Visualization Study on Film boiling in Narrow Channel under Superfluid Helium

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Contents

Background

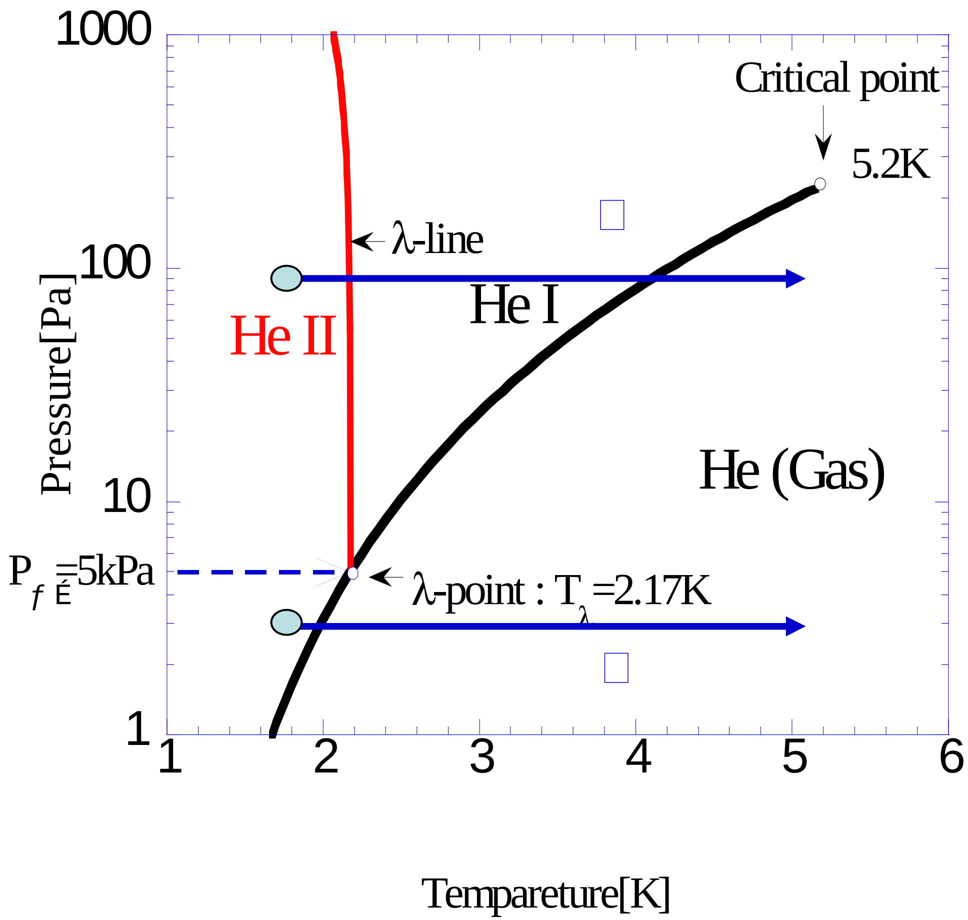
He II is applied as cooling media
for Large Scale Superconducting Magnet

In Narrow channel
Film boiling may occur, when Applied Small heat flux

Requirement
What is the difference between
Film boiling phenomenon
in narrow channel (2-D) and in open system (3-D) ??

Visualization approach may make clear this question.

Film boiling in He II

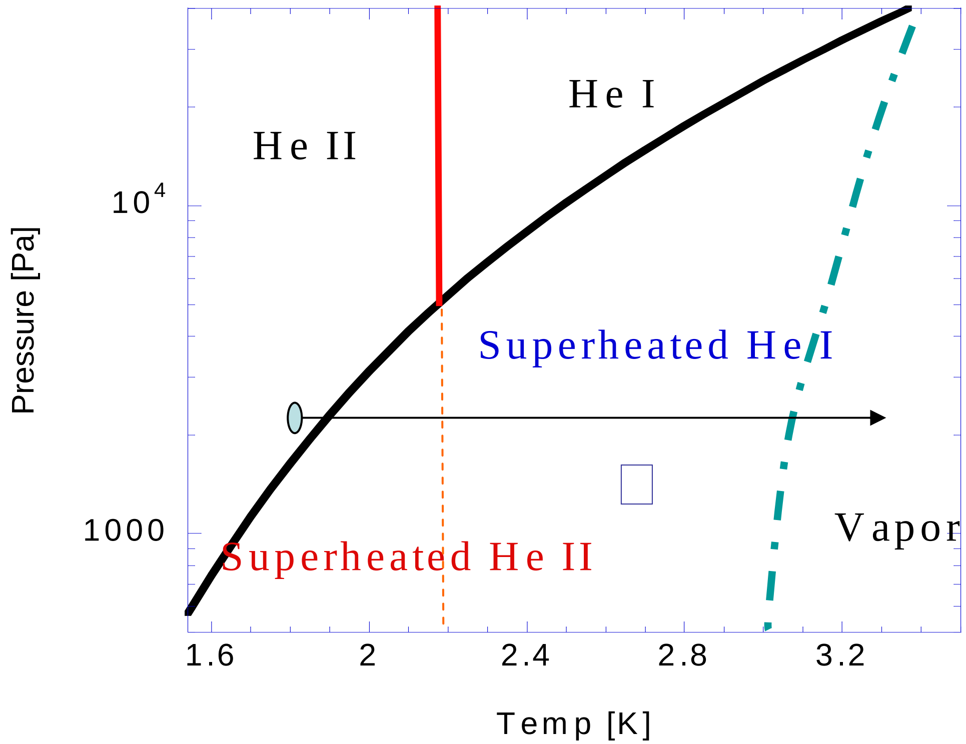


He II → He I → He Vapor

He II → He Vapor

The behavior of He II- He I interface caused by heating is still unknown.

Film boiling in He II;
superheated state is easily created in narrow channel



He II → ^{s}He II → ^{s}He I → He Vapor

Many researchers found the existence of Superheated He II and He

In the Specific Channels

Narrow Long Tube (G. Kraft),

Low Vibrating Cell Connected Capillary (Nishigaki, Ryback)

and Two Dimensional Channel (Kobayshi, Francois, Gentile)

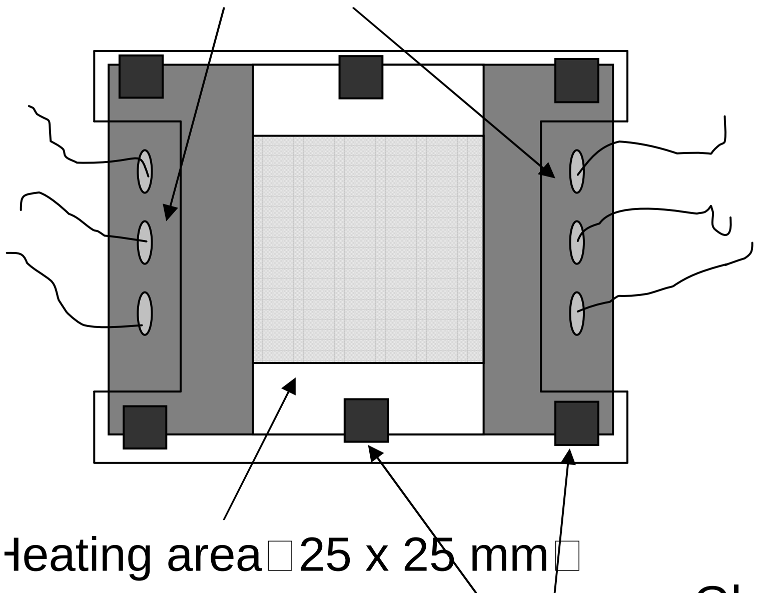
In narrow channel (two dimension)

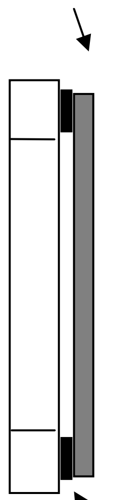
Transparent Heater□Indium Tin Oxide

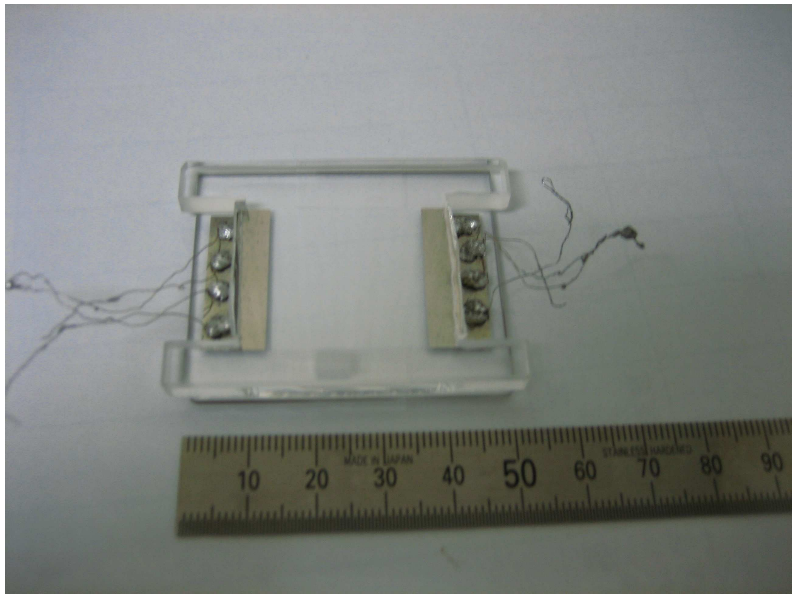
□Heat area; 25×25mm, 2 x 35x 55mm silica base□

