Physics-based vs. Data-driven Modeling

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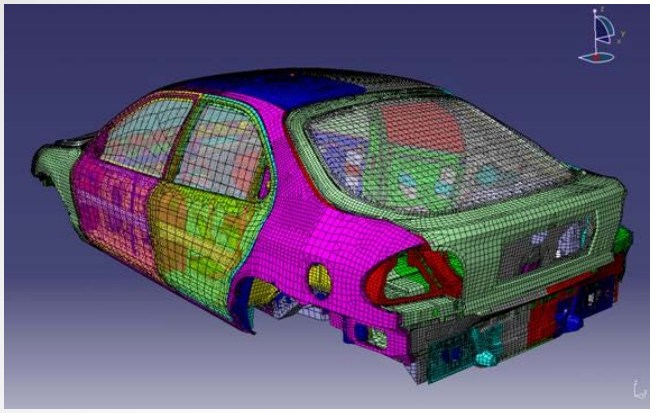
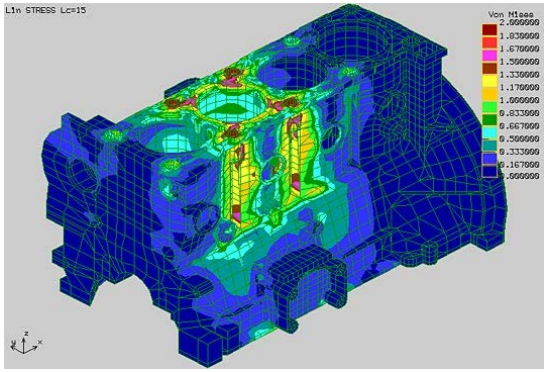
WISC-TNDL

Need for a Reduced-order Model

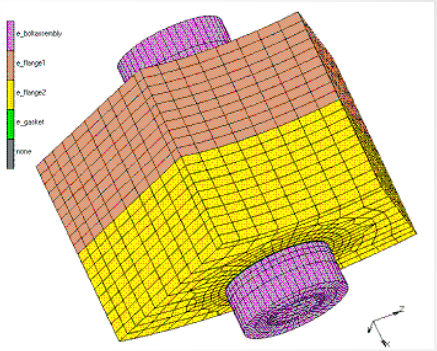
10^0 *m*, 10^1 *s*, 10^6 *DOFs*



10^{-1} *m*, 10^{-3} *s*, 10^6 *DOFs*



10^{-5} *m*, 10^{-5} *s*, 10^4 *DOFs*



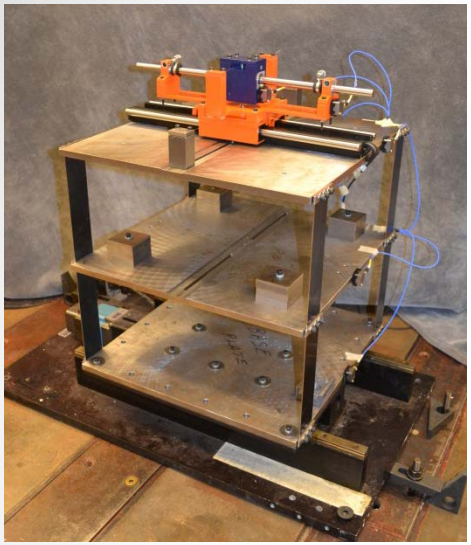
Multiple Length Scales

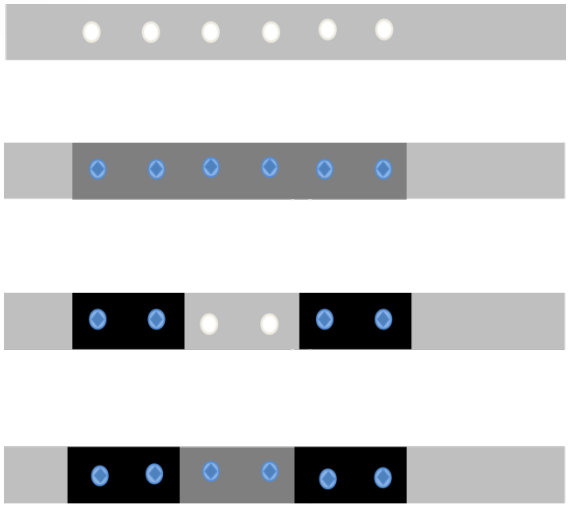
Multiple Time Scales

Numerous Coupled DOFs

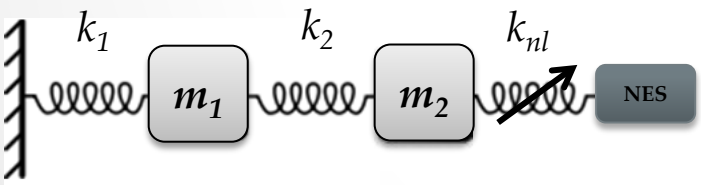
Reduced-order contact models are needed to bridge multi-temporal/length scales in modeling large-scale structural dynamics.

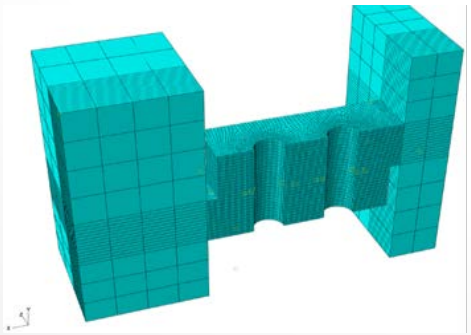
Multiscale Testing and Modeling: Two Approaches

