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Phase transitions of superconducting wire network under field modulation

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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 ($\psi = 0$)

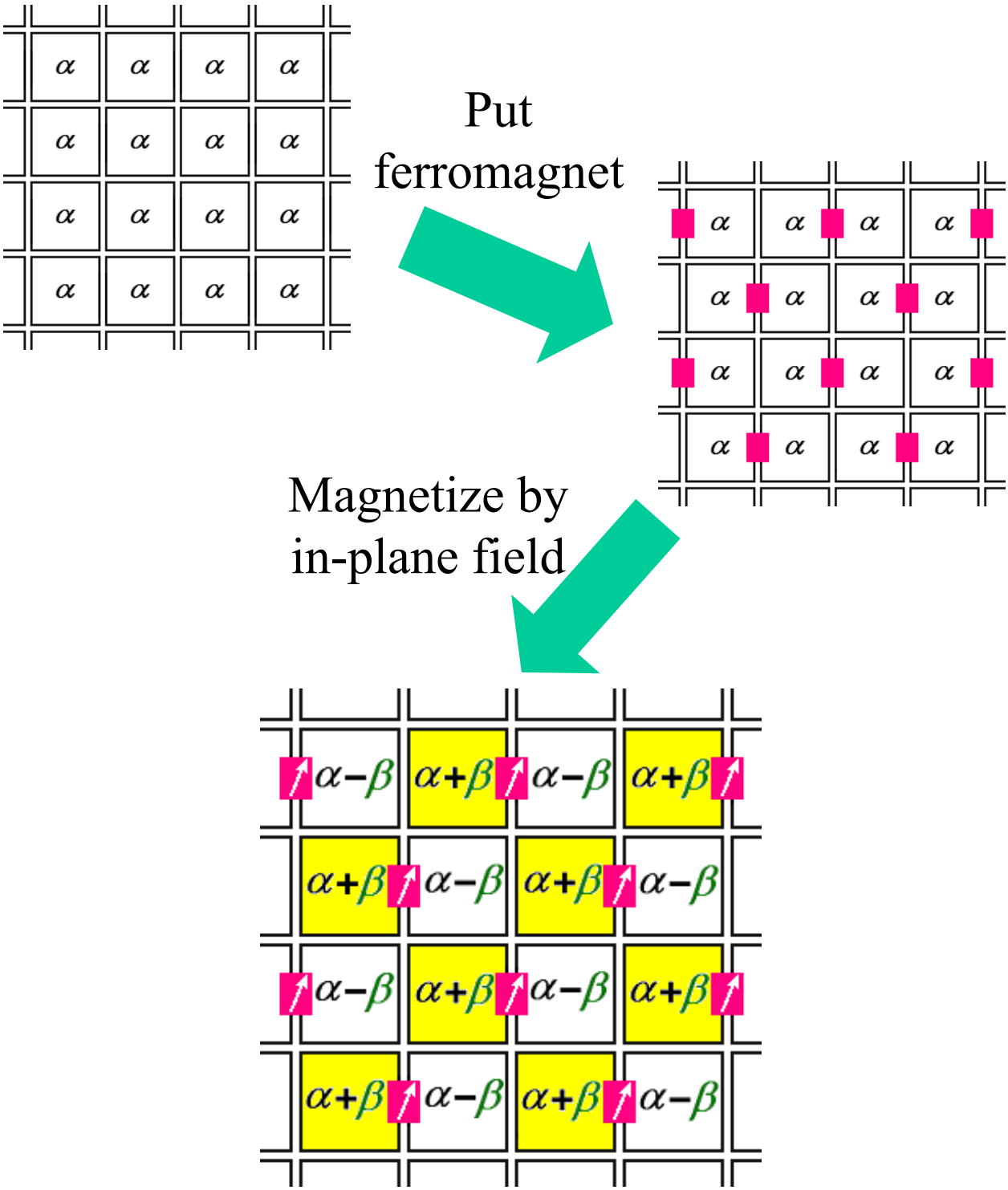
1. Mean field transition
   - $\psi = 0 \Leftrightarrow \psi \neq 0$
   - θ is still disordered --- $R \neq 0$
   - α causes the oscillation of T_c

