Dynamical Phenomena in 2D Yukawa Systems

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Overview

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- Main goal: study dynamical phenomena in 2D systems

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- Method: utilize *N*-body code (`box_tree`) to simulate realistic complex plasma crystals

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- Specific aims:
  - Anomalous diffusion
  - Self-organization

Diffusion Phenomena

Simulating an Experimental Crystal

- Meyer, et al. give the following experimental parameters for a complex plasma crystal:

Grain Diameter	$d \approx 9\,\mu\text{m}$
Grain Charge	$Q \approx -2 \times 10^4 e$
Kappa	$\kappa \approx 1.3$
Spacing	$a \approx 0.6\,\text{mm}$
Pressure	0.10-1.00 Pa
RF Power	25-200 W
Self-Bias	(-10)-(-40) V
T_e	1.5-7 eV
N_e	10^{14}-$10^{15}\,\text{m}^{-3}$

Meyer, J., Laut, I., Zhdanov, S., Nosenko, V. and Thomas, H. (2017). Coupling of Noncrossing Wave Modes in a Two-Dimensional Plasma Crystal. *Physical Review Letters*, 119(25).

Simulating an Experimental Crystal

- Under these conditions, Meyer, et al. obtained a crystal of approximate diameter 27 cm

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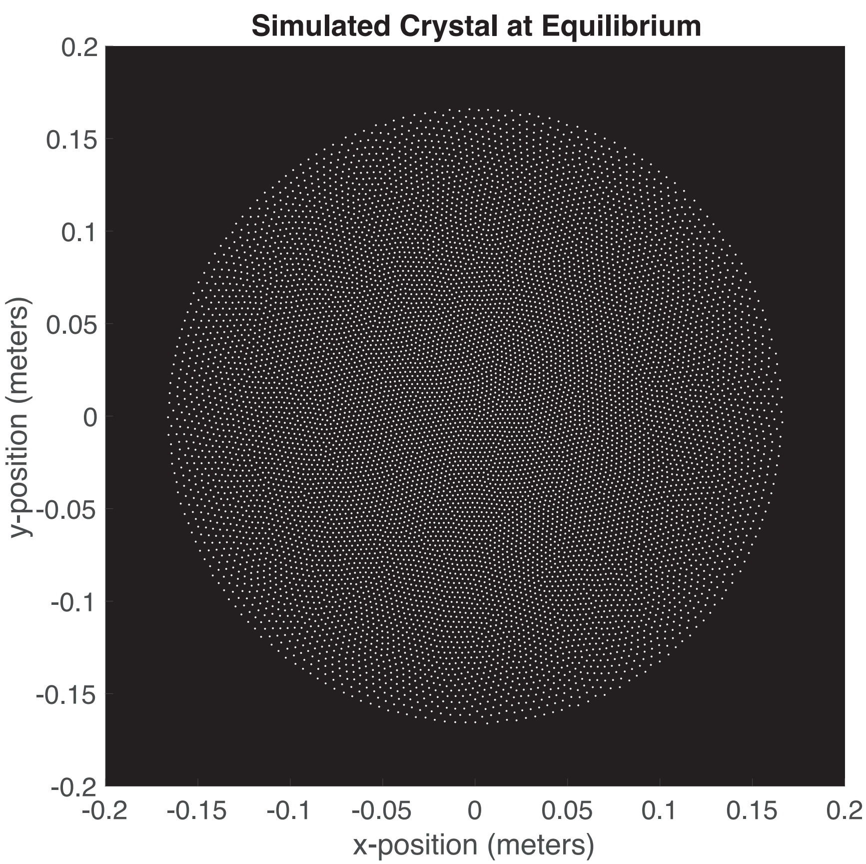
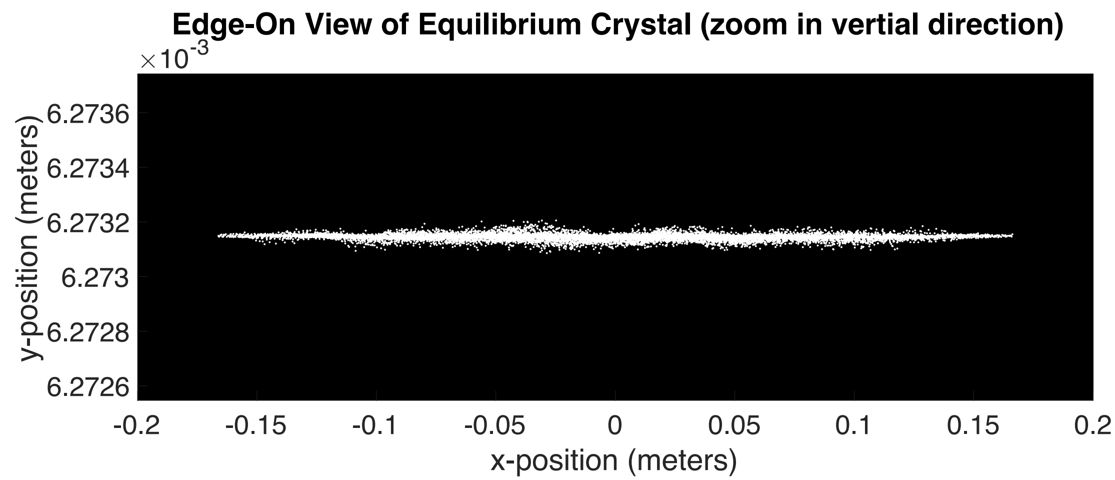
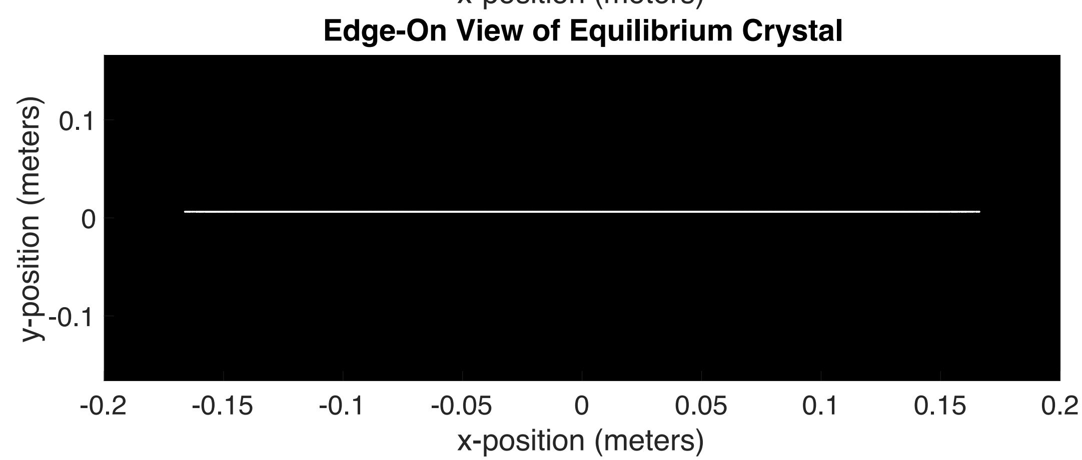
- Under these conditions, Meyer, et al. obtained a crystal of approximate diameter 27 cm
- Under these conditions, we obtained a crystal of approximate diameter 32 cm

Simulating an Experimental Crystal







Characterizing Diffusion

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- Mean-Squared Displacement (MSD)

$$\mathrm{MSD}(t) = \left\langle \left| \mathbf{r}_i(t) - \mathbf{r}_i(0) \right|^2 \right\rangle_{i=1}^{N}$$

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$$\mathrm{MSD} \propto t^{\alpha} \begin{cases} \alpha > 1 \implies \text{superdiffusion} \\ \alpha = 1 \implies \text{normal diffusion} \\ \alpha < 1 \implies \text{subdiffusion} \end{cases}$$

Diffusion in 2D Yukawa Systems

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- Liu, Goree, and Vaulina[1] use a molecular dynamics simulation to show that

$$88 < \Gamma < 145 \implies \text{normal diffusion}$$

[1]Liu, B., Goree, J. and Vaulina, O. (2006). Test of the Stokes-Einstein Relation in a Two-Dimensional Yukawa Liquid. *Physical Review Letters*, 96(1).

