

Single-pressure refractive-index gas thermometry below 25K

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1. INTRODUCTION

Since 2019, the base units of International System of Units have been redefined using universal constants. For the unit of thermodynamic temperature, the kelvin was redefined by fixing the value of the Boltzmann constant. This change allows for more accurate temperature measurements below 25K, which is crucial for metrology and various fields like frontier science, space science, and medical science. To implement the new kelvin below 25 K, the Consultative Committee for Temperature recommends three gas thermometry methods: acoustic gas thermometry, dielectric-constant gas thermometry, and refractive-index gas thermometry. Researchers, from LNE-CNAM, INRiM, PTB, NRC and TIPC-CAS, have made significant progress in this field.

To this end, TIPC-CAS and LNE-CNAM joint lab have jointly proposed a novel Single-pressure refractive-index gas thermometry technique, which we called SPRIGT. Based on this method, our joint lab has made substantial progress on thermodynamic temperature measurements below 25 K with uncertainties better than 0.17 mK, presenting a very promising picture.

2. Theory of SPRIGT [1]

➤ Virial equation $p = \rho k N_A T [1 + B(T)\rho + C(T)\rho^2 + \dots]$

$$\text{RIGT} \begin{cases} \square \text{ Lorentz-Lorenz equation} & T \approx \frac{3A_\epsilon p}{kN_A [n^2(T, p) - 1]} \\ \square n^2 \text{ can be estimated by the ratio of resonance frequencies} & n^2(T, p) \approx \left(\frac{(f_m)_{T,0}}{(f_m)_{T,p}} \left(1 + \frac{\kappa_T}{3} p \right) \right)^2 \end{cases}$$

SPRIGT $\square$ If p is fixed at 2 temperatures

$$\frac{T}{T_{\text{ref}}} \approx \frac{n^2(T_{\text{ref}}, p) - 1}{n^2(T, p) - 1}$$

