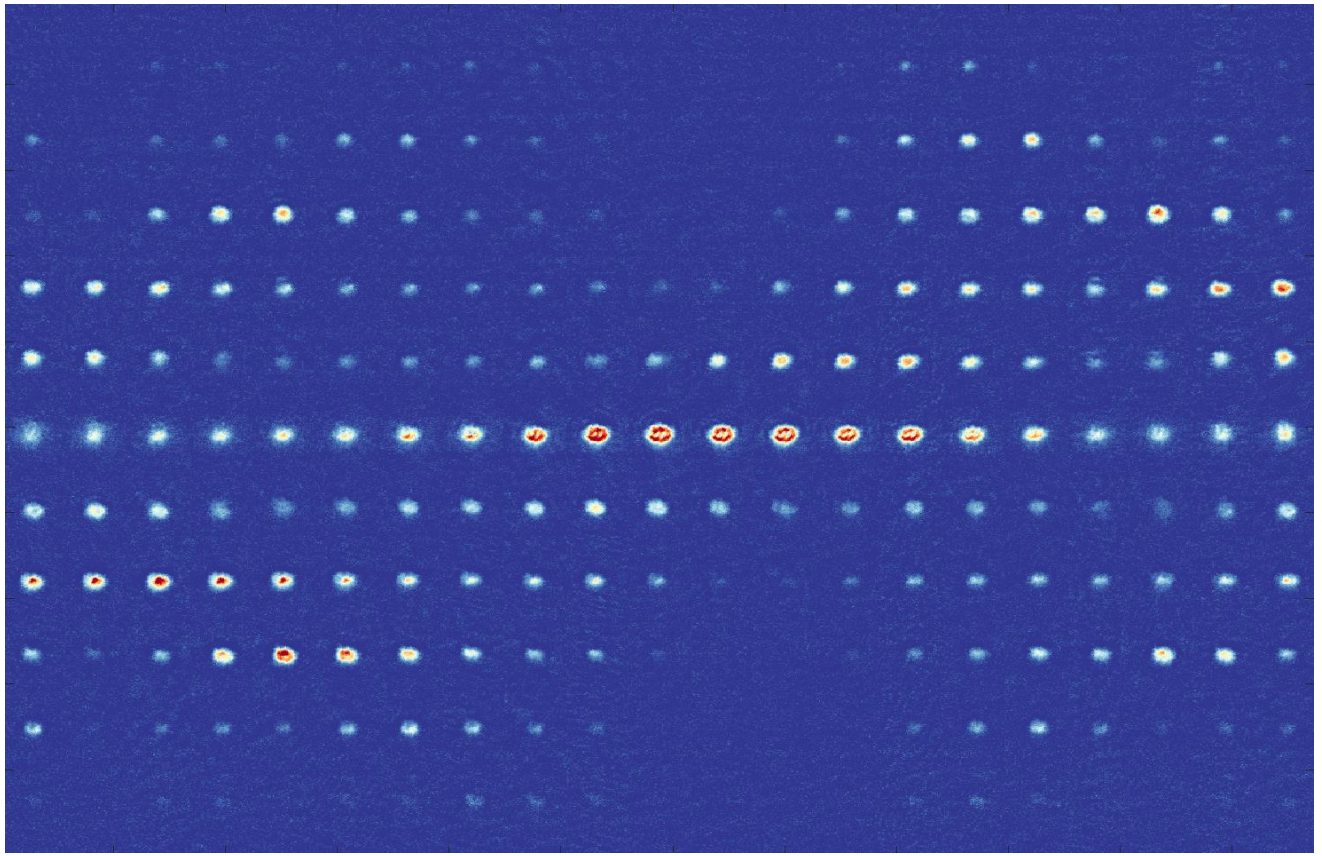
Localization and delocalization in kicked quantum matter



David Weld, UC Santa Barbara

SPICE Workshop: Dissipative Phases of Entangled Quantum Matter

May 5, 2021

Outline

- Many-body dynamical (de)localization in the quantum kicked rotor
- Controlling localization in a kicked quasicrystal
- Conclusions

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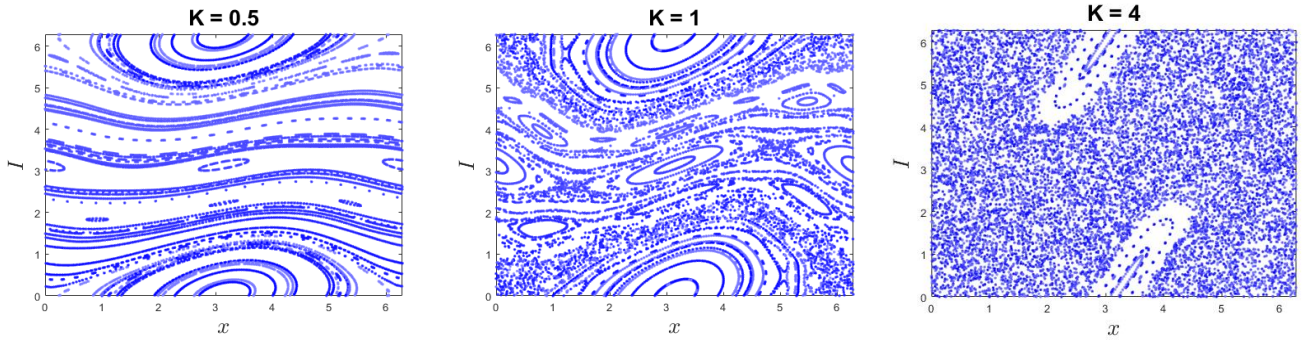
- **Many-body dynamical (de)localization in the quantum kicked rotor**

- Controlling localization in a kicked quasicrystal

- Conclusions

The quantum kicked rotor

- Central testbed of classical and quantum chaos
  - Kicked particle on a ring: $H = \frac{p^2}{2} + K\cos(x)\sum_{n=0}^{\infty}\delta(t-nT)$
  - Classical system: heats diffusively (K>0.97)



Chirikov, *Phys. Rep.* **52**, 5, 263 (1979)

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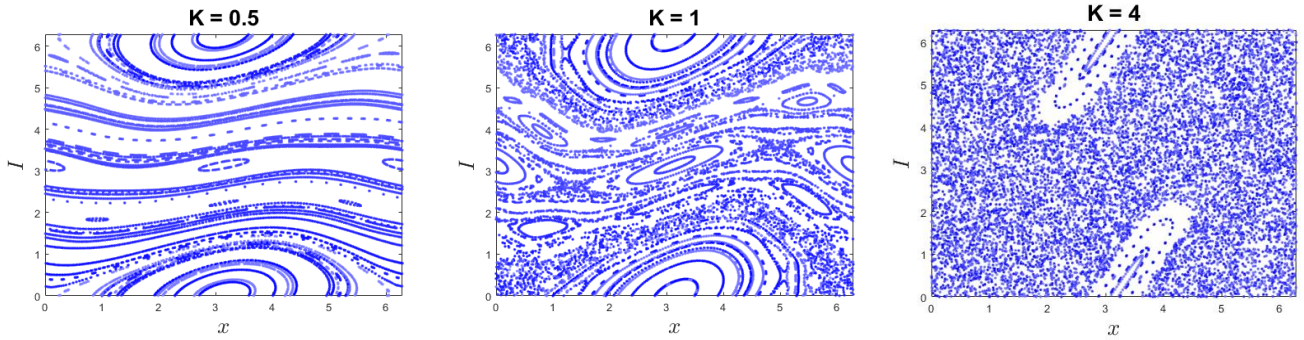

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  - Mapping to Anderson localization in momentum space

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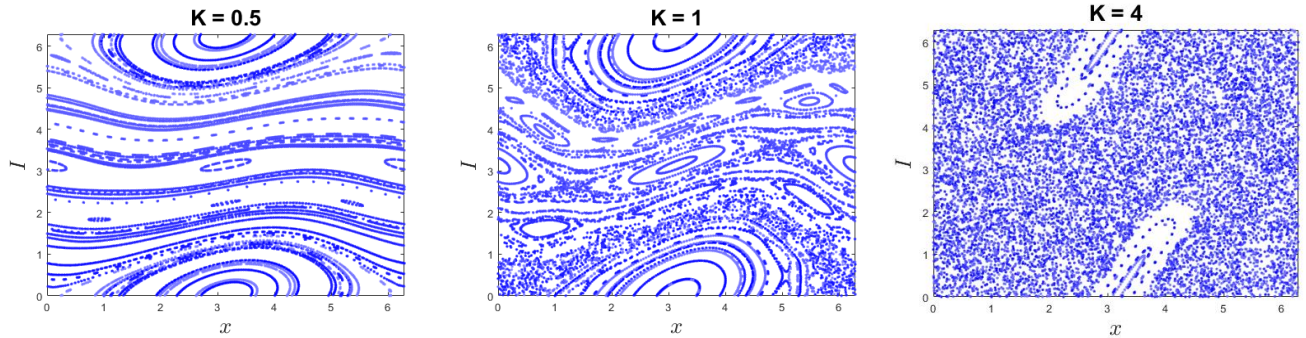
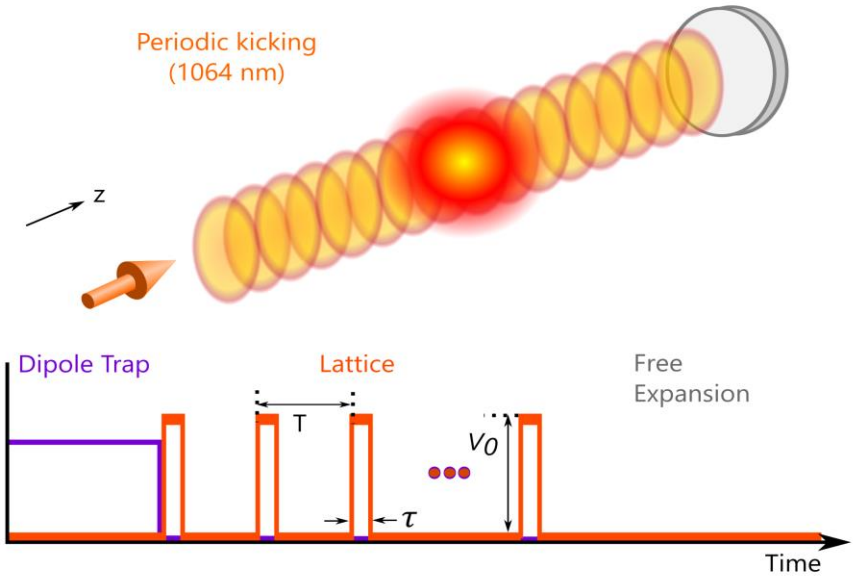


