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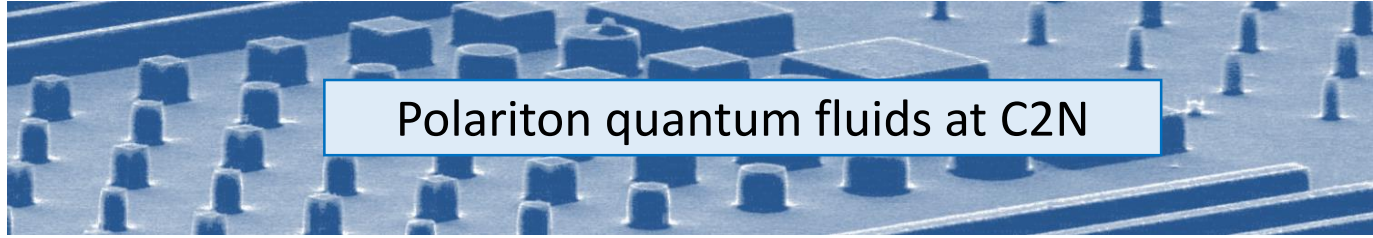

Measuring the topological properties of exciton-polariton lattices

05/07/2023

Martin Guillot – 3rd year Ph.D.

Supervisors: Jacqueline Bloch and Sylvain Ravets

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I. The valley Hall effect

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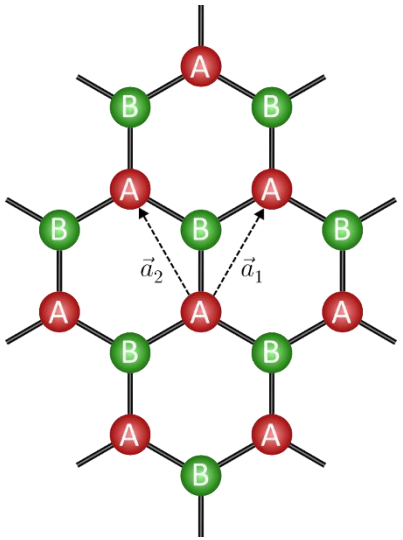
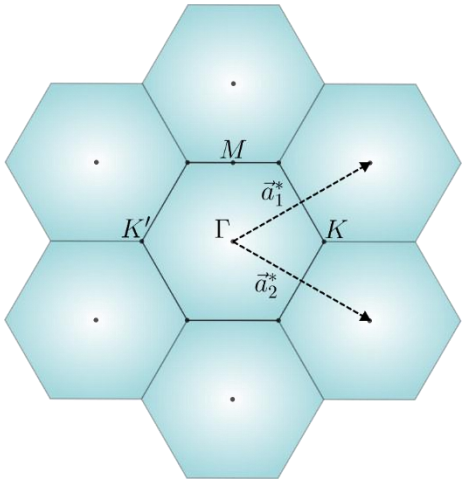
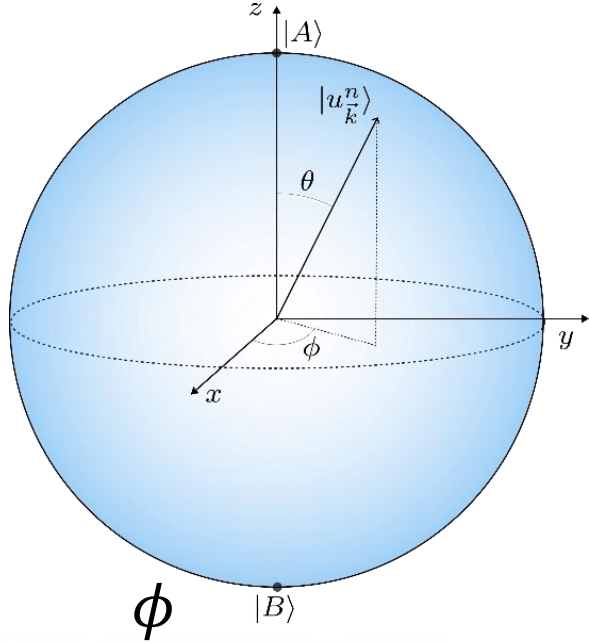
The staggered honeycomb lattice

$$u^n_{\vec{k}} = \begin{bmatrix} \cos(\theta/2)e^{i\phi} \\ \sin(\theta/2) \end{bmatrix}$$



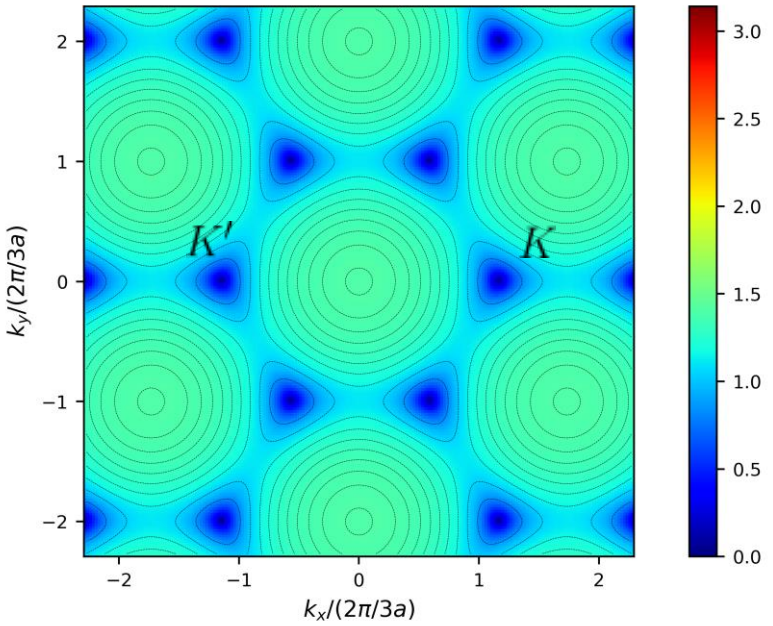




$$\hat{H}_{\vec{k}} = \begin{bmatrix} -\epsilon_0 & -t\gamma(\vec{k}) \\ -t\gamma^*(\vec{k}) & \epsilon_0 \end{bmatrix}$$

$$\gamma(\vec{k}) = 1 + e^{-i\vec{k}\cdot\vec{a}_1} + e^{-i\vec{k}\cdot\vec{a}_2}$$

θ



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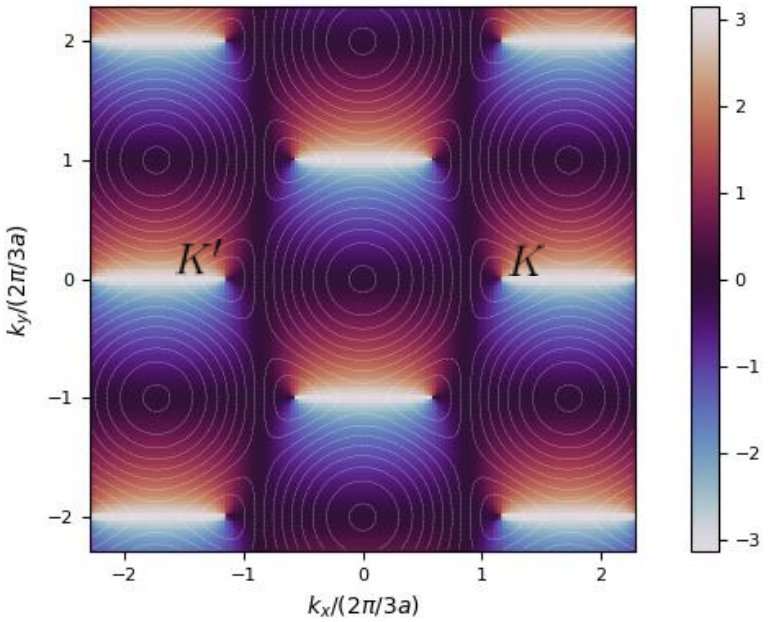
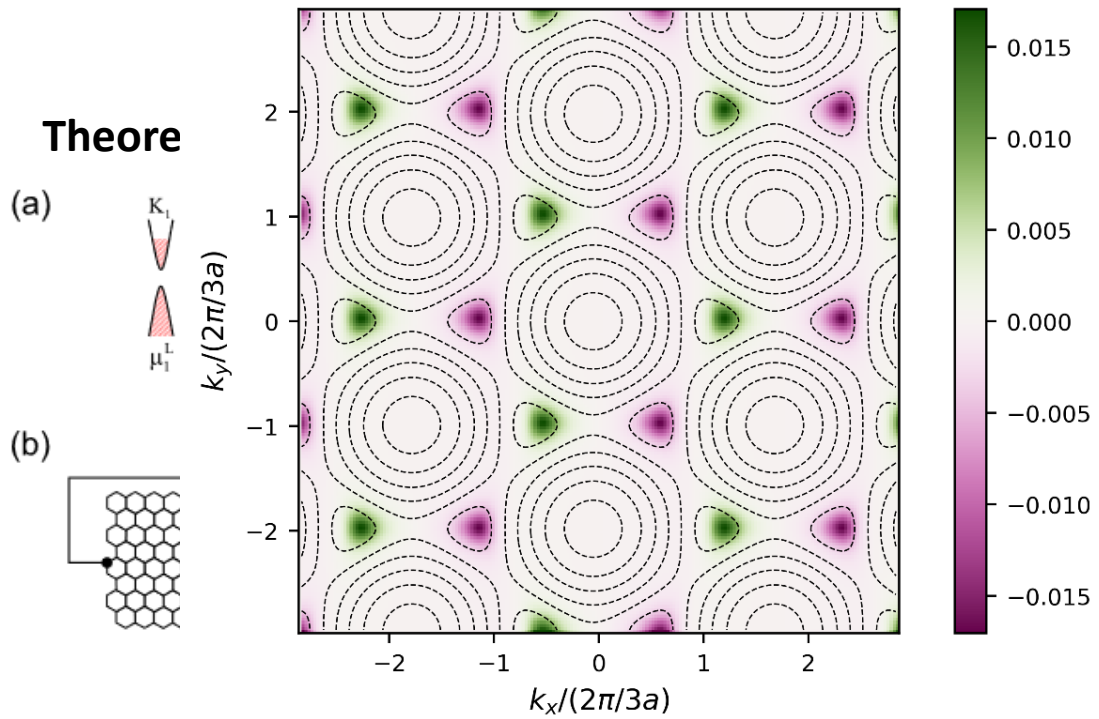


Topological Origin of Zero-Energy Edge States in Particle-Hole Symmetric Systems
Shinsei Ryu and Yasuhiro Hatsugai
Phys. Rev. Lett. **89**, 077002

The valley Hall effect in condensed matter

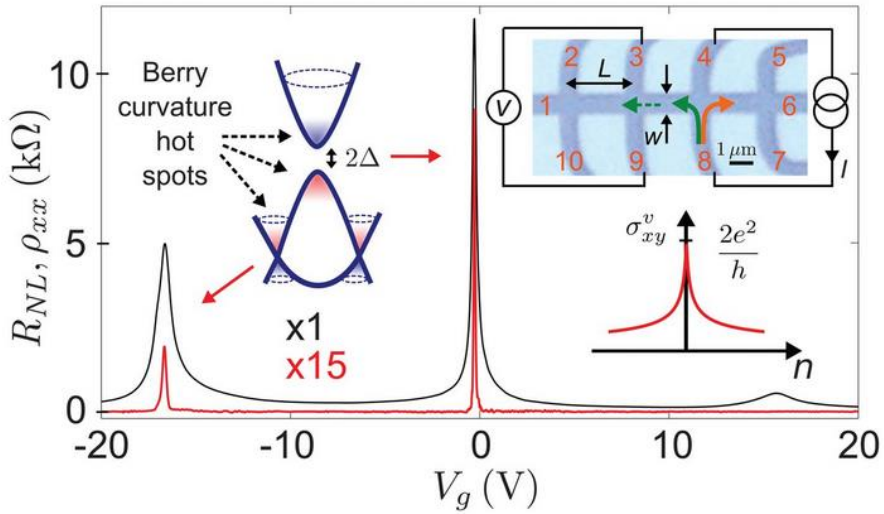
Berry curvature



Di Xiao, et al., Valley-Contrasting Physics in Graphene: Magnetic Moment and Topological Transport. Phys. Rev. Lett. **99**, 236809 (2007).

