







Systèmes de Référence Temps-Espace

Avancées scientifiques de l'instrument REFIMEVE

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Contents



Introduction (rather long)

- Status
- Signals source in SYRTE
- Frequency transfer technique

I. Scientific progresses of REFIMEVE

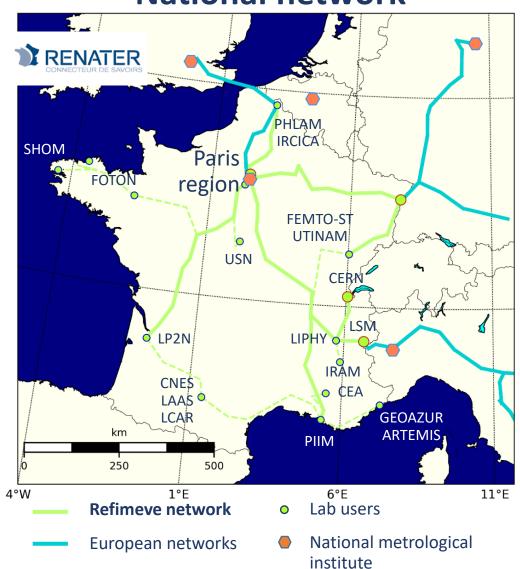
- Deployment to CERN
- Deployment to Bordeaux
- Deployments in Paris region
- Industrialisation
- Supervision of the network

II. Connection to the user's lab and scientific exploitation

Infrastructure de recherche REFIMEVE



National network



→ Transfer of frequency and time references through optical fibers

LPL, LNE-SYRTE and RENATER

- Collaboration of more than 30 lab users: 18 users currently connected
- European connection to Germany, England, Italy and Switzerland
 - → Future connection with Belgium, Netherlands, Spain, Poland...

The network

~8000km of fiber

→ Availability of the signal >90%

- \rightarrow ~250 equipment in the field
- → ~50 person-day of interventions in 2022

Infrastructure de recherche REFIMEVE

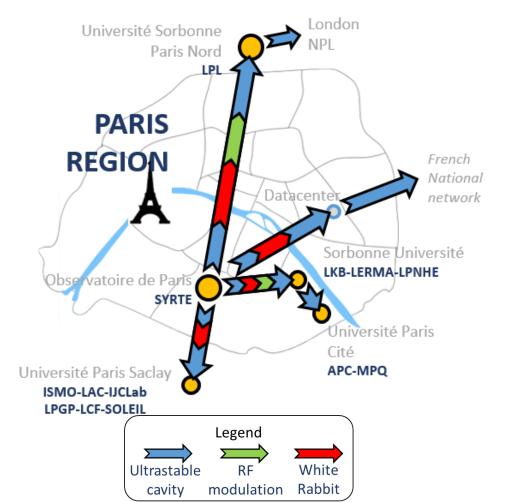








Regional network



→ Transfer of frequency and time references through optical fibers

- +10 users in Paris region
- Dissemination of 3 type of signals:
 - Optical (ultrastable cavity)
 - Time & frequency signals by White Rabbit transfer
 - RF modulation on optical career

Current White Rabbit network:

→ See Vincent Voisin and Daniel Charlet' talks

- 120 km of network
- 11 equipment in the field

→ Pave the way for the national White Rabbit network

Thèse N. Kaur, « Long range time transfer over optical fiber links and cross-comparison with satellite based methods. », SYRTE, 2018

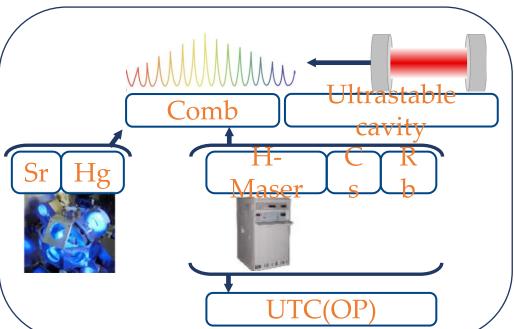
Caroline B. Lim et al., "Extension of REFIMEVE with a White Rabbit network", proceedings EFTF-IFCS 2023, To be published

Time and frequency references at SYRTE



Frequency reference (optical)