  - Quantum system: ergodicity breaking, localizes at finite energy
  - Mapping to Anderson localization in momentum space
- Seminal results by Raizen and others in 1990s (among the earliest OLQS work)
- Experimentally unexplored question: **what is the effect of interactions?**

Shepelyansky, *PRL* **70**, 1787 (1993)
Moore et al, *PRL* **75**, 4598 (1995)

Optical lattice tunably-interacting QKR experiment

- Physical realization: Fechbach-tunable ^{7}Li BEC in a periodically pulsed optical lattice

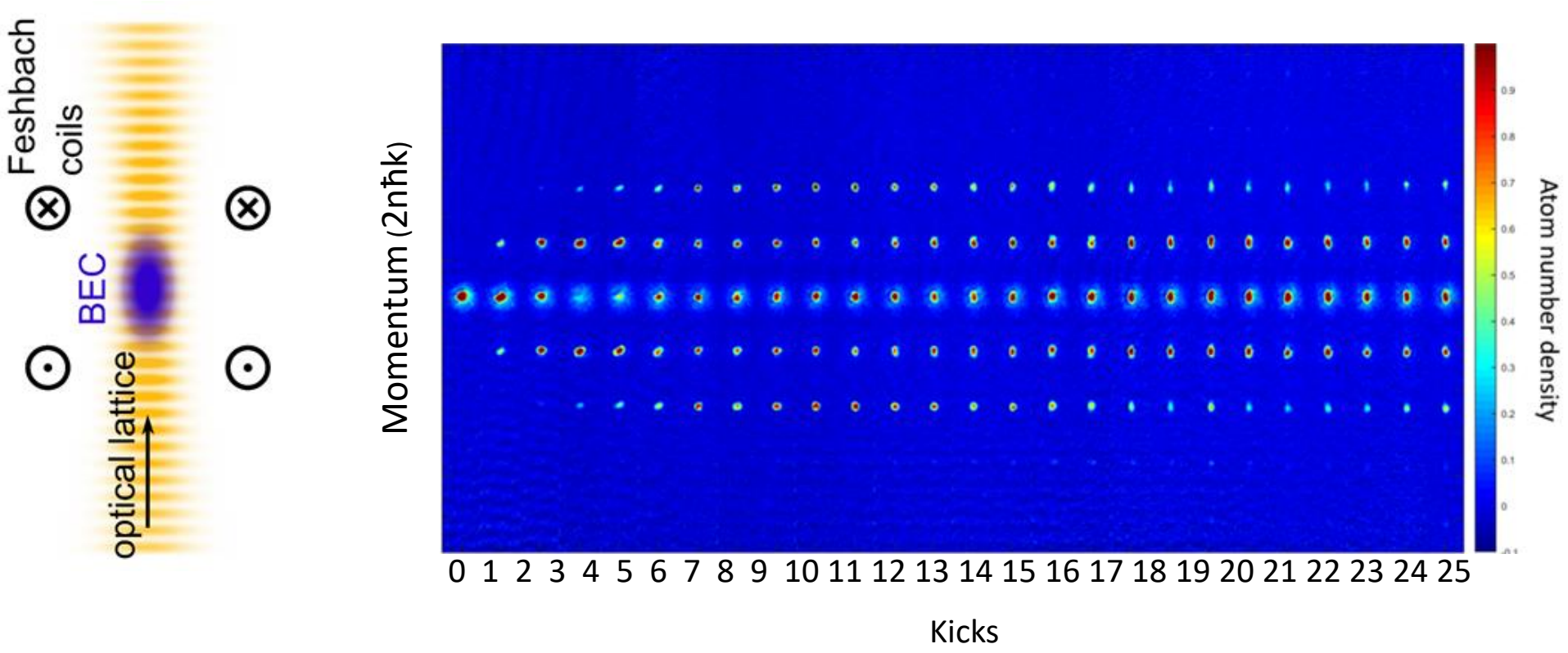


- Theory inspiration & collaboration: Victor Galitski

- Complementary experimental investigation: Deep Gupta

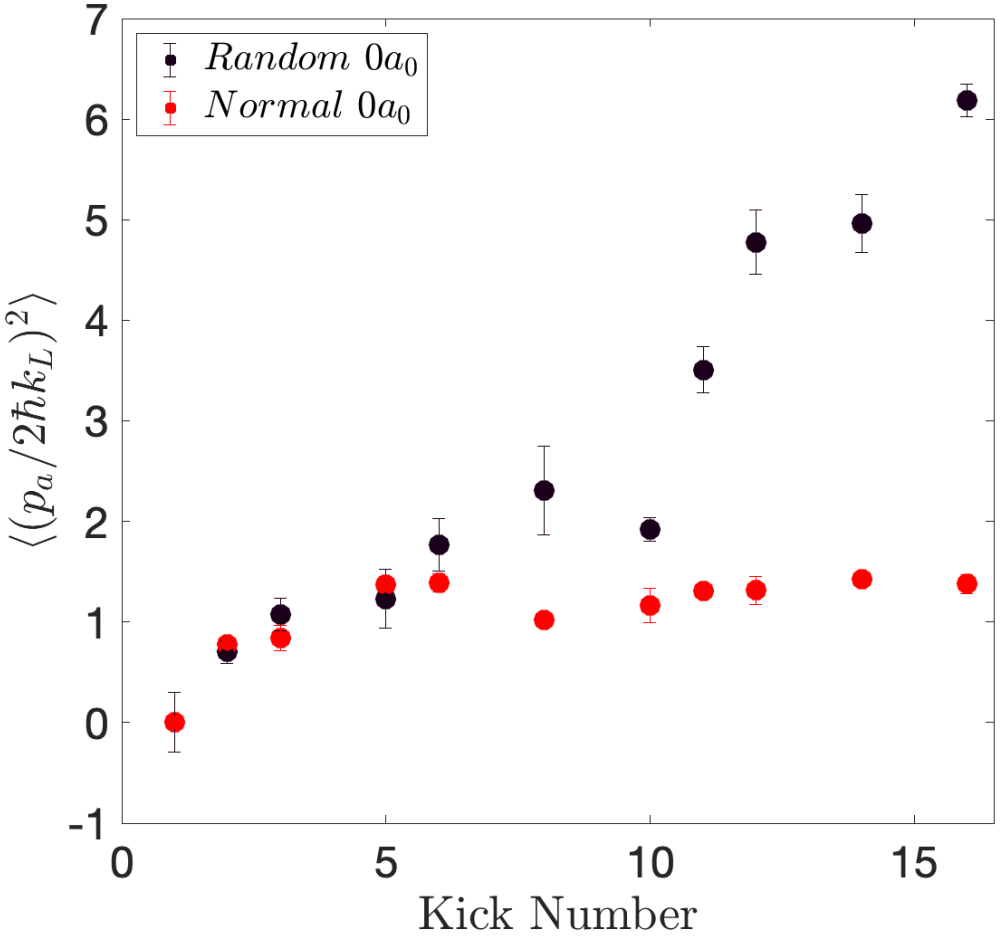
Localization in a non-interacting rotor

- At Feshbach zero-crossing, quantum localization is straightforward to observe
- Atoms absorb energy from drive up to a point, then stop



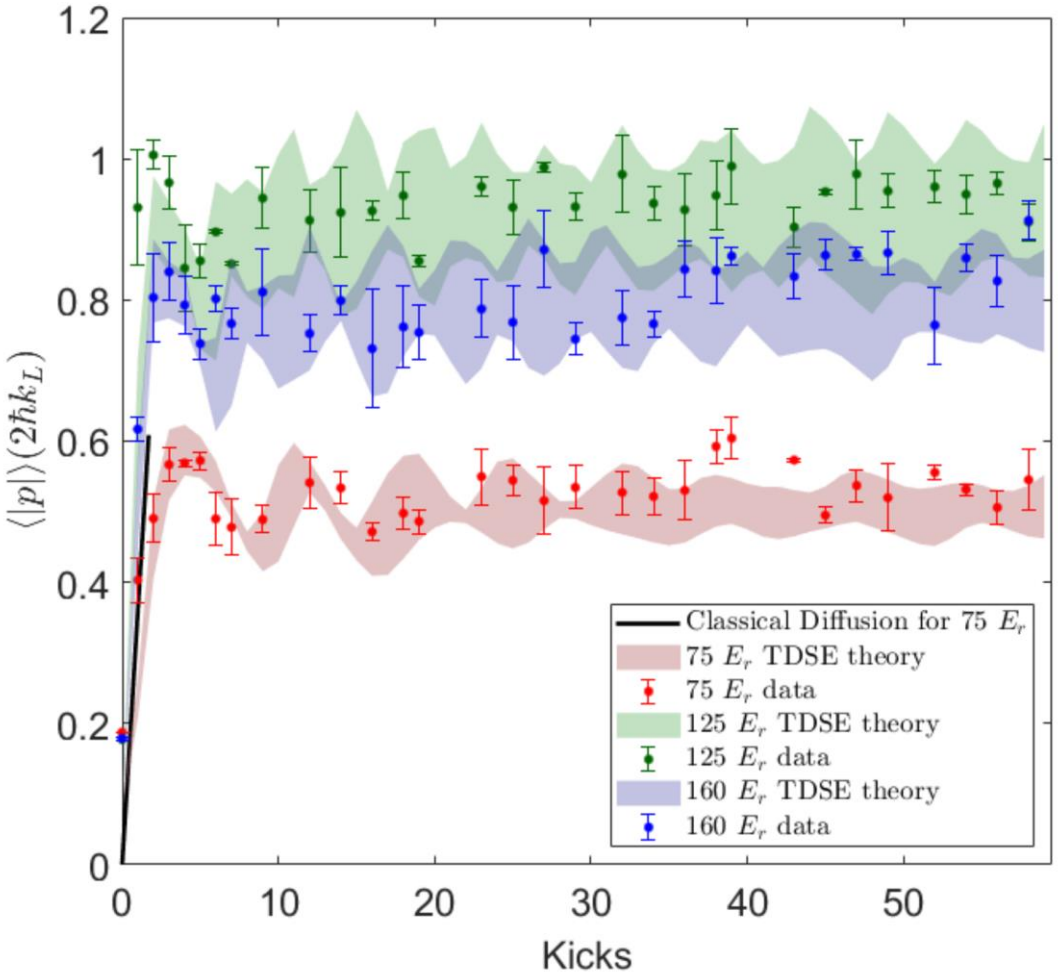
Random kicking can recover the classical behavior

