Research Project

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1) Spin system with Ring exchanges on Triangular Lattice

C. Yasuda, Y. Uchihira

ground state close to 120° Neel state

2) Magnetism on Generalized Partial Line Graph

C. Hotta, S. Miyahara, H. Nakamura

Spin system with Ring exchanges on Triangular Lattice

$$H = J \sum P_2 - J_4 \sum (P_4 + P_4^{-1}) + J_5 \sum (P_5 + P_5^{-1}) - J_6 \sum (P_6 + P_6^{-1})$$

AF

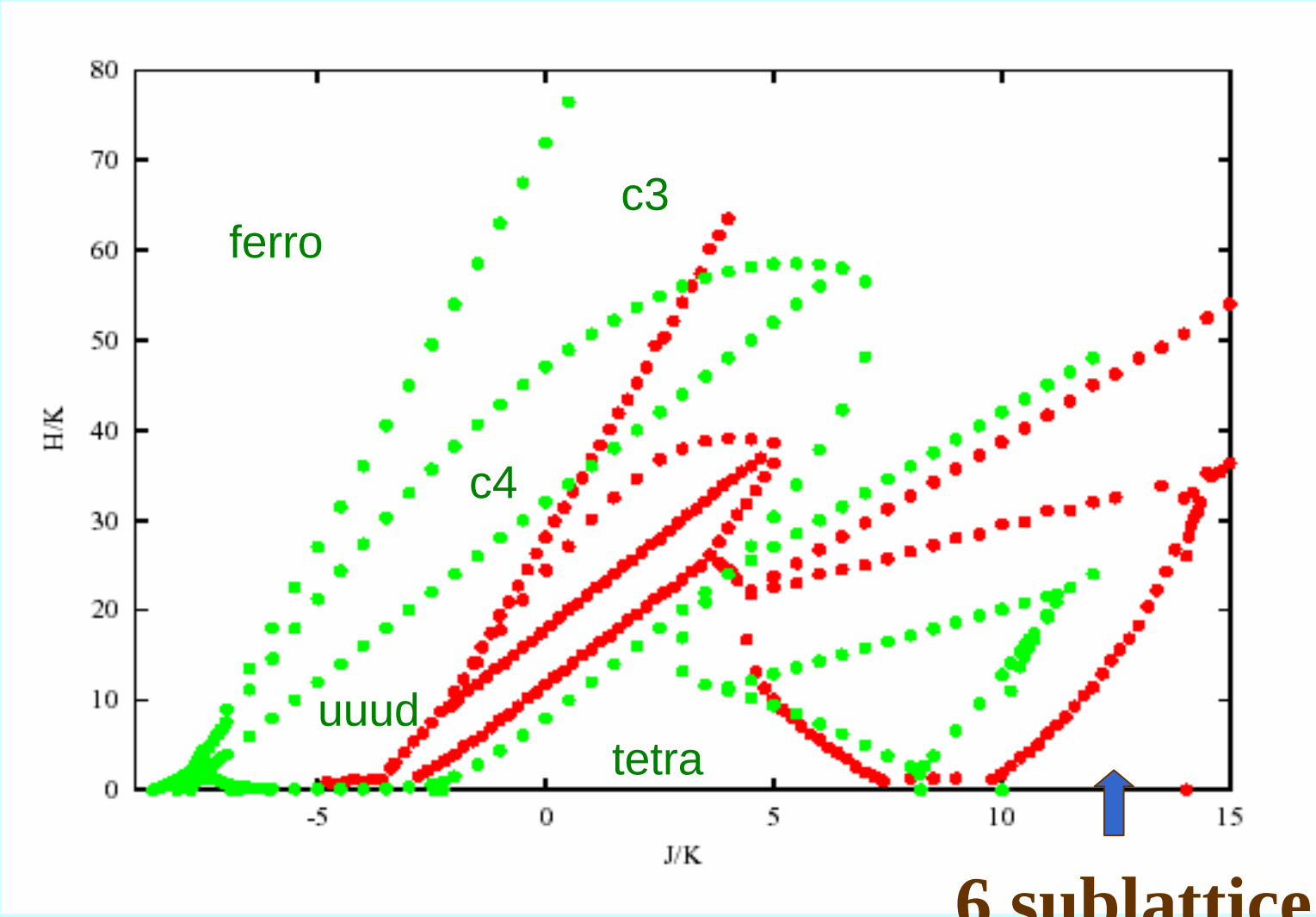
F

$$J = J_2 - J_3 / 2$$

Strong frustration

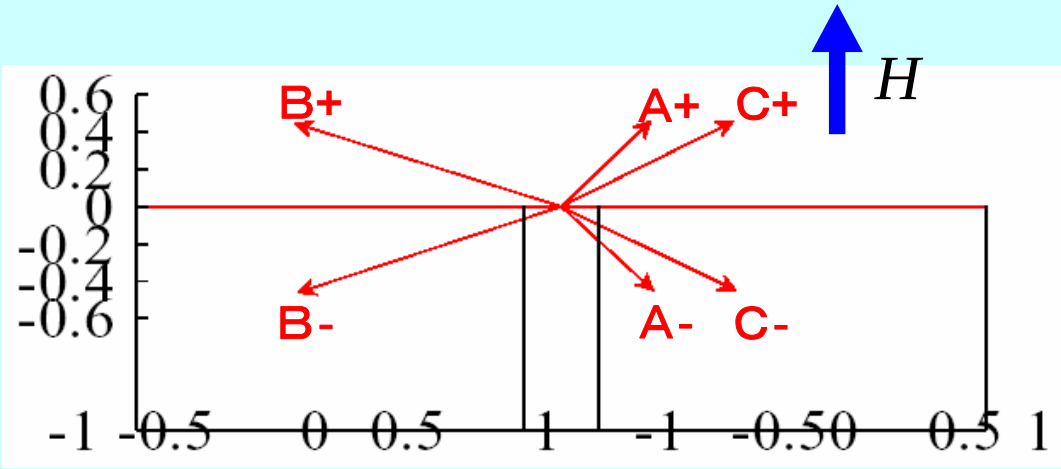
Quantum Effects （Low dimensionality、S=1／2）

