

# VIS-to-NIR absorption spectroscopy of magneto-optical materials for high-power laser applications

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## Faraday isolators

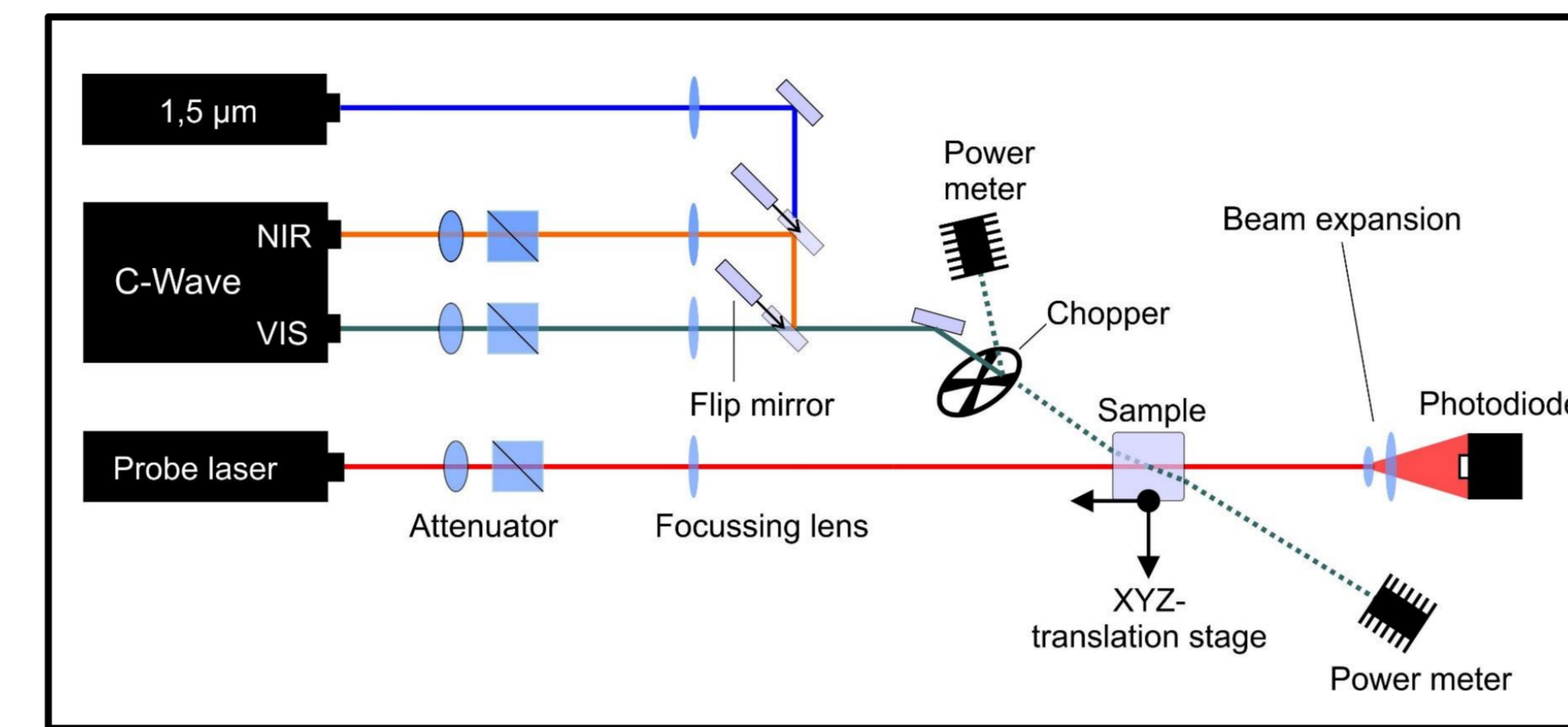
Faraday isolators are used in many laser systems in order to prevent optical feedback into the laser resonator.

The absorption by the material is a critical property, especially in the case of high-power laser applications (> 100 W): A thermal lens may lead to focal shifts and a distorted laser beam profile. In addition an inhomogeneous temperature profile in the crystal may degrade the isolator performance due to the temperature-dependence of the Verdet constant and strain-induced birefringence.

For many years, terbium gallium garnet (TGG) has been the standard material for isolators in the 1- $\mu\text{m}$  region. Only recently, potassium terbium fluoride (KTF) has emerged as a new material for high-power applications [Stevens2016].

