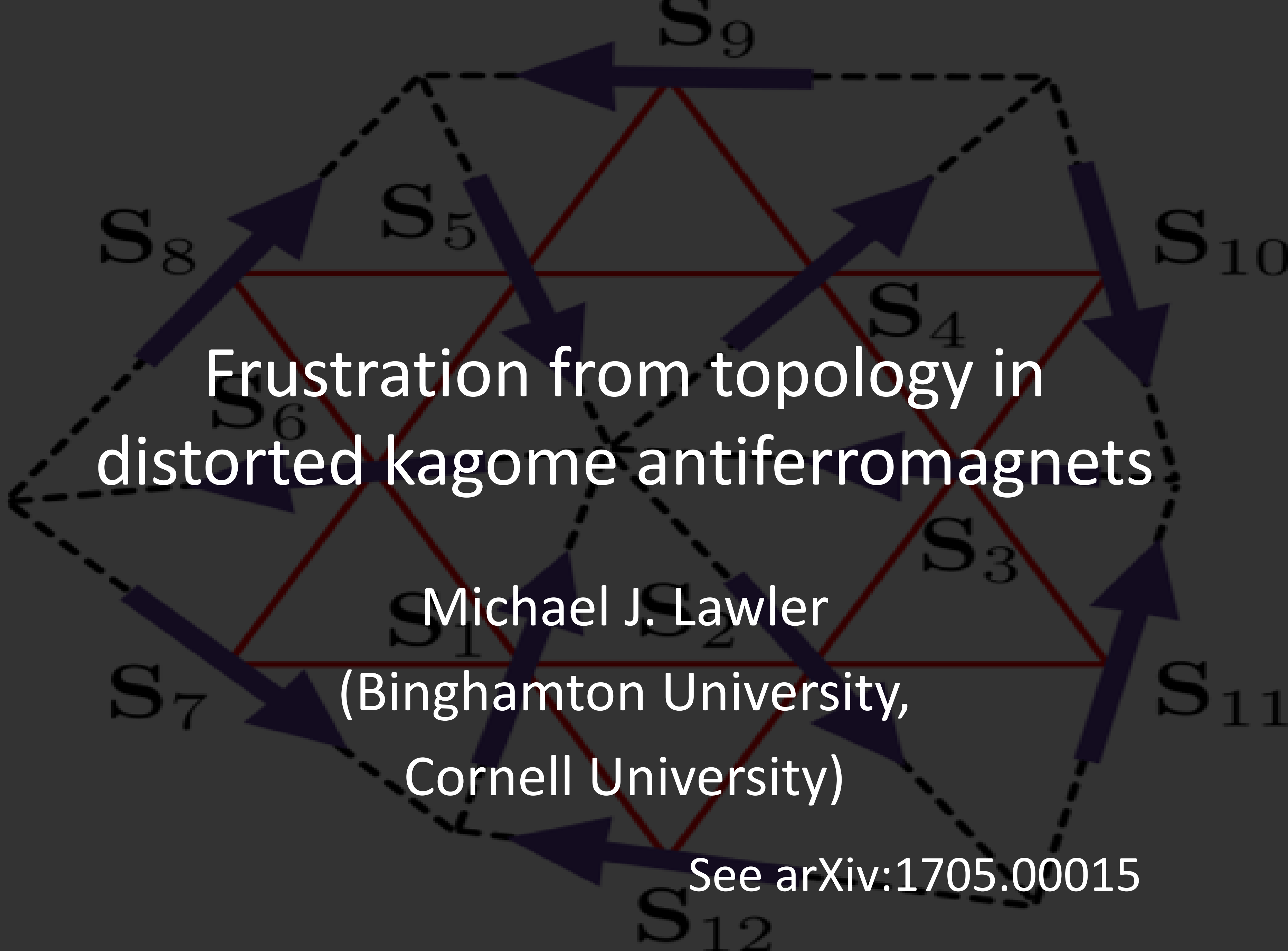

Frustration from topology in distorted kagome antiferromagnets

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Cornell University)

See arXiv:1705.00015

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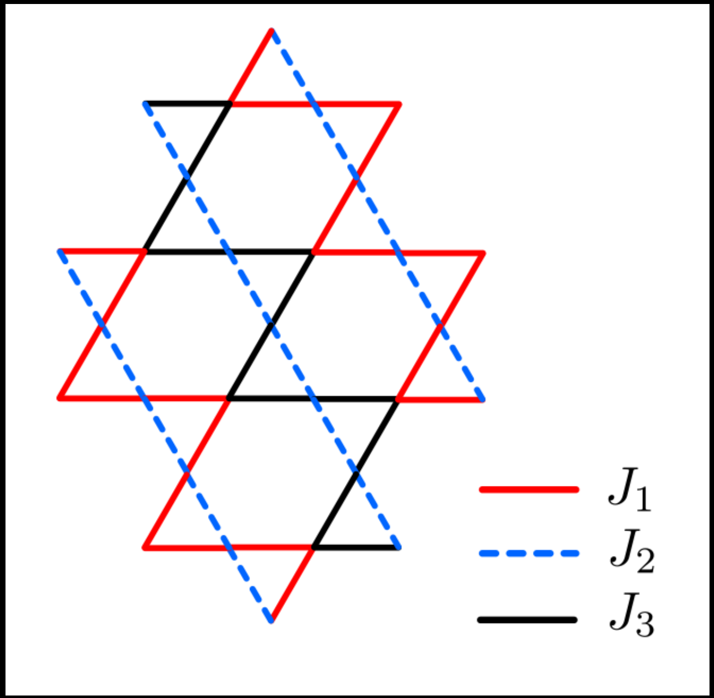
Krishanu Roychowdhury
Cornell University