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

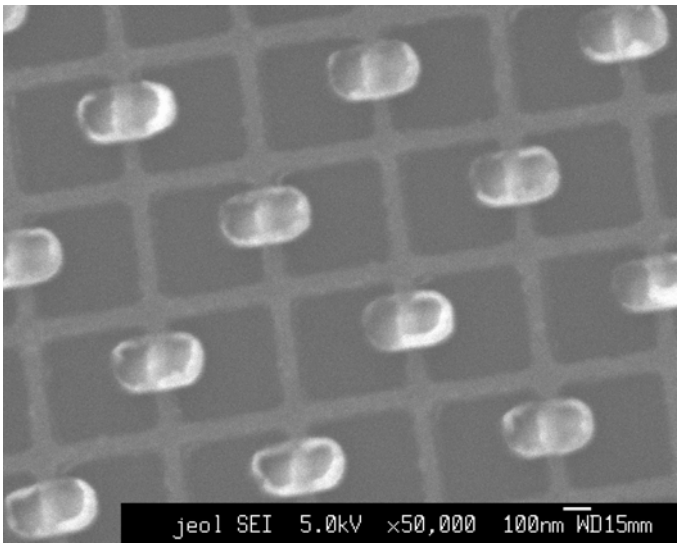
$R = 0$

Previous studies use only uniform magnetic field.
→ Let's apply spatially modulated magnetic field ***!!***



Checkerboard field modulation
Uniform component α
Modulated component β

Experiment



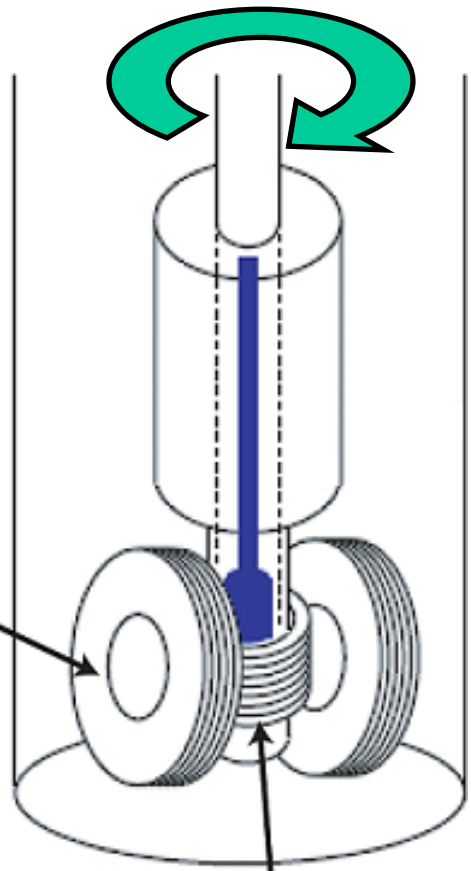
- 300×300 cells
- SWN = Al
- FM dot = Co
- β is controlled by rotating sample to avoid hysteresis

Rotating sample
→ angle of magnetization

control β

fixed

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

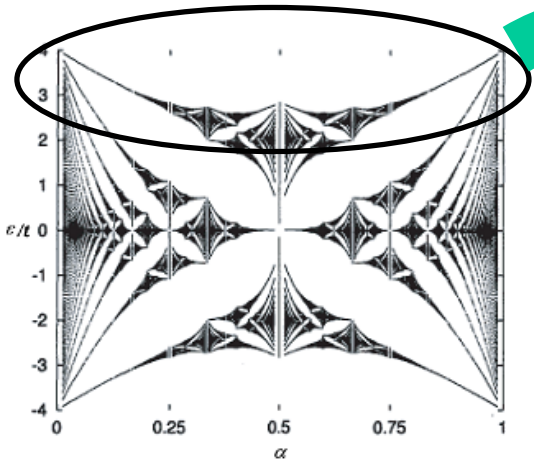


control α

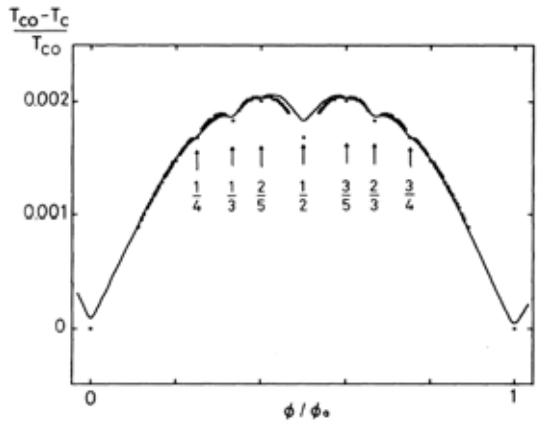
Solenoid coil (perpendicular field)

