Systemes de Reference Temps—Espace
Observatoire de Paris

Large Area Cold Atom Gyroscope

I. Dutta, D. Savoie, M. Meunier, B. Fang, R. Geiger, C. Garrido Alzar, A. Landragin

FIRST-TF General Assembly, March 16th, 2015

Layout

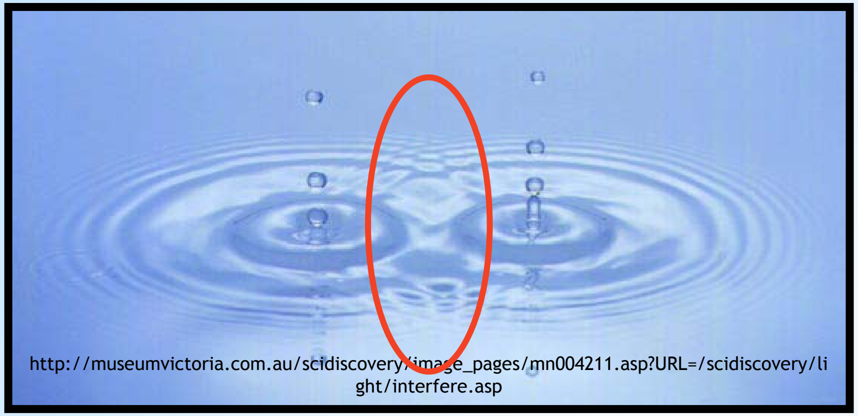
I.Interferometry to Cold Atom Gyroscope

II.Experimental Set-up and Measurements

III.Results and Further Improvements

IV.Remarks

Principles of Interferometry

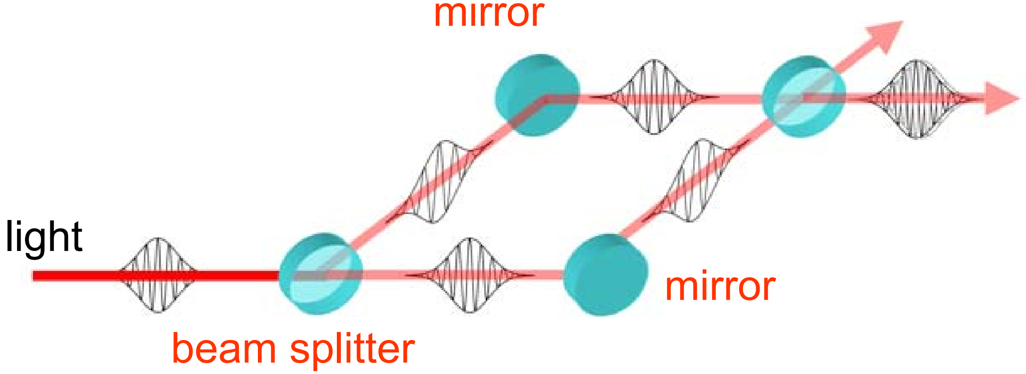


http://museumvictoria.com.au/scidiscovery/image_pages/mn004211.asp?URL=/scidiscovery/light/interfere.asp

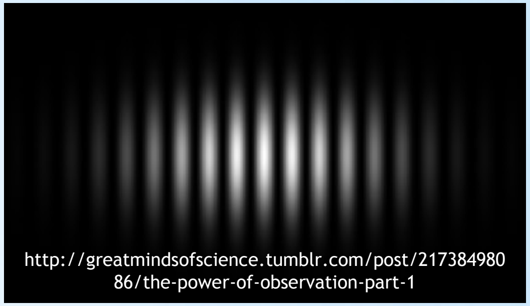
Principles of Interferometry

$\Delta\varphi$: difference of accumulated phase shift along the two arms : **2 waves interferences**

