Numerical study of parameters influence over the dynamics of a piezo-magneto-elastic energy harvesting device

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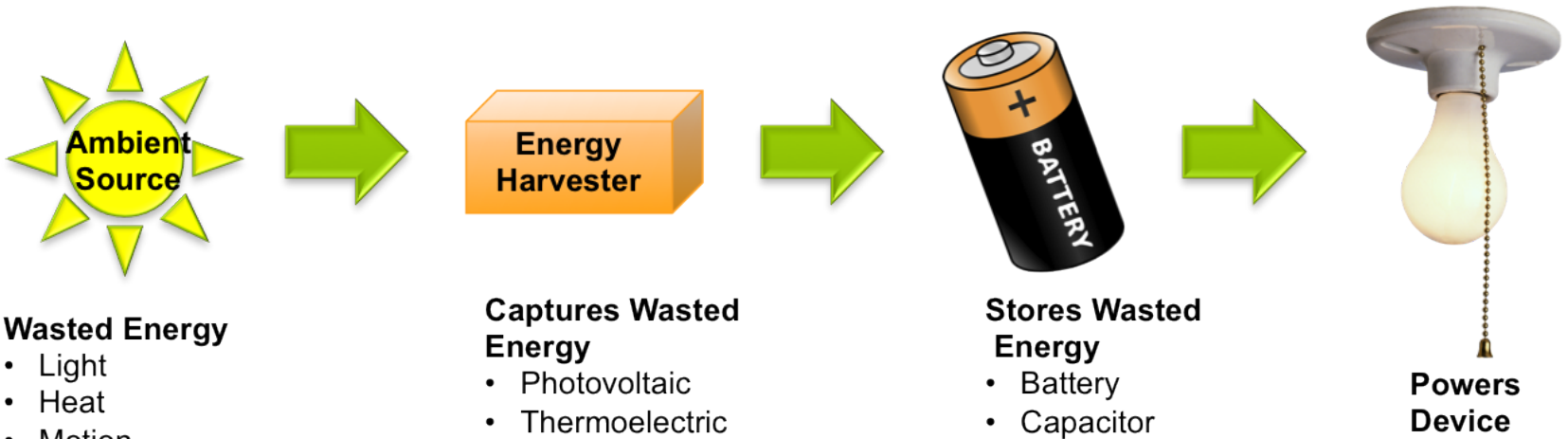
Section 1

Introduction

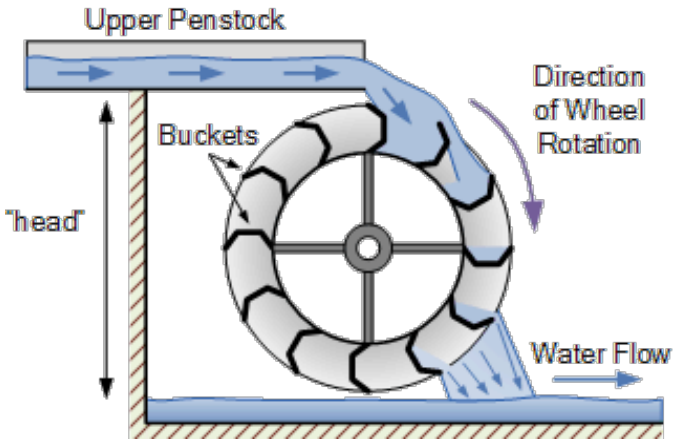
Energy Harvesting

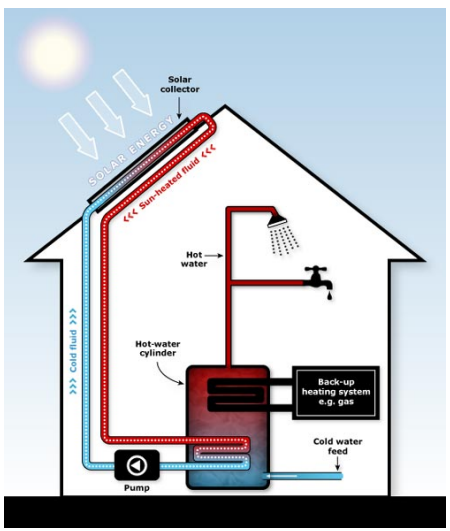


- Capture wasted energy from external sources
- Store this wasted energy for future use
- Use the stored energy to supply other devices

*Picture from http://hiddenjoules.com/intro/what/

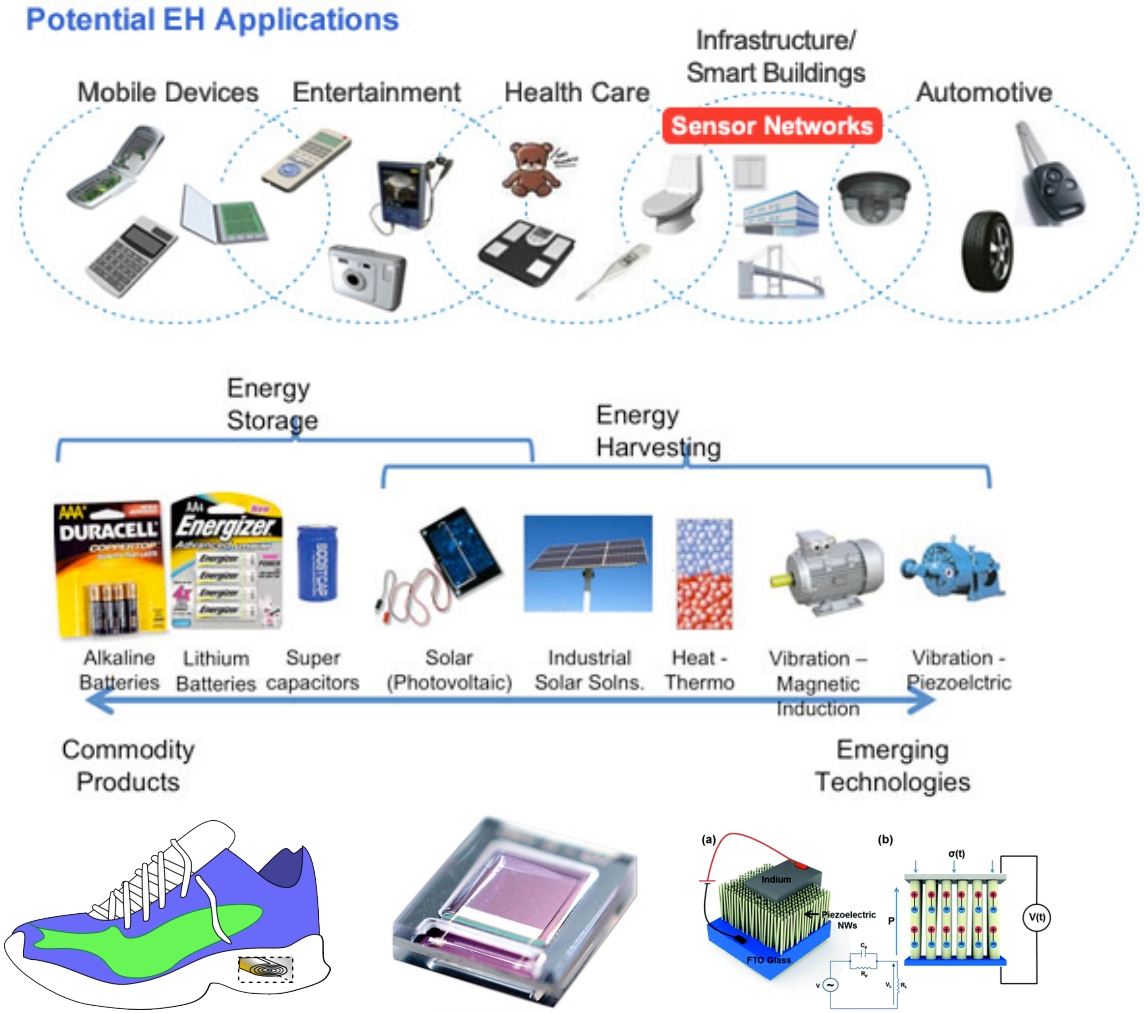
Classical Technologies in Energy Harvesting

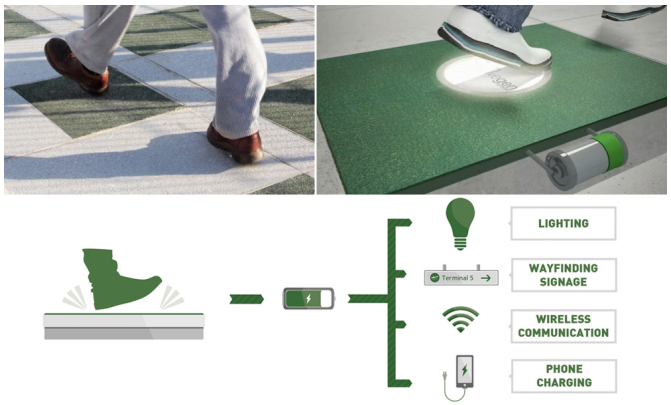




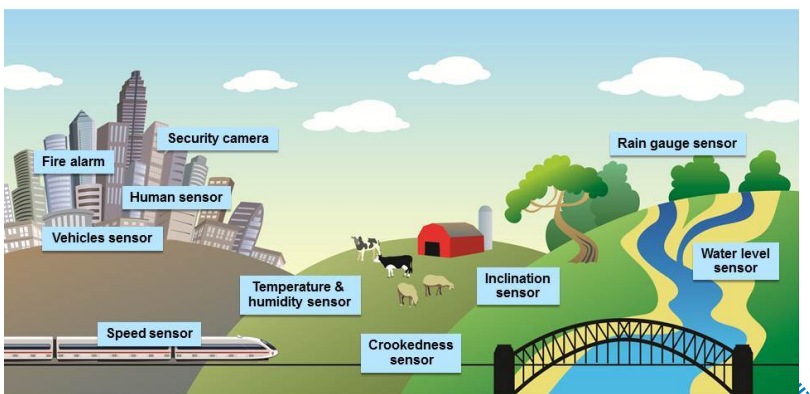
*Pictures obtainded from Google Images, several sources. If you are the owner of any one of these images, consider its use a compliment.

Emergent Technologies in Energy Harvesting



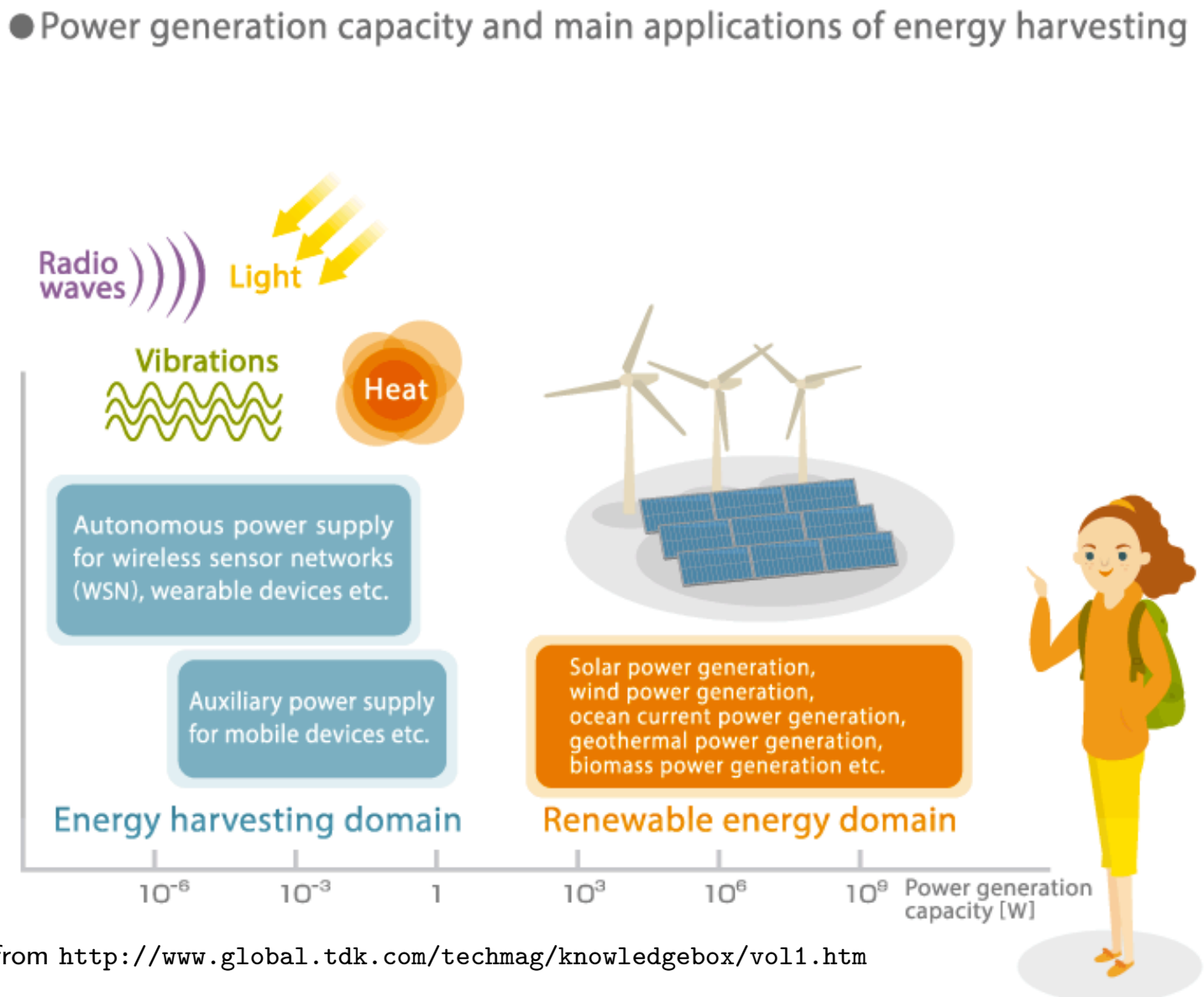


Spansion Energy Harvesting Technology Can Power the IoT



*Pictures obtainded from Google Images, several sources. If you are the owner of any one of these images, consider its use a compliment.

Energy Scale for Modern Harvesting Devices



*Picture from `http://www.global.tdk.com/techmag/knowledgebox/vol1.htm`

Research objectives

This research has several objectives:

- Investigate in detail the underlying nonlinear dynamics
  - Time series
  - Bifurcation diagrams
  - Basis of attractions
- Propose strategies to enhance the recovered energy
  - Nonlinear optimization
  - Control of chaos
- Model the underlying uncertainties and study their influence
  - System parameters variability
  - Noise in system excitation

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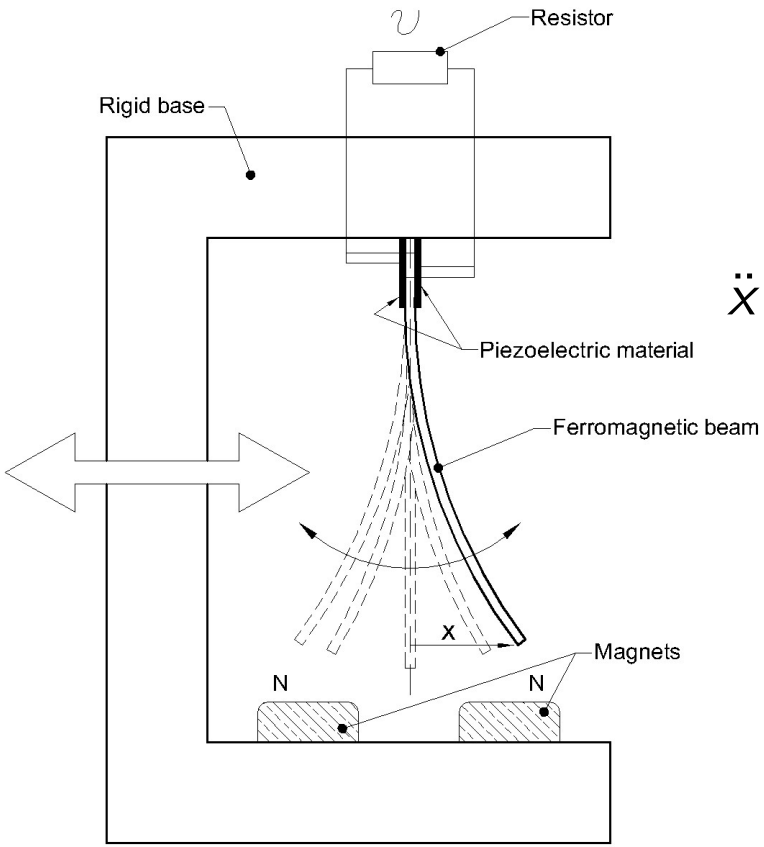
Section 2

Nonlinear Dynamics

Bi-stable energy harvesting device



$$\ddot{x} + 2\xi\dot{x} - \frac{1}{2}x(1 - x^2) - \chi\upsilon = f\cos\Omega t$$

$$\dot{\upsilon} + \lambda\upsilon + \kappa\dot{x} = 0$$

$$x(0) = x_0,\ \dot{x}(0) = \dot{x}_0,\ \upsilon(0) = \upsilon_0$$

A. Erturk, J. Hoffmann and D. J. Inman, *A piezomagnetoelastic structure for broadband vibration energy harvesting.* **Applied Physics Letters**, 94: 254102, 2009.

