To Reduce GUM’s Recommendations to Practice

Structure of Contributions to Combined Standard Uncerteinty

“Uncertainty Concepts in Thermo-Physical Measurement Methods”

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  …. Generalized Construction of an Uncertainty Model - a Proposal
- Application(s)
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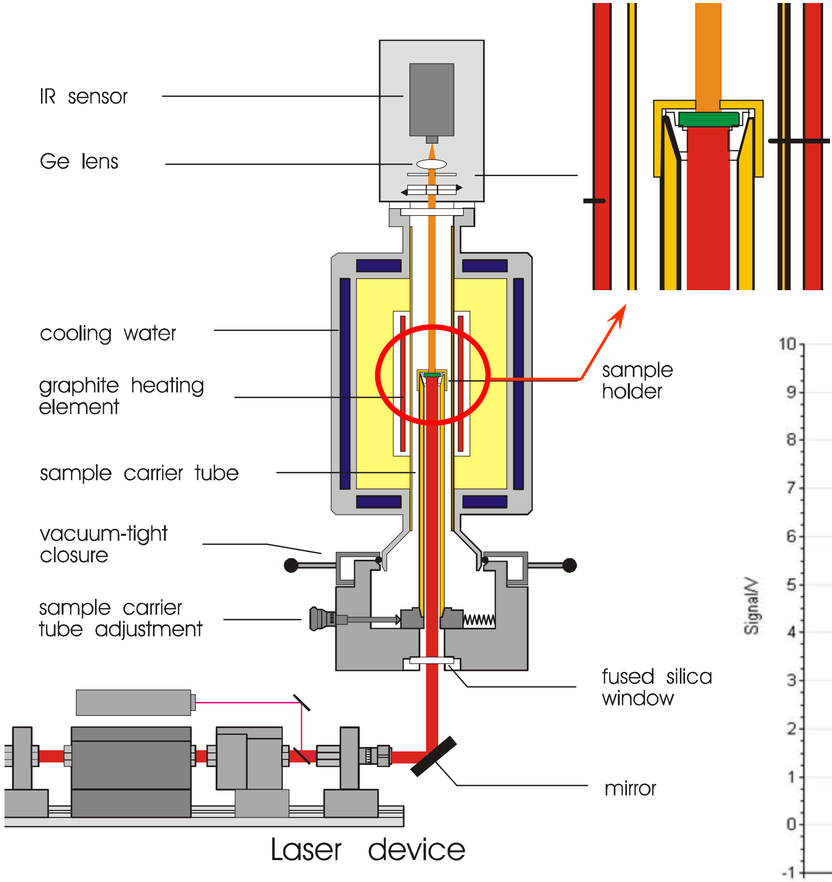
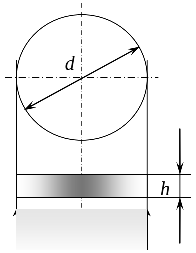
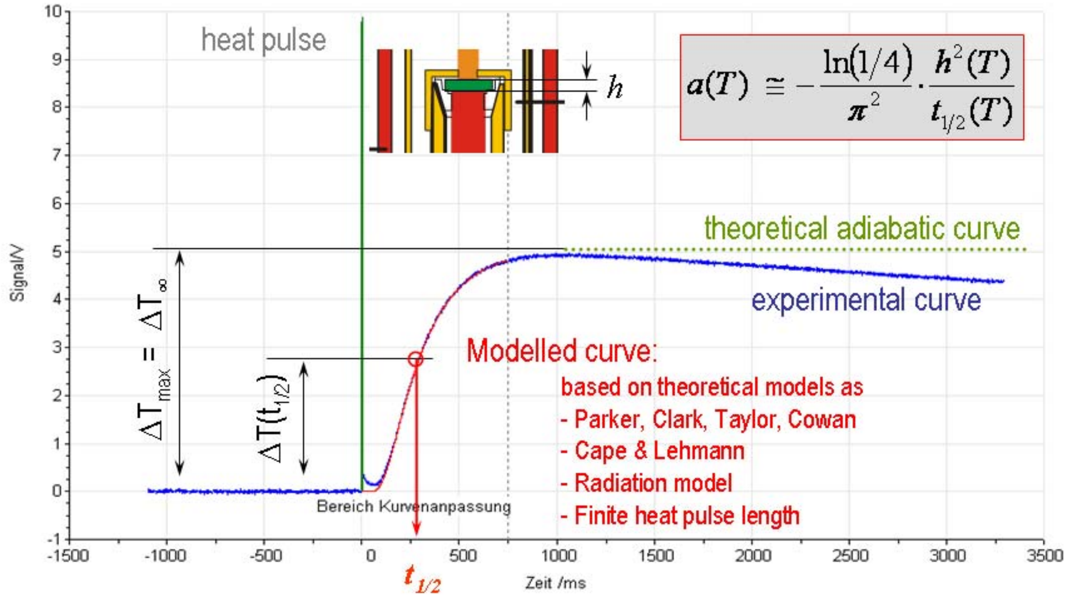
  - Dynamic Scanning Calorimetry
- Summary

Motivation

… Basics and Ideal Conditions







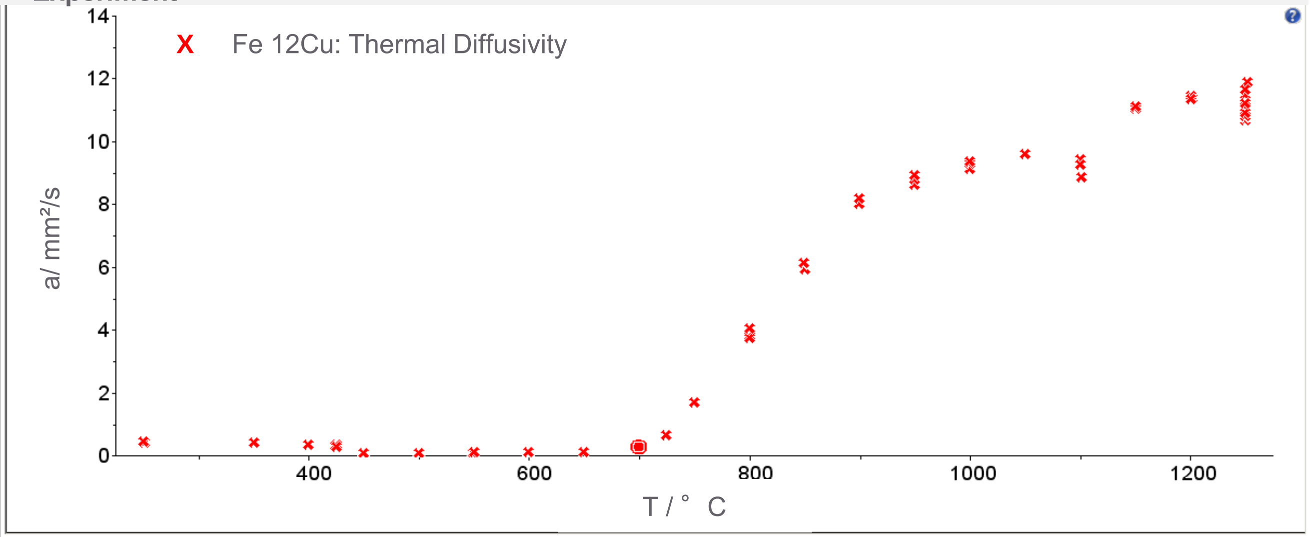
Motivation

… Ideal Conditions ???

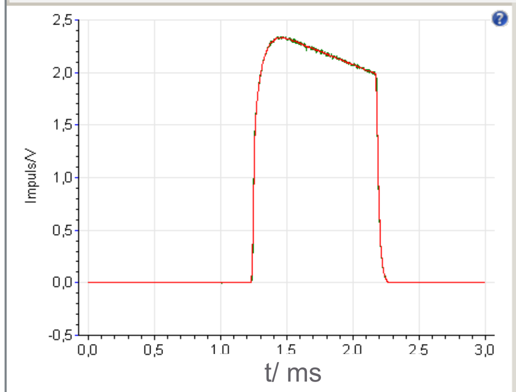
Results

Schuss	
Schuss	29 von 82
Kategorie	10 von 22
t(1/2) /ms	1117,400
Gesamte Messdauer /ms	-5196,562 ... 15610,500
Grenzen der Anpassung /ms	Volle Messdauer
klassisch	
Parker /(mm^2/s)	0,282
Clark-Taylor /(mm^2/s)	0,304
Azumi /(mm^2/s)	0,282
Cowan 5 /(mm^2/s)	0,243
Cowan 10 /(mm^2/s)	0,244
Cowan + Pulskorr.	
Temp.leitf./(mm^2/s)	0,263 ± 4,5750e-003
Wärmeverlust	0,272 ± 2,2603e-002
T unend./bel.Einh.	4,368 ± 6,0222e-002
Korr.koeff.	0,95753
Fexp. / Fkrit.	1 / 1,09

