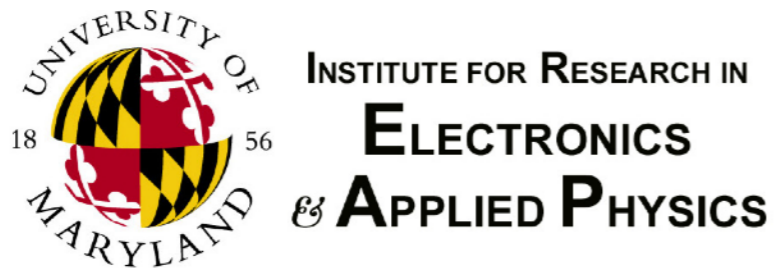


# Synthesized topology: from photons to matter

## From Reality to Fantasy

Mohammad Hafezi



KITP Topological Quantum Matter:  
From Fantasy to Reality (Oct 2019)



OPTICS &  
PHOTONICS NEWS



S. Mittal, W. DeGottardi, and M. Hafezi  
Optics and Photonics News, 29, 36 (2018)

## Topological Photonics

T. Ozawa, H. M. Price, A. Amo, N. Goldman, M. Hafezi, L. Lu, M. Rechtsman, D. Schuster, J. Simon, O. Zilberberg, I. Carusotto

Rev. Mod. Phys. 91, 015006 (2019)

see also topological phononics,  
mechanical, electrical circuits, waves on  
earth....

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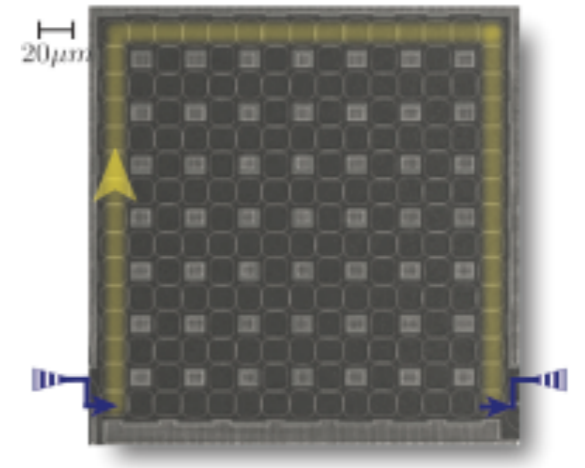
see also topological phononics,  
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Can we go beyond Maxwell's eqs?  
Some physics without an electronic equivalent?

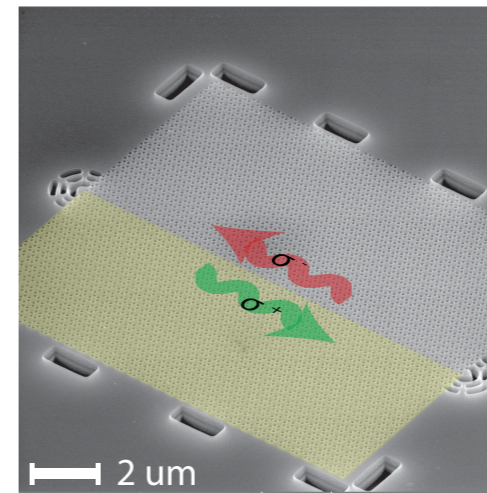
# Outline

- Quantum directions in topological photonics:

- Generation of photon pairs (rings)



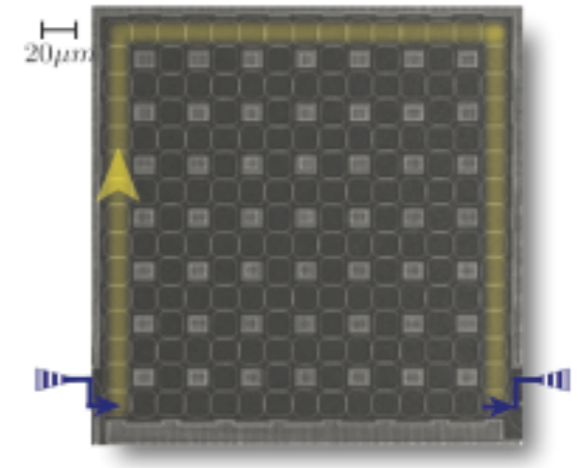
- Quantum optics interface (photonic crystal)



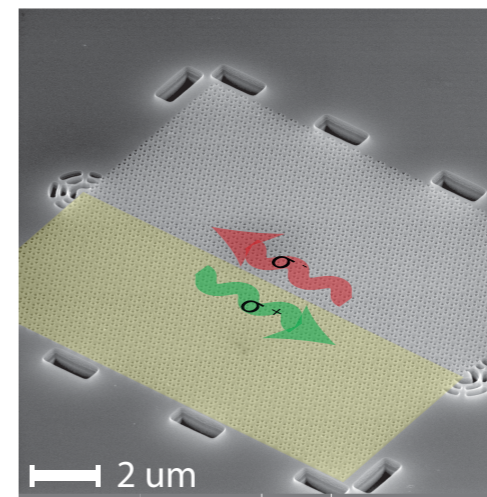
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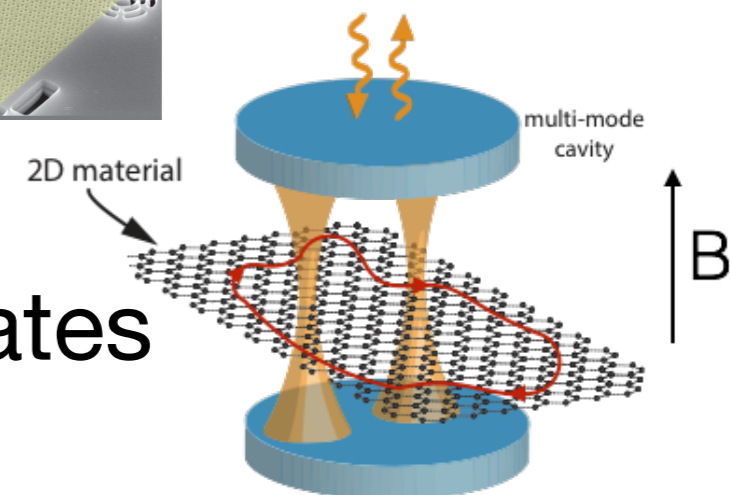
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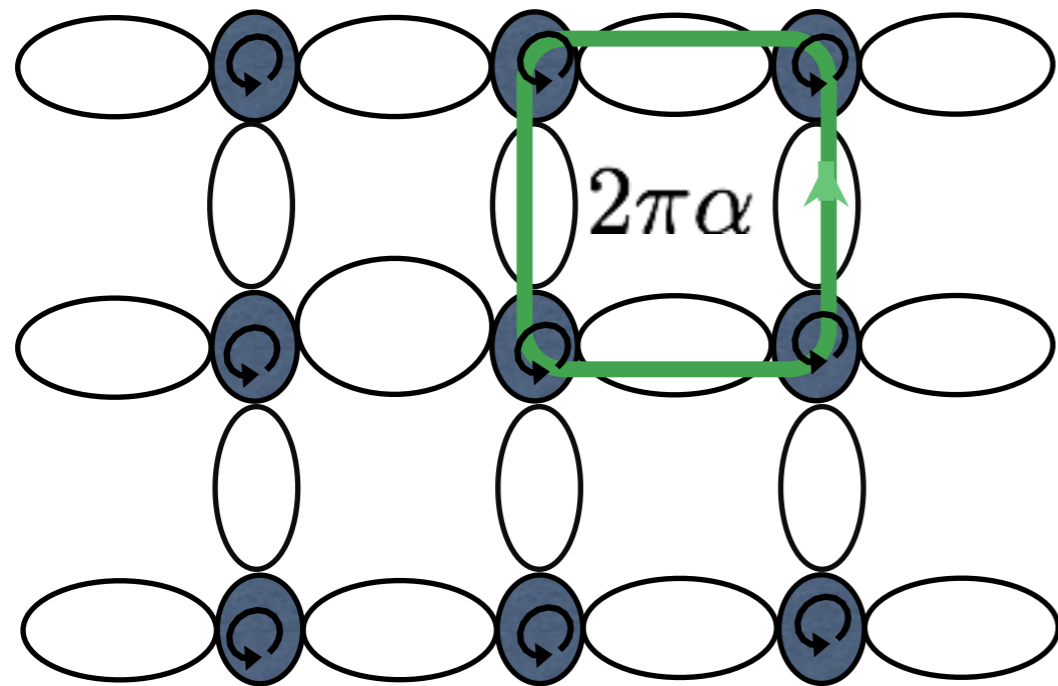
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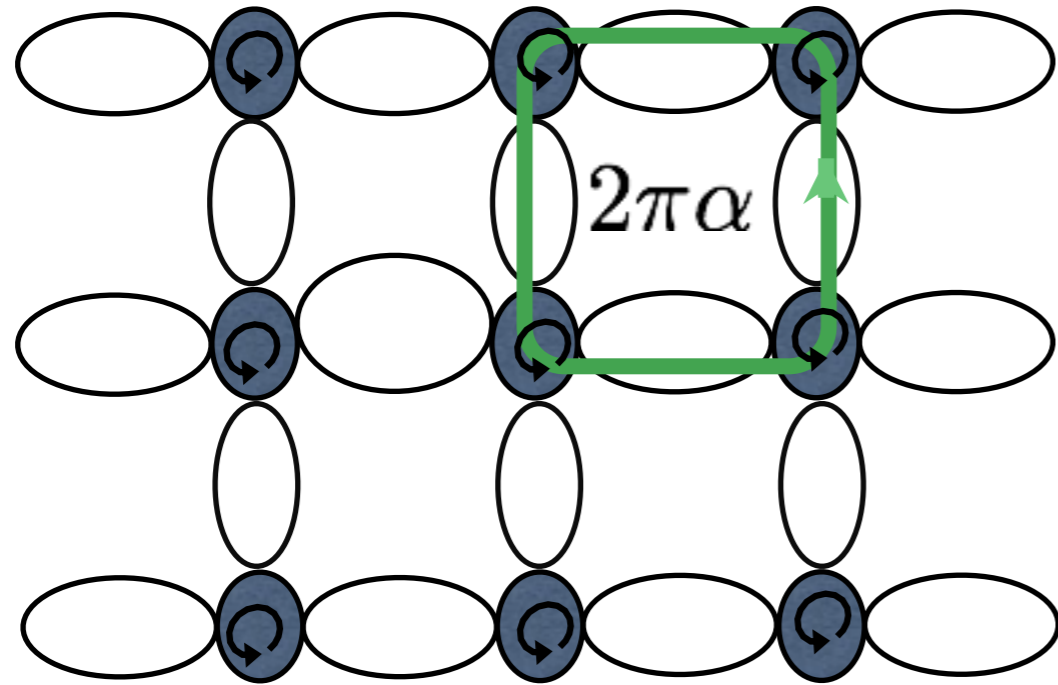
- Optical control of electronic topological states



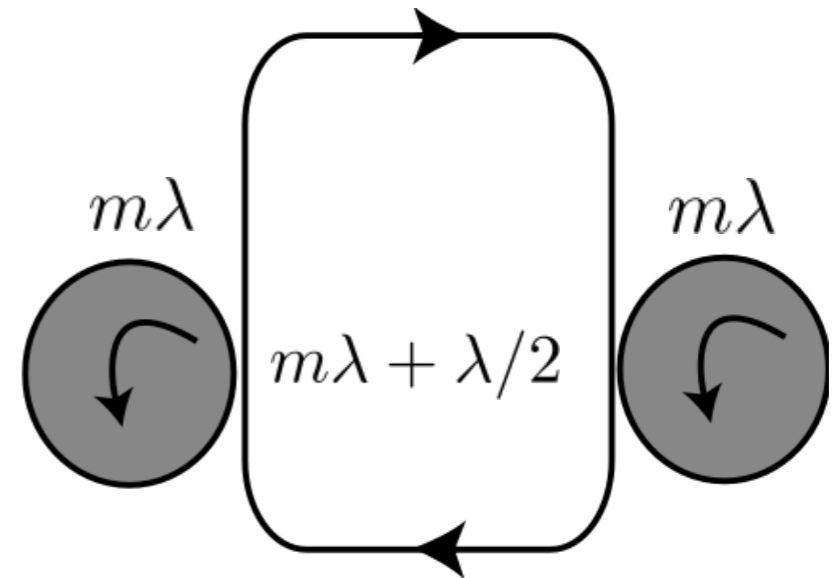
# Synthetic Magnetic Field



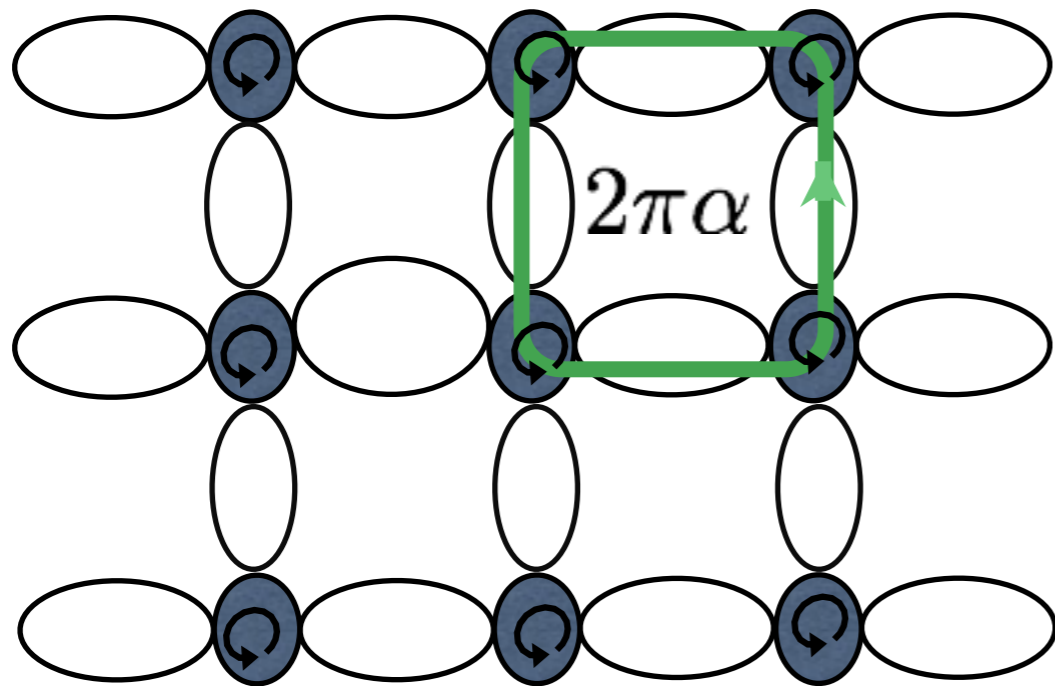
# Synthetic Magnetic Field



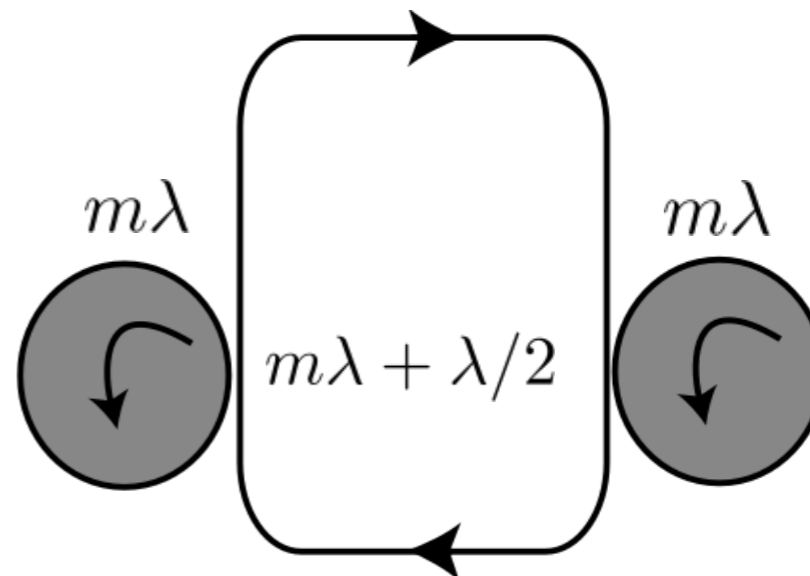
Two resonator case:



# Synthetic Magnetic Field



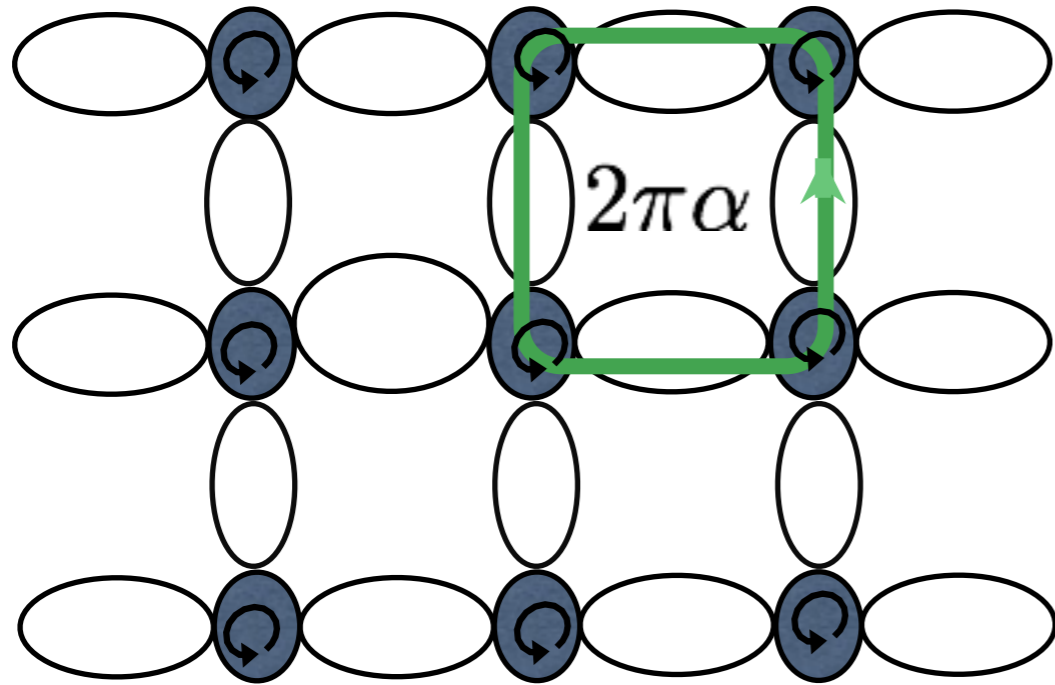
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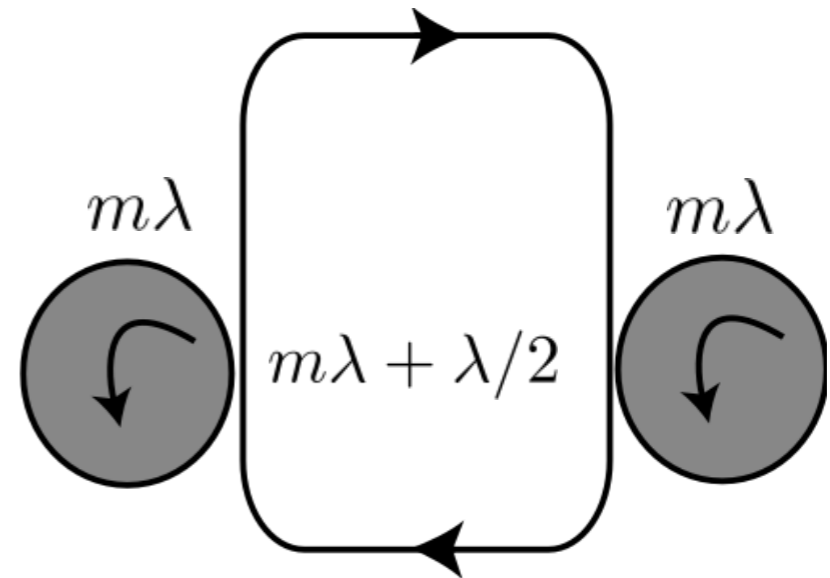
$$H_{eff} = -\kappa \hat{a}_L^\dagger \hat{a}_R e^{-2\pi i \alpha} + h.c.$$



# Synthetic Magnetic Field



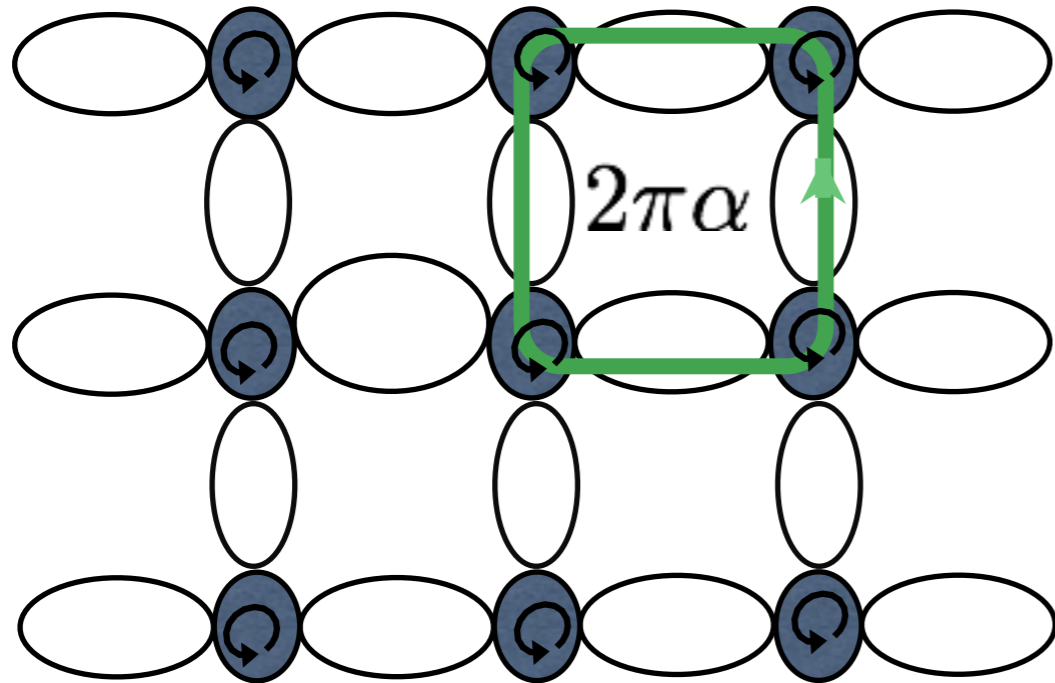
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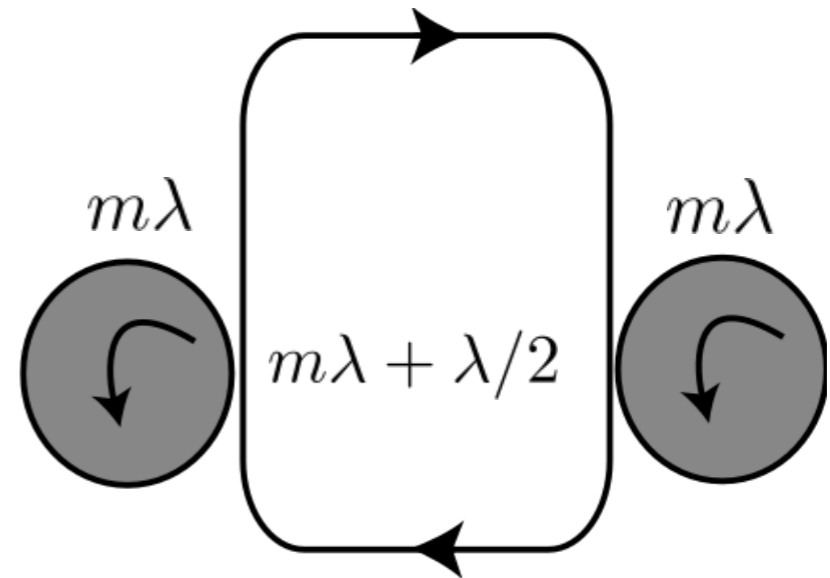
$$H_{eff} = -\kappa \hat{a}_L^\dagger \hat{a}_R e^{-2\pi i \alpha} + h.c.$$

$$H_0 = -J \sum_{x,y} \hat{a}_{x+1,y}^\dagger \hat{a}_{x,y} e^{-i2\pi\alpha y} + \hat{a}_{x,y}^\dagger \hat{a}_{x+1,y} e^{i2\pi\alpha y} \\ + \hat{a}_{x,y+1}^\dagger \hat{a}_{x,y} + \hat{a}_{x,y+1}^\dagger \hat{a}_{x,y}$$

# Synthetic Magnetic Field

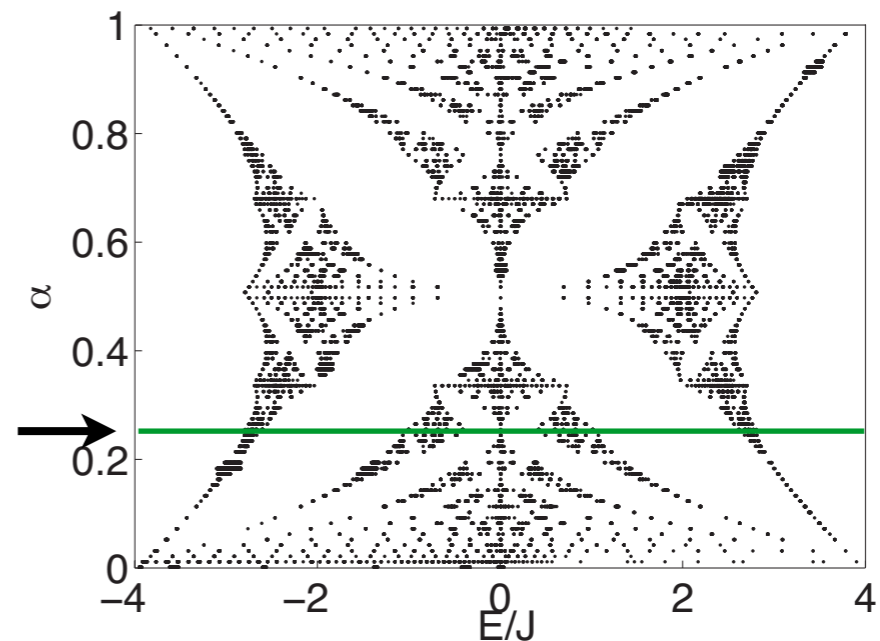


Two resonator case:



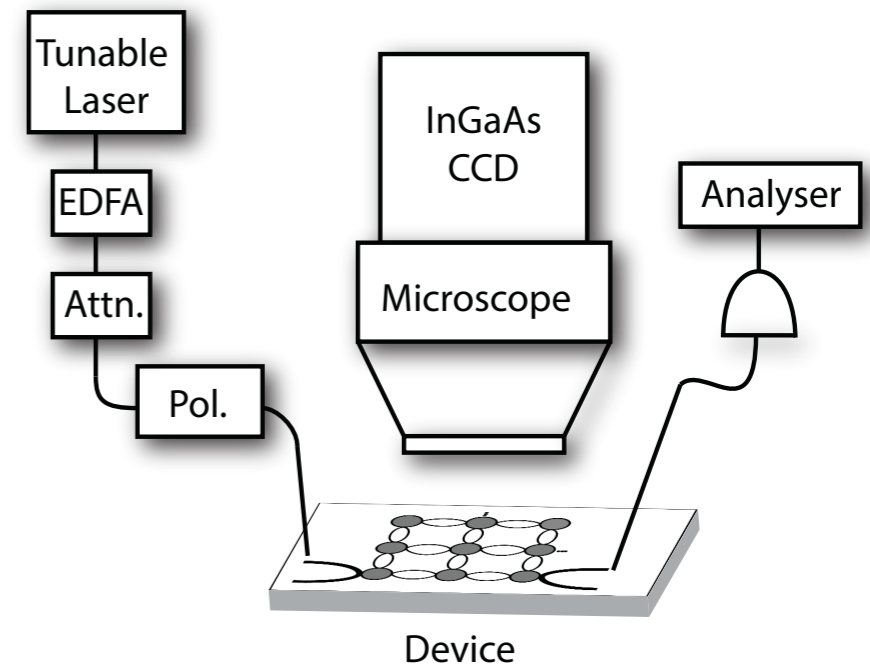
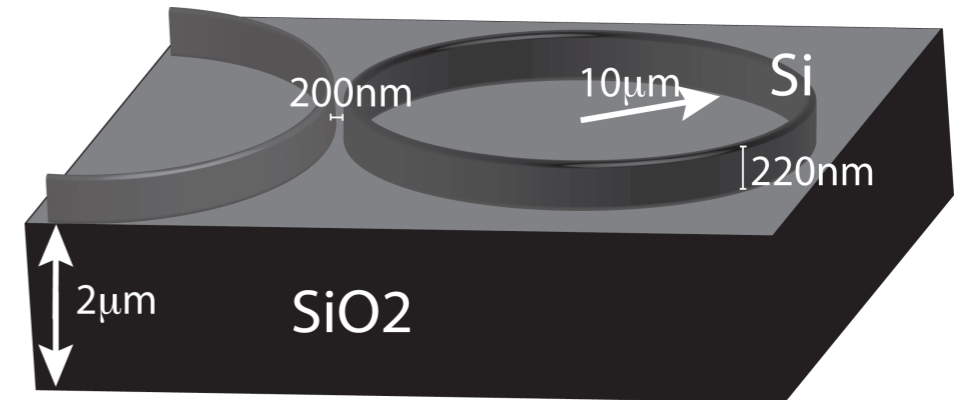
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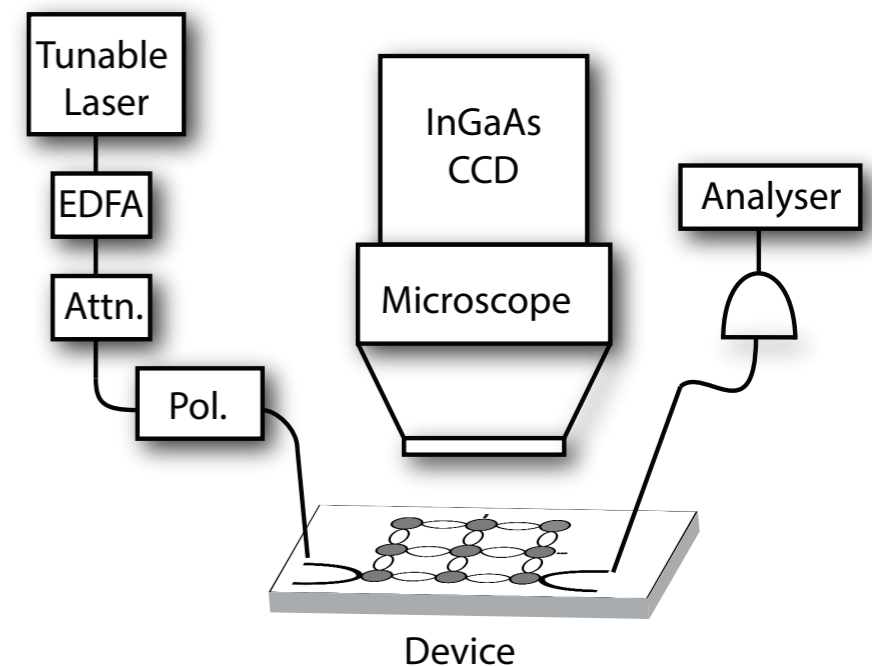
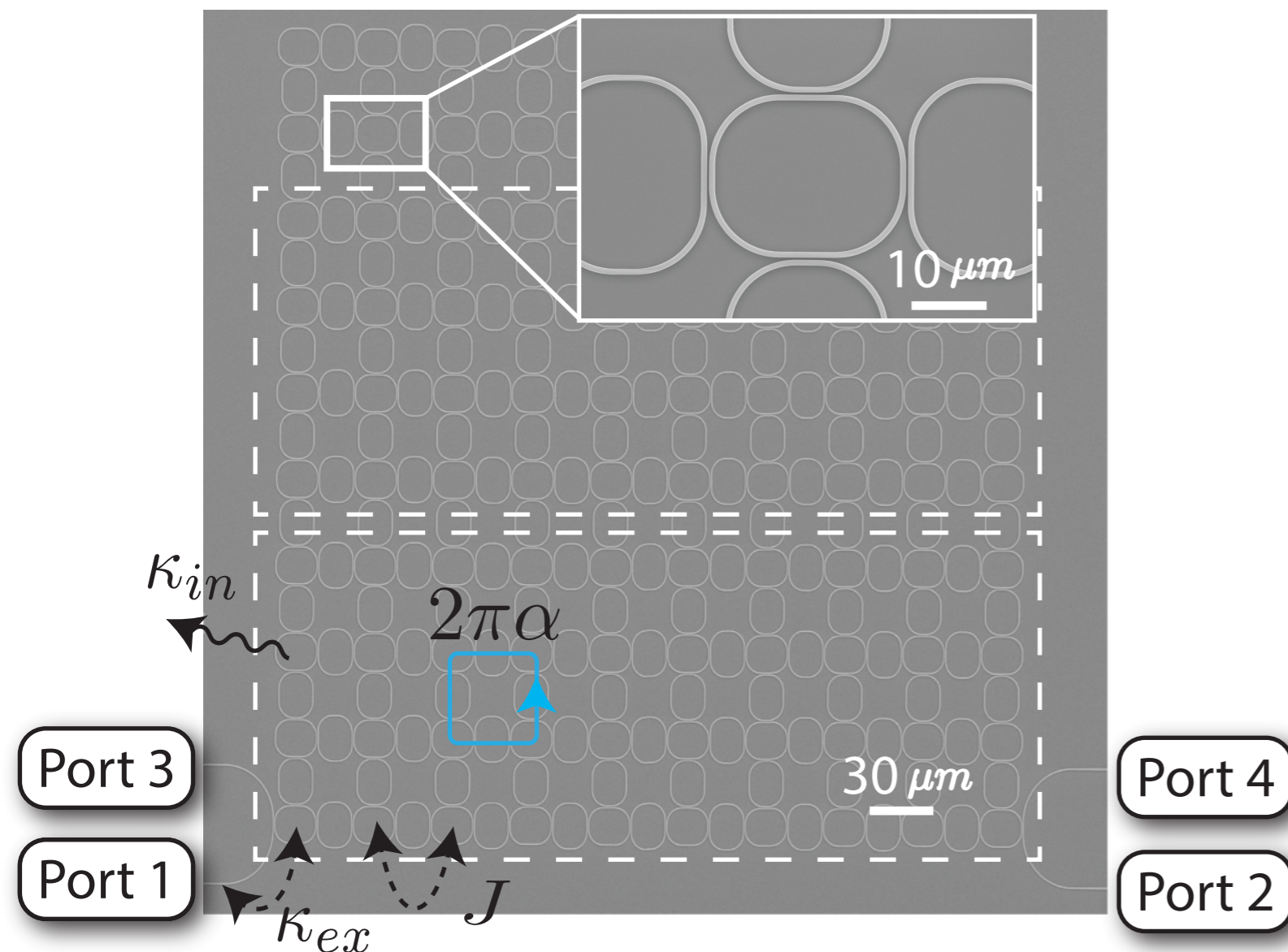
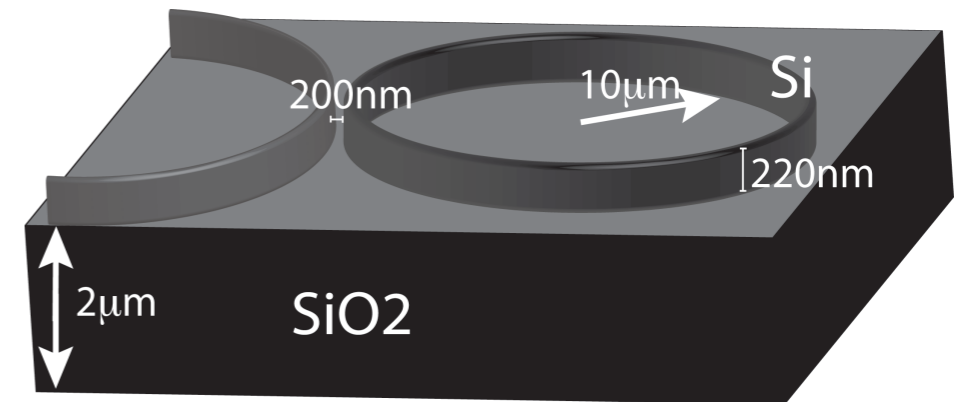
# Experimental realization of the gauge field

## Silicon-on-Insulator technology

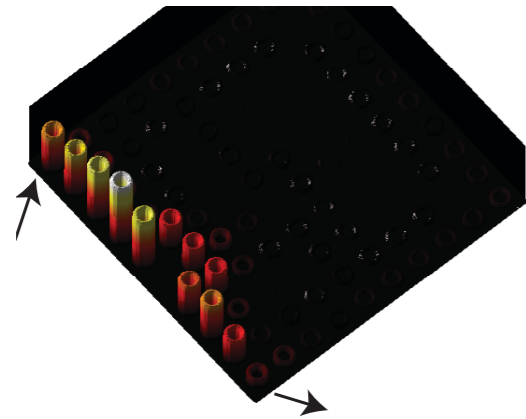


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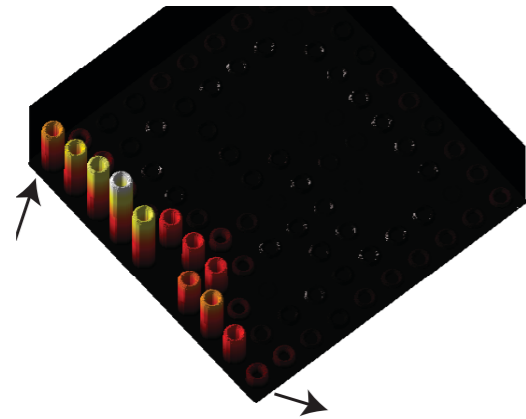
## Silicon-on-Insulator technology



Imaging photonic topological edge states  
Nature Photonics 7, 1001 (2013)

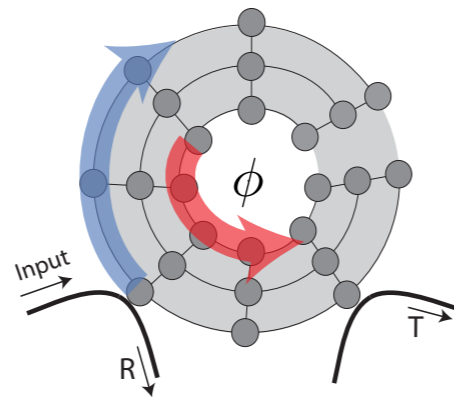
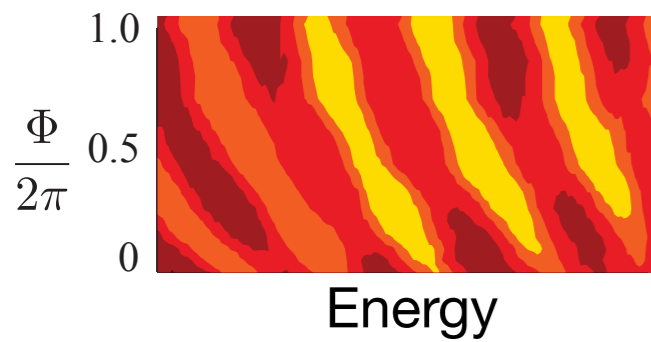


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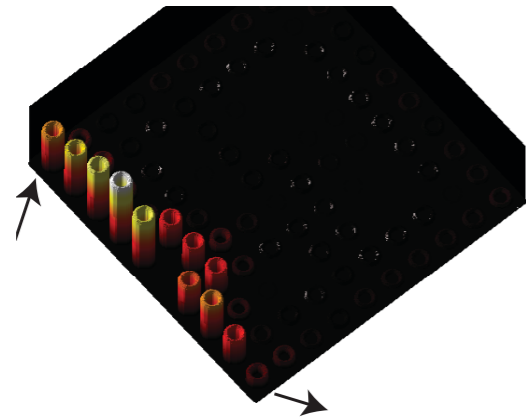
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Demonstration of spectral flow  
PRL 112, 210405 (2014)  
Nature Photonics 10, 180 (2016)



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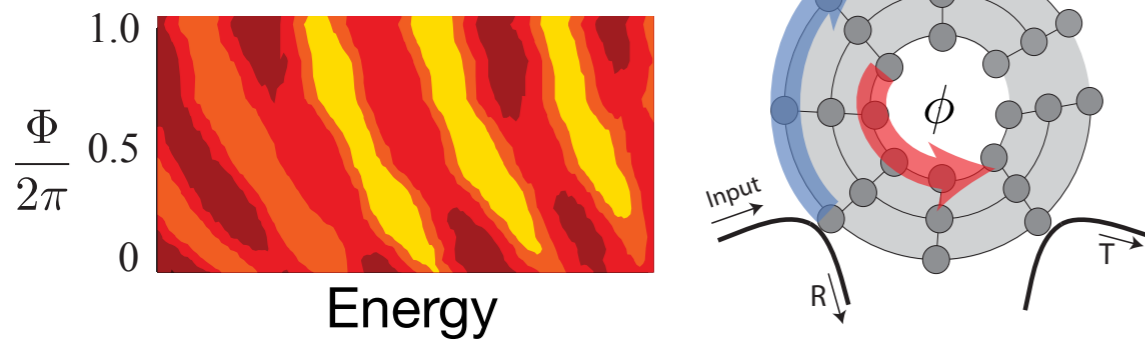
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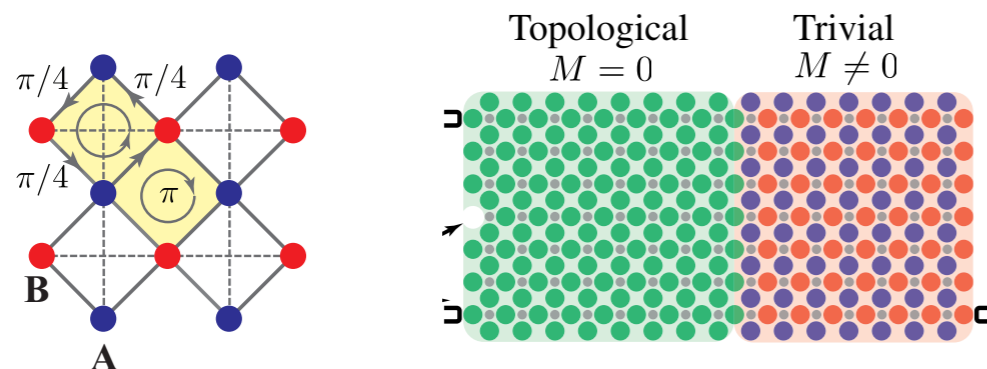
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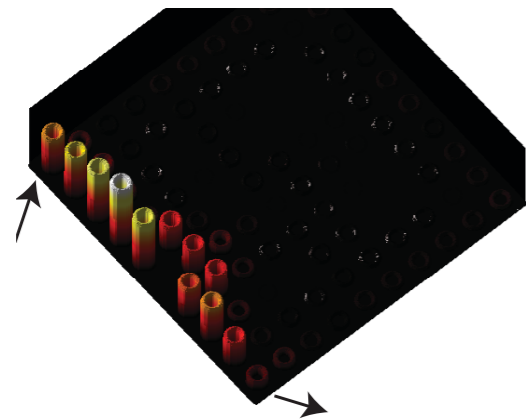


## Photonic Quantum Anomalous Hall effect

PRL 123, 043201 (2019)

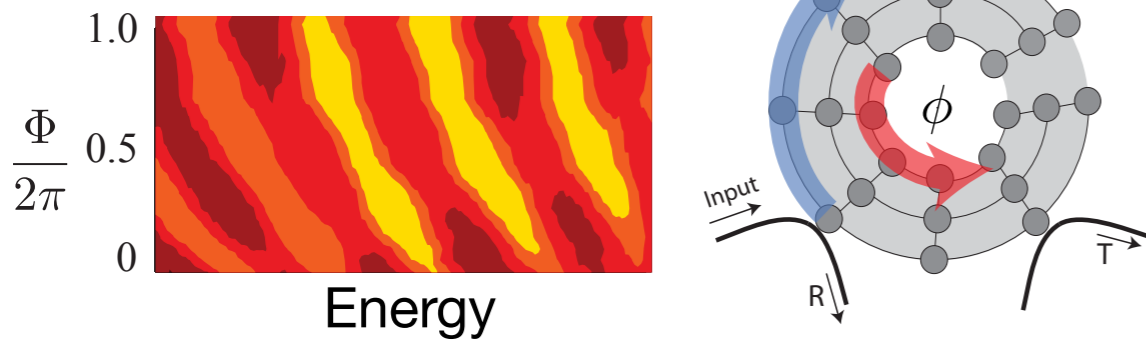


Imaging photonic topological edge states  
 Nature Photonics 7, 1001 (2013)