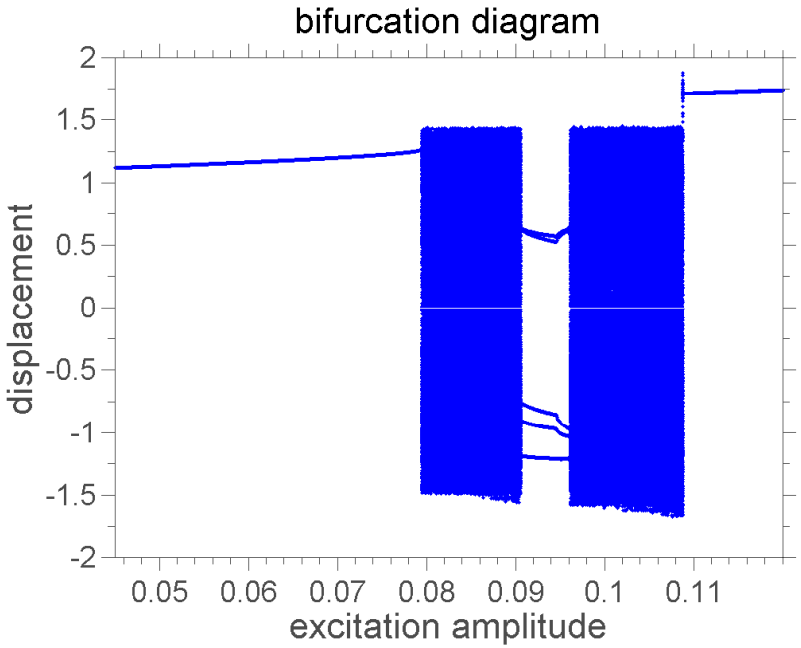
Section 3

Numerical Experiments

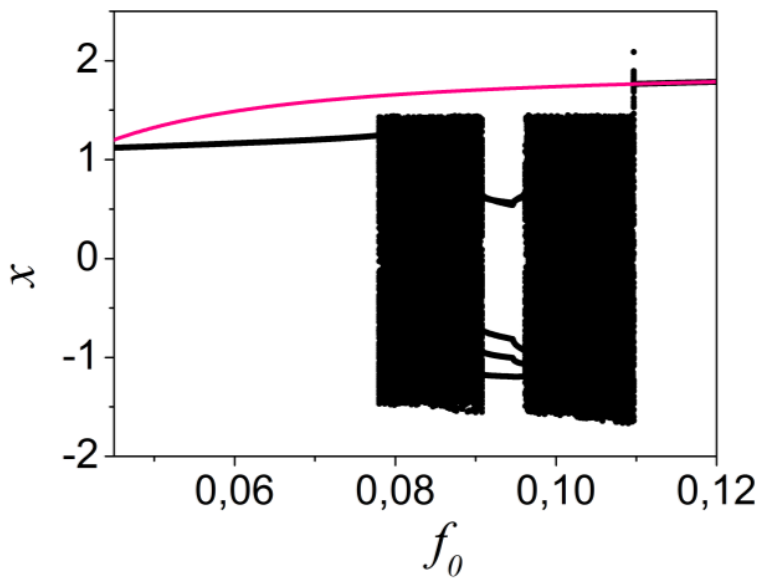
Nonlinear dynamics animation

Computational code verification

- Fixed $\Omega = 0.8$
- Initial condition: $(x_0, \dot{x}_0, v_0) = (1\ 0\ 0)$



(a) Computed diagram



(b) Reference diagram

T. Leite, A. S. de Paula, A. T. Fabro and M. Savi, A numerical analysis of the electrical output response of a nonlinear piezoelectric oscillator subjected to a harmonic and random excitation, *XXXVII Iberian Latin American Congress on Computational Methods in Engineering, Brasilia, DF, Brazil, 2016*.

Voltage vs excitation amplitude ($\Omega = 0.8$)

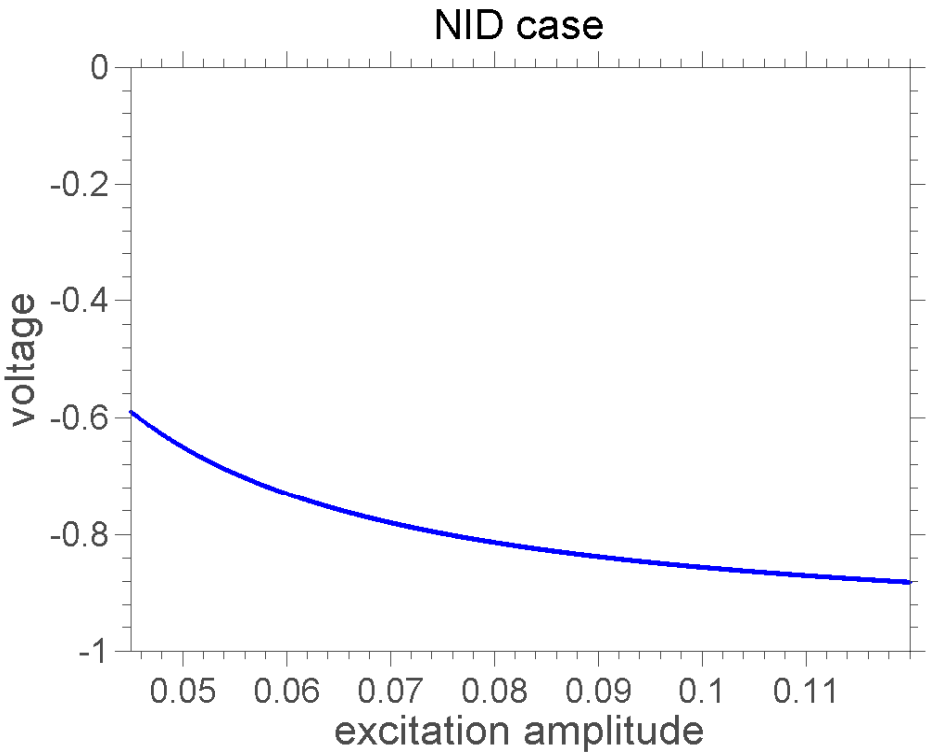
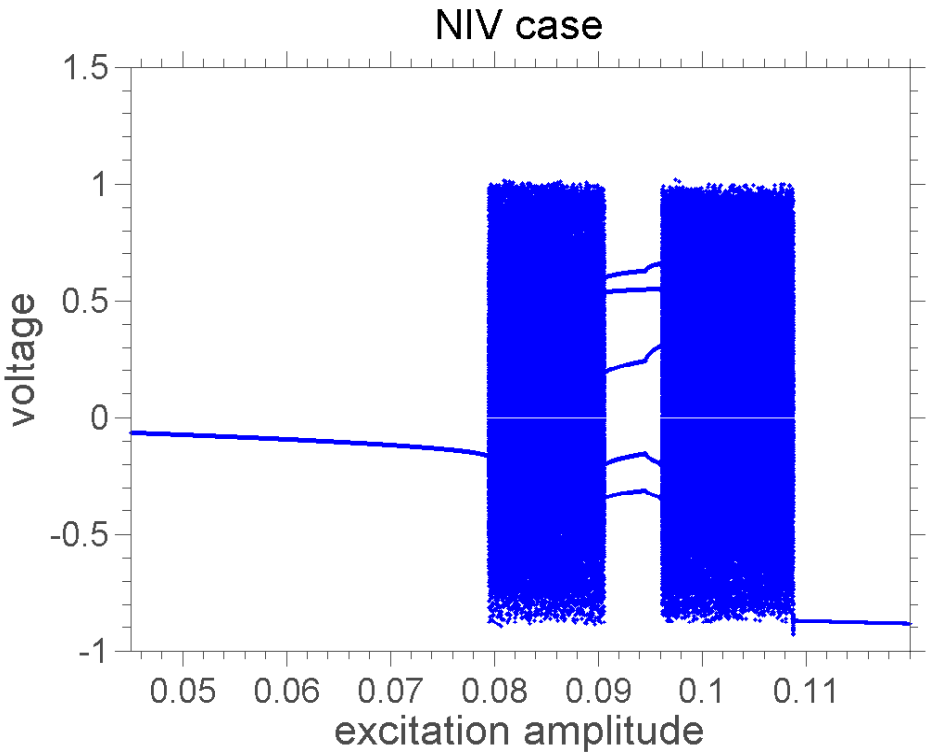


Figure: $(x_0, \dot{x}_0, v_0) = (0\ 1\ 1)$



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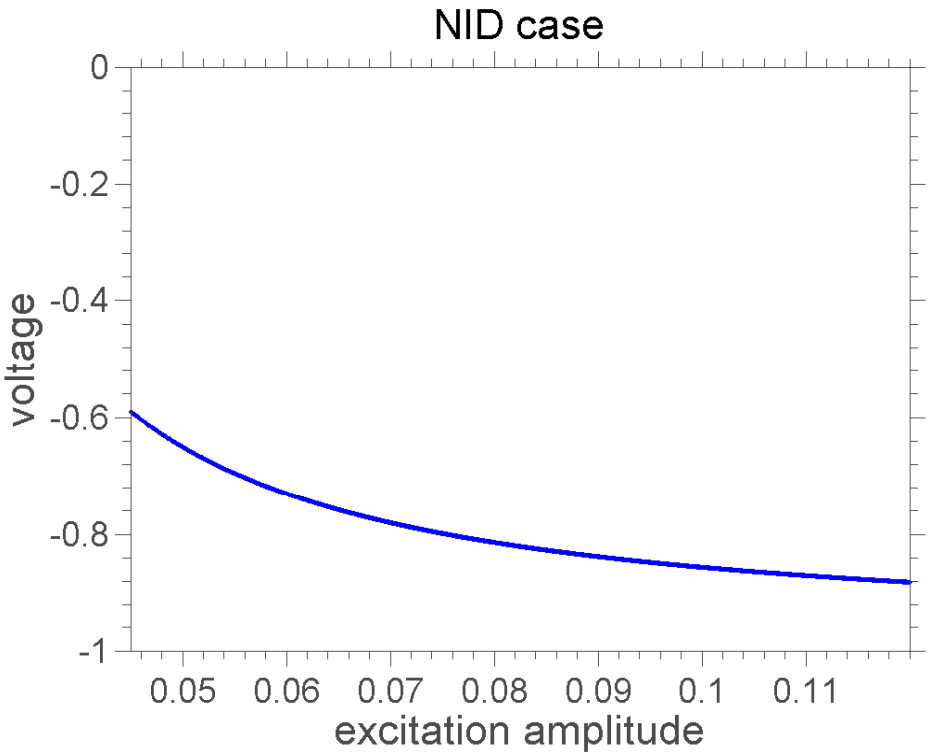

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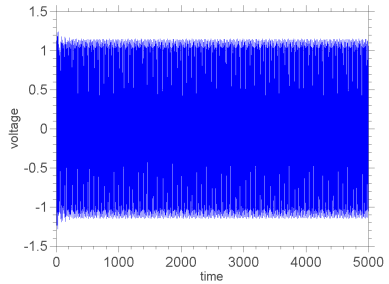
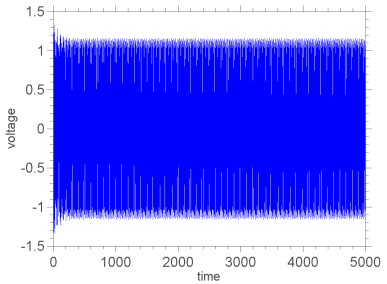
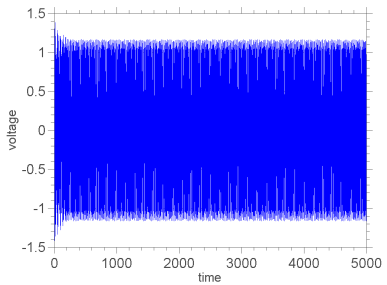


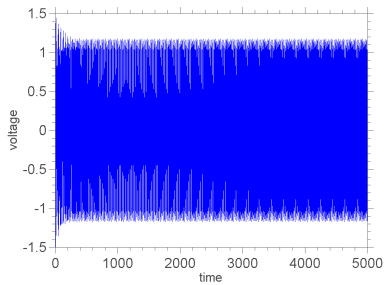
(a) $f = 0.05$



(b) $f = 0.07$

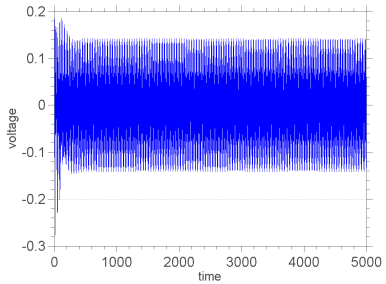


(c) $f = 0.09$

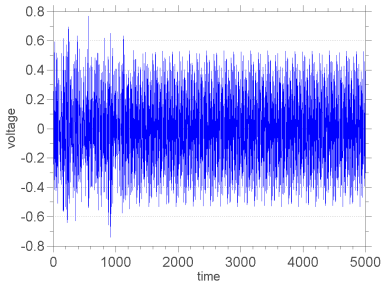


(d) $f = 0.11$

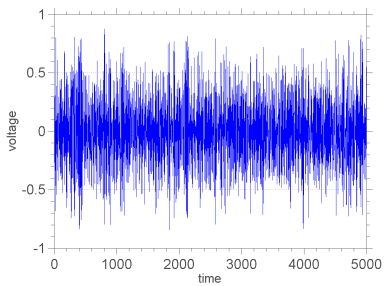
Voltage vs excitation amplitude ($\Omega = 0.8$)



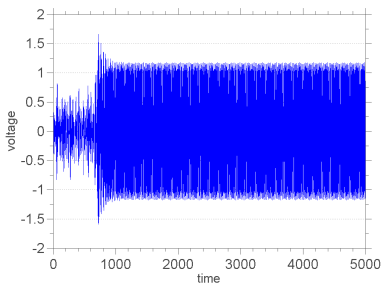
(e) $f = 0.060$



(f) $f = 0.092$



(g) $f = 0.100$



(h) $f = 0.116$

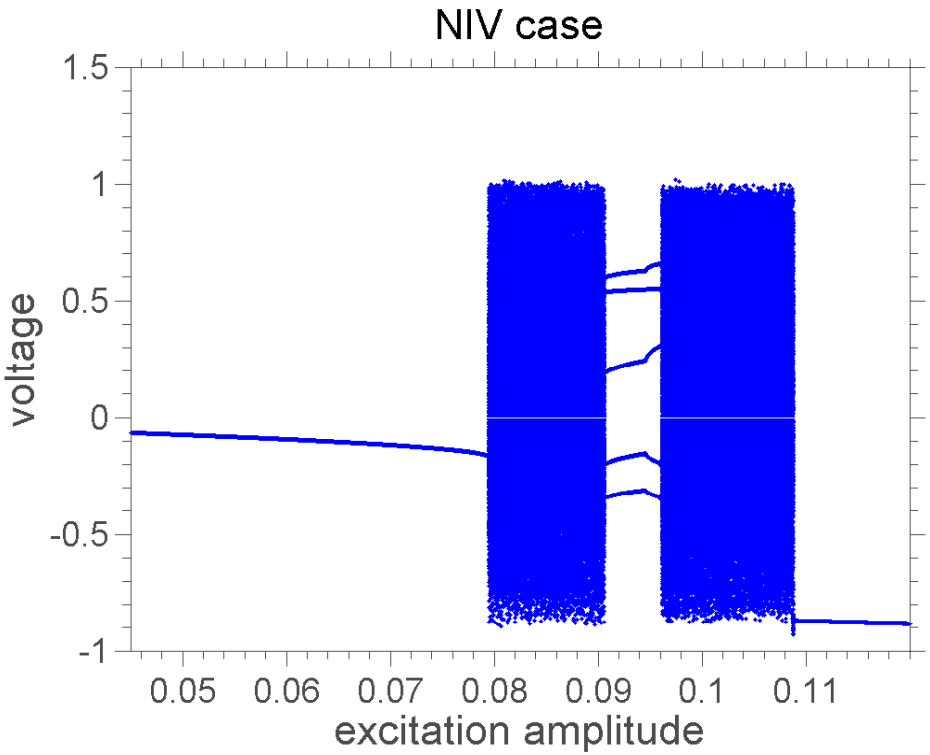


Figure: $(x_0, \dot{x}_0, v_0) = (1\ 0\ 1)$

Voltage vs excitation frequency ($f = 0.083$)

