Sudip Chakravarty Fest 2019

Sudip at the ITP 1979

Sudip Chakravarty Fest 2019

Pairing in a dry Fermi sea

Scientific Discovery through Advanced Computing (SciDAC), DOE

Thomas Maier, ORNL

Vivek Mishra, ORNL

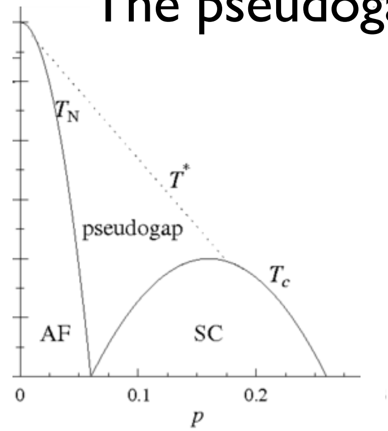
G. Balduzzi, ORNL

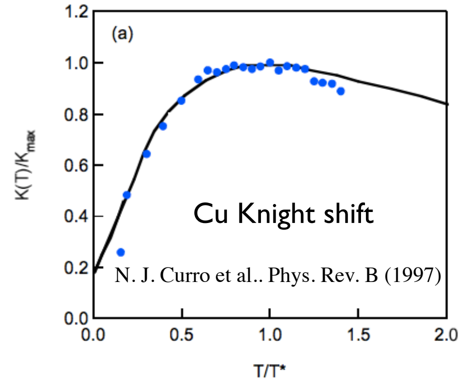
Pairing in a dry Fermi sea

The pseudogap

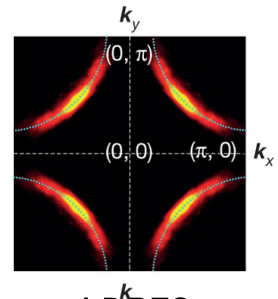
An incipient band

The pseudogap





The pseudogap is characterized by a suppression of the susceptibility and the loss of FS in the antinodal regions.



ARPES

Zhi-Xun Shen et al.

The underdoped Hubbard Model exhibits a pseudogap

$$H = -t \sum_{<i,j>s} (c_{is}^{\dagger} c_{js} + c_{js}^{\dagger} c_{is}) - \mu \sum_{is} n_{is} + U \sum_{i} n_{i\uparrow} n_{i\downarrow}$$

$$U/t = 7 \quad < n >= 0.92$$

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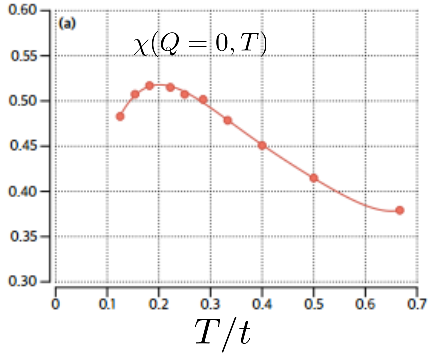
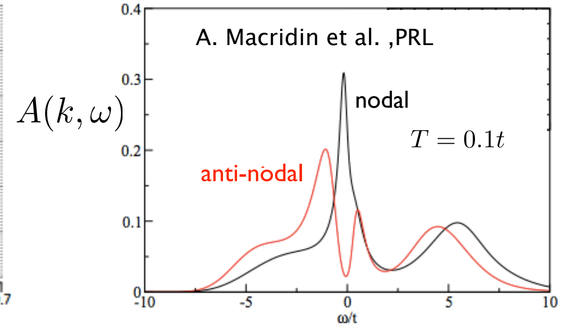
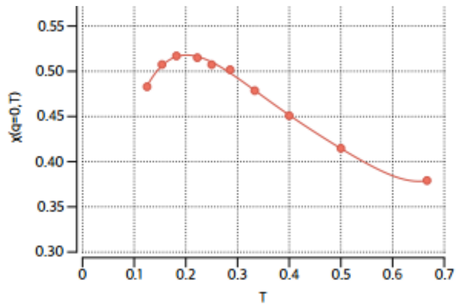
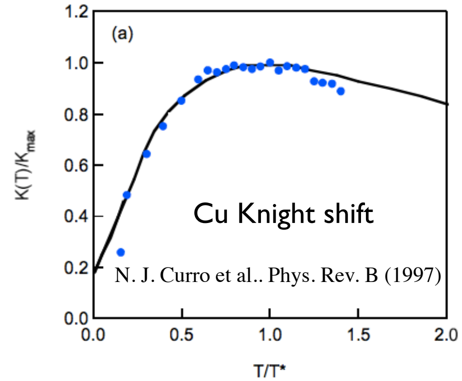
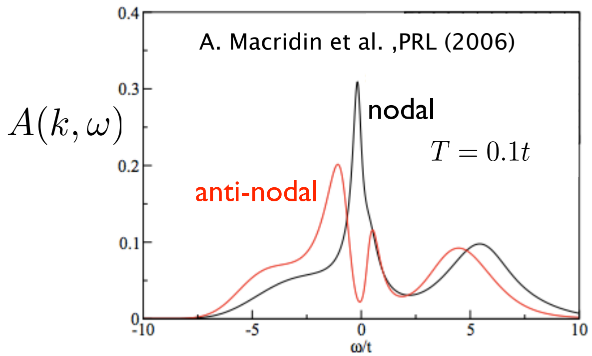


