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Challenges and achievements toward a new definition of the second

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Contents

- Challenges and Criteria
for the redefinition of the second

- Activities and Achievements

- Next steps



Roadmap towards the redefinition of the second

Prepared by the CCTF Task Force on the redefinition (> 35 persons from all RMOs)

Adressing key topics:

- Options for the new definition
- Criteria to be fulfilled before the redefinition
- Education and communication

Initial version endorsed by the 27th CGPM (2022)

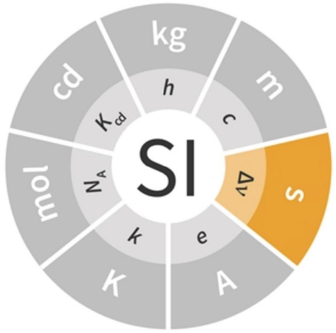
Draft Resolution B of the 28th CGPM (2026) based on the 2025 update version

CGPM → Target for the redefinition: 29th CGPM (2030)

Which Challenges for a solid redefiniton of the second?

CONSENSUS ON THE DEFINITION OPTIONS + CONSENSUS ON CRITERIA AND ACHIEVEMENT LEVEL

REDEFINITON 2030



NOW:

The second is defined by taking the transition frequency of Cs133, $\Delta\nu_{Cs}$ = 9 192 631 770 Hz (microwave domain)

FUTURE:

Significant advantages of taking optical atomic transitions, not microwave

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NEED	REQUESTED LEVEL
CLOCK ACCURACY	Uncertainty < 2×10^{-18}
COMPARISON AND AGREEMENT	Clocks comparisons < 5×10^{-18}
CONTRIBUTION TO GLOBAL INTERNATIONAL TIMEKEEPING	Constant TAI calibration <2×10^{-16}
APPROPRIATE RELATIVISTIC CORRECTIONS	Relativistic corrections < 5×10^{-18}
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From Challenges to Criteria for a redefinition

CLOCK ACCURACY

COMPARISON AND AGREEMENT

CONTRIBUTION TO GLOBAL INTERNATIONAL TIMEKEEPING

APPROPRIATE RELATIVISTIC CORRECTIONS

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STATUS of Optical Frequency Standard

Criterion I.1 - Accuracy budgets of optical frequency standards
Criterion I.2 - Validation of Optical Frequency Standard accuracy budgets – Frequency ratios
Condition III.3 - Continuous improvement of the realization and of time scales after redefinition
Condition III.4 - Availability of commercial optical frequency standards

OPERATIONS of Optical Frequency Standard

Criterion I.3 - Continuity with the definition based on Cs
Criterion I.4 - Regular contributions of optical frequency standards to TAI (as secondary representations of the second)
Condition I.5 – High reliability of OFS
Criterion II.2 – Knowledge of the local geopotential with an adequate uncertainty level
Criterion III.2 - Access to the realization of the new definition

DISSEMINATION of Optical Frequency Standard

Condition I.6 - Regular contributions of optical frequency standards to UTC(k)
Criterion II.1 – Availability of sustainable techniques for Optical Frequency Standards comparisons
Condition II.3 – High reliability of ultra high stability TF links
Criterion III.1 - Definition allowing future more accurate realizations
Condition III.5 - Improved quality of the dissemination towards users

N Dimarcq et al 2024 *Metrologia* 61 012001

2022-2026: what we did

- ✓ Analysis: Requirements for a Redefinition
- ✓ Formalization: Quantitative and Qualitative Criteria
- ✓ Monitoring: updated Factsheets and Fulfilment Index
- ✓ Complete Technical Dossier
- ✓ Supporting Member States: Surveys, Presentations, discussion
- ✓ Promoting Try&Error attitude to achieve the goal
- ✓ Communication

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2022: FOUR critical Criteria

