



SMR.959 - 40

**MINIWORKSHOP ON STRONG ELECTRON CORRELATIONS**  
**"Disorder and Interaction in Quantum Systems**  
**and Their Classical Analogs"**

(1 - 19 July 1996)

---

**"Theory of Magnetic Raman Scattering in the**  
**Normal State of High- $T_c$  Superconductors"**

**Dirk K. Morr**  
**University of Wisconsin-Madison**  
**Department of Physics**  
**Wisconsin, MA 53706**  
**U.S.A.**

---

***These are preliminary lecture notes, intended only for distribution to participants.***

# Theory of Magnetic Raman Scattering in the Normal State of High- $T_c$ Superconductors

Dirk K. Morr

Department of Physics,  
University of Wisconsin-Madison

A. Chubukov, UW-Madison  
G. Blumberg, UIUC  
A. Kampf, University of Cologne

*PRB*, July 1<sup>st</sup> '96

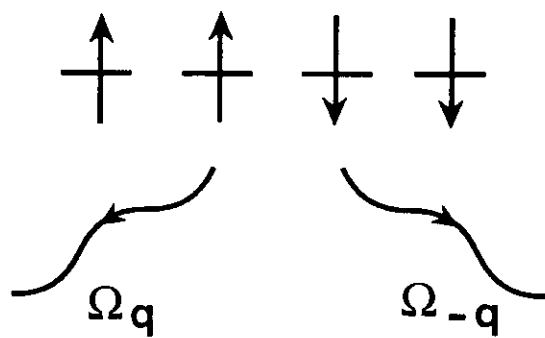
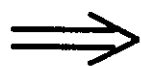
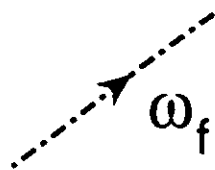
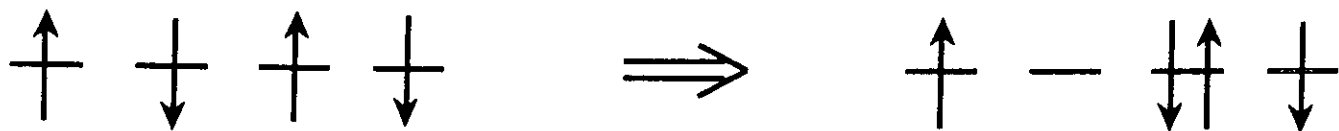
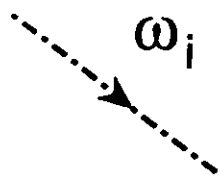
# Introduction

Why are magnetic Raman scattering (MRS) experiments important?

- It is widely believed that the pairing mechanism in high- $T_c$  superconductors is mainly due to the exchange of antiferromagnetic fluctuations.
- Raman scattering probes antiferromagnetism and can provide important input parameters for theoretical models (e.g.  $J_{1,2}, \Delta$ ).

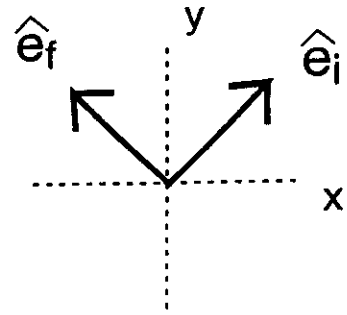
What is the current status of experimental work?

- Raman signals were not only found in the insulating parent compounds (e.g. in  $La_2CuO_4$  and  $Sr_2CuO_2Cl_2$ ) but also in doped systems like  $YBa_2Cu_3O_{6+x}$  up to  $x = 0.9$
- the dominant feature of the Raman signal is a pronounced "two-magnon" peak in  $B_{1g}$ -geometry

