Superconductivity and stripes in 2D electronic model

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1. Introduction

   d-p model stripes

   high-Tc superconductor

2. Method and Calculations
3. Stripes and Phase diagram

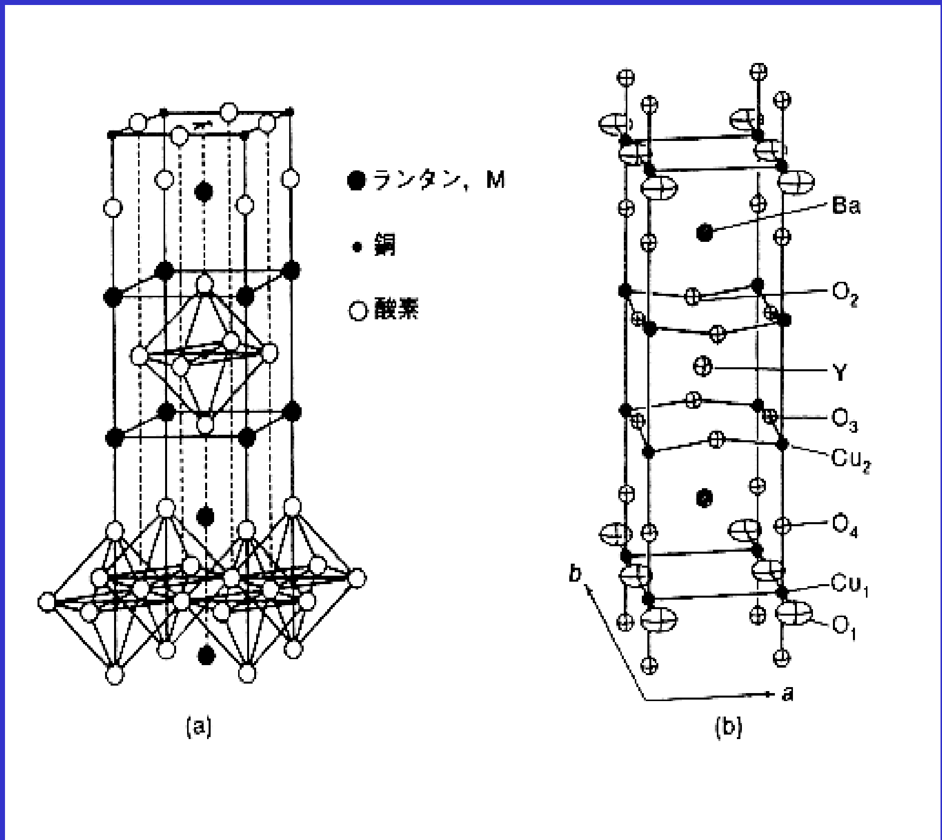
   Condensation energy

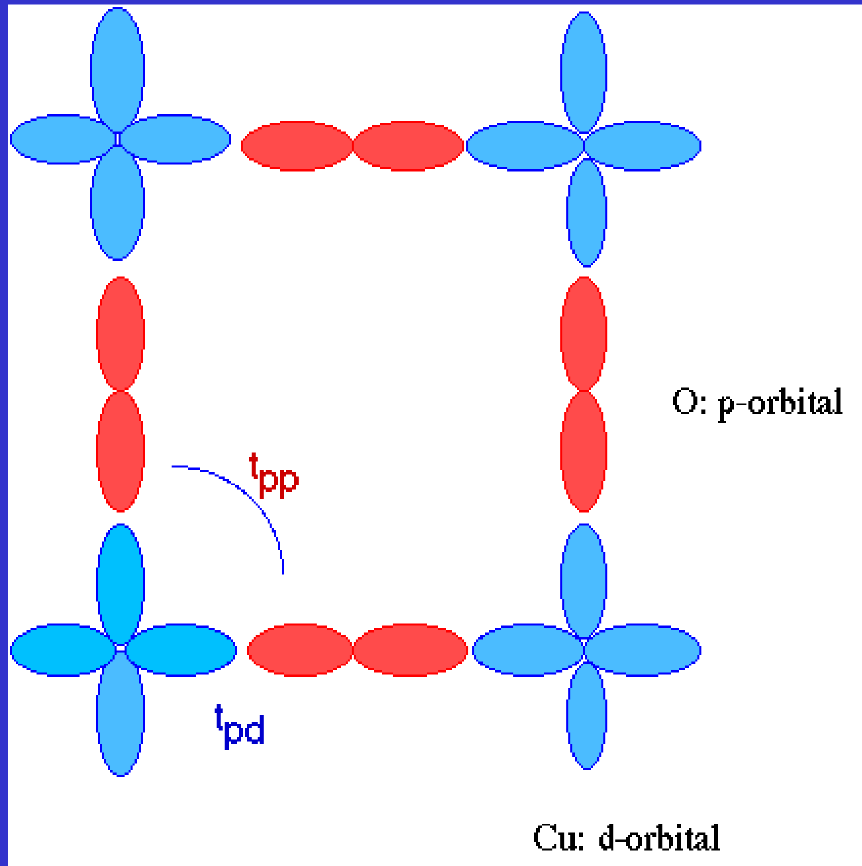
4. Summary

Introduction

High-Tc cuprates

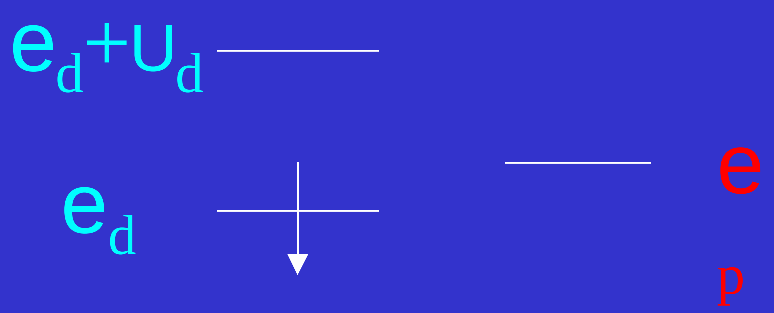
CuO_2 plane
2D d-p model





2D Cu-O model

Non-doping (half-filling)

