Probing Quantum Phase Transitions and Domain Dynamics with the Hall Effect

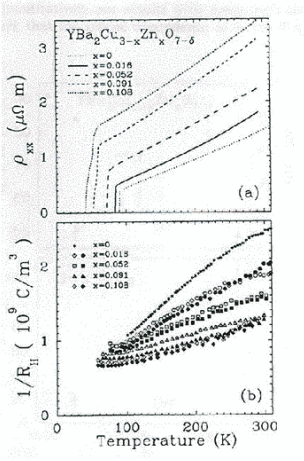
- **High-Tc's: YBCO**
- **Mott-Hubbard Transition: V_2O_3**
- **SDW Order: Cr**

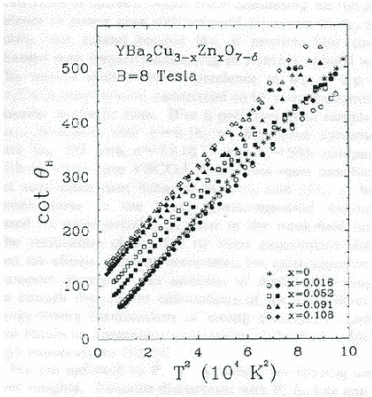
Approach to the QCP *(Minhyea Lee)*

Domain Wall Motion *(Rafael Jaramillo)*

THE UNIVERSITY OF CHICAGO

Hall Effect and YBCO



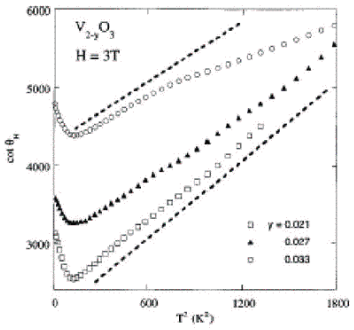


Chien, Wang & Ong, PRL 67, 2088 (1991)

$\sigma_{xx} \sim \tau_{tr}$; $\sigma_{xy} \sim \tau_{tr}\tau_H$: $\cot\theta_H = (\sigma_{xx}/\sigma_{xy}) \sim 1/\tau_H$

CHARGE & SPIN : $\tau_{tr} \sim 1/T$ vs. $\tau_H \sim 1/T^2$

Hall Effect and V_2O_3



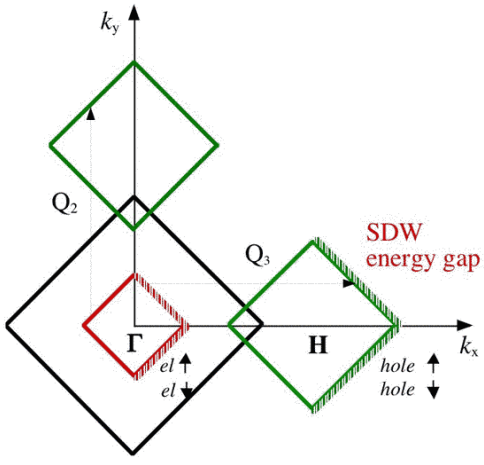
More Metallic

Rosenbaum, Husmann, Carter & Honig,
Phys. Rev. B 57, R13997 (1998)

$\tau_{tr} \sim 1/T^{3/2}$ (SCR) vs. $\tau_H \sim 1/T^2$

NEAR HALF-FILLING (Mott-Hubbard QCP)

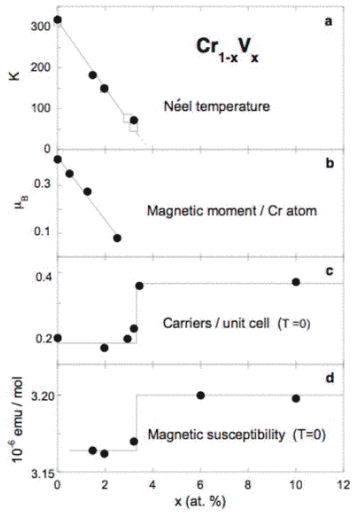
SDW in CHROMIUM



Fermi surface for Cr :
SDW of wave vector **Q** produces energy gap
(Fawcett, *RMP* **60,** 209 (1994))

- Cr is a 3*d*- transition metal with a simple BCC structure.
- The only elemental Antiferromagnet.
- Spin-density wave ground state at 311 K.
- Drive T_N to zero by **Doping with V**
(effectively increasing the size of the hole pocket)
or by **Applying Pressure**.