CLOCK ACCURACY

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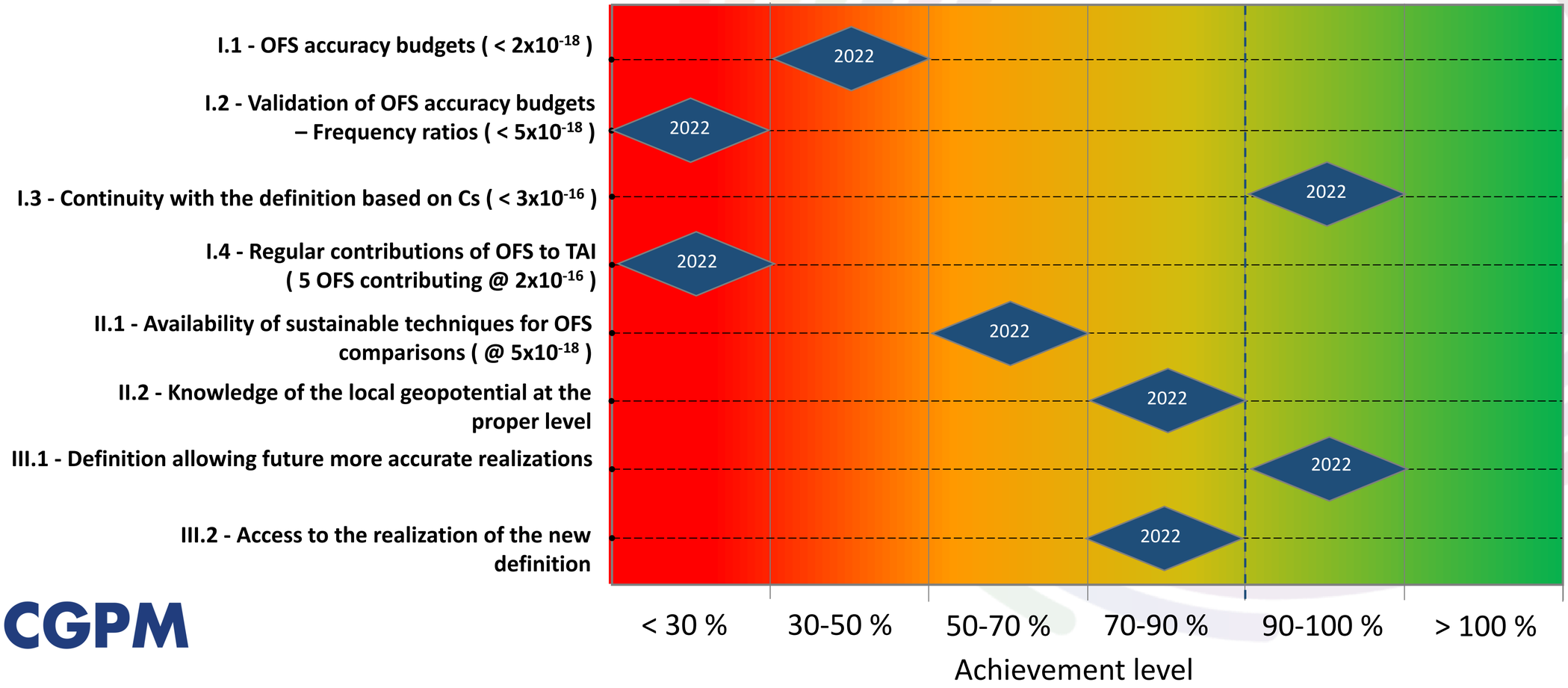
2022: Fulfilment level of mandatory criteria

Mandatory criteria



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2022-2026: what we achieved

ACTIONS

- TECHNICAL ASSESSMENT COMPLETED
- SURVEY, COMUNICATION, AND NMI SUPPORT
- BETTER UNDERSTANDING ON CLASSIFICATION of the REALIZATION (primary, secondary, secondary representation of the second)

RESULTS

- COMPARISONS PACE AND SUSTAINABILITY
- CLOCK ACCURACY
- CONSOLIDATION
  BEYOND CAESIUM BEST REALIZATION

CONSTANT GROWTH OF TANGIBLE EFFORTS AND RESULTS THANKS TO THE COMMITMENT OF MANY MEMBER STATES, NMIS, RESEARCH GROUPS, AND CCTF