Zeb D. Rocklin
Cornell University

See arXiv:1705.00015

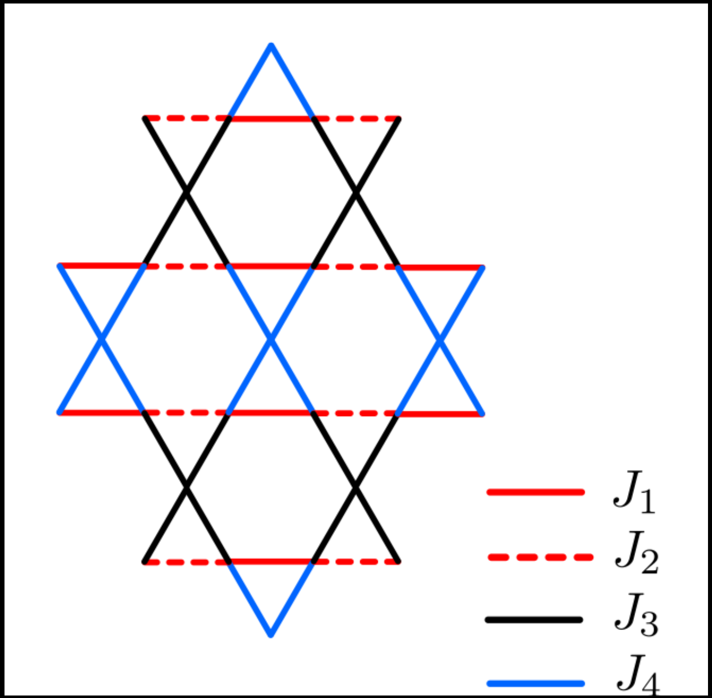
Distorted kagome antiferromagnets

See arXiv:1705.00015



$Cs_2ZrCu_3F_{12}$

Ono et. al,
PRB 79, 174407 (2009)

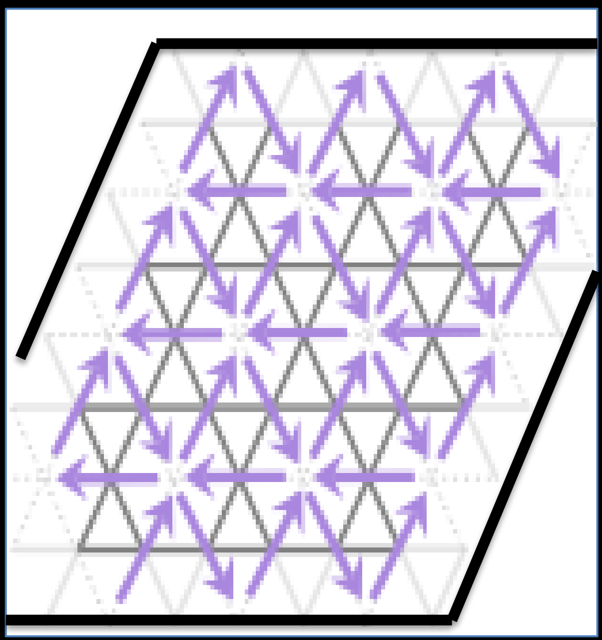


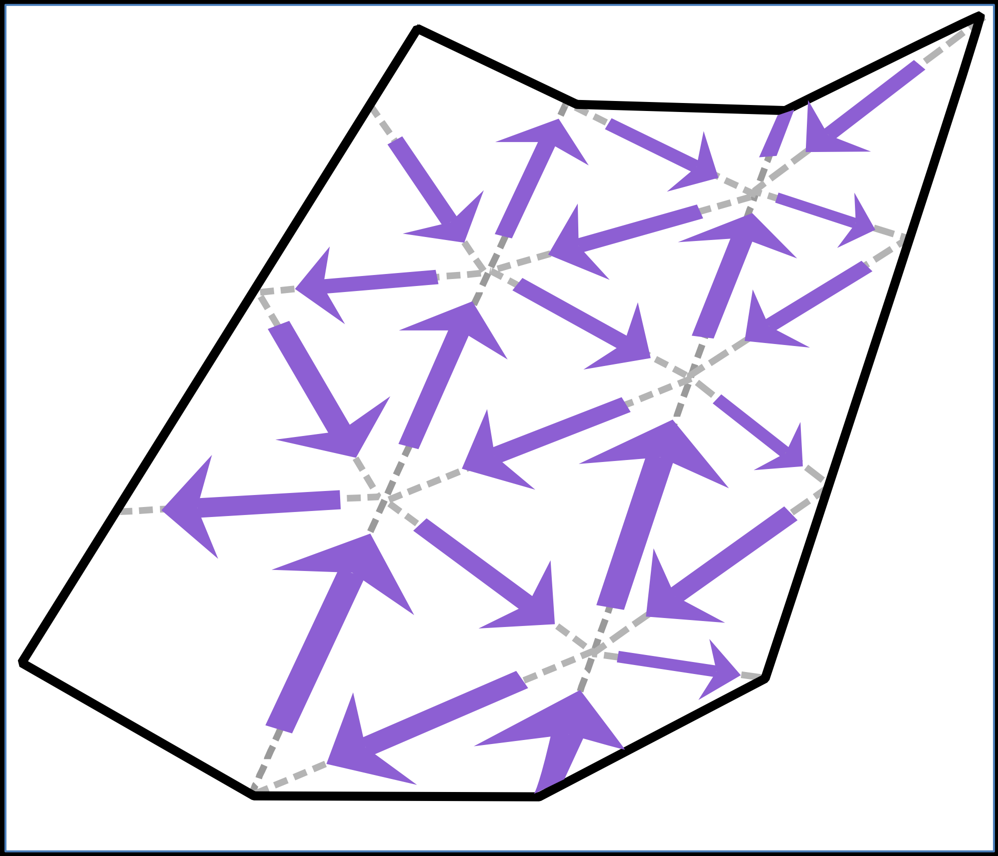
$Cs_2CeCu_3F_{12}$

Amemiya et. al.,
PRB 80, 100406R (2009)

