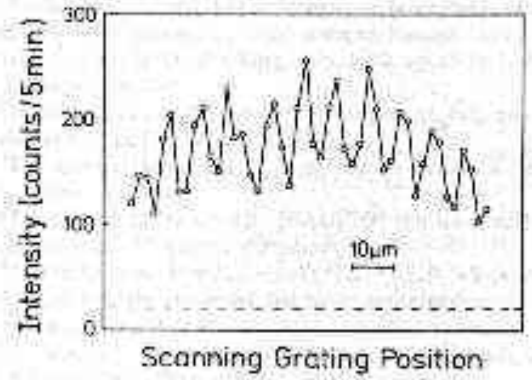
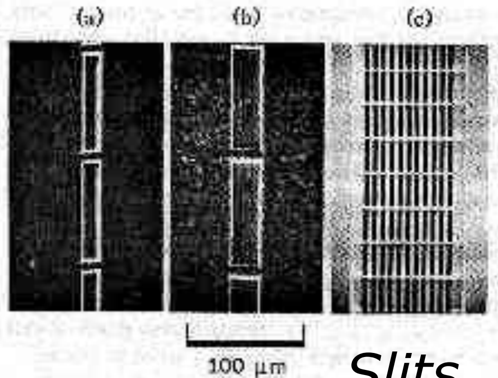


FIG. 5. Atomic density profile, monitored with the 8-µm grating in the detector plane, as a function of the lateral grating displacement. The dashed line is the detector background. The line connecting the experimental points is a guide to the eye.

Interference fringes 2691

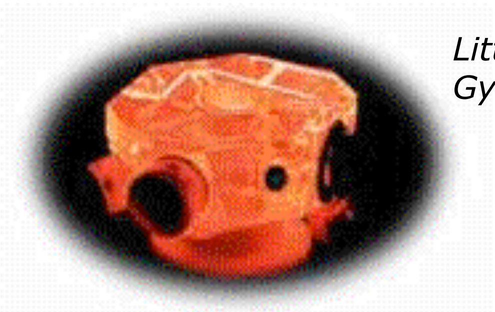


Slits

One of the first experiments to demonstrate de Broglie wave interference with atoms, 1991 (Mlynek, PRL, 1991)

Interferometric sensors

Optical Interferometry



Litton Ring Laser Gyroscope

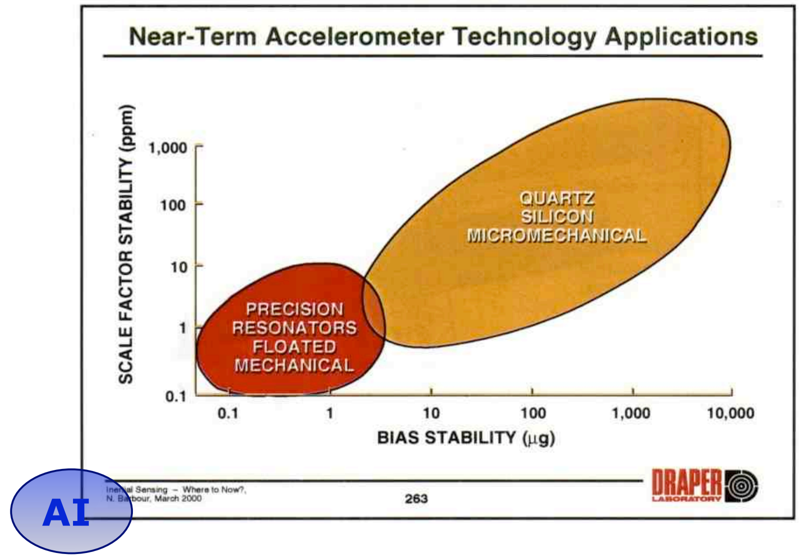
Fibersense Fiber-optic Gyroscope

Atom Interferometry

- Future atom optics-based sensors may outperform existing inertial sensors by a factor of 10^6.
- Current (laboratory) atom optics-based sensors outperform existing sensors.

Sensor characteristics

Light-puse AI accelerometer characteristics



Light-puse AI gyroscope characteristics

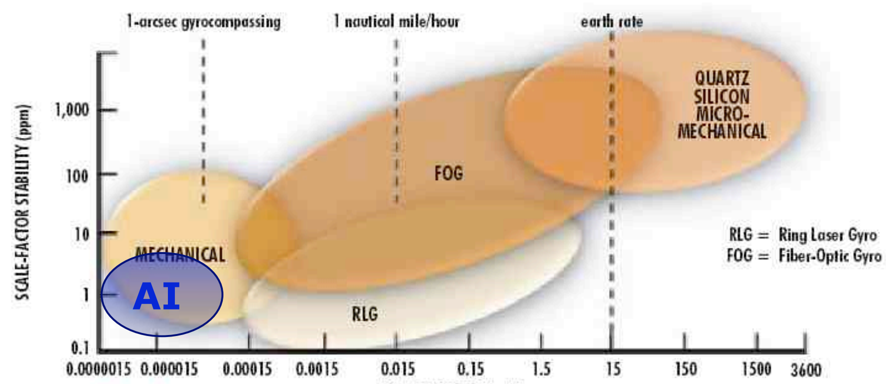


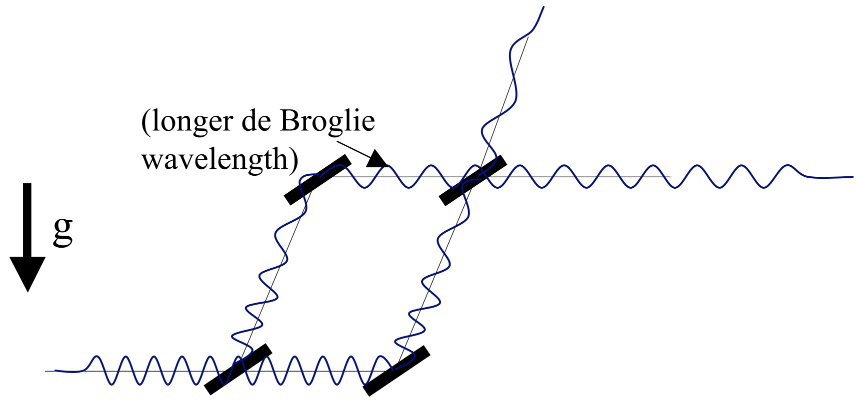
Figure 8

Source: Proc. IEEE/Workshop on Autonomous Underwater Vehicles

Simple models for inertial force sensitivity

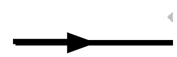
Gravity/Accelerations

As atom climbs gravitational potential, velocity decreases and wavelength increases



Rotations

Sagnac effect for de Broglie waves



Current ground based experiments with atomic Cs:

Wavepacket spatial separation ~ 1 cm

Phase shift resolution ~ 10^{-5} rad

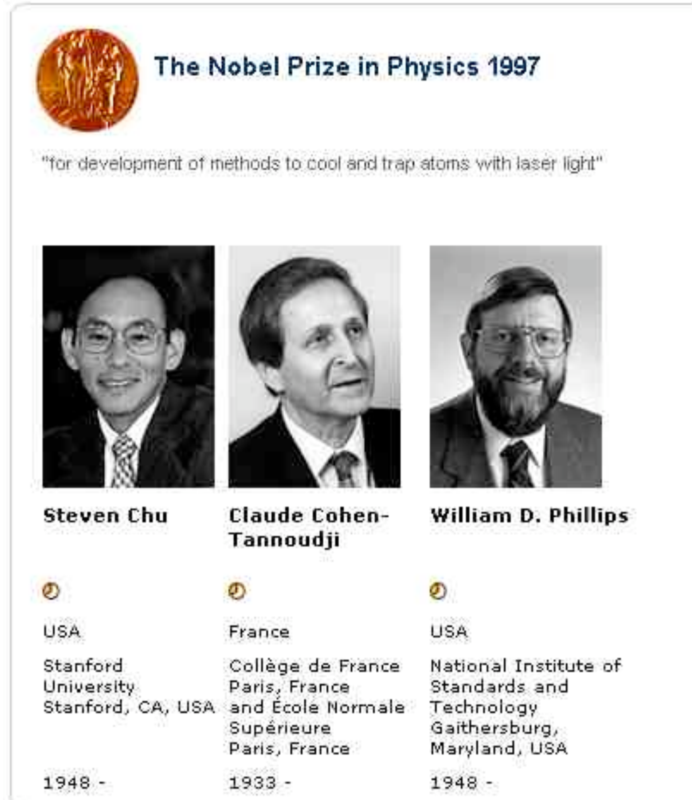
(Previous experiments with neutrons)

Laser cooling

Laser cooling techniques are used to achieve the required velocity (wavelength) control for the atom source.

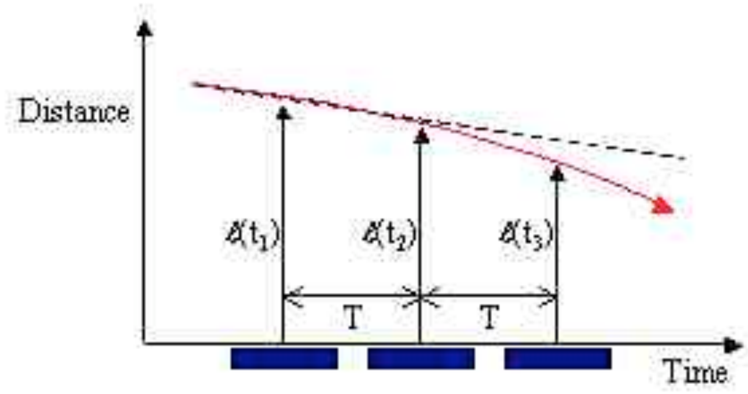
Laser cooling: Laser light is used to cool atomic vapors to temperatures of ~10^{-6} deg K.

Image source:www.nobel.se/physics



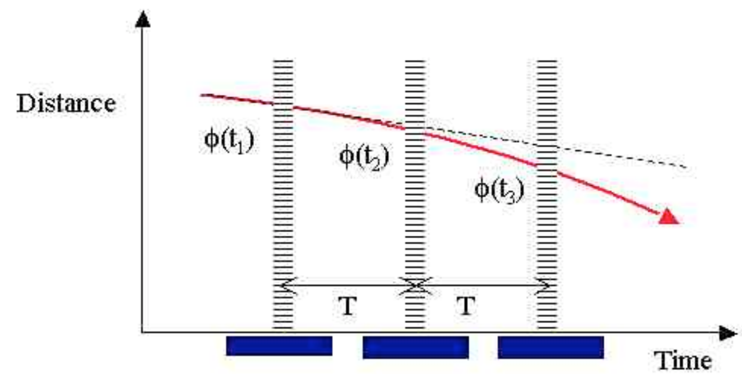
Approximate Kinematic Model

Falling rock



- Determine trajectory curvature with three distance measurements $\ell(t_1)$, $\ell(t_2)$ and $\ell(t_3)$
- For curvature induced by acceleration **a**,
  a ~ $[\ell(t_1) - 2\ell(t_2) + \ell(t_3)]$

Falling atom

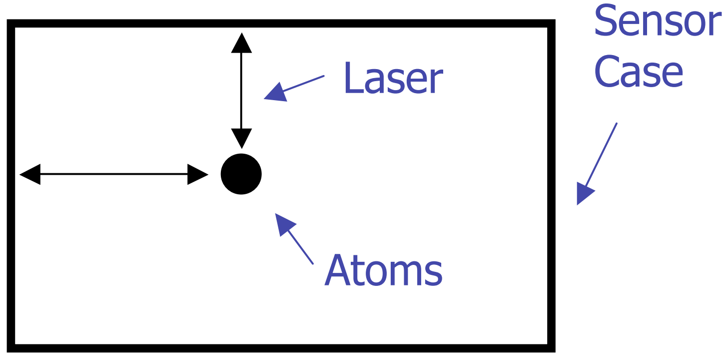


- Distances measured in terms of phases $\phi(t_1)$, $\phi(t_2)$ and $\phi(t_3)$ of optical laser field at position where atom interacts with laser beam
- Atomic physics processes yield
  a ~ $[\phi(t_1)-2\phi(t_2)+\phi(t_3)]$

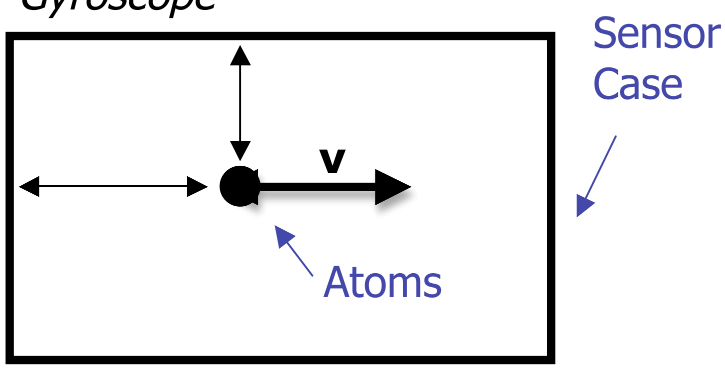
Light-pulse atom sensors

- **Atom is in a near perfect inertial frame of reference (*no spurious forces*).**
- **Laser/atomic physics interactions determine the the relative motion between the inertial frame (*defined by the atom deBroglie waves*) and the sensor case (*defined by the laser beams*).**
- **Sensor accuracy derives from the use of optical wavefronts to determine this relative motion.**
- **Sensor is kinematic: directly reads angular and linear displacements**

