EDGE STATES IN QUANTUM CAVITY SYSTEMS

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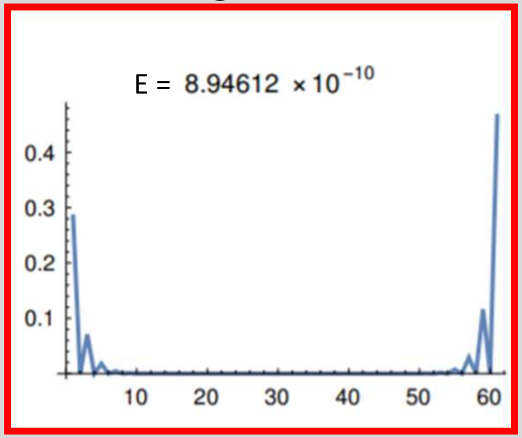
Edge States

- Topologically protected
  - Robust against perturbation
  - Good for quantum computing
- Named for high localization on either edge



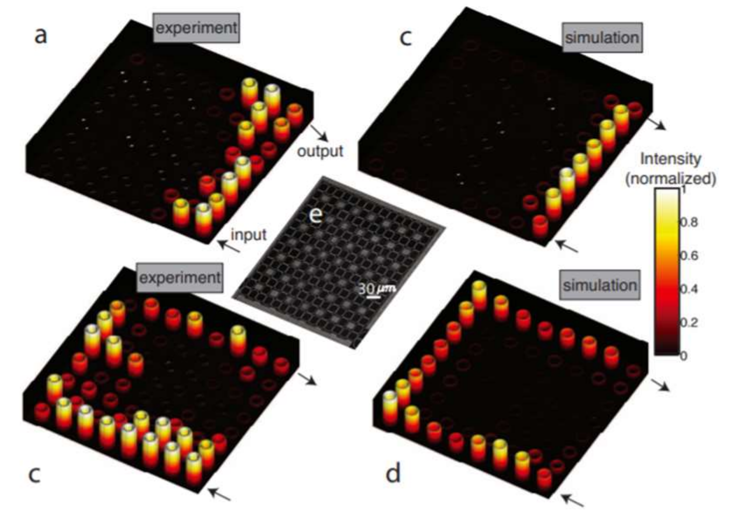
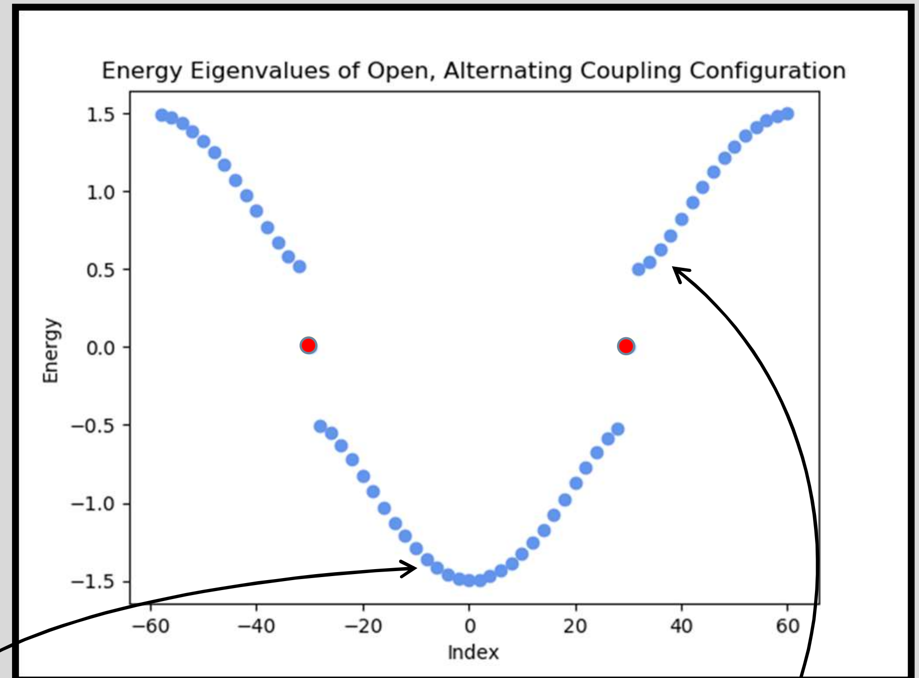


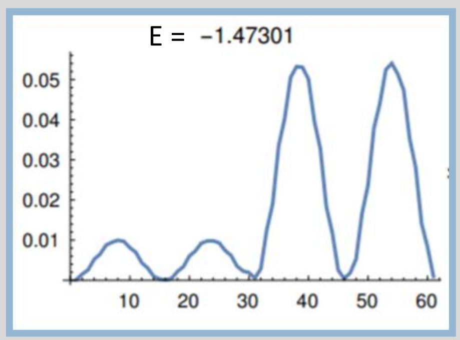
FIG. 3: **Edge state propagation in a homogenous magnetic field (8x8 array):** The light enters from one corner and exits from the other corner. The experiment shows that depending on the input frequency, the light takes the short edge (a) or the long edge (b). The experimental results (a-b) are in good agreement with the simulation results (c-d). The simulation parameters are $(\kappa_{\text{ex}}, \kappa_{\text{in}}, J) = (31, .57, 26)$GHz which are extracted from experimental measurement of simpler devices. (e) An SEM image of the system.

