Temporal instability of photodiodes in the UV

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Motivation

Detectors - when used as secondary standard - should be

- Linear
- Uniform
- Independent of temperature
- …
- **Stable**

Reality:

Photodiodes are not stable!

The spectral responsivity changes

- with time,
- due to exposure (in the UV)
- ….

Responsivity changes with time

Significant drift of spectral responsivity below 550 nm in the Key Comparison CCPR-K2.b

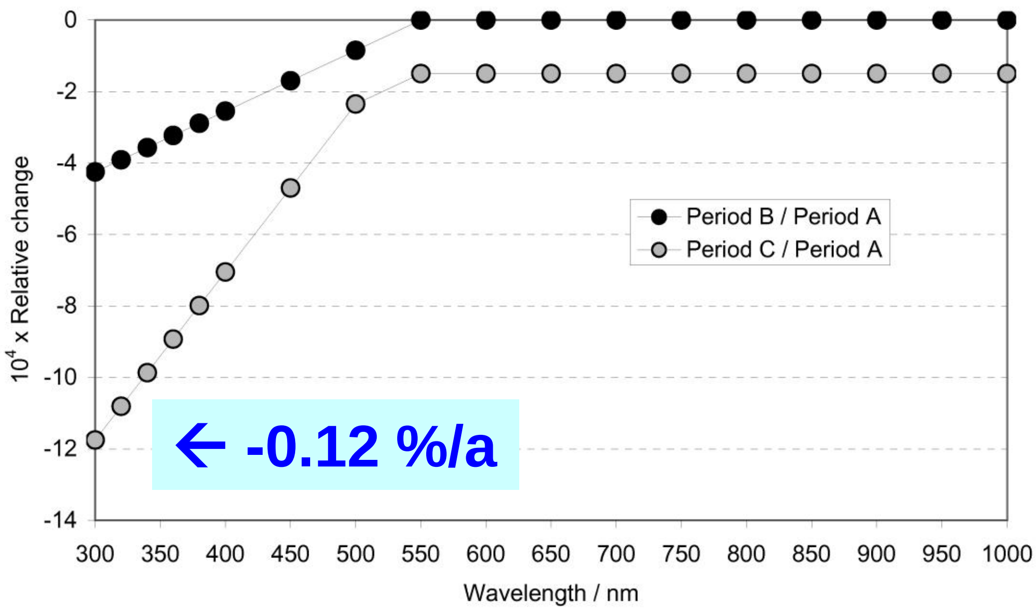


Figure 2 – Relative changes in spectral responsivity of the BIPM reference trap detector, as a function of time, based on measurements against the BIPM cryogenic radiometer (after linear interpolation and extrapolation). Periods A, B and C refer to June 2000, December 2000 and June 2001, respectively. A to B corresponds to Round 1 of the circulation of the transfer detectors, and B to C corresponds to Round 2.

R. Goebel, M. Stock, Report on the key comparison CCPR-K2.b of spectral responsivity measurements in the wavelength range 300 nm to 1000 nm, *Metrologia*, 2004, **41**, Tech. Suppl., 02004

Effects of low-power ultraviolet radiation on new and unused silicon photodiodes

Opposite behavior: increase of spectral responsivity during the first tens of seconds of exposure to UV

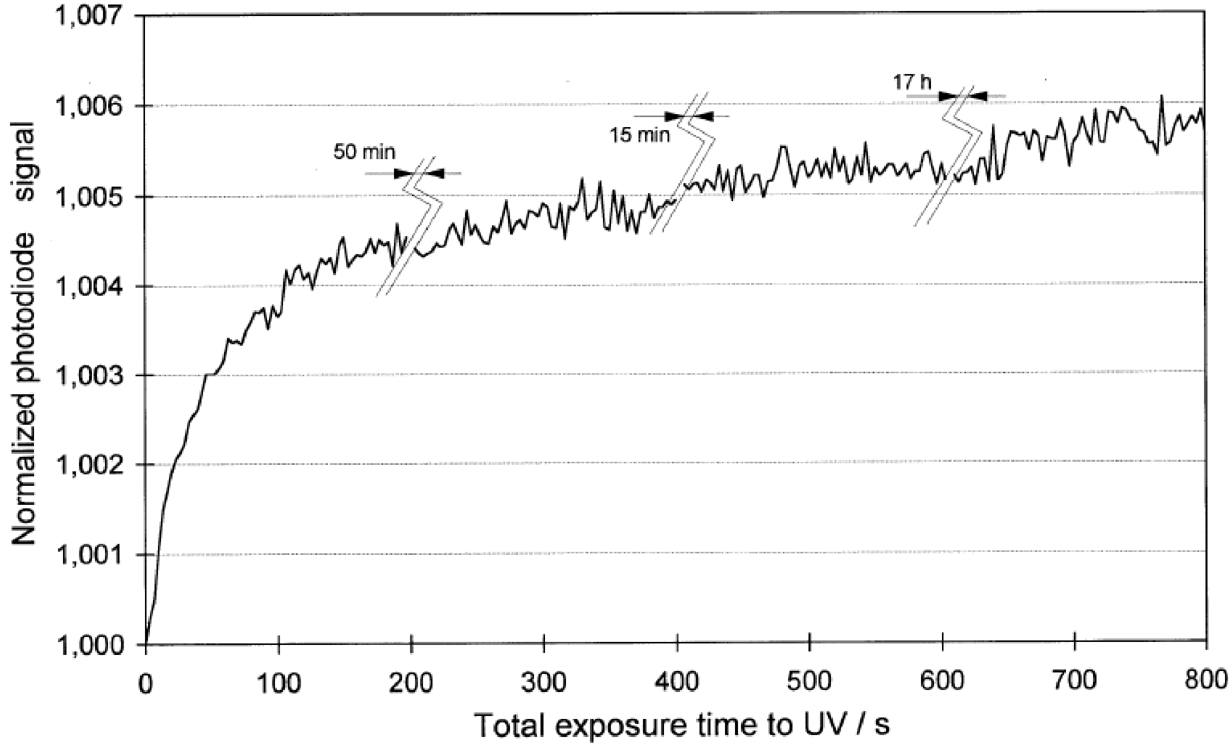


Figure 2. Relative change of responsivity during first exposure to UV ($\lambda = 248$ nm, 15 µW) of photodiode Hamamatsu 1337 # D90; broken parts of the curve correspond to interruption of exposure.

← 0.6%

R. Goebel, R. Köhler and R. Pello, Some effects of low-power ultraviolet radiation on silicon photodiodes, *Metrologia*, 1995/96, **32**, 515-518

