IRsweep

Innovation in sensing

Fast and broadband mid-IR sensing for multi-species detection

Andreas Hugi, CEO IRsweep

SWISS PHOTONICS

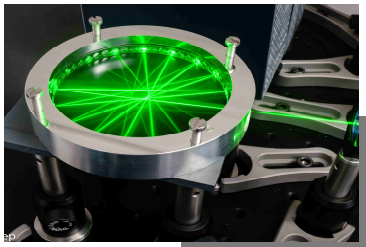
Company introduction

IRsweep is in the business of products and solutions for optical sensing. We use broadband mid-IR lasers (frequency combs) for optical gas sensing. The platform is offering **fast, high selectivity and multi substance** spectroscopy for downstream applications.

Key company features

- Founded in 2014 based in Zürich, Switzerland
- 8 full time equivalents of employees
- Global fulfillment capabilities
- Unique high speed solutions for mid-IR spectroscopy
- Pioneers in our products ideas and concepts

Products portfolio



IRCELL

- Circular multipass reflection cell for high sensitivity gas analysis

Commercially available

IRSPECTROMETER

- Dual frequency-comb QCL source and detection unit with optical spectrum recovery

Available for pre order

IRsweep

Now available: IRcell-4M from IRsweep

IRcell-4M specifications:

- Optical path: 399 cm / 157 inch
- Outer diameter: 10 cm / 4 inch
- Internal volume: 30 ml

IRcell USP

- robust ✓
- compact ✓
- temperature invariant ✓

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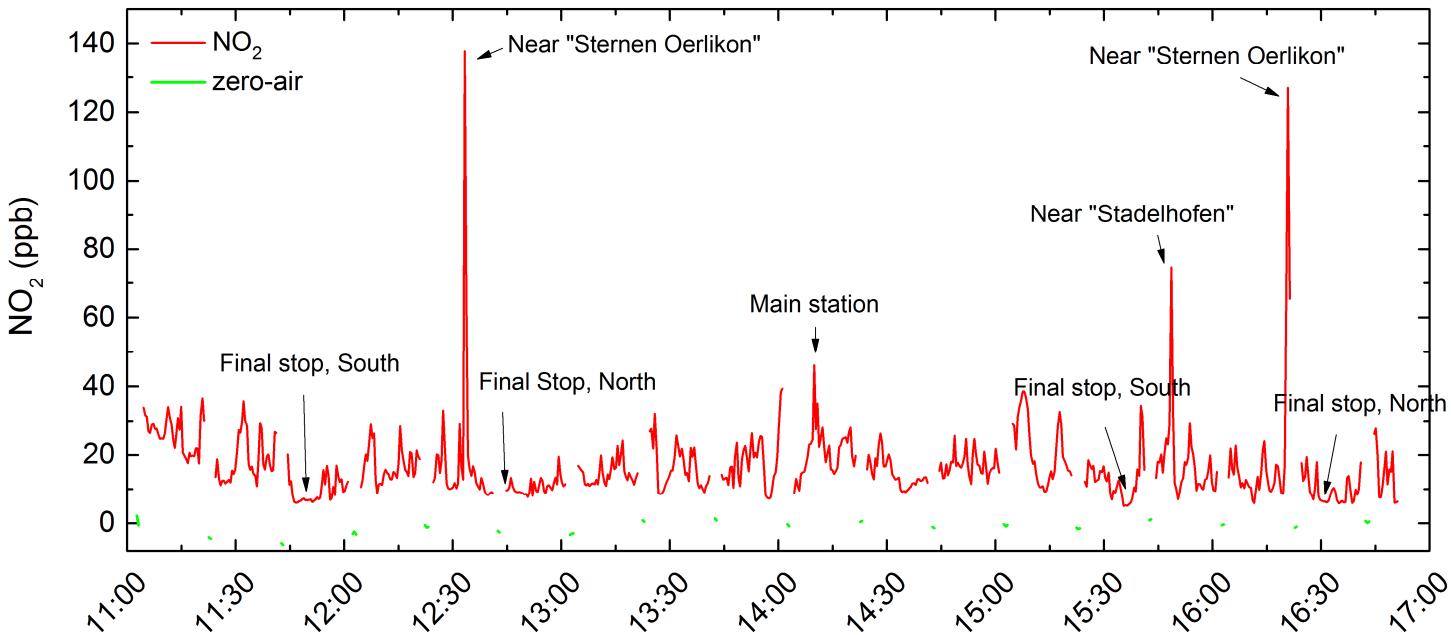
NO_2 measurements on Zürich Tram

EMPA
Materials Science & Technology

Tram line 11, 9/24/2015



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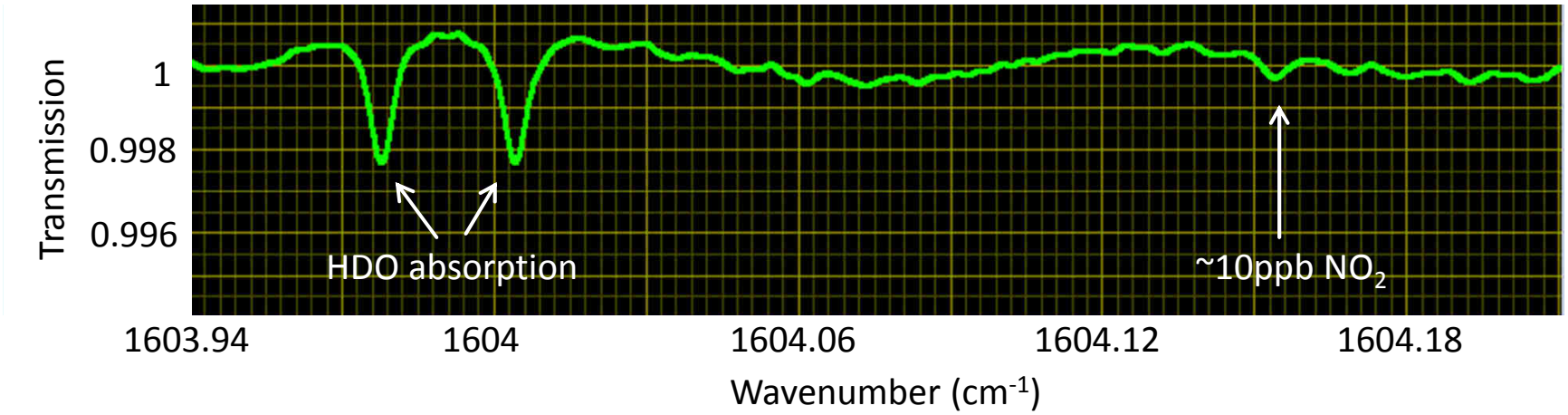
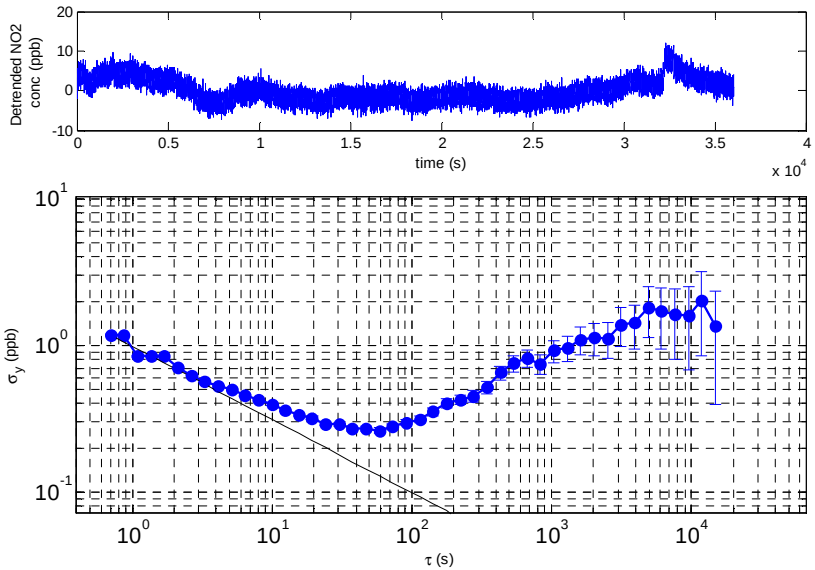
NO_2 absorption measurements





NO_2 measurement precision of

~ 1ppb at 1 second averaging

< 300ppt at 1 minute averaging

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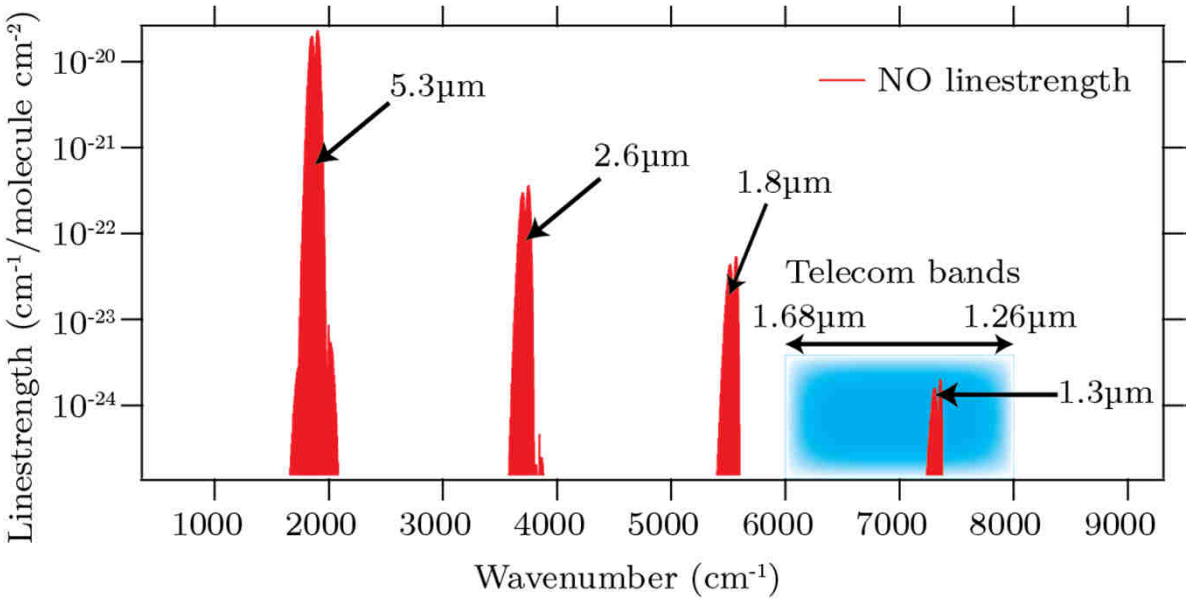
Mid-infrared vs. near-infrared



