

Torsion through time-loops on bidimensional Dirac materials

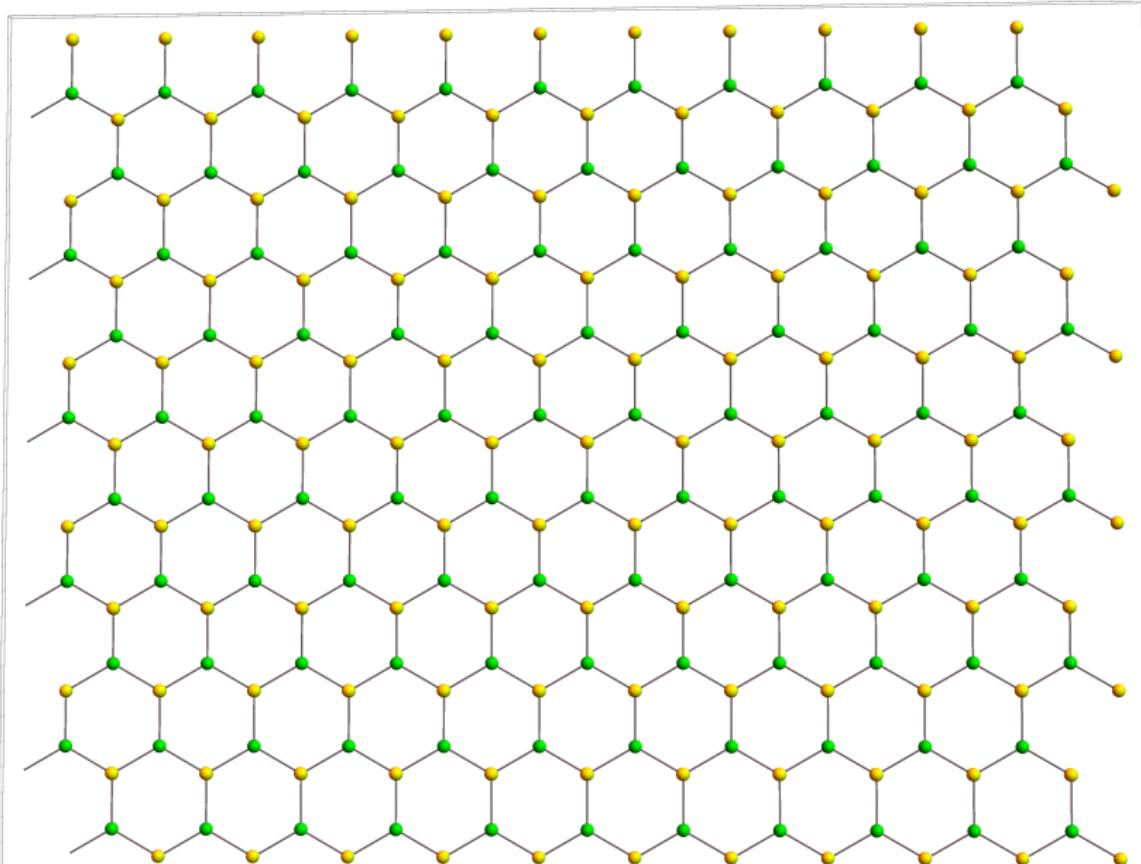
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Adamantia Zampeli**

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(arXiv:1907.00023 [hep-th])

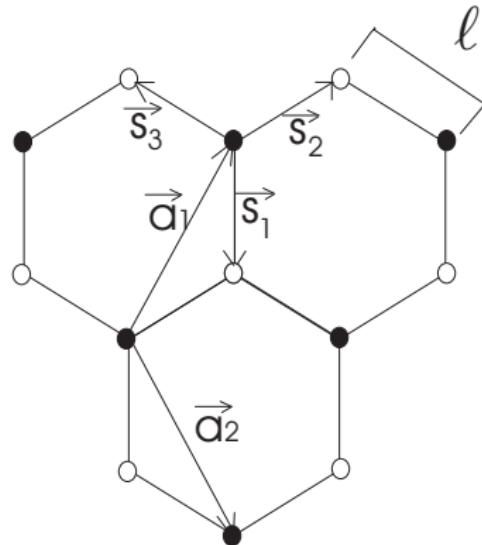
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Honeycomb lattice of graphene