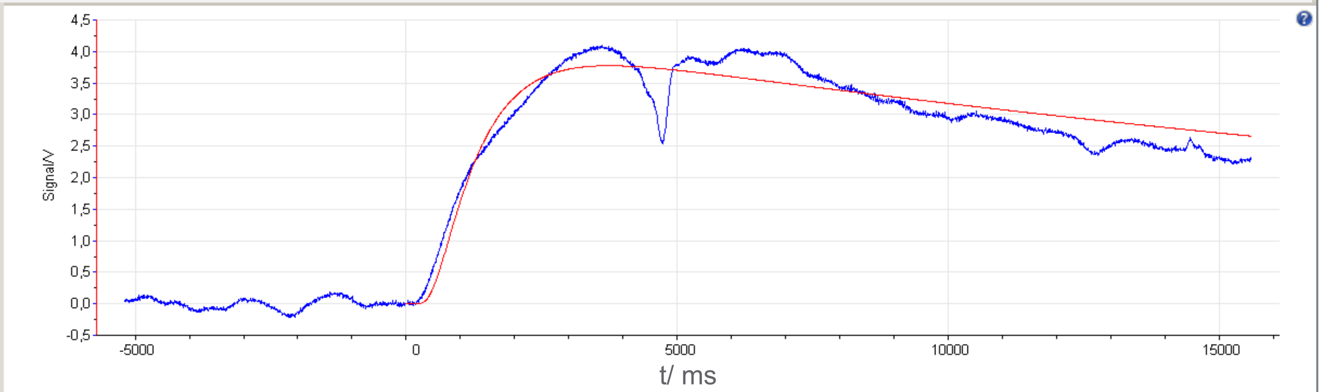
Experiment



Laser Pulse



Shot & Examining Model



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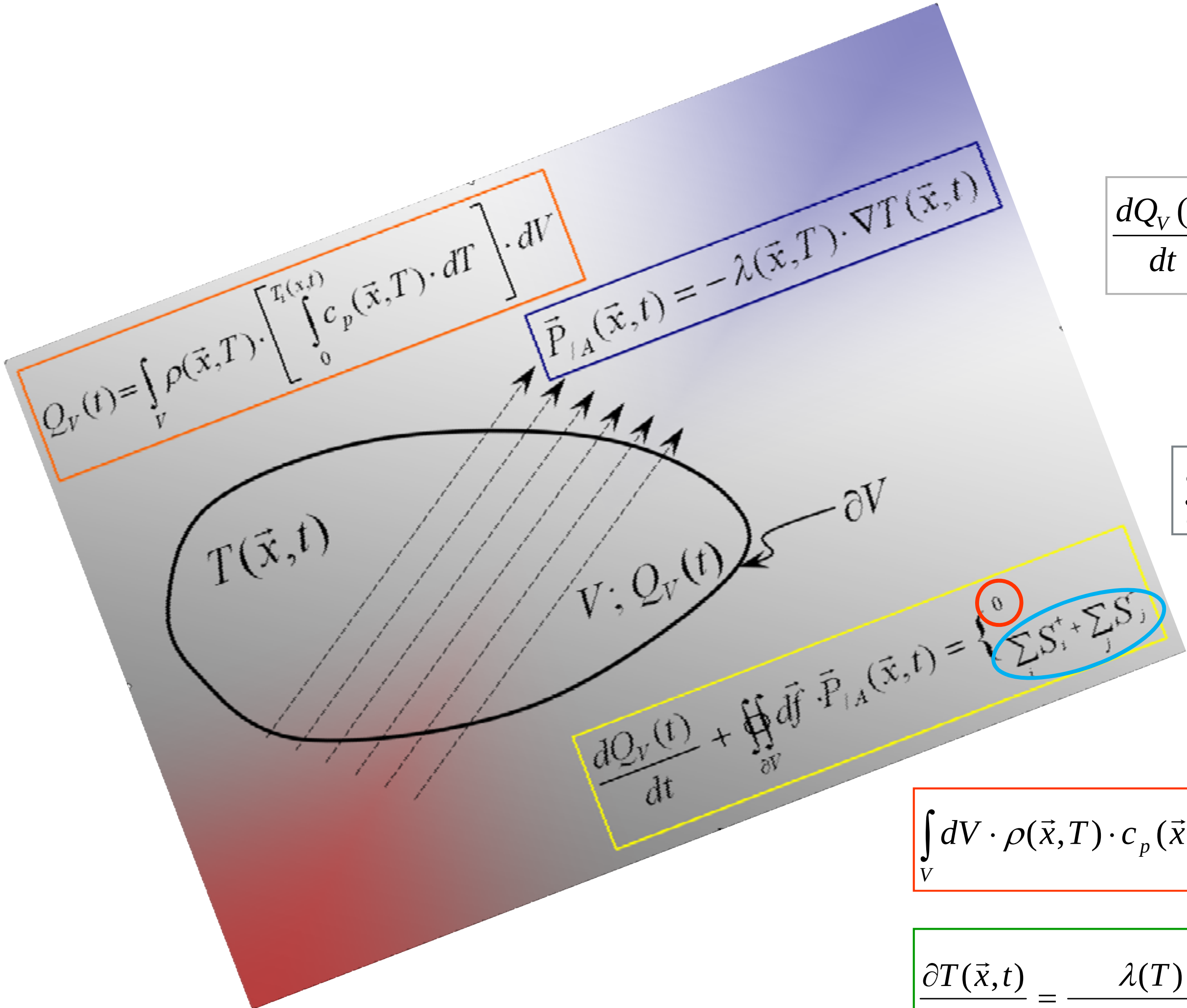
Motivation

… Phenomenology meets Physics – and Physics meets Maths



Change of Heat Content

$$\frac{dQ_V(t)}{dt} = \frac{\partial}{\partial t}\int_V \rho(\vec{x},T)\cdot\left[\int_0^{T_i(\vec{x},t)} c_p(\vec{x},T)\cdot dT\right]\cdot dV$$

Heat Flux

$$\oint_{\partial V} d\vec{f}\cdot\vec{P}_{I A}(\vec{x},t) = -\oint_{\partial V} d\vec{f}\cdot\lambda(\vec{x},t)\cdot\nabla T(\vec{x},T)$$

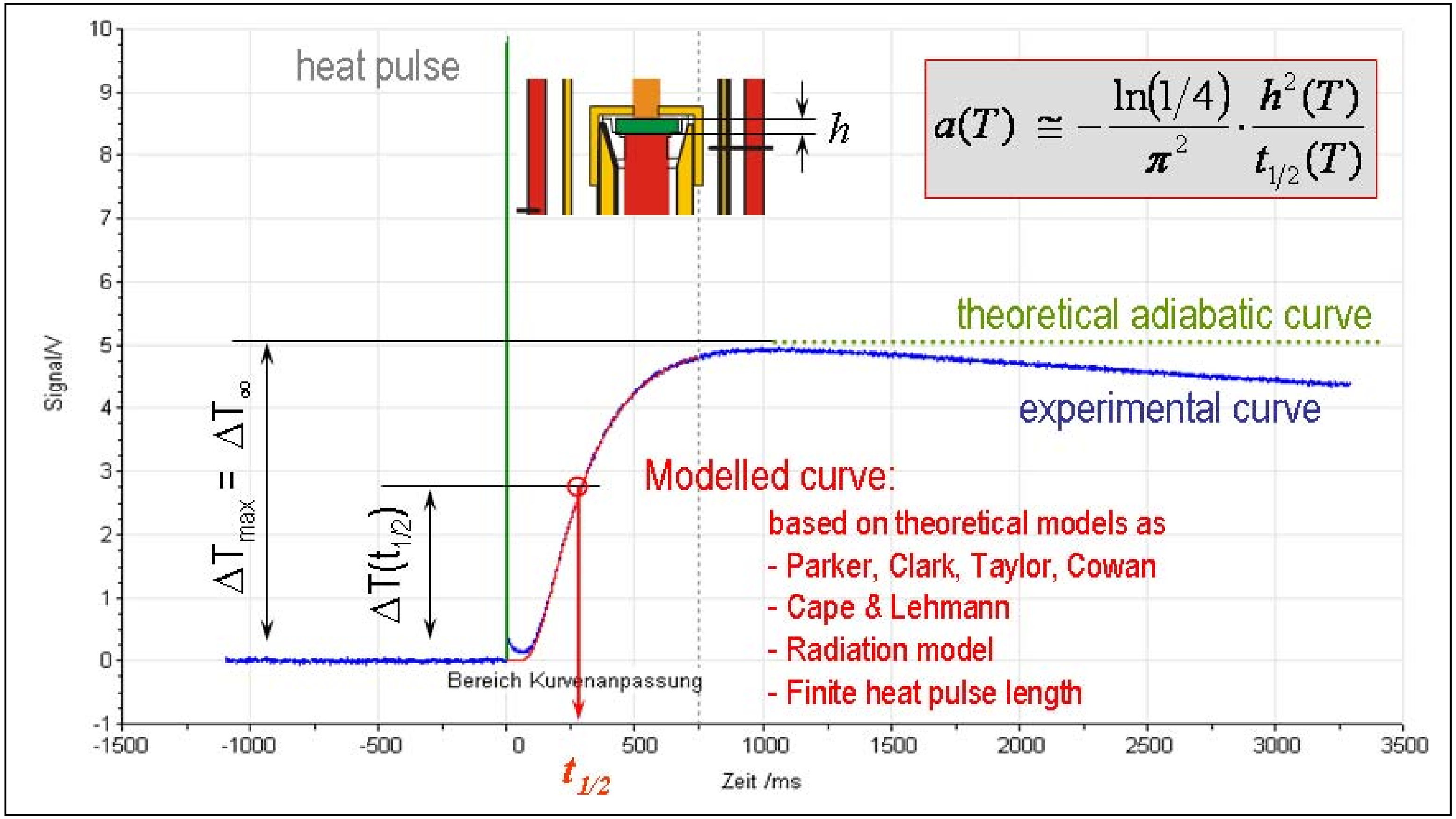
Thermal Balance of a Conservative System

$$\int_V dV\cdot\rho(\vec{x},T)\cdot c_p(\vec{x},T)\cdot\frac{\partial T(\vec{x},t)}{\partial t} - \oint_{\partial V}\lambda(\vec{x},T).\nabla T(\vec{x},t).d\vec{f} = 0$$

$$\frac{\partial T(\vec{x},t)}{\partial t} = \frac{\lambda(T)}{\rho(T)\cdot c_p(T)}.\Delta T(\vec{x},t)$$

