

Superconducting Wire Network under Spatially Modulated Magnetic Field

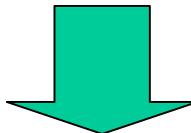
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Overview

- Previous studies
 - Critical temperature → Little-Parks oscillation
 - $I-V$ Characteristics → The nature of phase transition

All studies = under uniform field

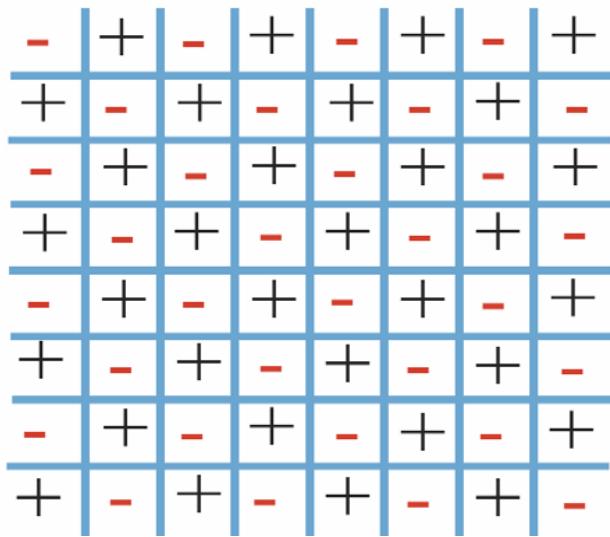
Uniform Field + Modulated Field



New aspects of superconducting wire network

Field Modulation

Checkerboard Pattern

