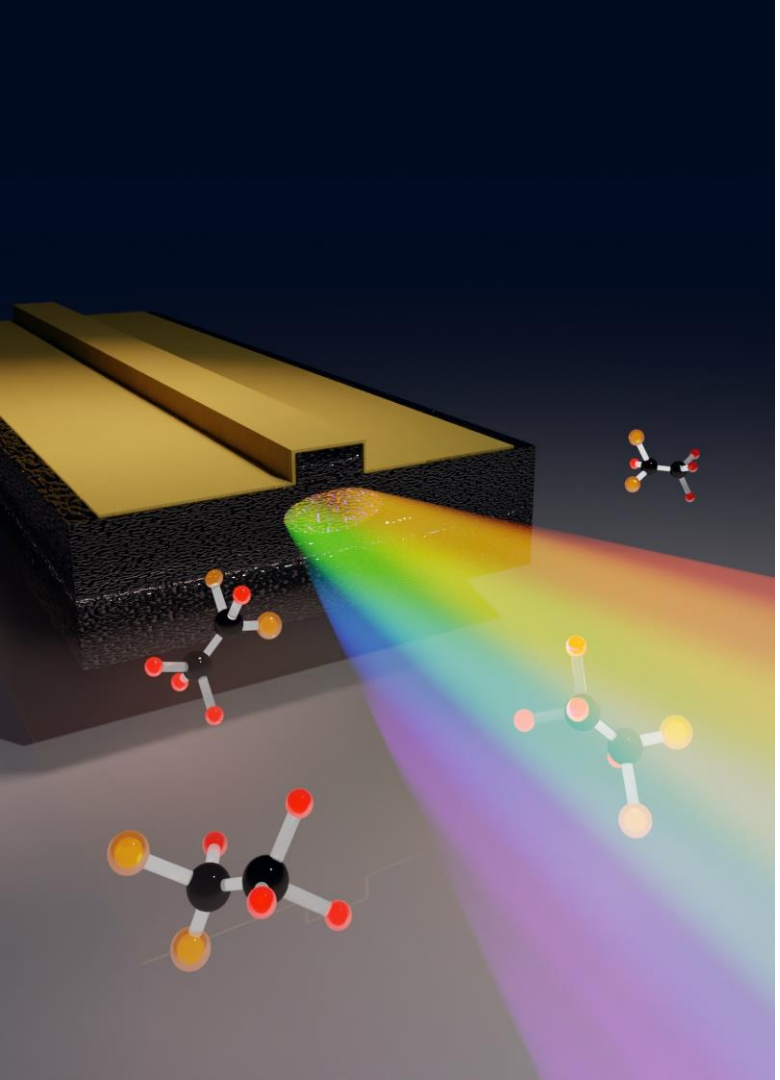

NLPQT Closing Conference
19/10/2023

Battery-operated mid-infrared diode laser frequency combs

Lukasz A. Sterczewski,[1,2]

[1]Wroclaw University of Science and Technology, 50-370 Wroclaw, Poland
[2]Previously: Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA