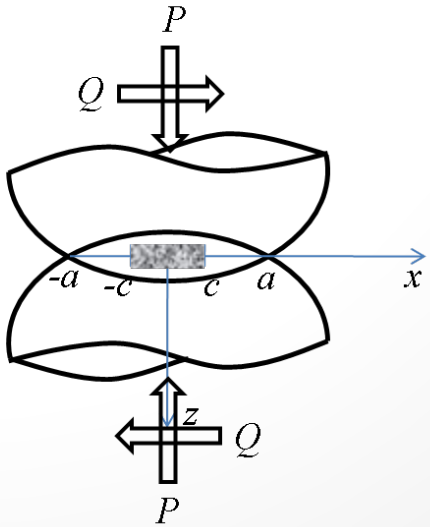


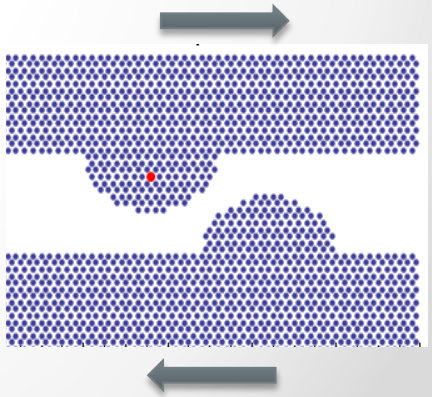


10^{2} 1 m 10^{-2} 10^{-4} 10^{-6}



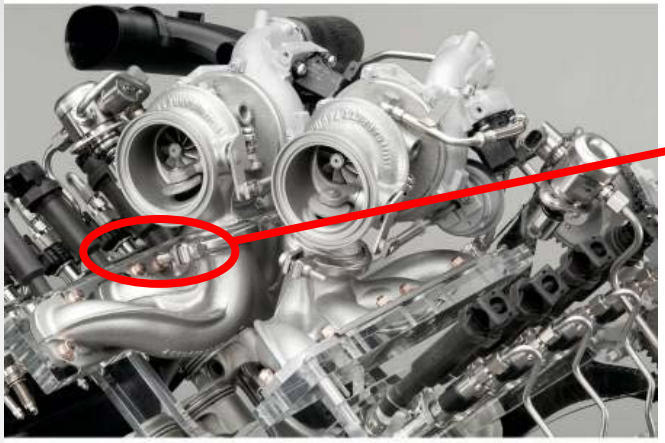


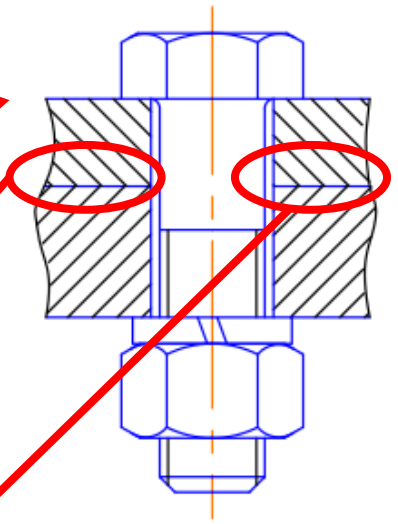


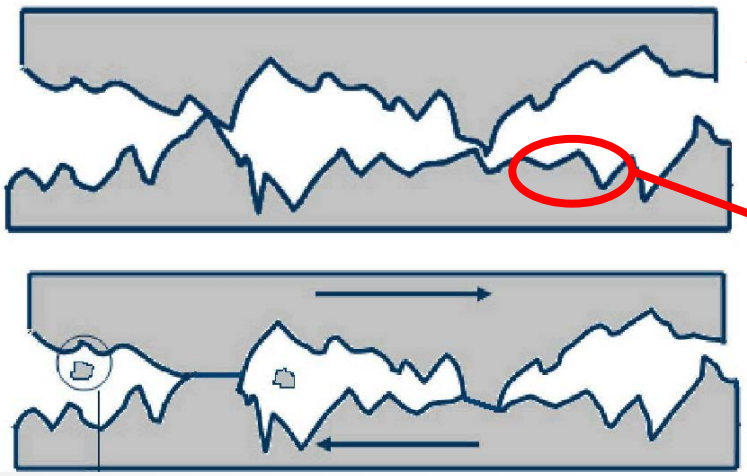


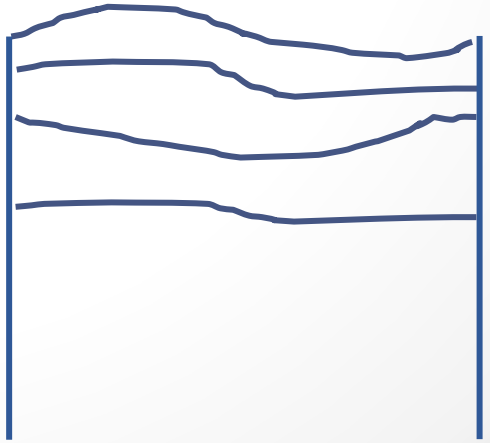
Bottom-Up Approach: Interface Mechanics

Internal combustion engine



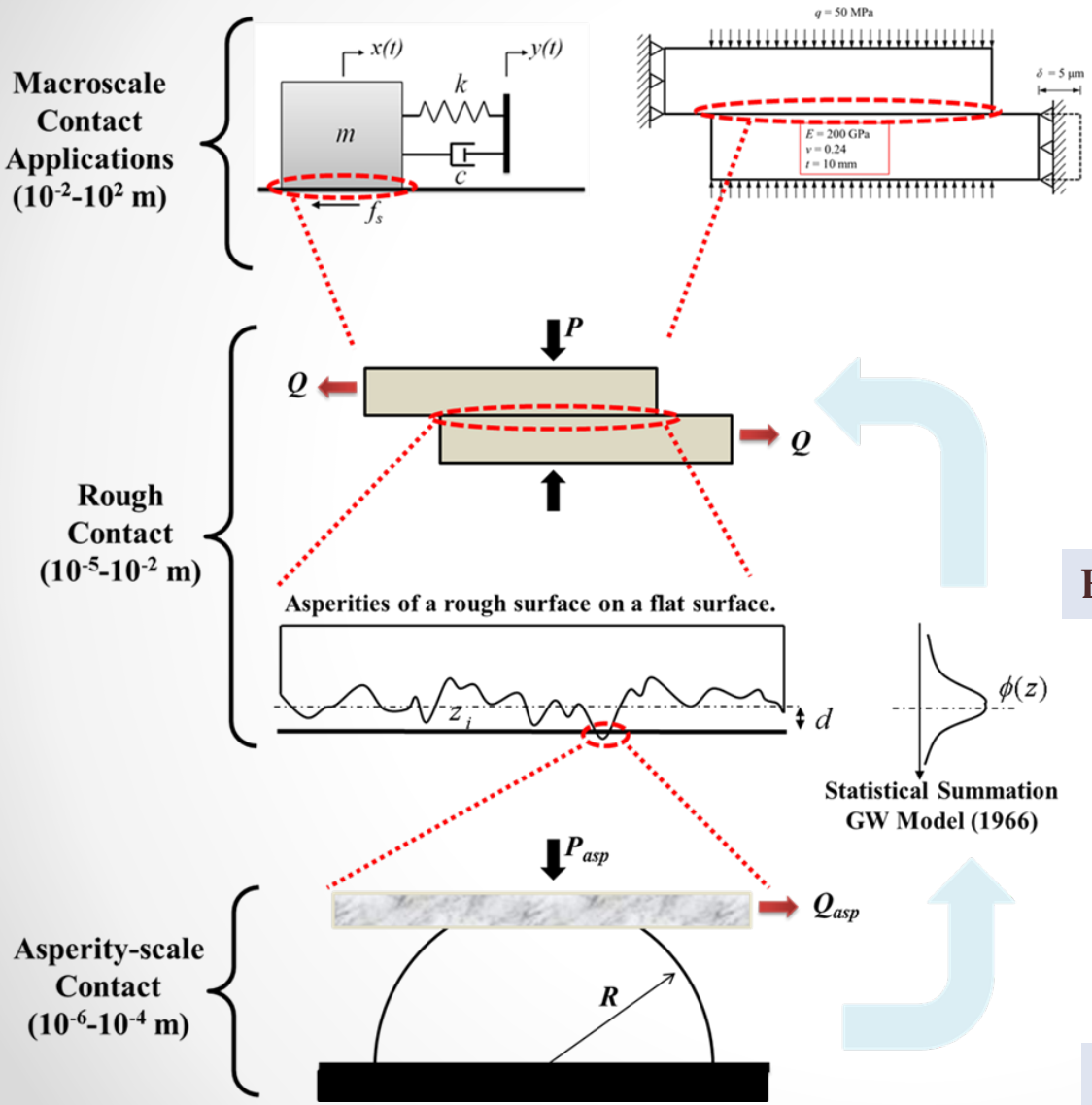






Multiscale Modeling: Outline

Eriten et al., *ASME J. Vib. Acoust.*, 2011.; Truster et al., *Int. J. Solids Struct.*, 2012.



Eriten et al., *Int. J. Solids Struct.*, 2011.

Eriten et al., *Int. J. Solids Struct.*, 2010.

Bottom-Up Approach Outcomes

- Joint Fretting Apparatus
- Multiscale Friction Model
- Journal articles:

1. Lee, C.-H.; Eriten, M.; Polycarpou, A. A. *ASME J. Tribology* **2010**, *132*, 031602–11.
2. Eriten, M.; Polycarpou, A. A.; Bergman, L. A. *Int. J. Solids Struct.* **2010**, *47*, 2554–2567.
