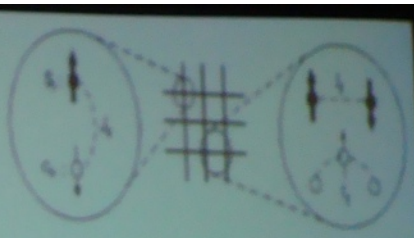
• Kondo lattices:

$$\mathcal{H} = \sum_{ij,\alpha} I^{\alpha}_{ij} S^{\alpha}_i S^{\alpha}_j + \sum_{ij,\sigma} t_{ij} c^{\dagger}_{i\sigma} c_{j\sigma} + \sum_{i,\alpha} J^{\alpha}_K S^{\alpha}_i s^{\alpha}_{ci}$$



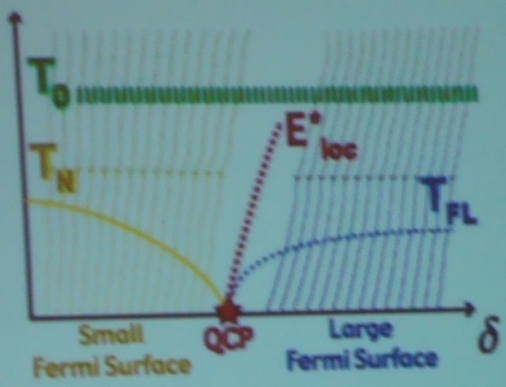
heavy Fermi liquid:

- Kondo singlet
- Kondo resonance

No symmetry breaking,
but macroscopic order

Critical Kondo Destruction

Critical Kondo Destruction (f-elec. Mott localization) at the T=0 onset of antiferromagnetism



QS, S. Rabello, K. Ingersent, & J. L. Smith, Nature 413, 804 (2001);
Phys. Rev. B68, 115103 (2003)

P. Coleman et al, JPCM 13, R723 (2001)

Dynamical Scaling of Local Quantum Critical Point

$$\chi(q,\omega) = \frac{1}{(I_q - I_Q) + A(-i\omega)^{\alpha} M(\omega/T)}$$

$\alpha = 0.72$ J-X Zhu, D. Grempel and QS, PRL (2003)

$\alpha = 0.83$ J-X Zhu, S. Kirchner, R. Bulla, and QS, PRL (2007)

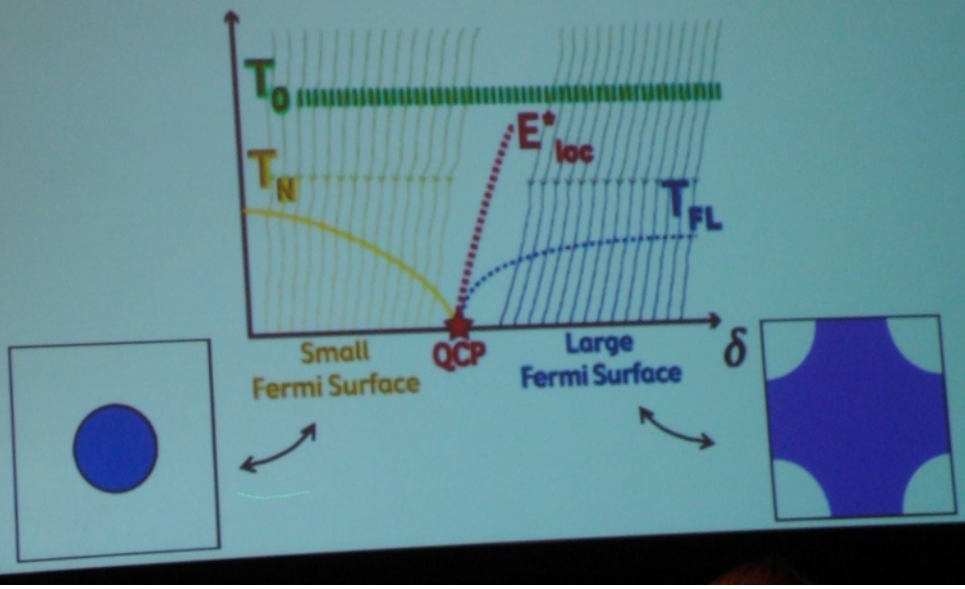
$\alpha = 0.78$ M. Glossop & K. Ingersent, PRL (2007)

