# NOVEL DESIGN OF MCT-DETECTOR OPTICS WITH ENHANCED PERFORMANCE

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## Abstract

In high resolution Fourier transform spectroscopy photoconductive MCT-detectors are widely used for measurements in the mid infrared region. In order to minimize measurement time and maximize precision a high signal to noise ratio (SNR) achieved for source photon noise and minimized background photon noise conditions is essential. A novel detector optics design for the Bruker IFS 120/125 is presented, consisting of a commercial 1 mm$^2$ area AG&G MCT detector chip (cutoff 725 cm$^{-1}$ @ 77 K, 640 cm$^{-1}$ @ 45 K), selectable cooled aperture, cooled optical filter and two imaging and one flat mirror which are placed in a standard Infrared Labs cryostat. The cryostat is cooled to 45 K instead of the usual 77 K to suppress thermal excitation noise. The performance of the detector unit was tested with a Bruker IFS 125 HR versus an Infrared Associates D316 detector unit as supplied usually by Bruker. As expected the new unit shows significantly higher SNR especially when operated with narrowband optical filters. It is also shown that optical modifications inside the Bruker have minor influence on the performance.

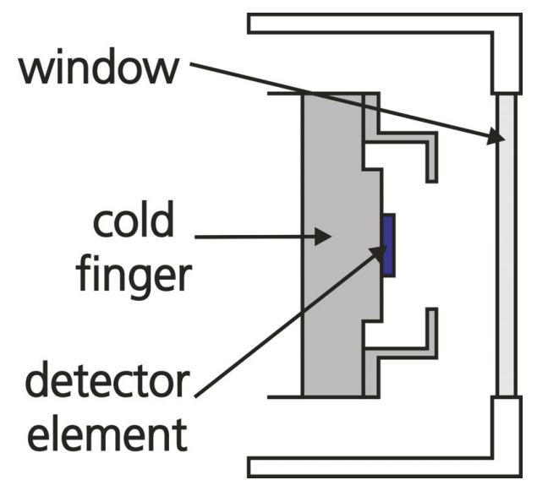
## Optical and mechanical design

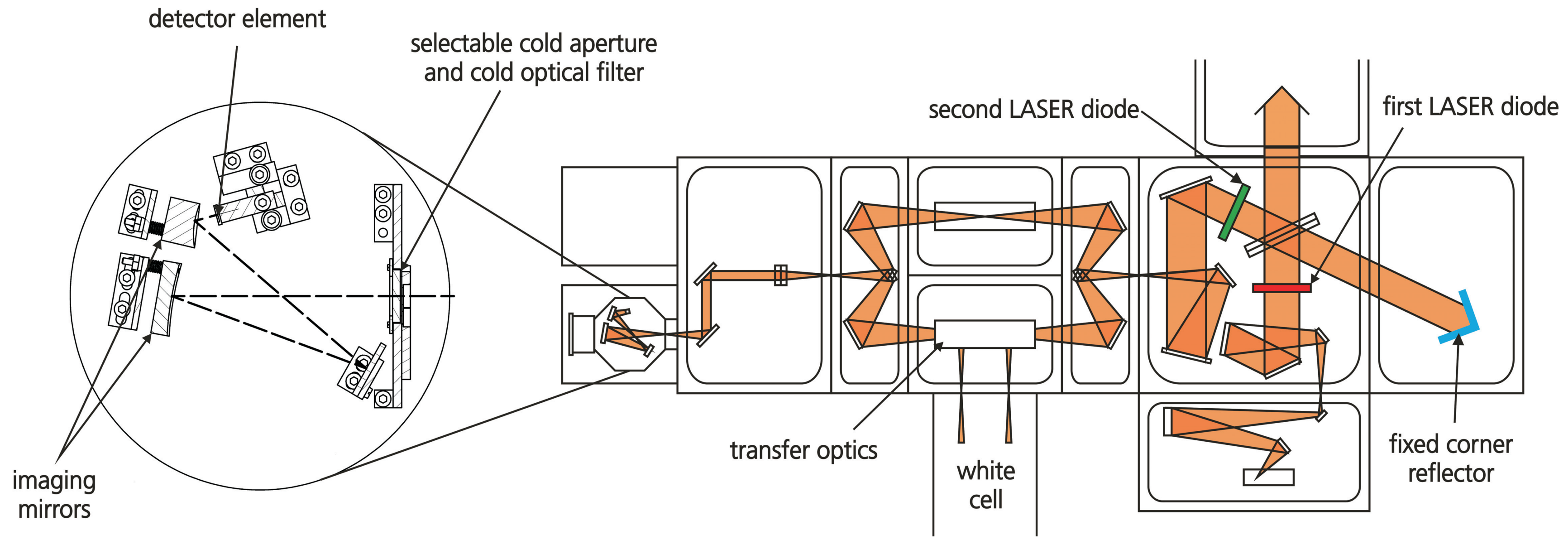
**DLR**

- cold selectable aperture, $A\Omega > 0.8\cdot10^{-3}$ cm$^2$str
- cold optical filter
- imaging optics (spherical, plane, paraboloidal mirror)
- optical beamsplitter image on detector element
- operation @ 45 K by pumping on LN$_2$