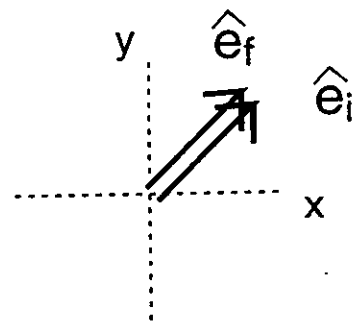


# Scattering Geometries

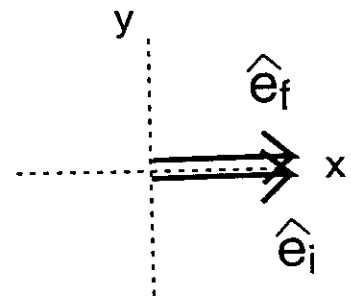
$$x' y' = B_{1g} + A_{2g}$$



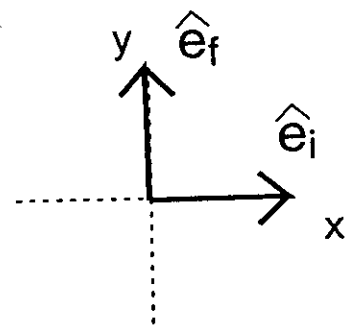
$$x' x' = A_{1g} + B_{2g}$$



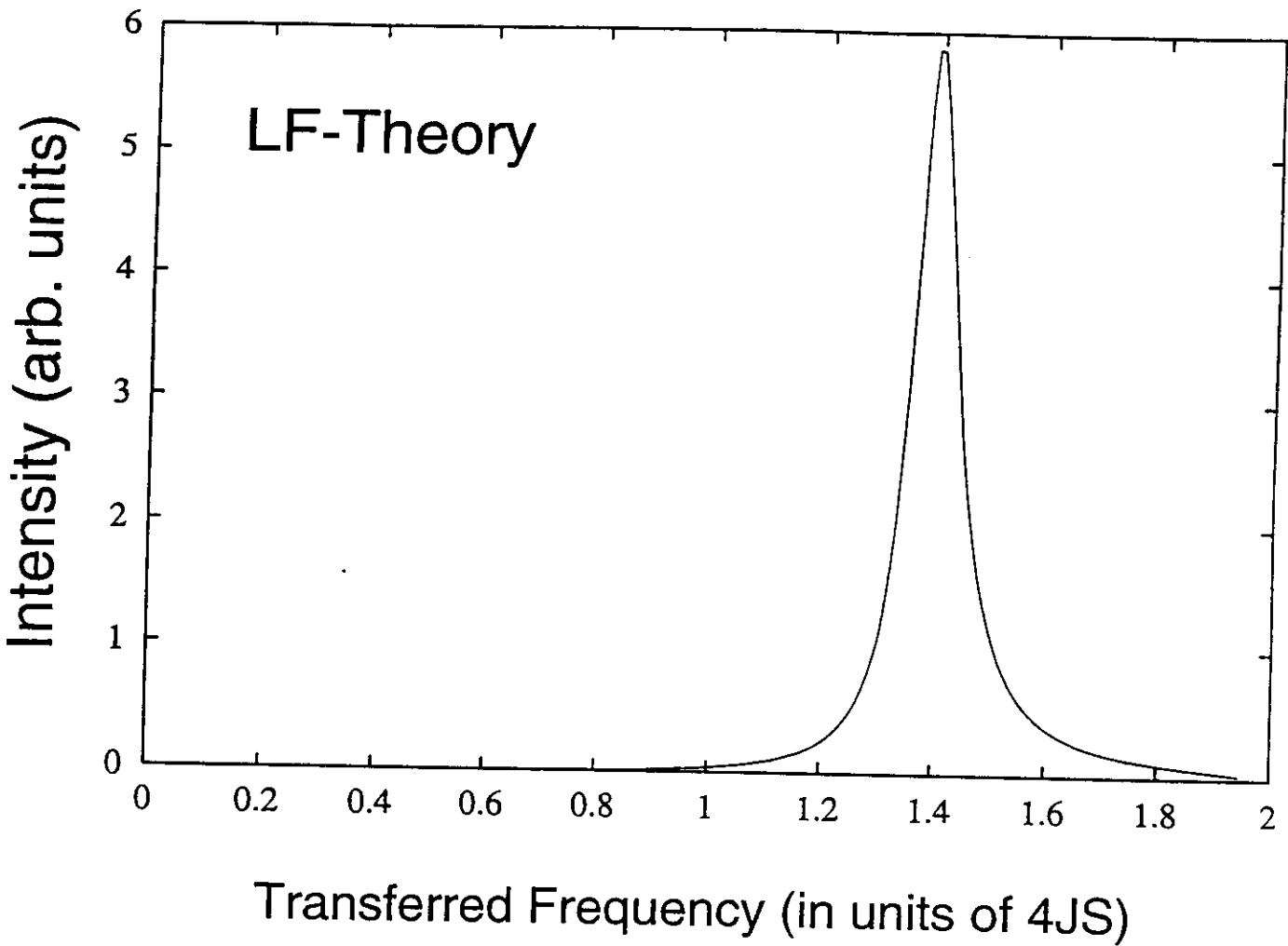
$$x x = A_{1g} + B_{1g}$$



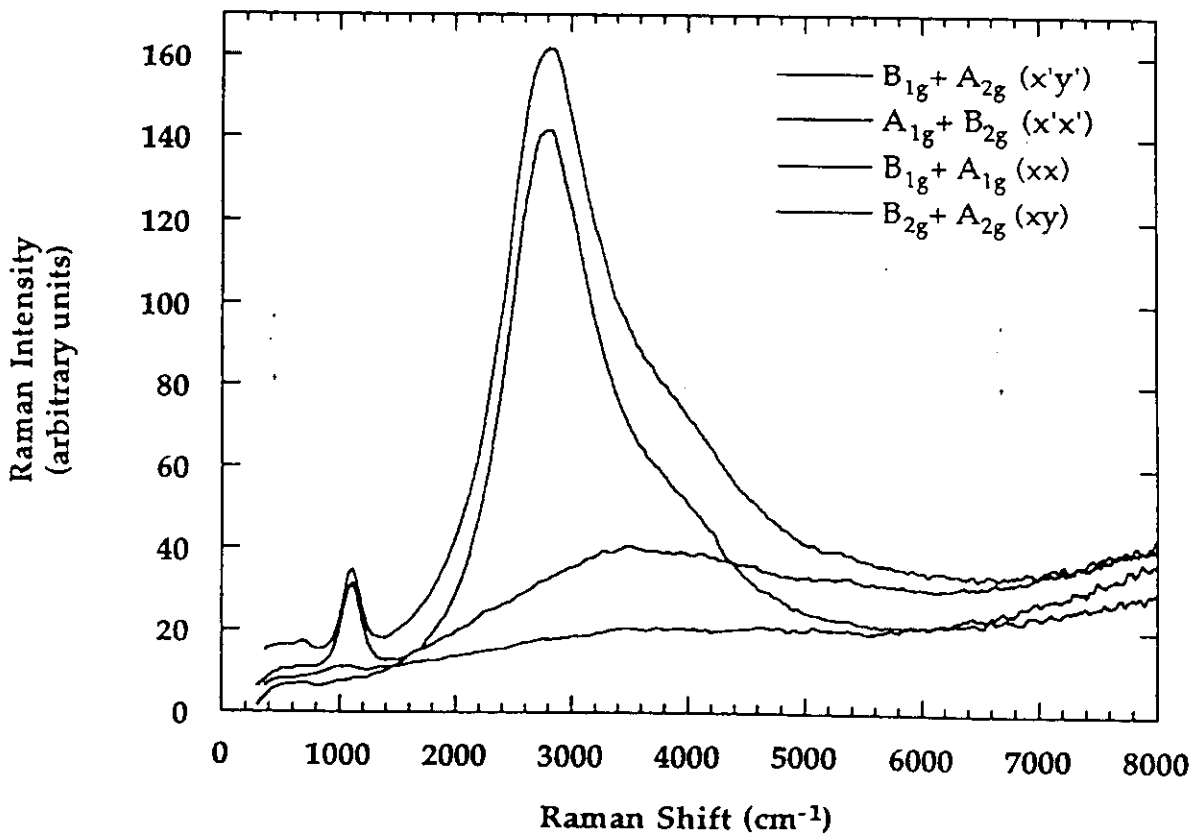
$$x y = A_{2g} + B_{2g}$$

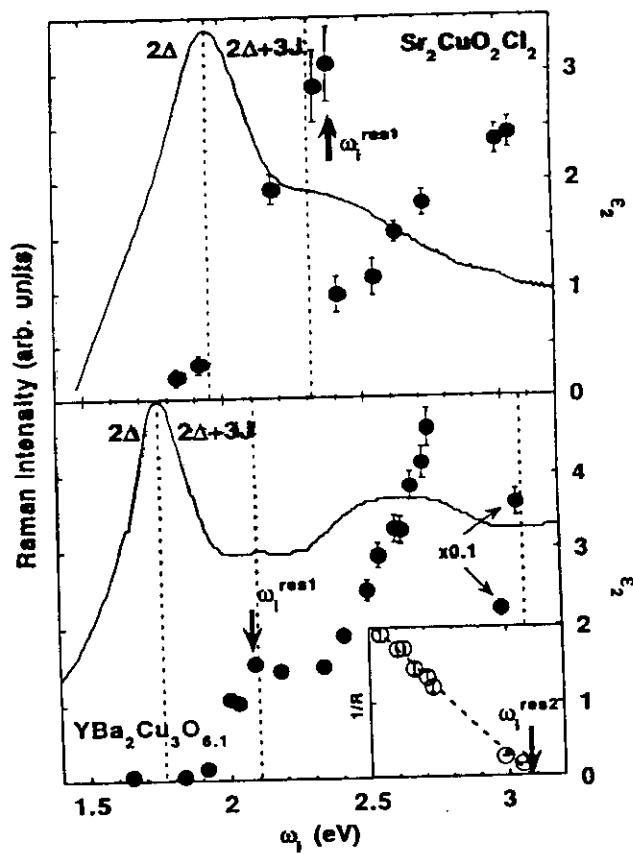
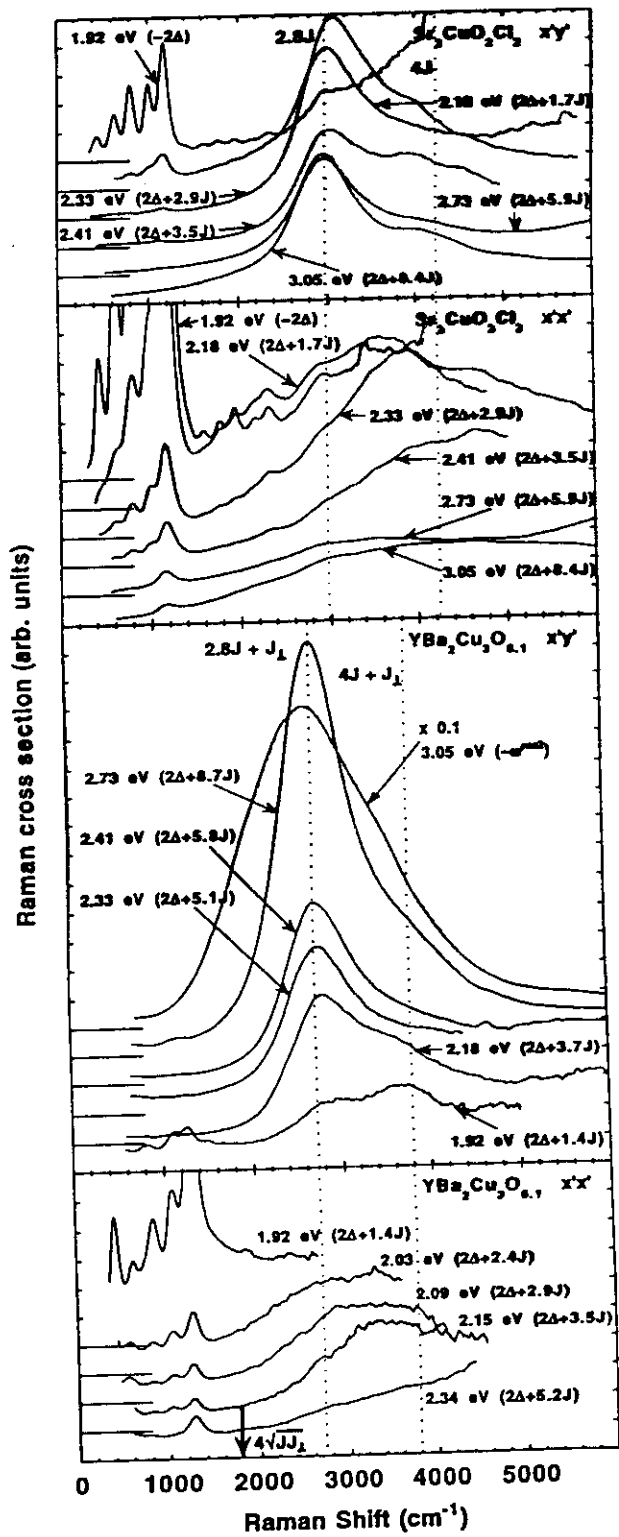


# B1g geometry



$Sr_2CuO_2Cl_2$ ;  $T=300K$ ;  $4545.2\text{\AA}$





In this talk I will focus on the following questions:

1. How can one explain the change in the shape of the Raman signal and the strong  $\omega_i$ -dependence of the two-magnon peak height (TMPH) in the resonant regime.
2. What is the effect of the double-layer structure on the Raman signal ? Can  $J_2$  be extracted from Raman experiments ?

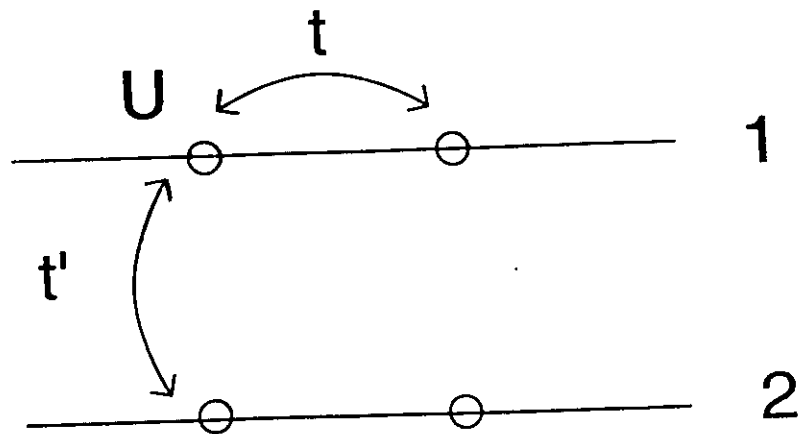
## The Formalism

The Raman scattering intensity is given by the lowest order Golden Rule as

$$I(\omega_{in}, \omega_{in} - \omega_{out}) = \alpha \sum_{i,f} | \langle f | M_R | i \rangle |^2 \delta(\hbar\omega_{in} - \hbar\omega_{out} + \epsilon_i - \epsilon_f)$$

We use the SDW formalism to calculate the matrix element in a diagrammatic language.

