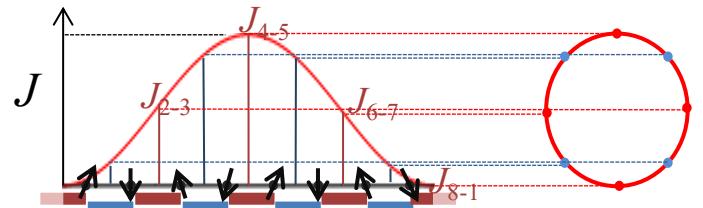


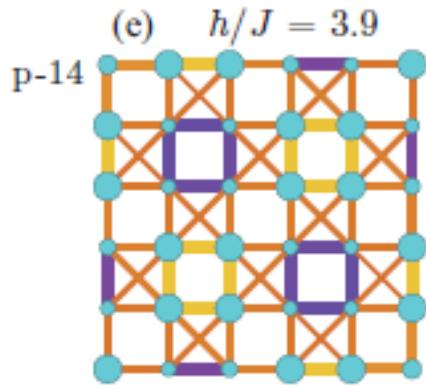
SSDを用いたフラストレート量子スピン系、多自由度電子系の解析

東北大理 柴田 尚和

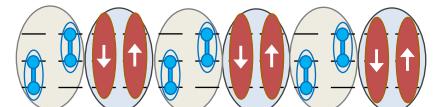
- 並進対称性の破れと境界条件
- 2次元フラストレート量子スピン系
- 多自由度強相関電子系



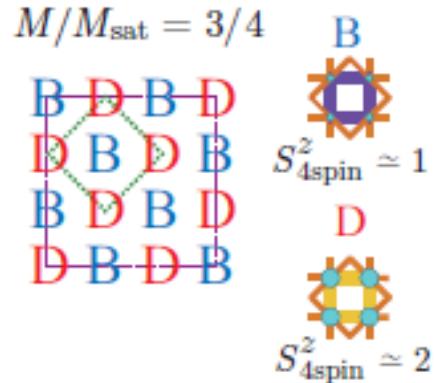
Checkerboard Lattice



2-Channel Kondo Lattice



Kurebayashi and Shibata (2019)

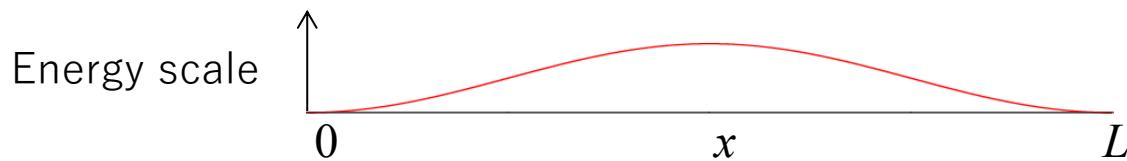


Morita and Shibata PRB (2016)

境界条件と対称性の破れ

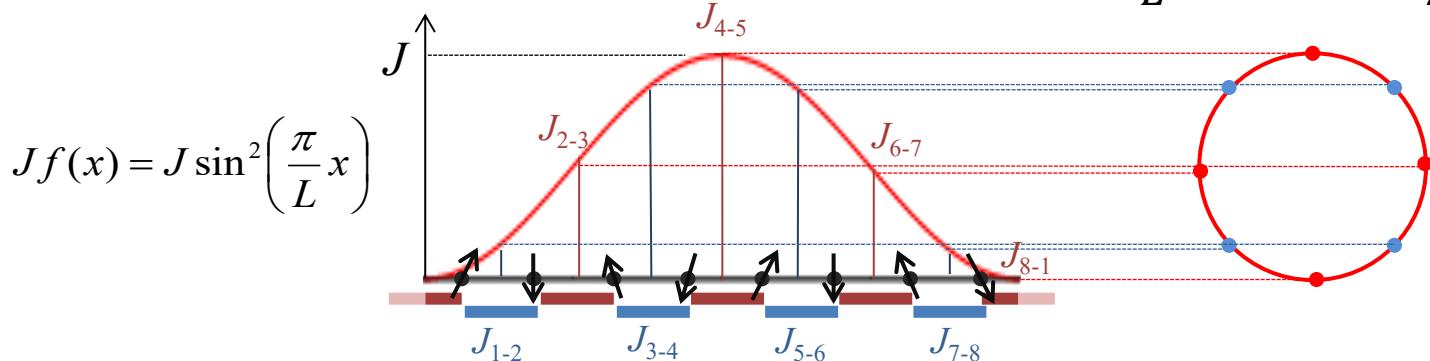
$$f(x) = \sin^2\left(\frac{\pi}{L}x\right)$$

Deformation



A. Gendiar, R. Krcmar, and T. Nishino, Prog. Theor. Phys. **122**, 953 (2009); **123**, 393 (2010).

$$\sin^2\left(\frac{\pi}{L}x\right) = \frac{1 - \cos\left(\frac{2\pi}{L}x\right)}{2}$$