Beer-Lambert law:

$$I = I_0 \exp(-\alpha l)$$

$$\frac{\Delta I}{I} \approx -\alpha l$$

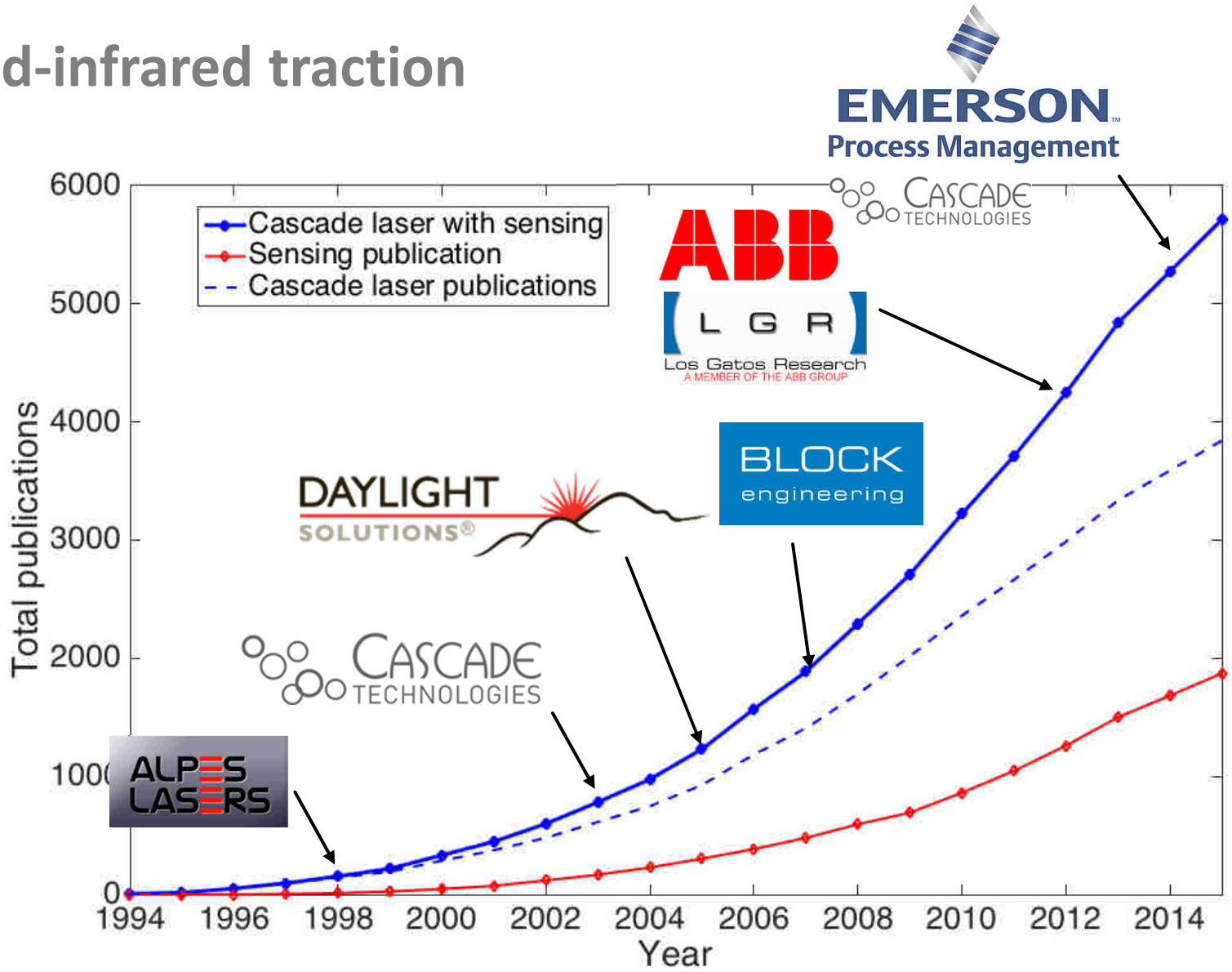
	MIR	NIR
Selectivity	++	O (Combination bands)
Sensitivity	++	O (Trade off with selectivity)
Price	-	+

Some numbers on detection limits

	Near-infrared	Mid-infrared
Ammonia NH_3		
Wavelength	1.532 µm	10.34 µm
Gas concentration	**0.7 ppb**	**0.2 ppb**
Technique	OA-ICOS	Direct TDLS
Path length	5 km	76 m
Integration time	1 s	1s
Methane CH_4		
Wavelength	1.654 µm	3.3 µm
Gas concentration	**20 ppb**	**15 ppb**
Technique	Direct TDLS	Direct TDLS
Path length	252 m	6.8 m
Integration time	2 s	60 s
Nitric Oxide NO		
Wavelength	1.81 µm	5.263 µm
Gas concentration	**100 ppm**	**2.7 ppm**
Technique	Direct TDLS	Direct TDLS
Path length	68 cm	21 cm
Integration time	10 s	1.25 s

Hodgkinson, Jane, and Ralph P. Tatam. "Optical Gas Sensing: A Review." *Measurement Science and Technology* 24, no. 1 (2013): 012004. doi:10.1088/0957-0233/24/1/012004.

Mid-infrared traction



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Mid-infrared traction - mature technology

THORLABS

QCL modules

Mid-IR fibers (5.5 µm)

Class 100 clean-room

2009 5500 m^2 cleanroom
Purchase 2012 Maxion QCL
Purchase 2014 Corning

HAMAMATSU
PHOTON IS OUR BUSINESS

QCL modules

InAsSb Photovoltaic Detector

IRsweep

Mid-infrared traction - mature technology

NORTHROP GRUMMAN

DAYLIGHT SOLUTIONS

Northrop Grumman partners with daylight solutions since 2011

US-Army contract August 2015

$35M

CIRCM program to provide protection of rotary-wing and medium fixed-wing aircraft against emerging infrared missile threats.

