International Association of Geodesy
Joint Working Group 2.1
Relativistic Geodesy: Towards a new geodetic technique

First Workshop
May 15 – 16, 2017, Leibniz Universitaẗ Hannover

STUDY GROUP ON OPTICAL FIBER LINKS FOR UTC UNDER THE CCTF WG AFTF

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SG chair
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Introduction

The Study Group focusing on the Optical Fiber Links for UTC (SGF) under the CCTF Working Group on Coordination of the Development of Advanced Time and Frequency Transfer Techniques (WG-ATFT) has been created.

The SGF will focus on

- **the developments and achievements in the field of frequency and time transfer using optical fibers,**
- **aiming at the comparison of atomic clocks, the comparison of timescale, the dissemination of T&F standards and of UTC to users.**

The Constitution of the Group has been on a volunteer basis, and the group is open to further contributions.

Study Group Members

In July 2015, the Study Group achieved its present composition:

Members:

Davide Calonico, INRIM <d.calonico@inrim.it> (Chair)
Wallin Anders, VTT, <anders.wallin@vtt.fi>,
Albin Czubla, GUM, <a.czubla@gum.gov.pl>,
Zhiheng Jiang, BIPM, <zjiang@bipm.org>
Kun Liang, NIM <liangk@nim.ac.cn>
Lennart Robertsson, BIPM <lennart.robertsson@gmail.com>,
Harald Schnatz, PTB, <Harald.Schnatz@ptb.de>,
Vladimir Smotlacha, CESNET, <vs@cesnet.cz>,
Wen-Hung Tseng, CHT, <whtseng@cht.com.tw>,
Ken Ichi Watabe, AIST, <k.watabe@aist.go.jp>

Other key persons:

Felicitas Arias, BIPM, <f.arias@bipm.it>
Feng Lei Hong, NICT, Chair WG AFTF <f.hong@aist.go.jp>

Terms of References

Background

1. **Attention** to the evolution of accurate time and frequency transfer techniques of various types, involved or not in the routine calculation of TAI/UTC.

2. **Expectation** that new fibre links will develop, and coordination and standardization will be necessary.

3. **Experience: i**n the past, the WGs of the CCTF have created ad-hoc study groups for studying particular issues; the outcomes have been very positive.

4. **Focus** on how optical fibre techniques can be used for
   (a) UTC(k) comparisons,
   (b) frequency standards comparison,
   (c) time link calibrations.

Terms of References

Objectives of the Study Group are:

- ✓ To make a review of the present status of the various optical fibre links with applications in time and frequency metrology,
- ✓ To propose technical directives for operating procedures, formats, including hardware, software and administrative issues,
- ✓ To study regulatory issues related to the availability of the services in a national context and the coordination between networks in different countries,
- ✓ To propose the appropriate recommendations for consideration of the BIPM and the CCTF.

Optical Fibre Links: realized long hauls

Location	Length	Performance (*)
France	540 km	FT $2.3\times10^{-15}/\tau$
Finland	900 km	TT 1 ns
Germany	1840 km	FT $1.3\times10^{-15}/\tau$
Italy	1284 km	FT $0.2\times10^{-15}/\tau$
France/Germany	1415 km	FT 0.02×10– 15/τ
Japan	120 km	FT $0.8\times10^{-15}/\tau$
Poland	420 km	TT 70 ps - FT $35\times10^{-15}/\tau$
UK	86 km	TT 150 ps - FT $6.3\times10^{-15}/\tau$
Check Rep/Austria	550 km	TT, evaluating accuracy 30 ps/20s
China	50 km	FT $20\times10^{-15}/\tau$

(*) accuracy for Time Transfer (TT)

Allan deviation for frequency Transfer (FT), extrapolated to 100 km (scaling law $L^{3/2}$).

