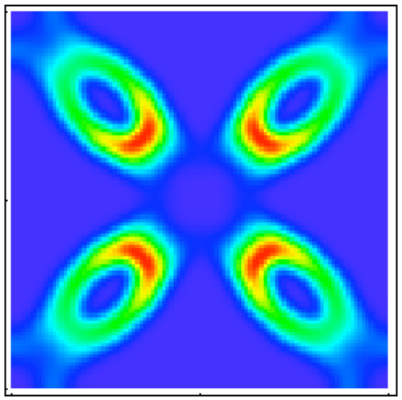
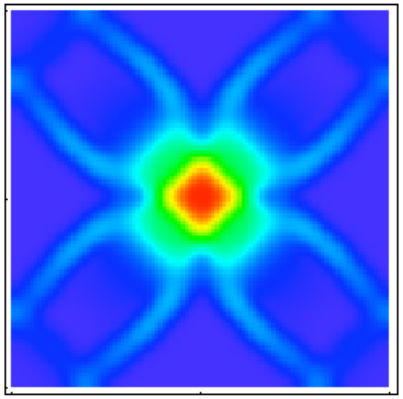
Magnetic Excitations of Stripes



E. W. Carlson
D. X. Yao
D. K. Campbell



PURDUE UNIVERSITY

BOSTON UNIVERSITY

Stripes: Why?

HTSC Dilemmas

Superconductivity from a non-Fermi liquid

High pairing scale despite strong repulsion

Metallic Charge Stripes: Spin-Charge Separation

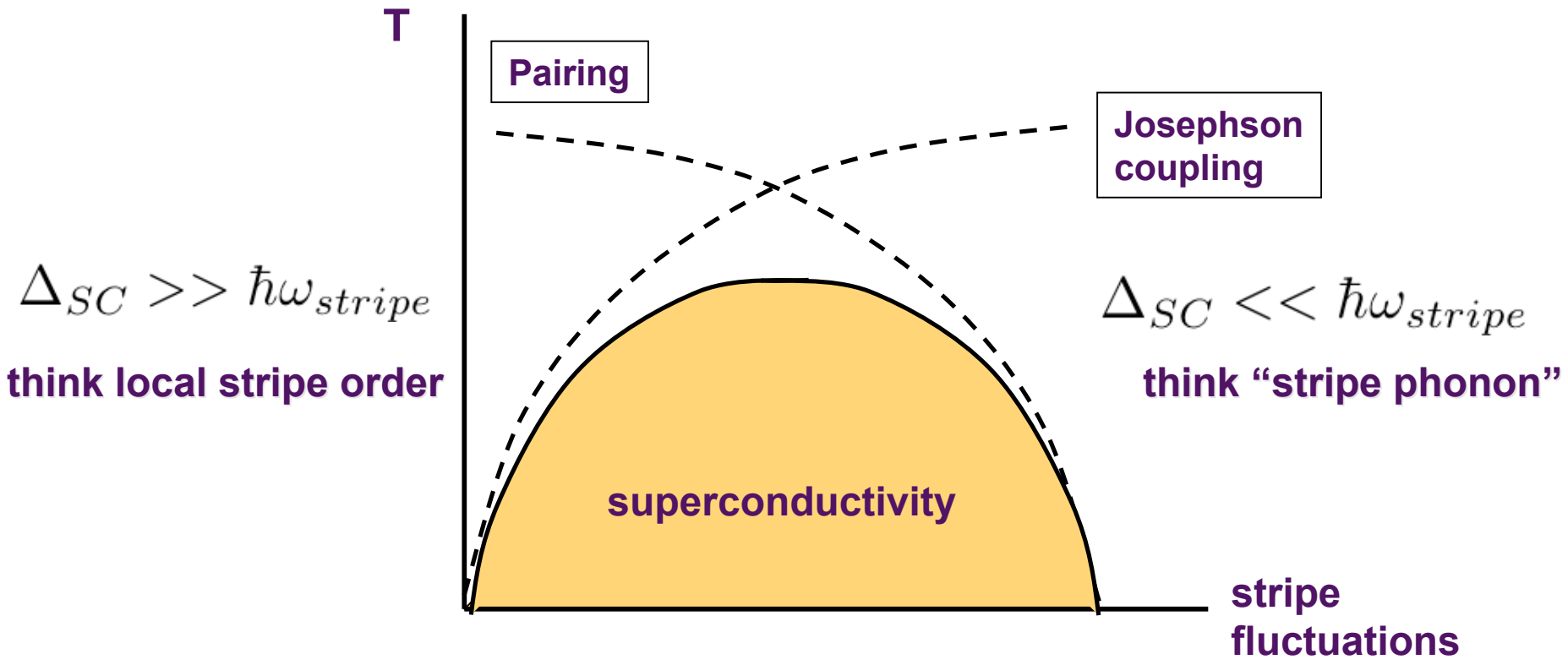
Non-Fermi liquid normal state (Luttinger liquid)

Pair the spin degrees of freedom,

and avoid the Coulomb repulsion.

EC, V. Emery, S. Kivelson, D. Orgad
in "Physics of Unconventional Superconductors"
ed. Bennemann and Ketterson, (2004)

Inherent Competition



Static Stripes
Good pairing
Bad phase coherence

Fluctuating Stripes
Bad pairing
Good phase coherence

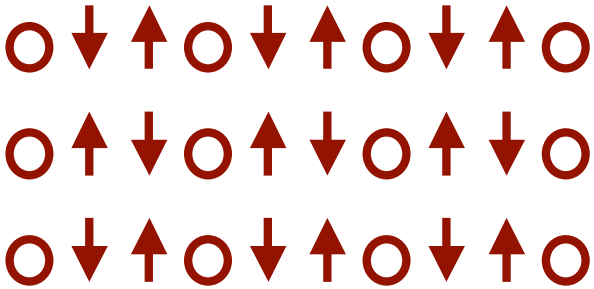
EC, V. Emery, S. Kivelson, D. Orgad
in "Physics of Unconventional Superconductors"
ed. Bennemann and Ketterson, (2004)

Stripes

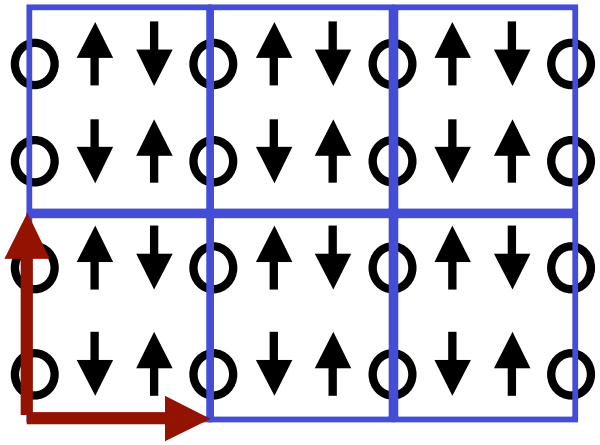
Unidirectional modulation in charge and spin

Charge: quasi-one-dimensional (rivers of charge)

