EMRP ENV03
Traceability for surface spectral solar ultraviolet radiation

EMRP
European Metrology Research Programme
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VSL

A Laser-Driven Light Source (LDLS) as a portable spectral irradiance calibration source in the UV range and other radiometric applications.

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Dutch Metrology Institute

Before we start…..

- VSL is the National Metrology Institute of the Netherlands, appointed by the Dutch government to maintain and develop the national measurement standards.

- Knowledge institute in the field of metrology.

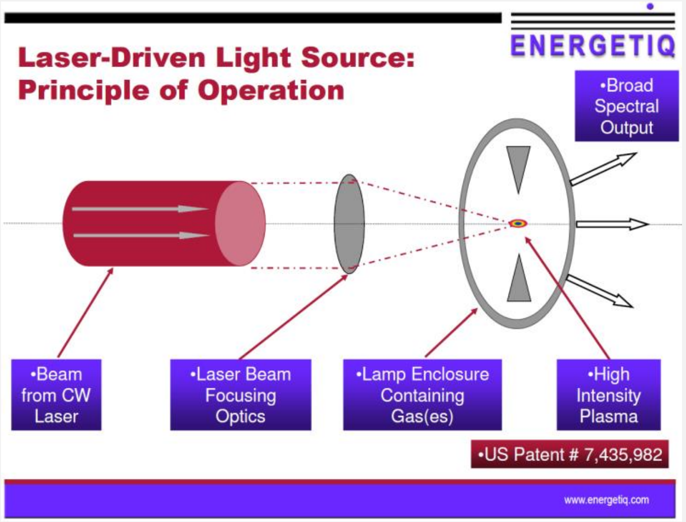
- We also provide metrology services to customers

- Only one location (Delft)

Outline

- General overview on a LDLS source
- Potential as spectral irradiance calibration source: pro and cons
- A practical example: calibration of an array spectroradiometer
- Some other special applications: wavelength calibration
- Conclusions

General overview of a Laser Driven Light Source (LDLS)



Warm-up time about 60 minutes to get excellent temporal stability (few ppm)
Irradiance level without collimation not very high but very flat when compared to a 1000 W FEL.
Need for nitrogen purging for high throughput in the short UV range.
Long term stability: ?? (operated for ≈ 600 hours so far)

Why interested in new sources for UV?

If we want to measure $E(\lambda)$ with a detector having a respons. $R_{\lambda^*}(\lambda)$

$$S_{\lambda^*} = \int E(\lambda) R_{\lambda^*}(\lambda) d\lambda$$

$$SNR = \frac{S_{\lambda^*} - S_{dark}}{\sqrt{\sigma^2(S_{\lambda^*}) + \sigma^2(S_{dark})}}$$

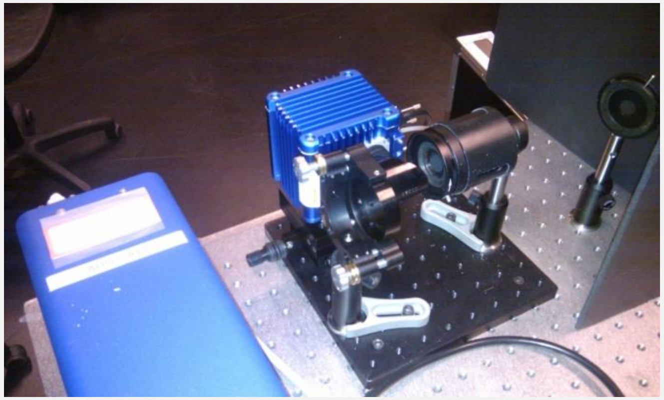
If the final goal uncertainty is u (%) then one has to have, as a rule of thumb,

