

Geodesy with fibre links: update from Italy

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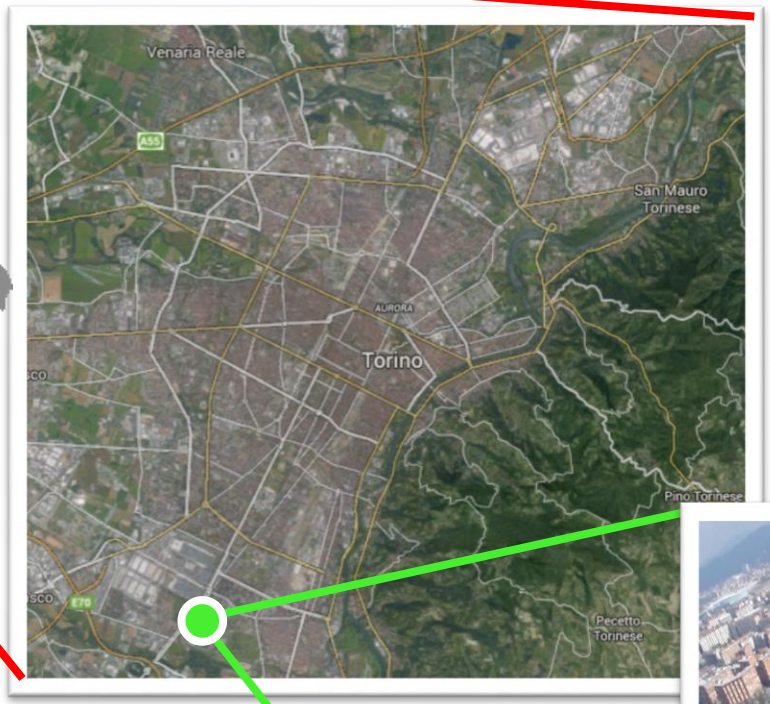
IAG Joint Working Group 2.1, BIPM, 10 Oct 2018

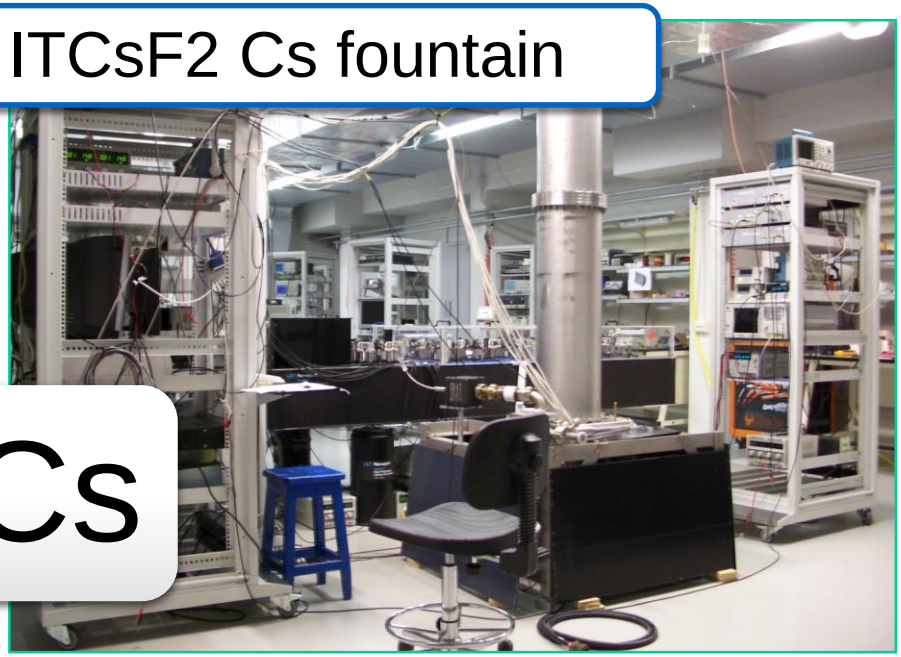
INRIM IN A NUTSHELL



- Italian Metrological Institute
- 4° Metrological Institute in Europe
- 5° Public Research Institute in Italy
- Strong Relationship with University and Industry

