# Avalanche Crystallization of $^4$He in Aerogel

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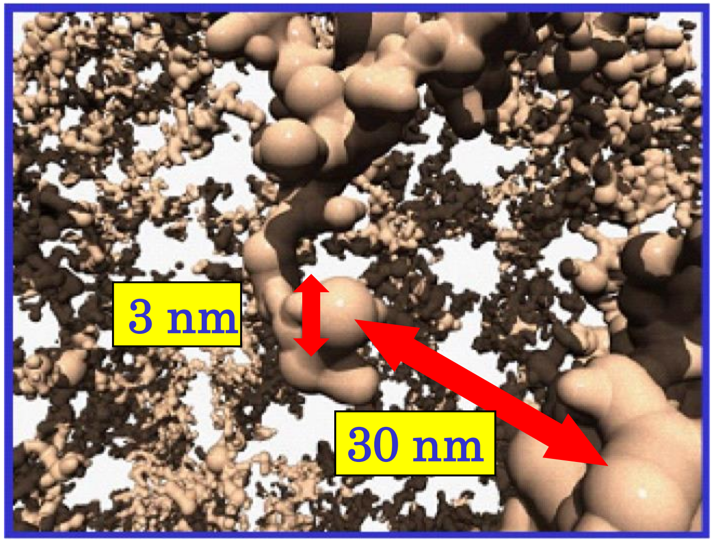
# 0. Introduction

Aerogel: ~ 98% high porosity,

very transparent,

suitable for visualizing the dynamics in it.




By Haard

By NASA

98% model aerogel

We are interested in the dynamics of the first order phase transition in disordered media at very low temperatures.

Why $^4He$?

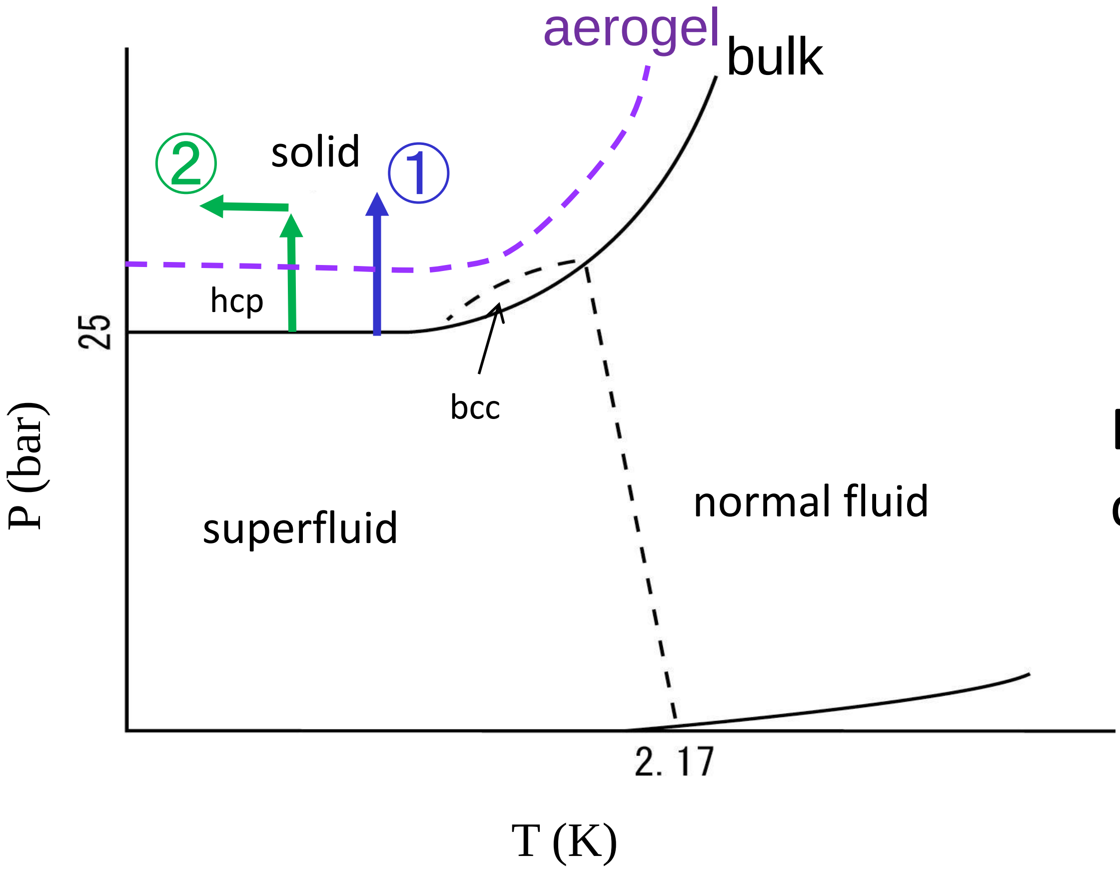
No viscous effect in pores.

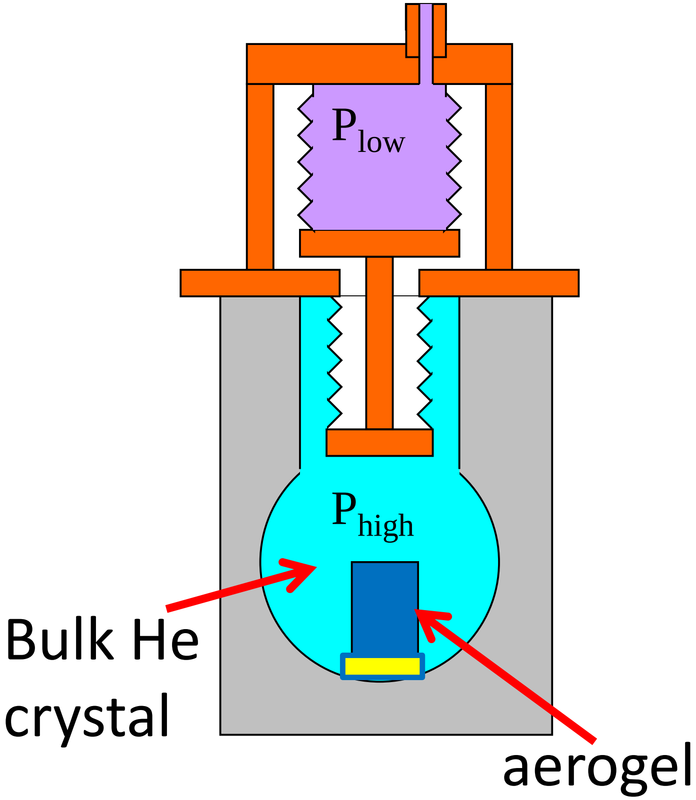
No release of latent heat.

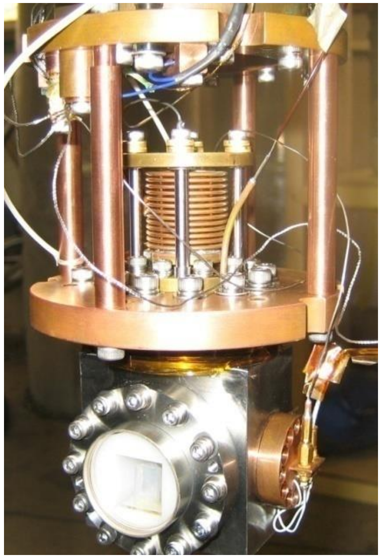
Effect of quenched disorder, which induces complex energy landscape, on the crystallization can be revealed down to absolute 0 K.