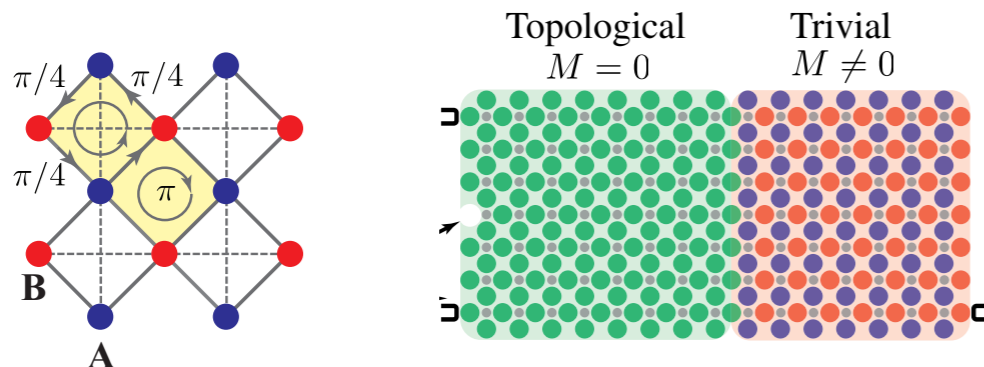
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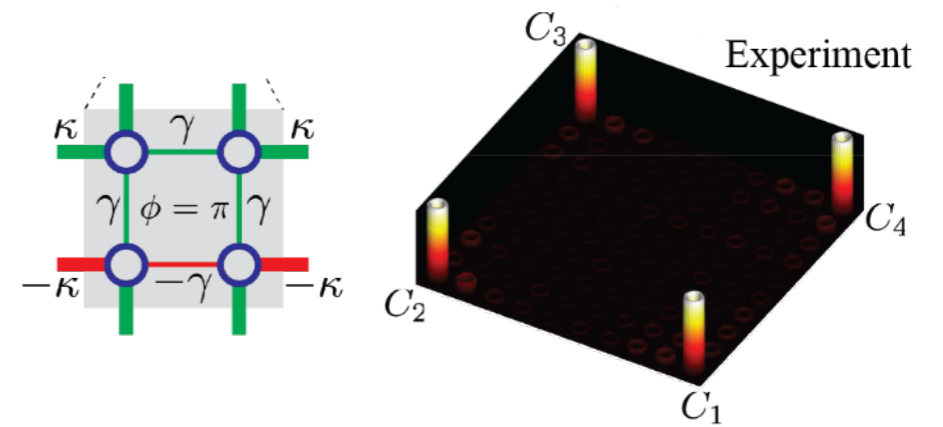


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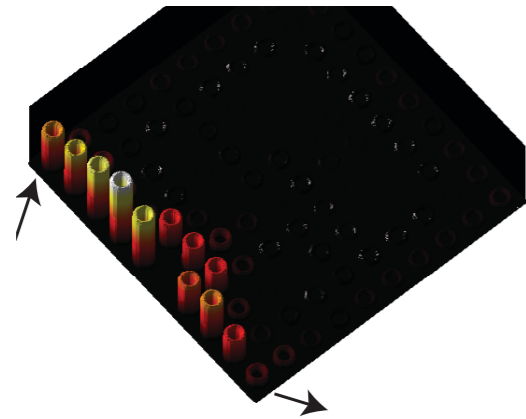


Photonic quadruple topological phases  
 Nature Photonics 13, 692 (2019)

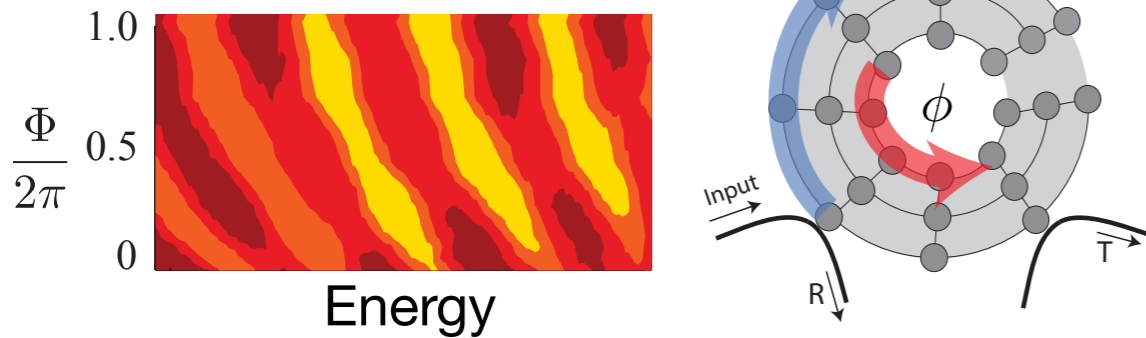




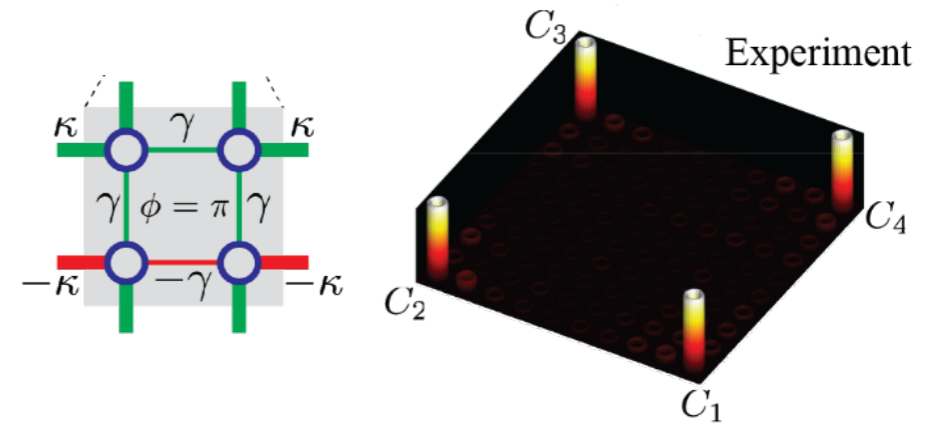
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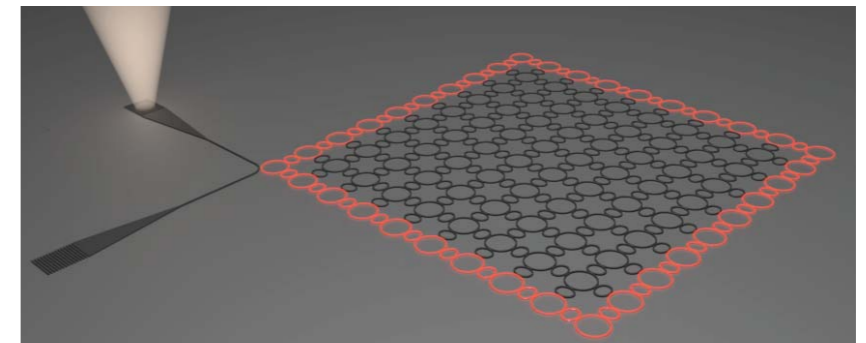
Demonstration of spectral flow  
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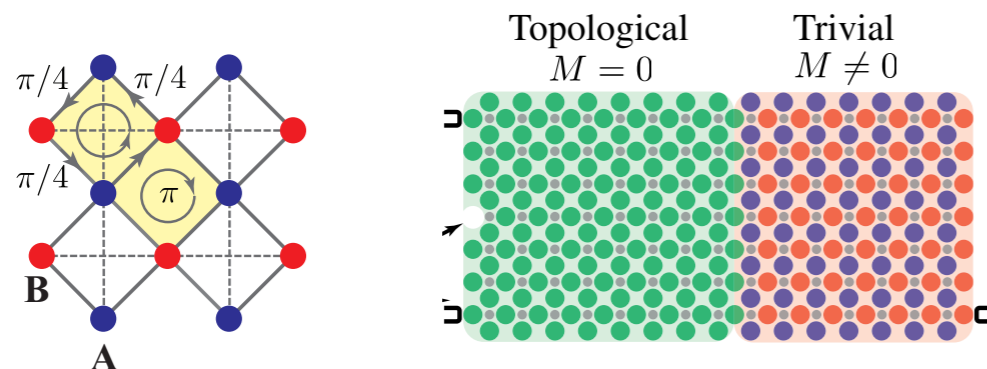
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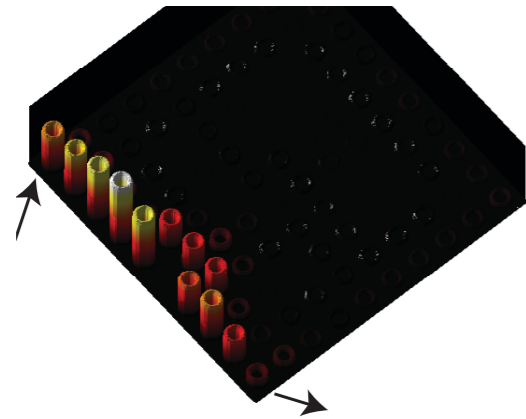
Topological laser  
 Khajavikhan & Segev's group Science 359 (2018)



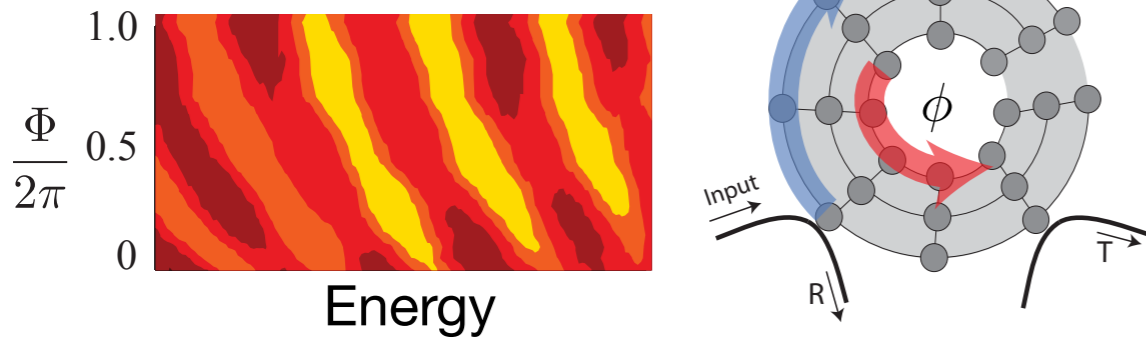
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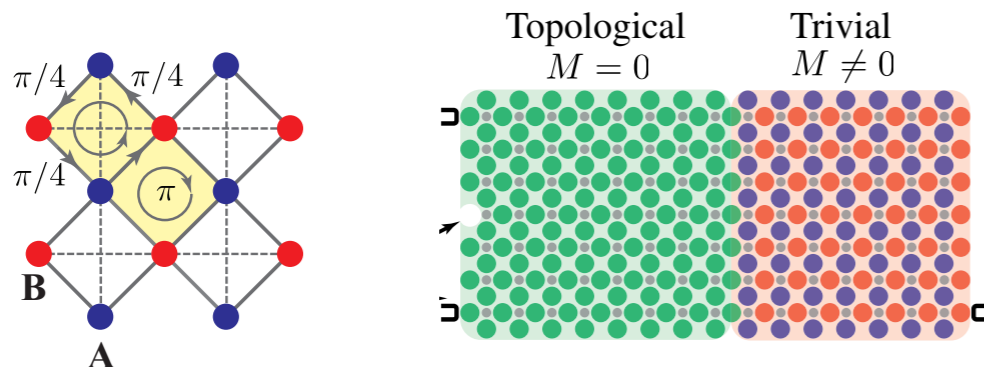
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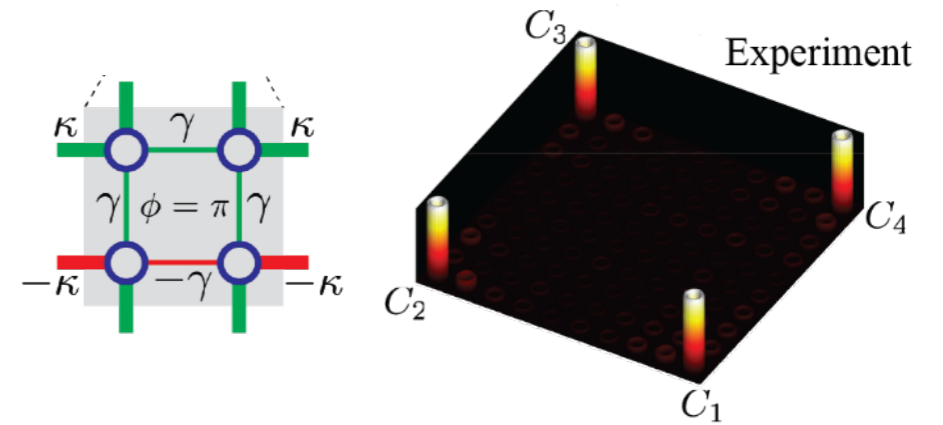
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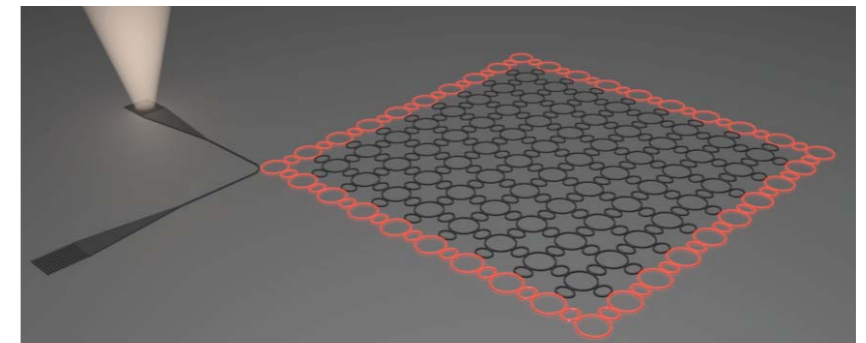
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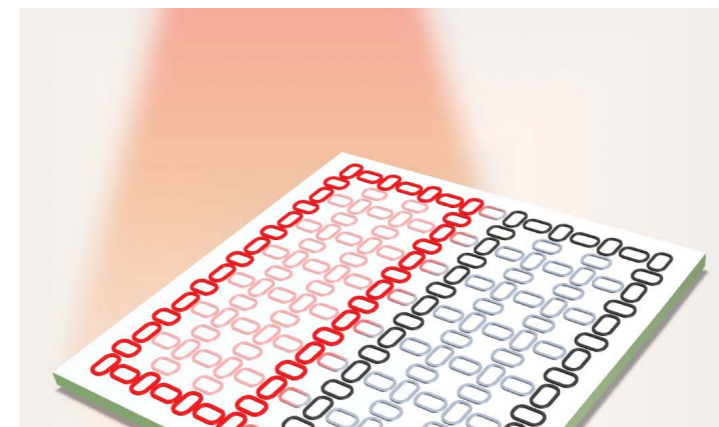
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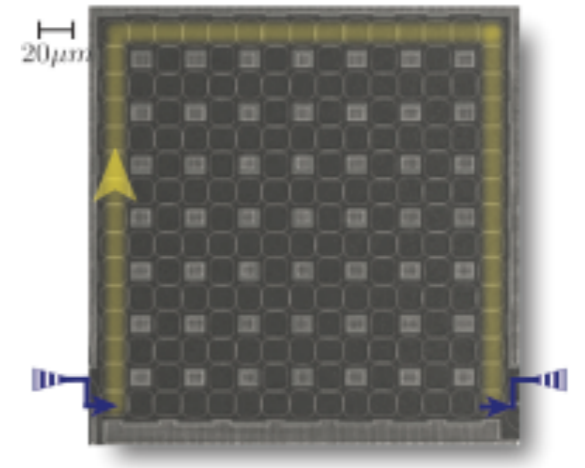
Reconfigurable topological states  
 Feng group (UPenn) Science 365, 1163 (2019)



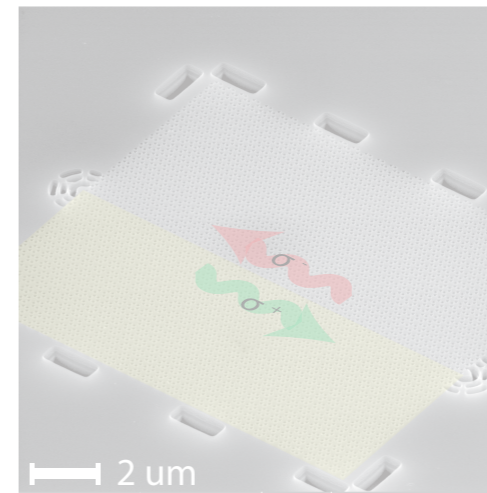
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- Generation of photon pairs (rings)



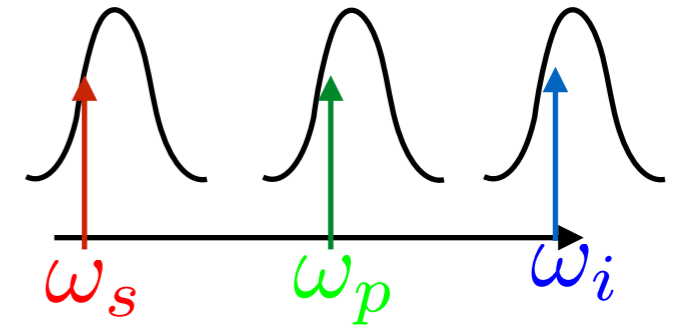
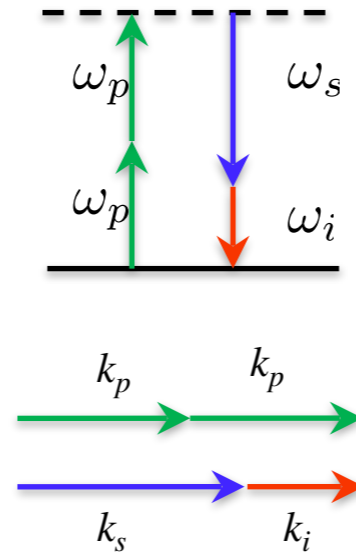
- Quantum optics interface (photonic crystal)



- Optical control of electronic topological states

# Photon pair generation

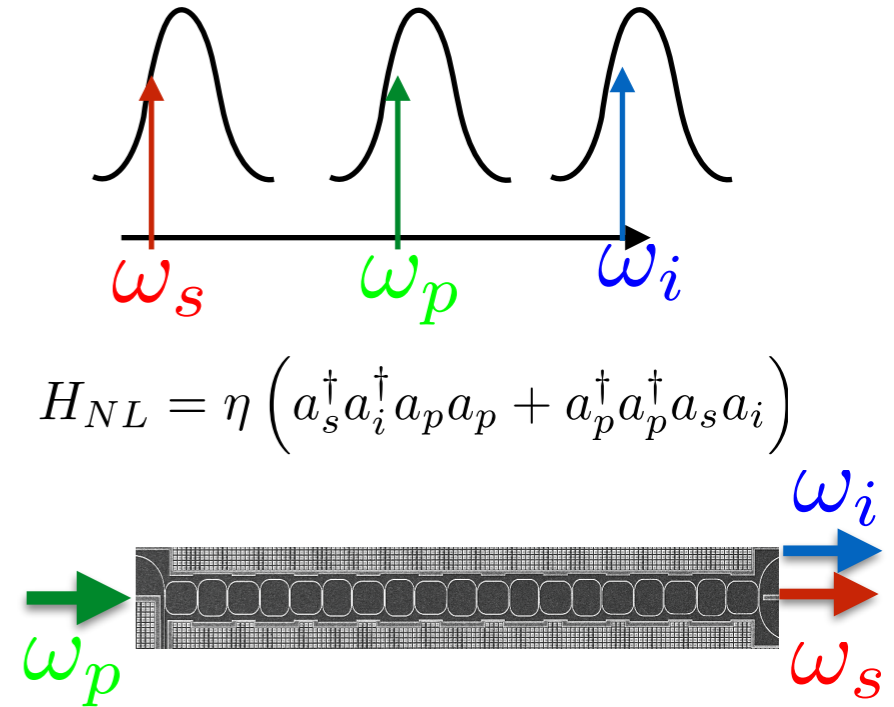
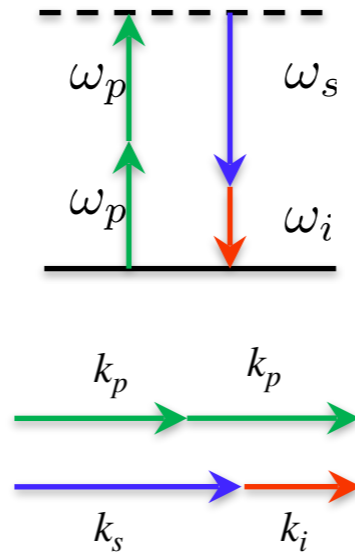
Spontaneous four-wave mixing  
(energy and momentum conservation)



$$H_{NL} = \eta \left( a_s^\dagger a_i^\dagger a_p a_p + a_p^\dagger a_p^\dagger a_s a_i \right)$$

# Photon pair generation

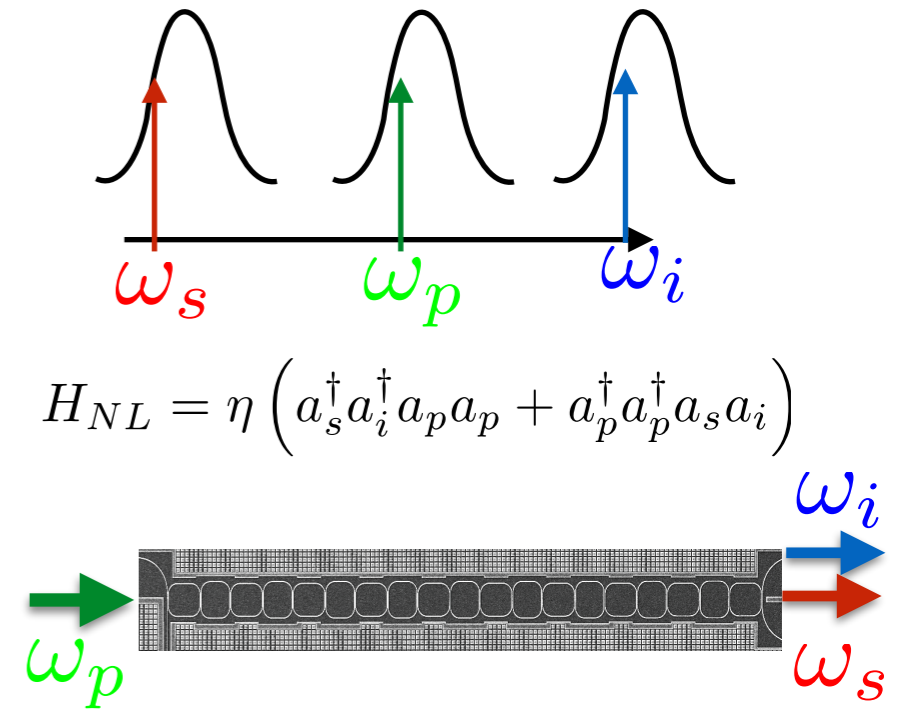
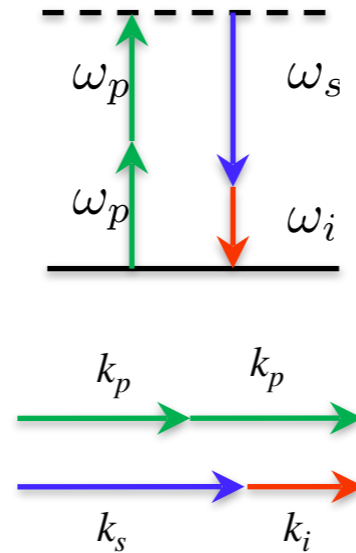
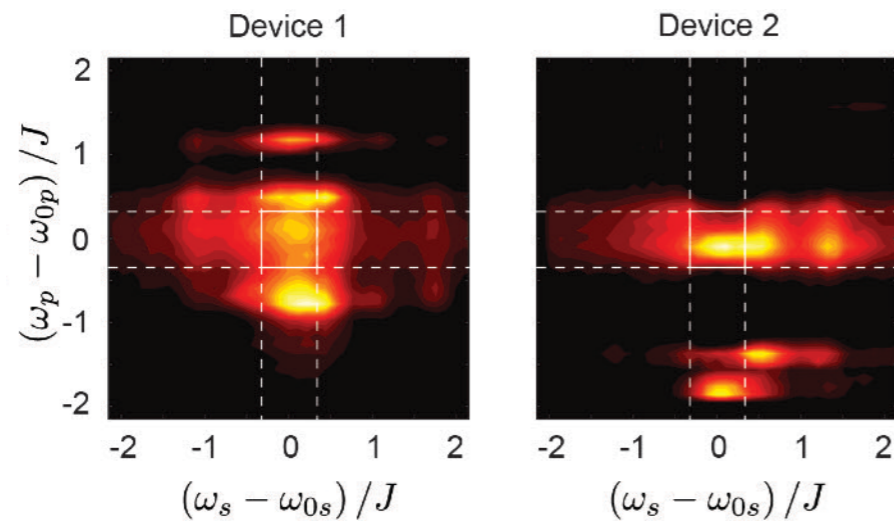
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1D array of ring resonators  
R. Kumar et. al., Nat. Comm. (2014)  
Davanco et. al., APL. (2014)

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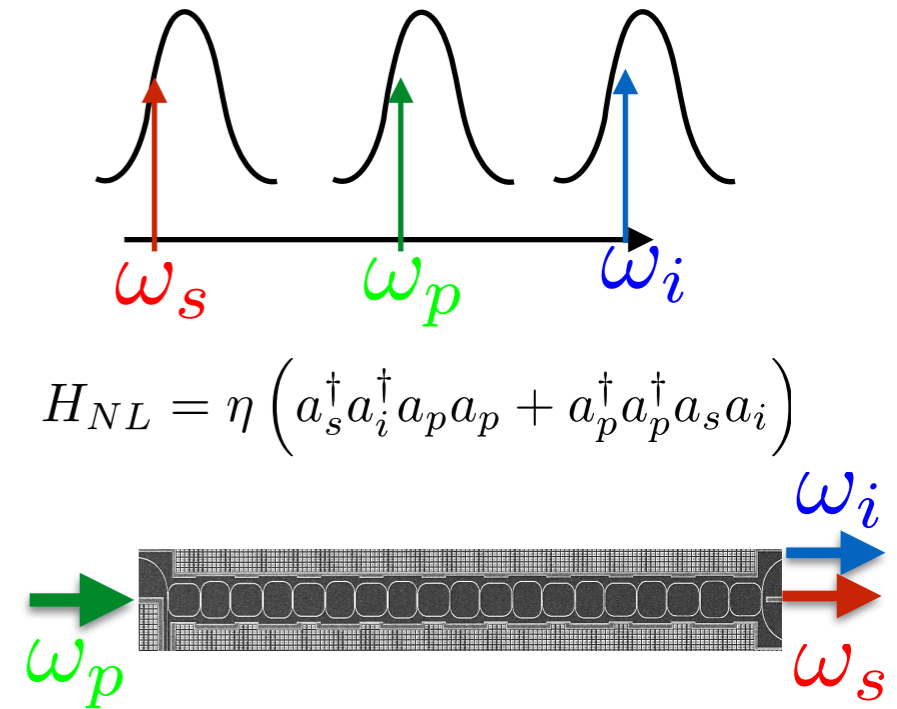
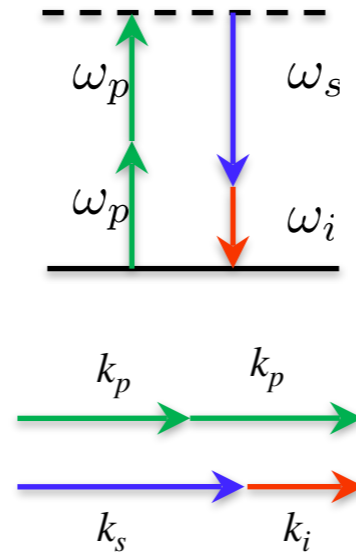
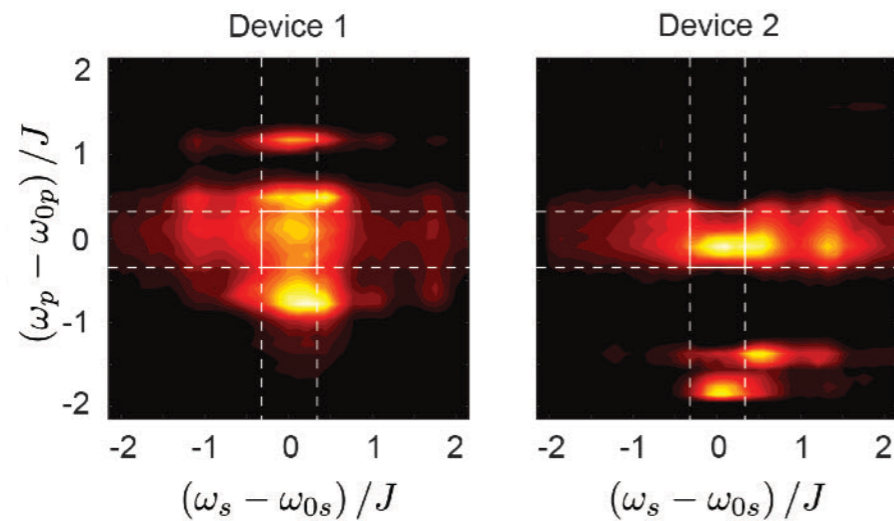
$$H_{NL} = \eta \left( a_s^\dagger a_i^\dagger a_p a_p + a_p^\dagger a_p^\dagger a_s a_i \right)$$

1D array of ring resonators  
R. Kumar et. al., Nat. Comm. (2014)  
Davanco et. al., APL. (2014)

- Photons come at random frequencies
- The spectrum changes from chip to chip
- phase-matching is challenging

# Photon pair generation

Spontaneous four-wave mixing  
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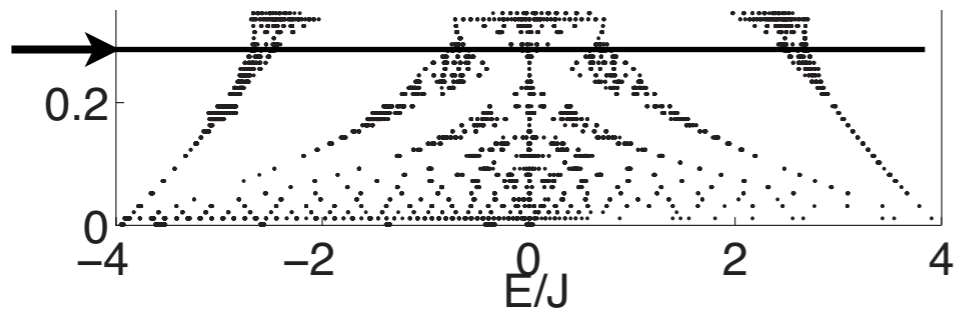
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1D array of ring resonators  
R. Kumar et. al., Nat. Comm. (2014)  
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- Photons come at random frequencies
- The spectrum changes from chip to chip
- phase-matching is challenging

Can topological protection help us?

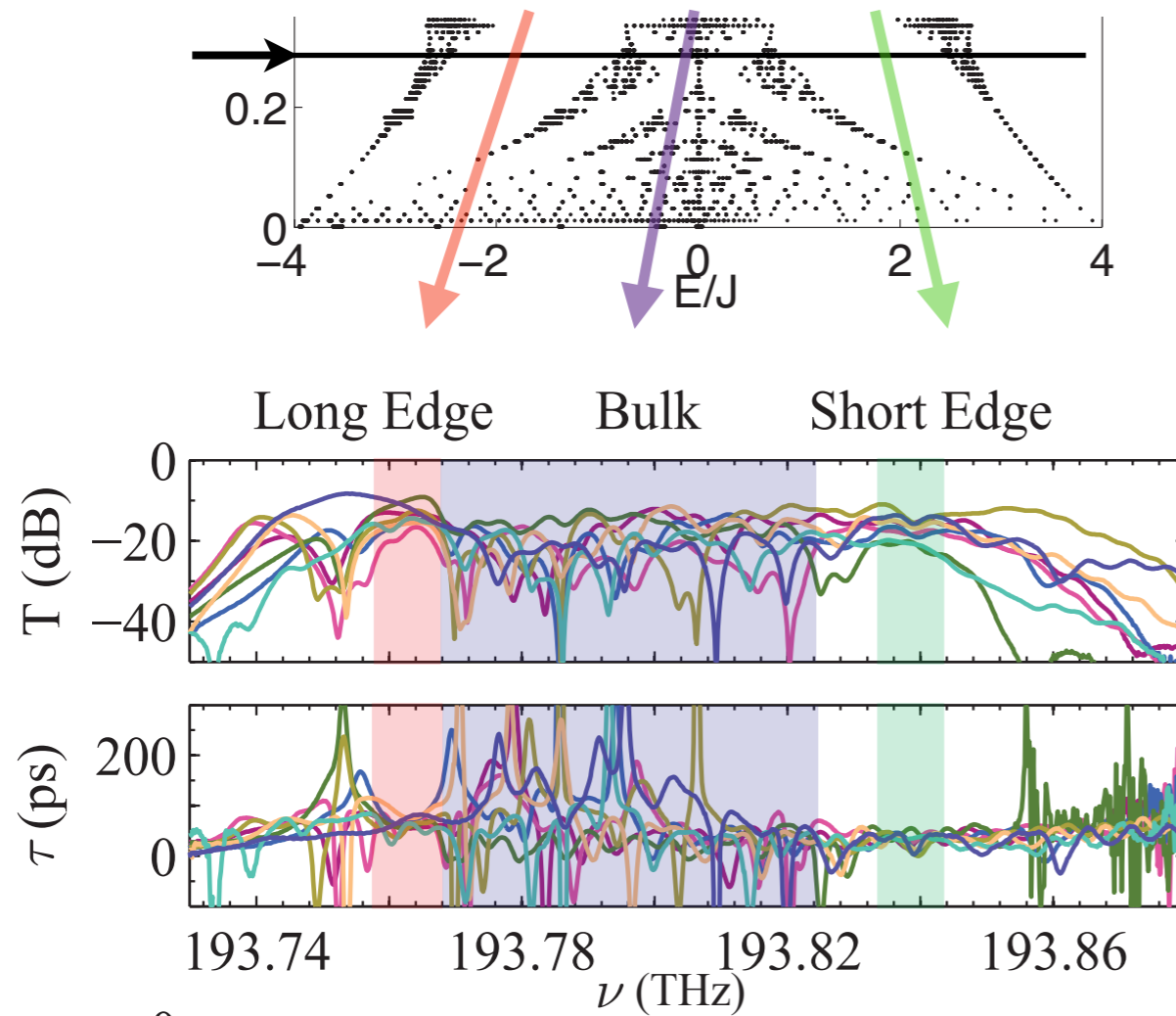
# Transport statistics (classical)



chiral edge states  
are indeed robust!



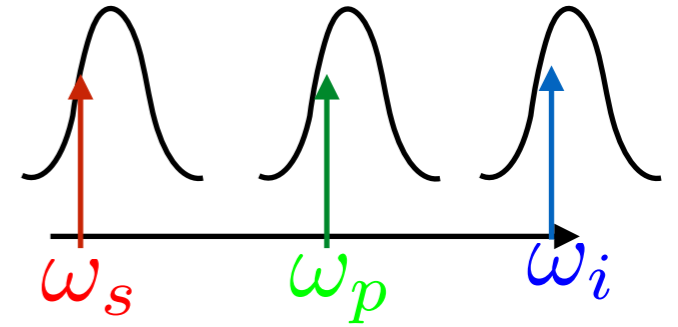
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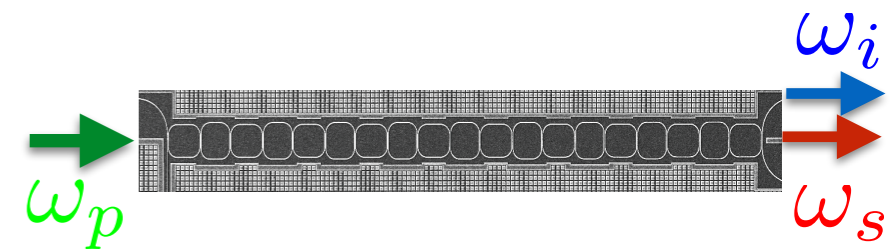
chiral edge states  
are indeed robust!

15x15 arrays  
Different colors: different samples

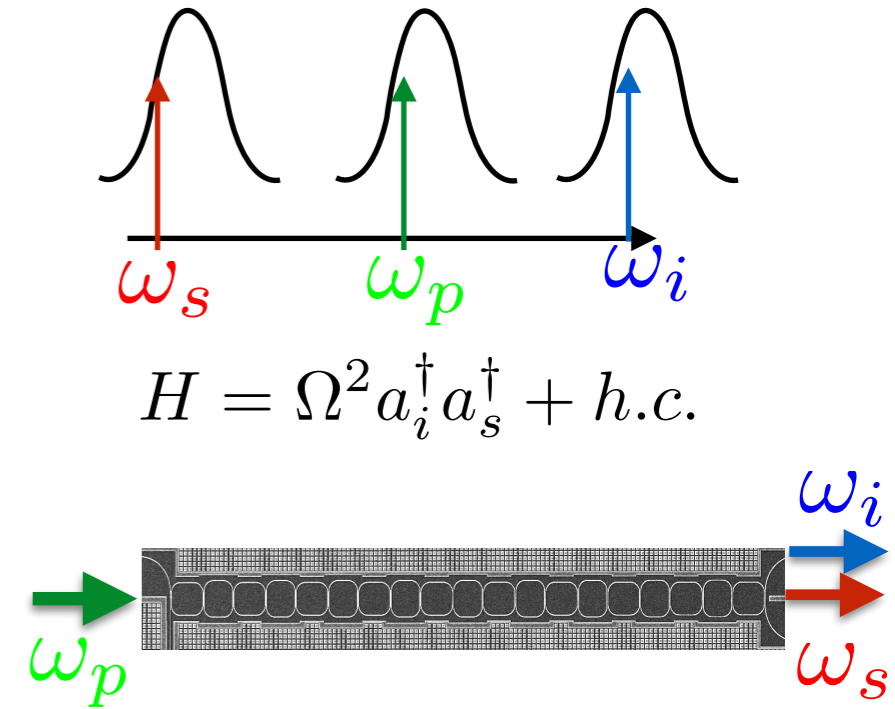
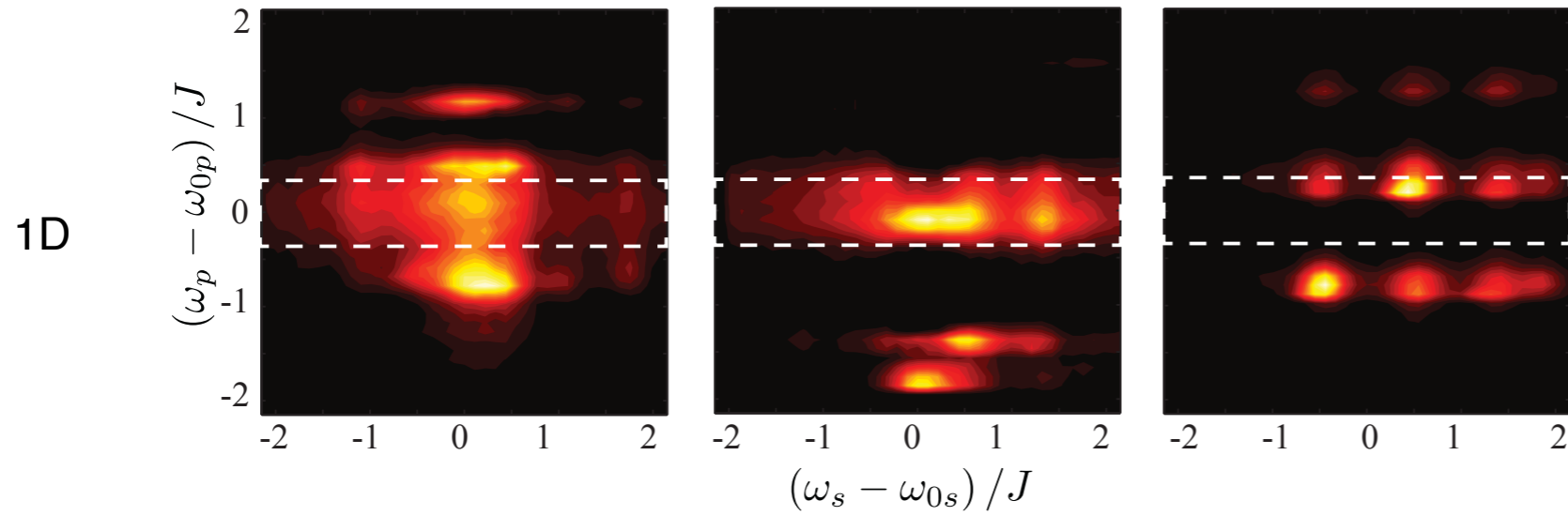
# Comparison between trivial and topological



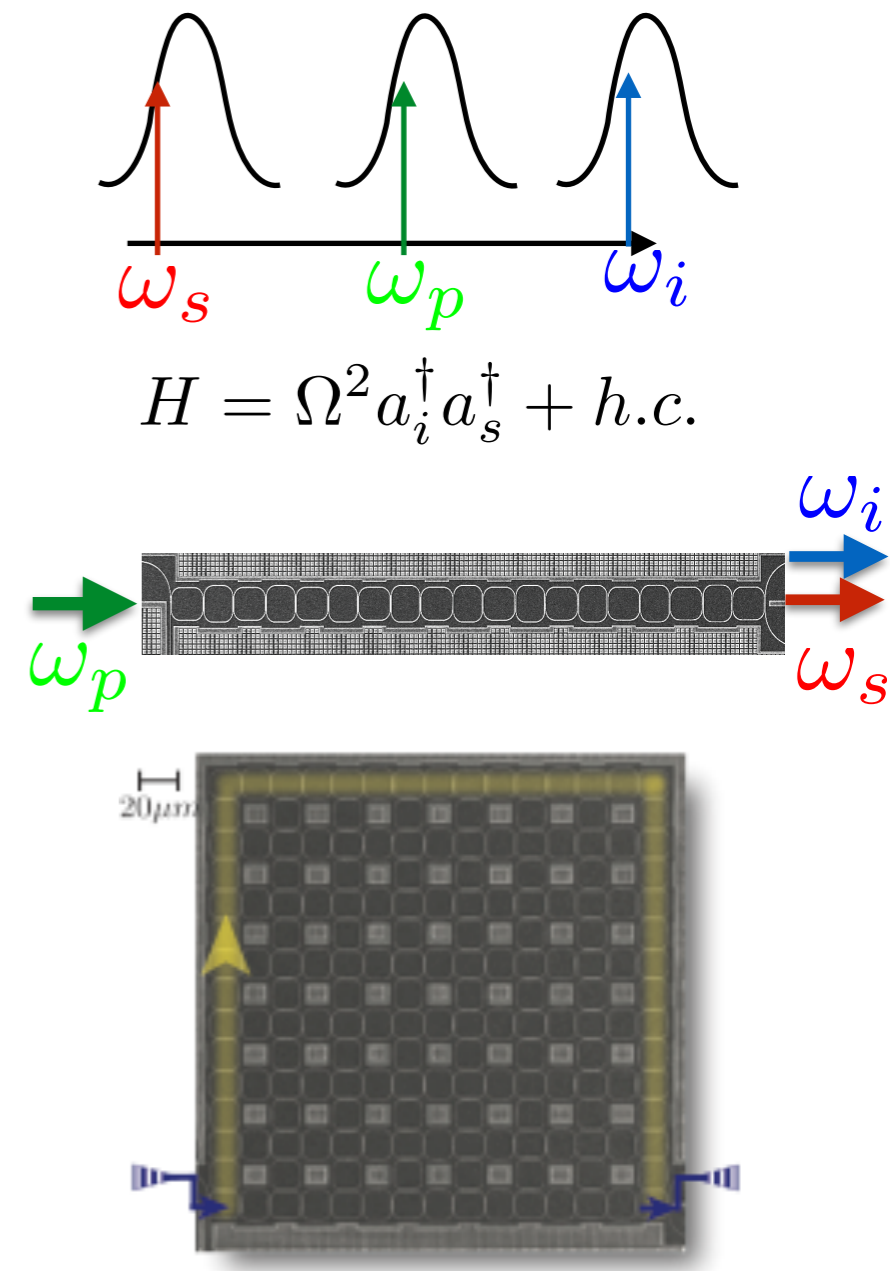
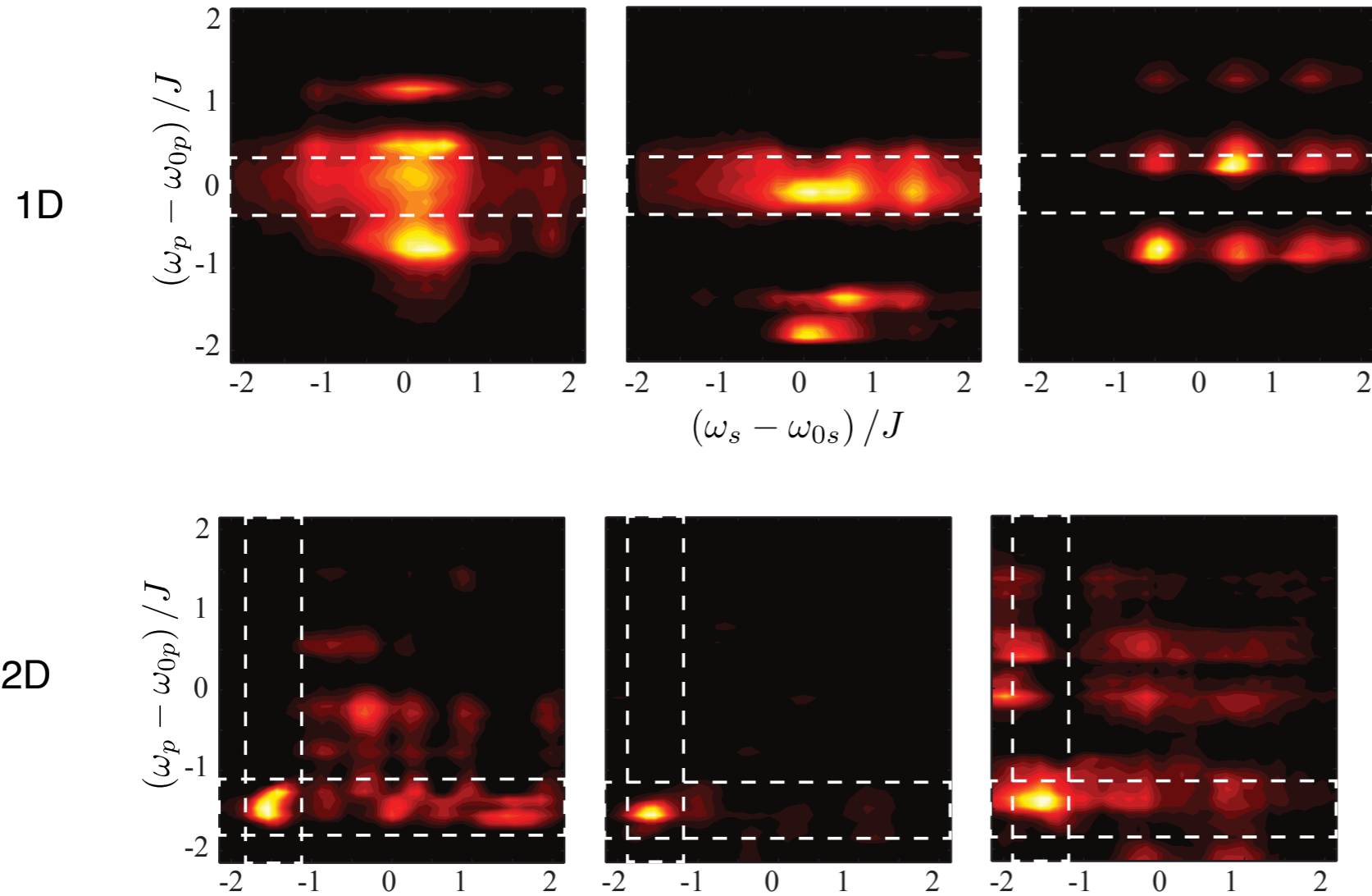
$$H = \Omega^2 a_i^\dagger a_s^\dagger + h.c.$$



