The University of Western Australia, School of Physics
Frequency and Quantum Metrology Research Group

- **Core membership**
- Michael Tobar
- Eugene Ivanov
- John McFerran
- Sascha Schediwy
- Jean-Michel Le Floch
- Yaohui Fan
- Daniel Creedon
- Stephen Parker
- Maxim Goryachev

- **Postgraduate students**

- Warwick Farr
- Romain Bara-Maillet
- Jeremy Bourhill
- Nikita Kostylev
- Natalia Carvalho
- Akhter Hoissan

THE UNIVERSITY OF WESTERN AUSTRALIA

TESTING LORENTZ INVARIANCE AND FUNDAMENTAL CONSTANTS WITH PRECISION CLOCKS AND OSCILLATORS

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1) Future plans in Western Australia for contribution to ACES
2) Rotating Michelson Morley Experiment from UWA to Berlin
3) Experiments at SYRTE Paris

UWA Contribution to ACES: Past Contributions

- Since 2000 the Australian Research Council has supported the FSM labs on research related to ACES
- Developed precision frequency technology
- Developed Expertise in testing Fundamental Physics
- 2000-2012 $4.5M for 8 projects in related research

- LONG TERM GOAL : To become the Southern Hemisphere hub for Space Missions involving precision clocks

- Complicated by no space Agency, but strong support in Australia through local funding agencies

UWA Contribution to ACES: Current Contribution

- **Four ARC Projects from 2009 – 15 worth $5.1M**
- **UWA to Further Upgrade Labs in 2013 by $0.5M (Spent $0.8M)**

- ARC Linkage Infrastructure LE110100054 2011-13 Funding ARC $1,230,000 Universities $601,917

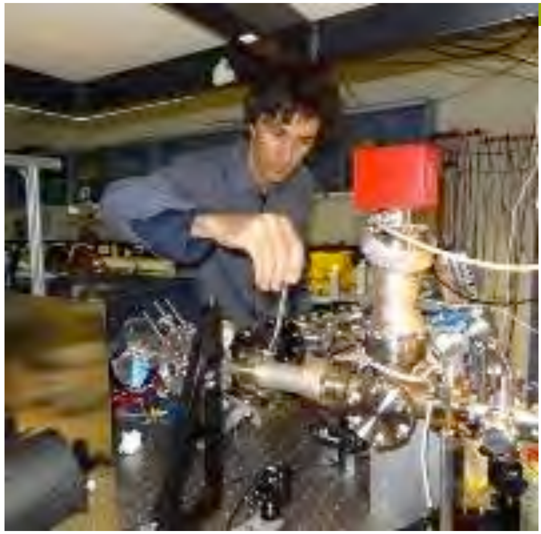
  To buy/develop infrastructure for ground station: JPL clocks and Yb Lattice clock
- Tobar ARC Laureate Fellowship FL0992016 2009-1 Funding $2,200,000ARC

  Salaries for Tobar, Postdoc, Technician plus project money
- Future Fellowship (John McFerran) FT110100392 2012-2015 Funding $540,000

  Salary for McFerran plus project money
- ARC Discovery DP130100205 2013-15

  Funding $500,000

  Salary for Postdoc and project money to use ACES ground clocks at UWA to test fundamental physics



Ytterbium Lattice Clock

http://www.news.uwa.edu.au/201310046103/research/ultimate-accuracy-machine

- Vacuum system is fully assembled including the Yb oven(effusion cell), Zeeman slower, main chamber and ion + getter pumps.
- The Zeeman slower is in operation (with 399nm): the most probable velocity for the slowed group of atoms is less than 10m/s (significantly less than the designed captured velocity of the MOT ~ 50m/s)
- Can see slowing on all the bosonic and relevant fermonic isotopes
- The MOT coils are in place and maintain current.
- Presently setting up the laser beams for the MOT (399nm).
- Conservative estimate by the end 2015 -> laser locked to the clock transition (with lattice trapping), possibly sooner.

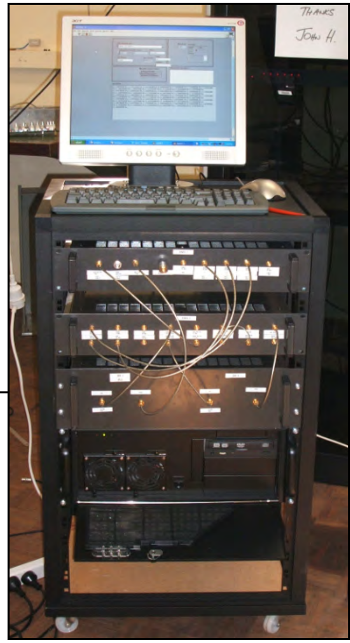
Currently at UWA site
Prior funding from ARC

GPS antenna

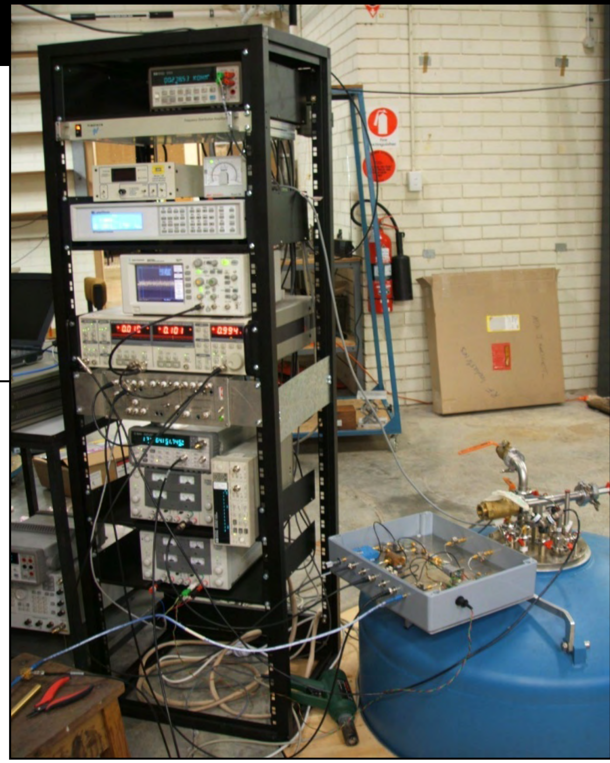
2.4 m antennaTWSTT

Kvarz H-Maser

f_{out}= 100 MHz
$\sigma_y(\tau) \sim 2.10^{-15}$
$\tau > 10^3$s
drift ~ 3.10^{-16}/day



Synthesis between H-Maser and CSO



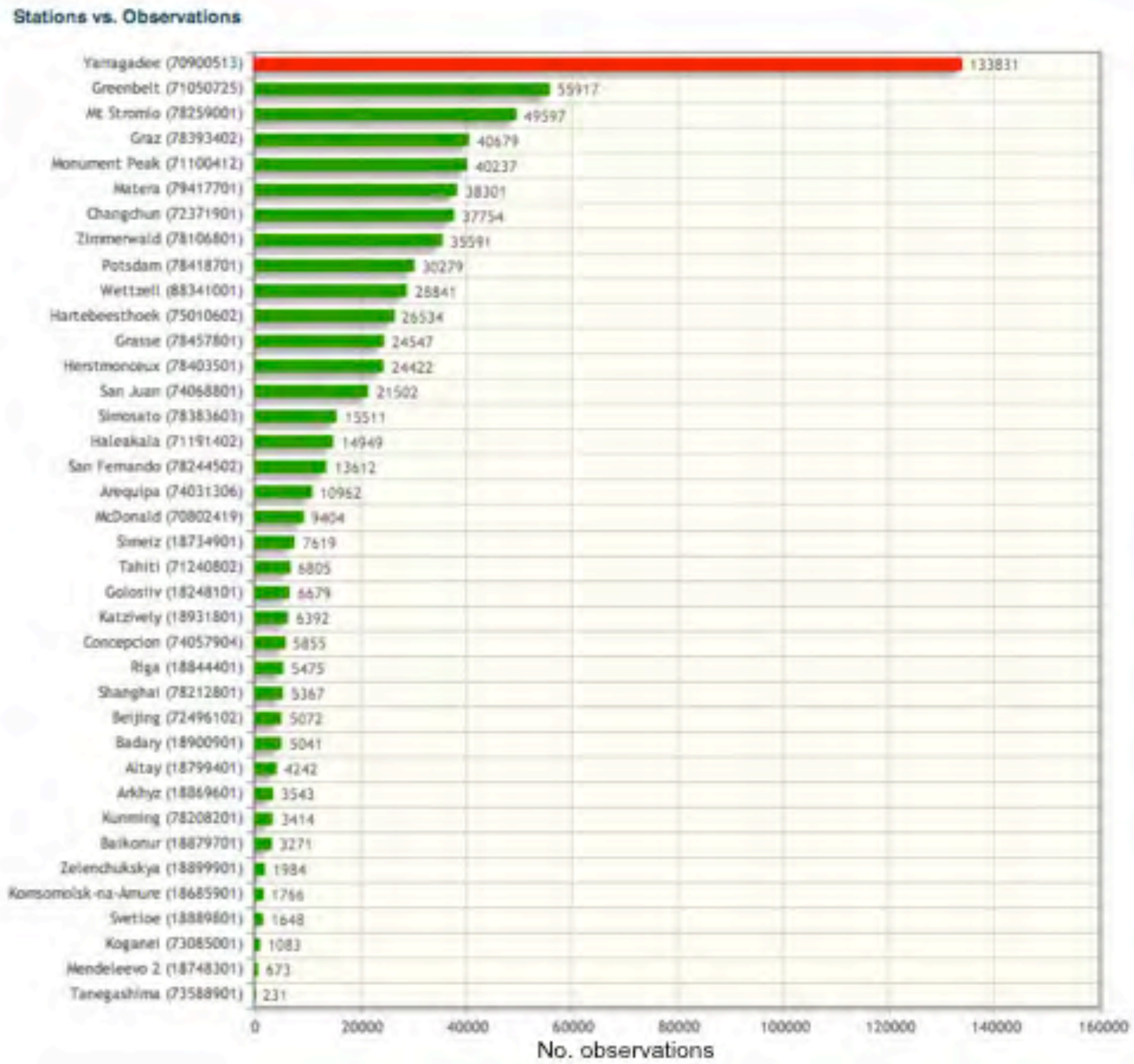
CSO

f_{out}= 11.200 GHz
$\sigma_y(\tau) < 1.10^{-15}$
$\tau < 1000$s
drift ~ 2.10^{-15}/day