Cover Glass Plate

Spacer □Kapton tape□5×5mm□thickness□155μm□



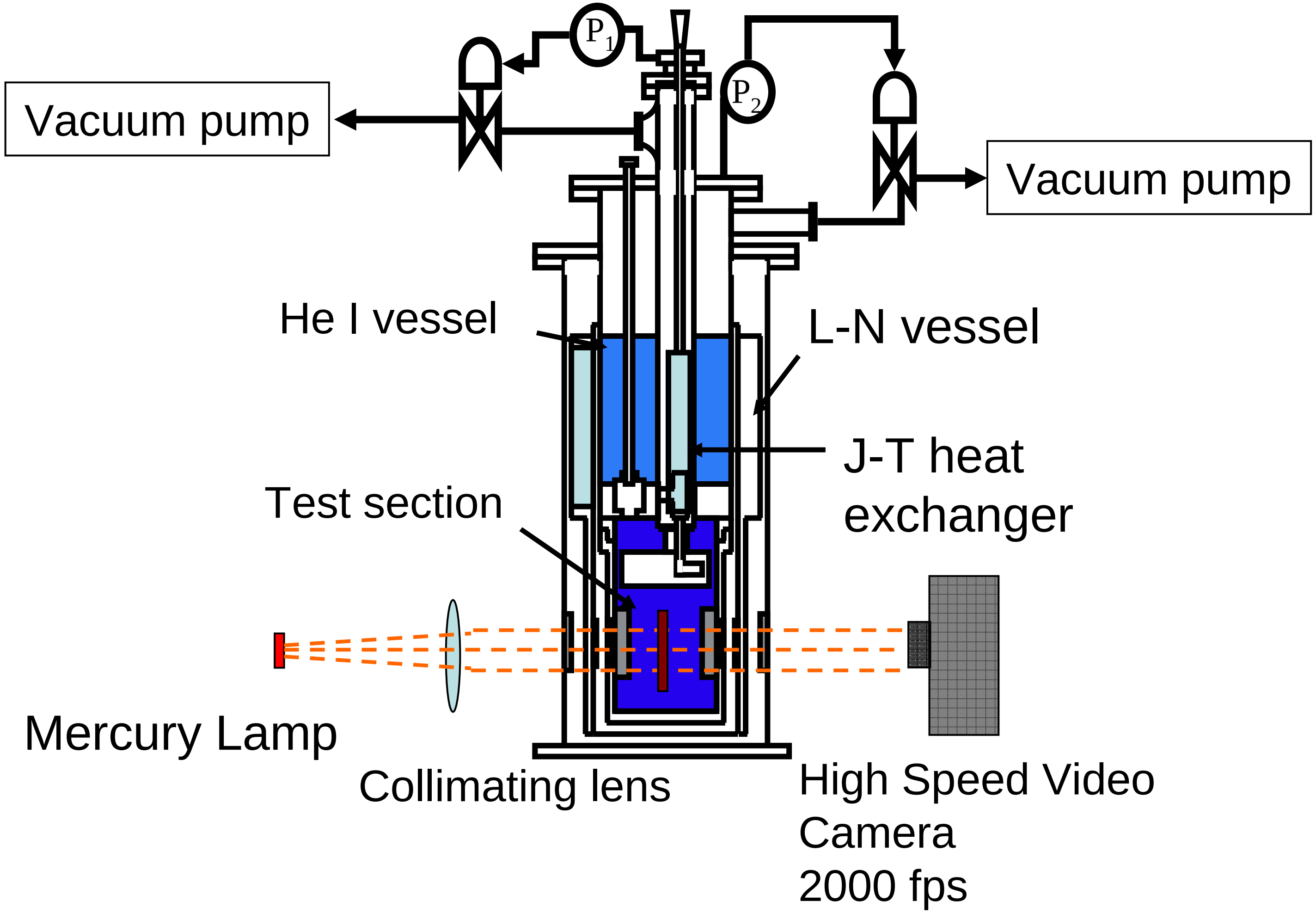




Experimental apparatus

Claudet type Cryostat; Bath temperature; 2.17□1.5K

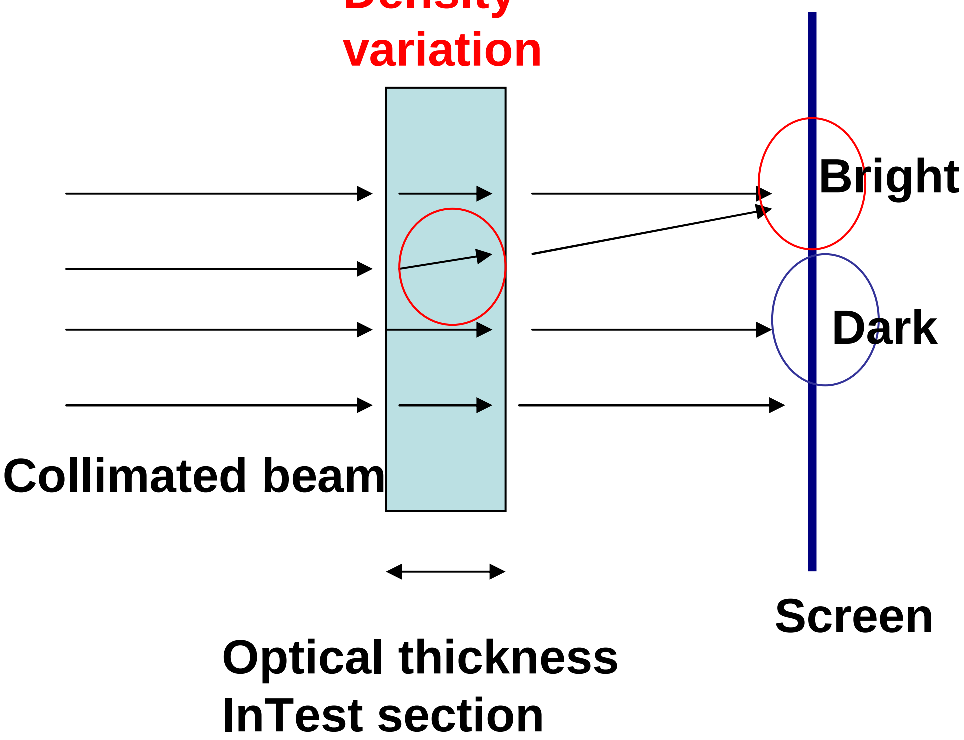
Hydrostatic Pressure;0.1MPa□saturated vapor pressure

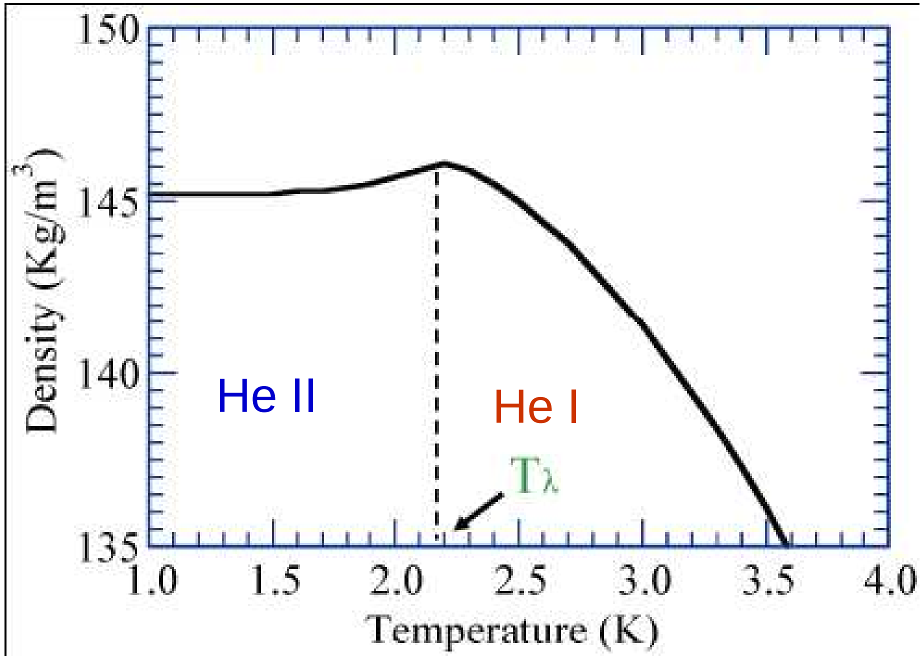


Shadowgraph Method

Visualization method

Shadowgraph Method

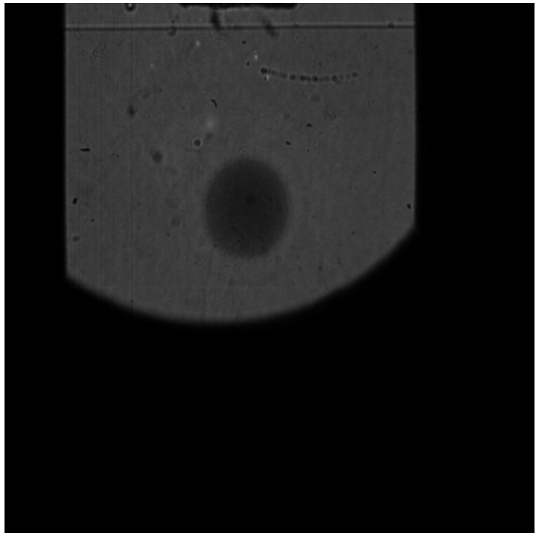




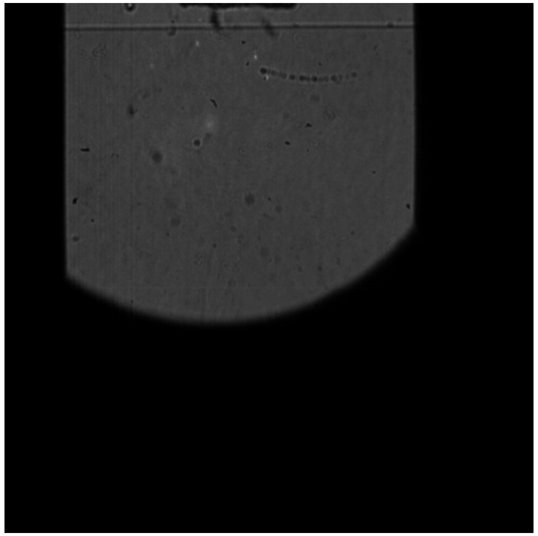
In He II experiment

He I-He II interface and temperature distribution of He I can be detected

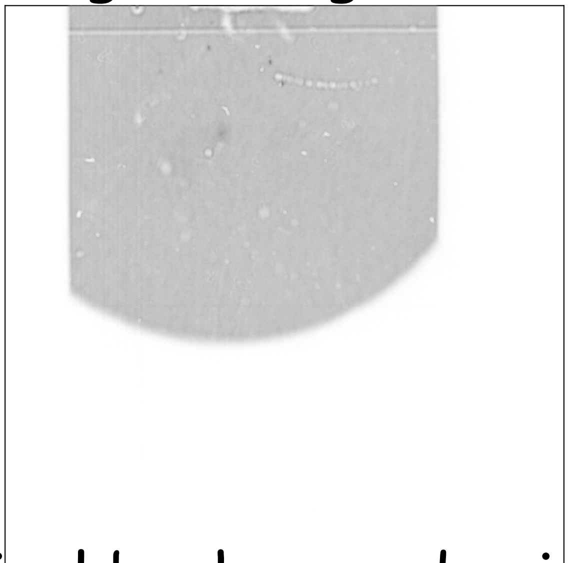
Image processing technique for signal enhancement