EDMFT: collapsing E_{loc}^{*} from paramagnetic side

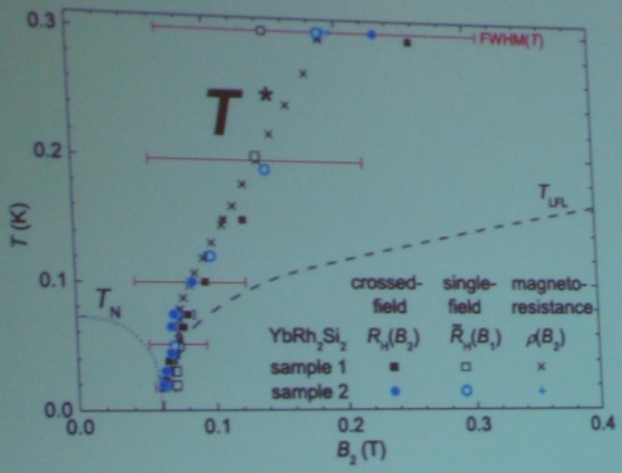
Cf. neutron scattering expts: A. Schröder et al., Nature('00); O. Stockert et al; M. Aronson et al.

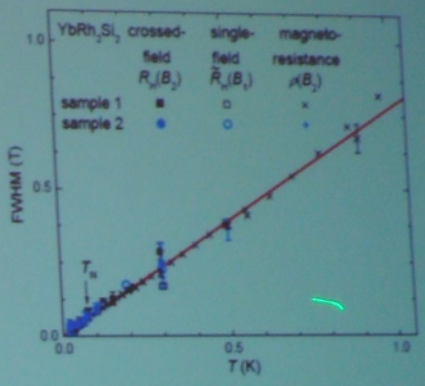
Local Quantum Critical Point

- ω/T scaling in χ(q,ω,T) and G(k,ω,T)
- Collapse of a large Fermi surface
- Multiple energy scales



