Bedrijfspresentatie VSL

Walter Knulst

3-6-2025

BigScience.nl Businessmiddag

VSL
National Metrology Institute

BIG FOR BUSINESS science.nl

Wereldwijd

Het succes van
het SI

National
Metrology
Institute

VSL

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Van constante waarde

CELEBRATING BIPM 150
1875 - 2025

- 1799: Presentatie van de eerste meter en kilogram
- 1870: Groeiende twijfel aan de stabiliteit; Napoleon III roept conferentie bijeen in Parijs
- 1870: Uitbraak van de Frans-Duitse oorlog
- **1875: Ondertekening van de Meterconventie**
- 1889: Nieuwe artefacten voor de meter en de kilogram
- 1921: Uitbreiding tot Système International (SI)
- 2019: Herdefinitie van het SI op basis van natuurconstantes

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Metrologie als ankerpunt

Système International

- 7 SI-basiseenheden
- Gedefinieerd door natuurconstantes
- Afgeleide eenheden voor alle fysische en chemische grootheden

Meterconventie

- Sinds 1875
- 64 lidstaten
- 36 associates

CIPM Mutual Recognition Arrangement

- 100 NMI’s
- ESA, IAEA, JRC, WMO
- 150 DI’s
- 1867 geregistreerde comparisons
- 25909 CMC’s

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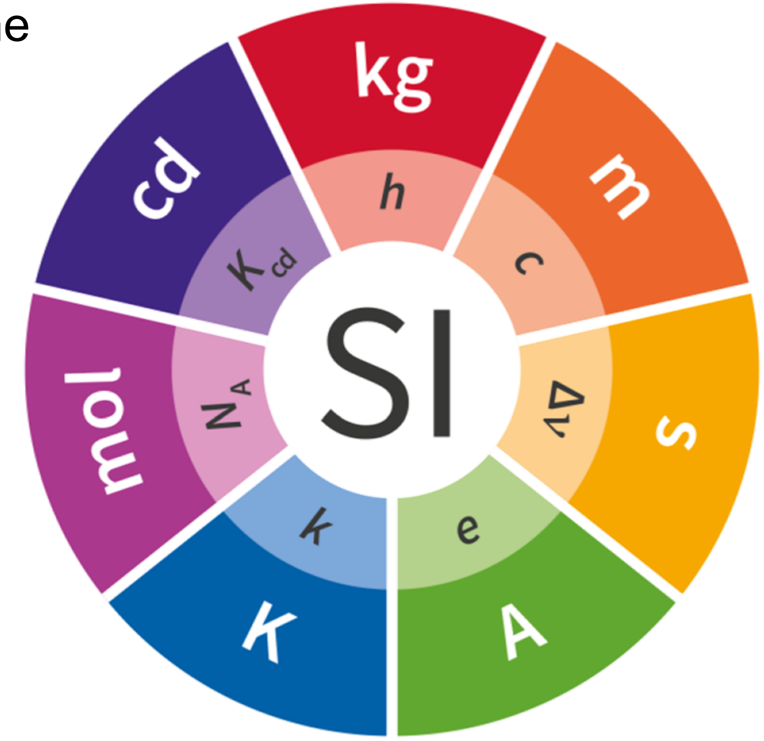
The final revision of the SI

The BIPM Member States voted on 16 November 2018 at the 26th meeting of the General Conference on Weights and Measures (CGPM) in Versailles, France, to revise the International System of Units (SI):

- the unperturbed ground state hyperfine transition frequency of the caesium 133 atom $\Delta\nu_{cs}$ is 9 192 631 770 Hz,
- the speed of light in vacuum c is 299 792 458 m/s,
- the Planck constant h is 6.626 070 15 × 10^{-34} J s,
- the elementary charge e is 1.602 176 634 × 10^{-19} C,
- the Boltzmann constant k is 1.380 649 × 10^{-23} J/K,
- the Avogadro constant N_A is 6.022 140 76 × 10^{23} mol^{-1},
- the luminous efficacy of monochromatic radiation of frequency 540 × 10^{12} Hz, K_{cd}, is 683 lm/W



https://www.bipm.org/en/measurement-units/rev-si/

Nederland

Meetstandaarden en nationale infrastructuur

National Metrology Institute

VSL

World Class National Metrology Institute

Develop Advanced Measurement Science & Technology

Create world class measurement capabilities in strategic areas for The Netherlands

Develop new ways of realizing the SI units

Develop measurement solutions & technologies for industry and society

Establish Internationally Recognised Measurement Standards & Capabilities

Develop, establish & maintain high accurate national standards & certified reference materials traceable to the SI units

Develop & maintain internationally recognised calibration & measurement capabilities

Participate in internationally comparisons and represent The Netherlands in global and regional metrology fora

Supporting the National Quality Infrastructure

Provide calibration and measurement services and reference values

Participate in national standards & conformance activities

Provide measurement skills training, consultancy and proficiency testing

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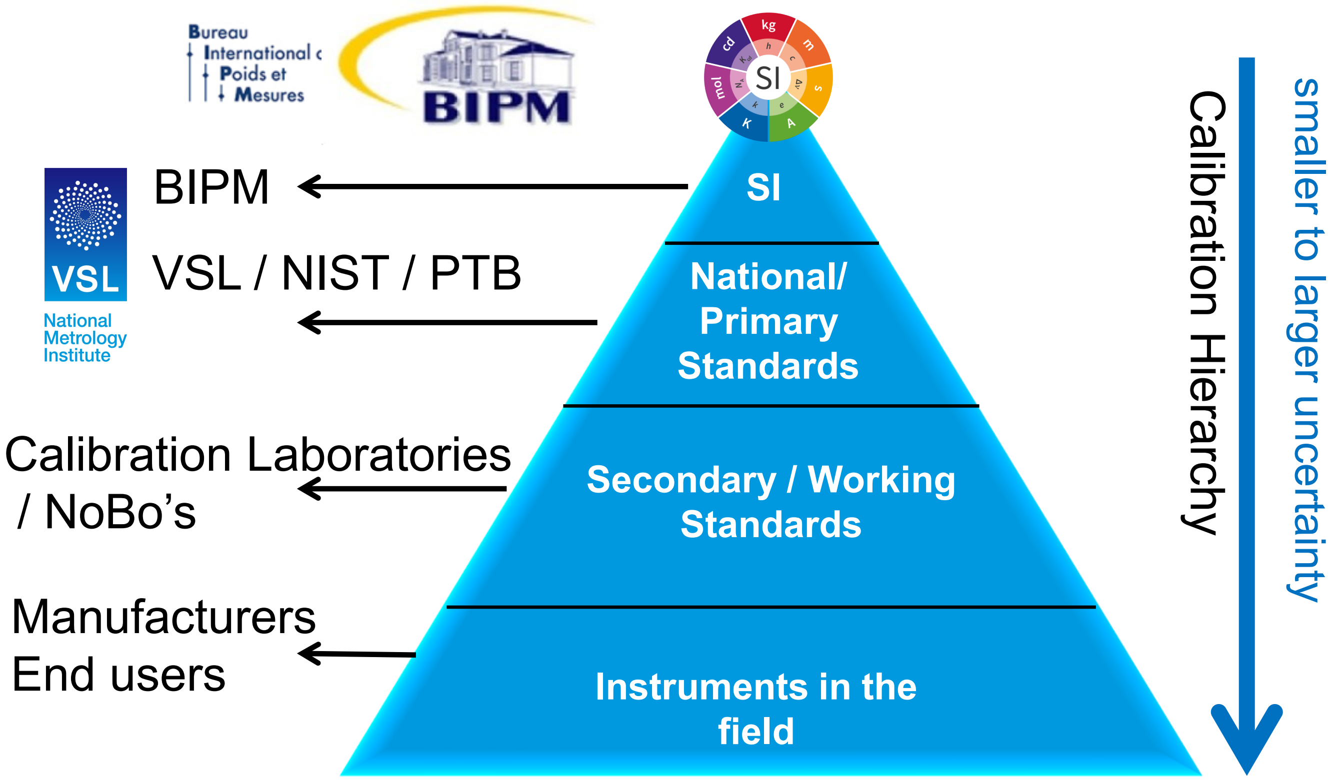
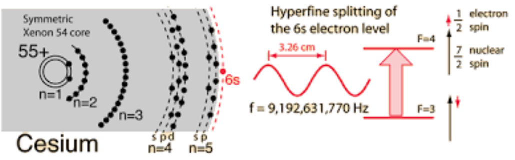
VSL – Traceable to SI standards