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$$\Gamma = \frac{Q^2_{\text{grain}}}{4\pi\varepsilon_0 r_{\text{Wigner-Seitz}} k_{\text{B}} T_{\text{grain}}}$$

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Diffusion in 2D Yukawa Systems

- To observe normal diffusion, we adjust Γ by adjusting the grain temperature

Diffusion in 2D Yukawa Systems

- To observe normal diffusion, we adjust Γ by adjusting the grain temperature
- The slope of the log-log plot of MSD vs. time indicates the diffusion regime

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Observed Normal Diffusion

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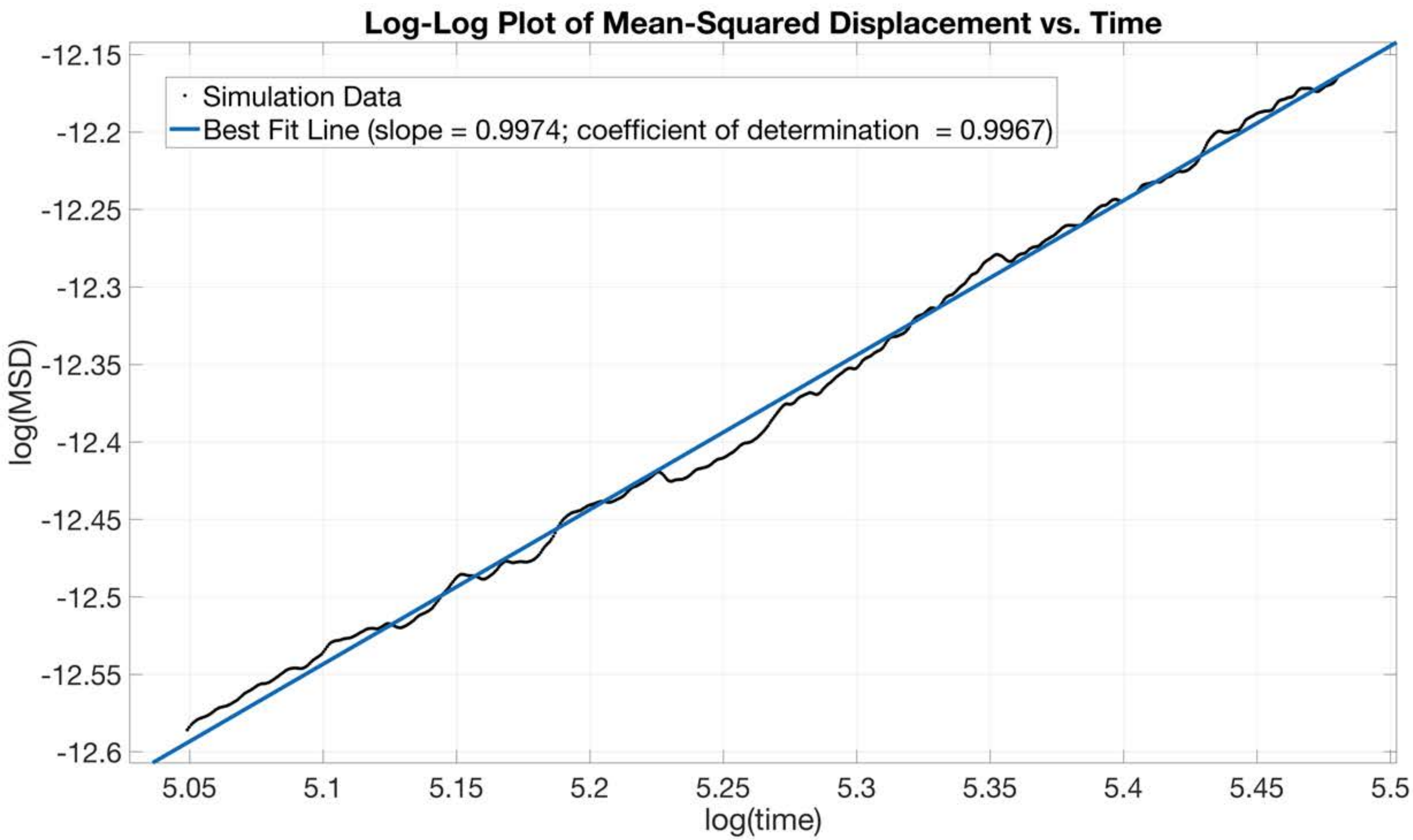