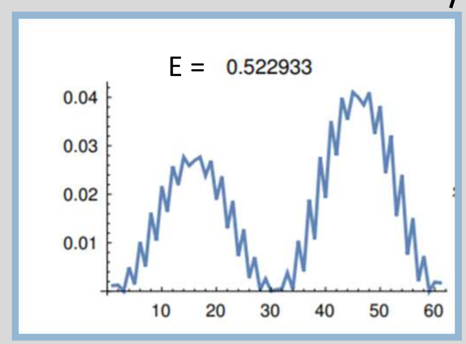
Image & caption from Hafezi M. *et al*. Imaging topological edge states in silicon photonics.

Rarity of edge states

- Only two edge states vs N-2 bulk states
- Edges states are energetically separate from other eigen energies – they fall in the band gap
- Other states are highly delocalized





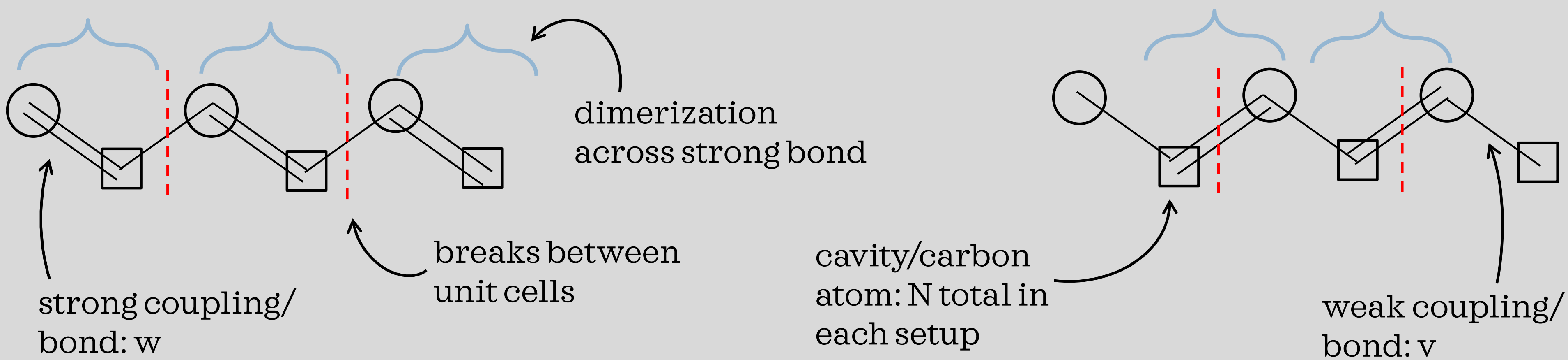


Su-Schrieffer–Heeger (SSH) Model

- Alternating coupling, open boundary conditions – polyacetylene
  - Two ways to arrange the coupling between N atoms if N is even
  - Looking at dimerization as compared to unit cells

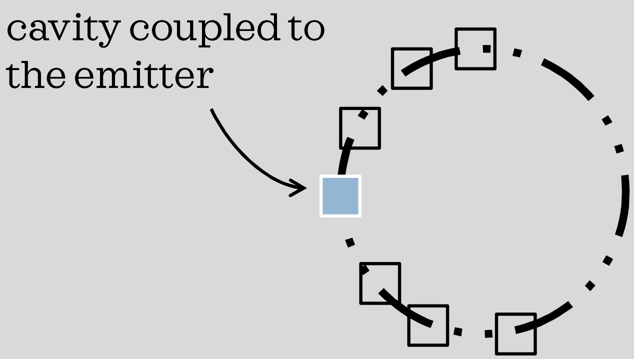
Natural case: dimerization matches divisions of unit cells: no edge states

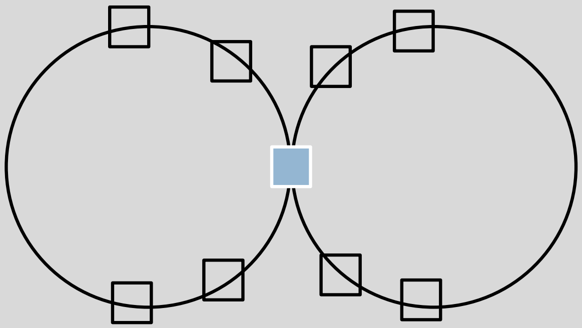
Special case: dimerization competes with divisions of unit cells: edge states