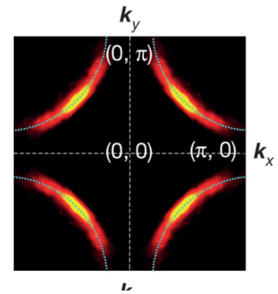


Hubbard Model







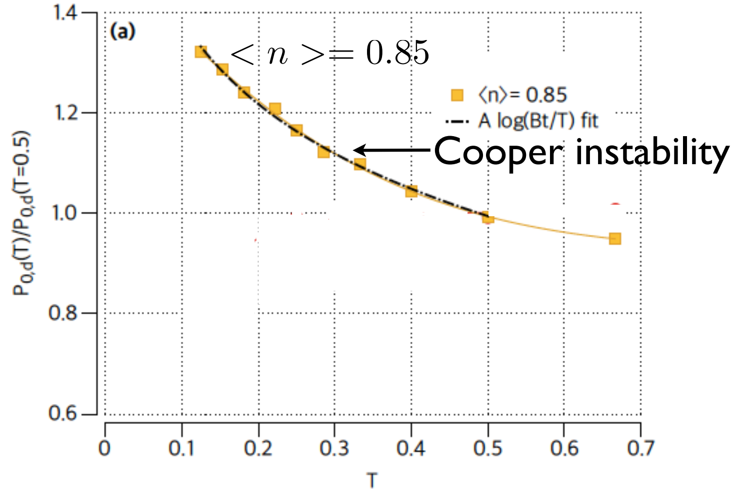


ARPES

Zhi-Xun Shen et al.

The Hubbard model with $U/t = 7$

$$P_{0d}(T) = \frac{T}{N}\sum_{k,n}\phi_d(k,\omega_n)G(k,\omega_n)G(-k,-\omega_n)\phi_d(k,\omega_n)$$
$$\approx N(0)log(\omega_0/T)$$



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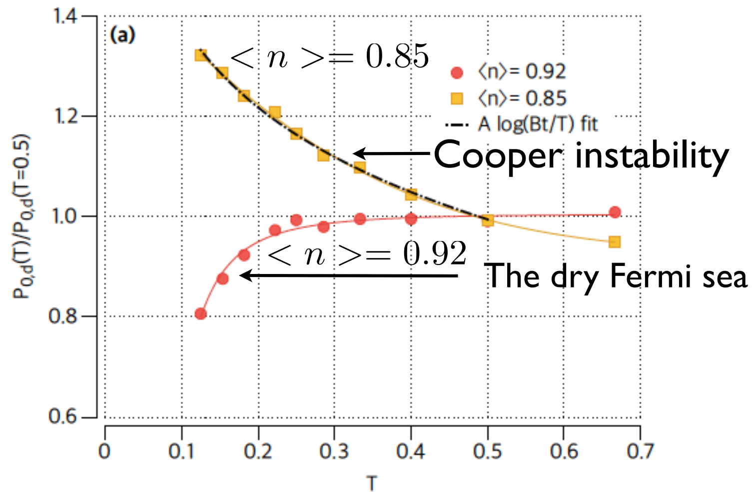
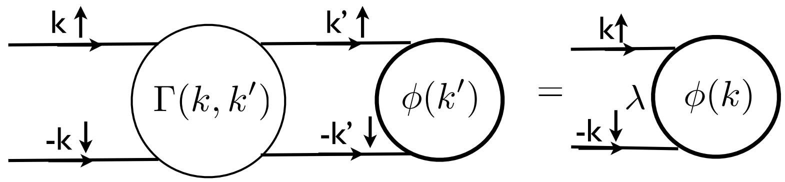


