DAY	TIME	LECTURE
Monday 05/11	14.00 -14.45	Historical Framework - A Global Dynamics Perspective in the Nonlinear Analysis of Systems/Structures
	15.00 -15.45	Achieving Load Carrying Capacity: Theoretical and Practical Stability
	16.00 -16.45	Dynamical Integrity: Concepts and Tools_1
Wednesday 07/11	14.00 -14.45	Dynamical Integrity: Concepts and Tools_2
	15.00 -15.45	Global Dynamics of Engineering Systems
	16.00 -16.45	Dynamical integrity: Interpreting/Predicting Experimental Response
Monday 12/11	14.00 -14.45	Techniques for Control of Chaos
	15.00 -15.45	A Unified Framework for Controlling Global Dynamics
	16.00 -16.45	Response of Uncontrolled/Controlled Systems in Macro- and Micro-mechanics
Wednesday 14/11	14.00 -14.45	**A Noncontact AFM:** (a) Nonlinear Dynamics and Feedback Control **(b) Global Effects of a Locally-tailored Control**
	15.00 -15.45	Exploiting Global Dynamics to Control AFM Robustness
	16.00 -16.45	Dynamical Integrity as a Novel Paradigm for Safe/Aware Design

12.1b – A Noncontact AFM: Global Effects of a Locally-tailored Control

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Coworker: V. Settimi

OUTLINE of 12.1b

1. **STRONGLY NONLINEAR DYNAMICS OF THE CONTROLLED SYSTEM**
2. **DYNAMICAL INTEGRITY OF THE CONTROLLED SYSTEM**

………………. towards a **GLOBAL DYNAMICS-BASED CONTROL**

NONCONTACT AFM WITH EXTERNAL FEEDBACK CONTROL

RESPONSE OF THE CONTROLLED SYSTEM

$$\ddot{x}\left(1+\alpha_2 x^2\right)+\alpha_1 x+\alpha_2 x\dot{x}^2+\alpha_3 x^3=-\Gamma_1\left(1+x+V_g+z-z_s\right)^{-2}-\left(\rho_1+\rho_2 x^2\right)\dot{x}$$
$$-\left(\ddot{V}_g+k_g\left(\dot{x}_{ref}-\dot{x}\right)+\nu_1\left(\dot{V}_g+k_g\left(x_{ref}-x\right)\right)\right)\nu_2+\left(x\mu_1+\mu_2 x^3\right)\left(\ddot{U}_g+\eta_1\dot{U}_g+\eta_2 U_g\right)$$

$$\dot{z}=k_g\left(x_{ref}-x\right)$$

ATOMIC INTERACTION

+

REFERENCE RESPONSE

$$\ddot{x}_{ref}\left(1+\alpha_2 x_{ref}^{\;2}\right)+\alpha_1 x_{ref}+\alpha_2 x_{ref}\dot{x}_{ref}^{\;2}+\alpha_3 x_{ref}^{\;3}=-\Gamma_1\left(1+x_{ref}+V_g\right)^{-2}$$
$$-\rho_1\dot{x}_{ref}-\rho_2\dot{x}_{ref}x_{ref}^{\;2}-\left(\left(\ddot{V}_g+\nu_1\dot{V}_g\right)\right)\nu_2+\left(x_{ref}\mu_1+\mu_2 x_{ref}^{\;3}\right)\left(\ddot{U}_g+\eta_1\dot{U}_g+\eta_2 U_g\right)$$

- INCREASED D.O.F. : **RICHER BIFURCATIVE SCENARIO**
- New TORUS and TRANSCRITICAL bifurcations: **STABILITY BOUNDARY REDUCTION**

STRONGLY NONLINEAR DYNAMICS

- System nonlinear response as function of MOST RELEVANT **DYNAMICAL PARAMETERS**:

  - **FORCING AMPLITUDE** $U(V)$
  - **FORCING FREQUENCY** $\omega_u(\omega_v)$
  - **ATOMIC INTERACTION** Γ_1
  - **FEEDBACK CONTROL PARAMETER** k_g

- BIFURCATION DIAGRAMS and RESPONSE CHARTS around **FUNDAMENTAL** and **PRINCIPAL** resonances

- **PARAMETRICALLY** and **EXTERNALLY** forced system

- **COMPARISON** with results obtained for **UNCONTROLLED** system

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INFLUENCE of **EXTERNAL FEEDBACK CONTROL** on **DYNAMIC BEHAVIOR**

PARAMETRIC EXCITATION - 1 -

$$\ddot{x} + \alpha_1 x + \alpha_3 x^3 = -\Gamma_1 \left(1 + x + z - z_s\right)^{-2} - \rho_1 \dot{x} - x \mu_1 U \omega_u^2 \sin(\omega_u t)$$

$$\dot{z} = k_g \left(x_{ref} - x\right)$$

ω_u-U

$\mu_2 = \rho_2 = 0$

$\eta_1 = \eta_2 = 0$

$V_g = \alpha_2 = 0$

$\alpha_1 = 1$

$\Gamma_1 = 0.1$

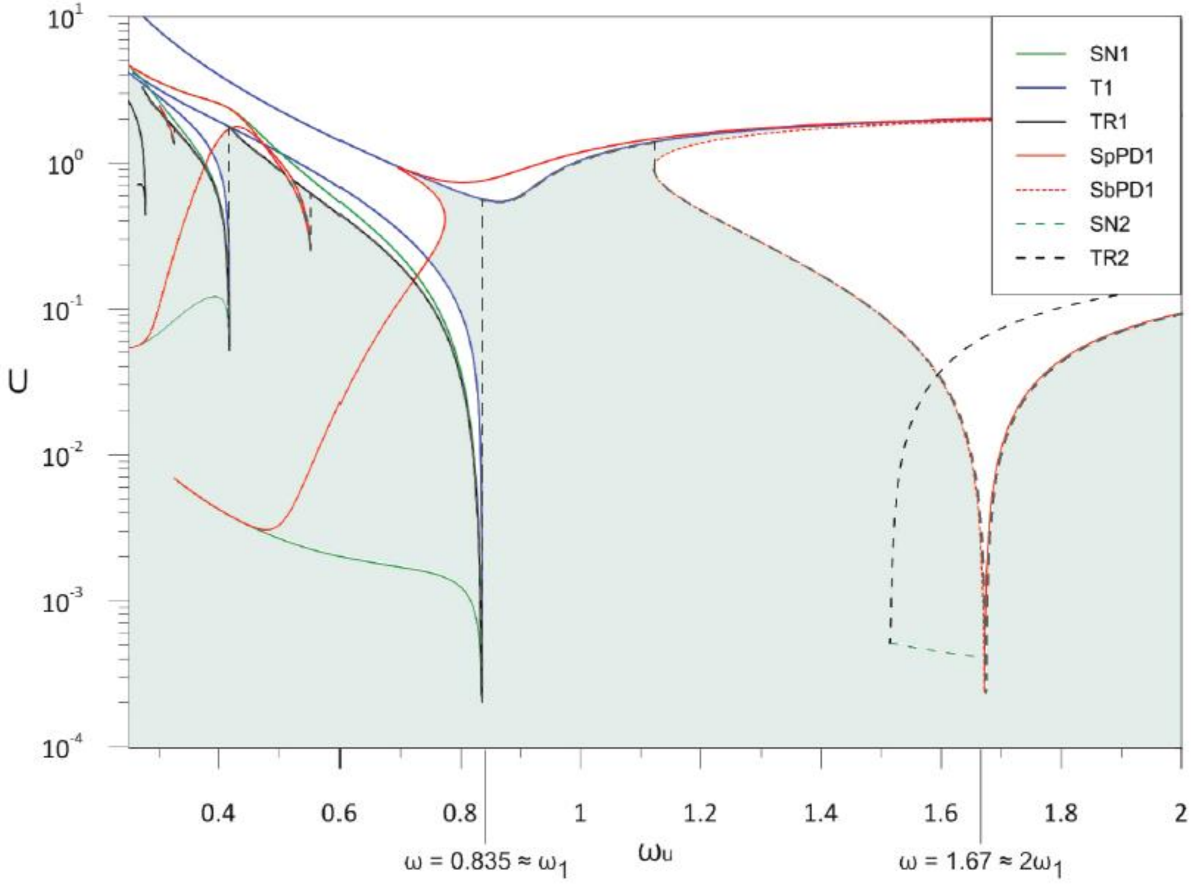
$\alpha_3 = 0.1$

$\mu_1 = 1.5708$

$\omega_1 = 0.8325$

$k_g = 0.001$

$z_s = 0.01$



PARAMETRIC EXCITATION - 1 -

$$\ddot{x} + \alpha_1 x + \alpha_3 x^3 = -\Gamma_1 \left(1 + x + z - z_s\right)^{-2} - \rho_1 \dot{x} - x \mu_1 U \omega_u^2 \sin(\omega_u t)$$

$$\dot{z} = k_g \left(x_{ref} - x\right)$$

ω_u-U

$\mu_2 = \rho_2 = 0$

$\eta_1 = \eta_2 = 0$

$V_g = \alpha_2 = 0$

$\alpha_1 = 1$

$\Gamma_1 = 0.1$

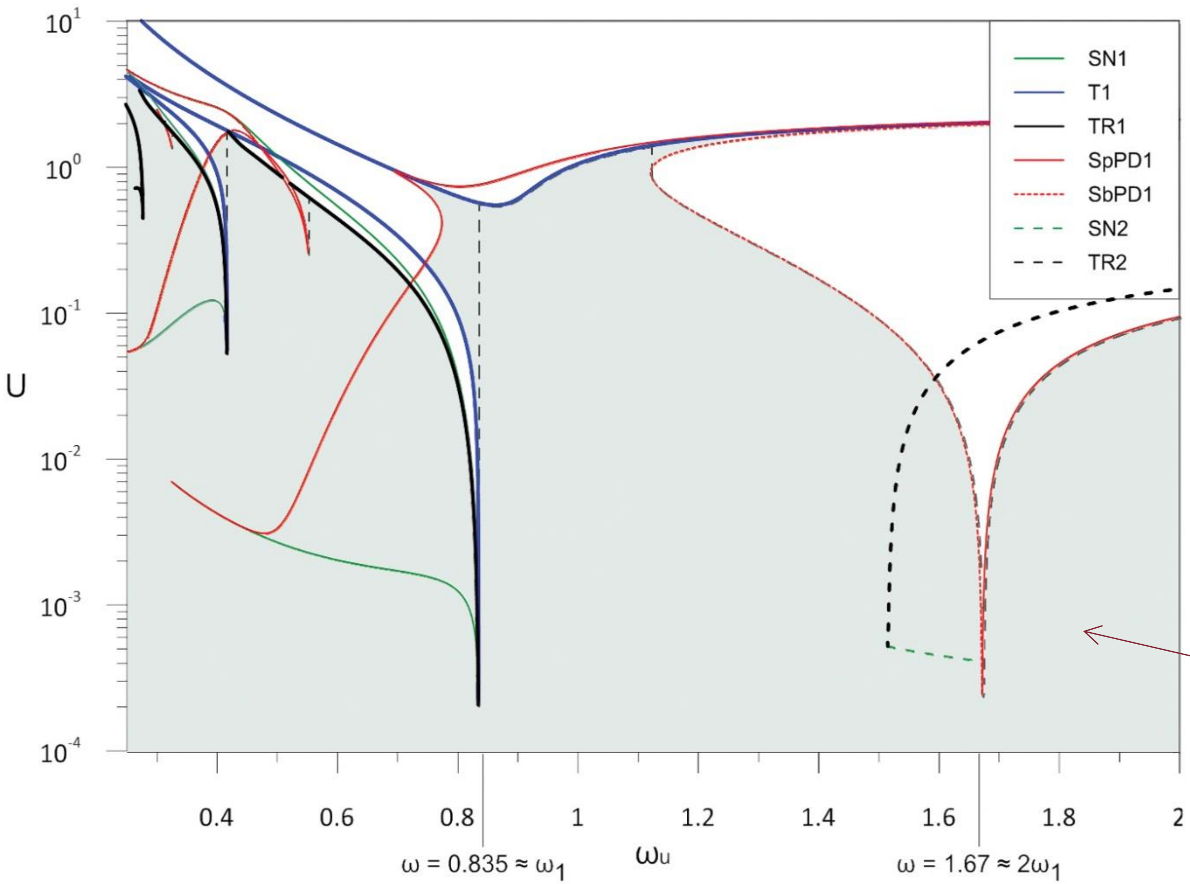
$\alpha_3 = 0.1$

$\mu_1 = 1.5708$

$\omega_1 = 0.8325$

$k_g = 0.001$

$z_s = 0.01$



NEW **TRANSCRITICAL** AND **TORUS** THRESHOLDS

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DECREASE OF ESCAPE VALUE

STABLE REGION: solutions for which **FEEDBACK CONTROL WORKS PROPERLY**

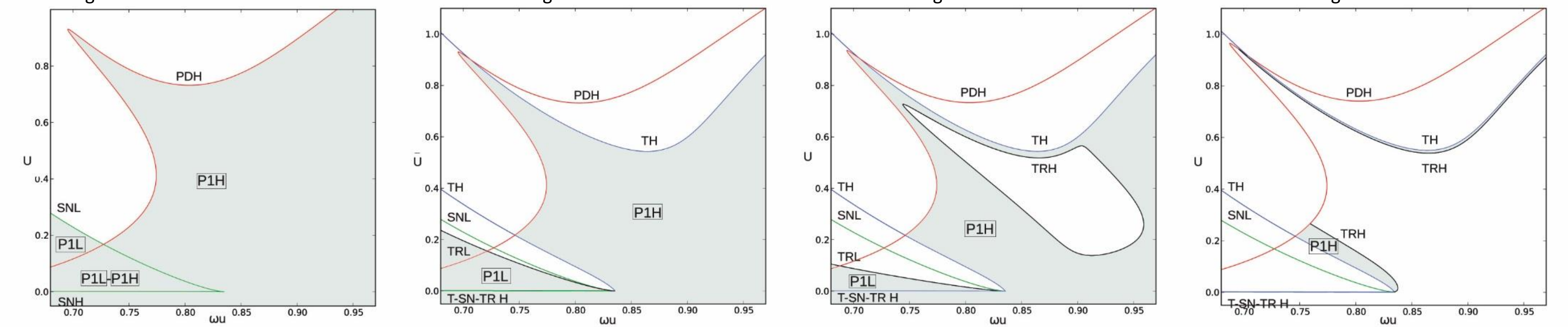
PARAMETRIC EXCITATION - 2 -

FUNDAMENTAL RESONANCE

ω_u-U

WITH VARYING **FEEDBACK CONTROL**

$k_g = 0$: REFERENCE CONFIG. | $k_g = 0.001$ | $k_g = 0.002$ | $k_g = 0.01$



FEEDBACK CONTROL

TORUS AND **TRANSCRITICAL** THRESHOLDS

- **UNSTABLE TONGUES** at **LOW** values of U
- TRIANGLE region **REDUCED**
- NO COEXISTENCE of P1L/P1H solutions

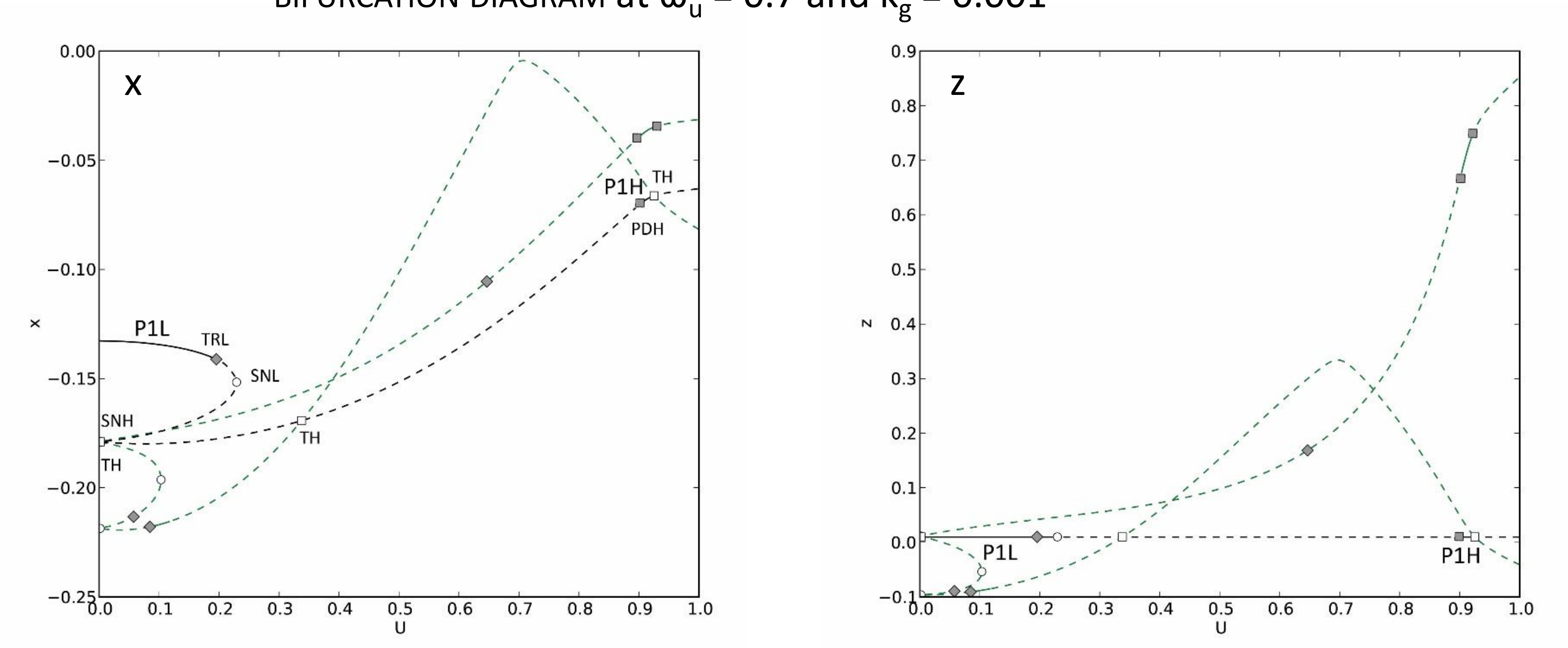
TOTAL **ESCAPE** occurs at **LOWER** VALUES OF U