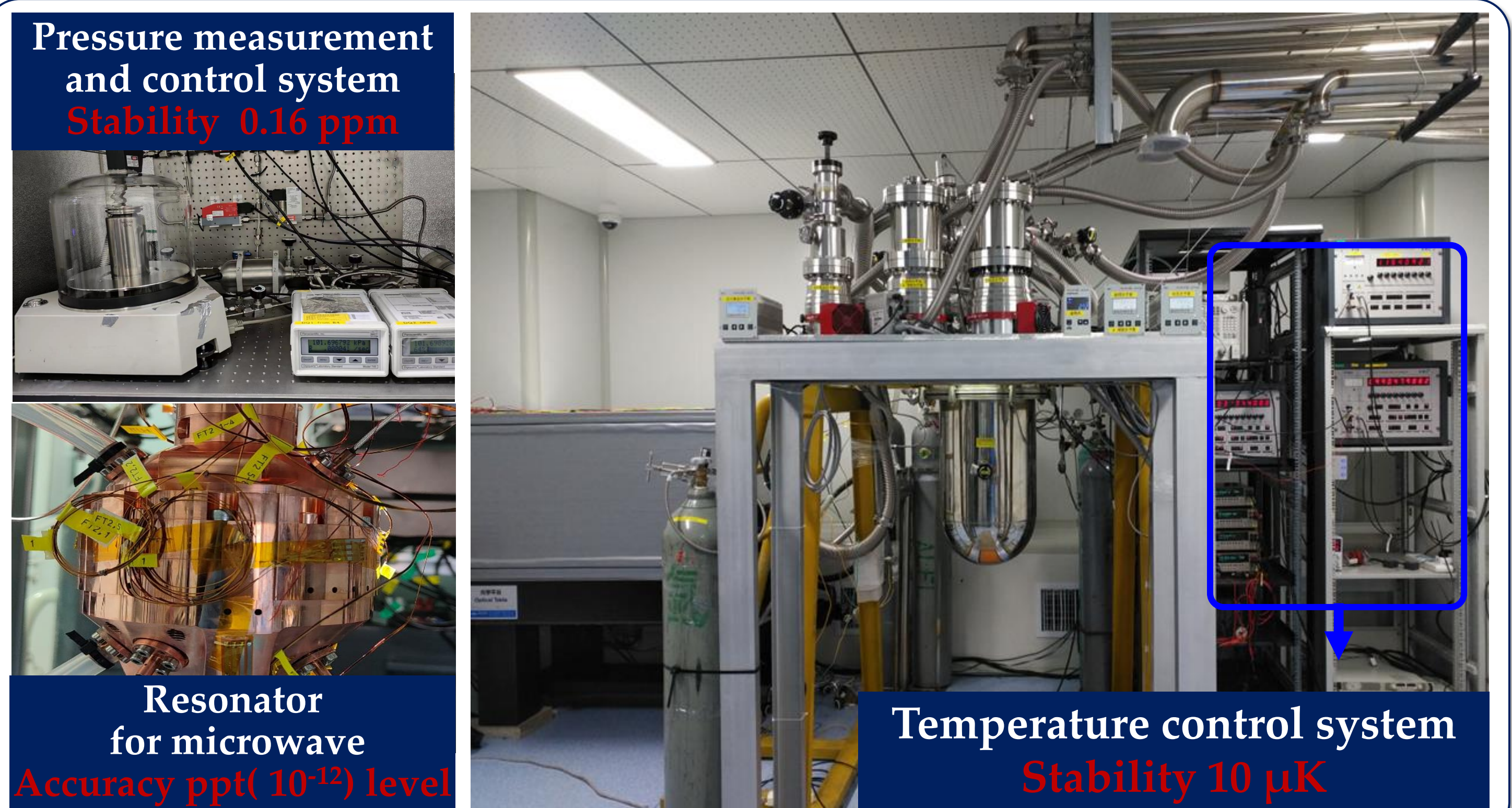
➤ Advantage

1. Ratio is used to reduce the absolute pressure and κ_T effect
2. Advance of the "ab initio" calculation of gas thermal-properties
3. High-accuracy of microwave resonance frequency