Motivation

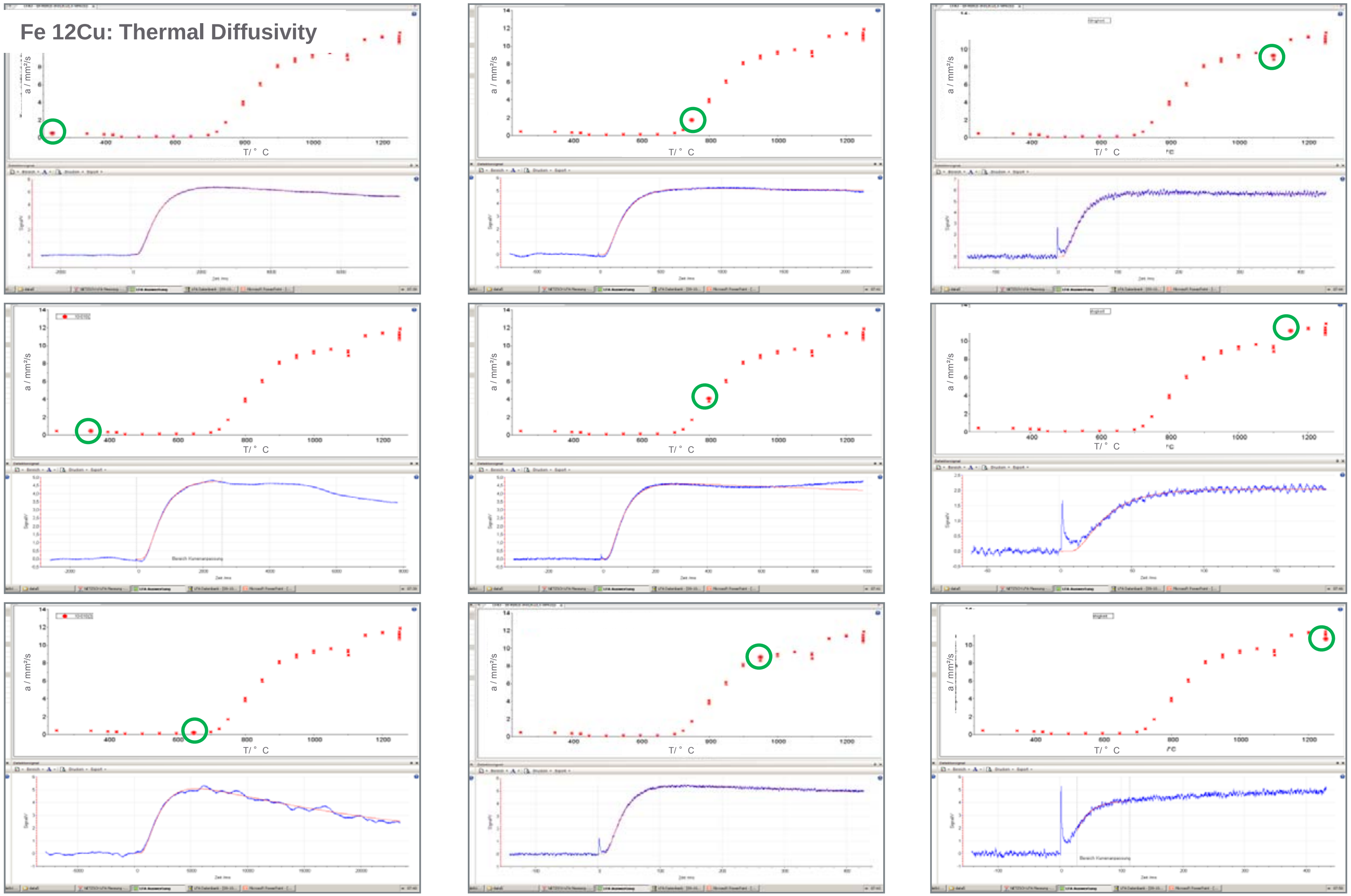
… 1𝔻, Adiabatic Boundries, δ - shaped Heat Impact, Series Expansion O(1)
… Adiabatic Model – PARKER Interpretation



Motivation

… Experimantal Reality: e.g. De-Binding and Sintering of Fe 12Cu

- **Fe 12Cu: Thermal Diffusivity**



Consequences:

… from these experiences

- Results of a measurement are determined from
  - Sample effects during the measurement
  - Equipment performance
  - Examining Model – restrictions, constraints, boundaries …
- THUS: Uncertainty considerations have to capture
  - Sample related effects
  - Equipment related effects
  - Model related effects
- How to formulate a sufficient UNCERTAINTY CONCEPT ???
- ⇒ ENV 13005 – GUM

GUM´s Recommendations *) - Type A

… Evaluation of standard uncertainty by
statistical analysis of a series of observations

… Best estimate of a the result of the repeated measurement of a *quantity* Q with n statistically independent obesrevations q_k is the arithmetic mean $\bar{q}$

$$\bar{q} = \frac{1}{n} \cdot \sum_{k=1}^{n} q_k$$

… Best estimate of the experimental standard deviation of the underlying probability distribution is the positive square root of the statistic variance $s^2(q_k)$

$$s(q_k) = \sqrt{\frac{1}{n-1} \cdot \sum_{k=1}^{n} (q_k - \bar{q})^2}$$

… Best estimate of the uncertainty of the arithmetic mean $\bar{q}$ of a series of n indpendent observations q_k is the positive square root of the experimental standard deviation of the mean

$$u(\bar{q}) = \frac{1}{\sqrt{n}} \cdot s(q_k) := u(x_i)$$

… The standard uncertainty of an output estimate y given from the model function $\boldsymbol{y = f(x_1, \ldots x_N)}$ of N input quantities $\{x_1, \ldots x_N\}$ is calculated from …..

$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 . u^2(x_i)$$

*) … ENV 13005

GUM´s Recommendations *) - Type B

… Evaluation of standard uncertainty by
scientific judgement - based on all available information

… 50% chance to measure the the estimate x_i *of an* input quantity X_i within the symmetrc intervall $[a_- / a_+]$.

The width of the intervall $[a_- / a_+]$ is $a = (a_- + a_+)/2$.

$$u(x_i) = 1{,}48\, a$$

… 66% chance to measure the the estimate x_i *of an* input quantity X_i within the symmetrc intervall $[a_- / a_+]$.

The width of the intervall $[a_- / a_+]$ is $a = (a_- + a_+)/2$.

$$\boxed{u(x_i) = a}$$

… 90% chance to measure the the estimate x_i *of an* input quantity X_i within the intervall $[b_- / b_+]$.
No information about the distribution of the input quantity X_i in $[b_- / b_+]$ available

$$u^2(x_i) = (b_+ - b_-)^2/12$$

so far $b = (b_+ - b_-)/2$

$$u^2(x_i) = b^2/3$$

*) … ENV 13005

EXTENSION of GUM´s Recommendations

… Proposal for a Generalized Construction of an Uncertainty Model

- ACCEPT the arithmetic mean
  … of a series of independent measurements is the best estimate of any input quantity
- CONSIDER dues to the uncertainty from their causation
  - sample related effects
  - equipment related effects
  - model related effects
- ESTABLISH a construction principle
  … to formulate uncertainty models considering equipment and/or model related effects
- ADD ZERO-QUANTITIES C_j to the mean
  … as corrections to the arithmetic mean representing effects
  … e.g. traceable back to the equipment or to the examining model.

$$q = \frac{1}{m} \cdot \sum_{k=1}^{m} q_k + \sum C_j \qquad C_j = 0 \; \forall \; j \, ; u(C_j) \neq 0$$

- ATTRIBUTE $u(C_j)$ as the uncertainty of any specific correction C_j

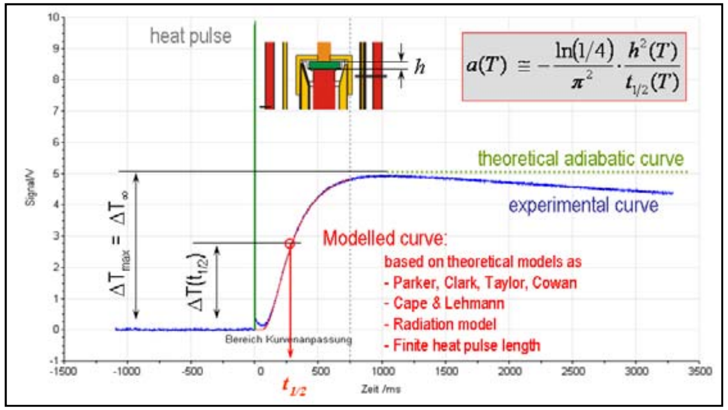
$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 \cdot u^2(x_i) + \sum u^2(C_j)$$

Applications

… Laser Flash Method

$$Y = f(X_1, X_2, \dots, X_i, \; \dots, X_N)$$
$$y = f(q_1, q_2, \dots, q_i, \; \dots, q_N)$$

$$\boxed{a\,(T) = \frac{-\ln(1/4)}{\pi^2} \cdot \frac{h^2}{t_{1/2}}}$$



$$\bar{q} = \frac{1}{n} \cdot \sum_{k=1}^{n} q_k$$

$$a = \frac{1}{n} \cdot \sum_{k=1}^{n} a_k + \sum_{j=1}^{m} C_j \, ; \quad C_j := 0 \; \forall \; j$$

$$s(q_k) = \sqrt{\frac{1}{n-1} \cdot \sum_{k=1}^{n} (q_k - \bar{q})^2}$$

$$u(\bar{q}) = \frac{1}{\sqrt{n}} \cdot s(q_k) \; := \; u(x_i)$$

$C_S := 0$ … *Correction from Sample Specific Effects*
$C_M := 0$ … *Correction from Model Specific Effects*

