# LIFT: ultra accurate time distributed over fiber

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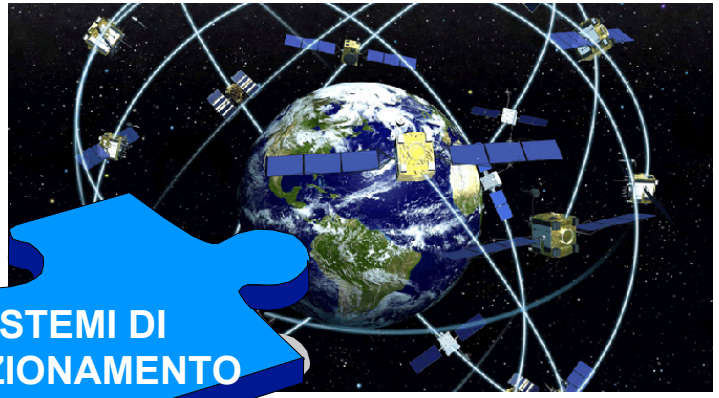
# Sommario

- ✓ Metrologia di Tempo e Frequenza
- ✓ Orologi Atomici
- ✓ Il Tempo in Fibra
- ✓ Sincronizzare la Radioastronomia
- ✓ Conclusioni

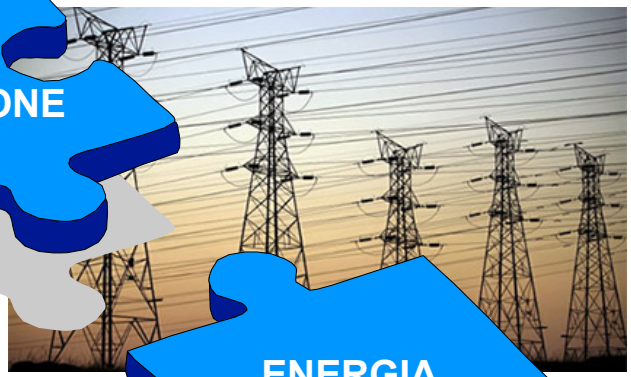
# Utenti T&F



SISTEMI DI POSIZIONAMENTO

TELECOMUNICAZIONI

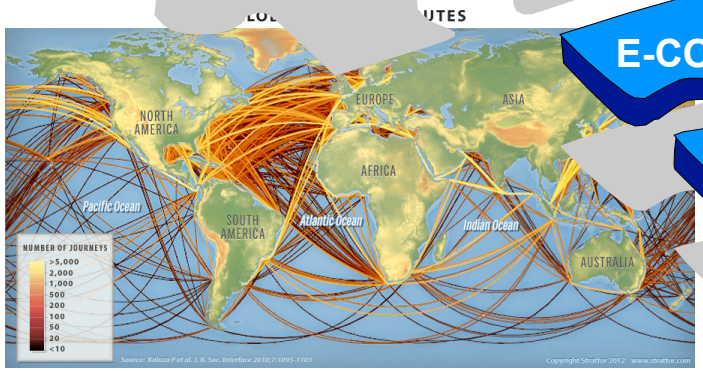
DATAZIONE

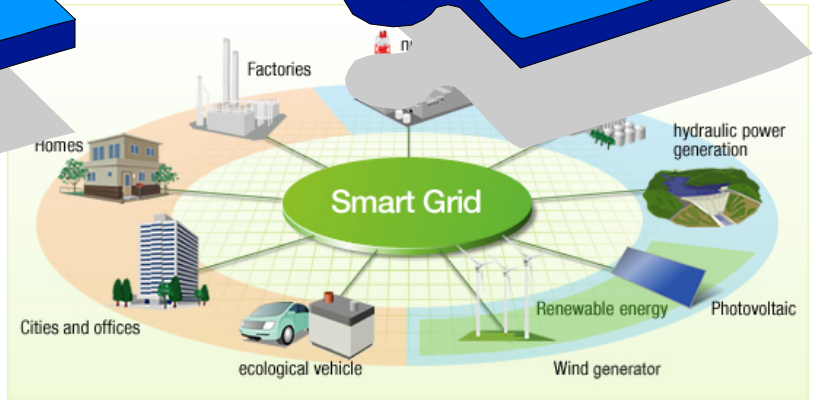


TRASPORTI E NAVIGAZIONE

ENERGIA ELETTRICA

E-COMMERCE



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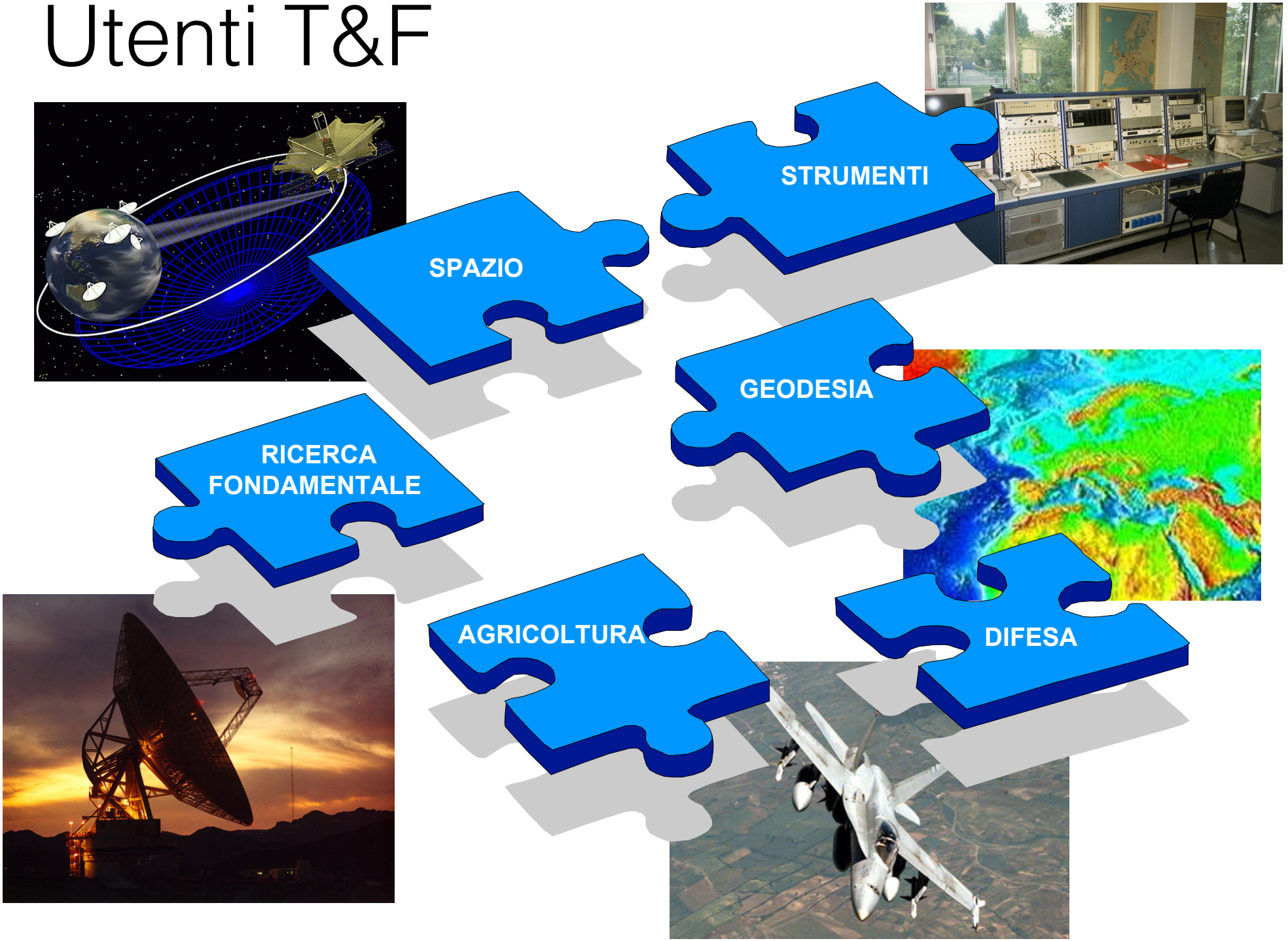
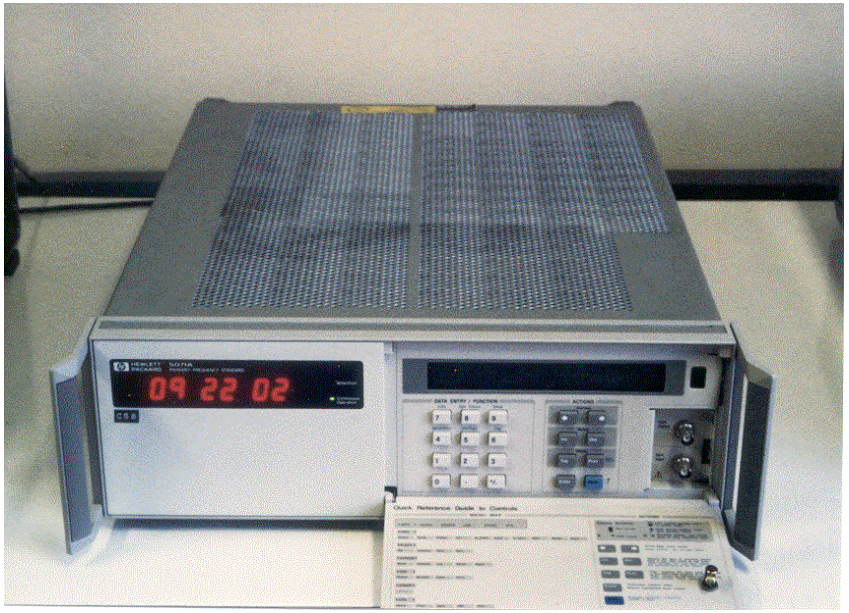

SPAZIO
STRUMENTI
GEODESIA
RICERCA FONDAMENTALE
AGRICOLTURA
DIFESA

# Nel cuore di T&F: Orologi Atomici



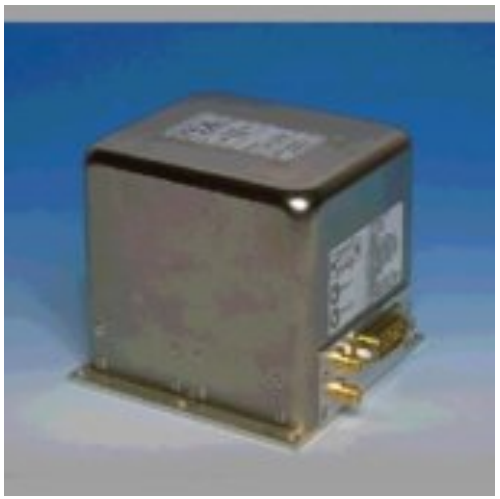

40 cm

**Orologio al Cesio Commerciale**

1 m

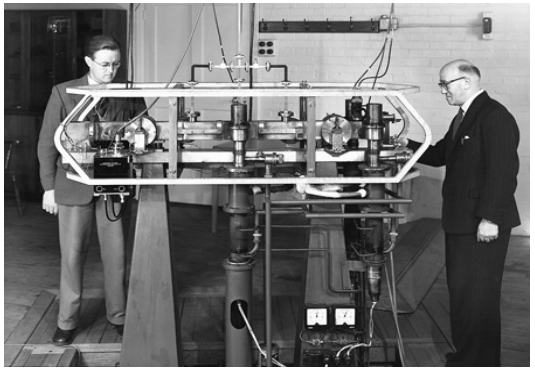
**Maser all'Idrogeno commerciale**

10 cm



**Orologio al Rubidio Commerciale**

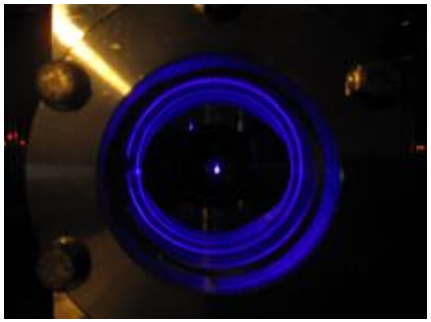
# Distribuire il Tempo Accurato



Primo Cs clock
(1955)

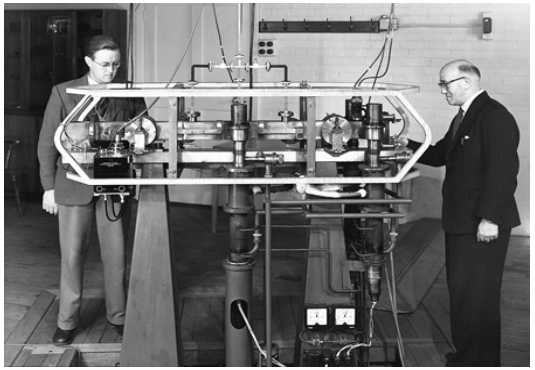
Prima Fontana Cs
(1996)

Fontana di Cs
(oggi)



Nuovi orologi
ottici (oggi)

# Distribuire il Tempo Accurato



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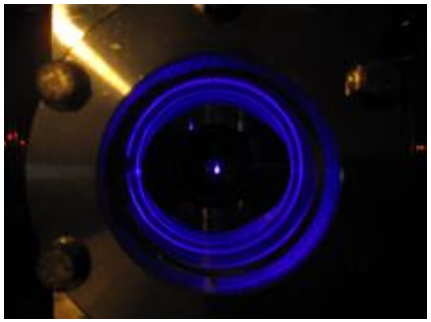


Fontana di Cs
(oggi)

Nuovi orologi
ottici (oggi)