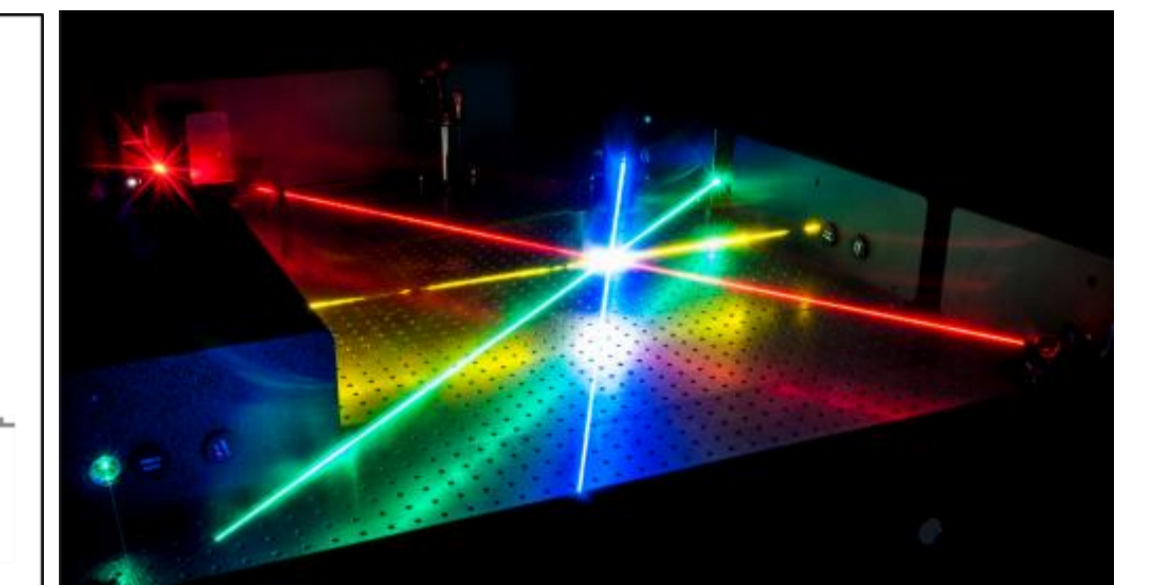
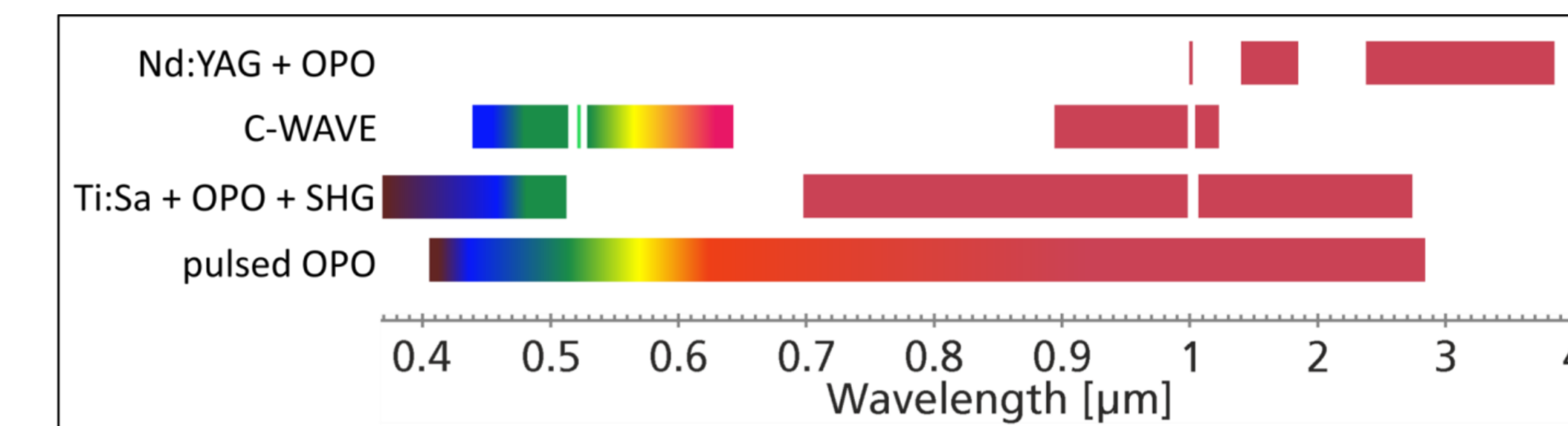
The present work aims at a detailed analysis of the absorption behavior of both materials.