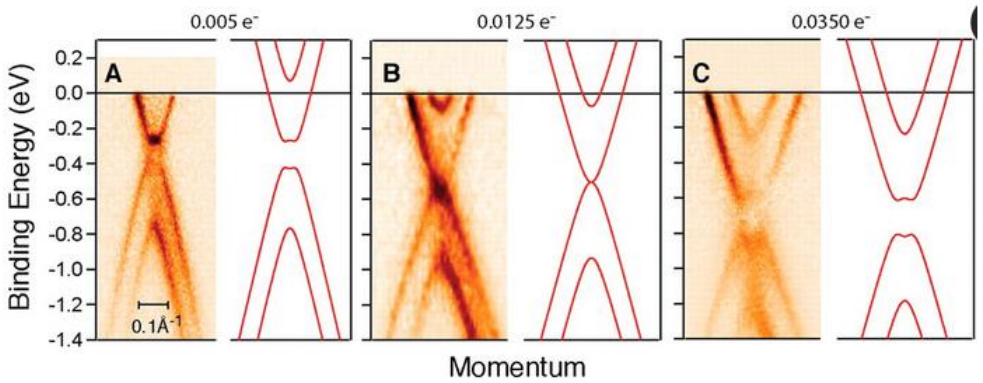
Rycerz, A., Tworzydło, J. & Beenakker, C. Valley filter and valley valve in graphene. *Nature Phys* **3**, 172–175 (2007).

Valley-Hall current measurements



R. V. Gorbachev et al., Detecting topological currents in graphene superlattices. *Science* **346**, 448-451 (2014)

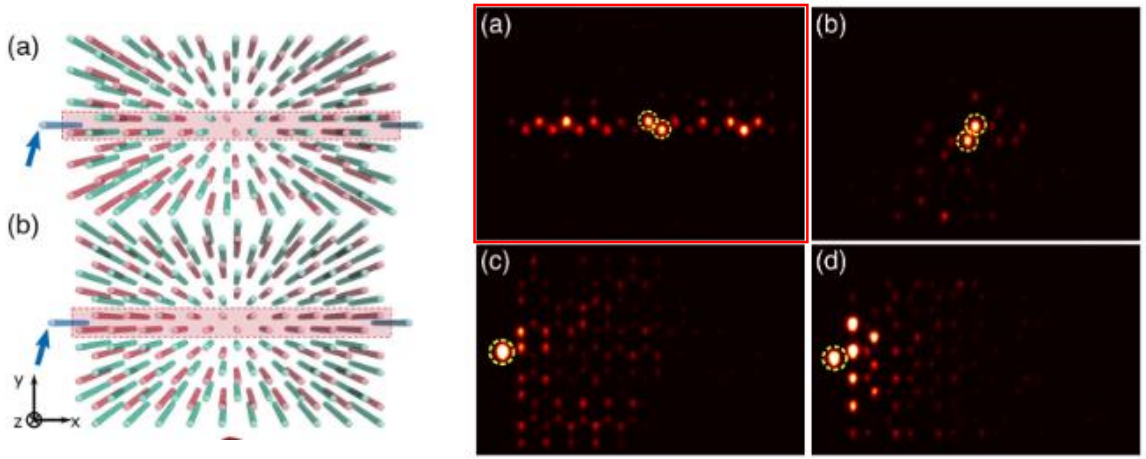
Band imaging



Taisuke Ohta et al., Controlling the Electronic Structure of Bilayer Graphene.
Science **313**, 951-954 (2006).

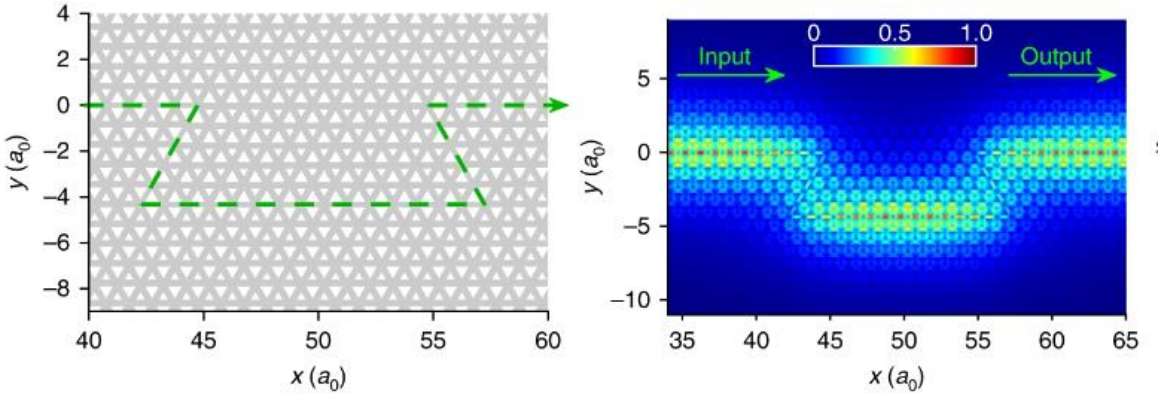
Photonic valley Hall insulators

In coupled waveguide arrays



Jiho Noh, et al., Observation of Photonic Topological Valley Hall Edge States. Phys. Rev. Lett. **120**, 063902 (2018)

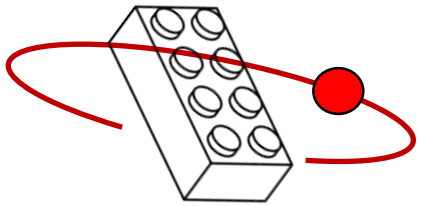
In photonic crystals



Shalaev, M.I., Walasik, W., Tsukernik, A. *et al.* Robust topologically protected transport in photonic crystals at telecommunication wavelengths. *Nature Nanotech* **14**, 31–34 (2019).

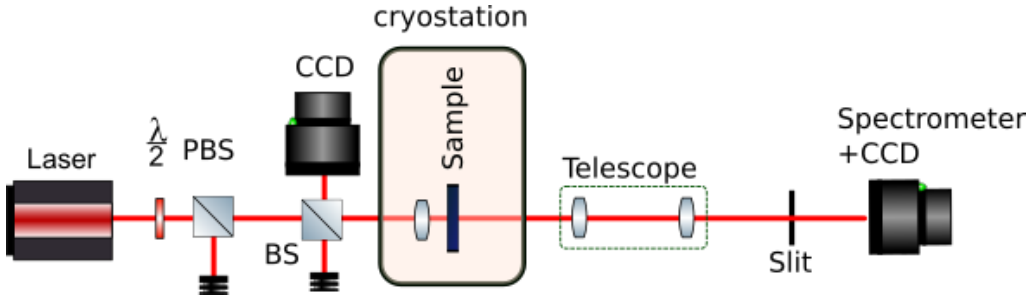
Can we get to the eigenvector structure ?

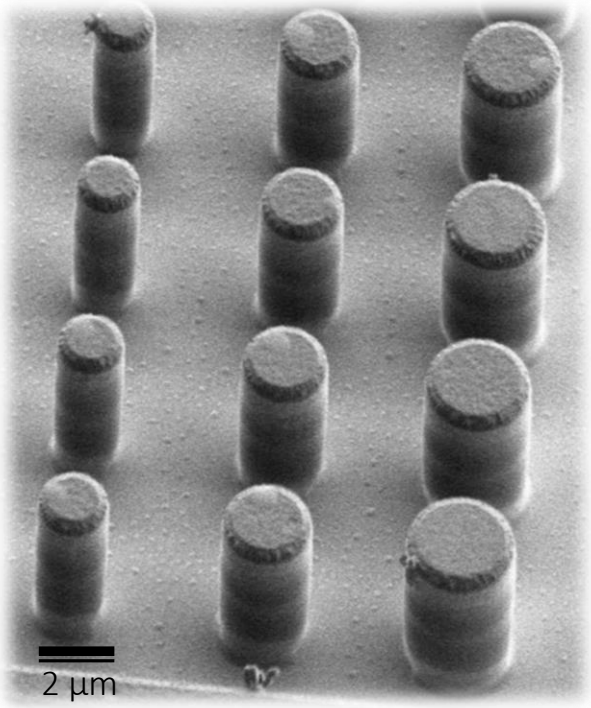
Engineering the photonic wavefunction



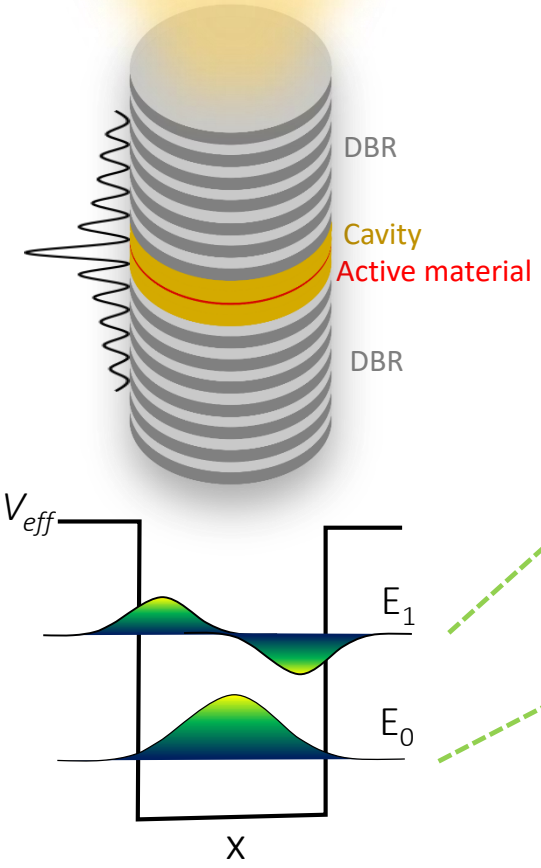
- Our bricks: Semiconductor micropillars

