Mass Flux Stability at the T_d Transition in Solid ^{3}He-^{4}He Mixtures

Yegor Vekhov and R.B. Hallock

Laboratory for Low Temperature Physics, Department of Physics
University of Massachusetts, Amherst, MA 01003, USA
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Abstract

Measurements of the ^{4}He mass superflux through a cell filled with solid ^{3}He-^{4}He mixtures in the ^{3}He concentration range $0.17 - 220$ ppm have demonstrated a reversible dramatic decrease in the flux on cooling through a concentration-dependent temperature T_d, close to the mixture phase separation temperature. On cooling, the flux decrease transition is complete within 2 mK. We report on the stability of the flux in this transition region.
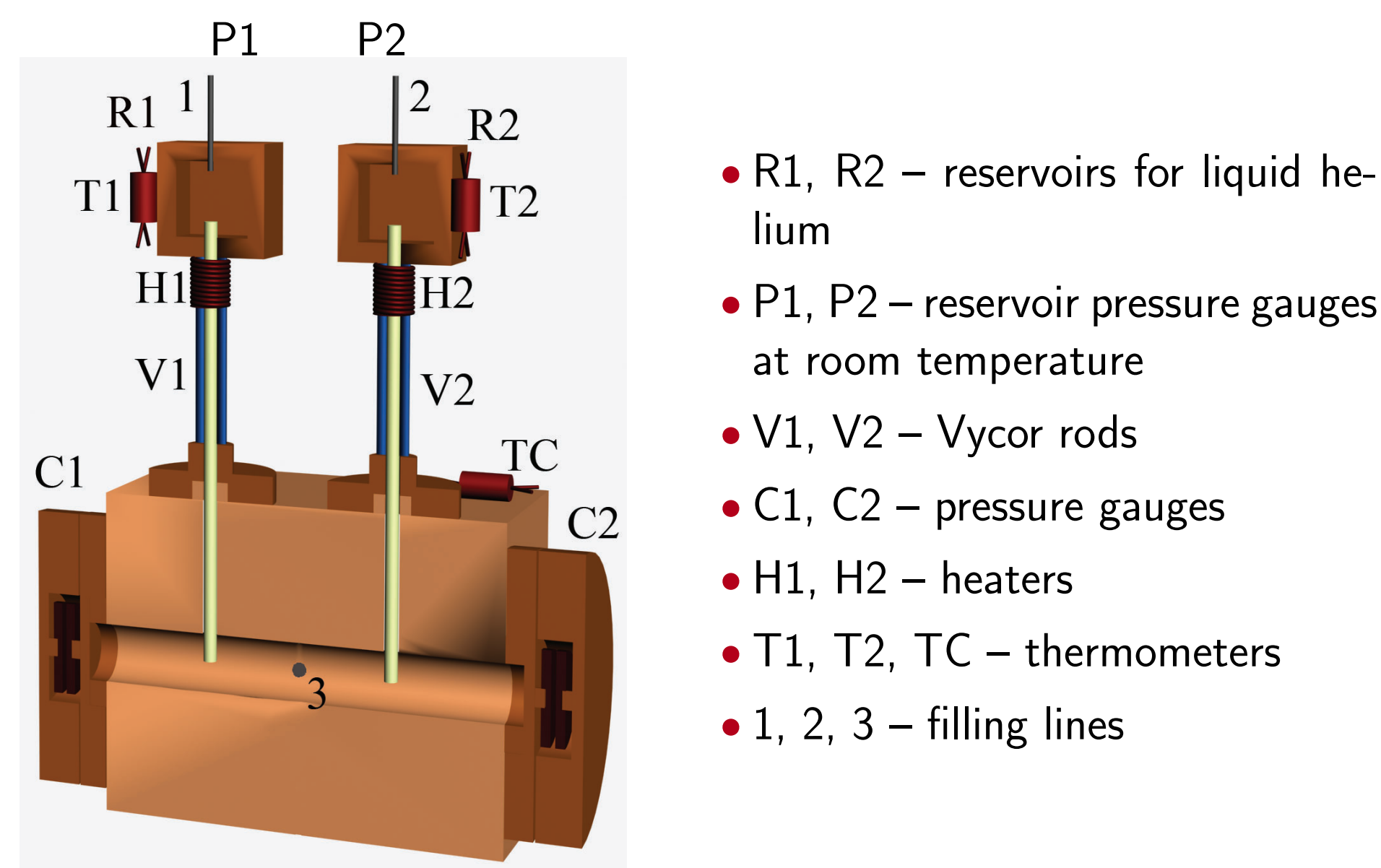
1. Experimental Cell

Fig.1 Sample cell.