Fermi Surface and Energy Scales in $YbRh_2Si_2$

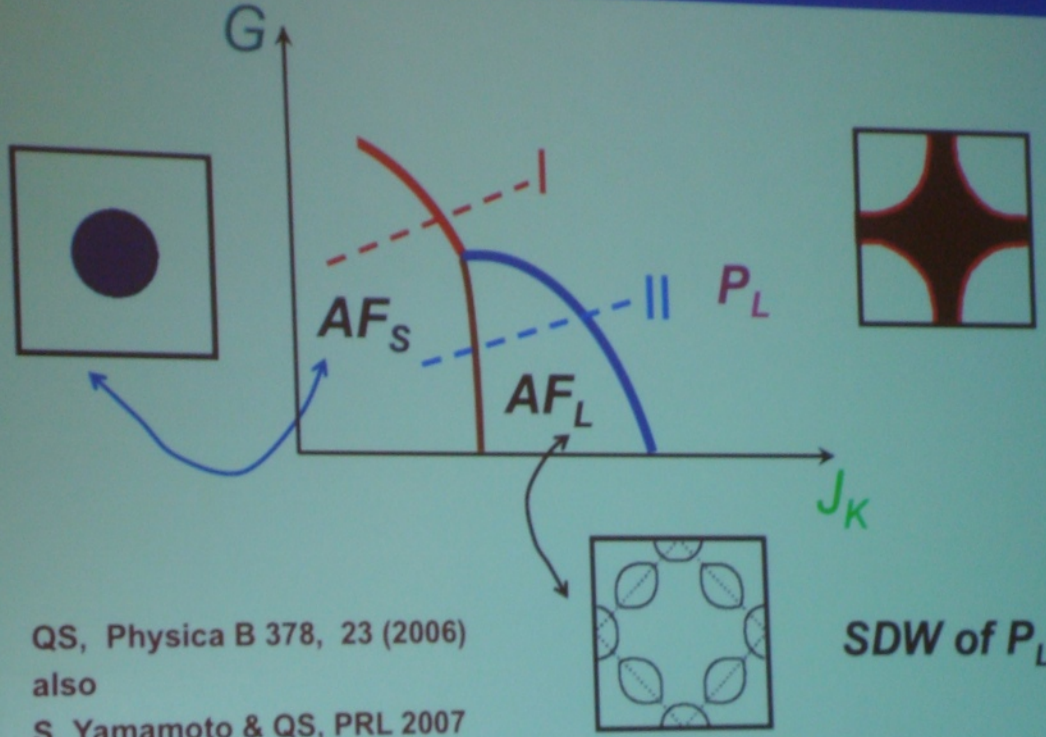




S. Friedemann, N. Oeschler, S. Wirth, C. Krellner, C. Geibel, F. Steglich, S. Paschen, S. Kirchner, and QS, PNAS 107, 14547 (2010)

S. Paschen et al, Nature (2004); P. Gegenwart et al, Science (2007)

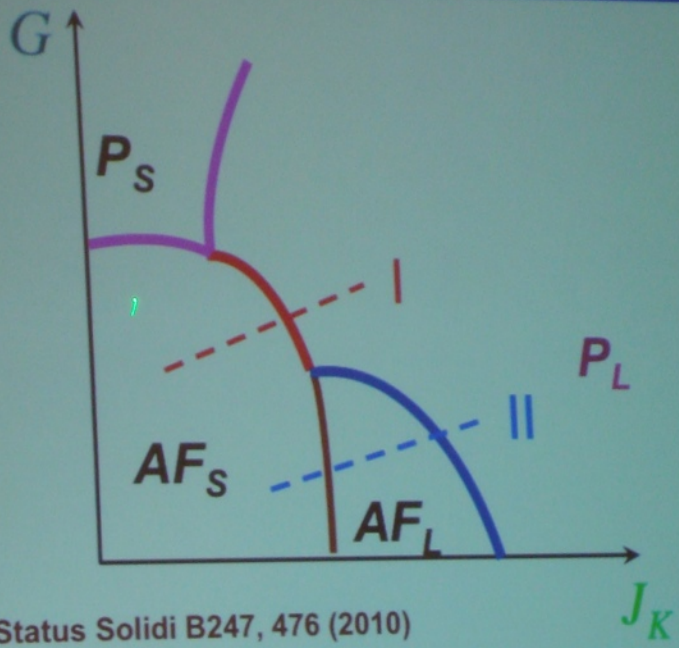
Global Phase Diagram



QS, Physica B 378, 23 (2006)
also
S. Yamamoto & QS, PRL 2007

SDW of P_L

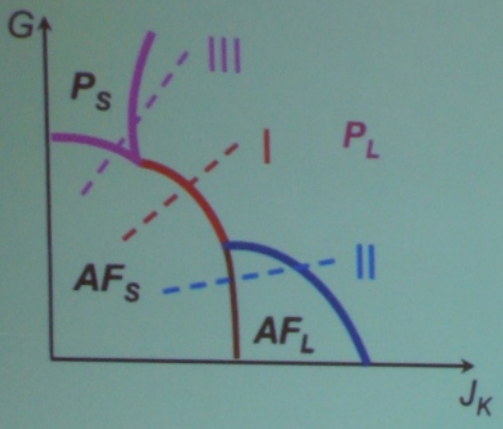
Global Phase Diagram



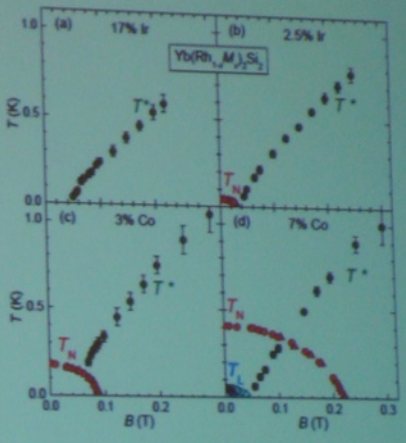
Q. Si, Phys. Status Solidi B247, 476 (2010)

also, P. Coleman & A. Nevidomskyy, JLTP 161, 182 (2010);
M. Vojta, JLTP 161, 203 (2010)