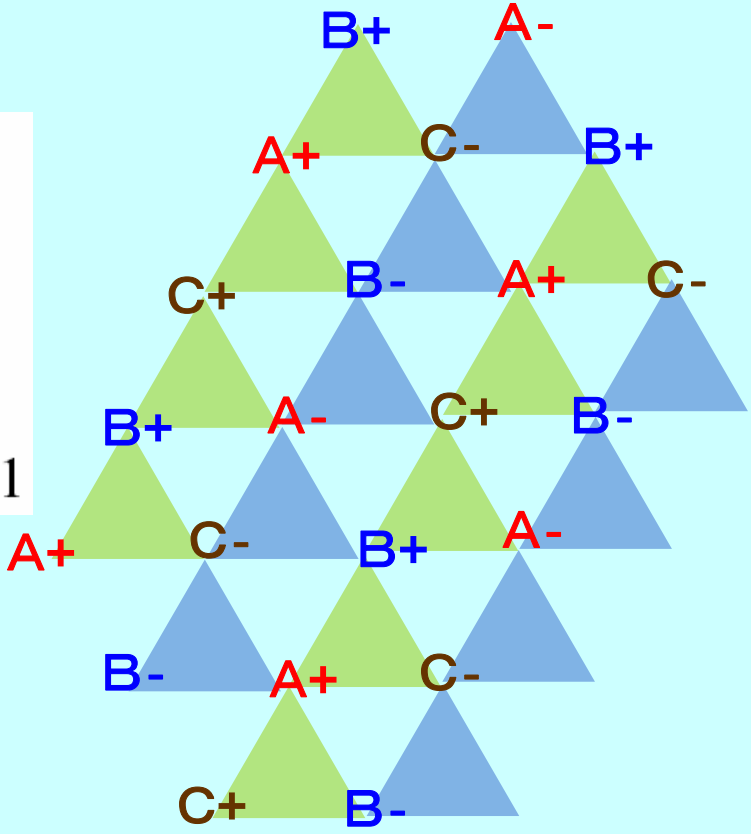
Phase Diagram by Mean Field Approximation