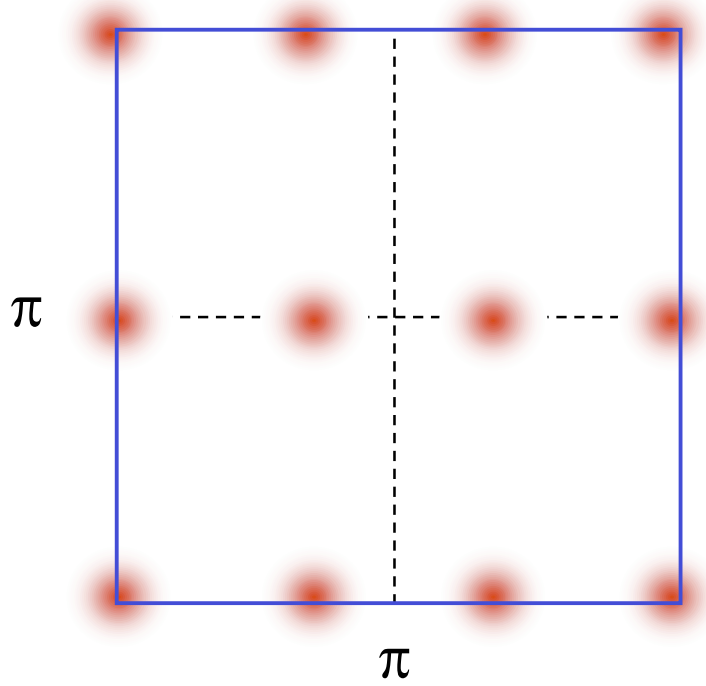
Spin: 2D Magnetic texture



Stripes Have 2D Magnetic Texture



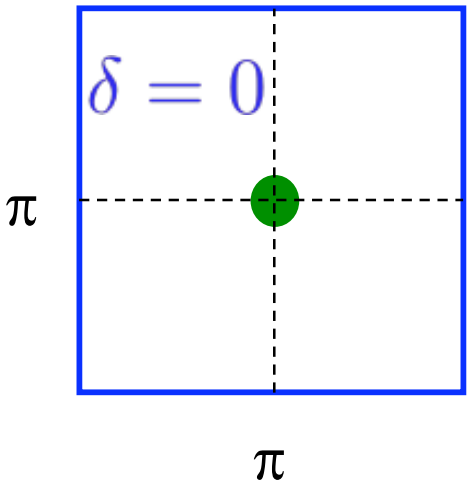
Real Space

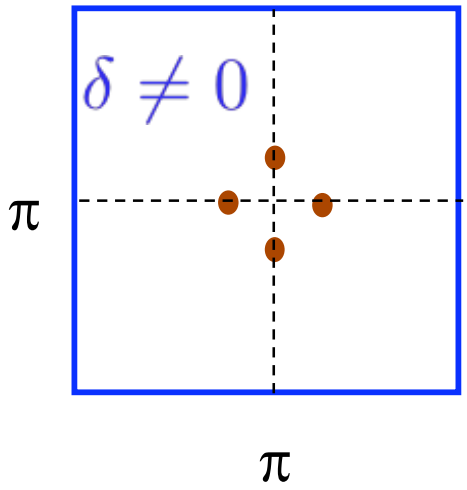


Reciprocal Lattice Vectors

2D spin waves disperse out of the reciprocal lattice vector positions

Neutron Scattering in Cuprates and Nickelates





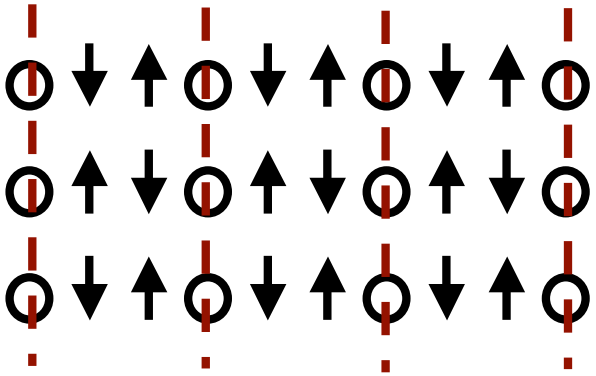
Disappearance of (π,π) peak with doping

Appearance of satellite peaks

AFM signal averages to zero

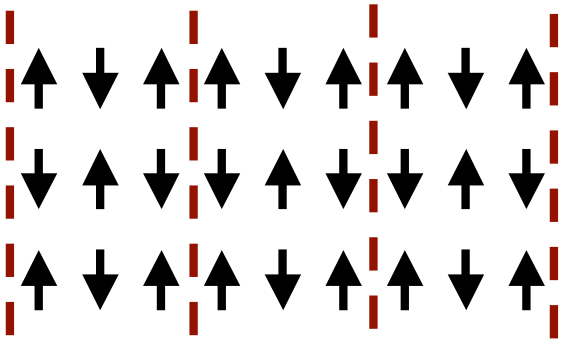
antiphase domain walls

site-centered

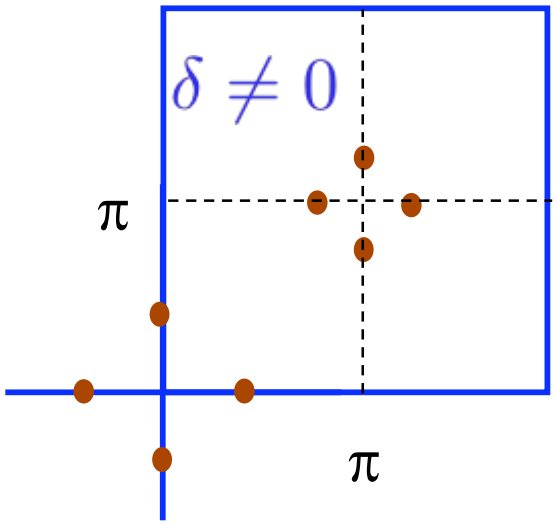


OR

bond-centered

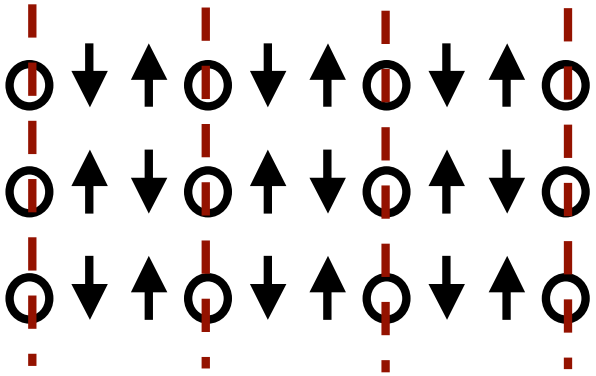


Neutron Scattering in Cuprates and Nickelates



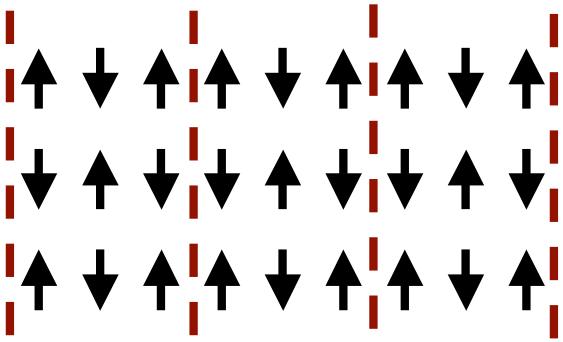
Charge Peaks related by X2

site-centered

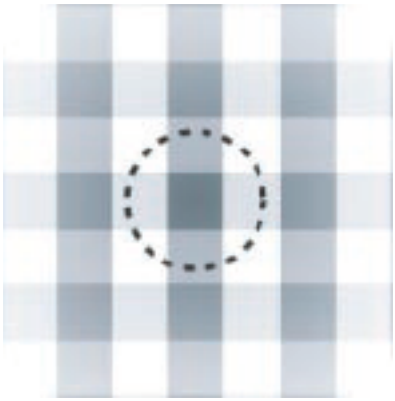


OR

bond-centered

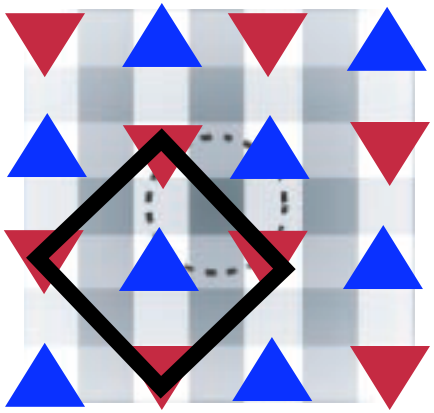


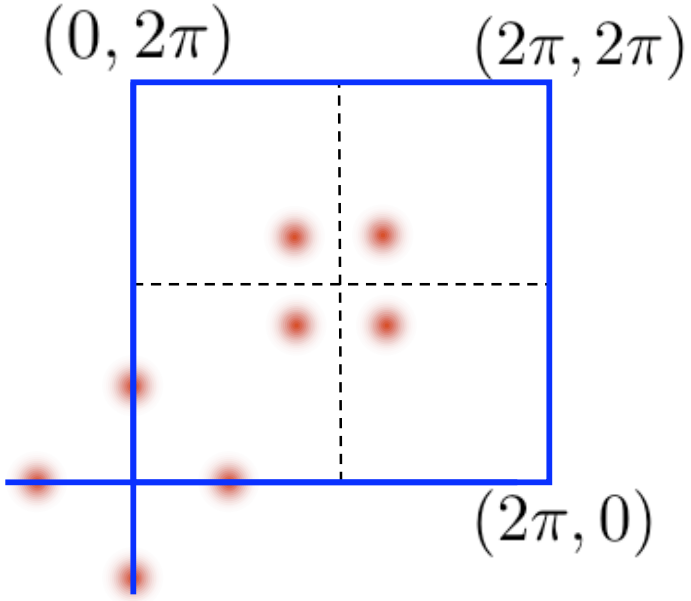
Checkerboards and Plaids?



Hoffman *et al.,* Science (2002)
Vershinin *et al.,* Science (2004)

Antiphase Domain Walls in Antiferromagnetism



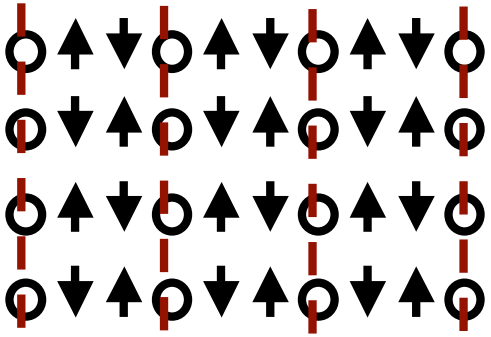


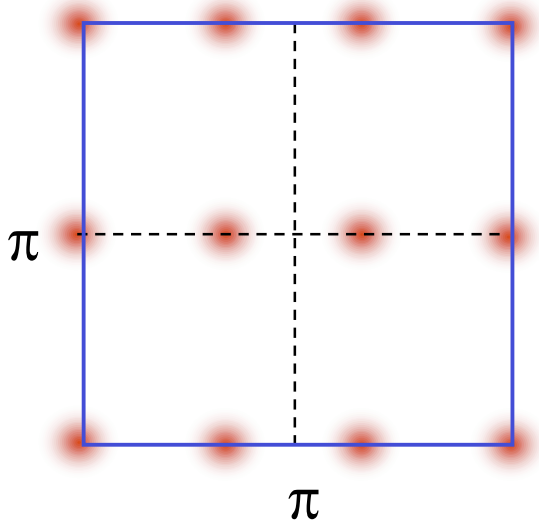
Charge Peaks

Spin Peaks in Wrong Direction!

