Magnetic interactions in AB-stacked kagome lattices: magnetic structure, symmetry, and duality

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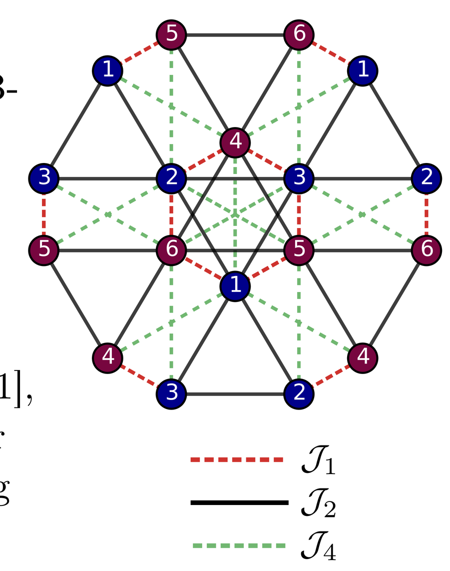
Background

Recently, large Anomalous Hall and Nernst effects (AHE) and (ANE) were experimentally observed in compounds with AB-stacked kagome layers and a general formula Mn_3X. These discoveries prompted theoretical and experimental studies of the magnetic properties in Mn_3X magnets. In our previous work [1], we derived a magnetic model for these magnetic compounds using general symmetry principles.



$$\mathcal{H} = \mathcal{H}_J + \mathcal{H}_D + \mathcal{H}_A + \mathcal{H}_K$$

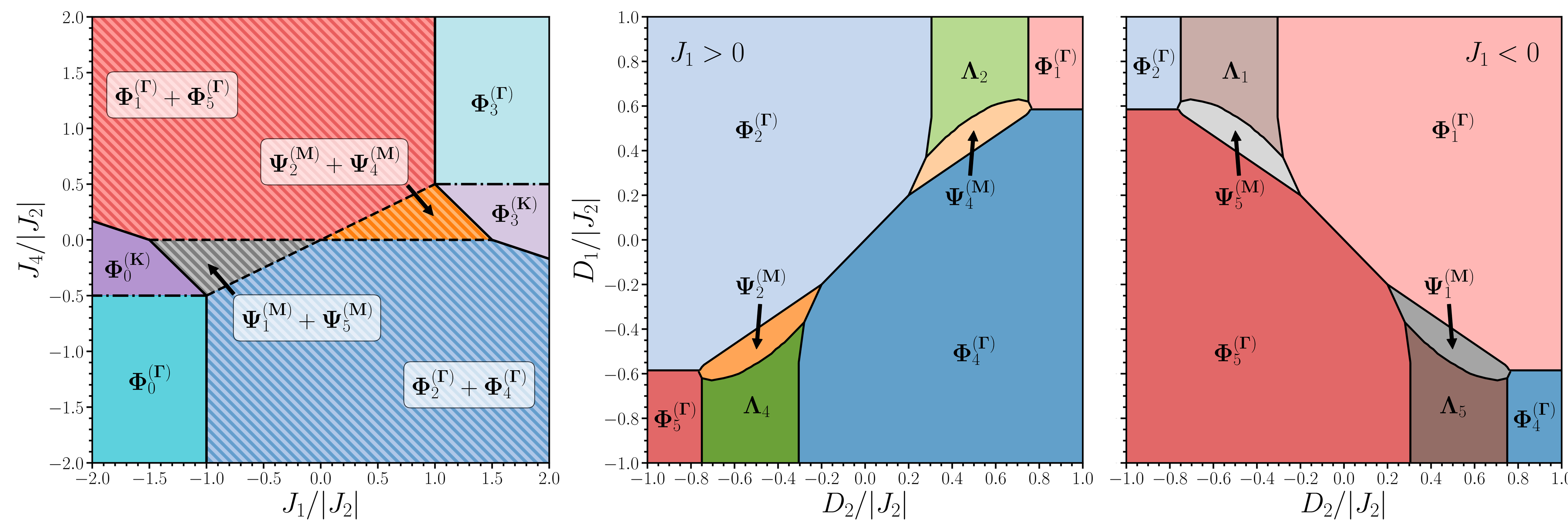
$$\mathcal{H}_J = \sum_{\mathbf{r}\mathbf{r}'}\sum_{ij} J_{ij}(\mathbf{r}-\mathbf{r}')\mathbf{S}_i(\mathbf{r})\cdot\mathbf{S}_j(\mathbf{r}')$$

