Clocks and Relativity: towards Relativistic Geodesy

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Outline

- INRIM (and clocks) in a Nutshell
- Gravitational Red Shift
- Relativistic Geodesy with clocks

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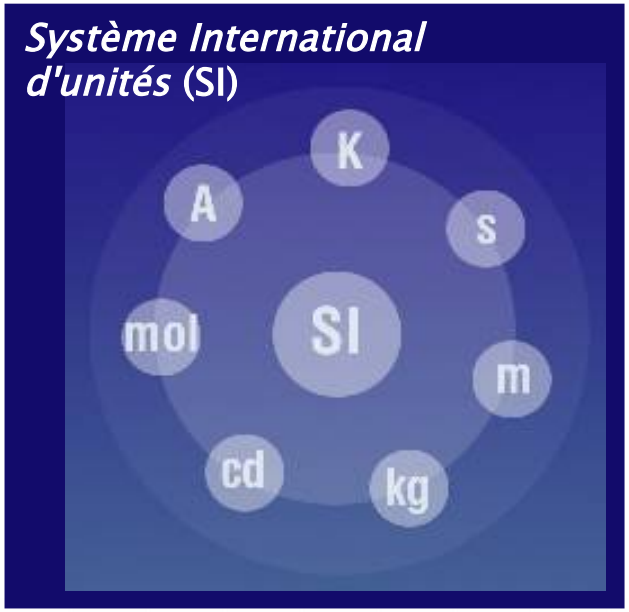
INRIM in a nutshell

- The Italian National Metrological Institute
- 200 employes, 24 M€ annual account
- 4th NMI in Europe (account/employers)
- 5th Public Research Institute in Italy
- Strong relations with Academia and Industry
- In charge of definition and realization of the SI



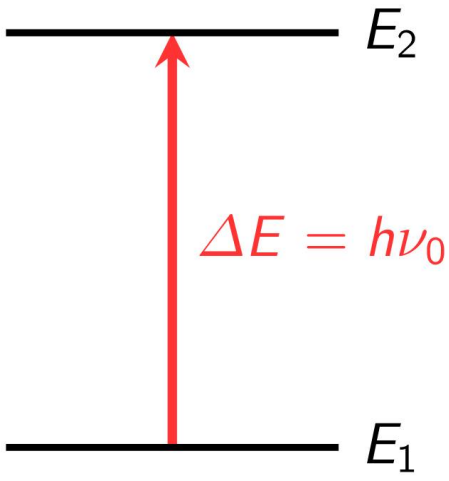
Realization of the second in the *Système International d'unités* (SI)

"The *second* is the duration of 9192631770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom."

- Realized by atomic clocks
- A microwave is used to probe Cs

  atoms that have by definition ν=9192631770 Hz
- The highest ΔE, the highest the precision

  → from microwave to optical radiation



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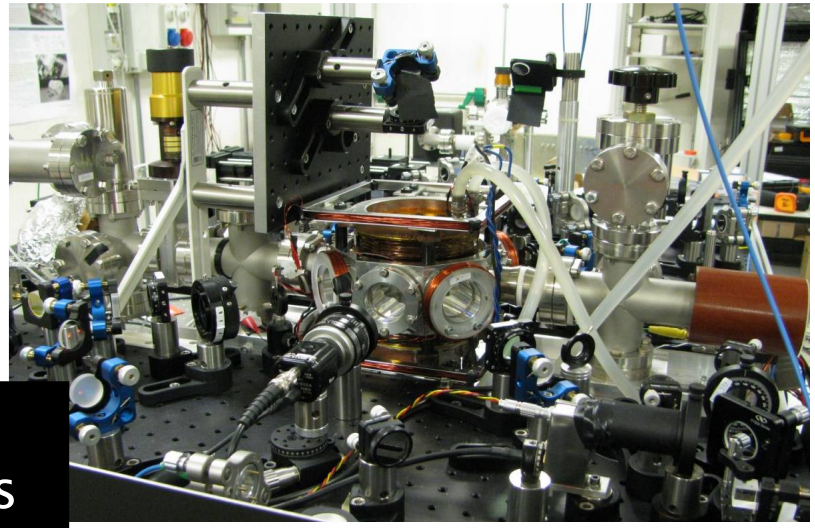
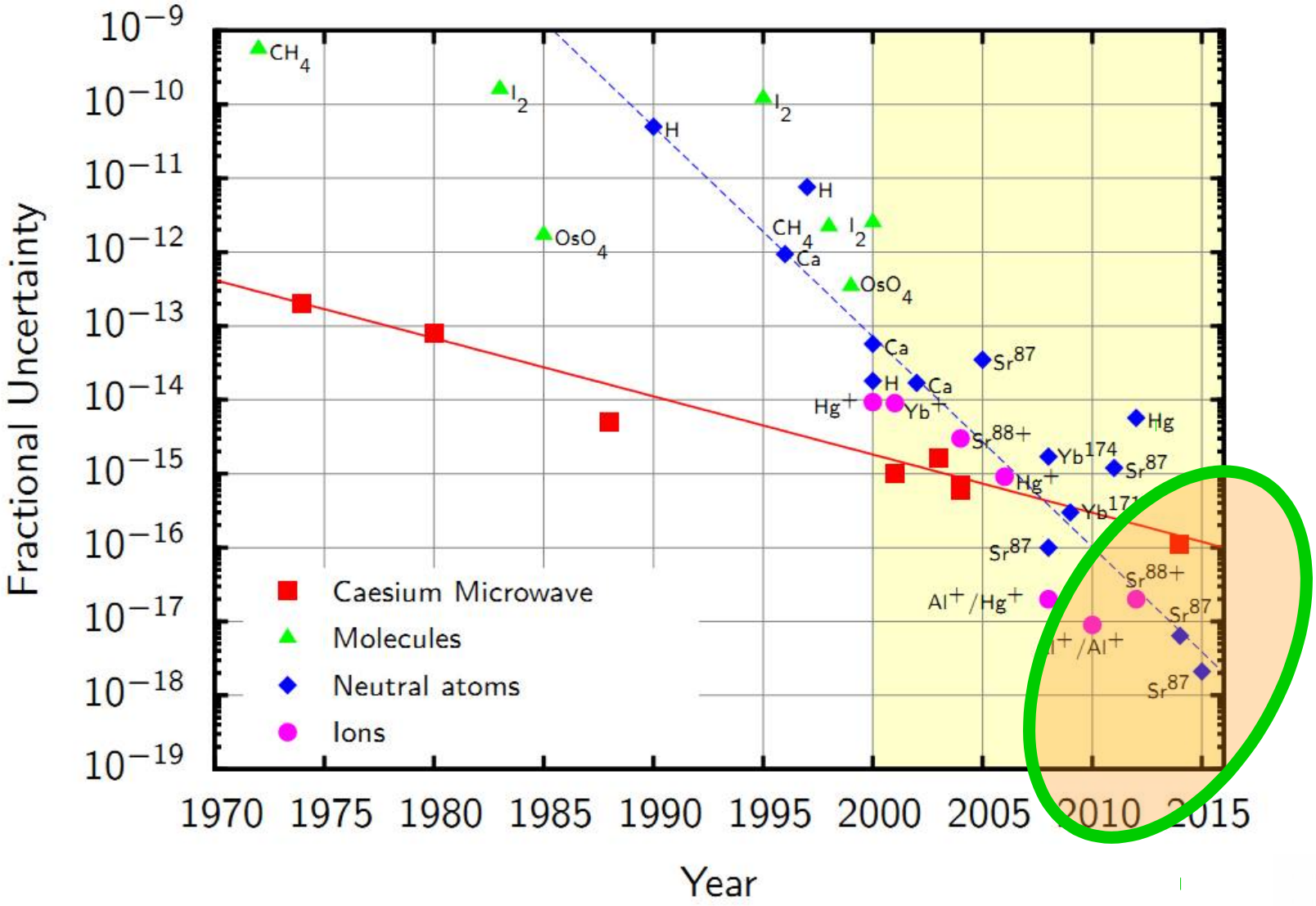
Primary atomic clock
based on a Cs fountain
Accuracy: $2 \cdot 10^{-16}$