INRIM 2018 : Atomic Frequency Standards

ITCsF2 Cs fountain

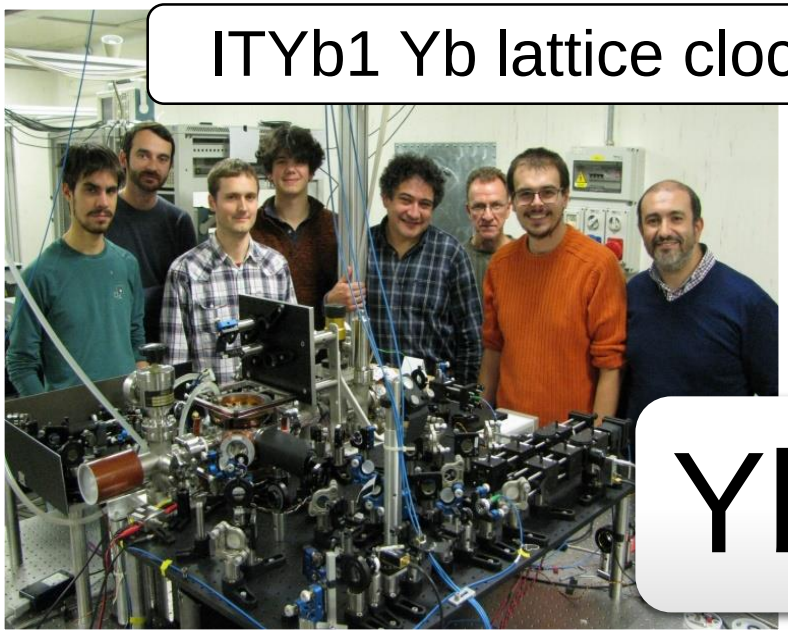


Cs

F. Levi, et al., Metrologia, 51, 270 (2014);

Accuracy: 2e-16

ITYb1 Yb lattice clock



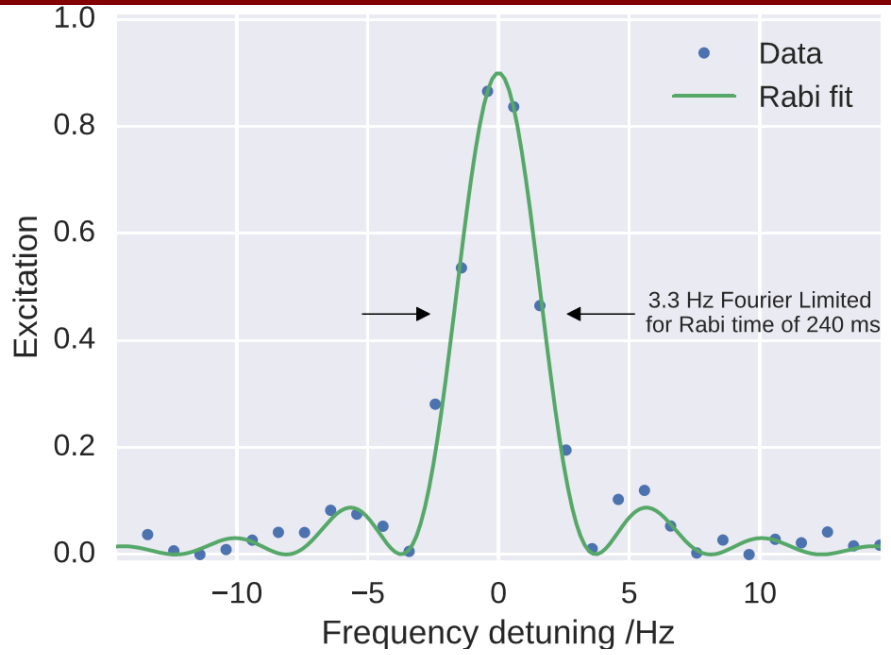
Yb

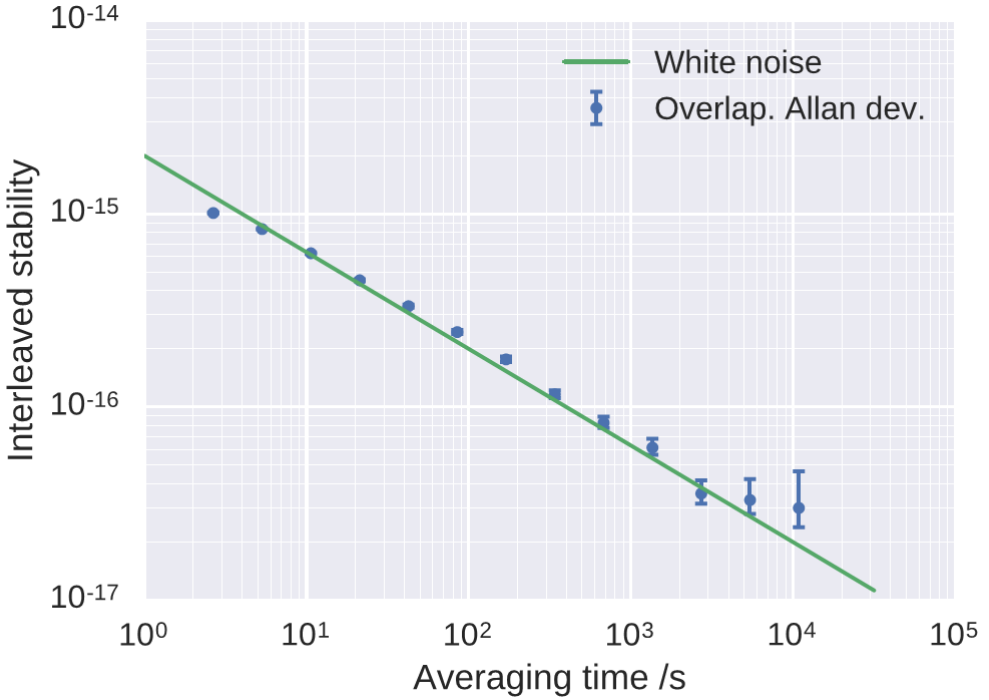
M. Pizzocaro, et al., Metrologia, 54, 102 (2017);

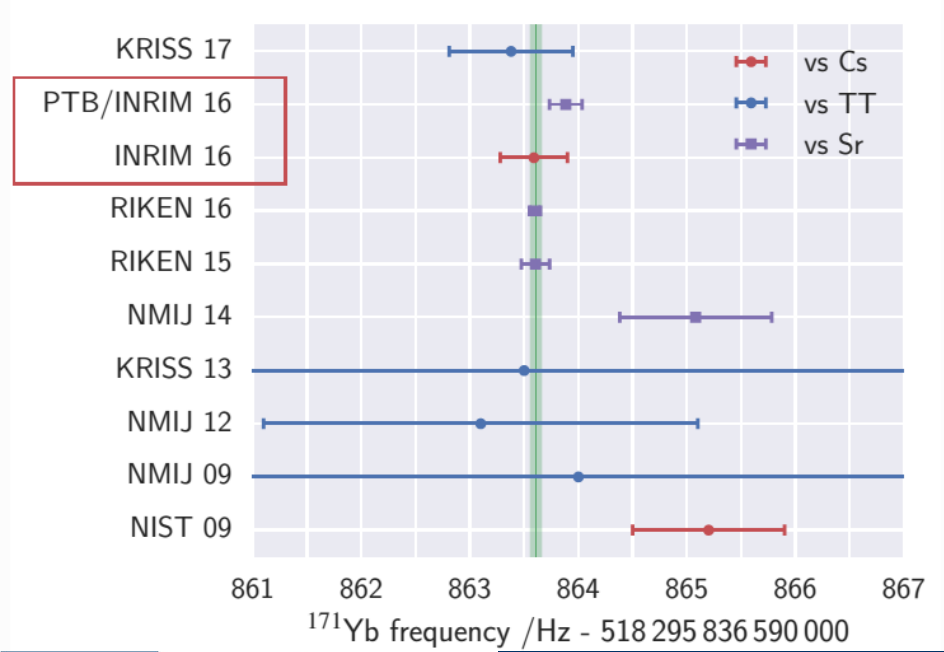
Accuracy: 4e-17

Realization of the SI second in Italy. UTC(IT) timescale
Fibre Link: dissemination to users and comparison of optical clocks (Turin-Paris Link ongoing)

INRIM Yb clock: main figures





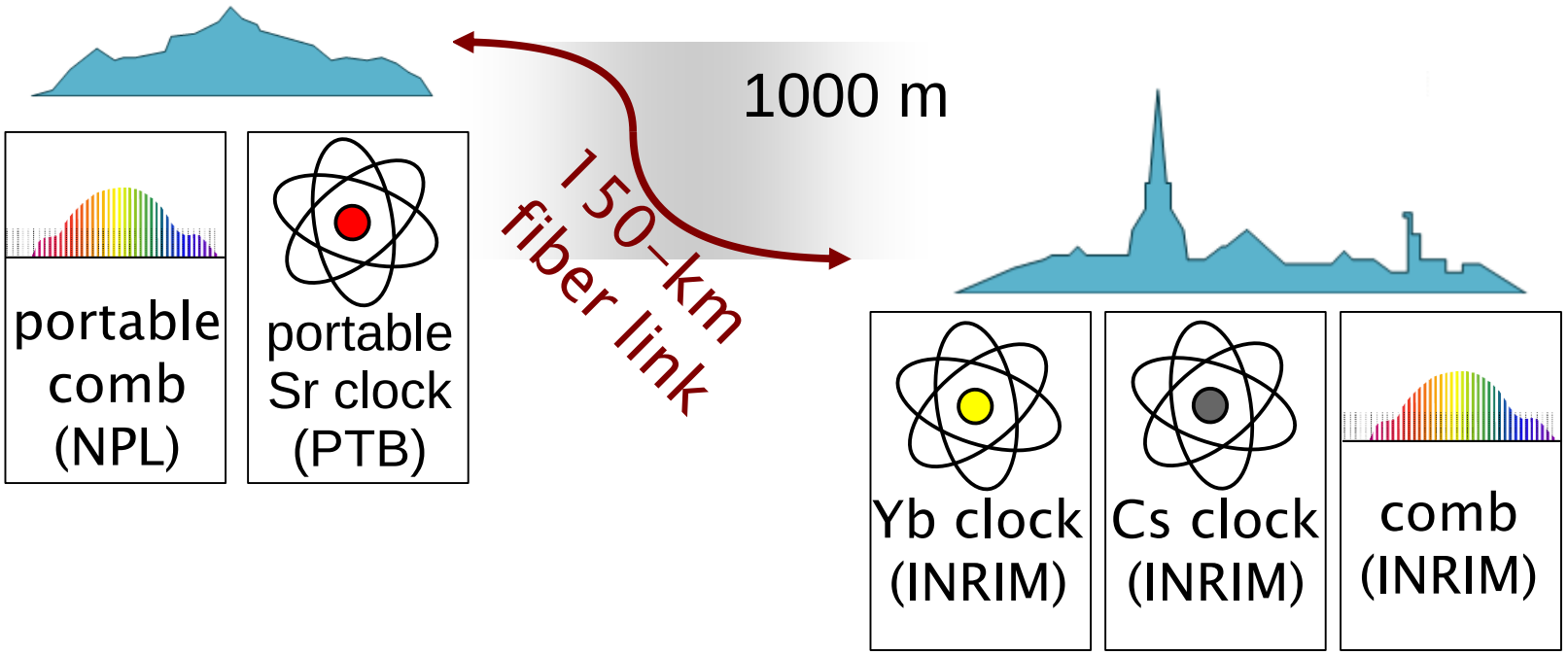


Effect	Rel. Shift $\times 10^{17}$	Rel. Unc. $\times 10^{17}$
Linear Lattice shift	2.5	2.8
Nonlinear Lattice shift	5.1	1.5
Density shift	−4.1	1.7
Zeeman shift	−0.8	0.1
BBR room	−236.1	1.0
BBR oven	−1.9	0.6
Probe light shift	0.2	0.9
Background gas shift	–	1.4
Others	–	1
Total	**-235.1**	**4.3**

Chronometric levelling

- How to translate this into a “real instrument”?

