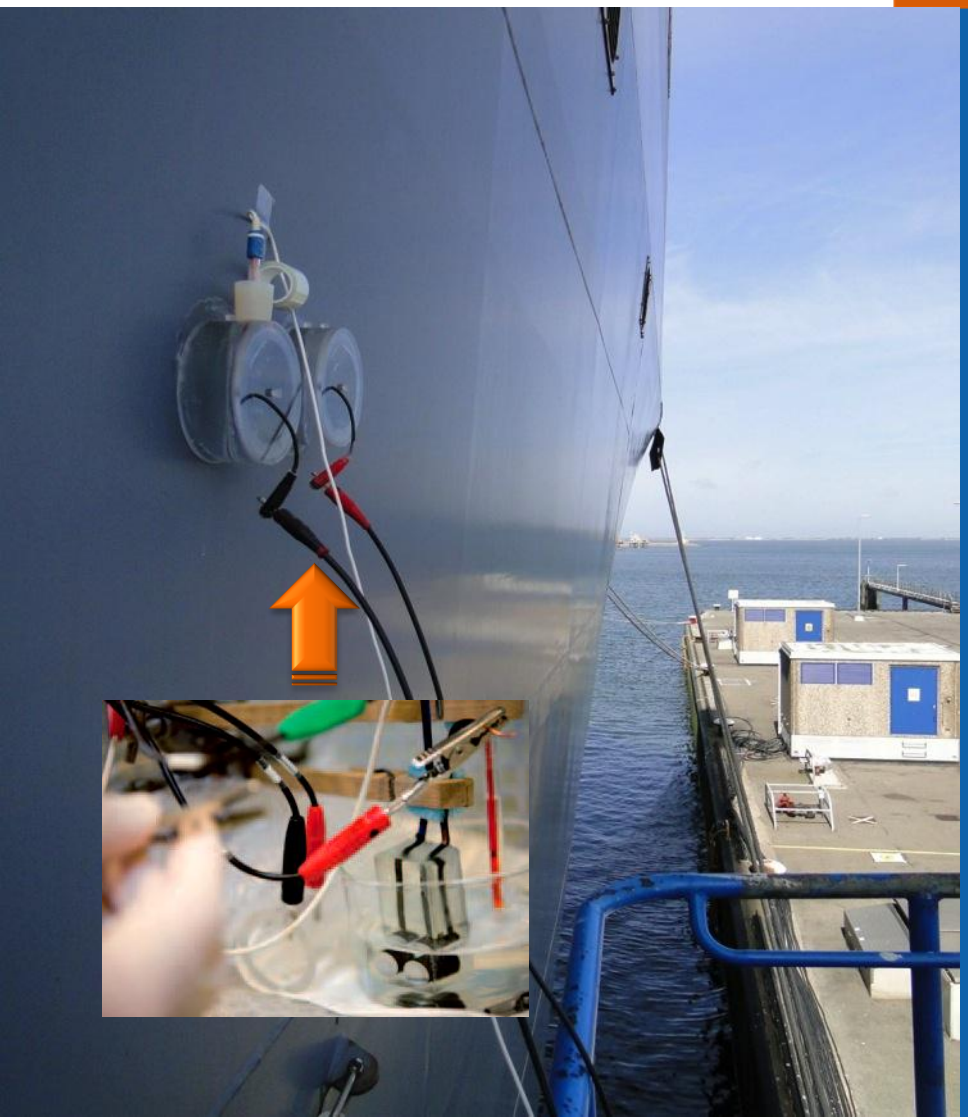
Maritime Campus NETHERLANDS

TU Delft Technische Universiteit Delft

M2i Materials innovation institute

TNO

Royal Netherlands Navy



Elektrochemische ruis: een vingerafdruk van corrosie

A.M. Homborg

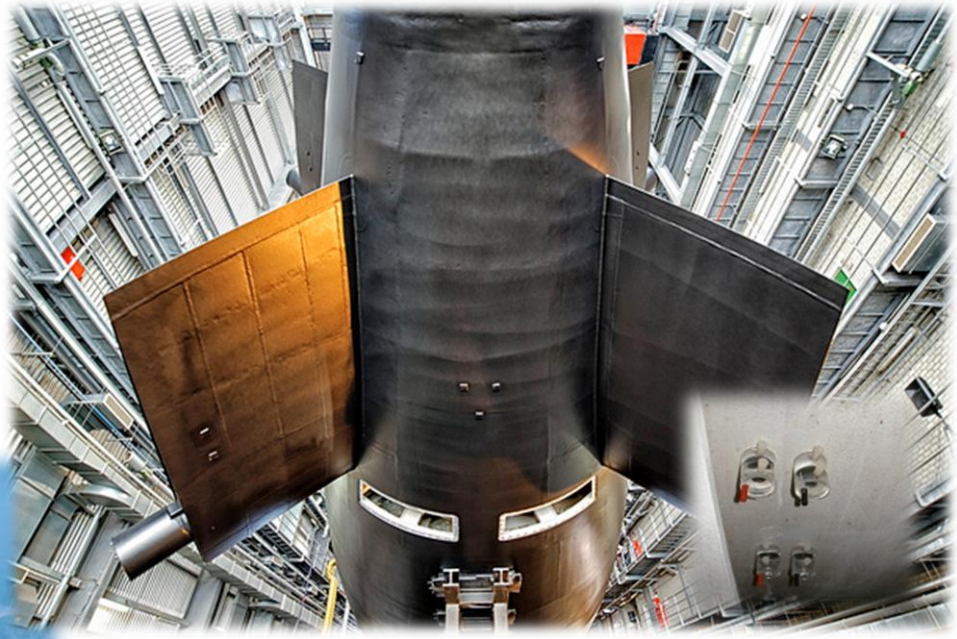
T. Tinga[1], E.P.M. van Westing[2], X. Zhang[3], P.J. Oonincx[1], G.M. Ferrari[3] J.H.W. de Wit[4] and J.M.C. Mol[4]

[1]Nederlandse defensie academie
[2]TATA Steel
[3]Endures BV
[4]TU Delft

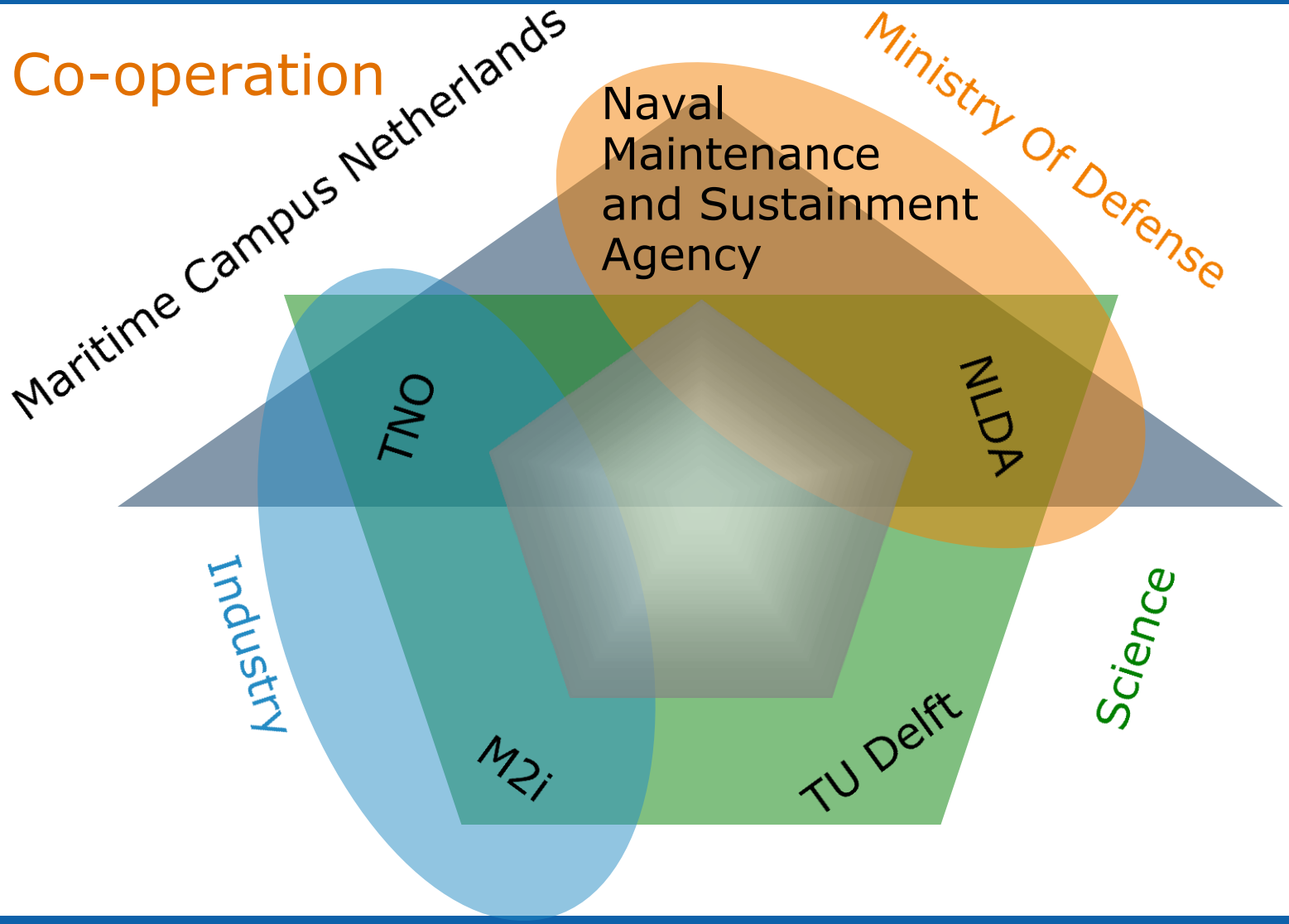
Naval Maintenance and Sustainment Agency

21 February 2014

Contents



Co-operation



Why corrosion research

- High load on structures and materials, e.g. due to extreme and highly variable conditions
- Reduction of operational and maintenance costs
- Reduction of unnecessary maintenance
- Specific military operational profile:

  Long term inactive vs. high operational demands

Relation with maintenance

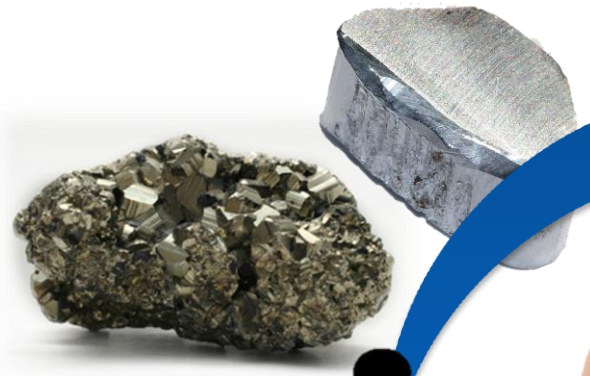
Life cycle costs ↓
Performance ↑

Condition Based Maintenance

corrosion prediction and (continuous in situ) monitoring

Electrochemical Noise Measurements

Corrosion – Why?



