UNIVERSITY OF CAMBRIDGE

Magnetic droplets in nearly ferromagnetic metals

Y. L. Loh, V. Tripathi, and M. Turlakov
Cavendish Laboratory, Cambridge, UK

- *Non-perturbative approach close to quantum criticality*
- *Logarithmic suppression of giant magnetic moment*

Phys. Rev. B **71**, 024429 (2005)

<u>Acknowledgements</u>

A. J. Millis	J. W. Loram
P. B. Littlewood	T. V. Ramakrishnan
G. G. Lonzarich	I. Smolyarenko

Outline

1. Magnetic impurities in metals
2. Magnetic droplets in nearly ferromagnetic metals
3. Weak-coupling theory
4. Strong-coupling approach (near quantum criticality)
   - Ising symmetry
   - XY symmetry
5. Phase diagram

Magnetic impurities in metals: Fe/Co/Ni in Au/Ag/Cu

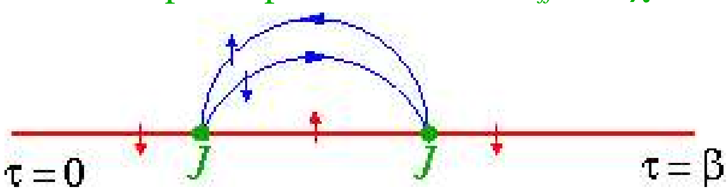
Kondo (1964); Abrikosov (1965); Anderson & Yuval (1969-)

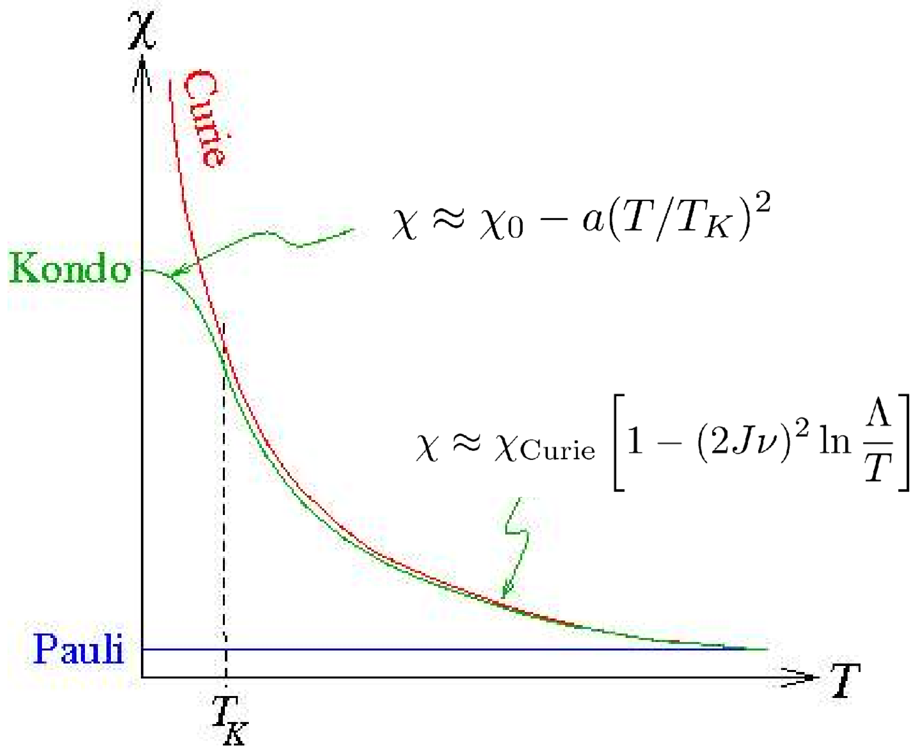
Itinerant electrons c
Pauli susceptibility $\chi \sim \mu_B^2 \nu$

Localized spins **S**
Curie susceptibility $\chi \sim S(S+1)\mu_B^2/T$

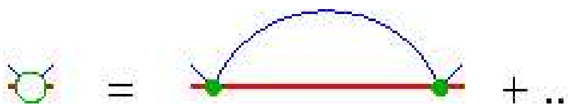
$$\hat{H} = \sum_{\mathbf{k}\alpha} \xi_{\mathbf{k}} c^\dagger_{\mathbf{k}\alpha} c_{\mathbf{k}\alpha} + 0 + J\hat{\mathbf{S}} \cdot \boldsymbol{\sigma}_{\alpha\beta} c^\dagger_{\mathbf{0}\alpha} c_{\mathbf{0}\beta}$$

Antiferromagnetic exchange coupling J
causes spin flips that reduce S_{eff} and χ





