Arrival of the signal in the laboratory

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Summary

Introduction

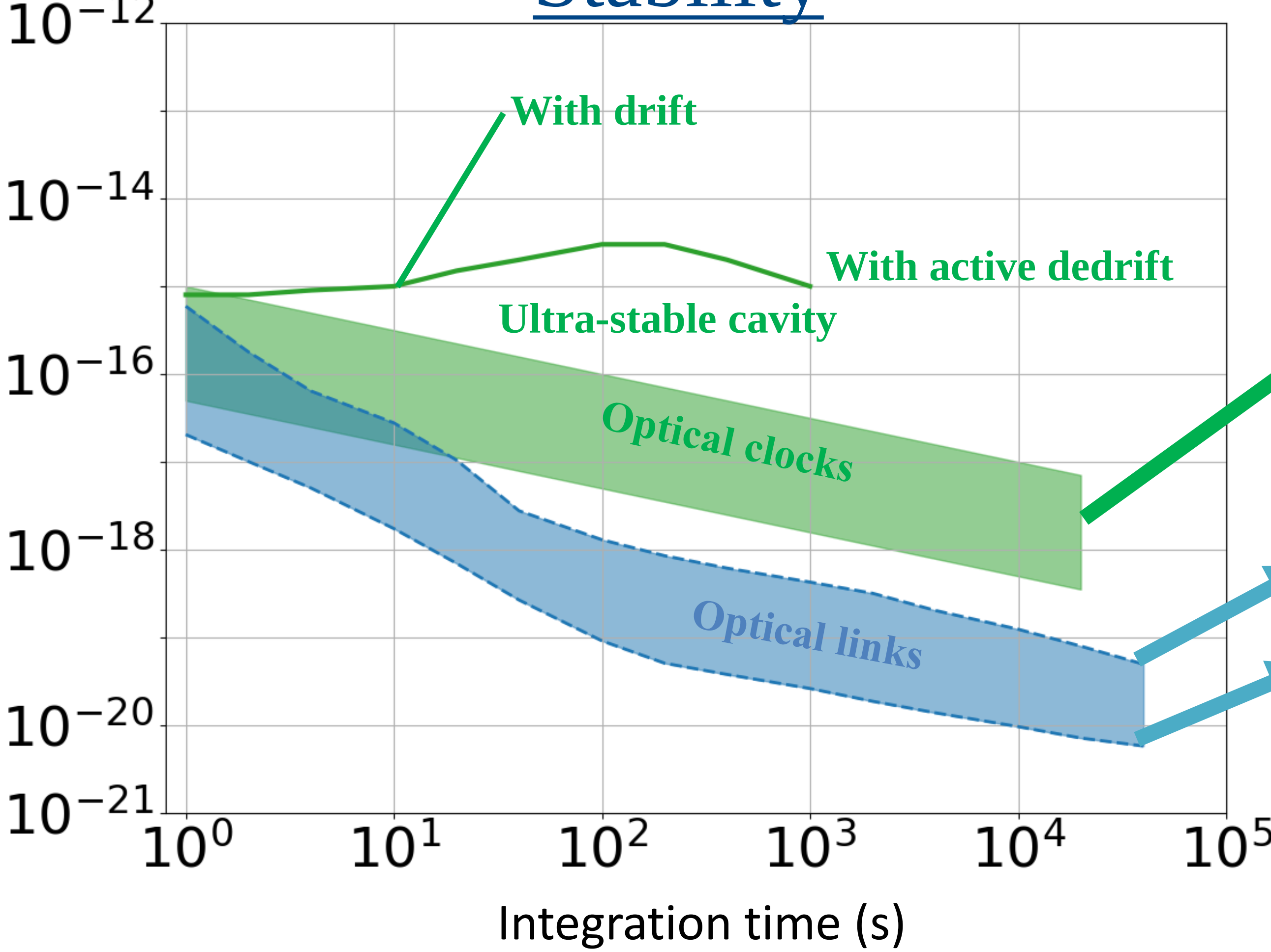
1. Source signal in SYRTE
2. Transfer of the signal
3. Signal in your laboratory
   - Specifications
   - Practical considerations