→ Laser emitting at 1542.14 nm



- → stabilized to an ultrastable cavity : stability
- → locked on local clocks : accuracy
- → fixed frequency at ±10 Hz (locked on H-maser)



Signal @ user		Stability @ 1s	Stability @ 1 day	Uncertainty (routine)
Optical frequency	1542nm	< 10 ⁻¹⁴	<3x10 ⁻¹⁶	10-14
Time	UTC(OP)	< 30 ps	< 30 ps	10 ns
RF		< 10 ⁻¹²	< 10 ⁻¹⁵	10 ⁻¹⁴

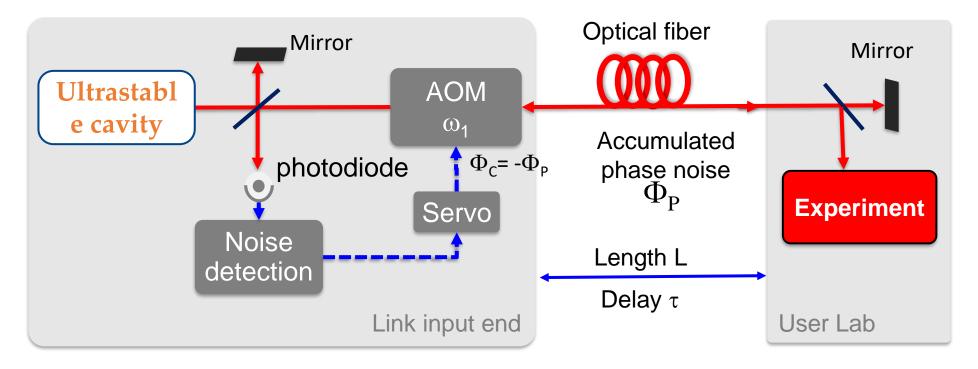
Time and frequency references (RF)

- →10 MHz and 1 Pulse Per Second (1PPS)
- → H-maser + steering by clocks
- → referenced to UTC(OP): traceability to SI-s / circular T

Frequency transfer technique

Refimeve+

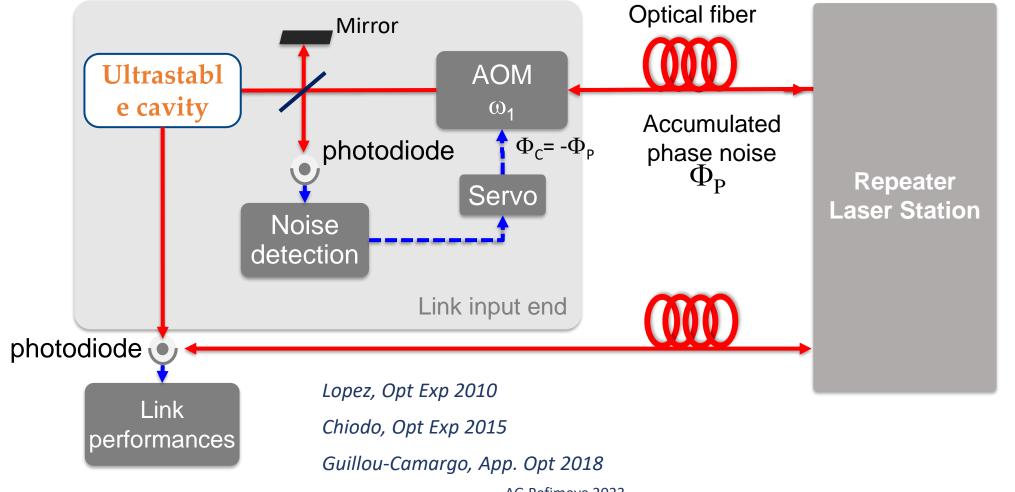
- Doppler noise compensation or active noise compensation
 - → Noise detection with a strongly unbalanced Michelson interferometer



- Noise correction $\Phi_{\rm C}$ applied at the link input: $\Phi_{\rm C} + \Phi_{\rm P} = 0$ \rightarrow Limit of the time delay propagation in the fiber
- N. R. Newbury et al., Optics Letters, vol. 32, n° 21, p. 3056, 2007