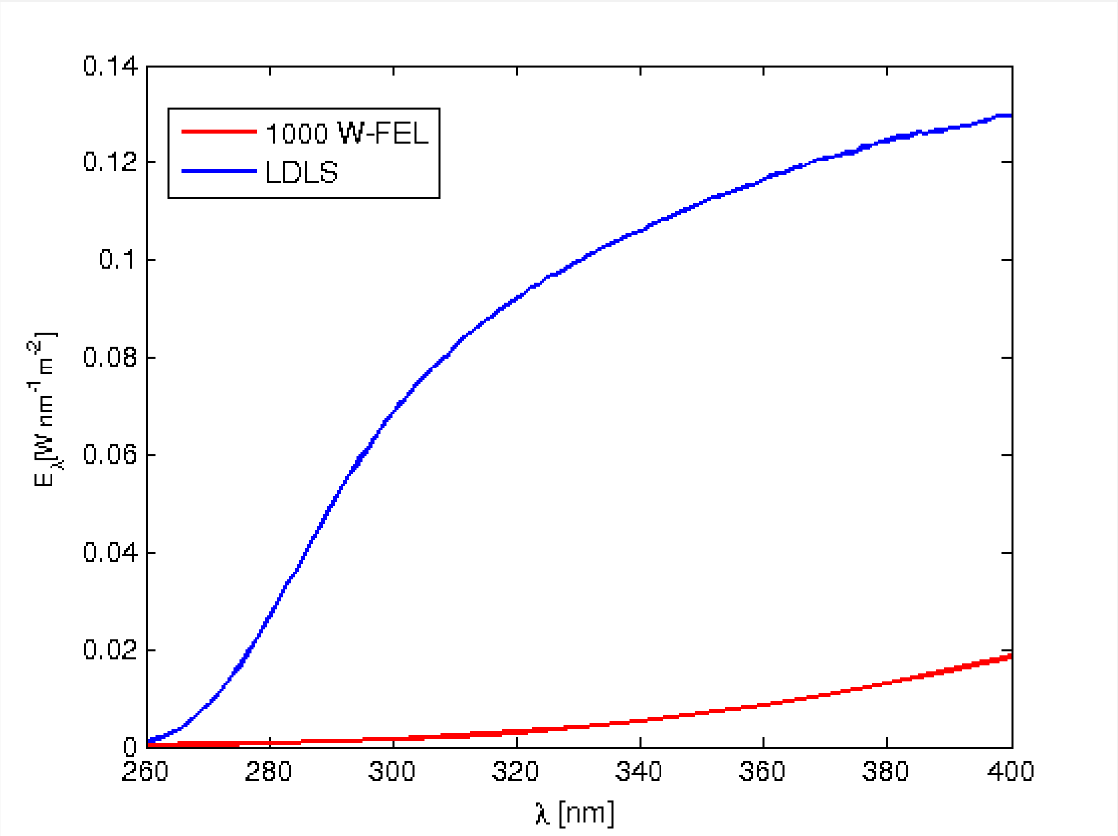
$$SNR > \frac{3}{u}$$

Ex. u= 1%
SNR>300

Spectral irradiance standard

At 50 cm distance, non collimated beam, irr. far below 0.003 W /(m2 nm)





The collimated LDLS gives higher spectral irradiance levels, but...

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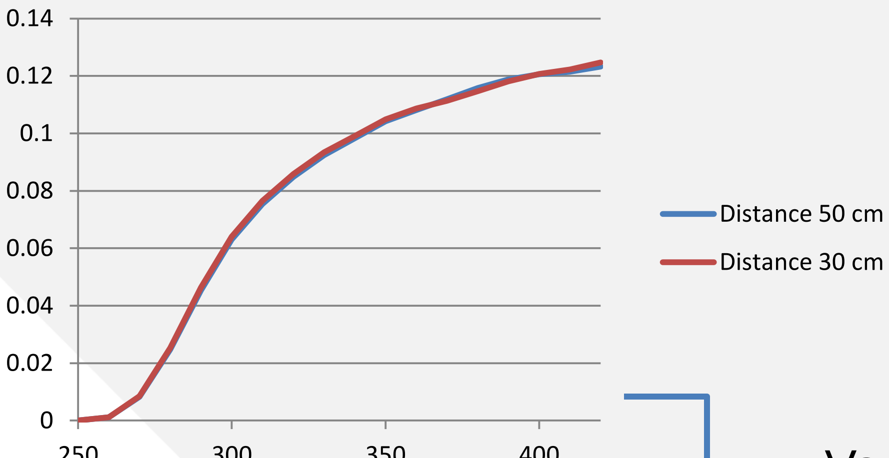
Beam profile: sensitivity in longitudinal and lateral positioning

Estimated positioning sensitivities (measured at three wavelengths, 280nm, 340nm and 400nm)

