Quantum cascade laser as local oscillator: Experiences from GREAT and upGREAT

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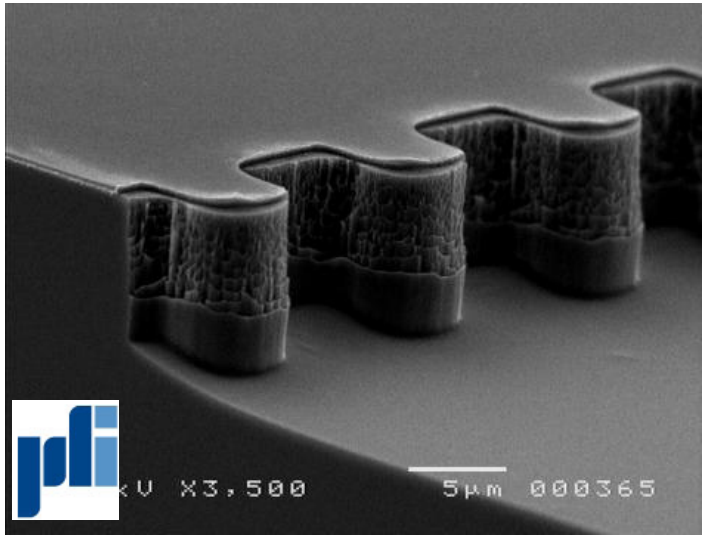
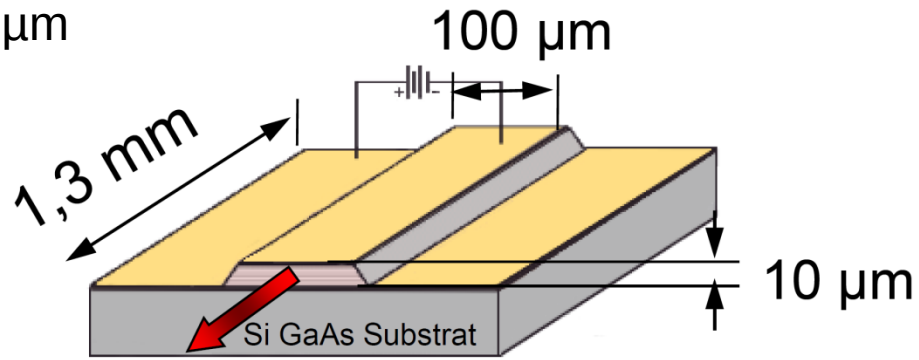
Outline

- The GREAT 4.7 THz QCL-LO
- The upGREAT 4.7 THz QCL LO
- New „high power“ QCLs

QCL with lateral DFB grating

- QCL fabricated at Paul-Drude Institut, Berlin
- Surface-plasmon waveguide
- Lateral, first order DFB grating
- Bragg wavelength: $\lambda_B = 2\,\Lambda\,n\,/m$
- Λ = 8.46 µm, *n* effective refractive index, *m* grating order
- Width of wide/narrow ridge: 92/80 µm
- Ridge length: 1.3 mm
- Grating fabricated by dry etching
- Facets as cleaved

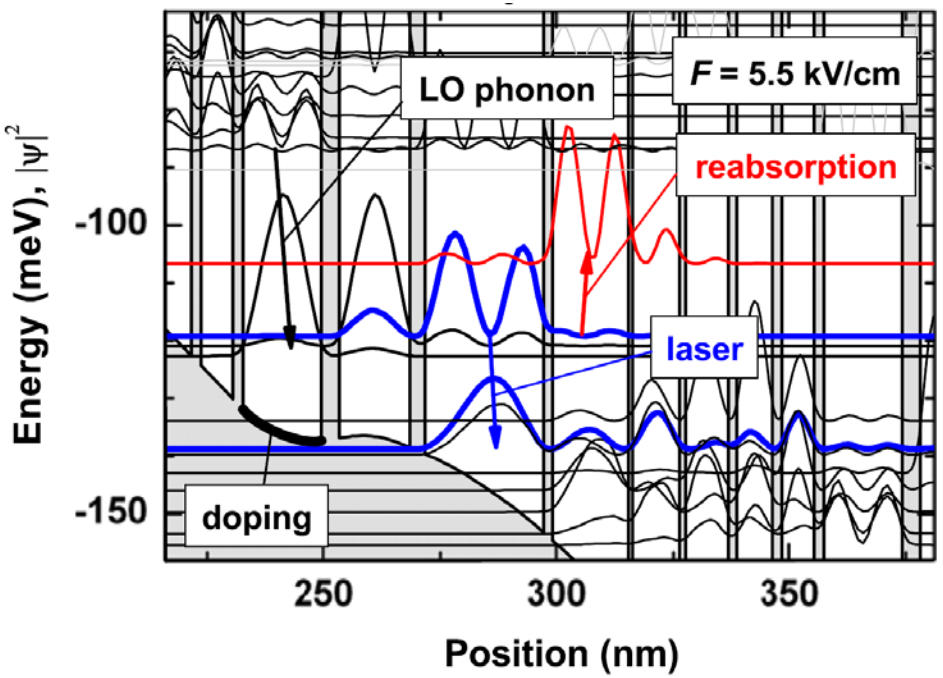


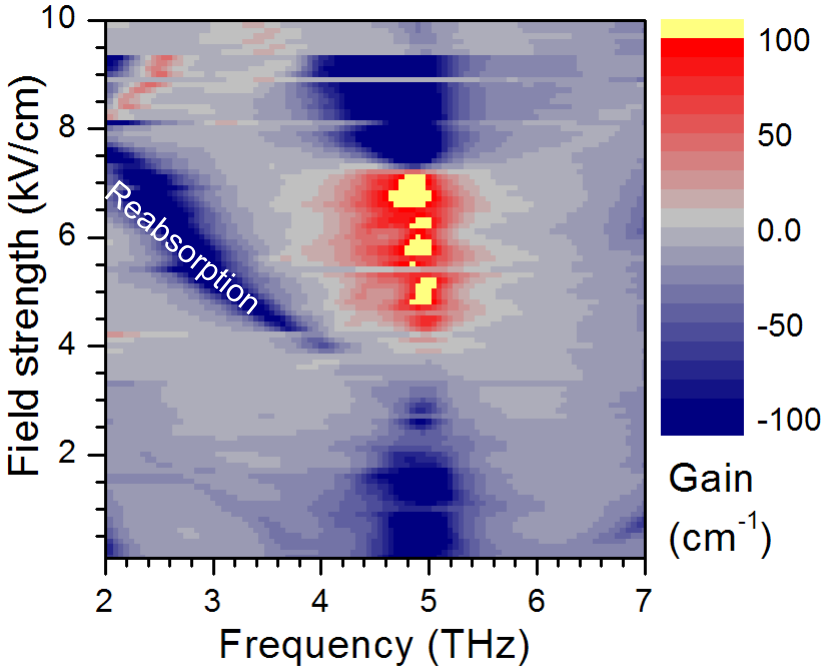


L. Schrottke et al., Semicond. Sci. Technol. **28**, 035011 (2013)

DLR

Active medium

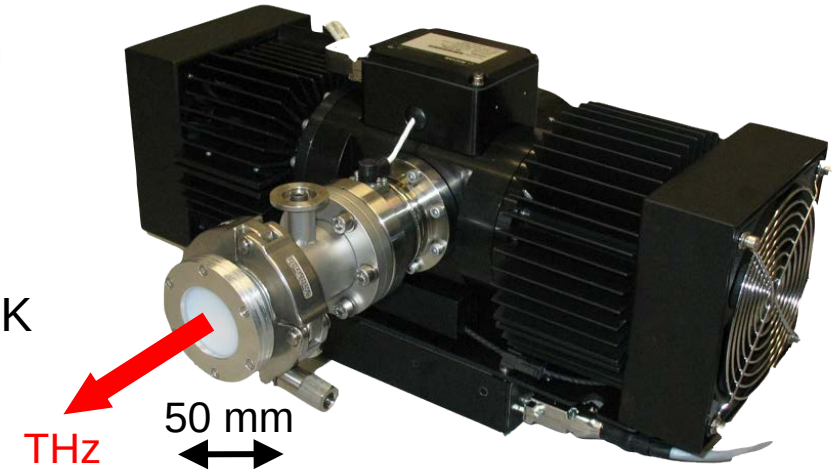


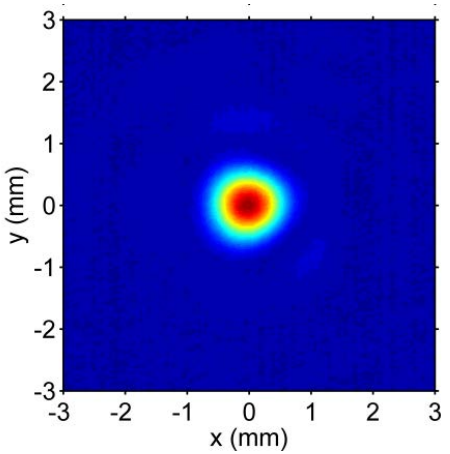


L. Schrottke et al., Semicond. Sci. Technol. **28**, 035011 (2013)

Operation in a cryocooler

- Twin-piston, linear-integrated Stirling cooler operating with a 45 Hz cycle
- Dynamically balanced in order to minimize mechanical vibrations
- Nominal cooling capacity: 7 W at 65 K for an ambient temperature of 23°C
- Weight: 9.5 kg
- Power supply: 2.6 kg, 10.2×13.0×33.6 cm^3
- Electrical input power <240 W

