ETH zürich

Axial gauge field in Weyl metamaterial

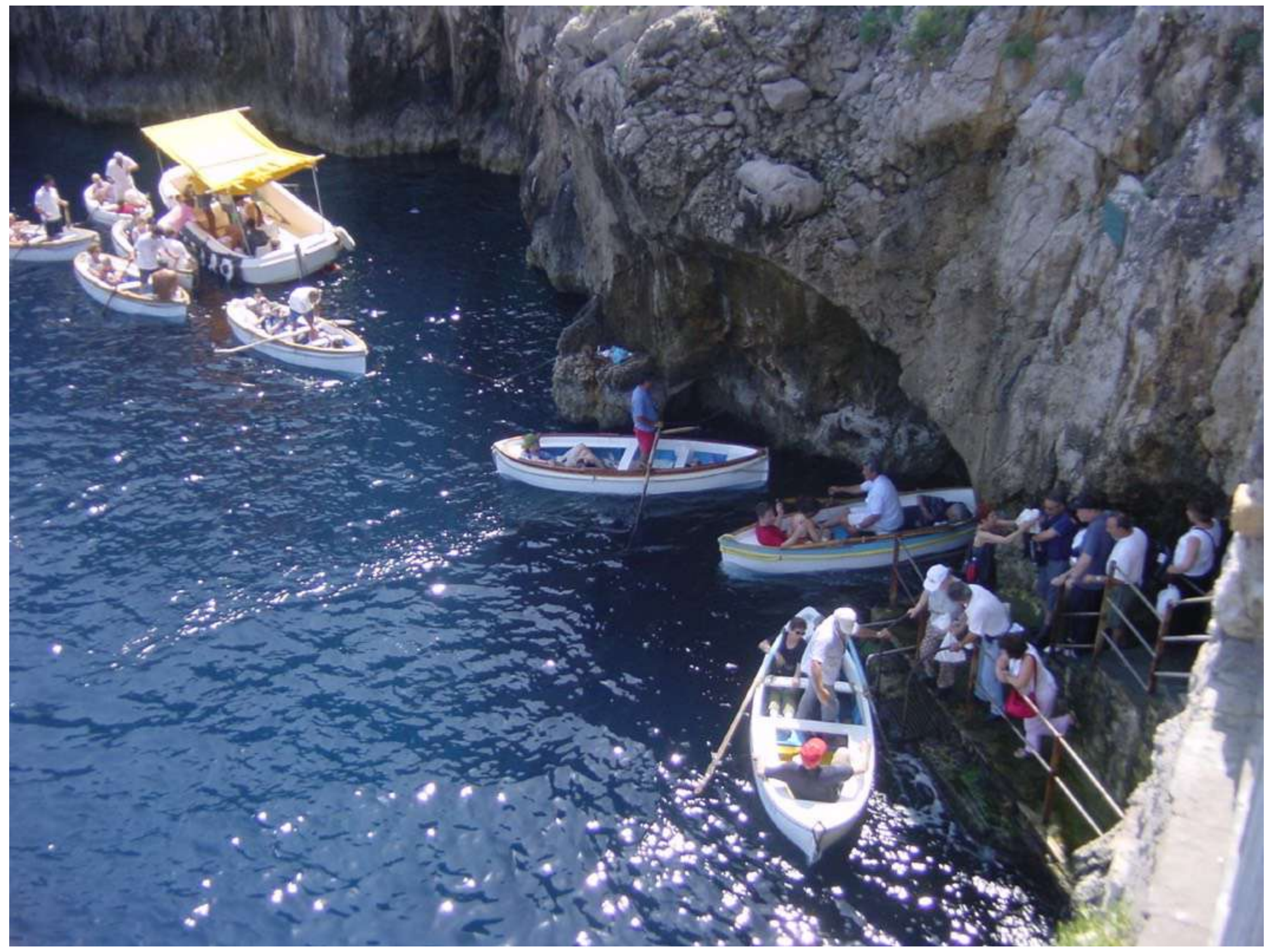
<u>Valerio Peri</u>, Marc Serra-Garcia, Roni Ilan, Sebastian D. Huber