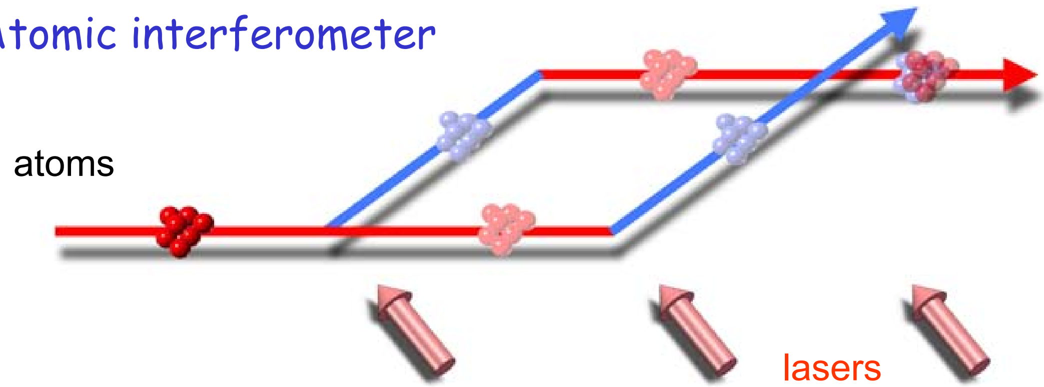
Light interferometer

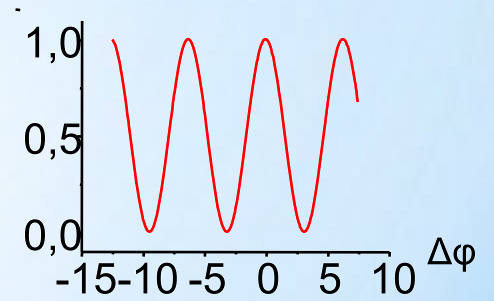


$$I \propto (1 + \cos(\Delta\Phi))$$



Atomic interferometer





$$P_1 = \frac{1}{2}(1 + \cos\Delta\Phi)$$

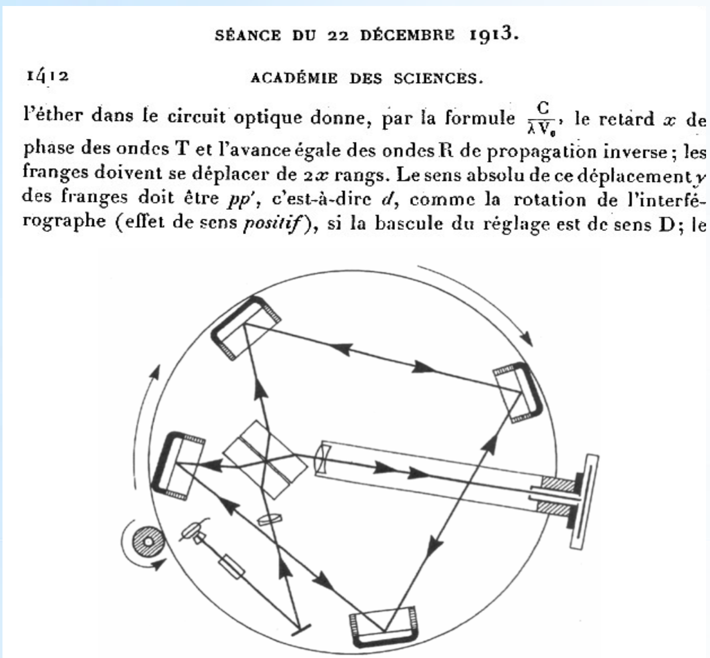
Transition in internal states

Wave-particle duality of atoms

« Quantum » regime: Cold Atoms

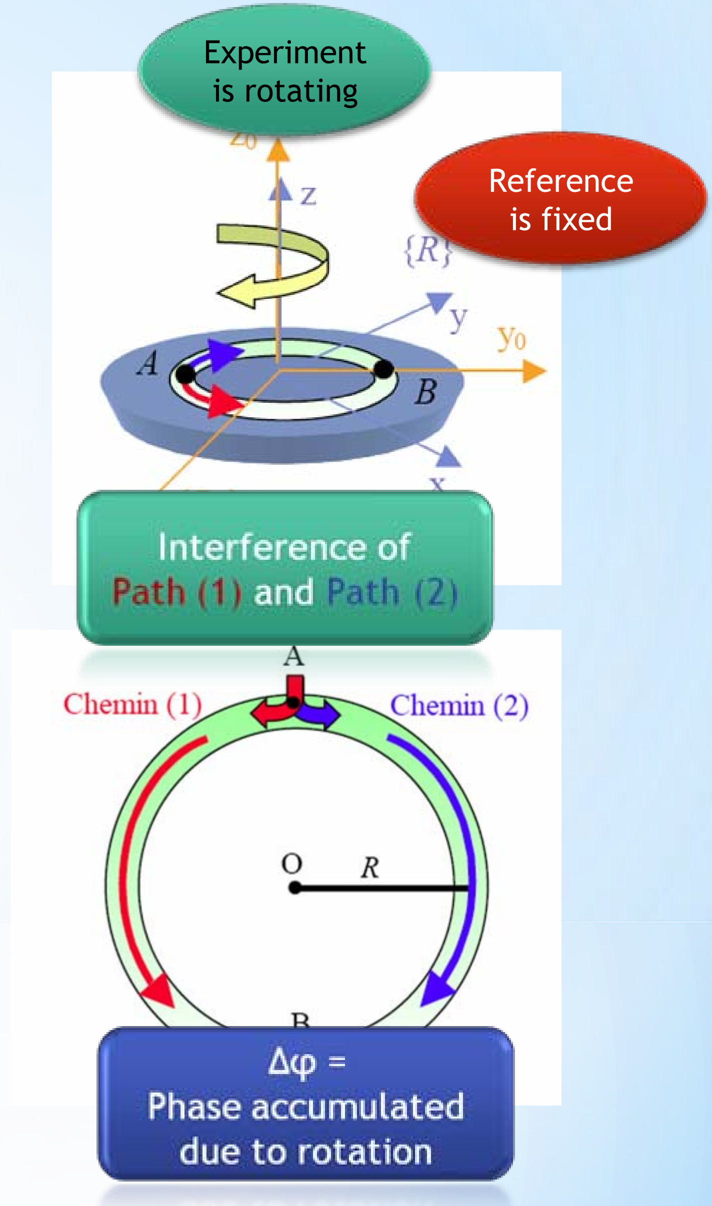
Gyroscope using Interferometry

Sagnac Effect

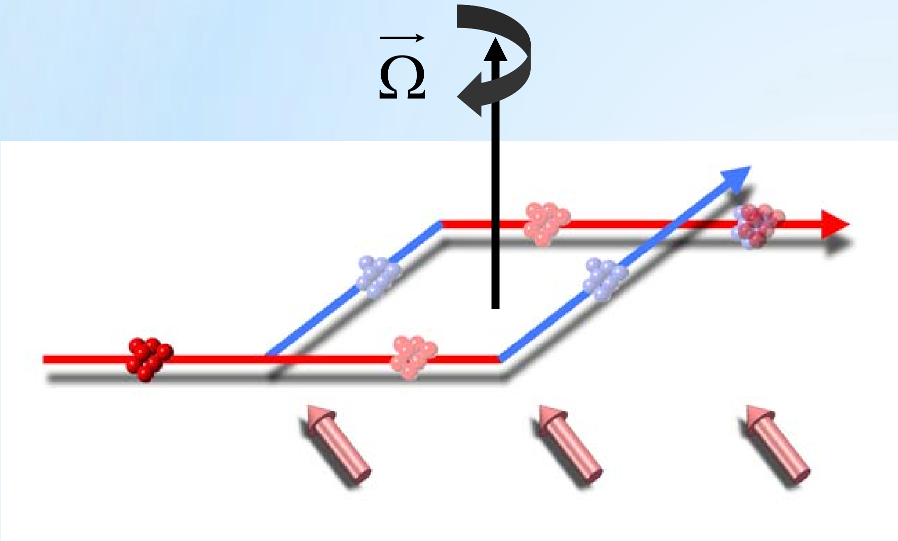

SÉANCE DU 22 DÉCEMBRE 1913.

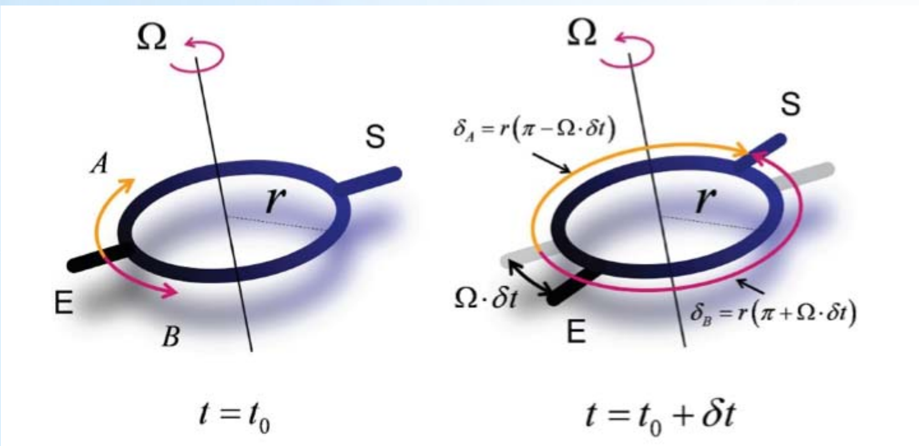
1412 ACADÉMIE DES SCIENCES.

l'éther dans le circuit optique donne, par la formule $\frac{C}{\lambda V_0}$, le retard x de phase des ondes T et l'avance égale des ondes