## Photothermal Common-Path Interferometer



PCI setup for the VIS-NIR measurements

## Wavelength coverage



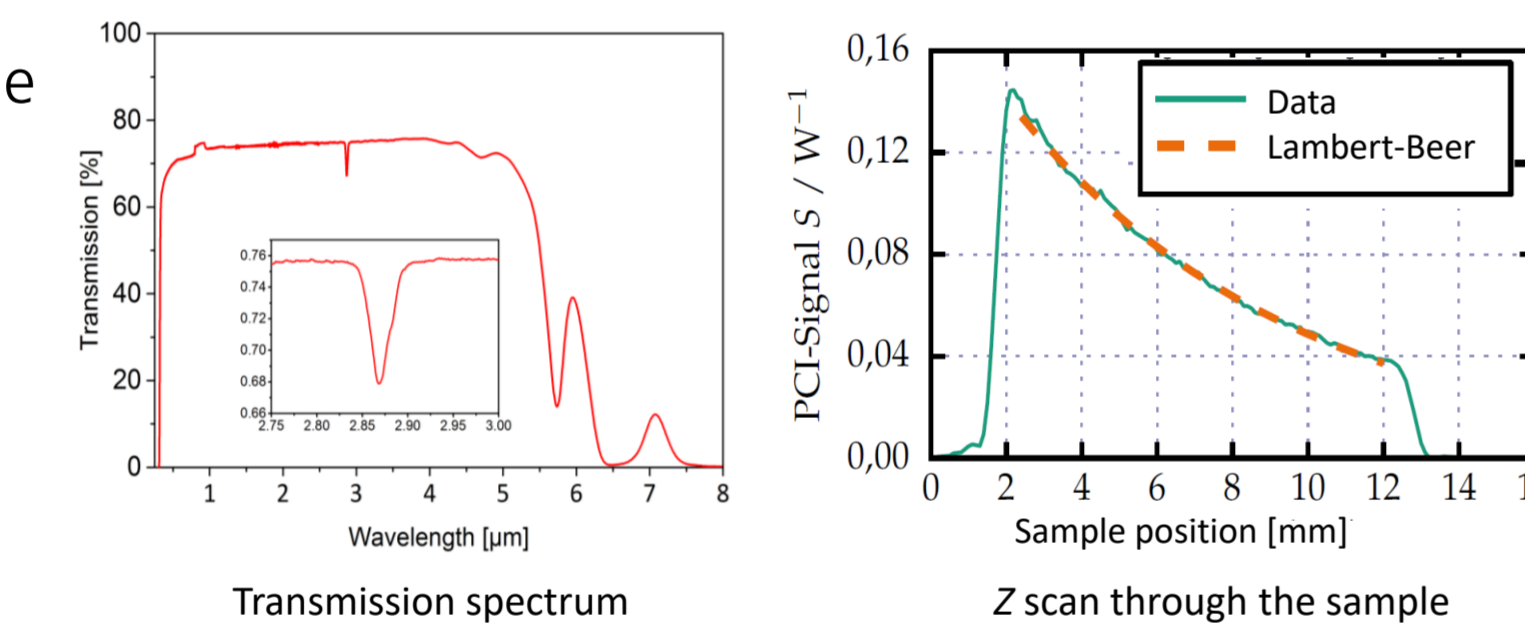
Continuous-wave optical parametric oscillators developed by Fraunhofer IPM and IMTEK/Freiburg University Freiburg are available as tunable pump sources for absorption measurements in the VIS, NIR and MIR regions.

Visible beams of four Hübner "C-WAVE" OPOs (developed at IPM) intersecting on the optical table

