Superconductivity in a strongly correlated Model system: A numerical study

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Title: Effects of Strong Correlations and Disorder in d-Wave Superconductors

Question asked:

Model studied

Tools used and variables monitored

Results and Conclusions

Usual Question

Given a model suggested by either experiments or experts, is it provable to be superconducting?

In the context of High Tc :

t-J model

t-t'-J model

Hubbard model

Three band models.......

- Too difficult to answer rigorously:
- Other phases intervene
- MFT unreliable (J_in -> J_out)
- Analytical tools not reliable enough: Leggett has highlighted the problem with Bose condensation with hard core interactions: Proof of LRO very subtle (Kennedy-Lieb-Shastry 1988)
- Numerical methods donot scale too well.

- We will ask a slightly different Question:
- We believe that strong correlations are involved, but do we know their fingerprints well enough?
- We know a common garden fermi liquid well but do we really know the characteristics of a strongly correlated metal well enough?

- Could it be that $H = H_{strong} + ?$
-

$$\mathrm{H} = \mathrm{H}_{tJ} + \mathcal{H}_d + \mathcal{H}_{random}$$

$$\mathcal{H}_{tJ} = -t \sum_{\langle i,j \rangle\, \sigma} \left[\tilde{c}^{\dagger}_{i\sigma} \tilde{c}_{j\sigma} + \mathrm{H.c.} \right] + J \sum_{\langle i,j \rangle} \left[\mathbf{S}_i \cdot \mathbf{S}_j - \frac{1}{4} n_i n_j \right], (2)$$

$$\mathcal{H}_d = -\frac{\lambda_d}{L} \sum_{i,j=1}^{L} D^{\dagger}_i \, D_j$$

$$\mathrm{D}_i = (\Delta_{i,i+\hat{\mathrm{x}}} - \Delta_{i,i+\hat{\mathrm{y}}})$$

$$\Delta_{ij} = \tilde{c}_{i\uparrow} \tilde{c}_{j\downarrow} + \tilde{c}_{j\uparrow} \tilde{c}_{i\downarrow}$$

$$\mathcal{H}_{random} = \sum_i \varepsilon_i n_i$$

- Certified superconductor for any value of λ
- By varying λ, we can study the adiabatic continuity of the superconducting state down to $\lambda=0$ and thus ask if SC persists in or favourite model
- Can study robustness against disorder
- Need to characterize LRO in a simple way

Tools: Study ODLRO density matrix

$$\Lambda(i,j) = \langle D_i^\dagger D_j \rangle$$

Λ is a Hermitean Matrix with real eigenvalues

$$\lambda_1 \geq \lambda_2 \geq ...\lambda_m$$

Penrose Onsager and C N Yang showed that true LRO means a certain structure of the evs

Conventionally λ1 is O(N) and λ2 is O(1)

