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Introduction to Draft Resolution B:

On the future definition of the second - Option Analysis

October 15, 2026

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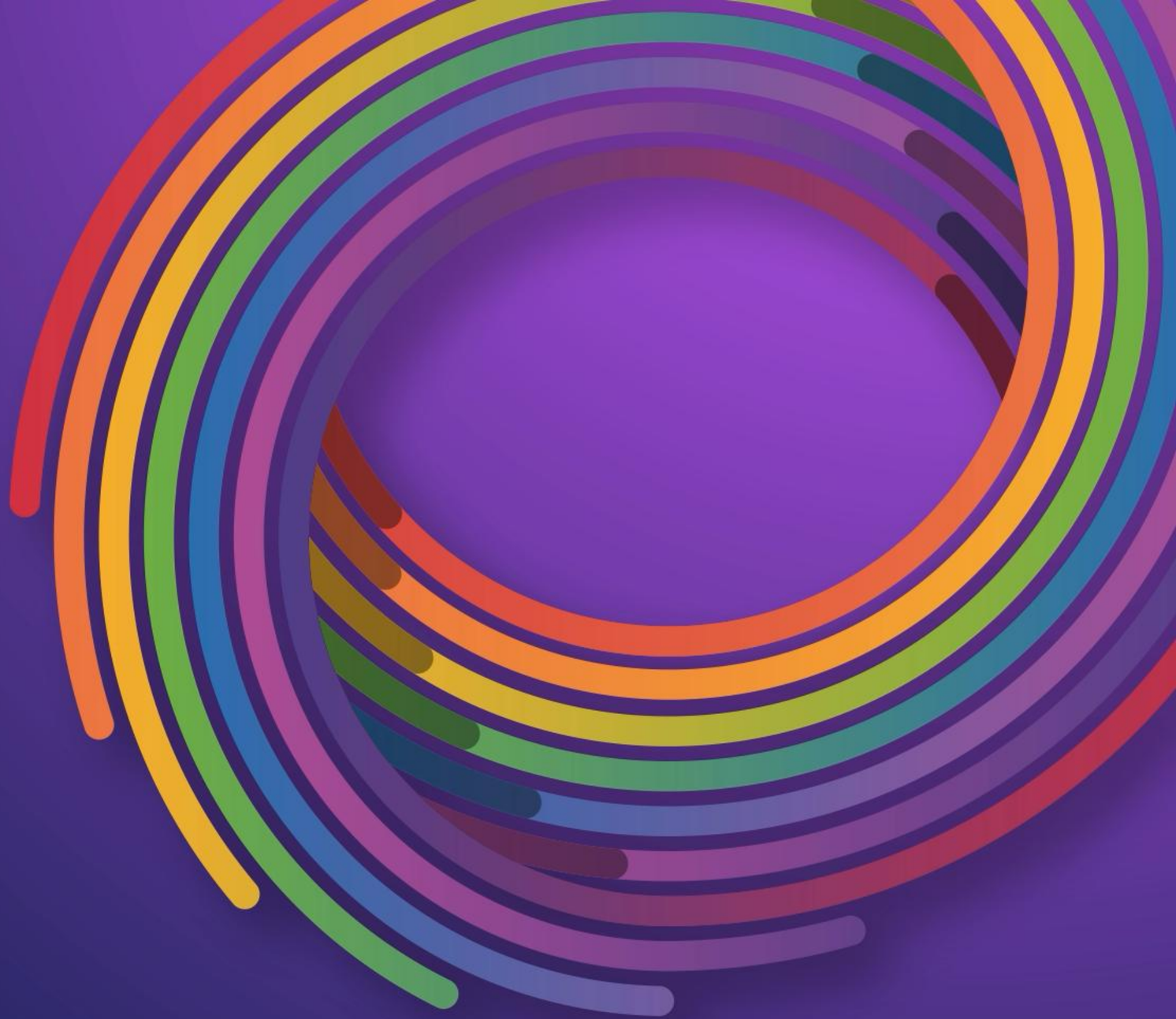
- TF organisation & SG1 activities
- Analysis of options
- Current situations
- Future plan



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)

