

# **Time and Frequency metrology: e-Infrastructures for Science and Society**

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# Time and Frequency Metrology: who cares?



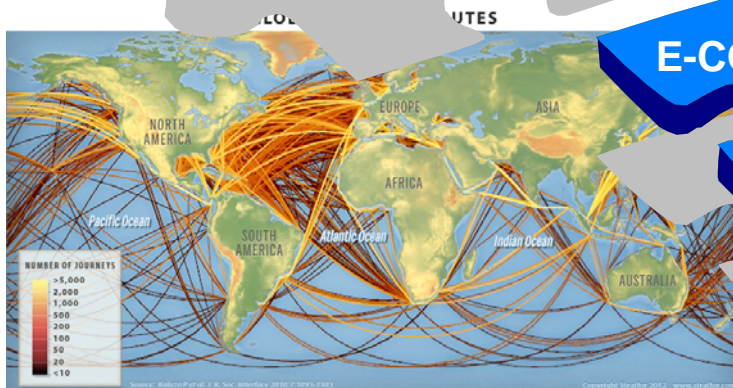
# T&F Users



TELECOMMUNICATIONS



TRANSPORTS  
AND NAVIGATION



E-COMMERCE

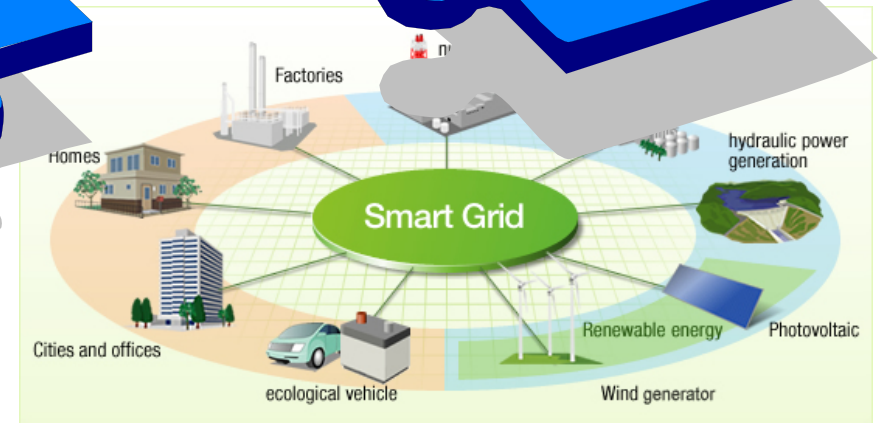


POSITIONING  
SYSTEMS

DATING

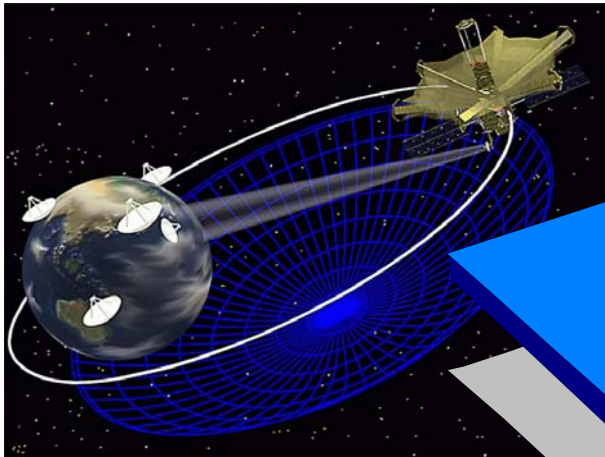


ELECTRIC  
POWER





# T&F Users

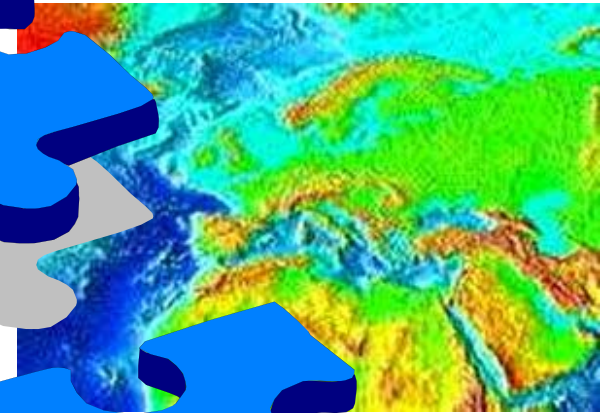


**SPACE**

**EQUIPMENT**



**GEODESY**



**FUNDAMENTAL  
RESEARCH**

**AGRICULTURE**



**DEFENCE**



# T&F Worldwide Market

**Frequency Control Devices:** 4,5 B\$/ year  
(Quartz oscillators, Atomic clocks)

**GNSS:** ~ 250 B€/year by 2022

source: European GNSS Agency (GSA), 3<sup>rd</sup> Market Report (2013)

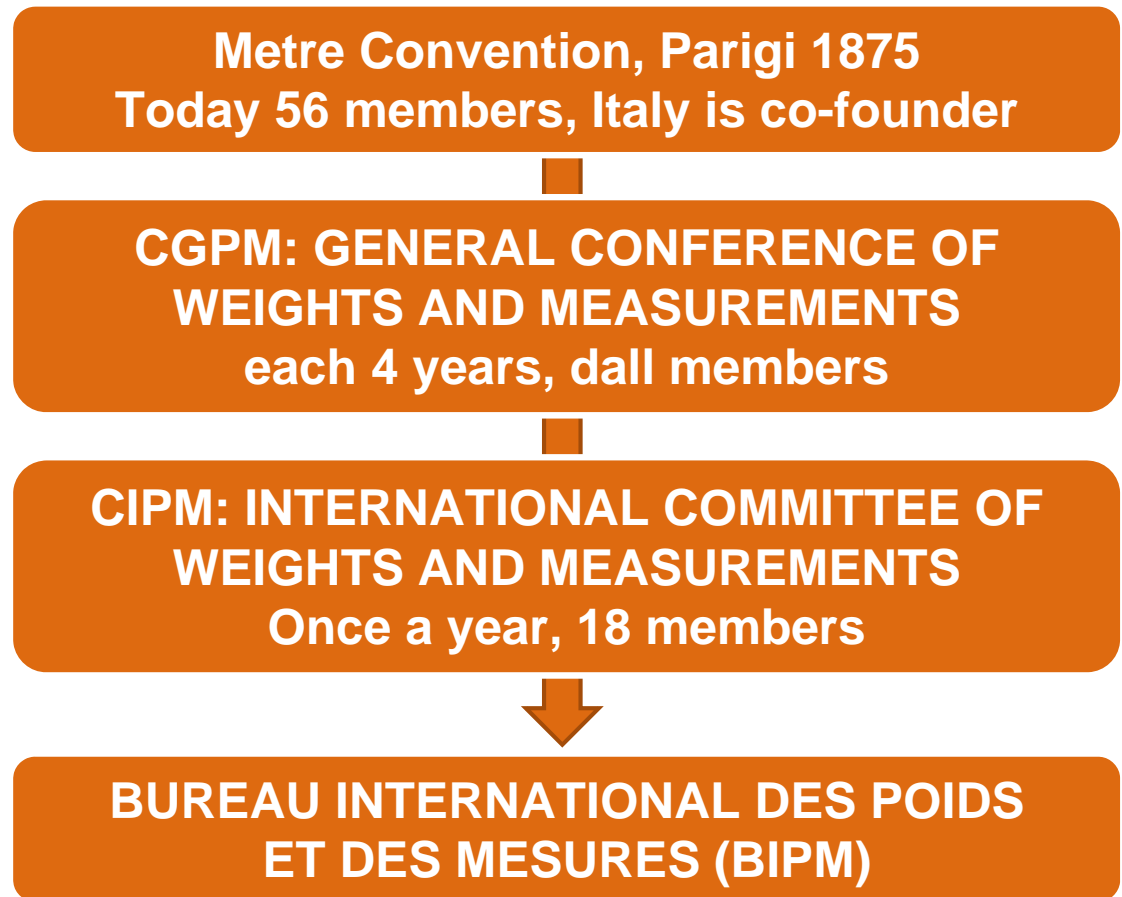
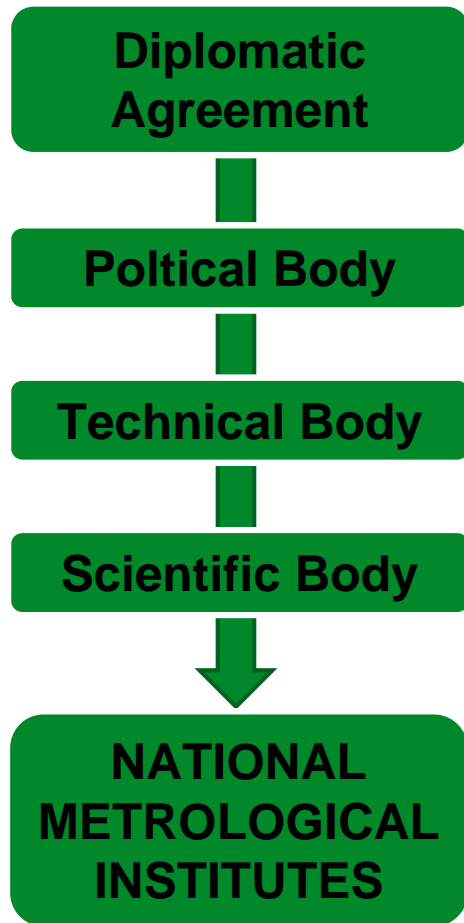
**Telecommunications:** 46.7 B\$ in 2014