Responsivity changes due to UV exposure

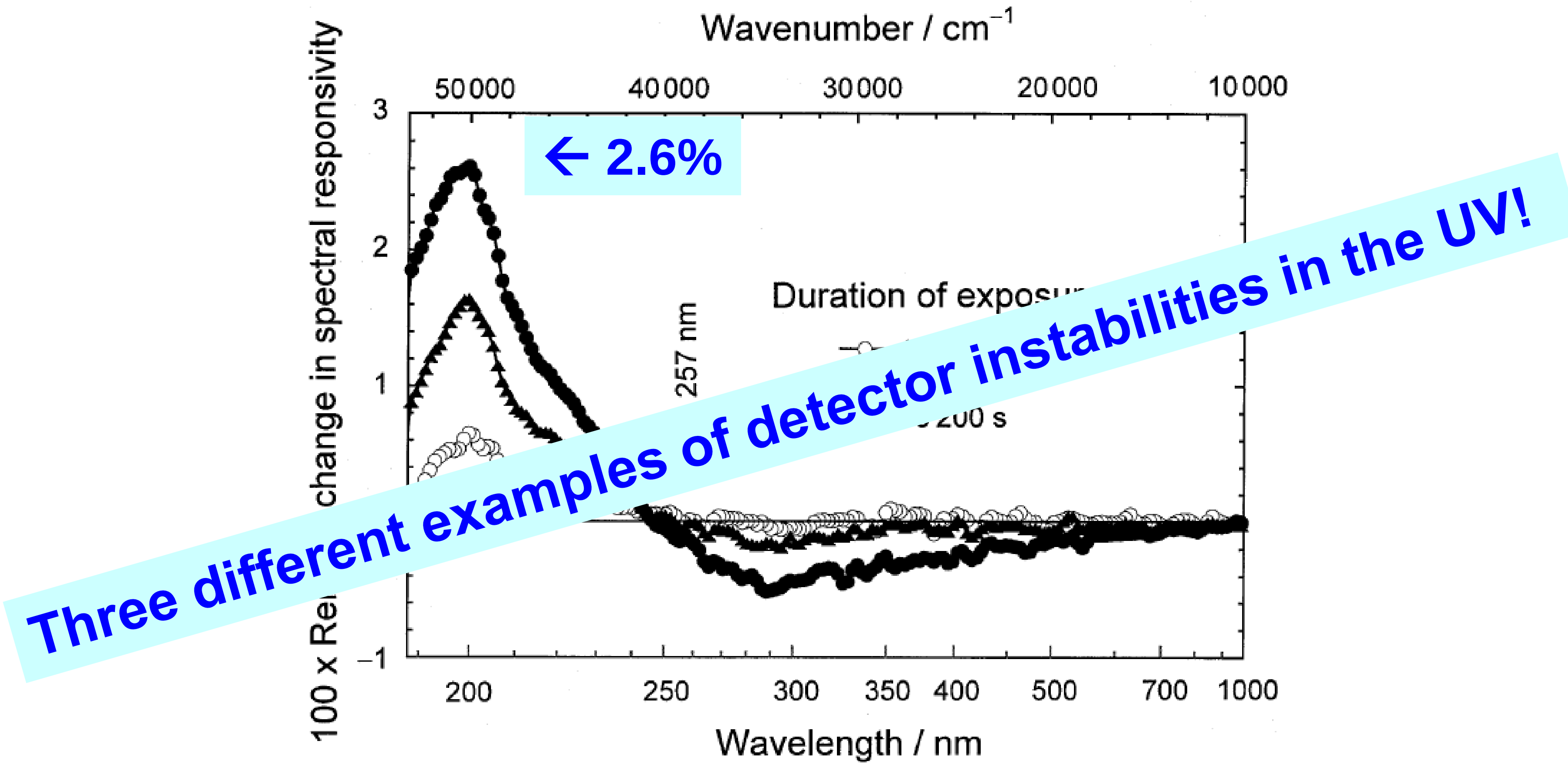
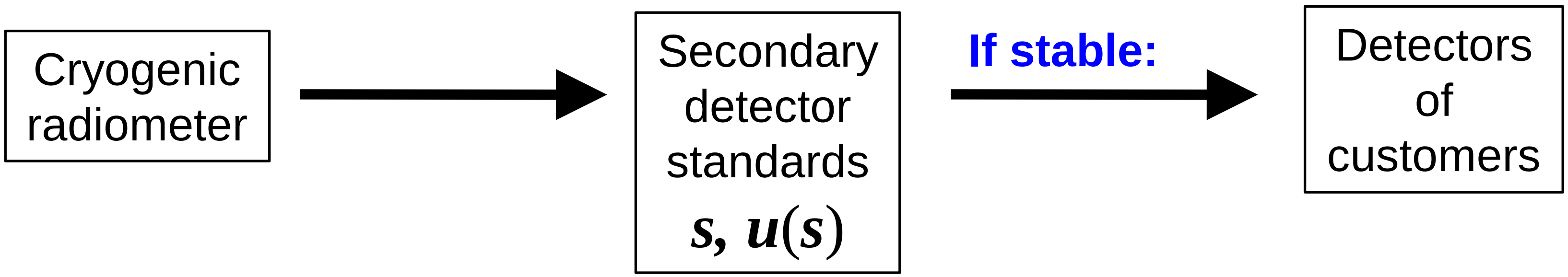


Figure 2. Relative change in spectral responsivity of an S1337 photodiode (#5) for different durations of UV exposure at 257 nm with 24 mW/cm^2.

L. Werner, Ultraviolet stability of silicon photodiodes, *Metrologia* **35** (1998) 407-411

Why and in what way is stability important?

Calibration chain for the spectral responsivity



What does it mean: stable?

- Comparison of calibration uncertainty $u(s)$ and temporal change of spectral responsivity Δs

Stable: $|\Delta s| << u(s)$

- **How often** should we **calibrate** our secondary standards?

If not stable: $|\Delta s| > u(s)$

Can we **predict the temporal change** of the spectral responsivity?

- $\Delta s(t)$, $u(\Delta s(t))$

Instability of spectral responsivity of our secondary detector standards in the UV

PTB

9 detectors of different types

- Trap detectors based on photodiodes of type
  - Hamamatsu S1337 (**T-S13**)
  - Hamamatsu S5227 (**T-S52**)
  - Schottky-type PtSi-nSi photodiodes of type SUV 100 (**T-SUV**)
- Single-element SUV 100 photodiodes (**SUV**)
- Different frequency of use

Low power levels: ≤ 10 µW (calibration) and ≤ 1 µW (dissemination)

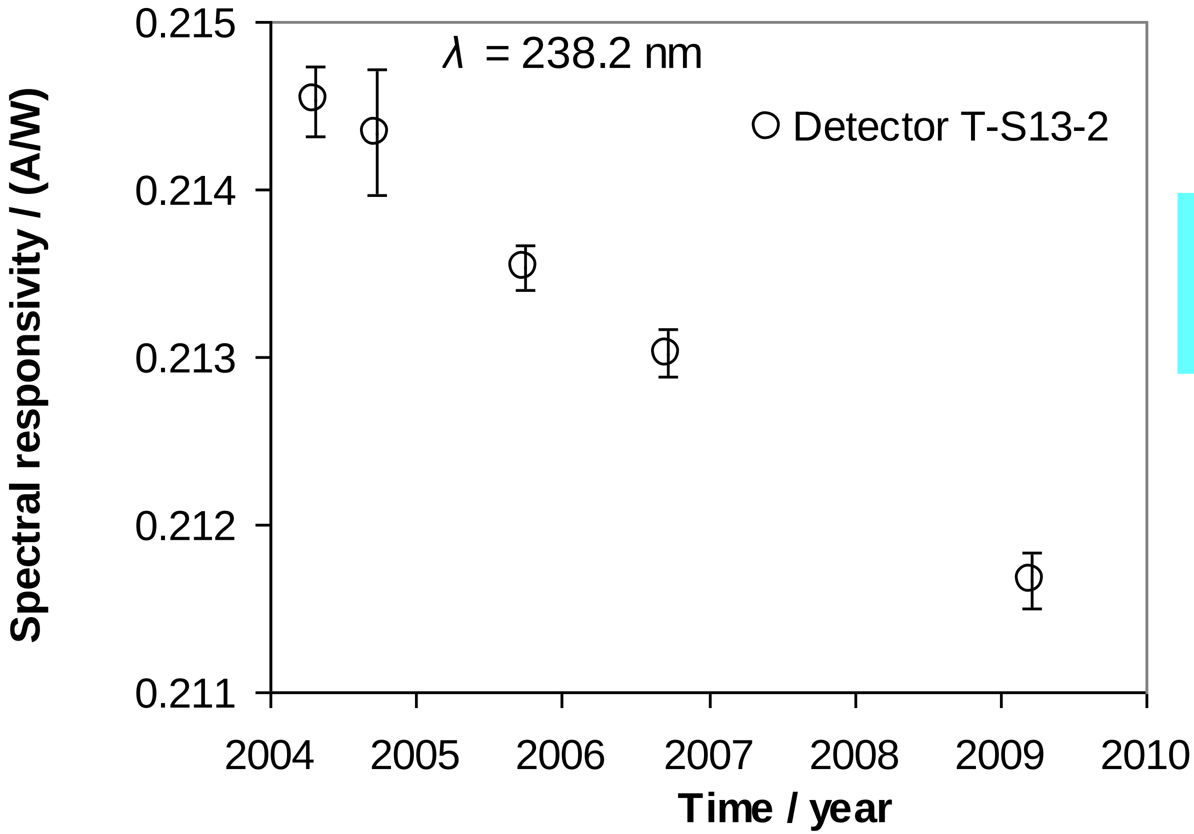
Wavelength range 200 nm to 410 nm: 50 to 60 calibration wavelengths

Five calibration campaigns over a period of five years

Can this effort (one calibration campaign per year) be reduced?

Example for temporal change of spectral responsivity

λ **= 238.2 nm**, trap detector with Hamamatsu S1337 (**T-S13-2**)



Not stable!