IRsweep

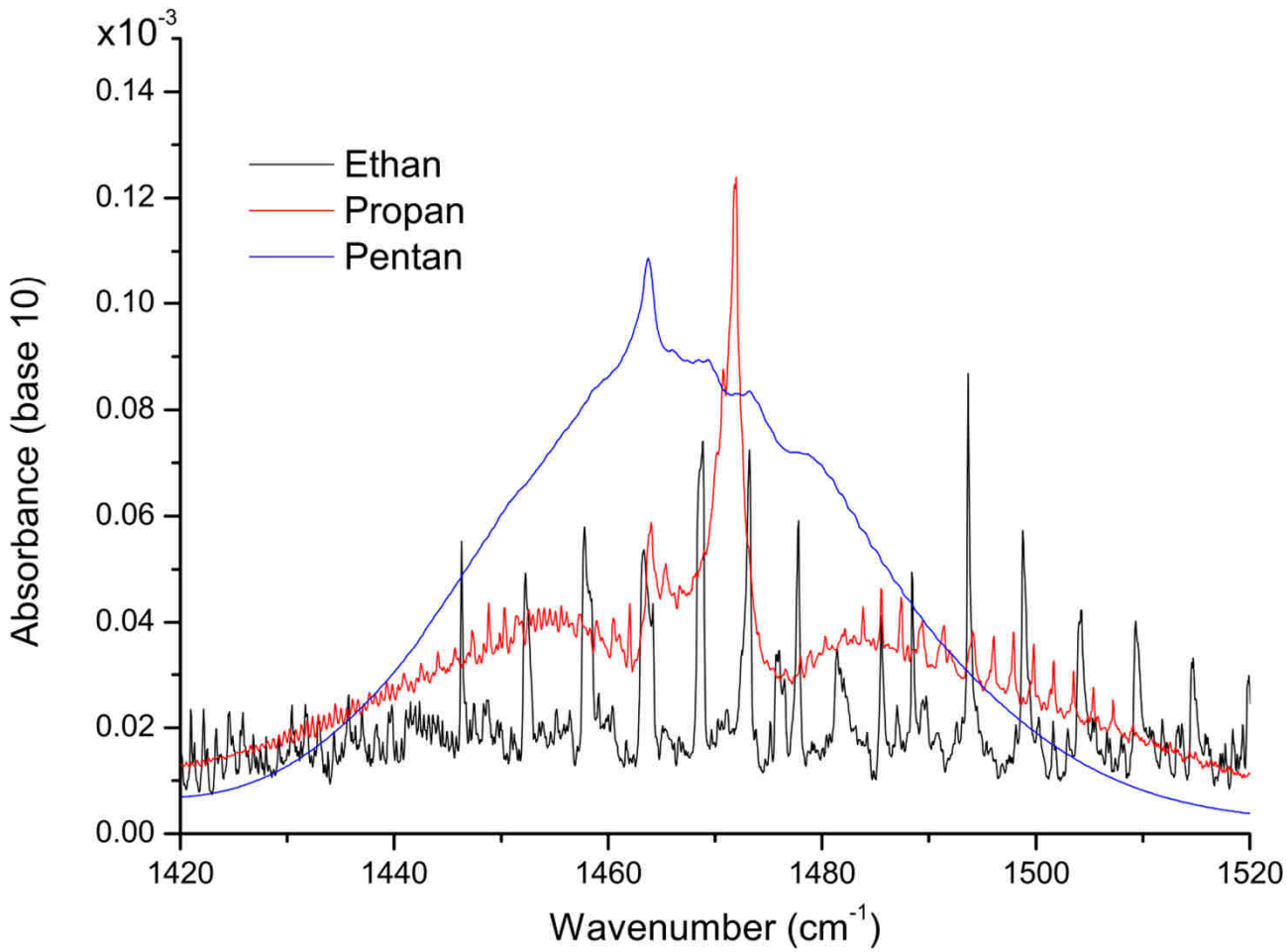
Pioneering mid-IR in Switzerland

- Prof. Jérôme Faist
  QCL inventor Bell Labs 1994

- Dr. Lukas Emmenegger
  Pioneer using QCL for
  enviromental monitoring

- Alpes Lasers S.A.
  First commercial QCL manufacturer

Broadband and high resolution requirements



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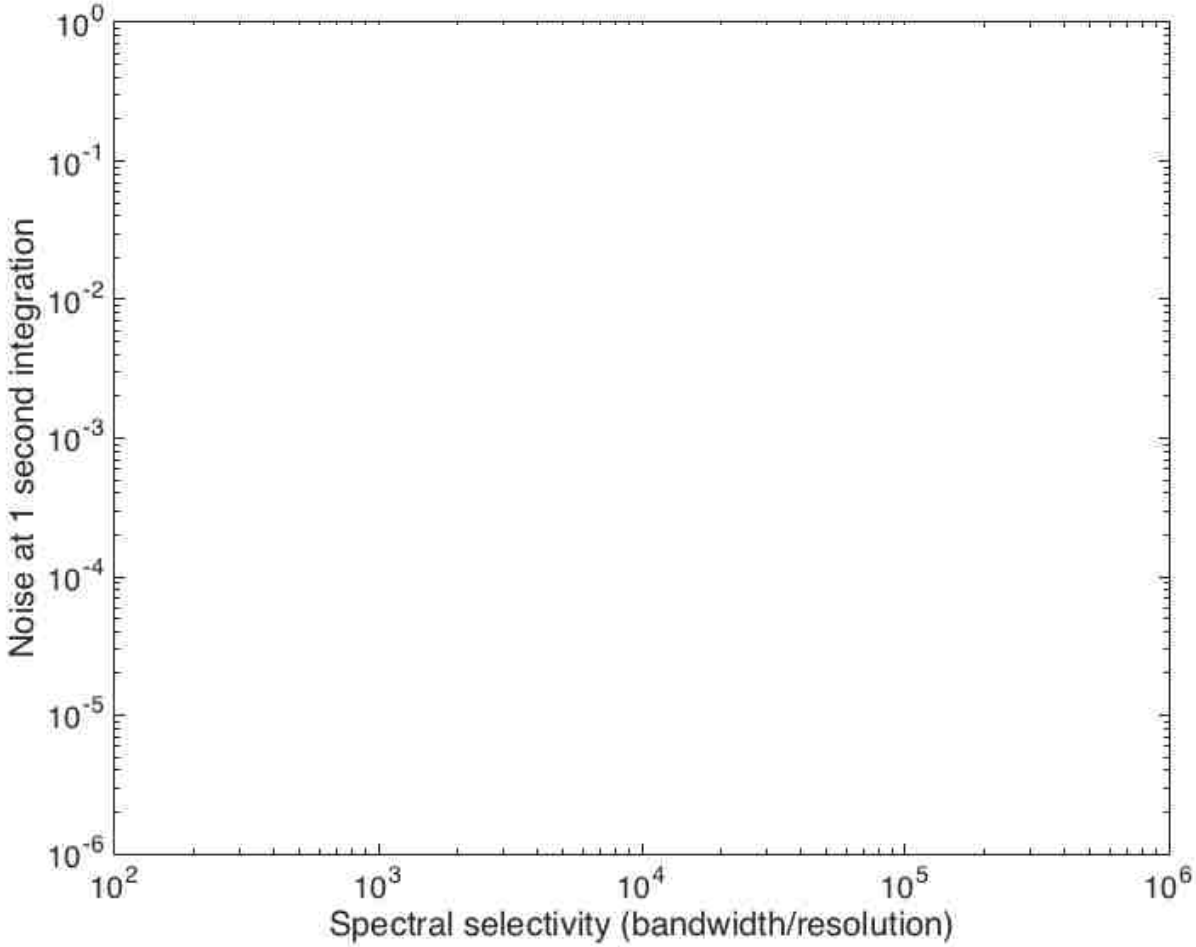
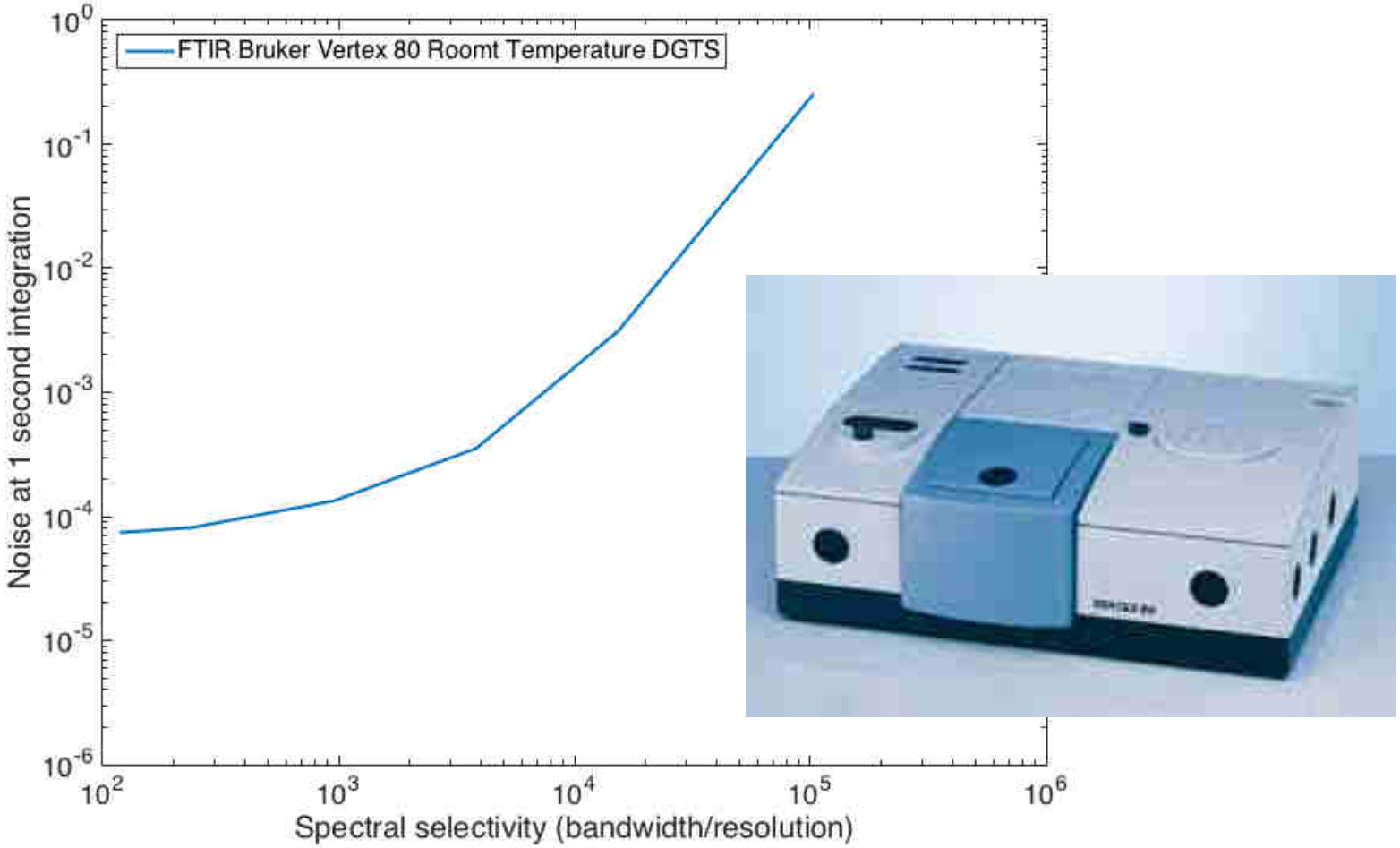
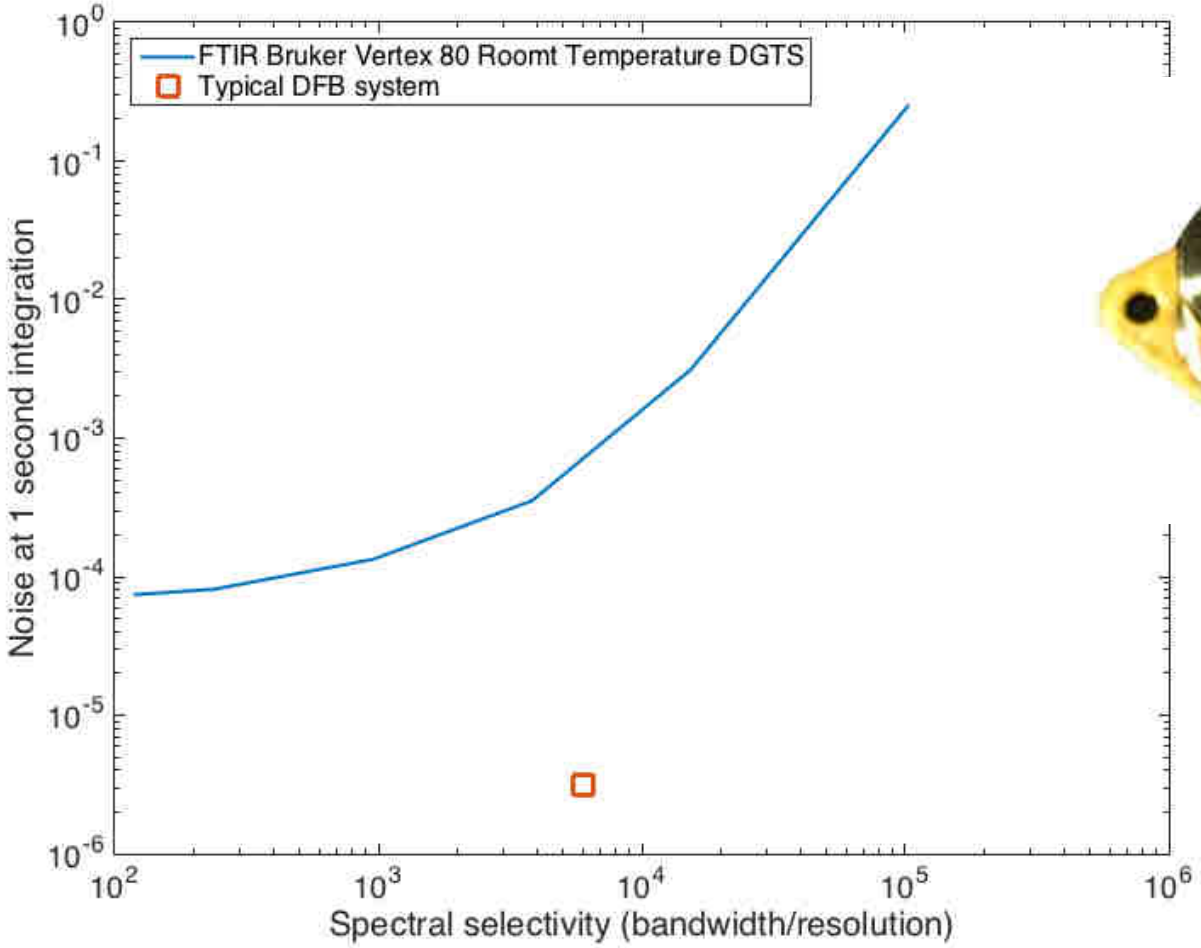
Selectivity vs. noise