Source: Visiongain, "Wireless Infrastructure Market Forecast 2014-2024"

**Smart electrical grid:** 400 B\$ by 2020

Source: GTM Research

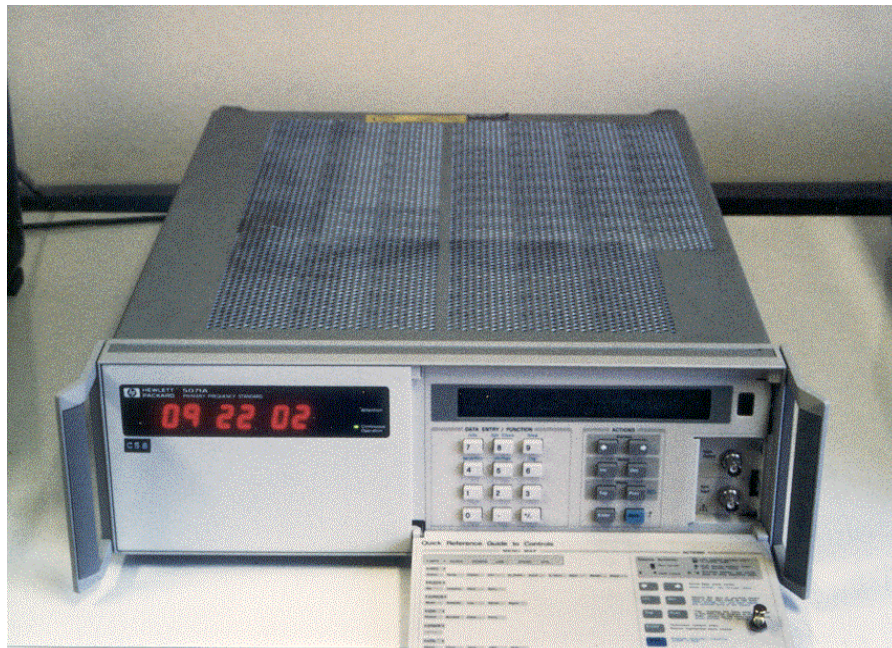
# The Metre Convention



**ITALY: INRiM in Torino**



# The Heart of T&F: Atomic Clocks



40 cm

**Commercial Cs clock**

1 m



**Commercial Hydrogen Maser clock**

10 cm



**Commercial Rb Clock**





# T&F Relative Accuracy

Quartz Oscillator  
1950-1970



$\sim 10^{-9}$   
1 s in 30 yr



Earth Rotation

$< 10^{-8}$   
1 s in 3 yr



Galileo  
Pendulum  
ca1650

$\sim 10^{-5}$   
10 s in 1 yr



Commercial Cs Clock  
Since '90s

$\sim 10^{-13}$   
1 s in 300.000 yr



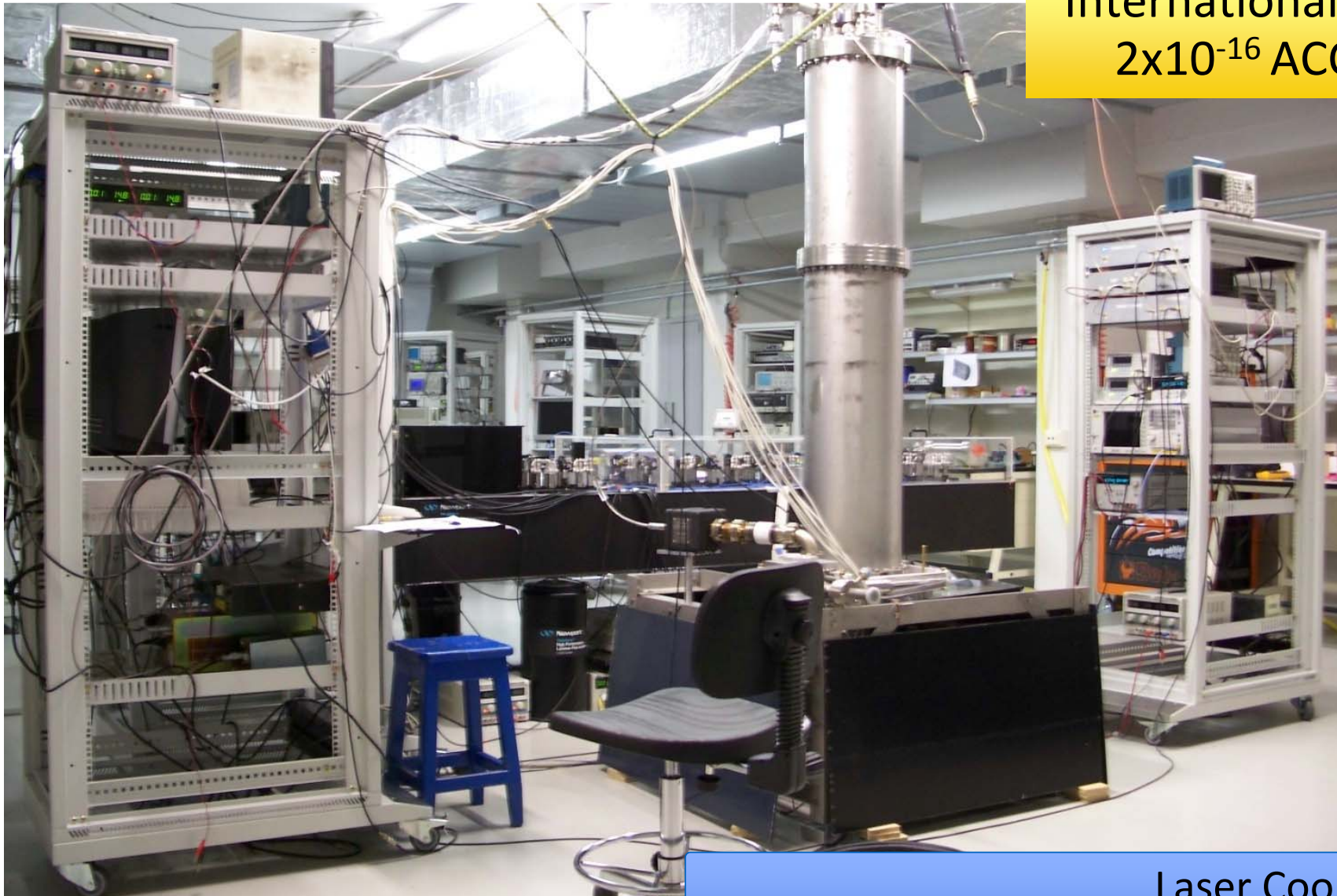
Cs fountain  
(today)

$\sim 2 \times 10^{-16}$   
1 s in 60 milion yrs



# Cs Cryogenic Fountain INRIM ITCsF2

International SI second  
 $2 \times 10^{-16}$  ACCURACY



Laser Cooled Cs at 1  $\mu$ K;  
Liquid Nitrogen Cooled Structure at 89 K

# Atomic Cs fountains worldwide

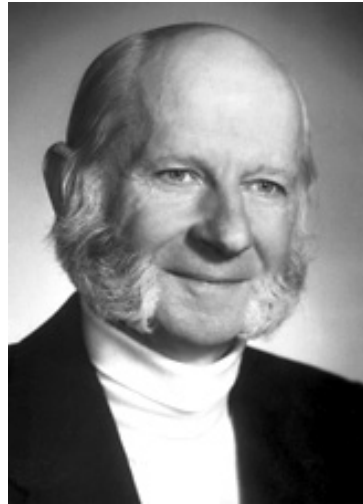
**Worldwide, six Laboratoris use Cs fountains  
for the generation of the International Atomic Time:**

USA (2 fontane); Francia (3); **Italia (2)**; Germania (2); UK (2); Giappone (2)