The Bethe-Salpeter (BCS gap) equation is



$$-\frac{T}{N}\sum_{k',n'}\Gamma(k,k')G(k',\omega_n')G(-k',-\omega_n')\phi_\alpha(k',\omega_n') = \lambda_d\phi_\alpha(k,\omega_n)$$

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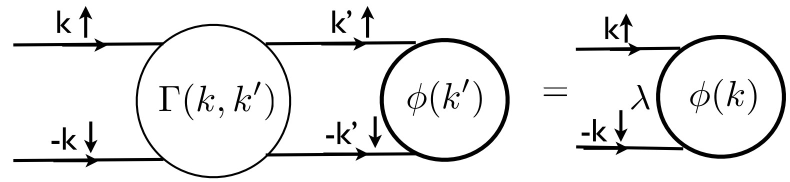

$$-\frac{T}{N}\sum_{k',n'}\Gamma(k,k')G(k',\omega_n')G(-k',-\omega_n')\phi_\alpha(k',\omega_n') = \lambda_d\phi_\alpha(k,\omega_n)$$

$$V_d(T) = -<\phi_d(k)\Gamma(k,k')\phi_d(k')>$$

$$P_{0d}(T) = -\frac{T}{N}\sum_{k,n}\phi_d(k,\omega_n)G(k,\omega_n)G(-k,-\omega_n)\phi_d(k,\omega_n)$$

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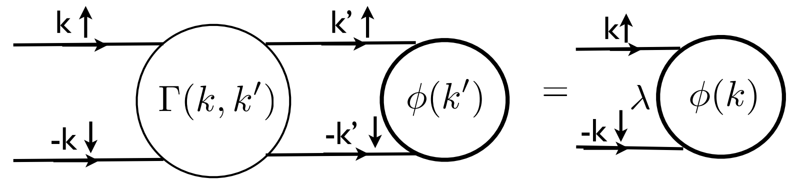

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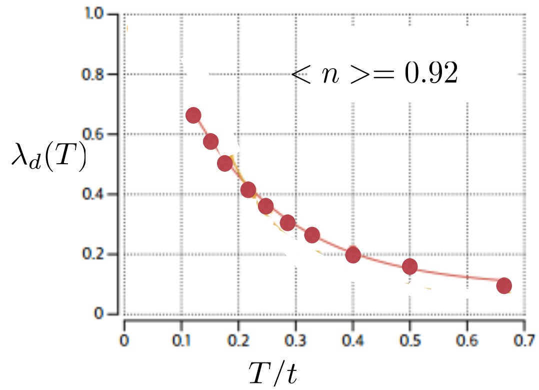
$$V_d(T) = - < \phi_d(k)\Gamma(k,k')\phi_d(k') >$$

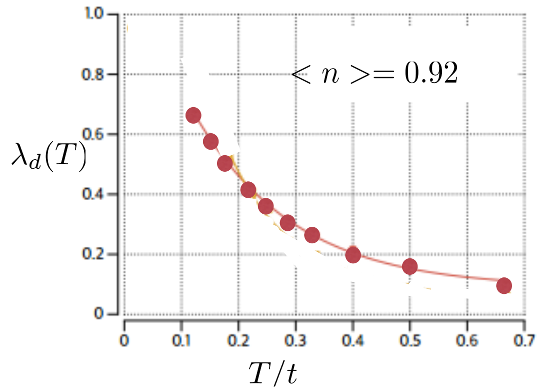
$$P_{0d}(T) = -\frac{T}{N}\sum_{k,n}\phi_d(k,\omega_n)G(k,\omega_n)G(-k,-\omega_n)\phi_d(k,\omega_n)$$

$$\boxed{\lambda_d(T) \approx V_d(T)P_{0d}(T)}$$

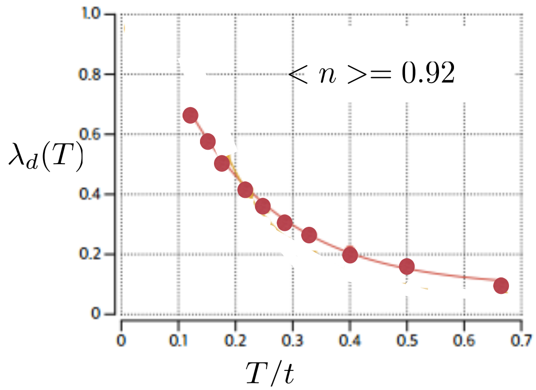
.