$$\mathcal{H}_D = \sum_{\mathbf{r}\mathbf{r}'}\sum_{ij} D_{ij}(\mathbf{r}-\mathbf{r}')\hat{\mathbf{z}}\cdot(\mathbf{S}_i(\mathbf{r})\times\mathbf{S}_j(\mathbf{r}'))$$

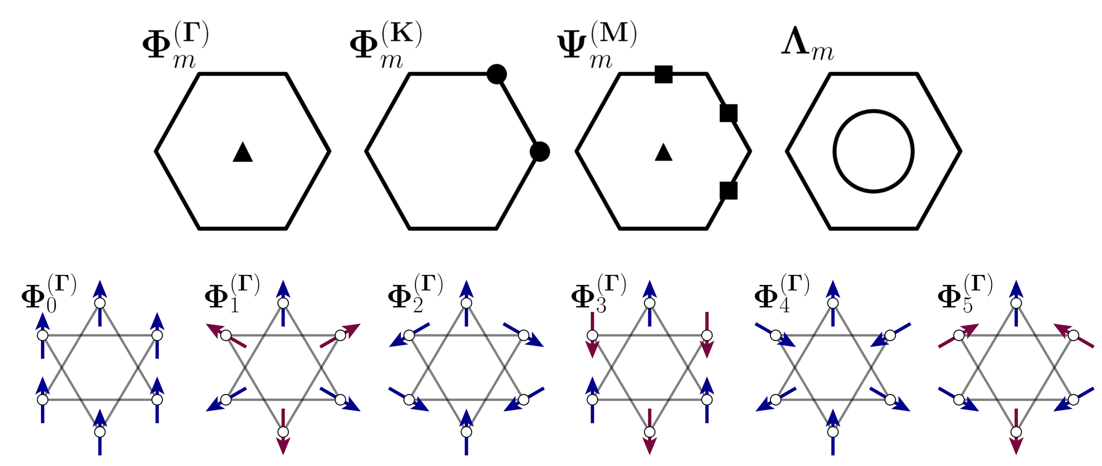
$$\mathcal{H}_A = \sum_{\mathbf{r}\mathbf{r}'}\sum_{ij}\sum_{\alpha} A_{ij\alpha}(\mathbf{r}-\mathbf{r}')\left(\hat{\mathbf{n}}_{i\alpha}\cdot\mathbf{S}_i(\mathbf{r})\right)\left(\hat{\mathbf{n}}_{j\alpha}\cdot\mathbf{S}_j(\mathbf{r}')\right),$$

$$\mathcal{H}_K = \sum_{\mathbf{r}}\sum_{i}\sum_{\alpha} K_\alpha\left(\hat{\mathbf{n}}_{i\alpha}\cdot\mathbf{S}_i(\mathbf{r})\right)^2.$$

Magnetic phases

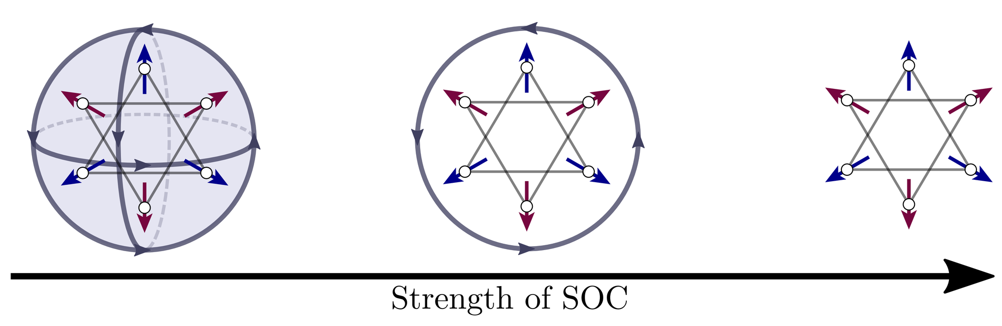


We determine the semi-classical ground state using a combination of analytical (Luttinger-Tisza) and numerical (simulated annealing) methods. The model gives rise to a wide range of magnetic phases, including configurations with single and multiple ordering wavevectors. For every type of magnetic order we find six states charchterized by a "winding" number.