On top of the metrological pyramid

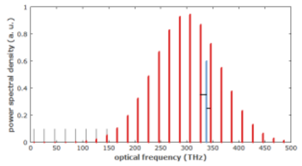


Calibration Hierarchy

Metrological traceability
requires an established calibration hierarchy



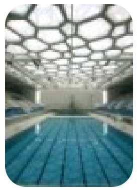
Clock (Time standard)



Frequency Comb

Laser interferometer

Coordinate Measurement Machine



Laser Distance Meter

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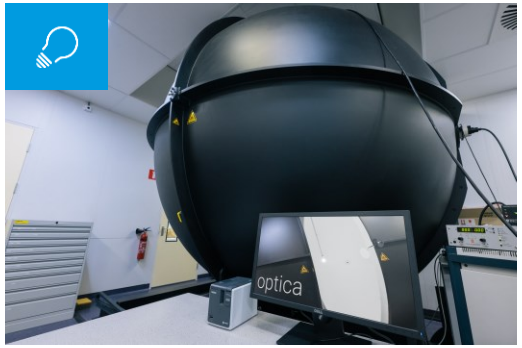
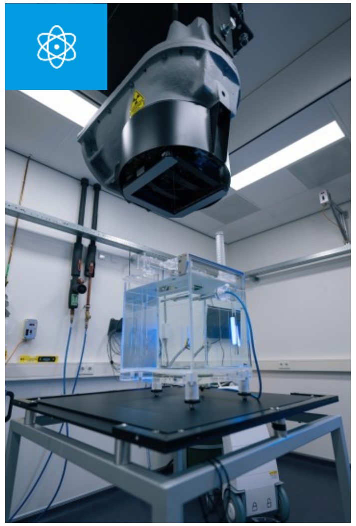
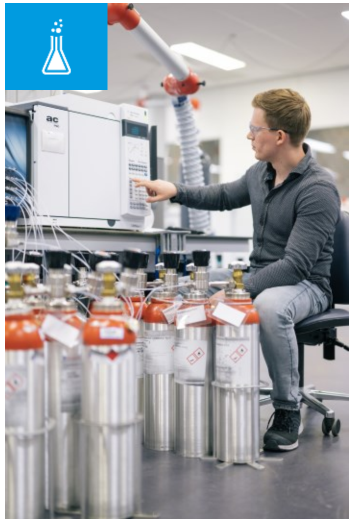
Nationale meetstandaarden







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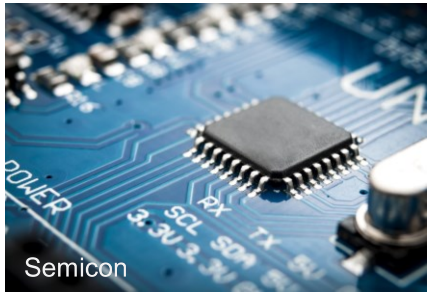
Strategische thema's VSL Meerjarenplan

- Energietransitie
- Gezonde leefruimte onder druk
- Versterking economische weerbaarheid
- Toenemende kosten van zorg
- Geopolitieke bedreigingen
- Digitalisering en de opkomst van kunstmatige intelligentie



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Time & Frequency

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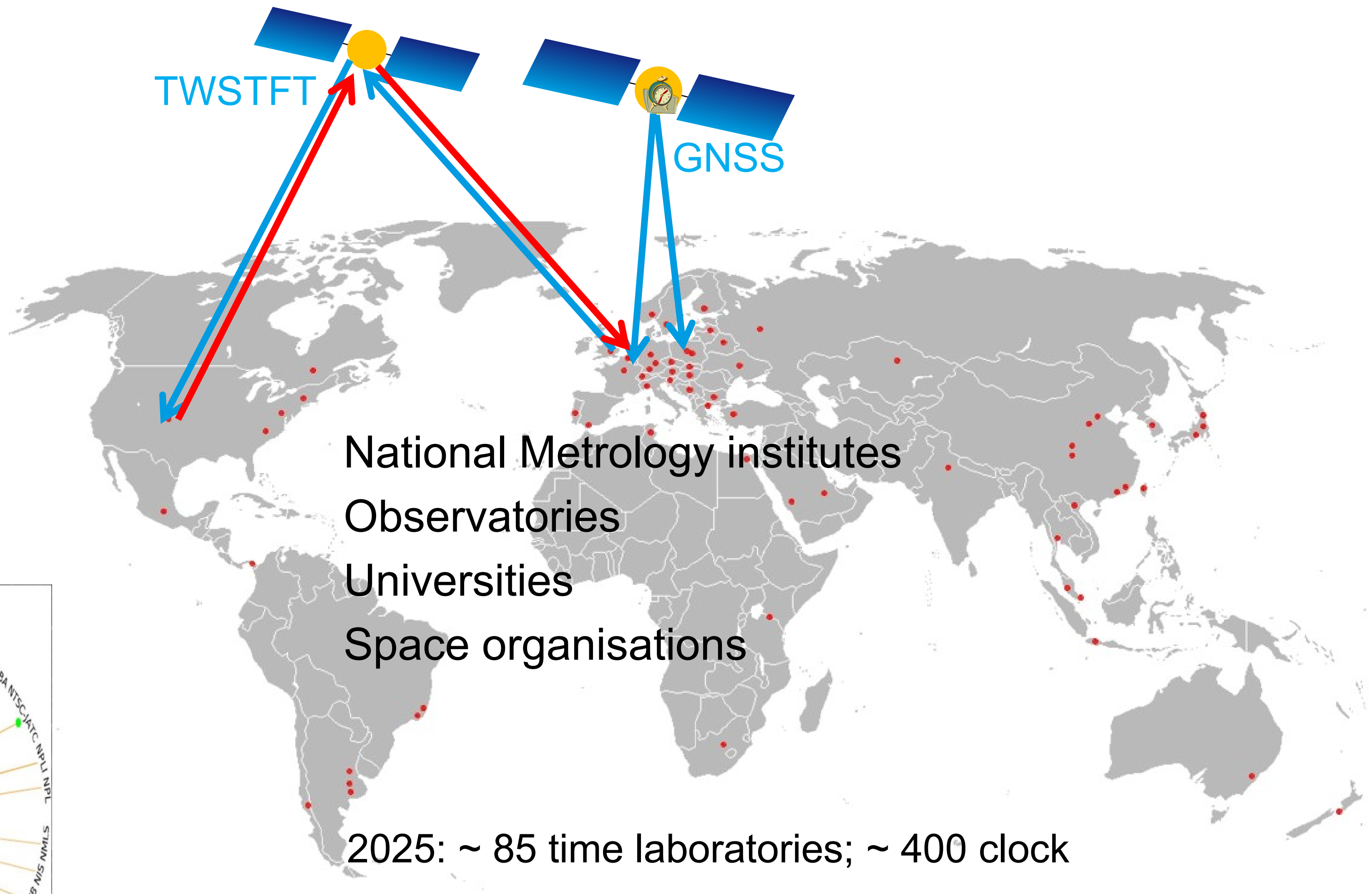
UTC



National Metrology institutes

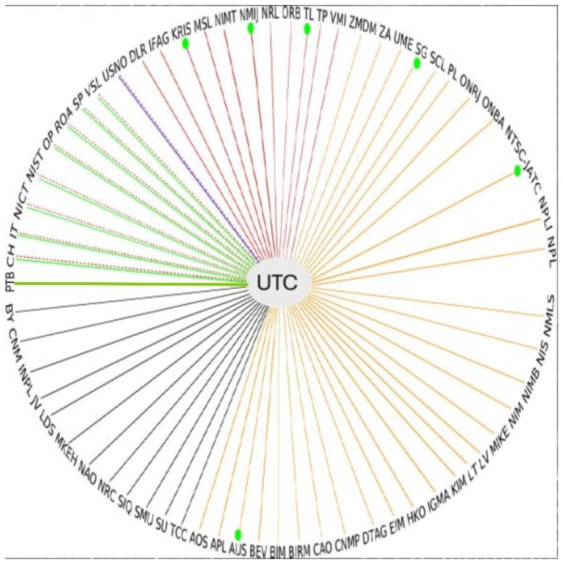
Observatories

Universities

Space organisations

2025: ~ 85 time laboratories; ~ 400 clock

International Bureau for Weights and Measures (BIPM) collects all data and computes the coordinated universal time scale UTC.