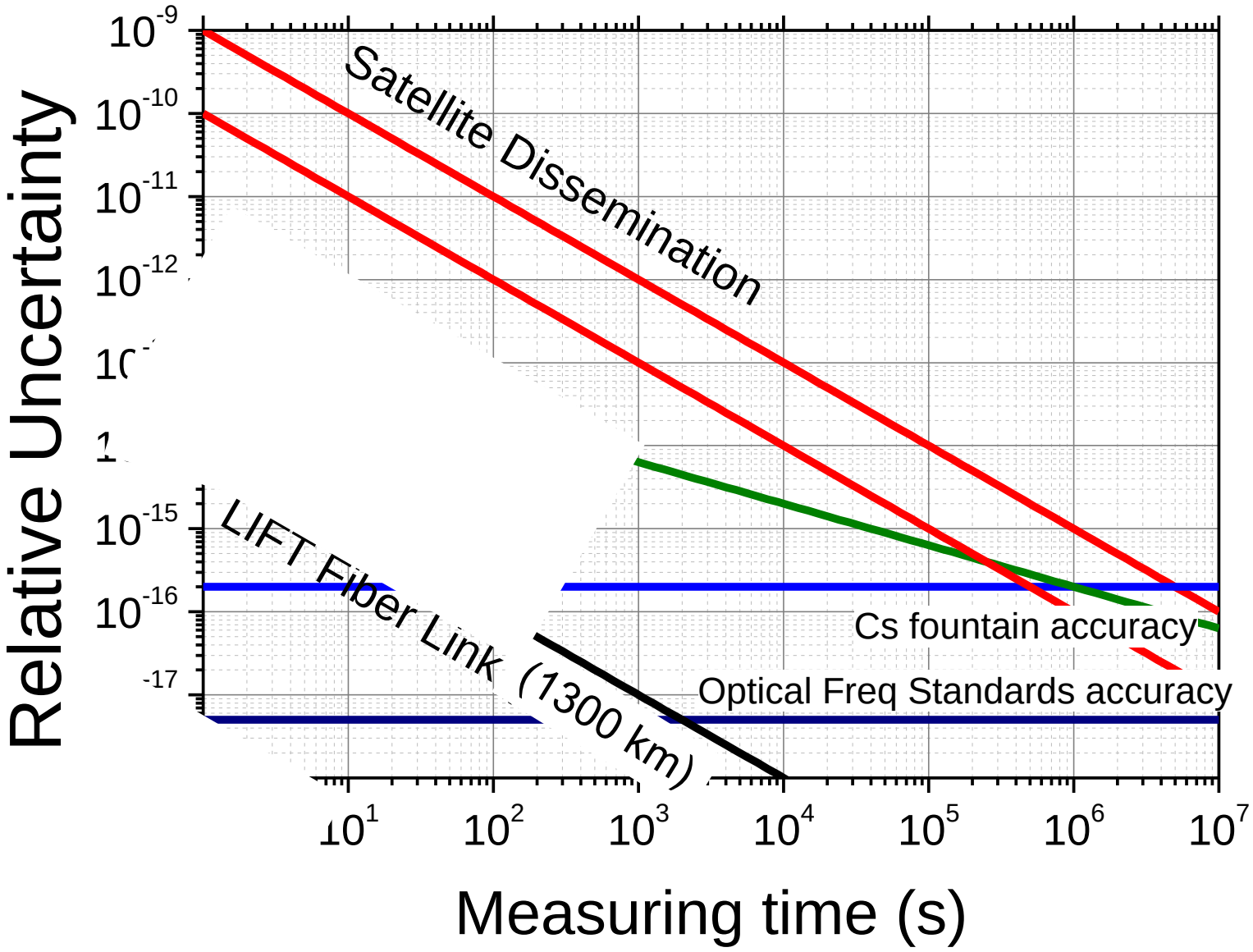
→ A proof-of-principle geodesy experiment between INRIM and the French Alps (Frejus Tunnel)



J. Grotti et al., Nature Phys. **14**, 2018

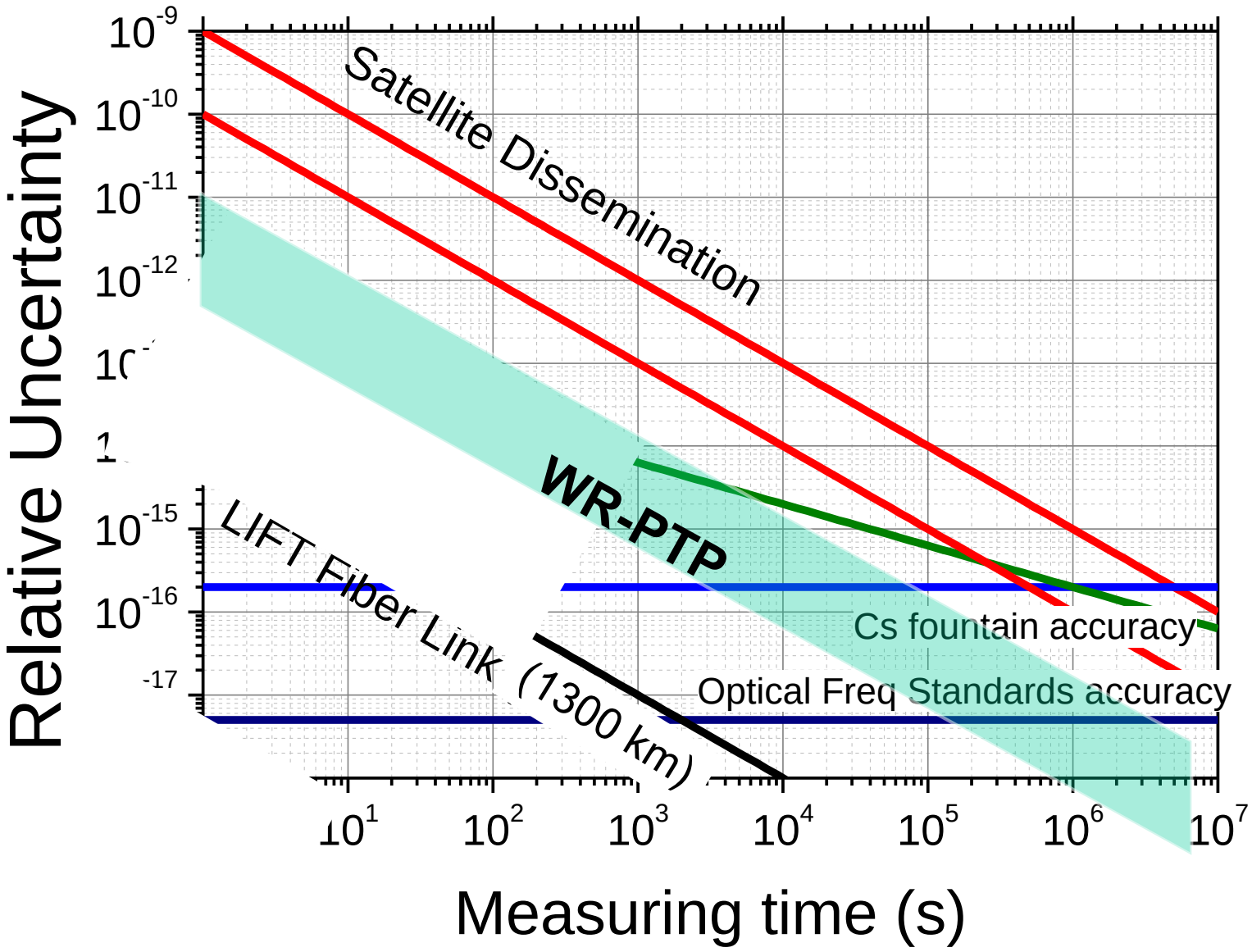
Transportable PTB Sr clock @Frejus Tunnel (LSM)

Atomic clocks: comparison and dissemination



When the redefinition of the second?