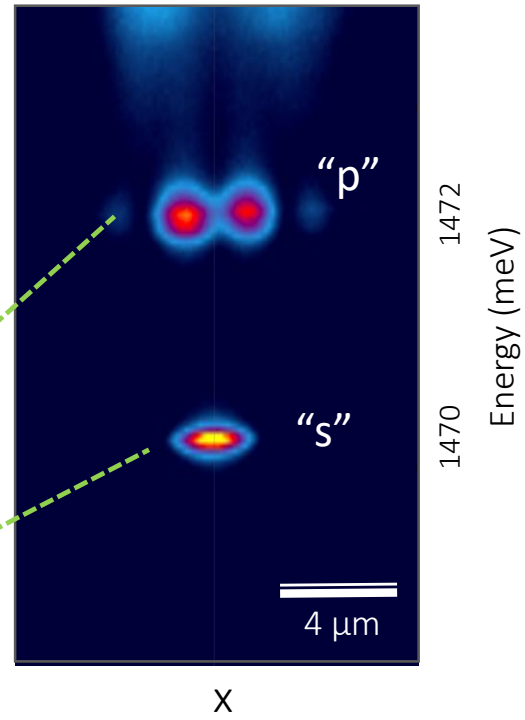
Experimental setup





SEM





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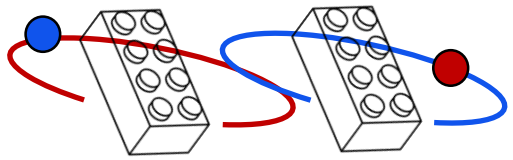
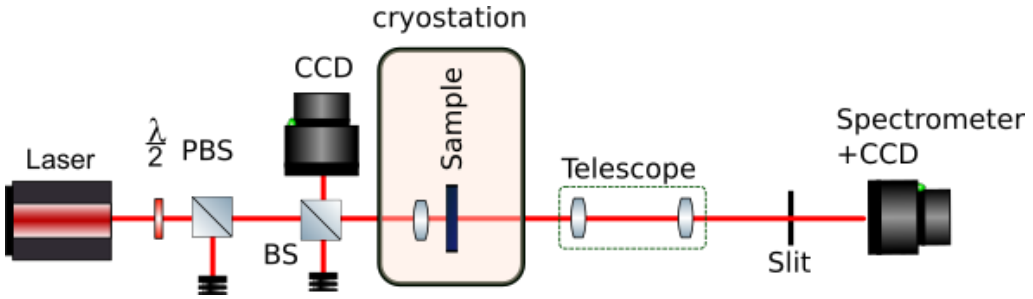
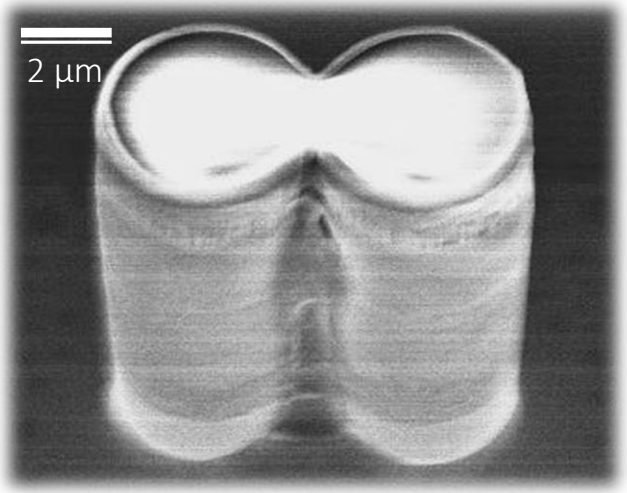
Engineering the photonic wavefunction

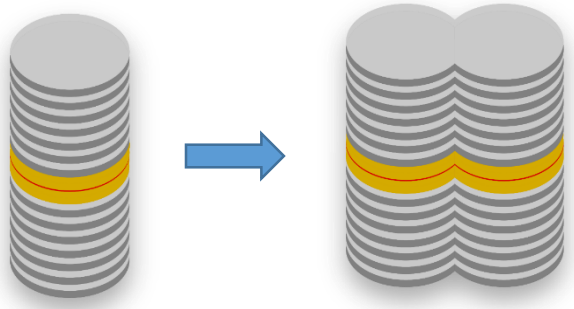


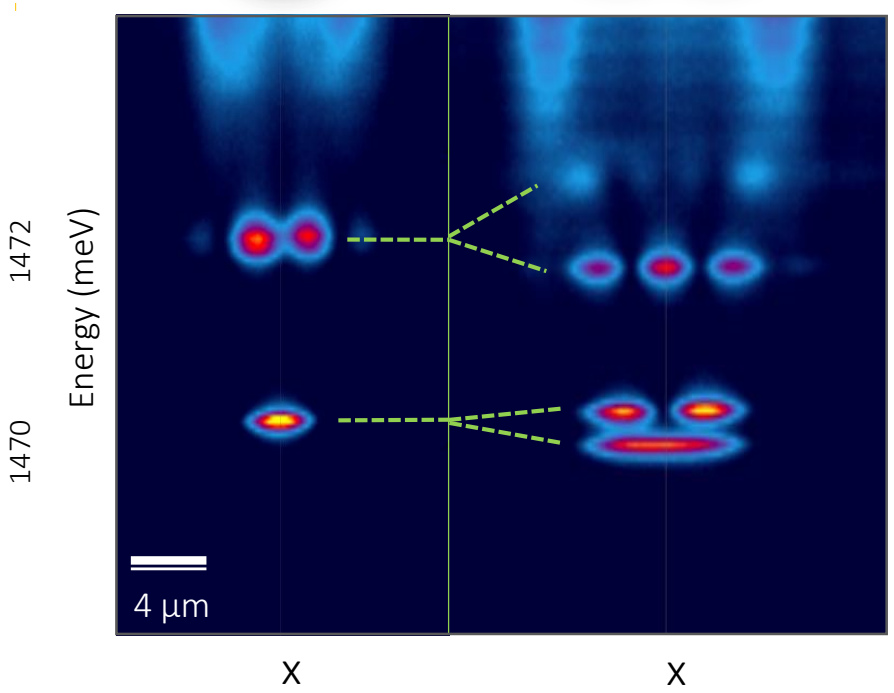
- Coupling the bricks





Galbiati et al., PRL **108**, 126403 (2012)





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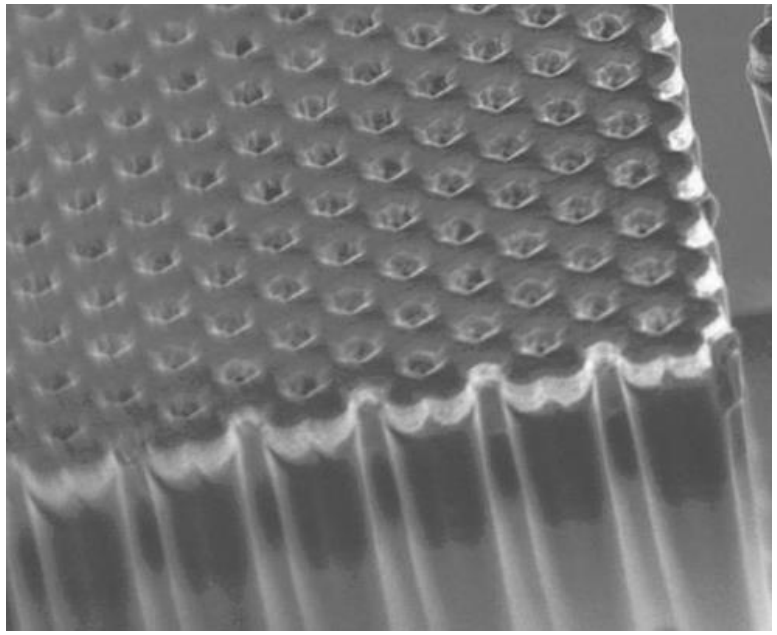
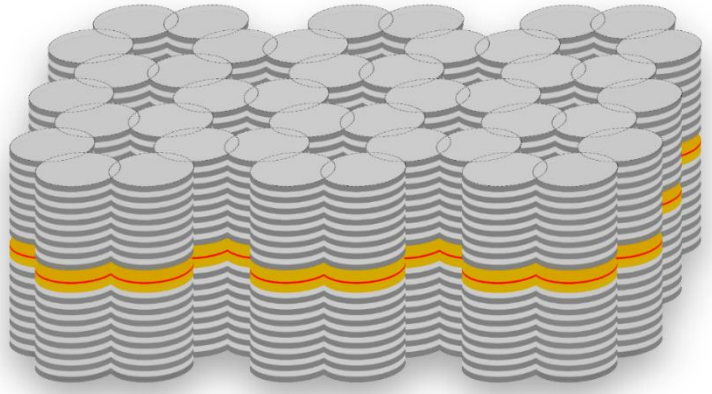
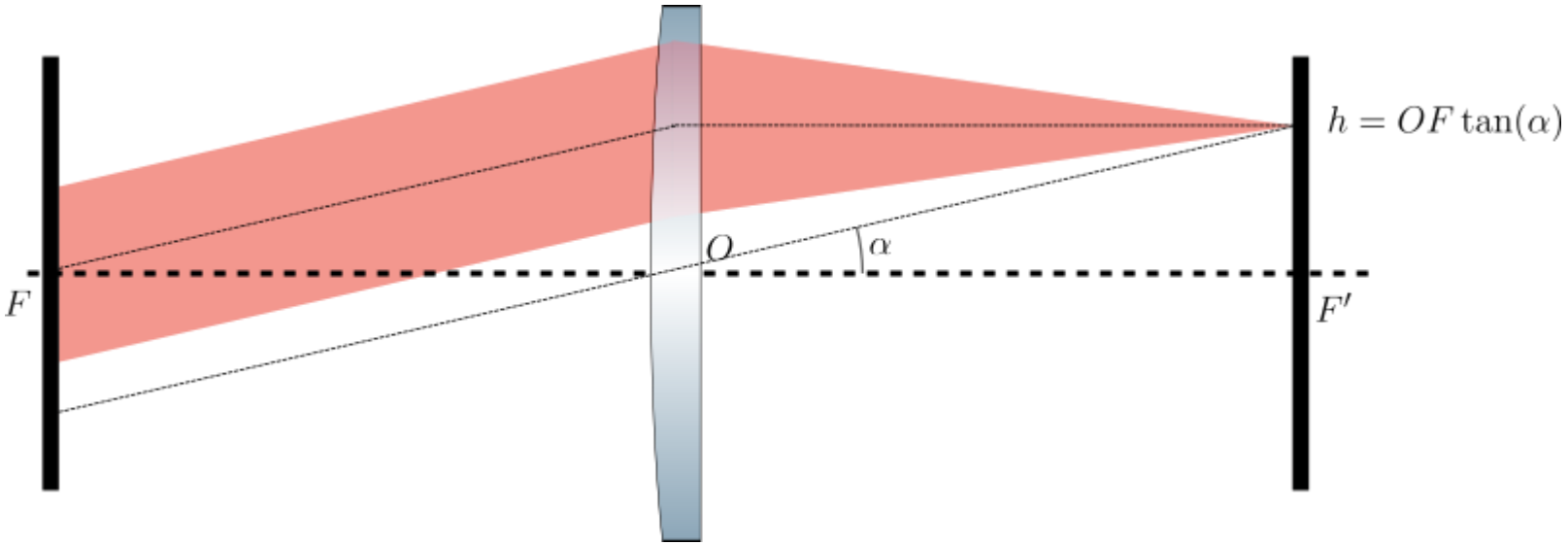
Engineering the photonic wavefunction