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● = sublattice L_A

○ = sublattice L_B

Tight-binding Hamiltonian

Considering just until near-neighbors (**NN**),

$$H = -\eta \sum_{\vec{r} \in L_A} \sum_{i=1}^{i=3} \left(a^\dagger(\vec{r}) b(\vec{r} + \vec{s}_i) + b^\dagger(\vec{r} + \vec{s}_i) a(\vec{r}) \right) ,$$

$\eta \sim 2,8$ eV is the hopping energy between NN

$a, a^\dagger (b, b^\dagger)$ are π electrons leader operators corresponding to the sublattice $L_A (L_B)$.

Tight-binding Hamiltonian

Performing a Fourier transformation

$$H = - \sum_{\vec{k}} \left[f_1(\vec{k}) a_{\vec{k}}^\dagger b_{\vec{k}} + f_1^*(\vec{k}) b_{\vec{k}}^\dagger a_{\vec{k}} \right] ,$$

where

$$f_1(\vec{k}) \equiv -\eta \sum_{i=1}^{i=3} e^{i\vec{k} \cdot \vec{s}_i} = -\eta e^{i\ell k_y} \left[1 + 2e^{\frac{3i}{2}\ell k_y} \cos\left(\frac{\sqrt{3}}{2}\ell k_x\right) \right] ,$$

Tight-binding Hamiltonian

The points in the momentum space where $|f_1(\vec{K})| = 0$ are called *Dirac points* ($K_{D\pm} = \pm \frac{4\pi}{3\sqrt{3}\ell}$). Expanding around one of these points¹

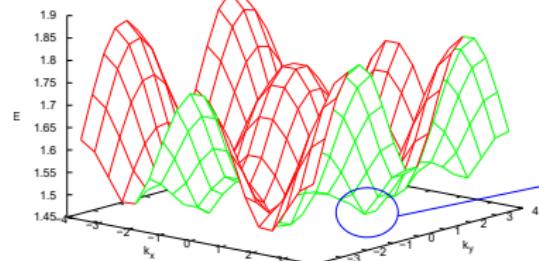
$$H = v_F \sum_{\vec{p}} \left[\psi_+^\dagger \vec{\sigma} \cdot \vec{p} \psi_+ \right] ,$$

where $\psi_{\pm} = \begin{pmatrix} b_{\pm} \\ a_{\pm} \end{pmatrix}$, $\psi_{\pm}^\dagger = \begin{pmatrix} b_{\pm}^\dagger & a_{\pm}^\dagger \end{pmatrix}$, $\vec{\sigma} = (\sigma_1, \sigma_2)$, and

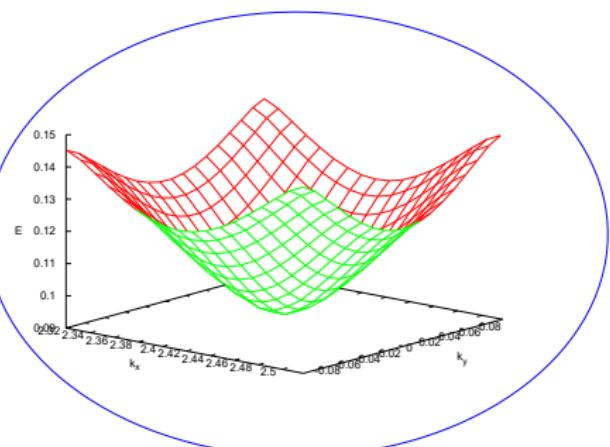
$$v_F = \frac{3}{2} \eta \ell .$$

¹ A. H. Castro Neto, F. Guinea, N. M. R. Peres, K. S. Novoselov, A. K. Geim, Rev. Mod. Phys. 81, 109 (2009).