Undistorted kagome: Spin origami

Shender et. al, 1993



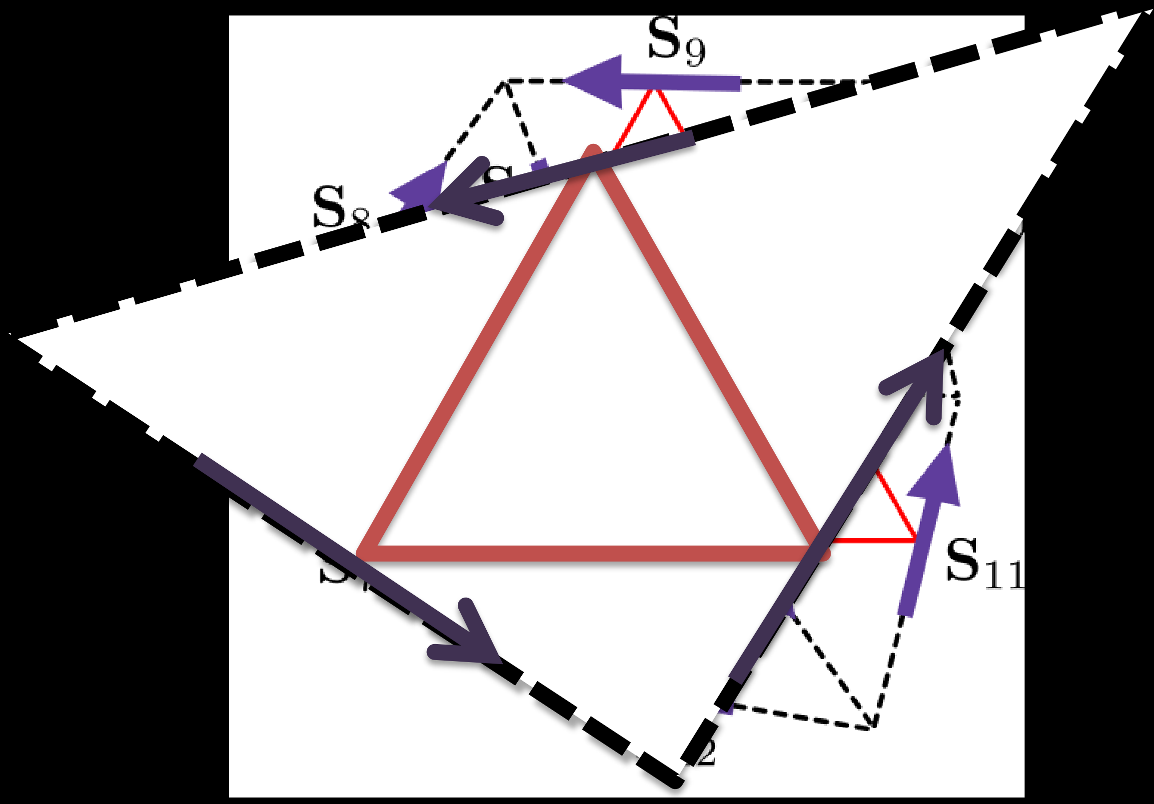


Ground states parameterized by an origami sheet!