- If we stochastically modulate the period between kicks, localization is destroyed
- Observe diffusive heating with approximately linear-time energy growth



Localization depends on kick strength

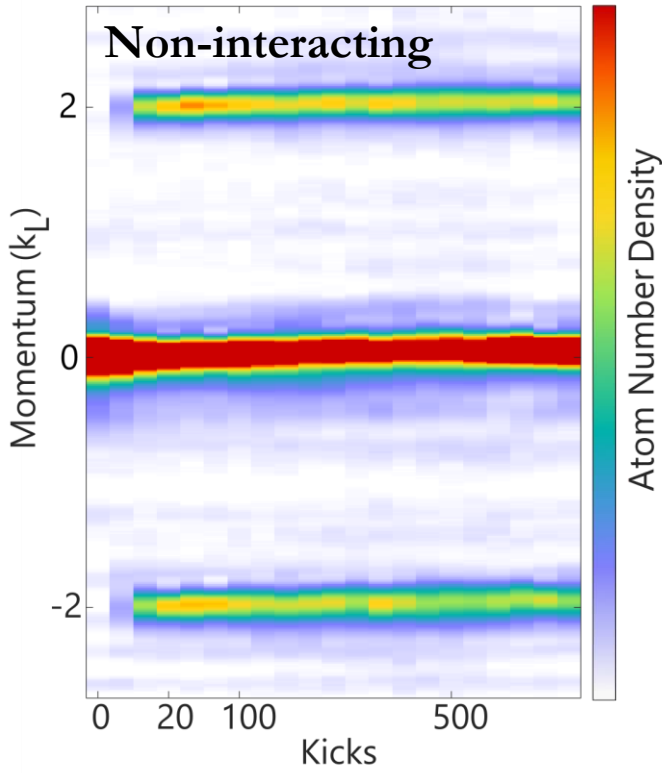
- Non-interacting data show good agreement with non-interacting theory



The interacting quantum kicked rotor

- ^{7}Li can realize QKR with Feshbach tuning of contact interactions
- Possibilities: many-body dynamical localization, delocalization, prethermalization
- Much-investigated theoretically, but validity of mean-field approaches unclear.

What happens when we turn on interactions?



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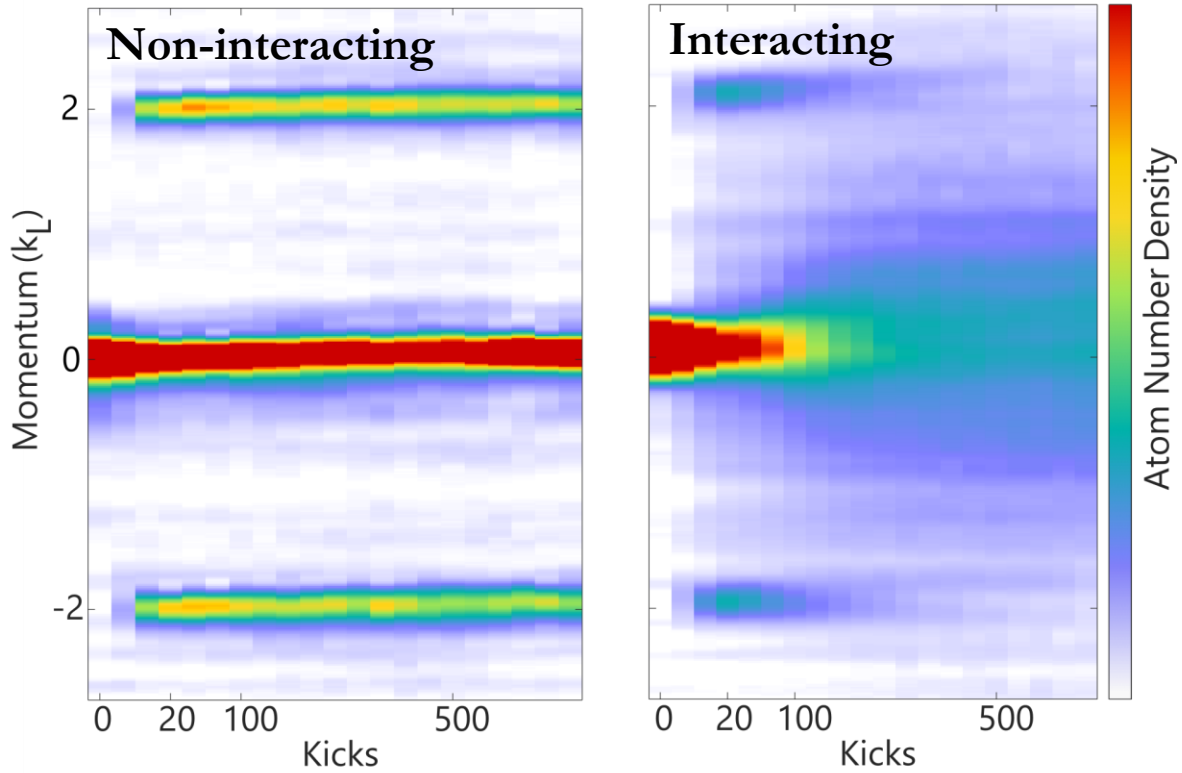

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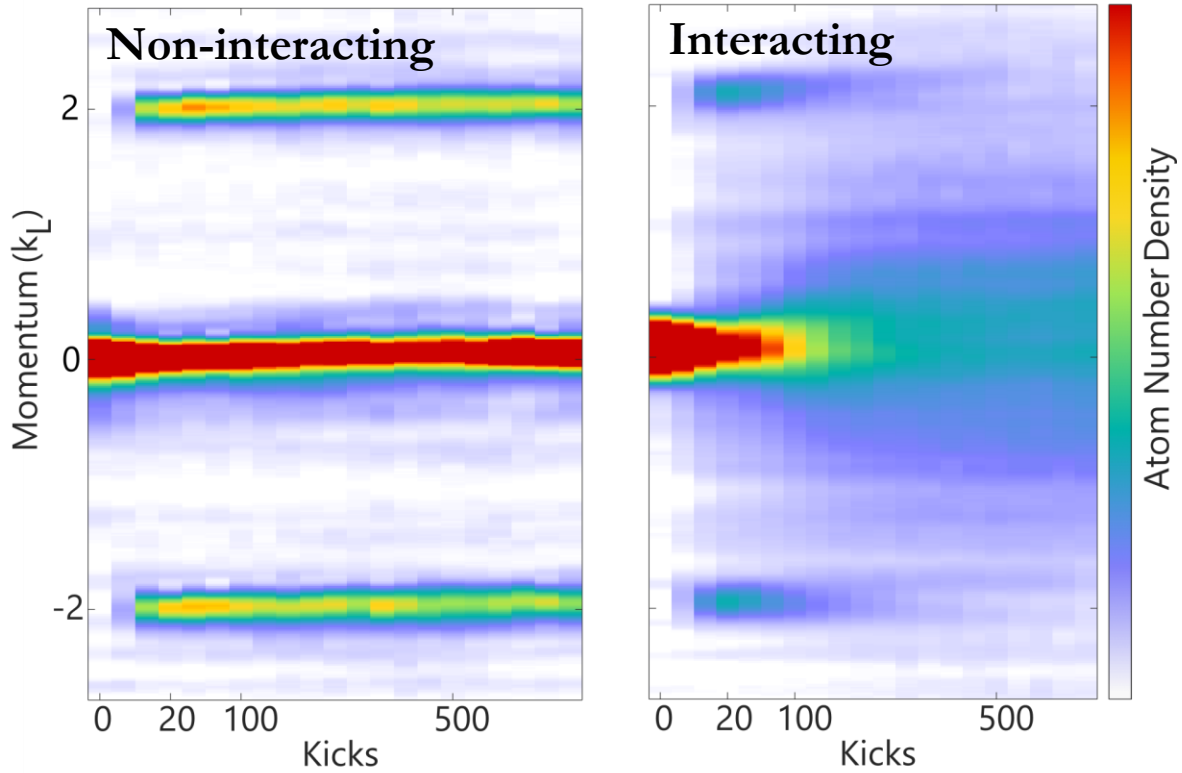