TF organisation

SG1 – Options for the new definition

- **Goals**
  - Provide analysis on option 1 & 2 and promising candidate species
  - Make proposals toward a consensus on the choice of options/species
- **Composition**
  - CoChairs: Sébastien Bize, Fang Fang, Ekkehard Peik
  - Executive secretary: Gianna Panfilo
  - Members: Pierre Dubé, Filippo Levi, Helen Margolis, Masami Yasuda, Dai-Hyuk Yu, Jérôme Lodewyck, Poonam Arora, Sherman Jeff, Tetsuya Ido, Davide Calonico, Stefan Weyers, Jacques Morel, Christian Lisdat, Christophe Salomon, Bill Philips, Vitaly Pal'chikov

18 Experts from different countries/institutes/fields

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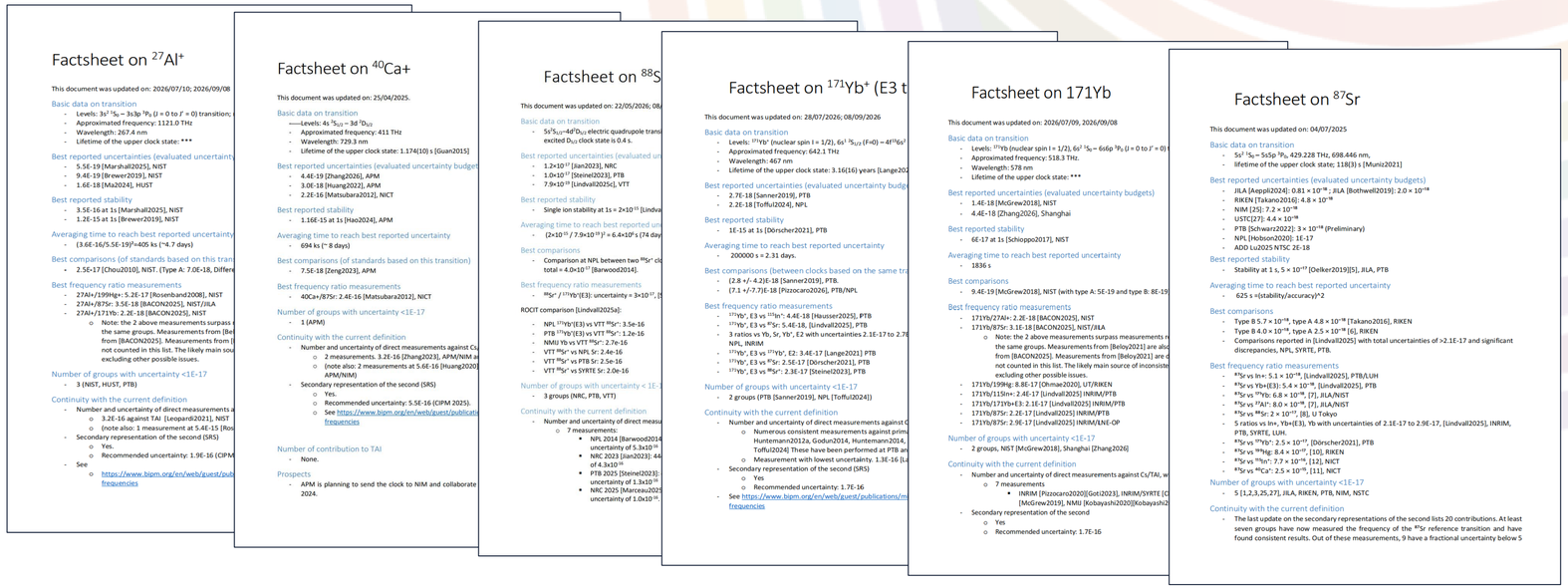
- Review: Bill Phillips

SG1 activities

- **Many meetings over the last few years**
- **Prepare and update documents/notes**
  - Definition of option 1 & 2
  - Practical implementation
  - Scenarios before, at and after the redefinition
  - Pros & cons analysis
  - Factsheets on promising atomic transitions

Factsheets on promising atomic transitions (11 SRS + Lu^+ transition)

- Basic data on transitions
- Quantitative indicators
- Qualitative analysis



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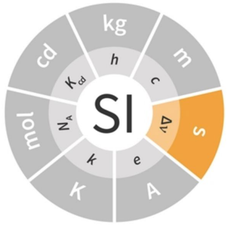


