Phononics of Magneto-Granular Graphene: edge waves

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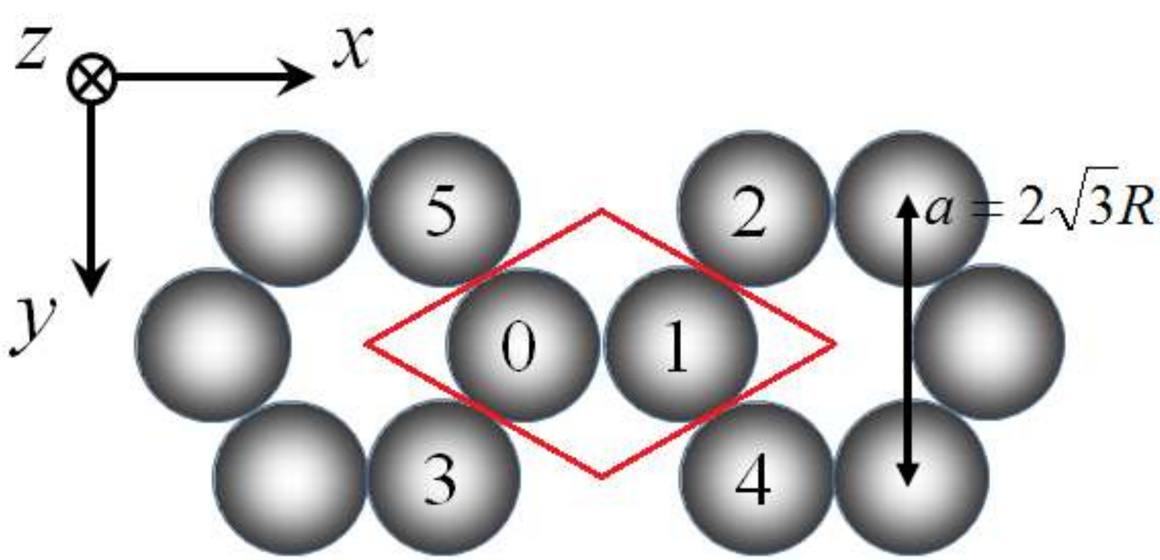
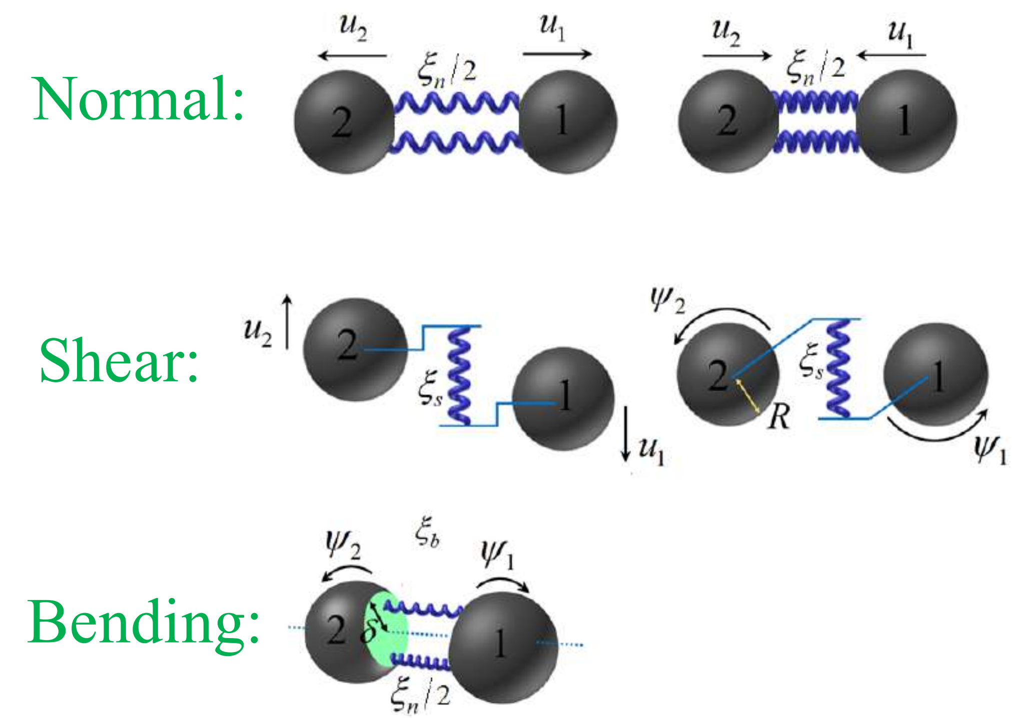
in collaboration with **F. Allein, L.-Y. Zheng**, V. Tournat, V. Gusev

-Karystos-

Granular Graphene





Equations of motion:

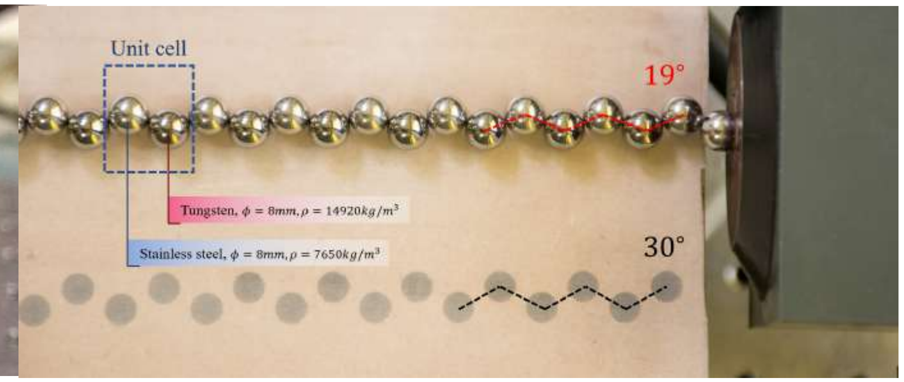
$$M\ddot{u}_{xj} = \sum_i \left(\xi_n \Delta n_i \vec{e}_i + \xi_s \Delta s_i \vec{d}_i\right)\vec{e}_x$$

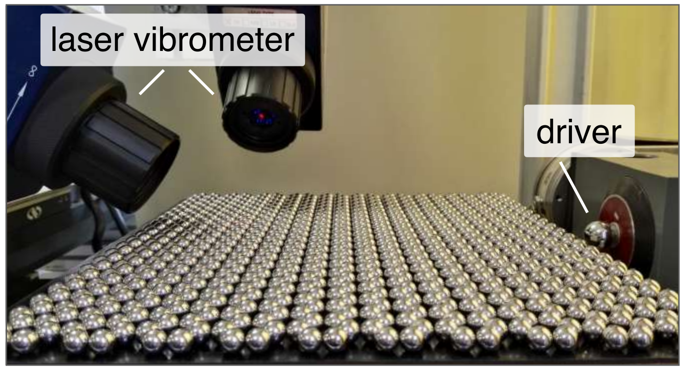
$$M\ddot{u}_{yj} = \sum_i \left(\xi_n \Delta n_i \vec{e}_i + \xi_s \Delta s_i \vec{d}_i\right)\vec{e}_y$$

$$I\ddot{\varphi}_j = R\sum_i \left(\xi_s \Delta s_i + \xi_b \Delta b_i\right)$$

where i denotes the neighbor index. j is the sublattice index.

Magneto Granular crystals





Monoatomic chain
F. Allein - LAUM 2016

Zig-zag chain
S. Qu, L.Zheng, F. Allein - LAUM 2019

2D Honeycomb
F. Allein - L.Zheng -LAUM 2018

Experimental setup:

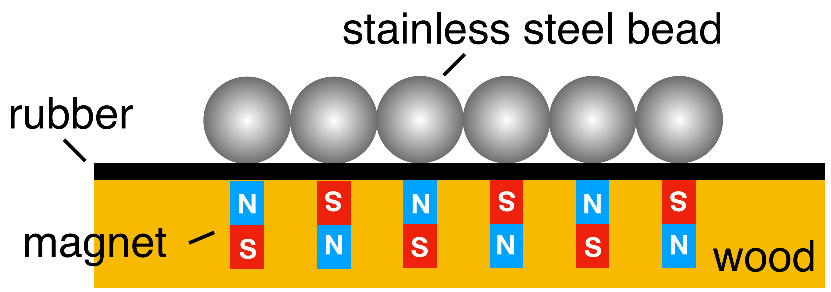
Periodic arrangements of elastic particles in contact under properly designed external magnetic fields, free of mechanical borders.