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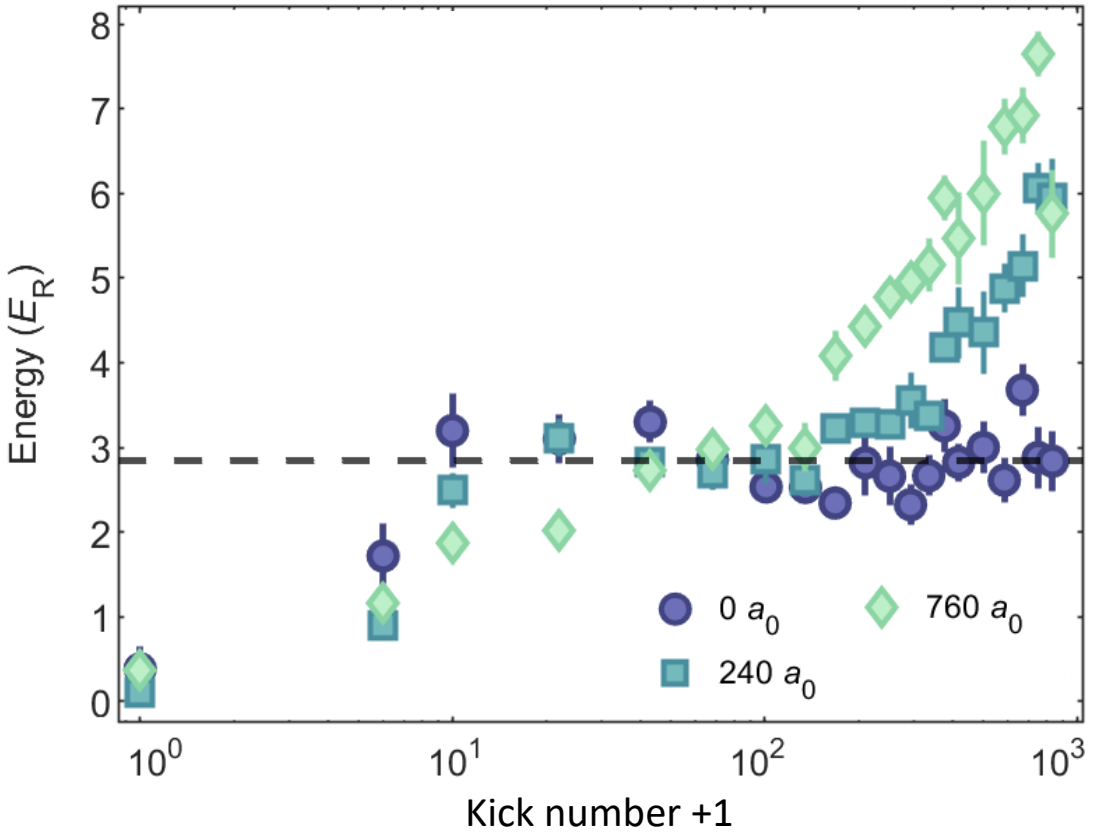

→ Prethermal plateau followed by interaction-dependent delocalization

→ After 100's of kicks, interacting samples diverge from non-interacting case

The interacting quantum kicked rotor

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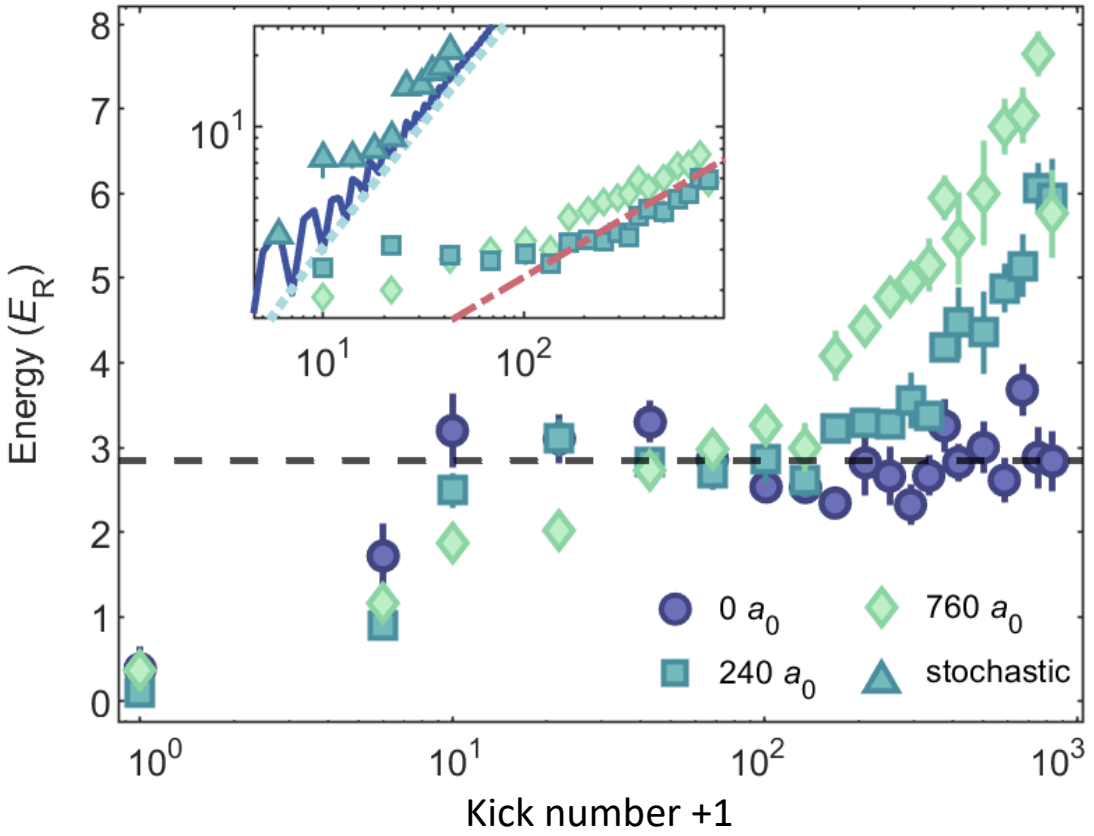
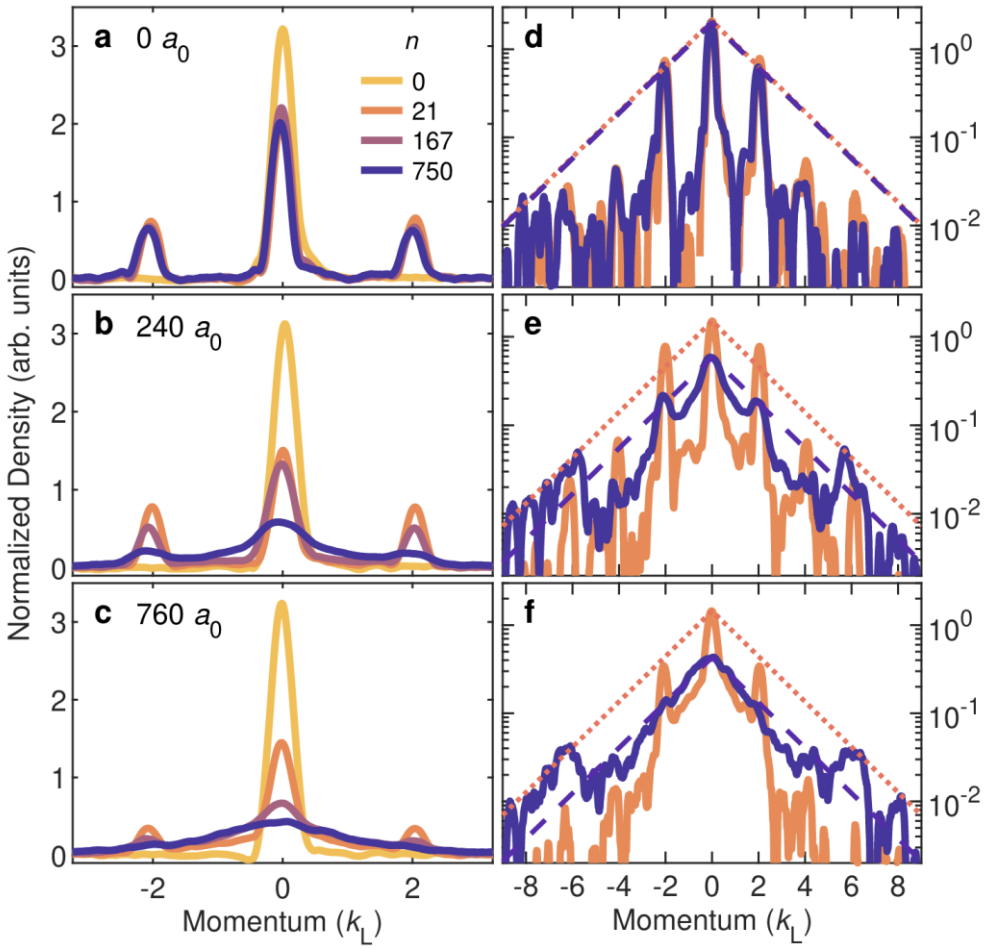


