Charge Instabilities At The Metamagnetic Transition

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1 Layered Sr-Ruthenates

2 Stoner and Pomeranchuk scenarios for the metamagnetic transition

3 2D Hubbard model perspective: mechanisms?

4 Micro phase separation?

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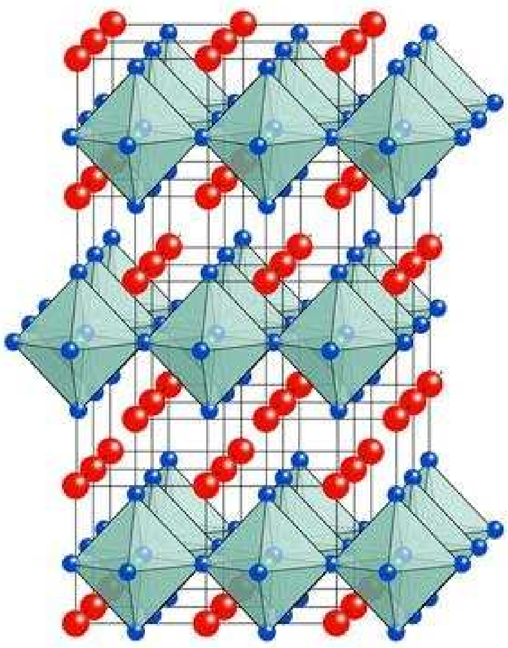
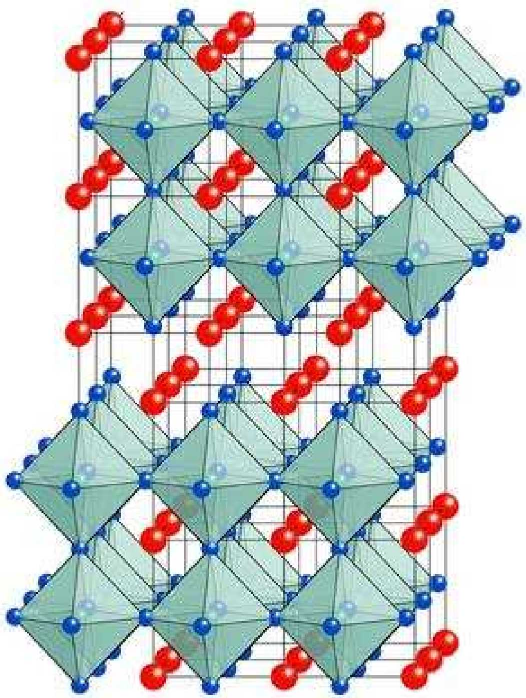
Layered Strontium-Ruthenates $Sr_{n+1}Ru_nO_{3n+1}$
Ruddlesden-Popper Series





Single layer: Sr_2RuO_4

Triplet superconductor, T_c=1.5K,

expanding FS volume: strong increase of χ

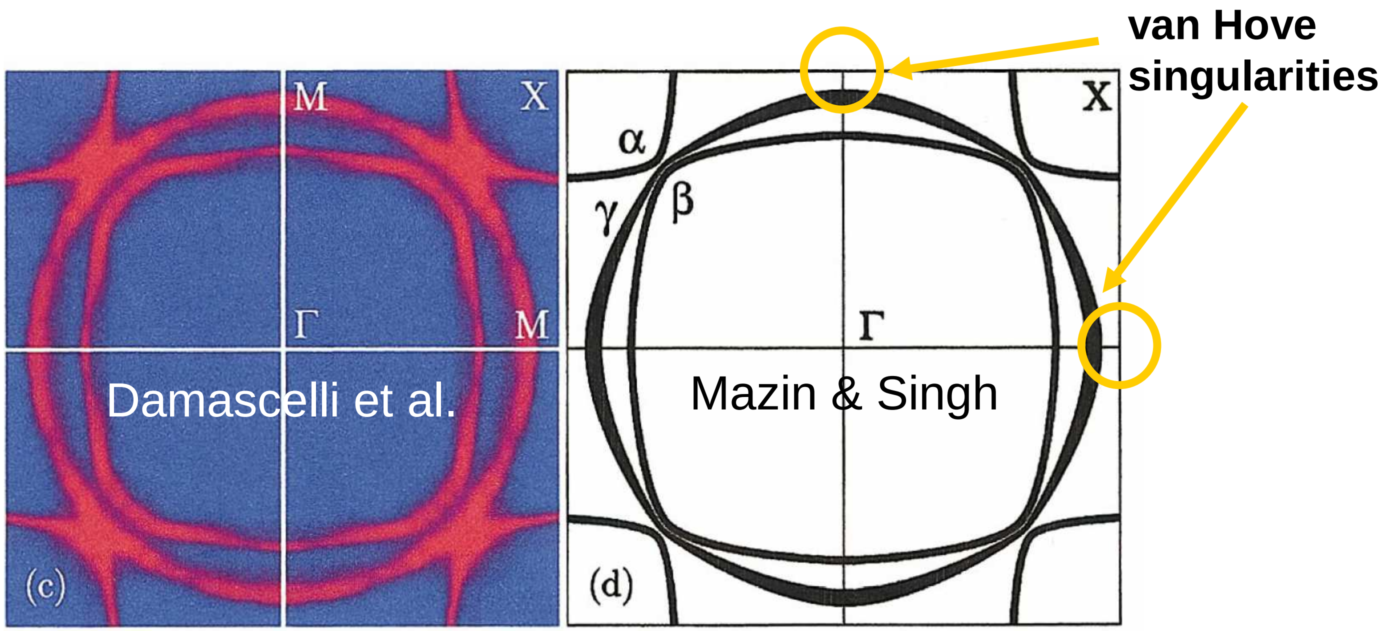
Double layer: $Sr_3Ru_2O_7$

close to ferromagnetism,

metamagnetic transition

Electronic Structure: Single Layer Sr_2RuO_4

- 3 t_{2g} bands (d_{xy},d_{xz},d_{yz}) cross Fermi level, almost 2D band structure
- LDA, dHvA and ARPES agree on Fermi surfaces
- Van Hove singularity near Fermi level