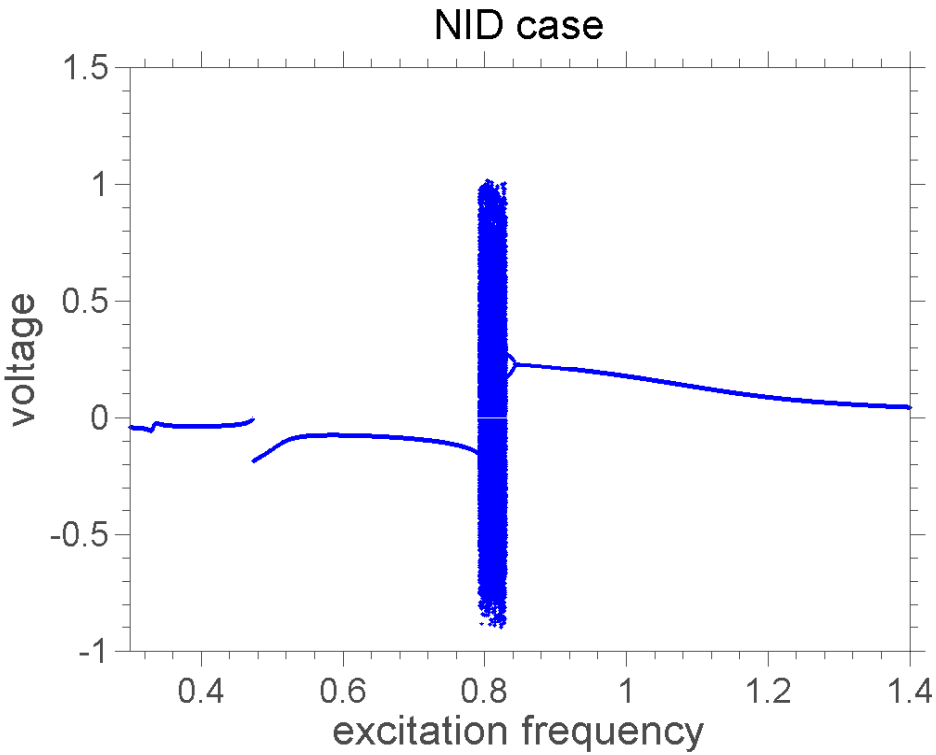


Figure: $(x_0, \dot{x}_0, v_0) = (0\ 1\ 1)$

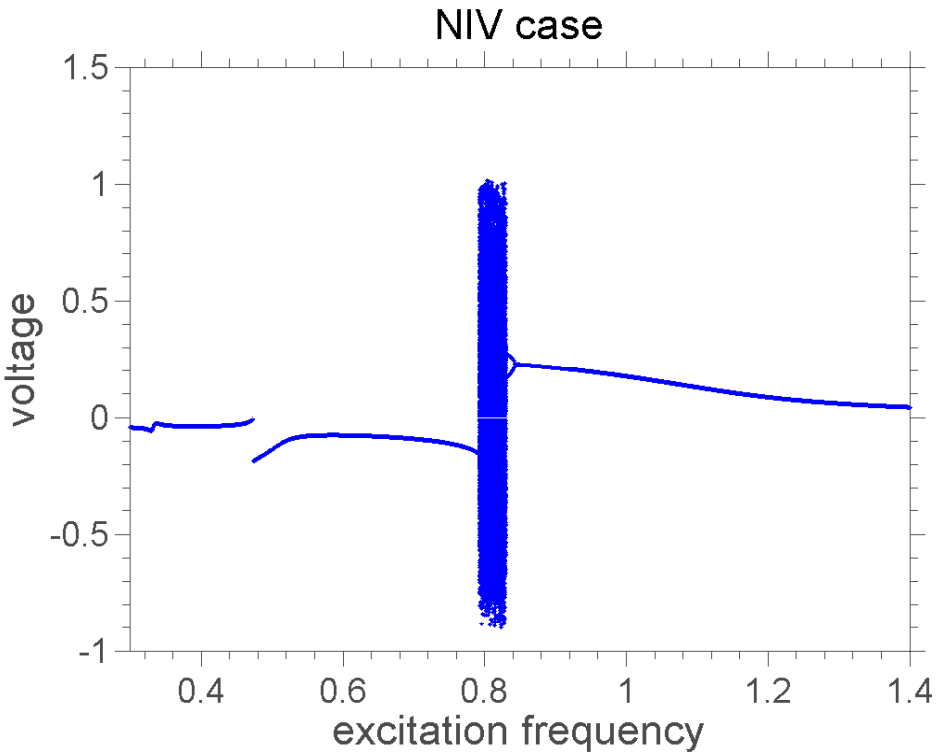


Figure: $(x_0, \dot{x}_0, v_0) = (1\ 0\ 1)$

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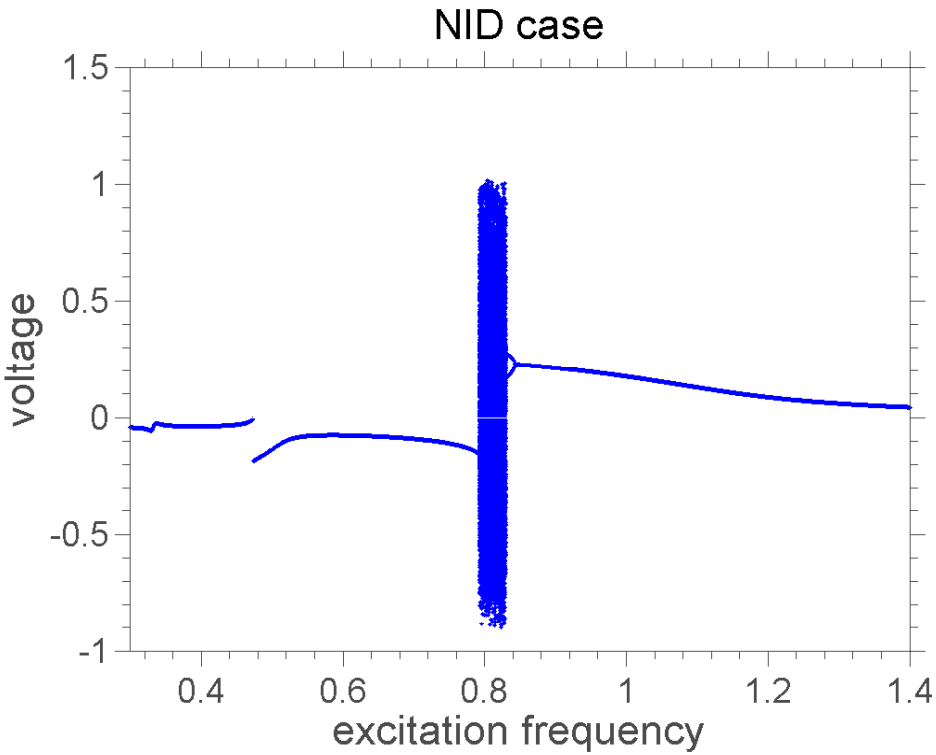
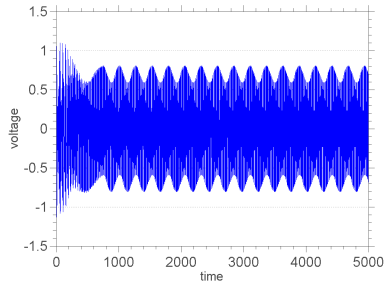
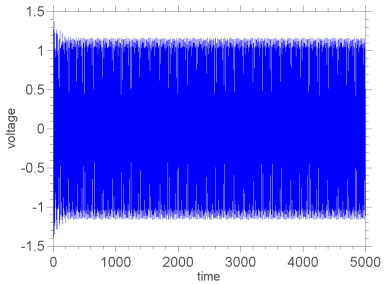


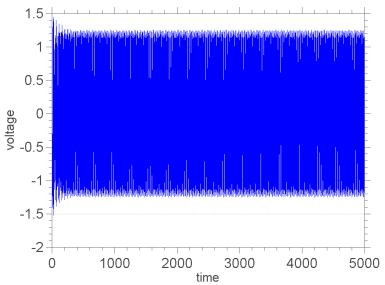
Figure: $(x_0, \dot{x}_0, v_0) = (0\ 1\ 1)$



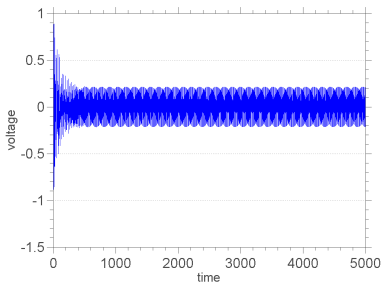
(a) $\Omega = 0.600$



(b) $\Omega = 0.800$

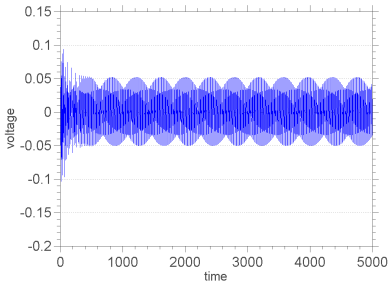


(c) $\Omega = 0.840$

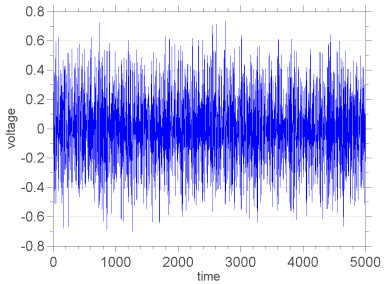


(d) $\Omega = 1.200$

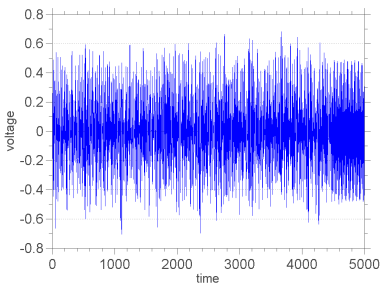
Voltage vs excitation frequency ($f = 0.083$)



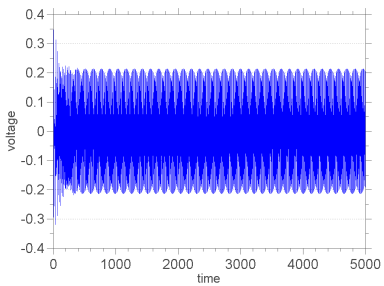
(e) $\Omega = 0.400$



(f) $\Omega = 0.800$



(g) $\Omega = 0.840$



(h) $\Omega = 1.200$

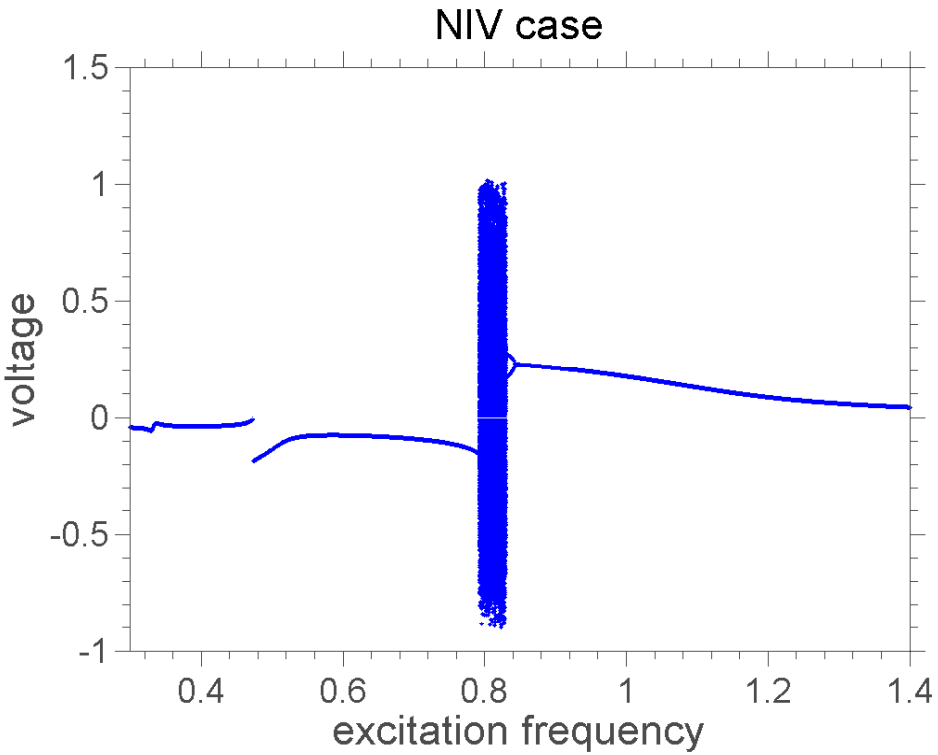
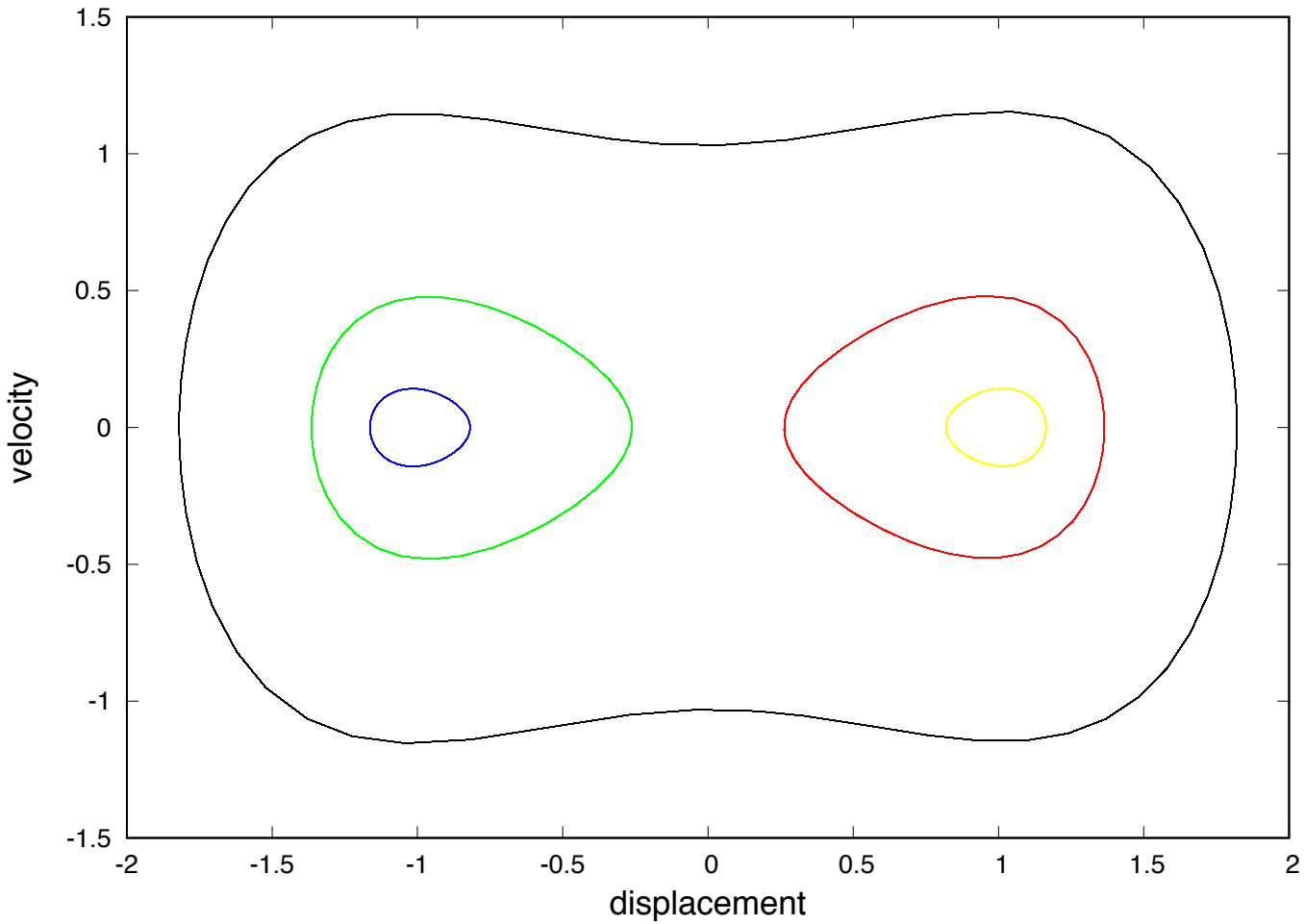