Conclusion

Context and motivations

Optical metrology: references and transfer

Stability



Accuracy

$10^{-17} - 10^{-18}$

$\sim 10^{-19}$

$\sim 10^{-20}$

- Total = quadratic sum of all contributions

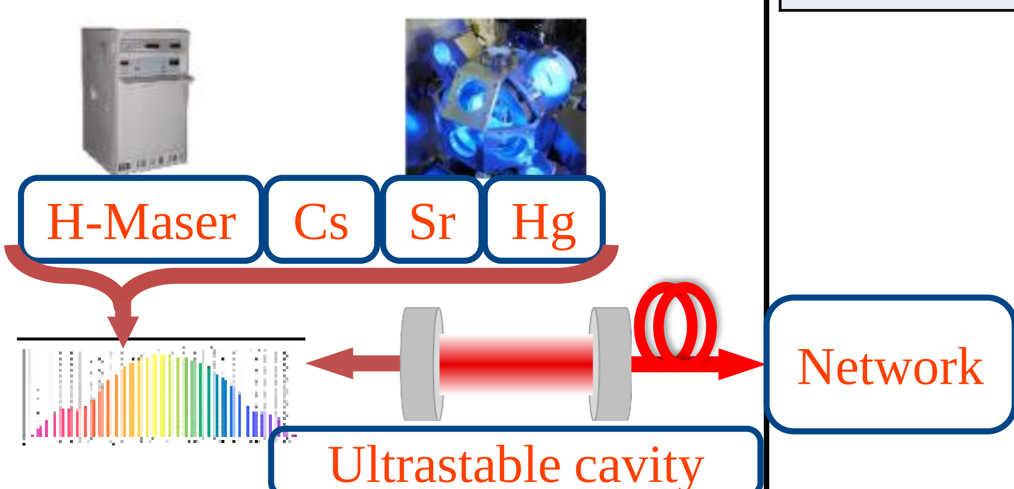
The SYRTE reference for REFIMEVE+

- **Laser emitting at 1,5 µm** (1542.14 nm)
  - stabilized to an ultrastable cavity : **stability**
  - controlled versus local clocks : **accuracy**

- **Current situation:** still operations devoted to improve reliability
  - Sometimes no accurate control of the frequency and with frequency drift <1 Hz/s (<100 kHz/day)
  - Sometimes : no signal

Stability or relative stab. @1s	Stability or relative stab. @1day	Uncertainty	
		routine	dedicated
1E-15	3E-16	1E-14	2E-17