$|\Delta s| > u(s)$ **!**

$\Delta s(t)$ **?**

$u(\Delta s(t))$ **?**

Linear drift model for the spectral responsivity

Analysis for one detector at a certain wavelength:

Data:

$$\mathbf{s} = (s_1, \ldots, s_N)^T \qquad \mathbf{t} = (t_1, \ldots, t_N)^T$$

$$\mathbf{U} = \begin{pmatrix} u^2(s_1) & & 0 \\ & \ddots & \\ 0 & & u^2(s_N) \end{pmatrix} \qquad \mathbf{A} = \begin{pmatrix} 1 & t_1 \\ \vdots & \vdots \\ 1 & t_N \end{pmatrix}$$

Model:

$$y(t) = a + b \cdot t$$

Least squares method:

The best fit $\mathbf{c}$ minimizes the sum of squared differences weighted with $u^{-2}(s_\mathrm{i})$.

$$\mathbf{c} = (a, b)^T$$

$$\chi^2 = (\mathbf{s} - \mathbf{A}\mathbf{c})^T \mathbf{U}^{-1} (\mathbf{s} - \mathbf{A}\mathbf{c}) = \sum_i \frac{(s_i - (a + b \cdot t_i))^2}{u^2(s_i)}$$

Solution:

$$\mathbf{c} = \mathrm{cov}(\mathbf{c}) \mathbf{A}^T \mathbf{U}^{-1} \mathbf{s} \qquad \mathrm{cov}(\mathbf{c}) = \begin{pmatrix} u^2(a) & u(a,b) \\ u(b,a) & u^2(b) \end{pmatrix} = (\mathbf{A}^T \mathbf{U}^{-1} \mathbf{A})^{-1}$$

Linear fit of spectral responsivity change

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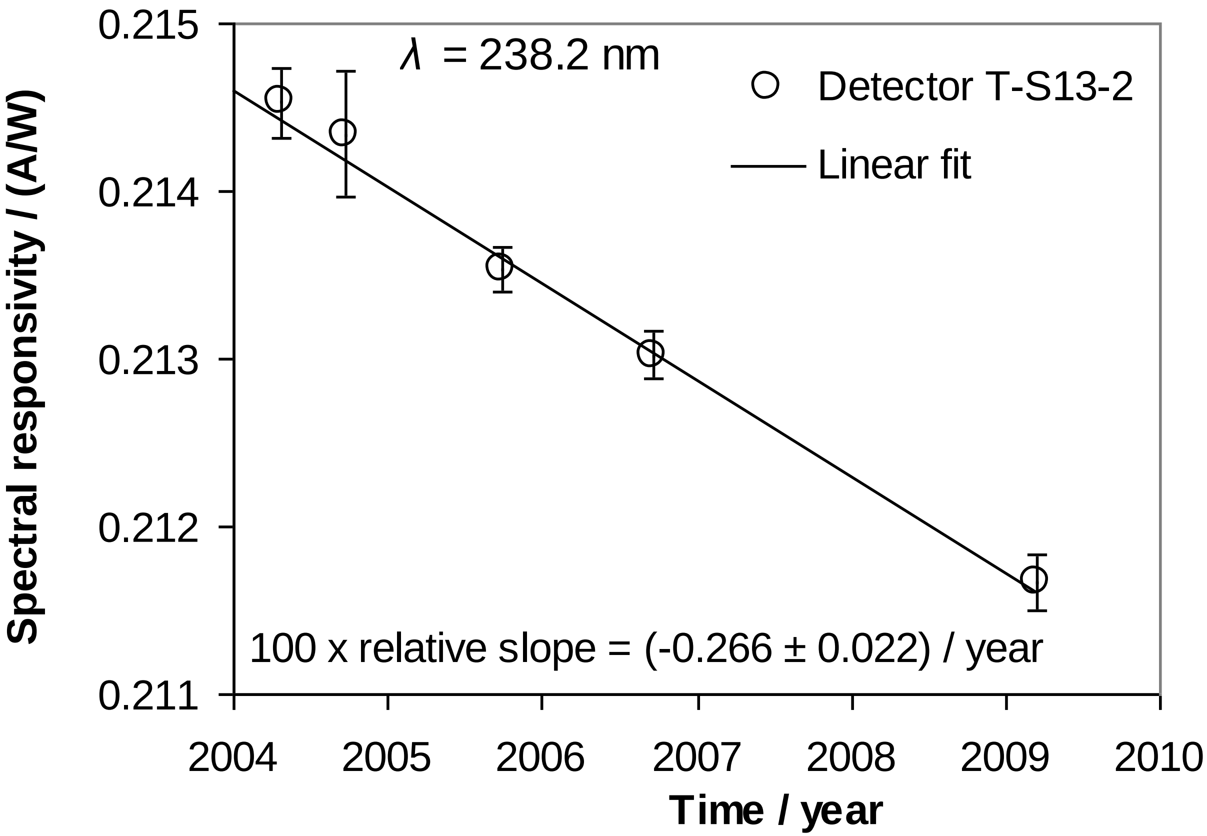
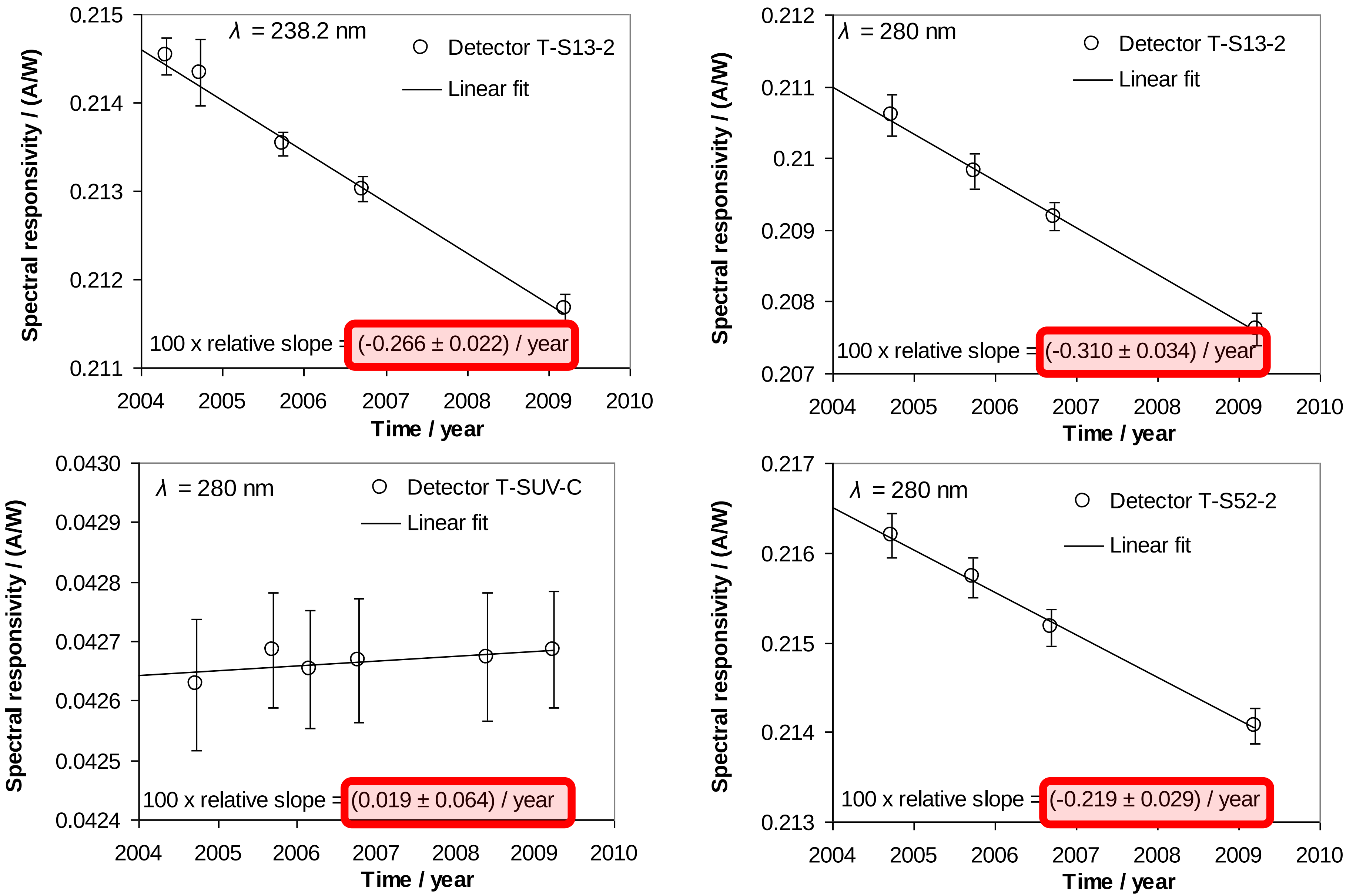
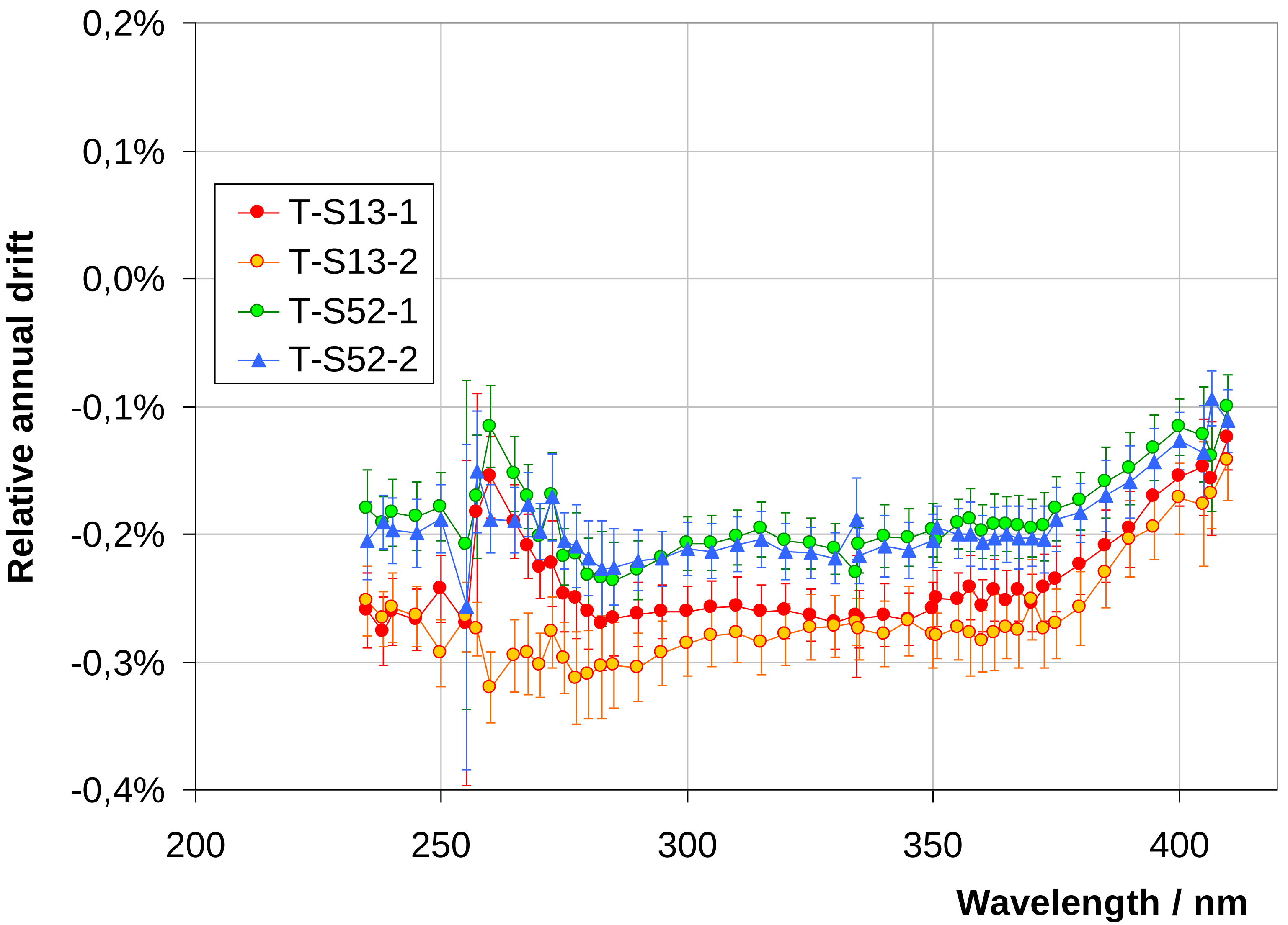