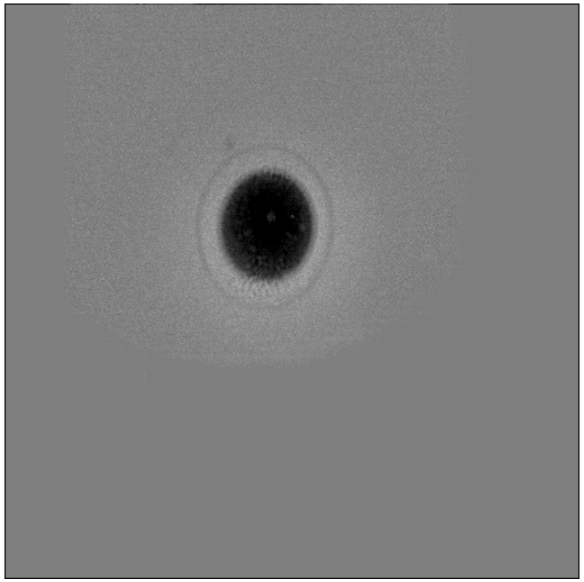
Raw Image during film boiling



Optical background noise



Optical background noise□negative□



Processed results

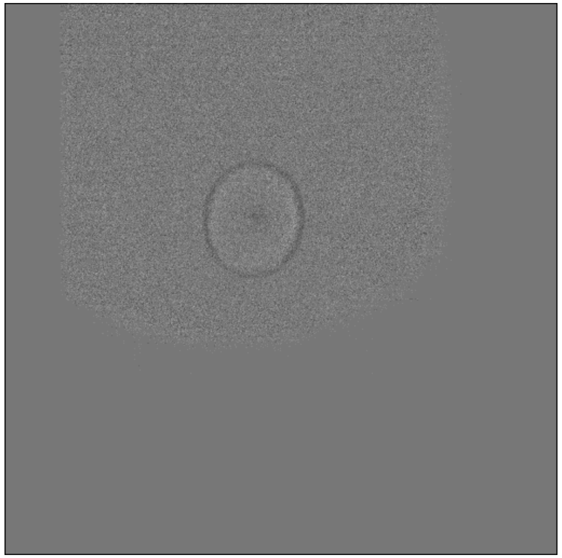
Visualization Results of film boiling onset (3 Cases)

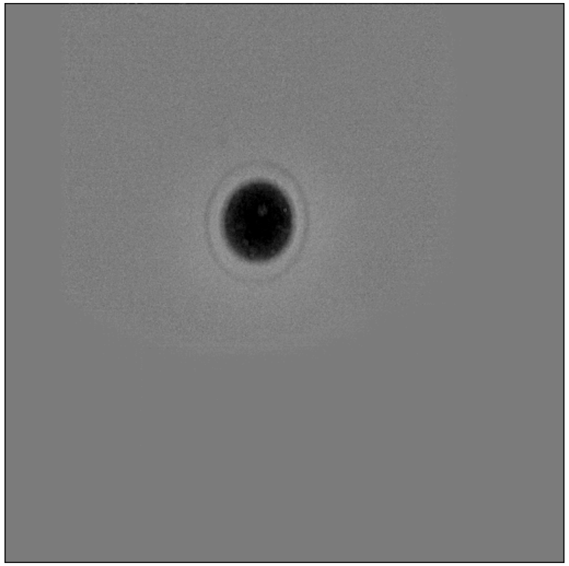
1. In Pressurized He II, 101.3 kPa T_b =1.9 K

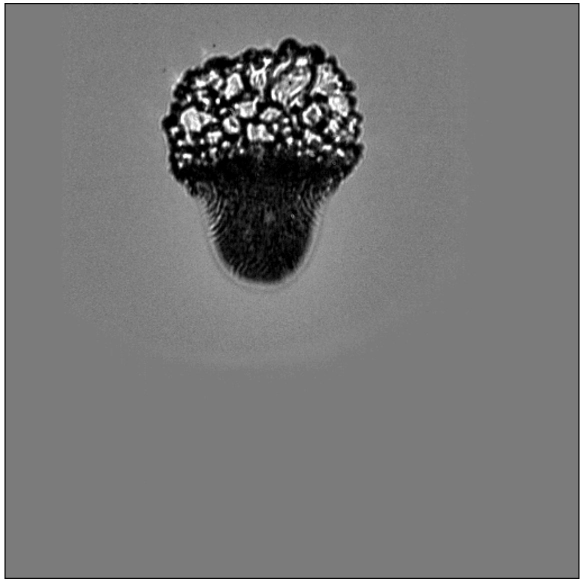
2. In Saturated He II T_b =1.9 K

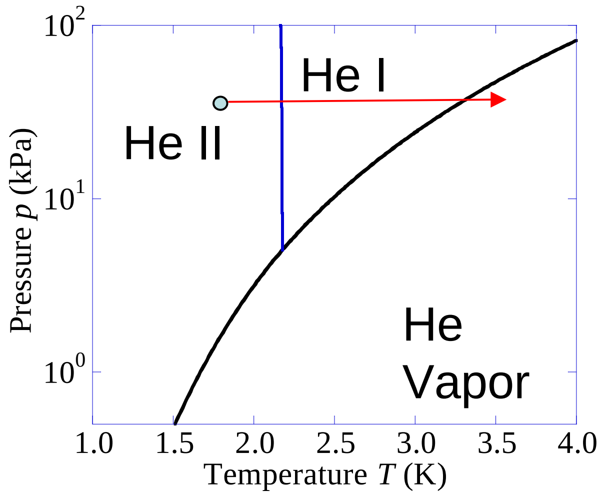
3. Superheated He II- He I interface, T_b = 2.1 K