Refining

Requires energy:
Non-spontaneous

Refined metal

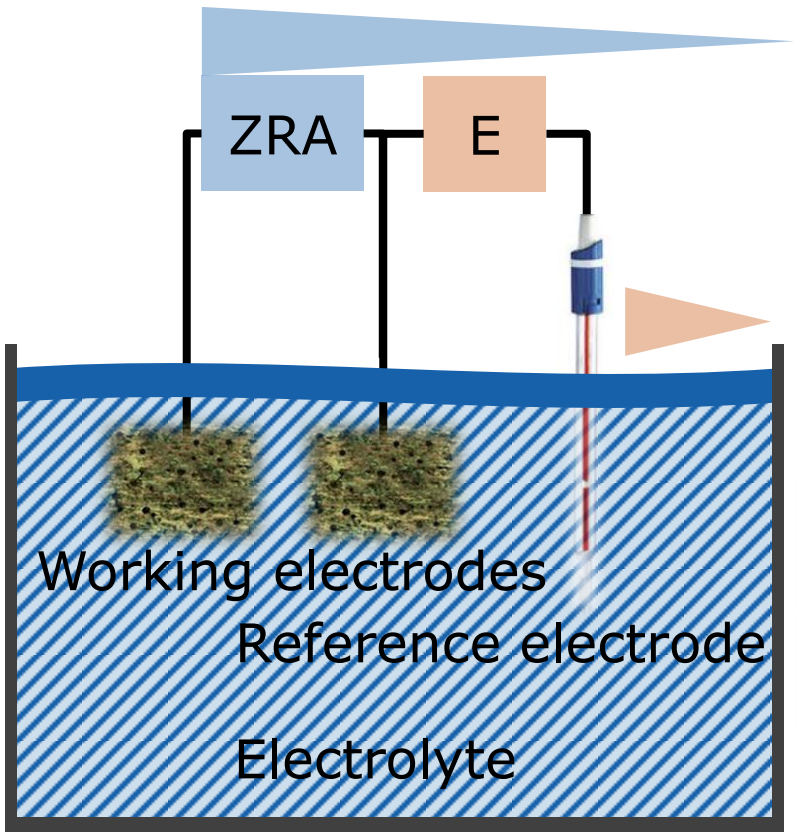
Mineral (ore)

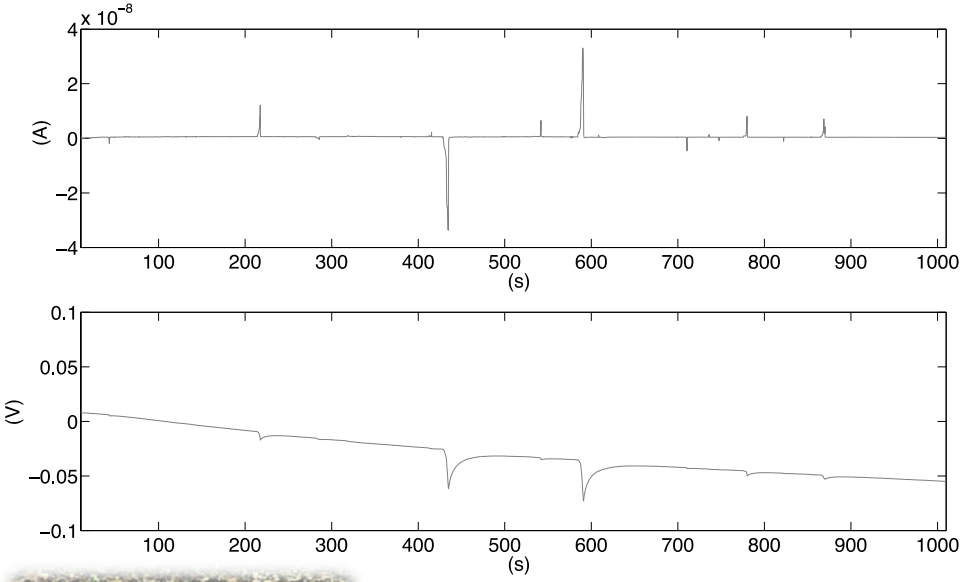
Spontaneous

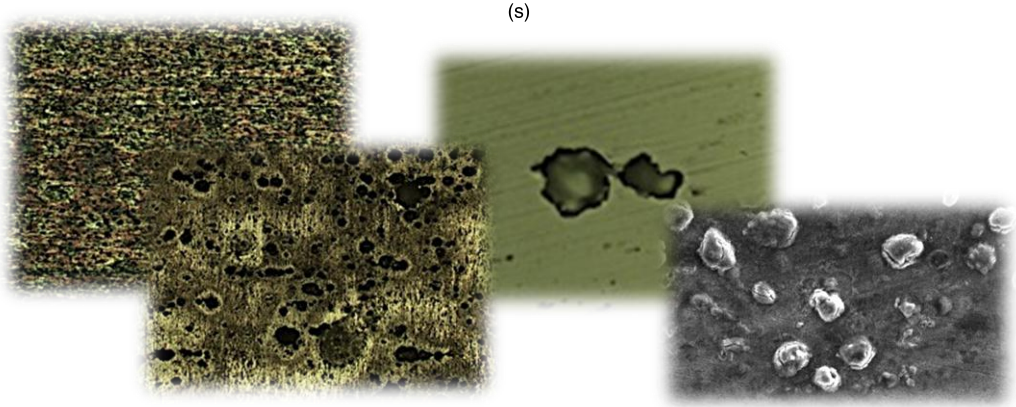
ENM

Corrosion

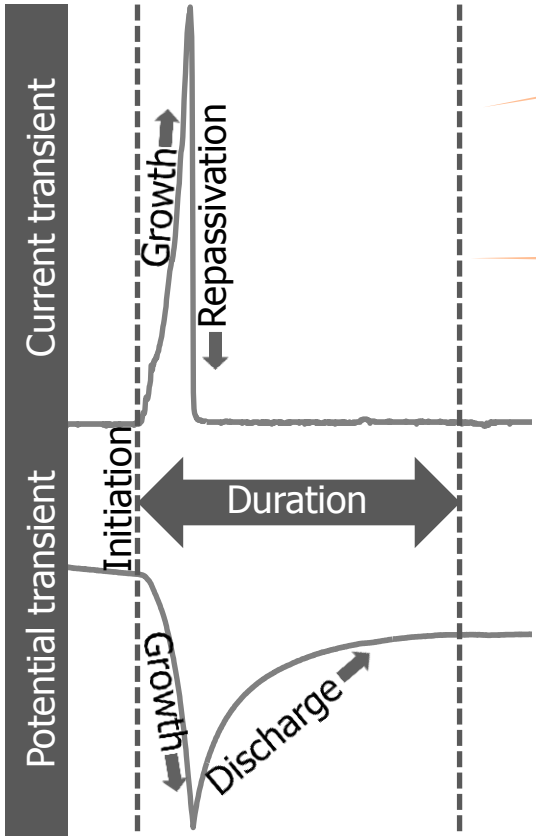
Electrochemical noise measurements

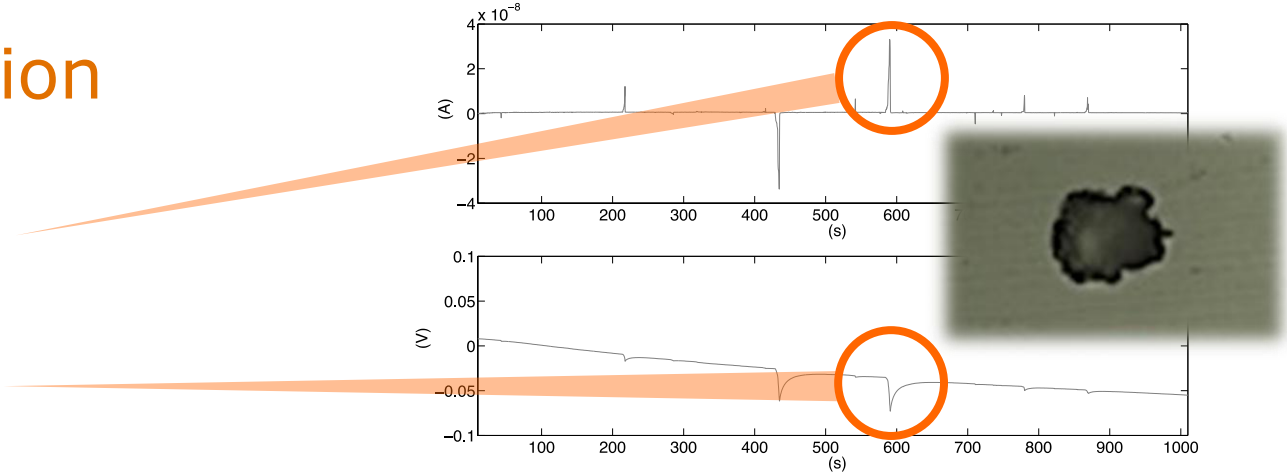






Characterization





Four phases during lifetime of a pit:

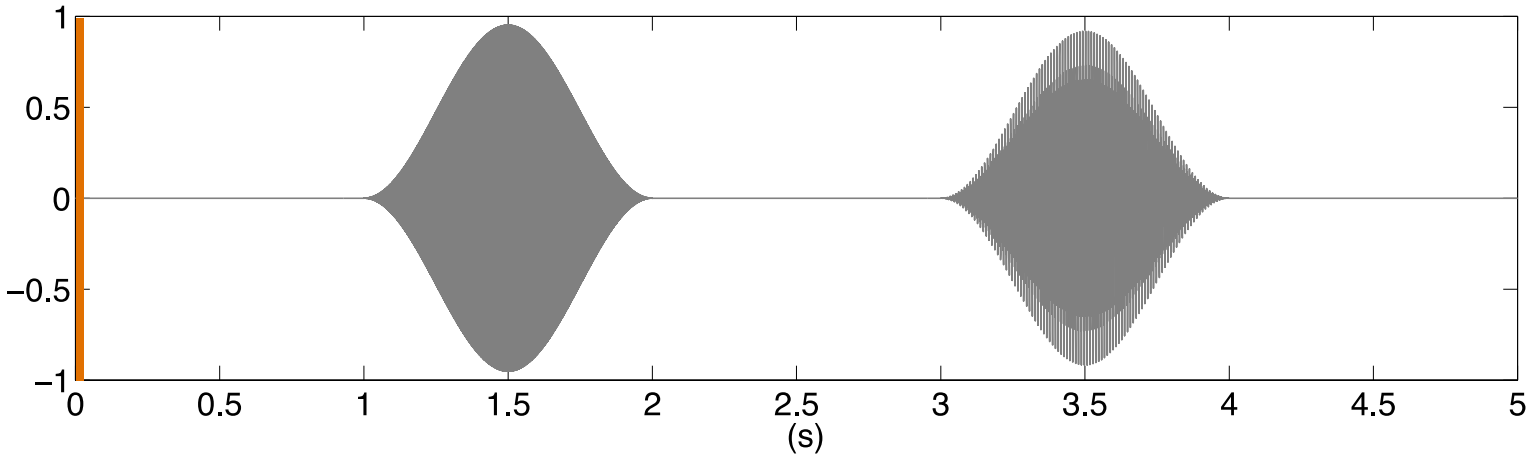
1. Pit initiation
2. Metastable growth
3. Pit repassivation
4. Regeneration of the passive film and discharge of the interface capacity of the repassivated surface