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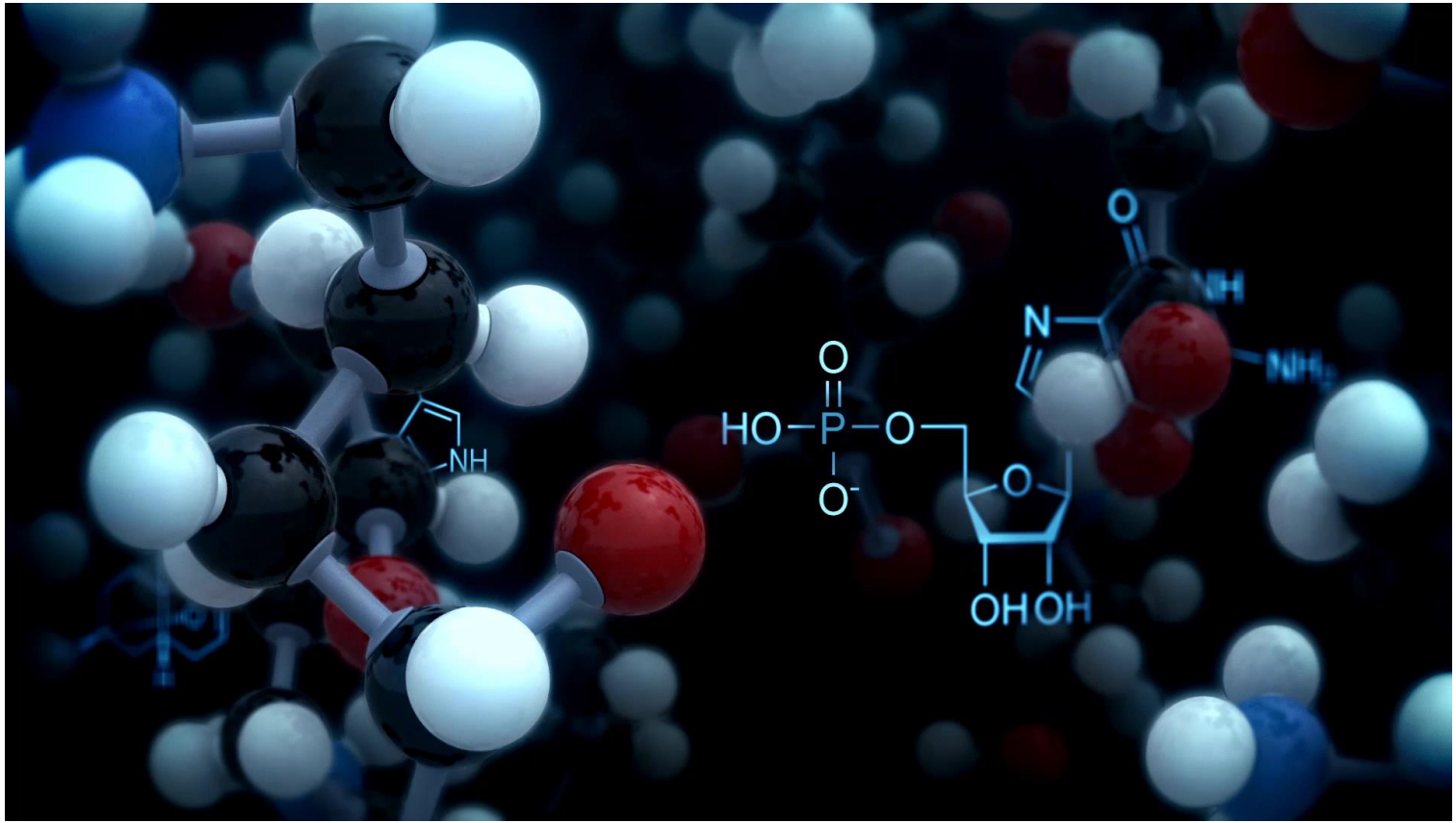
Contributors

