Topological Hall Effect in Topological Trivial Target Skyrmions

Tan Dao[1,2], Sergey Pershoguba[1], Jiadong Zang[1,3]

[1]Department of Physics and Astronomy, University of New Hampshire, Durham, New Hampshire 03824, USA

[2]Department of Physics, Harvard University, Cambridge, MA 02138, USA

[3]Materials Science Program, University of New Hampshire, Durham, New Hampshire 03824, USA

Introduction

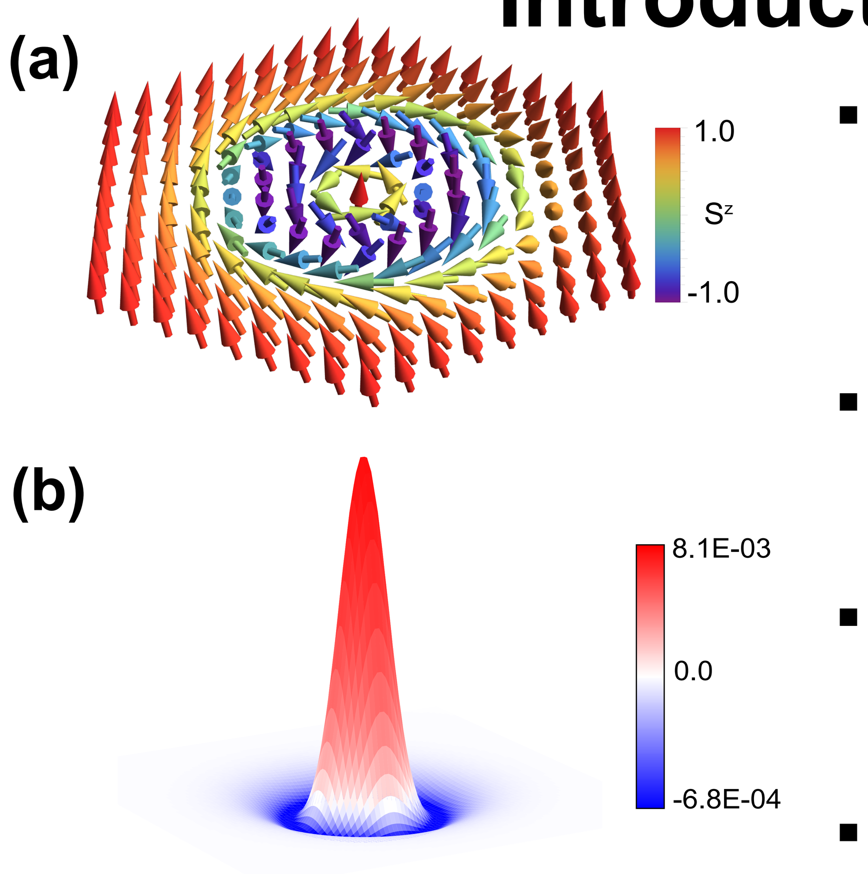

Figure 1: a) Target skyrmion spins configuration. b) The effective magnetic field of a target skyrmion.

- Target skyrmion is a concentric ring of two skyrmions
- Inner skyrmion rotates counterclockwise
- Outer skyrmion rotates clockwise
- Topological charge $Q = 0$

Topological trivial target skyrmion can be moved linearly by a small electric current make it promising for next-generation memory devices[1-3].

Electrons hopping through a topological spin texture acquire a Berry phase, which can be understood as the effective magnetic field[4,5]. This gives rise to a Hall effect known as the *topological Hall effect*. The Berry phase is zero for $Q = 0$ texture, hence it is expected that there is no Hall effect in the target skyrmion. **Here we show that there exist a *topological Hall effect* in *topological trivial* target skyrmion.**

Objectives and Methods

- Model classical system of electrons moving through a target skyrmion to show non-zero transverse current.
- Model the conduction electrons with the tight-binding model. $H = -t\sum_{\langle ij \rangle} c_i^\dagger c_j - J\sum_i c_i^\dagger \boldsymbol{\sigma} \cdot \boldsymbol{S} c_i$
- Use KWANT to calculate transmission probabilities from the ferromagnetic leads[6].
- Apply Landauer-Buttiker formalism to calculate the Hall resistance and Hall angle.
- Study the Hall effect dependence on target skyrmion radius r_0 and Hund's coupling strength J.