R de propagation inverse; les franges doivent se déplacer de $2x$ rangs. Le sens absolu de ce déplacement y des franges doit être pp', c'est-à-dire d, comme la rotation de l'interférographe (effet de sens *positif*), si la bascule du réglage est de sens D; le



Atomic Gyroscope





$$P = \frac{1}{2}\left(1 + \cos(\Delta\Phi)\right)$$

Sagnac phase shift :

$$\Delta\Phi_\Omega = \frac{4\pi E}{hc^2}\vec{A}\cdot\vec{\Omega}$$

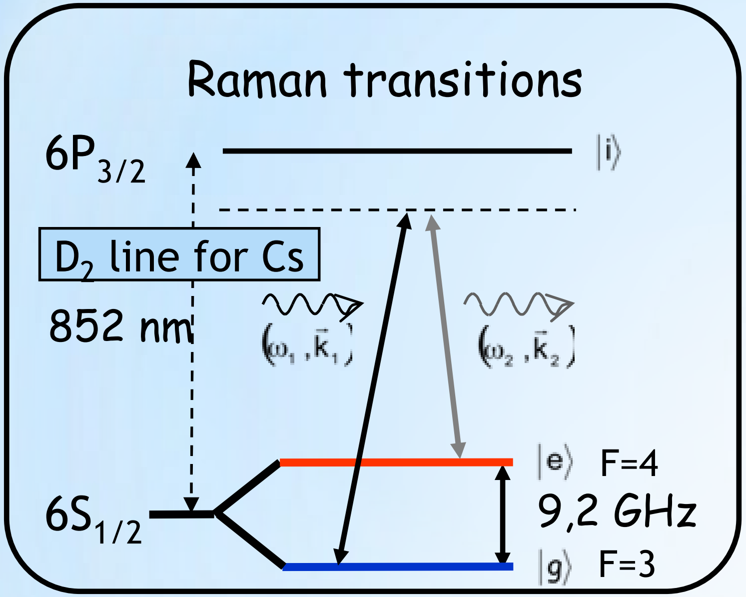
E : energy of atoms
A : physical area

Interest : $\frac{E_{atom}}{E_{photon}} \sim 10^{11}$

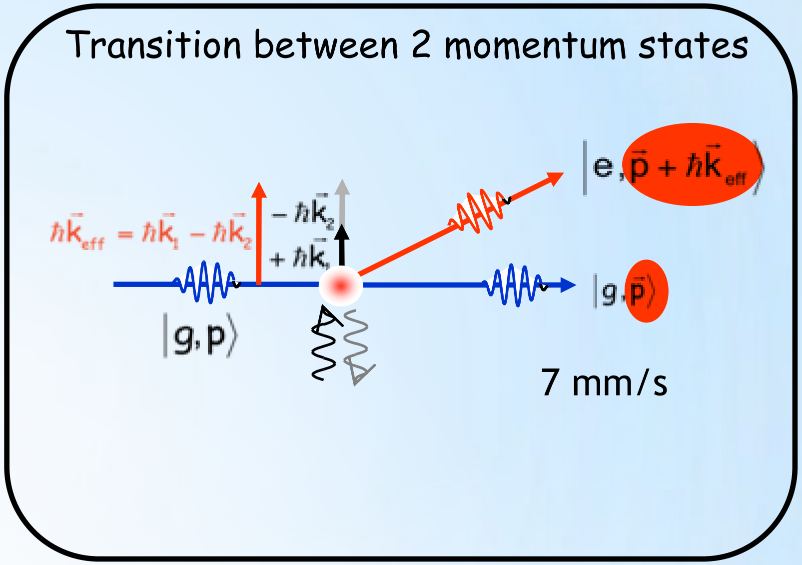
Bigger sensitivity

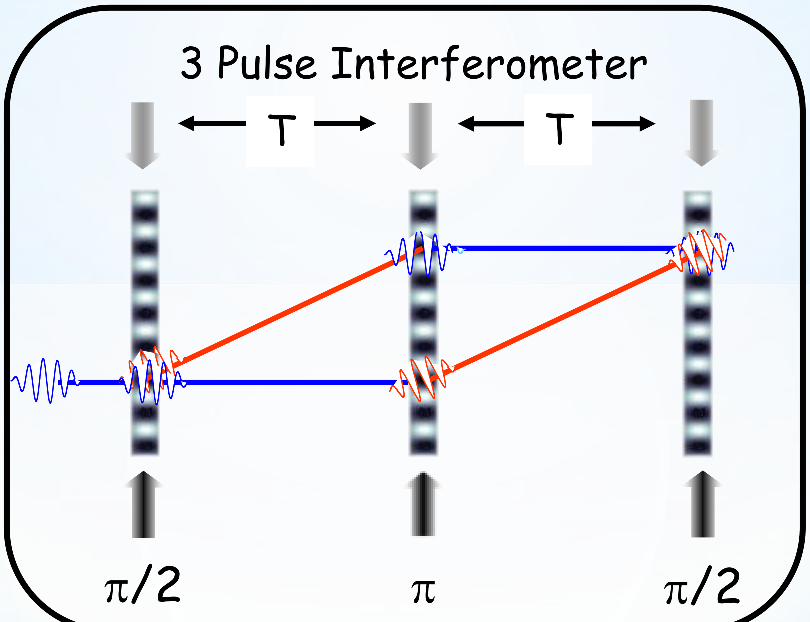
Manipulating atomic wave packets with light pulses