Linear fit of spectral responsivity change



Results for trap detectors based on Si photodiodes
of type Hamamatsu S1337 (T-S13) and S5227 (T-S52)



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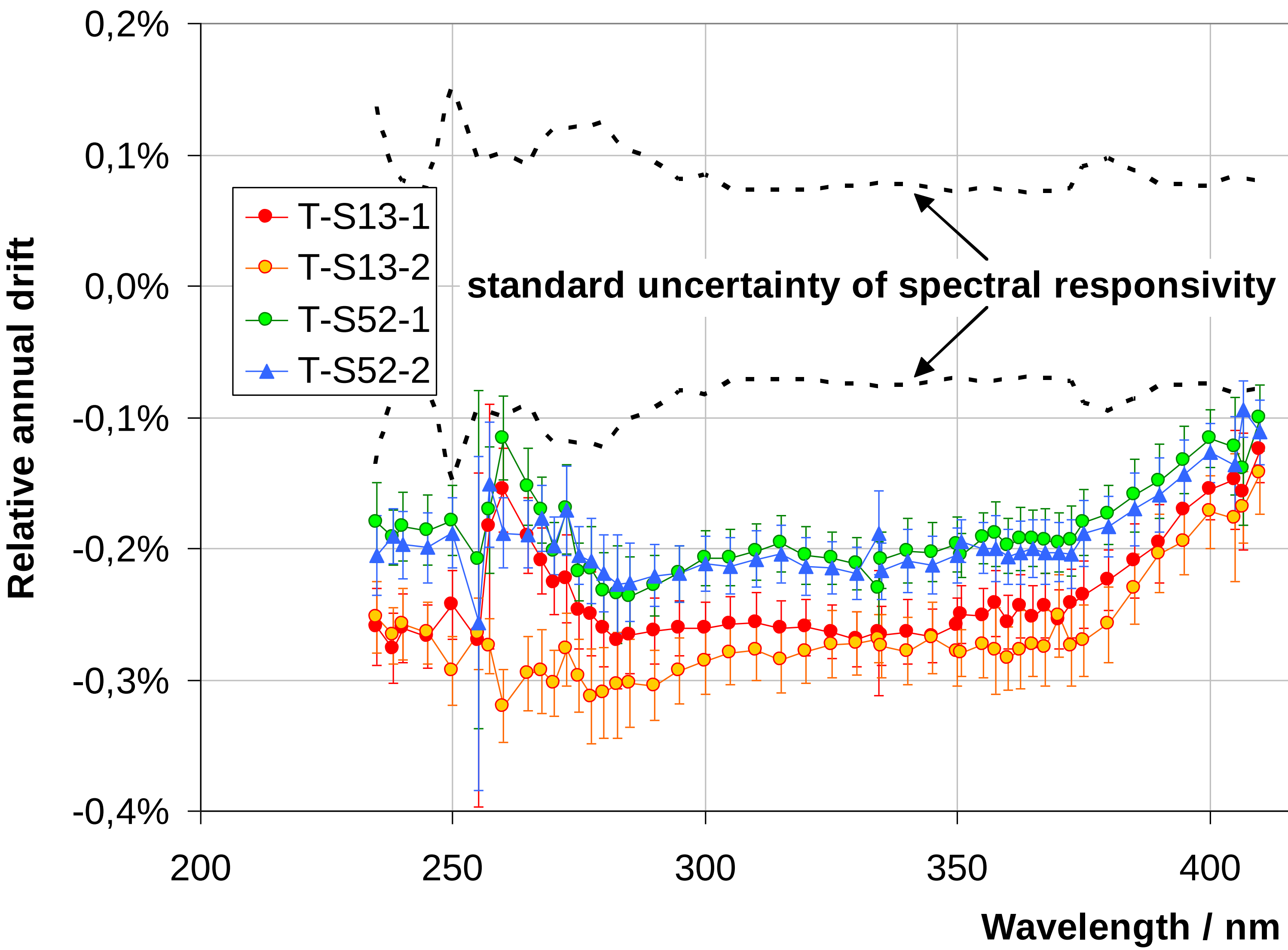
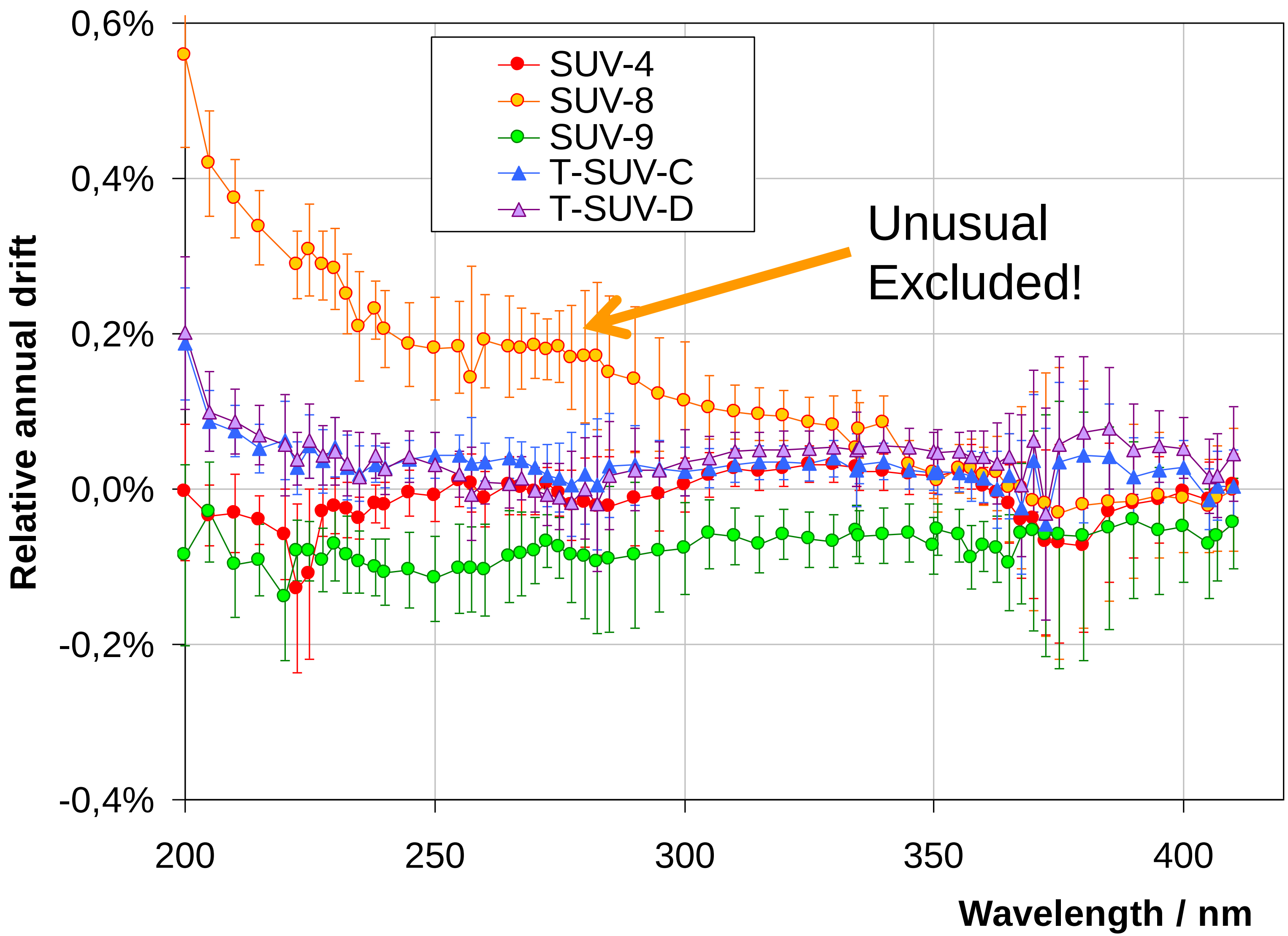
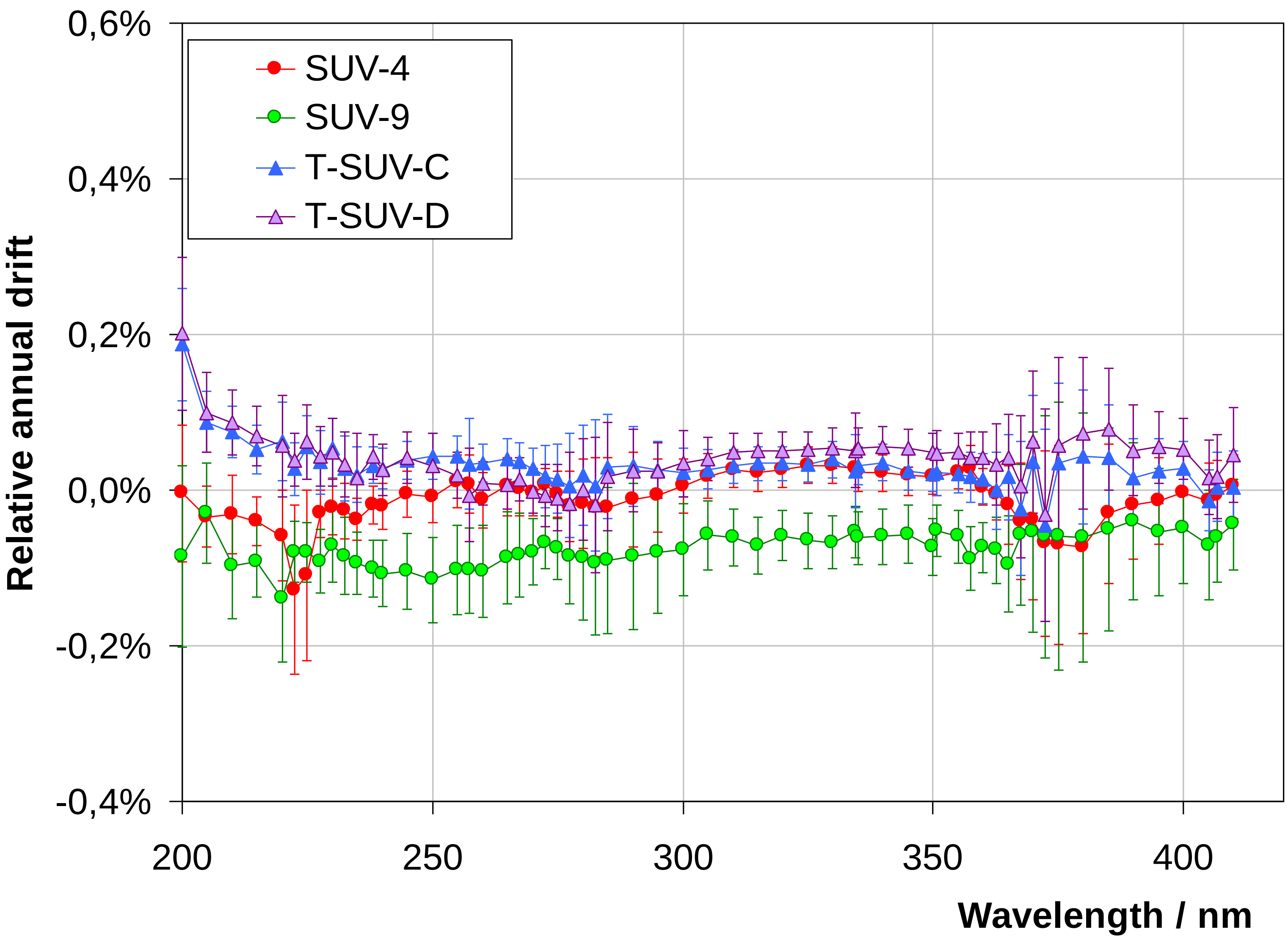


Results for Schottky-type PtSi-nSi photodiodes of type SUV 100 and trap detectors