Optical atomic clock
based on Ytterbium atoms
Target accuracy: 10^{-17}

Perspectives with optical clocks



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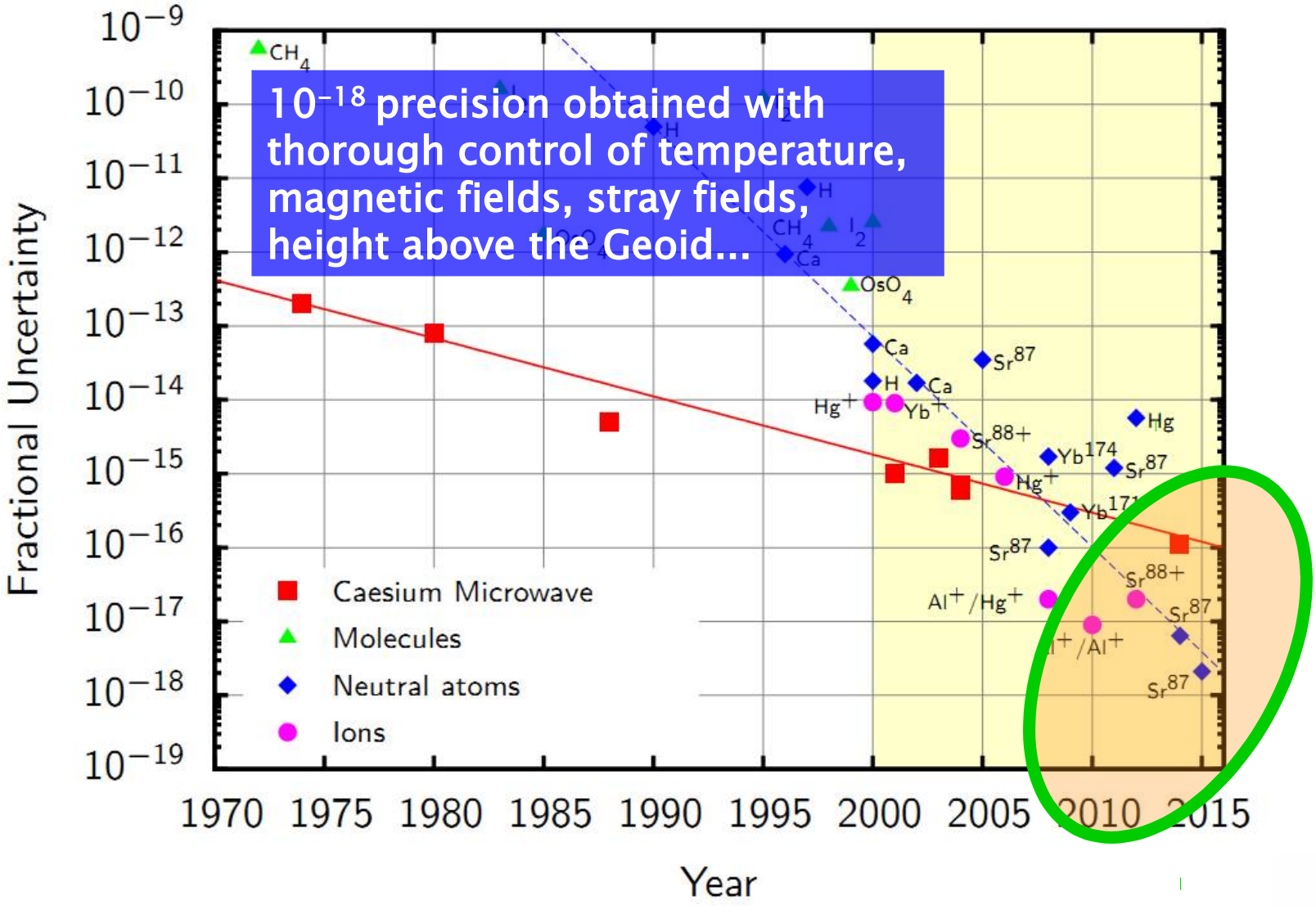

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Clocks and Gravitational Red-shift

In the weak field approximation (as in the Solar System), i.e.

$$W/c^2 \ll 1,$$

W gravitational potential
c speed of light,
given a reference potential W_0,

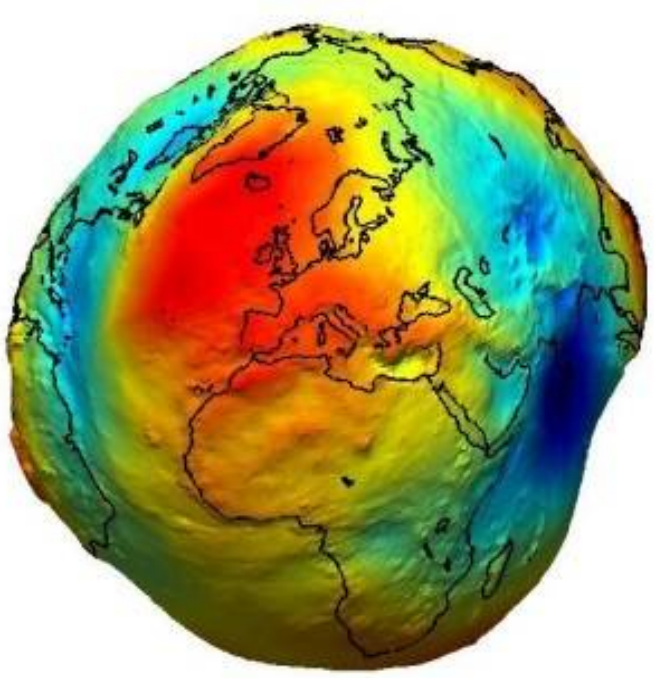
two clocks placed at two different location in the field have a frequency offset:

$$\frac{\nu_0 - \nu(\bar{r})}{\nu_0} = \frac{W(\bar{r}) - W_0}{c^2}$$

On Earth (W_0 is the Geoid potential):

$$\frac{\nu_0 - \nu(\bar{r})}{\nu_0} \approx \frac{g_0}{c^2} m^{-1} = 1.09 \times 10^{-16} m^{-1}$$

Clocks and Gravitational Red-shift



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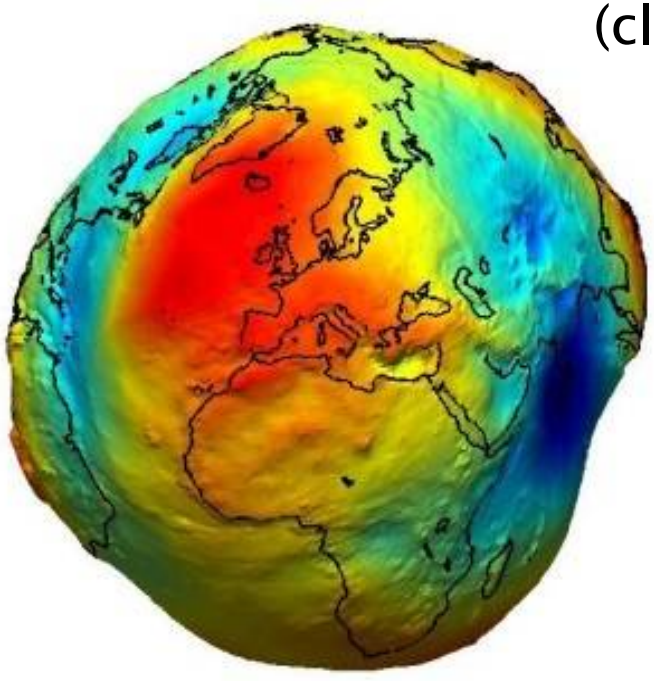
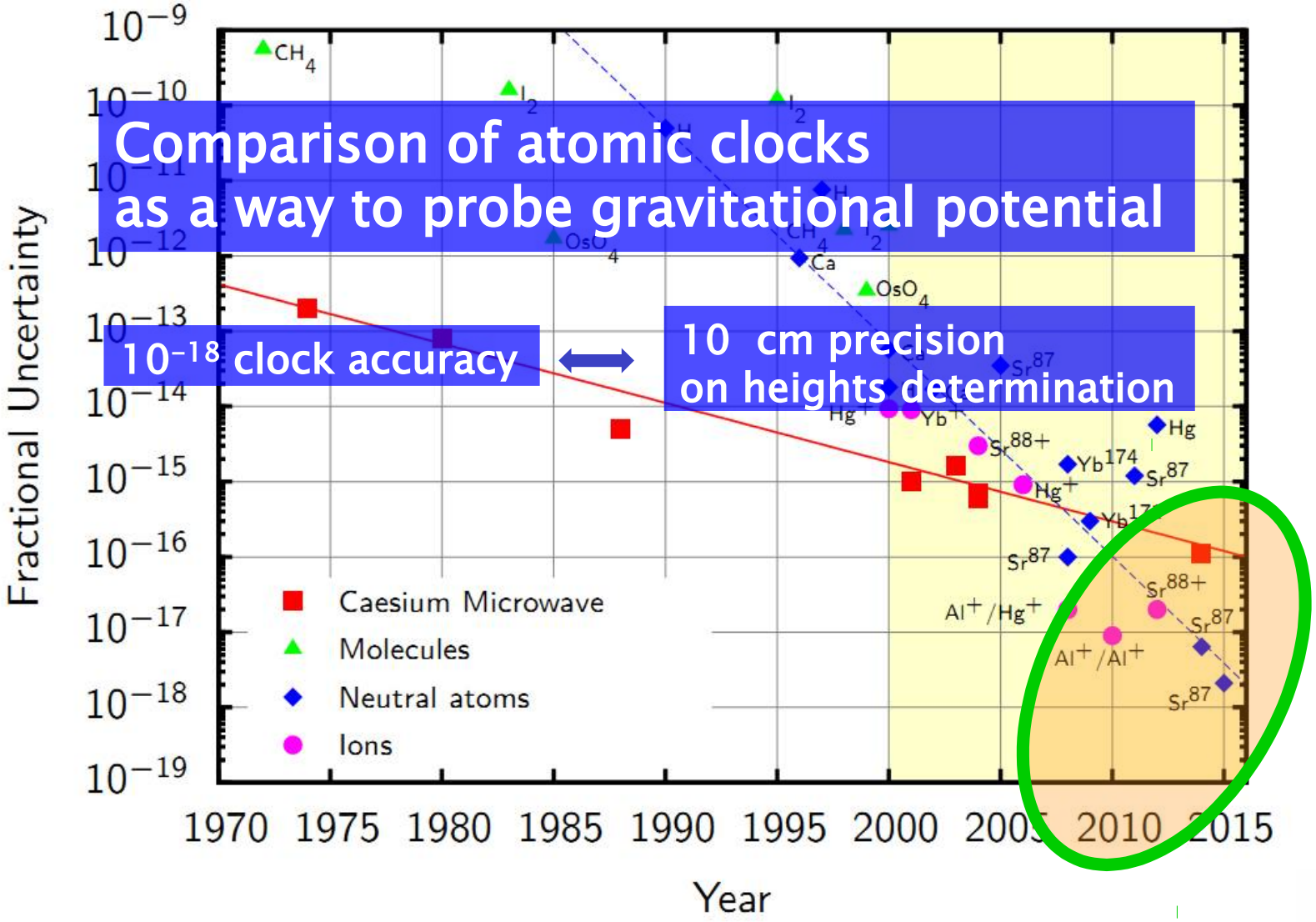