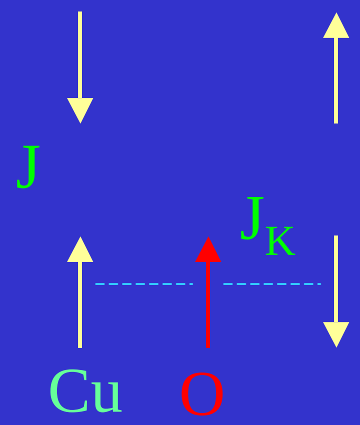


Antiferromagnetic Insulator

Hole doping

Hole is doped on O site.

1.Frustration



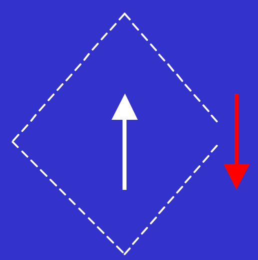
Frustration between Cu spins

Effect of disorder

2.Local singlet

(Zhang-Rice)

Singlet



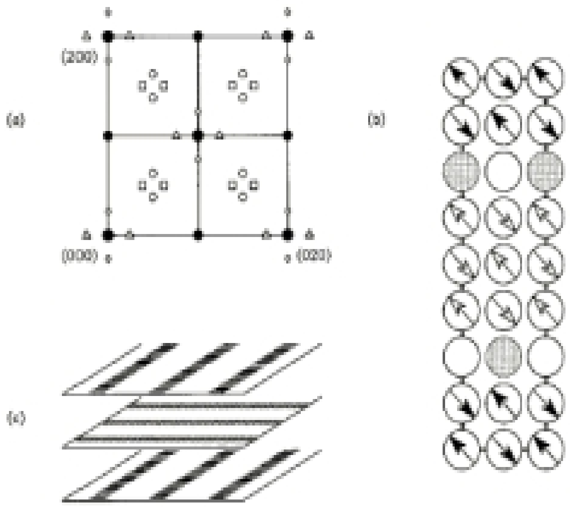
Hubbard model

t-J model

Characteristics of HTSC

	LaSrCuO	YBaCuO	BiSrCaCuO	NdCeCuO
d-wave paring	●	●	●	○
Pseudogap		●	●	
Incom. peaks	●	●		
Resonance peaks		●	●	
Stripes	●			