- R1, R2 – reservoirs for liquid helium
- P1, P2 – reservoir pressure gauges at room temperature
- V1, V2 – Vycor rods
- C1, C2 – pressure gauges
- H1, H2 – heaters
- T1, T2, TC – thermometers
- 1, 2, 3 – filling lines

The solid-filled region has diameter 6.25 mm and length 44 mm. The distance between the Vycor rods in the solid is 21 cm. Solid helium (hcp) is typically grown from the melting curve at a constant temperature near $0.35 - 0.4$ K. Samples are studied in the ranges $0.06 - 0.65$ K, $25.6 - 26.5$ bar and $0.17 - 220$ ppm ^{3}He impurity.
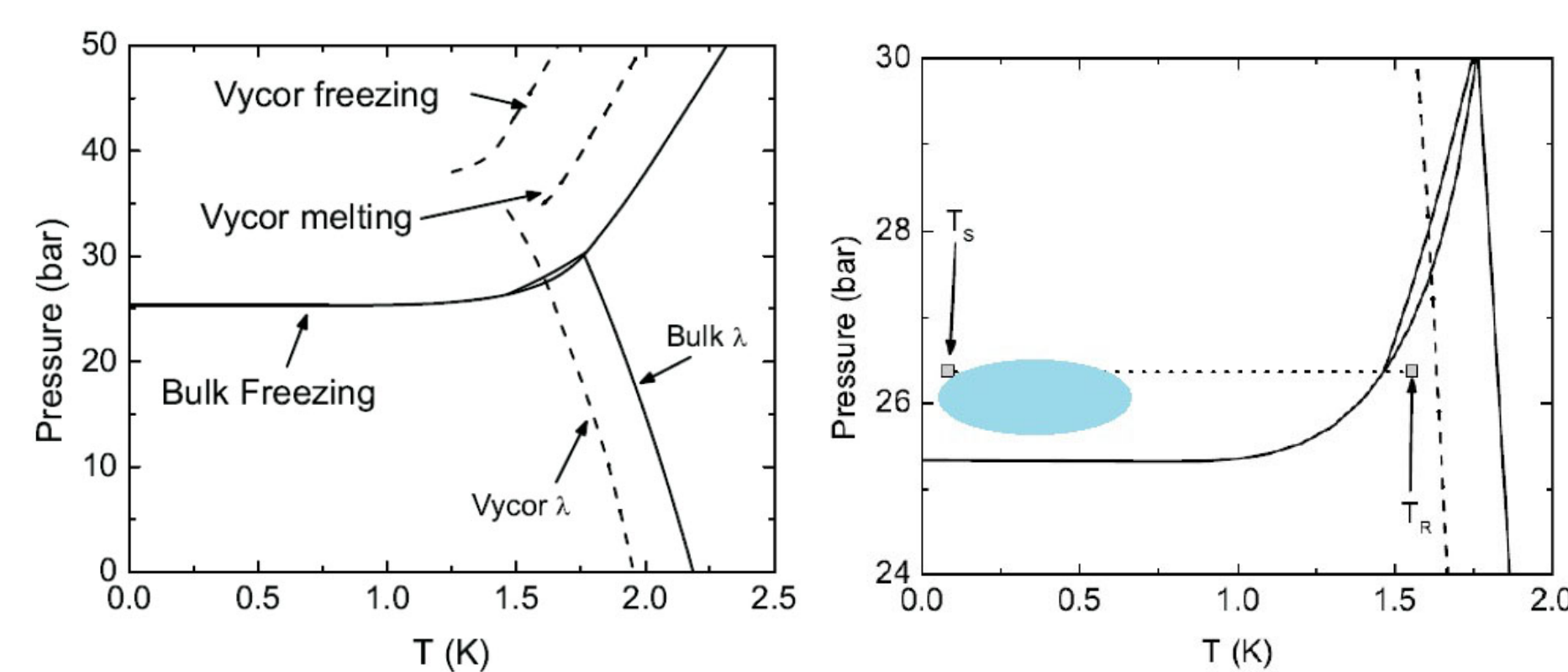
2. Phase Diagram