A. M. Homborg, T. Tinga, X. Zhang, E. P. M. van Westing, P. J. Oonincx, G. M. Ferrari, J. H. W. de Wit and J. M. C. Mol, Transient analysis through Hilbert spectra of electrochemical noise signals for the identification of localized corrosion of stainless steel, *Electrochimica Acta*, **104**, 84 (2013)

Data analysis: Sine waves

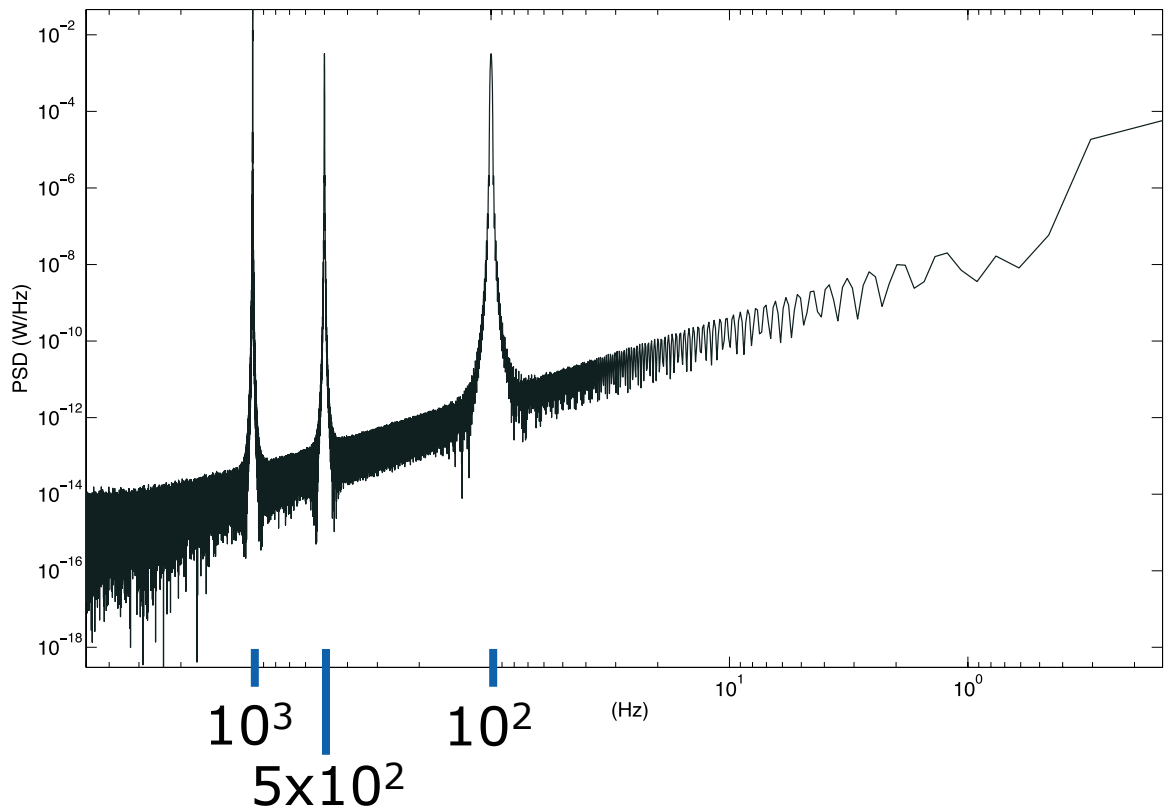
1 sine wave
10^3 Hz

3 sine waves
10^3 Hz
5×10^2 Hz
10^2 Hz



Sine waves: Fast Fourier transform

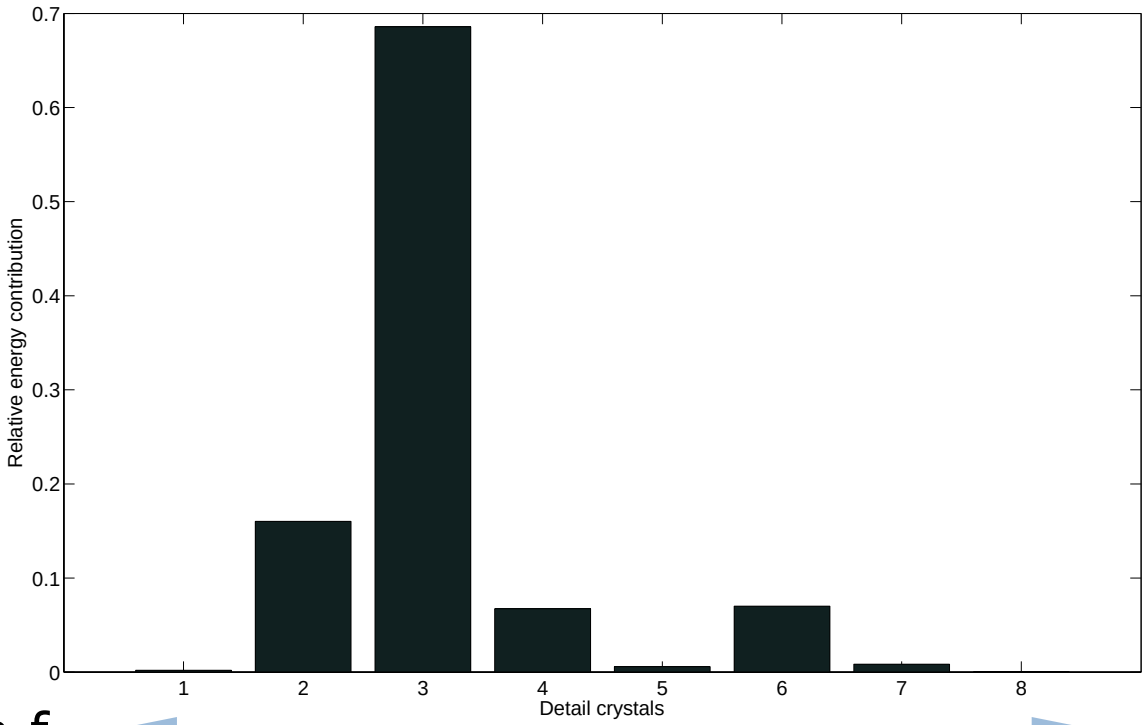
Determine the power spectral density



No localization in time

Sine waves: Wavelet transform

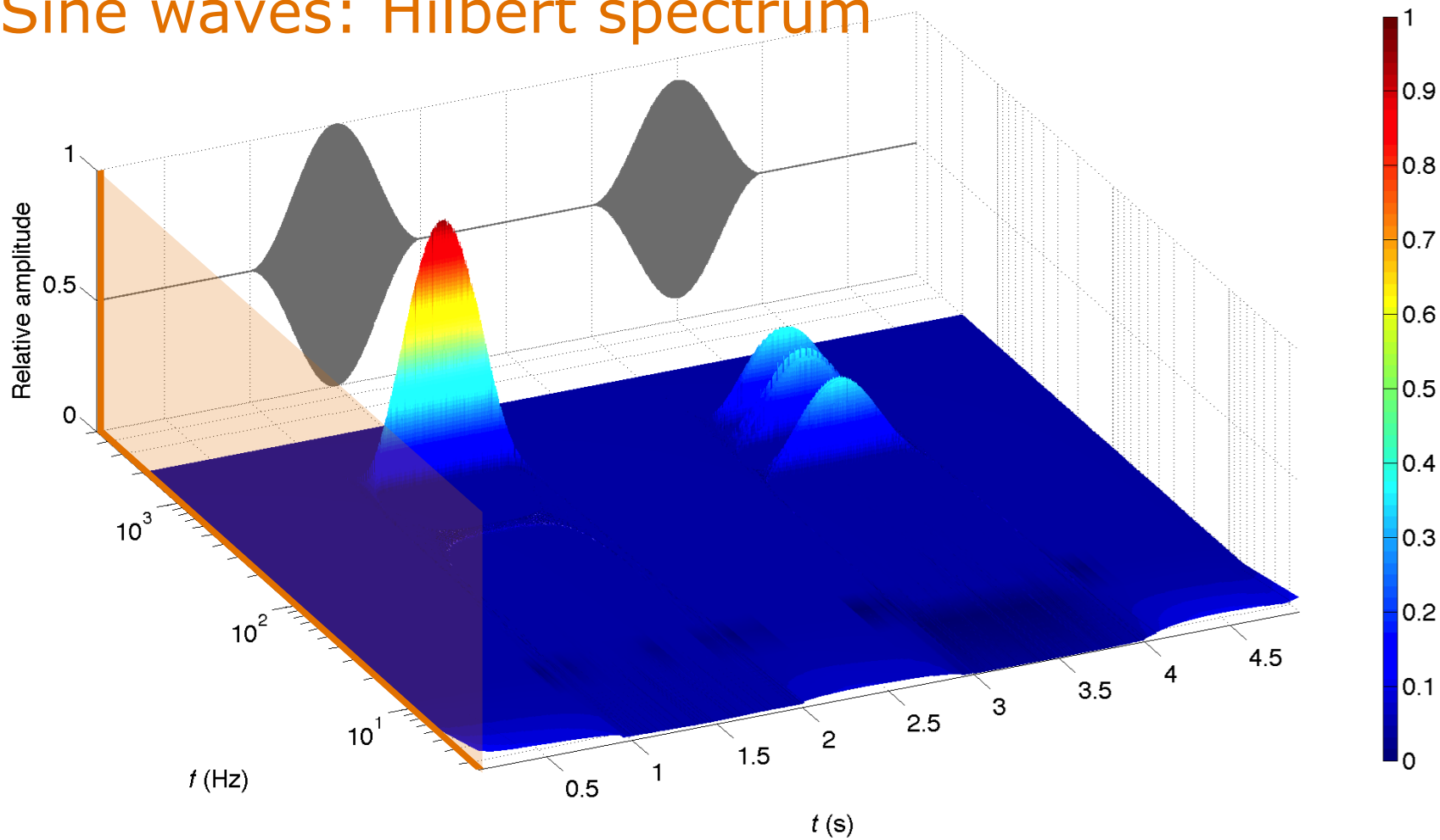
Determine the energy distribution plot



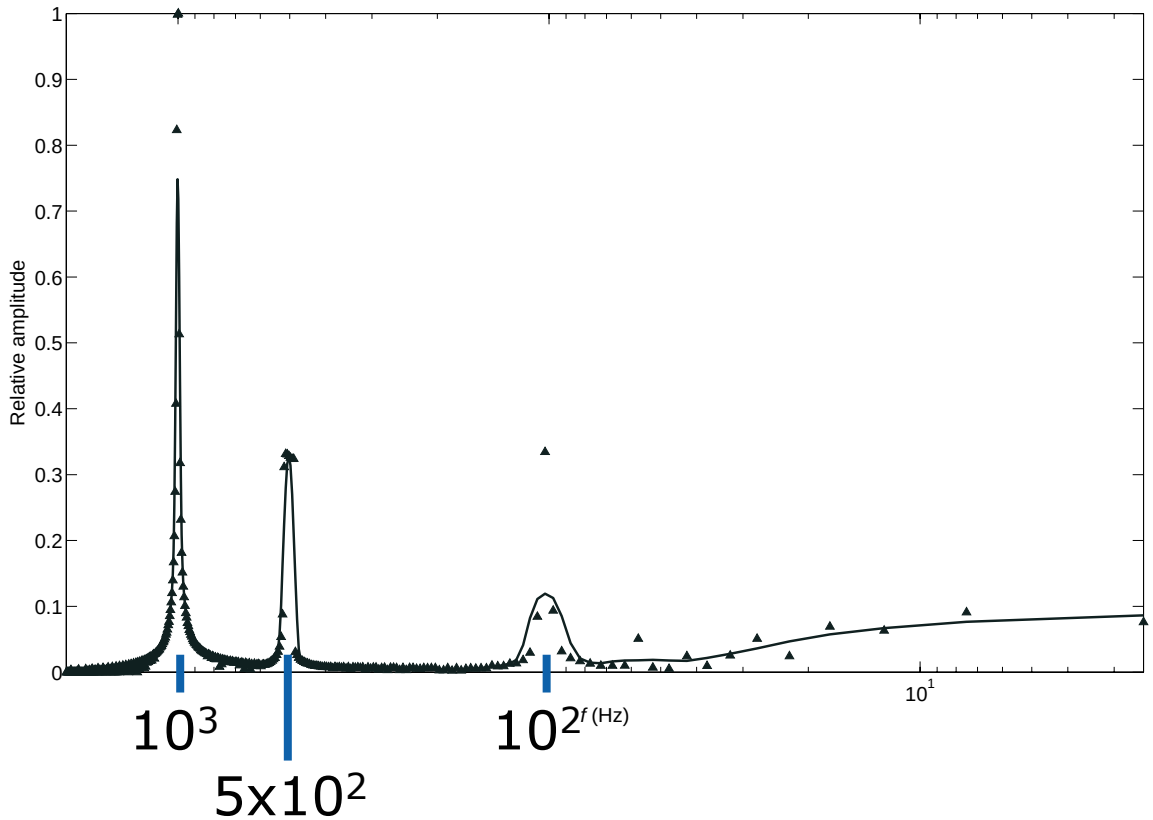