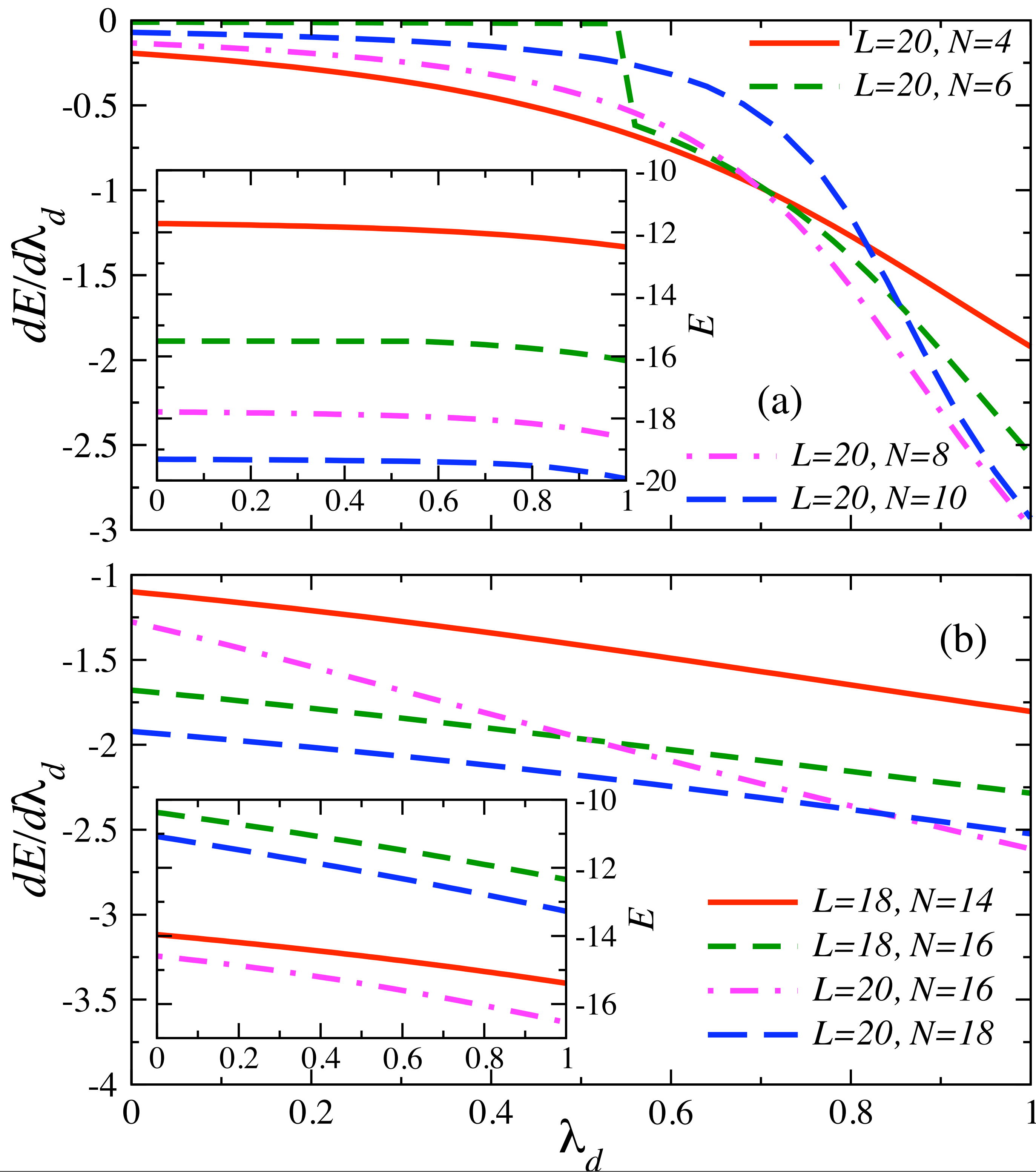
Also unconvetional possiblities exist: e.g. both EV's diverge for large systems (algebraic order)

- Need one extra insight:
- Due to Mott Hubbard Gutzwiller freezing near half filling x~0, the entire matrix scales down near half filling Λ ~ x^2
- Hence to get a true idea of LRO need to correct somehow