Stripes in High-Tc cuprates



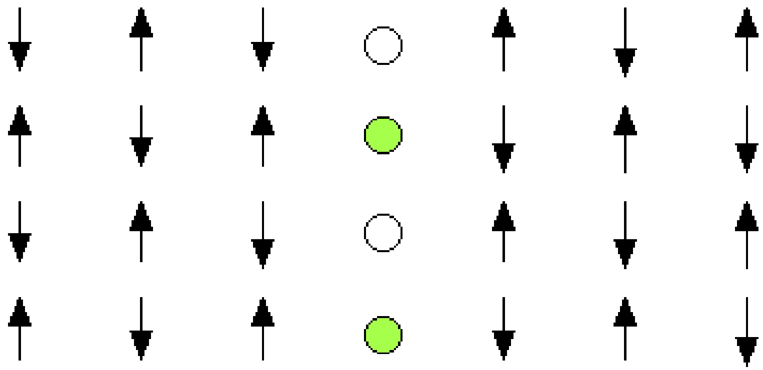
Incommensurate structure

Proposal of Stripes

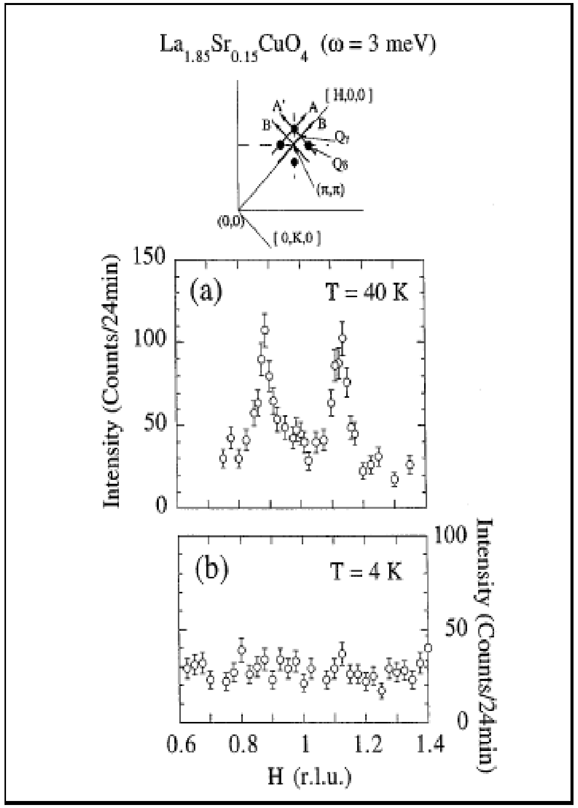
$La_{2-x-y}Nd_ySr_xCuO_4$
Tranquada et al.
Phys. Rev. B54,4596('96)

