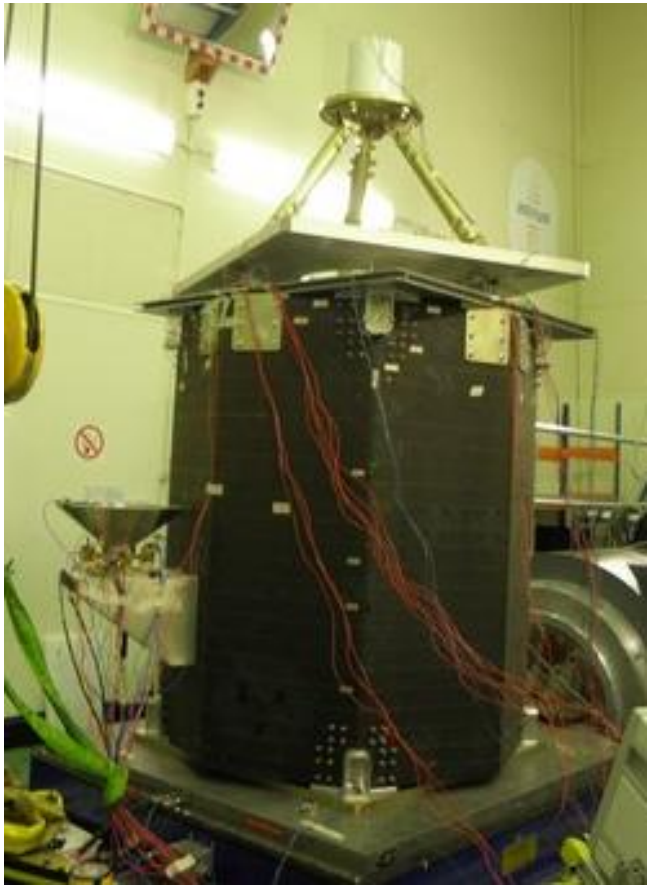
Nonlinear Modal Analysis of the SmallSat Spacecraft

Theory and Experiments



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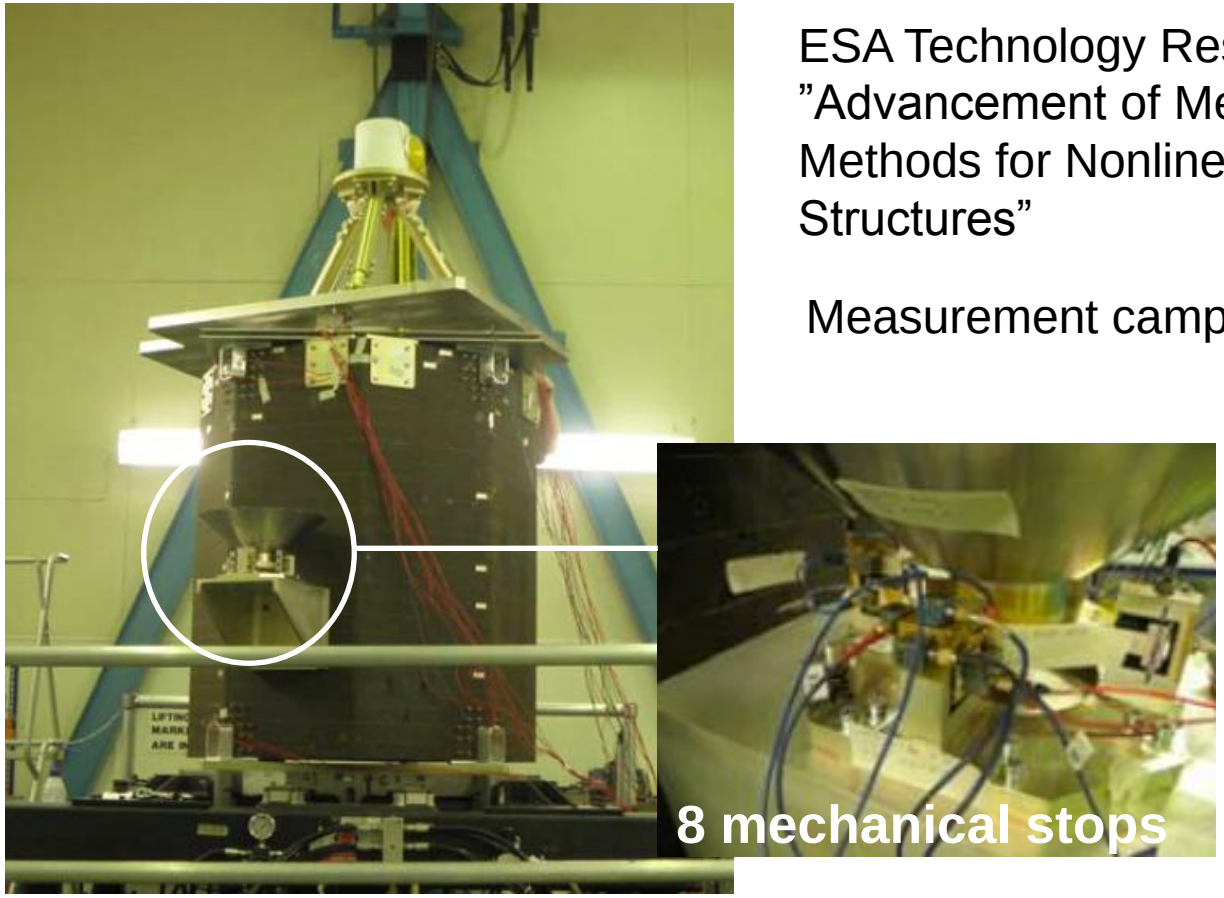
The SmallSat spacecraft



EADS-Astrium satellite

ESA Technology Research Programme ”Advancement of Mechanical Verification Methods for Nonlinear Spacecraft Structures”

Measurement campaign at EADS-Astrium.

The nonlinear WEMS device: filtering and protection

Goals	Solutions
Micro-vibration mitigation	Elastomer plots
Large amplitude limitation	Mechanical stops

Motivations are twofold

Experimental

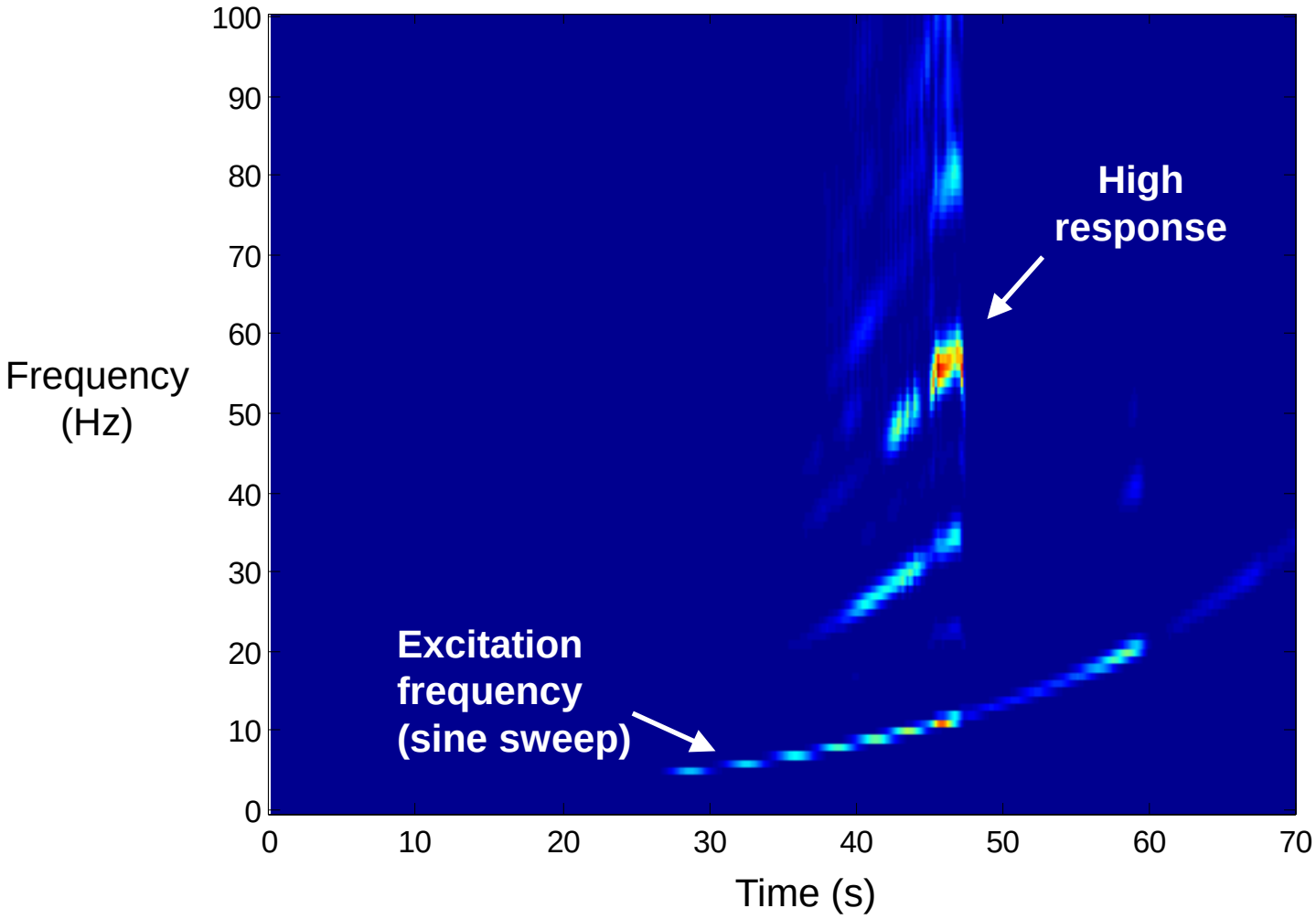
Accurately identify the underlying linear system and the parameters defining the nonlinearities

