



Sensing and Awareness in Microsystems

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Chip-Scale Atomic Devices

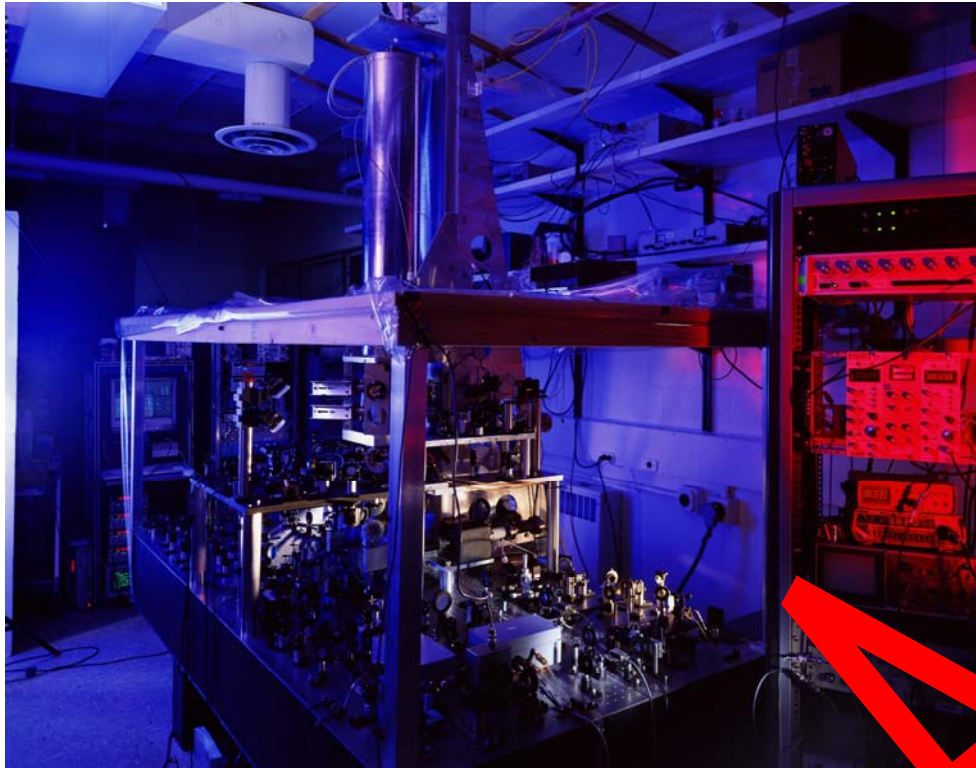
Precision Instruments based on
Lasers, Atoms and MEMS

John Kitching

Time and Frequency Division
NIST

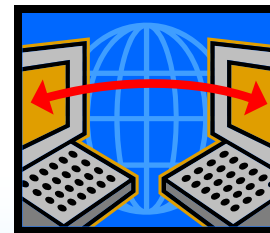
Microsystems Technology Symposium
San Jose, CA, March, 2009

Atomic Clocks

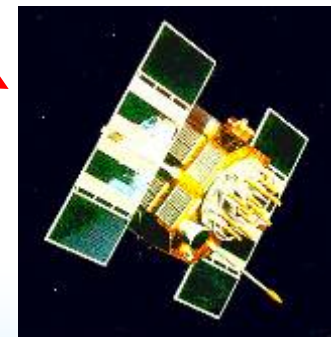


NIST F-1 Primary Atomic Frequency Standard

- Time: most accurately measured physical quantity
- NIST: most accurate clock in the world
 - Frequency uncertainty $\sim 4 \times 10^{-16}$
 - Timing instability < 1 ns over 1 week