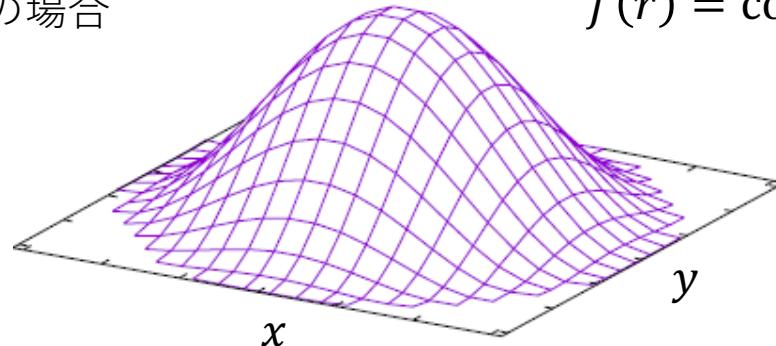


$$J_{1-2} + J_{3-4} + J_{5-6} + J_{7-8} = J_{2-3} + J_{4-5} + J_{6-7} + J_{8-1} = JN/2$$

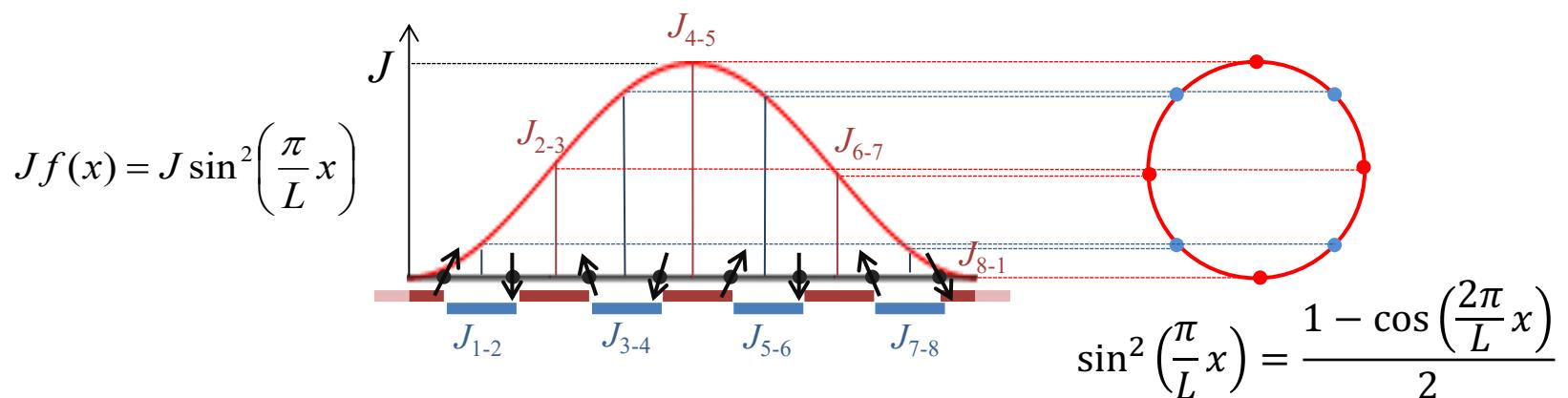
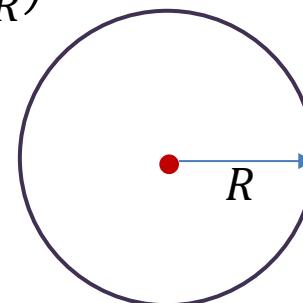
↑
0

境界条件と対称性の破れ

2次元の場合



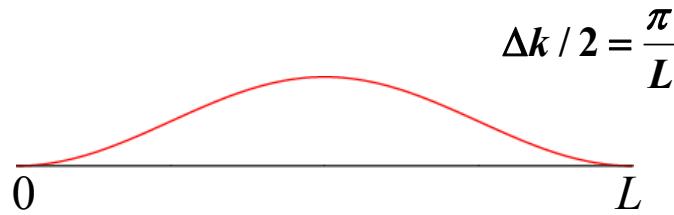
$$f(r) = \cos^2\left(\frac{\pi r}{2R}\right)$$



$$J_{1-2} + J_{3-4} + J_{5-6} + J_{7-8} = J_{2-3} + J_{4-5} + J_{6-7} + J_{8-1} = JN/2$$

↑
0

Sine-Square Deformation



$$H_{Original} = \sum_k (\varepsilon_k - \mu) c_k^+ c_k$$

$$H_{Deform} = \sum_k \frac{1}{2} (\varepsilon_k - \mu) c_k^+ c_k$$

$$- \sum_k \frac{1}{4} e^{-i\frac{\Delta k}{2}} (\varepsilon_{k+\frac{\Delta k}{2}} - \mu) c_{k+\Delta k}^+ c_k$$

$$- \sum_k \frac{1}{4} e^{i\frac{\Delta k}{2}} (\varepsilon_{k-\frac{\Delta k}{2}} - \mu) c_{k-\Delta k}^+ c_k$$

$$f(x) = \sin^2\left(\frac{\pi}{L}x\right)$$

$$\Delta k = \frac{2\pi}{L}$$

$$f(x) = \sin^2(\Delta k x / 2)$$

$$= \frac{1}{2} \{1 - \cos(\Delta k x)\}$$

$$= \frac{1}{2} - \frac{1}{4} \{\exp(i\Delta k x) + \exp(-i\Delta k x)\}$$

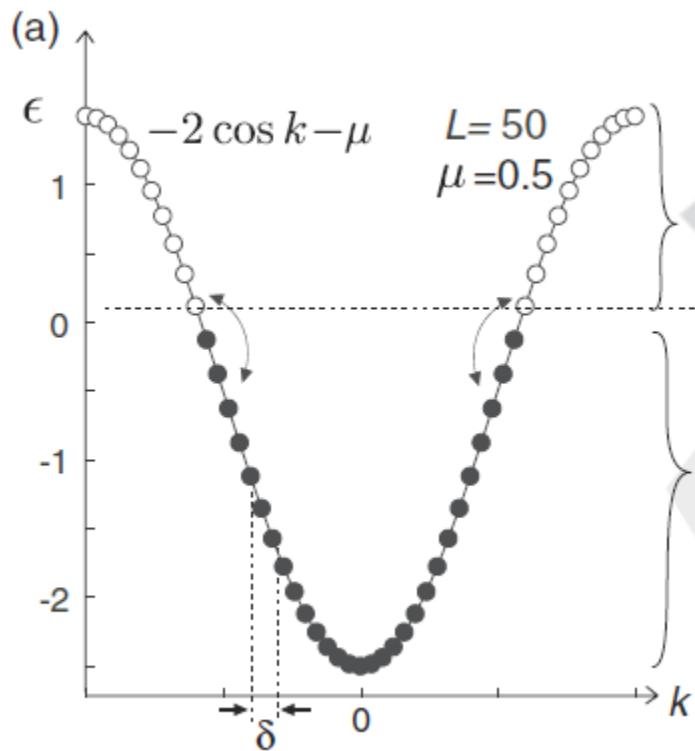
$$H_{Deform} = \begin{bmatrix} 1 & -0.4 & & & & & -0.4 \\ -0.4 & 0.7 & -0.3 & & & & \\ -0.3 & 0.3 & 0 & & & & \\ & & 0 & & & & \\ & & & -0.3 & 0.3 & & \\ & & & 0.3 & -0.7 & 0.4 & \\ & & & 0.4 & -1 & 0.4 & \\ & & & 0.4 & -0.7 & 0.3 & \\ & & & 0.3 & -0.3 & 0 & \\ & & & & 0.3 & -0.3 & \\ & & & & & 0 & \\ & & & & & & 0.3 & -0.3 \\ & & & & & & -0.3 & 0.7 \end{bmatrix}$$

