POS44

Phase transitions of superconducting wire network under field modulation

Institute for Solid State Physics,

University of Tokyo

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NVLS2006

Dec. 11-13 (2006) @ Kyoto Research Park

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Phase transition of superconducting wire network (SWN)

- in two steps
- affected by magnetic field → frustration

  Frustration parameter α = vortex filling

Normal ($\psi = 0$)

1. Mean field transition
   - $\psi = 0 \Leftrightarrow \psi \neq 0$
   - θ is still disordered --- $R \neq 0$
   - α causes the oscillation of T_c

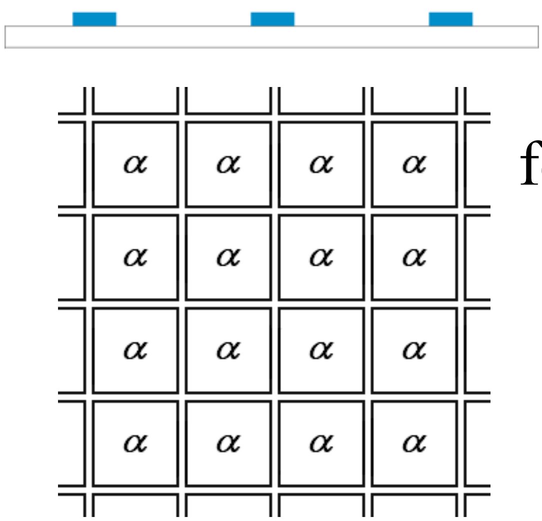
Superconducting ($\psi \neq 0$) but $R \neq 0$

2. True superconducting transition
   - $R \neq 0 \Leftrightarrow R = 0$
   - θ gets ordered.--- XY model
   - α changes the nature of the transition

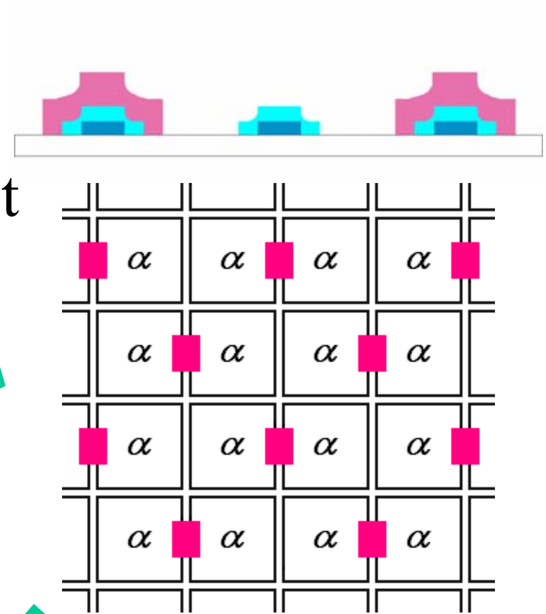
$R = 0$

Previous studies use only uniform magnetic field.

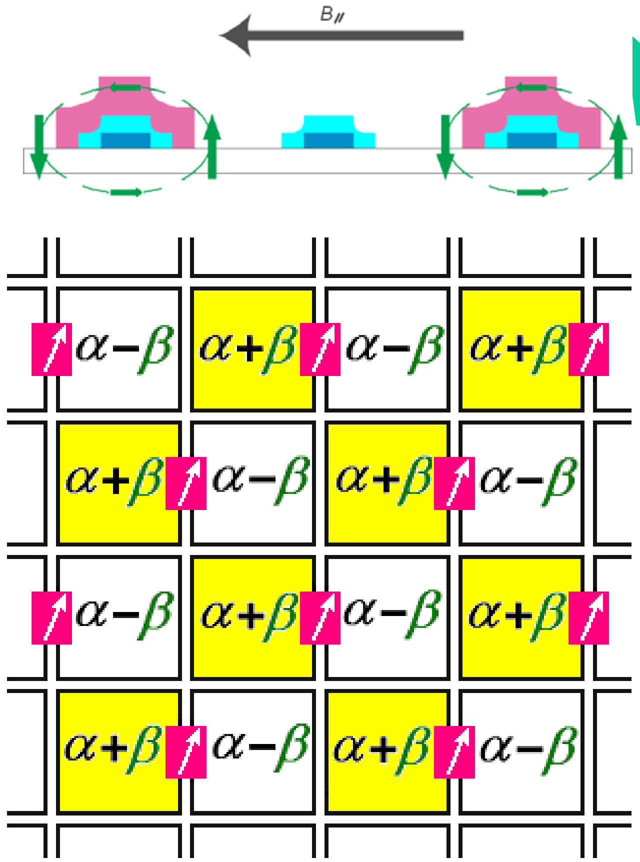
→ Let's apply spatially modulated magnetic field *!!*