High f ◄ ► Low f

Scales instead of 'real' frequencies

Sine waves: Hilbert spectrum

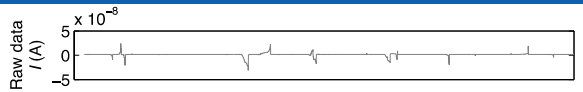


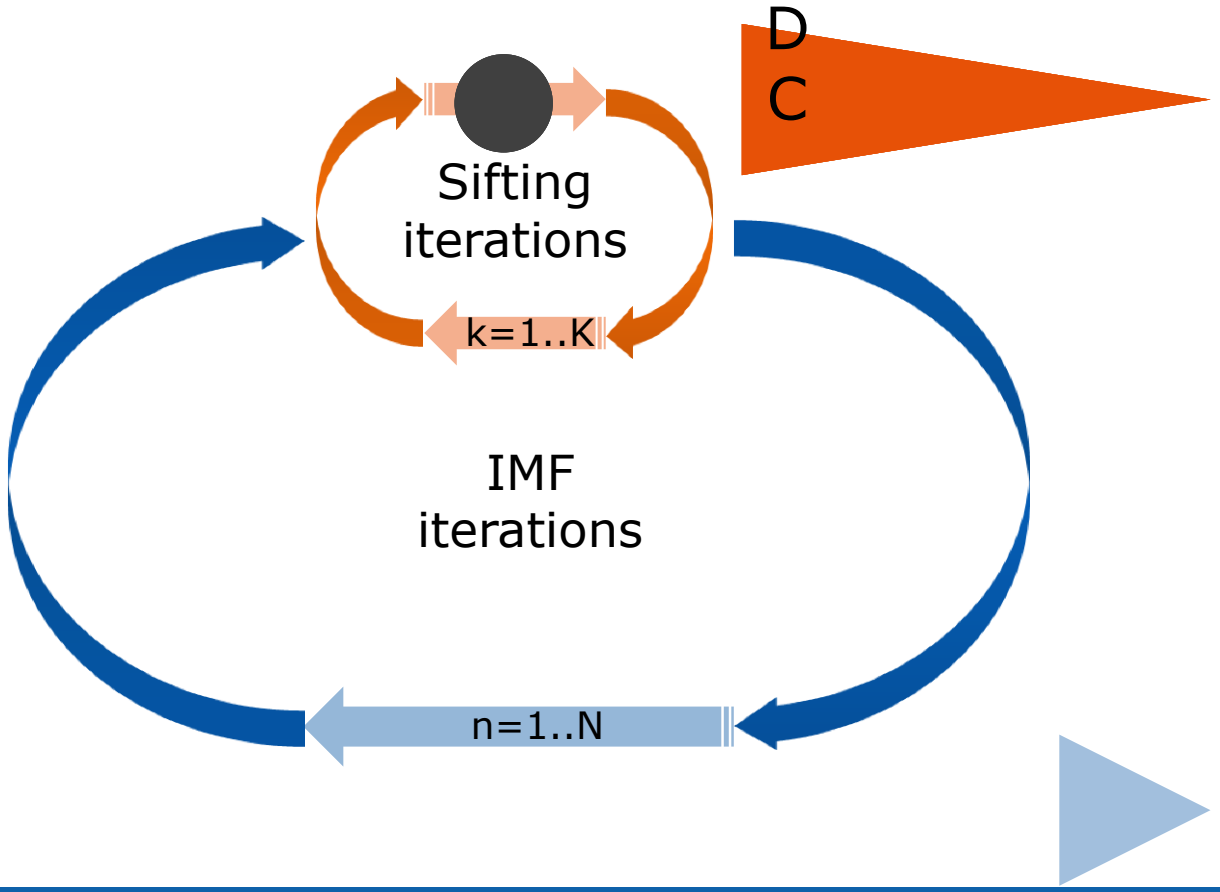
Accuracy of instantaneous frequencies



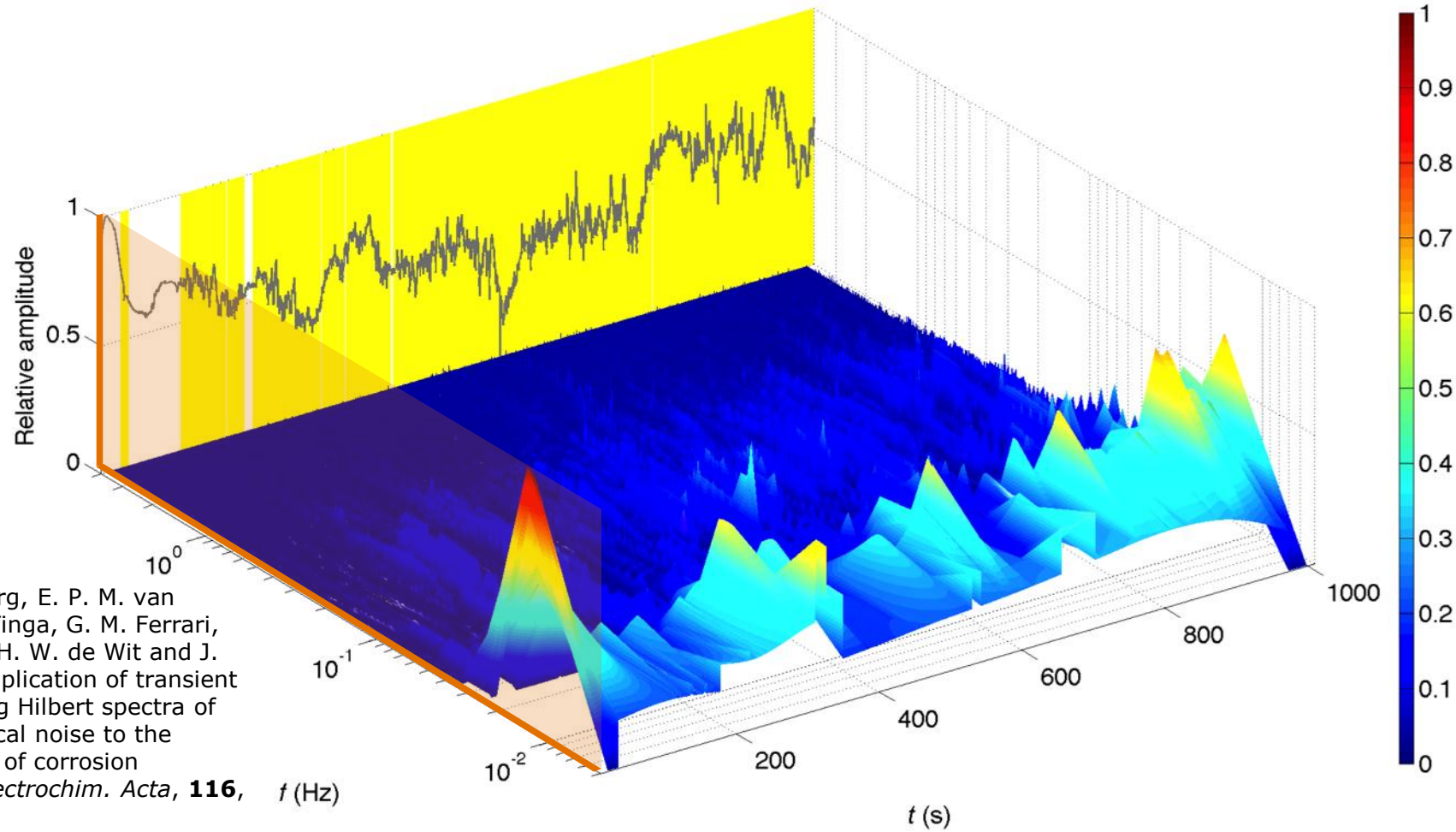
2D representation of Hilbert spectrum

EMD - Intrinsic mode functions





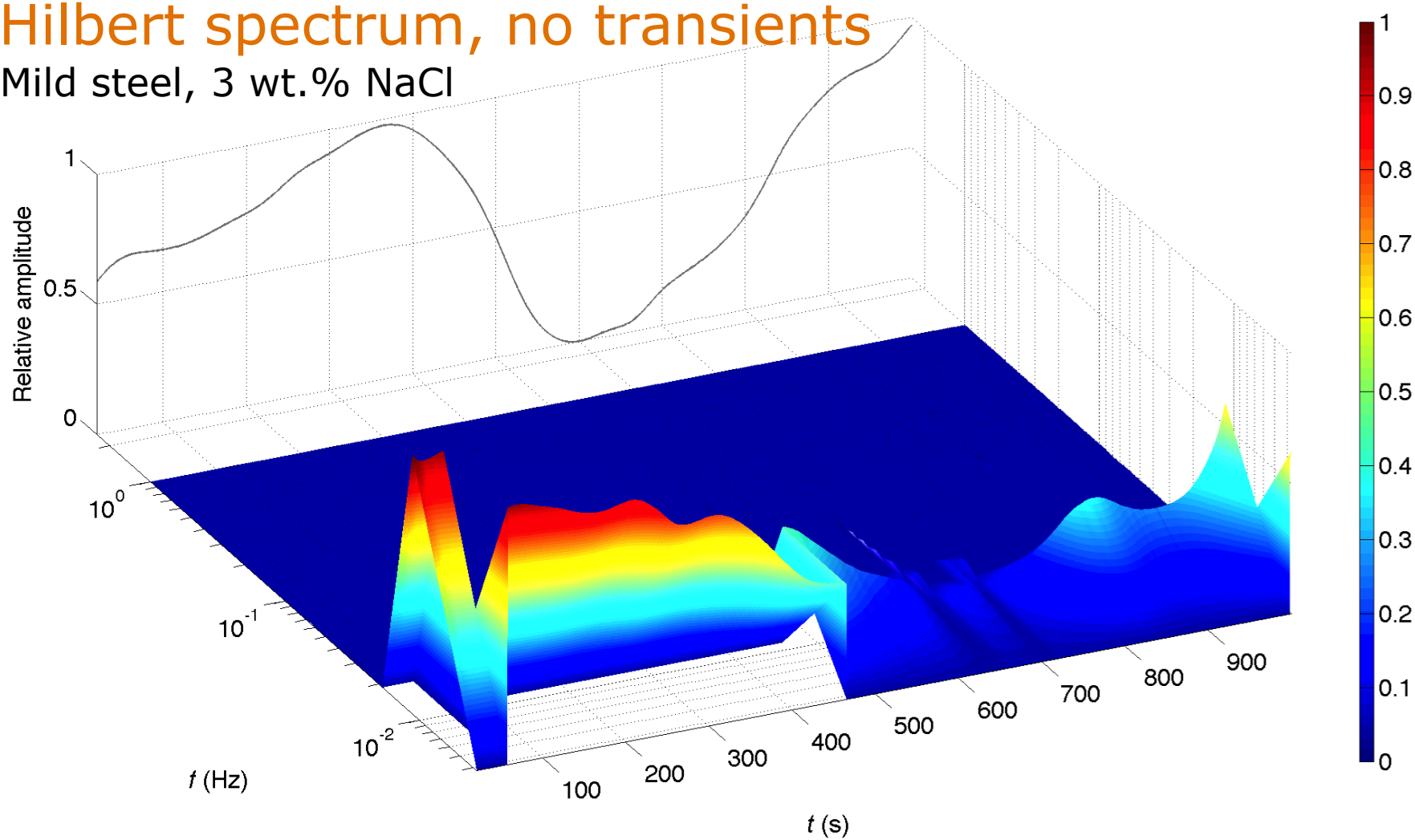
Corrosion: Hilbert spectrum (AA2024-T3)



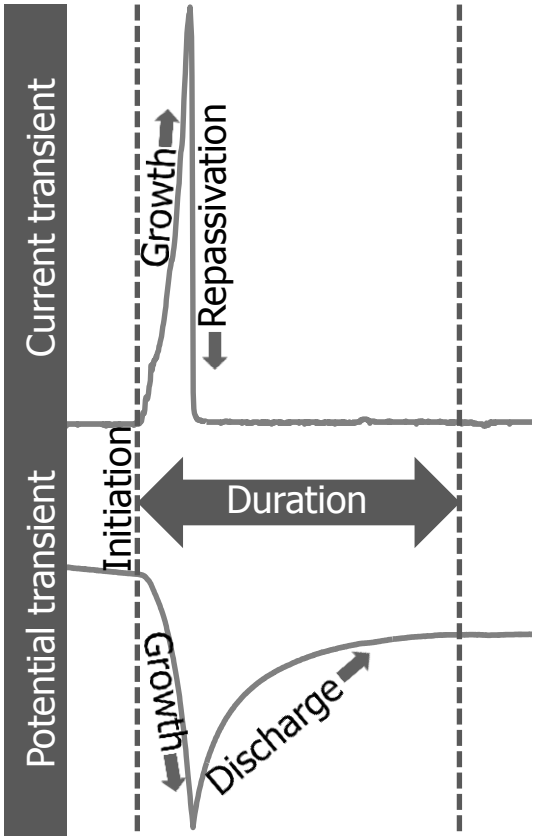
A. M. Homborg, E. P. M. van Westing, T. Tinga, G. M. Ferrari, X. Zhang, J. H. W. de Wit and J. M. C. Mol, Application of transient analysis using Hilbert spectra of electrochemical noise to the identification of corrosion inhibition, *Electrochim. Acta*, **116**, 355 (2014)