$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 . u^2(x_i)$$

$$u_c^2(a) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 \cdot u^2(x_i) + u^2(C_S) + u^2(C_M)$$

$$u_c^2(a) = \quad ESU^2(a) \quad + SSV^2(a) + MSU^2(a)$$

ESU: Equipment Specific Uncertainty
SSU: Sample Specific Uncertainty
MSU: Model Specific Uncertainty

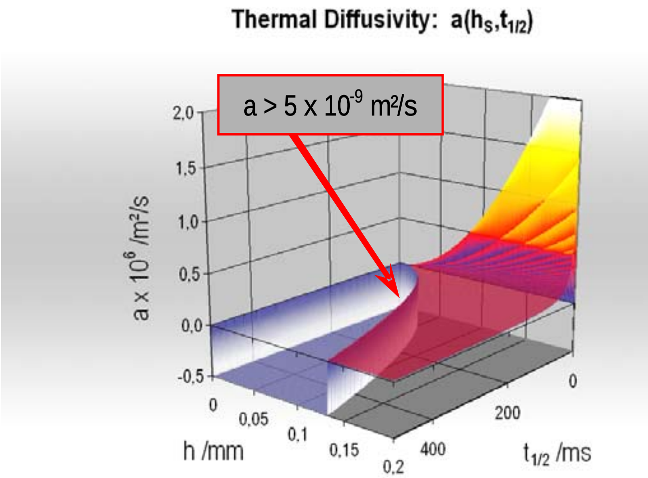
$$ESU^2(a) = a^2 \cdot \left[\frac{4}{h^2} \cdot u^2(h) - \left(\frac{a \cdot \pi^2}{\ln(1/4) \cdot h^2} \right)^2 \cdot u^2(t_{1/2}) \right]$$

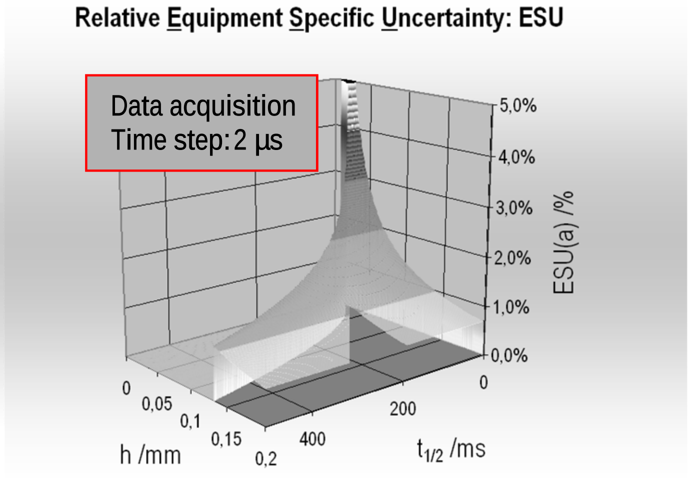
$$SSU^2(a) = s^2(a) = \frac{\sum_{k=1}^{n} (a_k - \bar{a})^2}{n \cdot (n-1)}$$

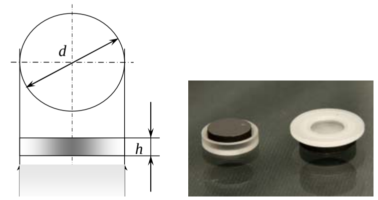
$MSU^2(a)$ …. *from individual $T(t)$ response*

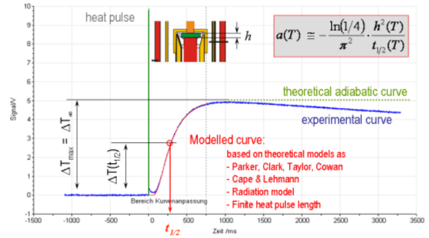
Applications

*… Laser Flash Method: ESU *)*





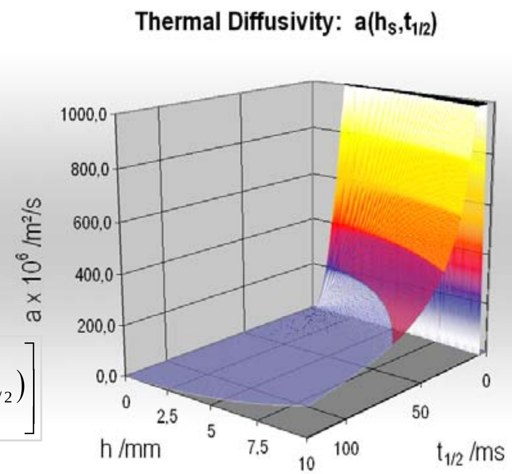


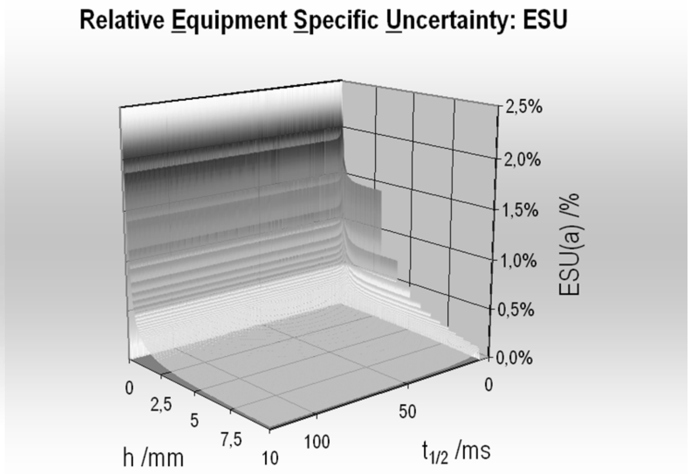


$$a(T) \cong -\frac{\ln(1/4)}{\pi^2}\cdot\frac{h^2(T)}{t_{1/2}(T)}$$

$$h_{\min} \cong \sqrt{\frac{\pi^2}{\ln 4}\cdot a\cdot t_{1/2}^{(\min)}} \cong 0{,}06\cdot\sqrt{a}$$

$$ESU^2(a) = a^2\cdot\left[\frac{4}{h^2}\cdot u^2(h) - \left(\frac{a\cdot\pi^2}{\ln(1/4)\cdot h^2}\right)^2\cdot u^2(t_{1/2})\right]$$

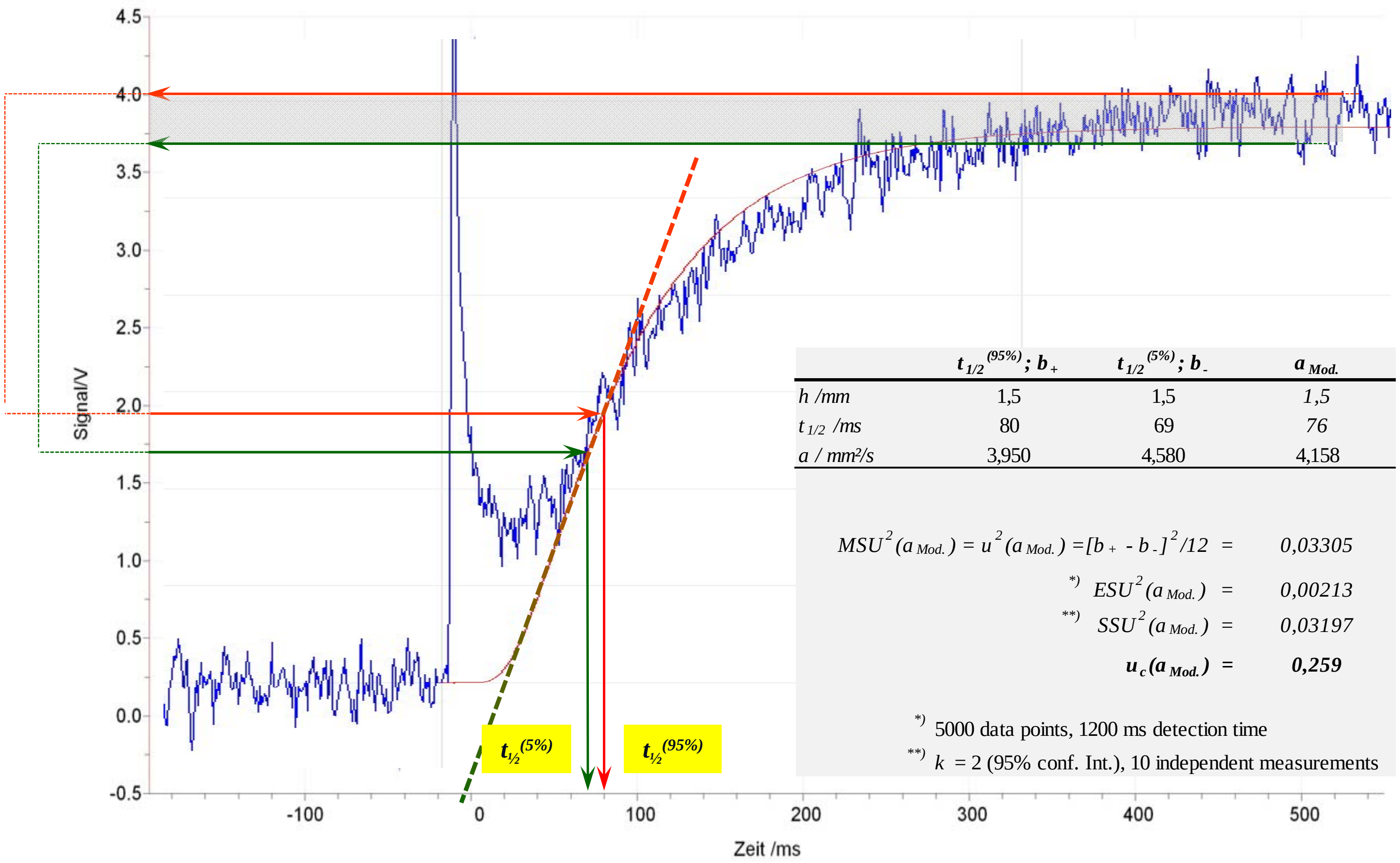




*) … HERE: NETZSCH® LFA 427

Applications

… Laser Flash Method: MSU



	$t_{1/2}^{(95\%)}$; b_+	$t_{1/2}^{(5\%)}$; b_-	$a_{Mod.}$
h /mm	1,5	1,5	*1,5*
$t_{1/2}$ */ms*	80	69	*76*
a / mm²/s	3,950	4,580	4,158