Put
ferromagnet



Magnetize by
in-plane field

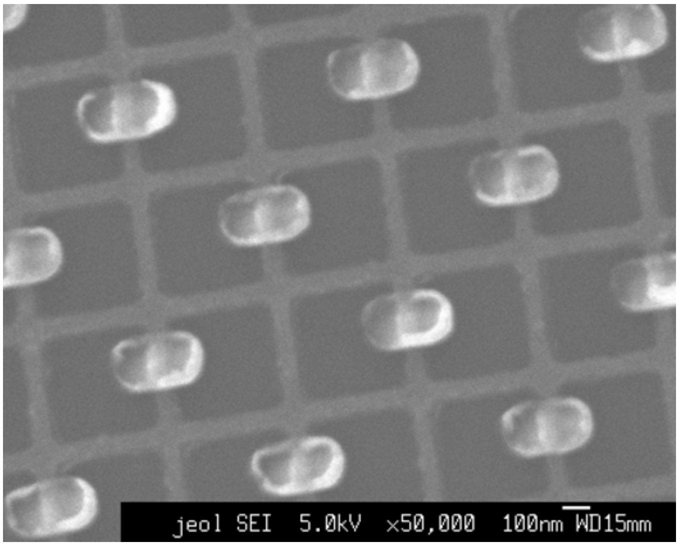


Checkerboard field
modulation

Uniform component α

Modulated component β

Experiment



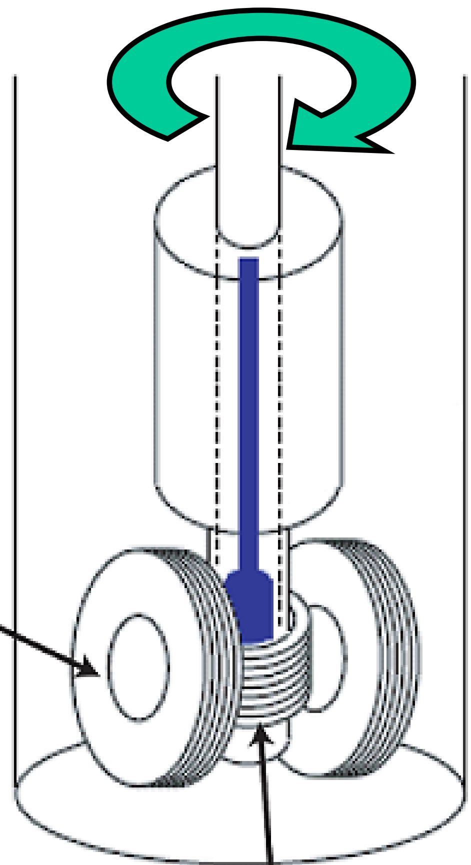
- 300×300 cells
- SWN = Al
- FM dot = Co
- β is controlled by rotating sample to avoid hysteresis

Rotating sample
→ angle of magnetization

control β

fixed

Split coil (in-plane field)
→ amplitude of magnetization

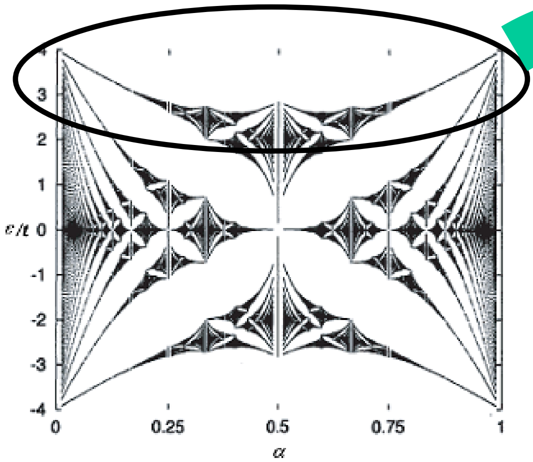


control α

Solenoid coil (perpendicular field)