Fig.2a, 2b Blue denotes the region of the phase diagram where data are collected. T_S is the typical lowest temperature studied (60 mK), and T_R is the typical reservoir temperature T1, T2 < 1.5 K.
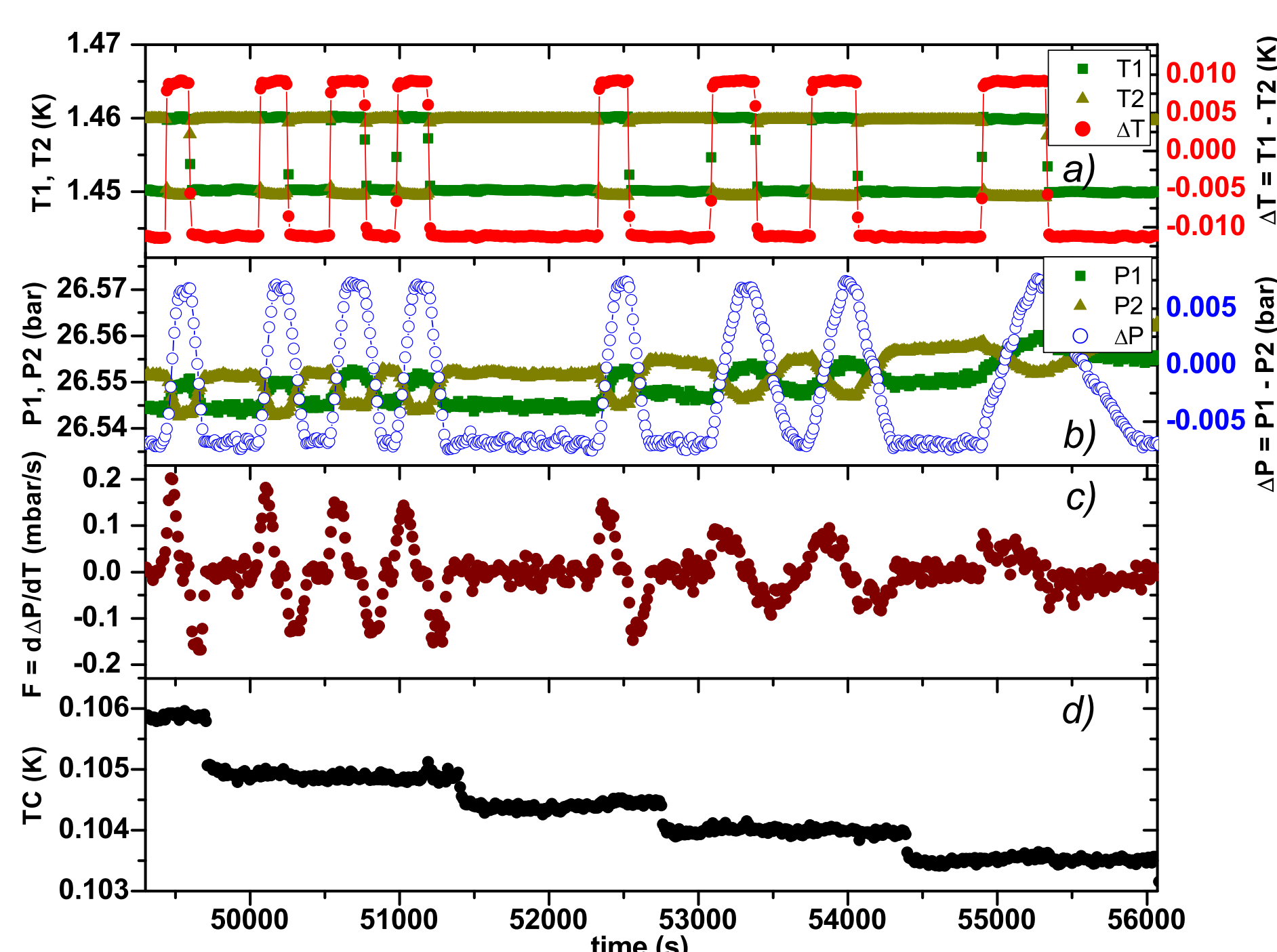
3. Experimental Procedure

Fig.3 An example of flux measurements for a 19.5 ppm sample [1, 2]. (a) T1 and T2 reservoir temperatures and flux initiating temperature difference, ΔT, imposed between R1 and R2; (b) P1 and P2 pressures and the difference $\Delta P = P1 - P2$; (c) $F = d(P1 - P2)/dt$ deduced from the data shown in subsection (b) as blue circles. The maximum value of F, F_{max} (defined here as the average of the largest value of F at a given temperature) is shown in Fig.4 as blue triangles; (d) the temperature of solid helium.