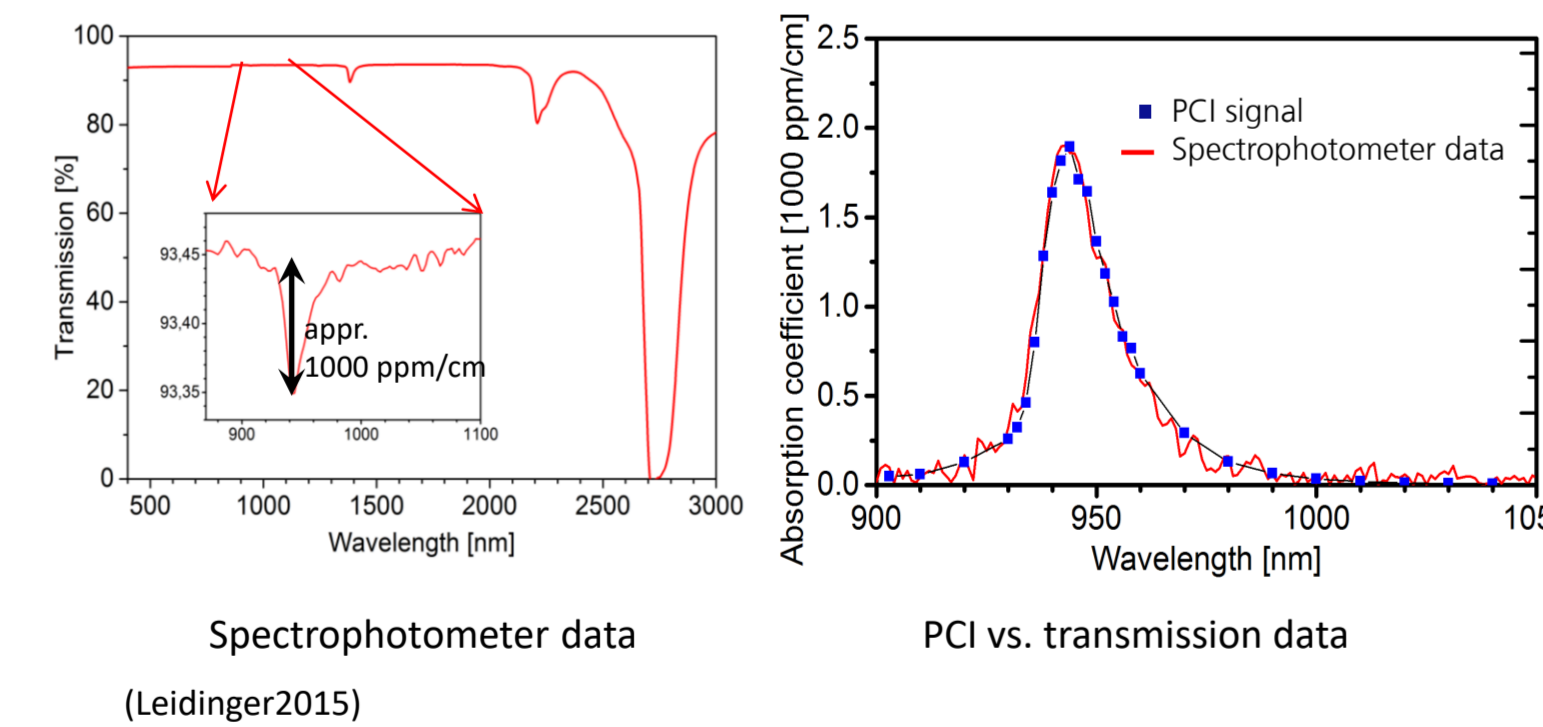
## Calibration methods

PCI, like all indirect absorption measurement methods, requires a calibration of the absorption scale. Here, the tuneability of the pump source is used to access absorption features in the spectra.

**Method 1:**  
Lambert-Beer decay visible in the PCI scan through the sample  
→ Direct determination of the extinction coefficient (example: lithium niobate)