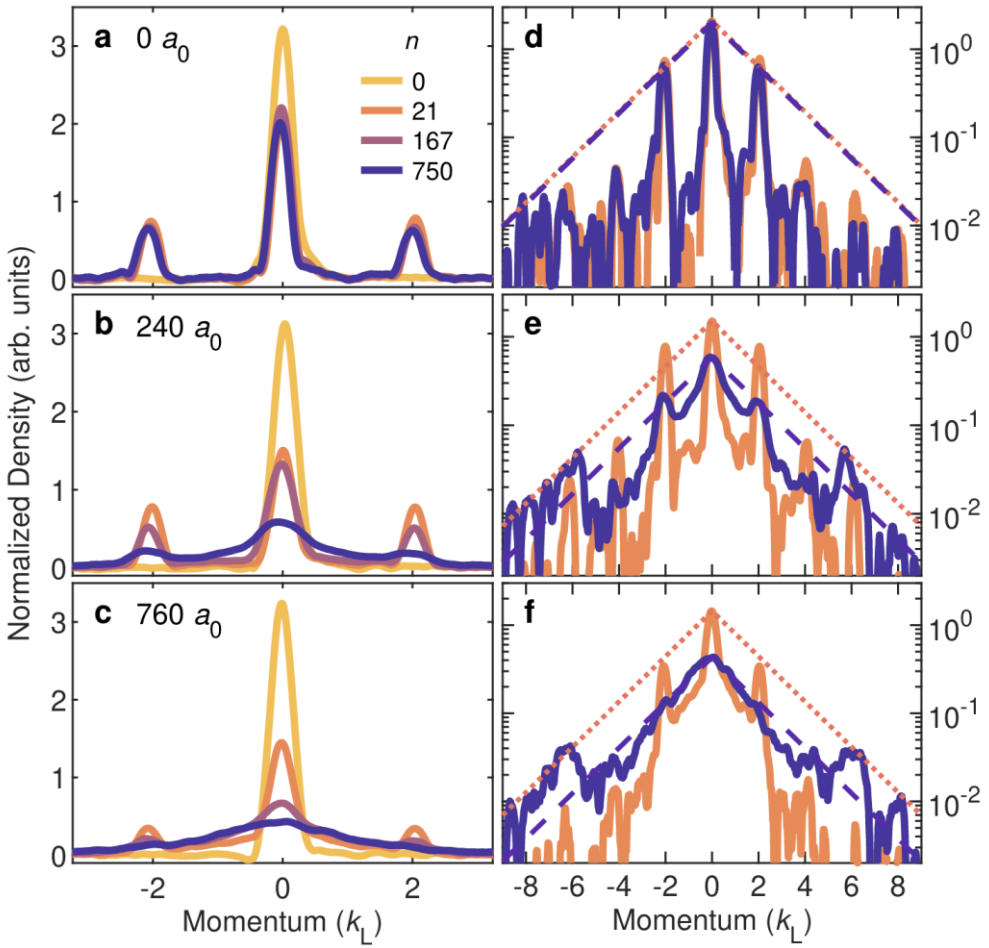
→ Delocalization is **sub-diffusive** at all times we study: even interacting quantum rotors absorb energy much more slowly than their classical counterparts

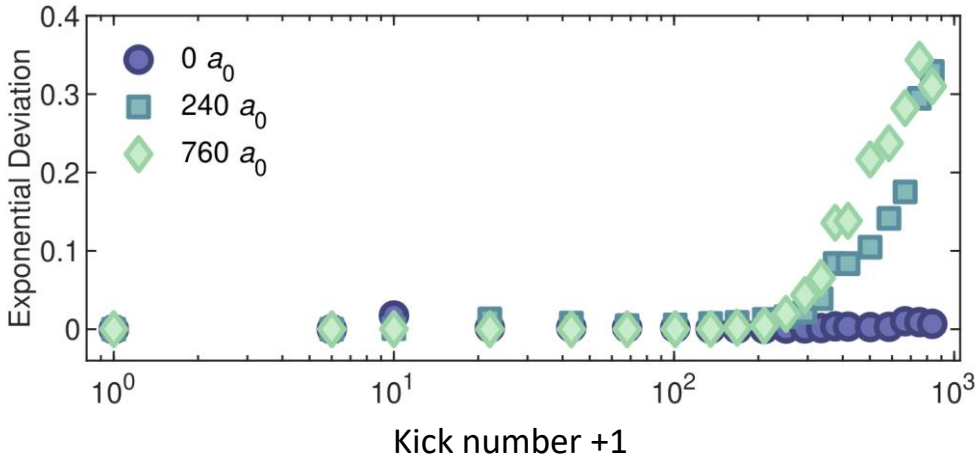
The interacting quantum kicked rotor



- Destruction of localization tracked by momentum-space distributions

The interacting quantum kicked rotor



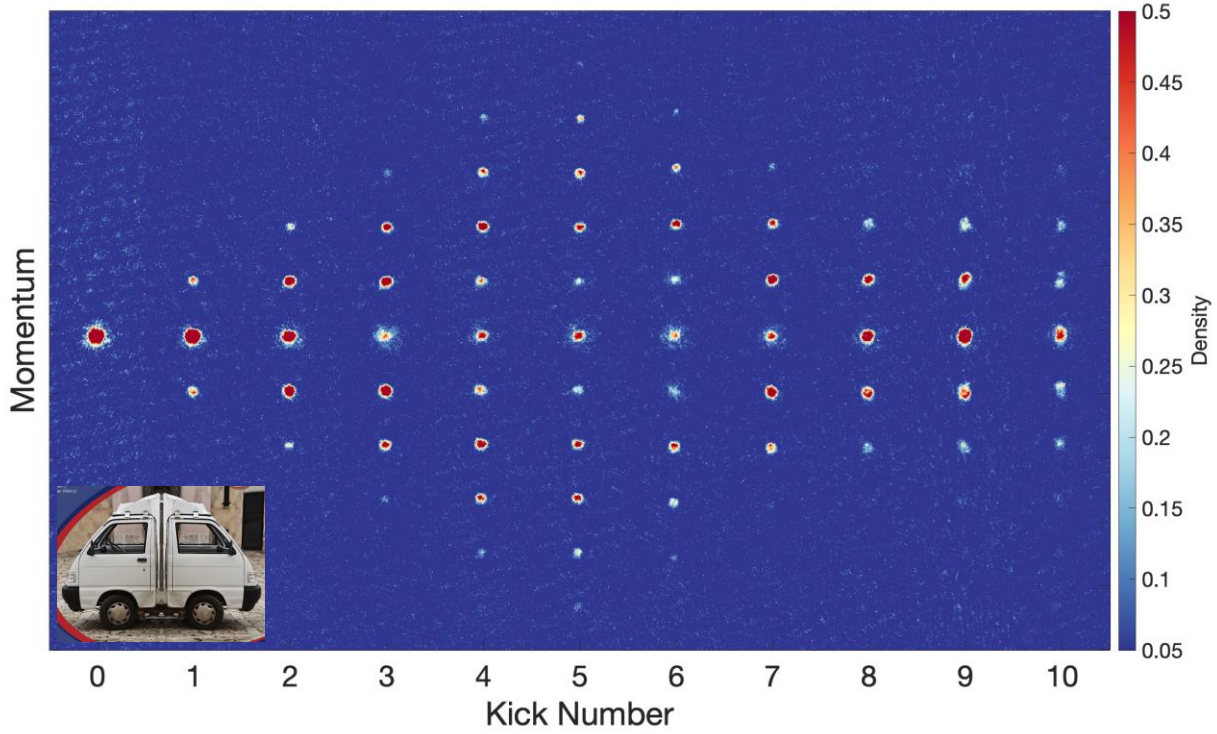


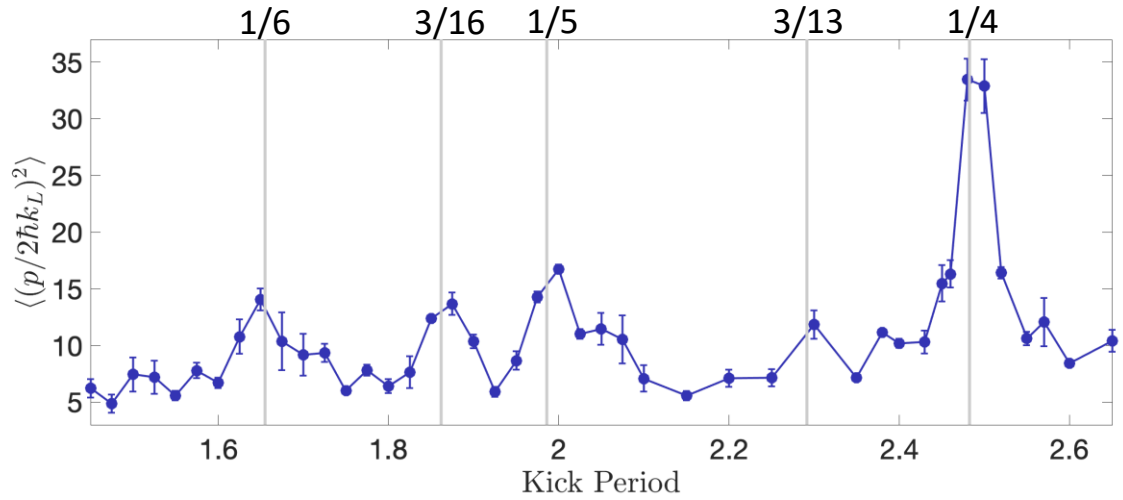
- Destruction of localization tracked by momentum-space distributions
- Deviation from exponential distribution is a sensitive probe of delocalization

The interacting quantum kicked rotor

- Main result: observed interaction-driven delocalization in many-body quantum kicked rotor

- Open questions and further work:
  - Loschmidt dynamics & time-reversal
  - Interactions & fractional resonances
  - Attractive interactions
  - Benchmarking theories





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Periodic quasiperiodicity

- Between-kick evolution in the QKR is maximally simple; no position-space structure. Richer possibilities?