New funding -> ACES Ground Station and Atomic Clocks

Reorganize Roof to install the Ground Station

Yarragadee Laser Ranging Station

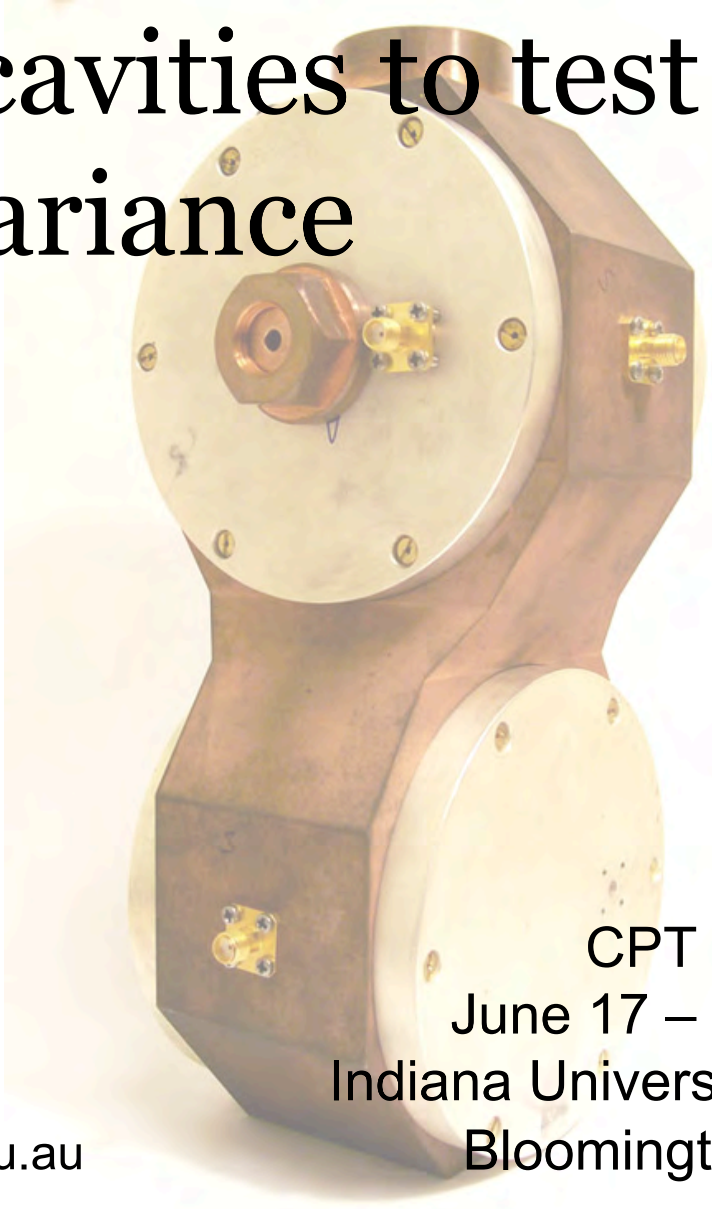


naomi.altman@uwa.edu.

Transfer over optical fibre

The University of Western Australia

Using microwave cavities to test Lorentz invariance

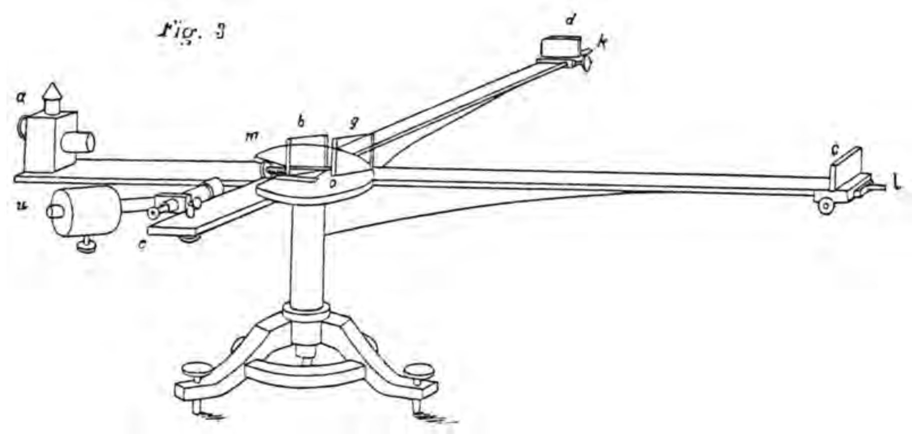


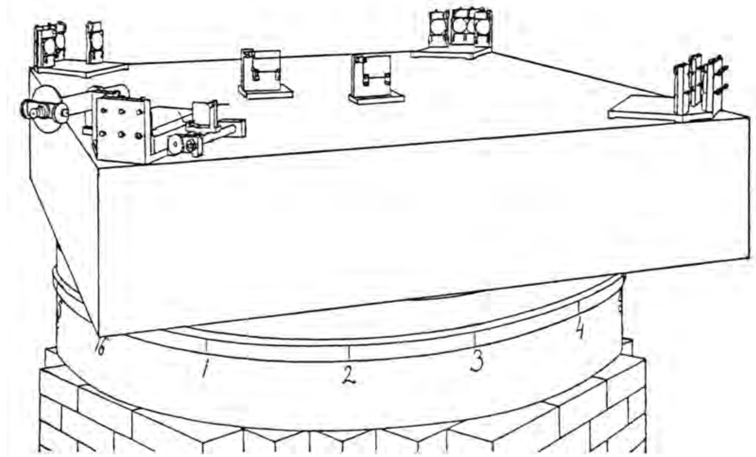
Stephen Parker, Paul Stanwix, Eugene Ivanov and others
Frequency & Quantum Metrology
School of Physics, UWA

Moritz Nagel, Evgeny Kovalchuk, Achim Peters and others
Quantum Optics & Metrology
Institute for Physics, HUB

Stephen.Parker@uwa.edu.au

CPT 13
June 17 – 21
Indiana University
Bloomington

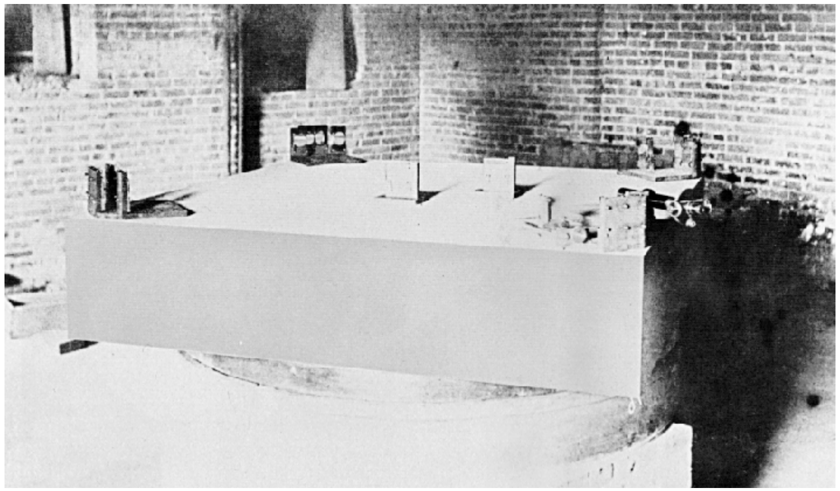




Light goes this way

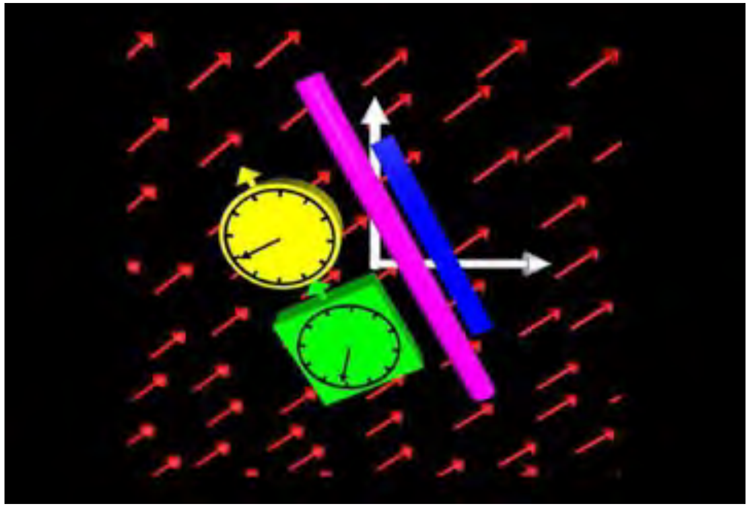
Light goes that way

Which way was faster?