Observed Normal Diffusion

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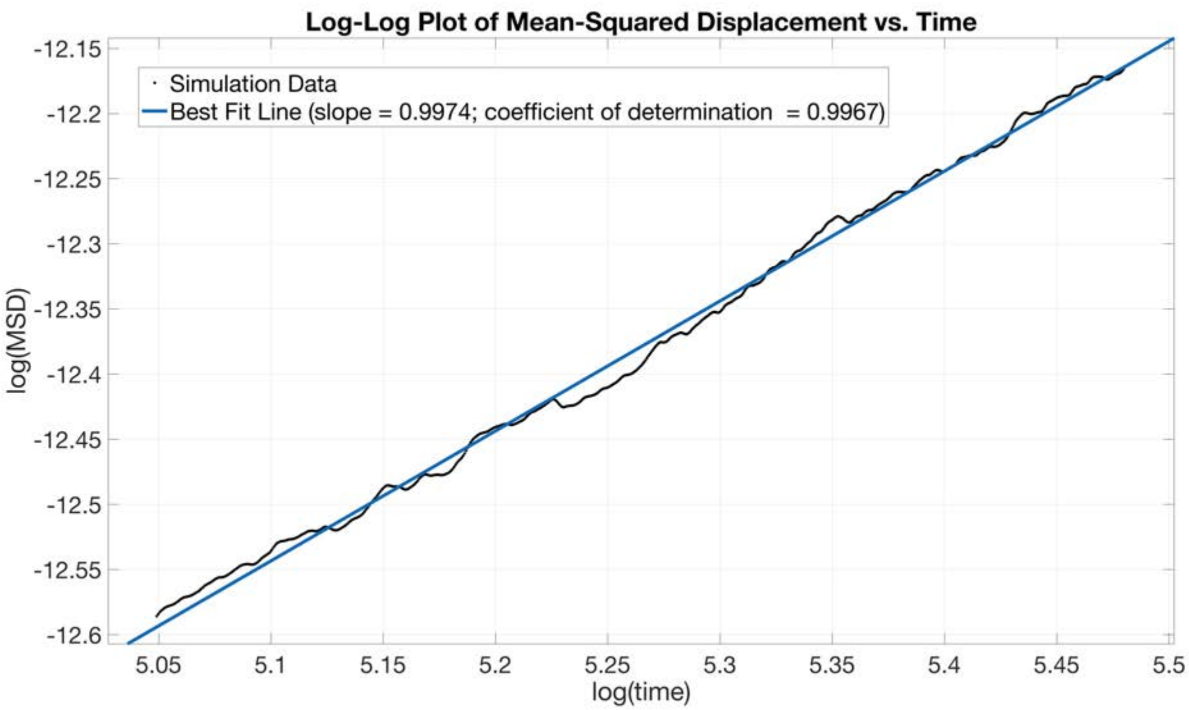
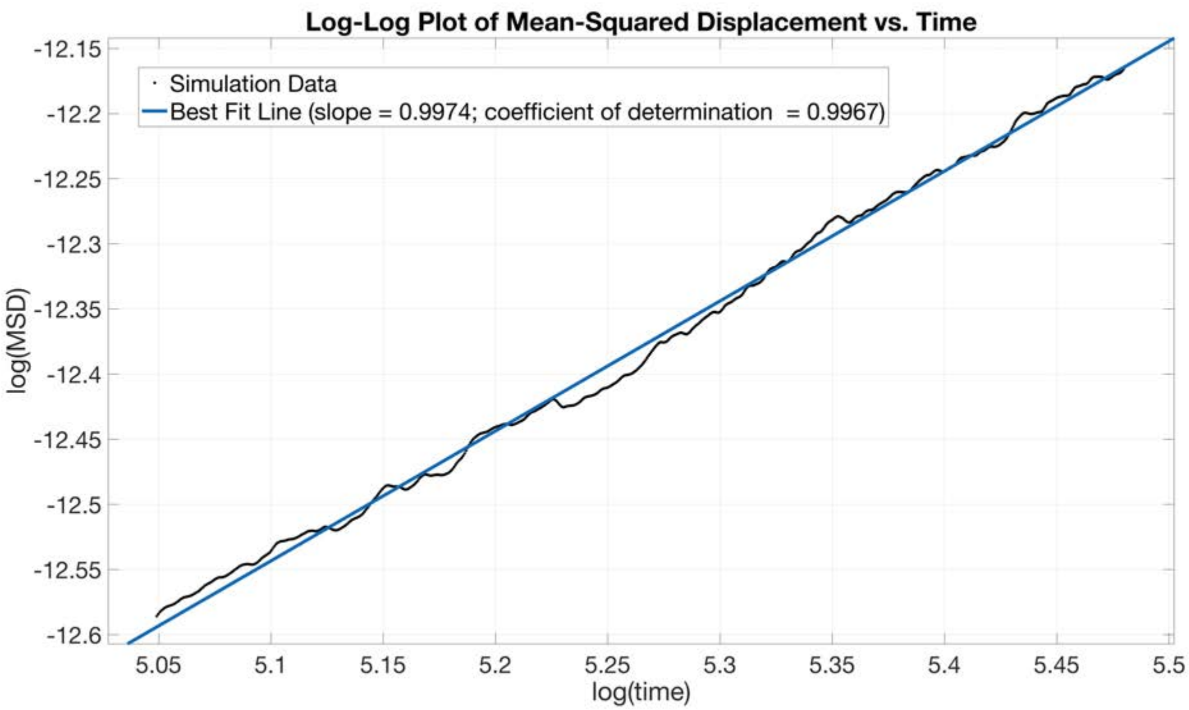