Two Q vectors

$Q_s = (\pi-2\pi\delta,\pi),\ldots$
$Q_c = (4\pi\delta,0),\ldots$



Incommensurate peaks



Yamada et al.
Phys. Rev. B

Method and Calculations

Variational Monte Carlo method

Wave functions

$\Psi_N = P_G|\text{Fermi sea})$

$\Psi_{BCS} = P_G|\text{BCS})$

$\Psi_{SDW} = P_G|\text{SDW})$

Gutzwiller Projection P_G

To control the on-site strong correlation

Weight g
Coulomb +U

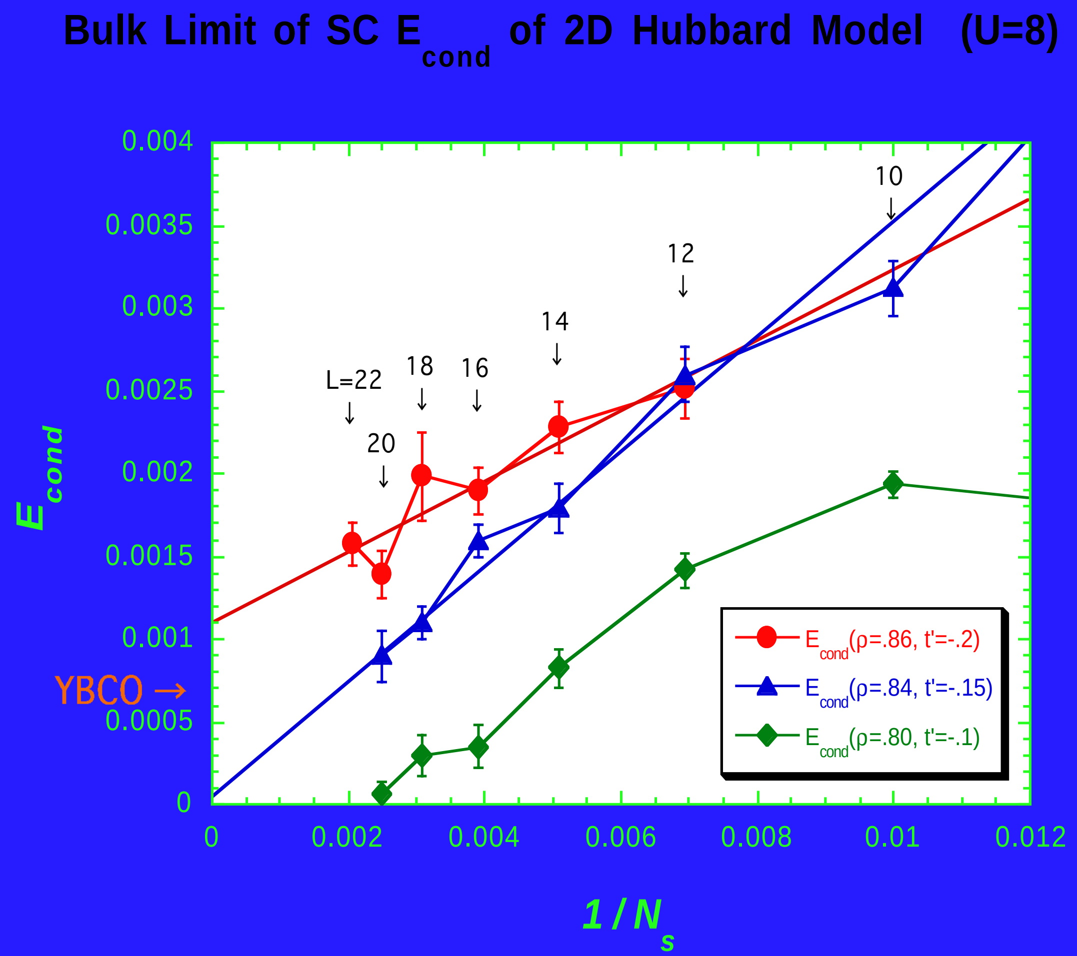
Weight 1
Parameter 0<g<1

P_G induces antiferromagnetic correlation

SC Condensation Energy

2D Hubbard model

Bulk limit



E_{cond} = 0.00117t
= 0.59 meV/site
(ρ=0.86, t'=-0.2, U=8)

Experiments
0.26 meV/site
（Critical Hc
0.17~0.26（C/T）

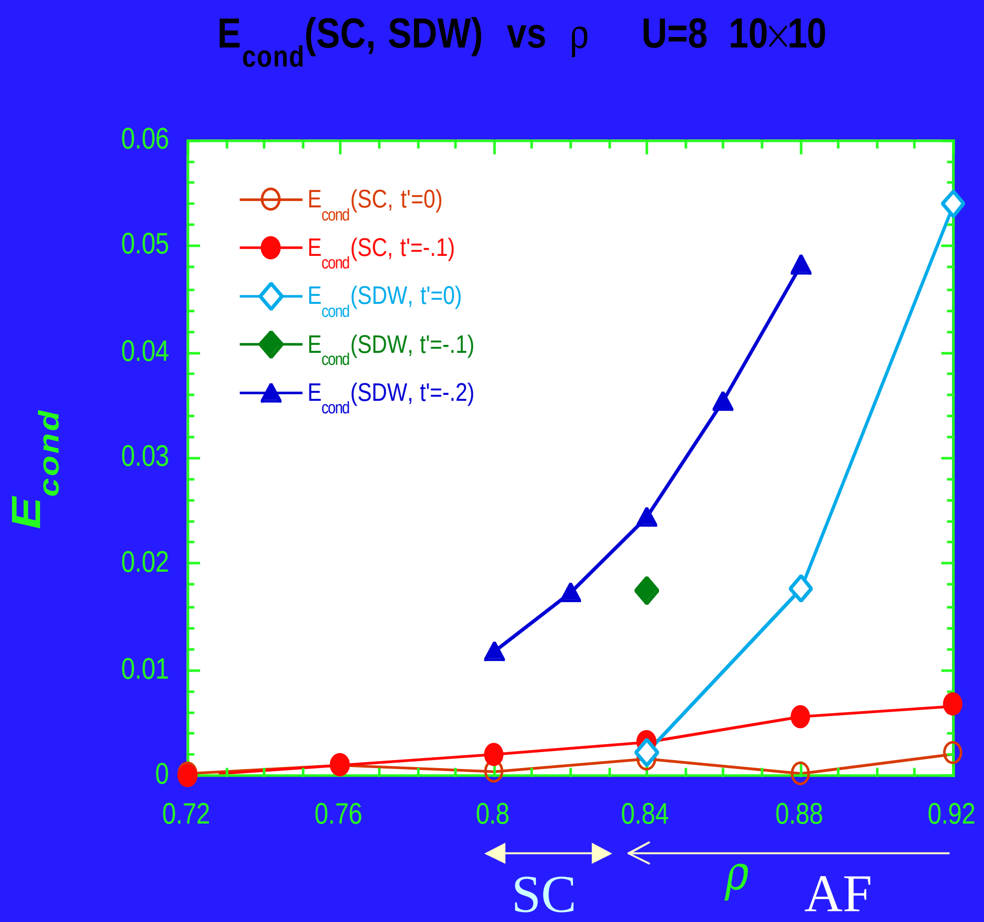
They agree very well.

