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A new model based method for generating superior endpoint traces using full range optical emission spectroscopy

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Outline

- Introduction
- Comparison of common used endpoint detection methods
- Model based approach for design of endpoint traces
  - Unfolded PCA - a basis for spectral information extraction
  - Regularization techniques for endpoint pattern design
- Application to production data
- Summary

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Introduction

- complex plasma interactions are indicated by the radiation of reactant gases, that qualifies OES as a superior method for
  - endpoint detection
  - process supervision and process control
- generally, a lot of different influences (chamber pollution, condition, process variations) are superimposed to the endpoint information in spectral data
- most of the common endpoint algorithms are not able to compensate such a wide variety of different influences

challenge: extraction of suitable endpoint traces from high dimensional spectral data

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Comparison of Methods for Endpoint Detection
→ Overview

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main tasks:

1. Generation of an endpoint relevant time signal
   - use of photo multiplier with fixed optical filter
   - use of spectroscope using CCD line image sensor

2. Detection of the endpoint time
   - definition of relative/absolute thresholds
   - heuristic algorithms (graphical differentiation)
   - model based methods
   - qualitative signal analysis

→ design of a suitable endpoint signal is most important for a reliable EP detection

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Comparison of Methods for Endpoint Detection
→ Generation of endpoint relevant time signals

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- „single/dual wavelength" analysis
  → use of a-priori knowledge about the chemical interactions
- analysis of the statistical variance
  → simple key numbers
    - spectral total power
    - general power

  → PCA based algorithm
    - T^2, Q;
    - Evolving Window Factor Analysis (EWFA)
    - Principle Component Orientation
- generation of a specific endpoint sensitive spectral pattern
  → weighting of the entire spectral range depending on specific wavelength („spectral software filter")

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Comparison of Methods for Endpoint Detection

→ single/dual wavelength analysis

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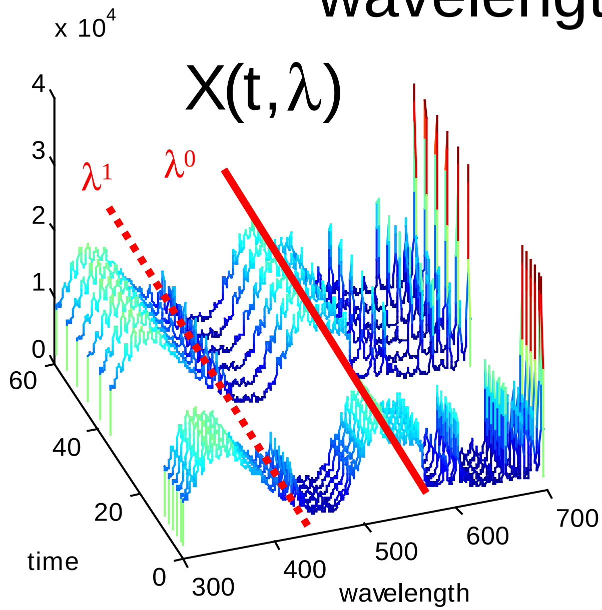
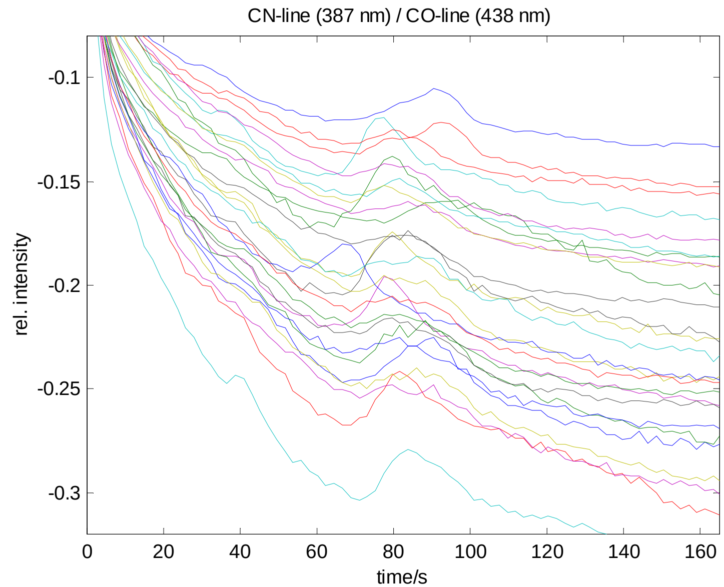
philosophy: assessment of spectral changes within individual wavelengths or ranges



$$y(t_i) = X(t_i, \lambda^0)$$

$$y(t) = \frac{X(t, \lambda^0)}{X(t, \lambda^1)}$$



- advantages: - simple design using a-priori knowledge
  - clear chemical interpretation of EP signal
- disadvantage: - waste of spectral information