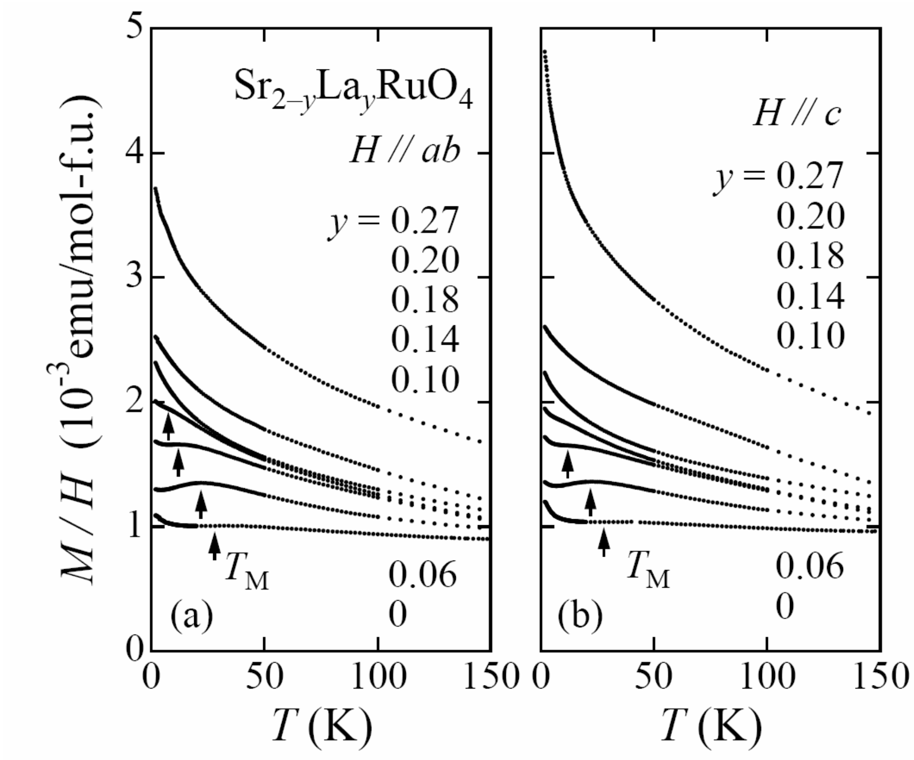


Sr_2RuO_4 cleaved at 180 K
T= 10 K hν=28 eV

Local-density-approximation
band-structure calculation

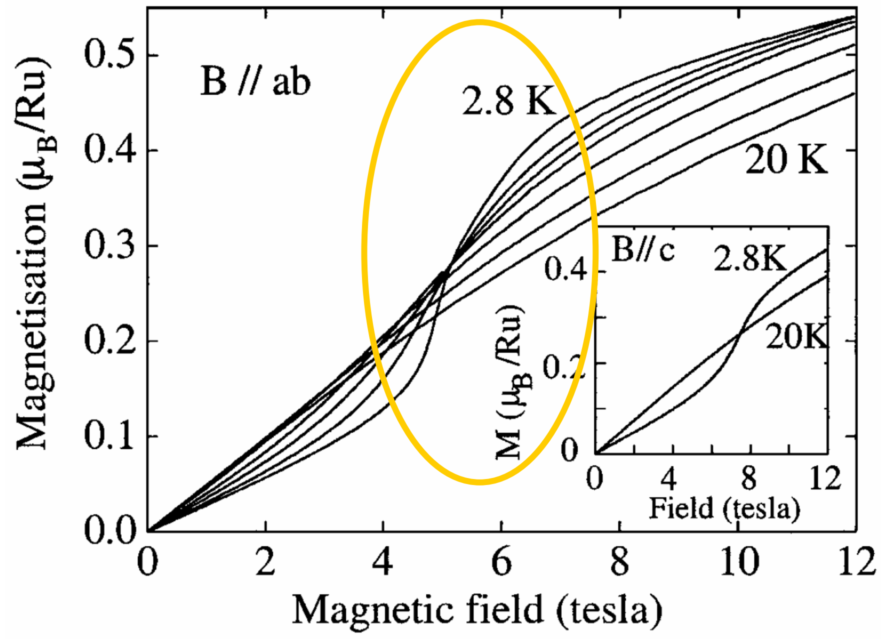
Doping La^{3+} For Sr^{2+}: Pushing The FS Closer To Van Hove Points & Ferromagnetism

- $Sr_{2-y}La_yRuO_4$: y>0 adds electrons, **expands all Fermi surfaces**
- Spin susceptibility χ **increases (FM tencencies!)**
- **FS pushed toward van Hove points**
- Multi-layer splittings push FS closer to VH points (Sigrist)

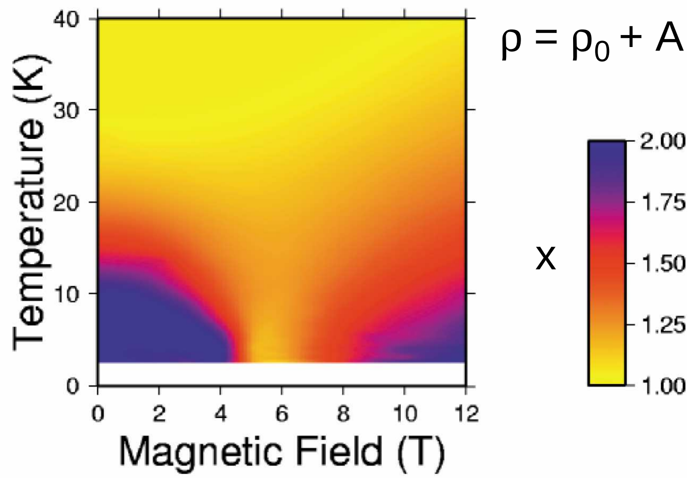


Kikugawa et al., 2004

Double-Layer $Sr_3Ru_2O_7$: Metamagnetic Transition



Perry et al. PRL 2001

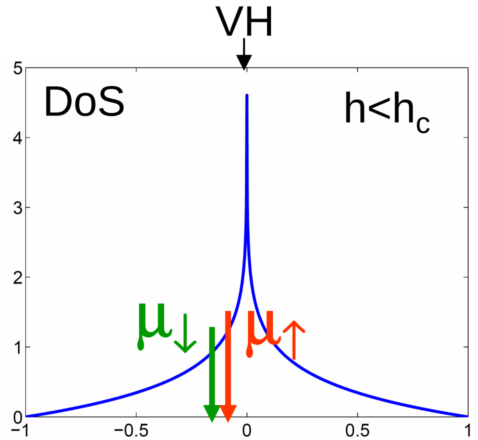


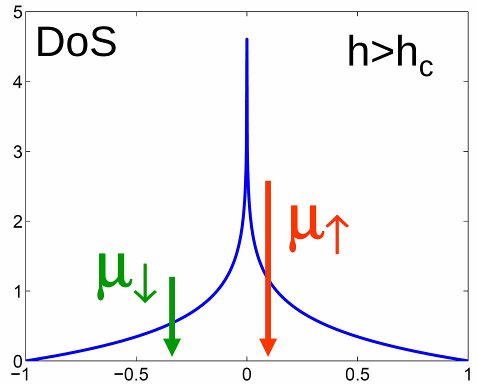
$\rho = \rho_0 + A\,T^x$

- Sharp increase of magnetization in magnetic field around 7.8T
- Feature in resistivity, anomalous T-dependence:
  $\rho = \rho_0 + A\,T^x$ with $x \neq 2$ in critical region.

Stoner Picture

- Mean field theory for local repulsion U: metamagnetic transition near van Hove filling