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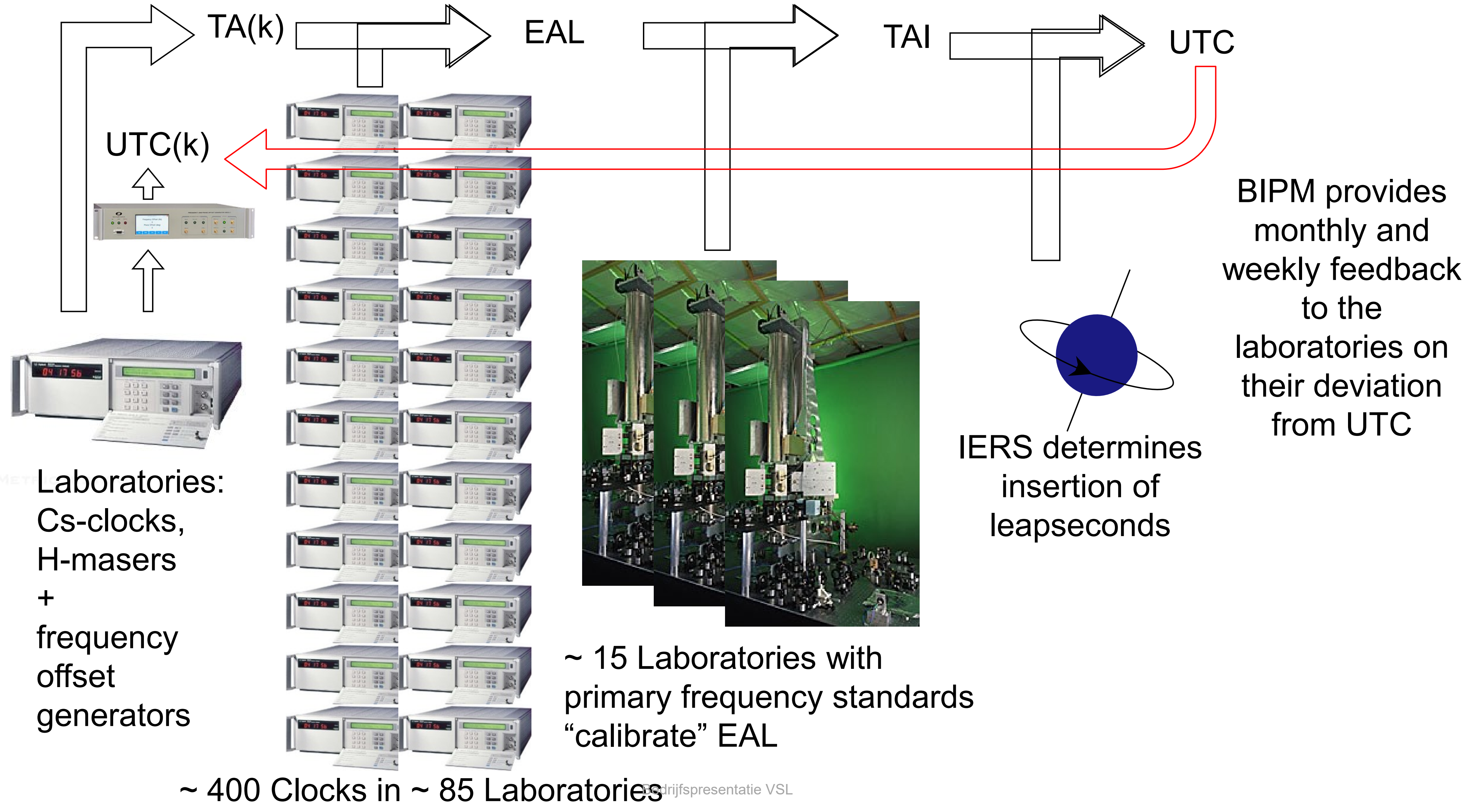
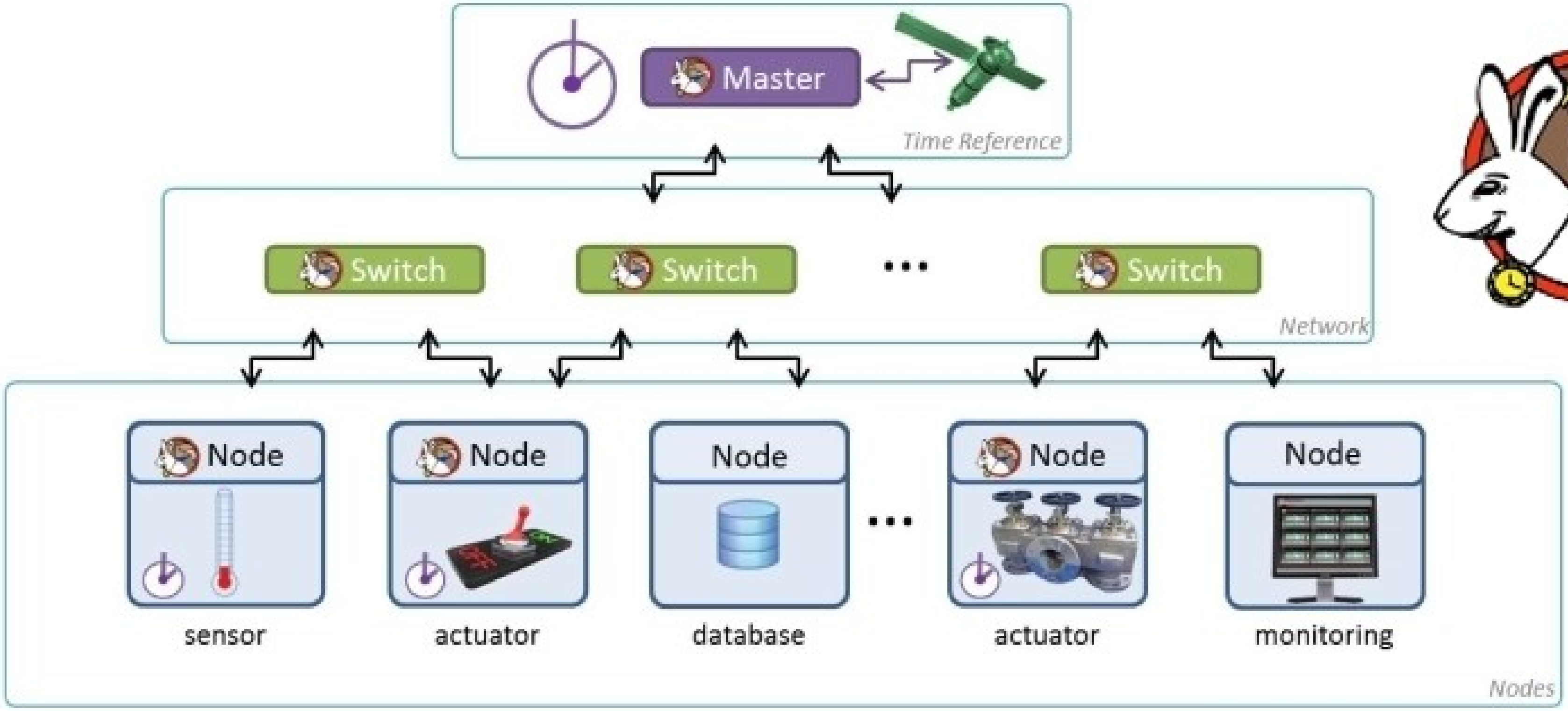
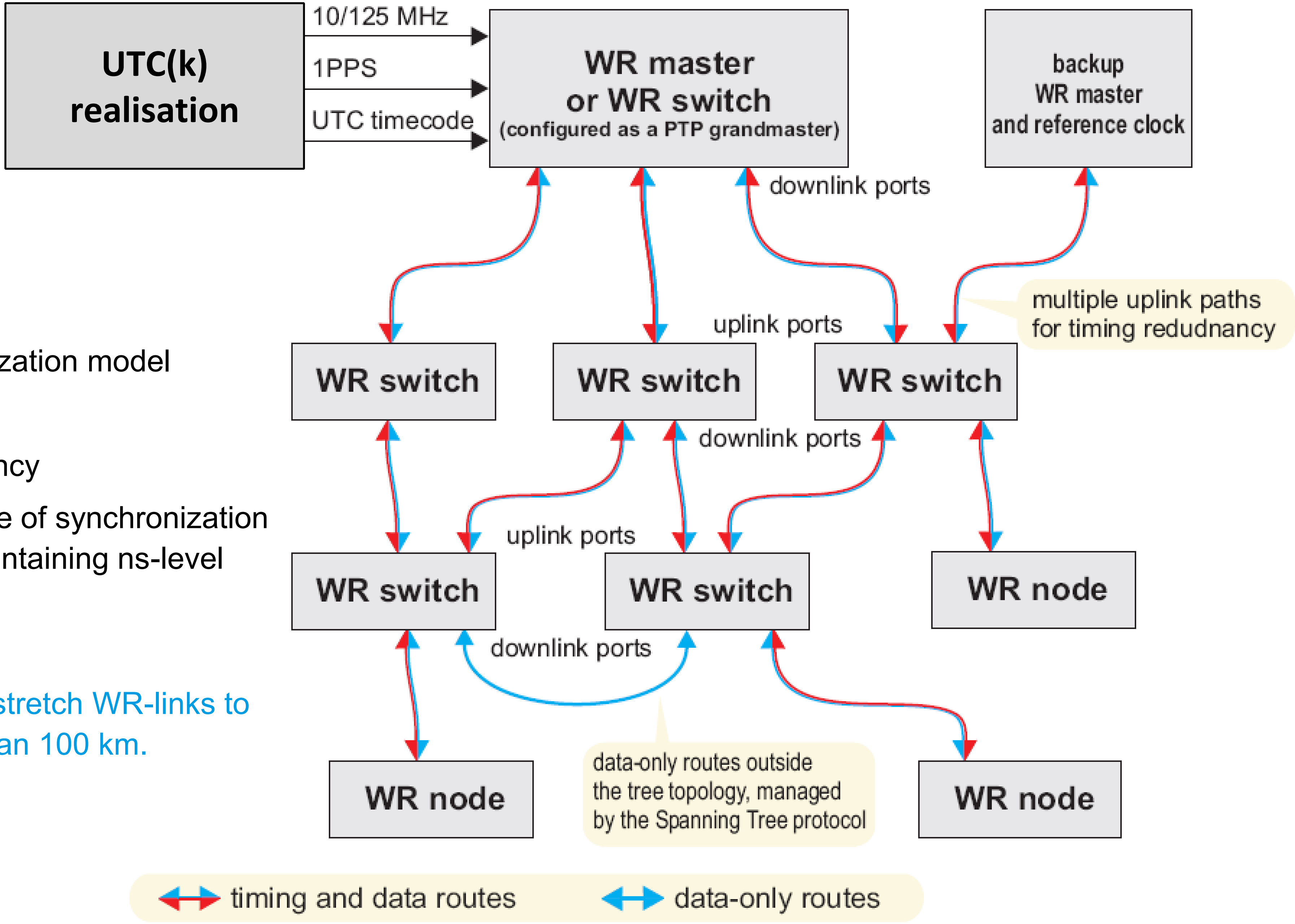
From clock to UTC - Coordinated Universal Time