6 sublattice

Spin Structure of the 6 sublattice state



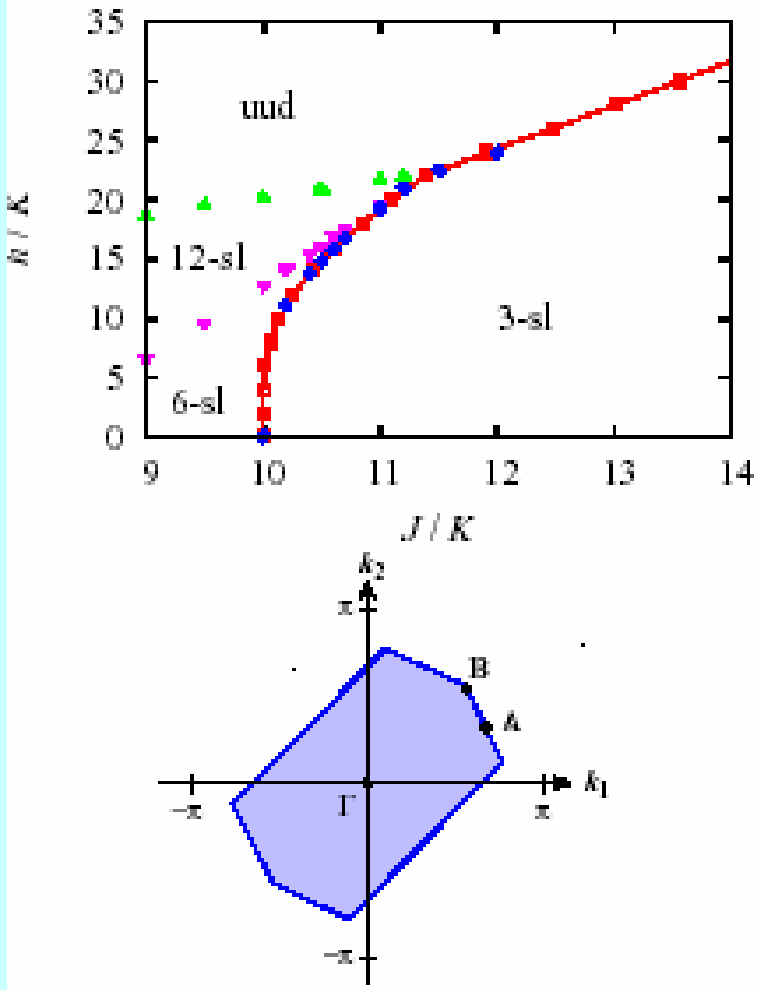


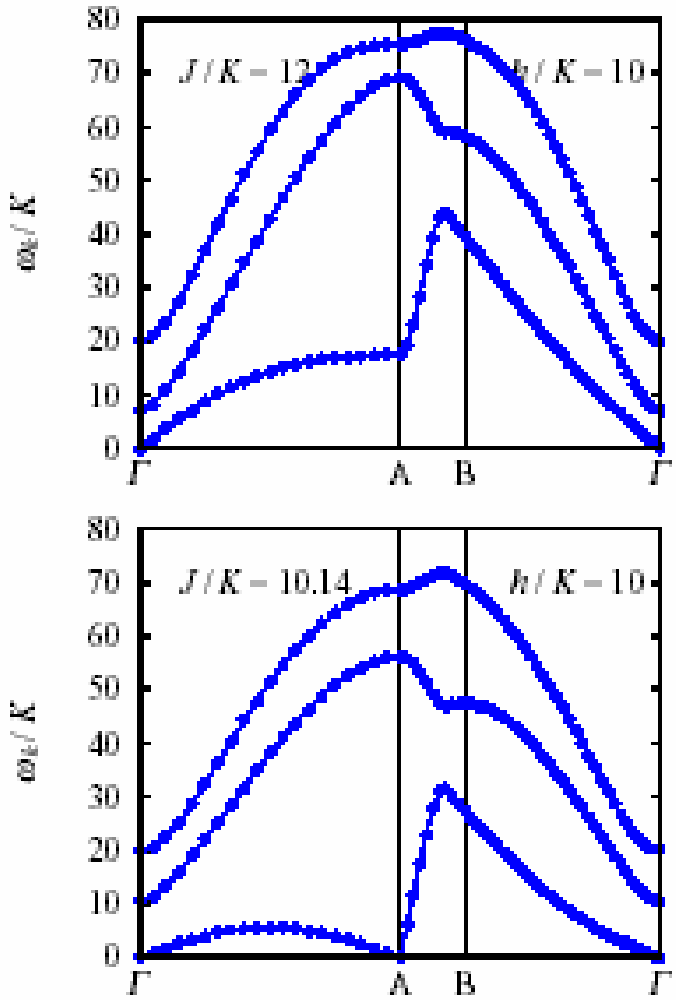
$\chi_s > 0$

$\chi_s < 0$

Need to Study Quantum Effects

$$H = J\sum_{(ij)} \sigma_i \cdot \sigma_j + K \sum_{plaquettes} h_p - HM$$





Magnetism on Generalized Partial Line Graph

In flat bands strong correlation effects are expected to work among electrons

Flat band ferromagnetism

Mielke, Tasaki

Antiferromagnetism on lattice structures with flat bands

kagome, pyrochlore, checkerboard

Flat Bands may enhance superconducting instability

Imada and Kohno 2000

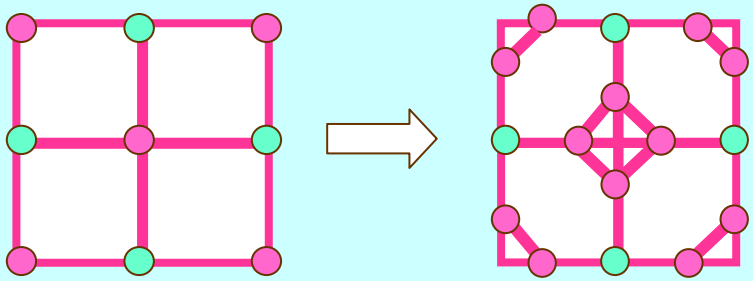
Partial Line Graph

a new simple way to generate flat bands.

1) Suppose a lattice with $N\,(\geq 2)$ **sublattices.**

2) Create z **lattice points (**A_1 **,** A_2 **, … ** A_z **)**
on each bond connected to an A site.

3) Replace each A site with created z **sites(➡ cluster)**
Connect these sites with bonds(zt **hopping integral** t **)**



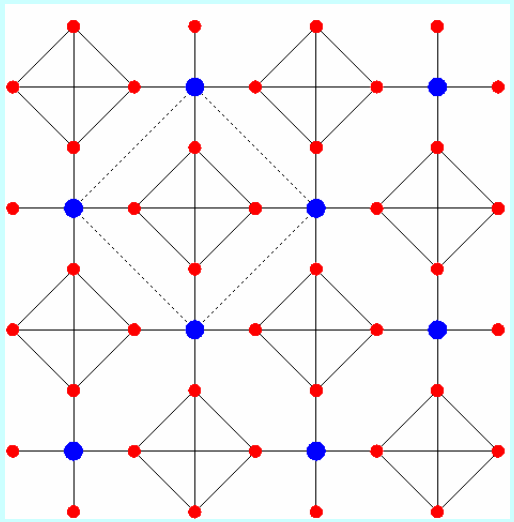
If $z > N$**, then** $z - N$**-fold degenerate flat bands**
at $E = -t$ **.**