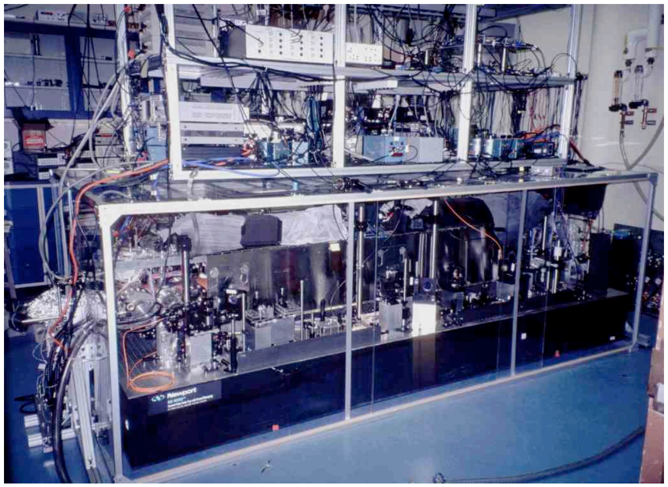
Accelerometer



Gyroscope



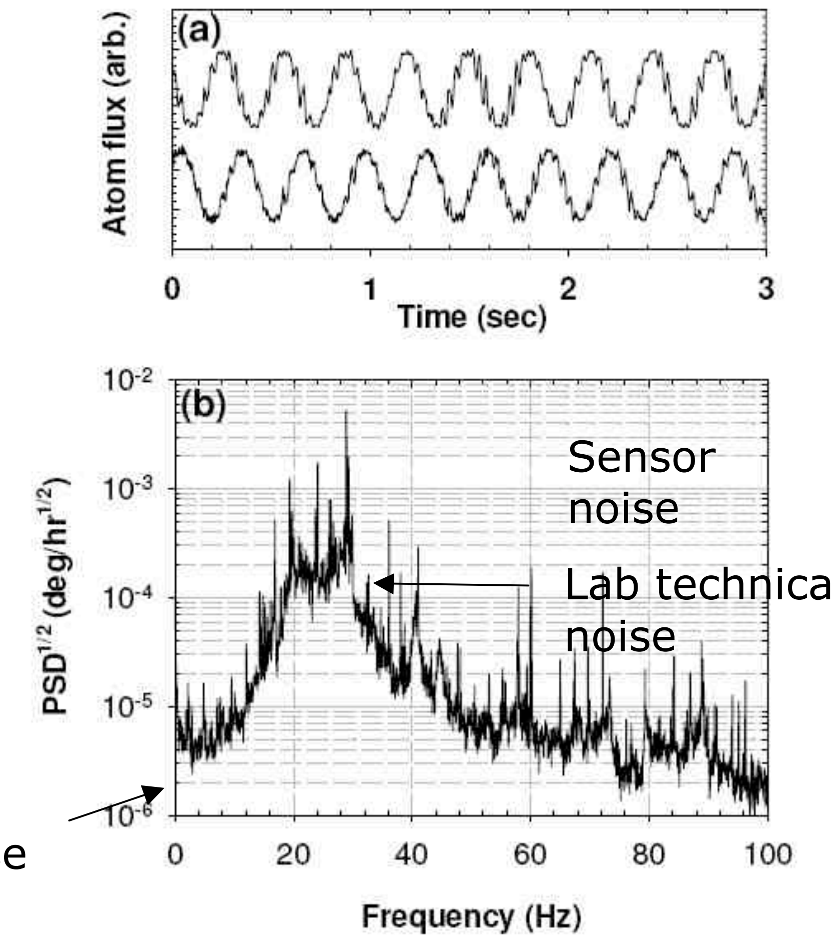
Laboratory gyroscope (1997)



AI gyroscope

Noise:	3 μdeg/hr$^{1/2}$
Bias stability:	< 60 μdeg/hr
Scale factor:	< 5 ppm

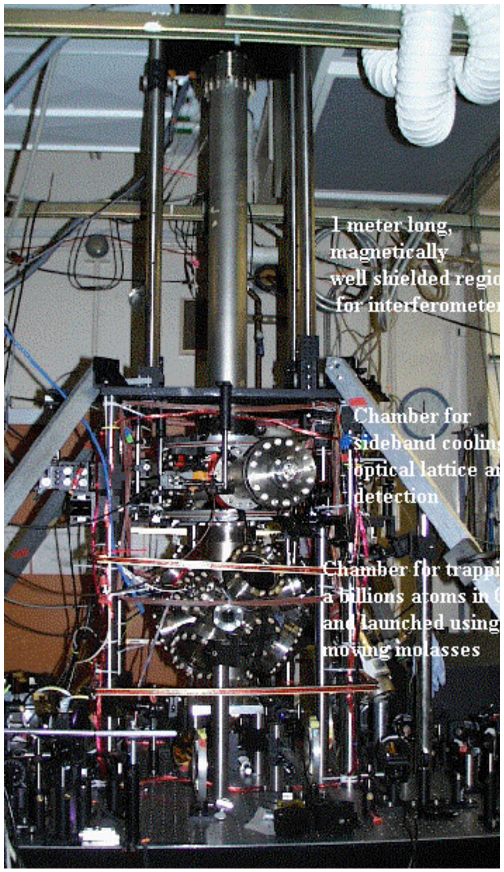
Gyroscope interference fringes:



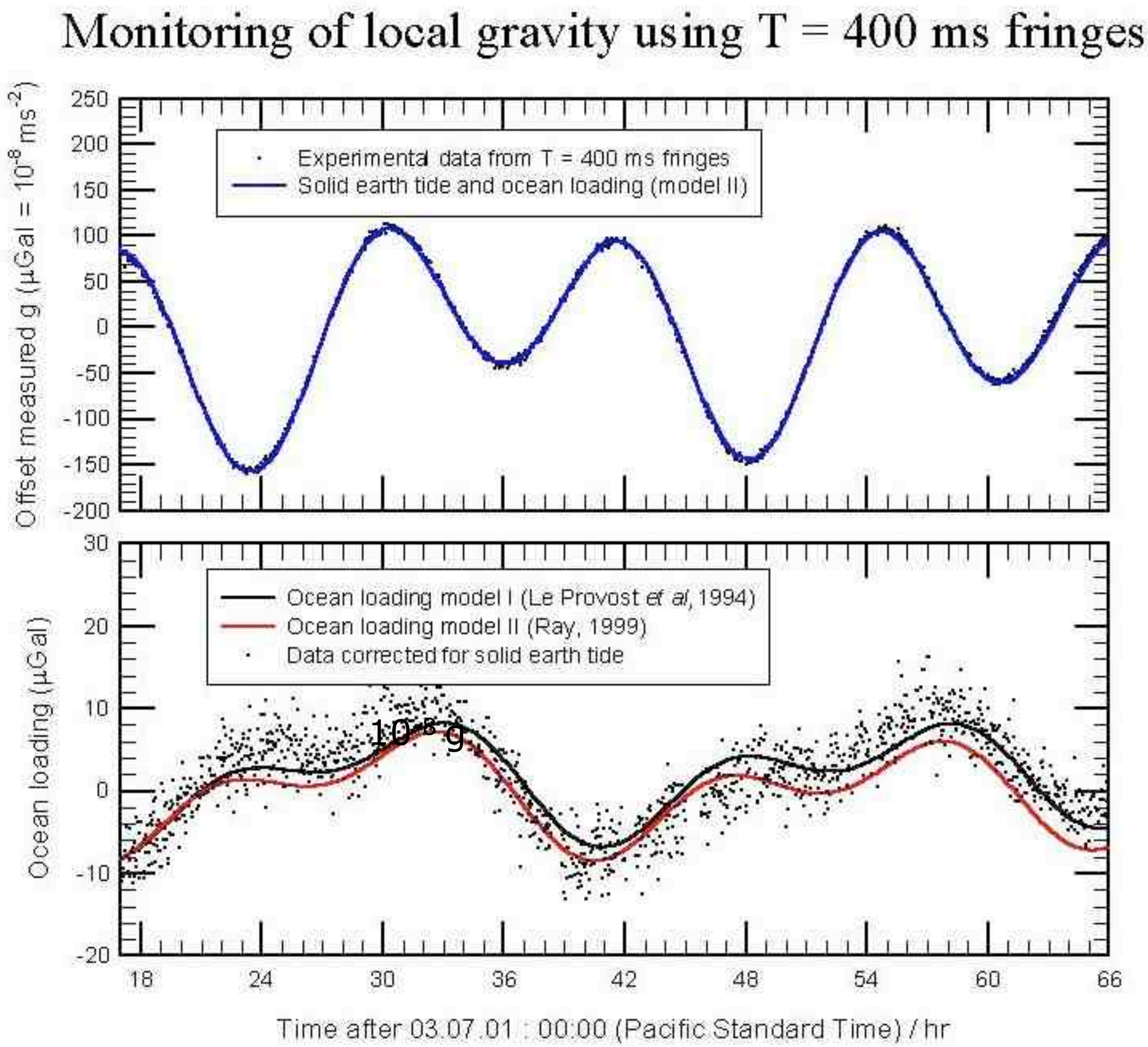
Atom shot noise

Gustavson, et al., PRL, 1997,
Durfee, et al., PRL, 2006

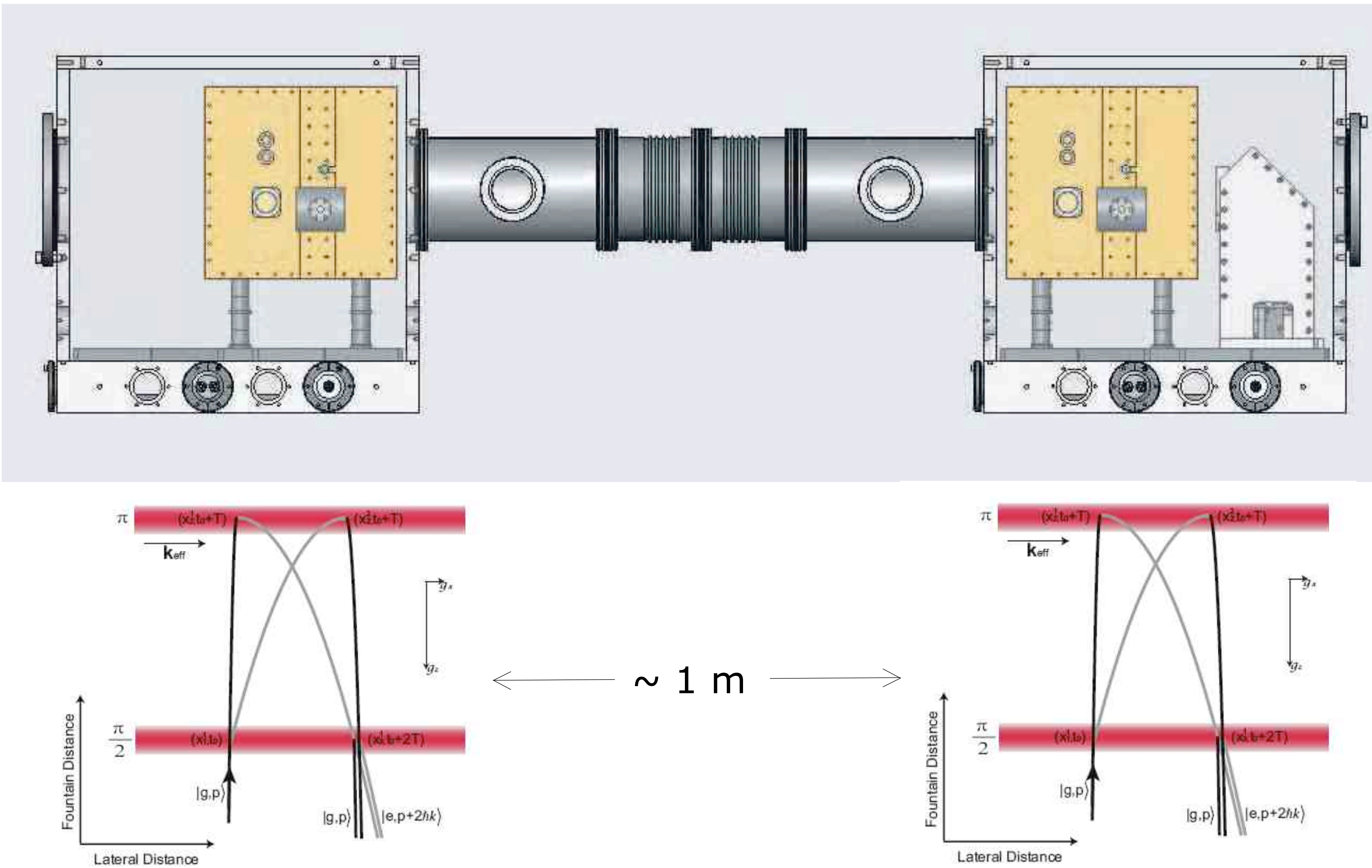
Stanford laboratory gravimeter (2000)



Courtesy of S. Chu, Stanford

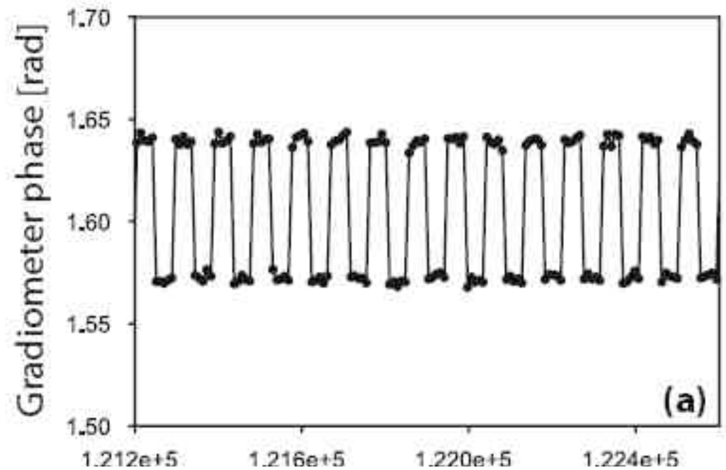


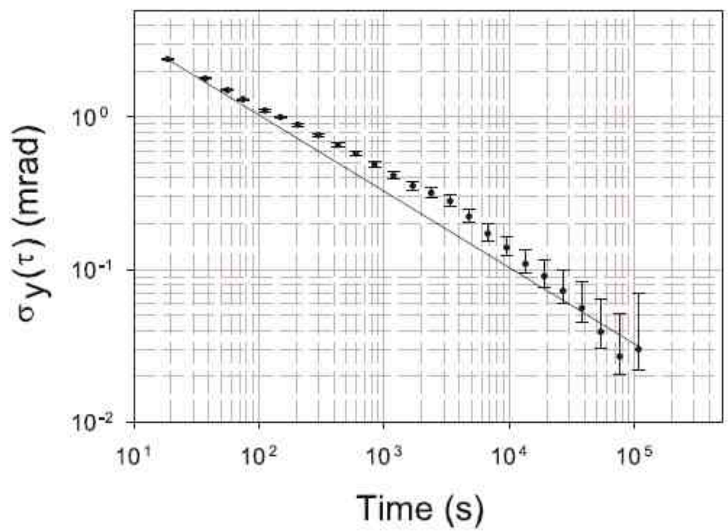
Differential accelerometer (2007)