Time dissemiation at VSL – What is White Rabbit?



- Developed at CERN
- To achieve sub-nanosecond synchronization White Rabbit utilizes
  - Synchronous Ethernet (SyncE) to achieve syntonization[4] and
  - IEEE_1588 Precision Time Protocol (PTP).



- Hierarchic synchronization model
- Easily extendable
- Support for redundancy
- Suitable for any scale of synchronization challenges while maintaining ns-level accuracy.

- VSL was the first to stretch WR-links to distances of more than 100 km.

Network for time distribution

NTP (network time protocol)

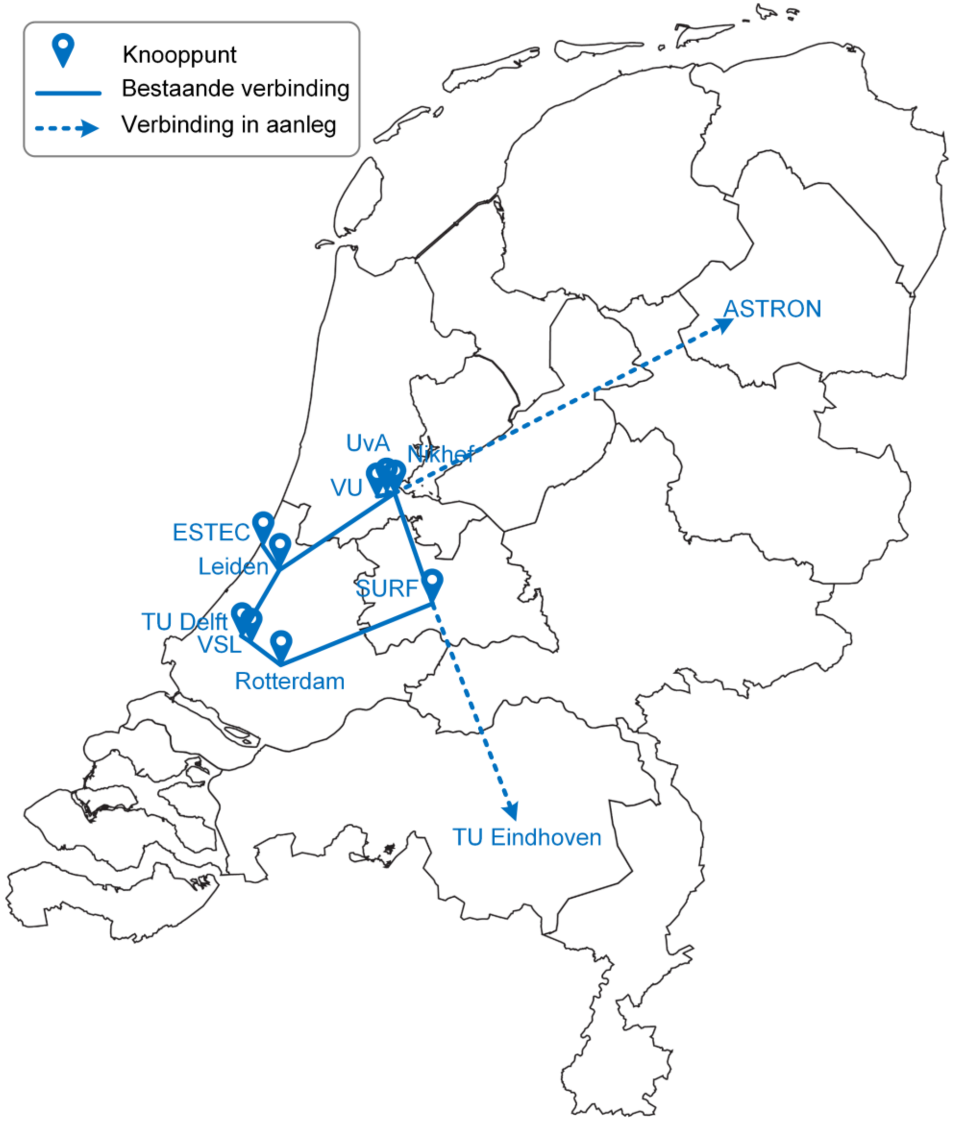
- ntp.vsl.nl
- uncertainty ~ ms

PTP (Precision Time Protocol)