- Dynamics can range **from near linear to highly nonlinear.**
- **Rotational degrees of freedom** play an important role

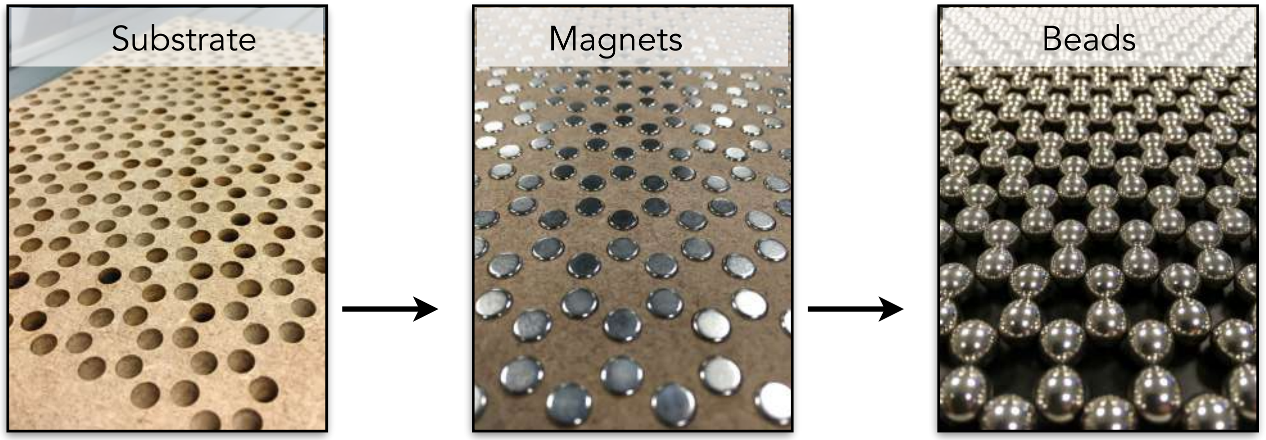
Granular crystals: Condensed Matter Physics meets materials

two other, overestimated features:
(in most of the studies, RDF have been ignored)

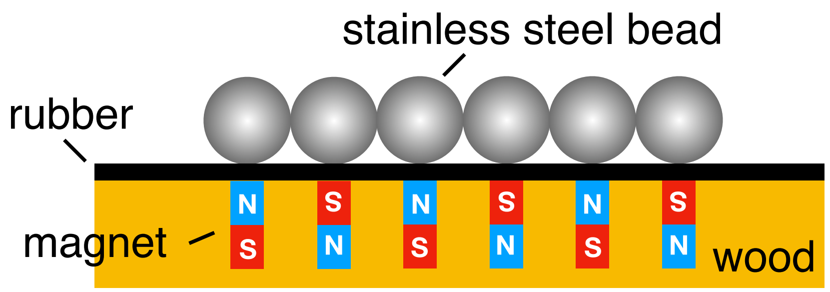
Magneto-Granular Graphene



Diameter of bead: 8 mm



Magneto-Granular Graphene



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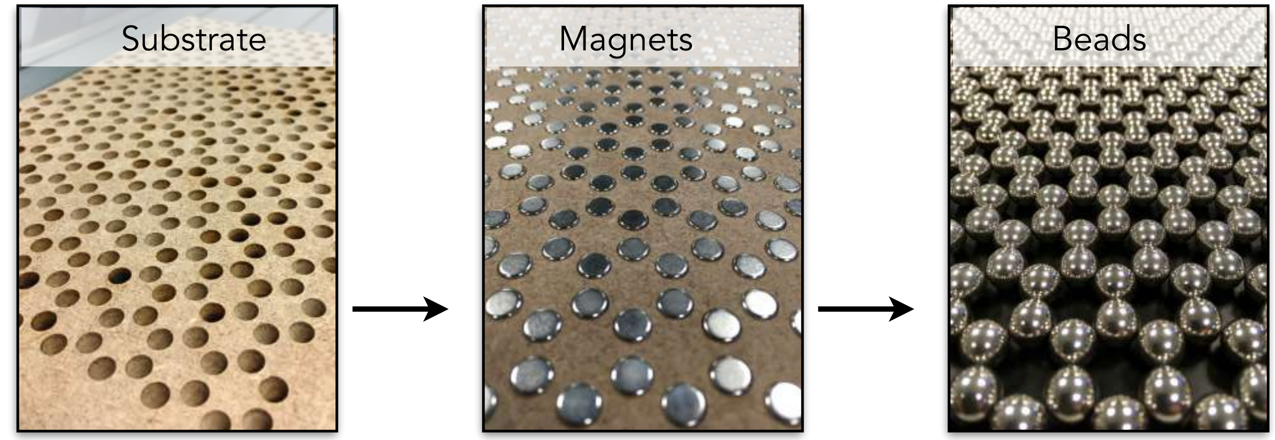
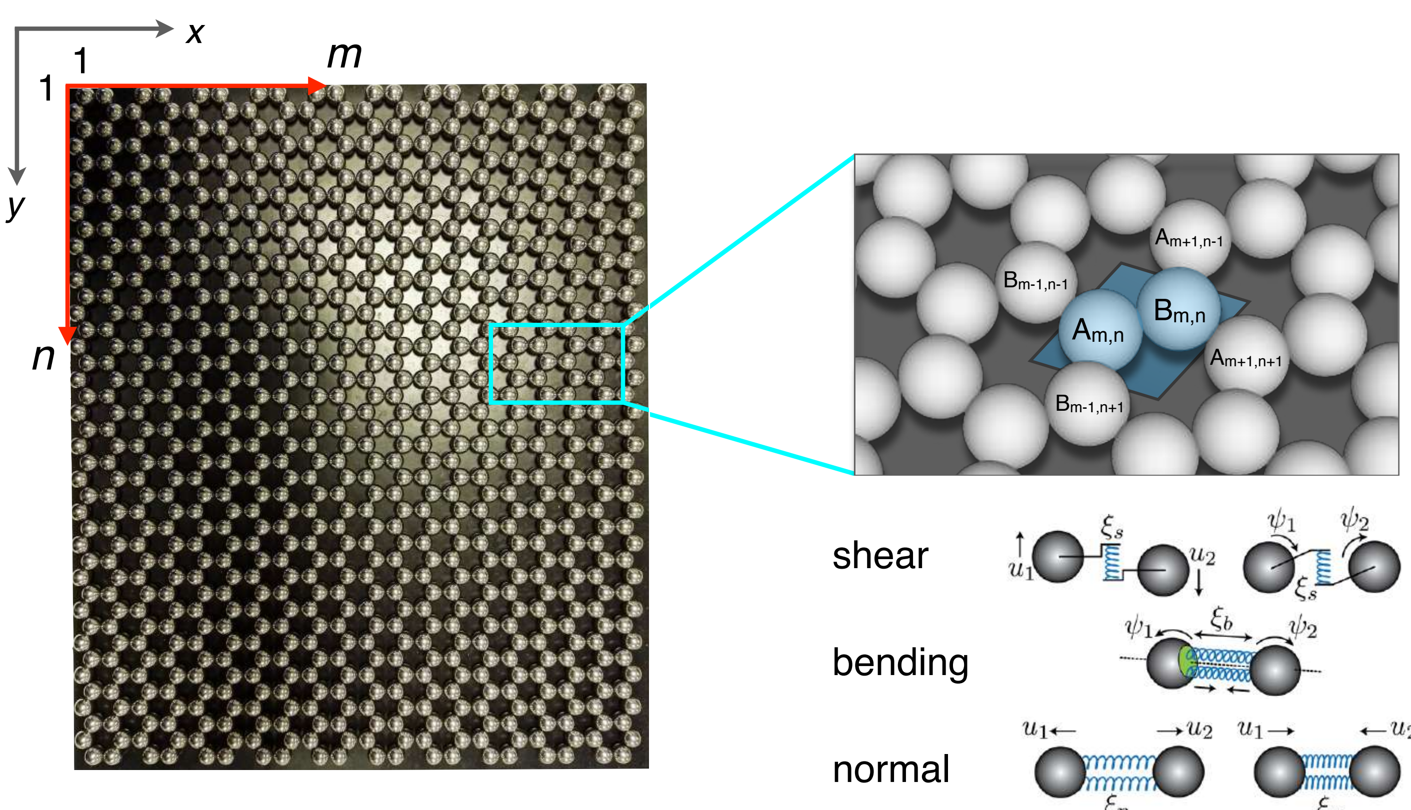