Overview of options

- Requirements for the new definition

Definition & Principle

- Long-lasting capacity of the new definition
- Realisation easily understood, with clear uncertainty evaluation
- Potential ultimate level of accuracy achievable

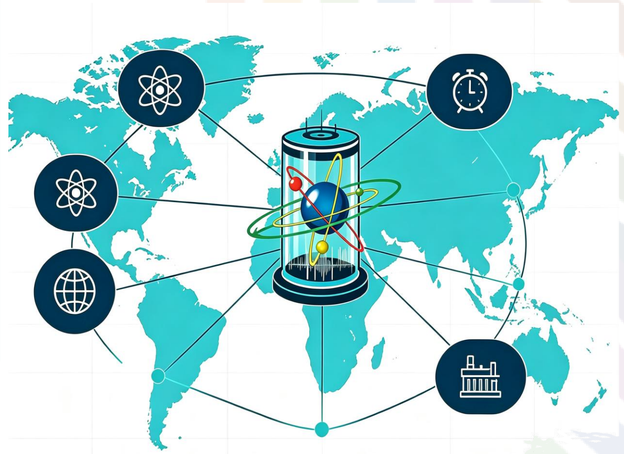
Instrumentation & Industry

- Availability of commercial optical clocks

SI unit second

Option 1: based on a single atomic transition

Option 2: based on an ensemble of atomic transitions



Dissemination

- Capacity of dissemination to low-accuracy users

Global NMI Ecosystem

- Easy access for a large number of NMIs to realise the definition
- Level of commitment of NMIs operating optical clocks
- Acceptability by NMIs without optical clocks

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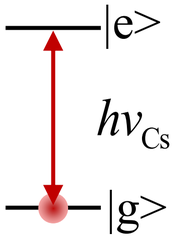
Analysis of options

Option 1: Single optical transition - similarly to the current definition



$\nu_{Cs} = 9\,192\,631\,770\ \text{Hz}$ → $\nu_X = N\ \text{Hz}$

New definition: Fix the value of the transition frequency ν_x of the species X

eg: $\upsilon_{87Sr} = 429\ 228\ 004\ 229\ 872.99\ \text{Hz}$

Realization of the definition:

Primary frequency standards based on the defining transition X

Other transitions, part of the CIPM list of recommended values for secondary representations of the second (SRS)



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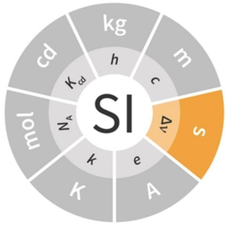
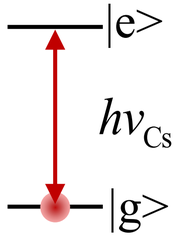


Analysis of options

Option 2: Ensemble of reference atomic transitions - the defined constant N is the weighted geometric mean of the chosen transitions.



$$h\nu_{Cs} = E_{|e>} - E_{|g>} \qquad \nu_{Cs} = 9192631770\ \text{Hz}$$

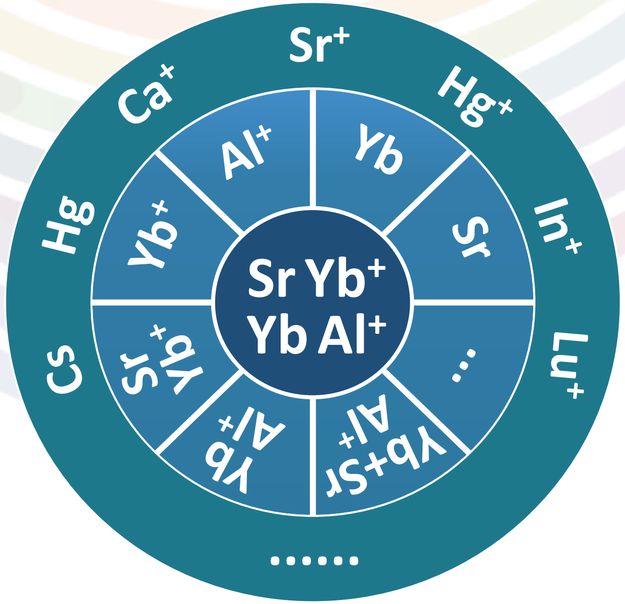
$$\prod_i \upsilon_i^{\omega_i} = N\ \text{Hz} \qquad (\text{with} \sum_i \omega_i = 1)$$