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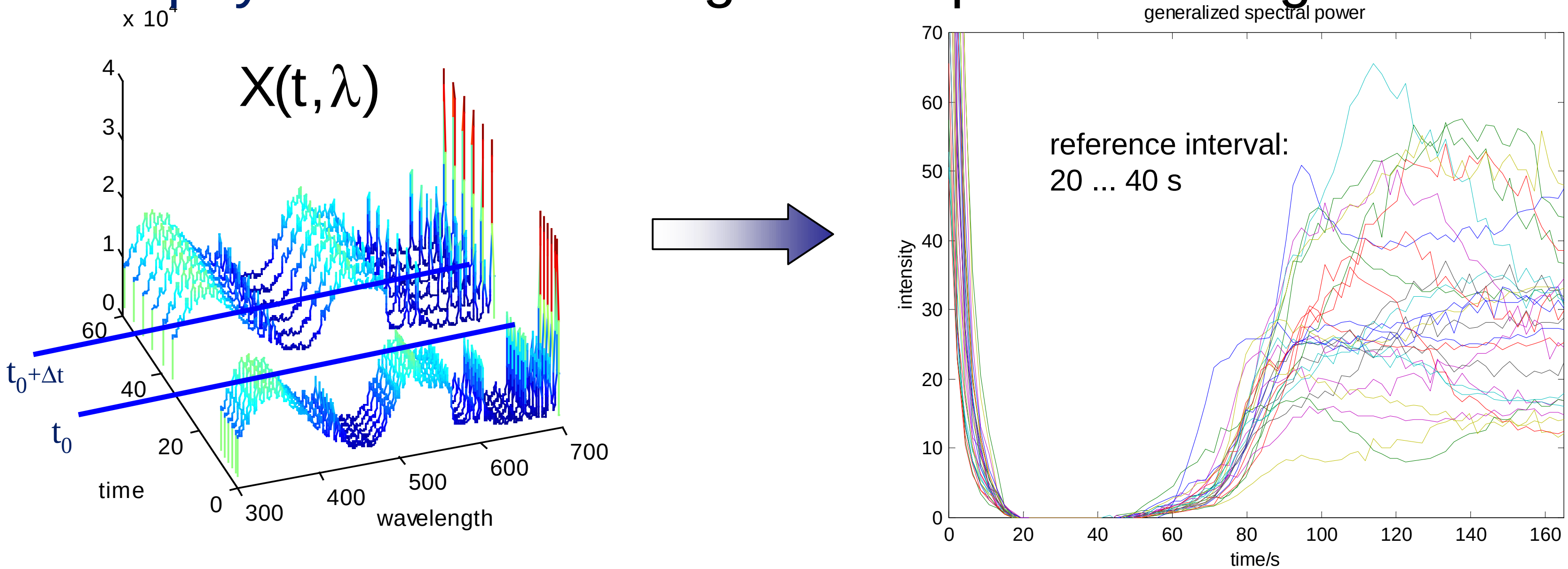
Comparison of Methods for Endpoint Detection
→ analysis of statistical variance – simple methods

philosophy: assessment of general spectral changes



→ simple methods: $y(t_i) = x(t_i)^T \cdot W \cdot x(t_i)$ W: unit or inv. covariance matrix

- advantage: - simple design and on-line calculation
- disadvantage: - unspecific sensitivity to all spectral changes
  - suitable only for large open-area

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Comparison of Methods for Endpoint Detection

→ analysis of statistical variance – PCA based methods

philosophy: statistical assessment of specific spectral changes

EWFA: $y(t_i) = \delta_n\{x(t_i)\cdots x(t_i + \Delta t)\}$

PCO: $y(t_i) = u_n\{x(t_0)\cdots x(t_0 + \Delta t)\}^T \cdot u_n\{x(t_i)\cdots x(t_i + \Delta t)\}$

T^2,Q: $y(t_i) = \|x(t_i)\|^2 - \|u_{1\cdots n}\{x(t_0)\cdots x(t_0 + \Delta t)\}\cdot x(t_i)\|^2$

δ_n: n-th singular value; u_n: n-th eigenvector of (X^TX)

- advantages: - enables to detect small spectral changes
- disadvantages: - EP-signal y(t) strongly depends on:
  - selection of n-th eigenvector resp. eigenvalue
  - selection of reference period of time Δt
  - the reasons of changes in resulting EP-signal are difficult to assess

→ not necessarily endpoint relevant !

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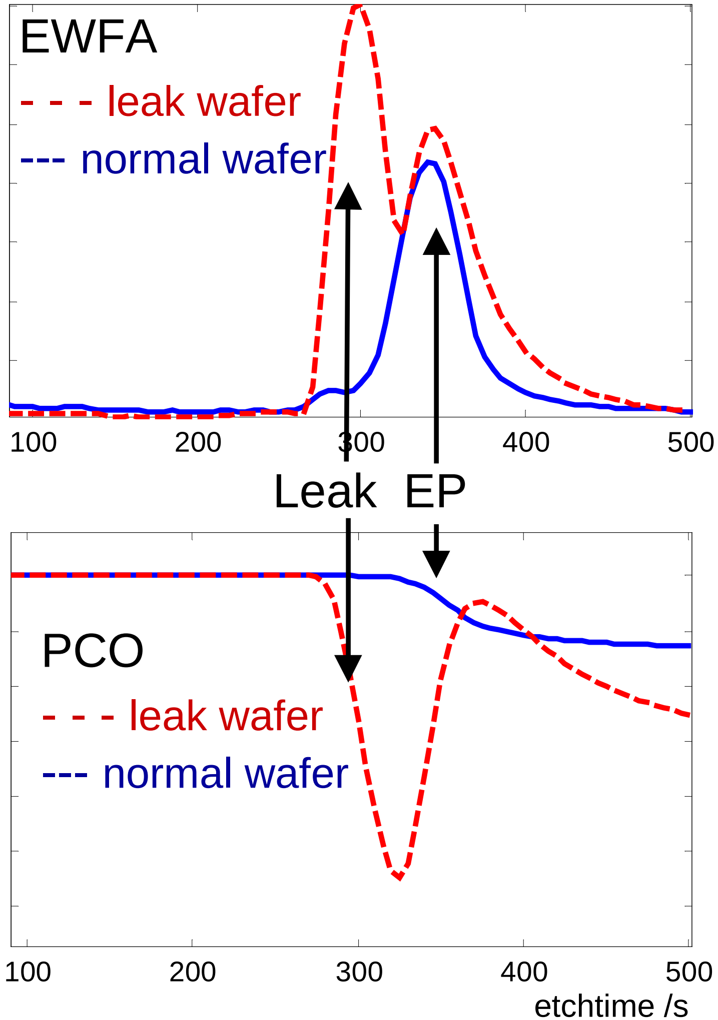
Comparison of Methods for Endpoint Detection

→ analysis of statistical variance – PCA based methods



- PCA methods are sensitive to various kinds of plasma changes
- the signal changes at EP as well as at leak
- calculation of EP-Signals require complex mathematical methods and computational power

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Comparison of Methods for Endpoint Detection
→ Generation of EP-signal using spectral software filter