Results for Schottky-type PtSi-nSi photodiodes of type SUV 100



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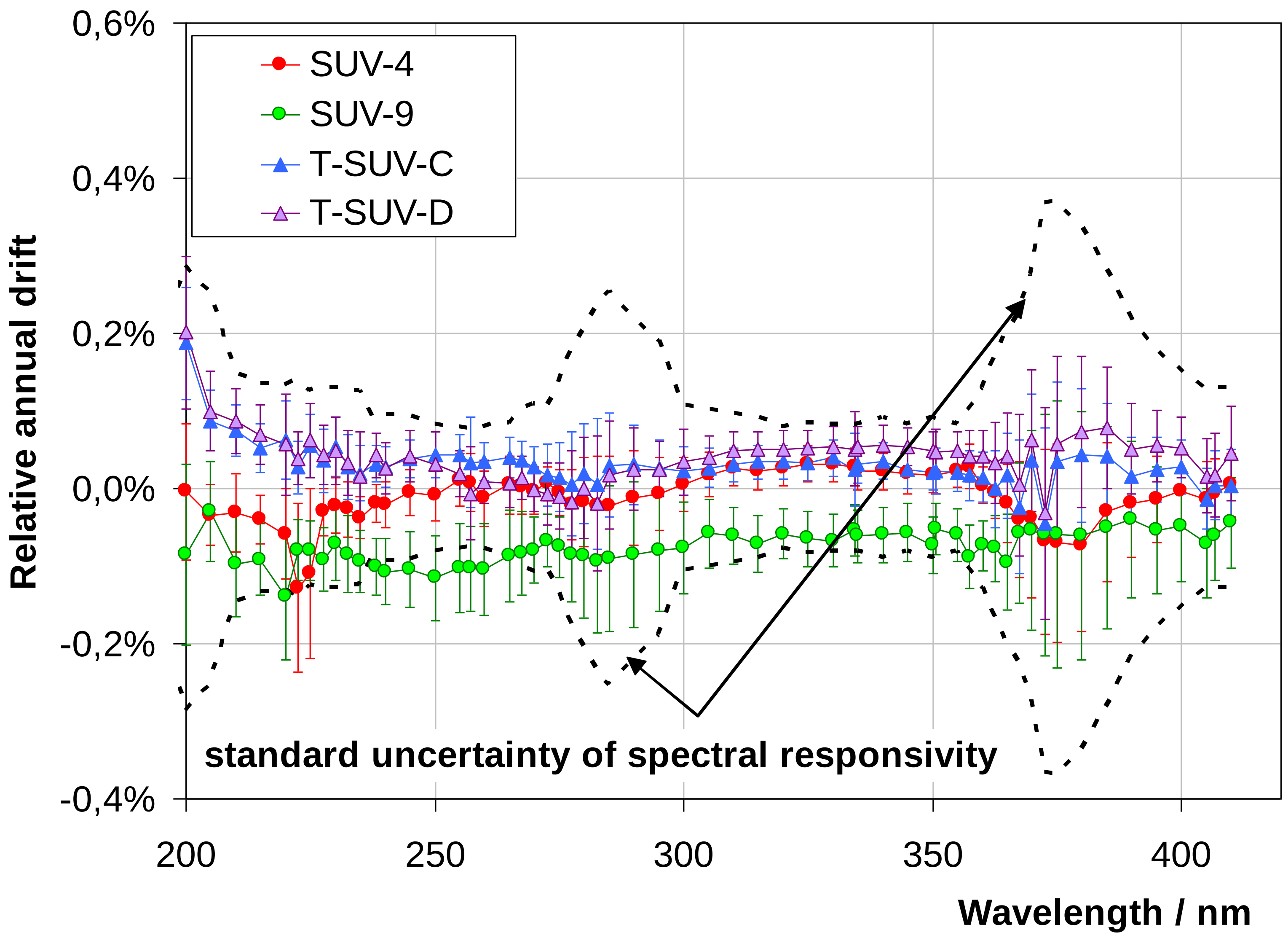
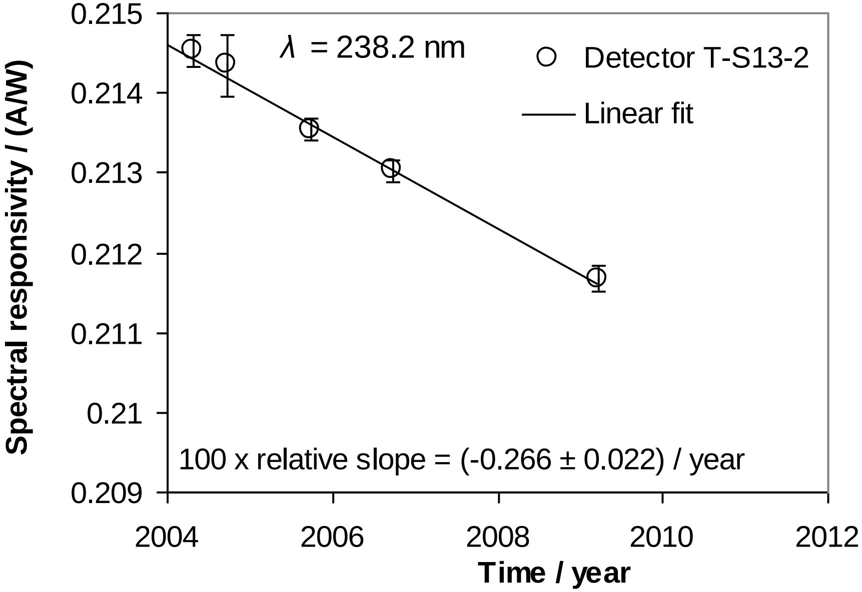
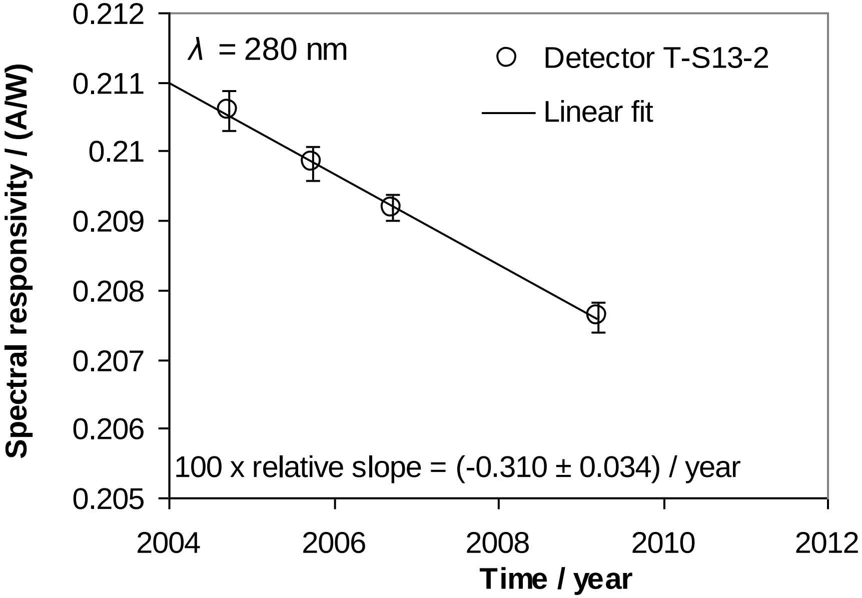


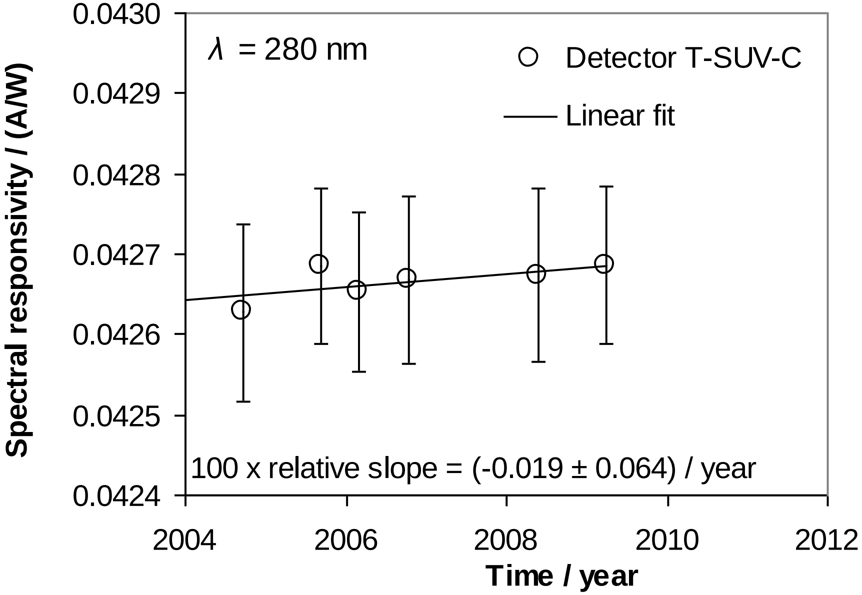
Annual drift in the past is known!