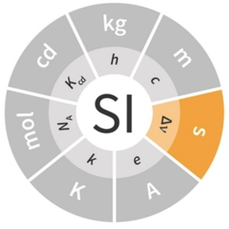
New definition: Fix the value of the geometric mean of transition frequencies of an ensemble species

eg: $(\upsilon_{Sr})^{0.25}(\upsilon_{Yb})^{0.25}(\upsilon_{Yb^+})^{0.2}(\upsilon_{Al^+})^{0.3} = 650464137090812.41\ \text{Hz}$

Realization of the definition:

- **Primary realization based on all defining transitions ν_i**
- **Realization based on one or a subset of the defining transitions**
- **Other transitions, part of the CIPM list of recommended values for secondary representations of the second (SRS)**





Analysis of options

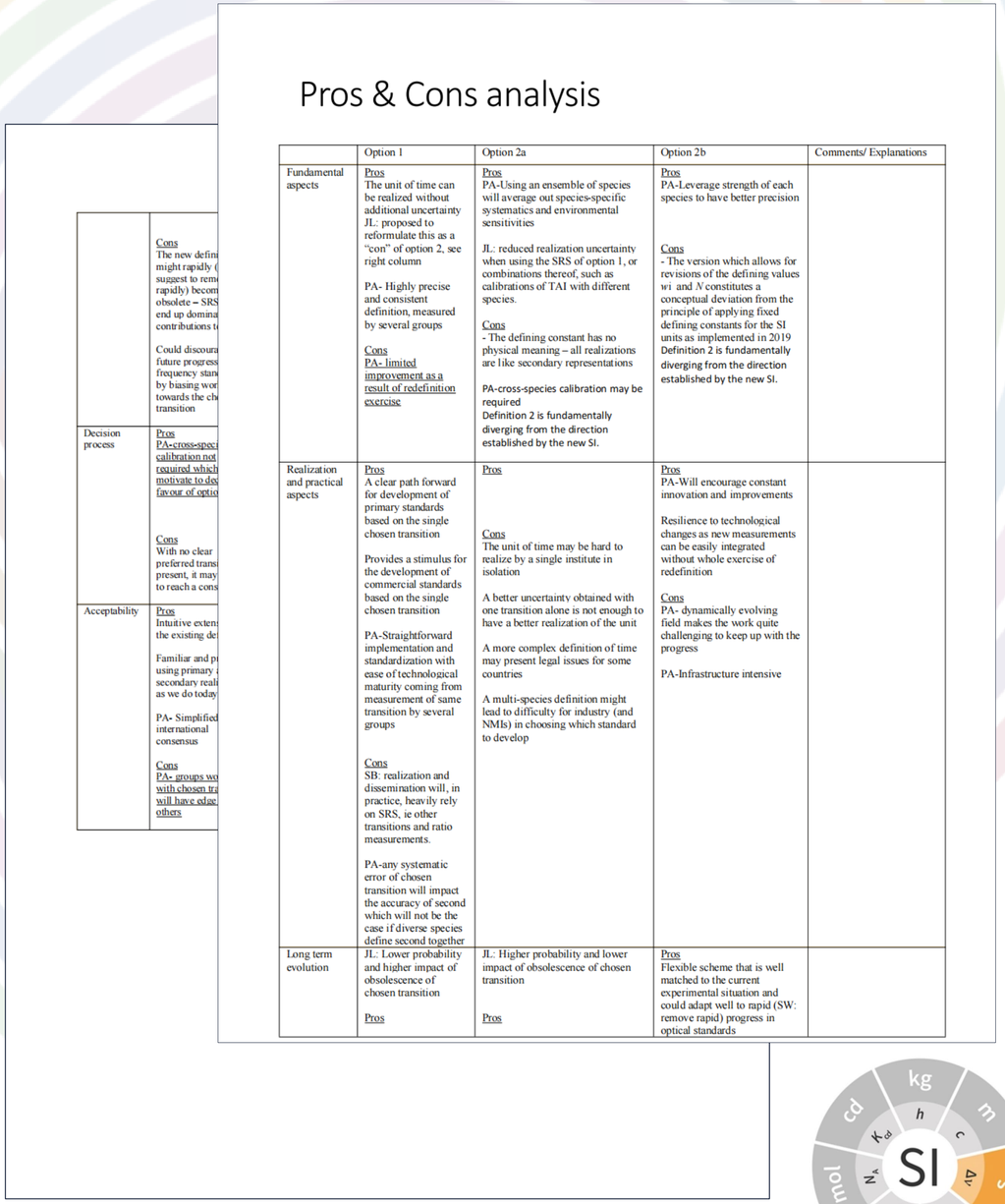
Pros and Cons analysis

- **for different options:**

•Fundamental aspects •Realization and practical aspects
•Long term evolution •Decision process •Acceptability

- **for different species:**

•Basic physical properties •Best uncertainty budget
•Achievable instability •Comparison results
•Number of participating laboratories



Pros & Cons analysis

	Option 1	Option 2a	Option 2b	Comments/ Explanations
Fundamental aspects	Pros The unit of time can be realized without additional uncertainty JL: proposed to reformulate this as a "con" of option 2, see right column PA- Highly precise and consistent definition, measured by several groups Cons PA- limited improvement as a result of redefinition exercise	Pros PA-Using an ensemble of species will average out species-specific systematics and environmental sensitivities JL: reduced realization uncertainty when using the SRS of option 1, or combinations thereof, such as calibrations of TAI with different species. Cons - The defining constant has no physical meaning – all realizations are like secondary representations PA-cross-species calibration may be required Definition 2 is fundamentally diverging from the direction established by the new SI.	Pros PA-Leverage strength of each species to have better precision Cons - The version which allows for revisions of the defining values w_i and N constitutes a conceptual deviation from the principle of applying fixed defining constants for the SI units as implemented in 2019 Definition 2 is fundamentally diverging from the direction established by the new SI.	