Nature Physics, 15, 357 (2019)
arXiv:1806.09628

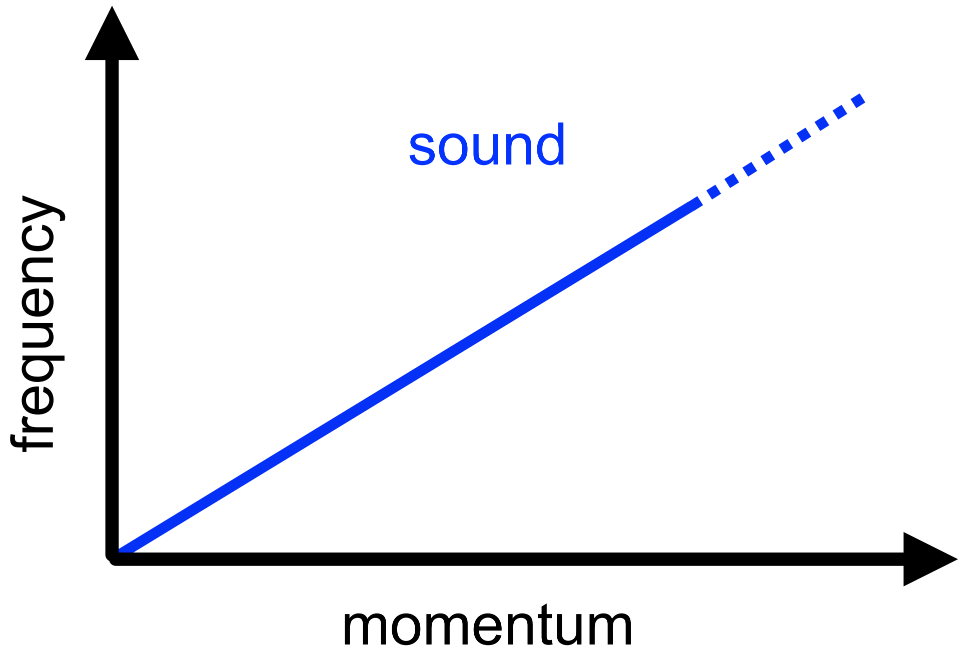
D PHYS

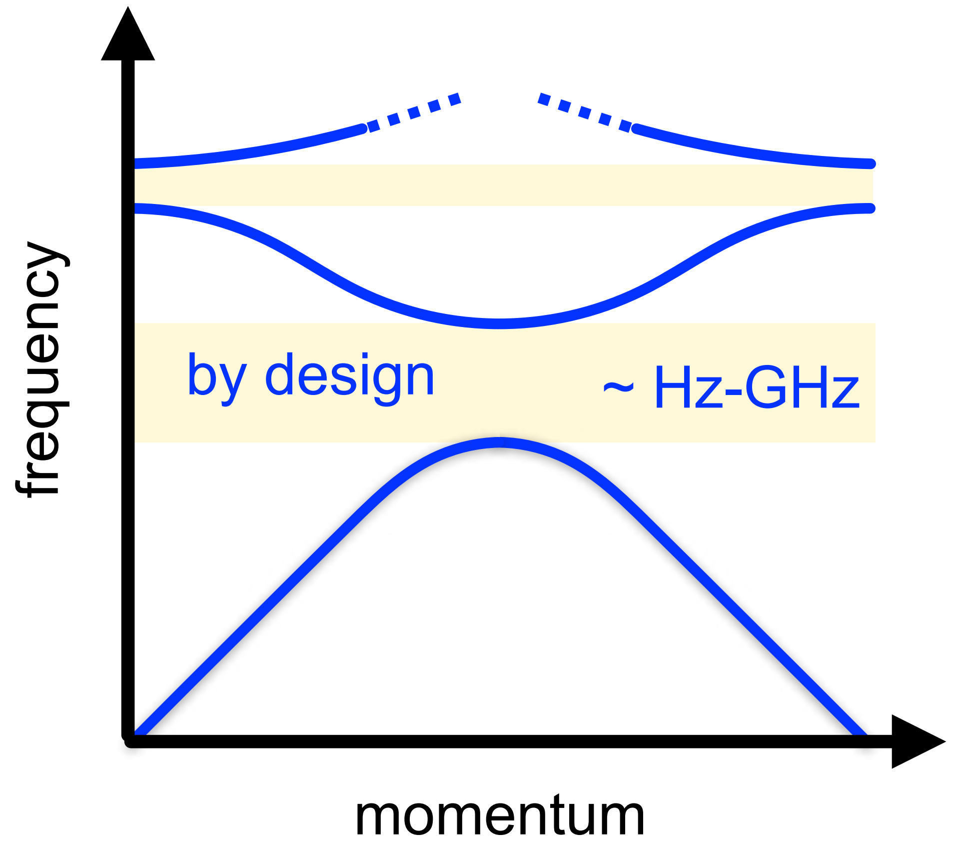
Acoustic metamaterials

$$\nabla^2 p - \frac{1}{v^2}\frac{\partial^2 p}{\partial t^2} = 0$$

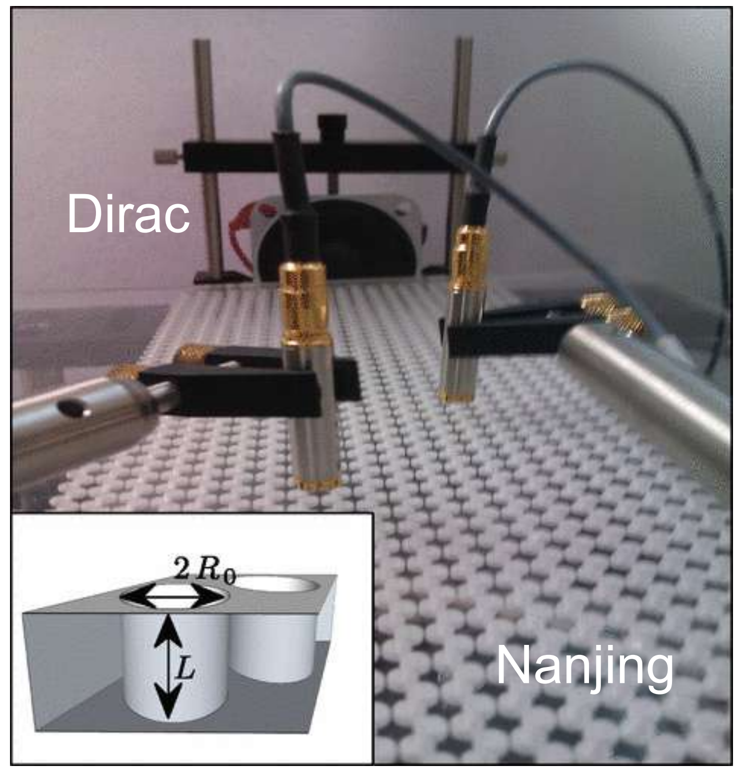


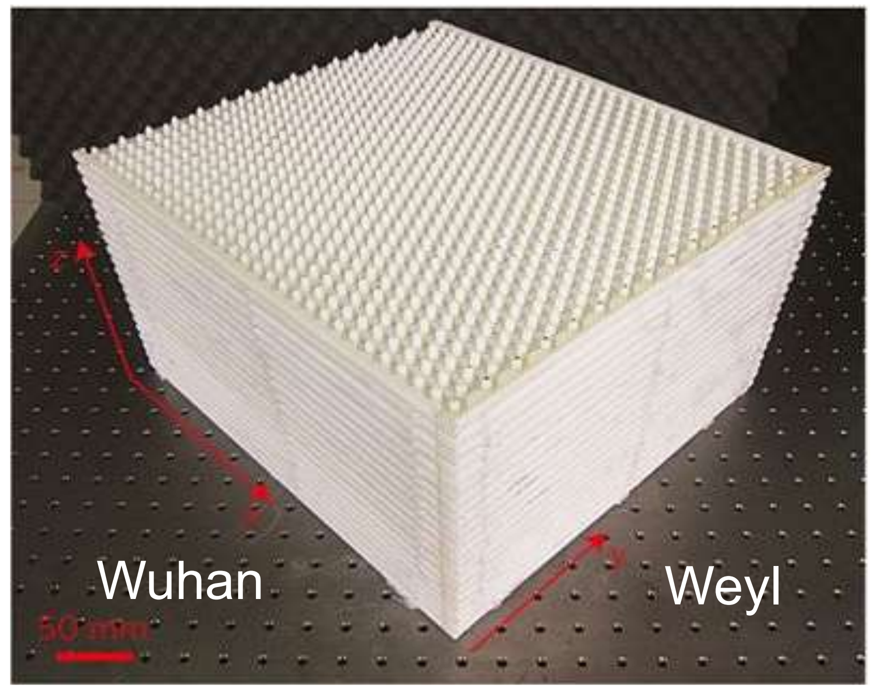
Eusebio Sempere - Madrid

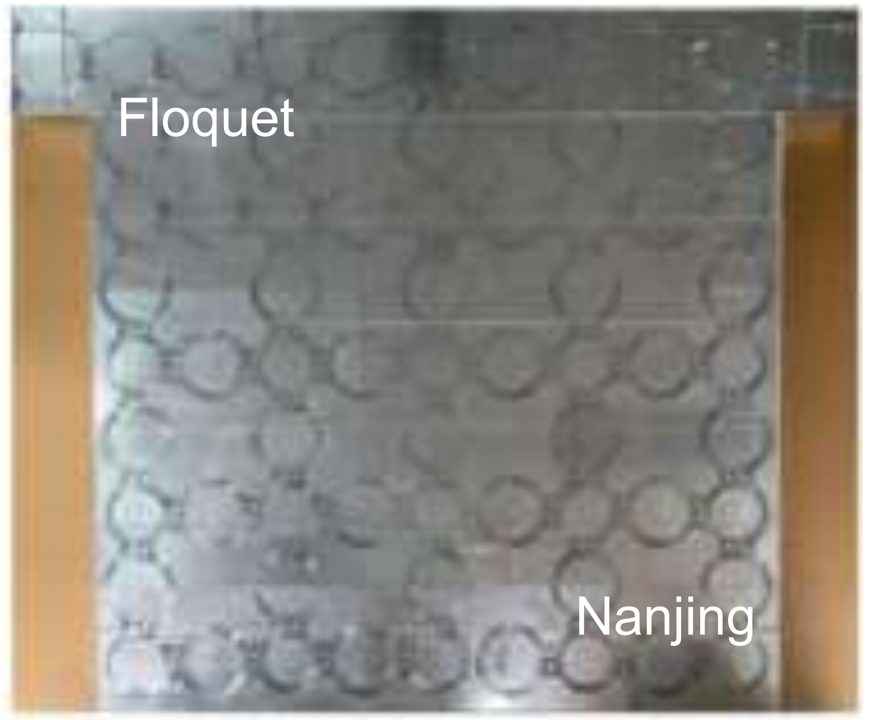


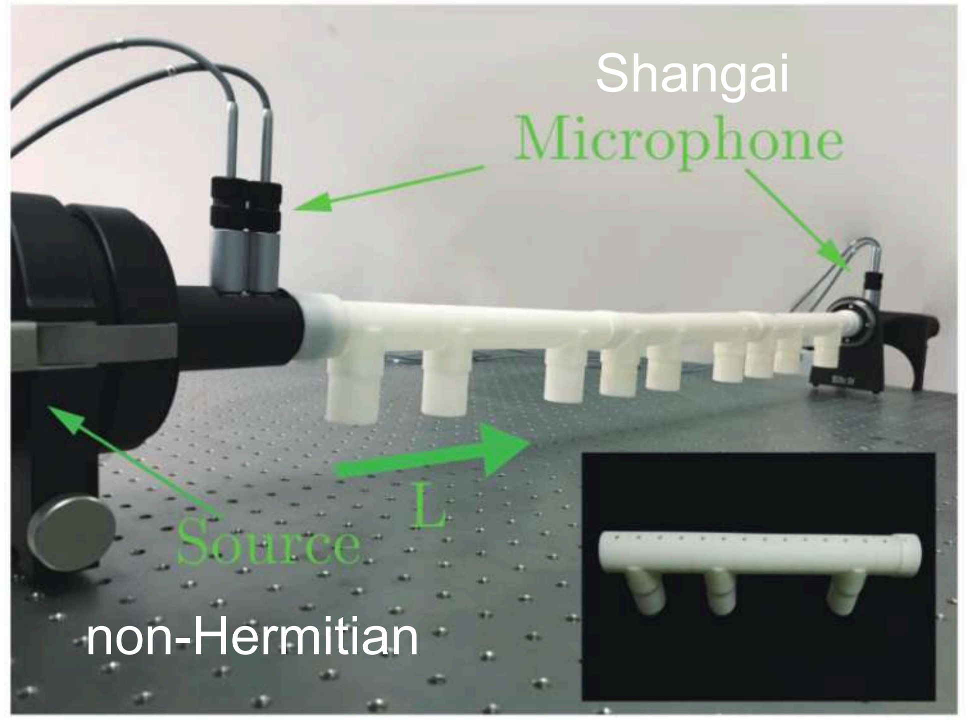


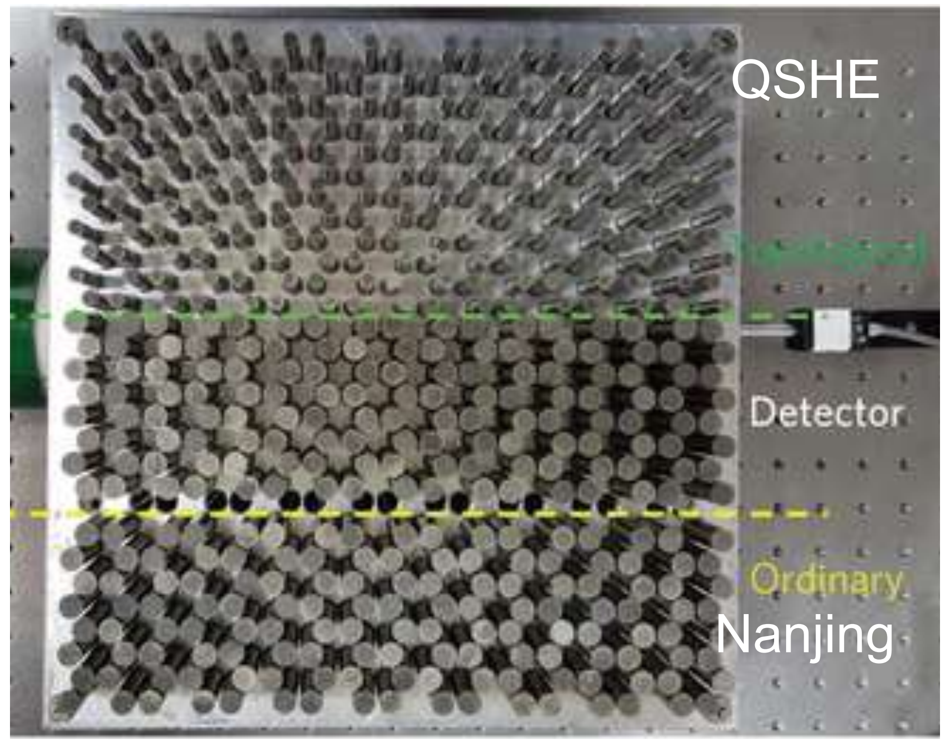
Topology in acoustic systems

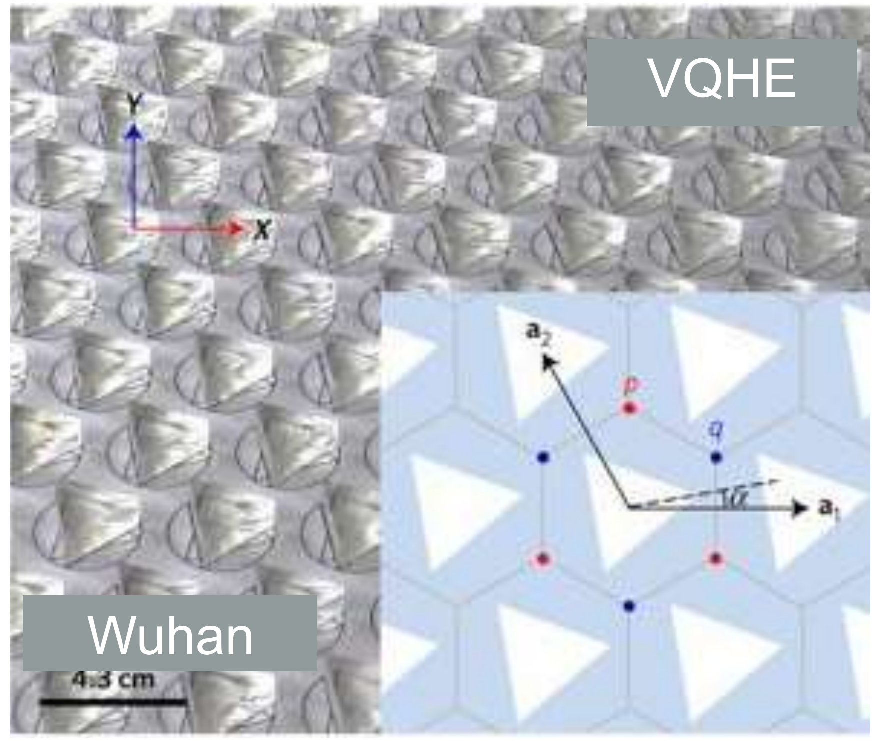






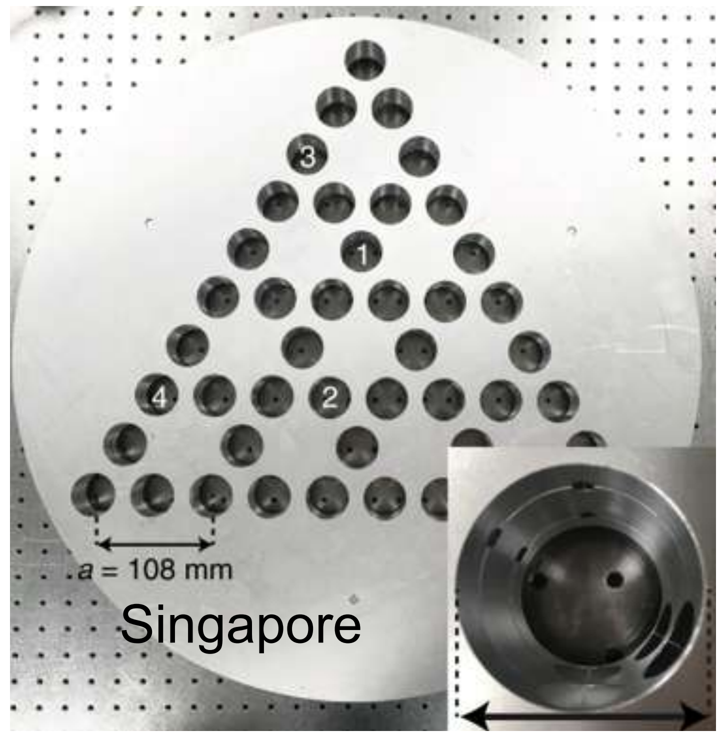






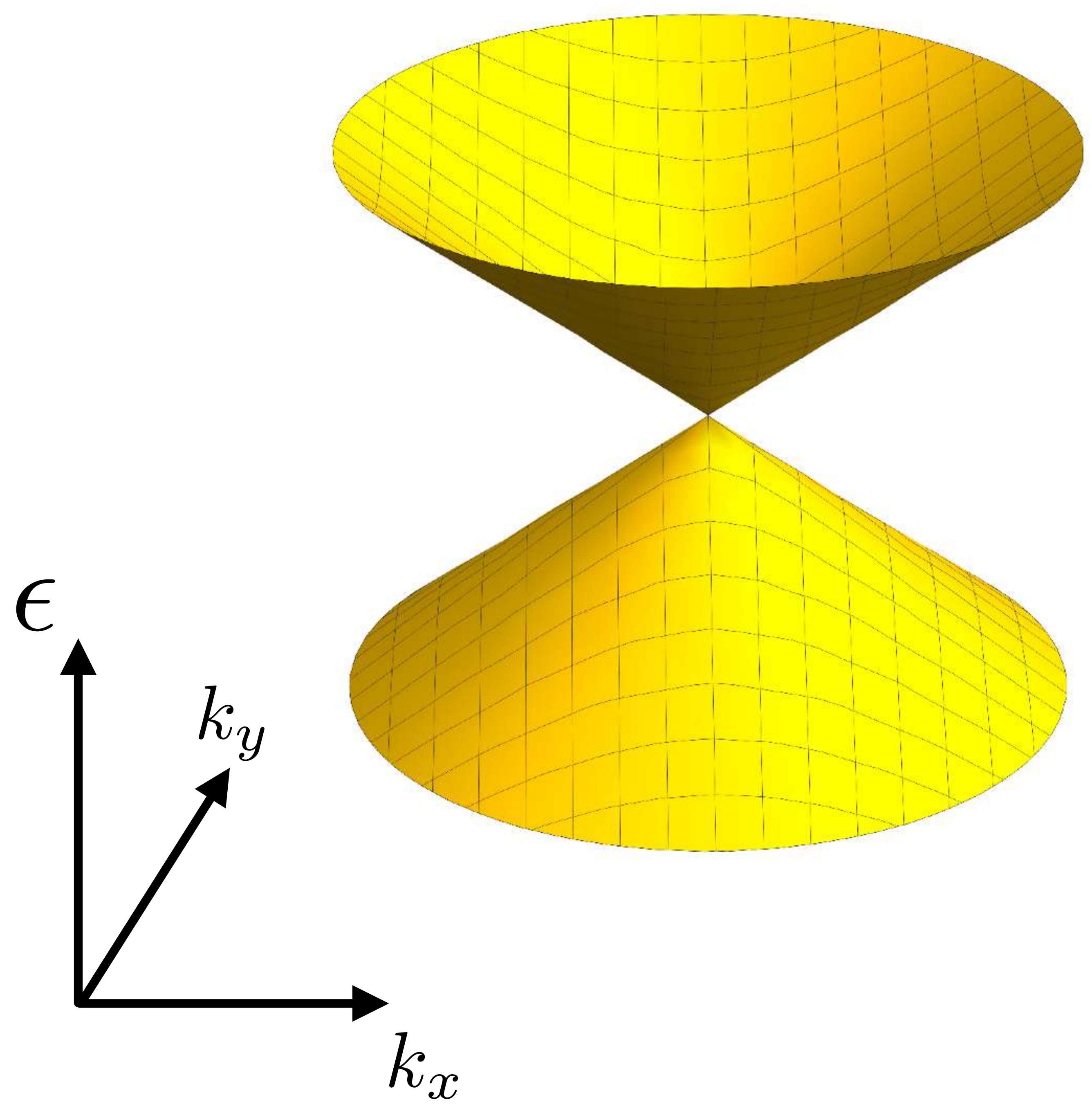
New York

HOTI



Ma, Xiao, CT Chan, Nature Physics Review (2019)

Weyl point



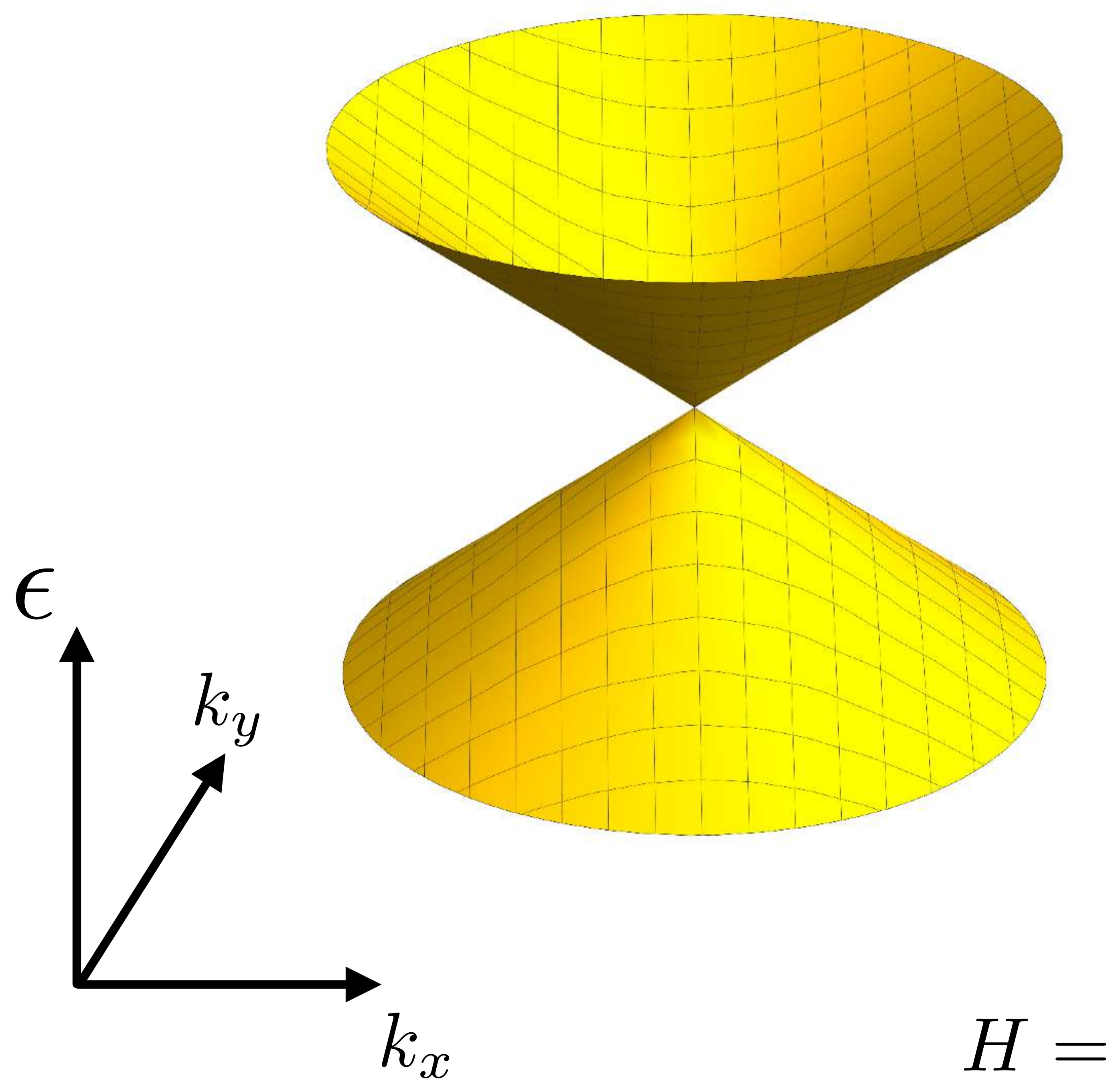
$$H = \begin{pmatrix} k_z & k_x - ik_y \\ k_x + ik_y & -k_z \end{pmatrix} = \mathbf{k} \cdot \boldsymbol{\sigma}$$

$$\epsilon = \pm\sqrt{k_x^2 + k_y^2 + k_z^2}$$

Like graphene in 3D…

…but different

Weyl point



$$H = \begin{pmatrix} k_z & k_x - ik_y \\ k_x + ik_y & -k_z \end{pmatrix} = \mathbf{k} \cdot \boldsymbol{\sigma}$$

$$\epsilon = \pm\sqrt{k_x^2 + k_y^2 + k_z^2}$$

$$H = \sum_{s=\pm} \sum_{i,j=x,y,z} s v_{ij}(k_i + s b_i)\sigma^j \qquad s = \mathrm{sgn}[\det(v_{ij})]$$