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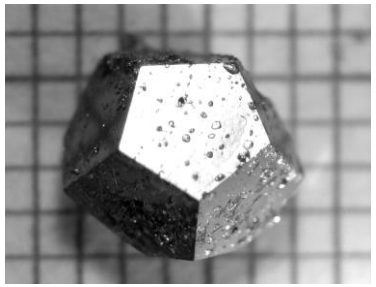
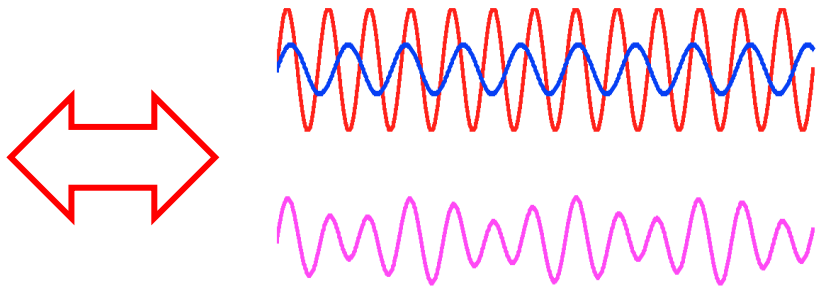
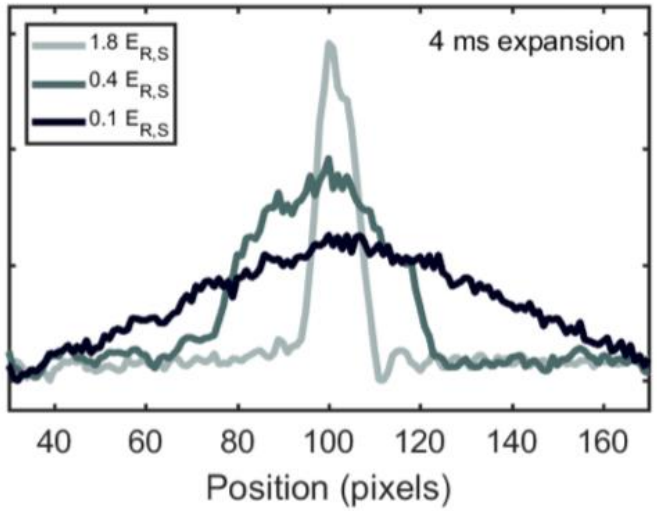
- Aubry-André-Harper model: a prototype of real-space localization phase transitions







Lots of nice cold atom work on this model: see e.g. An *et al*, *PRL* **126**, 040603 (2021)

Periodic quasiperiodicity

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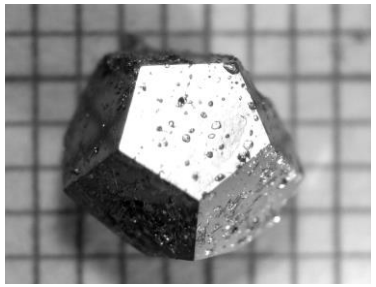
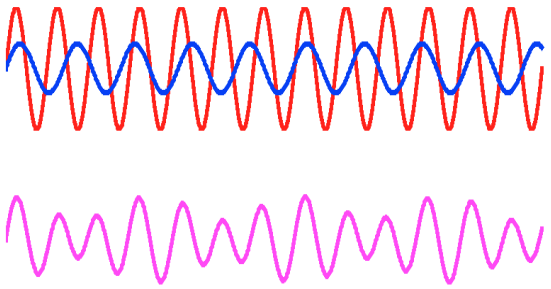
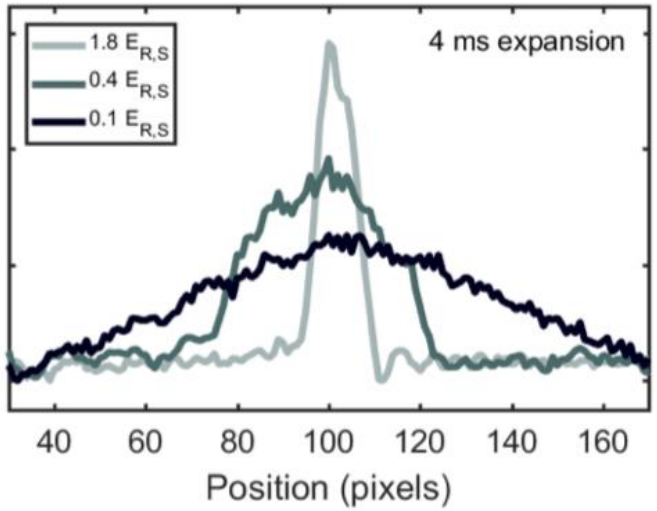
- Aubry-André-Harper model: a prototype of real-space localization phase transitions







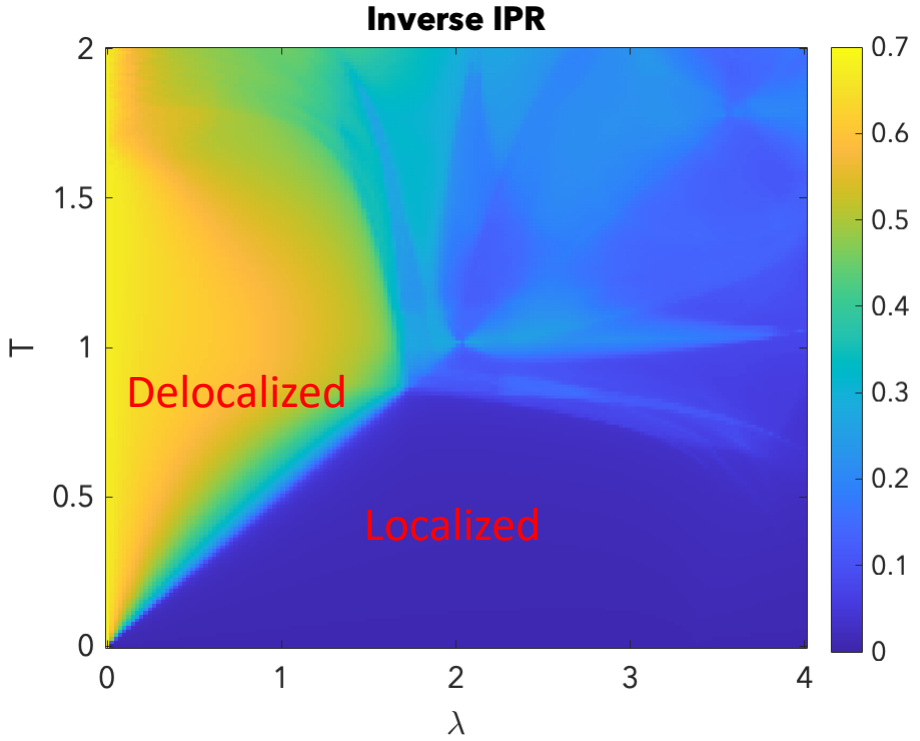
- <u>Kicked</u> Aubry-André-Harper model: lattice with **pulsed** incommensurate perturbation

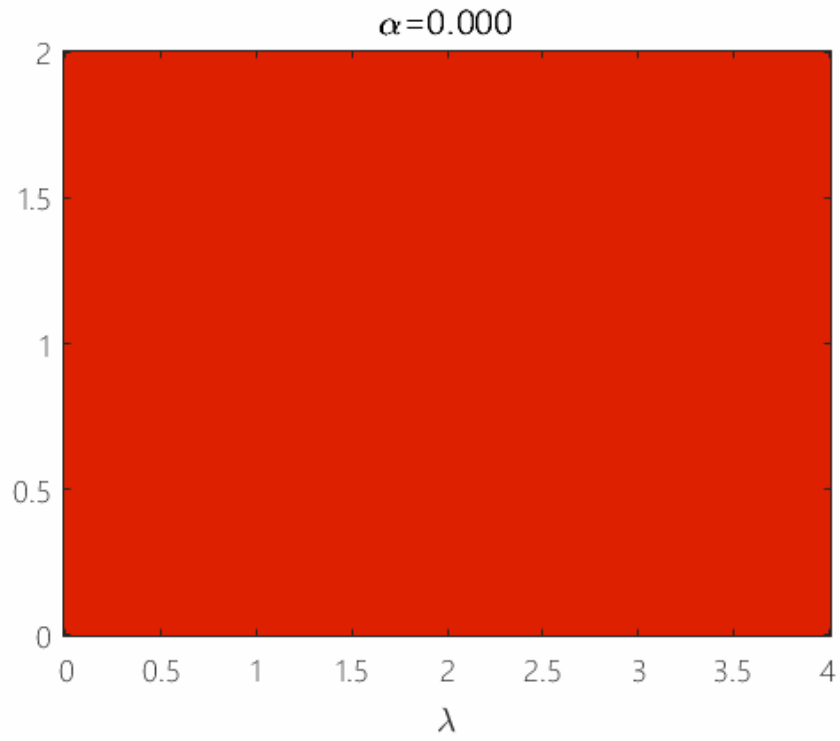
→ Can spatial localization occur in a system which is almost always periodic?

Localization in the kicked AAH model

- Phase diagram as a function of kick period and quasidisorder strength explored theoretically

$$H = \sum_i \left[-J\hat{a}_i^\dagger \hat{a}_i + \text{H.c.} + \sum_n \delta(t - nT)\lambda \cos(2\pi i\alpha)\hat{n}_i \right]$$

