Many-body spectral statistics of relativistic quantum billiards systems

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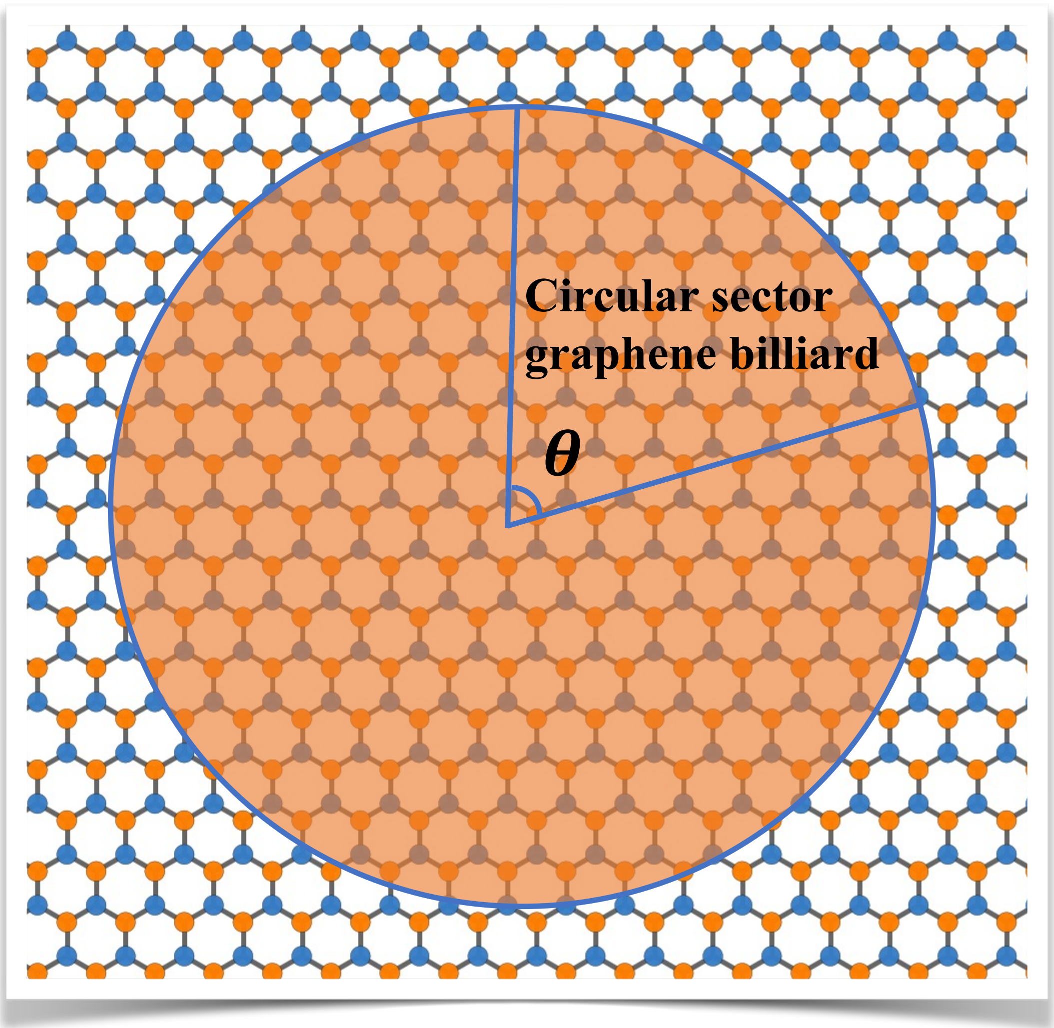
Motivation



Graphene: linear dispersion in low energy excitation

+

Many-body interactions

Spectral statistics?