1 ms/giorno

10 μs/giorno

100 ns/giorno

Distribuzione via Satellite
in1 giorno

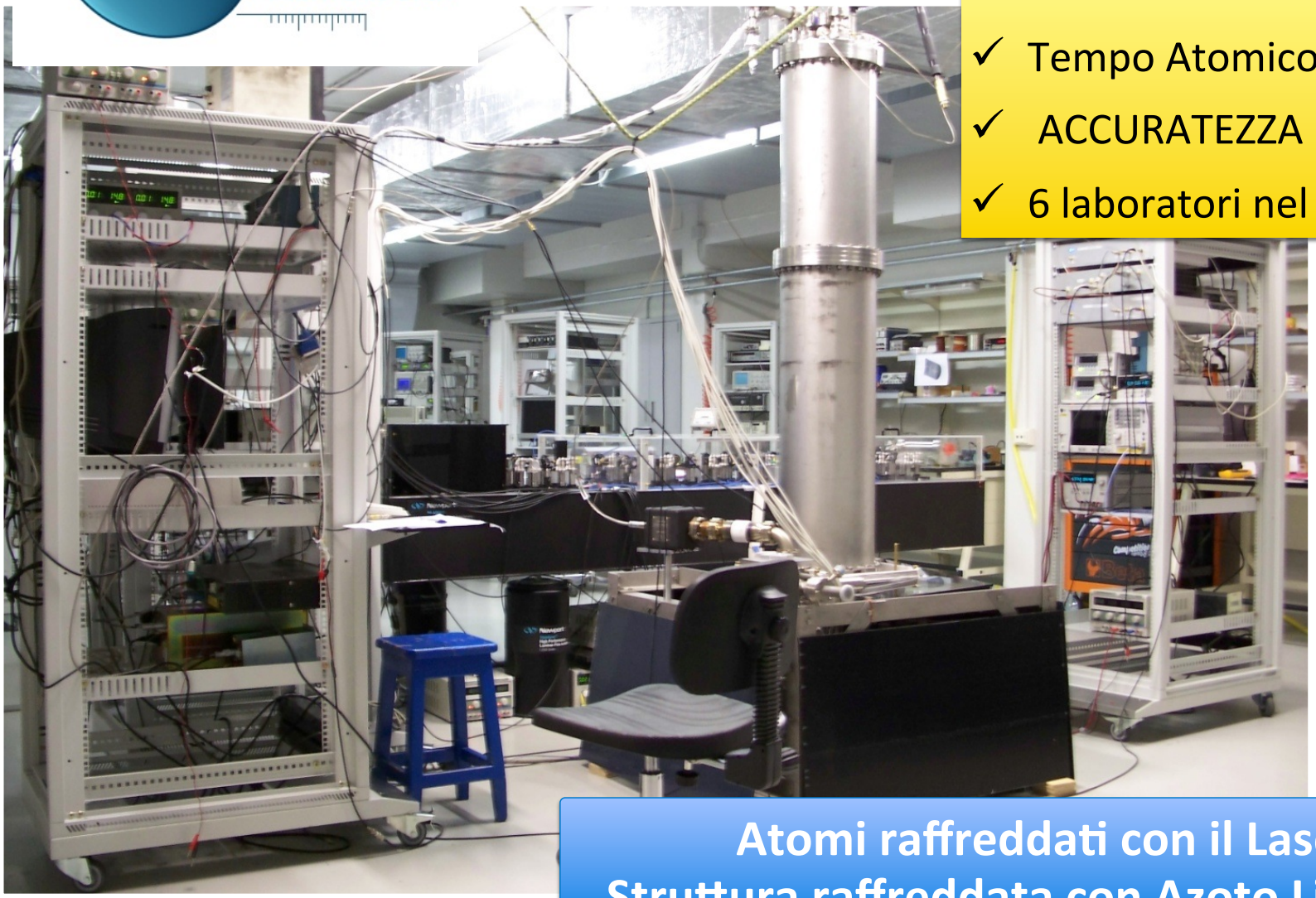
10 ps/giorno

100 fs/giorno

Distribuzione via Fibra
(1000 km) in1 giorno

# La Fontana al Cesio dell'INRIM

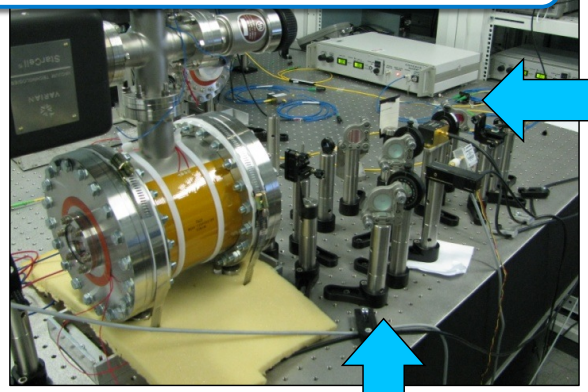
- ✓ Secondo SI in Italia
- ✓ Tempo Atomico Internazionale
- ✓ ACCURATEZZA $2x10^{-16}$
- ✓ 6 laboratori nel mondo