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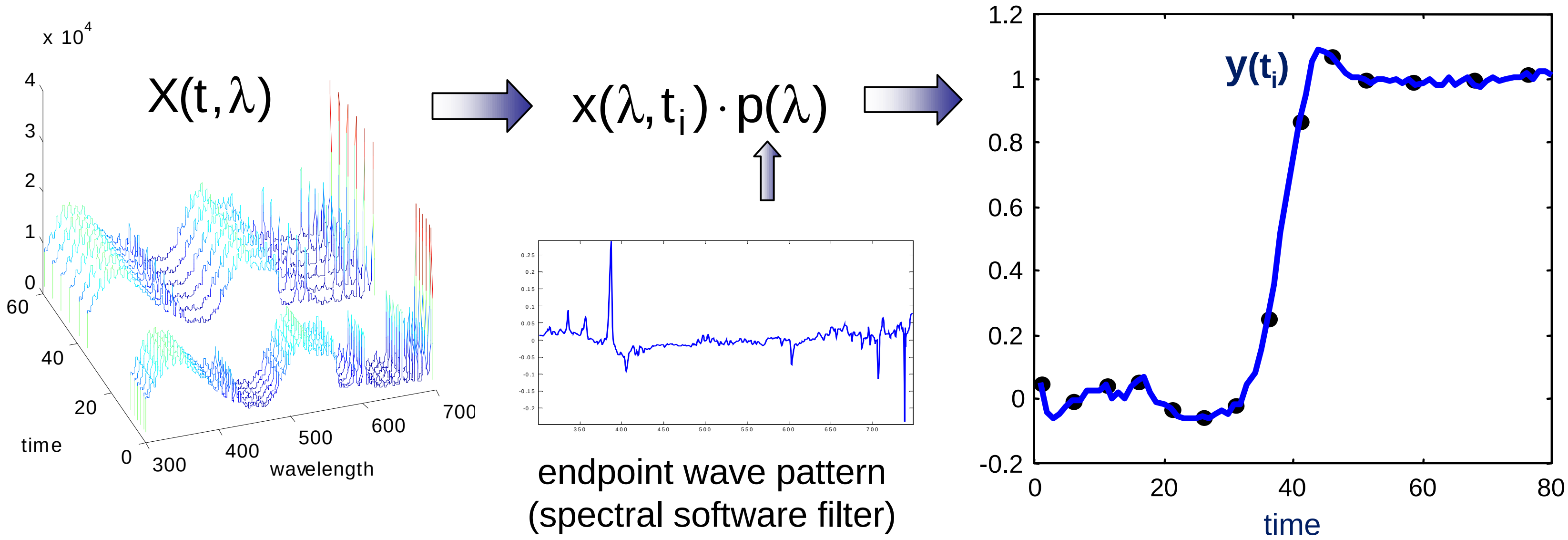
philosophy: calculation of the EP signal by multiplication of the spectral data with an endpoint sensitive spectral pattern



challenge: generation of a suitable wave pattern which yields to sensitive and long-term robust endpoint signals

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Comparison of Methods for Endpoint Detection
→ example for manual endpoint pattern design

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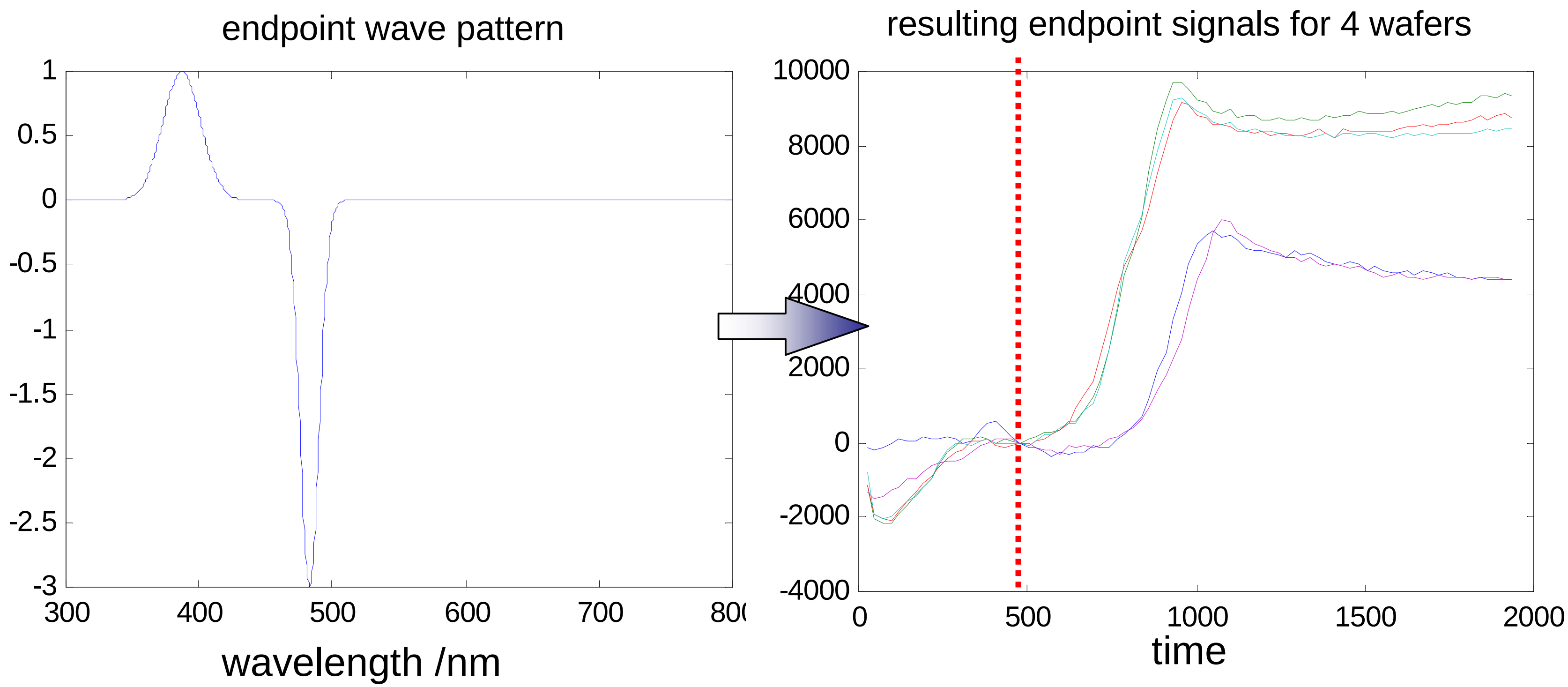
example for a simple endpoint pattern design (spectral software filter)