Perturbative RG:
J flows logarithmically towards ∞



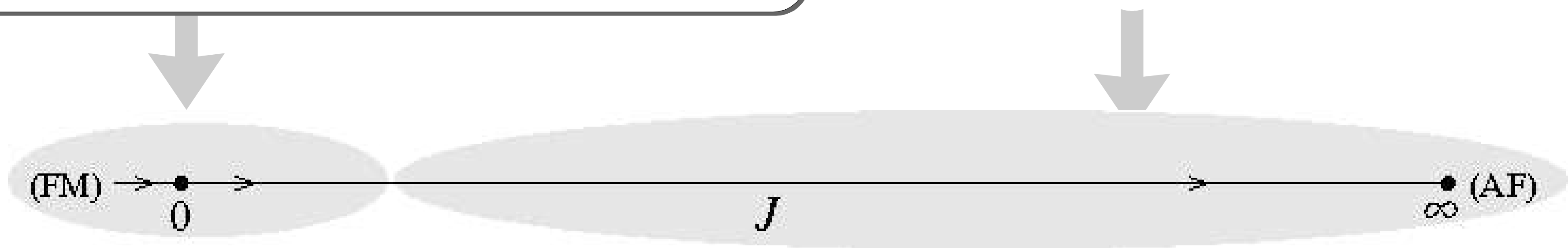
$$\frac{d(J\nu)}{d\ln\Lambda} = -(J\nu)^2 + \dots$$

$$\therefore \quad J = \frac{1}{\frac{1}{J_0} + \ln\frac{\Lambda}{\Lambda_0}}$$

$\rightarrow \chi$ reduced logarithmically

$$\chi \approx \chi_{\mathrm{Curie}}\left[1 - (2J\nu)^2 \ln\frac{\Lambda}{T}\right]$$

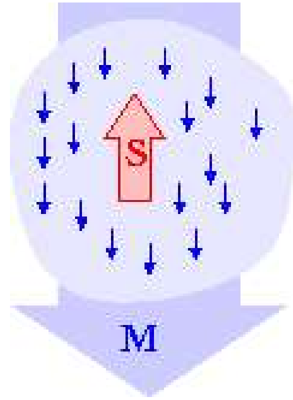
Numerical RG
Monte Carlo
Bethe ansatz



Host metal near a FM instability: Fe/Ni/Co in Pd/Pt

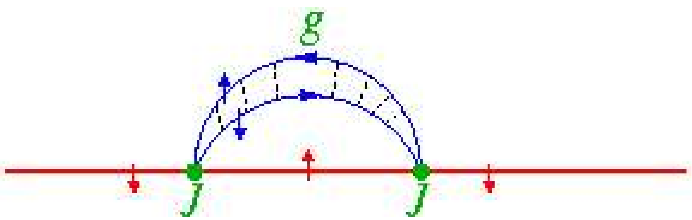
Larkin & Mel'nikov (1972); Nozières & Blandin (1980); Maebashi, Miyake & Varma (2002)

- Nearly ferromagnetic Fermi liquid: Exchange scattering amplitude $F_0 \sim -1$
- Pauli susceptibility enhanced by factor $1/(1+F)$
- Localized spin polarizes nearby electrons
  → localized droplet with giant moment $M = |1-1/(1+F)|S \sim 10\mu_B$
  → giant Curie susceptibility, $\chi \sim M^2/T \sim 100\mu_B{}^2/T$



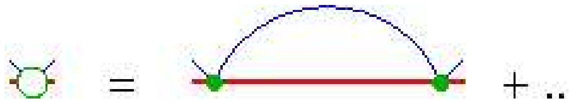
“overcompensation”

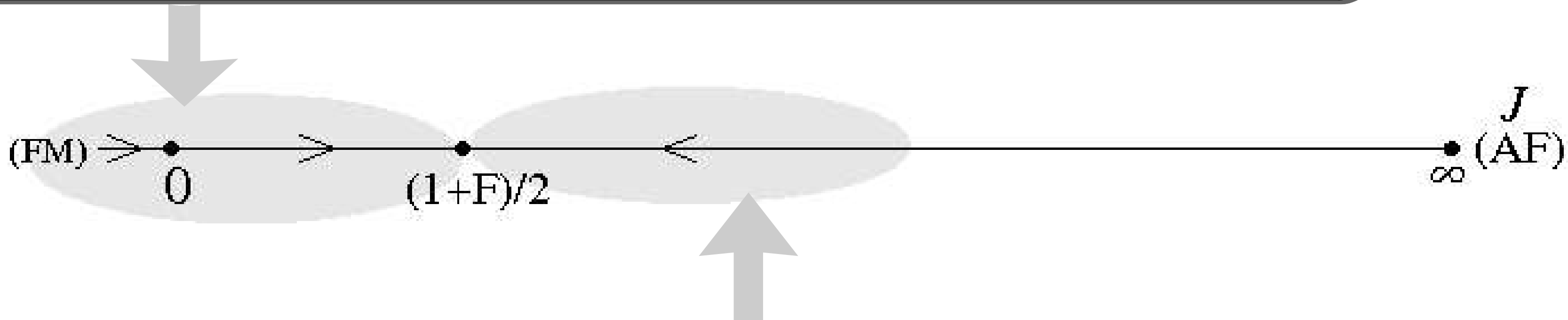
Paramagnon scattering, g,
causes spin flips that reduce M_{eff} and χ