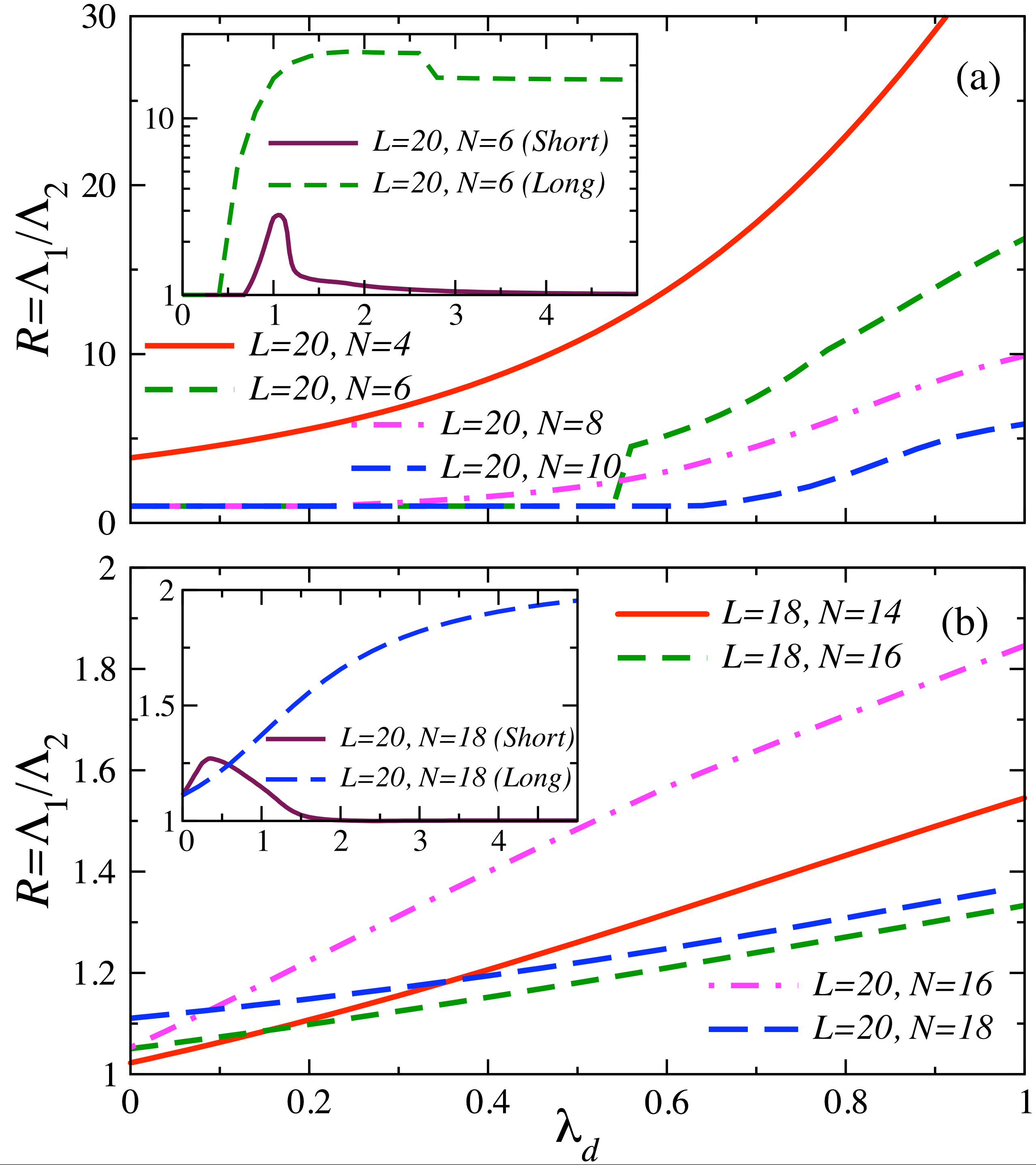
$$R = \frac{\lambda_1}{\lambda_2}$$