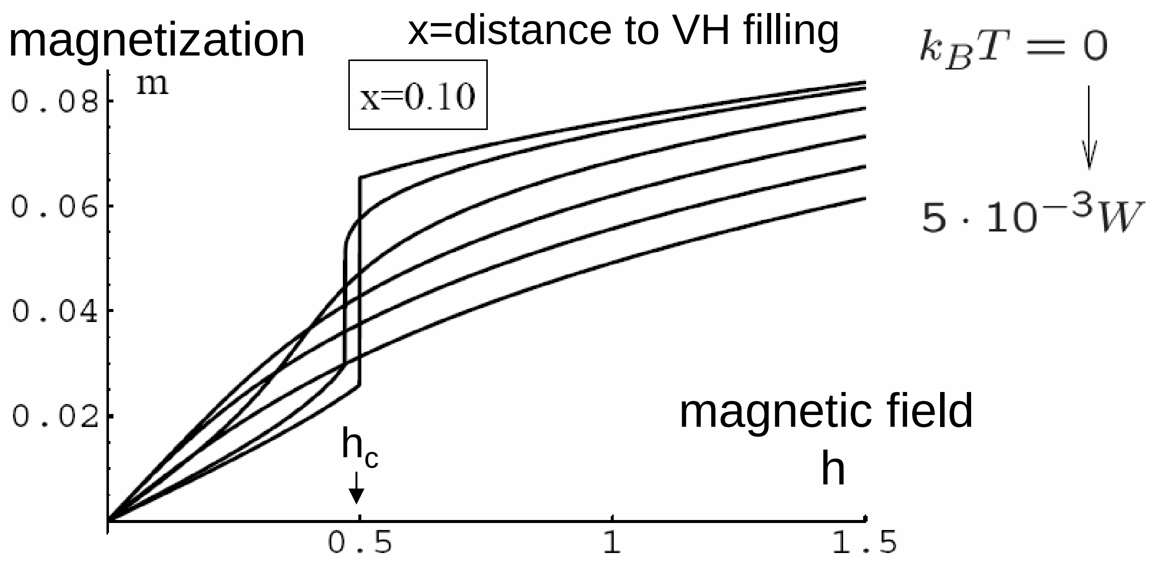




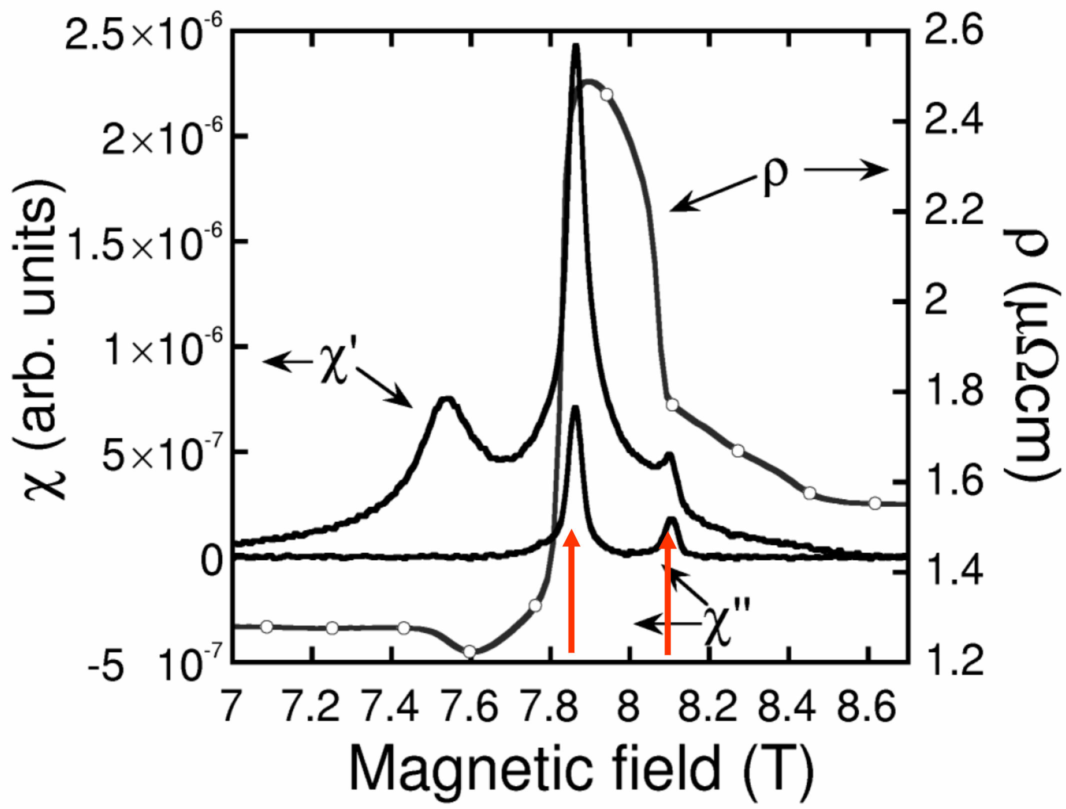
Binz & Sigrist 2003:

$$f_{\mathrm{HF}}(n,m,T) = f_0(n,m,T) + U n_\uparrow n_\downarrow$$

Minimize g(T,h,n)= $f_{HF} - hm$

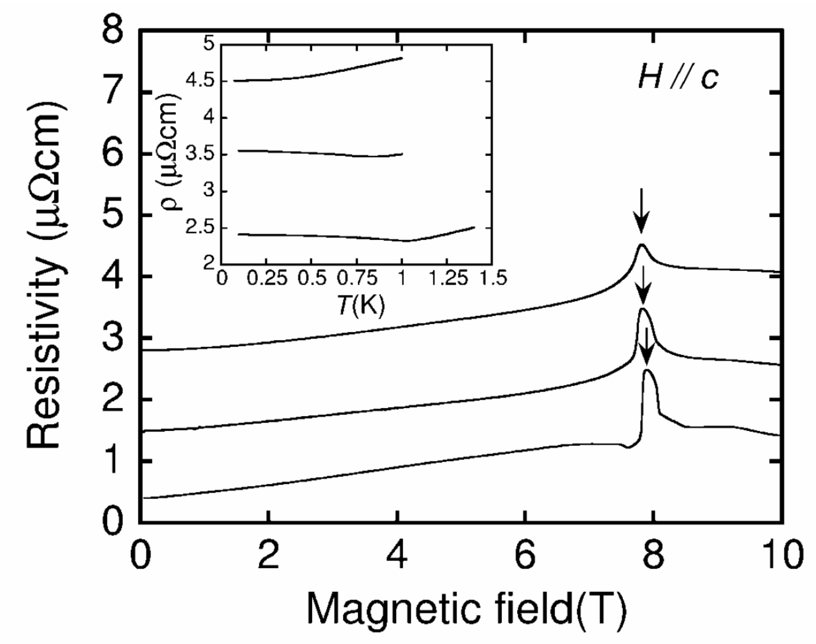


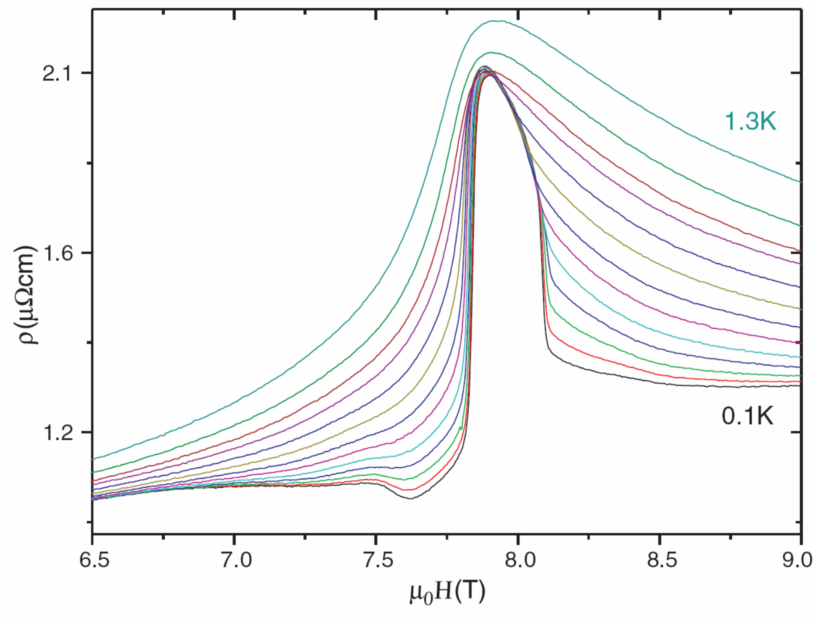
New Samples: At Least Two Jumps



- Ultraclean samples (ρ_0=0.4 μΩcm) show two or three peaks in low frequency susceptibility χ
- peaks in Im χ interpreted as hysteretic signals of **two 1st order transitions**