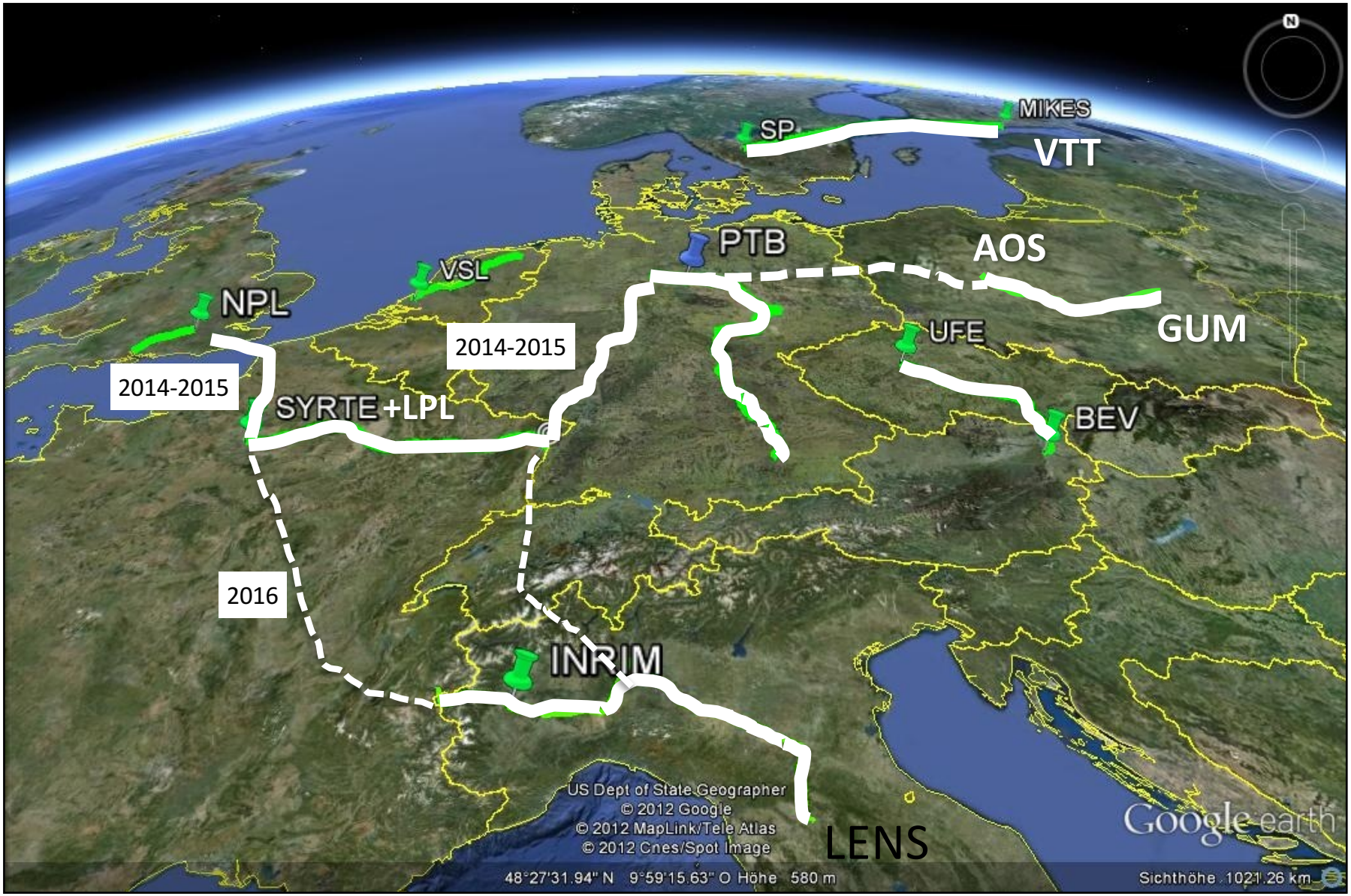
D. Calonico et al., European Phys Lett, 110 40001 (2015)