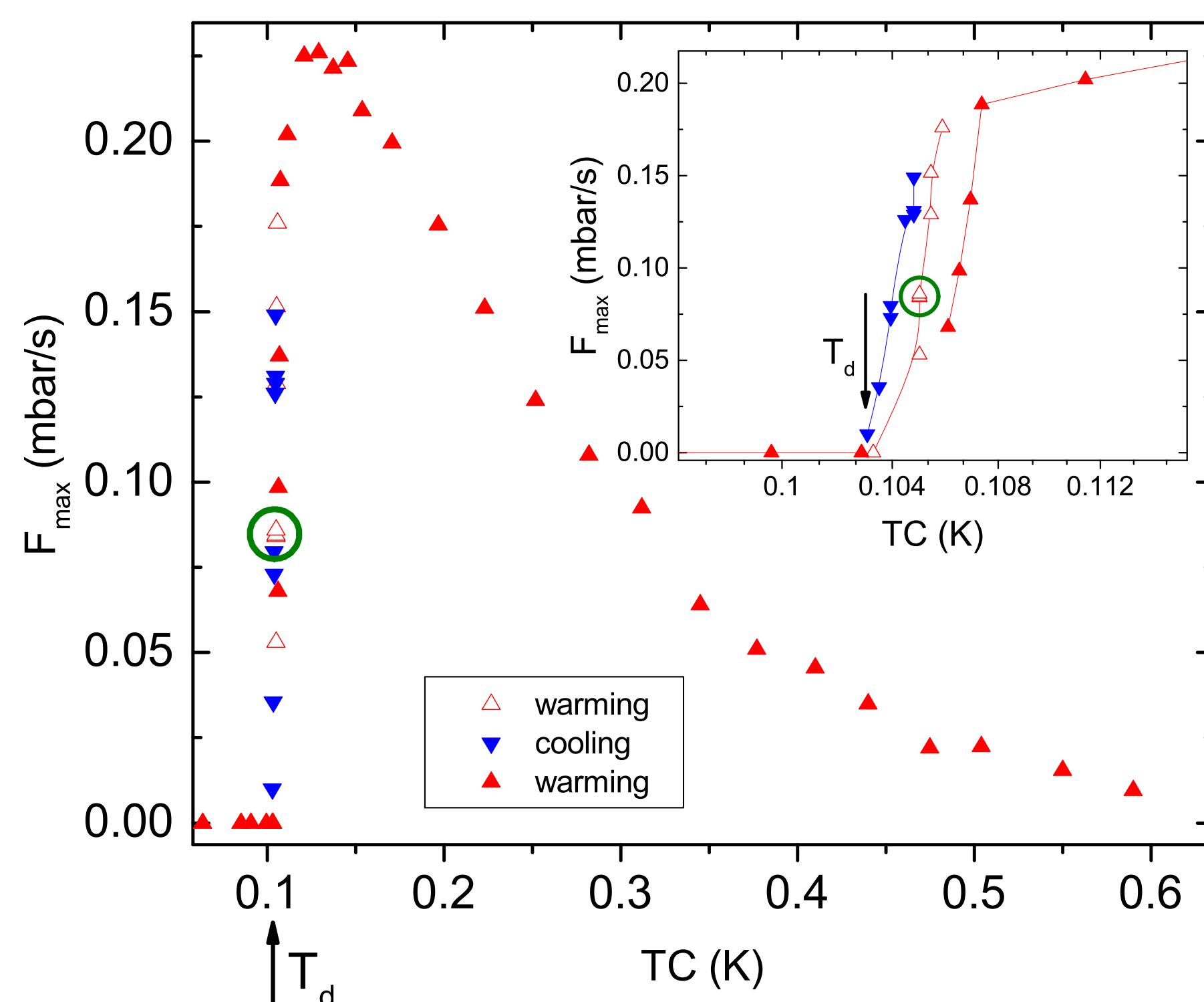## 4. Flux Temperature Dependence, 19.5 ppm