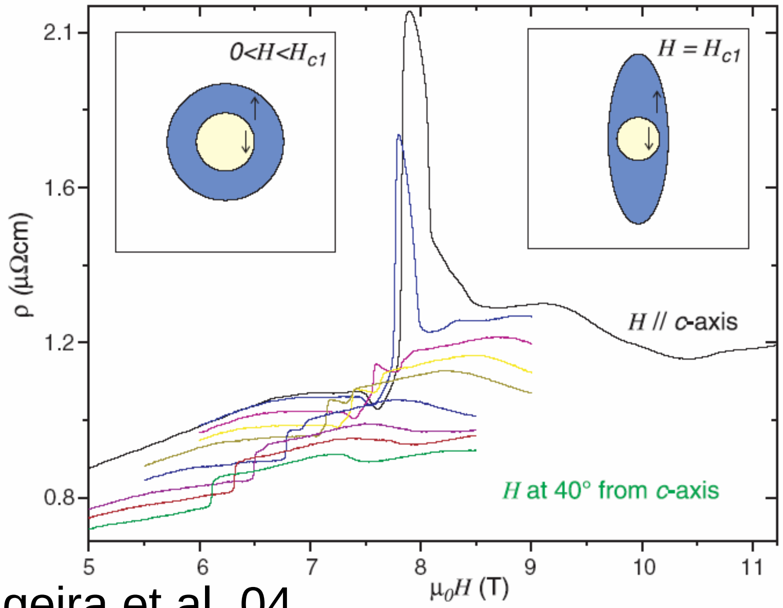
Resistivity Anomaly



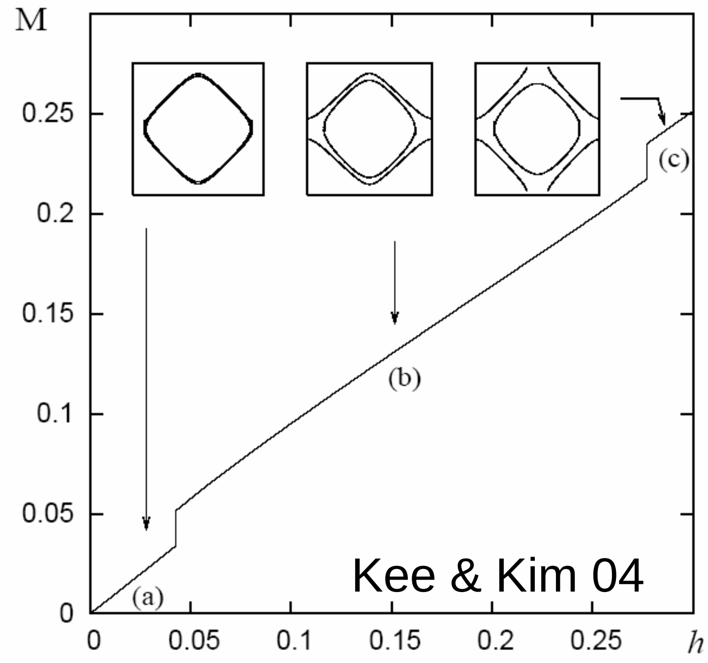


- Cleaner samples develop big (×2) resistivity anomaly at the metamagnetic transition
- In anomalous B-field range: no significant increase of ρ with T → elastic scattering
- Domains of something sensitive to impurities???

d-Pomeranchuk Scenario



Grigeira et al. 04



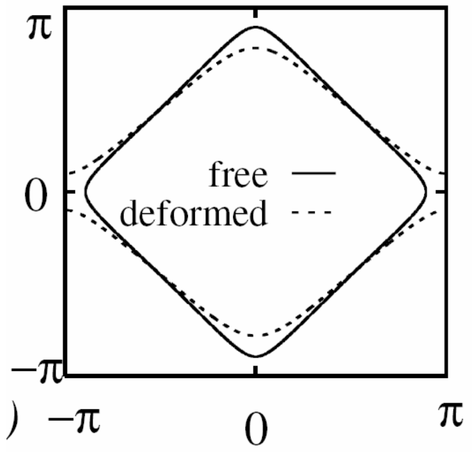
Kee & Kim 04

Proposal: *d*-wave ´Pomeranchuk´Fermi surface deformation

- increases magnetization
- makes domains responsible for resistivity anomaly
- should be sensitive to sample quality

d-Wave FS Deformation In 2D Hubbard Model

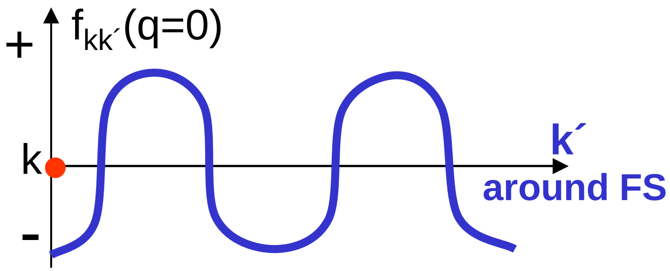
- RG in Hubbard model near half filling:
  - tendencies toward d-wave FS deformation (e.g. Halboth&Metzner 2000)
  - typically not strongest instability (CH et al. 2001), but generic tendency

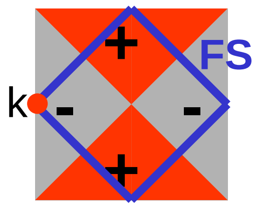


- Effective interaction

$$H^{eff.}_{dPom} = -g \sum_{\vec{k},\vec{k}',s,s'} f(\vec{k},\vec{k}')\, c^{+}_{\vec{k},s} c_{\vec{k},s}\, c^{+}_{\vec{k}',s'} c_{\vec{k}',s'}$$

$$f(\vec{k},\vec{k}') = \left(\cos k_x - \cos k_y\right) \times \left(\cos k'_x - \cos k'_y\right)$$





forward scattering needs this form with g>0

→ calculate $f_{kk'}$ with RG

Effective Interactions From Functional RG

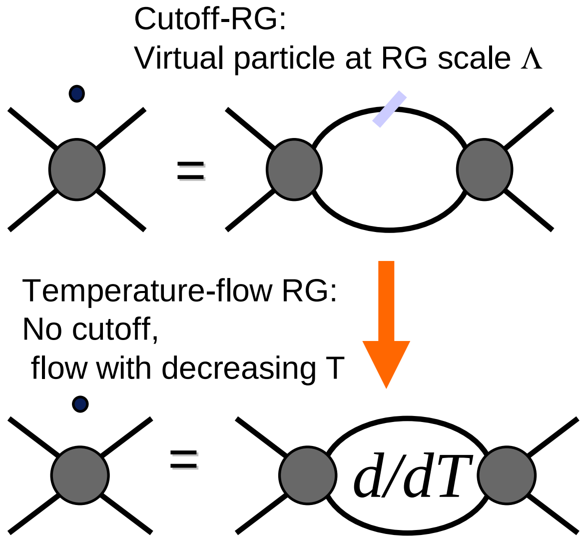
- Momentum-shell RG: integrate out shell around FS at decreasing energy scale Λ