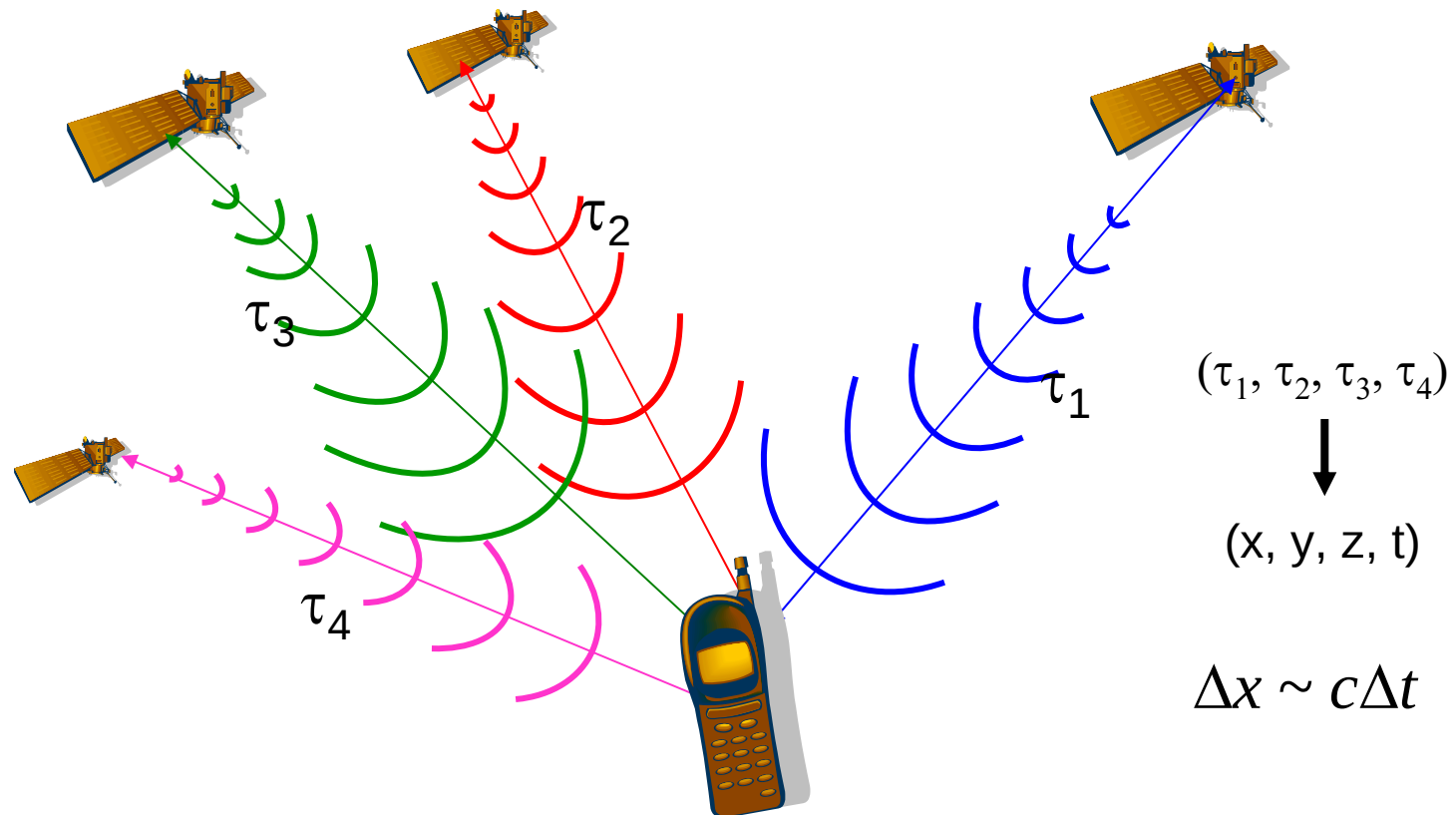
Telecom Sync



GPS System

Precision is a Big Deal

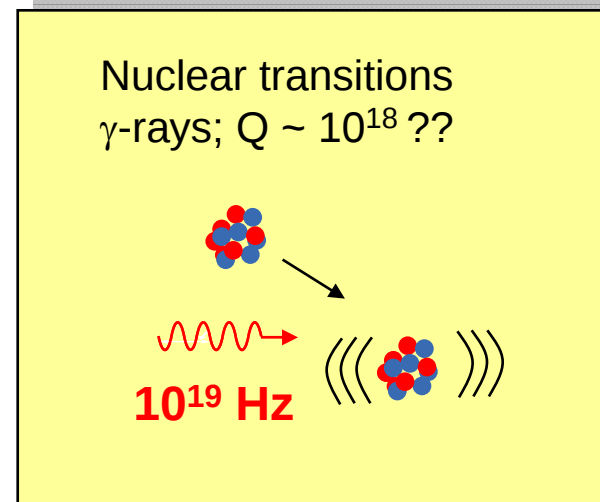
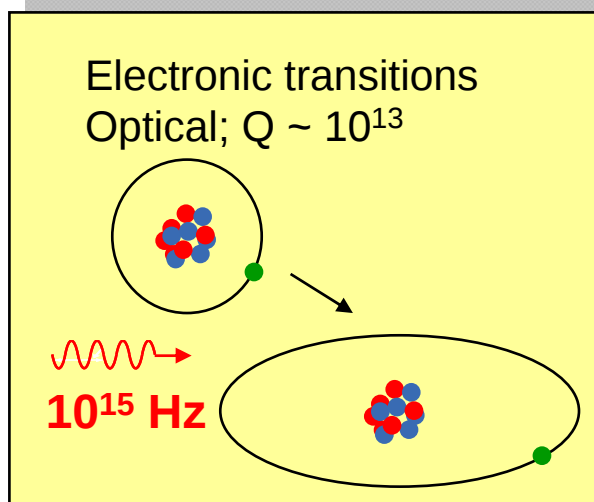
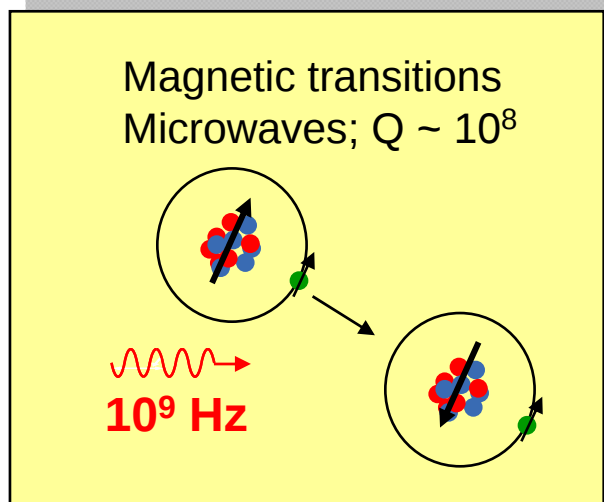
- Speed of light: 30 cm/ns



