Frequency transfer with optical fiber links

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CCTF Technical exchange, Feb. 23rd, 2026

1. **Motivation**
2. **Concept**
3. **Making *long* optical links**
4. **Comparing clocks using fibers**

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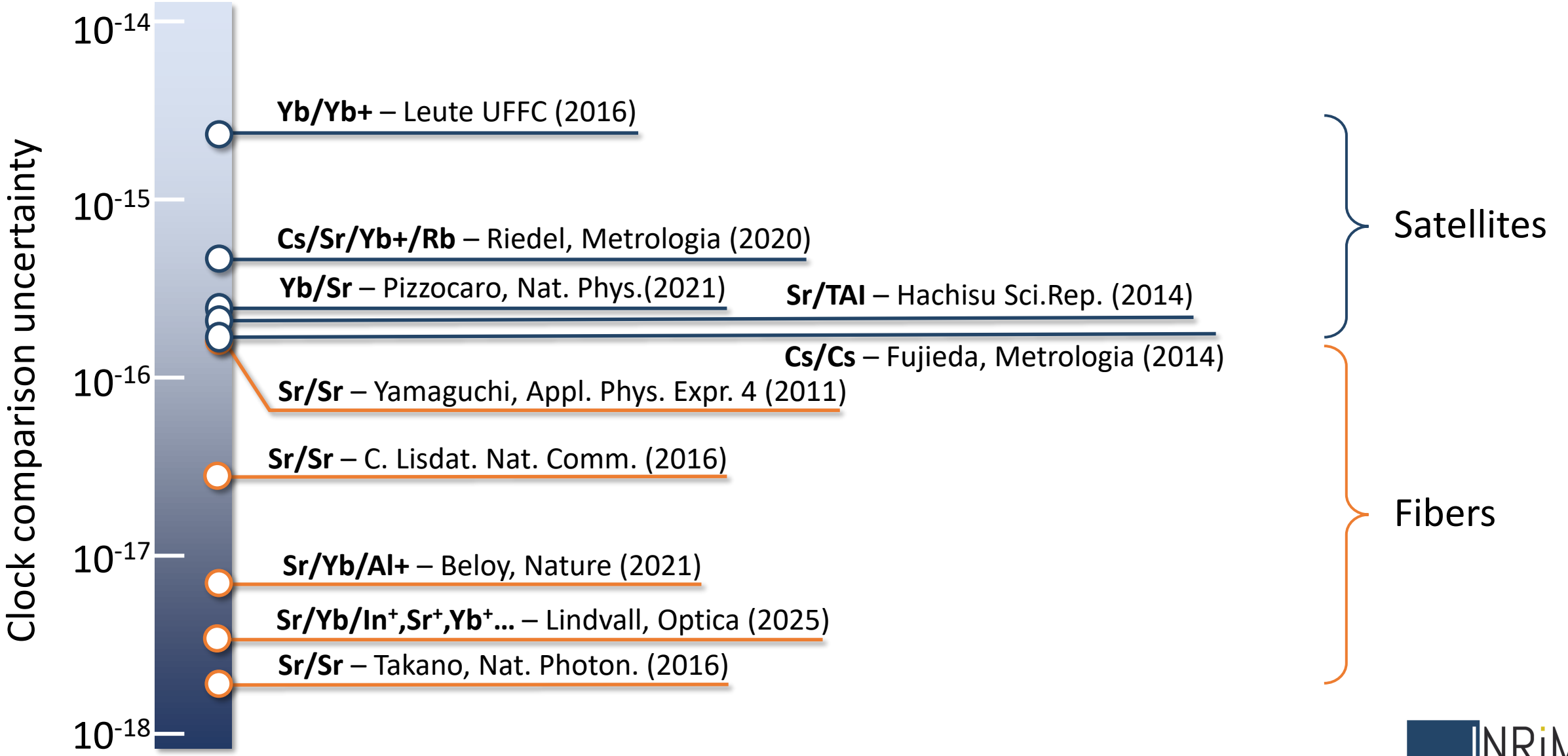
Fibers vs satellite atomic clock comparison



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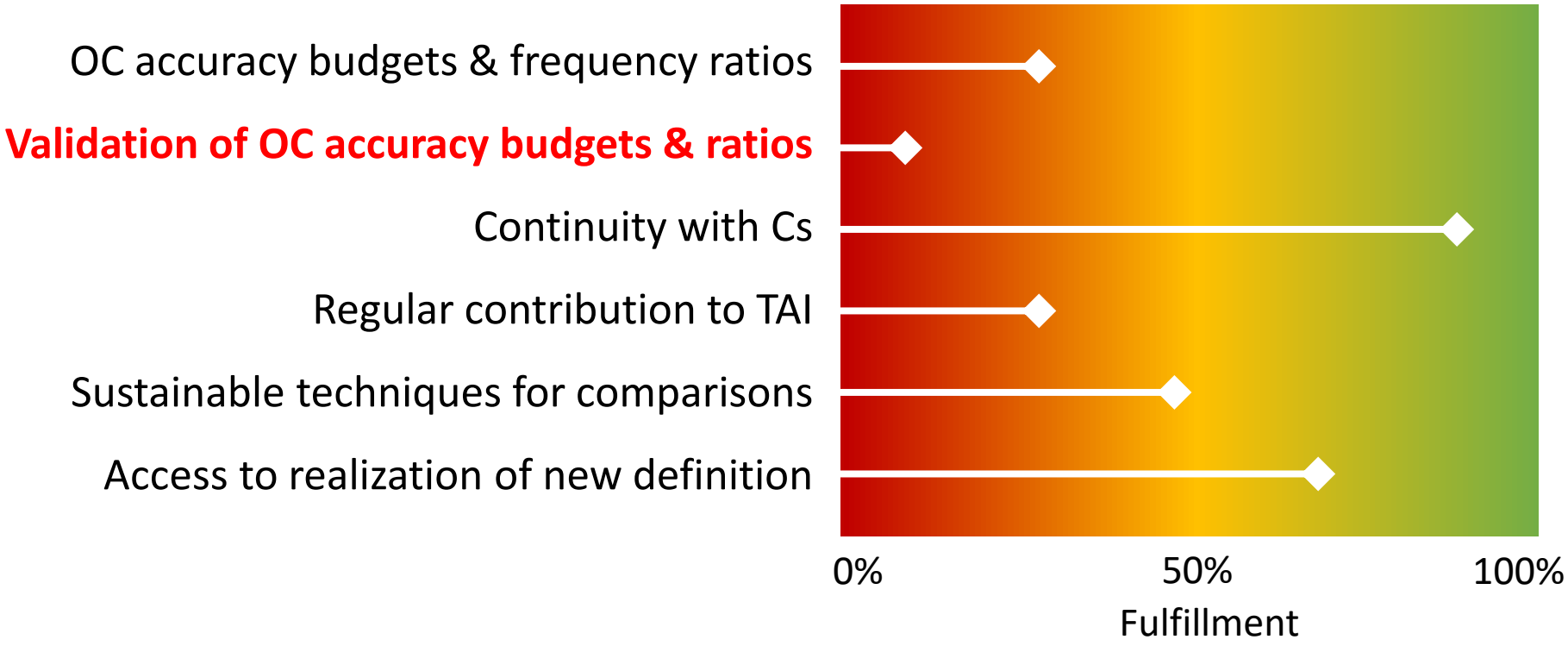
Fibers and the redefinition of the Second