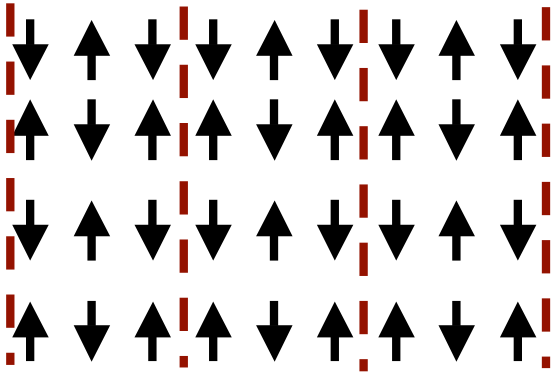
Odd Spacing

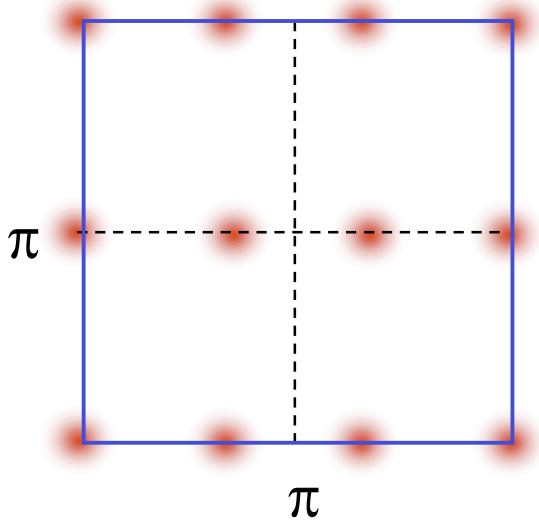
Site-centered





Bond-centered

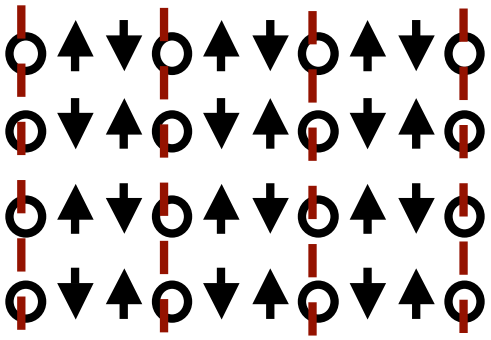


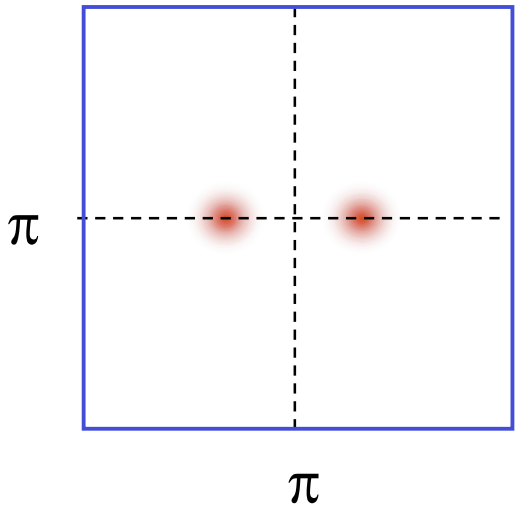


Magnetic Reciprocal Lattice Vectors

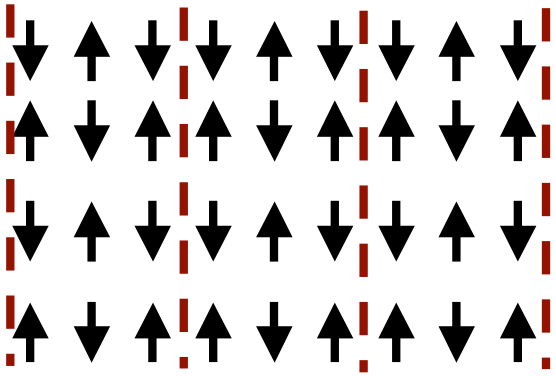
Odd Spacing

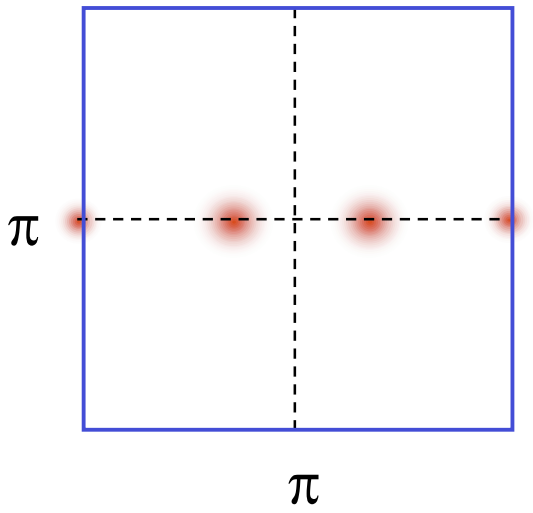
Site-centered





Bond-centered

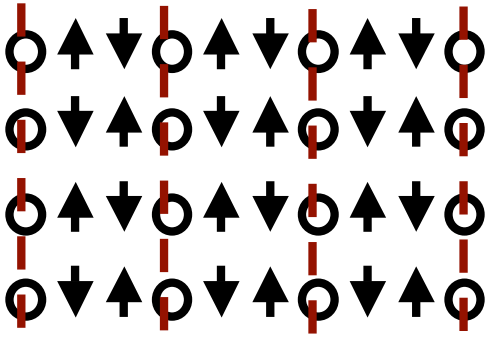


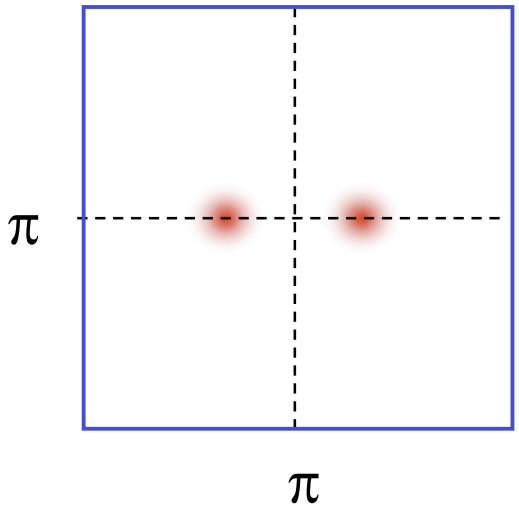


Intensities

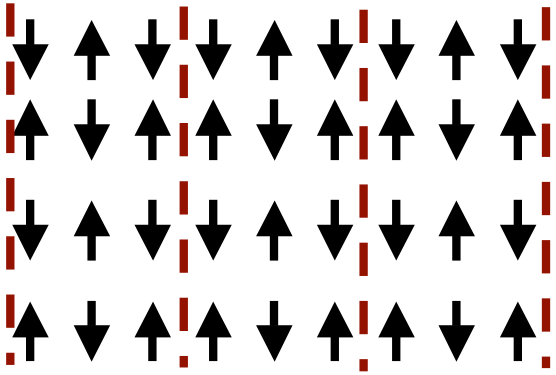
Odd Spacing

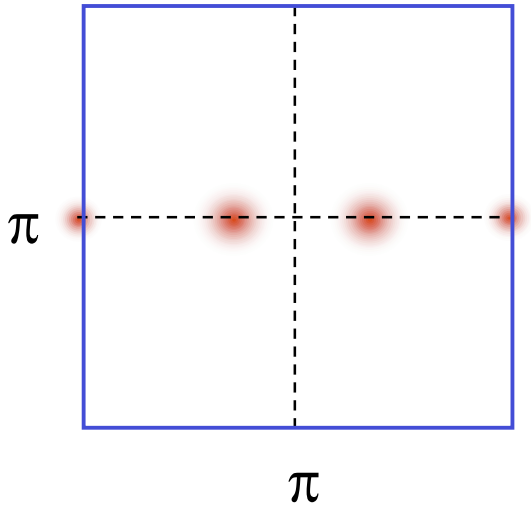
Site-centered





Bond-centered

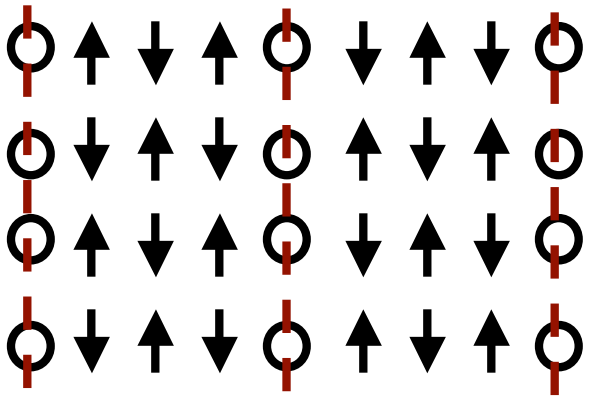


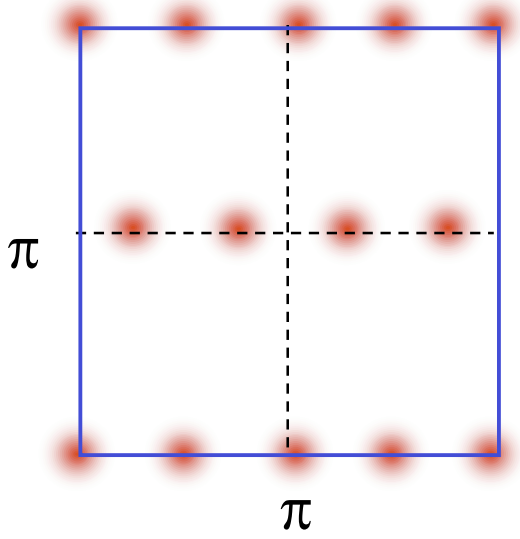


Observing weight here rules out site-centered stripes