FTIR selectivity vs noise



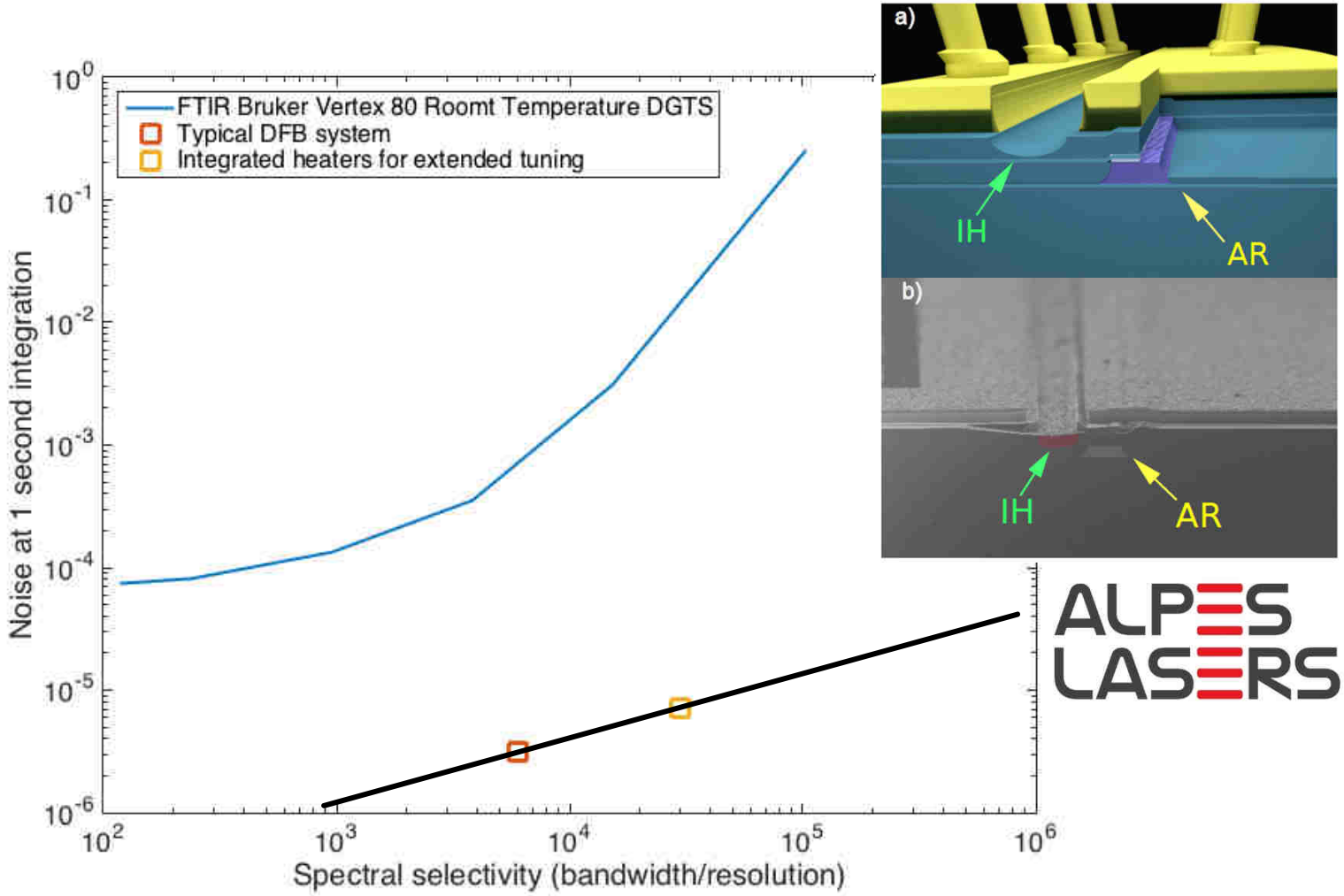
DFB QCL selectivity vs noise



TO-3

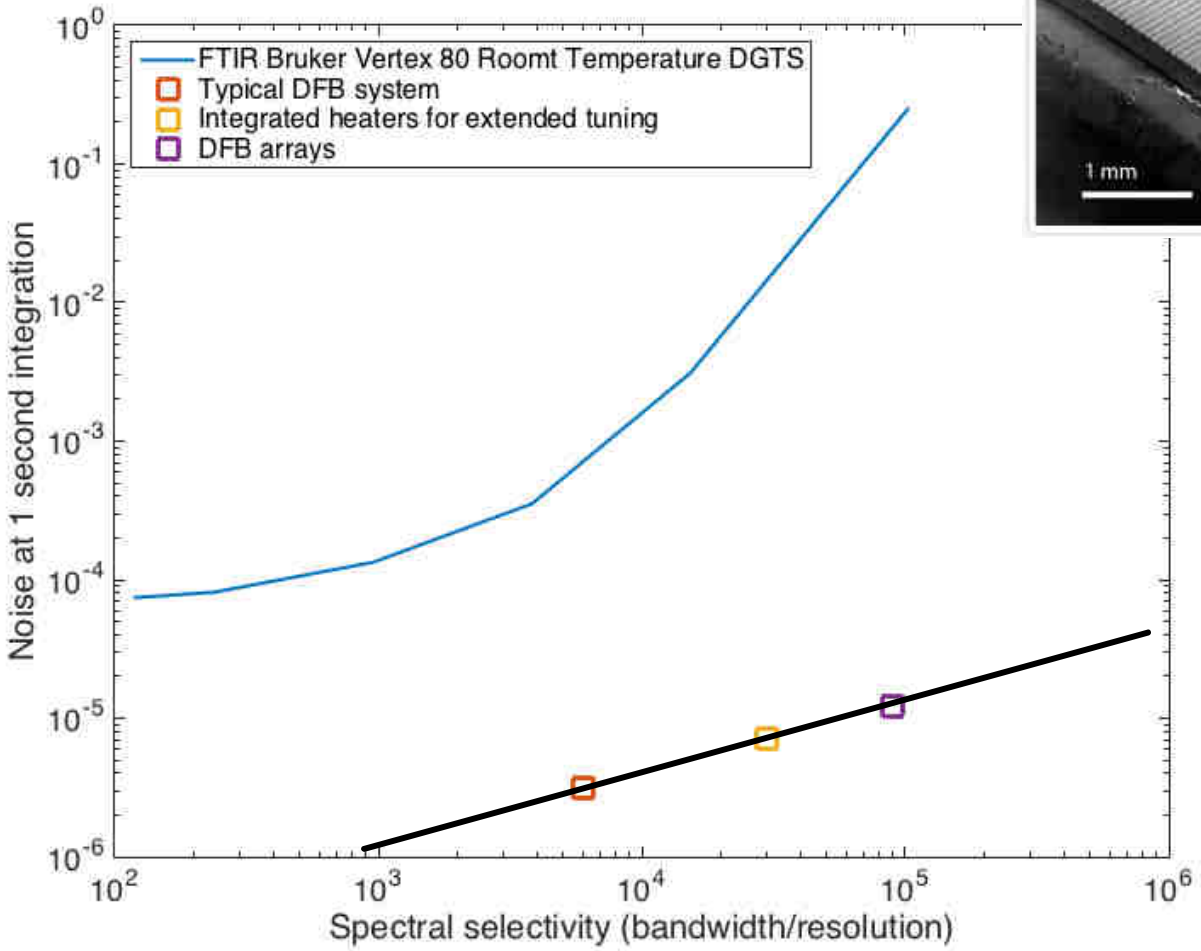
Fischer, M. et al *Optics Express* 22, no. 6 (March 24, 2014): 7014–27.