New quantum phenomena may emerge at very low temperatures.

# Variable volume cell

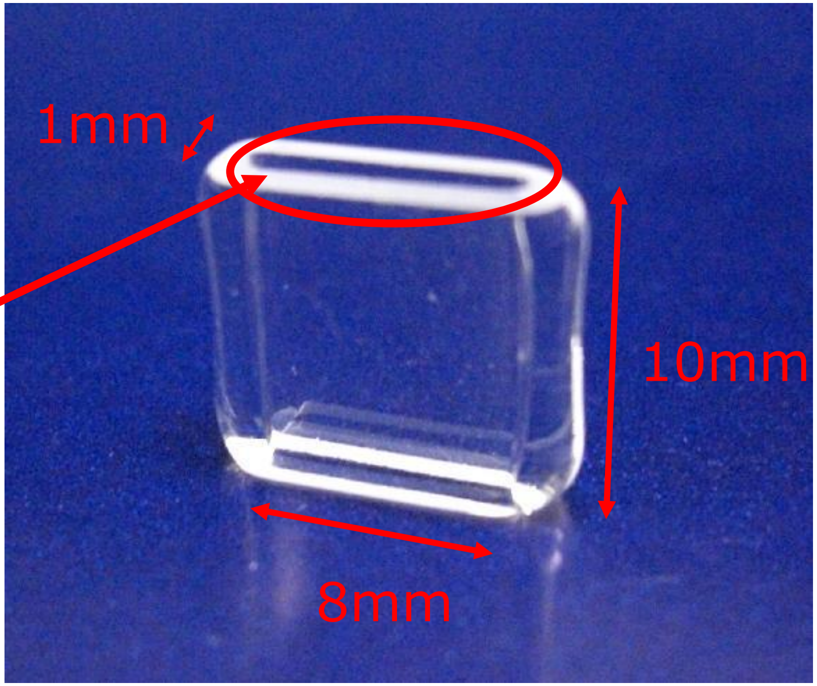


Crystallization at low temperatures can be investigated systematically.

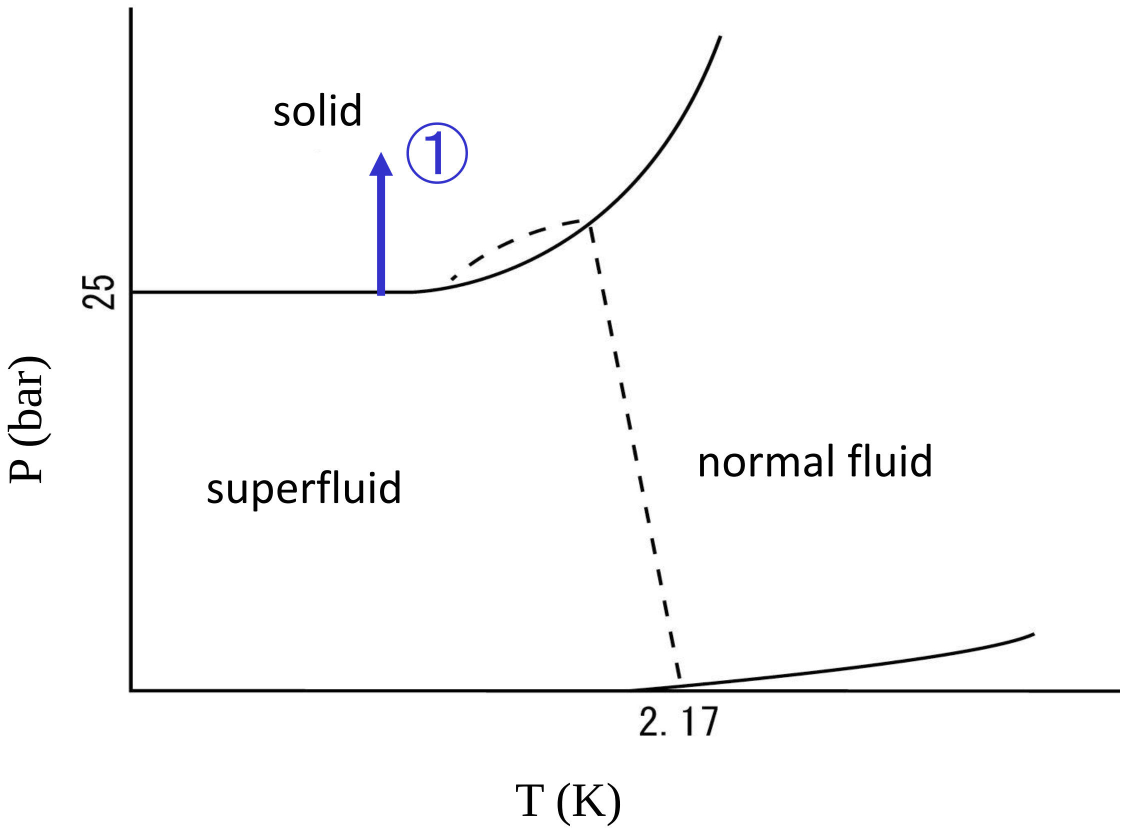
Aerogel is in a thin glass tube and has a contact with the bulk crystals on the upper surface.




Porosities: 96% made by Panasonic

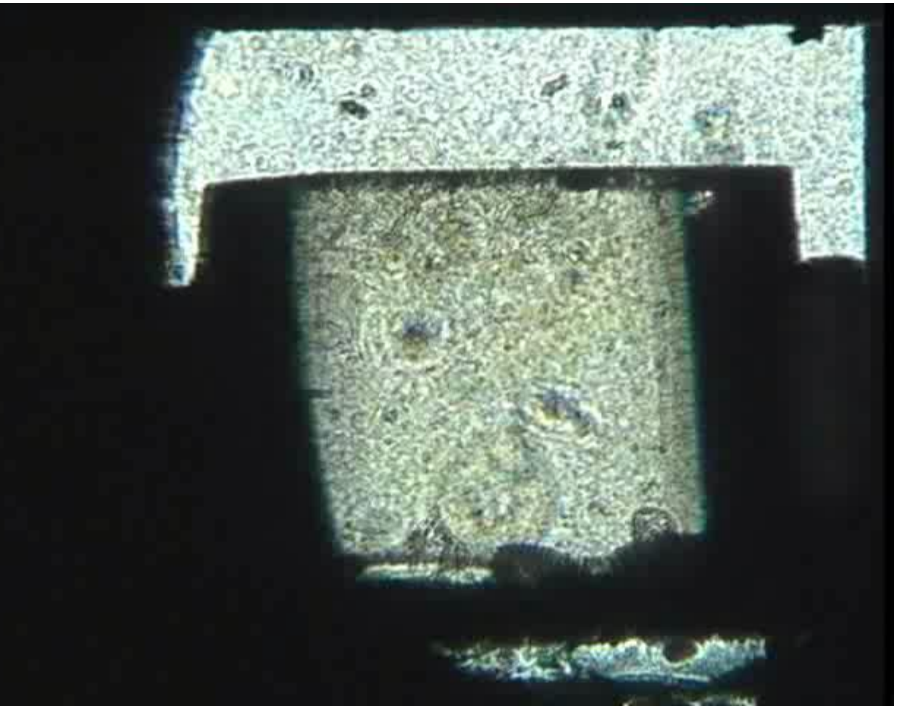
98% made by Pollanen and Halperin at Northwestern University