Optical Fiber Links: a worldwide snapshot

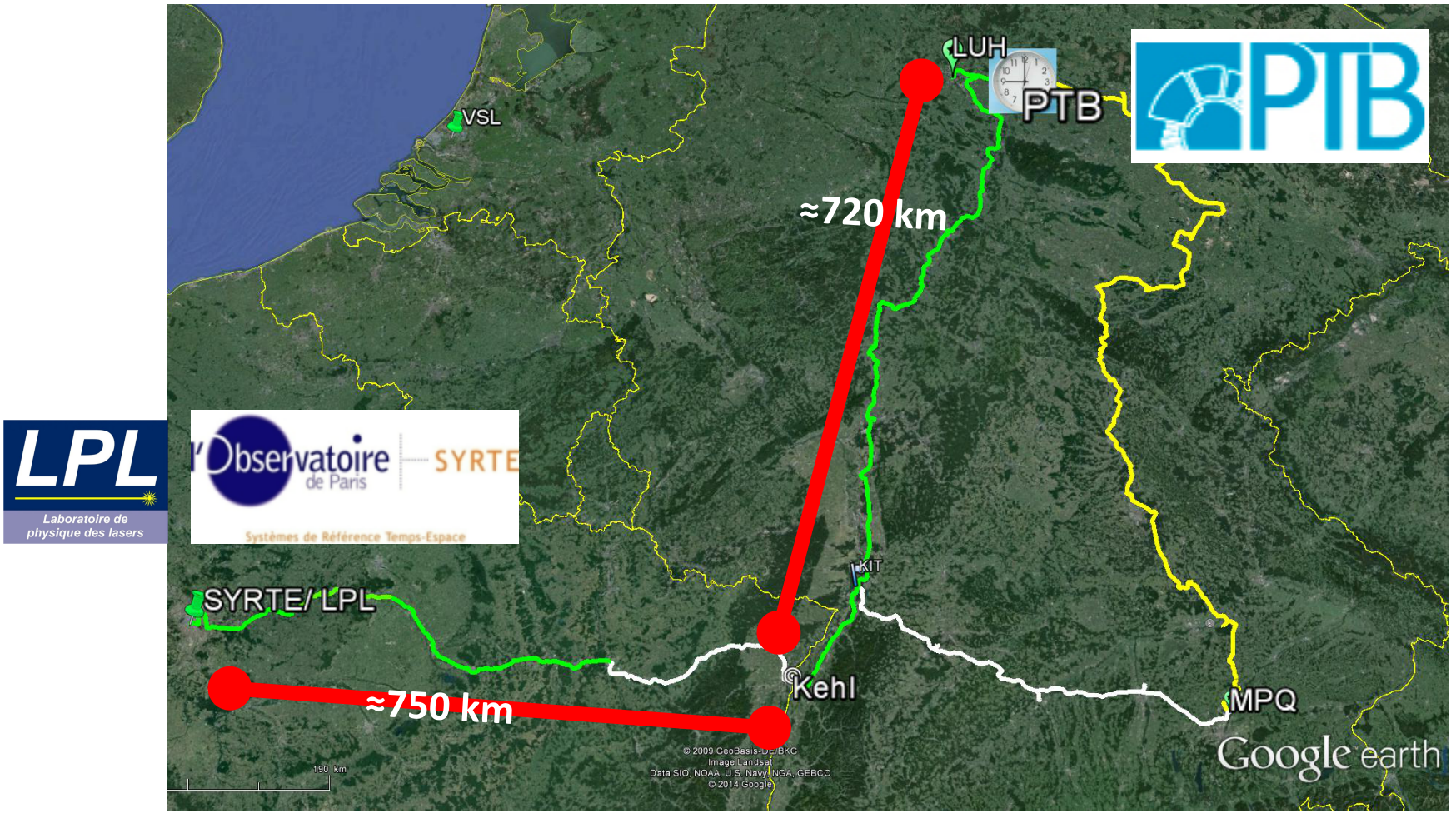
1 Fiber Link in use

Ongoing projects

Optical Fiber Link European Network

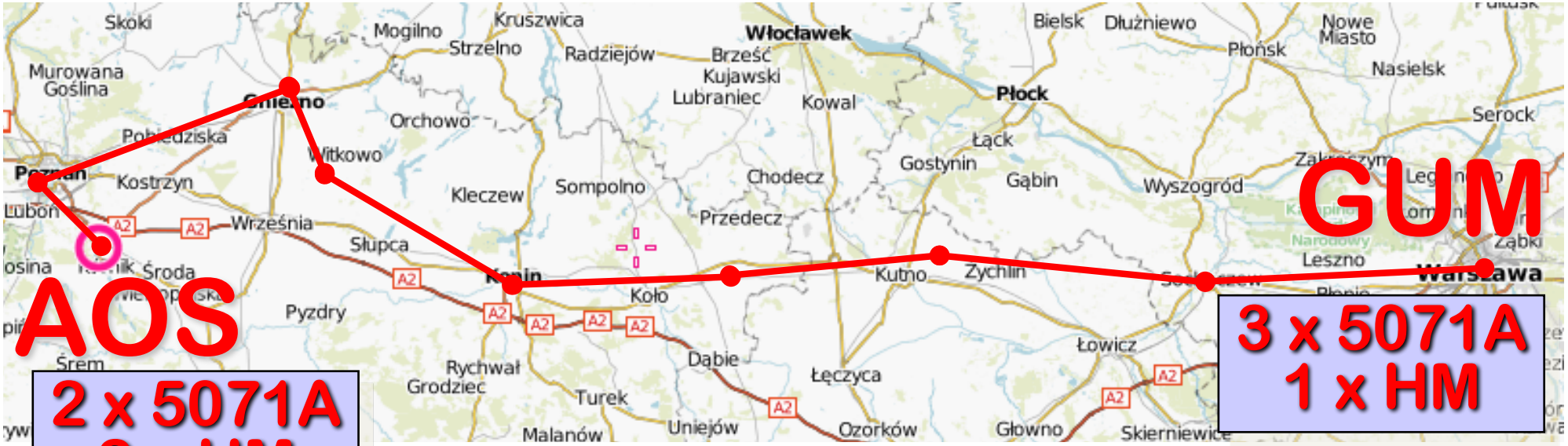


Sr Optical Frequency Standards comparison PTB- SYRTE



Lisdat C. et al., Nat Commun, 7, 12443 (2016)

Fibre link for UTC: GUM-AOS



270 km – the distance in a straight line

420 km – the distance along optical fiber

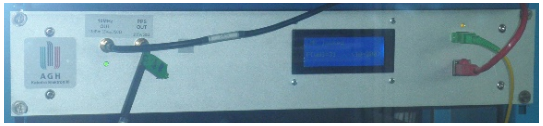
120 dB – attenuation (6 amplifiers)

300 ns – annual variations of optical fiber delay

1700 ps/nm – accumulated chromatic dispersion

Field instalation and first configuration in Jan/Febr 2012

Measurements with BIPM calibrator at optical fiber link GUM-AOS



$TTS4_{141}$(AOS)

Transceiver AOS

Transceiver GUM

UTCp(PL)

$TTS4_{112}$ (PL)

StdBIPM(AOS) 56503-509

moved to on 56502

StdBIPM(GUM) 56496-502

BIPM calibrator at AOS

BIPM calibrator at GUM

All measurements with UTC(PL) as a reference

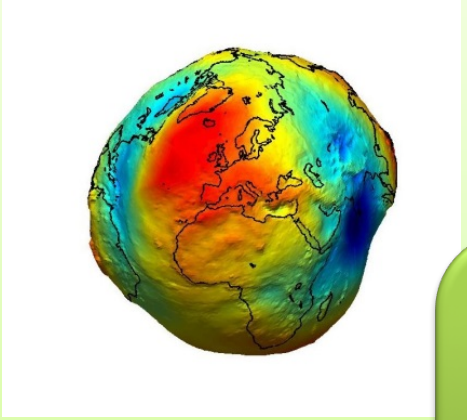
CCD

2 046 196.23 ns ± 0.06 ns (1-σ)

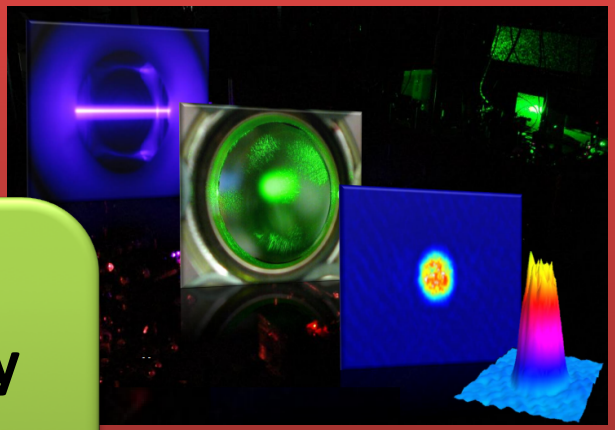
Jiang Z., Czubla A., Nawrocki J., Lewandowski W., Arias E. F.: Comparing a GPS time link calibration with an optical fibre self-calibration with 200 ps accuracy, *Metrologia*, vol. 52 (2015), pp. 384-391