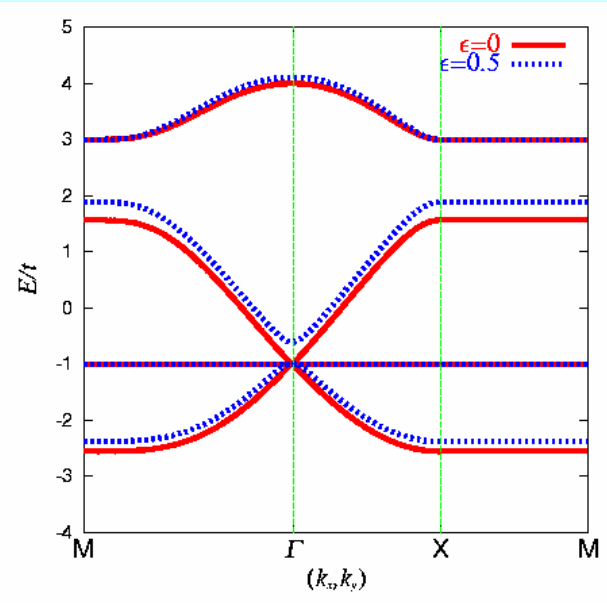
Examples

ε : site energy at B sites t : hopping integrals

Square lattice

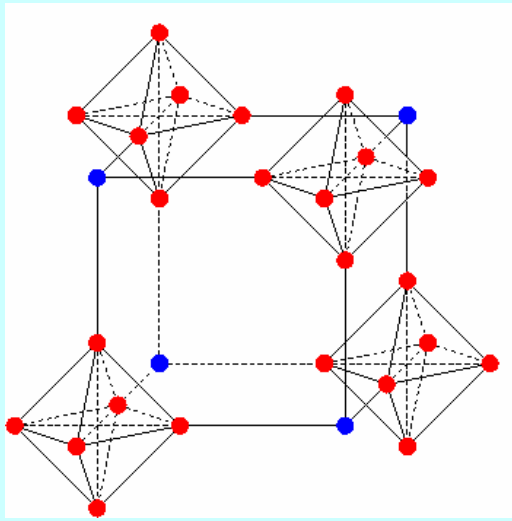
$N = 2 \quad z = 4 \quad D$=2

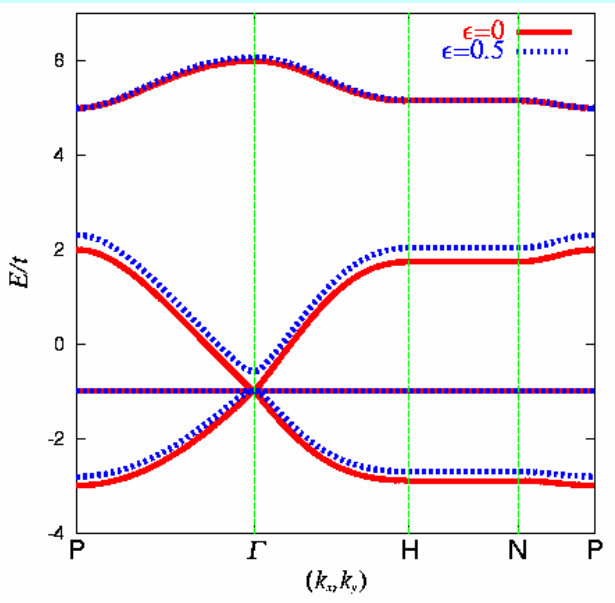




Simple cubic lattice

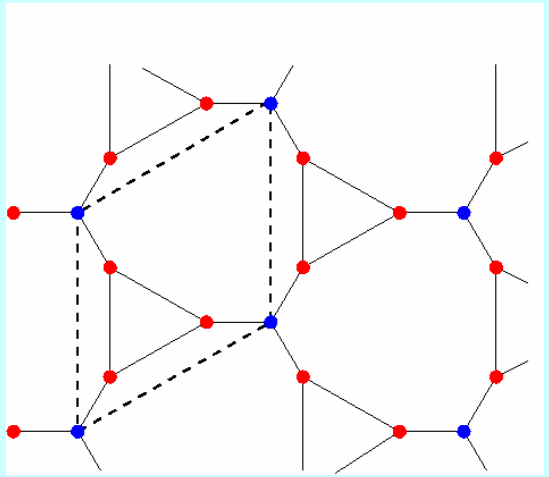
$N = 2 \quad z = 6 \quad D = 4$

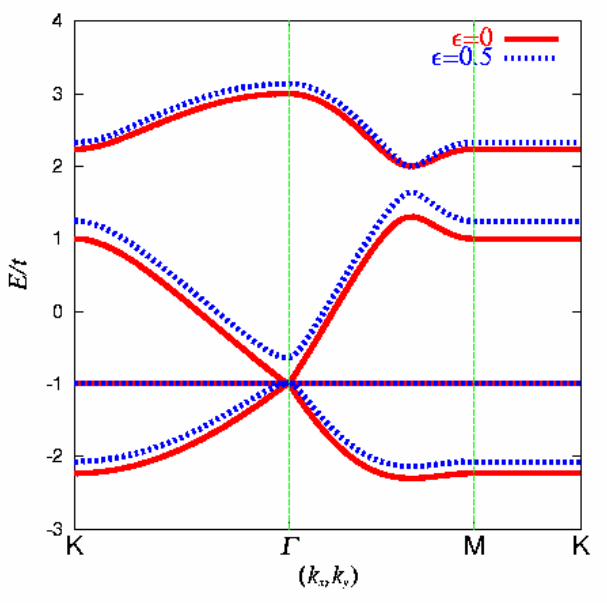




Honeycomb lattice

$N = 2 \quad z = 3 \quad D = 1$



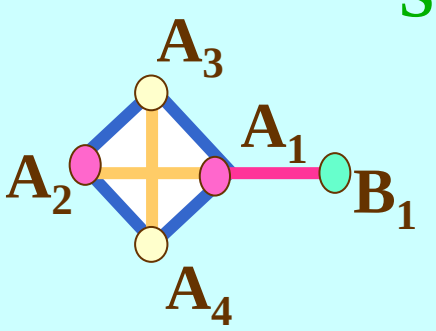


Generalized Partial Line Graph

1) Divide a cluster into M subsets

$(A_1, \ldots A_{m_1})$ $(A_{m_1+1}, \ldots A_{m_1+m_2})$ $\cdots$ $(\ldots A_z)$