- via optical fibres to e.g. data centres
- uncertainty ~ μs

White Rabbit

- National network via SURF for science and education
- Uncertainty < 5 ns



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Dimensional Metrology

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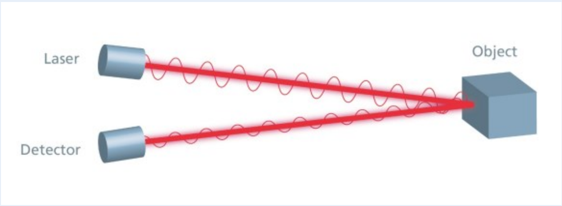
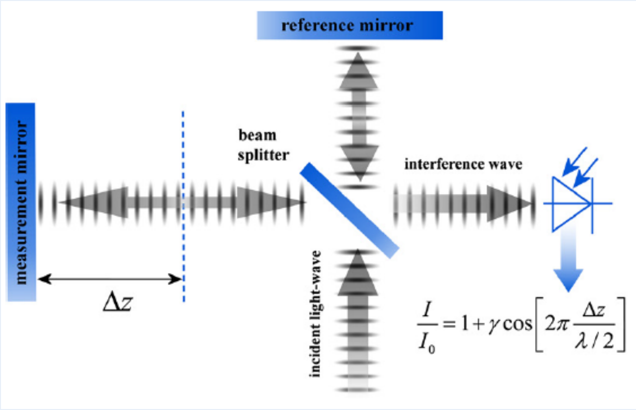
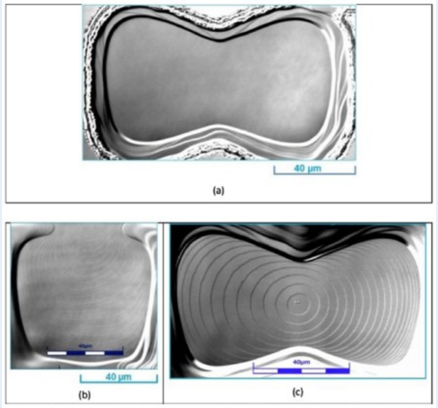
Mise en pratique for the metre –
Traceable length metrology and realization of the metre

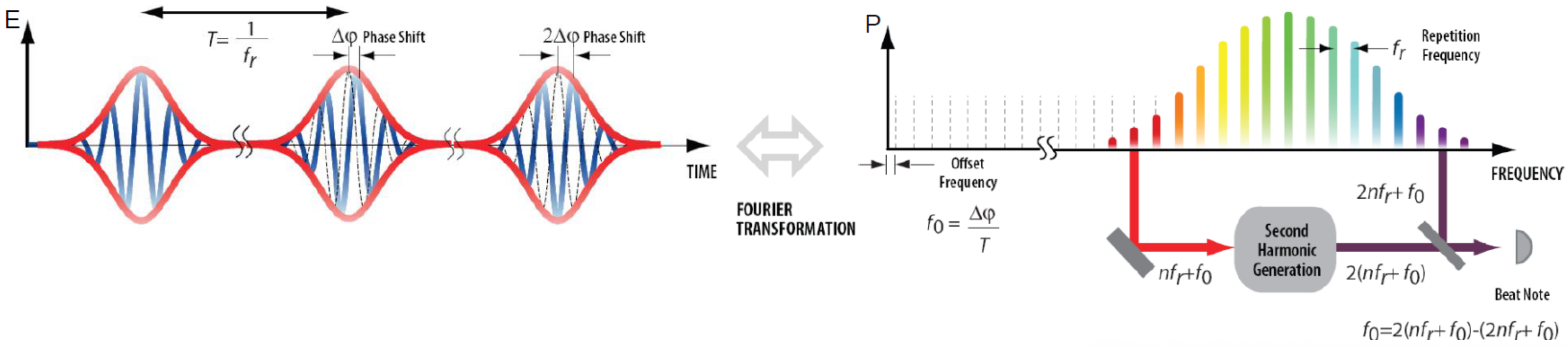
Time-of-flight (phase shift measurement)	Interferometry	Silicon Lattice
Directly traceable to the SI second	Primary realization by applying one of the recommended laser frequencies	Secondary realization by: $d_{002} = 192.0115716\ pm$
Suitable for longer distances	Suitable for from nanometers to tens of meters displacements	Suitable for nanometer and picometer for vertical scales (for SPM)
Subject to group refractive index of air	Subject to refractive index of air and non-linearity terms (sub-nanometer)	Subject to impurities and tilt
		

The new mise en pratique for the metre—a review of approaches for the practical realization of traceable length metrology from 10^{-11} m to 10^{13} m
René Schödel et al 2021 Metrologia ***58*** *052002*
https://iopscience.iop.org/article/10.1088/1681-7575/ac1456

Frequency Combs:
Phase-locked high-frequency femtosecond laser

TIME DOMAIN – Femtosecond Pulse Train

FREQUENCY DOMAIN – Frequency Comb

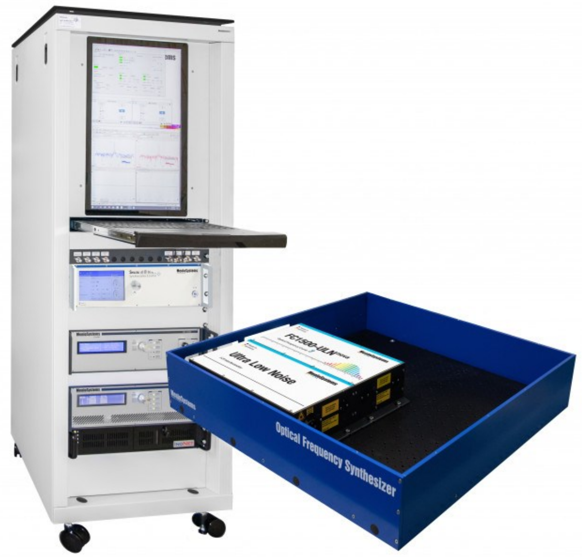


$$f_n = n \cdot f_r + f_0$$

$n \in \mathbb{N}$

e.g. 194 THz 250 MHz 35 MHz

Jones et al. Science 288 (2000)
Udem et al. Nature 416 (2002)
Diddams et al. Science 369 (2020)
Fortier et al. Comms Phys. 2 (2019)