Fig.4 Temperature dependence of the flux in the whole temperature range studied for a 19.5 ppm sample. The sharp flux change can be seen at solid helium temperature $TC = T_d$. The inset shows the hysteresis in the region of the T_d flux transition. The hysteresis width is shown in Fig.8. Green circle: see caption to Fig.5.
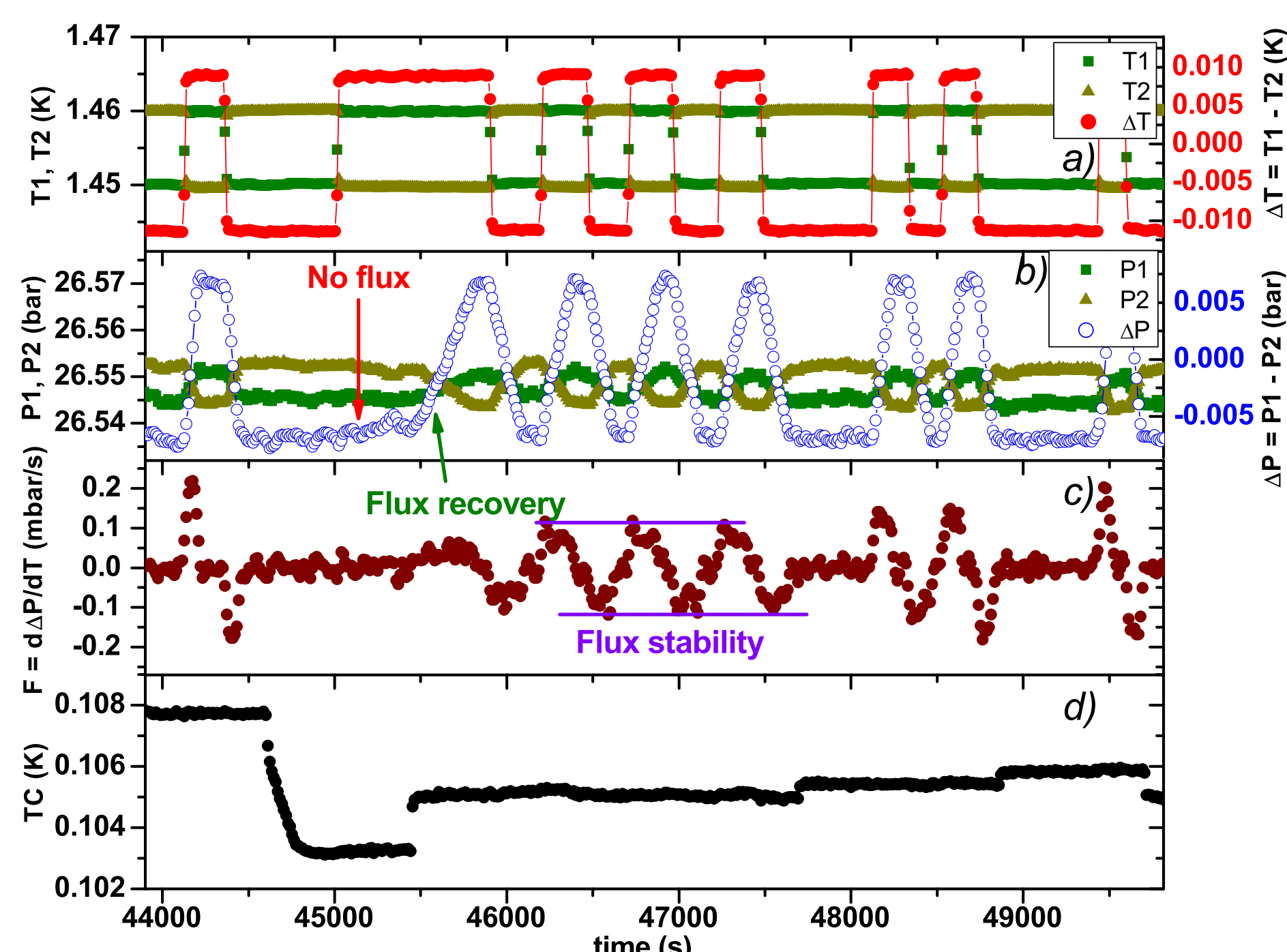
5. Flux Stability at T_d

Fig.5 An example of flux extinction and recovery near T_d. Long term flux stability is shown at 105.1 ± 0.1 mK for time $46000 - 47500$ sec for a 19.5 ppm sample. The data for the stability measurement are shown in the green circle enclosing data points in Fig.4. See Fig.3 caption for explanations. Other examples of flux stability are seen in Fig.3; e.g. near time 53500 sec.