# Physics and T&F metrology: a Nobel Path to get a Cs Fountain



**1989**

**Norman F. Ramsey**

**Hans G. Dehmelt Wolfgang Paul**



**1997**

**Stephen Chu, William Phillips,  
Claude Cohen-Tannoudj**

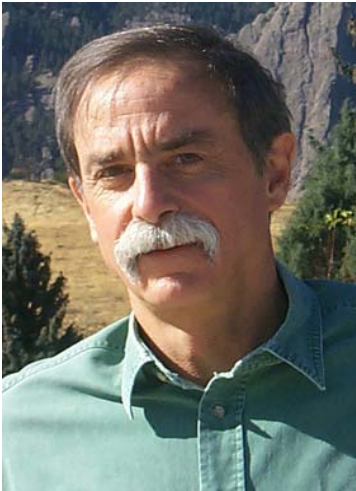
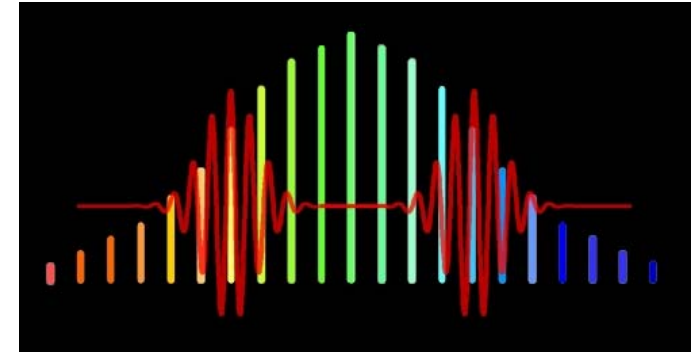


# Physics and T&F metrology: a Nobel Path going on...



**2005**

John L. Hall,  
Theodor W. Hänsch



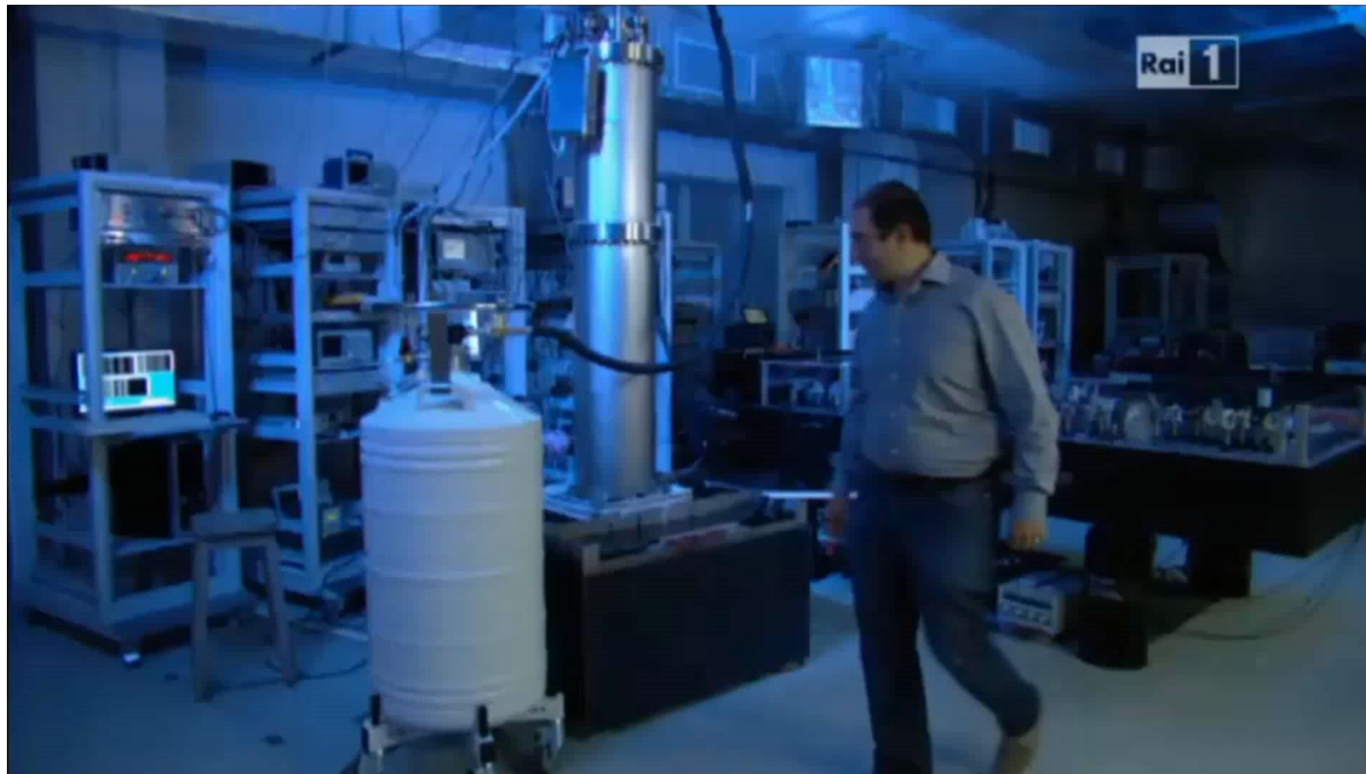
**2012**

David J. Wineland  
Serge Haroche



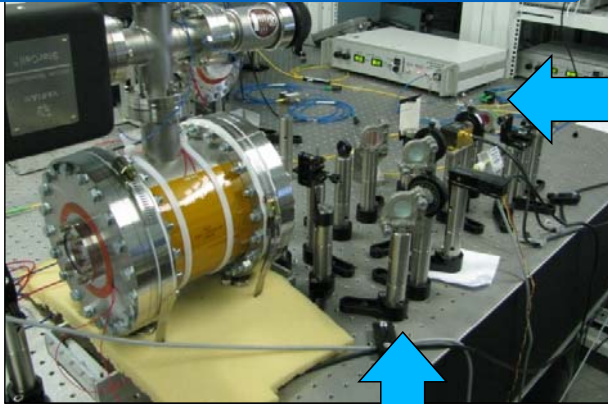


# Cs Fountain: how it works



# INRIM clock ensemble

Ultrastable Lasers



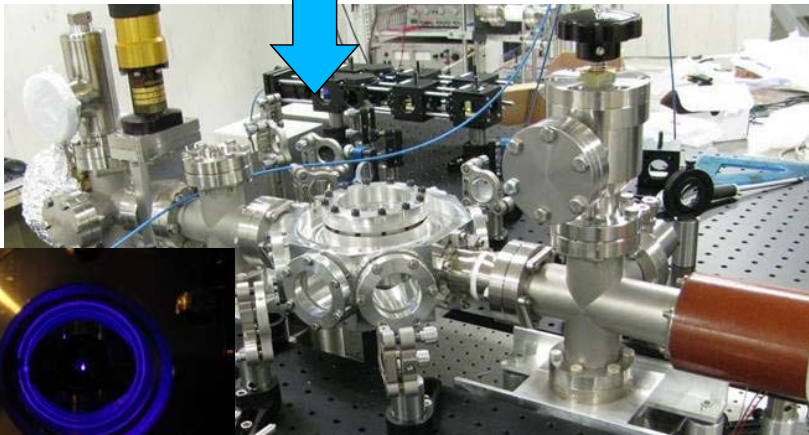
Optical Comb



Cs Fountains



H Masers

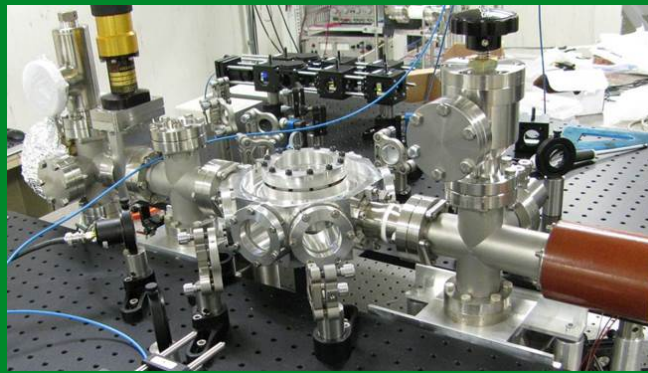


Yb Optical Clock



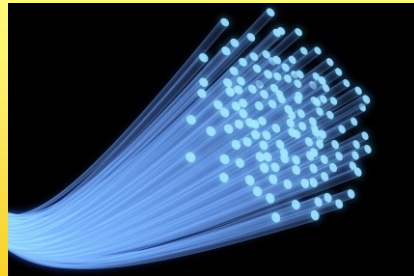


# Accurate Time for all: How to?



National Metrological Institutes  
(Atomic Clocks)

Optical Fiber  
Techniques

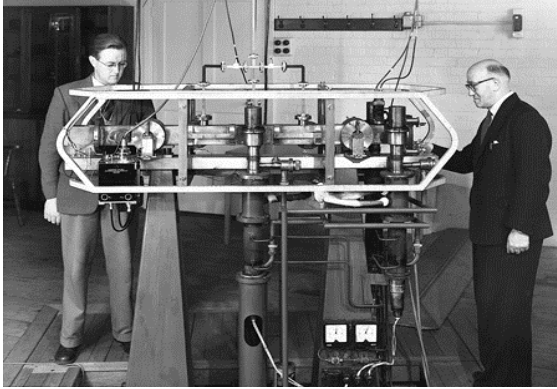


Satellite  
Techniques



**USERS**

# Spreading Accurate Time

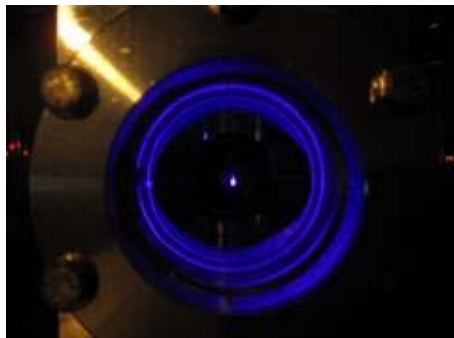


First Cs clock  
(1955)