$$MSU^2(a_{Mod.}) = u^2(a_{Mod.}) = [b_+ - b_-]^2/12 = 0{,}03305$$

$$^{*)}\ ESU^2(a_{Mod.}) = 0{,}00213$$

$$^{**)}\ SSU^2(a_{Mod.}) = 0{,}03197$$

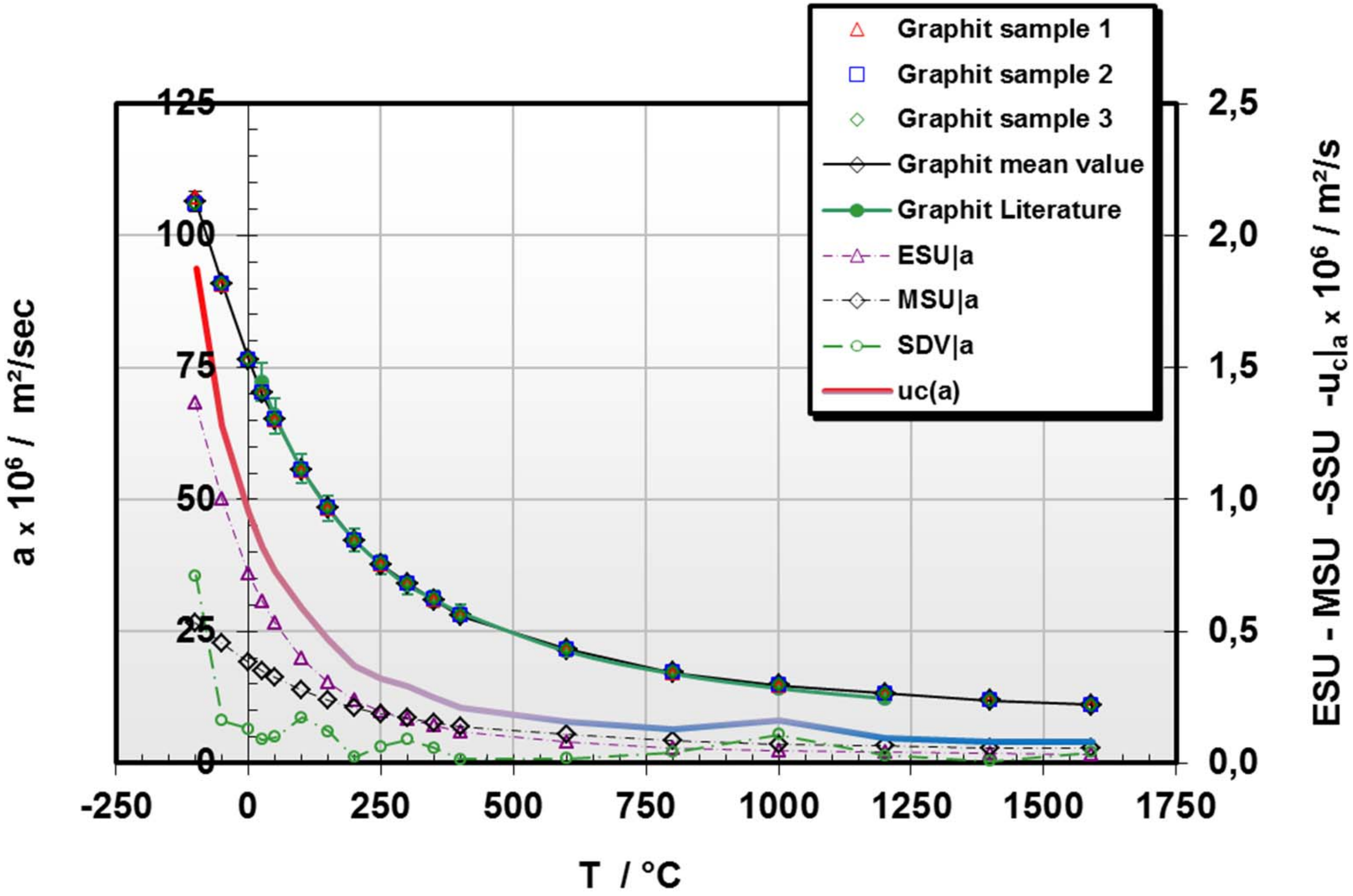
$$\mathbf{u_c(a_{Mod.}) = 0{,}259}$$

*) 5000 data points, 1200 ms detection time

**) *k* = 2 (95% conf. Int.), 10 independent measurements

Applications

… Laser Flash Method: $u_c(a)$ from a Graphite reference material



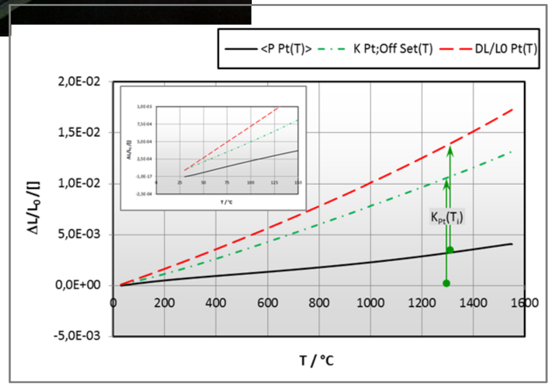
Applications

… Laser Flash Method: Conclusions

- 2 Zero-quantities C_j are added
  … C_E: equipment related
  … C_M: model related
- The arithmetic mean
  … remains to be the best estimate of the measurement result
- 3 dues to the uncertainty from their causation
  - SSU: sample related effects
  - ESU: equipment related effects
  - MSU: model related effects
- Construction principle $\boxed{u_c^2(a) = ESU^2(a) + SSV^2(a) + MSU^2(a)}$
  - SSU: from standard deviation of a series of measurements
  - ESU: from equipment performance parameters
  - MSU: from specifics of the transient temperature response of each shot
    … is time consuming therefor
    … BUT: it cannot be neglected – even NOT in case of optimum measurement conditions
- SSU, ESU, MSU – often do NOT scale from the same magnitude

Applications

… Push Rod Dilatometry



$$Y = f(X_1, X_2, \dots, X_i, \ \dots, X_N)$$

$$y = f(q_1, q_2, \dots, q_i, \ \dots, q_N)$$

$$K_R(T) = \left(\left.\frac{\Delta L_R(T)}{L_{0;R}}\right|_{Lit} - \frac{P_R(T)}{L_{0;R}} \right)$$

$$\left.\frac{\Delta L(T)}{L_0}\right|_S = \left.\frac{P(T)}{L_0}\right|_S + \left.\frac{K(T)}{L_0}\right|_R$$

$$\bar{q} = \frac{1}{n} \cdot \sum_{k=1}^{n} q_k$$

$$\left(\frac{\Delta L/L_0}{CTE}\right) = \frac{1}{n} \cdot \sum_{k=1}^{n} q_k + \sum_{j=1}^{m} C_j \, ; \quad C_j := 0 \ \forall \ j$$

$$s(q_k) = \sqrt{\frac{1}{n-1} \cdot \sum_{k=1}^{n} (q_k - \bar{q})^2}$$

$$u(\bar{q}) = \frac{1}{\sqrt{n}} \cdot s(q_k) := u(x_i)$$

$C_S := 0$ … *Correction from Sample Specific Effects*

$C_E := 0$ … *Correction from Equipment Specific Effects*

$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 \cdot u^2(x_i)$$

$$u_c^2\left(\frac{\Delta L/L_0}{CTE}\right) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 \cdot u^2(x_i) + u^2(C_S) + u^2(C_E)$$

$$u_c^2(x_i) = MSU^2(x_i) + SSV^2(x_i) + ESU^2(x_i)$$

ESU: Equipment Specific Uncertainty

SSU: Sample Specific Uncertainty

MSU: Model Specific Uncertainty

$$MSU^2\big|_{\Delta L/L_0} = u^2\left(\frac{P_R}{L_{0;R}}\right) + u^2\left(\left.\frac{\Delta L_R}{L_{0;R}}\right|_{Lit}\right) = s^2\left(\frac{P_R}{L_{0;R}}\right) + \left(0{,}01 \cdot \left.\frac{\Delta L_R}{L_{0;R}}\right|_{Lit}\right)^2$$

$$SSU^2\big|_{\Delta L/L_0} = s^2\left(\frac{P_S}{L_{0;S}}\right)$$

$$ESU^2\big|_{\Delta L/L_0} \cong \left(\frac{10^{-6}\,/\,m}{L_{0;i}\,/\,m}\right)^2 \cdot \left(\frac{\Delta L(T)}{L_0}\right)^2 \cong \left(10^{-3}\right)^2 \cdot \left(\frac{\Delta L(T)}{L_0}\right)^2$$