Like graphene in 3D…

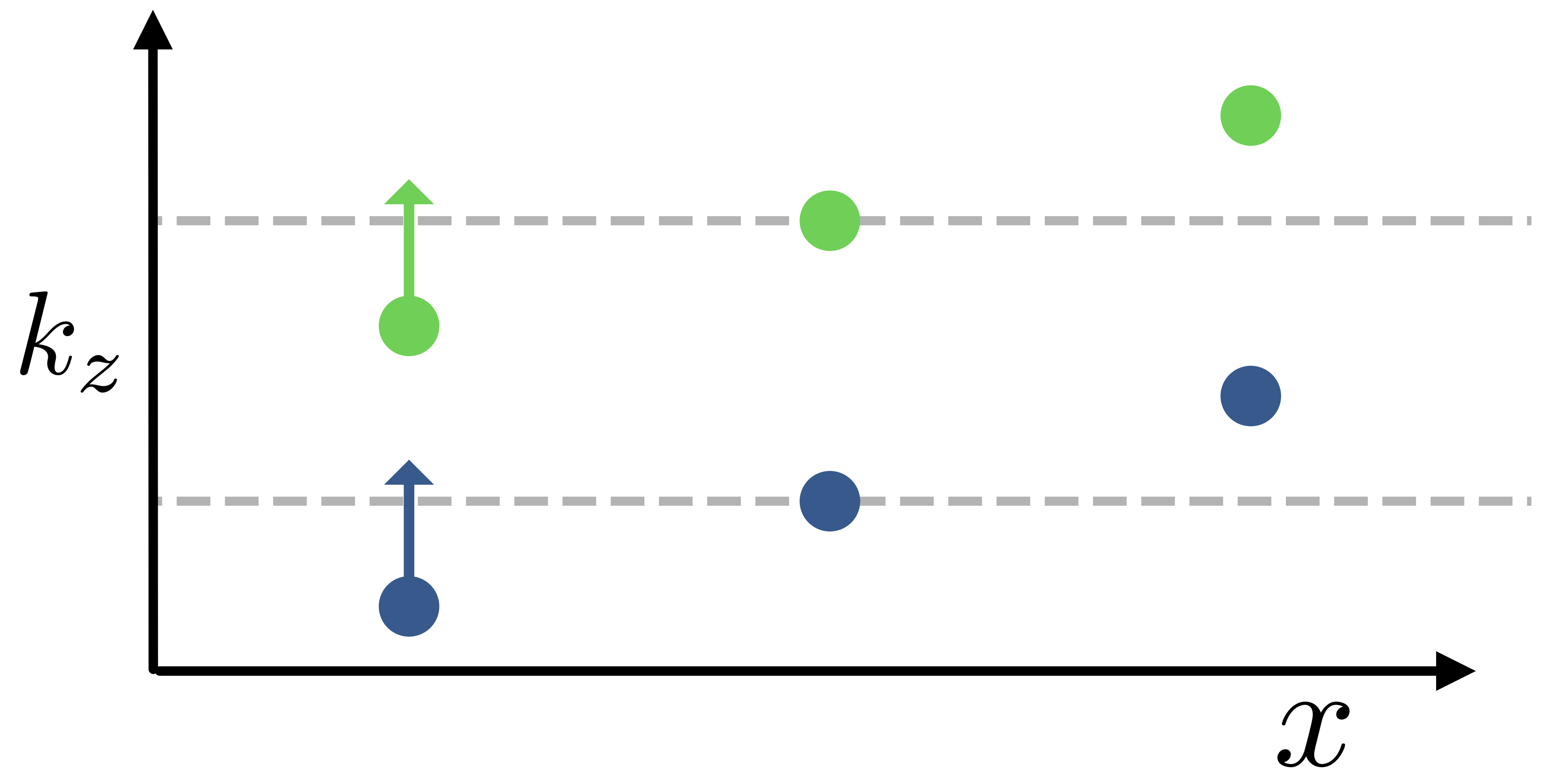
…but different

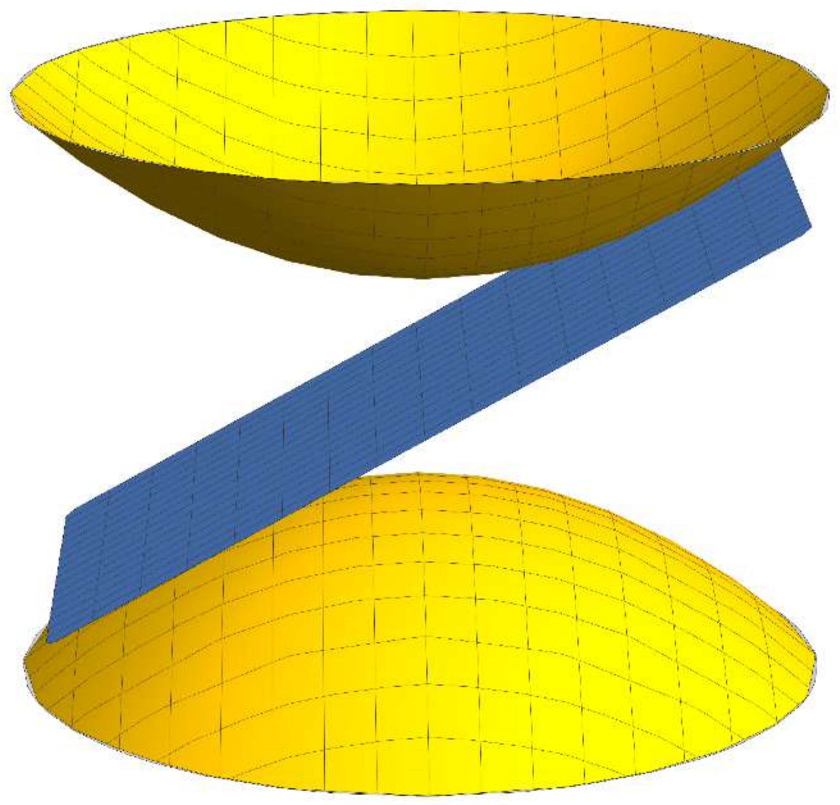
Adding a magnetic field

$$H = \frac{1}{2m}\left(\mathbf{p} + e\mathbf{A}\right)^2$$

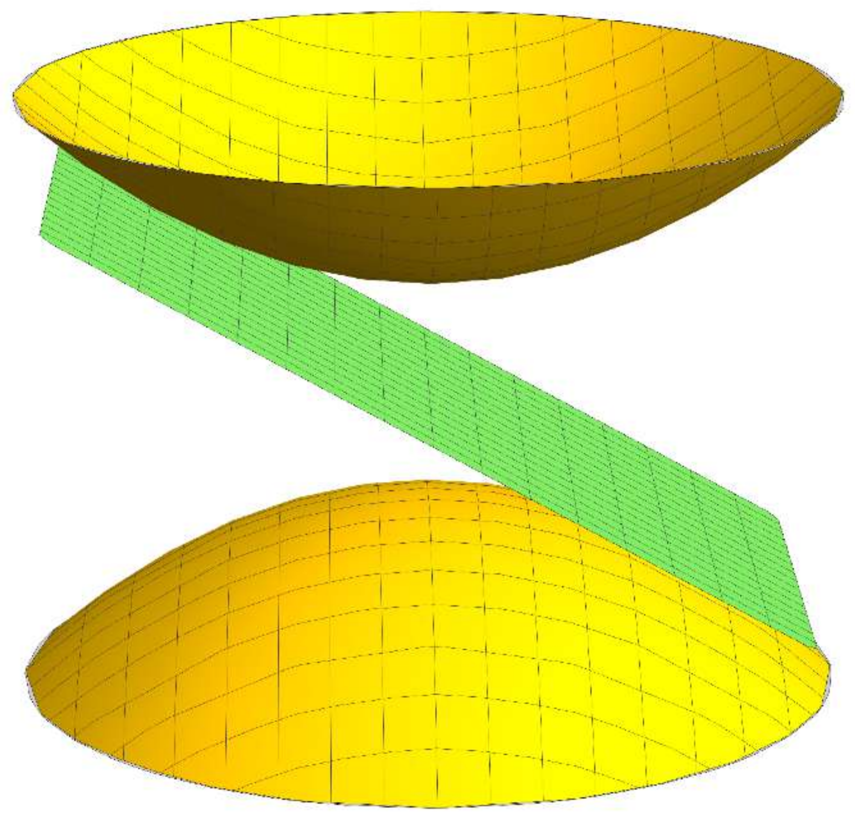
Minimal coupling

$$k_z \to k_z + Bx$$





Chiral Landau levels along the field direction



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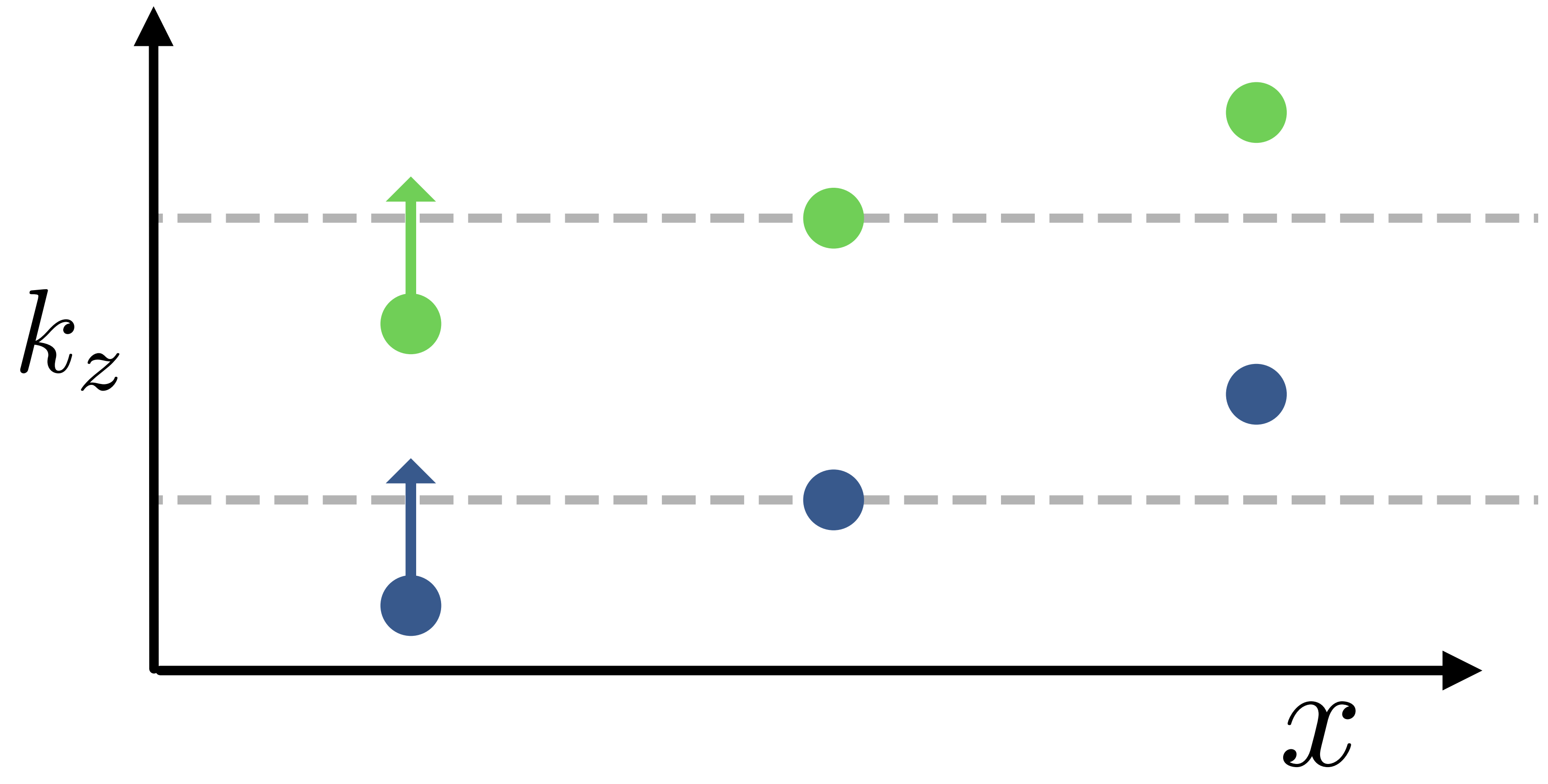
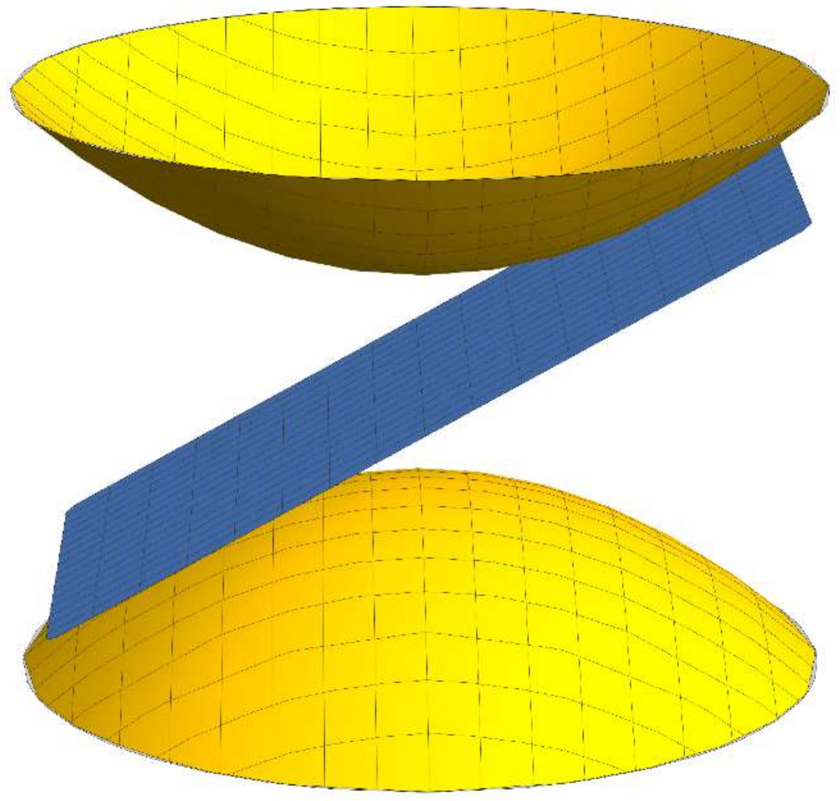
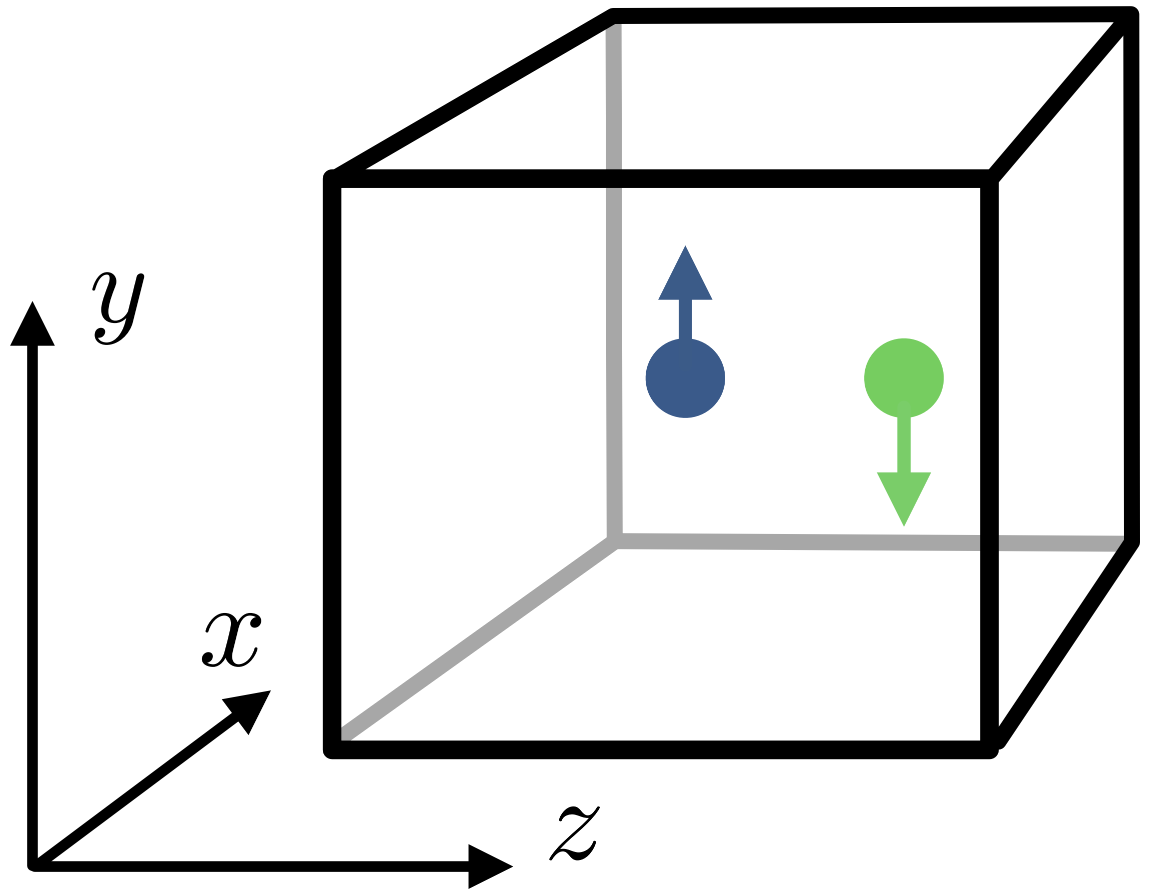
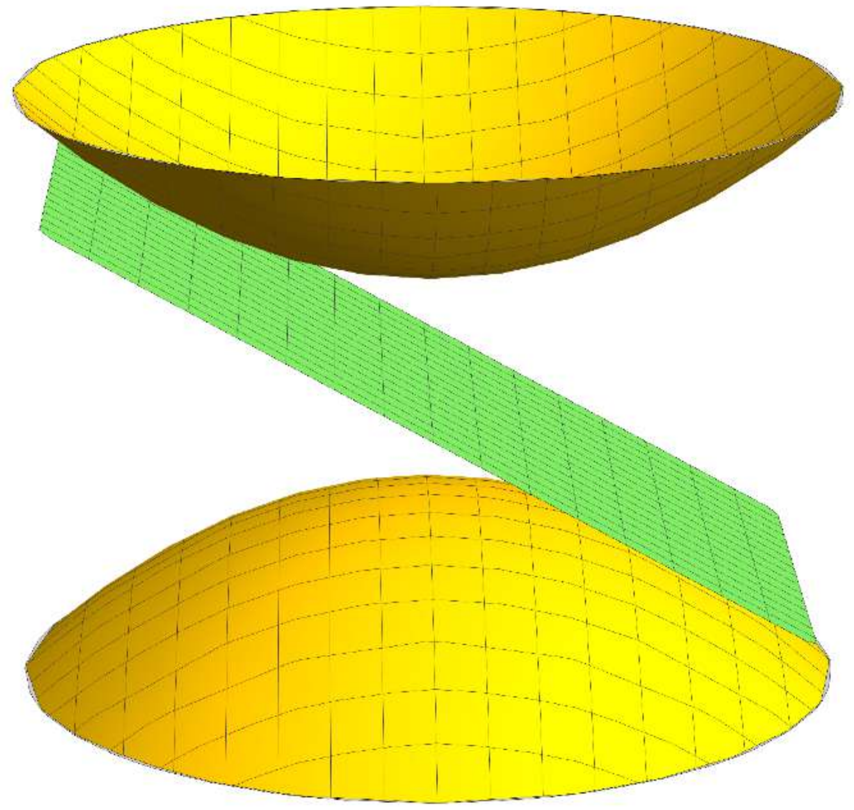


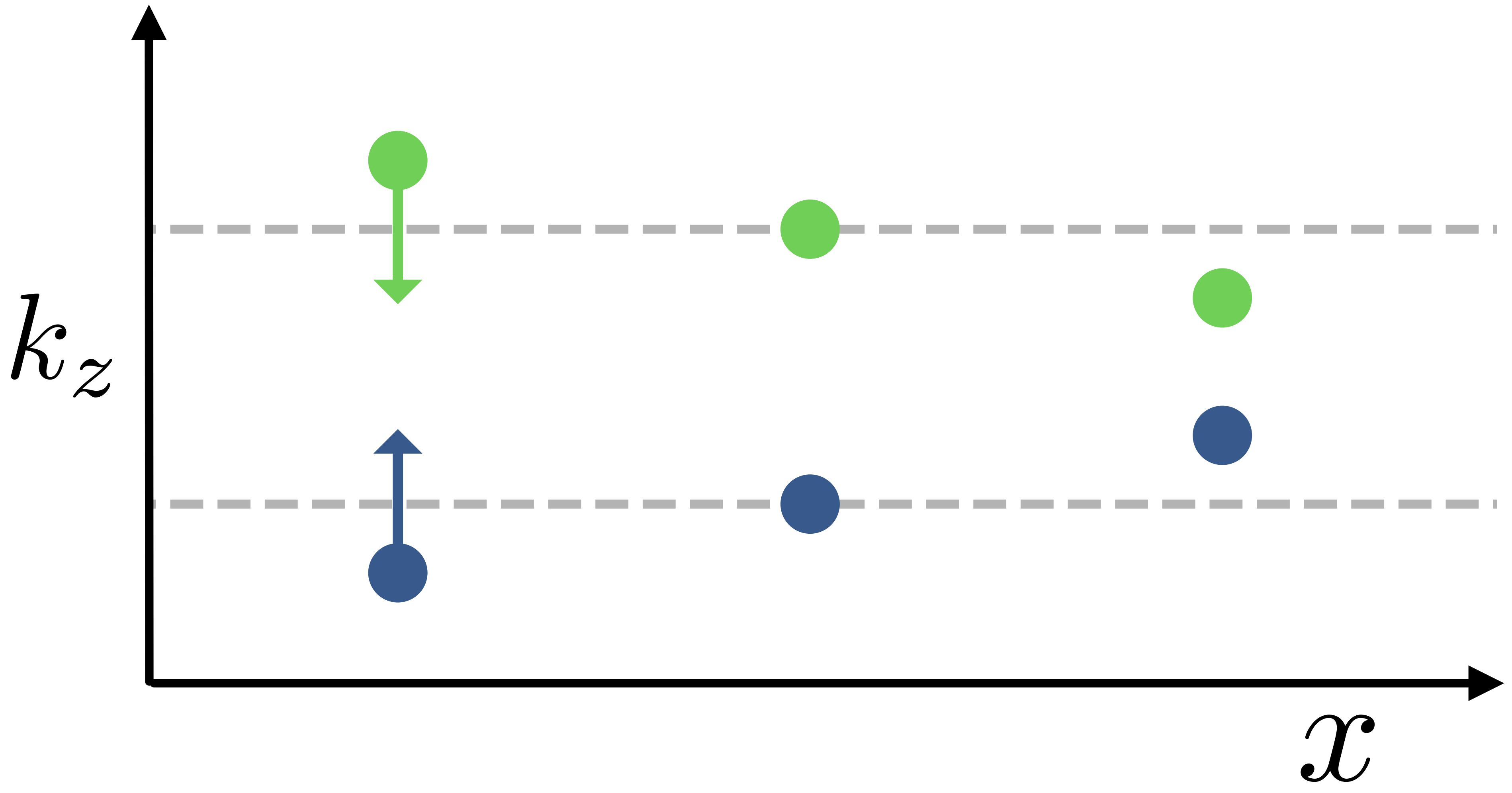






Weyl + Axial field

$$k_z \to k_z + sBx$$



Weyl + Axial field

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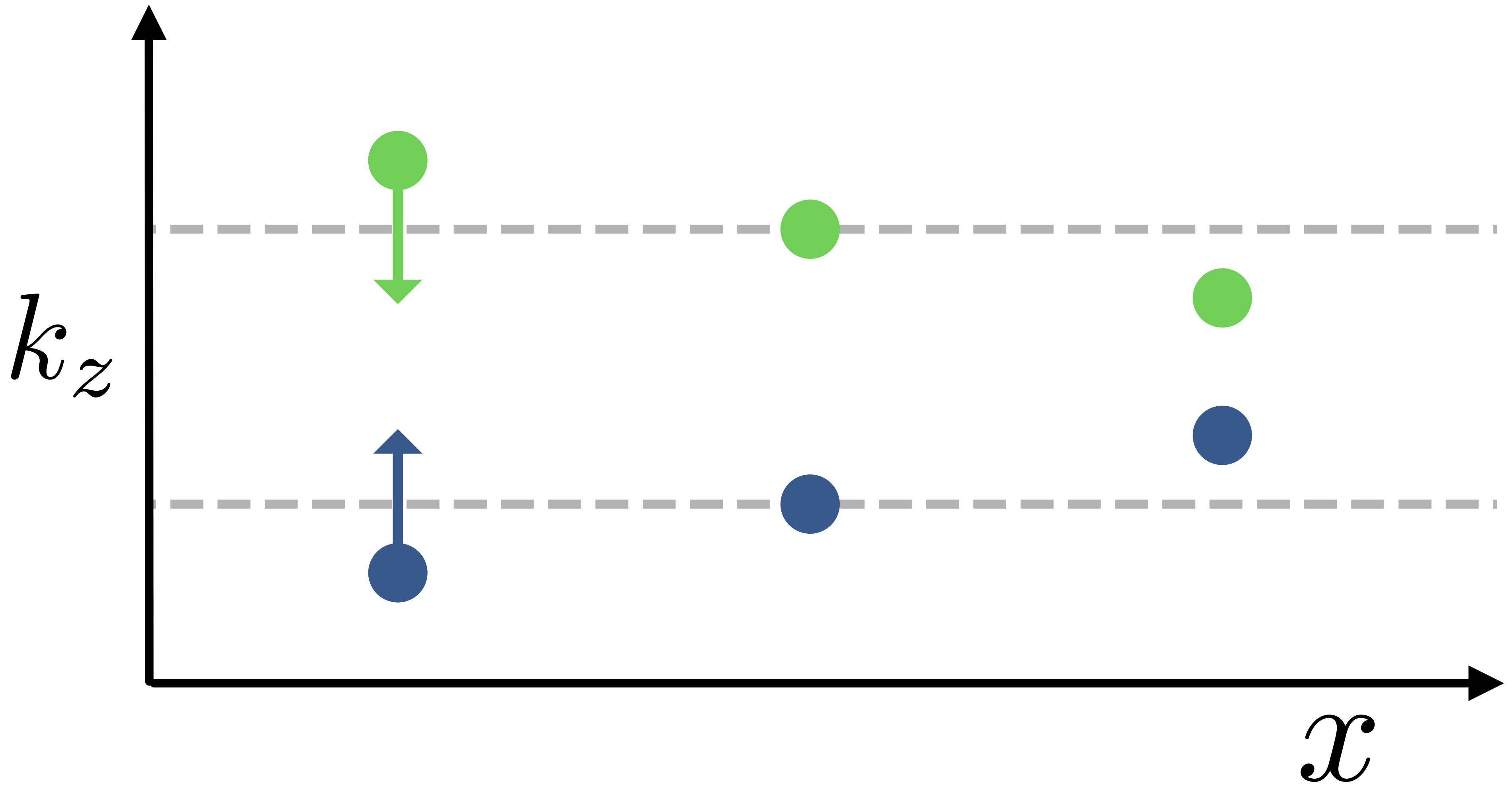
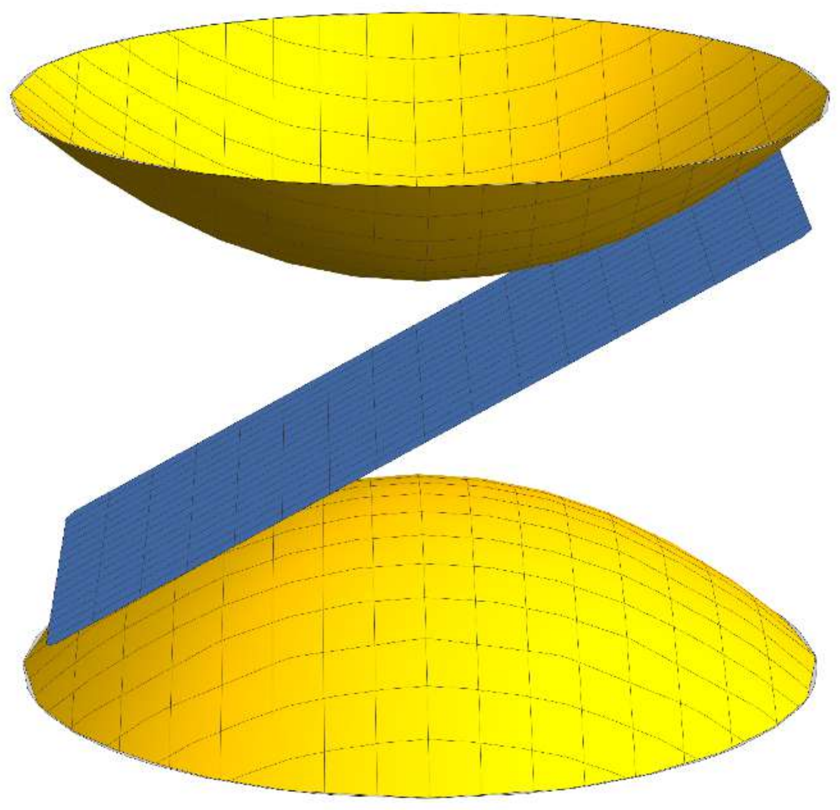
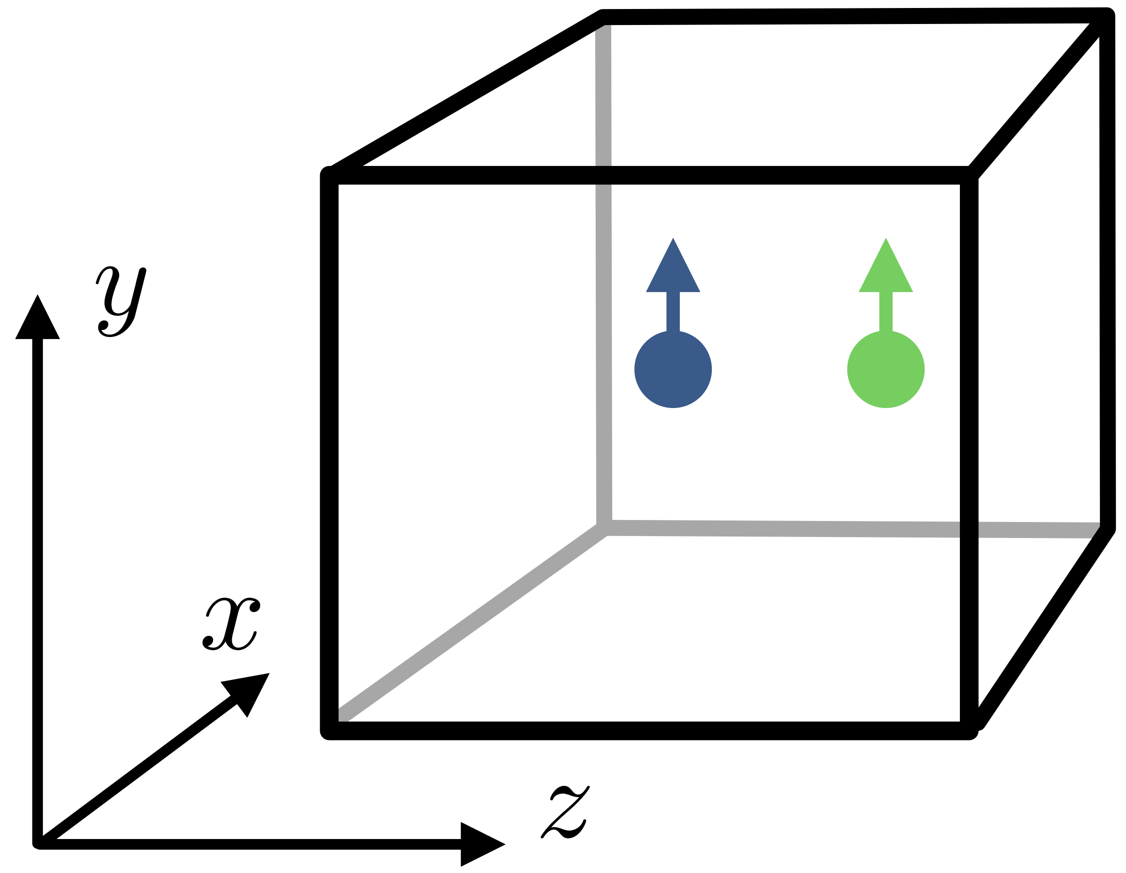
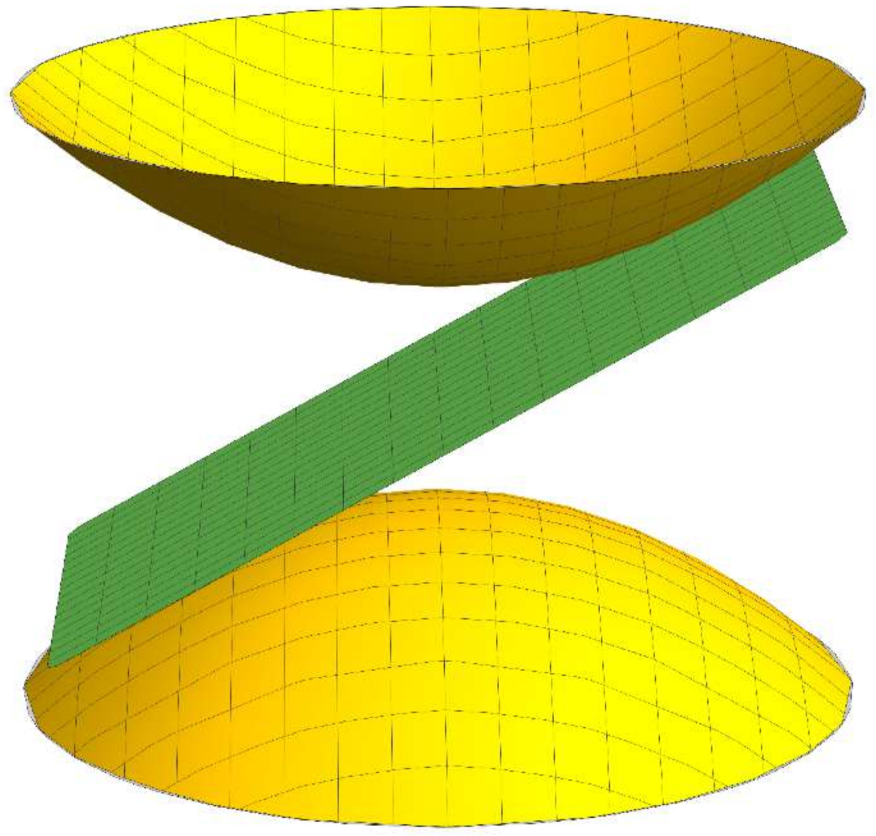