1. Visualization Result – Pressurized He II, 1.9 K



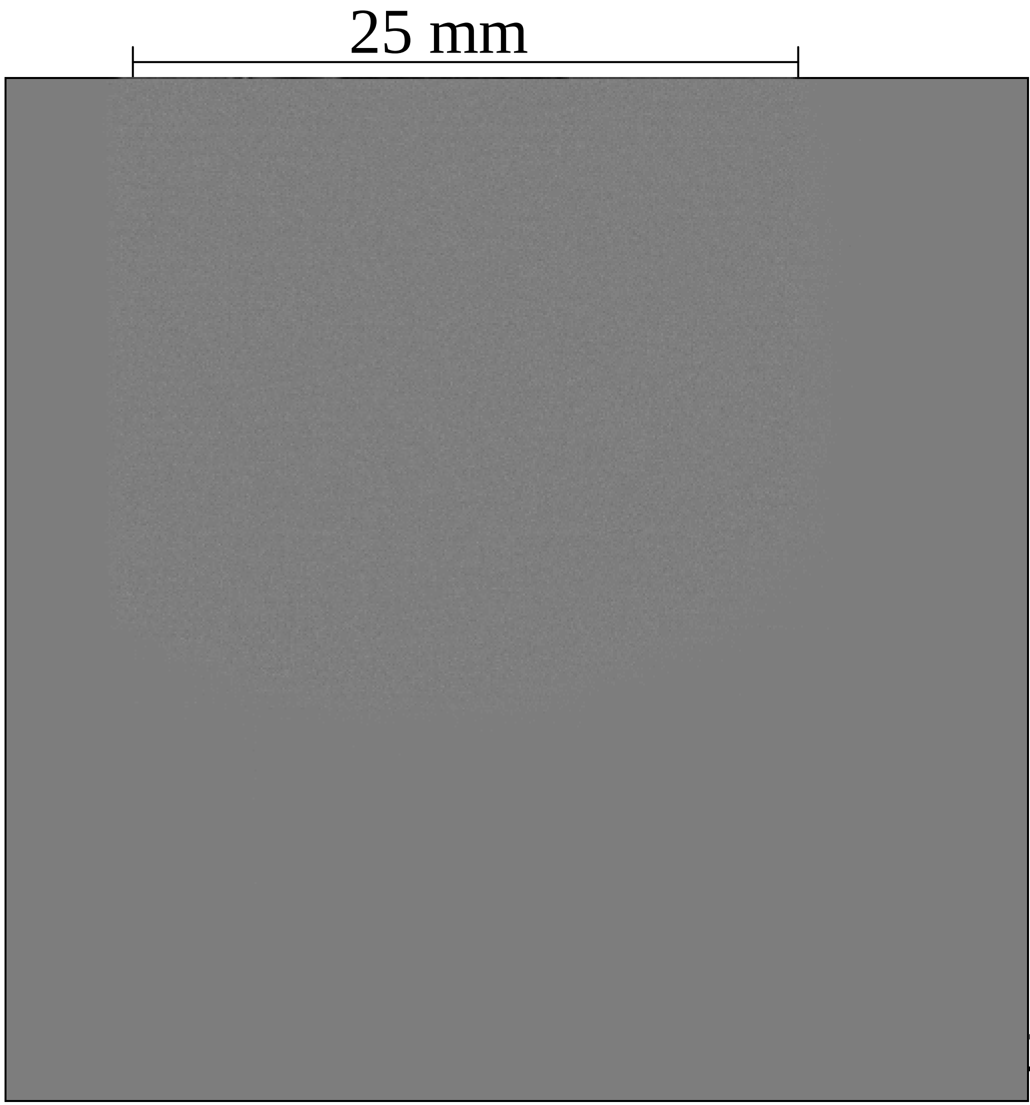


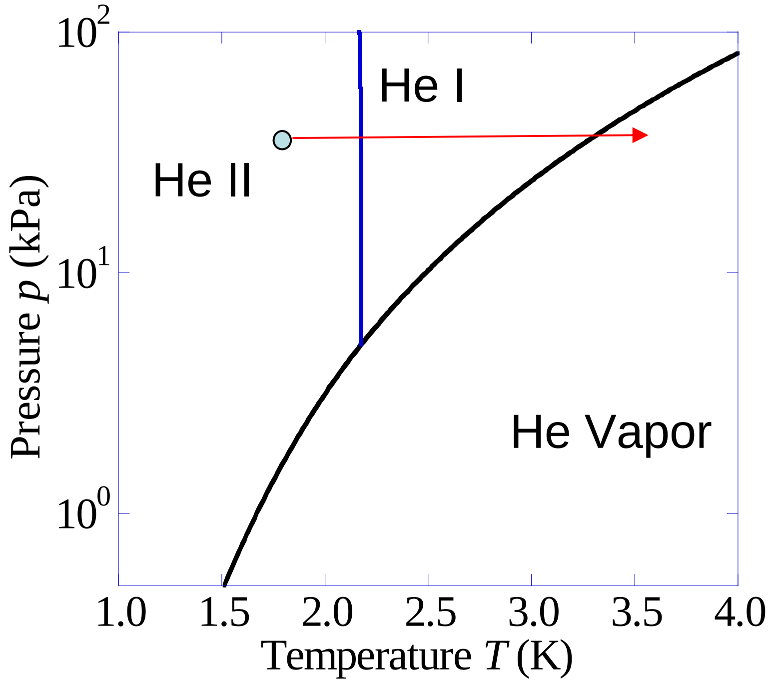




Onset of film boiling□101.3 □Pa□ 1.9 K, q = 1.25 W = 0.20 W/cm^2

1. Visualization Result – Pressurized He II, 1.9 K (2/2)



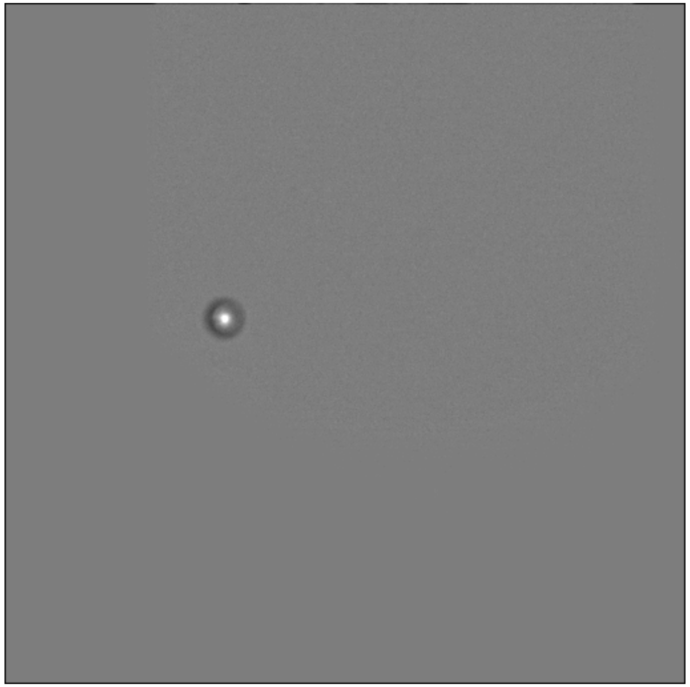


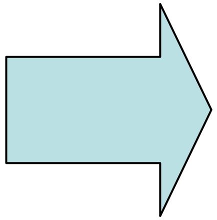
Running rate; 100 times slower

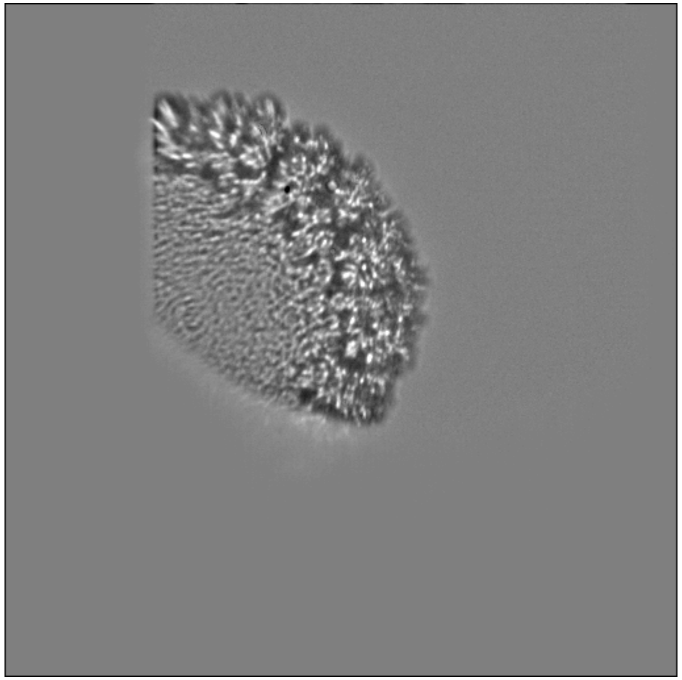
1.9 K, q = 1.25 W = 0.20 W/cm^2

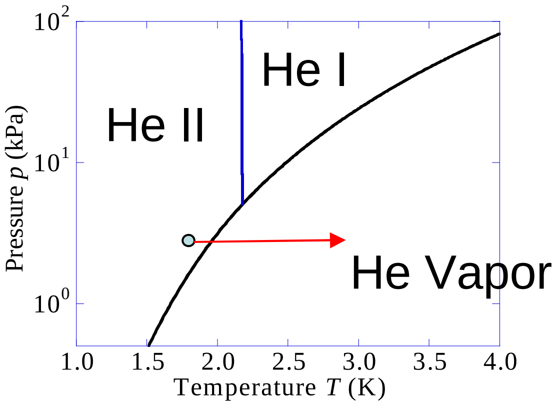
Onset of film boiling□1.9 K 101.3 □Pa□

