The Hall Number, Optical Sum Rule and Carrier Density for the t-t'-J model

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DOE

$$R_H \sim 1/q_e x_{eff}$$

Hall Number

Fermi Surface

Luttinger count

x_luttinger

Naïve Theory says all x are equal

Optical conductivity

$$\int_0^\infty \sigma(\omega)\, d\omega \sim x_{eff}$$

Chemical x

Various stages of naivety are best left unstated!!

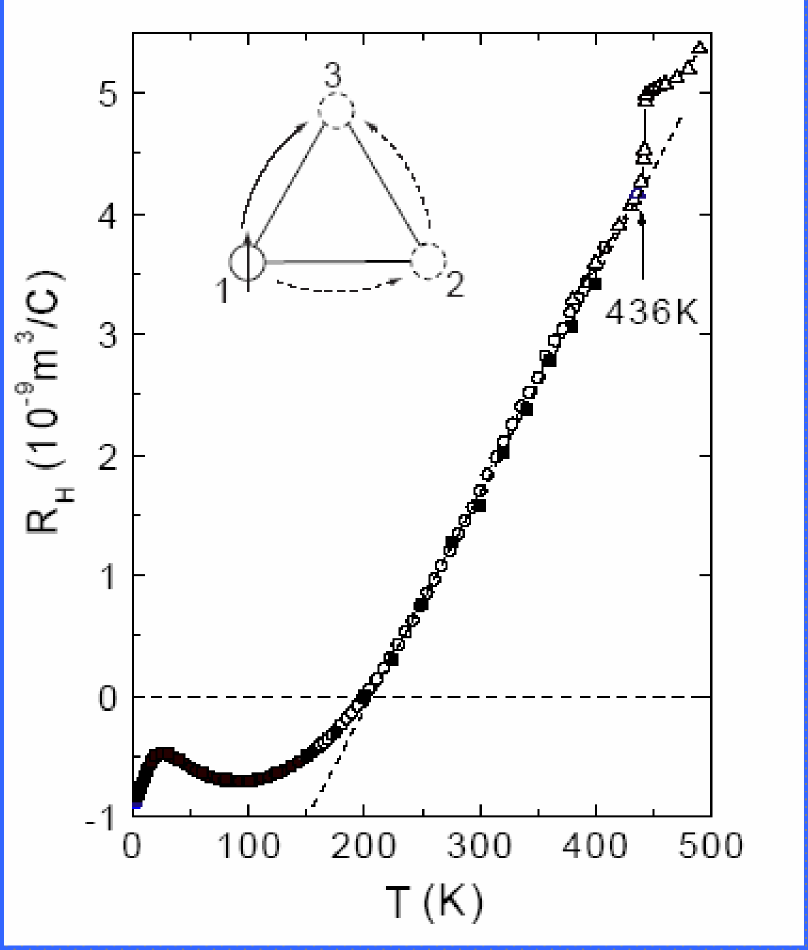
In reality, none of them really match

$$\mathrm{Na}_{.68}CoO_2$$

How bad can it get?

