# Strange Behavior of Boiling Around Wire Heater at The Pressure Condition Very Close to The Lambda Point

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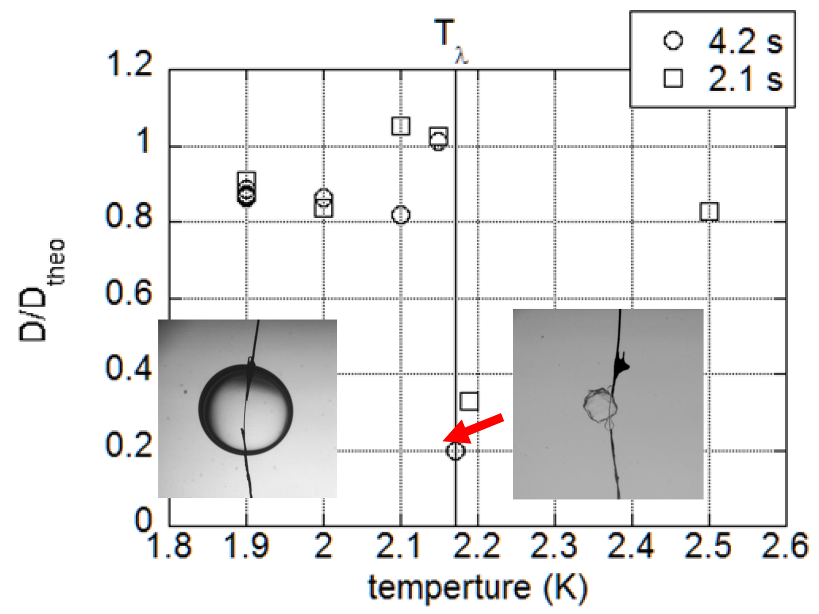
## Motivation

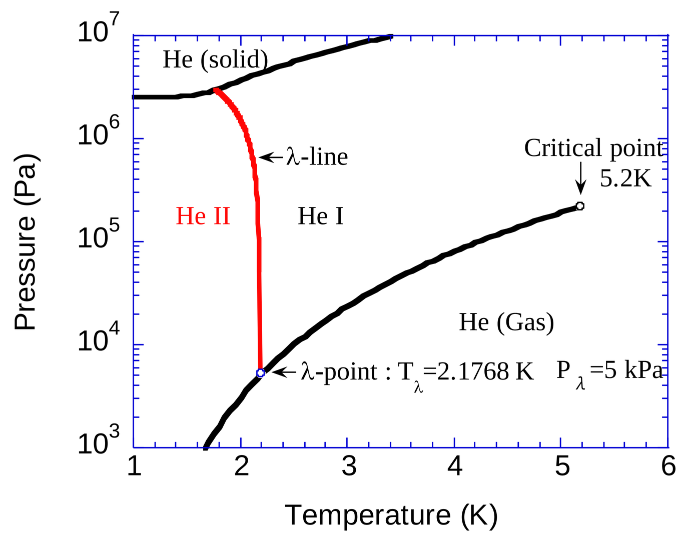
In our past microgravity experiment,
we found the anomalous boiling in superfluid helium (He II) at very vicinity of the Lambda point.

How about under the Earth Gravity condition??
Thus, we searched anomalous boiling in He II on the earth gravity condition.




Ratio of the diameter of vapor bubble between calculation and the μ–gravity experiment

127 m Drop tower experiment at ZARM, Bremen, Germany
Time duration; 4.7 sec.




Phase diagram He4

*S. Takada, N. Kimura, S. Pietrowicz, K. Grunt, M. Murakami and T. Okamura, 2018, Cryogenics, 89, 157