$$\alpha = 0.9974 \approx 1$$

Observed Normal Diffusion



$$\alpha = 0.9974 \approx 1$$
$$\implies \text{normal diffusion}$$

$$\Gamma \approx 170$$

Diffusion in 2D Yukawa Systems

- We observe diffusive motion at a higher coupling parameter than Liu and Goree

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- (They only simulated Yukawa systems with $\Gamma < 145$)

Self-Organization

Choice of System Parameters

- We simulate a crystal using parameters quoted by Gogia and Burton, and obtain one of similar dimensions

Gogia, G. and Burton, J. (2017). Emergent Bistability and Switching in a Nonequilibrium Crystal. *Physical Review Letters*, 119(17).

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Choice of System Parameters

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- We simulate the distribution of mass and charge that they claim leads to self-organizational behavior

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Choice of System Parameters

- We simulate a crystal using parameters quoted by Gogia and Burton, and obtain one of similar dimensions
- We simulate the distribution of mass and charge that they claim leads to self-organizational behavior
- And…

Simulation

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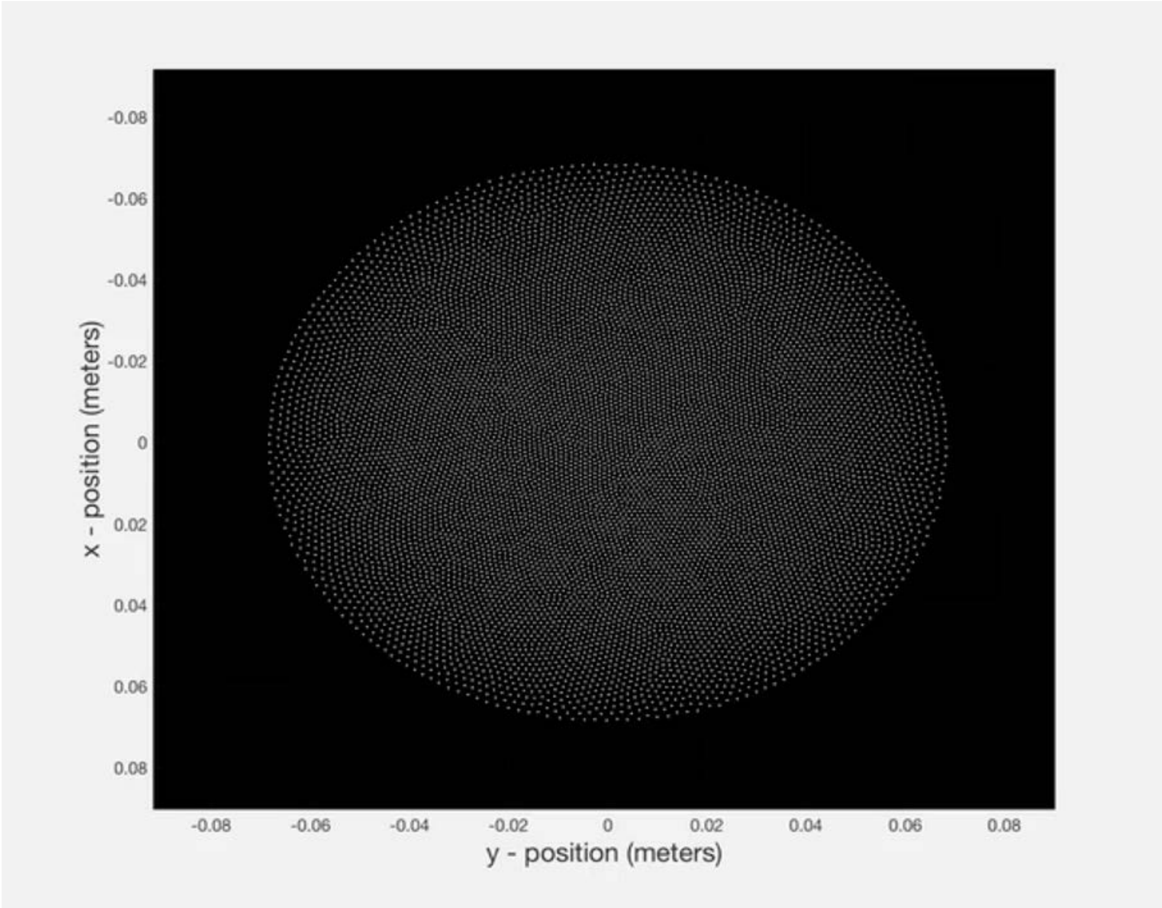