Little-Parks oscillation

Oscillation of the mean field $T_c(B)$



Maximum eigenvalues



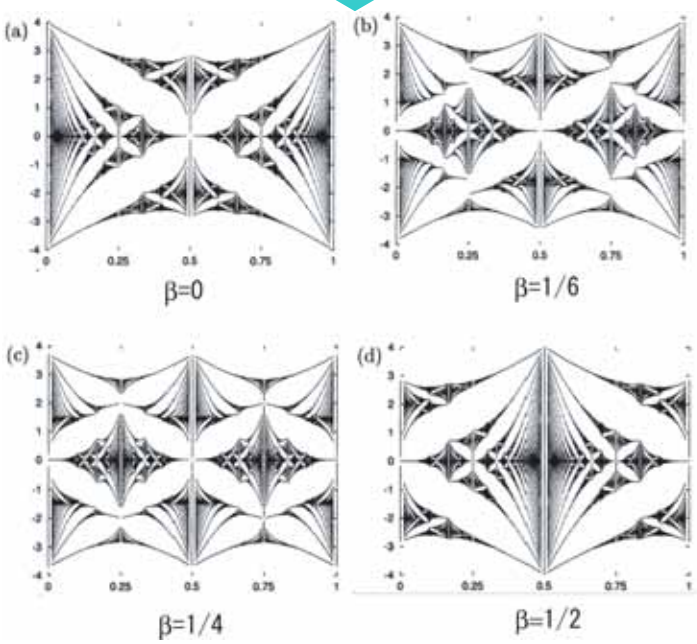
Hofstadter butterfly

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

LP oscillation of Al SWN

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

Checkerboard field modulation



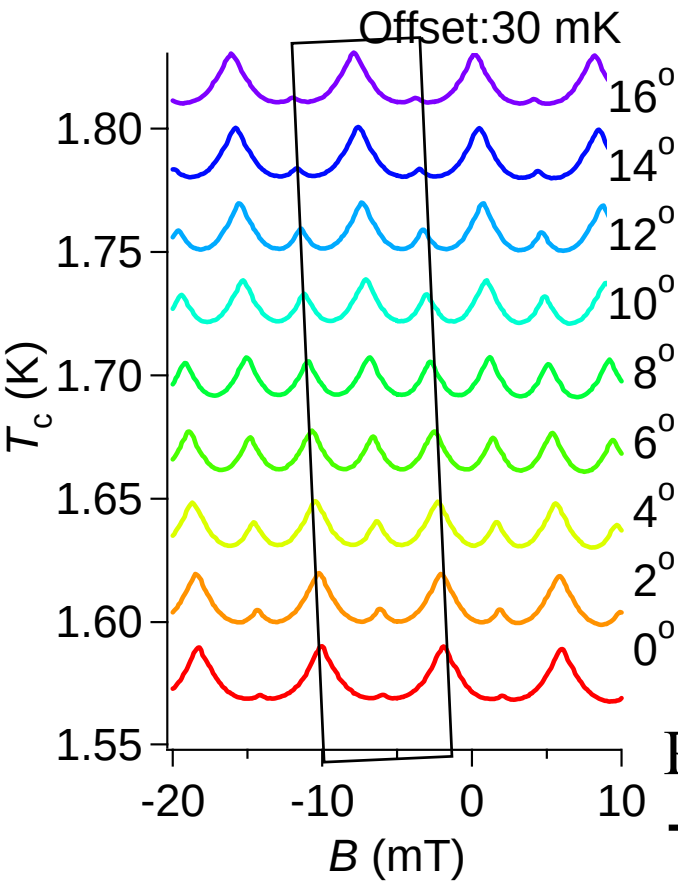