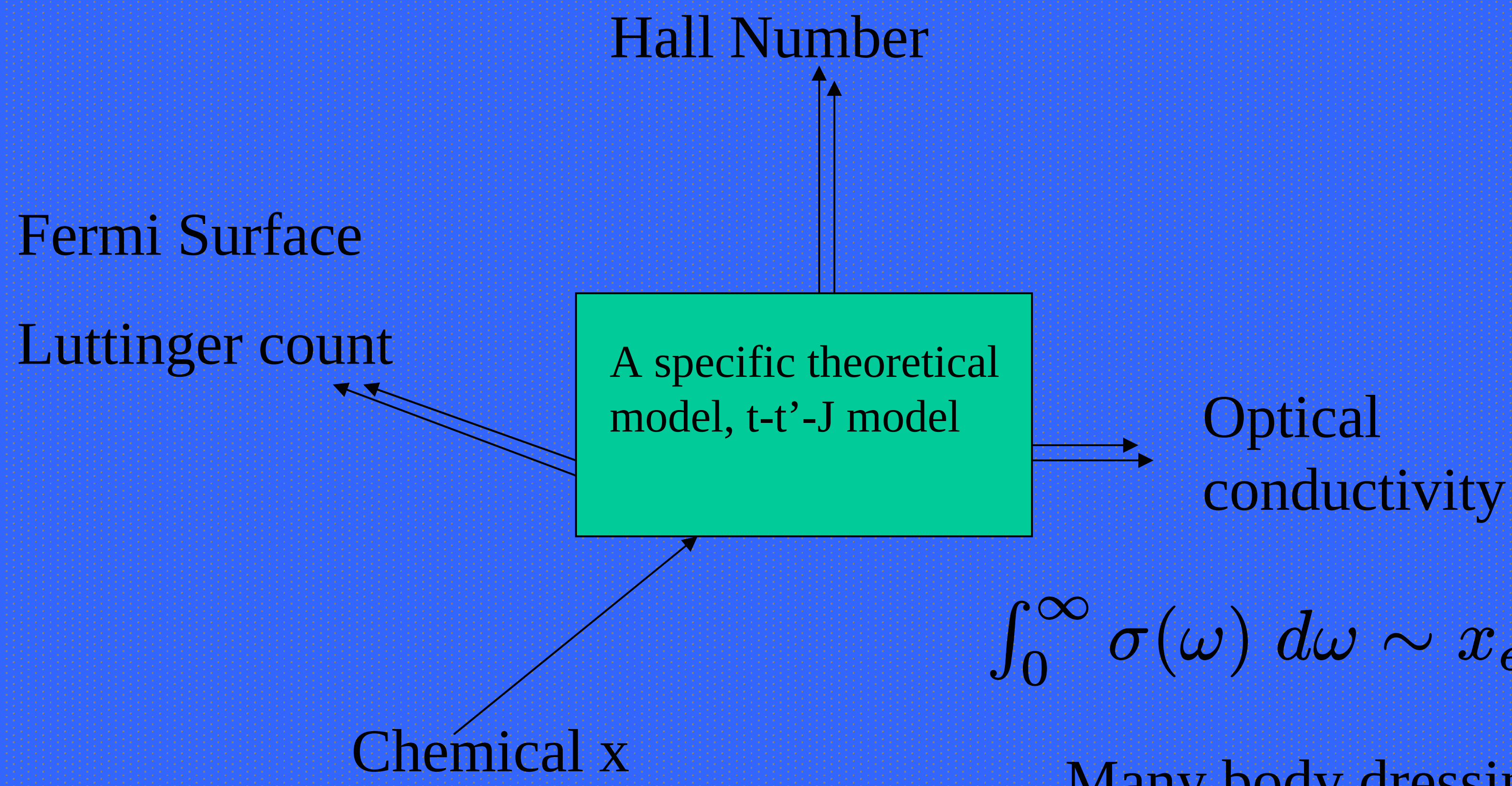
Princeton Data 2004

Consider recently found sodium cobaltate, a low Tc system but strongly correlated and on triangular lattice



Hmmm!

$$R_H \sim 1/q_e x_{eff}$$



$$\int_0^\infty \sigma(\omega)\, d\omega \sim x_{eff}$$

Input: Bare parameters t,t',J,x

+

Many body dressing (renormalization)

Strong correlation physics makes all calculations HARD

Early effort to understand Hall constant in correlated matter:

S S, Boris Shraiman and Rajiv Singh, Phys Rev Letts (1993)

Introduced object

$$R_H^* = \lim_{B\to 0} \lim_{\omega\to\infty} \rho_{xy}(\omega)/B$$

- **Easier to calculate than transport Hall constant**
- **Captures Mott Hubbard physics to large extent**

Motivation: **Drude theory** has well known feature

$$\sigma_{xy}(\omega) = \sigma_{xy}(0)/(1+i\omega\tau)^2$$

$$\sigma_{xx}(\omega) = \sigma_{xx}(0)/(1+i\omega\tau)$$

Hence **relaxation time cancels out in the Hall resistivity**

$$\rho_{xy}(\omega) = \frac{\sigma_{xy}}{(\sigma_{xx})^2}$$

$$R_H^* = \frac{-iN_s v}{B\hbar} \frac{\langle [J^x, J^y] \rangle}{\langle \tau^{xx} \rangle^2}$$

$\omega > J$ rather than $\omega > U$!!

- Very useful formula since
  - Captures Lower Hubbard Band physics. This is achieved by using the Gutzwiller projected fermi operators in defining J's
  - Exact in the limit of simple dynamics (e.g few frequencies involved), as in the Boltzmann eqn approach.
  - Can compute in various ways for all temperatures (exact diagonalization, high T expansion etc…..)
  - We have successfully removed the dissipational aspect of Hall constant from this object, and retained the correlations aspect.
  - Very good description of t-J model, not too useful for Hubbard model.
  - This asymptotic formula usually requires ω to be larger than J

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Faraday Rotation and the Hall Constant in Strongly Correlated Fermi Systems

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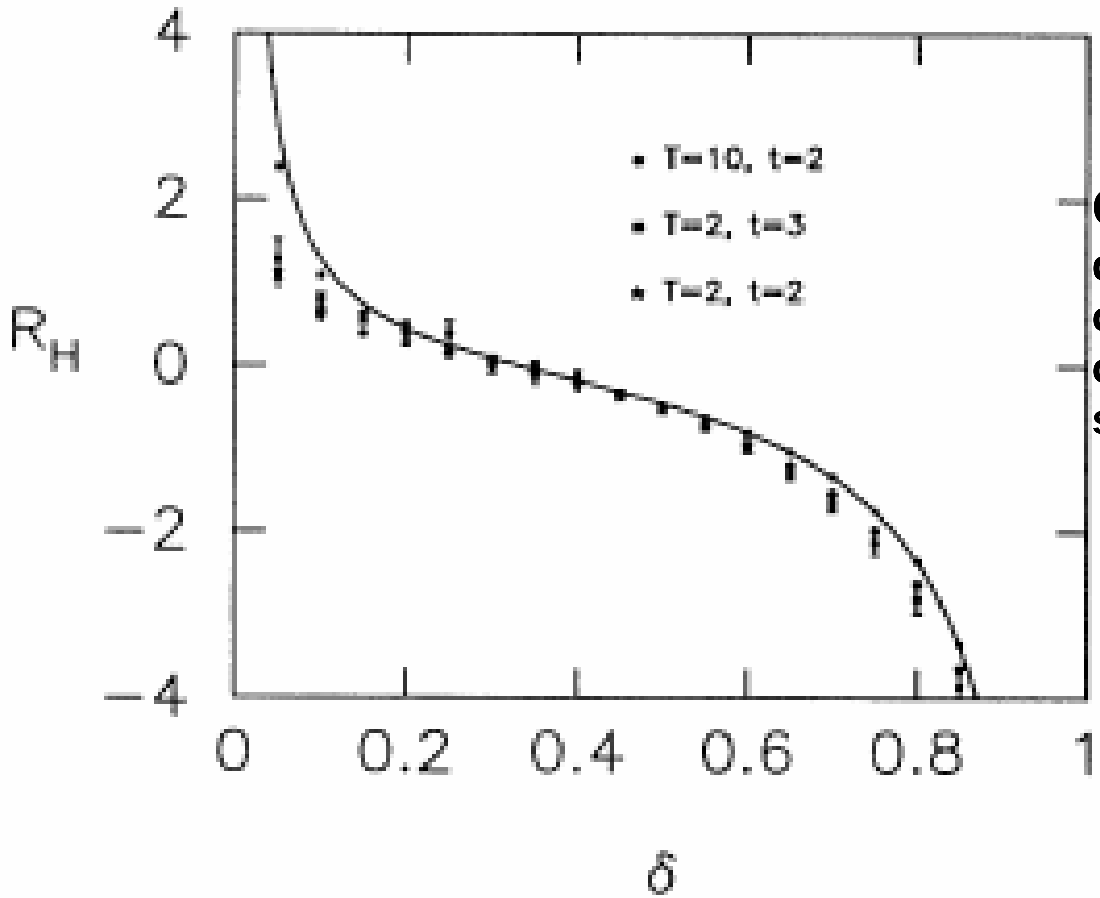