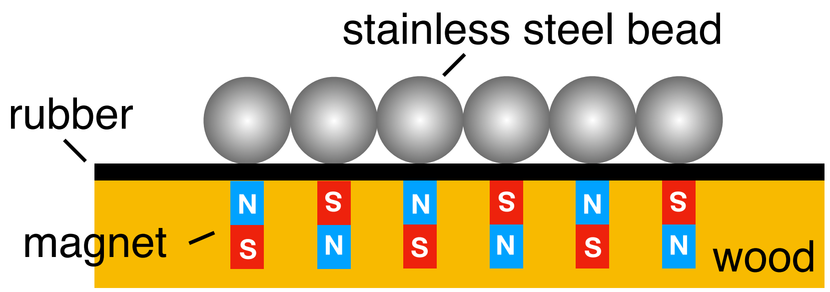
Precompression estimated: F_0 = 1.5 N

https://www.instagram.com/p/BpbqY5dFQyn/



820 particles

Magneto-Granular Graphene



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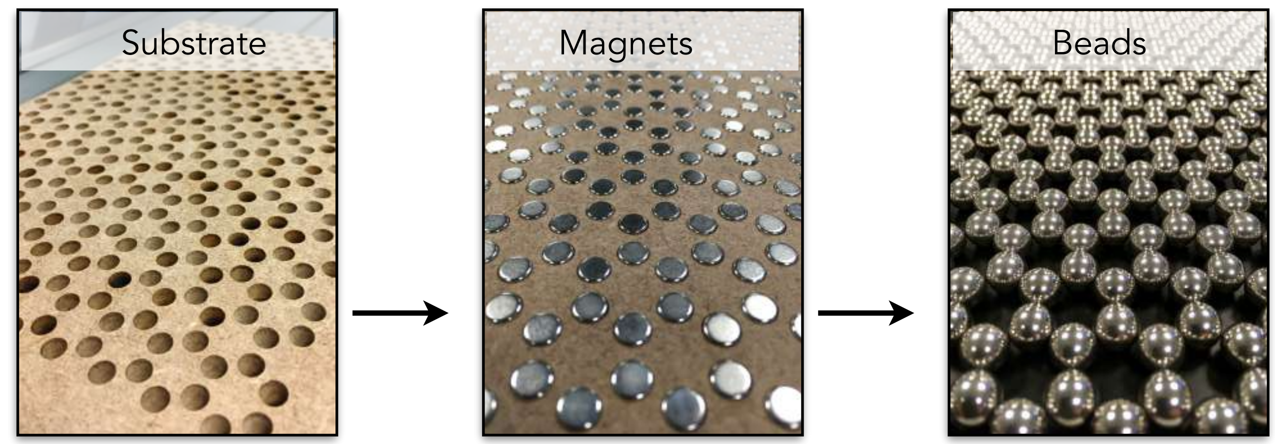

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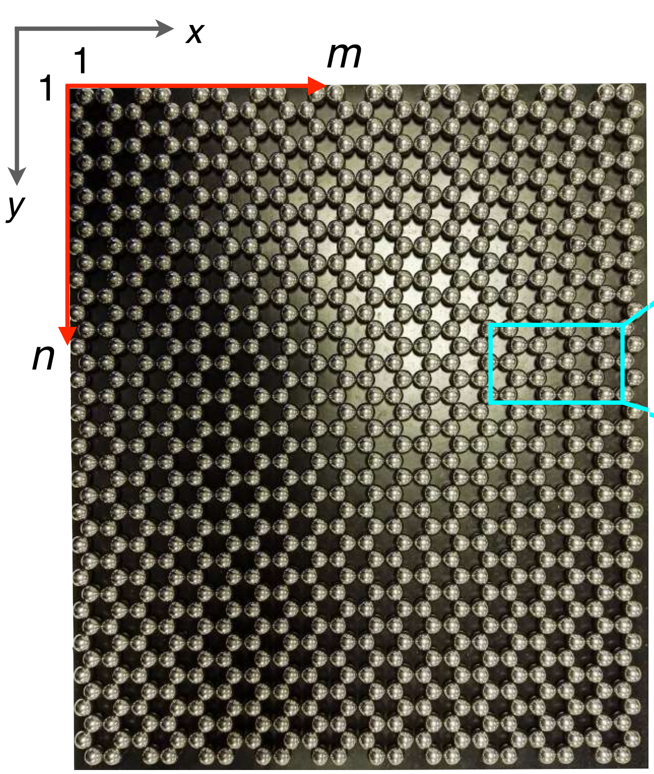

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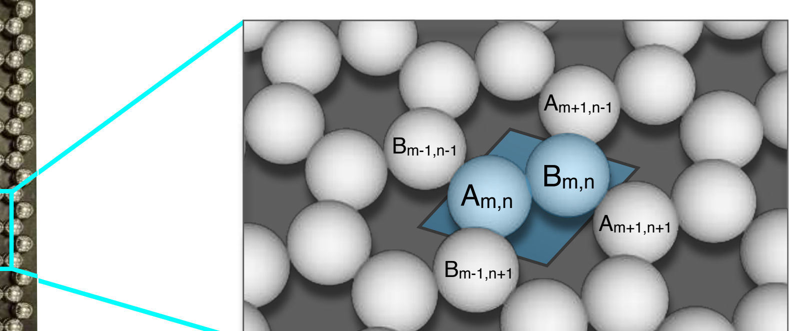
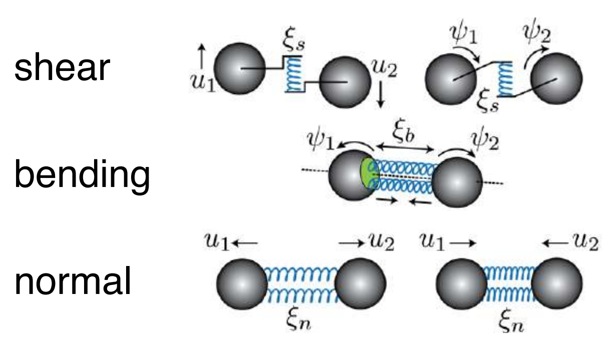
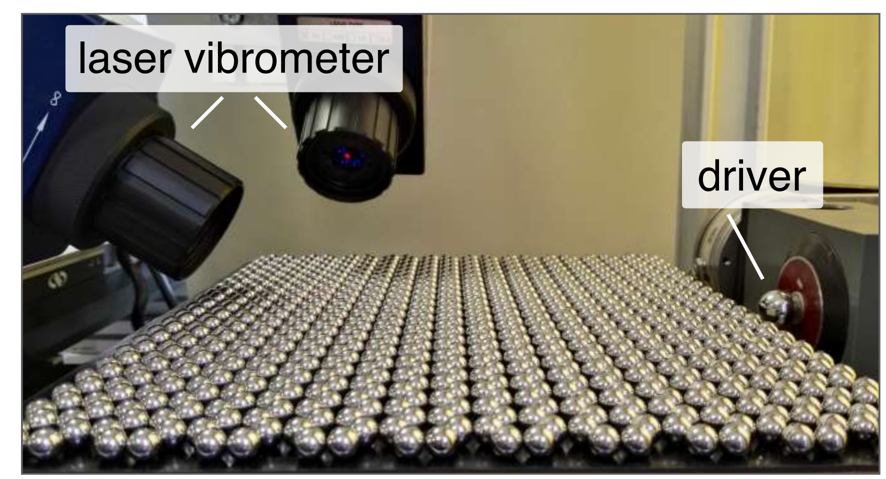
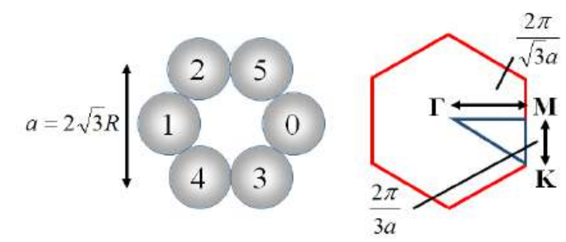