Figure: $(x_0, \dot{x}_0, v_0) = (1\ 0\ 1)$

Basins of Attraction ($f = 0.12$ and $\Omega = 0.8$)



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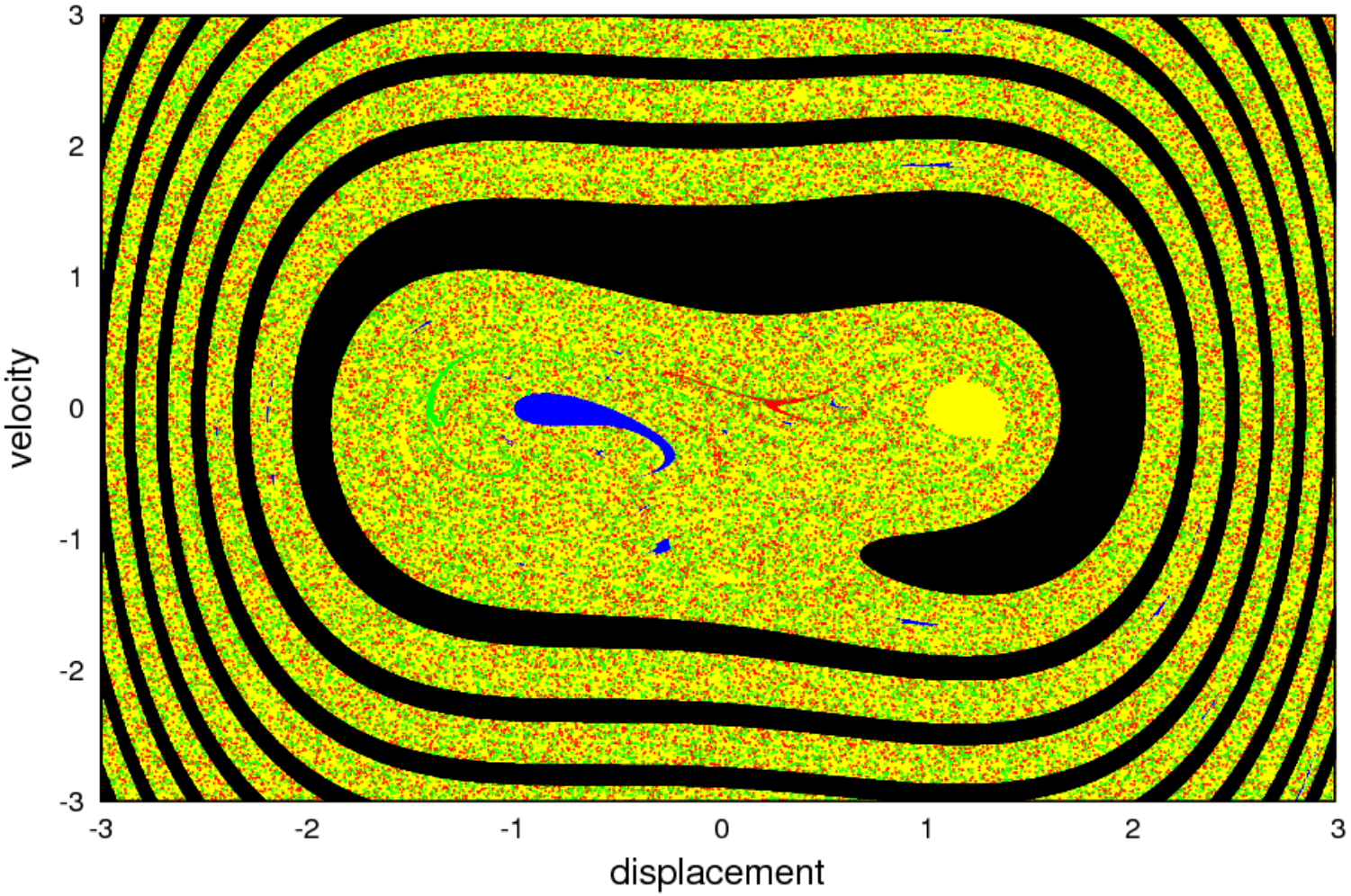
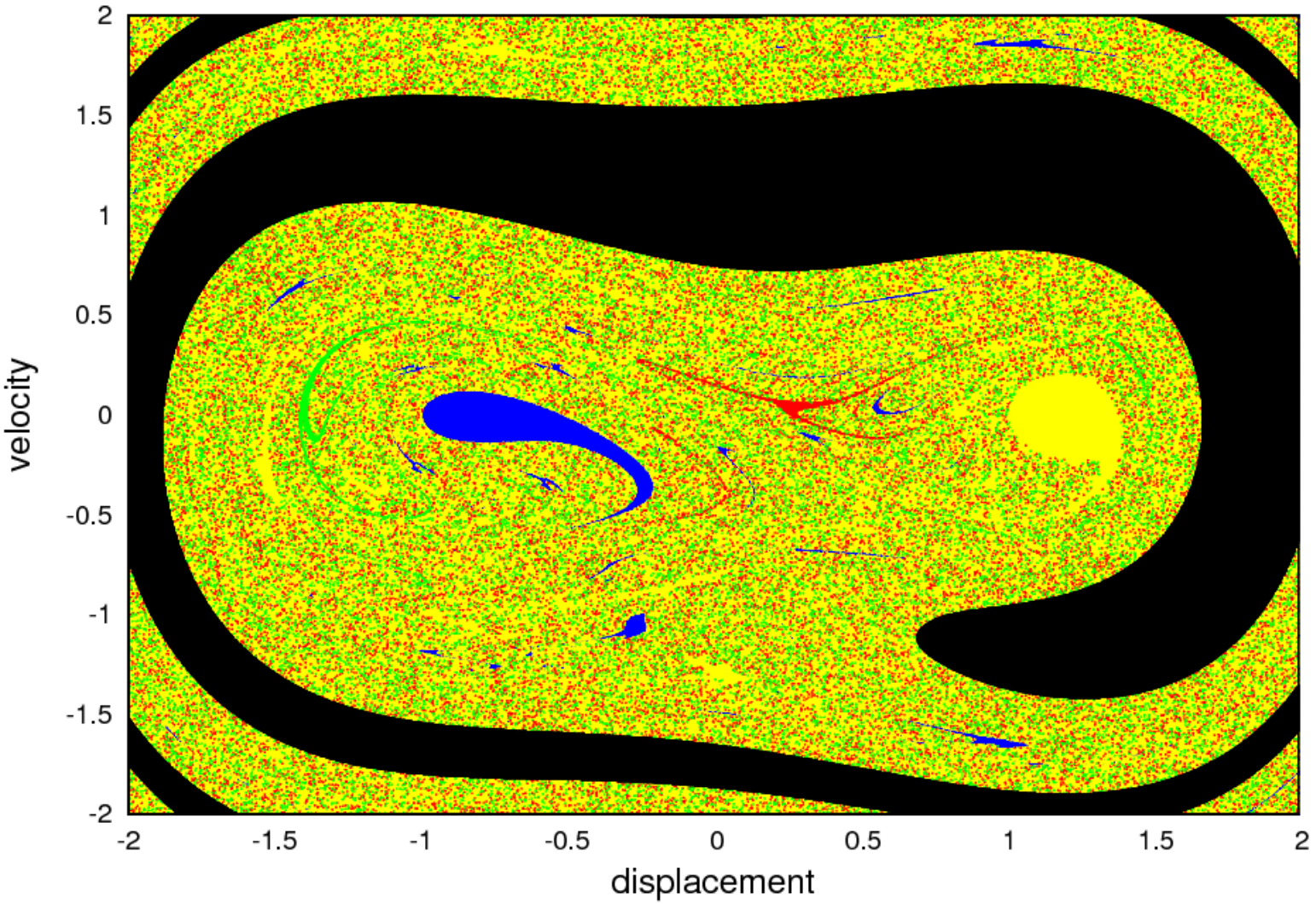


Basins of Attraction ($f = 0.12$ and $\Omega = 0.8$)



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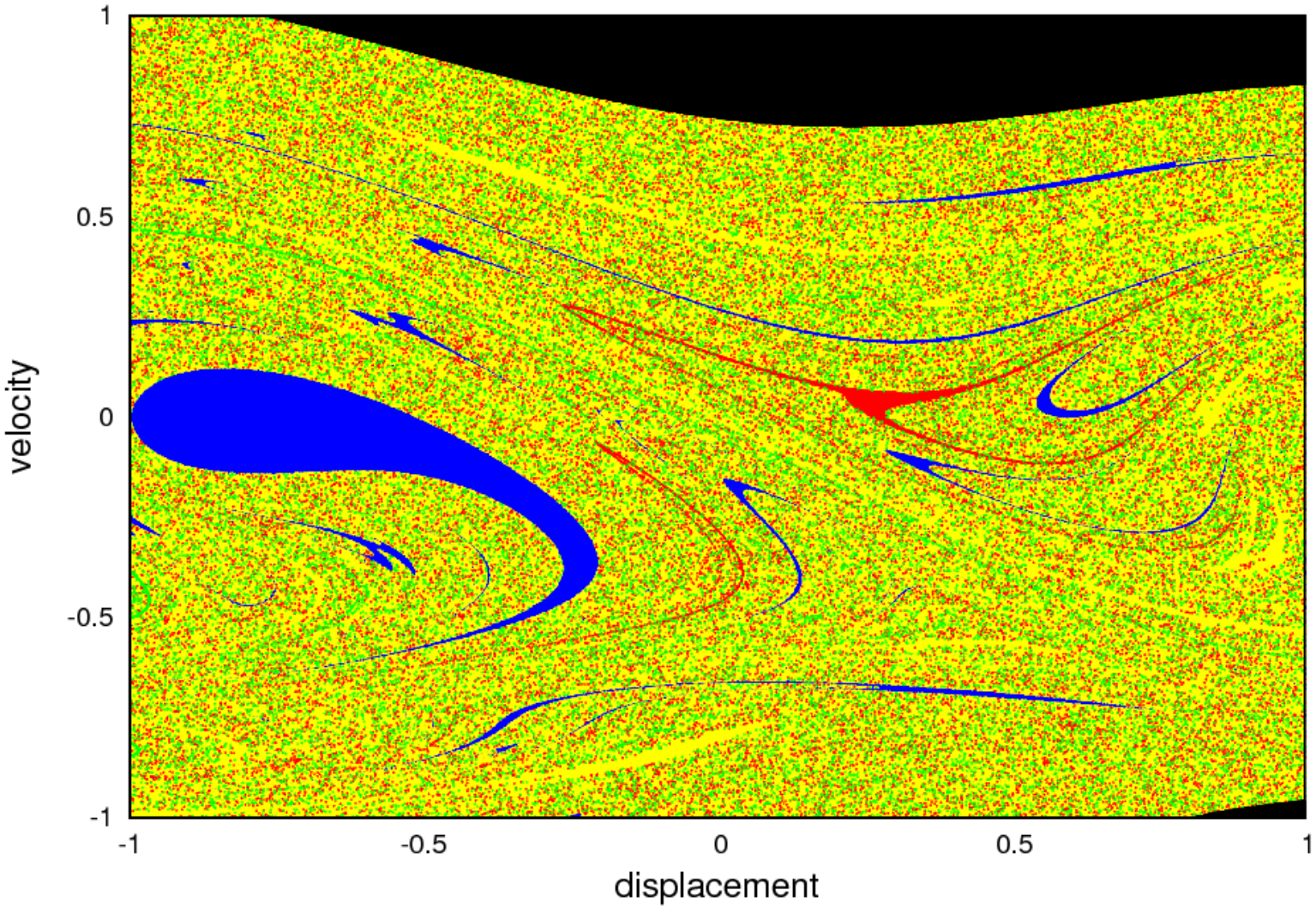
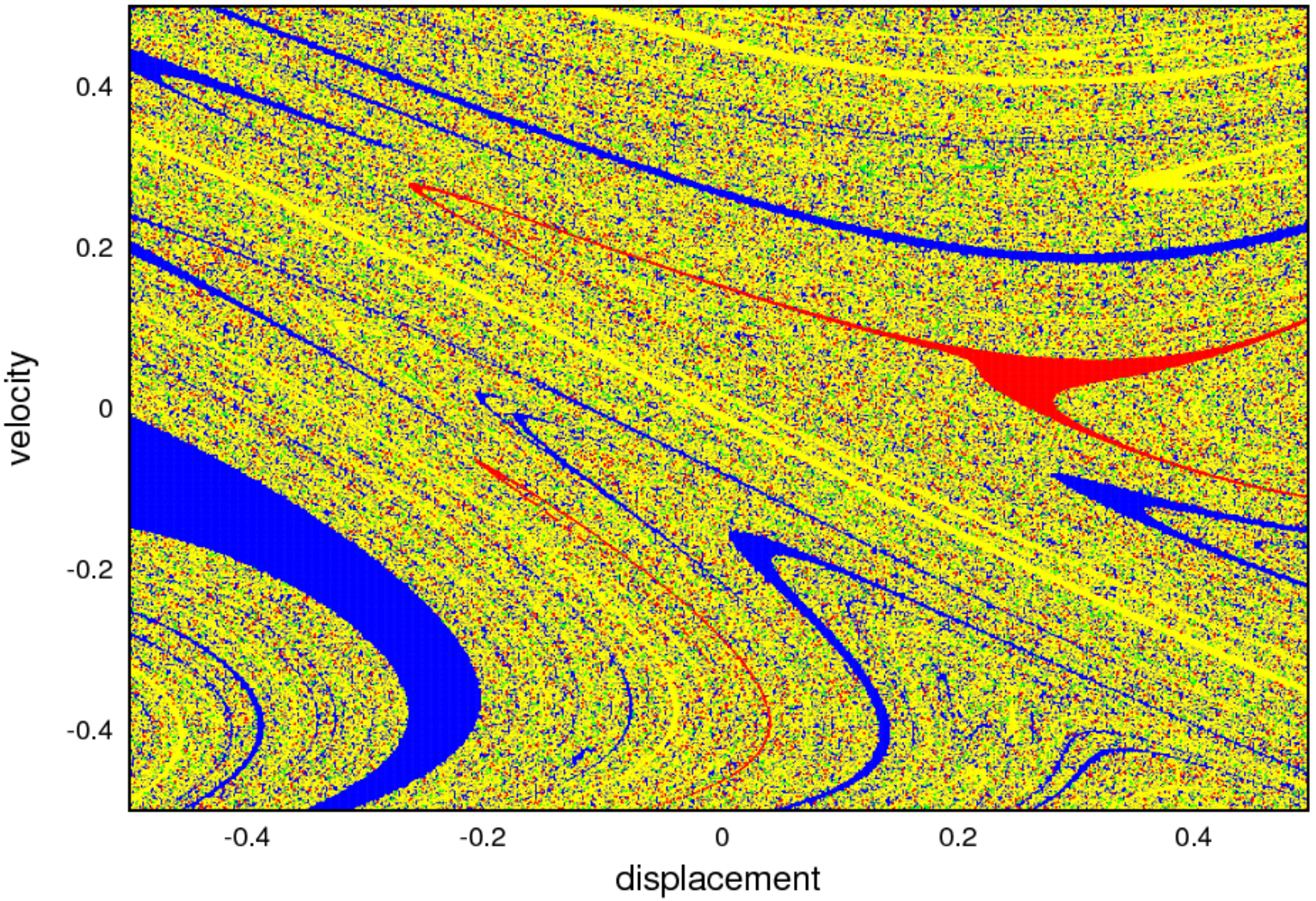