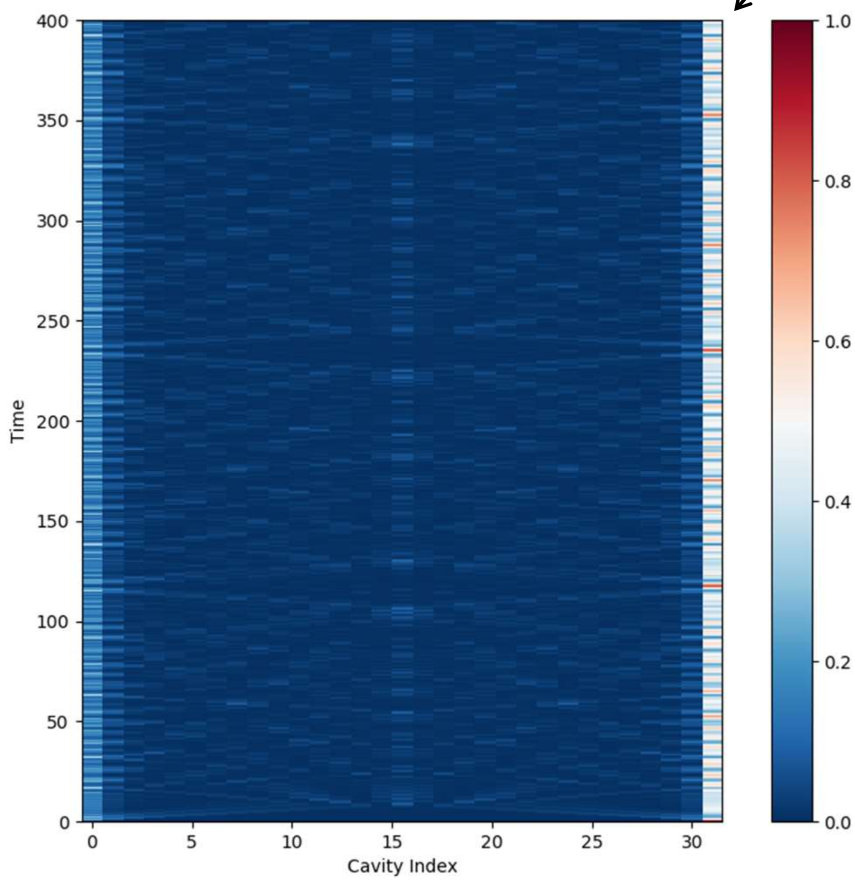
Motivation

- Investigate the properties of quantum cavity systems
  - Open vs closed boundary conditions
  - Alternating vs. uniform coupling
  - Add emitter
  - Compare new geometries
- Looking for behavior or patterns that have broader applications
  - Edge states are protected, could be useful in quantum computing
- Can you populate the edge state when starting from the emitter?
- Identify which portions of the system are responsible for the dynamics
  - Reduces the amount of information that must be stored/processed
  - Potential to select behaviors we want