**D316**

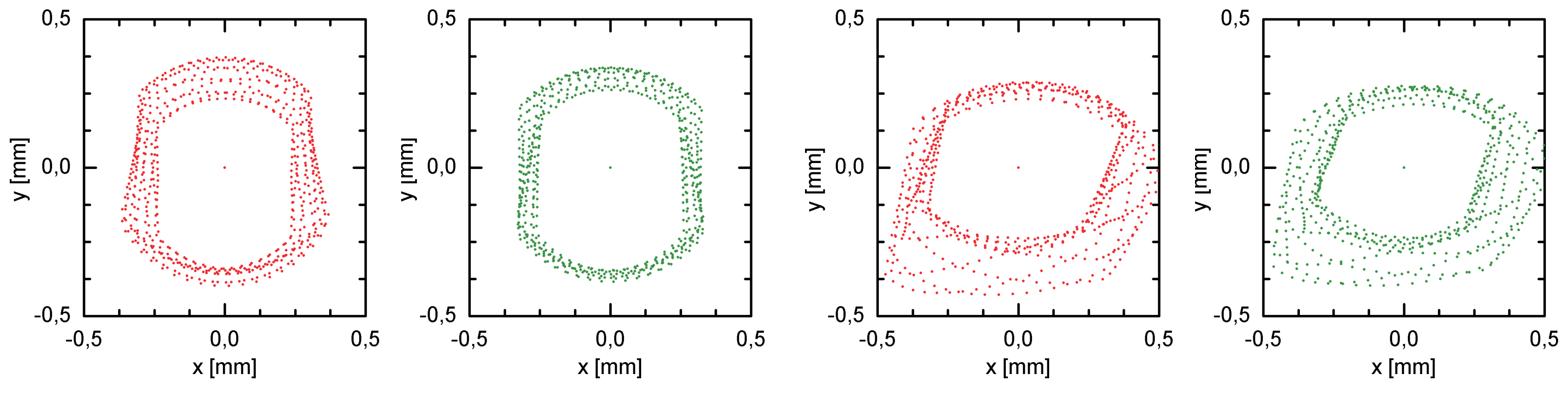
- fixed $A\Omega^* = 2.1\cdot10^{-3}$ cm$^2$str
- field stop image on detector element
- large field of view
- operation @ 77 K





## Raytracing

- entrance stop imaged into plane of cold aperture, which can be adapted (diameter 1.5, 2.1, 3, 4.5, 6 mm)
- aperture stop (consisting of 3 parts) imaged onto detector element
  - first LASER diode (distance to next focusing mirror: 169 cm)
  - fixed corner cube reflector (110 cm)
  - second LASER diode (48 cm)
- detector element illumination nearly independent of chosen field stop (against 1:3 field stop image with D316 setup)



short cell setup

80 m white cell setup

images of 2 mm field stop on detector element; aperture stop at first and second LASER diode position

→ minor influence of optical modifications inside the spectrometer

## The parametric model

### General remarks

- the model is designed to predict the signal to noise ratio improvement of the DLR detector compared to the Infrared Associates D316 detector setup
- source (globar) and background radiation are assumed as blackbody sources
- manufacturer's data as well as globar measurements (detector @ 77 K) with optical filter were used to adjust model parameters (see below), predictions for detector @ 45 K are used for model validation

### Signal to noise ratio

- background photon flux $$\Phi_{BG} = \int t_{det}\cdot t_f(\sigma)\cdot\eta(\sigma)\cdot A\Omega_{det}\cdot P_{phot}(T_{BG},\sigma)\,d\sigma$$
- signal photon flux $$\Phi_S = \int t_{Bruker}\cdot t_{det}\cdot t_f(\sigma)\cdot\eta(\sigma)\cdot\frac{1}{2}A\Omega_{Bruker}\cdot P_{phot}(T_S,\sigma)\,d\sigma$$
- thermal excitation noise $$\Phi_{TE} = k\cdot n_i(x,T_{det}) = k\cdot\mathrm{poly}(x,T_{det})\cdot T_{det}^{3/2}\cdot\sigma_{gap}^{3/4}\cdot\exp\left(-\frac{hc\sigma_{gap}}{kT_{det}}\right) \quad [1]$$