Determination of equipotential surfaces (classical methods):

On Earth (W_0 is the Geoid potential): $$\frac{v_0 - v(\bar{r})}{v_0} \approx \frac{g_0}{c^2} m^{-1} = 1.09 \times 10^{-16} m^{-1}$$

Perspectives with optical clocks



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International Timescales with Optical Clocks

(ITOC-JRP SIB55)

EMRP

European Metrology Research Programme

Programme of EURAMET

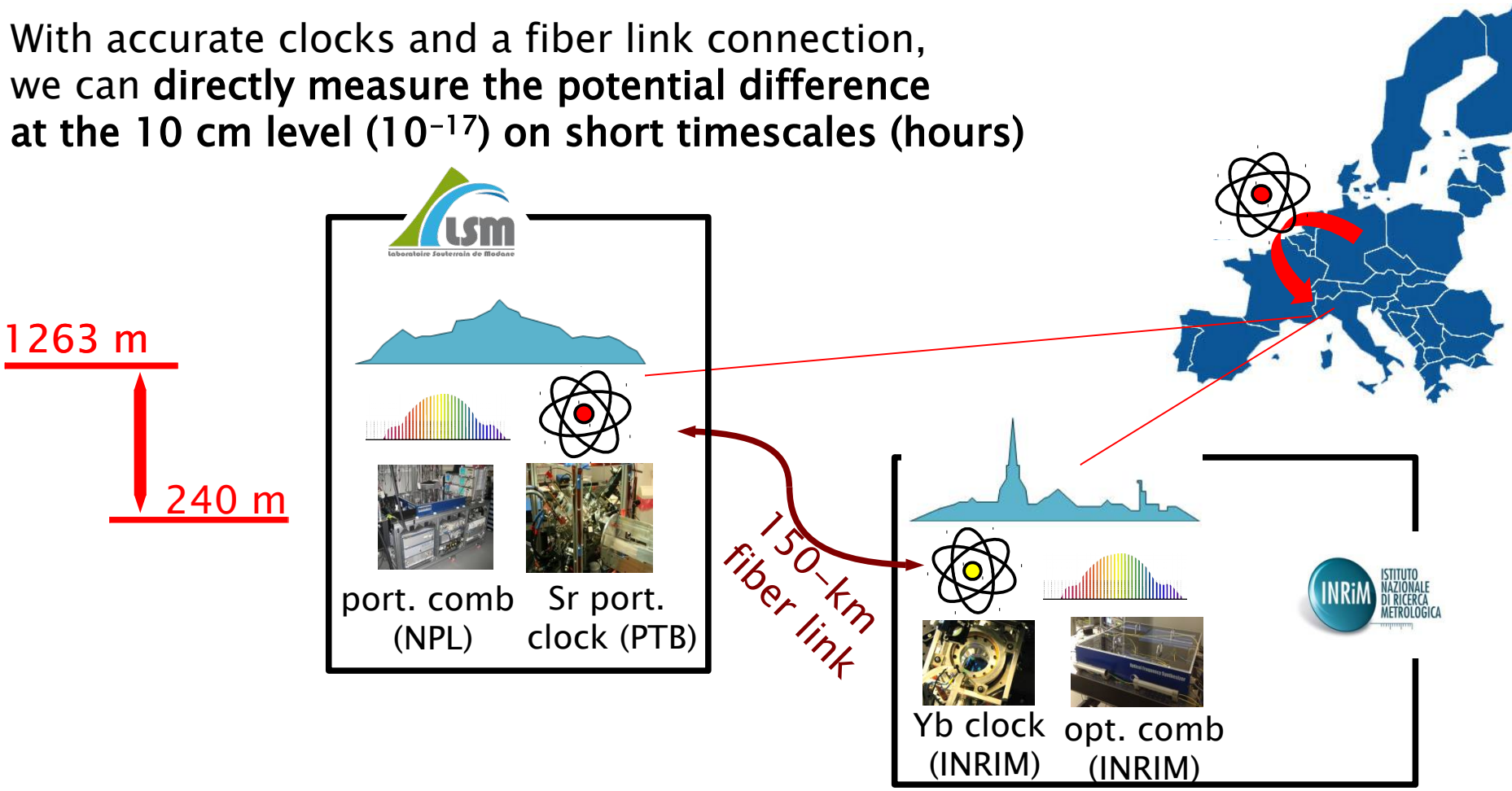
The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

Work Package 4:

Proof-of-principle relativistic geodesy experiment

Relativistic Geodesy on the Alps

With accurate clocks and a fiber link connection,
we can **directly measure the potential difference**
at the 10 cm level (10^{-17}) on short timescales (hours)



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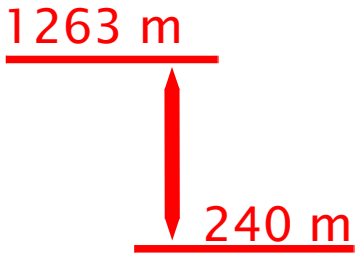
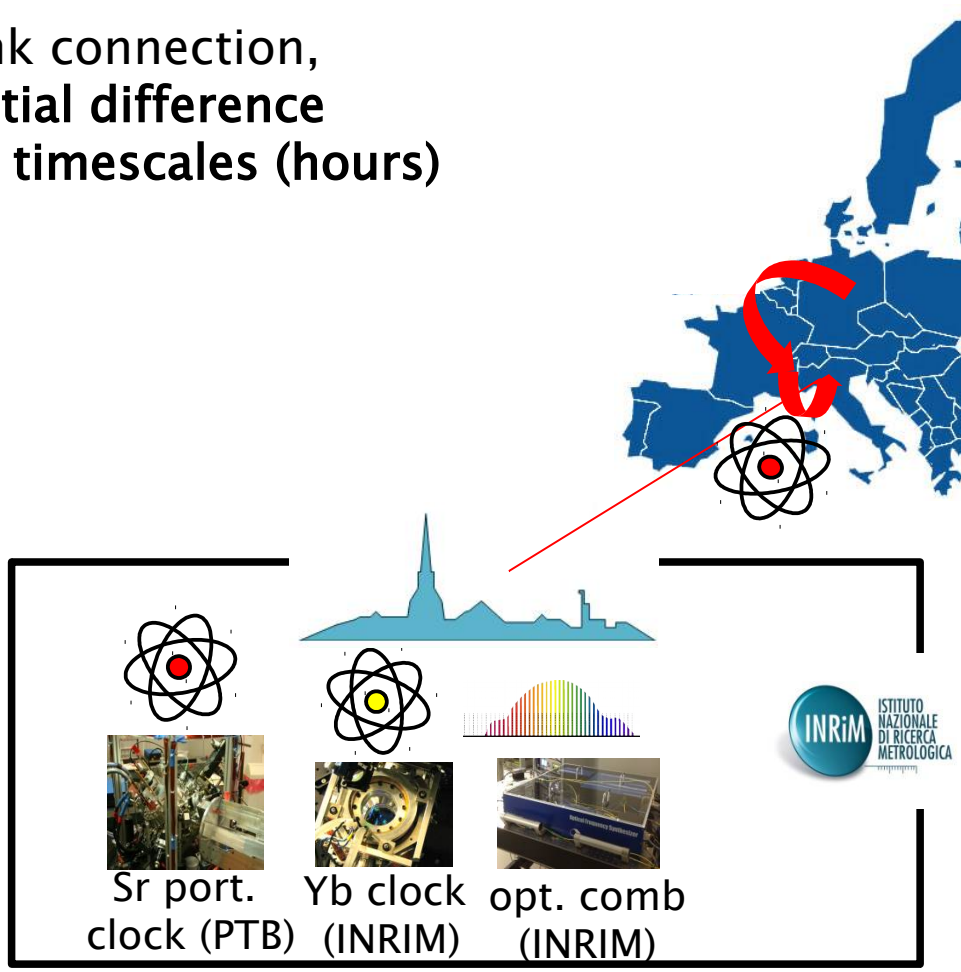
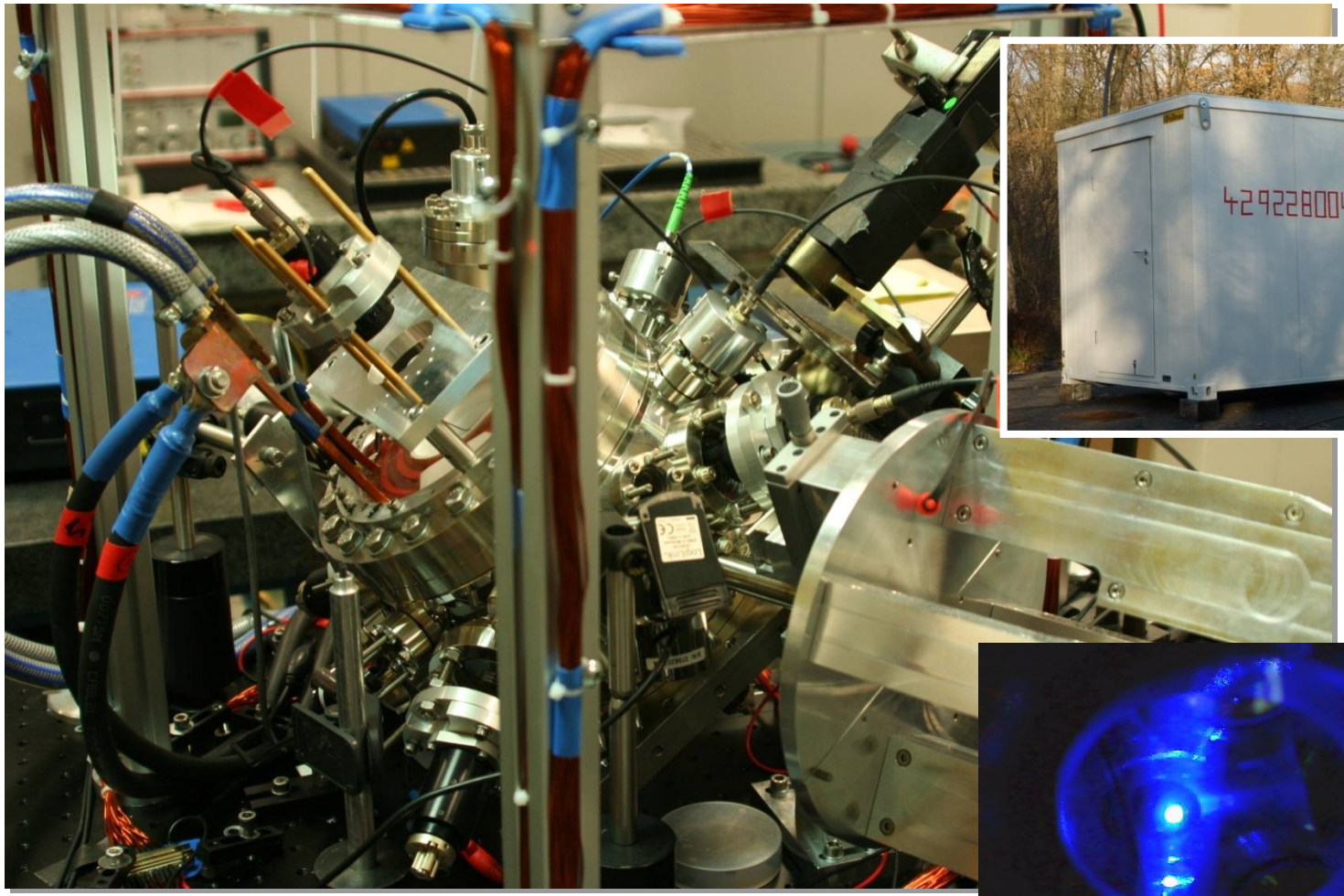