Atom Interferometer Mechanisms

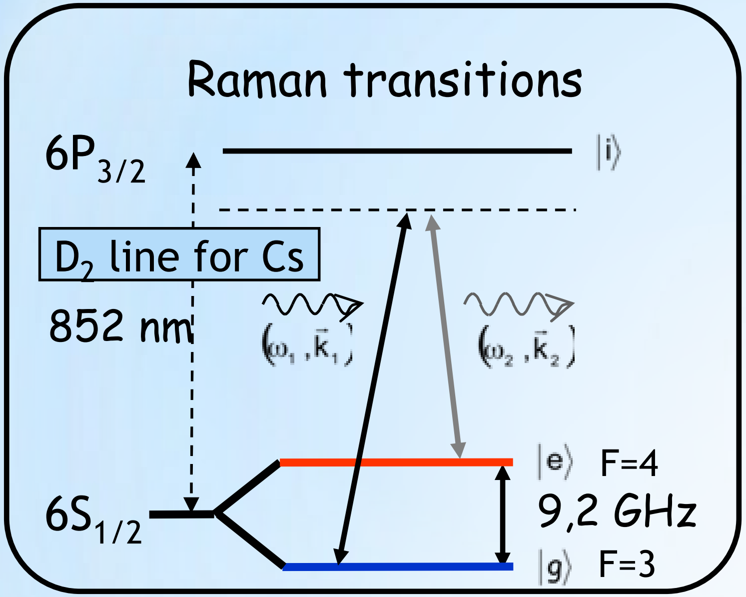


A two photon transition

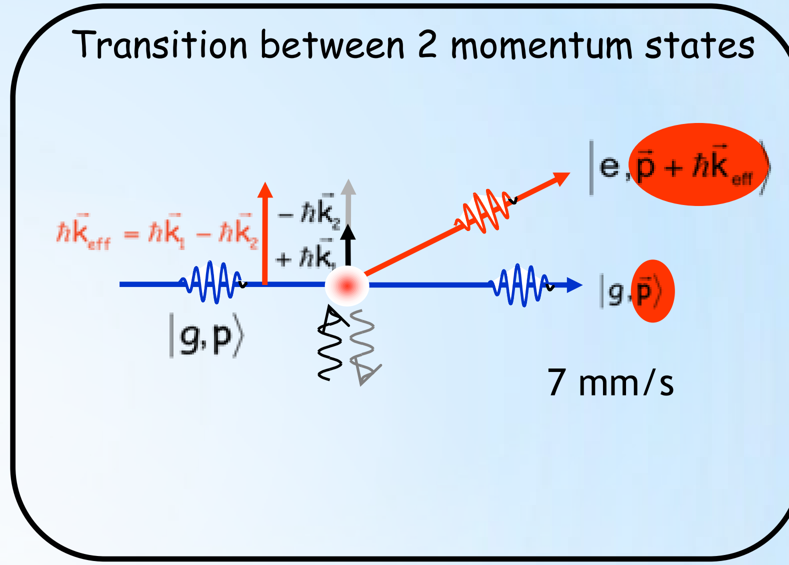


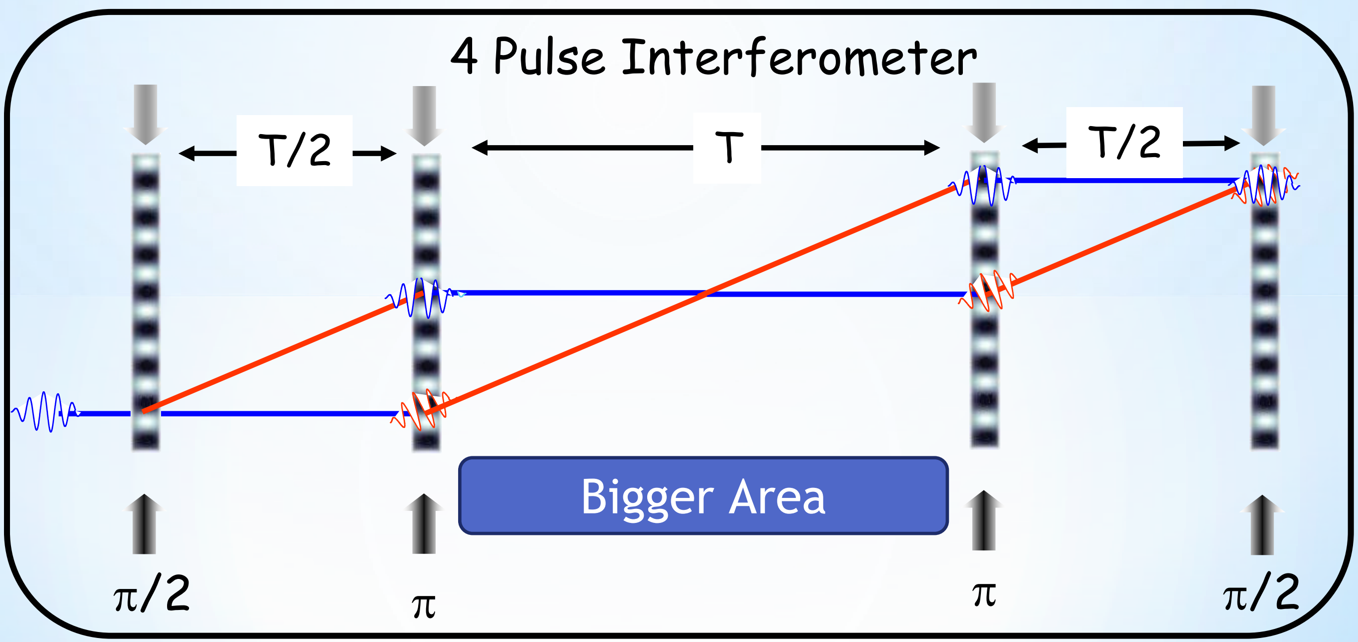


Atom Interferometer Mechanisms



A two photon transition

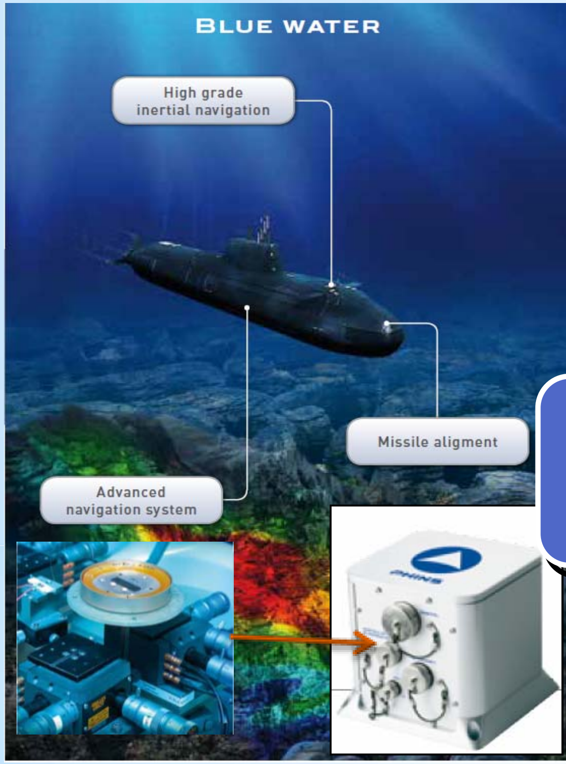


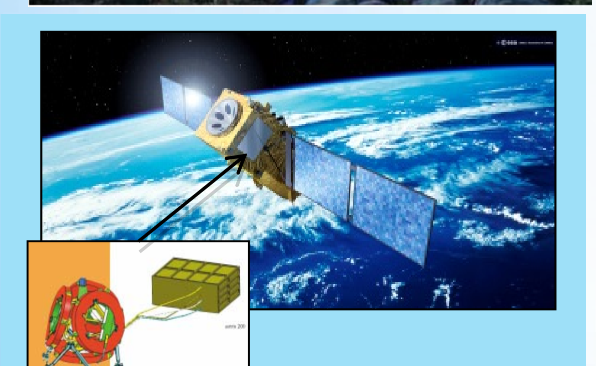


Gauguet et al., Phys. Rev. Lett. **97,** 010402 **(2006)**

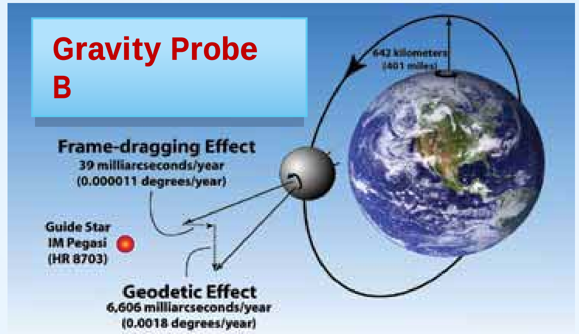
Gyroscope

Inertial Navigation

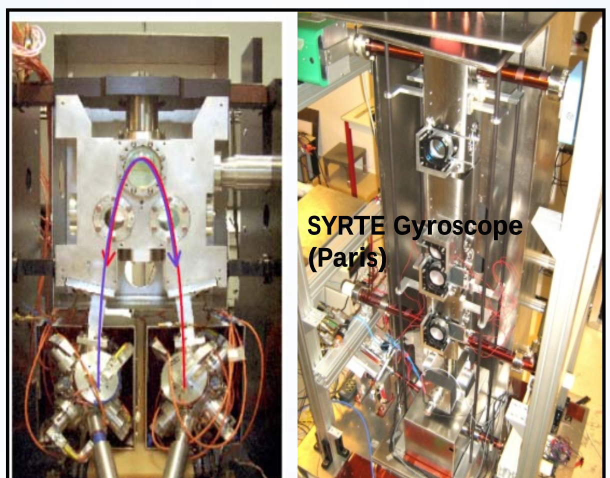




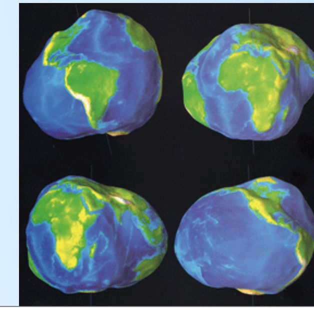