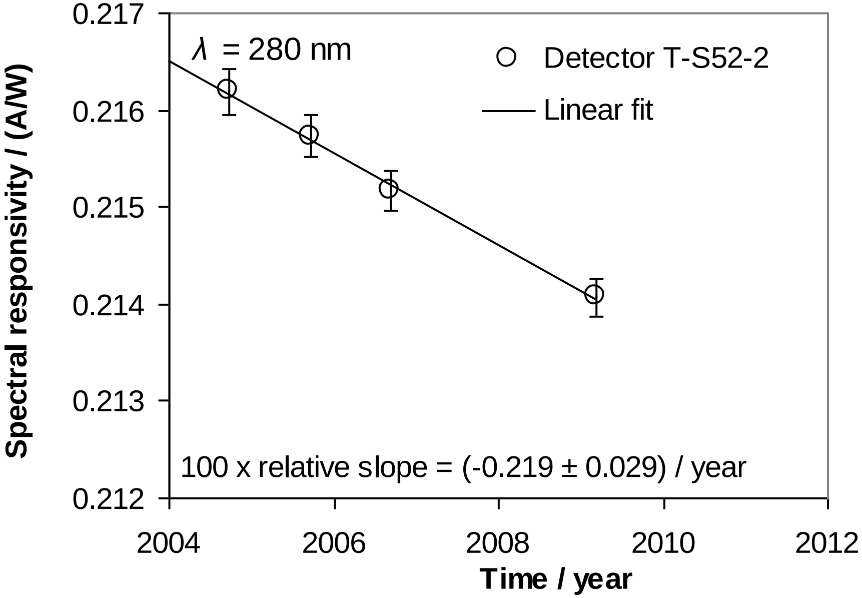
Correction of temporal drift possible?