Comparison with data for LSCO showing change of sign of Hall constant at delta=.33 for squar e lattice

RECENT REVIVAL OF THESE IDEAS Esp NCO

Results from this formalism:

PRL 97, 226402 (2006) PHYSICAL REVIEW LETTERS week ending 1 DECEMBER 2006

Strong Correlations Produce the Curie-Weiss Phase of Na_xCoO_2

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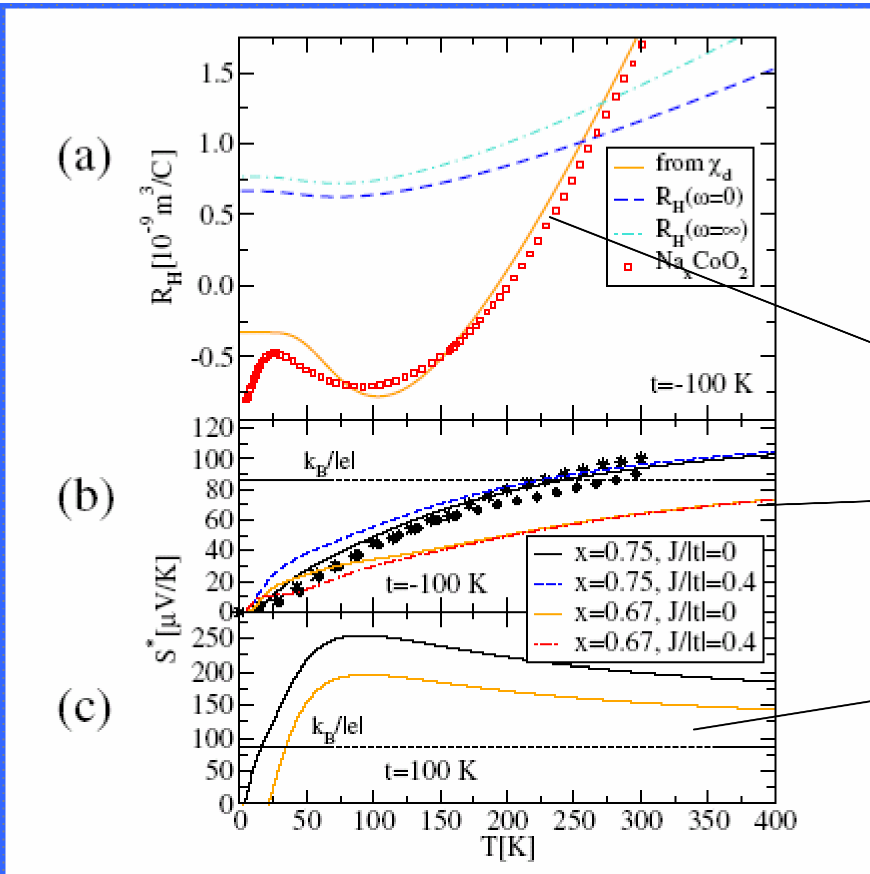


Comparision with data on absolute scale!

Prediction for t>0 material

High frequency limits that are feasible and sensible similar to R*

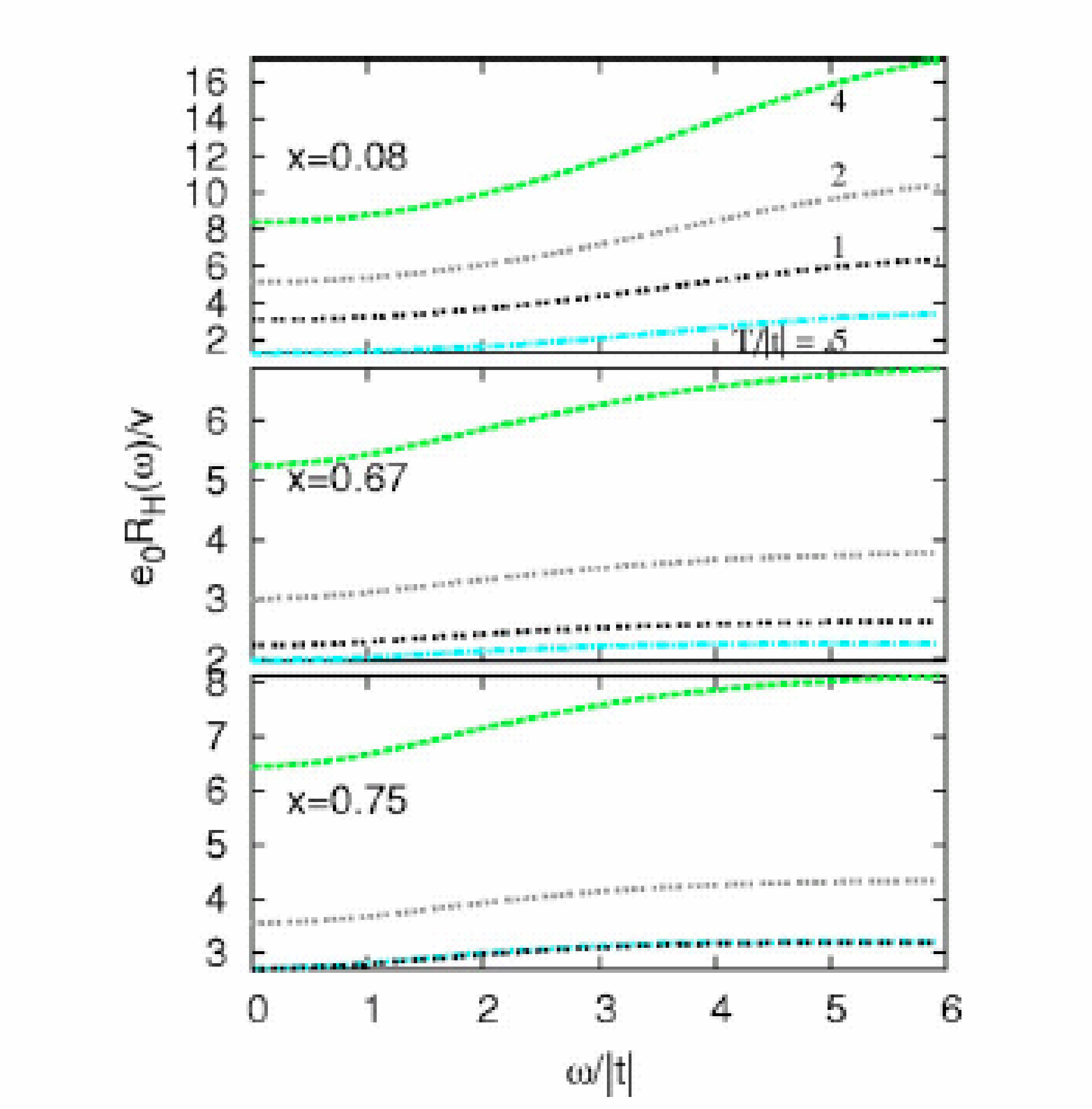
$$\mathbf{L}^* = \frac{\langle \Theta^{xx} \rangle}{T^2 \langle \tau^{xx} \rangle} \quad (1)$$