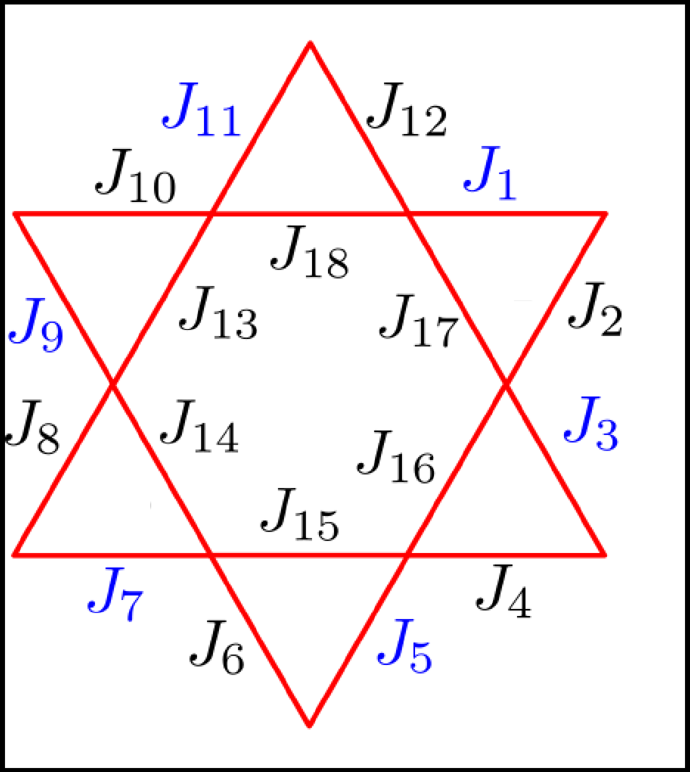
Generalized spin origami

$$\vec{S}_\Delta \equiv a_i \vec{S}_i + a_j \vec{S}_j + a_k \vec{S}_k = 0$$

"triangle" constraint

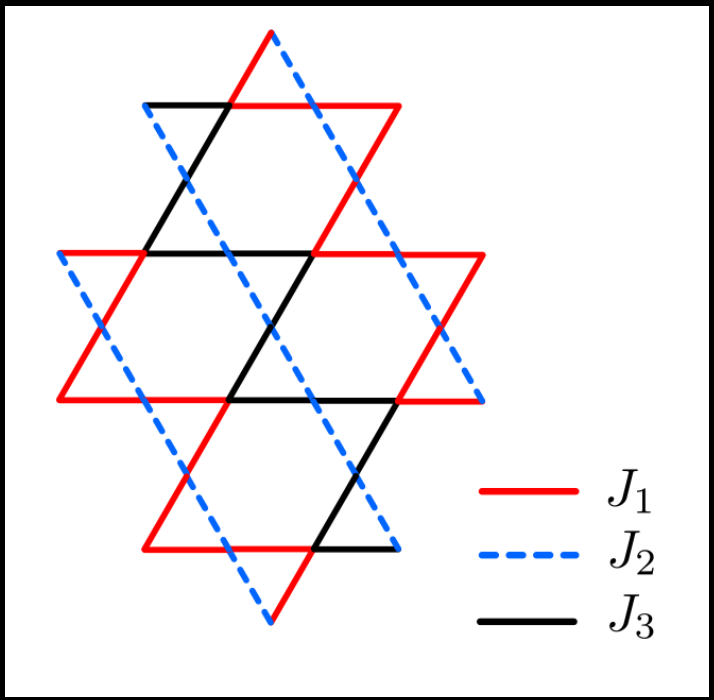


Star condition

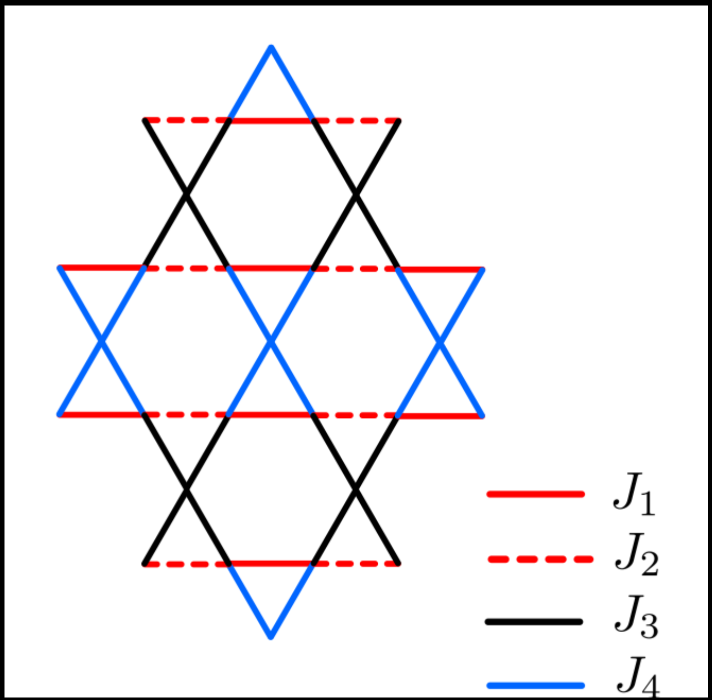


$$J_1 J_3 J_5 J_7 J_9 J_{11} = J_2 J_4 J_6 J_8 J_{10} J_{12}$$

Distorted kagome antiferromagnets



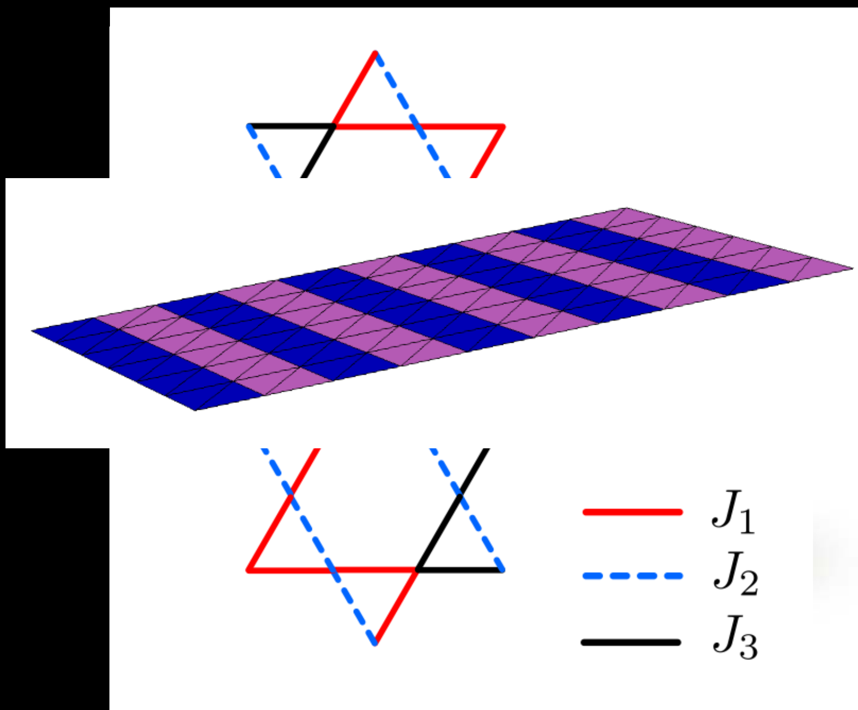
$Cs_2ZrCu_3F_{12}$

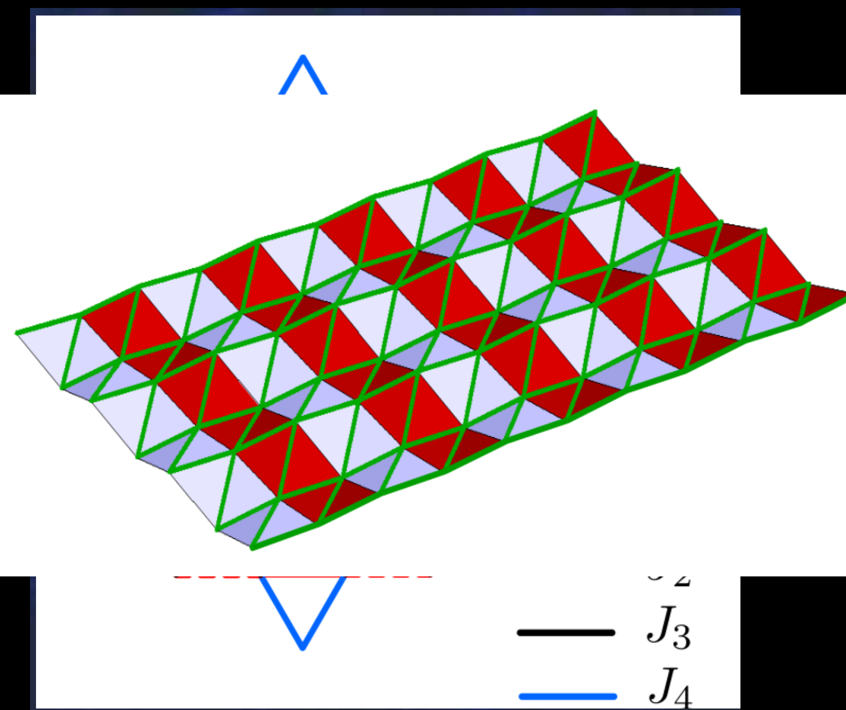


$Cs_2CeCu_3F_{12}$

Both obey the star condition

Two kinds of origami





Flattenable

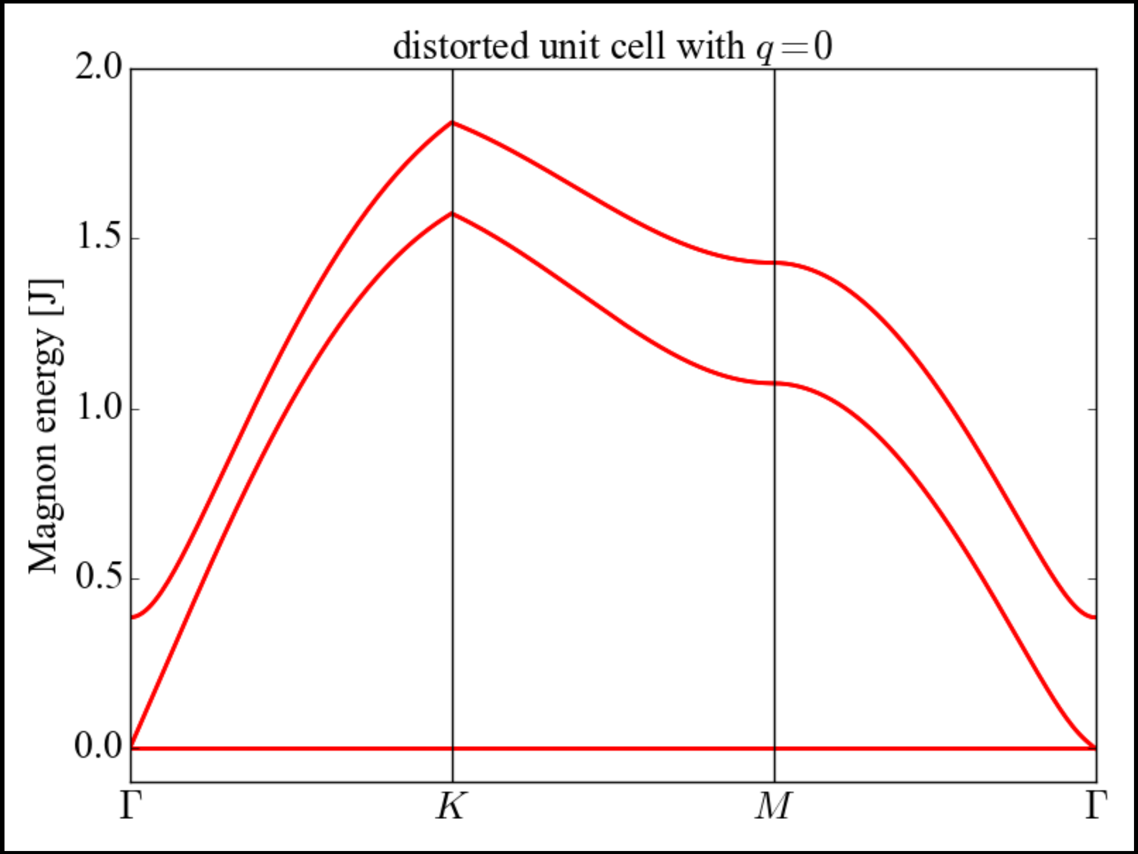
$Cs_2ZrCu_3F_{12}$

Crumpled

$Cs_2CeCu_3F_{12}$

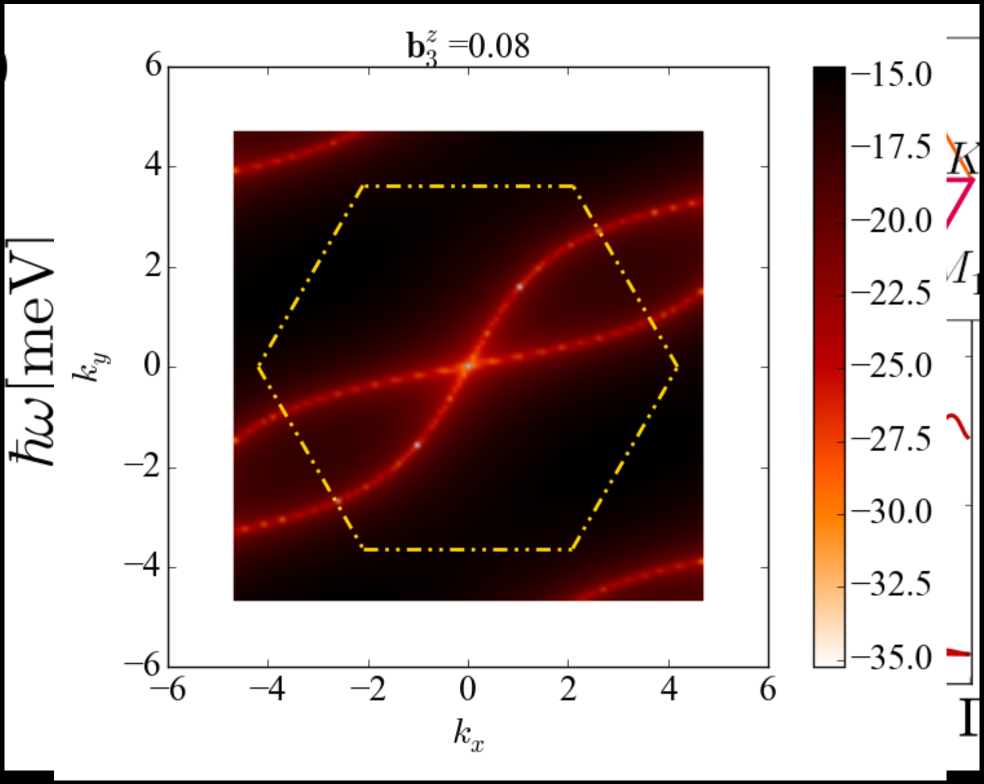
Spin wave dispersions

Flattenable spin origami systems