2. Visualization Result Saturated He II, 1.9 K





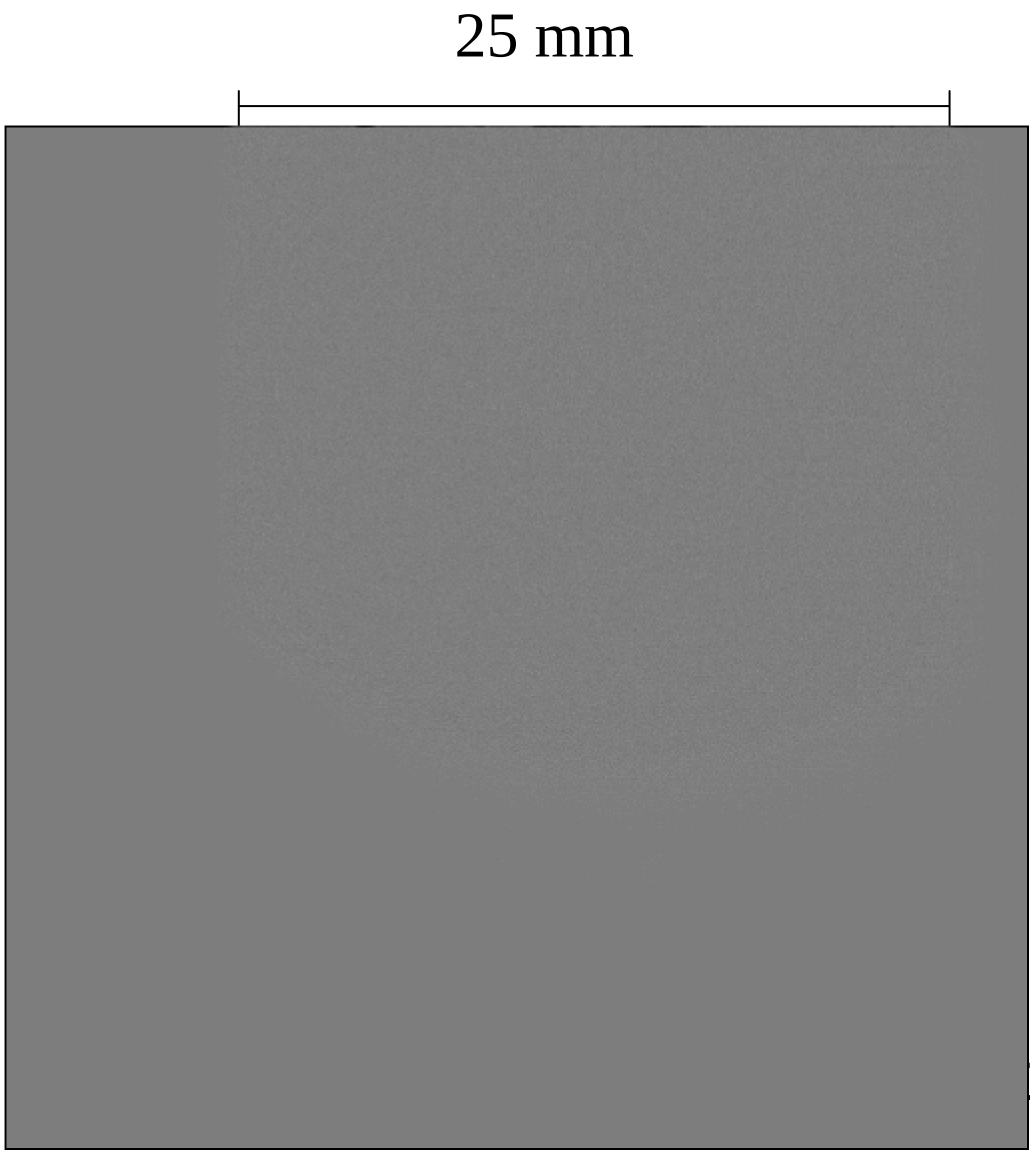


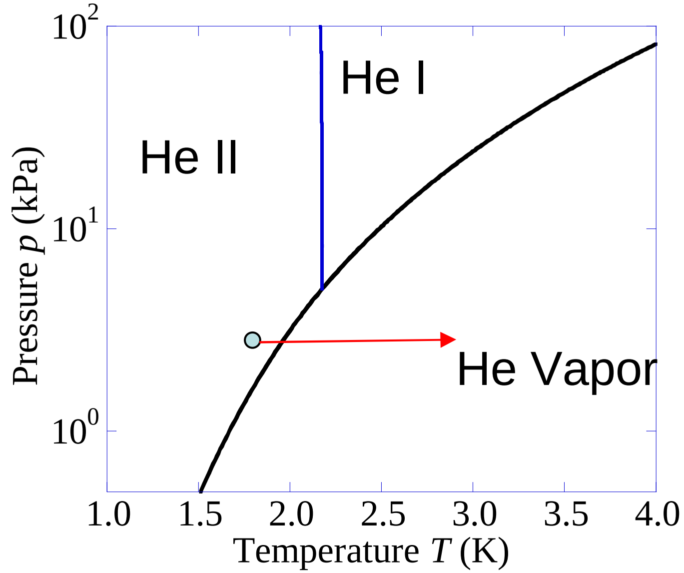


Saturated Vapor Pressure

1.9 K, q = 1.25 W = 0.20 W/cm^2

2. Visualization Result Saturated He II, 1.9 K (2 / 2)



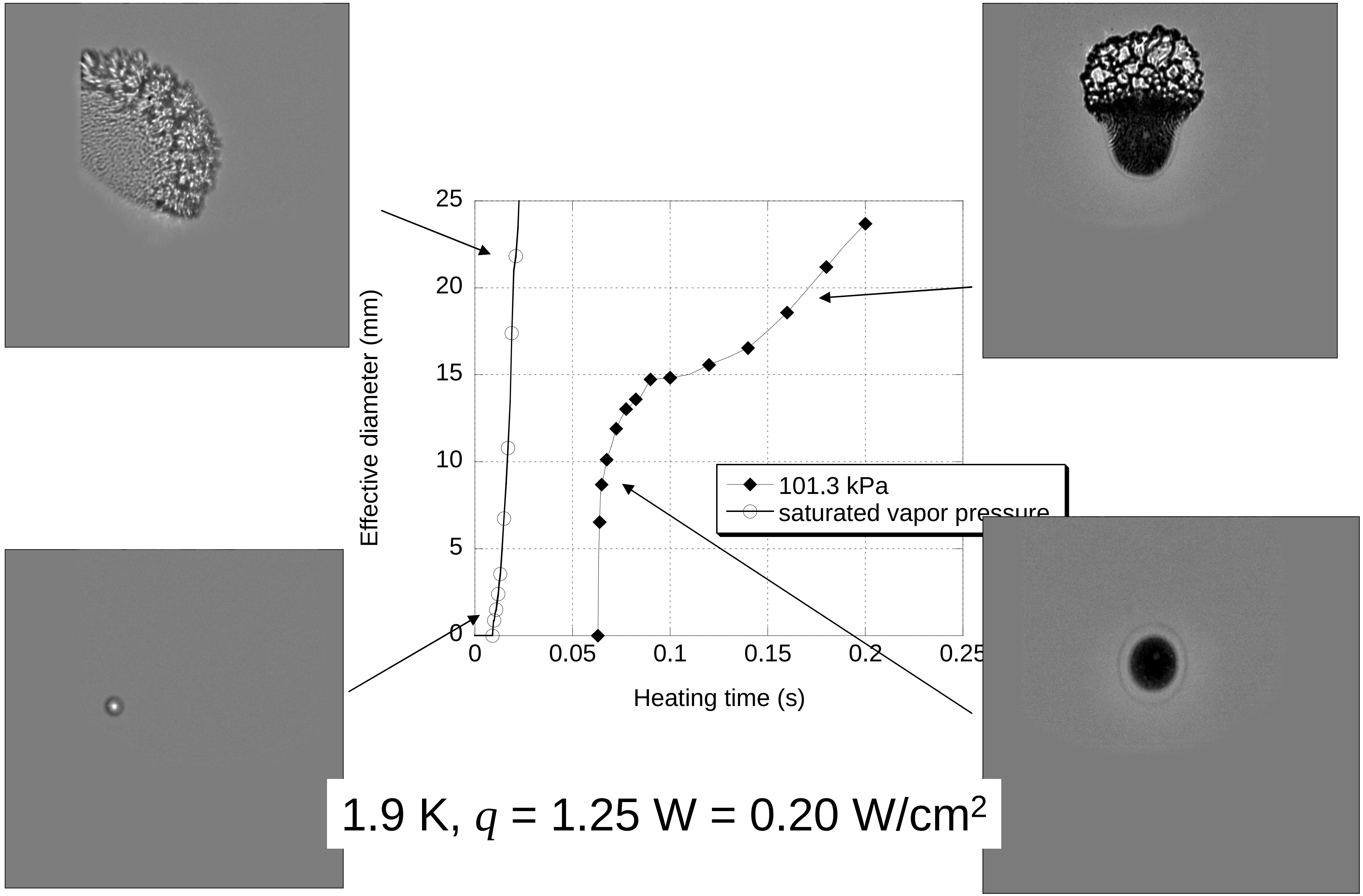


Running rate; 100 times slower

1.9 K, q = 1.25 W = 0.20 W/cm^2

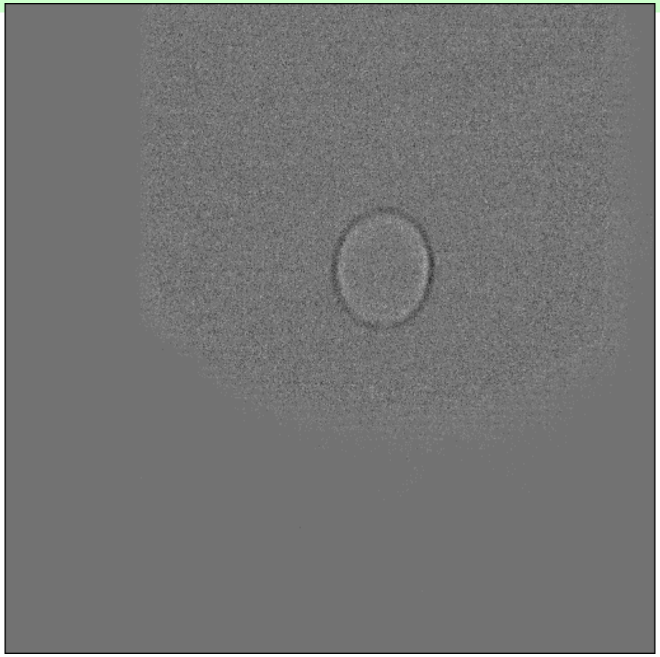
Under the Saturated Vapor Pressure Condition

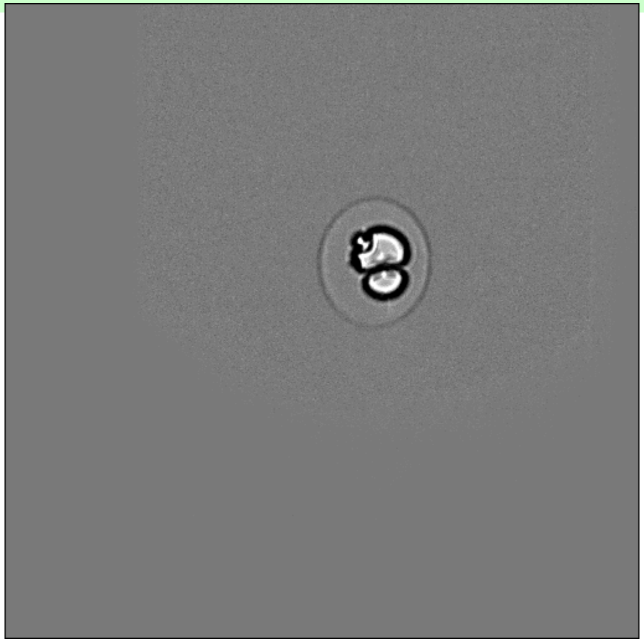
Dependence of Propagation speed on Pressure

