

Achievements and Future Research Directions of the Temperature Measurement Standards at KRISS

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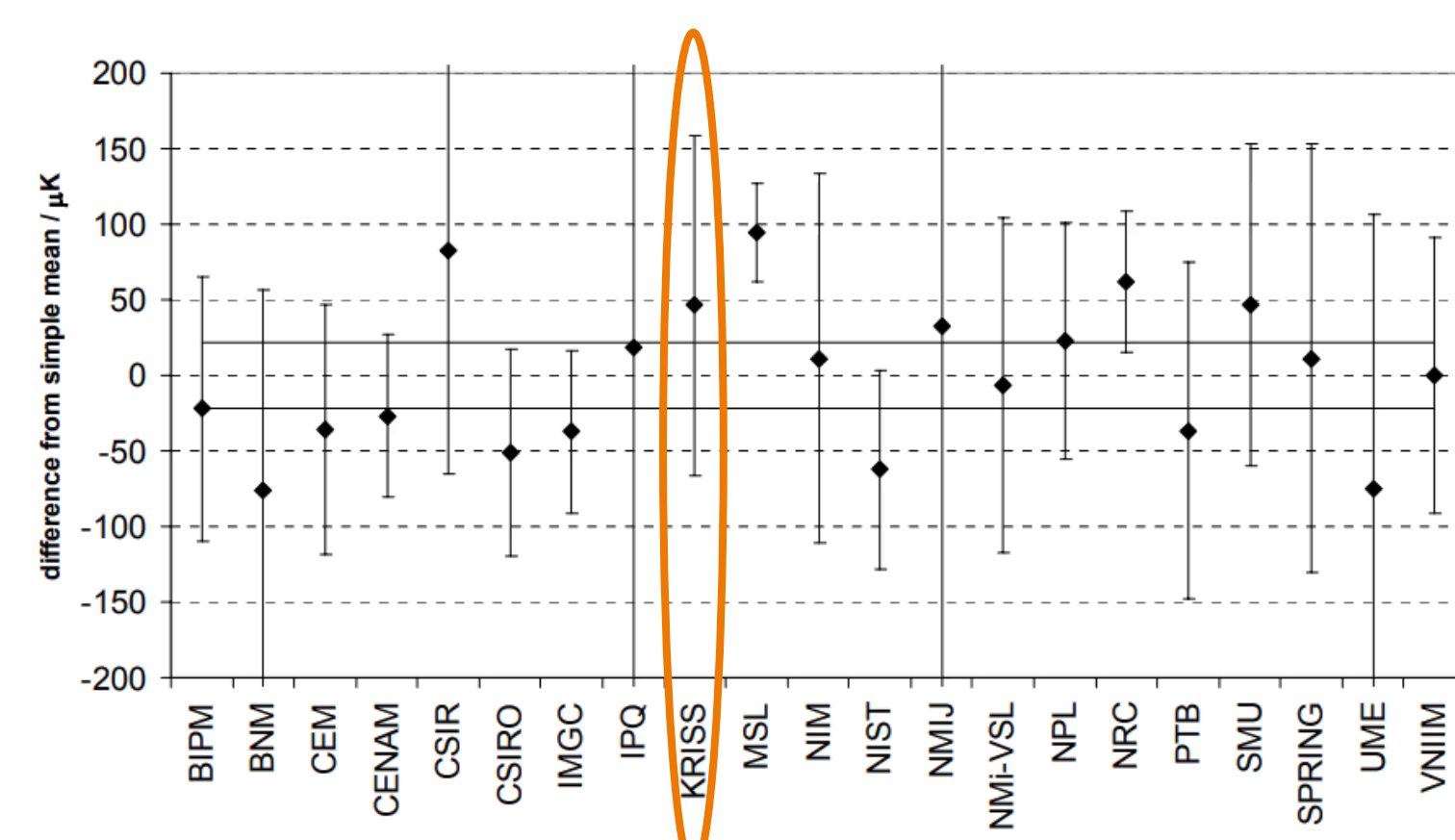
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Abstract