3. Eriten, M.; Polycarpou, A. A.; Bergman, L. A. *J. Appl. Mech.* **2011**, *78*, 021011.
4. Eriten, M.; Polycarpou, A. A.; Bergman, L. A. *Wear* **2011**, *271*, 2928–2939.
5. Eriten, M.; Polycarpou, A. A.; Bergman, L. A. *Exp. Mech.* **2011**, *51*, 1405–19.
6. Eriten, M.; Polycarpou, A. A.; Bergman, L. A. *Int. J. Solids Struct.* **2011**, *48*, 1436–1450.
7. Eriten, M.; Petlicki, D. T.; Polycarpou, A. A.; Bergman, L. A. *Mech. Mat.* **2012**, *48*, 26–42.
8. Eriten, M.; Polycarpou, A. A.; Bergman, L. A. *ASME J. Vib. Acoust.* **2012**, 134, 051012.
9. Chandrasekar, S.; Eriten, M.; Polycarpou, A. A. *J. Appl. Mech.* **2012**, doi: 10.1115/1.4007212.
10. Eriten, M.; Lee, C.-H.; Polycarpou, A. A. *Tribology Int.* **2012**, *50*, 35–44.
11. Truster, T. J.; Eriten, M.; Polycarpou, A. A.; Bergman, L. A.; Masud, A. *Int. J. Solids Struct.* **2012**, (in press).
12. Eriten, M. *J. Mech. Phys. Solids*, (submitted).