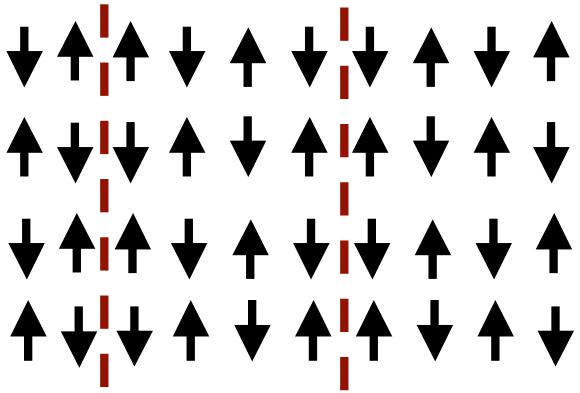
Even Spacing

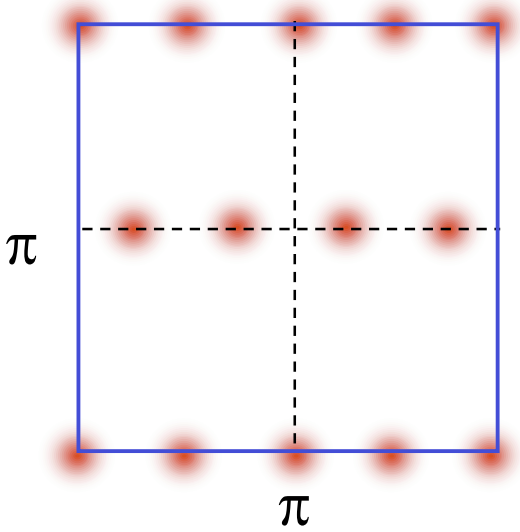
Site-centered





Bond-centered

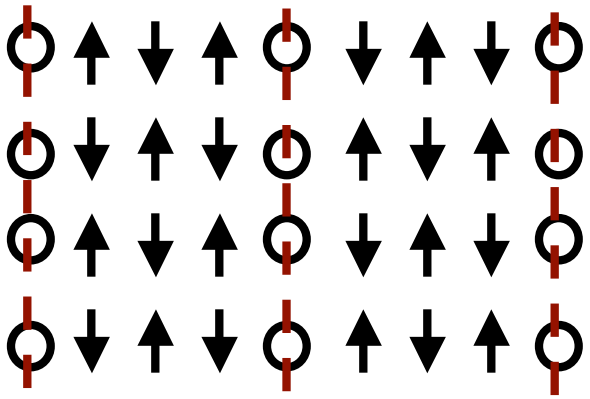


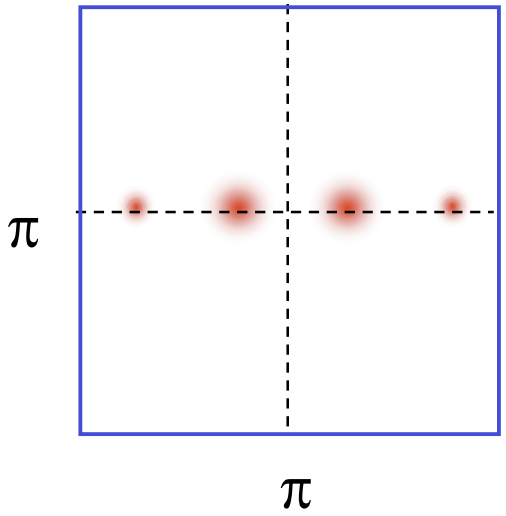


Magnetic Reciprocal Lattice Vectors

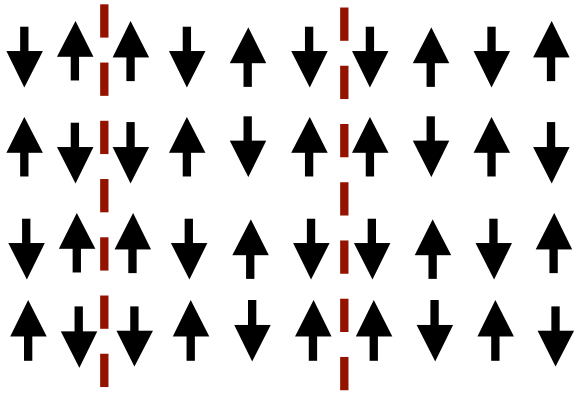
Even Spacing

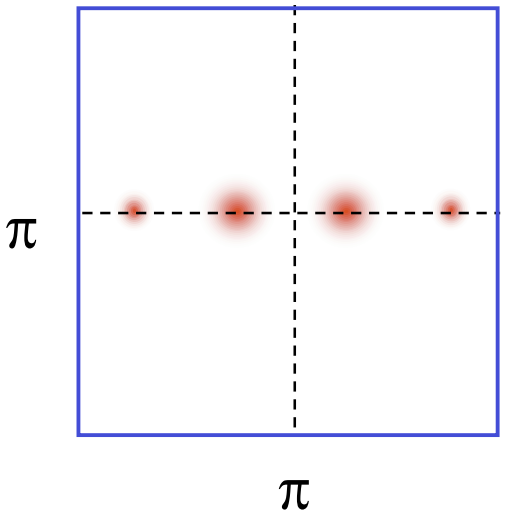
Site-centered





Bond-centered



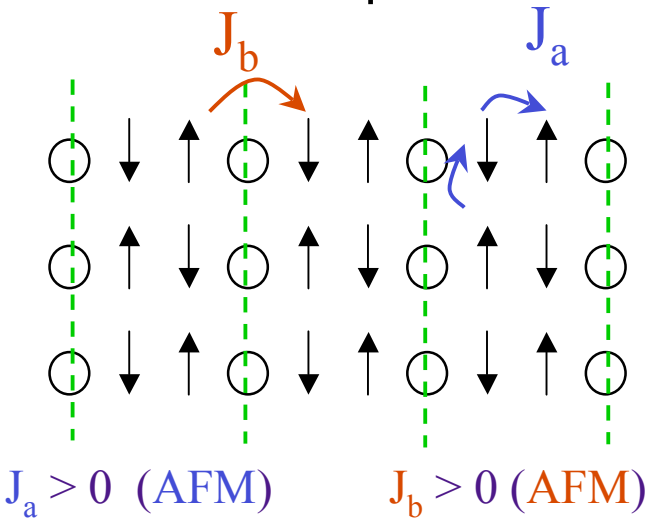


Intensities

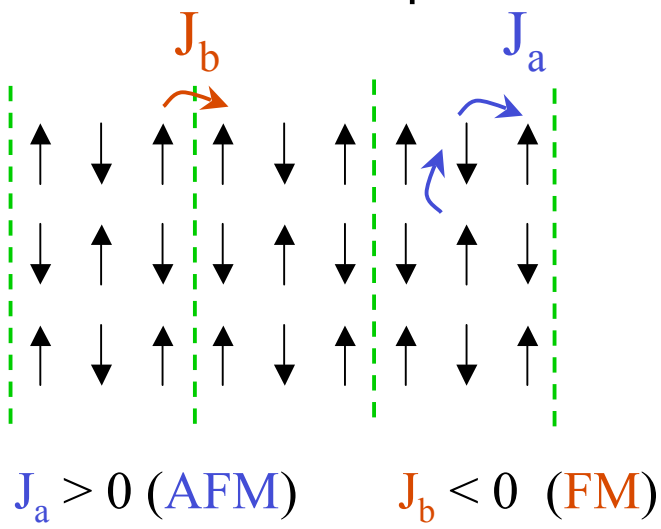
Inelastic Response: Spin Waves

Site or Bond-Centered

Site-centered p=3



Bond-centered p=3

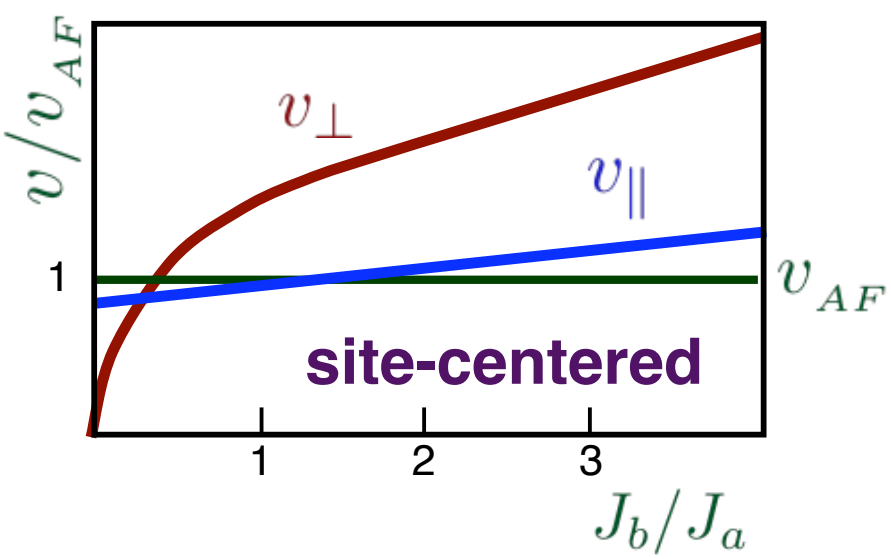


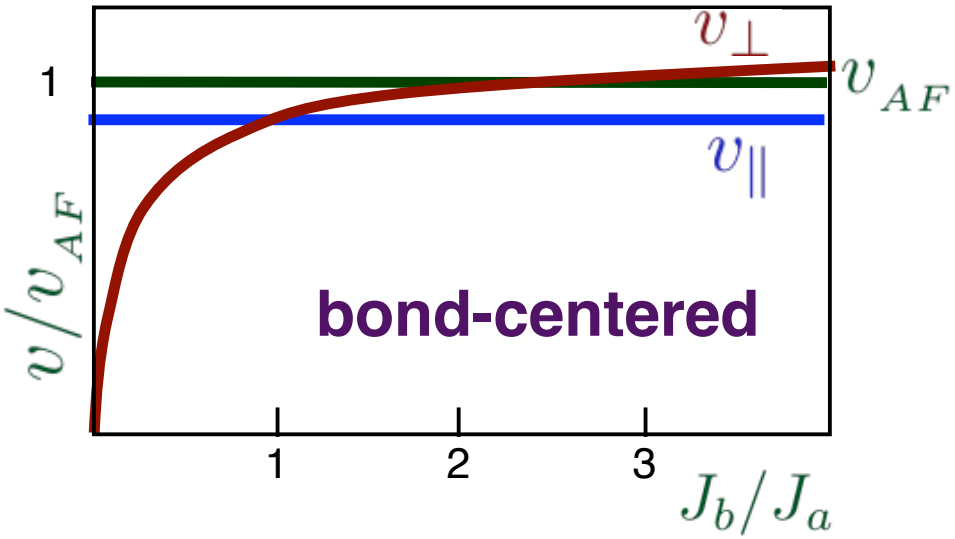
$$H = \frac{1}{2} \sum_{<ij>} J_{ij} \vec{S}_i \cdot \vec{S}_j$$