$$\mathbf{Z}^* T = \frac{\langle \Phi^{xx} \rangle^2}{\langle \Theta^{xx} \rangle \langle \tau^{xx} \rangle}. \quad (2)$$

$$S^* = \frac{\langle \Phi^{xx} \rangle}{T \langle \tau^{xx} \rangle}. \quad (3)$$

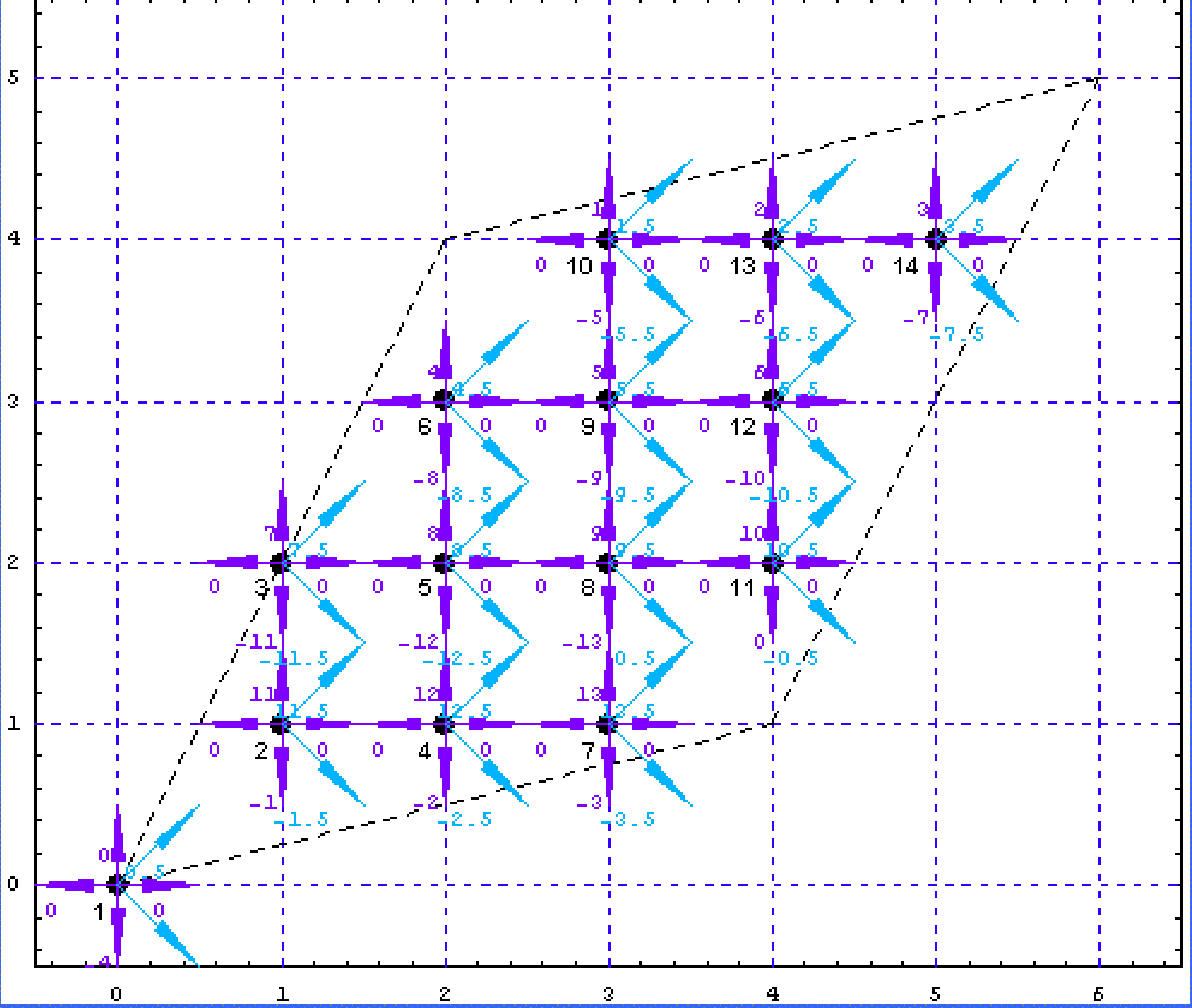
Hence for any model system, armed with these three operators, we can compute the Lorentz ratio, the thermopower and the thermoelectric figure of merit!

Sriram Shastry, Phys Rev B (2006)Long paper



What about frequency dependence? Calculations possible on finite clusters, using complete spectrum!!

Large scale numerical computations undertaken recently by us.