t-J model gives 50 times of condensation energy !

Ref. Physica C304 (1998) 225

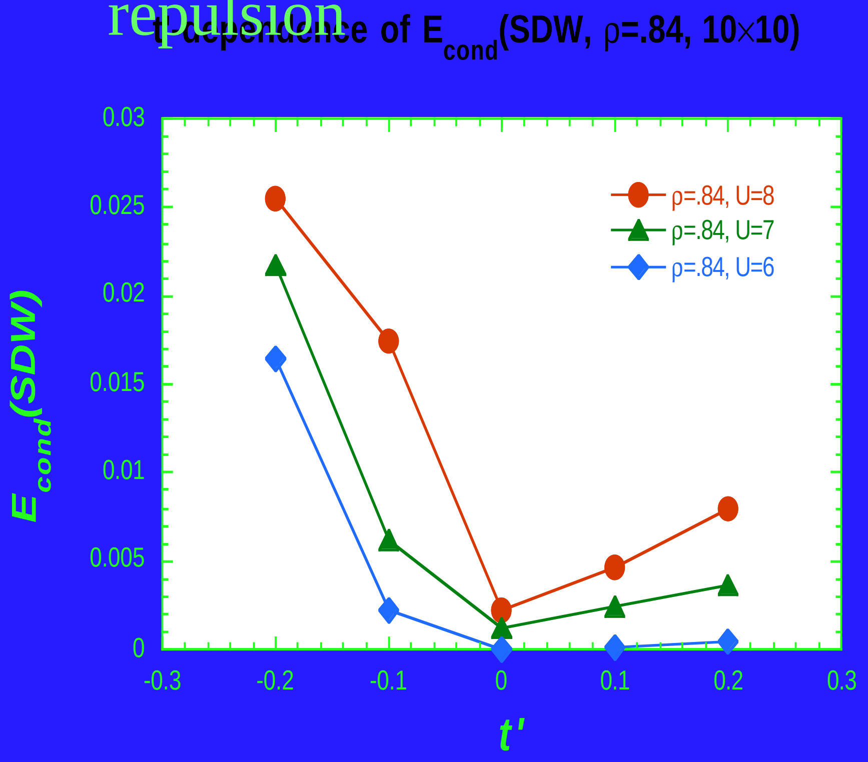
Competition between SC and AF

Energy gains of Sc and AF states



Important factors for SC

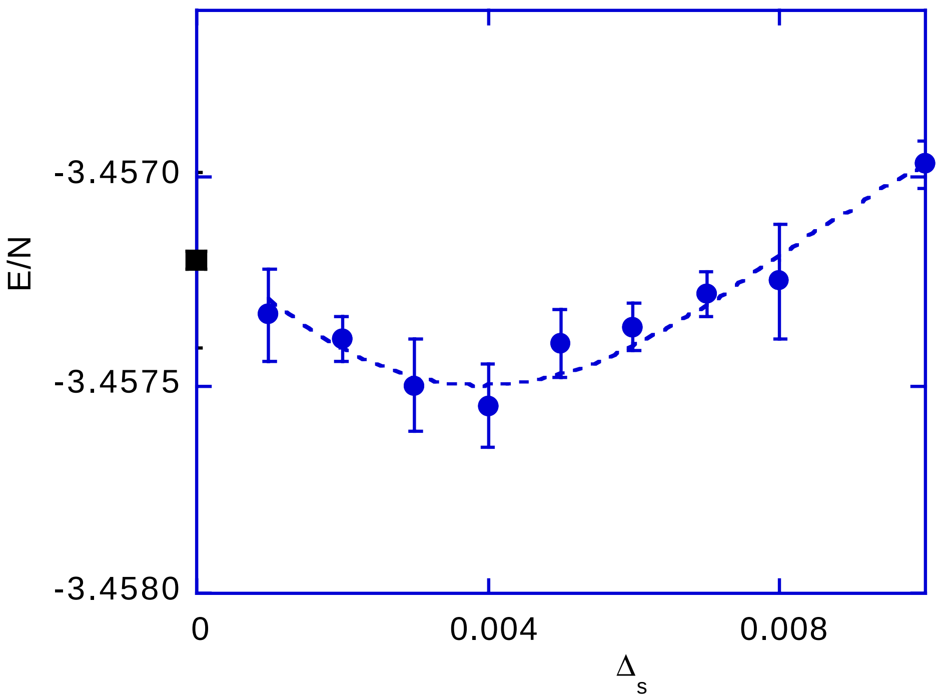
- Next n.n. transfer
- Correlation between neighboring sites
- Strength of the Coulomb repulsion