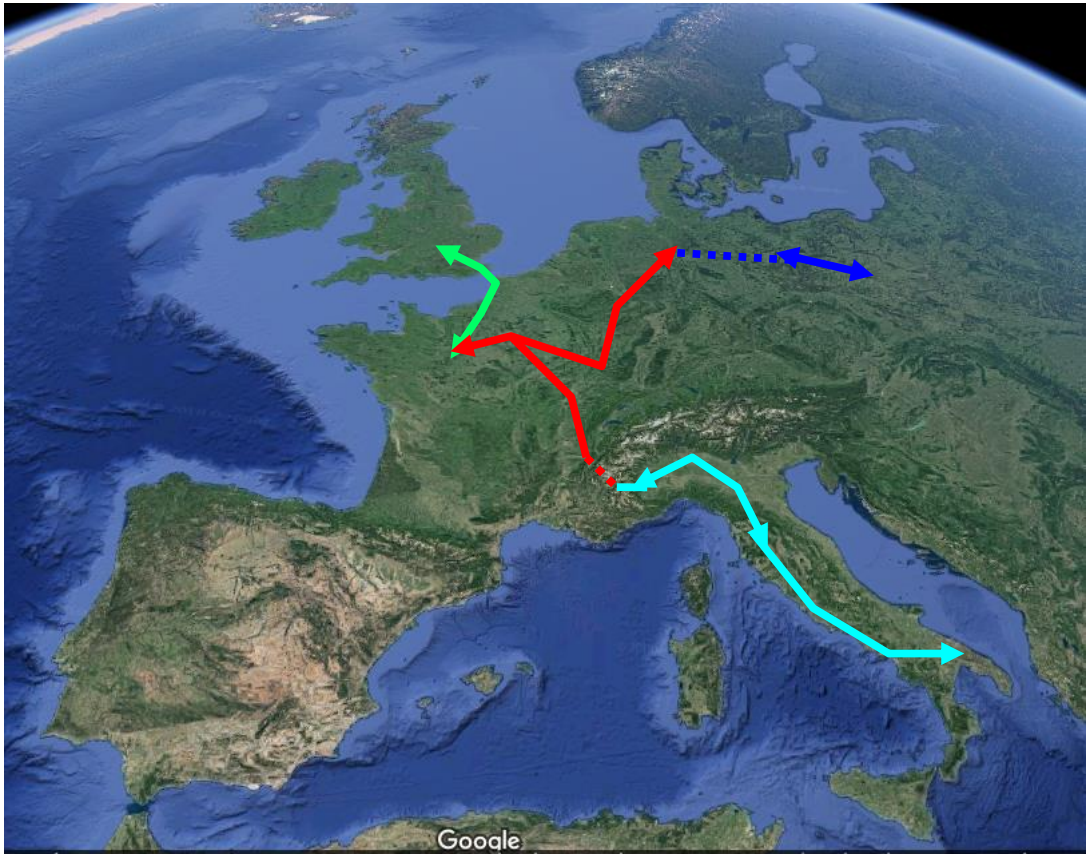
Atomic clocks: comparison and dissemination



When the redefinition of the second?

Fiber-based frequency dissemination

- First developed to compare remote atomic clocks
- Since 2008: operational fiber-based frequency dissemination in the world



Metrology

- fiber-based atomic clocks comparisons

[Ch. Lisdat et al., Nat.Comm. 7, 12443 (2016)]
[J. Guéna et al., Metrologia 54, 348 (2017)]
[P. Delva et al., Phys. Rev. Lett. 118, 221102 (2017)]

Fundamental Science

- Special relativity tests

[P. Delva et al., Phys. Rev. Lett. 118, 221102 (2017)]

- Relativistic geodesy

[T. Takano et al., Nat. Photon. 10, 662 (2016)]
[J. Grotti et al., Nature Physics (2018)]

Experimental physics

- Very Long Baseline Interferometry

[C. Clivati et al., Sci. Rep. 7, 40992 (2017)]
[P. Krehlik et al., Astron. Astrophys. 603, A48 (2017)]

- High-resolution spectroscopy

[B. Argence et al., Nature Photon. 9, 456 (2015)]
[C. Clivati et al., Opt. Express 24, 11865 (2016)]

- Seismology

[G. Marra et al., Science 361 (2018)]

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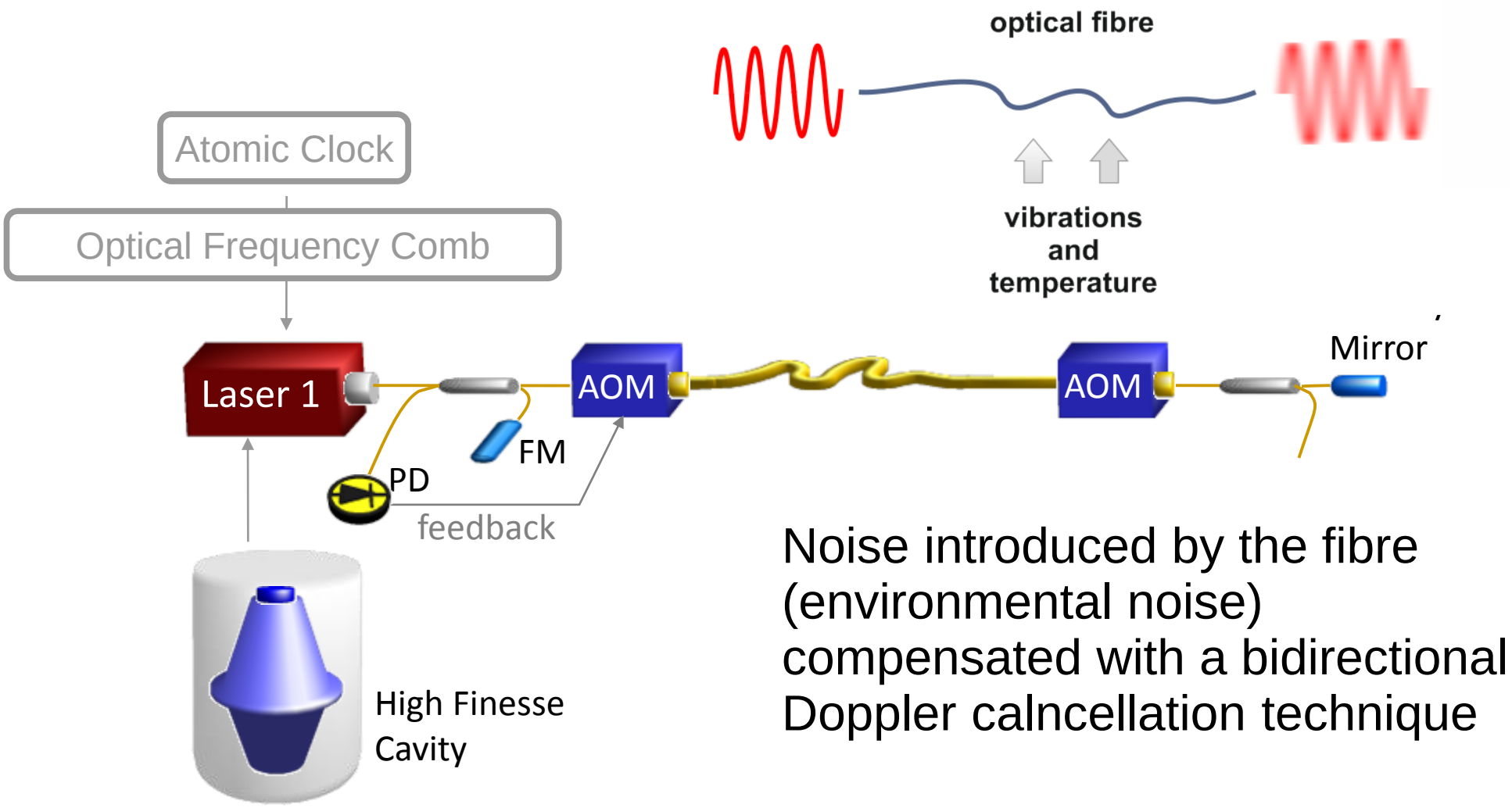
Towards a European Network of fibre links

H2020-INFRAINNOV

Strategy and innovation for clock services over optical-fibre networks
16 partners, Coordination: OP

Coherent optical fiber links



Noise introduced by the fibre (environmental noise) compensated with a bidirectional Doppler calncellation technique

P. A. M. Williams et al., JOSA B **25**, 2008

ITALIAN QUANTUM BACKBONE, 1800 km

- Quantum Technologies
- Radioastronomy
- Ultracold atoms Physics
- Space - Galileo
- Finance

7 Research Institutes linked:
CNR – National Research Council
ASI – Italian Space Agency
INAF – Italian Astrophysics Institute

3 Industrial Users
Thales Alenia Space Italy
Telespazio;
Consortium Top-IX

Dissemination for radioastronomy

Accurate Atomic Clocks +T/F fibre links :

- Faster operations
- Better mm-VLBI: above 80 GHz, H-Masers are the main limit to resolution, let's disseminate better atomic clocks

M. Rioja, et al. Astron. J., vol. 144, no. 4, art. no. 121, 2012.
B. Nikolic, et al. Astron. Astrophys., vl. 552, art. no. A104, Apr. 2013.
M. Rioja and R. Dodson, Astron. J., vol. 141, no. 4, art. no. 114, 2011

- Study of compact radio sources (better angular resolution) and interstellar molecular clouds
- In Geodesy VLBI, accuracy is relevant and 1-mm positioning accuracy requires clocks uncertainties at 1e-16.