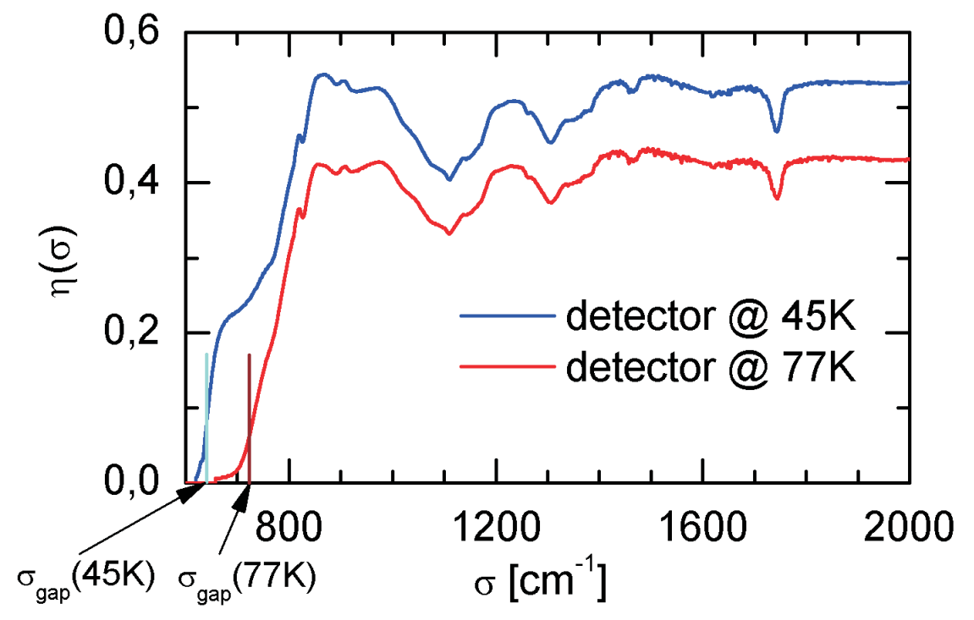
$$\mathrm{SNR}_{\mathrm{IFG}} = \frac{\Phi_S}{\sqrt{(\Phi_s+\Phi_{BG}+\Phi_{TE})\cdot 2\Delta f}}$$

$t_{det/Bruker}$: detector/spectrometer transmission; $t_f$: filter transmission; $\eta(\sigma)$: effective quantum efficiency; $A\Omega_{det/Bruker}$: optical throughput; $P_{phot}$: blackbody photon flux in photons/s cm$^{-1}$ cm$^2$; $T_{BG/S/det}$: background/source/detector temperatures; k: proportionality constant; x: mixing ratio $Hg_{1-x}Cd_xTe$; $\sigma_{gap}$: band gap wavenumber = poly(x,$T_{det}$) [2]; $\mathrm{SNR}_{IFG}$: signal to noise ratio in interferogram domain; $\Delta f$: frequency bandwidth

### effective spectral quantum efficiency

- experimentally determined
- scaled to proper mean value

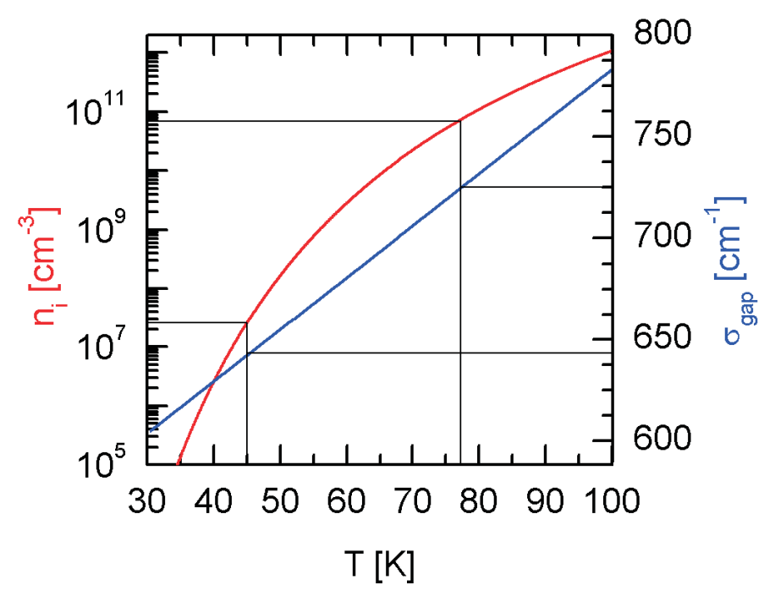
$$\eta(\sigma)\,\tilde{\propto}\,\frac{S_{globar}(\sigma)}{P_{phot}(T_S,\sigma)}$$