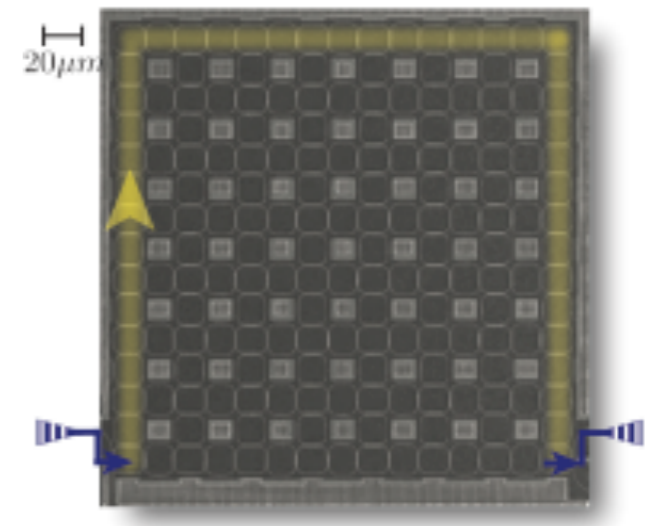
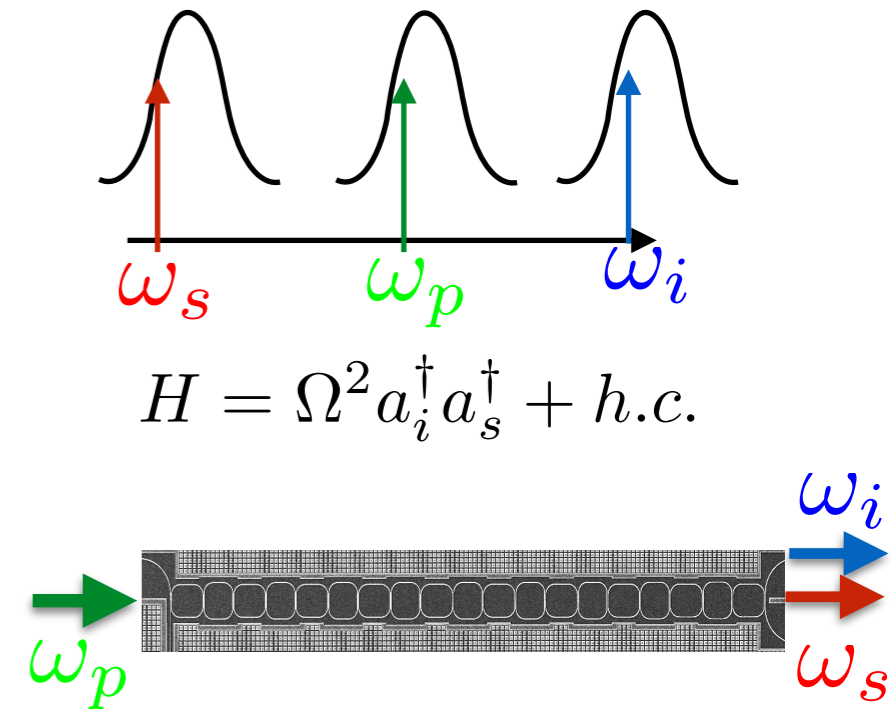
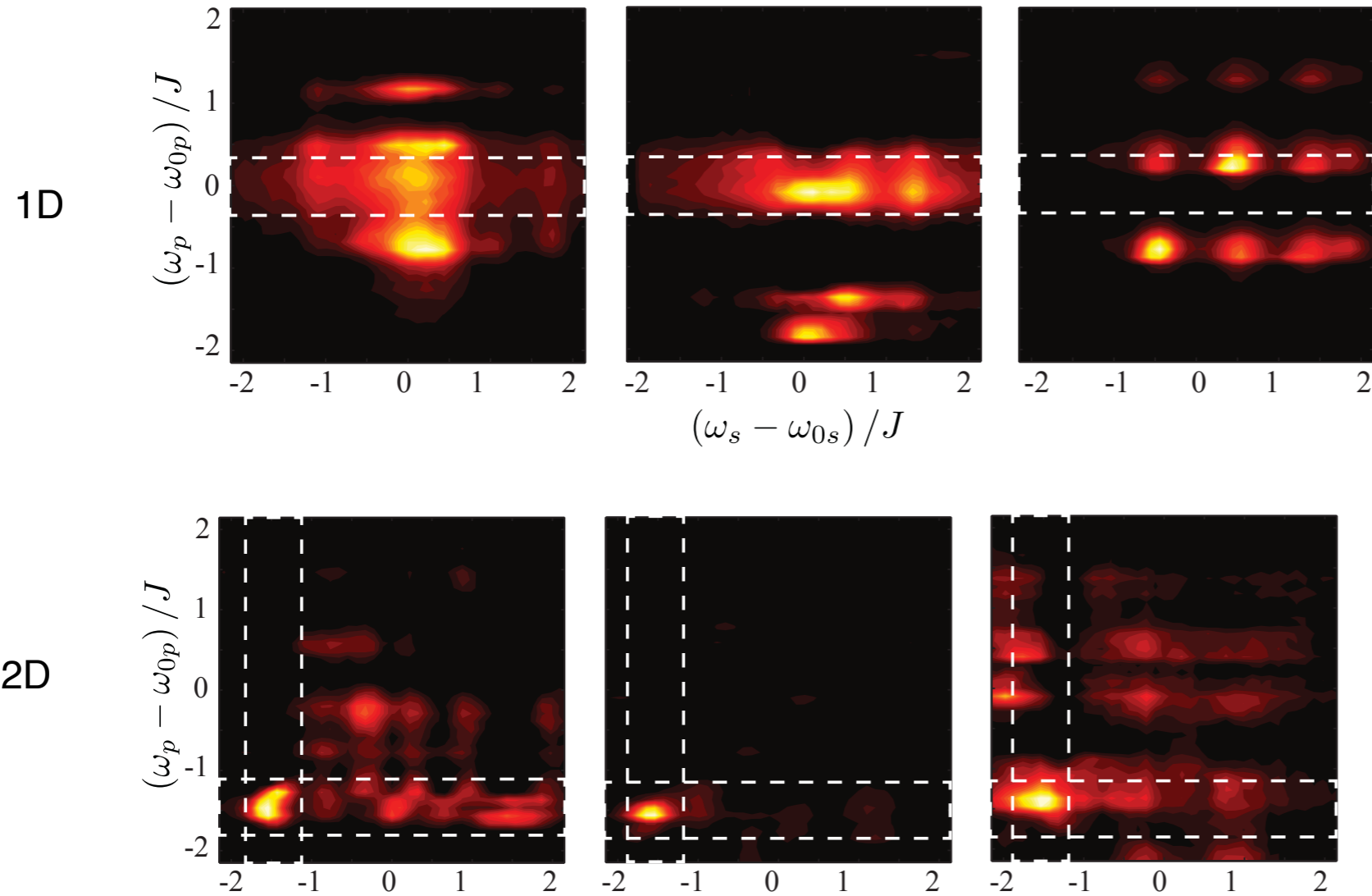
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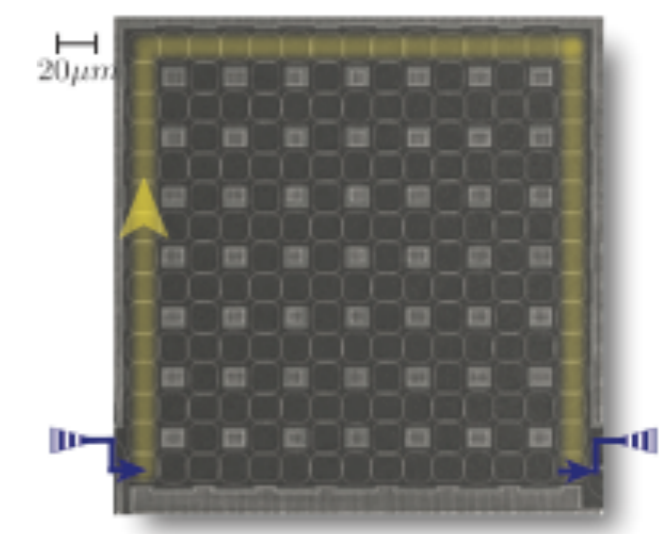
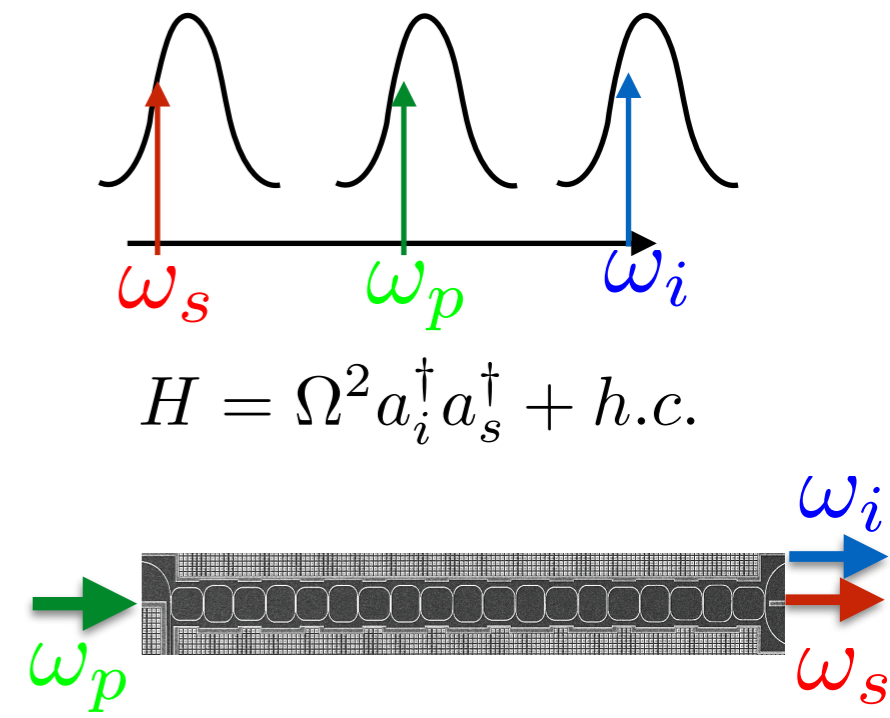
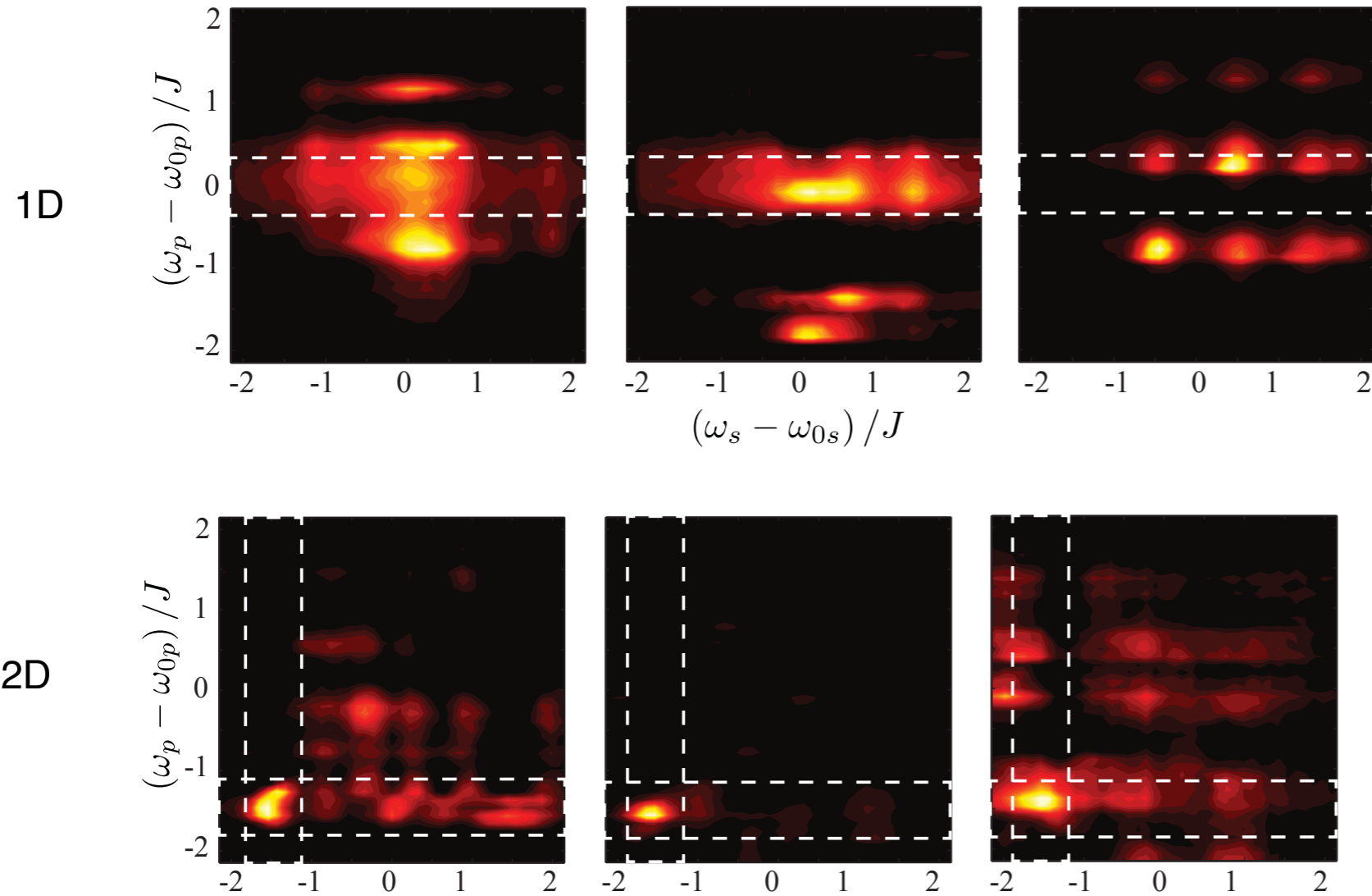


Despite strong disorder

$$\Delta\omega_0 \approx J$$

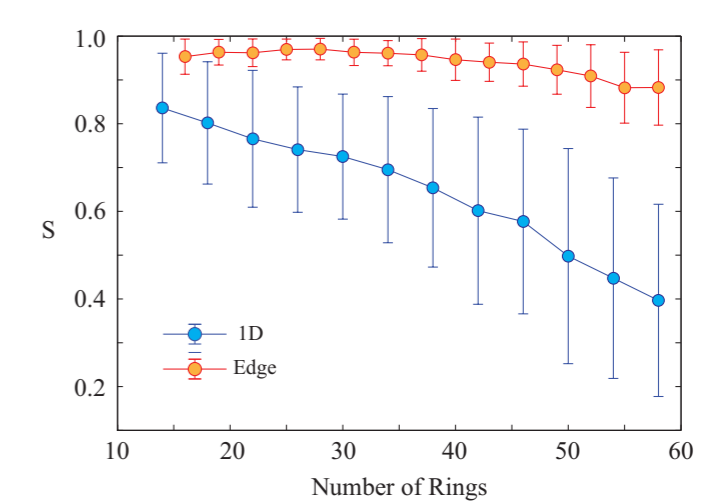
$$\Delta\phi \approx 0.1$$

# Comparison between trivial and topological

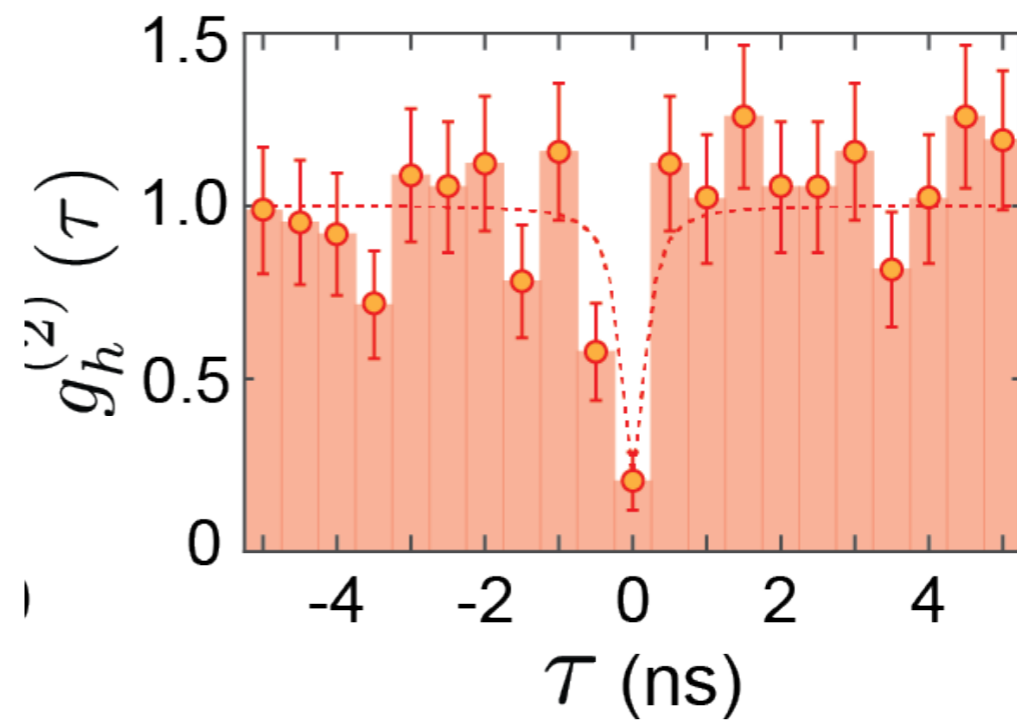
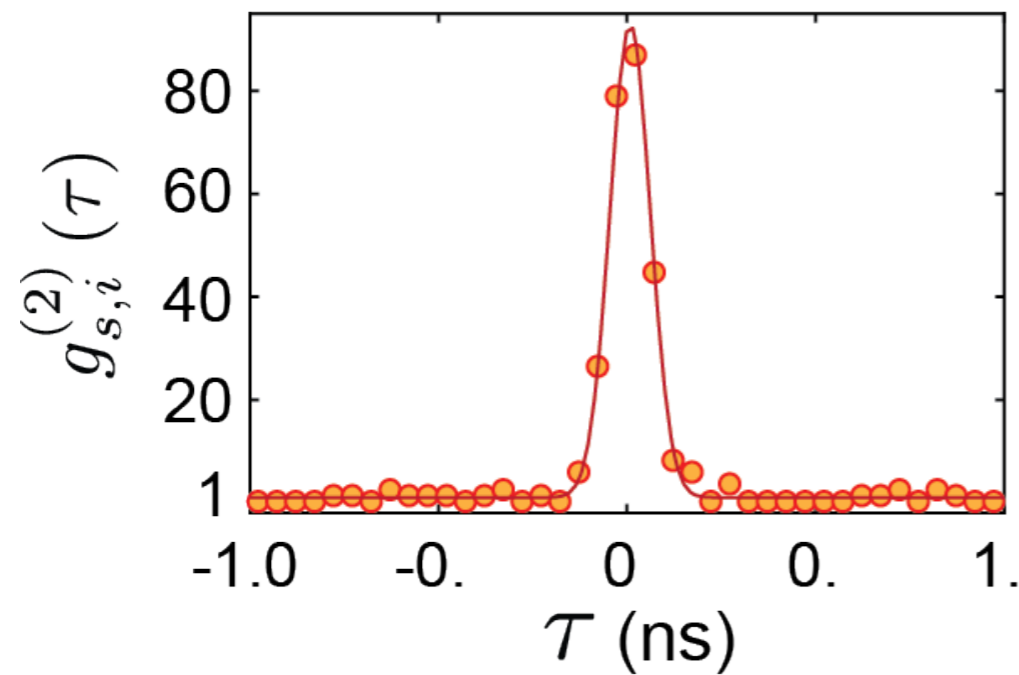


Despite strong disorder  $\Delta\omega_0 \approx J$   $\Delta\phi \approx 0.1$

2D structure gives a higher quality and reproducible spectra for the same yield



# Single photon source characterization by correlation function measurement



- Quantum directions in topological photonics:
  - Generation of photon pairs (rings)



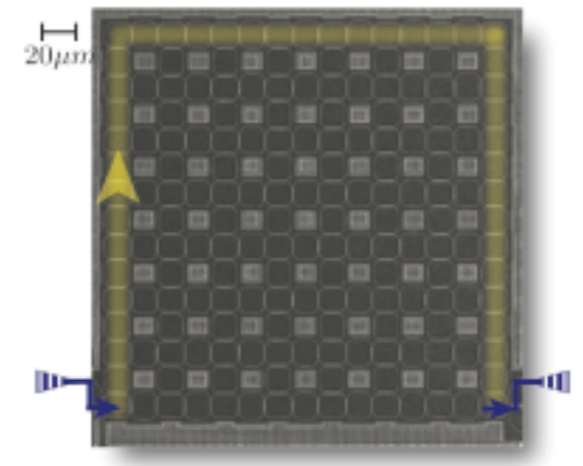
S. Mittal



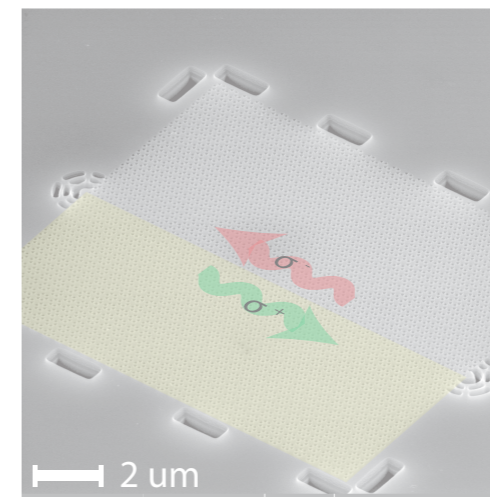
V. Orre



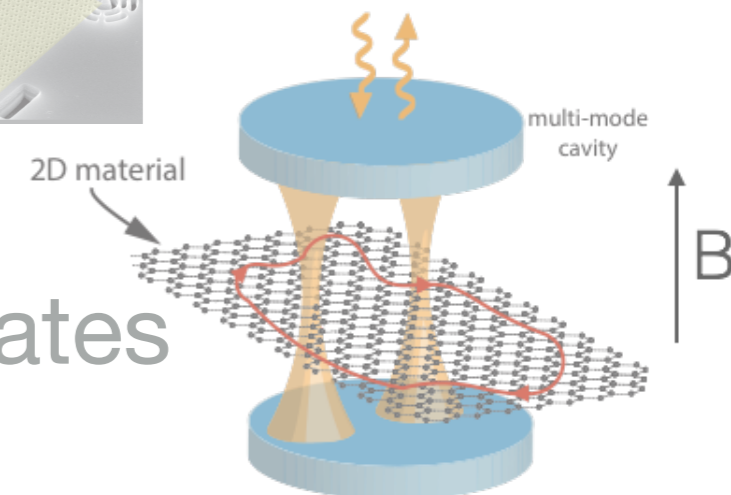
E. Goldschmidt  
(ARL → UIUC)



- Quantum optics interface (photonic crystal)



- Optical control of electronic topological states





- Quantum directions in topological photonics:
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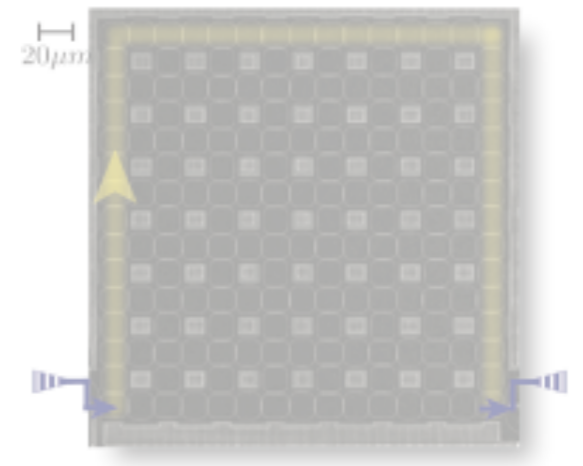
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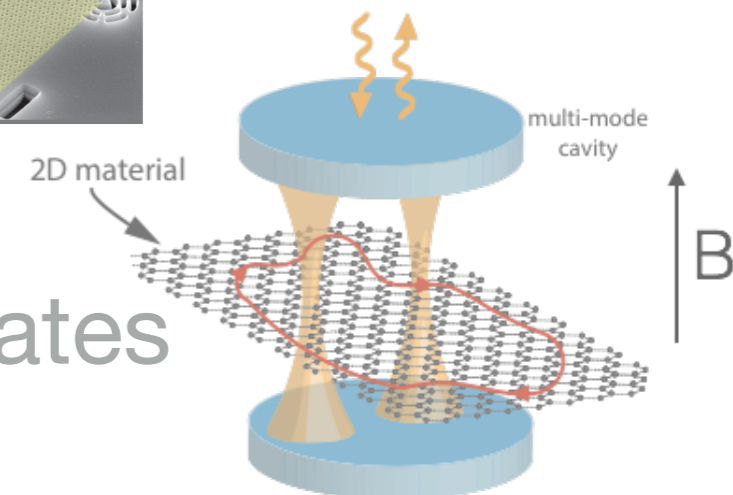
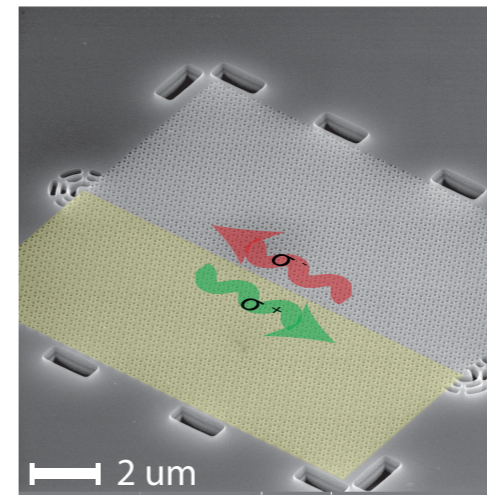
V. Orre



E. Goldschmidt  
(ARL → UIUC)



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(photonic crystal)



- Optical control of electronic topological states

# Topological photonic crystals

Goal: A compatible structure with **solid-state emitters**

Challenges:

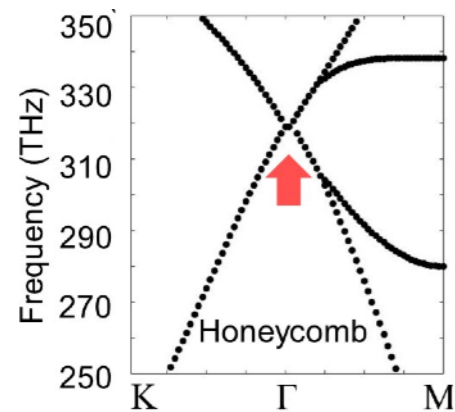
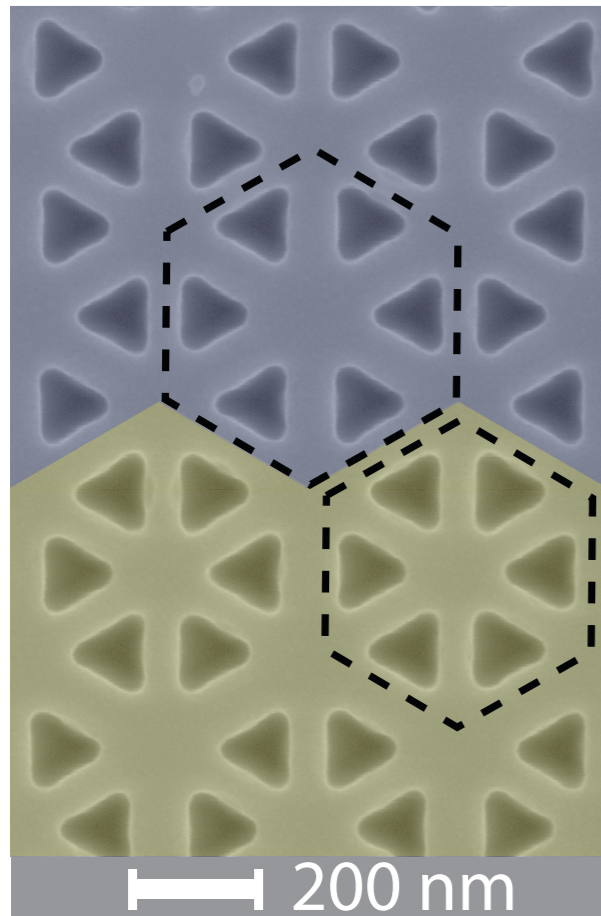
- ★ **Full bandgap** in the bulk
- ★ E&M field **confined in prep. direction** to the slab

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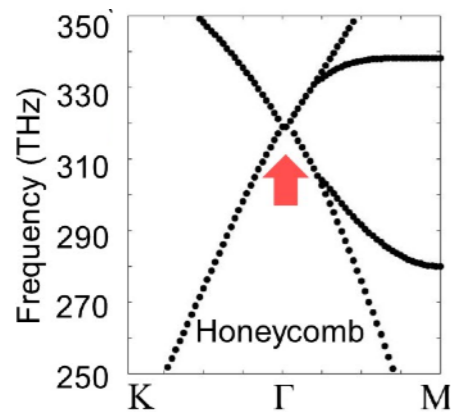
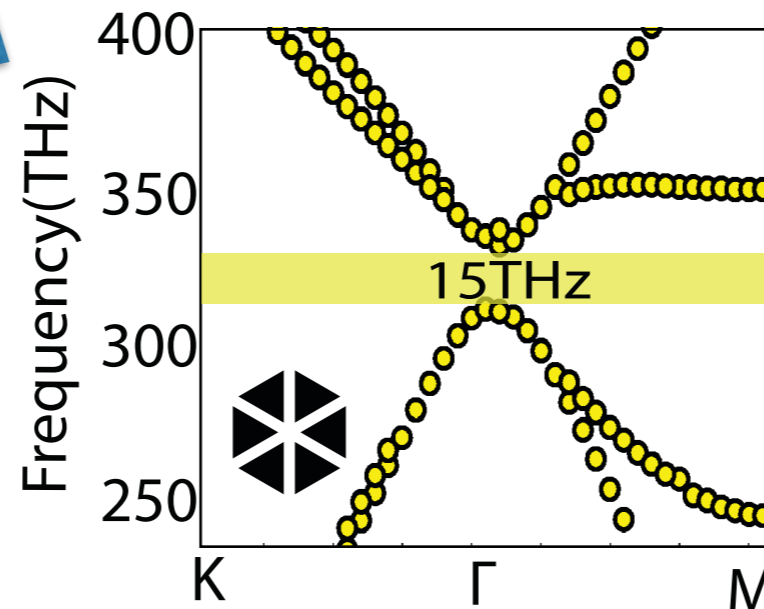
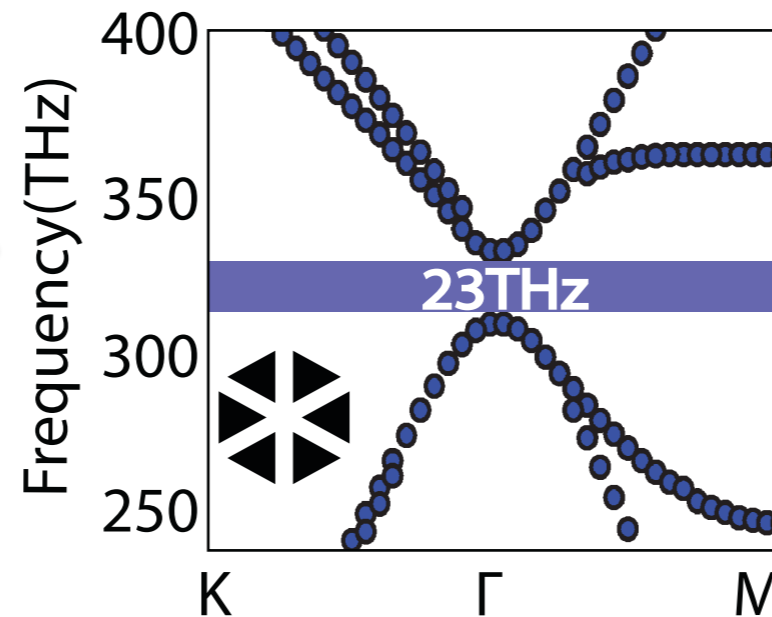
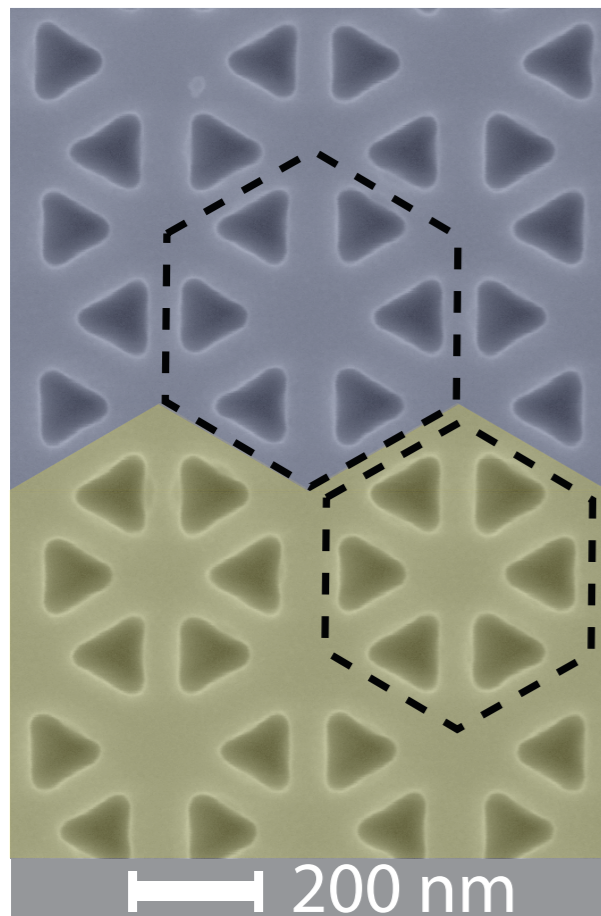
PFC-NSF collaboration with Waks  
S. Barik et al. NJP (2016)  
inspired by Wu and Hu PRL (2015)

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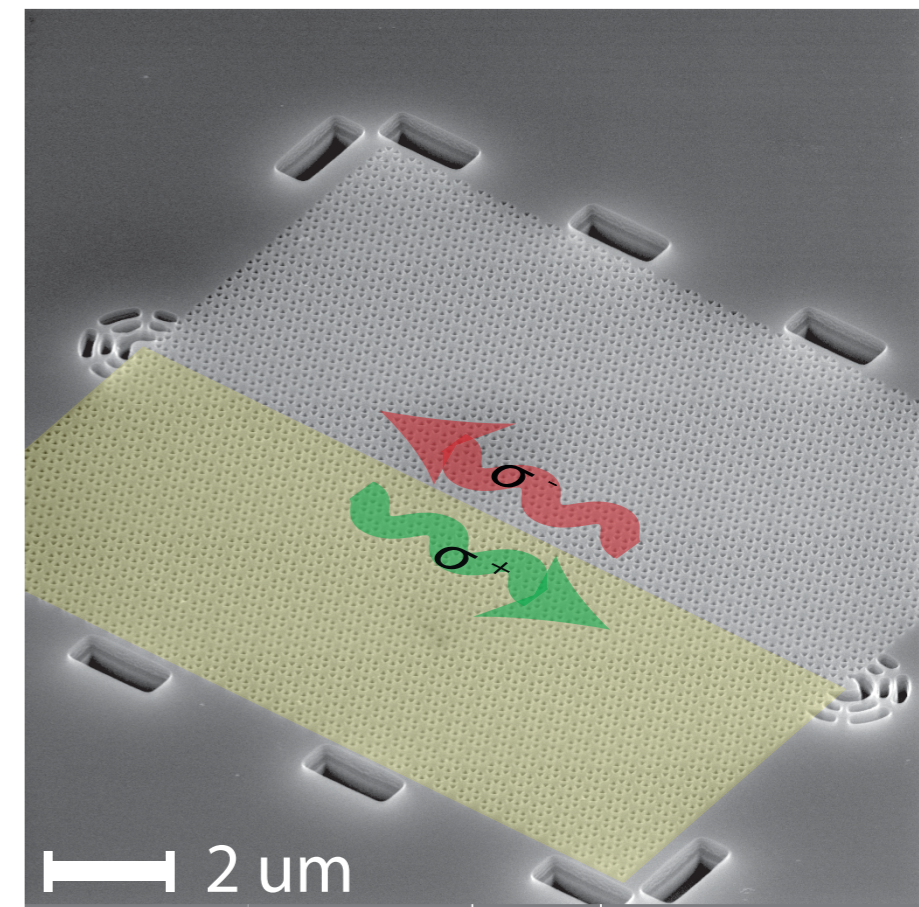
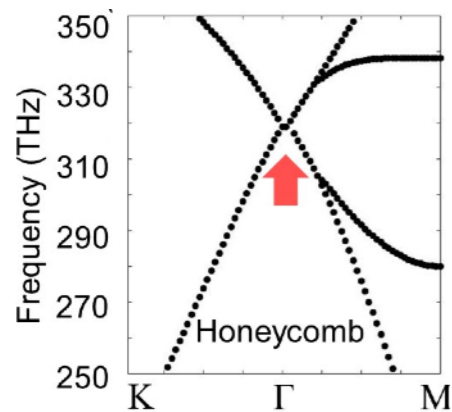
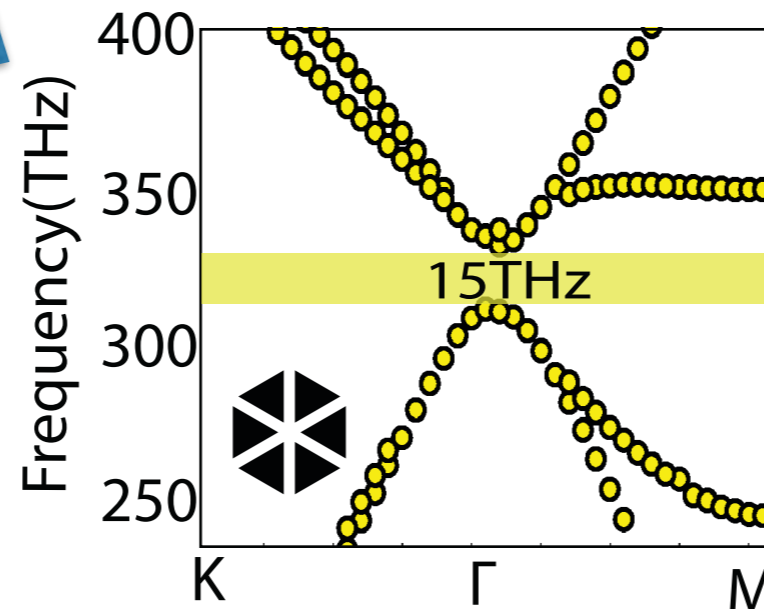
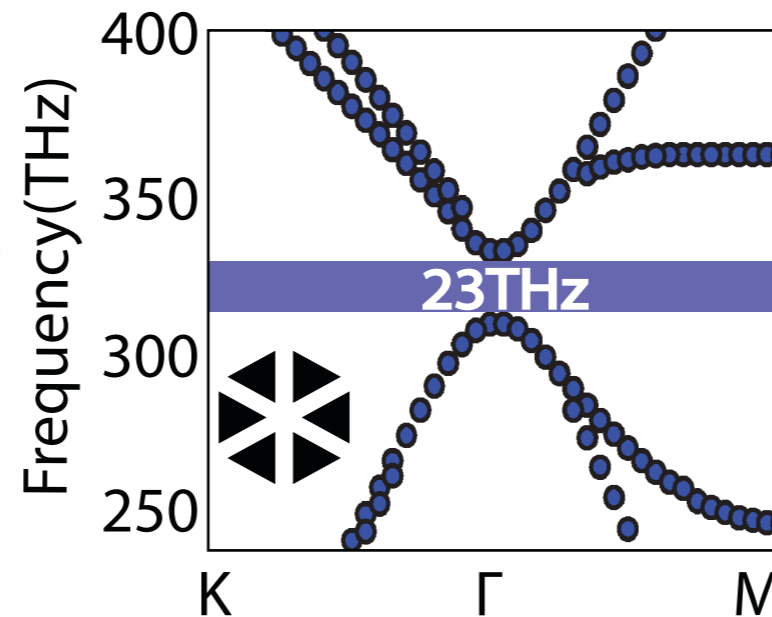
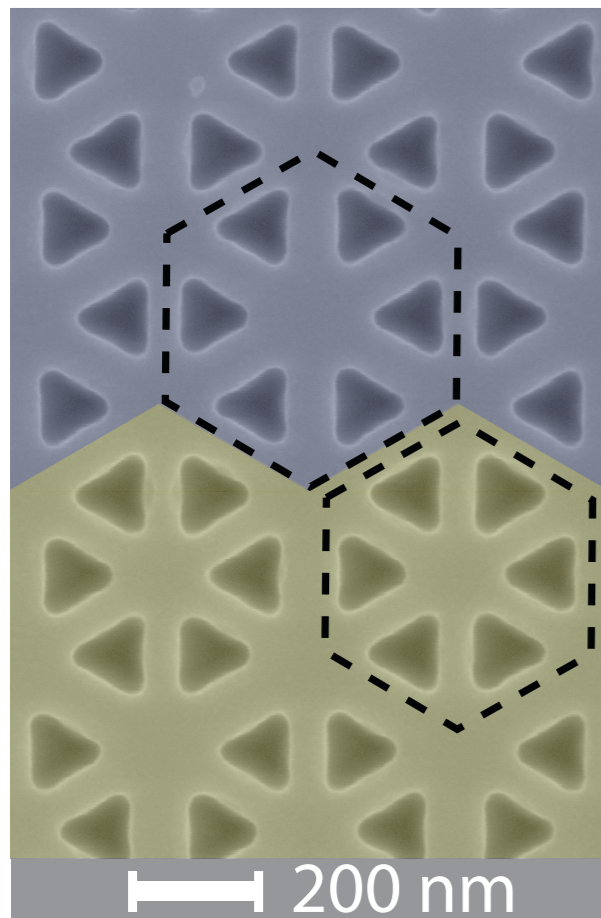
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# Topological photonic crystals