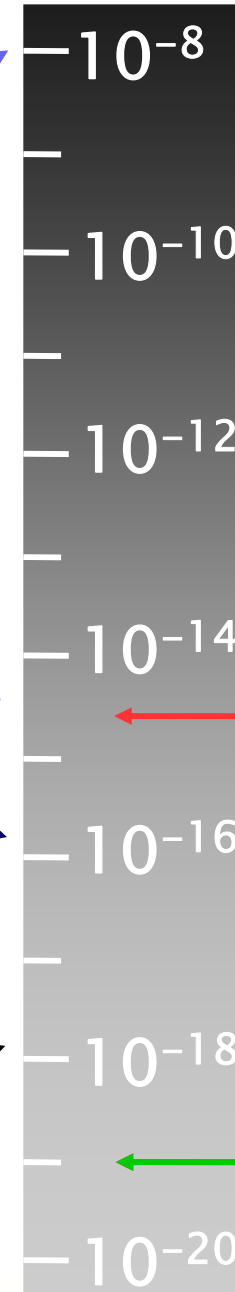


First Cs fountain  
(1996)

Cs fountain  
(today)



New optical  
clocks (today)



**Dissemination  
by Satellite  
in 1 day**

**Dissemination  
by Optical fiber  
in 1 day**



# LIFT



## The Italian T&F Optical Fiber Link

Funded by:

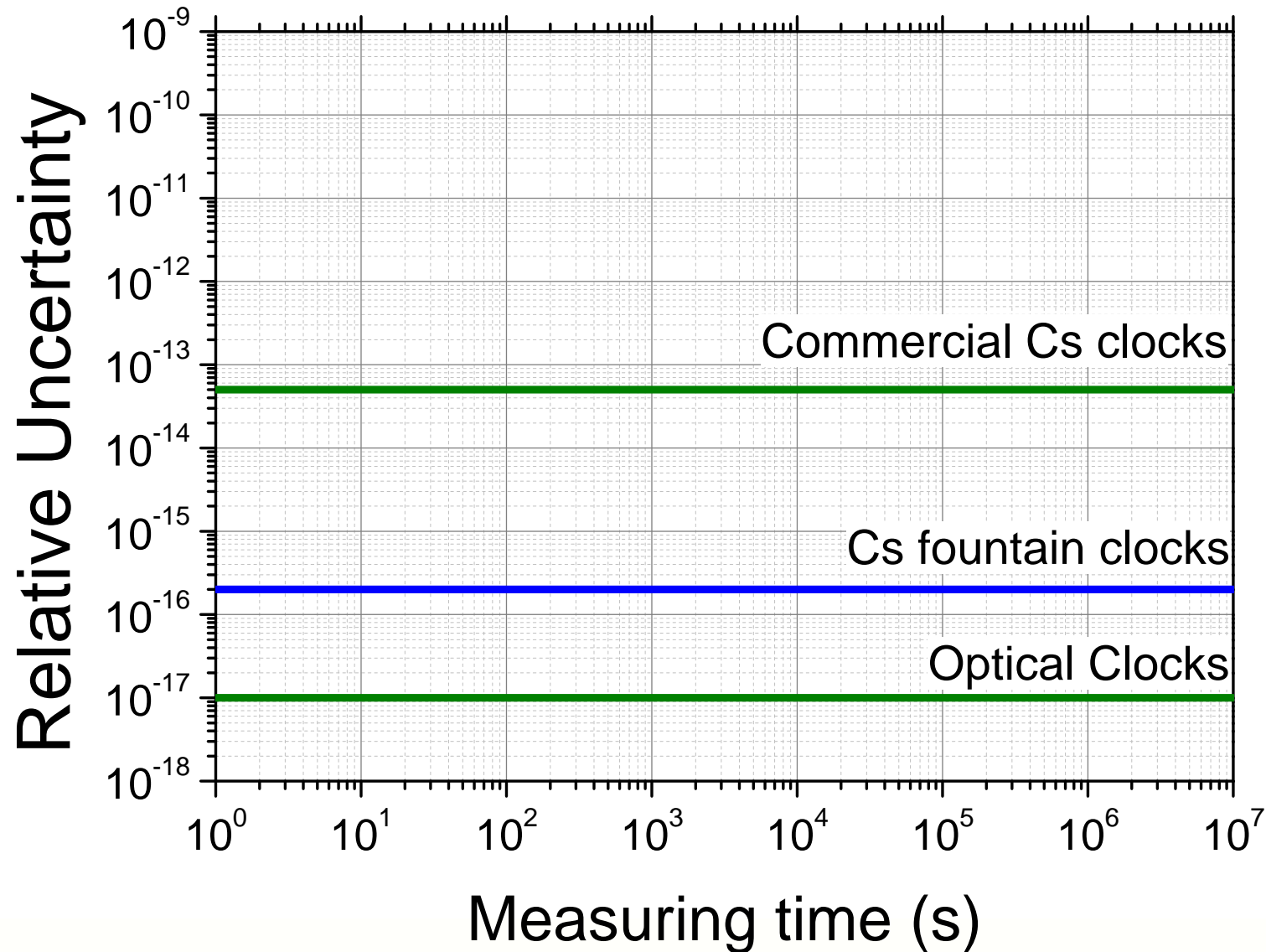


Optical Fiber by:



# Spreading Accurate Time

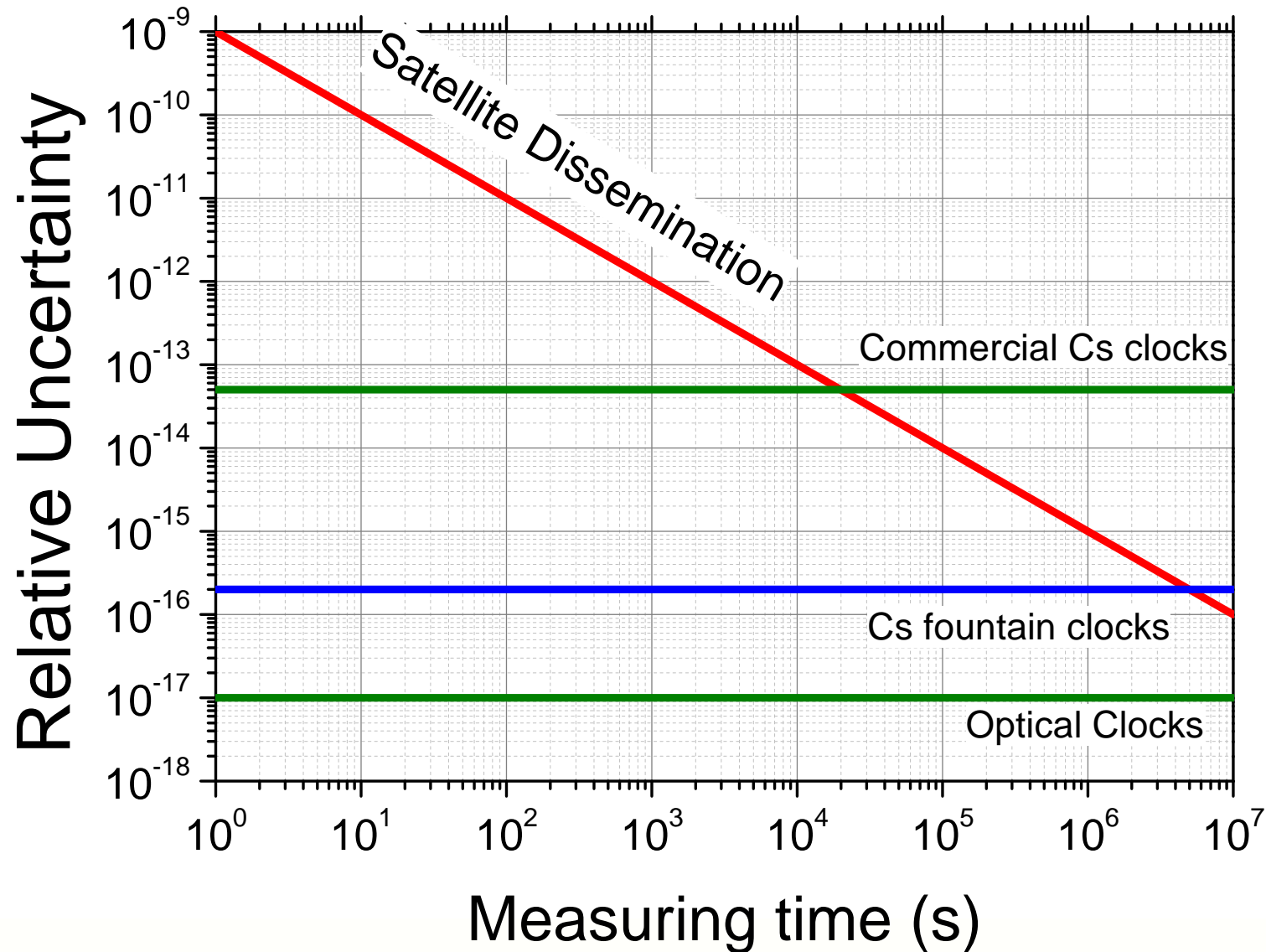
From NMI to users





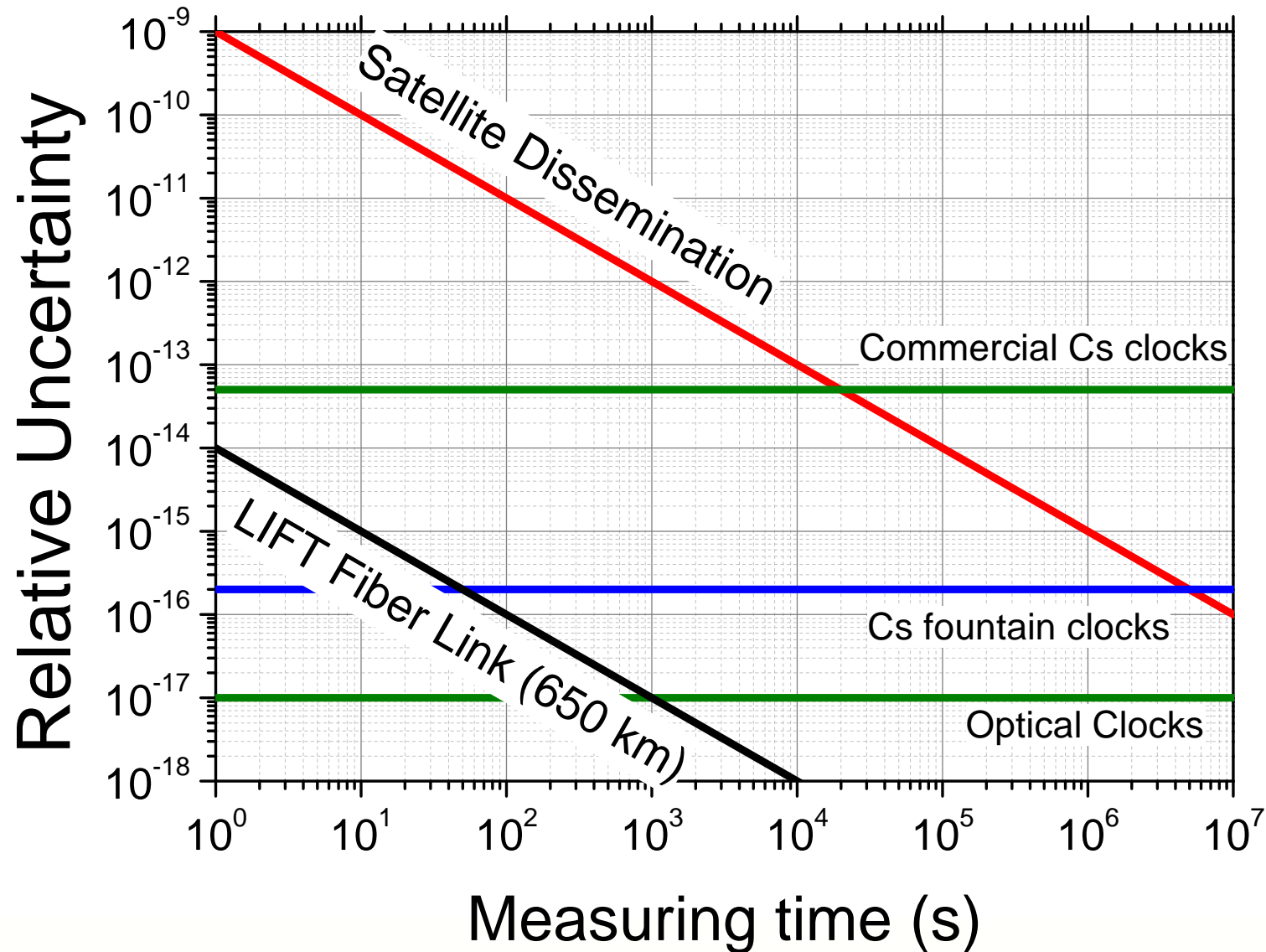
# Spreading Accurate Time

From NMI to users



# Spreading Accurate Time

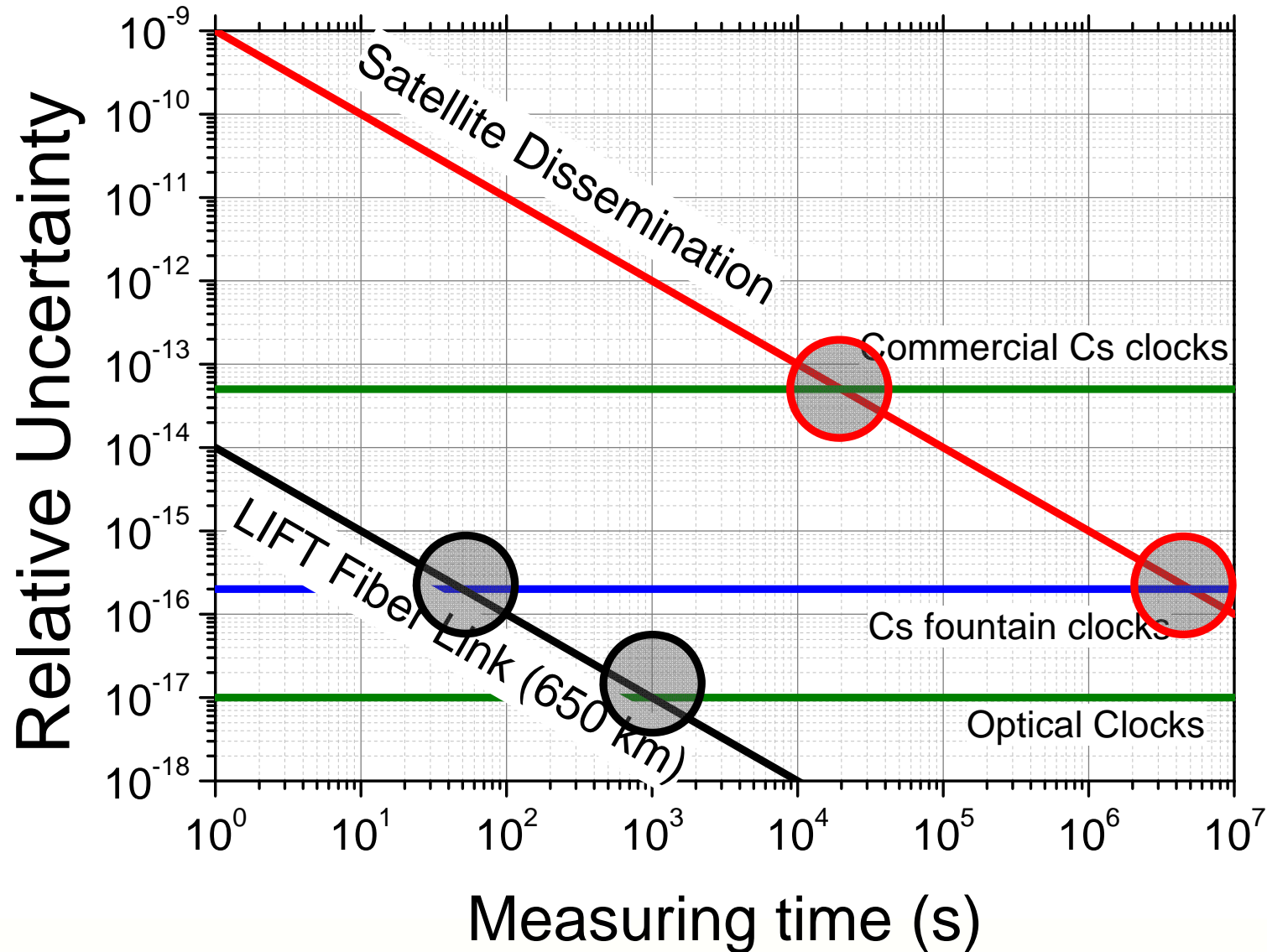
From NMI to users





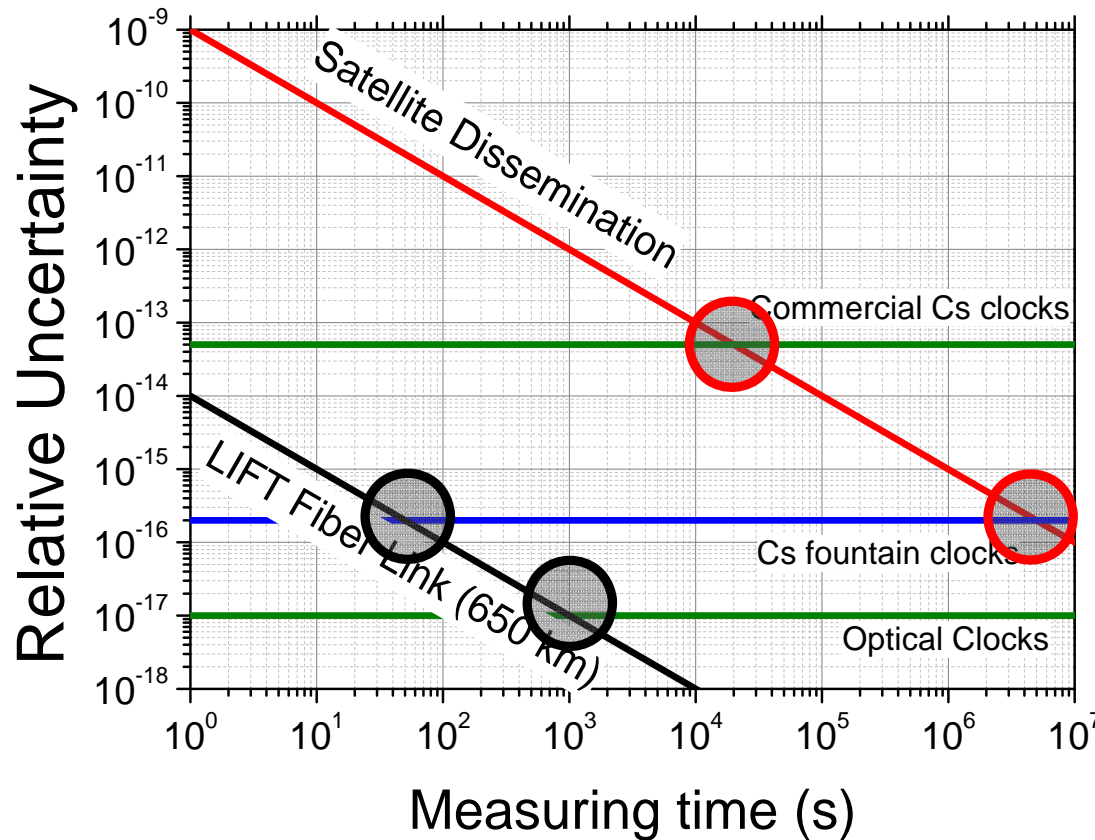
# Spreading Accurate Time

From NMI to users



# Spreading Accurate Time

From NMI to users



## Satellites:

>4 h to spread a Commercial Cs  
>20 days to spread Cs Fountains  
>100 days for optical clocks

## Fiber Links:

Always better than Commercial Cs  
100 s to spread Cs fountains  
1000 s for Optical Clocks