- Positioning to 1 m $\Rightarrow$ ns timing required
- Positioning to 1 mm $\Rightarrow$ ps timing

Origin of the Precision?

- High frequencies, long coherence times

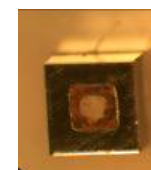
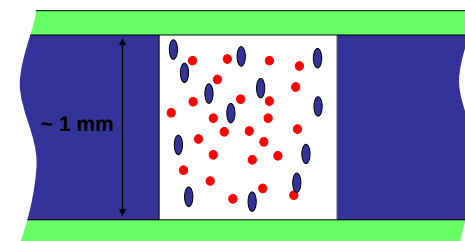
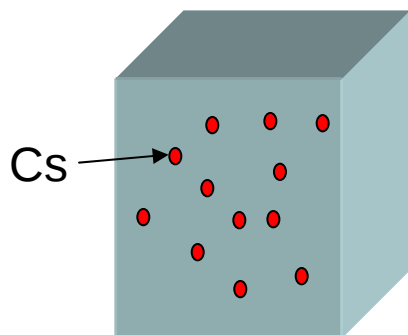


- High signal-to-noise
 - Spectroscopic measurements and/or large numbers of atoms
 - As high as 10^7 @ 1 sec
- Insensitive to environment

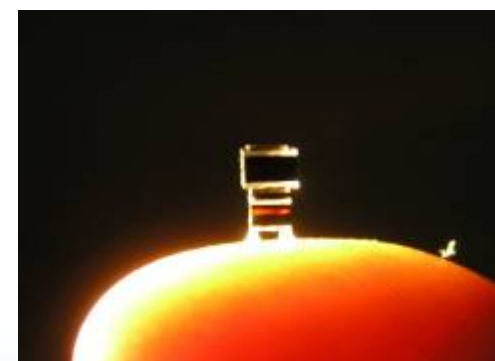
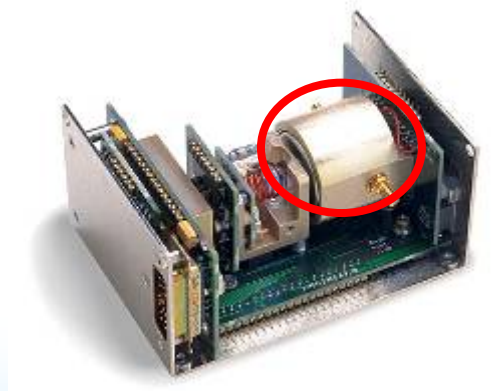
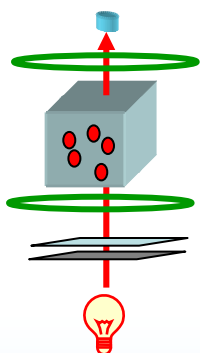