A. Neill, et al. Report of Working Group 3 to the IVS Directing Board, Sep. 2005.

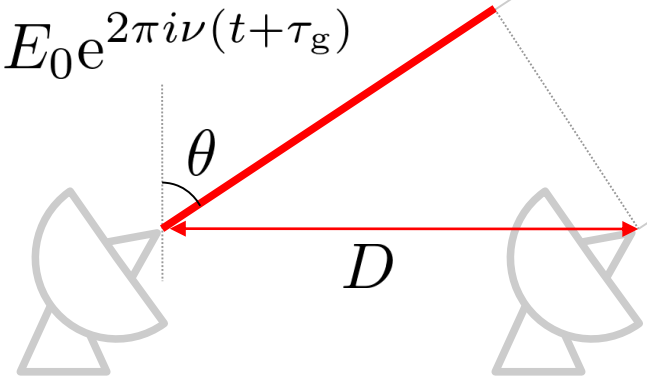
- Studying Pulsar through absolute accurate time

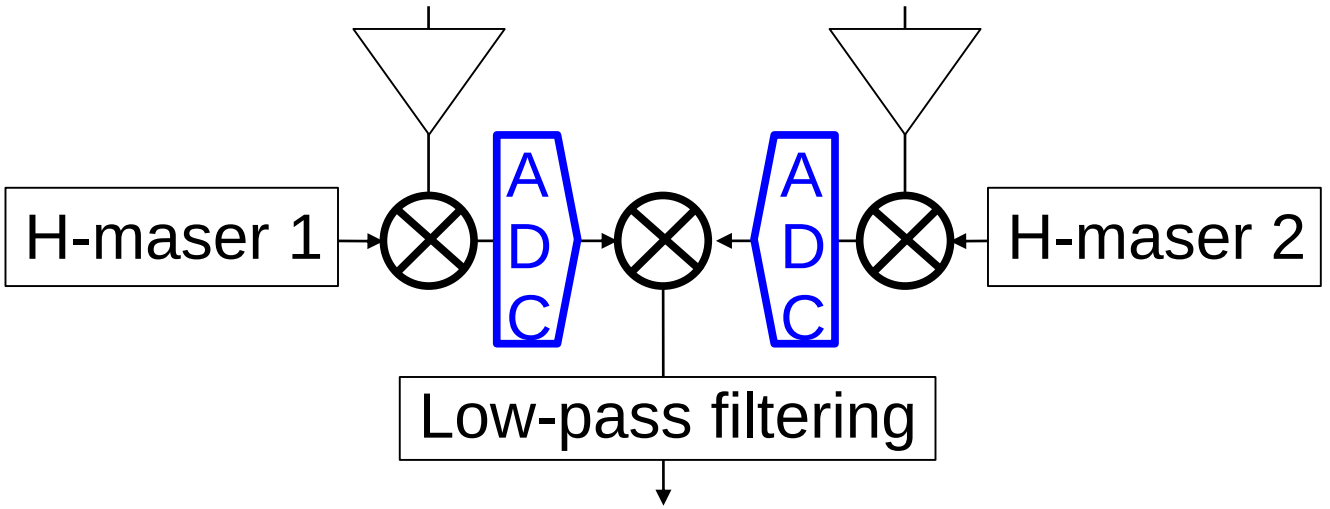
Very Long Baseline Interferometry

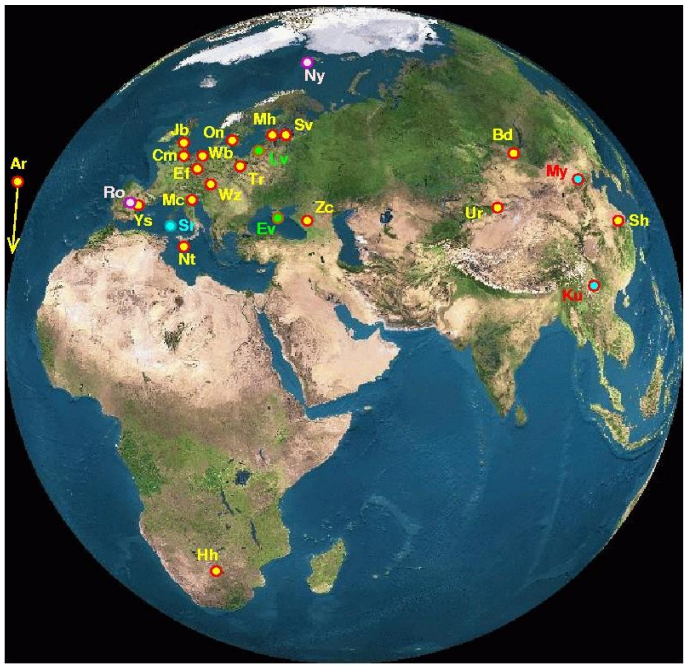
$$E_1 = E_0 \mathrm{e}^{2\pi i \nu (t+\tau_\mathrm{g})}$$