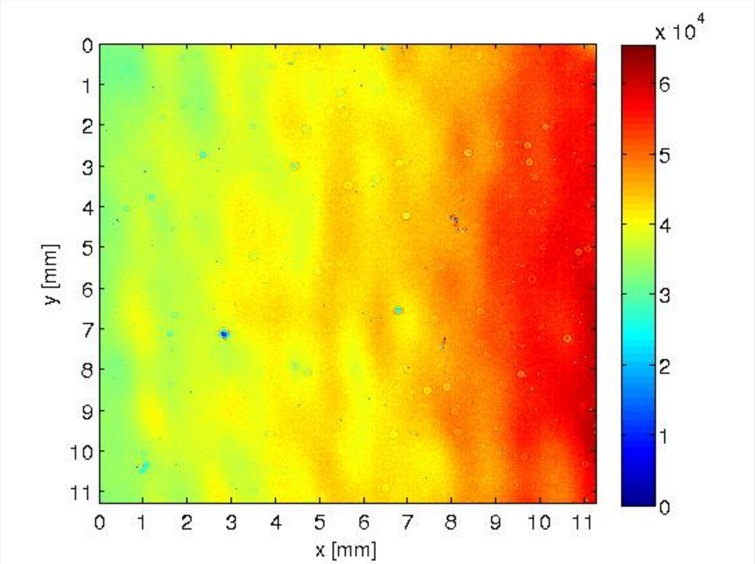
$S_x \approx 2\%/mm$

$S_y \approx 0.5\%/mm$

$S_z \approx 0.012\%/mm$



Spectrally integrated profile



Variation along z is negligible for most applications

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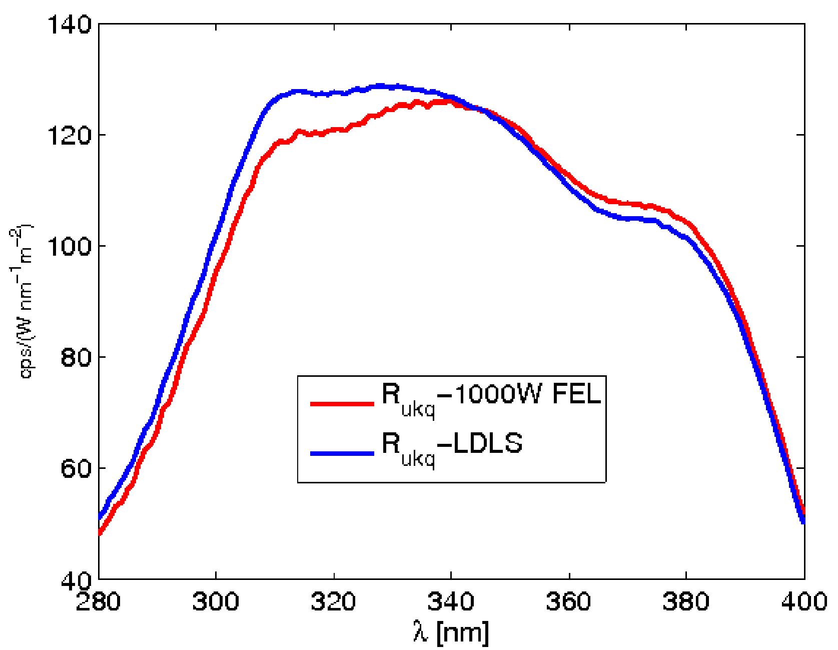
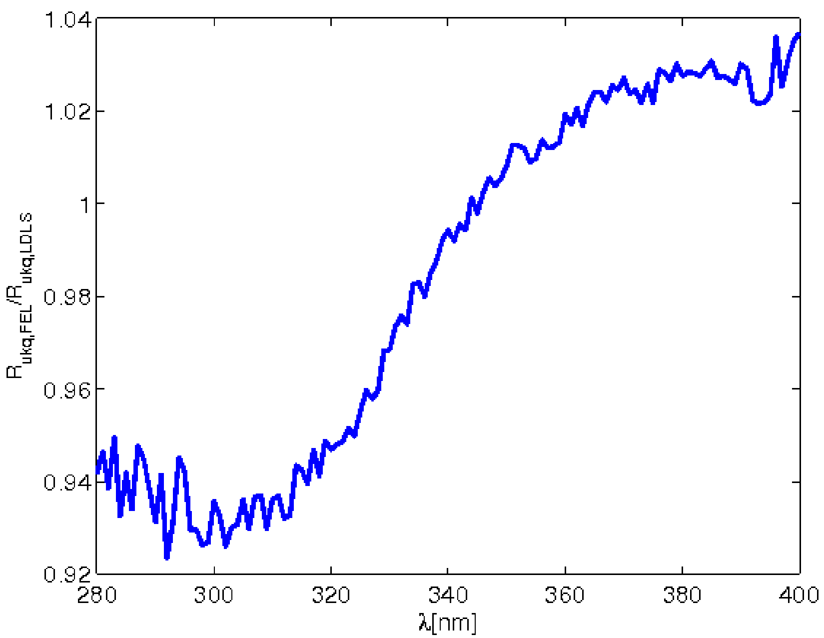
Determination of the responsivity of an array spectrometer: UKQ

Ocean Optics array spectrometer, (230-410)nm, 50 um slit, cooled.
Entrance optics a 2' averaging sphere, ½' input port, fiber coupled.