MEMS Fabrication

- Alkali atom vapor cells



- Atomic clock physics packages

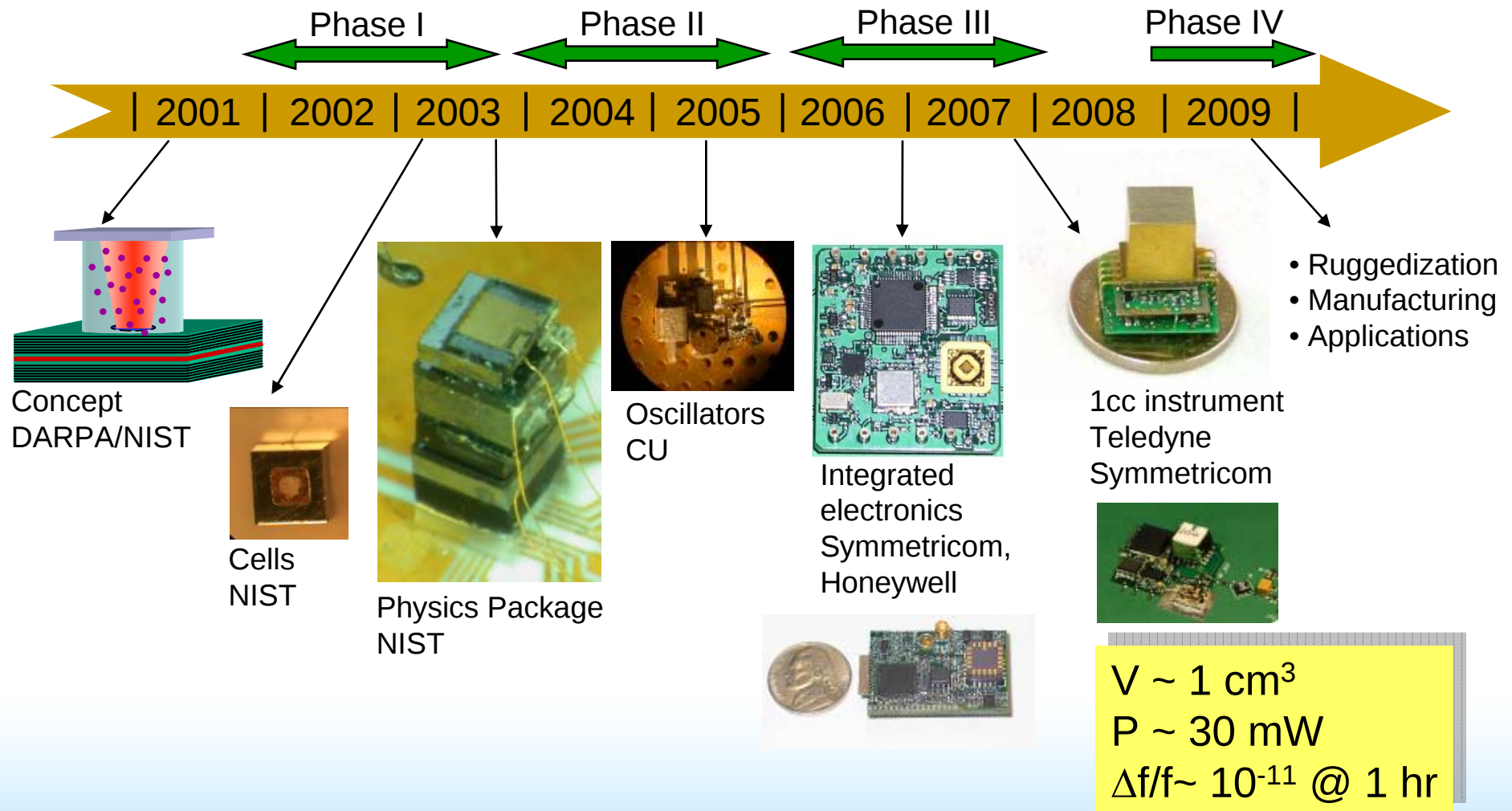




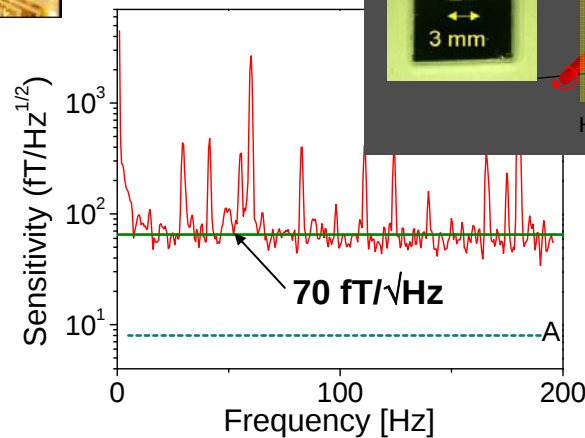
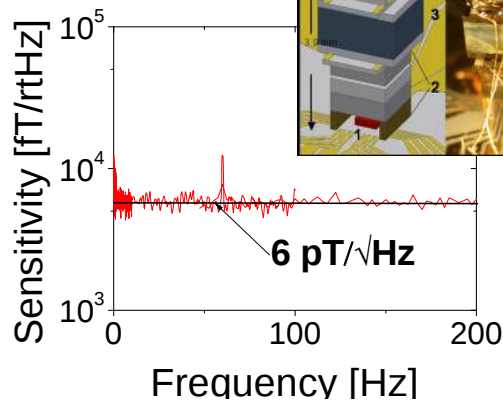
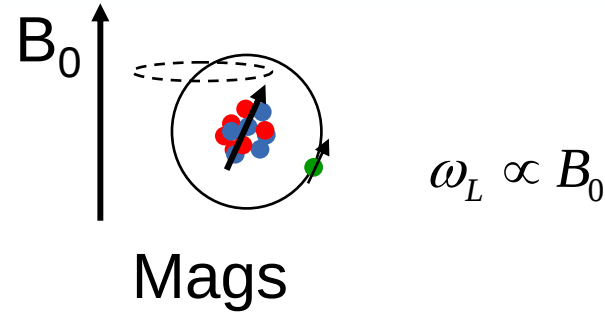
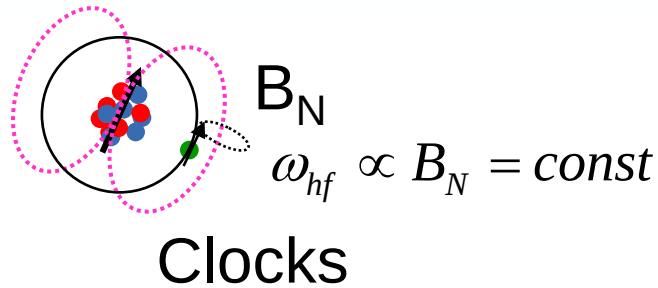
CSAC Program