# 1. Crystallization of $^4$He in aerogel by pressurization



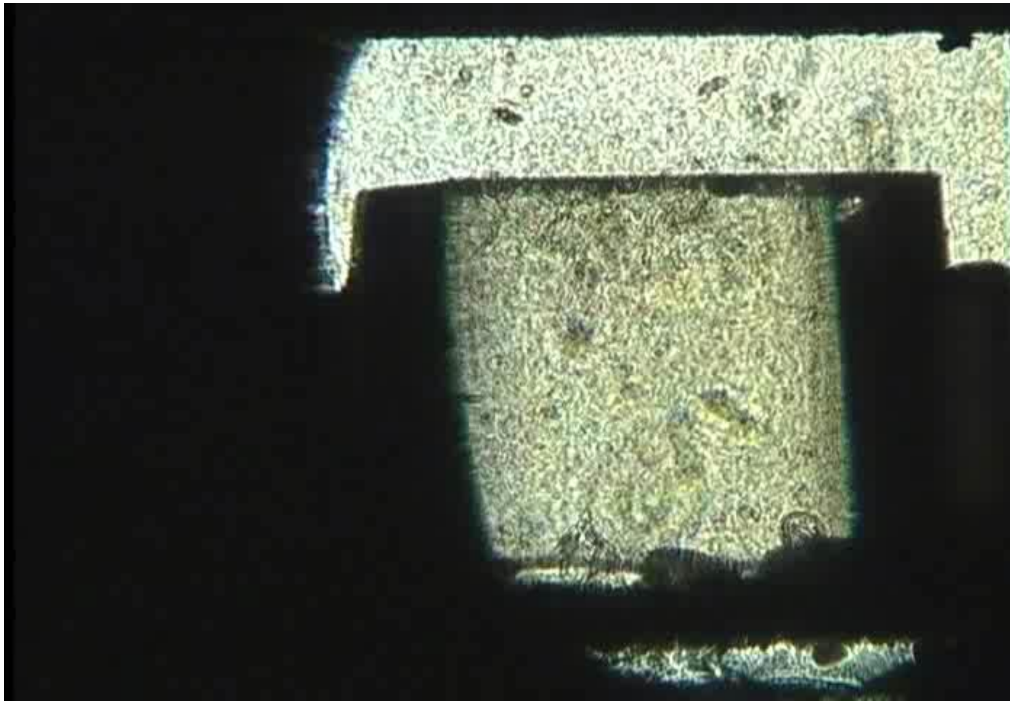
# Crystallization in 98% aerogel

170 mK



(50 times faster replay)

850 mK

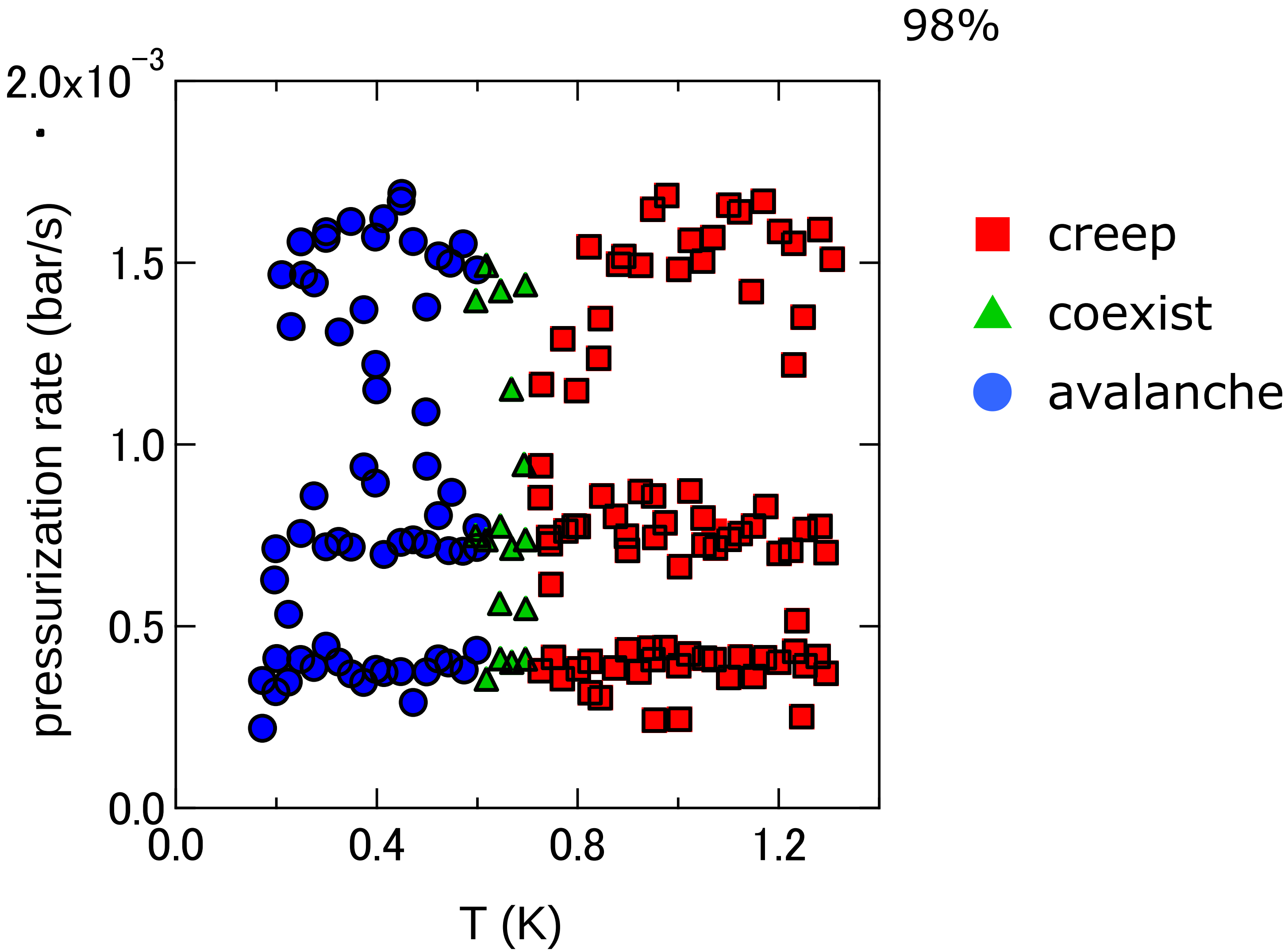


(100 times faster replay)