Semiclassical Spin Waves

$$S(\mathbf{k},\omega)^{in} = \sum_f \sum_{i=x,y,z} | < f|S^i(\mathbf{k})|0 > |^2 \delta(\omega - \omega_f)$$

Low Energy Velocities

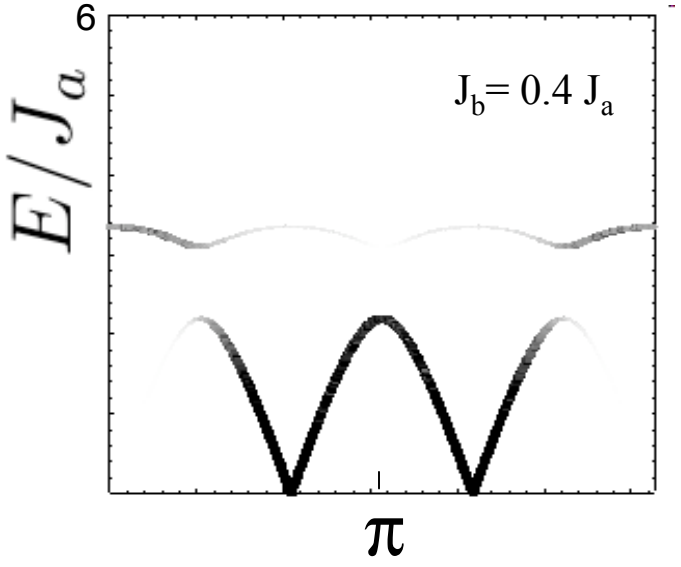


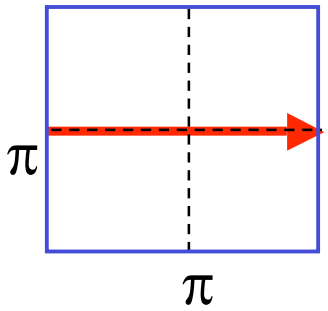


Spin wave cones may remain rather ***isotropic*** for bond-centered stripes, despite microscopic anisotropy.

Spin Wave Dispersions

Site-centered, p=3



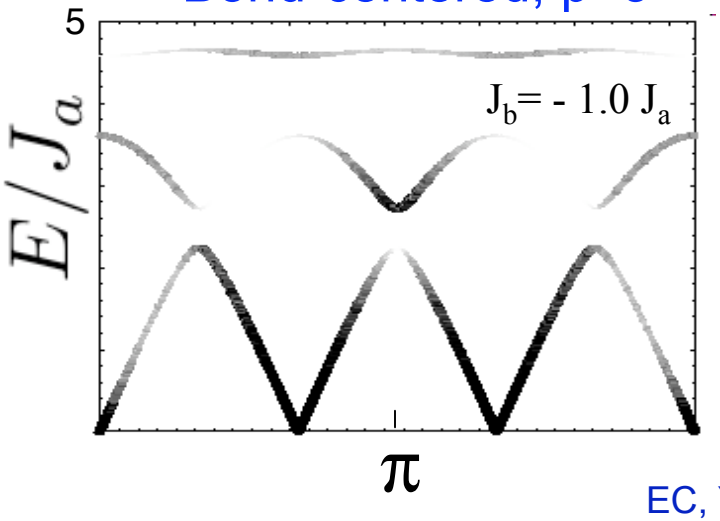


- Bond-centered has one more band
- Bond-centered has weight at (0,π)
- Bands repel, do not cross

Resonance unlikely from crossings

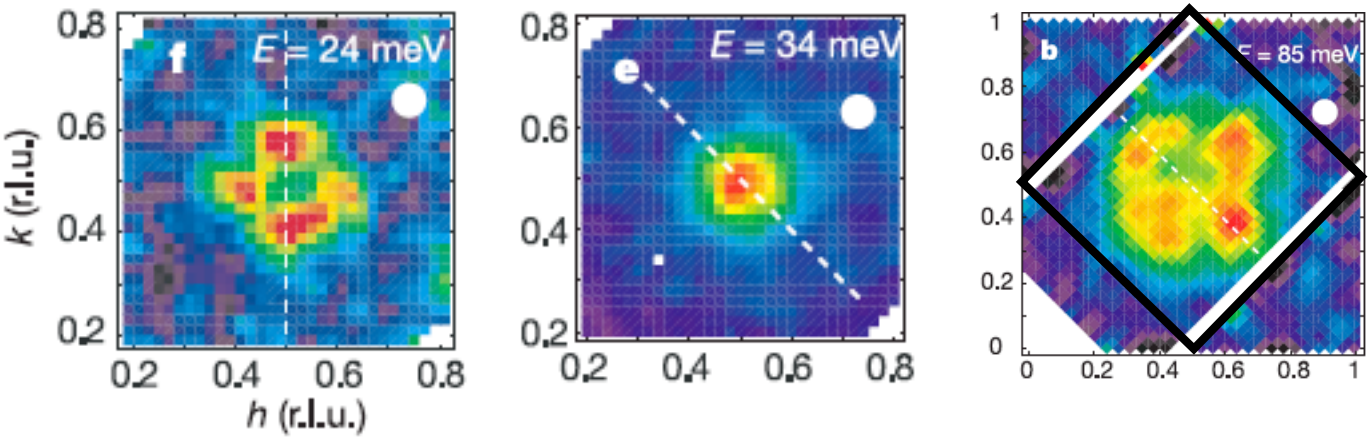
Batista *et al.*, PRB (2001)

Bond-centered, p=3

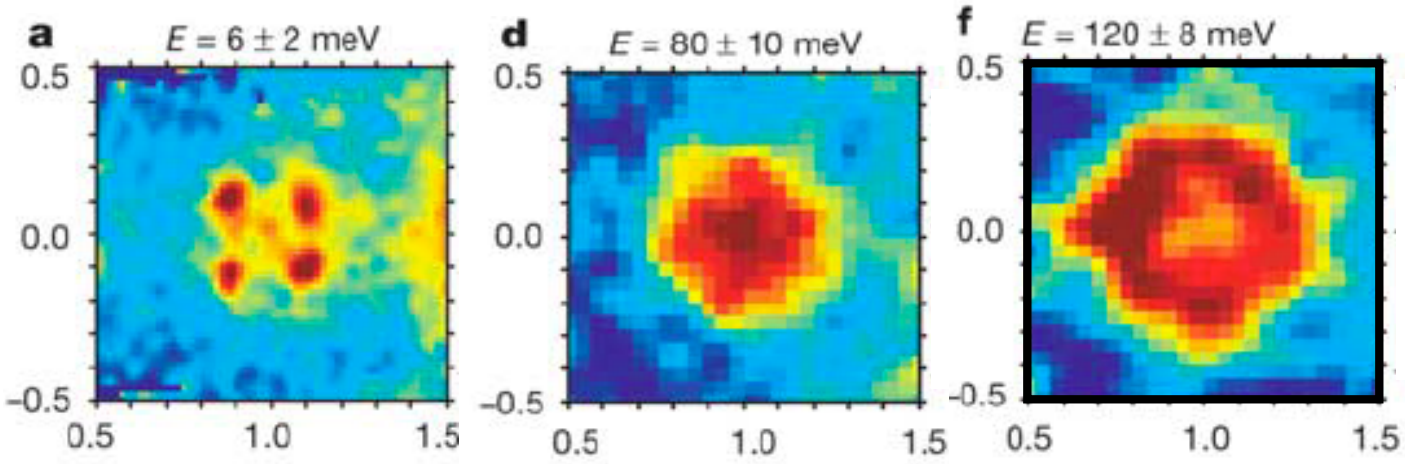


EC, Yao, *et al.*, PRB (2004)