Realization and practical aspects	Pros A clear path forward for development of primary standards based on the single chosen transition Provides a stimulus for the development of commercial standards based on the single chosen transition PA-Straightforward implementation and standardization with ease of technological maturity coming from measurement of same transition by several groups Cons SB: realization and dissemination will, in practice, heavily rely on SRS, ie other transitions and ratio measurements. PA-any systematic error of chosen transition will impact the accuracy of second which will not be the case if diverse species define second together	Pros Cons The unit of time may be hard to realize by a single institute in isolation A better uncertainty obtained with one transition alone is not enough to have a better realization of the unit A more complex definition of time may present legal issues for some countries A multi-species definition might lead to difficulty for industry (and NMIs) in choosing which standard to develop	Pros PA-Will encourage constant innovation and improvements Resilience to technological changes as new measurements can be easily integrated without whole exercise of redefinition Cons PA- dynamically evolving field makes the work quite challenging to keep up with the progress PA-Infrastructure intensive	
Long term evolution	JL: Lower probability and higher impact of obsolescence of chosen transition Pros	JL: Higher probability and lower impact of obsolescence of chosen transition Pros	Pros Flexible scheme that is well matched to the current experimental situation and could adapt well to rapid (SW: remove rapid) progress in optical standards	

Monitoring of progress and achievements to evaluate the readiness of species for a redefinition in 2030

c					^{40}Ca+	^{87}Sr	^{88}Sr	^{88}Sr+	^{171}Yb	^{171}Yb+(E3)	^{171}Yb+(E2)	^{199}Hg+	^{27}Al+	^{199}Hg	^{115}In+	^{176}Lu+
				#institutes	1	15	2	6	8	4	5	1	3	2	2	1
		UTC Lab	**CCTF member**	**#systems**	4	25	2	8	13	7	6	1	4	2	2	2
EURAMET	AT	yes		BEV							1					
EURAMET	PL	yes	yes	GUM/UMK			1									
EURAMET	IT	yes	yes	INRIM		1			2							
EURAMET	FR	yes	yes	LNE-OP		2								1		
EURAMET	UK	yes	yes	NPL		2		1	1	1	1					
EURAMET	DE	yes	yes	PTB		2	1	1		4	2		1		1	
EURAMET	SP	yes	yes	ROA		1										
EURAMET	TR	yes	yes	UME/TUBITAK		1										
EURAMET	FI	yes	yes	VTT				1								
APMP	KR	yes	yes	KRISS					1							
APMP	JP	yes	yes	NICT		1									1	
APMP	JP	yes	yes	NMIJ/AIST		1			1							
APMP	JP			RIKEN		1								1		
APMP	CN	yes	yes	NIM		2				1						
APMP	CN	yes		NTSC		1										
APMP	CN			USTC, ECNU		3			2							
APMP	CN			APM, HUST	4				1	1			2			
APMP	SG			CQT												2
SIM	US	yes	yes	NIST/JILA		3		1	3			1	1			
SIM	US	yes	yes	USNO		1										
SIM	CA	yes	yes	NRC				3								
COOMET	RU	yes	yes	VNIIFTRI		3			2							
COOMET	RU			Lebedev							1					
COOMET	RU			ILP							1					
COOMET	RU			MEPhI				1								