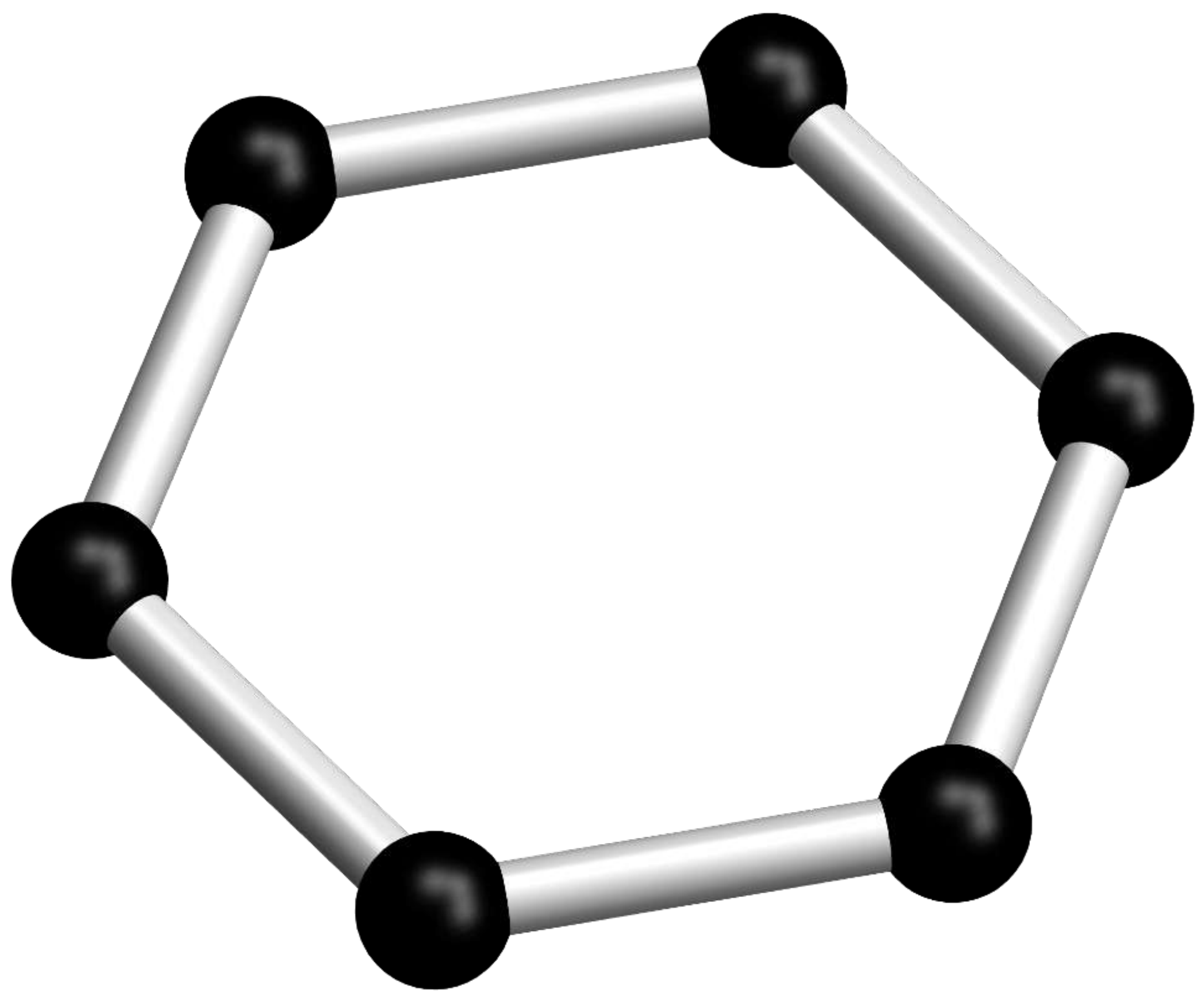




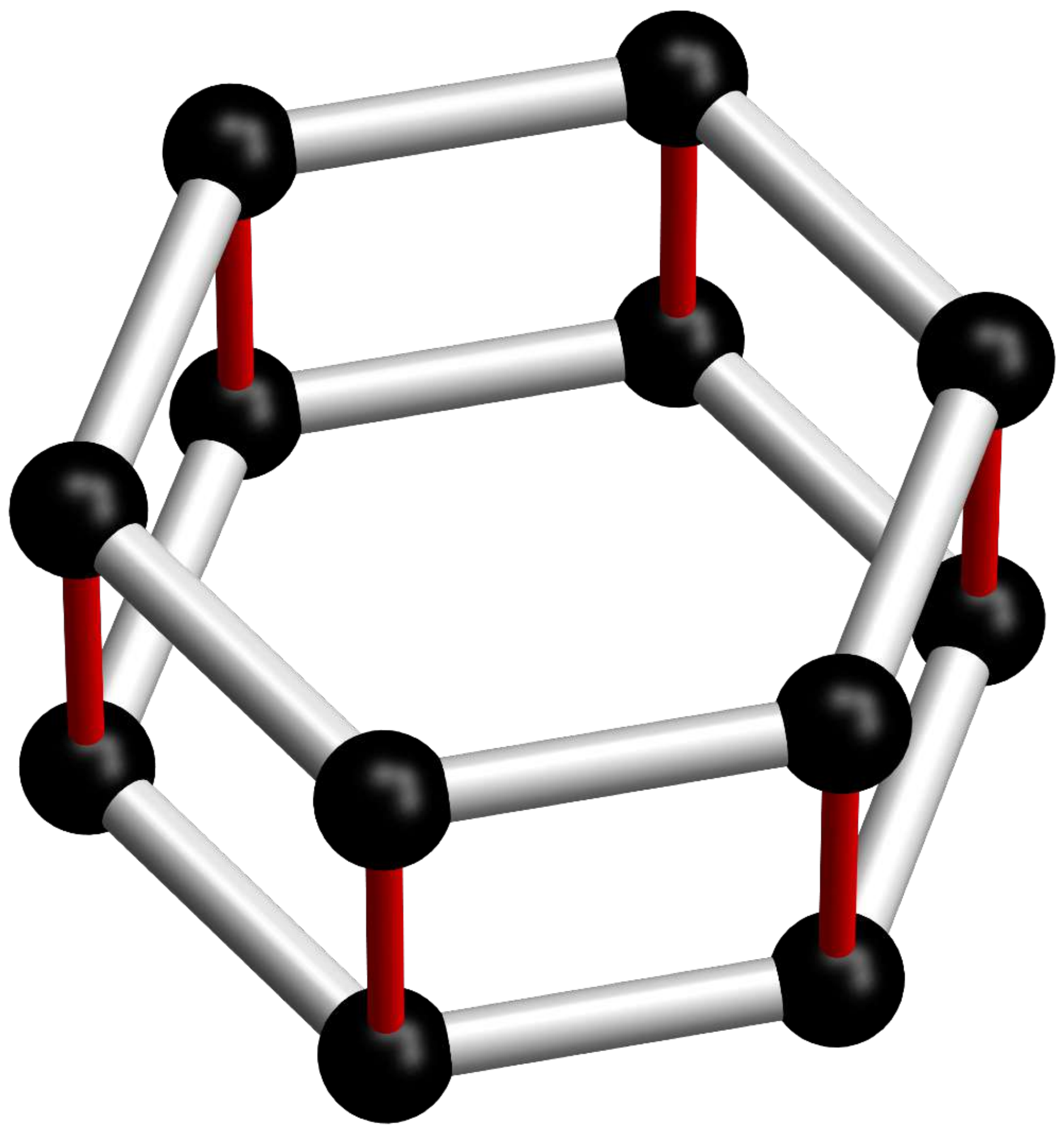


Ilan, Grushin, Pikulin - arXiv:1903.11088

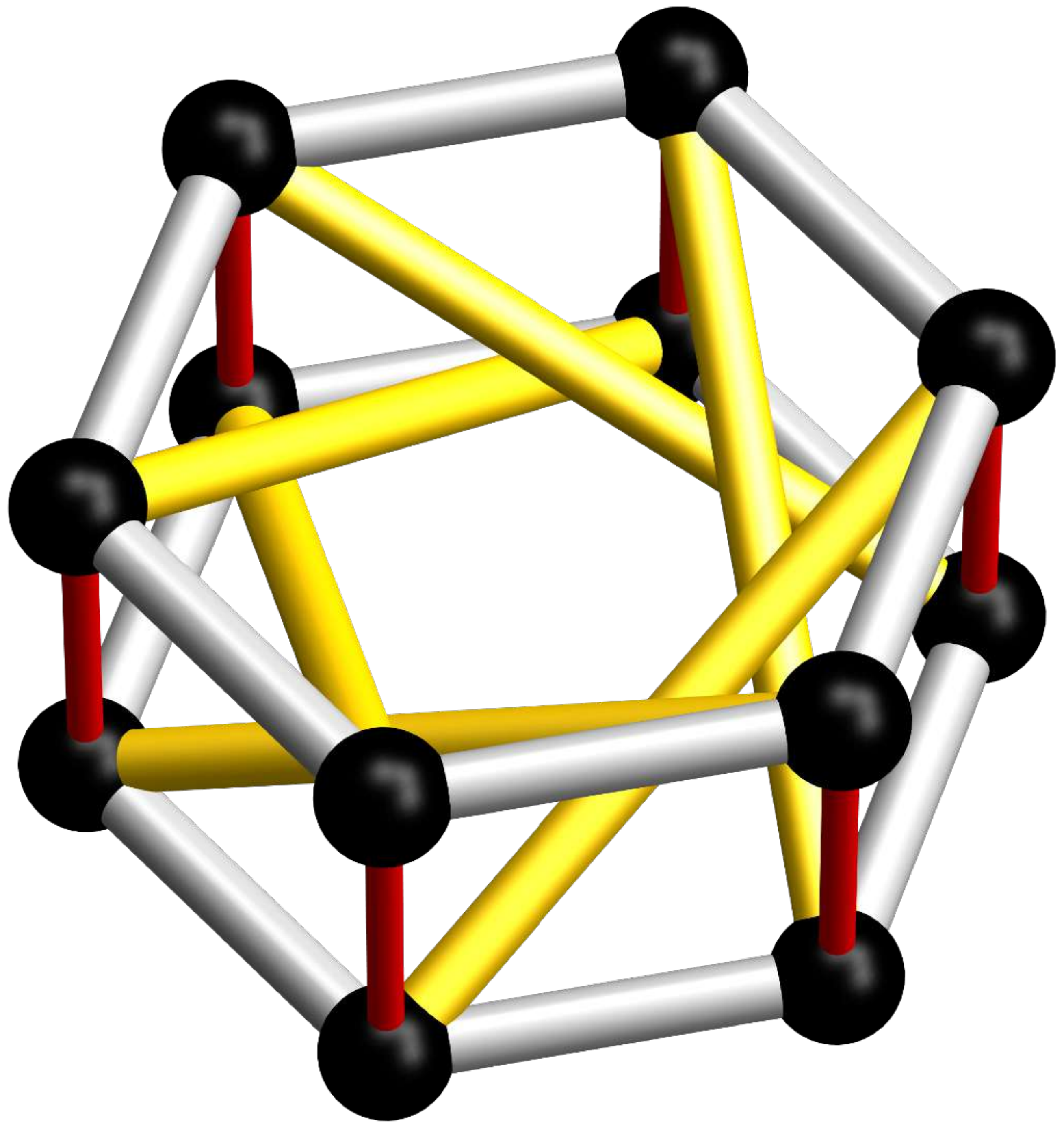
Tight-binding model



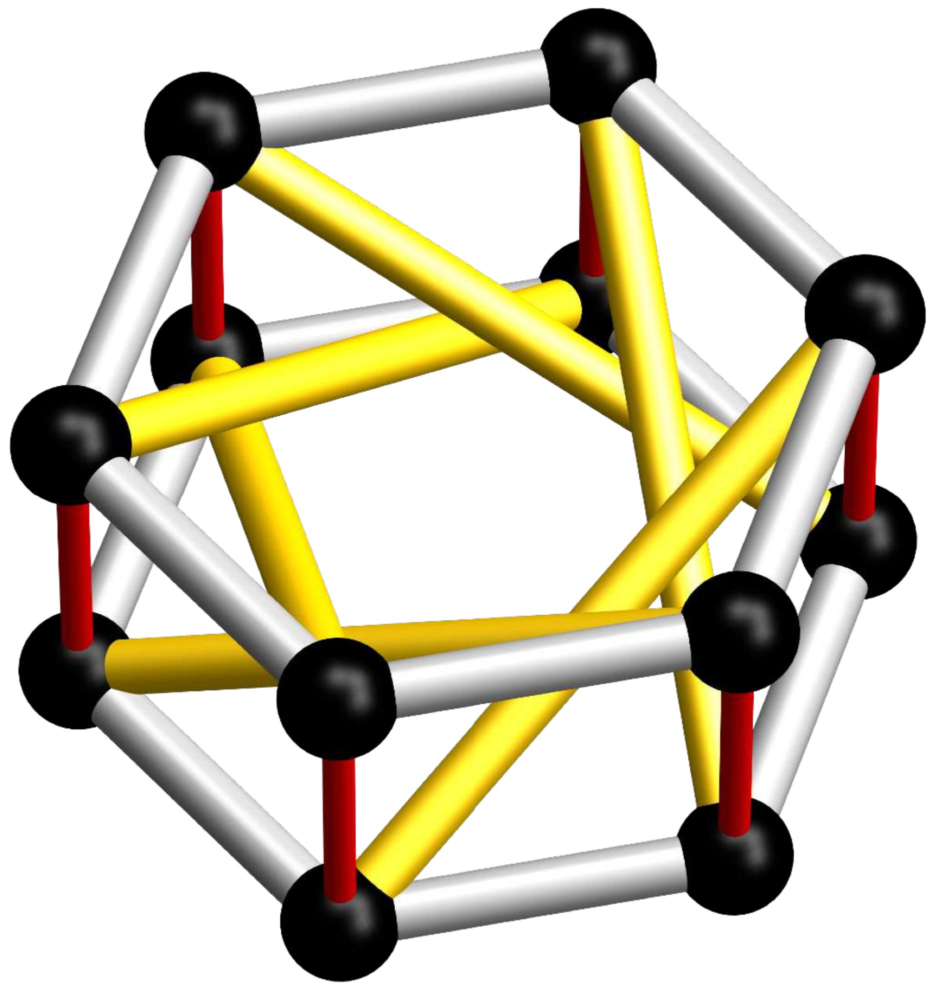
Tight-binding model



Tight-binding model



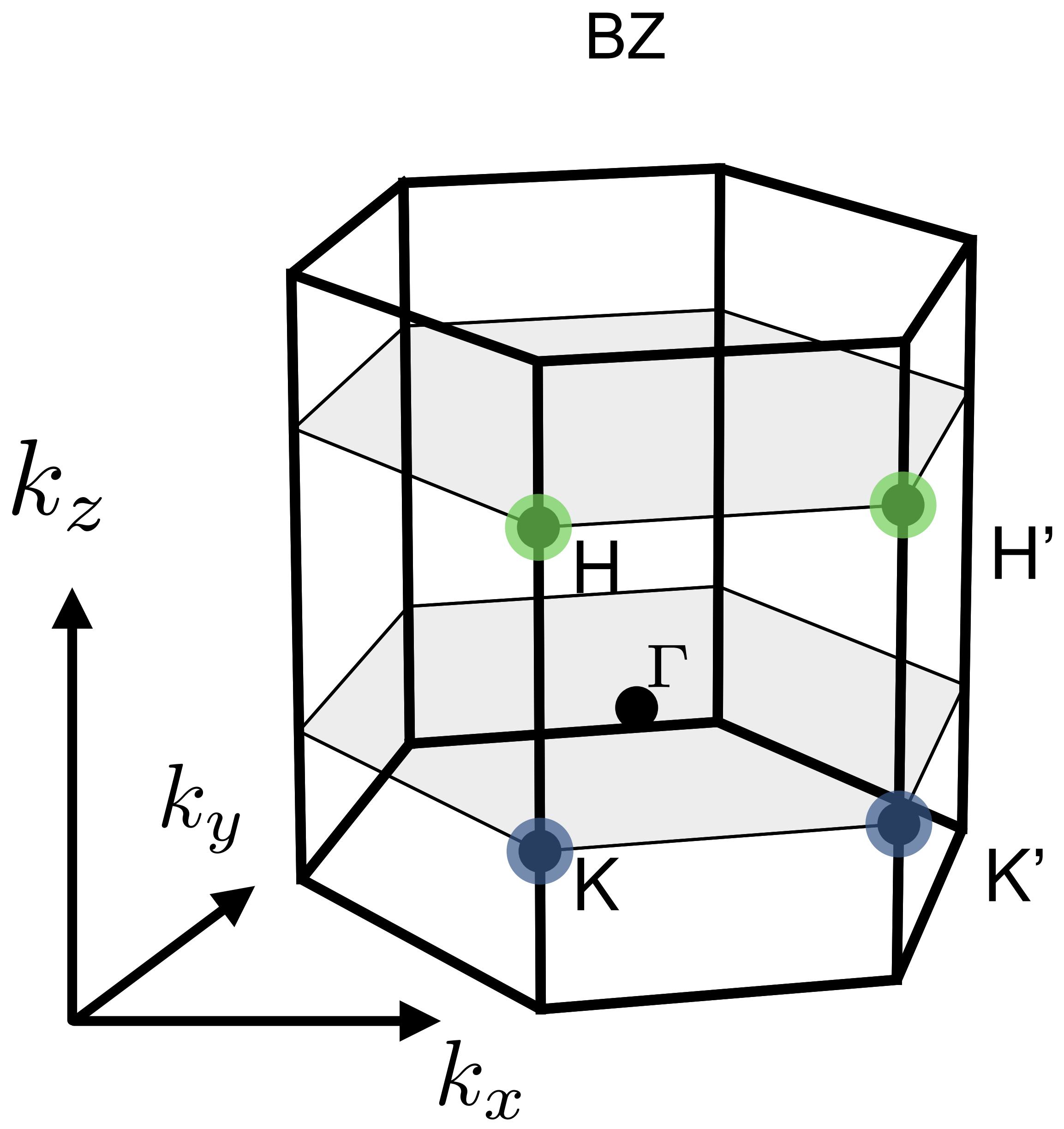
Tight-binding model



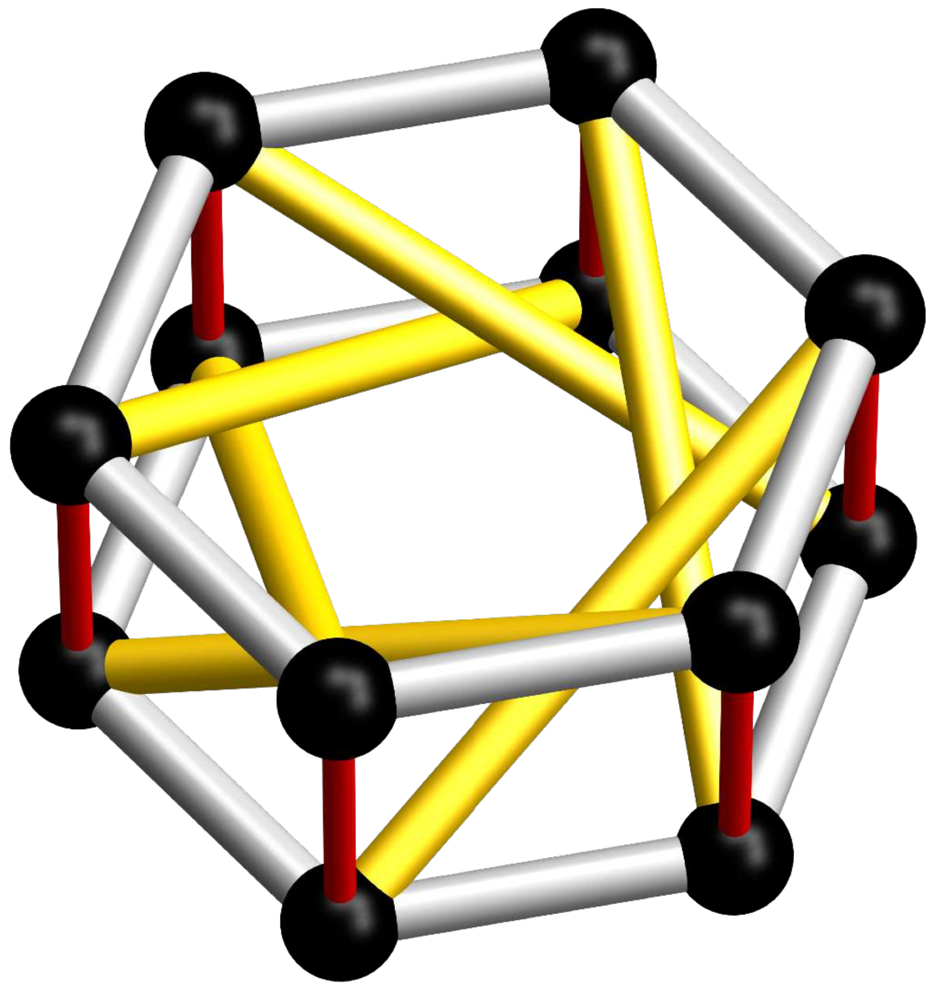
Low energy:

$$v_{ij}^{K} = \begin{pmatrix} 0 & \sqrt{3}t_n/2 & 0 \\ \sqrt{3}t_n/2 & 0 & 0 \\ 0 & 0 & +3\sqrt{3}t_c \end{pmatrix}$$ at K (+)

$$v_{ij}^{H} = \begin{pmatrix} 0 & \sqrt{3}t_n/2 & 0 \\ \sqrt{3}t_n/2 & 0 & 0 \\ 0 & 0 & -3\sqrt{3}t_c \end{pmatrix}$$ at H (-)



Tight-binding model



Low energy:

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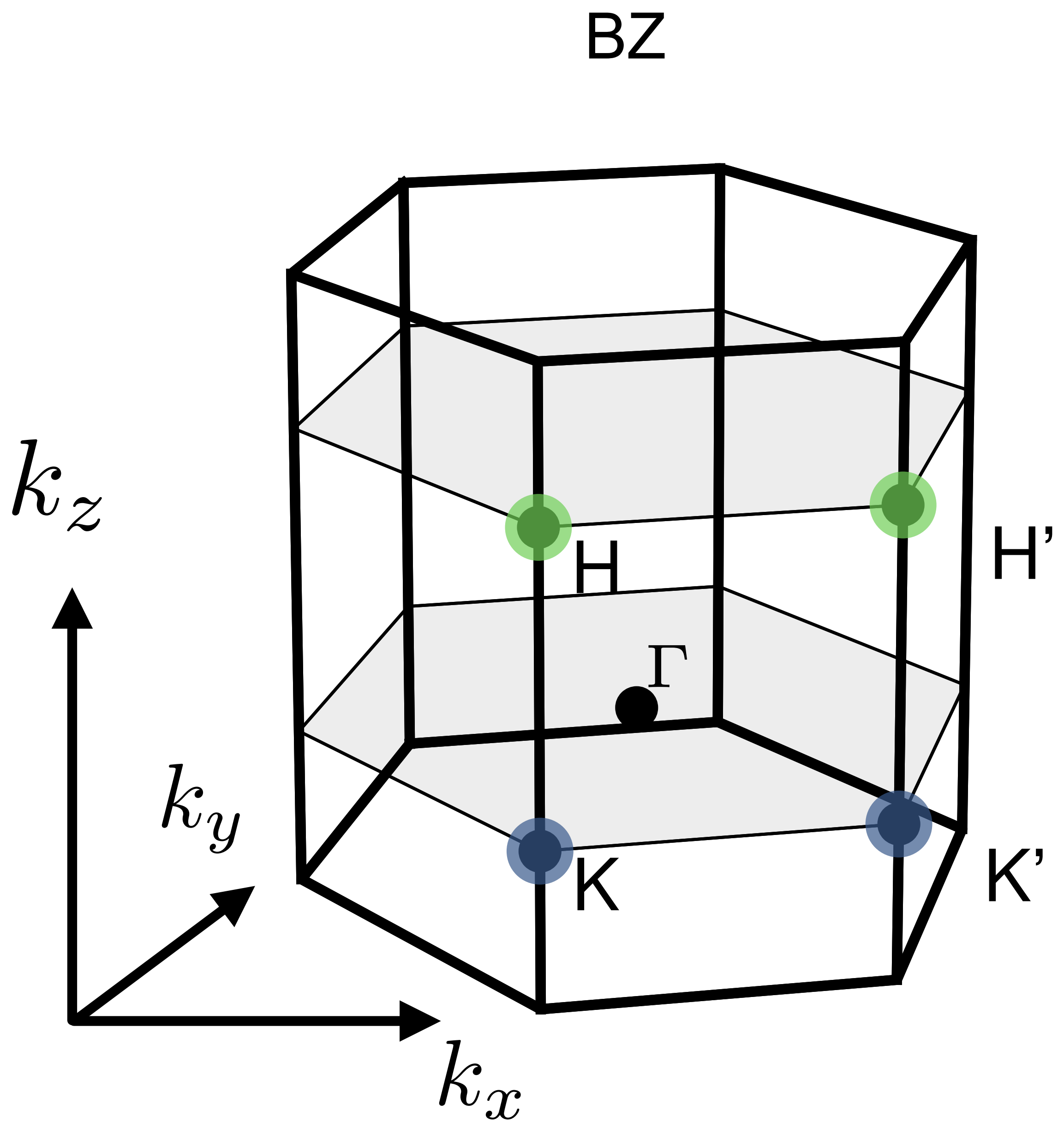
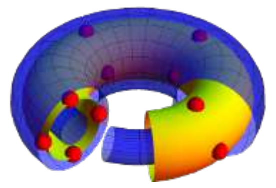
$$v_{ij}^{H} = \begin{pmatrix} 0 & \sqrt{3}t_n/2 & 0 \\ \sqrt{3}t_n/2 & 0 & 0 \\ 0 & 0 & -3\sqrt{3}t_c \end{pmatrix}$$ at H (-)



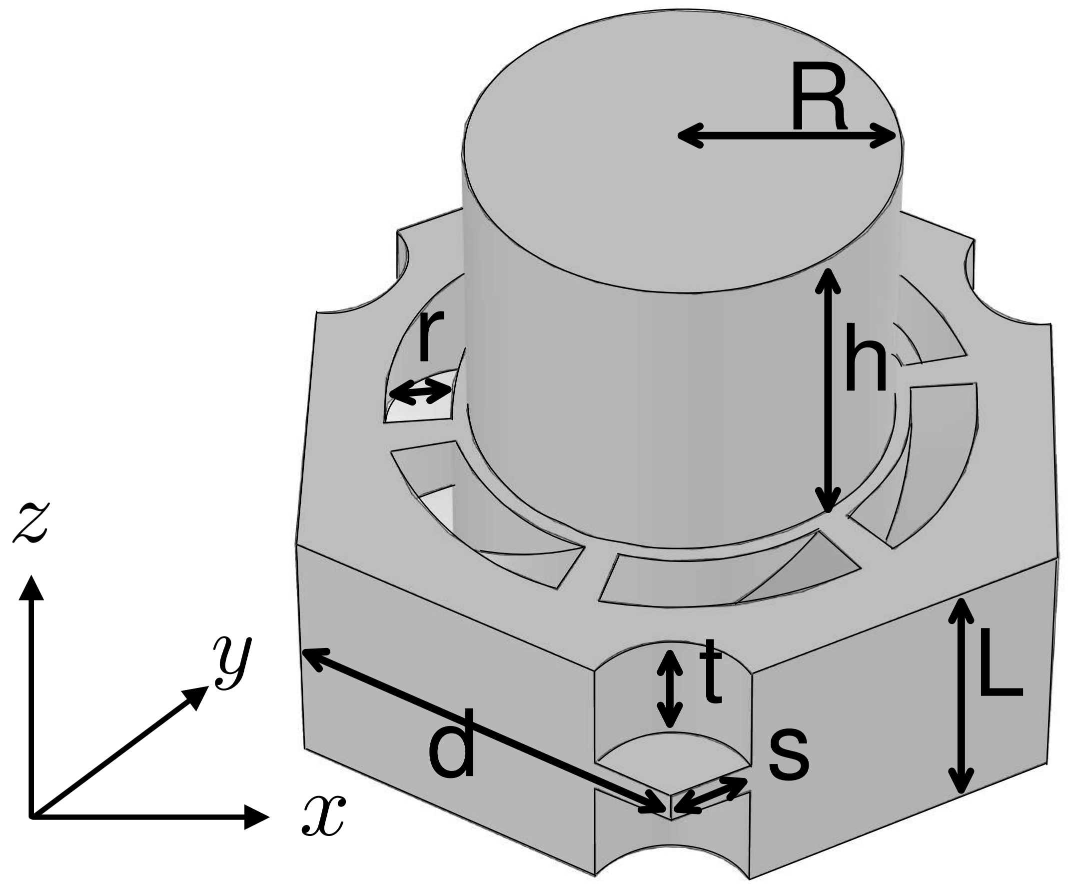
Axial field:

$$Bx\sigma^z$$

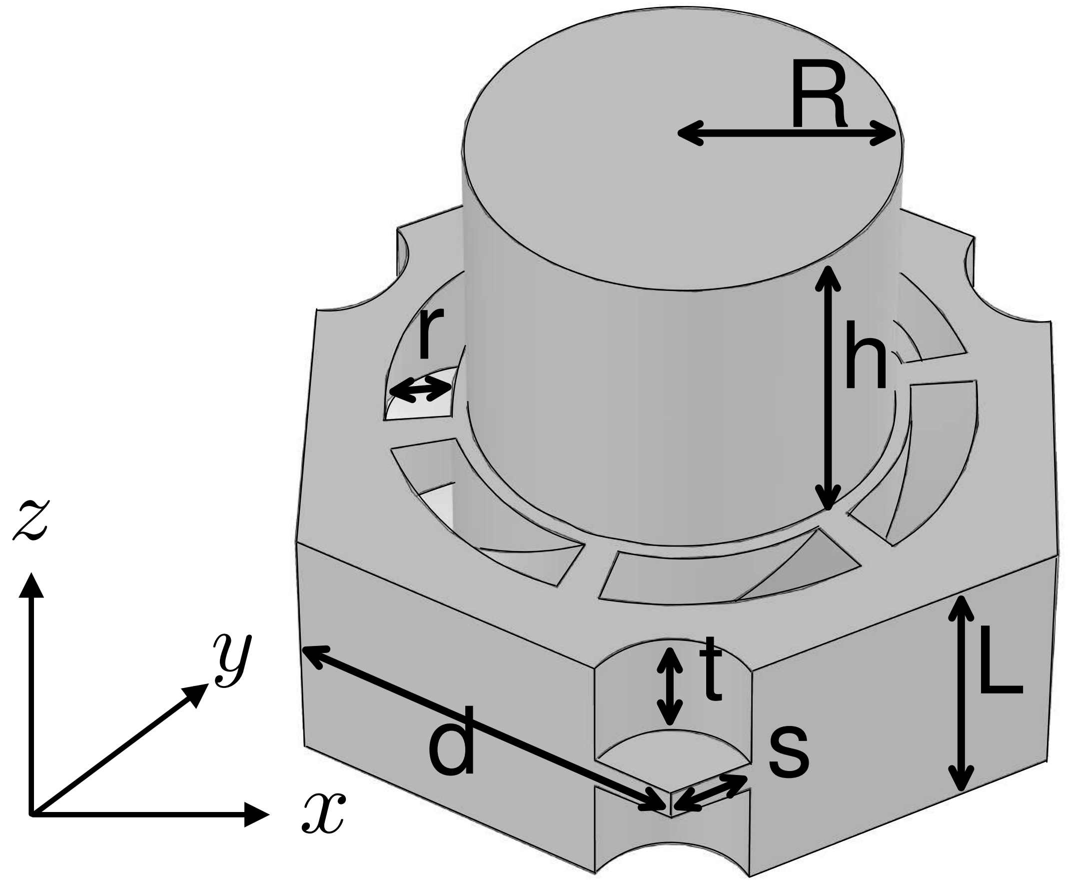
$$k_z \to k_z + sBx$$

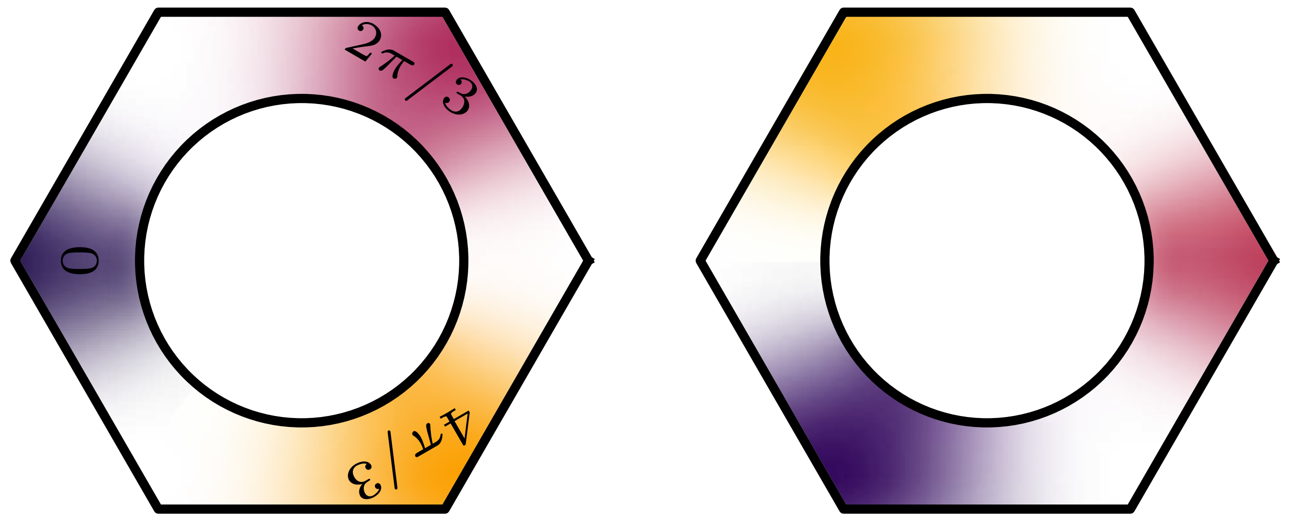


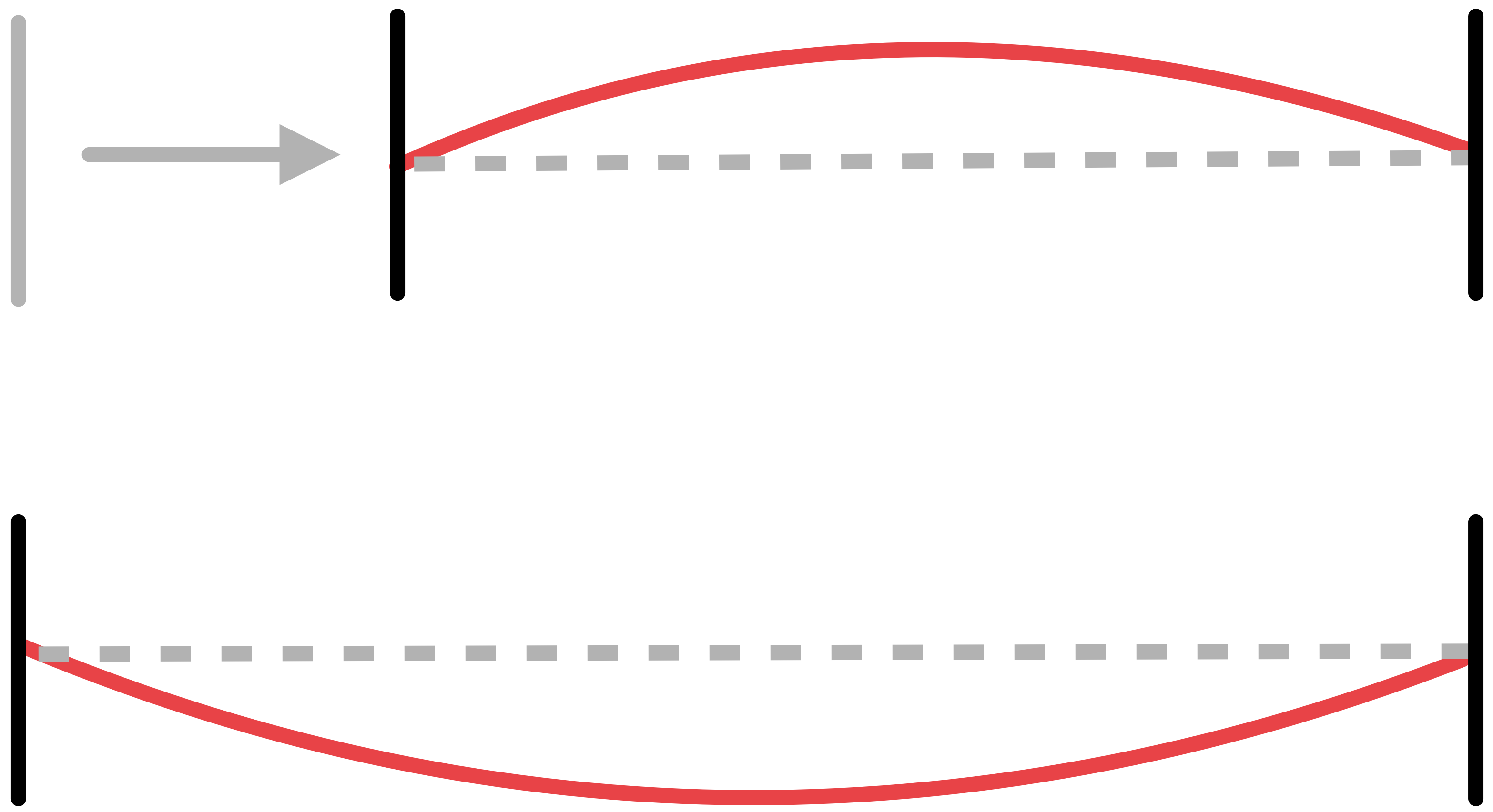
Acoustic metamaterial



Acoustic metamaterial



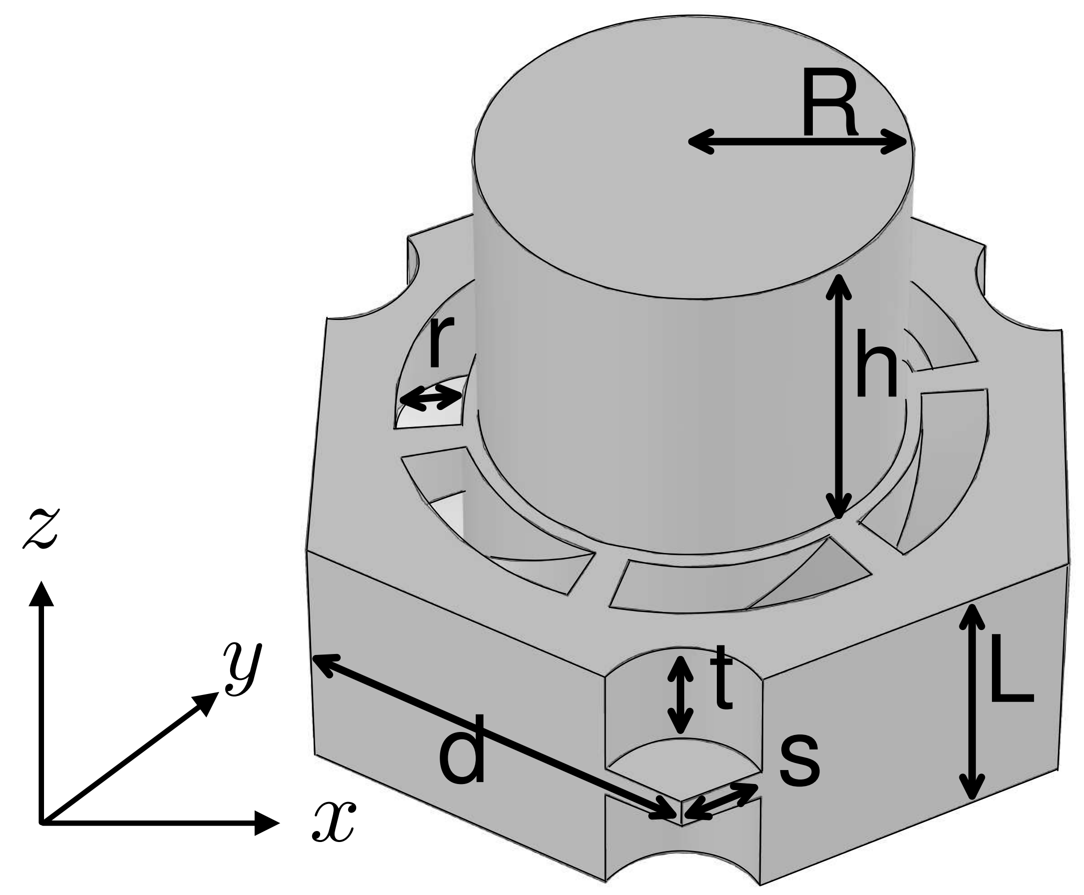




Gradient along x of the radius s
of the sublattice holes

$$k_z \to k_z + sBx$$

Acoustic metamaterial



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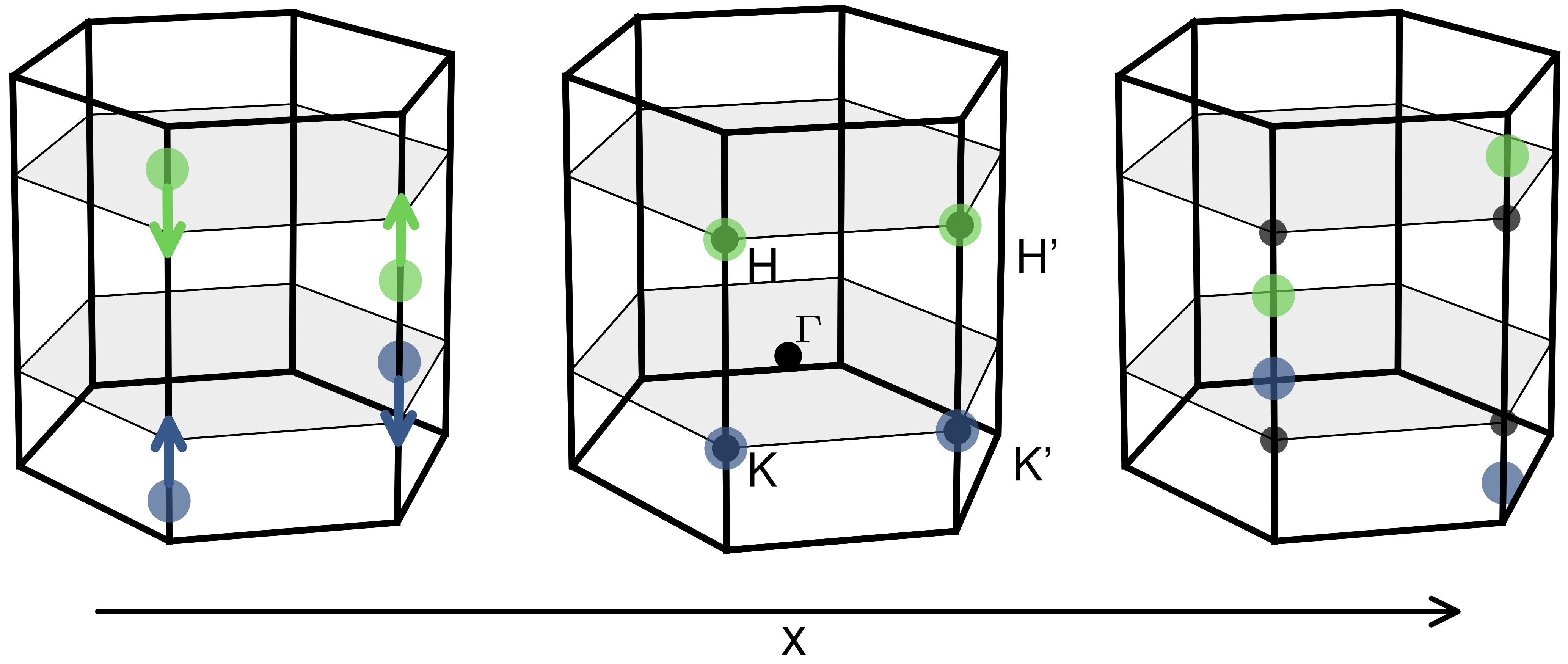
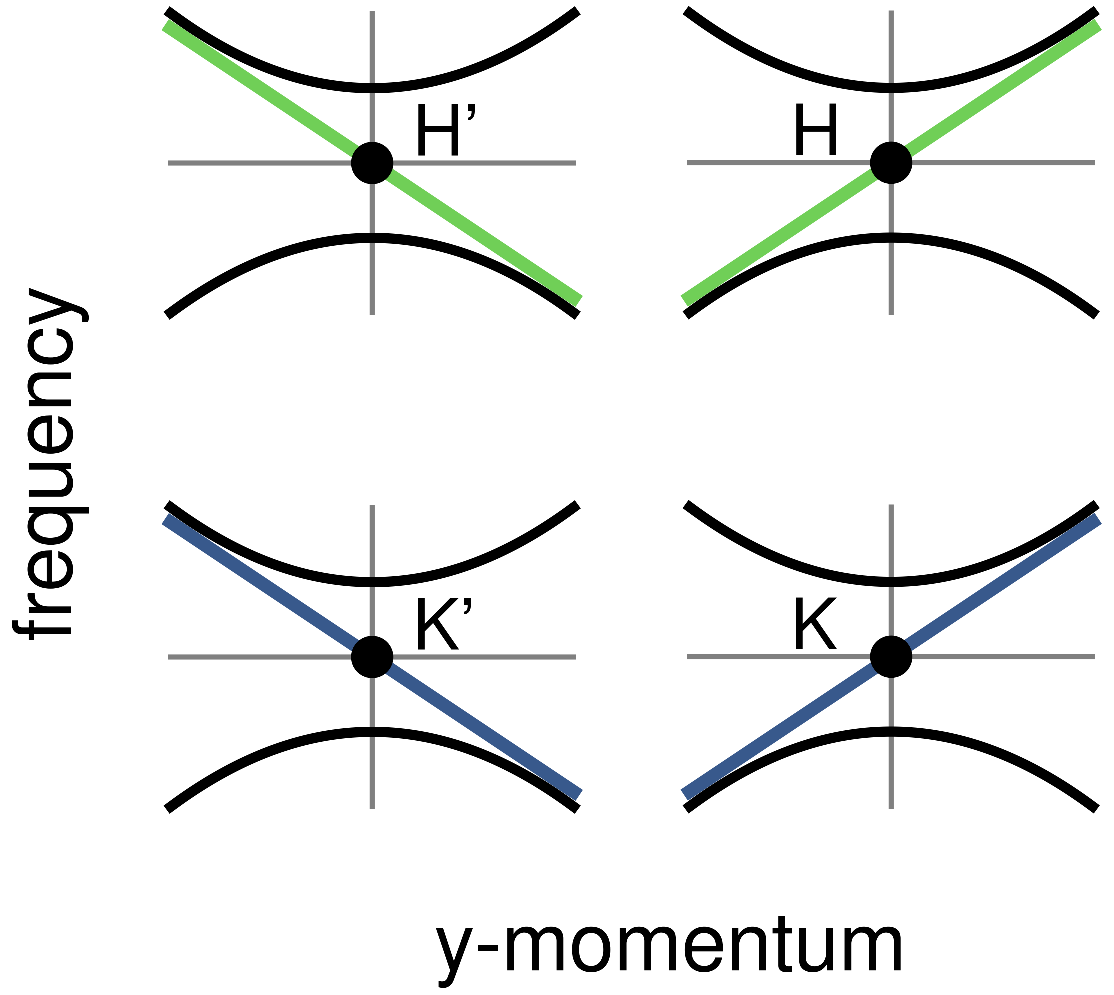
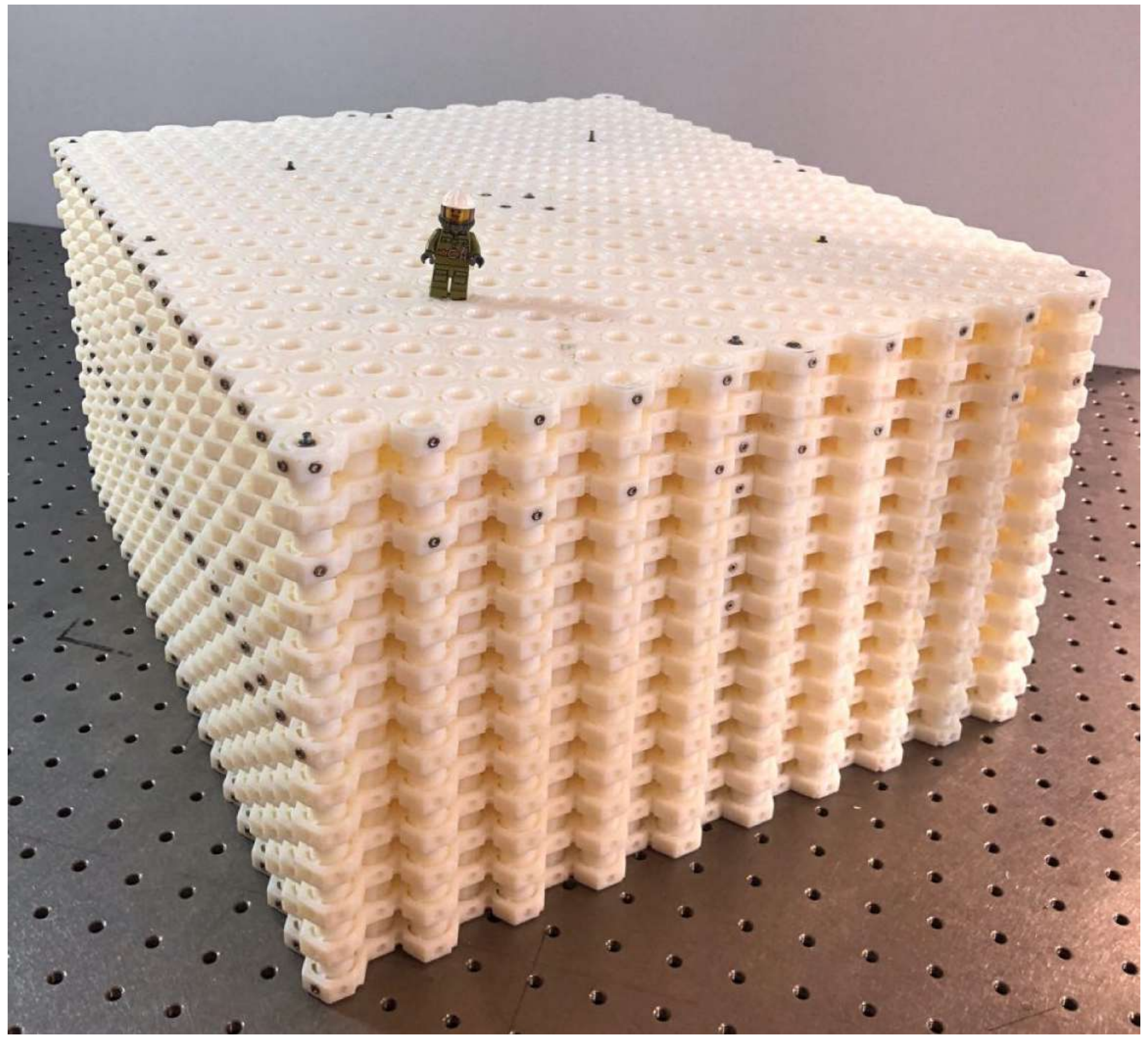




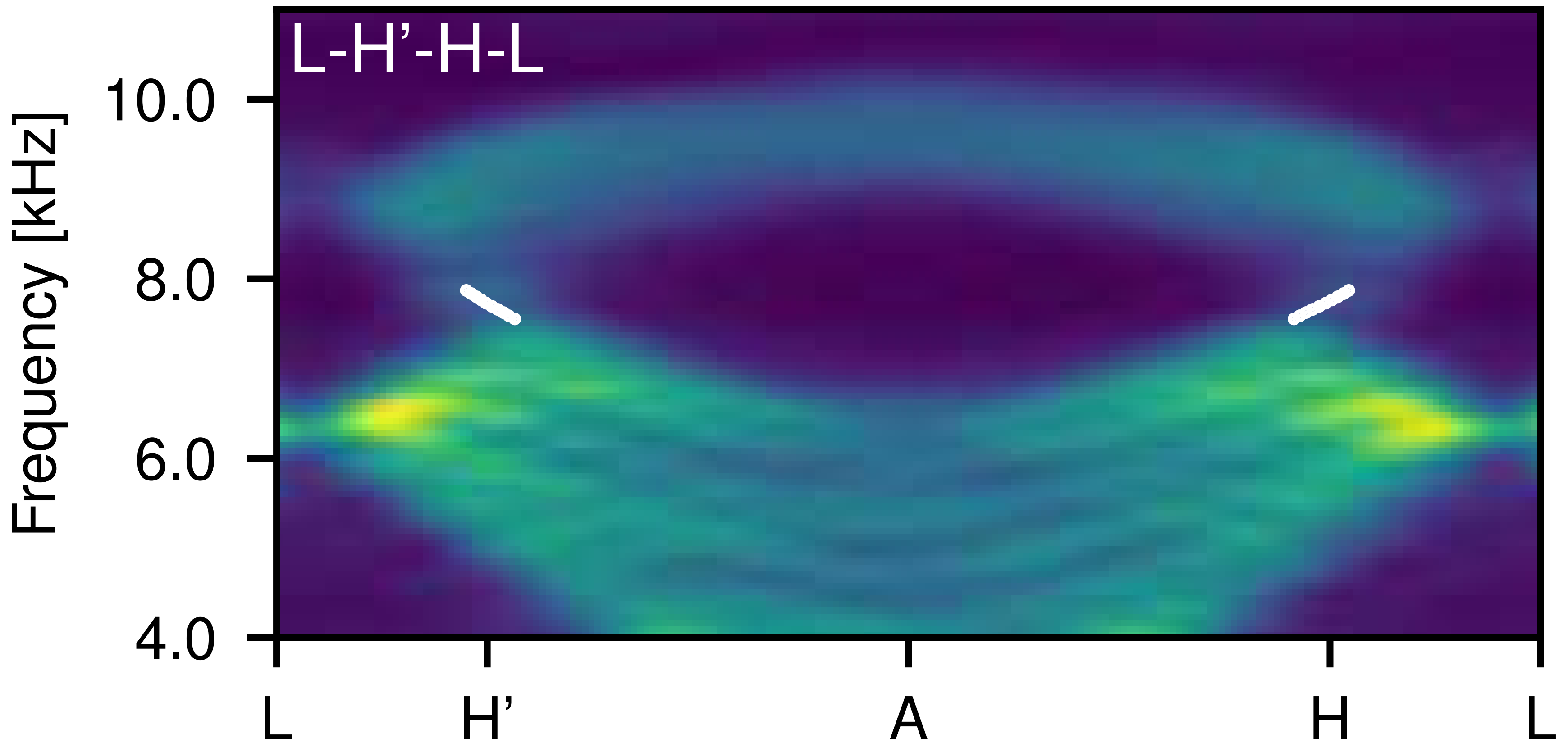
Acoustic metamaterial

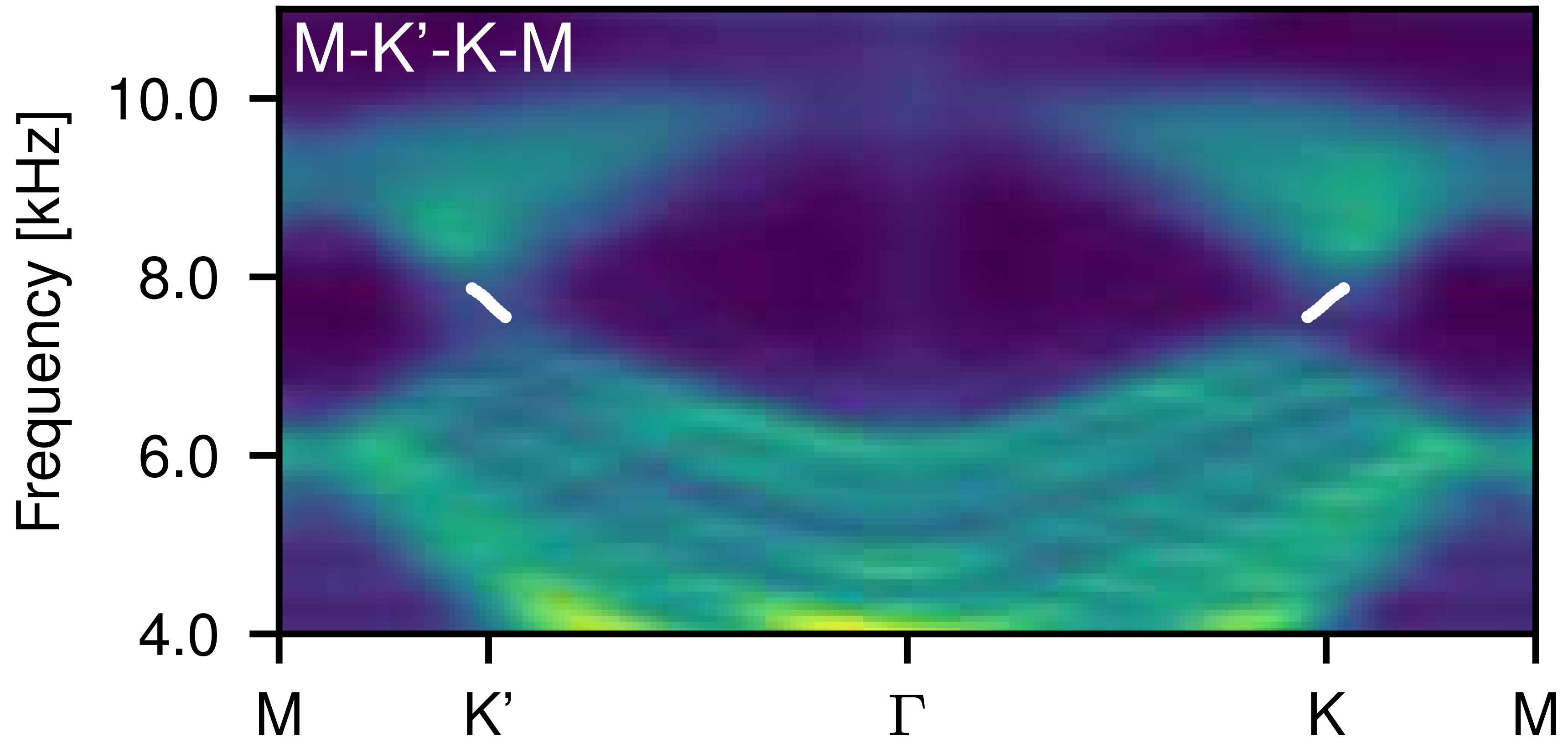


Full phase and amplitude
information

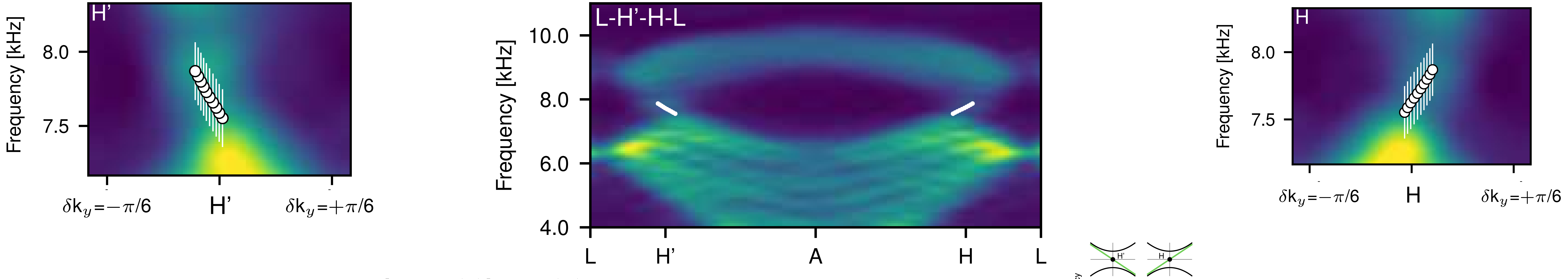
$$G(\mathbf{r}_i, \mathbf{r}_j, \omega) = \langle \psi_i^*(\omega) \psi_j(\omega) \rangle$$