Data

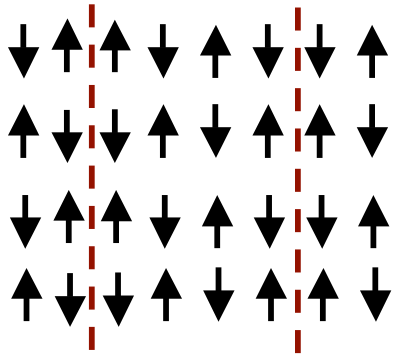


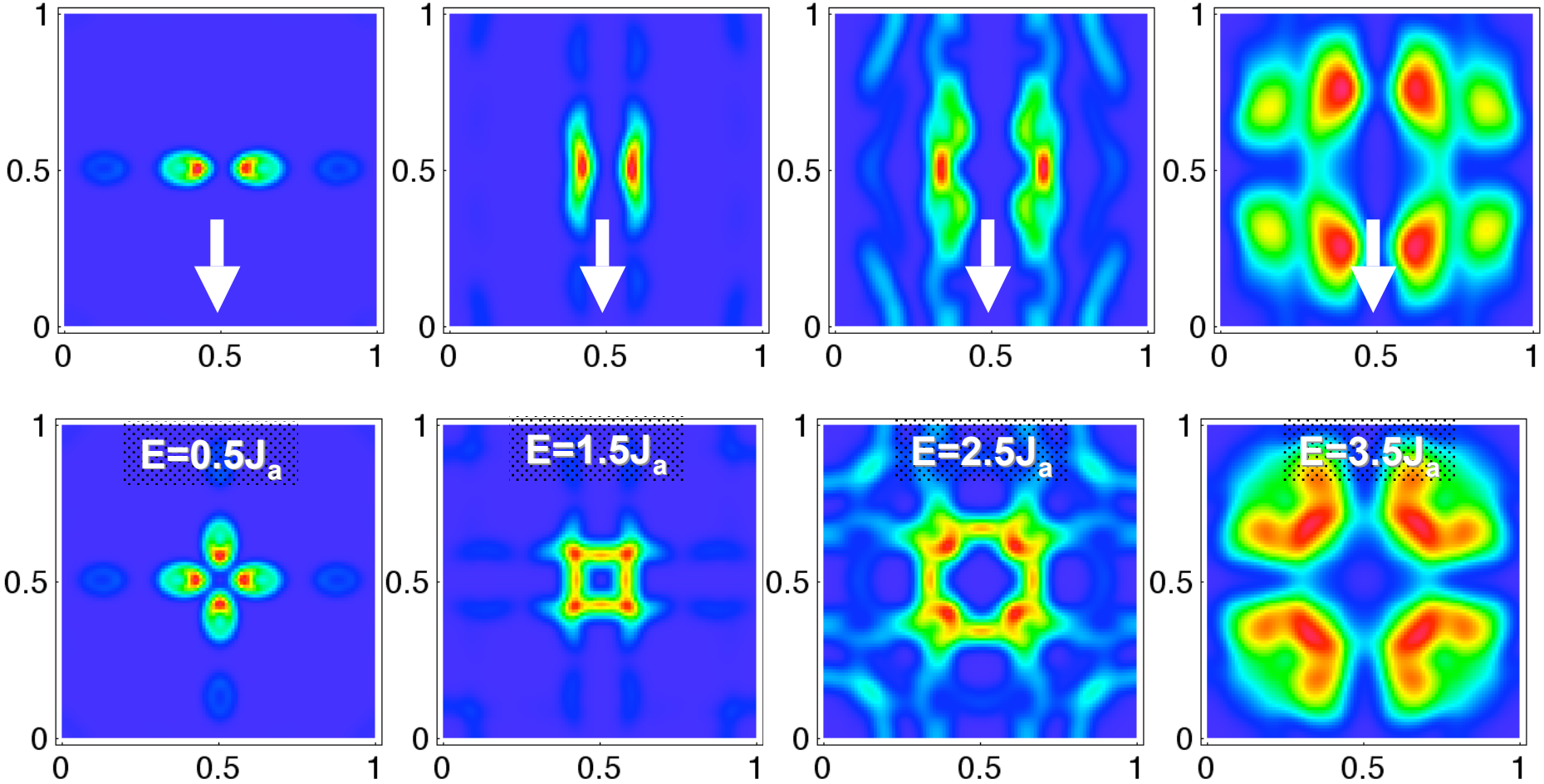
YBCO6.6, S. Hayden *et al.,* Nature 429, 531 (2004)



Stripe-ordered LBCO, S. Hayden *et al.,* Nature 429, 534 (2004)