# LIFT OPTICAL FIBER LINK

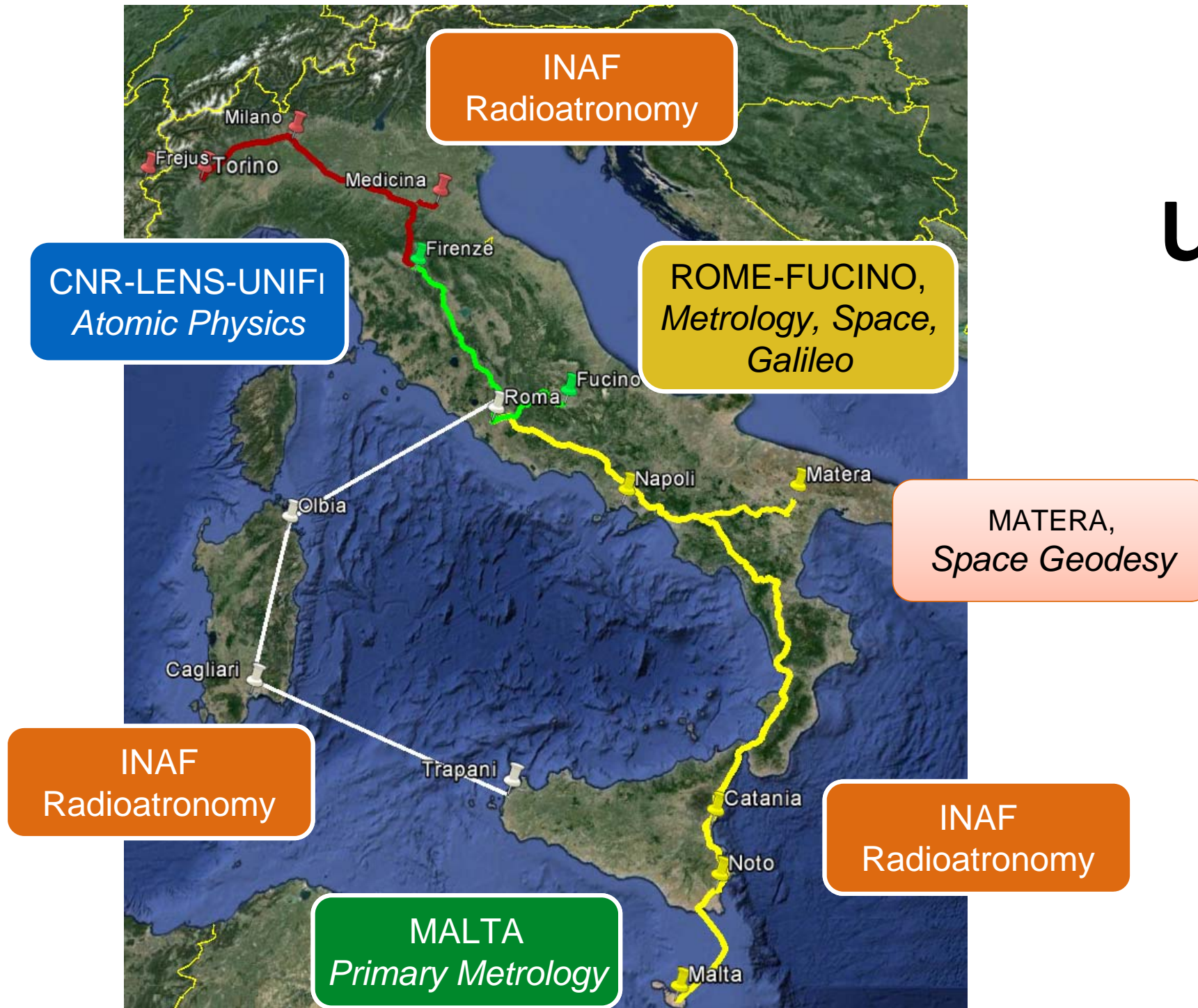




# LIFT OPTICAL FIBER LINK

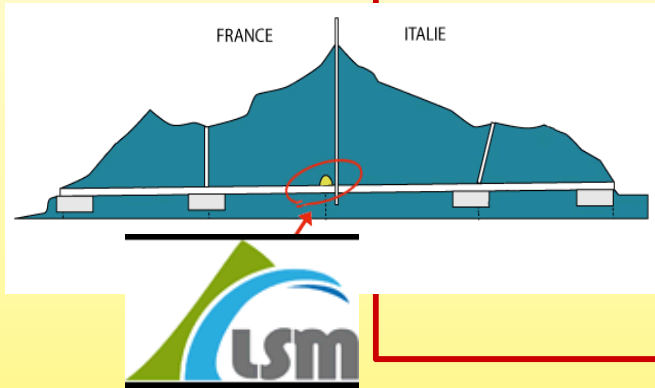


# LIFT users

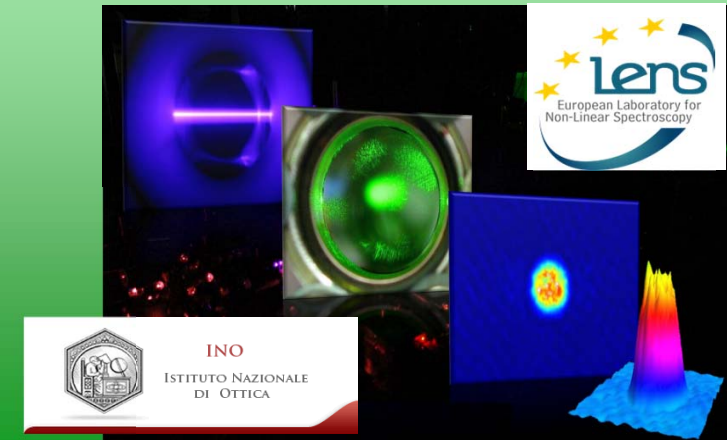


# LIFT present impact on research

## Frejus: Relativistic Geodesy



## Firenze: Atomic Physics



## Bologna Radio-astronomy VLBI



## Cagliari

**INAF**  
ISTITUTO NAZIONALE  
DI ASTROFISICA  
NATIONAL INSTITUTE  
FOR ASTROPHYSICS  
**Noto**

## Matera



## Space Geodesy





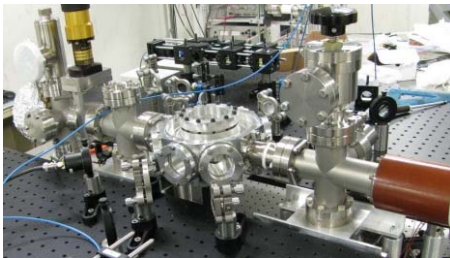
# Testing Einstein's geodetic motion

## INRIM-ASI-ISS triangle

(July 2016- January 2018)