SPRIGT has the potential to realize high-accuracy T measurement

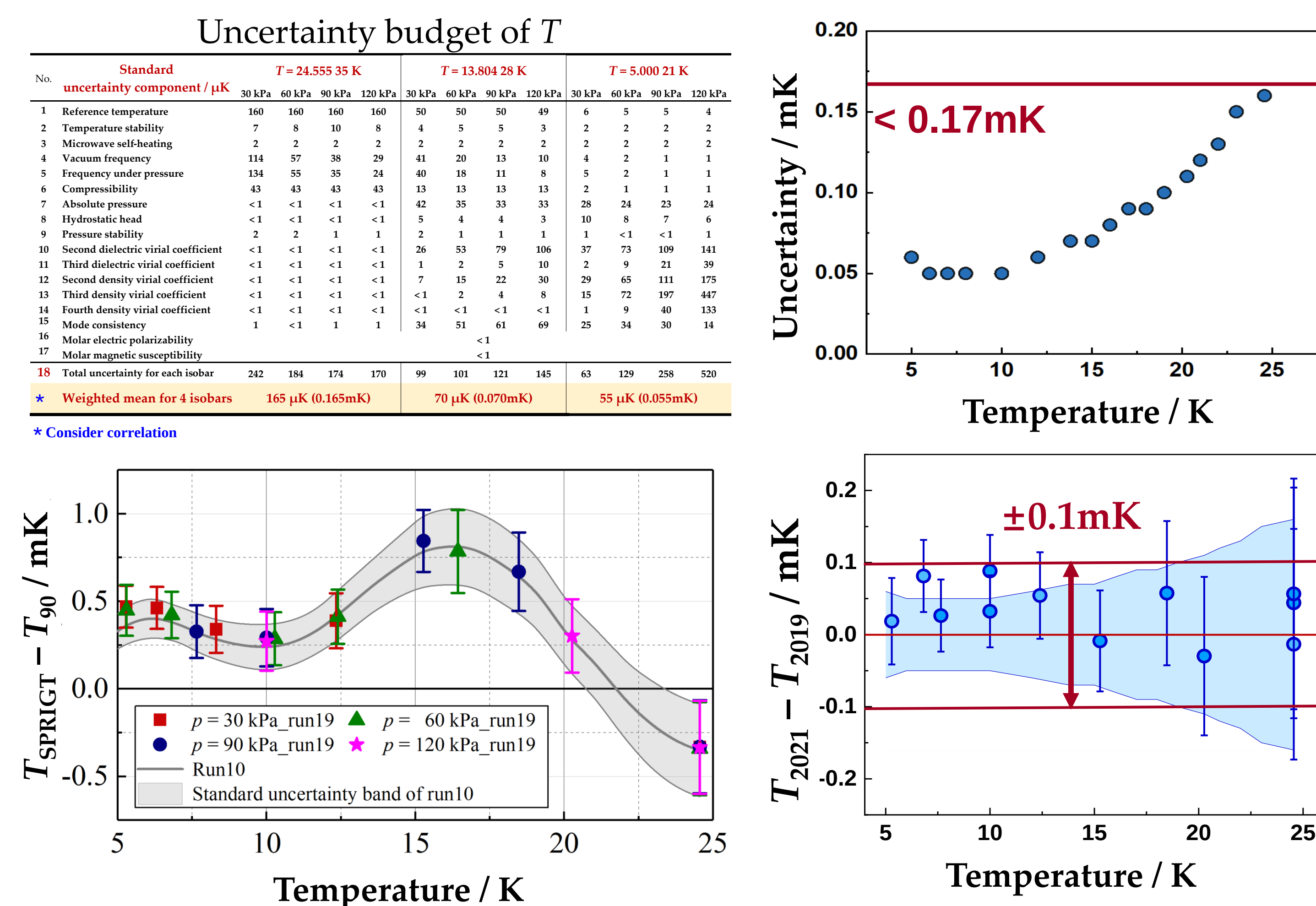
3. SPRIGT system

The first SPRIGT system at TIPC-CAS, which can measure thermodynamic temperatures T from 5 K to 25 K