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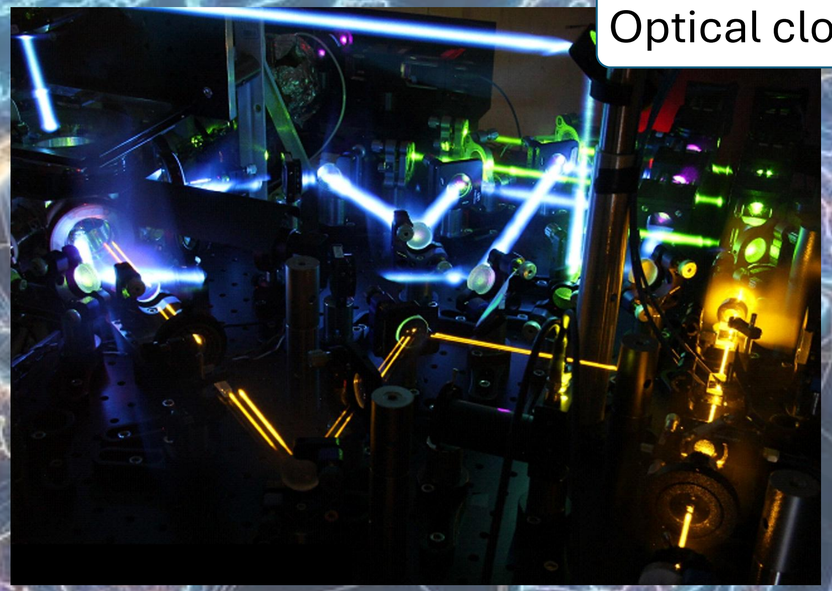
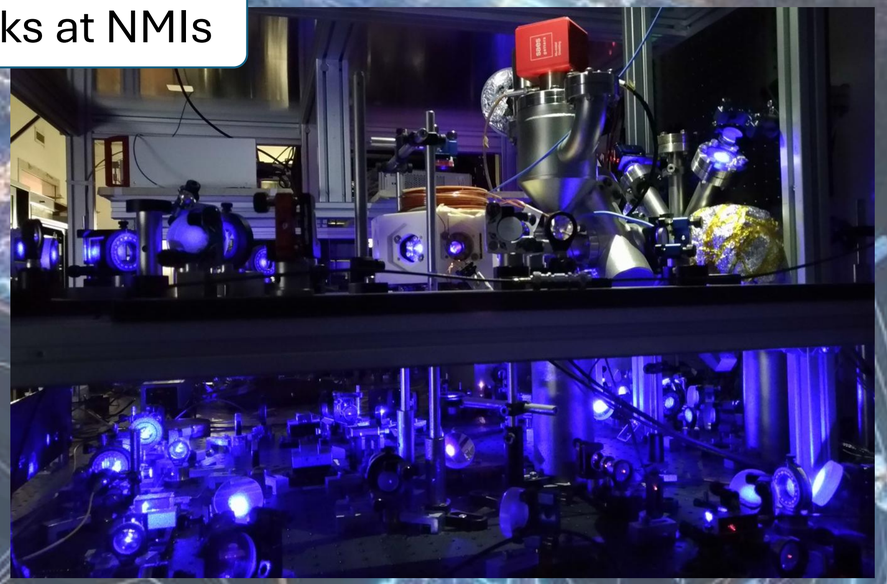
Extended comparisons, in 2022, 2023, 2025, >9 countries
>10 optical clocks, and 2 transportable clocks involved

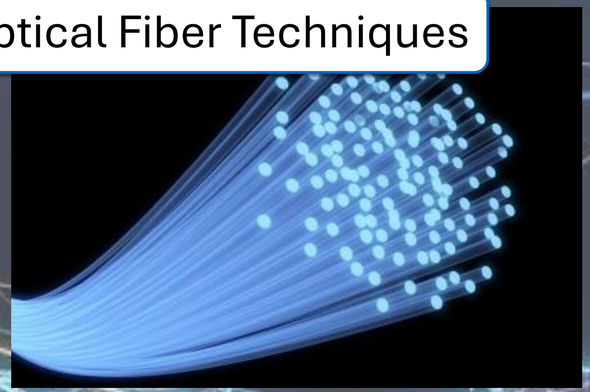
- ✓ GOOD PACE OF COMPARISONS
- ✓ SUSTAINABLE TECHNIQUES DEMONSTRATED
- ✓ TO IMPROVE UNCERTAINTY AND AGREEMENT LEVELS



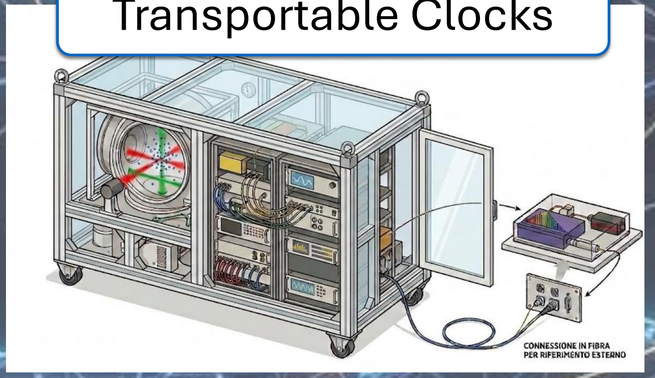
Optical clocks at NMIs



Optical Fiber Techniques



Transportable Clocks



Satellite Techniques



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Main Achievements in last 4 years

Clock accuracy (< 2×10^{-18})

- ✓ CLOCK ACCURACY ACHIEVED
- ✓ CRITICAL IN 2022
- ✓ MOST OF RESULTS AT THE APPROPRIATE LEVEL IN 2025/2026

Transition	Uncertainty (10^{-18})	Year	Reference	Type	Institutes
$^{27}Al^{+}$	0.5	2025	[Marshall2025]	ion	NIST
	1.6	2024	[Ma2024]	ion	PGMF
$^{115}In^{+}$	2.5	2025	[Hausser2025]	ion	PTB
$^{171}Yb^{+}$ (E3)	2.2	2024	[Tofful2024]	ion	NPL
	2.7	2019	[Sanner2019]	ion	PTB
^{171}Yb	1.4	2018	[McGrew2018]	lattice	NIST
$^{88}Sr^{+}$	0.8	2025	[Lindvall2025]	ion	VTT
^{87}Sr	0.8	2024	[Aeppli]	lattice	JILA
	0.9	**2026**	[Jia2026]	lattice	Hefei
	2.1	2025	[Nosske2025]	lattice	PTB
	2.8	**2026**	[Guo2026]	lattice	NTSC
	5.5	2020	[Takamoto2020]	lattice	RIKEN
$^{40}Ca^{+}$	0.4	**2026**	[Zhang2026]	ion	CAS
	3.0	2022	[Huang2022]	ion	WIPM
$^{176}Lu^{+}$	0.6	**2026**	[Arnold026]	ion	NUS