The theoretical calculation results is following Non equilibrium Energy balance equation based on the kinetic theory

$$2\sqrt{\pi}\left(\frac{1-0.4\beta}{\beta}\right)j-\Delta P\sqrt{2RT_i}+\frac{\sqrt{\pi}}{4}q_i=0 \quad \text{Eq.1}$$

$$\Delta P=\rho g h+\frac{4\sigma}{D}$$

$$\frac{dV}{dt}=\frac{Q-\pi D^2 q_i}{\rho_{sat}h_{fg}} \quad \text{Eq.2}$$

with an assumption $T_i \fallingdotseq T_b$

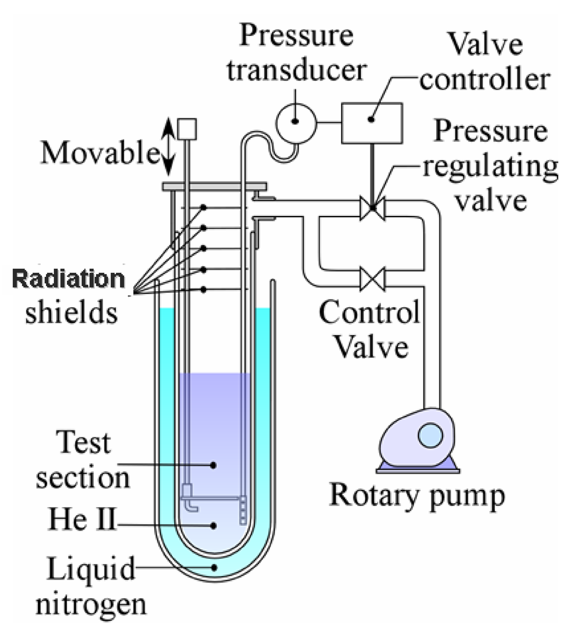
- $j$ ; mass flux across interface, (measured)
- β; thermal expansion ratio, 0.72 *
- σ: surface tension
- $q_i$ : heat flux across interface
- $\rho_{sat}$ : density on Saturated vapor pressure
- Q: heat input from heater
- $h_{fg}$ :Latent Heat

Steady heat flux across vapor-liquid interface can be obtained, when $j$ =0

$$q_i=\frac{4}{\sqrt{\pi}}\Delta P\sqrt{2RT_b} \quad \text{Eq.3}$$

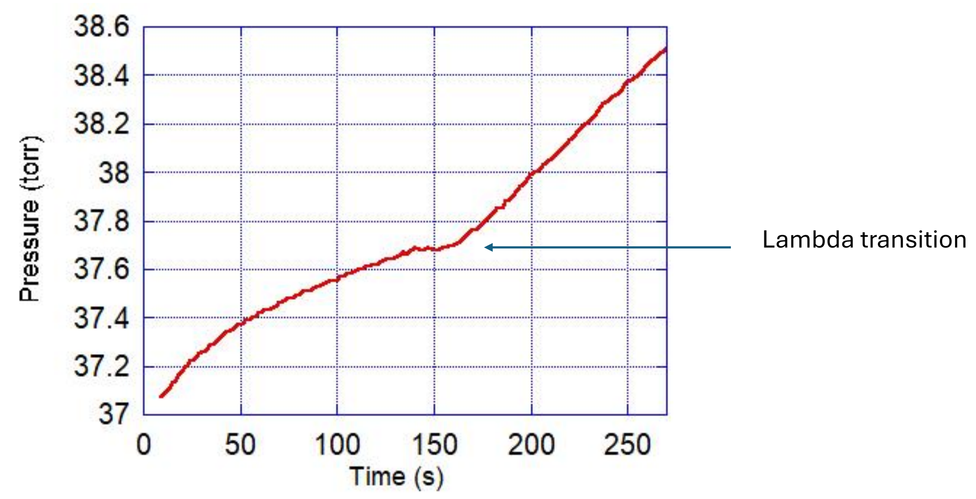
## Experimental setup

Manganin wire heater of 50 μm in diameter
was set on Horizontal position with movable stage to control immersion depth in He II