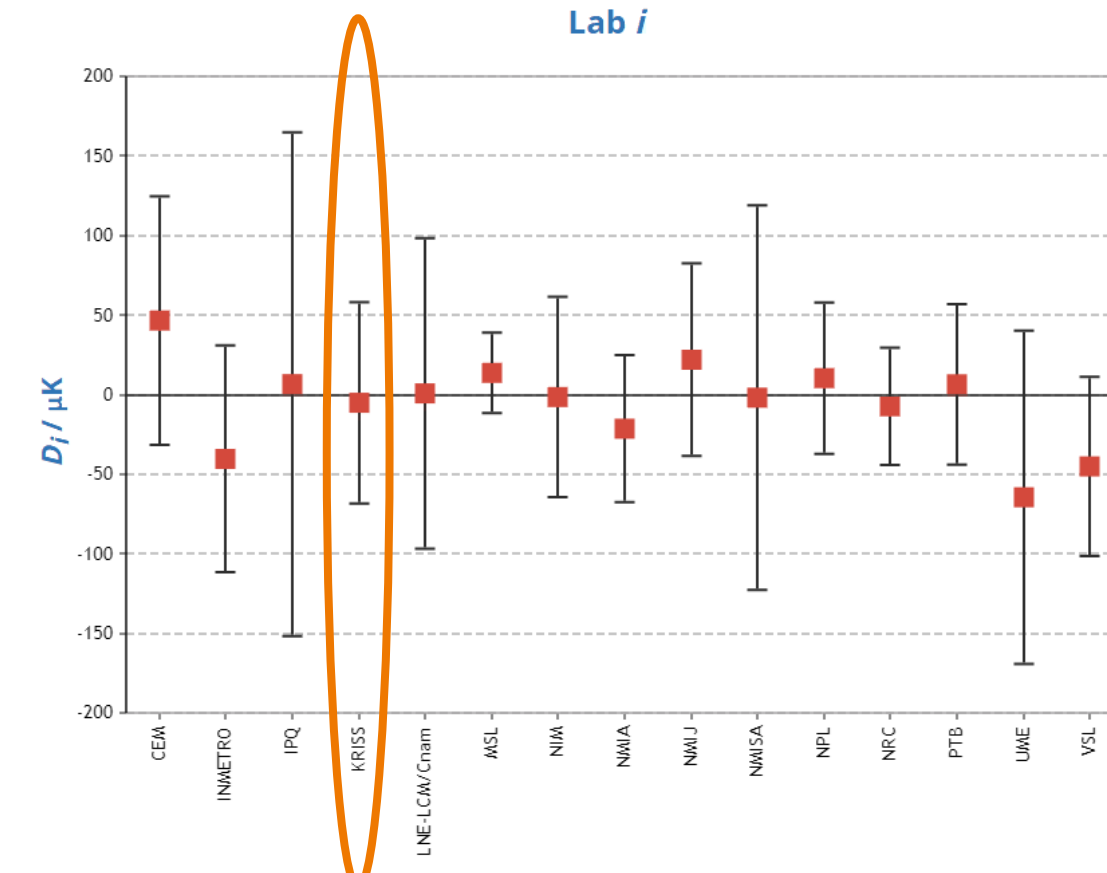
- **Participation in key comparisons (KCs) for the realization of the International Temperature Scale of 1990 (ITS-90)**
 - Involved in KCs CCT-K2, K3, K4, and K7 since the beginning of the MRA
 - Led APMP comparisons linked to CCT-K3, K4, and K7
- **Recent key comparisons in thermometry**
 - Participated in CCT-K9 and CCT-K7.2021, achieving excellent results
 - Leading APMP comparisons linked to CCT-K9 and K7.2021
- **Contribution to the redefinition of the kelvin**
 - Resolved discrepancies in the acoustic determinations of the Boltzmann constant in 2015 by the measurement of the molar mass of argon
- **Future research directions**
 - Ongoing work on thermodynamic temperature realization using acoustic gas thermometry.
 - Standard uncertainty <3 mK, plans to extend the temperature range.