... And finally lattices





Optical Fourier transform: Imaging reciprocal space



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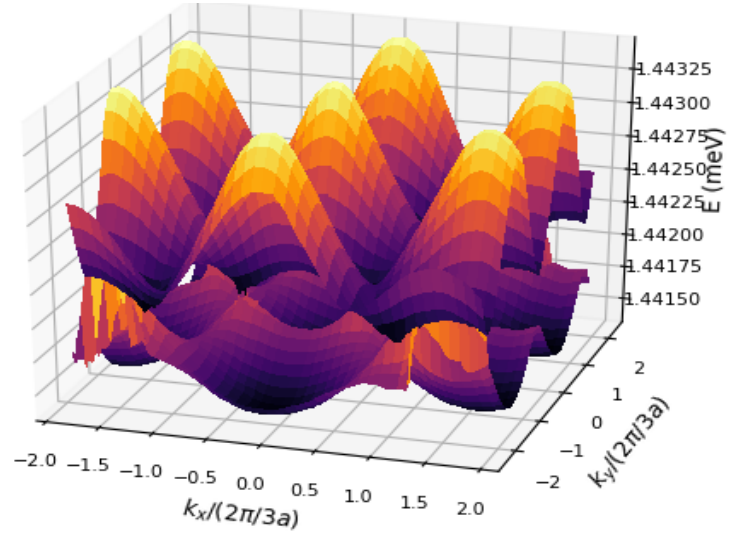
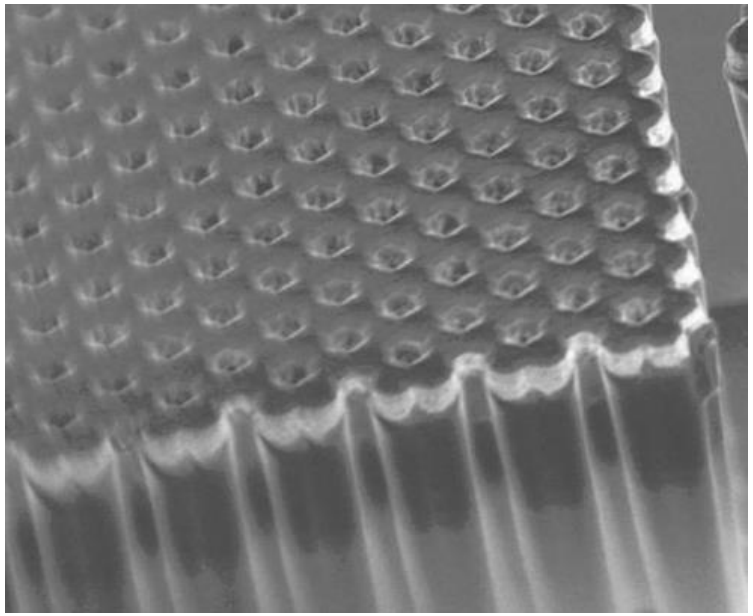
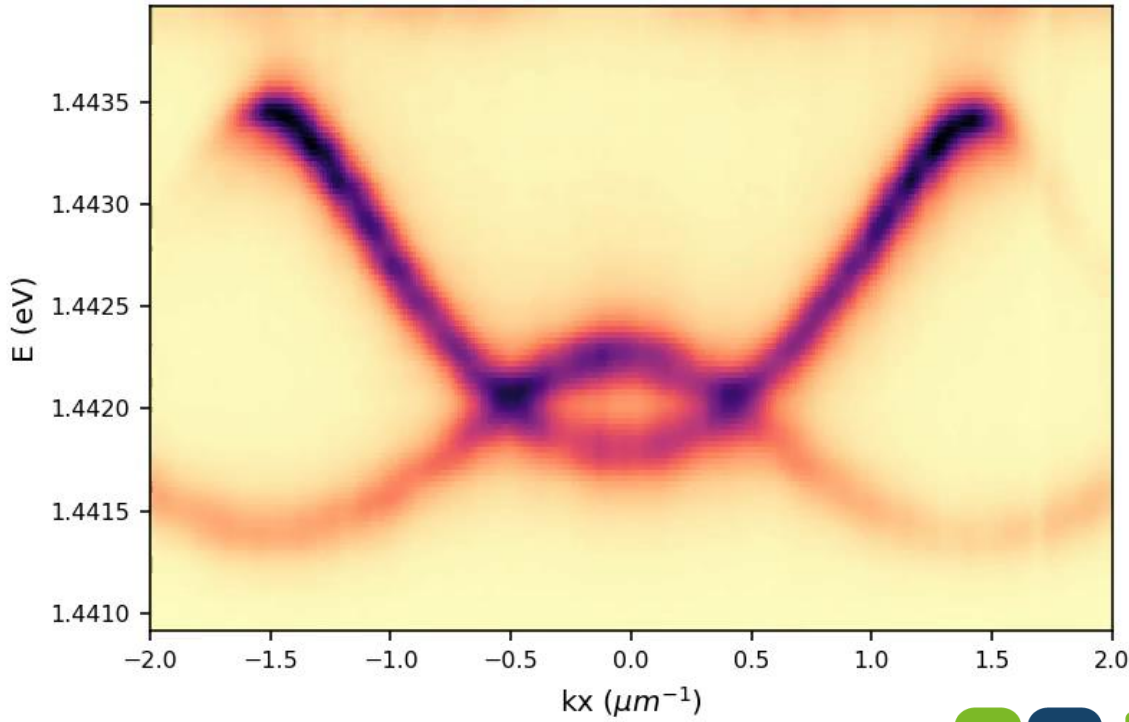
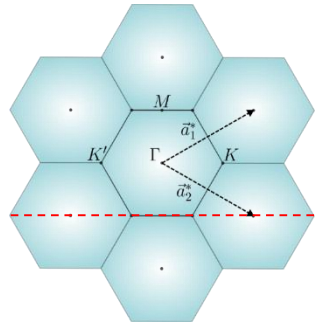
Engineering the photonic wavefunction

... And finally lattices









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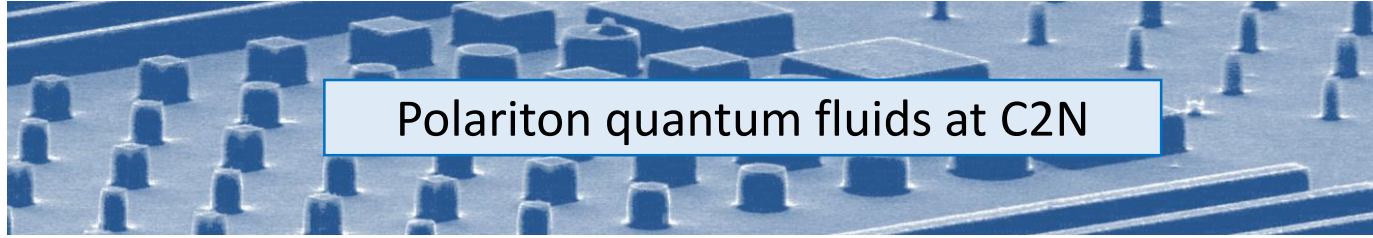

II. Valley Hall insulator in exciton-polaritons lattices

How to probe the eigenvector structure of a polaritonic platform ?

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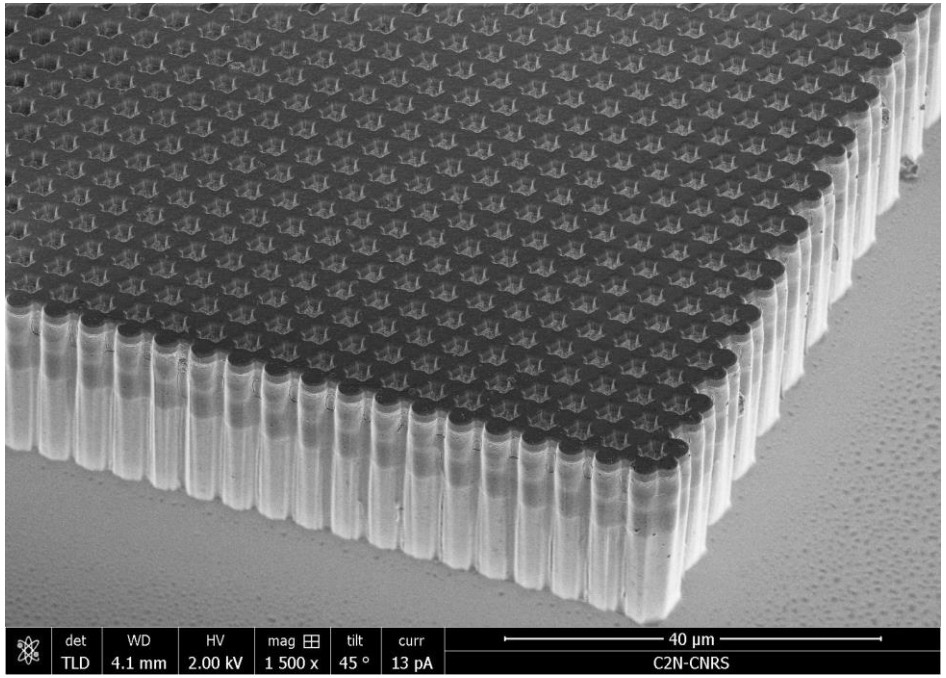
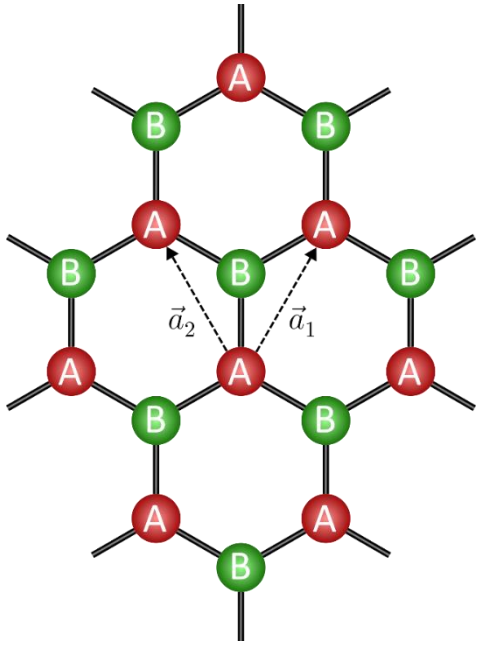
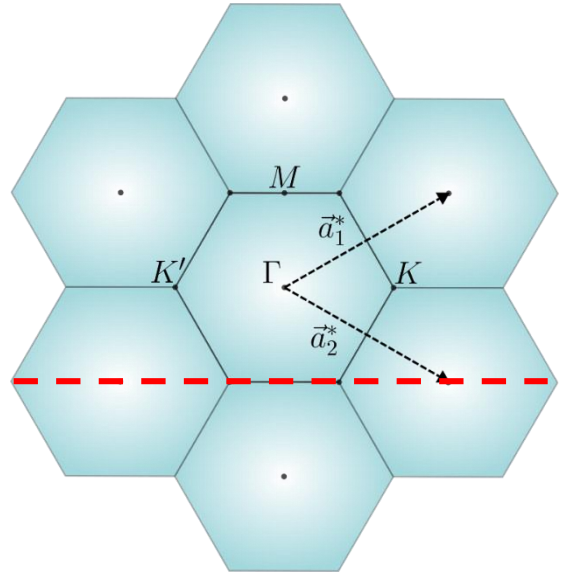
Polariton honeycomb lattices