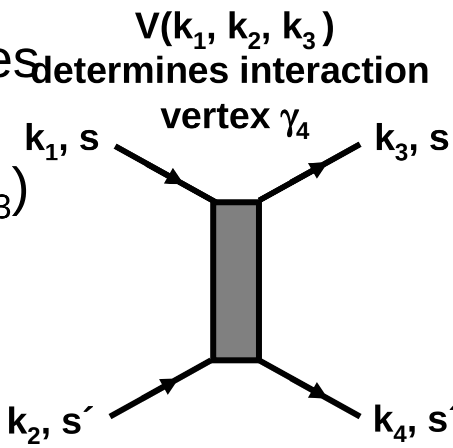
  $\rightarrow$ low energy interactions

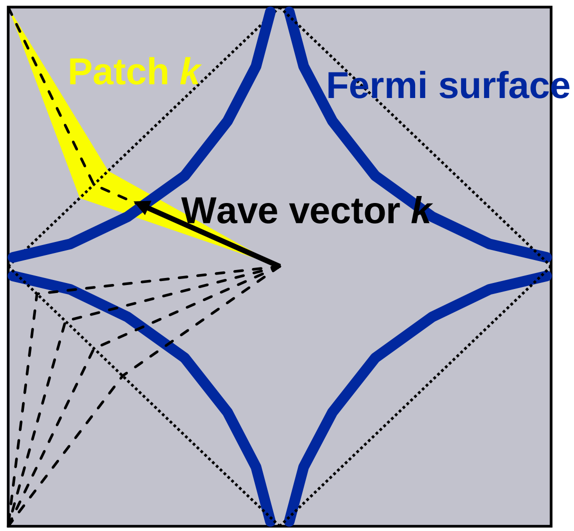
- **Temperature flow:** follow flow of vertex functions down to low T

  $\rightarrow$ effective low-T interactions

- ***N*-Patch implementation** gives detailed k-dependence of effective interactions $V(k_1,k_2,k_3)$

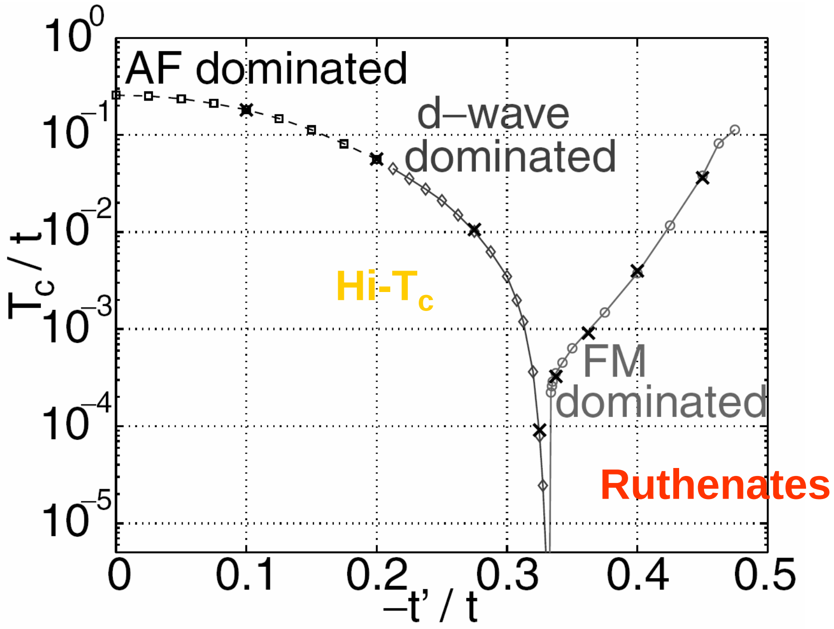


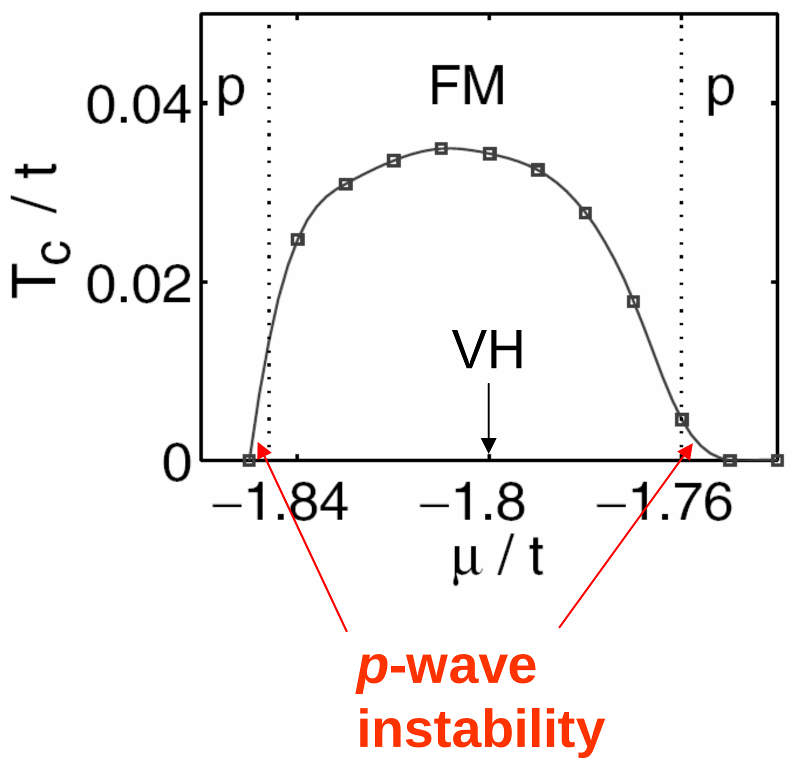




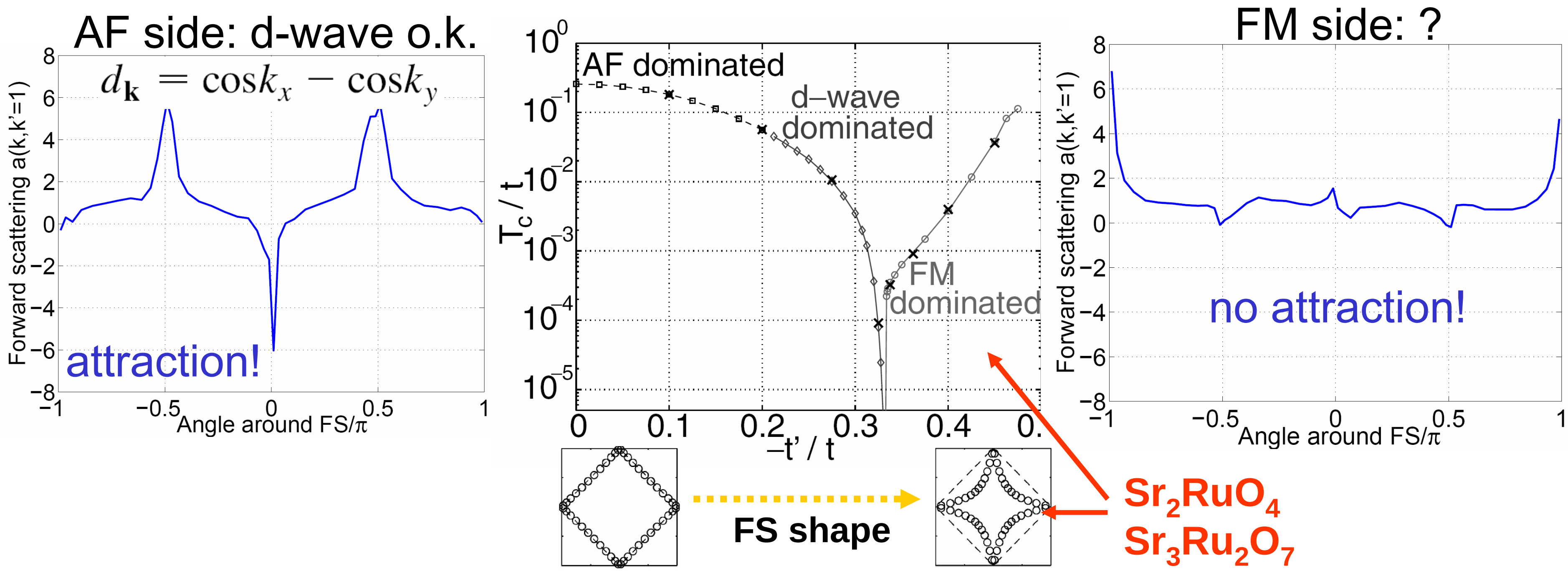
RG: Triplet Superconductivity Near Ferromagnetism