Positive and negative eigenvalues are separated

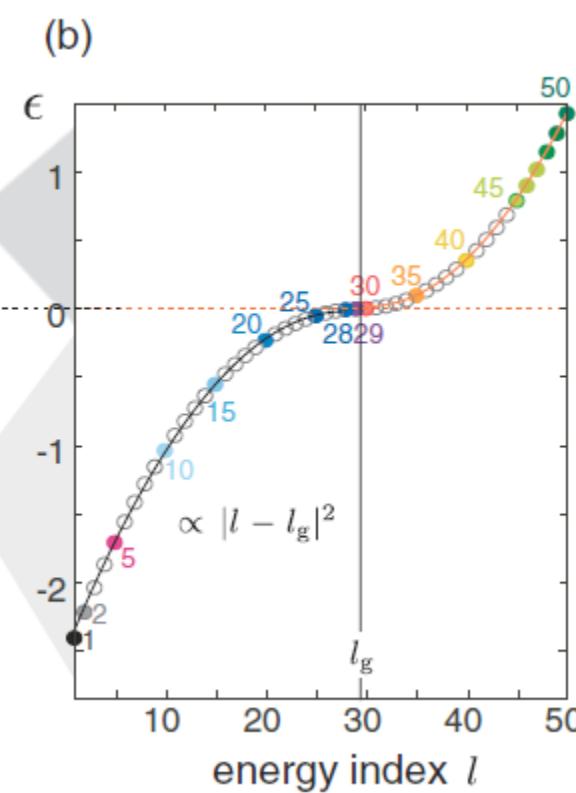
Ground state many-body wavefunction is identical to the original one

Energy spectrum

OBC

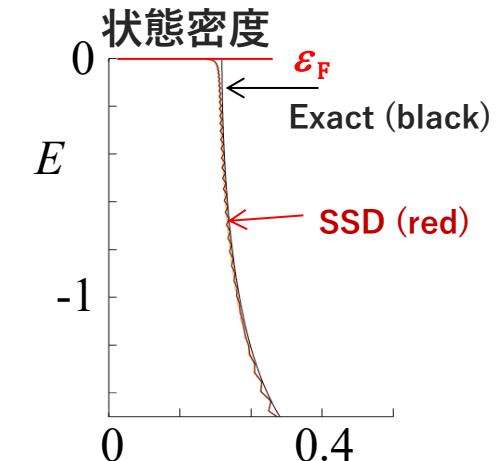
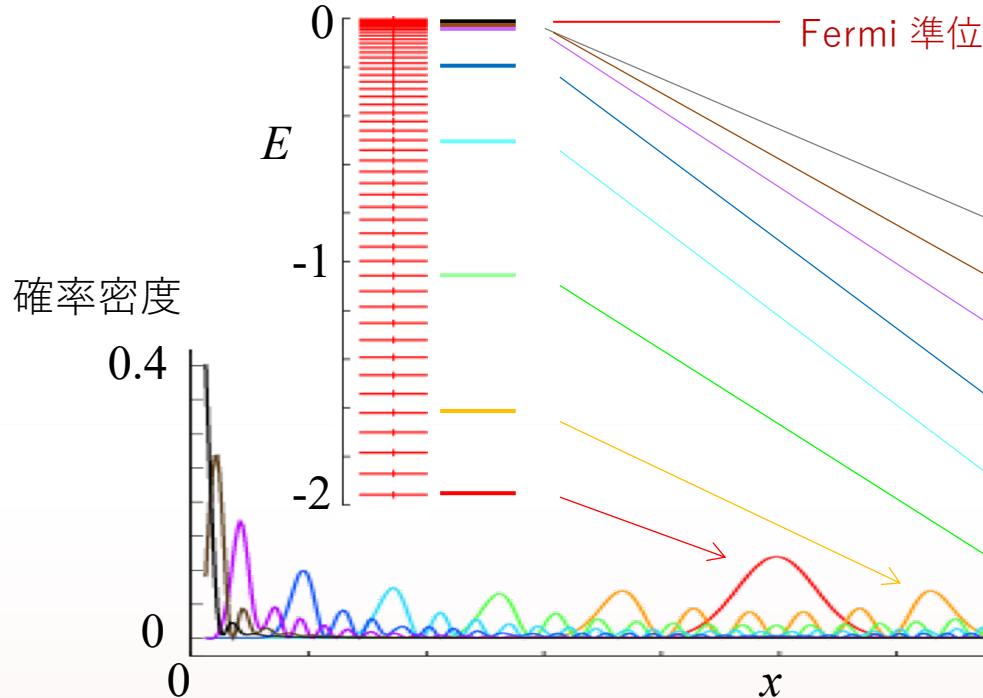