Applications in precision navigation and geodesy

Gravity gradiometer (2007)



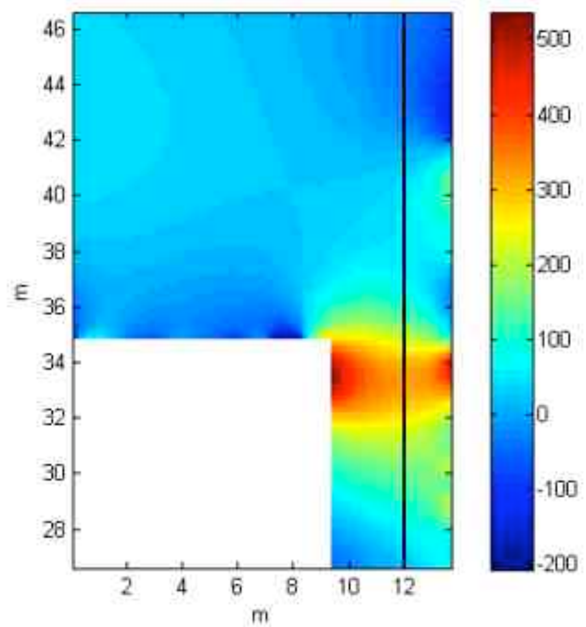


Demonstrated accelerometer resolution: $\sim 10^{-11}$ g.

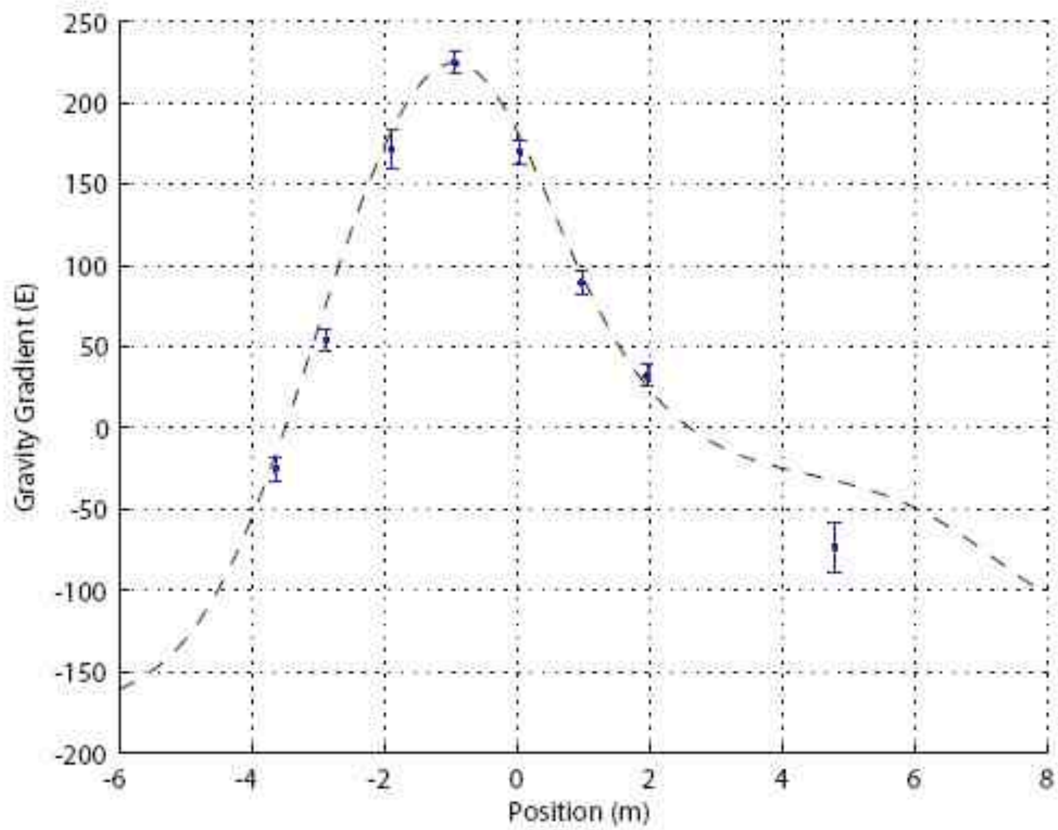
Truck-based gravity gradient survey (2007)

ESIII loading platform survey site

Gravity gradient survey



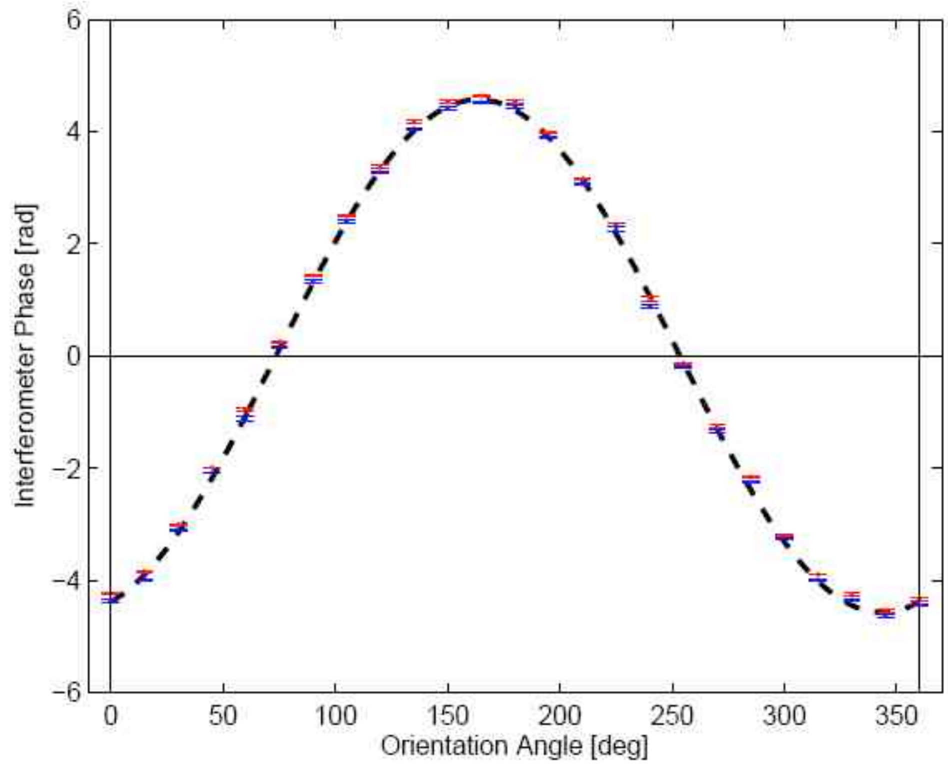
Gravity anomally map from ESIII facility