Symmetry

Depending on the strength of the spin-orbit coupling (SOC), the effective symmetry group of the system can be much larger than the magnetic space group [2,3].

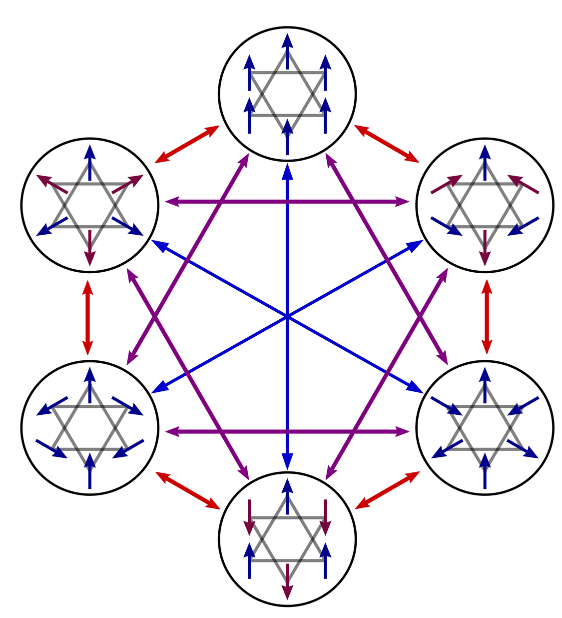


$D_{6h}^{(L)}\otimes SO^{(S)}(3)\otimes Z_2^{(T)}$	$\left(C_{6h}^{(L)}\otimes SO^{(S)}(2)\right)\ltimes C_2^{(SL)}\otimes Z_2^{(T)}$	$D_{6h}^{(L)}\otimes Z_2^{(T)}$
Magnetic space group + Full rotational symmetry	Magnetic space group + Axial rotational symmetry	Magnetic space group
$\mathcal{H}\approx\mathcal{H}_J$	$\mathcal{H}\approx\mathcal{H}_J+\mathcal{H}_D$	

In the case of Mn_3X, there are three different cases corresponding to decoupled, weak, and intermediate SOC. Each case results in effective Hamiltonians with different spin symmetry properties.

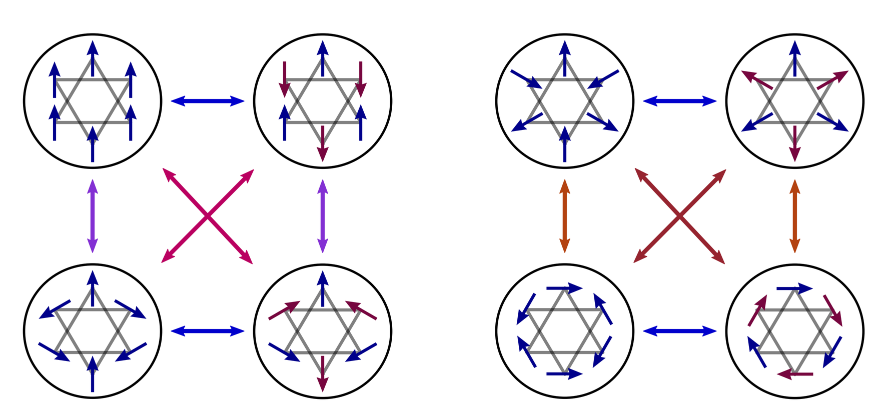
Self-duality

Besides the symmetry operations, there is a set of local spin transformations that only change the values of the coupling constants. Since these transformations map the Hamiltonian onto itself, they are called **self-dualities** [4,5].