### thermal excitation noise

- intrinsic equilibrium carrier density $n_i(x,T_{det})$
- used detector: x = 0.2042
- proportionality constant k experimentally determined using globar measurements @ 77 K with various field stops

$$\frac{n_i(77\,\mathrm{K})}{n_i(45\,\mathrm{K})} = 2.8\cdot10^3$$

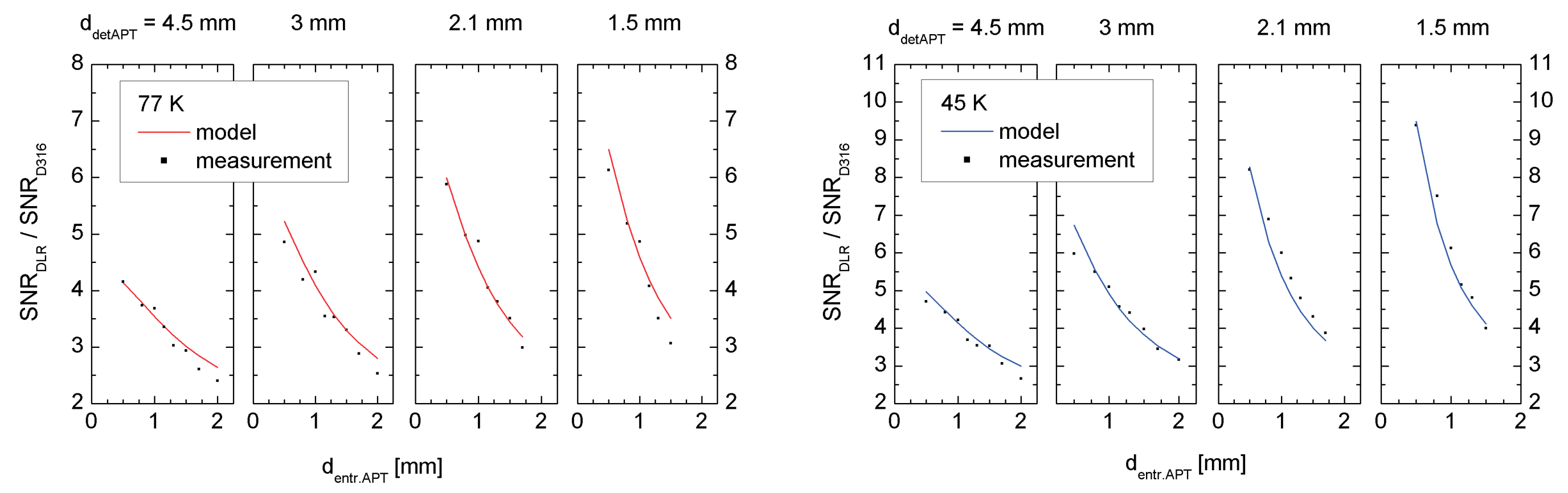


- thermal excitation noise can be reduced significantly!

## Intercomparison: Infrared Associates D316 vs. DLR

### test conditions

- evacuated spectrometer, evacuated short cell, KBr-beamsplitter, optical filter: 1200 - 1800 cm$^{-1}$
- Globar source $T_S$ = 1400K, calibrated using blackbody room temperature spectra
- DLR-detector operated @ 77 K and 45 K
- $\Delta\sigma$ = 1 cm$^{-1}$, MOPD = 0.9 cm, single sided acquisition, 1 sweep