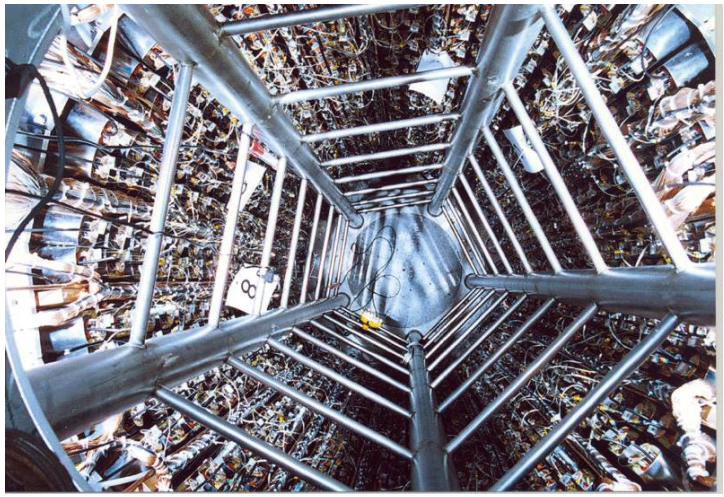


1000 m height difference → frequency offset ~10^{-13},
studied at the 10^{-17} level (test level ~10^{-4})