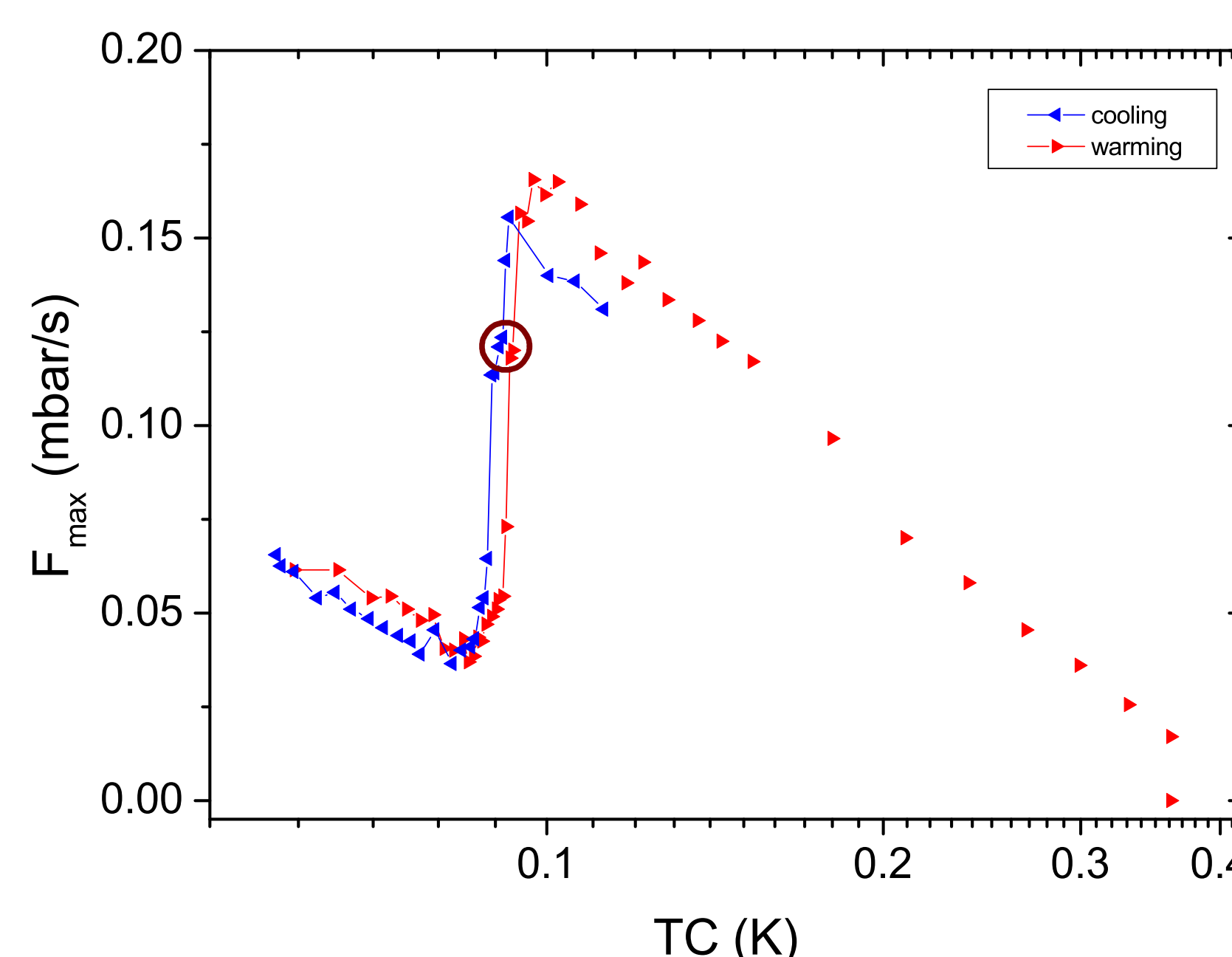## 6. Flux Temperature Dependence, 2 ppm

Fig.6 Temperature dependence of the flux in the whole temperature range studied for a 2 ppm sample. The sharp flux change can be seen at $TC = T_d$. There is also a flux recovery at $TC < T_d$ which is typical for small ^{3}He impurity concentrations, < 10 ppm. The flux stability in the transition region can be seen as well (two sets of data points which have very similar flux at almost the same temperatures – see brown circle in the figure).
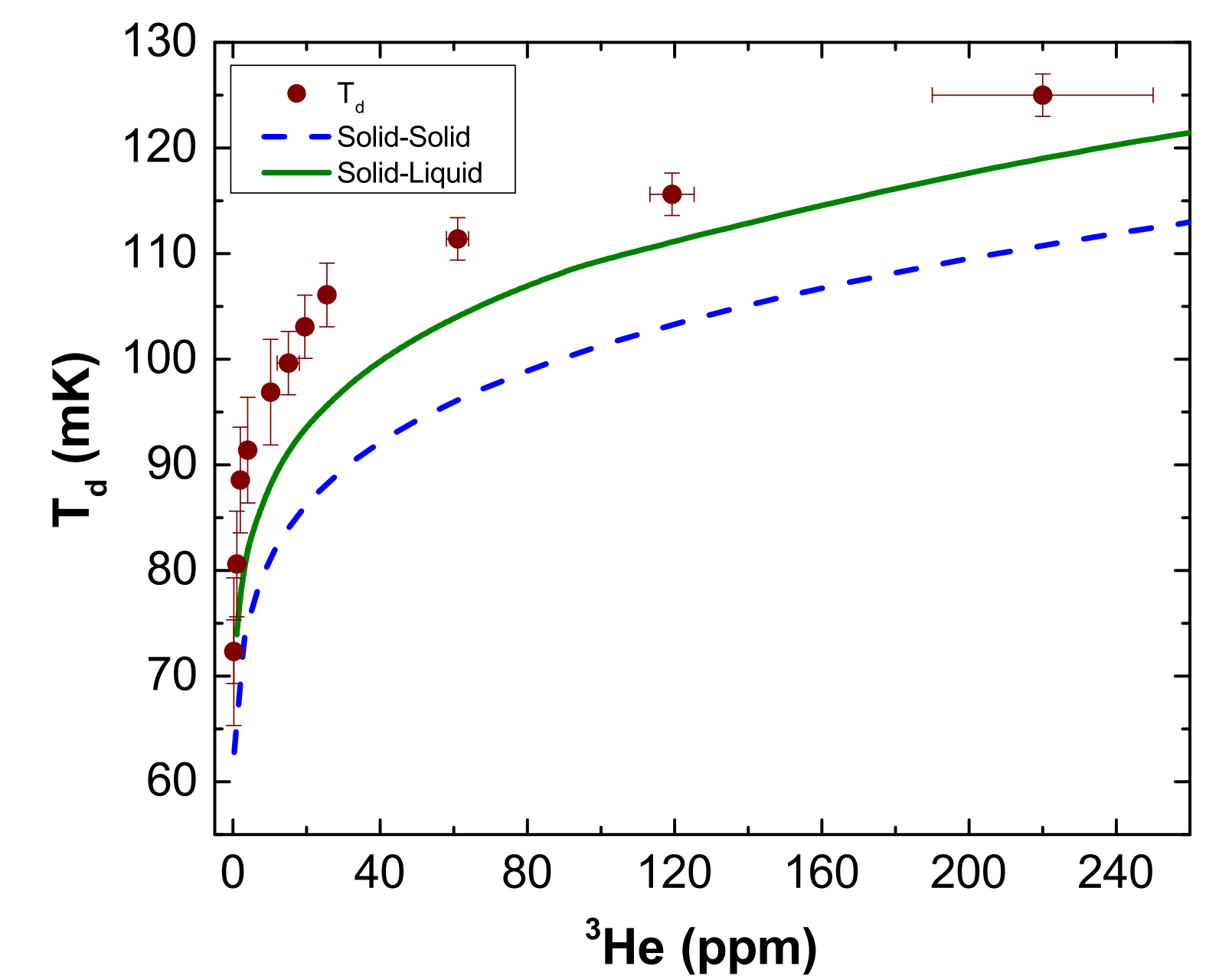
7. T_d Dependence on ^{3}He