Link impact outside primary metrology

Relativistic Geodesy



Atomic and Molecular Physics

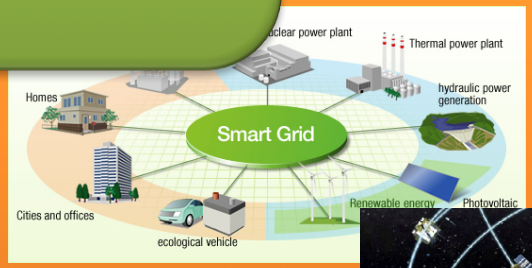


Primary Metrology
Clock comparison,
UTC

Radio-astronomy VLBI

Space Geodesy

GNSS, Industry



T/F Fibre Link: New experiences

- Radioastronomy

Spain/SKA: White Rabbit Technique
Italy: Coherent and WR Technique
Poland: Elstab Technique
Finland forthcoming (WR)

- Finance Sector Industry (see dedicated talk)

UK: PTP/White Rabbit
Italy: White Rabbit

- Telecom (see dedicated talk)

Germany: Elstab technique

- Aerospace/Galileo:

Italy: White Rabbit

Radioastronomy:
the SKA project will use White Rabbit

Artist impression of the Square Kilometre Array

Fibre link for Radioastronomy: Italy (coherent transfer)

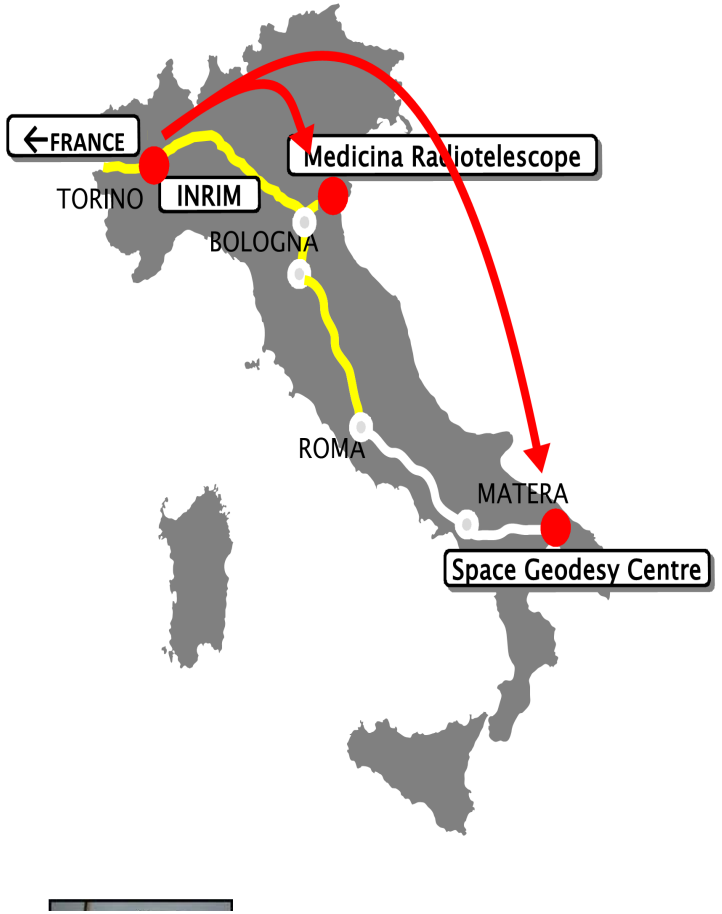
✔ **Towards a common-clock VLBI experiment**