Model and Methods

Spectral Statistics

$$H \to \mathrm{diag}[H] \to S = E_{k+1} - E_k$$

$$P(S) = \begin{cases} e^{-S}, \\ (\pi/2)Se^{-\pi S^2/4}. \end{cases}$$

Poisson → Integrable

GOE (Gaussian orthogonal ensemble) → Chaotic

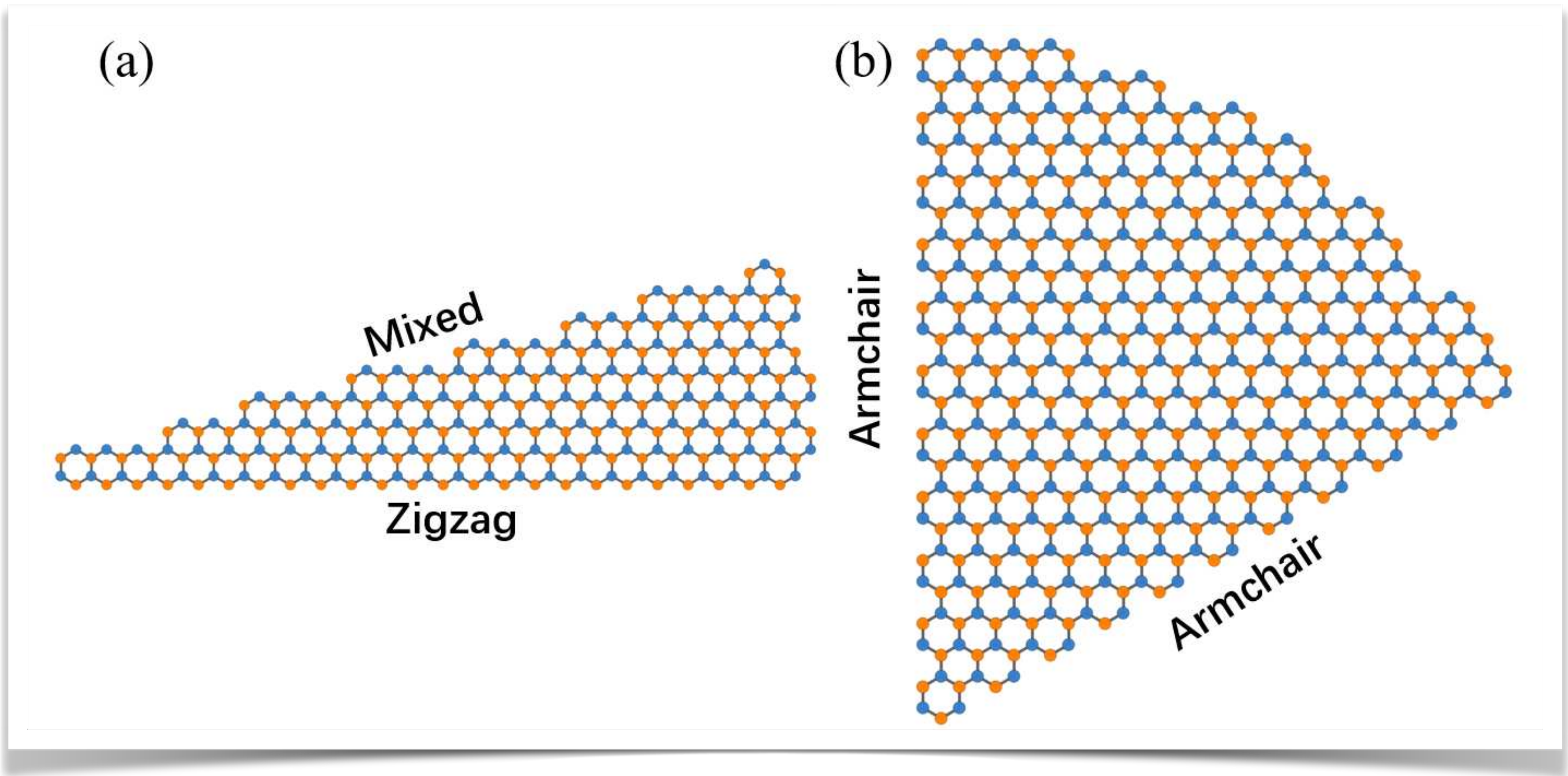
Additional statistical quantities:

* Accumulated $P(S)$ distribution $I(S)$,
* The number variance $\Sigma_2(L)$,
* The Spectral rigidity $\Delta_3(L)$,
where L is the number of mean level spacing.

Model and Methods

Mean-field Hubbard Hamiltonian

15° ZM $\qquad$ 60° AA



$$H = \boxed{-t \sum_{<i,j>,\sigma} c^{\dagger}_{i,\sigma} c_{j,\sigma}}$$

GOE

Poisson

P. Yu, et al, Phys. Rev. E, 2016

$$\boxed{+U \sum_{i,\sigma} \langle n_{i,\bar{\sigma}} \rangle \hat{n}_{i,\sigma}}$$

?

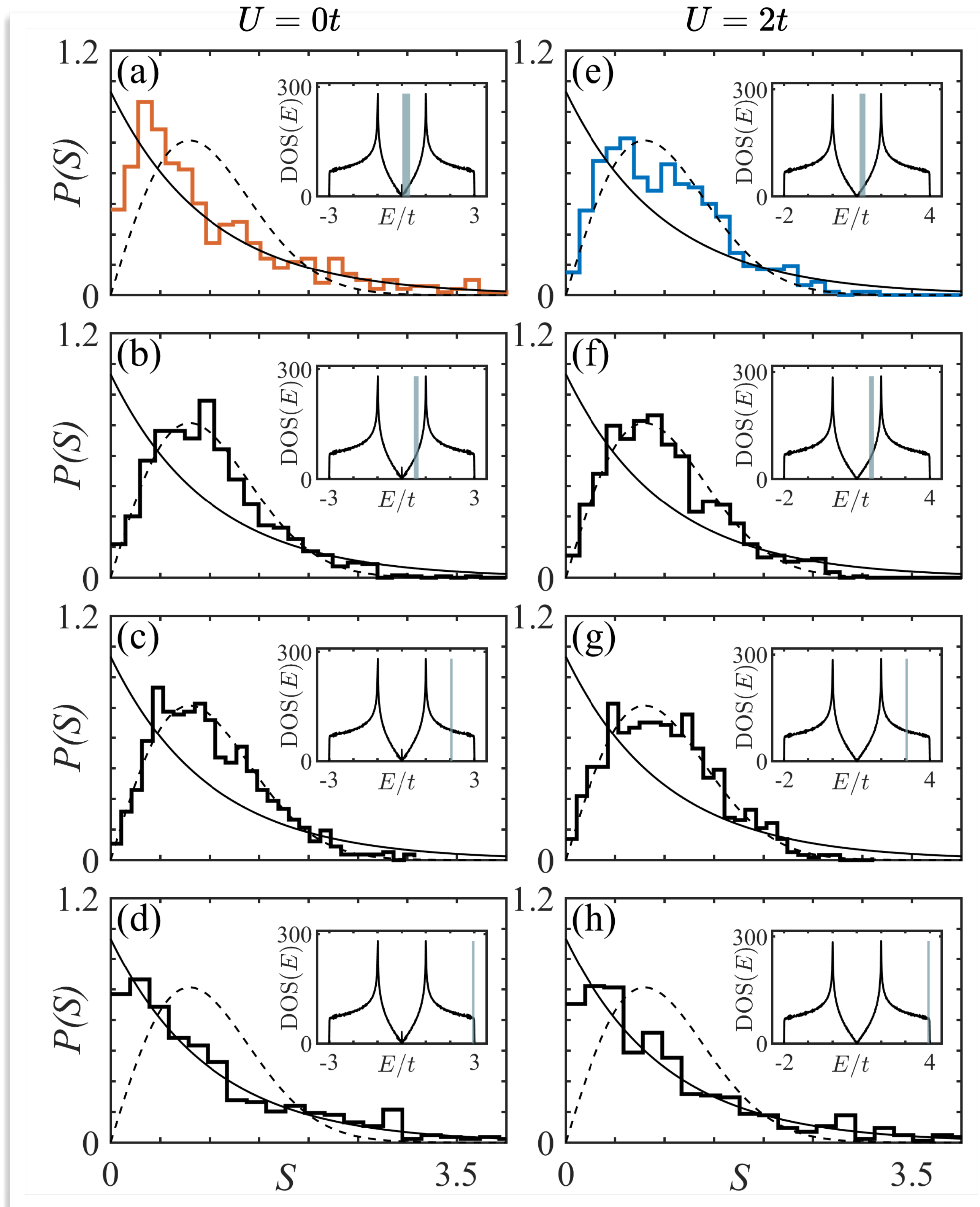
$\sigma = \downarrow$ $\quad$ U: the strength of Hubbard interaction $\quad$ $\langle n_{i,\bar{\sigma}} \rangle$: the mean occupation number at site i, with spin $\bar{\sigma}$