Results

Classical simulation of electrons in a target skyrmion's magnetic field

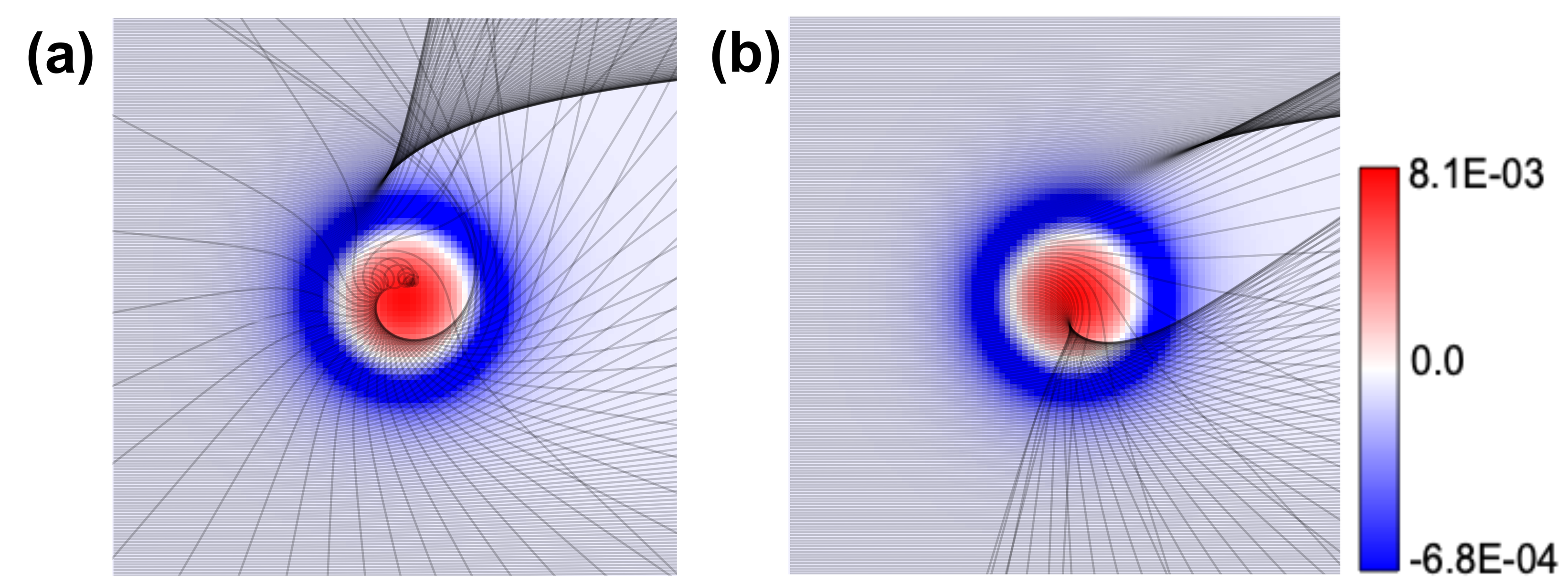

Figure 2: Electron trajectories (black lines) in a target skyrmion's effective field for momentum (a) p = 5 and (b) p = 15. Electron mass = charge = 1.