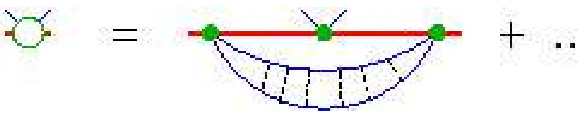
$$g = \frac{(J\nu S^2)}{1+F}$$

Vertex correction dominated by spin flips





Vertex correction dominated by
'potential scattering' from droplet
in many angular-momentum channels



$$\frac{d(J\nu)}{d\ln\Lambda} = \frac{2}{1+F}(J\nu)^3 + \ldots$$

Useful to work with $g = \frac{(J\nu S^2)}{1+F}$

g flows logarithmically towards 0

$$\frac{dg}{d\ln\Lambda} = g^2$$

$$\therefore \quad g = \frac{1}{\frac{1}{g_0} + \ln\frac{\Lambda_0}{\Lambda}}$$

→ χ has log in denominator

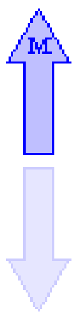
$$\chi = \frac{M^2}{T} \times \frac{1}{1 + g\ln\frac{E_0}{T}}$$

Strong-coupling approach for large g (near QCP)

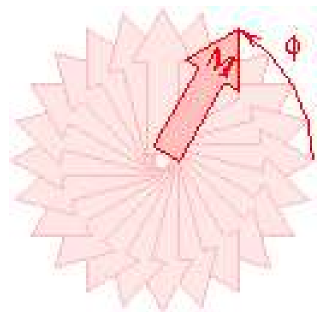
Millis, Morr, Schmalian (2001); Loh, Tripathi, Turlakov (2005)

- Describe droplet magnetization field $m(\mathbf{r})$ by dissipative Ginzburg-Landau action $S[m]$
  - Fluctuations of droplet moment **M** governed by local susceptibility of Fermi liquid $\chi(\mathbf{r}=\mathbf{0}) \sim \alpha_\tau \sim 1/\tau^2$

- Discrete 'Ising' symmetry
  - maps to classical Ising chain with $1/\tau^2$ interactions
  - chain has long-range order for $g > g_c$
  - χ diverges at T=0



- Continuous 'XY' symmetry
  - maps to classical XY chain with $1/\tau^2$ interactions
  - chain is always disordered
  - χ saturates at low T



$$S[\varphi] = -\underbrace{\int_0^\beta d\tau\, \frac{1}{4E_A}(\partial_\tau\varphi_\tau)^2}_{\text{inertia}} + \underbrace{\iint_0^\beta d\tau\, d\tau'\, \frac{\pi g}{2}\alpha_{\tau-\tau'}\cos(\varphi_\tau-\varphi_{\tau'})}_{\text{paramagnons}}, \quad \alpha_\tau = \frac{T^2}{\sin^2 \pi T\tau}$$

XY droplet, perturbative RG about saddle point:

g flows logarithmically towards 0

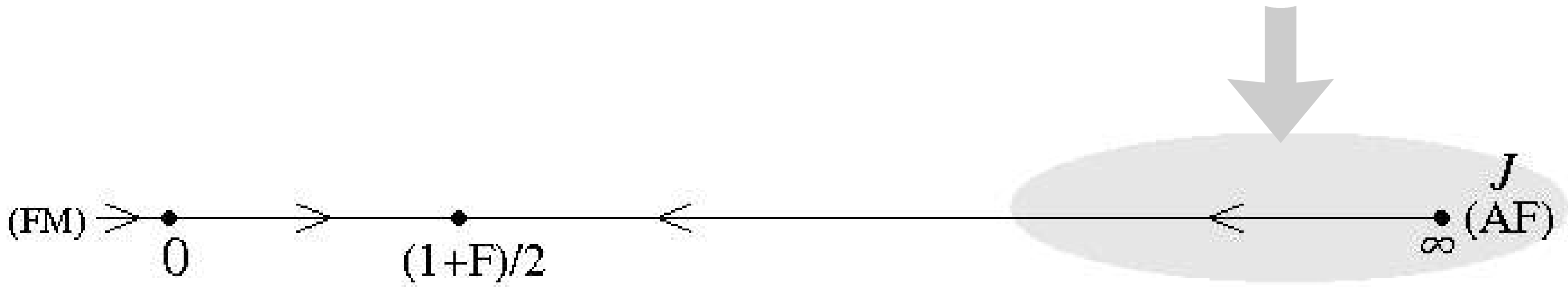
$$\frac{dg}{d\ln\Lambda} = g^2$$

$$\therefore \quad g = g_0 - \frac{1}{\pi}\ln\frac{g\Lambda_0}{\Lambda}$$

$\rightarrow \chi$ reduced logarithmically

$$\chi \sim \frac{M^2}{T}\left(1 - \frac{1}{\pi g}\ln\frac{gE_A}{T}\right)$$

Logs in numerator
– different from weak-coupling logs!



- Logarithmic reduction of susceptibility
- For sufficiently low T, g renormalizes to <1 $\rightarrow$ crossover to weak-coupling regime.
- Expect similar scenario in case of ‘Heisenberg’ symmetry.

Phase diagram