Fig.7 Temperature of the sharp drop in the flux, T_d, versus ^{3}He concentration together with the phase separation temperature dependences: the dashed line – the phase separation for the solid-solid case (bcc ^{3}He-rich inclusions form inside the hcp ^{4}He-rich matrix); the solid line – the phase separation for the solid-liquid case [1] (liquid ^{3}He-rich regions form inside the solid ^{4}He-rich matrix) which is more relevant for the pressures of solid helium samples studied here.
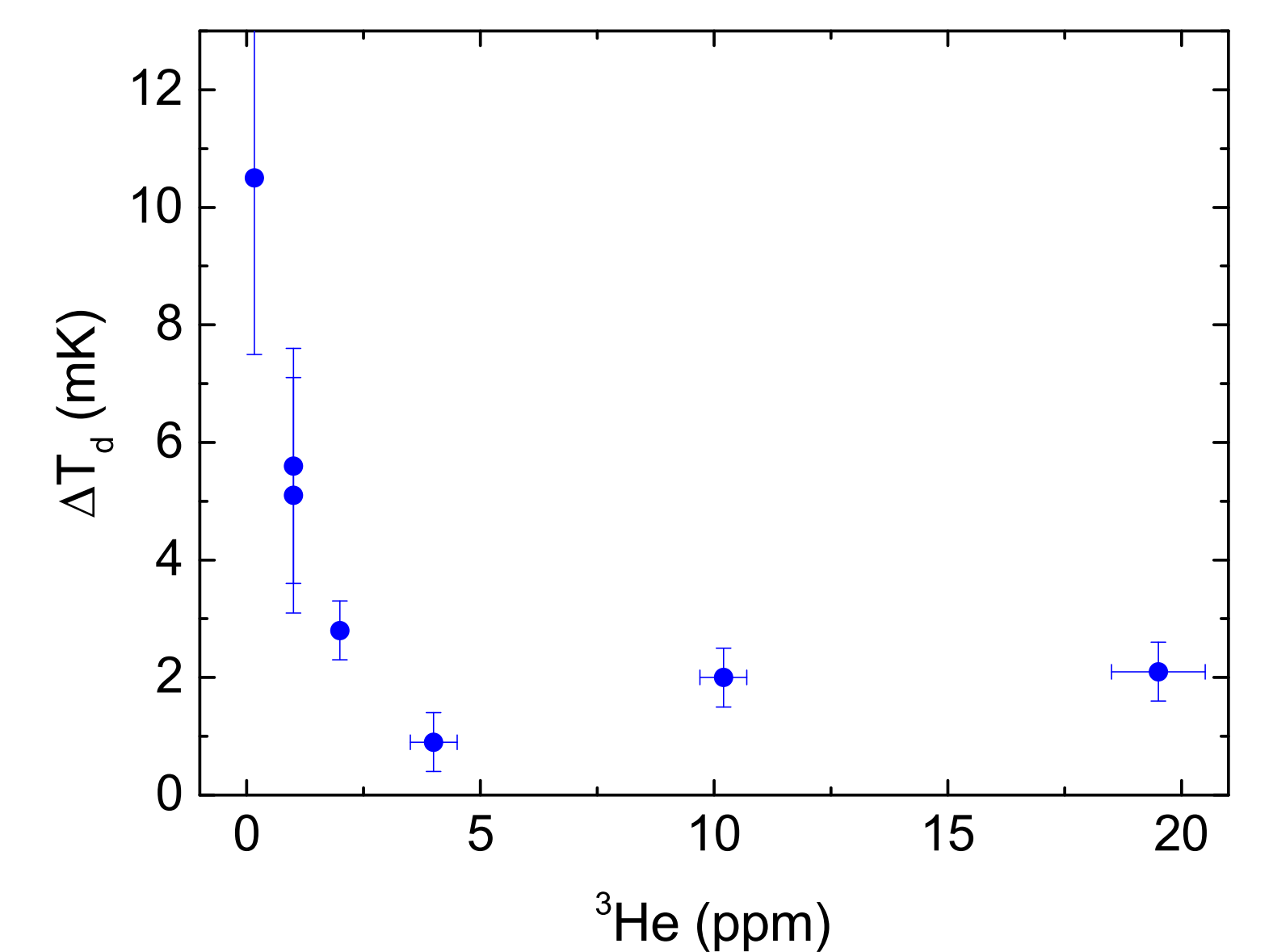
8. Hysteresis

Fig.8 Hysteresis at the T_d transition as a function of ^{3}He concentration.

Conclusions

- There is a reversible sharp decrease in the mass superflux on cooling through a impurity-dependent temperature T_d [1, 3].
- This sharp decrease demonstrates hysteresis on cycling the temperature across T_d — a feature of a first order phase transition.
- The closeness of the T_d temperature to the predicted phase separation transition suggests that the sharp flux decrease is due to phase separation, especially when fluctuations are considered [4]. Phase separation liberates ^{3}He atoms from the solid matrix and makes them available to block the flux.
- At small ^{3}He concentrations, the flux is not extinguished and grows with decreasing temperature below $TC < T_d$ [1, 3].

References

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