Key comparisons in thermometry

- **CCT-K7 (published in 2006) and CCT-K7.2021 (published in 2023)**
 - Key comparisons on the realization of the triple point of water temperature (273.16 K), piloted by NRC, Canada
 - KRISS has participated in both the original (CCT-K7) and subsequent (CCT-K7.2021) comparisons, 17 years apart.
 - CCT-K7: difference to the KCRV $D_i = +47 \mu\text{K}$ with the expanded uncertainty of $115 \mu\text{K}$ [1]
 - CCT-K7.2021: $D_i = -4.7 \mu\text{K}$ with expanded uncertainty of $63.2 \mu\text{K}$ [2]
 - **Tenfold improvement in terms of D_i , twofold improvement in terms of its uncertainty**



<Result of CCT-K7 comparison (KRISS result highlighted) [1]>



<Result of CCT-K7.2021 comparison (KRISS result highlighted) [2]>

CCT-K3 & CCT-K4 and CCT-K9

- Key comparisons on the calibration of SPRTs in the range between the triple point of argon (83.8058 K) and the freezing point of silver (1234.93 K) (long-stem SPRT and high-temperature SPRT range)
- the most recent KC for SPRT calibration (CCT-K9, from Ar to Zn, piloted by NIST), the results from KRISS show consistent measurements with the KCRV at every fixed point involved [3].
- **Due to these good results, KRISS is being considered as the candidate for the next round KC in this temperature range by the CCT-WG-KC**
- **Linking CCT comparison to the RMO: APMP comparisons**
 - APMP.T-K3: KRISS provided link
 - APMP.T-K3.4: piloted by KRISS
 - APMP.T-K4: piloted by KRISS
 - APMP.T-K4.2: piloted by KRISS
 - APMP.T-K7.2021: piloted by KRISS

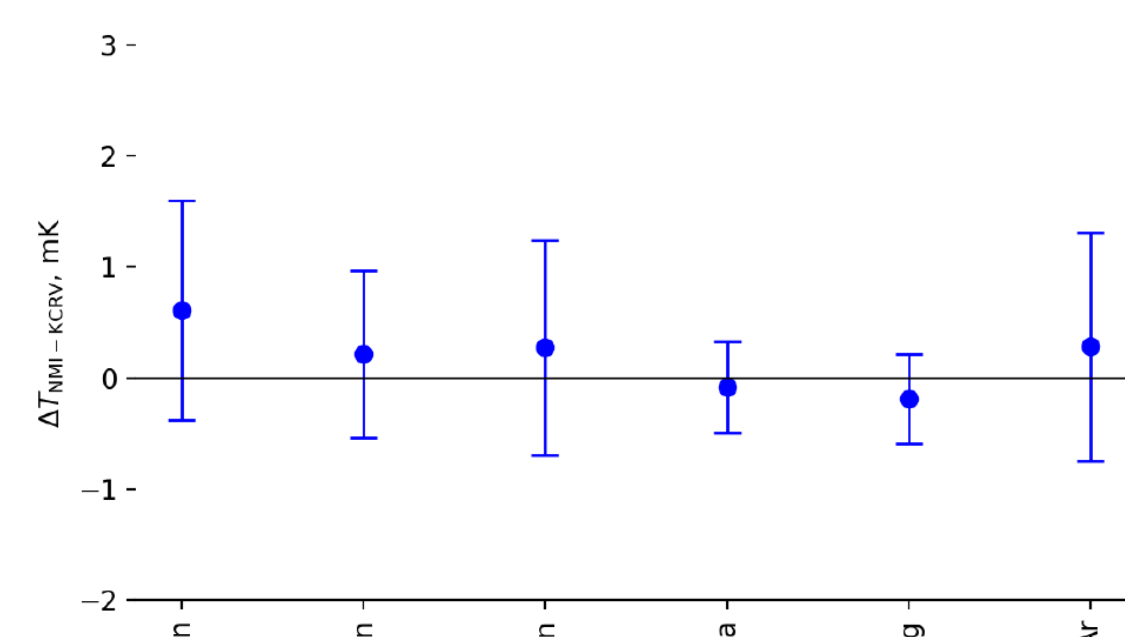


Figure 5.11: Deviation of ΔT_{901} from ΔT at each fixed-point measured at KRISS.
<Difference between KRISS result and the KCRV of the CCT-K9>

