WS-C Poster

Scaling of the Anomalous Hall effect at finite temperature

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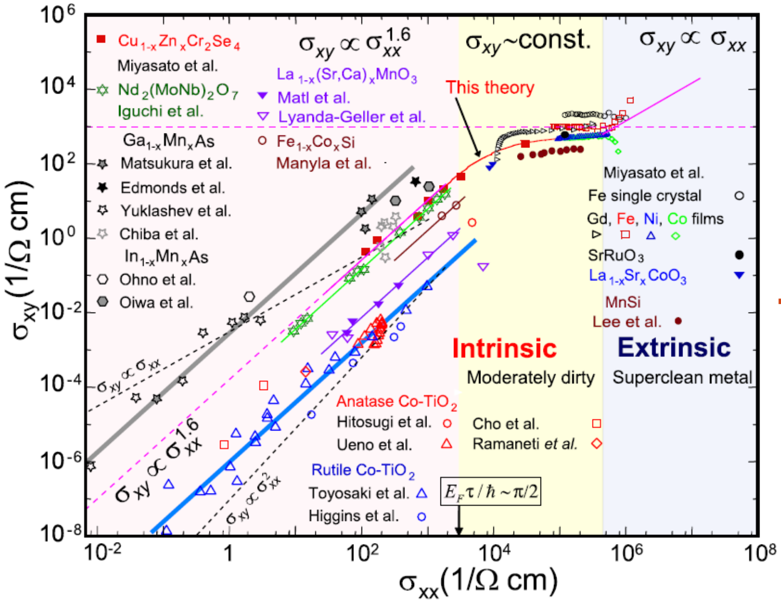
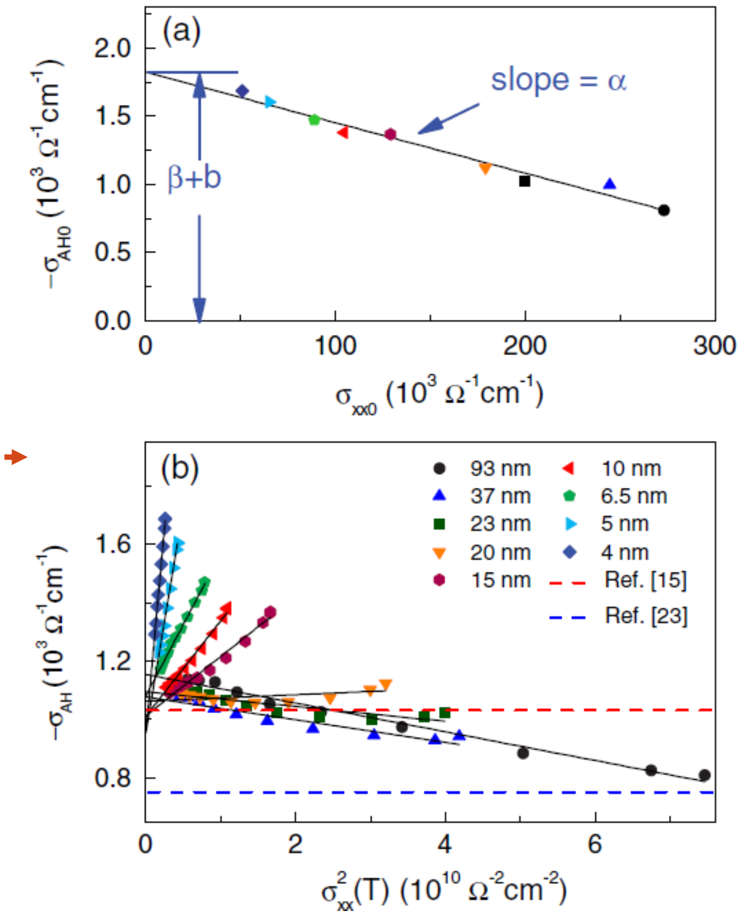
Scaling relation in the AHE

T=0 without inelastic scattering



Onoda *et al.*, PRB**77**, 165103 (2008).
Tian *et al.*, PRL**103**, 087206(2009).