FUNDAMENTAL RESONANCE

ω_u-U

BIFURCATION DIAGRAM at $\omega_u = 0.7$ and $k_g = 0.001$

TRL: TORUS bif. of P1L
TH: TRANSCRITICAL bif. of P1H



PARAMETRIC EXCITATION - 3 -

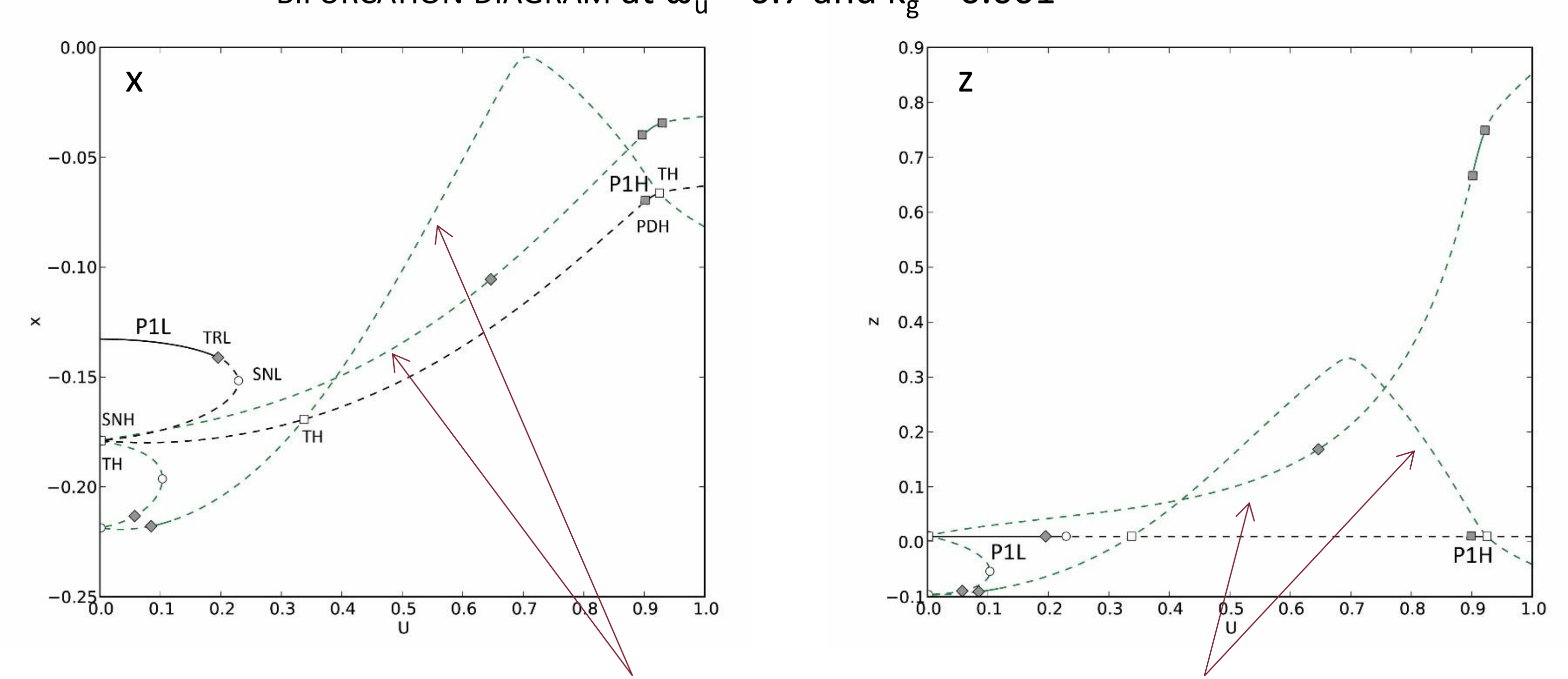
FUNDAMENTAL RESONANCE

ω_u-U

BIFURCATION DIAGRAM at ω_u = 0.7 and k_g = 0.001

TRL: TORUS bif. of P1L

TH: TRANSCRITICAL bif. of P1H



From **TRANSCRITICAL** BIF.: new **STABLE P1** solutions $\rightarrow$ INEFFICIENCY OF CONTROL

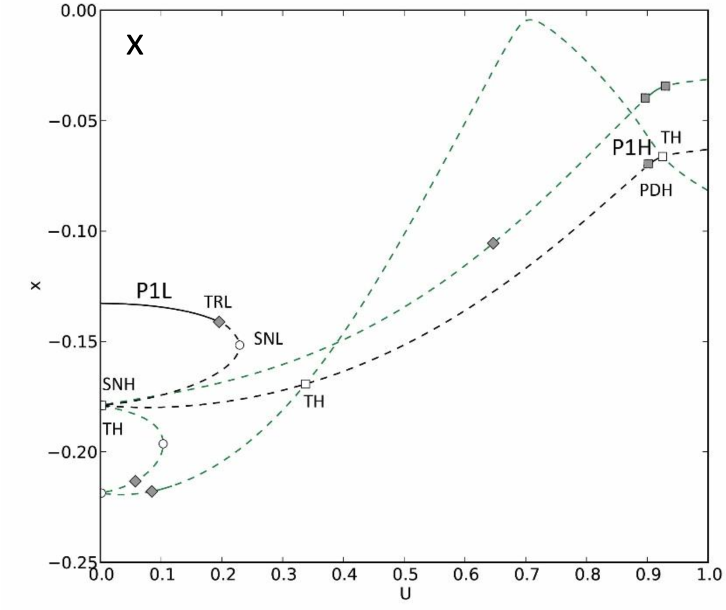
PARAMETRIC EXCITATION - 3 -

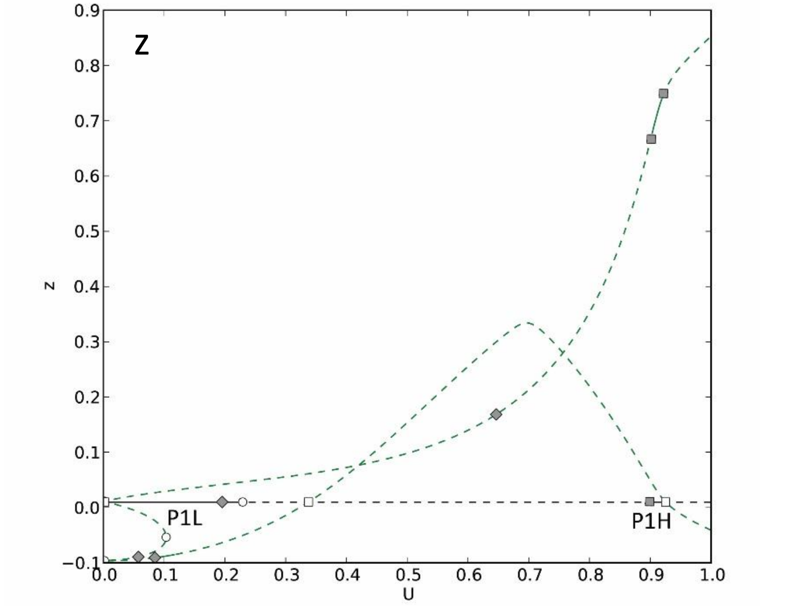
FUNDAMENTAL RESONANCE

ω_u-U

BIFURCATION DIAGRAM at $\omega_u = 0.7$ and $k_g = 0.001$

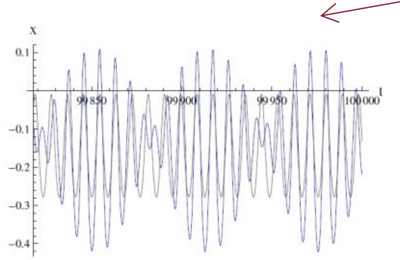
TRL: TORUS bif. of P1L
TH: TRANSCRITICAL bif. of P1H

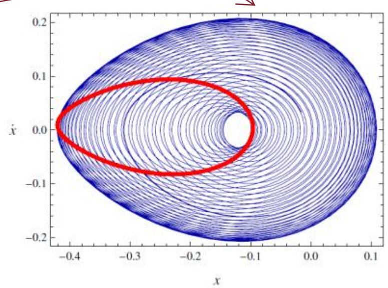




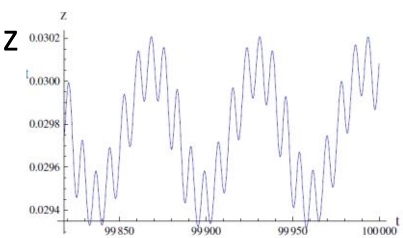
From **TORUS** BIF.: new **STABLE QUASIPERIODIC** solutions $\rightarrow$ INEFFICIENCY OF CONTROL

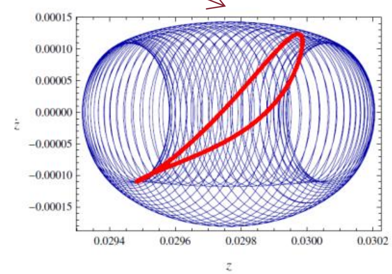
X





Z

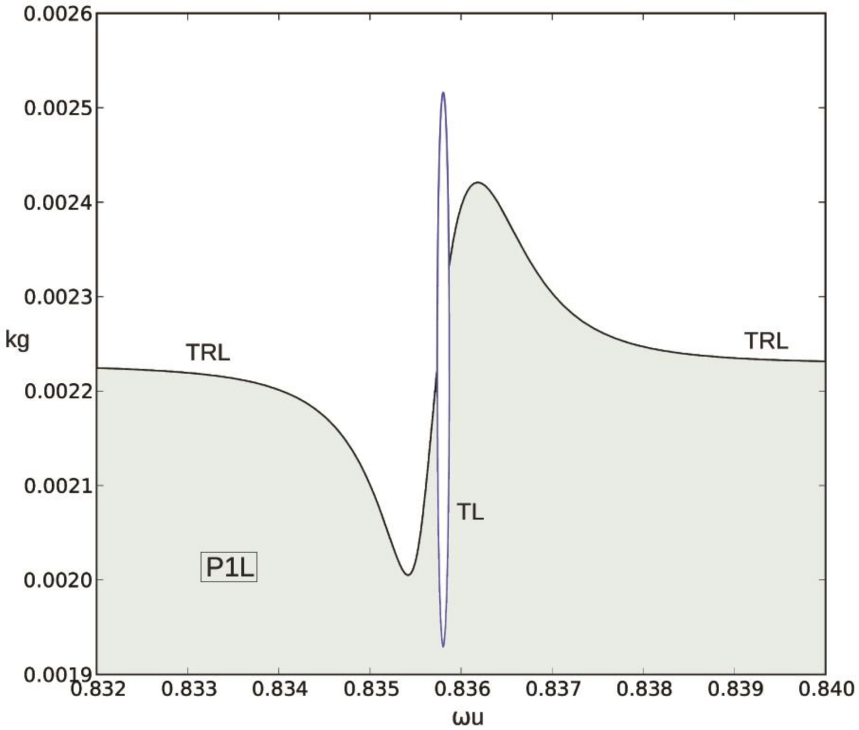




FUNDAMENTAL RESONANCE

ω_u- k_g

U = 0.0001

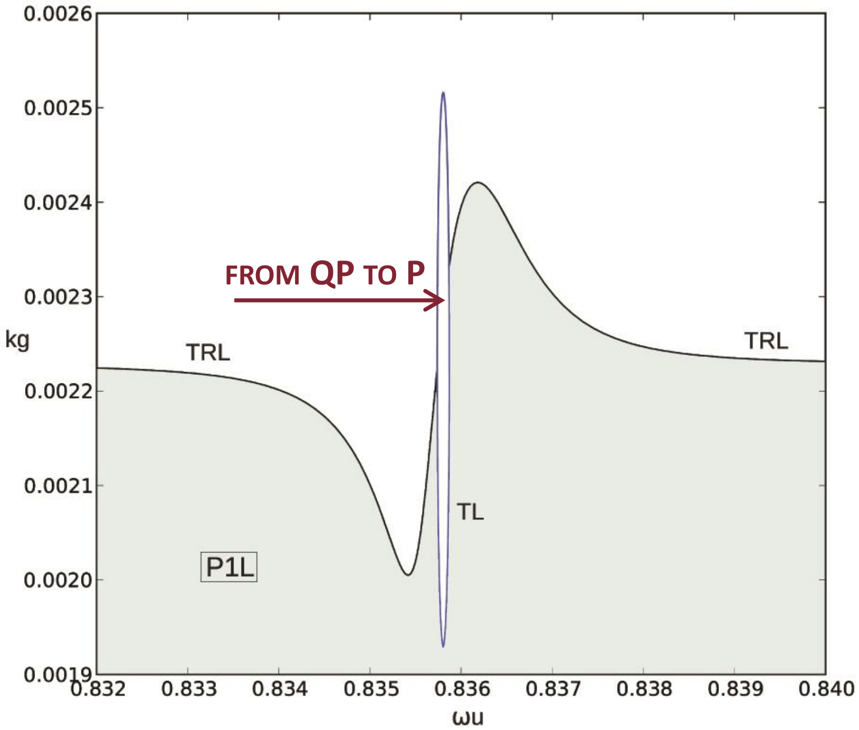


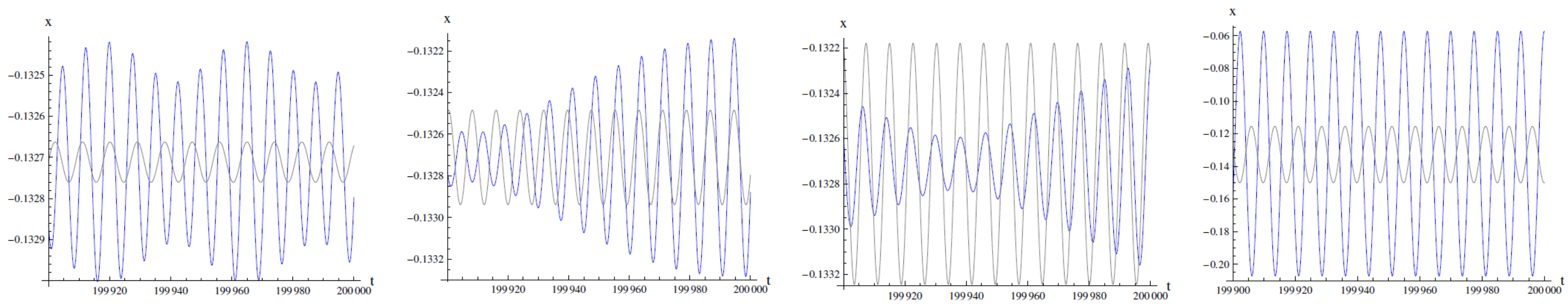
FUNDAMENTAL RESONANCE

$\omega_u - k_g$

PHASE LOCKING (from QP to P):
synchronization of response frequency to forcing one

U = 0.0001



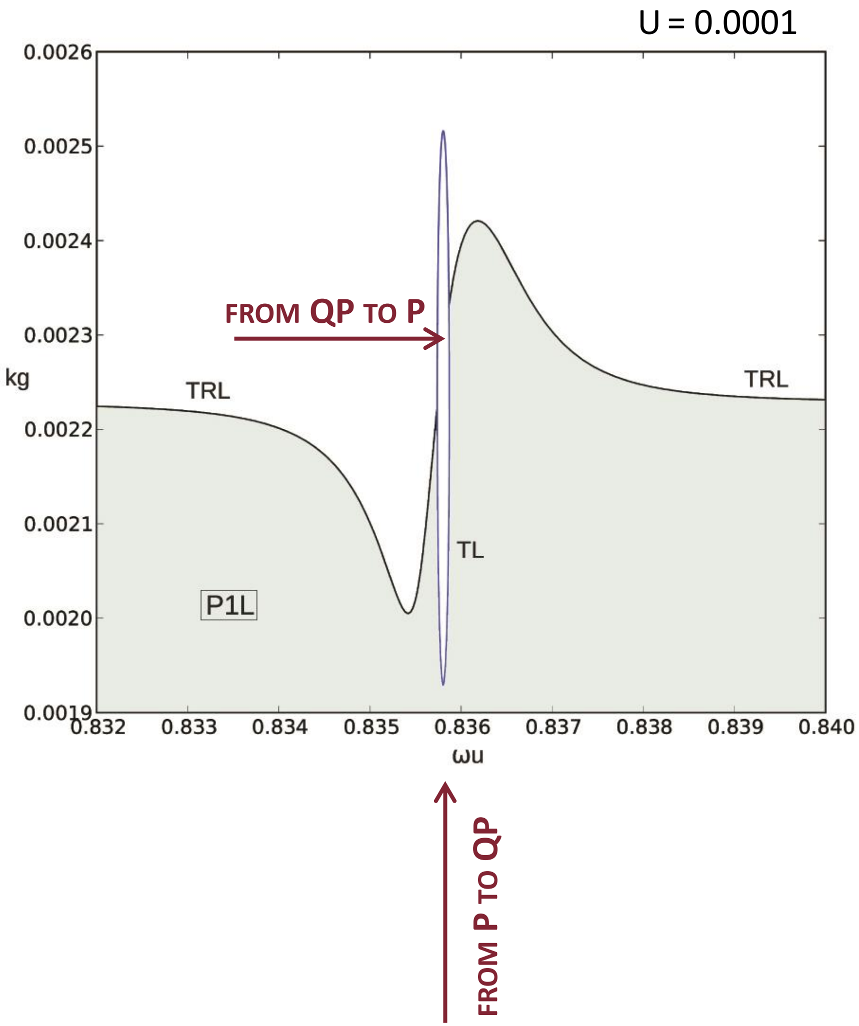


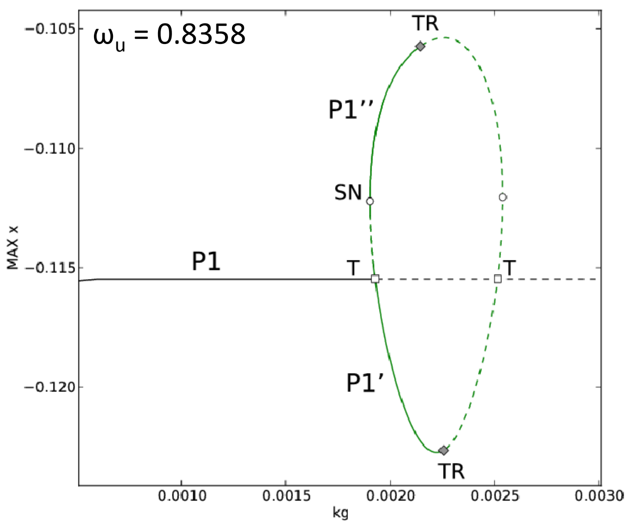
FUNDAMENTAL RESONANCE

$\boxed{\omega_u - k_g}$

PHASE LOCKING (from QP to P):
synchronization of response frequency to forcing one