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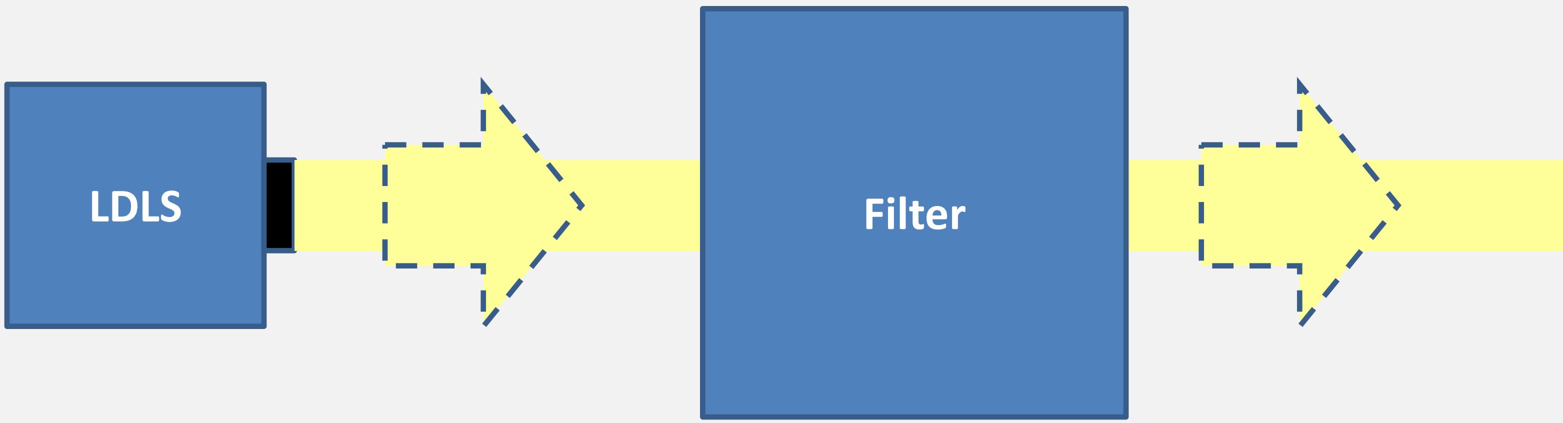
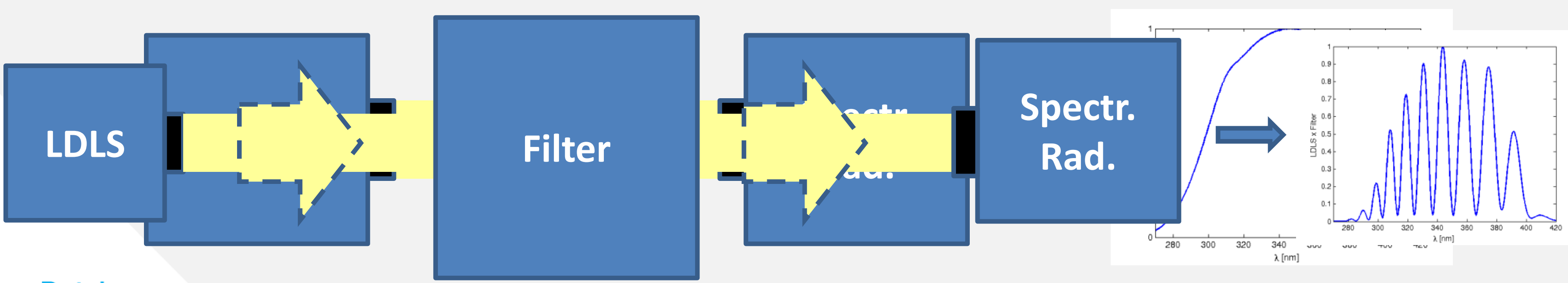
Courtesy Marina Kazhova.

Application # 2: wavelength calibration

Goal: realization of a portable wavelength calibration system in the UV

The collimated source, coupled to a proper filter, can be part of an accurate wavelength calibration tool





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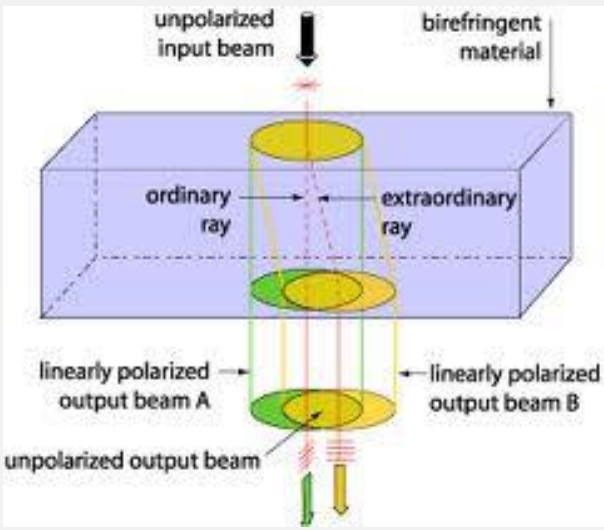
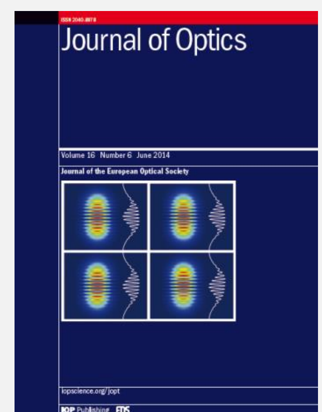
Birefringence-based filter

Birefringence:
A material shows different refractive indices
for different polarization states → **Anisotropic medium**





It can be used for many different goals in metrology.
R. Koops *et al* 2014 *J. Opt.* **16** 065701

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Birefringence-based UV wavelength ruler