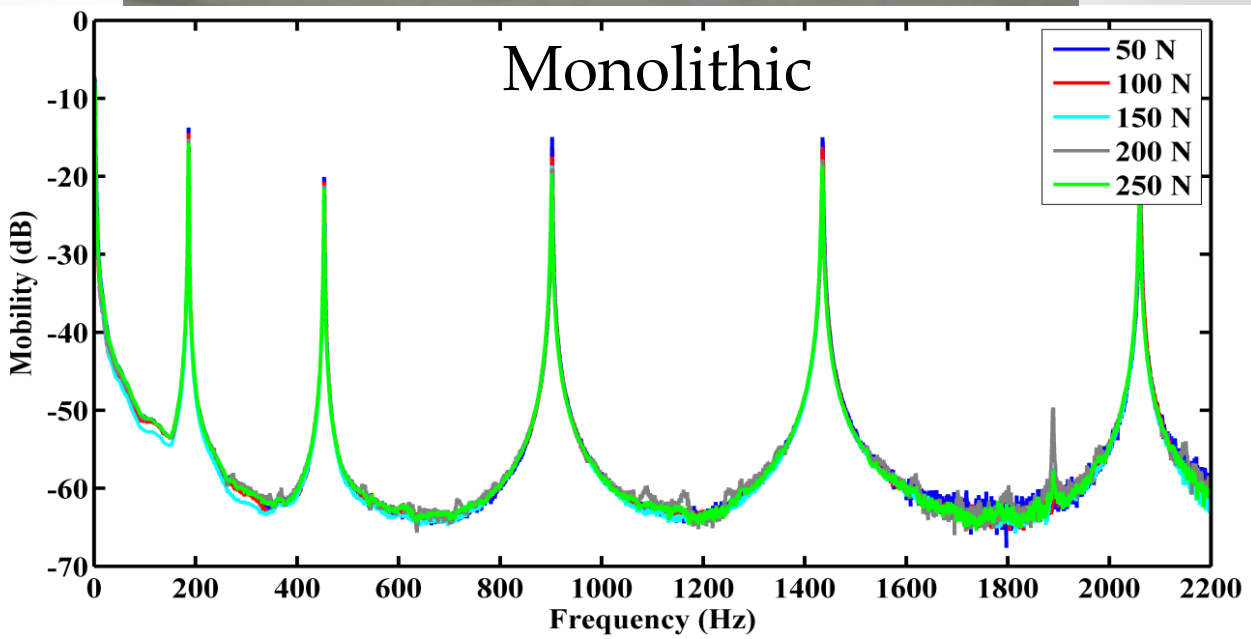
Top-Down Approach: Need for the NSI

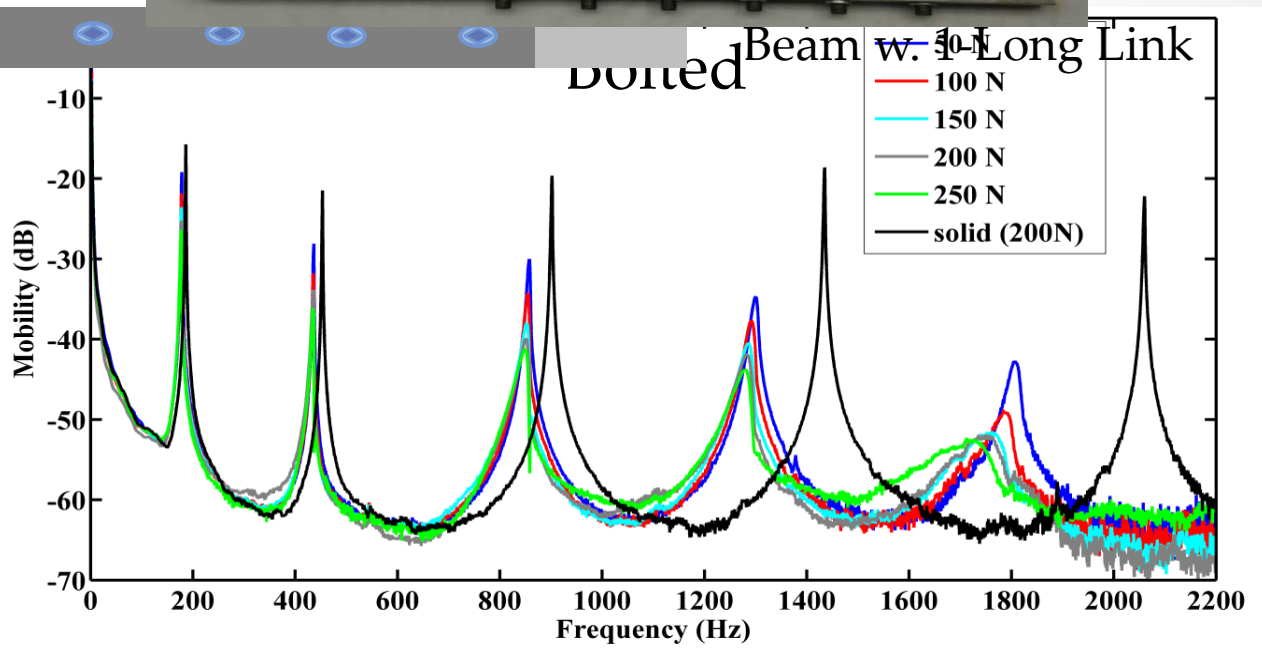
Amplitude dependent damping/stiffness

Discontinuities, impacts, clearance, backlash, etc.

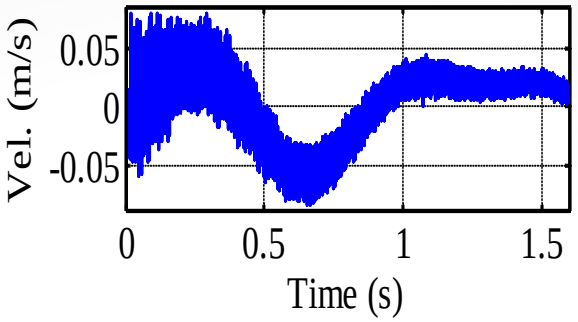
Case study:

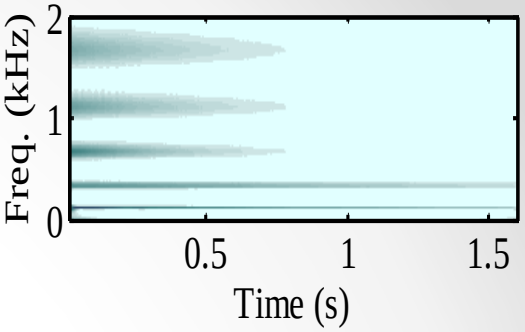
- Added damping due to friction
- Essential nonlinearities