Testing Relativity: Standard Model Extension (SME)

Ansatz: Extend the Standard Model of elementary particle physics by all Lorentz violating terms which leave observer transformations invariant.



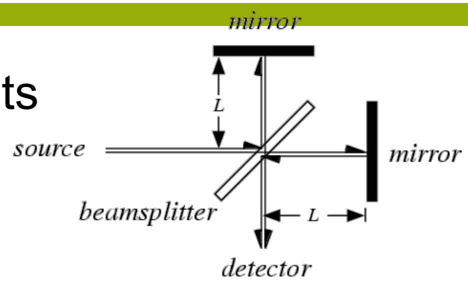
Example: $$\mathcal{L} = \underbrace{-\frac{1}{4}F^{\mu\nu}F_{\mu\nu}}_{\text{Standard}} \underbrace{-\frac{1}{4}(k_F)_{\kappa\lambda\mu\nu}F^{\kappa\lambda}F^{\mu\nu}}_{\text{Lorentz Invariance}}$$

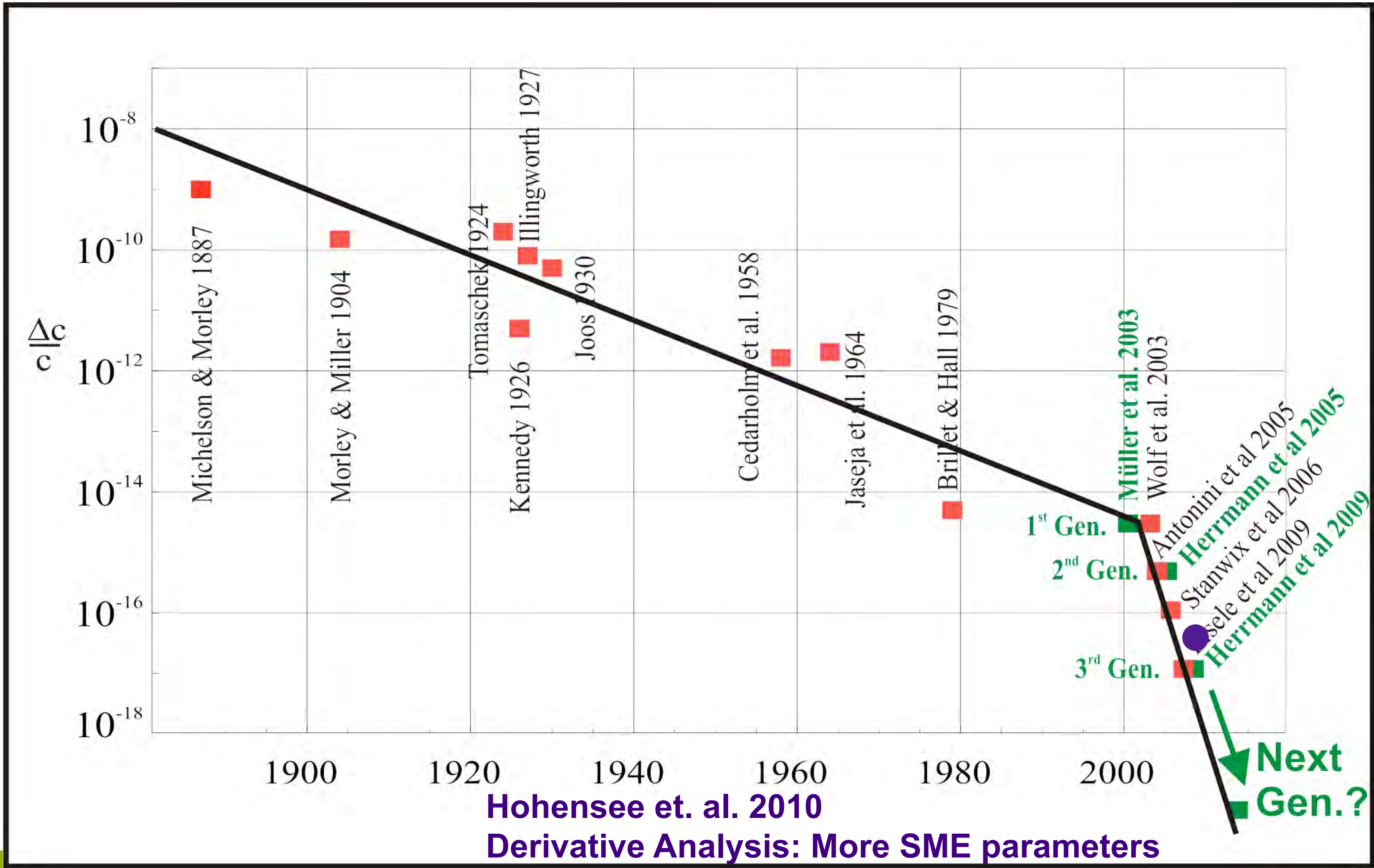
The magnitude or vanishing of these terms should give hints for structure of an unified theory!

Colladay & Kostelecký, Phys. Rev. D55, 6760 (1997),
Colladay & Kostelecký, Phys. Rev. D58, 116002 (1998)

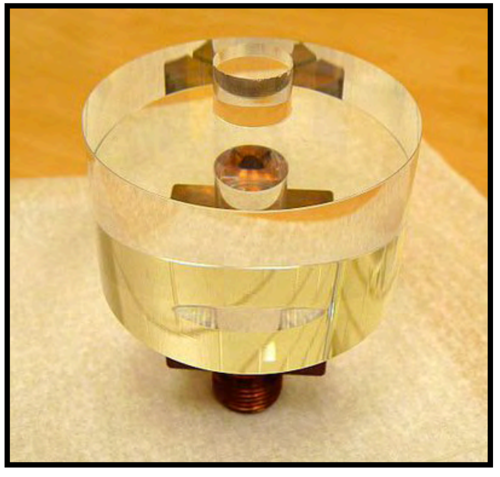
Rapid Improvements in Michelson-Morley Experiments