Important thermometry CMCs registered at the KCDB

- **KRISS CMCs for the realization of the ITS-90**
 - 31 CMCs of fixed-point cells, SPRT at fixed points, and SPRT subranges from 24.5561 K to 1234.93 K
 - These CMCs are supported by the CCT key comparisons CCT-K4, CCT-K7, and CCT-K9 (CCT-K7.2021 result has not been used yet.)
 - Other CMCs in contact thermometry: 10 CMCs in thermocouples, 7 in industrial platinum resistance thermometers, 1 in air temperature sensors

Reference

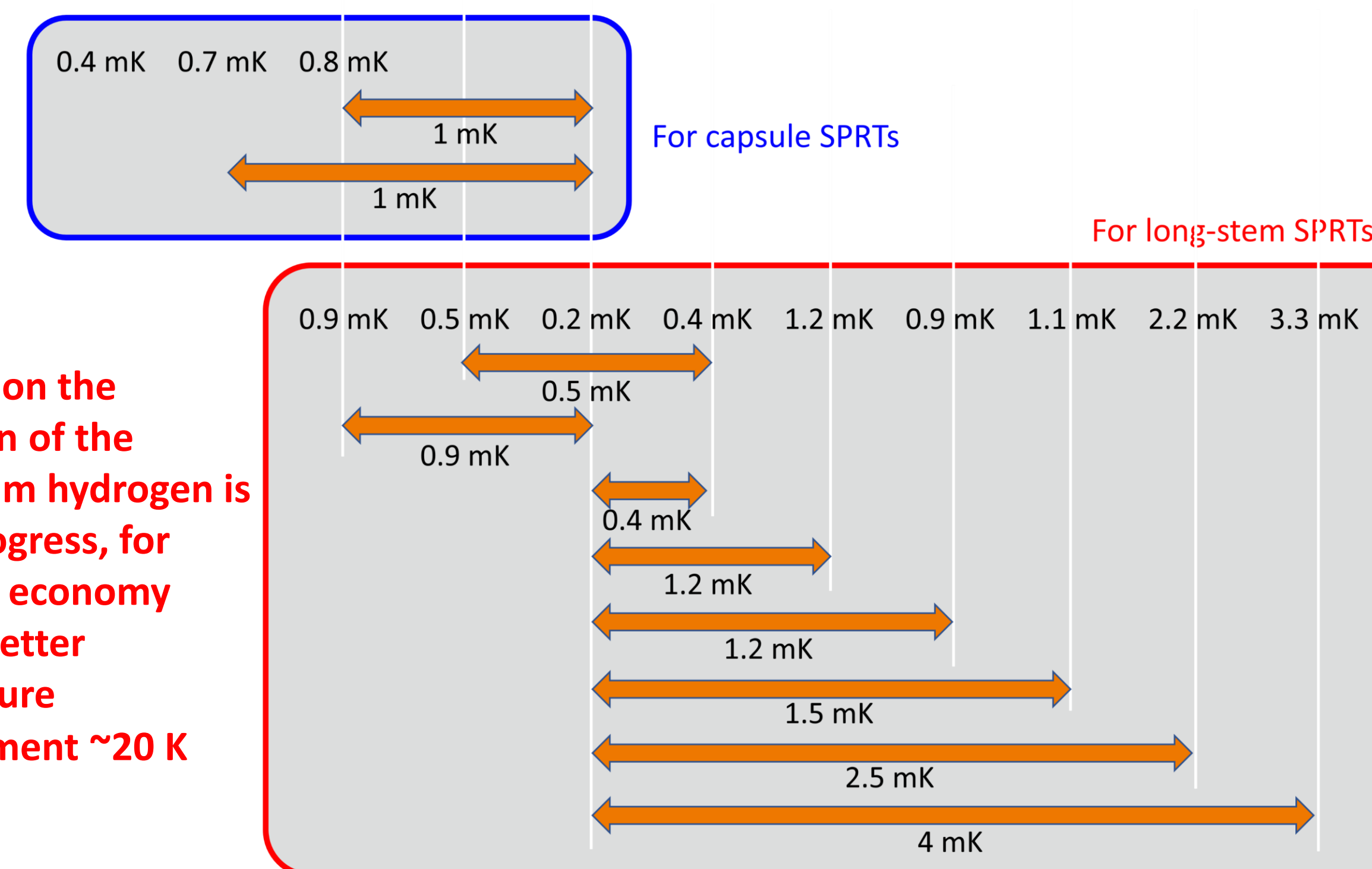
- [1] M Stock *et al* 2006 *Metrologia* **43** 03001
- [2] A Peruzzi *et al* 2023 *Metrologia* **60** 03002
- [3] T Herman *et al* 2023 *Metrologia* **60** 03001