SSD

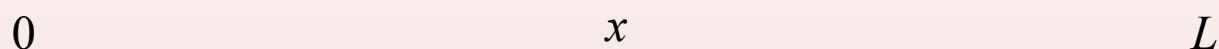


エネルギー準位と確率密度分布

エネルギー準位

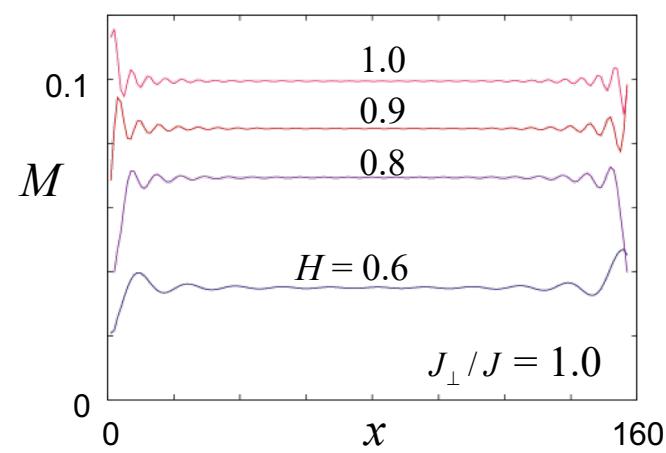
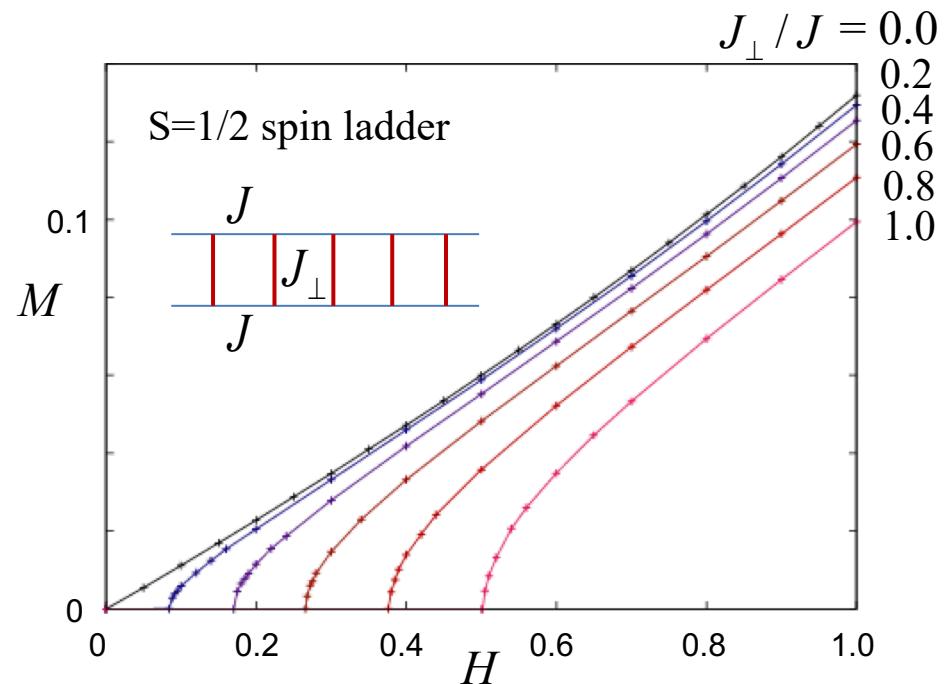
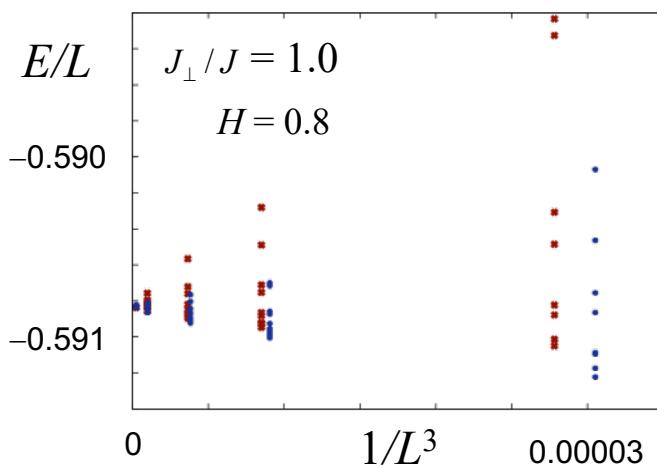
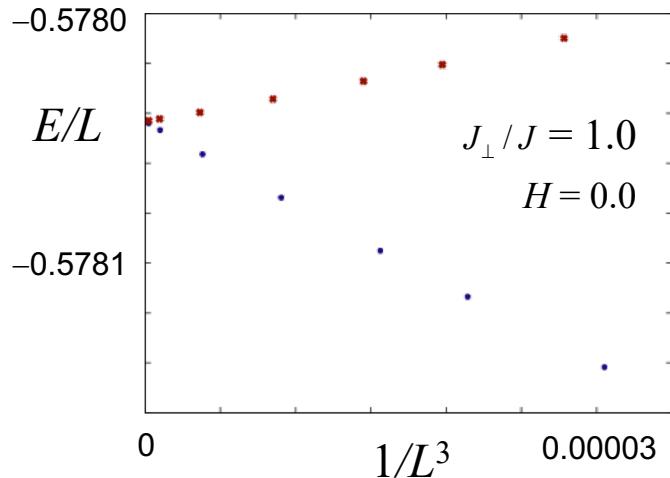