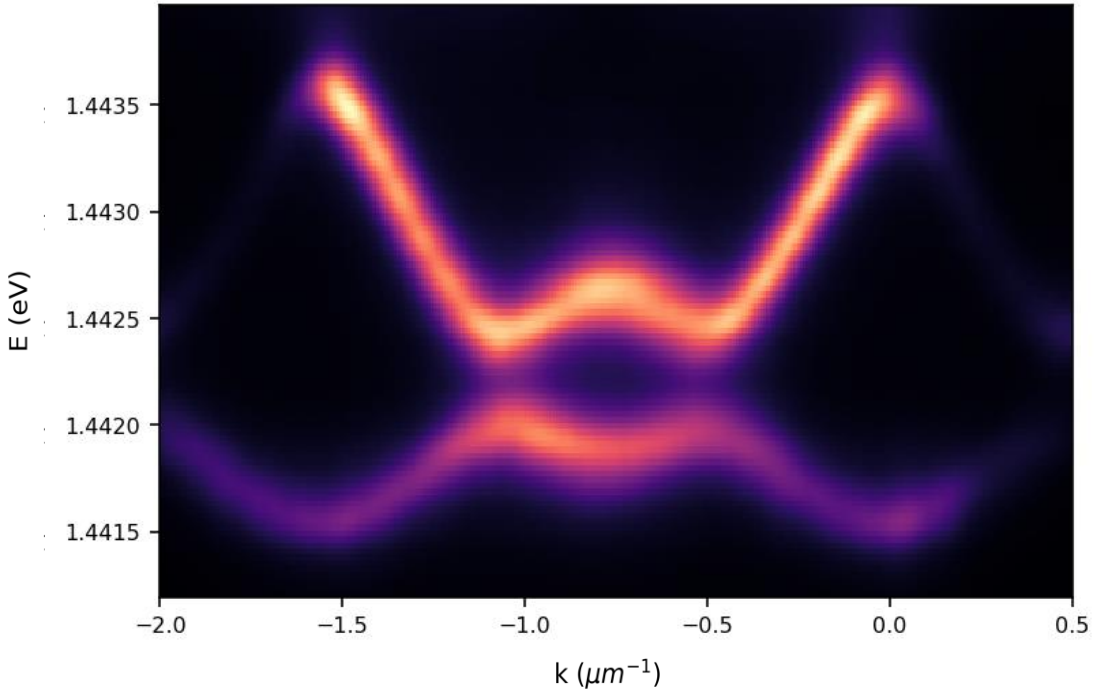




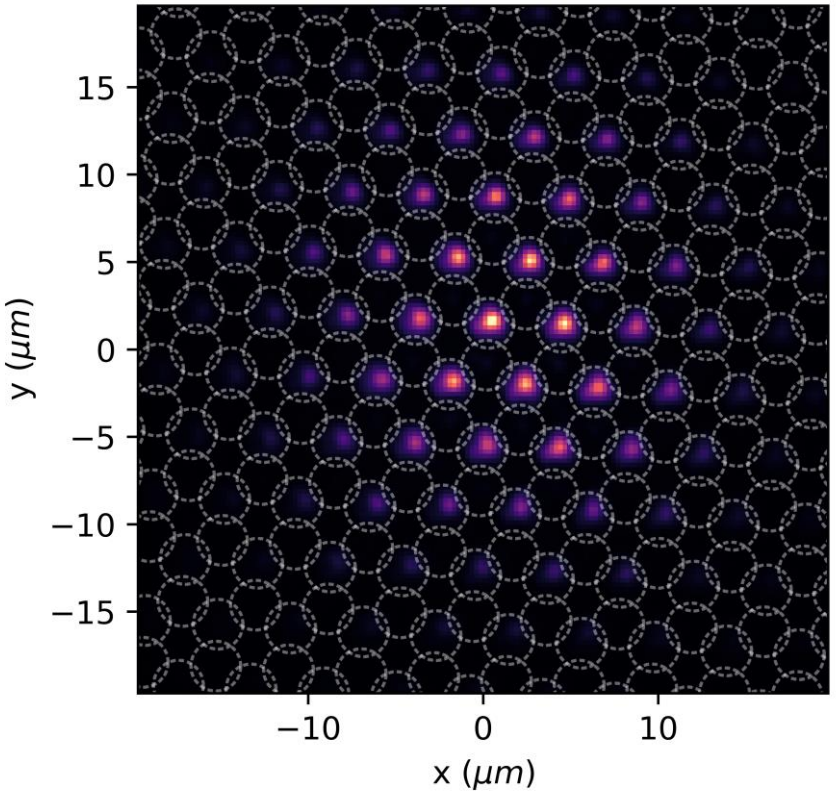


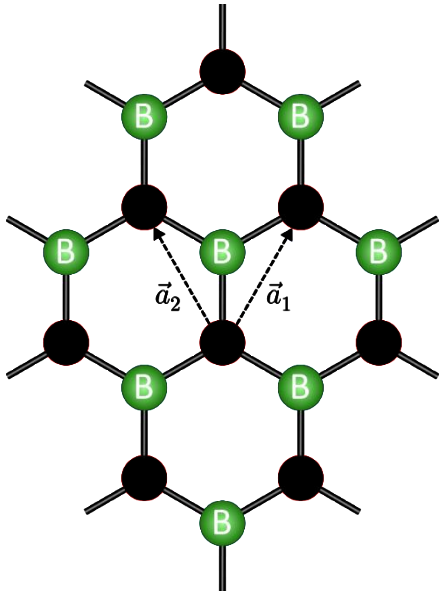
The bloch's eigenvectors are encoded in a sublattice pseudospin:

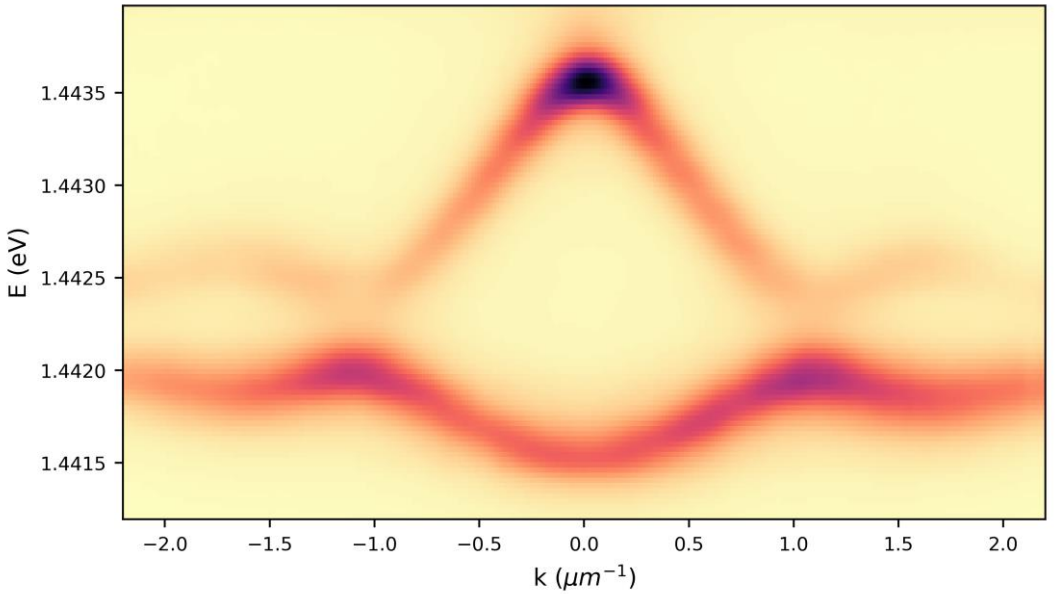
$$u_{\vec{k}}^{n} = \begin{bmatrix} \cos(\theta/2)e^{i\phi} \\ \sin(\theta/2) \end{bmatrix}$$