Little-Parks oscillation

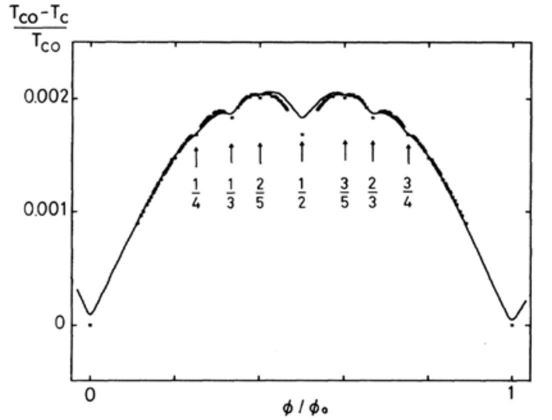
Oscillation of the mean field $T_c(B)$



Maximum eigenvalues

Hofstadter butterfly

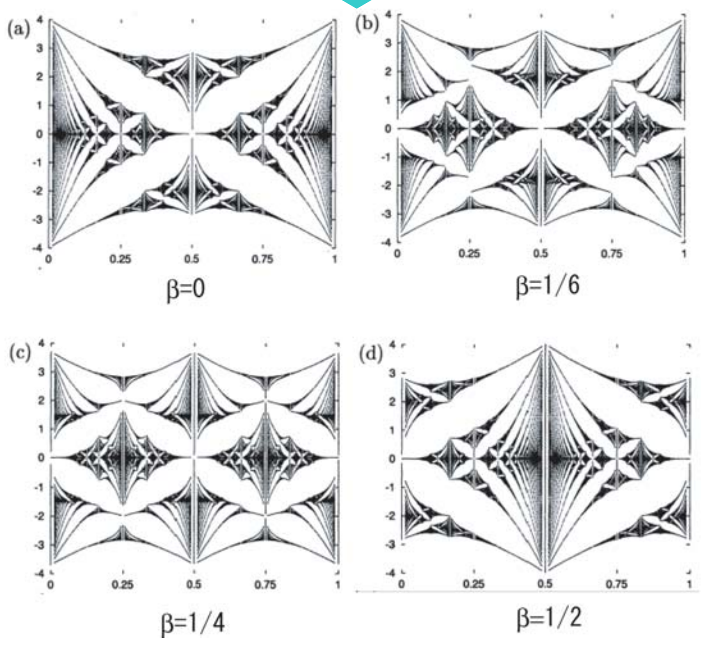
D. R. Hofstadter, *PRB*, **14,** 2339.