$< n >= 0.92$
$\lambda_d(T)$
T/t
1.0
0.8
0.6
0.4
0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7



$$\lambda_d(T) \approx V_d(T) P_{0d}(T)$$



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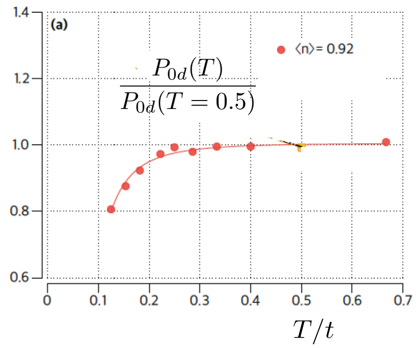
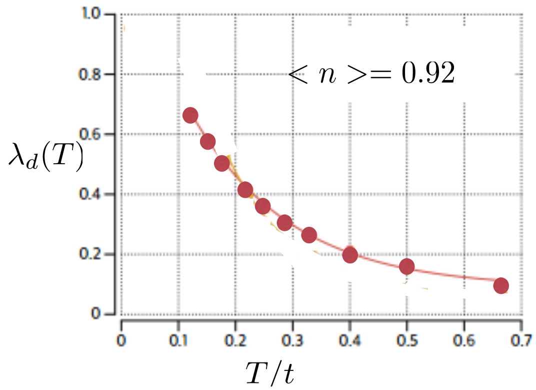
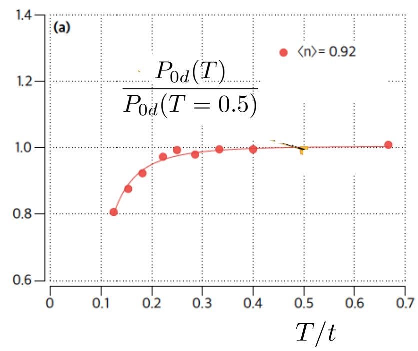
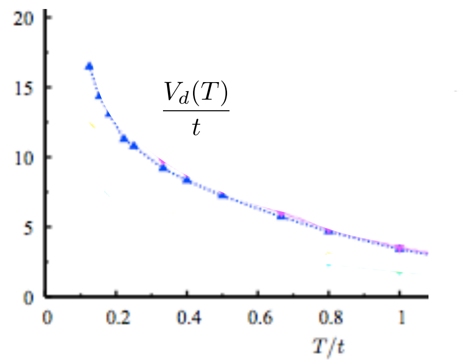
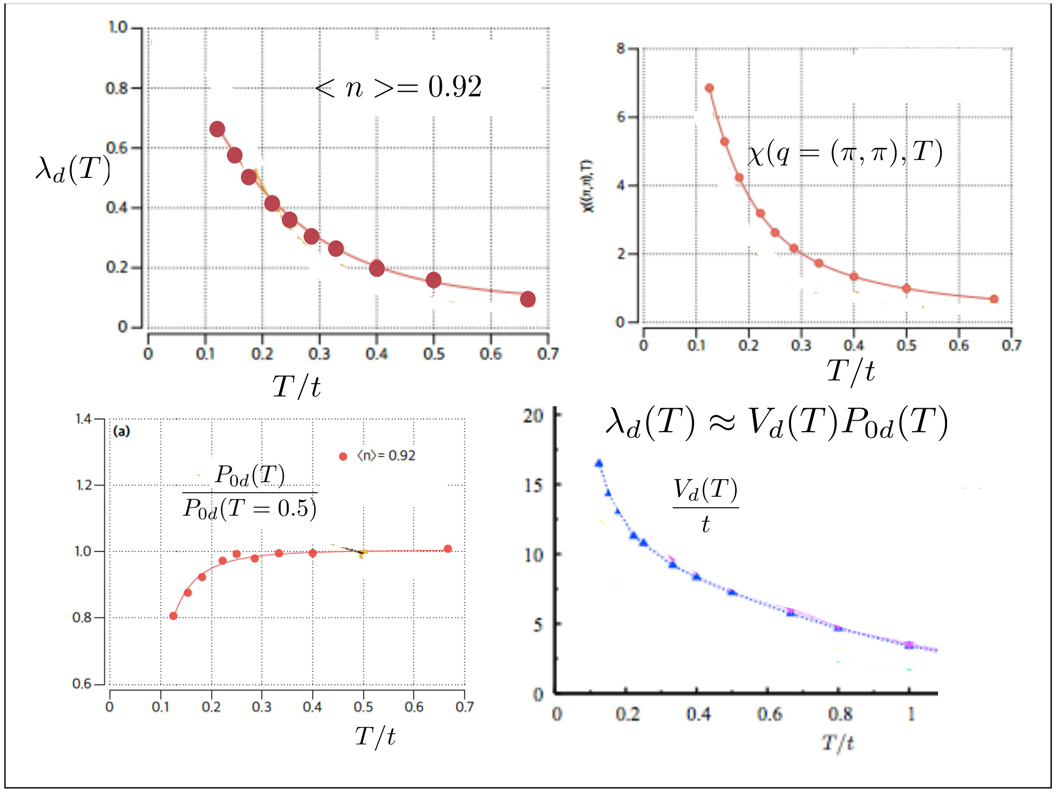