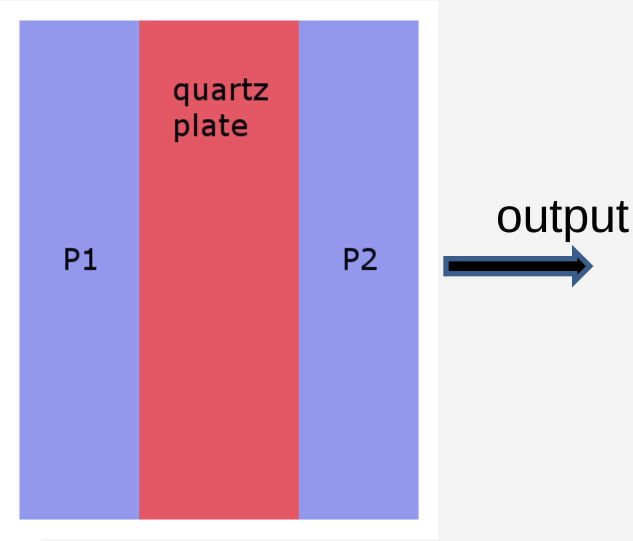
Requirements:

•Spectral range 280nm-400nm

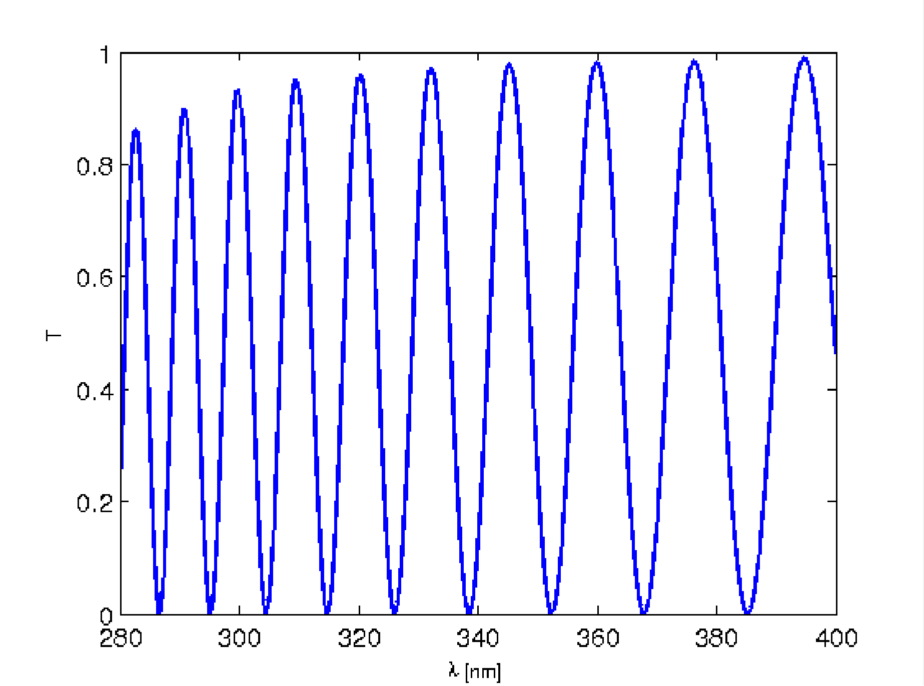
•Temperature variations should be controlled within at least 0.1 Cº.

•We need enough intense lines, but not too narrow (FWHM~10-20nm)