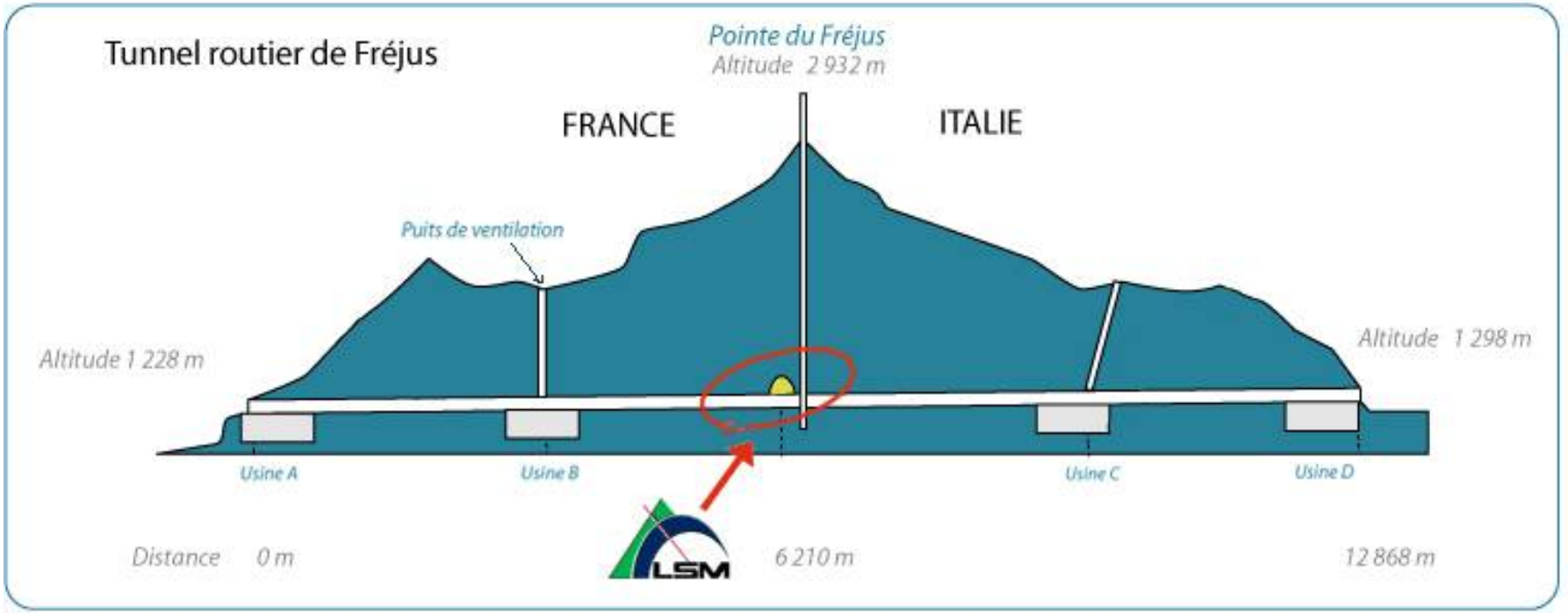
Transportable Sr lattice clock of PTB



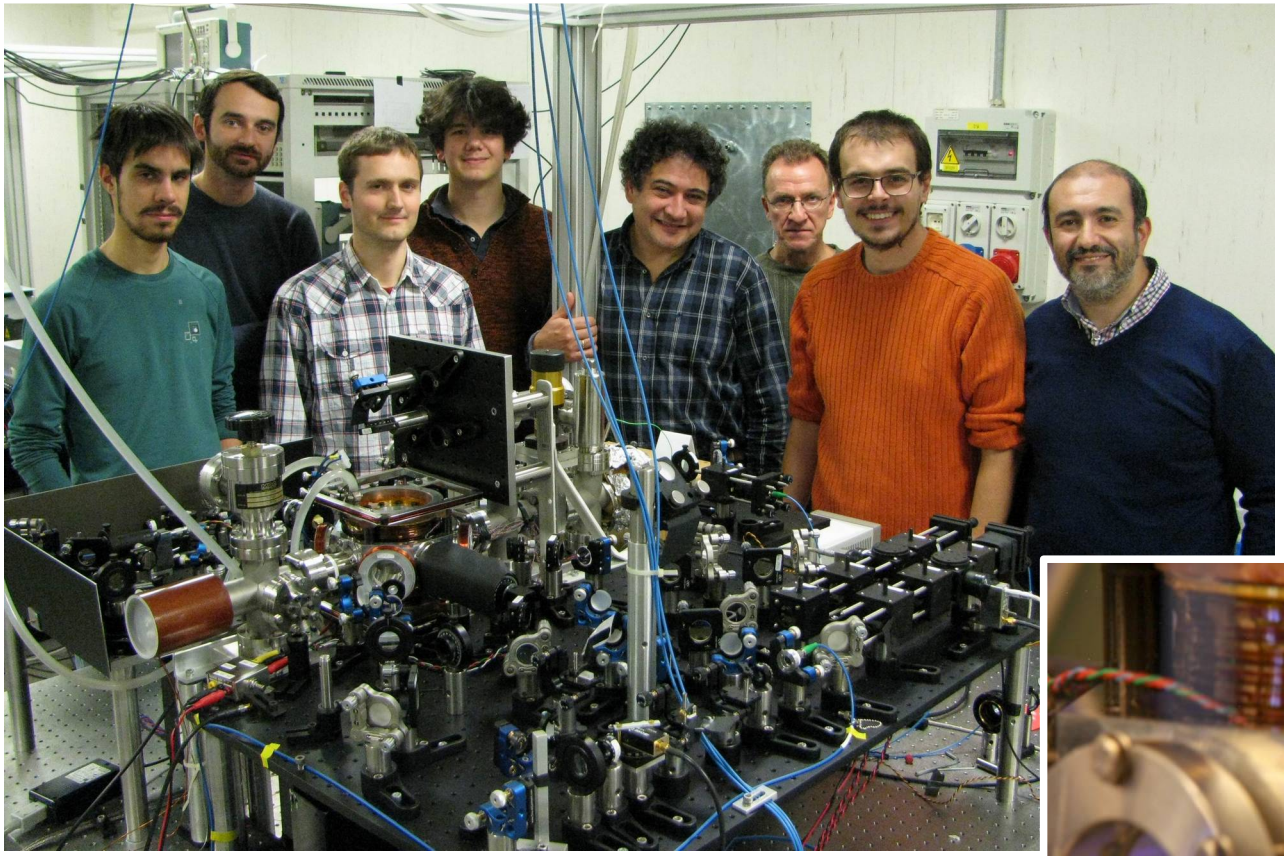
LABORATOIRE
SOUTERRAIN
DE MODANE

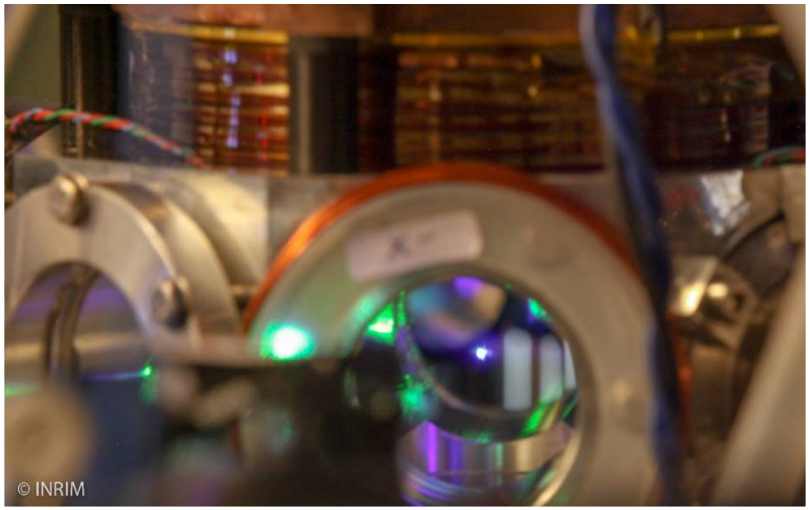


Solar Neutrinos detector «NEMO» in LSM



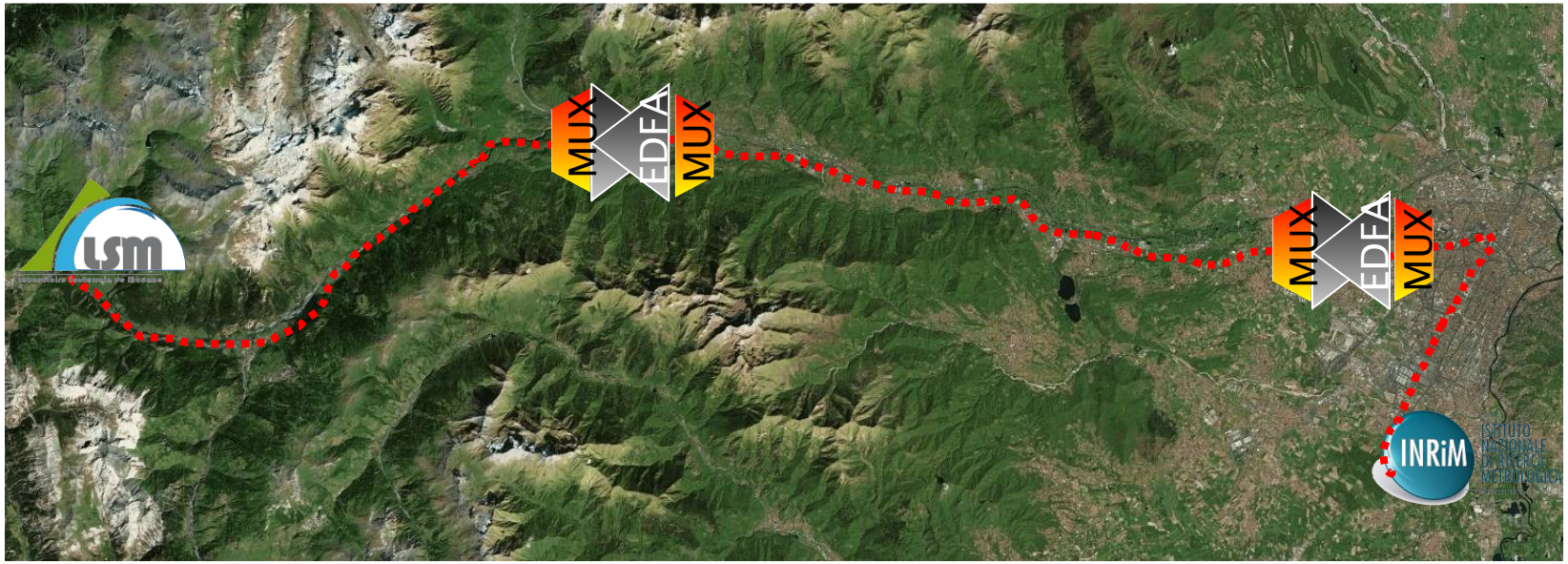
Stationary Yb lattice clock at INRIM





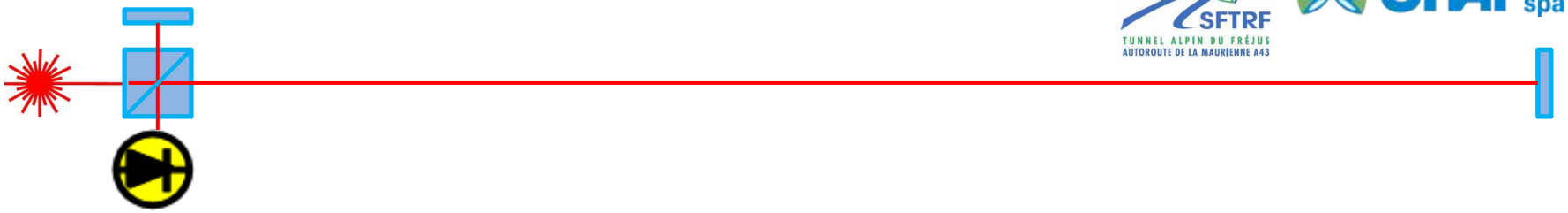
INRIM –LSM optical link

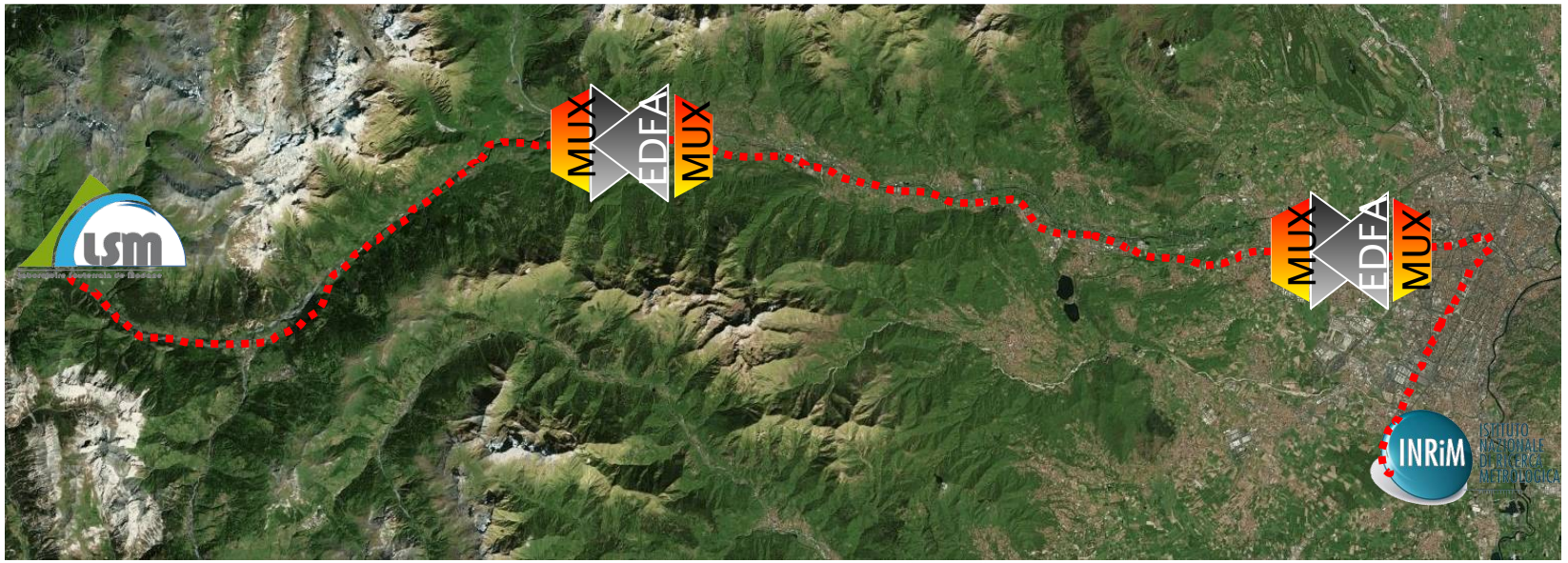
- INRIM–LSM, commercial fiber, 151 km
- 2 fibers, one dedicated ITU channel
- Data and metrological channel at the same time
- EDFA amplifiers