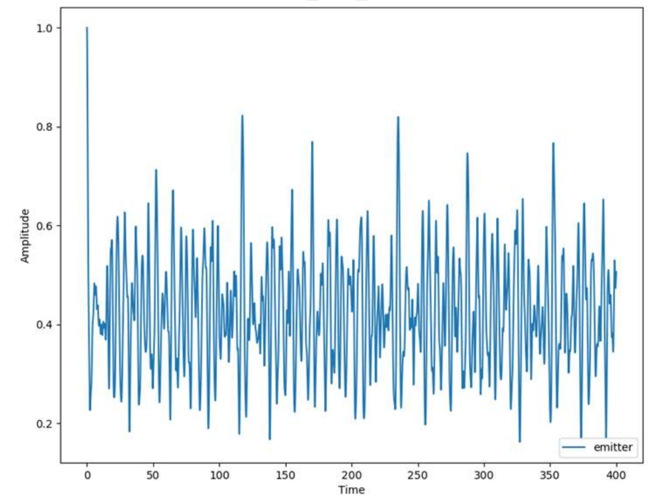




Population for periodic, uniform system

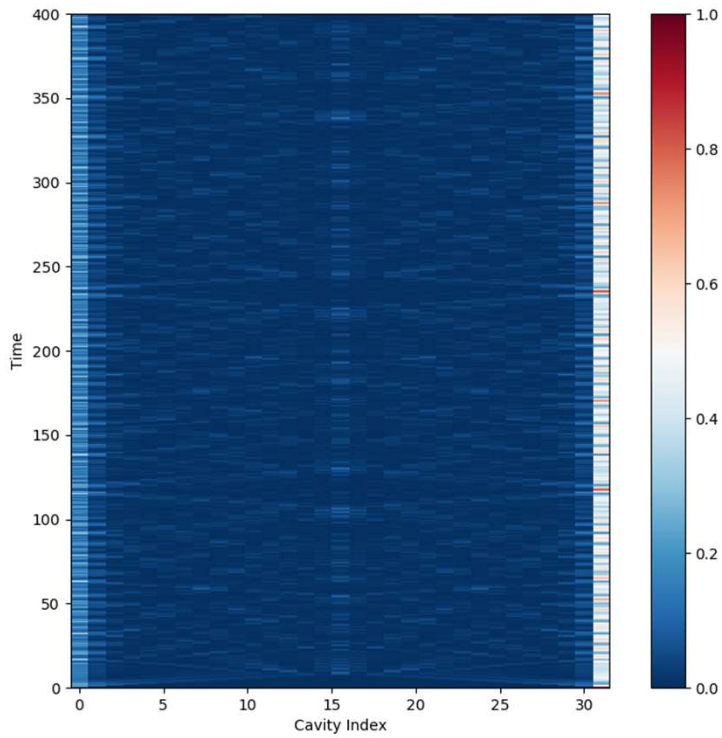


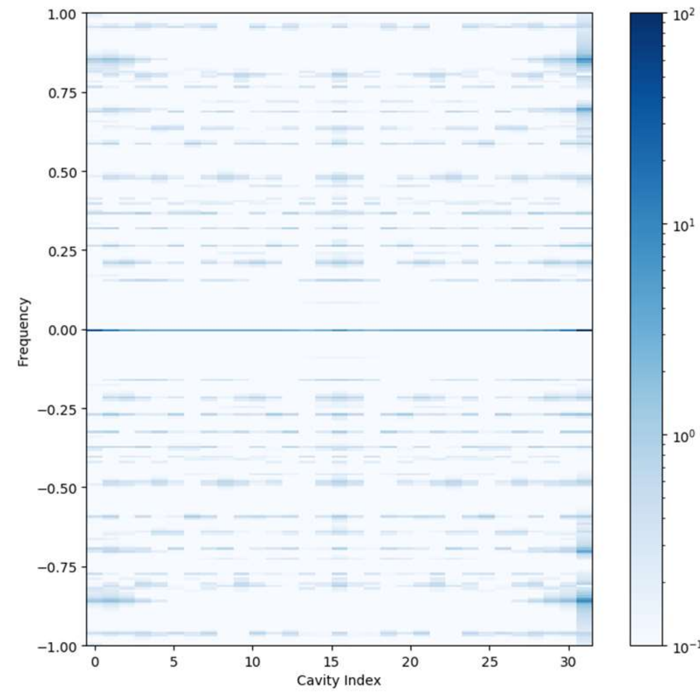
Emitter population



Dynamics

- Starting with all the population in the excited state of the emitter (#31 in the cavity basis)
- Population spreads to multiple cavities
- g=1 : emitter well connected to cavities
- Complex periodic behavior
- Fourier Transform to extract the key components





EXTRACT FREQUENCY FROM TIME DYNAMICS

- Strongest frequencies at zero and in the emitter
- Every cavity does not have an identical frequency profile
- Frequencies related to energy differences