Frequency transfer technique

- Refimeve+
- Characterization of the link: out-of-loop detection of the transferred signal
 - →a parallel downlink is implemented to assess link performance



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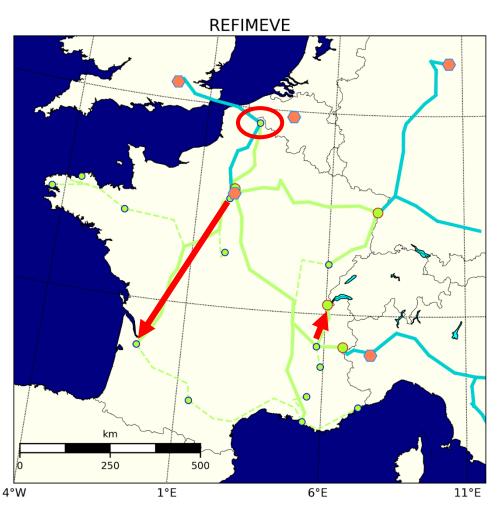
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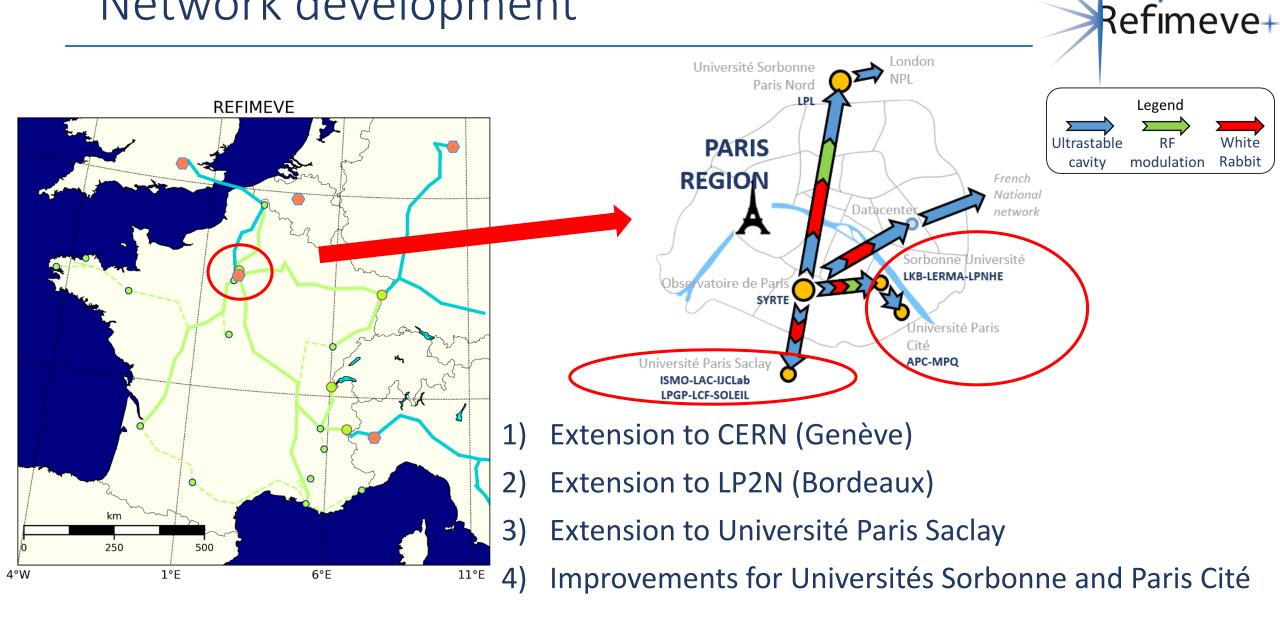
Network development





- 1) Extension to CERN (Genève)
- 2) Extension to LP2N (Bordeaux)

Network development



Extension to CERN (Genève)