→ Ongoing extension on Italian link to connect 2 telescopes

→ Low-noise microwave generation stage in progress

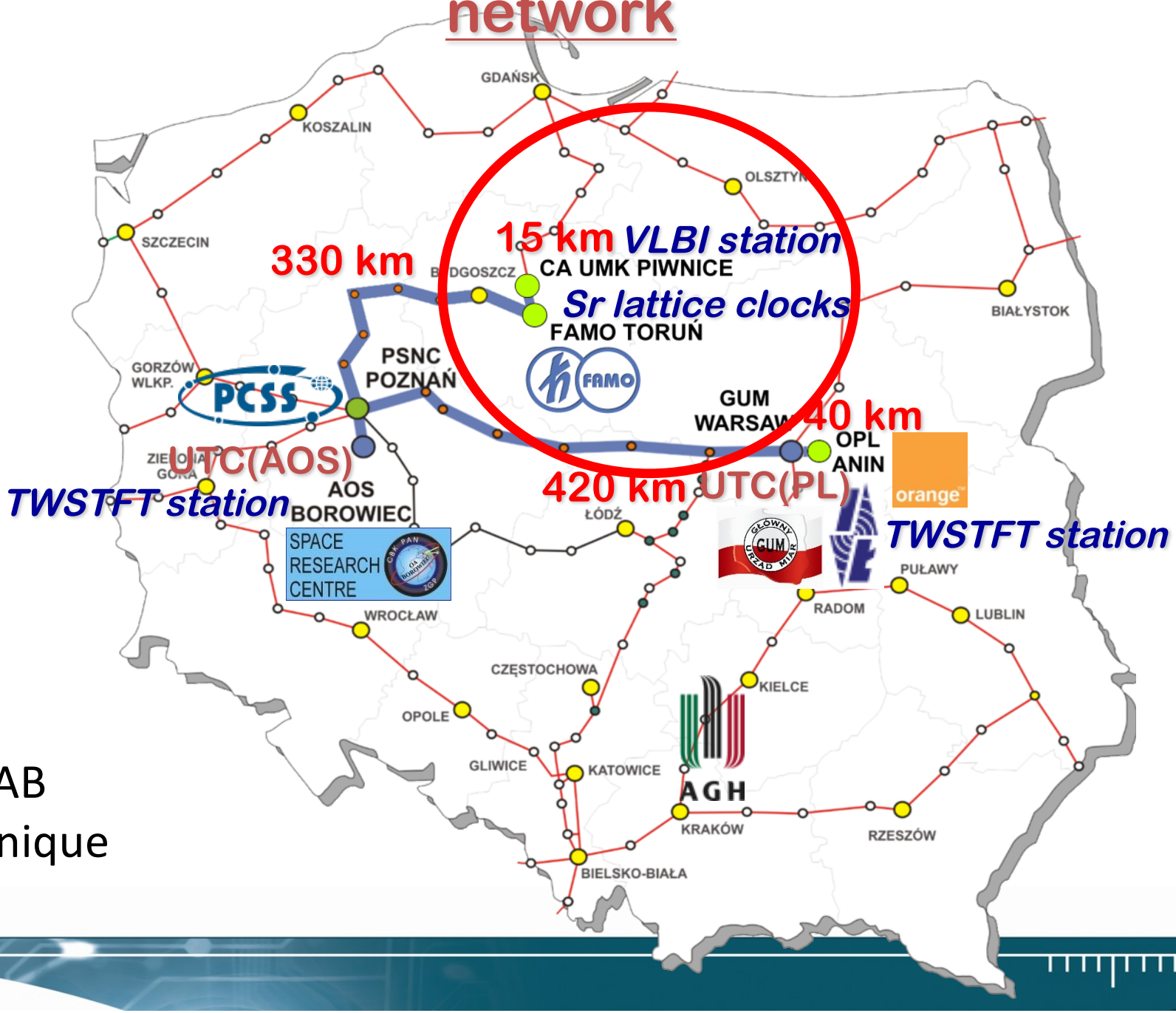
→ 2 VLBI campaigns with fiber-disseminated INRIM clock to Medicina already performed

C. Clivati, Sci. Rep. 7, 40992 (2017)



Next Steps: also White Rabbit

OPTIME – the Polish optical fiber T&F transfer network



ELSTAB
Technique

AEROSPACE: LIFT+

1800 km

Frejus-Turin-Matera

Realization: 2017

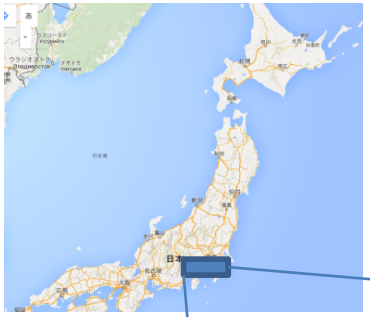
Fucino:

Esperimentation of Traceability of Galileo GCC

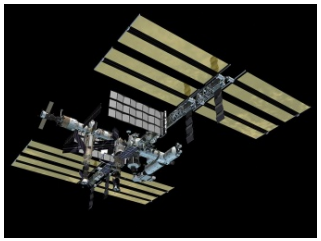
To UTC via fibre link

(accuracy target <1ns)

Fibre Links in Japan:
Institutes & Universities around Tokyo



Japan



?

NMIJ

RIKEN

Sr, Hg, Yb lattice

Sr lattice

Yb, Sr lattice

?