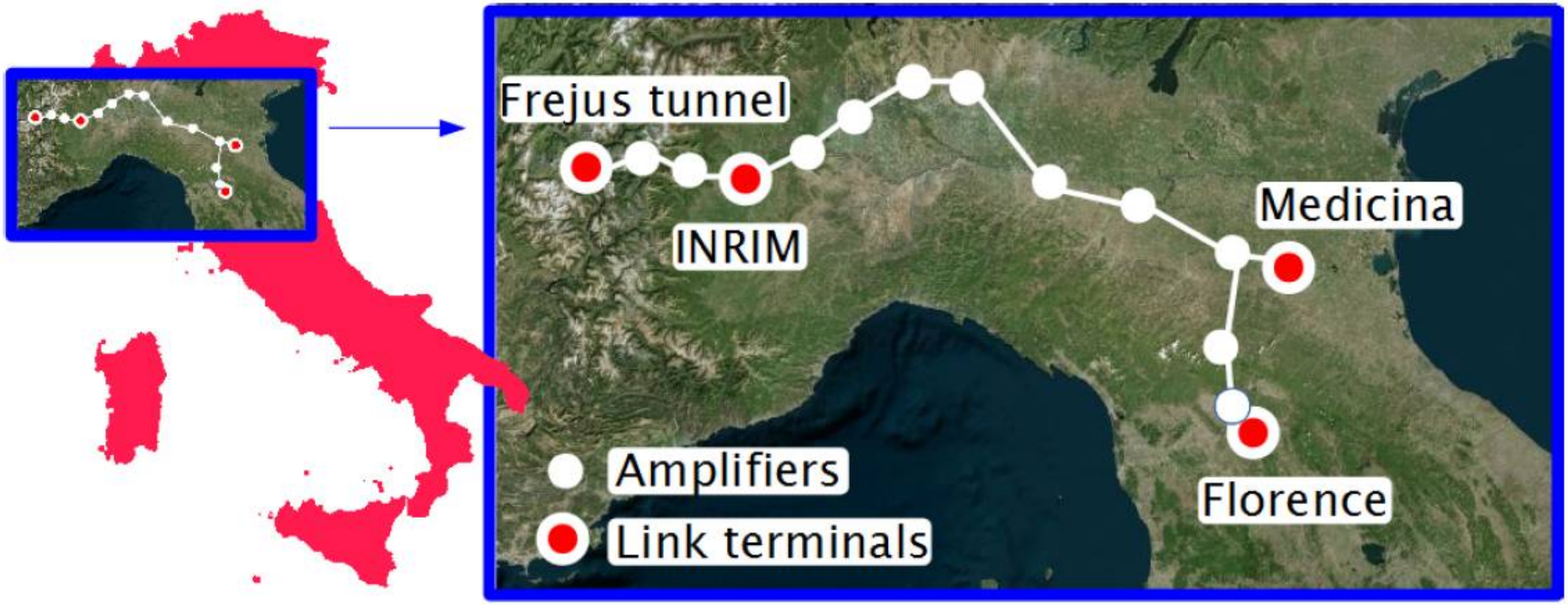
INRIM –LSM optical link

- Length variations due to temperature and acoustics → cancelled



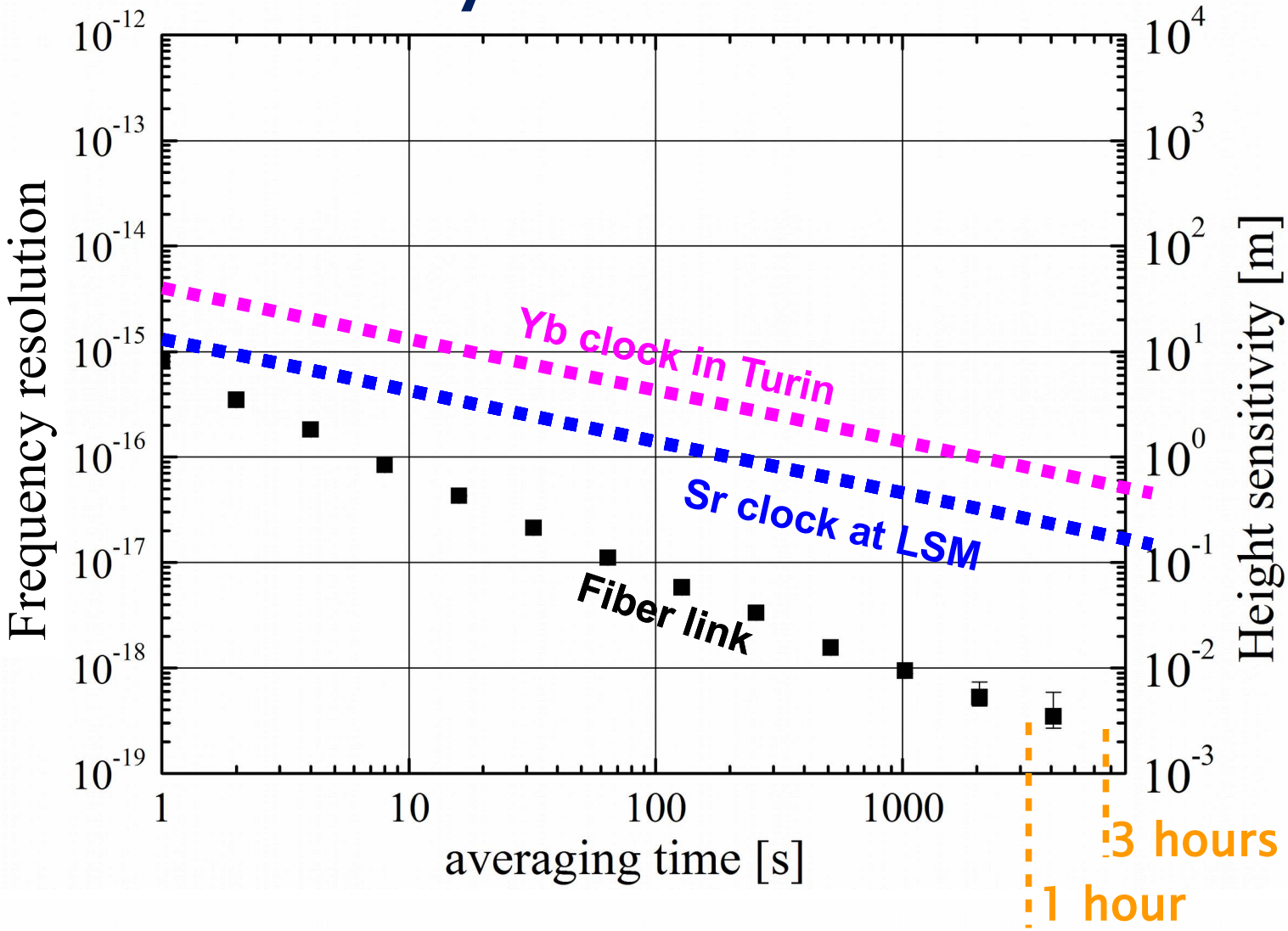


LIFT–the Italian Link for Time and Frequency



- Total Fiber Haul 800 km
- Two Commercial Dark Fibers available / DWDM and CWDM channels
- Fiber provided by Consortium GARR and Consortium TOP-IX
- Applications: relativistic geodesy, radioastronomy, spectroscopy…

Geodetic height: which sensitivity from clocks?