- Temperature RG flow ***p*-wave instability near FM regime** at van Hove filling (CH & Salmhofer 01, Katanin 03,04)



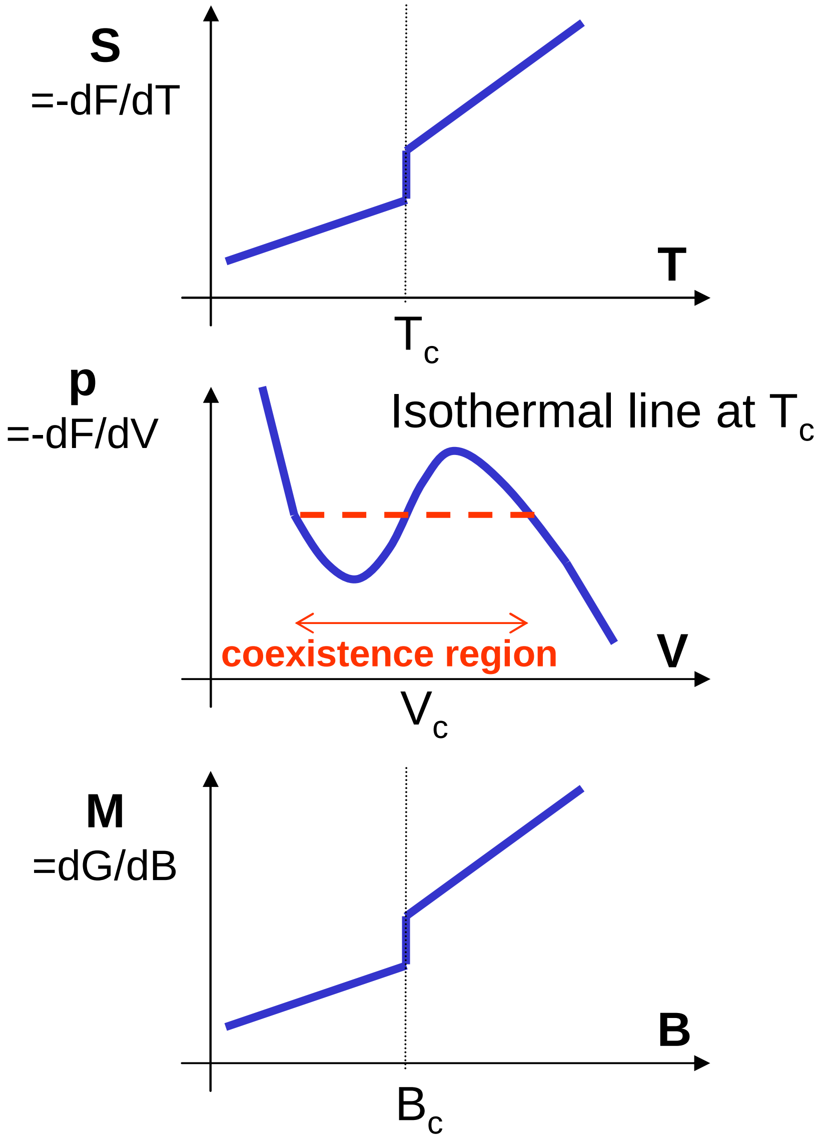


Forward Scattering In Hubbard Model



- RG finds contradiction: **d-wave FS deformations unfavorable (no attractive coupling constant) in FM regime!**
- Alternative explanations?

Similarity To Liquid-Gas Transition

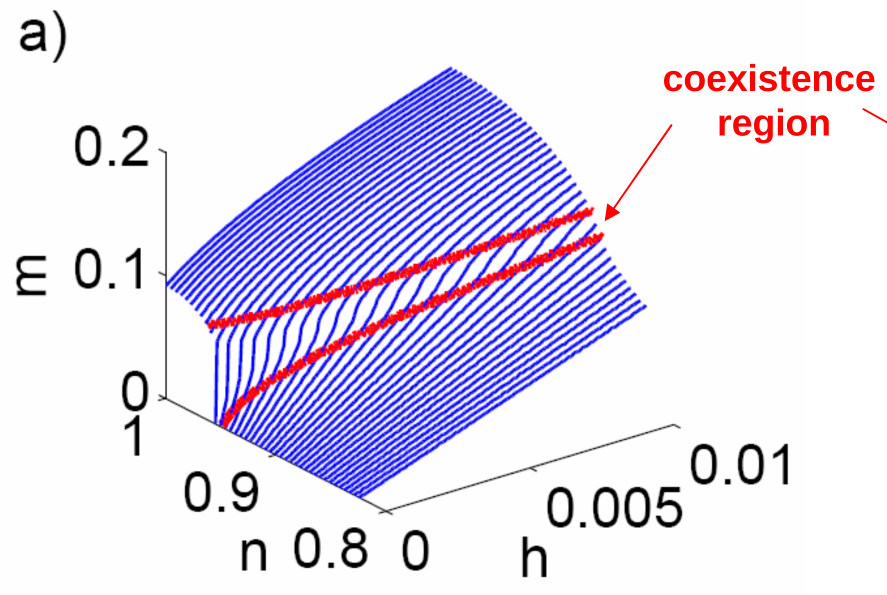


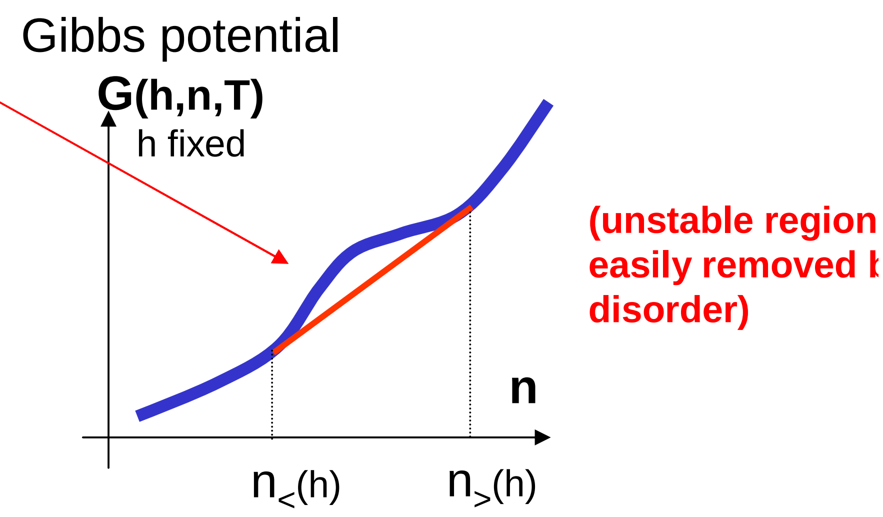
Liquid gas transition:

- Jump in entropy S vs. T at T_c
- Also feature in F as function of V
- Regions with negative curvature wrt V $\rightarrow$ phase coexistence

Analogue for metamagnetic transition?