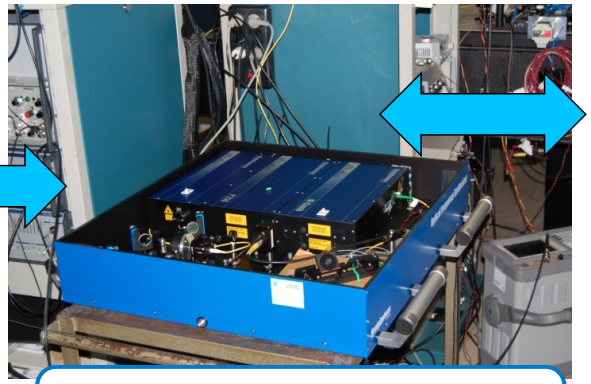


**Atomi raffreddati con il Laser: Cs a 1 µK;**
**Struttura raffreddata con Azoto Liquido a 89 K**

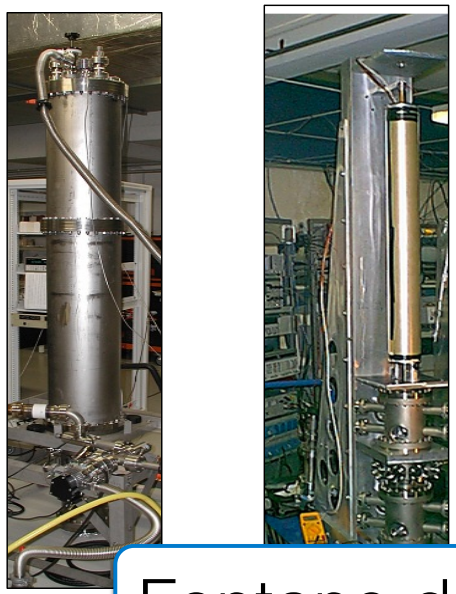
# Gli orologi atomici dell'INRIM

Laser Ultrastabile

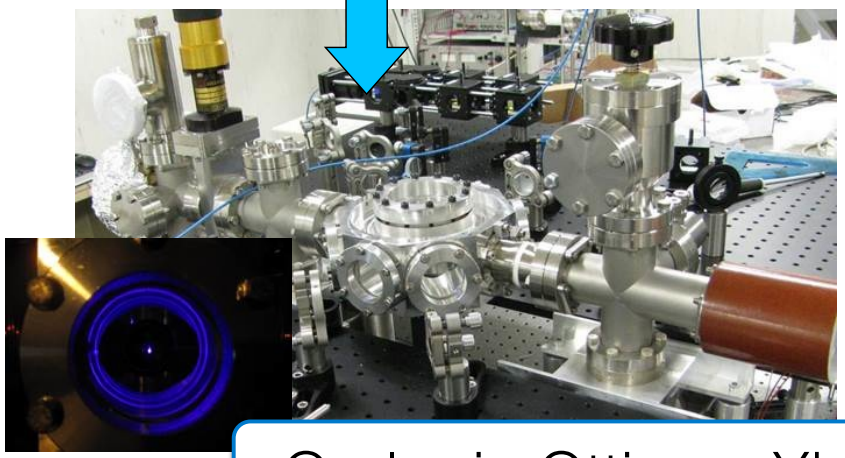




Optical Comb



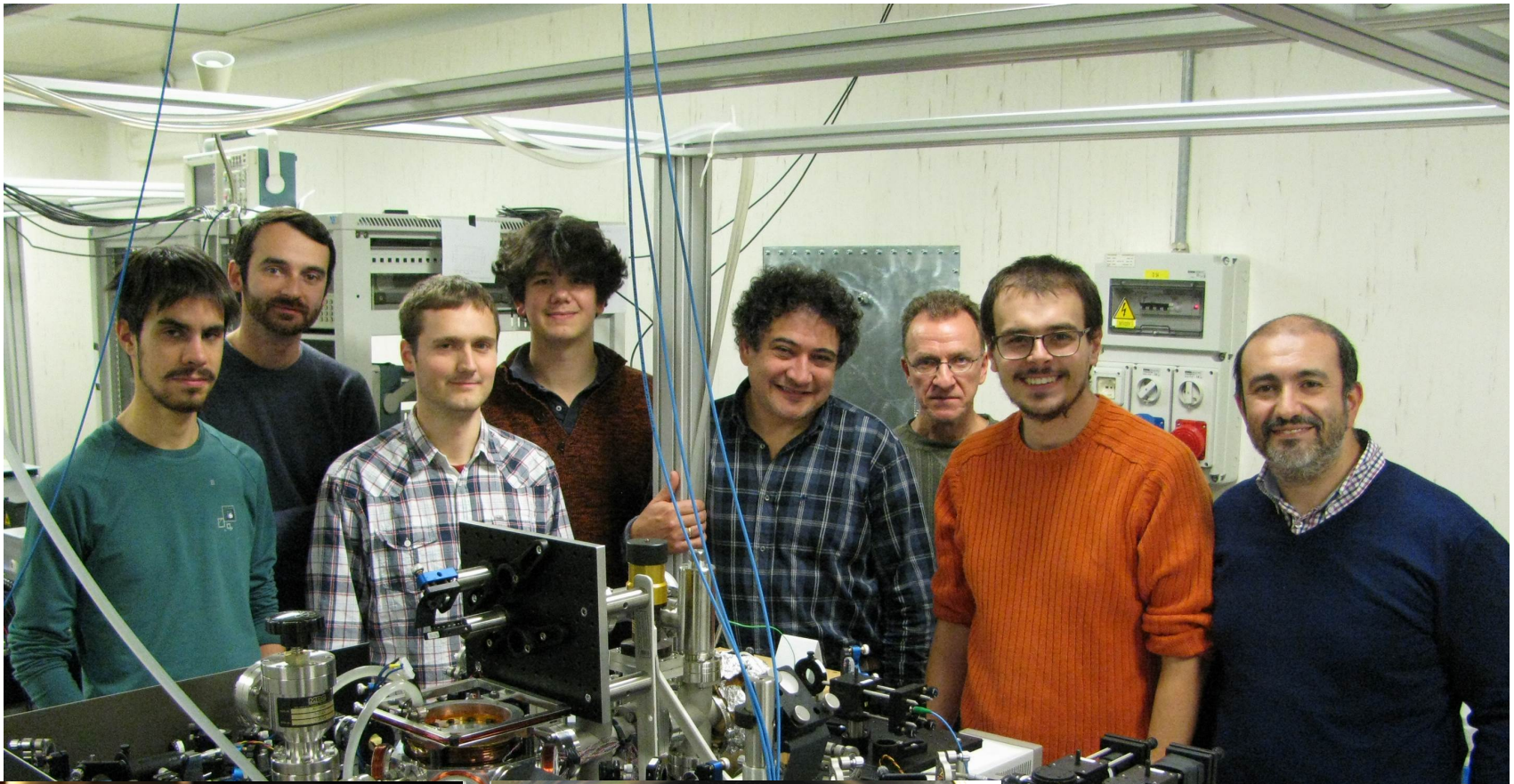
Fontane di Cs

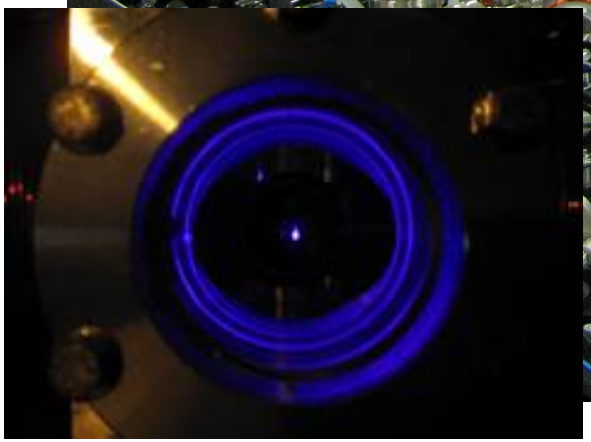


Orologio Ottico a Yb

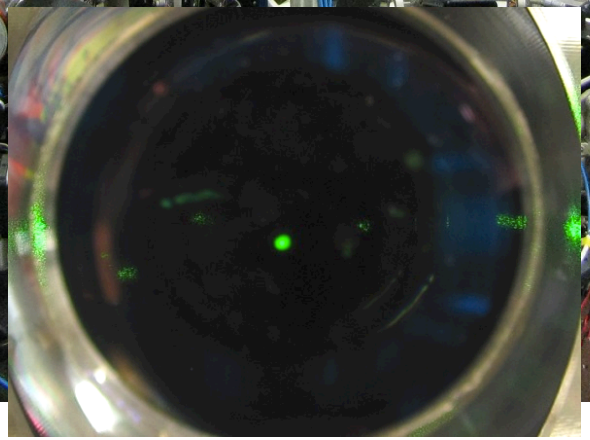
H Masers

# Un orologio ottico in Italia:  l'Yb dell' INRIM



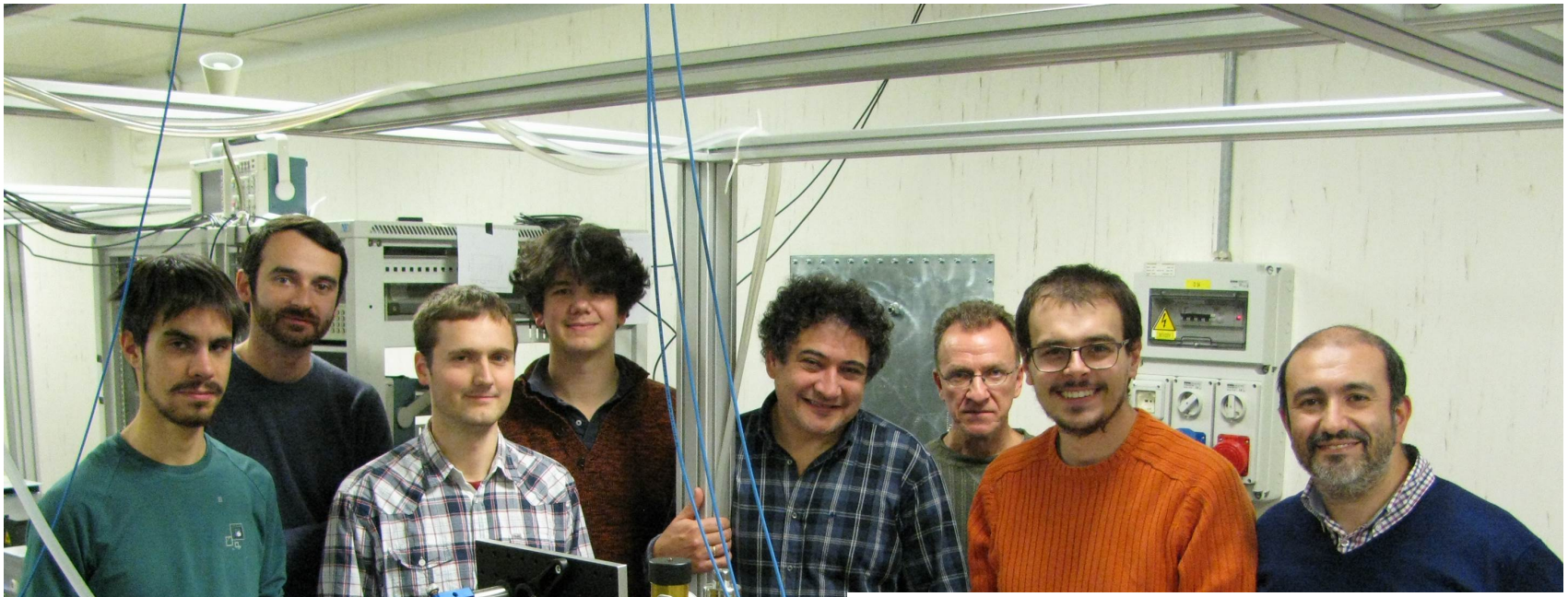


Yb freddo a 399 nm

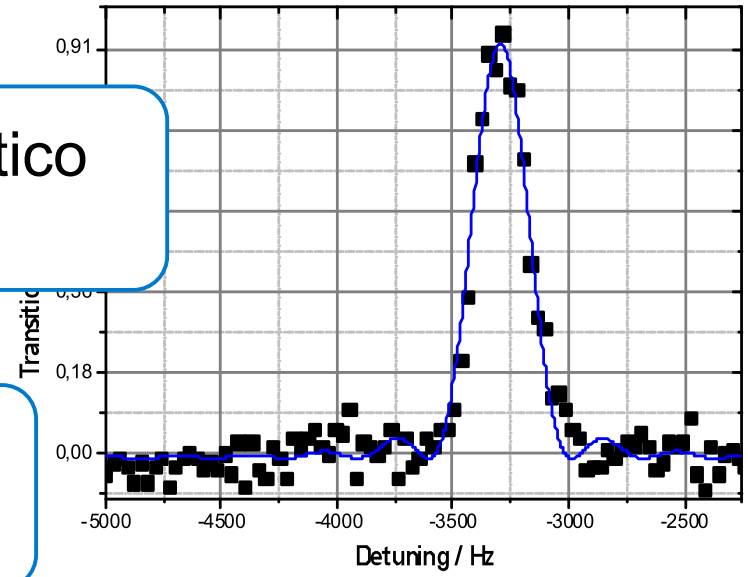


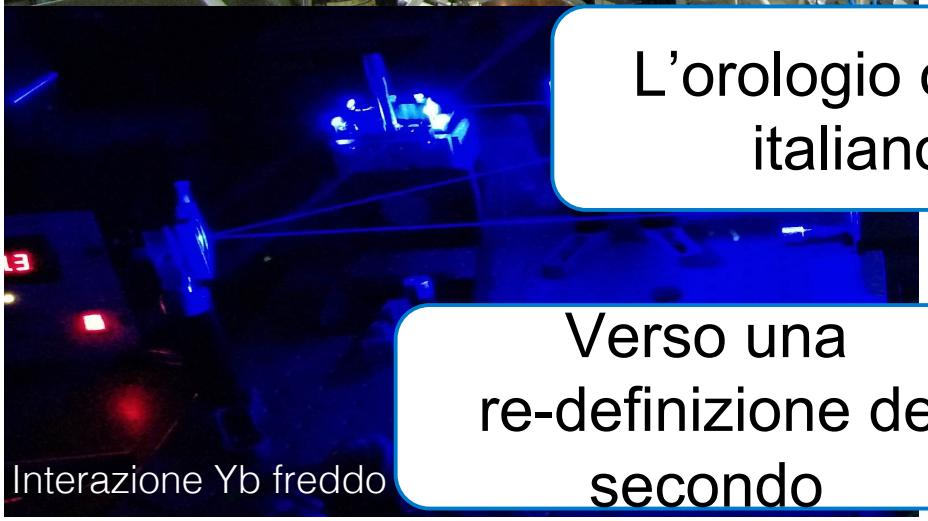
Yb freddo a 556 nm

# Un orologio ottico in Italia: l'Yb dell' INRIM



Il primo segnale di orologio a Yb



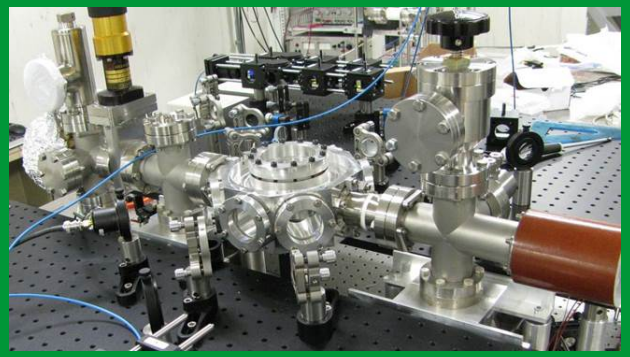



Interazione Yb freddo

L'orologio ottico italiano

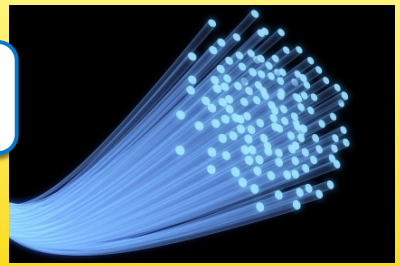
Verso una re-definizione del secondo

# Disseminare T&F accurato



Istituto Nazionale di Metrologia
(Orologi Atomici)