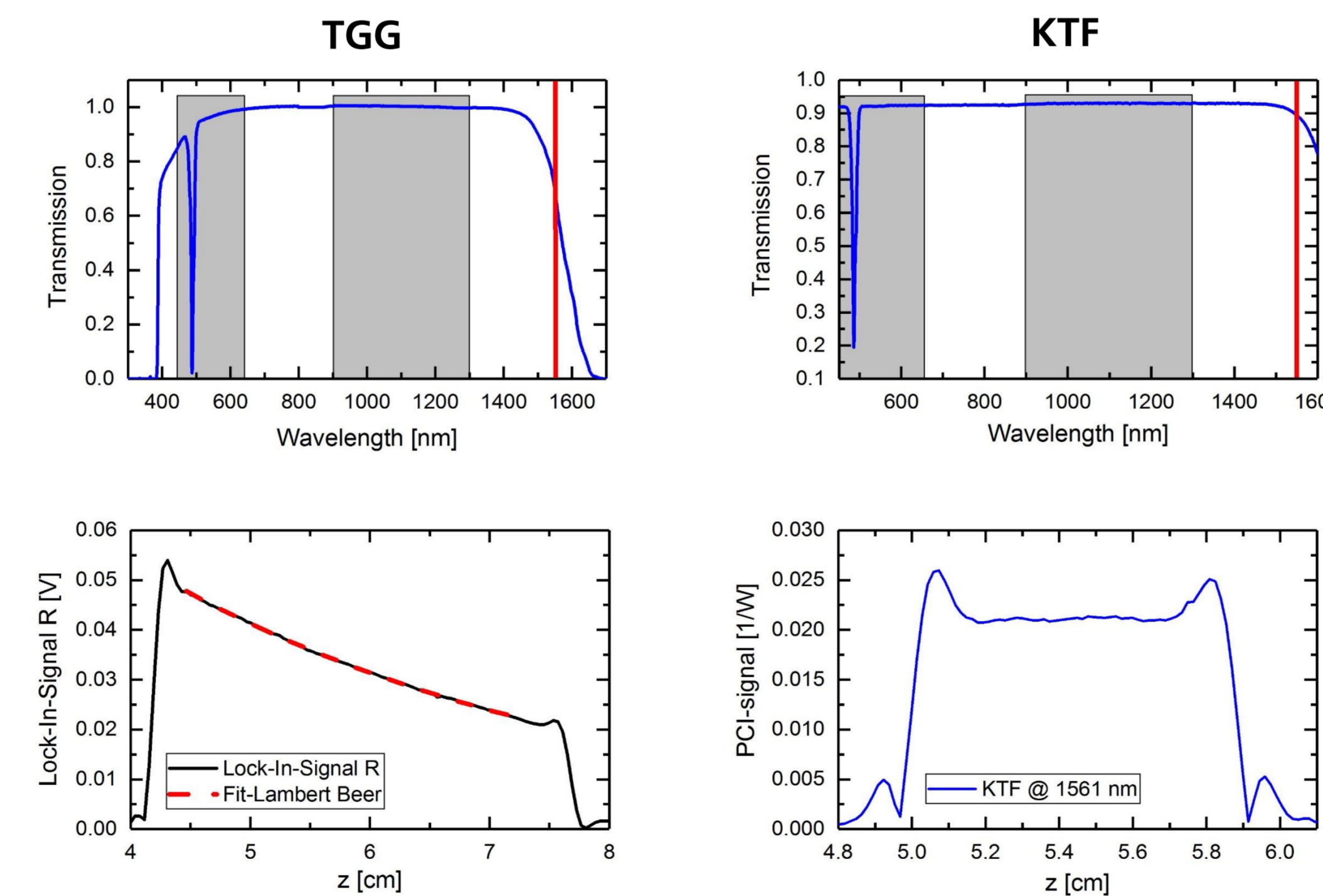


**Method 2:**  
Comparison of transmission and PCI scan data  
→ Scaling of the PCI signal (example: fused silica)



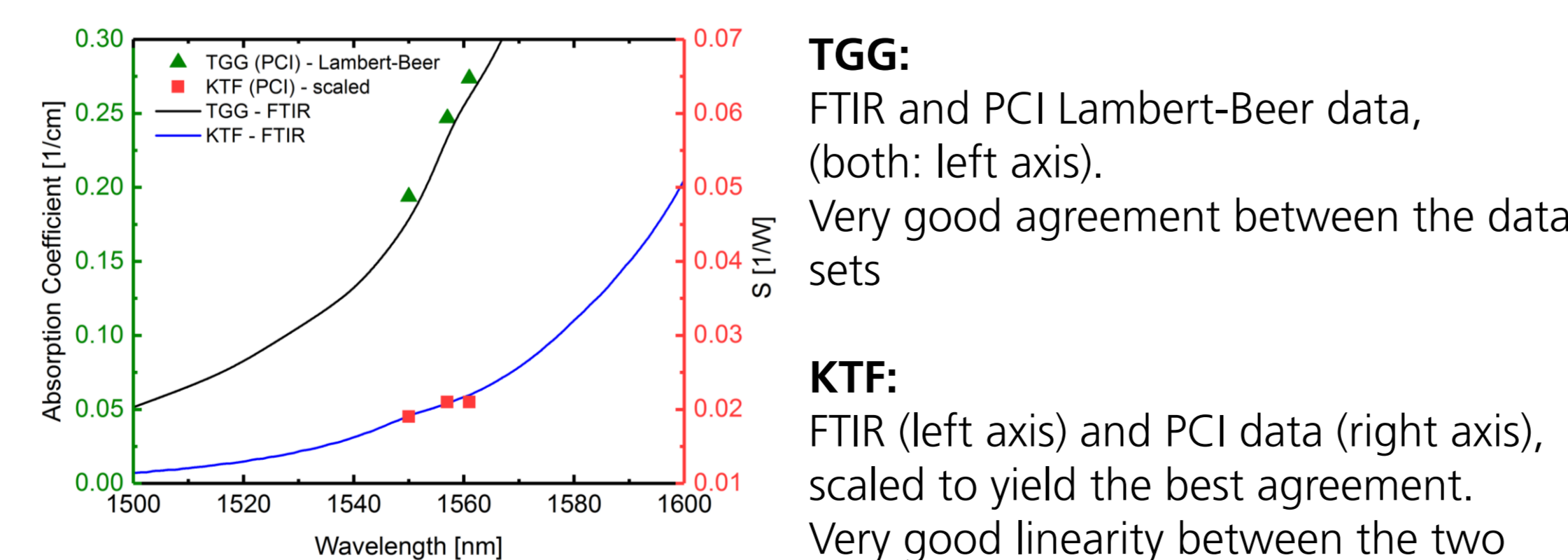
## Calibration for TGG and KTF

Both TGG and KTF feature a prominent absorption peak in the VIS operation range of the C-WAVE which is due to a Terbium transition around 480 nm. In both materials, the absorbed light is partially re-emitted as fluorescence. In KTF, scattering contributes to the total extinction. As a consequence, the multiphonon absorption at 1.5  $\mu\text{m}$  is used for the calibration utilizing an additional laser. At that wavelength fluorescence is absent and scattering losses can be neglected, i.e. the extinction data represent the absorption in the material.