Goal: A compatible structure with **solid-state emitters**

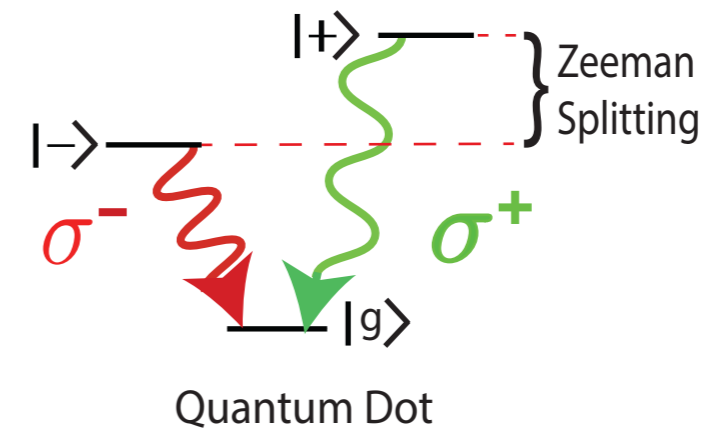
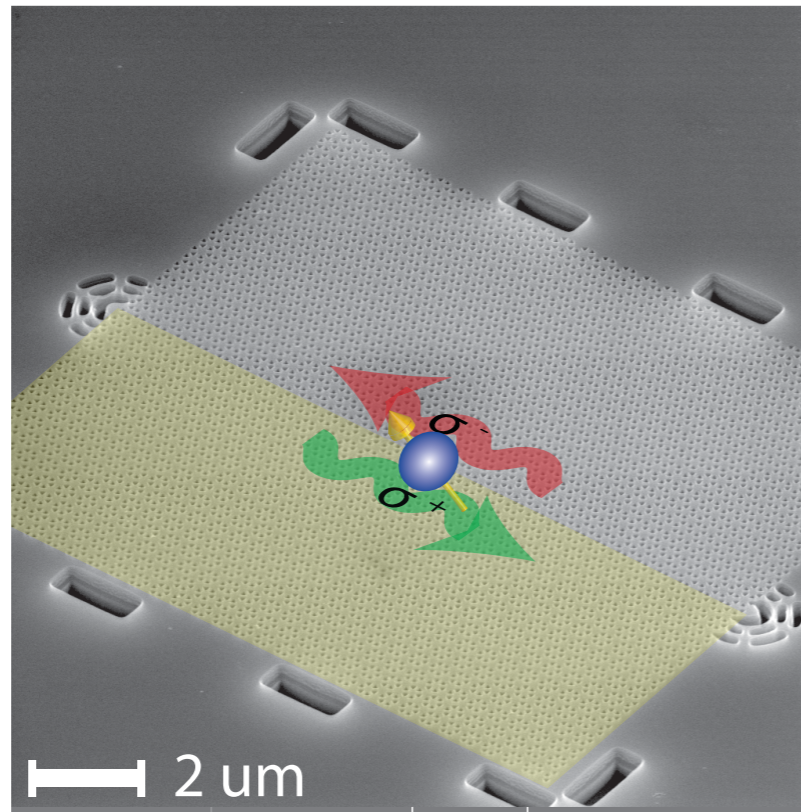
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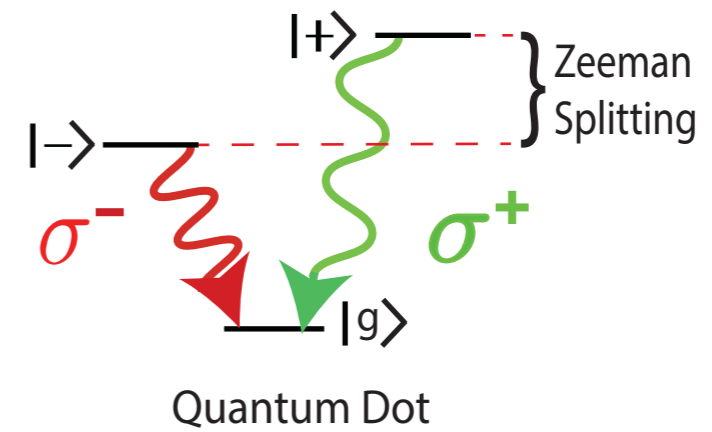
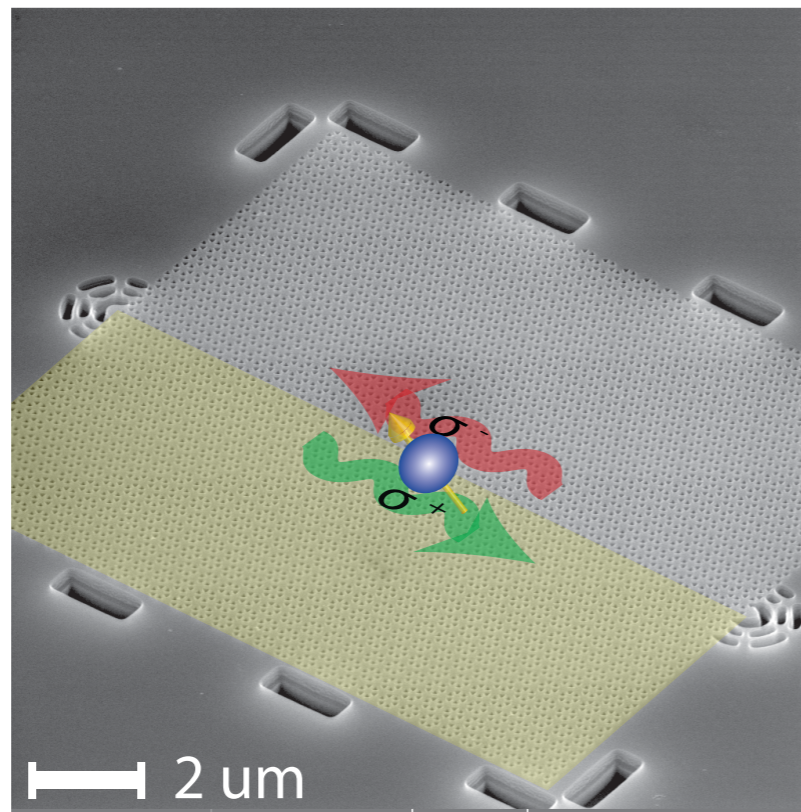
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# Chiral topological emission

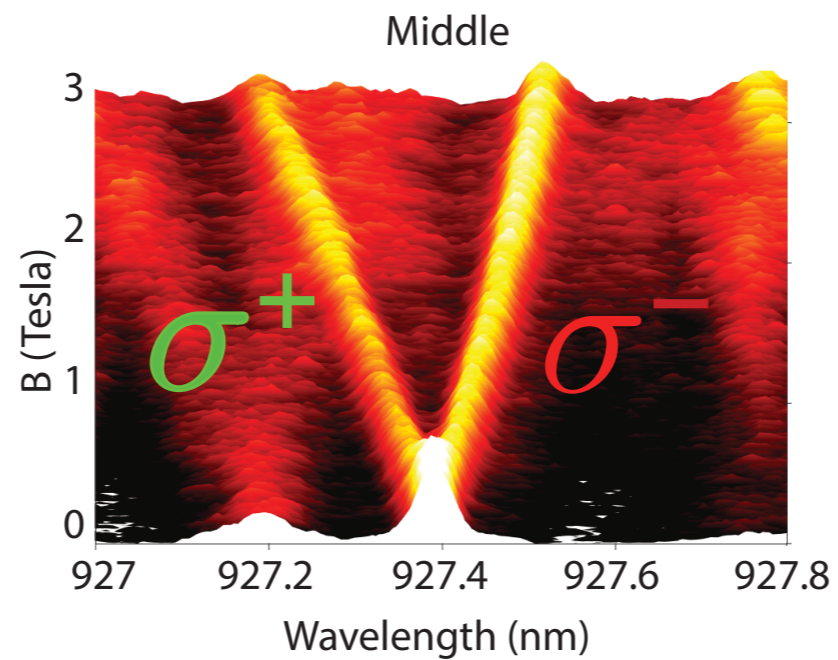


Compare with 1D:  
Lodahl/Rauschenbeutel/Zoller Nature (2017)

# Chiral topological emission

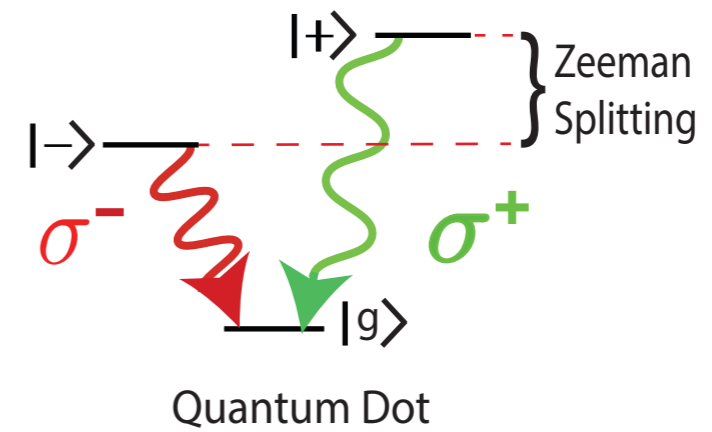
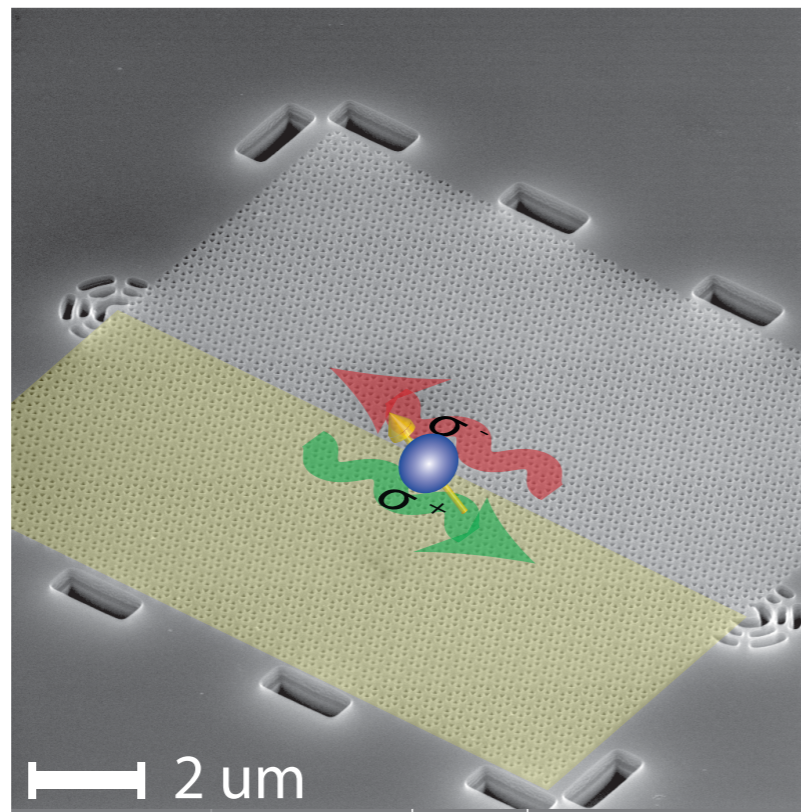


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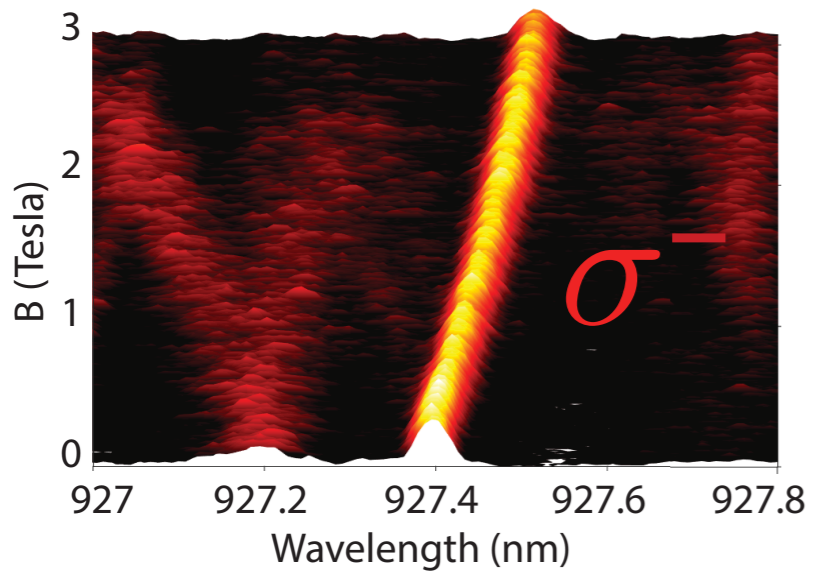
well below the saturation power (10 nW)

# Chiral topological emission

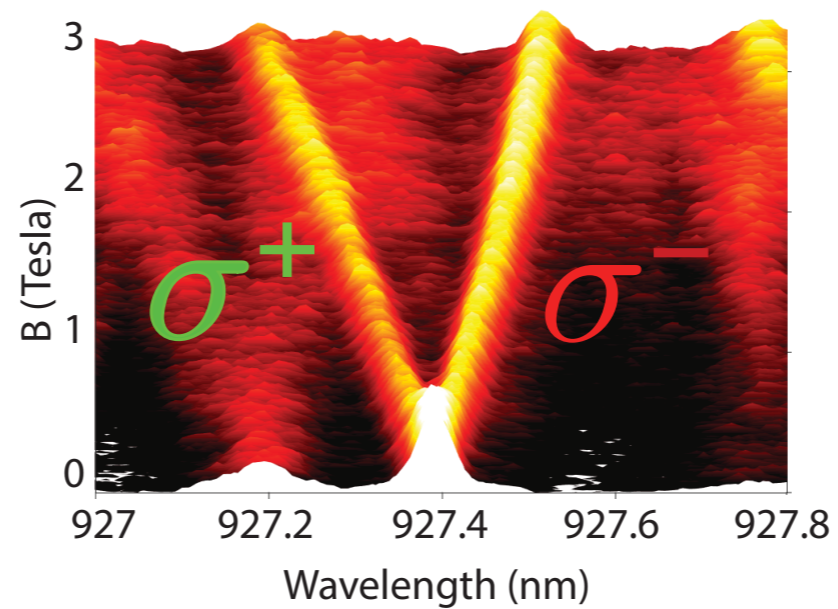


Compare with 1D:  
Lodahl/Rauschenbeutel/Zoller Nature (2017)

Left



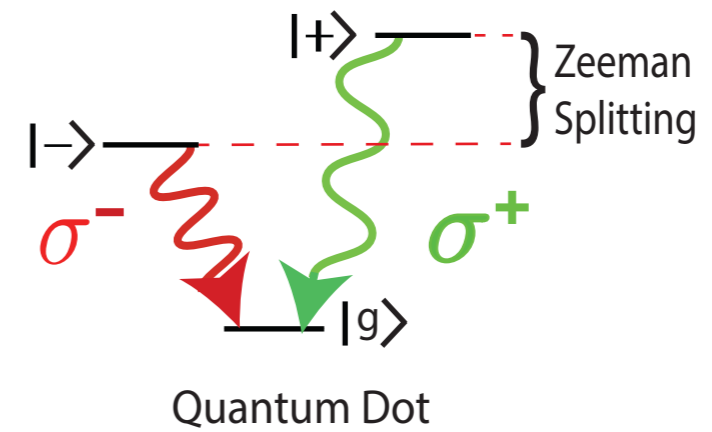
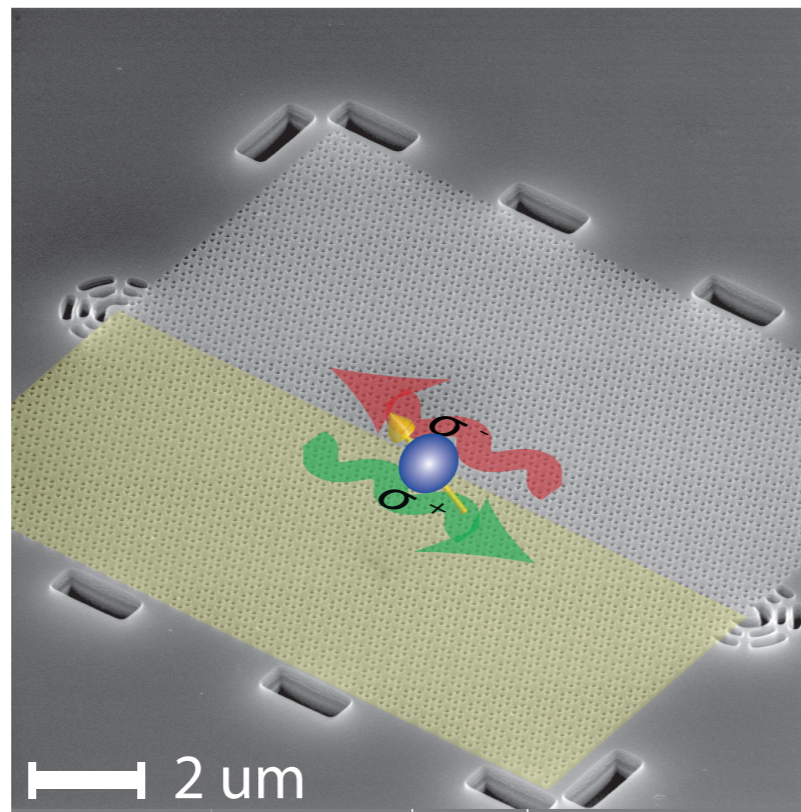
Middle



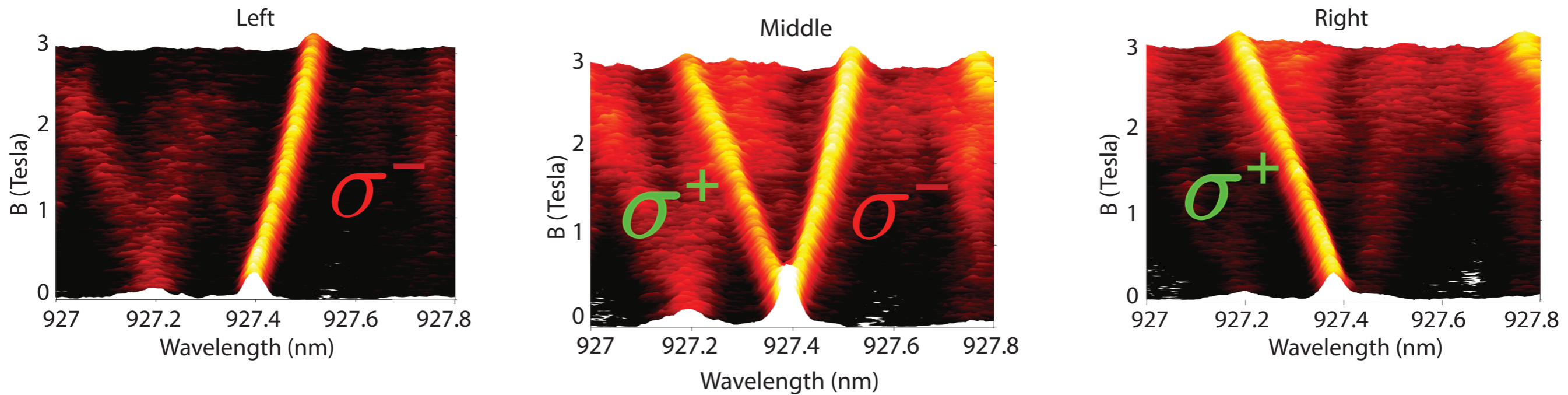
well below the saturation power (10 nW)



# Chiral topological emission

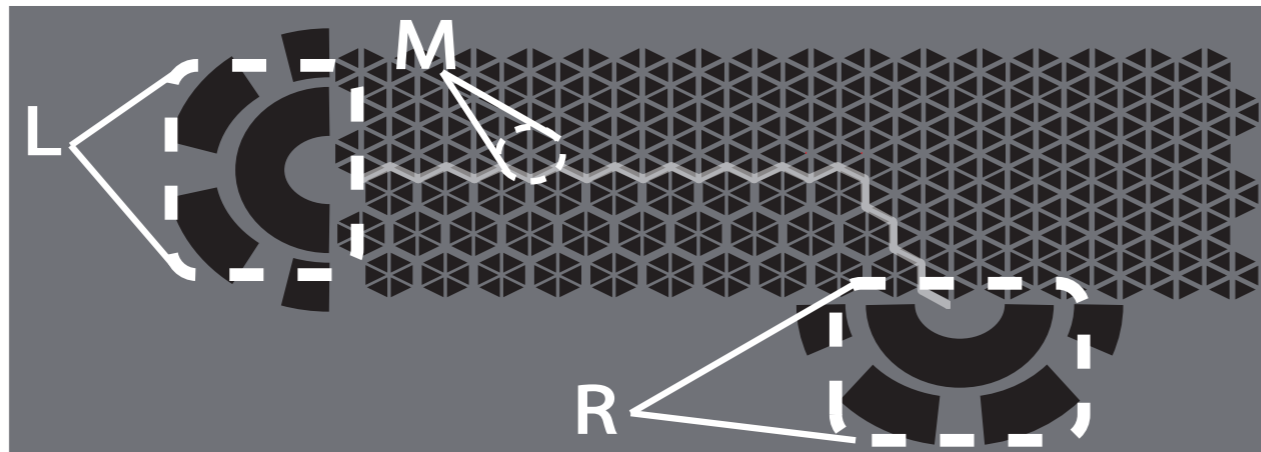


Compare with 1D:  
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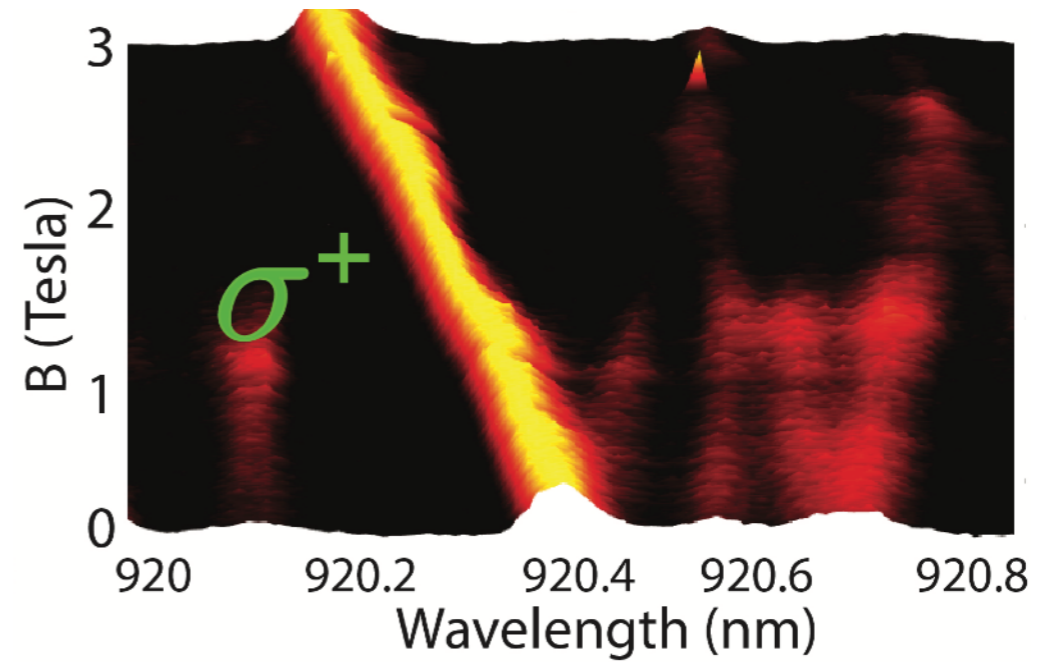
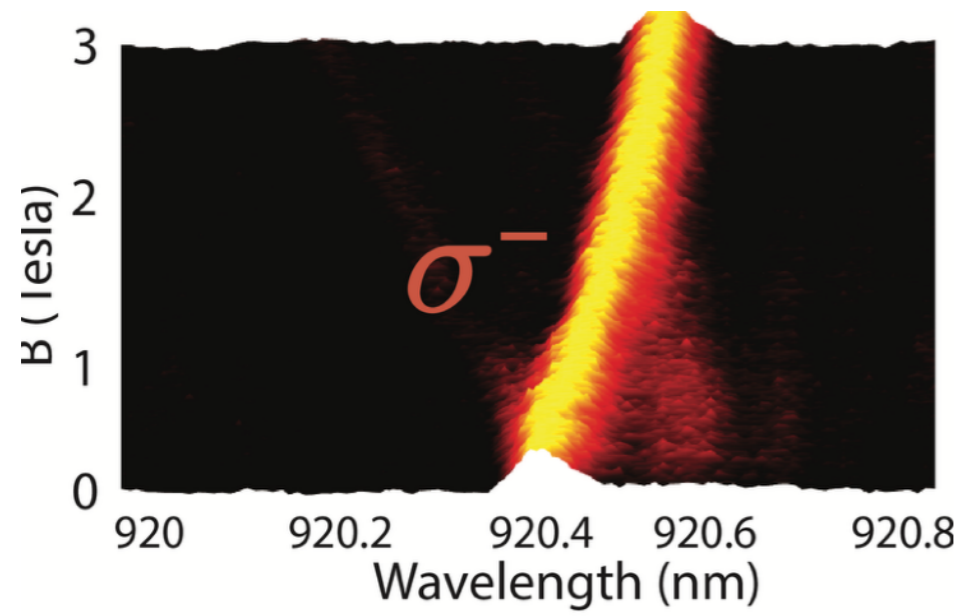
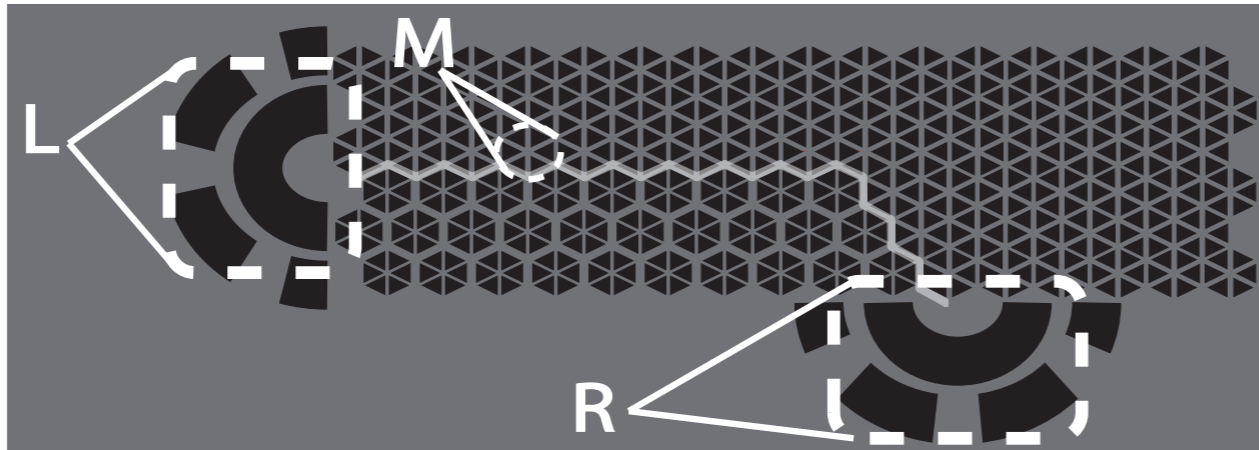


well below the saturation power (10 nW)

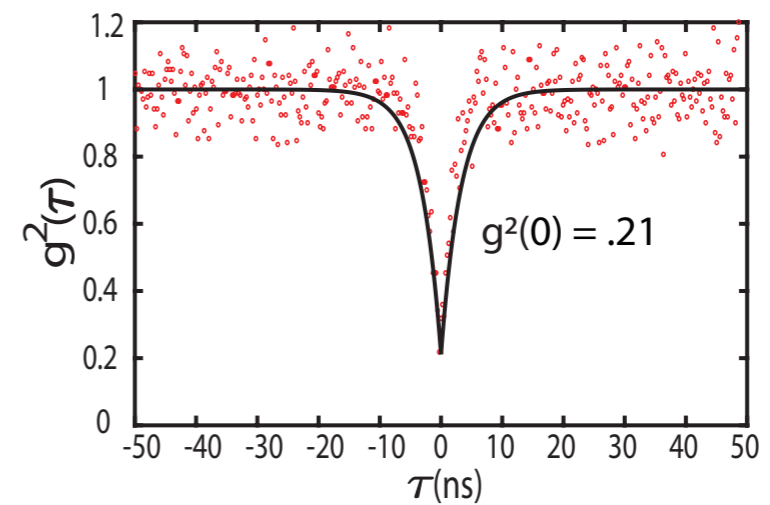
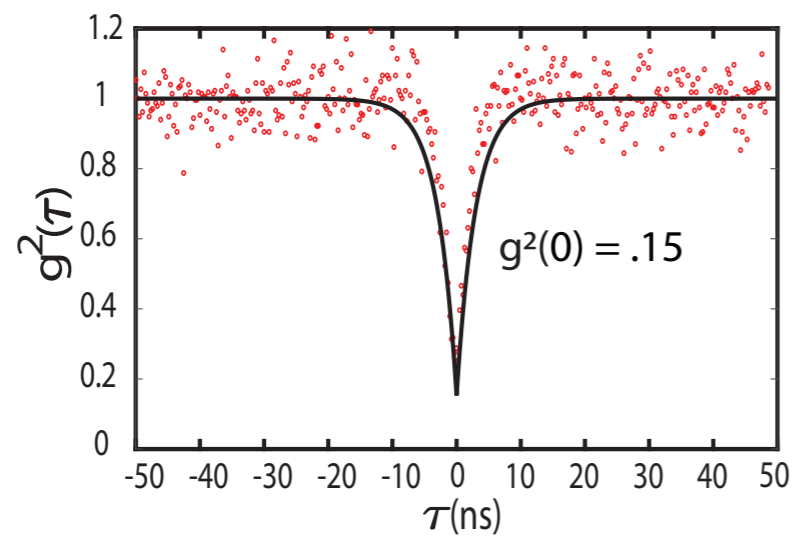
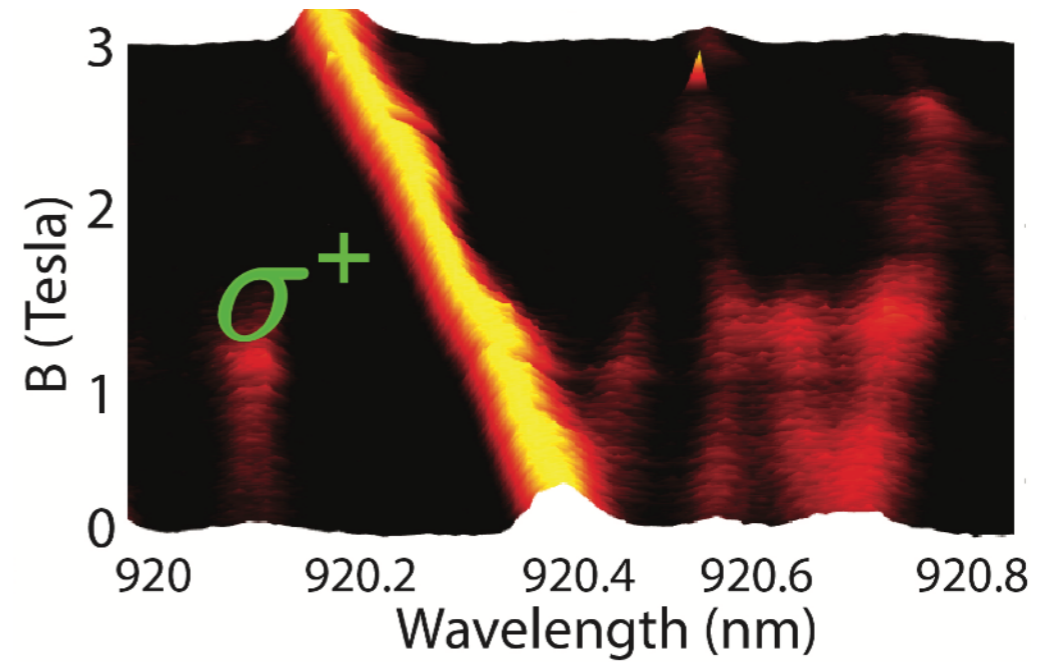
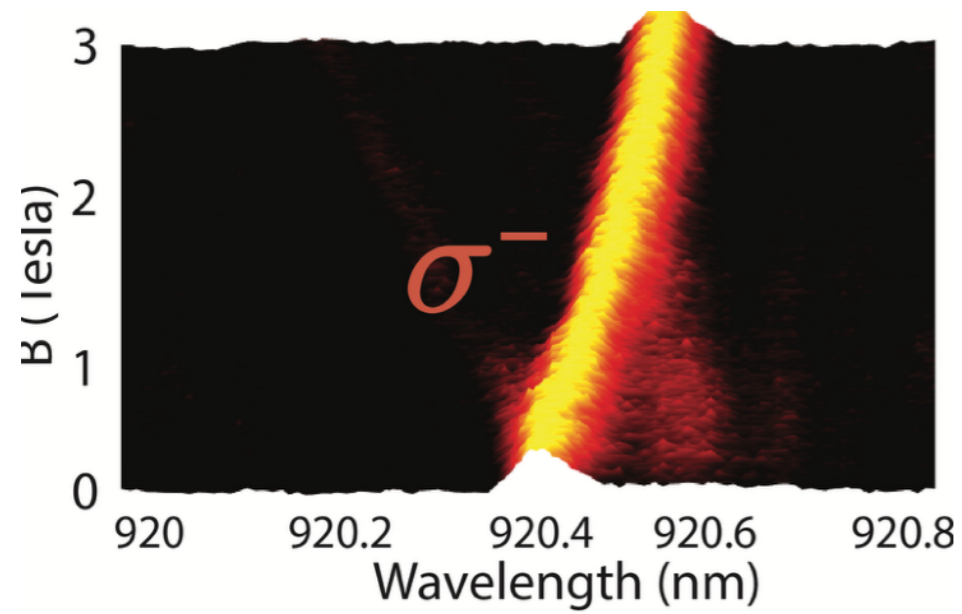
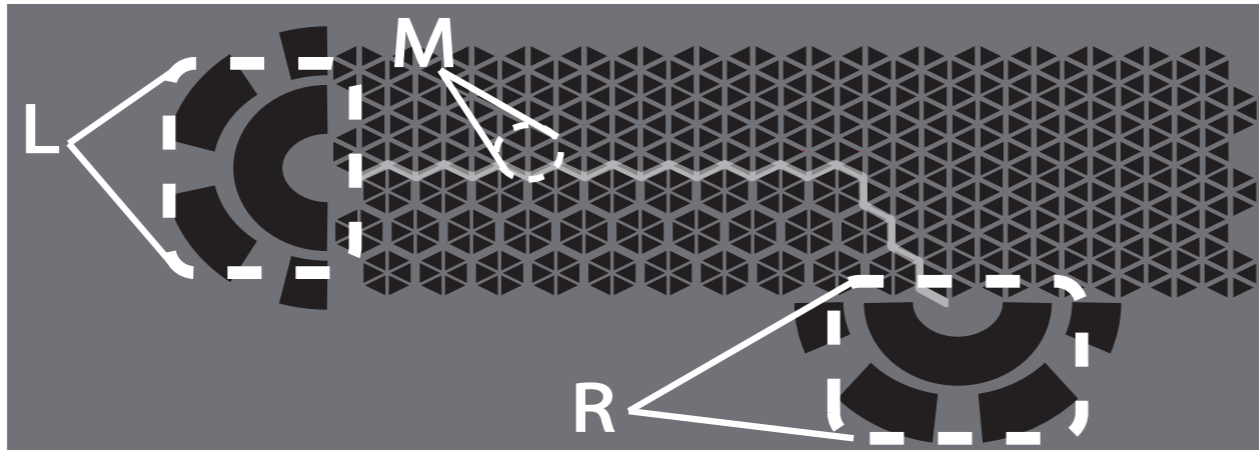
# Robustness against bend



# Robustness against bend

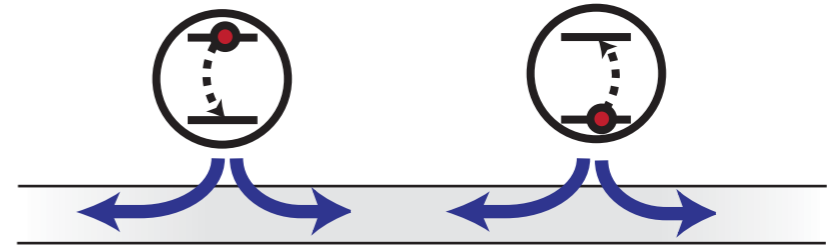


# Robustness against bend



# Chiral quantum optics

$$\begin{aligned} \dot{\rho} = & -i[H_{\text{sys}} + \gamma \sin(k|x_1 - x_2|)(\sigma_1^+ \sigma_2^- + \sigma_2^+ \sigma_1^-), \rho] \\ & + 2\gamma \sum_{i,j=1,2} \cos(k|x_i - x_j|)(\sigma_i^- \rho \sigma_j^+ - \frac{1}{2}\{\sigma_i^+ \sigma_j^-, \rho\}) \end{aligned}$$



# Chiral quantum optics

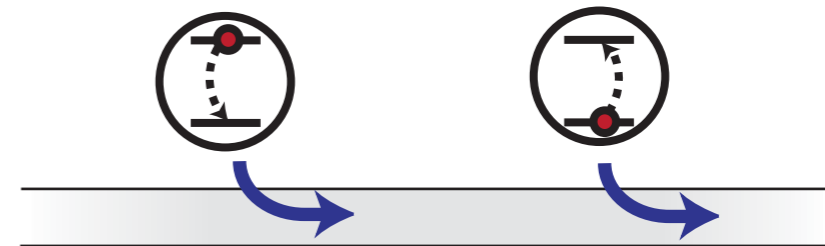
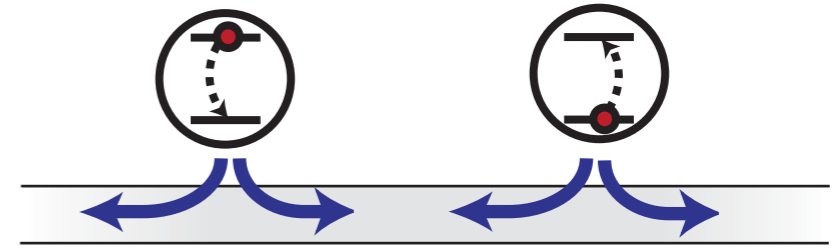
$$\dot{\rho} = -i[H_{\text{sys}} + \gamma \sin(k|x_1 - x_2|)(\sigma_1^+ \sigma_2^- + \sigma_2^+ \sigma_1^-), \rho] \\ + 2\gamma \sum_{i,j=1,2} \cos(k|x_i - x_j|)(\sigma_i^- \rho \sigma_j^+ - \frac{1}{2}\{\sigma_i^+ \sigma_j^-, \rho\})$$

$$\dot{\rho} = \mathcal{L}\rho \equiv -i(H_{\text{eff}}\rho - \rho H_{\text{eff}}^\dagger) + \sigma\rho\sigma^\dagger$$

$$H_{\text{eff}} = H_{\text{sys}} - i\frac{\gamma}{2} (\sigma_1^+ \sigma_1^- + \sigma_2^+ \sigma_2^- + 2\sigma_2^+ \sigma_1^-)$$

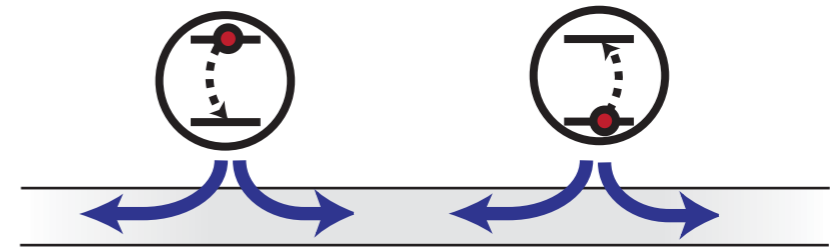
$$\sigma = \sigma_1^- + \sigma_2^-$$

- location independent coupling



# Chiral quantum optics

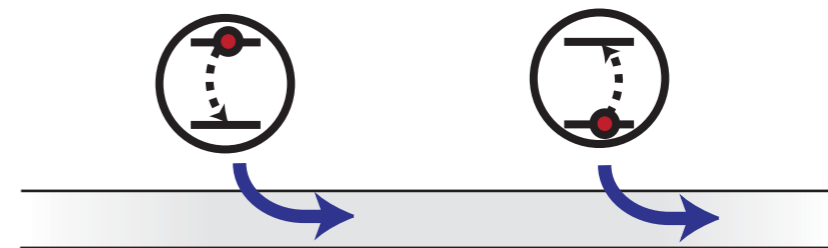
$$\dot{\rho} = -i[H_{\text{sys}} + \gamma \sin(k|x_1 - x_2|)(\sigma_1^+ \sigma_2^- + \sigma_2^+ \sigma_1^-), \rho] + 2\gamma \sum_{i,j=1,2} \cos(k|x_i - x_j|)(\sigma_i^- \rho \sigma_j^+ - \frac{1}{2}\{\sigma_i^+ \sigma_j^-, \rho\})$$



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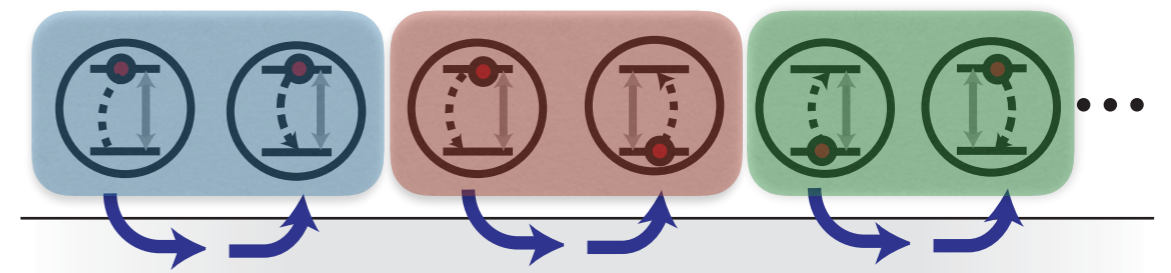
$$H_{\text{eff}} = H_{\text{sys}} - i\frac{\gamma}{2} (\sigma_1^+ \sigma_1^- + \sigma_2^+ \sigma_2^- + 2\sigma_2^+ \sigma_1^-)$$

$$\sigma = \sigma_1^- + \sigma_2^-$$



- location independent coupling

$$\Omega(\sigma + \sigma^\dagger)$$



- Pichler/Zoller

# Chiral quantum optics

$$\dot{\rho} = -i[H_{\text{sys}} + \gamma \sin(k|x_1 - x_2|)(\sigma_1^+ \sigma_2^- + \sigma_2^+ \sigma_1^-), \rho] + 2\gamma \sum_{i,j=1,2} \cos(k|x_i - x_j|)(\sigma_i^- \rho \sigma_j^+ - \frac{1}{2}\{\sigma_i^+ \sigma_j^-, \rho\})$$

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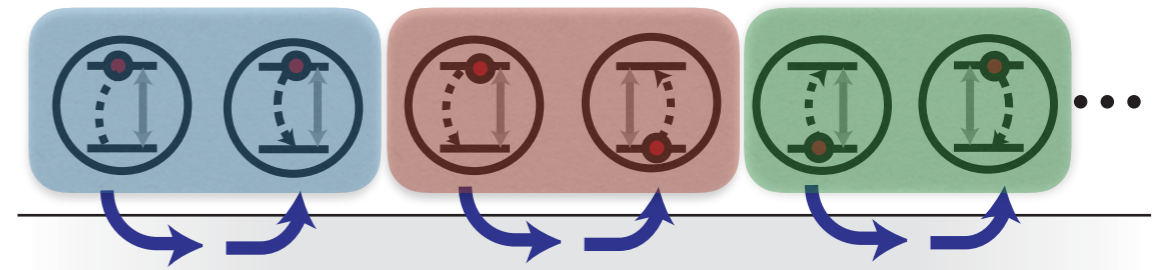
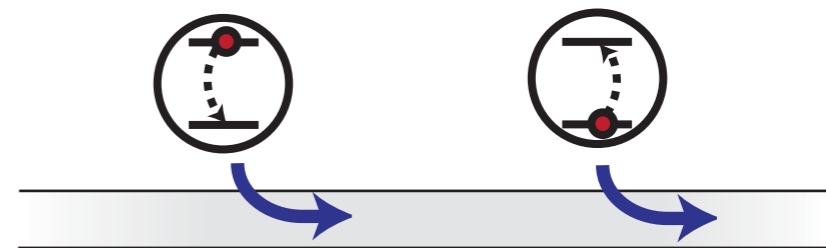
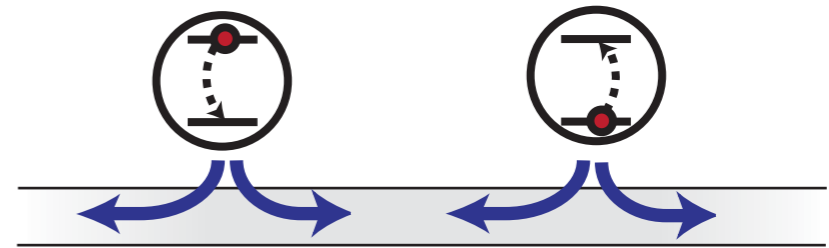
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$$\sigma = \sigma_1^- + \sigma_2^-$$

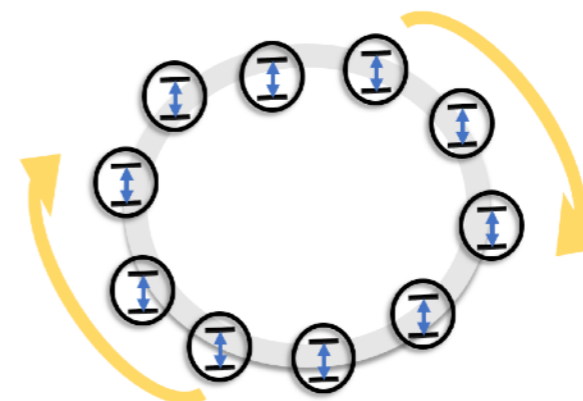
- location independent coupling

$$\Omega(\sigma + \sigma^\dagger)$$

- Chiral coupling overcomes the inhomogeneity of emitter locations: large entanglement
- Topology provides an added robustness

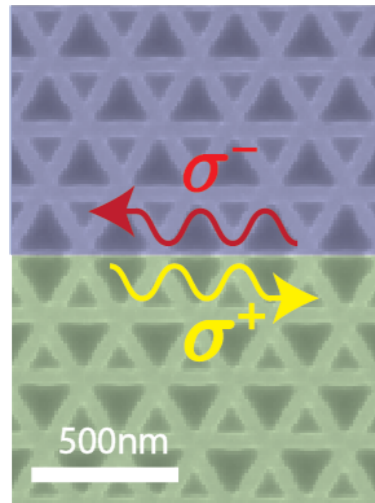


• Pichler/Zoller

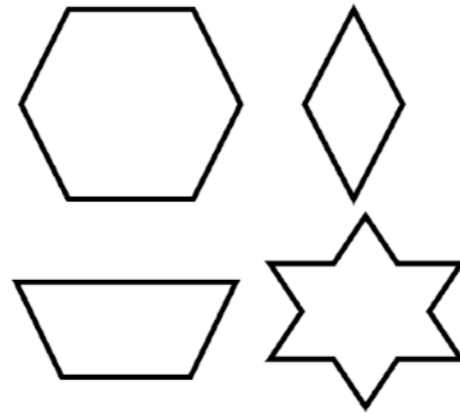
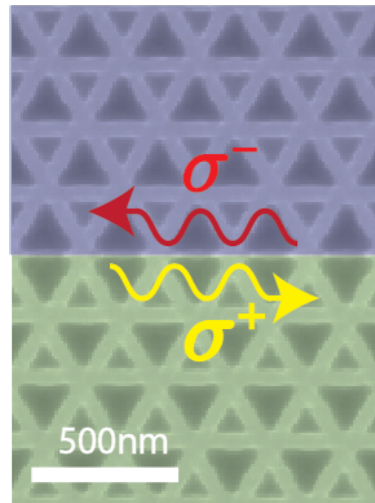




# Topological cavity-QED

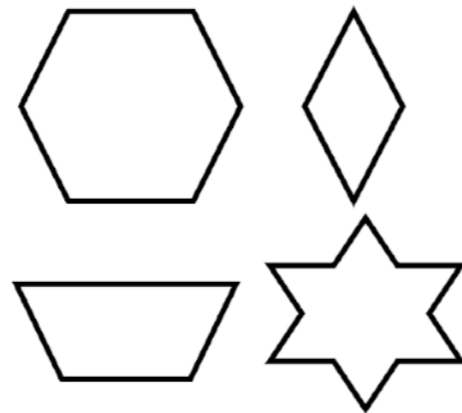
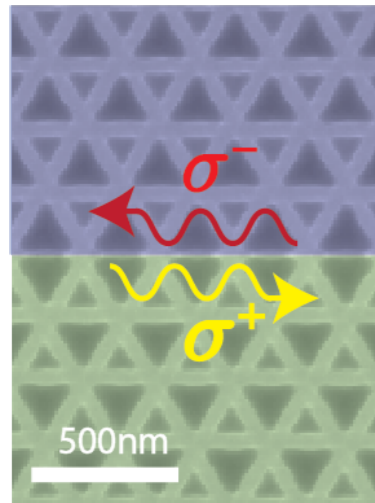


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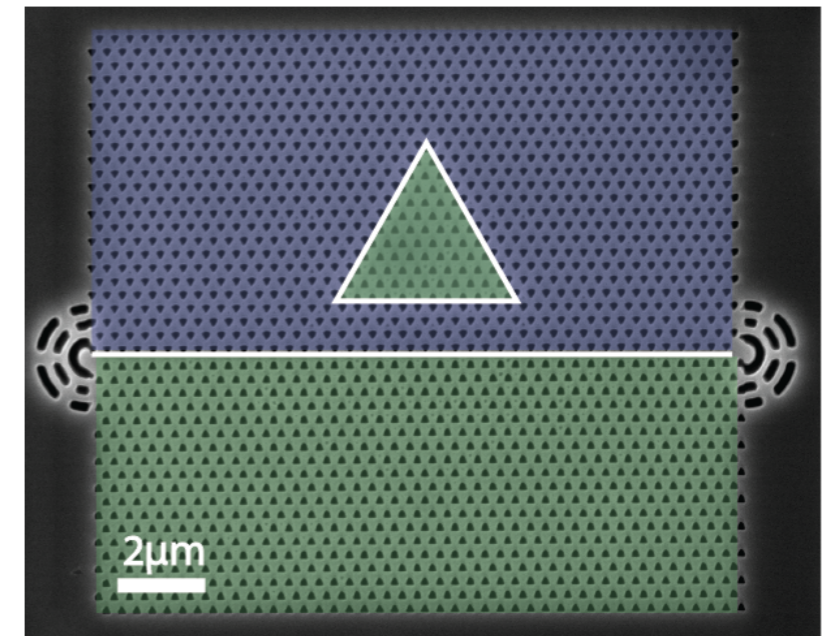


no fine-tuning!