N. Dimarcq et al., Metrologia 61, 012001 (2024)

Fibers and the redefinition of the Second

OC accuracy budgets & frequency ratios

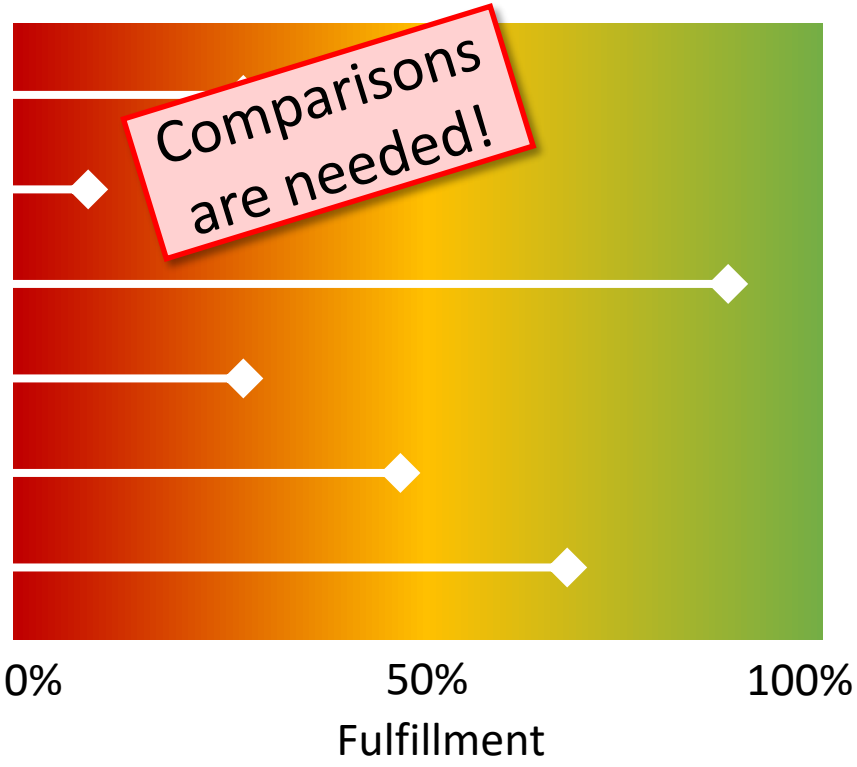
Validation of OC accuracy budgets & ratios

Continuity with Cs

Regular contribution to TAI

Sustainable techniques for comparisons

Access to realization of new definition



N. Dimarcq et al., Metrologia 61, 012001 (2024)

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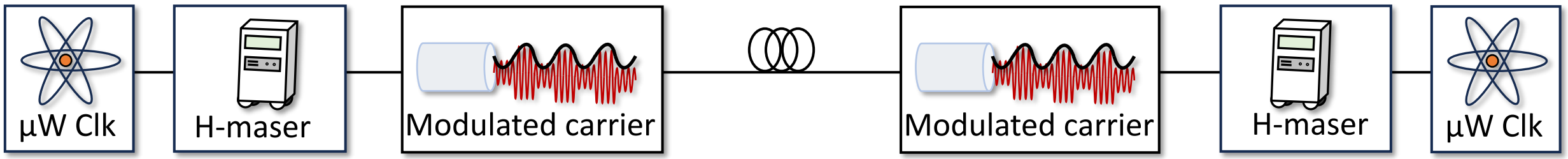
Comparing distant optical clocks



O. Lopez et al Applied Physics B 98, 723 (2010)

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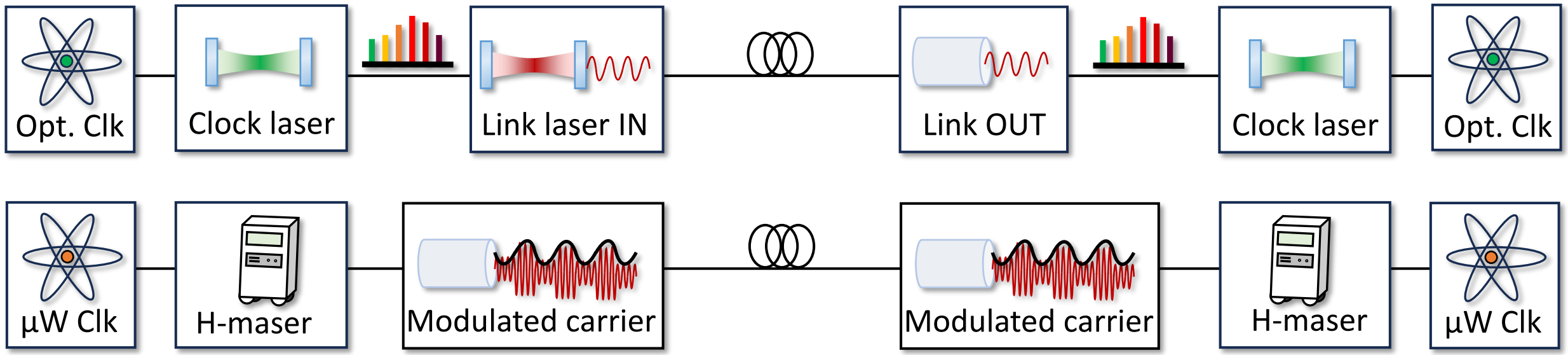

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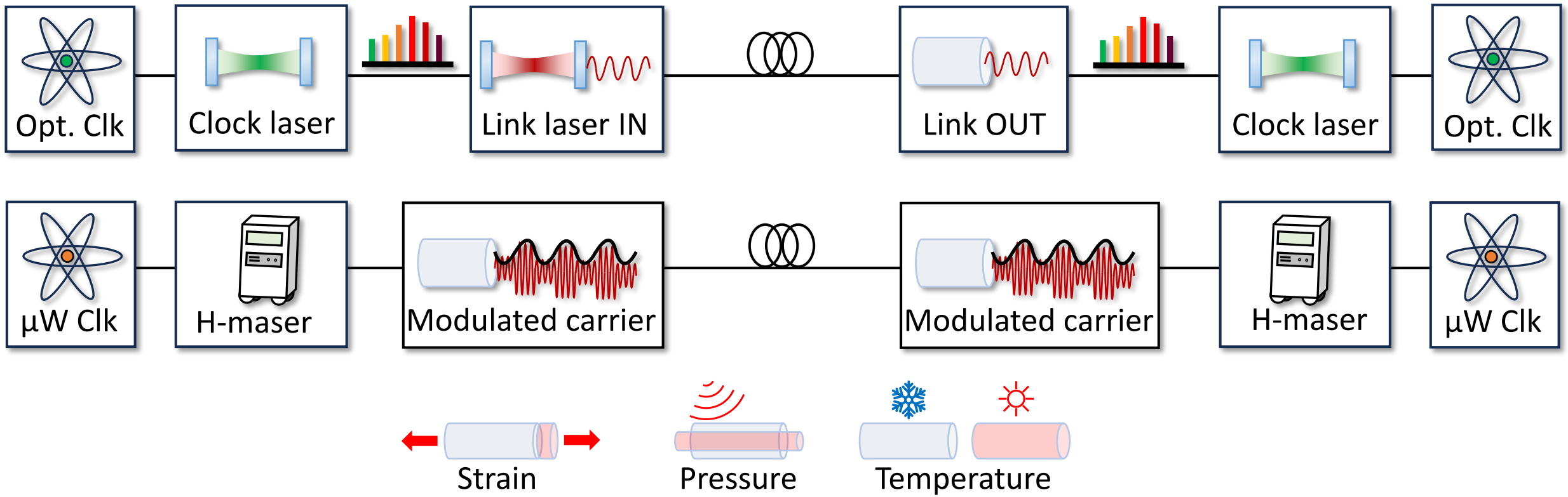