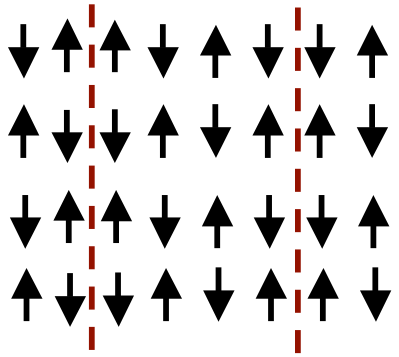
Symmetrize

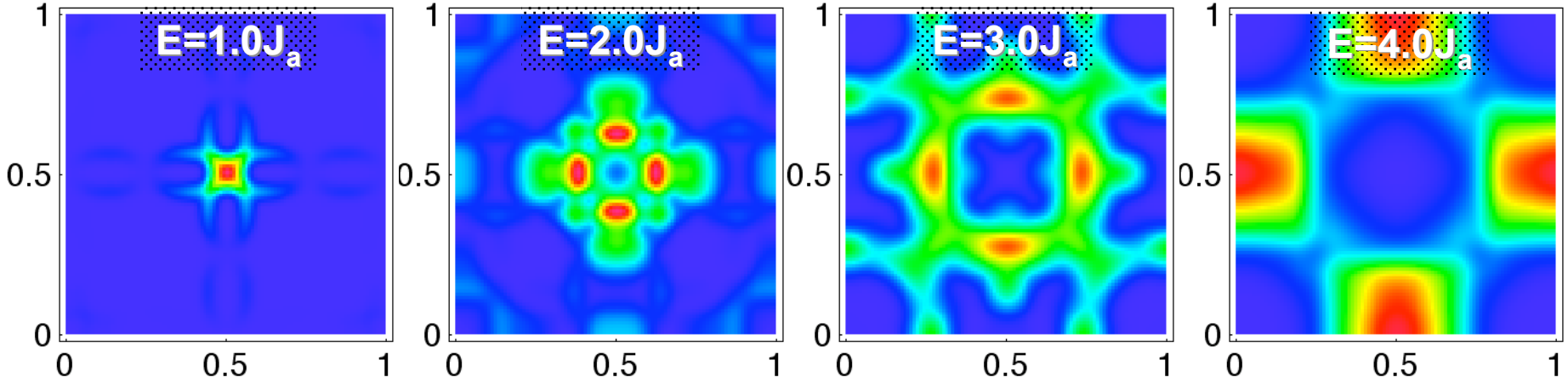


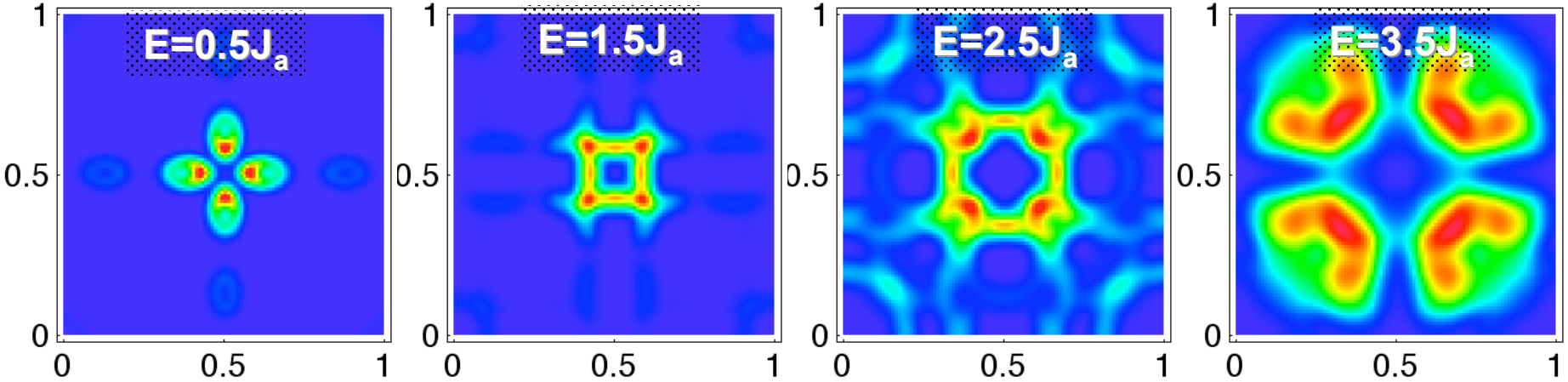


VB4 $J_b = -.1\ J_a$

Vertical, Bond-centered, Spacing = 4

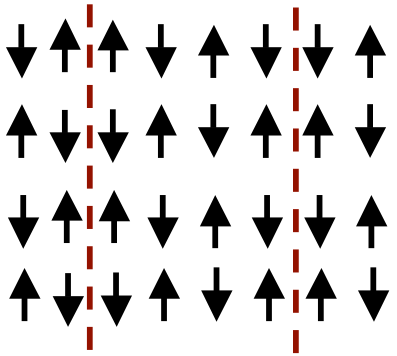


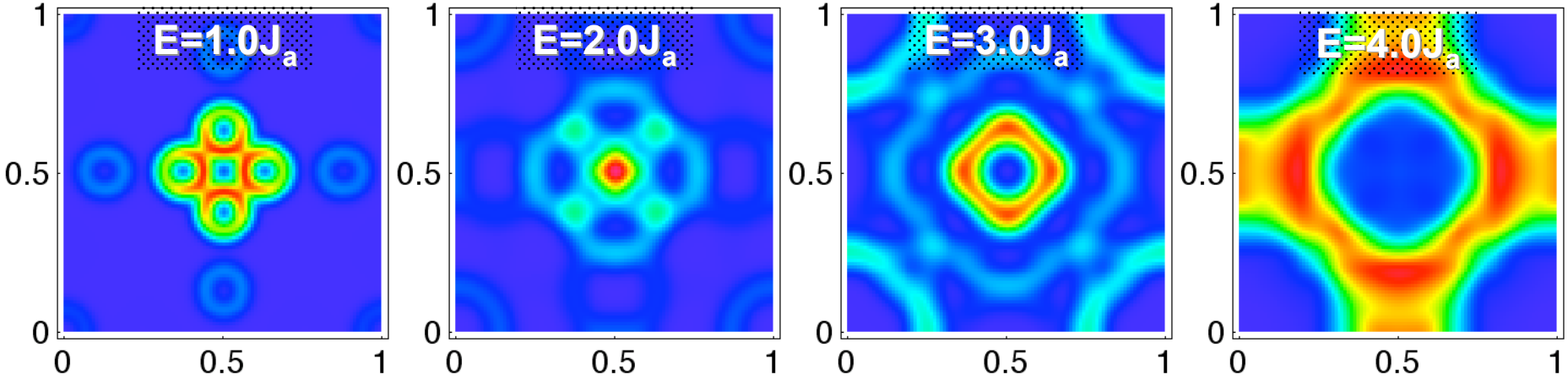


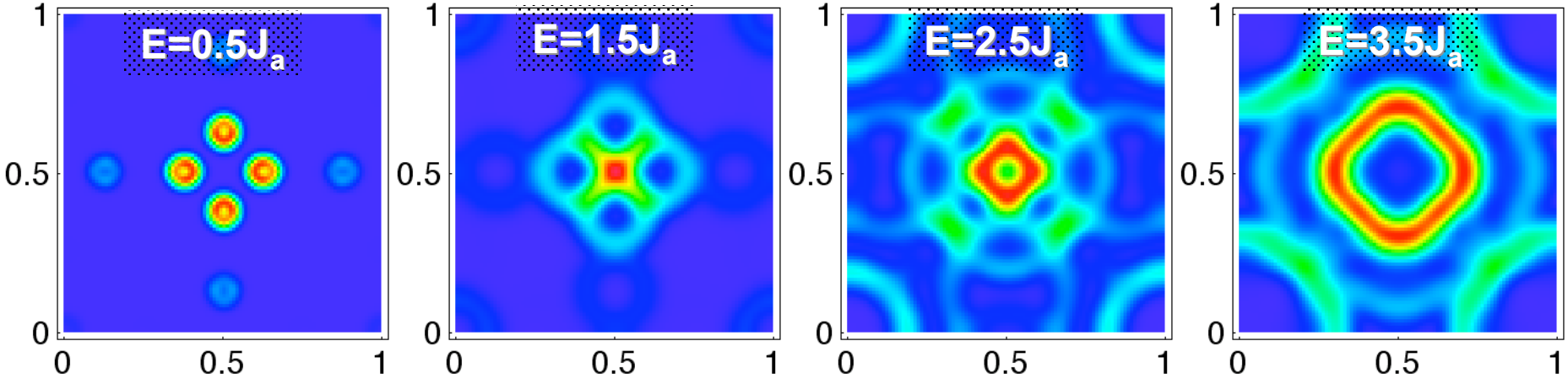


VB4 $J_b = -.56\ J_a$

Vertical, Bond-centered, Spacing = 4

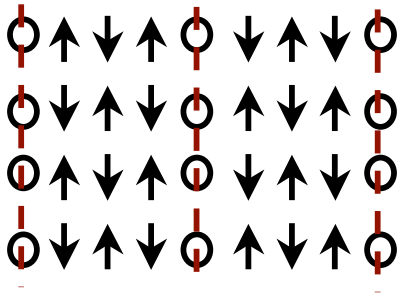


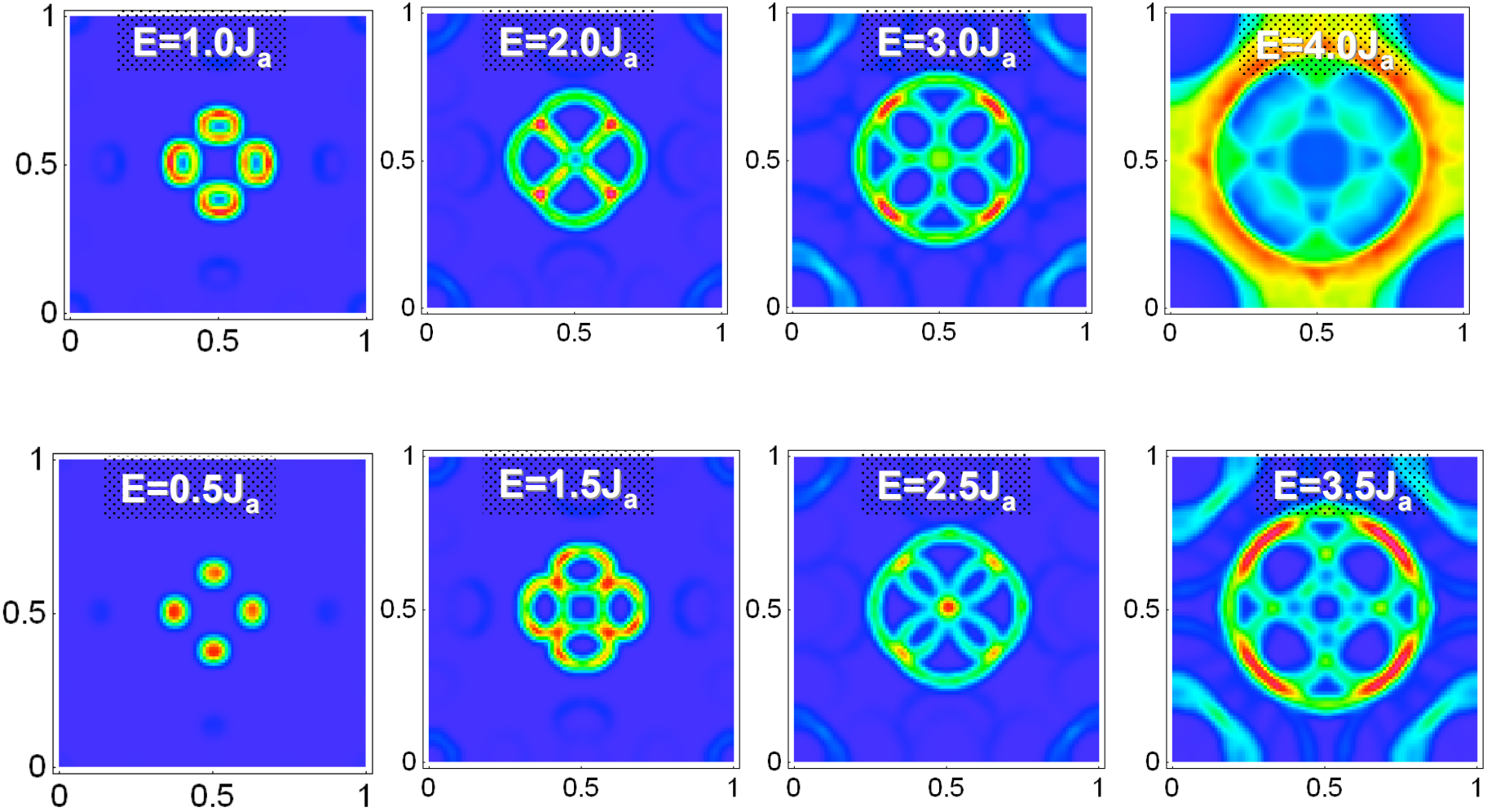




VS4 Jb = Ja

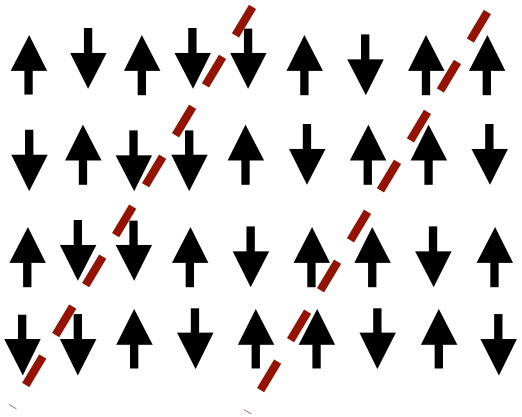
Vertical, Site-centered, Spacing = 4





Other Stripe Patterns

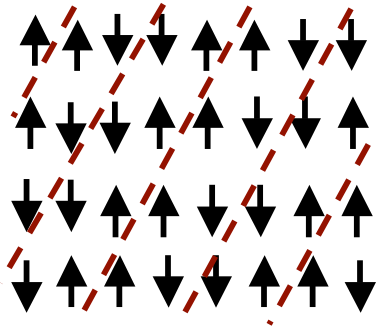
Diagonal

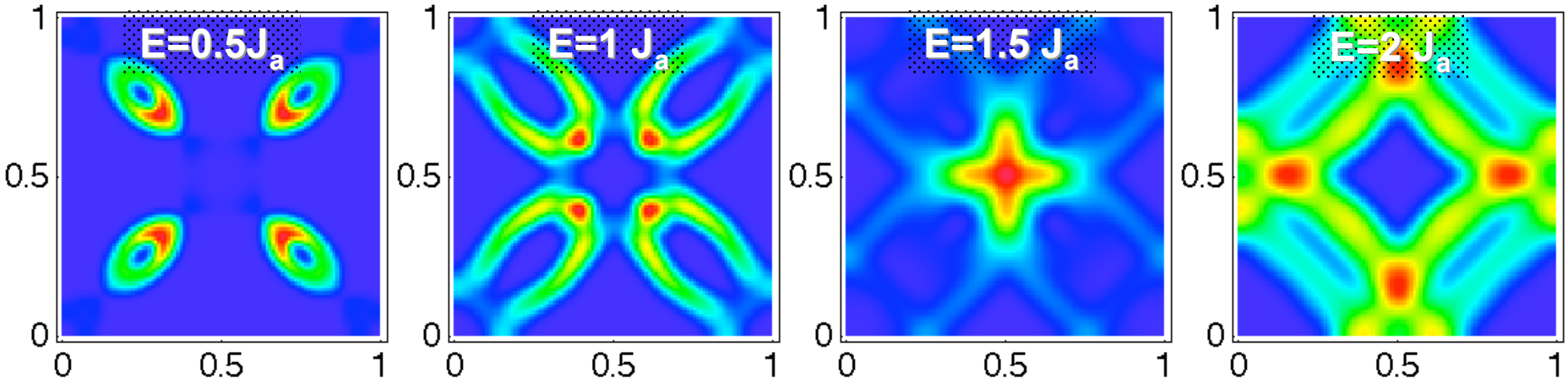


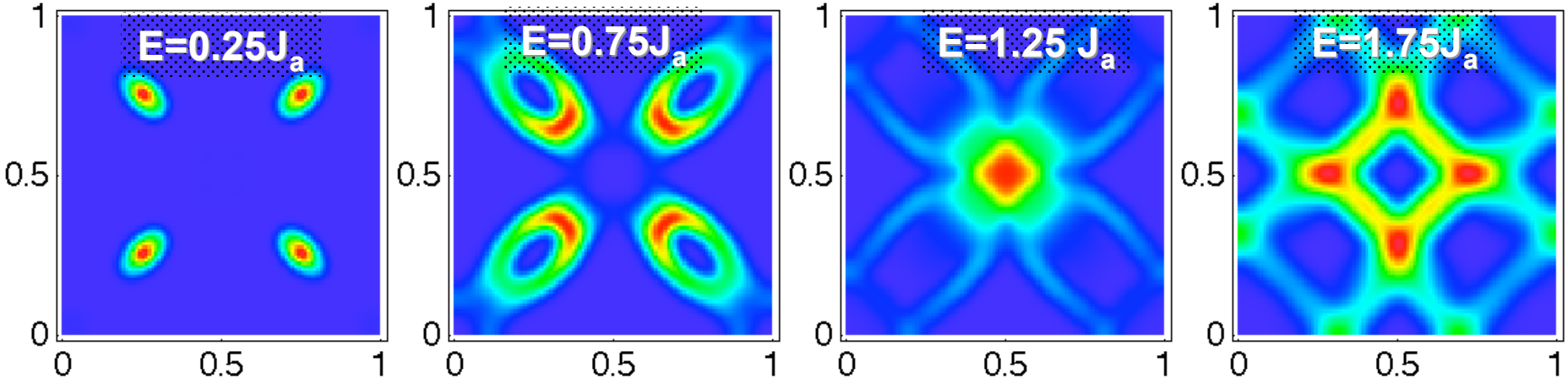
"DB4"

DB2 $J_b = -.1\ J_a$

Diagonal, Bond-centered, Spacing = 2

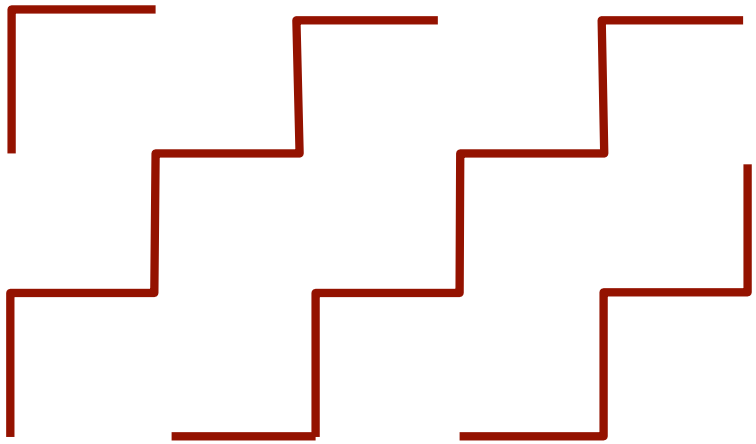






Other Stripe Patterns

Staircase