Guided by: Bill Tang ... Clark Nguyen ... Amit Lal ...

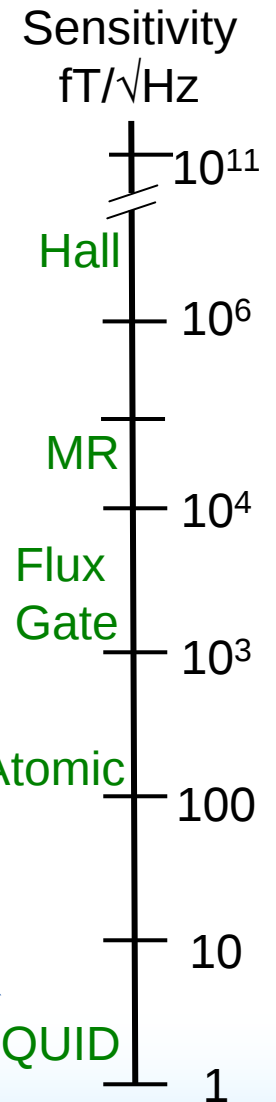


Beyond CSAC: Magnetometers



SQUID sensitivity

~~Cryogenics~~

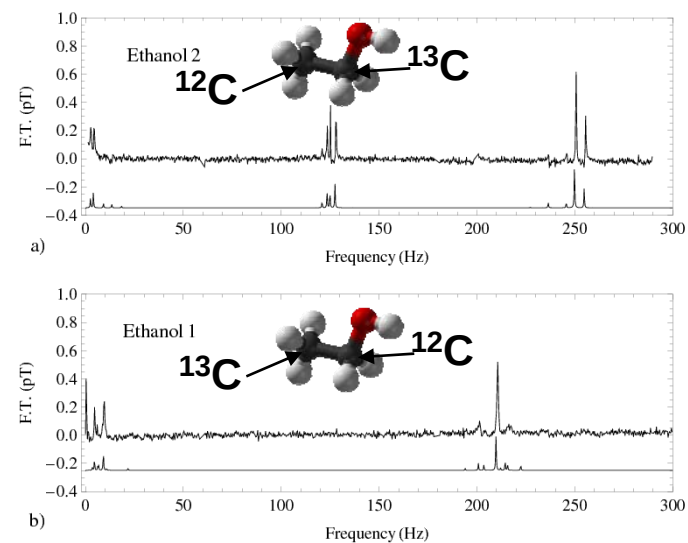
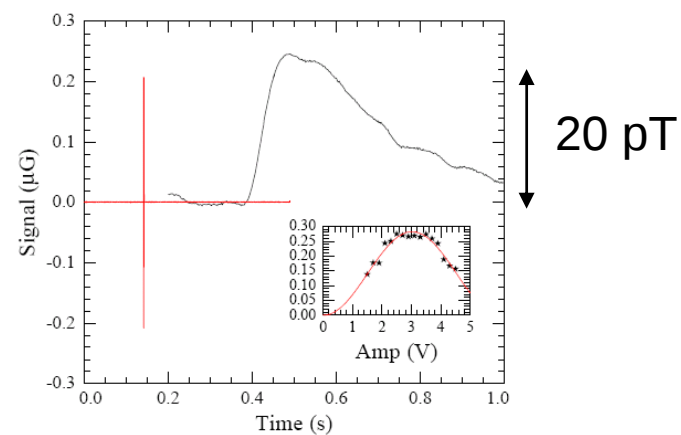


Microfluidic NMR



With A. Pines, D. Budker, UC-Berkeley

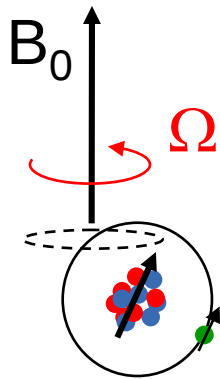
M. Ledbetter, et al., PNAS, **105**, 2286, 2008