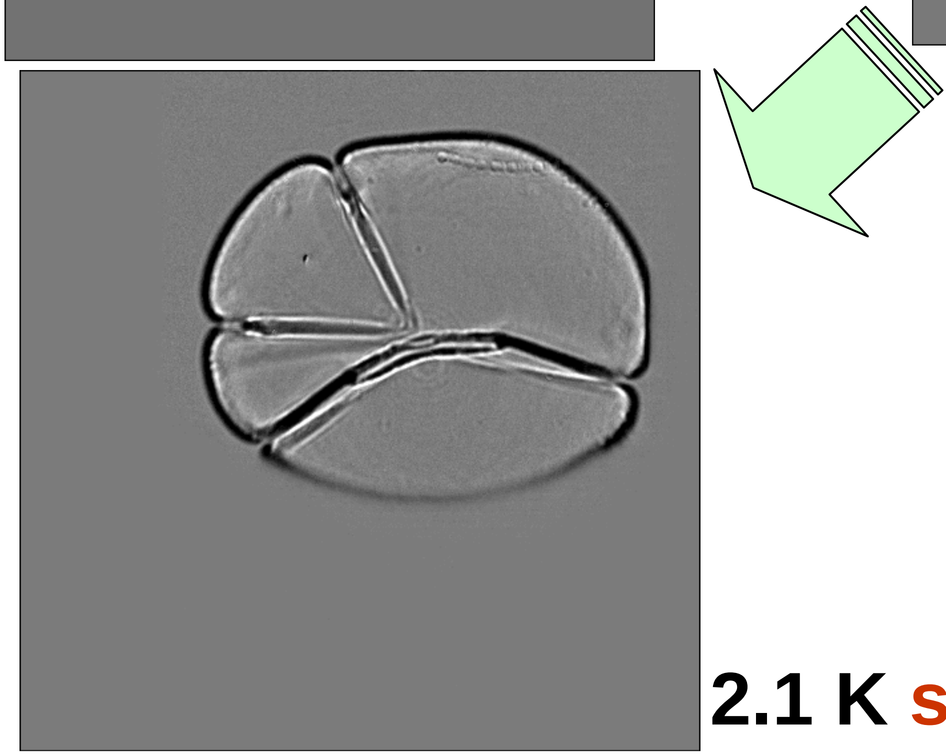


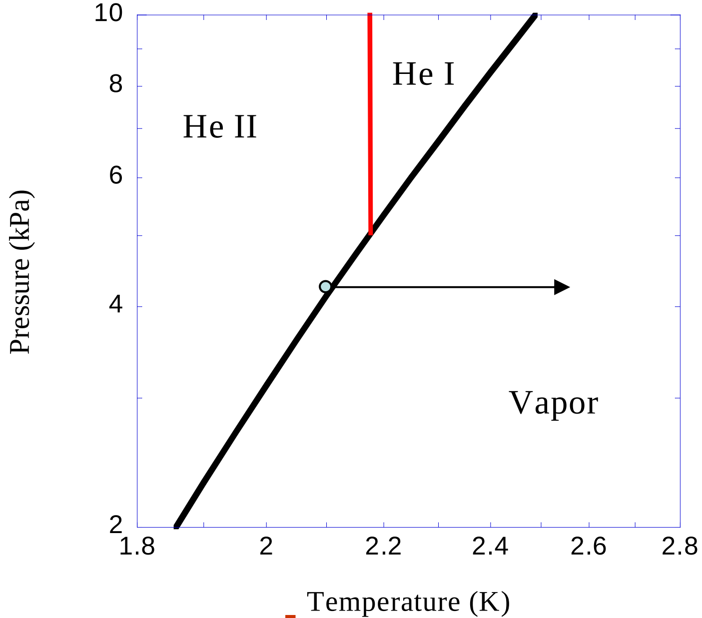
1.9 K, q = 1.25 W = 0.20 W/cm^2

3. Visualization Result ^{s}He II-^{s}He I interface



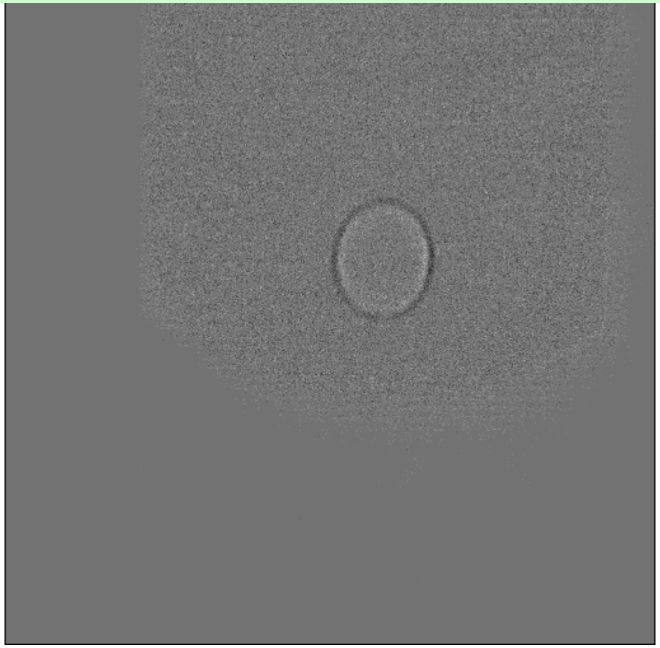


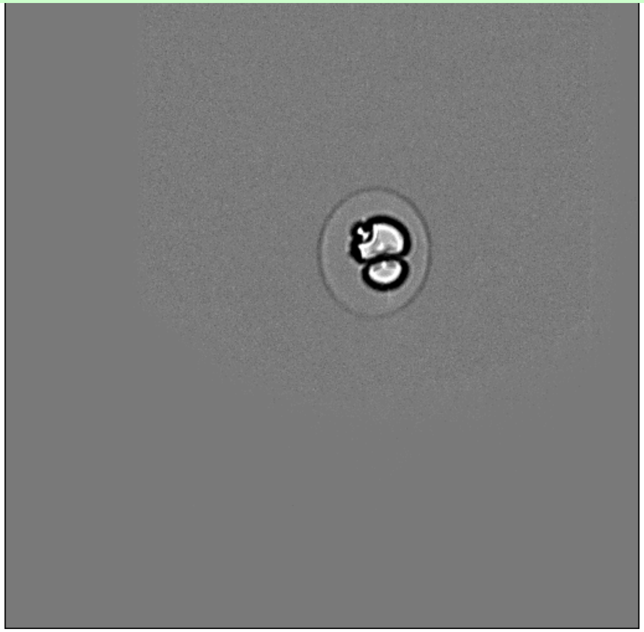


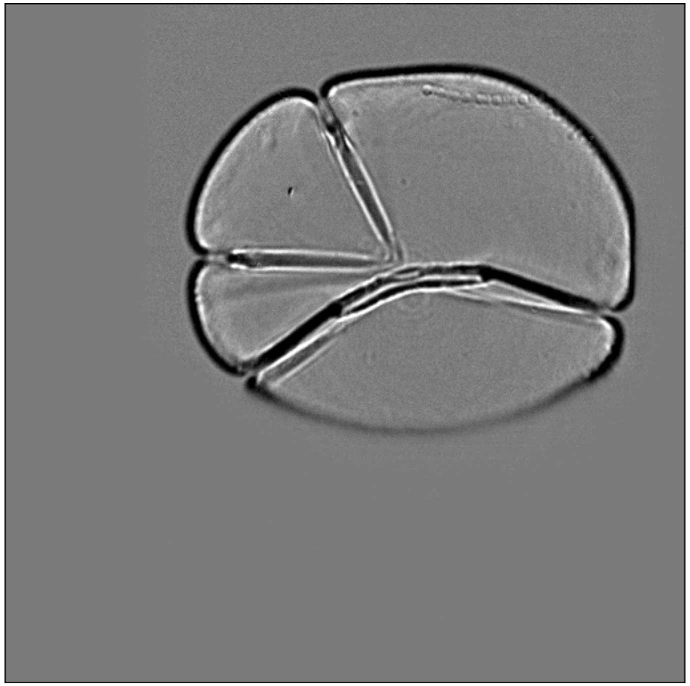


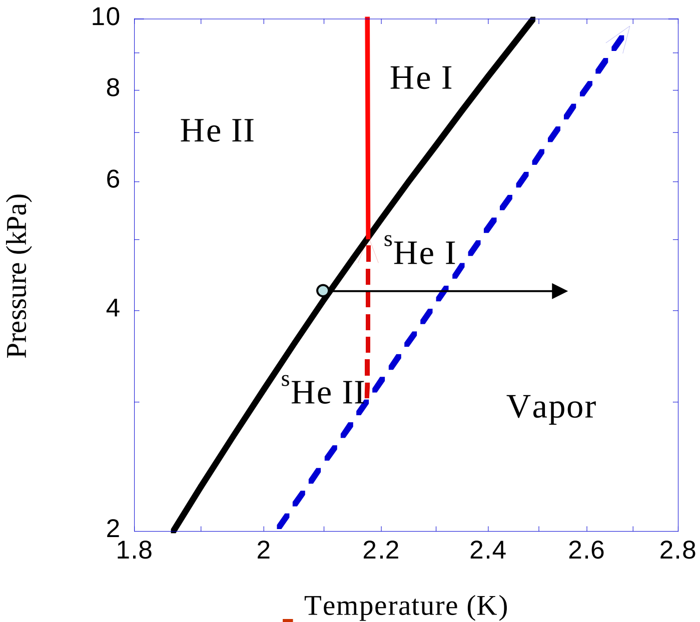
2.1 K saturated vapor pressure

3. Visualization Result ^{s}He II-^{s}He I interface