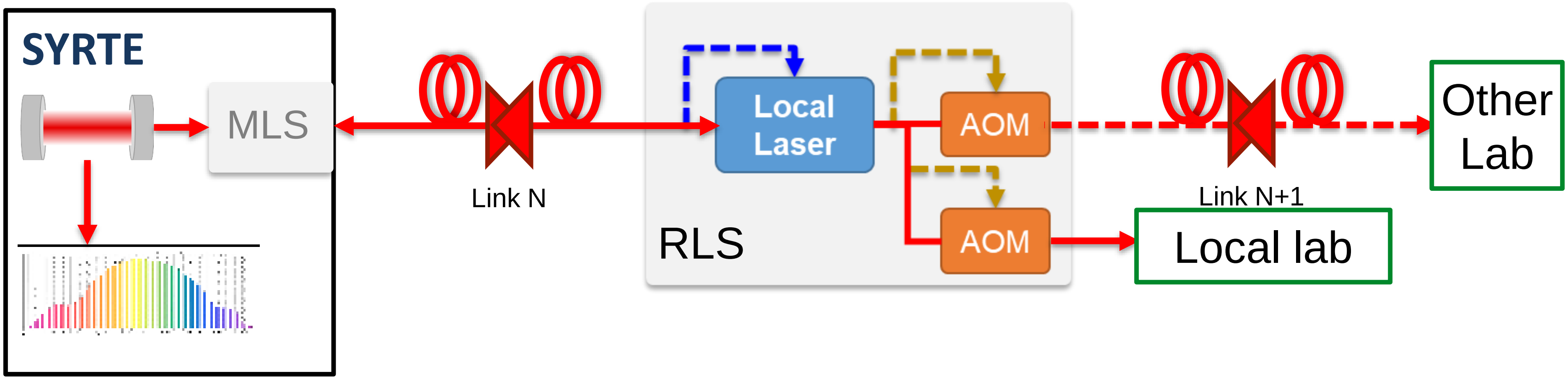
Metrological setup in LNE-SYRTE



Transfer: performances

- Dissemination with active noise compensation

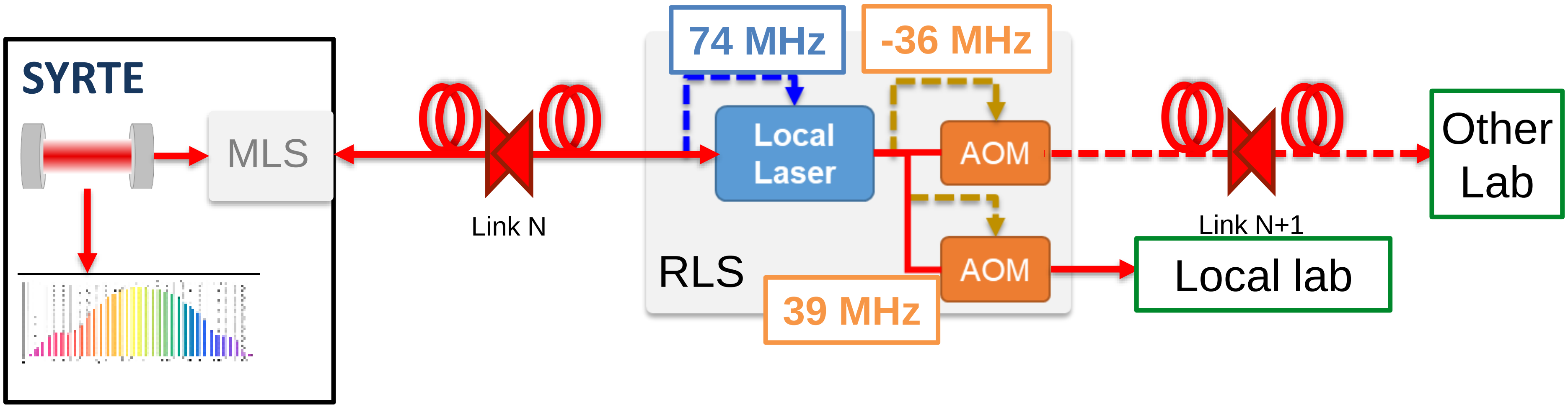
  Regeneration laser station (RLS) + amplifiers



- **Performances of the transfer:** End to End measurement
  - **Accuracy** < 10^{-19} (contribution from mean frequency and its statistical fluctuations)
  - **Stability** < 10^{-15} @ 1s and <10^{-19} @ 1 day (depends on link length and noise)

Transfer: frequency shift

- Frequency shifts from laser and link locks



Frequency shifts are known and fixed

- Frequency received in the laboratory = frequency of the source + frequency shifts through transfer