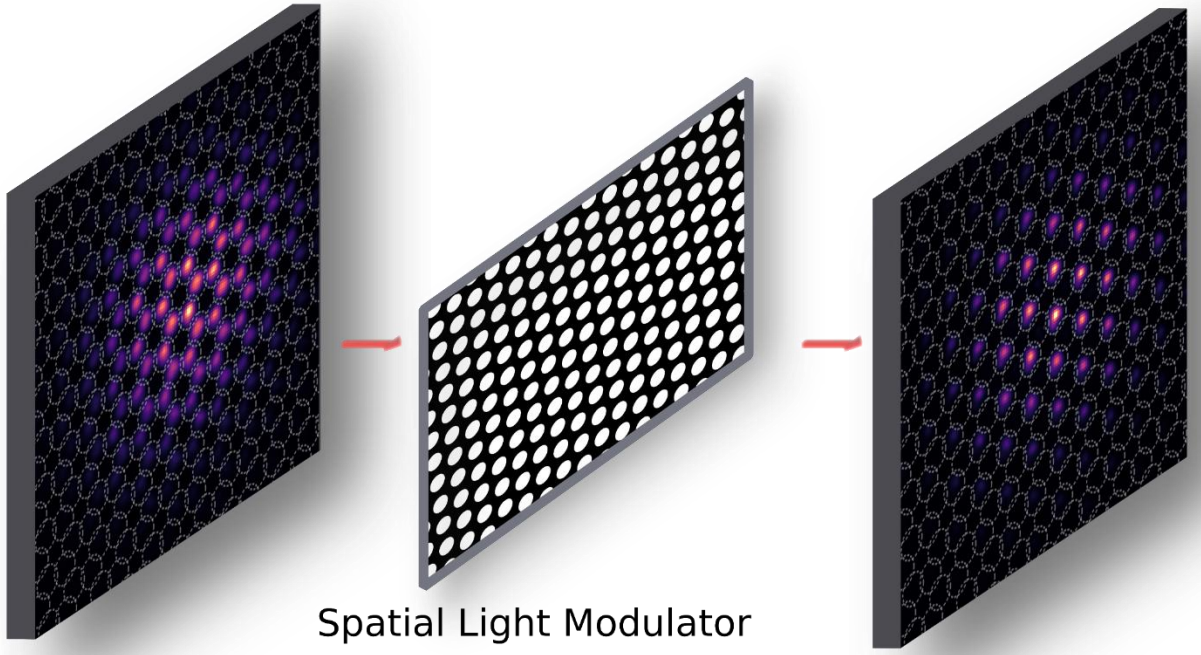


Accessing the eigenvector structure







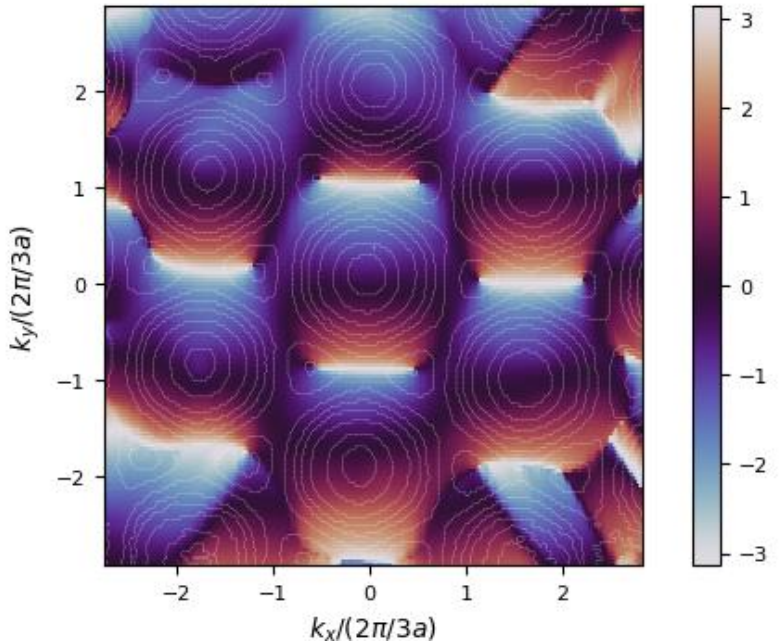


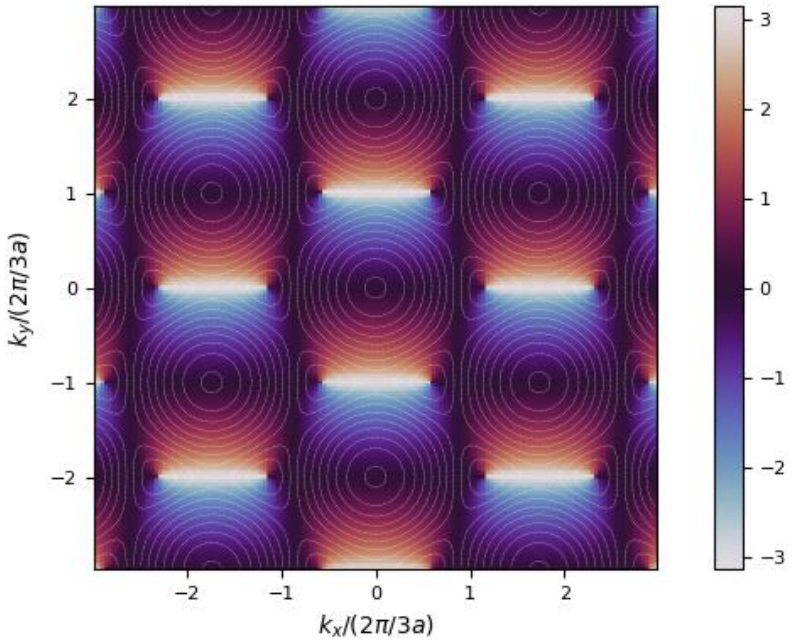
Experimental

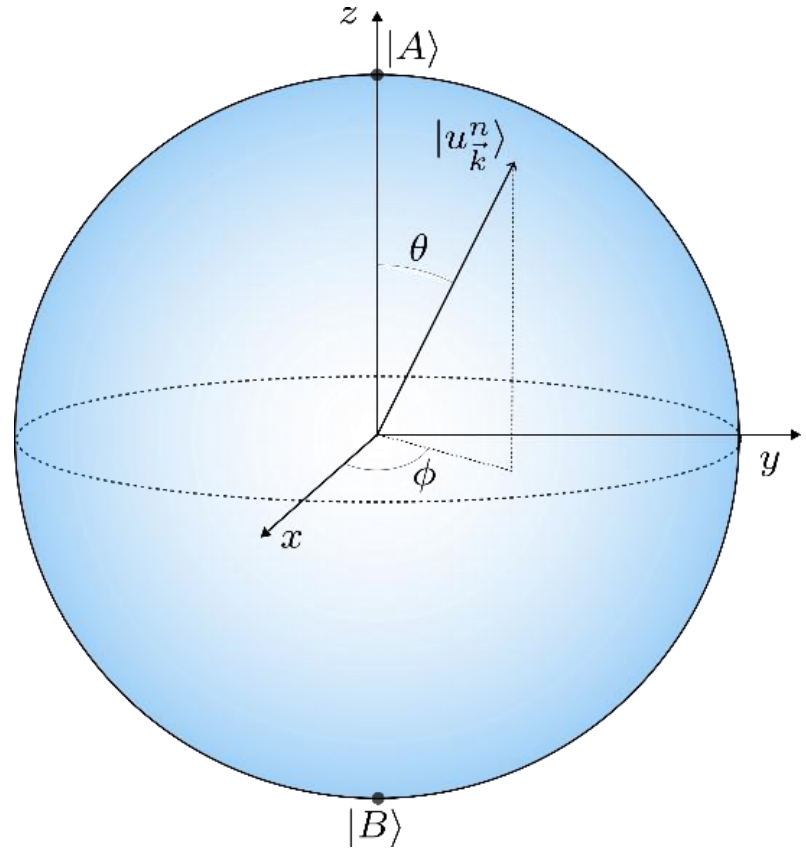
Theory

Lower band

φ







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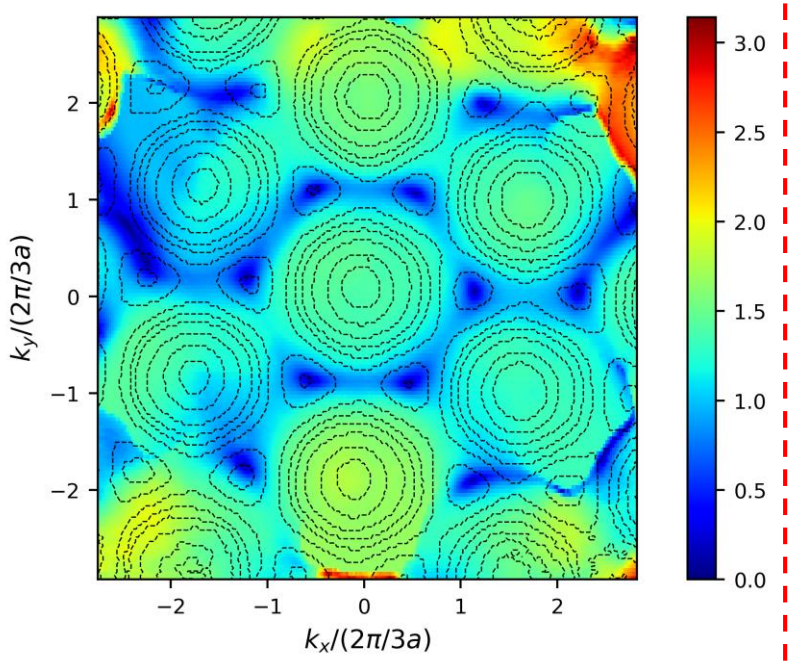
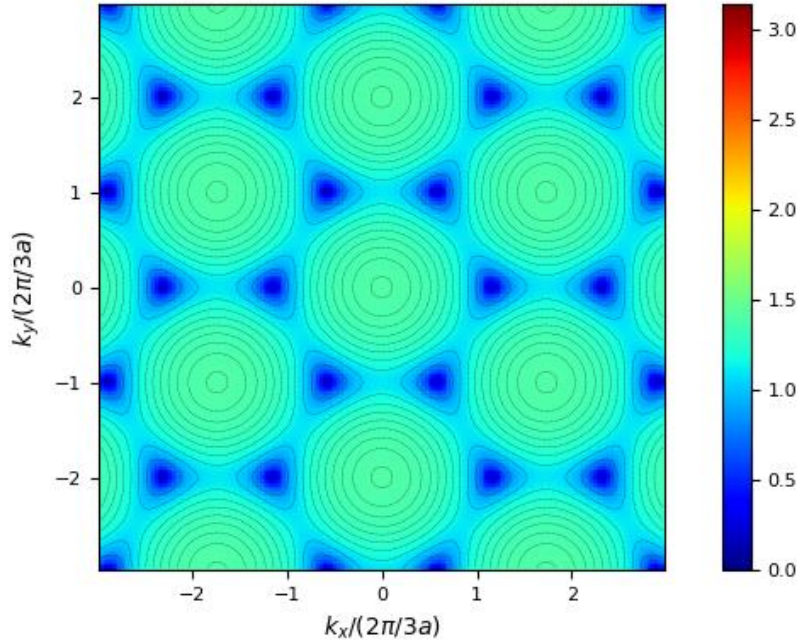




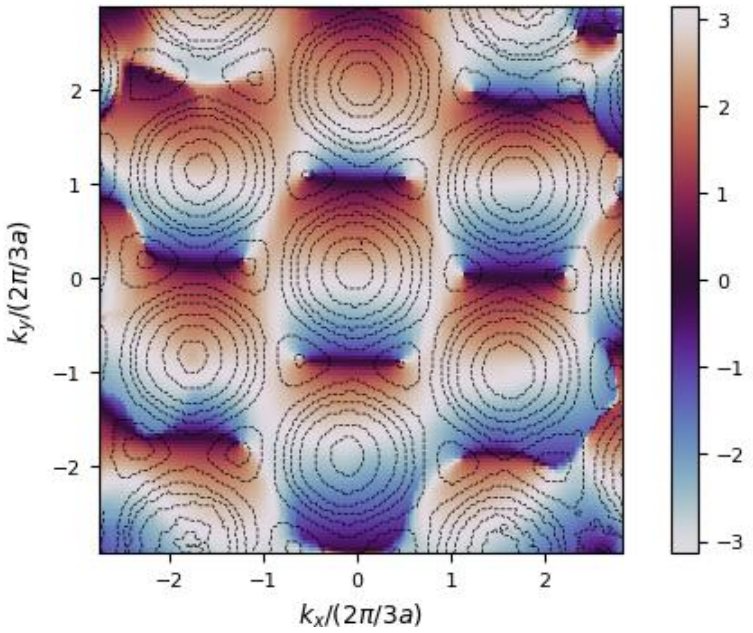
$$u_{\vec{k}}^n = \begin{bmatrix} \cos(\theta/2)e^{i\phi} \\ \sin(\theta/2) \end{bmatrix}$$