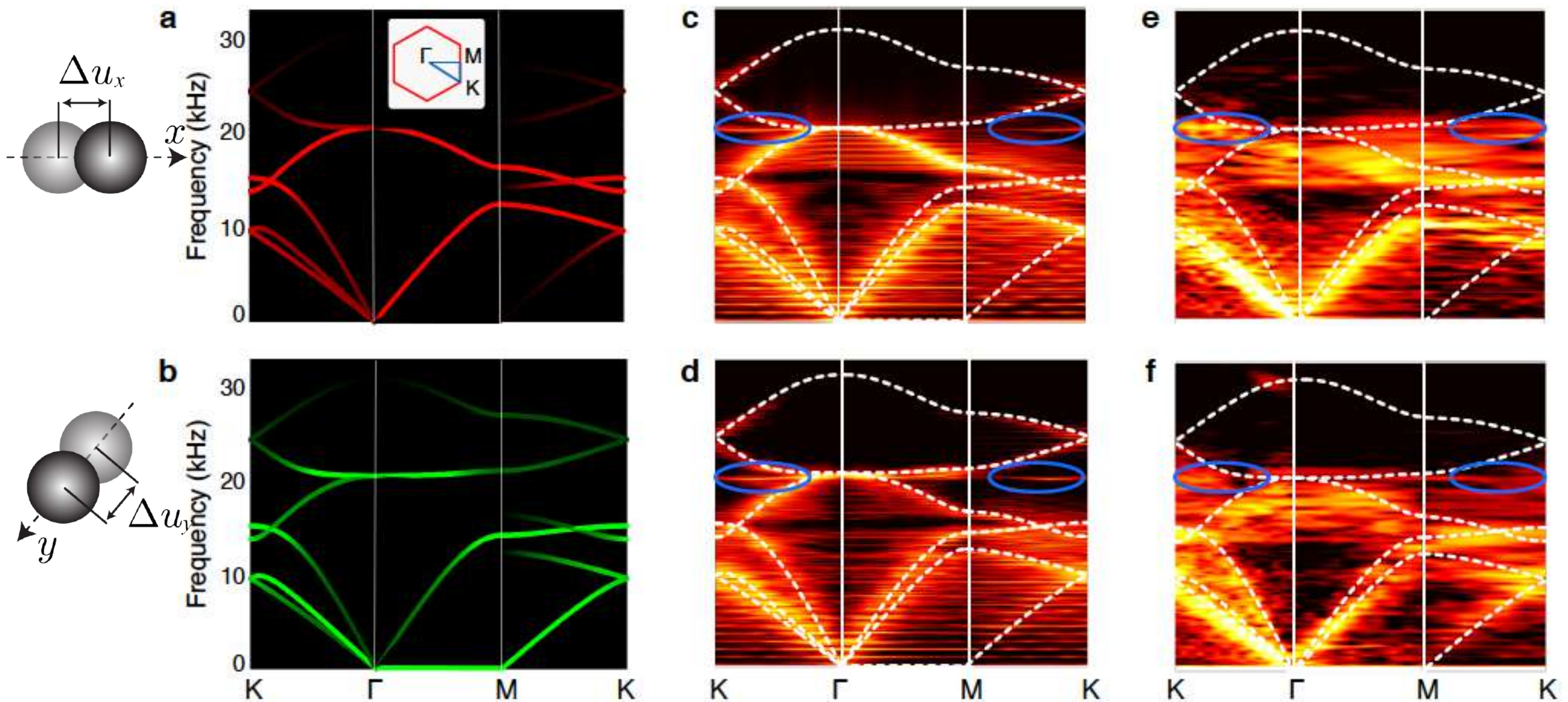




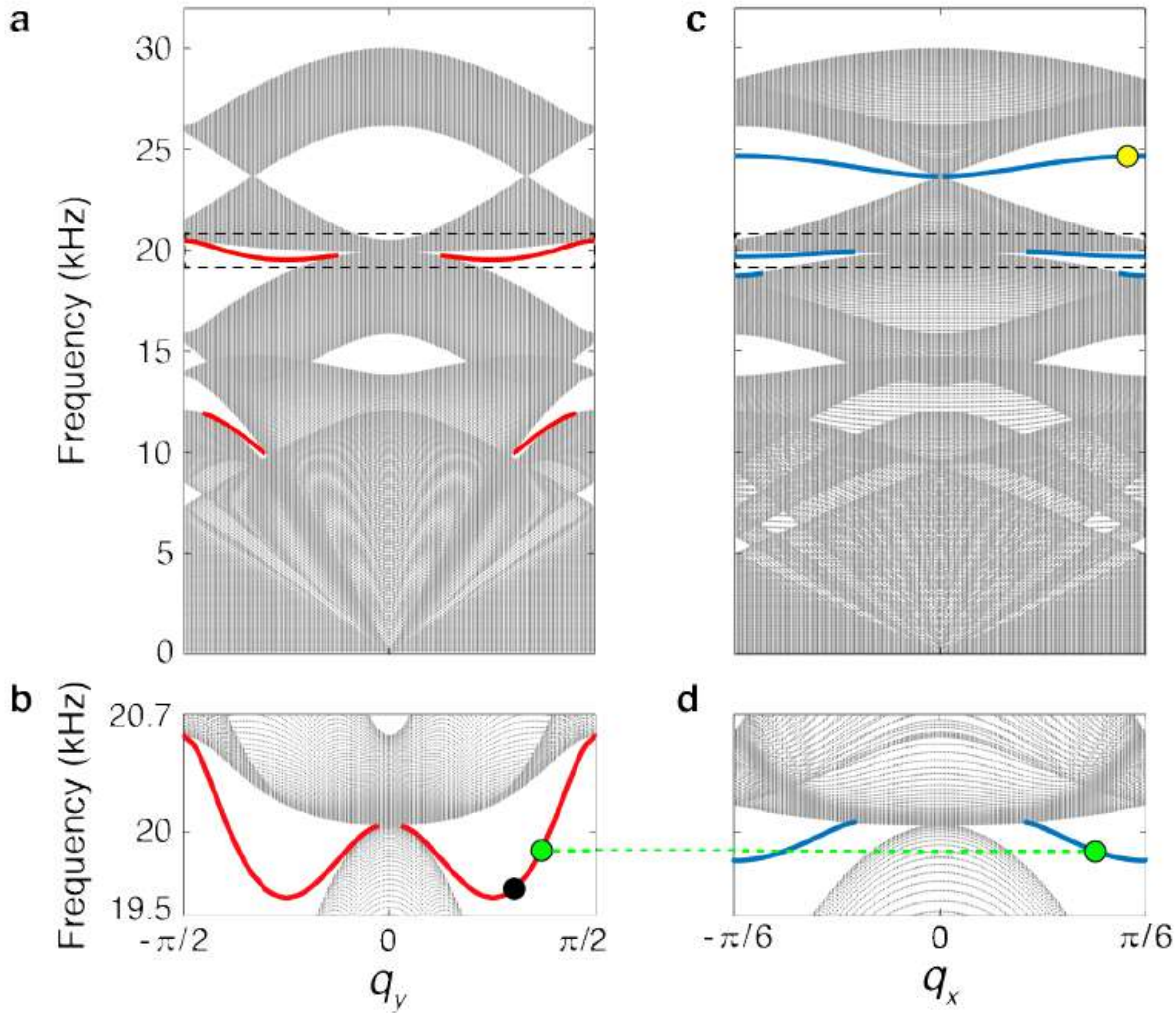
Magneto-Granular Graphene

Dispersion curves:



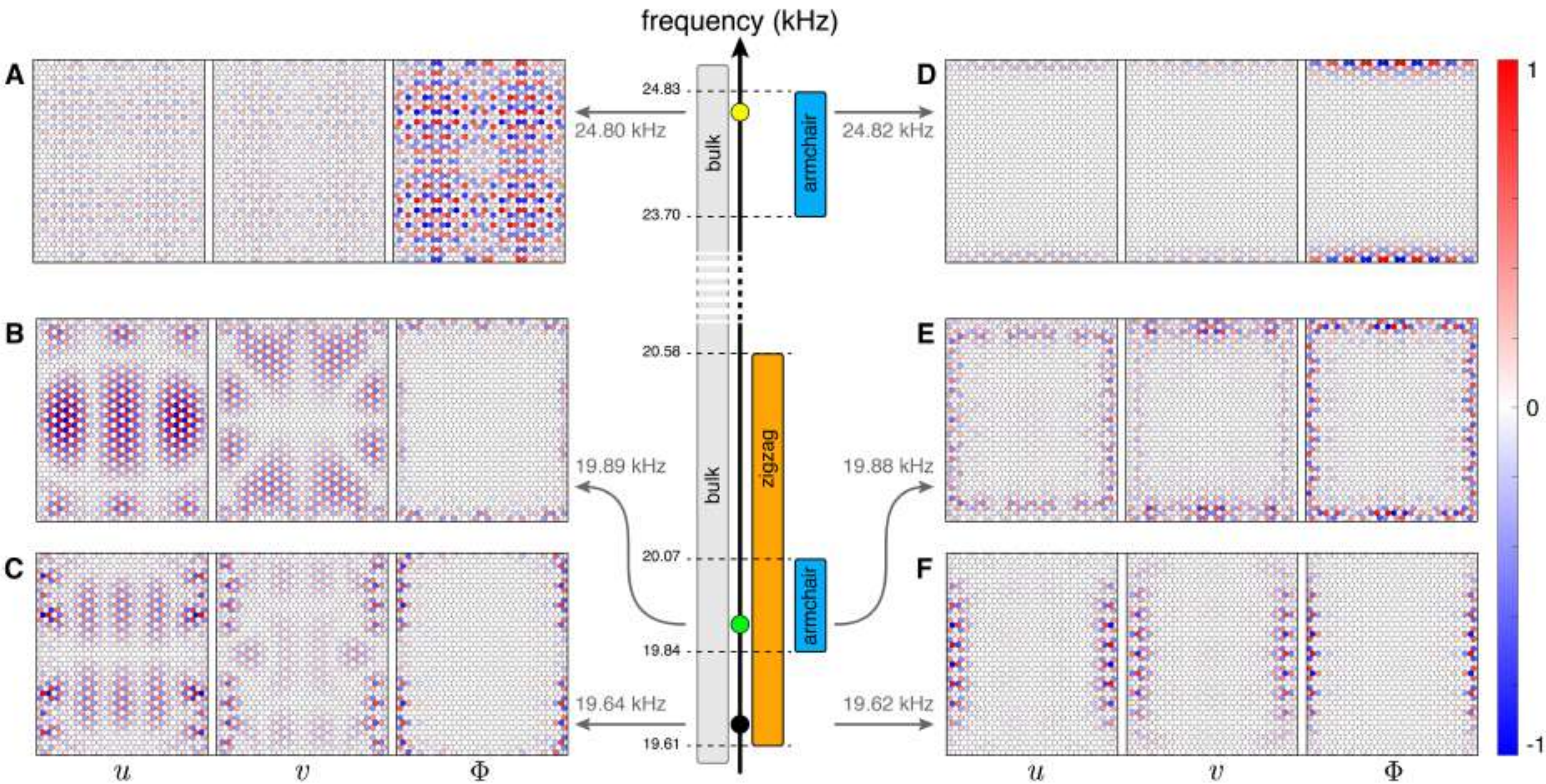


Edge Waves



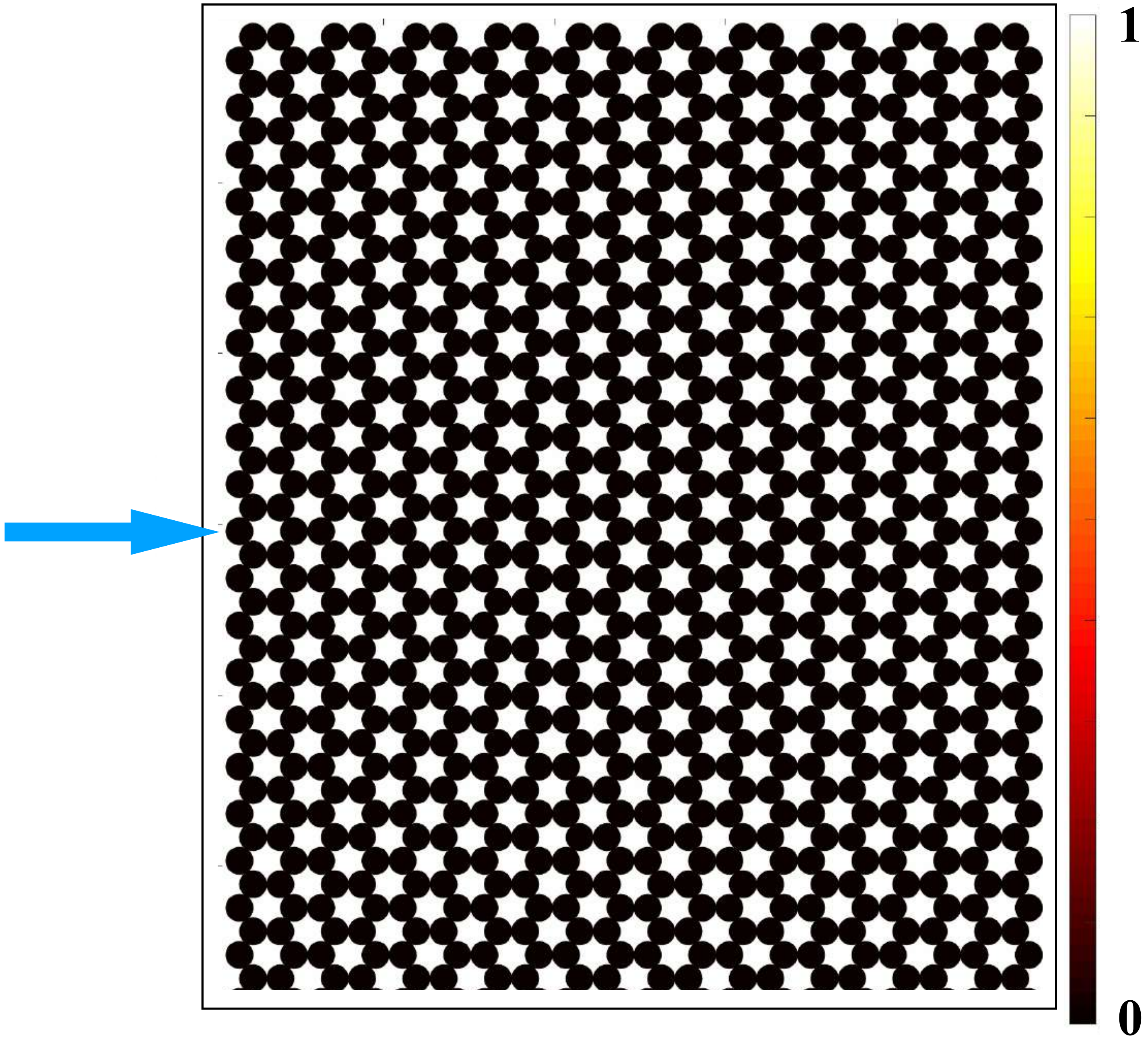
Zigzag **Armchair**

Edge Waves



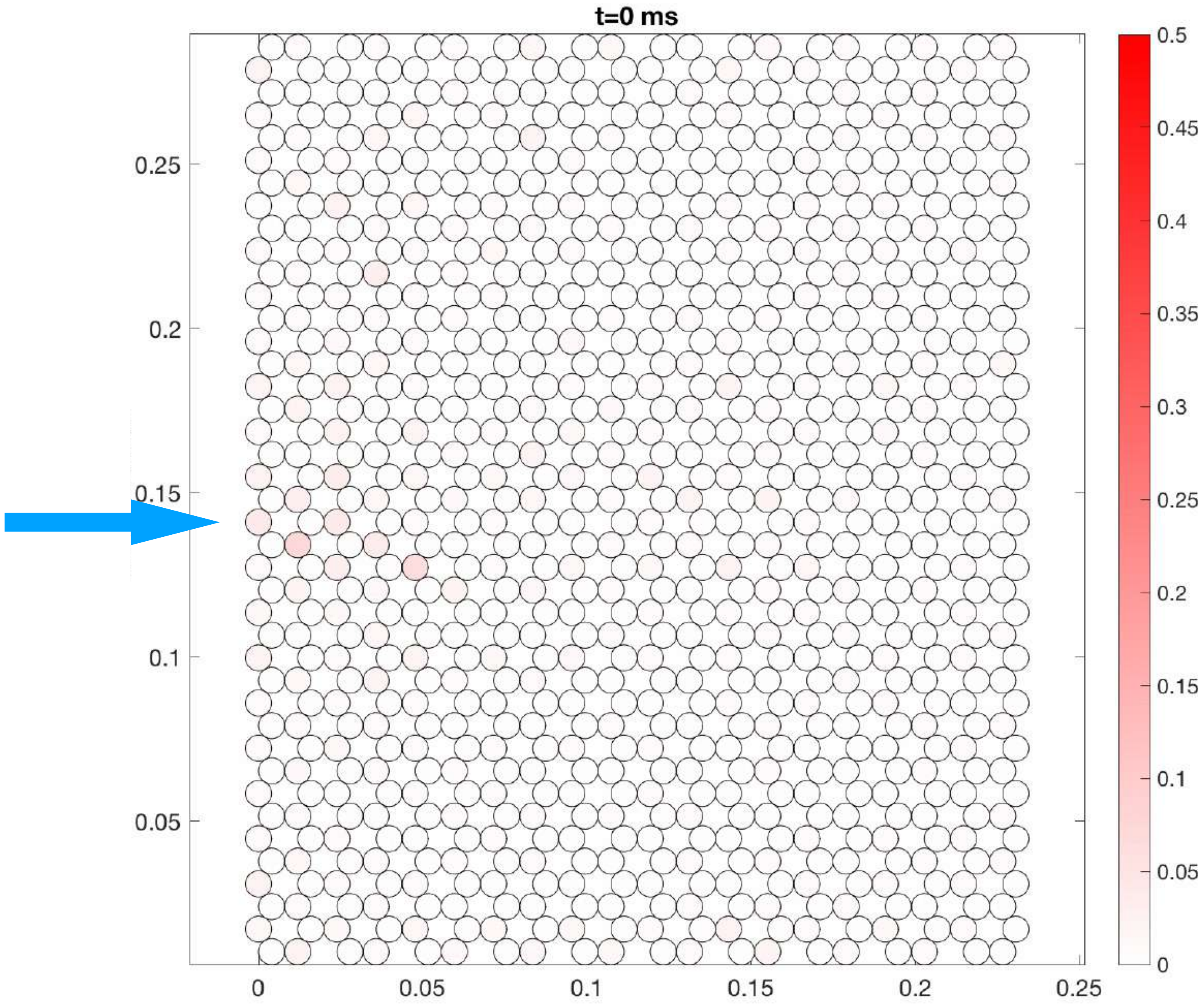
frequency (kHz)
A
B
C
D
E
F
24.83
23.70
20.58
20.07
19.84
19.61
24.80 kHz
24.82 kHz
19.89 kHz
19.88 kHz
19.64 kHz
19.62 kHz
bulk
bulk
armchair
armchair
zigzag
u
v
Φ
u
v
Φ
1
0
-1