$$\varphi(t) = 2\pi\nu_0 t + \varphi_0$$

$$\varphi_{\text{out}}(t) = 2\pi\nu_0 t + \varphi_0 + 2\pi\nu_0 \frac{nL}{c}$$

$$\nu(t) = \frac{1}{2\pi}\frac{d\varphi(t)}{dt} = \nu_0$$

$$\nu(t) = \frac{1}{2\pi}\frac{d\varphi(t)}{dt} = \nu_0 + \delta\nu$$

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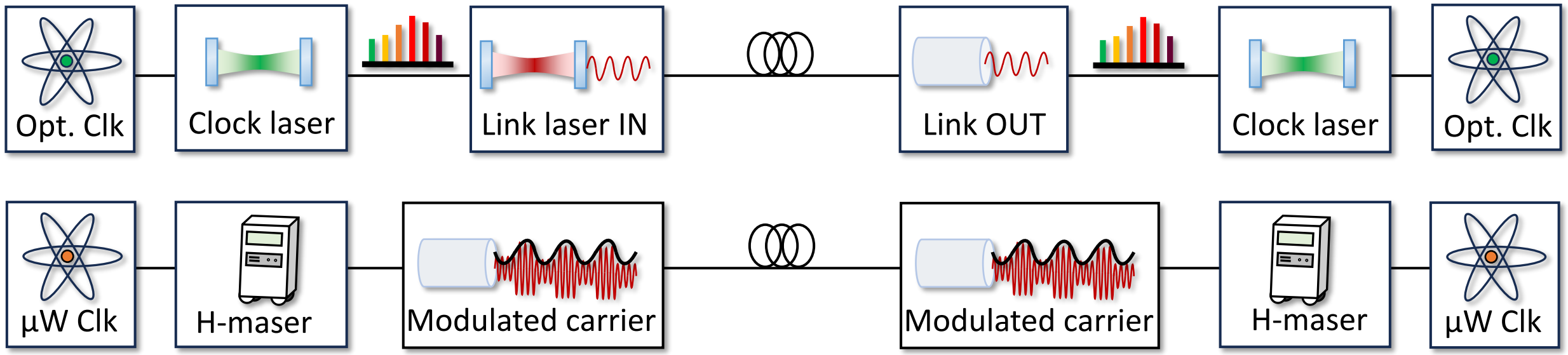

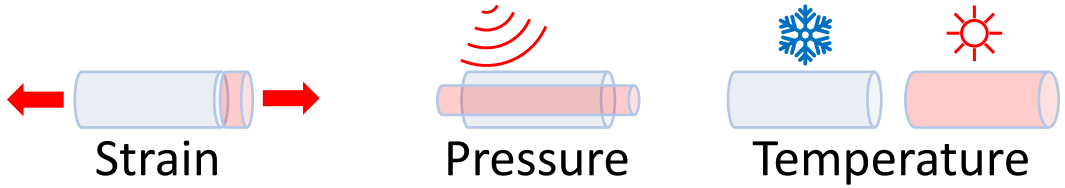

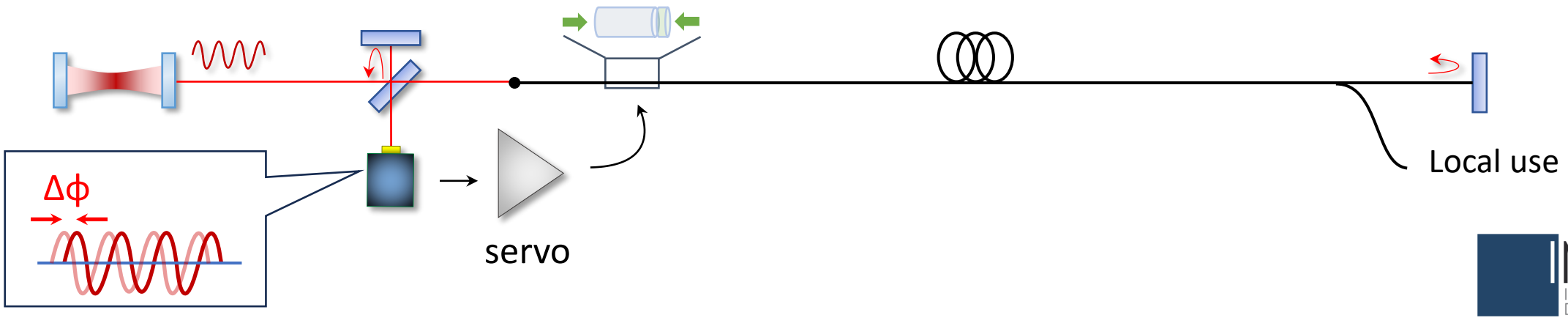

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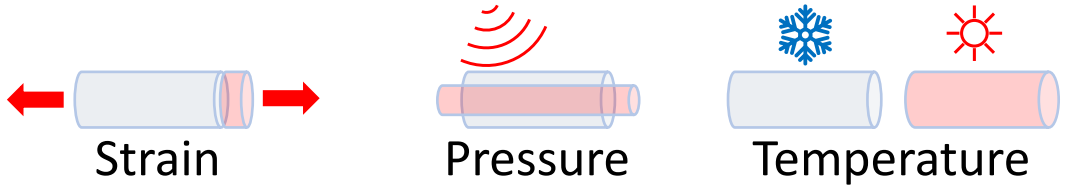
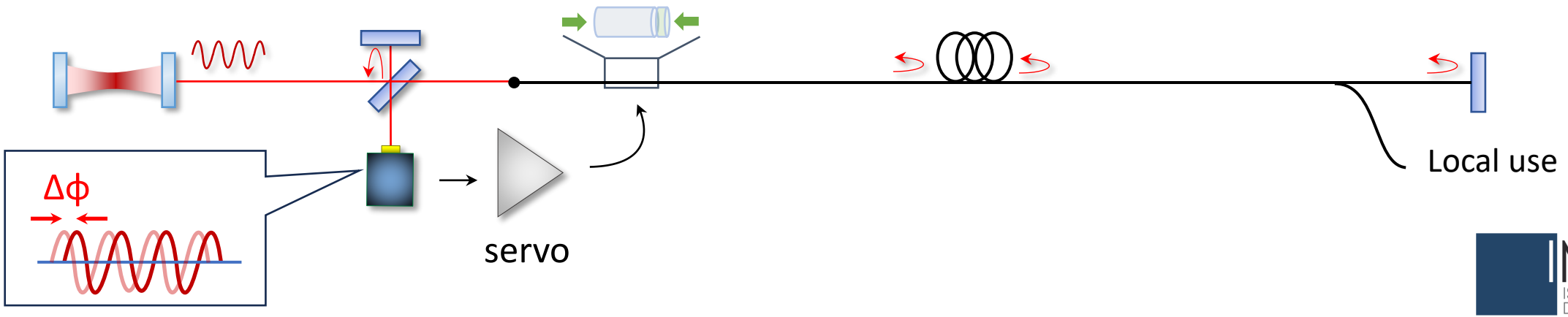
Comparing distant optical clocks

Important notes:

1. Optical phase has ambiguities (λ=1550 nm): we **can transfer frequency, not time** (i.e. phase variations, not *absolute* phase)





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Important notes:

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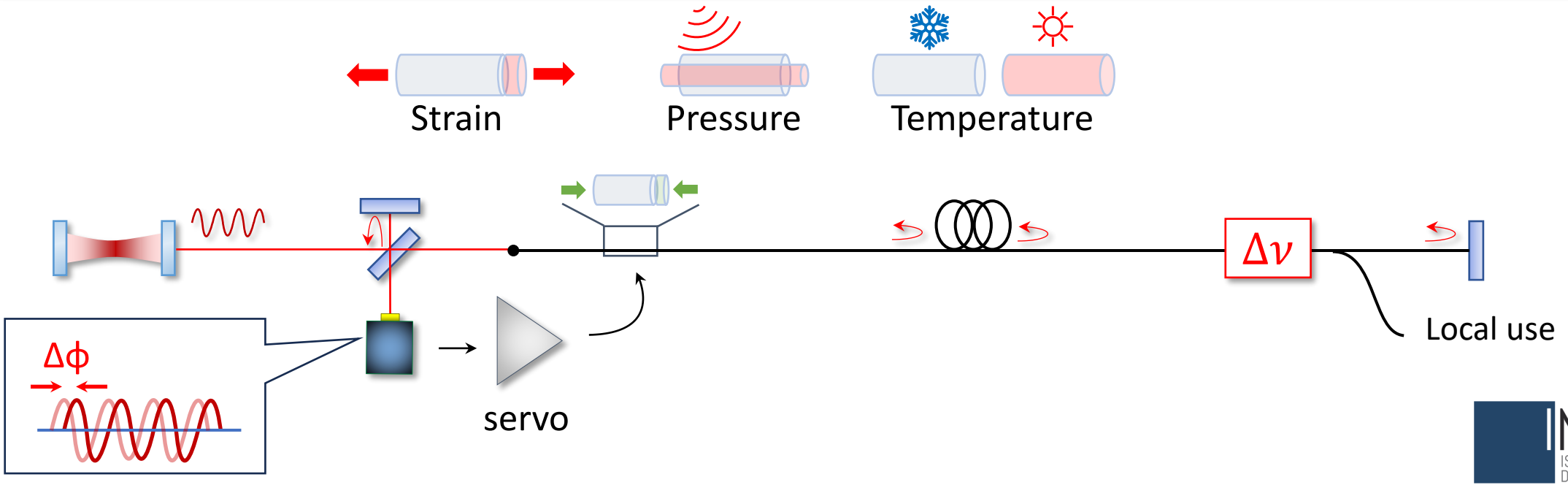
2. Bidirectional vs unidirectional fiber? Unidirectional not better than 10^{-16}



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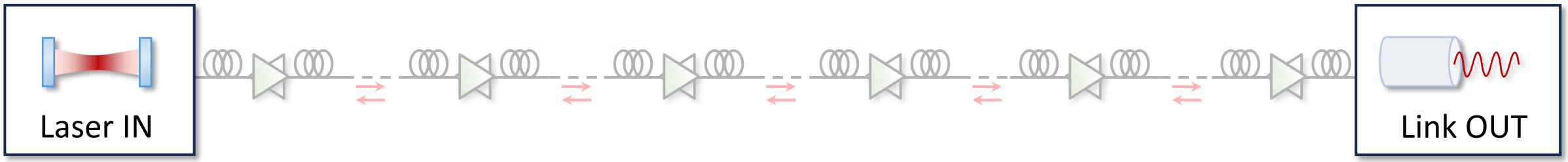
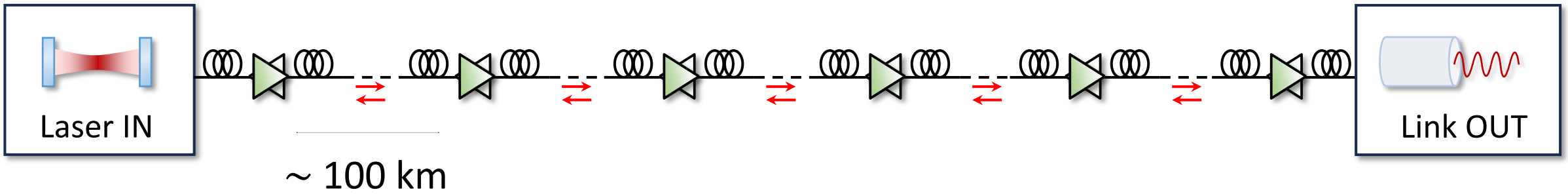
Long optical links: validation

- Laser source: high coherence length (**narrow linewidth**)

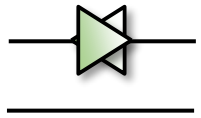


Long optical links: validation

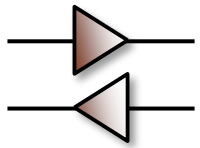
- Laser source: high coherence length (**narrow linewidth**)
- Bypass unidirectional equipment (= use dedicated **bidirectional optical amplifiers**)



Links for optical frequency metrology:



Links for telecommunications:



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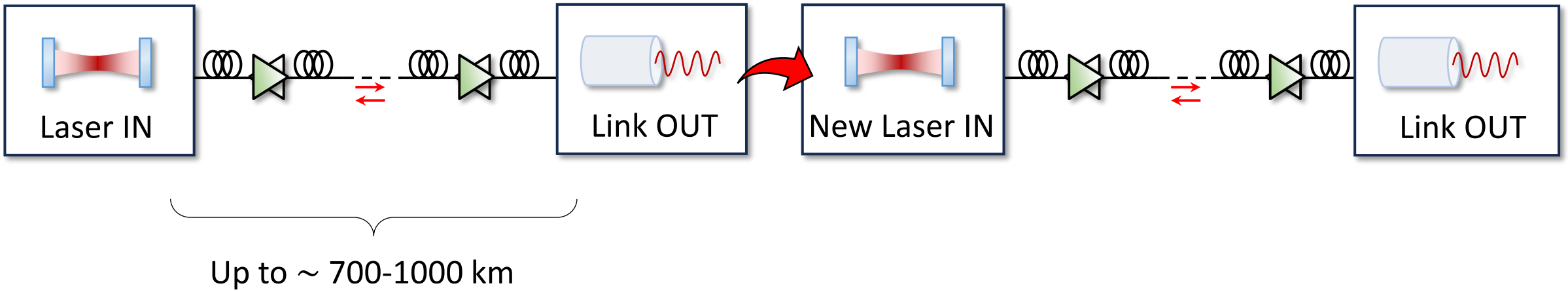
- **Optical signal regeneration** (Repeater Laser Stations)



N. Chiodo et al.,Opt. Expr. **23**, 33927 (2015)
F. Guillou-Camargo, Appl. Opt. **57**, 7203 (2018)
T. Akatsuka et al. ,Opt. Exp. **20**, 9186 (2020)