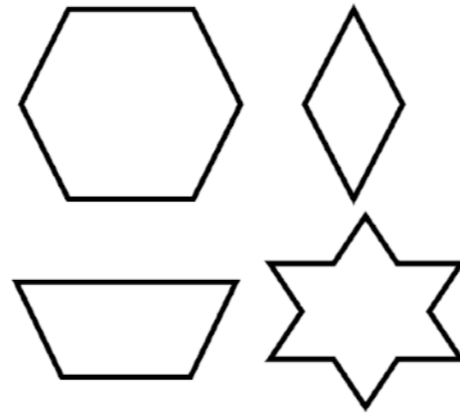
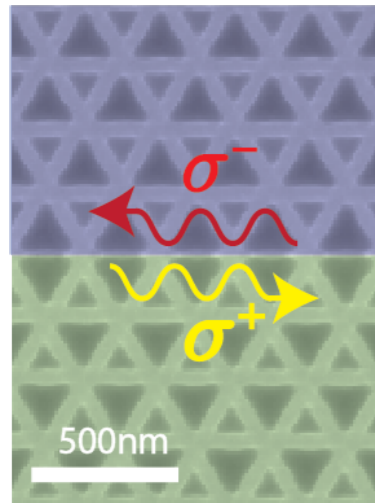
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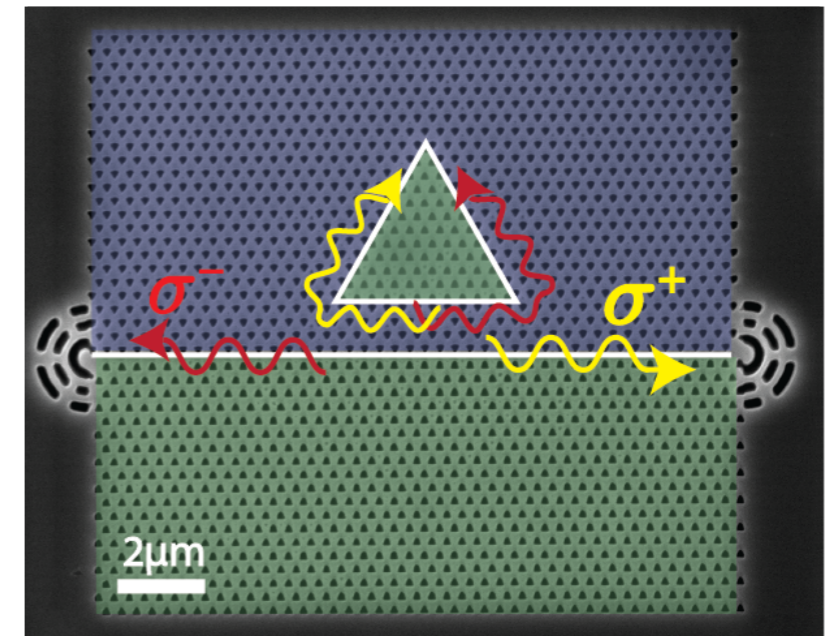
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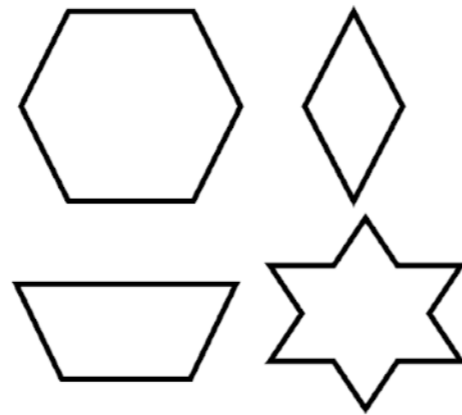
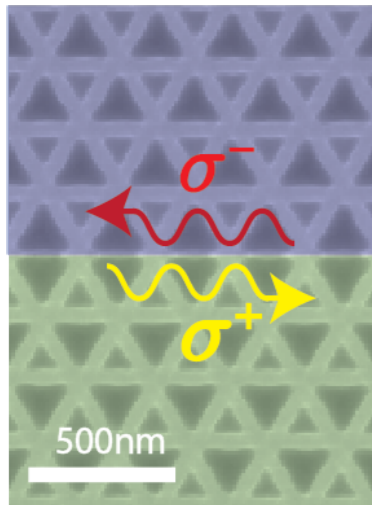
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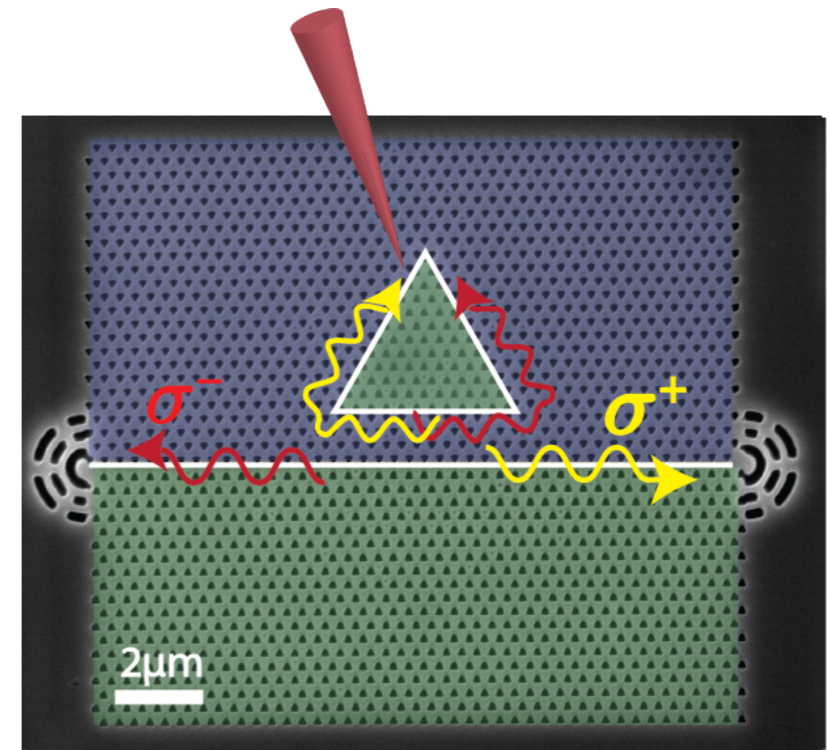
no fine-tuning!



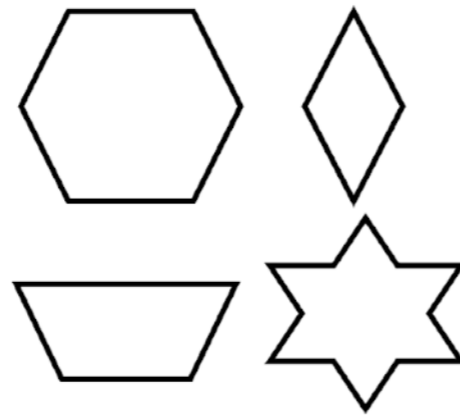
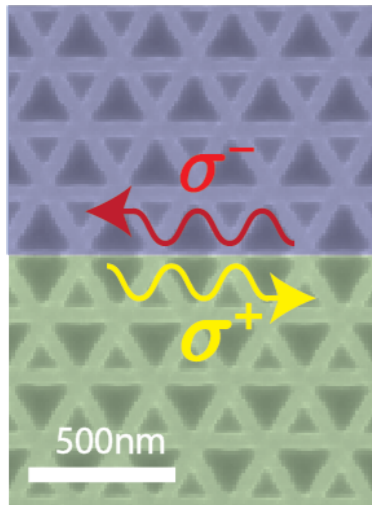
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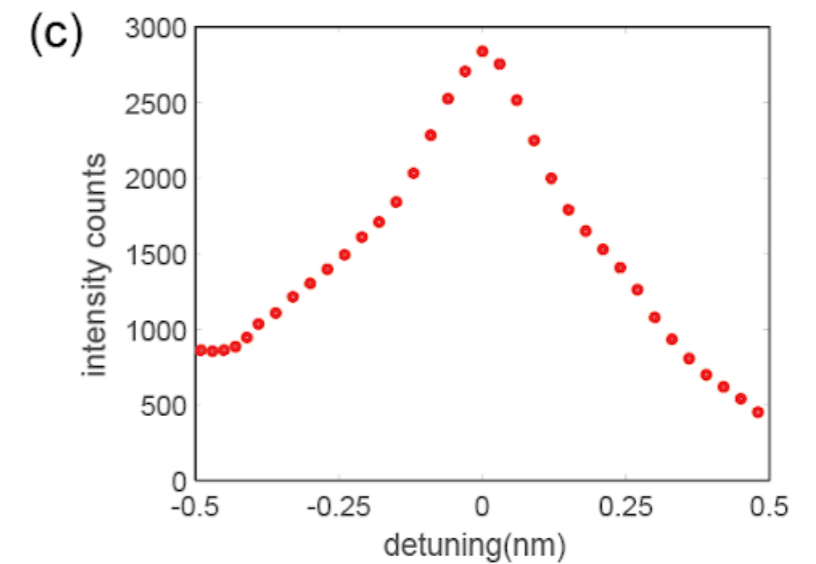
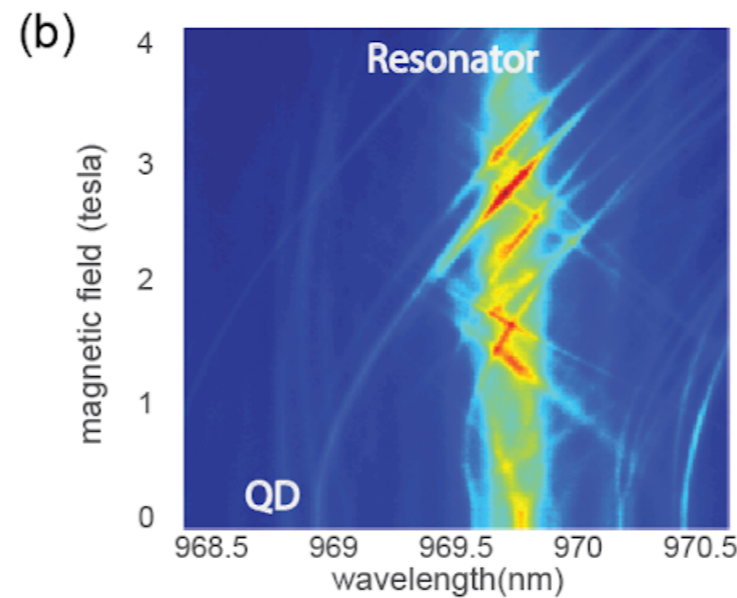
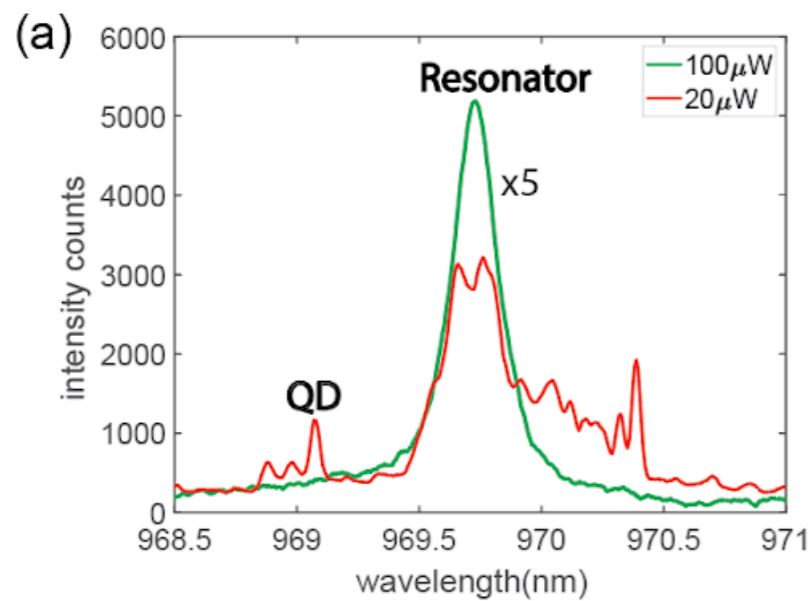
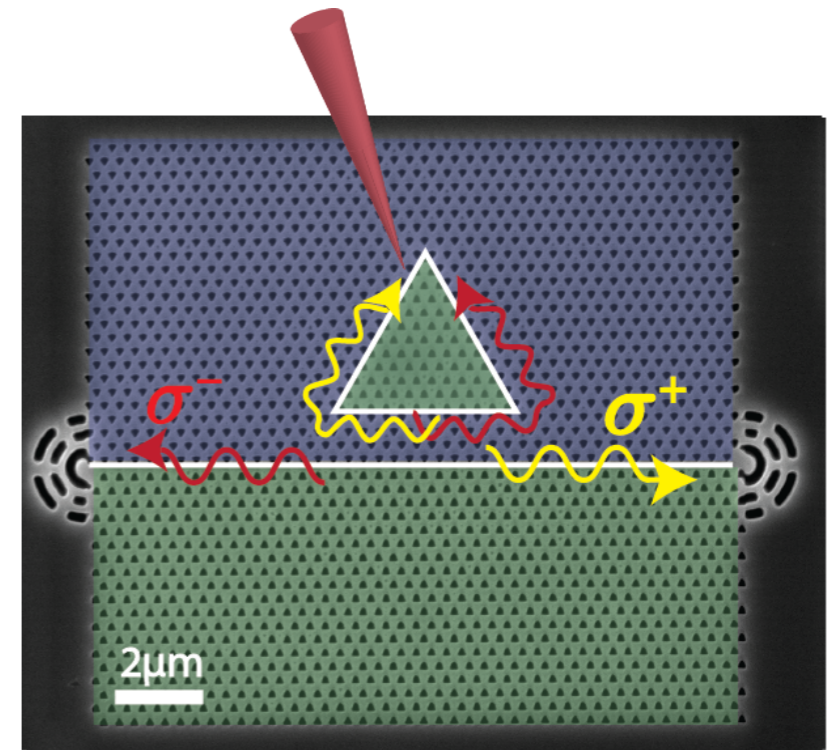
no fine-tuning!



# Topological cavity-QED

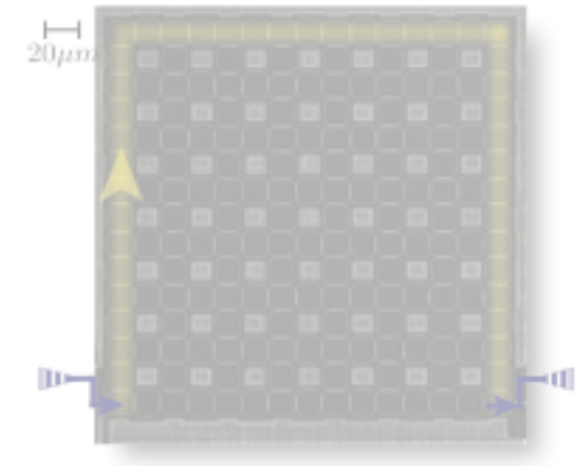


no fine-tuning!



# Outline

- Quantum directions in topological photonics:
  - Generation of photon pairs (rings)
  - Quantum optics interface (photonic crystal)



S. Barik



A. Karasahin



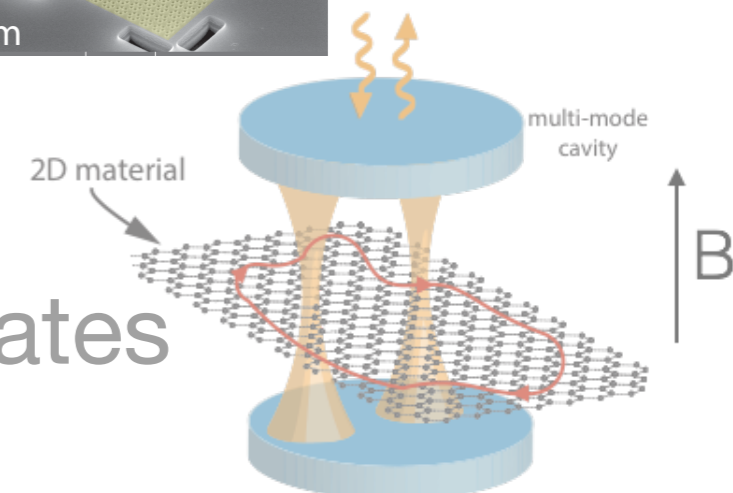
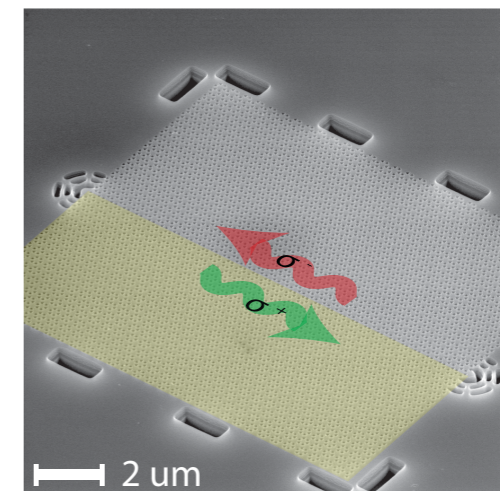
C. Flower



S. Mittal



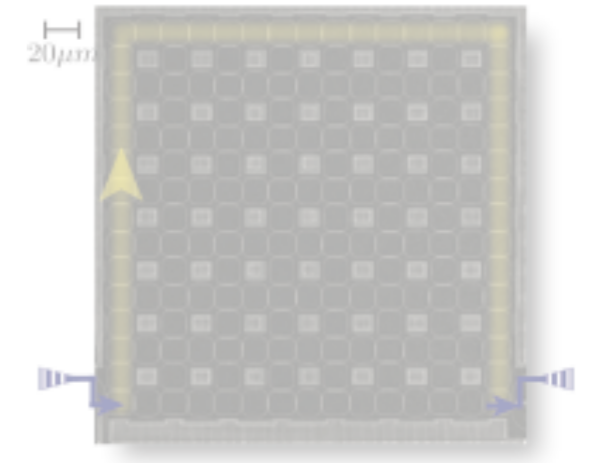
E. Waks



- Optical control of electronic topological states

# Outline

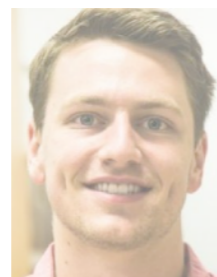
- Quantum directions in topological photonics:
  - Generation of photon pairs (rings)
  - Quantum optics interface (photonic crystal)



S. Barik



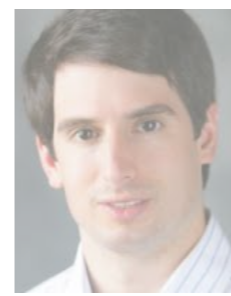
A. Karasahin



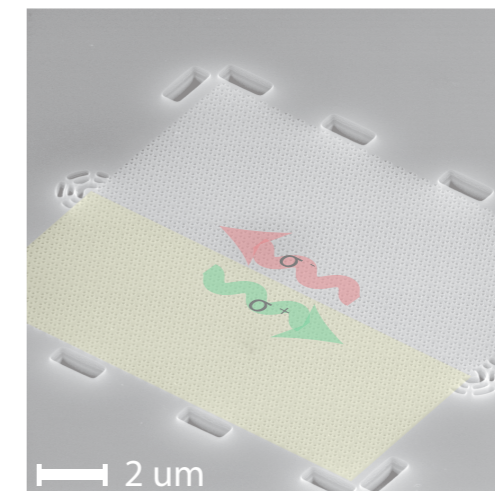
C. Flower



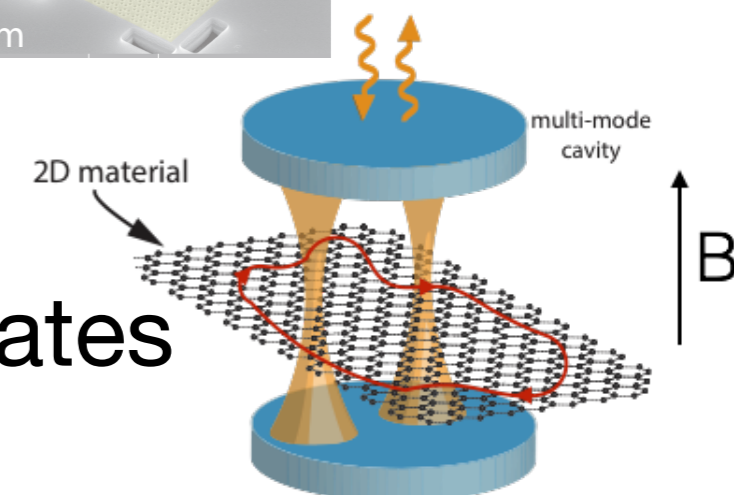
S. Mittal



E. Waks

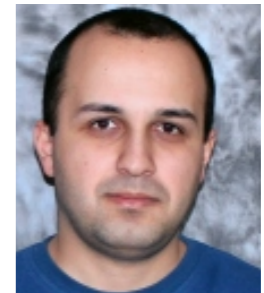
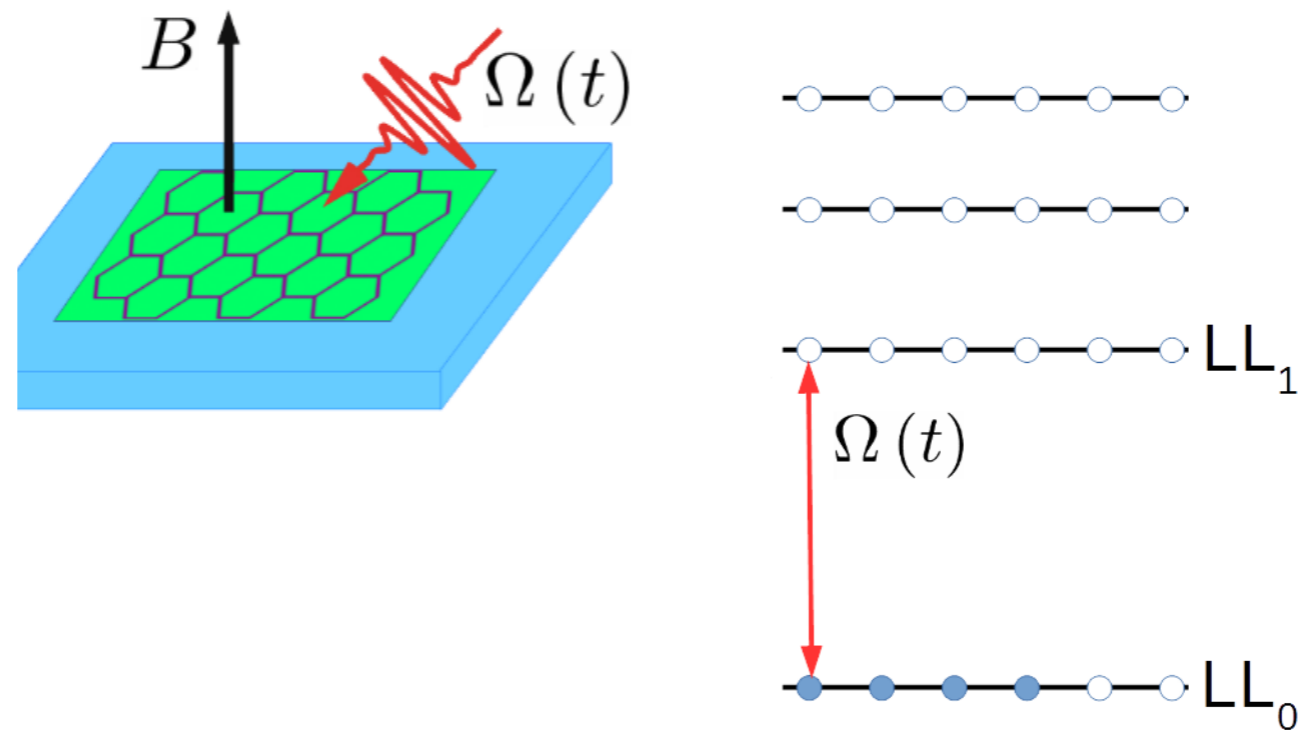


- **Optical control of electronic topological states**



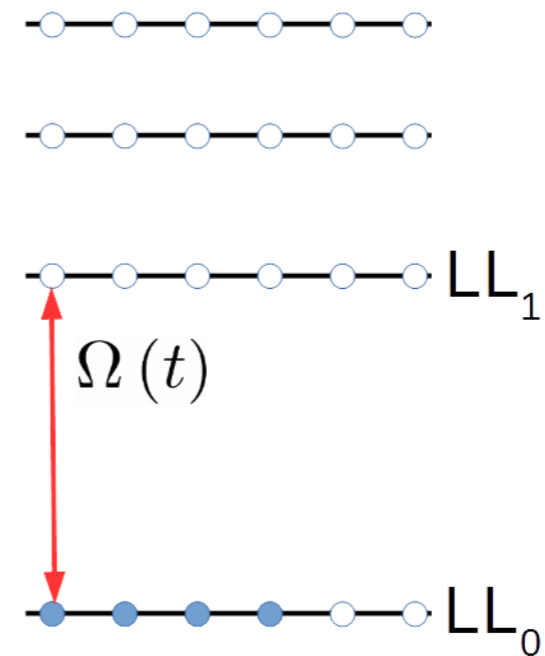
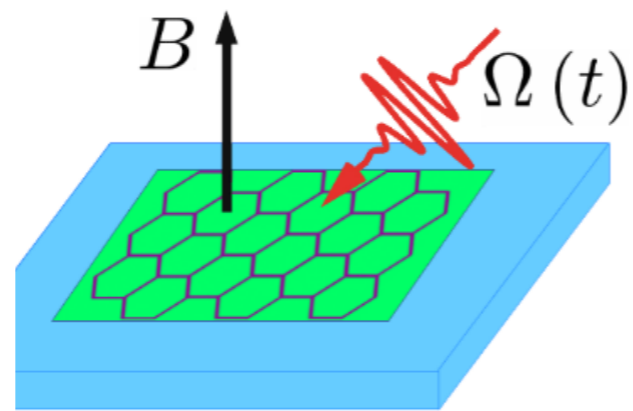


# Synthetic bilayer Graphene (?)



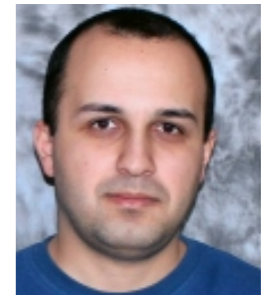
A. Ghazaryan, T. Grass, P. Ghaermi et al. PRL (2017)  
c.f. Topological Floquet insulators

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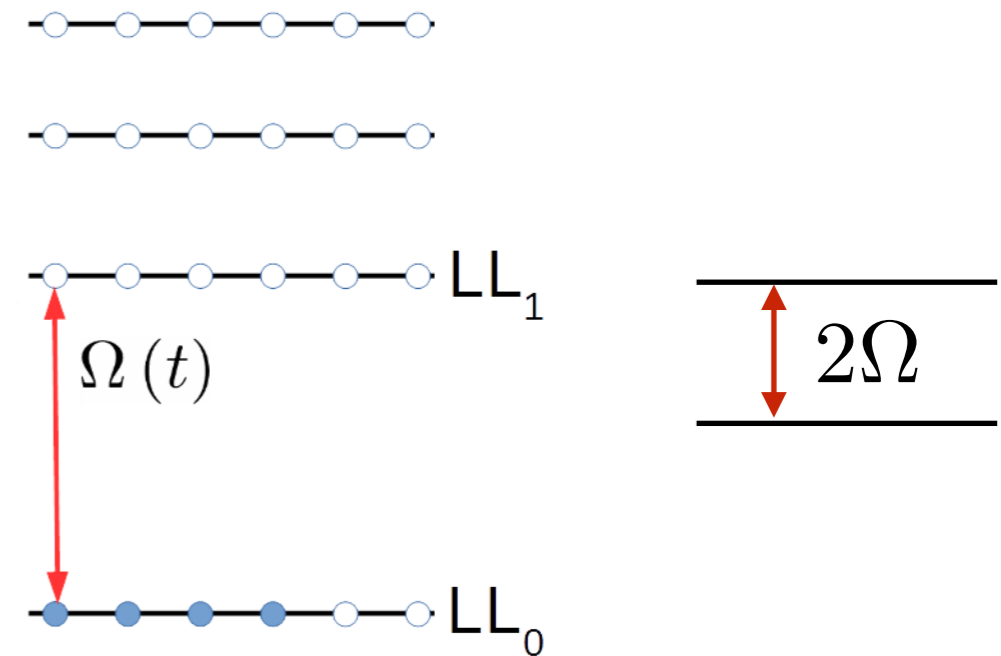
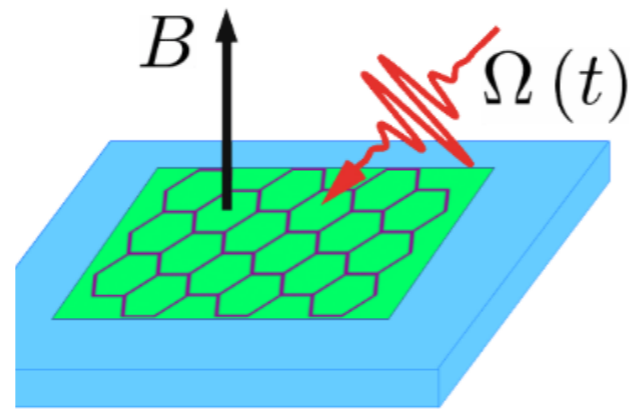
Use light to couple two LLs:

- (1) Different LLs play the role of layers
- (2) Light plays the role of tunneling



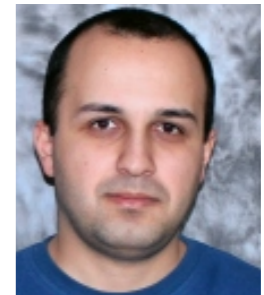
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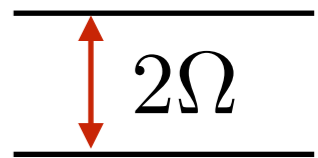
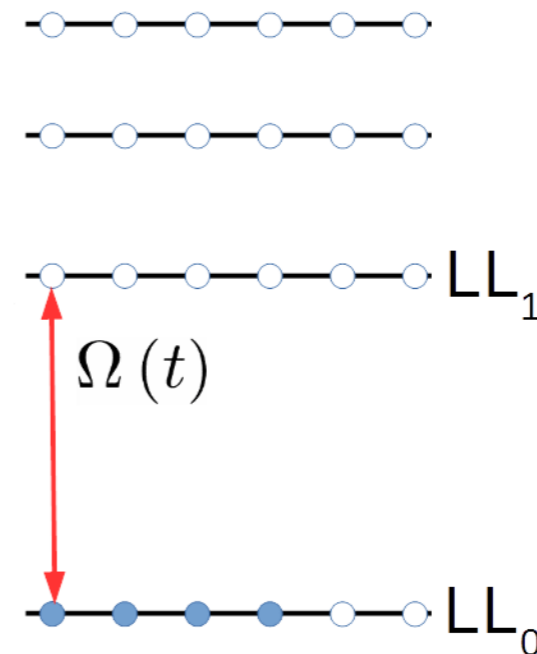
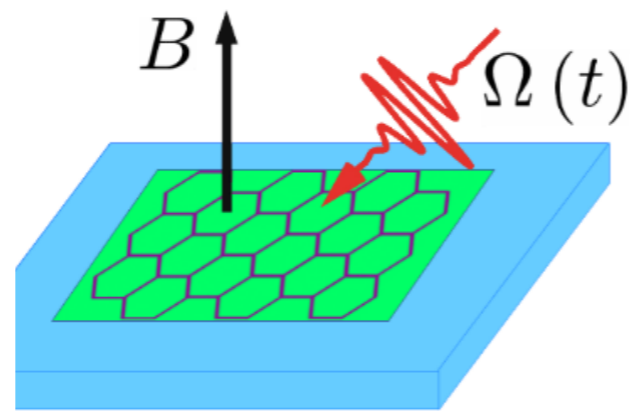
Use light to couple two LLs:

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A. Ghazaryan, T. Grass, P. Ghaermi al. PRL (2017)  
c.f. Topoloigcal Floquet insulators

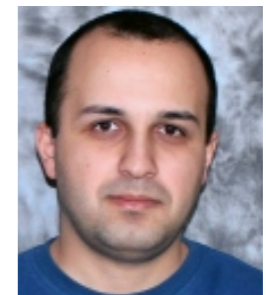
# Synthetic bilayer Graphene (?)



Use light to couple two LLs:

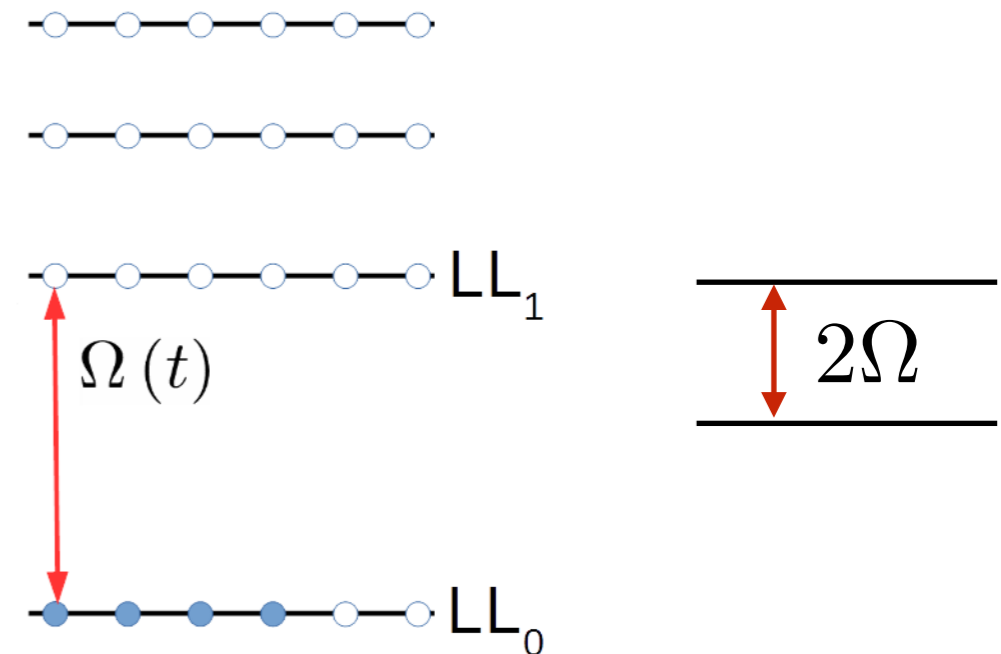
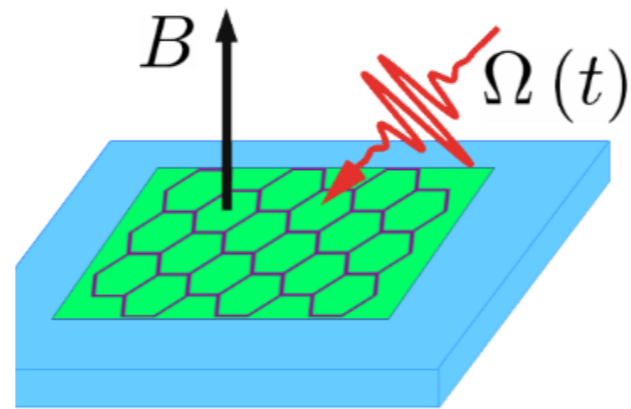
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- (2) Light plays the role of tunneling

- What type of states can one engineer with light?