Numerical Simulation



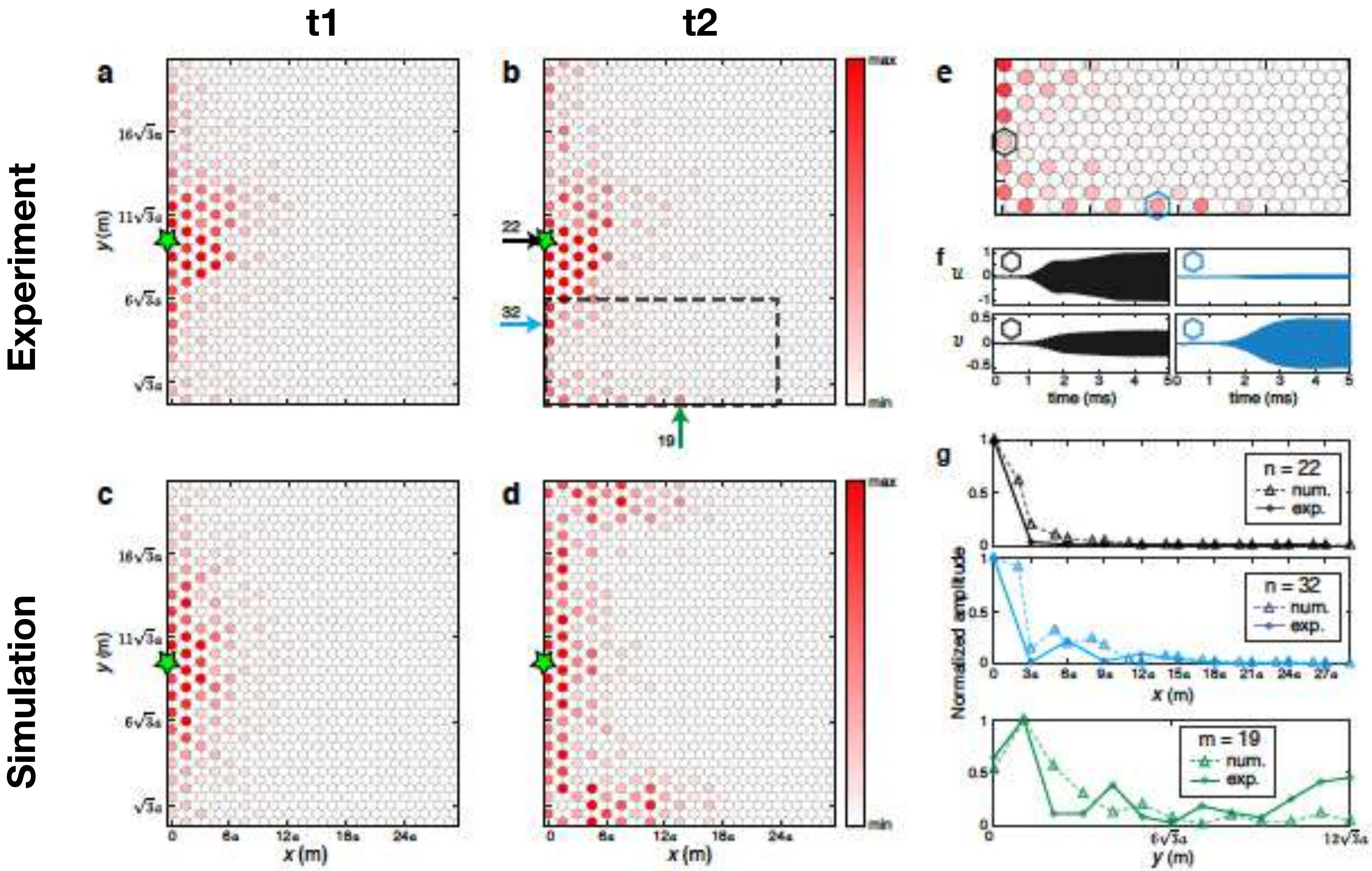
Harmonic excitation at *20* kHz

Experimental Observation



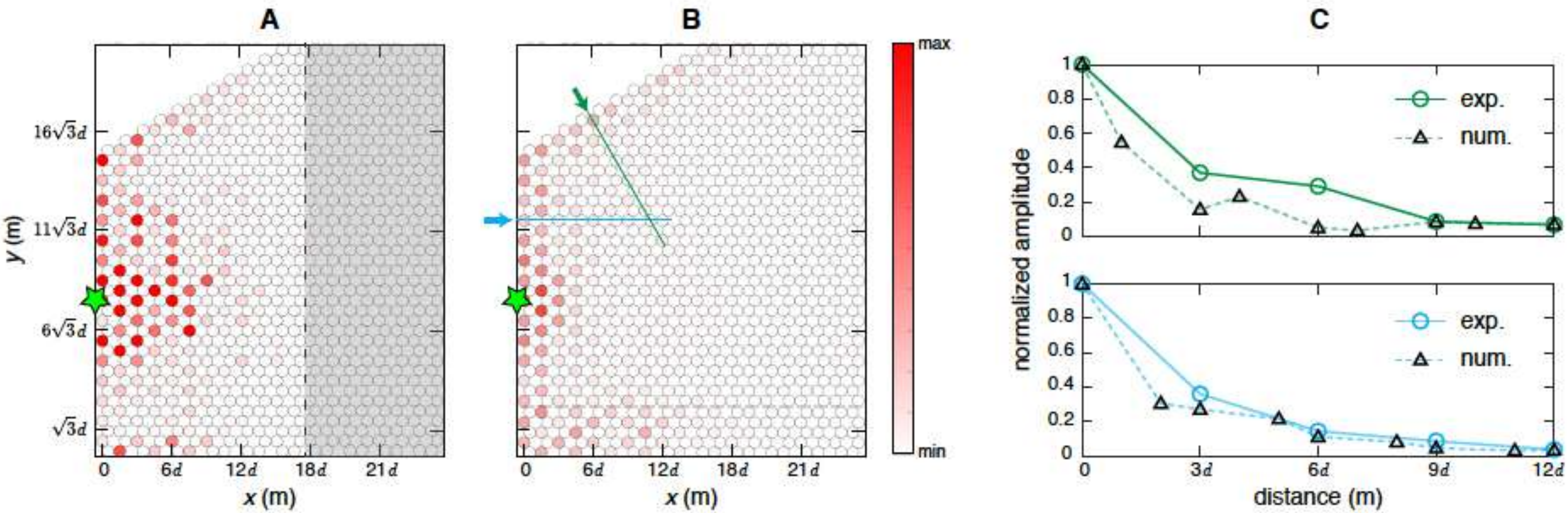
Harmonic excitation at *20* kHz

Edge Waves - Turning

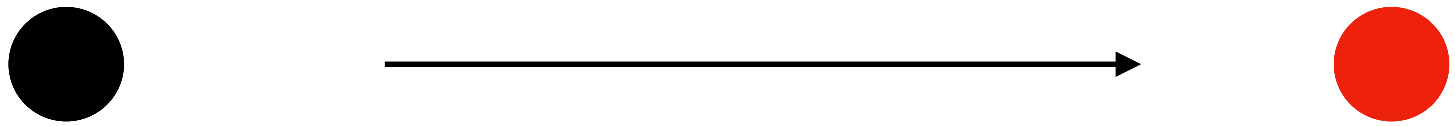


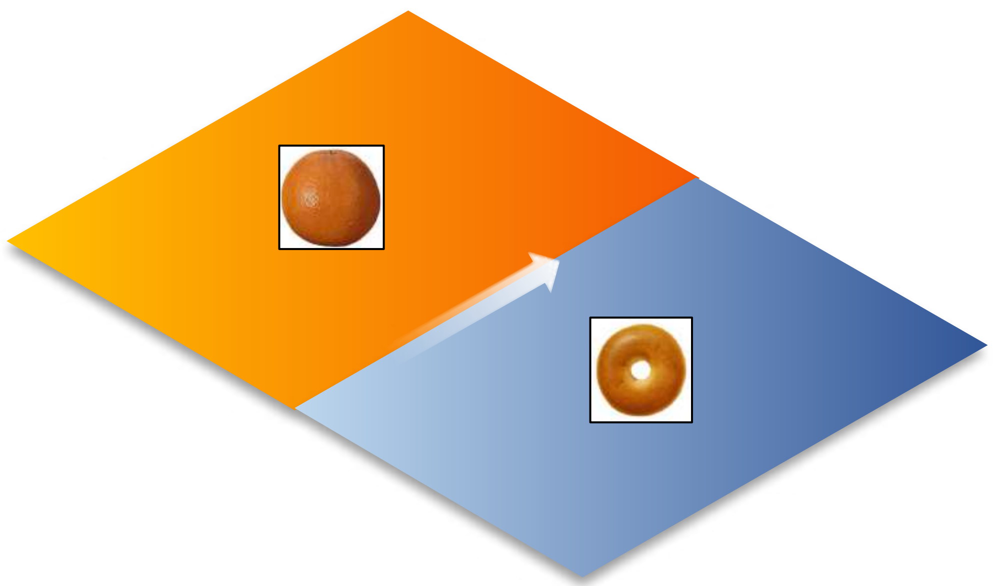
- L-Y Zheng, F; Allein, V. Tournat, V. Gusev, G. Theocharis, Granular Graphene: Direct observation