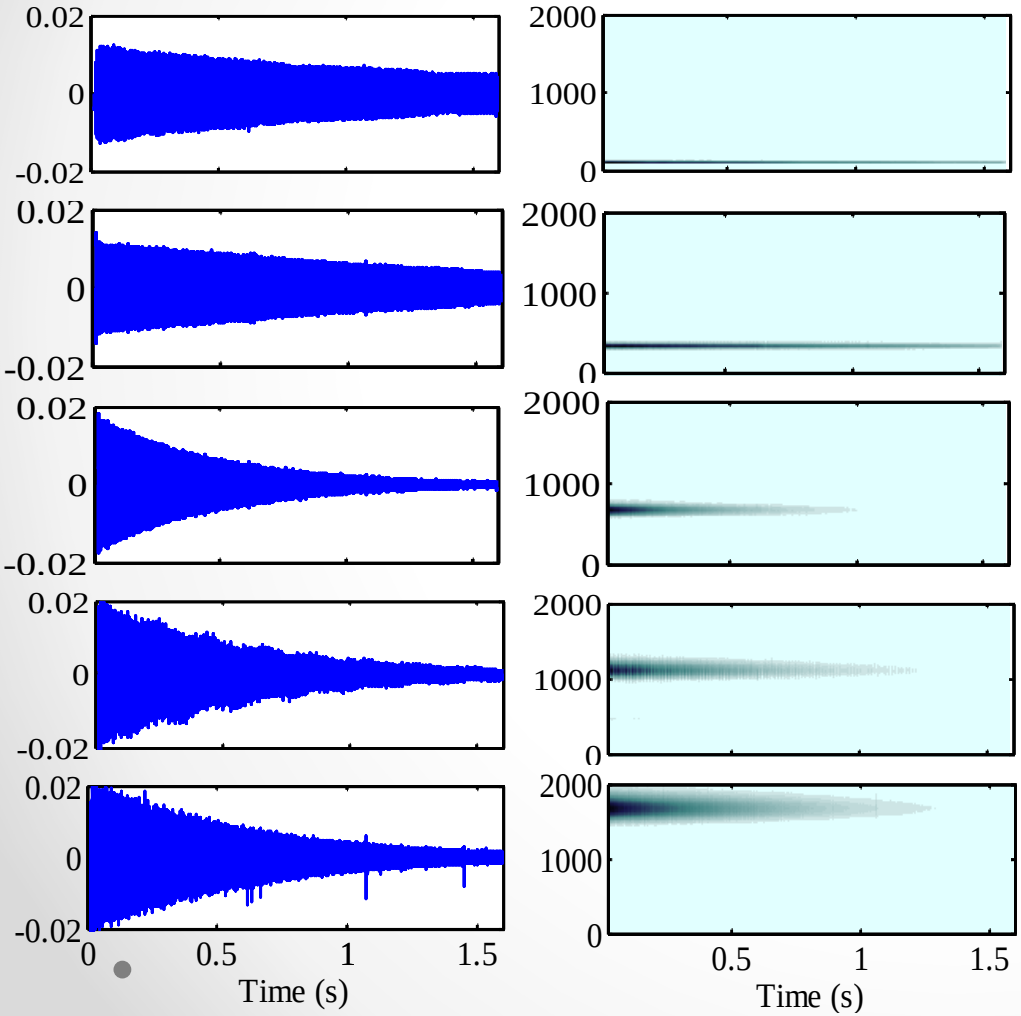




Measured time series to Intrinsic Modal Frequencies (IMF) by EMD

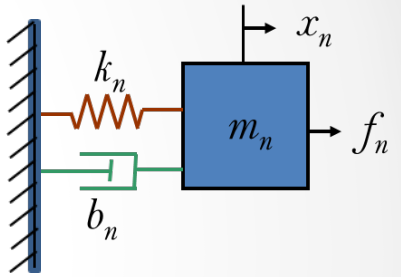






IMF to Intrinsic Modal Oscillators (IMO)

by slow-flow equivalence



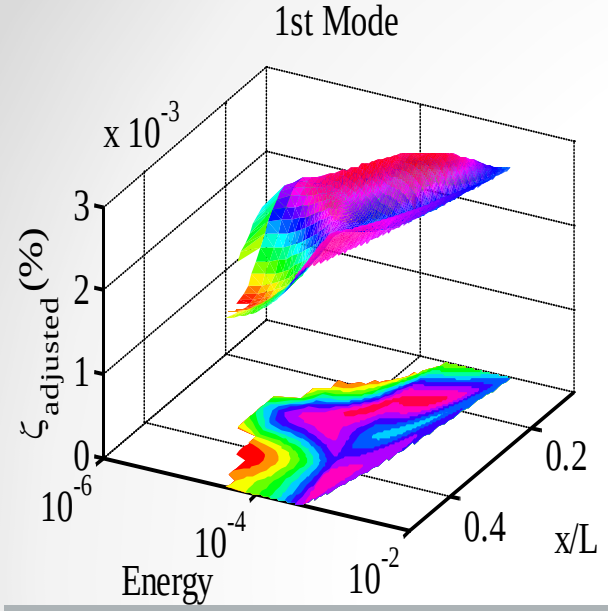
$$\ddot{x}_n(t)+b_n\dot{x}_n(t)+\omega^2 x_n(t)=f_n(t)=Re\left\{\Lambda_n(t)e^{j\omega t}\right\}$$

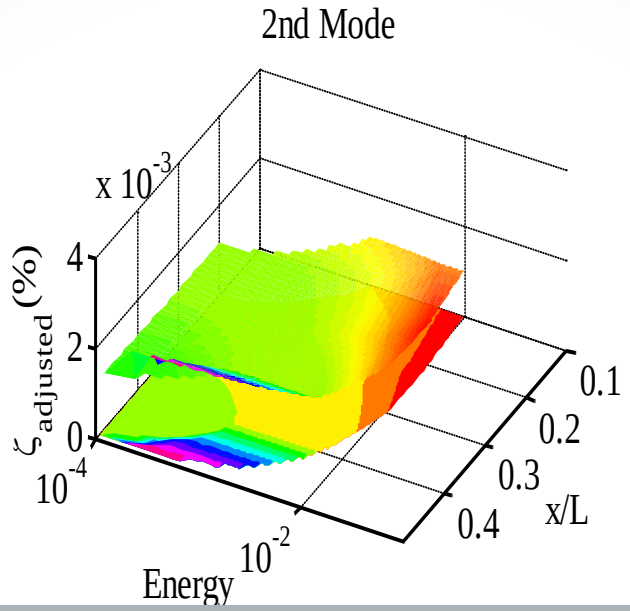
$$\Lambda_n(t)=2\left[\frac{d}{dt}\left(j\omega A_n(t)e^{j\left[\theta_n(t)-\omega t\right]}\right)+ jb_n\omega^2 A_n(t)e^{j\left[\theta_n(t)-\omega t\right]}\right]$$