A. Ghazaryan, T. Grass, P. Ghaermi al. PRL (2017)  
c.f. Topoloigcal Floquet insulators

# Synthetic bilayer Graphene (?)

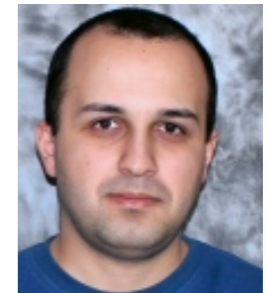


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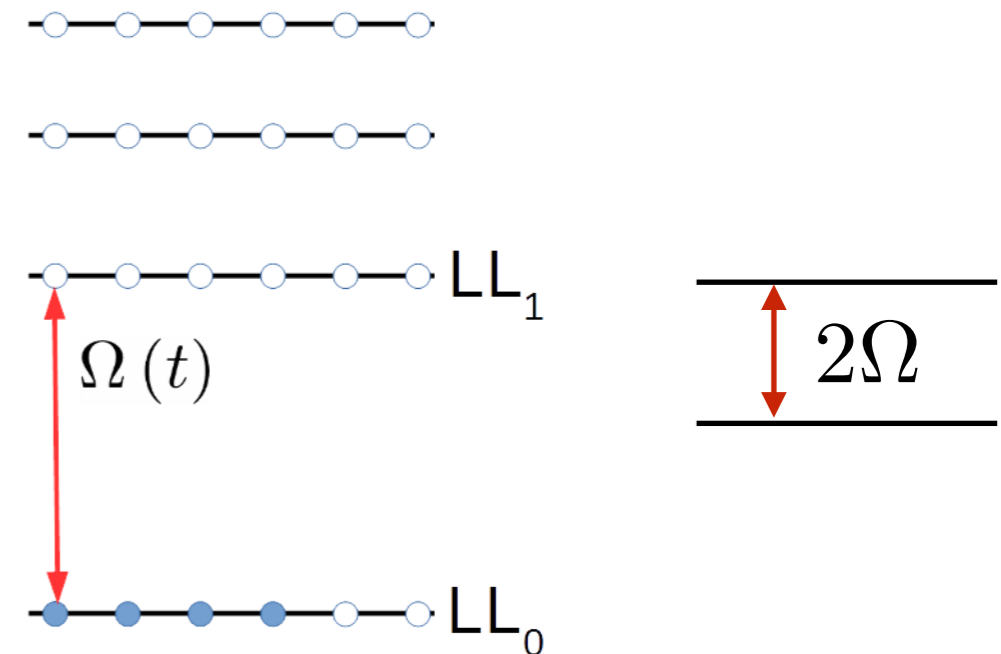
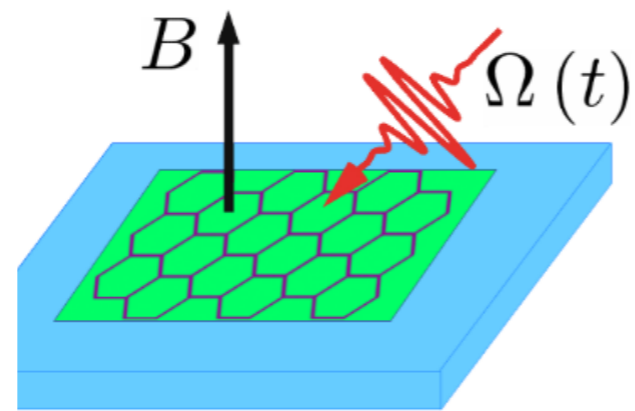
• What type of states can one engineer with light?

$$\mathcal{H}_{\text{int}} = \sum_{\{n,j\}} A_{n_3,j_3,n_4,j_4}^{n_1,j_1,n_2,j_2} \delta_{n_1+n_2,n_3+n_4} c_{n_1,j_1}^\dagger c_{n_2,j_2}^\dagger c_{n_3,j_3} c_{n_4,j_4}$$



A. Ghazaryan, T. Grass, P. Ghaermi al. PRL (2017)  
c.f. Topoloigcal Floquet insulators

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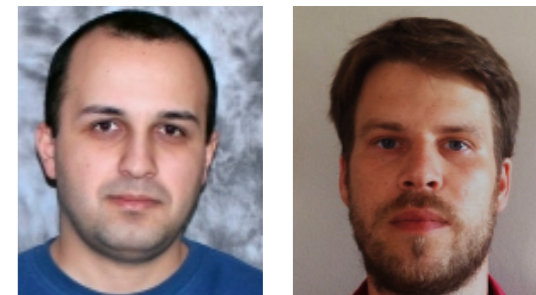
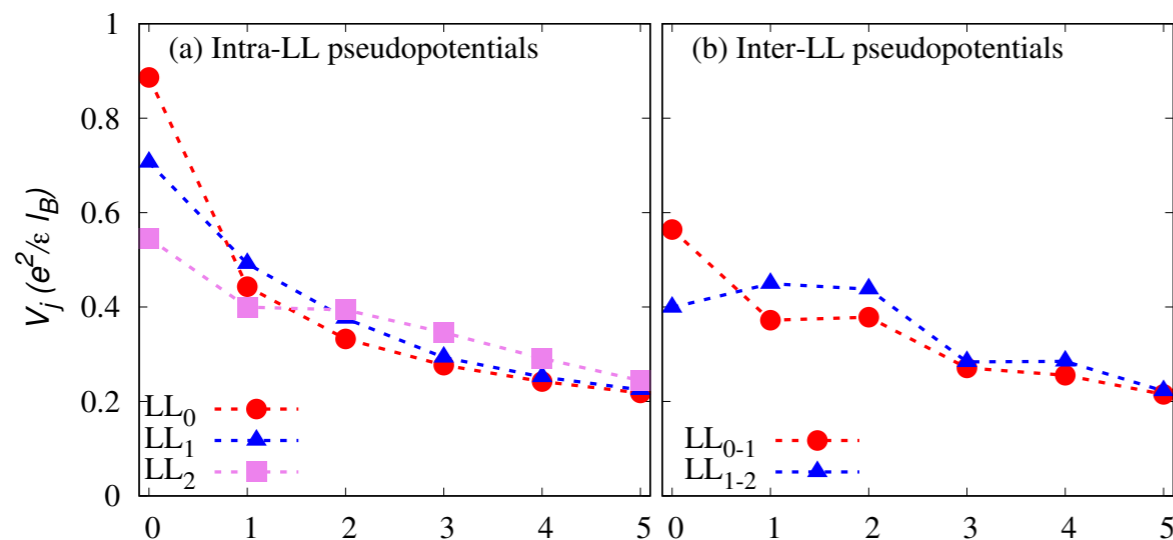


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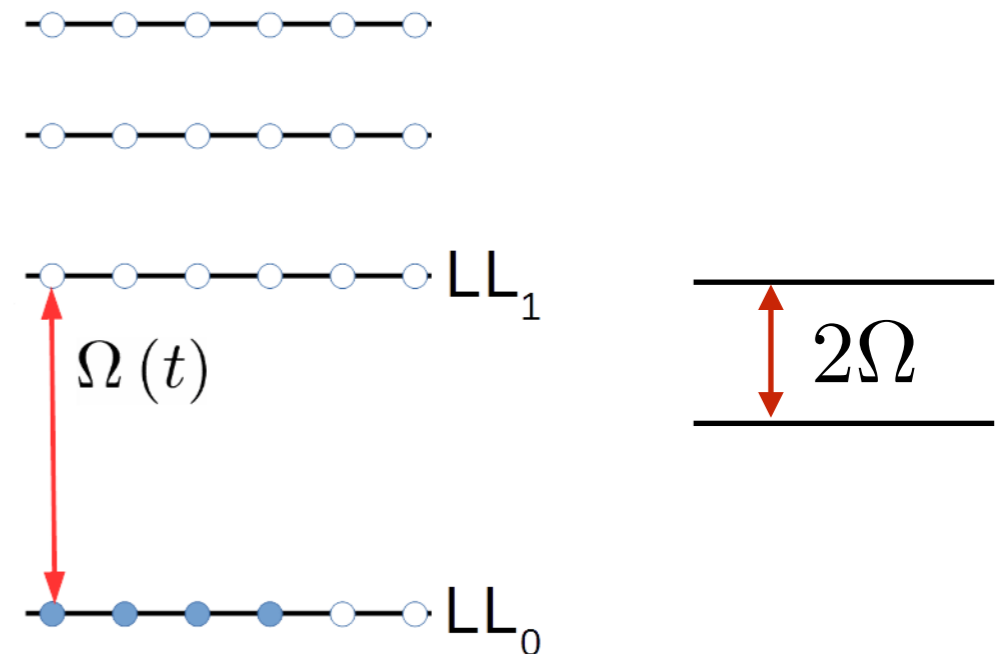
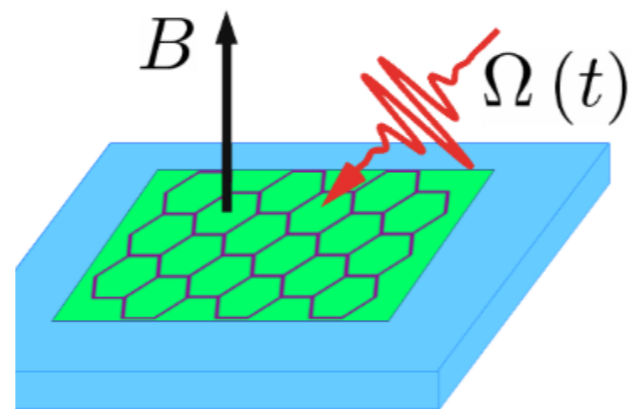
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A. Ghazaryan, T. Grass, P. Ghaermi et al. PRL (2017)  
c.f. Topological Floquet insulators

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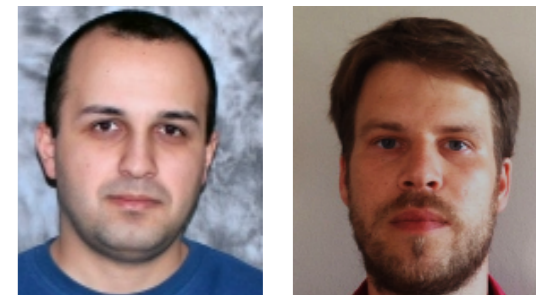
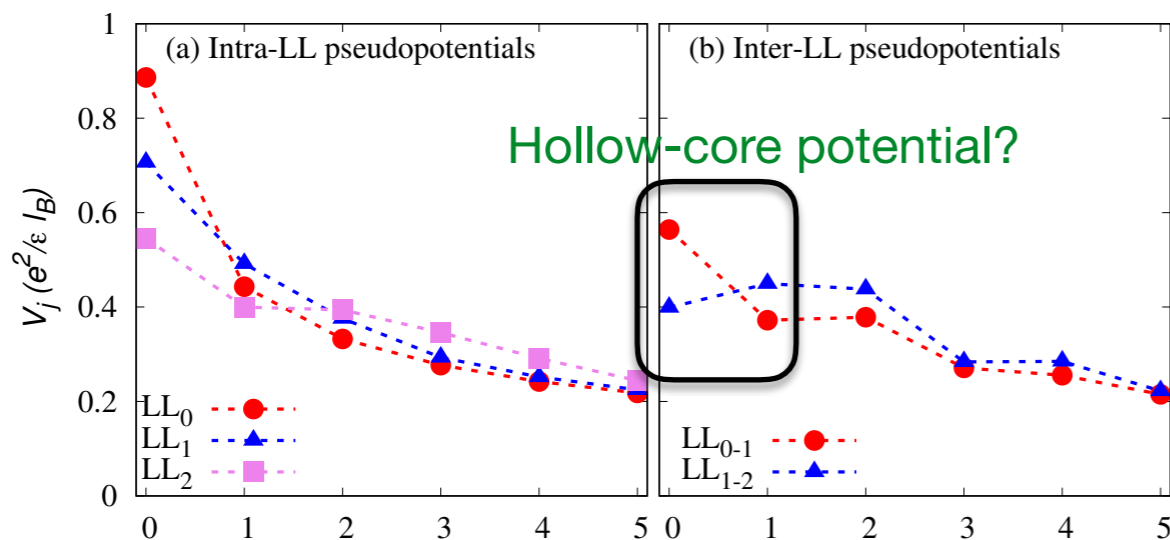


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- What type of states can one engineer with light?

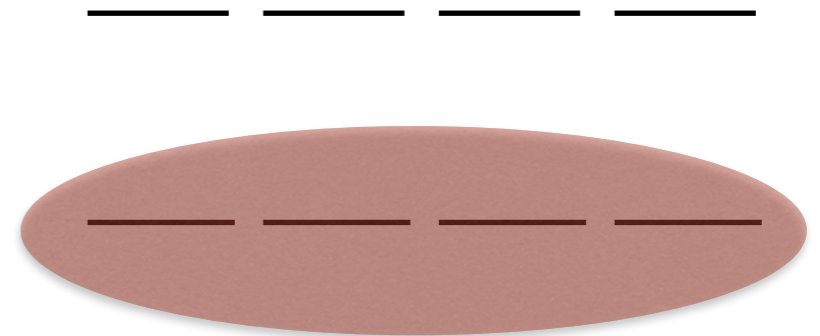
$$\mathcal{H}_{\text{int}} = \sum_{\{n,j\}} A_{n_3,j_3,n_4,j_4}^{n_1,j_1,n_2,j_2} \delta_{n_1+n_2,n_3+n_4} c_{n_1,j_1}^\dagger c_{n_2,j_2}^\dagger c_{n_3,j_3} c_{n_4,j_4}$$



A. Ghazaryan, T. Grass, P. Ghaermi et al. PRL (2017)  
c.f. Topological Floquet insulators

- Filling factor  $\nu = 2/3$

Dressed Laughlin  $\Omega \gg e^2/l_B$

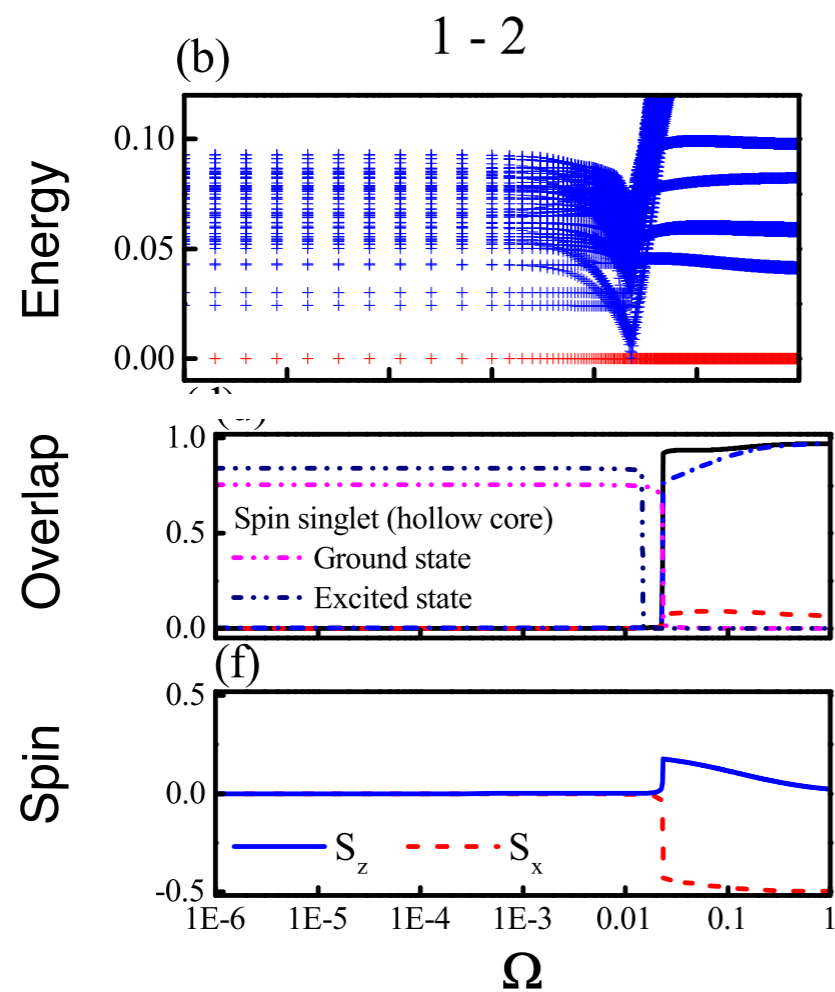


$$z_i^m \longrightarrow \prod_{i < j} (z_i - z_j)^m$$

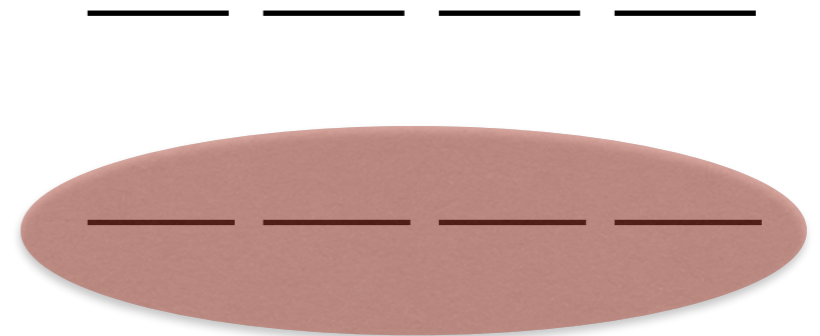
Z. Liu, A. Vaezi, K. Lee, and E.-A. Kim, PRB (2015) and others



- Filling factor  $\nu = 2/3$



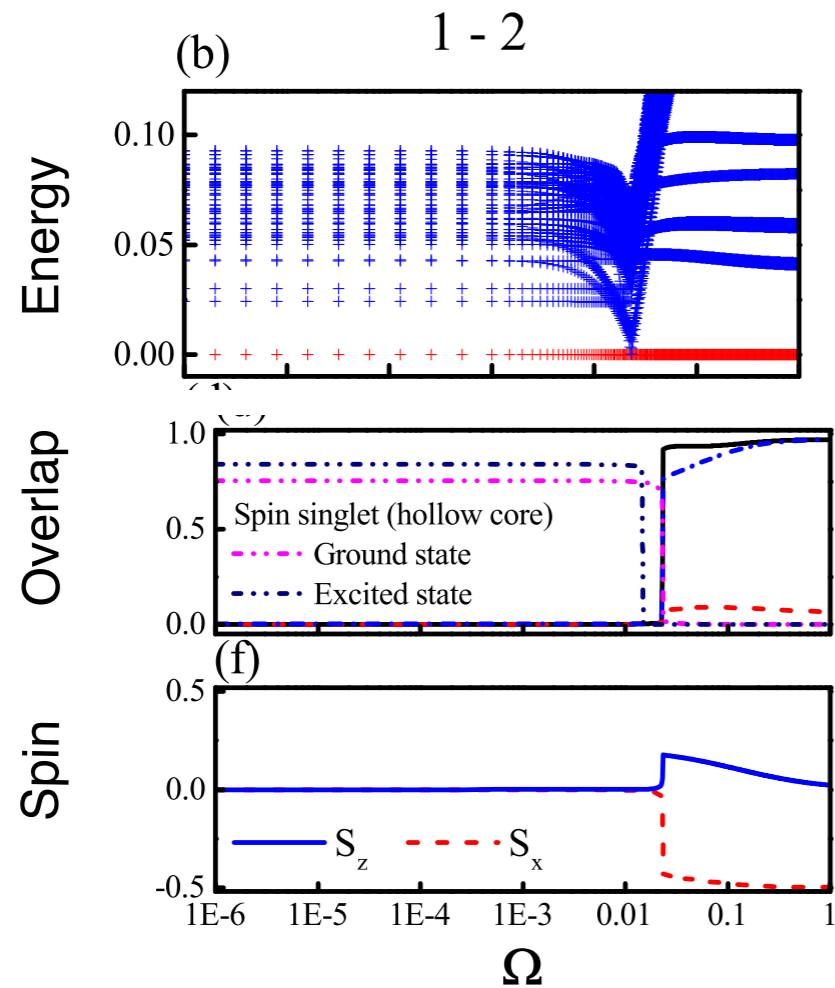
Dressed Laughlin  $\Omega \gg e^2/l_B$



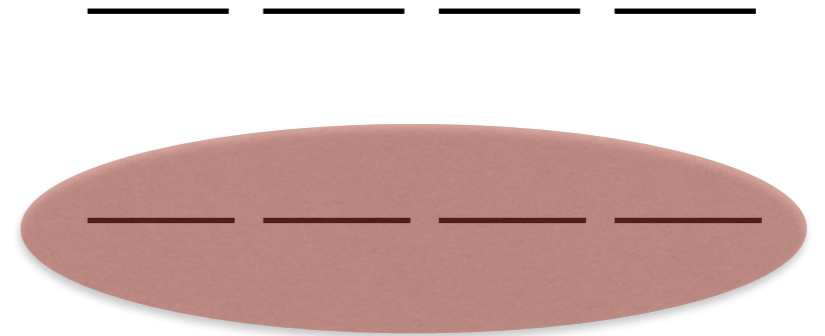
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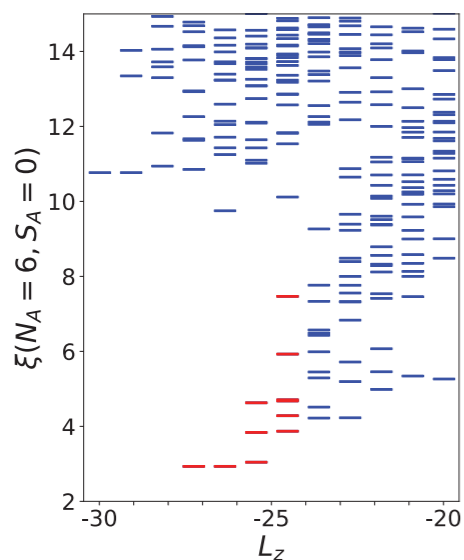
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Dressed Laughlin  $\Omega \gg e^2/l_B$



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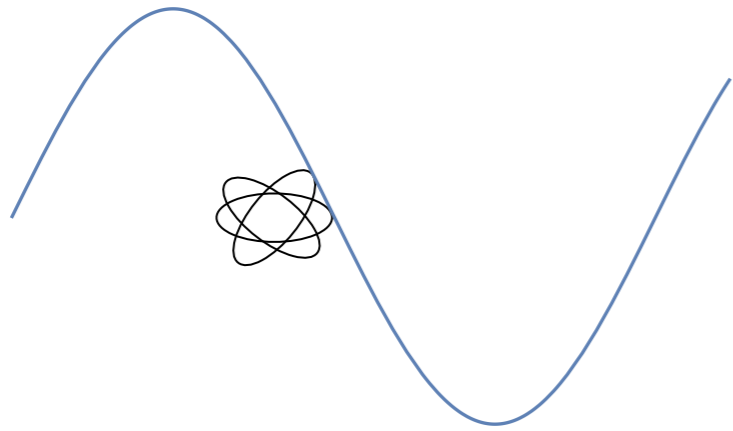
Chiral counting and ground state degen.  
 suggests Fibonacci states



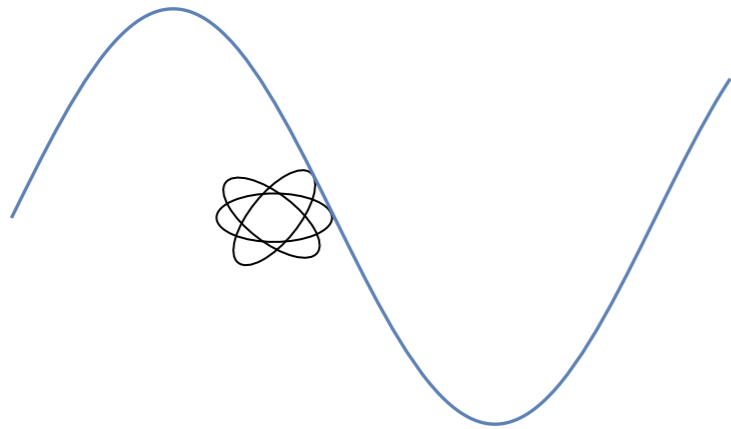
Zepei Cian

Z. Liu, A. Vaezi, K. Lee, and E.-A. Kim, PRB (2015) and others

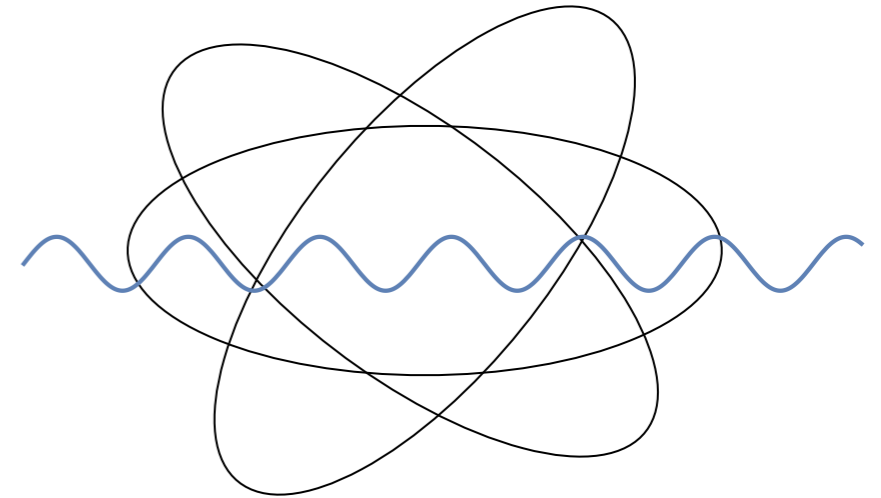
Most cases:  
dipole approximation



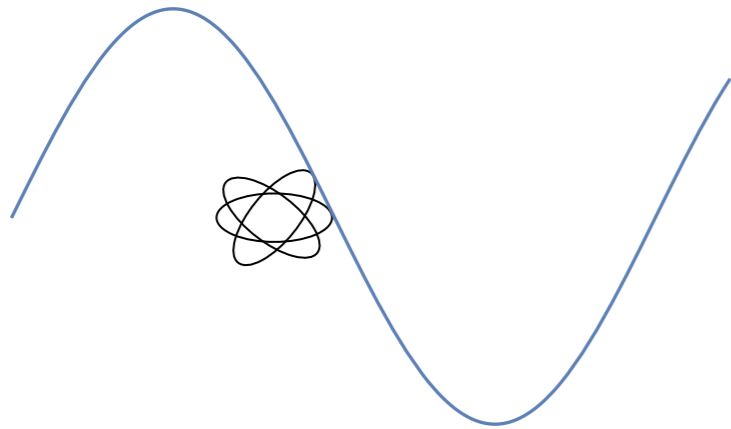
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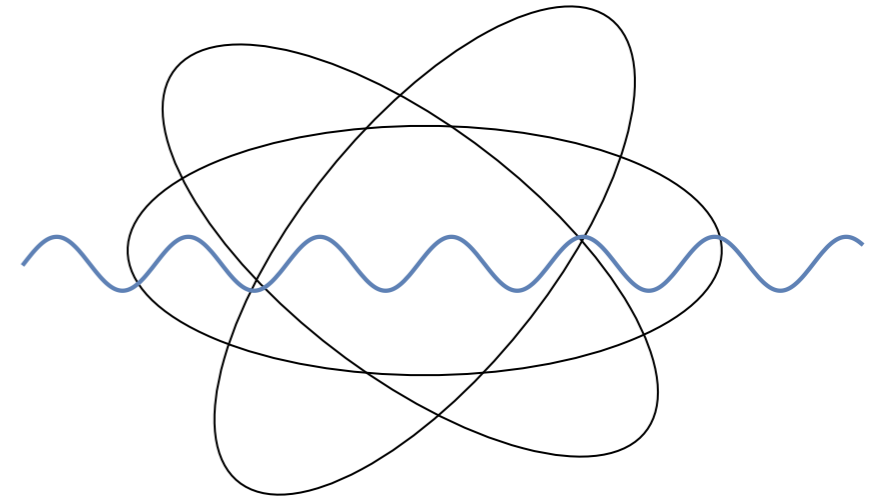
Multipole emission



Most cases:  
dipole approximation

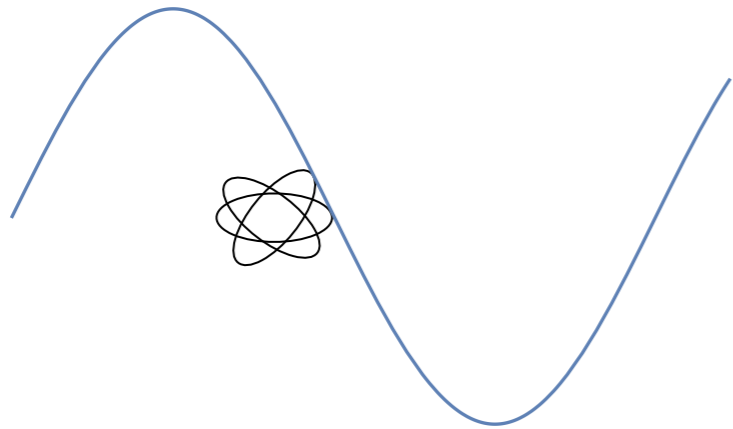


Multipole emission

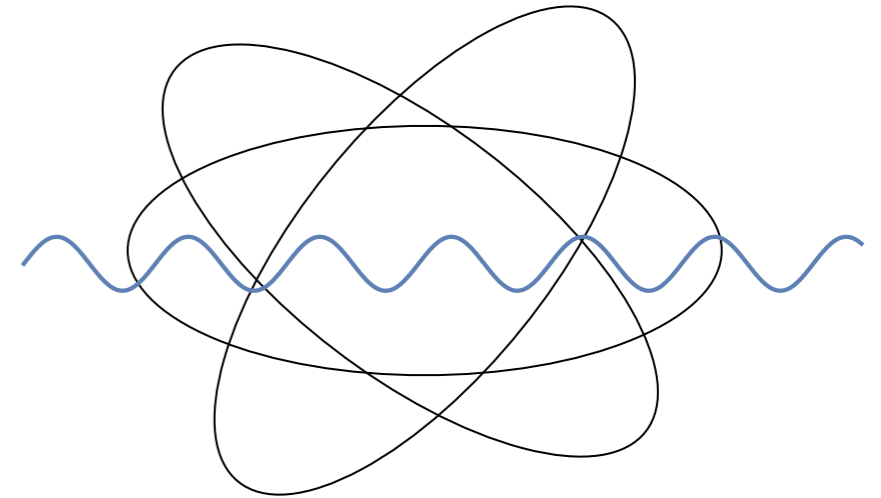


Extended states of electrons,  
e.g. Quantum Hall, Rydberg excitations

Most cases:  
dipole approximation



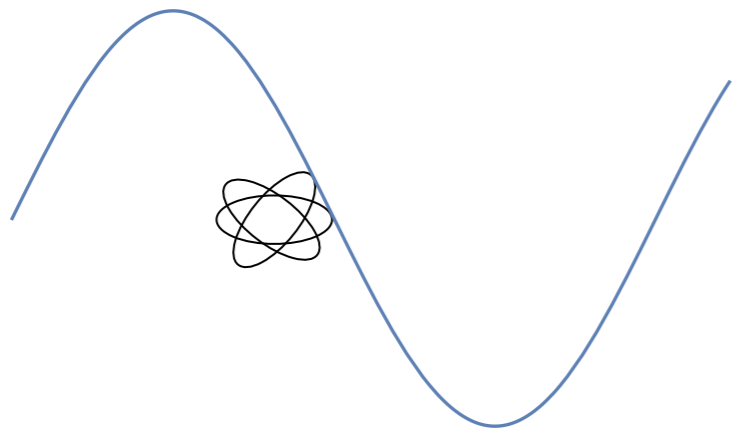
Multipole emission



Extended states of electrons,  
e.g. Quantum Hall, Rydberg excitations

$$ev_f \langle 1, m' | \tau_+ \mathbf{A} | 0, m \rangle$$

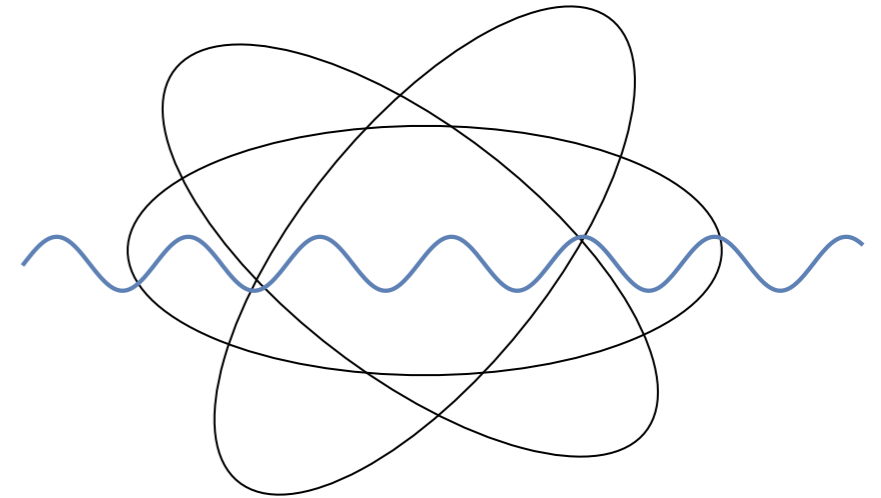
Most cases:  
dipole approximation



$$(r e^{-i\theta})^{m'}$$

$$e v_f \langle 1, m' | \tau_+ \mathbf{A} | 0, m \rangle$$

Multipole emission

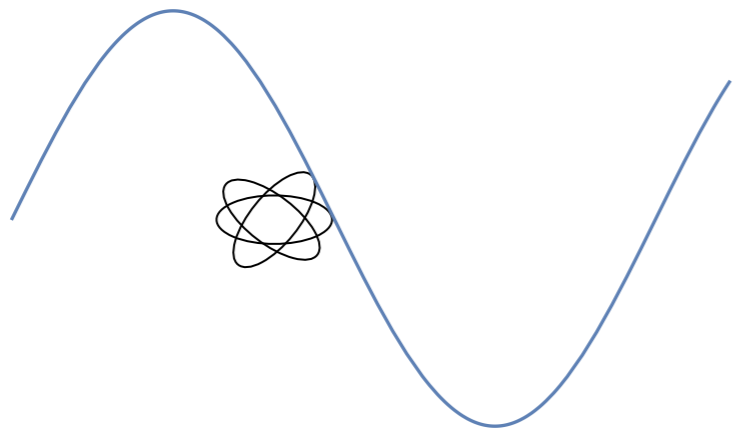


Extended states of electrons,  
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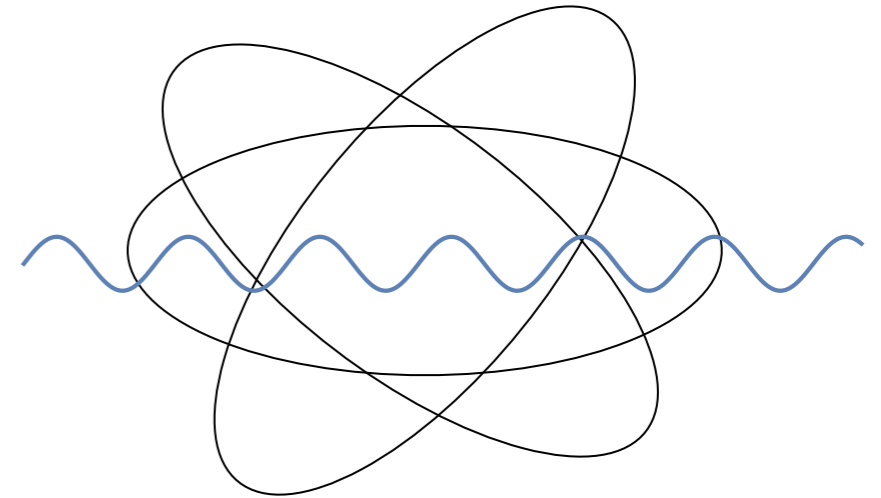
$$(r e^{i\theta})^m$$

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Multipole emission



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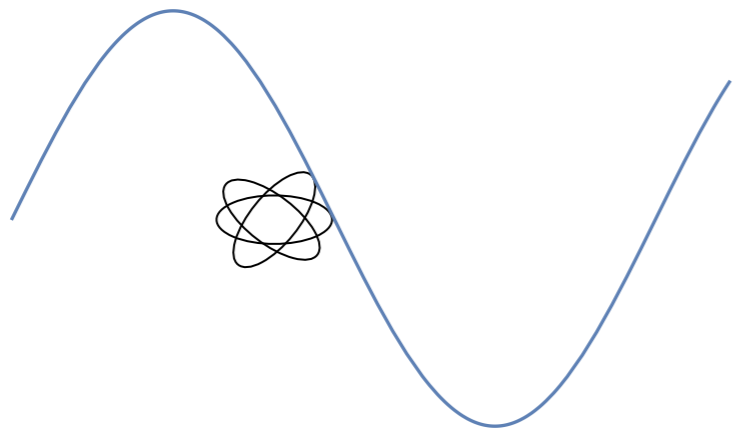
$$e v_f \langle 1, m' | \tau_+ \mathbf{A} | 0, m \rangle$$

$$A \propto e^{i k z + i l \theta} J_l(k_{\perp} r)$$

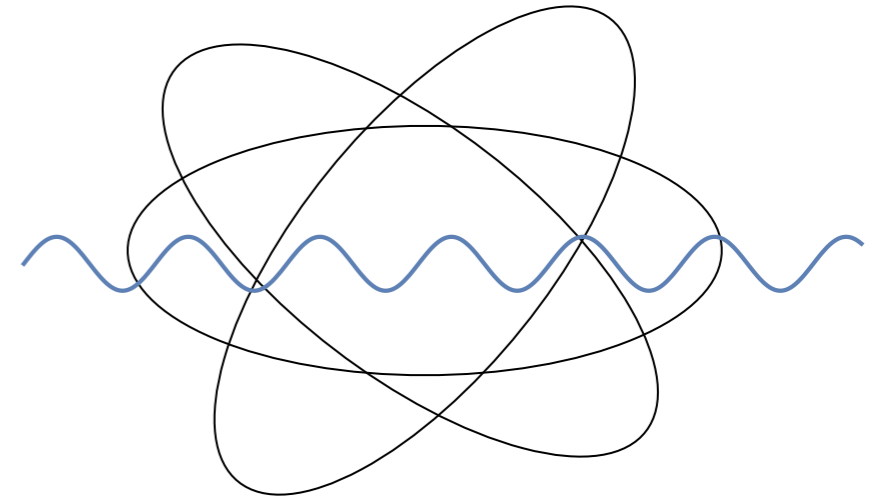
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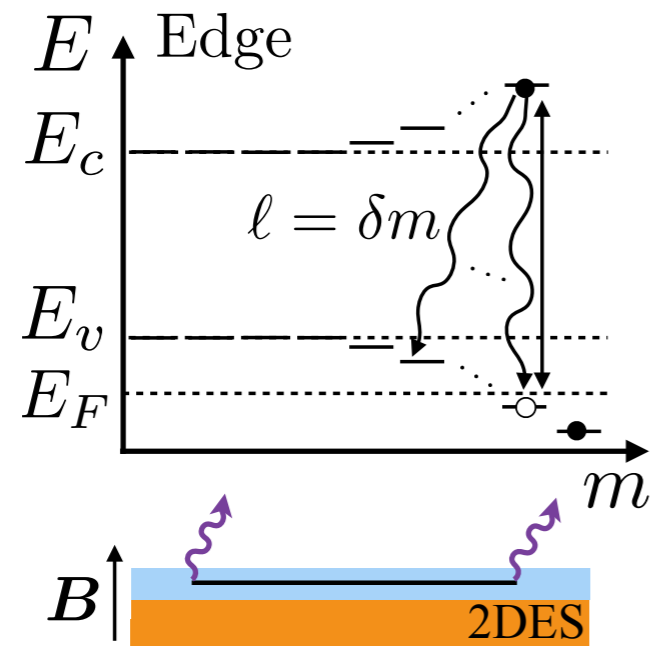
$$(r e^{-i\theta})^{m'}$$

$$e v_f \langle 1, m' | \tau_+ \mathbf{A} | 0, m \rangle \rightarrow \delta_{m', m+1}$$

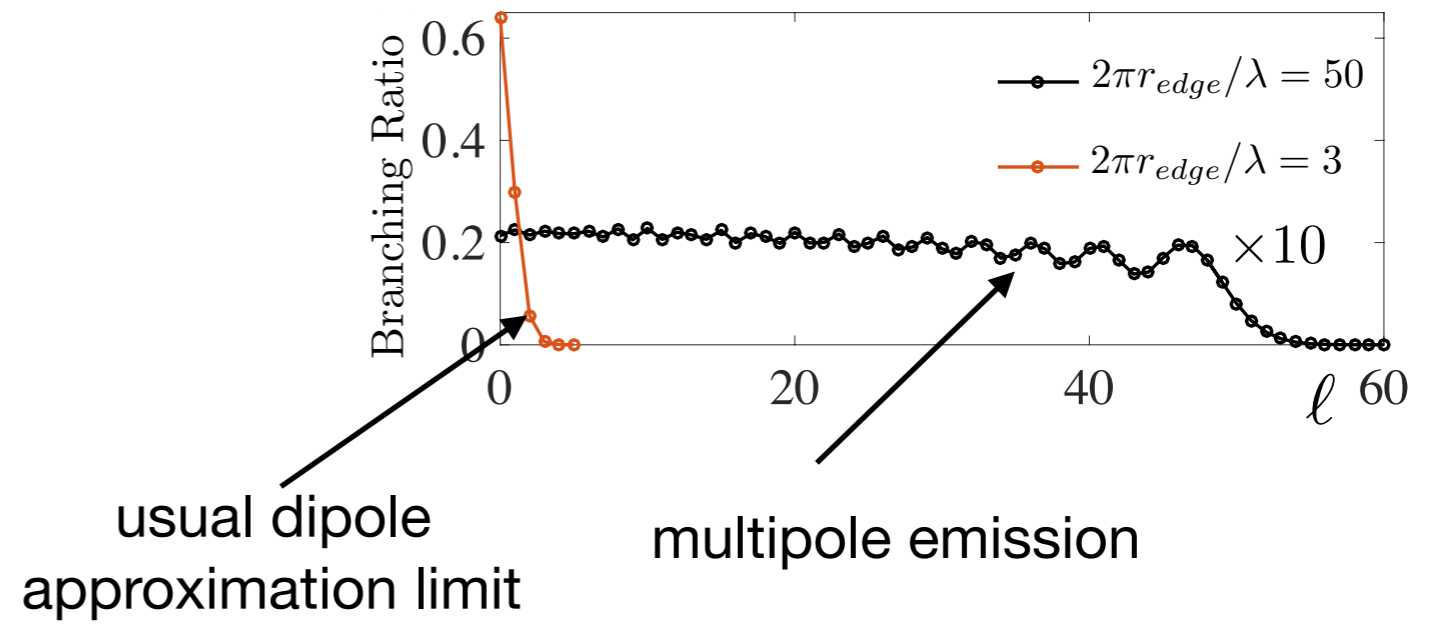
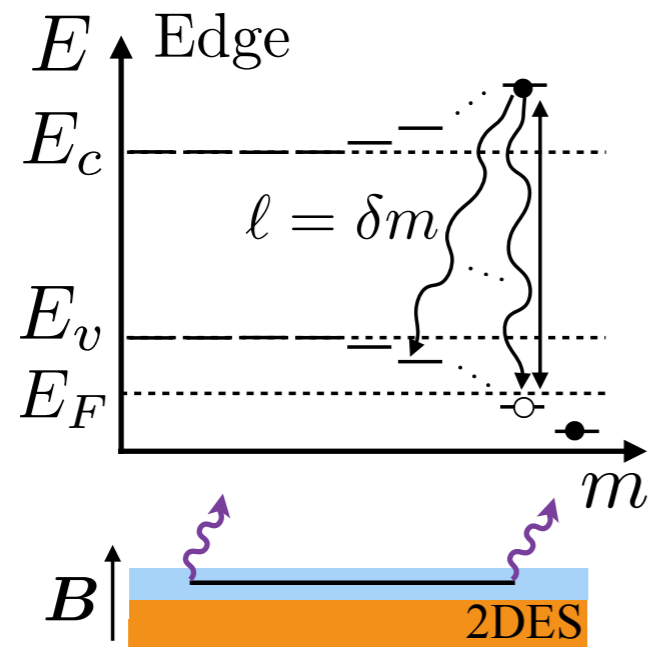
$$A \propto e^{i k z + i l \theta} J_l(k_{\perp} r)$$

$$(r e^{i\theta})^m$$

# higher orbital angular momentum emission

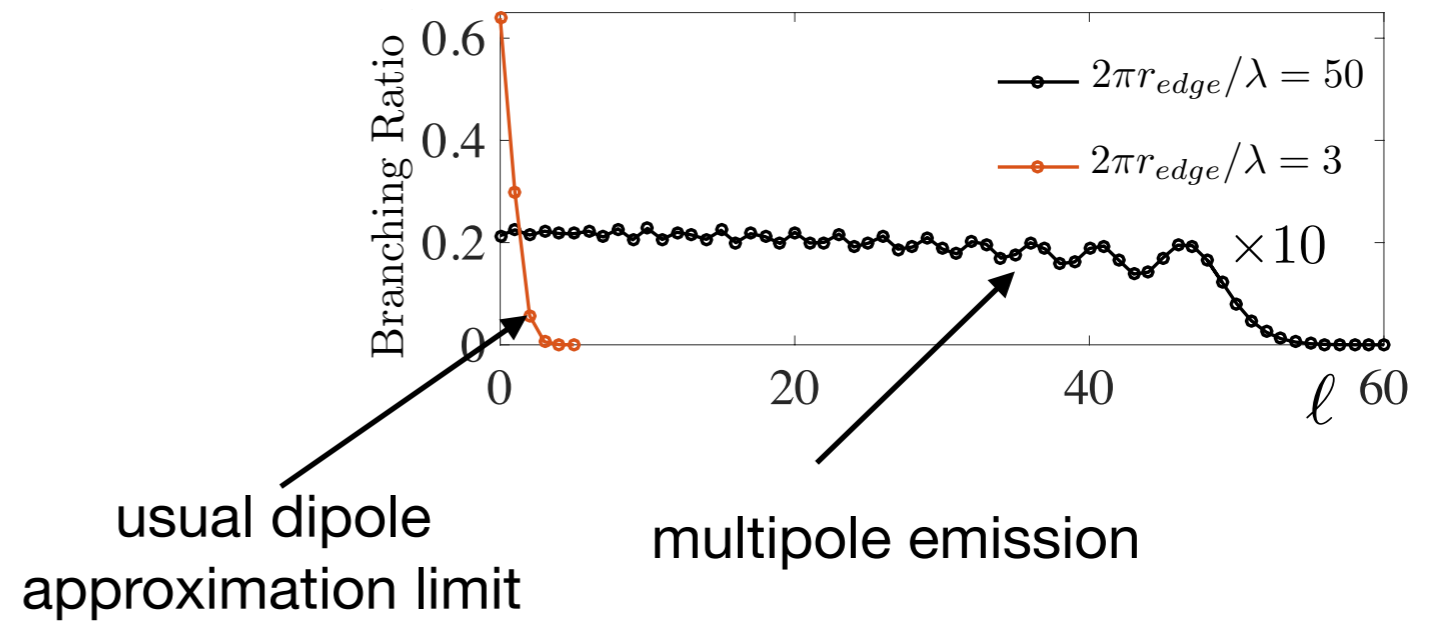
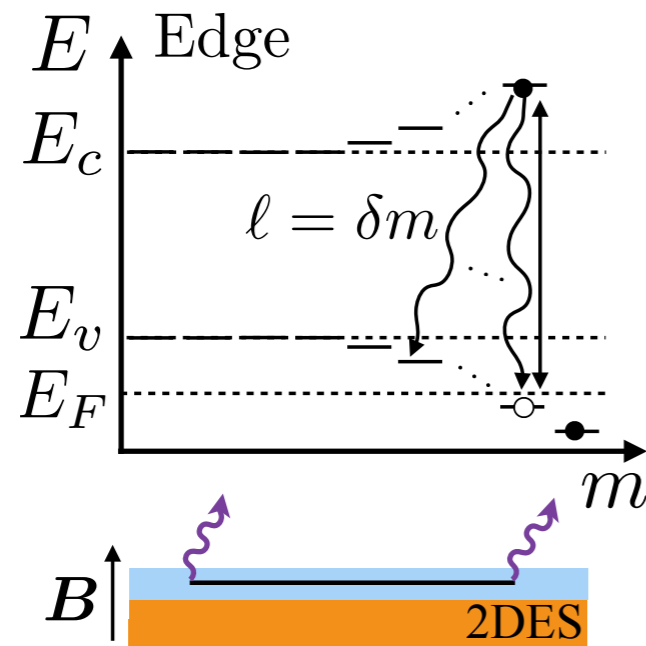