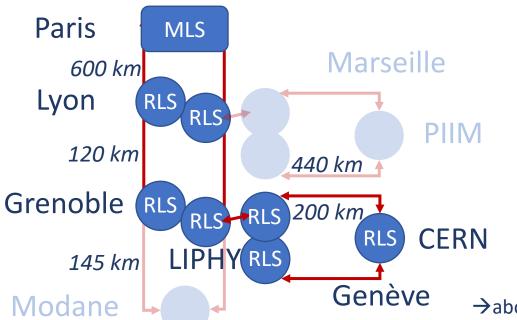
Refimeve+

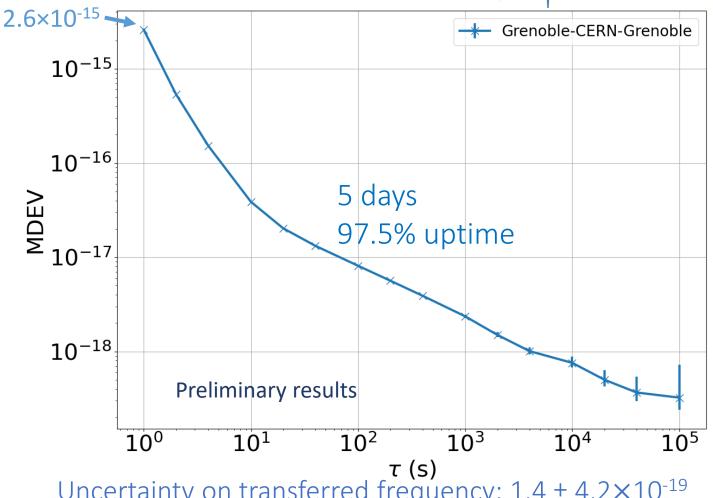
Operational since 24th March 2023

→operational 1 week after installation

→ Important interconnection with Europe, **NRENs and Géant (OTFN project)**

→ Future scientific applications (Gbar, Alpha...)





Uncertainty on transferred frequency: $1.4 \pm 4.2 \times 10^{-19}$

→about data processing: Thèse M. B. K. Tønnes and M. B. K. Tønnes et al., Metrologia, 2022

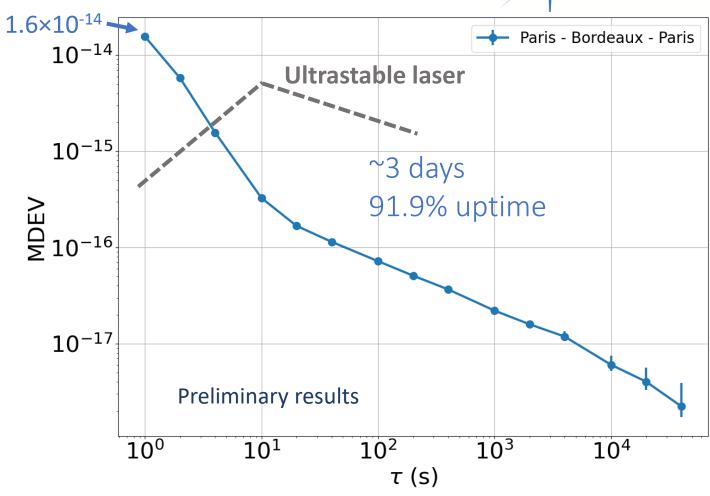
→ must take into account Paris-Grenoble performances

Extension to LP2N (Bordeaux)

Refimeve+

- Operational since July 2022
- →deployed in one week only
- →1400km long / more than 280 dB total losses
- → future branches to Toulouse, Nançay and Bretagne to construct





Uncertainty on transferred frequency: $1.9 \pm 3.2 \times 10^{-18}$

Extension to LP2N (Bordeaux)



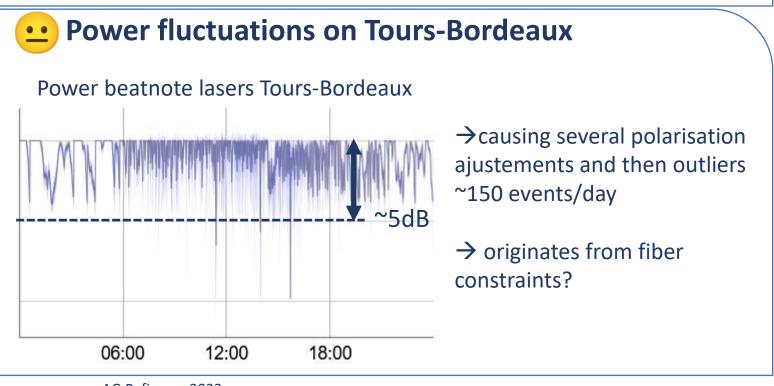
Difficulties



Stability @1s: 2×10⁻¹⁴

- → 1 order of magnitude higher than other link
- → Under investigation (embedded noise PSD measure, intermediate out-of-loop measurement...) → Regeneration in between Tours and Bordeaux?