Theoretical

Numerically reproduce nonlinear phenomena experimentally observed

1. Nonlinearity detection: a rich frequency content …

Energy transfer to higher frequencies !

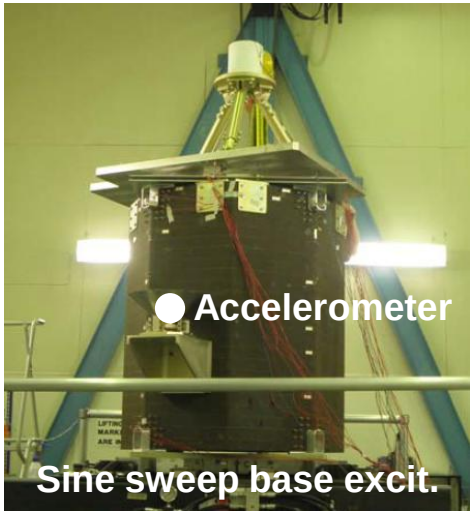


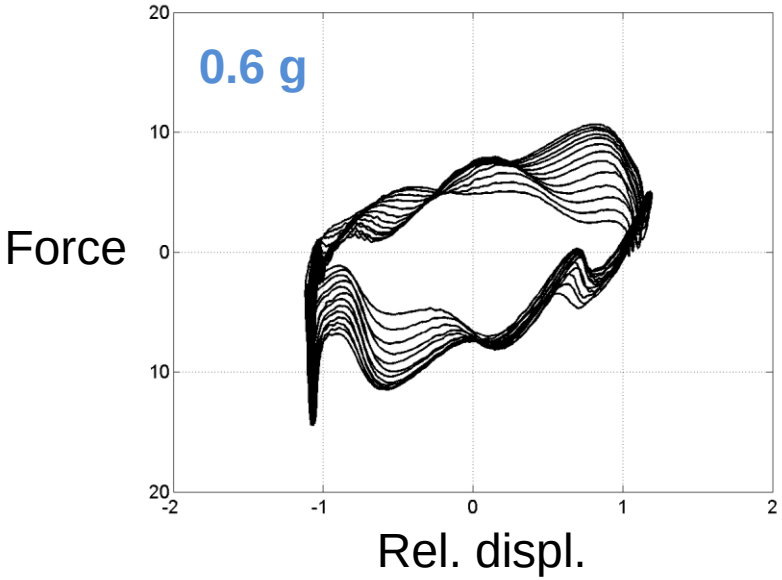
2. Nonlinearity characterization: RFS method

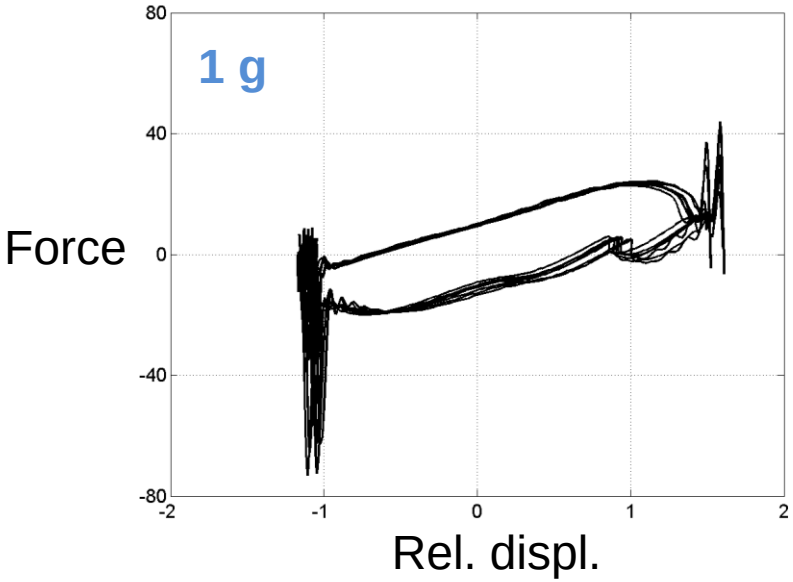
Restoring forces can be conveniently visualized (Masri and Caughey, 1979)

For this application, qualitative information only: $f_{nl}(x, \dot{x}) = f(t) - m\ddot{x}$

$\sim -\ddot{x}$

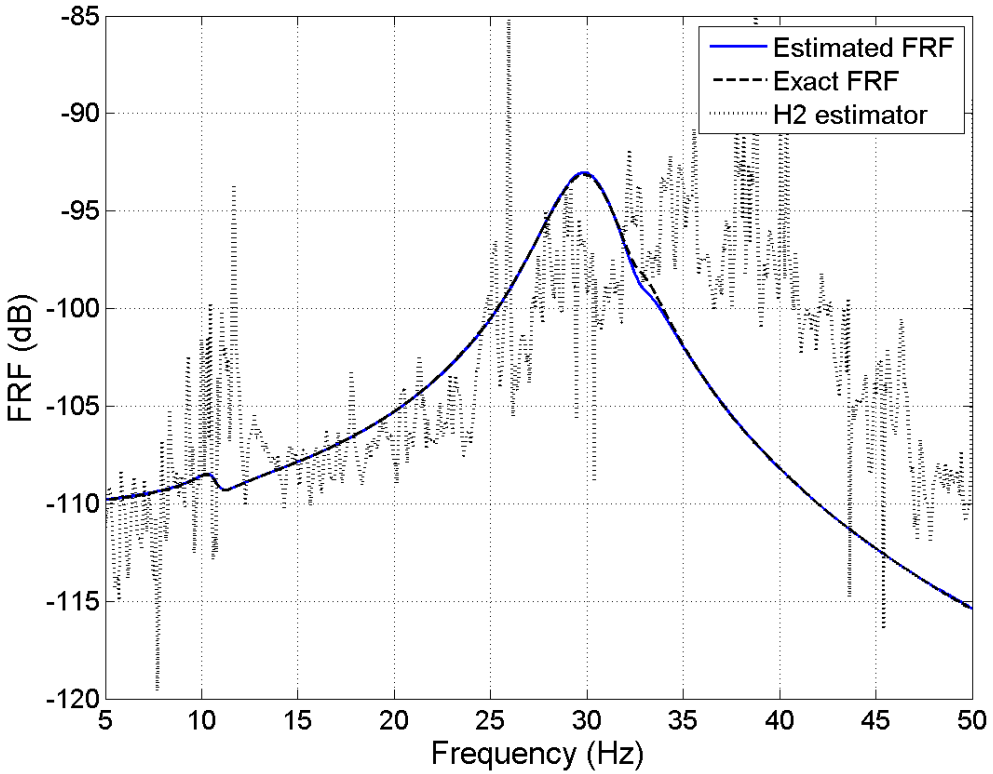






3. Nonlinear parameter estimation: FNSI method

Rigorous nonlinear generalization of subspace identification methods to nonlinear systems (developed at ULg)