Avalanche at low temperatures ⟷ Creep at high temperatures

Transition in a growth mode

# Dynamical phase diagram

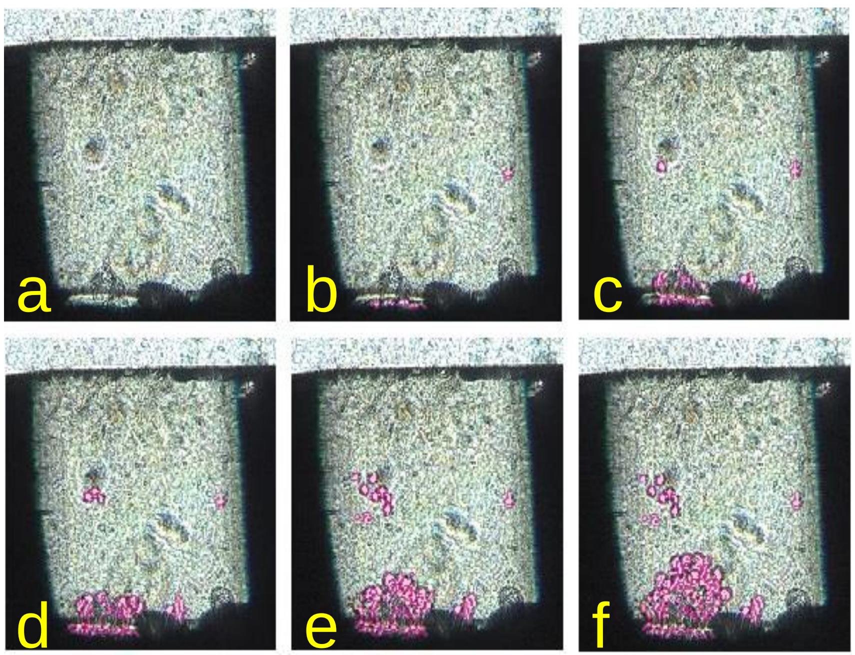


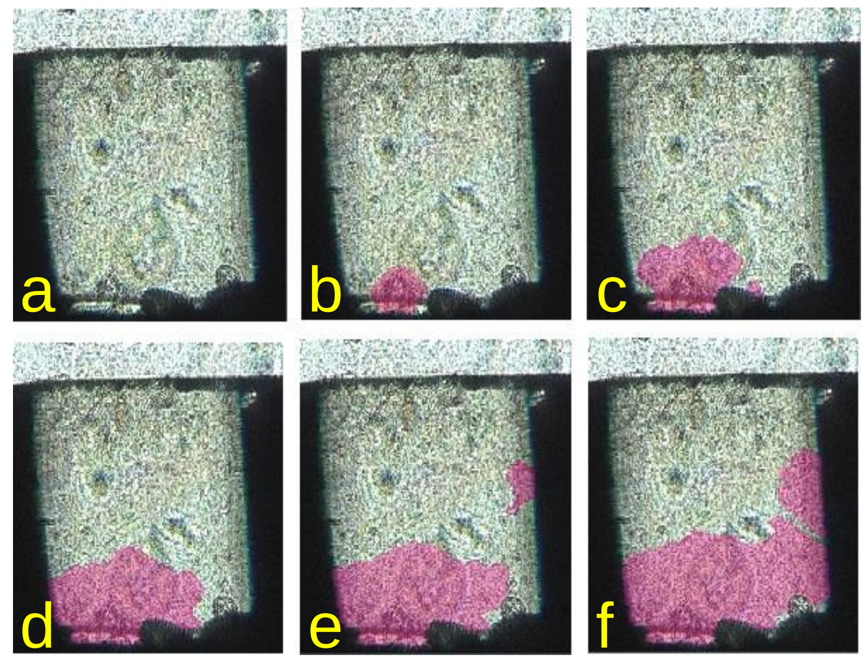

Competition between thermal fluctuation and disorder

Nomura *et al*. PRL **101**, 175703 (2008)

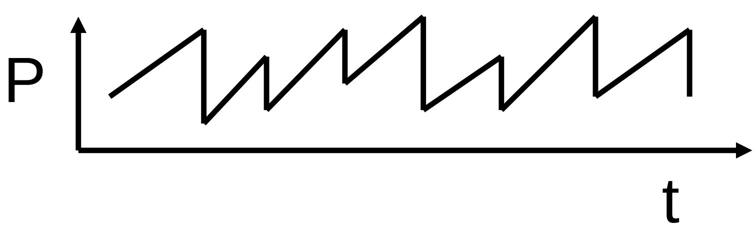
Mass has to be transferred for the crystallization.
$^4$He crystals are formed deep in the aerogel.

Outer bulk crystal has to be melted by the stress,
and enter the aerogel in the superfluid state.

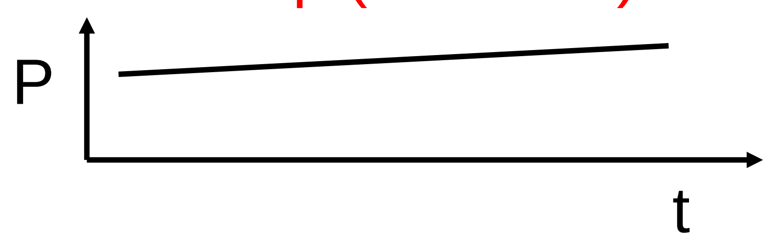



Avalanche (quantum?)

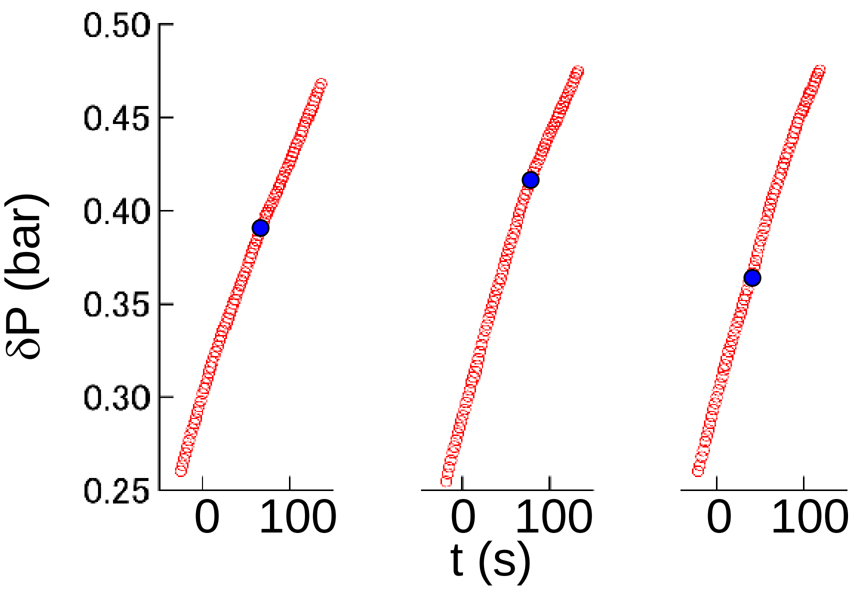



Creep (thermal?)