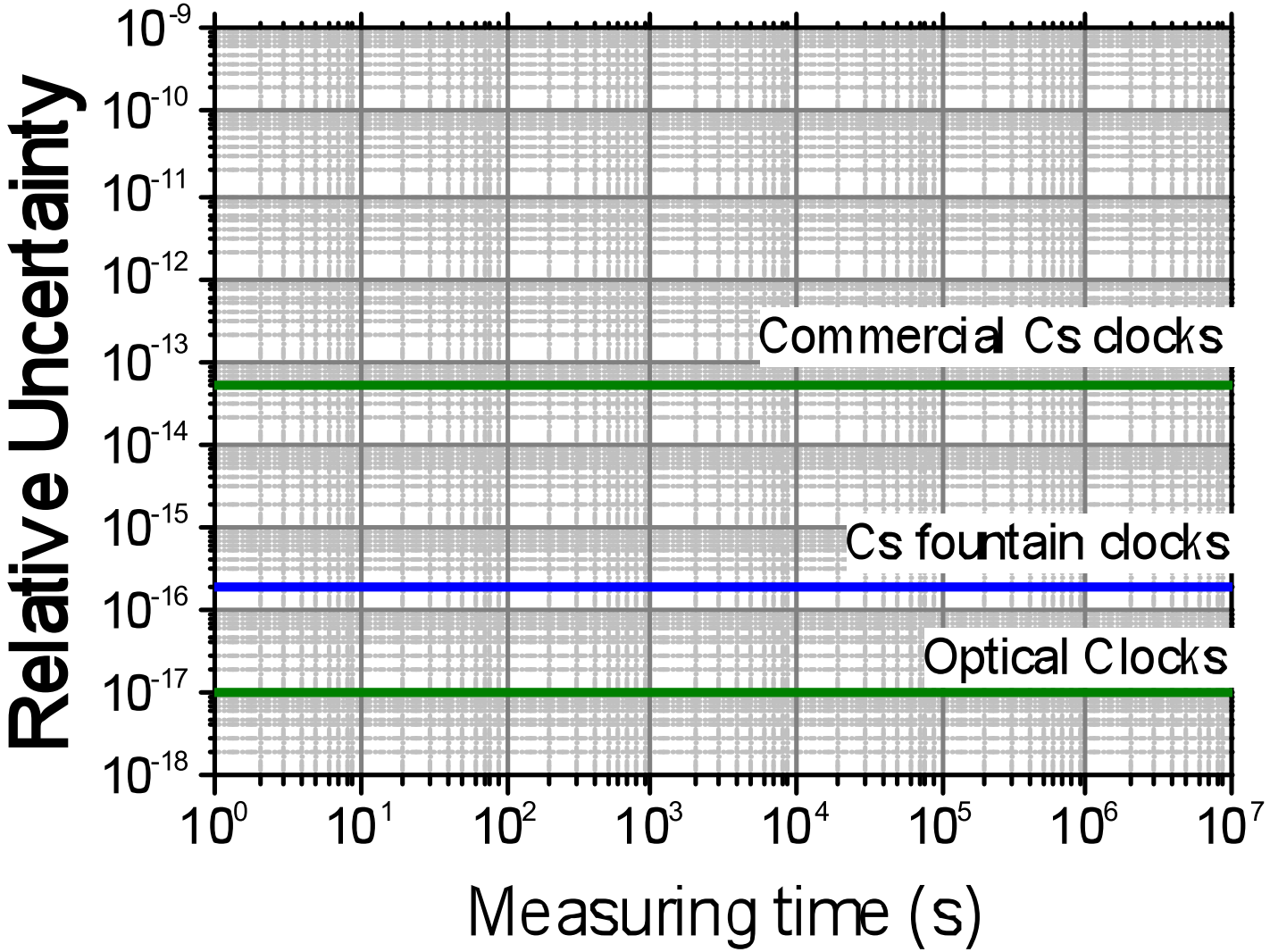
Fibre Ottiche



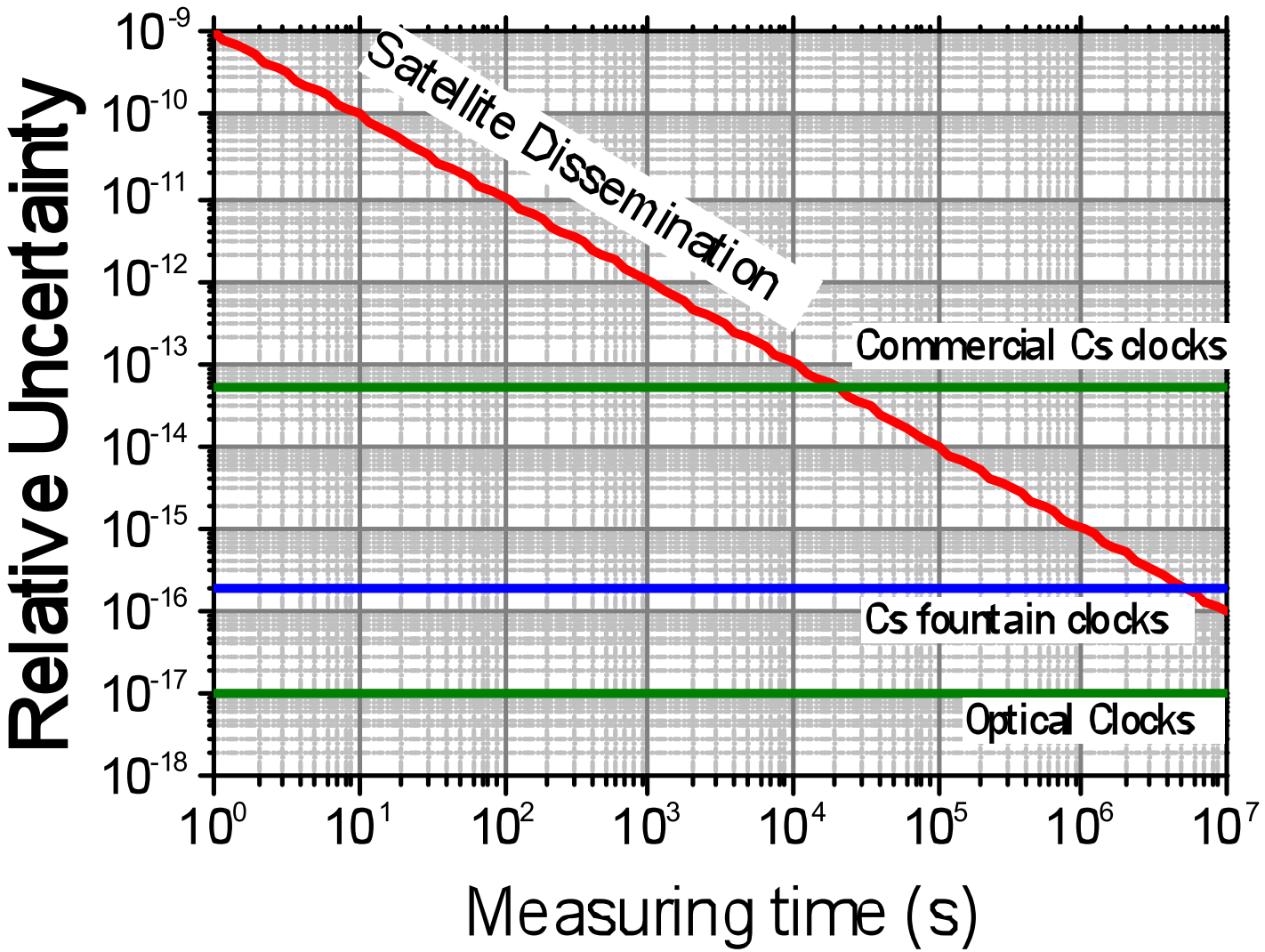
Satelliti

**UTENTI**

# Distribuire il Tempo



# Distribuire il Tempo



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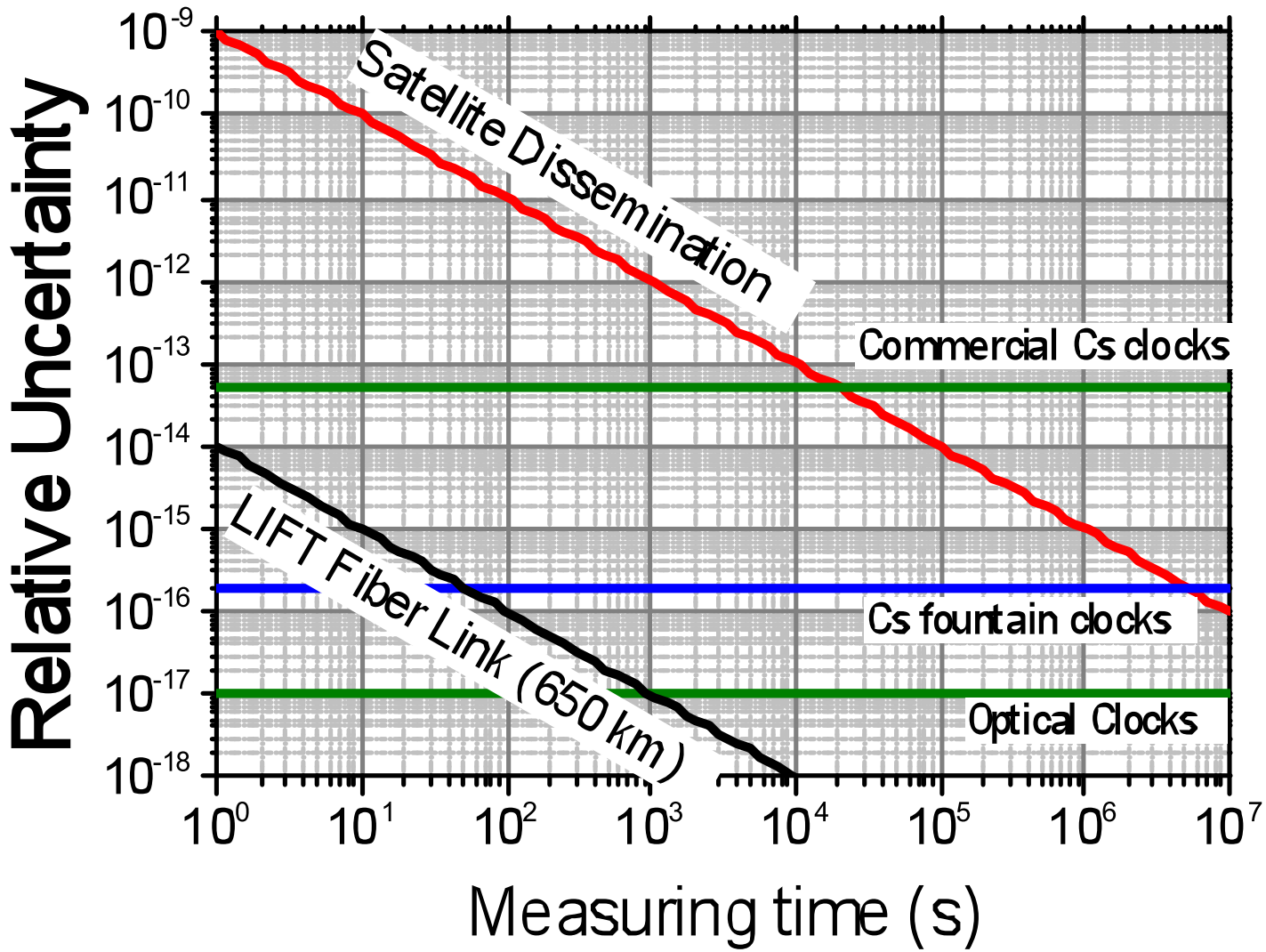

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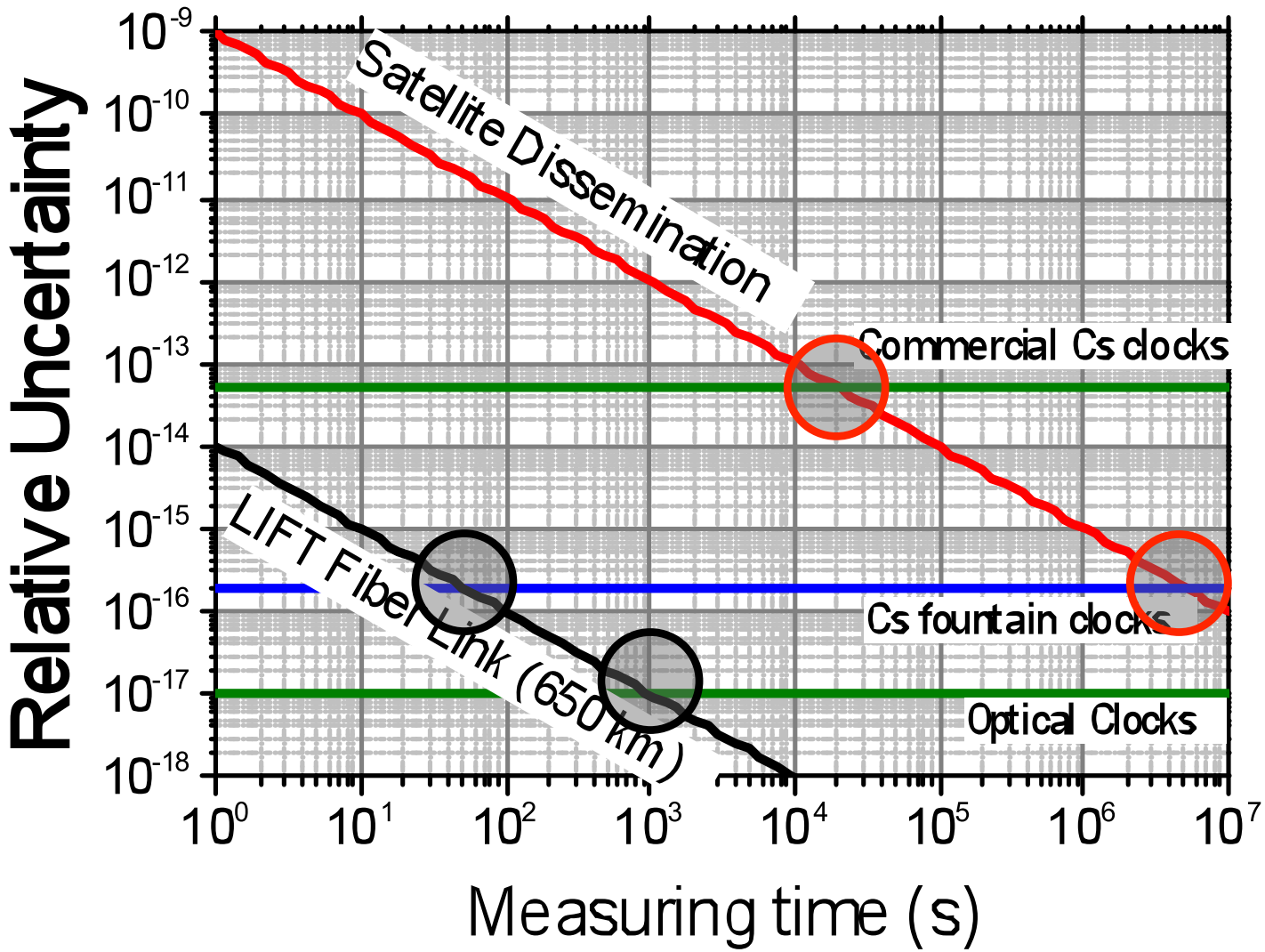

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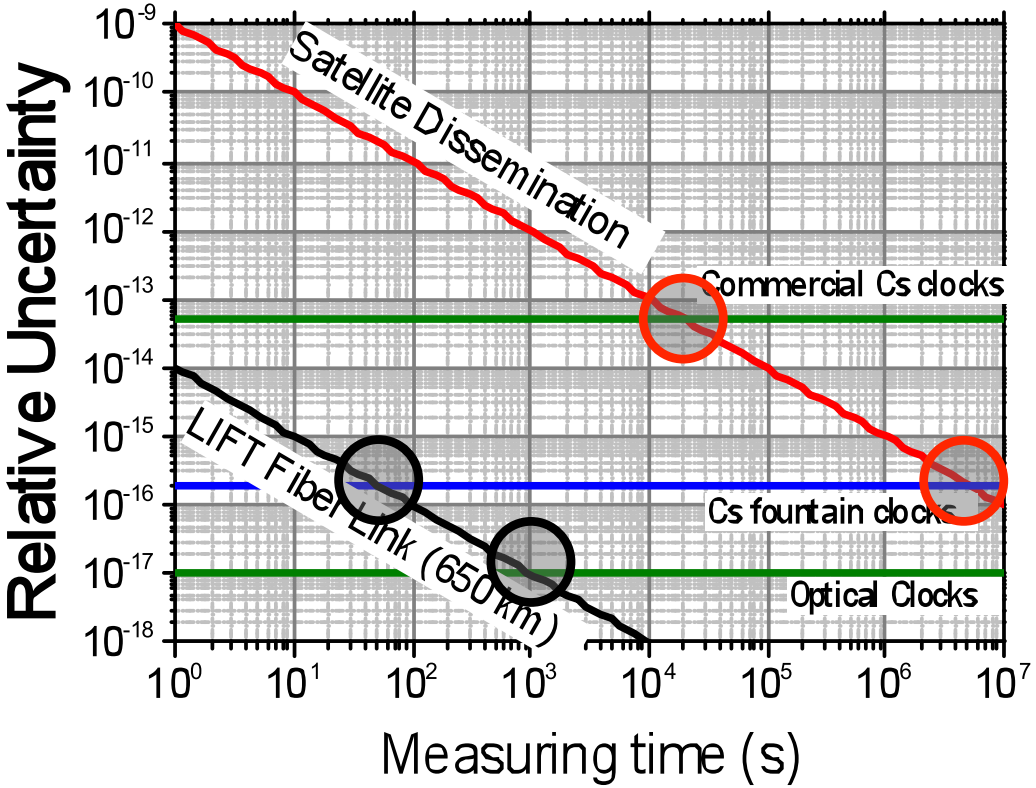



Satelliti:

>4 h per un Cs Commerciale

>20 g to per Fontane Cs

>100 g per orologi ottici

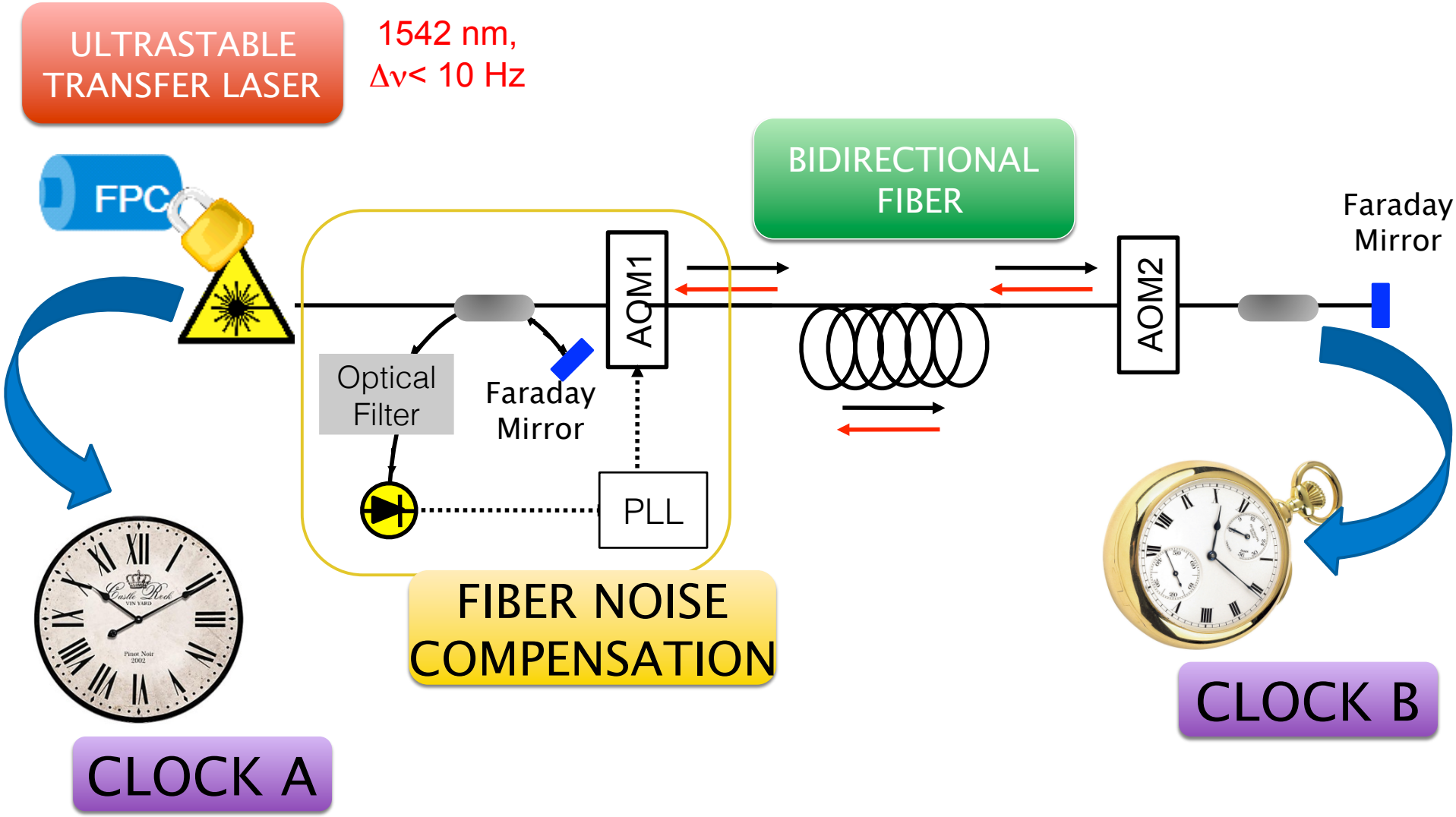
Link in Fibra:

Sempre meglio di un Cs Commerciale

100 s per la Fontana Cs

1000 s per l'Orologio Ottico

# Coherent Link in Fibra: come funziona



# LIFT

ISTITUTO NAZIONALE DI RICERCA METROLOGICA

## Link Italiano per Il Tempo e la Frequenza

Funded by:

Ministero Istruzione Università Ricerca

Compagnia di San Paolo

EMRP
European Metrology Research Programme
Programme of EURAMET
The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

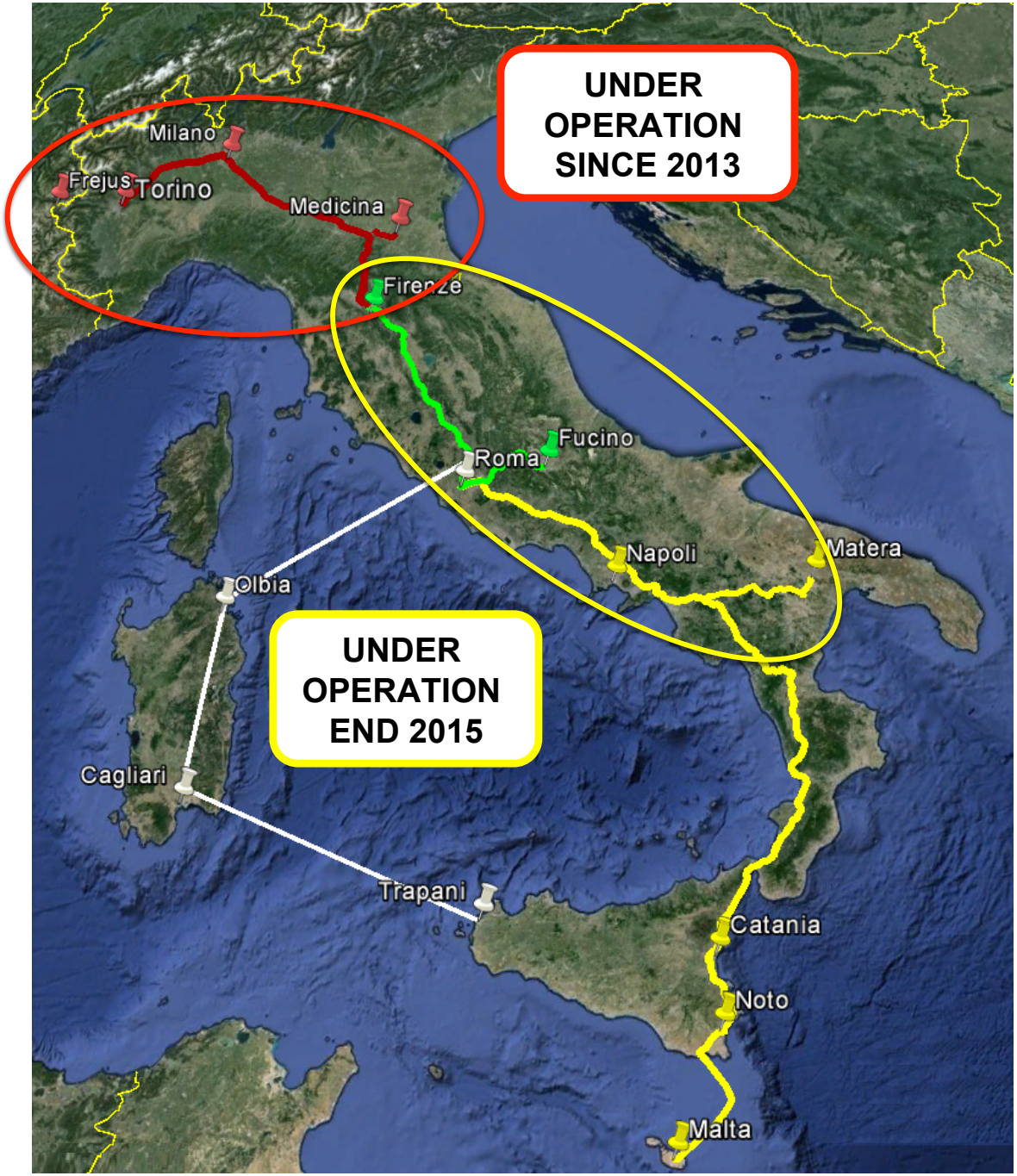
Optical Fiber by:

Consortium GARR

ISTITUTO NAZIONALE DI RICERCA METROLOGICA

# LIFT OPTICAL FIBER LINK

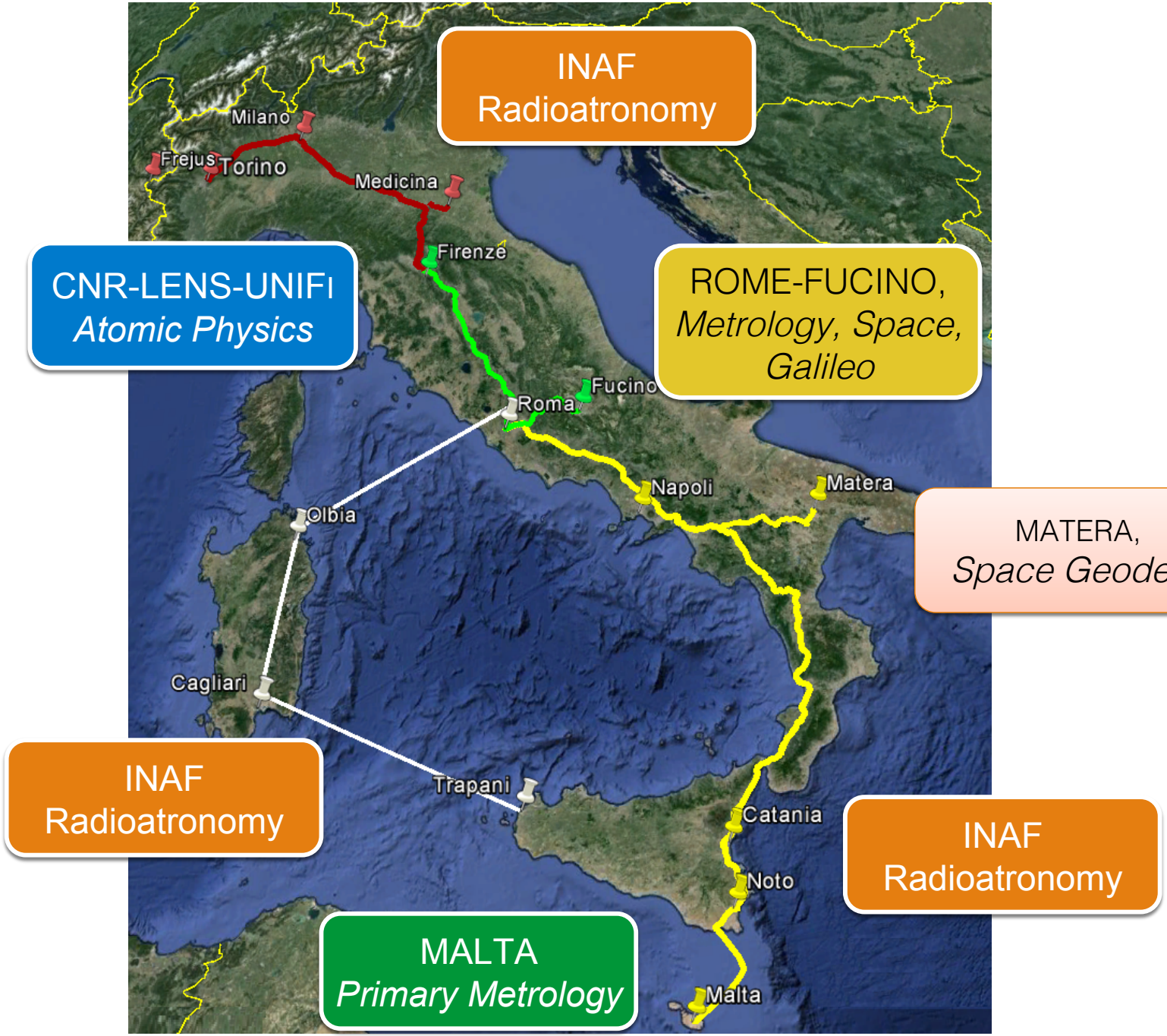
Consortium GARR




INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

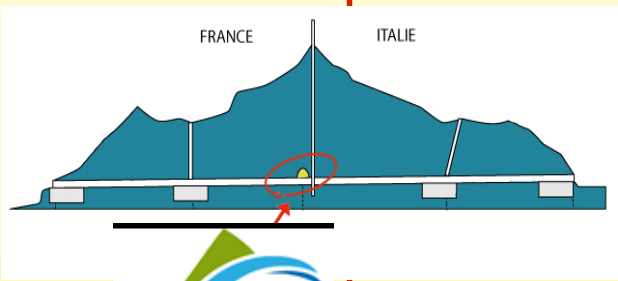
# LIFT OPTICAL FIBER LINK

# LIFT users

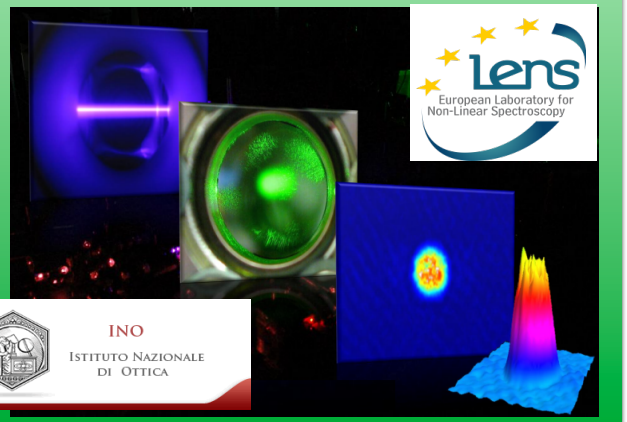

INAF
Radioatronomy
Milano
Frejus
Torino
Medicina
Firenze
CNR-LENS-UNIFI
*Atomic Physics*
ROME-FUCINO,
*Metrology, Space, Galileo*
Fucino
Roma
Napoli
Matera
Olbia
MATERA,
*Space Geodesy*
Cagliari
INAF
Radioatronomy
Trapani
Catania
INAF
Radioatronomy
Noto
MALTA
*Primary Metrology*
Malta

# LIFT present impact on research

**Frejus: Relativistic Geodesy**




**Firenze: Atomic and Molecular Physics**



**Bologna**

**Radio-astronomy**

**VLBI**

Cagliari

Noto

Matera

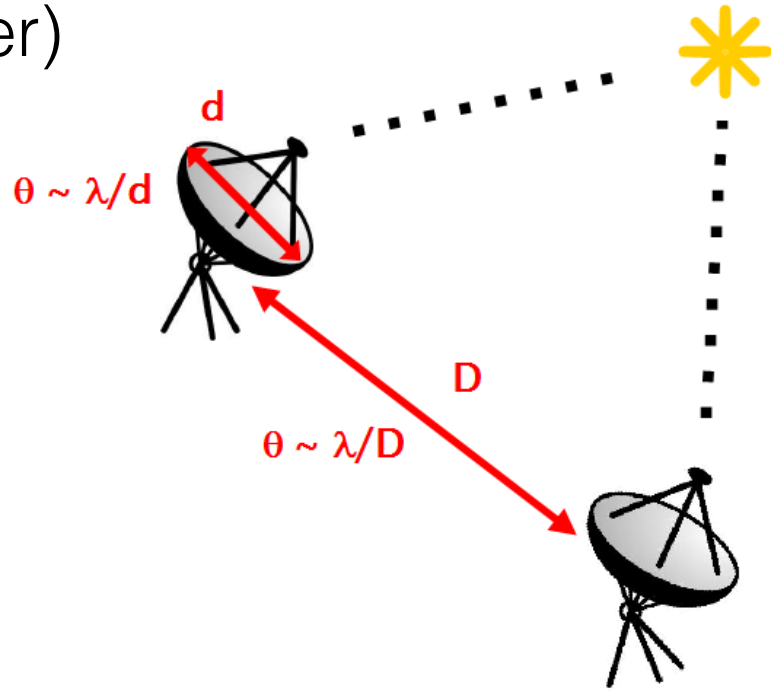
**Space Geodesy**

# INRIM per la Radioastronomia

INAF-IRA: Radioastronomia in Italia (e nel mondo)

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

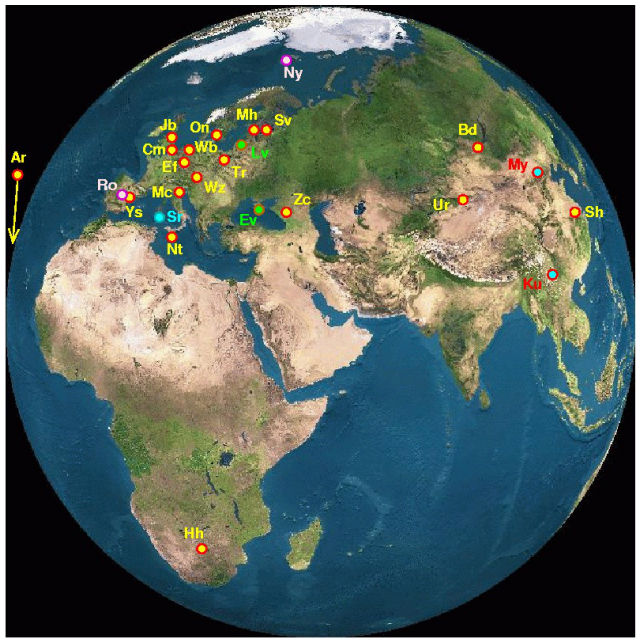
# Radioastronomia e VLBI
# (Very Large Baseline Interferometer)