Results

Energy ranges for spectral statistics

Dirac point

Energy ranges



Results

Best-fit parameter λ

$$H(\lambda) = (H_0 + \lambda H_1)\sqrt{1+\lambda^2}$$

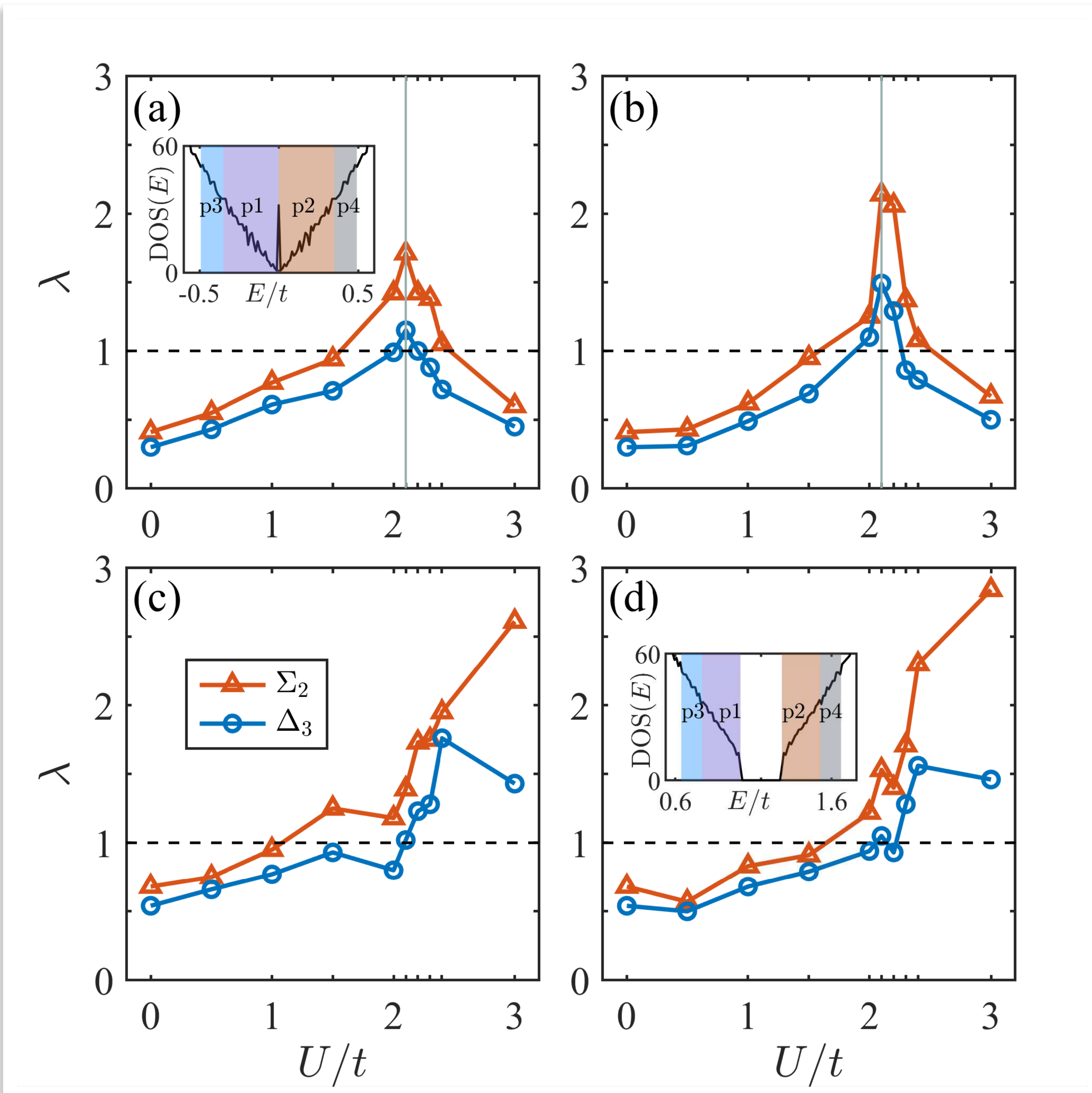
where H_0 belongs to a diagonal matrix of random Poisson numbers and H_1 is a random matrix from GOE.