$$\lambda_d(T) \approx V_d(T)P_{0d}(T)$$

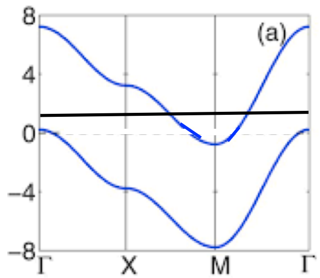


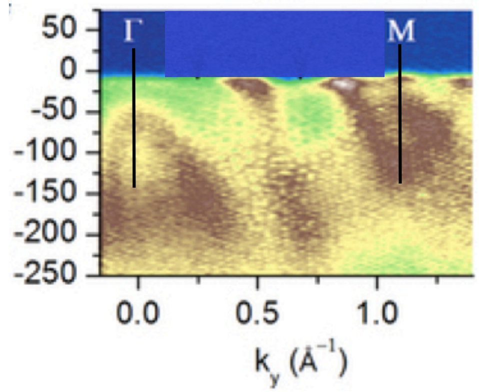




$\lambda_d(T)$
$< n >= 0.92$
T/t
$\chi(q = (\pi, \pi), T)$
$\chi((\pi,\pi),T)$
T/t
(a)
⟨n⟩= 0.92
$\frac{P_{0d}(T)}{P_{0d}(T = 0.5)}$
T/t
$\lambda_d(T) \approx V_d(T) P_{0d}(T)$
$\frac{V_d(T)}{t}$
T/t

An incipient band



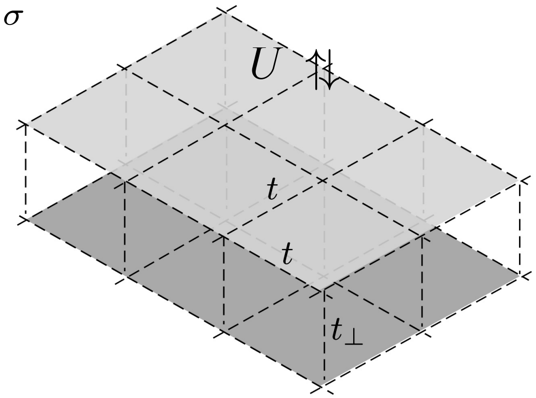


SmFe0.92Co0.08AsO

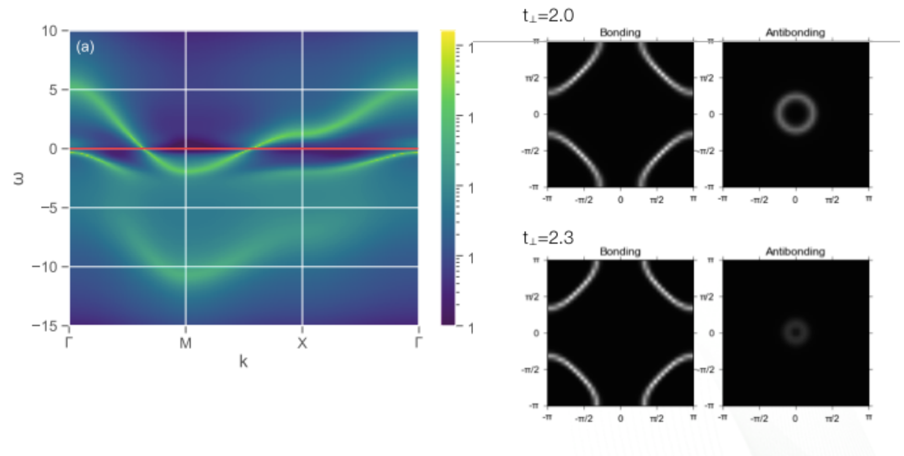
A. Charnukha , D. V. Evtushinsky , C. E. Matt , N. Xu , M. Shi , B. Buchner , N. D. Zhigadlo , B. Batlogg & S. V. Borisenko Sci. Rep. 5, 18273 (2015)