$\alpha$  (1550 nm)  $\approx$  0.2 / cm  
→ direct determination of the extinction coefficient from the PCI Lambert-Beer decay

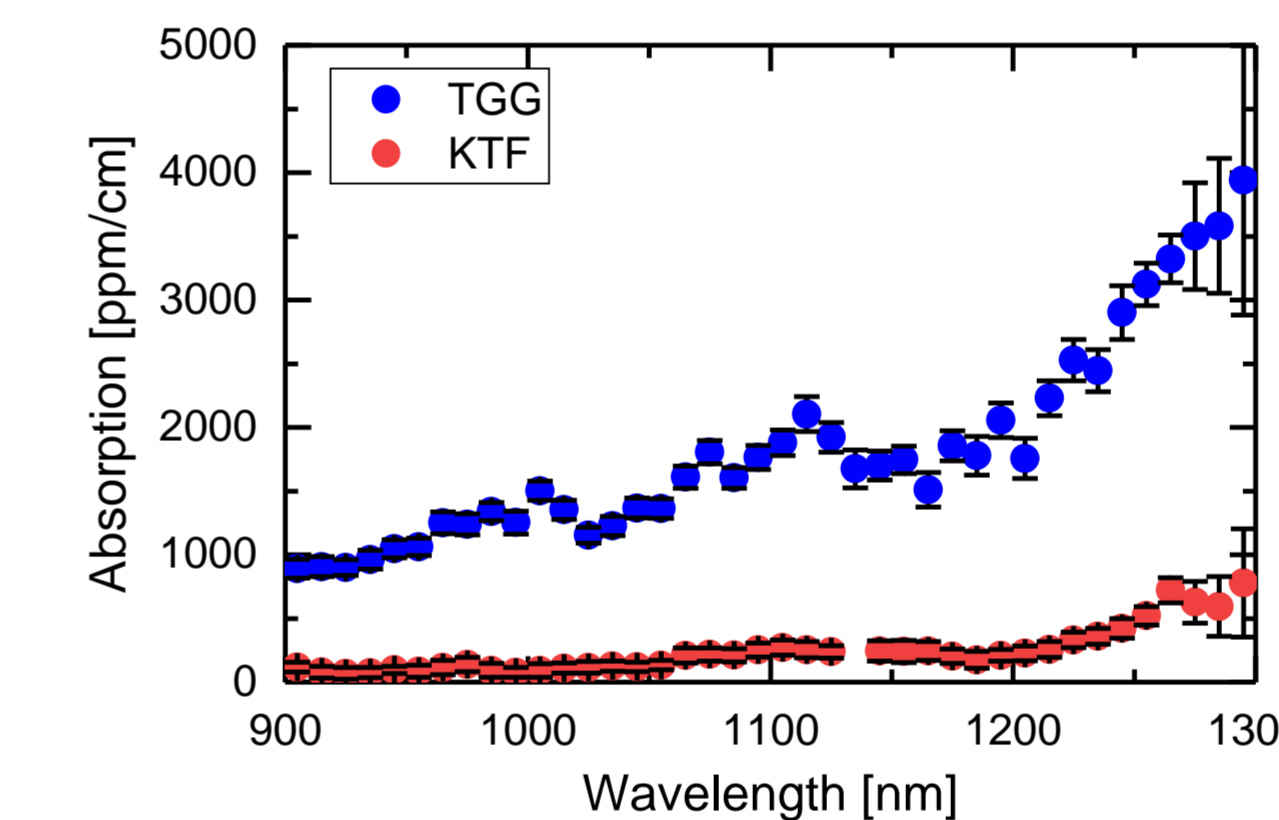
$\alpha$  (1550 nm)  $\approx$  0.05 / cm  
→ comparison between PCI and FTIR data for the scaling of the absorption



**TGG:**  
FTIR and PCI Lambert-Beer data, (both: left axis).  
Very good agreement between the data sets

**KTF:**  
FTIR (left axis) and PCI data (right axis), scaled to yield the best agreement.  
Very good linearity between the two data sets