Spin wave dispersions

Crumpled spin origami systems



Lines of zero modes like a Fermi surface!

In both cases, distortion doesn’t just lift the accidental degeneracy!

Protected by a topological invariant?

Definition “topological invariant”:

A number that cannot change unless the energy gap closes

Maxwell counting

See Moessner and Chalker, 1998

Number of vertices n_v per unit cell:

2

Number of edges n_e per unit cell:

6

Maxwell d.o.f. count per unit cell:

$$\nu = dn_v - n_e = 0, \quad d = 3$$

ν is deformation invariant

$\nu\Bigg($  $\Bigg) = \nu\Bigg($  $\Bigg)$

Maxwell counting as topological invariant

Kane and Lubensky,Nature Physics, 2014

Maxwell condition: $\nu=0$ (Origami)

Isostatic condition: $\nu=0$, $\Delta > 0$

$\nu=0 \longrightarrow \nu = 1$ Gap closes ($\Delta = 0$)

Focus on the rigidity matrix

Kane and Lubensky, Nature Physics 2014

Expand the constraint functions in spin waves

$$S_{\Delta\alpha} \equiv a_i S_{i\alpha} + a_j S_{j\alpha} + a_k S_{k\alpha}$$
$$= R_{\Delta\alpha, i\mu} x^{i\mu}$$

R determines everything $H = \frac{1}{2}\mathbf{x}^T \mathbf{R}^T \mathbf{R} \mathbf{x}$

$$\nu = \#\text{ of cols of } R - \#\text{ of rows of } R$$
$$= \text{rank} R + \text{nullity} R - \text{rank} R^T - \text{nullity} R^T$$
$$= \text{nullity} R - \text{nullity} R^T$$

Topological invariant of crumpled case

*R(**k**)* is a complex square matrix but ν(k)=0

Origami realness condition: det *R(**k**)* is real!

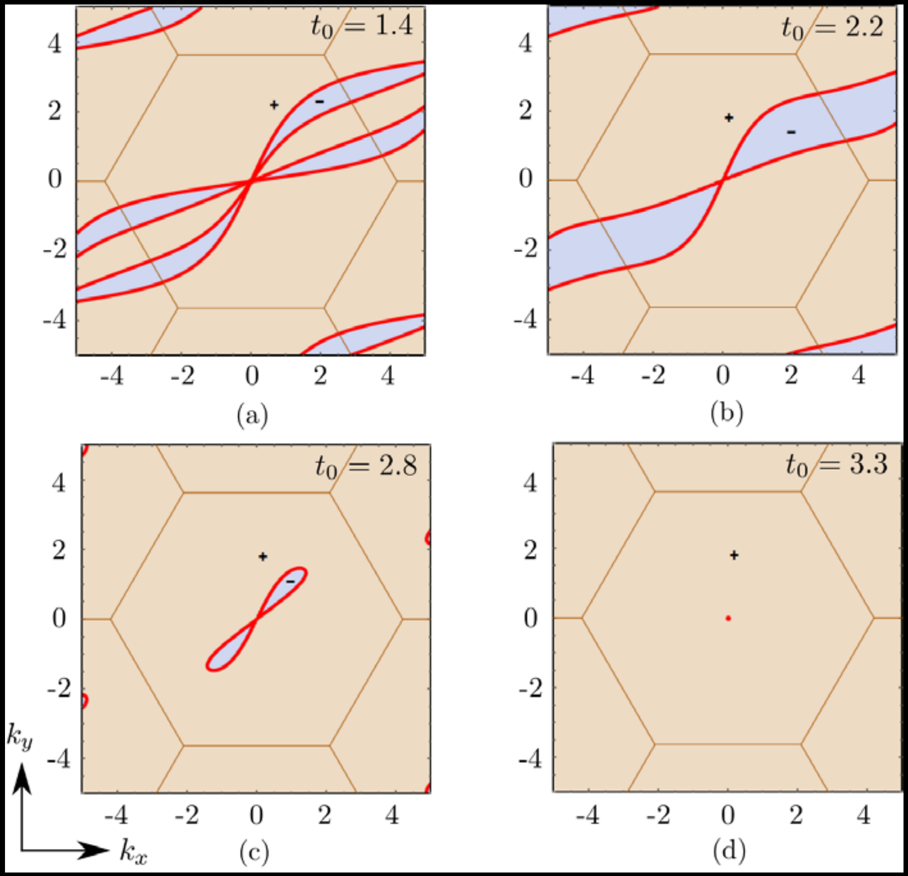
Chen et. al. PRL 116, 135501 (2016)