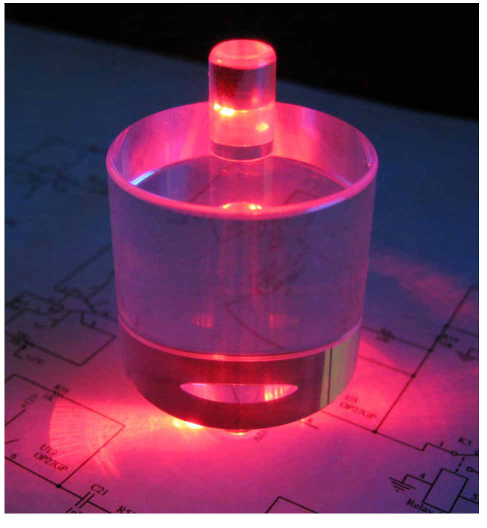
Next version will probe the Plank Scale

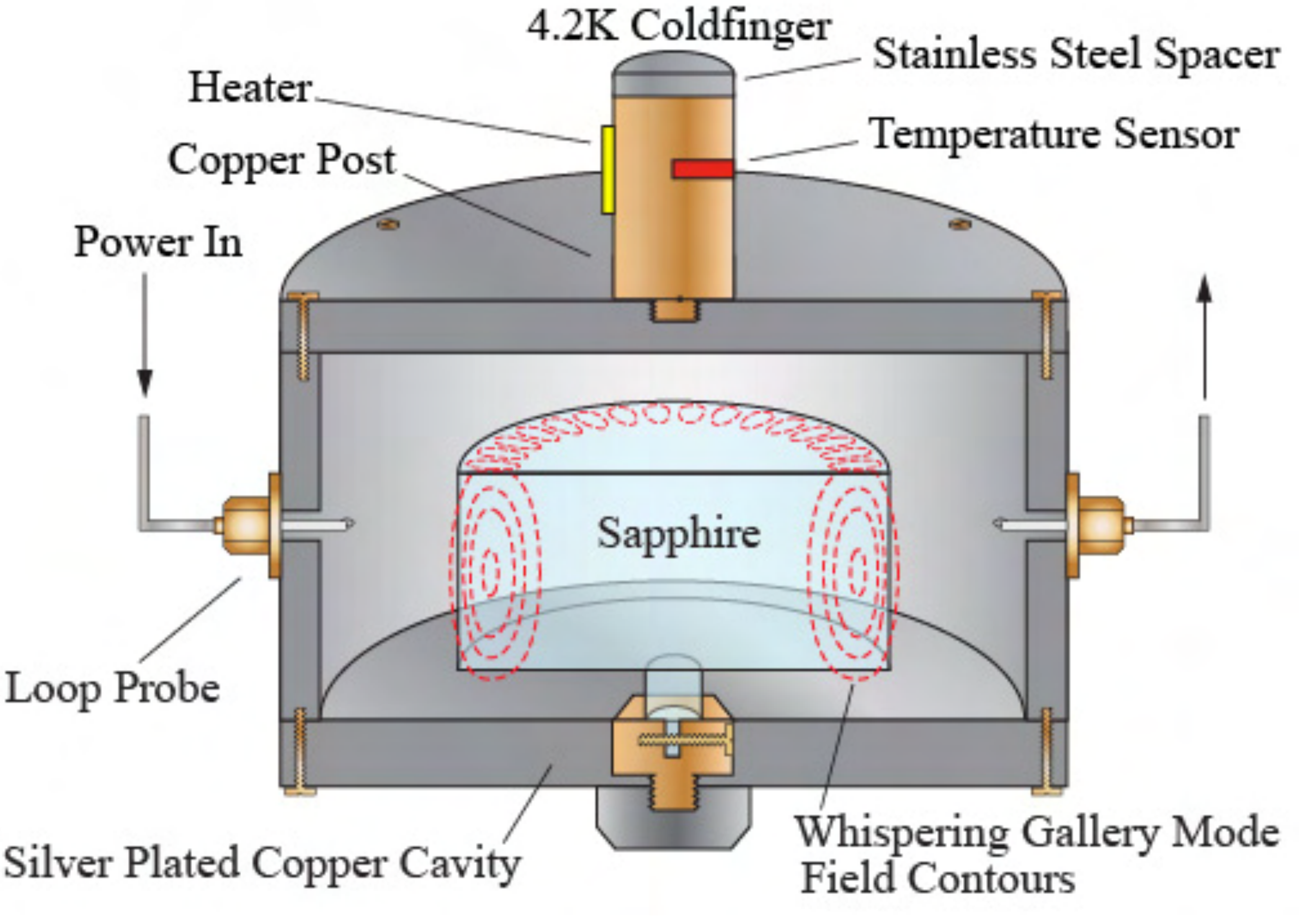




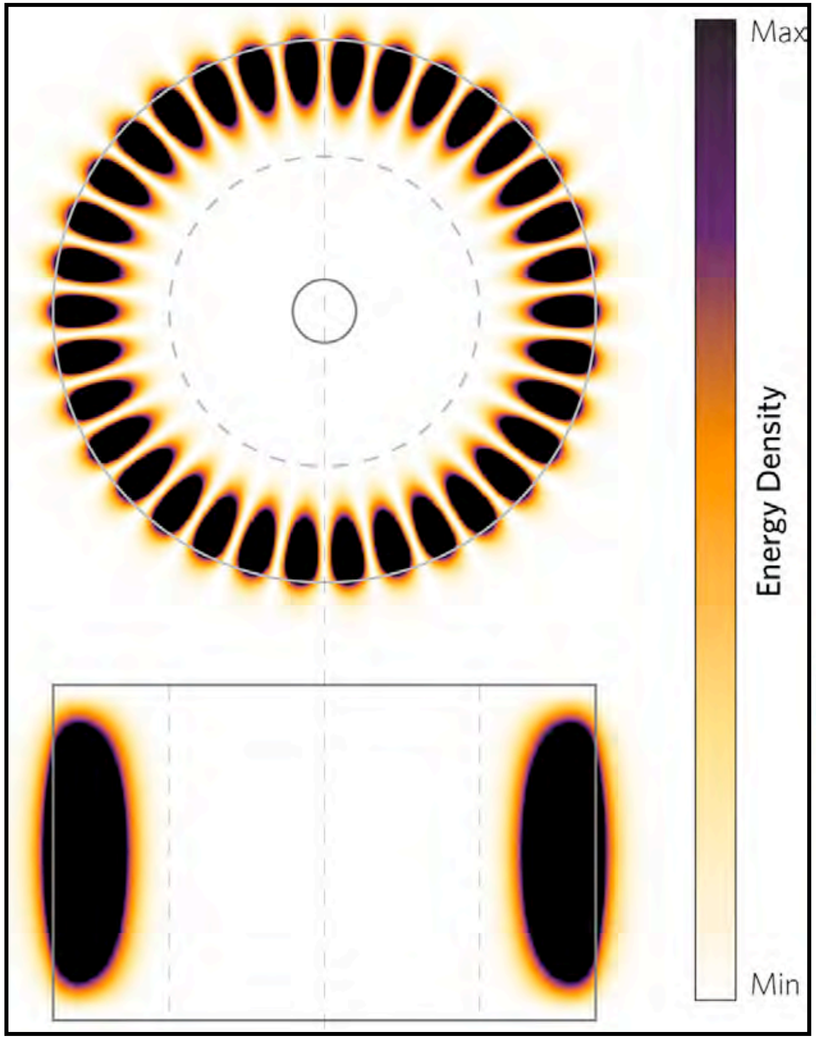
Sapphire Loaded Cavity Resonator





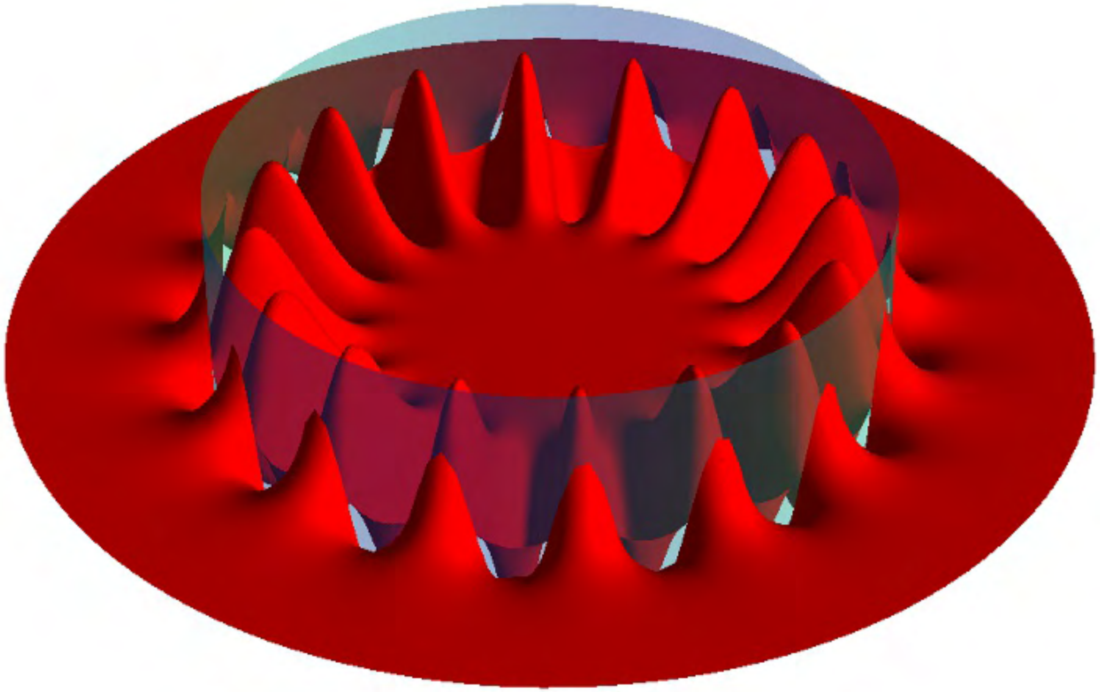


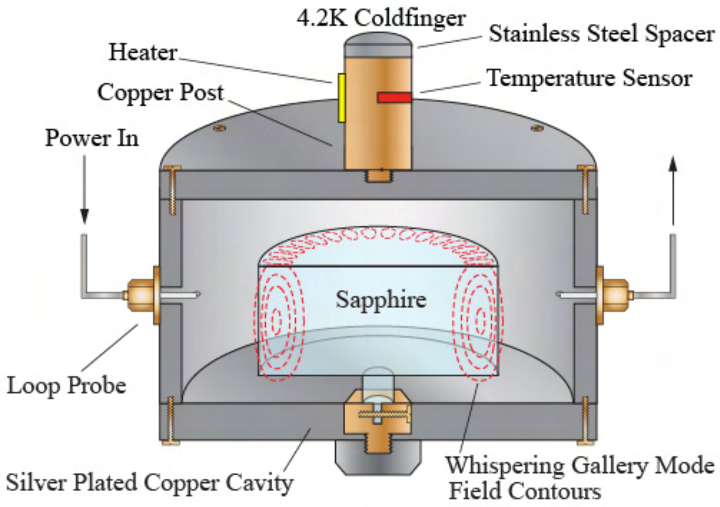
Whispering Gallery Modes in Sapphire

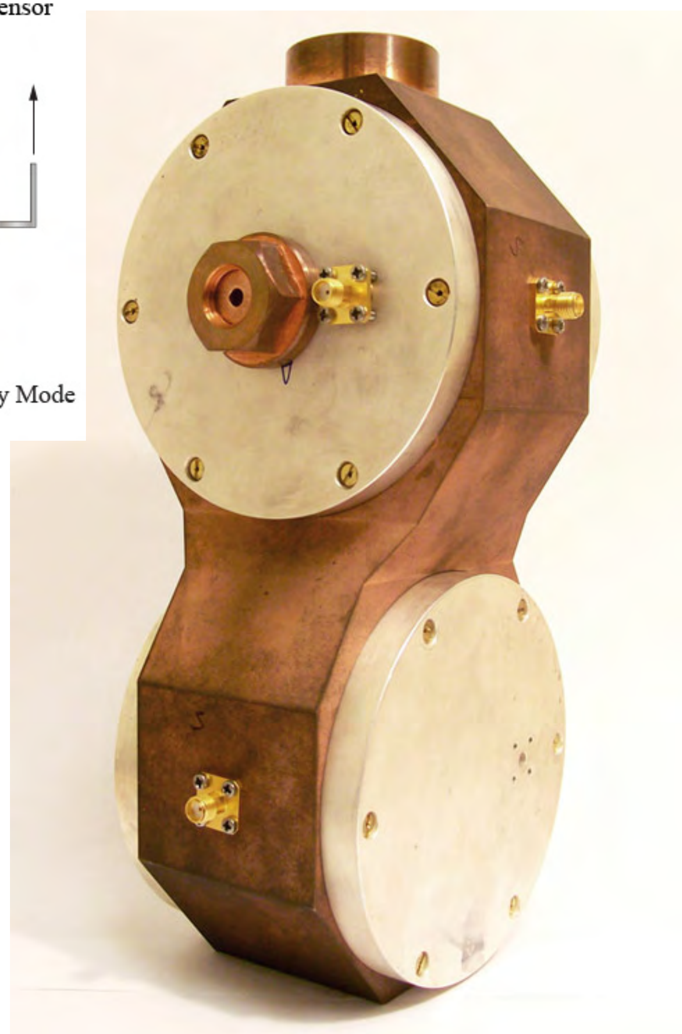


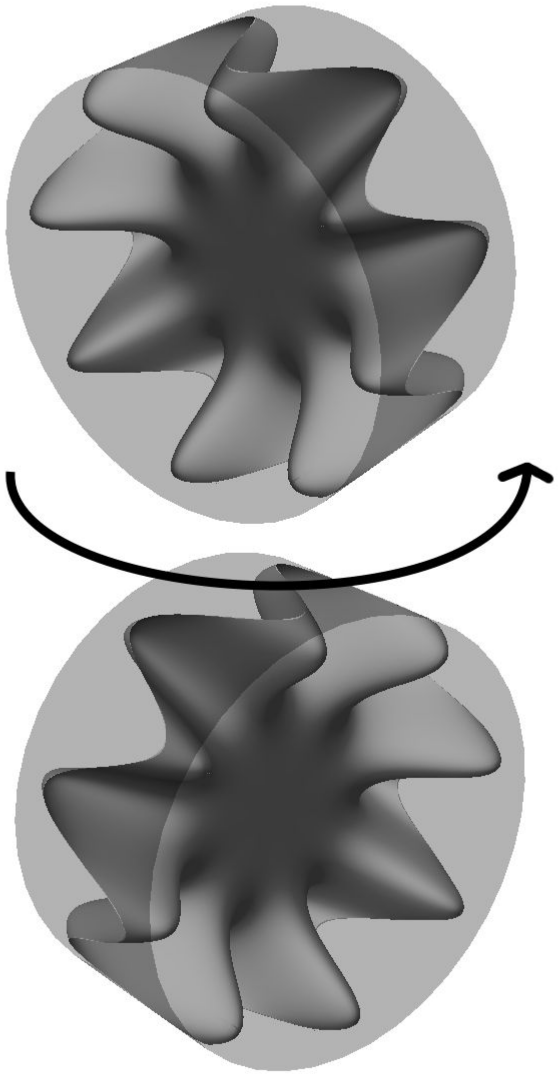