Gravity gradient survey of ESIII facility

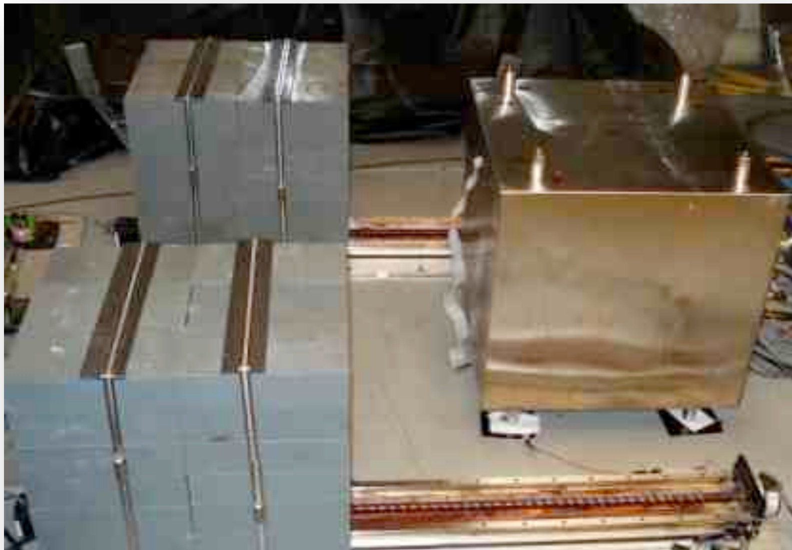
Hybrid sensor (2007)/Gyroscope mode

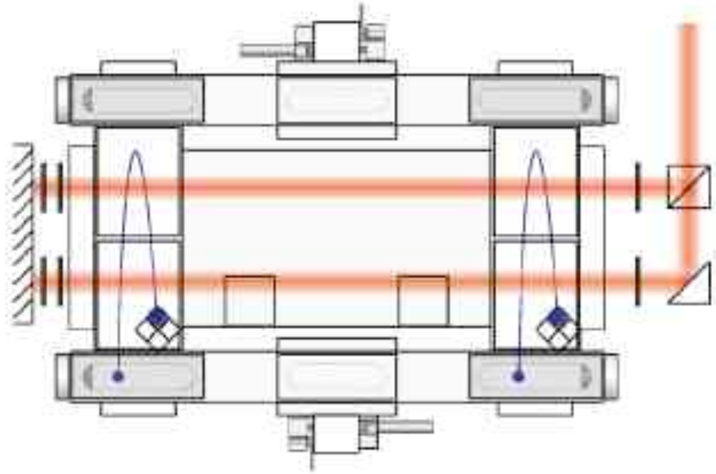
Measured gyroscope output vs.orientation:

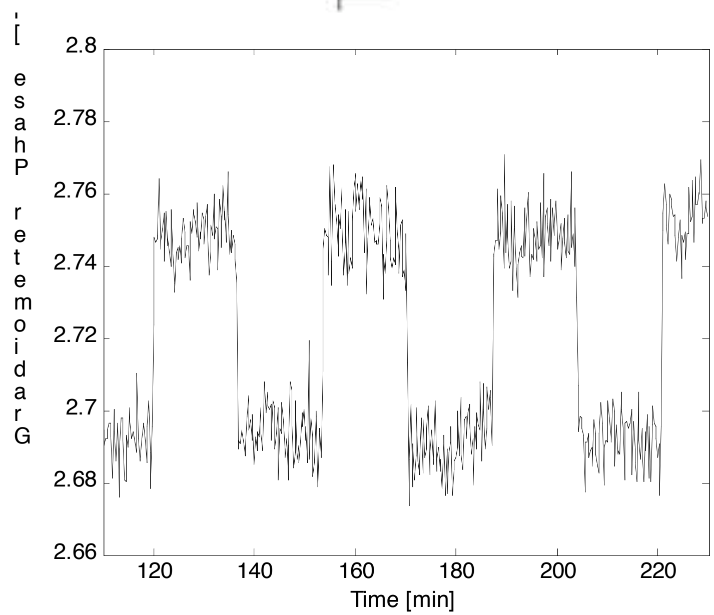


- Inferred ARW: < 100 μdeg/hr$^{1/2}$
- 10 deg/s max input
- <100 ppm absolute accuracy

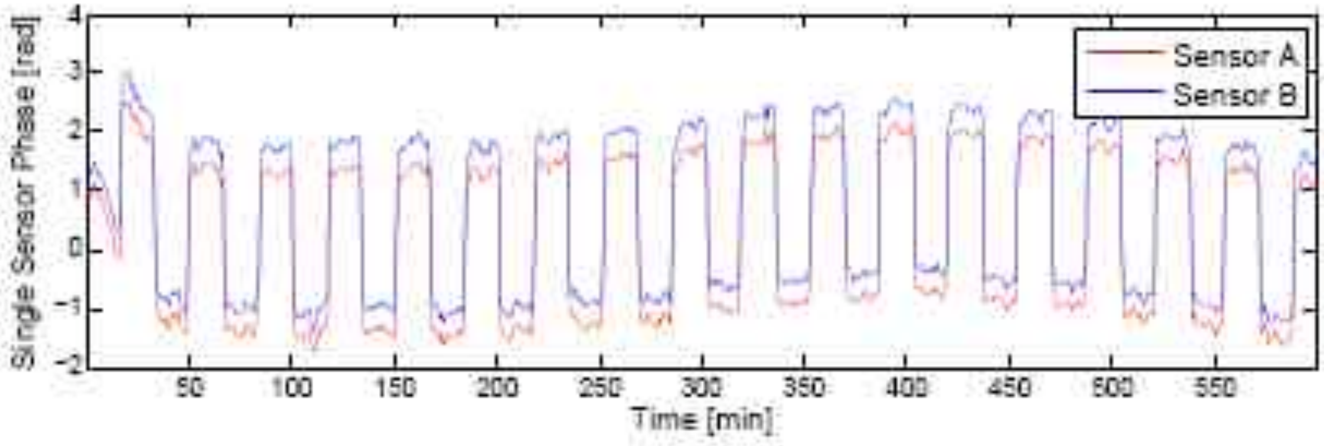
Hybrid sensor (2007)/Gravity gradient mode







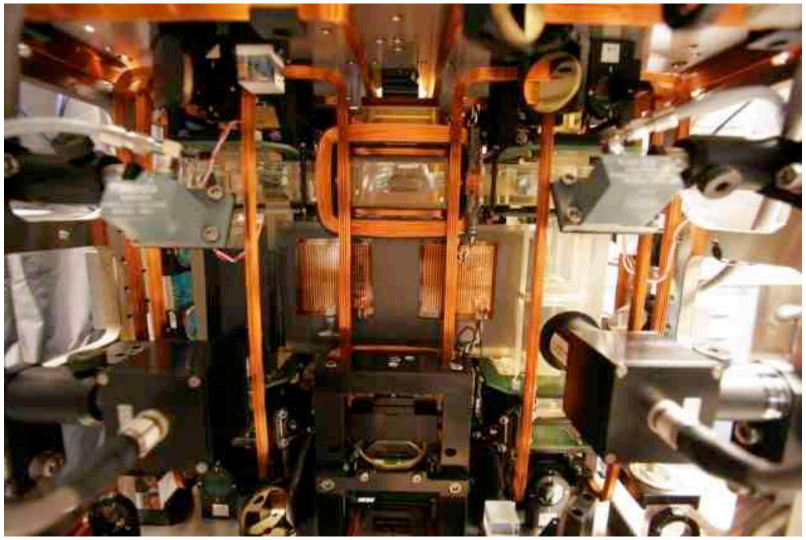
Hybrid sensor (2007)/Absolute accelerometer