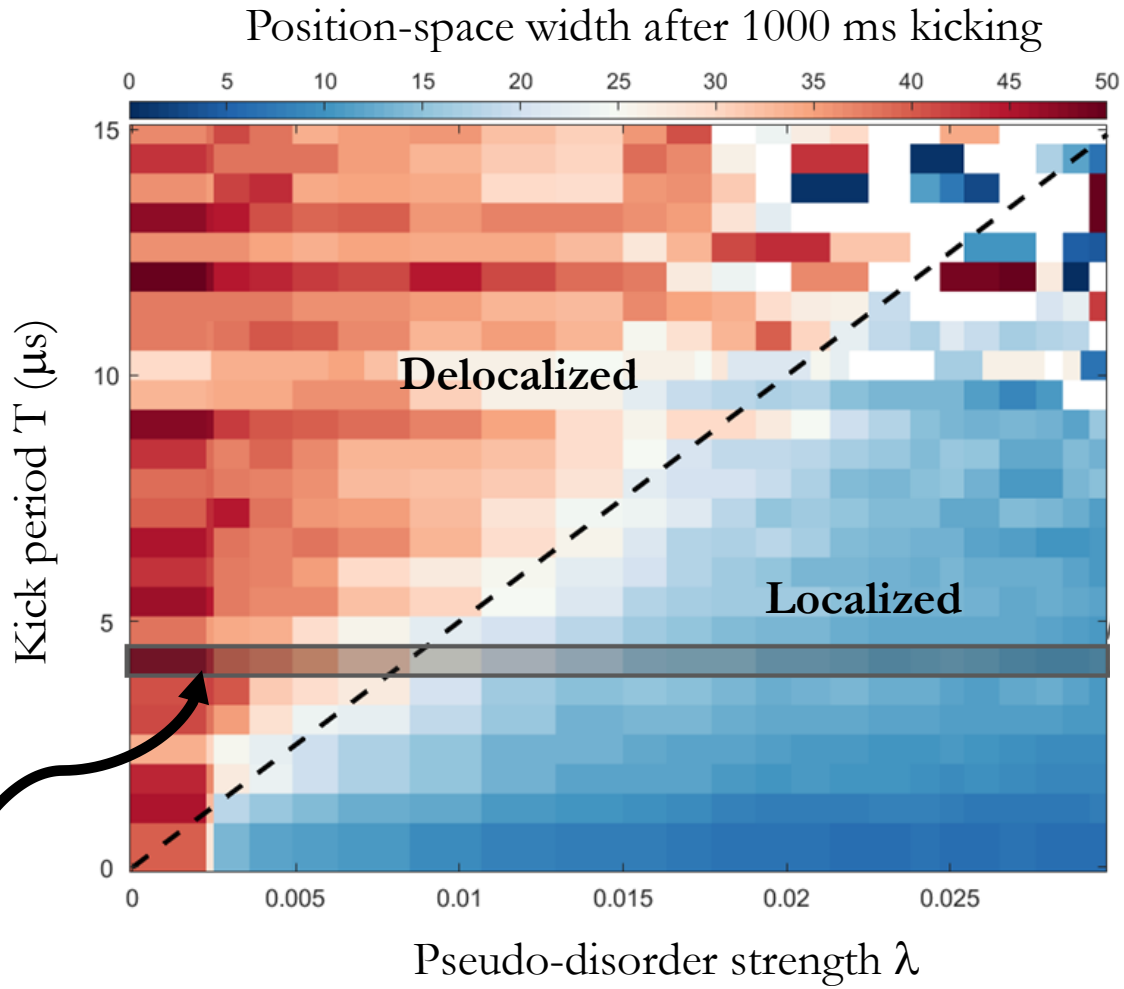


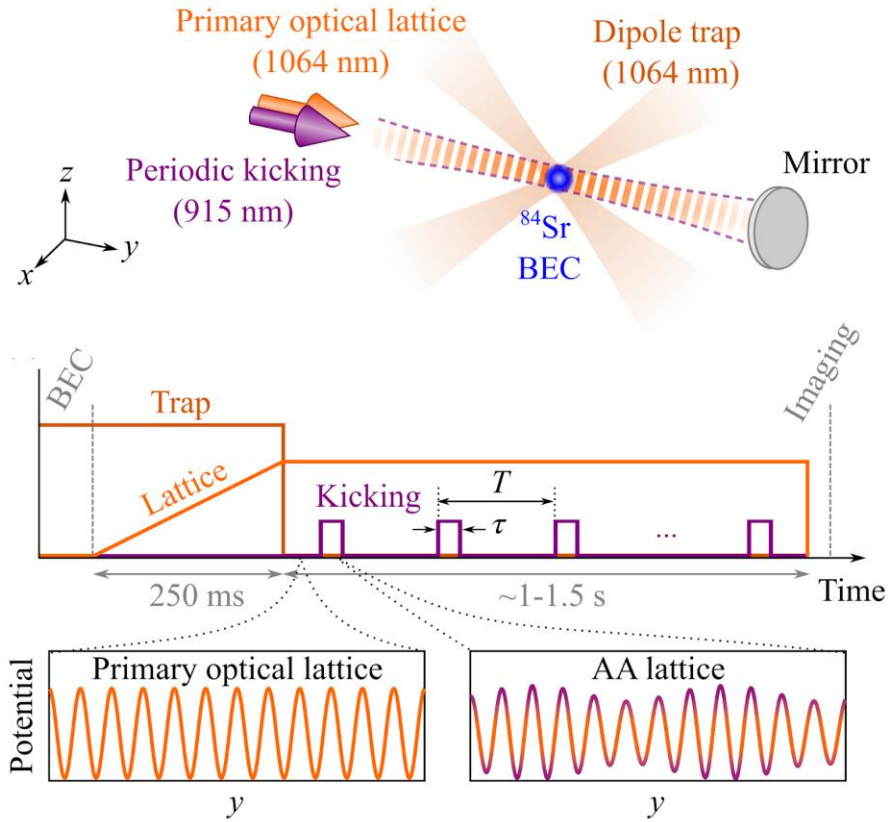


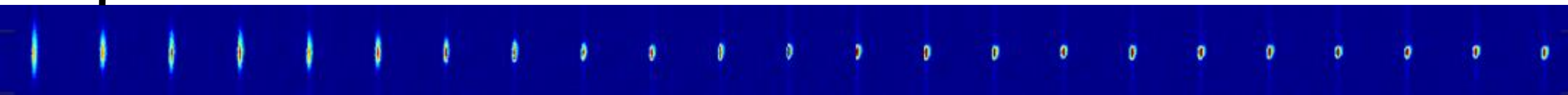
Qin *et al*, *Phys. Rev. B* **90**, 054303 (2014)
Čadež *et al*, *Phys. Rev. B* **96**, 144301 (2017)

Phase diagram of the kicked AAH model

- We observe a period-dependent localization transition.

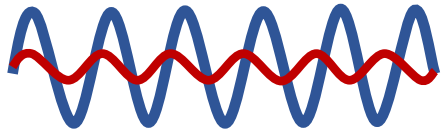




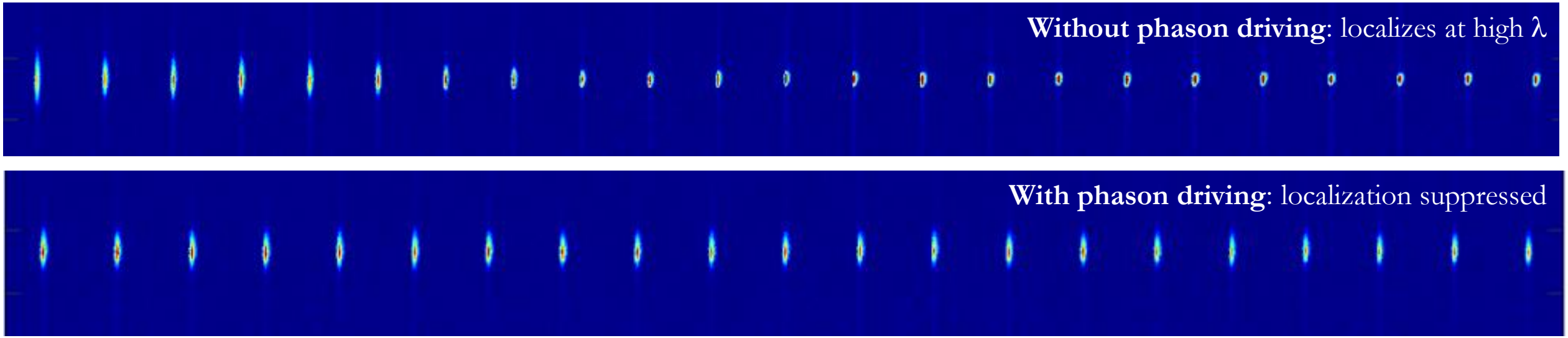


Phason modulation suppresses KAAH localization

- Modulating phasonic offset (slowly, periodically) while kicking kills the transition