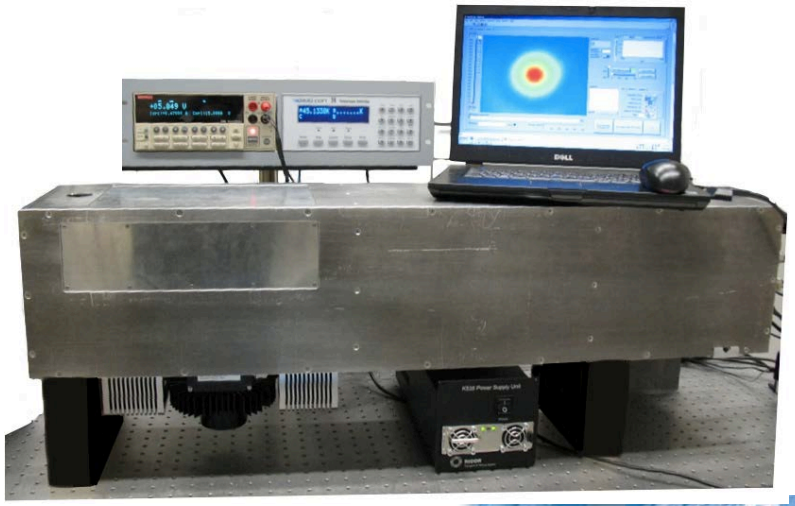




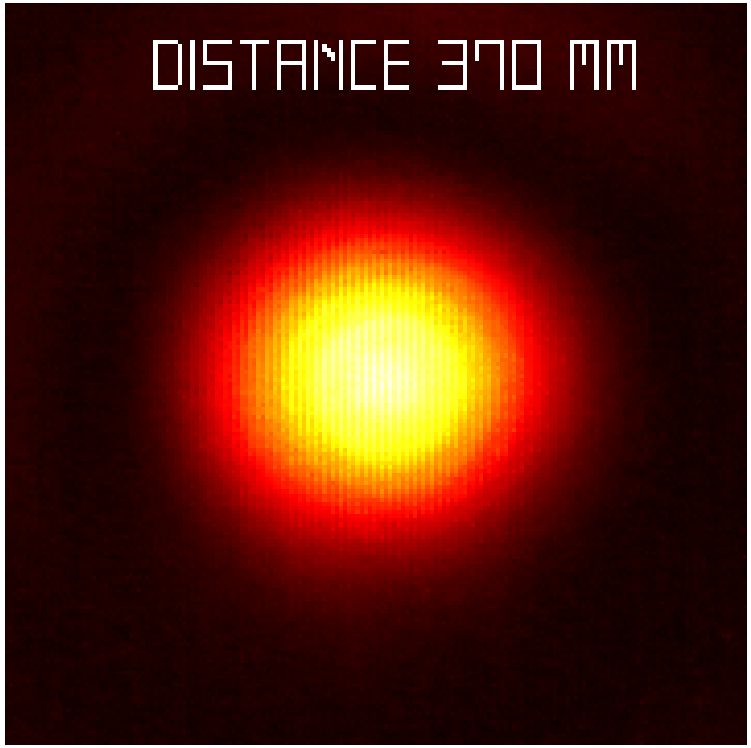
H. Richter et al., Optics Express **18**, 10177 (2010)

The GREAT 4.7-THz LO

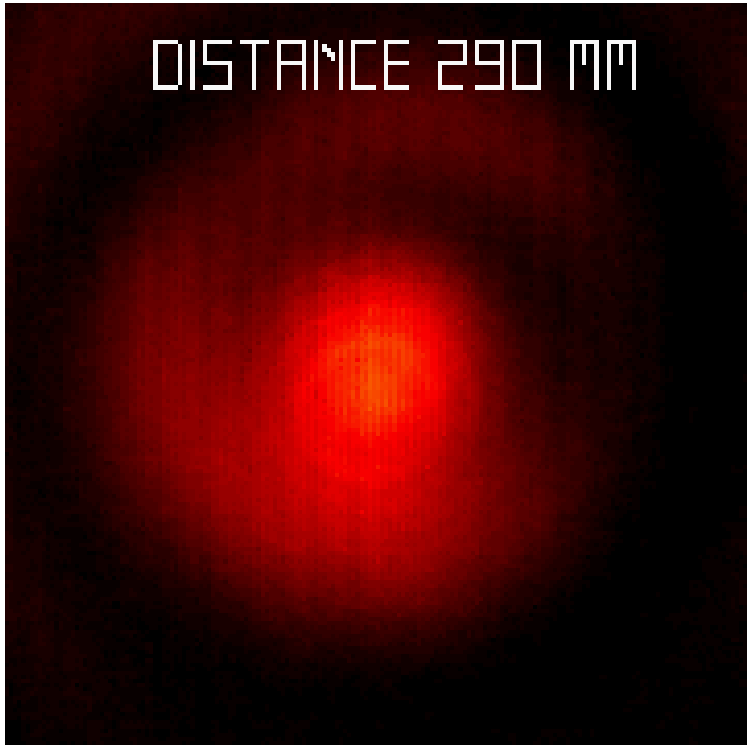
- 4.7-THz QCL with lateral DFB grating
- Single mode emission
- Tunable from approx. -2 to +4 GHz around the OI rest frequency
- Almost fundamental Gaussian mode
- About 120µW power at the OI frequency
- 16 successful flights from May 2014 until July 2016