# Nucleation probability

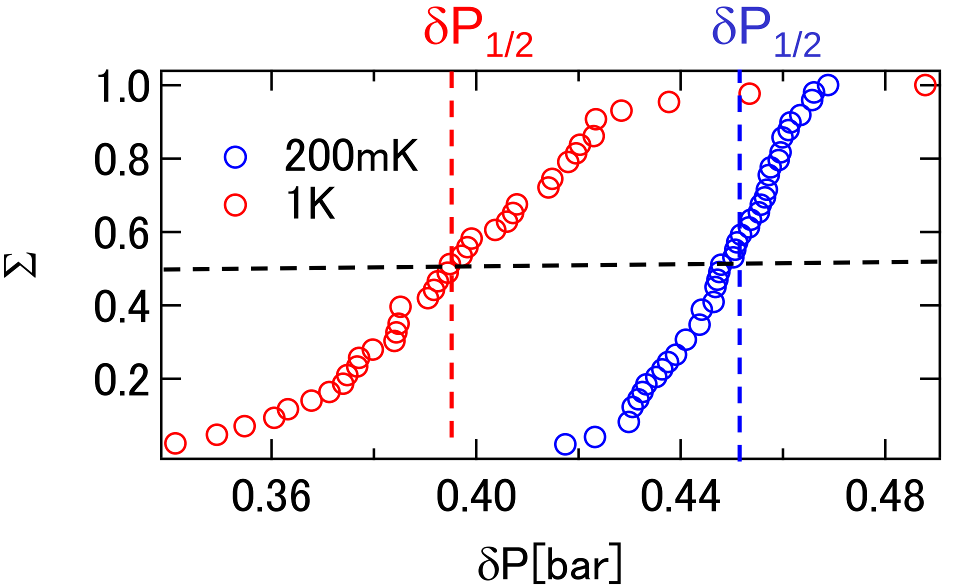
Critical overpressure at which the first crystal appeared.



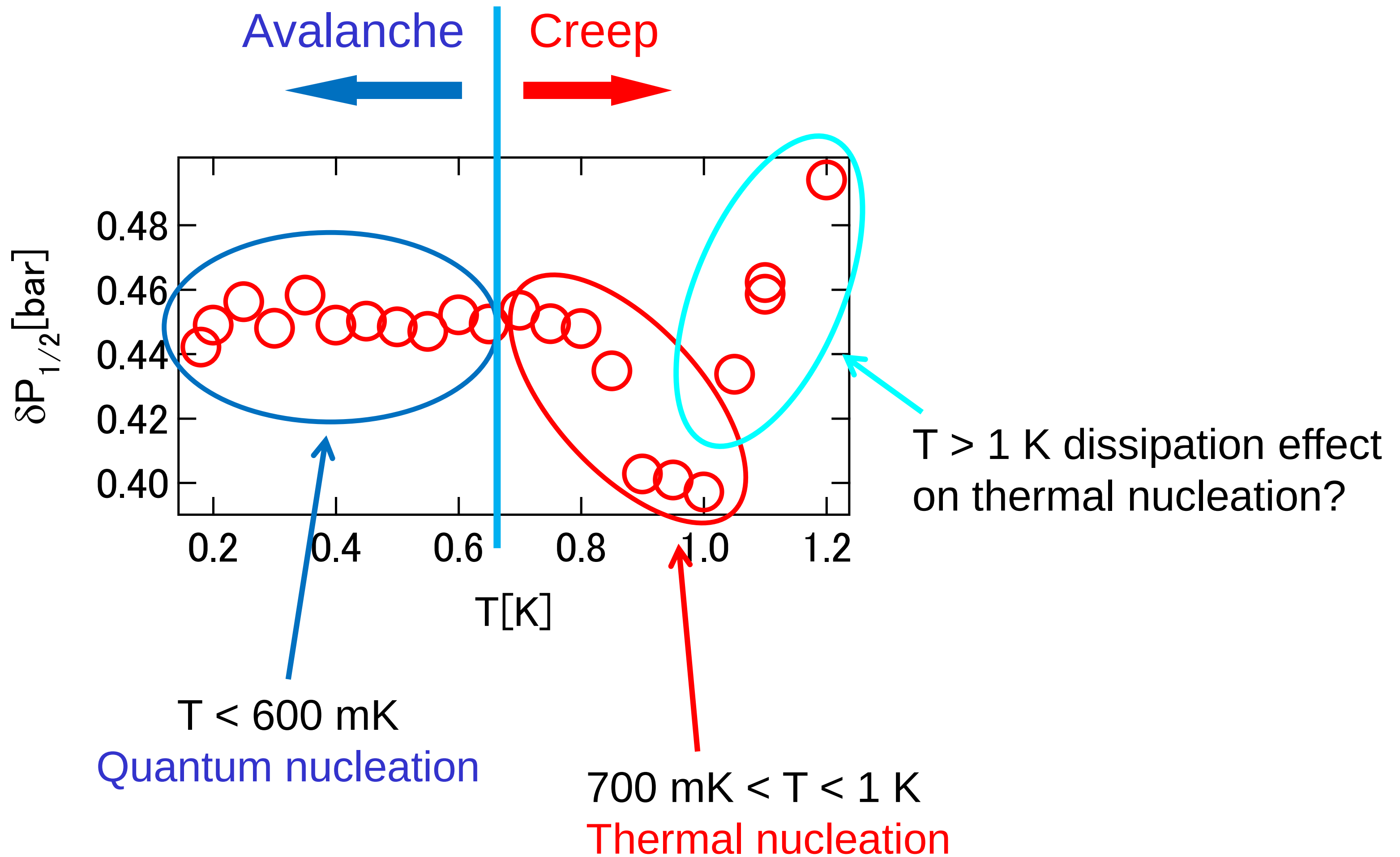

Clear metastability:

not instability but nucleation

The critical overpressure was measured 50 times at constant temperature.