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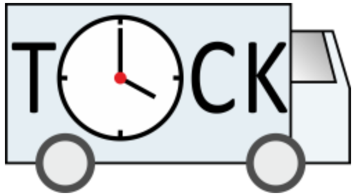
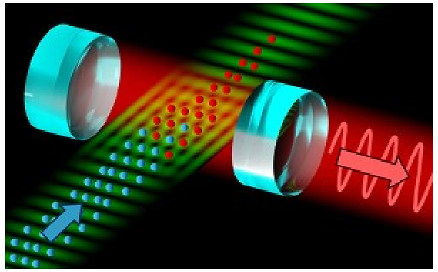
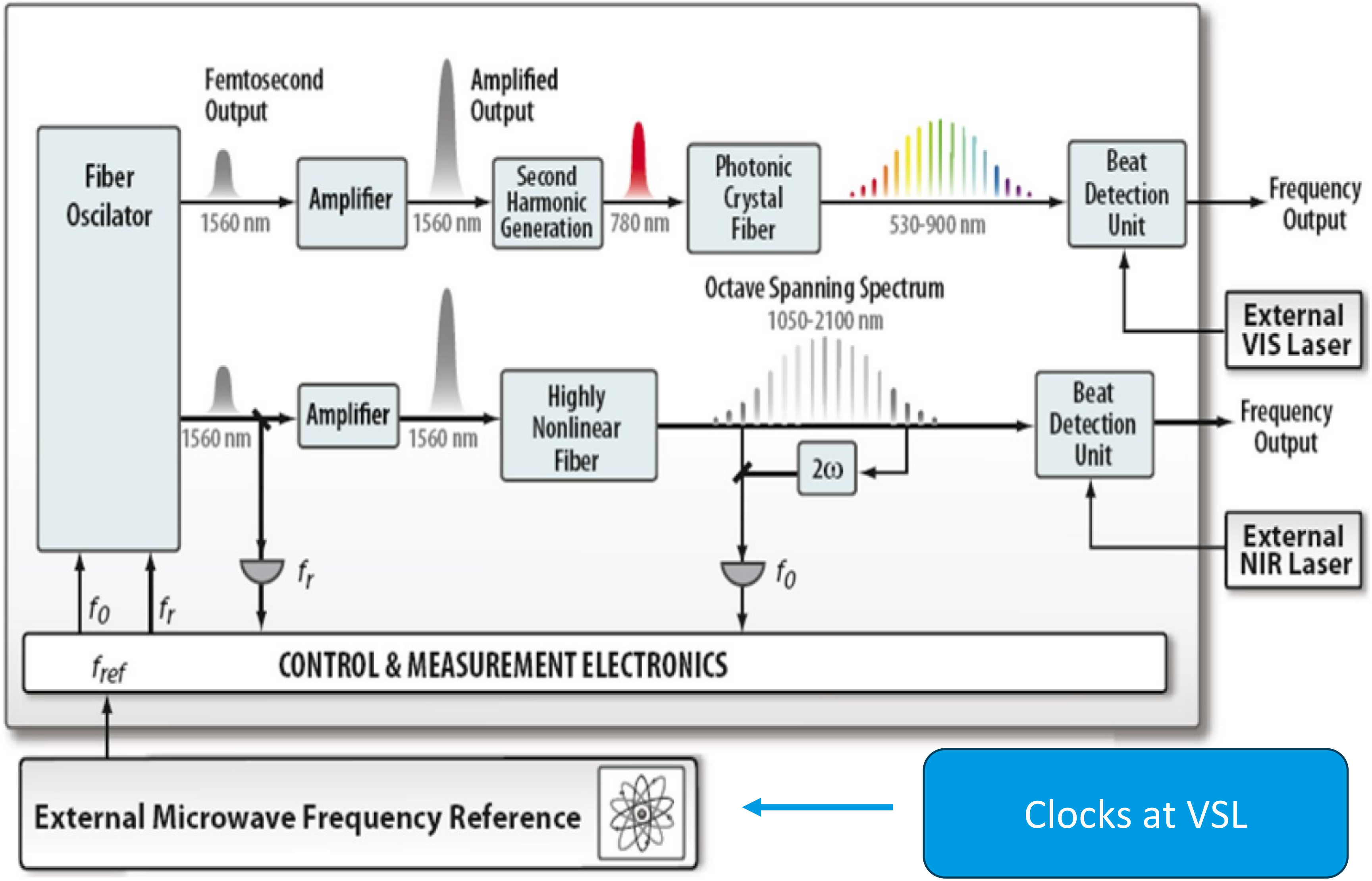
New frequency comb for length metrology and new opportunities for time and frequency