Hofstadter Butterfly is changed

LP oscillation must be changed

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

Observe LP oscillation
→ Compare with Hofstadter butterfly

Result

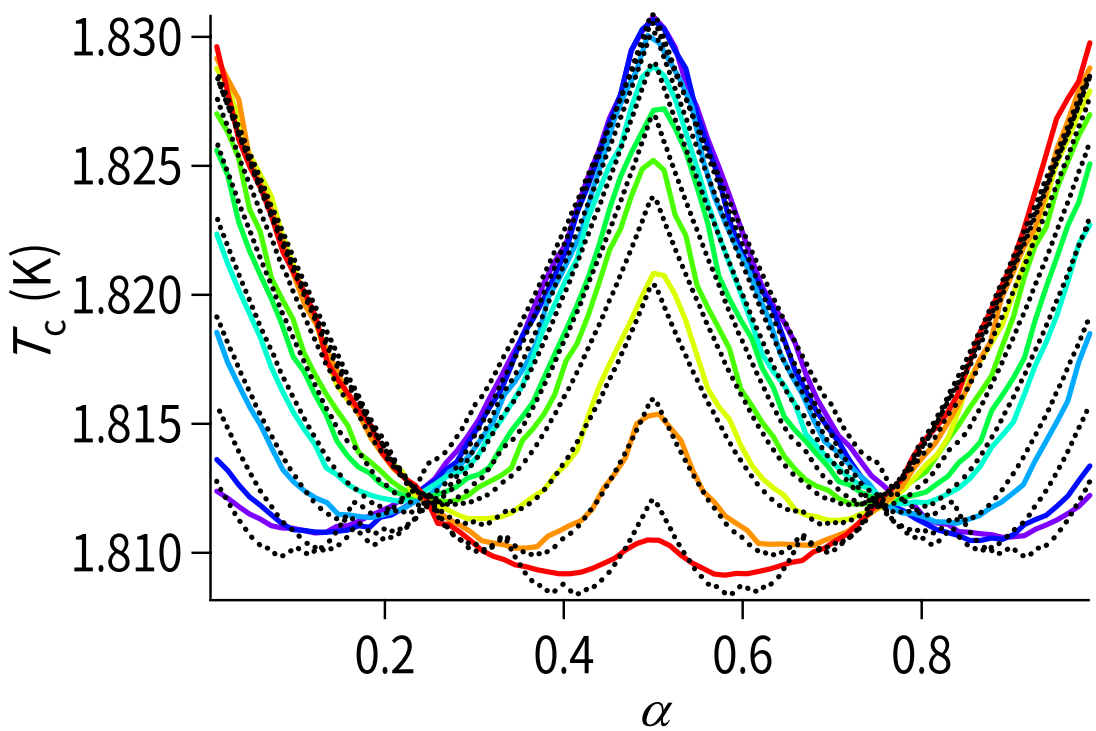


8 mT → $\alpha = 1$

0° → $\beta = 0$

16° → $\beta = 1/2$

Pick up one period
→Compare with calculation
(black dotted line)