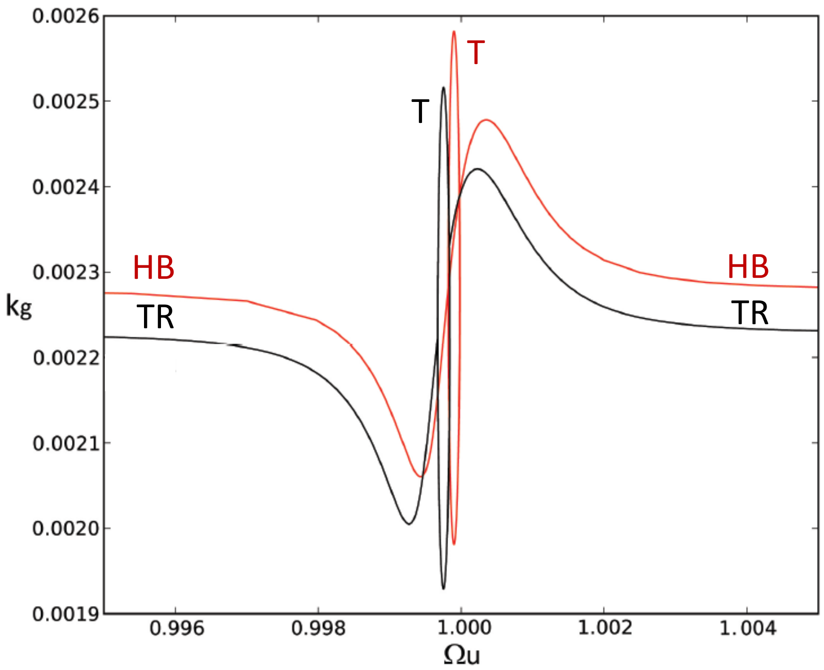
RESONANCE FREQUENCY (from P to QP):
increase of response amplitude that feedback control barely dominates





GOOD AGREEMENT between **AMEs** and **ODEs**

- **BIFURCATION BEHAVIOR**
- **STABILITY THRESHOLD** OF BOUNDED REFERENCE SOLUTION

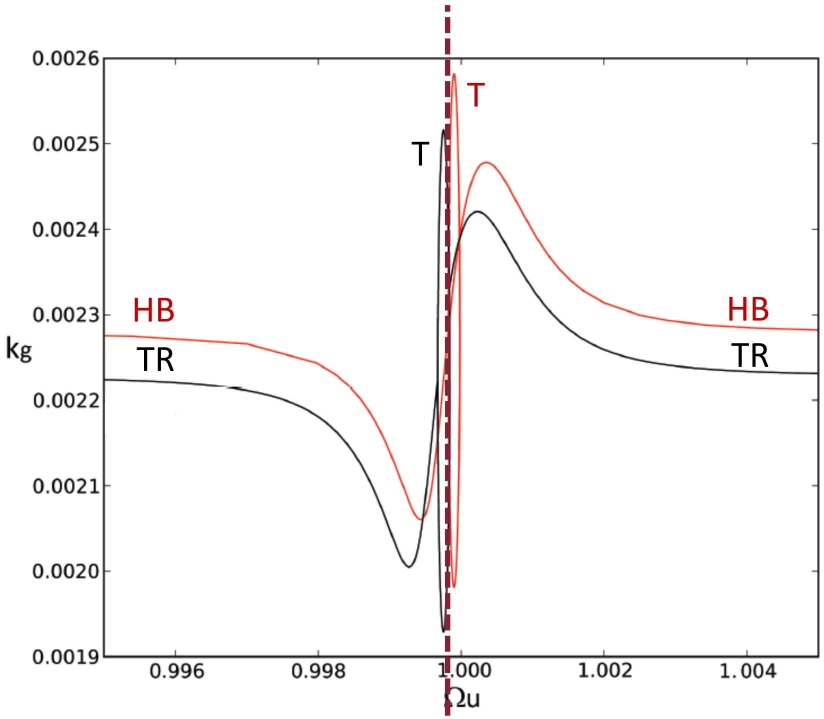


STABILITY THRESHOLD: **Hopf HB** (**Torus TR**) bifurcation

AROUND RESONANCE: **Transcritical T** bifurcation

GOOD AGREEMENT between AMEs and ODEs

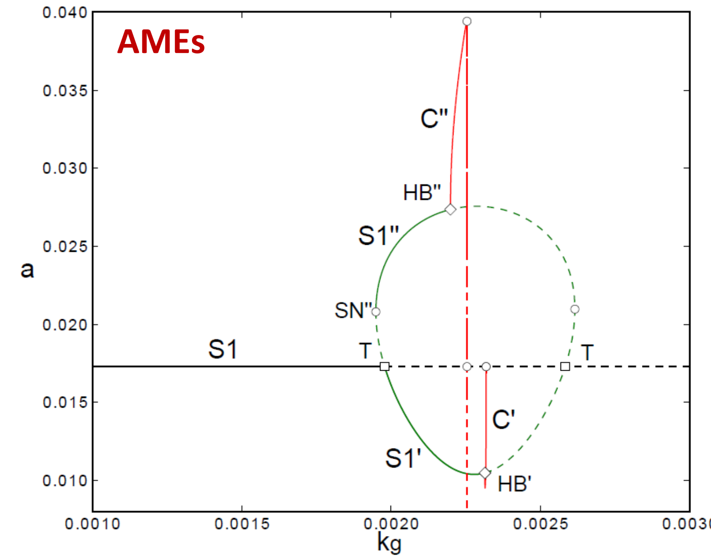
- **BIFURCATION BEHAVIOR**
- **STABILITY THRESHOLD** OF BOUNDED REFERENCE SOLUTION

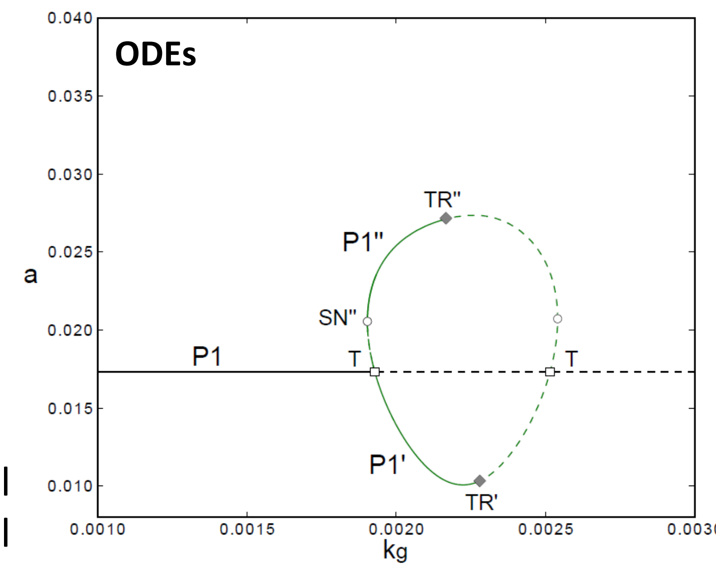


1-period REFERENCE Solution S1 (P1) → ok control

1-period NEW Solutions S1',S1''(P1',P1'') → failure of control

QUASIPERIODIC Solutions C',C'' only AMEs → failure of control



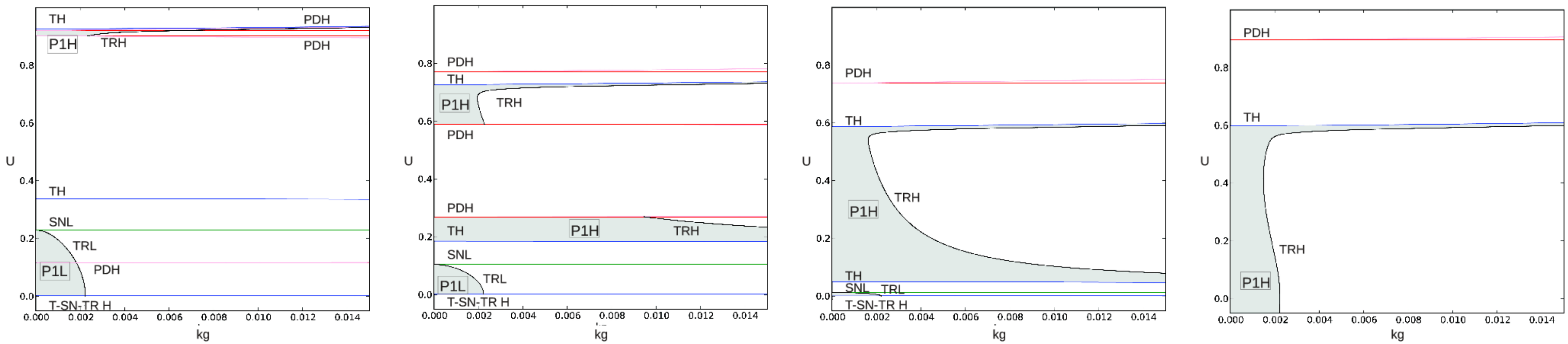


FUNDAMENTAL RESONANCE

k_g - U

WITH VARYING **FORCING FREQUENCY**

$\omega_u = 0.7$ | $\omega_u = 0.76$ | $\omega_u = 0.82$ | $\omega_u = 0.9$



FORCING FREQUENCY

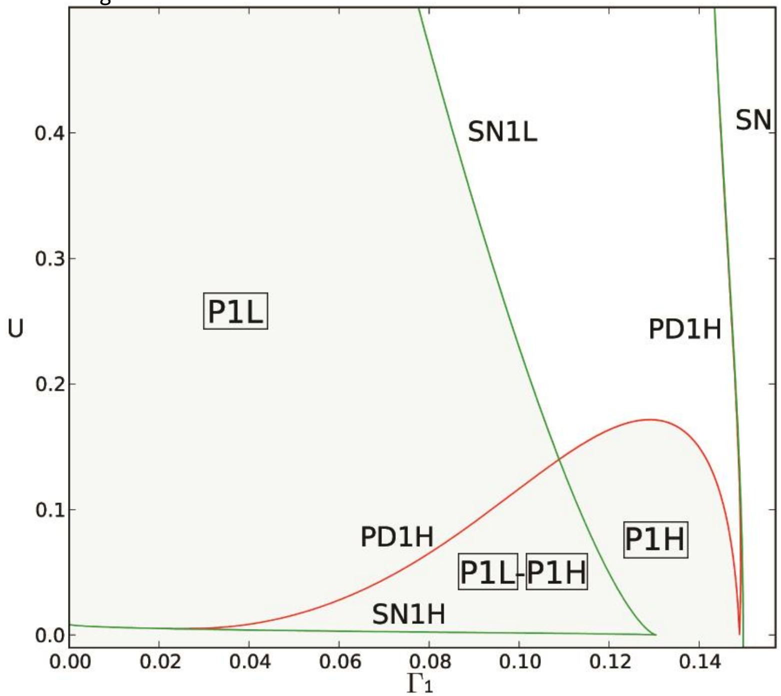
PRESENCE OF **CONFINED STABLE** REGIONS (P1H):
- HIGH U
- HIGH k_G