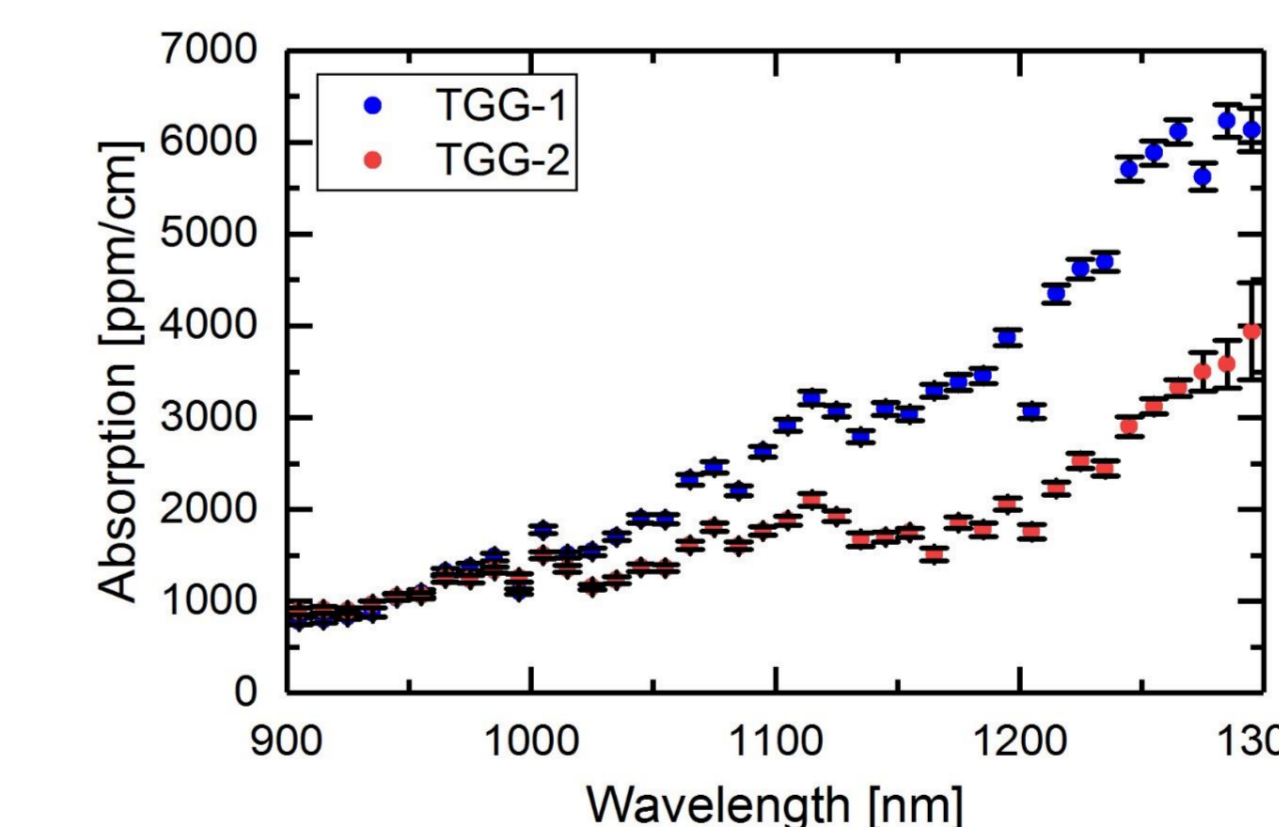
## NIR absorption spectra



Property	TGG	KTF
Verdet constant (1064 nm) [rad/T*m]	39	36
Refractive index (1064 nm)	1.944	~ 1.5
Thermo-optic coefficient [ $10^{-6}/\text{K}$ ]	17.9	1
Thermal conductivity [W/m*K]	7.4	1.67
Specific heat [J/(g*K)]	0.40	0.43
Thermal expansion coefficient [ $10^{-6}/\text{K}$ ]	7	13
<b>Absorption coefficient (1065 nm) [ppm/cm<sup>-1</sup>]</b>	<b>1610 ± 90</b>	<b>210 ± 60</b>

Data: Stevens2016, Jalali2017, this work

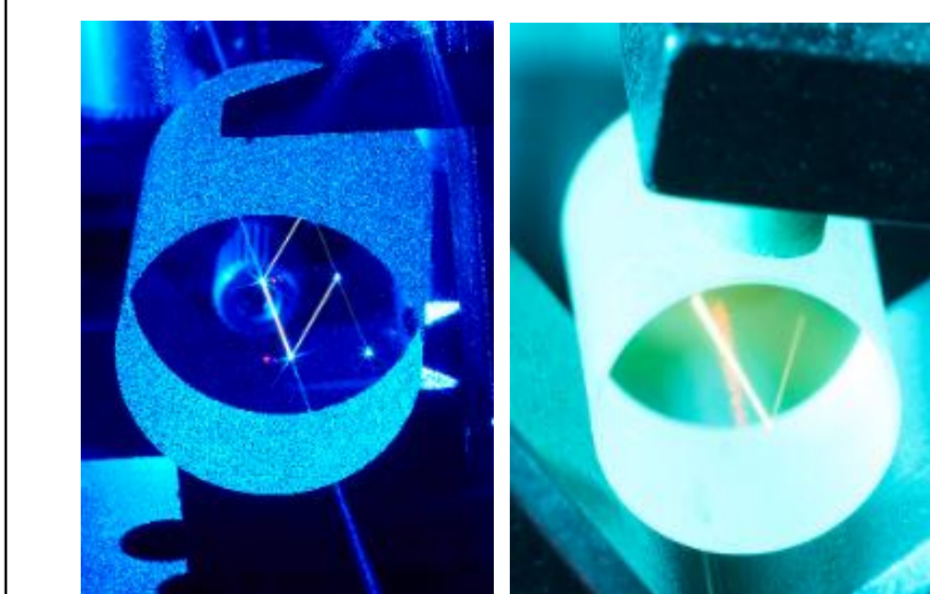
→ The combination of lower absorption and smaller thermo-optic coefficient in KTF leads to much weaker thermal lenses in the new material compared to TGG.