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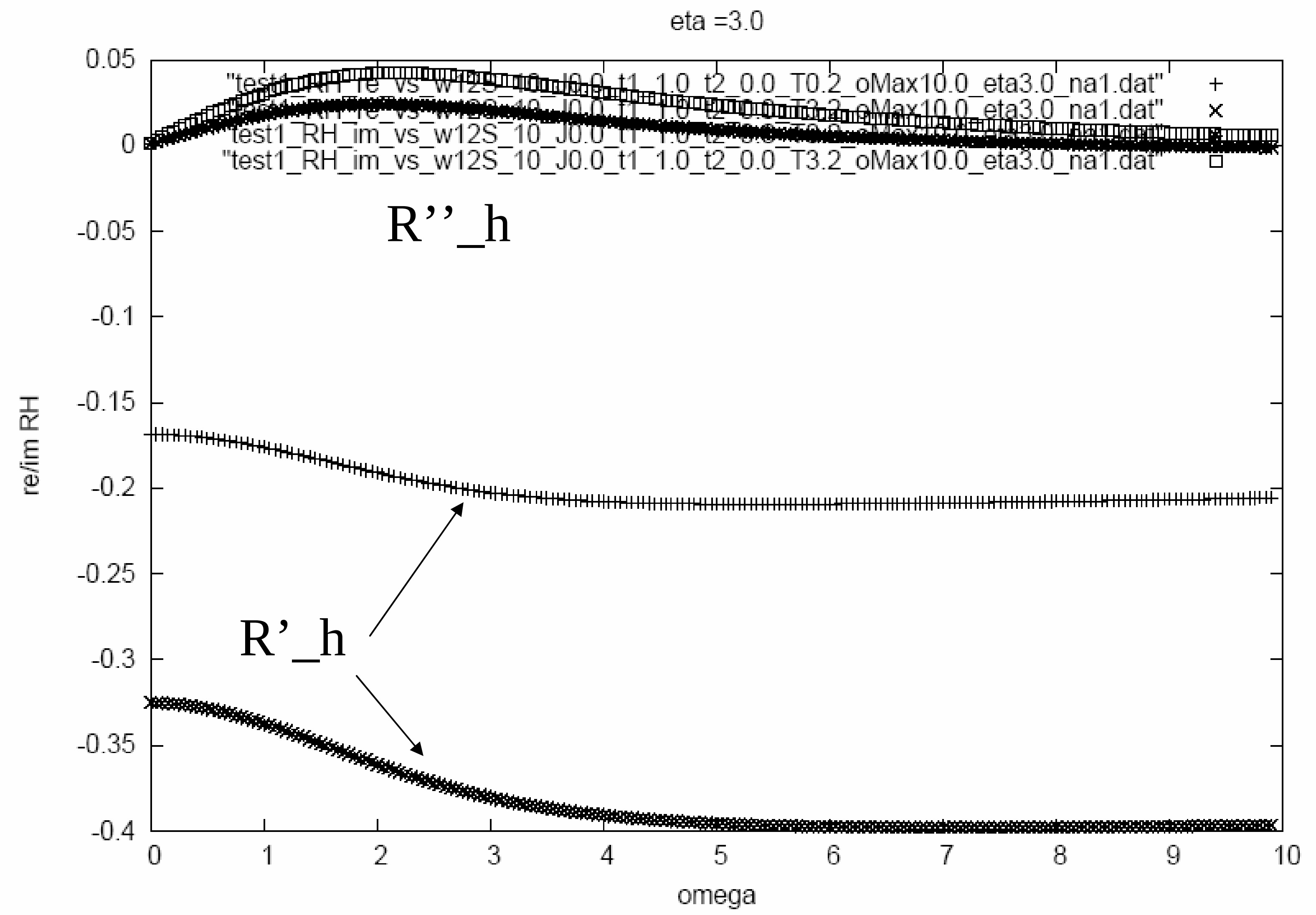
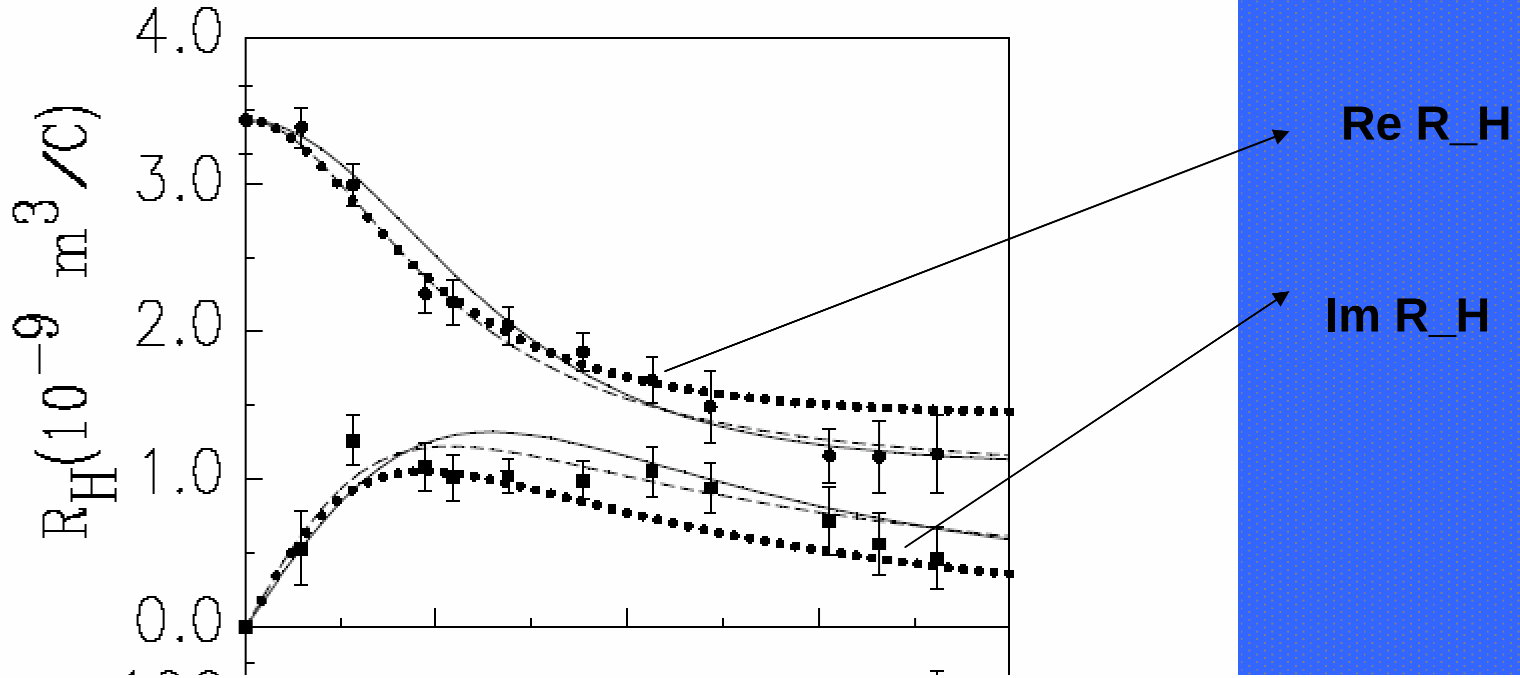
$$R_H/_{Transport} = R_H^* + \int_0^\infty \Im m[R_H(\omega)]/\omega \;\; d\omega/\pi$$