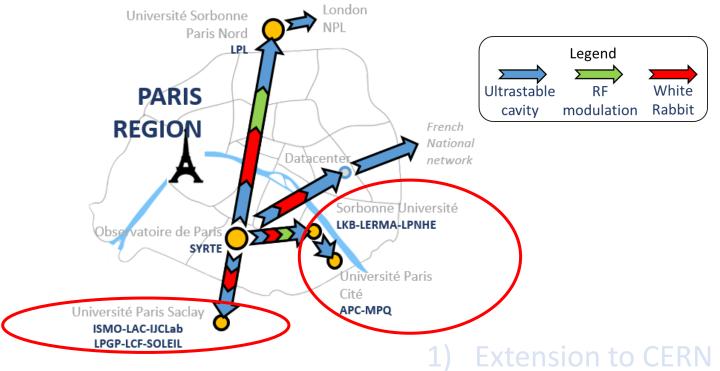


AG Refimeve 2023

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Development in regional network





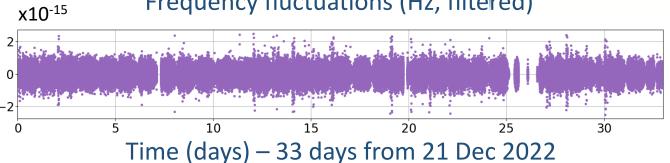
- Extension to CERN (Genève)
- Extension to LP2N (Bordeaux)
- Extension to Université Paris Saclay
- Improvements for Universités Sorbonne and Paris Cité

Extension to Université Paris Saclay

Refimeve+

Lien	Uptime	Accuracy (× 10 ⁻²¹)
SYRTE-Paris Saclay	85.1 %	0.3 ± 19.2

Frequency fluctuations (Hz, filtered)



SYRTE - LPL

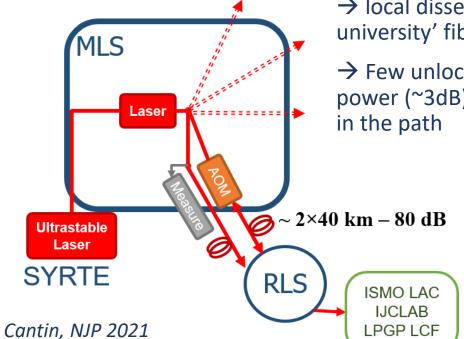
 10^{4}

10⁵

SYRTE - Jussieu - UPCité

Operational since December 2022

→add additional electronic to the MLS



→ local dissemination on university' fibers

→ Few unlocks from loss of power (\sim 3dB) \rightarrow amplifier needed

SYRTE - Orsay 10^{-17} ₩ 10⁻¹⁸ 10^{-19} 10^{-20} 10^{-21}

10²

 10^{3}

τ (s)