LP oscillation of Al SWN

B. Pannetier *et al.*, *PRL*, **53,** 1854.

Checkerboard field modulation



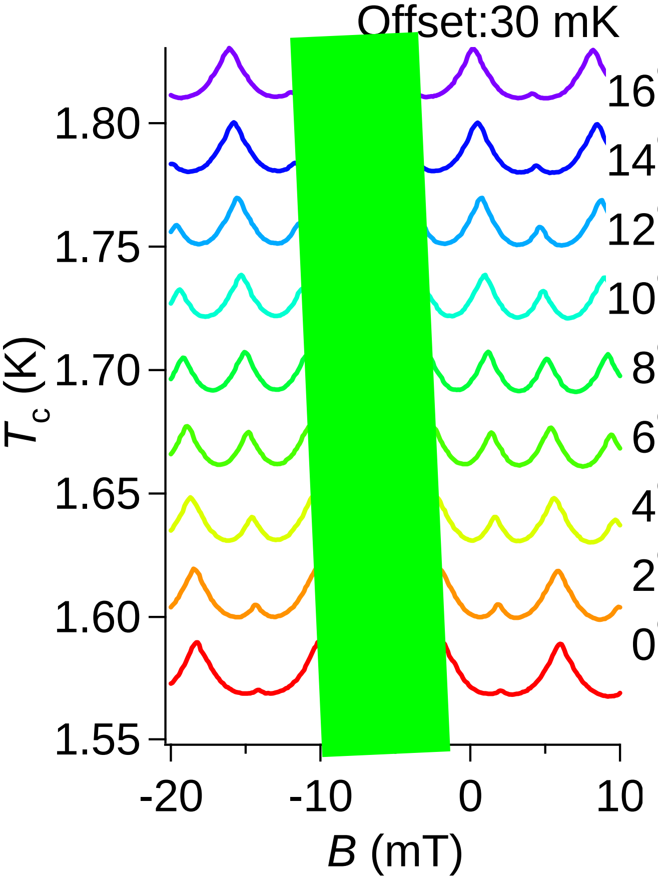
Hofstadter Butterfly is changed

LP oscillation must be changed

M. Ando *et al.*, *JPSJ*, **68,** 3462.

Observe LP oscillation
→ Compare with Hofstadter butterfly

Result



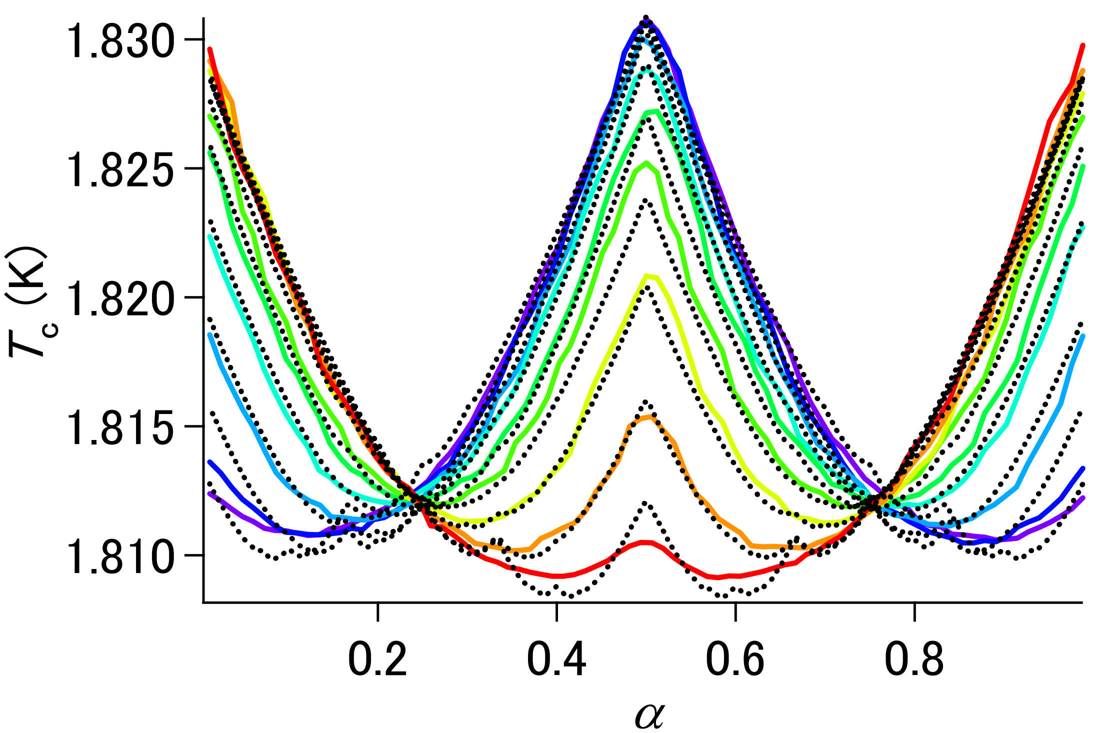
8 mT → $\alpha = 1$

0° → $\beta = 0$

16° → $\beta = 1/2$

Pick up one period

→Compare with calculation (black dotted line)