Precision Measurements

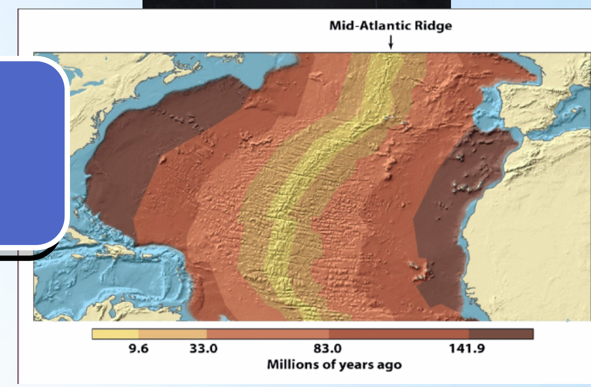


Aim:
Extremely
Precise and Stable

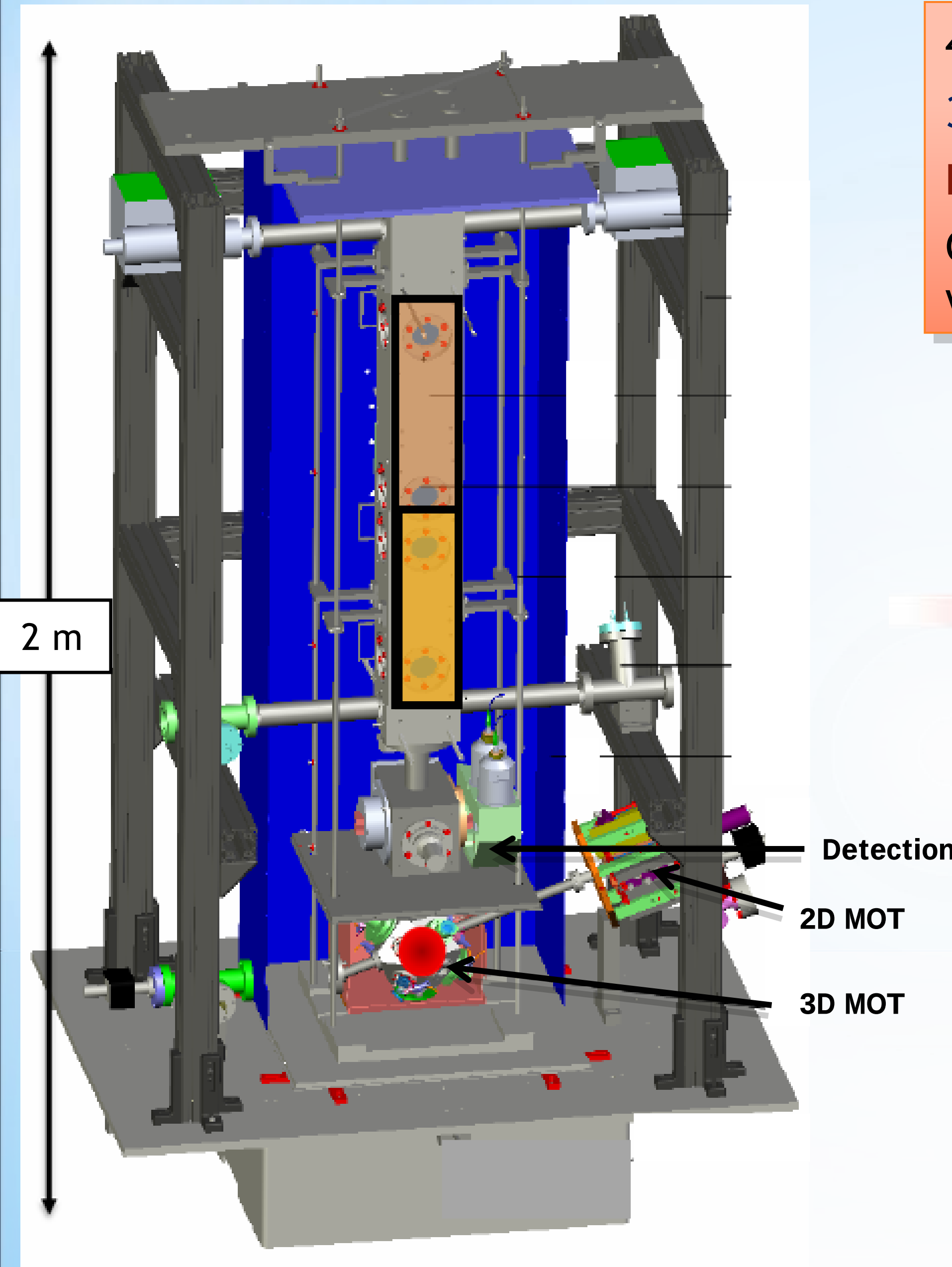


Applications in Geodesy and Seismology





Experimental Set Up @ SYRTE

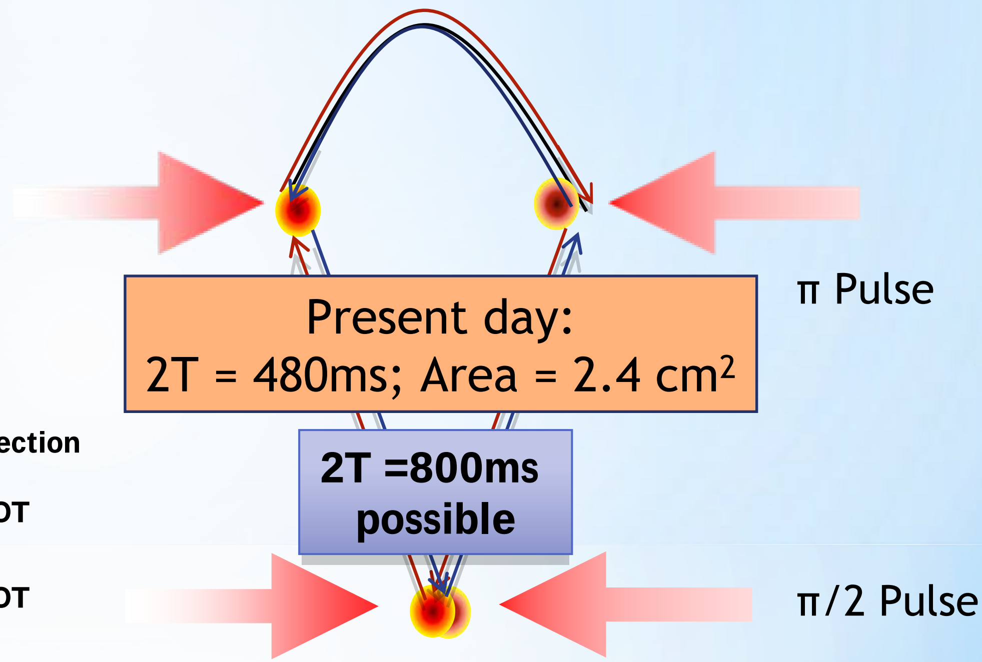


4 Pulse Geometry: **11cm² area (max.)**

30 times bigger area than existing atom gyros

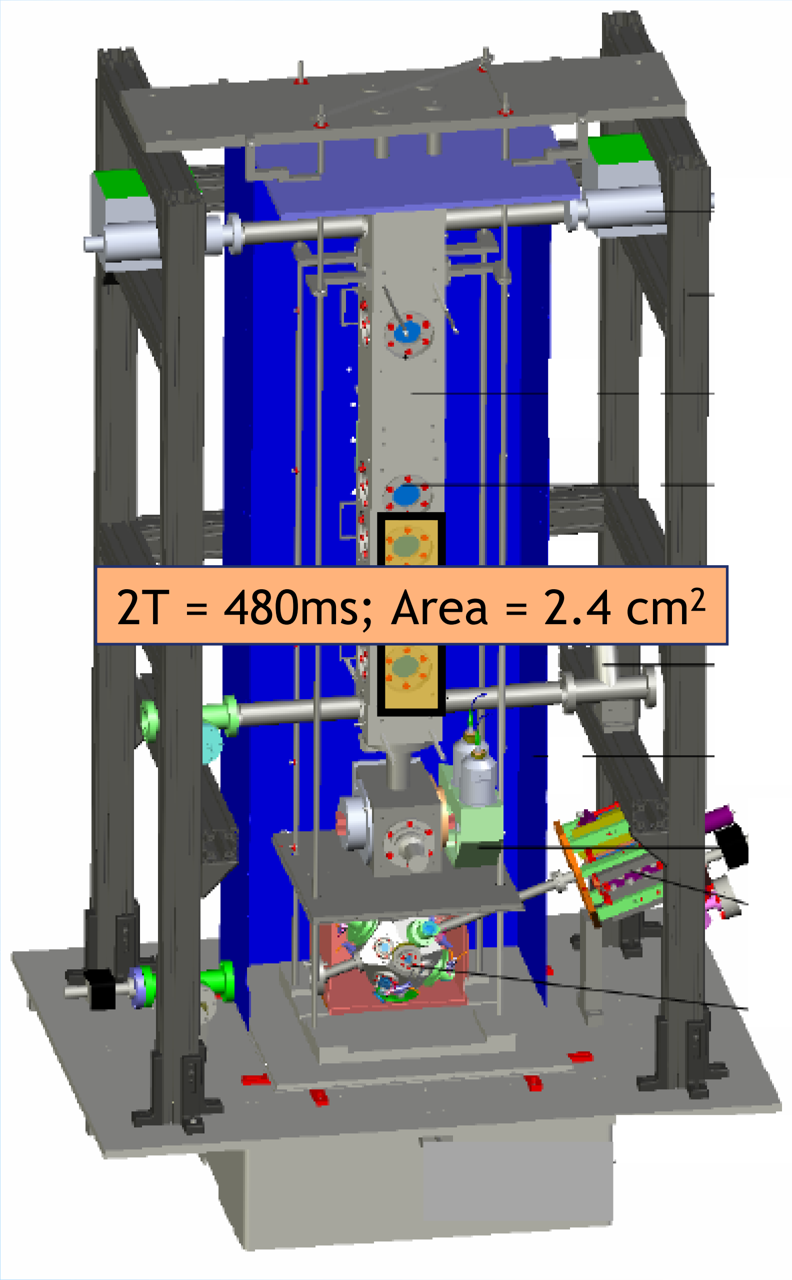
Large baseline but human-size

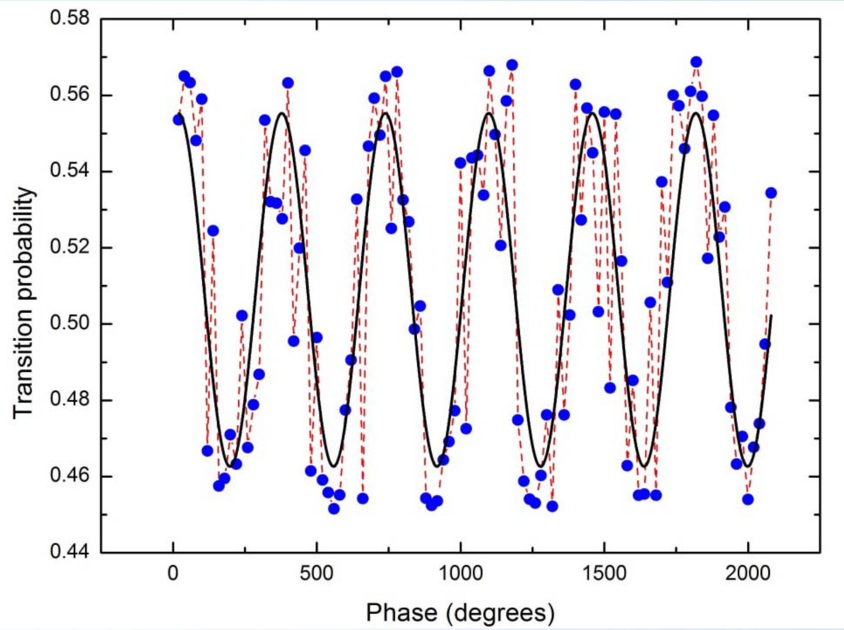
Cold Atomic Source (1.4μK)
with fast repeatability