Basins of Attraction ($f = 0.12$ and $\Omega = 0.8$)



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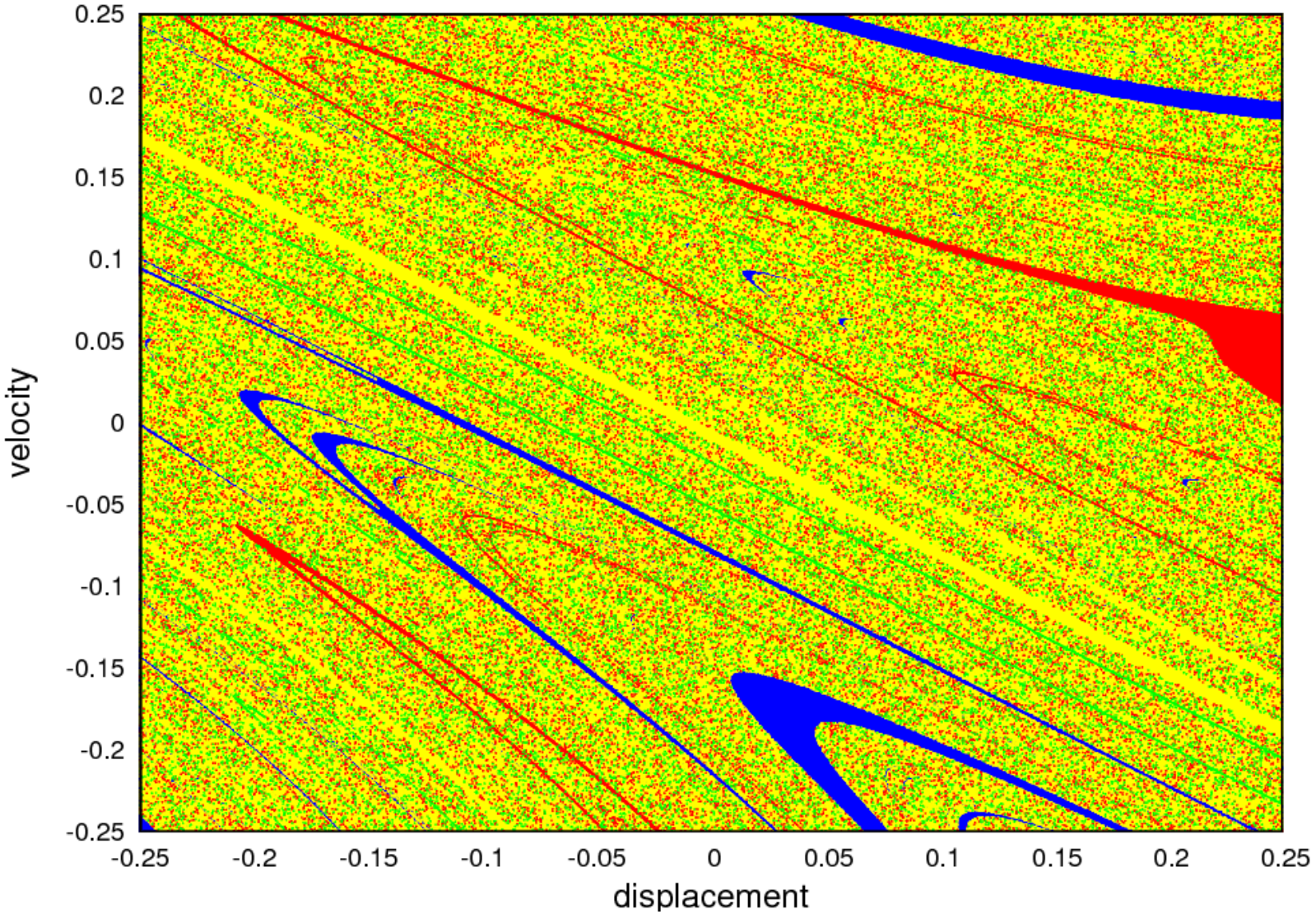

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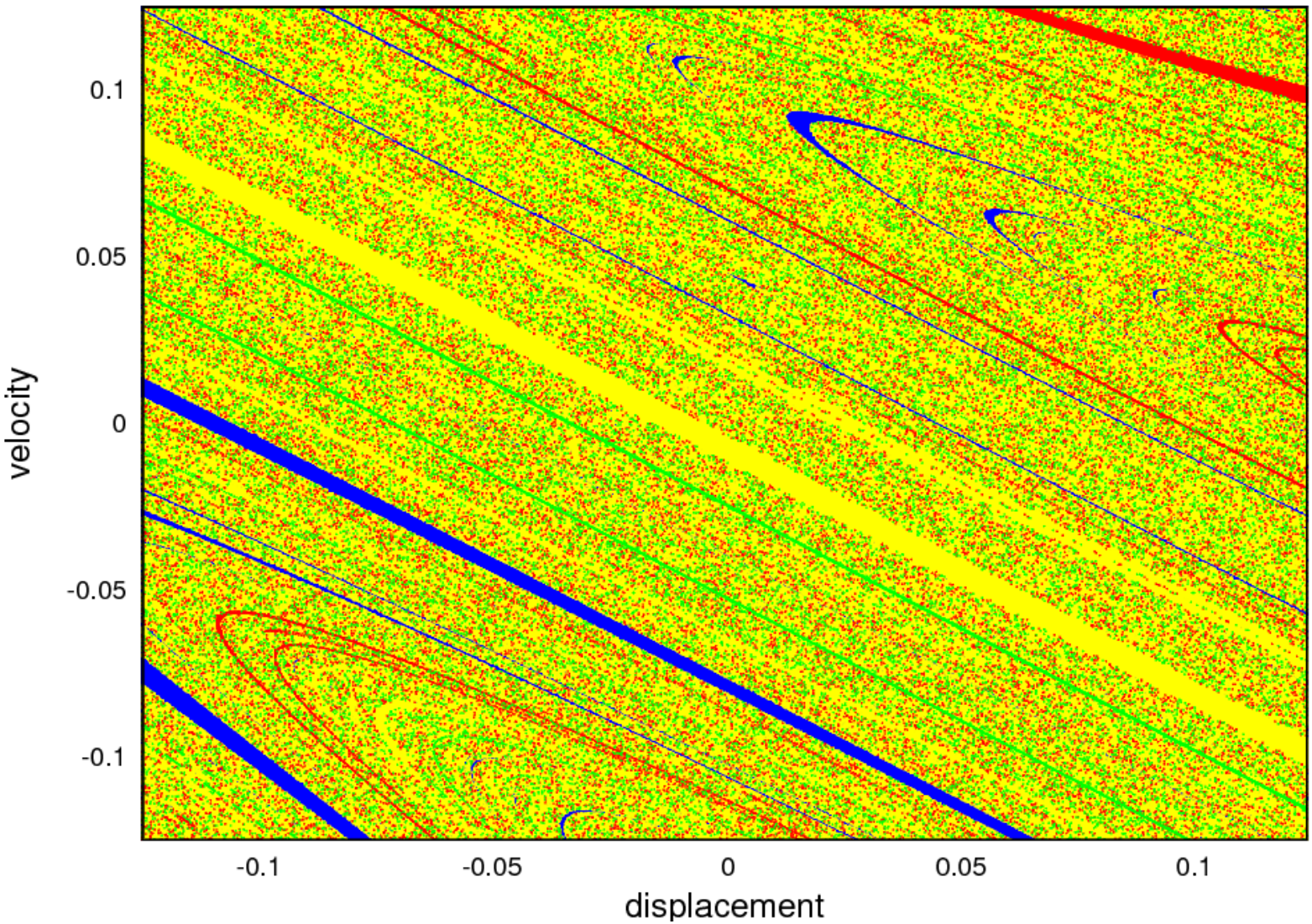
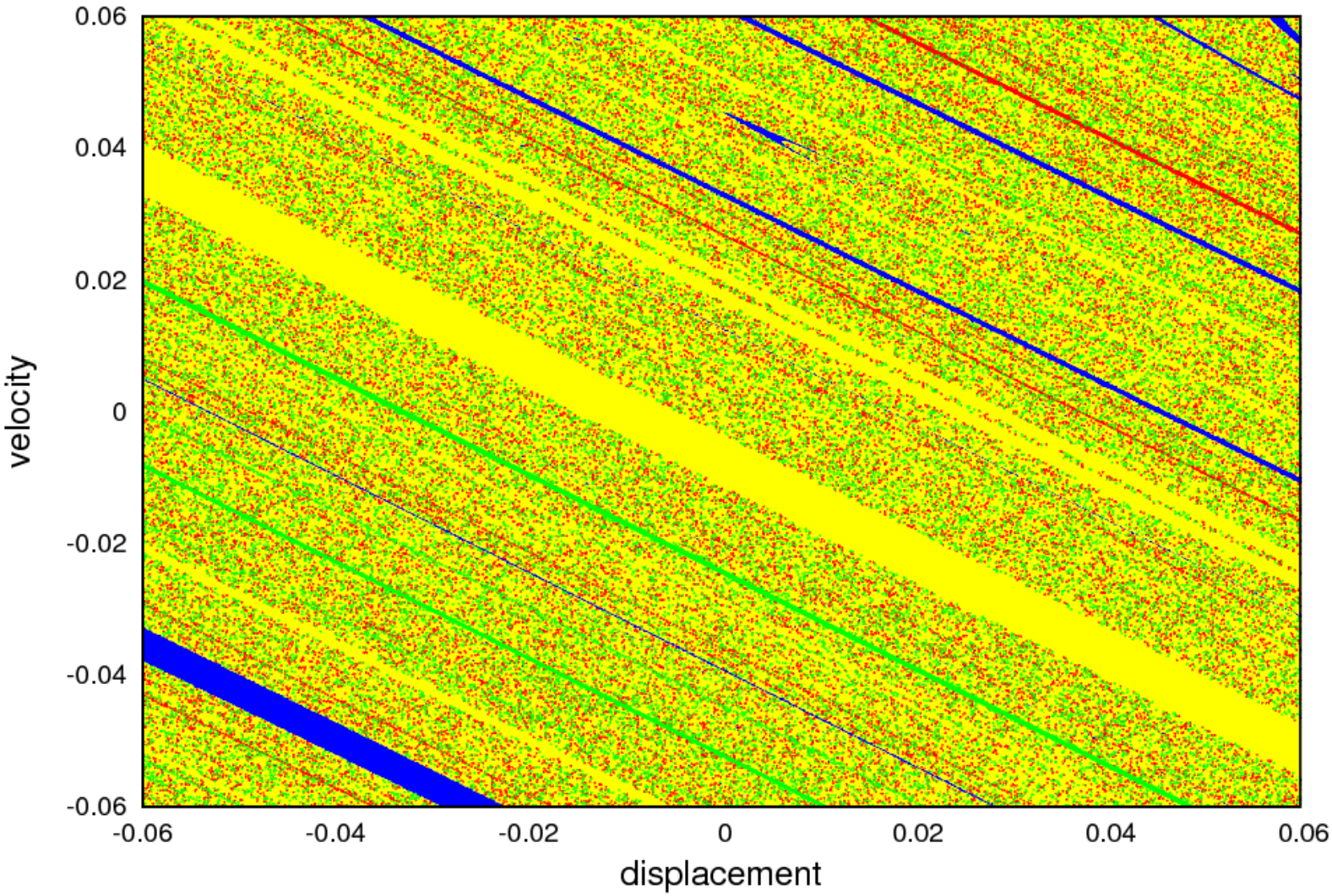


Basins of Attraction ($f = 0.12$ and $\Omega = 0.8$)



Section 4

Final Remarks

Final remarks

Contributions:

- Detailed investigation of the system nonlinear dynamics
  - Bifurcation in system response due to external excitation
  - Sensitivity to initial conditions

Ongoing research:

- Modeling of system parameters uncertainties
- Control of chaos to improve the system efficiency

Acknowledgments

Academic discussion:

- Profª. Aline de Paula (UnB)
- Prof. Adriano Fabro (UnB)
- Mr. Tiago Pereira (UnB)

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- CNPq
- CAPES
- FAPERJ

Thank you for your attention!

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joao.peterson@uerj.br
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A. Cunha Jr,
Enhancing the performance of a bi-stable energy harvesting device via cross-entropy method.
(under review) https://hal.archives-ouvertes.fr/hal-01531845


J. V. L. L. Peterson, V. G. Lopes, and A. Cunha Jr,
Numerically exploring the nonlinear dynamics of a piezo-magneto-elastic energy harvesting device.
(in preparation)

Physical system parameters

parameter	value
ξ	0.01
χ	0.05
f	0.083
Ω	0.8
λ	0.05
κ	0.5

Displacement vs excitation amplitude ($\Omega = 0.8$)

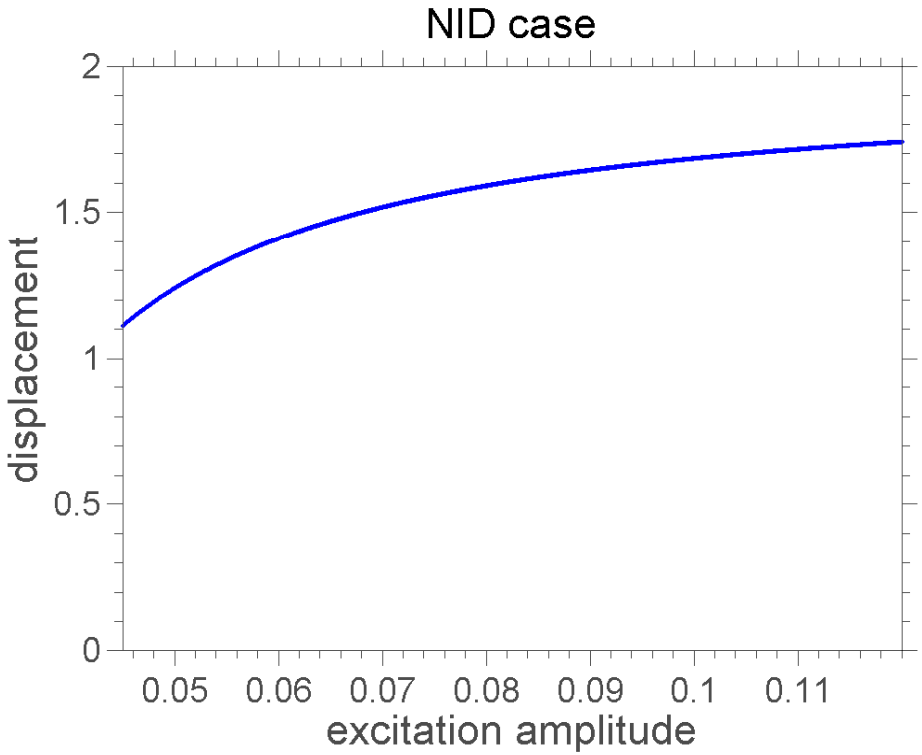
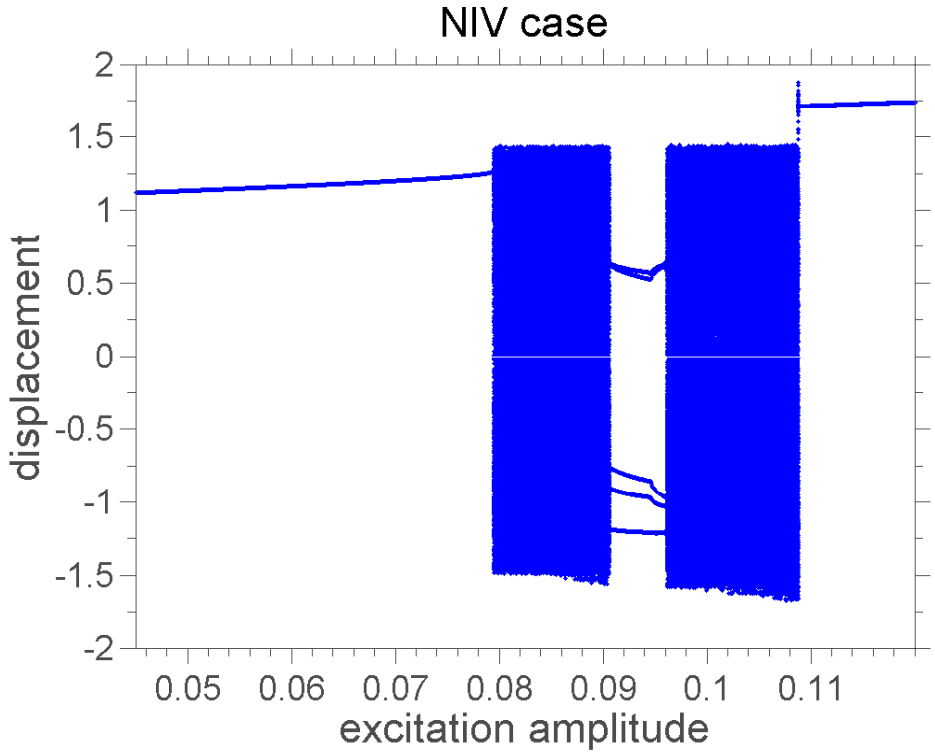