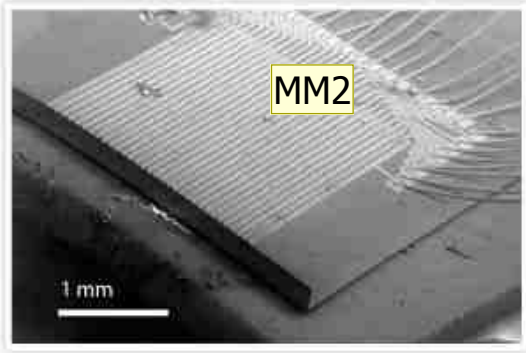
Extended tuning DFB-QCLs selectivity vs noise



Bismuto, Alfredo et al. *Optics Express* 23, no. 23 (November 16, 2015): 29715.

QCL arrays selectivity vs noise





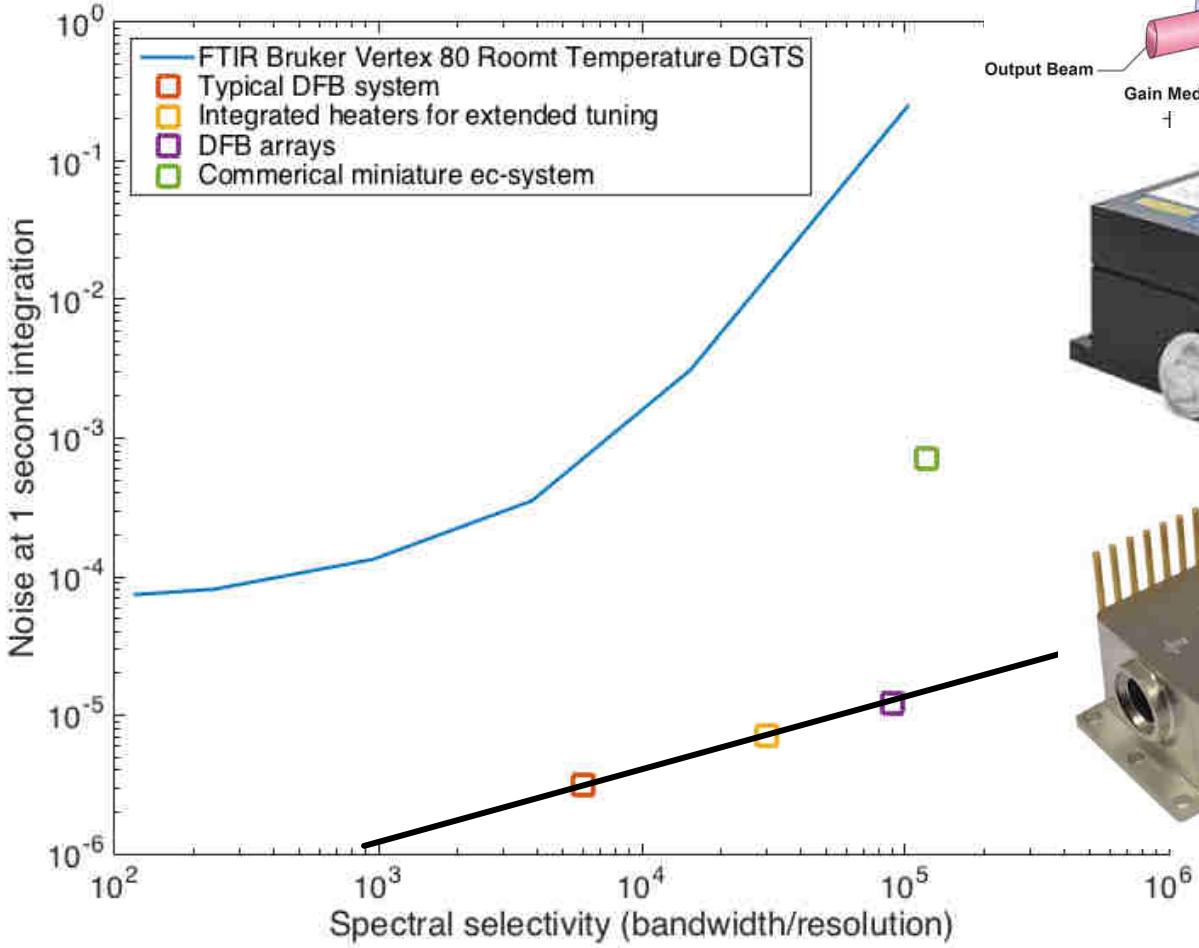
mir sense

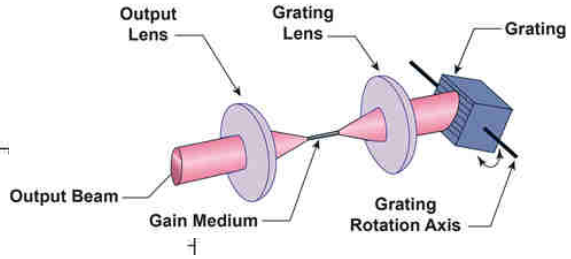
IRsweep

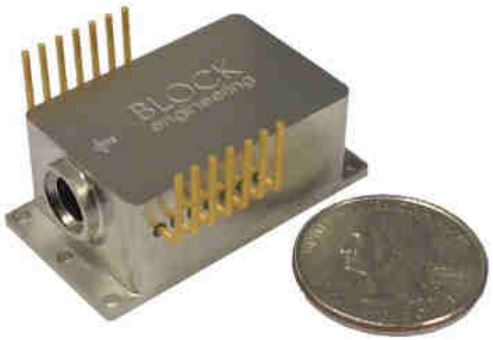
Folie 18

MM2 I would change order: 1. FTIR, 2. DFB, 3. heater, 4. array, 5 mini ec, 6 large ec
Markus Mangold; 29.03.2016

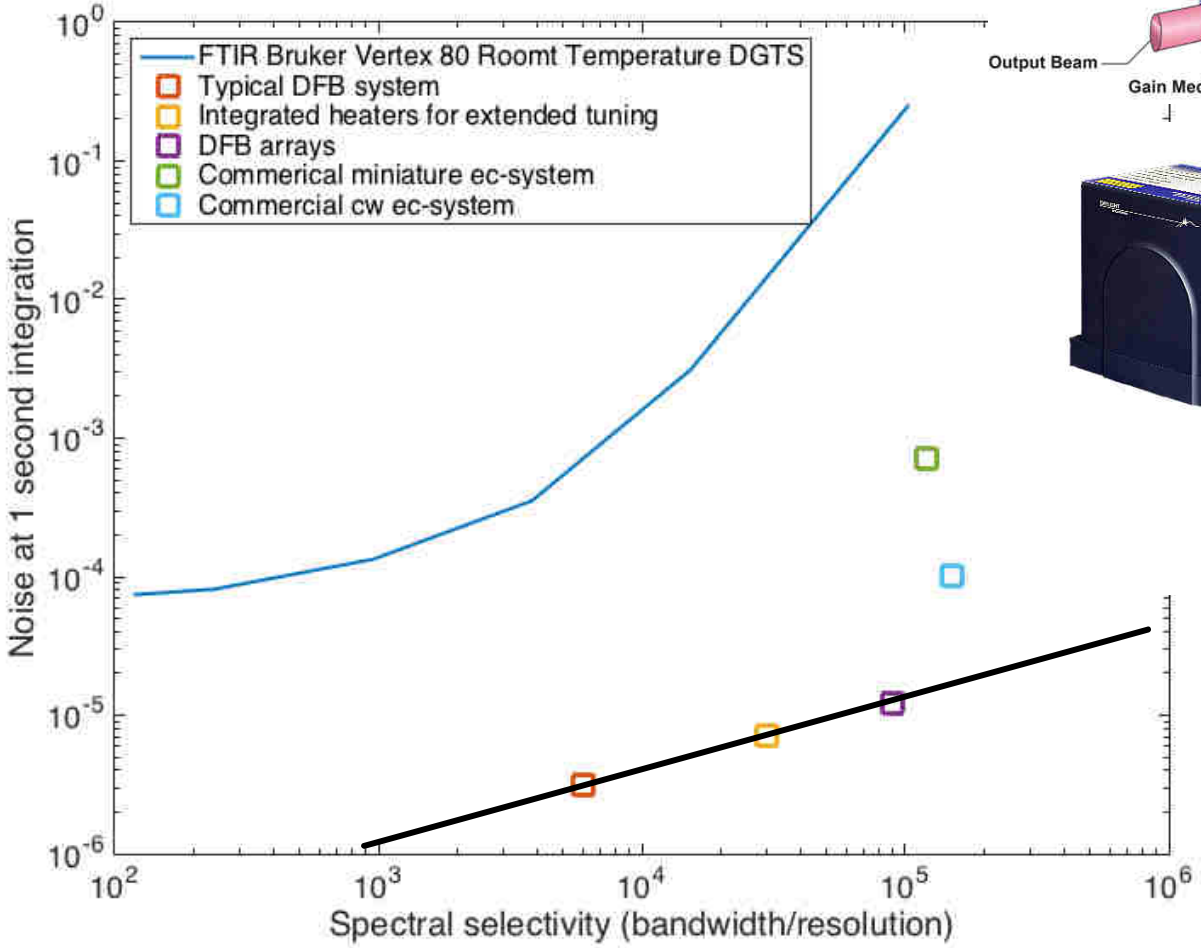
External-cavity QCLs selectivity vs noise