FUNDAMENTAL RESONANCE

Γ_1 - U

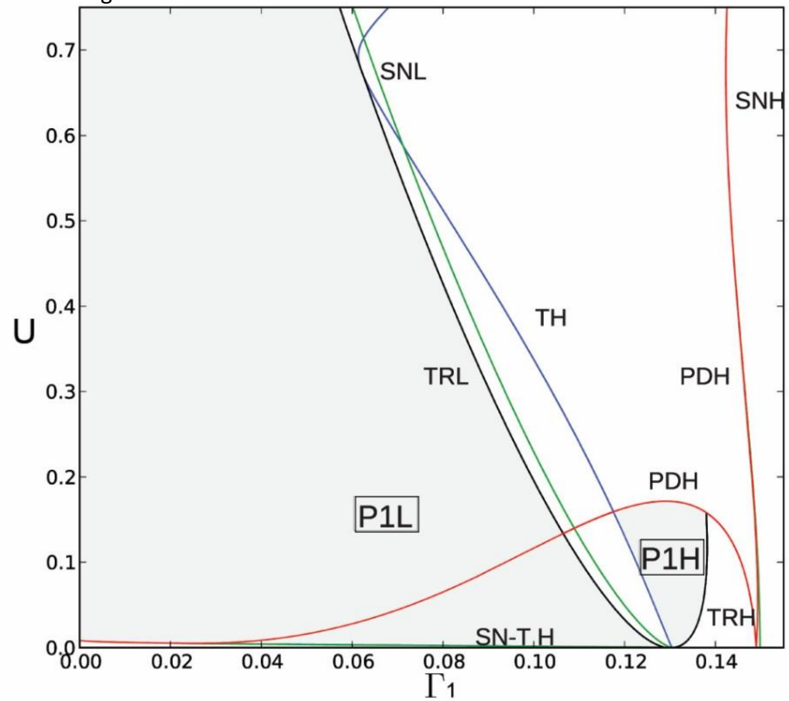
WITH VARYING **ATOMIC INTERACTION**

$k_g = 0$: REFERENCE CONFIGURATION



UNCONTROLLED

$k_g = 0.001$



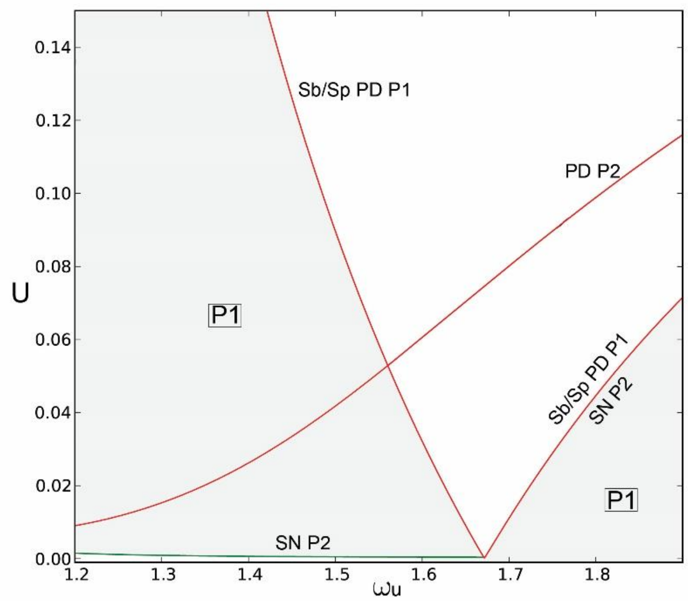
CONTROLLED

PRINCIPAL RESONANCE

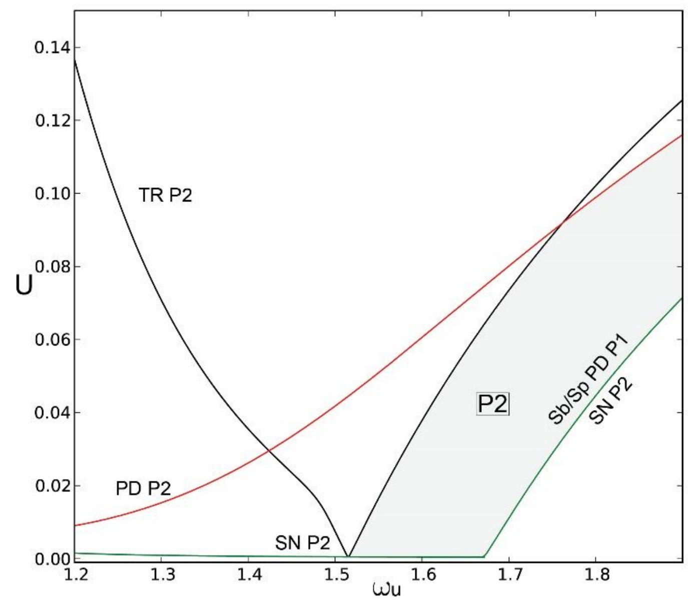
ω_u-U

P1+P2 SOLUTIONS

P1 SOLUTION



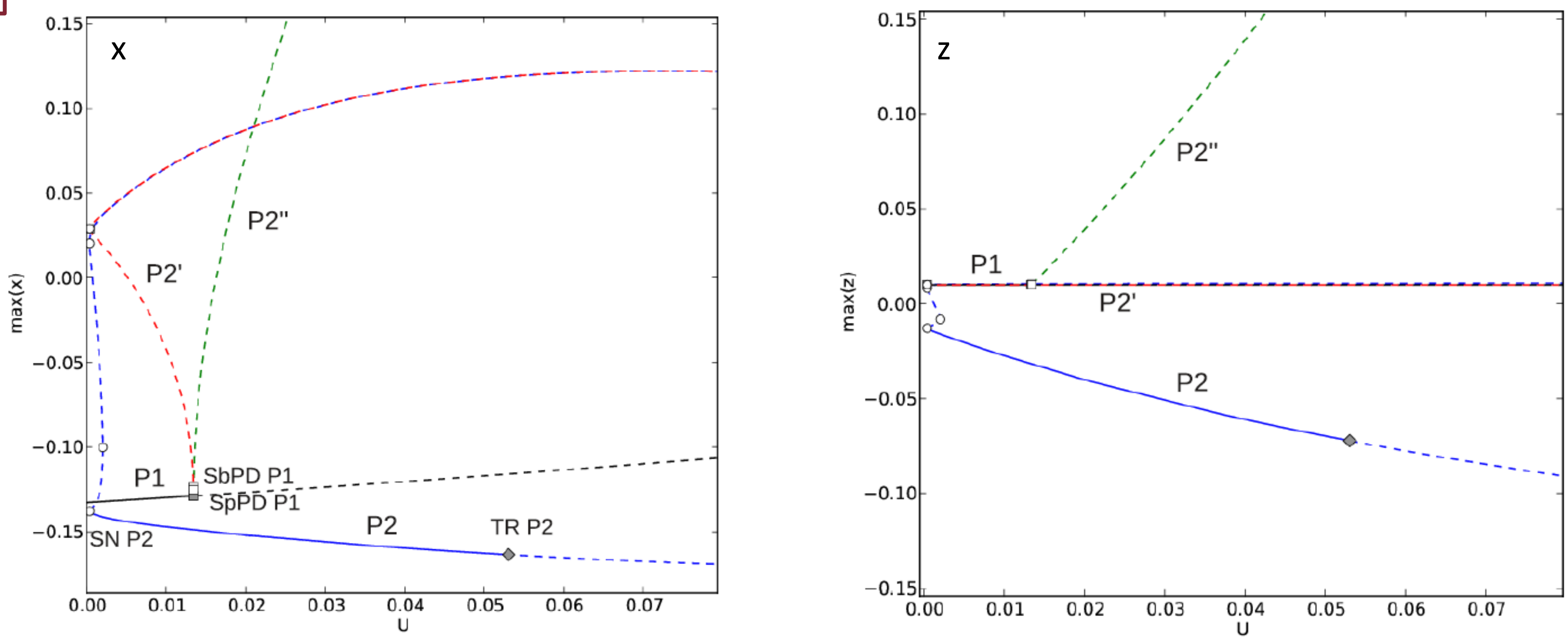
P2 SOLUTION



PRINCIPAL RESONANCE

ω_u-U

BIFURCATION DIAGRAM at ω_u = 1.64 and k_g = 0.001



Three P2 SOLUTIONS: from Subcritical Period Doubling (SbPD P1) **P2'**

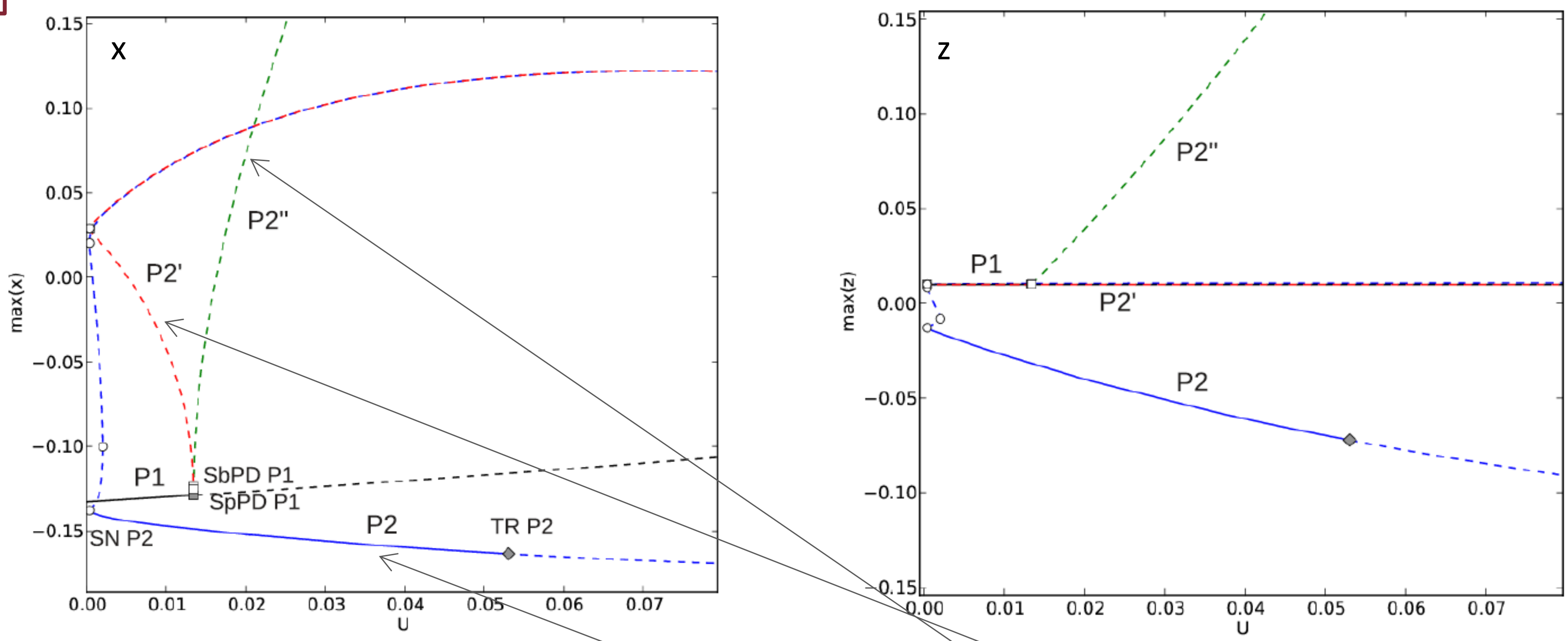
from Supercritical Period Doubling (SpPD P1) **P2''**

disconnected **P2**

PRINCIPAL RESONANCE

ω_u-U

BIFURCATION DIAGRAM at ω_u = 1.64 and k_g = 0.001



Three P2 SOLUTIONS: from Subcritical Period Doubling (SbPD P1) **P2'** UNSTABLE

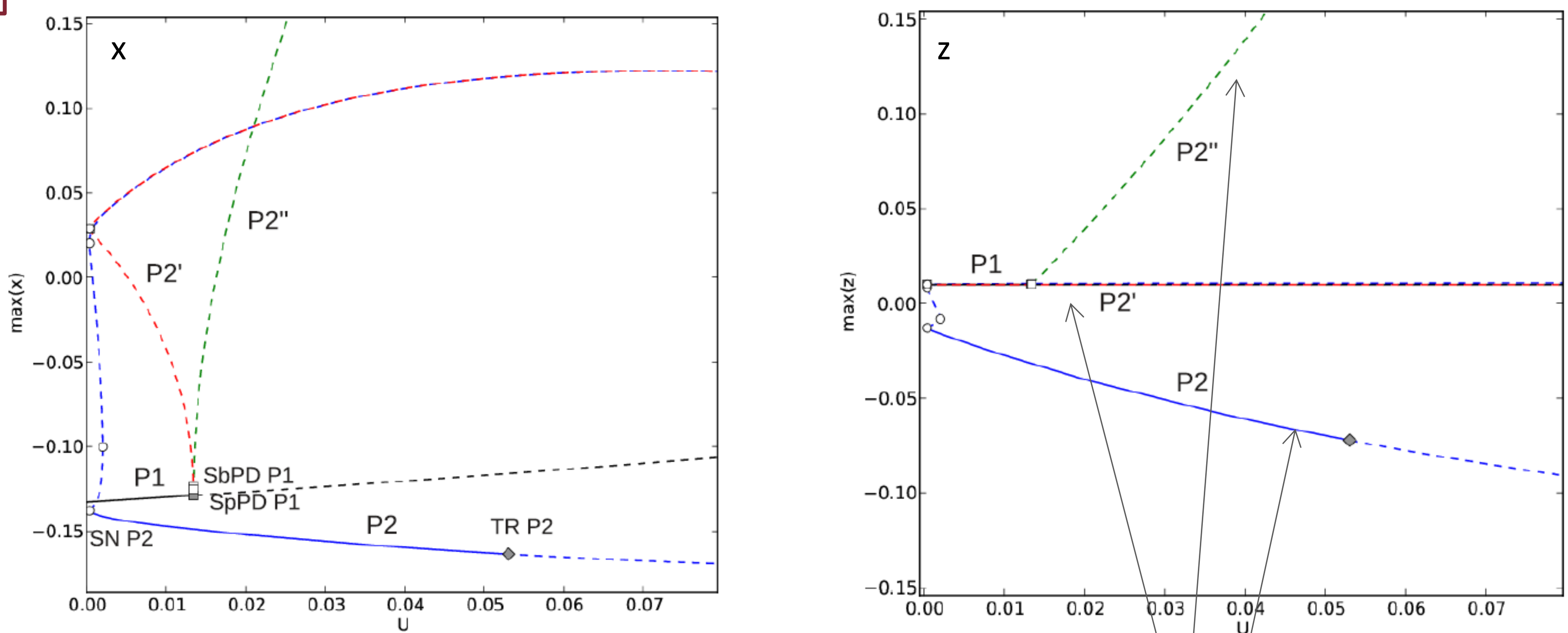
from Supercritical Period Doubling (SpPD P1) **P2''** UNSTABLE

disconnected **P2** STABLE

PRINCIPAL RESONANCE

ω_u-U

BIFURCATION DIAGRAM at ω_u = 1.64 and k_g = 0.001



Three P2 SOLUTIONS: from Subcritical Period Doubling (SbPD P1) **P2’** UNSTABLE OK CONTROL

from Supercritical Period Doubling (SpPD P1) **P2’’** UNSTABLE NO CONTROL

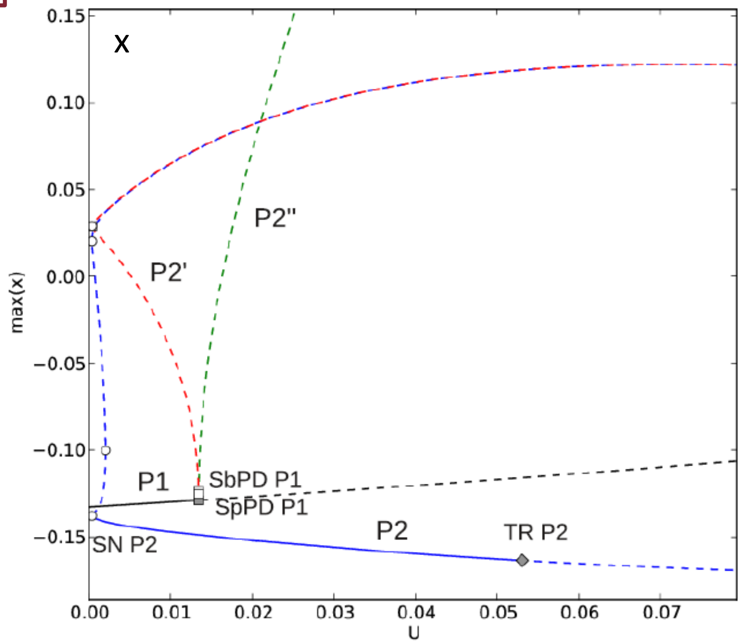
disconnected **P2** STABLE NO CONTROL

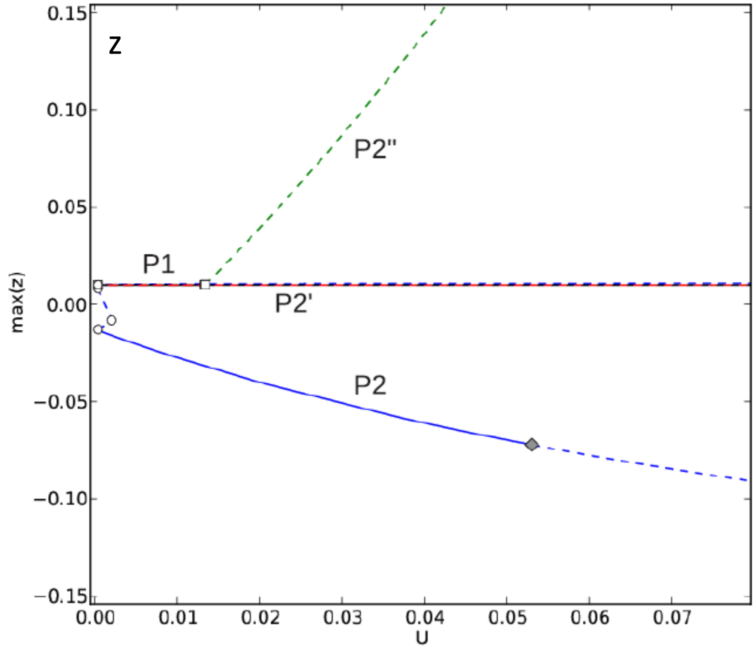
Control works only on P2’, the **only 2-period solution of uncontrolled system**, here unstable

PRINCIPAL RESONANCE

ω_u-U

BIFURCATION DIAGRAM at $\omega_u = 1.64$ and $k_g = 0.001$





Three P2 SOLUTIONS: from Subcritical Period Doubling (SbPD P1)	**P2'**	UNSTABLE	OK CONTROL
from Supercritical Period Doubling (SpPD P1)	**P2''**	UNSTABLE	NO CONTROL
disconnected	**P2**	STABLE	NO CONTROL

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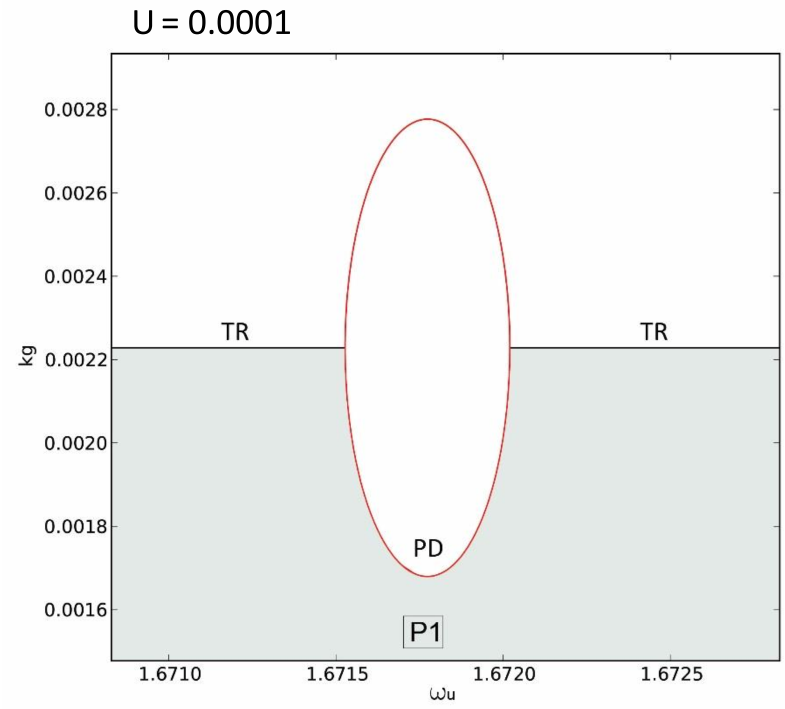
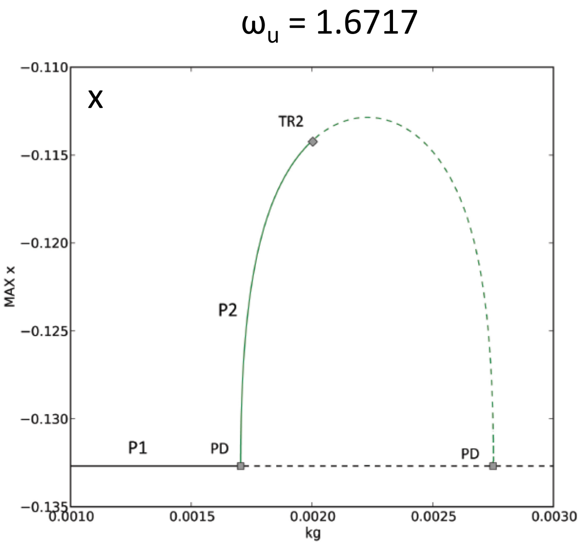
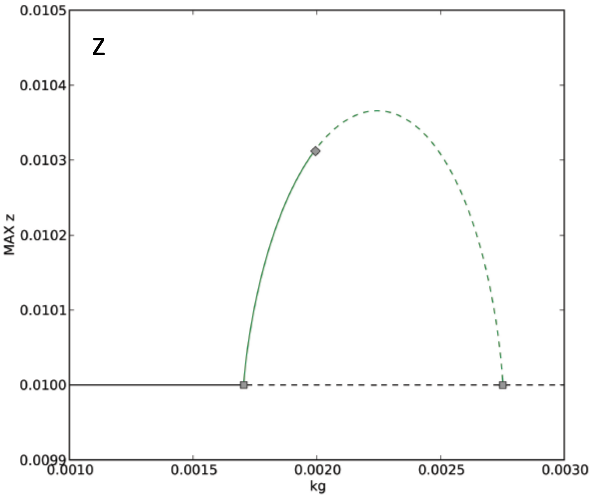
ESCAPE THRESHOLD: RELATED **ONLY** TO **P1** SOLUTION

PRINCIPAL RESONANCE

ω_u- k_g







RESONANCE LOOP : **PERIOD DOUBLING**

- period-doubled solution → coherent with principal resonance
- loop size increased → PRINCIPAL resonance : MAIN region for PARAMETRIC system
  (with respect to fundamental resonance)

EXTERNAL EXCITATION - 1 -

$$\ddot{x}+\alpha_1 x+\alpha_3 x^3=-\Gamma_1\left(1+x+V\sin(\omega_v t)+z-z_s\right)^{-2}-\rho_1\dot{x}$$
$$-\left(-\omega_v^2 V\sin(\omega_v t)+k_g\left(\dot{x}_{ref}-\dot{x}\right)+\nu_1\left(\omega_v V\cos(\omega_v t)+k_g\left(x_{ref}-x\right)\right)\right)\nu_2$$
$$\dot{z}=k_g\left(x_{ref}-x\right)$$