Use initial state to find key energy levels

The Hamiltonian

eigenstates

$$H|\phi_j\rangle = E_j|\phi_j\rangle$$

eigenvalues

Some initial state

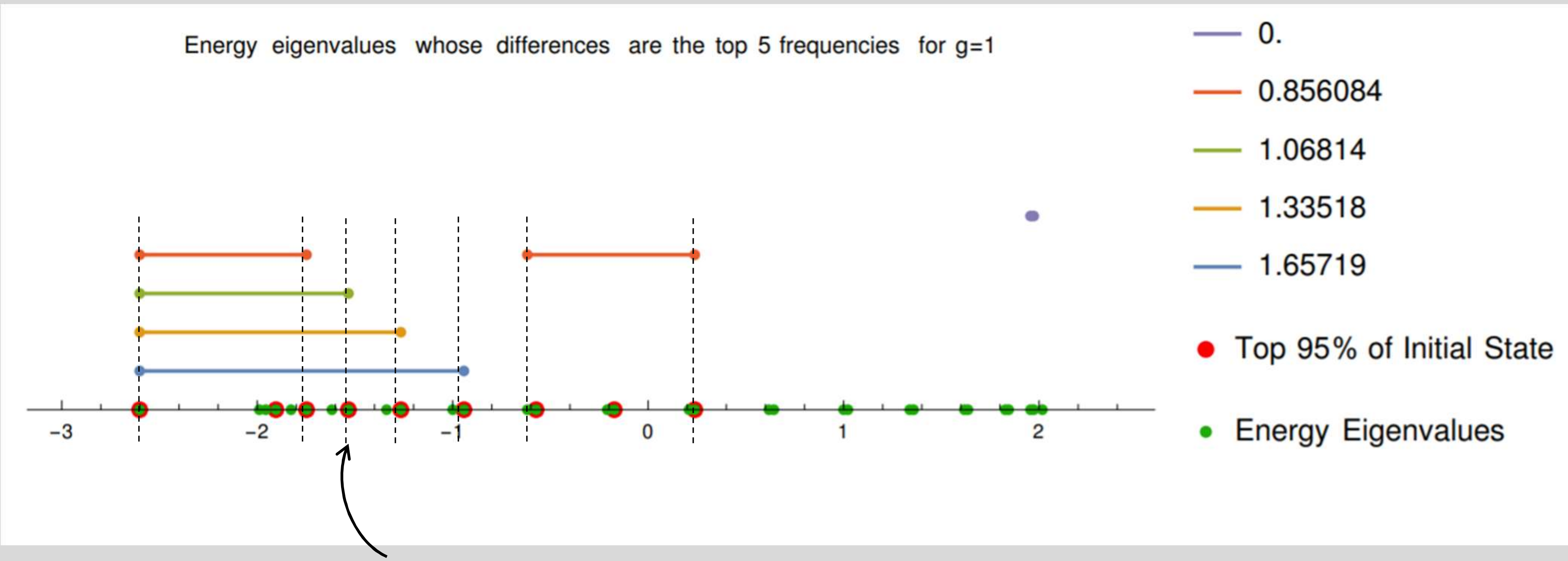
normalized coefficients

$$|\psi_0\rangle = \sum_j c_j\,|\phi_j\rangle$$

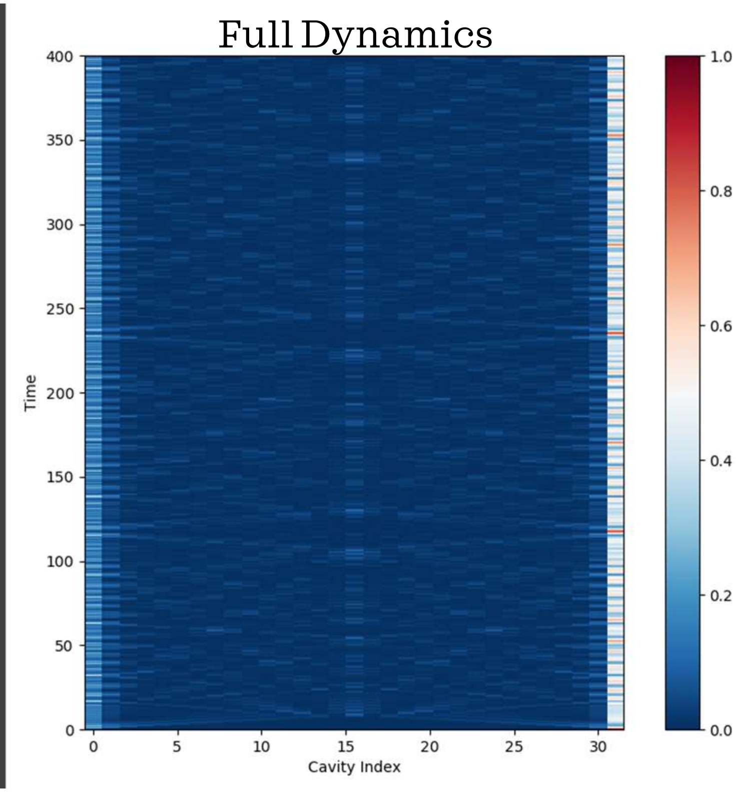
$$\psi(t) = \sum_j c_j\, e^{-iE_j t/\hbar}|\phi_j\rangle$$

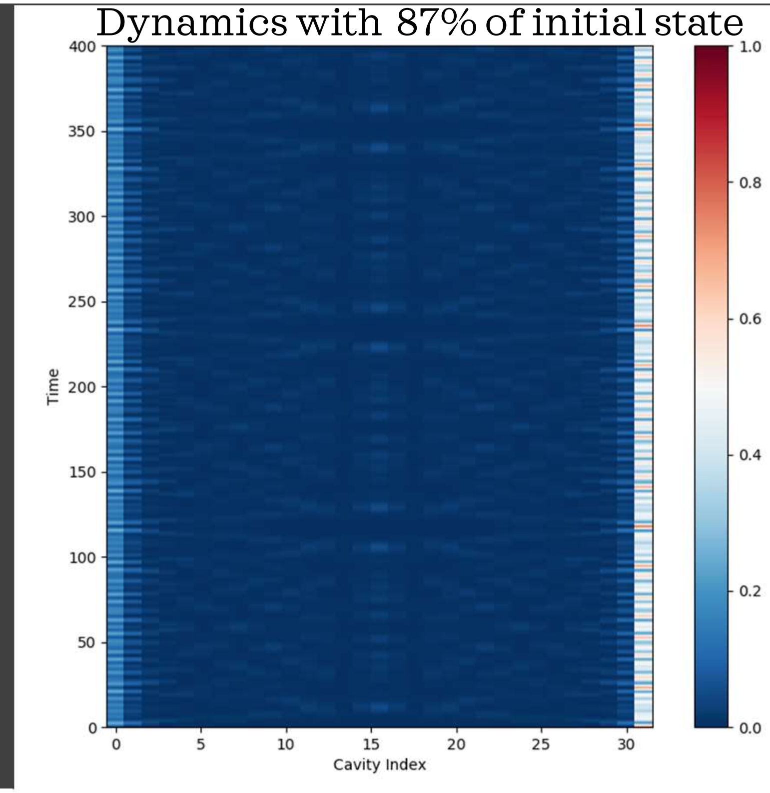
Evolution of the initial state over time