Define:

$$\eta = \mathrm{sign}\ \det R(\mathbf{k})$$

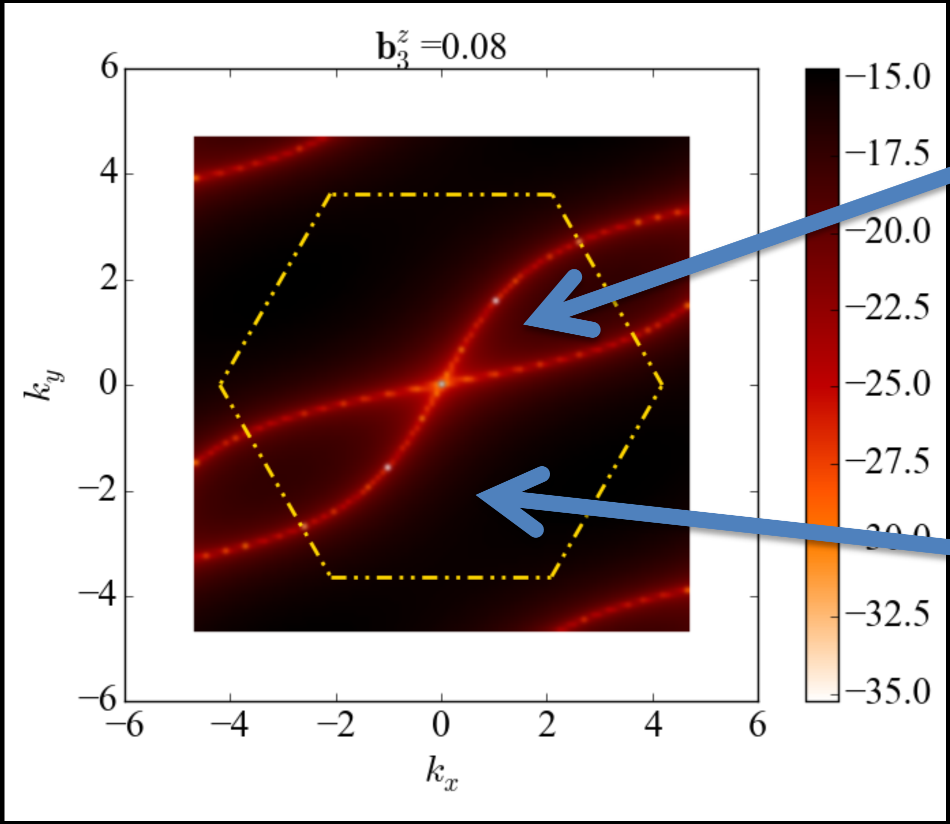
η is a "topological invariant"!

Weyl line nodes of generic origami



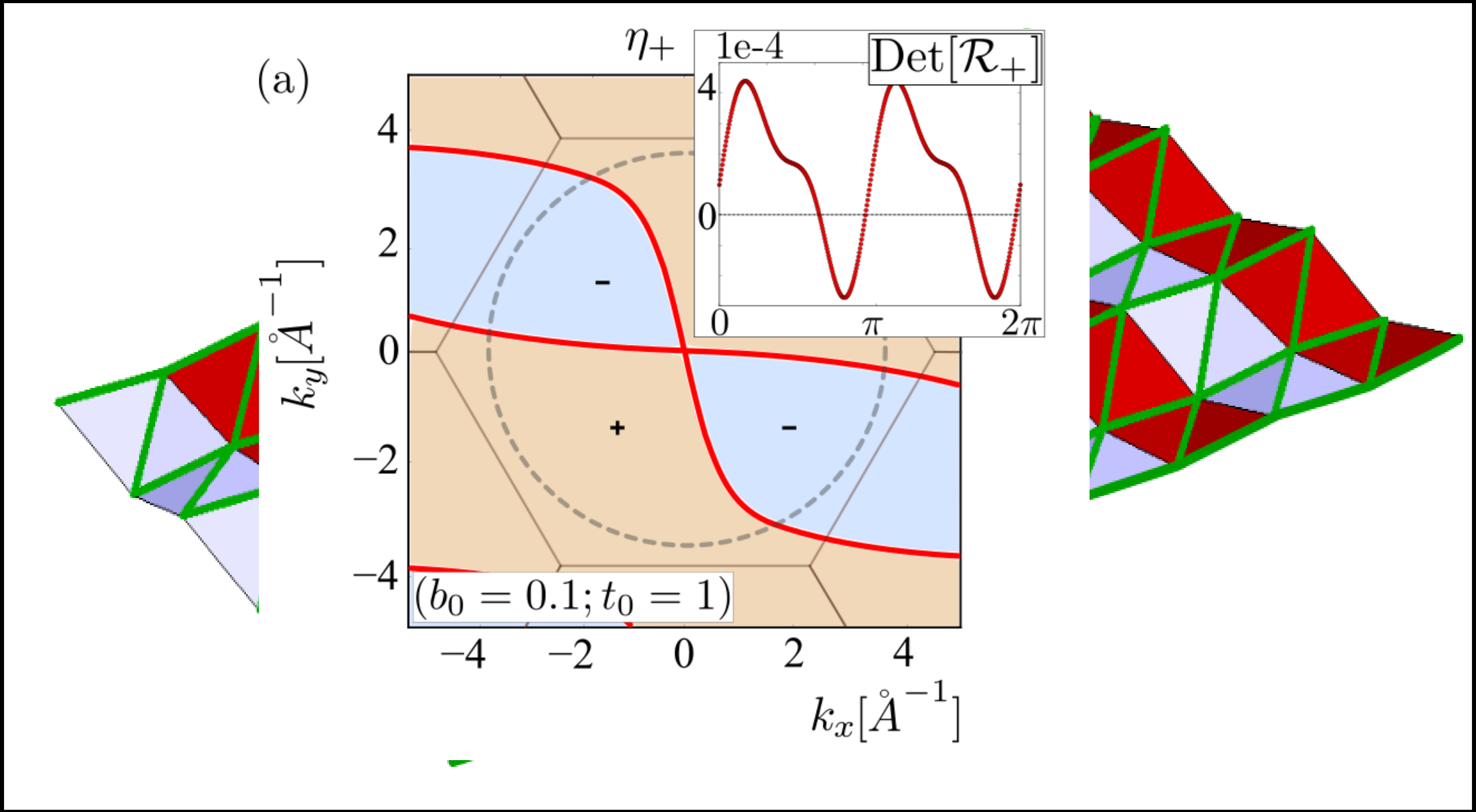
Changing ground states just moves the line nodes!