Beam profiles



Beam profile @ waist



Size: 4.5 mm x 4.5 mm

M^2: approx. 1.3

H. Richter et al., APL 93, 141108 (2008)
H. Richter et al., JIMT 35, 686 (2014)

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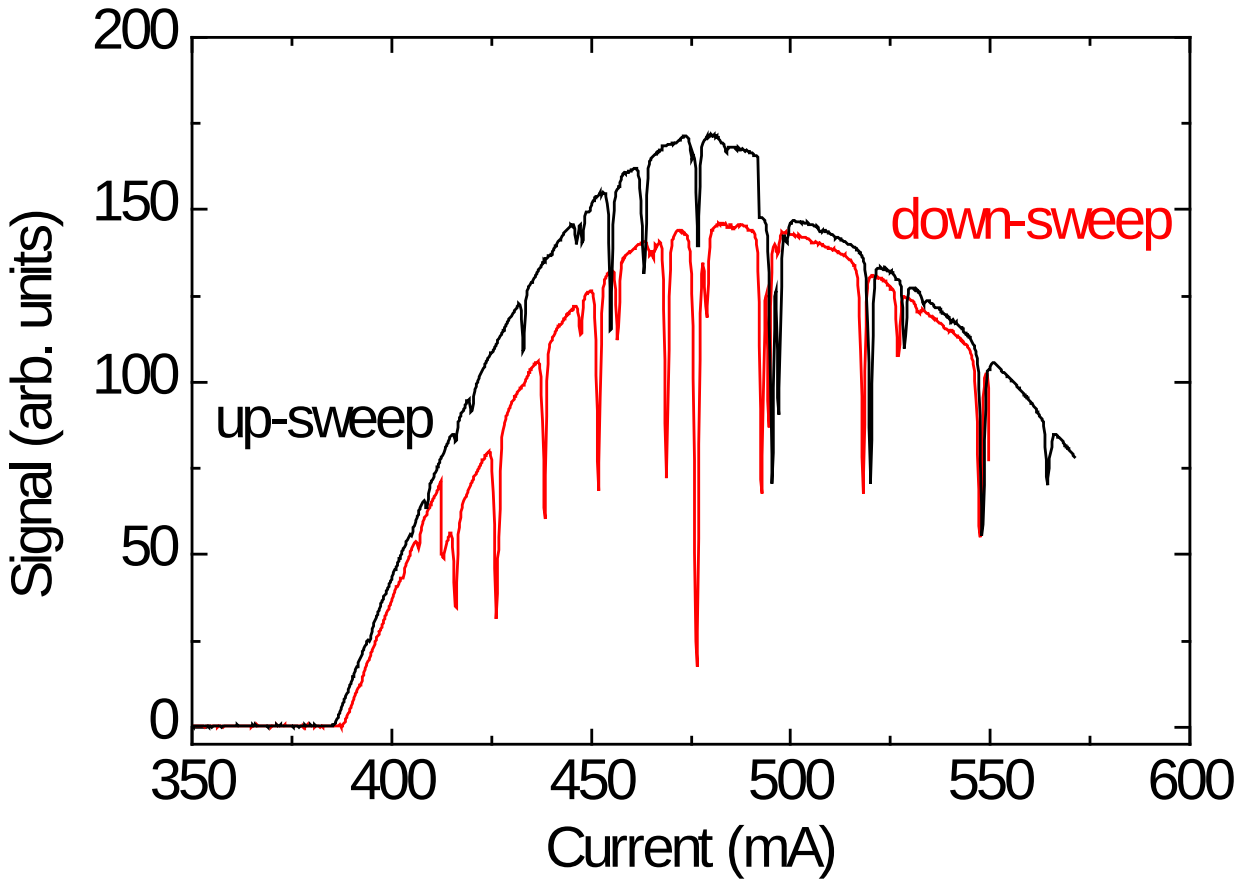
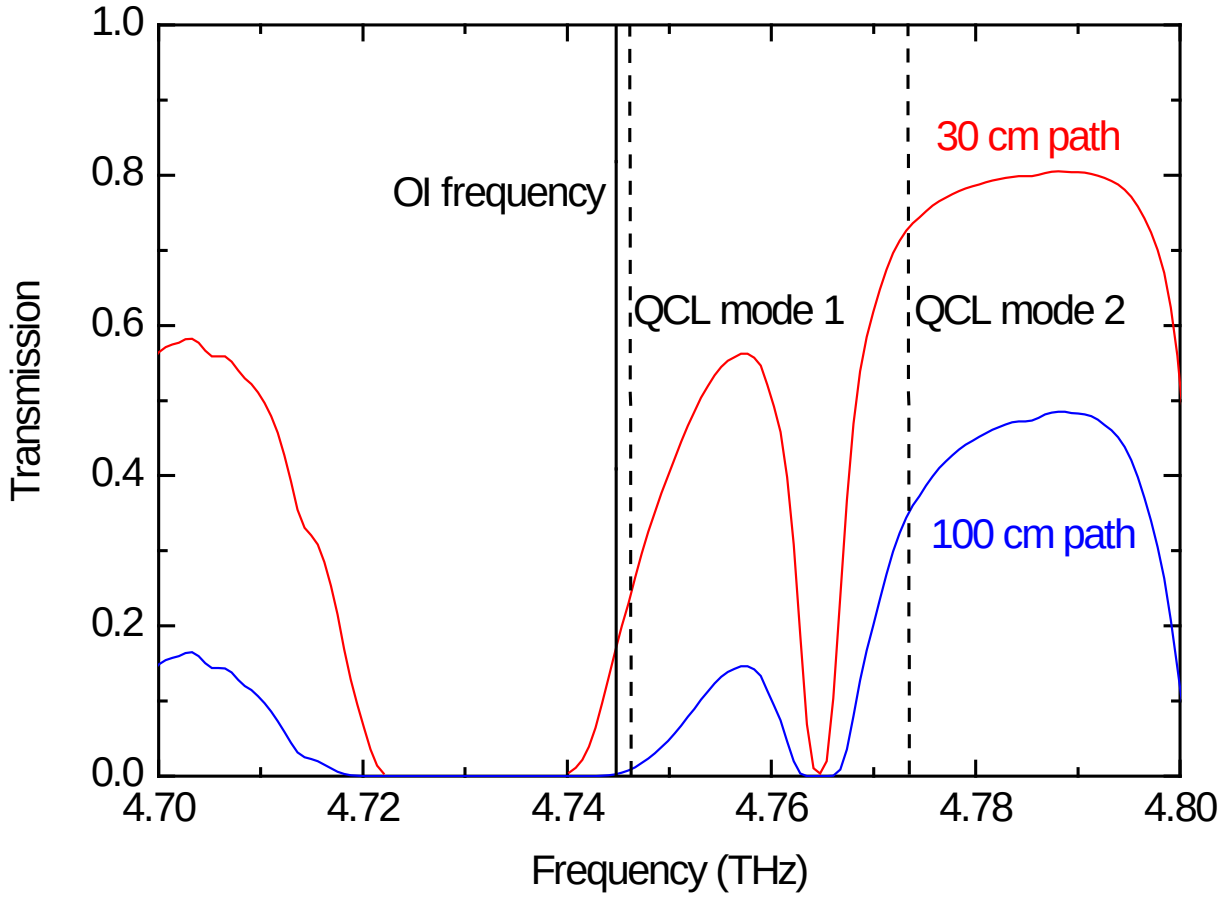
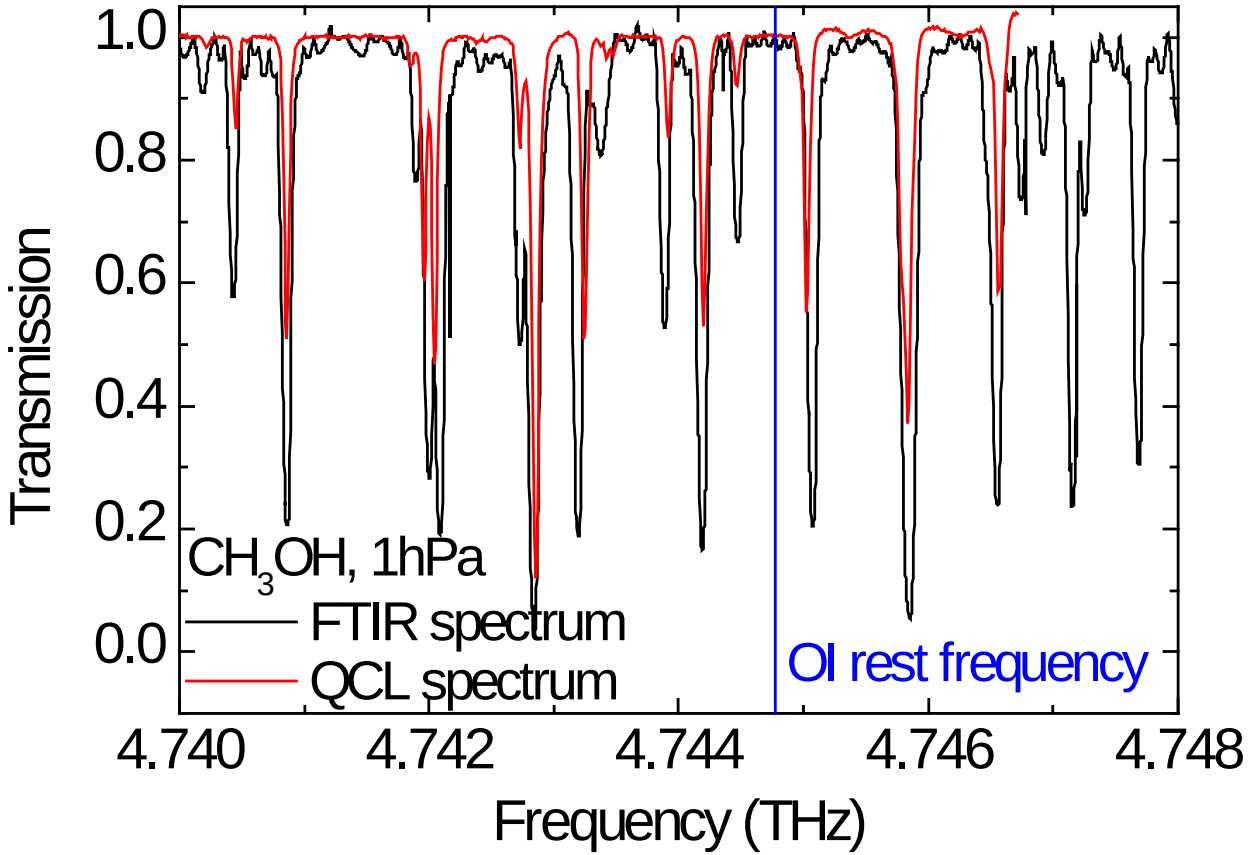
Frequency calibration