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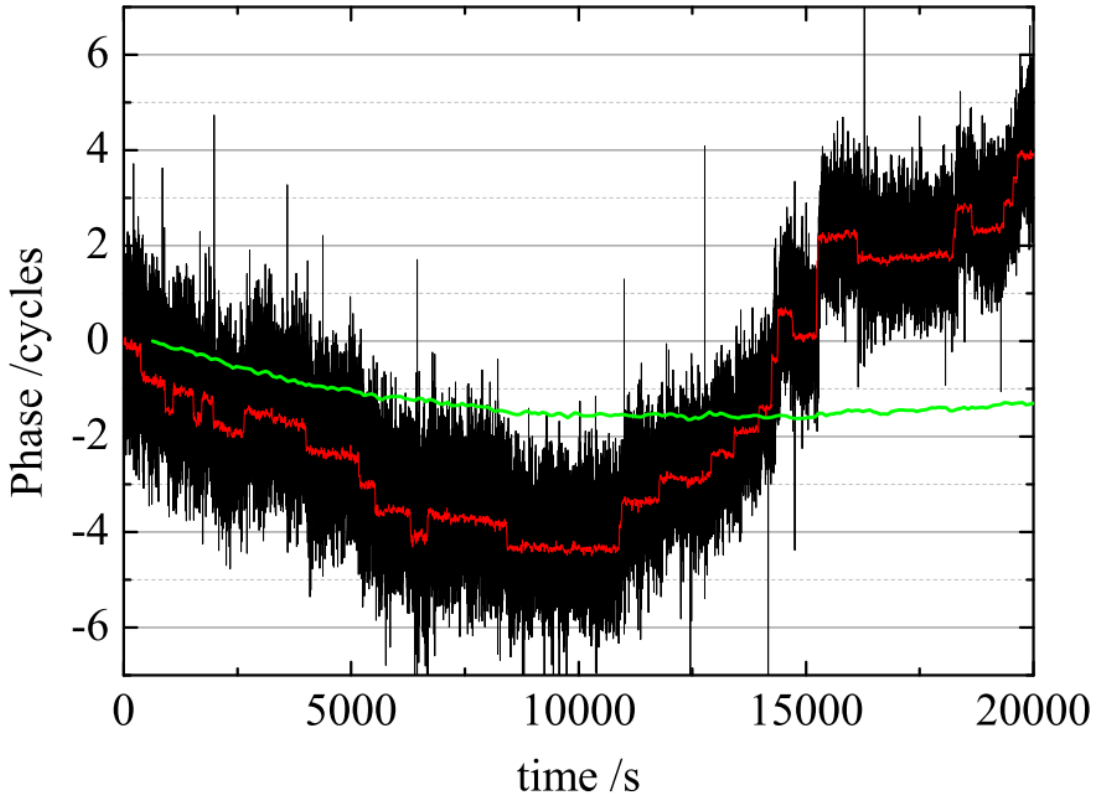

1 cycle lost in 1000 s → 1 mHz or $5 \cdot 10^{-18}$ bias

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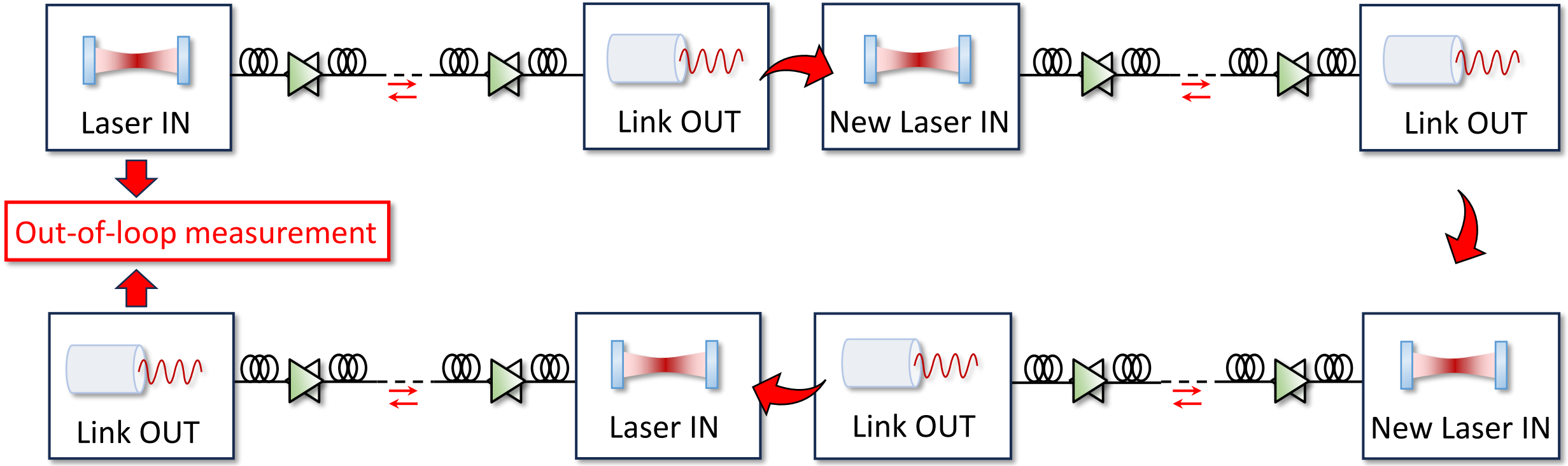
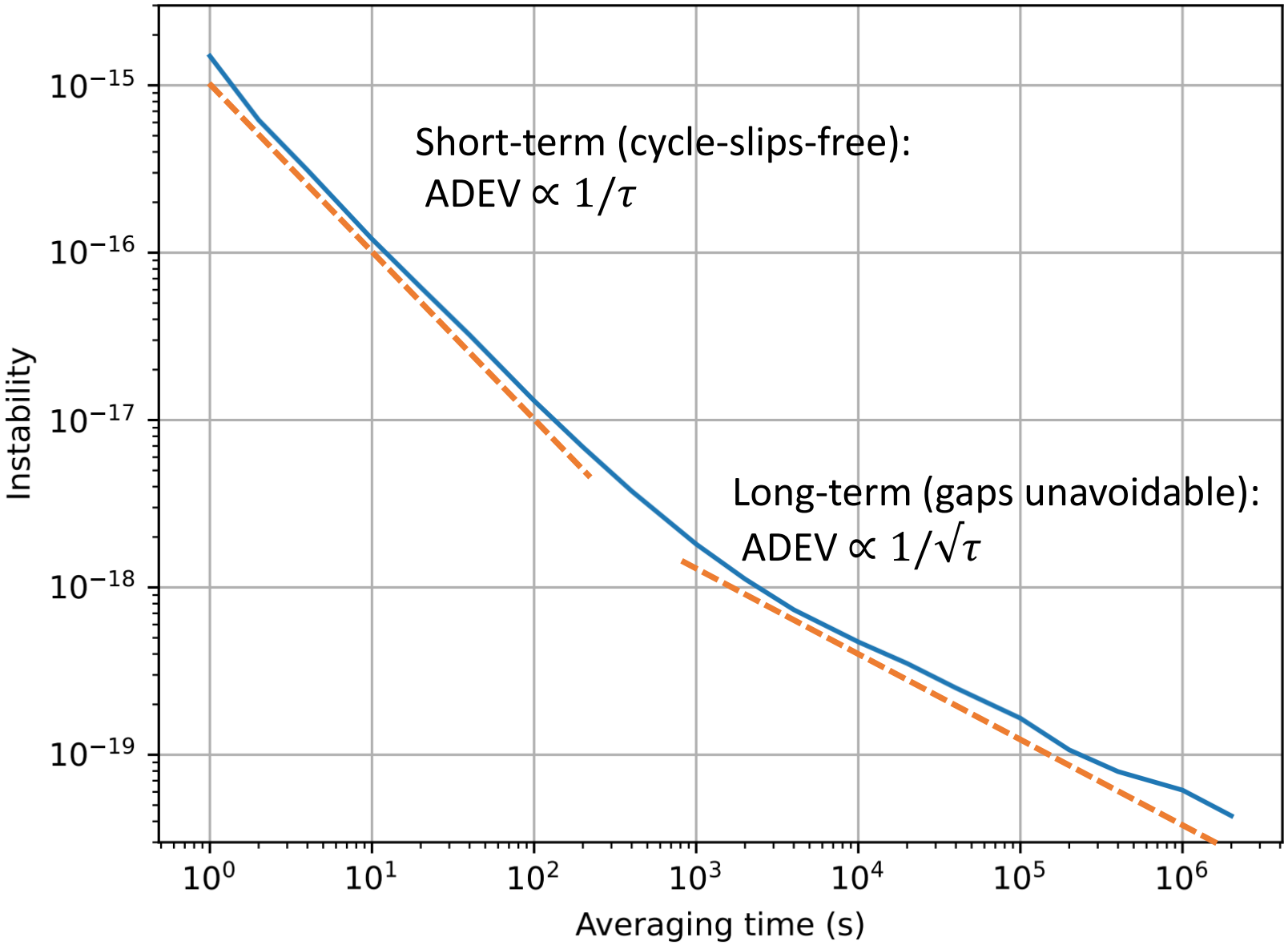