U. Tokyo

NICT
headquarter

NICT
Ohtemachi office

Sr lattice, Ca^+, In^+

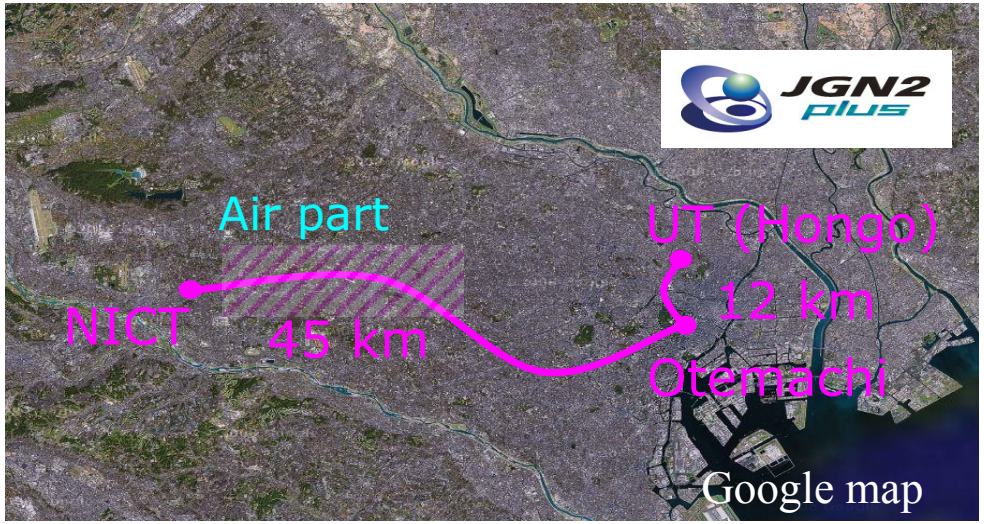
ACES Ground
Terminal

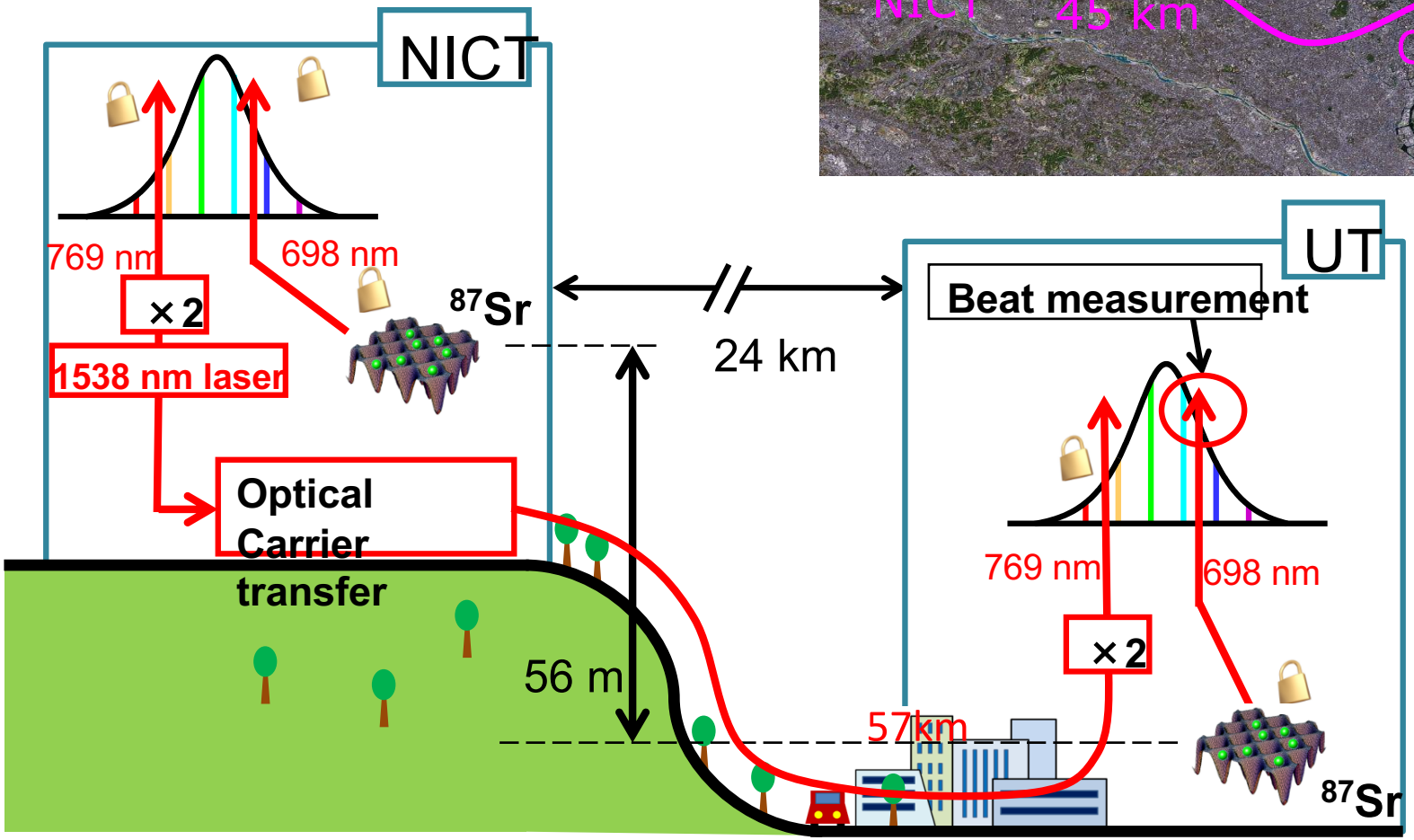
The link between NICT & NMIJ will be established either by fiber link or Two-way carrier phase (TWCP)