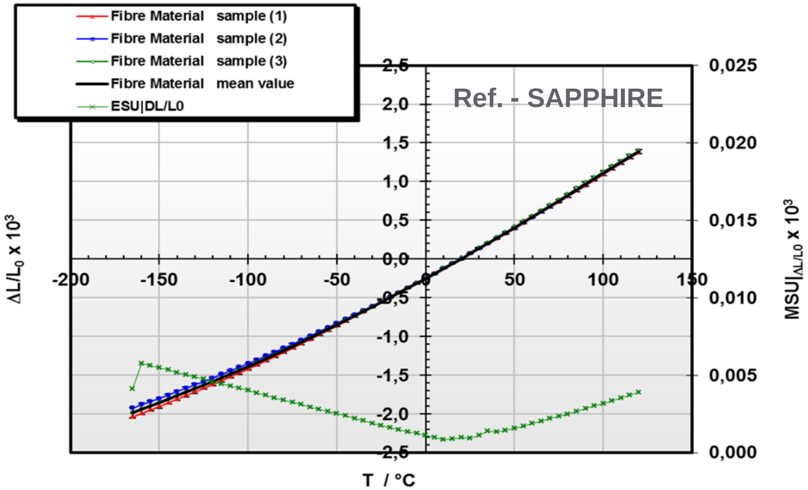
$$MSU^2\big|_{CTE} = \frac{1}{\Delta T^2} \cdot MSU^2\left(\frac{\Delta L_R}{L_{0;R}}\right)$$

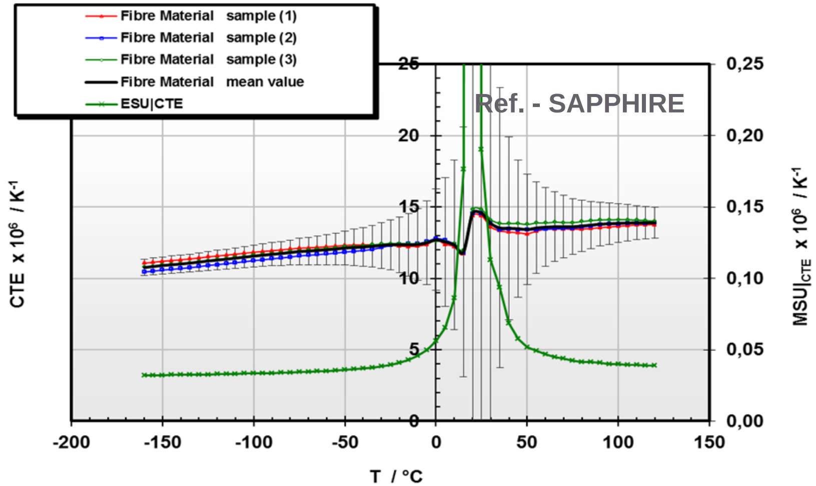
$$SSU^2\big|_{CTE} = \frac{1}{\Delta T^2} \cdot s^2\left(\frac{P_S}{L_{0;S}}\right)$$

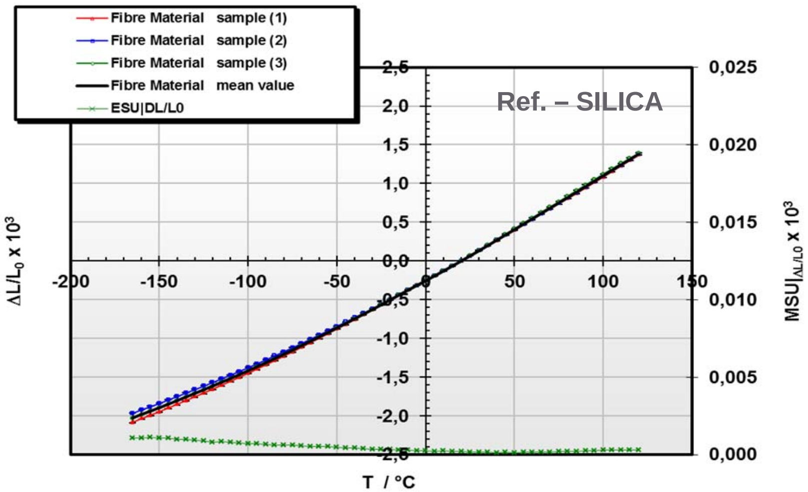
$$ESU^2\big|_{CTE} = \frac{1}{\Delta T^2} \cdot \left[ESU^2\big|_{\Delta L/L_0} + CTE_R^2 \cdot u_C^2(\Delta T)\right] \cong \frac{1}{\Delta T^2} \cdot \left[\left(10^{-3}\right)^2 \cdot CTE_S^2(T) + CTE_R^2(T) \cdot u_C^2(\Delta T)\right]$$