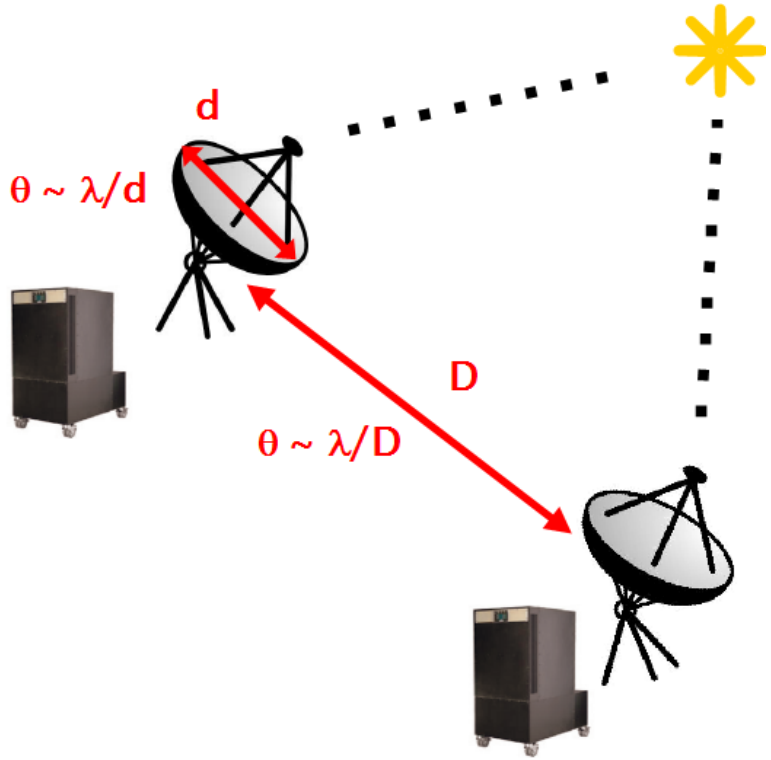



Radiotelescopi a IRA-INAF di Medicina

Antenne remote aumentano la risoluzione angolare di un fattore D/d (Es. 9000 km/ 30 m = 300.000)
**ma le osservazioni devono essere sincrone**

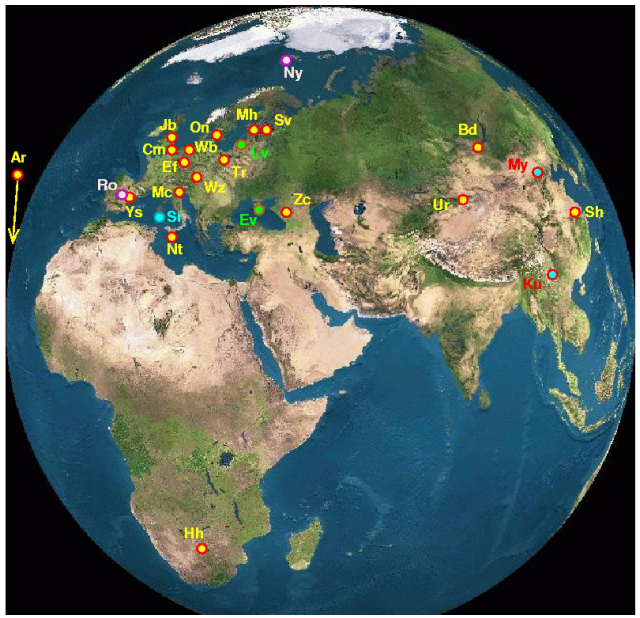
# VLBI e orologi atomici

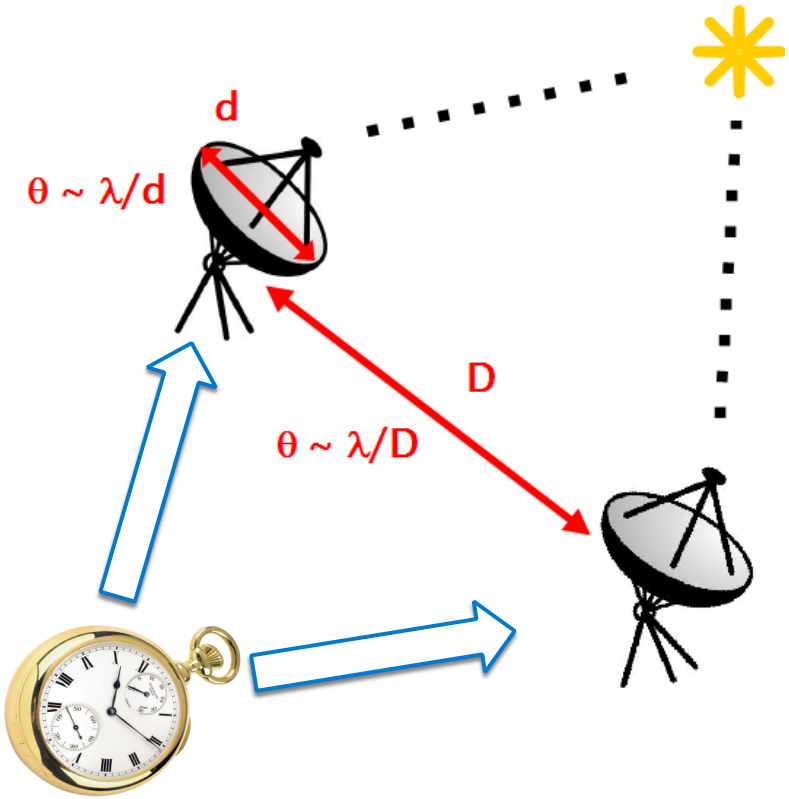



La sincronizzazione necessaria
solo se si usano
orologi atomici ultrastabili
come i **Maser all'Idrogeno**

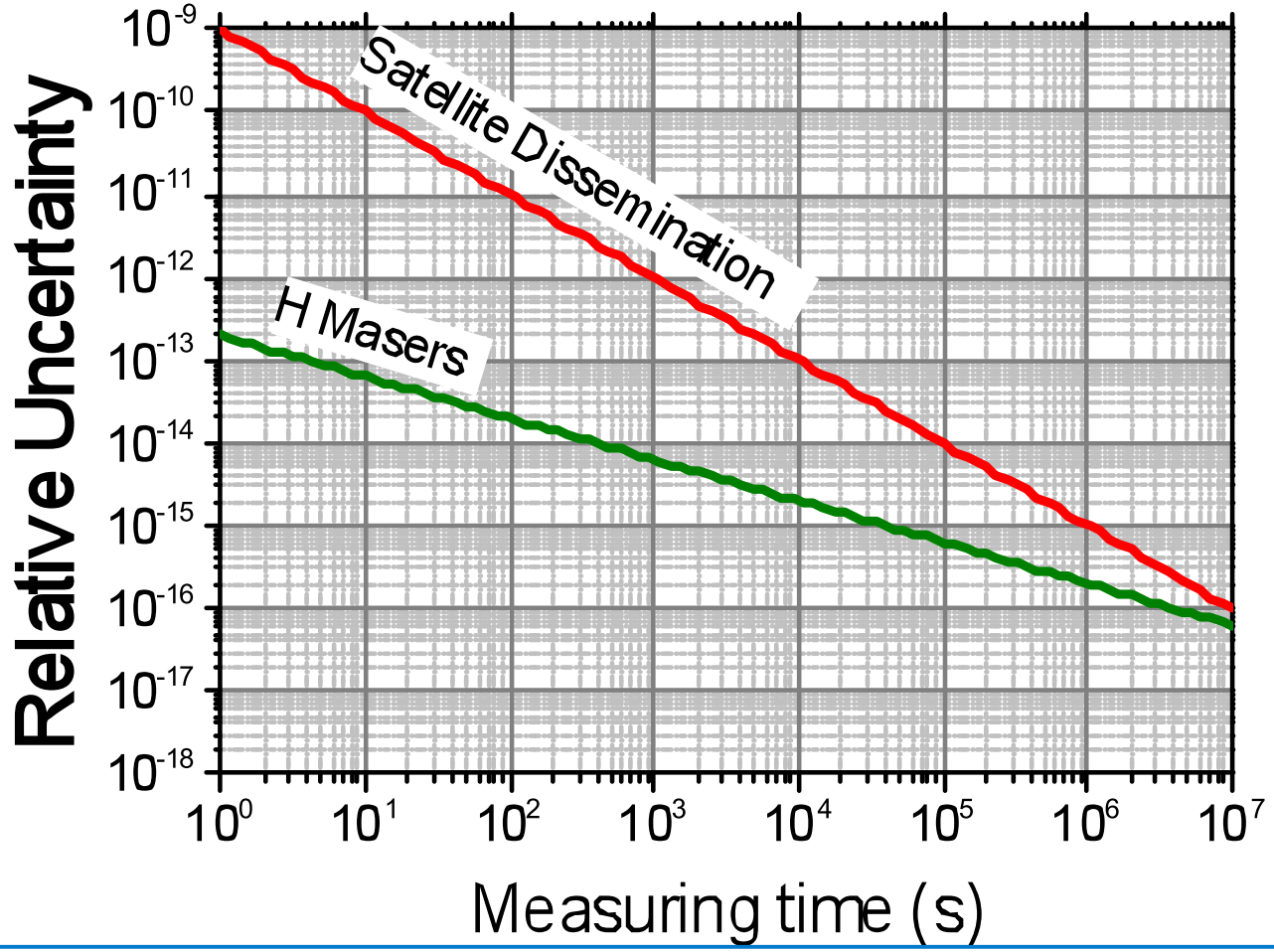
# VLBI e orologi atomici



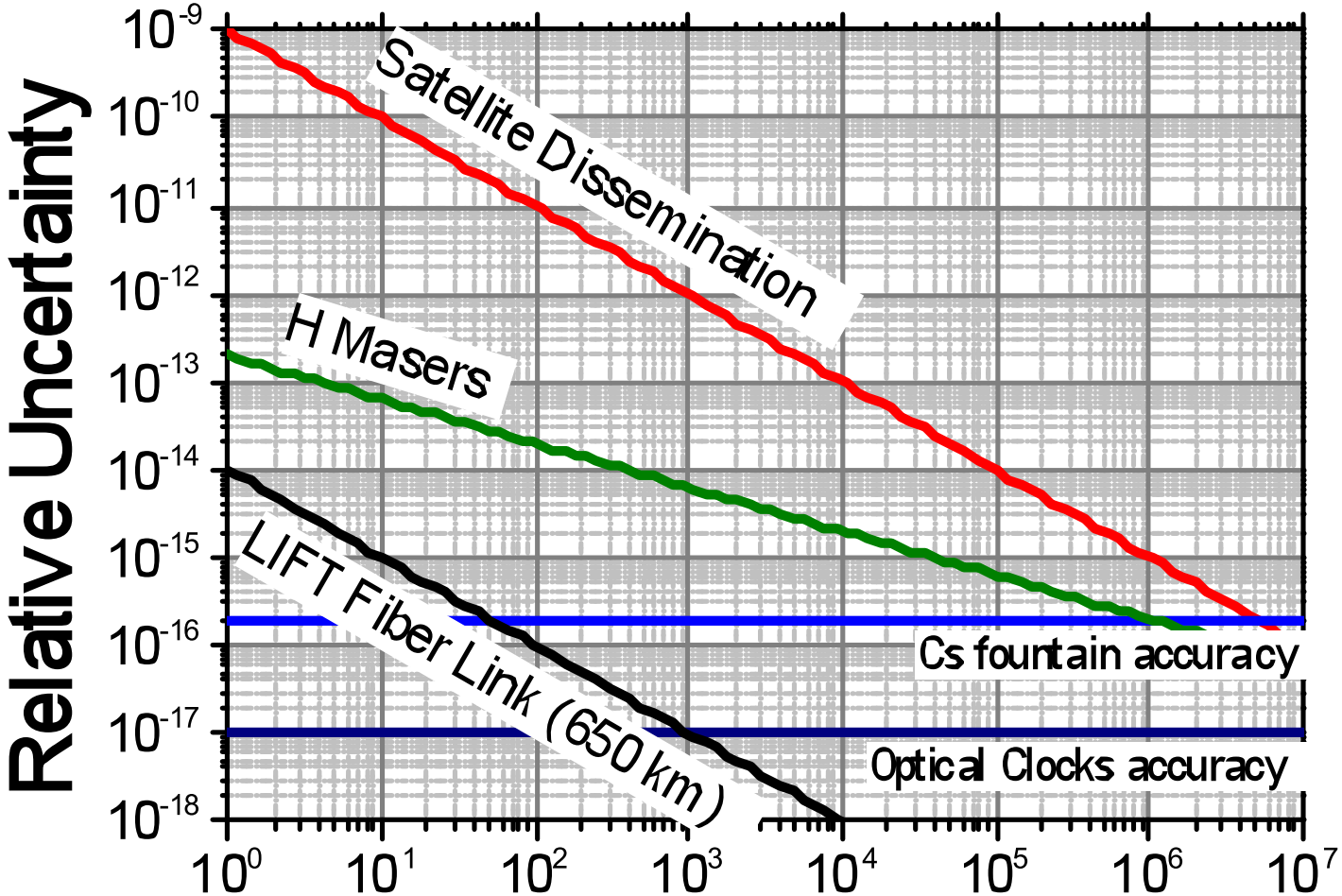

Perché non usare
un common clock?