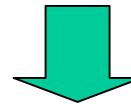


Flux through a cell = $\alpha \pm \beta$

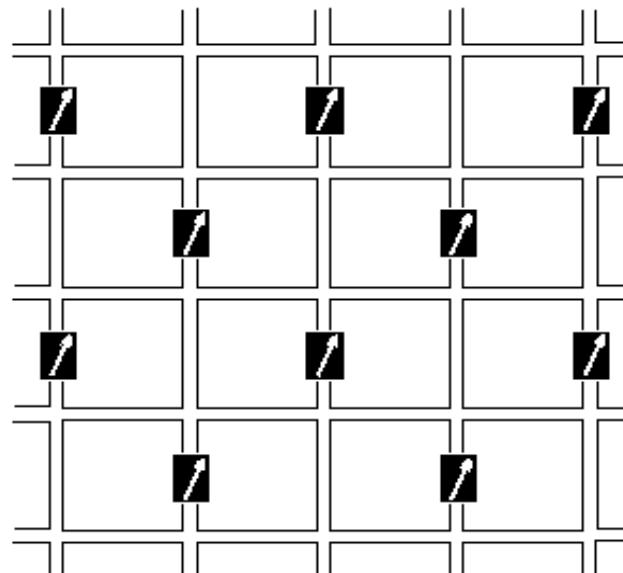
α : Uniform field

β : Modulated field

Stray field from FM dot

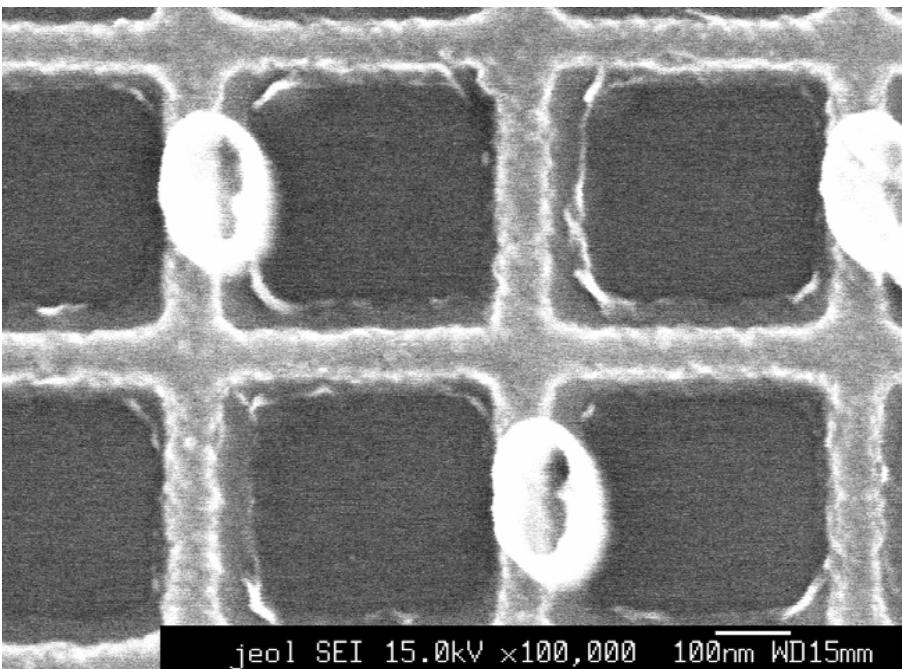


field modulation



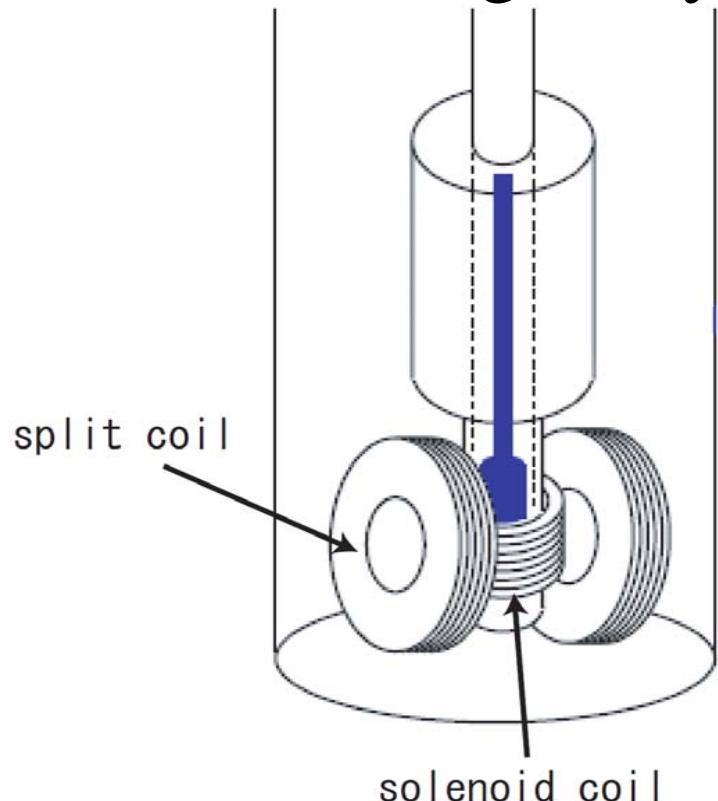
Control β by rotating magnetization

Experimental Settings



- Al network
 - 70 nm wide
 - 35 nm thick
 - Period = 500 nm
- Co dots
 - $200 \text{ nm} \times 130 \text{ nm}$
 - 80 nm thick