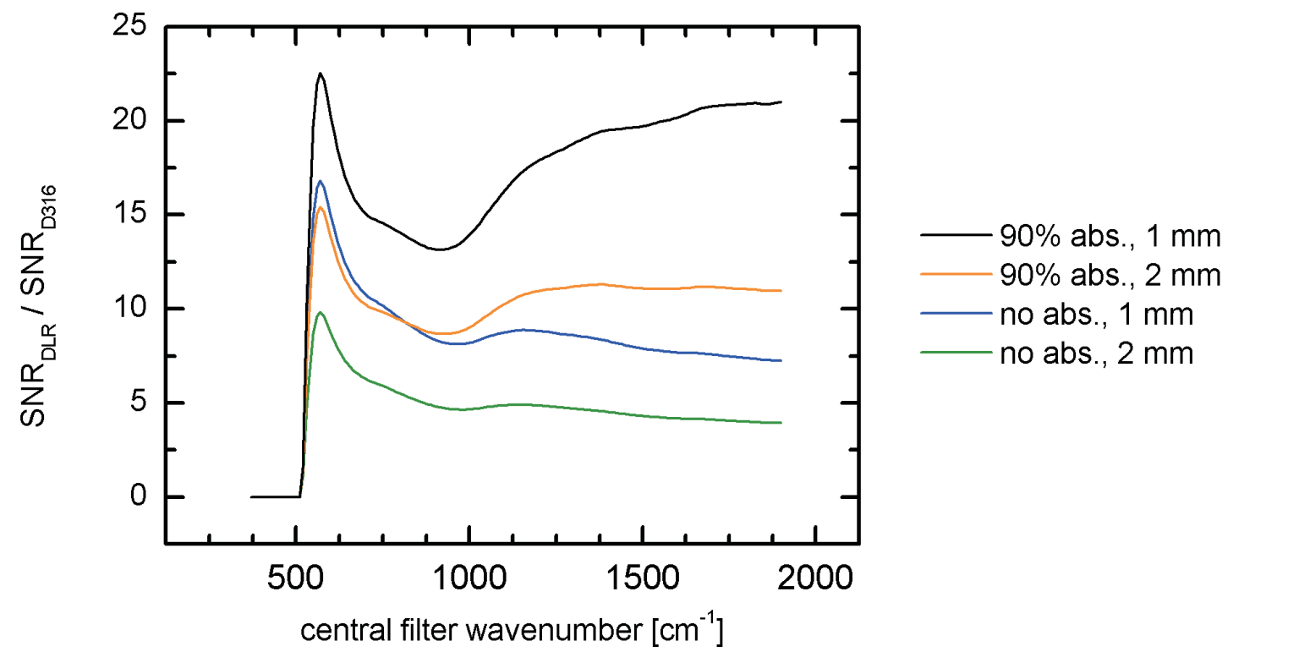
- DLR-detector shows superior signal to noise ratio compared to D316 (up to a factor of 9; 4 w/o filter)
- D316 effective quantum efficiency adjusted for the model to match @ 77 K*
- results @ 45 K validate the parametric model, differences might be due to inhomogeneous illumination*