B. Dietz, et al, Phys. Rev. Lett., 2017

$\lambda \to 0$	Poisson
$\lambda > 1$	GOE

Results

60° **AA graphene billiard**



U

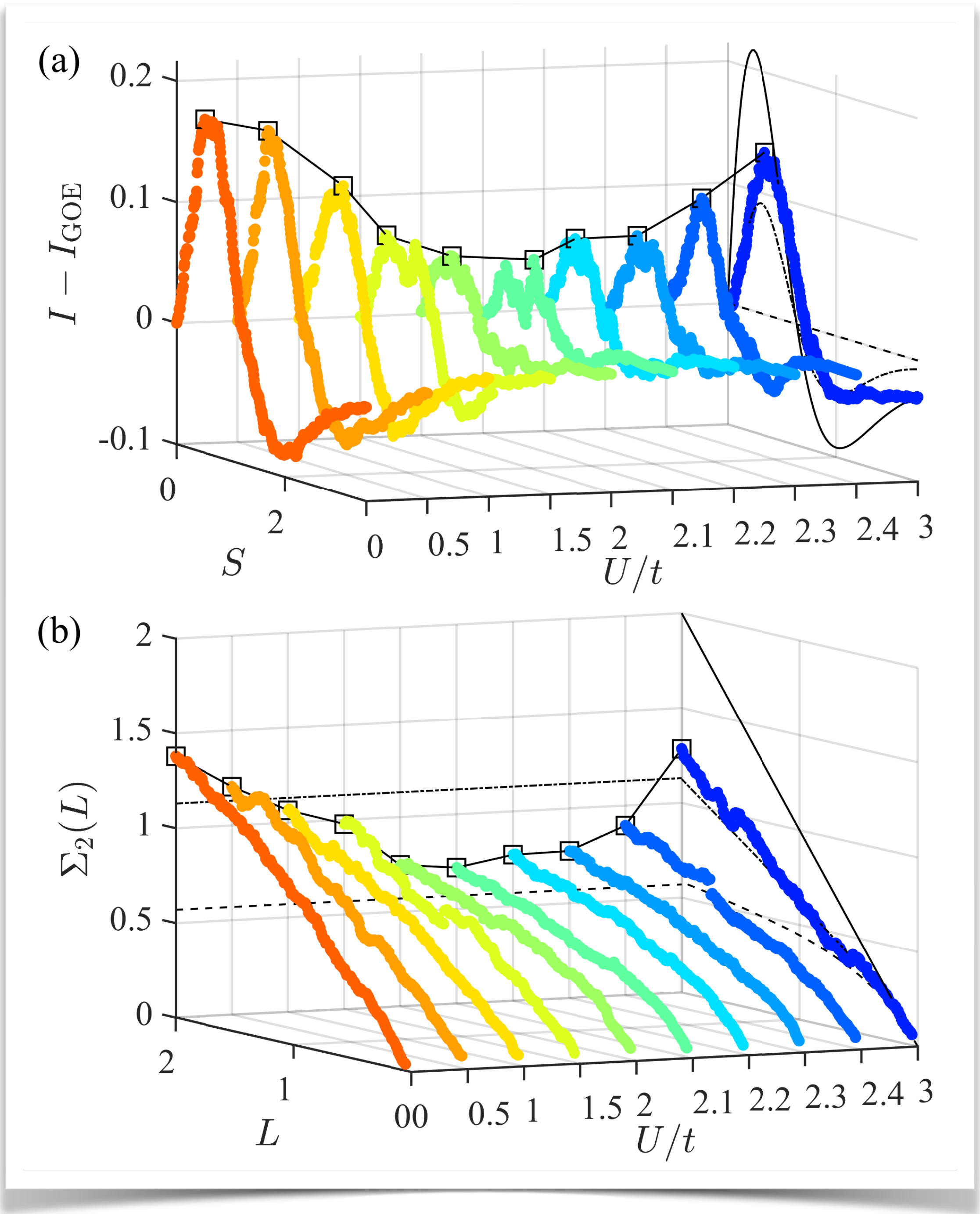
Poisson

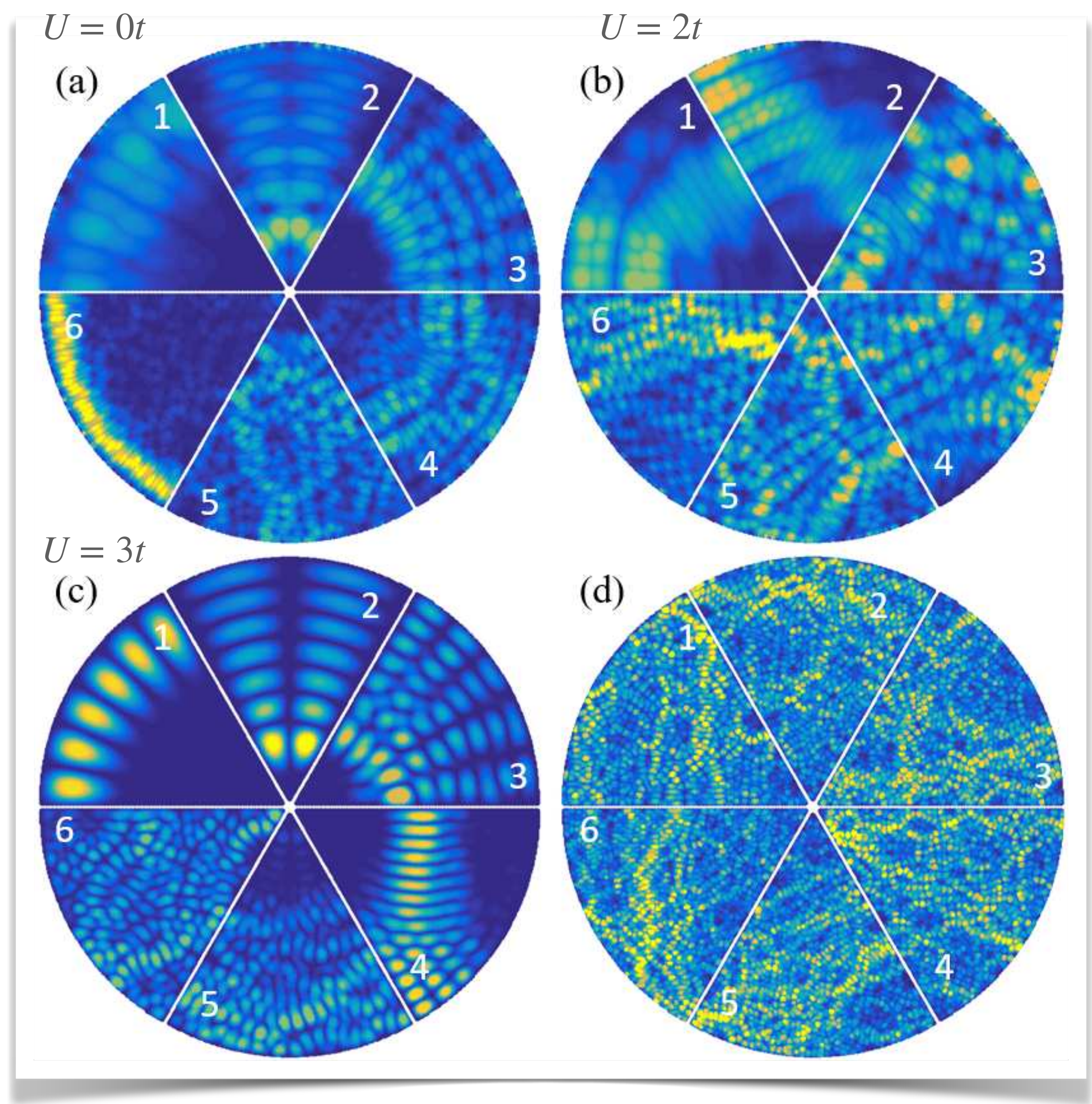
GOE

Poisson

Results