The Bilayer Hubbard model

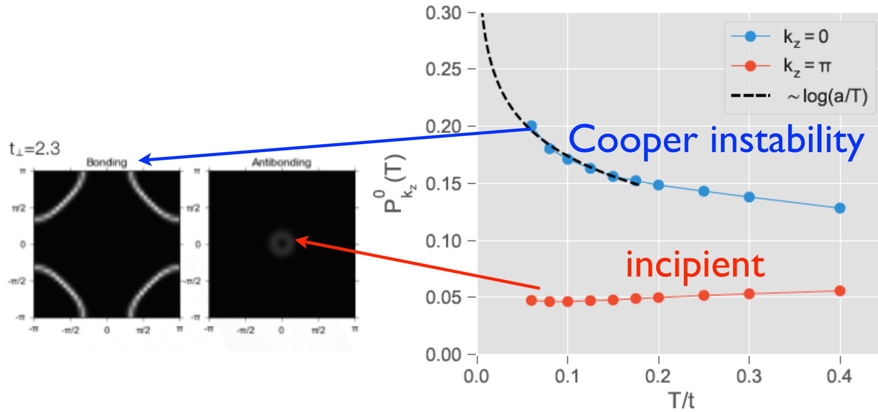
$$H = \sum_{i,j,\sigma} t_{ij}(c^\dagger_{i\sigma}c_{j\sigma} + c^\dagger_{j\sigma}c_{i\sigma}) + U\sum_i n_{i\uparrow}n_{i\downarrow}$$

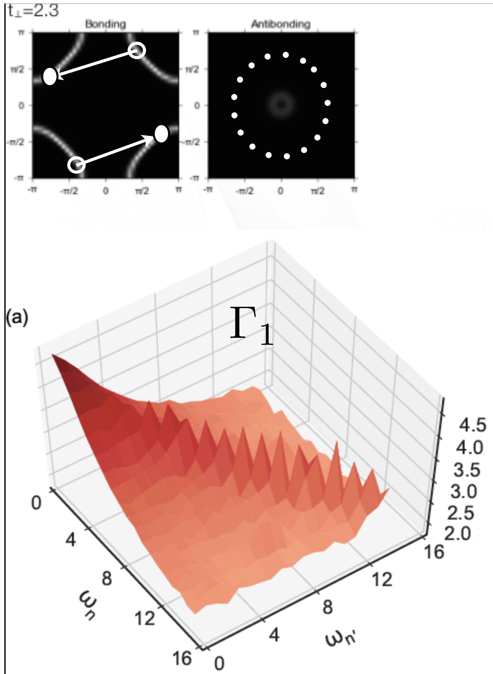


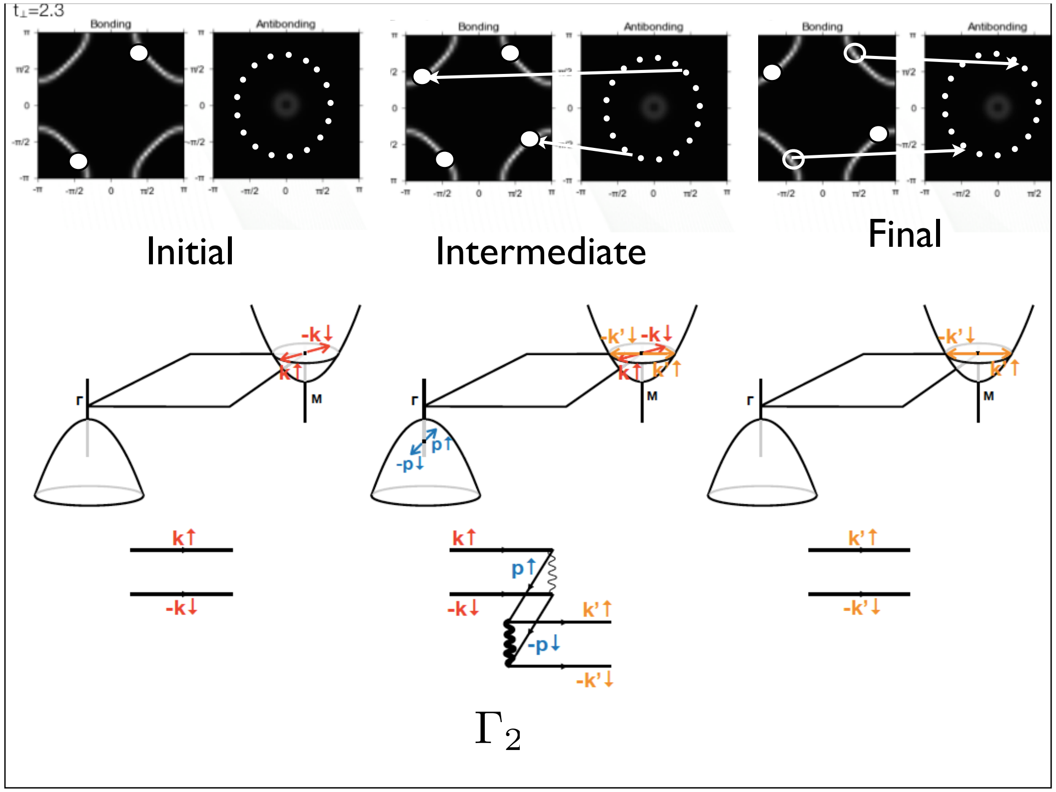
An incipient band as $t_\perp/t$ increases