$WGH_{x,1,1}$ – transverse magnetic, Ez and Hr
$WGE_{x,1,1}$ – transverse electric, Hz and Er

WGE is more sensitive due to larger magnetic filling factor

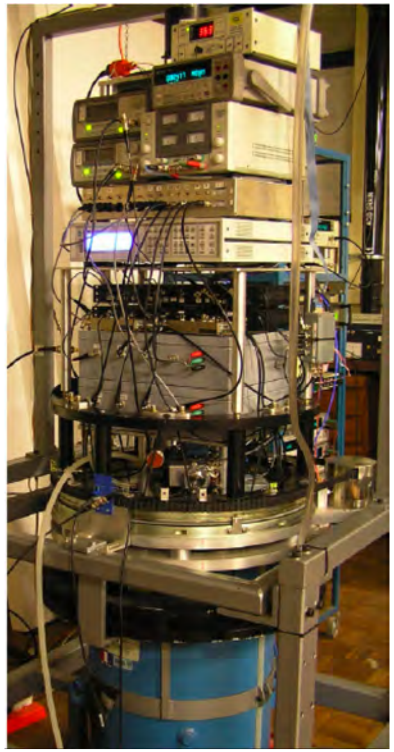


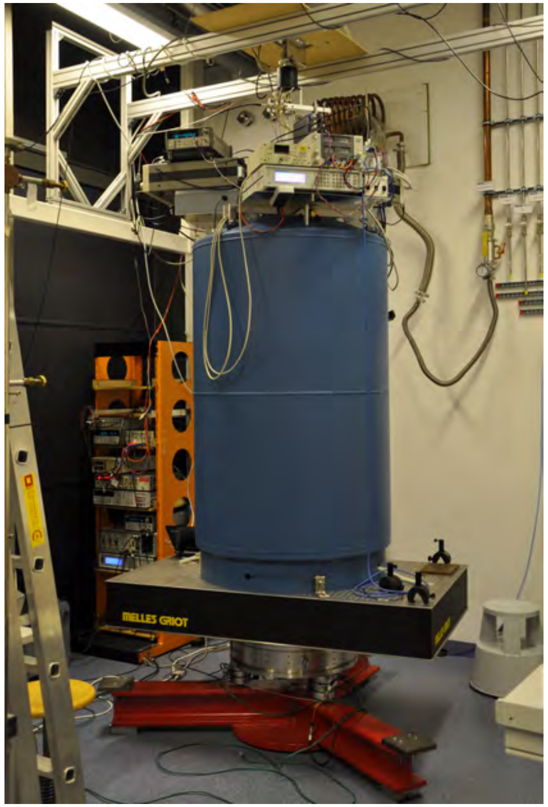

4.2K Coldfinger
Stainless Steel Spacer
Heater
Temperature Sensor
Copper Post
Power In
Sapphire
Loop Probe
Silver Plated Copper Cavity
Whispering Gallery Mode Field Contours