# $\delta P_{1/2}$ mean critical overpressure in 98% aerogel

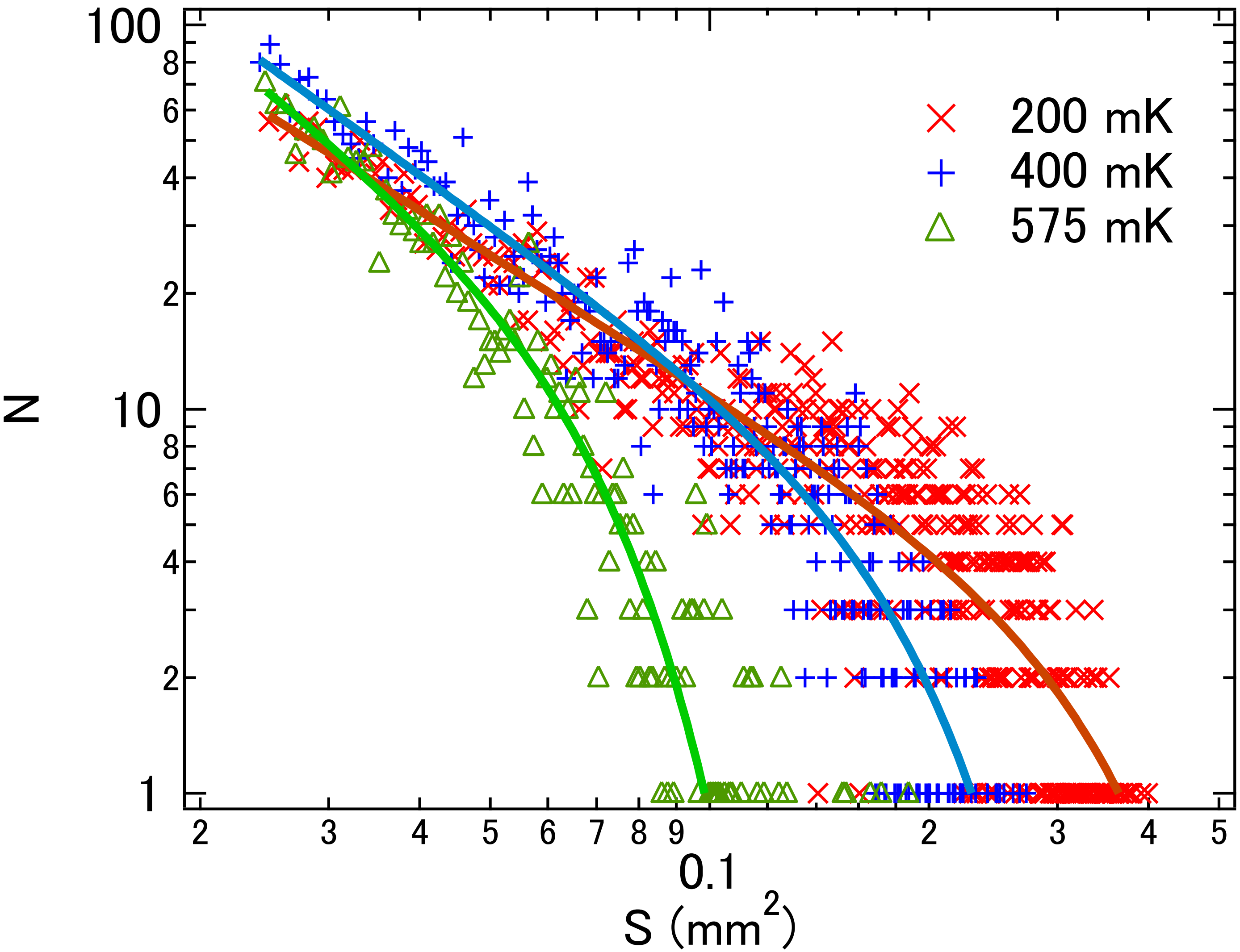



Avalanche: quantum nucleation

Creep: thermal activation

Matsuda *et al*. PRE (2013)

# Power law in the avalanche size distribution in 98% aerogel

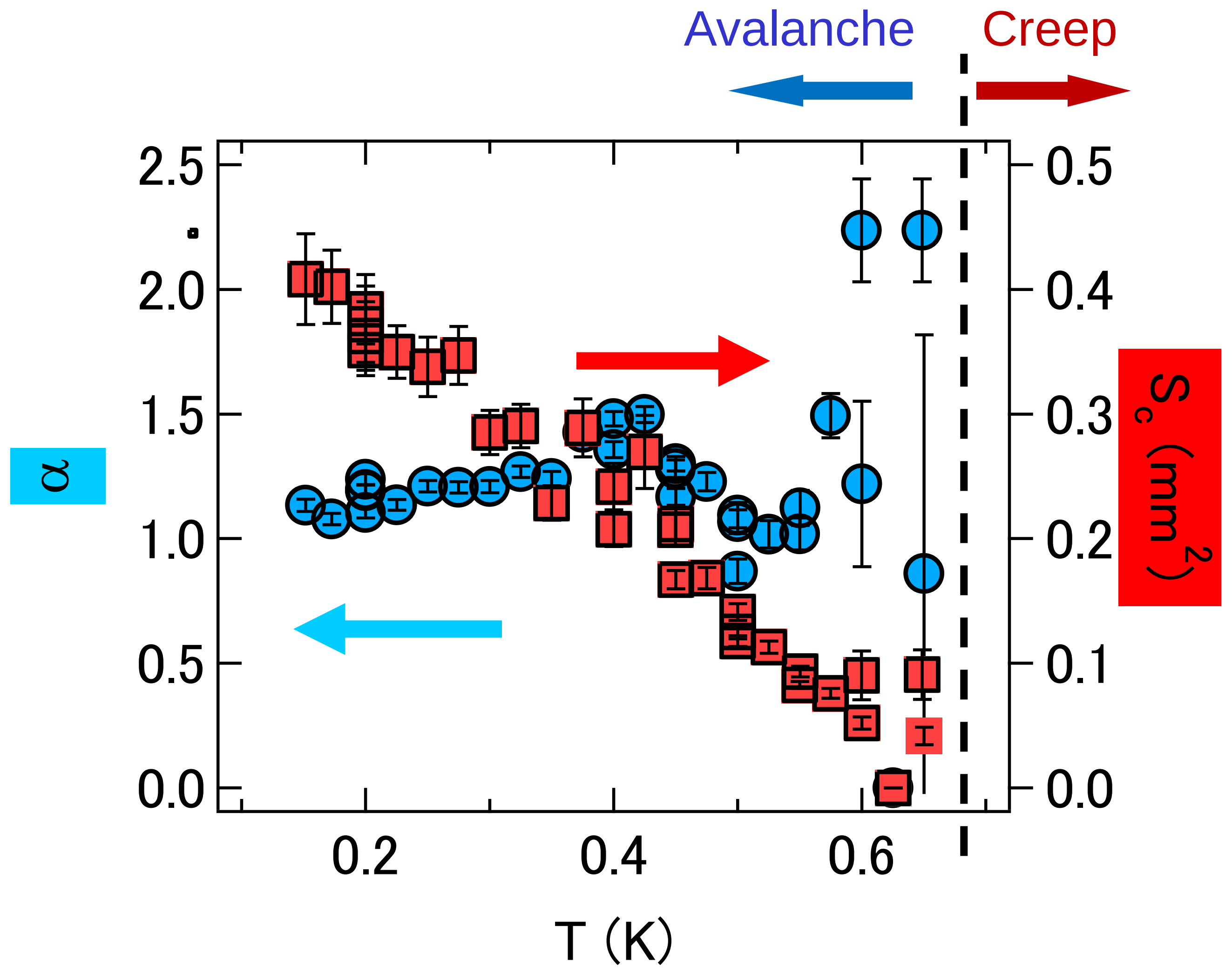



Self-organized criticality (SOC) in quantum growth

$$\beta = 3$$

$$N = AS^{-\alpha} \exp\left(-\left(\frac{S}{S_c}\right)^{\beta}\right)$$

Nomura *et al.*, JPSJ **80**, 123601 (2011).
Editors' choice




$S_c$ decrease as approaching the transition.
(due to dissipation?)