Underlying linear system

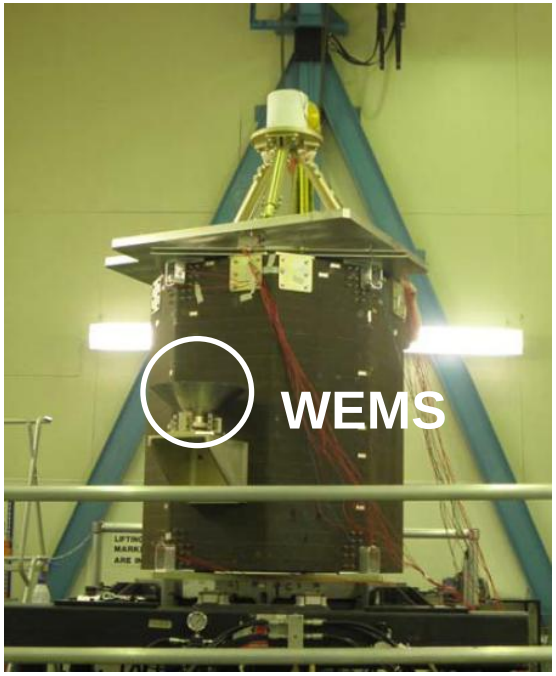
NL	Error
1-x	0.78 %
2-x	0.66 %
3-y	0.67 %
4-y	1.44 %
1-z	0.01 %
2-z	2.53 %
3-z	0.98 %
4-z	1.01 %

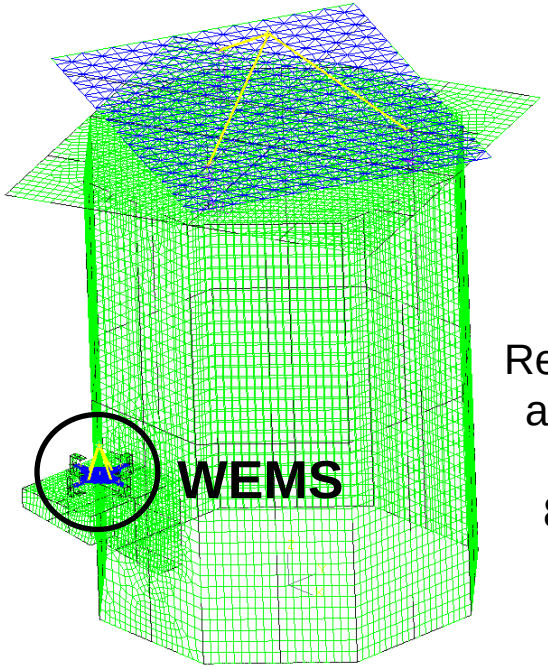
Nonlinear coefficients

Outcomes of the experimental campaign

Complex nonlinear dynamics observed on a real-world spacecraft structure and also accurately identified.

Information gathered is used to build a computational model and for further analysis of the observed dynamics.