Typical performances



C. Clivati et al.,
Phys. Rev. Applied 18, 054009 (2022)

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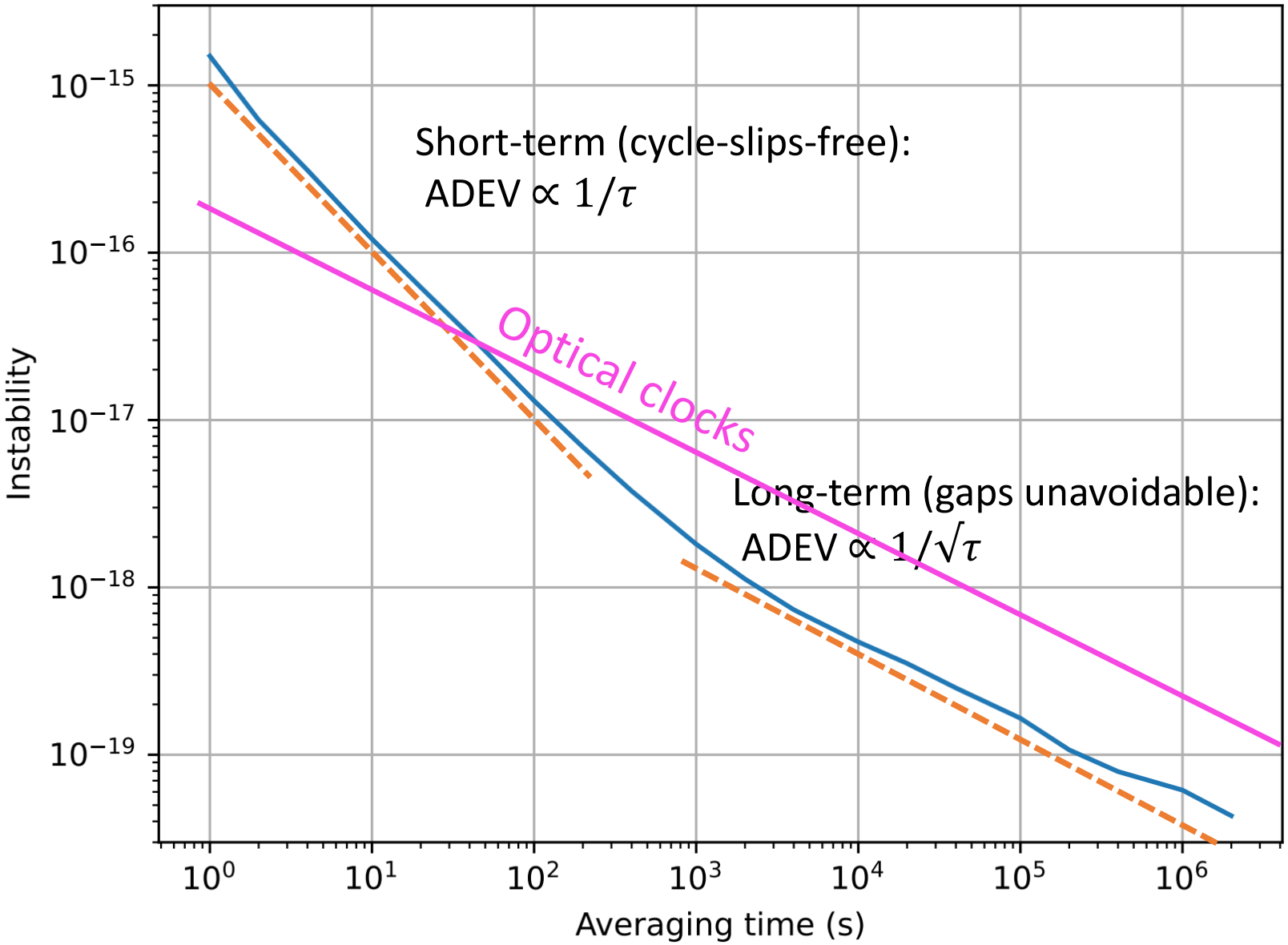

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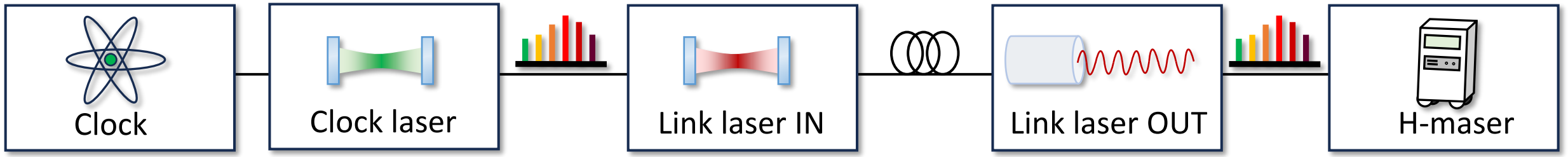