Quantum transport

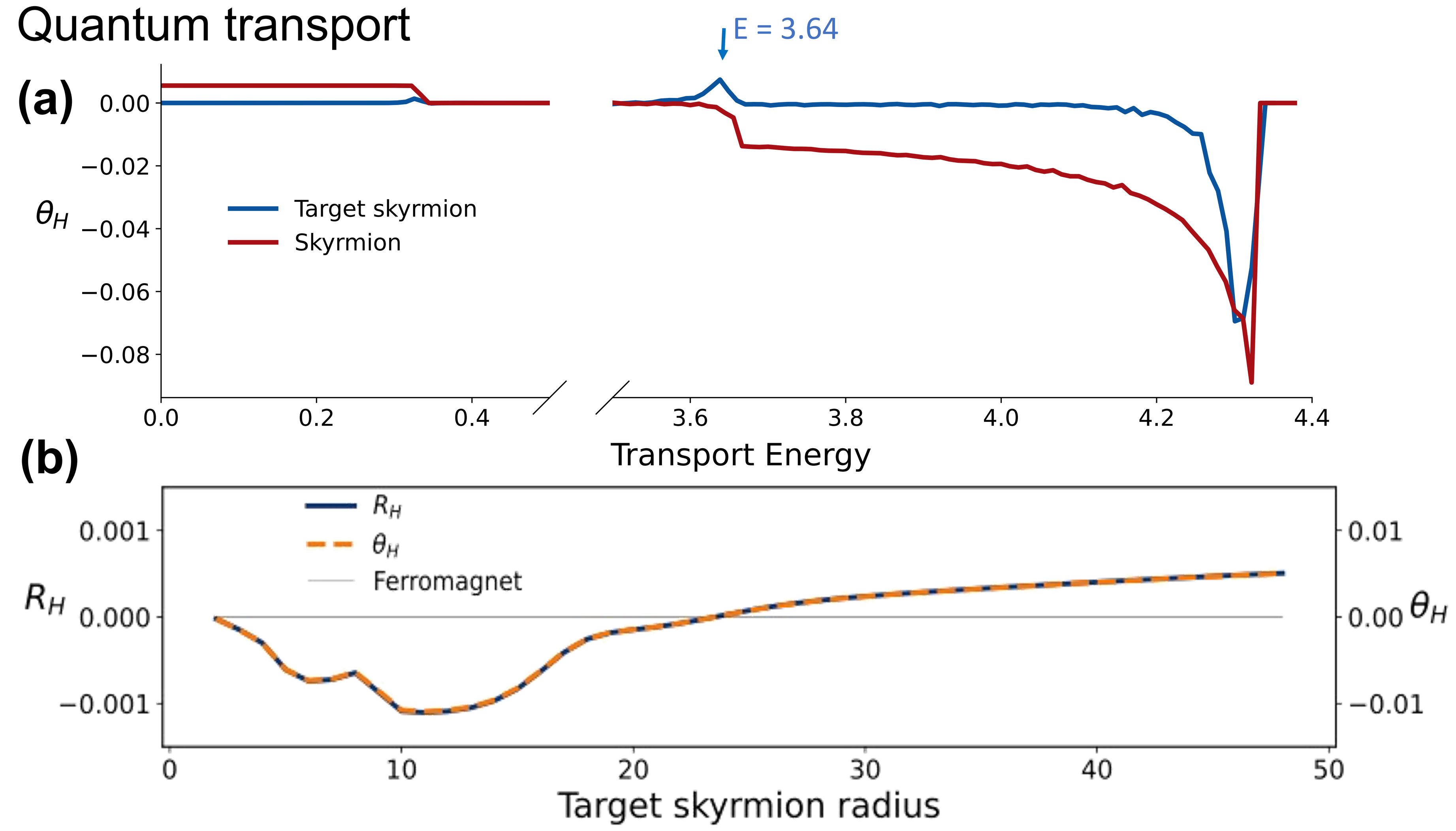

Figure 3: a) Target skyrmion and skyrmion Hall angle as a function of energy for $N = 96a_0$, $r_0 = 48$, and $J = 1/3$. b) The Hall resistance and Hall angle dependence of target skyrmion radius for E = 3.64. Hall resistance unit $h/e^2 = 1$.