→ a manual design of an endpoint sensitive wave pattern is possible by using a-priori knowledge about the chemical plasma interactions

Model based approach for Endpoint Design

objective: automatic synthesis of a spectral pattern, which yields to a sensitive and robust EP-signal

methods: formulation of a parameter estimation problem based on a predefined endpoint trace

problems:
- ill conditioned spectral data (strong correlated data)
- underdetermined estimation problem
- predefinition of wanted endpoint trace

solution:
- unfolded PCA for data conditioning
- regularization methods for parameter estimation

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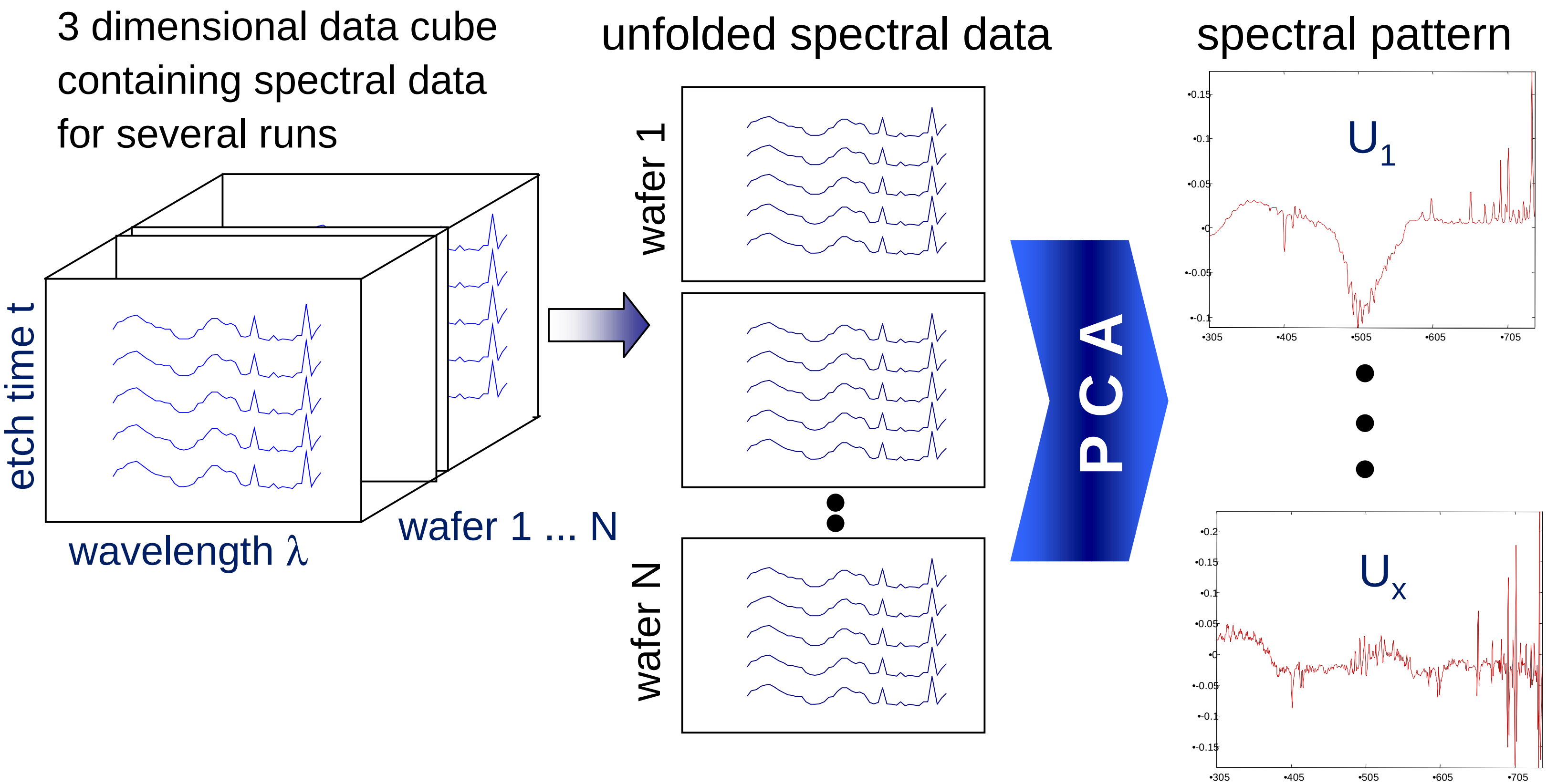
Model based approach for Endpoint Design
→ Unfolded PCA – a basis for spectral information extraction

philosophy: calculation of orthogonal wave pattern u_i using PCA after unfolding the original data cube