Global Phase Diagram



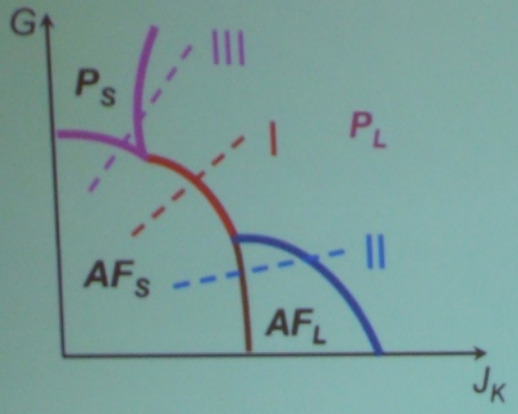
Pure and doped $YbRh_2Si_2$



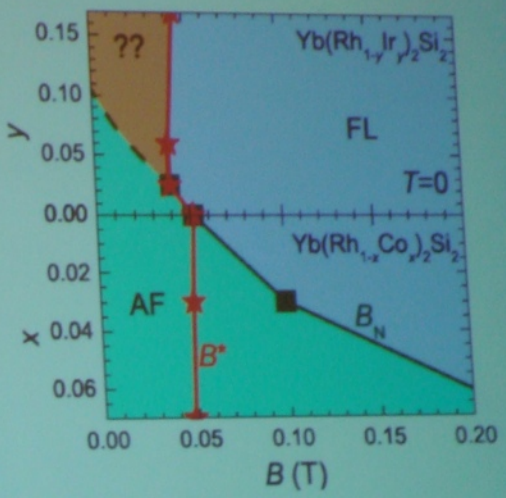
S. Friedemann et al,
Nat. Phys. 5, 465 (2009)

J. Custers et al.,
PRL 104, 186402 (2010)

Global Phase Diagram

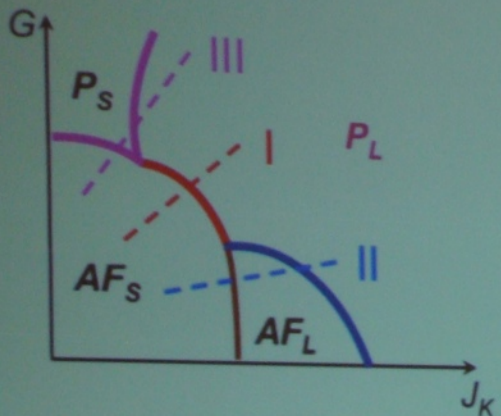


Pure and doped $YbRh_2Si_2$



S. Friedemann et al,
Nat. Phys. 5, 465 (2009)

Global Phase Diagram



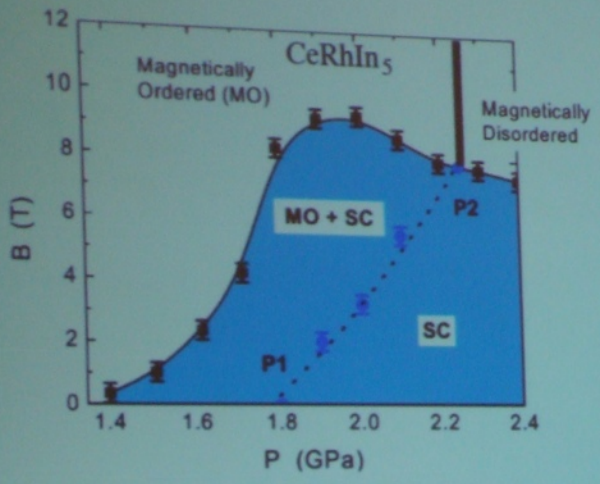
$CeCu_{6-x}Au_x$ (I)
$YbRh_2Si_2$ (I)