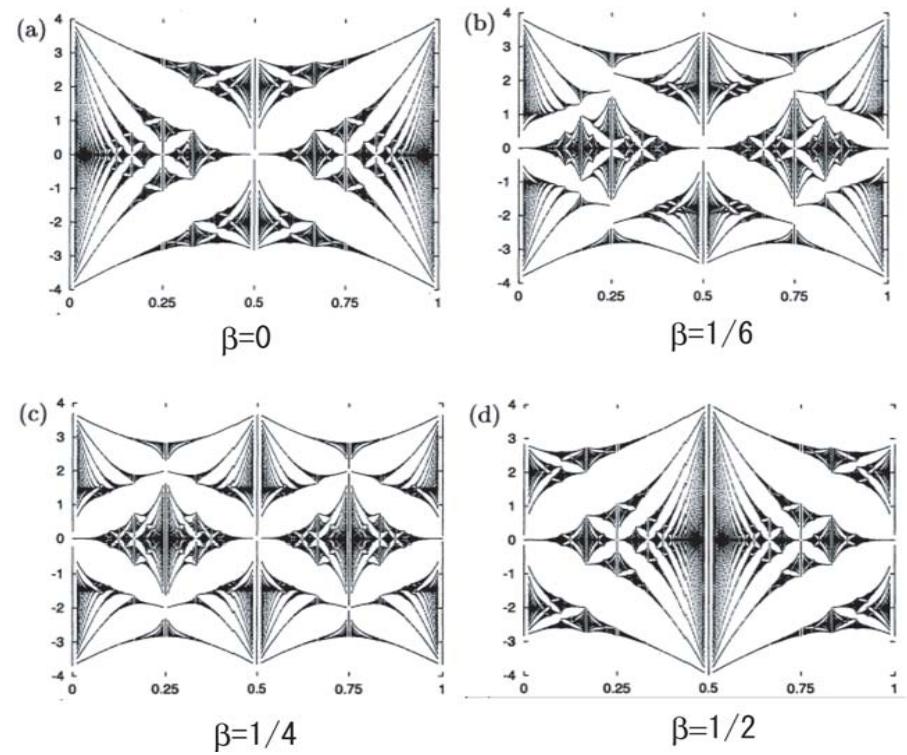
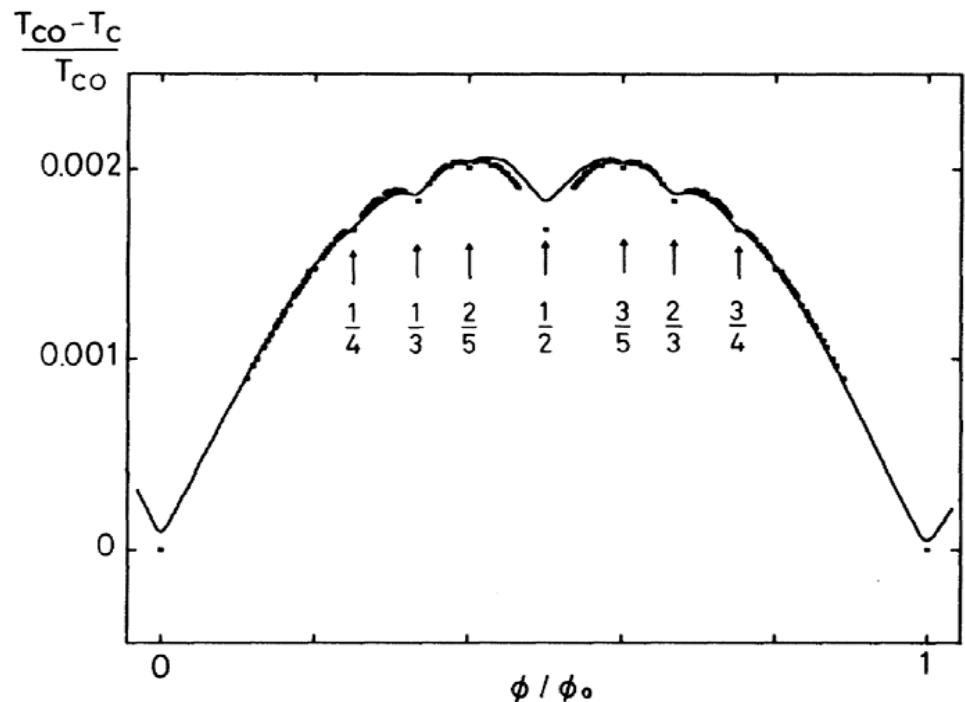
Cross coil magnet system



Solenoid coil $\rightarrow \alpha$
Split coil $\rightarrow \beta$

Little-Parks Oscillation

$$T_c(B) = T_{c0} \left(1 - \left(\frac{\xi(0)}{l} \arccos \left(\frac{\varepsilon_{\max}}{4} \right) \right)^2 \right)$$