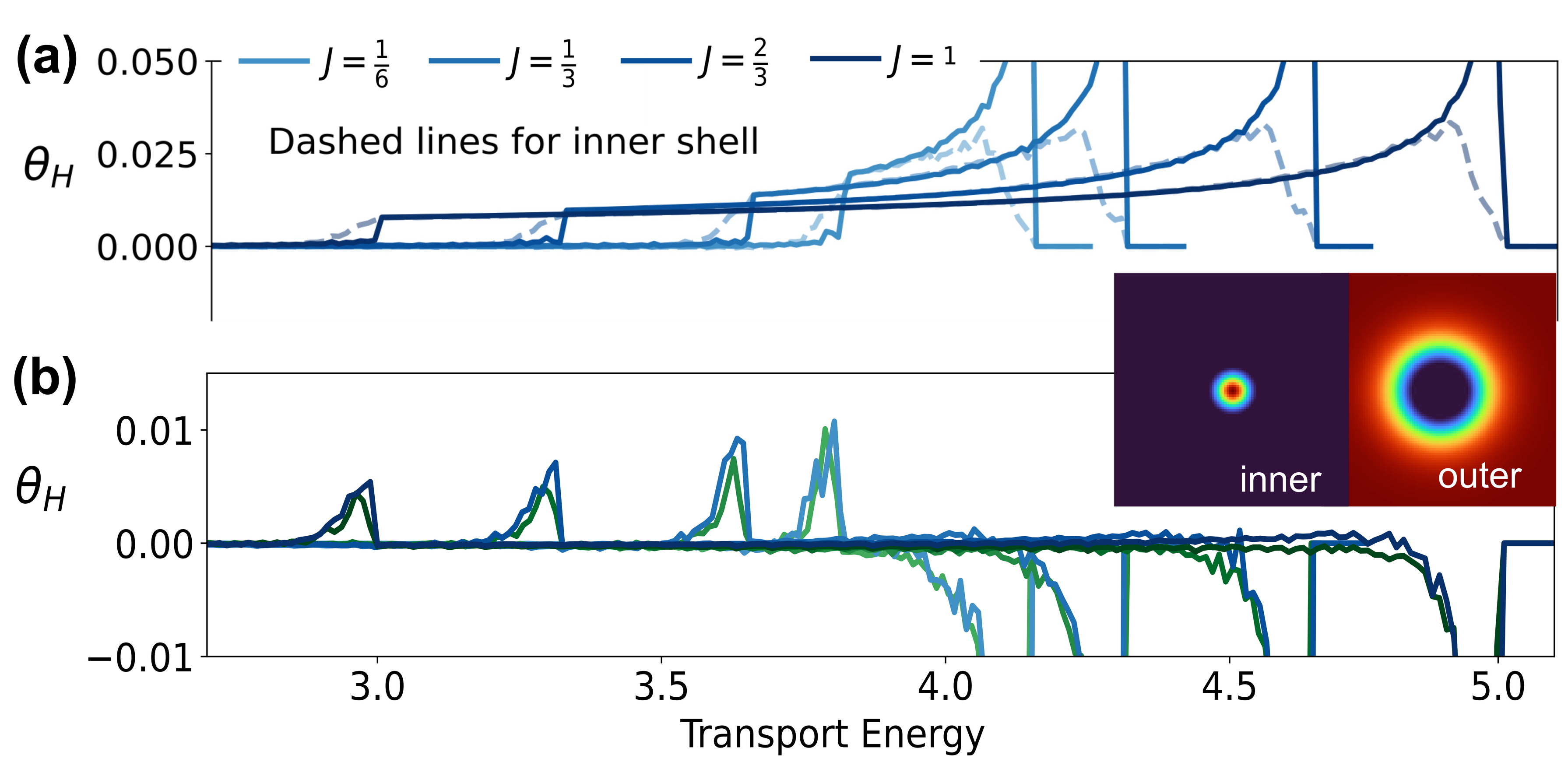

Figure 4: a) zoomed in $|\theta_H|$ for the inner and outer shell for various Hund's coupling strength. b) Hall angle plots of a target skyrmion (green plots) and combined Hall angle of the inner and outer shell (blue plots). Inset figures show S^z profiles.

Discussion

- Starting from a classical model, we show the transverse current has a nonmonotonic behavior and sign switch, indicating a competing order in the target skyrmion.
- Transport calculations also show the nonmonotonic Hall angle dependence on target skyrmion radius.
  - For small radius, the negative Hall angle is contributed by the outer skyrmion.
  - For large radius, the positive Hall angle is contributed by the inner skyrmion.
- The Hall angle of a target skyrmion is the sum of the inner and outer shell's Hall angles.
  - The Hall angle magnitude is set by the skyrmion, which respect the adiabatic approximation.
  - We can interpret this Hall effect as the topological Hall effect

Significant

- We demonstrated the topological Hall effect can exist in a topological trivial texture. This may be used to detect the presence of target skyrmion in experiment.
- We show a method of separating complex spin texture into its topological components. This allows us to understand the contribution of each component. This method can be used for other composite spin textures.

Acknowledgement

This work was supported by Department of Energy, Basic Energy Science under award No. DE-SC0020221

References

1. J. Tang *et al* "Magnetic skyrmion bundles and their current-driven dynamics," Nature Nanotechnology.
2. X. Zhang *et al* "Control and manipulation of a mag- netic skyrmionium in nanostructures," Physical Review B.
3. A. G. Kolesnikov *et al* "Skyrmionium–high velocity without the skyrmion hall effect," Scientific reports.
4. R. Karplus and J. Luttinger, "Hall effect in ferromagnetics," Physical Review
5. N. Nagaosa *et al*, "Anomalous hall effect," Reviews of modern physics.
6. C. W. Groth *et al* "Kwant: a software package for quantum transport," New Journal of Physics.