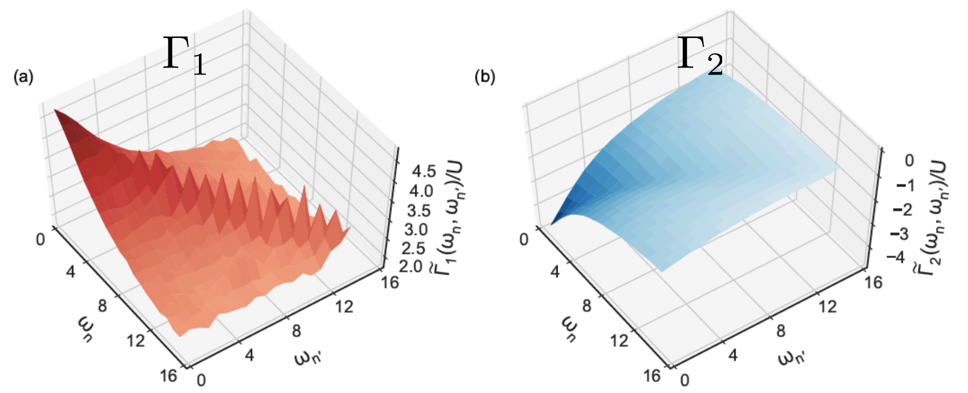
$$P^0 = (T/N) \sum_k G(k, w_n) G(-k, -w_n)$$

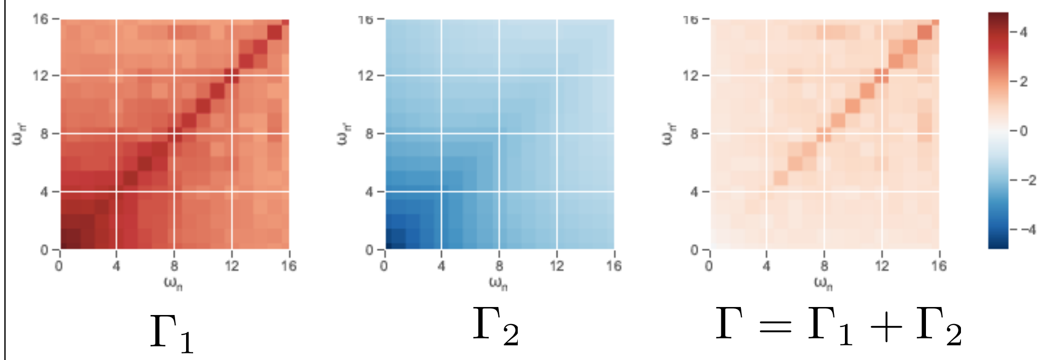



t⊥=2.3
Bonding
Antibonding
π
π/2
0
-π/2
-π
-π/2
0
π/2
π
(a)
Γ1
4.5
4.0
3.5
3.0
2.5
2.0
0
4
8
12
16
ωn
0
4
8
12
16
ωn'


t⊥=2.3
Bonding
Antibonding
Initial
Intermediate
Final
Γ
M
-k↓
k↑
-k'↓ -k↓
k↑ k'↑
p↑
-p↓
-k'↓
k'↑
k↑
-k↓
k'↑
-k'↓
Γ2