エネルギースケール

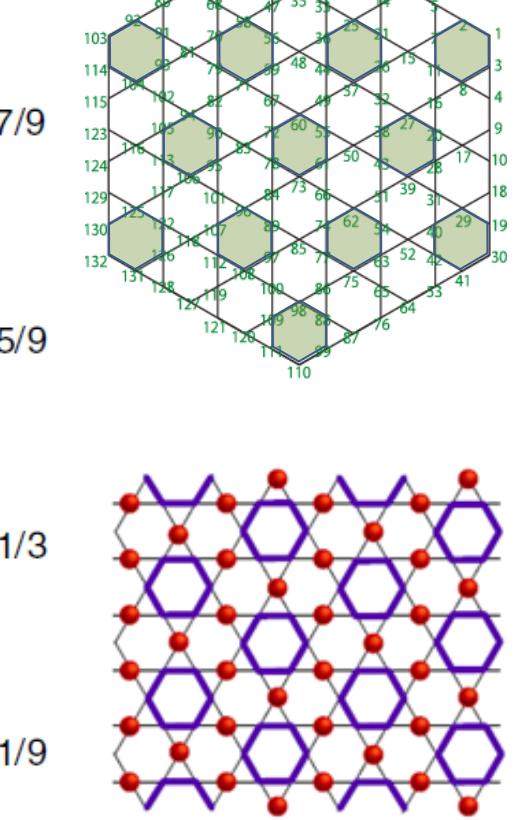
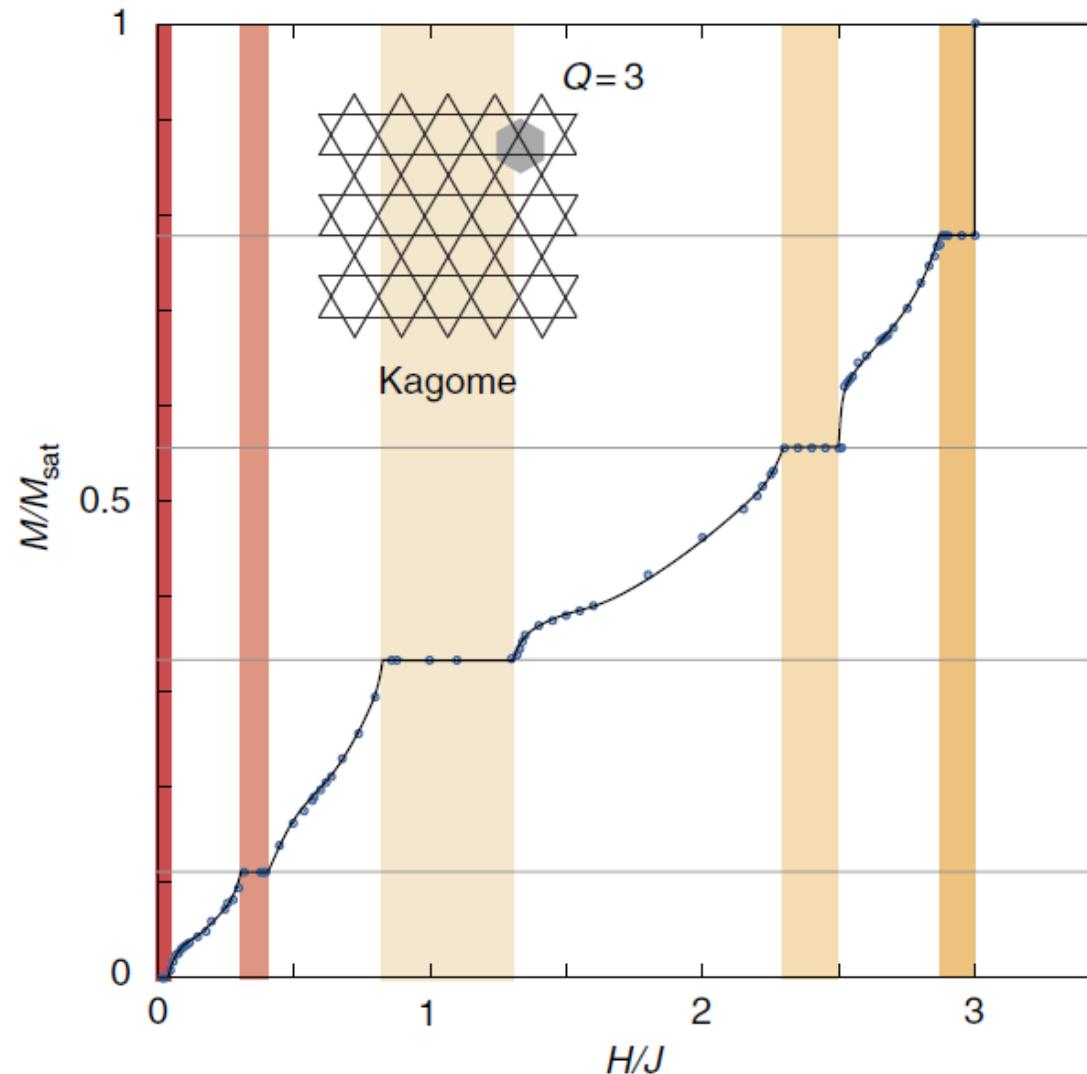


Size scaling and magnetization (SSD)

S=1/2 Heisenberg spin ladder

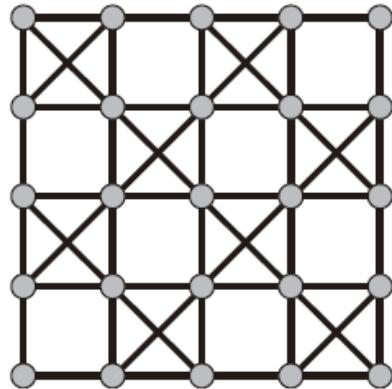


Kagome lattice

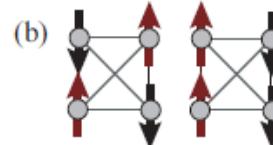


Checkerboard lattice

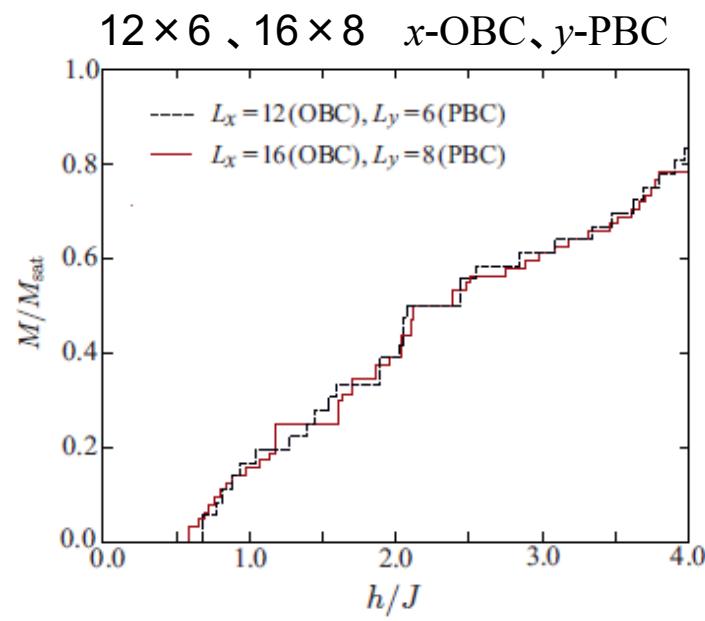
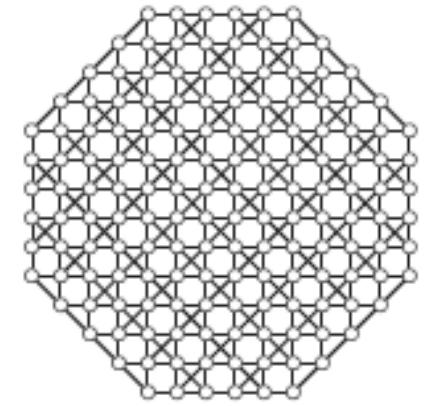
S=1/2 antiferromagnetic Heisenberg interaction