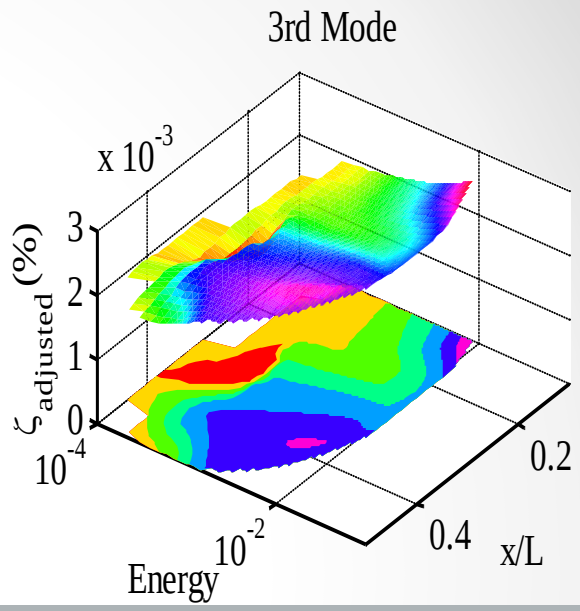
$$A_n(t)=\sqrt{\left\{c_n(t)\right\}^2+\left\{\mathrm{H}\left[c_n(t)\right]\right\}^2}$$

$$\theta_n(t)=\arctan\left\{\mathrm{H}\left[c_n(t)\right]/c_n(t)\right\}$$

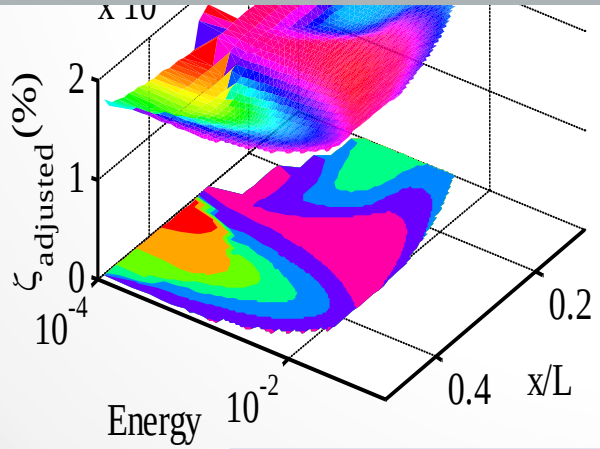
Energy-Dependence of Structural Damping

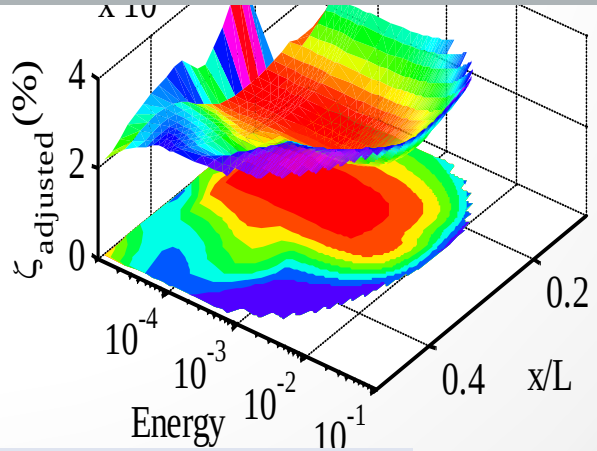






- Clear indication of nonlinearity in damping distribution
- Comprehensive identification in modal, spatial, and energy domain
- Damping increases with increasing hammer excitation in a nonlinear manner → joint-like

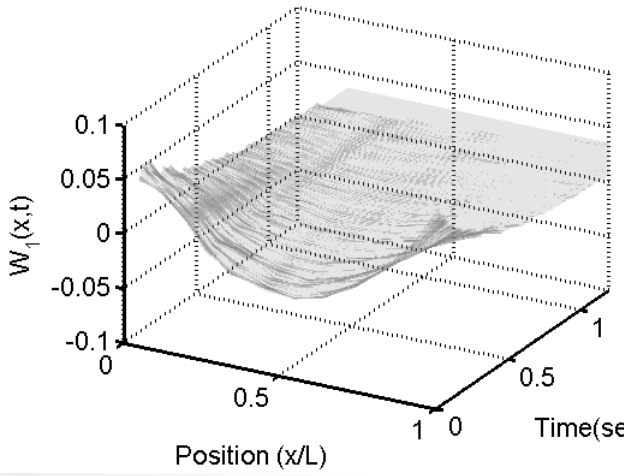




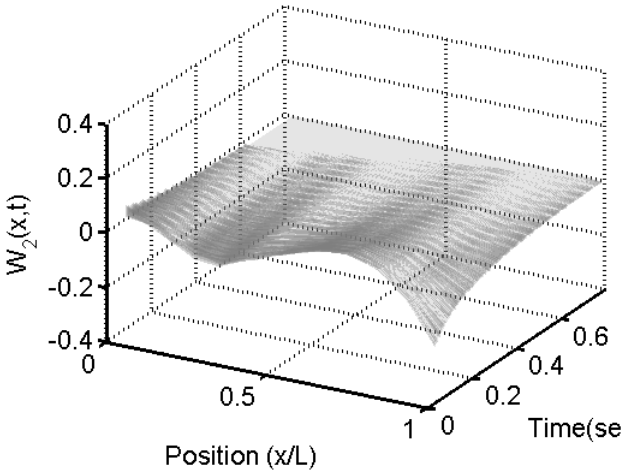
Eriten et al., *Mech. Syst. Signal Pr.* submitted.