$$E_2 = E_0 \mathrm{e}^{2\pi i \nu t}$$

$$\tau_\mathrm{g} = \frac{D \sin\theta}{c}$$

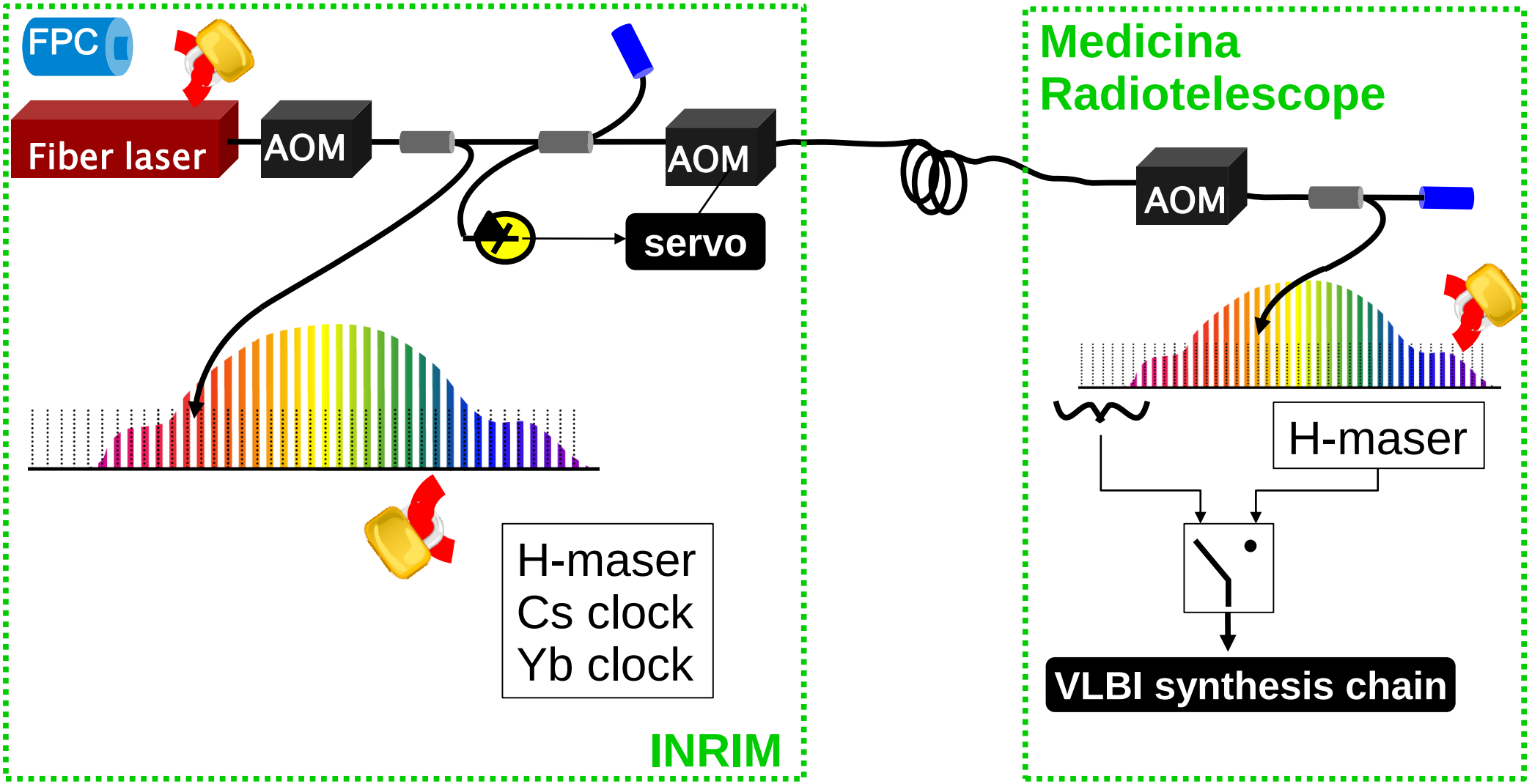




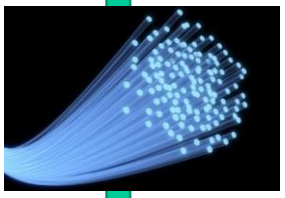


$$r = \cos\left(2\pi\nu\frac{D\sin\theta}{c} + \phi_\mathrm{clocks} + \phi_\mathrm{atm} + \phi_\mathrm{instr}\right) * \{I(\theta)\}$$

Delivering the same clock to multiple telescopes

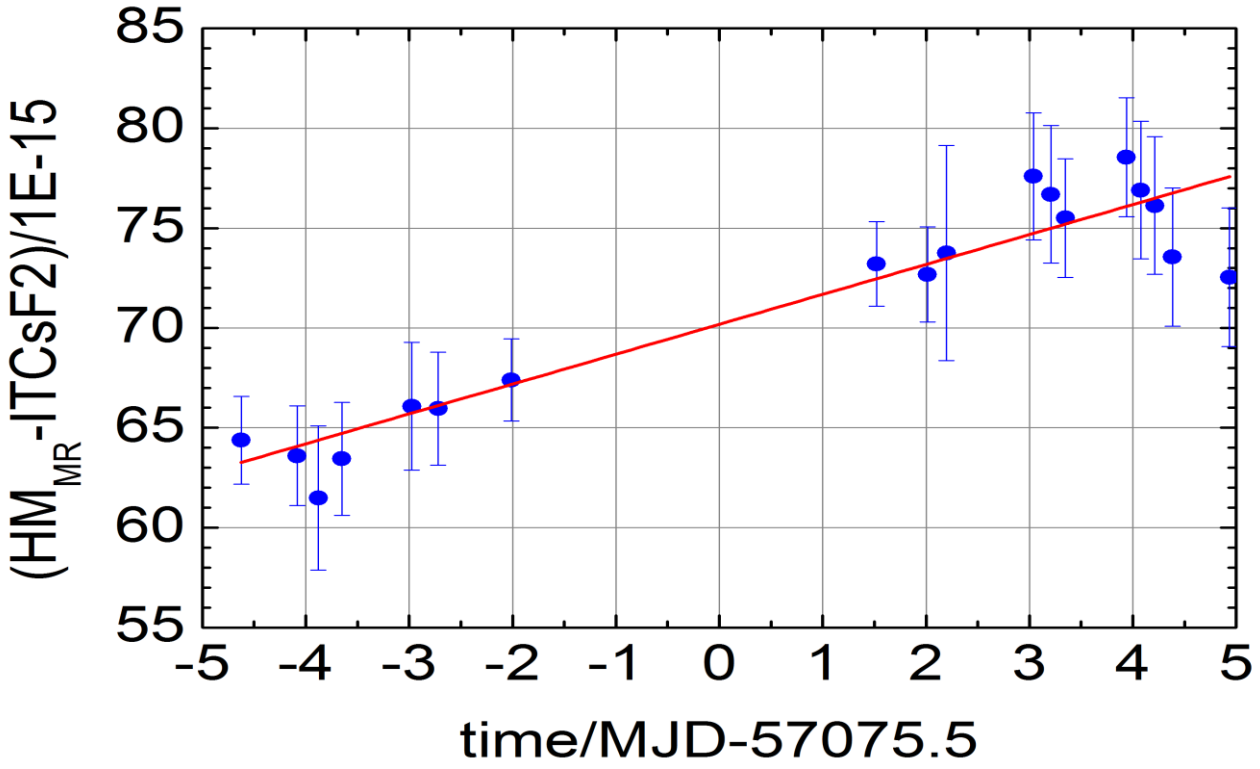


Medicina H-Maser Absolute calibration



- HM frequency = (70.2 ± 0.4)10^{-15}
- HM drift = (1.5 ± 0.1)10^{-15}/day

- 4 x10^{-16} Uncertainty, dominated by HMs
- Accuracy and resolution otherwise impossible



C. Clivati er al., IEEE TRANS. UFFC, 62, 1907 (2015)

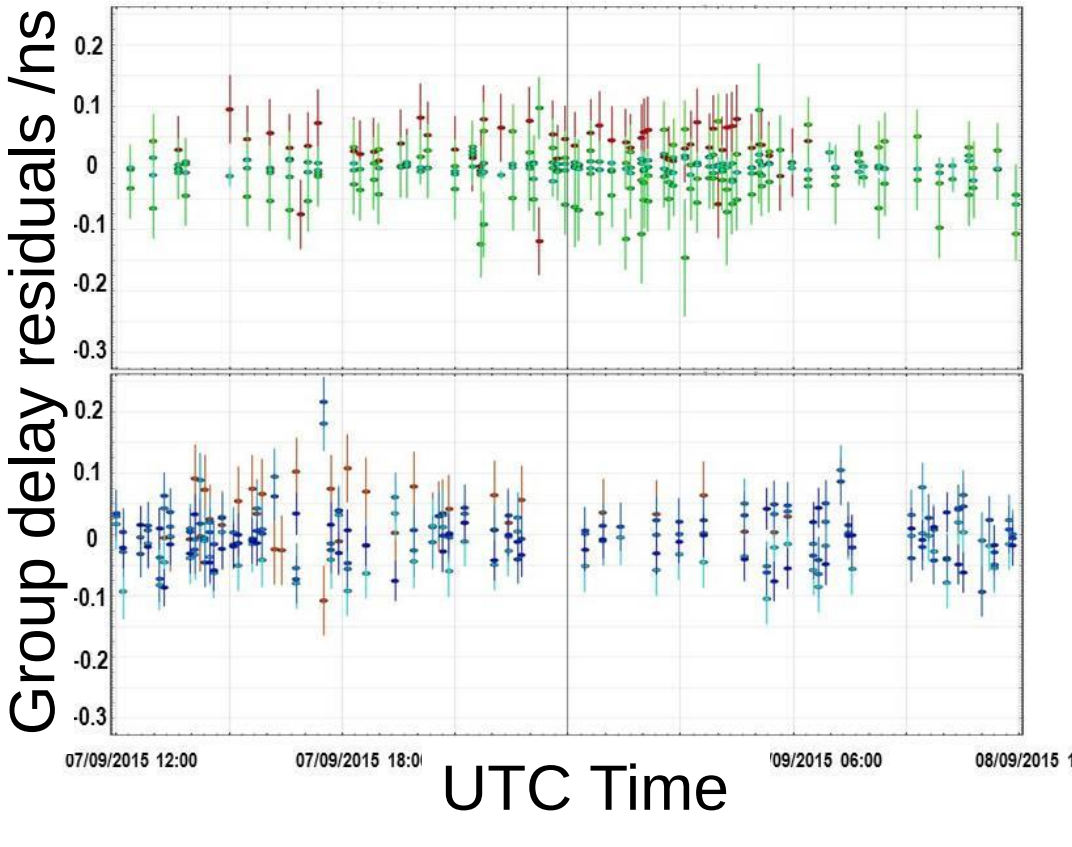
International VLBI campaigns

- Radioastronomical Fringes recovery using a remote H-maser

- 6 Radioantennas involved: Dss65a (Spain); Medicina (Italy); Metsahov (Finland); Nyales20 (Svalbard); Onsala60 (Sweden); Wettzell (Germany)

→ Residuals of Φ after modeling at the same level using local or remote clock (Hydrogen Masers in both cases)

→ Next improvements….