Phenomenological interpretations of the ac Hall effect in the normal state of $YBa_2Cu_3O_7$

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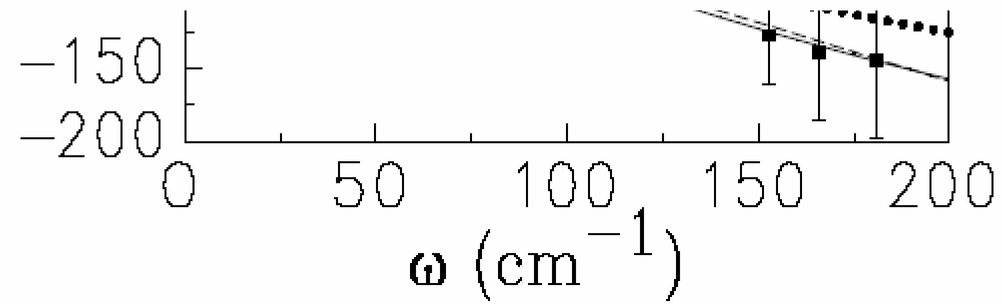
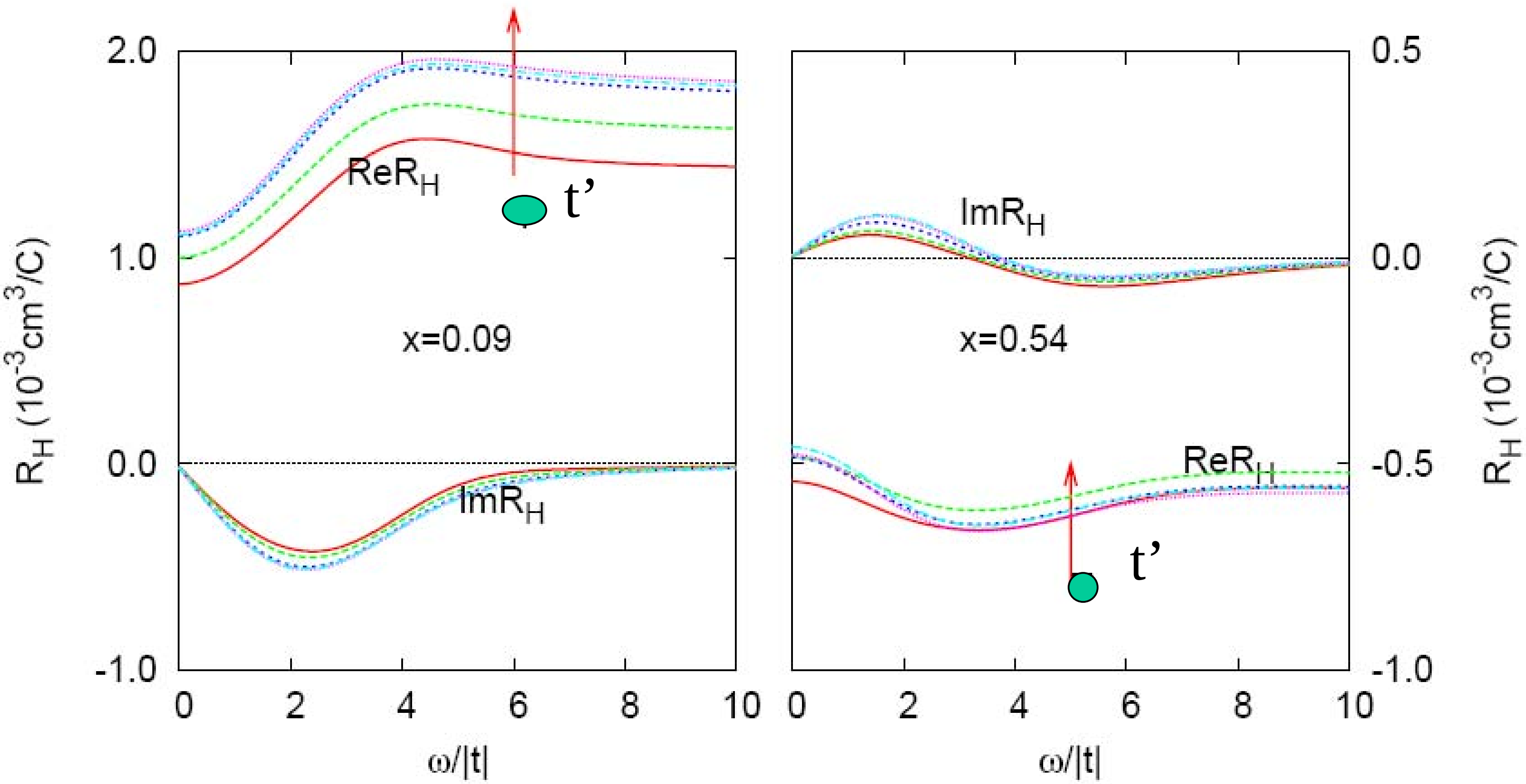
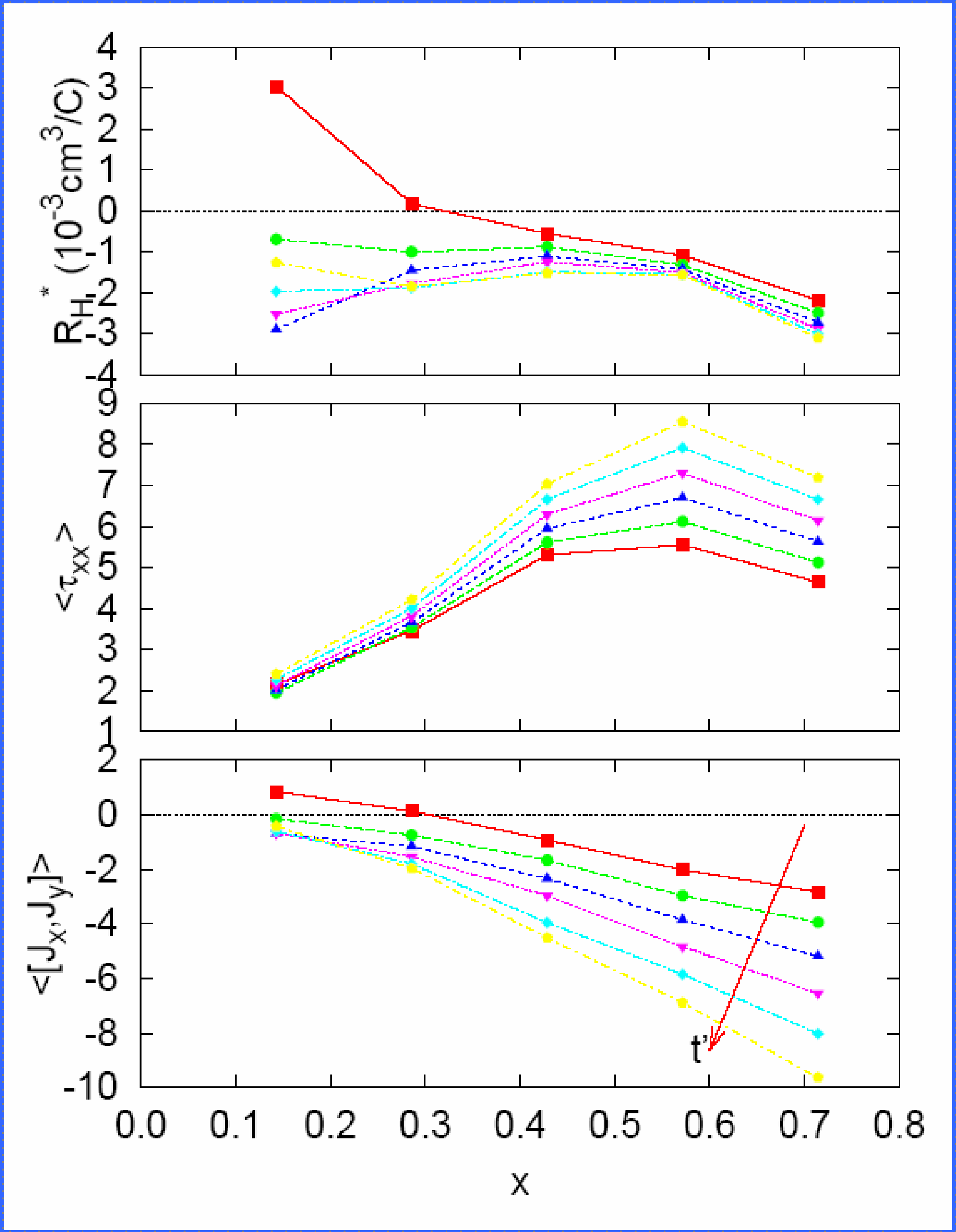
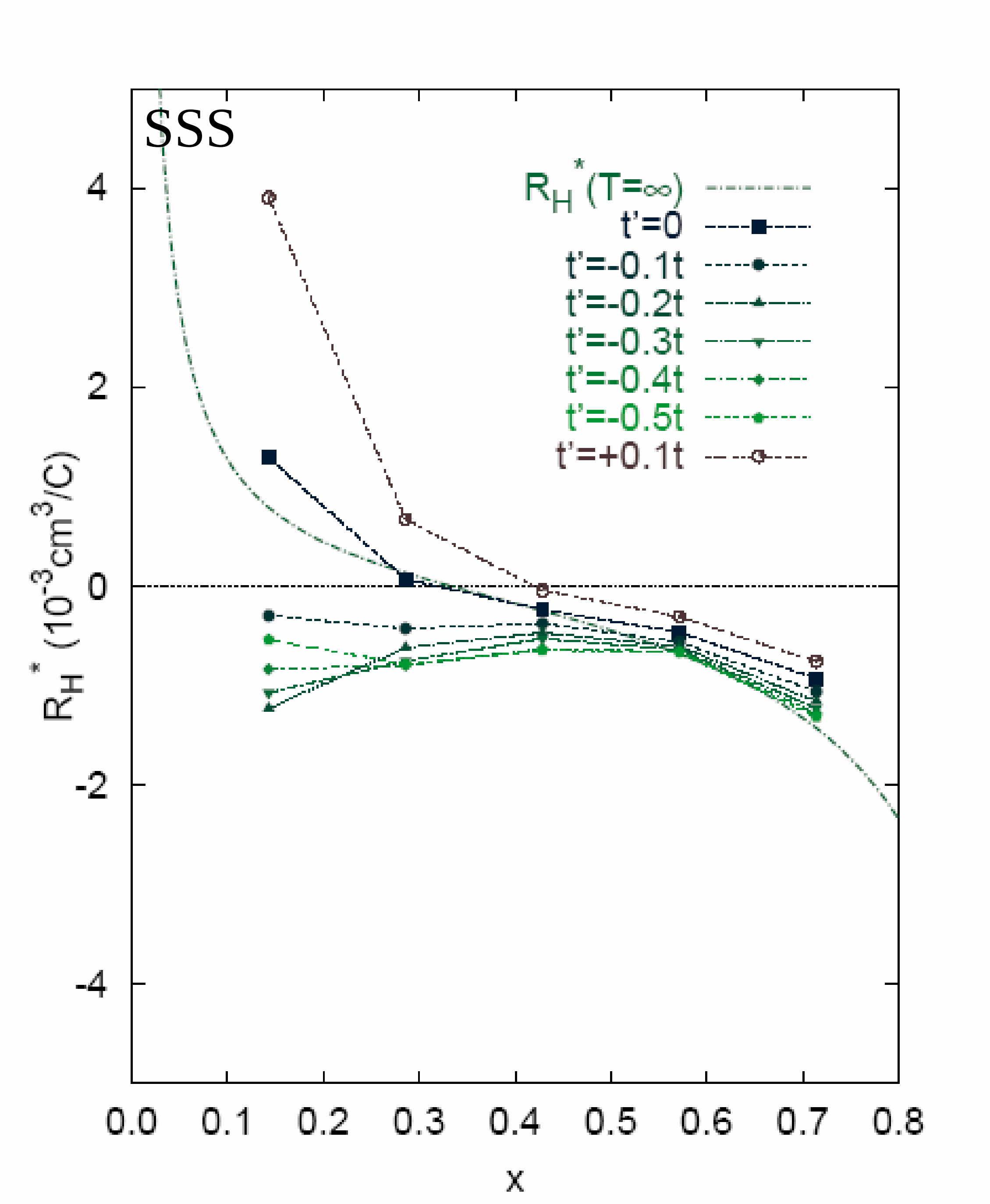