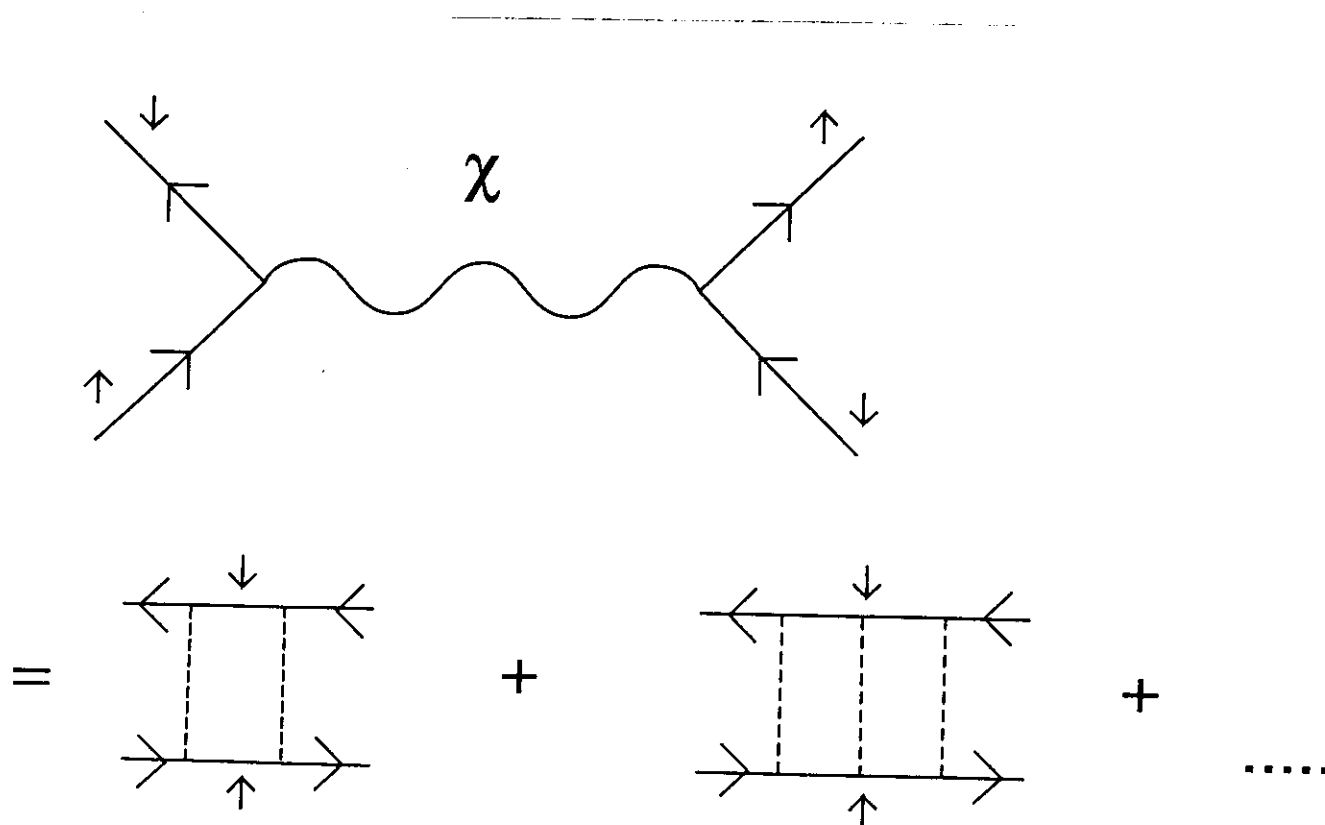
The  $CuO_2$  layers are represented by a single/double layer quantum antiferromagnet with  $S = 1/2$  on a square lattice which is described by the Hubbard Hamiltonian ( $t \ll U$ ).



For the matrix element one has to compute:

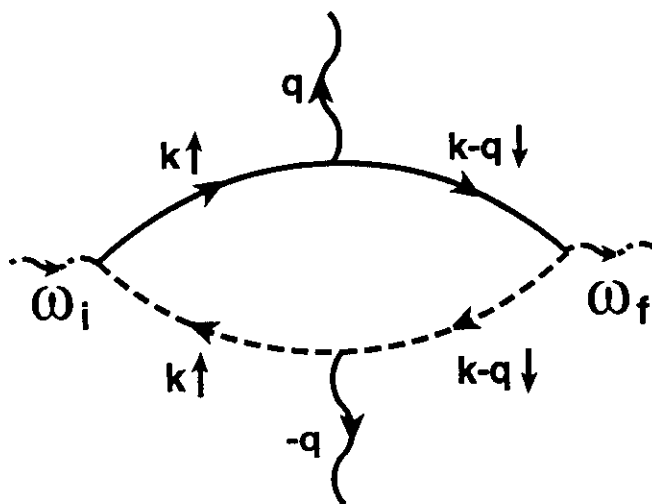
1. the excitation spectrum of the fermionic quasiparticles
2. the interaction vertex between the quasiparticles and the incoming and outgoing light
3. the excitation spectrum of the magnons
4. the interaction vertex between the quasiparticles and the magnons

for example:



## The resonant regime

In this case  $\omega_i - 2\Delta \sim O(J_1)$  the dominant contribution to  $M_R$  is given by



and we obtain

$$M_R \propto \sum'_k \frac{\left(\frac{\partial \epsilon_k}{\partial k} \hat{e}_i\right) \left(\frac{\partial \epsilon_{k-q}}{\partial k} \hat{e}_f\right) [\mu_q \epsilon_{k-q} - \lambda_q \epsilon_k]^2}{(\omega_i - 2E_k)(\omega_i - \omega_f - E_k - E_{k-q})(\omega_f - 2E_{k-q})}$$

which is the so-called triple resonance diagram.