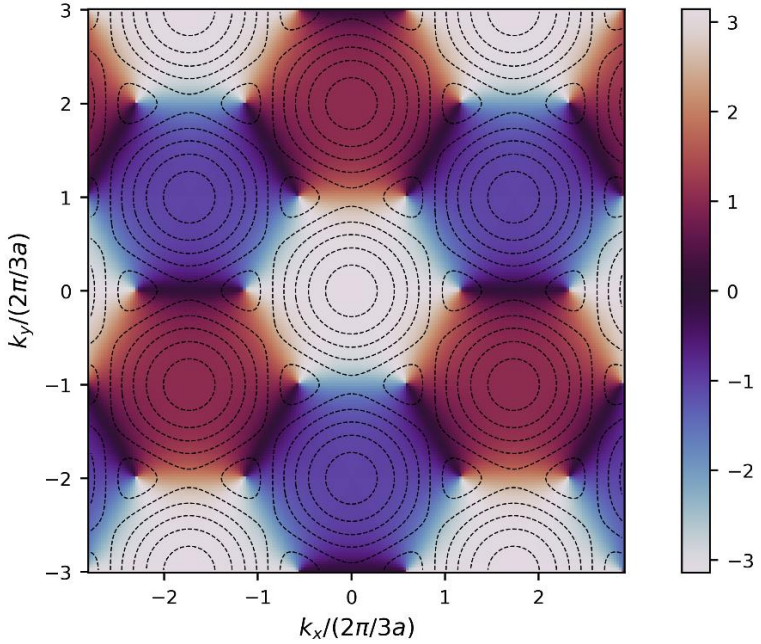
Experimental

Theory

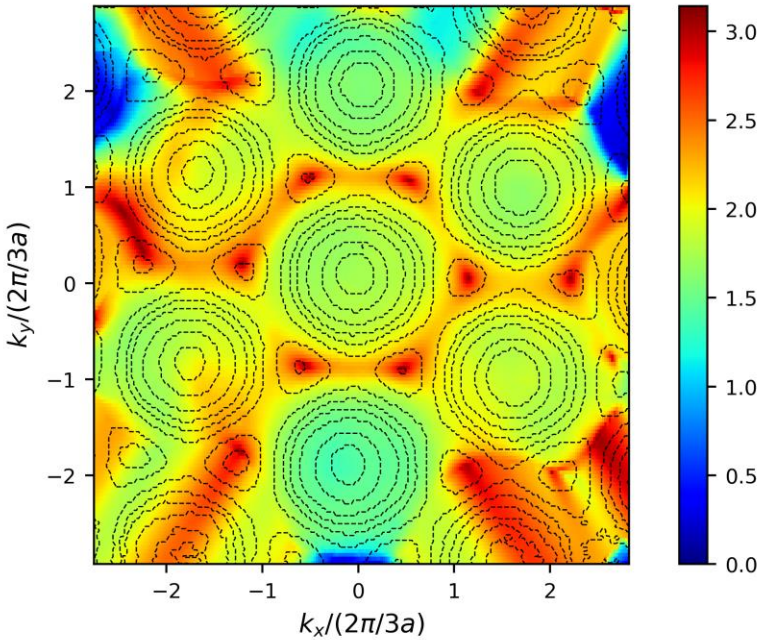
Upper band

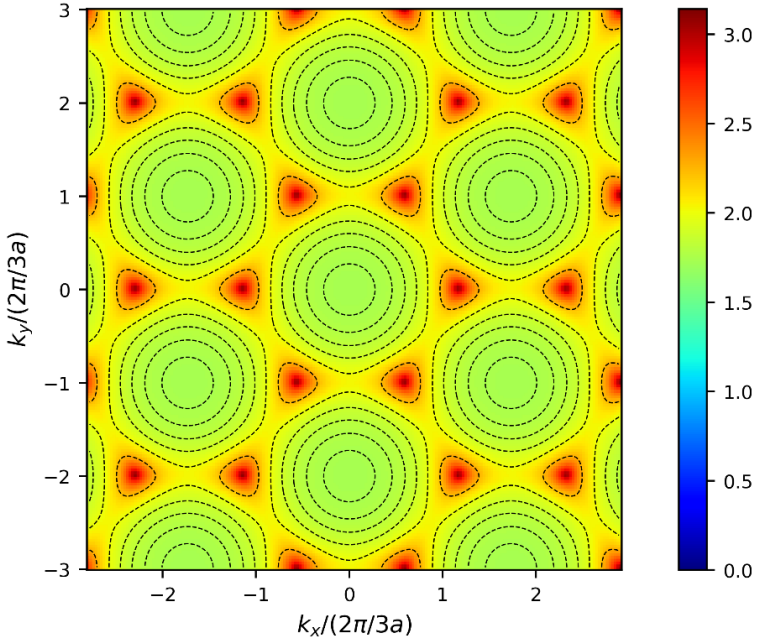
φ

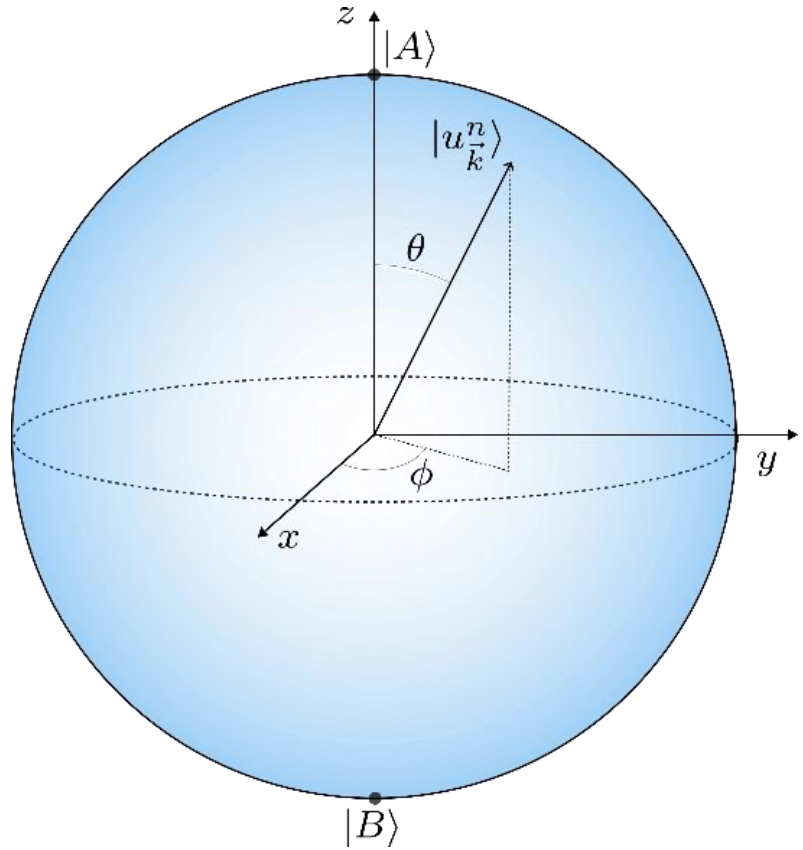




θ





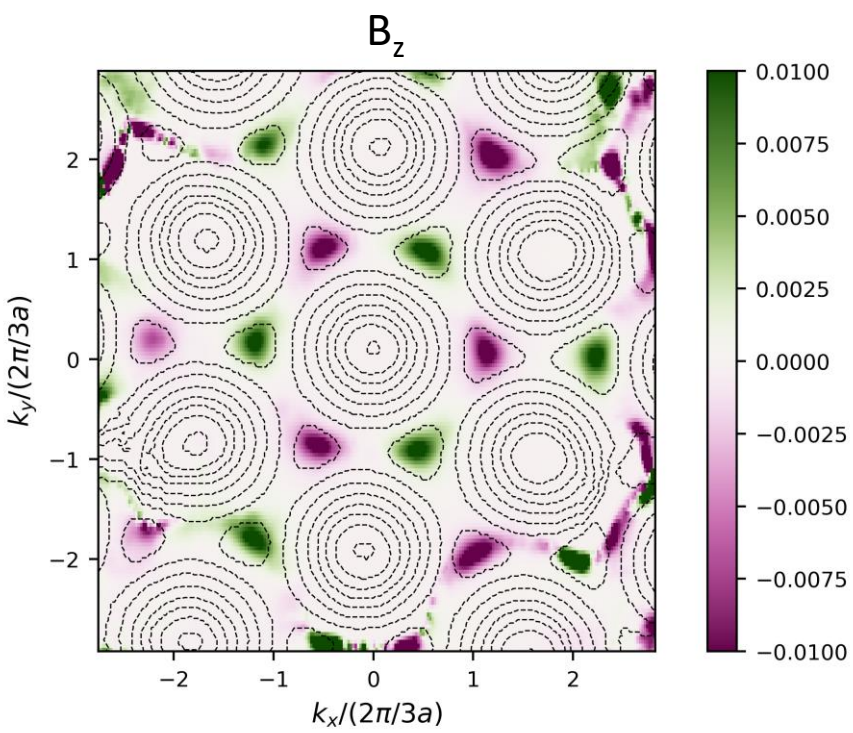


$$u_{\vec{k}}^n = \begin{bmatrix} \cos(\theta/2)e^{i\phi} \\ \sin(\theta/2) \end{bmatrix}$$

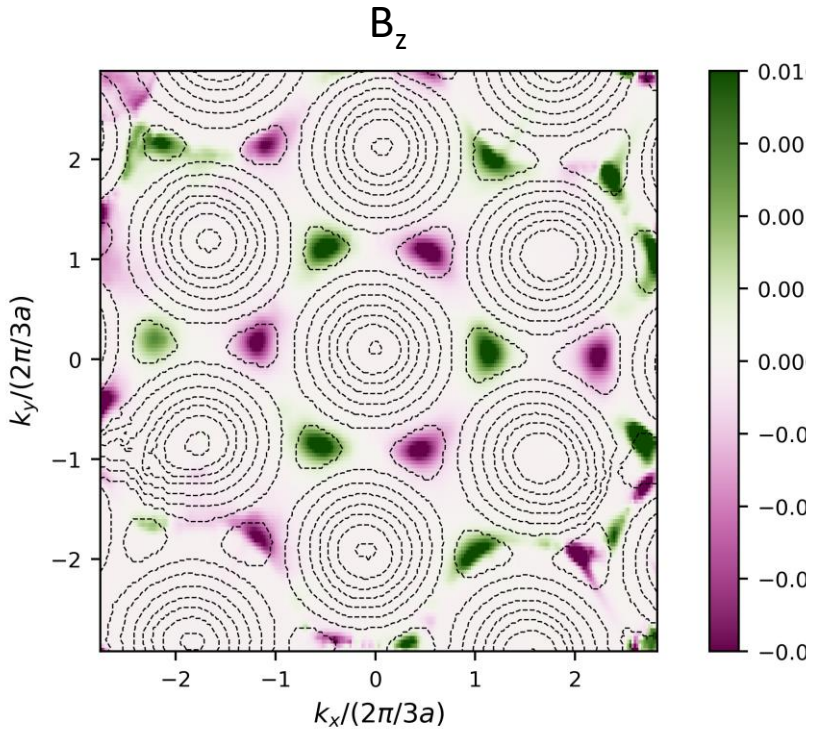
Berry curvature computation

$$\vec{\mathcal{B}}_n(\mathbf{k}) = \nabla_{\mathbf{k}} \times \vec{\mathcal{A}}_n(\mathbf{k}) = i\langle \nabla_{\mathbf{k}} u_n | \times | \nabla_{\mathbf{k}} u_n \rangle.$$