Dispersion relation around K_{D+}

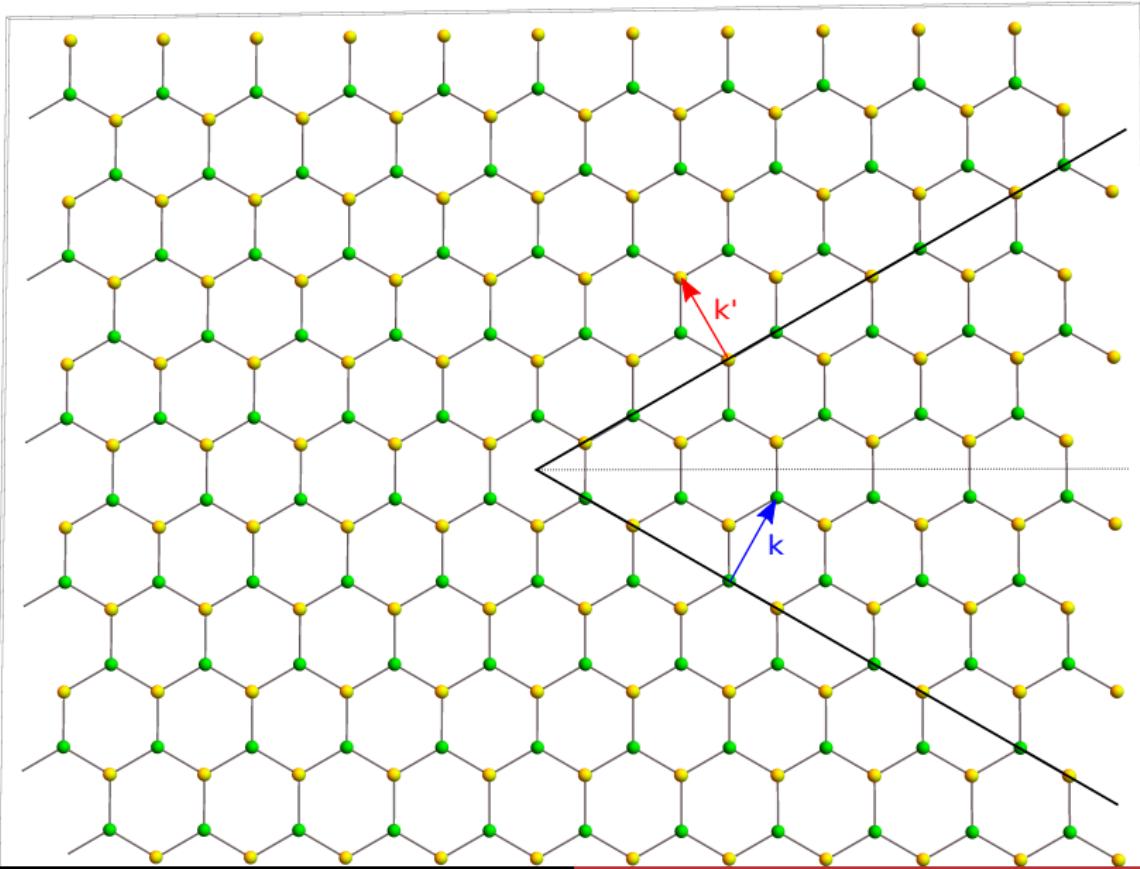


(a)