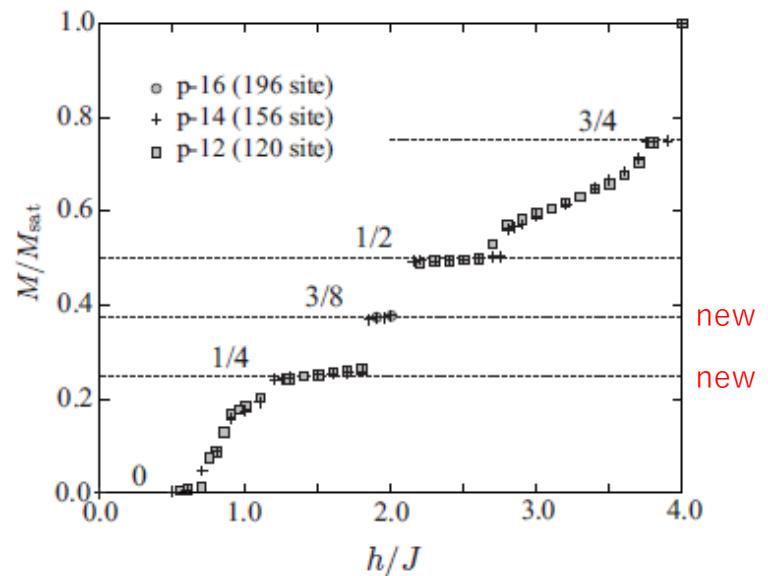
$$H = J \sum_{\langle i,j \rangle} \mathbf{S}_i \cdot \mathbf{S}_j - h \sum_i S_i^z$$



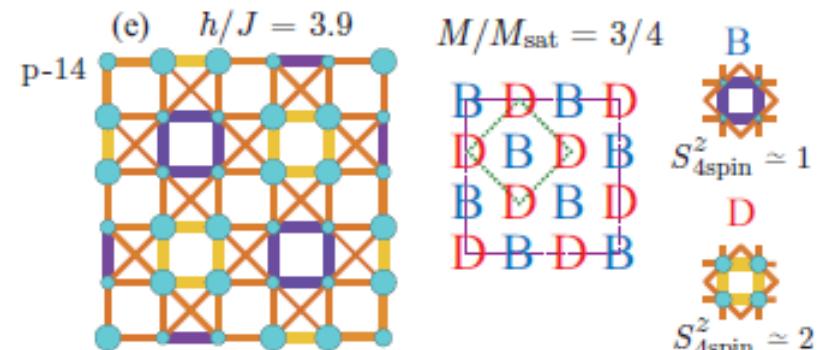
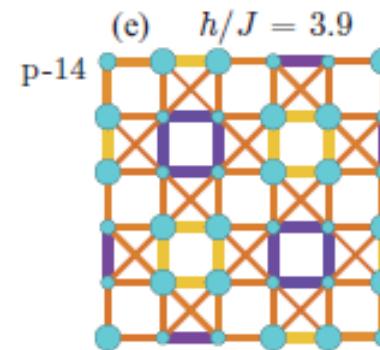
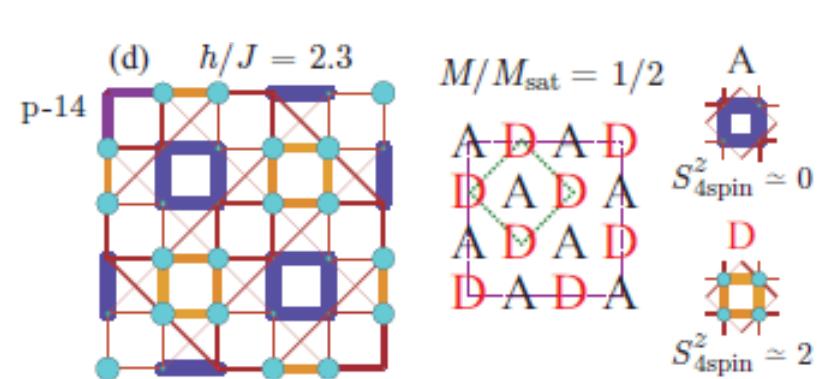
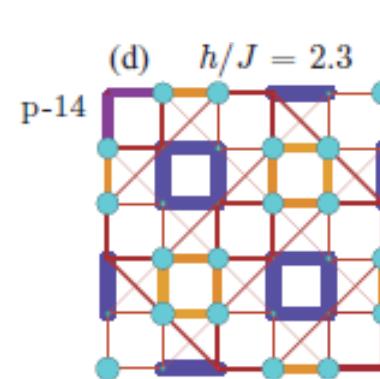
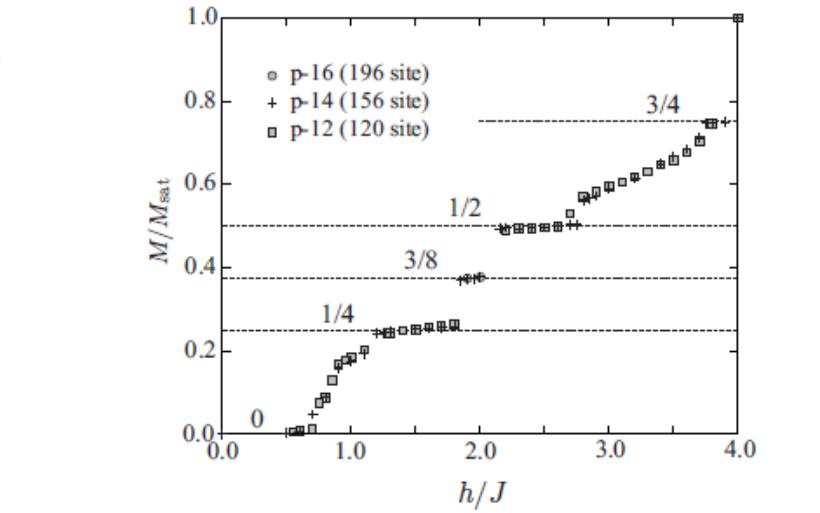
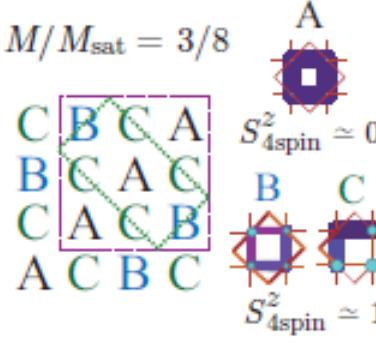
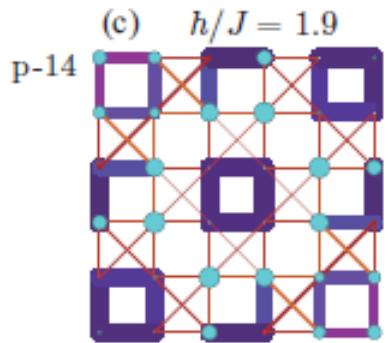
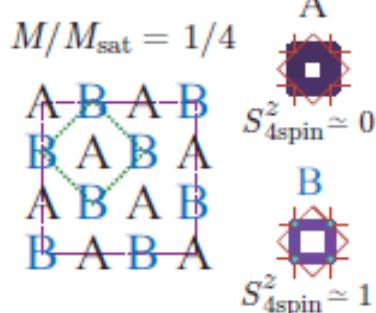
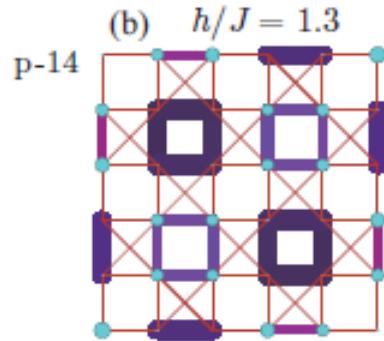
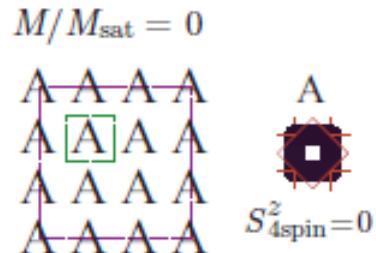
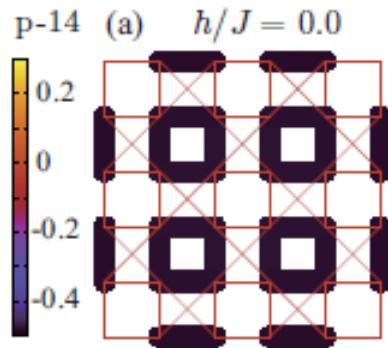
p-14