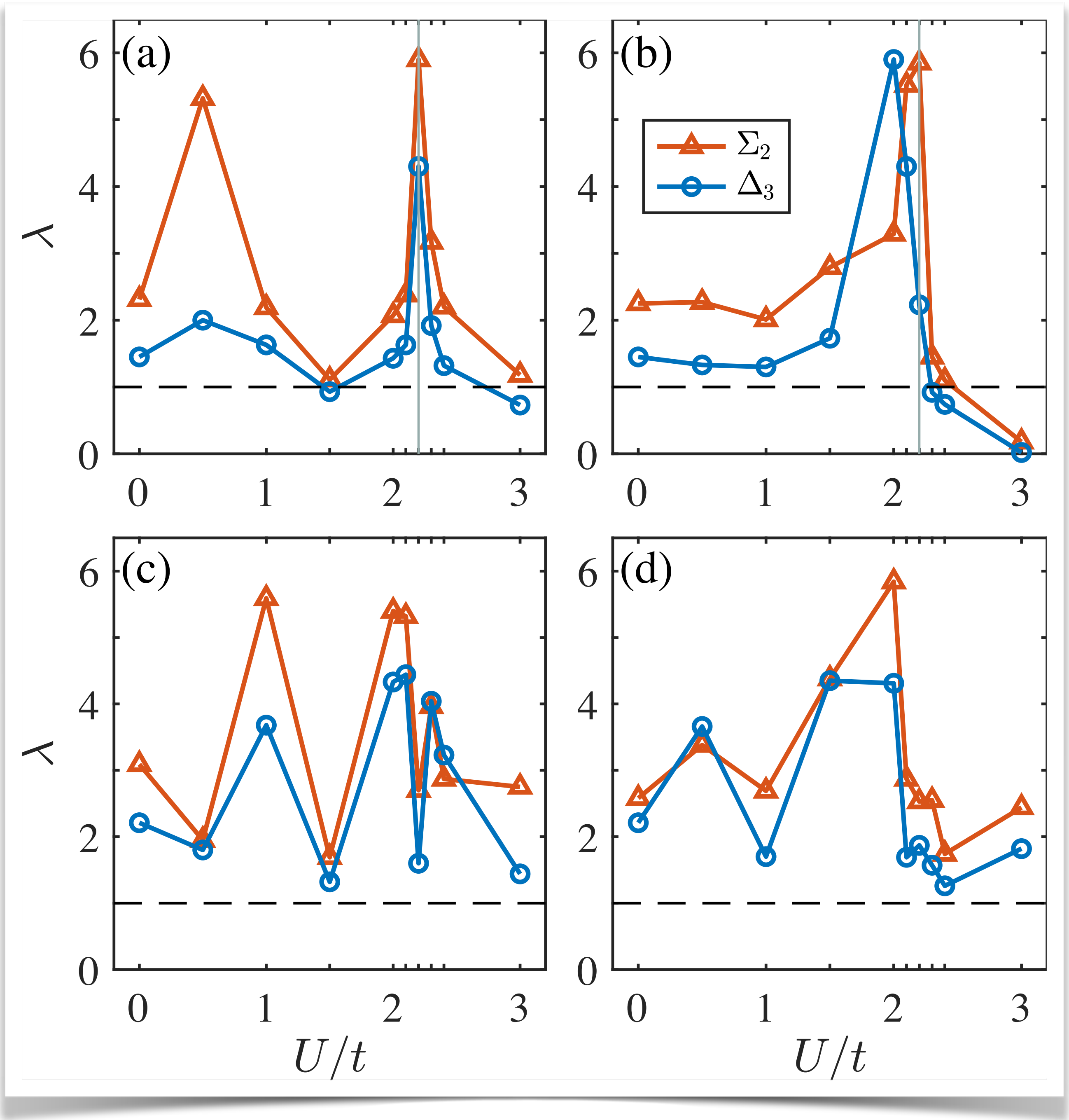
60° **AA graphene billiard**

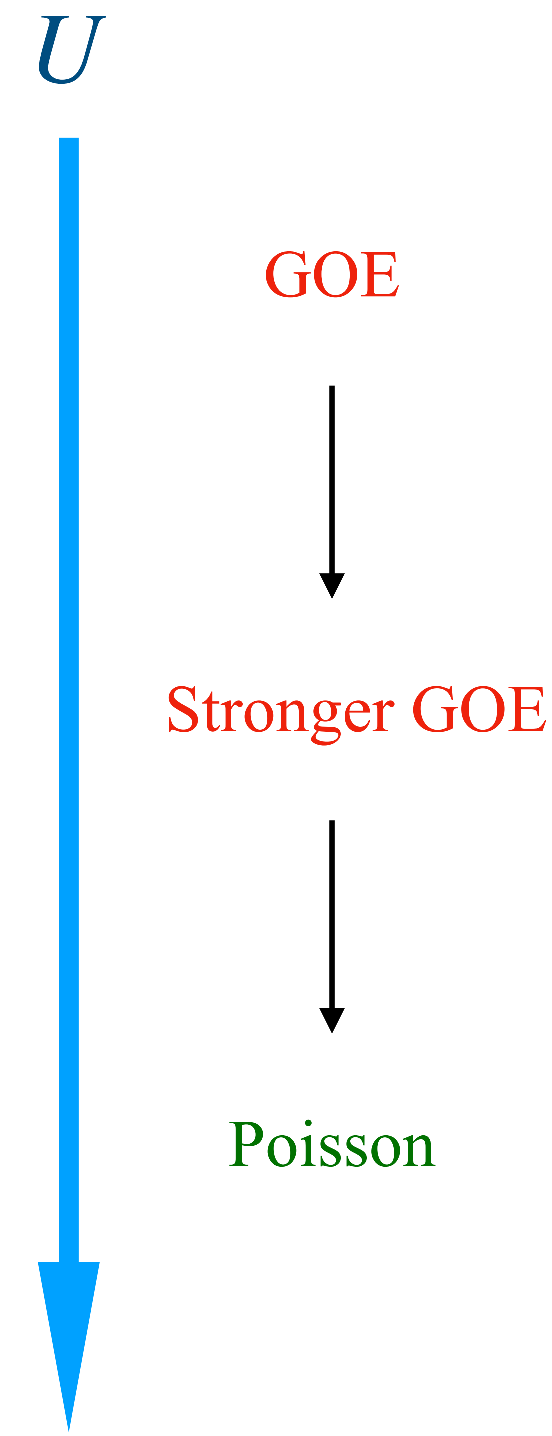




Results

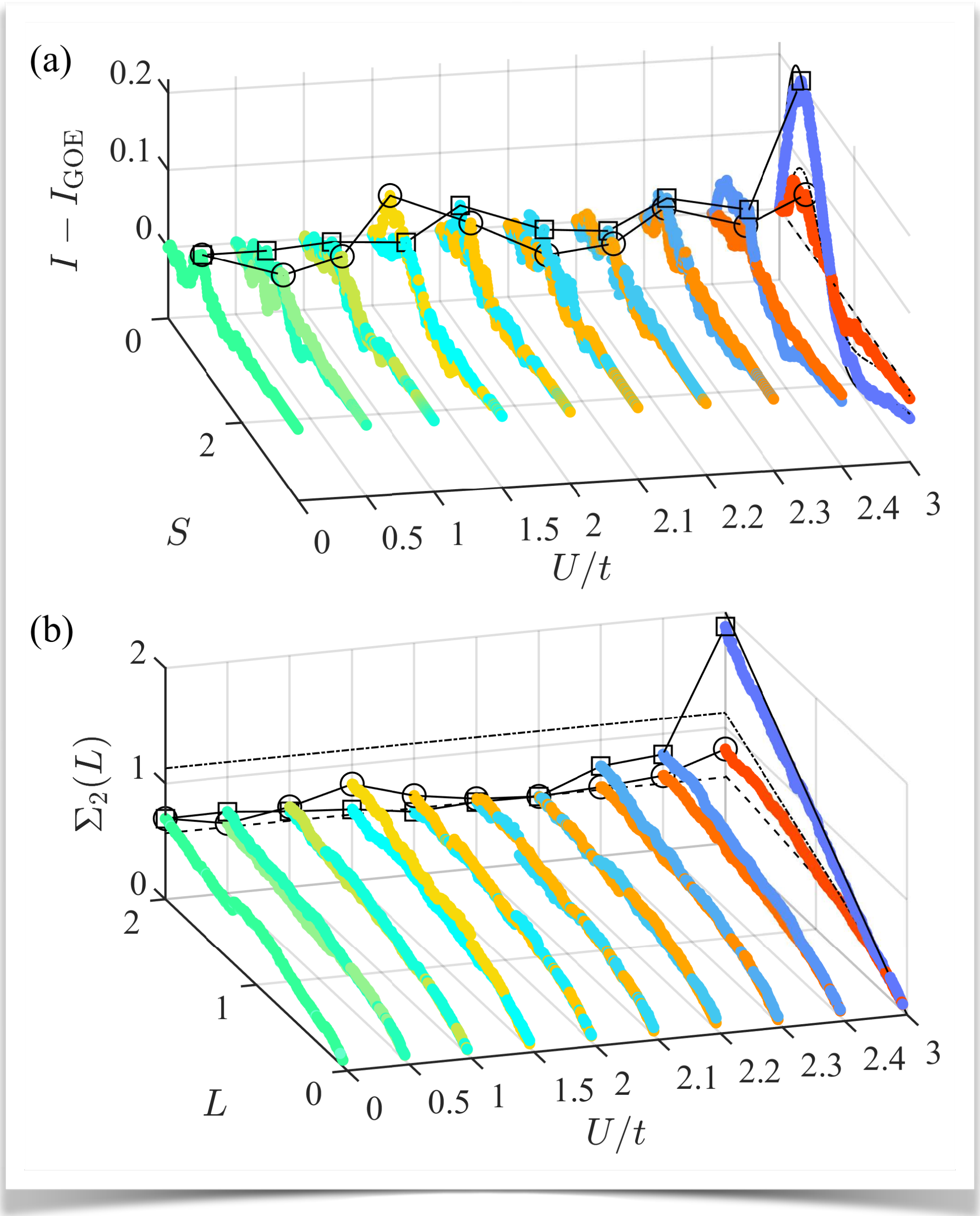
15° **ZM graphene billiard**

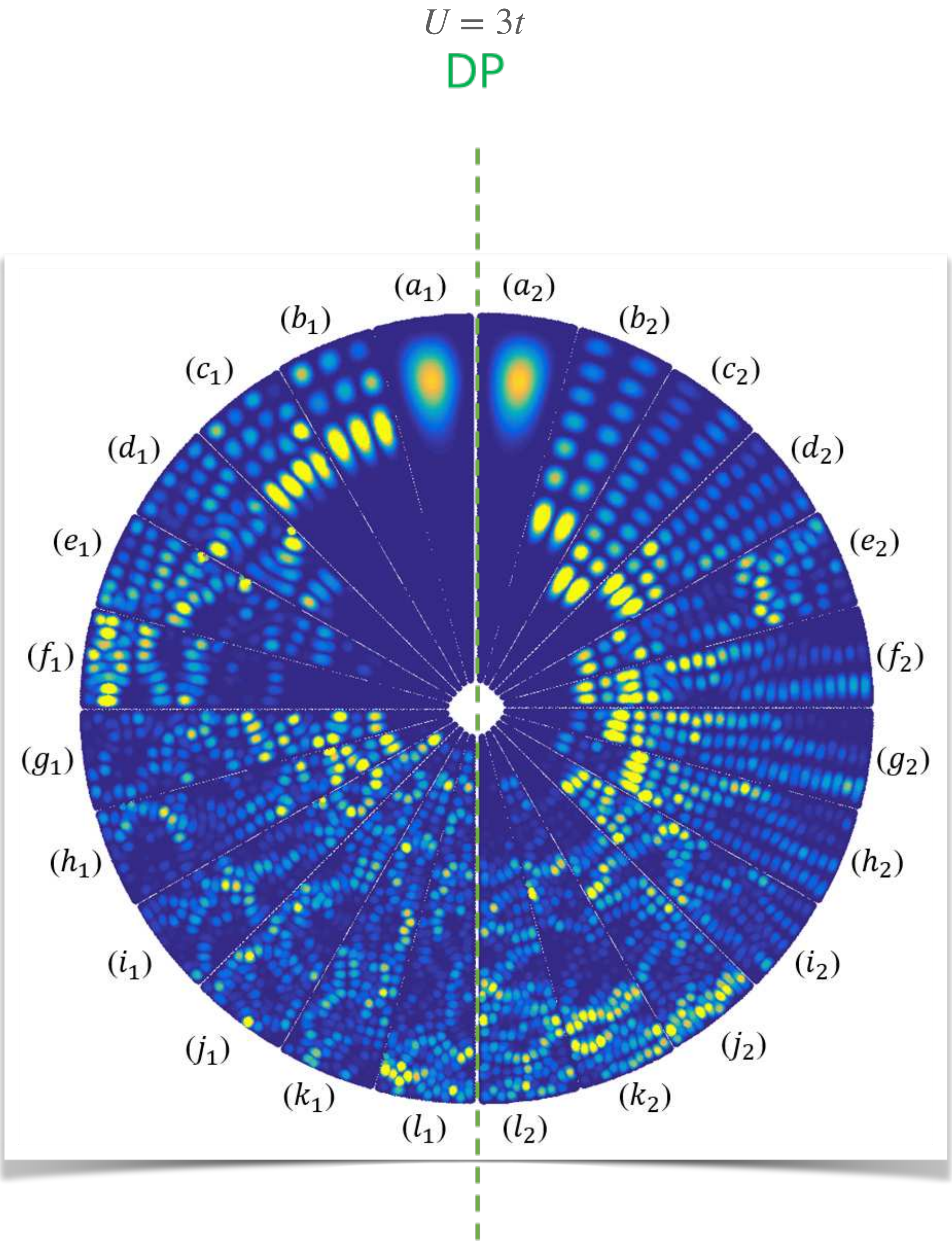




Results

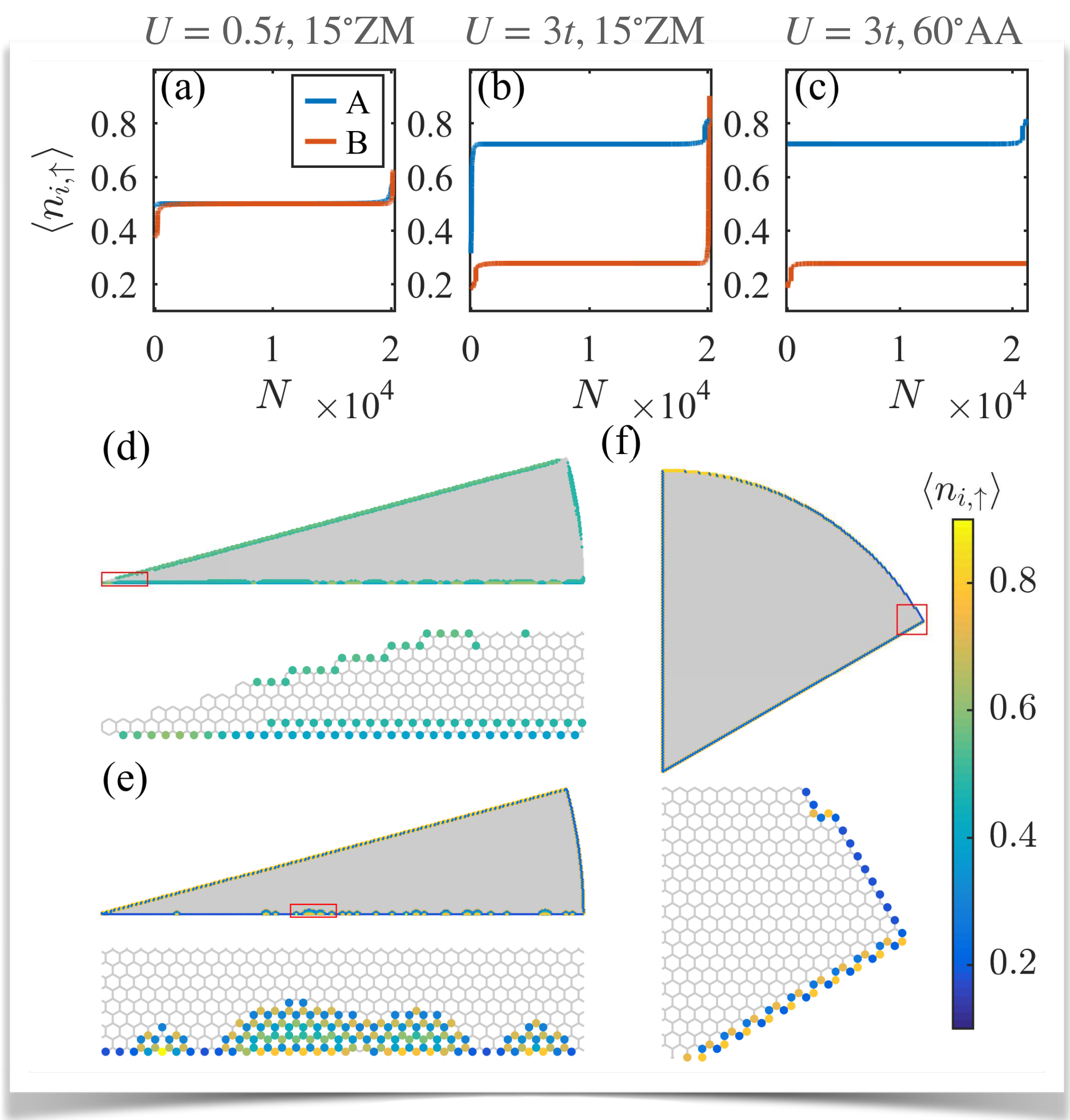