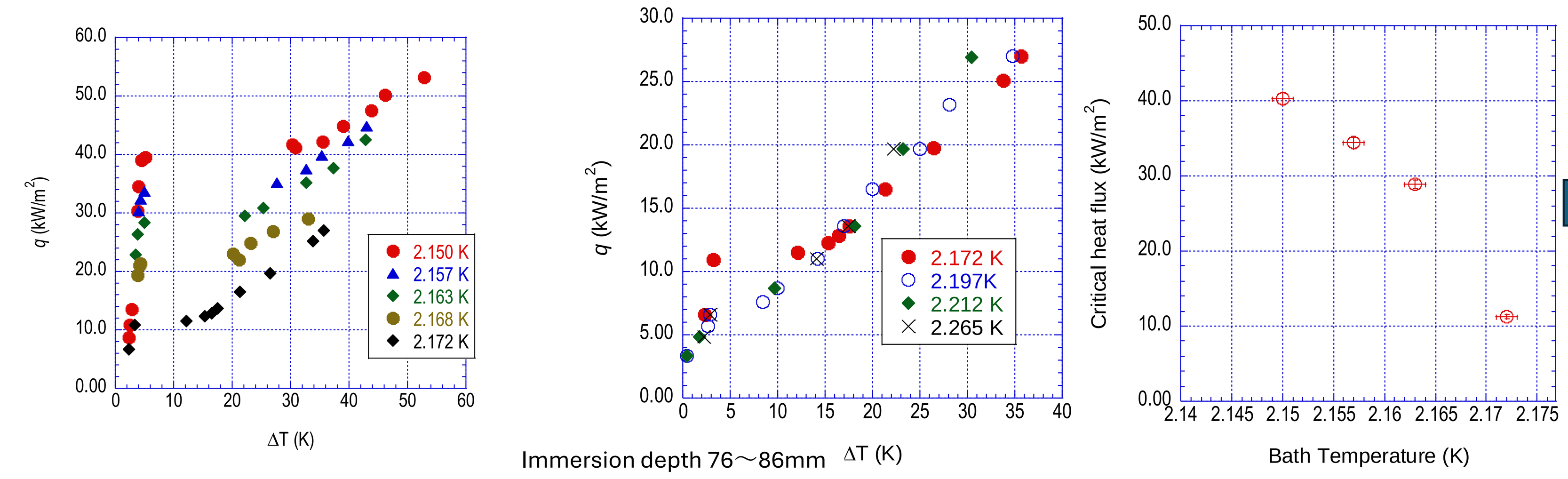

Sketch of experimental setup of glass Dewer

The saturation temperature control by pressure regulation can be realized ± 1mK below about 2.17 K or above 2.19 K
However, the temperature control is very difficult around the λ point because of the anomaly of heat capacity.
⇒ Around the λ point, quasi- steady pressure variation with constant pressure valve position.