Courtesy of T. Ido

Optical Fiber Links and Relativistic (Chronometric) Geodesy

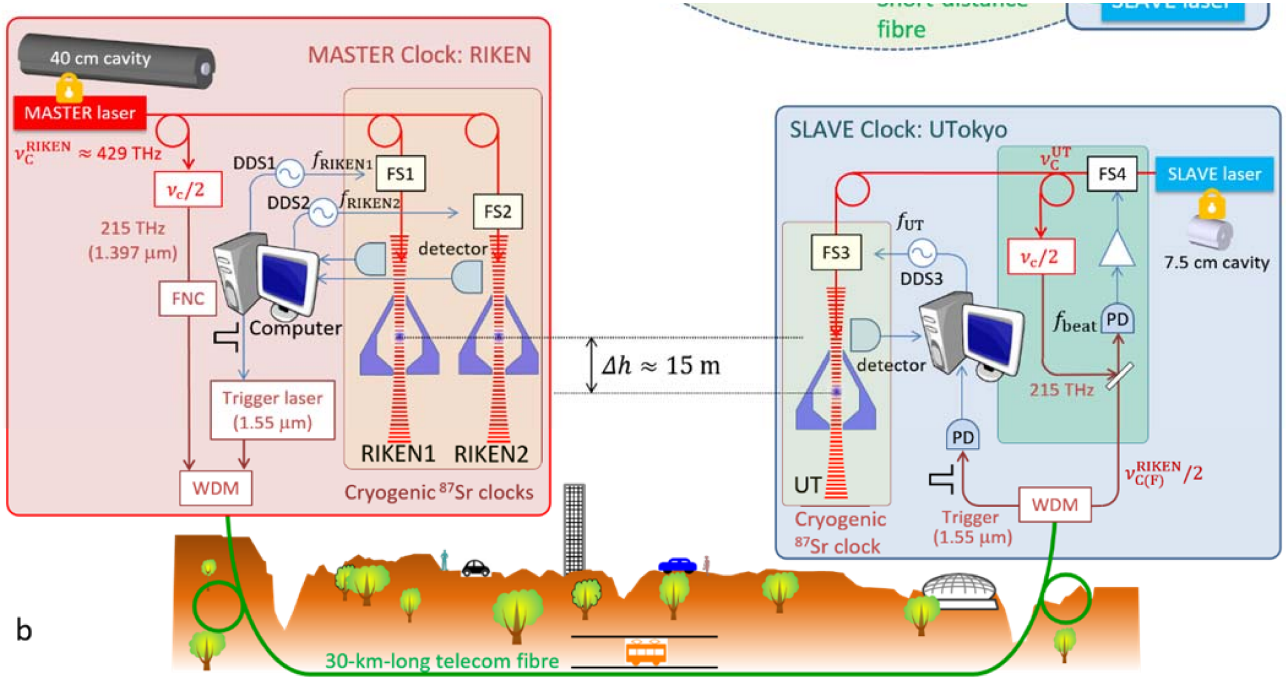
All-optical direct comparison between NICT & UT clock (2011)

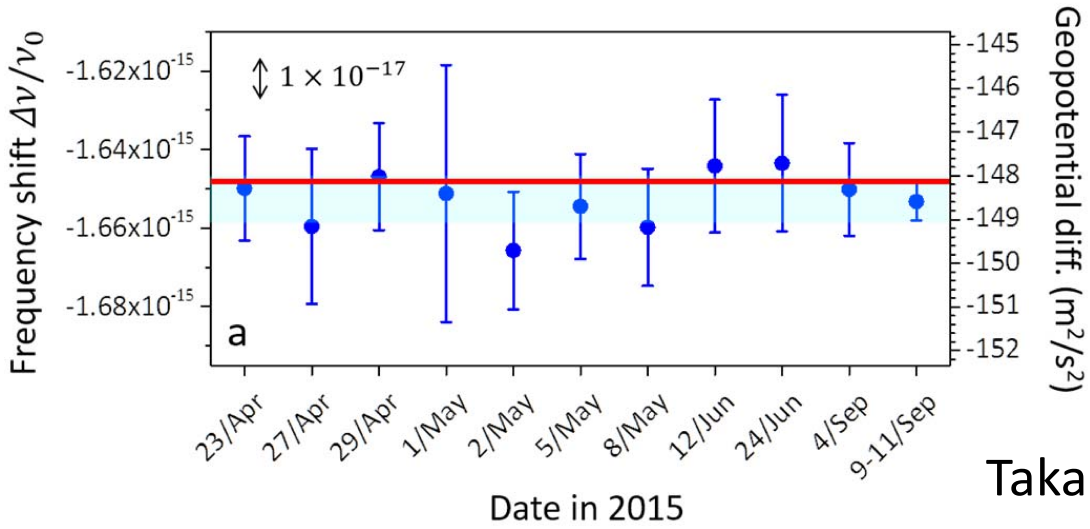




Yamaguchi, *et al*., Appl. Phys. Express 4, 082203(2011).

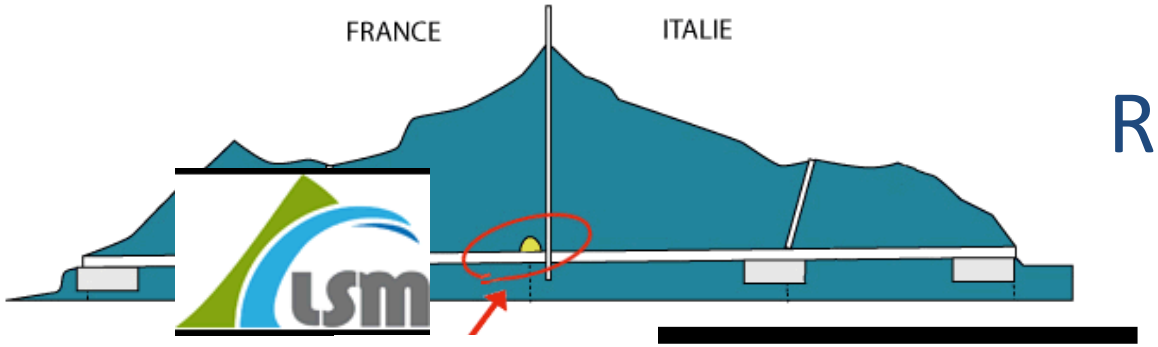
All-optical direct comparison between Riken & UT clock (2016)





Takano, *et al*., Nat Phot., 10, 662 (2016).