C. Clivati et al., Sci. Rep **7**, 2017

ITALIAN QUANTUM BACKBONE, 1800 km

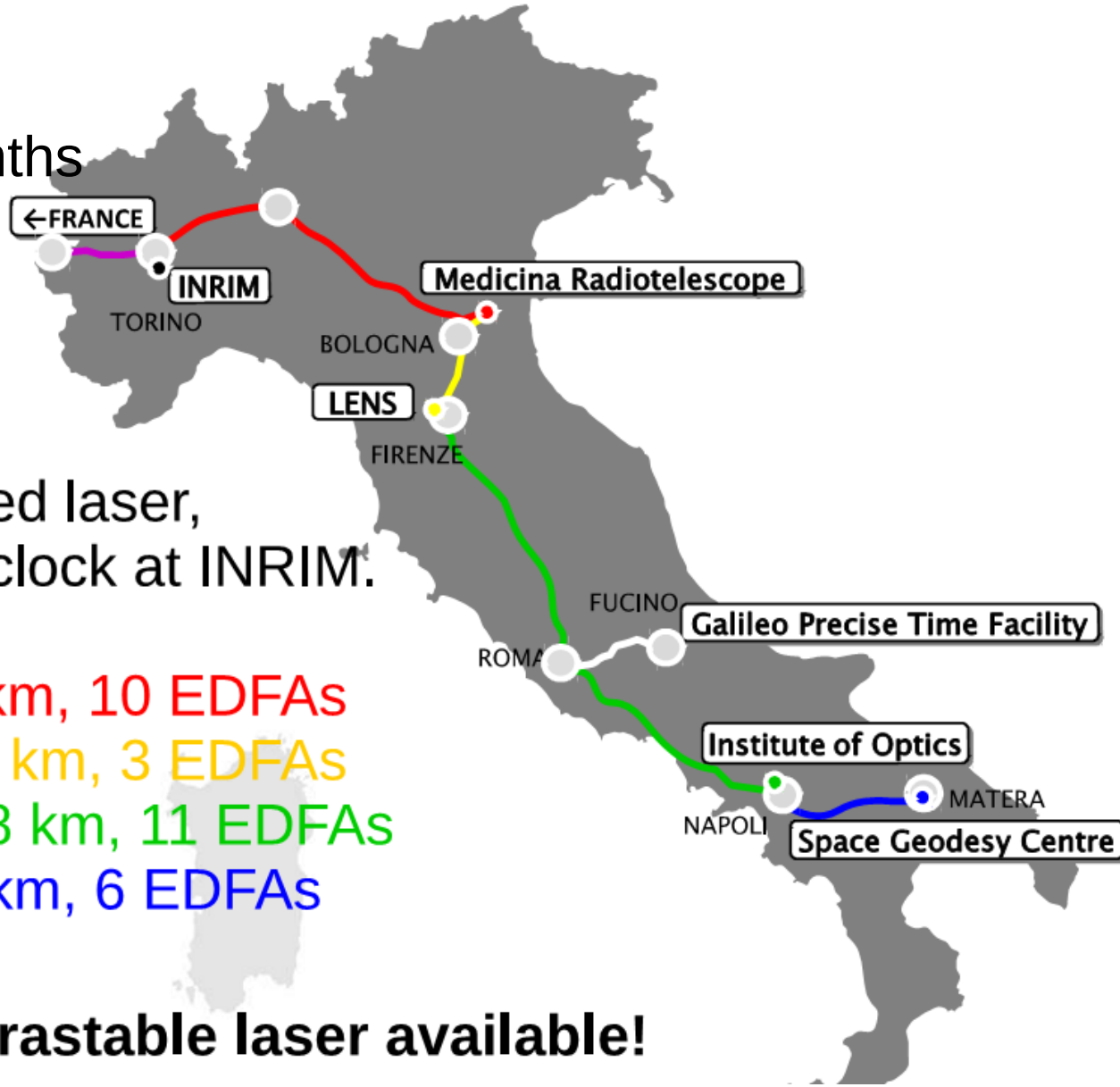
Next Steps:

- Optical clock to the Radioantenna
- Same clock to 2 radioantennas (Medicina and Matera)
- High Accurate Atomic Clock via fibre for Galileo System and Earth Observation (Fucino and Matera)

ITALIAN QUANTUM BACKBONE, 1800 km

Present Status:

- Infrastructure completed
- Single segments tested
- Under operation next months



- High-finesse cavity-stabilised laser, referenced to H-maser/Yb clock at INRIM.
- 4 cascaded optical links:
  - → INRIM-Medicina: 535 km, 10 EDFAs
  - → Medicina-Firenze: 149 km, 3 EDFAs
  - → Florence-Pozzuoli: 668 km, 11 EDFAs
  - → Pozzuoli-Matera: 387 km, 6 EDFAs