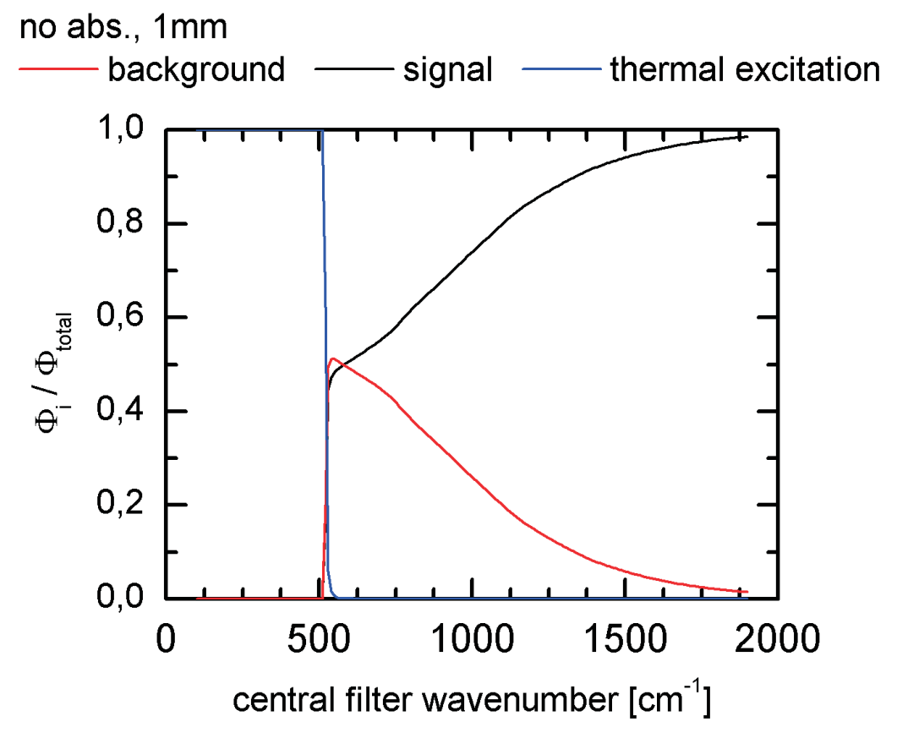
→ significantly better performance

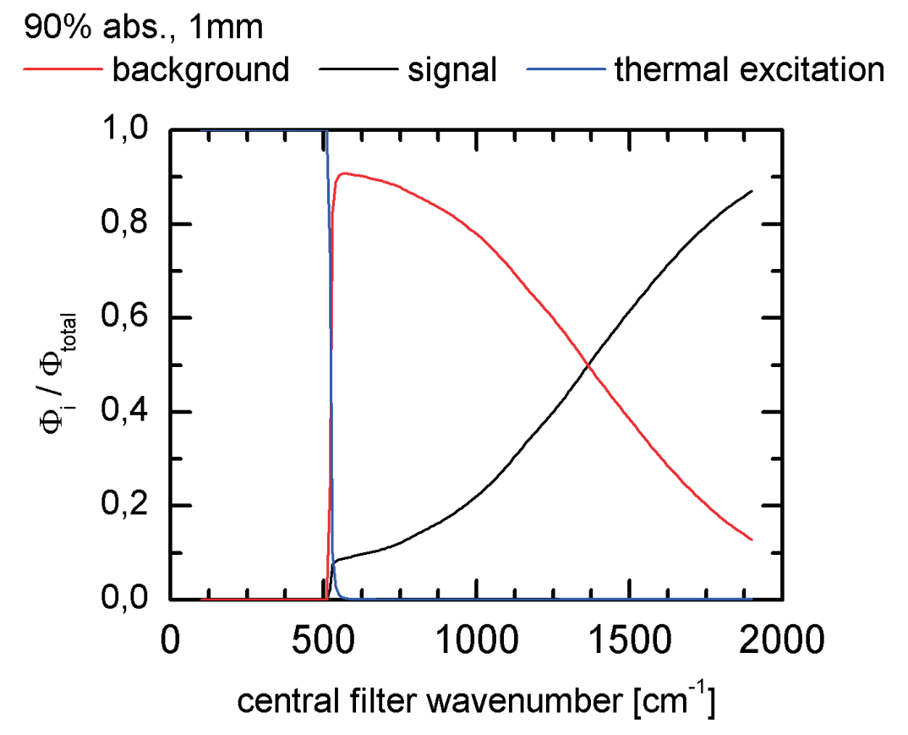
## Beyond the test conditions

### optical band pass filter, varying central wavenumber

- detector @ 45 K
- 200 cm$^{-1}$ filter bandwidth
- 1 mm and 2 mm Bruker entrance aperture (1.5 mm and 2.1 mm detector aperture)
- no absorber- and 90% absorption-setup