Hall Effect and $Cr_{1-x}V_x$



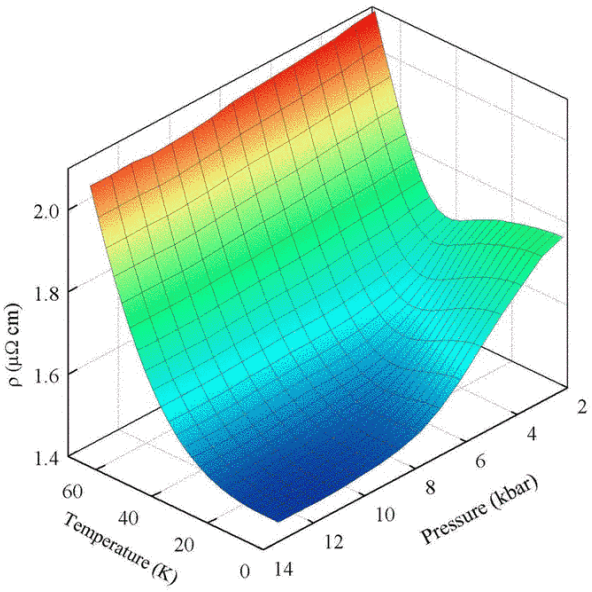
- **Hall Coefficient jumps by a factor of two at the QCP!**

A. Yeh et al., Nature **419**, 459 (2002)

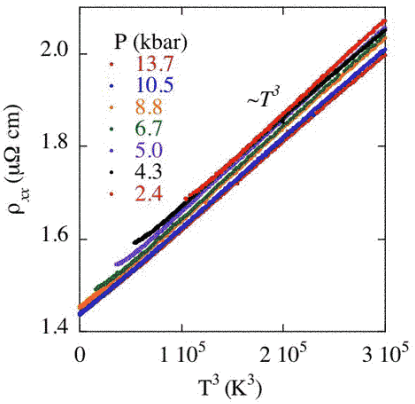
Does the Longitudinal Resistivity see the QCP?

Does R_H really jump?

Temperature dependence of ρ_{xx} at various P

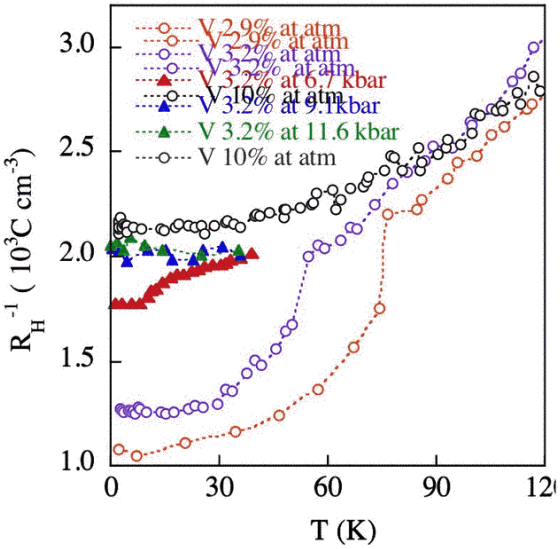


• Temperature dependence of resistivity evolves smoothly through the QCP
• $\rho\,(T) \sim T^3$ due to phonons in the paramagnetic phase.
• No non-Fermi liquid signature.

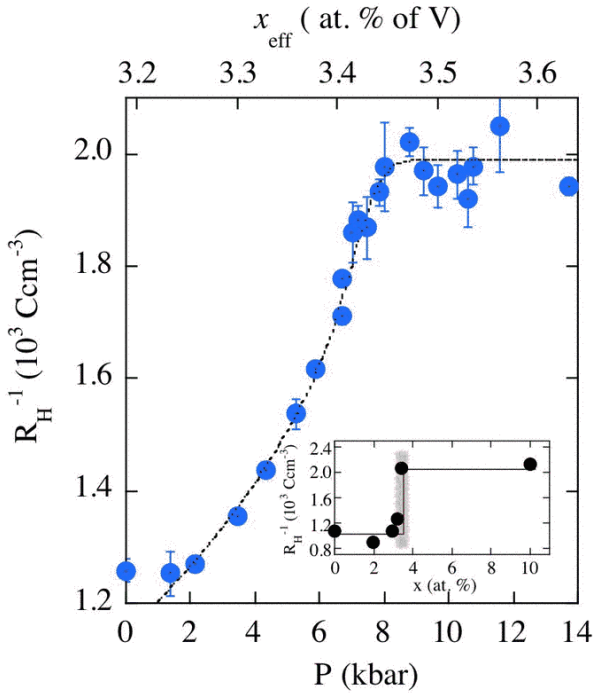


Temperature Dependence of the Hall Coefficient:

- **High T Evolution, viz. YBCO**
- **Sharp decrease in $1/R_H$ as SDW Gap opens**
- **T = 0 Discontinuity?**



Pressure Dependence of Inverse Hall Coefficient



At the T → 0 QCP:

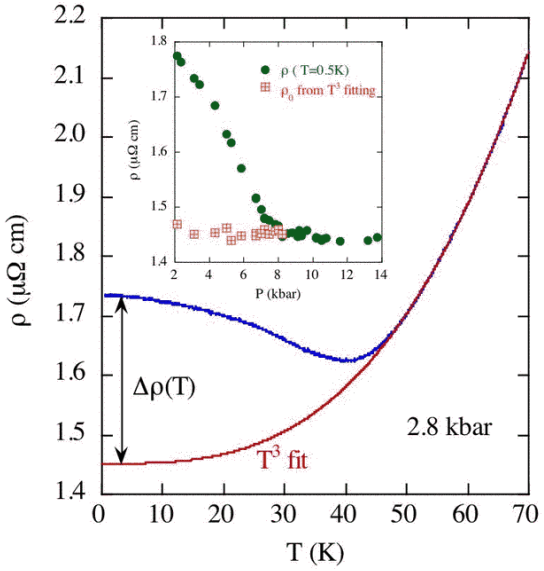
Continuous Evolution of

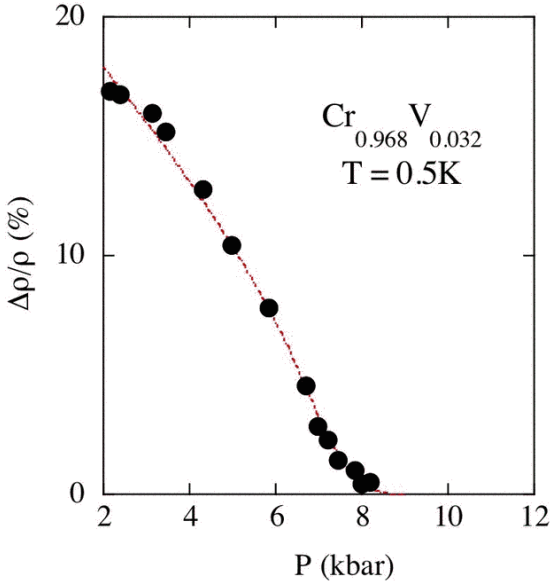
$R^{-1}_H \sim (P_c\text{-}P)^{0.50\pm0.02}$,

with $P_c = 7.5 \pm 0.1$ *kbar,*

M. Lee et al., PRL **92**, 187201 (2004)

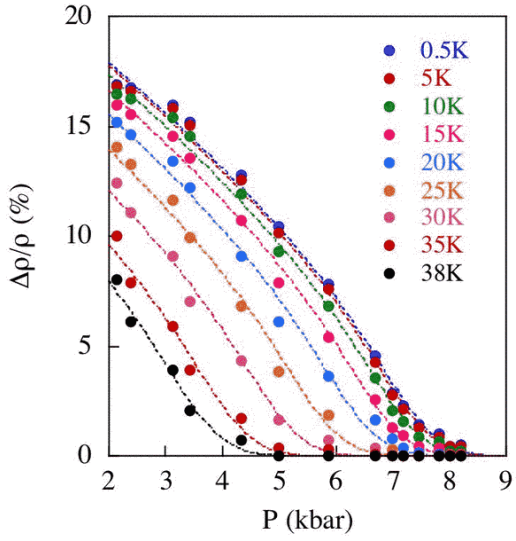
$\Delta\rho/\rho\,(T)$ as measure of SDW Order Parameter





$\Delta\rho/\rho \sim (P_c\text{-}P)^{0.68\pm0.03}$ *with* $P_c = 7.5 \pm 0.1$ *kbar.*

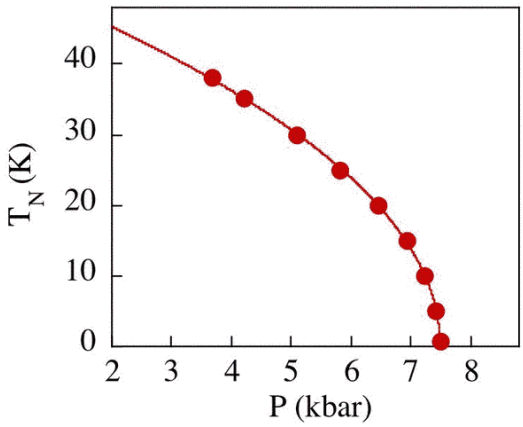
Final Exponent: Isothermal Cut of $\Delta\rho\,(T,P)$



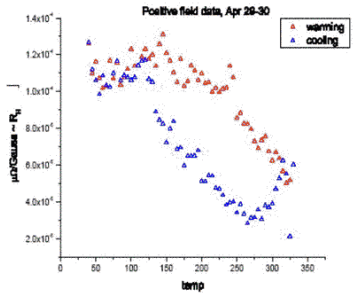
▪ Δρ/ρ(P) at all T fits $(P_c\text{-}P)^{0.68\pm0.03}$ with inhomogeneity $\Delta x = 0.019\%$.