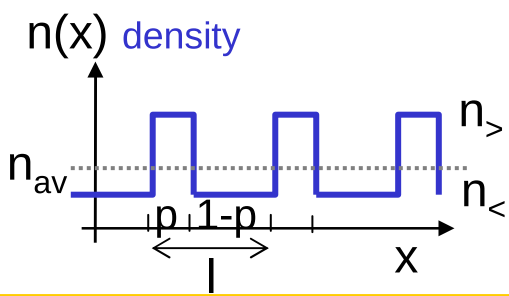
Unstable Density Regions Near MM Transition

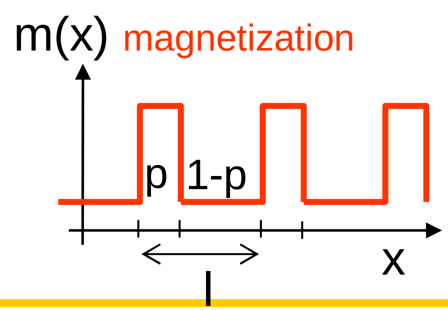




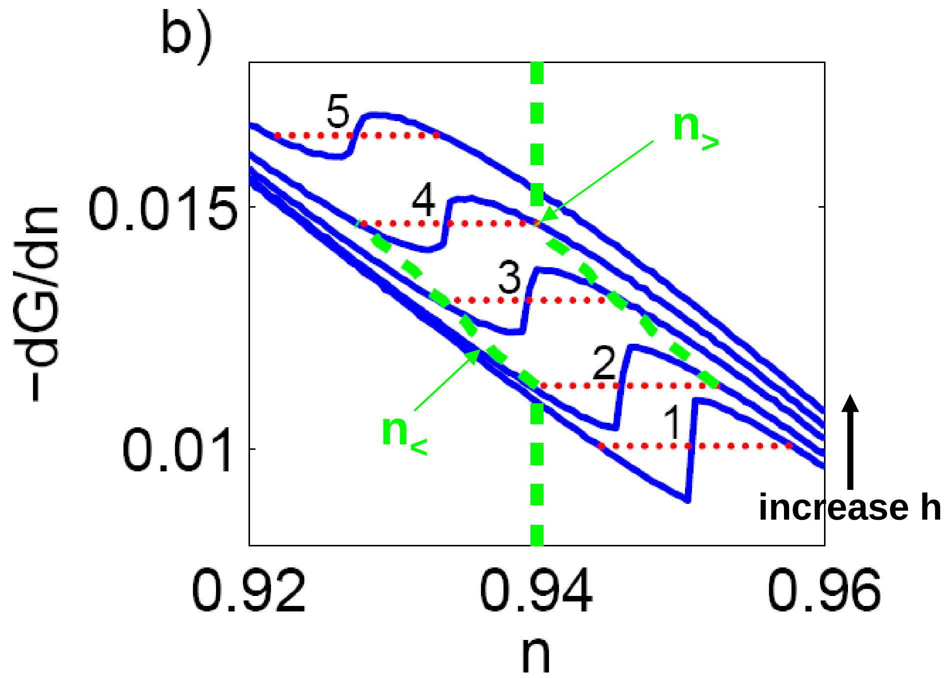
- Gibbs potential G(T,h,n) in Binz-Sigrist mean-field model has negative curvature wrt density n

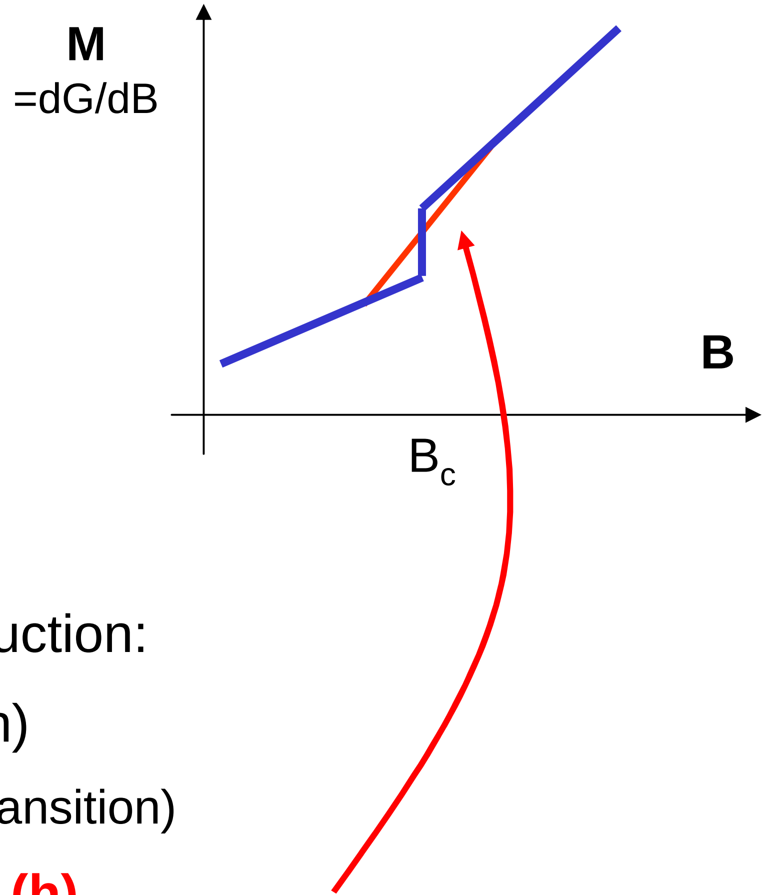
$\rightarrow$ Coulomb-frustrated phase separation?





Maxwell Destruction Of Magnetization Jump?





- Mixing parameter p from Maxwell construction:

  Density: $n_{tot} = (1-p)\, n_<(h) + p\, n_>(h)$

  (p varies continuously from 0 to 1 through transition)