T>0 with inelastic scattering



mechanism	conductivity	resistivity	conductivity	resistivity
intrinsic	$\sigma_{xy} \sim$ const.	$\rho_{xy} \propto \rho_{xx}^2$	$\sigma_{xy} \sim$ const.	$\rho_{xy} \propto \rho_{xx}^2(T)$
skew	$\sigma_{xy} \propto \sigma_{xx}$	$\rho_{xy} \propto \rho_{xx}$	$\sigma_{xy} \propto \sigma_{xx}^2/\sigma_{xx0}$	$\rho_{xy} \propto \rho_{xx0}$
side jump	$\sigma_{xy} \sim$ const.	$\rho_{xy} \propto \rho_{xx}^2$	$\sigma_{xy} \propto \sigma_{xx}^2/\sigma_{xx0}^2$	$\rho_{xy} \propto \rho_{xx0}^2$

Model and Method

$$H = -t_0 \sum_{\langle ij \rangle} c_i^\dagger c_j + \epsilon_1 \sum_i^{\text{random}} s_i^\dagger s_i - V_1 \sum_i^{\text{random}} c_i^\dagger s_i + \text{H.c.}$$

$$+ \epsilon_2 \sum_i^{\text{random}} p_i^\dagger p_i - V_2 \sum_{\langle ij \rangle}^{\text{random}} e^{-i\theta_{ij}} c_i^\dagger p_j + \text{H.c.}$$

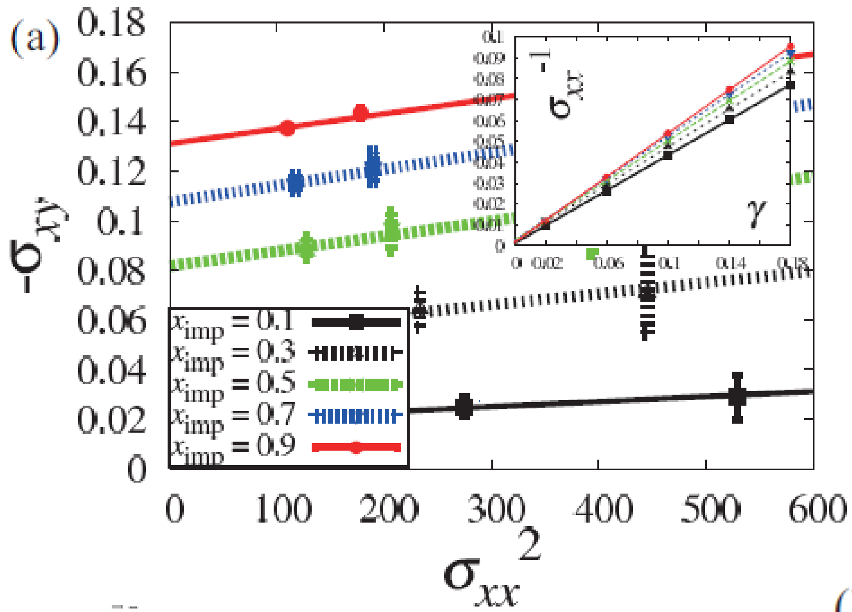
$p^x - ip^y$

Interference between *s*+*p* → skew scattering
Hybridization to p^x-ip^y → intrinsic mechanism

$$\sigma_{\mu\nu} = \frac{2\pi}{iN_s} \sum_{mn} \frac{f(E_m) - f(E_n)}{E_m - E_n} \frac{\langle m|J^\mu|n\rangle\langle n|J^\nu|m\rangle}{E_m - E_n + i\gamma}$$

The inelastic scattering phenomenologically introduced as
-ImΣ of electrons due to the electron correlation or phonons