- [4] I Yang *et al* 2015 *Metrologia* **52** S394
- [5] D B Newell *et al* 2018 *Metrologia* **55** L13
- [6] I Yang *et al* 2018 *Meas. Sci. Technol.* **29** 075013

List of Acronyms (alphabetical order)

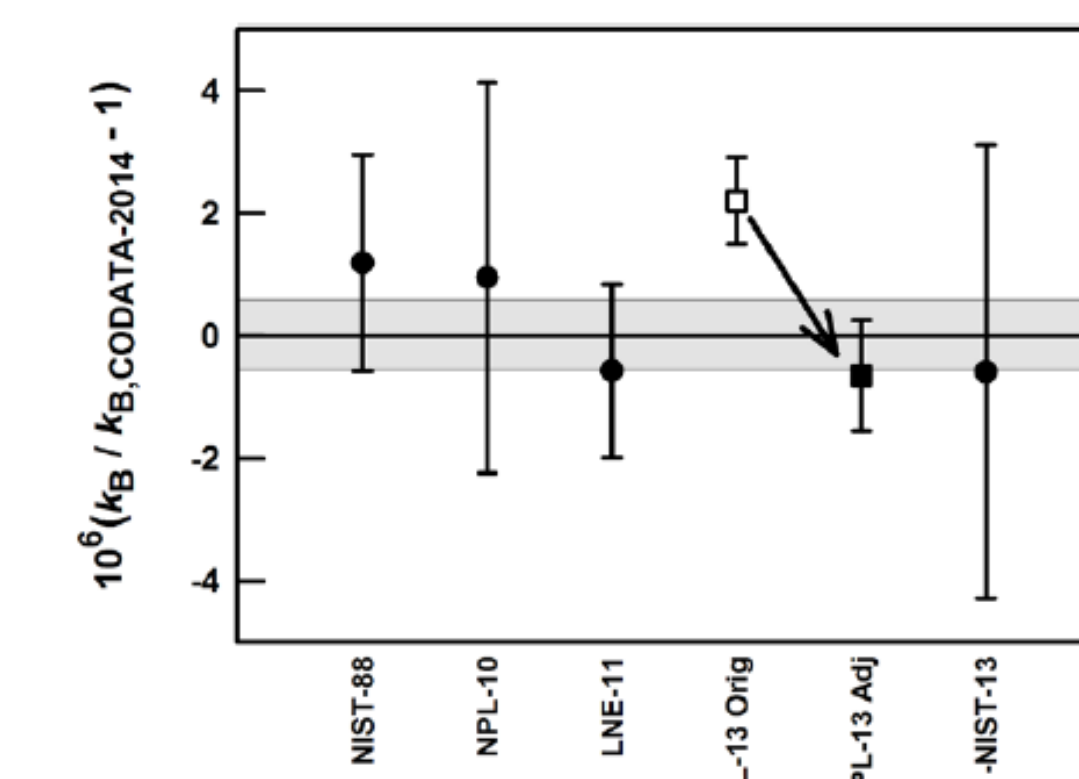
EPM: European Partnership in Metrology
KCRV: key comparison reference value
MRA: mutual recognition arrangement