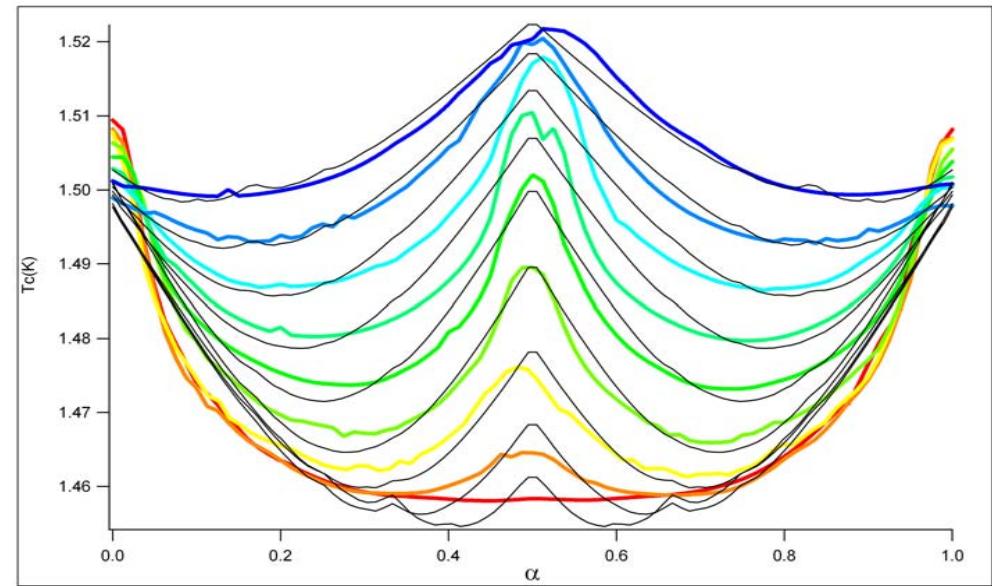
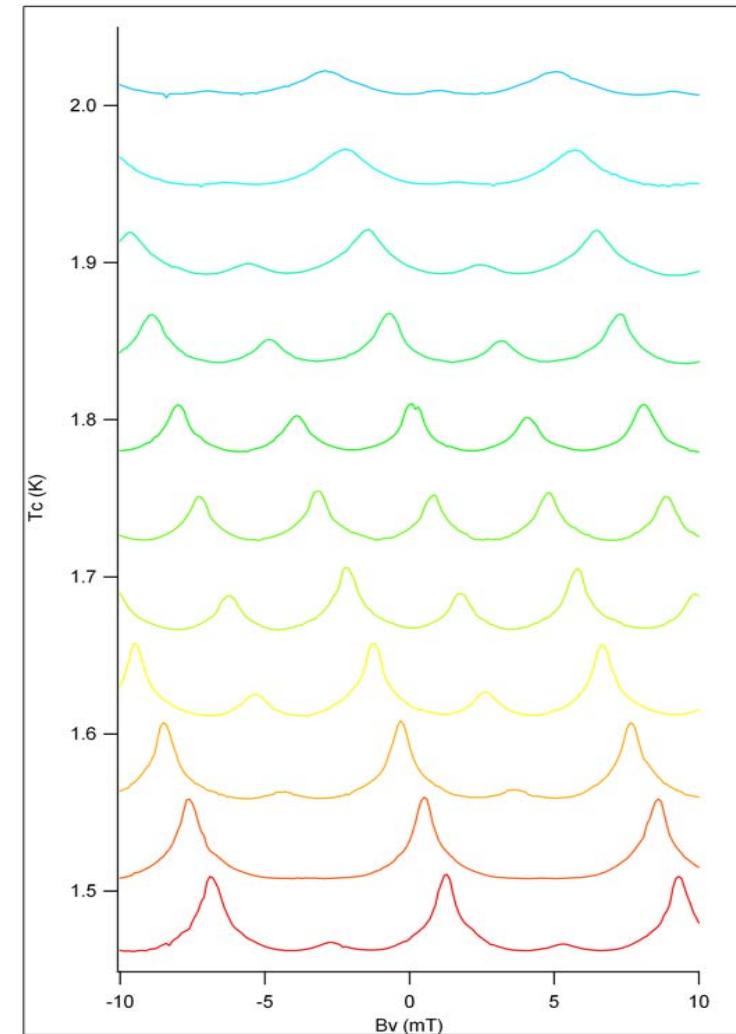
B. Pannetier *et al.*, Phys. Rev. Lett. **53**, 1845

Hofstadter butterfly
under checkerboard modulation

Result

$$R(B, T) \rightarrow T_c(B)$$

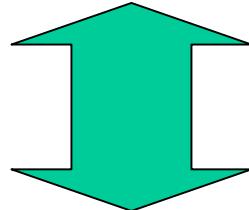
Comparison with calculation



Main feature : consistent
detail : inconsistent

I-V Characteristics

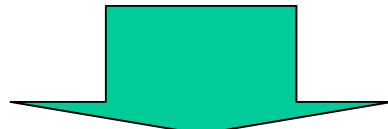
- Superconducting state $R \rightarrow 0$ ($I \rightarrow 0$)
 - No free vortex without current