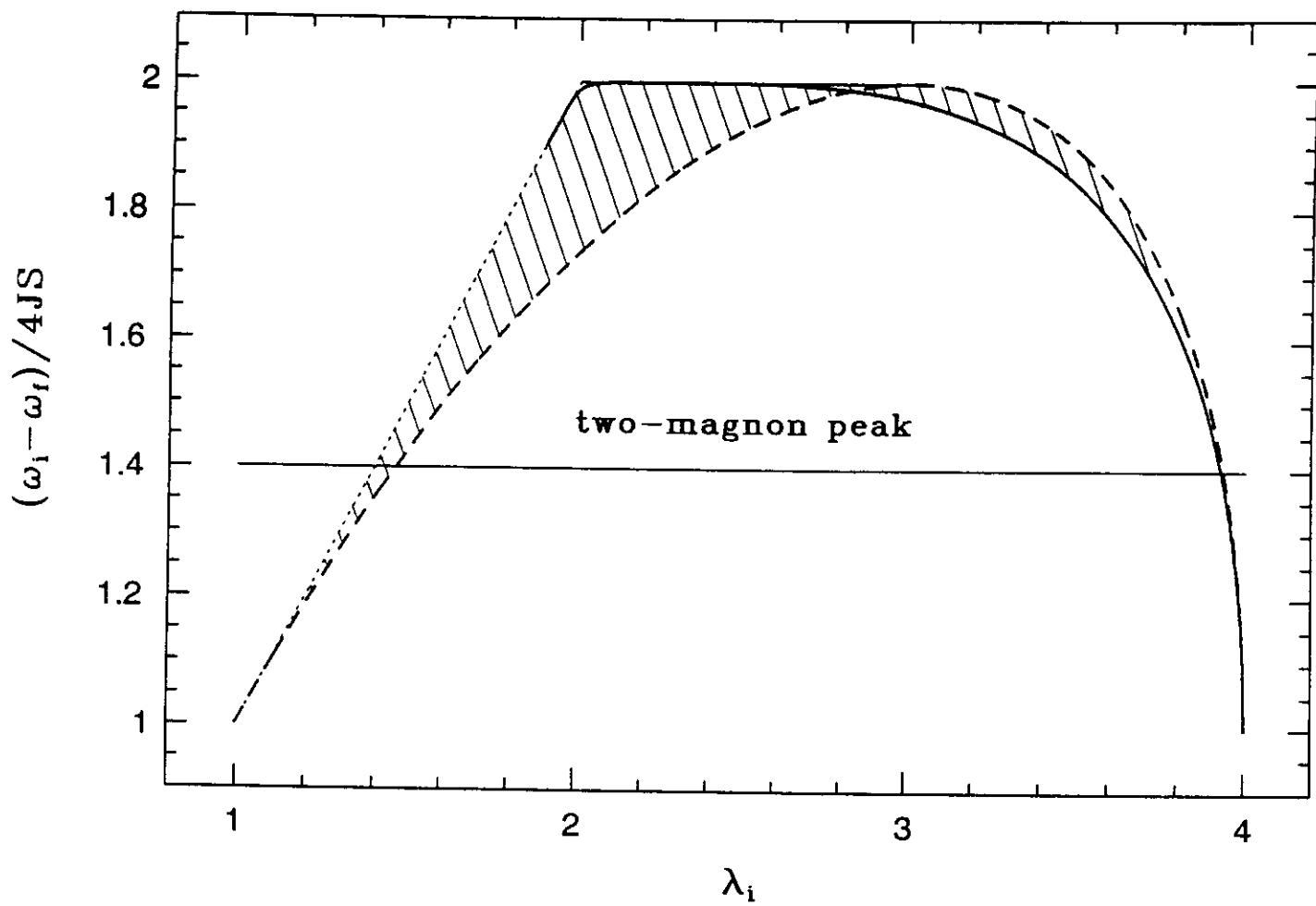
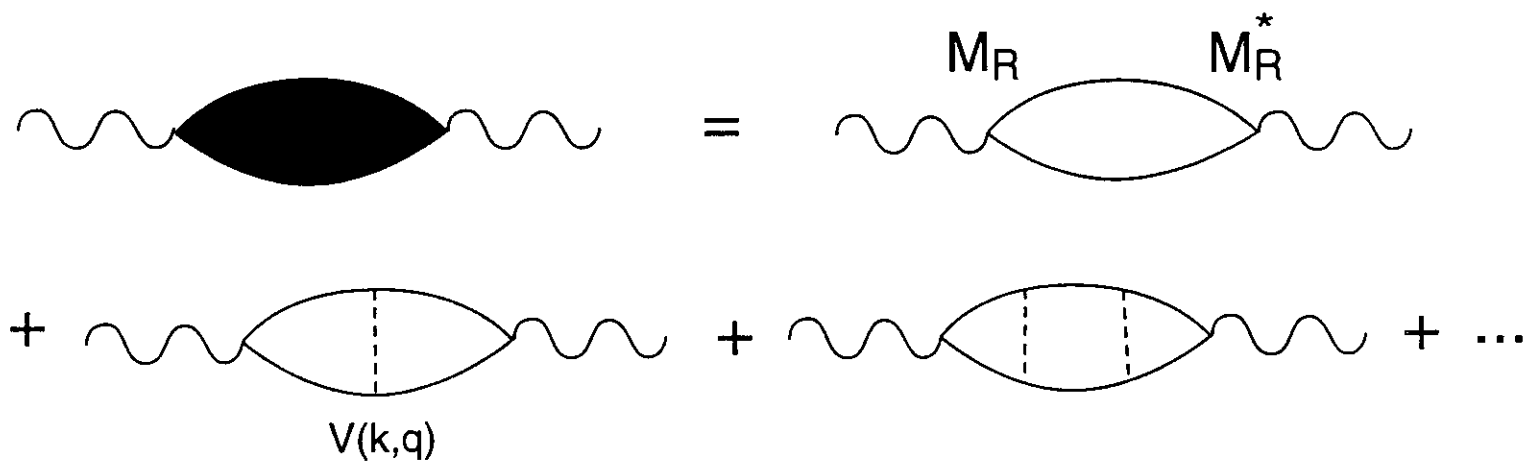