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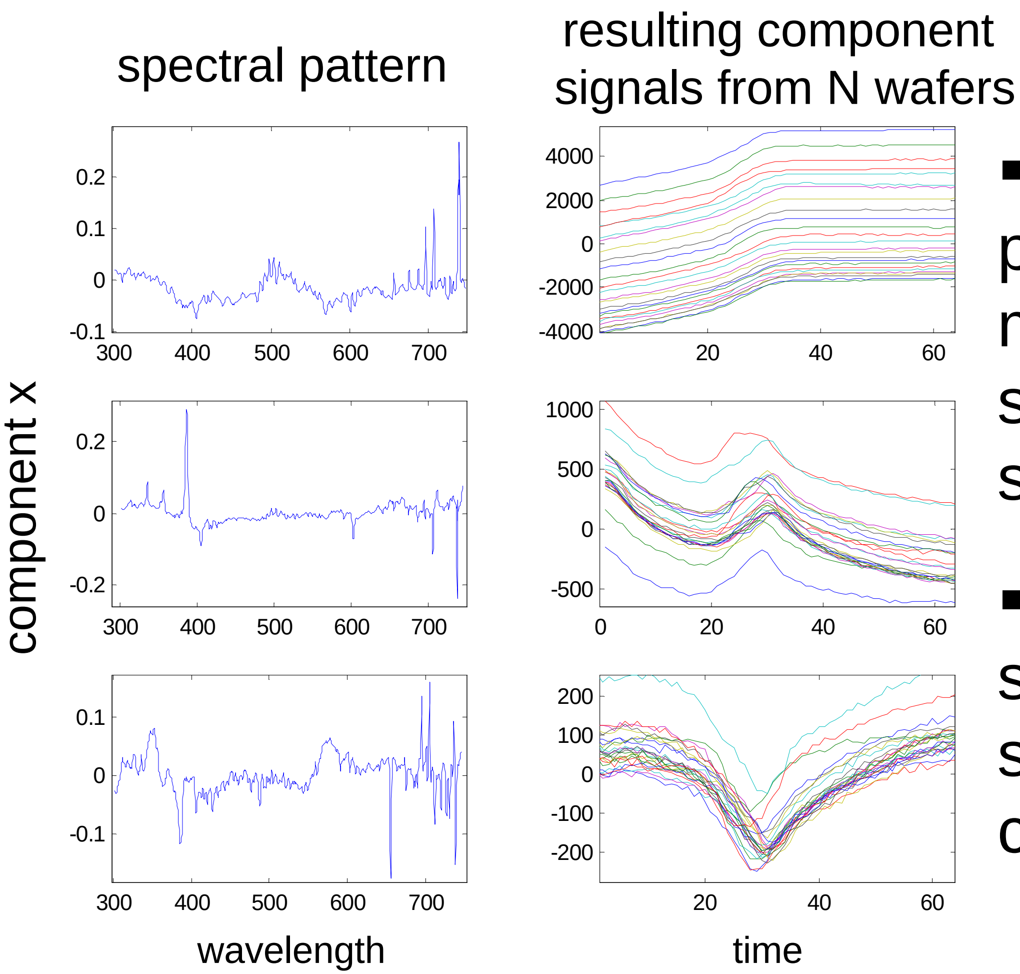
Model based approach for Endpoint Design

→ Unfolded PCA – basis for spectral information extraction



- application of spectral pattern to original measured data results in specific component time signals
- generation of endpoint signal by suitable superimposition of the components

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Model based approach for Endpoint Design
→ Regularization

philosophy: smooth adjustment of the condition of the estimation problem to prevent overfitting

model: $Xp \sim y$ (X: component signals; y: predef. EP shape)

solution: $p := (X^T X + I\theta^2)^{-1} X^T y$ (p: est. parameter)

application: $\lambda = \Lambda p$ (λ: res. wave pattern; Λ: spectral pattern)

⇨ adjustment of sensitivity parameter θ as a compromise between endpoint sensitivity and robustness

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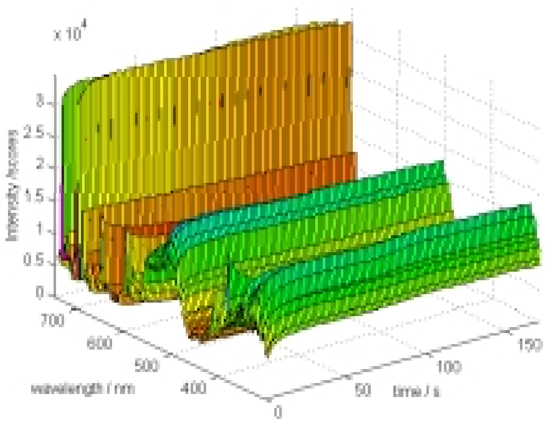
Features of used Hamamatsu Multiband Plasma Monitor



- spectral range: 200 - 950 nm
- resolution: < 2 nm; channel: 1024
- connection to Host PC via TCP-IP
- internal data processing for endpoint detection with a DB for spectral wave patterns and EP-Scripts
- on-line application of spectral wave pattern
- digital / analog ports for connection to tools