Axial field induced chiral Landau levels

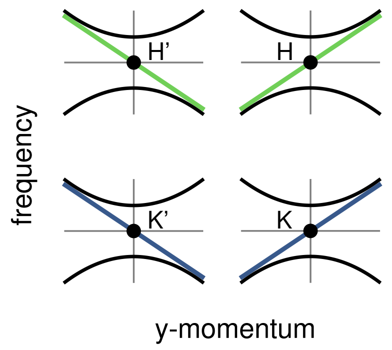


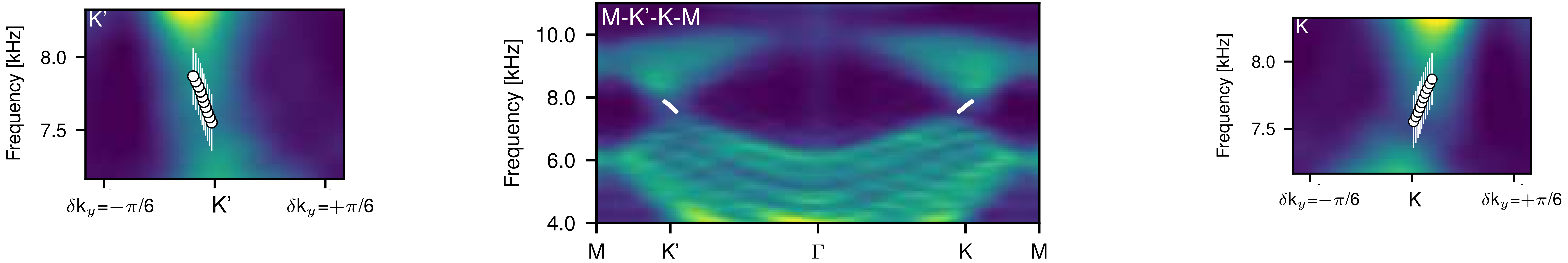


Axial field induced chiral Landau levels



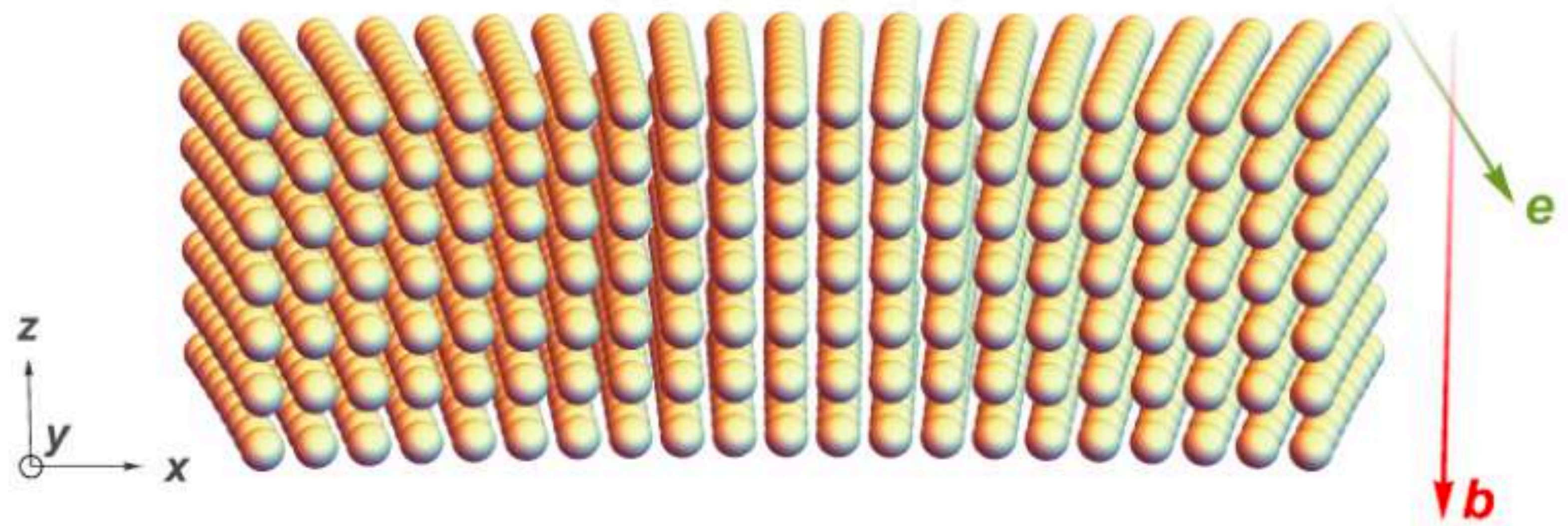
$$\arg[\psi_{k_x,k_z}(y)] \approx k_y(\omega)y$$



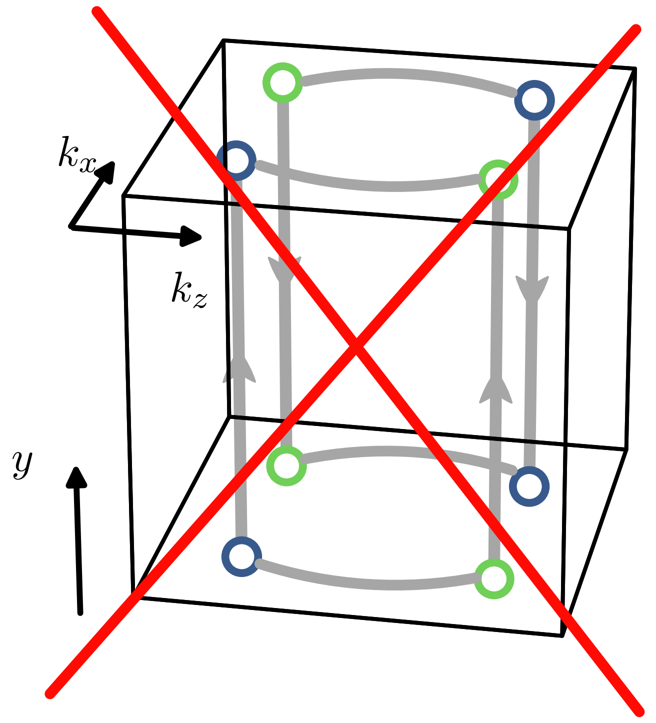


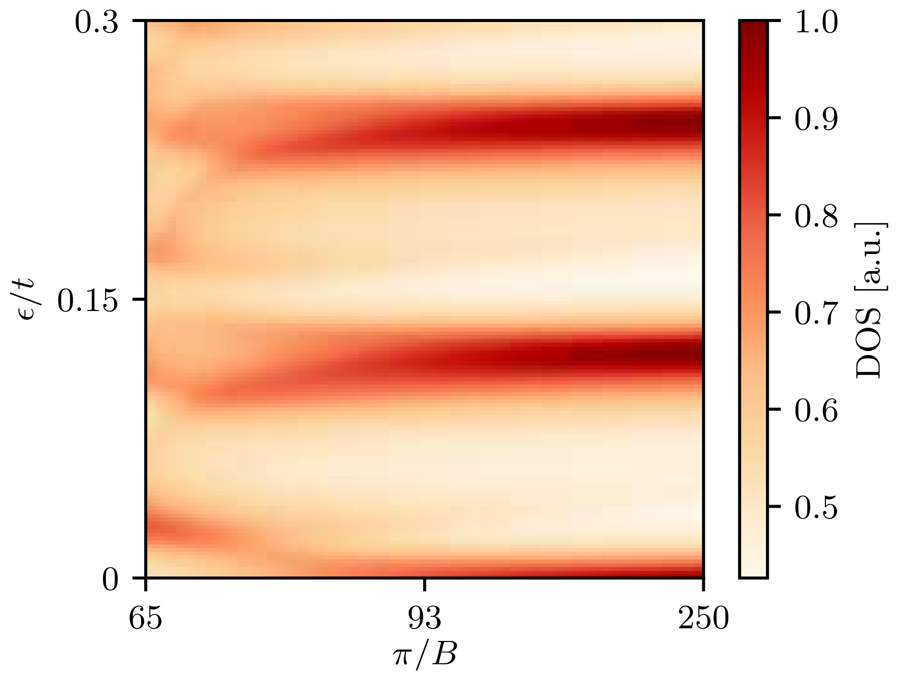
Axial field in real materials?

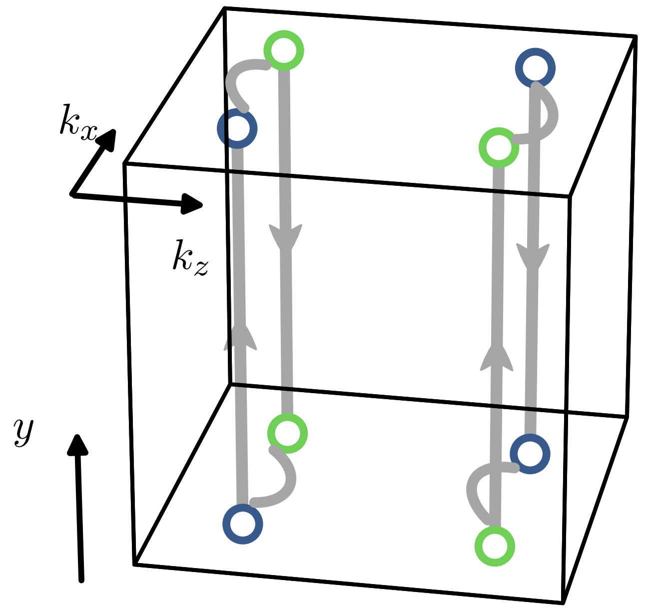
Arjona et al., PRB , 96 (2017)

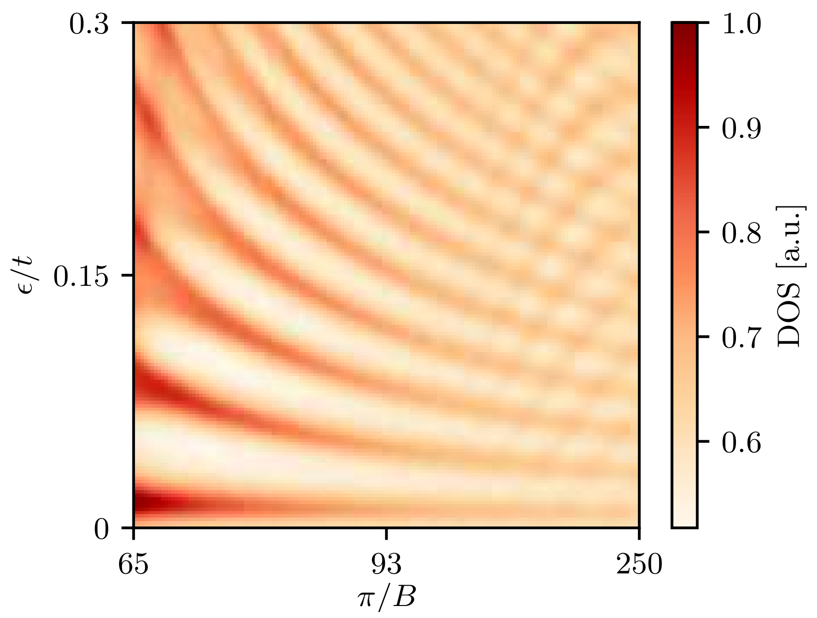


Pikulin et al., PRX , 6 (2016)









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Nature Phys., **15**, 357-361 (2019)

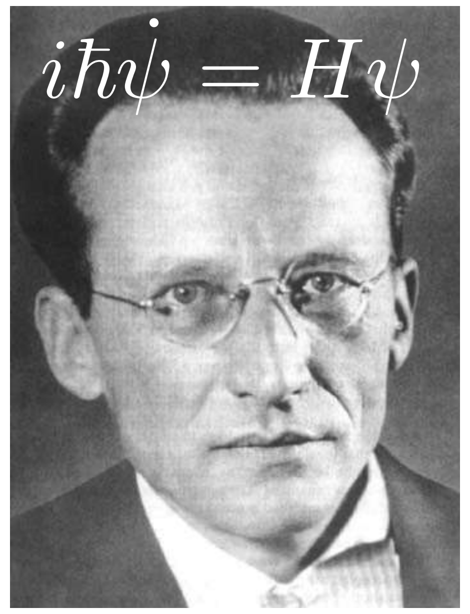
arXiv:1806.09628

FNSNF Swiss National Science Foundation

QSIT Quantum Science and Technology
National Centre of Competence in Research

erc European Research Council
Established by the European Commission

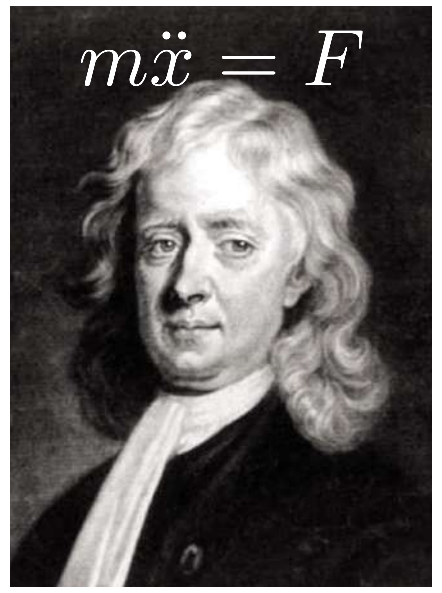
Topology in acoustic systems



$$i\hbar\dot{\psi}_a(\mathbf{r}_i) = \mathcal{H}_{ab}(\mathbf{r}_i,\mathbf{r}_j)\psi_b(\mathbf{r}_j)$$

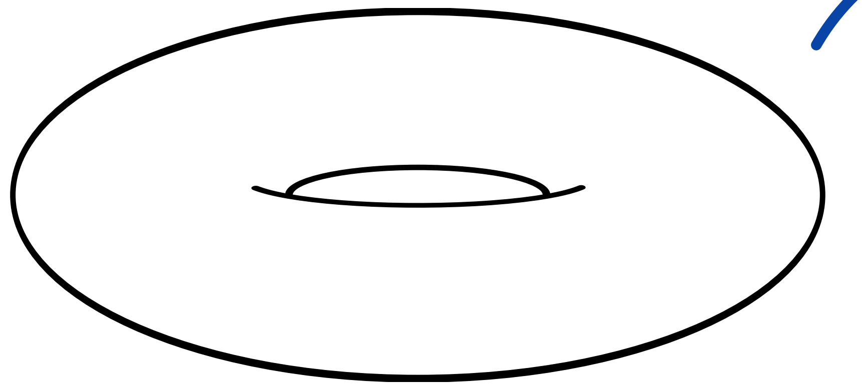
$$\ddot{x}_a(\mathbf{r}_i) = -\mathcal{D}_{ab}(\mathbf{r}_i,\mathbf{r}_j)x_a(\mathbf{r}_j)$$

$$i\frac{\partial}{\partial t}\begin{pmatrix}\sqrt{\mathcal{D}}^T x \\ i\dot{x}\end{pmatrix} = \begin{pmatrix}0 & \sqrt{\mathcal{D}}^T \\ \sqrt{\mathcal{D}} & 0\end{pmatrix}\begin{pmatrix}\sqrt{\mathcal{D}}^T x \\ i\dot{x}\end{pmatrix}$$



Topological insulators → Classification of matrices

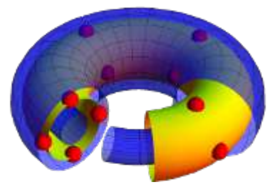
$$\mathcal{H}(\mathbf{k}) : \mathbb{T}^d \to M$$



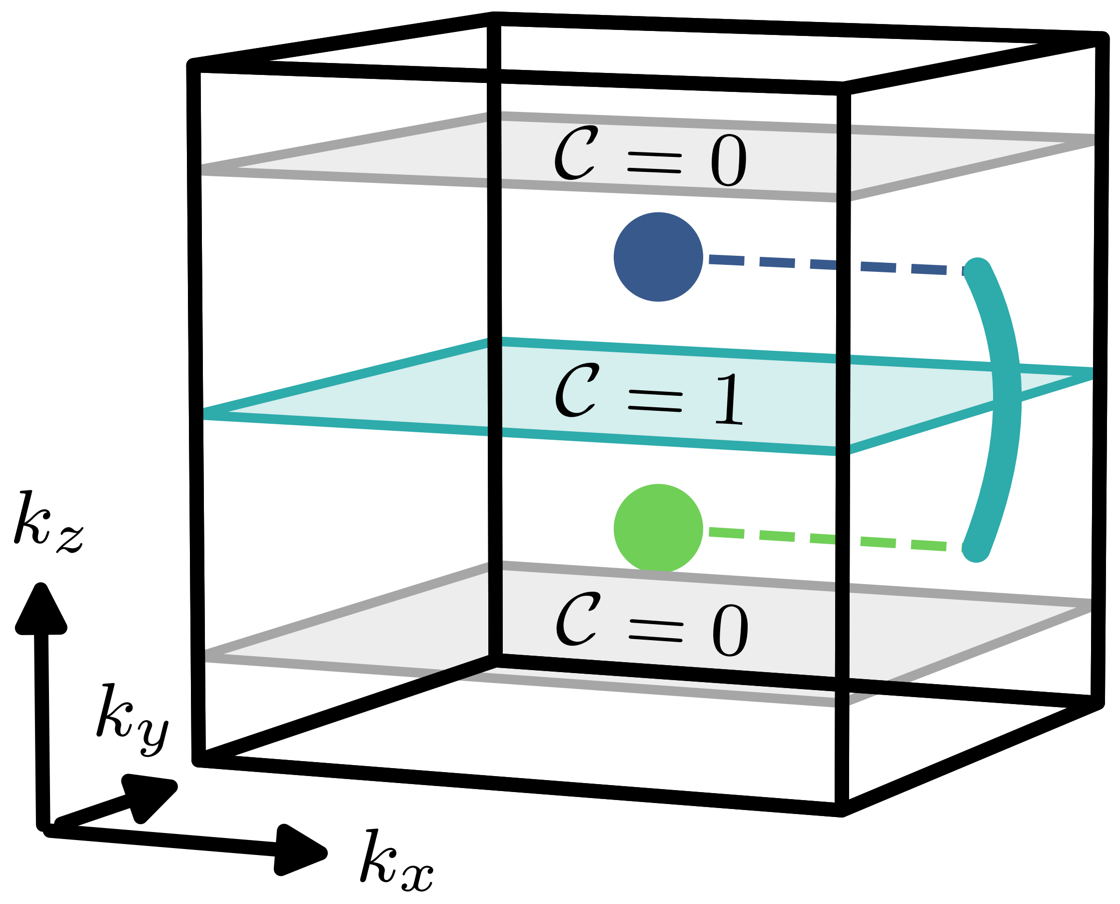
Brillouin Zone

$$|\psi_0(\mathbf{k})\rangle\langle\psi_0(\mathbf{k})|$$

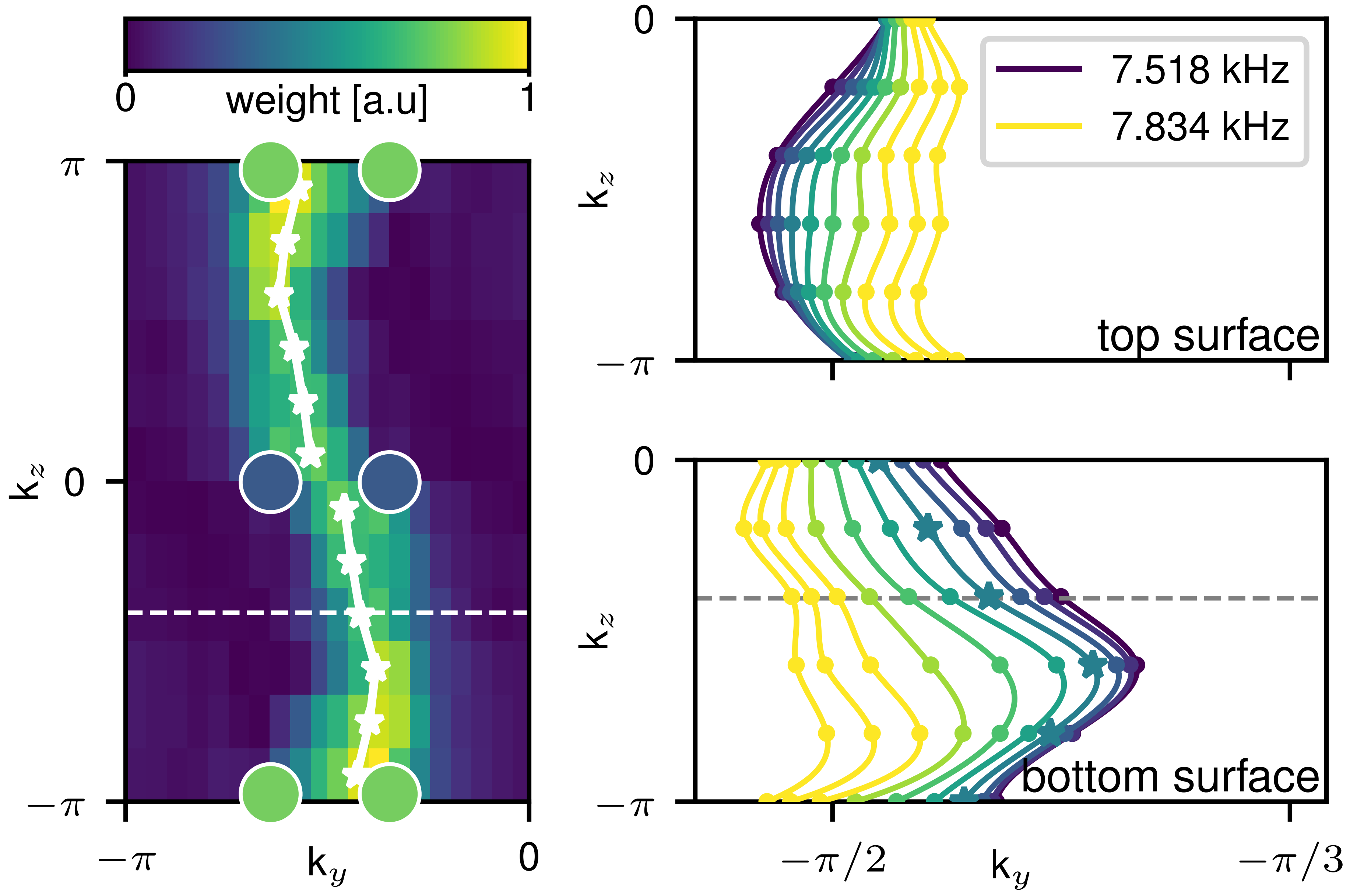
R Süsstrunk & SD Huber - PNAS (2016)