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Transfer: linewidth

- **Laser linewidth at LNE-SYRTE :** around 1 Hz

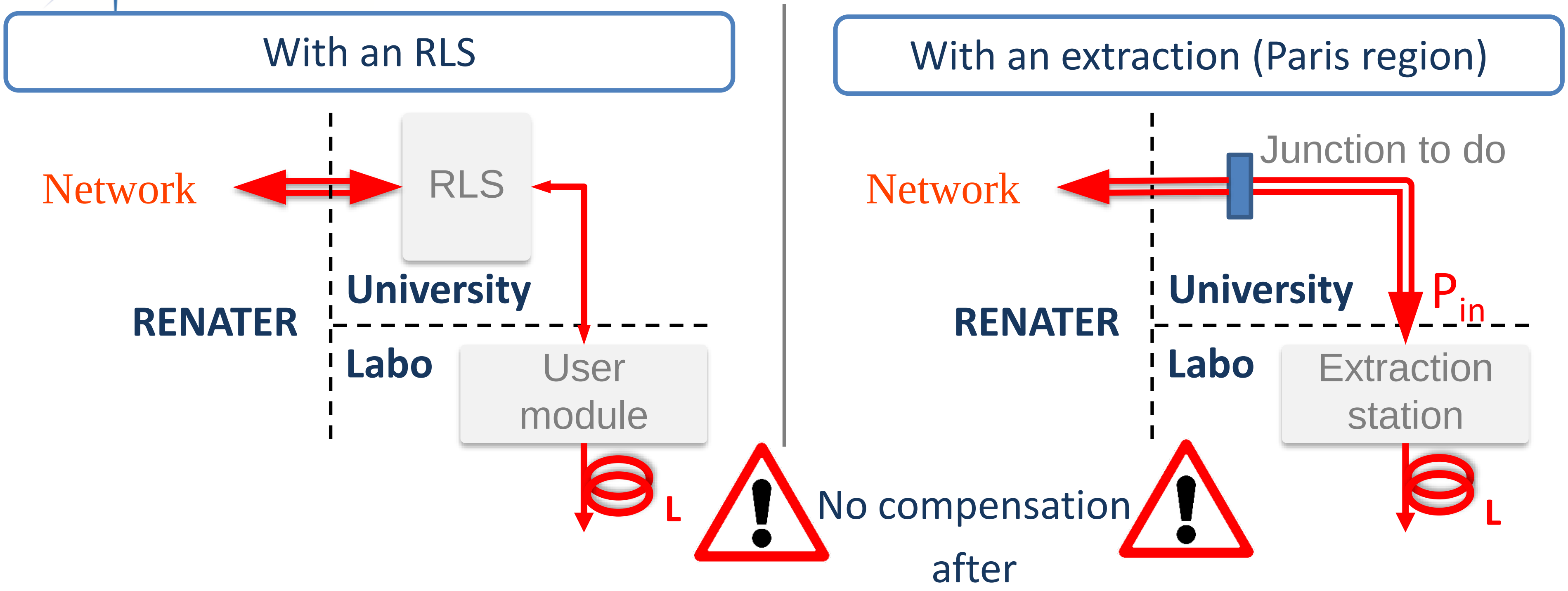
- **Phase noise accumulation during the transfer**
  - Rule by hand:

  Below 100 km of transfer: no effect

  Above 100 km of transfer: linewidth below (or well below) 10 kHz (@1s measurement time)

  - Depends of link length and noise

Arrival at the laboratory



- **Compensation of noise** up to the last equipment
- Performances of a non-compensated fiber: **below 10^{-15}** for **L** < 30m

See *Xu et al., Opt. Express 27, 36965-36975 (2019)*

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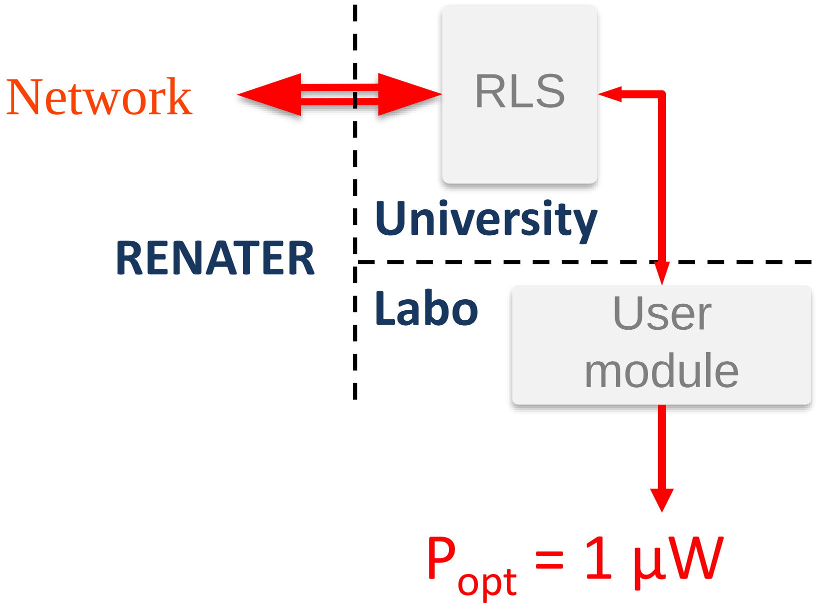
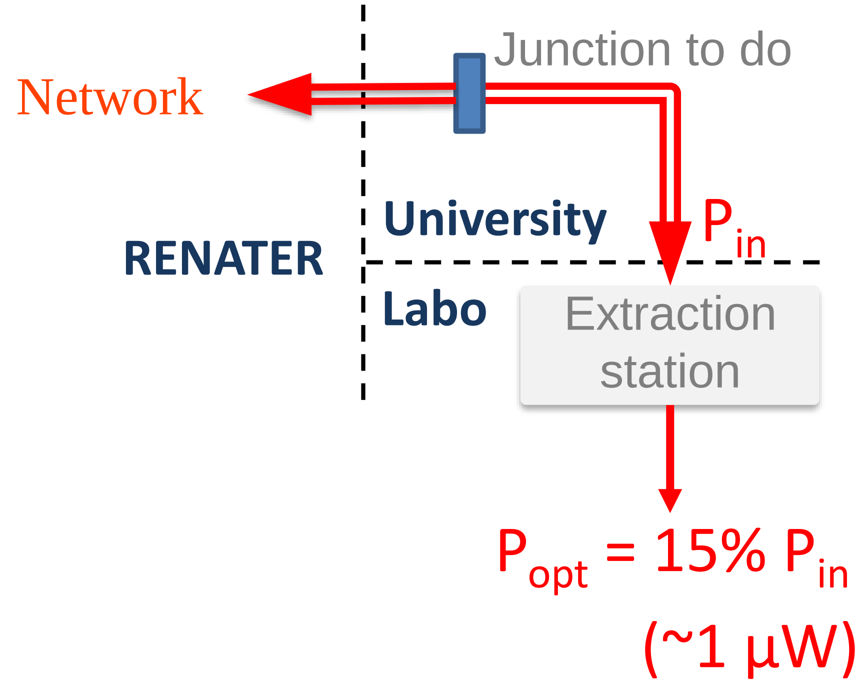
Arrival at the laboratory