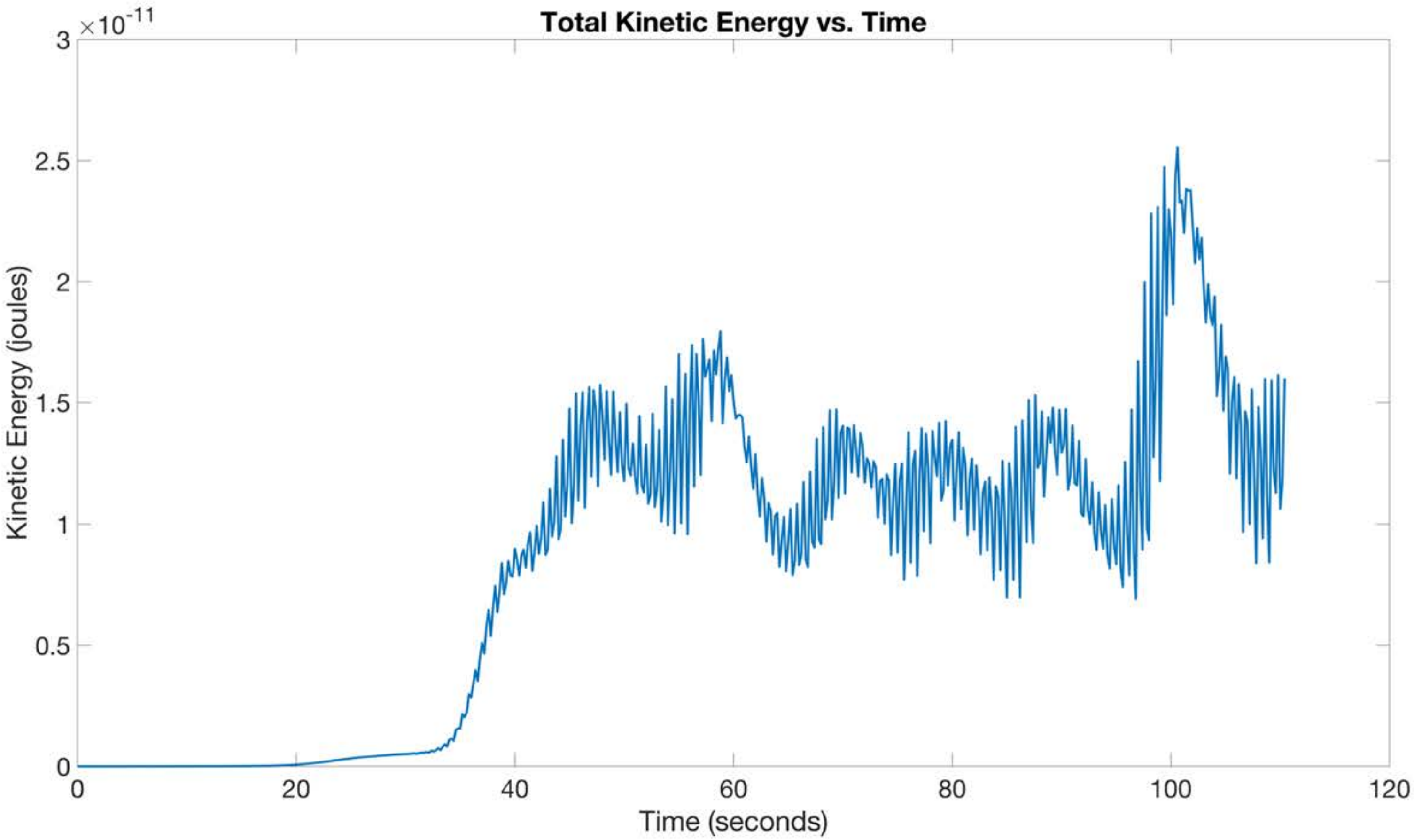
Simulation Results

- We simulate a crystal using parameters quoted by Gogia and Burton, and obtain one of similar dimensions
- We simulate the distribution of mass and charge that they claim leads to self-organizational behavior
- And…we never seem to re-organize

Simulation Results

- This different dynamical behavior is likely due to a different confinement in the *z*-direction

Simulation Results



Future Work

Diffusion and Temperature

- The coupling parameter is defined in terms of the grain temperature

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- The coupling parameter is defined in terms of the grain temperature
- Diffusive behavior is predicted for certain ranges of the coupling parameter
- Therefore, it's crucial to be able to simulate reliably at constant temperatures

Future Work

- Simulate conditions leading to subdiffusion and superdiffusion

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- Simulate conditions leading to subdiffusion and superdiffusion
  - Implement Lévy-stable distributions in `box_tree` to determine which lead to subdiffusion and superdiffusion
- Adjust simulation parameters to observe self-organizational phenomena

Thank you for your attention!

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