QCL modes and atmospheric transmission

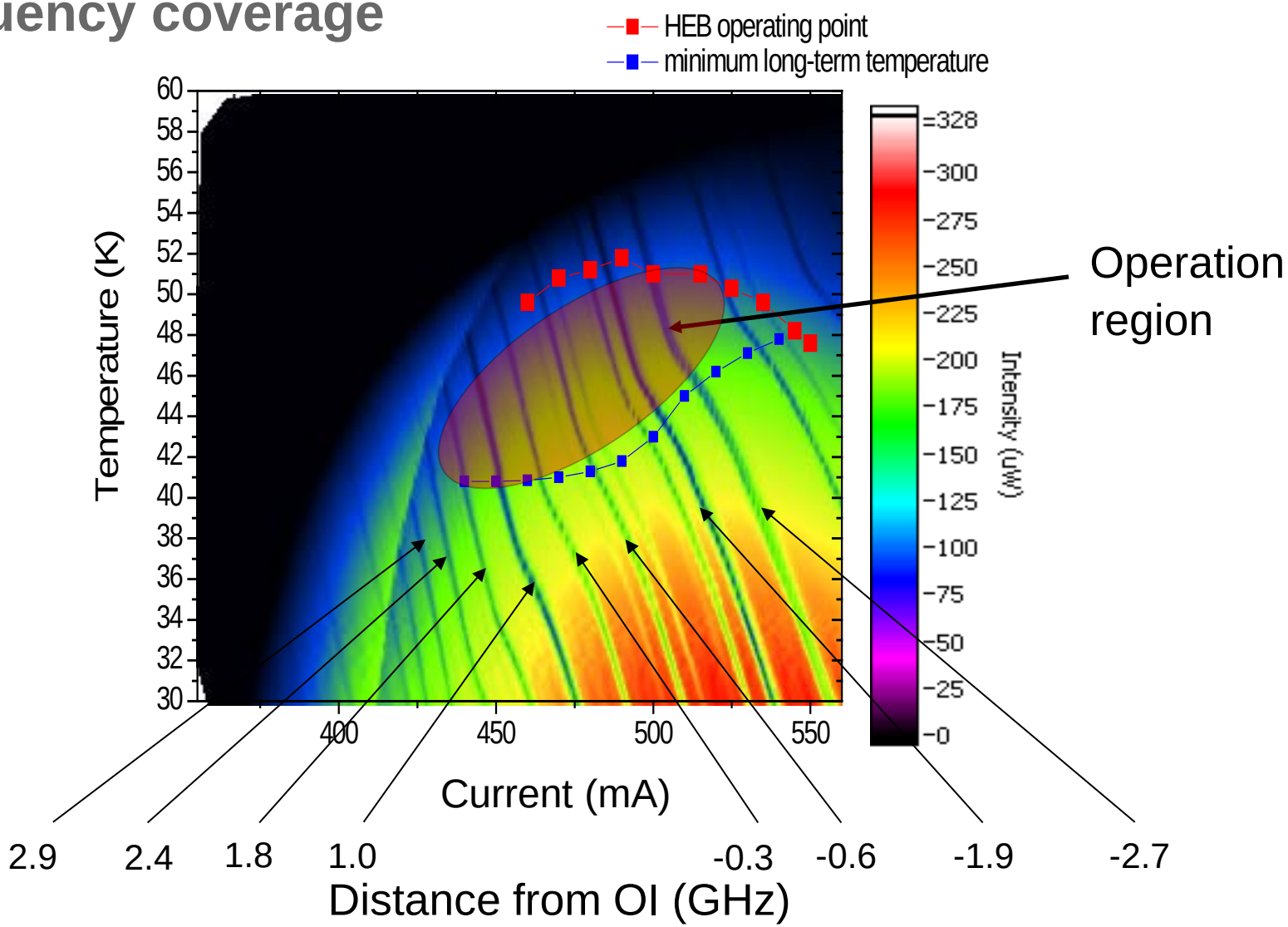


Frequency calibration



Frequency coverage: +2GHz to -4GHz around the OI rest frequency

Frequency coverage



H. Richter et al., IEEE Terahertz Science and Technol. 5, 539 (2015)

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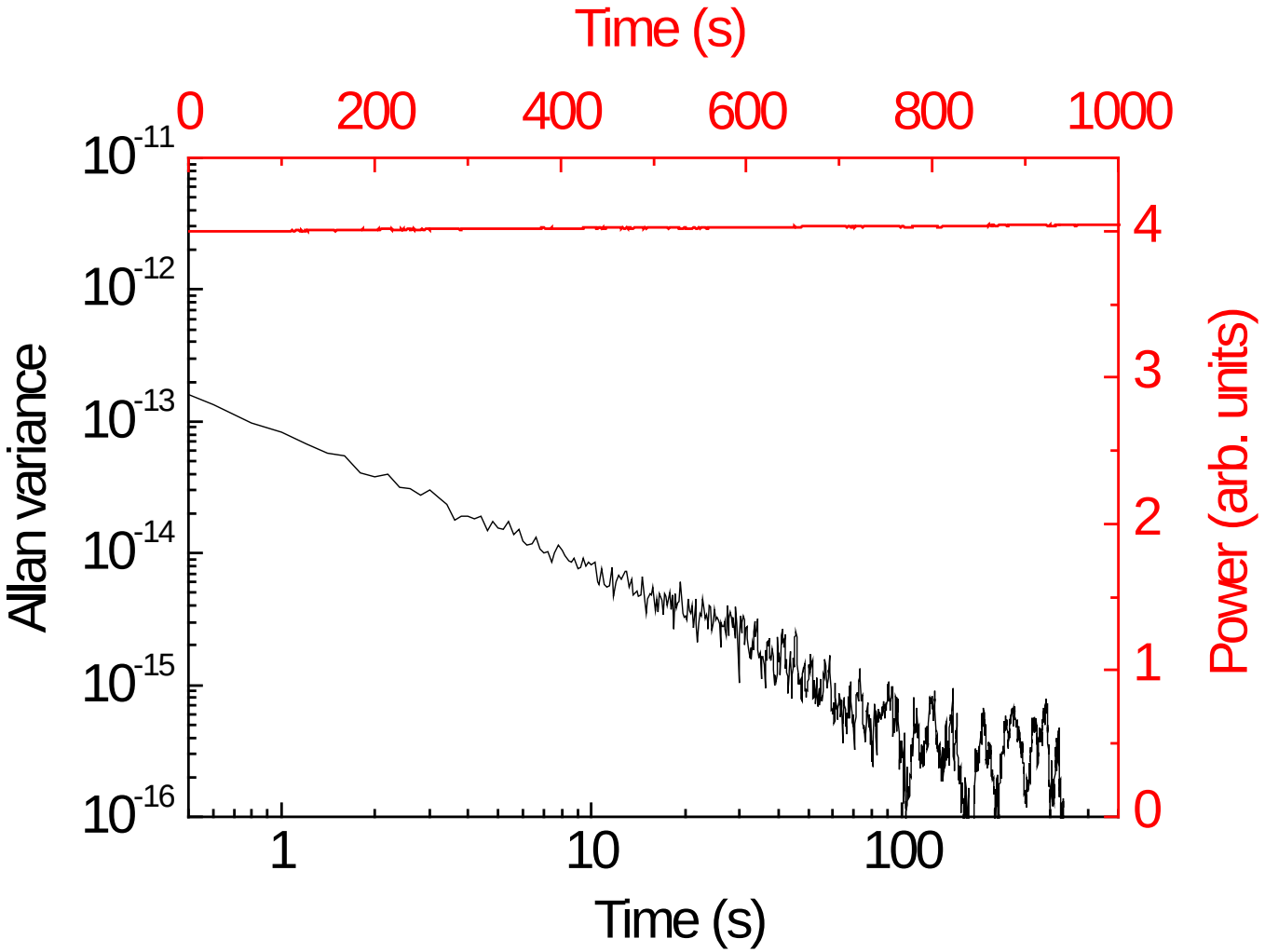
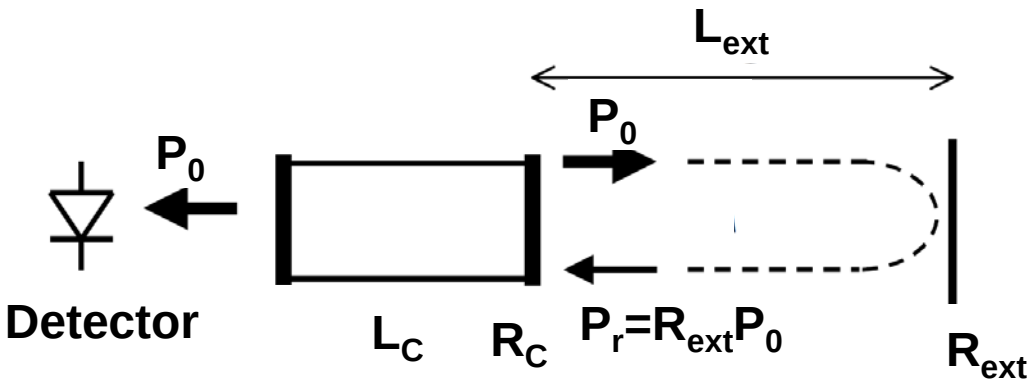
Power stability



Standing waves and QCL -> optical feedback



Theory of Lang and Kobayashi (originally for laser diodes)

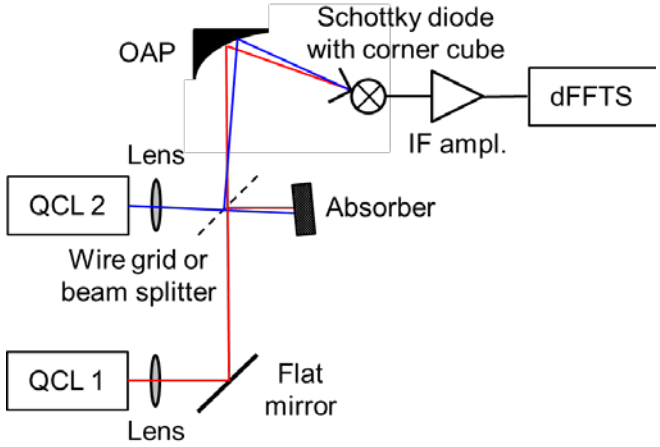
- Frequency shift $2\pi(\nu_0 - \nu)\tau_{\text{ext}} = C\sin[2\pi\nu\tau_{\text{ext}} - \arctan(\alpha)]$
- Feedback parameter $C = \varepsilon\sqrt{R_{\text{ext}}}\,\frac{(1-R_C)}{\sqrt{R_C}}\,\frac{L_{\text{ext}}}{n_c L_C}\sqrt{1+\alpha^2}$
- Weak feedback: C < 1

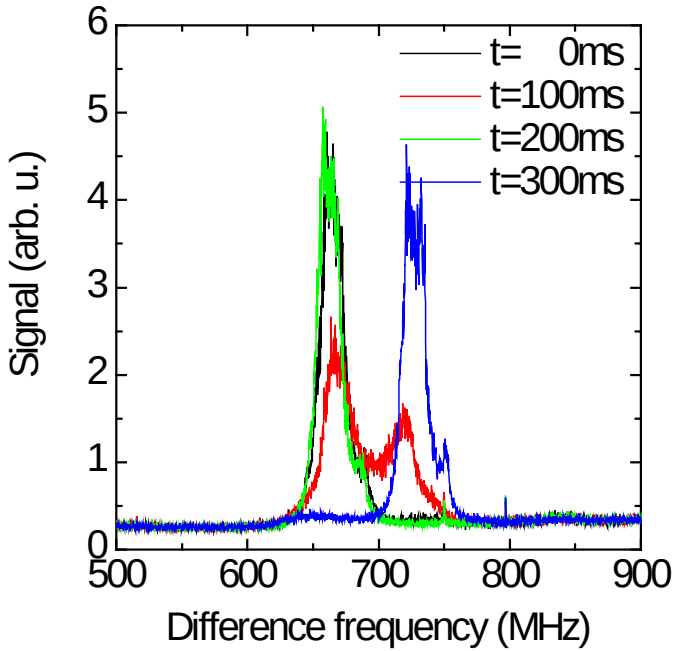
R. Lang and K. Kobayashi, IEEE J. Quantum Electron. **16**, 347 (1980)
G. Giuliani et al., J. Opt. A: Pure Appl. Opt. **4**, S283 (2002)

Feedback power & frequency shift

$$C = \varepsilon\sqrt{R_{\text{ext}}}\,\frac{(1-R_C)}{\sqrt{R_C}}\,\frac{L_{\text{ext}}}{n_c L_C}\sqrt{1+\alpha^2}$$

- Typical values: C =0.9, L_C = 1.4 mm, L_{ext} = 0.8 m, R_C = 0.33, n_C = 3.74
- Field: $\varepsilon\sqrt{R_{\text{ext}}} = 3.8 \times 10^{-3}$
- Power: 1.4×10^{-5}
- Note: This small fraction changes the emission frequency by up to 70 MHz.

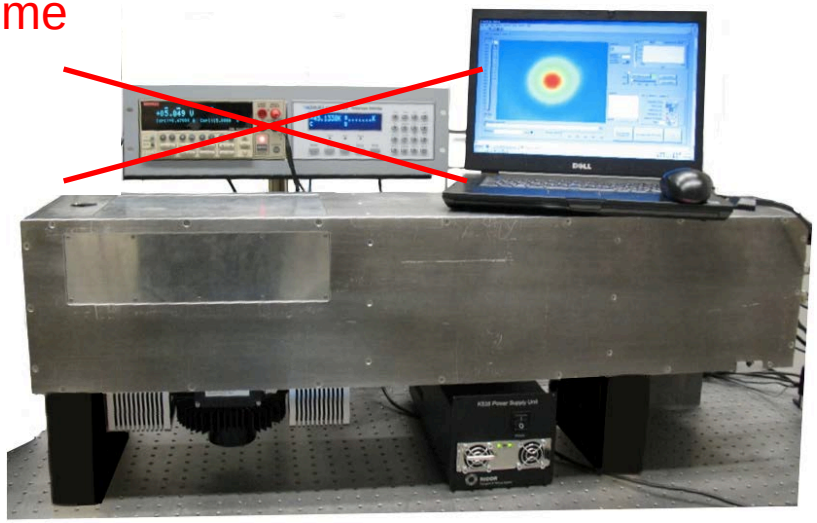




accepted for publication in J. Sel. Topics in Quant. Electr. (2017)