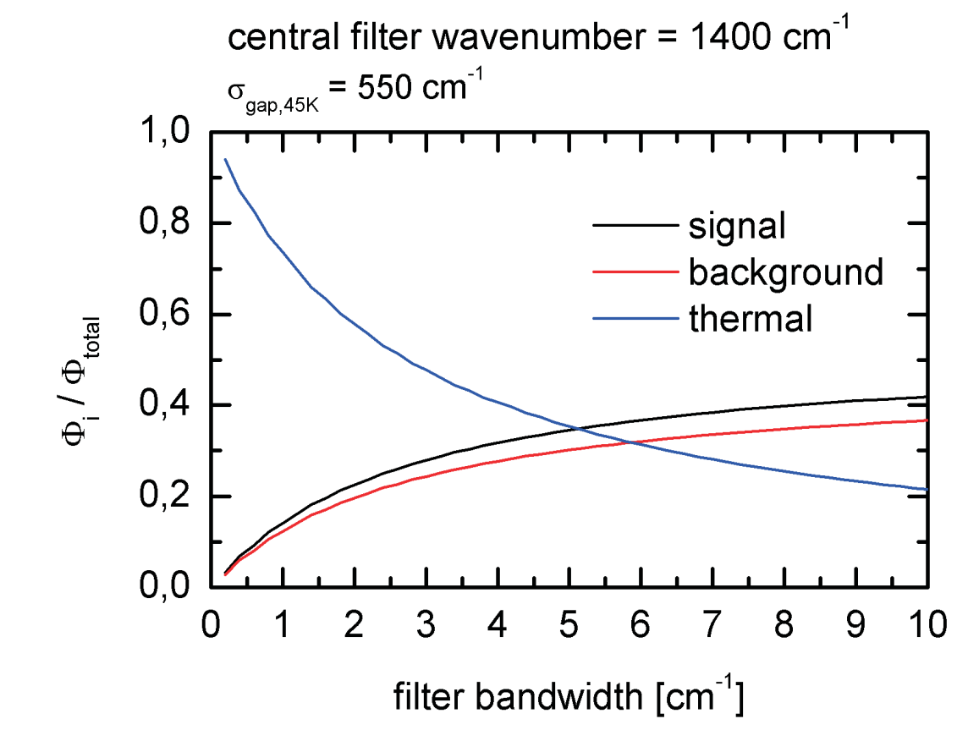


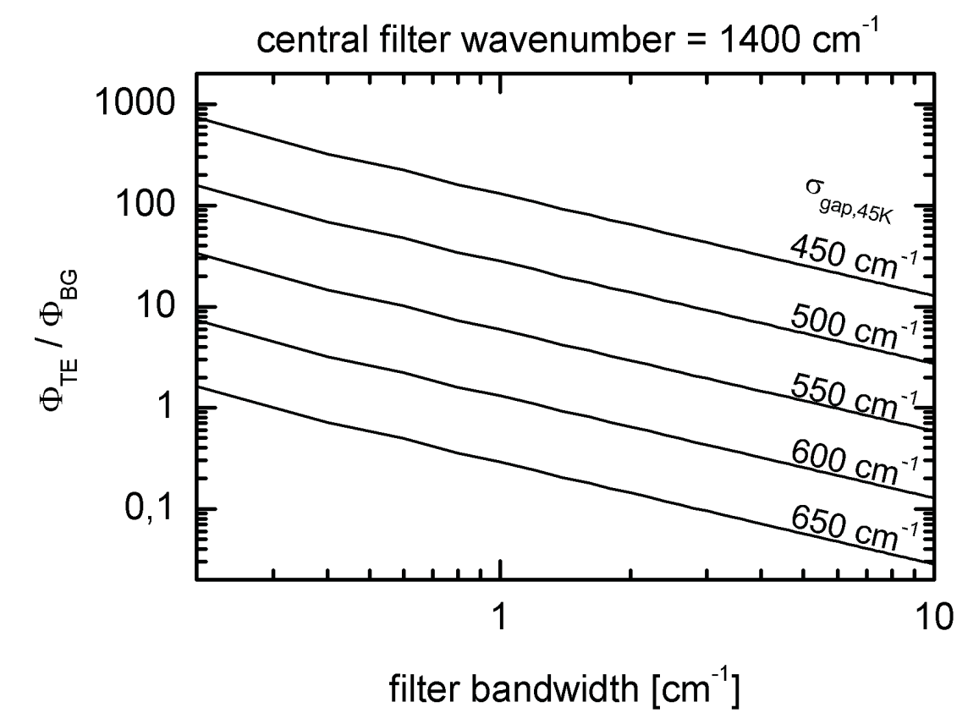


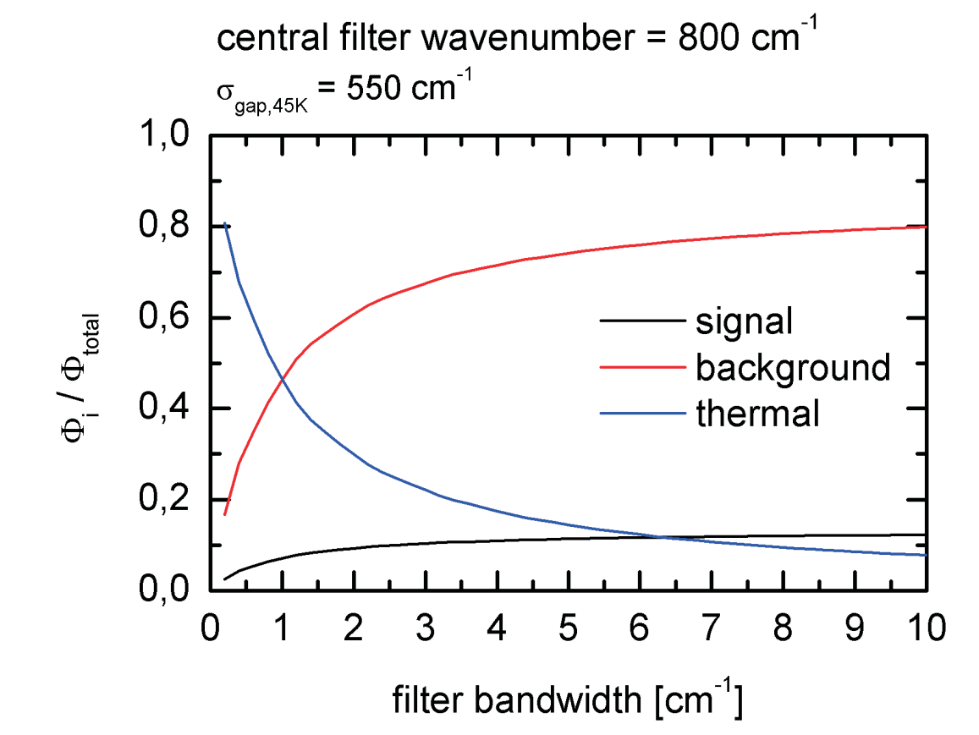
- signal-dominated in absence of strong adsorption
- practically no influence of thermal excitation noise
- superior performance when operated in low signal domain