• Pressure dependence of T_N can be determined from the fitting results:

$T_N \sim (P_c\text{-}P)^{0.49\pm0.02}$ *with* $P_c = 7.5 \pm 0.1$ *kbar*



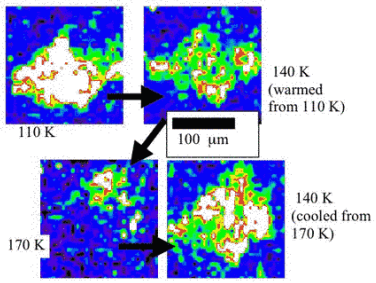
Domain Structure and Dynamics in Cr



Hall Hysteresis of SDW Domains:

T_N = 311 K; T_{SF} = 123 K

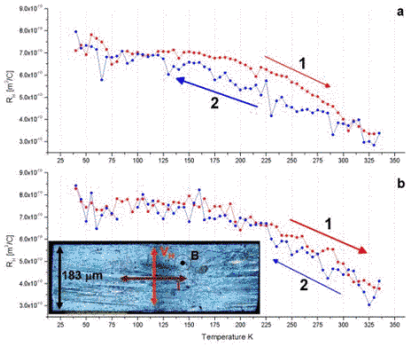
R. Jaramillo et al.



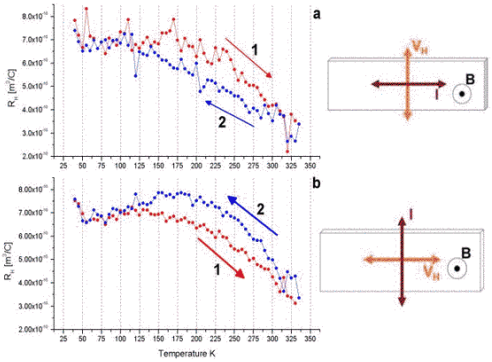
X-ray Microscopy:
S and Q Domains

E. Isaacs et al.

Pinning and Fluctuations



Scratching the surface orients the domains: *Collapse hysteresis*



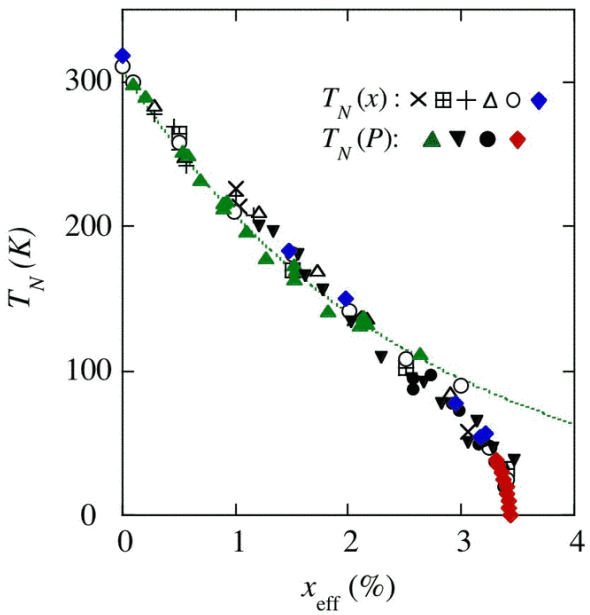
Different scattering modes:
Hysteretic reversal and noise

Summary

- ✓ Hall coefficient reveals relationship between spin & charge in cuprates, heavy fermions and at Mott-Hubbard transition in V_2O_3.
- ✓ Hall coefficient is the most sensitive probe of the QCP in $Cr_{1-x}V_x$:
  - ** Factor of two change with $1/R_H \sim (P_c\text{-}P)^{0.50\pm0.02}$
  - ** Strong temperature dependence above T_N
- ✓ Hall coefficient remarkably sensitive to microscopic structure and dynamics of SDW domains (cf. CMR materials?).

R_H a POWERFUL and UNDERUSED TOOL

Universal Relation of T_N (P, x) Obtained from Different Experiments on CrV alloy : Disorder Not Dominant



- × Arajs et al., 1969; Resistivity
- ⊞ White et al., 1986; Thermal expansion
- \+ Komura et al., 1967; Neutron Diffraction
- △ Barnes and Graham. 1965 ; NMR
- ○ Trego and Mackintosh, 1968: Resistivity
- ◆ Yeh et al., 2002 ; Resistivity
- ▲ Pure Cr by McWhan, 1968 : Resistivity
- ● V 2.8% by Rice et al., 1969 ; Resistivity
- ▼ V 1.2% by Rice et al., 1969 ; Resistivity
- ◆ V 3.2% by Lee et al., 2004 ; Resistivity