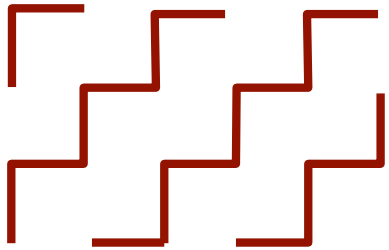


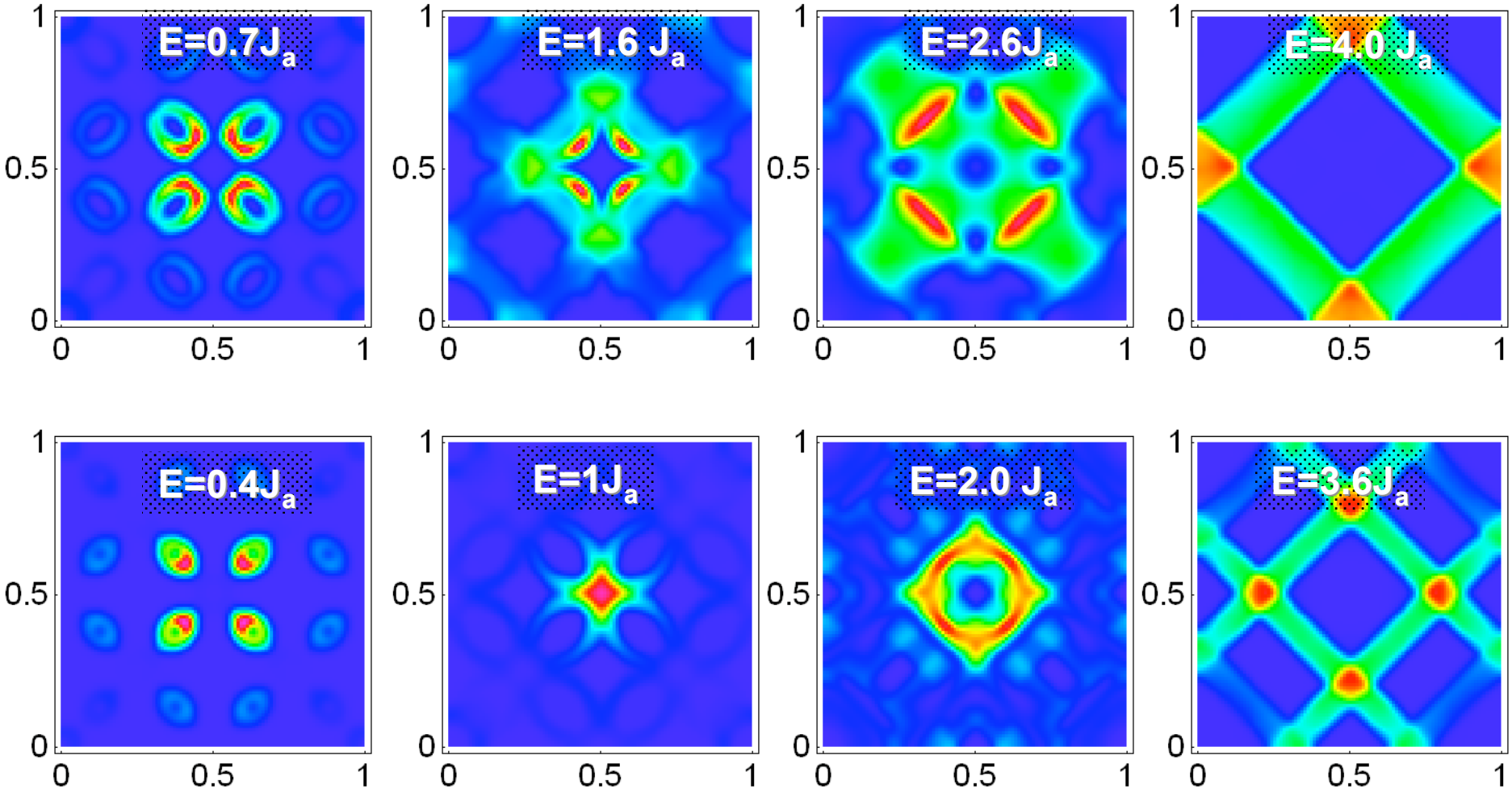
Globally diagonal
Locally vertical
Antiphase domain walls

M. Granath, PRB (2004)
Smooth transition from diagonal to vertical peaks
Fermi Surface Arcs

SB2 $J_b = -.1\ J_a$

Staircase, Bond-centered, Spacing = 2





Conclusions

2D magnetic texture

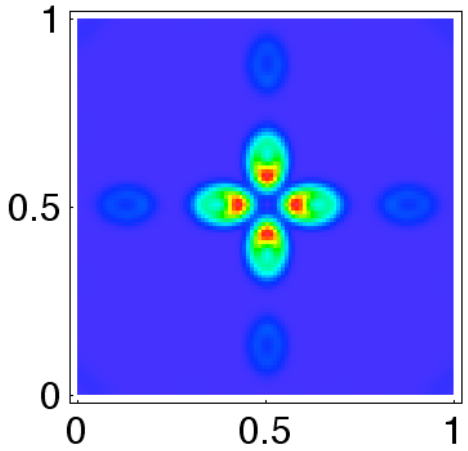
- Stripes produce 2D spin waves.
- Finite energy weight at (π, π) is natural from stripes, but not from a pure antiferromagnet.

Resonance peak

- Unlikely from crossing (bands repel)

Bond-centered stripes:

- Ferromagnetic coupling across domain wall
- One more band than site-centered
- Odd spacing has *new elastic peaks*, forbidden for site-centered stripes
- Isotropic spin wave cones
- "Legs" of scattering



Comparison to Recent Cuprate Data

- Low energy could be semiclassical spin waves
- High energy is not