Phase transition
→ Change of vortex dynamics

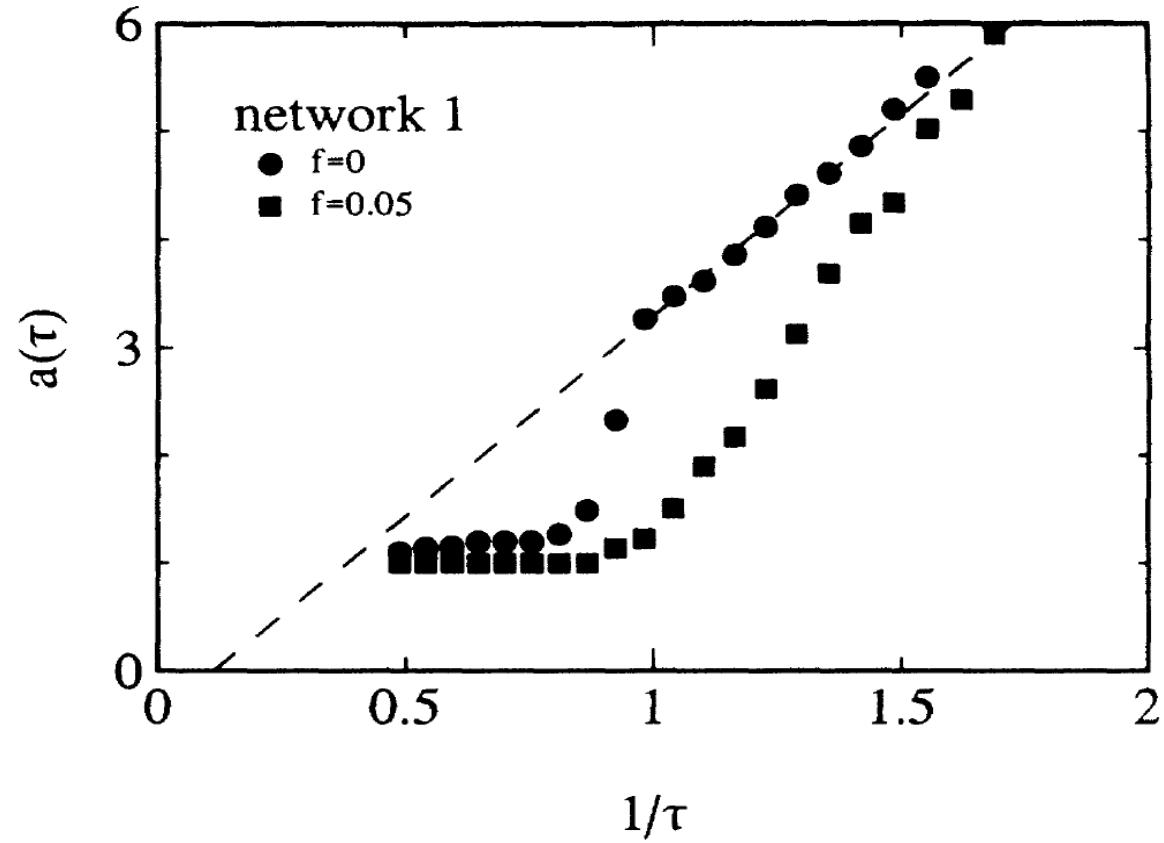
- Resistive state $R \neq 0$ ($I \rightarrow 0$)
 - Free vortex exists without current