NMR at zero field: simple spectra, compact apparatus

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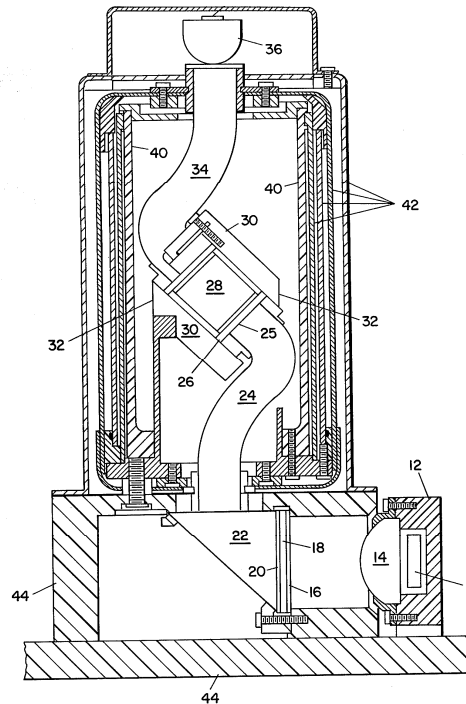
Beyond CSAC: Gyroscopes



$$\omega_L = \gamma B_0 + \Omega$$

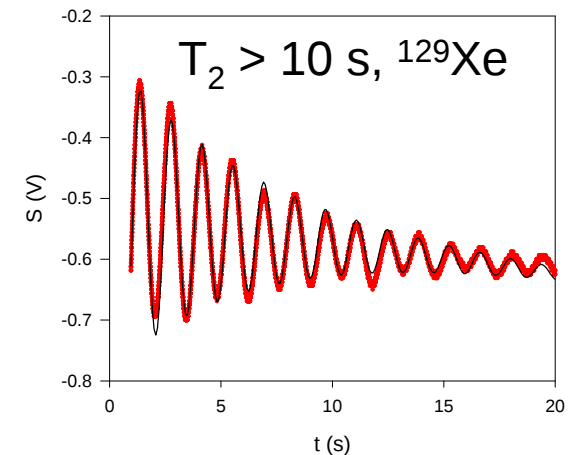
Nuclear spins

- Longer coherence time
- Lower field sensitivity
- ^{129}Xe , ^{21}Ne , ^{199}Hg ...
- Read out precession with alkali magnetometer



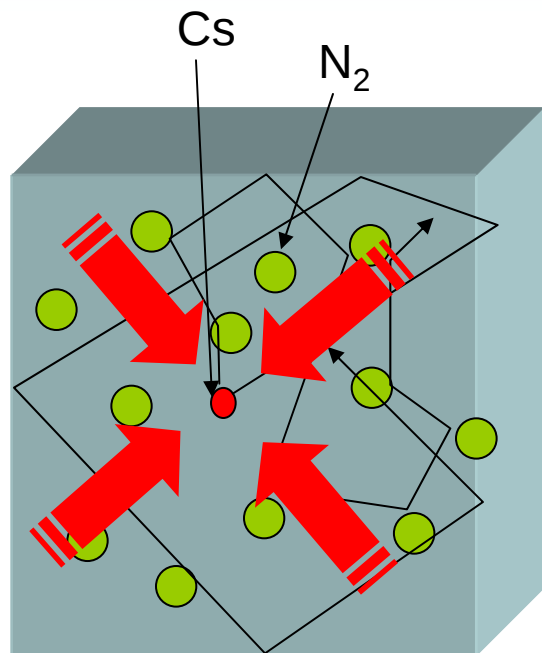
Litton, 1979
1000 cm³, 0.1 °/hr

+ MEMS



NGIMG:
1 cm³, 5 mW, Nav-grade

Laser-Cooled Atoms



$V_{at} \sim 500 \text{ m/s} \rightarrow 1 \text{ cm/s}$
 $\sim 1 \mu\text{s/cm} \rightarrow T_c \sim 1 \text{ s}$

- Wall coatings
- Buffer gases
- Laser cooling

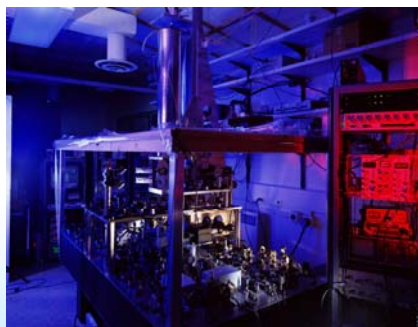
Nobel Prize (1997)
C. Cohen-Tannoudji,
W. D. Phillips, S. Chu