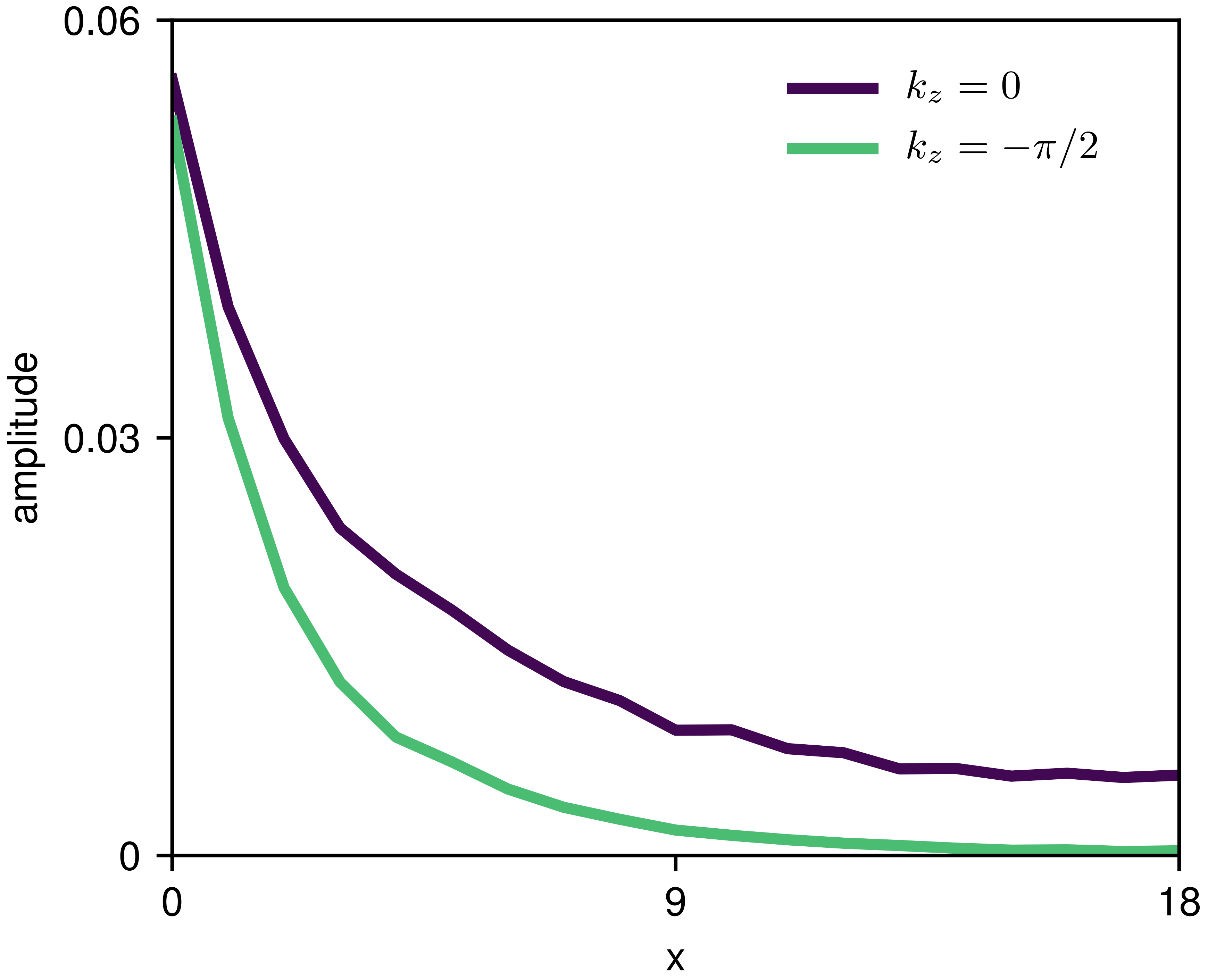
Fermi arcs



$\mathcal{C} = 0$
$\mathcal{C} = 1$
$\mathcal{C} = 0$
k_z
k_y
k_x

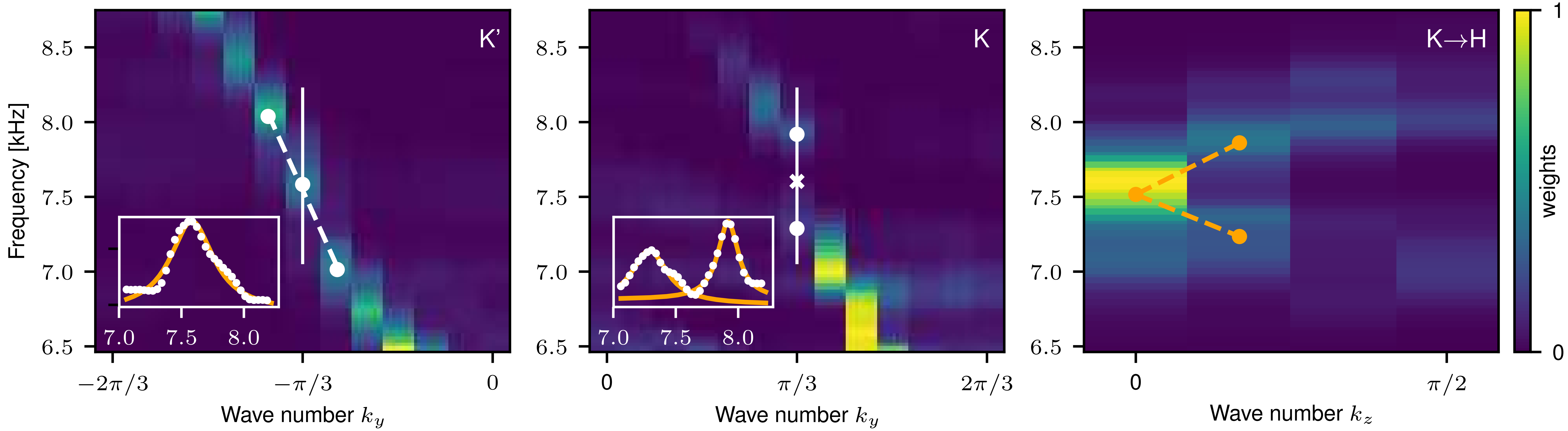


0
weight [a.u]
1
π
0
$-\pi$
k$_z$
k$_y$
$-\pi$
0
7.518 kHz
7.834 kHz
top surface
bottom surface
$-\pi/2$
$-\pi/3$



$k_z = 0$
$k_z = -\pi/2$
amplitude
0.06
0.03
0
9
18
x

Tight-binding fit



$$\epsilon_0 = 7.71 \pm 0.06\,\mathrm{kHz}$$

$$t_n = 20.80 \pm 1.41\,\mathrm{kHz}^2$$

$$t_c = 1.48 \pm 0.15\,\mathrm{kHz}^2$$

$$B_5 = 0.08 \pm 0.03 \approx 0.01 \times 2\pi$$

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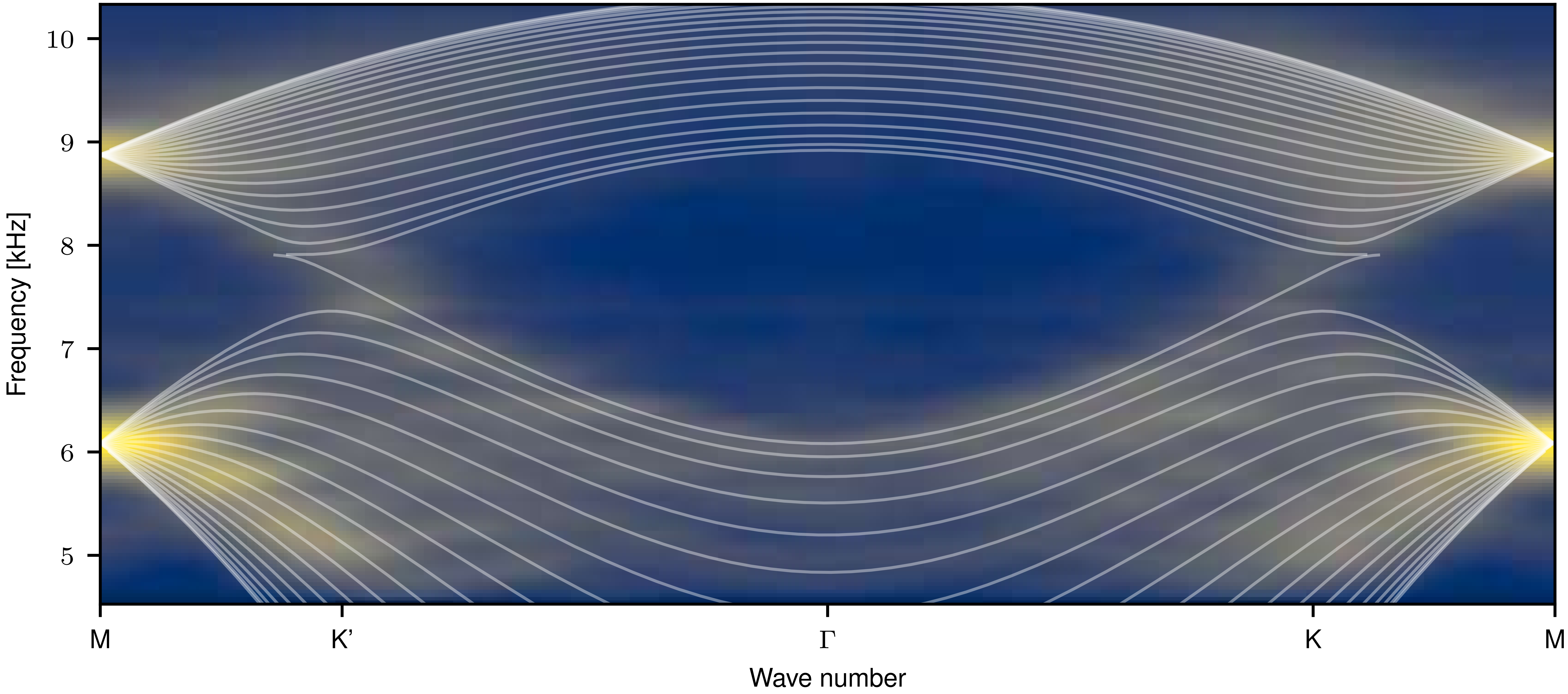
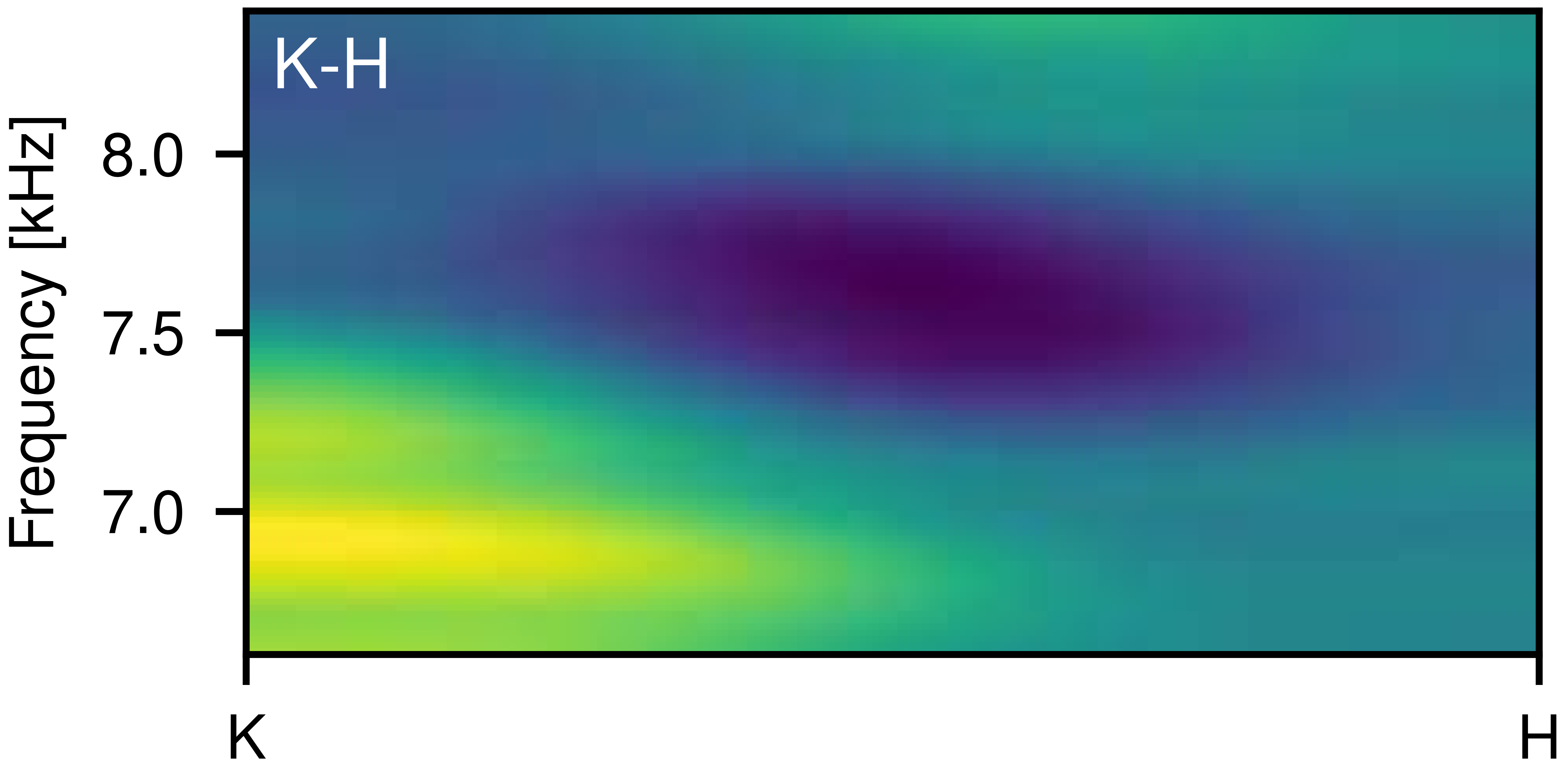
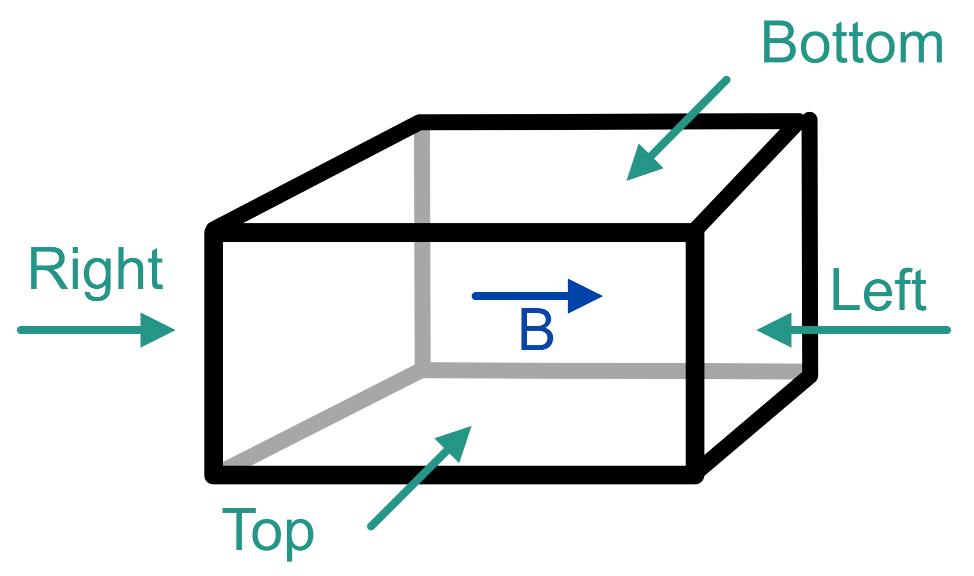
Tight-binding fit



Band structure along kz

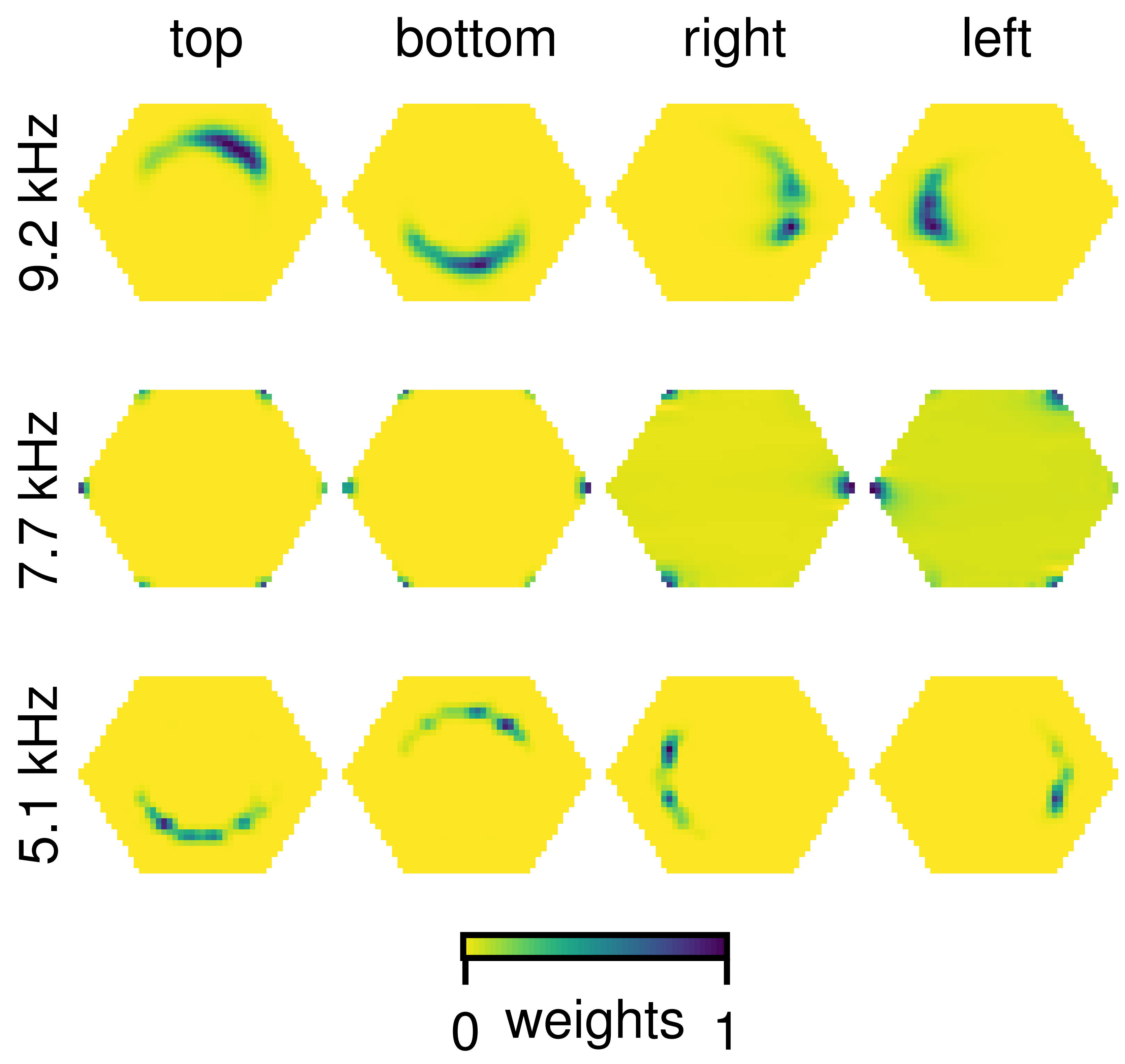


Sensitivity on excitation point



Only modes with certain group velocity get excited

Exciting from different surfaces
at $k_z = 0$



Comsol Optimization