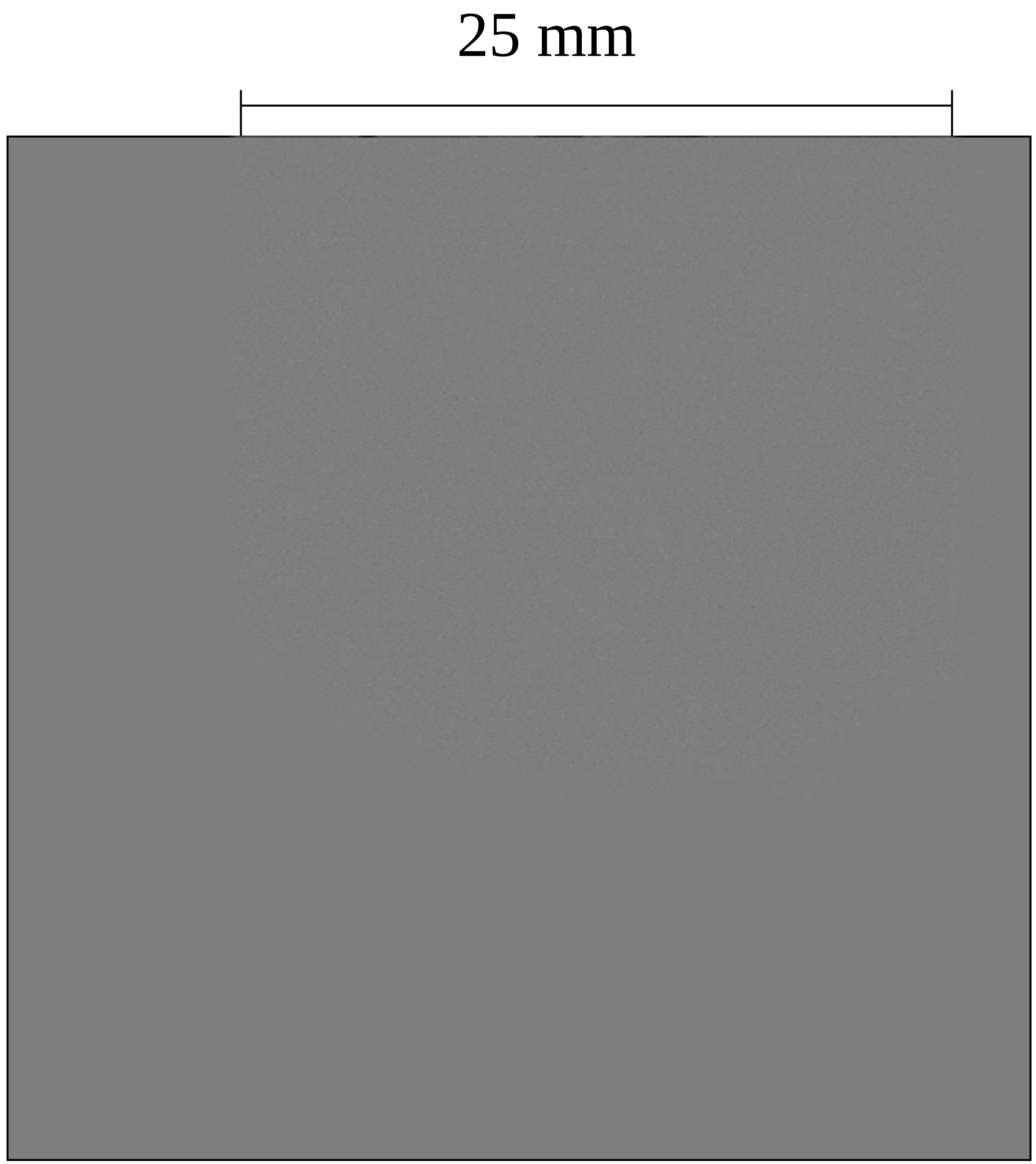


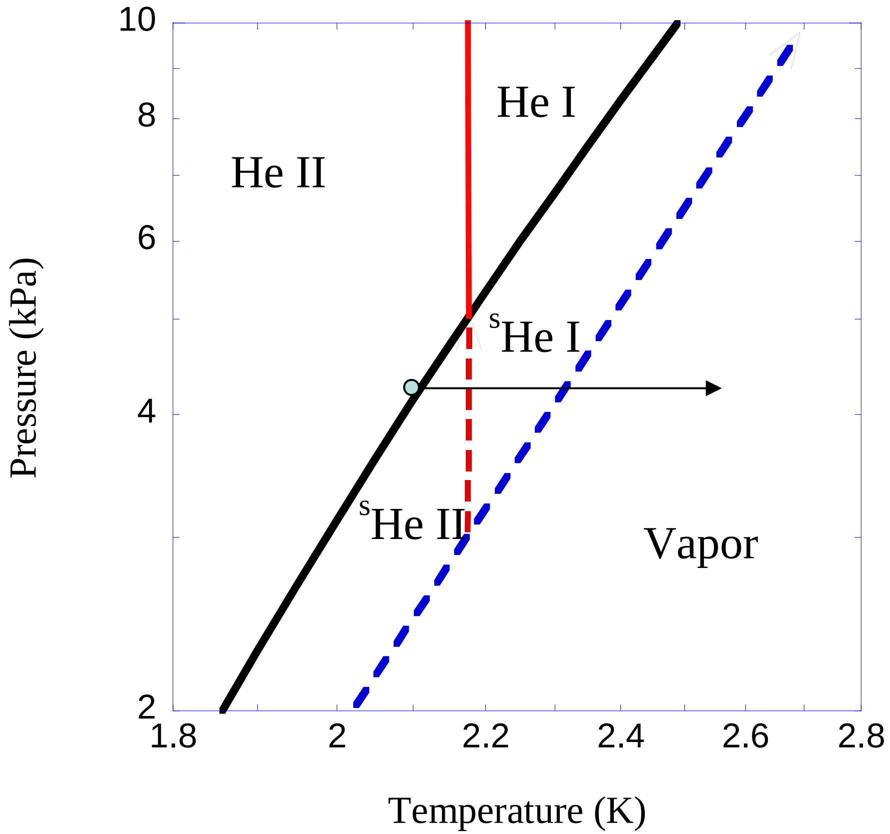




2.1 K saturated vapor pressure

3. Visualization Result ^{s}He II-^{s}He I interface (2 / 2)

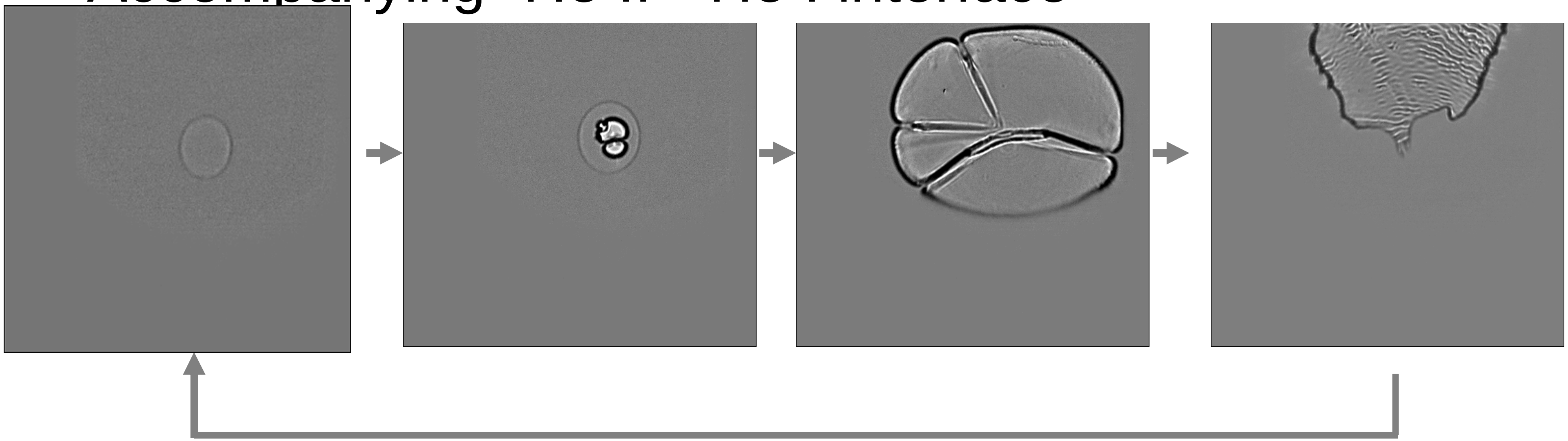


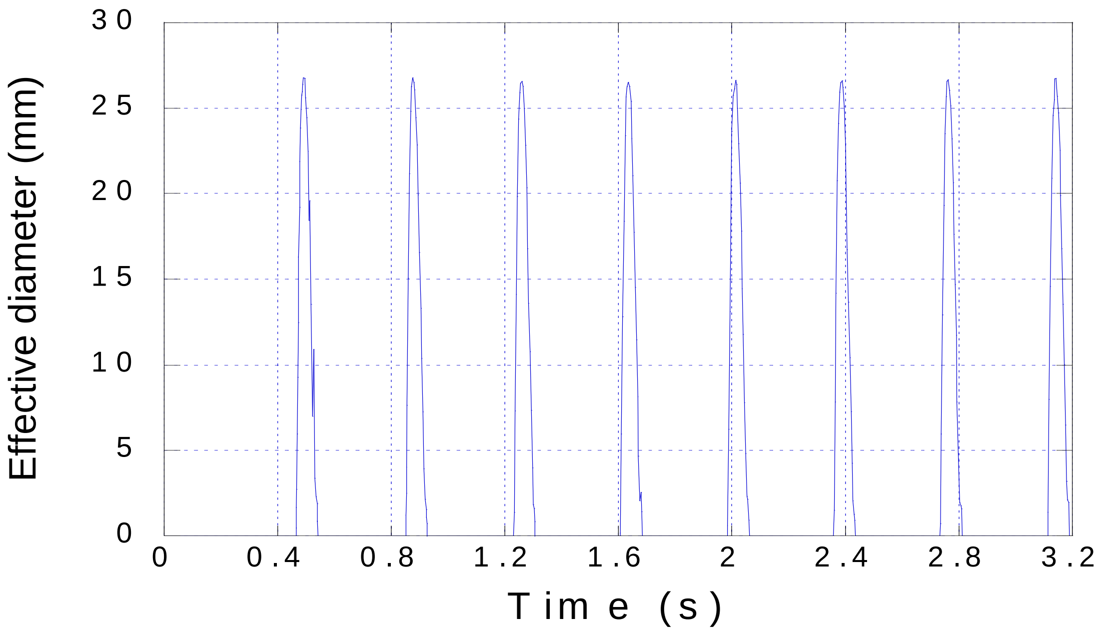


q = 0.457 W = 0.073 W/cm^2

2.1 K **saturated vapor pressure**

Periodic cycle of Vapor Generation and Collapse
q small□p; 13 kPa□saturated vapor pressure
Accompanying ^{s}He II- ^{s}He I interface