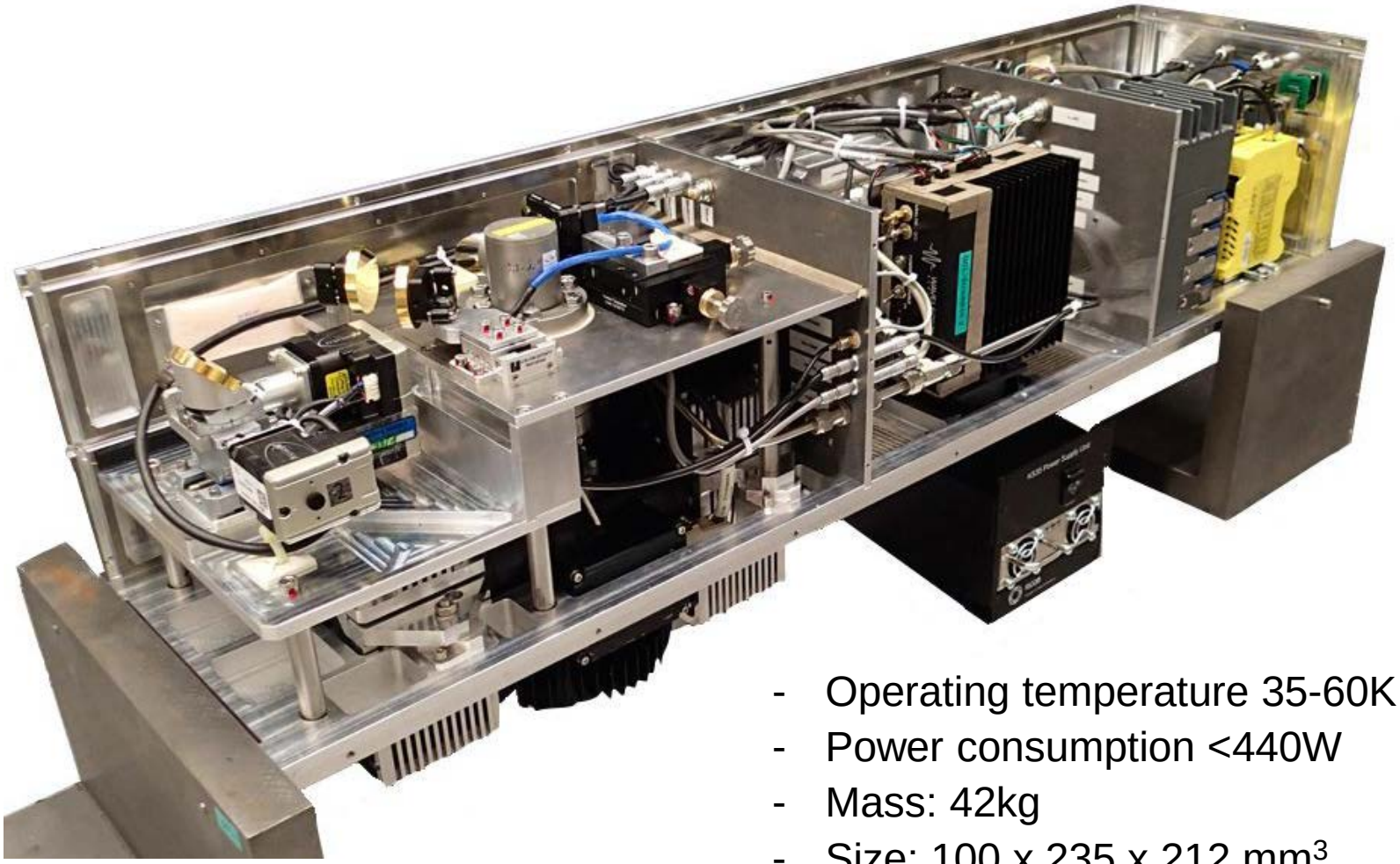
The GREAT 4.7-THz QCL local oscillator

- Objective: OI atomic fine structure line
- 4.7-THz QCL with lateral DFB grating
- Single mode emission
- Tunable from approx. -2 to +4 GHz around the OI rest frequency
- Almost fundamental Gaussian mode
- About 120µW power at OI frequency upGREAT: >1mW for 7 pixel
- 16 successful flights from May 2014 until July 2016
- upGREAT: reduced mass and volume
- First light: Oct. 2016



H. Richter et al., THz Science and Technol. **5**, 539 (2015)

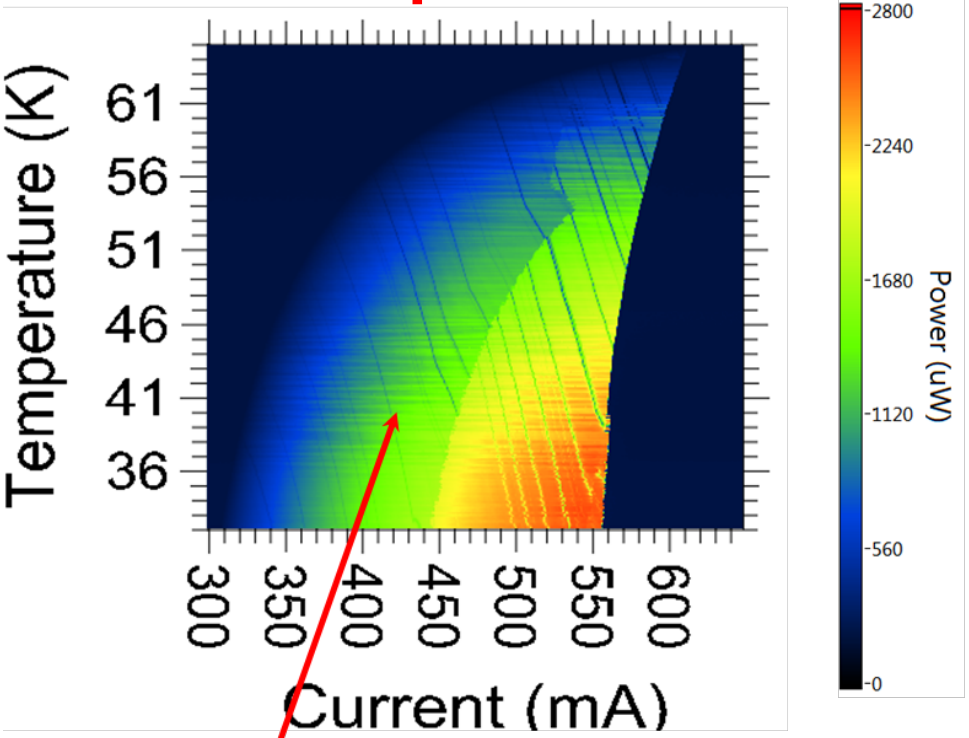
The upGREAT 4.7-THz local oscillator



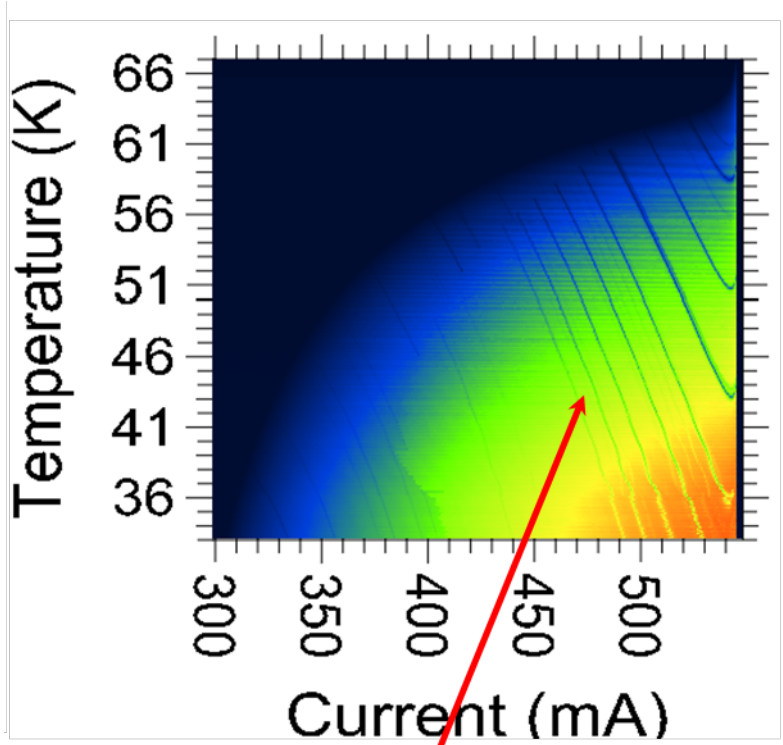
- Operating temperature 35-60K
- Power consumption <440W
- Mass: 42kg
- Size: 100 x 235 x 212 mm^3
- Remote control via ethernet