Progress and achievement - Status of OFS

Species ordered by ascending transition frequencies	Number of systems / institutes developing OFS	I.1 - OFS accuracy budgets		I.2 - Validation of accuracy budgets		I.3 - Continuity with the current definition		I.4 – Calibration of TAI
		Lowest u_B /1E-18	Number of groups with uncertainty ≲ 2E-18 (+ number with larger uncertainty but ≲ 1E-17)	Same clock comparisons to ≲ 5E-18	Frequency ratio measurements to ≲ 5E-18	Direct measurements vs Cs to <5E-16	SRS recommended uncertainty (CIPM 2025)	Number of calibrations of the TAI scale interval delivered on time the next month
^{40}Ca+ 411 THz	4 systems 1 institute	0.44	1 (+1)	(1 comp. ≲ 7.5E-18)	0 meas. ≲ 5E-18 (1 meas. ≲ 2.4E-16)	2 meas. to <5E-16, 2 meas. close to 5E-16	5.5E-16	
^{87}Sr 429 THz	25 systems 15 institutes	0.81	3(+4)	2 comp. ≲ 5E-18	4 meas. ≲ 5.4E-18 + 2 meas. ≲ 8E-18 (+7 meas.<5E-17)	10 meas. vs Cs to <5E-16	1.7E-16	54 (+35 deflayed) by 5 institutes (most calibrations do not meet the requirement ≤ 2E-16)
^{88}Sr 429 THz	2 institutes 2 systems	20	0 (+0)		0 meas. ≲ 5E-18 (2 meas. ≲ 3E-17)		1.9E-16	
^{88}Sr^{+} 445 THz	8 systems 6 institutes	0.79	1(+2)		0 meas. ≲ 5E-18 (1 meas. ≲ 3E-17)	7 meas. vs Cs to <5E-16	1.7E-16	4 (+23 delayed) by 2 institutes (most calibrations do not meet the requirement ≤ 2E-16)
^{171}Yb 518 THz	13 systems 8 institutes	1.4	2 (+3)	1 comp. ≲ 1E-18	2 meas. ≲ 3.1E-18 (+5 meas. to 8.8E-17)	7 meas. vs Cs to <5E-16	1.7E-16	59 (+59 deflayed) by 4 institutes (most calibrations do not meet the requirement ≤ 2E-16)
^{171}Yb^{+}(E3) 642 THz	7 systems 4 institutes	2.2	2 (+0)	1 comp. ≲ 5E-18 (1 comp. ≲ 8E-18)	2 meas. ≲ 5E-18 (6 meas. ≲ 3.4E-17)	3 meas. vs Cs to <5E-16	1.7E-16	5 (+50 delayed) by 2 institutes (4 meet the requirement ≤ 2E-16)
^{171}Yb+(E2) 688 THz	6 systems 5 institutes	33	0 (+0)		0 meas. ≲ 5E-18 (2 meas. ≲ 3.4E-17)	2 meas. vs Cs close to 5E-16	1.9E-16	
^{199}Hg+ 1065 THz	1 system 1 institute	19	0 (+0)		0 meas. ≲ 5E-18 (1 meas. ≲ 5.2E-17)	1 meas. vs Cs at 6.5E-16	2.5E-16	
^{27}Al^{+} 1121 THz	4 systems 3 institutes	0.55	2 (+0)		2 meas. ≲ 5E-18 (1 meas. ≲ 5.2E-17)	2 meas. vs Cs to <5E-16	1.9E-16	
^{199}Hg 1129 THz	2 systems 2 institute	54	0 (+0)		0 meas. ≲ 5E-18 (6 meas. ≲ 1E-16)	1 meas. vs Cs to <5E-16	2.5E-16	
^{115}In+ 1267 THz	2 systems 2 institute	2.5	1 (+0)		1 meas. ≲ 5E-18 (1 meas. ≲ 2.9E-17)	2 meas. vs Cs to <5E-16	1.8E-16	