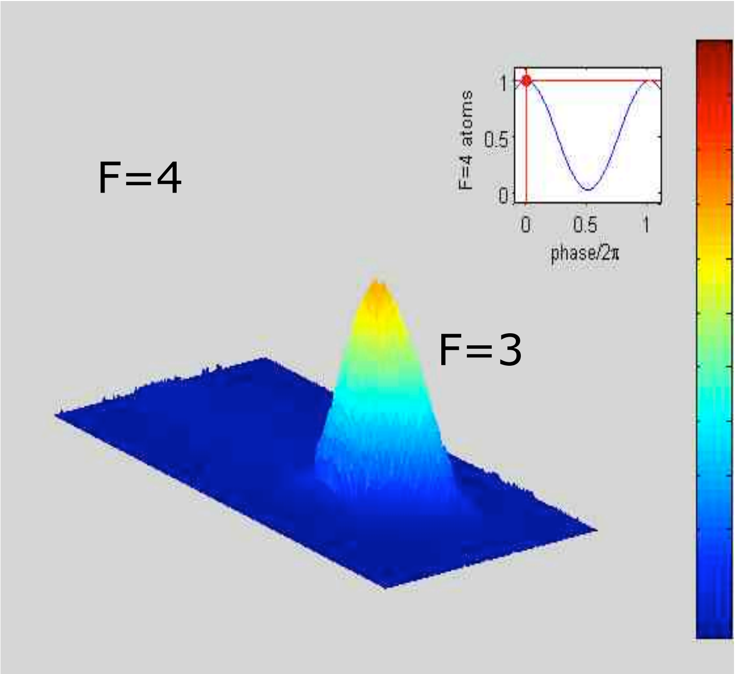
Direct accelerometer outputs.

Horizontal input axis, microGal resolution.

Gyroscope operation



Interior view of sensor



Interference fringes are recorded by measuring number of atoms in each quantum state.

Fringes are scanned electro-optically.

DARPA PINS Sensors

DARPA PINS sensors:
POC Jay Lowell, DARPA

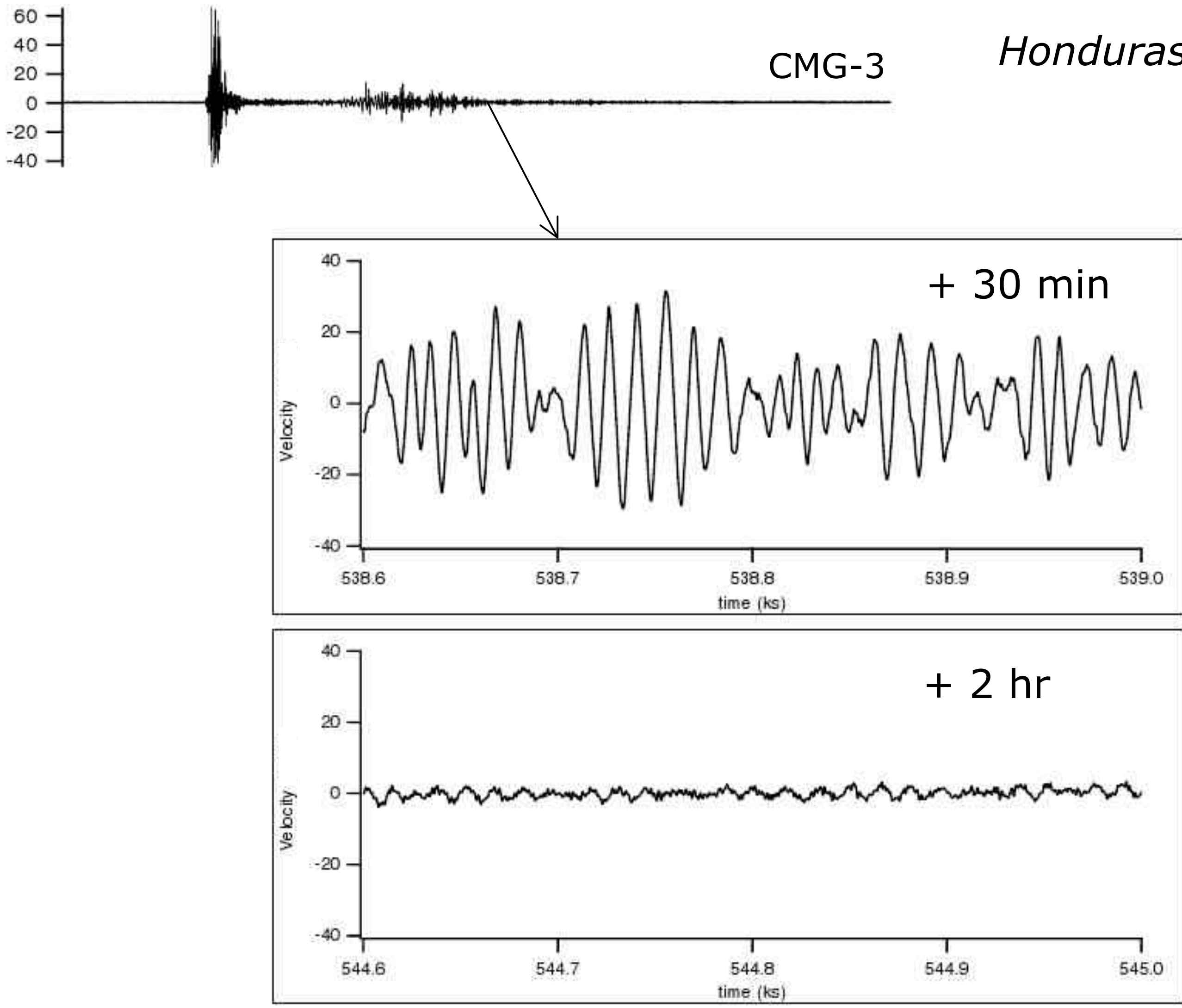
Fabricated and tested at AOSense, Inc., Sunnyvale, CA.

Sensors designed for precision navigation.

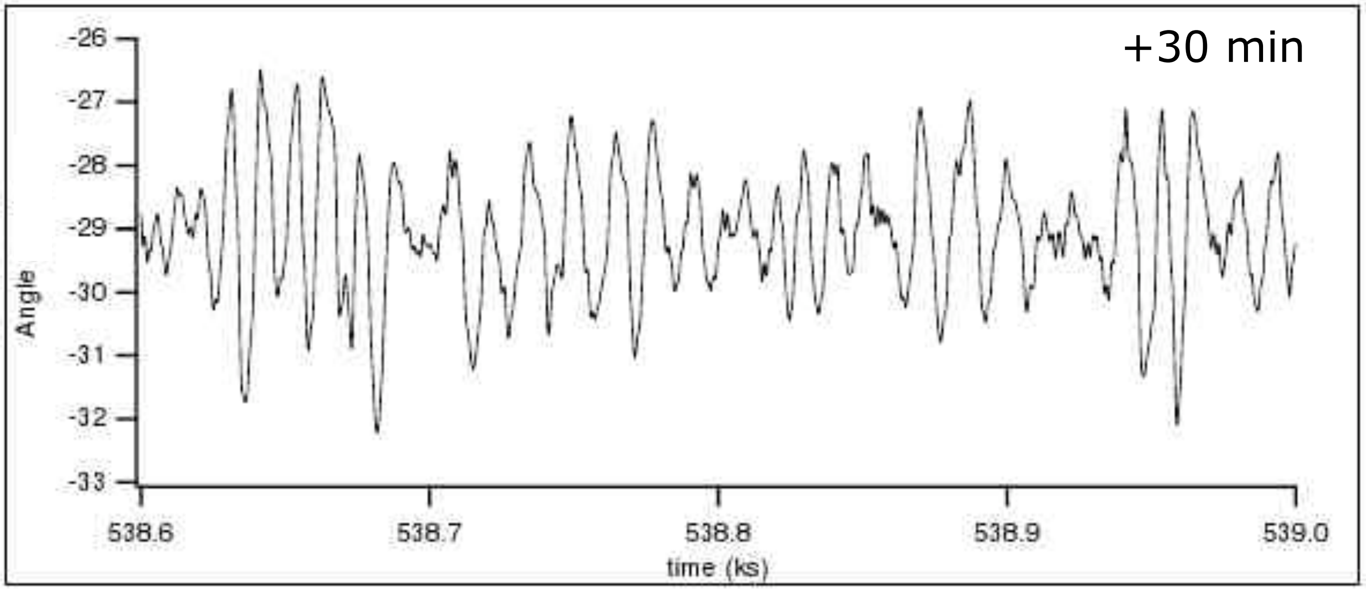
Candidate for possible testing in ASL vault.