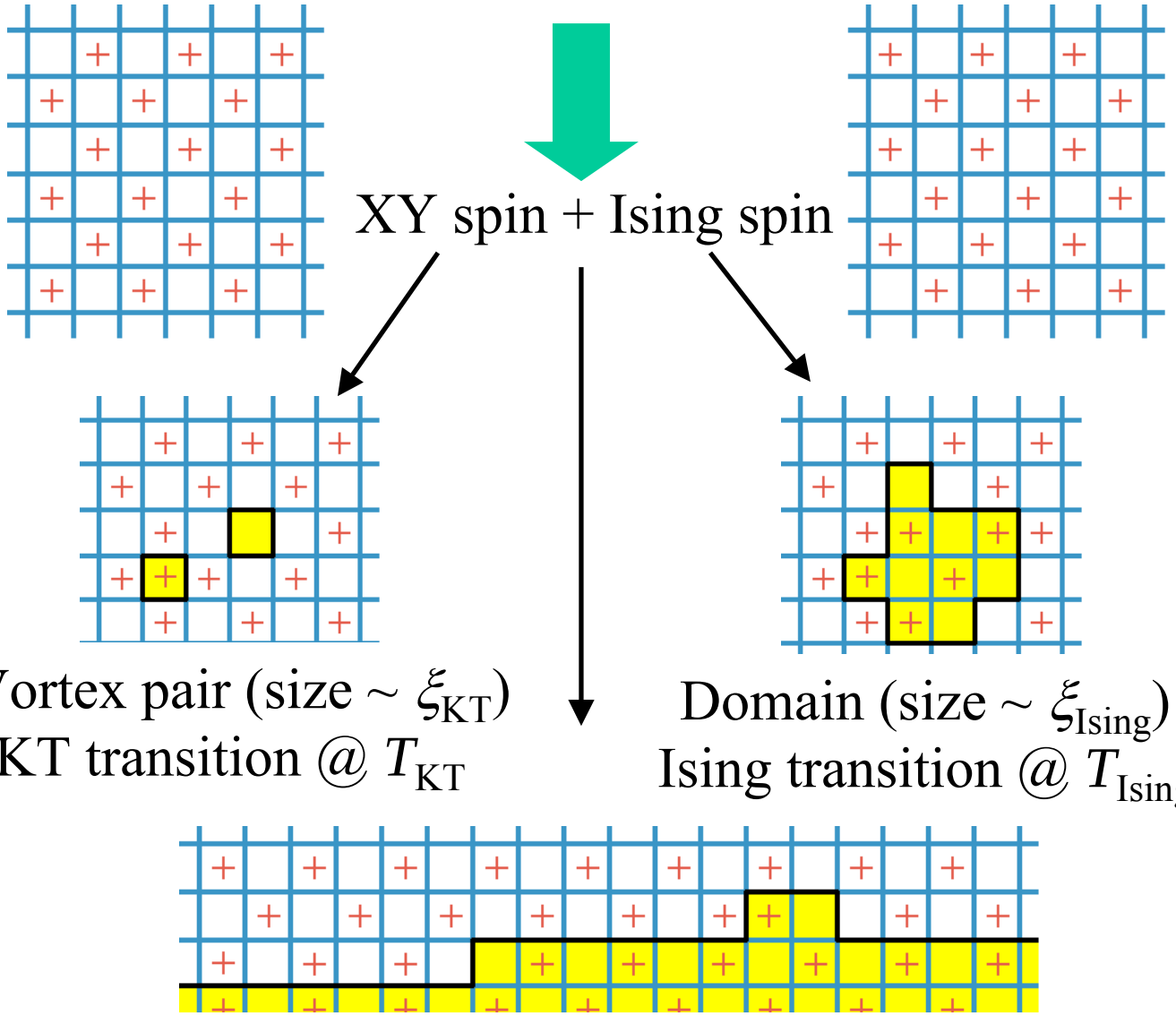


Good agreement

FFXY model

$\alpha = 1/2$: half-filled with vortex

---Two vortex configurations are degenerated.