Frequency-power maps

Upscan



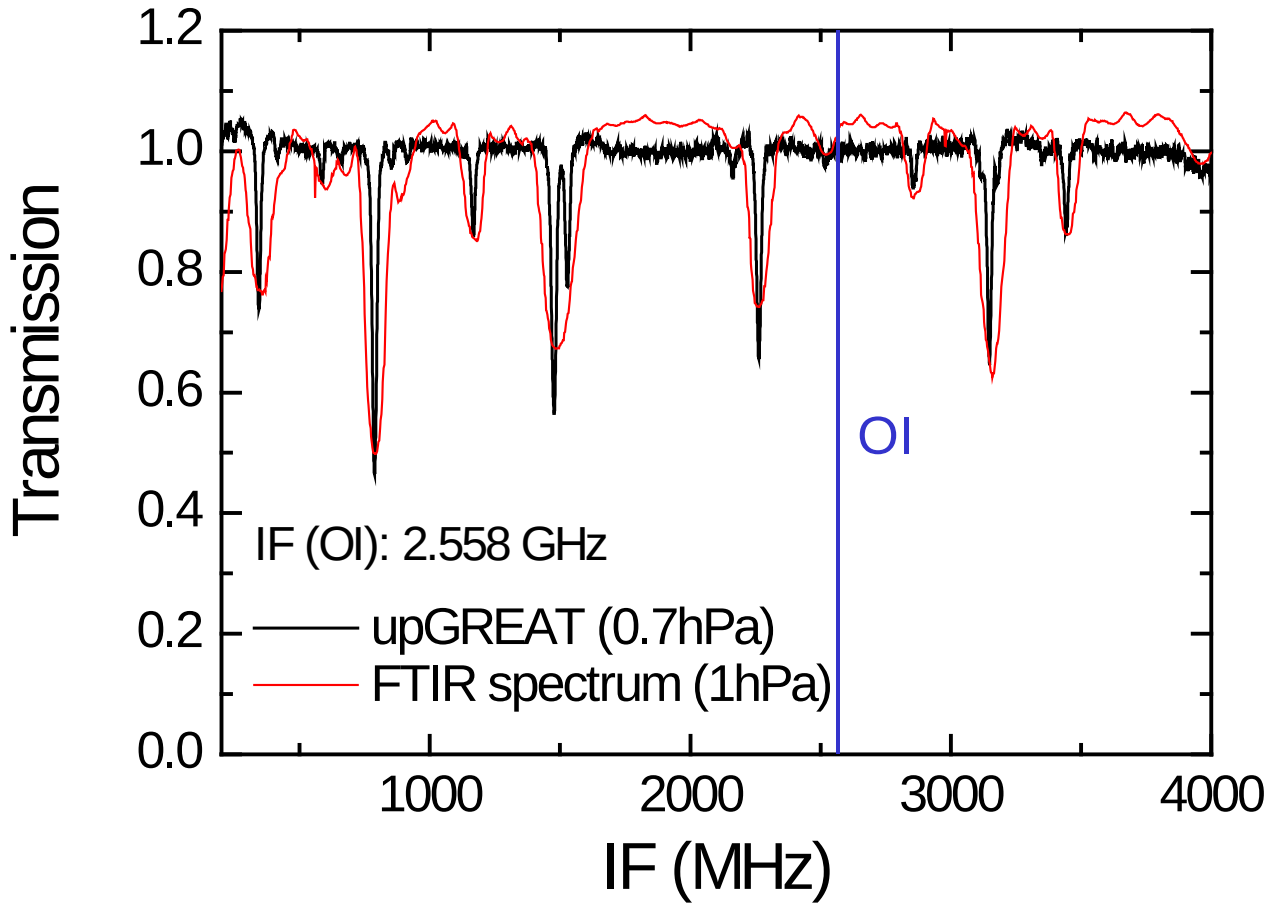
Downscan



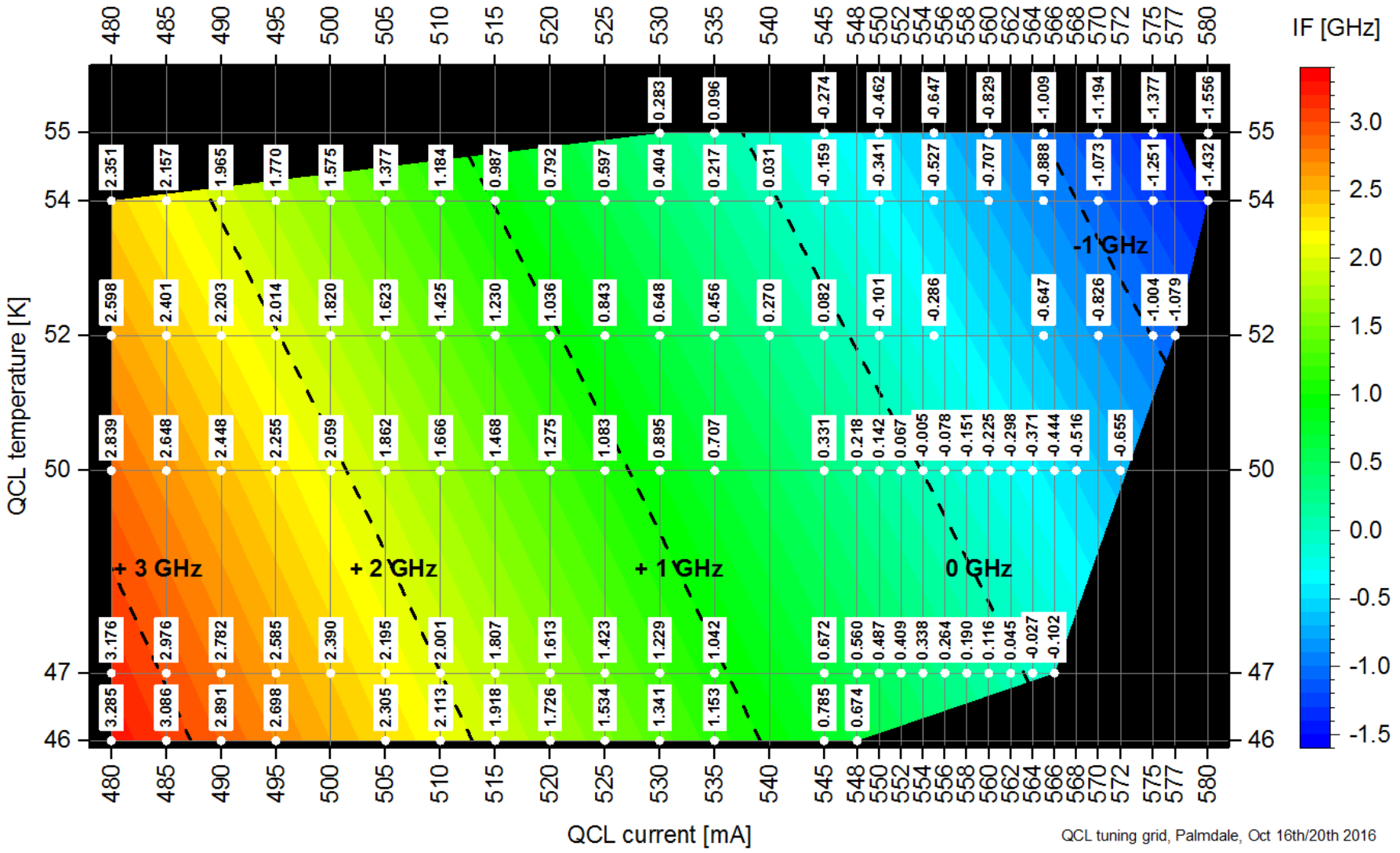
Mode with high atmospheric transmission (OI+30GHz)

