Sanity checks
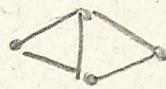
- rotate all cilia by constant angle

→ add other cilia in random phase

$T_{ij}(\varphi_i = \hat{\varphi}_i, \varphi_j = \hat{\varphi}_j, \varphi_k = \hat{\varphi} \; \forall k \neq i, j)$.

- add next-to-nearest neighbor interactions.

start at $\varphi_1 + \ldots + \varphi_N \equiv 0 \mod 2\pi$. $\sum e^{i\varphi_{k_1, k_2}}$

Model extensions

- other beat patterns?
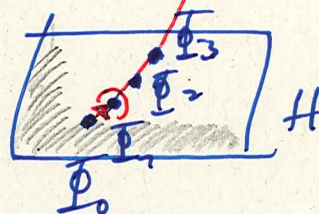- cilia bundles?
- (Waveform compliance)
  internal dissipation

Multistability

- basins-of-attraction.
  (No: L_p-adaptation)

Noise:

- multiple isolated regions of stable states in reciprocal lattice ⟹ stochastic transitions.

Multistability

- ### test 1a (brute-force).

  ~~ϕ_i~~

  $N = 10$ cilia chain.

  ensemble of $n = 100$ random initial cond.

  $\downarrow$ propagate in time
  for long time

  decide which $\vec{\phi}^*$ is close.

- ### test 1b

  6×6 cilia carpet.

- ### test 2 (flow-field).

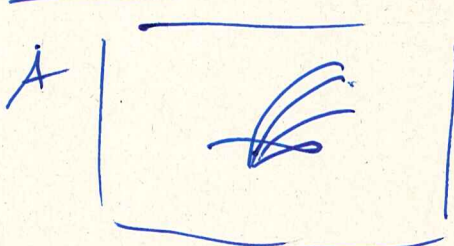 $\mathbb{R}^N \cdot 10^{36}/36. \ \ y$

Results

- Multi-scale sims with exp. beat pattern
- Poincaré maps

↓

linear stability analysis

- eigen value spectrum

- "Mermin-Wagner" theorem

Fig 1

A

cilia beat

B
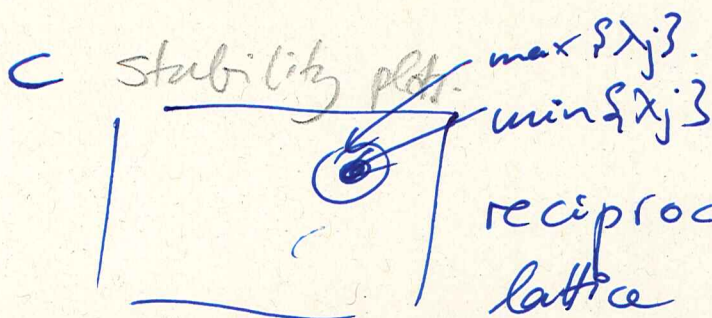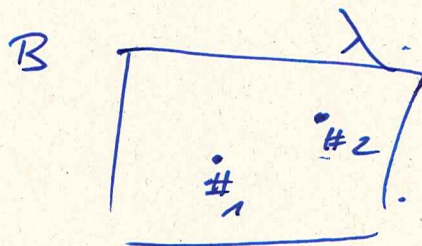
C stability plot.   max $\{x_j\}$ C' example spectrum.
min $\{x_j\}$

reciprocal   C" example
lattice   fixed points / eigenvalues.