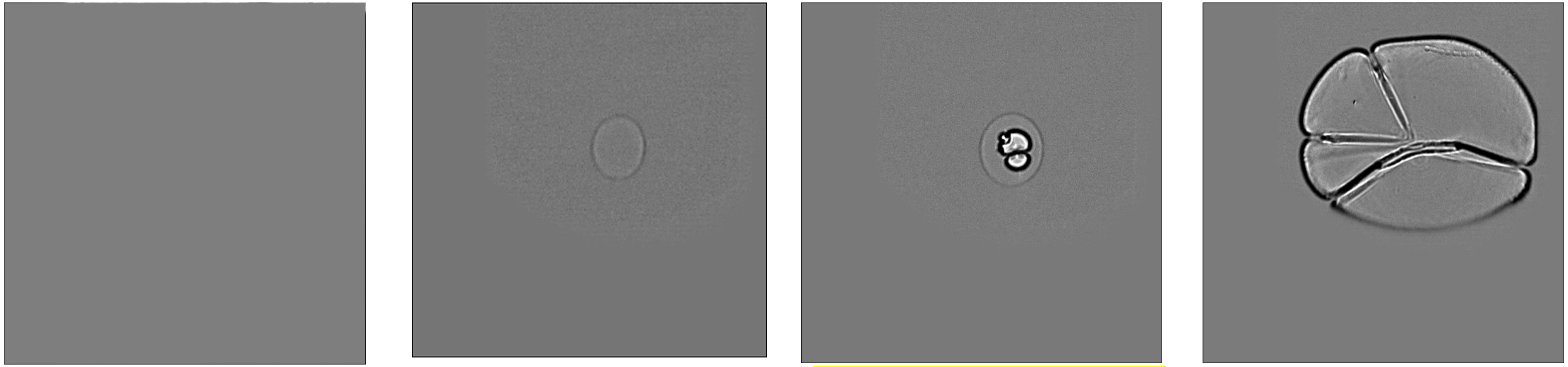


Saturated vapor pressure
2.1 K

q = 0.0848 W/cm²

q↑ □ frequency ↑

Frequency; 2□5 Hz

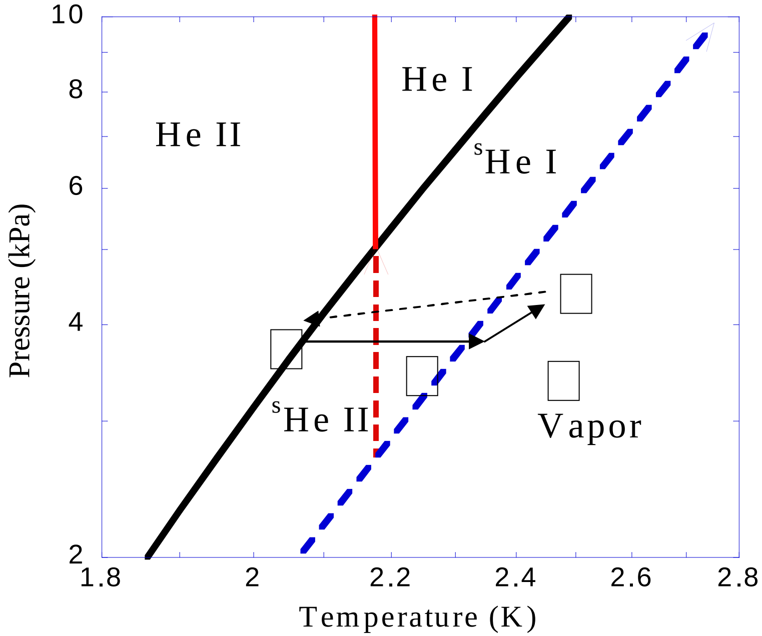


initial condition

^{s}He II-^{s}He I

^{s}He II-^{s}He I +Vapor

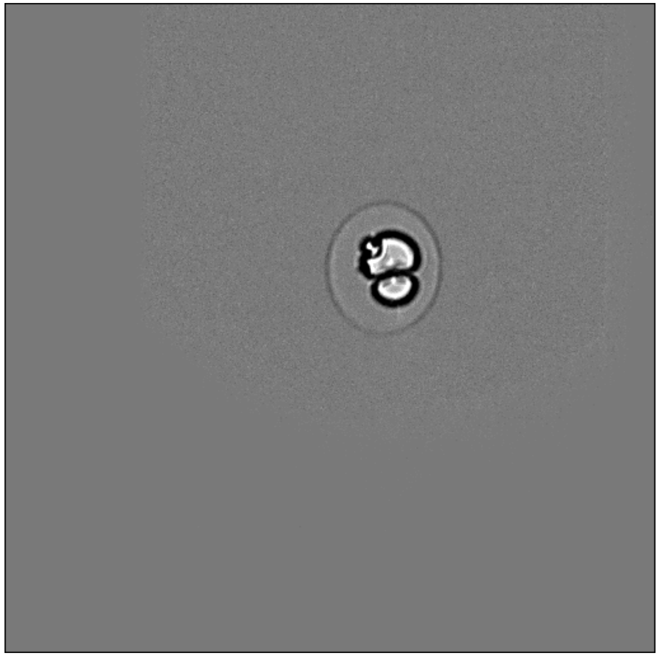
vapor expansion



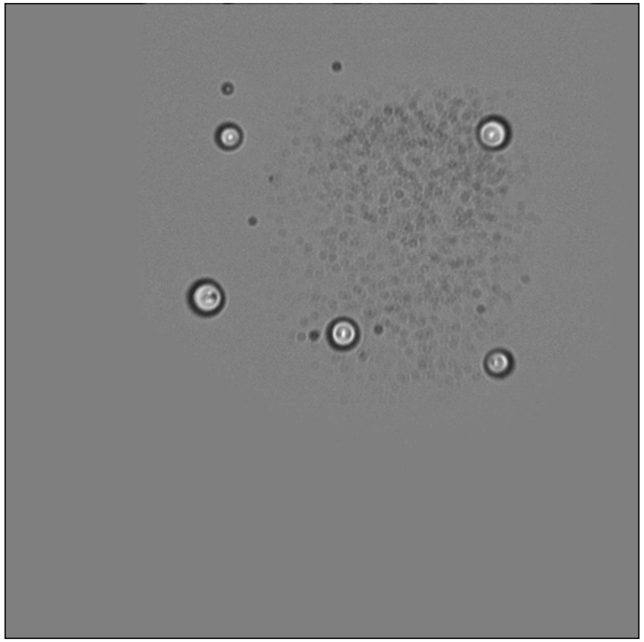
Heat cycle
around specific heat anomaly

High heat transfer coefficient

Condition of appearance of superheated He II –He I, Rather Small Heat flux



Small heat flux
T_b = 2.1 K,
q = 0.0733 W/cm2



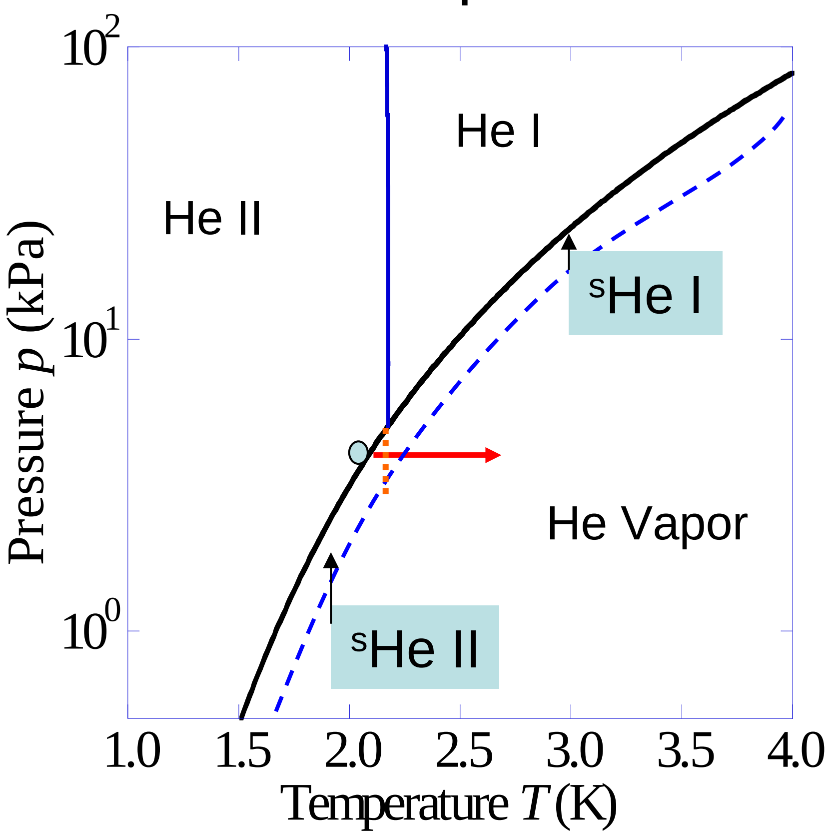
Large heat flux
T_b = 2.1 K,
q = 0.325 W/cm2

When rather large heat flux is applied,
Superheated He II-He I interface is not observed

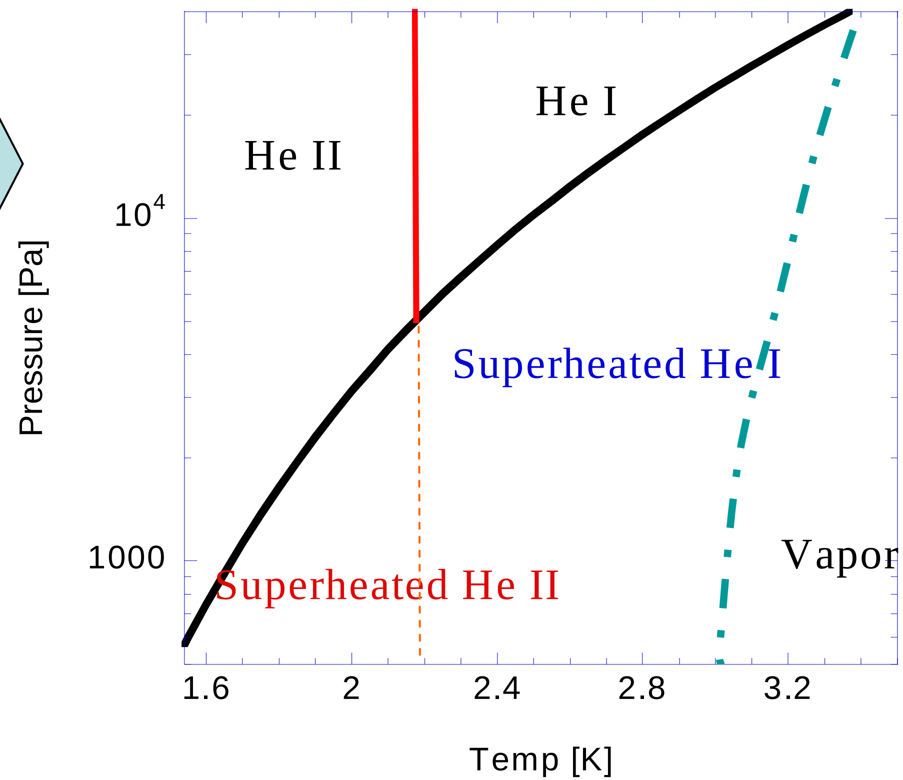
The narrow channel plays the role of stabilizer for superheated He II

But under the noise-free condition,
superheated region was expanded

Present experiment



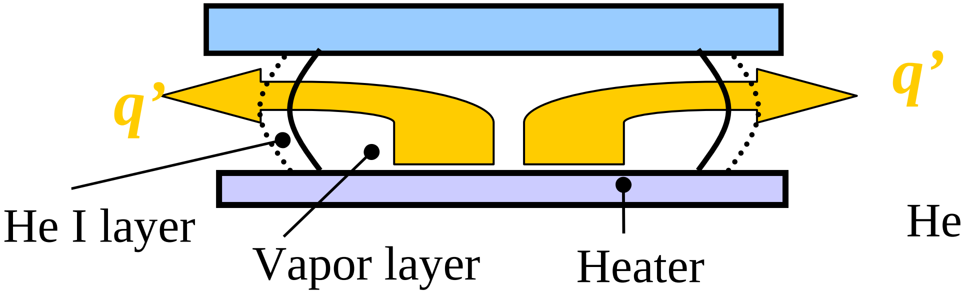
Noise-free Condition

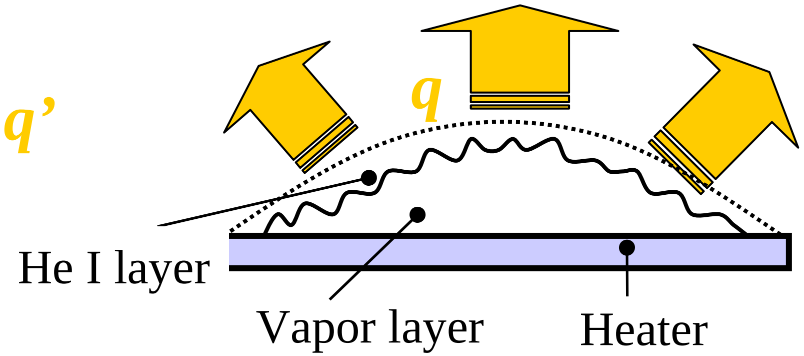


Summary

- The visualization of phase transition are succeeded.
- Superheated He II is easily created in the narrow channel
- Boiling accompanying superheated state is expected high heat transfer

Difference in calculation of heat flux





$$q = \frac{Q}{a}$$

$$a;\_heating\_area$$

$$q' = \frac{Q}{R \cdot d}$$

$$R;Peripherical\_length,\_\_d;gap\_thickness$$

^{s}He II-^{s}He I□□□□□

□□□□□□