Fountain clocks
Atom interferometers

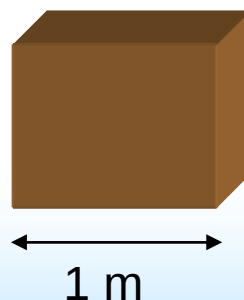
- Gyros
- Gravimeters, accelerometers
- Magnetometers

Bose-Einstein condensates

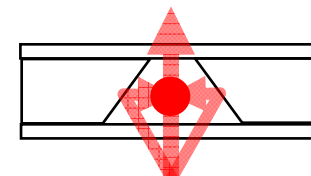
$\Delta t/t \sim 10^{-16}$
 $\Delta\Omega/\Delta t \sim 10^{-6} \text{ }^\circ/\text{hr}$
 $\Delta x/\Delta t \sim 5 \text{ m/h}$
 $\delta B/dx \sim 10 \text{ fT}/\sqrt{\text{Hz/mm}}$




 gBECi
 PINS
 (DSO)



w/ MTO ?

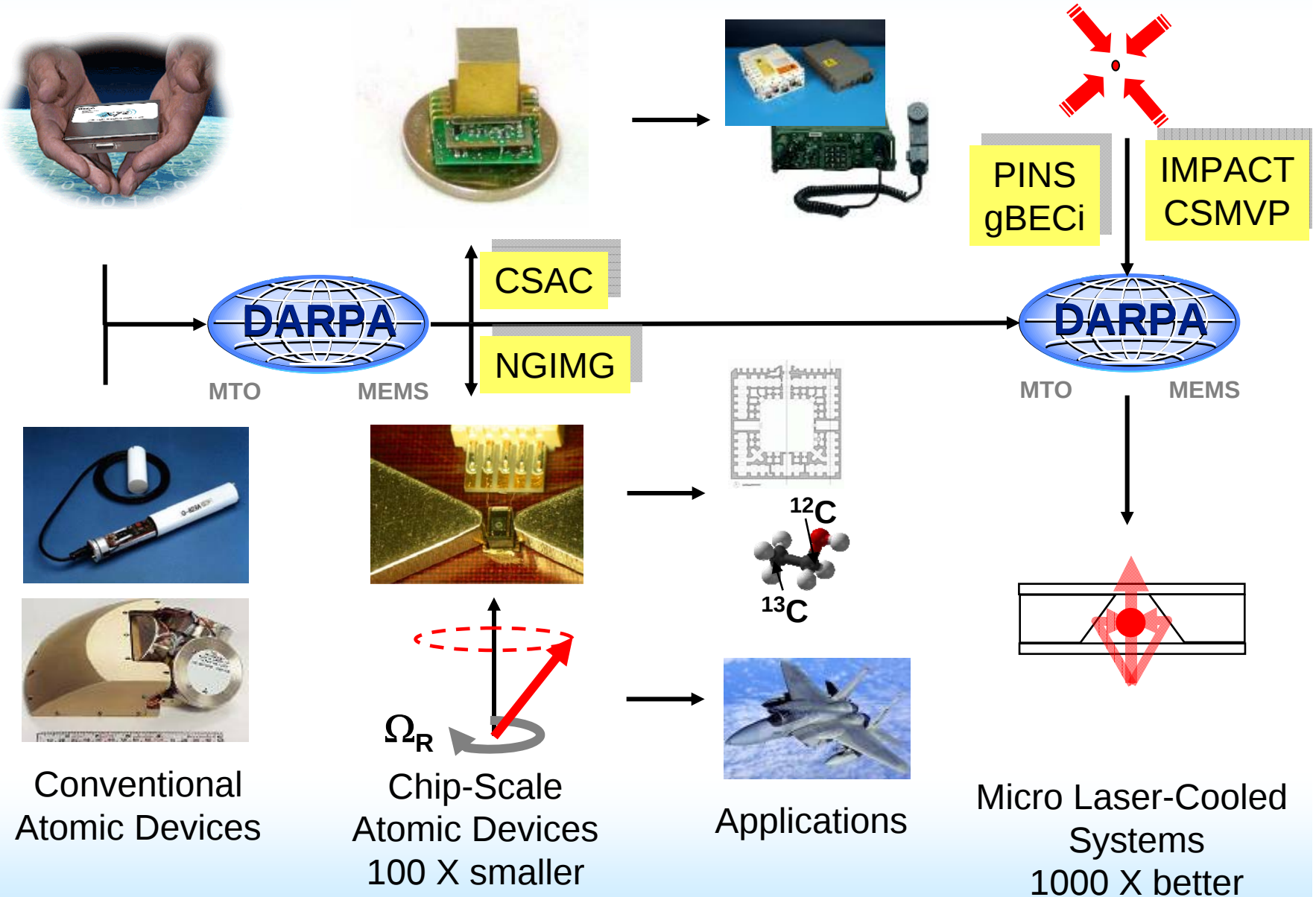


1 cm ?
 5 mW ?