T-t'-J model, typical frequency dependence is very small . This is very encouraging for the program of x_eff

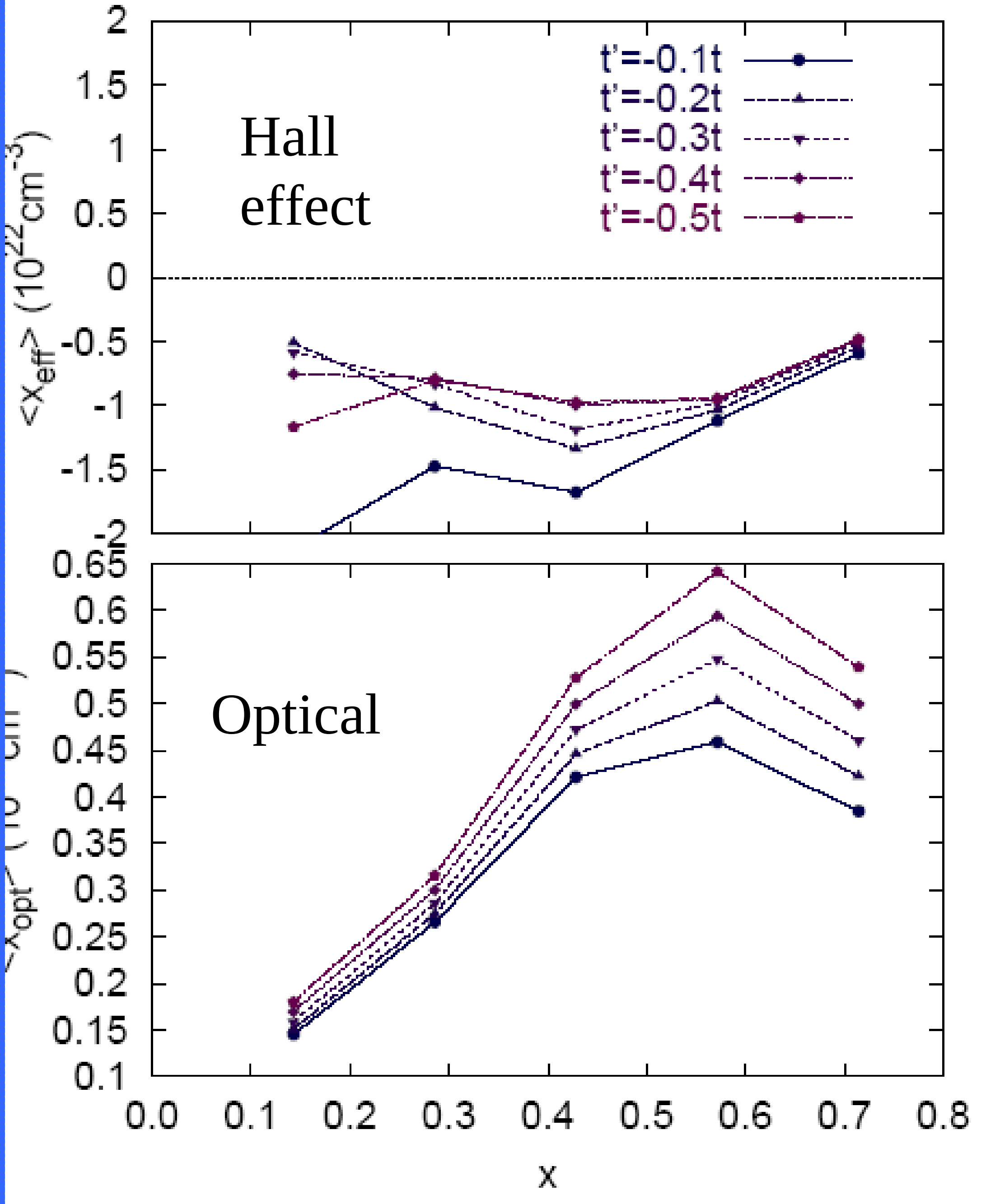




Change in sign of Hall constant is severely modified by t'. Interference effect, and is ascribable to electronic frustration!!(i.e. sign of hopping)



Remarkably, a small t' of either sign shifts the zero crossing of Hall constant significantly!



Optical x_eff is much smoother, and tracks roughly the chemical x.

•Preliminary results for small clusters give some insights

•X_eff from optics is a good bet, if we can set up a table where the MB renormalizations are computed.

•Hall constant is very sensitive to t' the second nighbour frustrating hop. Luckily, our techniques are improving, and we hope to get reliable results for the models, that can be tested against the commonly held parameters and data in High Tc systems. Time scale 1 to 2 years!

•Fermi surface is much harder for us…work in progress