ω_v-V

$\mu_2=\rho_2=0$

$\eta_1=\eta_2=0$

$U_g=\alpha_2=0$

$\alpha_1=1$

$\Gamma_1=0.1$

$\alpha_3=0.1$

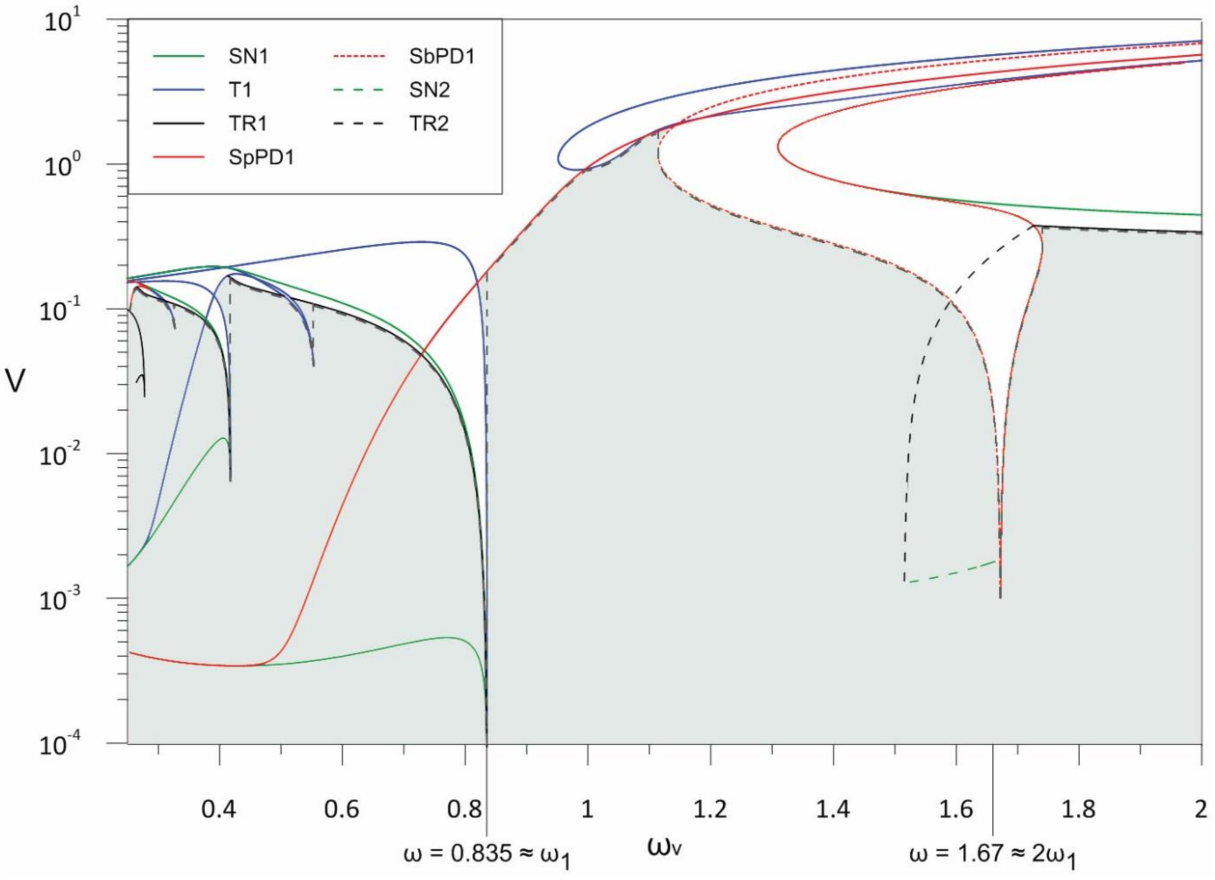
$\nu_1=0.01$

$\nu_2=0.01$

$\omega_1=0.8325$

$k_g=0.001$

$z_s=0.01$



EXTERNAL EXCITATION - 1 -

$$\ddot{x} + \alpha_1 x + \alpha_3 x^3 = -\Gamma_1 \left(1 + x + V\sin(\omega_v t) + z - z_s\right)^{-2} - \rho_1 \dot{x}$$
$$-\left(-\omega_v^2 V \sin(\omega_v t) + k_g\left(\dot{x}_{ref} - \dot{x}\right) + \nu_1\left(\omega_v V\cos(\omega_v t) + k_g\left(x_{ref} - x\right)\right)\right)\nu_2$$
$$\dot{z} = k_g\left(x_{ref} - x\right)$$

ω_v-V

$\mu_2 = \rho_2 = 0$

$\eta_1 = \eta_2 = 0$

$U_g = \alpha_2 = 0$

$\alpha_1 = 1$

$\Gamma_1 = 0.1$

$\alpha_3 = 0.1$

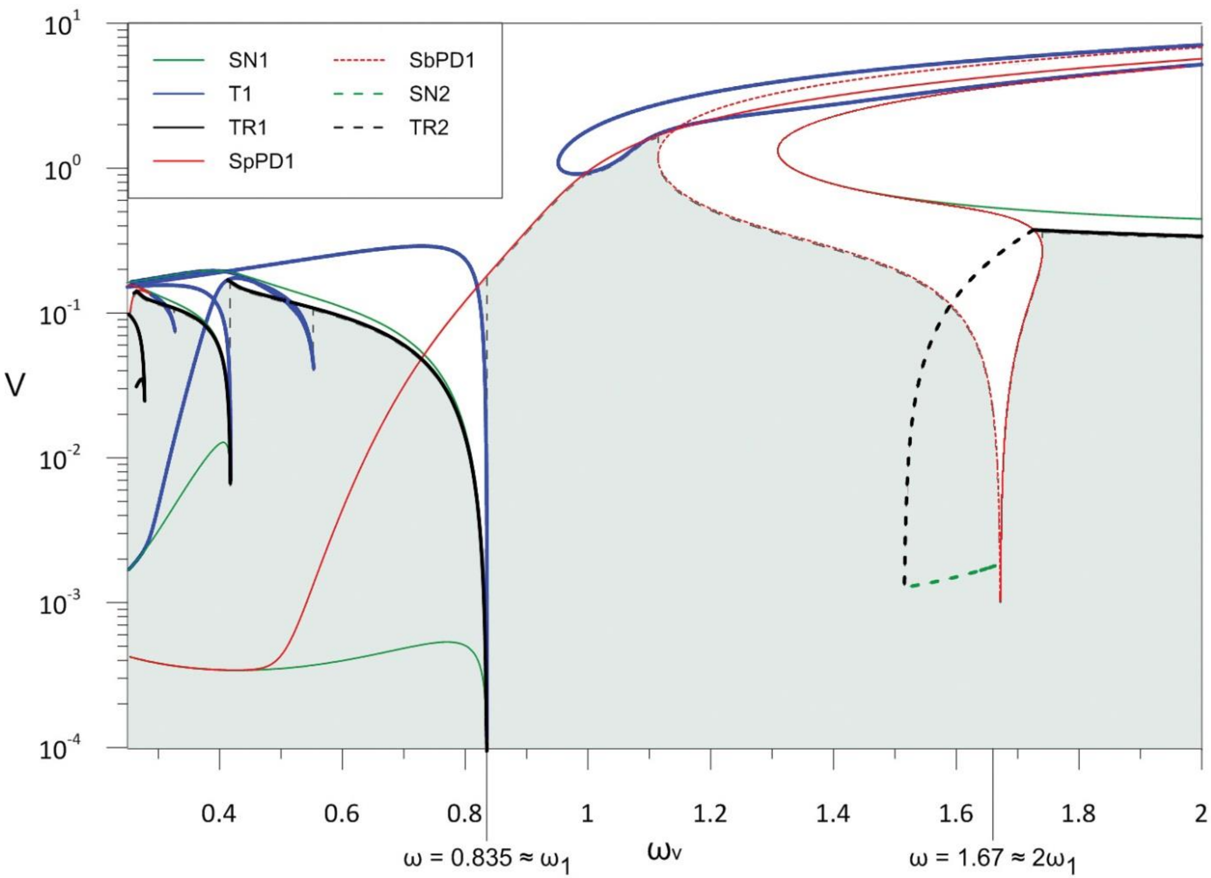
$\nu_1 = 0.01$

$\nu_2 = 0.01$

$\omega_1 = 0.8325$

$k_g = 0.001$

$z_s = 0.01$



SAME BEHAVIOR OF PARAMETRIC CASE

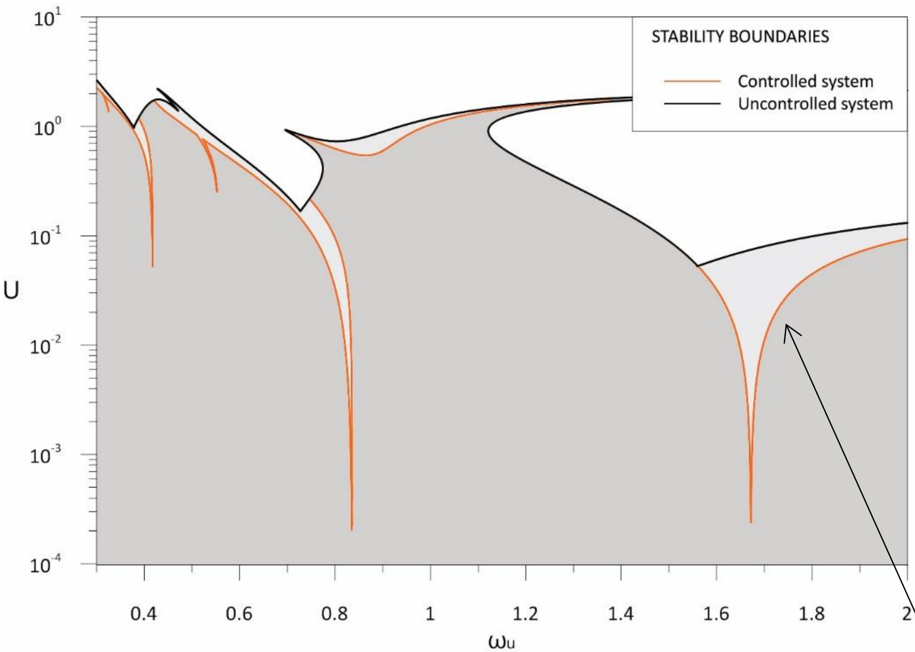
NEW **TRANSCRITICAL** AND **TORUS** THRESHOLDS

DECREASE OF ESCAPE VALUE

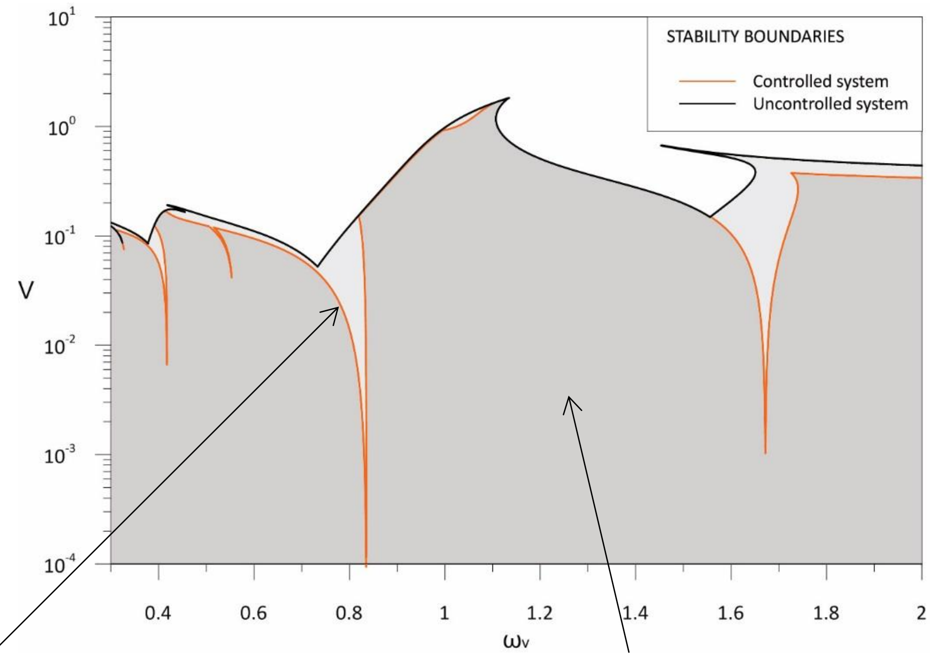
STABLE REGION: solutions for which FEEDBACK CONTROL WORKS PROPERLY

STABILITY REGIONS WITH/WITHOUT CONTROL

PARAMETRIC EXCITATION



EXTERNAL EXCITATION



MAIN RESONANCE FREQUENCIES: deep **INSTABILITY TONGUES**

→ reductions of ≈ 99,9%

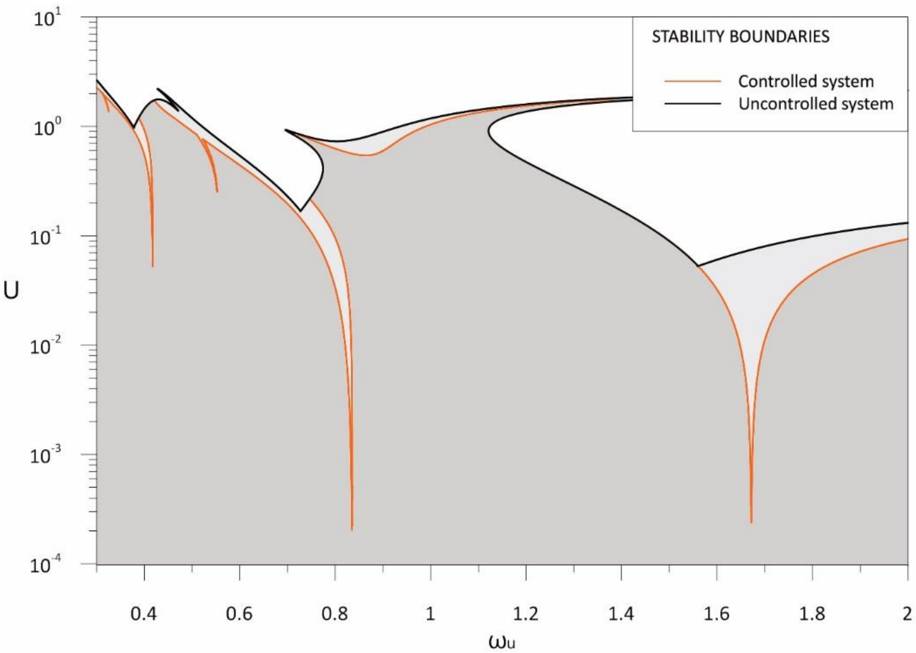
stable region:

solutions for which **feedback control works properly**

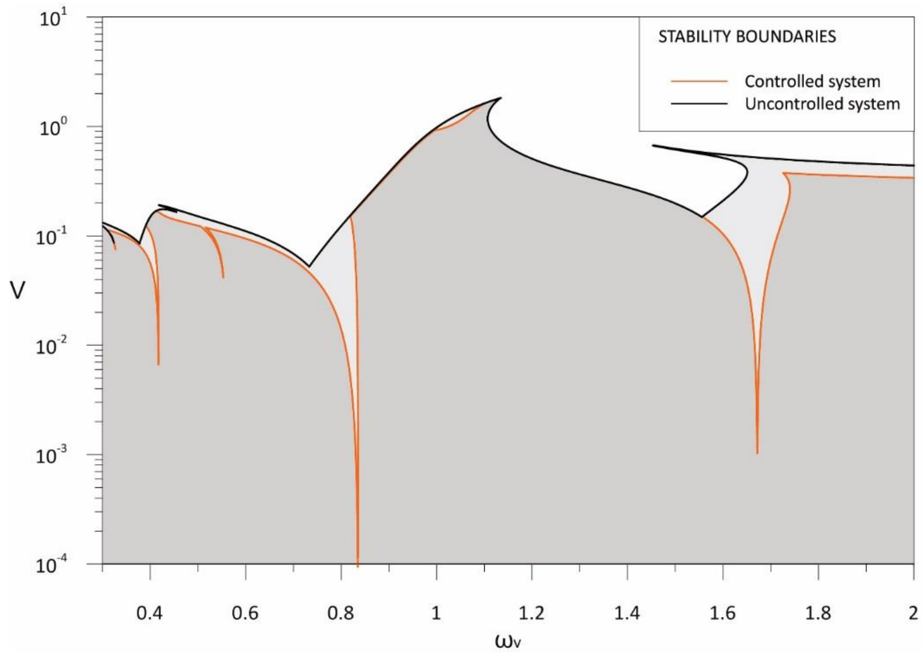
due to a substantial **increase of response amplitude** that **LOCAL feedback control barely dominates** ➡ **need** of a **GLOBAL control !?**

STABILITY REGIONS WITH/WITHOUT CONTROL

PARAMETRIC EXCITATION



EXTERNAL EXCITATION



STABILITY of **CONTROLLED SYSTEM**: **ONLY** solutions on which the **CONTROL** works **PROPERLY**

AROUND $\mathbf{2\omega_1}$ **:** **UNCONTROLLED** : governed by **P2** response

CONTROLLED : ESCAPE related to **P1** solution

P2 solution **NOT acceptable**

ADDITIONAL REDUCTION OF ESCAPE VALUE

DYNAMICAL INTEGRITY OF THE CONTROLLED SYSTEM

AIM:

- complete the evaluation of the **GLOBAL PERFORMANCE** of a **LOCAL** external feedback **CONTROL** technique
- properly identify the **DESIGN PARAMETERS** RANGES able to guarantee the **SECURE OPERATION** of the AFM

NUMERICAL ANALYSES:

- BASINS EROSION PROCESS as a function of the most relevant dynamical parameters around the resonance frequency
- EROSION PROFILES by means of two integrity measures (IF, GIM)
- THRESHOLDS of RESIDUAL INTEGRITY in system parameters space

CONTROLLED SYSTEM UNDER PARAMETRIC EXCITATION (HARMONIC)

Orders of magnitude of coefficients in commercial AFMs → feedback controls (η_1, η_2, ρ_2) and the nonlinear term related to α_2 can be neglected

$$\begin{cases} \dot{x}=y \\ \dot{y}=-\alpha_1 x-\alpha_3 x^3 \boxed{-\dfrac{\Gamma_1}{(1+x+z-z_s)^2}} -\rho_1 y - x\mu_1\omega_u^2 U\sin(\omega_u t) \\ \boxed{\dot{z}=k_g\left(x_{ref}-x\right)} \\ \dot{x}_{ref}=y_{ref} \\ \dot{y}_{ref}=-\alpha_1 x_{ref}-\alpha_3 x_{ref}{}^3-\dfrac{\Gamma_1}{(1+x_{ref})^2}-\rho_1 y_{ref}-x_{ref}\mu_1\omega_u^2 U\sin(\omega_u t) \end{cases}$$