of edge states in zigzag and armchair boundaries, **PRB 99, 184113 (2019)**

Edge Waves - Turning

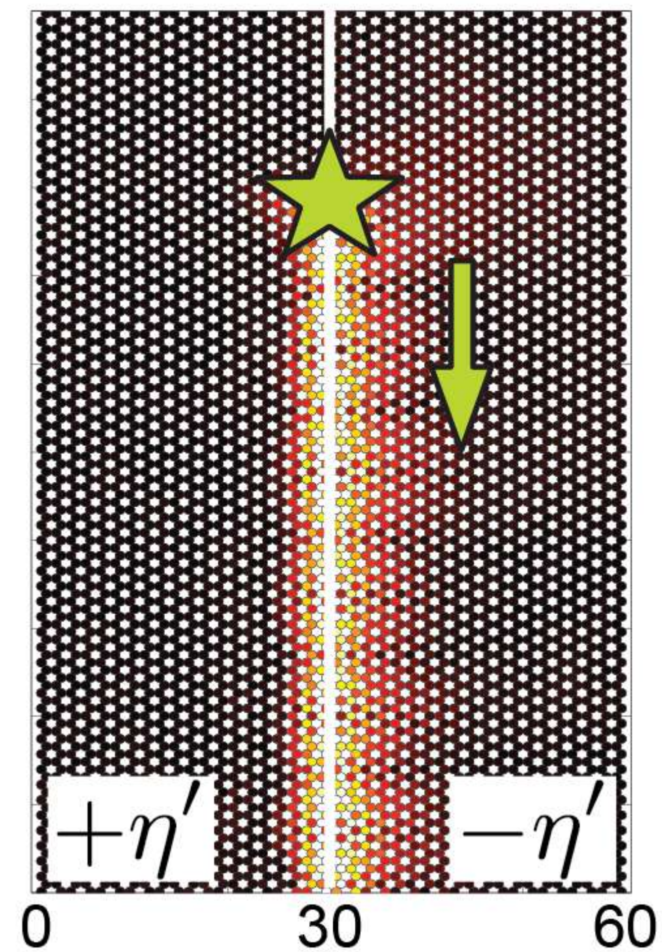


Robust Transfer/ Waveguiding of Modes



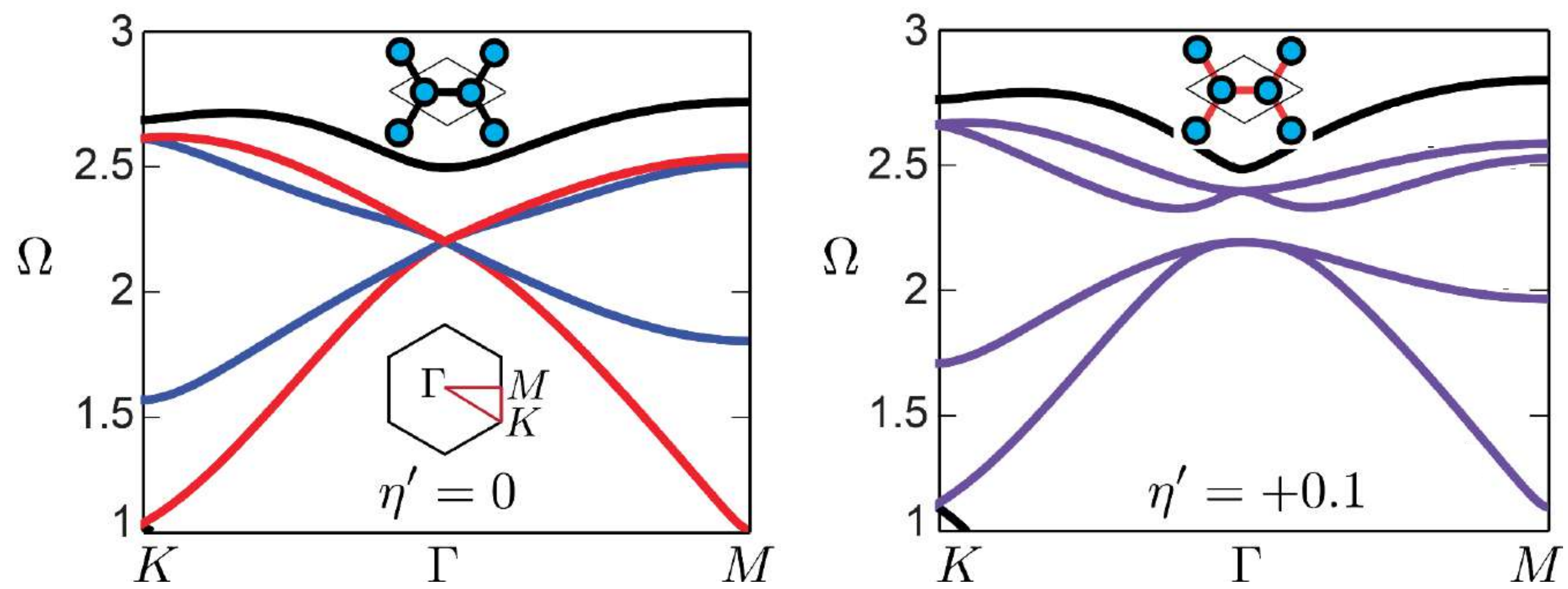


Topologically *distinct* structures



Topological Granular Graphene: mechanical analogue of Quantum Spin Hall effect

Topological Granular Graphene



Hamiltonian around Γ point:

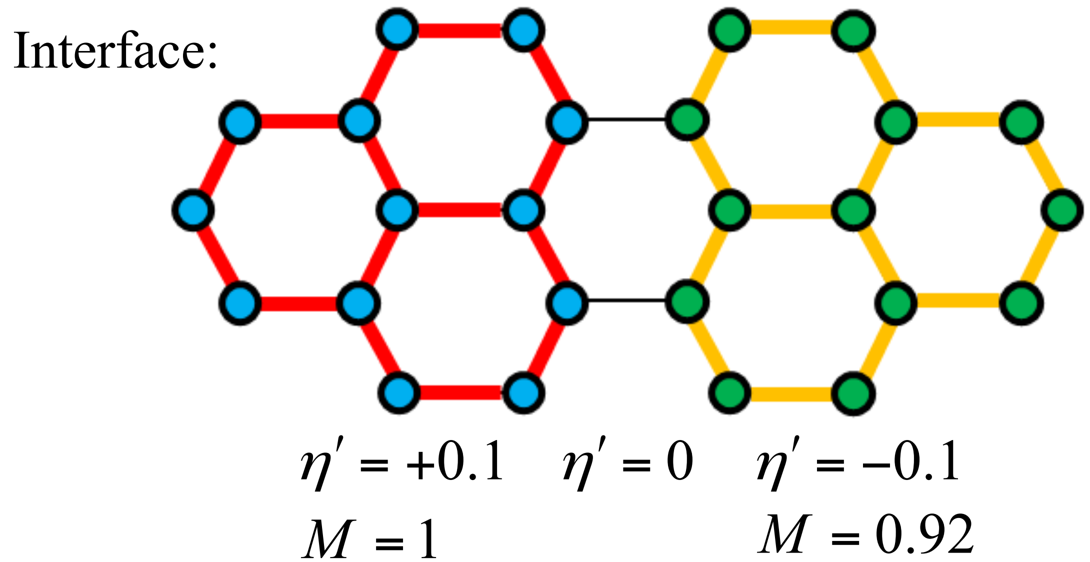
$$H = V_D \vec{\sigma} \cdot \Delta \vec{k}$$

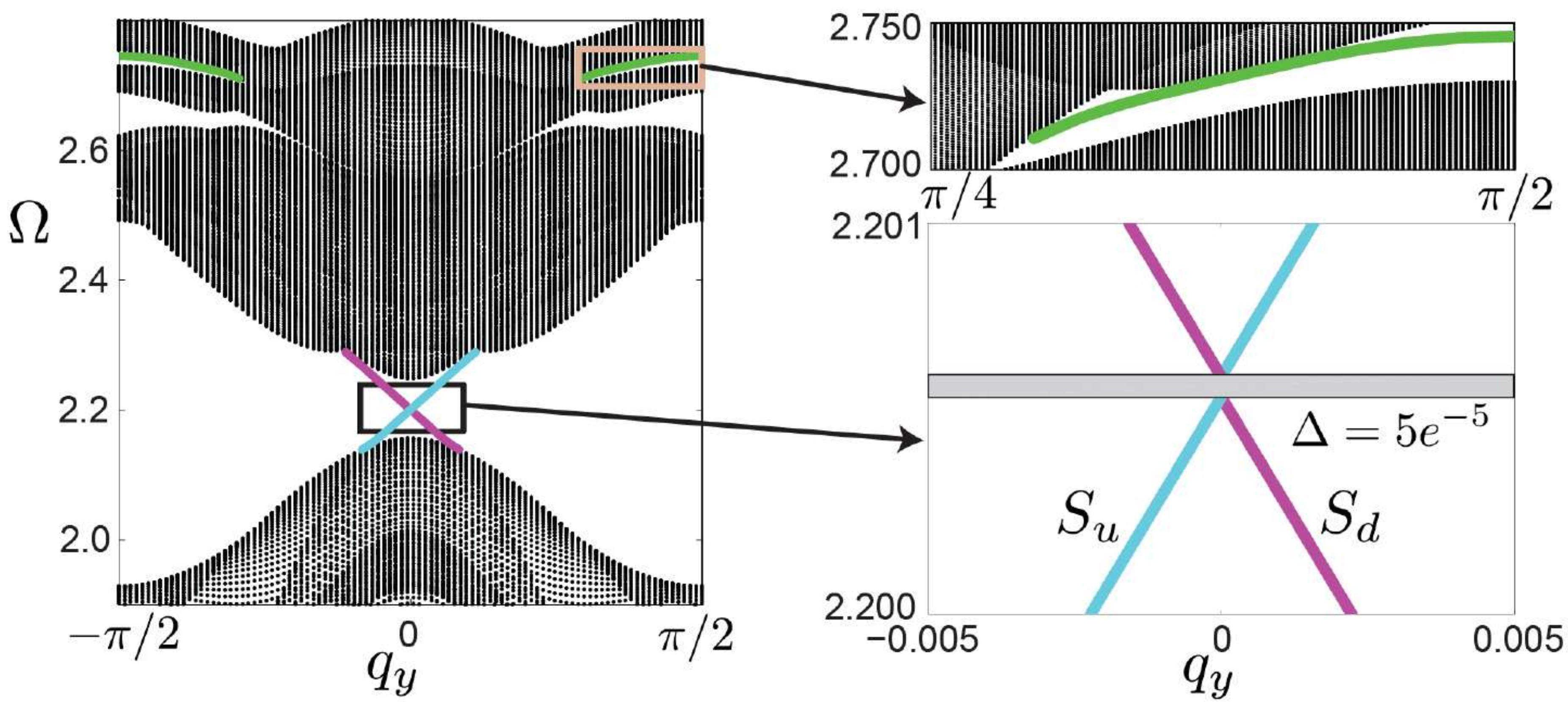
$$H_{\pm} = V_D \vec{\sigma} \cdot \Delta \vec{k} \pm m \sigma_z$$

Double Dirac Cone by fine tuning of the stiffnesses

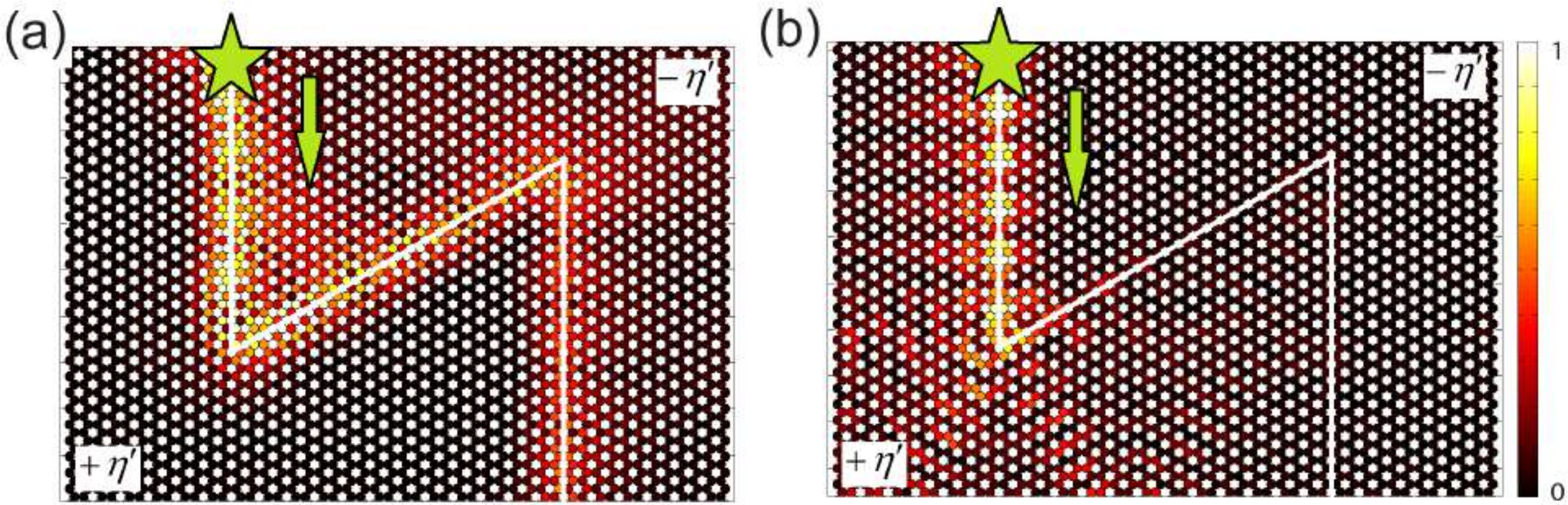
Mechanical Analogue of Quantum Spin Hall effect

Topological Granular Graphene





Topological Granular Mechanical Insulators



- L-Y Zheng, G. Theocharis, V. Tournat, V. Gusev, Quasi Topological Rotational Edge Waves in Mechanical Granular Graphene, **PRB 97, 060101(R) (2018)**