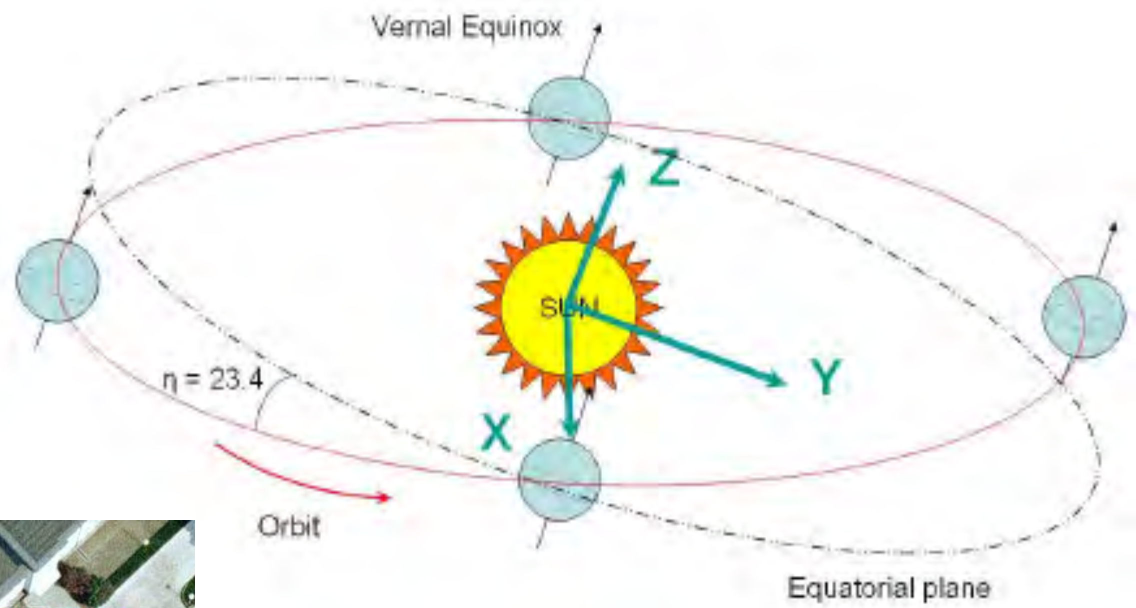


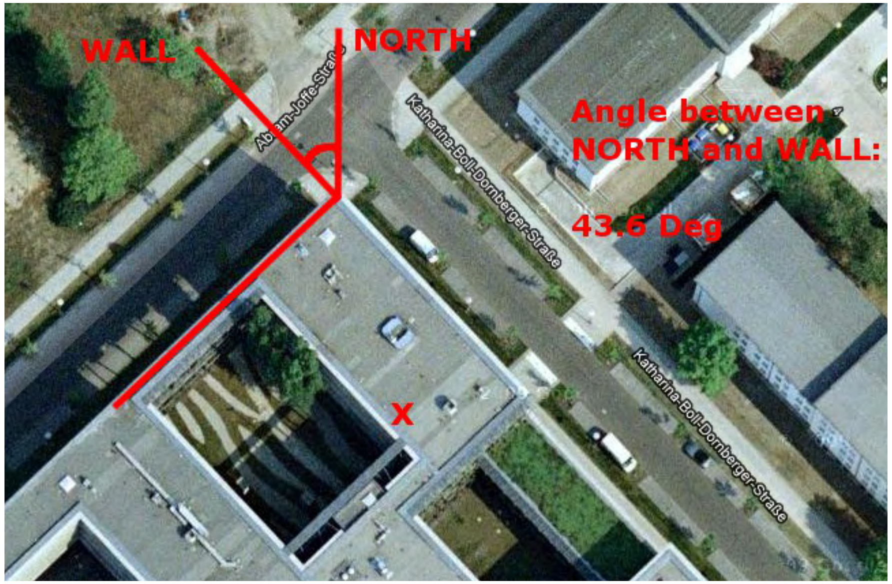


UWA rotating Michelson-Morley experiment re-visited -> Berlin



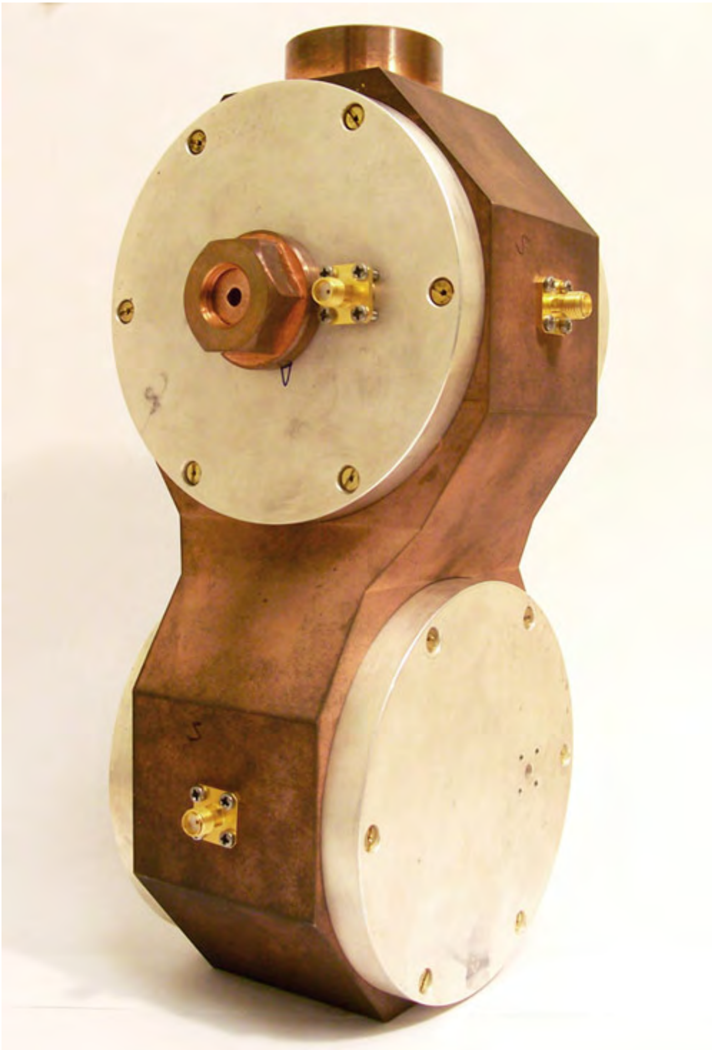



Vernal Equinox
Z
SUN
Y
X
η = 23.4
Orbit
Equatorial plane


WALL
NORTH
Angle between NORTH and WALL:
43.6 Deg
X
Katharina-Boll-Dornberger-Straße
Katharina-Boll-Dornberger-Straße

New Experiment -> Berlin

New dual cavity design (right) allows for better thermal stability



Larger sapphire crystals have a higher quality factor ≈ 2×10^9 (compared to 2×10^8 the prior experiment) allows better frequency stability

$WGE_{16,0,0}$ mode is more sensitive to Lorentz violating parameters (S = 0.4567 compared to S = 0.1958) -> over all near two orders of magnitude improvement.

Reduction of noise-inducing systematics (i.e. tilt) use Berlin system.

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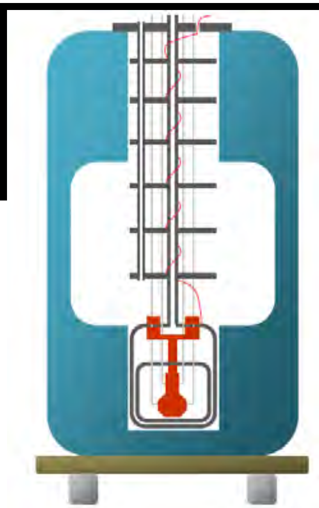
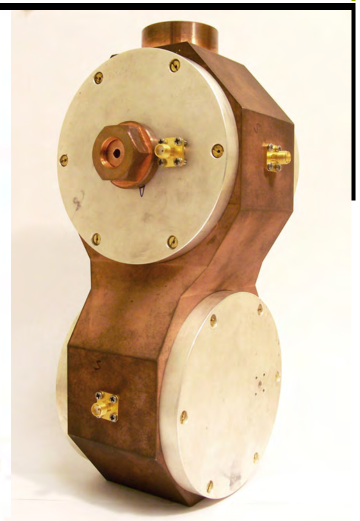
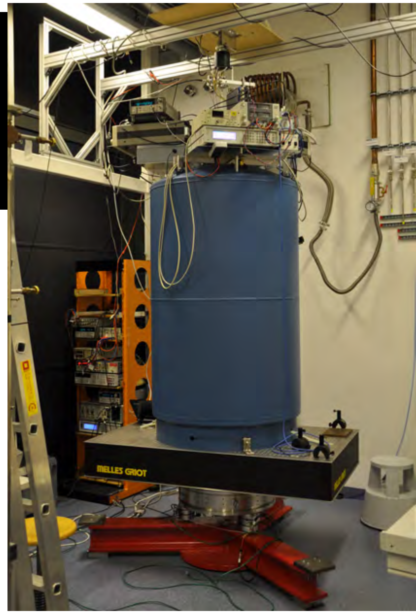
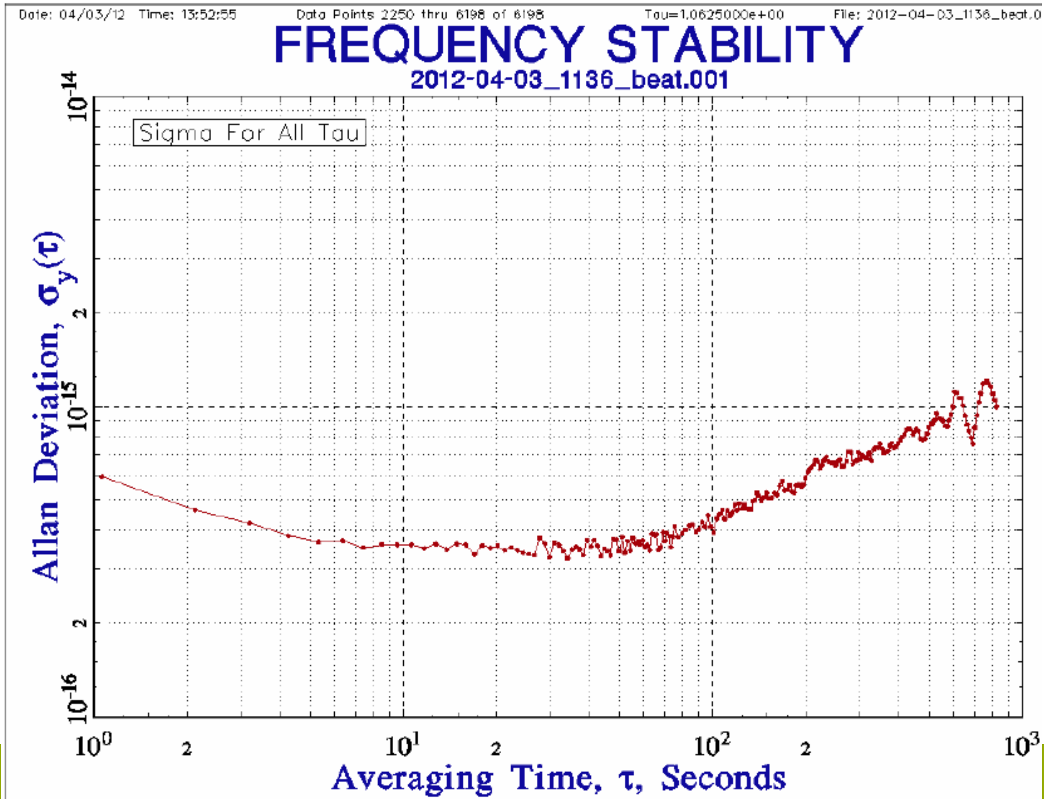






Cryogenic Sapphire Oscillators in Berlin, started operation August 2011

Ready for new limits ~ 10^{-18}



Long process of eliminating hard to diagnose systematic errors and bugs in data acquisition.