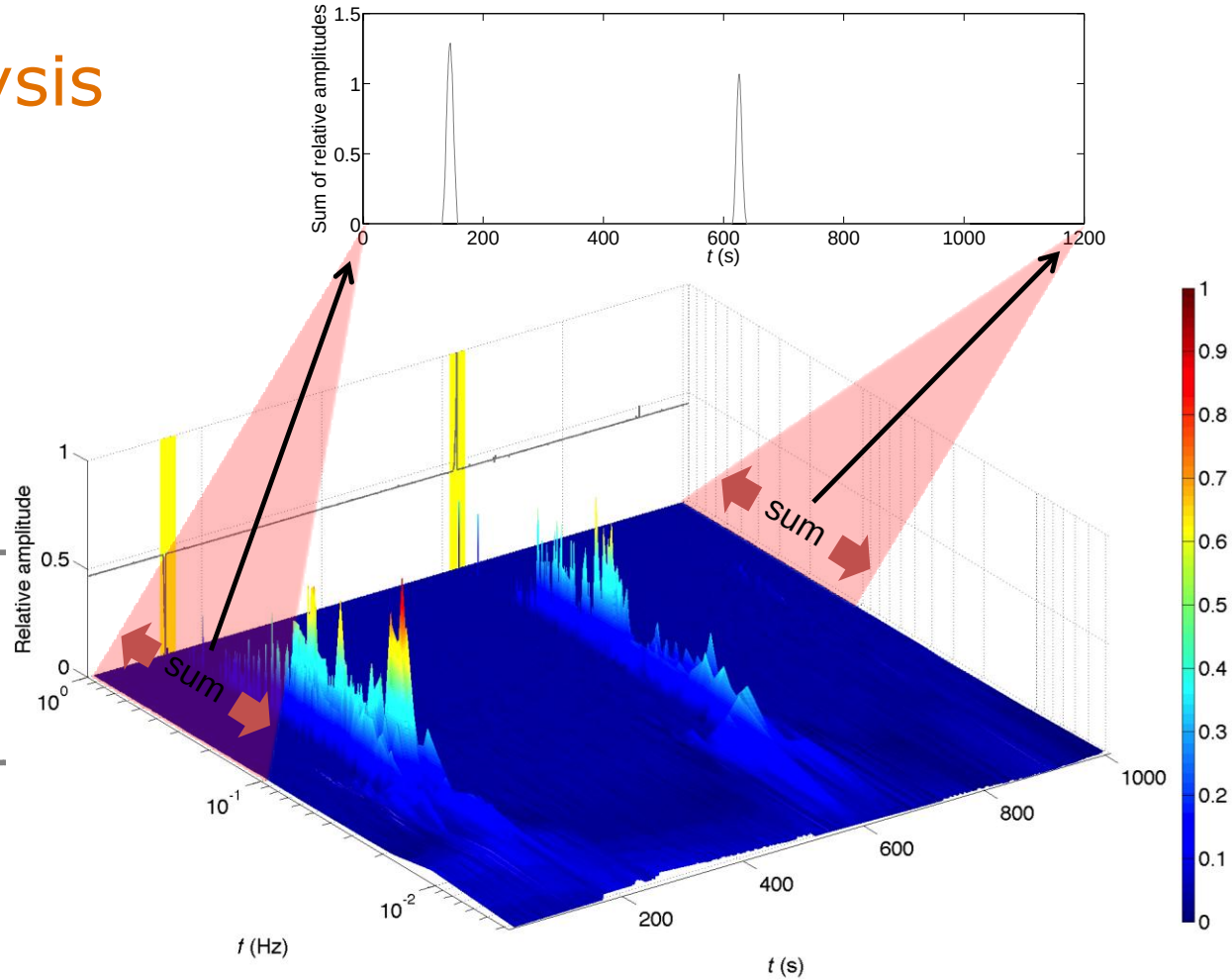
Hilbert spectrum, no transients

Mild steel, 3 wt.% NaCl



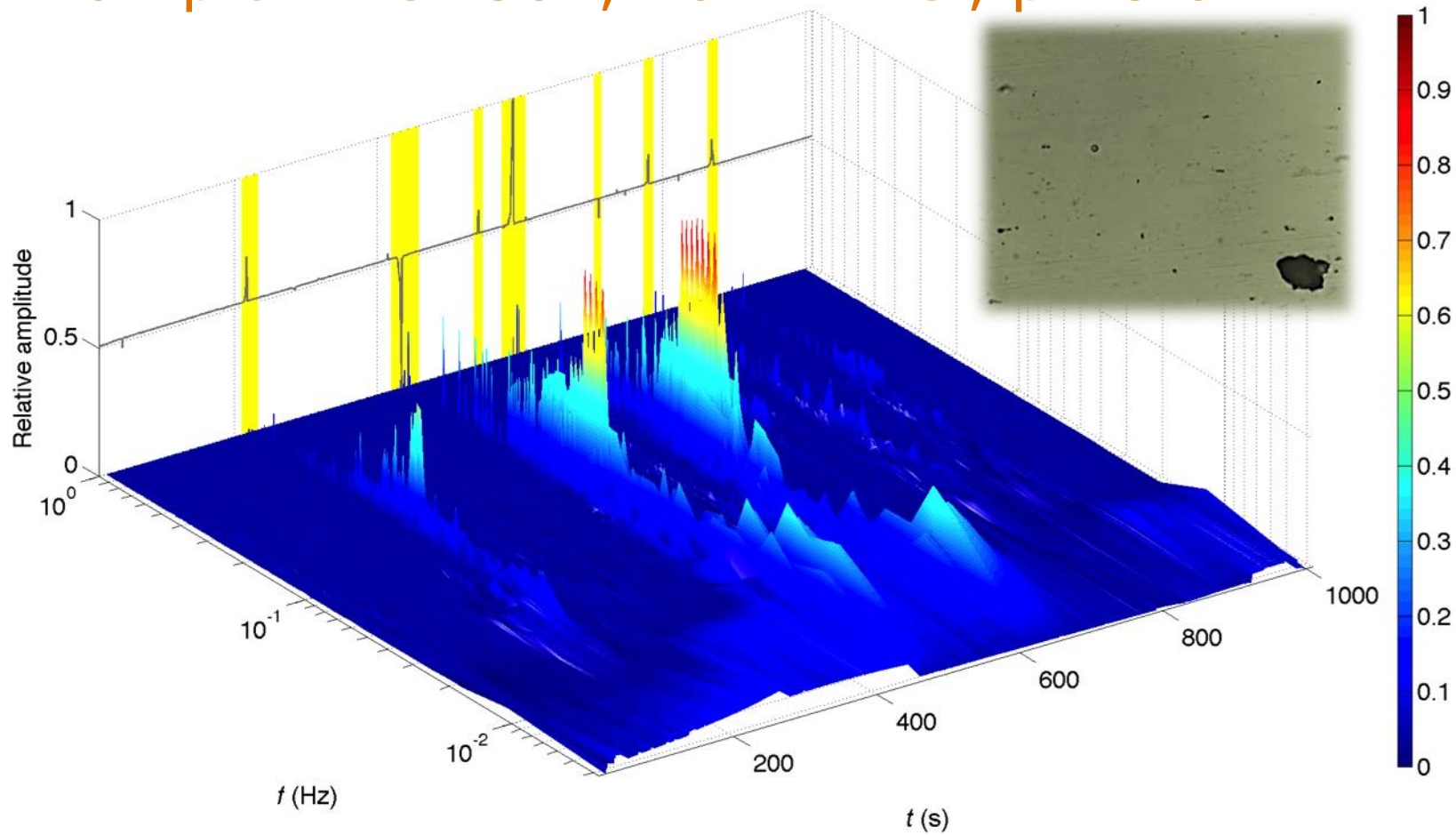
Transient analysis



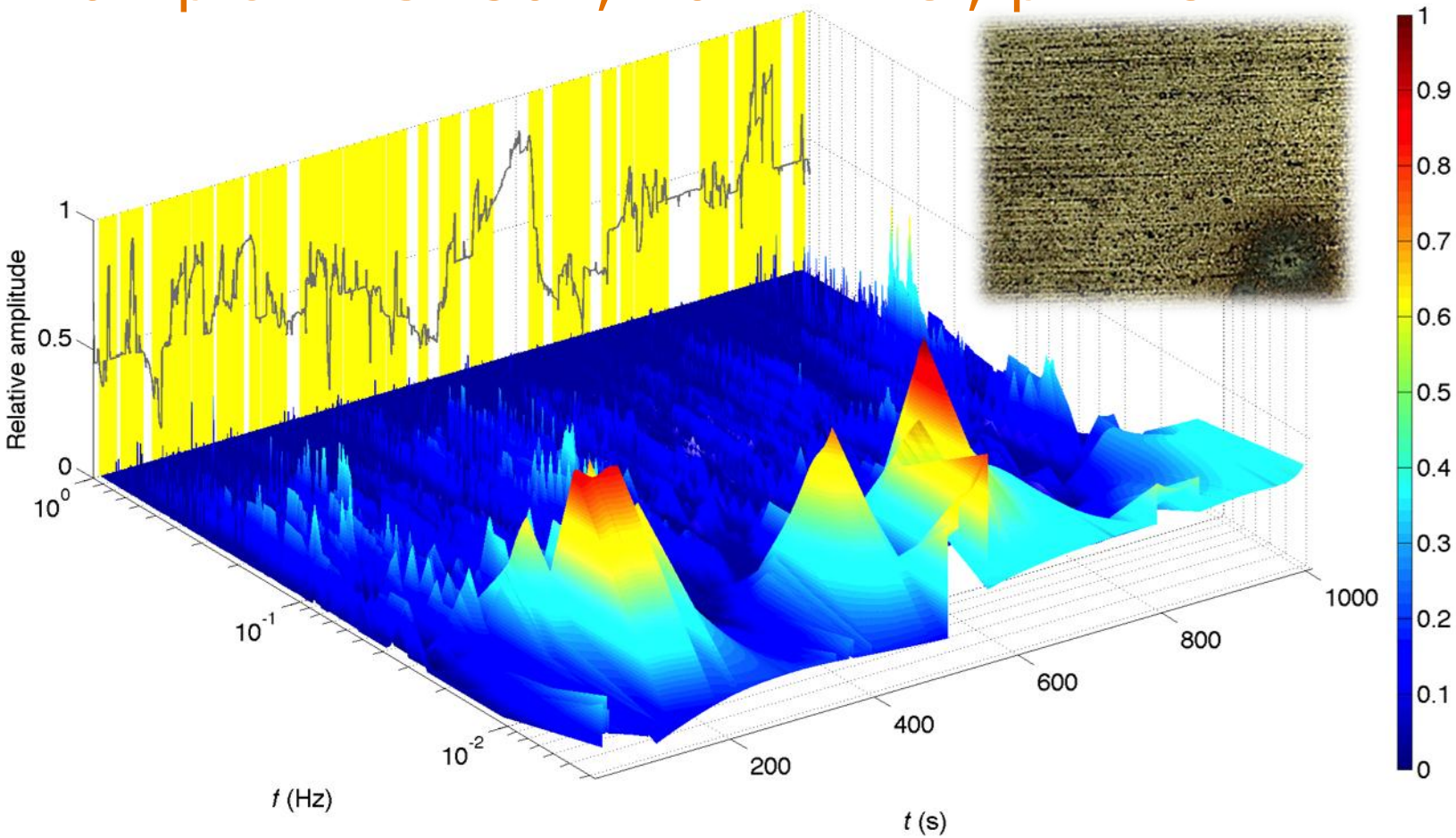


A. M. Homborg, T. Tinga, X. Zhang, E. P. M. van Westing, P. J. Oonincx, G. M. Ferrari, J. H. W. de Wit and J. M. C. Mol, Transient analysis through Hilbert spectra of electrochemical noise signals for the identification of localized corrosion of stainless steel, *Electrochimica Acta*, **104**, 84 (2013)

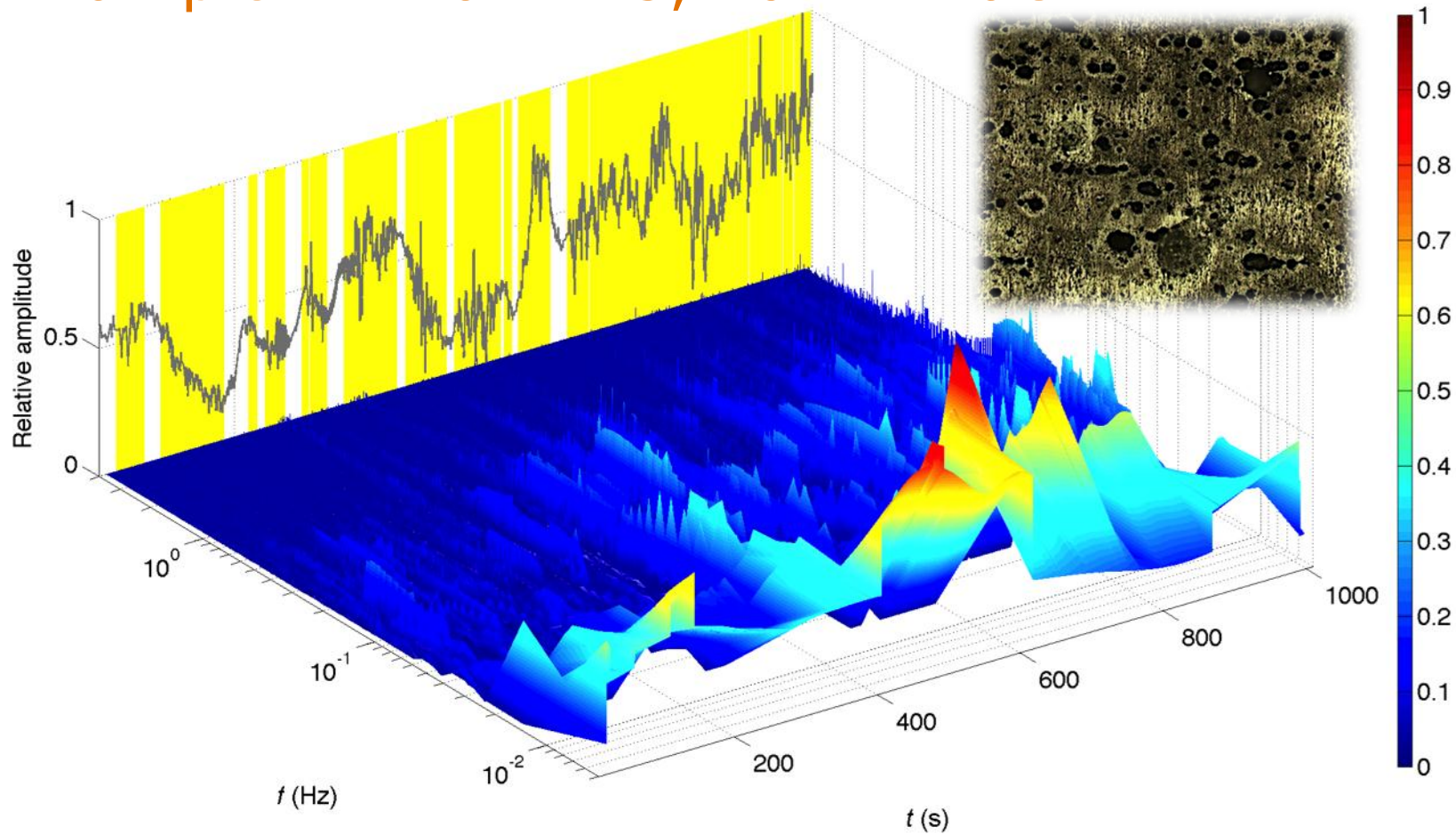
Example: AISI 304, 10^{-3} M HCl, pH 3.0