$$\Delta\Omega = \frac{\Delta\Phi}{\frac{1}{2}\, k_{eff}\, g\, T^3}$$

Interferometric Perfomances

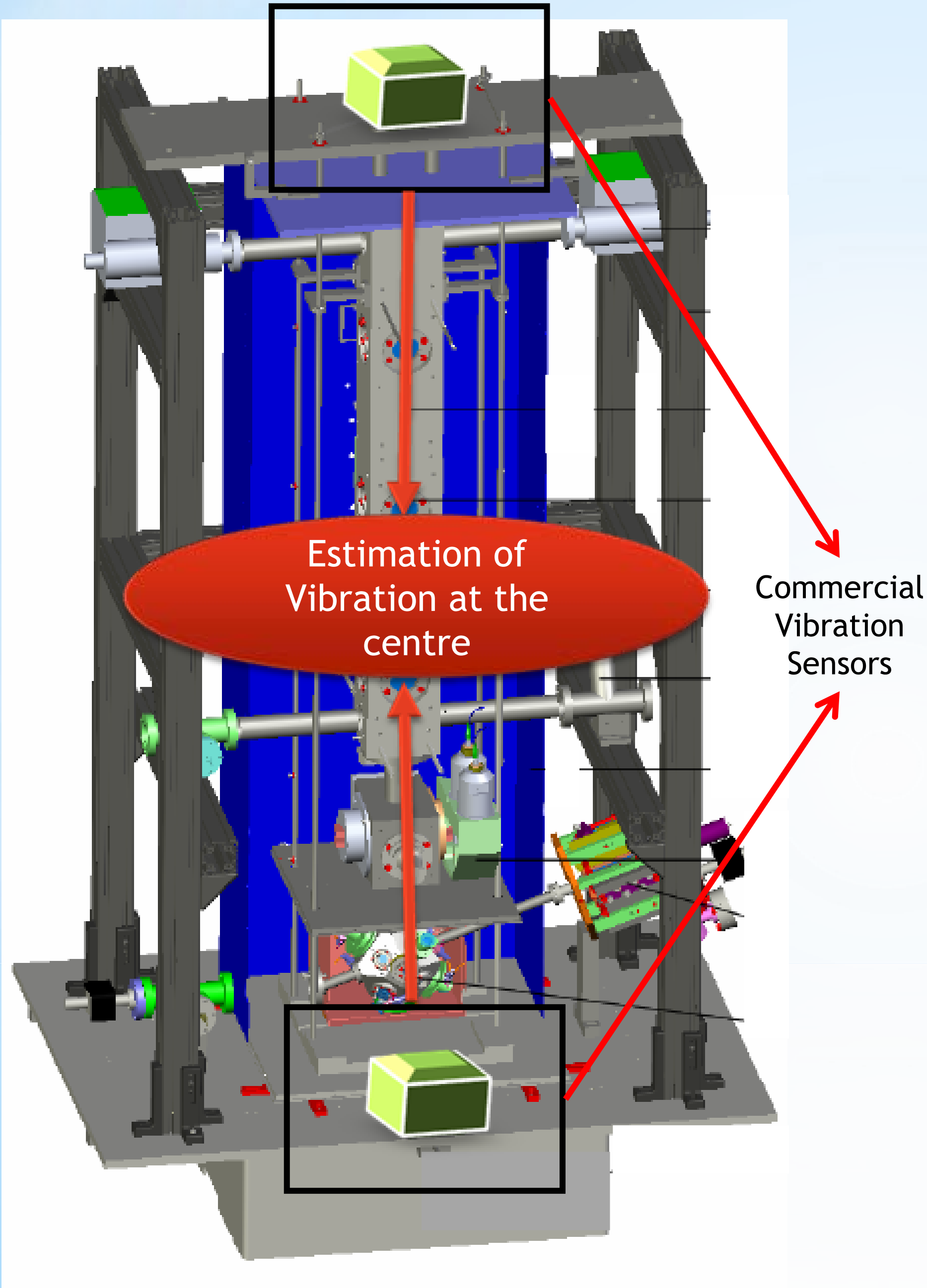


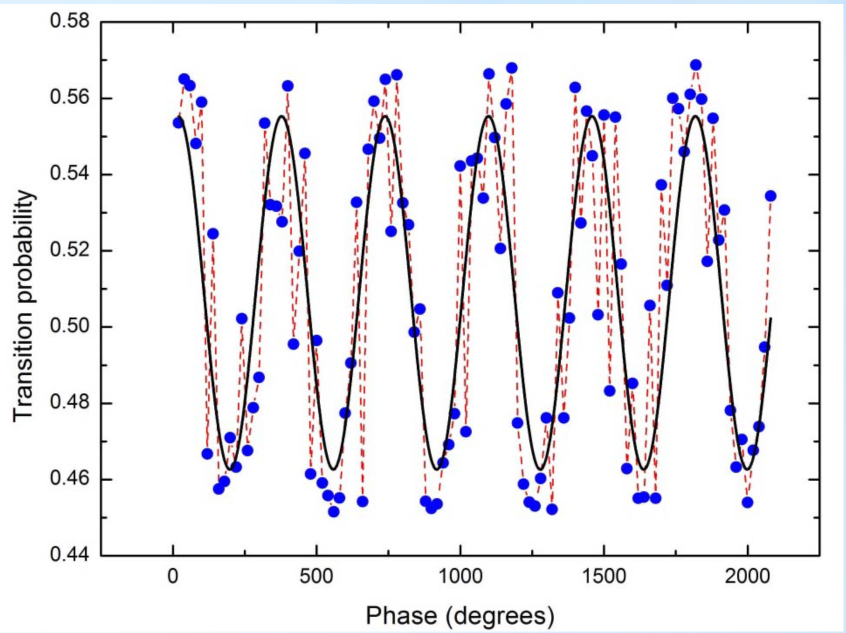


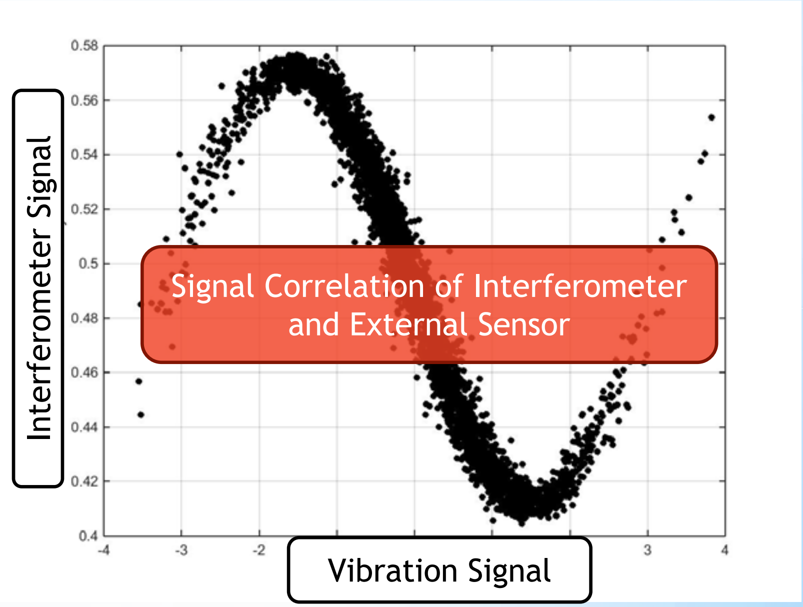
Reduced Fringe visibility :

Vibration Noise

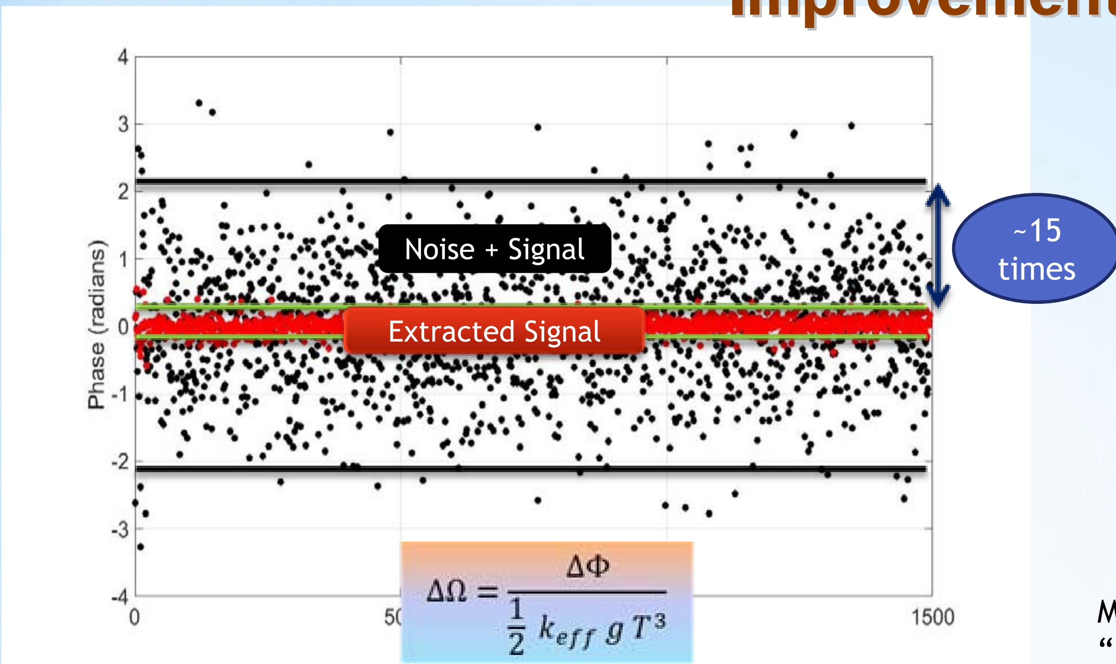
Effect of Vibration Noise





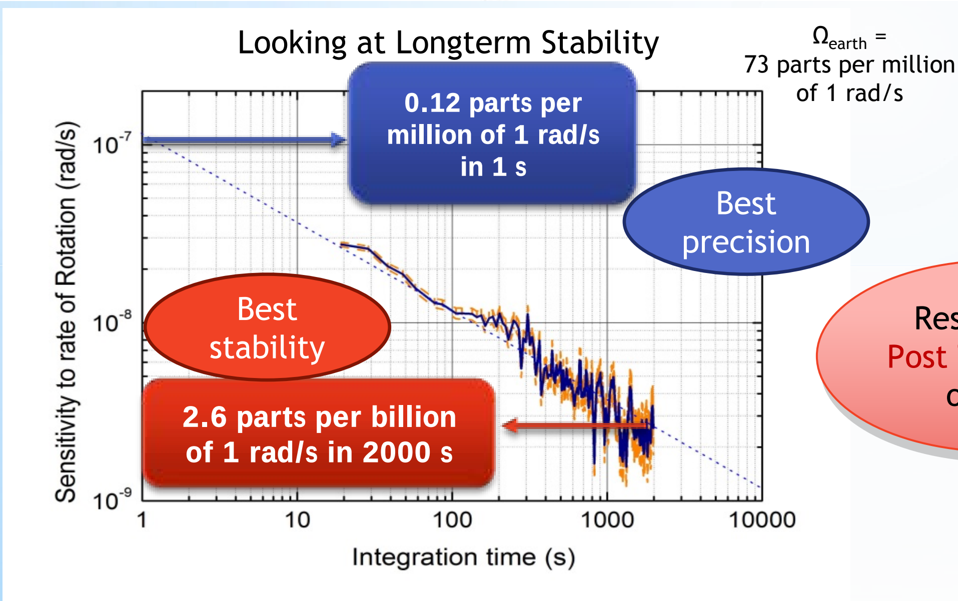


Gryoscopic Results and Towards Improvements



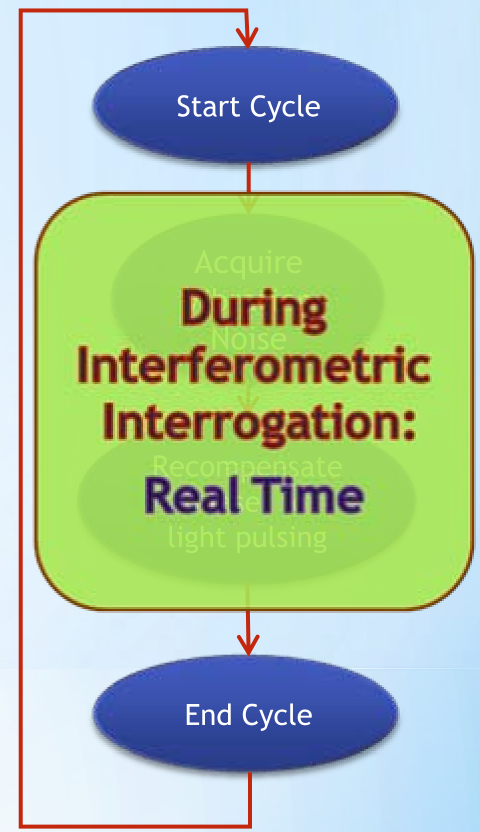
$$\Delta\Omega = \frac{\Delta\Phi}{\frac{1}{2}\, k_{eff}\, g\, T^3}$$