I-V characteristics = vortex dynamics

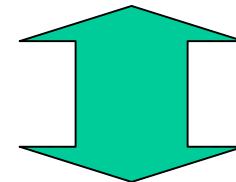


nature of phase transition

Kosterlitz – Thouless Transition



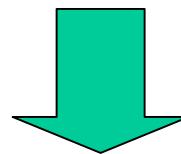
$$T > T_{KT} \dots V \sim I$$



Universal Jump

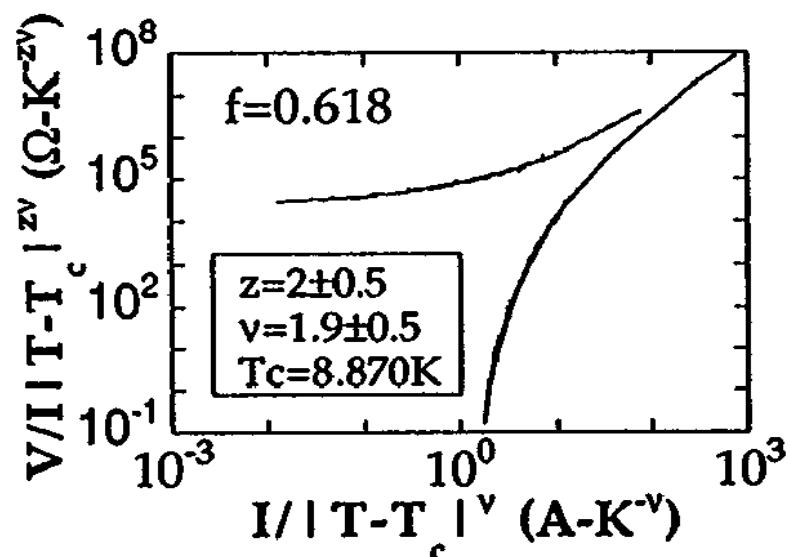
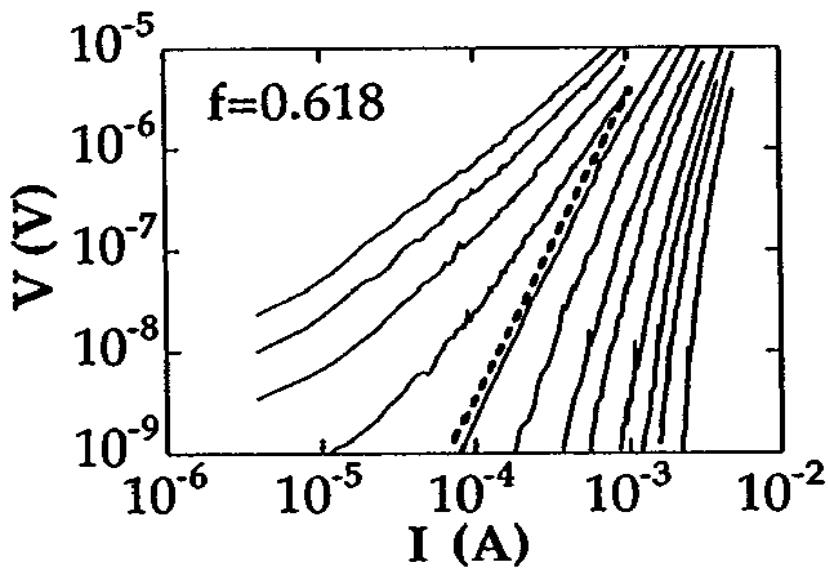
$$T < T_{KT} \dots V \sim I^{a(T)}$$