S_1 S_2 $\cdots$ S_M



hopping

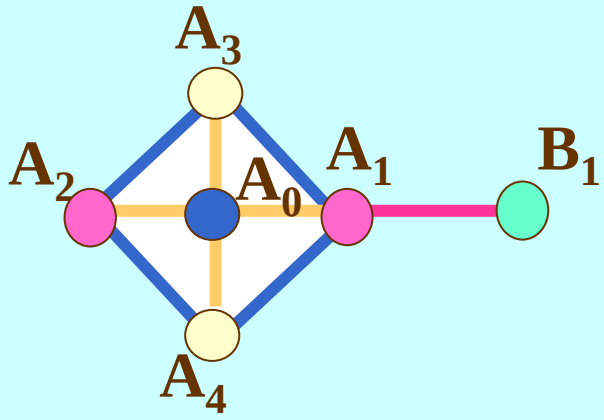
in the same subset $= t_0$

between S_i and S_j $= t_{ij}$

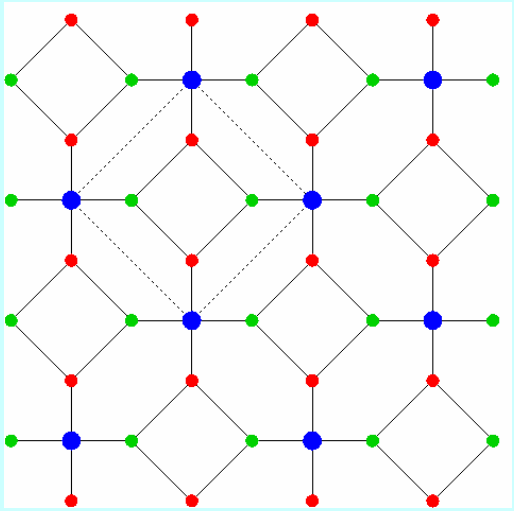
$z - N - M + 1$ -fold degenerate flat bands at $E_{\mathbf{k}} = -t_0$

2) Maintain original A sites within clusters.

(clusters with $z+1$ sites)