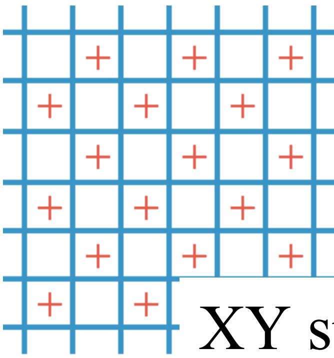
Good agreement

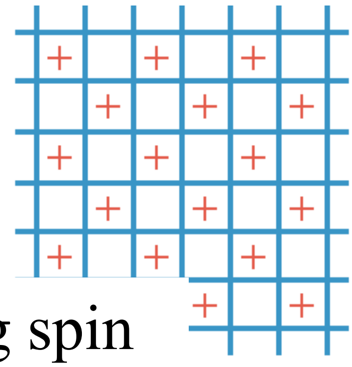
FFXY model

$\alpha = 1/2$: Fully Frustrated XY model

Half-filled with vortex

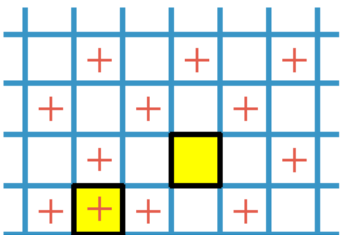
→ Two degenerated vortex configurations





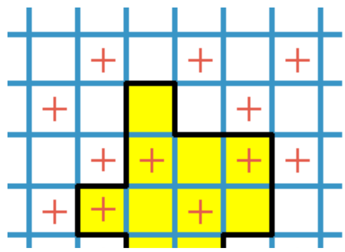
XY spin + Ising spin

(phase) (degeneracy)



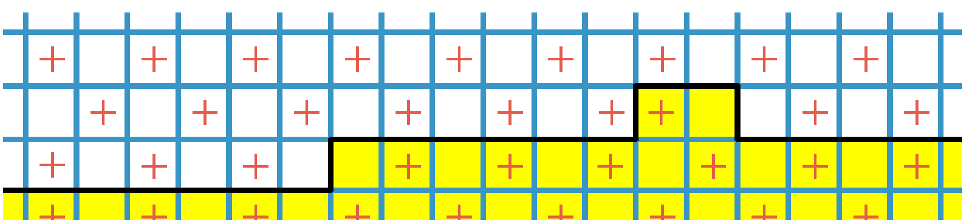
Vortex pair (size ~ ξ_{KT})

KT transition @ T_{KT}



Domain (size ~ ξ_{Ising})

Ising transition @ T_{Ising}



kink pair on Domain Wall (size ~ ξ_{kink})

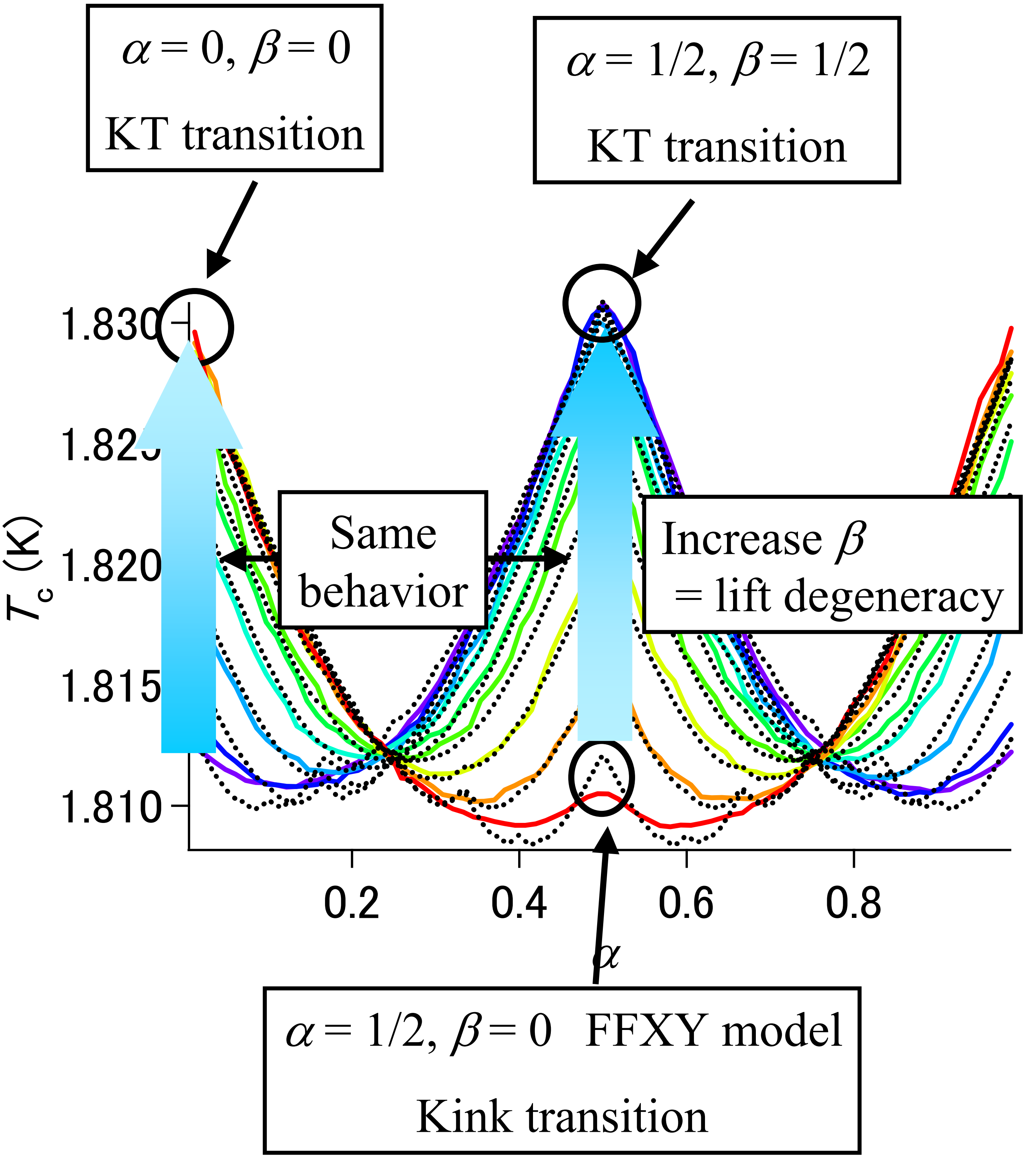
- Simple kink destroys the correlation of XY spin
- Nucleation / depairing transition at @ T_{kink}