→ **At every terminal, ultrastable laser available!**

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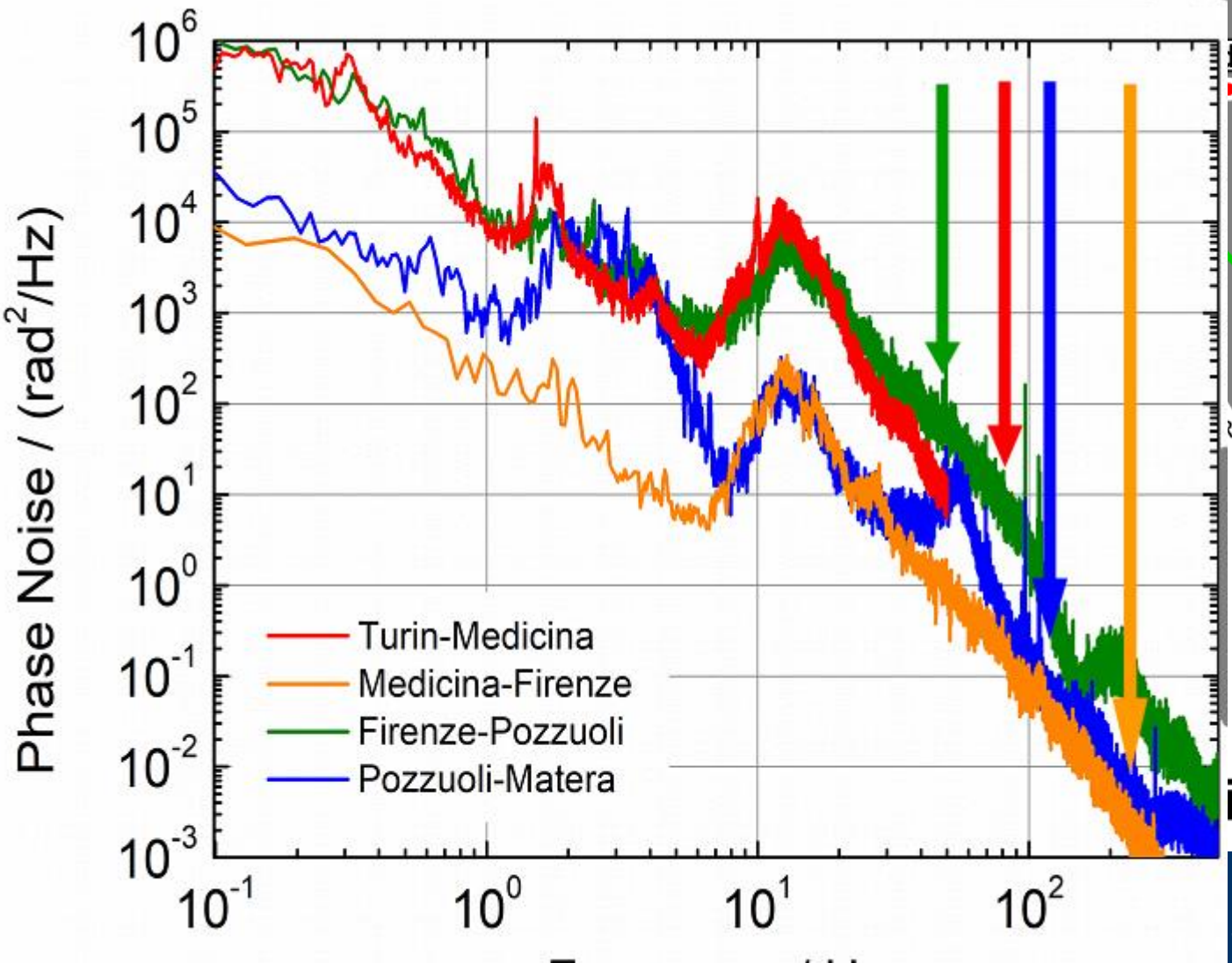
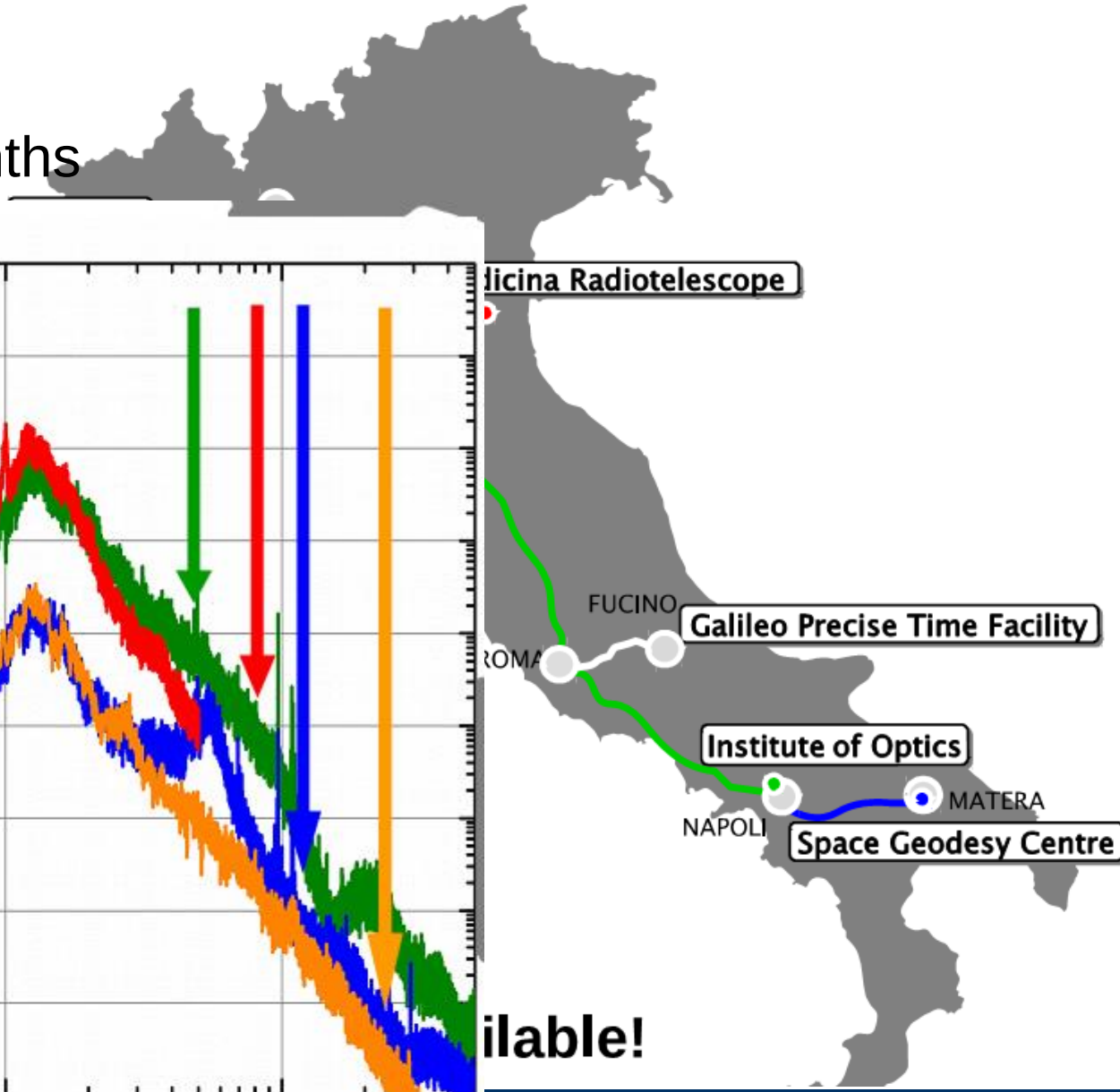




ilable!

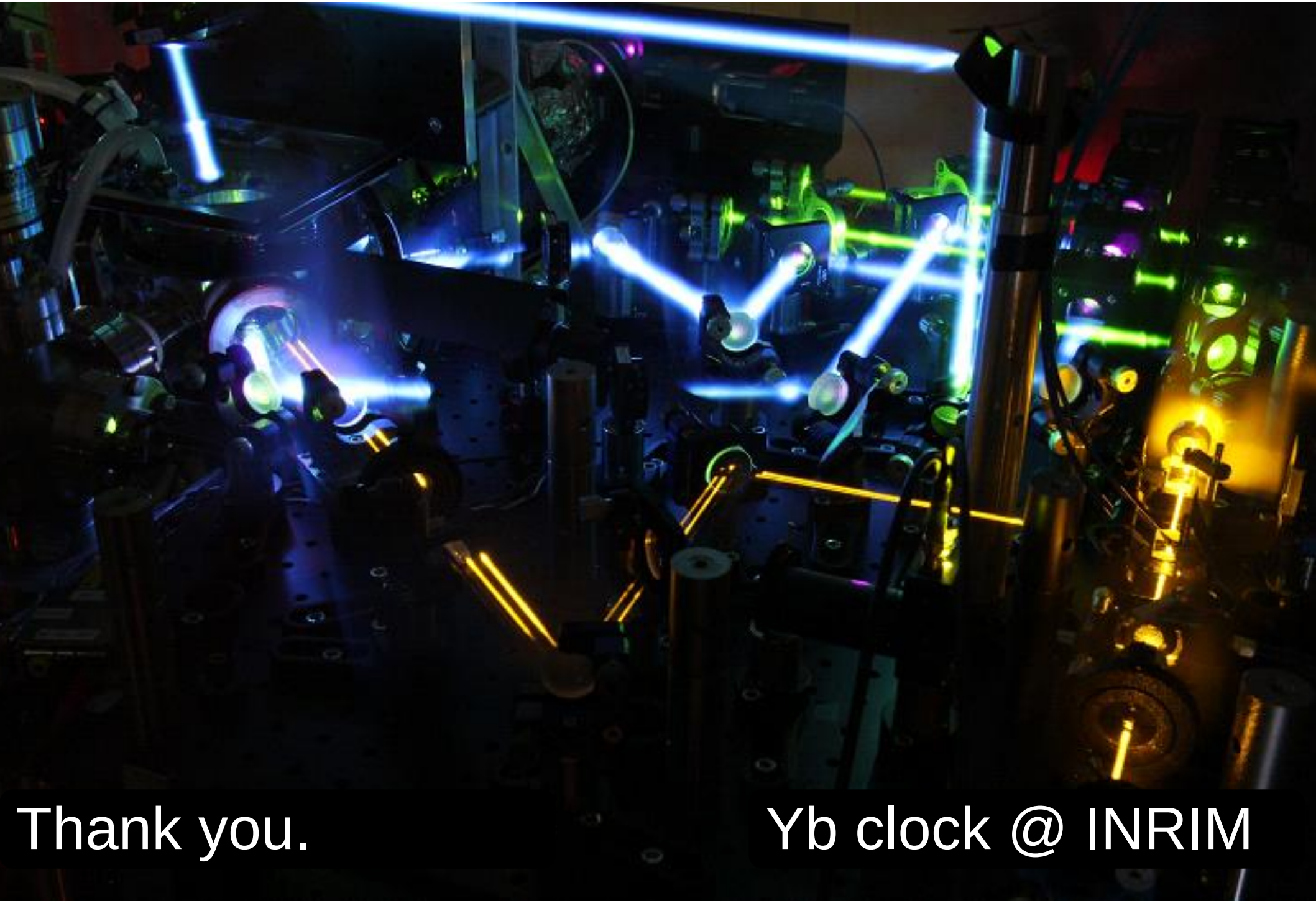
Credits

Fiber links for radioastronomy and geodesy:

R. Ambrosini, C. Bortolotti, M. Nanni, G. Maccaferri, M. Negusini, F. Perini, R. Ricci, M. Roma, M. Stagni (INAF)

Conclusions

- Gedetic VLBI experiments are ongoing on the LIFT project
- Chronometric Leveling on relevant sites in the next future?


Thank you.
Yb clock @ INRIM