→ See Manuel Andia and Daniel Charlet' talks

 10^{1}

3×10⁻¹⁶

 10^{-16}

Improvements for Sorbonne and Paris Cité

x10⁻¹⁶

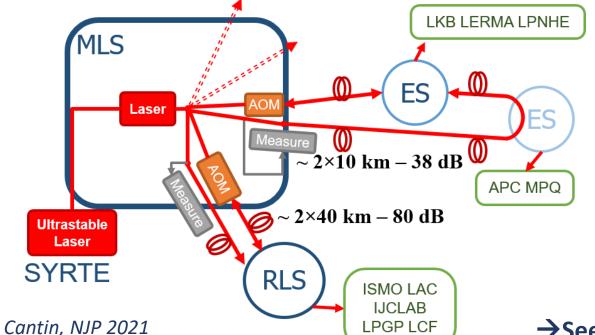
Refimeve+

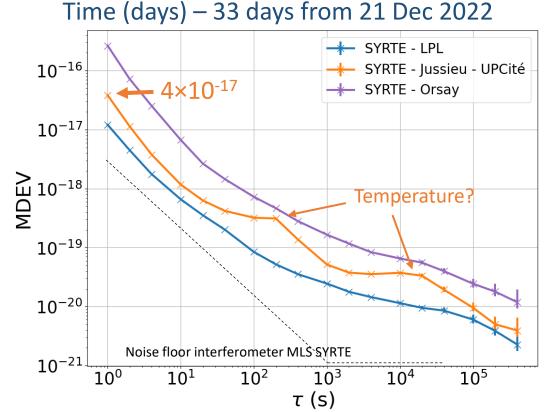
Lien	Uptime	Accuracy (× 10 ⁻²¹)
SYRTE-Jussieu - UPCité	98.6 %	3.2 ± 5.9 0. -2.

Frequency fluctuations (Hz , filtered)



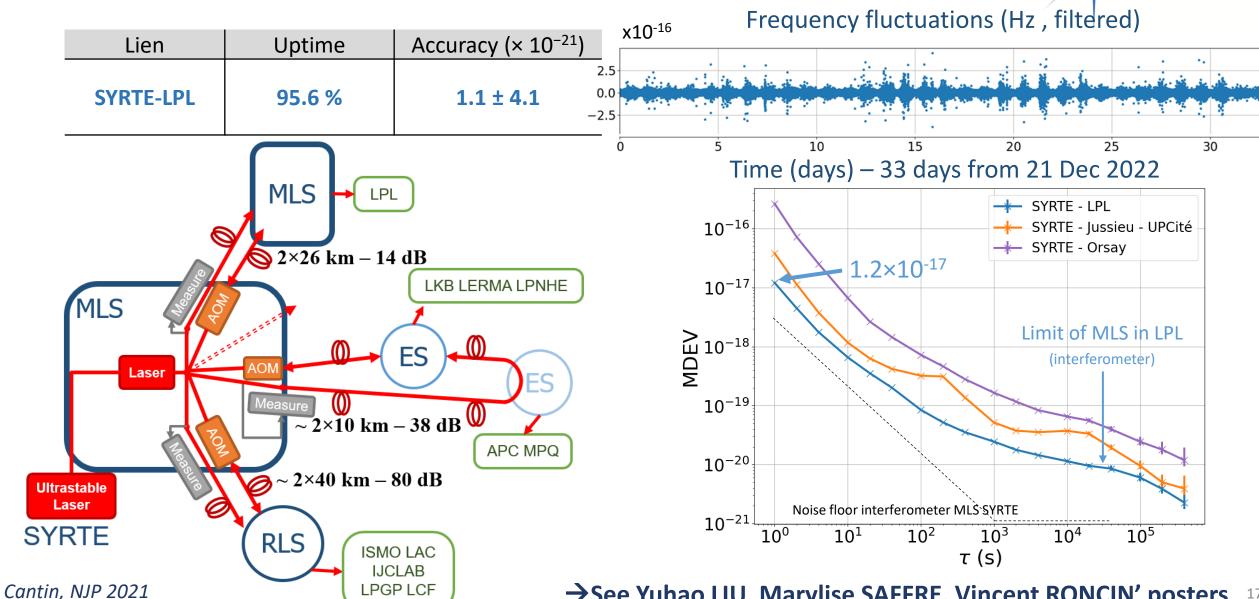
- Noise compensated since Dec 2022
- →Loop architecture with extraction →publication