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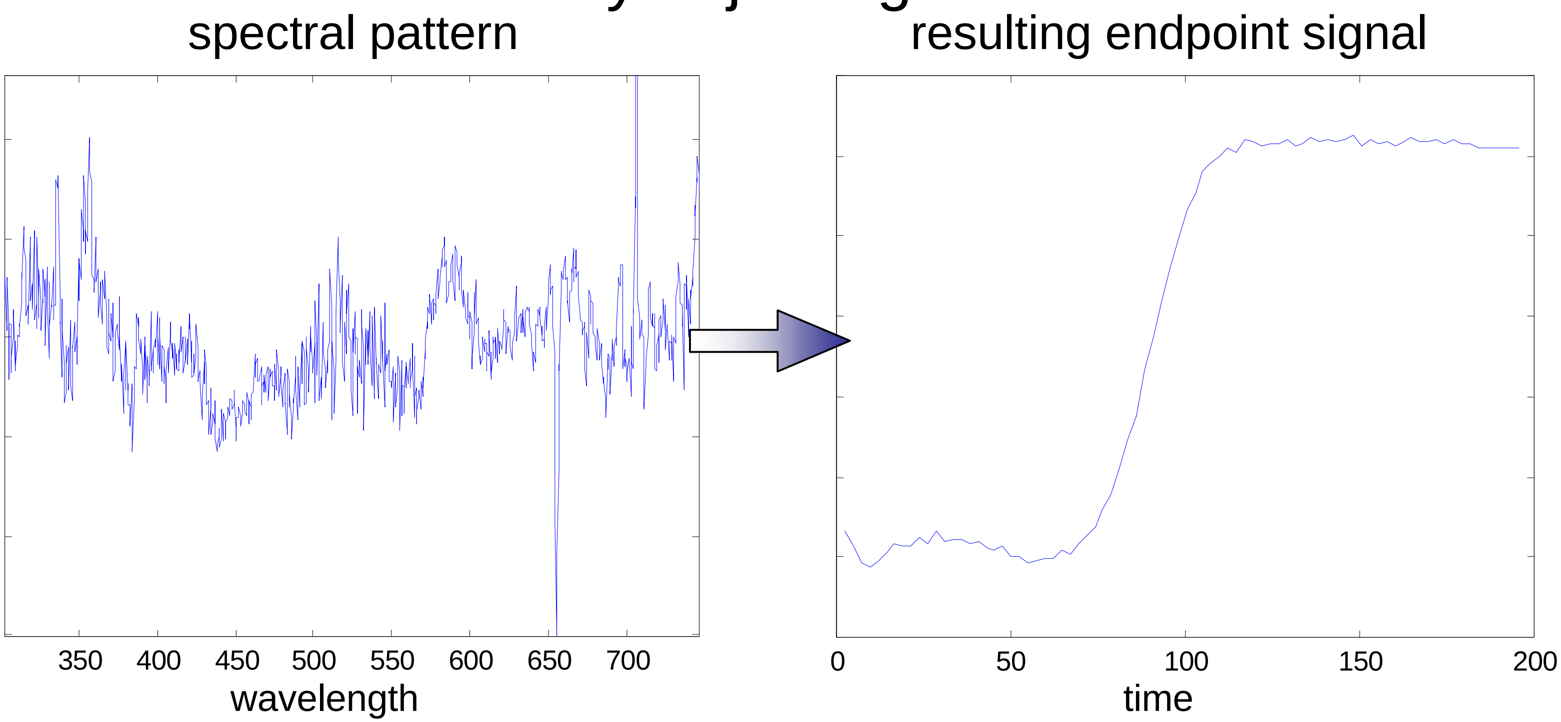
Application to Production Data
→ long term robustness

objective: synthesis of a suitable pattern using data from one etch by adjusting θ



→ to assess the long term robustness the pattern is now applied to a set of validation data

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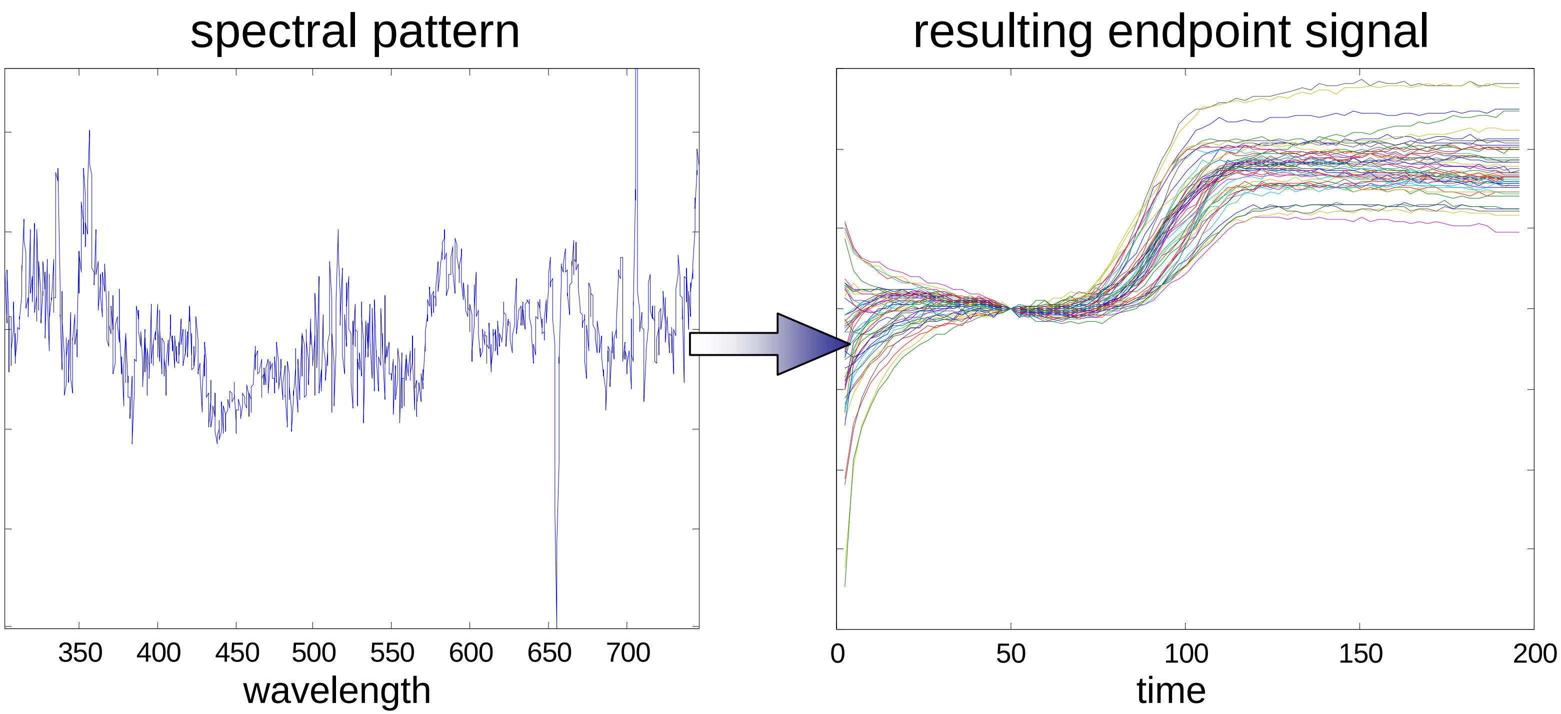
Application to Production Data
→ long term robustness

validation: application of the generated pattern to a set of spectral data from different Wet Clean cycles



essence: variation of θ permits to adjust compromise between sensitivity and robustness of the endpoint signal