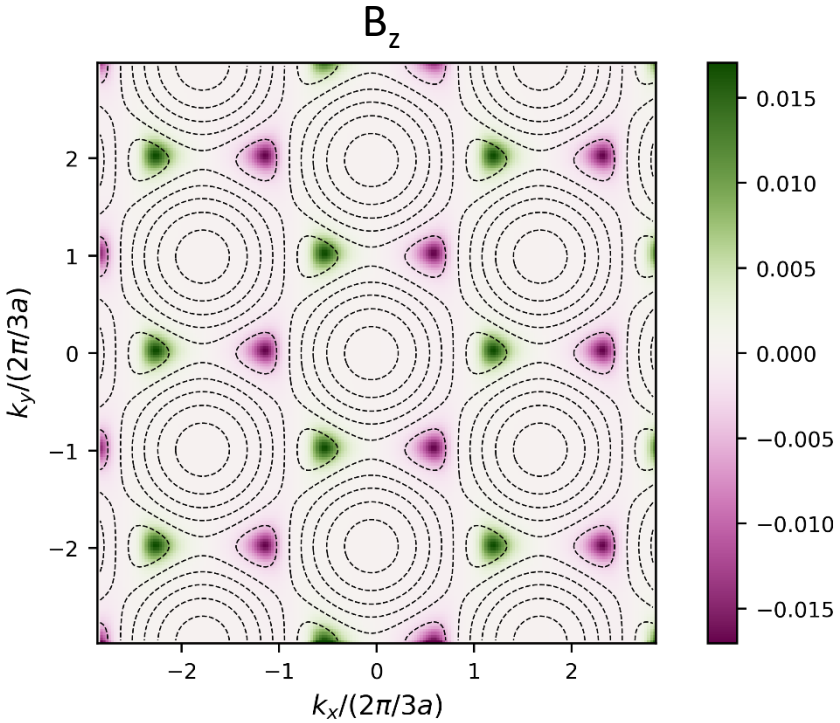
Lower band



Upper band



Upper band (theory)



- Berry curvature of opposite sign in both valleys

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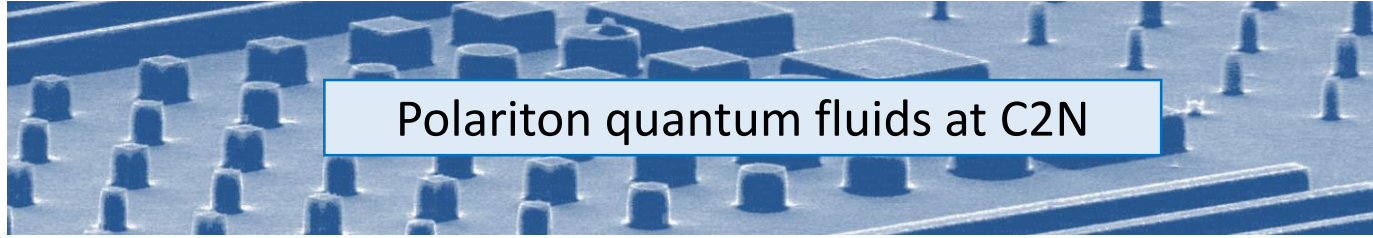

III. Outlook: The $\mathbb{Z}$-topological insulator

Resolving the band inversion in a 4-band system

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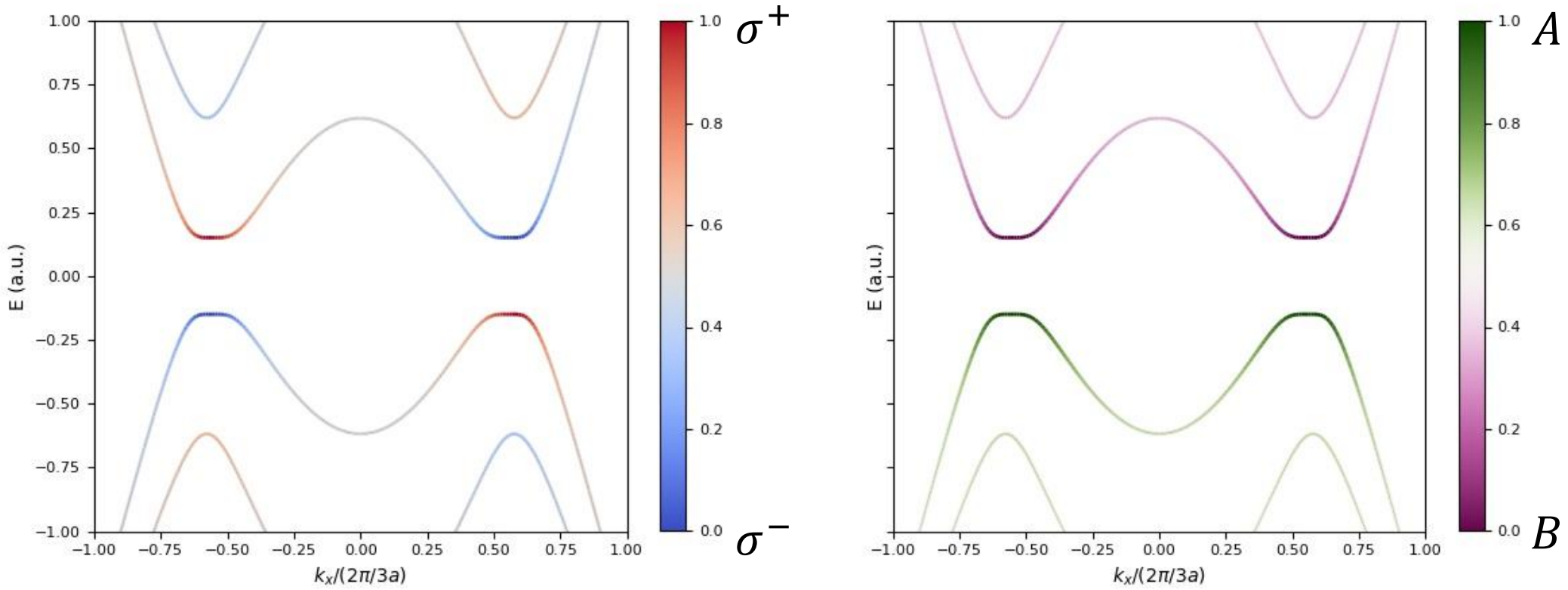
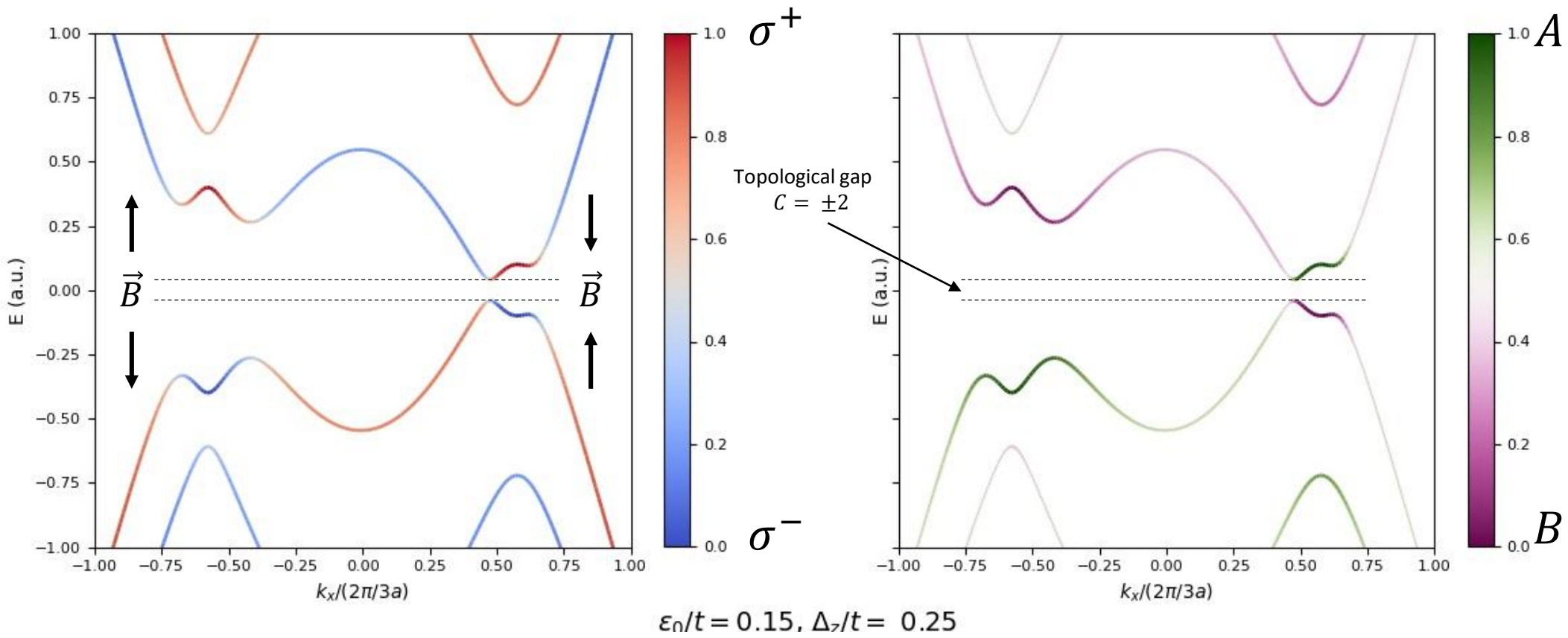
Tunable spin-orbit coupling



Polariton Z Topological Insulator
A. V. Nalitov, D. D. Solnyshkov, and G. Malpuech
Phys. Rev. Lett. **114**, 116401 (2015)

Klembt, S., Harder, T.H., Egorov, O.A. *et al.* Exciton-polariton topological insulator.
Nature **562**, 552–556 (2018)

Optical Zeeman splitting



Polariton Z Topological Insulator
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Klembt, S., Harder, T.H., Egorov, O.A. *et al.* Exciton-polariton topological insulator.
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Thanks you for listening !