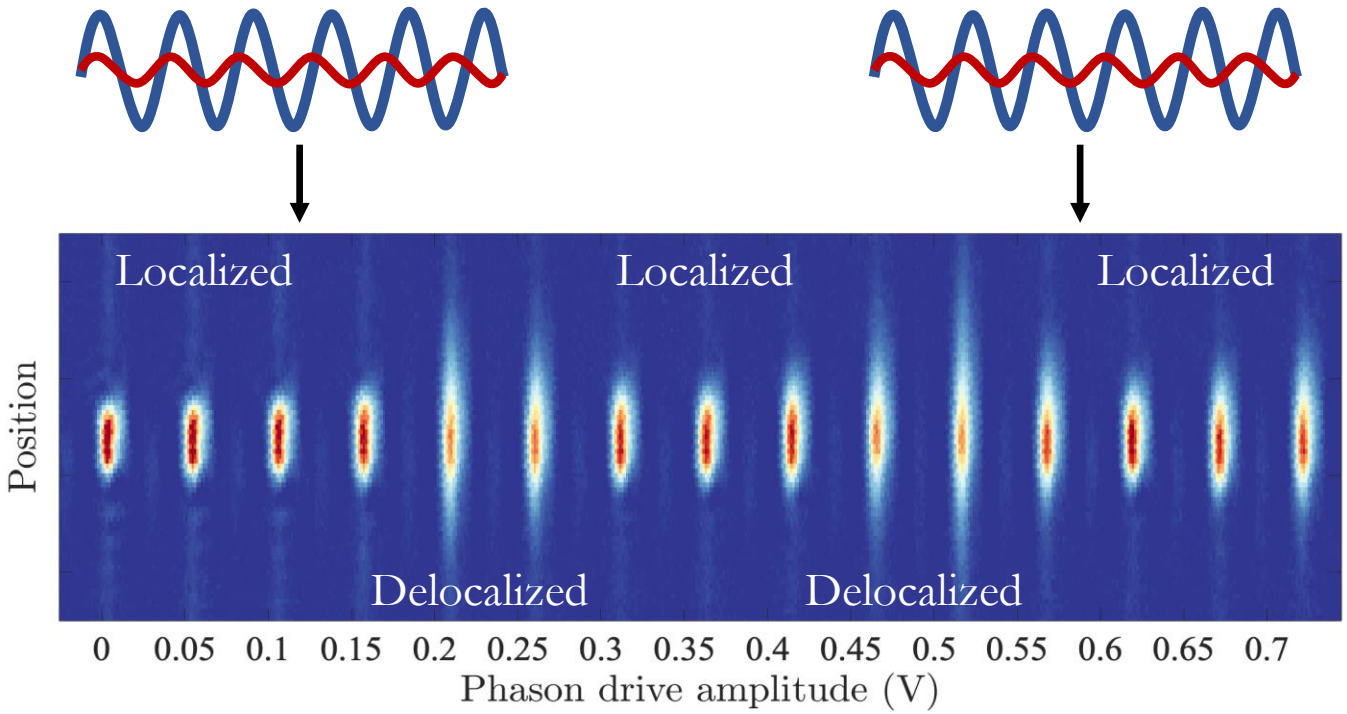
Increasing pseudo-disorder strength λ →

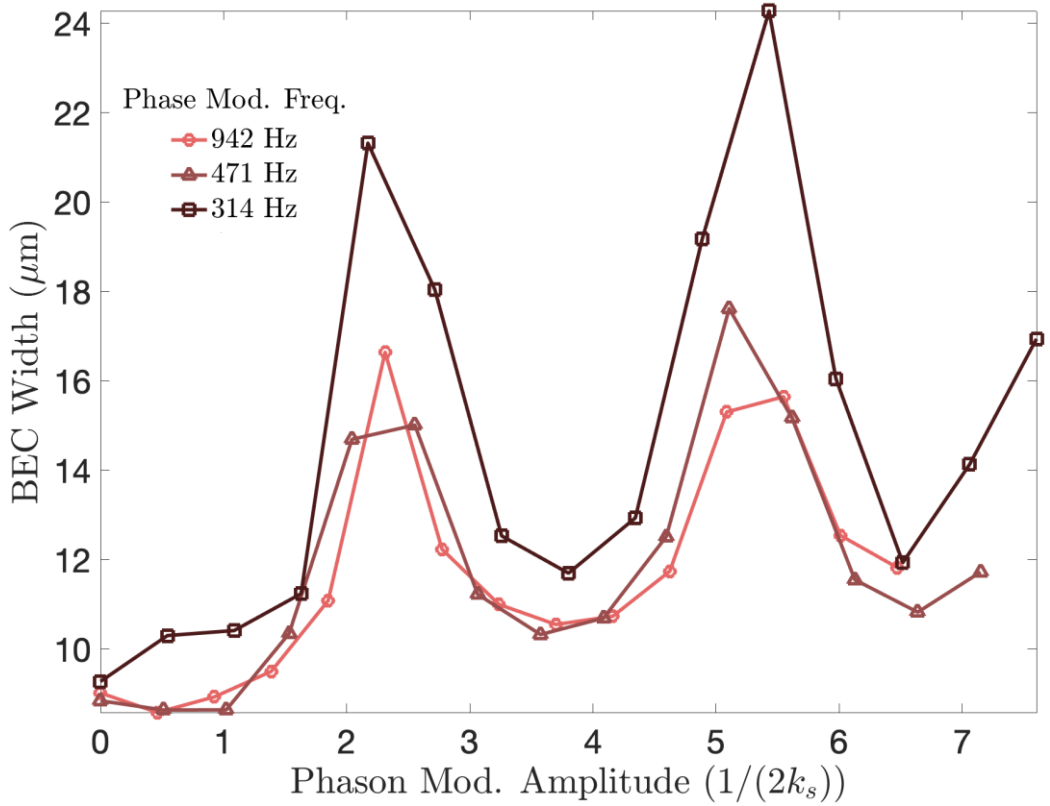


→ But are we just heating everything up?

Phason modulation suppresses KAAH localization

- No: observe **re-entrant localization** at higher phasonic drive amplitudes





→ What's happening here?

Dynamical modification of pseudo-disorder

- Delocalization peaks occur at Bessel zeros

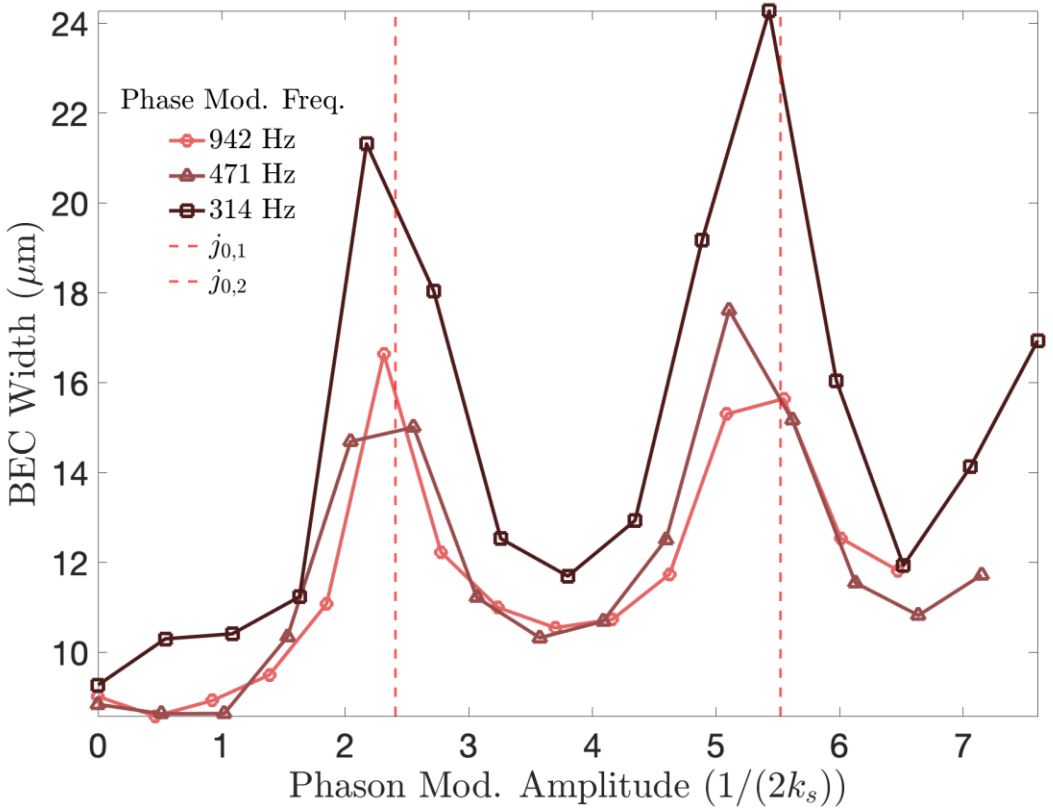
- Jacobi-Anger expansion:

$$\cos\left(2k_S\left[x - A\sin(\omega t)\right]\right) \simeq J_0(2k_S A)\cos\left(2k_S x\right)$$

→ **Dynamical renormalization of λ**

→ **Coherent control of localization in a kicked quasicrystal**

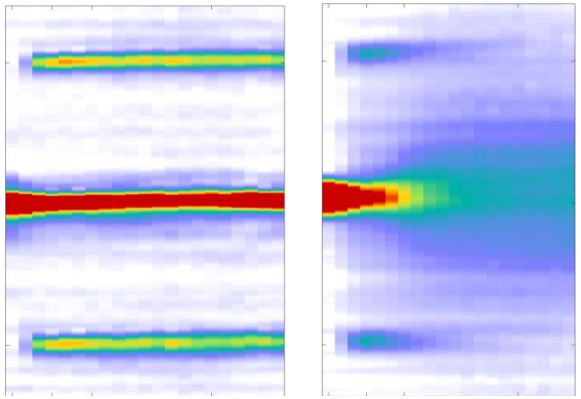
(*cf* dynamical tunneling modification)

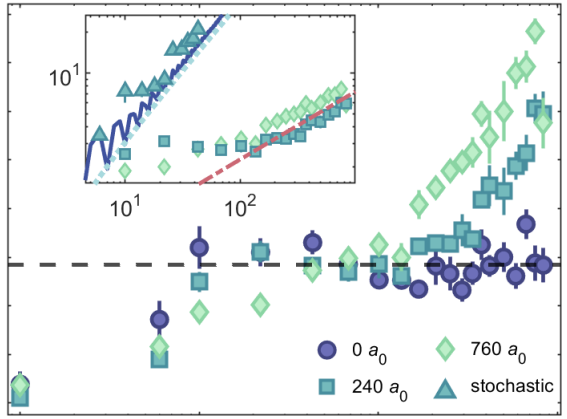


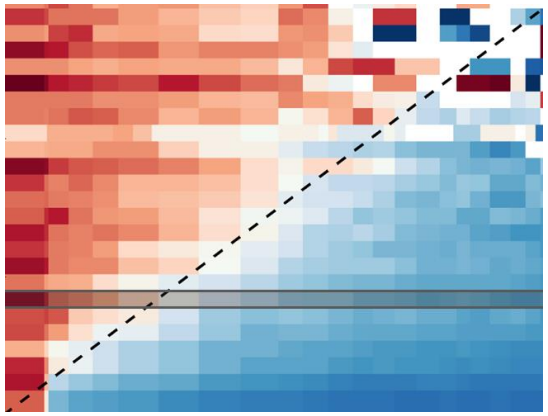
See also: Rajagopal *et al*, *PRL* **123**, 223201 (2019)

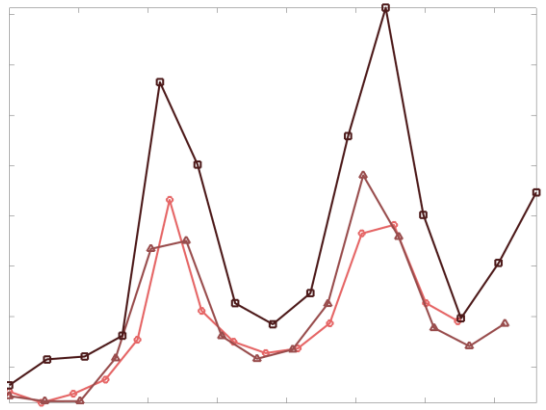
Conclusions

- Kicked quantum matter is a rich playground for dynamics and many-body QM
- Realized an interacting quantum kicked rotor and observed interaction-driven delocalization from a prethermal plateau
- Observed the localization phase transition of the kicked AAH model, and demonstrated coherent dynamical control of it via phasonic driving









Acknowledgements

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Deep Gupta