  ・・・the same mechanism as KT transition

In FFXY model, $T_{kink} < T_{KT} < T_{Ising}$

→ Phases has been already disordered @ T_{kink}.

Effect of checkerboard field modulation



Observe the change of phase transition caused by field modulation

I –V characteristics

- Power-law behavior $V \sim I^{a}$
  - large a = large phase correlation
  - Temperature dependence of a

    → nature of true superconducting transition

Resistive state

- $a = 1$: $R = V/I \to$ const ($I \to 0$)
- Positive curvature in Log I – Log V Plot

True superconducting transition

True superconducting state

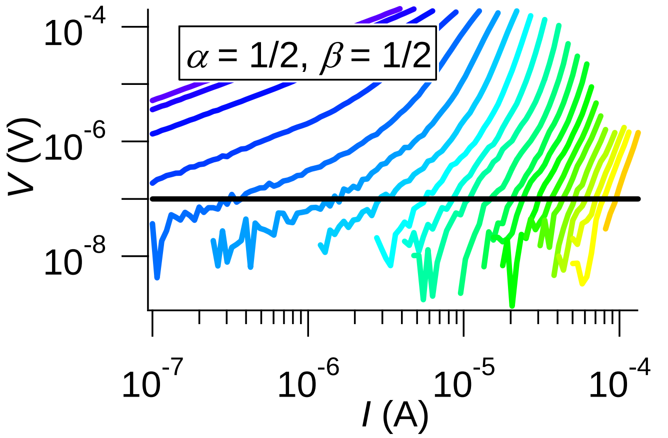
- $a > 1$: $R = V/I \to 0$ ($I \to 0$)
- Negative curvature in log I – log V Plot