Seismometer mode

Honduras/offshore 7.3

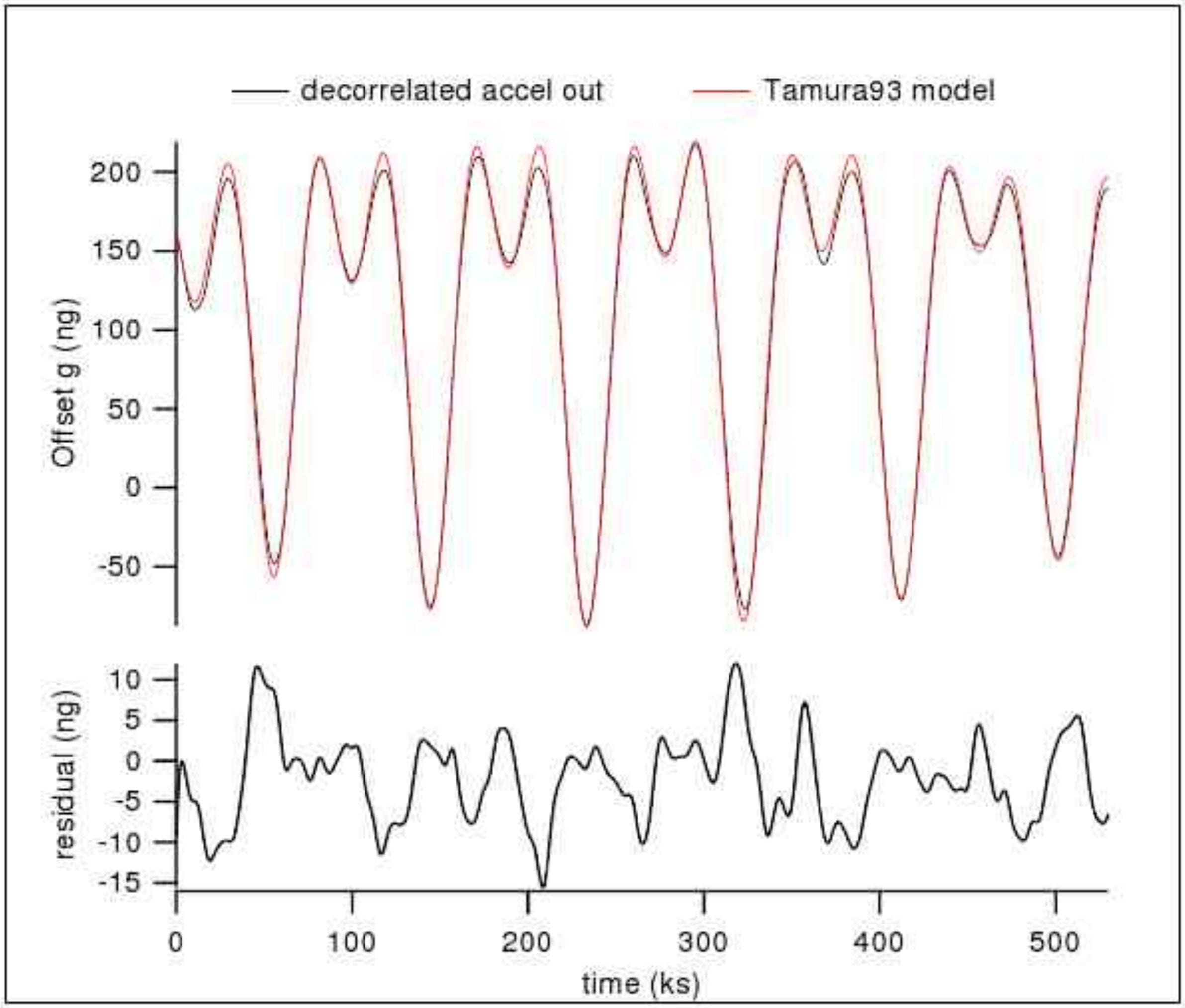


Gyroscope mode

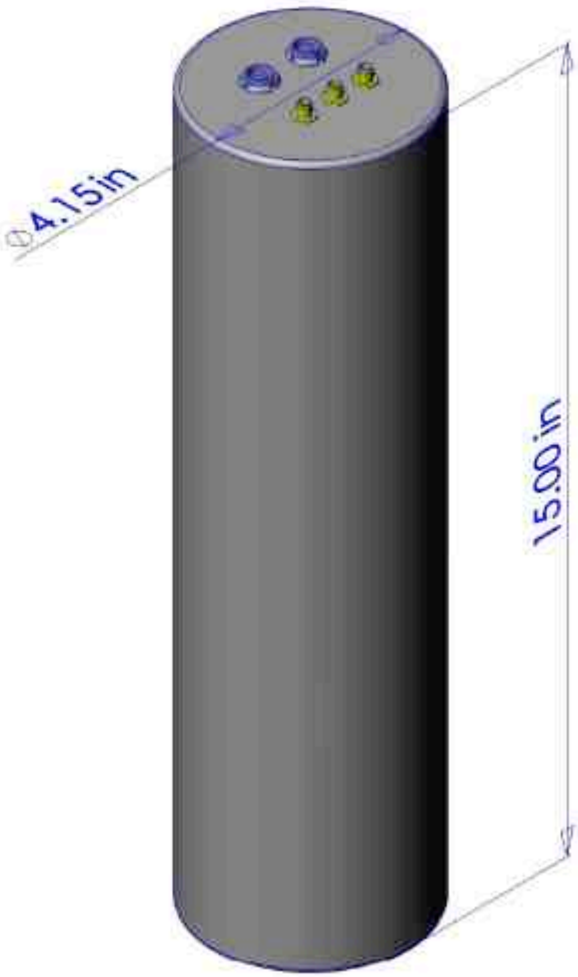


Gyroscope output necessary to disambiguate tilt from horizontal motion (navigation problem).

Gravimeter mode



AOSense compact gravimeter



High accuracy absolute accelerometer.

Currently under fabrication at AOSense, Inc.

AOSense, Inc.