Have 1.25 years data-> ~10^{-18} in the photon sector

PHYSICAL REVIEW D **87,** 122004 (2013)

Testing local position and fundamental constant invariance due to periodic gravitational and boost using long-term comparison of the SYRTE atomic fountains and H-masers

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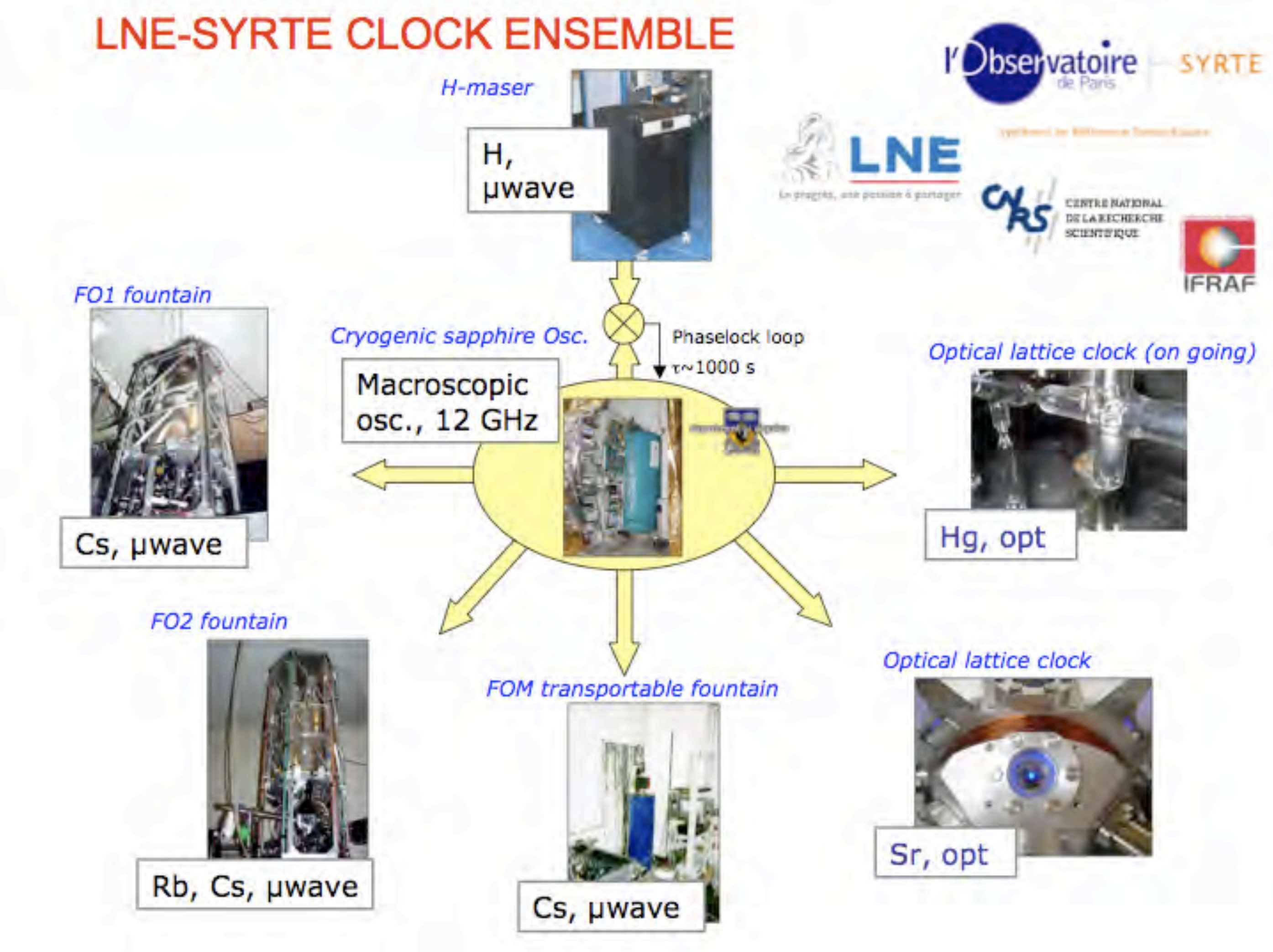
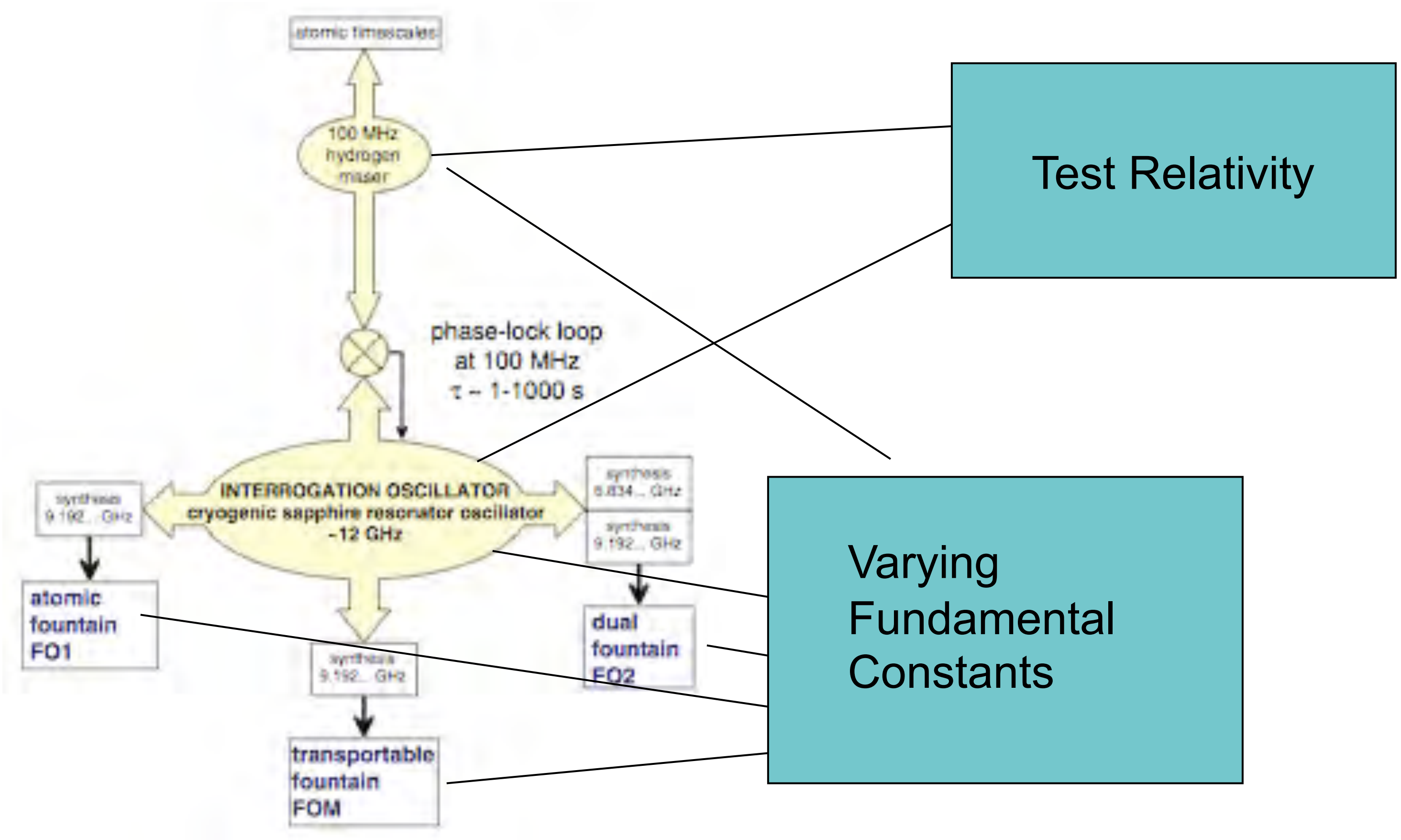
(Received 28 March 2013; published 5 June 2013)



l'Observatoire de Paris — SYRTE

$$x_{1\text{-}2} = \frac{\nu_1}{\nu_2} = \mathrm{const} \times \alpha^{n_\alpha} \mu_e^{n_e} \mu_q^{n_q}$$