Analysis



Intrinsic and extrinsic

$$-\sigma_{xy}(T,\gamma) = \rho^{\rm ext}_{xy0}(T)\sigma^2_{xx}(T,\gamma) + b(T)$$

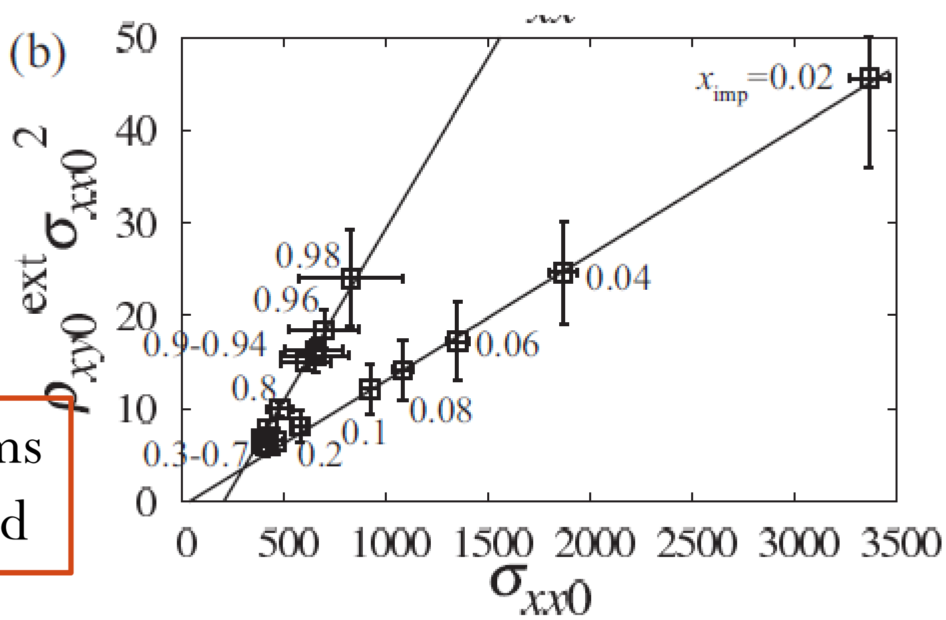
$$\sigma^{-1}_{xx}(T,\gamma) = \sigma^{-1}_{xx0}(T)(\gamma/\gamma_0 + 1)$$

The extrinsic mechanisms are rapidly suppressed by the inelastic scattering.

Skew and side jump

$$\rho^{\rm ext}_{xy0}(T) = \alpha(T)/\sigma_{xx0}(T) + \beta(T)/\sigma^2_{xx0}(T)$$

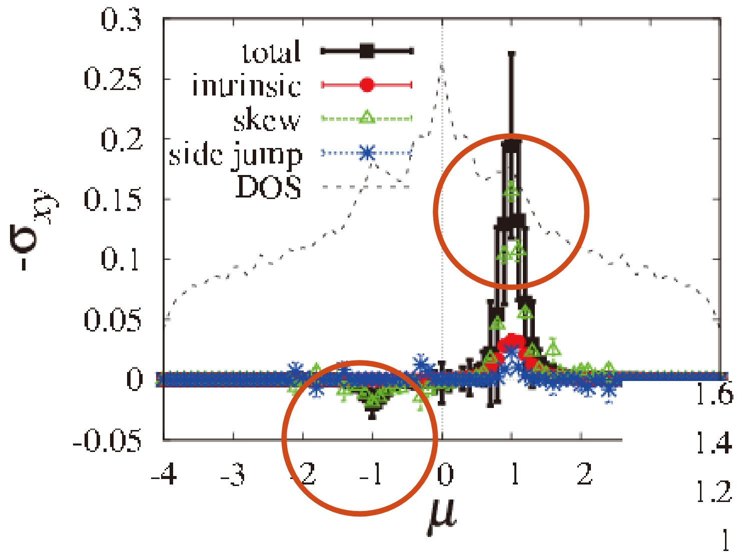
Separation of the extrinsic mechanisms are possible when band is well-defined