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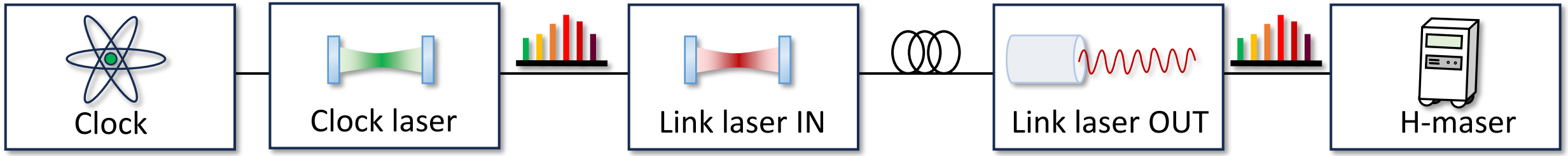
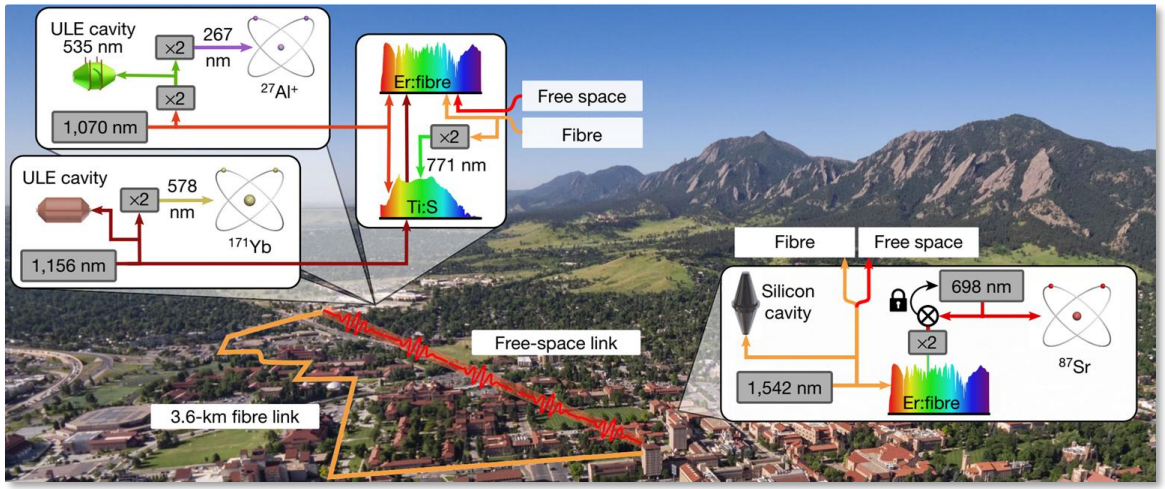
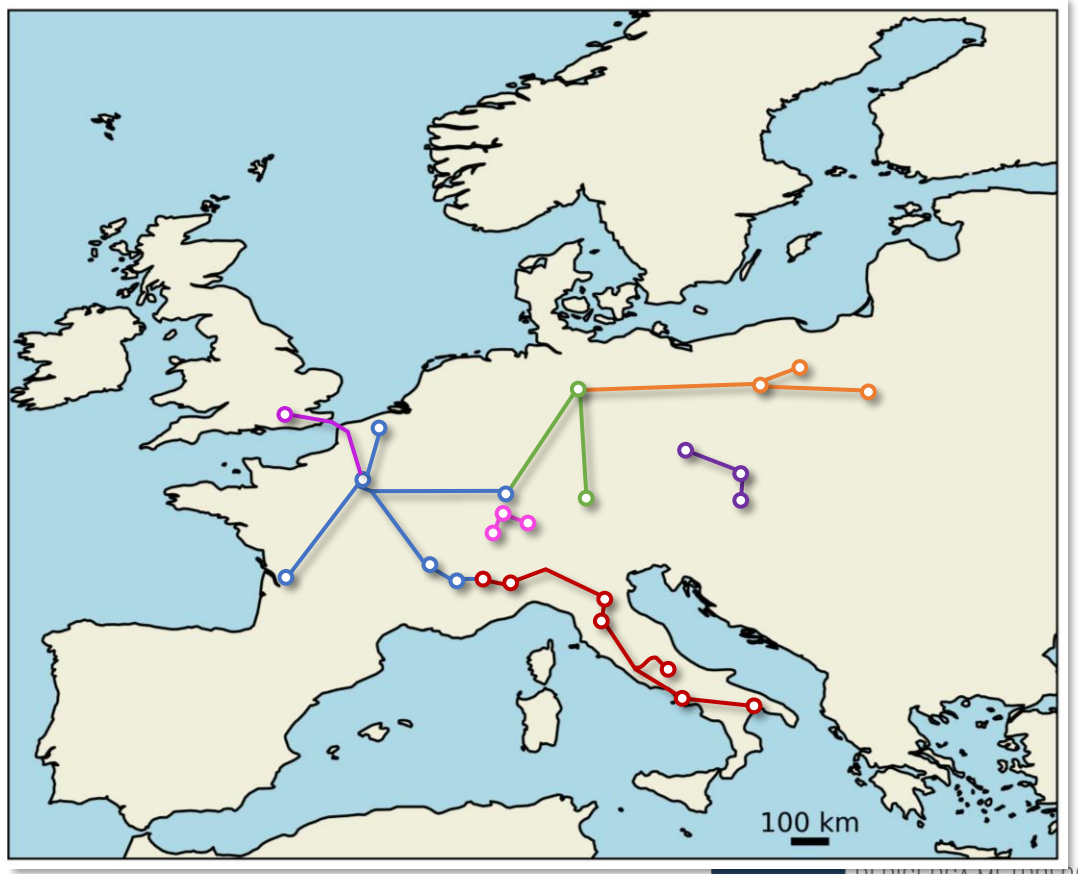


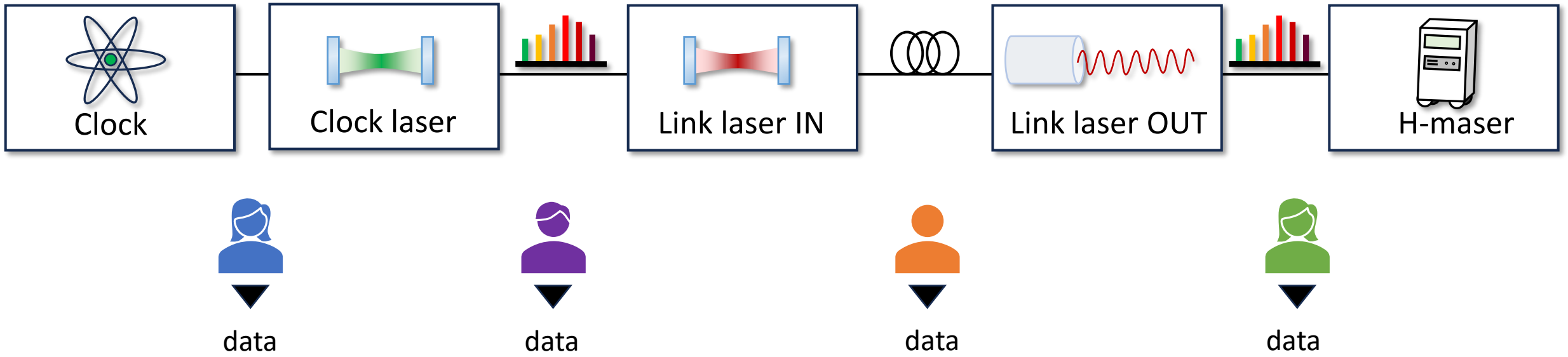


3 optical clocks
[Boulder Atomic Clock Network *Nature* **591**, (2021)]



4/5 metrology institutes,
>11 optical clocks
[Lindvall, Optica 12 (2025)]

Building a protocol



- Many different teams & type of data
- Universal formalism for combining data
  [Lodewyck, PR Research (2020), code: github.com/INRIM/optical-link-data-format]

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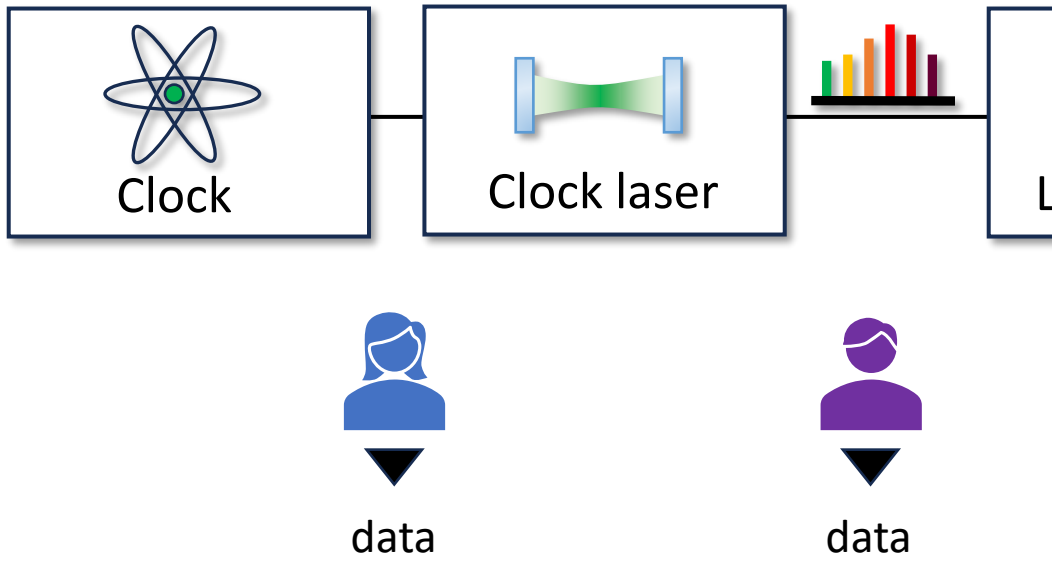