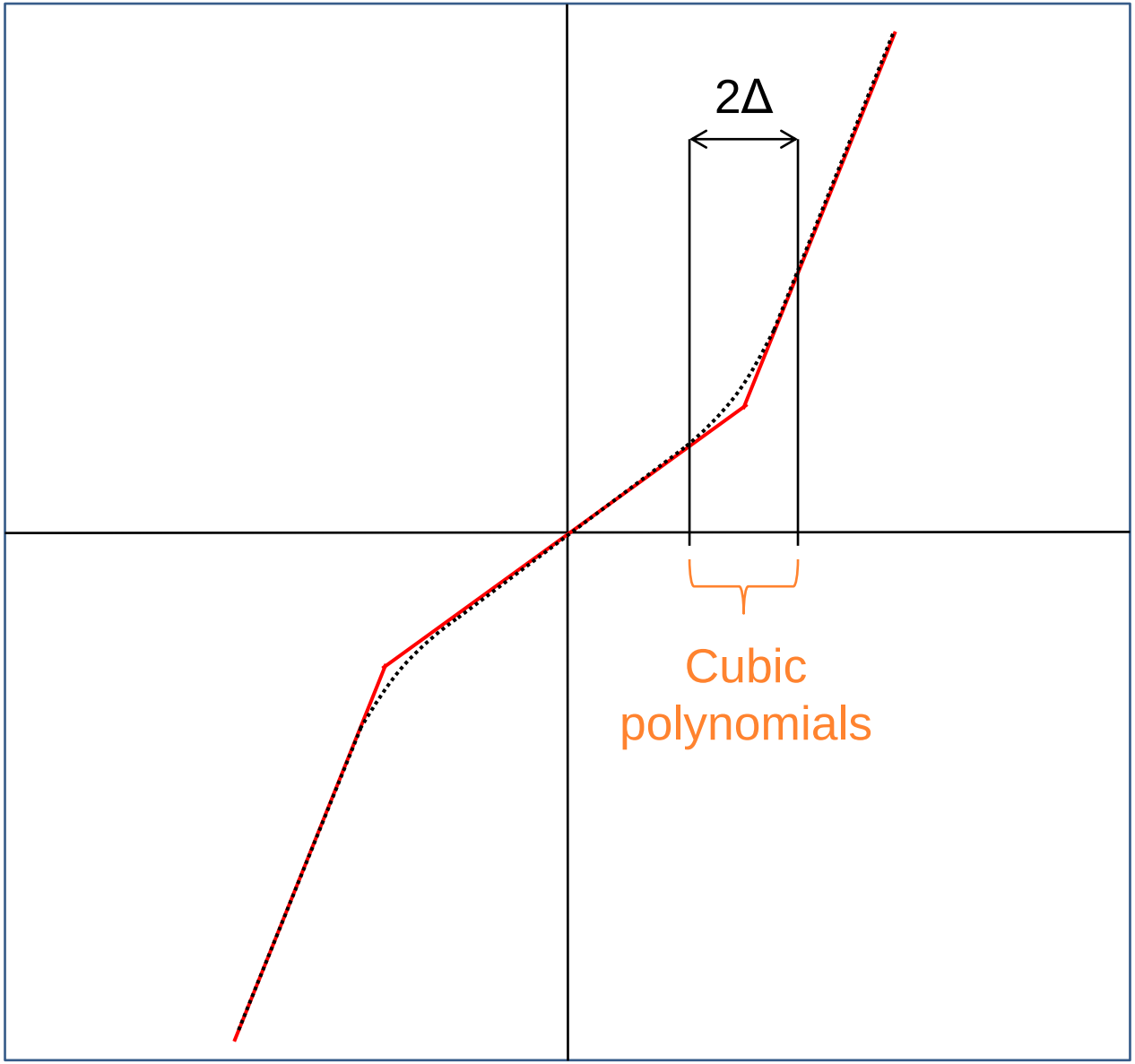


Initial model: 65000 DOFs

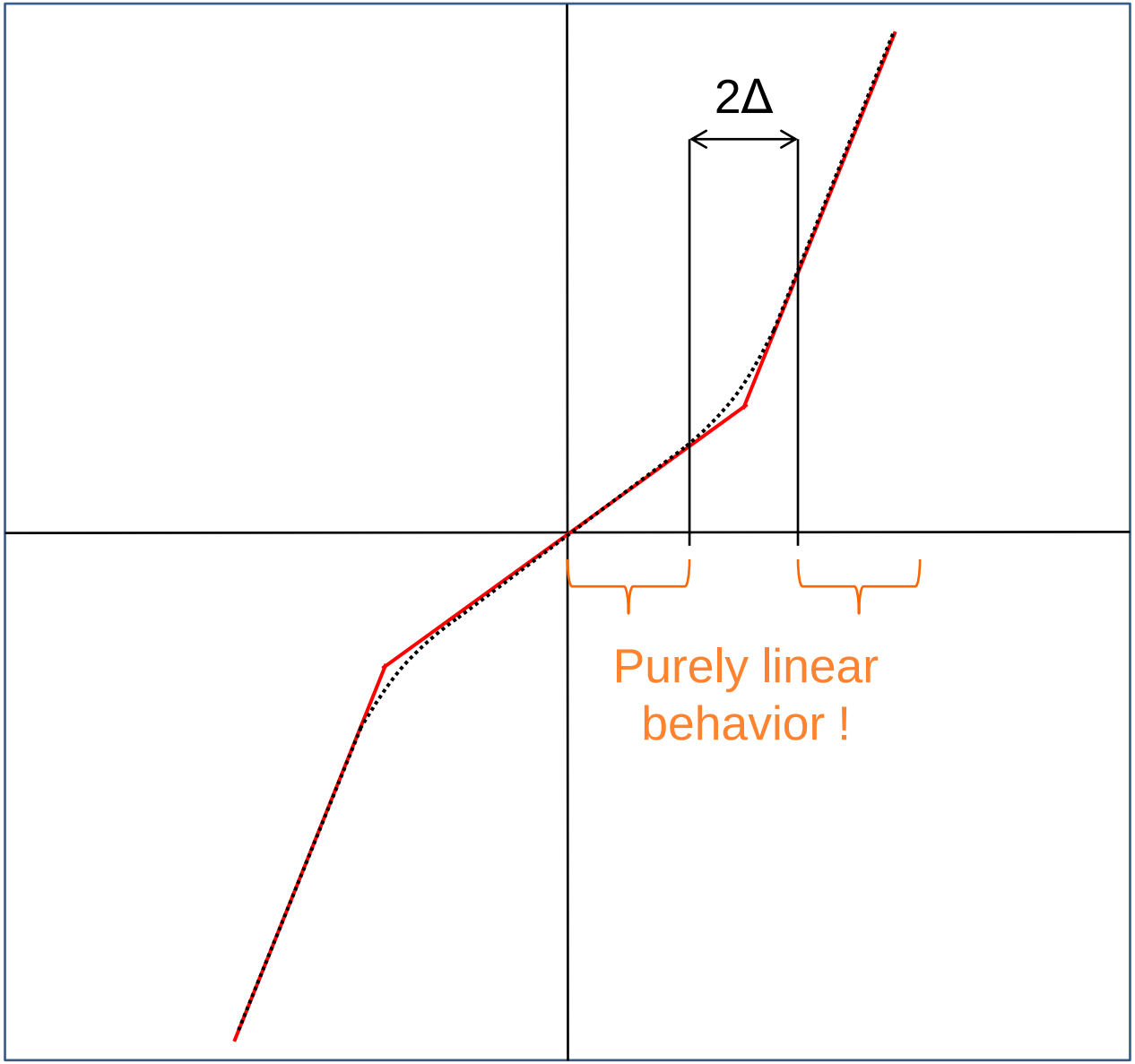
Reduced model: 34 DOFs and accurate between [0-100Hz]

8 nonsmooth (regularized) nonlinearities

Regularization using Hermite polynomials



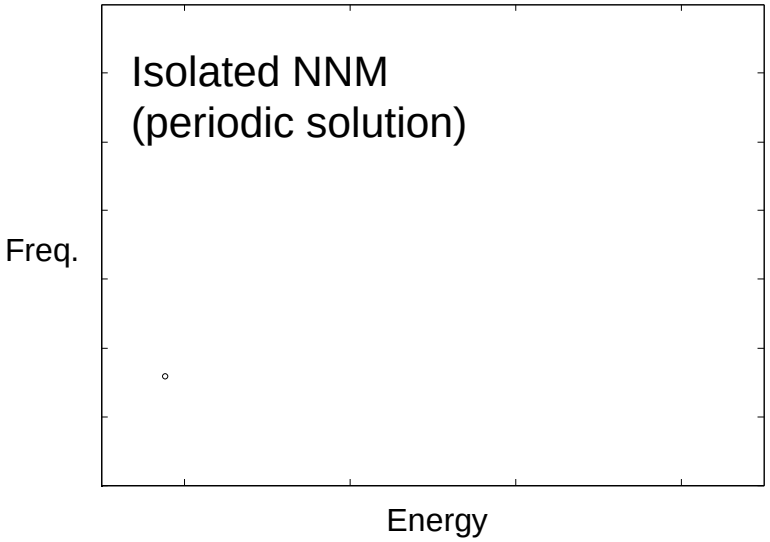
Regularization using Hermite polynomials



Two-step architecture of computational methods

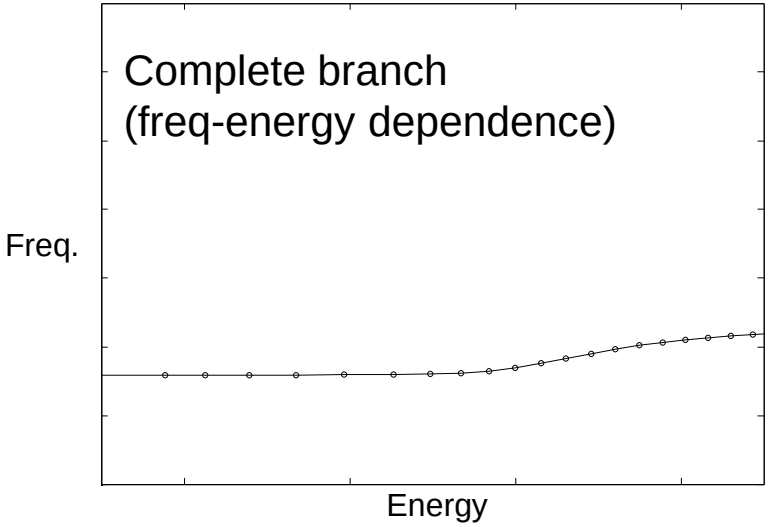
STEP 1:

- Shooting algorithm
- Finite differences
- Harmonic balance

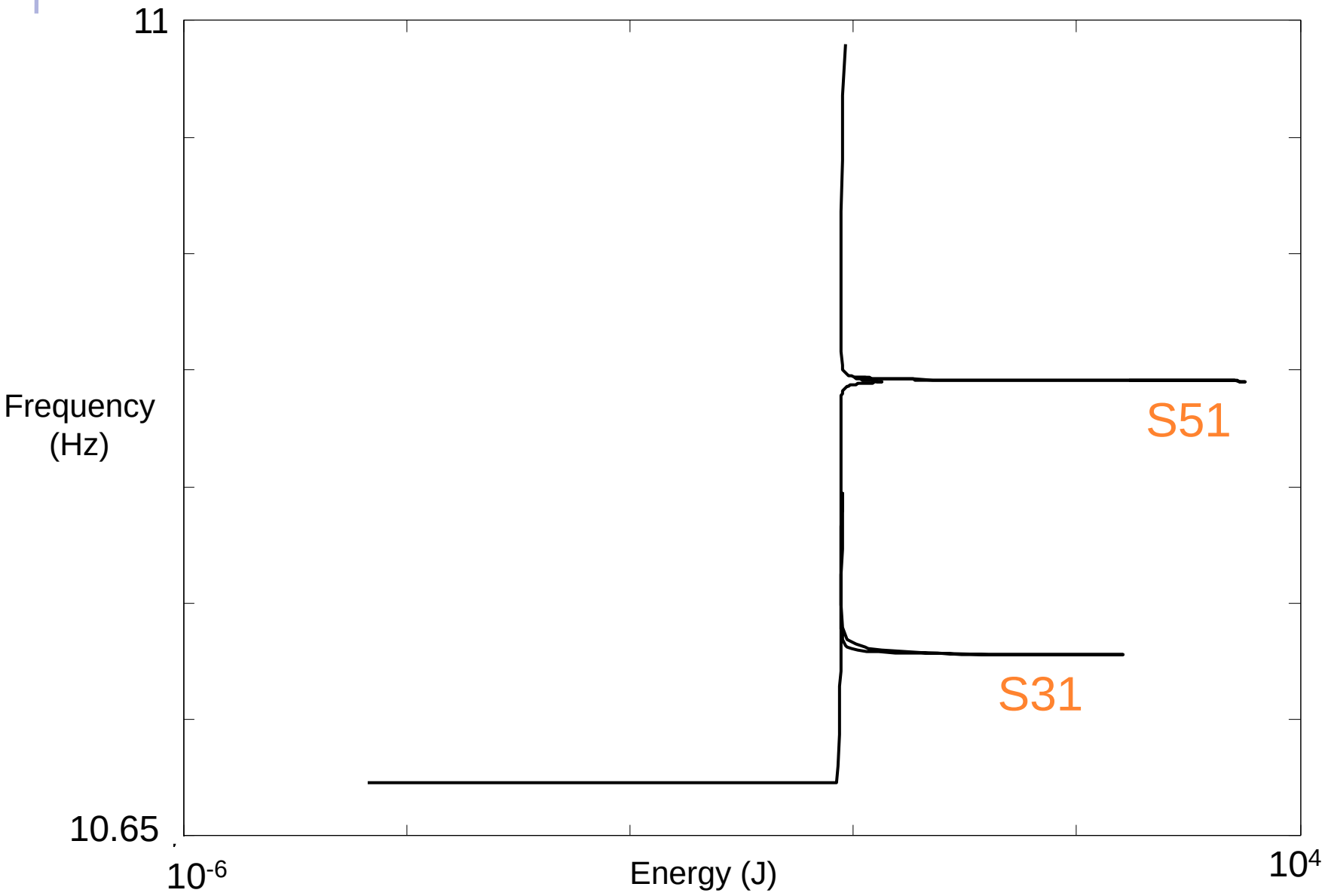


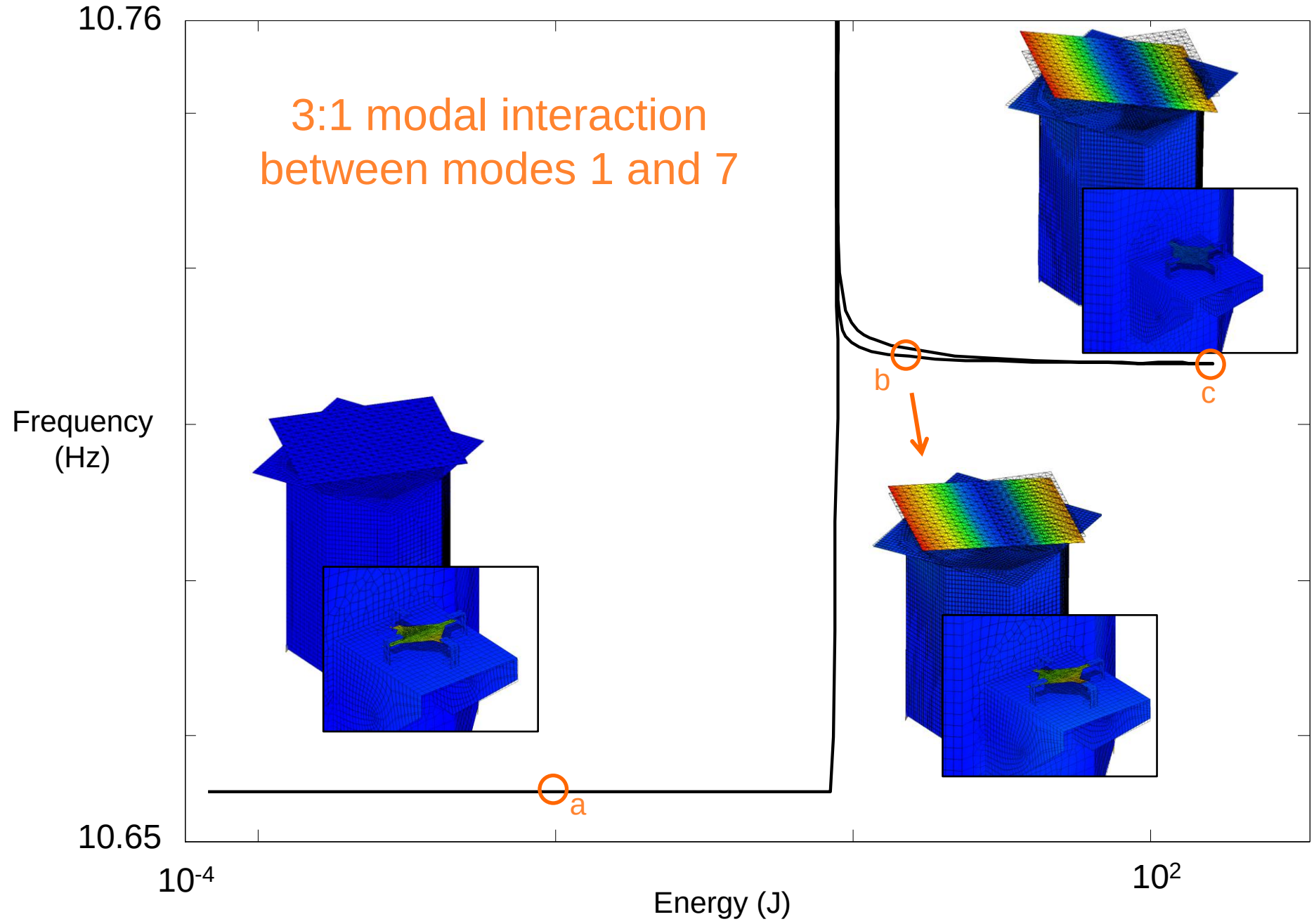
STEP 2:

- Pseudo-arclength continuation
- Asymptotic-numerical continuation

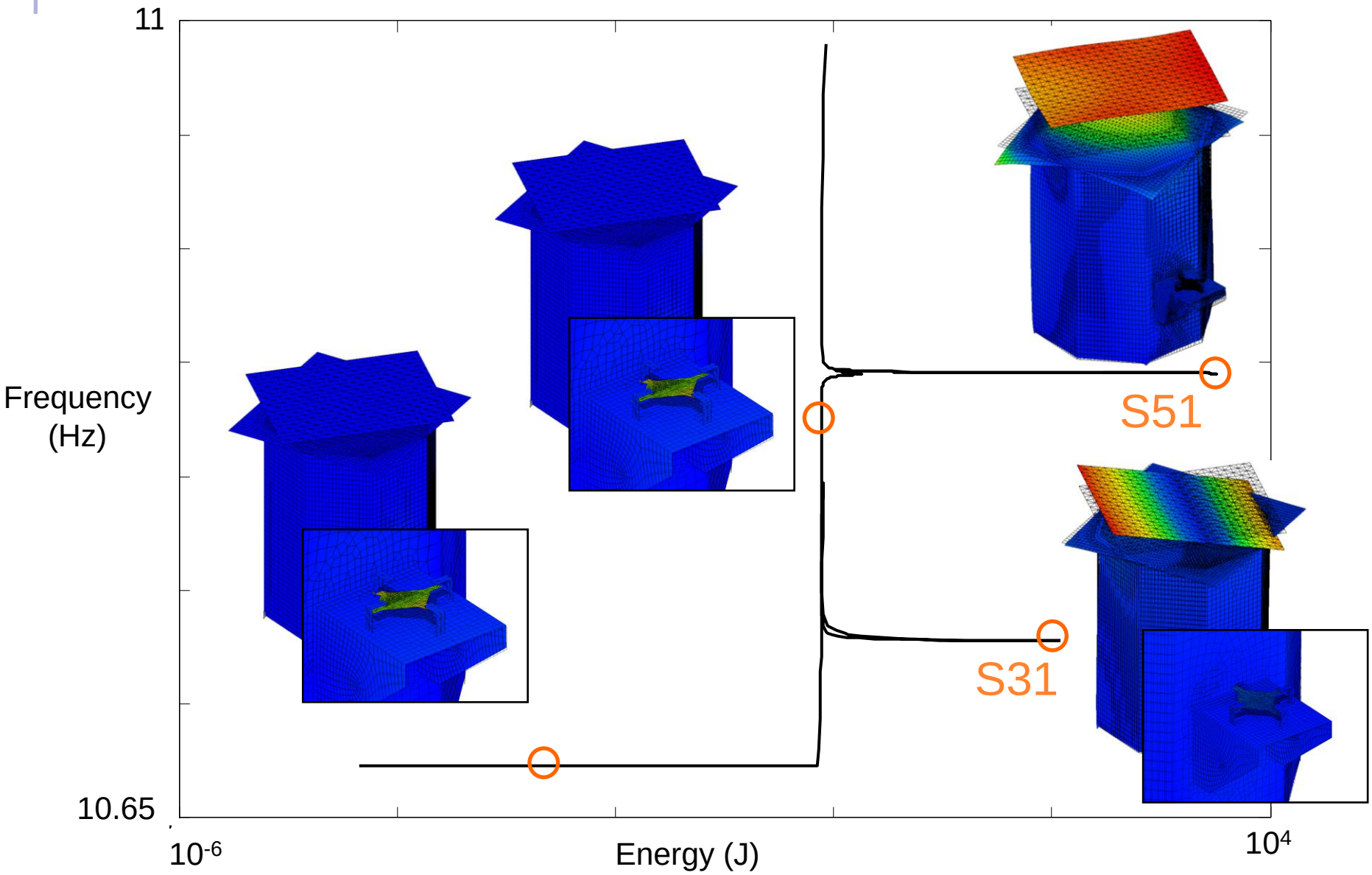


The first mode is nonlinear (WEMS local mode)

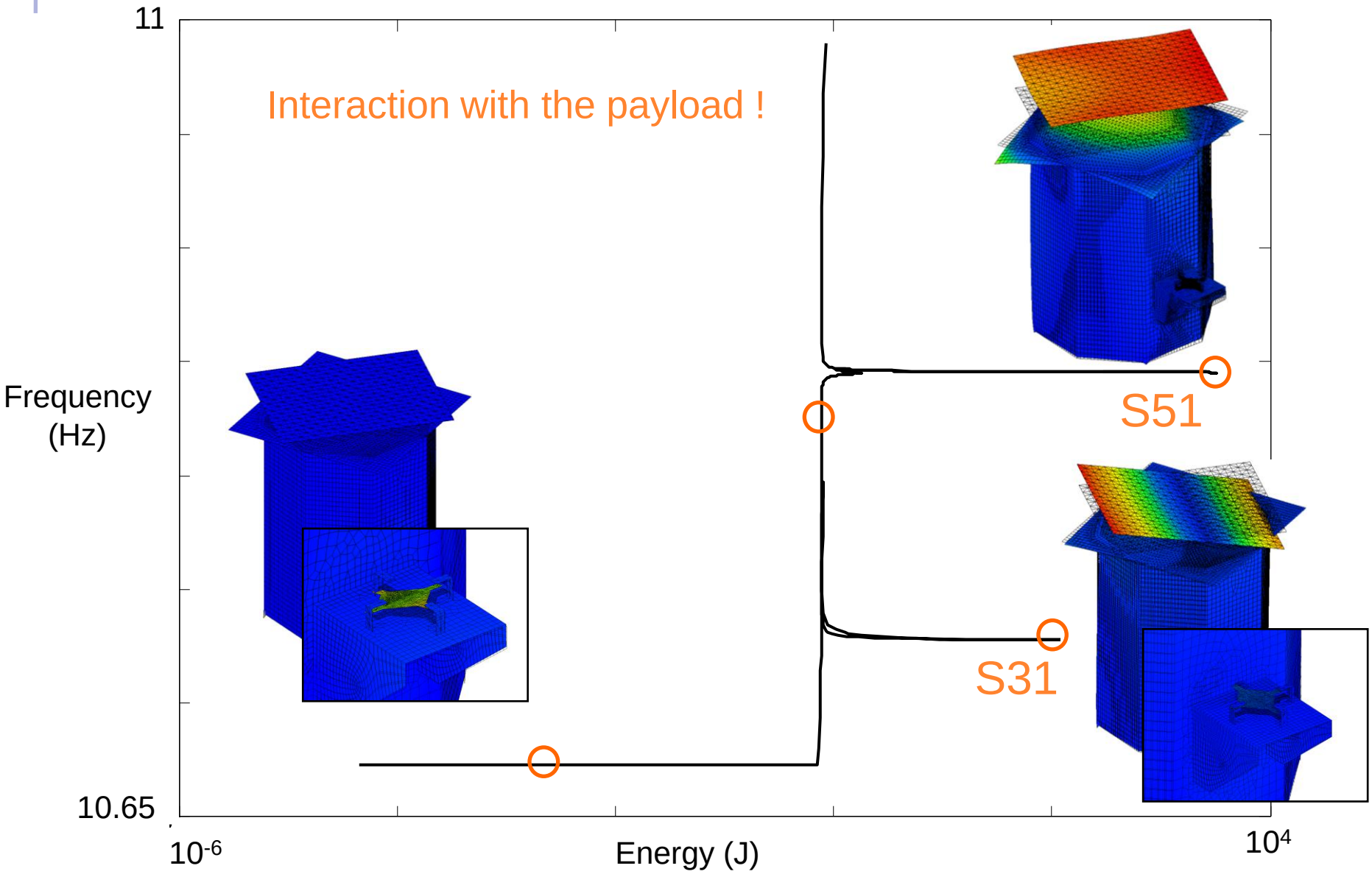



10.76
3:1 modal interaction
between modes 1 and 7
Frequency
(Hz)
10.65
10-4
10²
Energy (J)
a
b
c