4 Possibilities for the new definition

Option 1 (single species)			Option 2 (ensemble of species)
^{87}Sr	^{171}Yb	$^{171}Yb^{+}$ (E3)	^{87}Sr, ^{171}Yb, $^{171}Yb^{+}$ (E3), $^{40}Ca^{+}$, $^{88}Sr^{+}$, $^{27}Al^{+}$, (Cs?)
~25 systems in ~15 institutes	**~13 systems in ~8 institutes**	**~7 systems in ~4 institutes**	**~61 systems in ~20 institutes**
EURAMET: 9 systems in 6 institutes APMP: 9 systems in 6 institutes SIM: 4 systems in 2 institutes COOMET: 3 systems in 1 institute	EURAMET: 3 systems in 2 institutes APMP: 5 systems in 4 institutes SIM: 3 systems in 1 institute COOMET: 2 systems in 1 institute	EURAMET: 5 systems in 2 institutes APMP: 2 systems in 2 institutes	EURAMET: 21 systems in 7 institutes APMP: 22 systems in 8 institutes SIM: 12 systems in 3 institutes COOMET: 6 systems in 2 institutes

- Sr, Yb, Yb^{+}(E3): Fully/partially meet criteria: accuracy budget, validation, continuity with current definition, TAI calibration
- Ca^{+}, Sr^{+}, Al^{+} : 1-2 criteria unmet
- Cs: Current definition, widely used

No Clear Best Choice Yet

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Option 1 (single species)			Option 2 (ensemble of species)
^{87}Sr	^{171}Yb	$^{171}Yb^{+}$ (E3)	^{87}Sr, ^{171}Yb, $^{171}Yb^{+}$ (E3), $^{40}Ca^{+}$, $^{88}Sr^{+}$, $^{27}Al^{+}$, (Cs?)
~25 systems in ~15 institutes	**~13 systems in ~8 institutes**	**~7 systems in ~4 institutes**	**~61 systems in ~20 institutes**
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No Clear Best Choice Yet

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Future plans

- **Monitor & analyse candidates**
  - Track lab progress across all species and options
  - Follow clock comparisons to validate the uncertainty evaluations
  - Monitor clock contributions to TAI
- **More meetings & discussions on**
  - Pros & Cons of 4 proposed possiblities
  - Implementation on/after redefinition
  - Evolution of UTC time scale after redefinition

→ **One single choice of the preferred option and species by 2030**

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

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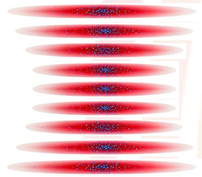
Thank you
for your attention

No Clear Best Choice Yet

- Rapid progress across the field: Decision Remains Open

OPTION 1 · SINGLE ATOMIC TRANSITION - All species have both strengths & weakness

Neutral-atom lattice clocks



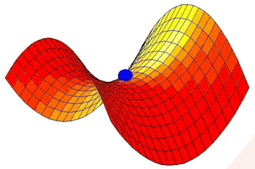
STRENGTHS

- Many labs actively working on Sr, Yb
- Excellent stability

WEAKNESSS

- Sensitive to envirements (T, light)
- Intercomparison agreement not yet fully consistent

Ion clocks



STRENGTHS

- Several ion species are intrinsically temperature-insensitive
- Sr+ and Yb+ comparisons show good agreement

WEAKNESSS

- Field is diverse, no single species widely adopted
- Single-ion instability is inherently poorer

OPTION 2 · MULTI-CLOCK ENSEMBLE

Combining several optical clocks is conceptually attractive, but it is difficult for the public and users to accept.

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For now, there is no single, self-evident best decision.

