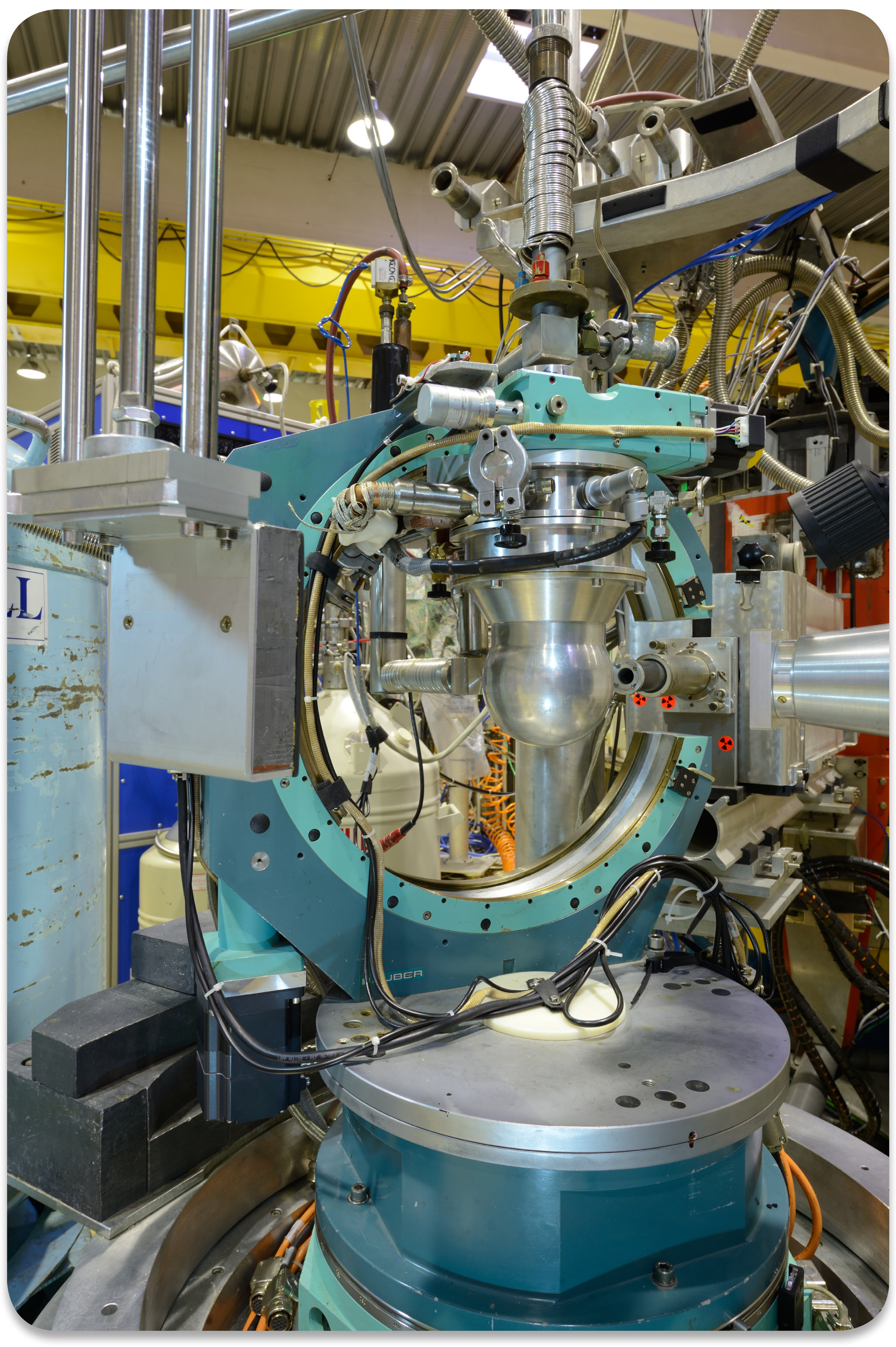
100 mK Closed-Cycle 4-Circle Dilution Cryostat

N. Belkhier, Ph. Decarpentrie, J. Gonthier, E. Lelièvre-Berna, P. Martin, B. Ouladdiaf, X. Tonon — ILL
Ph. Camus, G. Donnier-Valentin, G. Garde, Y. Launay, O. Tissot — Institut Néel, CNRS



The closed-cycle dilution refrigerator mounted on the cradle of D10. © Ecliptique – Laurent Thion

The full determination of magnetic ground states is a key point in understanding the fundamental properties of magnetic materials. The determination of the magnetic structure factors requires access to the three dimensions of reciprocal space using single-crystal four-circle geometry.

A four-circle dilution cryostat that avoids the influence of gravity by using a capillary dilution chamber was developed [1,2] for experiments down to 100 mK. This system was successfully used on D10 for several years but it did present certain disadvantages: autonomy was limited to several hours, the re-distillation of the ^{3}He was done off-site, and temperature stability was difficult to maintain when rotating the φ shaft.