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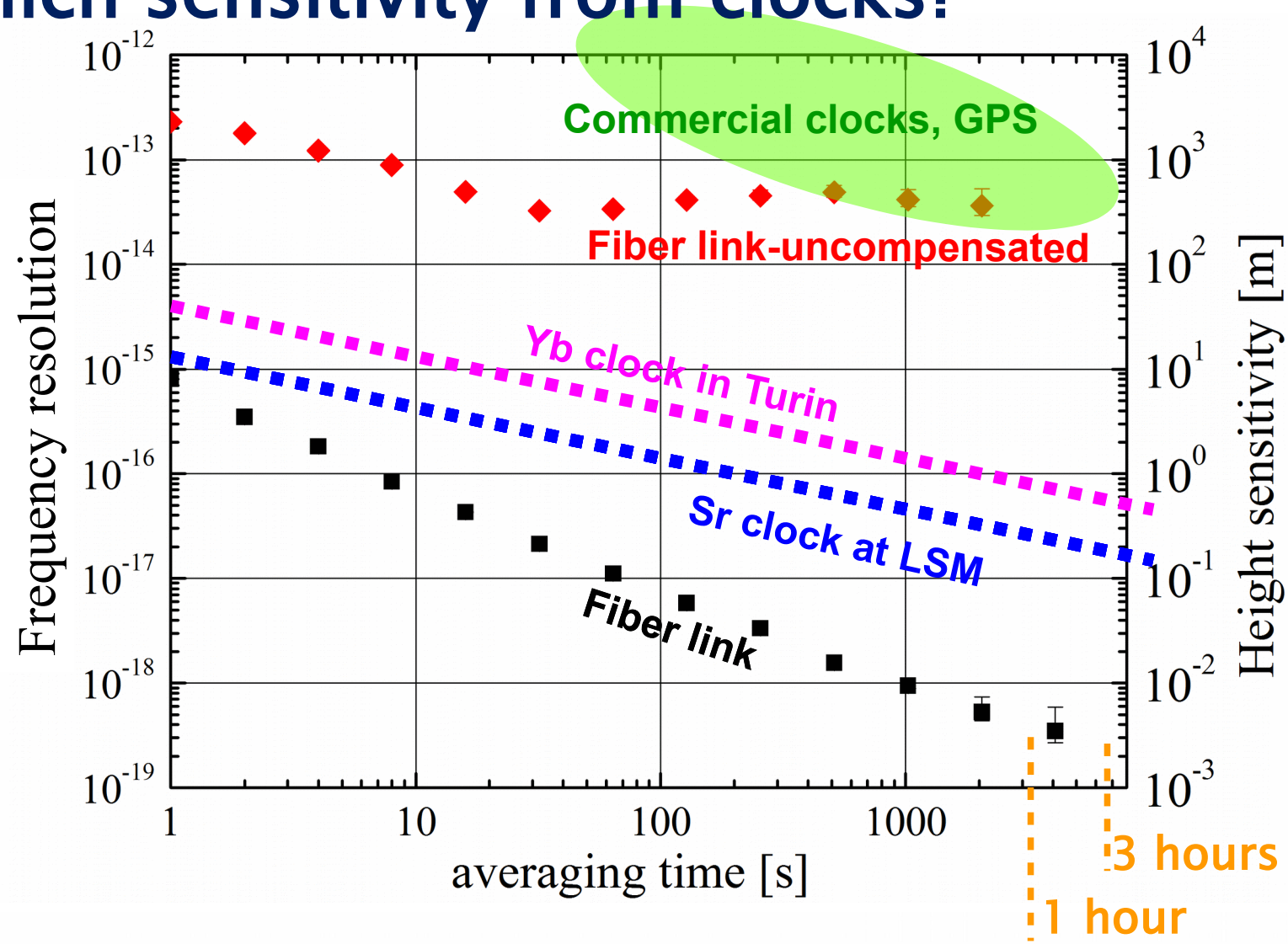

Gravity Measurements at INRIM/LSM

- to define the gravity datum level required by the relative observations
- Measurements done for INRIM and LSM in September 2013
- Also INRIM contributes with its own absolute gravimetry

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LSM

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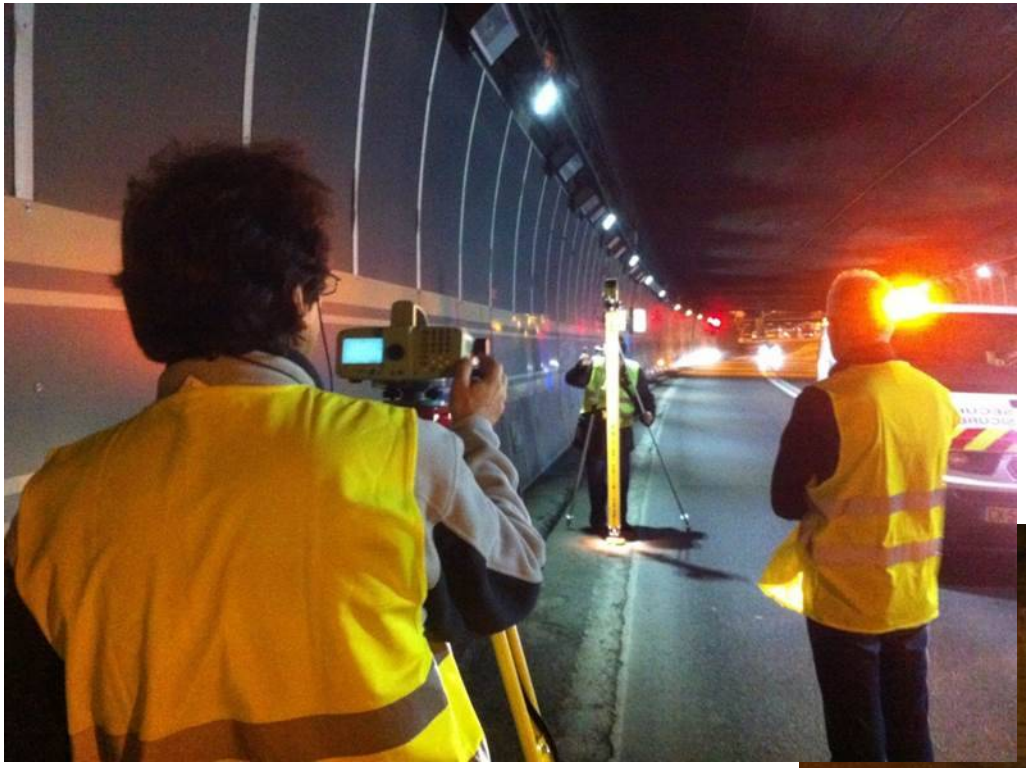
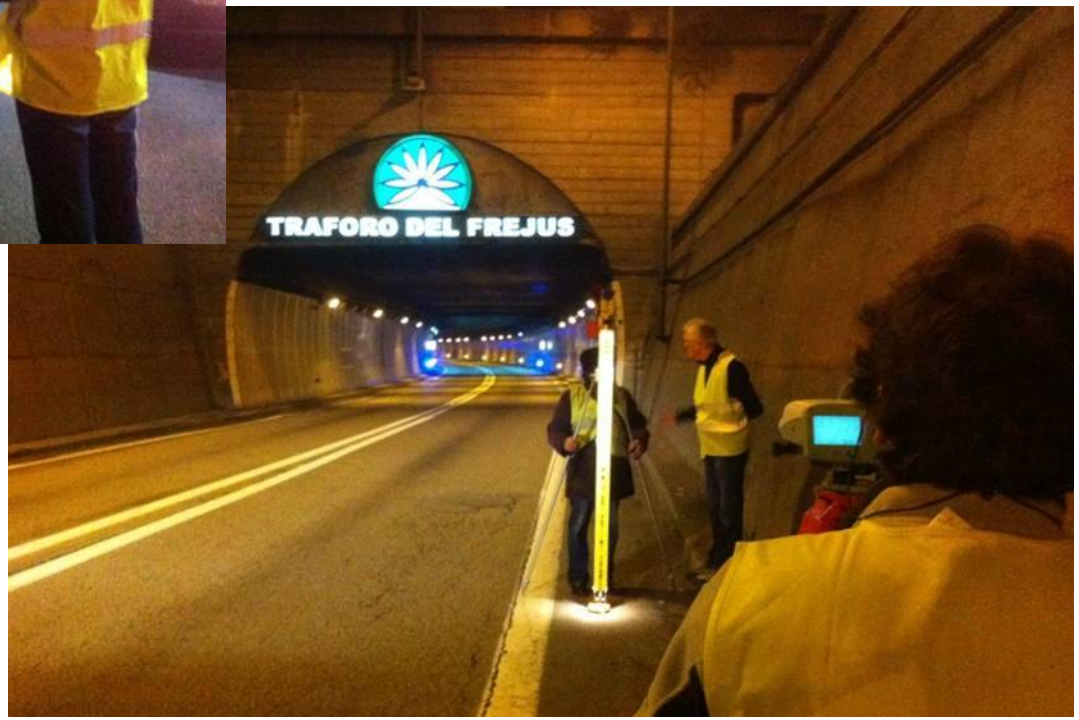
The FG5X-220 corner-cube gravimeter (32 cm free fall, counter weights for drag-free cart) at LSM and at INRIM

Levelling at INRIM

Yb optical clock, floor:

$H_{INRIM,Yb} = 373.41 \pm 0.03$ m





Starting the Levelling
on October, 24th, after 11 p.m.

POLITECNICO DI TORINO

lsm

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GEF

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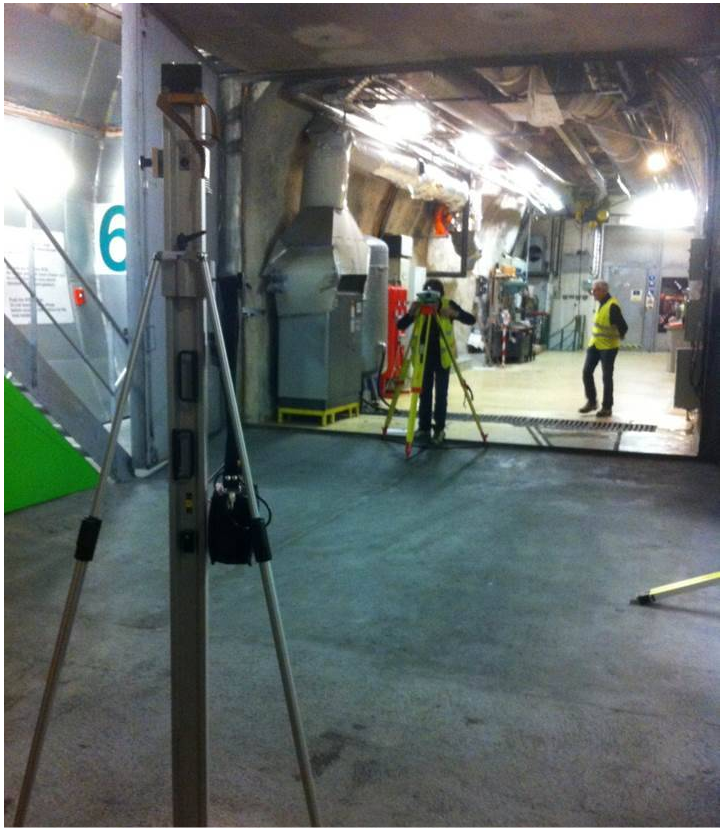
Levelling external reference markers (GNSS receiver, LEICA DNA03 and invar stadia)