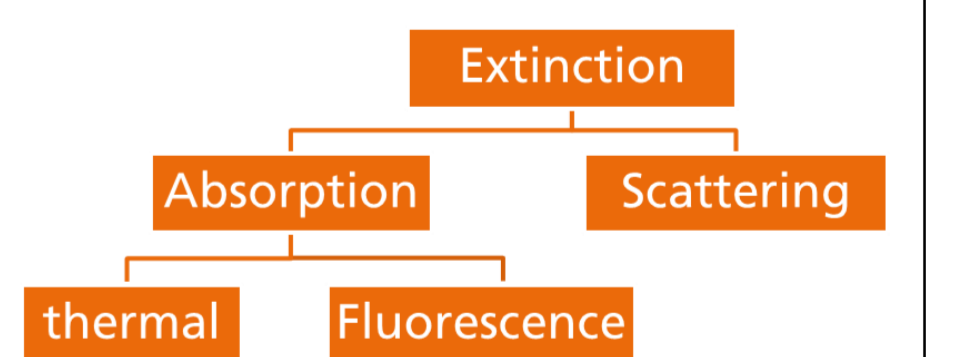
NIR spectra of two TGG crystals. The structure is caused by the multi-phonon bands.

## Crystals under illumination

Scattering and strong green fluorescence in the KTF crystal.

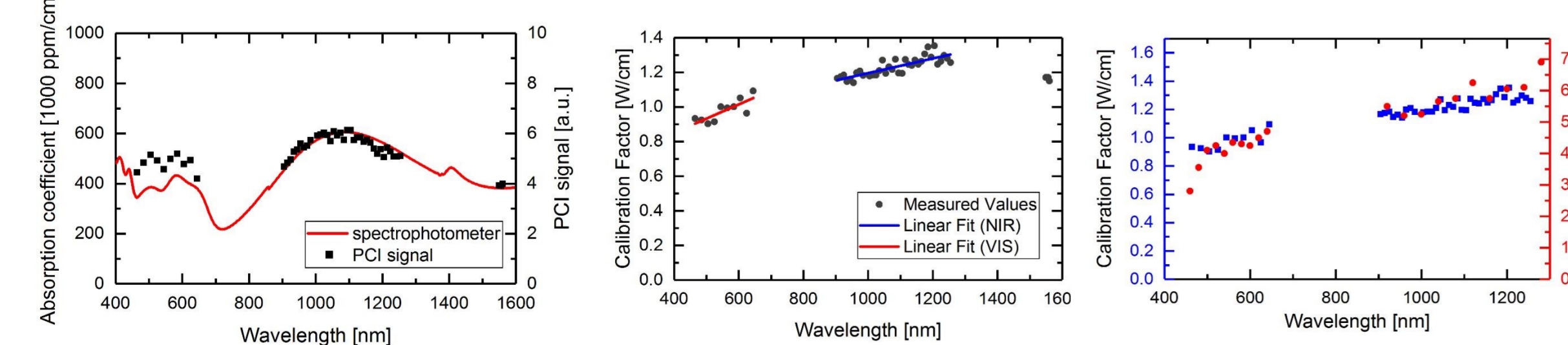


Energy pathways at short wavelengths



## From VIS to NIR

Is a calibration performed at one wavelength valid for the full wavelength range of the spectrometer?



Absorption spectrum of a neutral density filter as function of wavelength vs. PCI data  
→ wavelength-dependent scaling factor

Wavelength-dependent scaling factor with a linear fit for VIS and NIR ranges, respectively

The wavelength dependence is caused by the change in the beam waist of the pump laser in the sample

→ The calibration can be transferred across the whole wavelength range with a maximum uncertainty of 10%

## Acknowledgements

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The KTF sample was provided by Northrop Grumman Synoptics.

## References

Jalali2017: Amir Jalali et al., "Characterization and extinction measurement of potassium terbium fluoride single crystal for high laser power applications". Opt. Lett. 42, 899 (2017)

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