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Application to Production Data

→ product robustness

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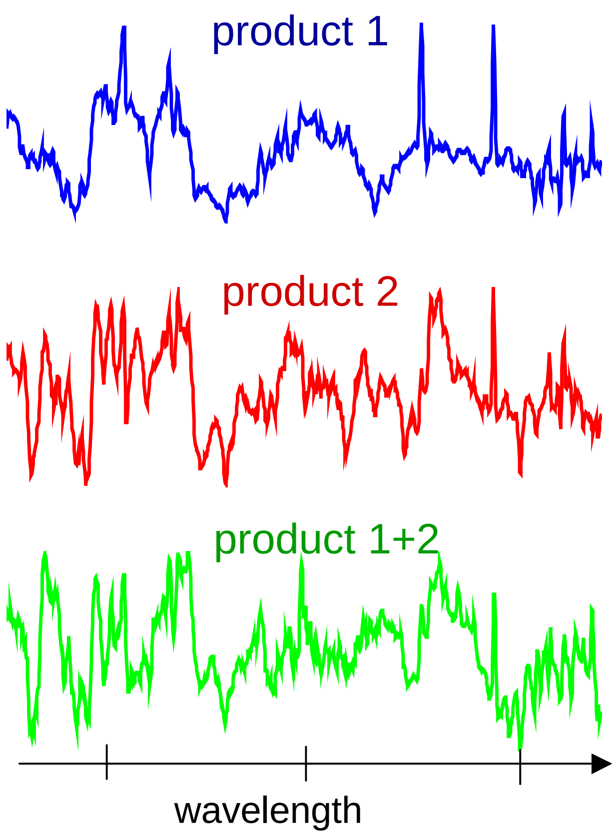
designed pattern using
spectral data from:



- in order to cope with spectral variations caused by different products (processed with the same recipe) it is useful to incorporate spectral data from several etches

- all influences incorporated in the data will be considered during the modeling process in order to prevent variations and drifts in resulting EP-signal

Application to Production Data

→ product robustness

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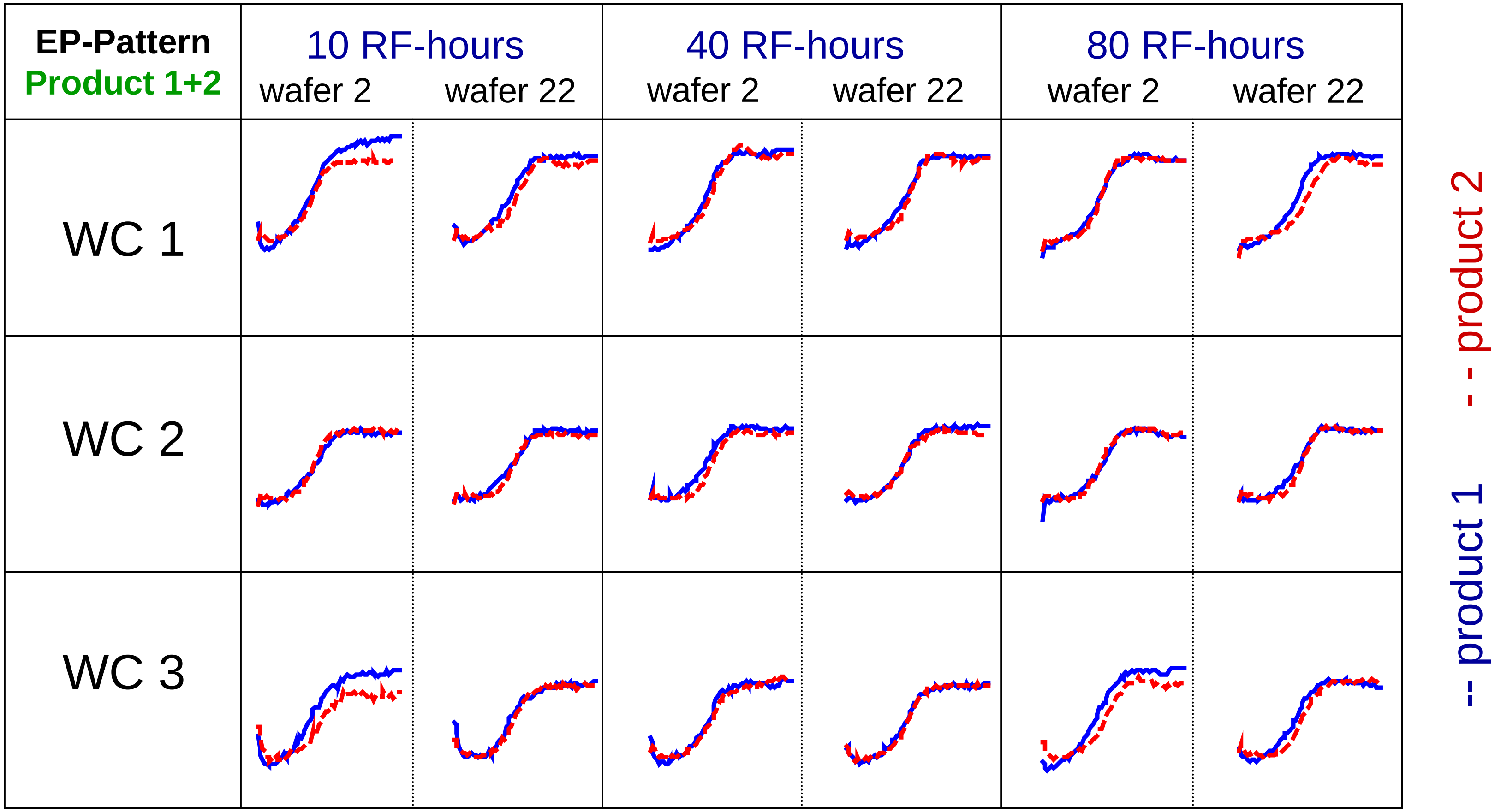