  Magnetization: $\mathbf{m_{tot} = (1-p)\, m_<(h) + p\, m_>(h)}$

- **Does phase separation wipe out magnetization-step?**

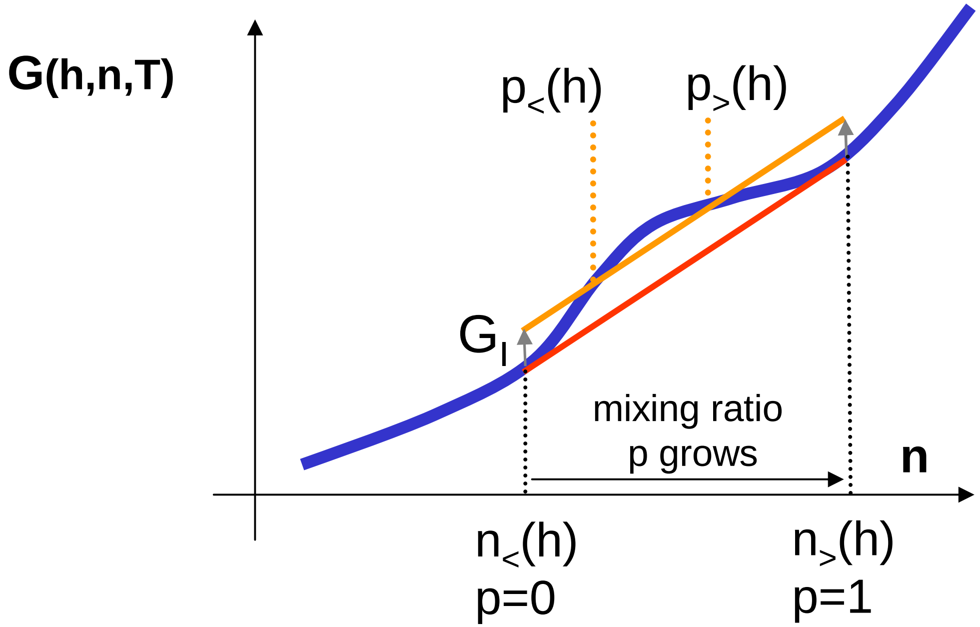
Coulomb & Interface Energies

Coulomb energy frustrates phase separation

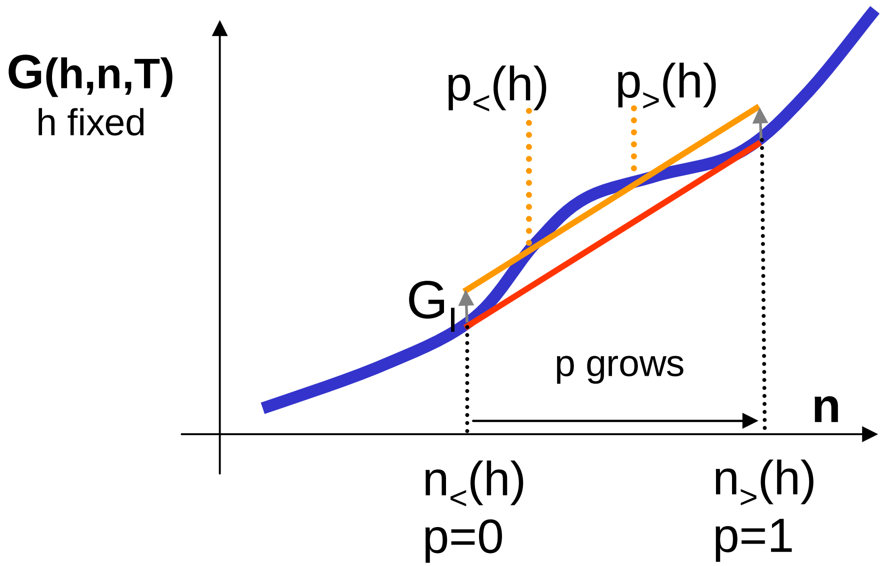
→ **micro phase separation** on nanoscale

→ **interfaces** between high- and low-density phases cost additional energy G_I

→ not all mixing ratios p energtically favorable, very thin stripes don´t pay

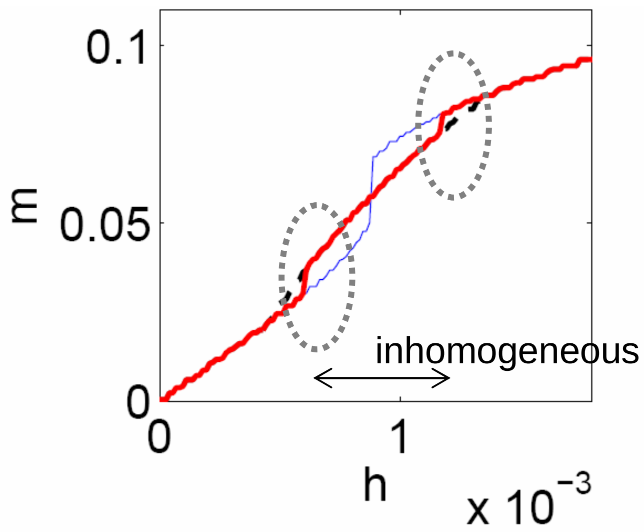


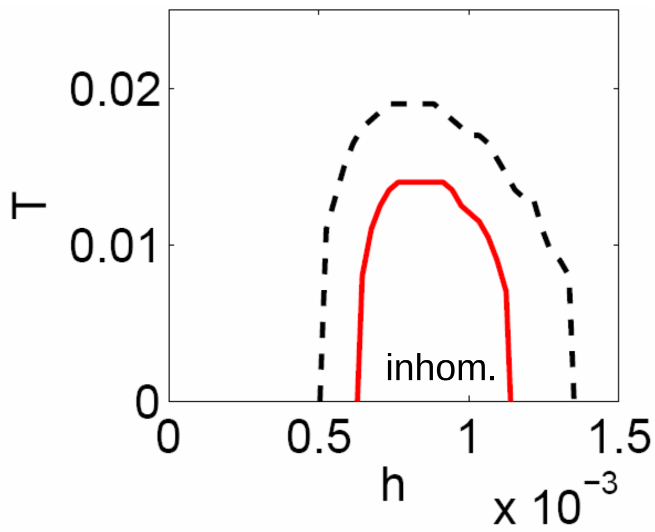
Two Jumps

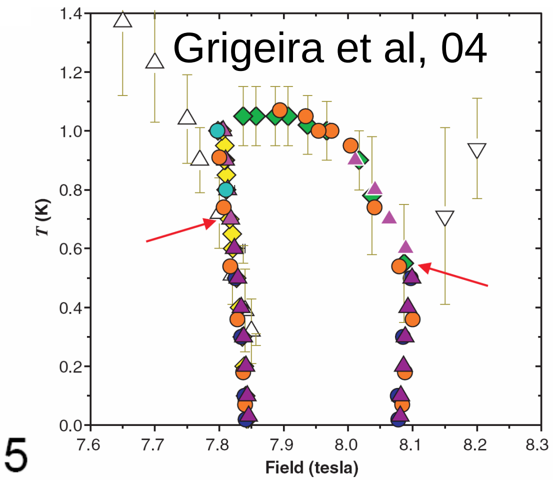


Increasing h: two jumps

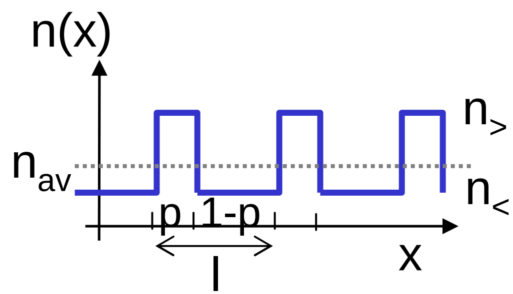
- from 0 to $p_<$ on entry into inhomogeneous phase
- from $p_>$ to 1 on exit







Length Scale Of Domains



- stripes in metals (Lorenzana et al.):

  size of domains ~ screening length ~ lattice distance

$$l_s^2 = \varepsilon_0 /(4\pi e^2 \kappa)$$

κ = compressibility

  Is our description sensible? BUT:

- only one Fermi surface (of 6) near VH points, other FS are spectators
- mutual screening by other FS reduces effective charge of domains → screening length increases

$$l_s^2 = \varepsilon_0 /(4\pi e^2 Z^* \kappa)$$

$Z^* < 1$ charge reduction

Conclusions

- Strontium-Ruthenates are good test case for understanding of correlation effects
- Scenarios for resistivity anomaly at metamagnetic transition
  - Pomeranchuk **FS deformation hard to reconcile** with FM tendencies and Hubbrd-type models
  - MM transition invites **micro phase separation**, Coulomb+interface energies might create two magnetization jumps
  - Alternative: **uncharged Condon domains** due to demagnetization (Binz, Sigrist et al.)

Possible experimental test: STM (Cornell group)