$$R \sim N m^2 + c$$

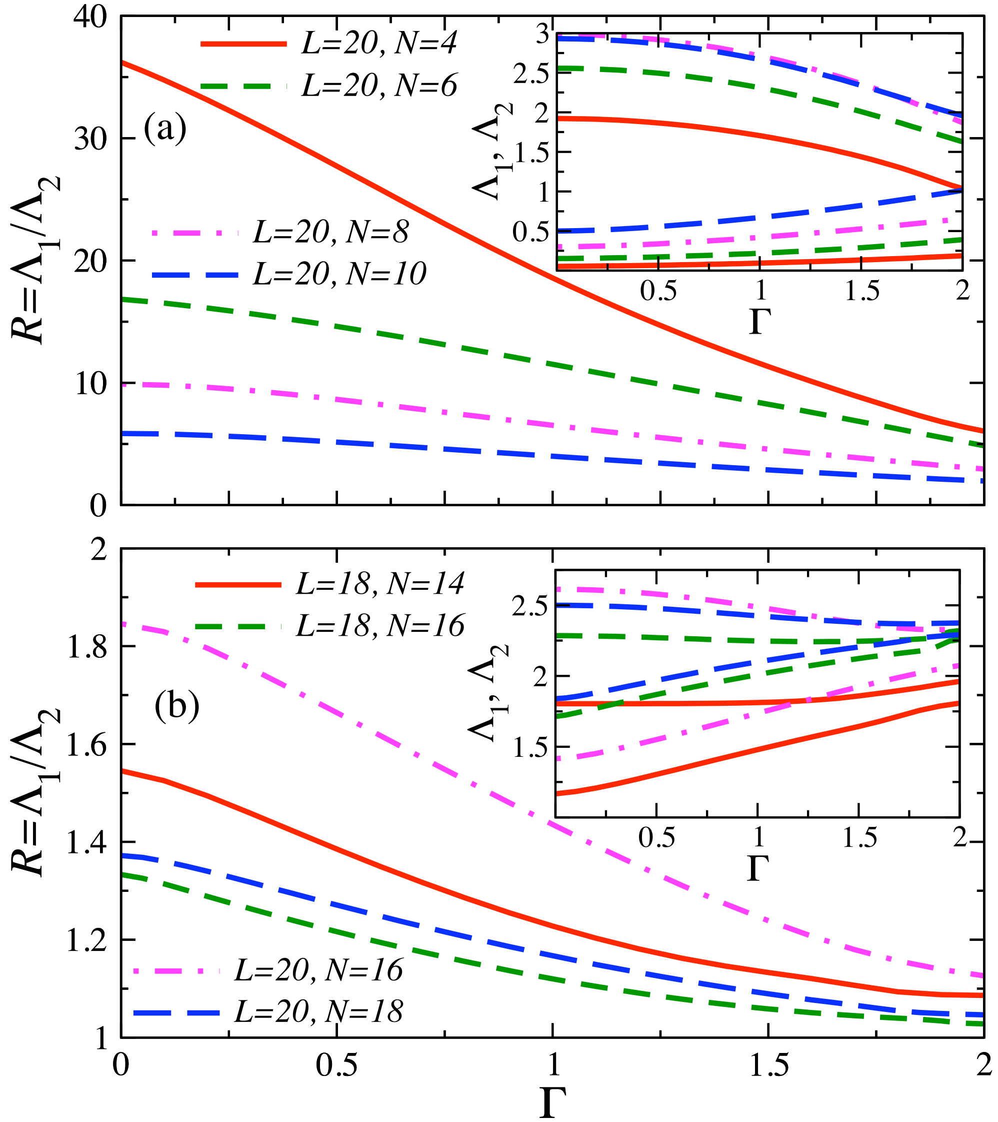
Expect m~ O(1)
c~O(1)