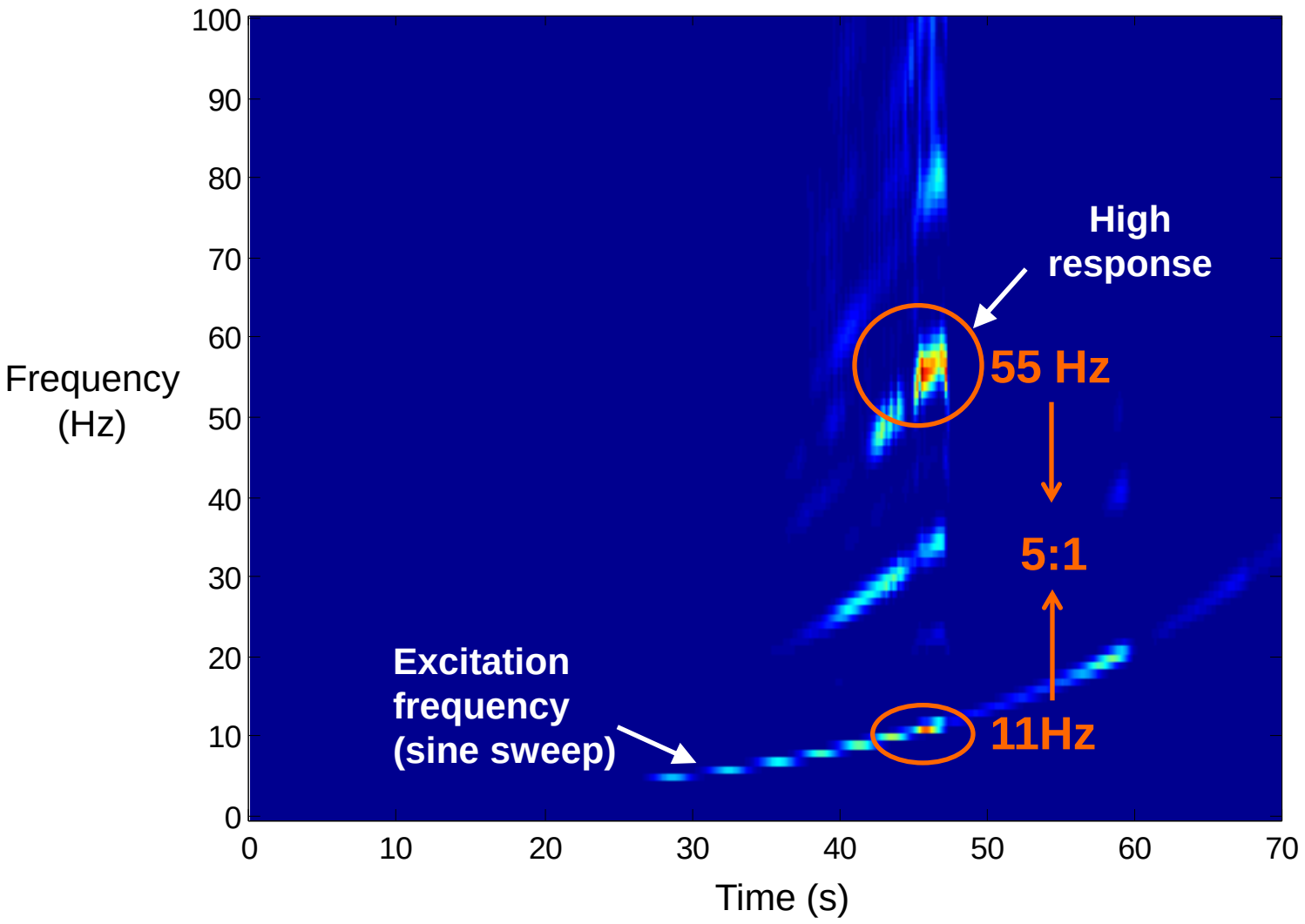
5:1 modal interaction between modes 1 and 12



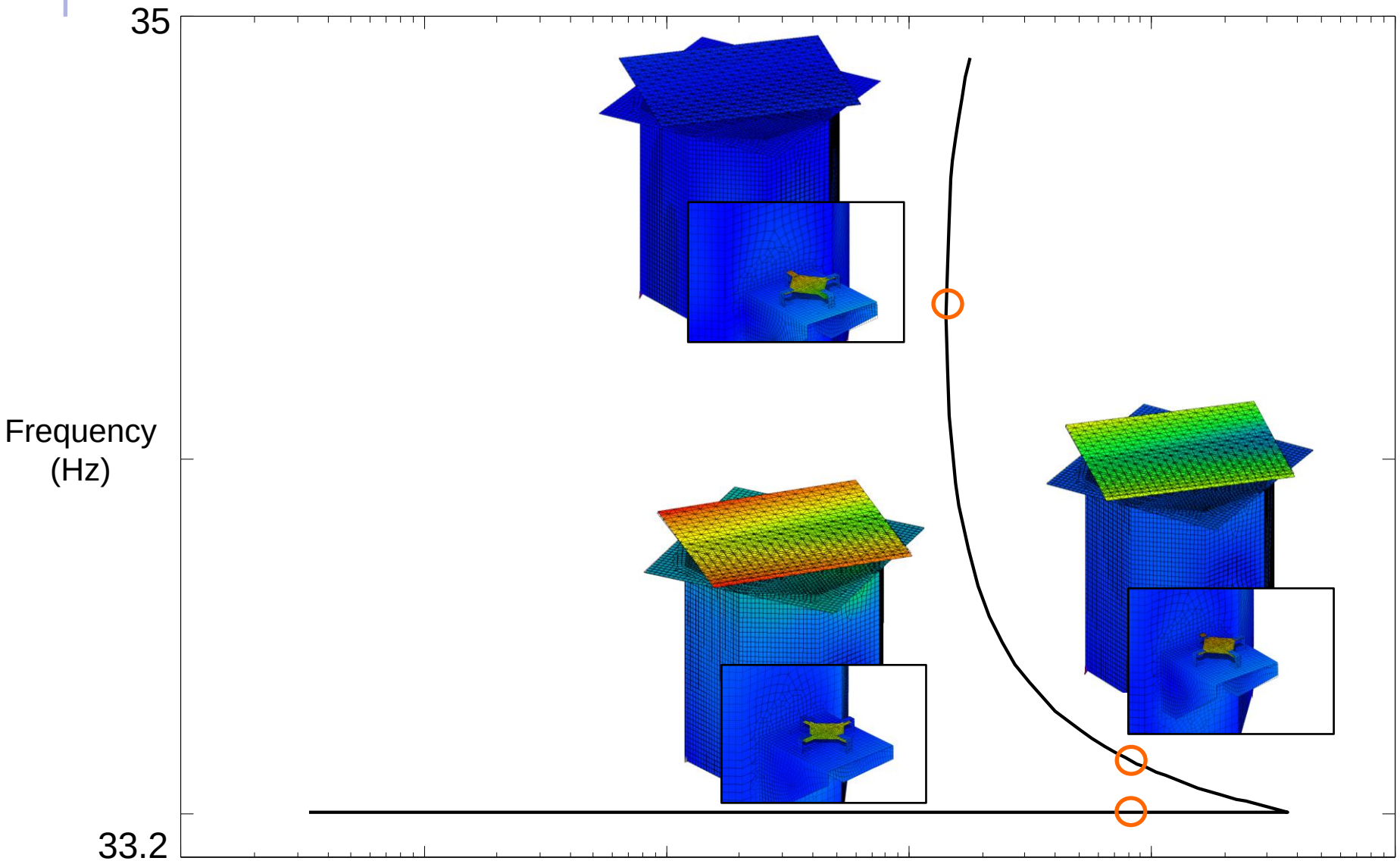
5:1 modal interaction between modes 1 and 12



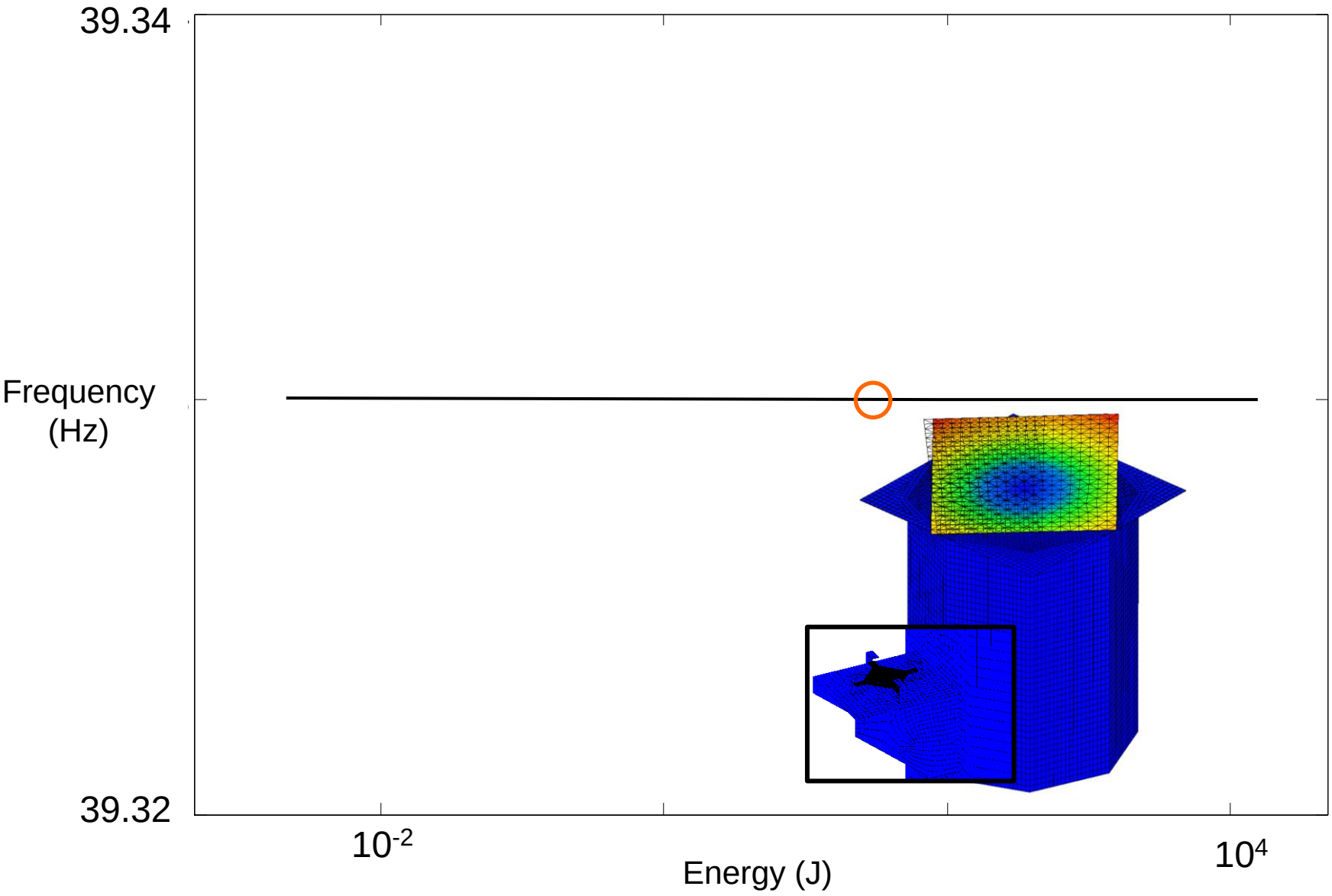
Correspondence with the measurements !