With an RLS

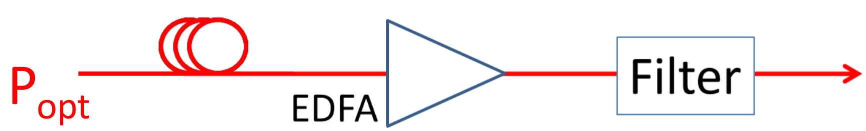


With an extraction (Paris region)



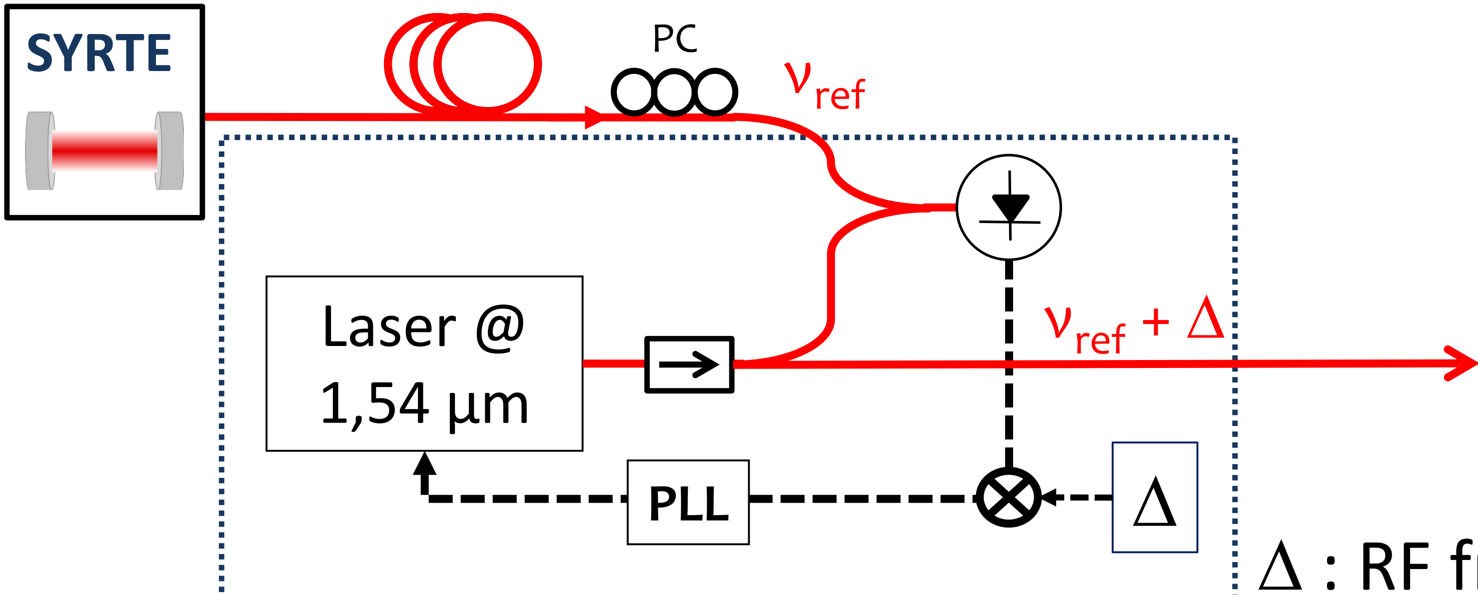
- Depending on applications, the signal should be **amplified**
- **Method # 1** : Erbium-doped fiber amplifier