This work: Test 3 Cs and 1 Rb Fountains against H-maser

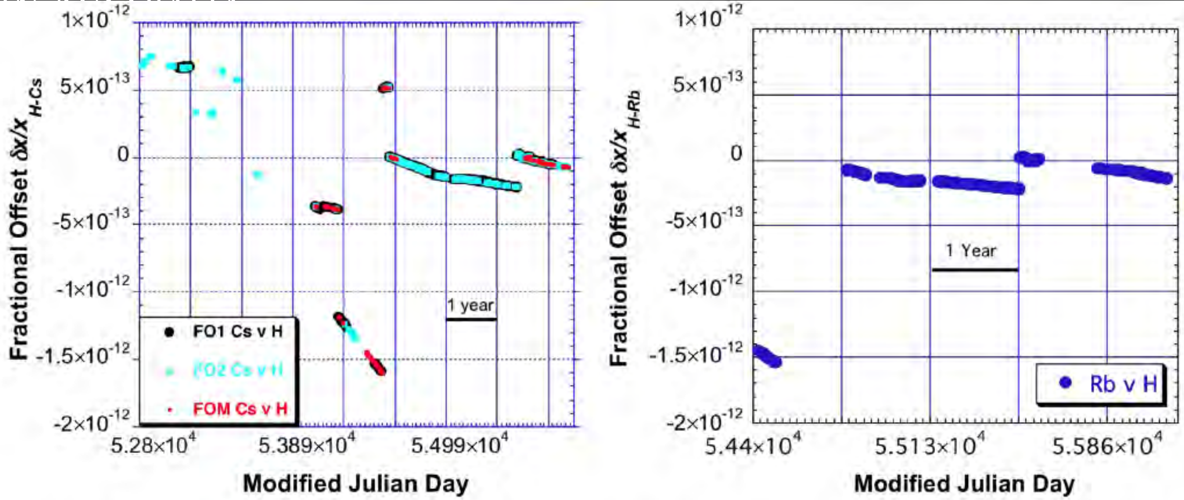


FIG. 1 (color online). Left: Measured fractional offset variations of the frequency ratio between three Cs fountains (FO1, FO2, and FOM as identified by the legend) and various H-masers. Long-term results span from 2/7/2003 to 2/11/2011, which is 3,045 days (8 yr and 4 months). Right: Measurement between the FO2 Rb fountain and various H-masers over nearly a 5 yr span.

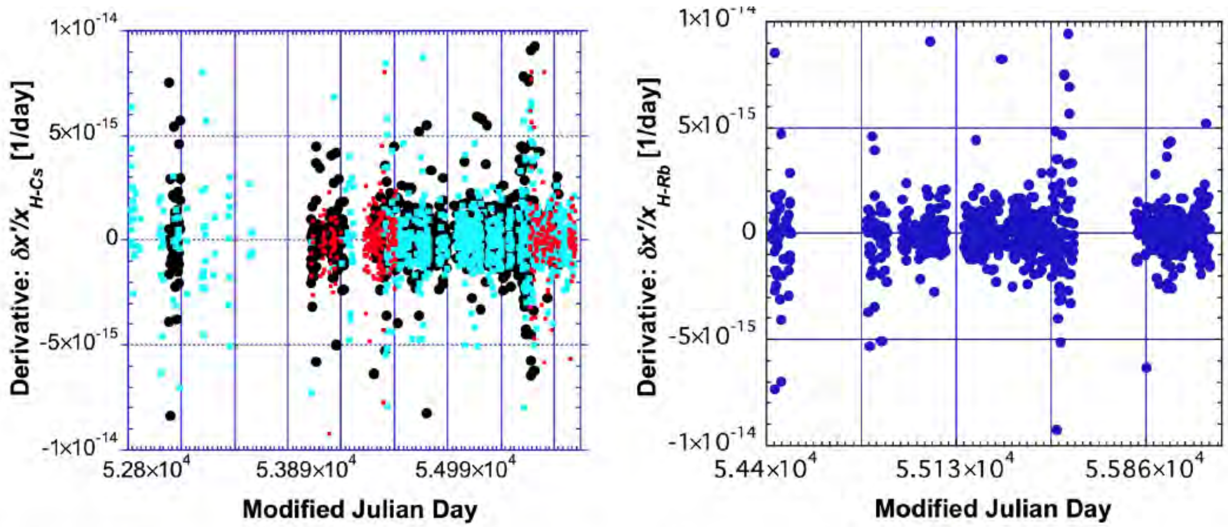
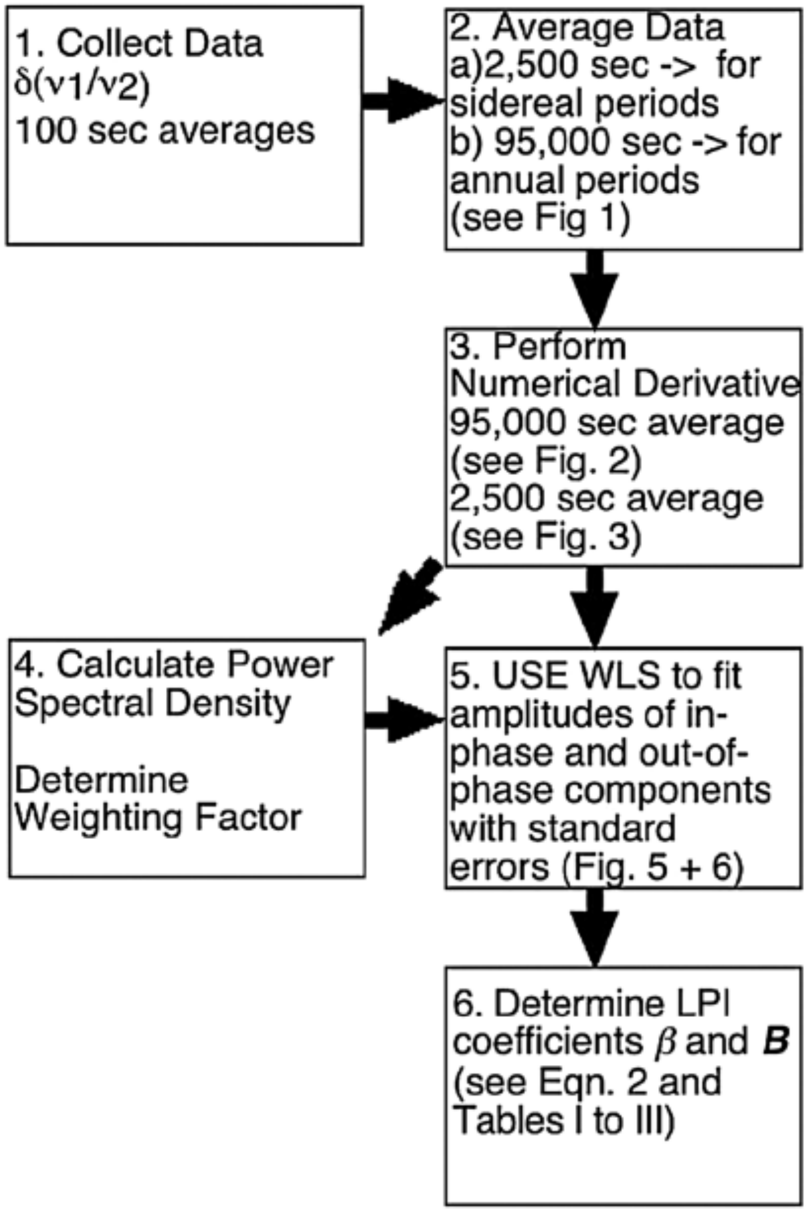


FIG. 2 (color online). Left: The derivative with respect to time of the Cs vs H data shown in Fig. 1, in units of fractional frequency per day. Each frequency measurement is averaged over 95,000 sec (1.1 days) before the derivative is taken. Right: Rb vs H data after following the same procedures. This data are used for searching for variations at the annual period.



"null red-shift experiment"
Due to change in sun potential

"null Doppler-shift experiment"
With respect to CMB
"Cosmic Doppler Shift"

TABLE II. The data in Table I are overconstrained by the measurements. Thus, a least squares analysis was implemented to determine each component of the boost-violation vector with the associated standard error.

Boost-Violation vector component	H-maser/CSO [24]	Cs/H-maser	Rb/H-maser
B_x	$-12.6(9.1) \times 10^{-11}$	$1.6(1.1) \times 10^{-11}$	$-2.2(2.6) \times 10^{-11}$
B_y	$6.5(9.8) \times 10^{-11}$	$-7.6(3.3) \times 10^{-11}$	$-0.8(3.6) \times 10^{-11}$
B_z	$-46.8(48.5) \times 10^{-11}$	$-15(15) \times 10^{-11}$	$-5.6(9.7) \times 10^{-11}$

TABLE III. Decomposition of the boost-violation vectors in Table II to limits on the invariance of fundamental constants with respect to boost. The values range from 10^{-10} to a few parts in 10^{-9}.

Fundamental constant boost-violation vector	$i = x$	$i = y$	$i = z$
$B_{\alpha i}$	$1.1(0.9) \times 10^{-10}$	$-1.6(1.4) \times 10^{-10}$	$-2.0(4.8) \times 10^{-10}$
B_{ei}	$-5.3(3.4) \times 10^{-10}$	$6.2(5.2) \times 10^{-10}$	$1.4(18) \times 10^{-10}$
B_{qi}	$-7.3(6.7) \times 10^{-10}$	$5.9(9.8) \times 10^{-10}$	$1.4(29) \times 10^{-10}$

THE END