# higher orbital angular momentum emission



M. Gullans et al. PRB (2017)

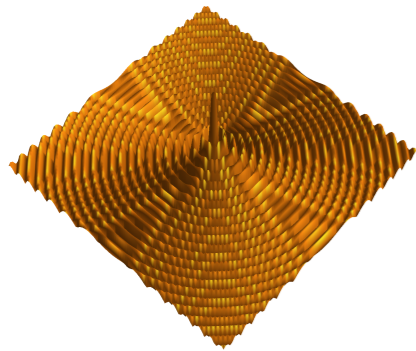
# higher orbital angular momentum emission



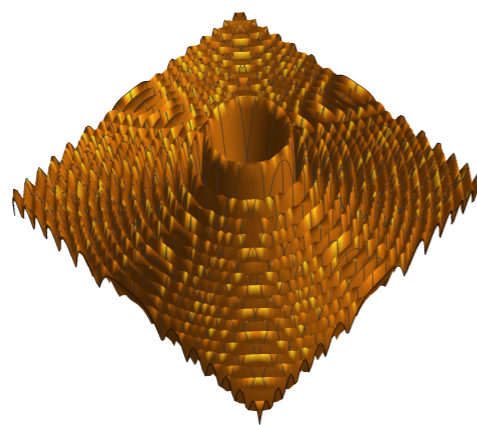
Solutions of Maxwell's equations are given by Bessel functions:

$$k_{\perp} r_{vortex} = l$$

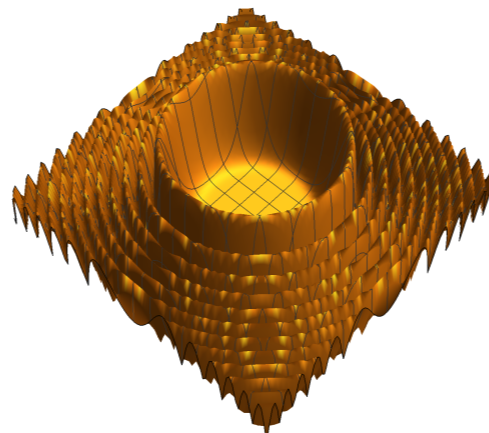
$$k_{\perp} = \sqrt{(\omega/c)^2 - k_{\parallel}^2}$$



$l = 0$



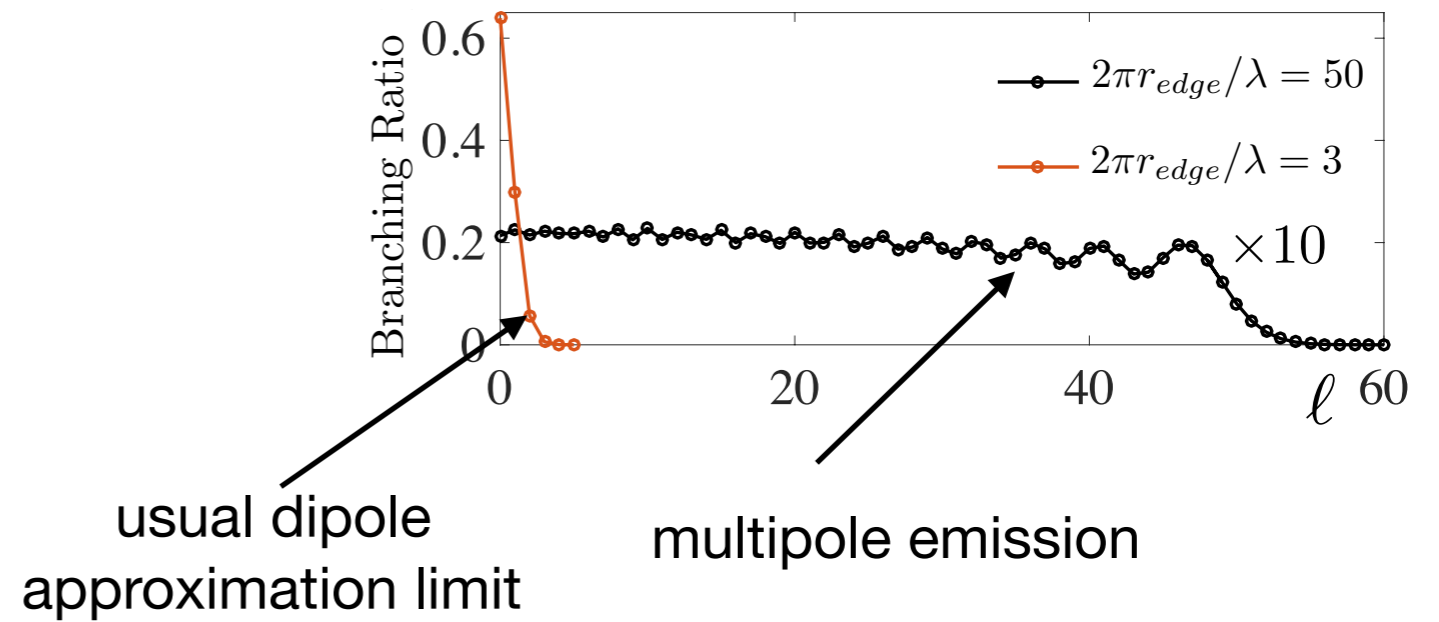
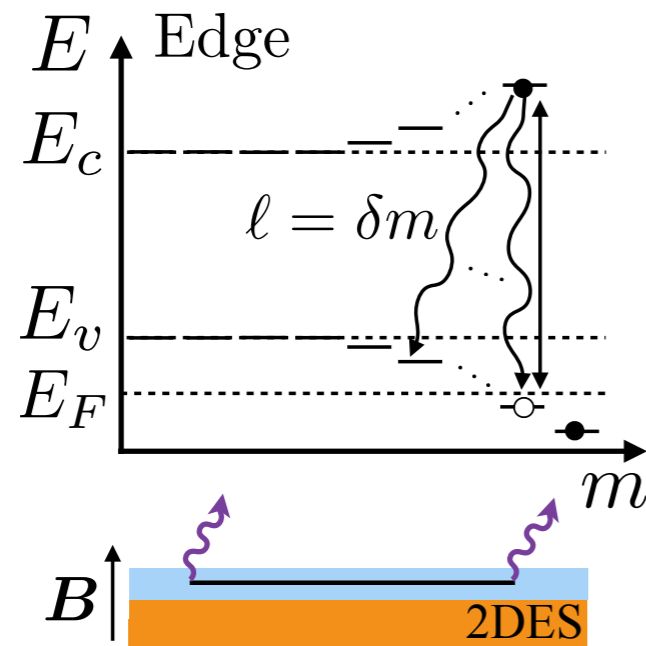
$l = 10$



$l = 25$



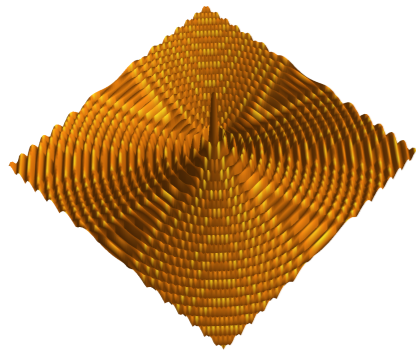
# higher orbital angular momentum emission



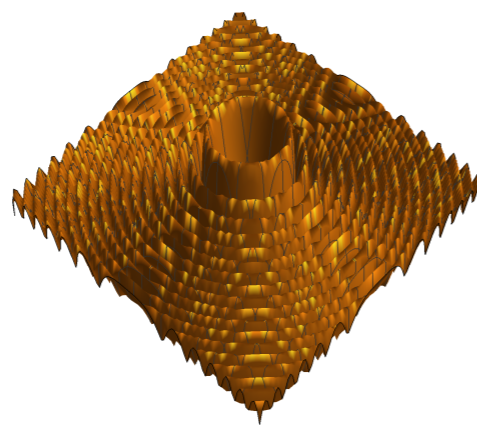
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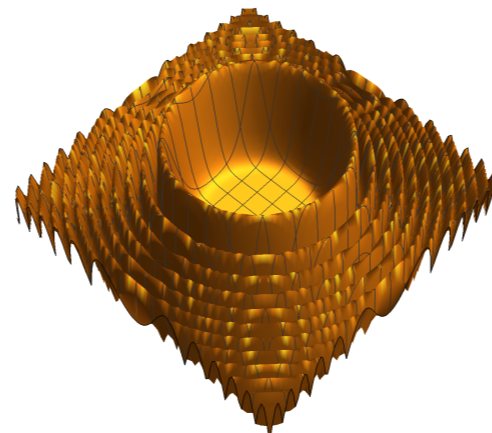
$$k_{\perp} = \sqrt{(\omega/c)^2 - k_{\parallel}^2}$$



$l = 0$



$l = 10$



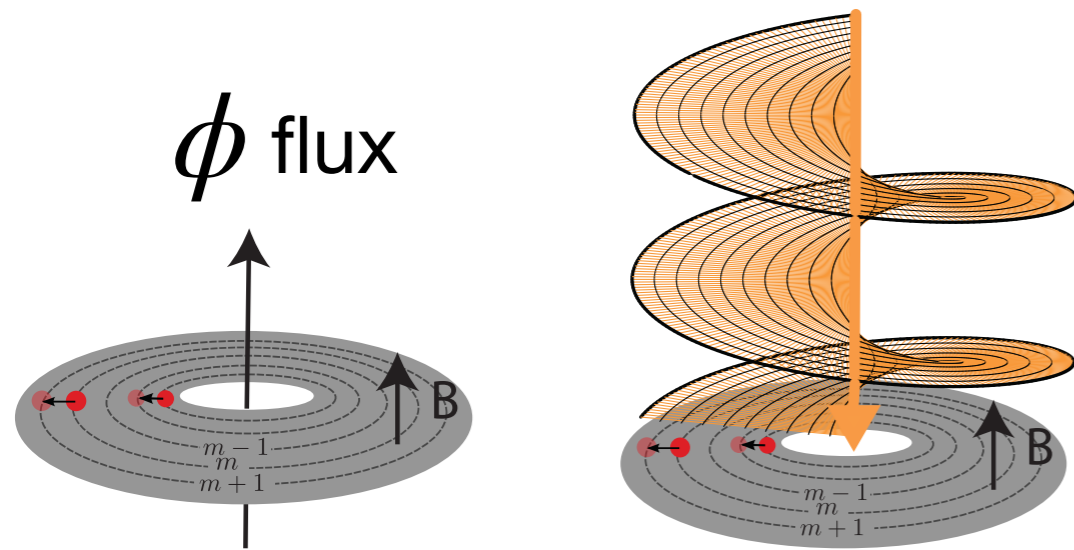
$l = 25$

so the maximum OAM:  $\frac{2\pi}{\lambda} r_{edge} = l_{max}$



M. Gullans et al. PRB (2017)

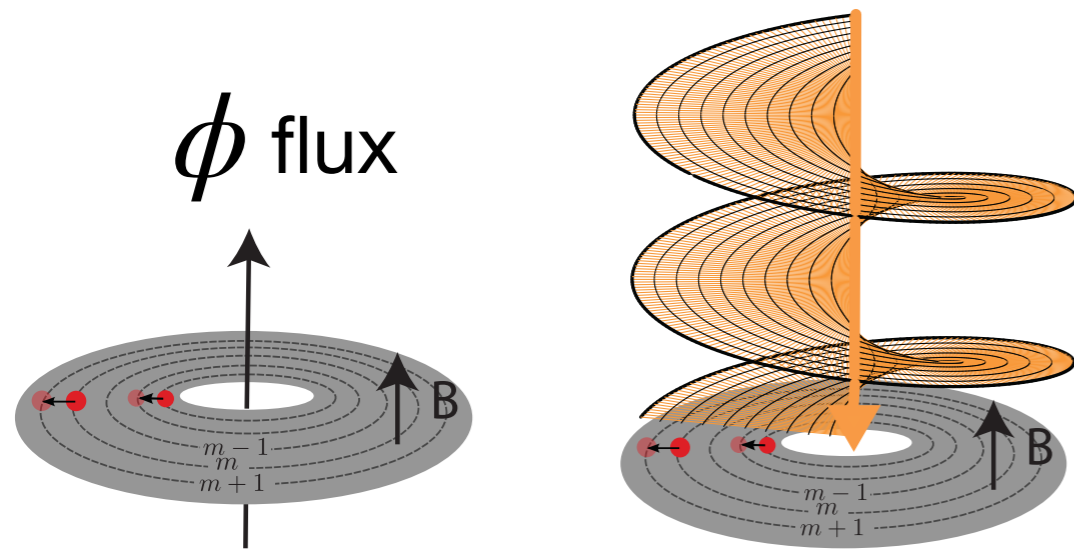
# Optical control of quantum Hall states



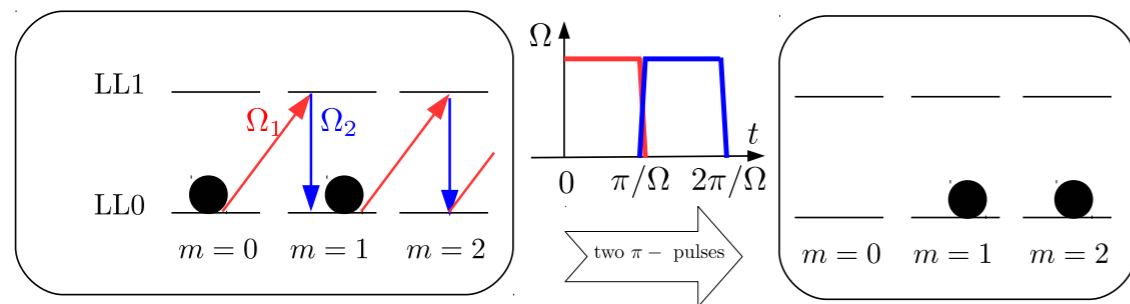
Laughlin pump with OAM of light



# Optical control of quantum Hall states



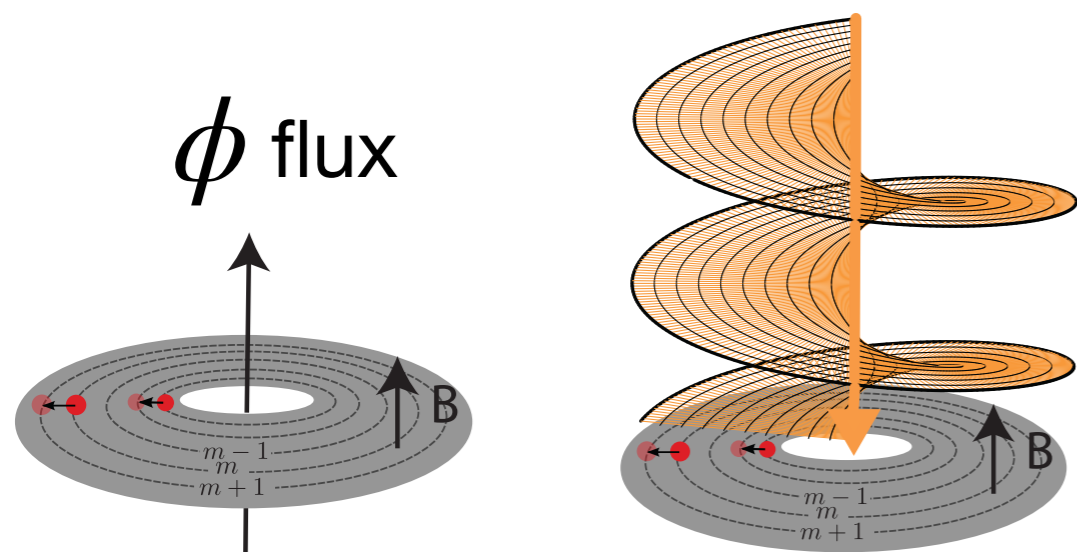
Laughlin pump with OAM of light



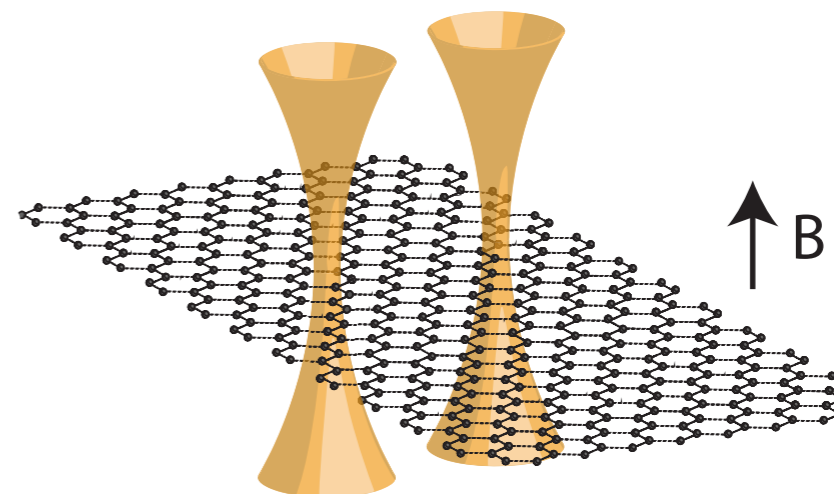
- Dirac material:  $\pi$ -pulse to impart angular momentum



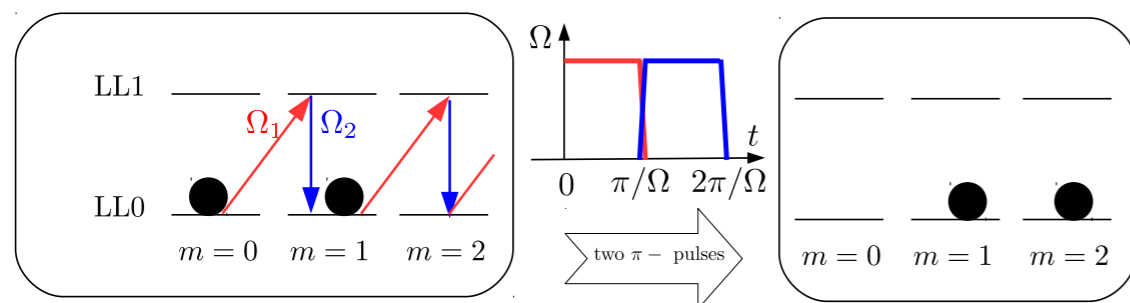
# Optical control of quantum Hall states



Laughlin pump with OAM of light



Optical tweezer to confine FQH excitation

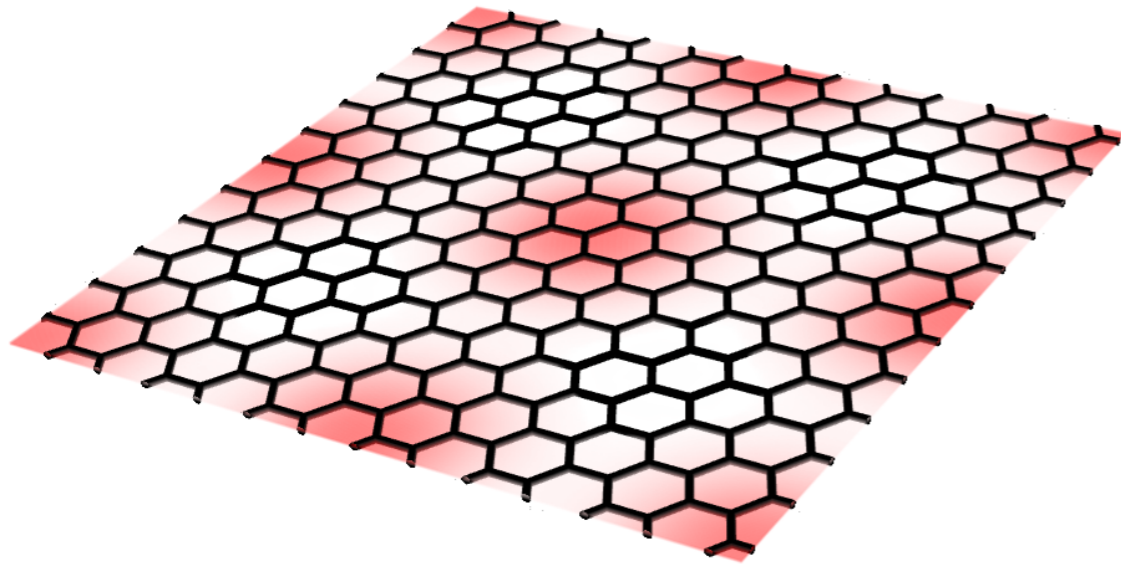


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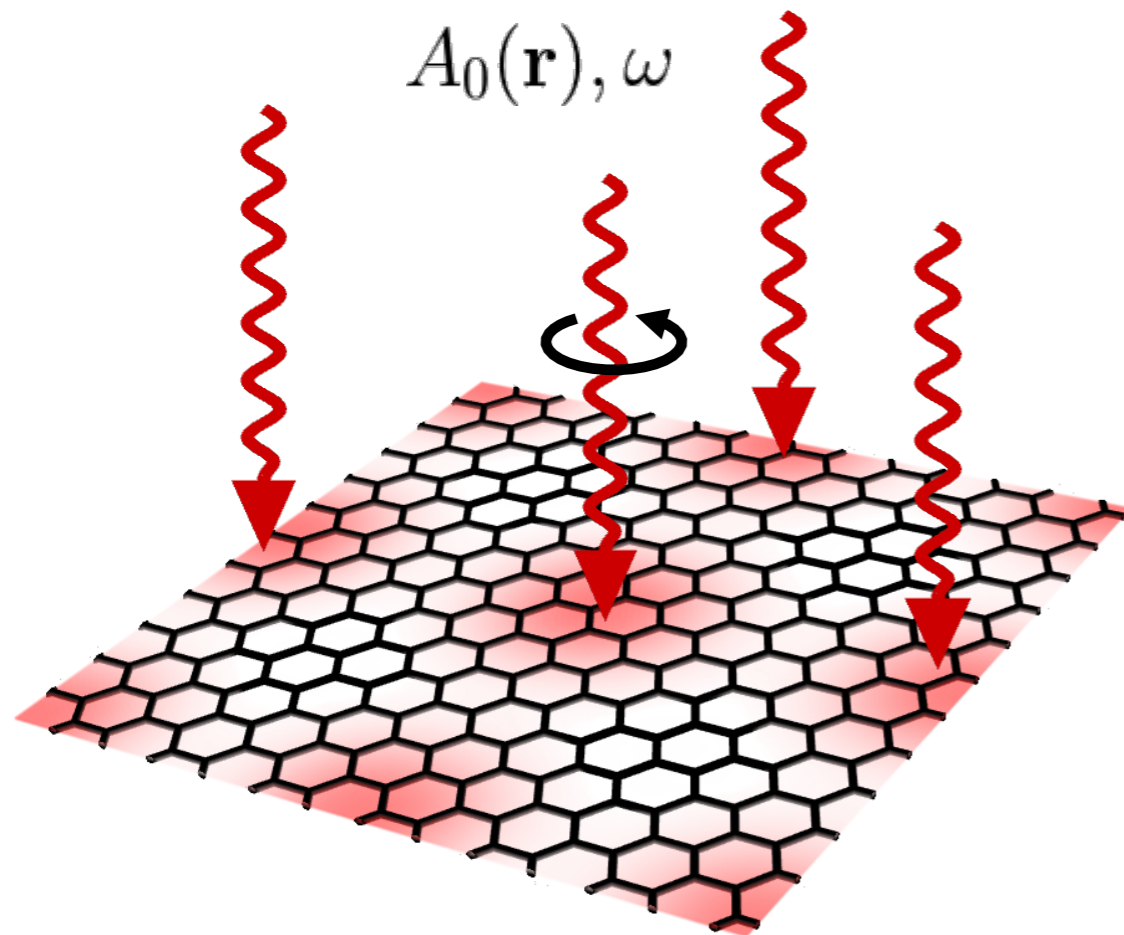


# Synthetic superlattice with light



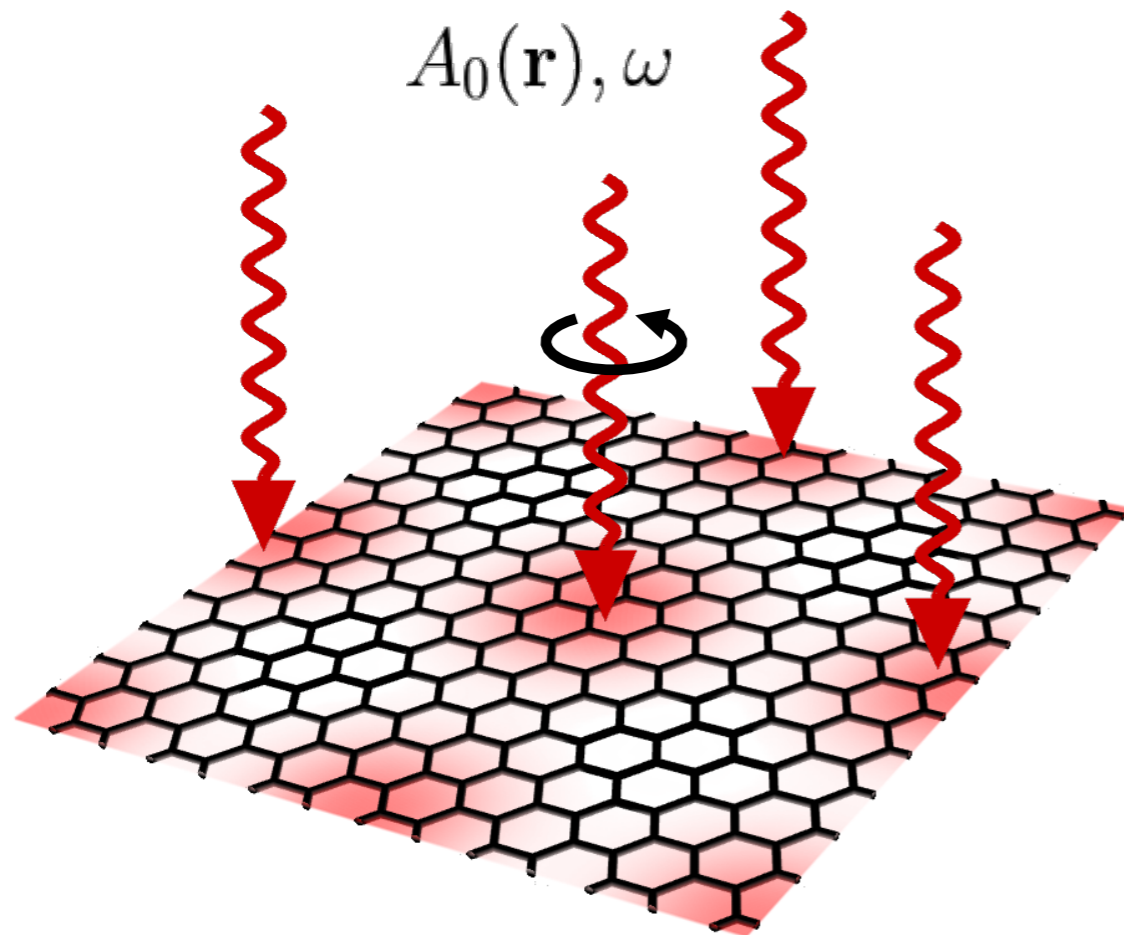
Hwanmun Kim, Hossein Dehghani  
in collaboration with H. Aoki and I. Martin

# Synthetic superlattice with light



Hwanmun Kim, Hossein Dehghani  
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# Synthetic superlattice with light

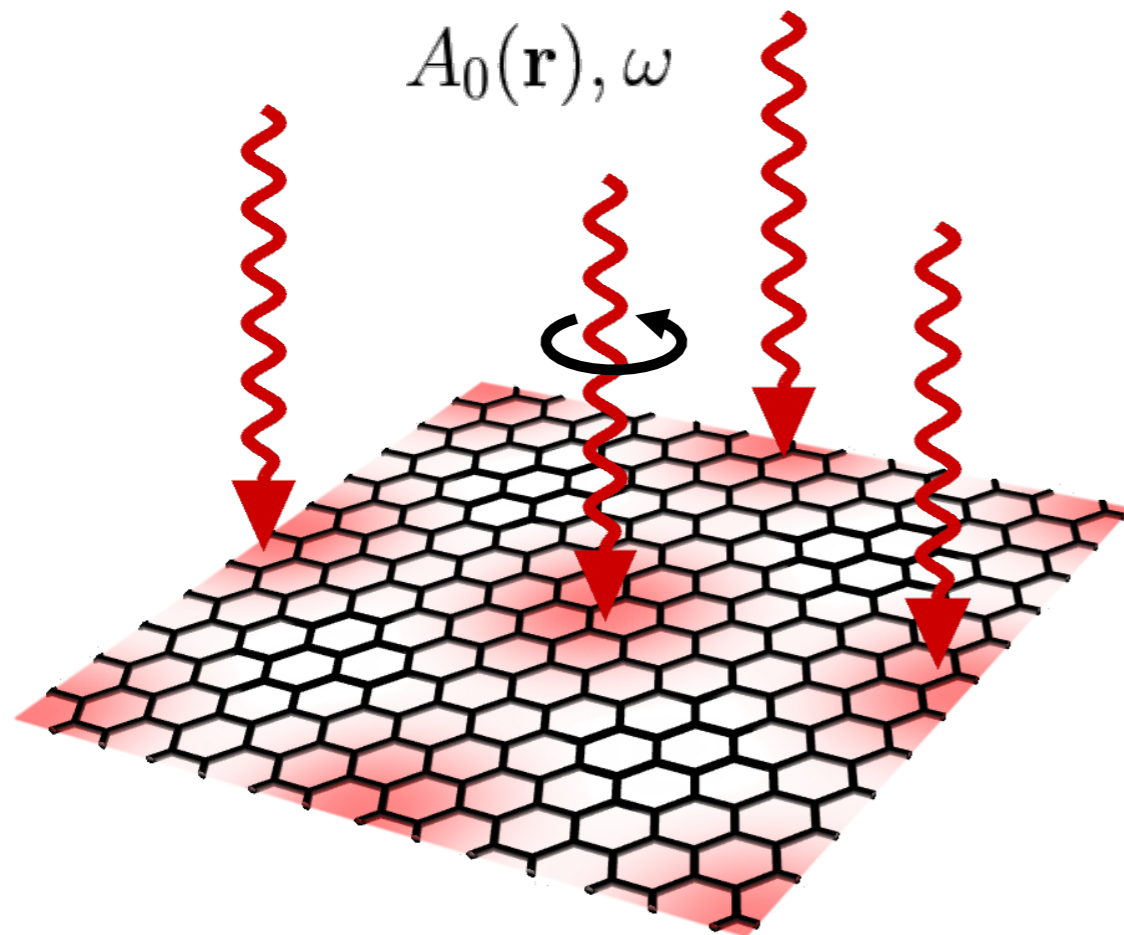


$$H_{\text{eff}} = v(p_x \sigma_x + p_y \sigma_y) + \frac{4e^2 v^2}{\omega} |A_0(\mathbf{r})|^2 \sigma_z$$



Hwanmun Kim, Hossein Dehghani  
in collaboration with H. Aoki and I. Martin

# Synthetic superlattice with light

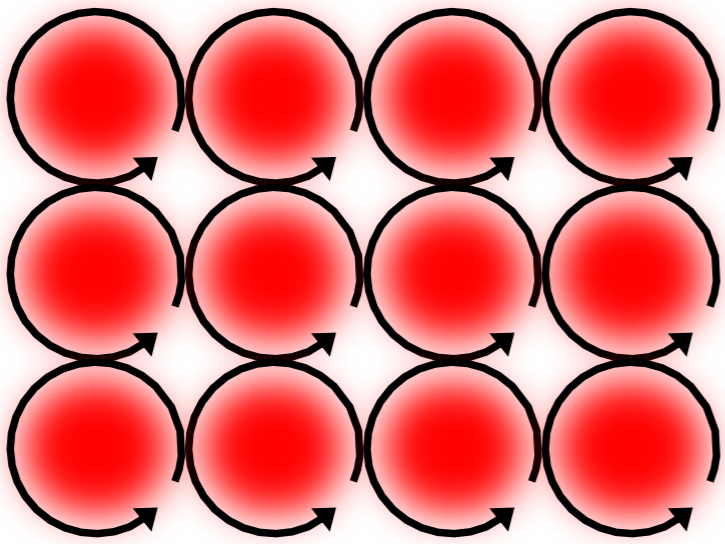


$$H_{\text{eff}} = v(p_x \sigma_x + p_y \sigma_y) + \frac{4e^2 v^2}{\omega} |A_0(\mathbf{r})|^2 \sigma_z$$

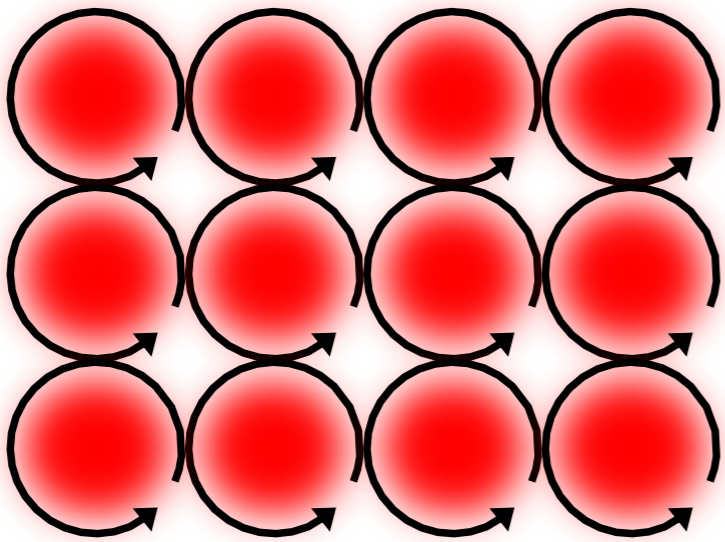
- Optical potential superlattice
- Superlattice spacing bigger than the original lattice spacing
- Simplest: square lattice



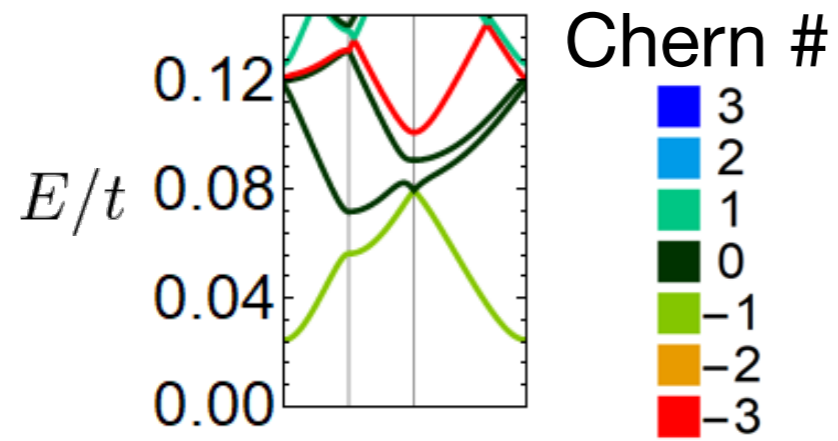
Hwanmun Kim, Hossein Dehghani  
in collaboration with H. Aoki and I. Martin

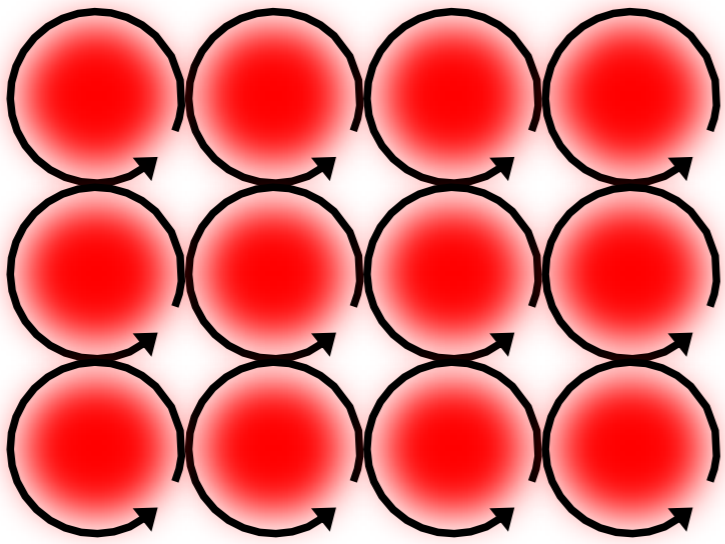


shallow lattice

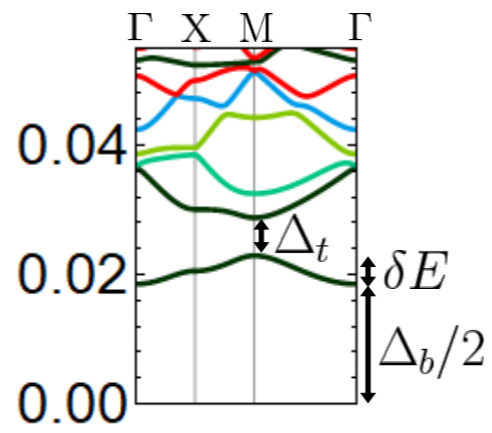
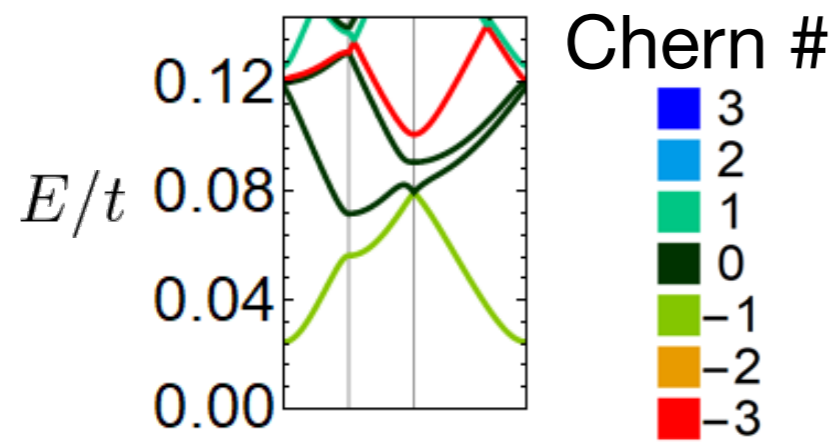


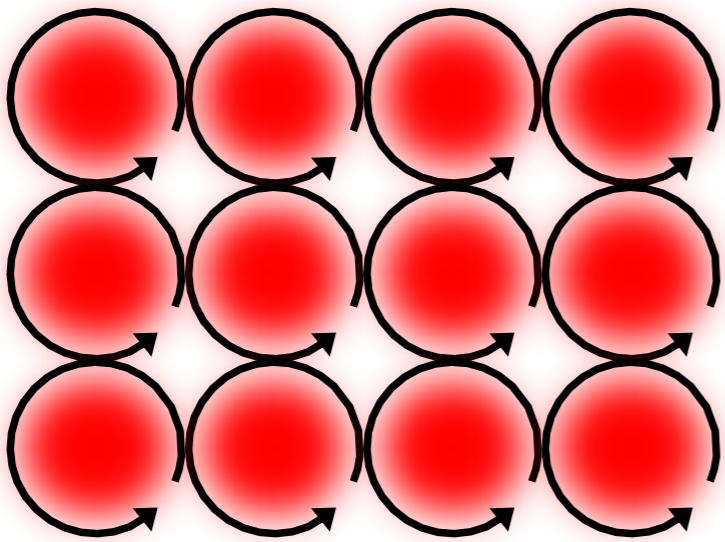
shallow lattice



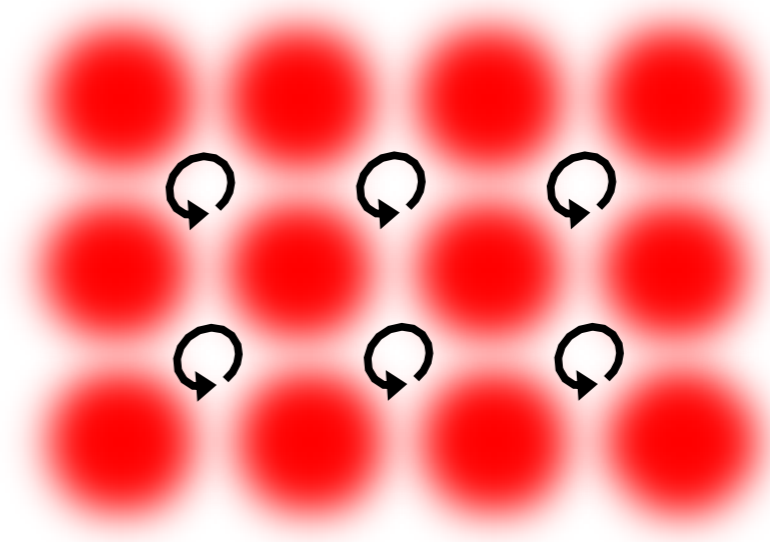


shallow lattice

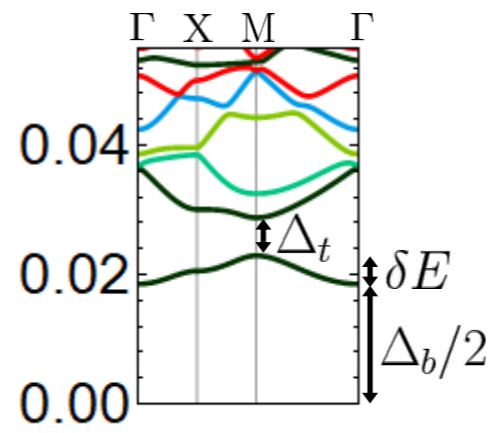
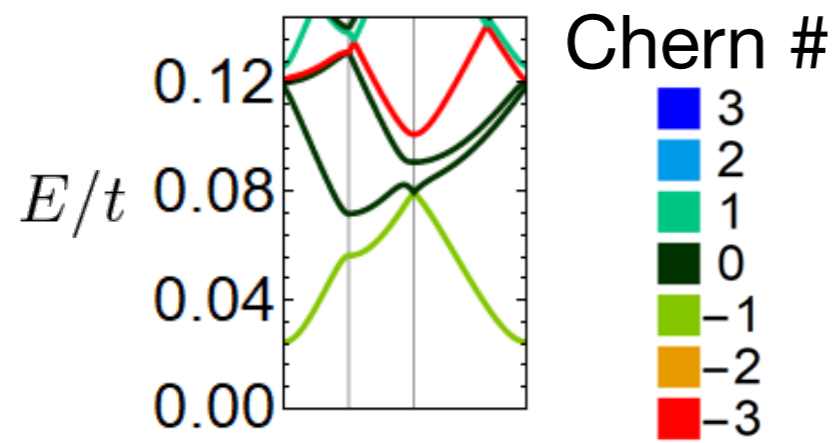