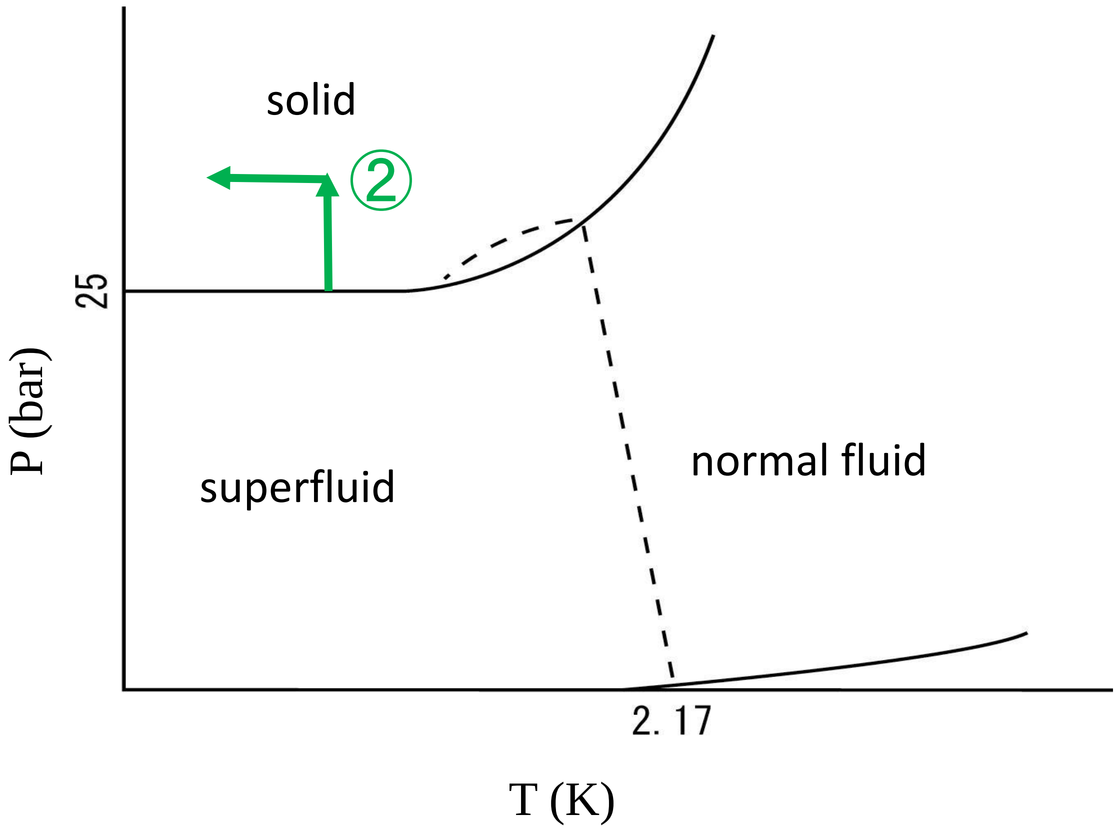
$$N = AS^{-\alpha} \exp\left(-\left(\frac{S}{S_c}\right)^{\beta}\right)$$

Looks like a crossover.

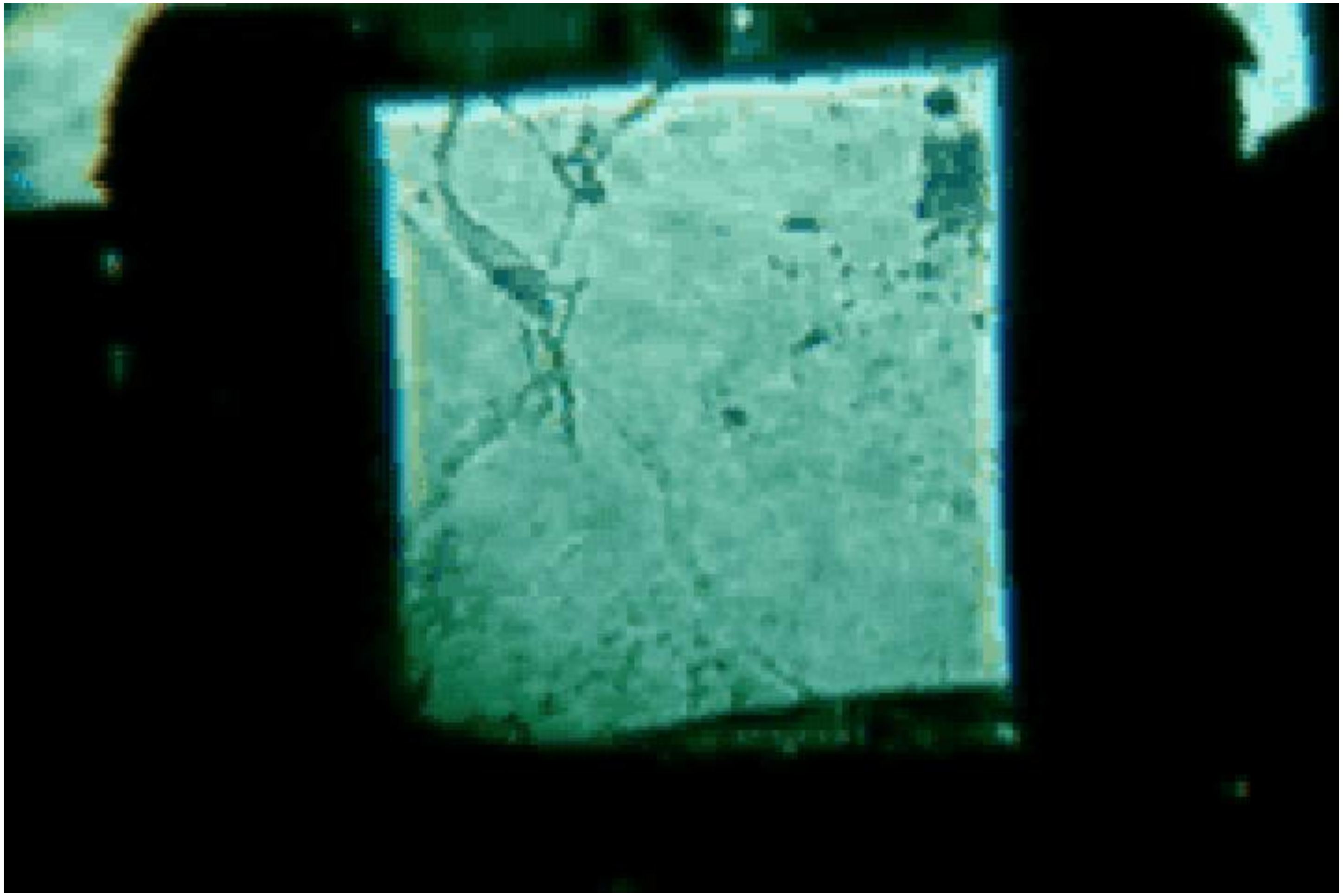
$$\alpha' \approx \frac{2}{3}\alpha \approx 0.8$$

2. Crystallization of $^4$He in aerogel on cooling

Due to “supersolidity”?