EMRP-SIB55- ITOC
Relativistic Geodesy Exp



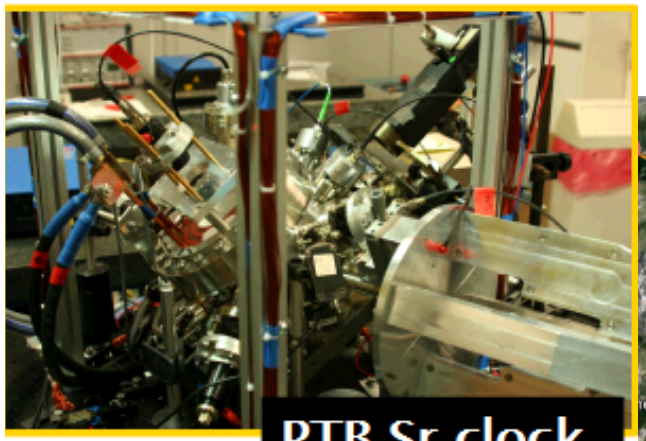
150 km

1263 m slm

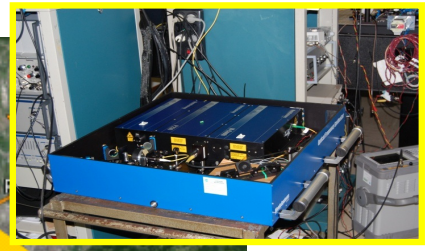
240 m slm

INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

Paper submitted
https://arxiv.org/abs/1705.04089

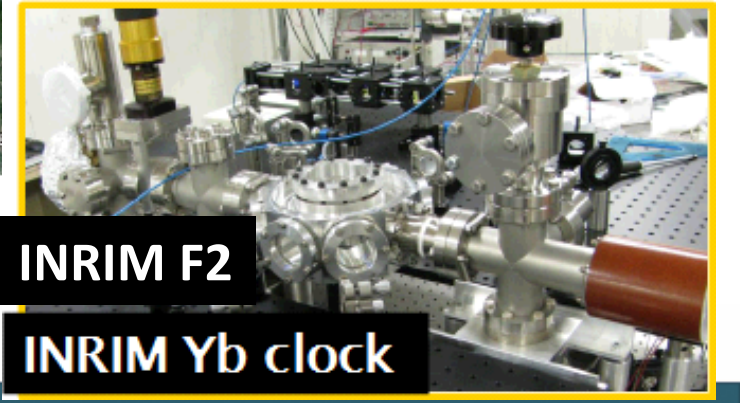


PTB Sr clock



INRIM comb

NPL comb



INRIM F2

INRIM Yb clock

New IAG WG
Relativistic geodesy: First steps towards a new geodetic technique

Chair: Jacob Flury/Gerard Petit

- Under the auspices of IAG Commission 2 (Gravity Field)
  - Joint with Sub--Commission 1--2 on Global Reference Frames

The objectives of the Working Group are to:

- Act as interface between groups in geodesy (gravity fields, reference frames…) and in time and frequency metrology (clock development, clock comparisons …);
- Provide a platform to promote the further development and application of relativistic geodesy, e.g. in physics, astronomy and other fields of geodesy and metrology;
- Foster the geodetic interests in the realization of the concept of relativistic geodesy;
- Develop an optimal strategy for the installation and analysis of clock networks and for the combination of clock data with classical geodetic data (e.g. for height systems);
- Advocate the implementation of a clock network of sufficient capability to obtain data products essential for geodetic applications;
- Study the use of clock networks in space;
- Provide relevant information for the geodetic community including key contacts and links;
- Organize meetings and sessions on relativistic geodesy;
- Prepare a document on the perspectives and applications of relativistic geodesy.

chair

H2020-INFRAINNOV

CLONETS - CLOck NETwork Services:

Strategy and innovation for clock services over optical-fibre networks

16 partners, Coordination: OP

l'Observatoire de Paris – SYRTE
Systèmes de Référence Temps-Espace

INRiM Istituto Nazionale di Ricerca Metrologica

NPL National Physical Laboratory

PTB Physikalisch-Technische Bundesanstalt Braunschweig und Berlin

LPL Laboratoire de physique des lasers

PSNC

RENATER Connecteur de savoirs

MenloSystems GmbH

AGH University of Science and Technology

top ix

Consortium GARR

µQUANS

CLONETS - Objectives

a) to collect information from research infrastructures and national research and education networks (NRENs) as input for the formulation of roadmaps

b) to study applications beyond research infrastructures: identifying the other users and stakeholders/estimating the future economic and societal impact

c) to define roadmaps and strategies to support future work

d) to create the environment necessary for future work through recommendations to policy makers/ dissemination/training of engineers and researchers

e) to study the evolution of the partnership created by this project necessary for a future exploitation phase of the created clock services network.

II Level Specializing Master in Photonics for Networks and Metrology

DELIVERING **DATA** AND **TIMING** AT THE **SPEED OF LIGHT**

12 Months, starting in Sep 2018

Politecnico di Torino

480 hours mixing lectures and hands-on lab activities
2 Months Internship in European Companies and Research Centers

Lecturers from Academia and Research Community

Optical Communications and Networking, Photonics in Metrology, Quantum Communications, Security for ICT

VITTORIO.CURRI@POLITO.IT WWW.OPTCOM.POLITO.IT D.CALONICO@INRIM.IT

Conclusions

- ✓ Fiber Links are developed worldwide, largest efforts in europe
- ✓ Different techniques for different objectives: time, frequency, T&F, different performances and complexity.
- ✓ They allow to compare remote frequency standards at their best accuracy. They are suitable for accurate time transfer
- ✓ They enable chronometric (relativistic) geodesy
- ✓ Efforts to be done to ensure reliable continous systems and to cope for weaknesses

Thank you.