One/-stage Lyot filter



Simulations.
Nominal thickness quartz plate of 0.7mm+0.02mm



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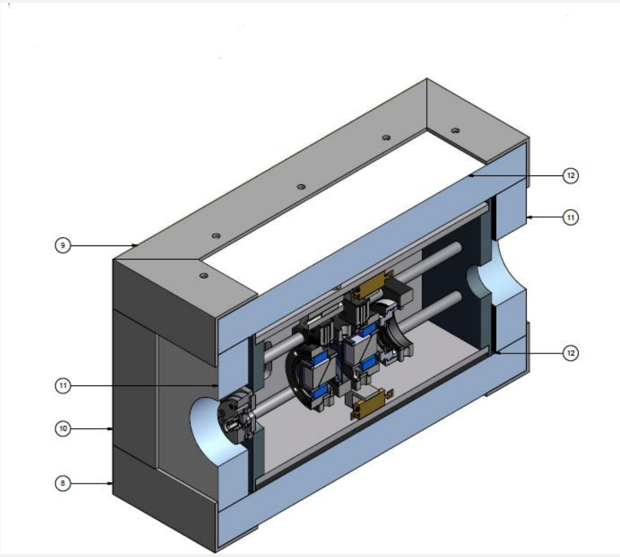
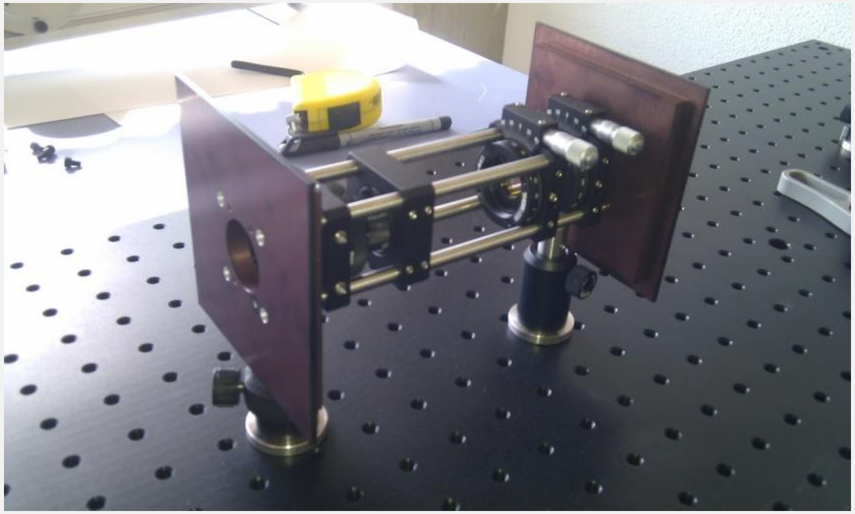
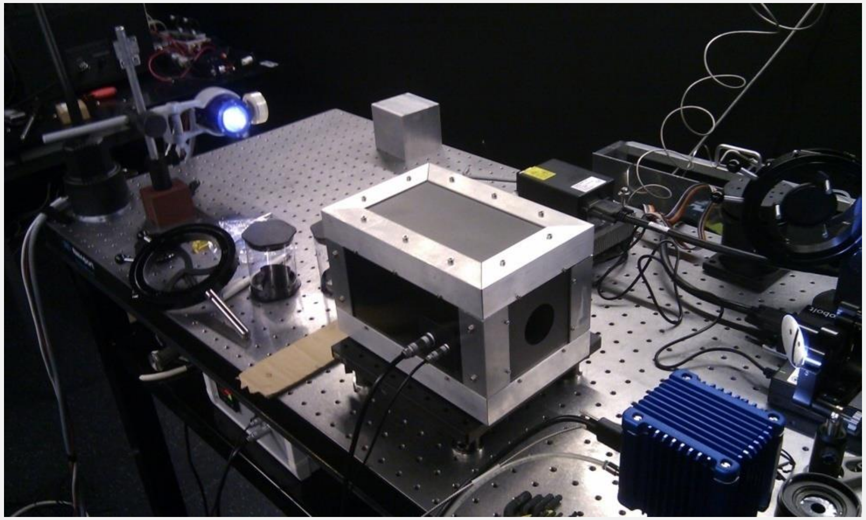
Design and implementation of a on-field calibration unit







Method for data analysis

How to solve the inverse problem?

First we choose a merit function to minimize:

$$\chi^2 = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{\mathbf{I}_i^{(m)} - \mathbf{I}(\mathbf{p}_i, \mathbf{a})}{\sigma_i}\right]^2,$$

The parameters **a** are adjusted in order to minimize the distance between measurements and simulations

While the uncertainty is estimated through:

$$\Delta a_j = 3\sqrt{C_{jj}},$$

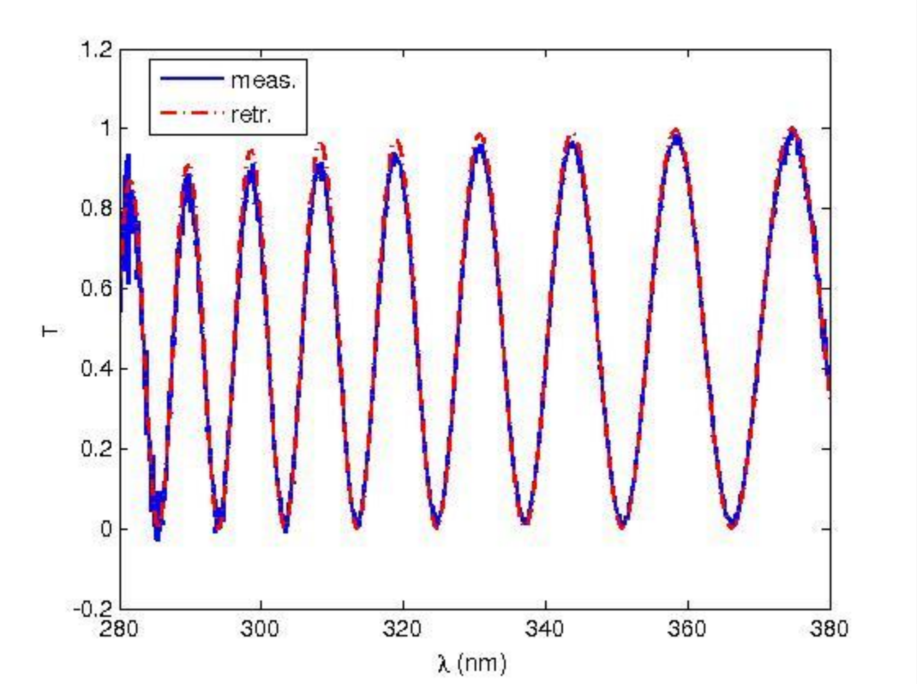
where

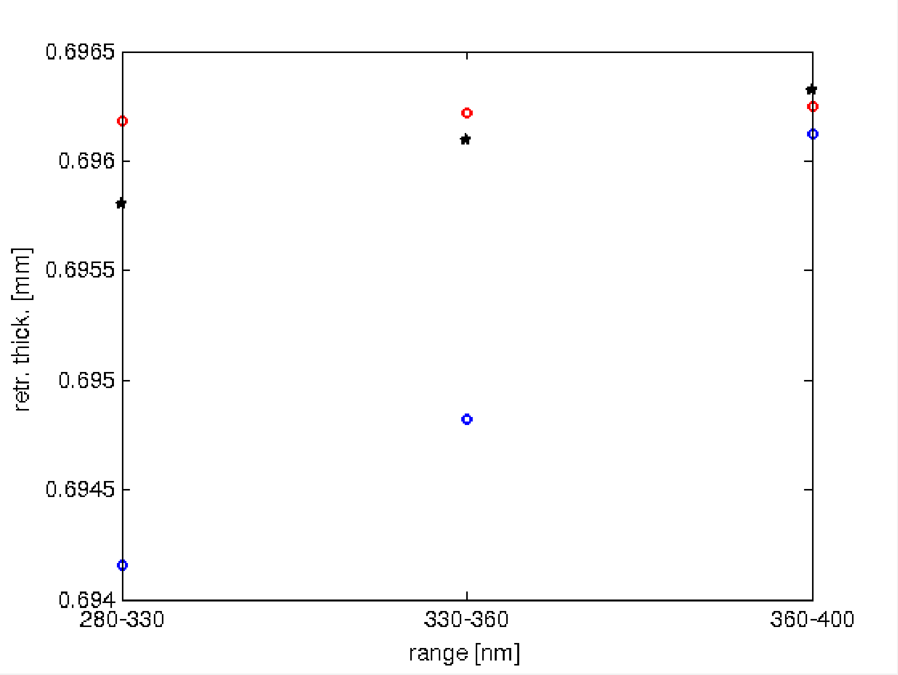
$$\left[C_{jk}\right] = \left[\alpha_{jk}\right]^{-1}$$

$$[\alpha_{jk}] = \frac{1}{2}\frac{\partial^2\chi^2}{\partial a_k \partial a_l} = \frac{1}{N}\sum_{i=1}^{N}\frac{1}{\sigma_i^2}\left[\frac{\partial \mathbf{I}(\mathbf{p}_i, \mathbf{a})}{\partial a_j}\frac{\partial \mathbf{I}(\mathbf{p}_i, \mathbf{a})}{\partial a_k}\right]_{\mathbf{a}=\mathbf{a}_{\min}}$$

Ideal vs actual transmission

Hence, we need a parametrized forward model which is fed into a Levenberg-Marquardt algorithm





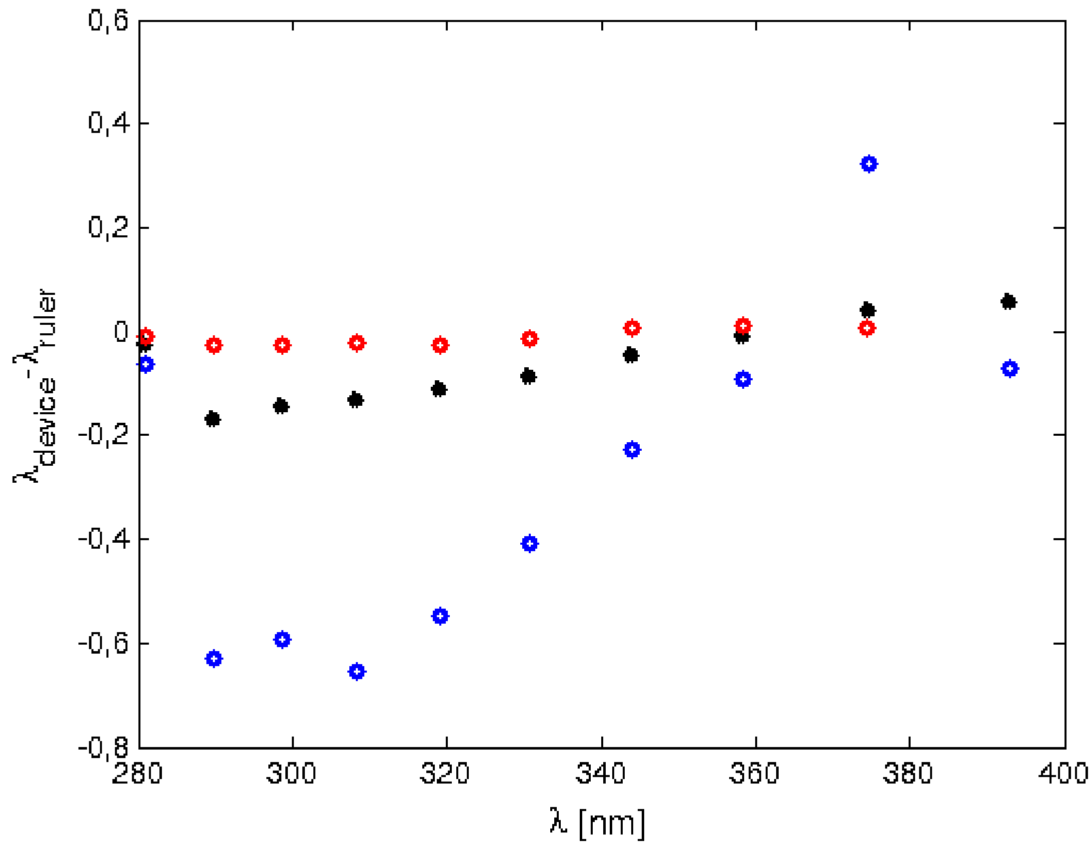
From a set of calibrated instruments (in a limited spectral region) the actual thickness is retrieved off-line