Mode for OI

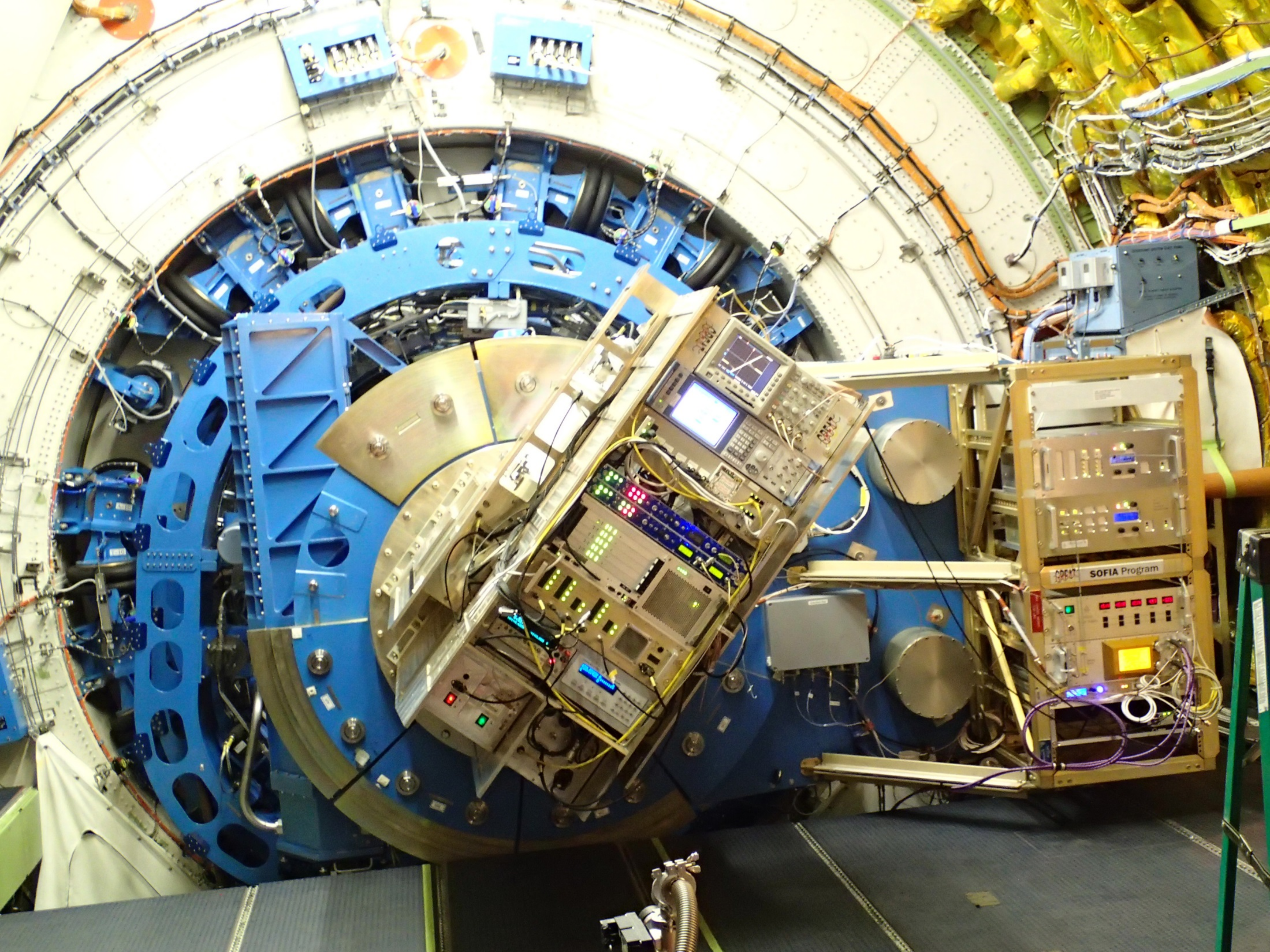
Fingerprint spectrum with upGREAT



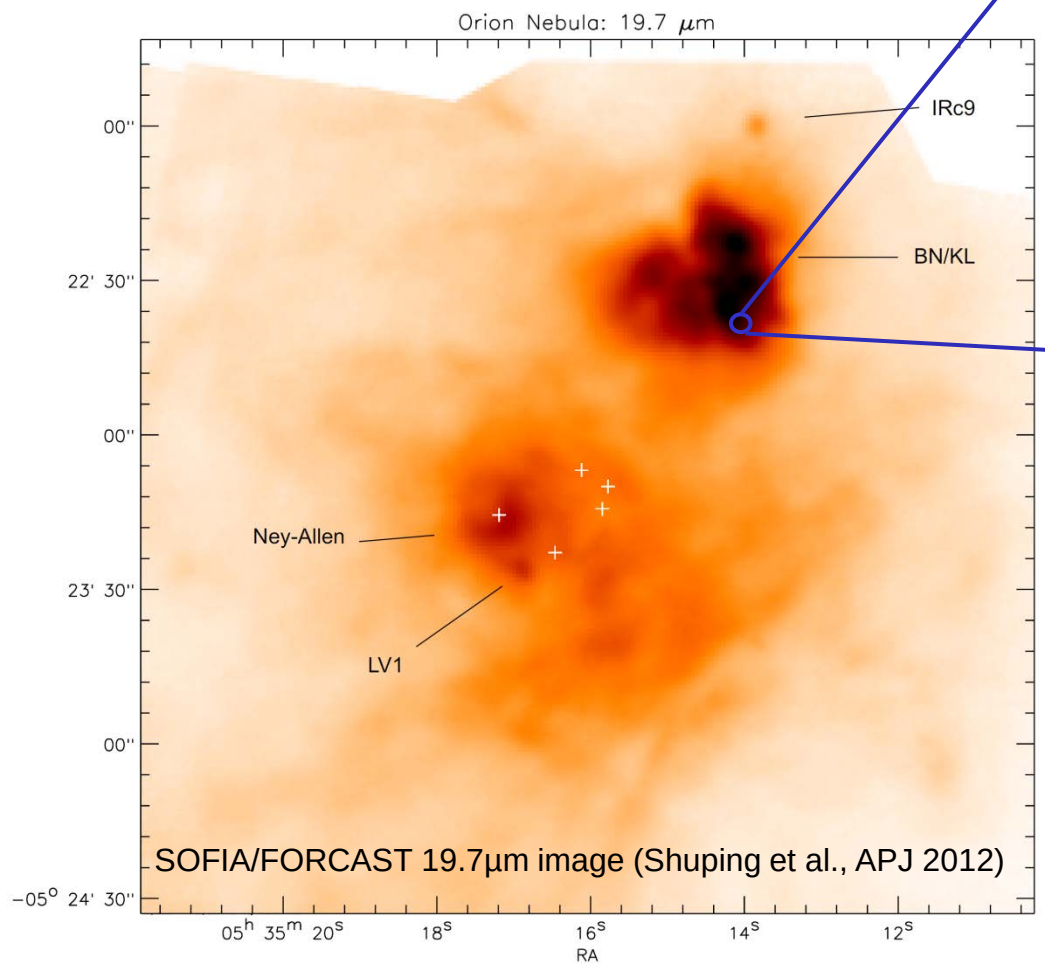
QCL frequency tuning grid



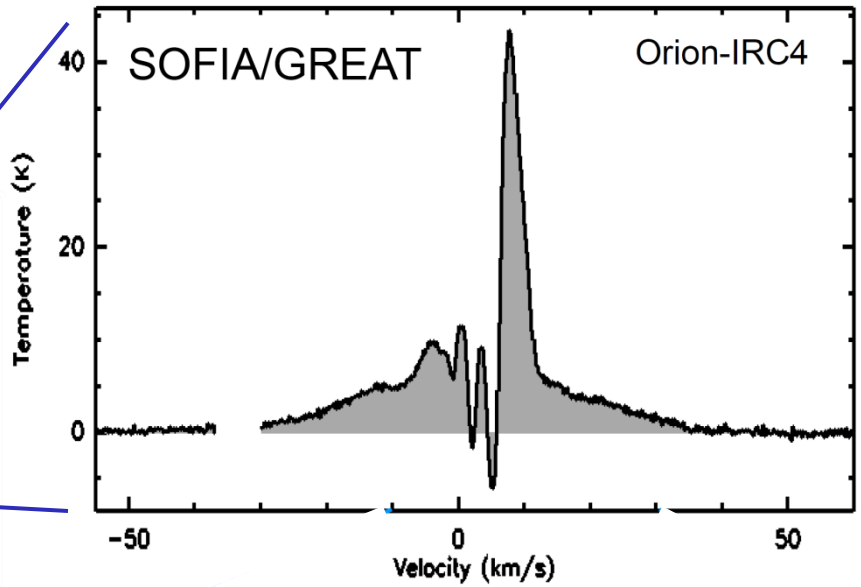
QCL tuning grid, Palmdale, Oct 16th/20th 2016


SOFIA Program

Orion-BN/KL (GREAT result)



SOFIA/FORCAST 19.7μm image (Shuping et al., APJ 2012)



1km/s = 16MHz

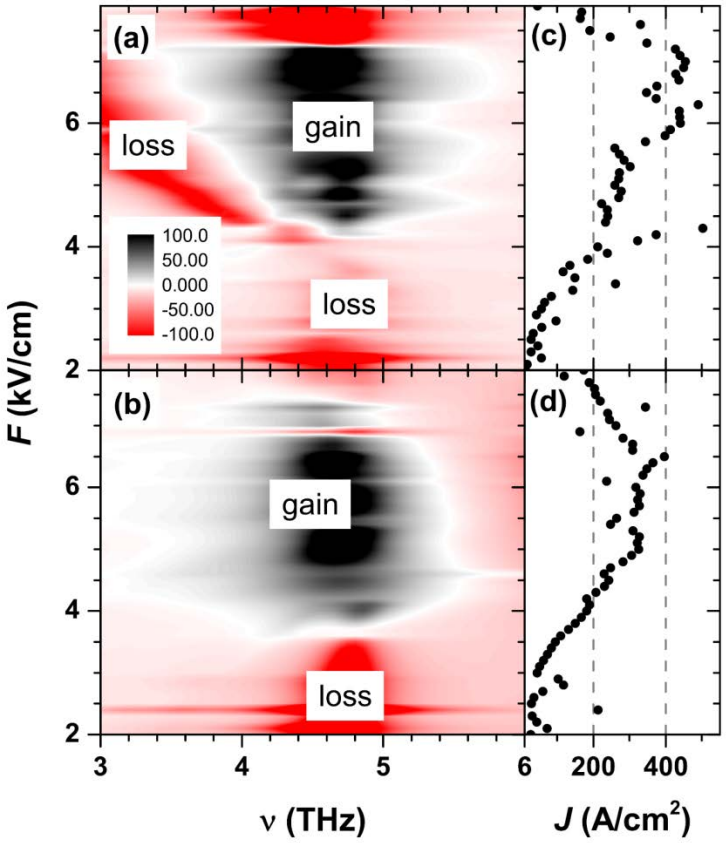
- Excellent SNR within 20s integration time
- Emission from IRC hot core
- Strong, narrow absorption lines along the line-of-sight
- Powerful high-velocity outflow indicated by the wings
- OI is a main coolant line

In preparation for Astron. & Astrophys., 2017

Terahertz GaAs/AlAs quantum-cascade lasers

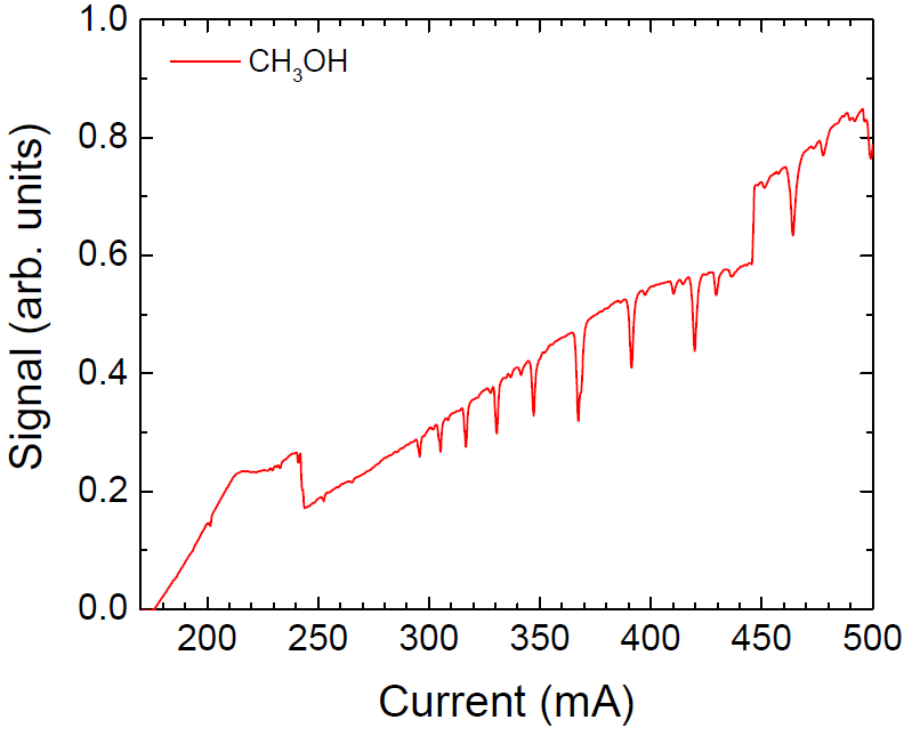
- AlAs barriers (instead of AlGaAs)
  - Larger subband separation, lower leakage current
  - No ternary alloy („better“ barriers)