IMPACT, CSVMP

Chip-Scale Atomic Devices: 2001-2009

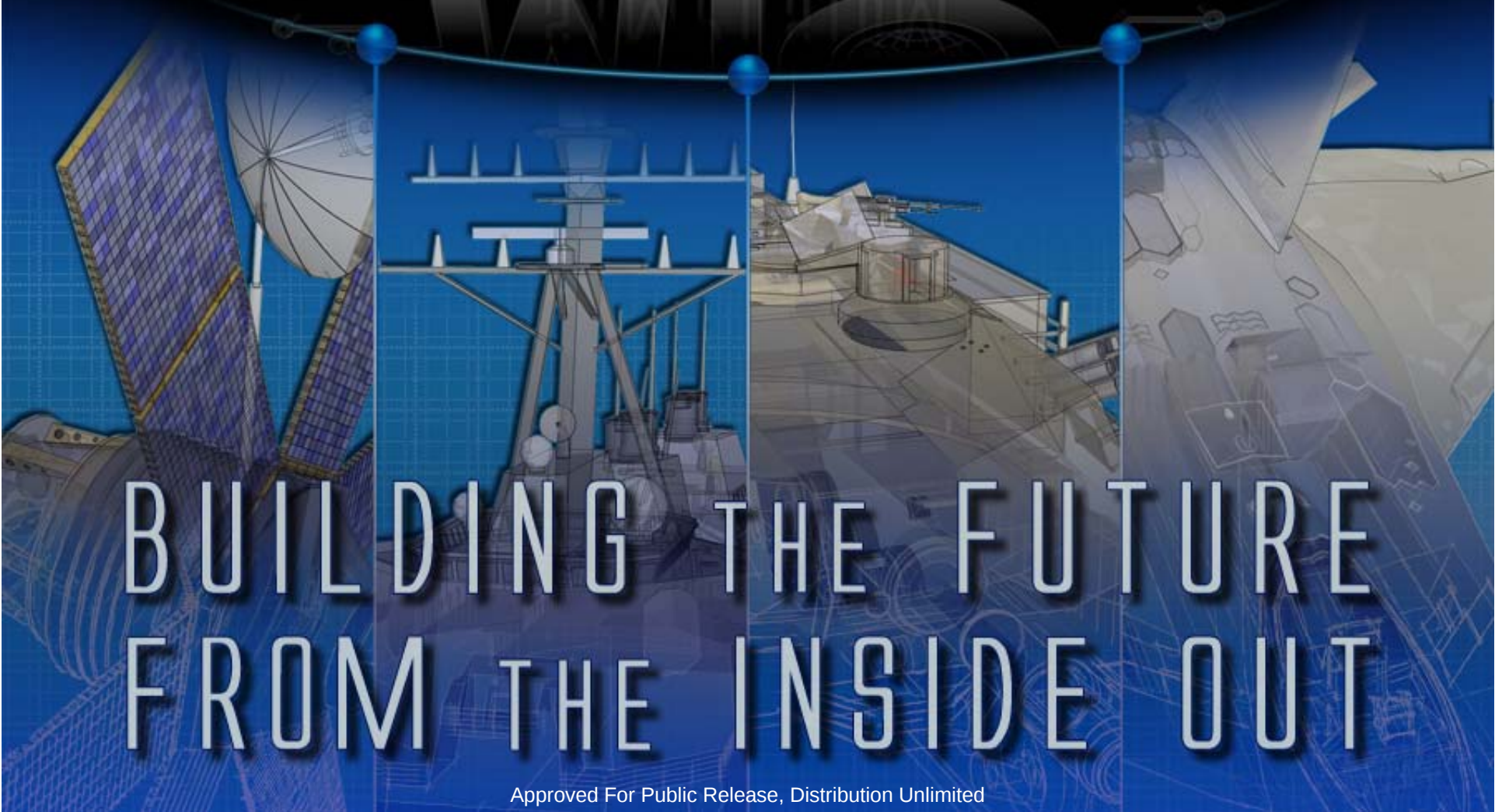


MICROSYSTEMS TECHNOLOGY OFFICE

MTO SYMPOSIUM

The logo for the Microsystems Technology Office (MTO) Symposium. It features the letters 'MTO' in a large, bold, metallic font. A globe with the word 'DARPA' on it is integrated into the 'O'. Circuit traces extend from the 'M' and 'O'. Below 'MTO' is the word 'SYMPOSIUM' in a smaller, white, sans-serif font. The entire logo is set against a dark background with a reflection effect below it.

BUILDING THE FUTURE
FROM THE INSIDE OUT

The background of the poster is a collage of various technological and infrastructure elements. On the left, there's a large satellite dish and a solar panel array. In the center, a complex antenna structure is visible. On the right, there's a detailed view of a ship's deck with various equipment. The entire background is overlaid with a blue grid pattern and connected by a thin blue line with three blue spheres at the top.

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