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

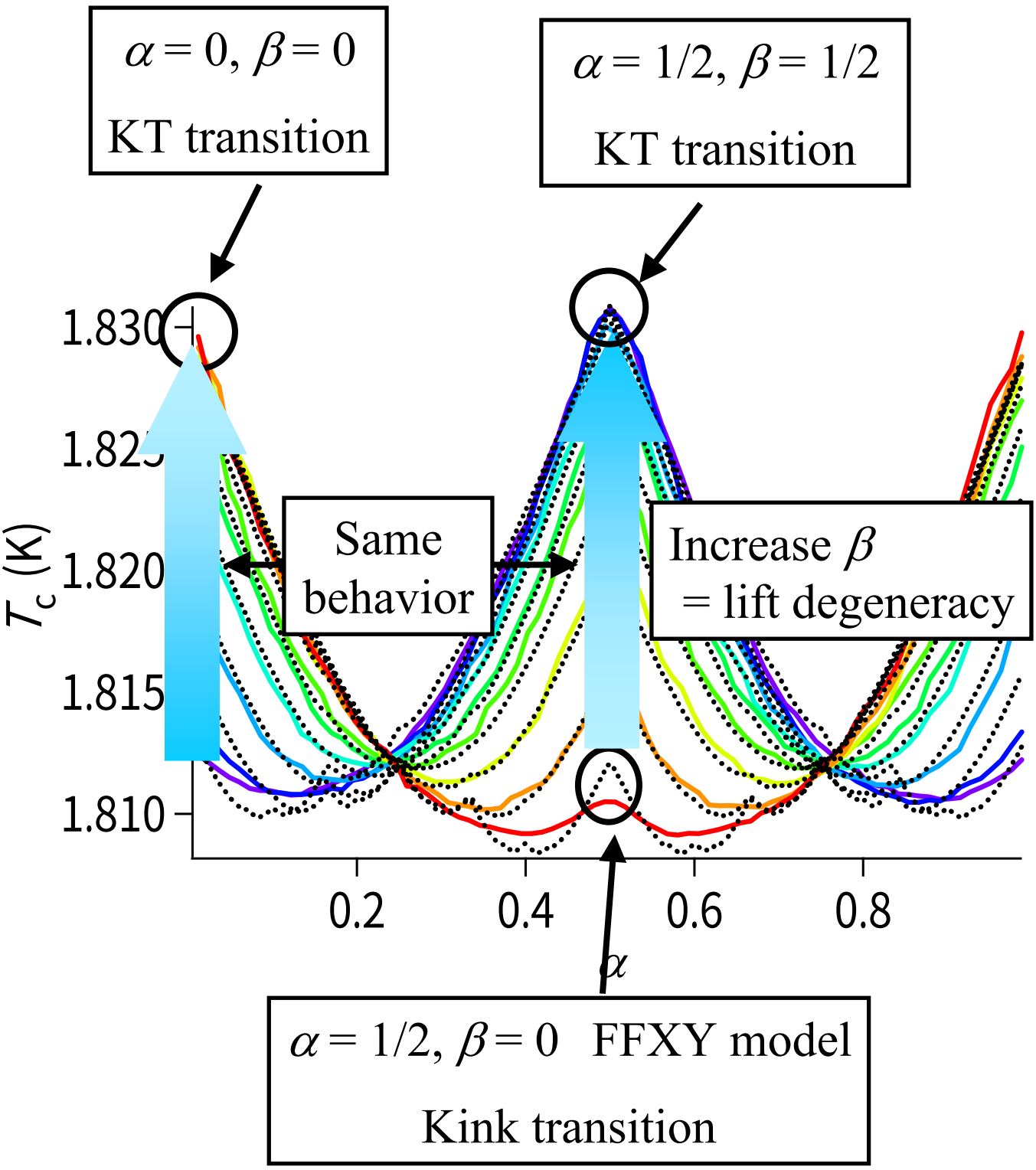
- Simple kink destroys the correlation of XY spin
- Nucleation / depairing transition at @ T_{kink}

  ・・・the same mechanism as KT transition

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

→ Phase ordering transition is kink transition.

Effect of checkerboard field modulation



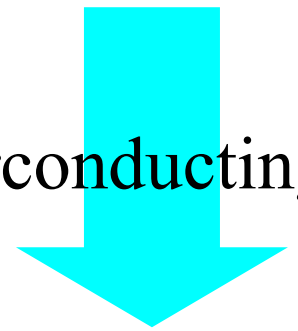
Observe the change of phase transition caused by field modulation

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

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



True superconducting transition

True superconducting state

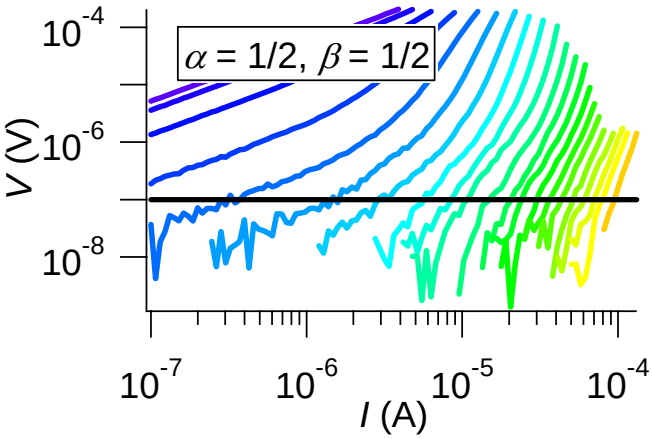
- $a > 1$: $R = V/I \rightarrow 0$ $(I \rightarrow 0)$
- Negative curvature in log I – log V Plot