Linear fit of data from 2004 to 2009

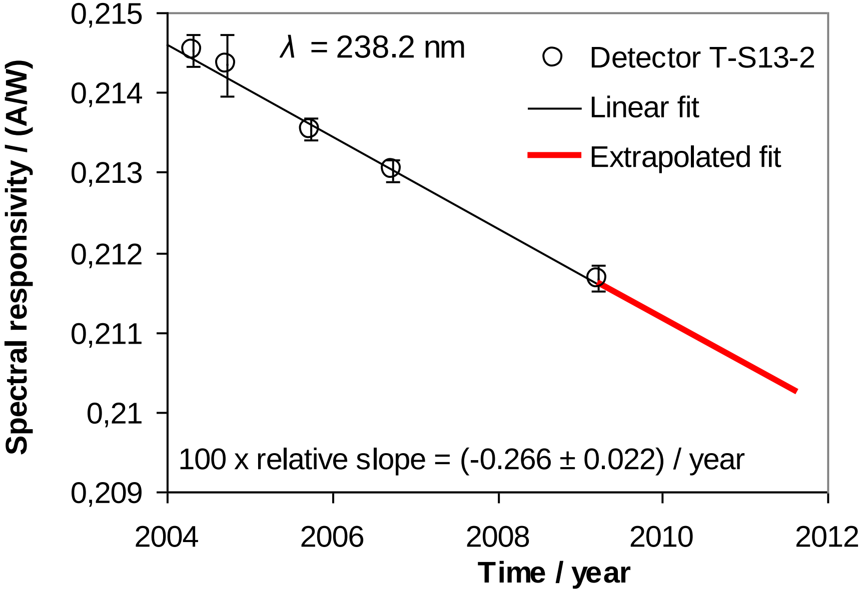


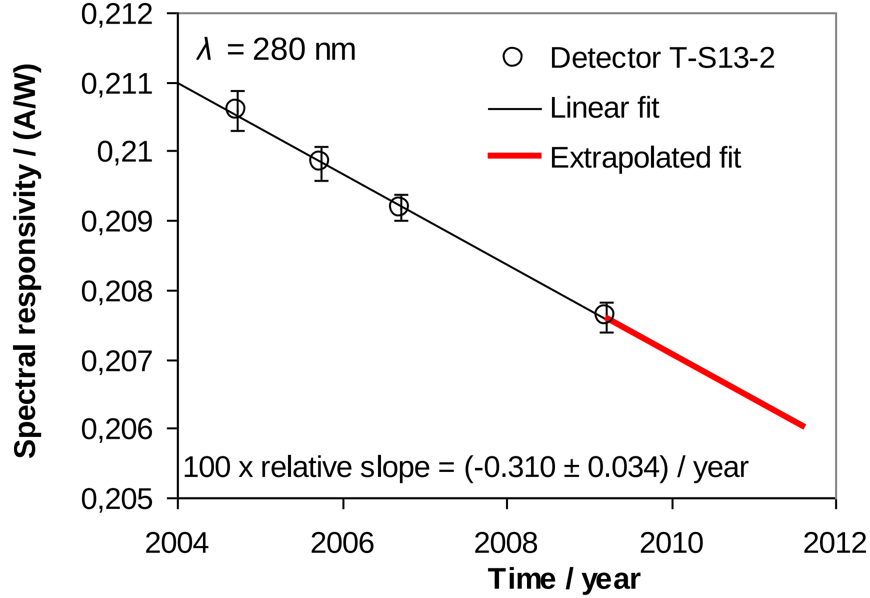


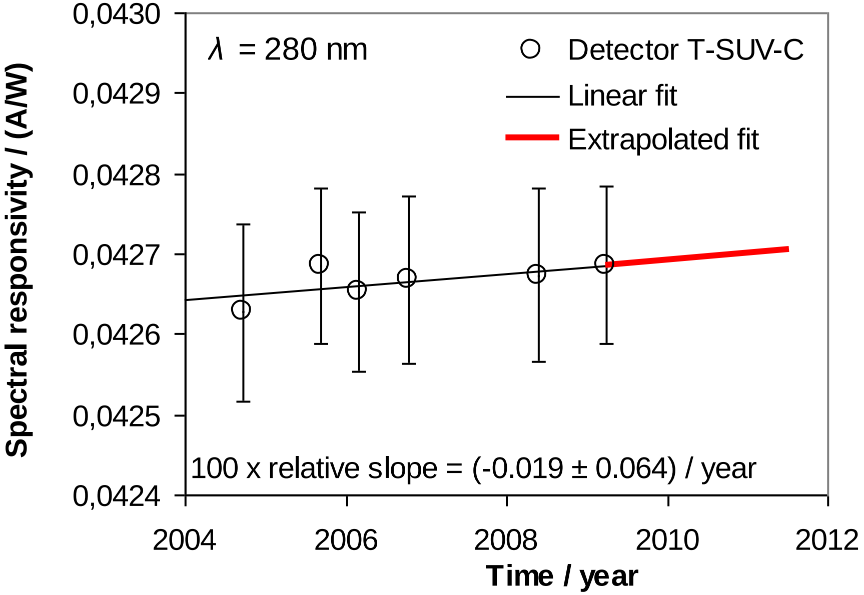


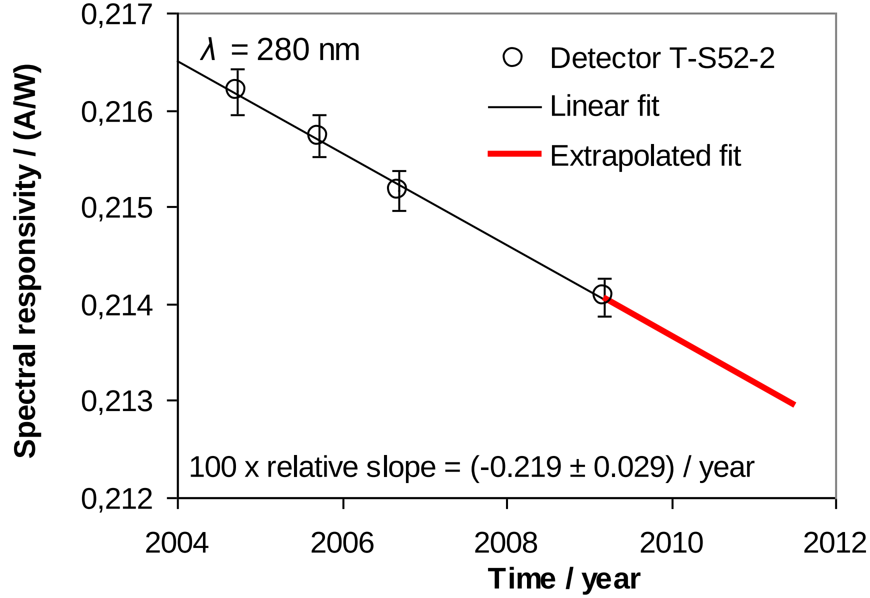


Extrapolation of the fit to 2011

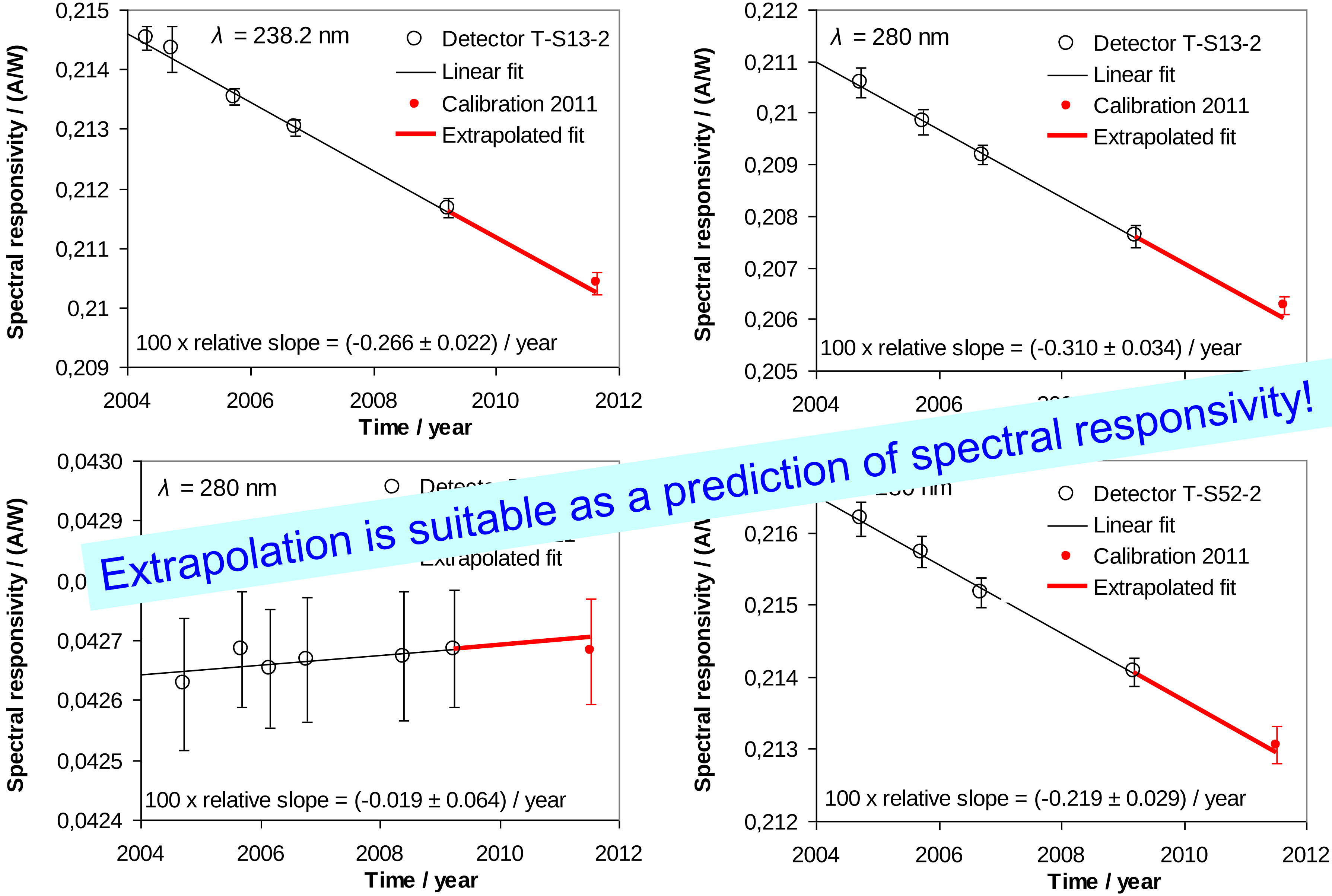








Results of calibration in 2011



Extrapolation is suitable as a prediction of spectral responsivity!

How often should we calibrate our standards?

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Uncertainty of
drift correction

$$u(drift) \cdot \Delta t$$

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Uncertainty of
drift correction

$$u(drift) \cdot \Delta t$$

Uncertainty of
spectral responsivity
obtained in last calibration

$$u(s_{cal})$$

How often should we calibrate our standards?

Uncertainty of drift correction		Uncertainty of spectral responsivity obtained in last calibration
$u(drift) \cdot \Delta t$	$\leq$	$u(s_{cal})$