Frequency to Energy - Uniform, periodic



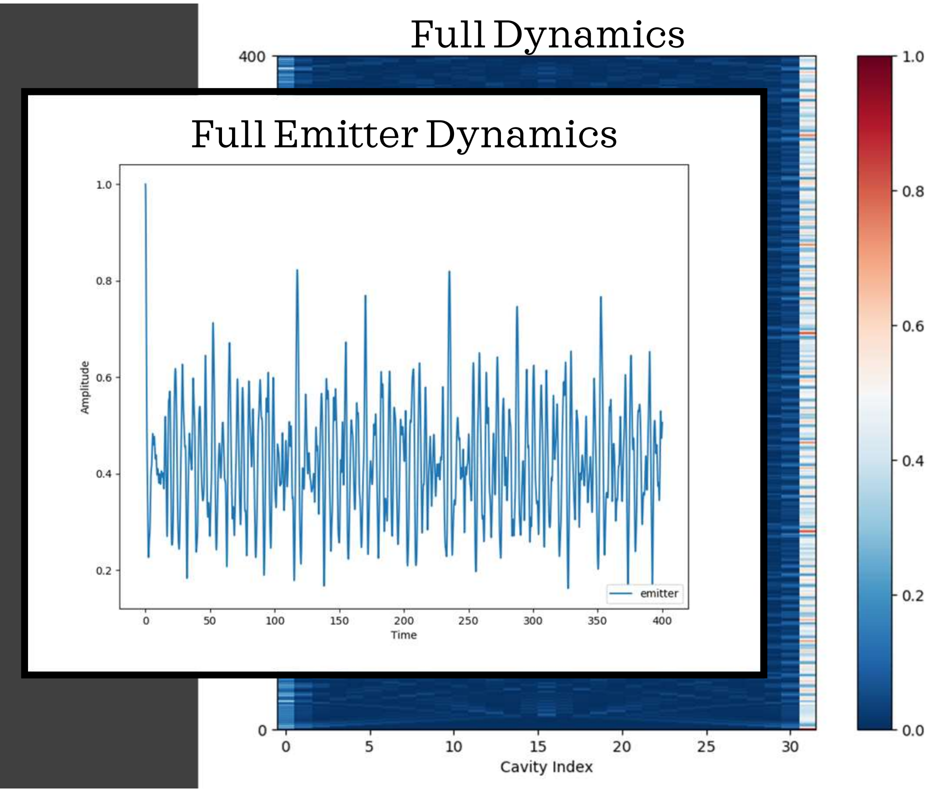
Good agreement between energies from frequency analysis and from initial state breakdown