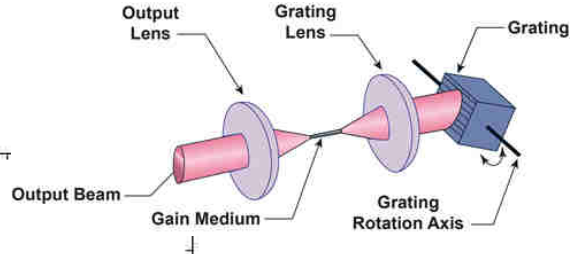




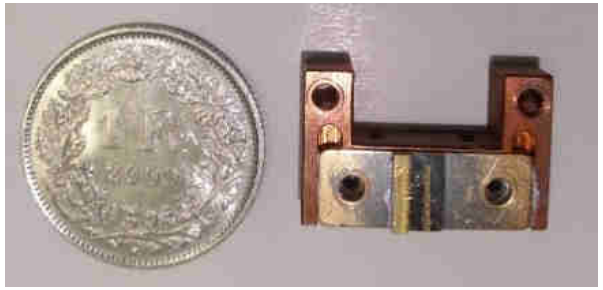


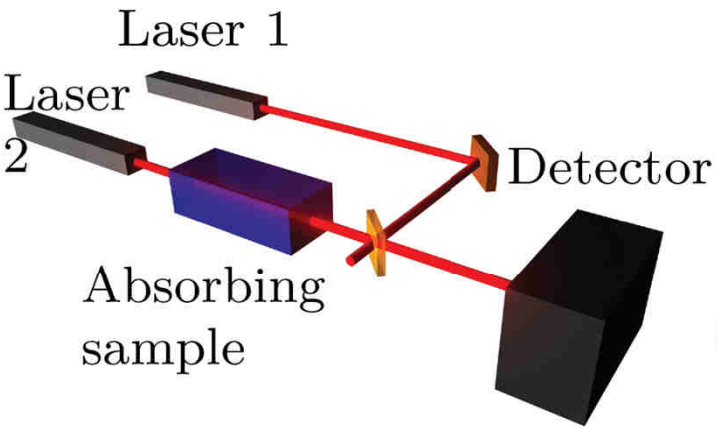
External-cavity QCLs selectivity vs noise

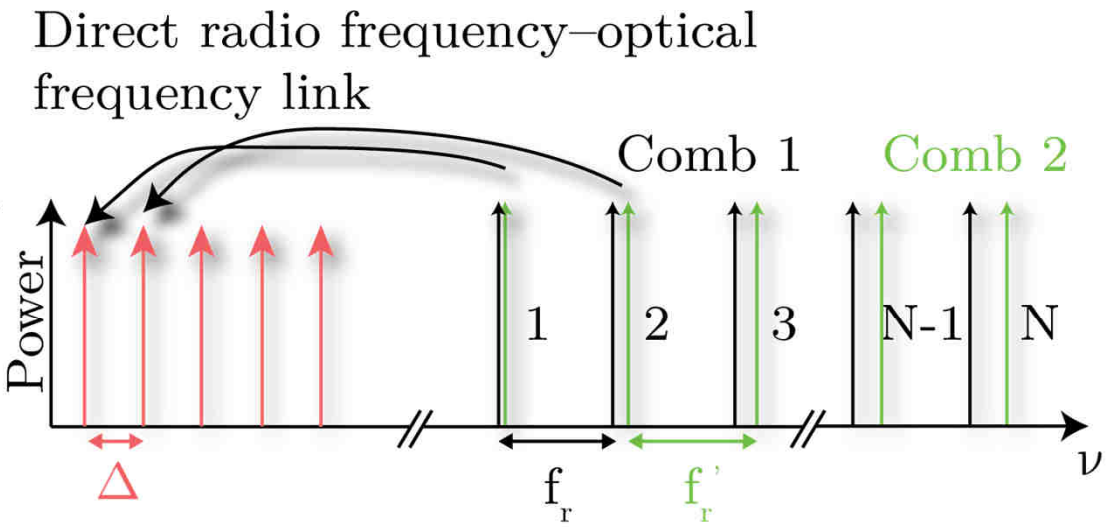




IRsweep approach
Dual-comb spectroscopy



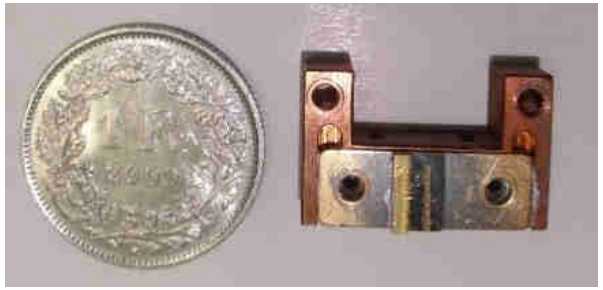


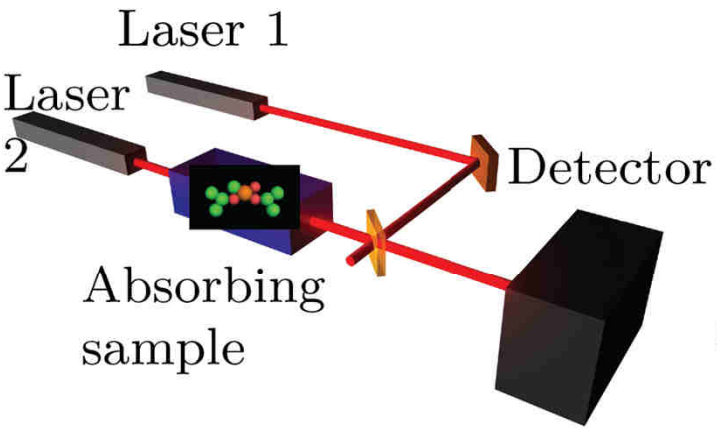


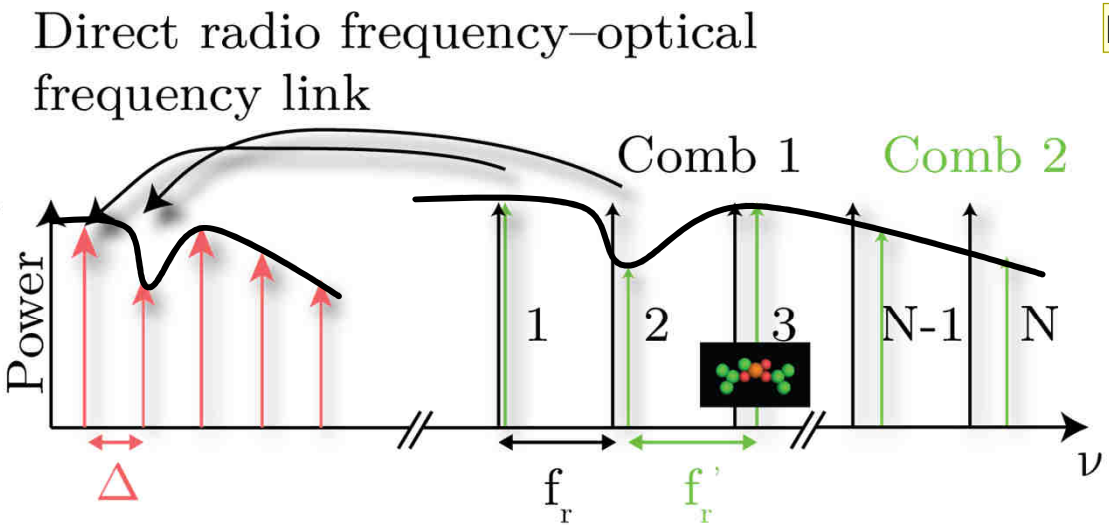
Hugi, Andreas, et al. “Mid-Infrared Frequency Comb Based on a Quantum Cascade Laser.” **Nature** 492, 2012 229.

S. Schiller, “Spectrometry with frequency combs,” **Opt Lett**, vol. 27, no. 9, pp. 766–768, 2002.

Dual-comb spectroscopy







S. Schiller, “Spectrometry with frequency combs,” Opt Lett, vol. 27, no. 9, pp. 766–768, 2002.
Keilmann, F., et al. Time-domain mid-infrared frequency-comb spectrometer. Opt. Lett. 29, 1542–1544 (2004).

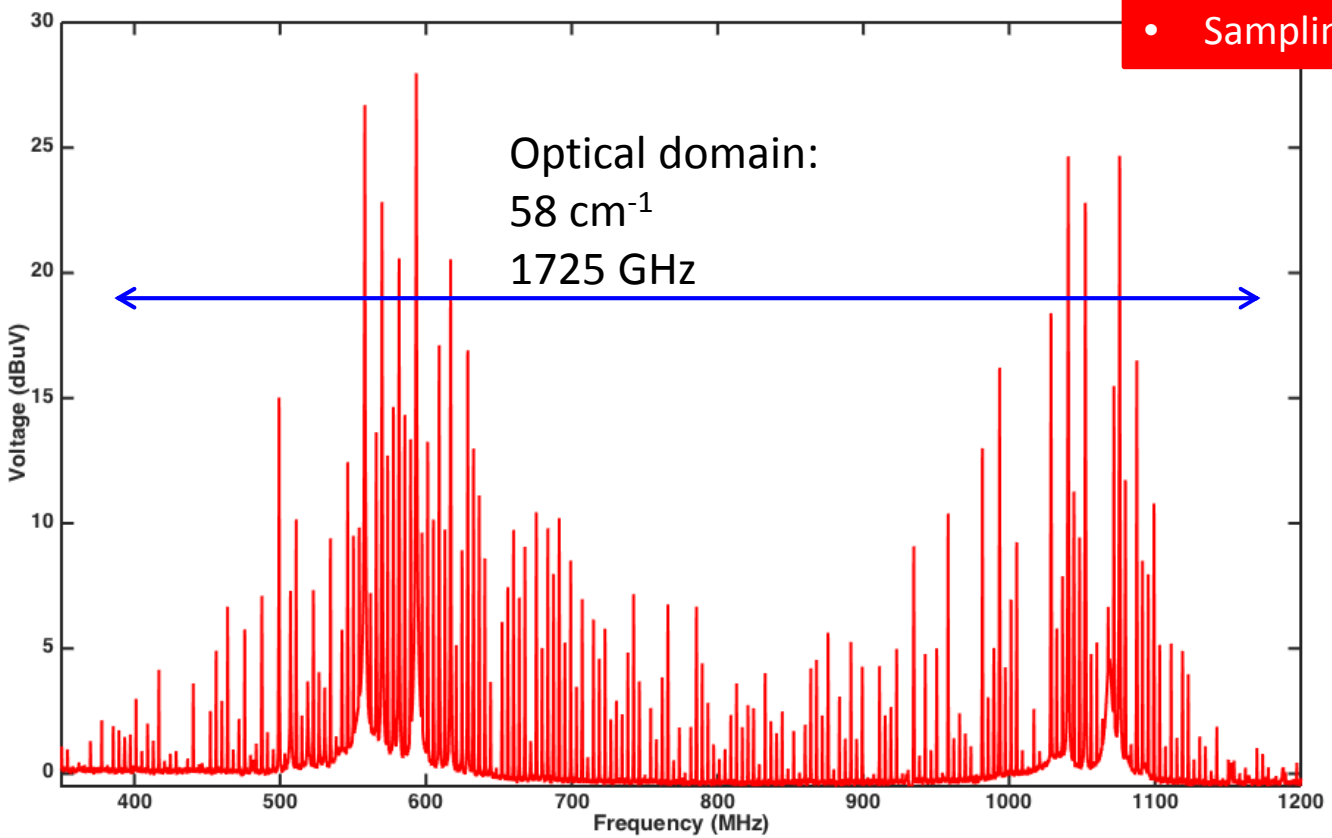
Coddington, W. Swann, and N. Newbury, “Coherent dual-comb spectroscopy at high signal-to-noise ratio," Phys. Rev. A 82, 043817 (2010).