Retrieved thickness

d = 0.6962 mm
U (k=2) = 40 nm

With this value we can generate the wavelength scale

For one single device:
SNR = 1000
the uncertainty on the retrieved thickness is at 0.1 nm level (!)



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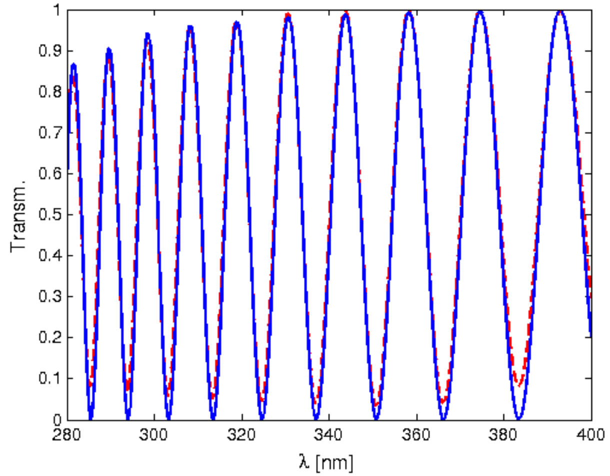
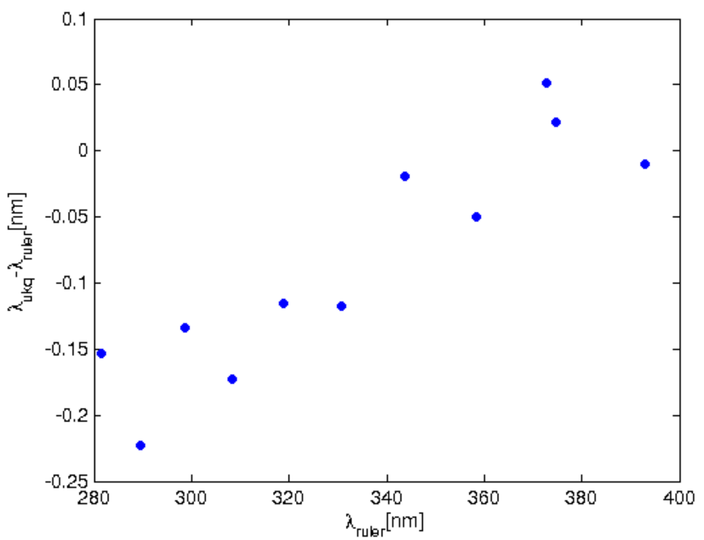
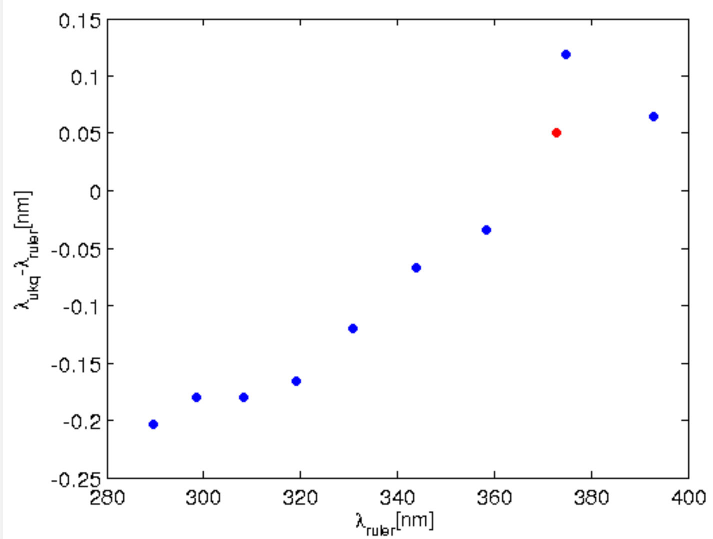
Example UKQ



Some slight difference is obtained according to which criterion is used to determine the peaks wavelengths



Peak finder



Center of mass

Conclusions

- We have discussed the general properties of a LDLS as spectral irradiance source
- Interesting applications for UV metrology, but still some improvements is necessary, especially in the beam homogenization
- Practical use as portable transfer standard and as a tool for new wavelength calibration approaches.

Aknowledgements

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THANKS!