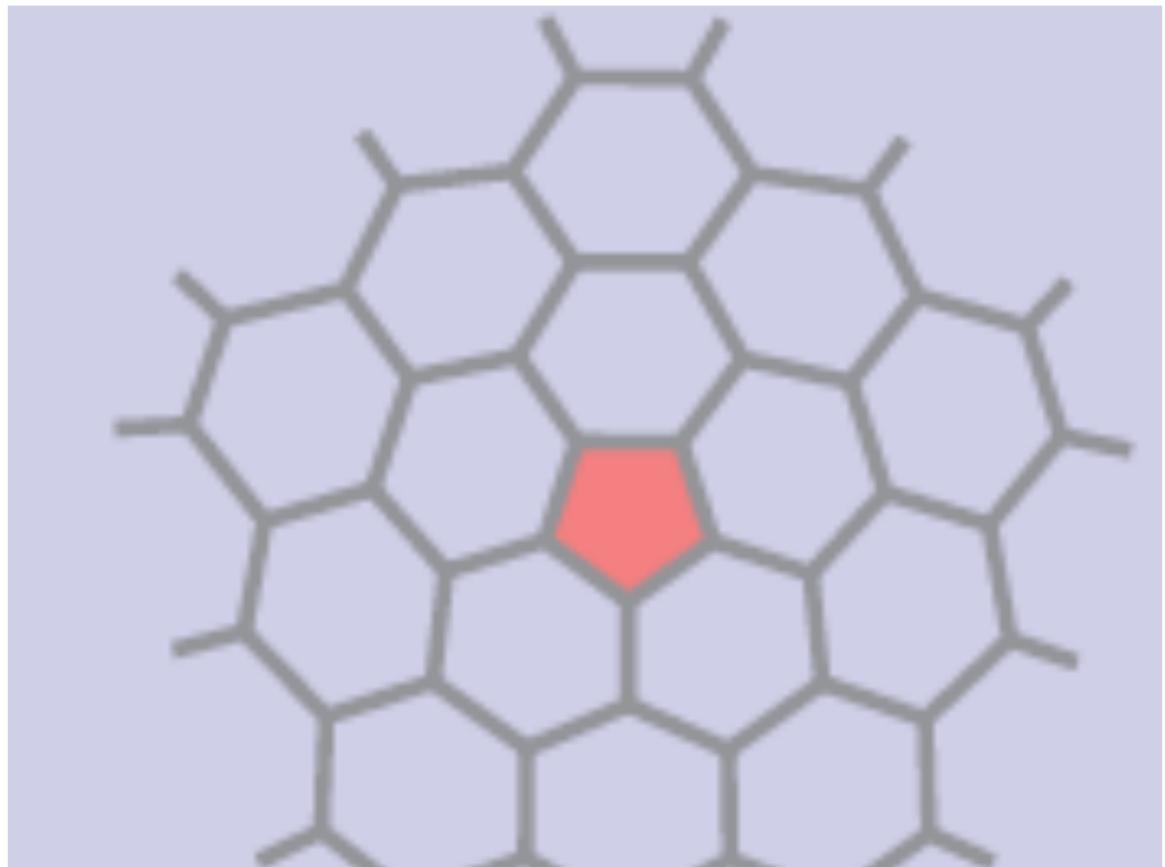


(b)