Figure: $(x_0, \dot{x}_0, \upsilon_0) = (0\ 1\ 1)$



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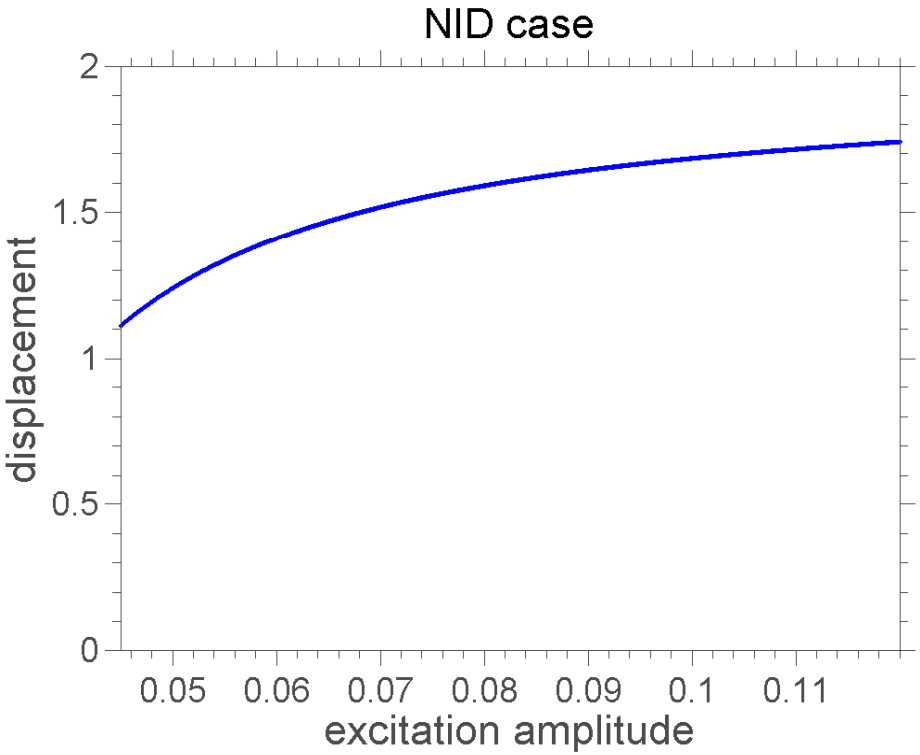

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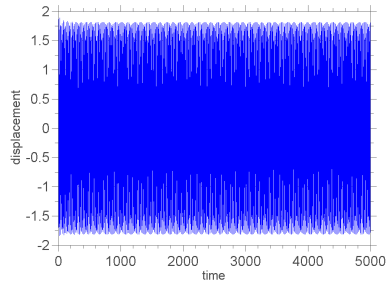
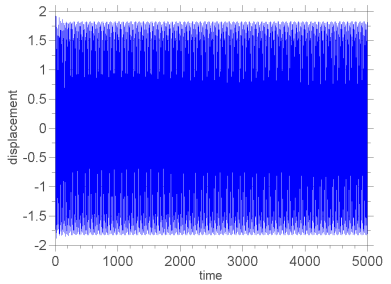
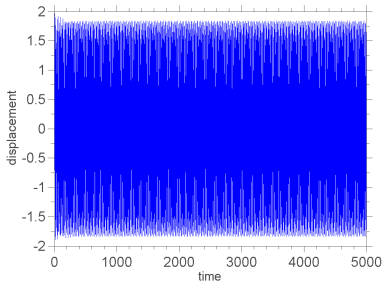


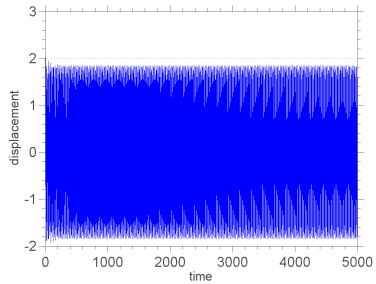
(a) $f = 0.05$



(b) $f = 0.07$

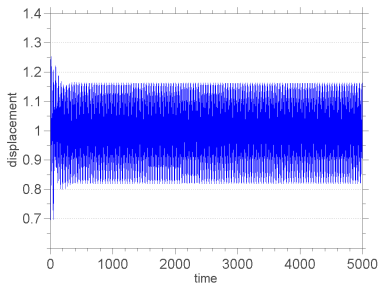


(c) $f = 0.09$

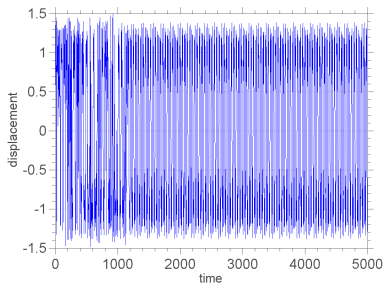


(d) $f = 0.11$

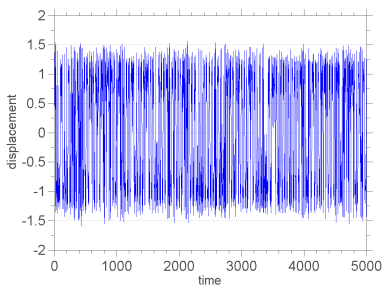
Displacement vs excitation amplitude ($\Omega = 0.8$)



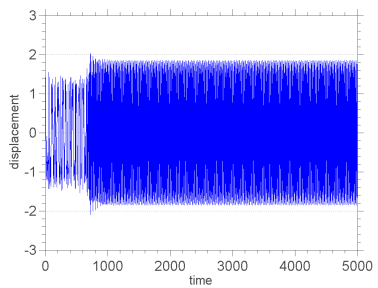
(e) $f = 0.060$



(f) $f = 0.092$



(g) $f = 0.100$



(h) $f = 0.116$

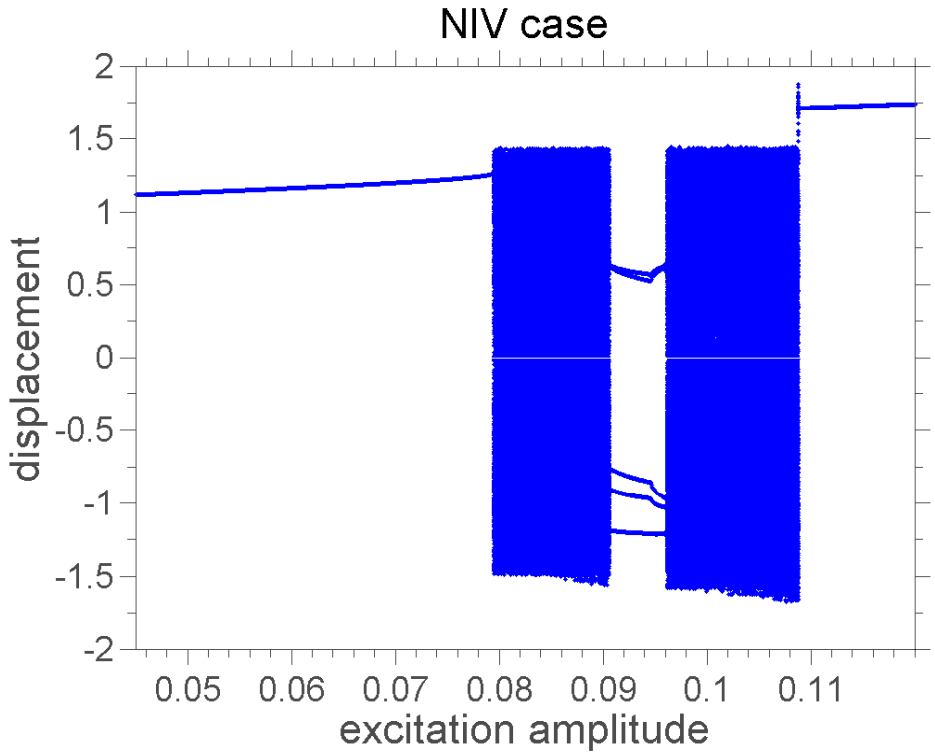


Figure: $(x_0, \dot{x}_0, v_0) = (1\ 0\ 1)$

Displacement vs excitation frequency ($f = 0.083$)

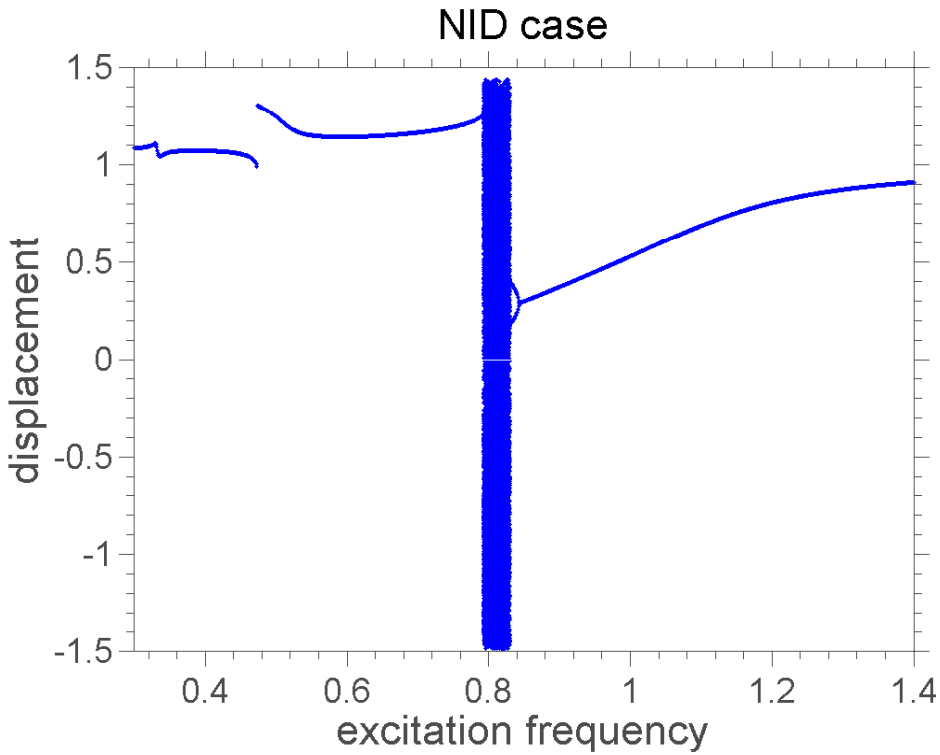


Figure: $(x_0, \dot{x}_0, \upsilon_0) = (0\ 1\ 1)$

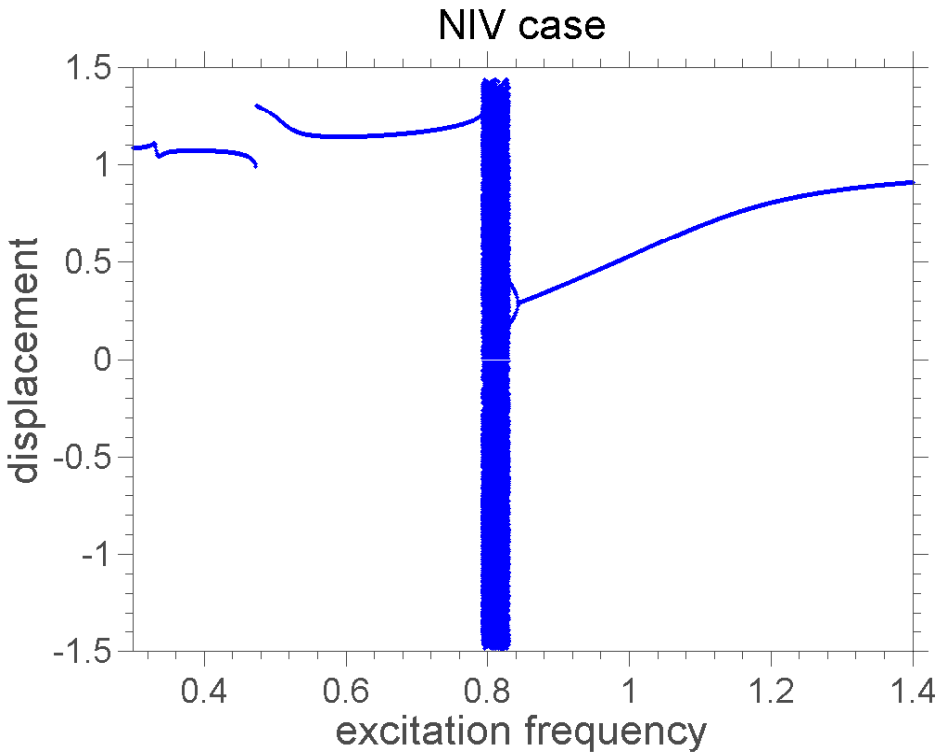


Figure: $(x_0, \dot{x}_0, \upsilon_0) = (1\ 0\ 1)$

Displacement vs excitation frequency ($f = 0.083$)