Spatio-Temporal Decomposition (Mode Shapes)

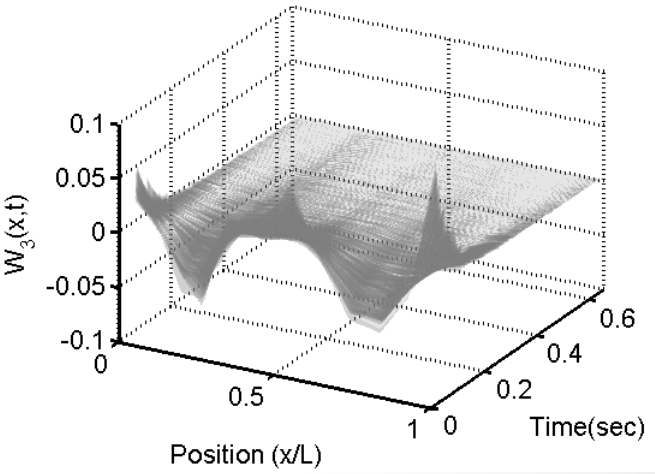
1st Mode



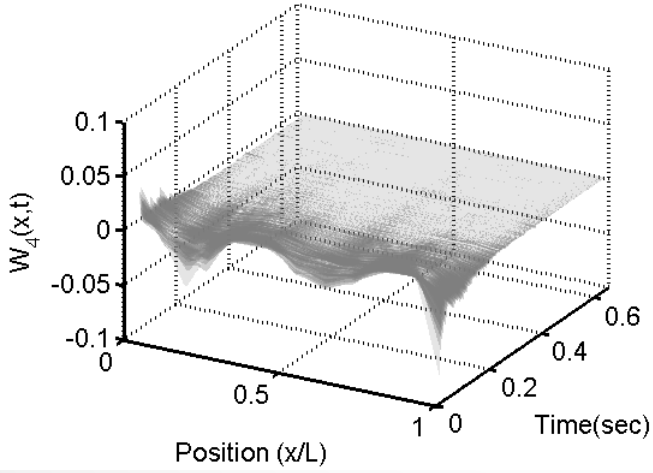
2nd Mode



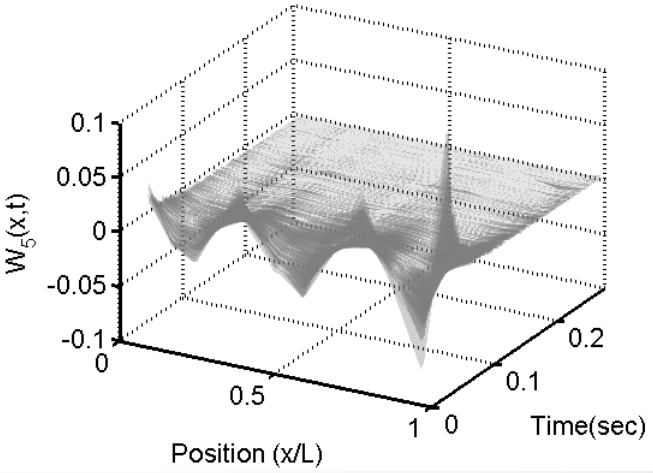
3rd Mode



4th Mode



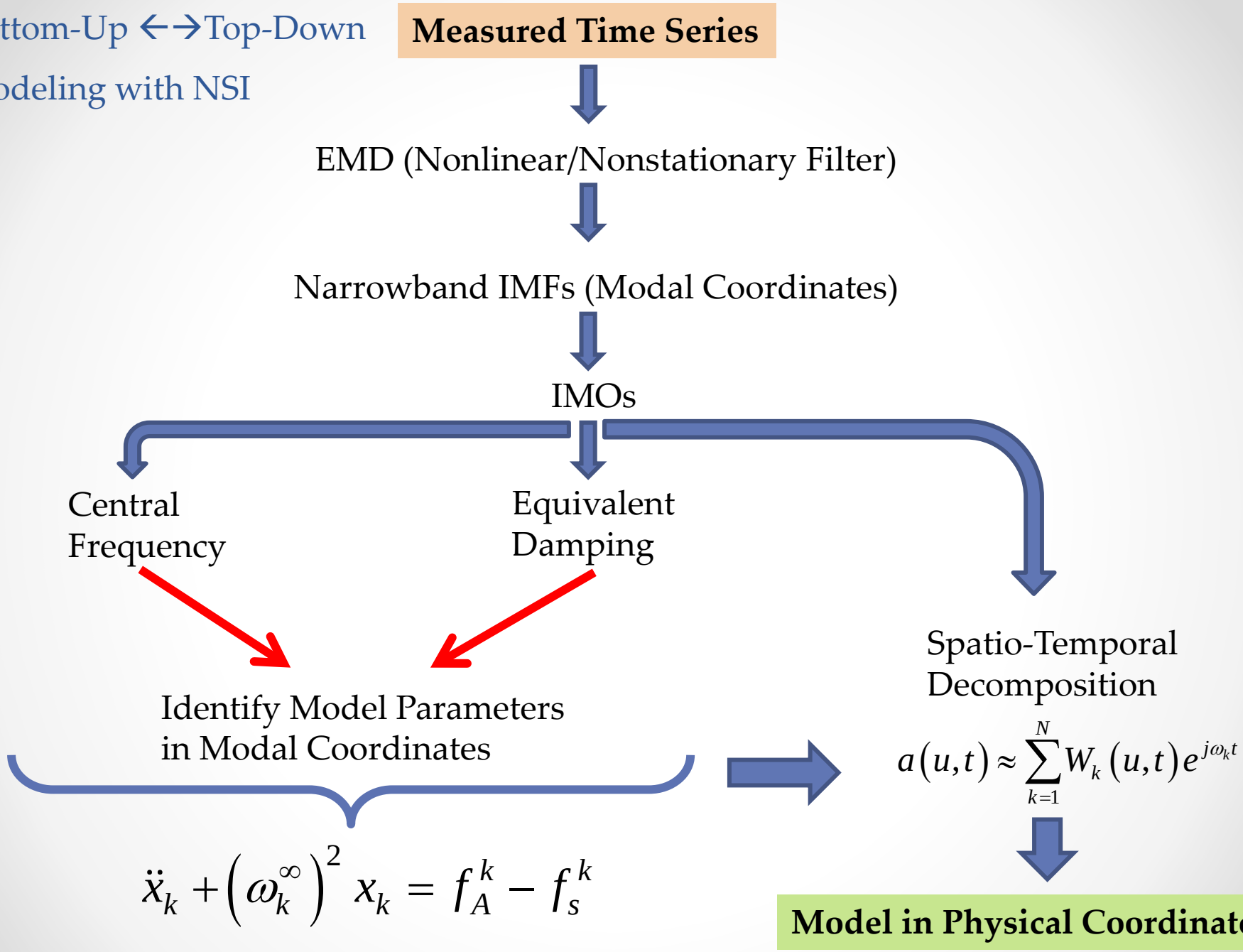
5th Mode



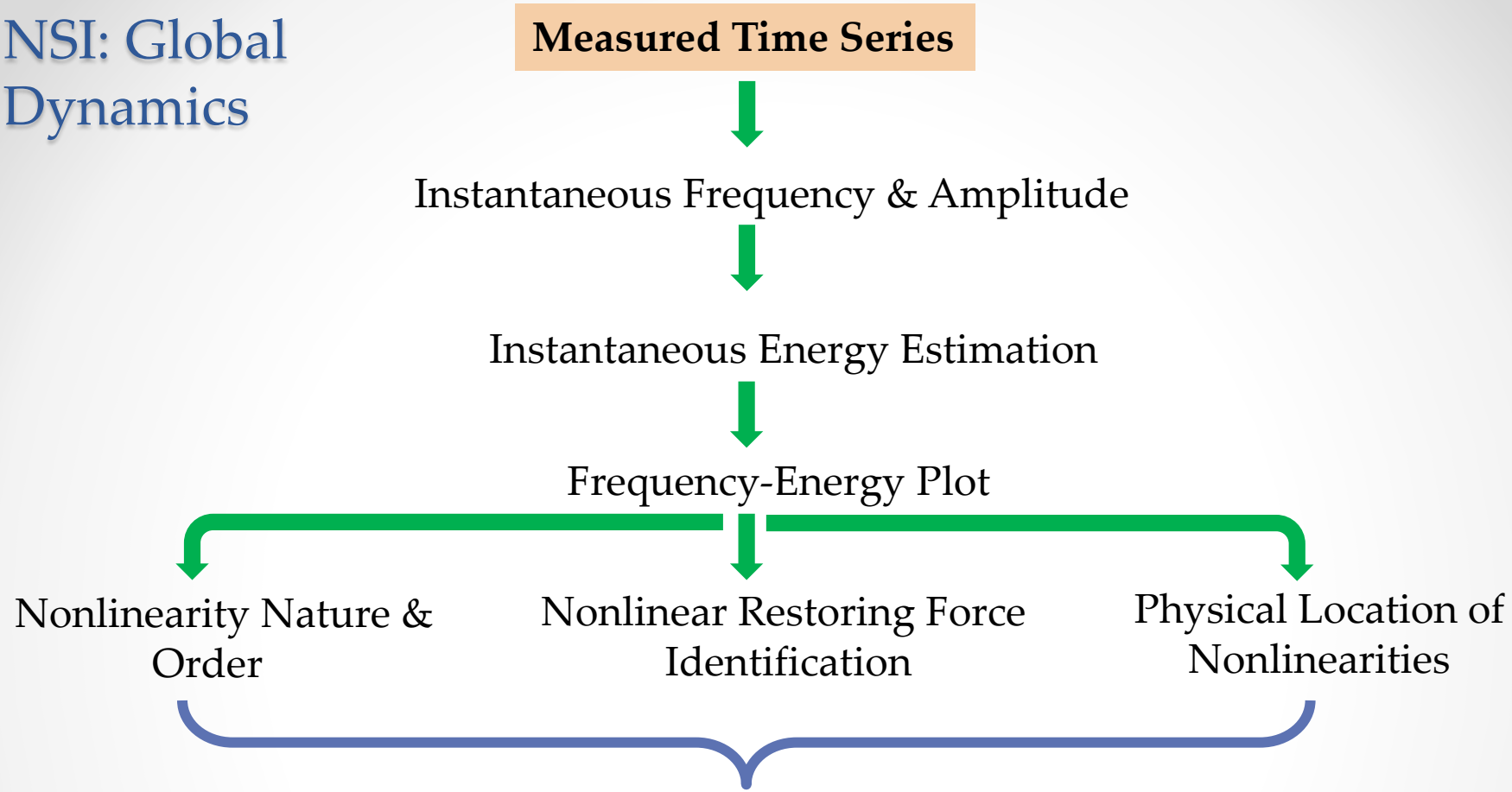
Top-Down Approach Outcomes

- Identification technique: NSI
- Journal articles:

1. Eriten, M.; Kurt, M.; Luo, G.; McFarland, D. M.; Vakakis, A. F.; Bergman, L. A. *Mech. Syst. Signal Pr.*, (submitted).
2. Kurt, M., Eriten, M., McFarland, D. M., Bergman, L. A., and Vakakis, A. F. *J. of Sound and Vibration* (submitted).


Measured Time Series
EMD (Nonlinear/Nonstationary Filter)
Narrowband IMFs (Modal Coordinates)
IMOs
Central Frequency
Equivalent Damping
Identify Model Parameters in Modal Coordinates
$\ddot{x}_k + \left(\omega_k^{\infty}\right)^2 x_k = f_A^k - f_s^k$
Spatio-Temporal Decomposition
$a(u,t) \approx \sum_{k=1}^{N} W_k(u,t) e^{j\omega_k t}$
Model in Physical Coordinates

NSI: Global Dynamics



Reduced-order Models with Essential Nonlinearities

- Softening/hardening
- Backlash
- Clearance
- Impacts
- Misalignment
- Loose Joints
- Interfacial cracks