# Disseminare Segnali di Tempo




La disseminazione del common clock via satellite per VLBI è sempre peggio di Maser separati

# Disseminare Segnali di Tempo

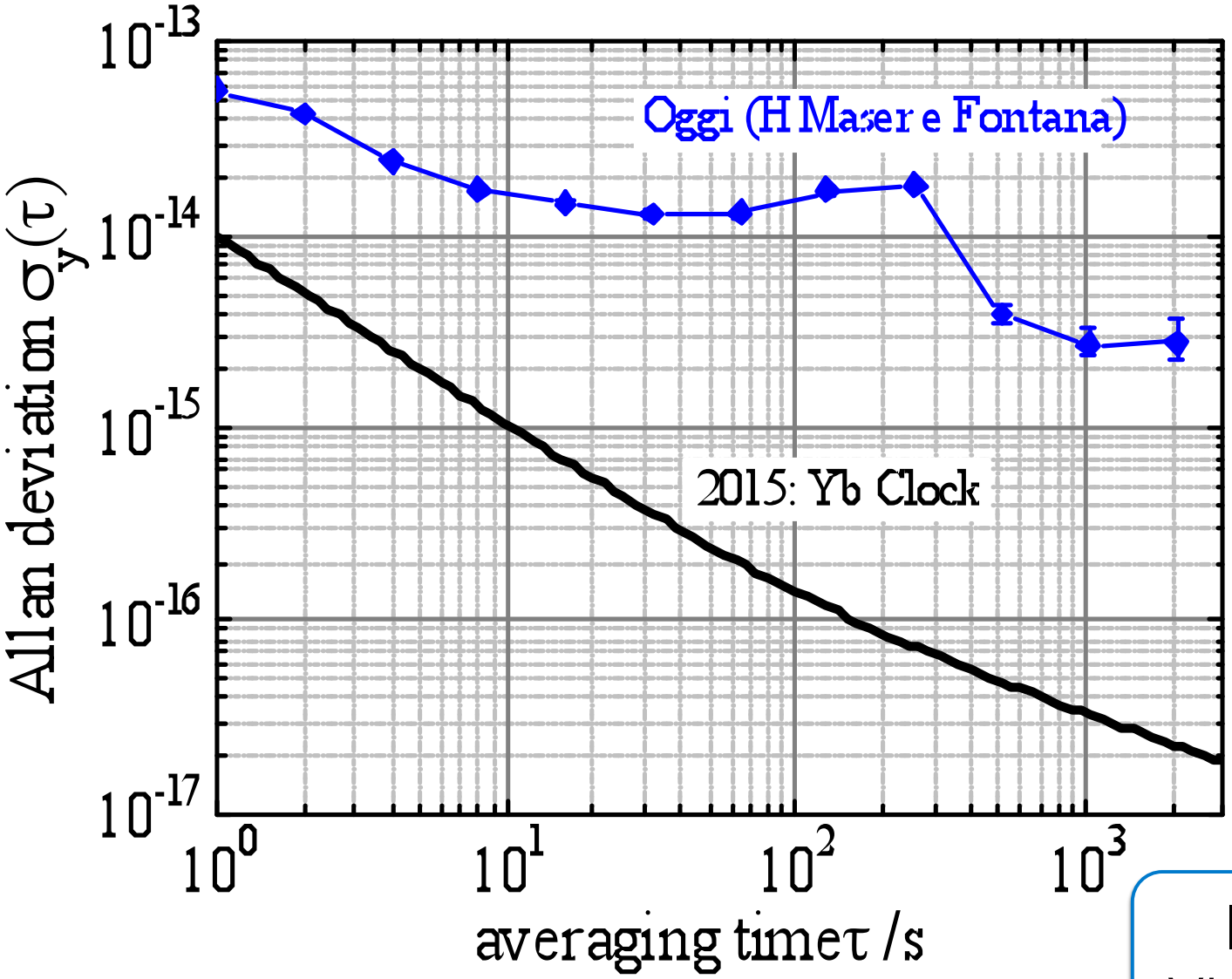



La nuova disseminazione del common clock con fibra ottica puo' funzionare!

# Remote calibration of H-Maser at Medicina-radiotelescopes

- No need of local instrument
- No need of periodic calibration
- Potentially better long-term stability than Maser

# Maser INRIM trasferito in fibra a Medicina



Medicina radiotelescope

IDONEO PER VLBI AVANZATO?

# Testing Einstein geodetic motion
# INRIM-ASI- ESA
# (July 2016- January 2018)

Microwave Link
Torino-ISS

Optical Link
Torino-Matera

Laser Ranging
Matera-ISS

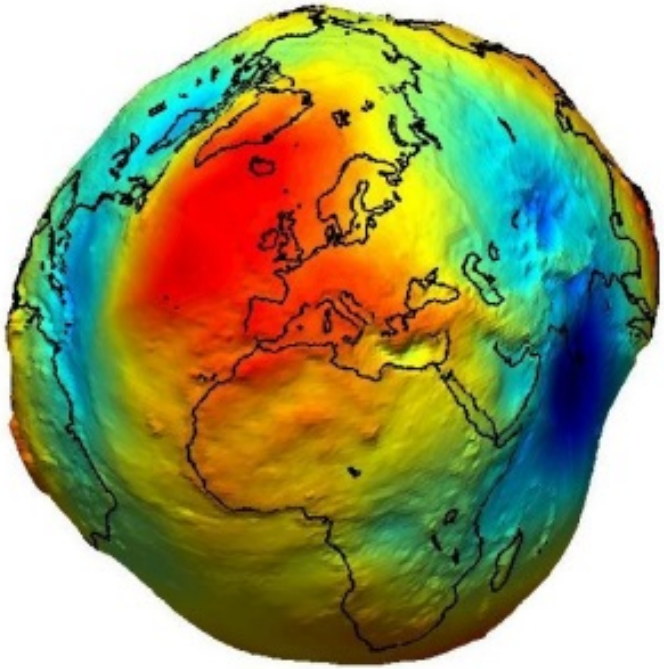
High accurate Atomic clocks

Consortium GARR

1500 km optical fiber

Space Geodesy
Center Bepi Colombo

# Red-shift Gravitazionale



Relatività Generale :

Un potenziale gravitazionale W deforma la metrica spaziotemporale e sposta la frequenza di un orologio $\nu$ rispetto a $\nu_0$ su un potenziale di riferimento $W_0$

Nel limite di campo debole $W/c^2 << 1$, c velocità della luce, $W_0$ riferimento di potenziale):

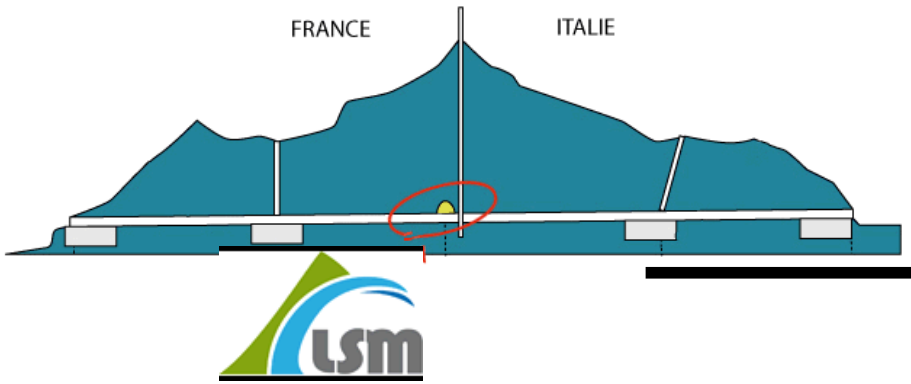
$$\frac{\nu_0 - \nu(\bar{r})}{\nu_0} = \frac{W(\bar{r}) - W_0}{c^2}$$

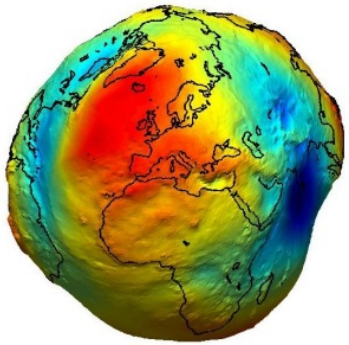
Sulla Terra (rispetto al $W_0$ del Geoide):

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

# Geodesia Relativistica

Studiare i cambiamenti del geoide a 10 cm ($10^{-17}$) su tempi di alcune oreC



Tunnel del Frejus,1263 m

Torino, 240 m

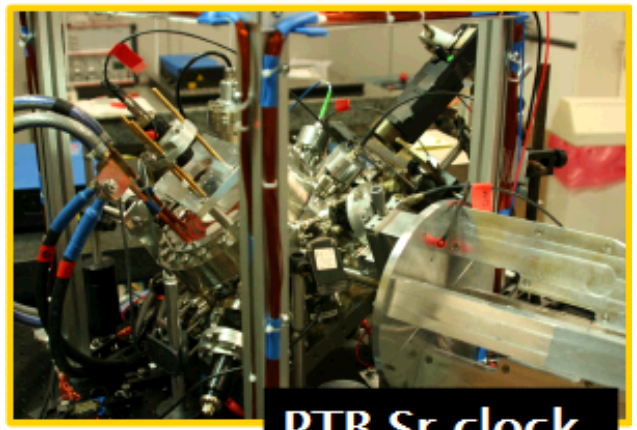
1000 m di dislivello portanto un differenza degli orologi di ~$10^{-13}$ da studiare a livello $10^{-17}$ e inferiore

# Geodesia Relativistica

Studiare il geoide a 10 cm ($10^{-17}$) su tempi di alcune ore:

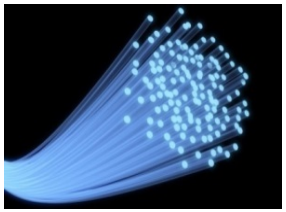
**NECESSARI**

- **OROLOGI OTTICI**
- **LINK IN FIBRA OTTICA**



PTB Sr clock

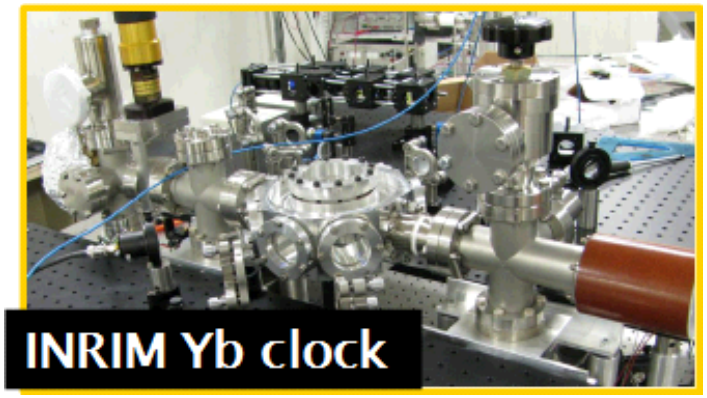
150 km FIBER (highway)