Separation of three mechanisms

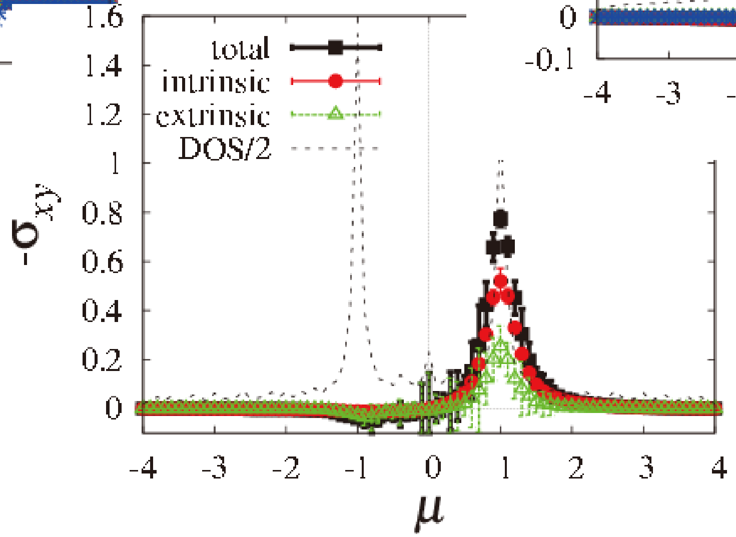
$$-\sigma_{xy}(T,\gamma) = \boxed{\alpha(T)\sigma_{xx}^2(T,\gamma)/\sigma_{xx0}(T)} + \boxed{\beta(T)\sigma_{xx}^2(T,\gamma)/\sigma_{xx0}^2(T)} + \boxed{b(T)}$$

$x_{\text{imp}} = 0.02$

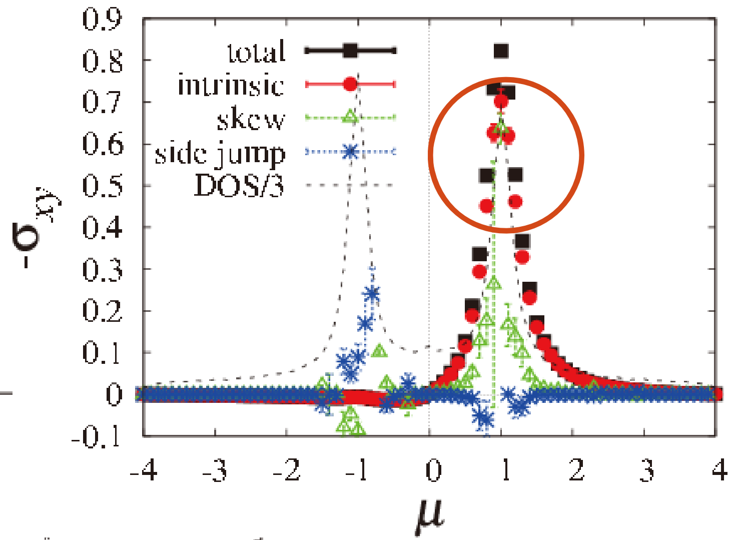


$T = \gamma = 0.06$

$x_{\text{imp}} = 0.50$



$x_{\text{imp}} = 0.98$



The extrinsic mechanisms can be decomposed only in dilute and dense regimes

Summary

- We numerically studied the effect of the inelastic scattering at finite temperature in the AHE.
- We found in the simple model
  1. A new scaling relation holds
  2. The extrinsic mechanisms are rapidly suppressed by the inelastic scattering.
  3. The side jump contribution is smaller than the others.
  4. The intrinsic mechanism depends on temperature on the resonance condition of monopole (cf. Ni thin films)
- We have to consider in the future
  - ω-dependence of the self energy due to phonons
  - Inelastic scattering on magnons