→ the assessment of several etches during the modeling yields to long term and product robust EP-signals

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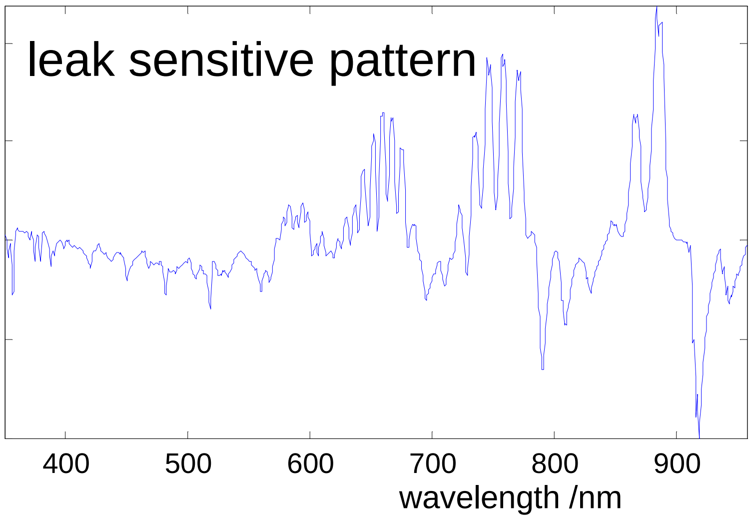
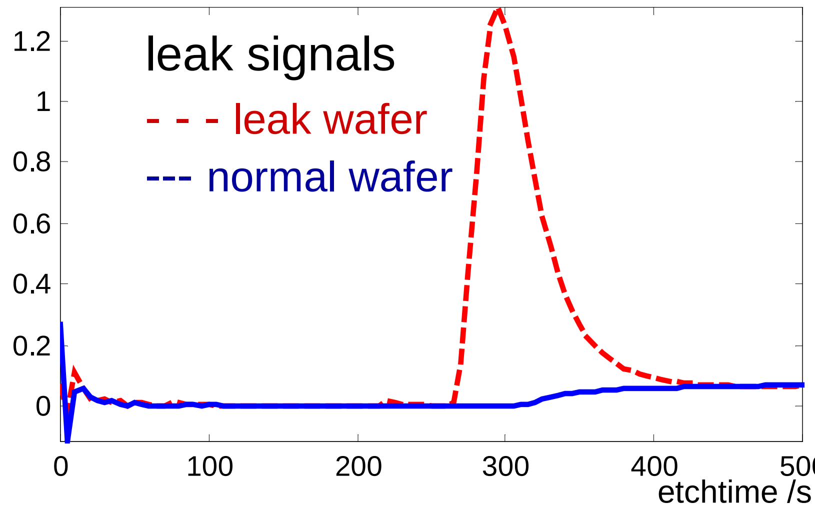
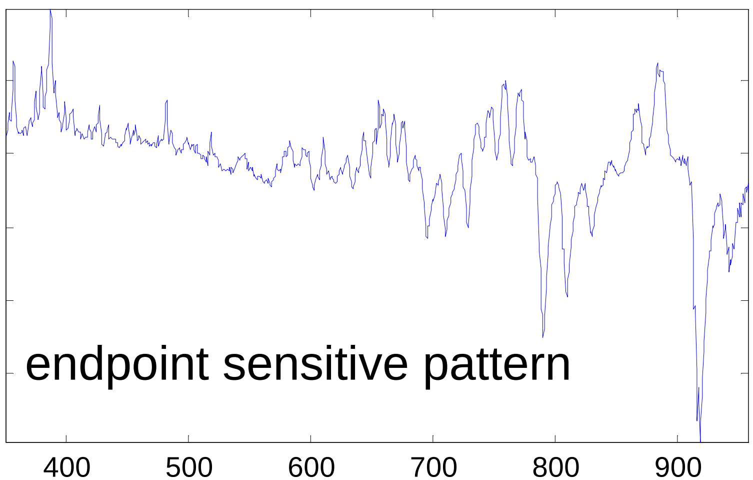
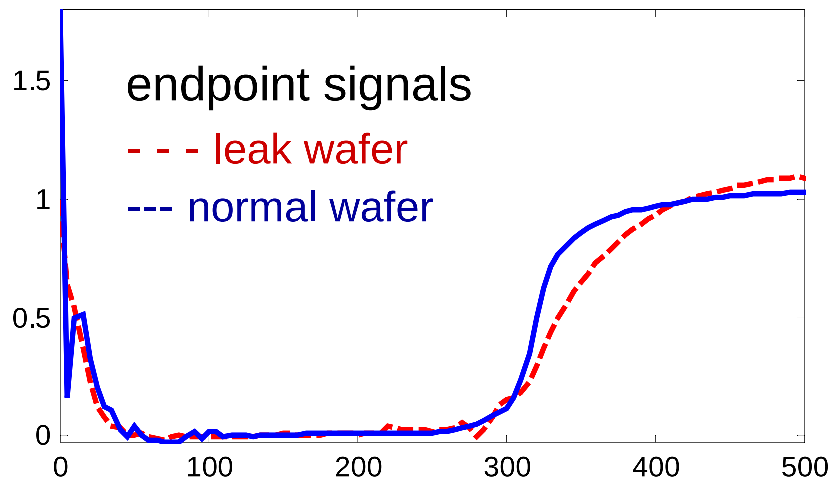
Application to Production Data

→ pattern based seperation of influences









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Summary

- a model based approach for designing endpoint specific wave pattern was shown
- easy and fast on-line calculation of an endpoint signal is possibly by a simple multiplication of the endpoint pattern with the measured spectra
- short and long term variations like chamber pollution, conditioning, product influences etc. are taken into account, using spectral data from more than one process for endpoint pattern design
- the sensitivity parameter θ allows a convenient adjustment of the sensitivity / robustness compromise

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