How often should we calibrate our standards?

Uncertainty of drift correction

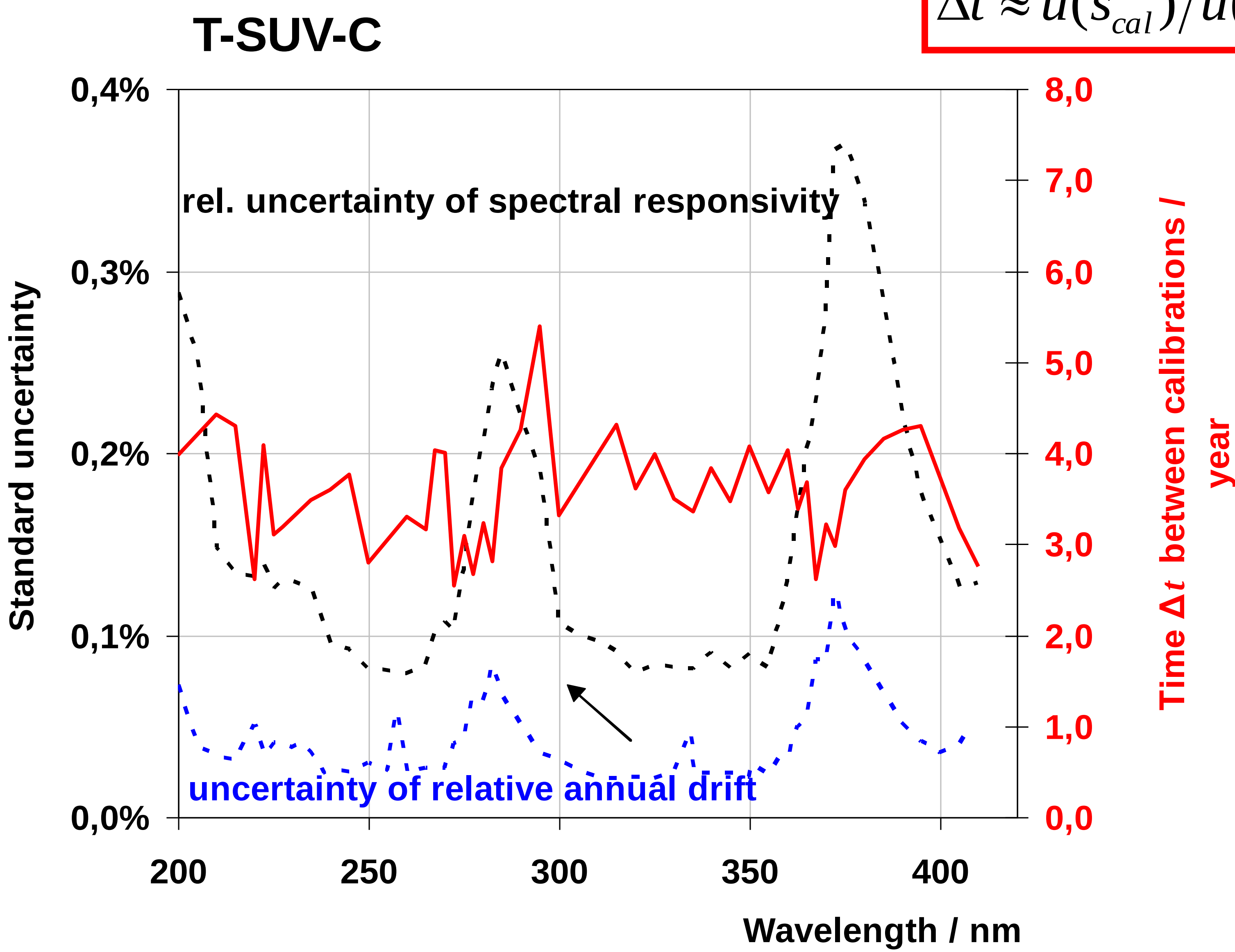
Uncertainty of spectral responsivity obtained in last calibration

$$u(drift) \cdot \Delta t \leq u(s_{cal})$$

$$\longrightarrow \quad \Delta t \leq u(s_{cal}) / u(drift)$$

How often should we calibrate our standards?

$$\Delta t \approx u(s_{cal})/u(drift)$$



Summary

The **temporal change** of the spectral responsivity in the UV

- depends on the wavelength and the type of detector,
- does not depend on the frequency of use of the detector,
- has been well described by a **linear drift model.**

The annual drift

- is comparable to or larger than the uncertainty of the spectral responsivity,
- can be used for the prediction of the spectral responsivity.

We correct for the temporal drift and take into account the uncertainty of this correction.

Thank you for your attention!