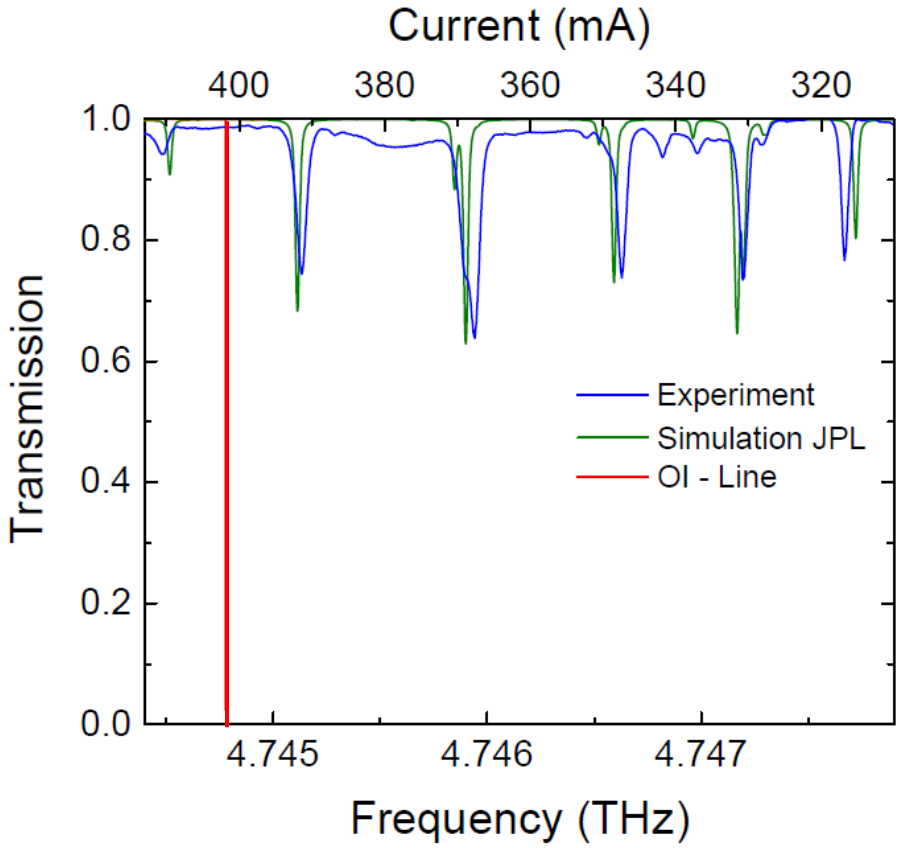
- Otherwise the same as the SOFIA QCLs
  - SP waveguide
  - 1.2mm long
  - Facets as cleaved
  - Lateral DFB grating



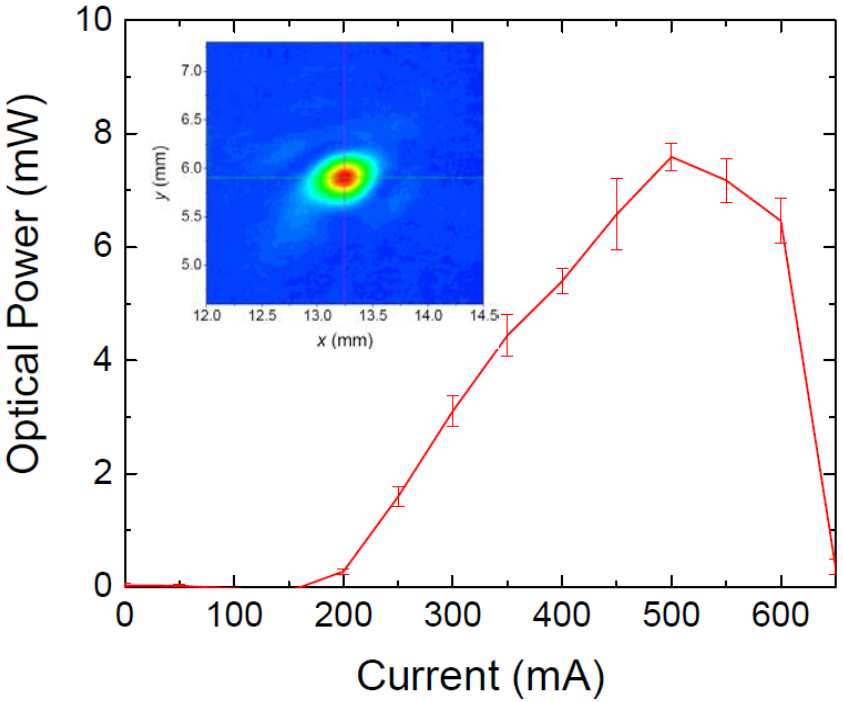
L. Schrottke et al., Appl. Phys. Lett. **108**, 102102 (2016)

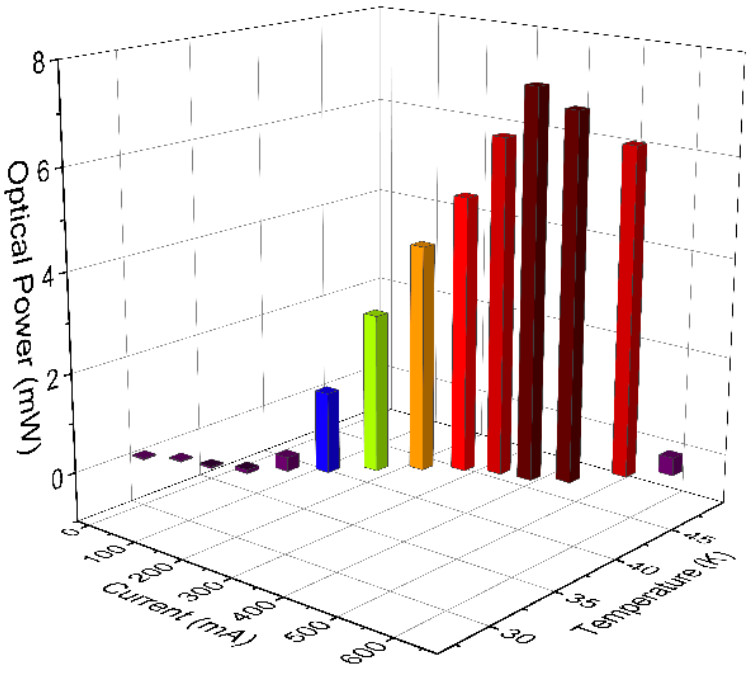
GaAs/AlAs QCL: Frequency





Power, beam profile, operating temperature

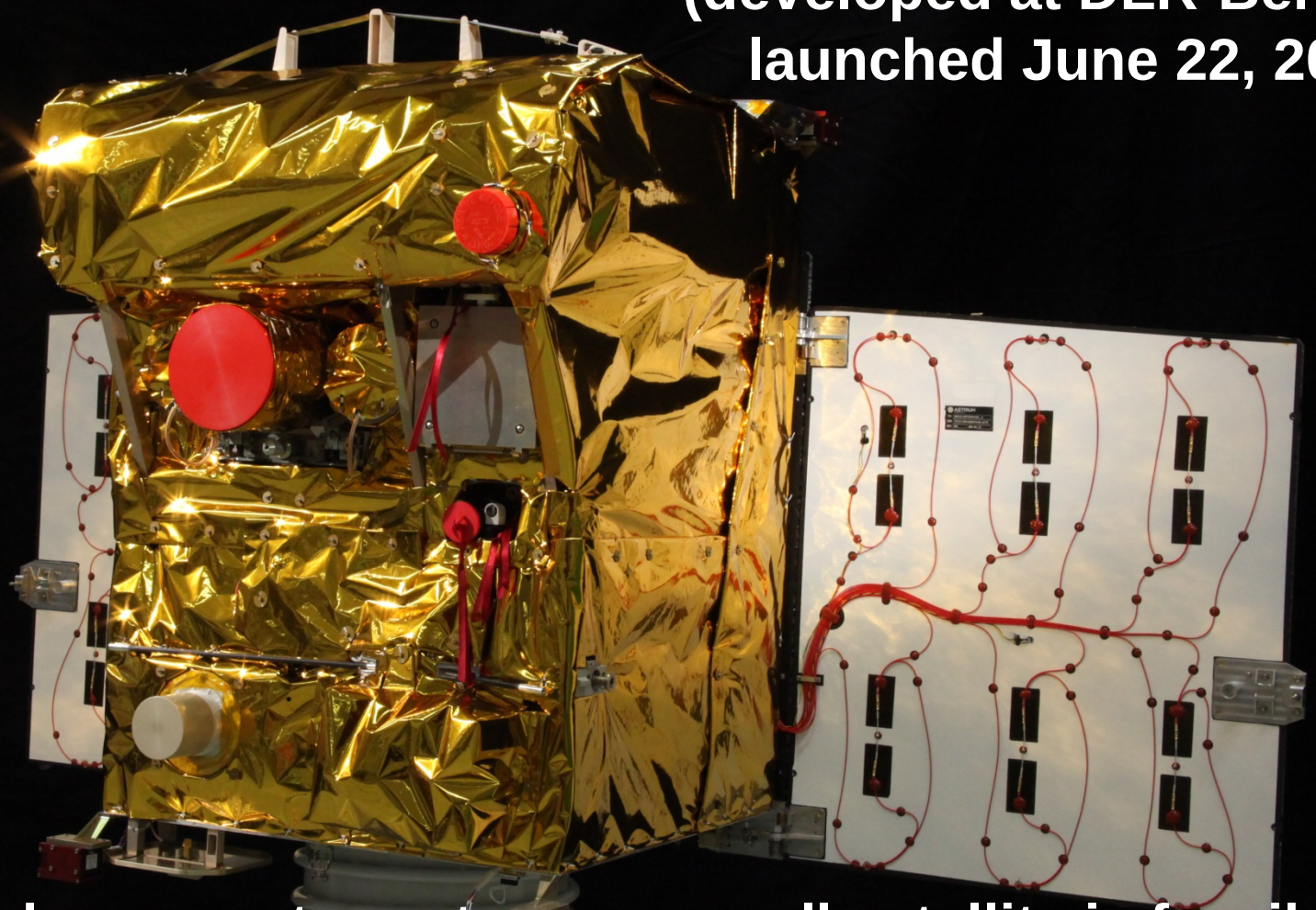




- up to 7.5mW output power (42K, 2.8W electr. power)
- laser threshold at 165mA (0.6W electr. power)
- 270µW @ 200mA, 0.8W electr. power
- almost Gaussian beam profile (without optimazition)

--> good for several 10 pixel

BiROS: Bispectral InfraRed Optical System
(developed at DLR-Berlin, launched June 22, 2016)



-> Heterodyne spectrometer on a small satellite is feasible (for a dedicated mission)