Coexistence of uniform AF and SC

Gutzwiller wave function with SC and AF order parameters

VMC results



SC order parameter

6x6
d = 0.111

U_d = 8

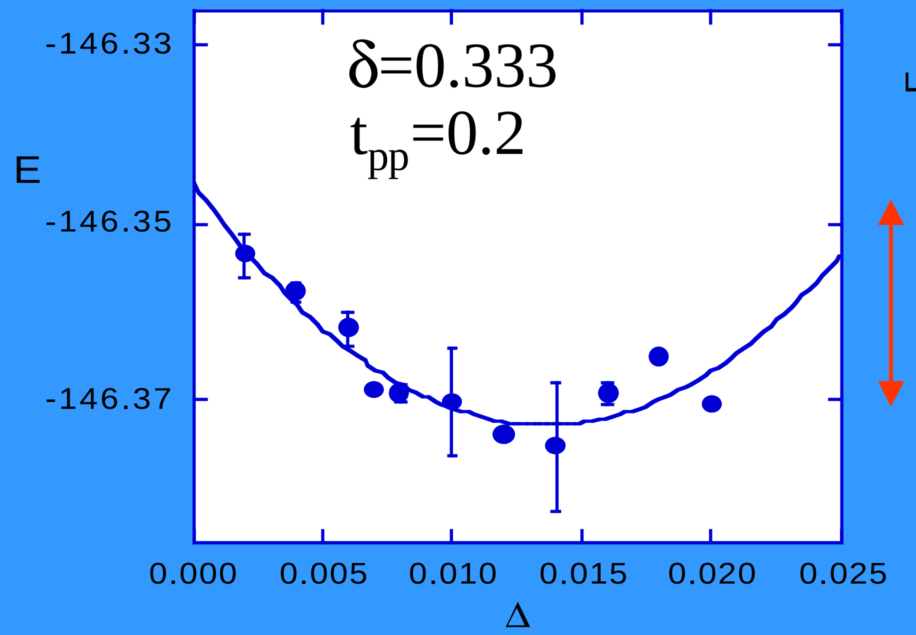
Phase diagram of d-p model

Condensation energy

$E_{cond} \sim 0.00038 t_{dp}$
$= 0.56$ meV/site

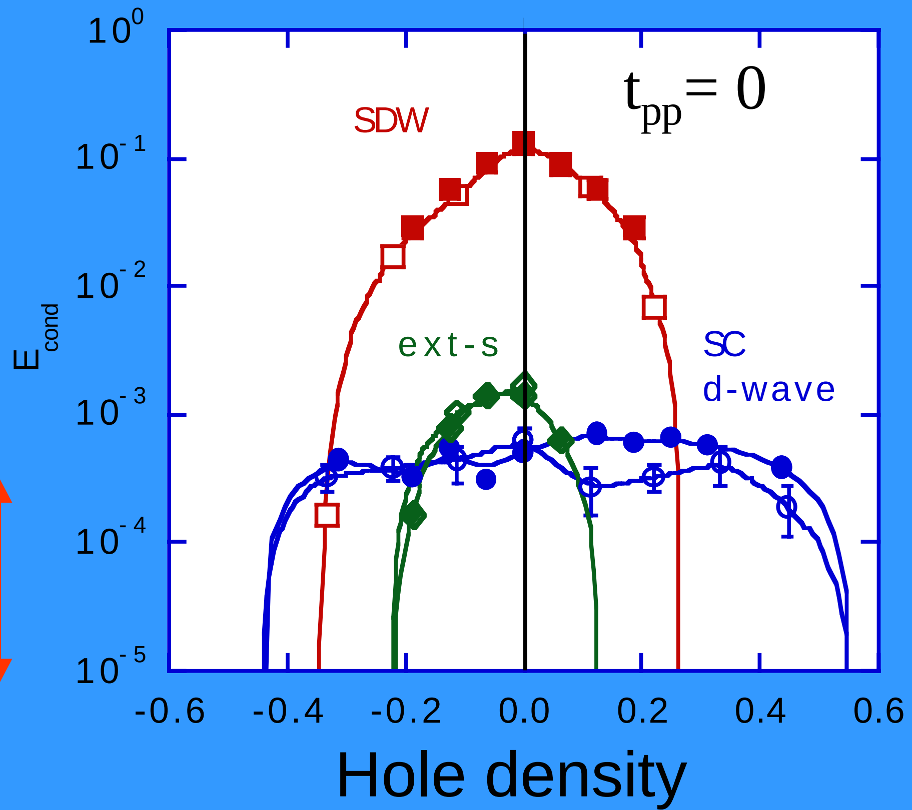
Specific heat ~ 0.26

Agreement is excellent!



SC order parameter

2D d-p model 6x6 and 8x8



Ref. Phys. Rev. B64, 184509 (2001)

Wave functions for Stripes

SDW potential

$$H_{AF} = \frac{U}{2}\sum_{i,\sigma}[n_i - \sigma(-1)^{x_i+y_i} m_i] c^{\dagger}_{i,\sigma} c_{i,\sigma}$$ d electron part

$$n_i = 1 - \alpha/\cosh[(y_i - y_1)/\xi_\rho] - \alpha/\cosh[(y_i - y_2)/\xi_\rho]$$

$$m_i = m \tanh[(y_i - y_1)/\xi_\sigma]\tanh[(y_i - y_2)/\xi_\sigma] .$$

(2-stripe case)

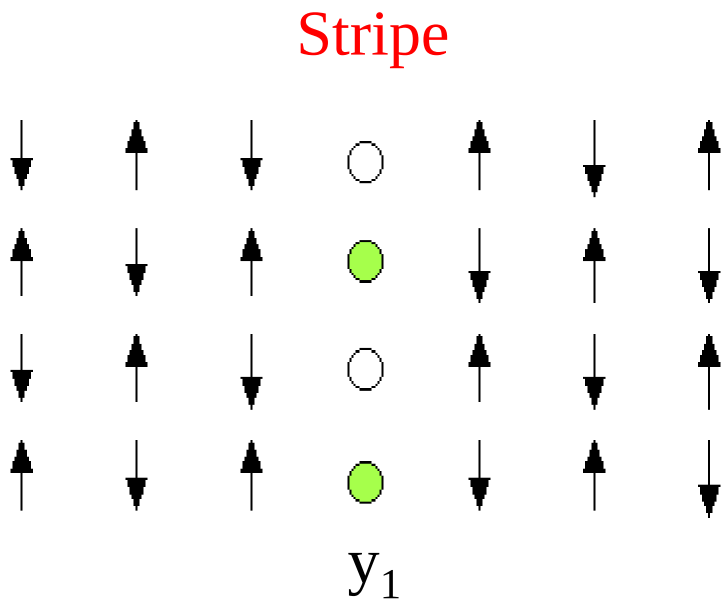
or

$n_i \sim -a \cos(4pdy_i)$

$m_i = m \cos(2pdy_i)$

Giamarchi et al.

Phys. Rev. B43, 12943 ('91)



Gutzwiller function

$$\psi = P_G \psi_{stripe}$$

Non-uniform Spin-density wave

What spin structures are stable?