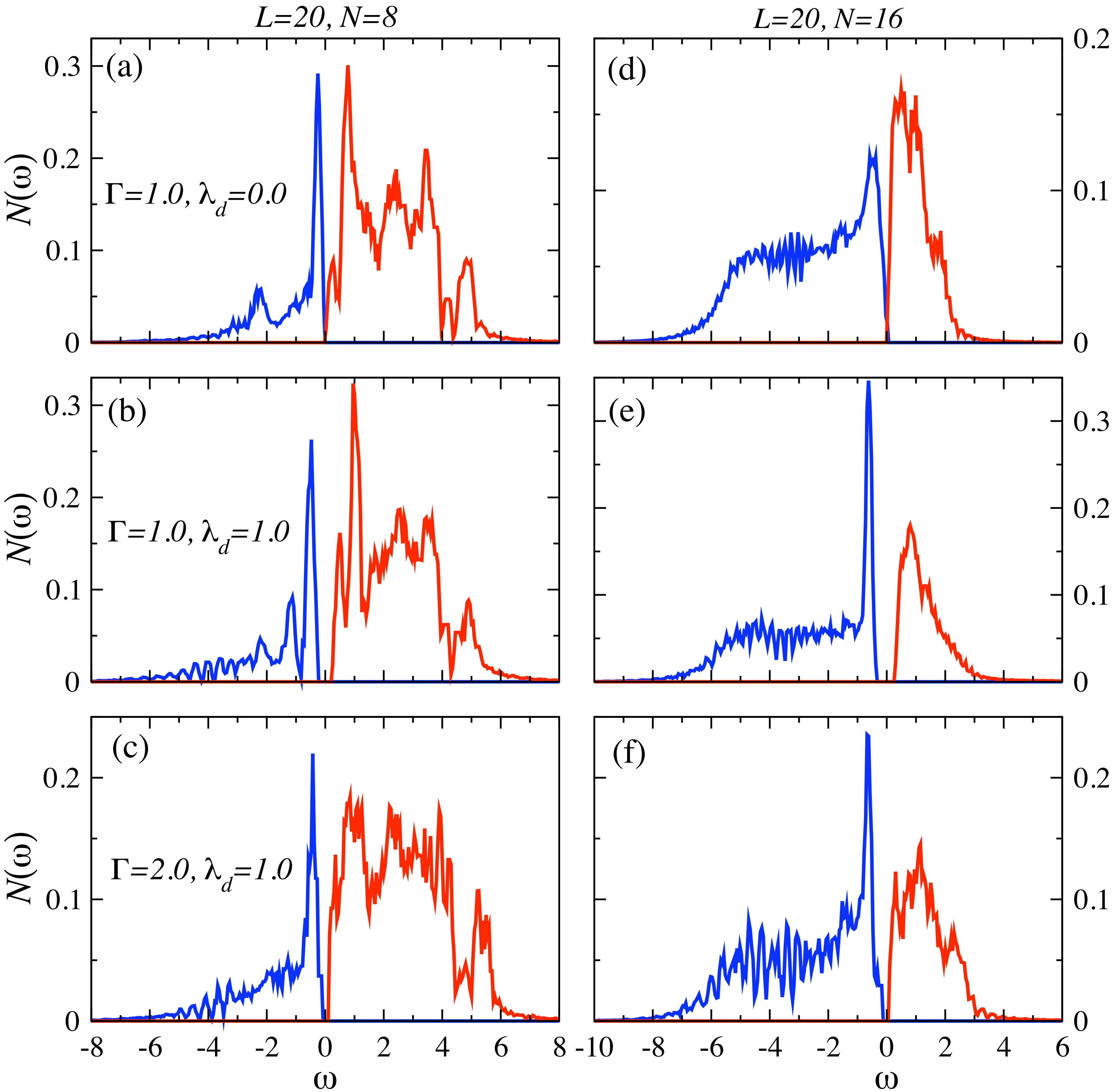
L=20, N=4
L=20, N=6
L=20, N=8
L=20, N=10
(a)
dE/dλ_d
E
(b)
L=18, N=14
L=18, N=16
L=20, N=16
L=20, N=18
λ_d



(a)
L=20, N=6 (Short)
L=20, N=6 (Long)
L=20, N=4
L=20, N=6
L=20, N=8
L=20, N=10
(b)
L=18, N=14
L=18, N=16
L=20, N=18 (Short)
L=20, N=18 (Long)
L=20, N=16
L=20, N=18
R=Λ1/Λ2
λd



(a)
L=20, N=4
L=20, N=6
L=20, N=8
L=20, N=10
$R=\Lambda_1/\Lambda_2$
Λ_1, Λ_2
Γ
(b)
L=18, N=14
L=18, N=16
L=20, N=16
L=20, N=18
$R=\Lambda_1/\Lambda_2$
Λ_1, Λ_2
Γ



L=20, N=8
L=20, N=16
(a)
Γ=1.0, λ_d=0.0
(b)
Γ=1.0, λ_d=1.0
(c)
Γ=2.0, λ_d=1.0
(d)
(e)
(f)
N(ω)
ω

Conclusions:

1) m is very small near half filling after the Gutzwiller correction: Thus very strong quantum fluctuations of the amplitude of the OP

2)Interesting adiabatic continuity between finite \lambda and tJ model. Is the latter at the verge of d-wave SC?

3) With disorder R drops due to the rise of the second largest EV...algebraic order type scenario.

4) Get the high energyscales for tunneling and their J dependence, as well as asymmetry between adding and removing a particle near half filling.