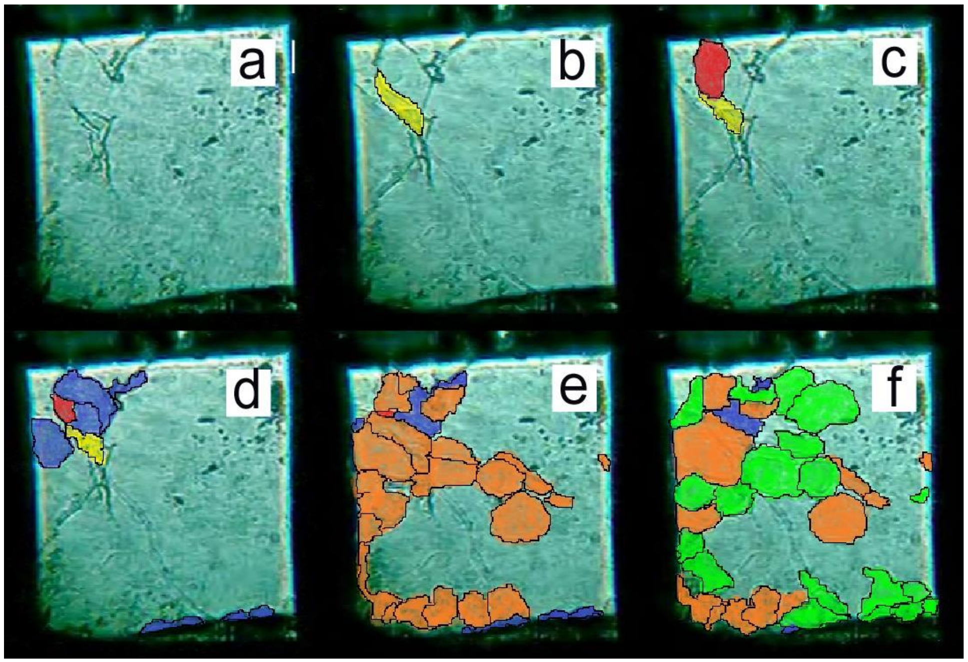


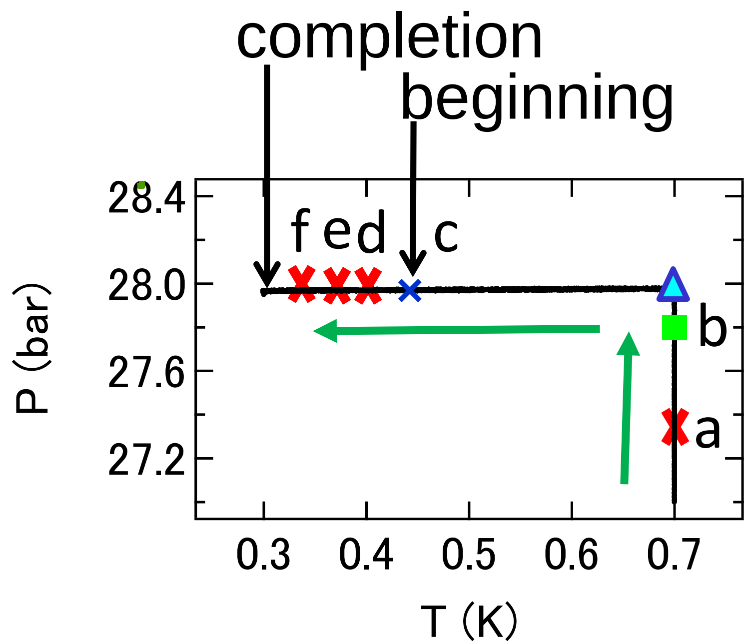
# Crystallization of $^4$He in 96% aerogel on cooling



100 times faster

# Crystallization of $^4$He in 96% aerogel on cooling

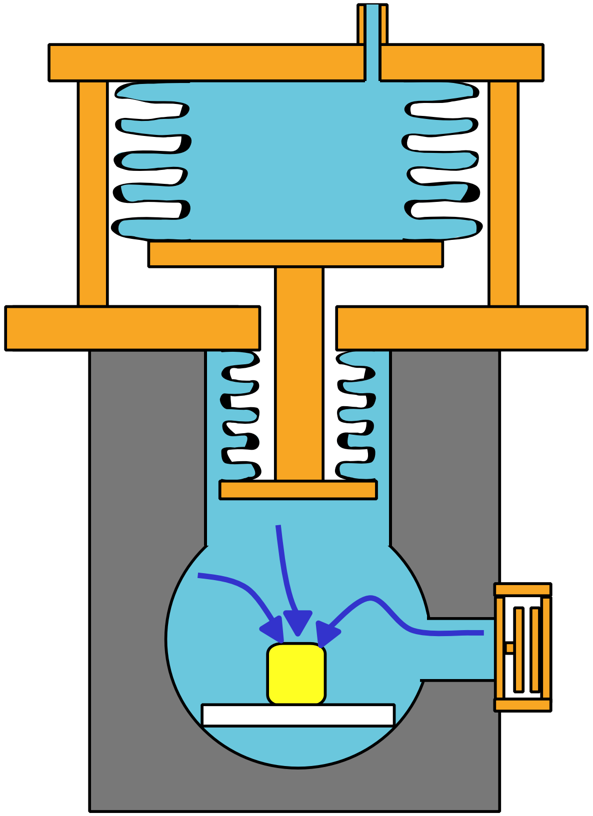



Mass supply from the surrounding bulk crystals into aerogel is needed to grow crystal in aerogel, even without pressurization.

# Crystallization rate and Pressure of bulk crystals on cooling

Mass flowed from the surrounding bulk crystals into aerogel.



1. What is the driving force for crystallization on cooling?

Equilibrium crystallization pressure is temperature independent at low temperatures in $^4$He.

$$\Delta\mu = \left\{\frac{1}{\rho_l} - \frac{1}{\rho_s}\right\}\Delta P - \cancel{(S_l - S_s)\Delta T}$$

Usually neglected

2. How mass is transported in bulk $^4$He crystals?

May be related to the so called "supersolidity".

# Mass flow experiment

$T_{flow}$ = 630 mK

Original torsional oscillator experiment by Kim and Chan (Nature 2004) was retracted.

But, occurrence of mass flows in $^4He$ crystal was reported by Hallock *et al*. (PRL 2008) by direct flow measurements.

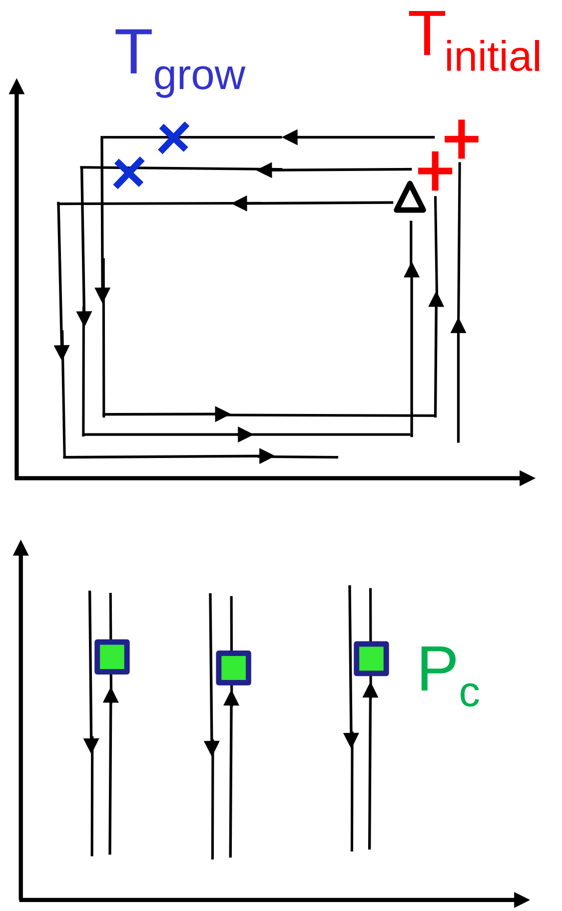
# Superfluid components at a core of edge dislocation

Path integral Monte Carlo technique

Boninsegni *et al*., PRL **99,** 035301 (2007)

This issue has not been is settled, yet.

# Crystallization diagram in aerogel on cooling




$T_{grow} < T_{flow} = 630$ mK

by Hallock

# Summary

Crystallization in aerogel is via creep at high T and via avalanche at low T by pressurization.

Creep growth is thermal activation and avalanche growth is macroscopic quantum tunneling from both crystallization rate and nucleation probability measurements.

Avalanche size follows a power low: Self-organized critical states in macroscopic quantum tunneling.

Crystallization on cooling was observed.

$T_{grow}$ was lower than $T_{flow}$.

$T_{grow}$ had a anomalous pressure dependence.

$T_{grow}$ had a anomalously wide distribution; large supercooling in nucleation process.

This can be an observation of a new crystallization mode as "supersolidity"-assisted crystallization in pores.