High accurate  
Atomic clocks



Microwave Link  
Torino-ISS



Optical Link  
Matera-ISS

Optical Link  
Torino-Matera



Space Geodesy  
Center Bepi Colombo





# LIFT present impact on industry

## Development Of Atomic Clocks for Space



Milano



Roma



Activities based on  
Galileo (Ground Segment )



# Optical Fiber Link European Network







# INRIM is partner of the project

## NEAT-FT (2012-2015)

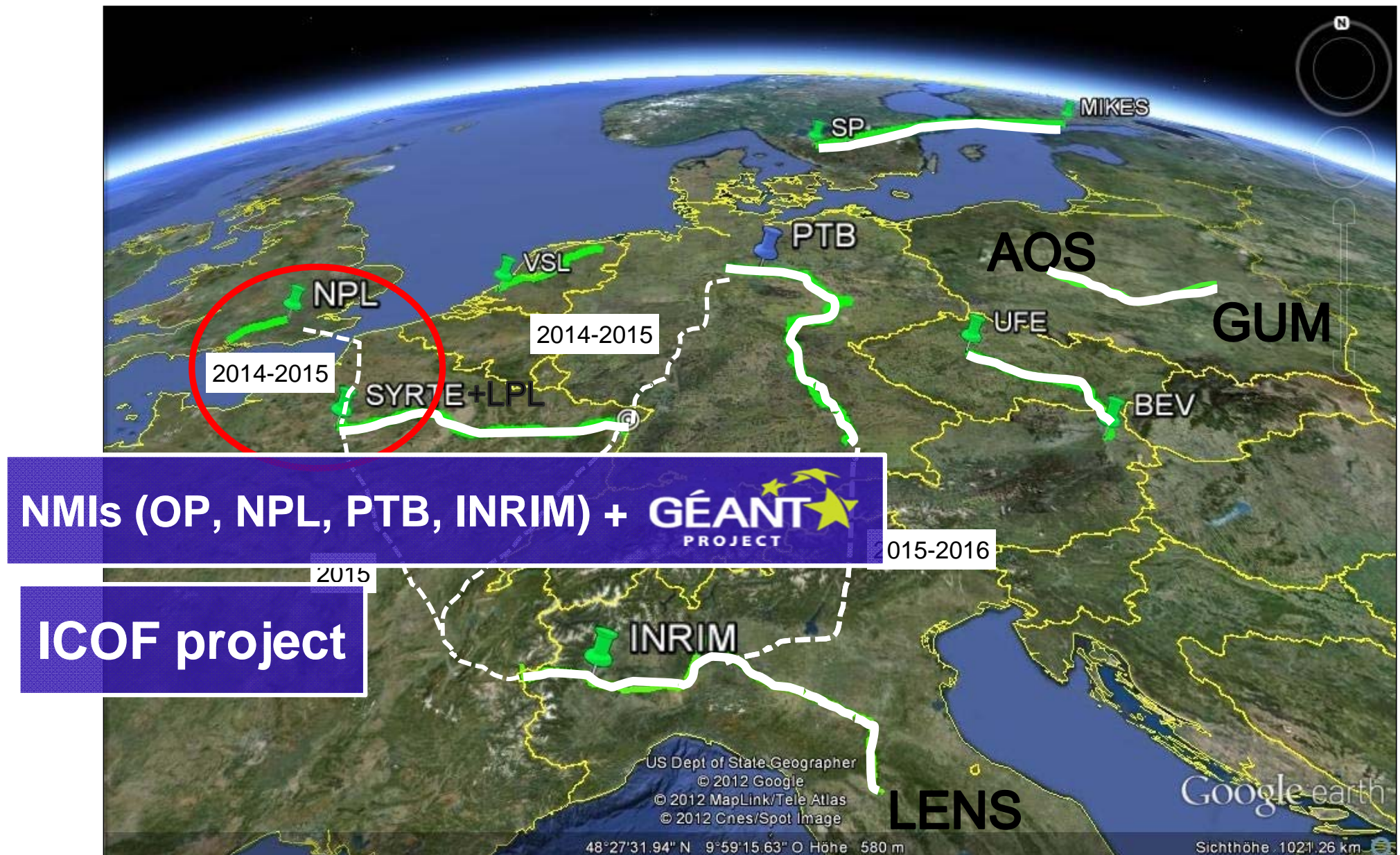
### Accurate time/frequency comparison and dissemination through optical telecommunication networks



**Partners:** PTB-Germany (Coordinator), BEV (Austria), INRIM (Italy), MIKES (Finland), NPL (United Kingdom), OBSPARIS (France), SP (Sweden), UFE (Czech Republic), VSL (The Netherlands), CESNET (Czech Republic), AGH (Poland)



# Optical Fiber Link European Network





# Optical Fiber Link European Network

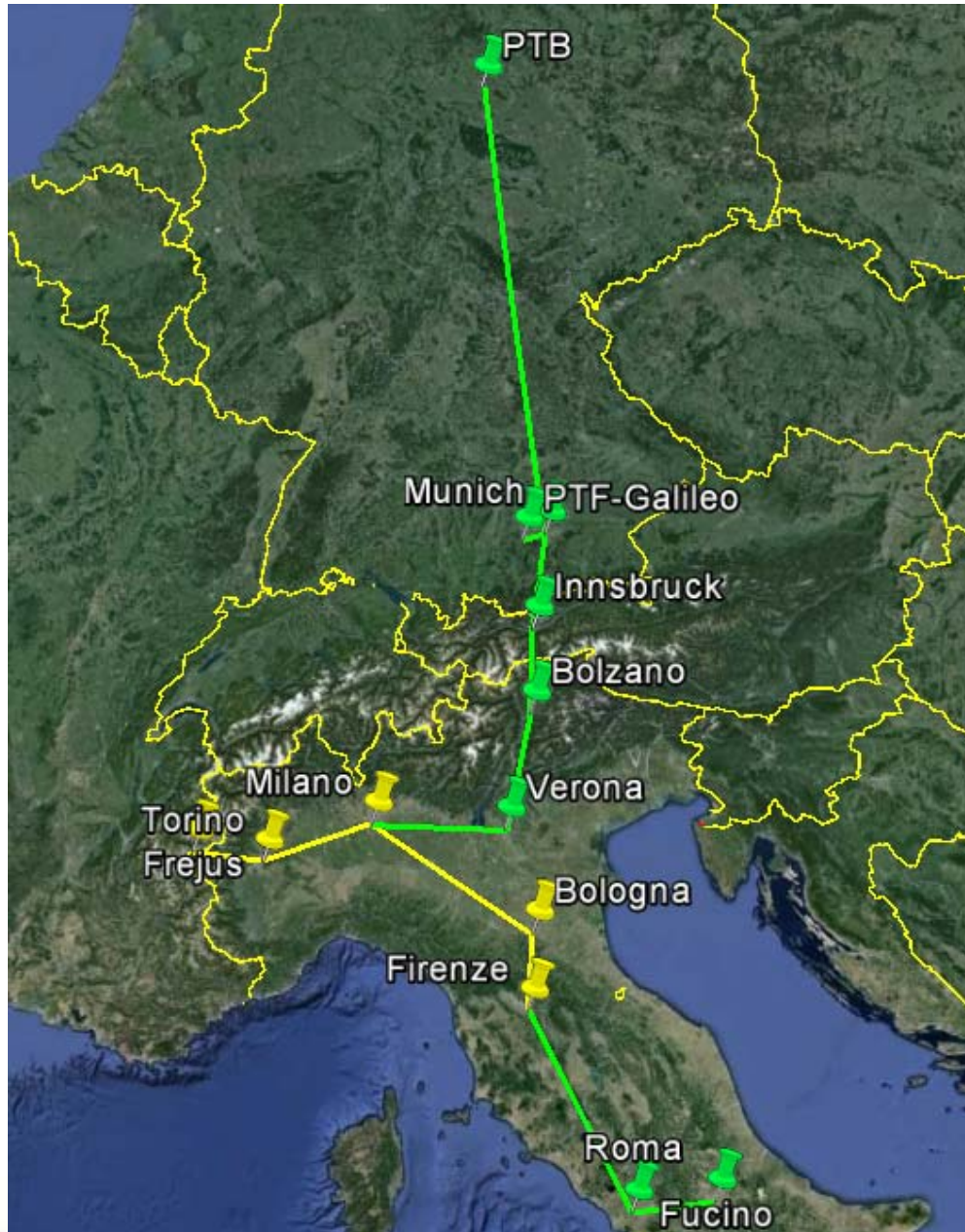


# Conclusions

- ✓ Time and Frequency metrology is a relevant infrastructure for Science and Society;
- ✓ A wide variety of users depends upon T&F facilities;
- ✓ Spreading accurate time: from the most accurate atomic clocks to the user;
- ✓ The role of an Optical Fiber T&F Infrastructure;
- ✓ Forthcoming European Infrastructure for T&F Optical Fiber Dissemination;
- ✓ Which will be the role of European Union?