Apply magnetic field



Destroy KT transition

Vortex Glass Transition



$T > T_g : V \sim I \rightarrow \text{Nonlinear}$

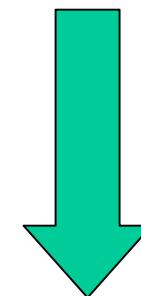
positive curvature

$T = T_g : V \sim I^{z+1}$

$T < T_g : V \sim \exp(-a/I^\mu)$

negative curvature

Scaling Plot

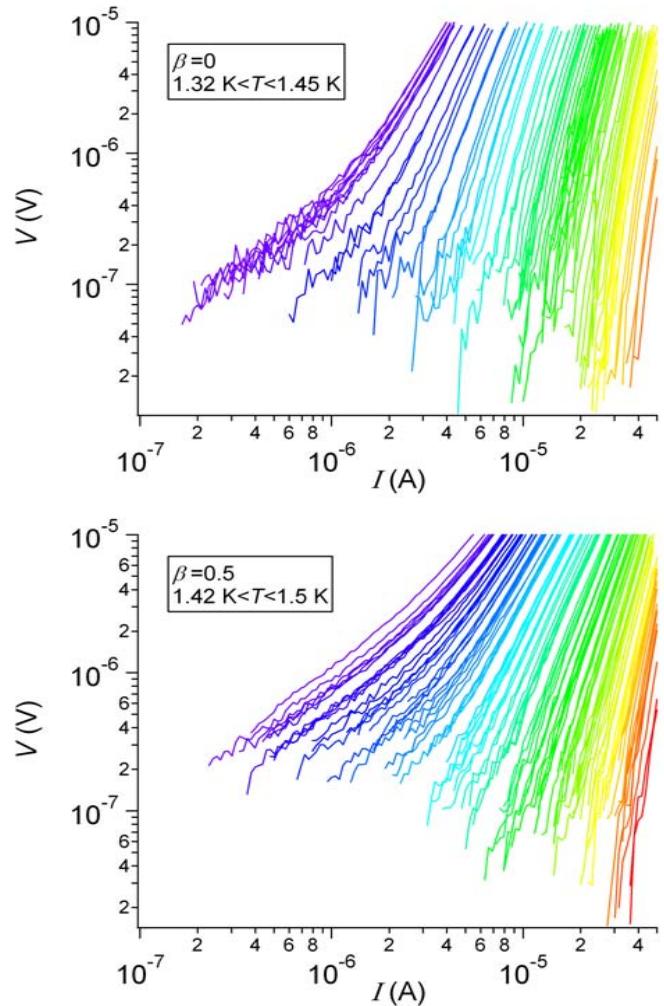


$$V\xi^{z+1} = f_\pm(I\xi)$$

$$\xi \sim |T - T_g|^{-\nu}$$

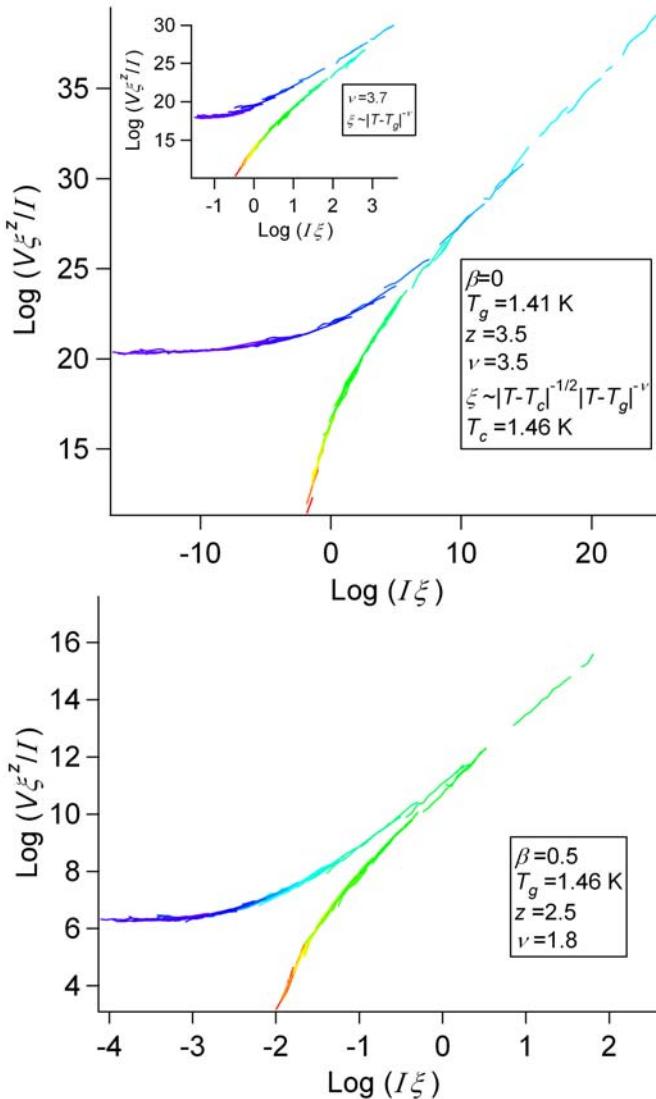
Two universal curve

Results (I - V Measurements)



- DC measurement
 - $\alpha = 0, 0.618, 1/2$
 - $\beta = 0, 1/2$
- α -independent

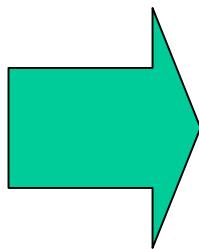
Results (Scaling Plot)



- $\beta = 0$: Bad scaling plot
 - T_g is too close to T_c

$\xi \sim |T - T_c|^{-1/2}$
Good plot

- $\beta = 1/2$: Good scaling plot



VG transition at all α and β
(Previous studies : KT at $\alpha = \beta = 0$)

Conclusion

Under checkerboard field modulation,

- Little-Parks oscillation
 - Consistent with calculation
- I - V characteristics
 - VG transition is observed at all α and β

Inconsistency --- Lithographical irregularity