15° ZM graphene billiard





Physical Understanding

Hubbard interactions act as a mass term



Poisson $\xrightarrow{1}$ GOE $\xrightarrow{2}$ Poisson

U ⟶

1: Many-body interactions introduce complexity in classical dynamics

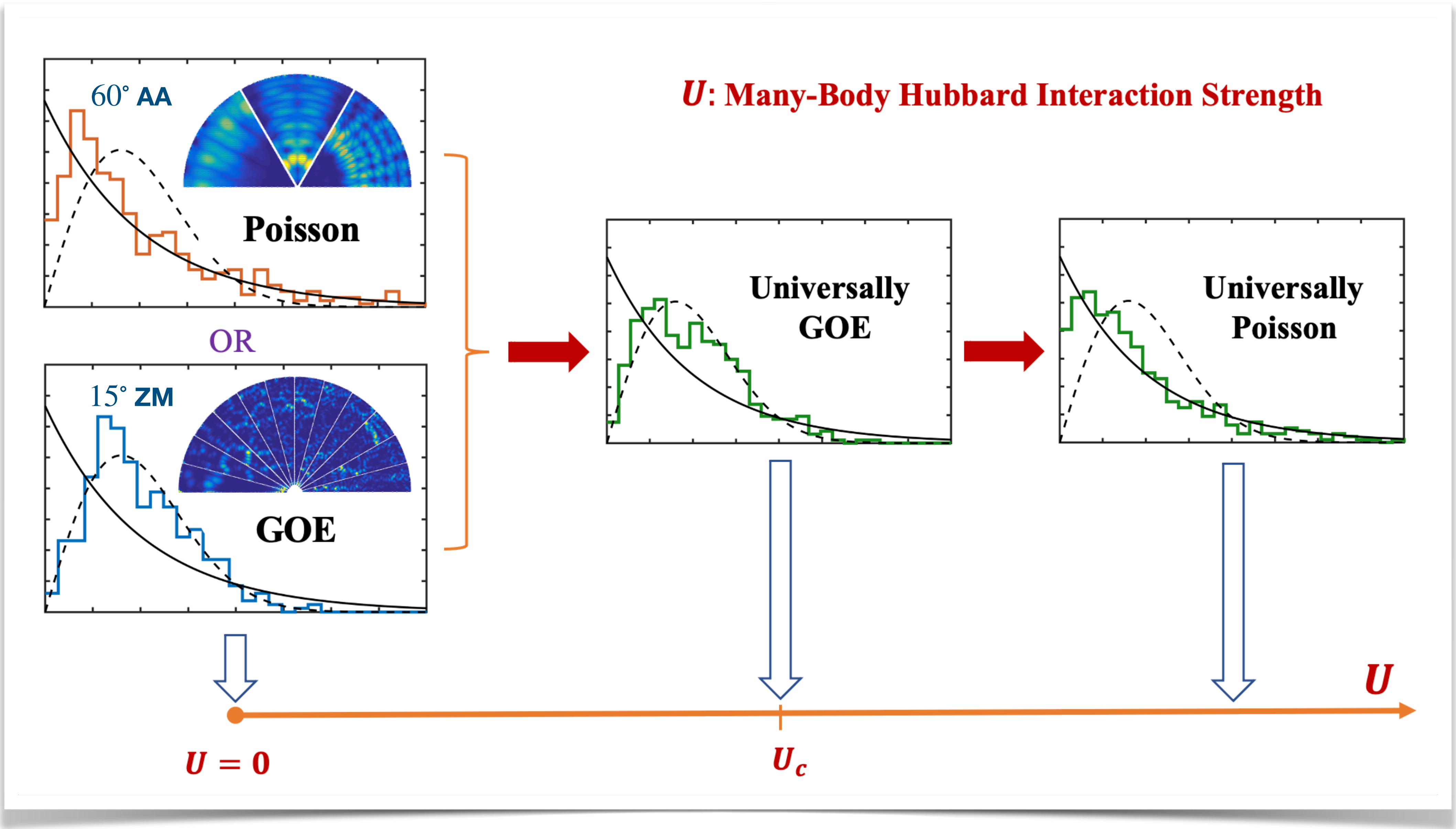
2: Hubbard interactions act as a mass term

$$H_{\mathrm{MF},\sigma} = \mathscr{H}_{\mathrm{TB}} + \mathscr{H}_{U,\sigma}$$

$$\mathscr{H}_{U\sigma,ii} = U\langle n_{i,\bar{\sigma}} \rangle$$

Massless Dirac equation → Massive Dirac equation

Summary



Xianzhang Chen, Zhenqi Chen, Liang Huang, Celso Grebogi, and Ying-Cheng Lai, "Many-body spectral statistics of relativistic quantum billiards systems", submitted to Phys. Rev. Research.

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