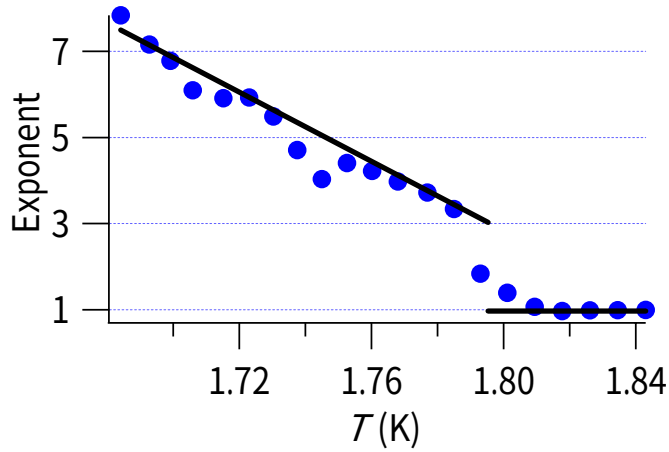
Measure a (T) for different β
→ Consider the origin of the change

Result

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

$a : 1 \leftrightarrow 3$ @ $T = T_c$ → universal jump

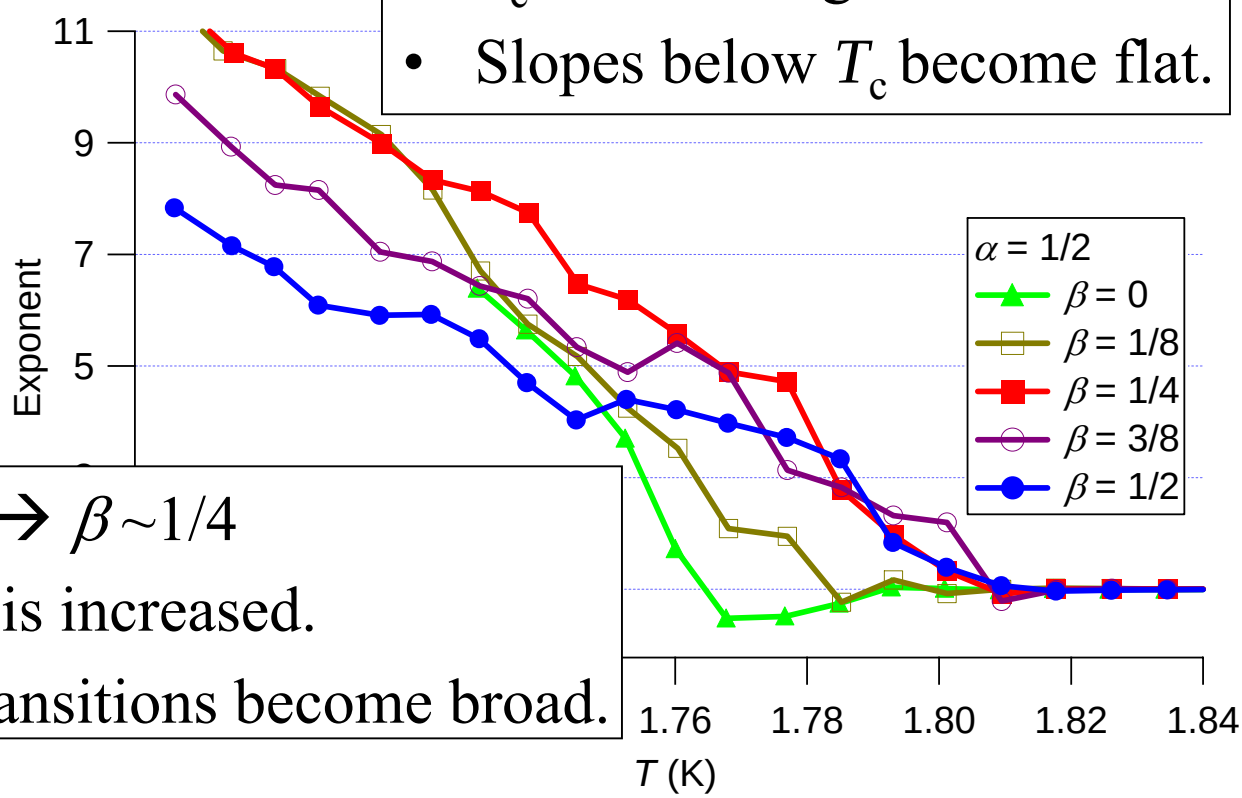




Compare temperature dependence of a

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

- 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.

Change of phase transition

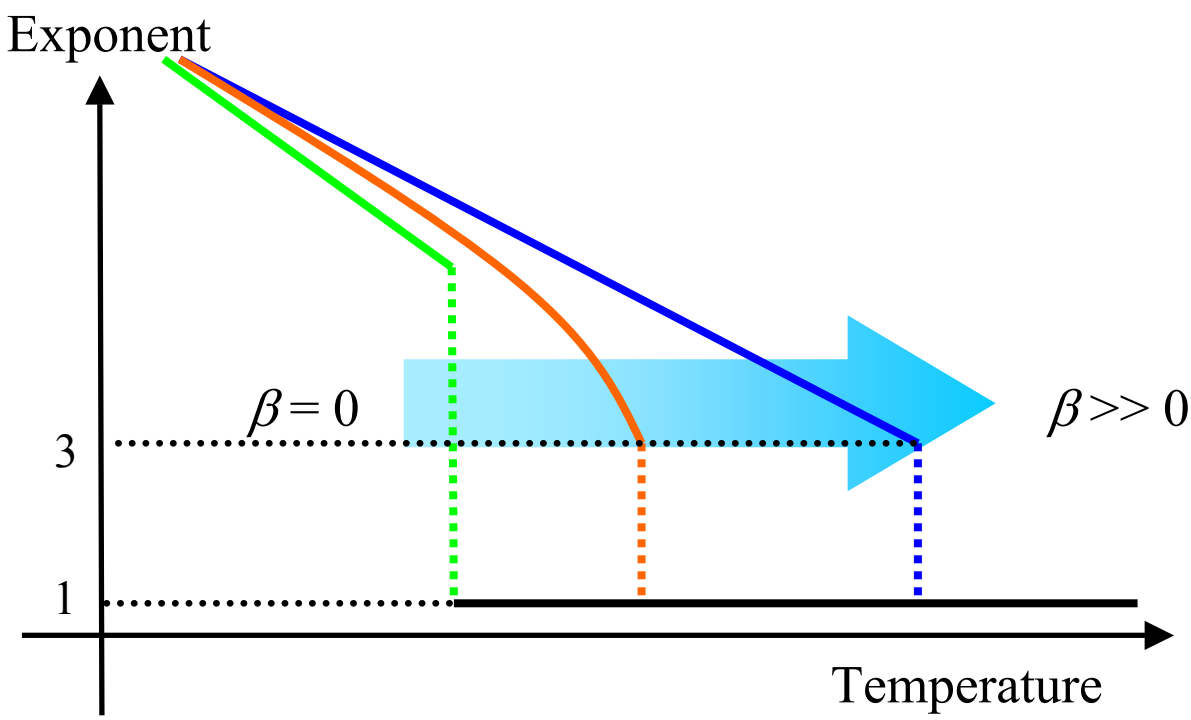
$\beta = 0$ (FFXY model) ・・・kink transition

1. one vortex configuration is stabilized
2. T_{Ising} is increased
3. $\xi_{\mathrm{Ising}}\ (T_{\mathrm{kink}})$ gets smaller
4. $\xi_{\mathrm{kink}} < \xi_{\mathrm{Ising}}$ → ξ_{kink} can't diverge.
5. Kink transition gets less important for phase disordering

$\xi_{\mathrm{Ising}}\ (T \sim T_{\mathrm{kink}}) < \xi_{\mathrm{KT}}\ (T \sim T_{\mathrm{kink}})$

Mainly vortex pairs disorder the phase correlation.

→ KT transition



Expected change agree with experiment.