  + DWDM filter (to eliminate the wideband ASE)



Amplification

- **Method #2** : optical tracking
  - Local laser phase-locked to the metrological signal
  - Local laser can be stabilized to an ultra-stable cavity



Δ : RF frequency

General comments:

1. Minimize the non-common optical paths to minimize non-common noises
2. RF can limit

See *Santagata et al., Optica 6, 411-423 (2019)*

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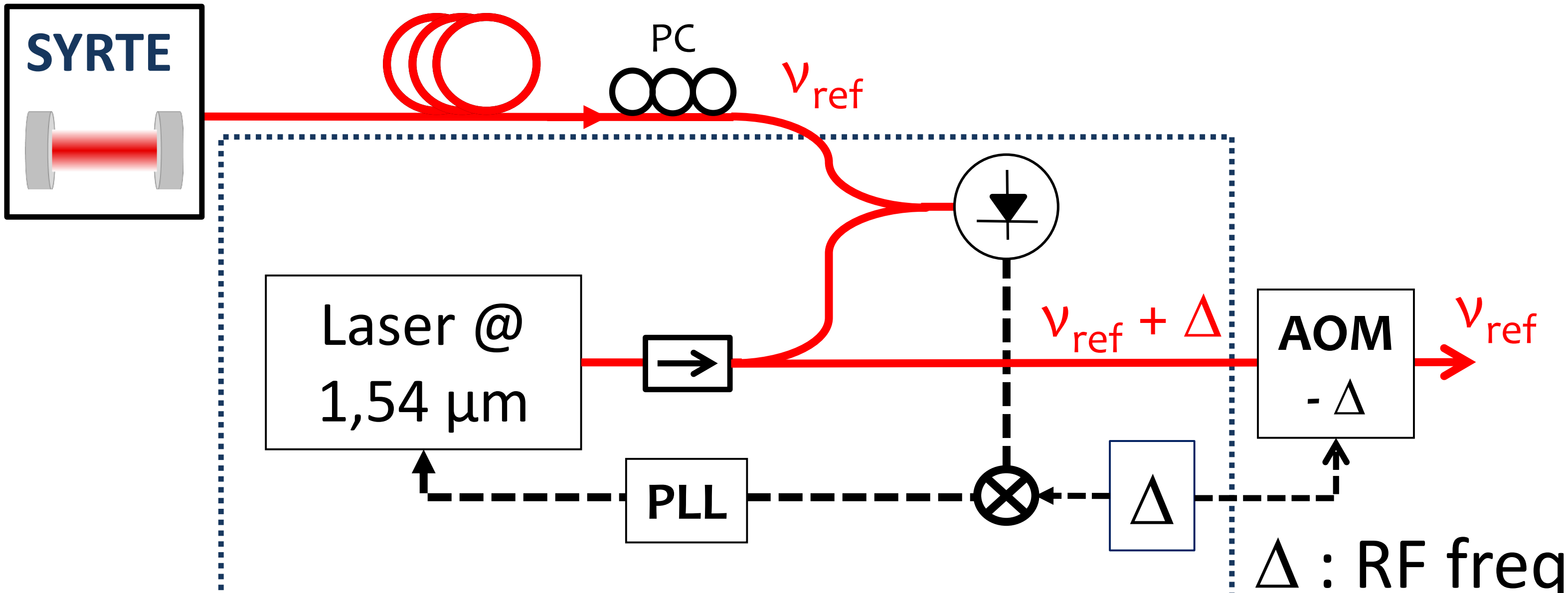