Folie 22

MM1 Add absorption featureas as a line in the right hand figure part.
Markus Mangold; 29.03.2016

Spectrum

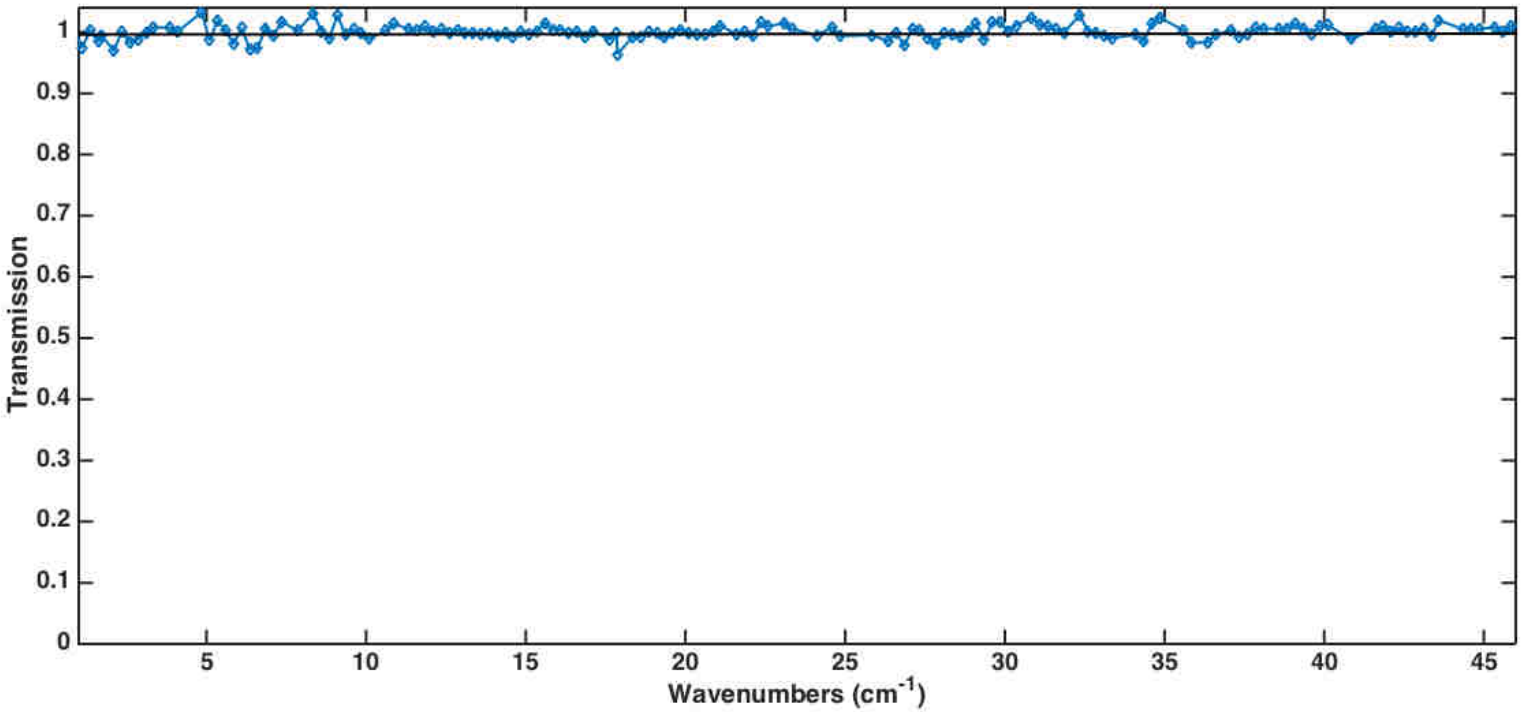
Important numbers:
- Lines = 230;
- Sampling = 0.25 cm^{-1}



30 conventional single mode DFB lasers

IRsweep

Baseline measurement IRspectrometer



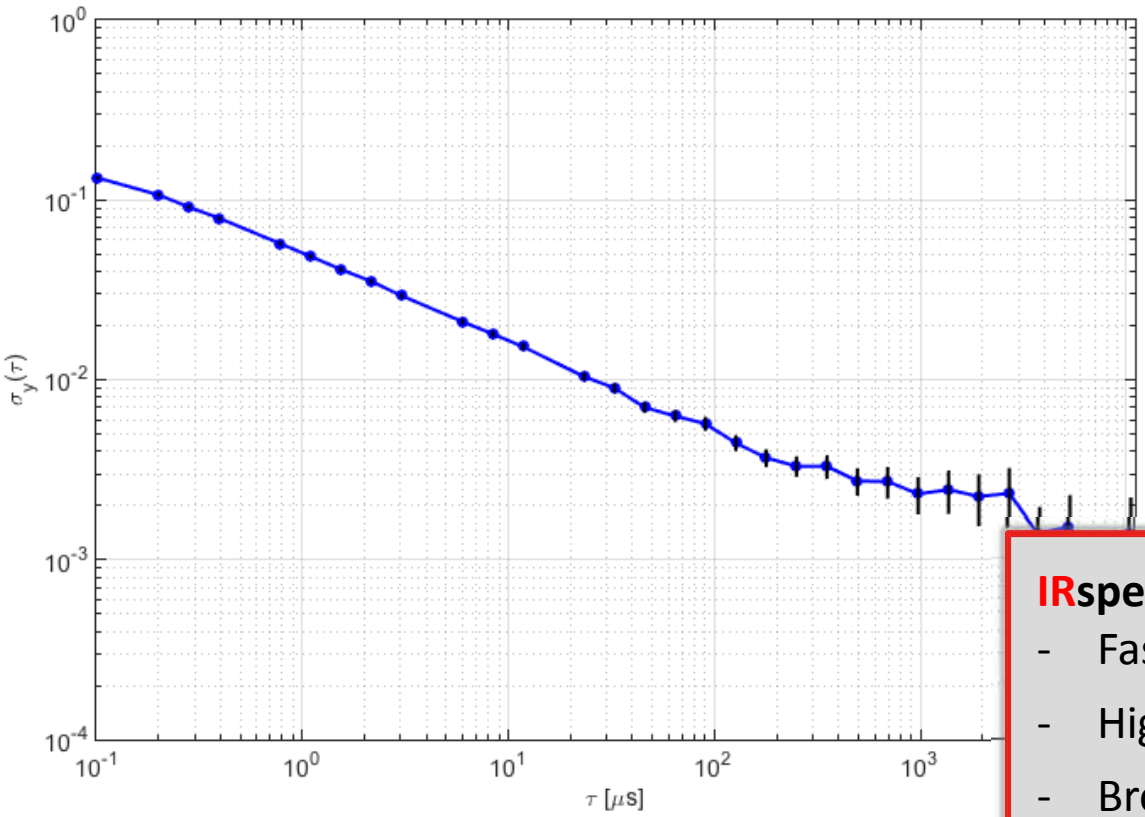
High power peaks:
SNR → ‰
Low power peaks:
SNR → %