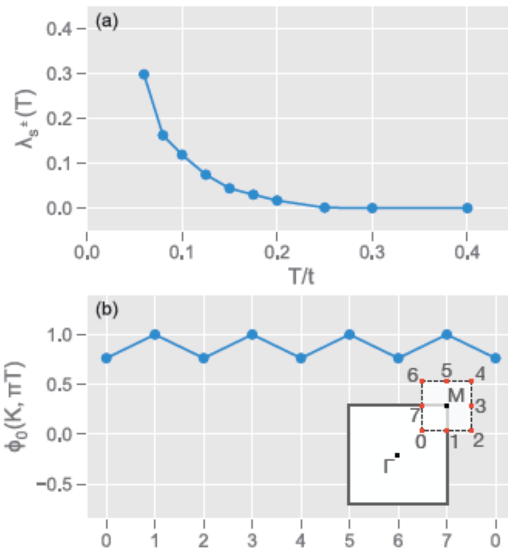
$$\Gamma = \Gamma_1 + \Gamma_2$$



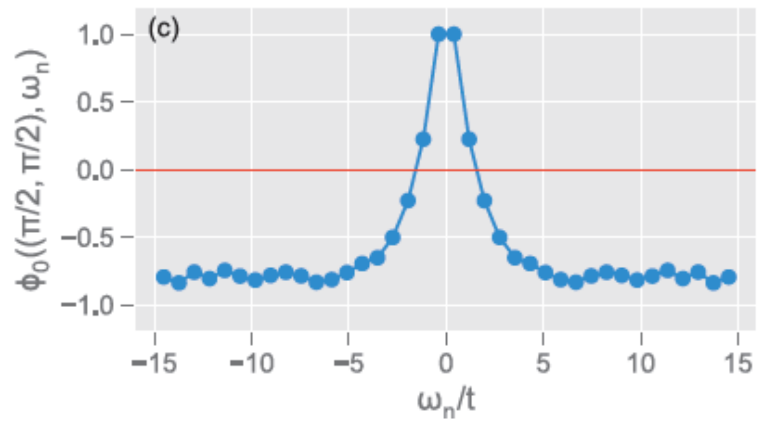


0
4
8
12
16
ω_n
$\omega_{n'}$
Γ_1
Γ_2
$\Gamma = \Gamma_1 + \Gamma_2$
4
2
0
−2
−4

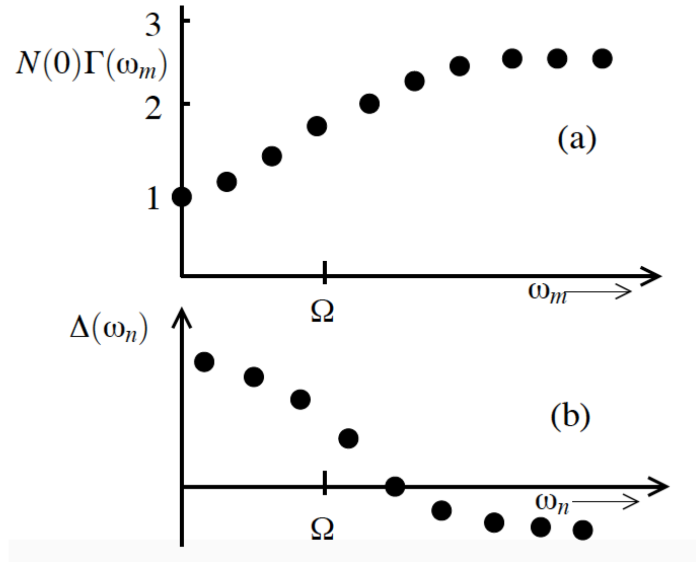
$$-\frac{T}{N}\sum_{k'w'_n}\Gamma(k,\omega_n;k',\omega'_n)G(k',w'_n)G(-k',-w'_n)\phi(k',w'_n)=\lambda\phi(k,\omega_n)$$



Retardation and a sign changing gap in Matsubara frequency



$$-\frac{T}{N}\sum_{k'w'_n}\Gamma(k,\omega_n;k',\omega'_n)G(k',w'_n)G(-k',-w'_n)\phi(k',w'_n)=\lambda\phi(k,\omega_n)$$



A sign changing gap in Matsubara frequency

$$-\frac{T}{N}\sum_{k'wn'}\Gamma(\omega_n-\omega_n')G(k',w_n')G(-k',-w_n')\Delta(w_n')=\lambda\Delta(\omega_n)$$