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Local RF frequency

1. RF can limit: choice of the RF oscillator

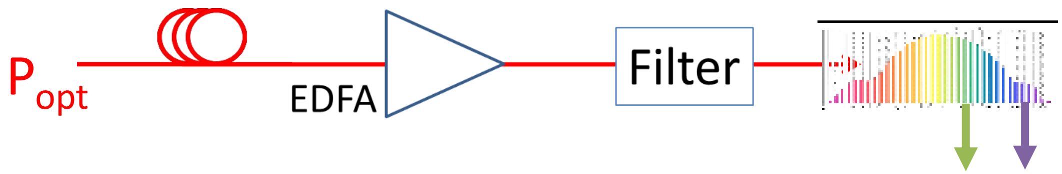
- **Usual RF frequency (from synthesizer)**
  - Accuracy = 10^{-6} → $\times \frac{100\ MHz}{200\ THz}$
  - If **Δ=100 MHz**, accuracy 100 Hz → 5×10^{-13} @ **200 THz**
- **GPS-disciplined low-noise RF oscillator**
  - Accuracy < 10^{-11} → $\times \frac{10\ MHz}{200\ THz}$
  - If **Δ=10 MHz**, accuracy 10^{-4} Hz → < 5×10^{-19} @ **200 THz**

✓ Ratio between Δ and 200 THz release the specifications

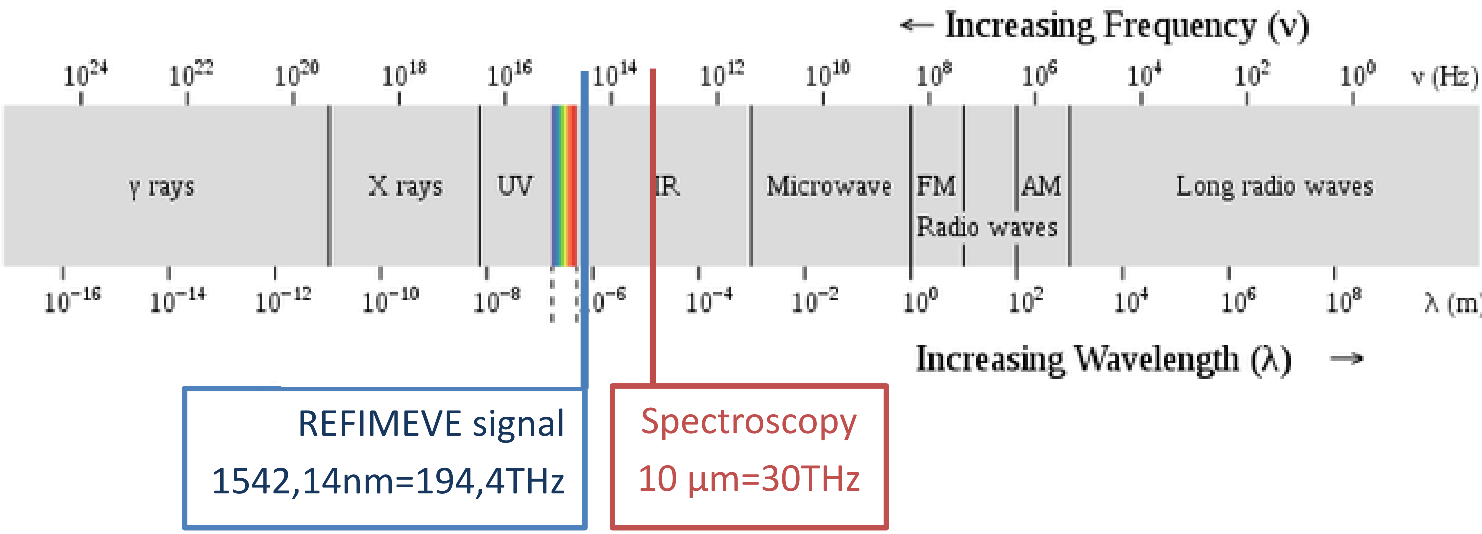
✓ Minimize Δ: as we do for clock comparison