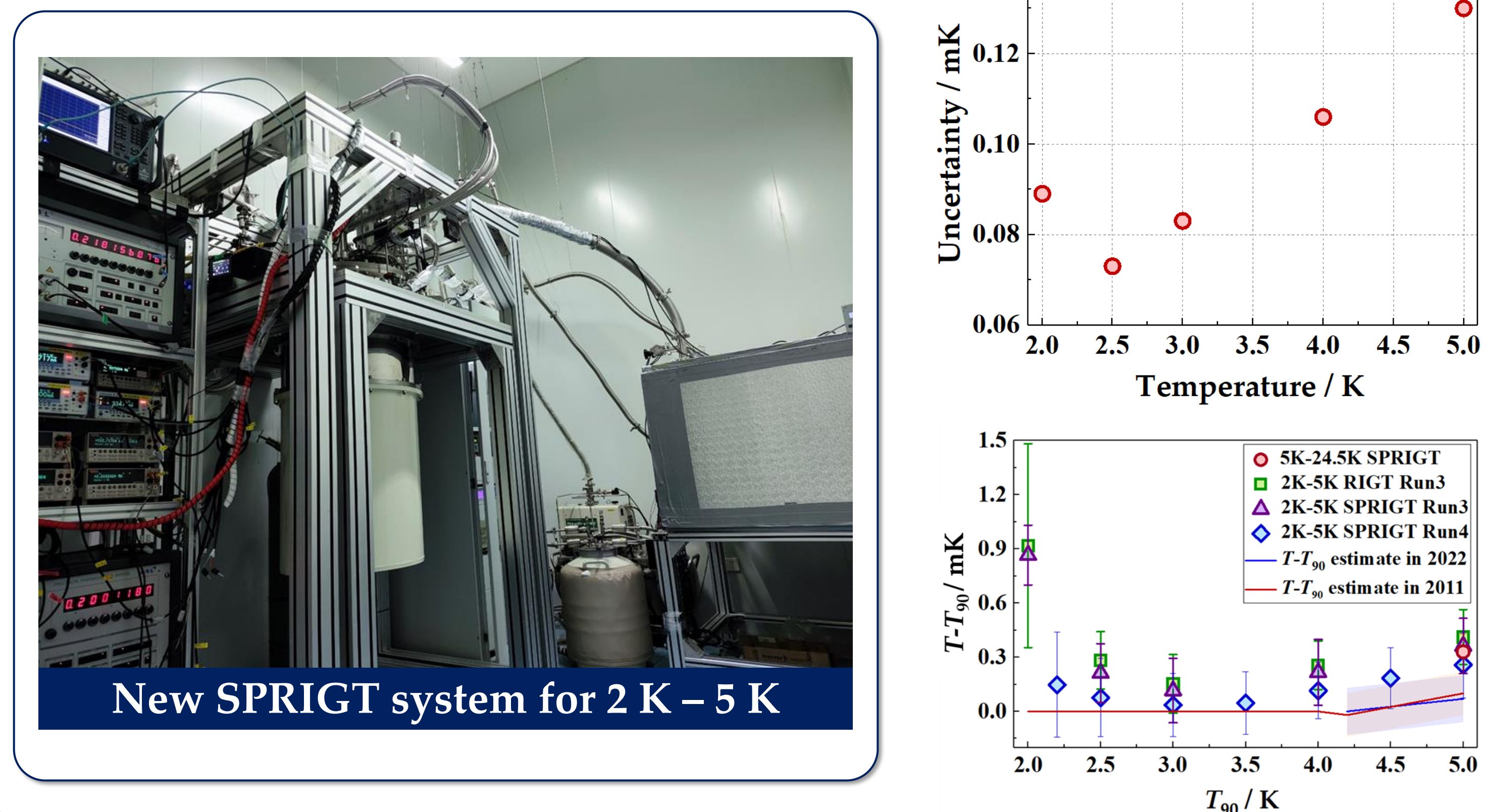
4. Results of SPRIGT in 5K-25K

The total standard uncertainty of thermodynamic temperature is **better than 0.17mK for 5K-24.5K** [2, 3], which is the lowest uncertainty in this temperature range so far. Furthermore, we repeated these measurements 2.5 years later, in 2021, and found good repeatability of $T_{\text{SPRIGT}} - T_{90}$ and T with difference **within $\pm 0.1\text{mK}$** [4].



5. Preliminary results of SPRIGT in 2K-5K

We have redesigned a new SPRIGT system with a GM cryocooler and a closed-cycle helium-4 Joule-Thomson cryocooler. Our preliminary uncertainty budget for 2K to 5K suggests a combined standard uncertainty **better than 0.13mK**. And the preliminary $T - T_{90}$ data from 2K to 5K looks promising. Each point is measured at several pressures. For example, at 2K, we only use pressures below 1.5 kPa, about half of the vapor pressure, to avoid possible condensation. We are continuously testing for repeatability and verifying the accuracy of these data.



4. CONCLUSION

SPRIGT is one promising primary gas thermometry to implement the new kelvin below 25K, which has been realized down to 2 K preliminarily at TIPC-CAS. Our work should provide valuable input data for any future revisions of the International Temperature Scale. In future, SPRIGT still has potential to be used for even lower temperature measurements by using helium-3 working gas and improving the accuracy of low-pressure measurements.

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