Consortium GARR

top ix

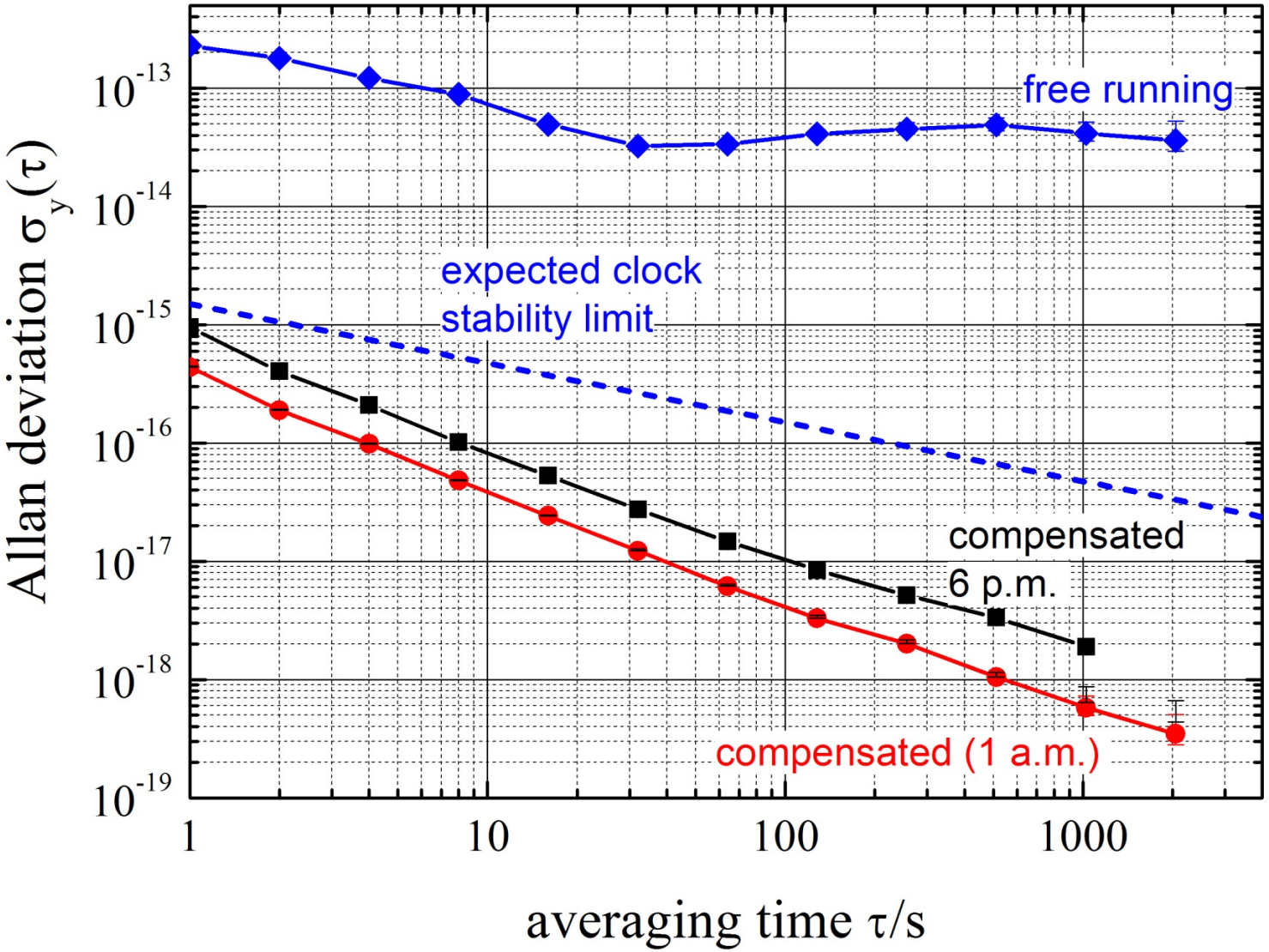
NPL comb



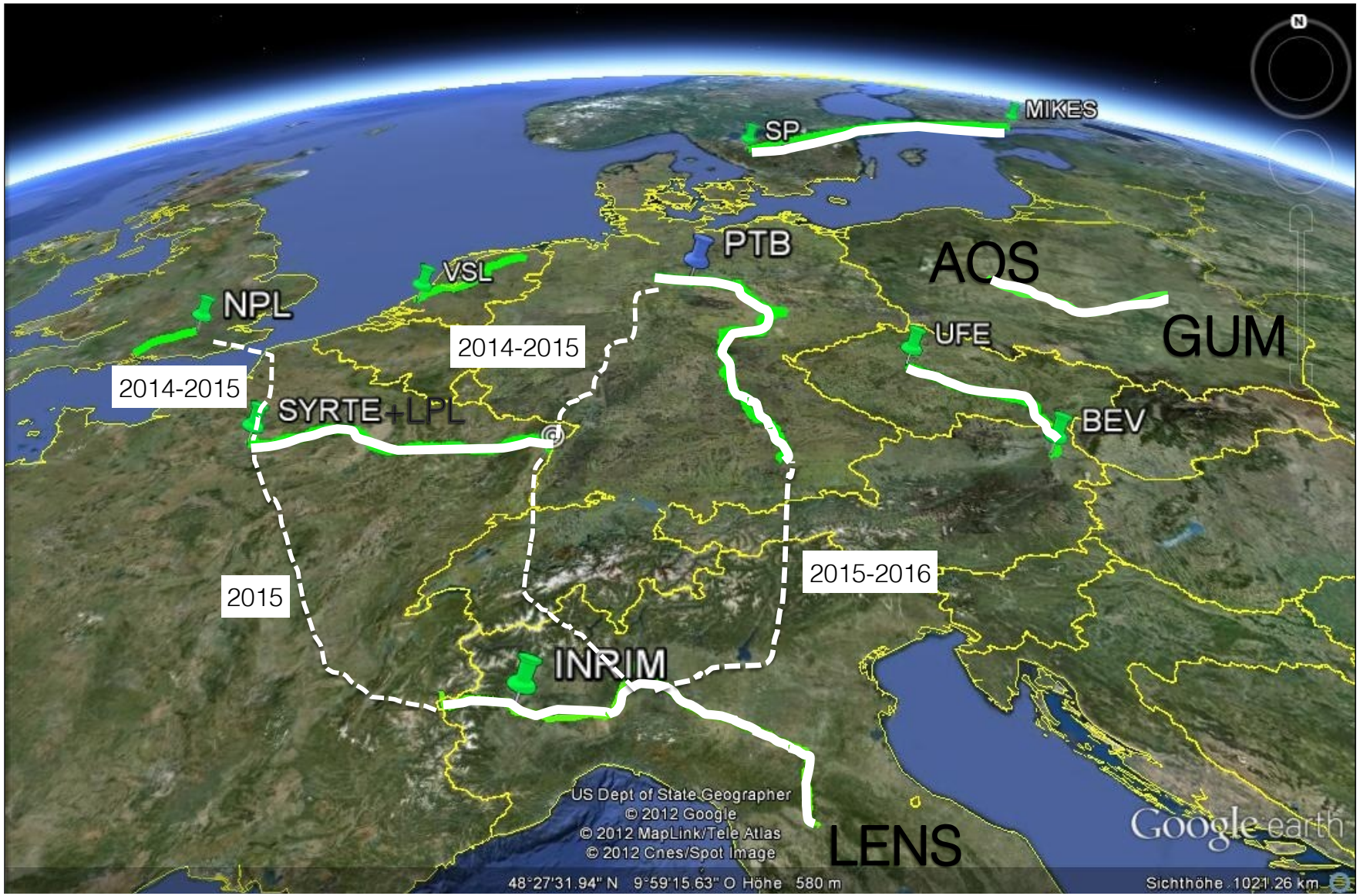
INRIM Yb clock

# Geodesia Relativistica: risultati preliminari

INRIM-Frejus 150 km fiber haul



# Optical Fiber Link European Network



EMRP
European Metrology Research Programme
Programme of EURAMET

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

EURAMET
European Association of National Metrology Institutes

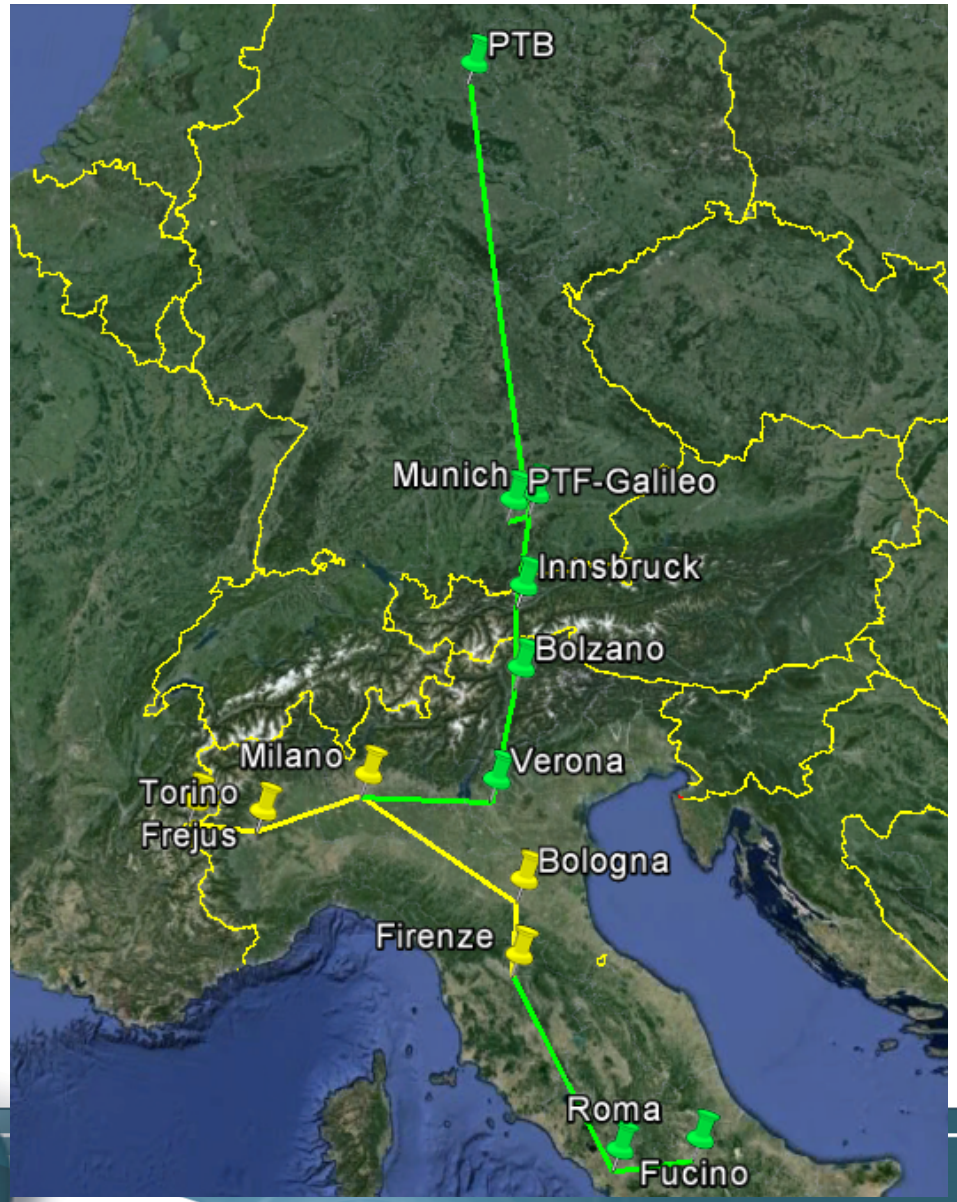
# INRIM is partner of the project

## 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)

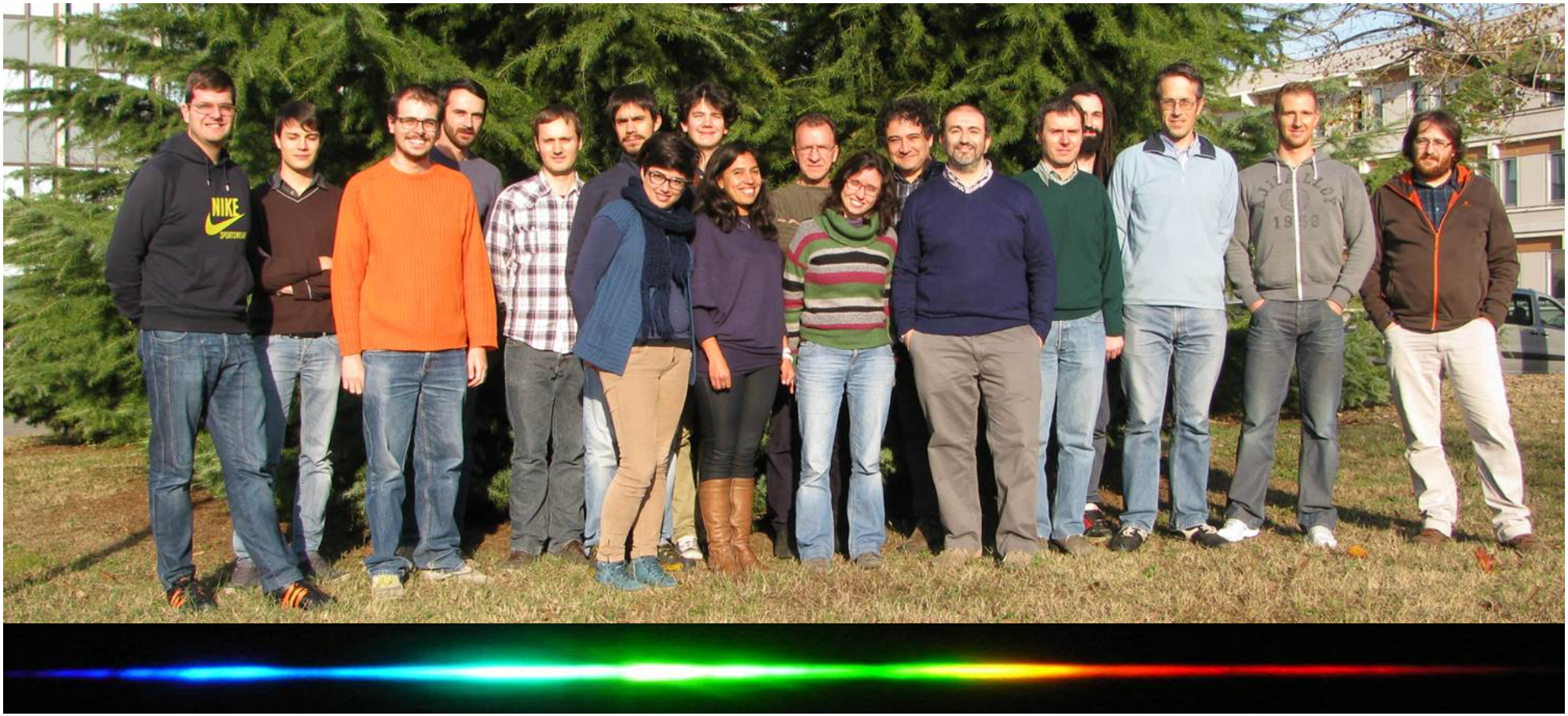
# Italia-Germania: un link per la Scienza e l'Industria europea




**GNSS GALILEO – INRIM – PTB:**

- Galileo Ground Control (Fucino, Oberpfaffenhofen)
- Collegato agli Istituti di Metrologia (INRIM-PTB)
- Link tra INRIM e PTB
- Link tra INRIM- Munich- Innsbruck- Firenze (Fisica Atomica)

# INRIM: Gruppo Orologi Atomici



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

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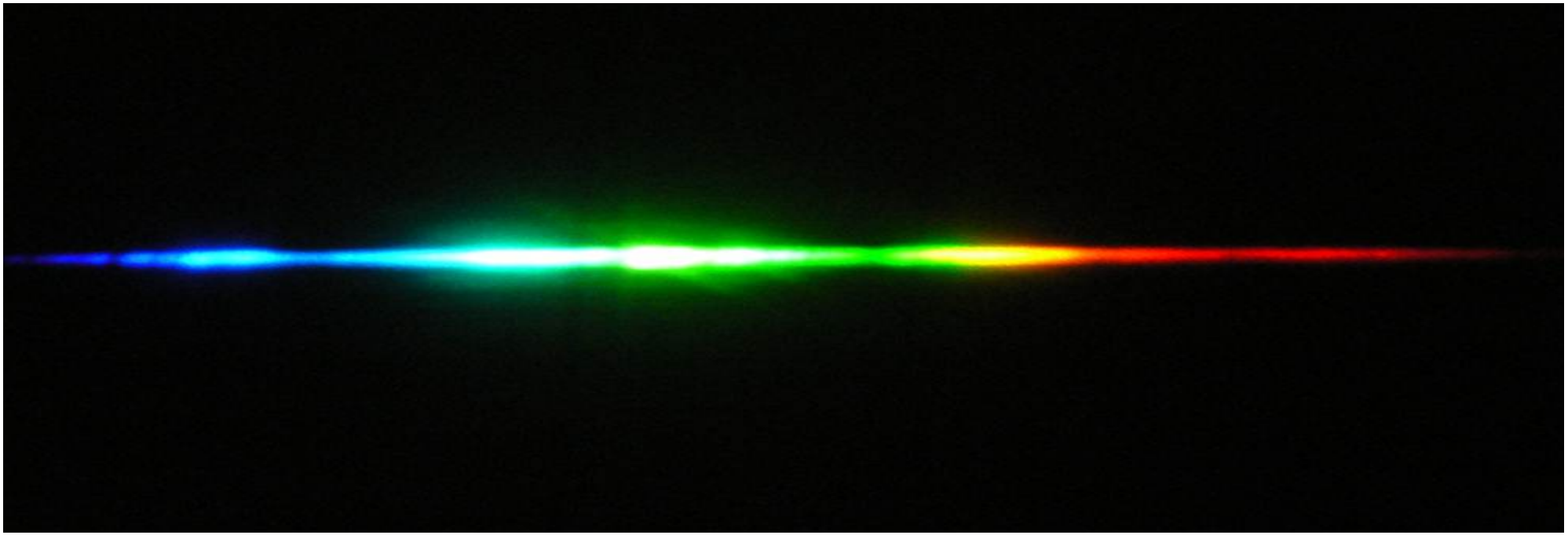
# Conclusioni

- ✓ La precisione degli orologi atomici di nuova generazione porterà a una ridefinizione del secondo;
- ✓ La Fibra Ottica oggi è in grado di offrire una distribuzione di tempo accurato molto superiore e molto più veloce rispetto ai satelliti
- ✓ In Italia il progetto LIFT è all'avanguardia nel mondo
- ✓ Tempi maturi per una rete europea di link ottici
- ✓ Quale sarà il ruolo dell'Unione Europea?

# Grazie per l'attenzione!



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