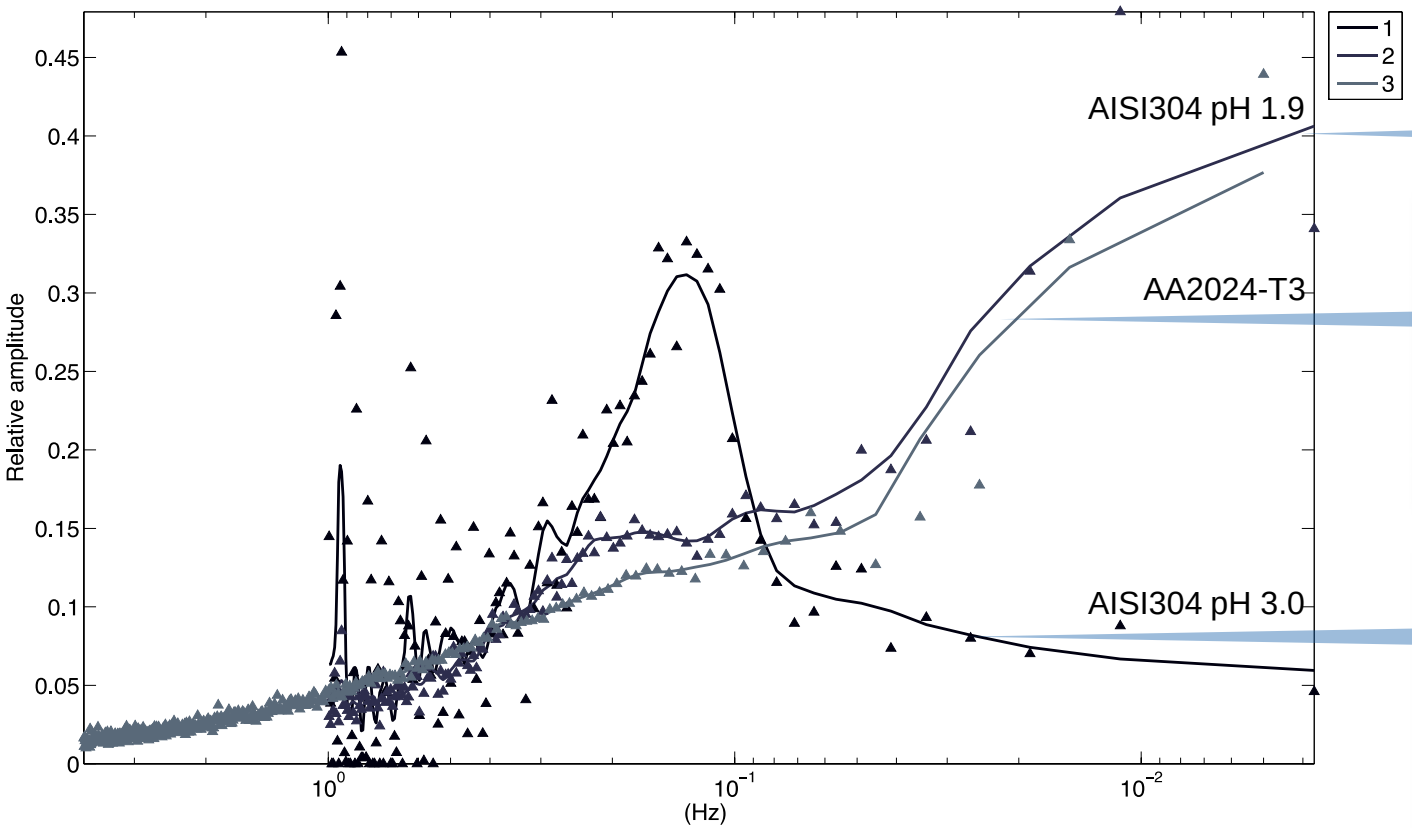
Example: AISI 304, 10^{-2} M HCl, pH 1.9