Topological defects



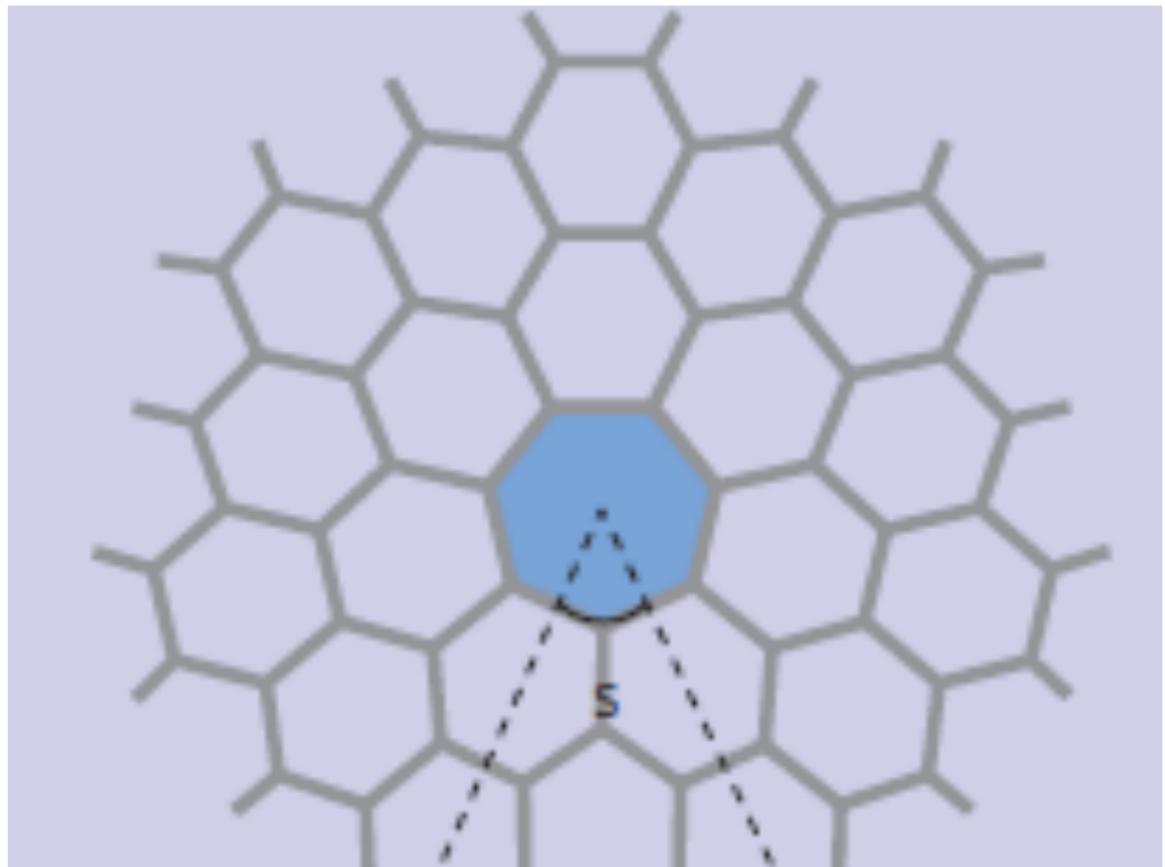
Topological defects

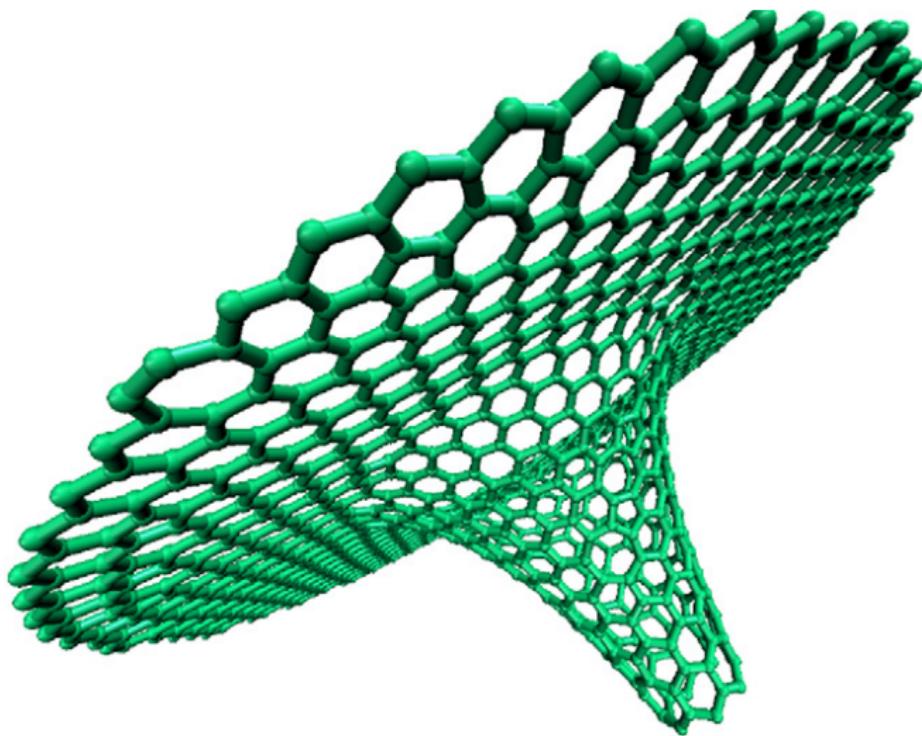


Topological defects



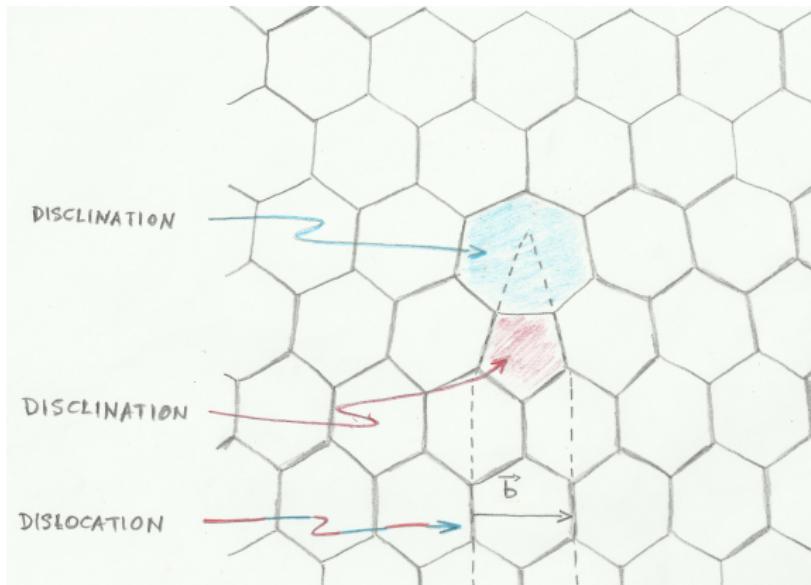
Topological defects





² S. Taioli, R. Gabbielli, S. Simonucci, N. M. Pugno, A. Iorio J. Phys.: Condens. Matter **28** (2016) 13LT01 .

Topological defects



Dislocations → Torsion

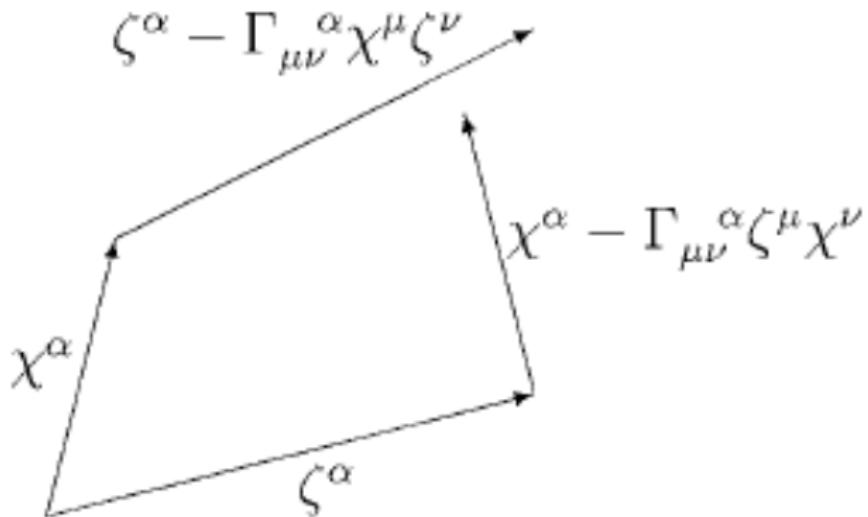
The torsion tensor $T_{\mu\nu}^i$ and the Burger vector \vec{b} are related²

$$b^i \approx \int \int_{\Sigma} T_{\mu\nu}^i dx^\mu \wedge dx^\nu , \quad (1)$$

where Σ is the surface containing some dislocation.

² H. Kleinert, *Gauge fields in condensed matter. Vol. 2: Stresses and defects. Differential geometry, crystal melting*, World Scientific (1989).

Geometrical interpretation of Torsion



But...