Real Time Noise Removal = Real Time Rotation Signal



Method similar to "Hybridization" Lautier & Lours et al. Appl. Phys. Lett. **105**, 144102 (2014)

Result after Post Treatment of Data



No post analysis: More Automation

Way to Improve:
No Dead Time

Waiting to Prepare

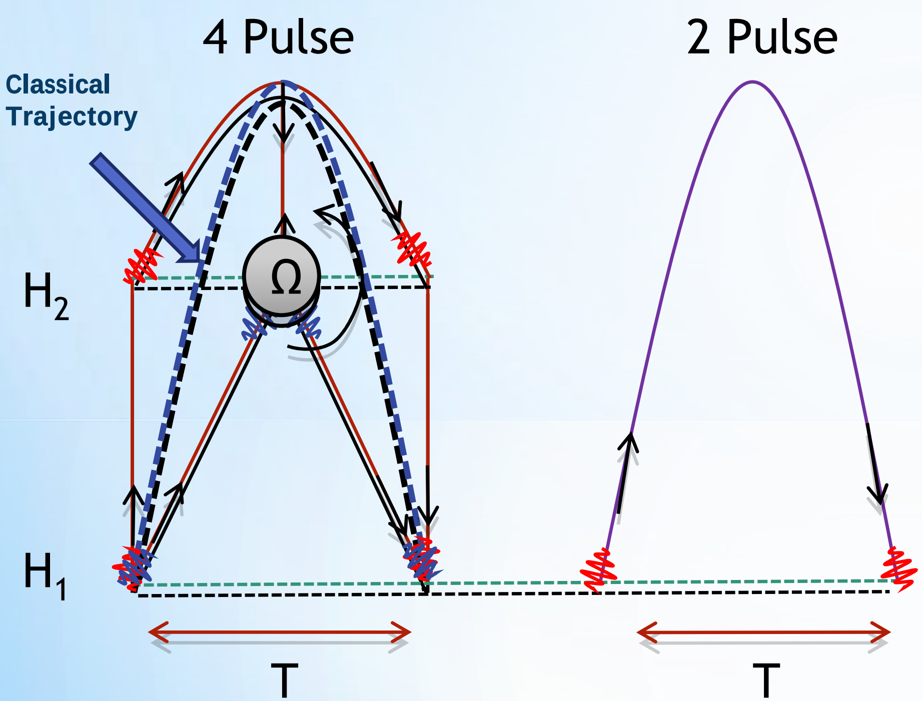
Short term Limitation:
Under-sampled Parasitic Vibration Noise

We lose information

No-Dead-Time:
No loss of Information

Testing as a Fountain Clock

Useful for Inertial Navigation

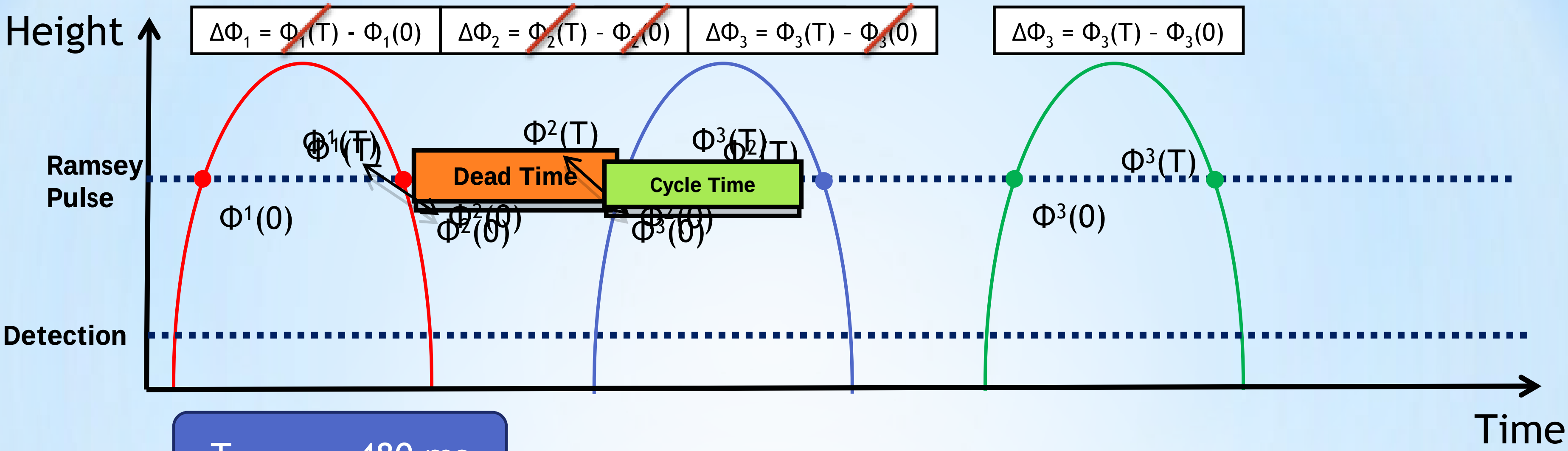


Inertial Noise in Gyro
=
Local Oscillator Noise in Fountain Clock

Average faster to Intrinsic Fundamental Noise

Working with No Dead Time

Meunier and Dutta et al.
Phys. Rev. A **90**, 063633 (2014)