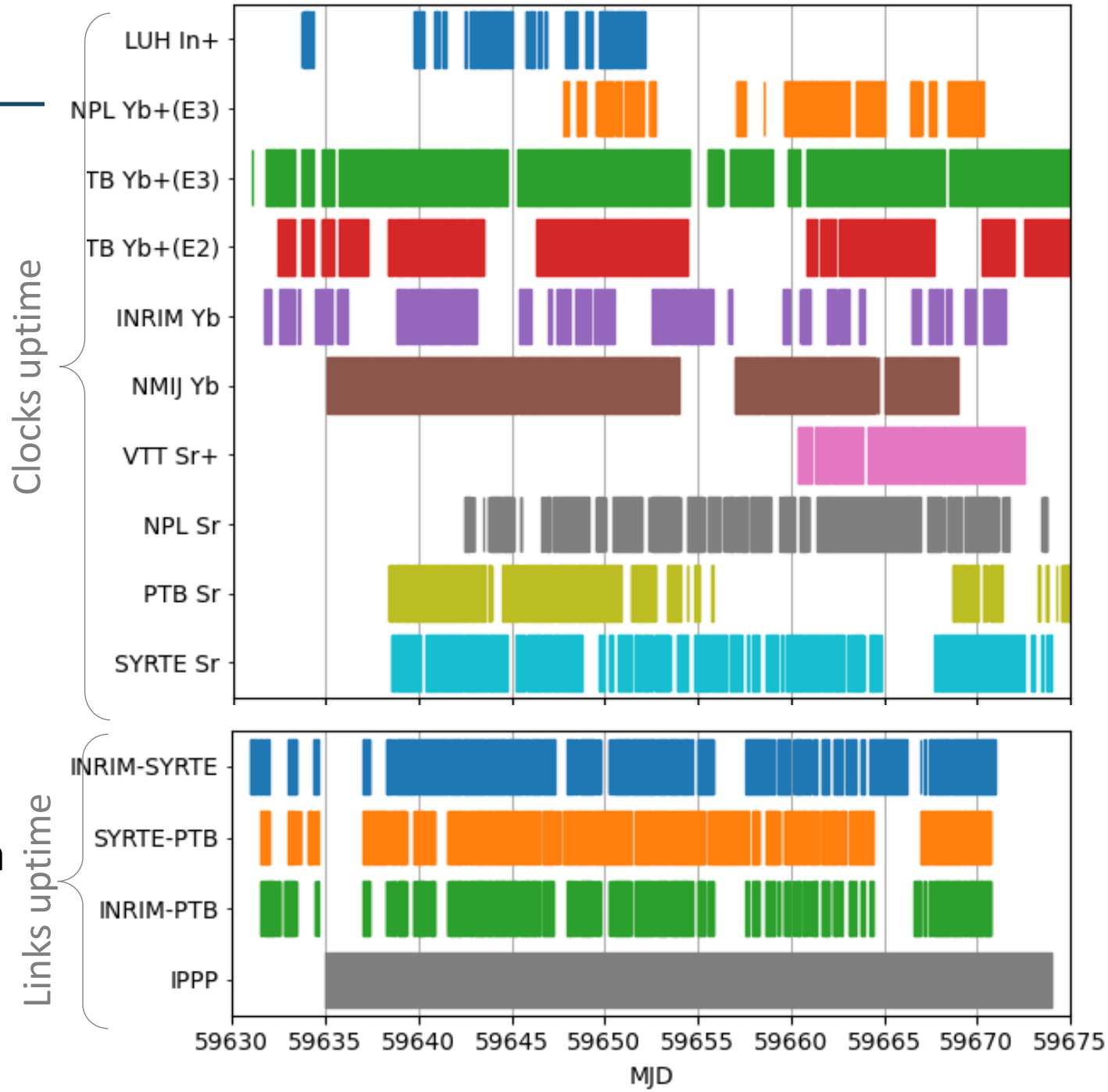

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- Still room for uptime improvement

Summary of 2022 campaign

No.	Value of frequency ratio	Fractional uncertainty	Link	Clock 1	Clock 2
1	1.973 773 591 557 215 789(10)	5.0×10^{-18}	Fibre	LUH In+	PTB Yb+(E3)
2	2.445 326 324 126 950 199(59)	2.4×10^{-17}	Fibre	LUH In+	INRIM Yb
3	2.952 748 749 874 860 909(16)	5.3×10^{-18}	Fibre	LUH In+	PTB Sr
4	2.952 748 749 874 861 331(71)	2.4×10^{-17}	Fibre	LUH In+	SYRTE Sr
5	1.072 007 373 634 205 468(29)	2.7×10^{-17}	Local	PTB Yb+(E2)	PTB Yb+(E3)
6	1.238 909 231 832 259 569(26)	2.1×10^{-17}	Fibre	PTB Yb+(E3)	INRIM Yb
7	1.495 991 618 544 900 525(36)	2.4×10^{-17}	Fibre	NPL Yb+(E3)	NPL Sr
8	1.495 991 618 544 900 659(8)	5.6×10^{-18}	Fibre	PTB Yb+(E3)	PTB Sr
9	1.495 991 618 544 900 897(32)	2.1×10^{-17}	Fibre	PTB Yb+(E3)	SYRTE Sr
10	1.207 507 039 343 337 793(27)	2.2×10^{-17}	Fibre	INRIM Yb	PTB Sr
11	1.207 507 039 343 337 981(36)	3.0×10^{-17}	Fibre	INRIM Yb	SYRTE Sr
12	1.000 000 000 000 000 146(21)	2.1×10^{-17}	Fibre	PTB Sr	SYRTE Sr

Lindvall, Optica 12, 843 (2025)

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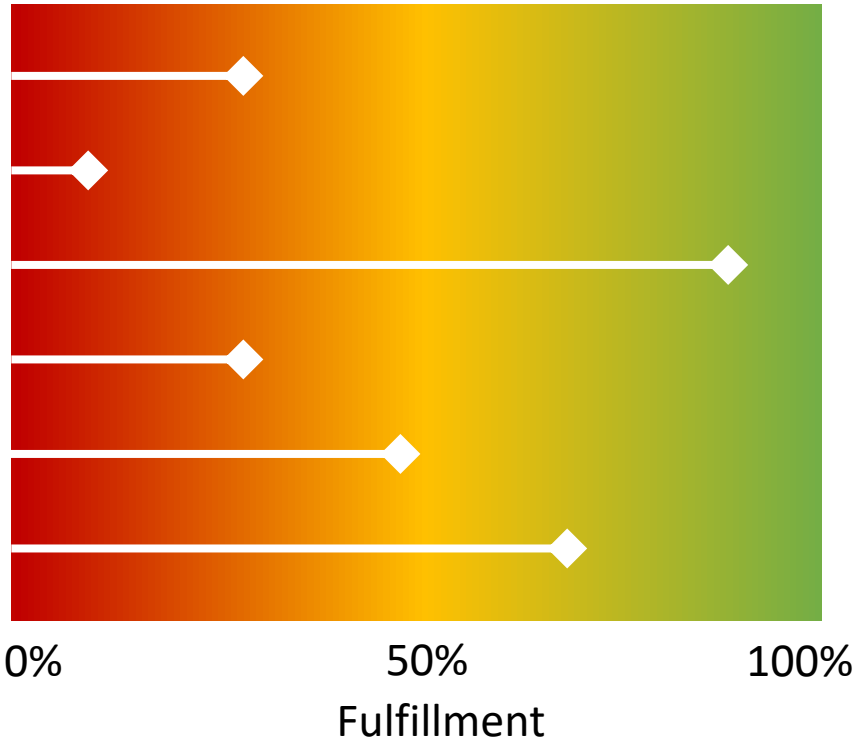

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Acknowledgments

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Thank you for your attention!