Clocks at VSL

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Gravitational Wave Detector

Einstein Telescope – Third Generation

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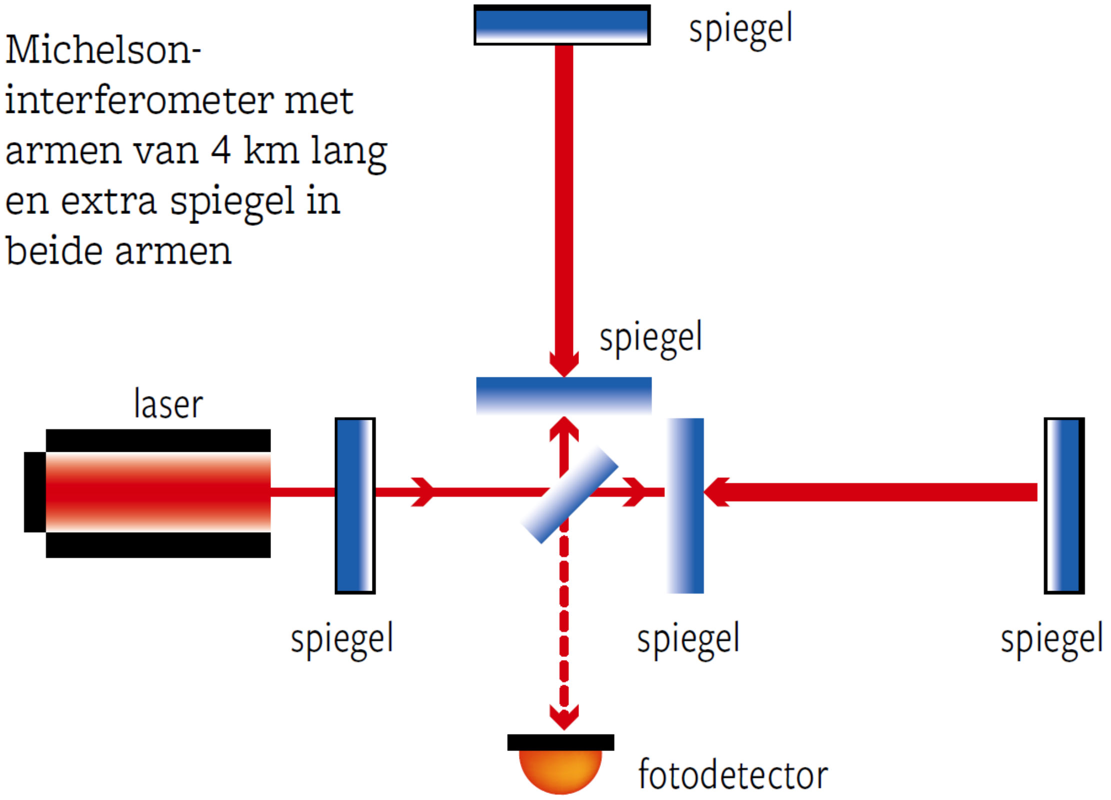
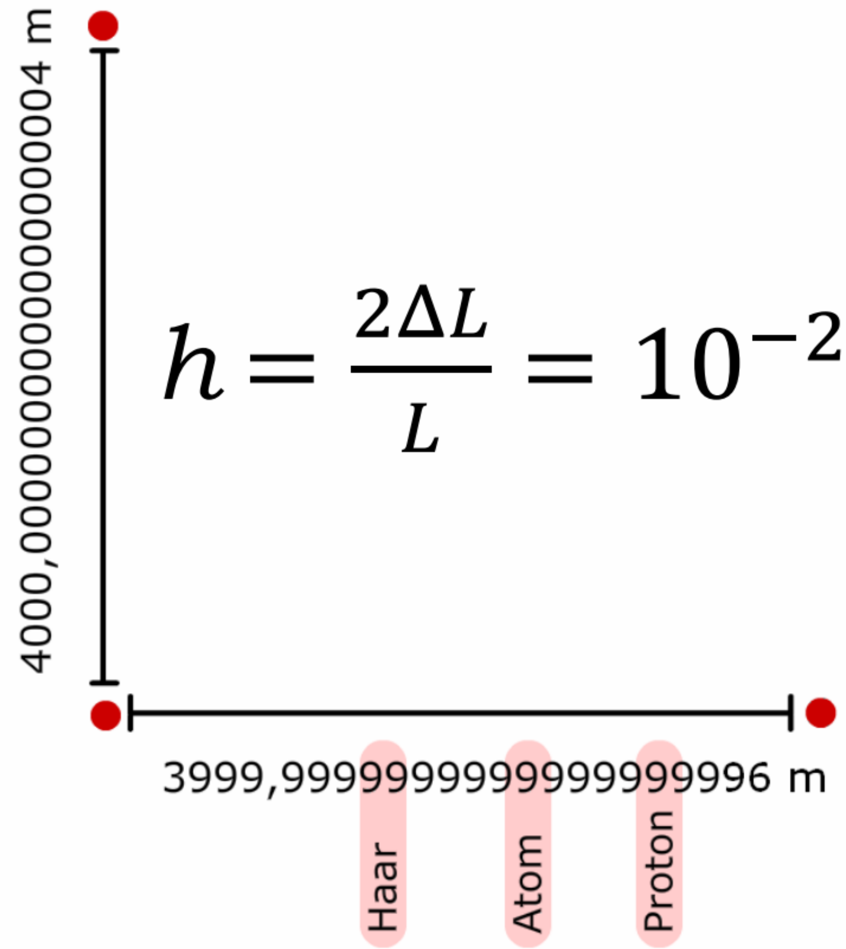
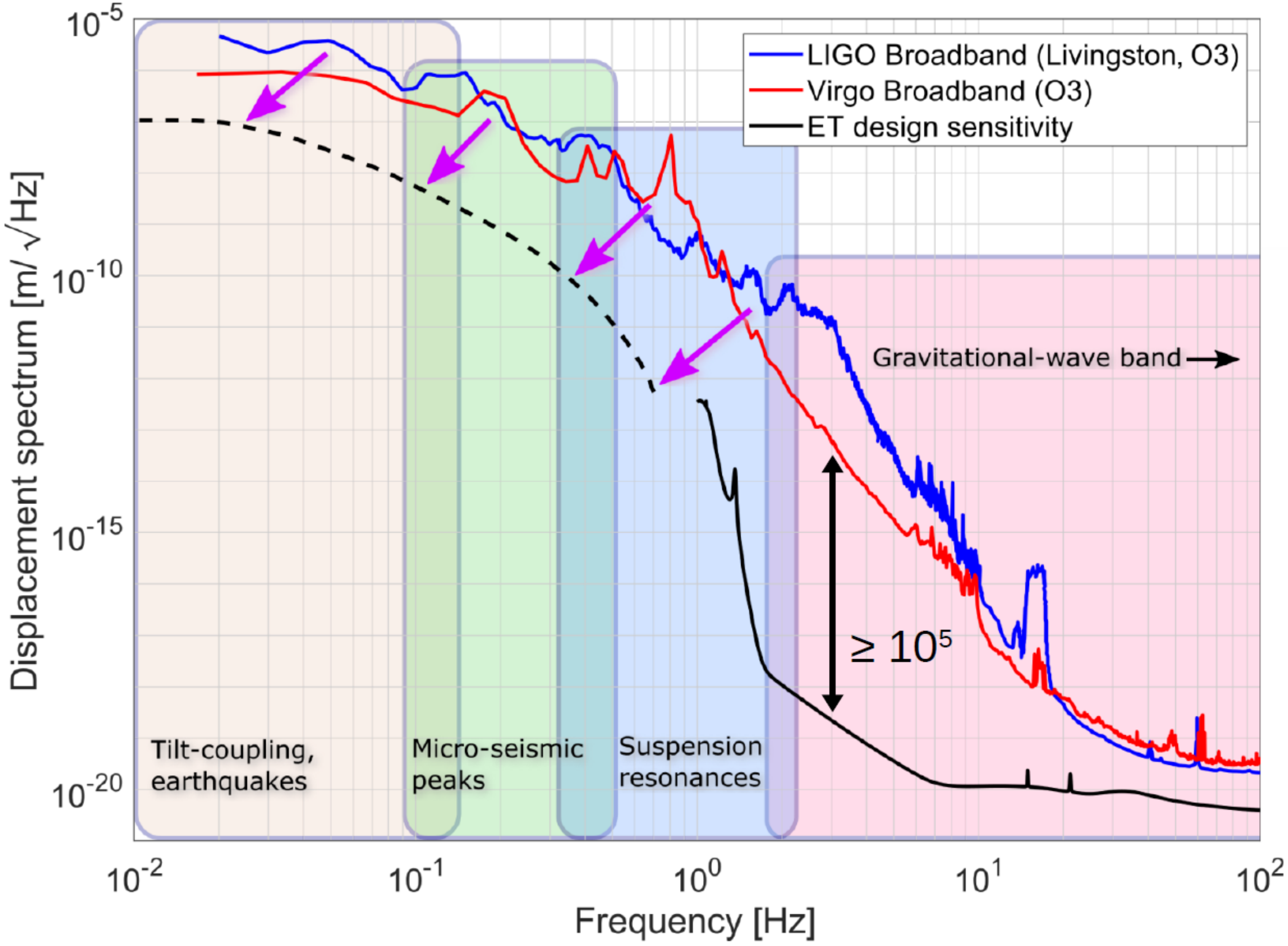
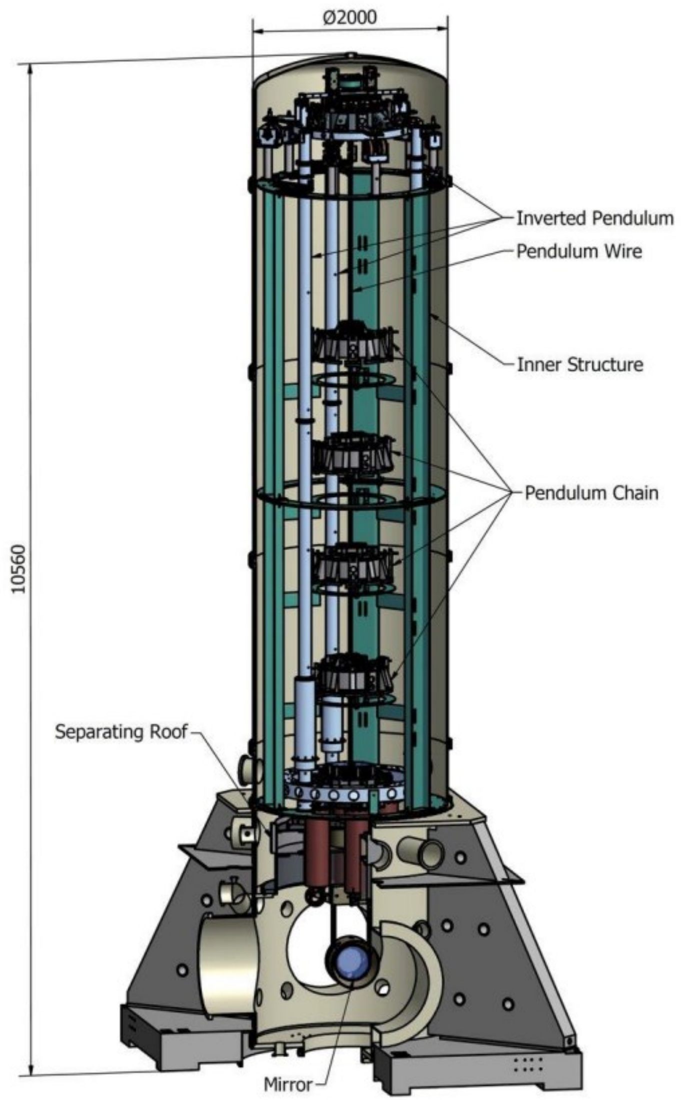
Michelson-interferometer met armen van 4 km lang en extra spiegel in beide armen





$$h = \frac{2\Delta L}{L} = 10^{-22}$$





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Great potential for interferometric sensors for gravitational wave detectors

Review of Scientific Instruments | ARTICLE | scitation.org/journal/rsi

Reducing control noise in gravitational wave detectors with interferometric local damping of suspended optics

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ABSTRACT

Control noise is a limiting factor in the low-frequency performance of the Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO). In this paper, we model the effects of using new sensors called Homodyne Quadrature Interferometers (HoQIs) to control the suspension resonances. We show that if we were to use HoQIs, instead of the standard shadow sensors, we could suppress resonance peaks up to tenfold more while simultaneously reducing the noise injected by the damping system. Through a cascade of effects, this will reduce the resonant cross-coupling of the suspensions, allow for improved stability for feed-forward control, and result in improved sensitivity of the detectors in the 10–20 Hz band. This analysis shows that improved local sensors, such as HoQIs, should be used in current and future detectors to improve low-frequency performance.

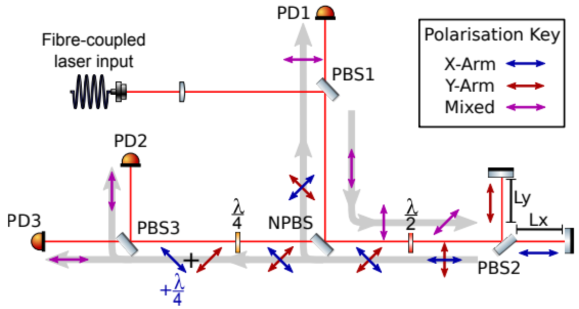


FIG. 1: The optical layout of HoQI. Orthogonal polarisation states are used to track the length difference between Lx and Ly over multiple optical fringes. The input beam is split at polarising beamsplitter PBS2 and interferometrically recombined at PBS1 and PBS3, producing signals proportional to the sine, cosine, and minus cosine of the optical phase difference. Grey arrows indicate the direction of propagation.