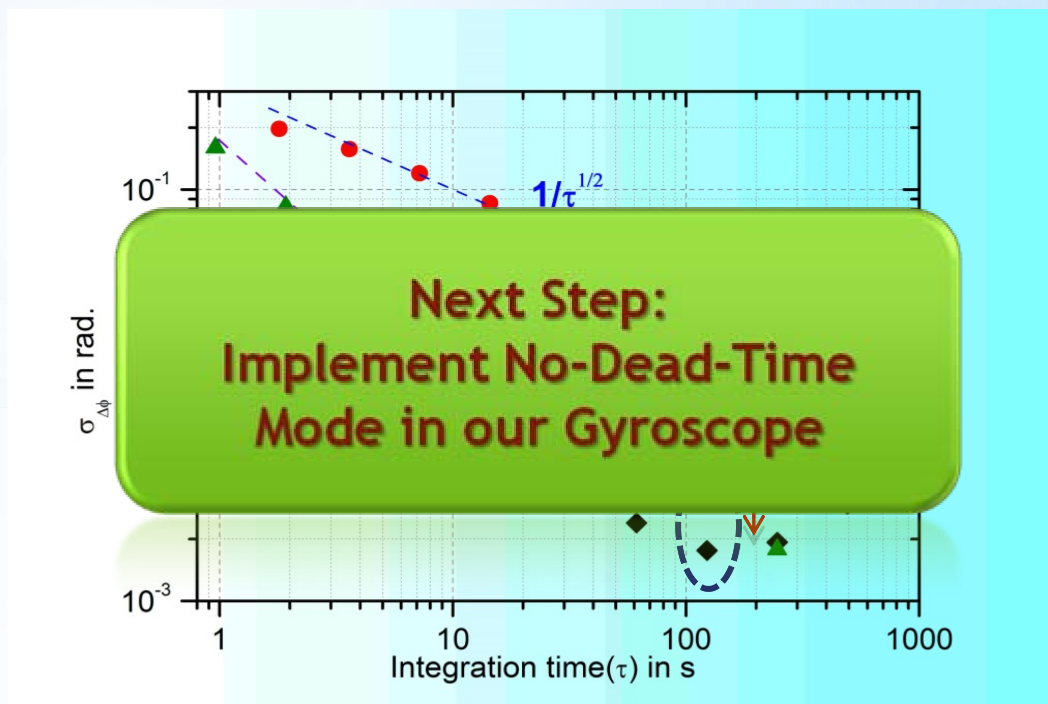
T_{Ramsey} = 480 ms

Fundamental Noise Limit

With Added Phase Noise

With Added Noise and No Dead Time

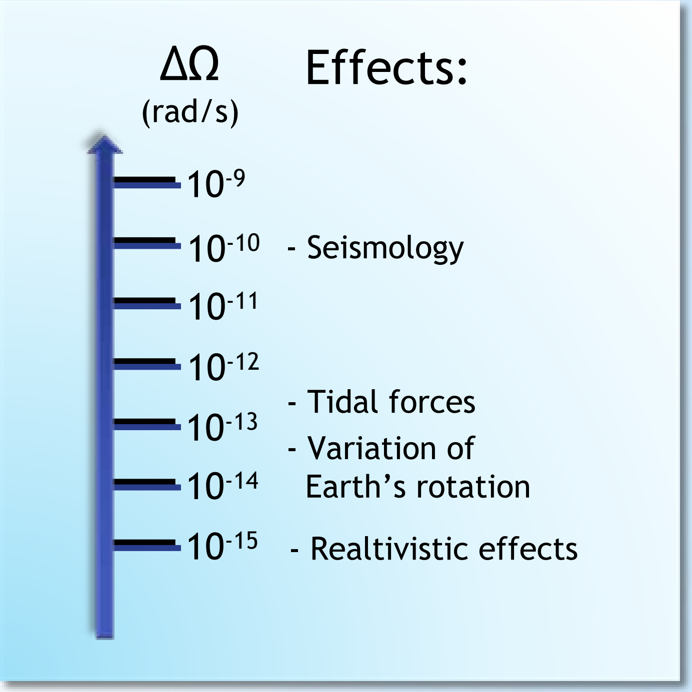
Average faster to Fundamental Noise



**Next Step:
Implement No-Dead-Time Mode in our Gyroscope**

Stability Comparisons and Future Prospects

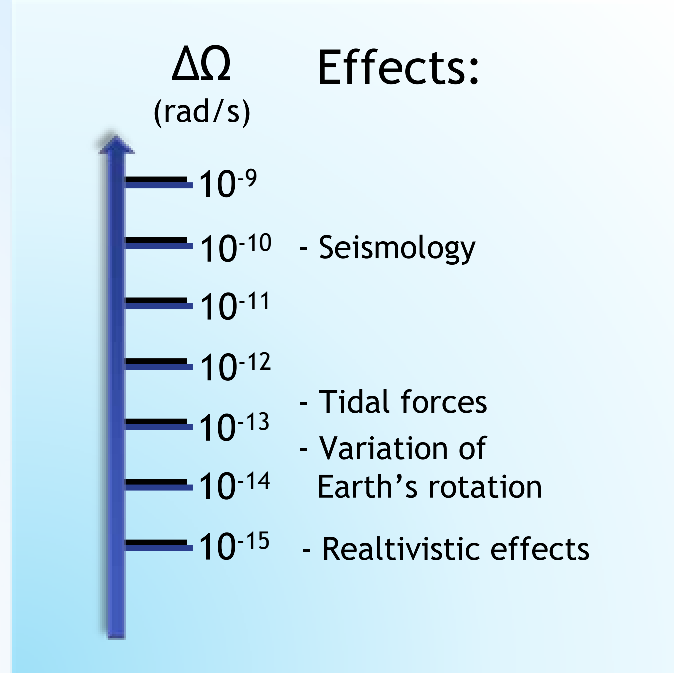
Type of Gyro	Research Group/ Industry	Area	Long term stability (rad/s)	Integration time
Atomic	SYRTE Gryo (Old Set Up) (2009)[1]	20 mm^2	1×10^{-8}	~15 mins
	SYRTE Gyro (New Set Up) (2014)	**2.4 cm^2**	**2.6×10^{-9}**	**~30 mins**
	< 10^{-8} rad/s in 1 sec	**11cm^2**	**< 10^{-10}**	**~30 mins**
Optical	Fiber Optic Gyro (IXBLUE) (FR) (2014) [2]	3 km Long Fiber in loops	5×10^{-11}	38 days
	Ring Laser Gyro (DE) (2014) [3]	16 m^2	6×10^{-13}	2 hours



[1] Gauguet et al., PHYSICAL REVIEW A 80, 063604 (2009)
[2] LEFEVRE, IXBLUE, Comptes Rendus Physique (2014)
[3] Schreiber et al.,IOPScience, Quantum Electronics, (2014)

Stability Comparisons and Future Prospects

Type of Gyro	Research Group/ Industry	Area	Long term stability (rad/s)	Integration time
Atomic	SYRTE Gryo (Old Set Up) (2009)[1]	20 mm^2	1×10^{-8}	~15 mins
	SYRTE Gyro (New Set Up) (2014)	**2.4 cm^2**	**2.6×10^{-9}**	**~30 mins**
	< 10^{-8} rad/s in 1 sec	**11cm^2**	**< 10^{-10}**	**~30 mins**



Larger Area
+
No-Dead-Time Mode
+
Real Time Rotation Signal

→

Large Area Atom Gyroscope: Extremely Precise and Stable

[1] Gauguet et al., PHYSICAL REVIEW A 80, 063604 (2009)
[2] LEFEVRE, IXBLUE, Comptes Rendus Physique (2014)
[3] Schreiber et al.,IOPScience, Quantum Electronics, (2014)

End Remarks

Large Area Atomic Gyroscope Scheme

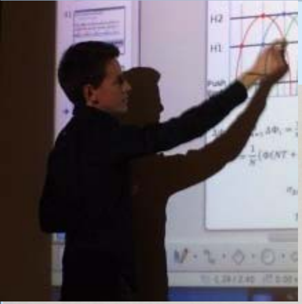
Extracting Signal from Vibration Noise

Best Precision and Stability with 2.6 ppb of 1 rad/s in ~30 mins

Towards a Standard with bigger area:
11 cm^2 area
(2T = 800 ms)

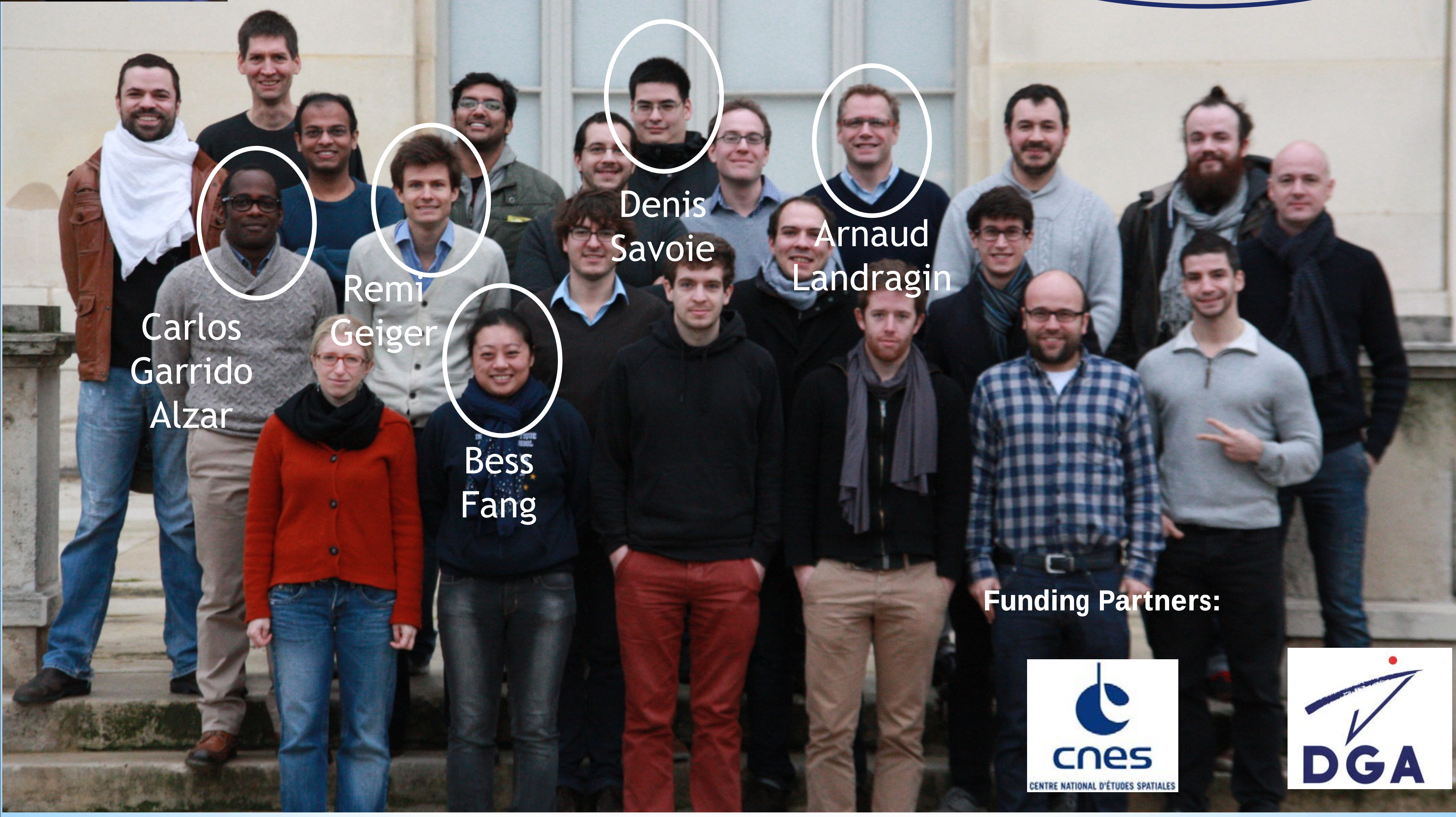
Way to Improvement:
Real Time Signal & No Dead Time

Future prospects: Improvement methods for our Gyroscope



Matthieu
Meunier

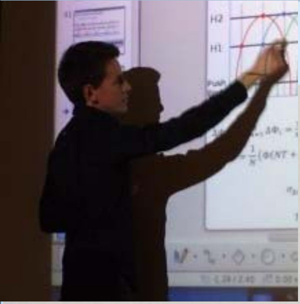
Team:
Atom Interferometers
and Inertial Sensors



Funding Partners:

cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES

DGA



Team:
Atom Interferometers
and Inertial Sensors

THANK YOU

Funding Partners:

CNES
CENTRE NATIONAL D'ÉTUDES SPATIALES

DGA