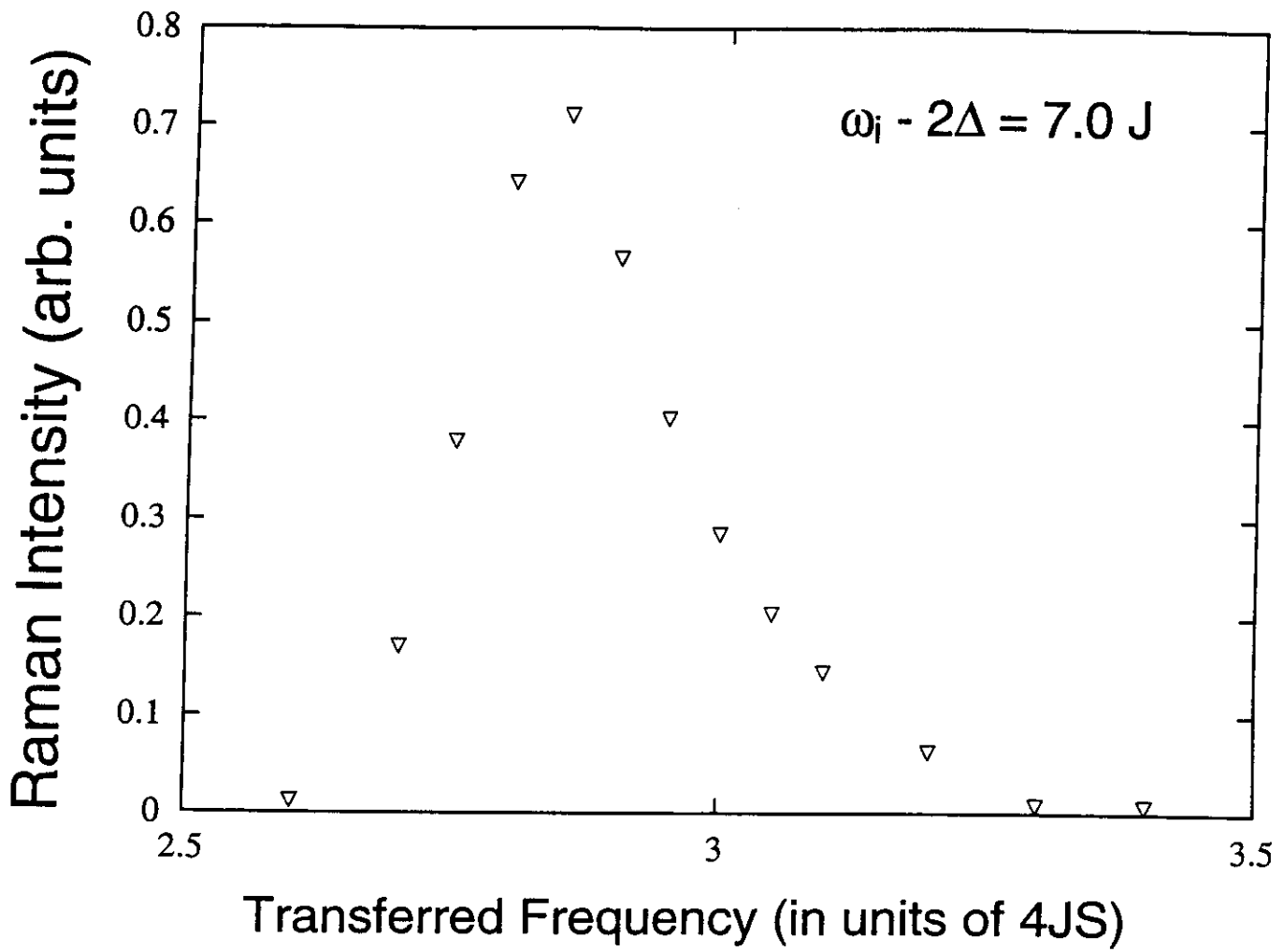
Fig. 10

We now include the final state magnon-magnon interaction. The interaction vertex between magnons is found from the quartic terms in the Heisenberg Hamiltonian after introducing a standard bosonization (HP or DM).

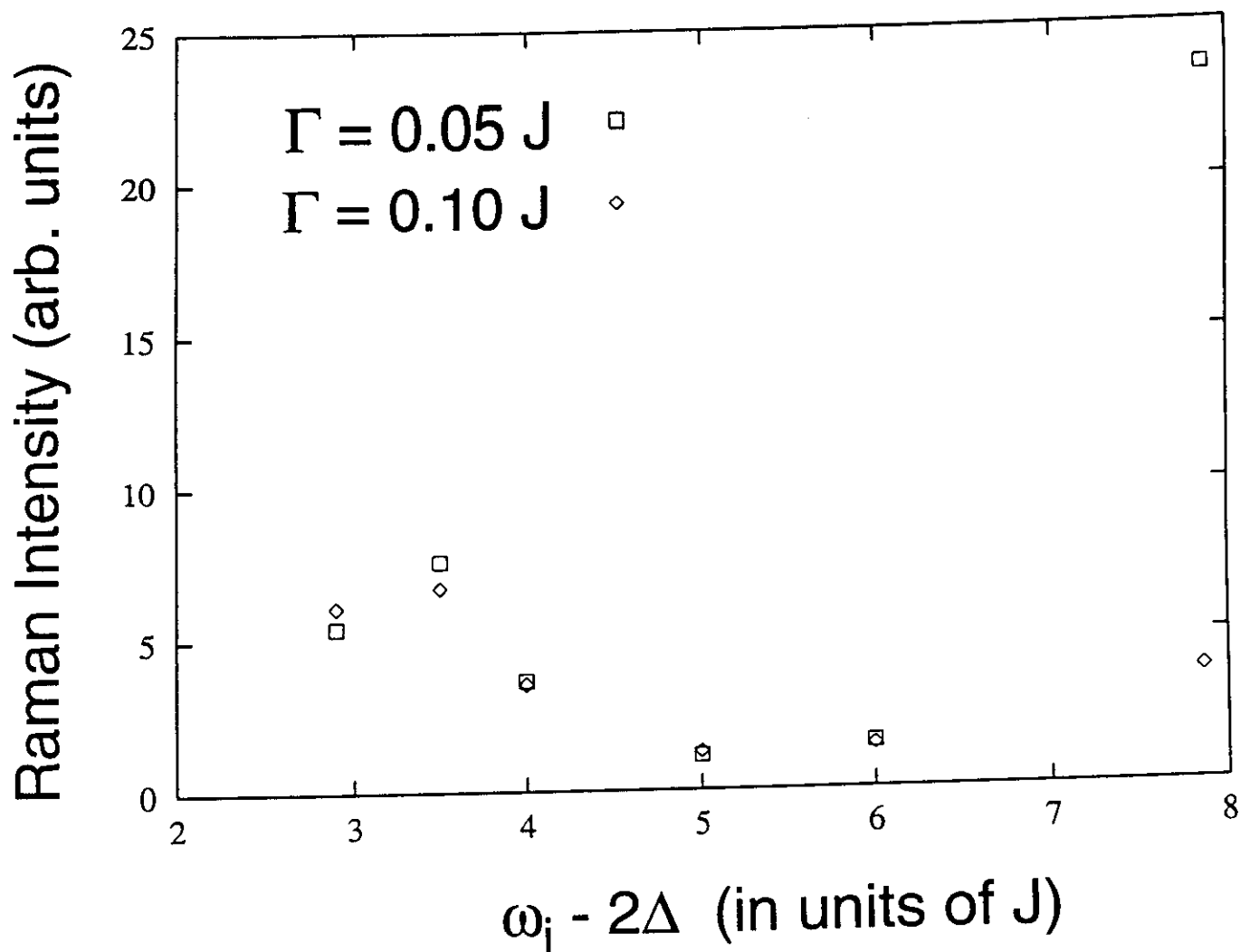
The full Raman intensity is then given as an infinite series of bubble diagrams:



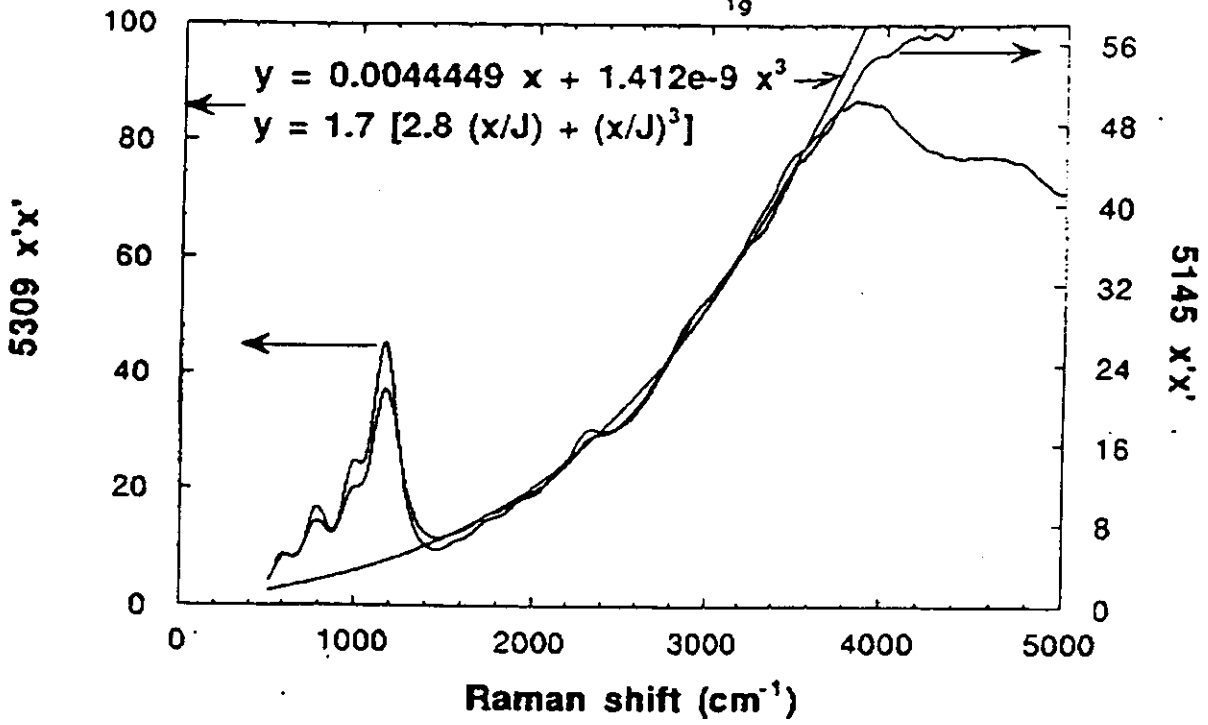
# B<sub>1g</sub> geometry



# Two-Magnon Peak Height



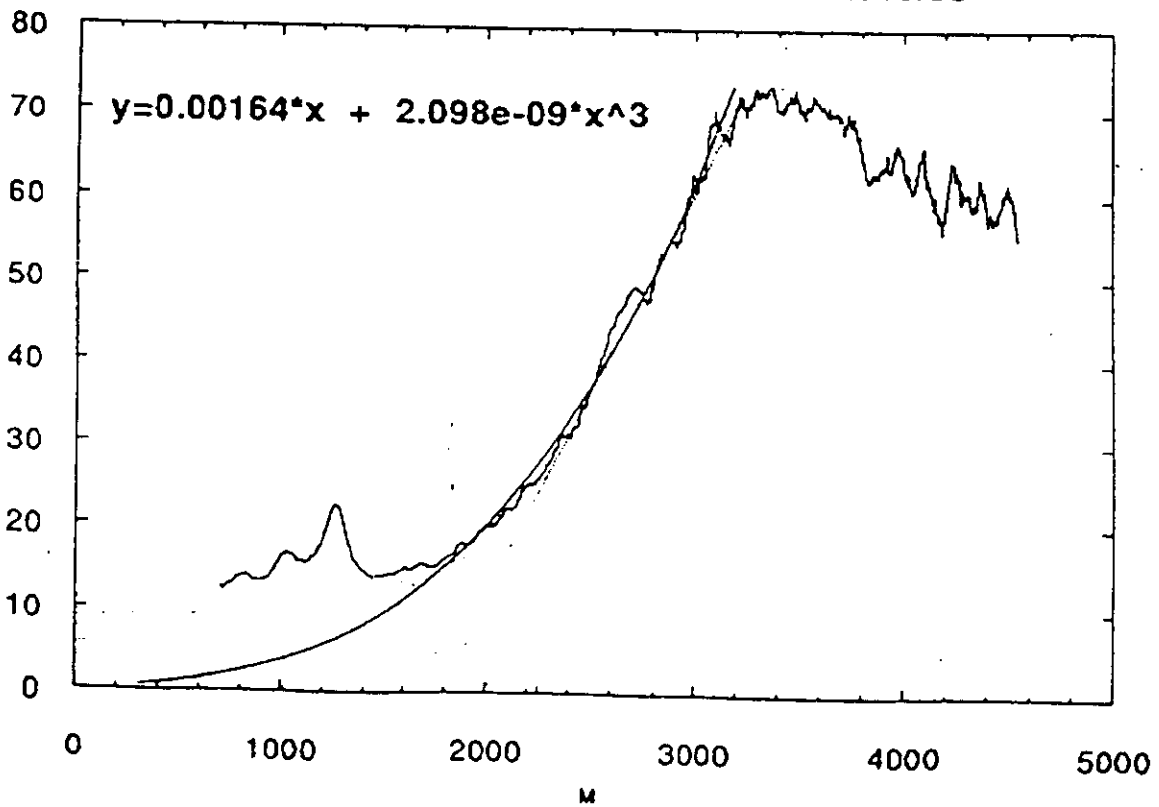
SCOC A<sub>1g</sub>



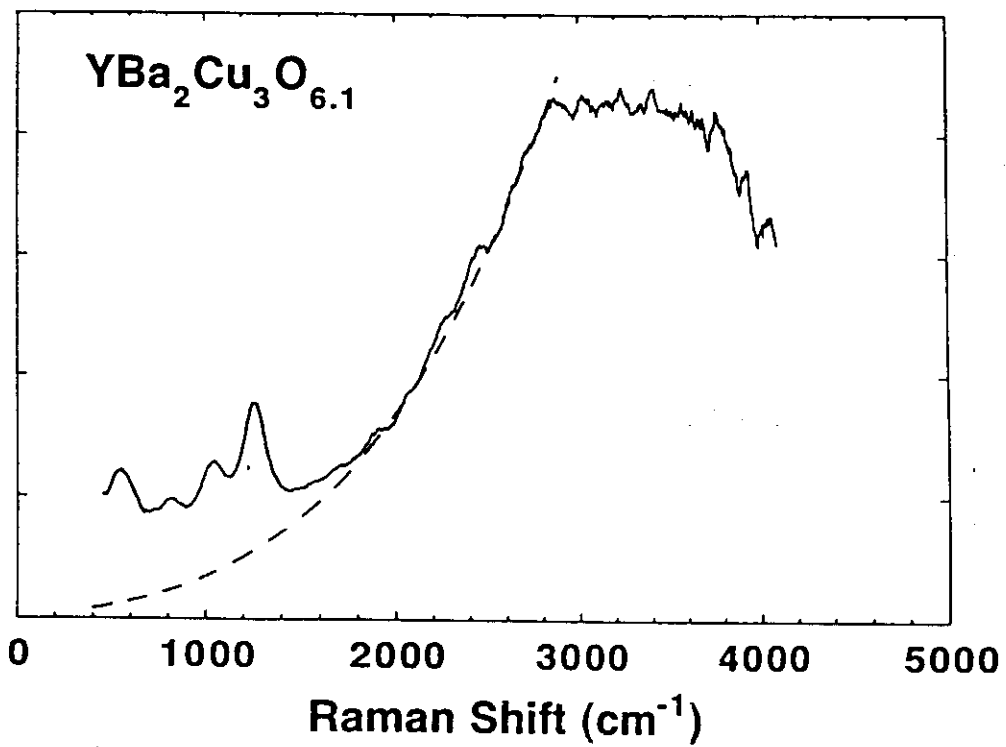
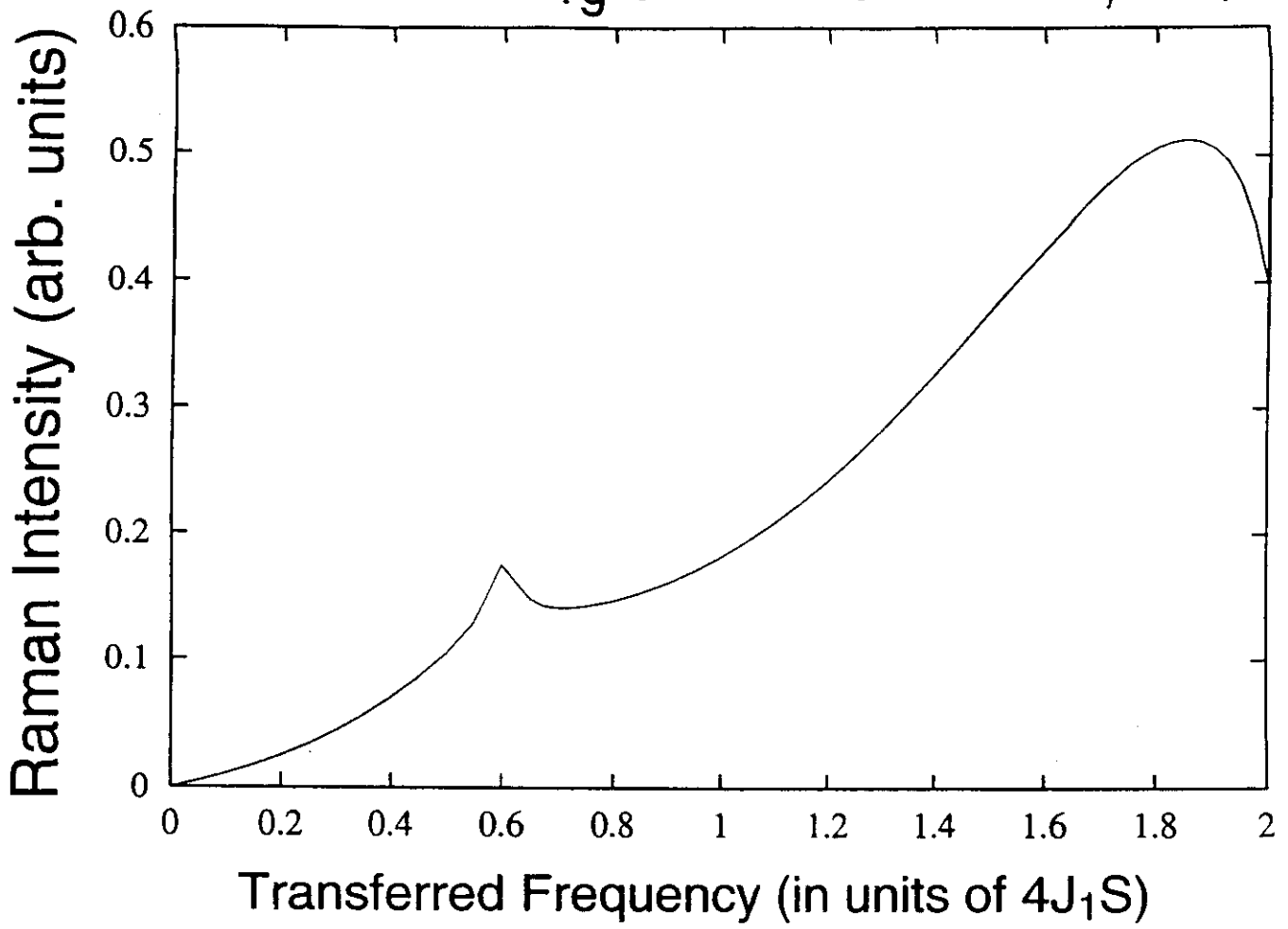
— 5762 x'x' Corrected  
— N

YBCO x'x'

5762 x'x' corrected 6:50:54 PM 10/15/95



$A_{1g}$  geometry (2 Layers)



## Conclusion

- a comparison with experimental data shows that the resonant diagram is mainly responsible for the form of the MRS signal
- the triple resonance diagram yields a qualitative good agreement for the overall shape of the Raman intensity as well as the TMPH as a function of  $\omega_i$  in  $B_{1g}$  geometry
- we derived the matrix elements for MRS in a 2LAFM in the non-resonant and the resonant regime
- a finite  $J_2$  leads to a non-vanishing signal in  $A_{1g}$  geometry already in the non-resonant case
- comparing our results for the  $A_{1g}$  geometry with experiments, we can establish an upper limit of  $J_2 \leq 0.2J_1$  on the magnitude of  $J_2$ . This result is in good agreement with the analysis of recent NMR experiments using Monte Carlo calculations (Sandvik *et al.*'95) and with recent neutron scattering experiments (Hayden *et al.*'96).