EXTERNAL FEEDBACK CONTROL

REFERENCE RESPONSE

5 state variables → **5-DIMENSIONAL BASINS OF ATTRACTION**

- COMPUTATIONALLY DEMANDING task
- RESULTS INTERPRETATION considerably DIFFICULT

⇓

PLANAR SECTIONS in ($x=x_{\mathrm{ref}}$, $y=y_{\mathrm{ref}}$) plane with fixed z

BASIN EROSION FOR INCREASING FORCING AMPLITUDE (ω_u=0.8)

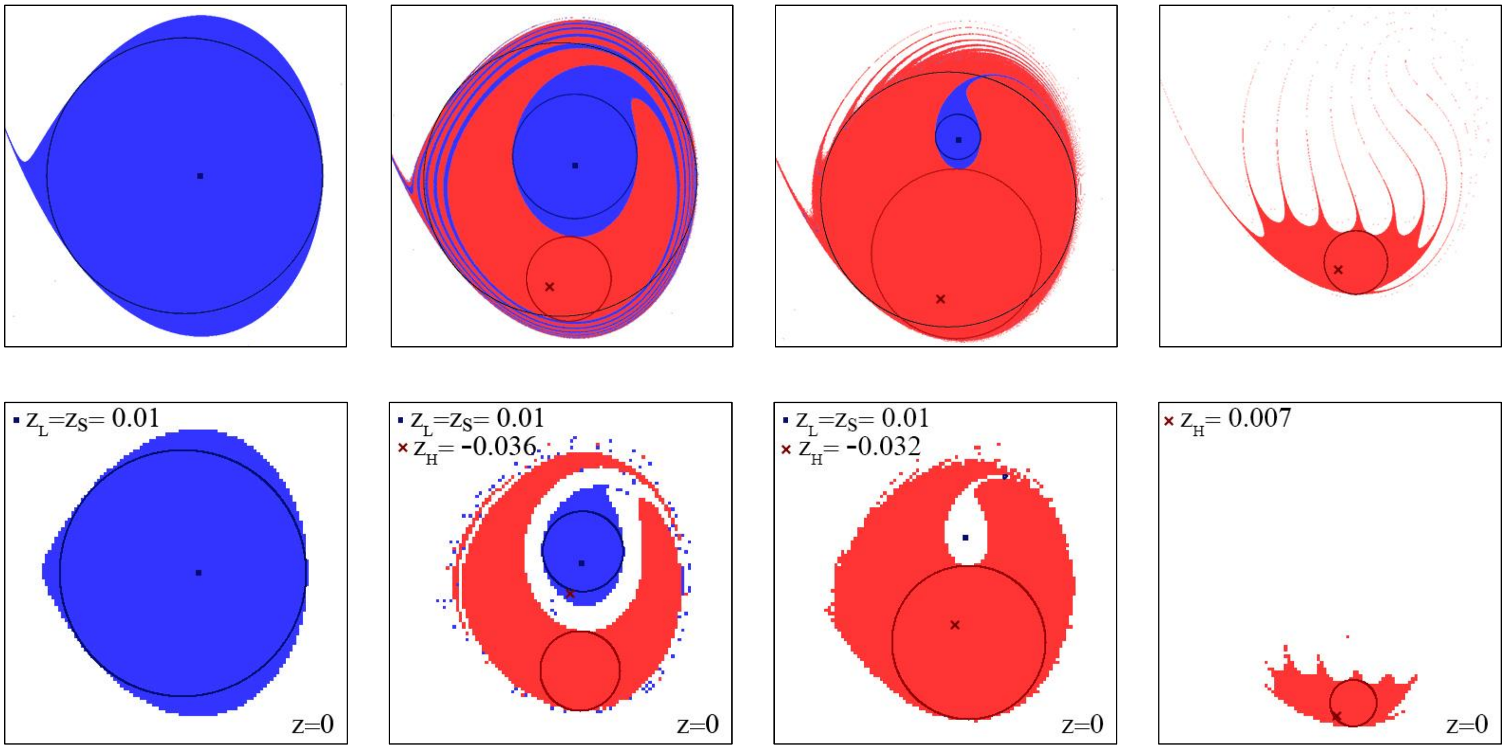
FORCING AMPLITUDE

REFERENCE (UNCONTROLLED) SYSTEM

CONTROLLED SYSTEM

$z(0) = 0$

$z_s = 0.01$



INFLUENCE OF THE EXCITATION PARAMETERS - 1 -

BASIN EROSION FOR INCREASING FORCING AMPLITUDE (ω_u=0.8)

FORCING AMPLITUDE

REFERENCE (UNCONTROLLED) SYSTEM

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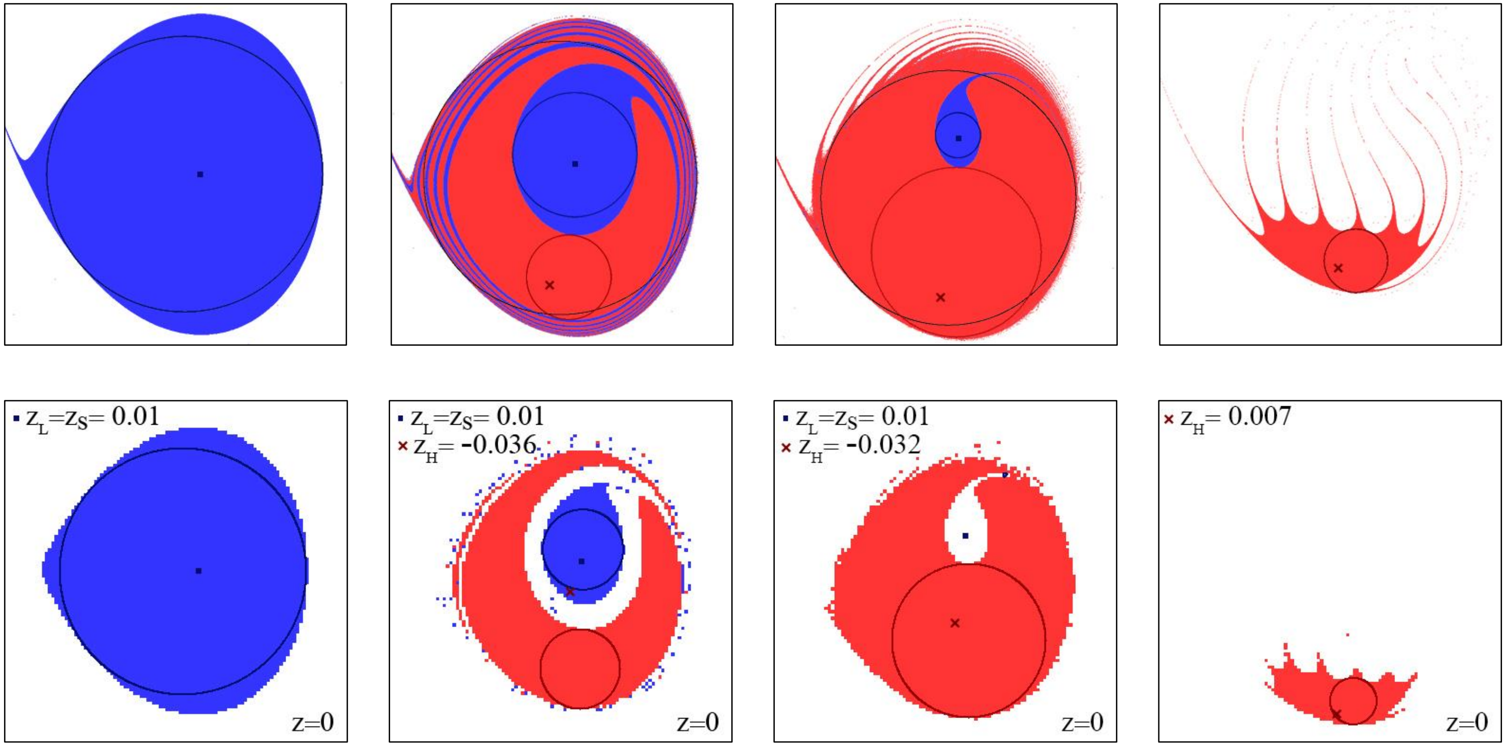
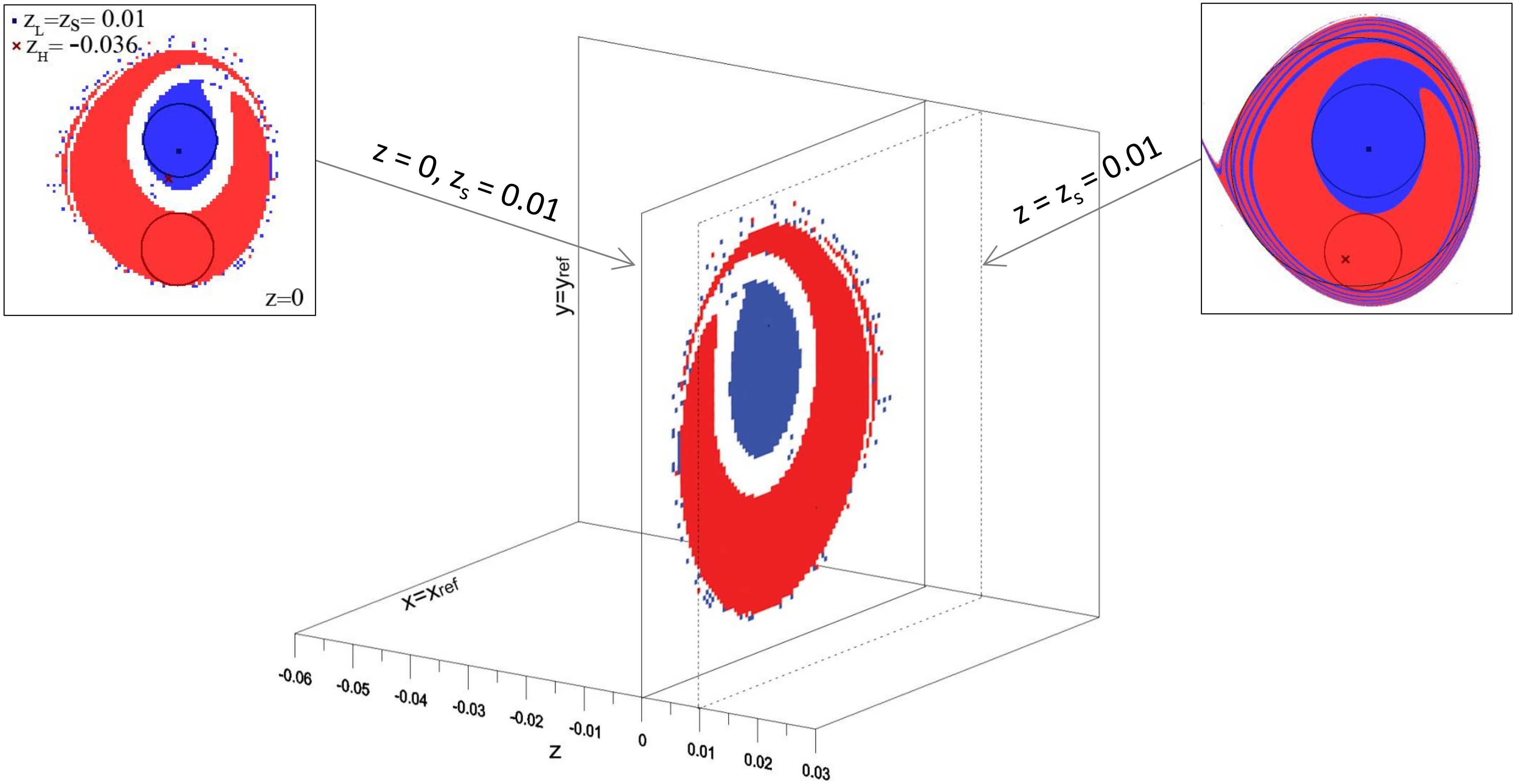


- **CONTROL**: **TONGUES** of the **UNBOUNDED** solution basin (white) inside the potential well
- BASIN SEPARATION for LOW amplitude
- **NONRESONANT** basin: strongly **REDUCED** $\rightarrow$ **TOPOLOGICAL** SCENARIO **MODIFIED**

INFLUENCE OF THE EXCITATION PARAMETERS - 2 -

BASIN EROSION FOR INCREASING FORCING AMPLITUDE (ω_u=0.8)

Phase-plane of the uncontrolled system



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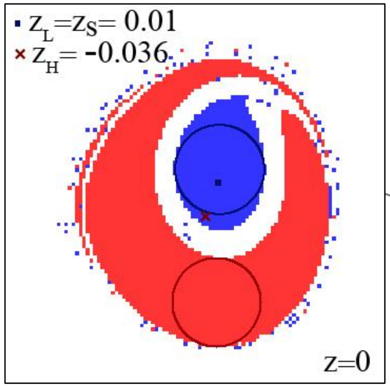
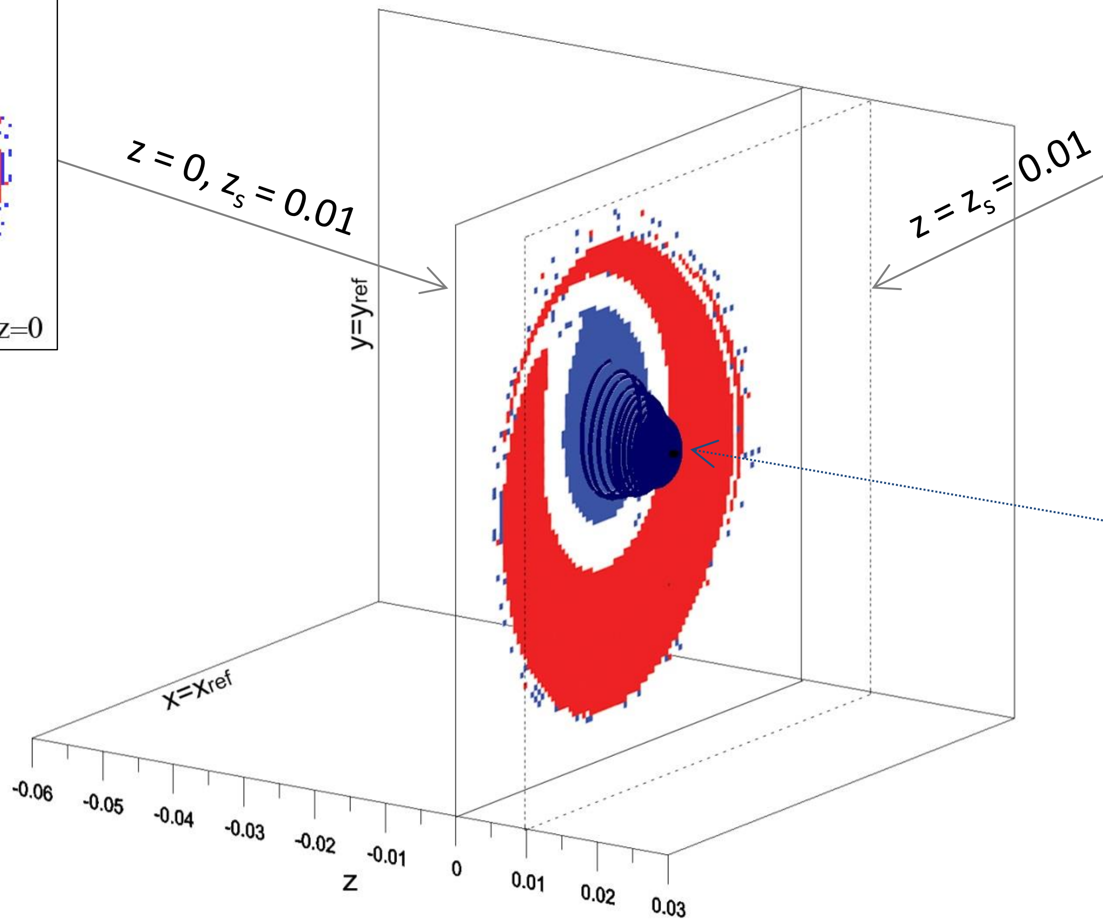
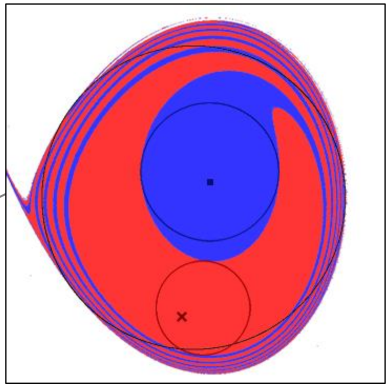




Phase-plane of the uncontrolled system



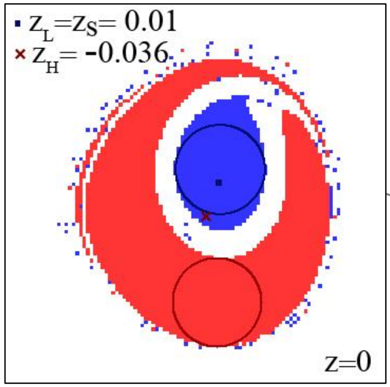
NONRESONANT SOLUTION:

$z = z_s$

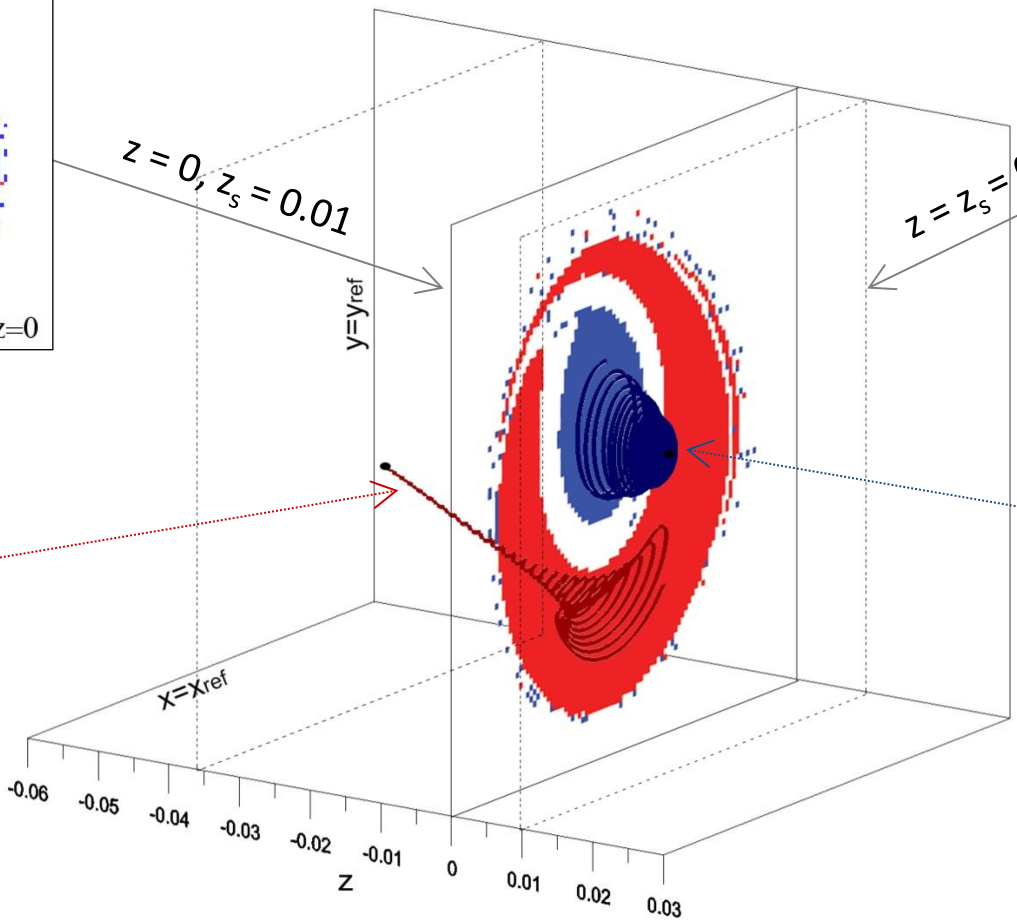
EFFICIENCY of CONTROL

SAFE BASIN

BASIN EROSION FOR INCREASING FORCING AMPLITUDE (ω_u=0.8)

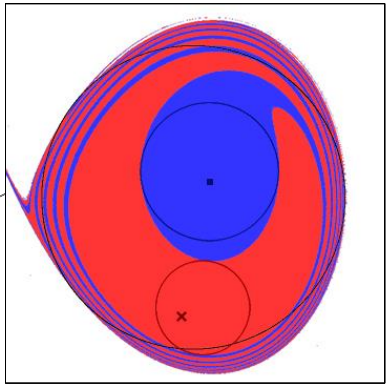


z = 0, z_s = 0.01



z = z_s = 0.01

Phase-plane of the uncontrolled system



RESONANT SOLUTION:

$z \neq z_s$

INEFFICIENCY of CONTROL

⇩

UNACCEPTABLE

NONRESONANT SOLUTION:

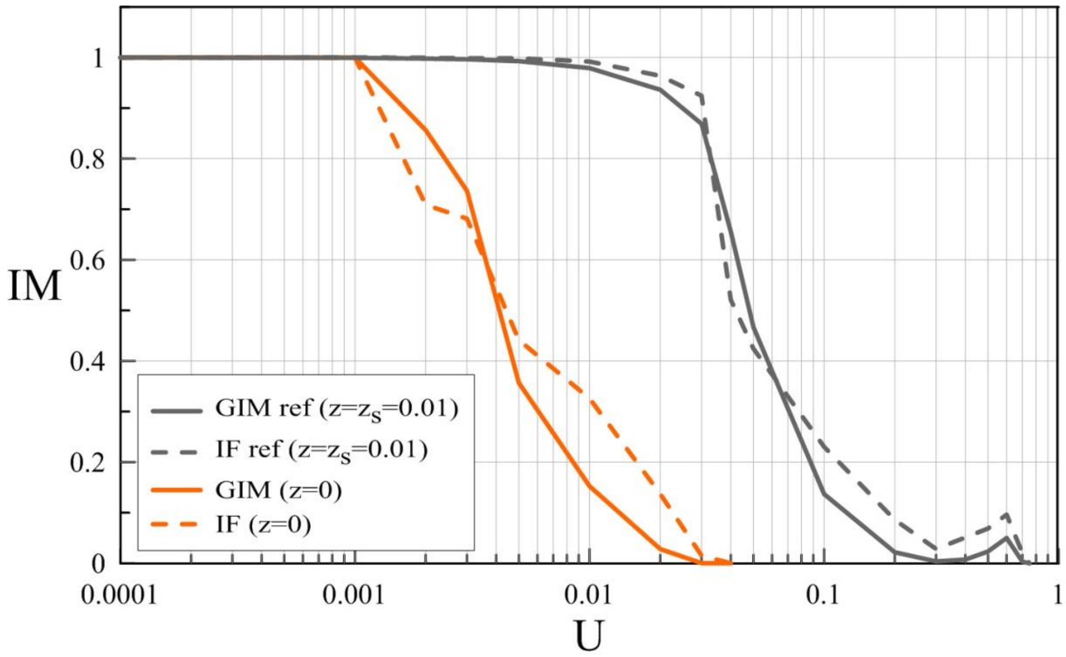
$z = z_s$

EFFICIENCY of CONTROL

⇩

SAFE BASIN

EROSION PROFILES FOR INCREASING FORCING AMPLITUDE (ω_u=0.8)



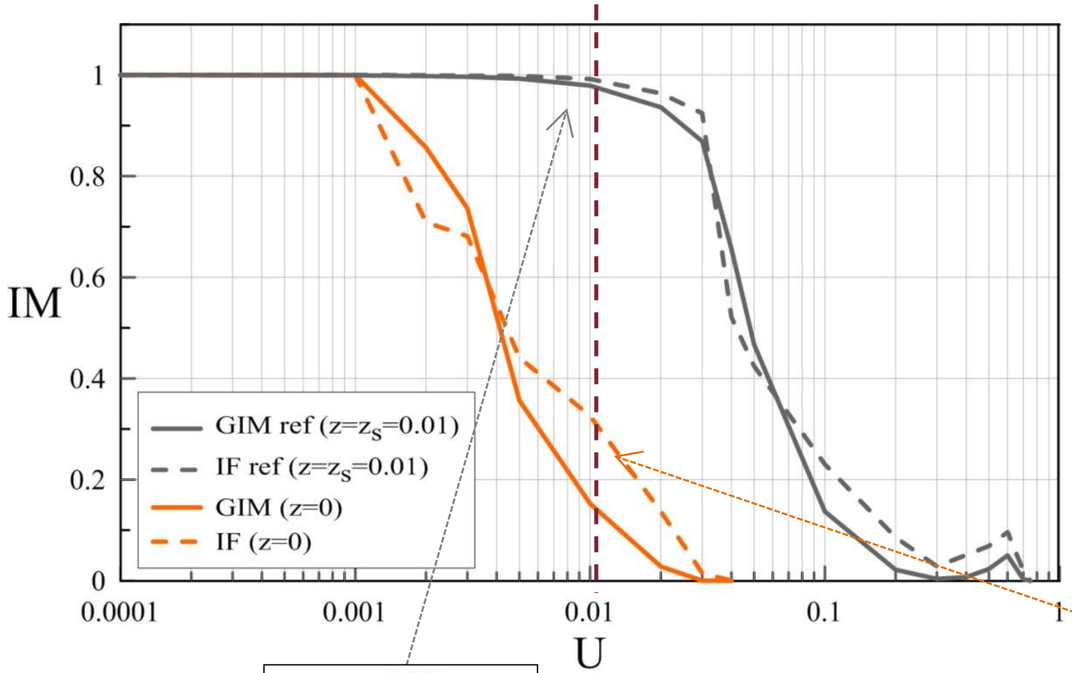
INTEGRITY MEASURES

Global Integrity Measure (**GIM**):
normalized AREA of the safe basin

Integrity Factor (**IF**):
normalized RADIUS of the largest CIRCLE entirely BELONGING to the safe basin (sole compact part)

INFLUENCE OF THE EXCITATION PARAMETERS - 3 -

EROSION PROFILES FOR INCREASING FORCING AMPLITUDE (ω_u=0.8)



INTEGRITY MEASURES

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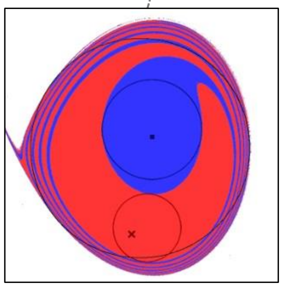
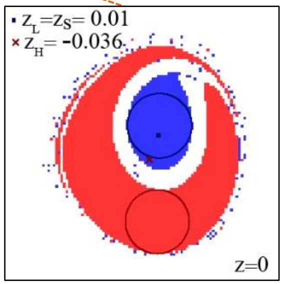
SAFE BASIN



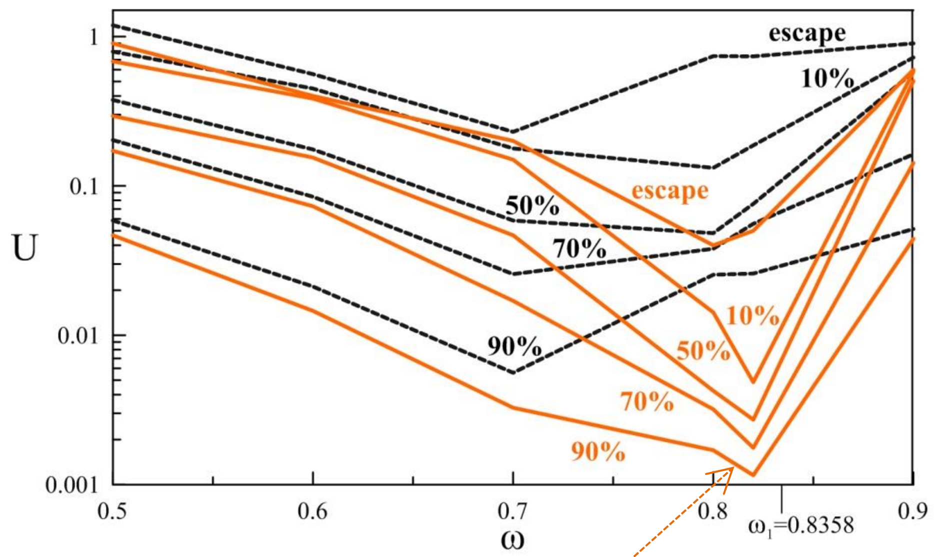
UNCONTROLLED system: **RESONANT** + **NONRESONANT** basins



CONTROLLED system: **NONRESONANT** basin

CONTROLLED SYSTEM : much **MORE DANGEROUS** THAN the UNCONTROLLED one

RESIDUAL ISO-INTEGRITY CURVES



AROUND **RESONANCE FREQUENCY**: severe **WORSENING** of **PRACTICAL STABILITY**

(residual integrity from 90% to 10% in $\Delta U = 3.6 \cdot 10^{-3}$)

SHIFT of **LOWEST PEAK** from nonlinear (**uncontrolled**) to linear (**controlled**) resonance frequency

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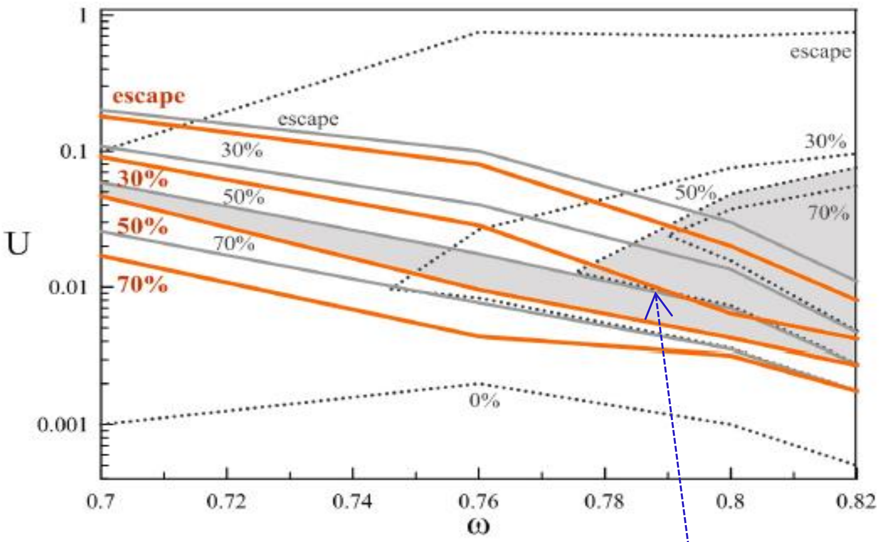

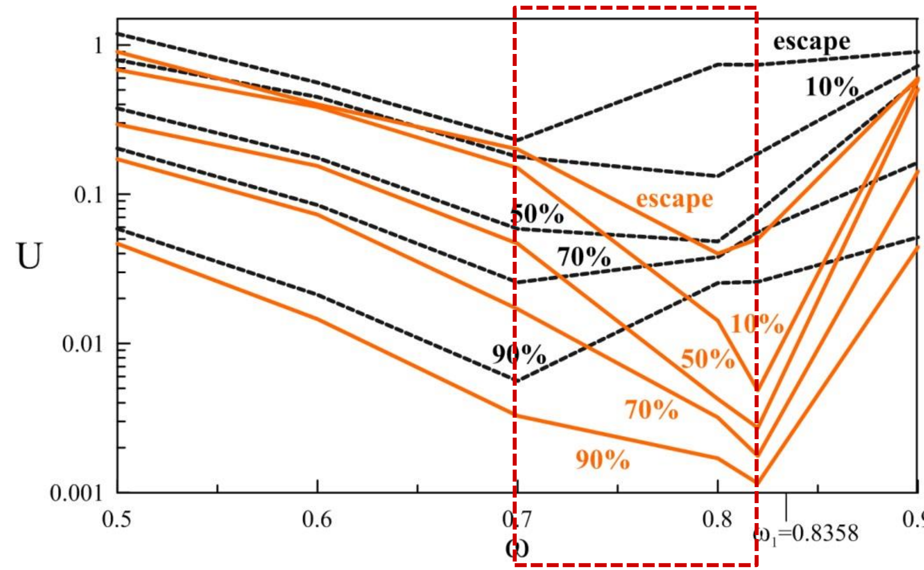

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SHIFT of **LOWEST PEAK** from nonlinear (**uncontrolled**) to linear (**controlled**) resonance frequency

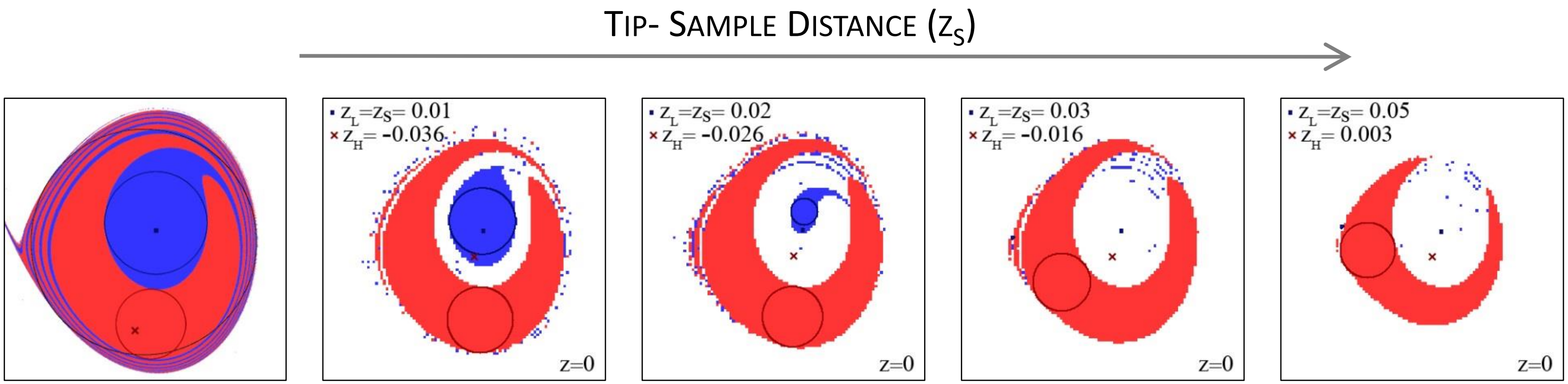
RESONANT solution P1H: **no longer acceptable** for the system

NONRESONANT solution P1L: **solely governing** the response robustness

Meaningful loss of controlled (orange curves) **stability domain with respect to uncontrolled** (grey curves) **one for given** (e.g. 50%) **iso-integrity**

INFLUENCE OF TIP-SAMPLE DISTANCE

- DEPENDENCE on the ROUGHNESS of the SAMPLE to be scanned → high VARIABILITY during the AFM scanning OPERATION
- its EFFECT on the global behavior: particularly IMPORTANT to assess the system ACTUAL SAFETY in operating conditions



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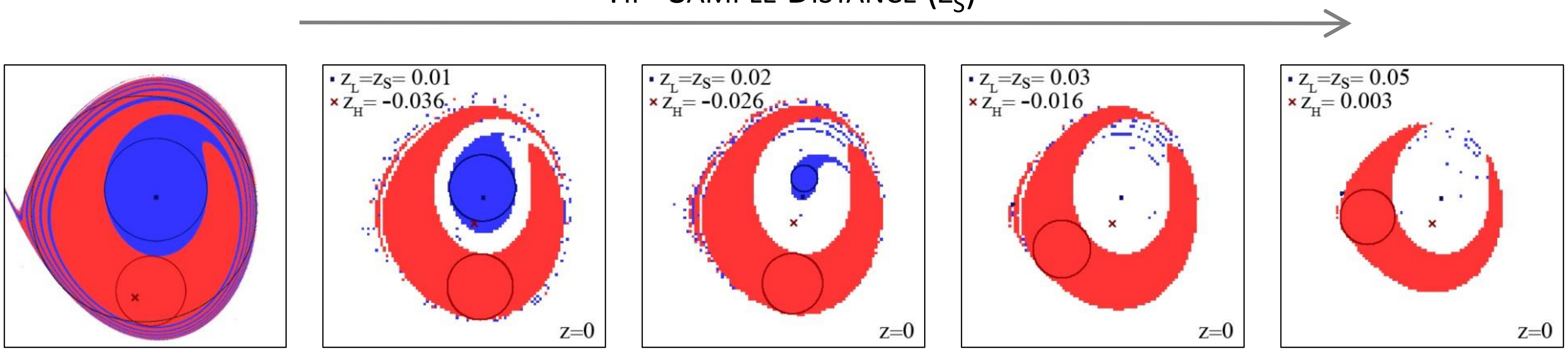
TIP- SAMPLE DISTANCE (z_S)