Line nodes of $Cs_2CeCu_3F_{12}$

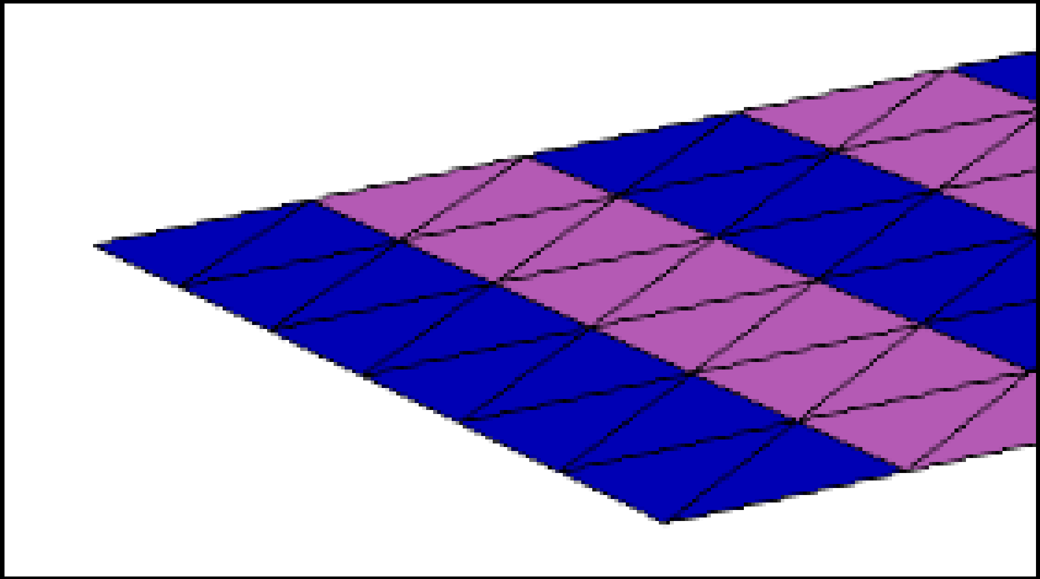


Doubly degenerate Dirac line nodes!

Diamond origami



Topological invariants of flattenable origami



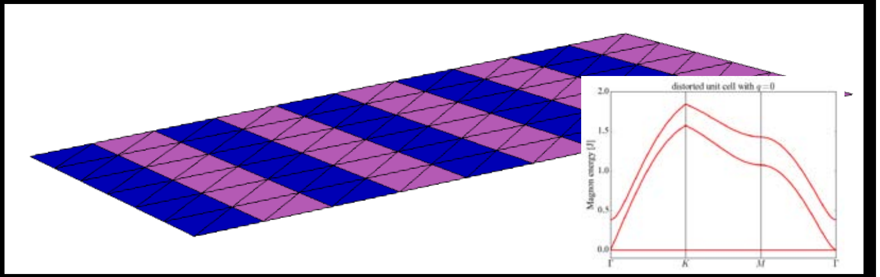
One zero mode per flat vertex

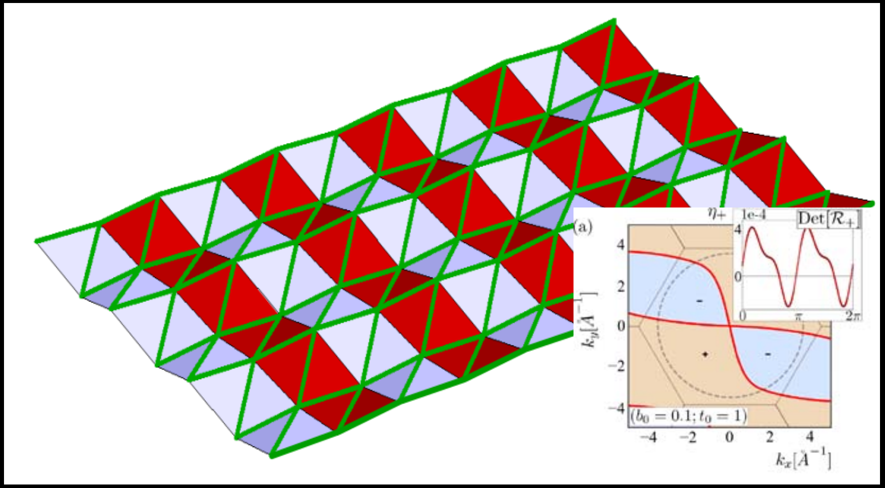
Build a topological invariant from curvature?

Conclusions

Frustration characterized by topological invariants

Spin origami and distorted Kagome antiferromagnets





$Cs_2ZrCu_3F_{12}$ $Cs_2CeCu_3F_{12}$

Generic frustration is an intertwined order!

Intertwined orders refers to the case in which $T^0_{SC} \sim T^0_{CDW}$ over a range of situations, i.e., in the case of the cuprates, over a range of doping concentrations and material families. Where this occurs…it has no natural explanation simply in terms of robust and generic features of coupled order parameters.

Fradkin, Kivelson, Tranquada, RMP 87, 457 (2015)