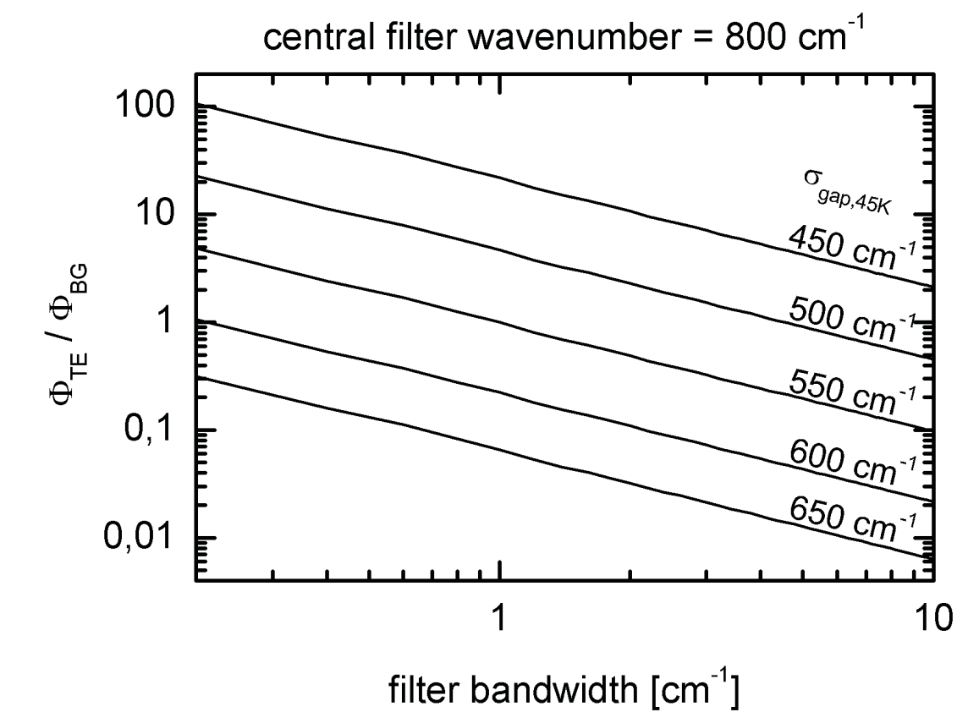
### optical band pass filter with varying bandwidth and varying MCT-composition x

- detector @ 45 K
- 800 cm$^{-1}$ and 1400 cm$^{-1}$ central filter wavenumber (background- and signal dominated domain)
- 1 mm Bruker entrance aperture (1.5 mm detector aperture)
- 90% absorption-setup









- worst case scenario
- not necessarily limited by thermal excitation noise - even when using narrow band filters

→ minor effect of thermal excitation noise

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* the interplay of AΩ and the effective spectral quantum efficiency η(σ) plays a major role in the D316 modeled performance. Since neither could be measured directly, AΩ was calculated using a FOV of 30° (manufacturer's data) and η(σ) was adjusted to a mean value of 0.11 (with respect to a 296 K blackbody source). This treatment might seem rather arbitrary, but there are some motivating indications. First, a previously used MCT with equal cutoff wavenumber showed a mean quantum efficiency of 23% - significantly lower than the measured value of 35% for a 725 cm$^{-1}$ cutoff detector. Second, the D316 effective AΩ might be underestimated (stray light, baffle heat junction, ...). Third, the detector's illumination depends on the chosen field stop which gives rise to unaccounted nonlinearity effects. - Open for discussion.

[1] Hansen, G.L. *et al.*: *Calculation of intrinsic carrier concentration in $Hg_{1-x}Cd_xTe$*, J. Appl. Phys. **54** (1983), 1639-40
[2] Hansen, G.L. *et al.*: *Energy gap versus alloy composition and temperature in $Hg_{1-x}Cd_xTe$*, J. Appl. Phys. **53** (1982), 7099-101

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