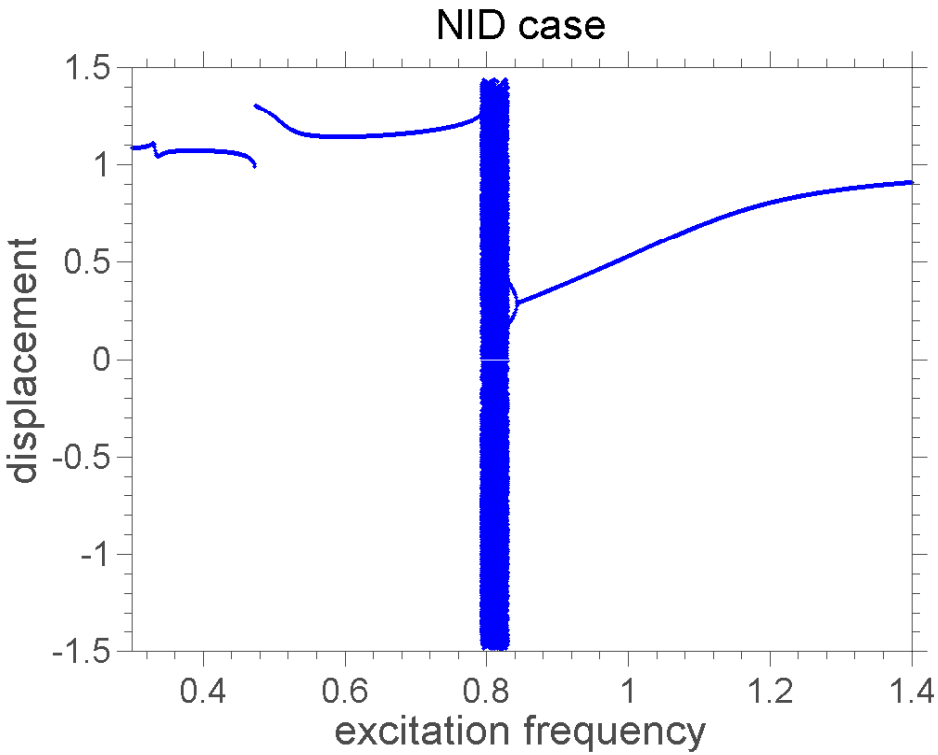
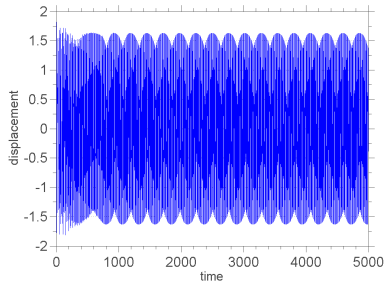
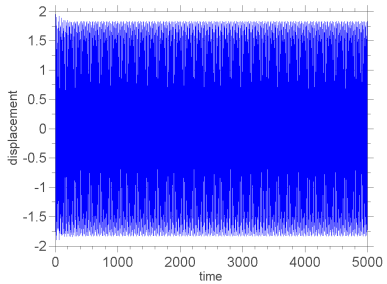


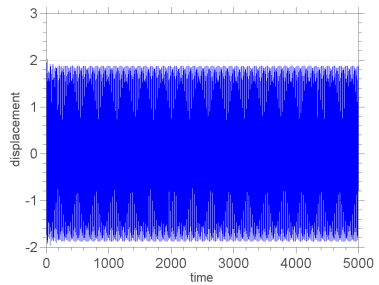
Figure: $(x_0, \dot{x}_0, v_0) = (0\ 1\ 1)$



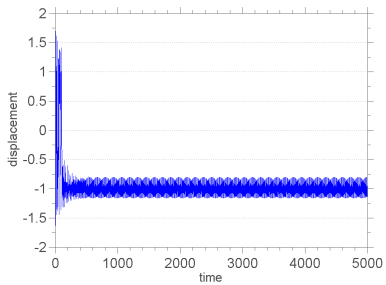
(a) $\Omega = 0.600$



(b) $\Omega = 0.800$

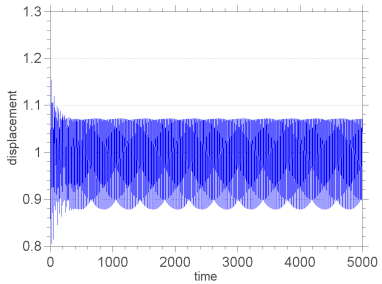


(c) $\Omega = 0.840$

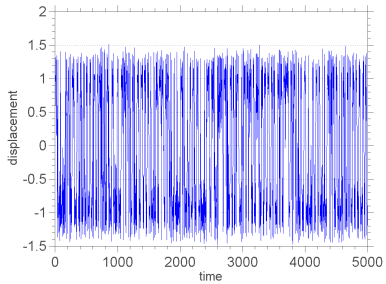


(d) $\Omega = 1.200$

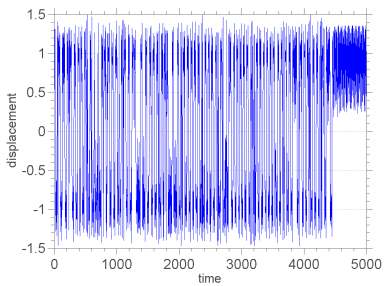
Displacement vs excitation frequency ($f = 0.083$)



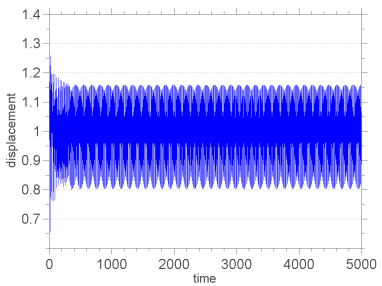
(e) $\Omega = 0.400$



(f) $\Omega = 0.800$



(g) $\Omega = 0.840$



(h) $\Omega = 1.200$

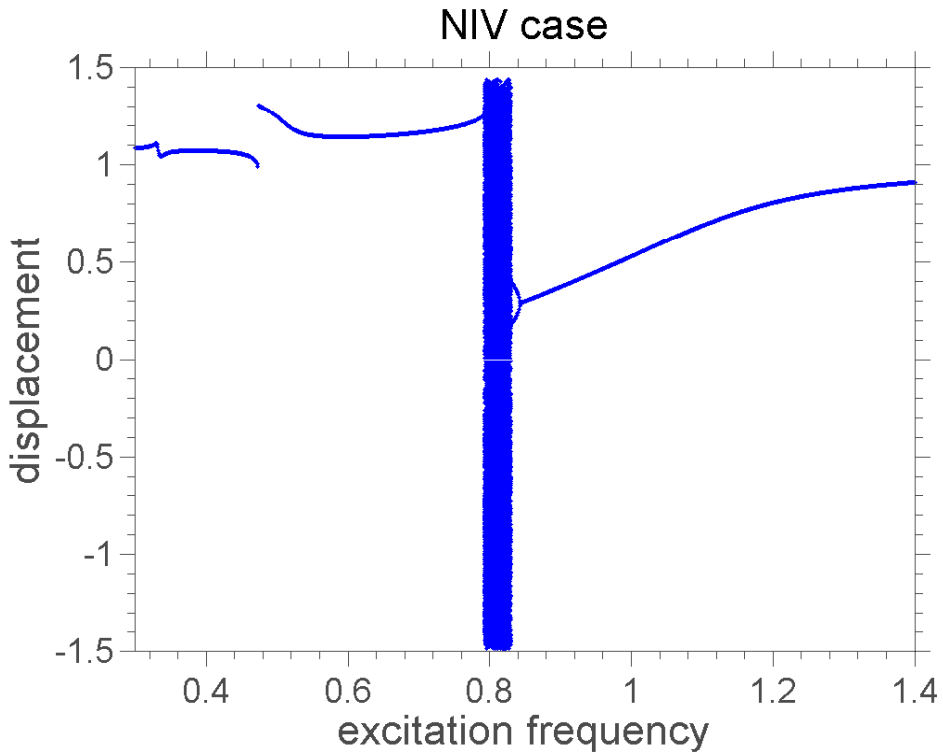


Figure: $(x_0, \dot{x}_0, v_0) = (1\ 0\ 1)$

Velocity vs excitation amplitude ($\Omega = 0.8$)

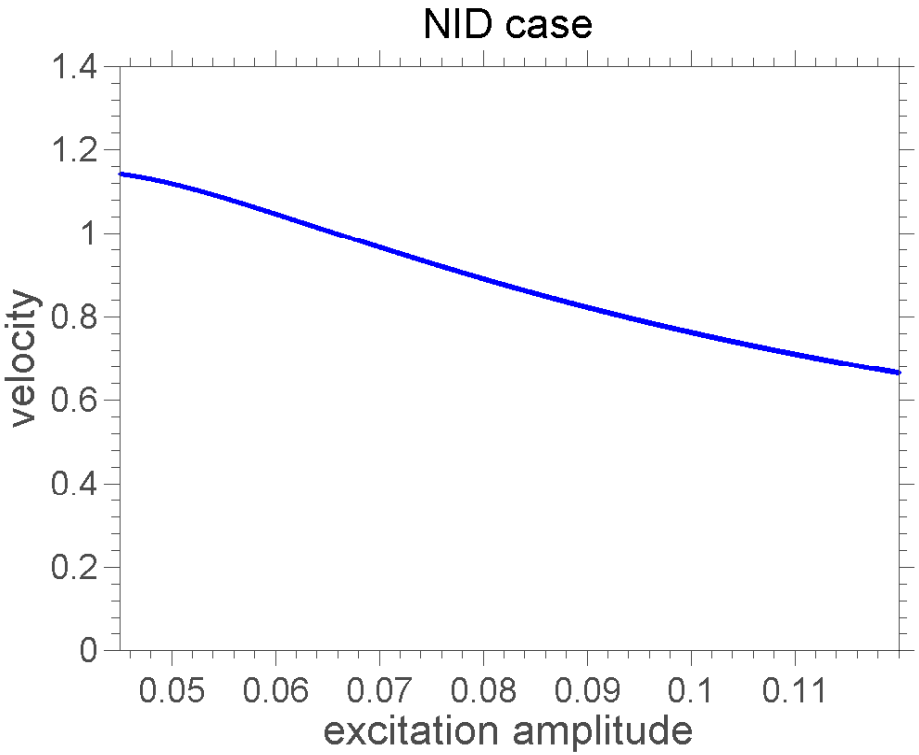


Figure: $(x_0, \dot{x}_0, \upsilon_0) = (0\ 1\ 1)$

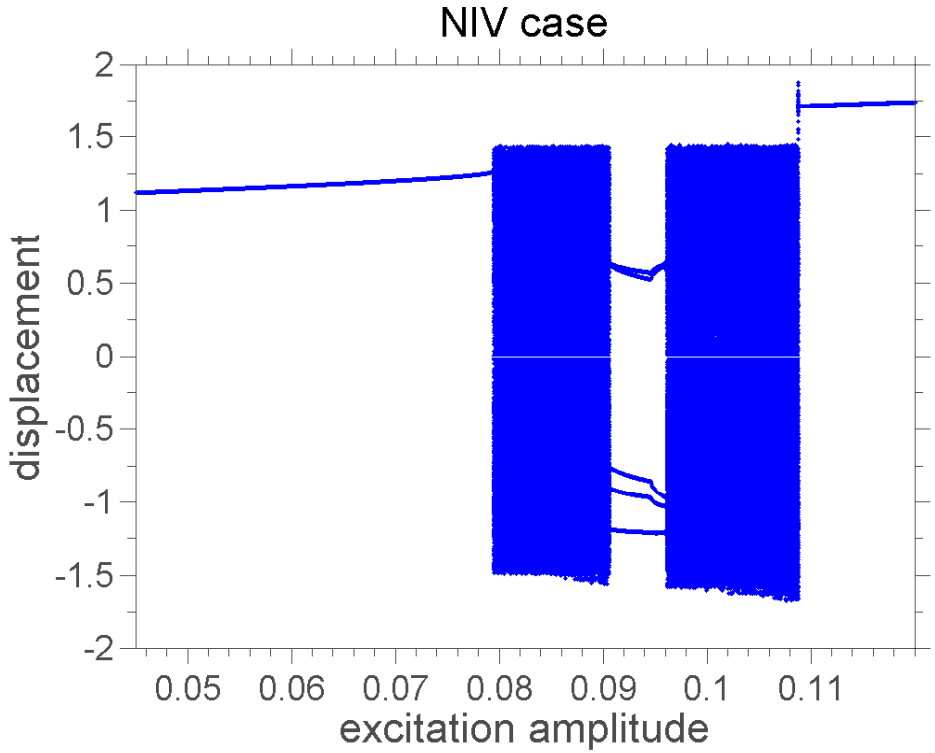


Figure: $(x_0, \dot{x}_0, \upsilon_0) = (1\ 0\ 1)$

Velocity vs excitation amplitude ($\Omega = 0.8$)

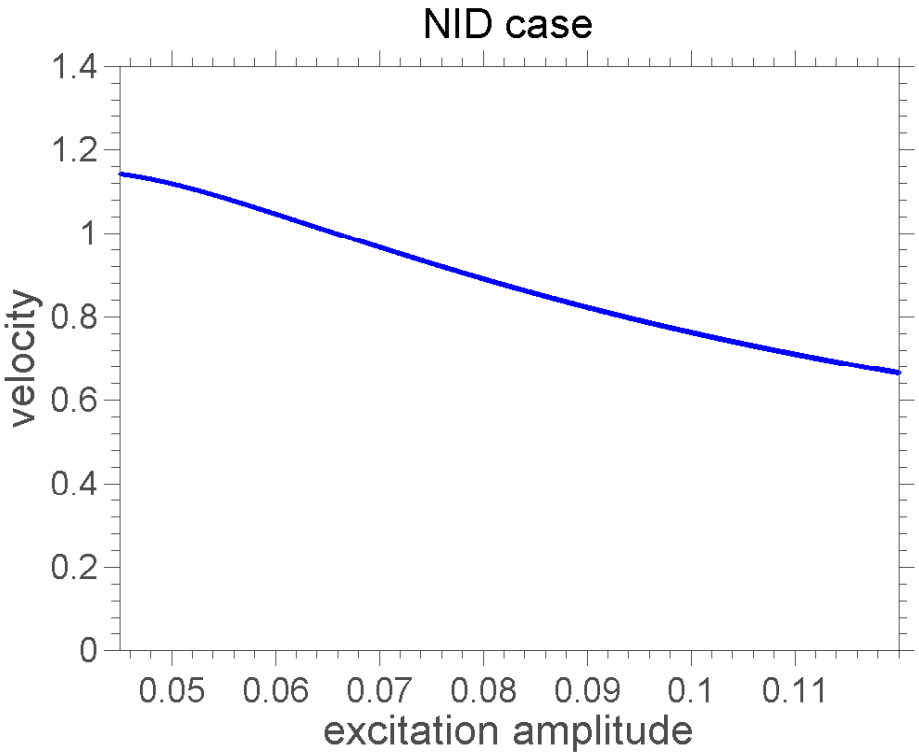
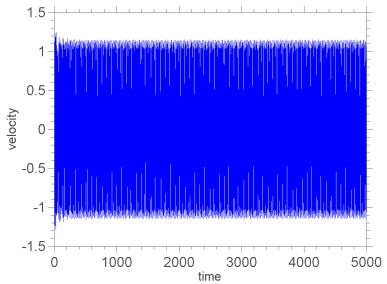
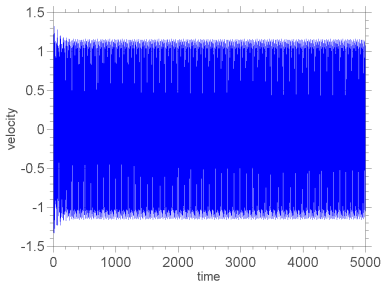


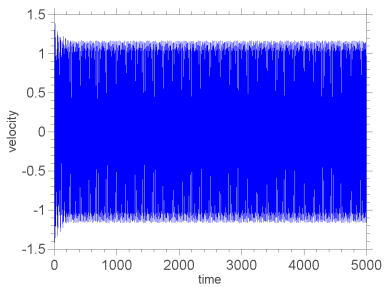
Figure: $(x_0, \dot{x}_0, \upsilon_0) = (0\ 1\ 1)$



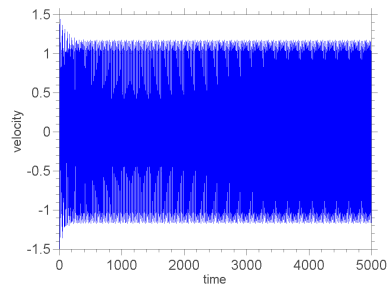
(a) $f = 0.05$



(b) $f = 0.07$

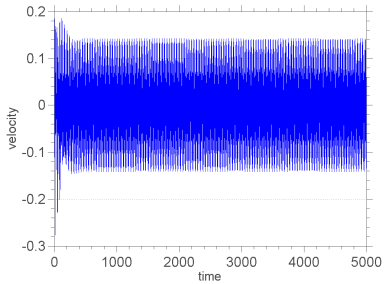


(c) $f = 0.09$

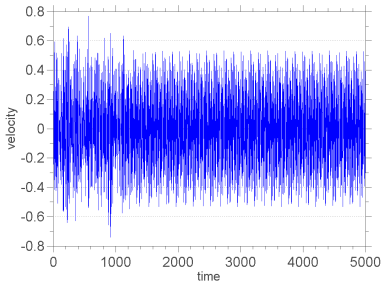


(d) $f = 0.11$

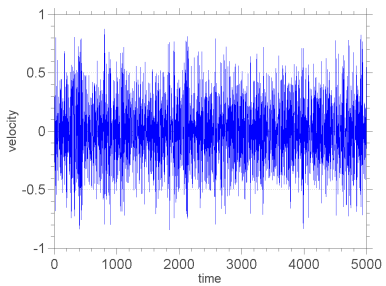
Velocity vs excitation amplitude ($\Omega = 0.8$)