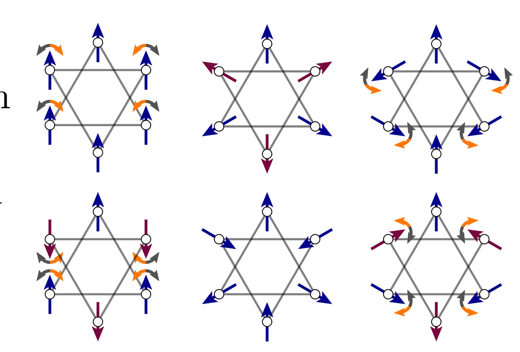
In the weak SOC limit, the self-dualities change the winding of the local axes.

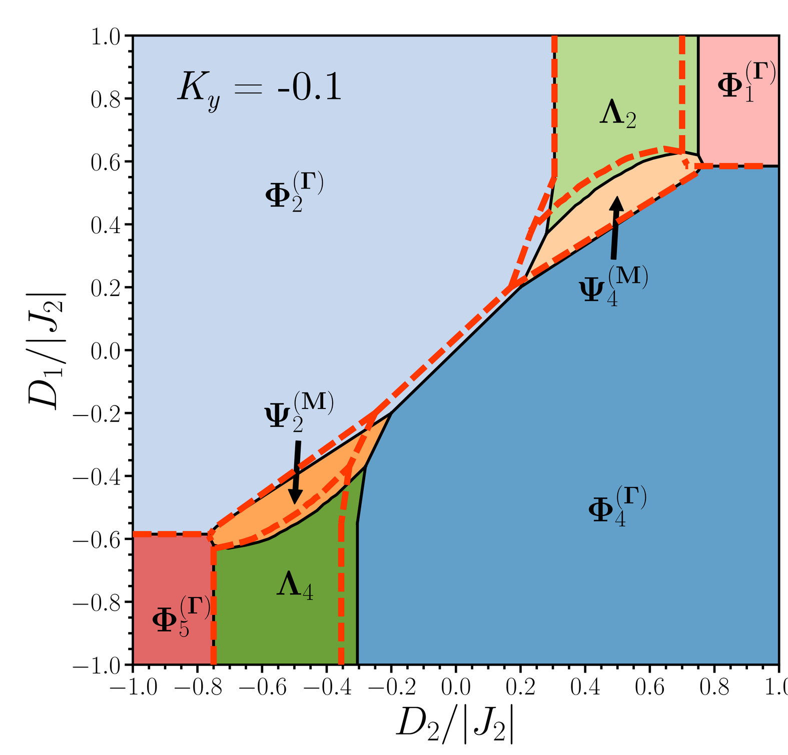
In the intermediate SOC limit, there are still more than a dozen duality transformations.



Anisotropy

Single-ion and bond-dependent anisotropy, which result from intermediate SOC, favour the states with spins collinear with the anisotropy axes, thus breaking the symmetry of the phase diagrams.





Conclusions

The strength of the SOC has a direct effect on the symmetry of the magnetic Hamiltonian.

For Mn_3X, there are three distinct SOC limits, each characterized by different symmetry properties.

Competing magnetic **interactions stabilize a wide range of magnetic phases.**

The model exhibits a large number of self-dualities, which relate the properties of different phases.

The self-dualities remain even in the most general case of intermediate SOC.

Acknowledgements

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References

[1] **Zelenskiy A.**, Monchesky T. L., Plumer M. L., and Southern B. W., Phys. Rev. B **103**, 144401 (2021)

[2] Brinkman W. F. and Elliott R. J., Proc. R. Soc. Lond. A **294** 343–358 (1966).

[3] Pengfei L., *et. al.*, Phys. Rev. X **12**, 021016 (2022)

[4] Kimchi I. and Vishwanath A., Phys. Rev. B **89**, 014414 (2014)

[5] Maksimov P. A., *et. al.*, Phys. Rev. X **9**, 021017 (2019).