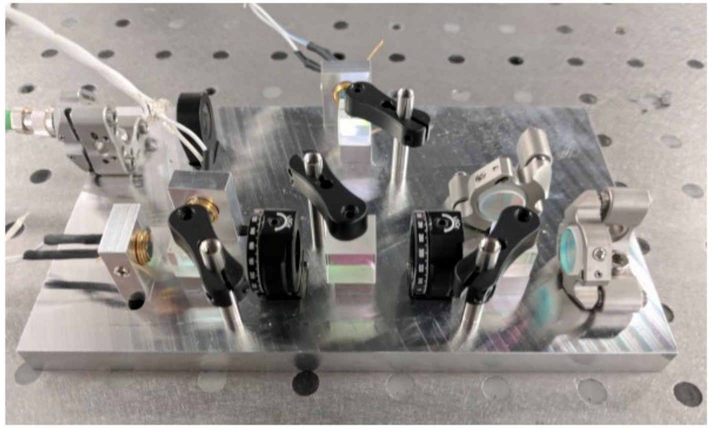
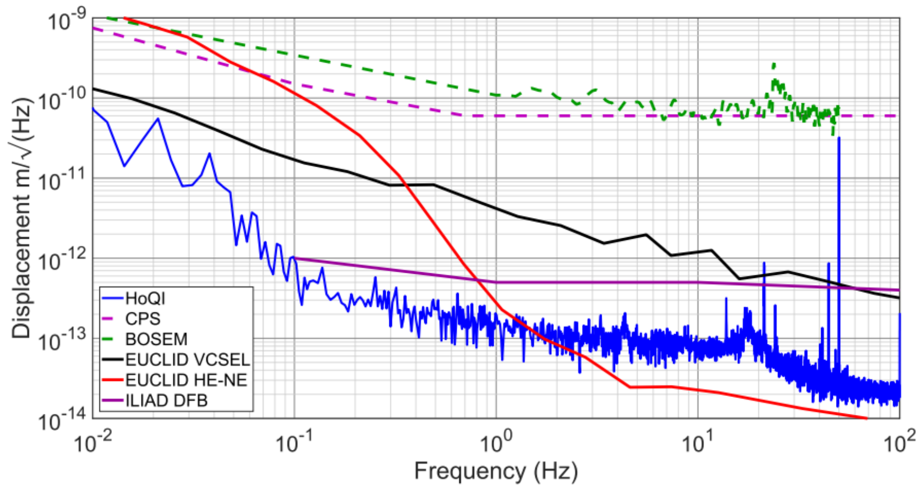


FIG. 2: The prototype version of HoQI, the base plate is 170 × 100 mm with 10 mm gaps between components.



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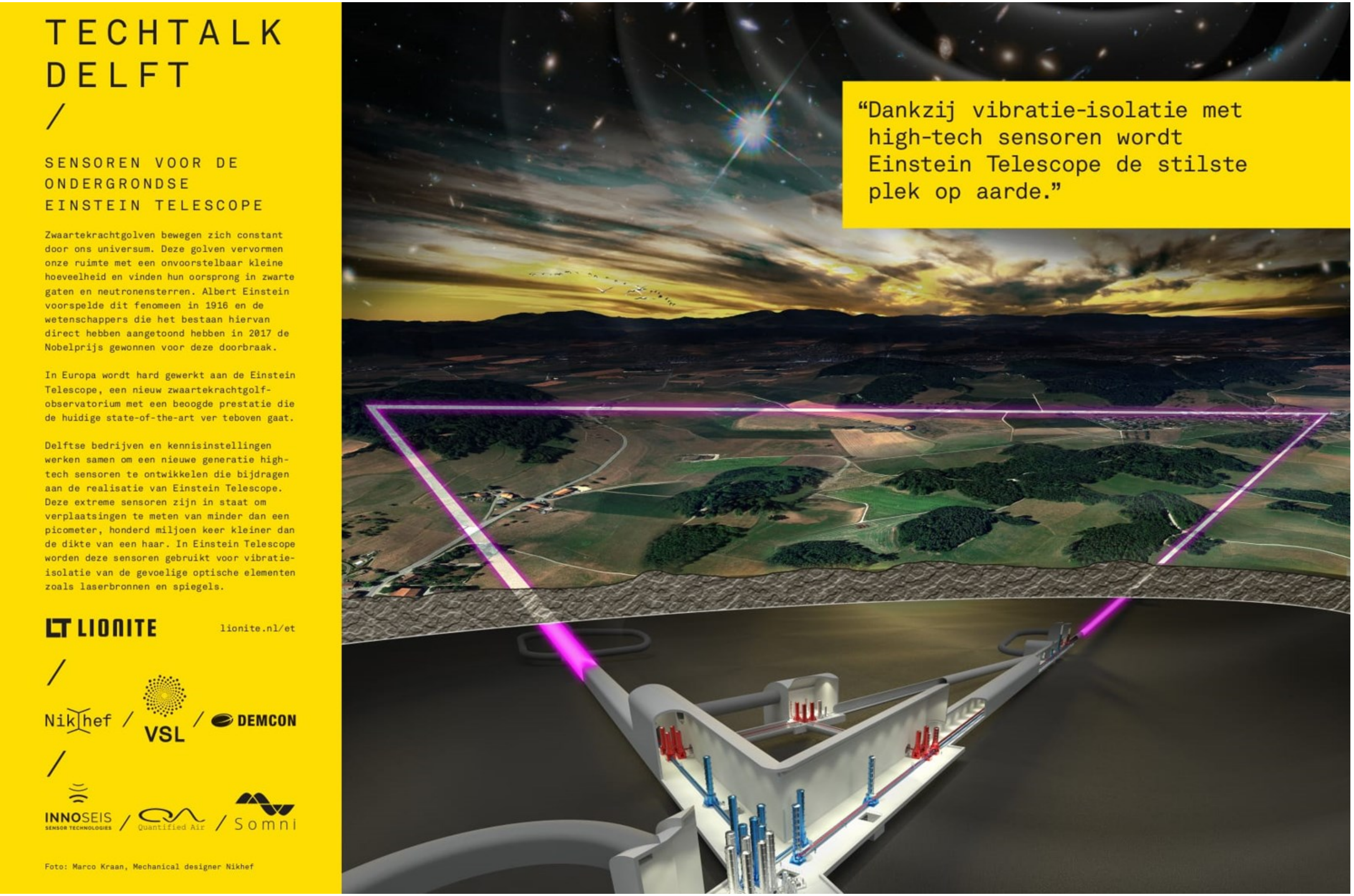
SENVIDET



Supported by the R&D program technology domains Einstein Telescope

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Einstein Telescope – SENVIDET 2024 - 2027

Einstein Telescope

Somni
fiber optic sensor systems

LIONITE

INNOSEIS
SENSOR TECHNOLOGIES

Quantified

Develop sensors

Validatie

VSL

Walter Knulst

Dimensional Metrology

Picodrift interferometer

SI

National Metrology Institute

Vacuum

National
Metrology
Institute

VSL

Vacuüm Kalibratie opstelling

Vacuüm Kalibratie opstelling

- Uitbreiding accreditatie tot 10^{-8} mbar
- Slechts 8 NMI's in de wereld die deze druk herleidbaar kunnen kalibreren

- Breed toepasbaar in verschillende vakgebieden met enkele voorbeelden:
  - **Semicon:** Het creëren van zuivere omstandigheden voor de productie van microchips
  - **Medisch en Farma:** Productie van titanium implantaten en onderzoek naar nieuwe behandelmethodes.
  - **Lucht- en ruimtevaart:** Testen en valideren van apparatuur.
  - **Energie en materialen:** Genereren en gebruik van Plasma.

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The End

Thank you for your attention.

Any questions? Contact me at wknulst@vsl.nl or by in or after the talk

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