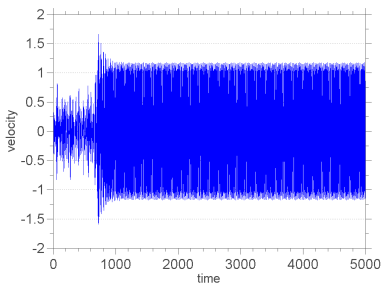
(e) $f = 0.060$



(f) $f = 0.092$



(g) $f = 0.100$



(h) $f = 0.116$

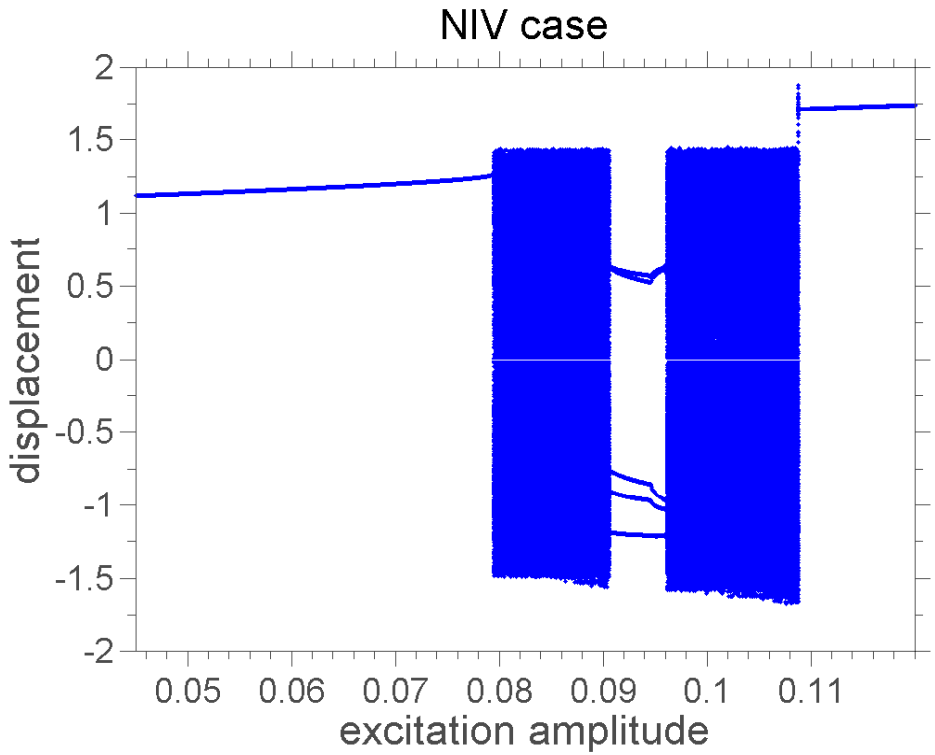


Figure: $(x_0, \dot{x}_0, v_0) = (1\ 0\ 1)$

Velocity vs excitation frequency ($f = 0.083$)

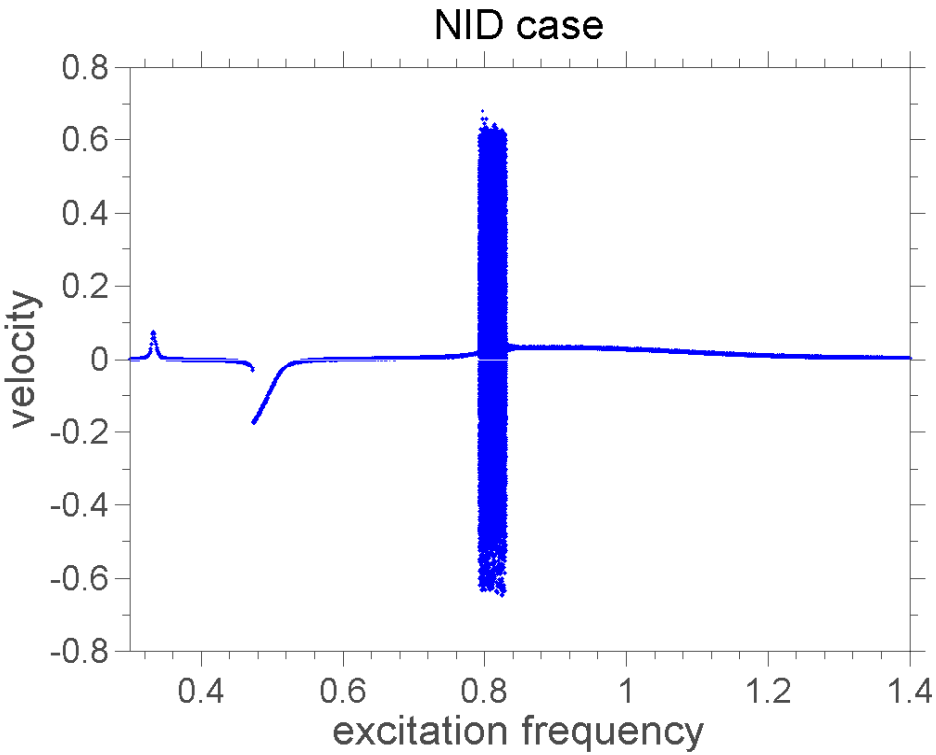


Figure: $(x_0, \dot{x}_0, \upsilon_0) = (0\ 1\ 1)$

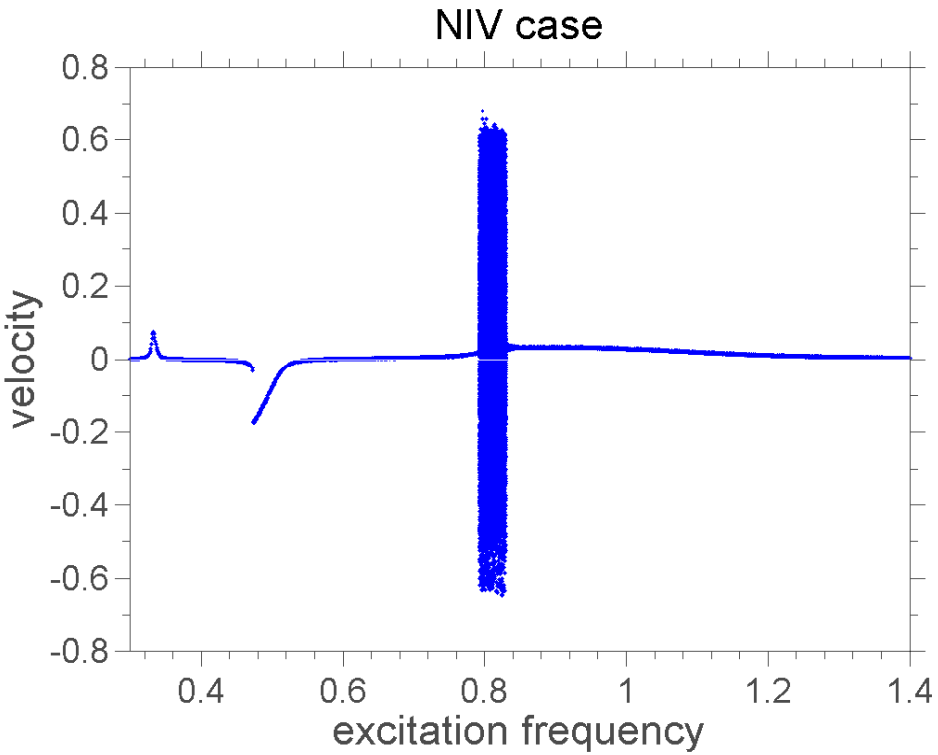


Figure: $(x_0, \dot{x}_0, \upsilon_0) = (1\ 0\ 1)$

Velocity vs excitation frequency ($f = 0.083$)

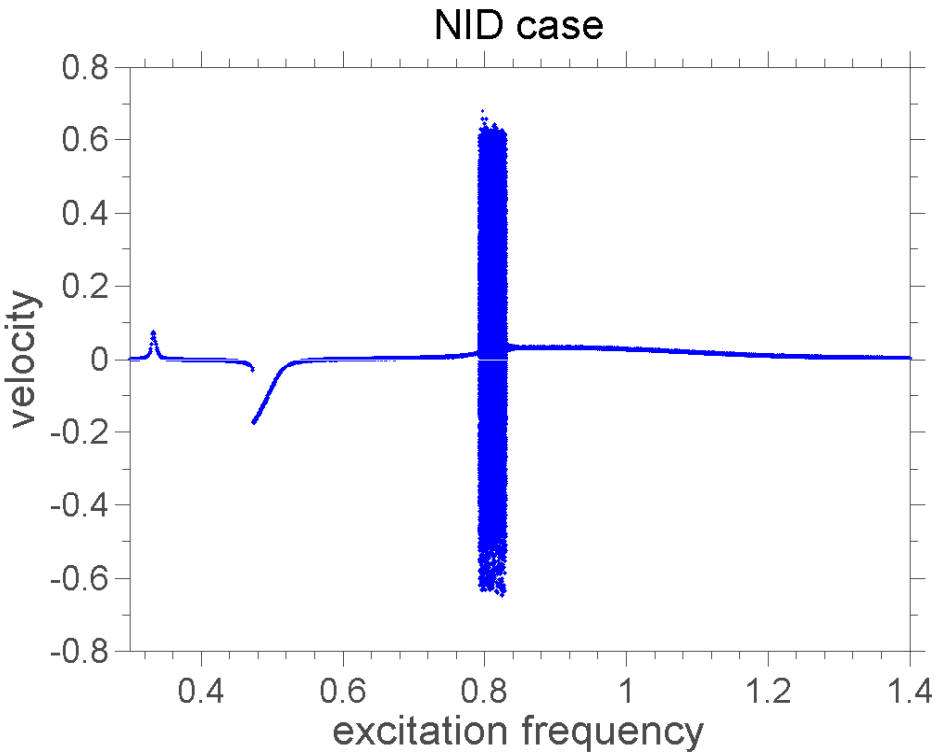
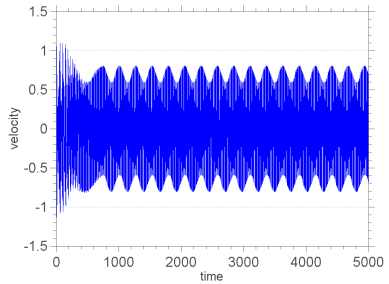
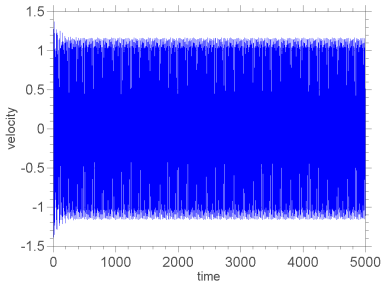


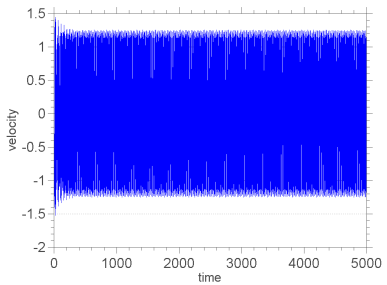
Figure: $(x_0, \dot{x}_0, v_0) = (0\ 1\ 1)$



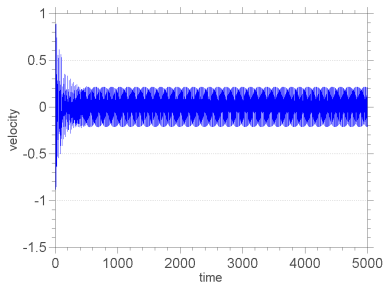
(a) $\Omega = 0.600$



(b) $\Omega = 0.800$

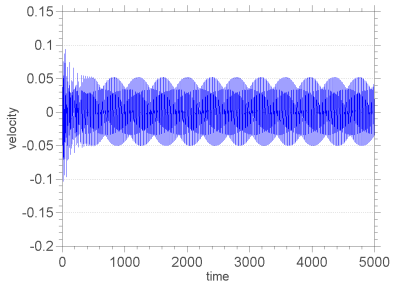


(c) $\Omega = 0.840$

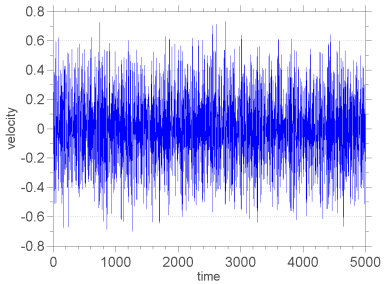


(d) $\Omega = 1.200$

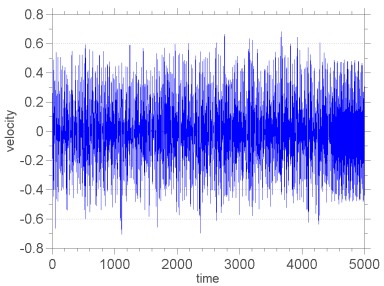
Velocity vs excitation frequency ($f = 0.083$)



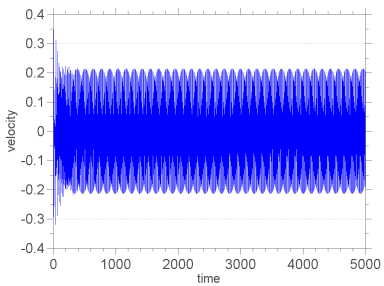
(e) $\Omega = 0.400$



(f) $\Omega = 0.800$



(g) $\Omega = 0.840$



(h) $\Omega = 1.200$

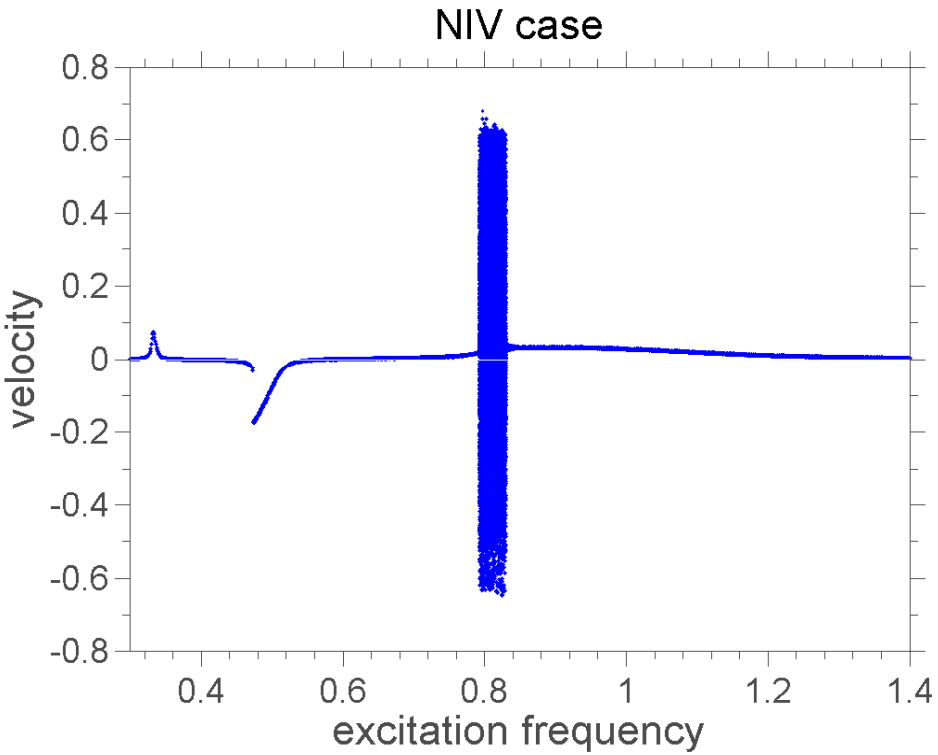


Figure: $(x_0, \dot{x}_0, v_0) = (1\ 0\ 1)$