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From Challenges to Criteria for a redefinition

Clock ACCURACY

COMPARISON AND AGREEMENT

CONTRIBUTION TO GLOBAL INTERNATIONAL TIMEKEEPING

Under reasonable control:
e.g. this month 7 optical clocks together for the first time

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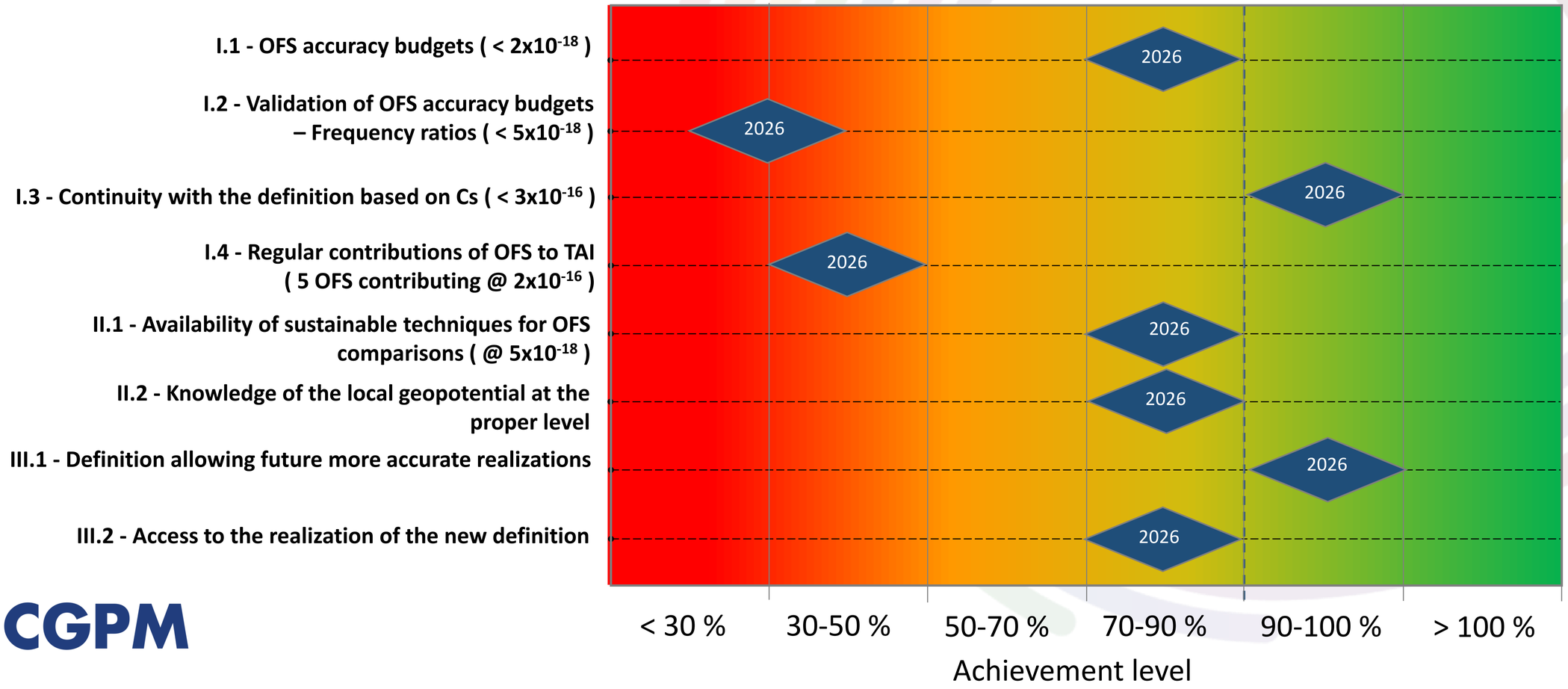

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Future plans and Conclusions

- Build on the Commitment by Member States, their outstanding results, and keep on encouraging and supporting them
- Consolidate the achievements
- Complete the challenging contribution to TAI (International Atomic Time)
- Support More Comparisons at the appropriate level
- Find a Consensus of possible definition and the realization level
- Build a solid decisional case by 2030

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Thank you
for your attention