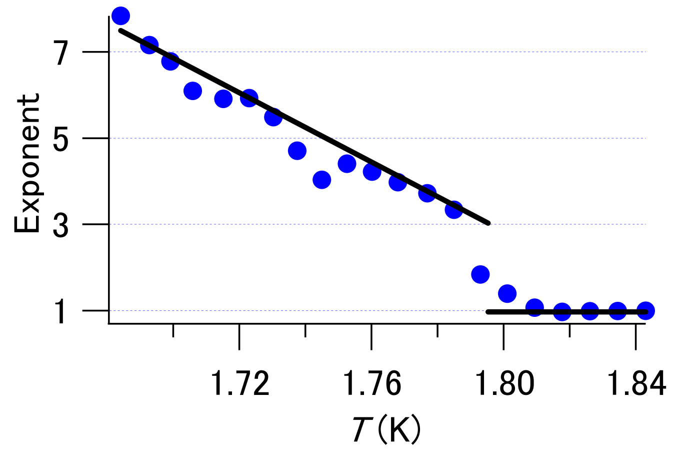
Measure a (T) for different β
→ Consider the origin of the change

Result

ex） $\alpha = 1/2, \beta = 1/2$ ・・・ KT transition

a : 1↔3 @ $T = T_c$ → universal jump

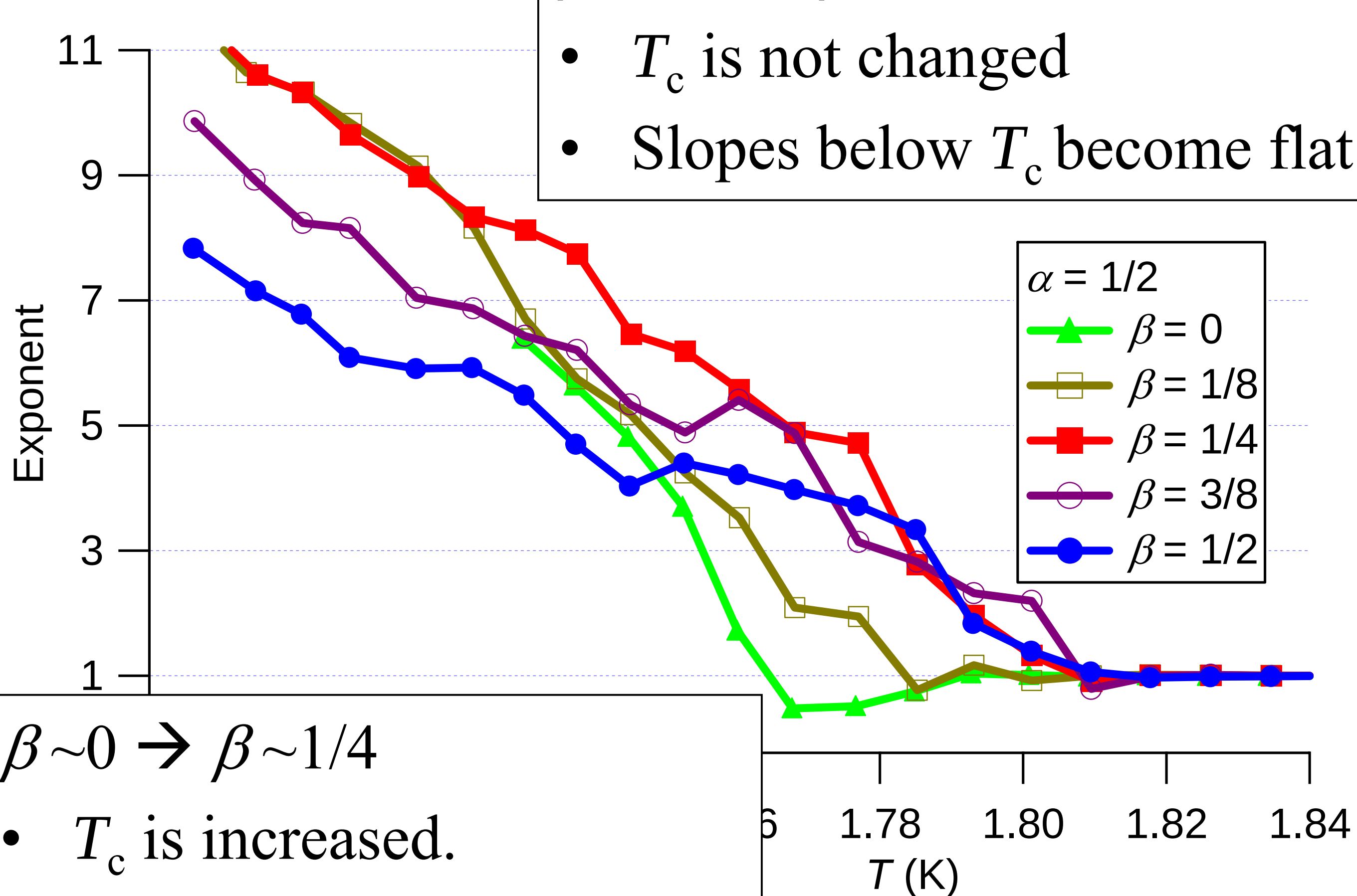




Compare temperature dependence of a

$\beta \sim 1/4 \rightarrow \beta \sim 1/2$

- T_c is not changed
- Slopes below T_c become flat.



$\beta \sim 0 \rightarrow \beta \sim 1/4$

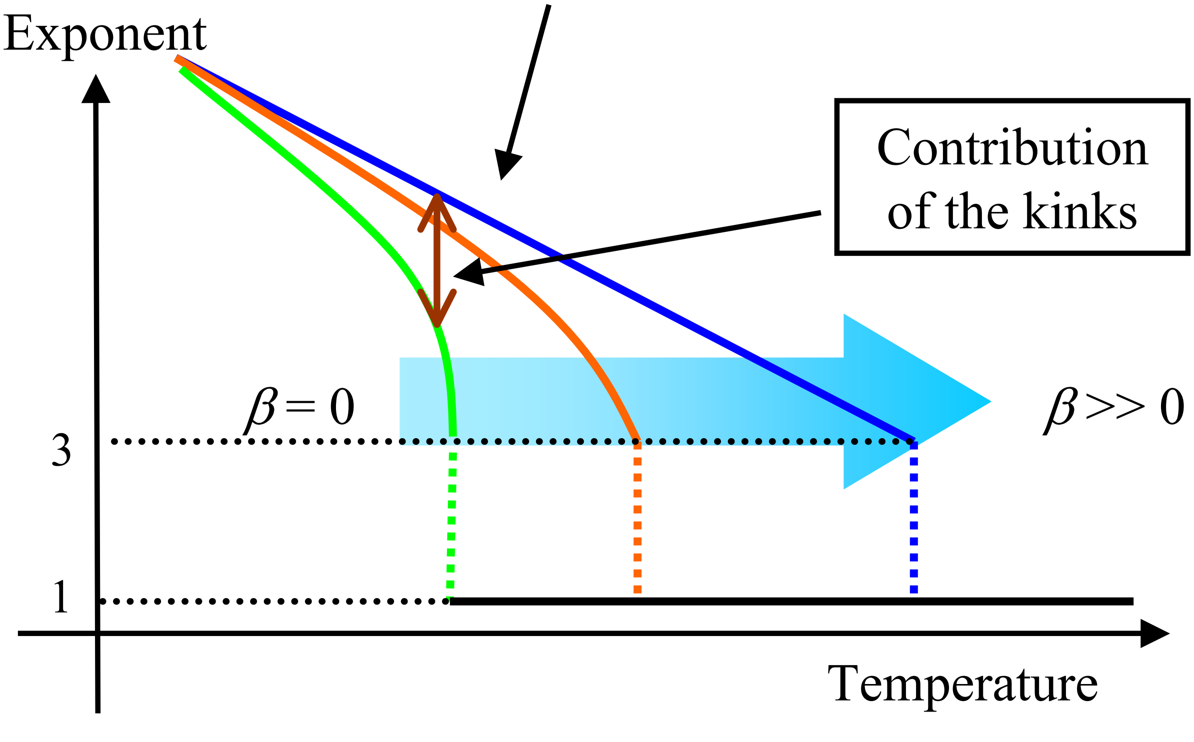
- T_c is increased.
- Transitions become broad.

If β is increased…

$\beta = 0$ (FFXY model)・・・kink transition

1. One of the vortex configurations (= Ising spin) is stabilized
2. Nucleation of Ising-domain is suppressed.
3. $\xi_{\mathrm{Ising}}\ (T_{\mathrm{kink}})$ gets smaller
4. The region disordered by kinks becomes small. (Kinks exist only on domain wall)
5. Contribution of kinks for phase disordering is suppressed.

KT transition



Expected changes agree with experiment.