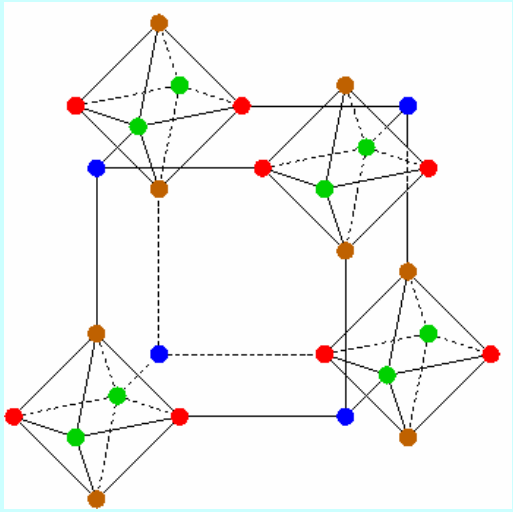


Examples of generalized partial line graph



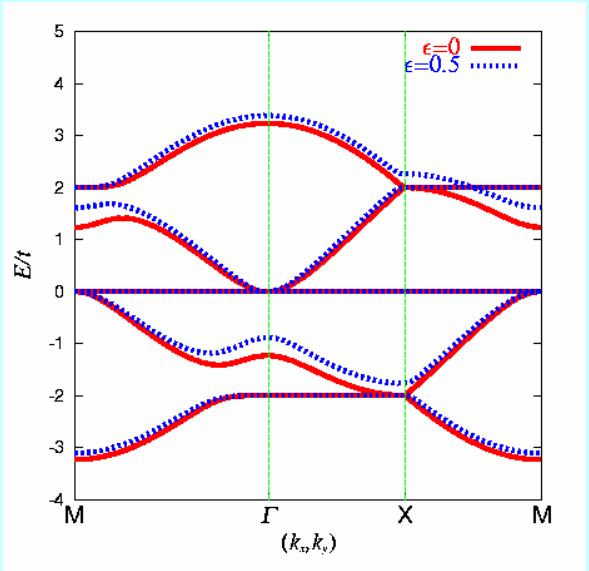
$N = 2 \quad z = 4 \quad M = 2$

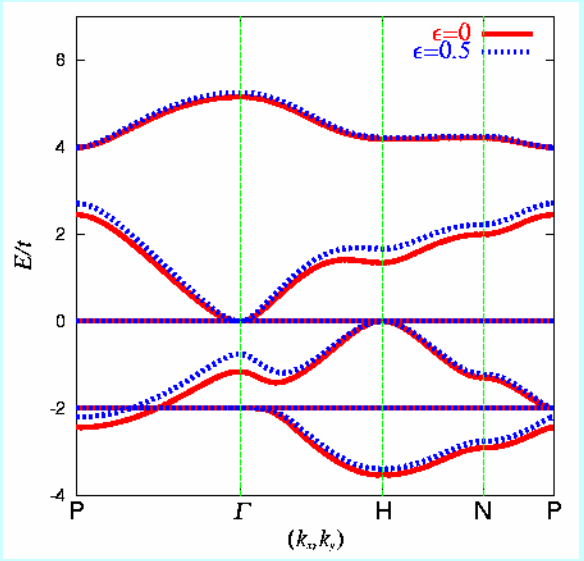
$t_0 = 0 \qquad D = 1$



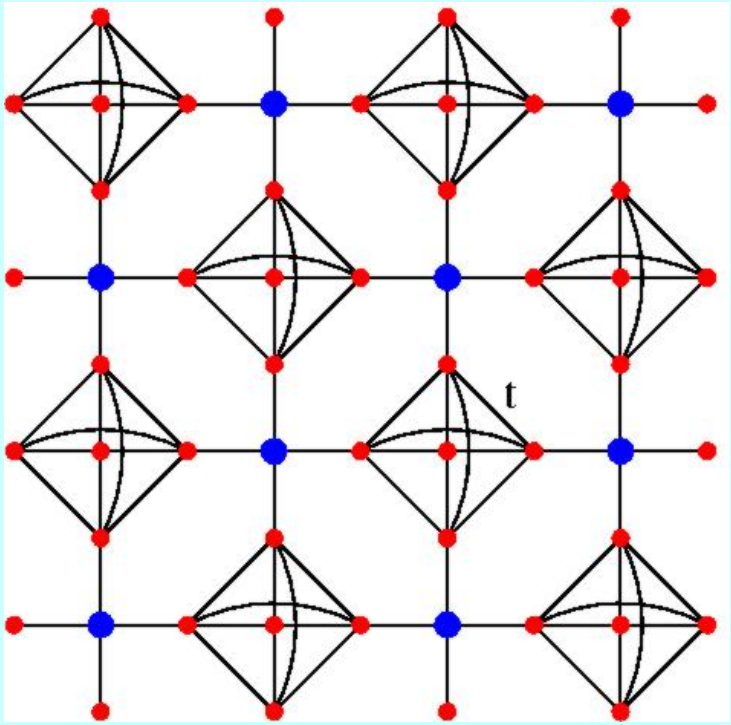
$N = 2 \quad z = 6 \quad M = 3$

$t_0 = 0 \quad t_{12} = t_{23} = t_{31} = t \quad D = 2$

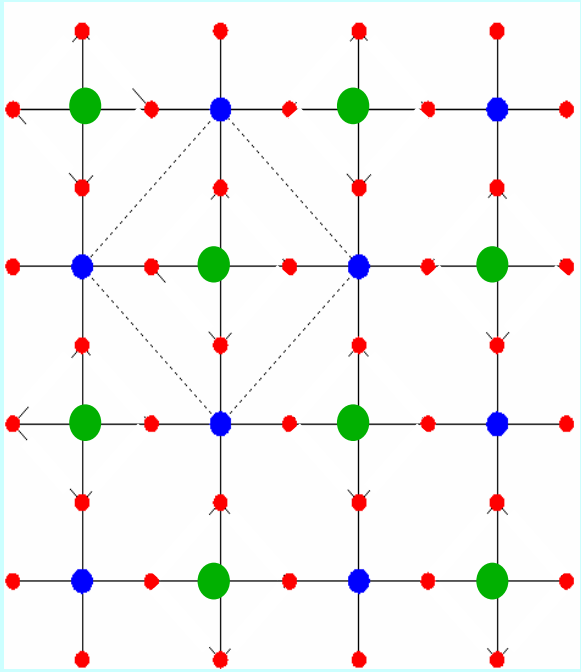




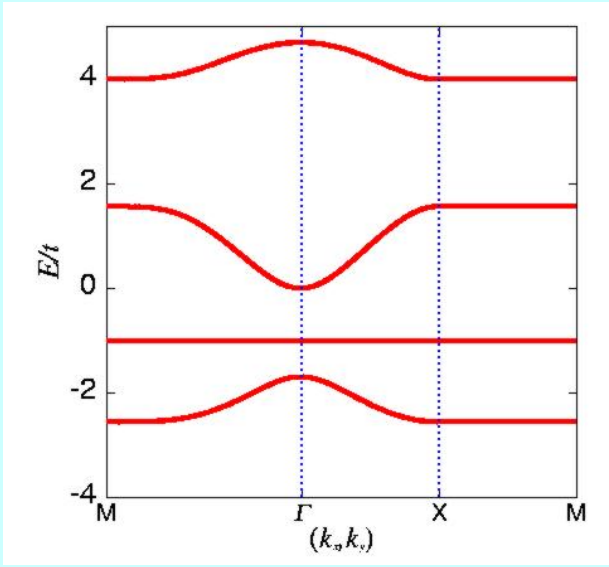
Another flat band at $E = -2t$



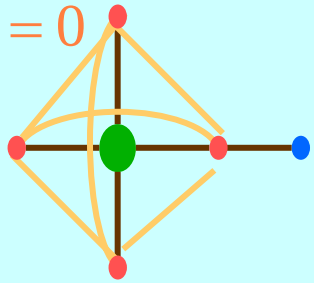
Lieb model is one of the generalized partial line graphs !