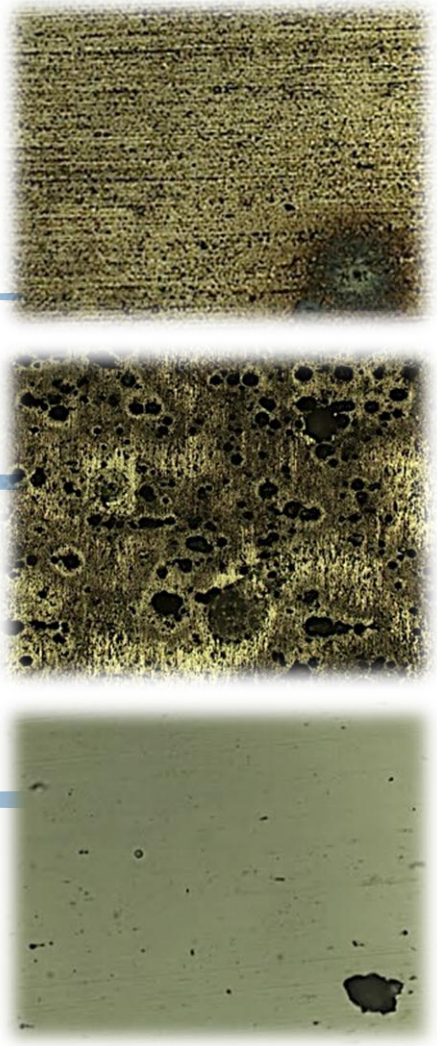


Example: AA2024-T3, 10^{-1} M NaCl

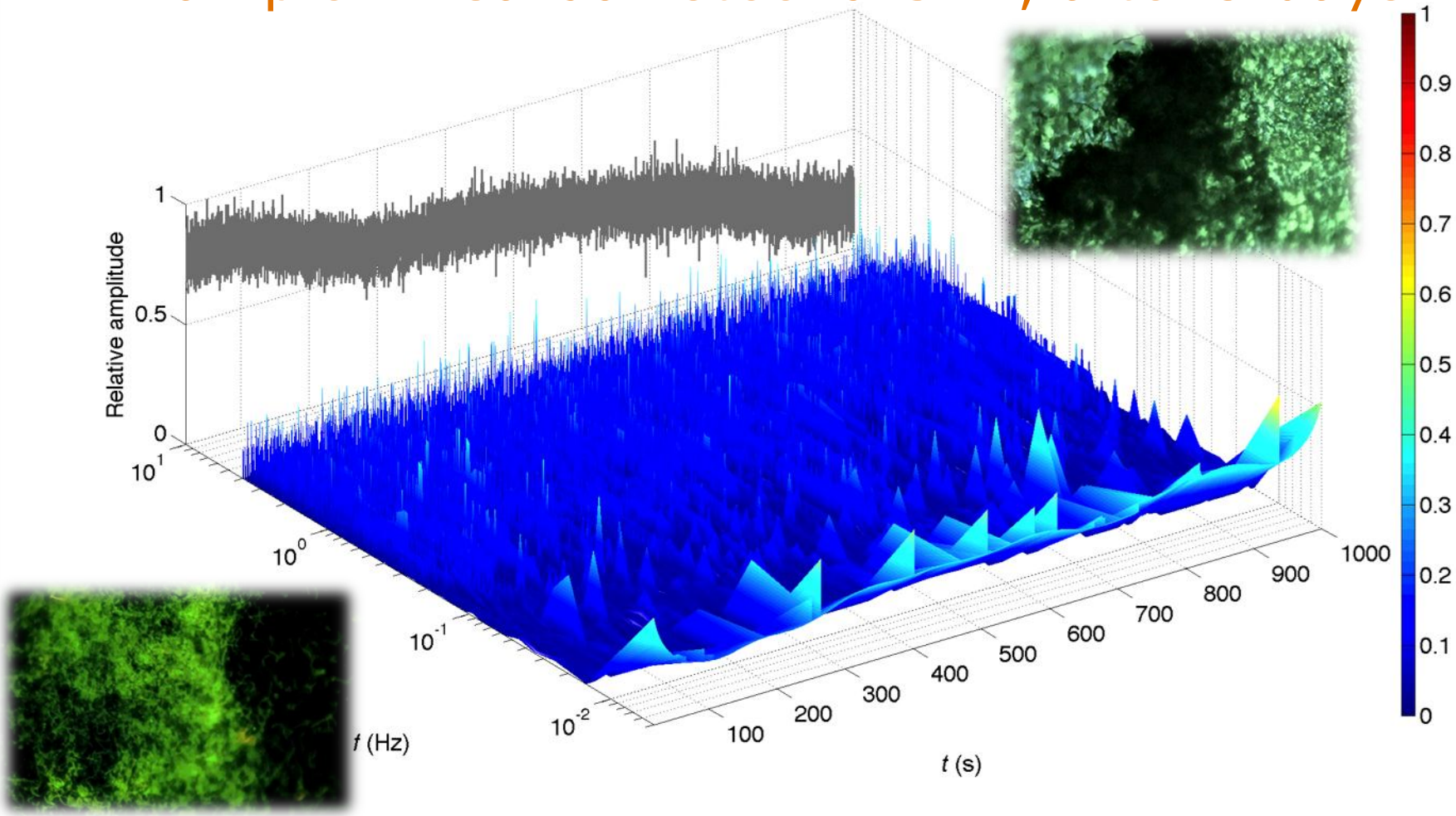


Example: 2-D Hilbert spectrum

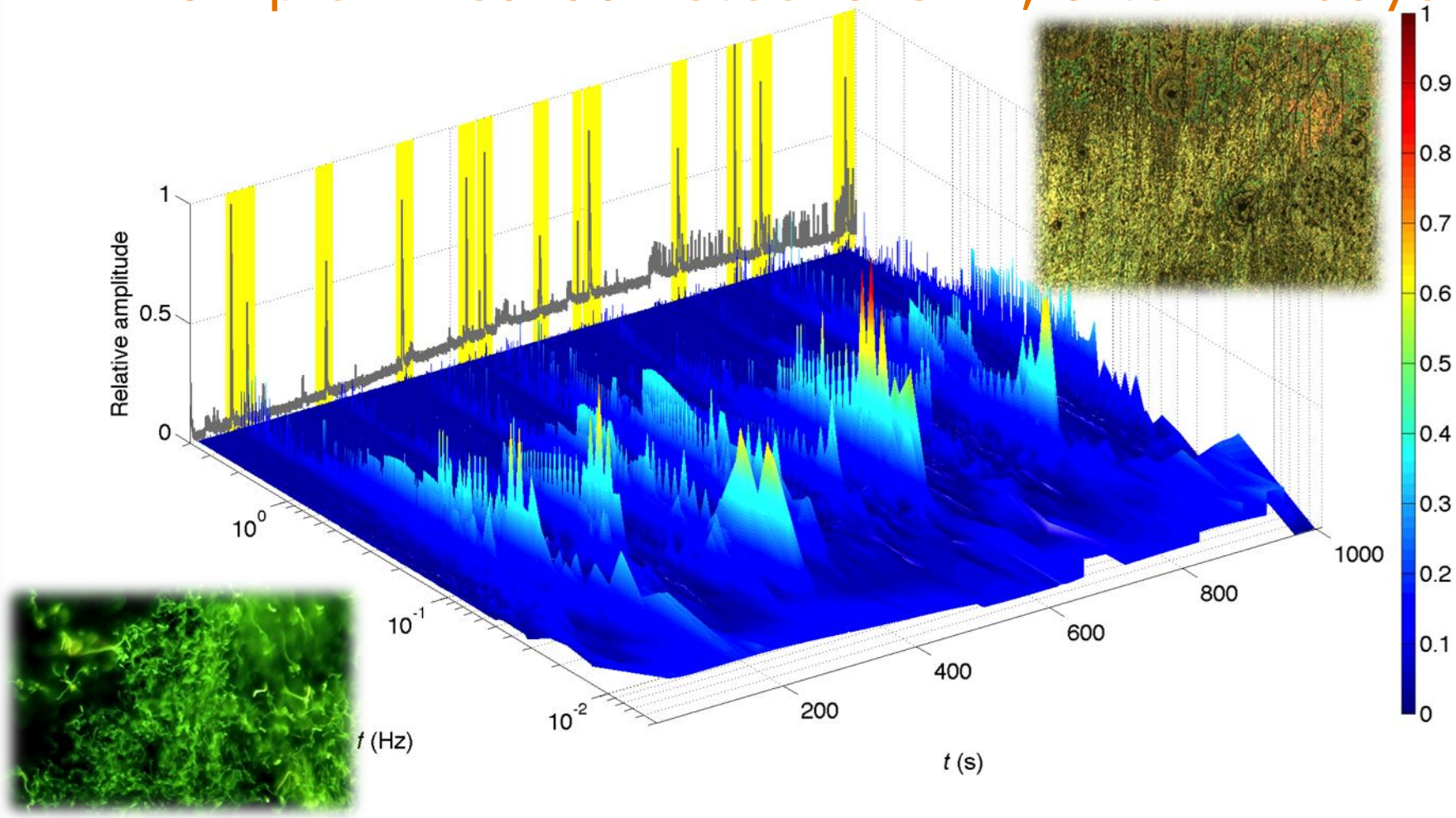




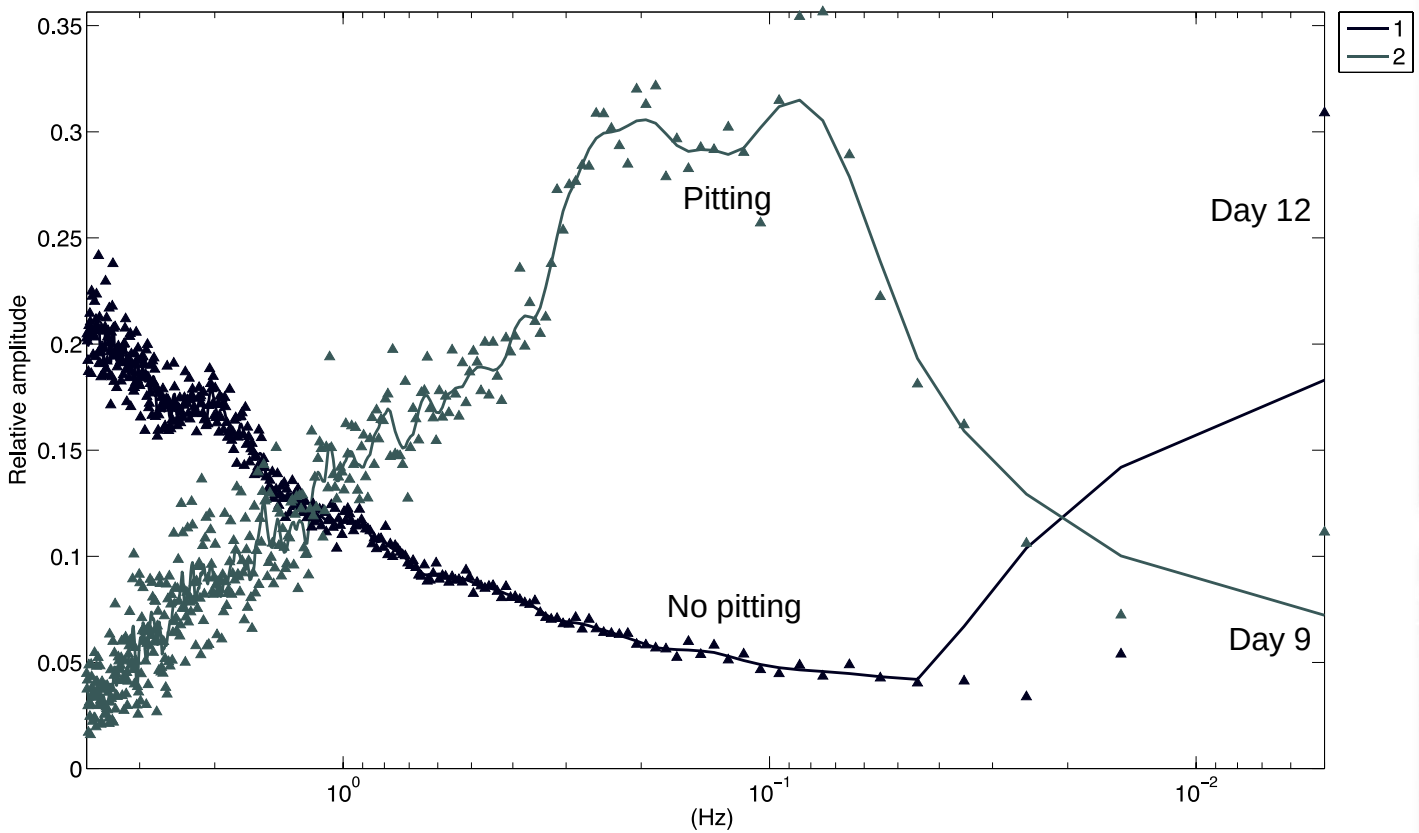
Example 2: Carbon steel & SRB, after 9 days

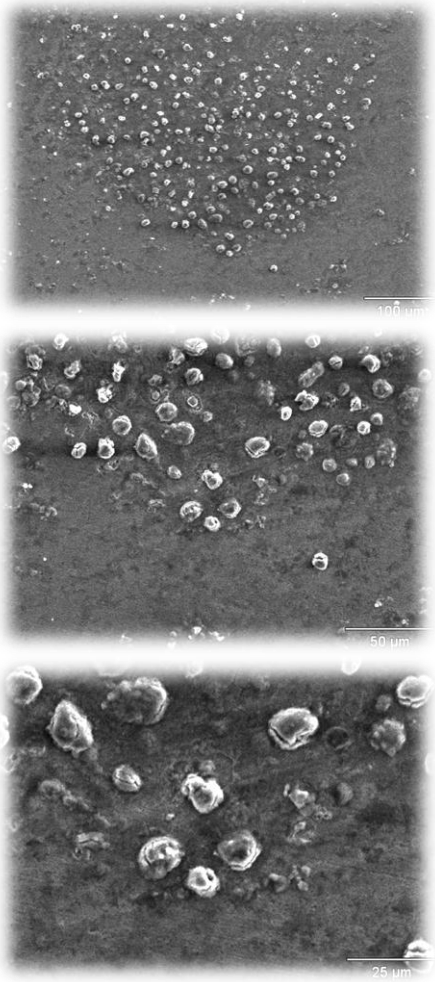


Example 2: Carbon steel & SRB, after 12 days



Example 2: 2-D Hilbert spectrum



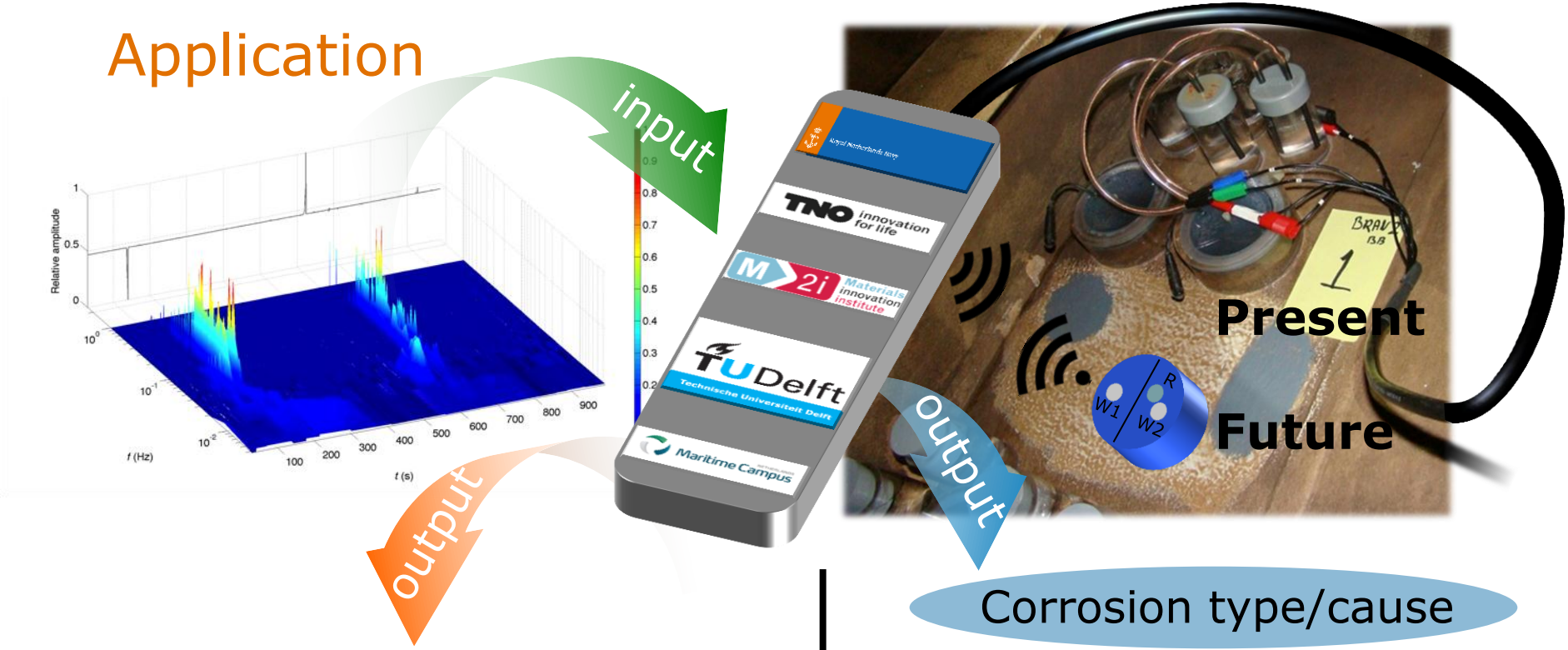


Concluding remarks

- Hilbert spectra interesting for investigation of localized corrosion processes through EN
- Simultaneous identification and localization in time of individual corrosion processes
- Good discrimination between different types of corrosion

➔ Value: corrosion monitoring and early warning of occurrence of specific corrosion phenomena

Application



Corrosion attack

None — Severe

User level

Corrosion type/cause

Condition based maintenance

Decision support

Maintainer level

Thank you for your attention – questions?

Publications

➔ DC drift removal