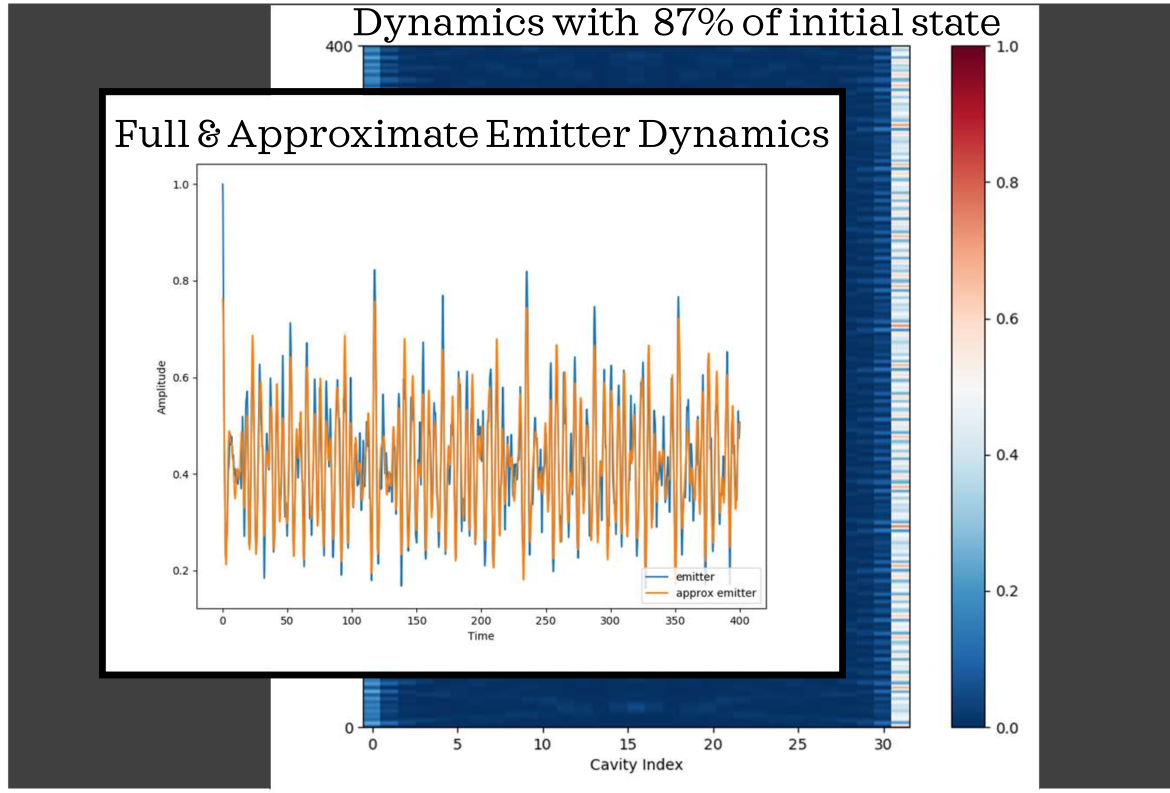




RECONSTRUCTION OF DYNAMICS WITH MOST SIGNIFICANT EIGENSTATES ONLY

- Compare full dynamics to time evolution using only eigenstates with $|c_j|^2 > 0.04$ (5 total states)
- Still see large- and small-scale periodic behavior





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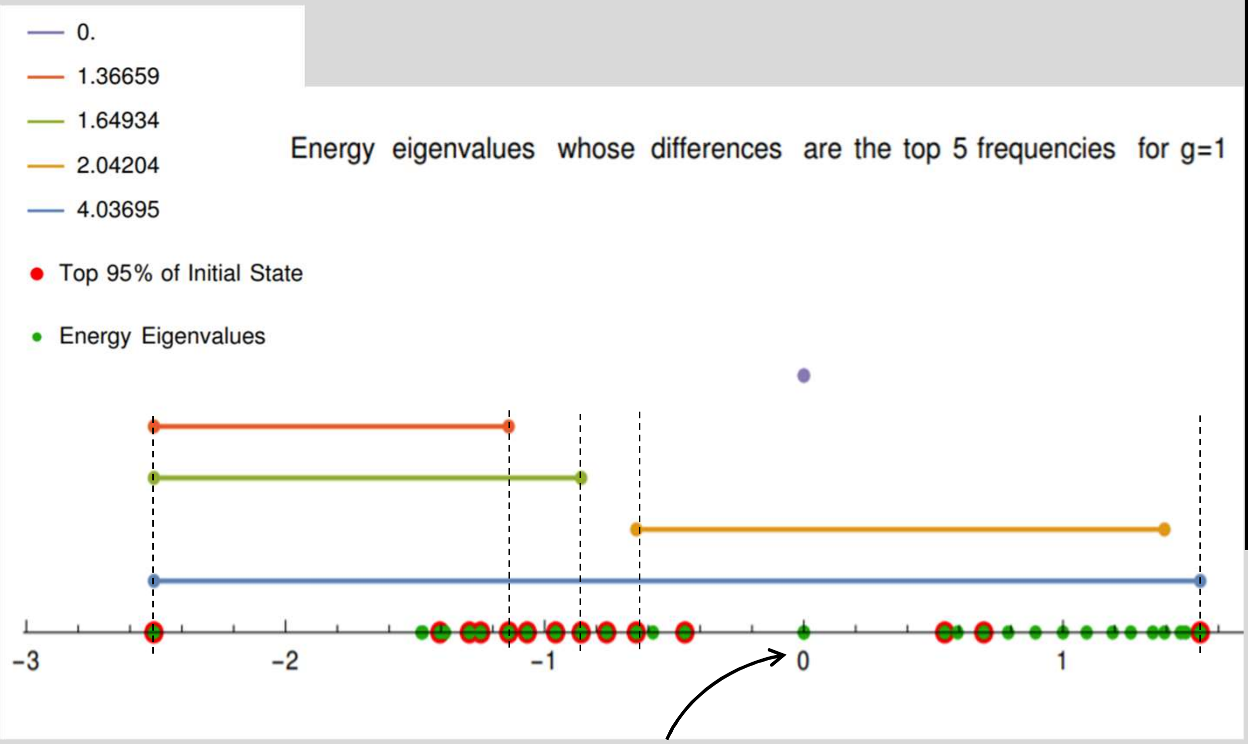
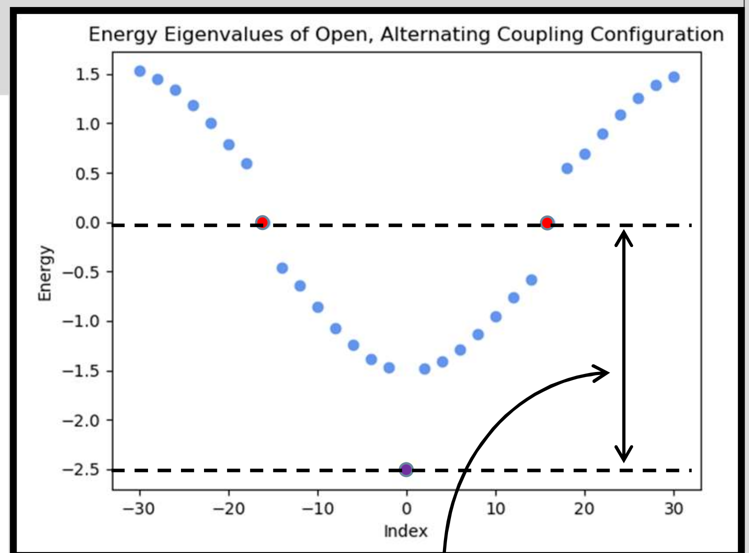
Frequency to Energy – Alternating, open