It depends on parameters in d-p model

t_{pp}, $\Delta = \varepsilon_p - \varepsilon_d$

Long-period stripes

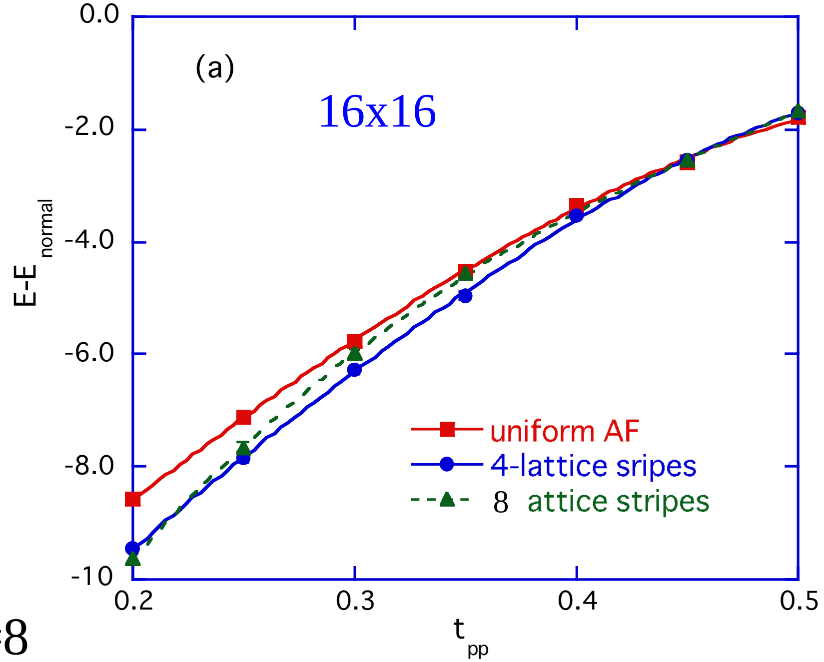
Uniform SDW

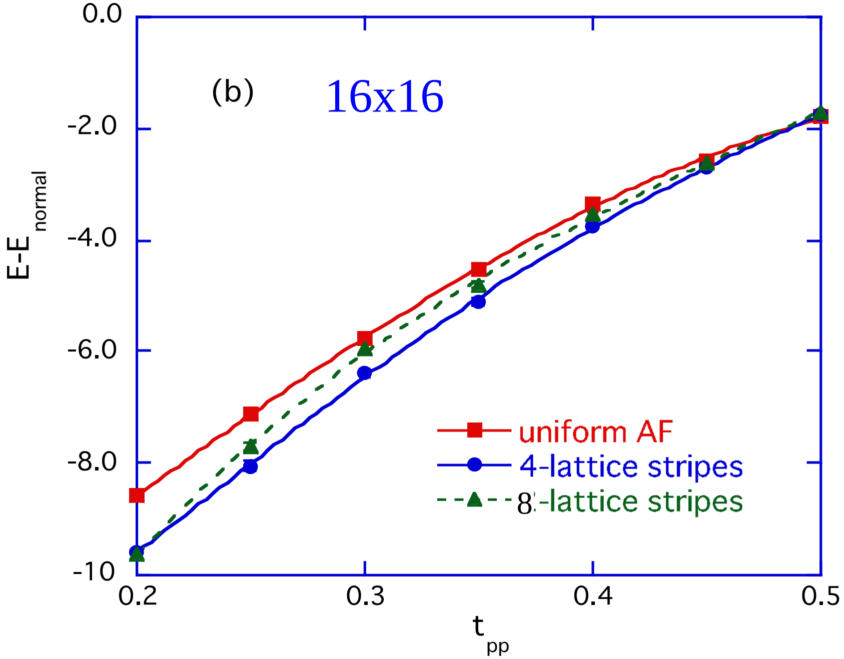
t_{pp}/t_{pd}

0

Stripes with short periods

Uniform distributions of holes





$U_d=8$
$\Delta=2$

Antiperiodic-periodic b.c.s

Periodic-antiperiodic b.c.s

Summary

2D Hubbard model (single-band and three-band)

- Overdoped region

  d-wave SC originating from U

- Underdoped region

  Antiferromagnetism
  = Non-uniform SDW (Stripes)

Coexistent of SC and AF (stripes)