A. M. Homborg, T. Tinga, X. Zhang, E.P.M. van Westing, P.J. Oonincx, J.H.W. de Wit and J.M.C. Mol, Time-frequency methods for trend removal in electrochemical noise data, *Electrochim. Acta*, **70**, 199 (2012).

➔ Hilbert spectra for analysis of EN

A. M. Homborg, E.P.M. van Westing, T. Tinga, X. Zhang, P.J. Oonincx, G.M. Ferrari, J.H.W. de Wit and J.M.C. Mol, Novel time–frequency characterization of electrochemical noise data in corrosion studies using Hilbert spectra, *Corros. Sci.*, **66**, 97 (2013).

➔ Transient analysis using Hilbert spectra

A. M. Homborg, T. Tinga, X. Zhang, E. P. M. van Westing, P. J. Oonincx, G. M. Ferrari, J. H. W. de Wit and J. M. C. Mol, Transient analysis through Hilbert spectra of electrochemical noise signals for the identification of localized corrosion of stainless steel, *Electrochim. Acta*, **104**, 84 (2013)

➔ Transient analysis for characterization of corrosion inhibition

A. M. Homborg, E. P. M. van Westing, T. Tinga, G. M. Ferrari, X. Zhang, J. H. W. de Wit and J. M. C. Mol, Application of transient analysis using Hilbert spectra of electrochemical noise to the identification of corrosion inhibition, *Electrochim. Acta*, **116**, 355 (2014)