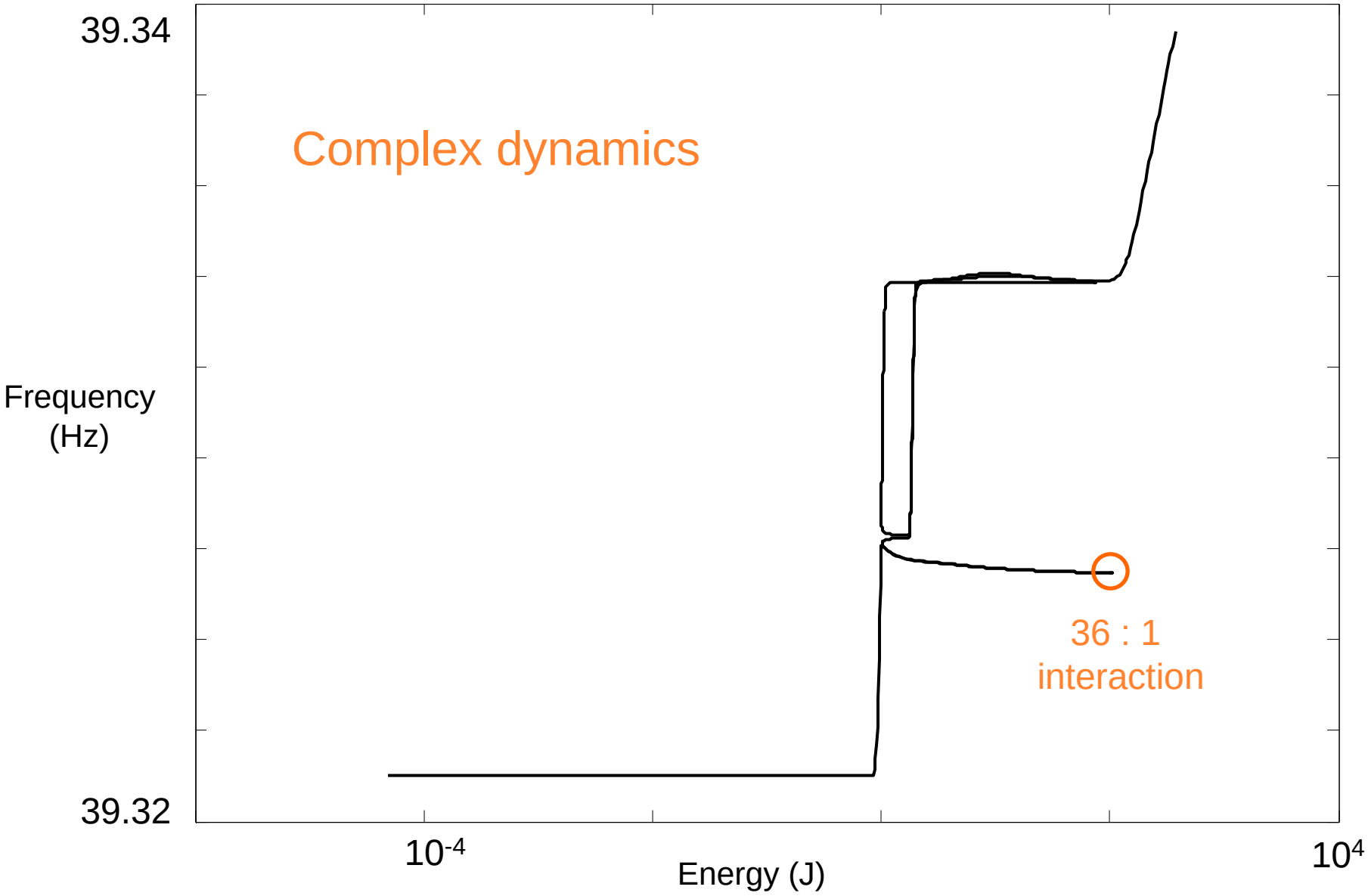
Motion localized at the WEMS



Mode 9 remains linear



Third mode is nonlinear (again WEMS local mode)

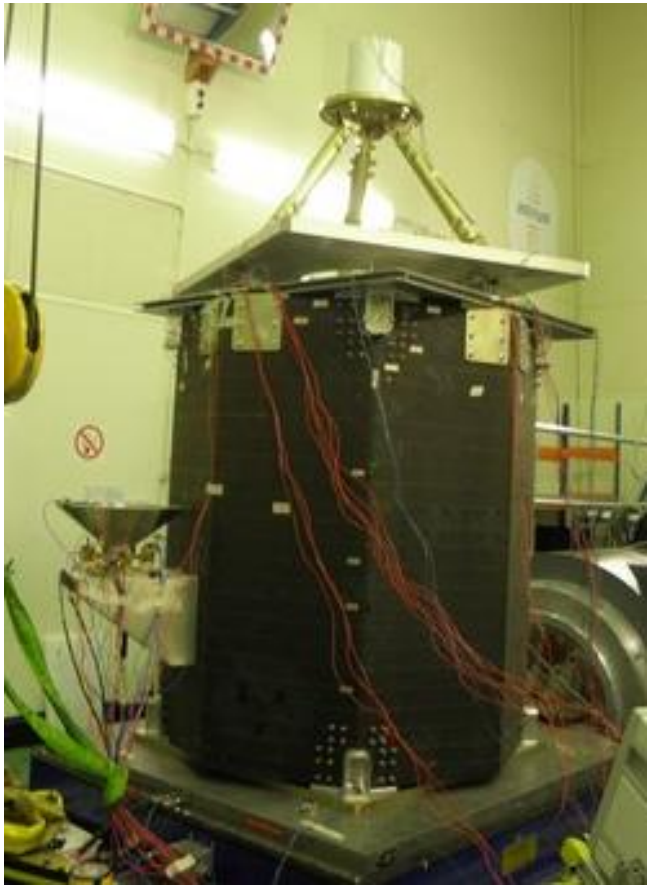


Conclusion

A real-life structure with strong, multiple piecewise-linear nonlinearities showed a complex behavior

Observed phenomena are explained by Nonlinear Normal Modes !

Thank you for your attention.



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