Good performance
for broadband spectroscopy systems

Integration time = 25 ms
Bandwidth 45 cm^{-1}

IRsweep

Enhanced time-resolution - IRspectrometer



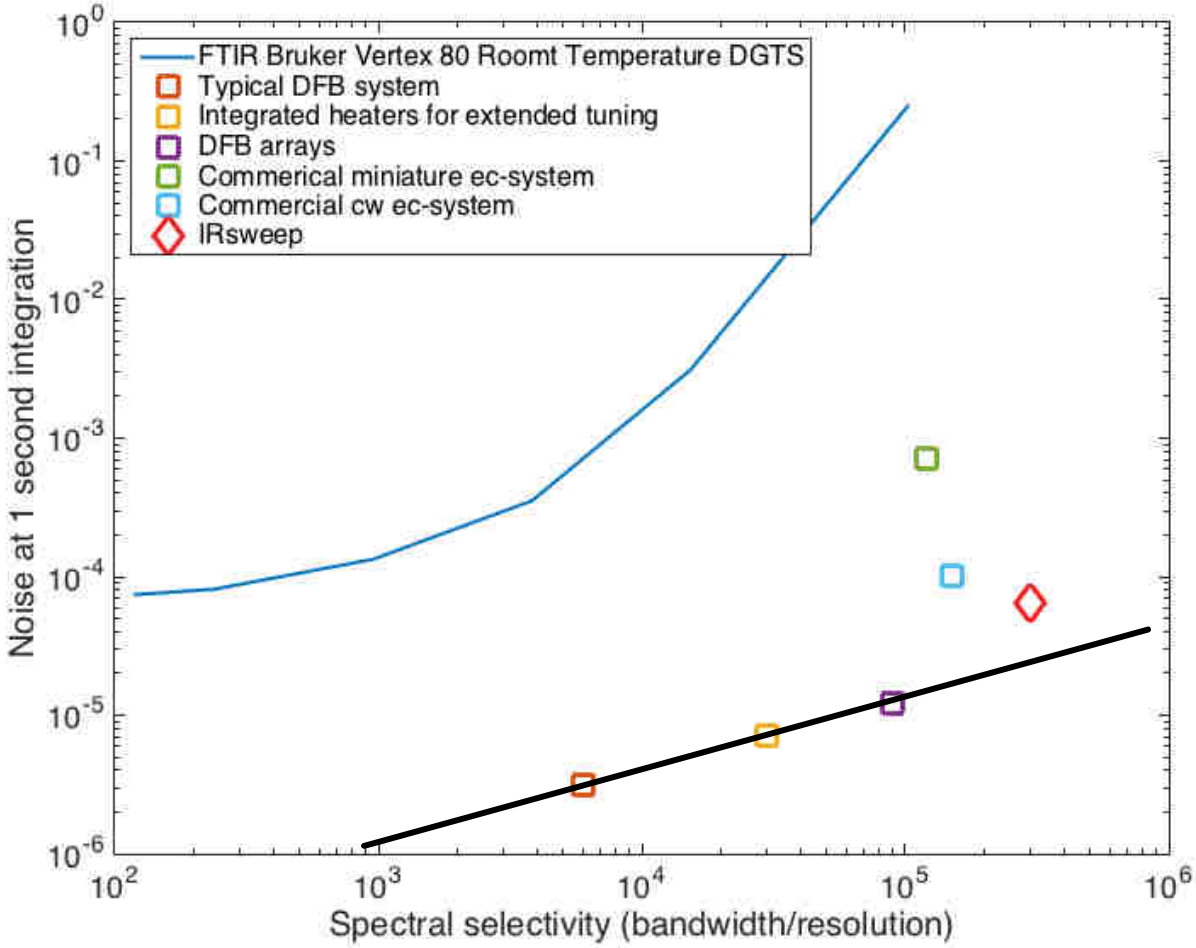
- **100 ns time** resolution over entire bandwidth
- **10 MHz repetition rate**
- Entire spectrum is acquired in parallel at this time-resolution

IRspectrometer

- Fast time-resolution (µs) ✓
- High brightness (laser) ✓
- Broadband (100 cm^{-1}) ✓
- High resolution (MHz) ✓

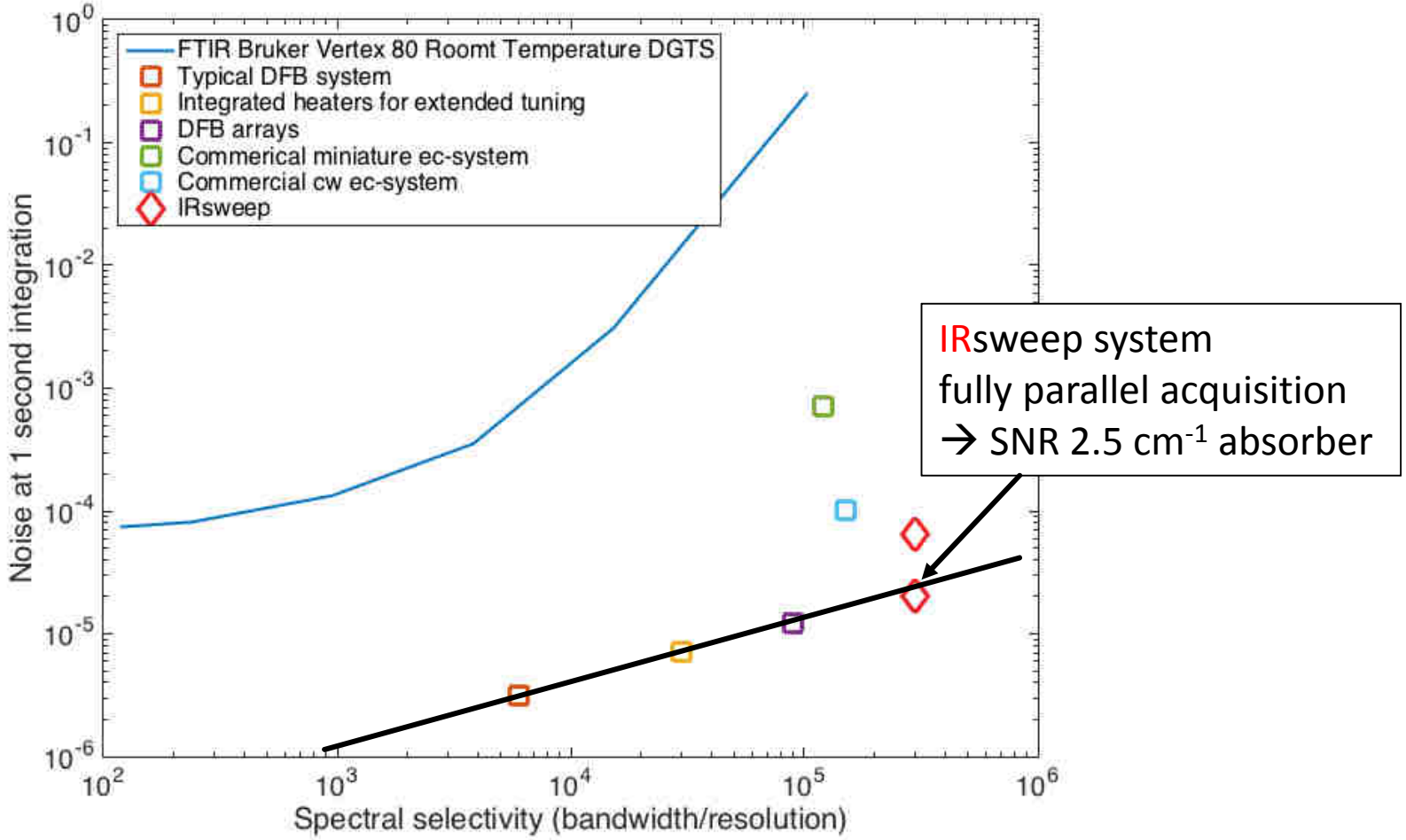
IRsweep

IRsweep selectivity vs noise

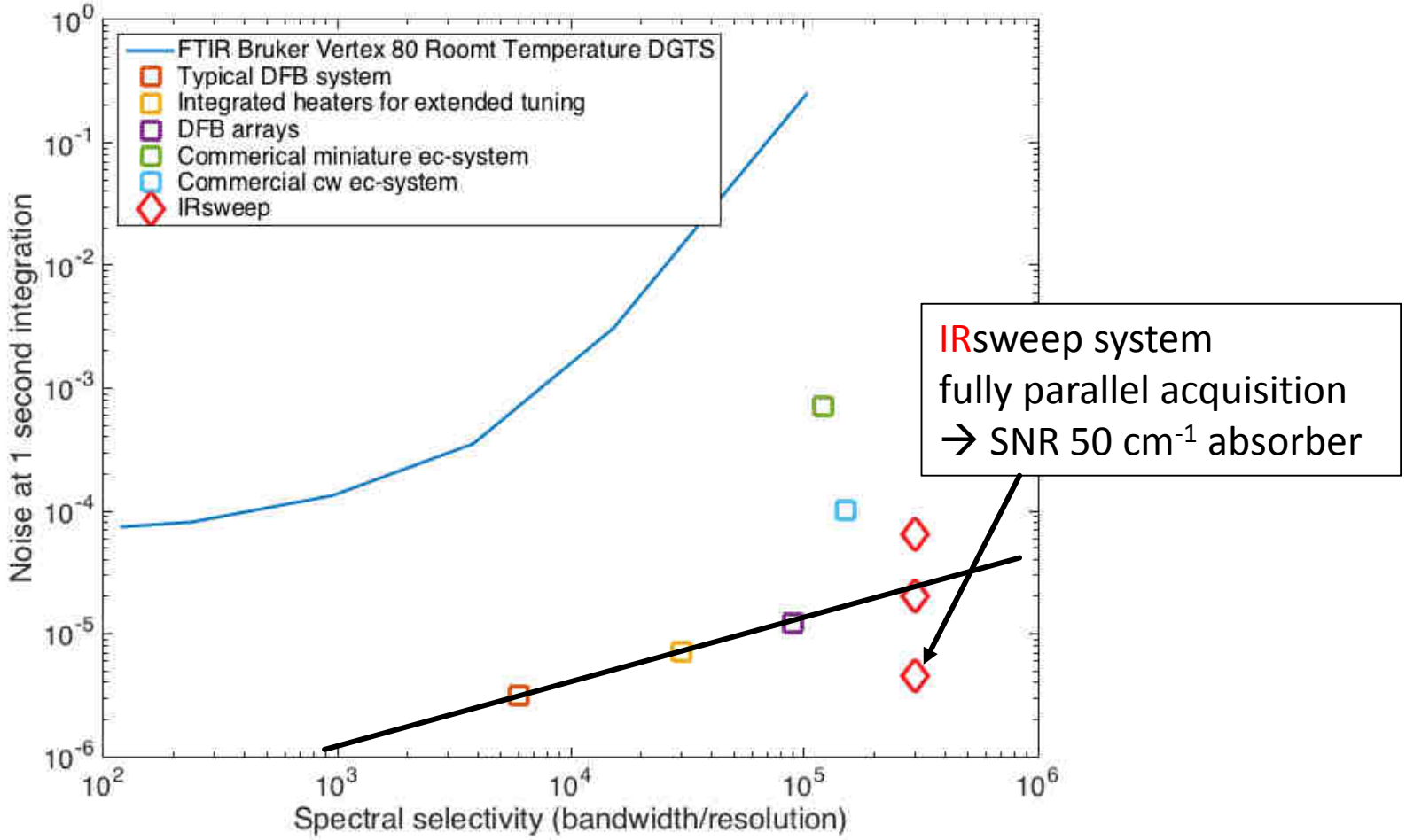


IRsweep

IRsweep selectivity vs noise



IRsweep selectivity vs noise



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