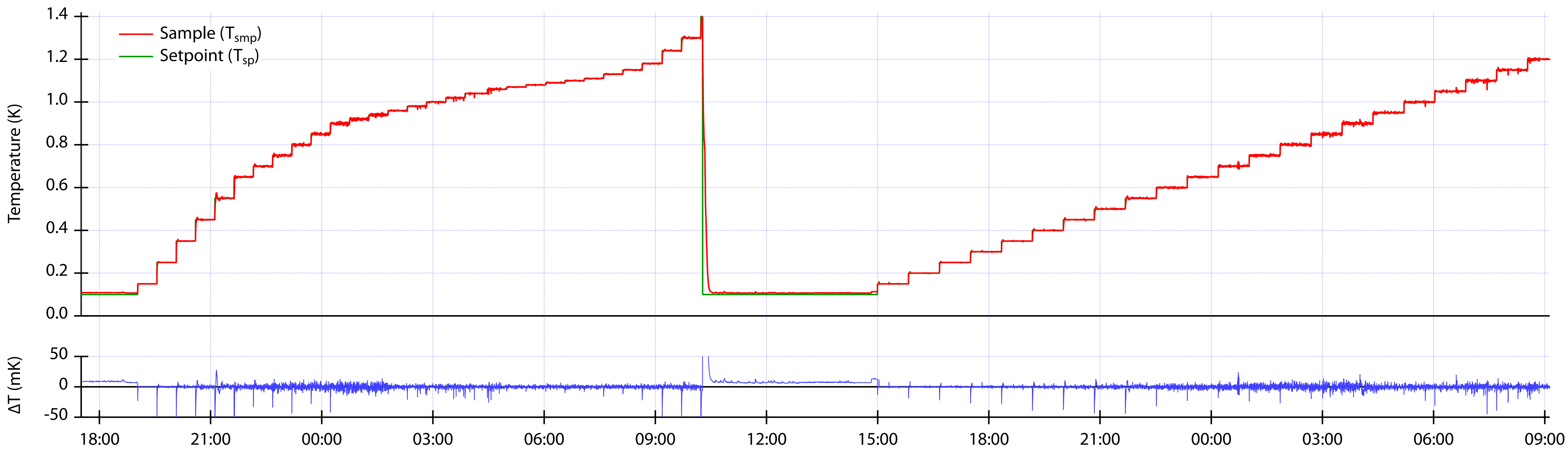
For applications where the system has to support a random position on the earth or even for space applications, a gravity-independent dilution refrigerator can be made by directly mixing the two isotopes in narrow capillaries. The key idea of the dilution process is to inject and mix ^{3}He and ^{4}He isotopes through two capillaries in a Y-junction, and to recover the mixture through a third capillary.

At low temperature (< 0.1 K), the dilute phase has a finite solubility of ^{3}He of 6.6 %. If the ^{3}He concentration exceeds this value, not all ^{3}He is diluted and some stays in the ^{3}He-rich phase, forming ^{3}He droplets. In this design, the ^{3}He-rich phase droplets fill the cross-section of the capillaries where the capillary forces play the role of gravity.

The complex automated gas-handling system of the closed-cycle dilution system on D10. © Ecliptique – Laurent Thion

Once mixed in the dilution refrigerator, the ^{4}He and ^{3}He are pumped at low pressure and processed in the isotope separation system. The continuous separation process is still based on conventional dilution at about 0.8 K, where the ^{3}He concentration in the vapour is about 95%. In this process, originally developed for space applications [4], the ^{4}He is extracted by a fountain pump exploiting the unique superfluid properties of this isotope.

The fully automated gas-handling system shown above was developed in order to operate the isotope separation system. The flows required for the dilution refrigerator are regulated by two mass flow controllers: about 20 cc/min ^{3}He and 40 cc/min ^{4}He. The gases are then recompressed to the required dilution-refrigerator inlet pressure of about 2 bar.



Temperature stability of the new closed-cycle dilution system commissioned on D10. The inset shows temperature steps performed during the experiment.

[1] A. Benoît and S. Pujol, "A dilution refrigerator insensitive to gravity", *Physica B* **169** (1991) 457 — [2] A. Benoît, M. Caussignac and S. Pujol, "New types of dilution refrigerator and space applications", *Physica B* **197** (1994) 48 — [3] S. Triqueneaux, L. Sentis, Ph. Camus, A. Benoit and G. Guyot, "Design and performance of the dilution cooler system for the Plank mission ", *Cryogenics* **46** (2006) 288 — [4] Ph. Camus, G. Vermeulen, A. Volpe, S. Triqueneaux, A. Benoit, J. Butterworth, S. d'Escrivan and T. Tirolien, "Status of the Closed-Cycle Dilution Refrigerator Development for Space Astrophysics", *J. of Low Temp. Physics* **176**, 5-6, (2014) 1069

Institut Laue Langevin, 71 avenue des Martyrs, CS 20156, 38042 Grenoble Cedex 9, France — sane@ill.eu — http://www.ill.eu/sane
Institut Néel - CNRS/UJF, 25 avenue des Martyrs, BP 166, 38042 Grenoble Cedex 9, France — neel.contact@neel.cnrs.fr — http://neel.cnrs.fr

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