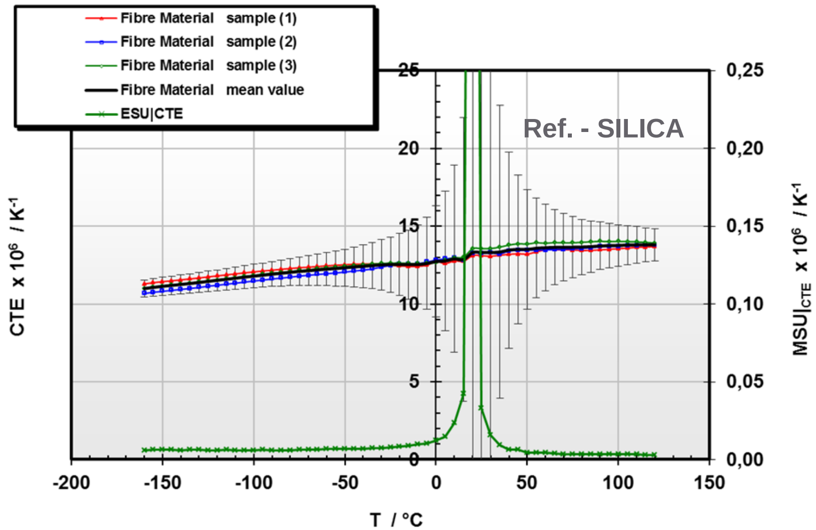
Applications

… Push Rod Dilatometry





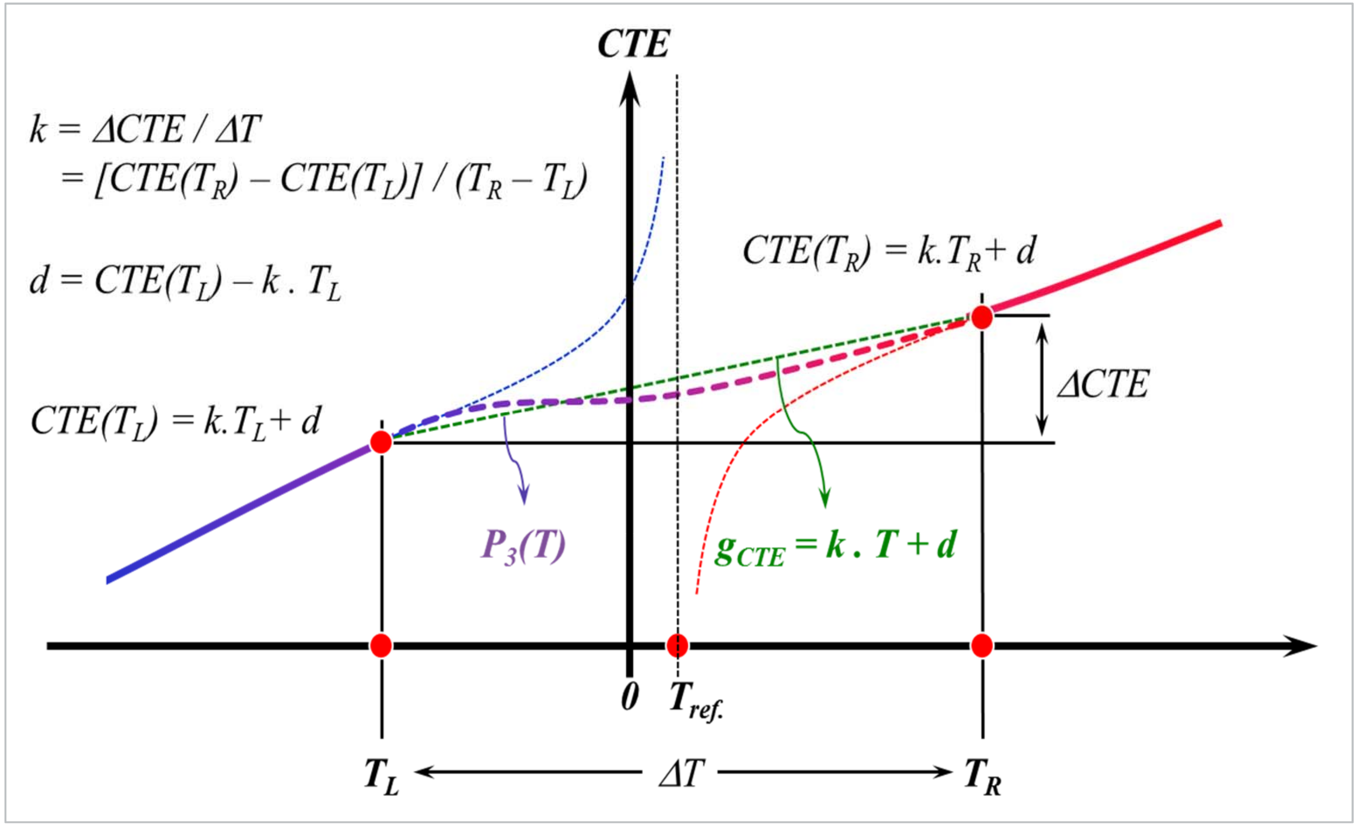




Applications

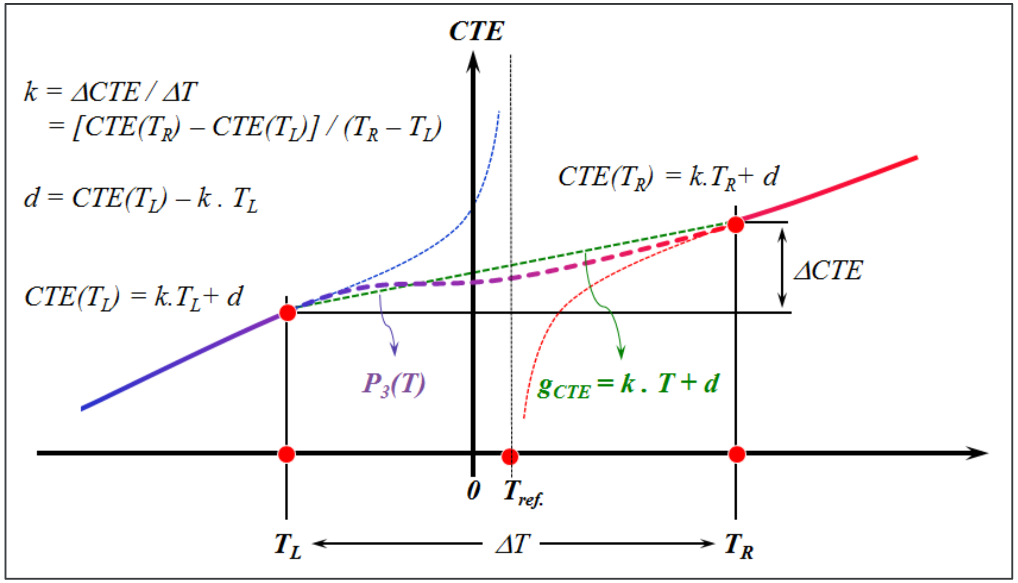
… Push Rod Dilatometry

$$\boxed{u_C^2\left(P_3(T)\right) \;\le\; 2\cdot u_C^2\left(CTE(T_L)\right)}$$



Applications

… Push Rod Dilatometry



$$k = \frac{\Delta CTE}{\Delta T}; \quad d = CTE_L - \frac{CTE_R - CTE_L}{T_R - T_L} \cdot T_L = CTE_L - \frac{\Delta CTE}{\Delta T} \cdot T_L$$

$$g_{CTE}(T) = \frac{\Delta CTE}{\Delta T} \cdot T + CTE_L - \frac{\Delta CTE}{\Delta T} \cdot T_L$$

$$g_{CTE}(T) = \frac{\Delta CTE}{\Delta T} \cdot (T - T_L) + CTE_L$$

$$\text{Definition 1}: \; \Delta T = (T_R - T_L)$$
$$\text{Definition 2}: \; (T - T_L) = \kappa \cdot \Delta T; \; \kappa \in [0;1]$$

$$g_{CTE}(T) = \kappa \cdot \Delta CTE + CTE_L$$

$$u_C^2(g_{CTE}(T)) = \sum \left(\frac{\partial g_{CTE}(x_i)}{\partial x_i} \right)^2 \cdot u^2(x_i)$$

$$\text{Variables}: \; \{x_i\} = \{\Delta CTE; CTE_L\}$$

$$u_C^2(g_{CTE}(T)) = \kappa^2 \cdot u^2(\Delta CTE) + 1 \cdot u^2(CTE_L)$$

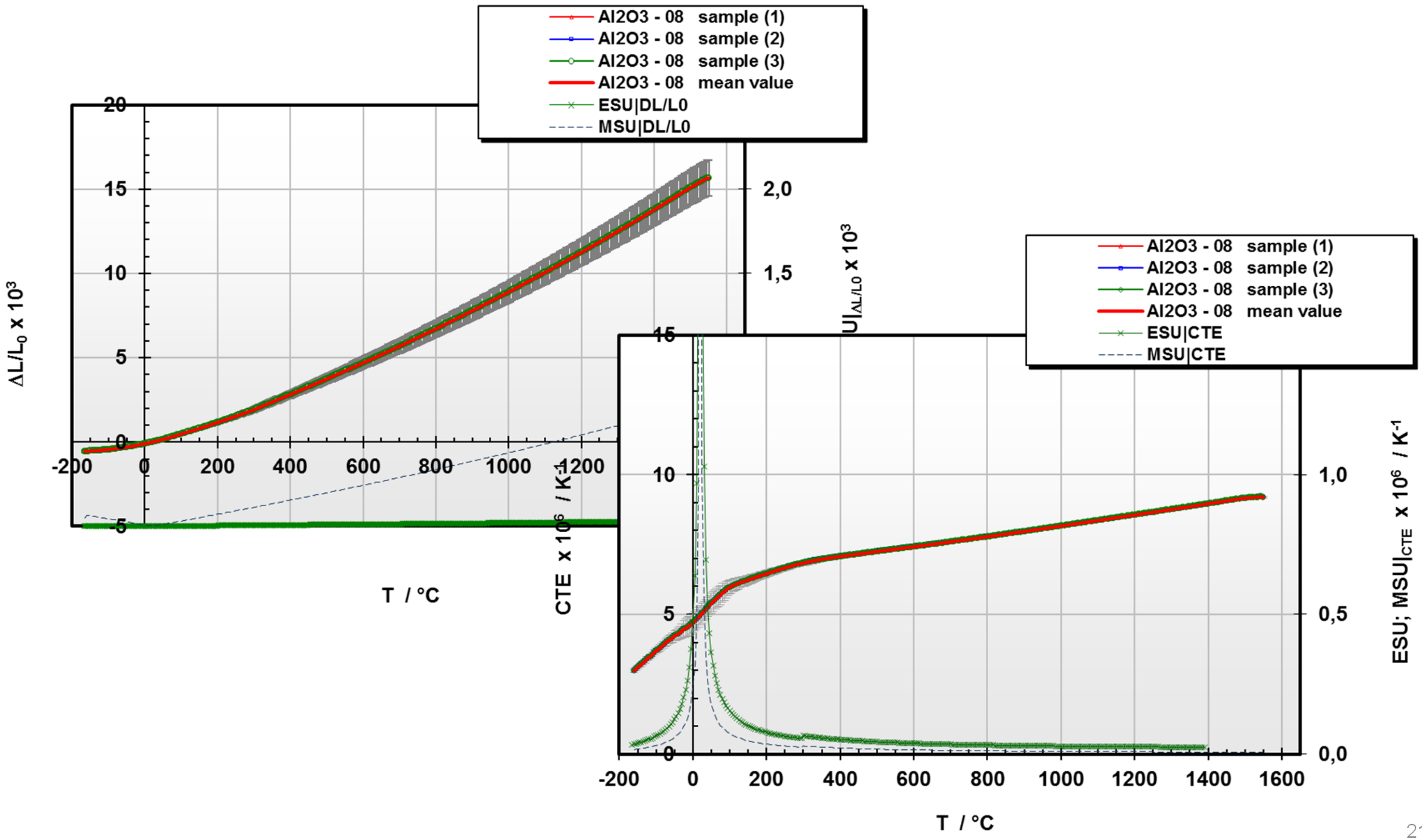
$$\text{Assumption}: \; |T_L| \cong |T_R|$$
$$u^2(\Delta CTE) \cong u^2(CTE_L) \cong u^2(CTE_R)$$

$$u_C^2(g_{CTE}(T)) \approx (\kappa^2 + 1) \cdot u^2(CTE(T_L))$$

$$u_C^2(g_{CTE}(T)) \leq 2 \cdot u^2(CTE(T_L))$$

Applications

… Push Rod Dilatometry



Applications

… Push Rod Dilatometry: Conclusions

- 2 Zero-quantities C_j are added
  … C_E: equipment related
  … C_S: sample related
- The arithmetic mean
  … remains to be the best estimate of the measurement result

- 3 dues to the uncertainty from their causation
  - SSU: sample related effects
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- Construction principle $\boxed{u_c^2(x_i) = ESU^2(x_i) + SSV^2(x_i) + MSU^2(x_i)}$
  - SSU: from standard deviation of a series of measurements
  - ESU: from equipment performance parameters – <u>including thermocouples</u>
    … can casually be neglected – but NOT in case of zero expansion materials
  - MSU: from specifics of the used reference material – and $K_R(T)$ therefor
    … good choice depends strongly on the optimum consilience on transient thermal histories of reference and sample

- SSU, ESU, MSU – do NOT scale from the same magnitude

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Applications

… Dynamic Scanning Calorimetry

$$Y = f(X_1, X_2, \dots, X_i, \; \dots, X_N)$$
$$y = f(q_1, q_2, \dots, q_i, \; \dots, q_N)$$

$$c_p^{(S)}(T) = \left[\frac{DSC^{(S)}(T) - DSC^{(B)}(T)}{DSC^{(R)}(T) - DSC^{(B)}(T)}\right] \cdot \left[\frac{m^{(R)}}{m^{(S)}} \cdot c_p^{(R)}(T)\right] =: [DSC(T)] \cdot [f_E(T)]$$

$$\overline{q} = \frac{1}{n} \cdot \sum_{k=1}^{n} q_k$$

$$s(q_k) = \sqrt{\frac{1}{n-1} \cdot \sum_{k=1}^{n} (q_k - \overline{q})^2}$$

$$u(\overline{q}) = \frac{1}{\sqrt{n}} \cdot s(q_k) := u(x_i)$$

$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 \cdot u^2(x_i)$$

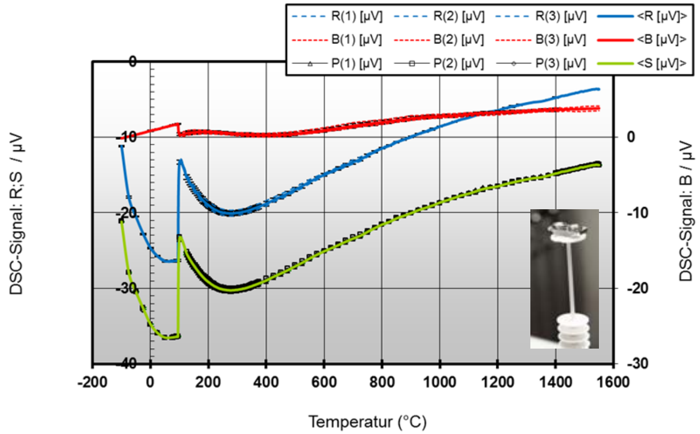
$$c_P = \frac{1}{n} \cdot \sum_{k=1}^{n} c_{p;k} + \sum_{j=1}^{m} C_j \, ; \quad C_j := 0 \; \forall \; j$$