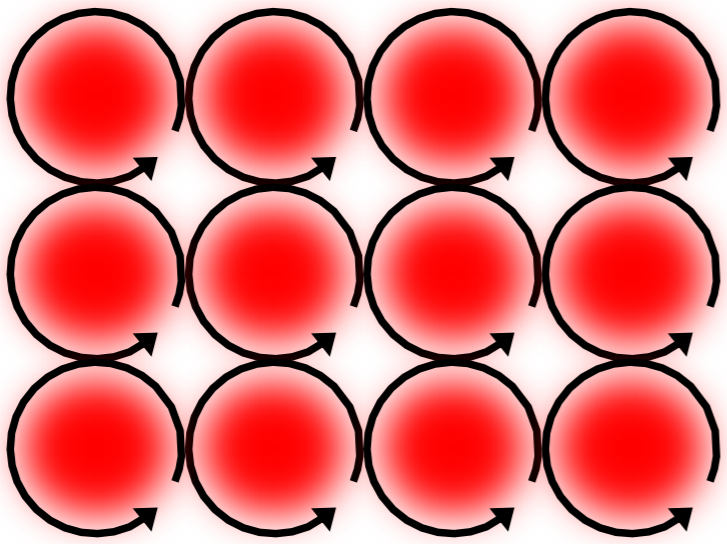
shallow lattice



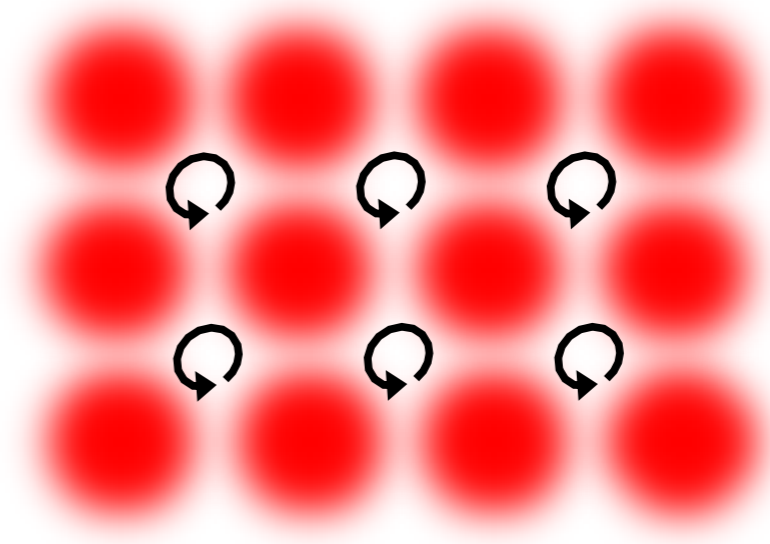
deep lattice



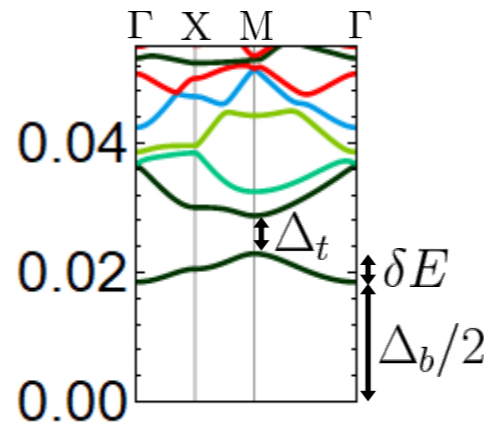
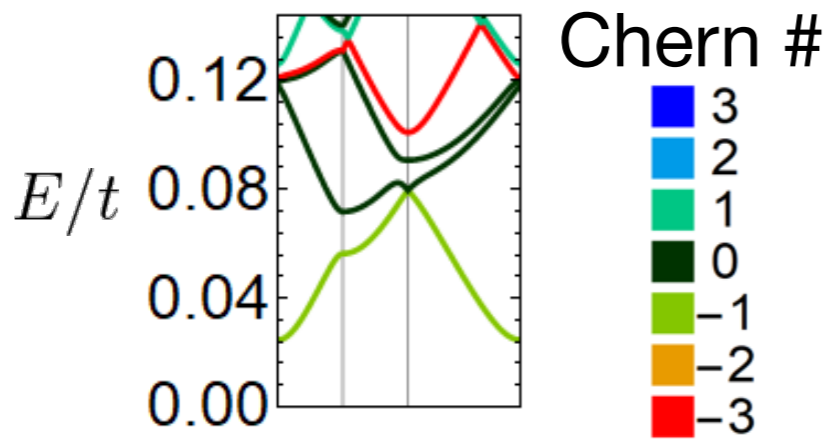
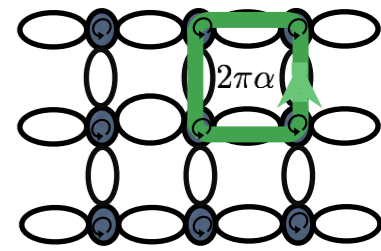


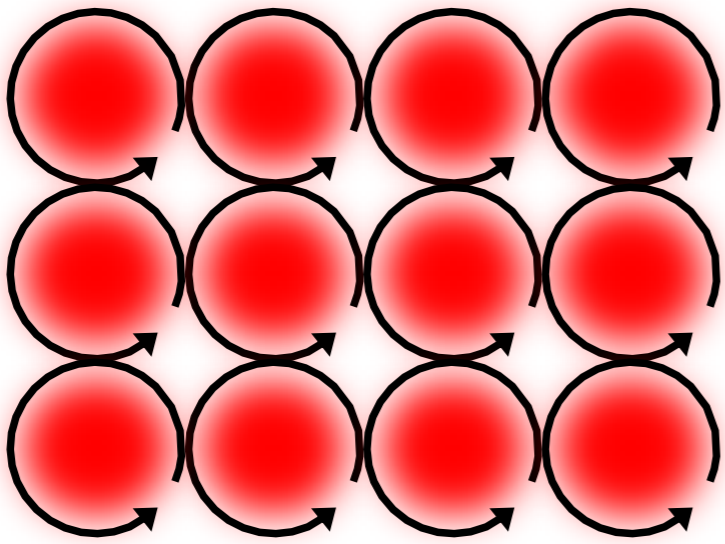


shallow lattice

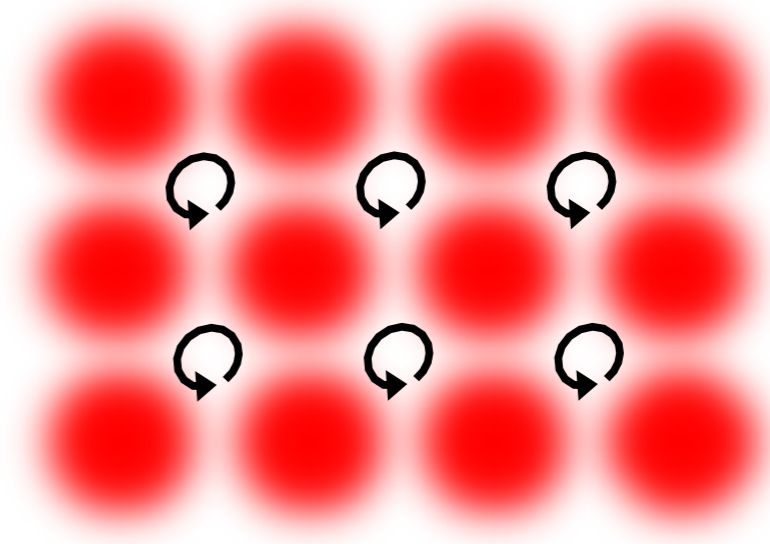
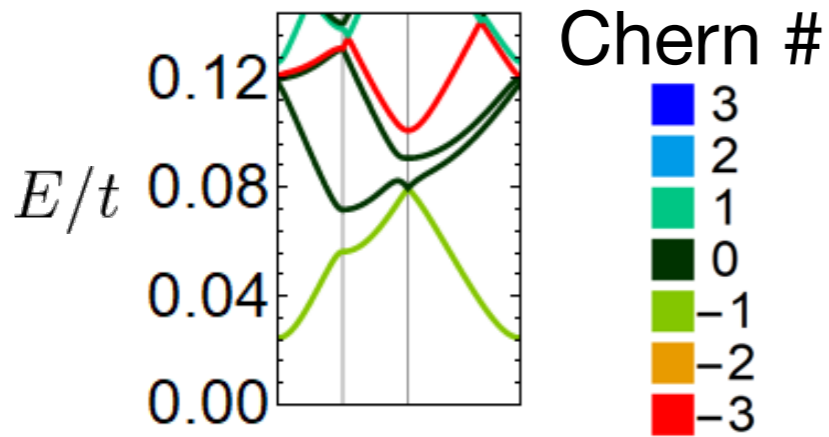


deep lattice

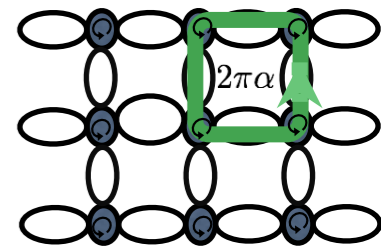
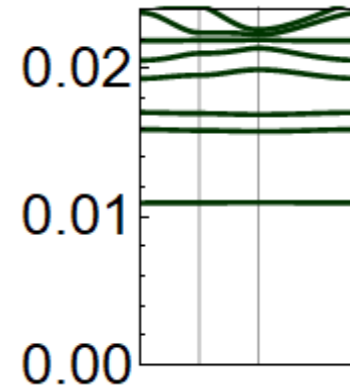
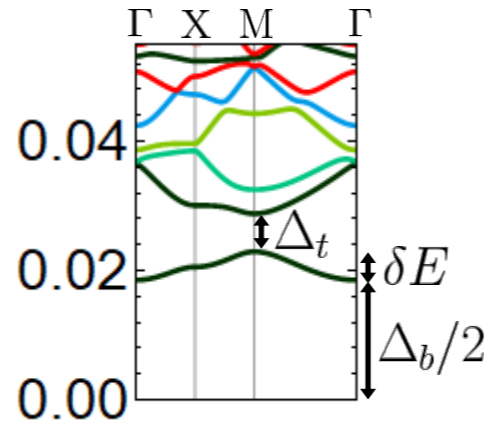


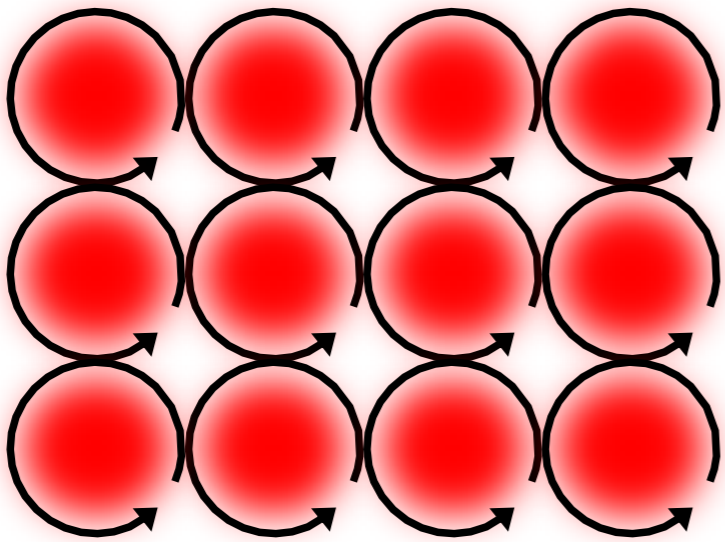


shallow lattice

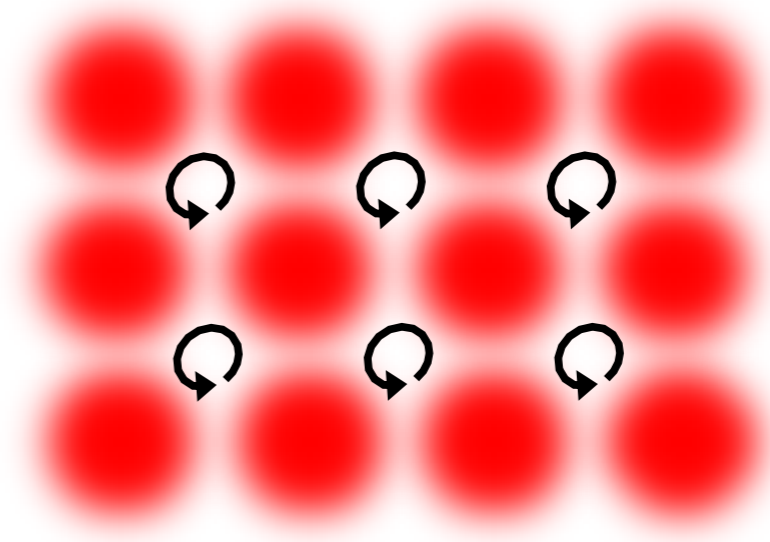


deep lattice

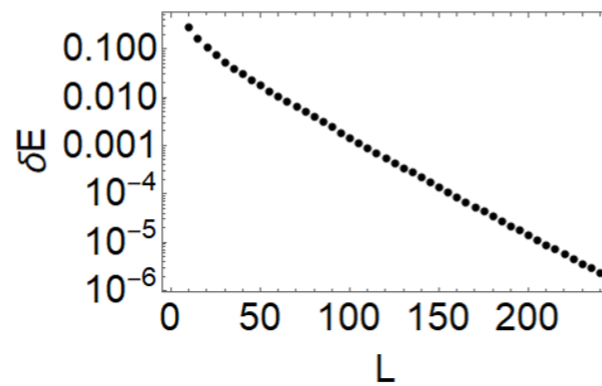
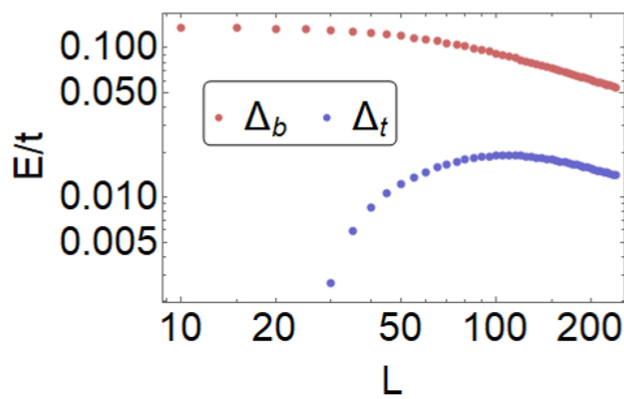
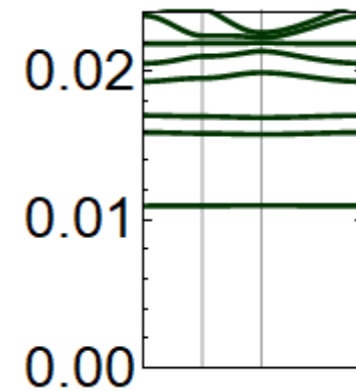
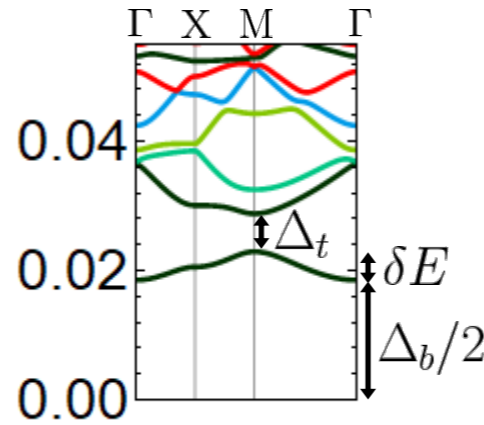
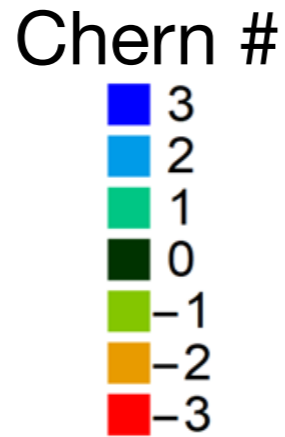
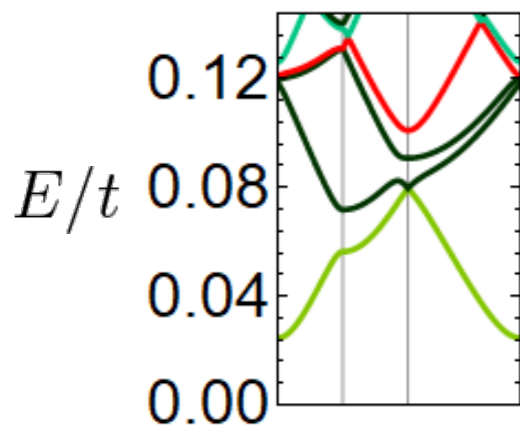
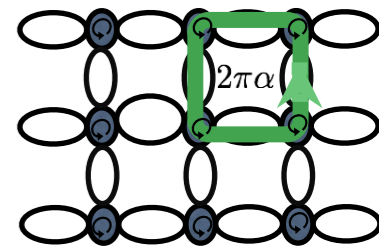




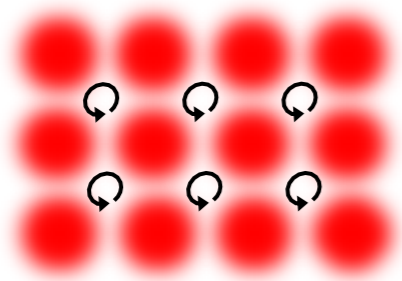
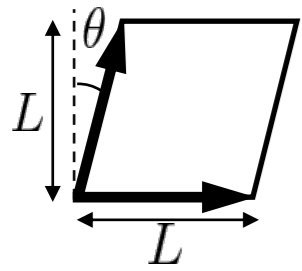
shallow lattice



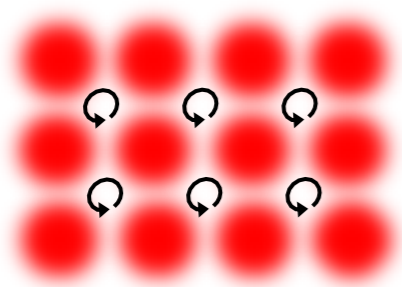
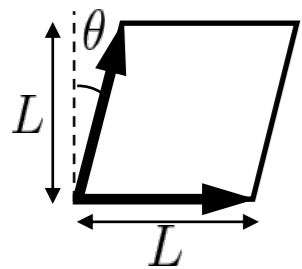
deep lattice



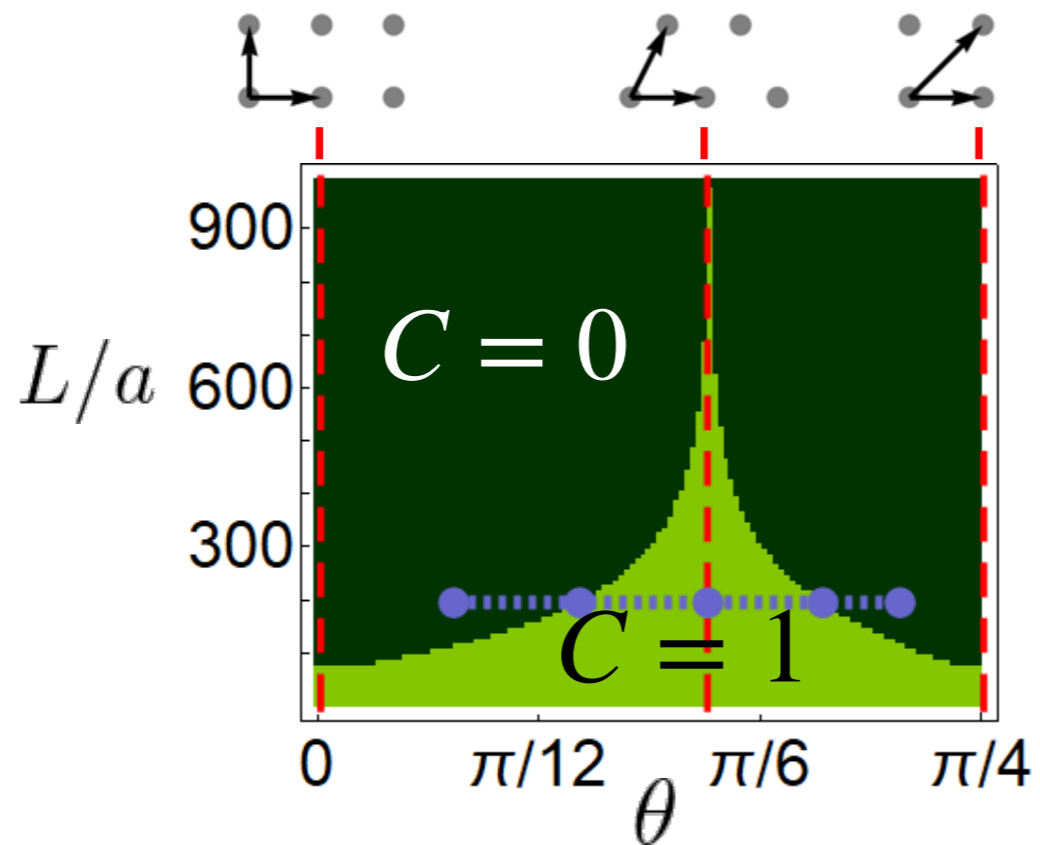
- Power law decrease in gap
- Exponential band-flattening



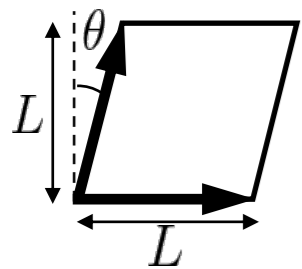
What happens if we tilt the system?



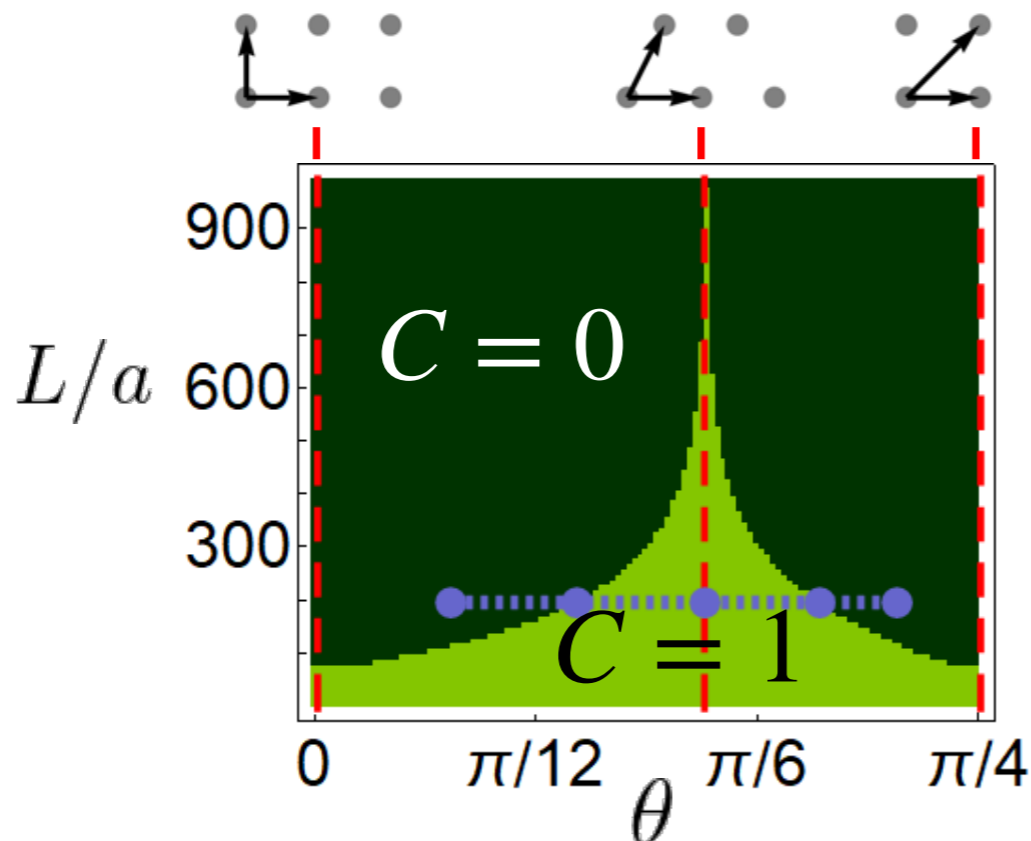
What happens if we tilt the system?



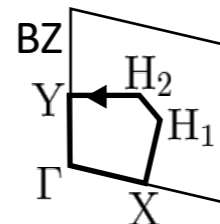
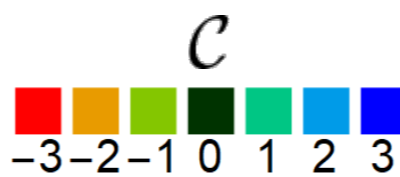
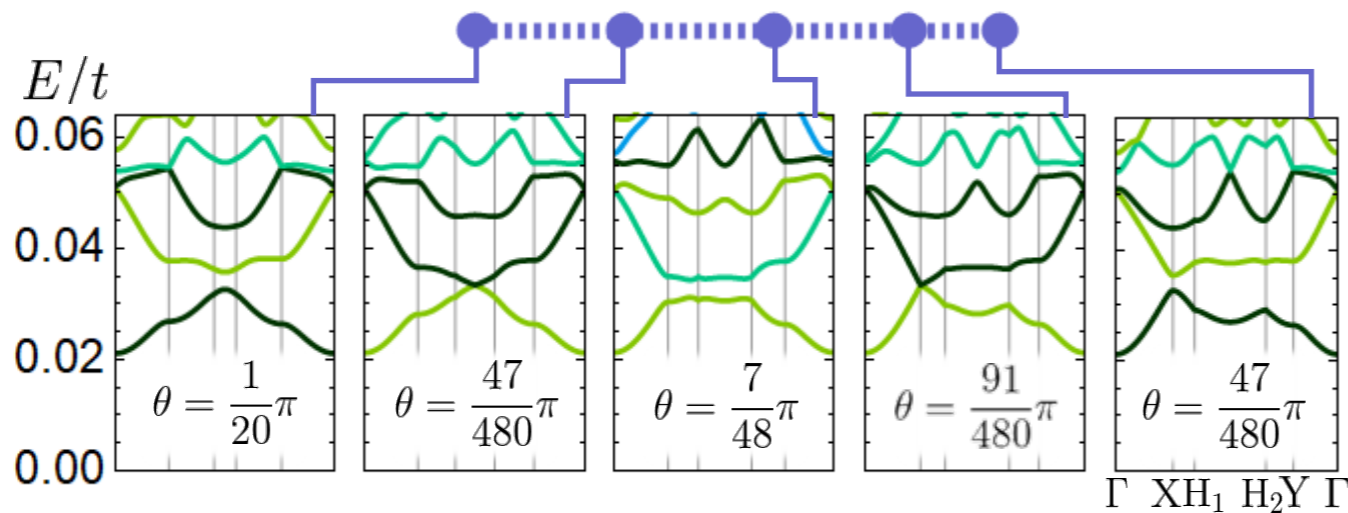
- Next-nearest neighbor hopping becomes stronger by tilting

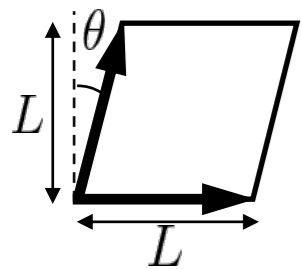


What happens if we tilt the system?

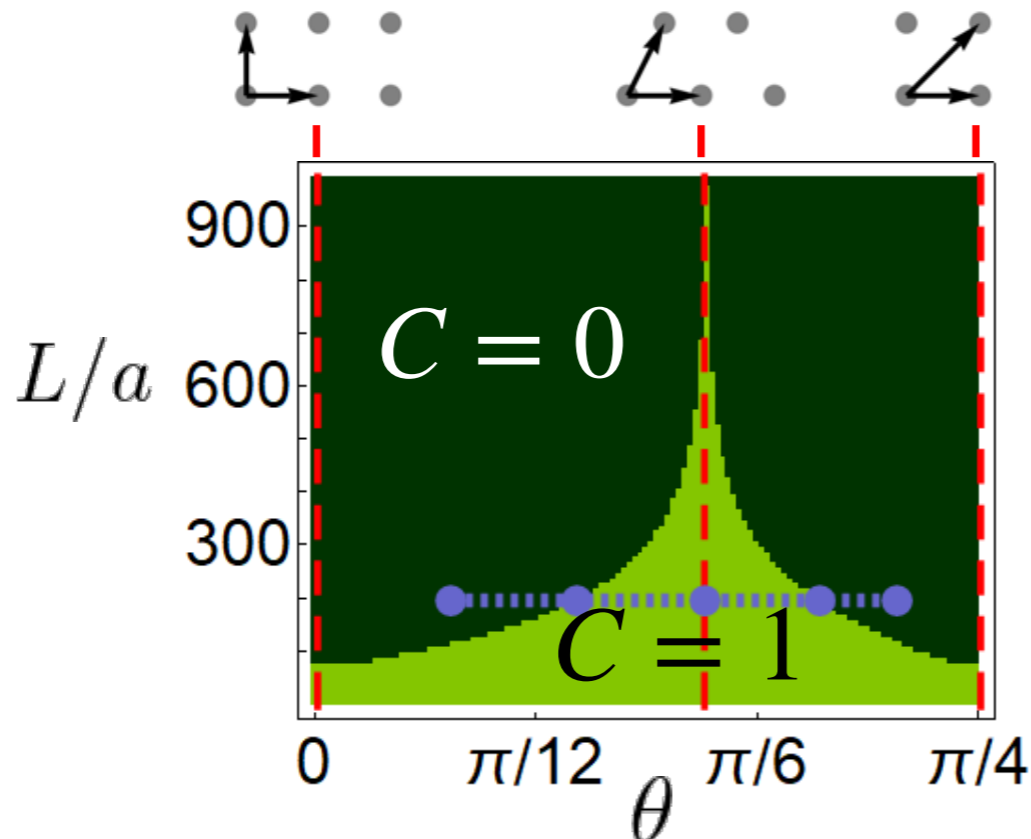


- Next-nearest neighbor hopping becomes stronger by tilting

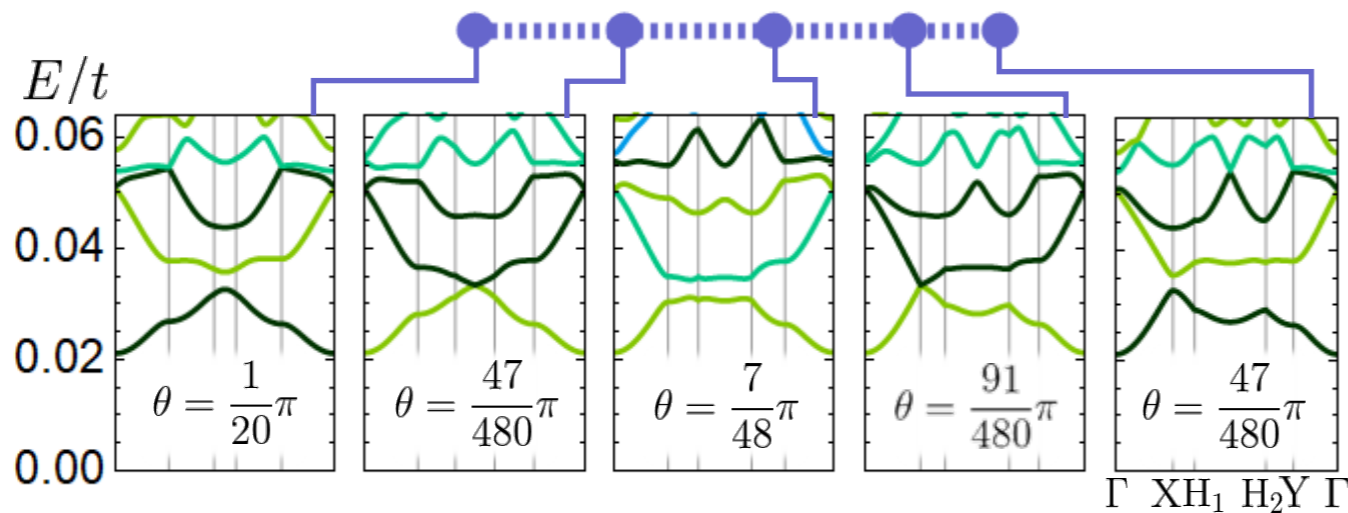




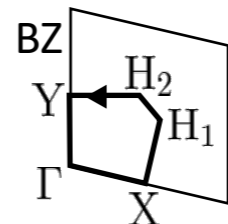
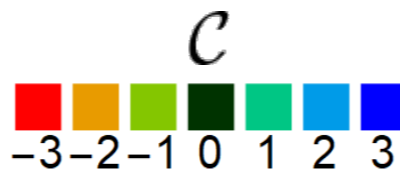
What happens if we tilt the system?



- Next-nearest neighbor hopping becomes stronger by tilting



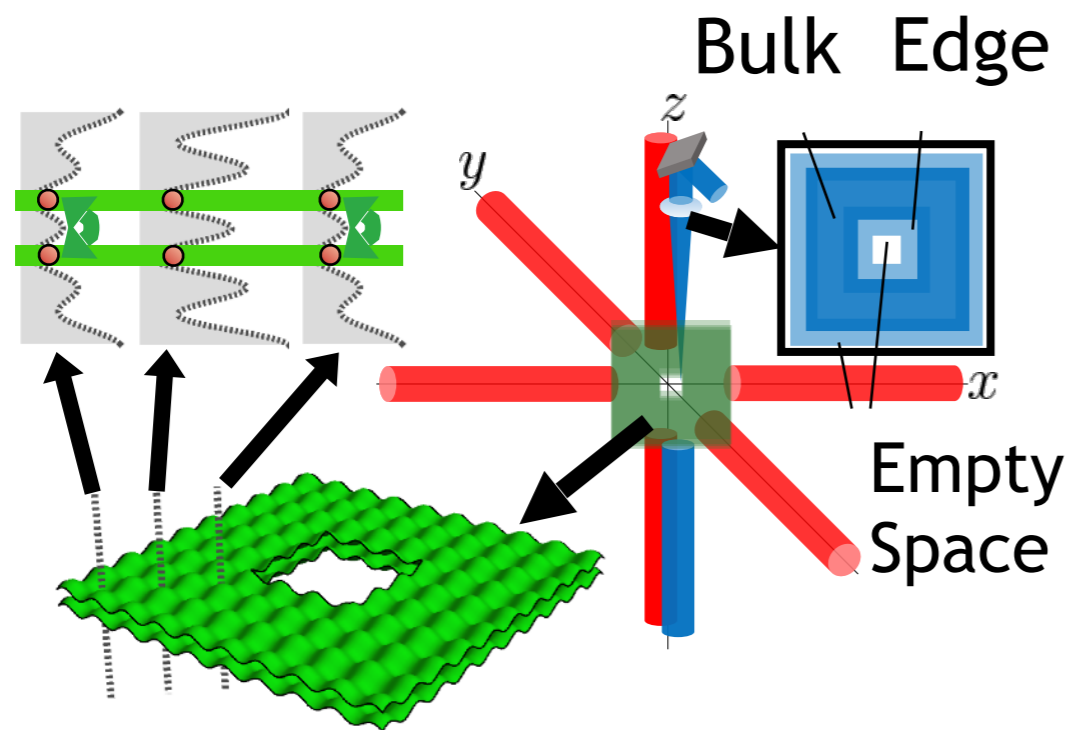
- Other lattice structure?
- Interaction?
- Floquet (resonance) case?



# Synthetic topology in ultracold atoms

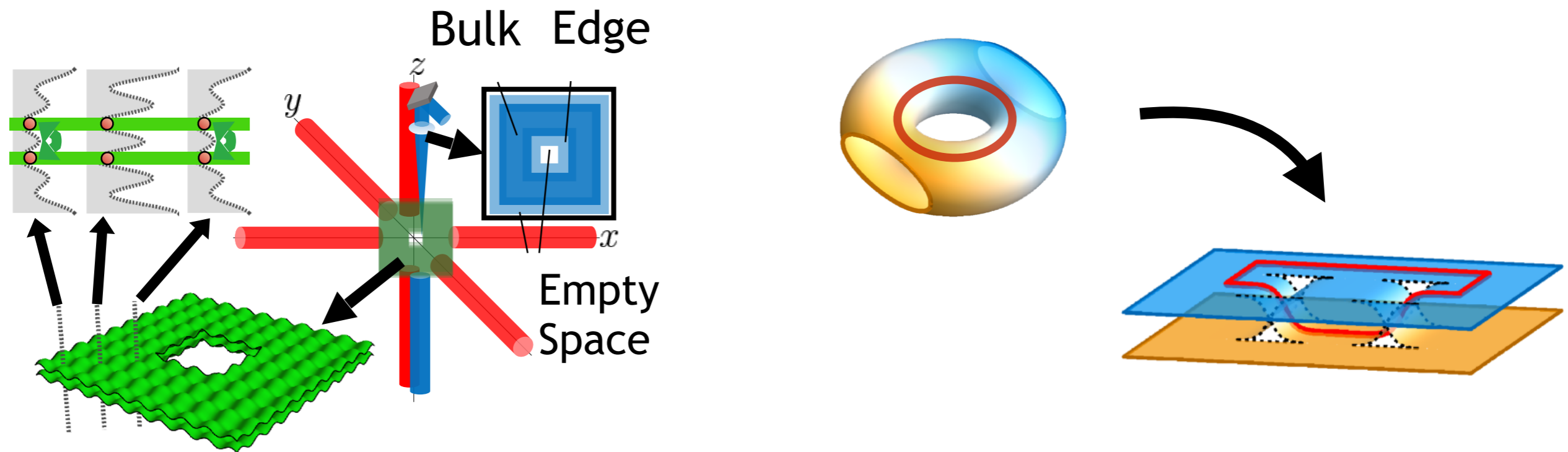


# Synthetic topology in ultracold atoms



Kim, Zhu, Porto, MH PRL 121,133002 (2018)

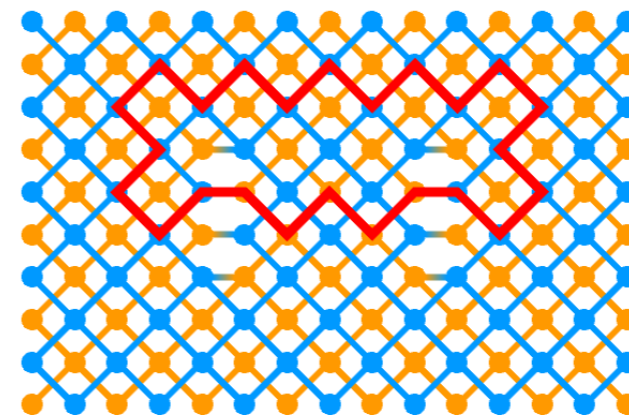
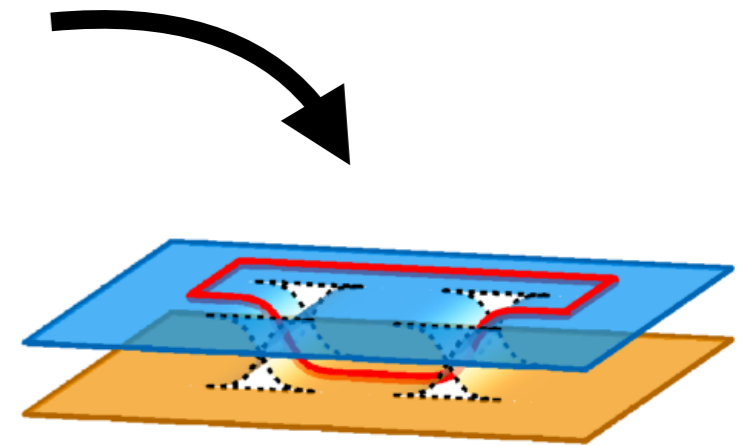
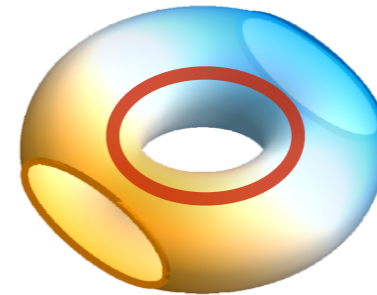
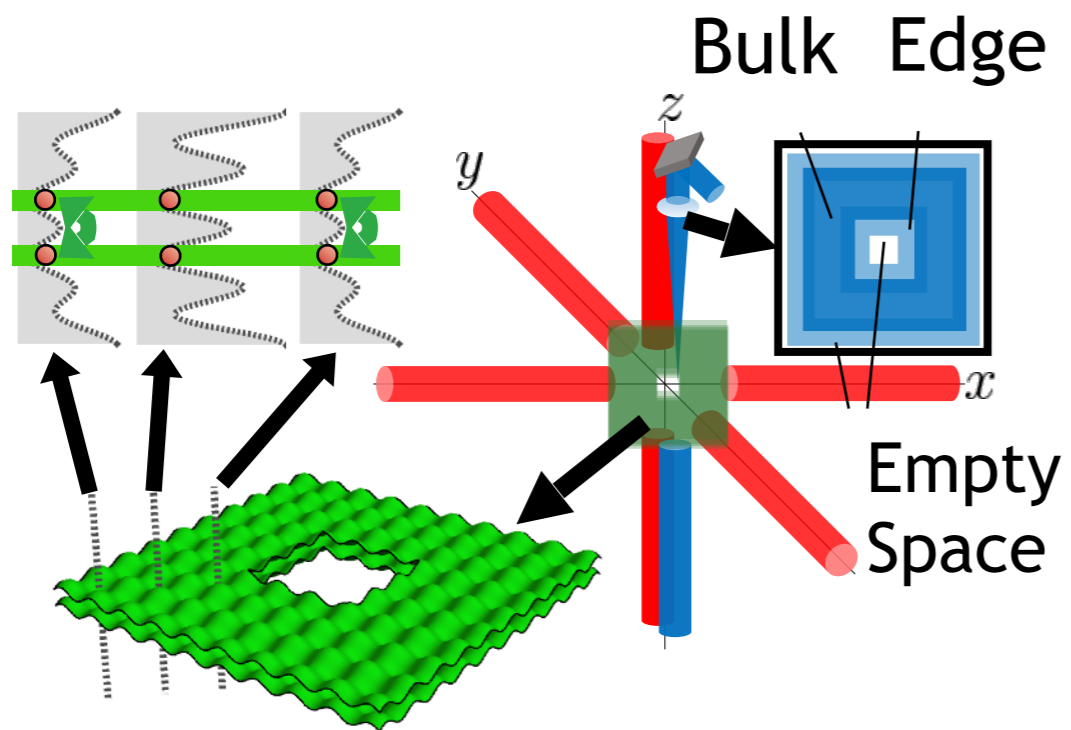
# Synthetic topology in ultracold atoms



Kim, Zhu, Porto, MH PRL 121,133002 (2018)

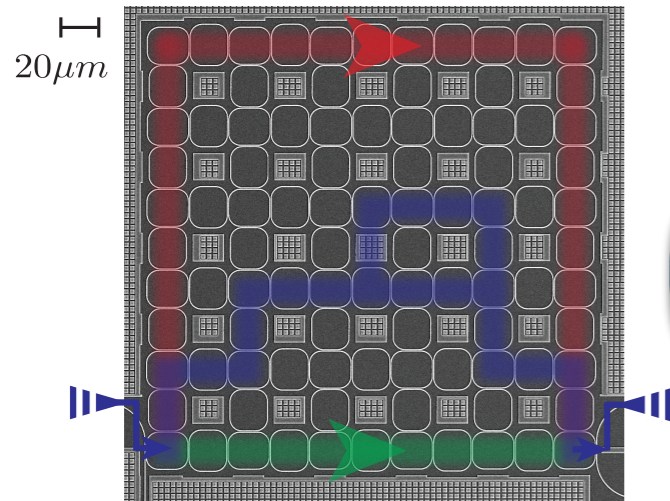
with M. Barkeshli

# Synthetic topology in ultracold atoms

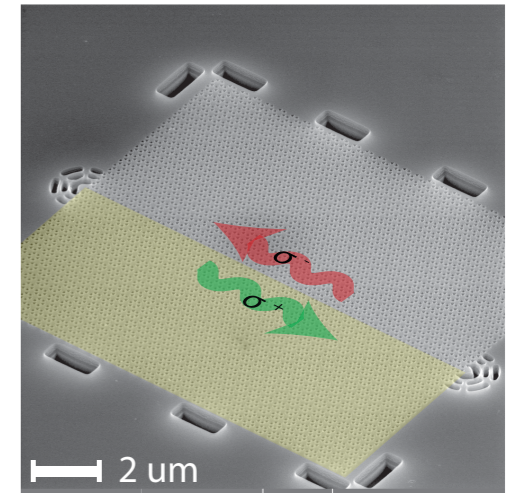


Kim, Zhu, Porto, MH PRL 121,133002 (2018)

with M. Barkeshli

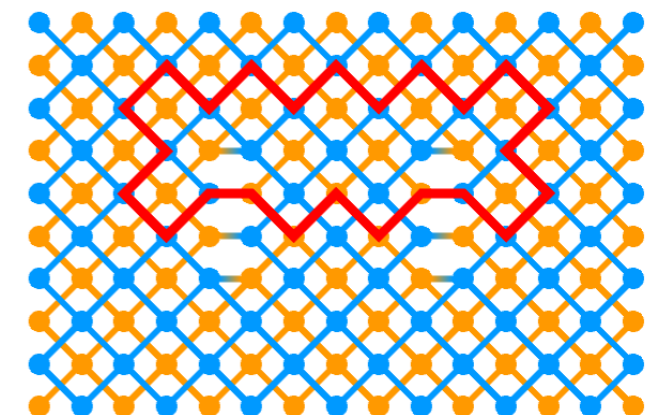
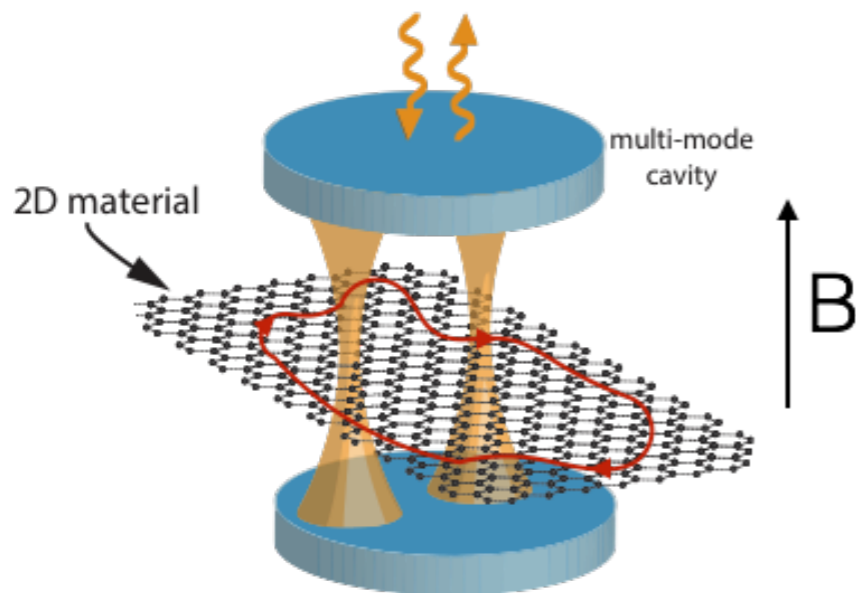


# Topological photonics



Probing/ Controlling electronic states

Topology in ultracold atoms



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- Chris Flower
- Alireza Seif
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