## Results and Discussion

**Boiling curves and critical heat fluxes**

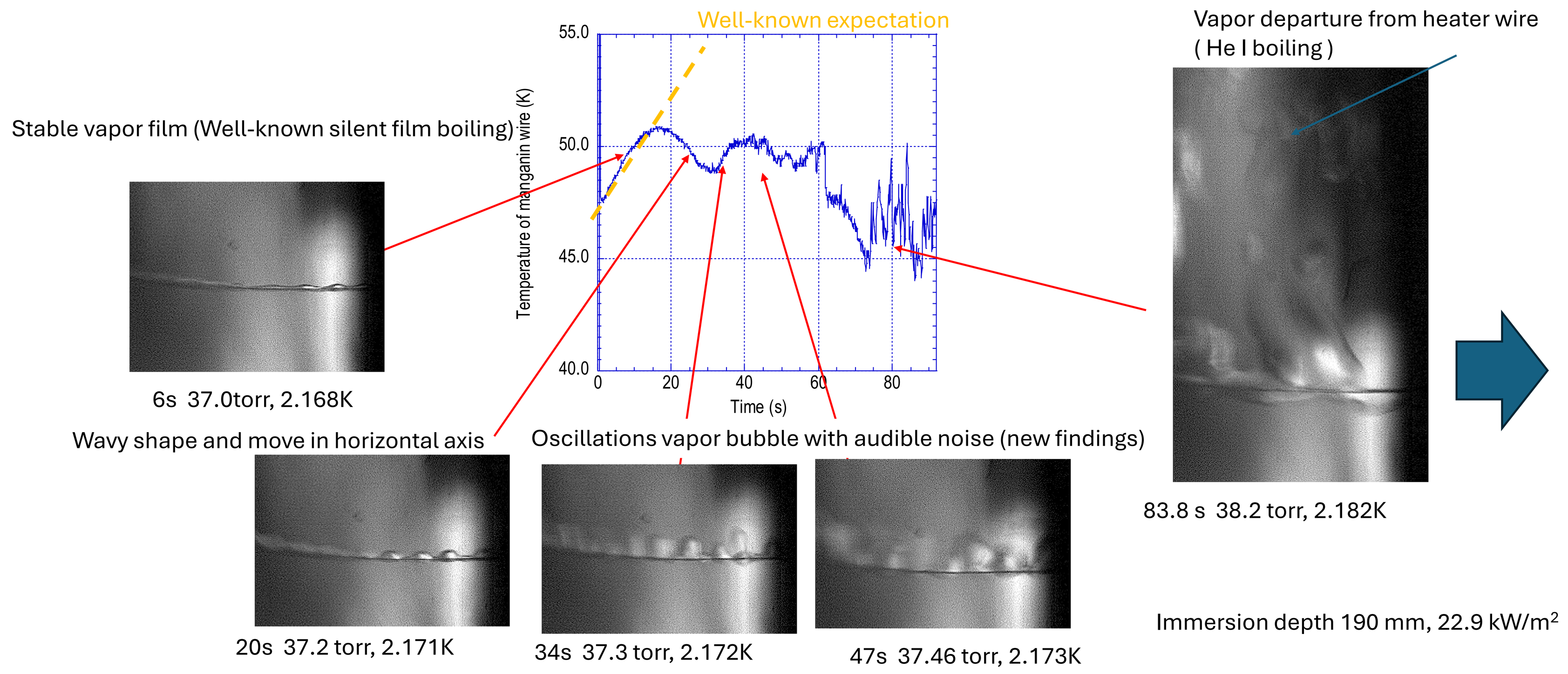



The steady experiment
$T_b$ <2. 17 K, $T_b$ > 2.19 K.

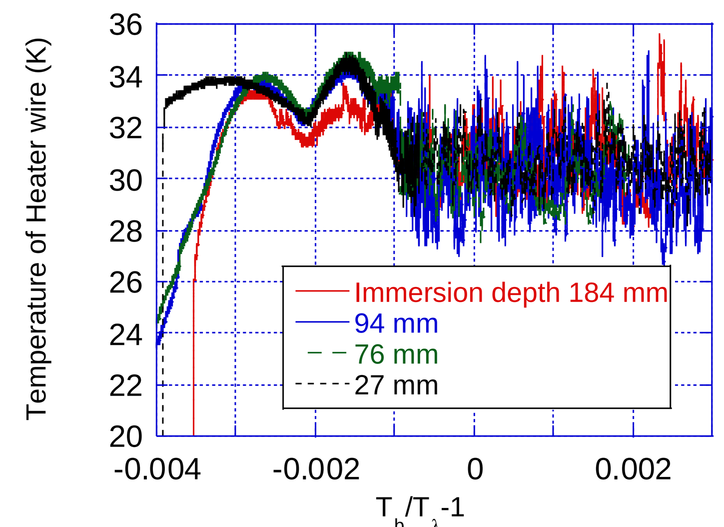
No new findings at all.

When $T_b \rightarrow T_\lambda$ , The heat transfer coefficient h ↓
Critical heat flux ↓

**Quasi-steady temperature condition experiment**



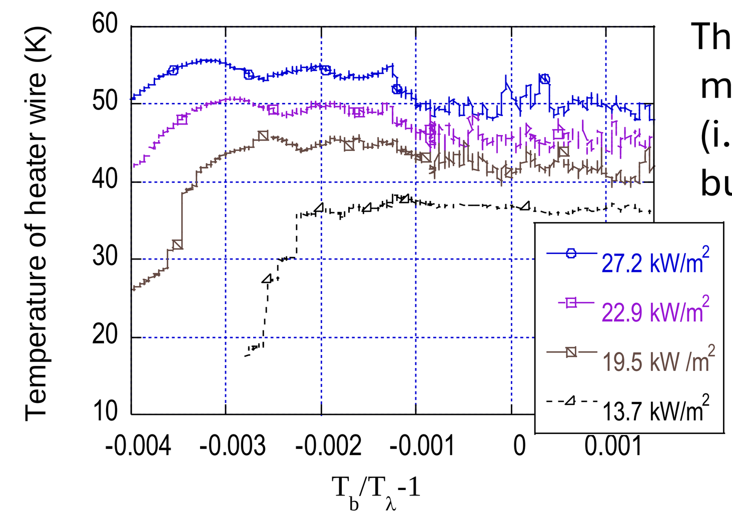

Typical time variation of heater temperature and visualization results. (λ–Point; 2.1768K, 37.68 torr)




Independence on immersion depth

Just below λ–point,
heat transfer is changing complicatedly.