See *Lodewyck et al., PRR 2, 043269 (2020)*

Performance of the spectral transfer



- **Performances translated to different wavelength**

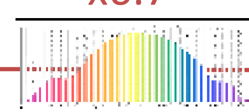


Performances if <u>coherent transfer</u>

Stability @1s for example

10^{-15} @ 1542,14nm

x6.7



10^{-15} @ 10 µm

Pratical use in the lab

- **User interface** (under development)
  - **Frequency** of the delivered signal (including the shifts)
  - **Source and link availability** (“weather map”)

- **Transfer of the stability performance to another frequency**
  - With a frequency **comb**: from UV to MIR (10 µm) and RF
  - With a **transfer cavity** (limited range and performance)

- **Frequency measurements**
  - **Accuracy = quadratic sum of the source accuracy** (+link accuracy) + **<u>local accuracy</u>** (contribution from comb, local RF…)

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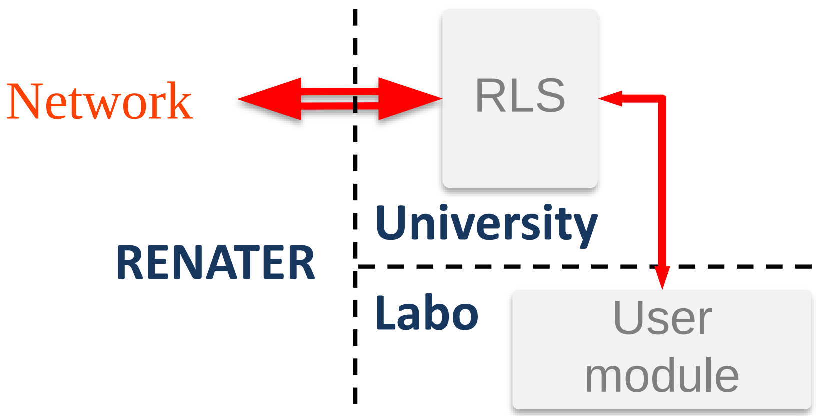
Arrival at the laboratory

With an RLS



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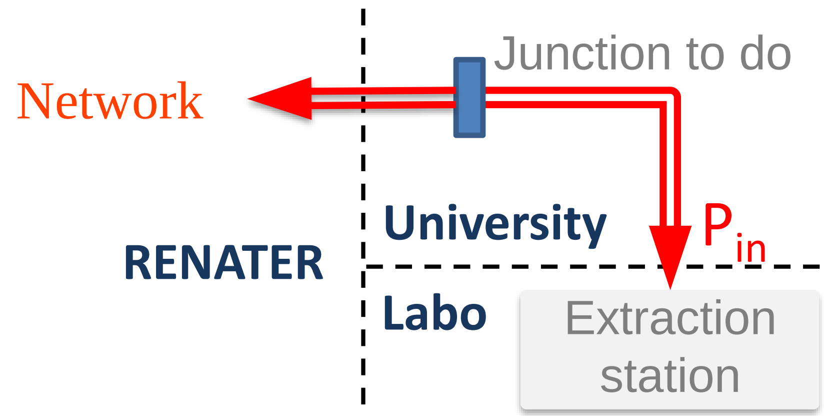

1. Stations and module **supplied by REFIMEVE**

2. **Rack needed to store** this equipment:
   - Station in DSI room
   - Module or station in your lab

   Most of the information services (DSI) are contacted already

3. **Check fiber availability** in your university: **1 or 2 singlemode fibers** with
   - connections in both side with FC/APC connectors
   - dedicated to the project
   - the less intermediate connections possible

   Preferably but non necessary

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Conclusion

- **Please contact** your information services of university (DSI)

- **Signal you receive**
  - Laser stable and accurate (transfer don't degrade) with known frequency around 1542.14nm
  - Signal with power of 1µW and linewidth from 1Hz to 10kHz (depending on links)

- **Use of the signal**
  - Amplification and spectral transfer (recommendations on RF, optical paths…)
  - User interface to help (under development)