Fixed points in the ITS-90 e-H₂ Ne O₂ Ar Hg TPW Ga In Sn Zn Al Ag

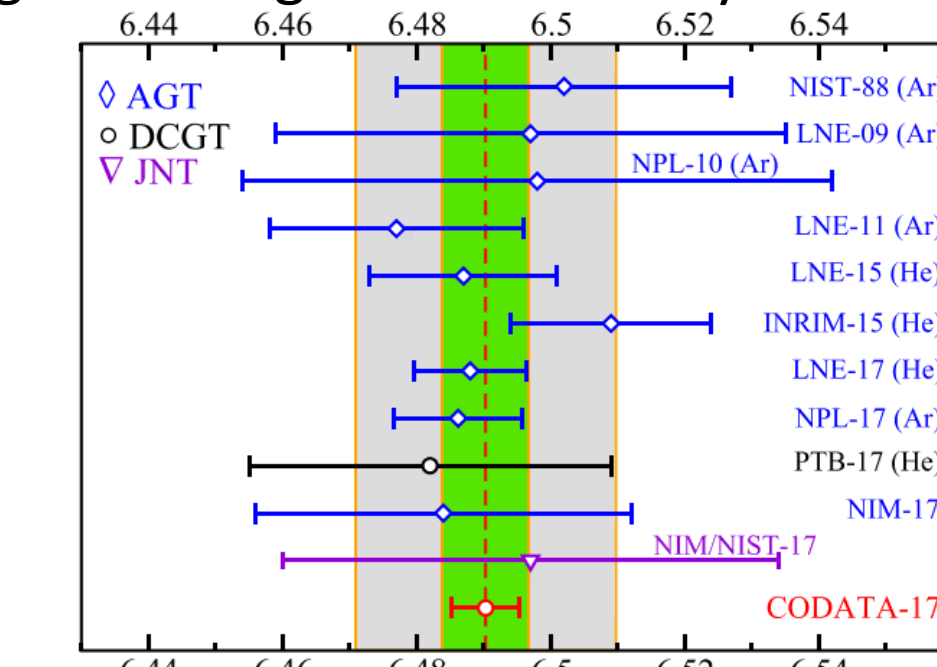


Contribution to the Determination of the Boltzmann constant

- **Improvement of acoustic determinations of the Boltzmann constant k for the redefinition of the kelvin**
 - Determination of k with an uncertainty less than 10^{-6} was necessary for the redefinition of the kelvin (unit of thermodynamic temperature).
 - Around 2014, two determinations of k with the best uncertainties differed by more than the combined uncertainty of the two (2.77×10^{-6}), potentially jeopardizing the planned redefinition of the kelvin.
 - KRISS mass spectrometry measurement revealed the cause of the discrepancy lay in the determination of the molar mass of argon used in the k determination, completely eliminating the discrepancy, thus making the redefinition of the kelvin possible [4].
 - The published paper was selected as *Metrologia* Highlight of 2015.



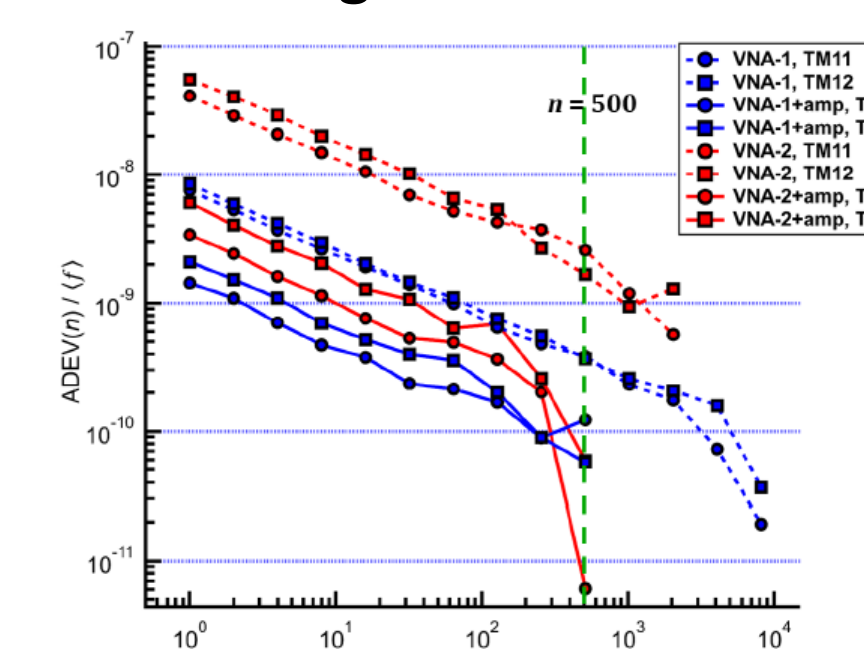
<Contribution of KRISS argon molar mass measurement in the determination of k using acoustic gas thermometry>