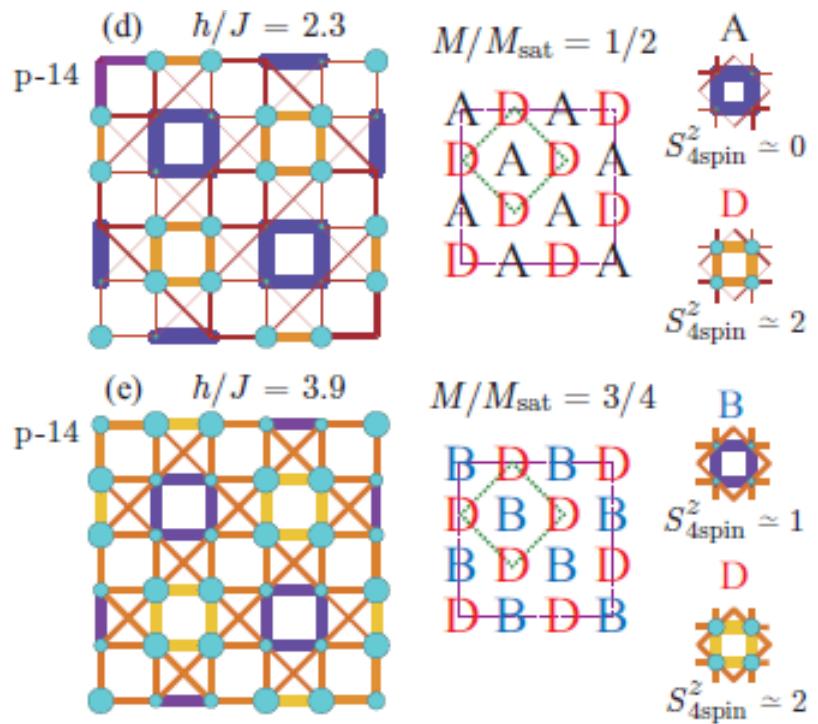
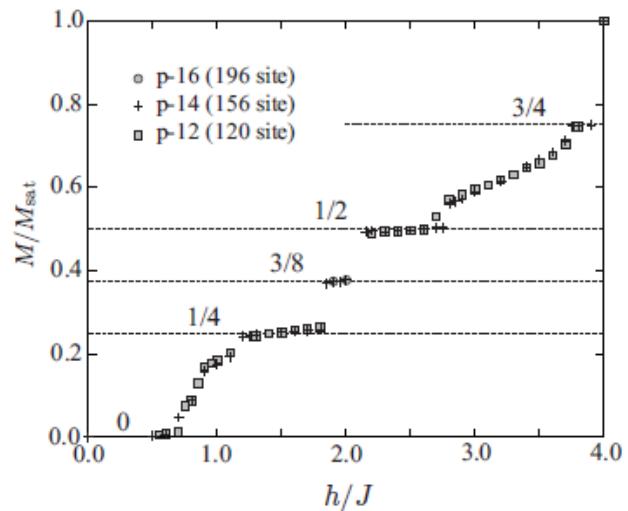
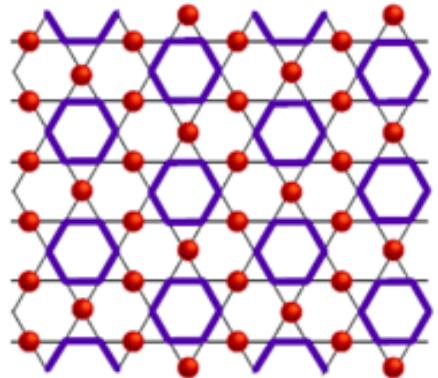
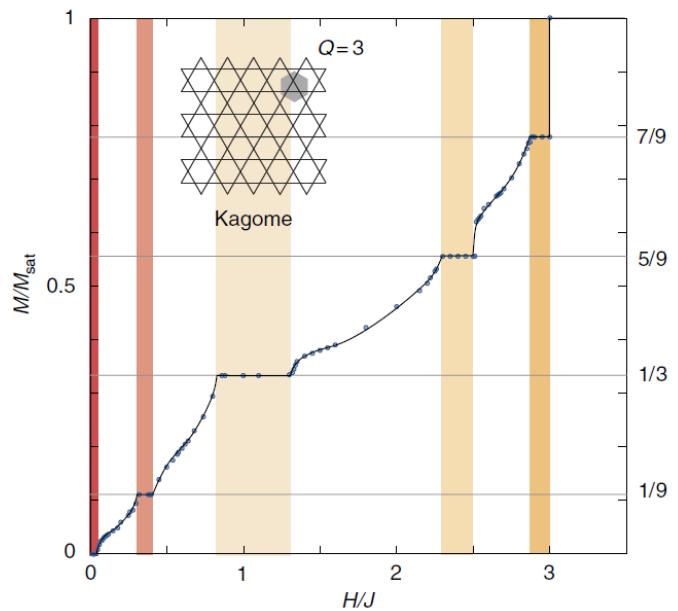
Morita and Shibata: PRB 94 140404 (2016)