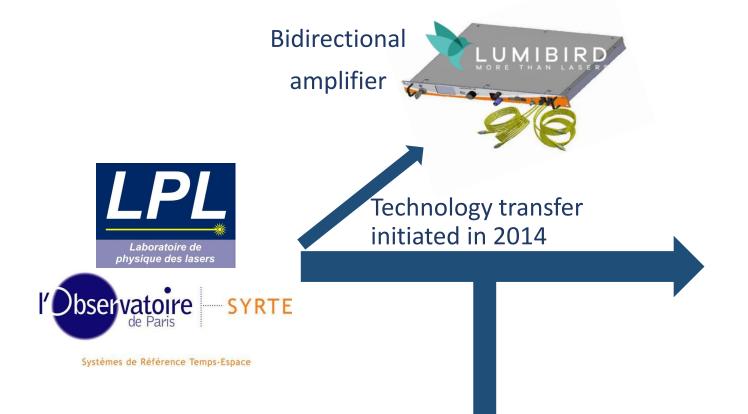


New fibres between SYRTE and LPL





Industrialisation



2022-2023



Refimeve+



Repeater Laser Station / Extraction station / User module

Current technology transfer for the industrialisation of the Multibranch Laser Station MLS

- → Better performances
- → Rescale the network

Guillou-Camargo, App. Opt 2018

→ See Grégoire Coget's talk

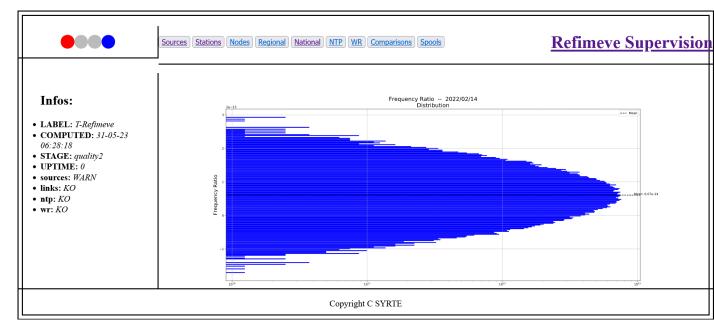
Network supervision

Refimeve+

- Fully manageable equipment
 - →temperature, status, dds settings, adc/dac...
- Communicate with the equipment (IT network)



- →operated by RENATER, benefit from their expertise
- Softwares and databases
 developments
 - → Centralize all the data
 - → Automatic process and analysis



→ See Maxime MAZOUTH-LAUROL poster

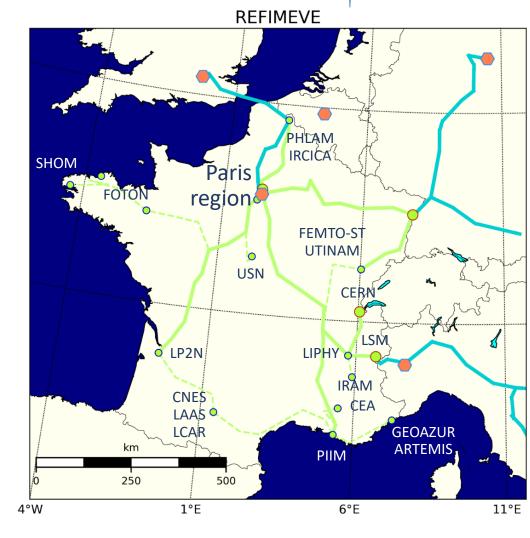
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Conclusion and perspectives

- 4 new links in 2022-2023
- Development of the instrumentation

Extensions of the network

- → Toulouse, PACA, Nançay...
- →T-Refimeve extensions
- Upgrade of the network with multibranch stations
- Extend the White Rabbit network
- Finalise the supervision development
 - → deliver the frequency value to users in real time

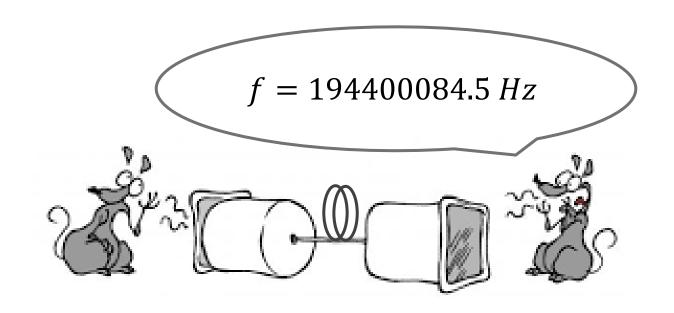


→ Support the exploitation by the users!!

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Refimeve+

Thank you for your attention!



For more details

- → See Maxime's poster on network supervision
- → See Refimeve poster on RLS/MLS