TIP-SAMPLE DISTANCE INCREASE → **ENLARGEMENT** of the **UNBOUNDED** solution basin (white)

→ **REDUCTION** of the **NONRESONANT** (controllable) basin (blue) up to its disappearance

INFLUENCE OF INTRINSIC PARAMETERS - 1 -

INFLUENCE OF TIP-SAMPLE DISTANCE

- **NONRESONANT** profile: much **LOWER** than RESONANT profile
- **BASIN EROSION**: from the outer edge preserving the compact part of the basins

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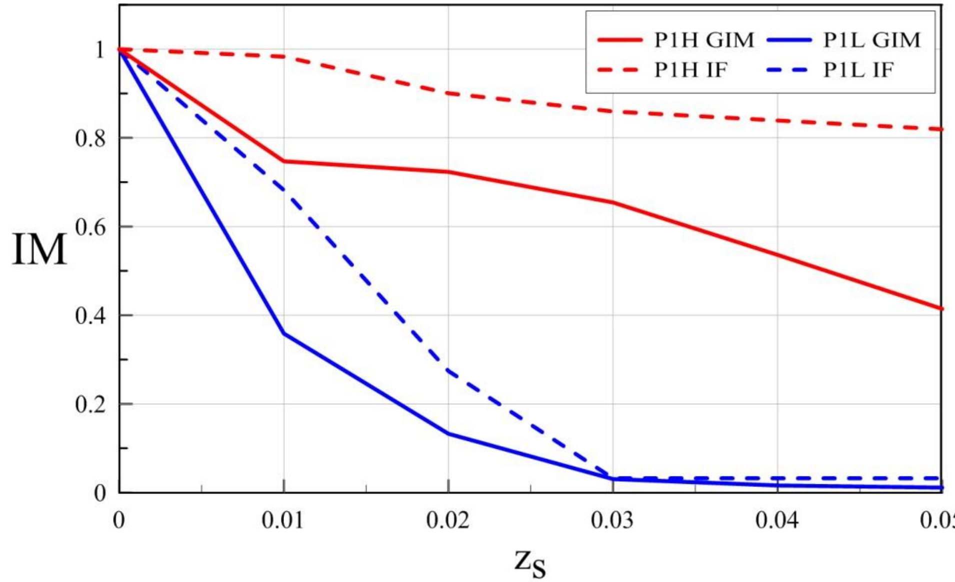
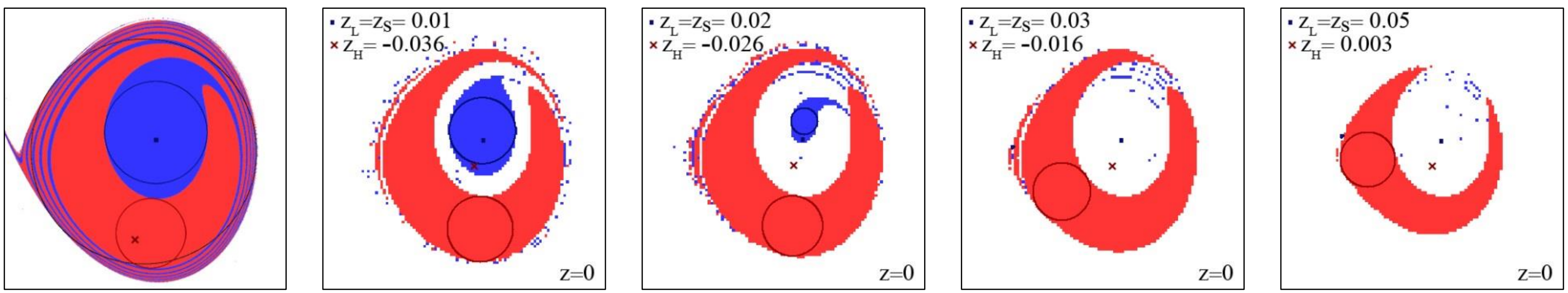
GIM more **CONSERVATIVE** than IF





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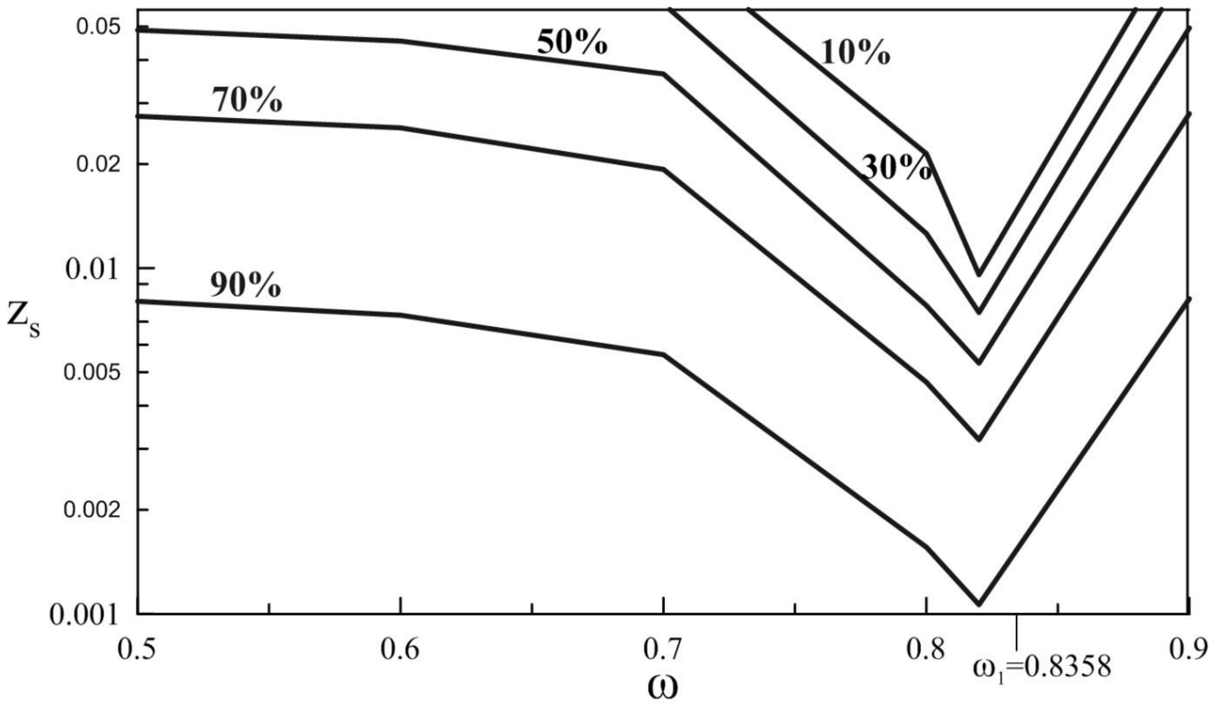

RESONANCE REGION: **CRITICAL** also with respect to VARIATION of the TIP-SAMPLE DISTANCE

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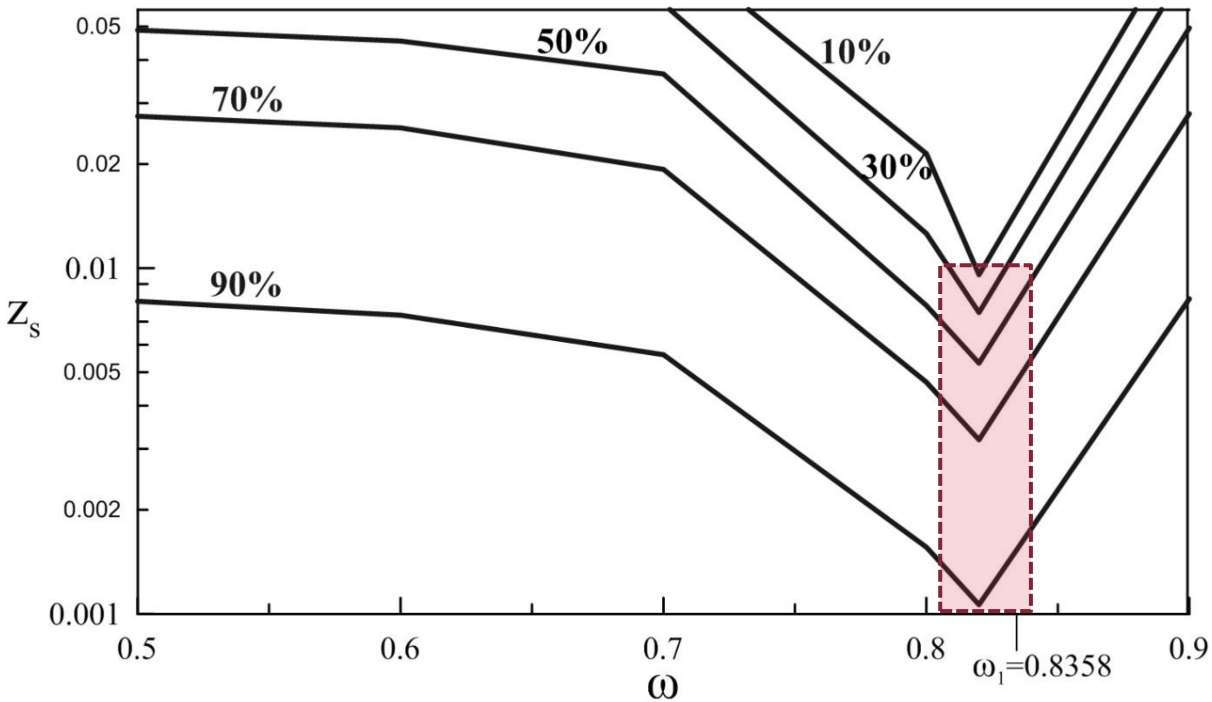
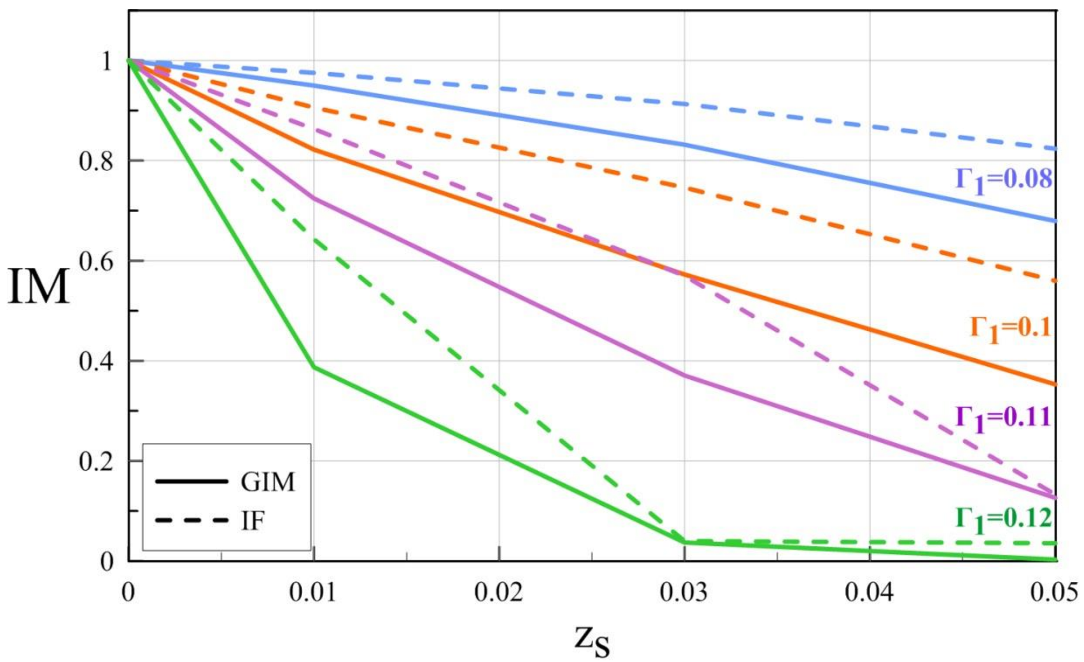


RESONANCE REGION: **CRITICAL** also with respect to VARIATION of the TIP-SAMPLE DISTANCE

z_s from **0 (uncontrolled)** to **0.01** → **DYNAMICAL INTEGRITY** from **100%** to **10%**

INFLUENCE OF NONLINEAR INTERACTION (Γ_1)

- Depends on tip and sample materials and on their distance at nanoscale level
- Characterizing ingredient of an AFM model



INFLUENCE OF NONLINEAR INTERACTION (Γ_1)

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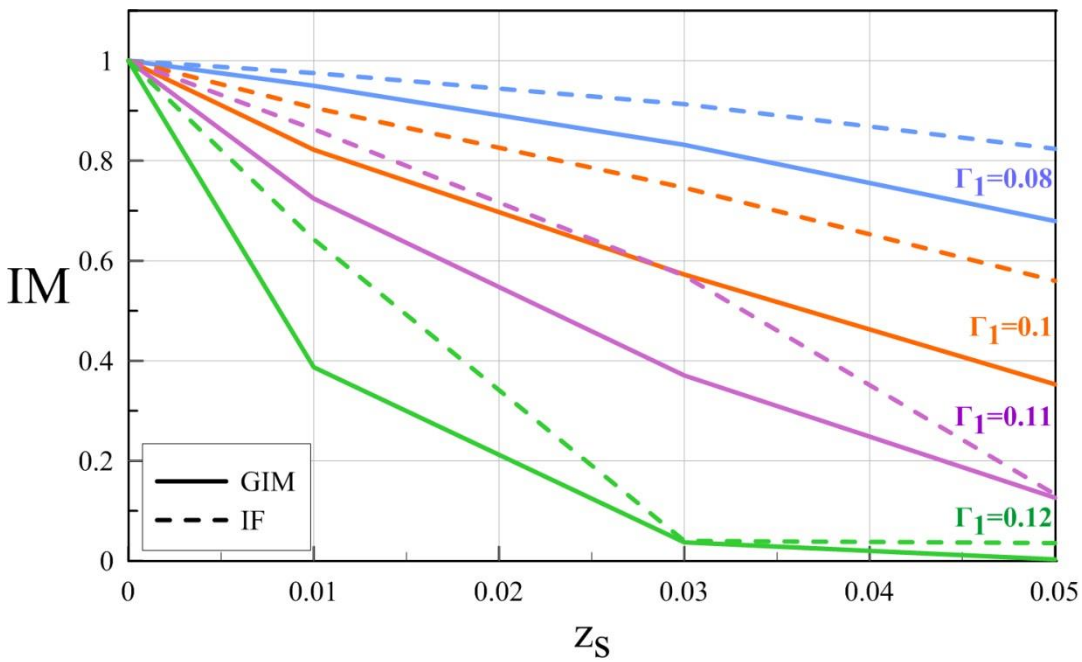
- Characterizing ingredient of an AFM model

- **INCREASE** of Γ_1 or z_s $\rightarrow$ evident **NEGATIVE** effect on the system **ROBUSTNESS**
- **Safe z_s** value becomes **smaller** as the atomic interaction **Γ_1 increases**



INFLUENCE OF INTRINSIC PARAMETERS - 3 -

INFLUENCE OF NONLINEAR INTERACTION (Γ_1)

- Depends on tip and sample materials and on their distance at nanoscale level
- Characterizing ingredient of an AFM model

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⇩

PRACTICAL CONSEQUENCES:

- **ROUGH** sample **SURFACE** and/or a **STRONG** atomic tip-sample **INTERACTION** represent **DANGEROUS** situations for the application of the external feedback control to an AFM
- useful **HINTS** to **CALIBRATE** the tip-sample interaction (e.g., tip material choice) depending of the sample characteristics

STRONGLY NONLINEAR DYNAMICS OF AFM WITH EXTERNAL FEEDBACK CONTROL

- STRONGLY NONLINEAR DYNAMICS analysis for **PARAMETRICAL** and **EXTERNAL** excitation, around **PRIMARY** and **SUBHARMONIC** resonances

RESULTS:

- INCREASED D.O.F. : **RICHER BIFURCATIVE SCENARIO**
- New TORUS and TRANSCRITICAL bifurcations: **STABILITY BOUNDARY REDUCTION**
- **ESCAPE THRESHOLD**: **DEPENDENT** on the **ACTUAL** existence of **SOLUTIONS** which are the **GOAL** of the **CONTROL** procedure
- **CONTROL WORKS PROPERLY** for **SPECIFIC DESIGN PURPOSES**, but **STRONGLY REDUCES ESCAPE THRESHOLD** when operating at resonances

GLOBAL DYNAMICS OF NONCONTACT AFM WITH EXTERNAL FEEDBACK CONTROL

- **DYNAMICAL INTEGRITY** as a function of the most relevant system parameters
- CROSS SECTIONS of 5D basins of attraction
- **BASIN EROSION** and **INTEGRITY CHARTS** providing thresholds of constant residual integrity
- **COMPARISON** with the results already obtained for the **UNCONTROLLED** system to highlight changes and criticalities in the system global response due to the control

RESULTS:

- Generalized **DETRIMENTAL EFFECT** of the **CONTROL** on the system **ROBUSTNESS**
- **RESONANCE REGION: CRITICAL**
  - → COEXISTENCE of resonant and nonresonant solutions DISAPPEARS
  - → SMALL PERTURBATIONS of parameters → DRAMATIC CHANGES in the system SAFETY

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NEXT LECTURE

GLOBAL DYNAMICS-BASED CONTROL of AFM