NO Correction needed

IX / 2014 (!)

$$u_c^2(c_P) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 \cdot u^2(x_i)$$

$$u_c^2(c_p) = ESU^2(c_p) + MSV^2(c_p) + SSU^2(c_p)$$



ESU: Equipment Specific Uncertainty
SSU: Sample Specific Uncertainty
MSU: Model Specific Uncertainty

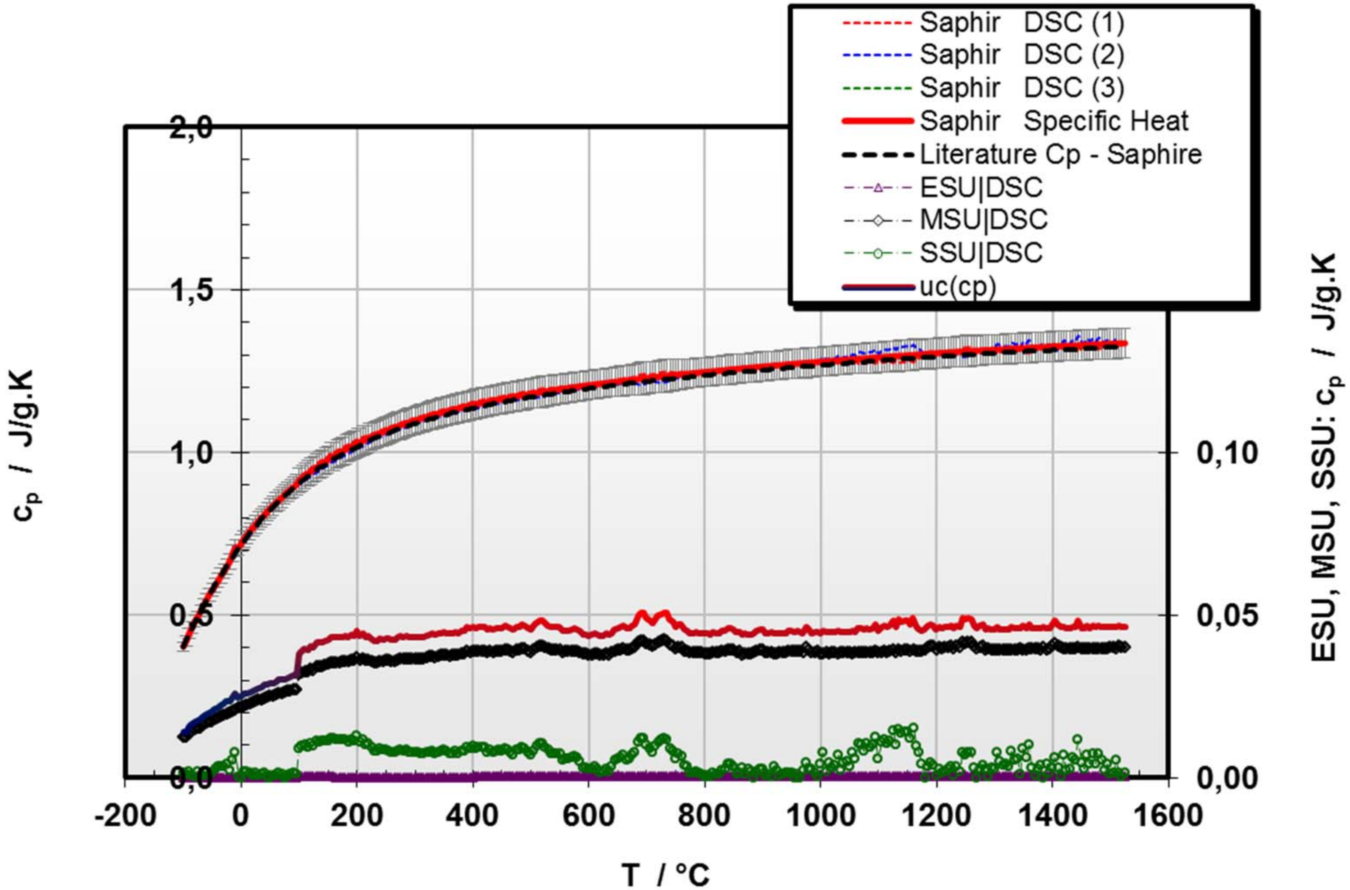
$$ESU^2|_{Cp} \cong f_E^2 \cdot \frac{\left(DSC^{(S)} - DSC^{(R)}\right)^2}{\left(DSC^{(R)} - DSC^{(B)}\right)^4} \cdot u^2(DSC^{(B)})$$

$$SSU^2|_{Cp} \cong f_E^2 \cdot \frac{u^2(DSC^{(S)})}{\left(DSC^{(R)} - DSC^{(B)}\right)^2}$$

$$MSU^2|_{Cp} \cong f_E^2 \cdot \frac{\left(DSC^{(S)} - DSC^{(B)}\right)^2}{\left(DSC^{(R)} - DSC^{(B)}\right)^4} \cdot u^2(DSC^{(R)}) \; + \; DSC^2(T) \cdot \left(\frac{m^{(R)}}{m^{(S)}}\right)^2 \cdot u^2\left(c_p^R\right)$$

Applications

… Dynamic Scanning Calorimetry



Applications

… Dynamic Scanning Calorimetry: Conclusions

- The arithmetic mean
  … remains to be the best estimate of the measurement result

- 3 dues to the uncertainty from their causation
  - SSU: sample related effects
  - ESU: equipment related effects
  - MSU: model related effects

- Construction principle $\boxed{u_c^2(c_p) = \quad ESU^2(c_p) + SSV^2(c_p) + MSU^2(c_p)}$
  - SSU: from standard deviation of a series of sample measurements
  - ESU: from standard deviation of a series of empty measurements
    … can casually be neglected – but performance is mapped to measurements of references and samples
  - MSU: from specifics of the used reference material – and $c_p(T)$ therefor
    … main contribution to the standard uncertainty $u_c(c_p)$ – *because of uncertainty of reference data*
  - <u>THUS</u>: the derived uncertainty model does NOT require to add zero-quantities C_j
  - <u>BUT</u>: in more complex models this might be different
- SSU, ESU, MSU – do NOT scale from the same magnitude

Summary

Proposal to Reduce GUM's Recommendations to Practice in Standard Methods of Thermophysics

- Using *GUM / ENV 13005* – Uncertainty Models are constructed for
  - Laser Flash
  - Push Rod Dilatometry
  - Dynamic Scanning Calorimetry
  - Hot Wire Method
  - Heat Flow Meter
  - Comparative Method
- Construction Principle
  - Dues to the uncertainty from their causation are implemented
    - *ESU*: equipment related effects
    - *MSU*: model related effects
    - *SSU*: sample related effects
  - The arithmetic mean
    - … Remains to be the best estimate of the measurement result
    - … Zero-quantities C_j necessary to be added
    - … $u(C_j)$ are attributed to *ESU / MSU*
  - Effects from calibrations to be implemented (T-Calib. S-Calib, …)
- Best Practice Recommendations from Uncertainty Analysis

$$\boxed{u_c^2(a) = ESU^2(a) + SSV^2(a) + MSU^2(a)}$$

Structure of Contributions: Special Issue HTHP

To Reduce GUM's Recommendations to Practice in <METHOD>

AUSTRIAN INSTITUTE OF TECHNOLOGY

- Introduction
  … deducing < *METHOD* > from basic concepts of thermodynamics
- Experimental Description of < *METHOD* >
  - … Experimental Requirements
- Theory to < *METHOD* >
  - … including constraints and boundaries
- Uncertainty Concept
  - … based on Theory to < *METHOD* >
  - … referring to calibration needs (e.g. T-calibration)
  - … FINALLY: dues attributed to: *ESU*, *MSU*, *SSU*
  - … discussion of the uncertainty concept and conclusions thereof → referring to "Examples" (see downwards)
- Hints to "Good Laboratory Practice" for < *METHOD* >
  … derived from uncertainty concept
- Examples
  - Analysis of Measurement Results from a Reference Material
  - Analysis of Measurement Results from a Material
    …which fits to basic constraints and boundaries of < *METHOD* >
  - Analysis of Measurement Results from a Material
    …which does not fully fit to basic constraints and boundaries of < *METHOD* >
  - Figures should explicitly show *ESU*, *MSU*, *SSU*
- Summary

Contributions

To Reduce GUM's Recommendations to Practice in Standard Methods of Thermophysics

8	Contributions	Special Emphasis to ...
Hohenauer		
1	Introduction & Concept	Concept to construct uncertainty models
Blumm, Hohenauer, Moukhina		
1	Dilatometry	Equipment specific uncertainty in push rod dilatometry
Hemberger, Mehling		
1	DSC	Main contribution to combined standard uncertainty in Dynamic Scanning Calorimetry DSC
Moukhina, Blumm, ...		
1	Laser Flash	Model specific uncertainty of diffusivity data from FLASH DEVICES
Rohde		
1	Thermal Reflectance	Main contribution to combined standard uncertainty in ALTERNATIVE FLASH CONCEPTS
Ebert, ...		
1	Heat Flow Meter	Equipment specific and model specific contributions to standard uncertainty in heat flow meters
1	Hot Wire Method	Equipment specific and model specific contributions to standard uncertainty in hot wire devices
Kaschnitz		
1	Cmparative Method	Equipment specific and model specific contributions to standard uncertainty in comparative devices