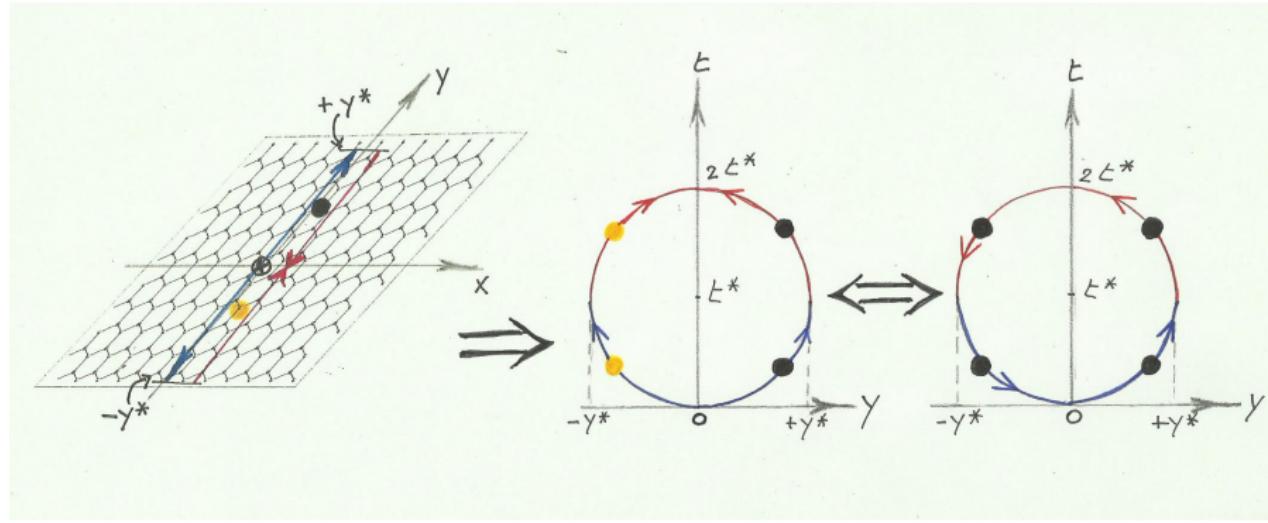
- At minimal coupling, the spinors are coupled only with the totally antisymmetric part of the torsion tensor
 $\sim \epsilon^{\mu\nu\rho} T_{\mu\nu\rho} \bar{\psi} \psi$
- In principle, there should not be such a coupling in two-dimensional materials³

³ F. De Juan, A. Cortijo, M.A..H. Vozmediano *Nucl. Phys. B* **828**, 625 (2010).

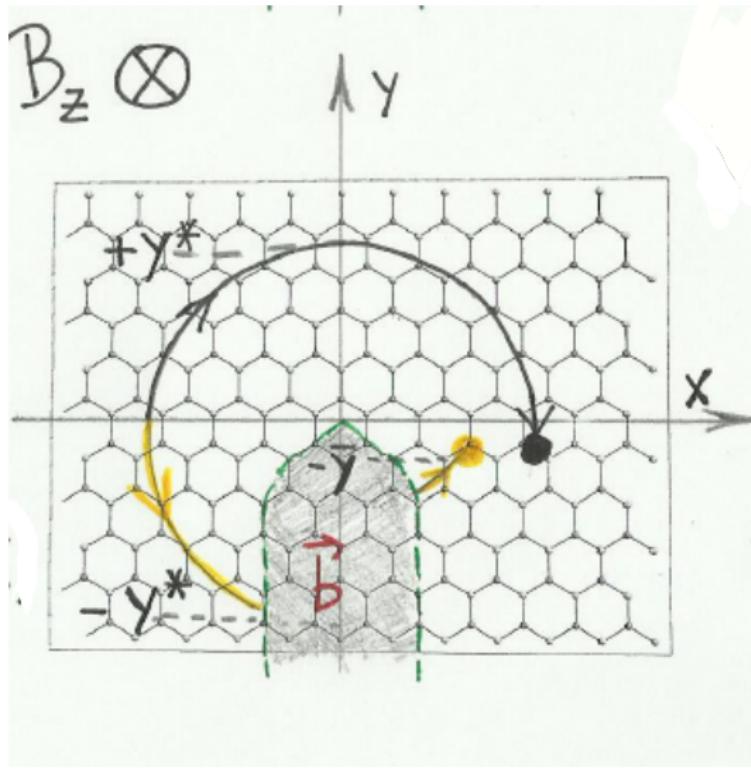
Unless...

- We allow time dimension to play the game
- In such a case there could survive a term of the kind
 $\epsilon^{012} T_{012}$

Time-loops in Dirac materials



Time-loops in Dirac materials



Future work

- How to translate all this on a measurable quantity?

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- Computing (numerically in principle) such a quantity identifying the suitable kind of defect

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- Computing (numerically in principle) such a quantity identifying the suitable kind of defect
- Making the experiment in a real lab

Thank you