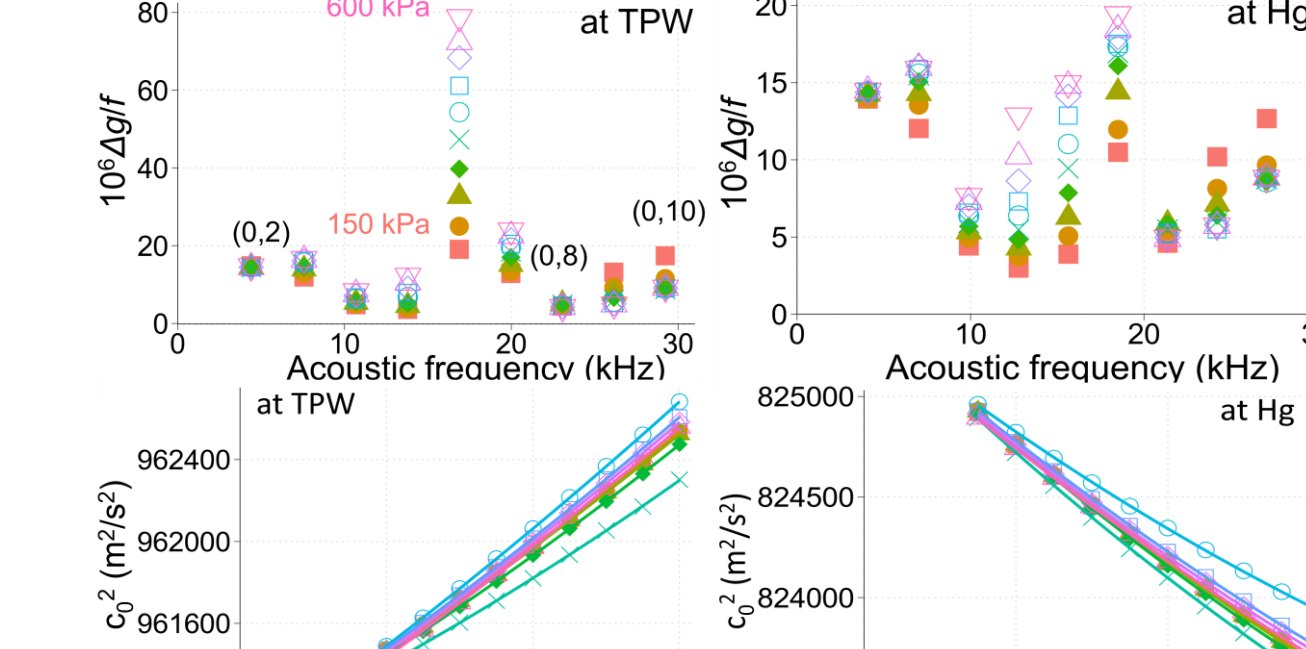
<CODATA-2017 special adjustment of k [5]>

Acoustic gas thermometry and thermodynamic temperature measurement

- **Contribution to the primary thermometry after the redefinition of the kelvin**
 - Innovative work in the microwave resonance measurement in QSR using lost-cost VNA and microwave amplifier [Yang18]
 - Determination of microwave resonance frequency with a relative uncertainty below 10^{-9} became possible and is now used in both acoustic gas thermometry and refractive index gas thermometry
- **Acoustic gas thermometry at KRISS**
 - Thermodynamic temperature measurement using acoustic gas thermometry with a copper QSR of nominal radius of 50 mm
 - Temperature control using (1) liquid-free cryostat, (2) LN₂-cooled ethanol bath, (3) water bath, and (4) electric furnace
 - Participating in the EPM project Dissemination of the Redefined Kelvin (DireK-T) as an official collaborator
 - Will take part in the direct comparison of the realization of thermodynamic temperature in the range between 173.15 K and 302.9146 K



<Relative uncertainty in determination of resonance microwave frequency in quasi-spherical resonator [6]>



<Excess half-width and speed-of-sound measurement in the KRISS acoustic gas thermometer>



low temperature high temperature
<Acoustic gas thermometry setup at KRISS>



KRISS

BIPM 150
1875-2025