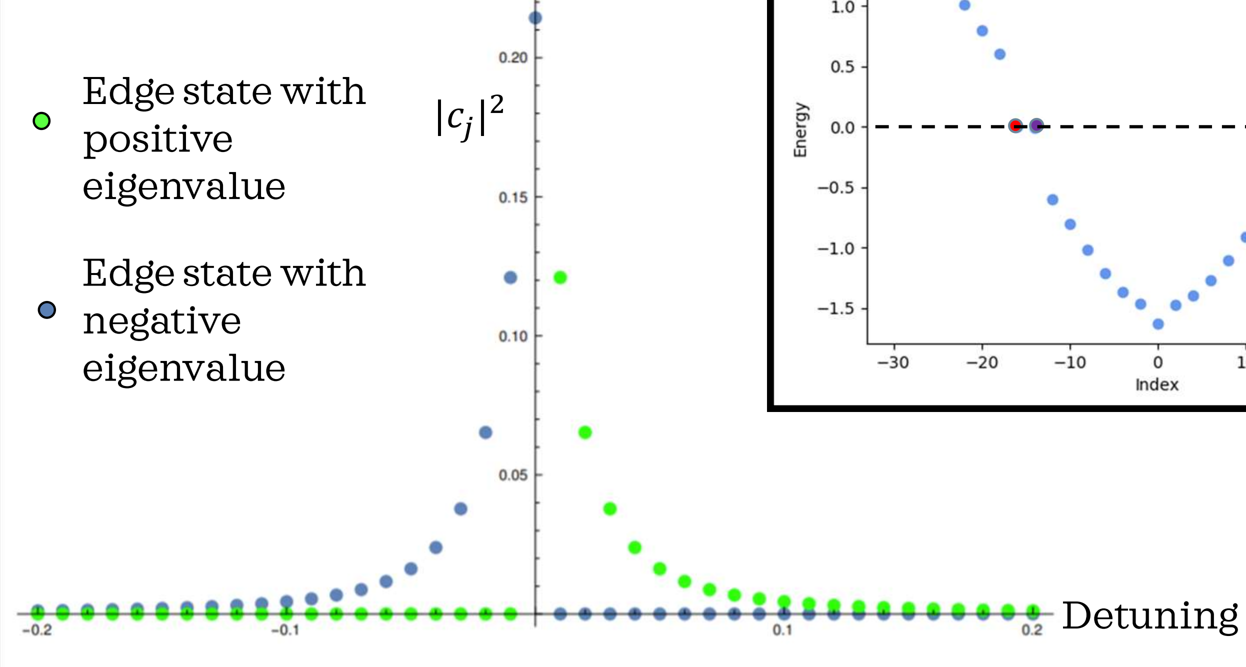


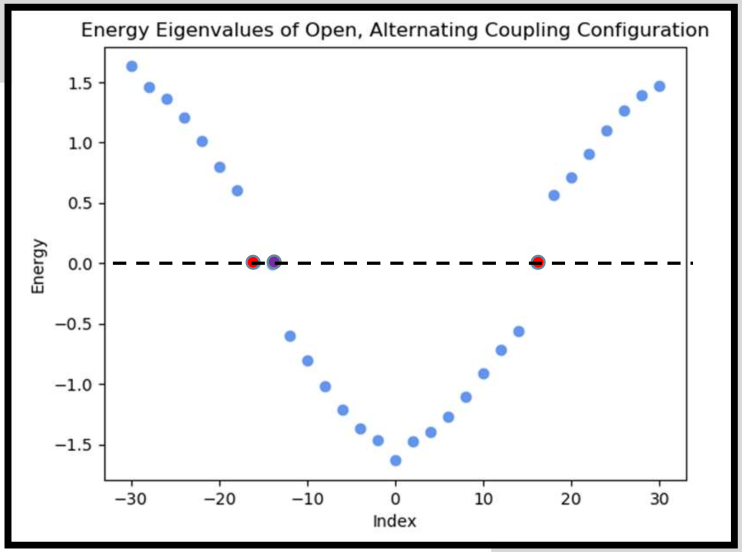


Edge states not identified as highly significant for this set of initial conditions

Detuning indicates energy of emitter state is far from edge states' energies

Adjusting Detuning to Populate Edge State





- Detuning defined as the difference between the energy of a cavity and the energy of the excited state of the emitter
- Edge states have highest contribution to the initial state when the emitter is in resonance with them

Conclusion

- Good agreement between energies found from breakdown of initial state and energies found from numerical frequency analysis
  - Allows selection of most important data
  - Can now design system to behave as desired
- Adjust detuning to maximize edge state contribution
- Further analysis: two alternating systems connected at the emitter & other novel geometries