Just above λ–point,
He I film boiling may occur.




Slight dependence on heat flux

This complicated transition of film boiling mode is independent of Immersion depth (i.e. subcooling )
but depends on heat flux slightly.

Modification of Eq.3 with thermal resistance $R_i$ across vapor-liquid interface supposed by Ametitov**

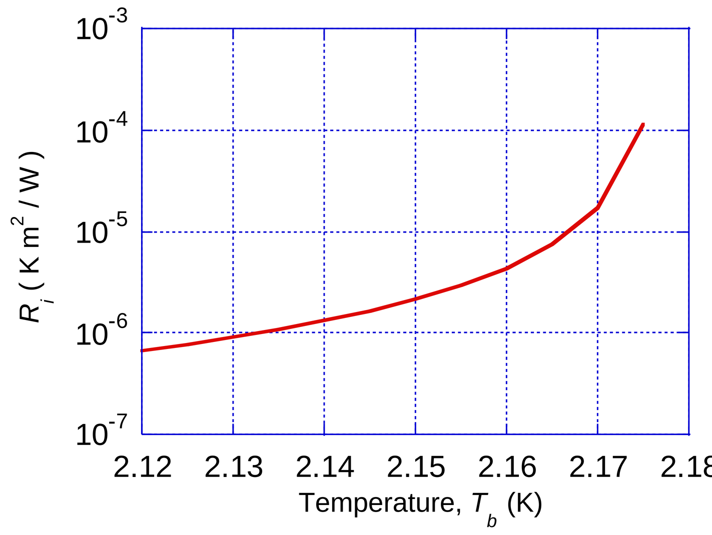
$$q_i=\frac{4}{\sqrt{\pi}}\varepsilon\rho g h\sqrt{2RT_b}$$

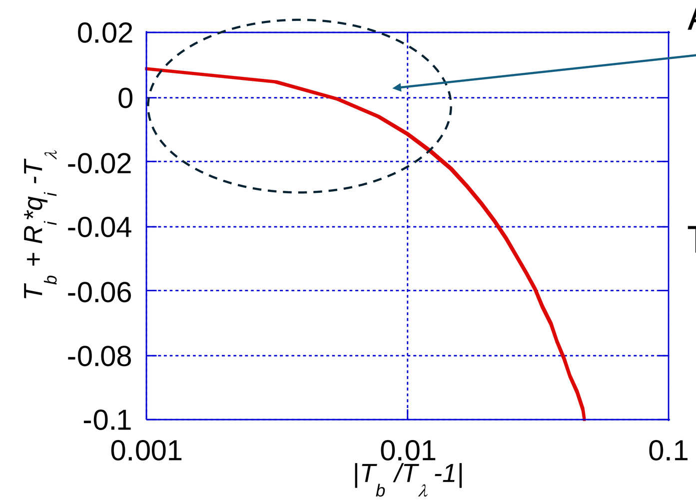
$$\varepsilon=\frac{1}{1+R_i(\partial P/\partial T)_{sat}\sqrt{2RT_b}}$$

Semi-empirical Expression of $R_i$

$$R_i=\frac{10^{-9}}{\lambda_L^{\frac{3}{4}}(T_\lambda-T)^{1/2}}\left(\frac{\rho_n}{\rho_s}\right)$$

**Ametitov Y., 1983, Cryogenics 23, pp.179–184




At liquid-vapor interface, He I-He II transition may occur.

The existence of He I at vapor –liquid interface may cause this complicated phenomena

**Summary**

- Under 1-g condition, the anomalous boiling in He II is also observed in the vicinity of the λ-point. Some film boiling modes were seen in narrow region.
- The heat transfer coefficient is getting higher, when getting close the λ point. That tendency is contrary to previous expectations.
- This strange behavior may be caused by the extremely high thermal resistance between liquid-vapor interface due to anomaly of heat capacity at λ-point.

**Acknowledgement**

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