Checkerboard lattice

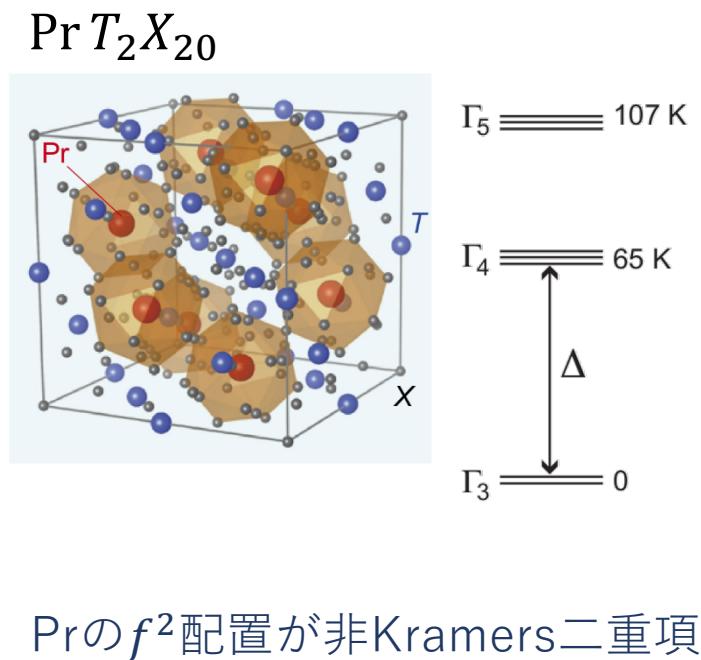


Magnetization plateau



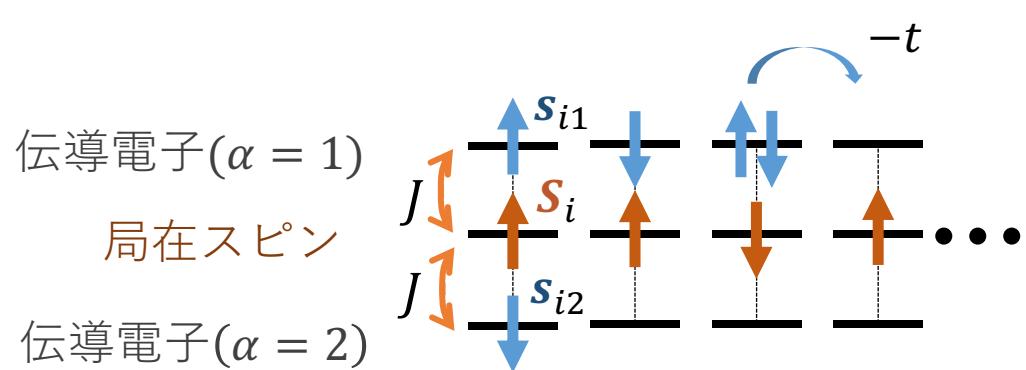
Two-channel Kondo lattice model

Pr籠型化合物 ※



f -電子の軌道自由度と伝導電子の混成模型

$$H = -t \sum_{i\sigma\alpha} (c_{i\alpha\sigma}^\dagger c_{i+1,\alpha\sigma} + \text{h. c.}) + J \sum_{i\alpha} \mathbf{s}_{i\alpha} \cdot \mathbf{S}_i$$



まとめ

- SSD により、境界条件の影響を効果的に抑制できる
(並進対称性、外場応答、サイズ外挿)
- 局所的量子もつれが生み出す安定秩序相
(磁化プラトー相、ダイマー絶縁相)
- 複数の自由度の協調による量子相の形成
(軌道自由度がスピングャップ相、絶縁相への転移を促進)