# Italy-Germany fiber link: science and navigation



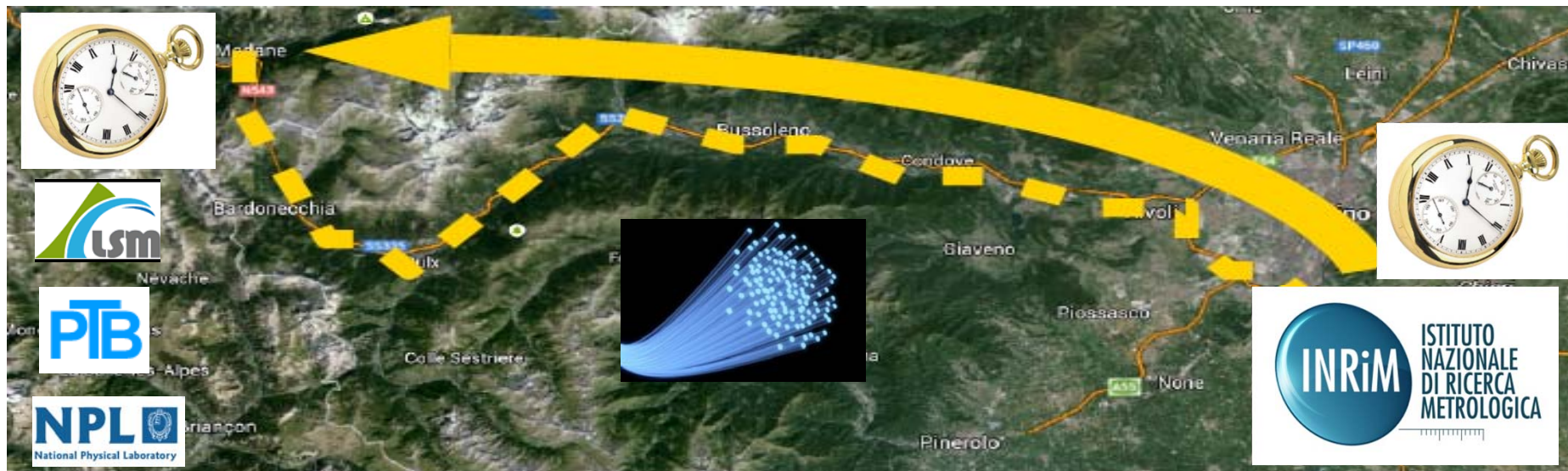
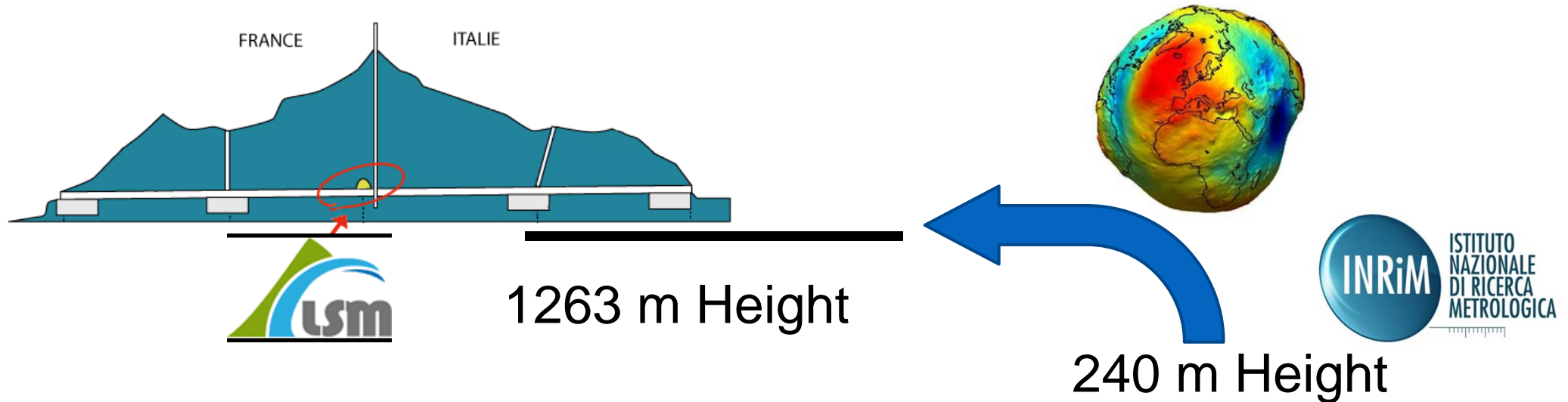
## **GNSS GALILEO – INRIM – PTB:**

- Link the Galileo Control Centers (Fucino, Oberpfaffenhofen) to National Metrological Institutes (INRIM-PTB)
- Link INRIM and PTB
- Link Munich-Innsbruck-Florence (Atomic Physics Centers) together and to PTB and INRIM



# T&F metrology and Earth Survey

General Relativity: on Earth, clock shift  $\sim 10^{-16}/\text{m}$  over the Geoid.  
Investigation on Geoid changes at 10 cm level ( $10^{-17}$ )

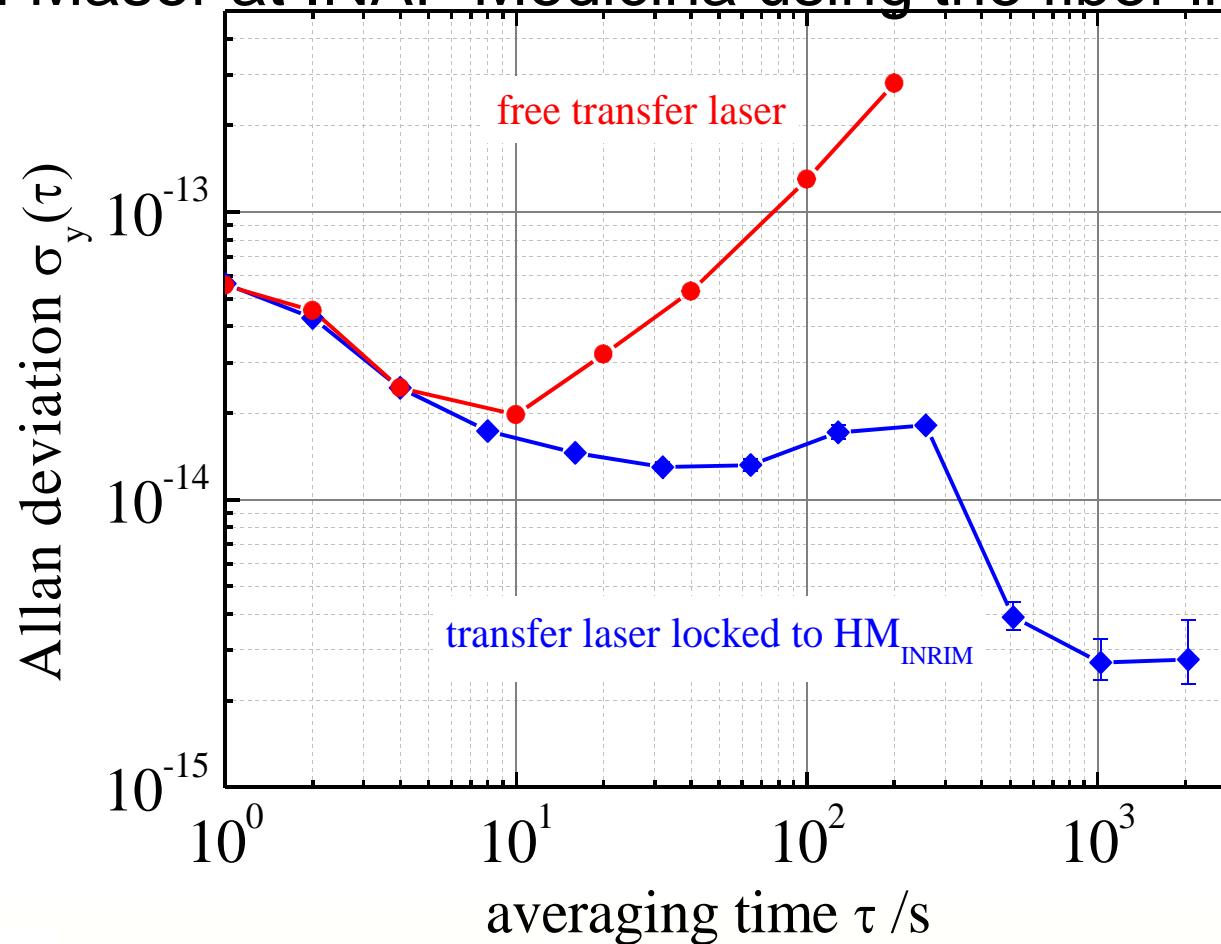


# INRIM to Bologna: Frequency reference For Radioastronomy



Medicina  
radiotelescope

INRIM Maser at INAF Medicina using the fiber link





# Fiber Link: how it works