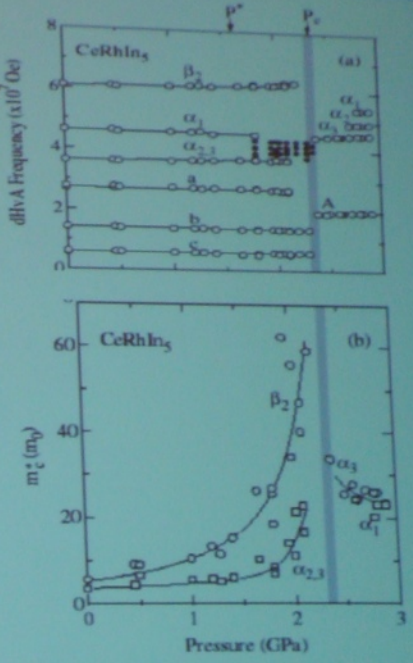
$YbRh_{2-x}Co_xSi_2$ (II)
$CeRu_{2-x}Rh_xSi_2$ (II)
$CeIn_3$ (II)

$YbRh_{2-x}Ir_xSi_2$ (III)

YbAgGe (many phases)
$YbAlB_4$
Yb_2Pt_2Pb

Superconductivity near Kondo-destroying AF QCP in $CeRhIn_5$

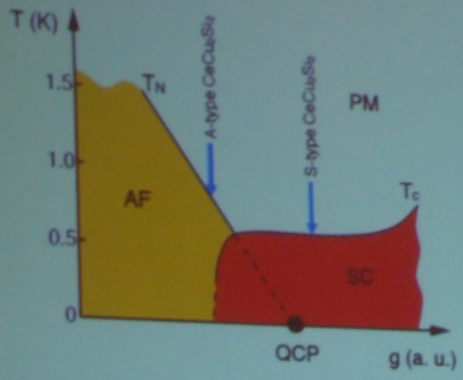


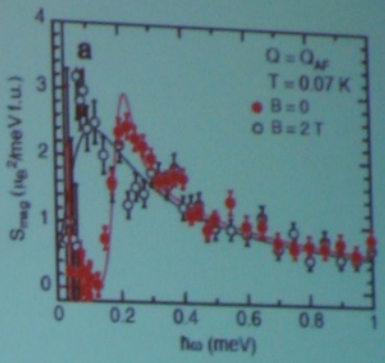


T. Park et al., Nature 440, 65 ('06);
G. Knebel et al., PRB74, 020501 ('06)

H. Shishido, R. Settai, H. Harima, & Y. Ōnuki, JPSJ 74, 1103 ('05)

Superconductivity in $CeCu_2Si_2$

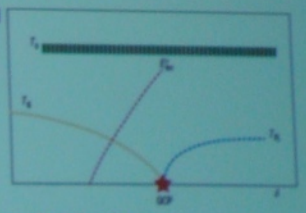




Exchange energy saving
≈ 20 times of SC condensation energy

➔ large kinetic energy loss

May reflect transfer of spectral weight



O.Stockert, J.Arndt, E.Faulhaber, C.Geibel, H.S. Jeevan, S.Kirchner, M.Loewenhaupt, K.Schmalzl, W.Schmidt, QS, & F.Steglich, Nat. Phys. 7, 119 (2011)

SUMMARY

- **Antiferromagnetic quantum critical points in heavy fermion metals**
  - SDW type: Order-parameter fluctuations
  - Local quantum criticality: electronic localization in the form of Kondo destruction
- **Emergent phases:**
  - Global phase diagram
  - Superconductivity: Role of both critical spin fluctuations and electron localizations