October, 2nd and 24th



Gravity measurements at LSM

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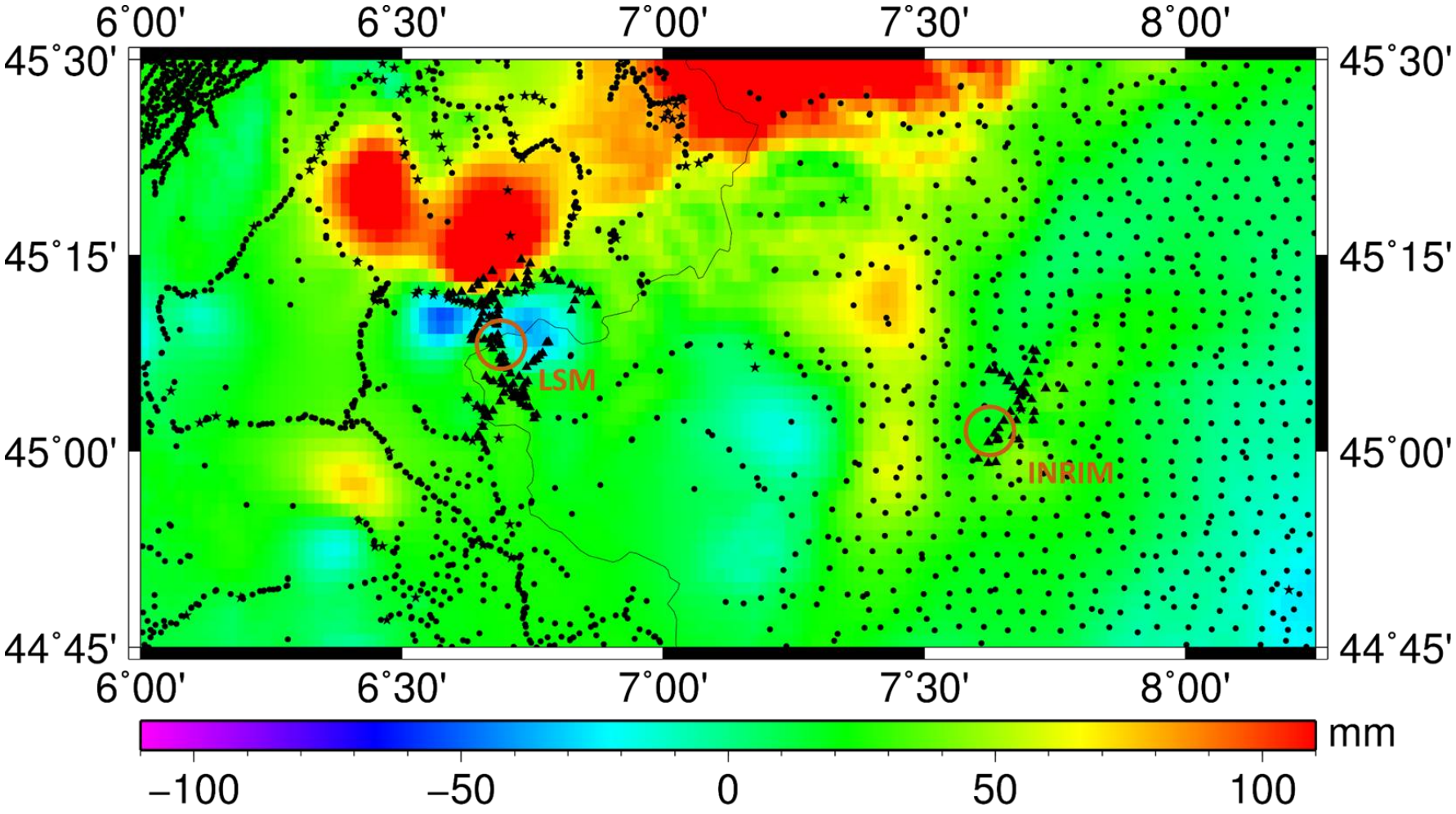
Gravity measurements at INRIM/LSM



Differences EGG2015 minus EGG2008 around INRIM and LSM

plus gravity stations (▲: new ITOC pt.; ●: old pt.; *: old pt. with error flag)

Gravity measurements at INRIM/LSM

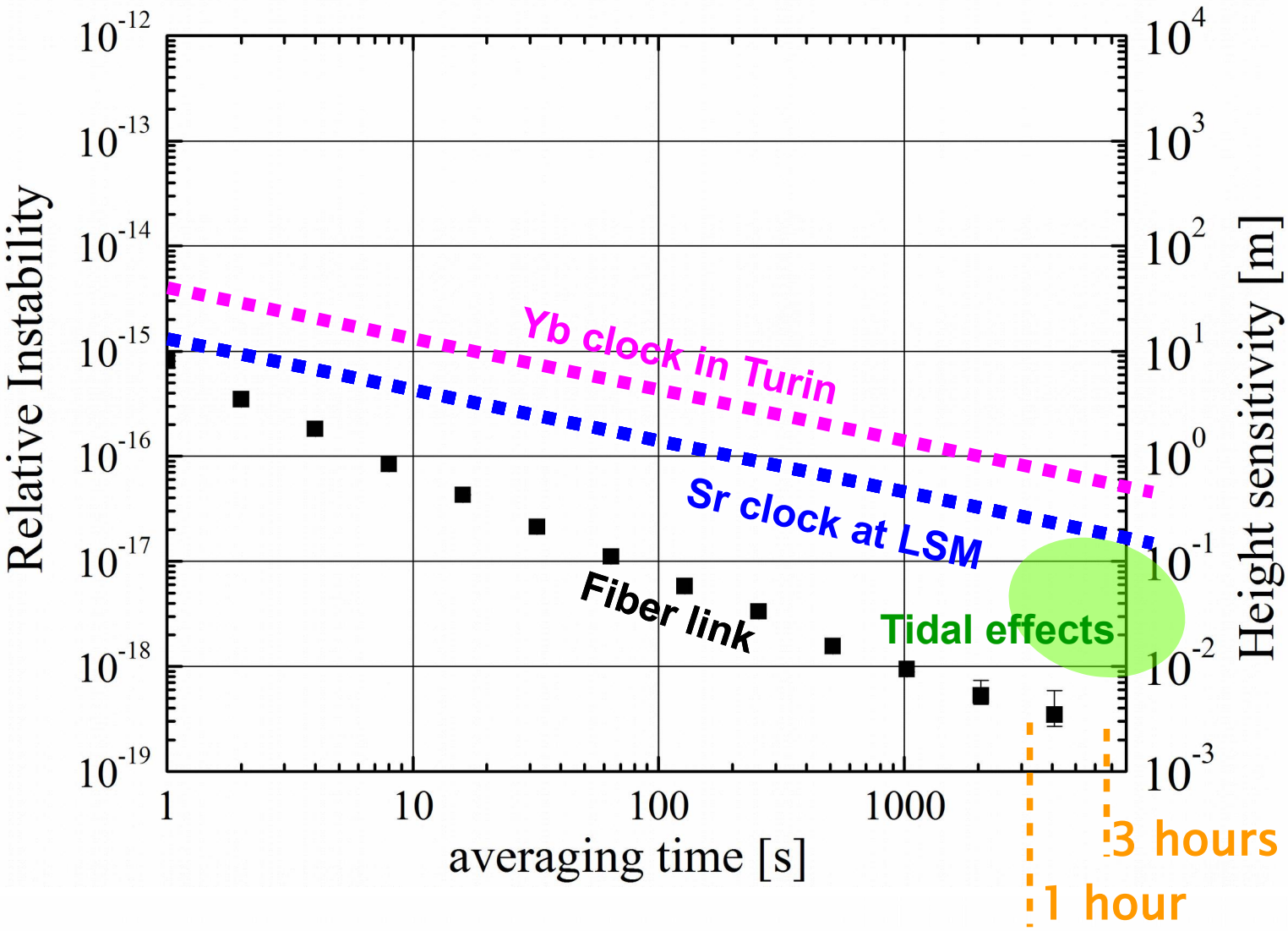
	Name	Site	Orthometric Height H/m
1	CS1LAB	ITOC Lab	1263.539(16)
2	CS2LAB	Absolute gravity Measurement	1263.627(16)
3	CS7	Tunnel Entrance (IT)	1297.604(16)
4	CS12800AF	Ventilation Tunnel (PM12800m)	1301.303(16)
5	IGM95	Benchmark Levelling IGM (BF15) - IT National Ref – nearby Tunnel	1291.66816)
6	CS6500	LSM entrance	1263.230(16)

INRIM, Yb lab: H = 237.41(3) m
LSM, Sr lab: H = 1263.539(15) m

H(LSM)- H(INRIM) = 1026.13(3) m

Close to the start…

Geodesy with clocks: perspectives



A Fiber Links European Network

- Metrology at improved precision
- Various users outside metrology
- Multi-node

INRIM Atomic Clocks group

Group Leaders: F. Levi, D. Calonico
Optical Link and Combs: C. Clivati, A. Mura, M. Frittelli, M. Zucco, A. Tampellini
Yb Clock: M. Pizzocaro, P, Thoumany, G. Bolognesi, B. Rauf, G. Milani, F. Bregolin
Cell Clocks: S. Micalizio, B. François
Atomic Fountain: G. A. Costanzo
Electronics: C. E. Calosso, E. K. Bertacco, C. Cardenas

thanks for your attention