$N = 2 \quad z = 4 \quad M = 1$



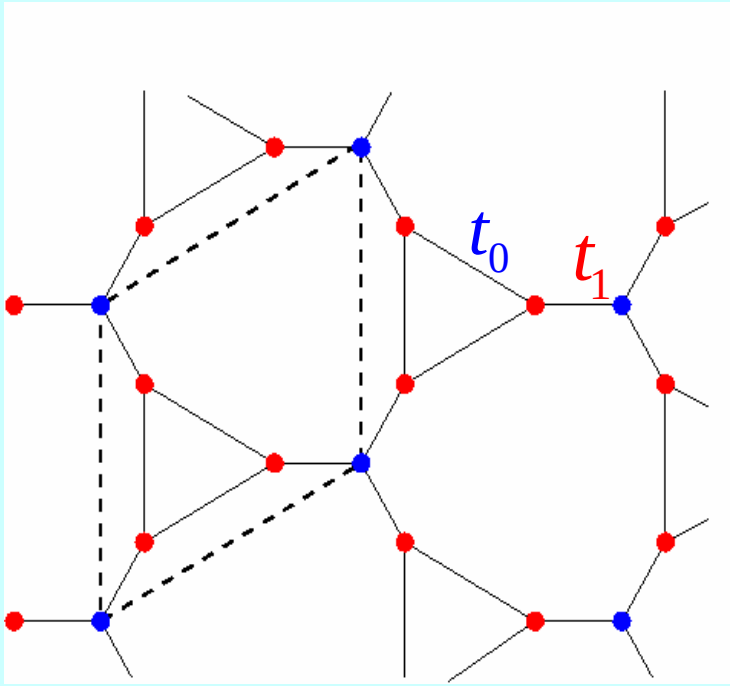
$t_2 = 0$

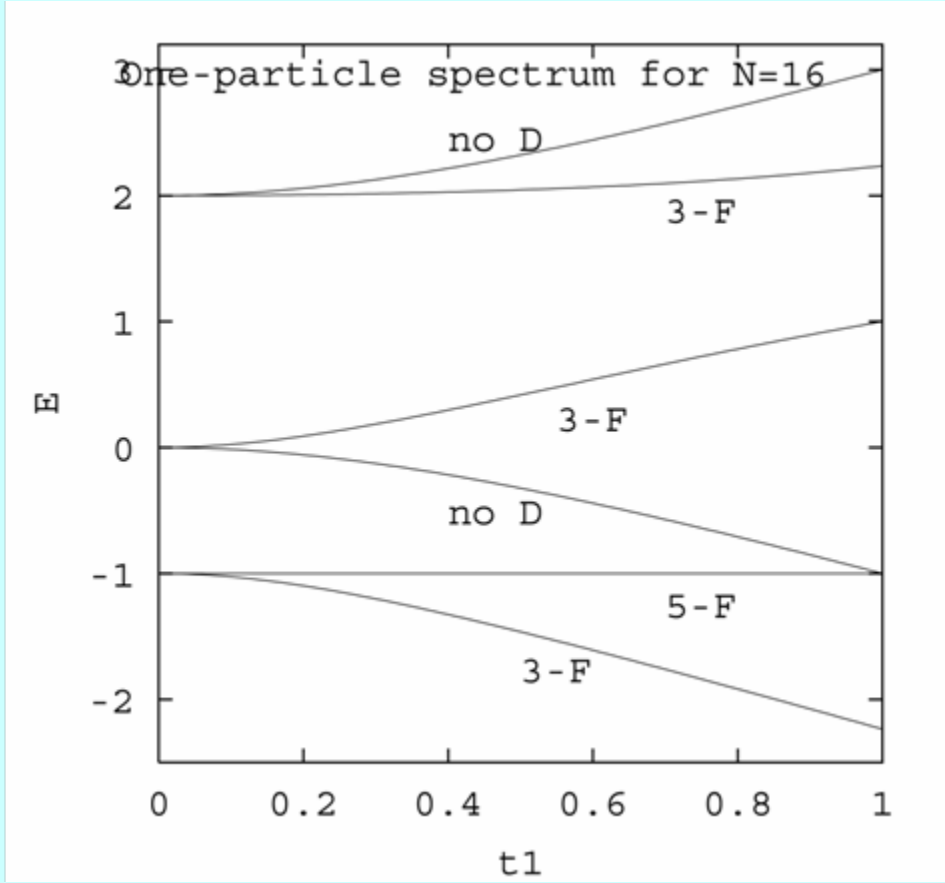


$t_0 = 0 \quad D = 3$

Hubbard model on partial line graph

Example

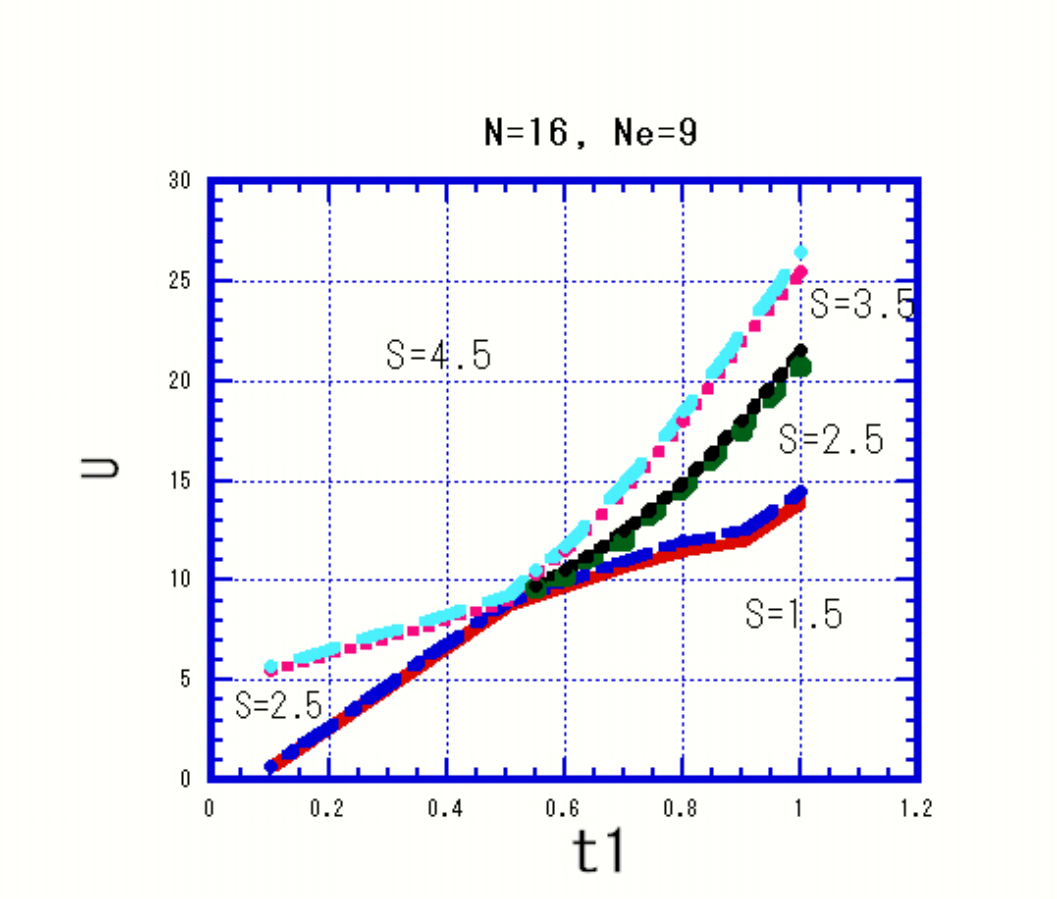




Calculations for $N = 16$ **and** $N_e / N_u > 1$

$N_e = 5, 6, 7, 8$ **No ferromagnetism**

$N_e = 9$ **One electron in the flat band**

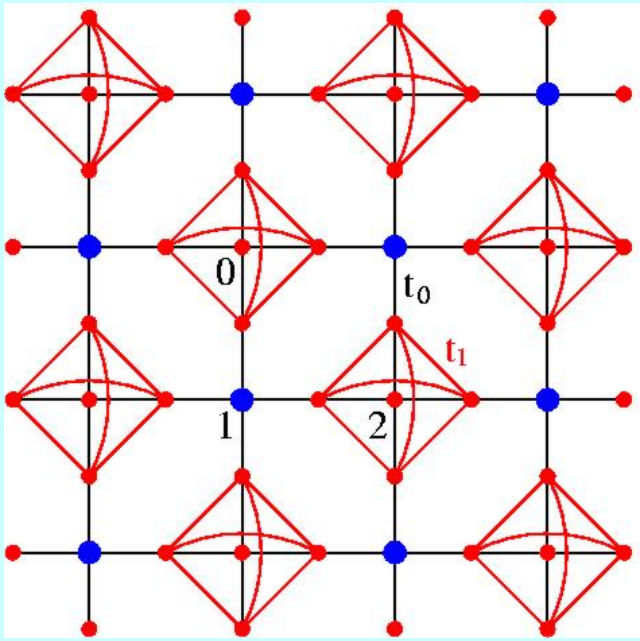


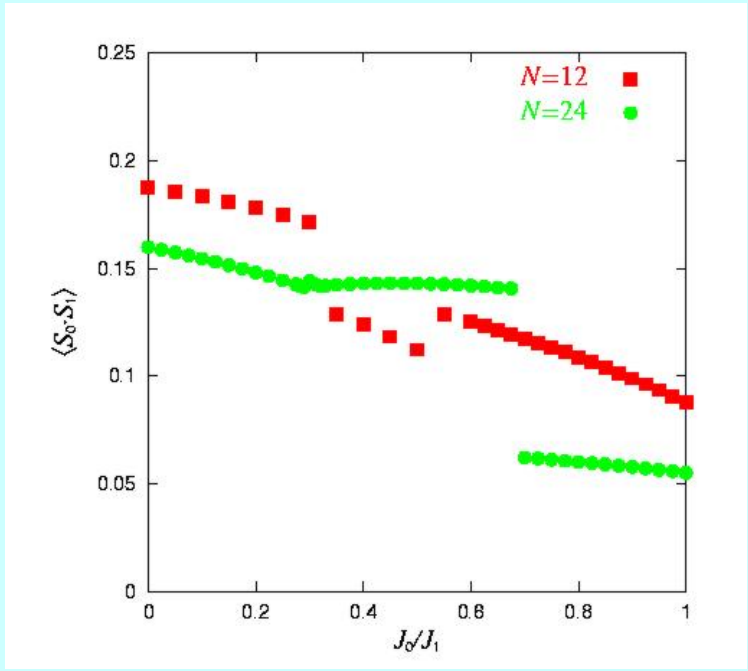
Heisenberg Antiferromagnet on generalized Lieb model

$J_0 \gg J_1$ **ferrimagnetism**

ferrimagnetism is unstable for $J_1 >\sim 0.3 J_0$

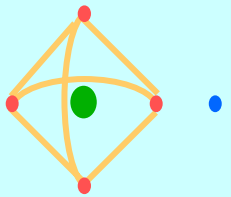
Two more phases?





$\langle S_0 S_1 \rangle$

What happens when $J_1 \gg J_0$ **?**

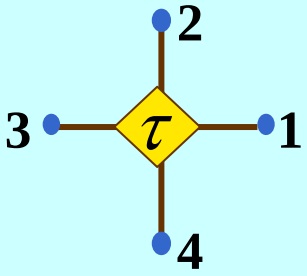


4 spins form a singlet state(doubly degenerate).

➡ **Pseudospin** τ **(chirality)**

2nd order perturbation in terms of J_0

Effective coupling between spin 1,2,3,4 and τ



$$h = -\frac{J_0^2}{6J_1}\left\{(-\frac{1}{2}+\tau^- +\tau^+)(S_1 \bullet S_2 + S_3 \bullet S_4)\right.$$

$$+(-\frac{1}{2}+\omega^2\tau^- +\omega\tau^+)(S_1 \bullet S_3 + S_2 \bullet S_4)$$

$$\left.+(-\frac{1}{2}+\omega\tau^- +\omega^2\tau^+)(S_2 \bullet S_3 + S_4 \bullet S_1)\right\}$$

Infinite degeneracies of the classical ground state

Novel Spin Liquid ?

Summary

1) Magnetic LRO, such as ferro- and ferri- magnetism is expected to occur if the interaction is turned on.

2) Antiferromagnets on generalized partial line graphs may realize novel spin states

Effective theory is necessary