Jet Propulsion Laboratory
California Institute of Technology

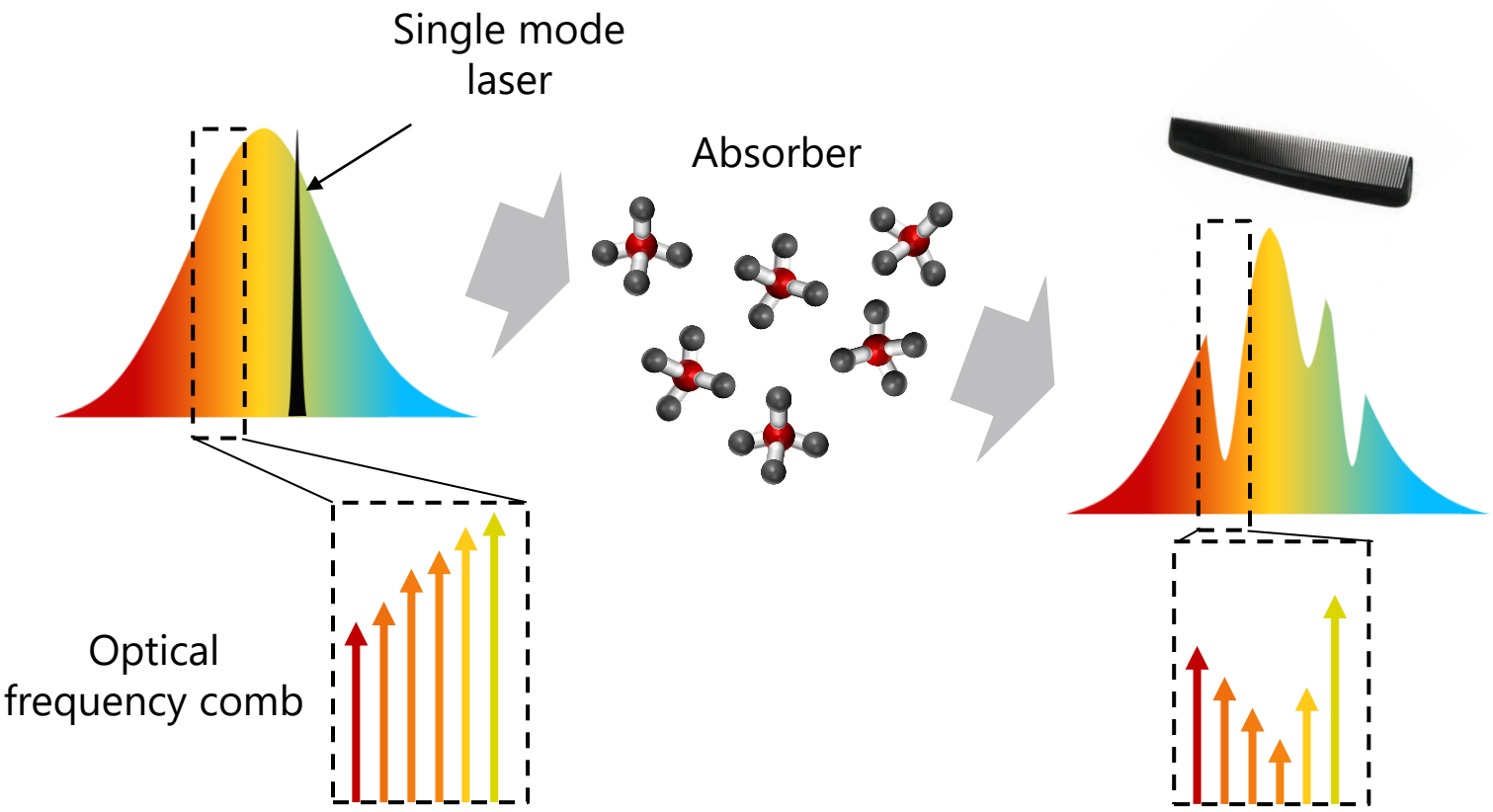
Jet Propulsion Laboratory, California Institute of Technology,
Pasadena, CA 91109, USA

Mahmood Bagheri, Clifford Frez, Siamak Forouhar

Molecular sensing – need for broadband measurements



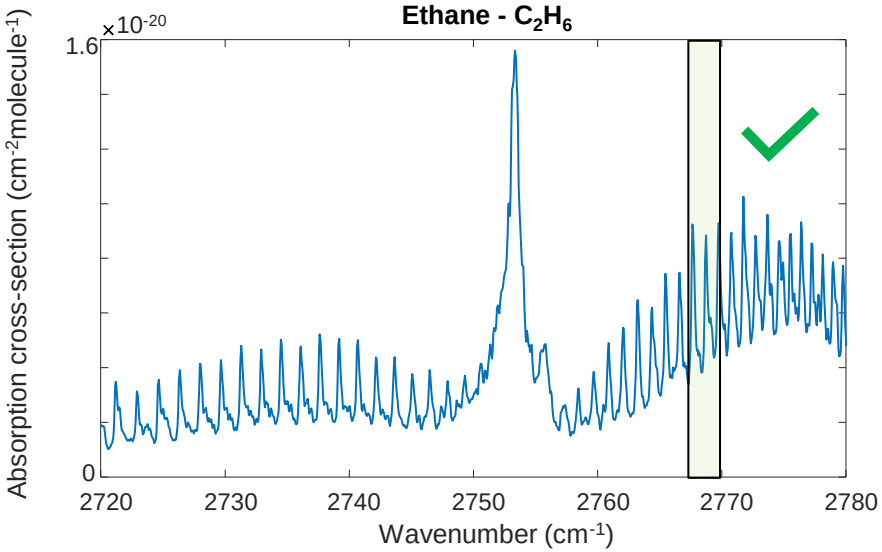
Broadband sources for spectroscopy

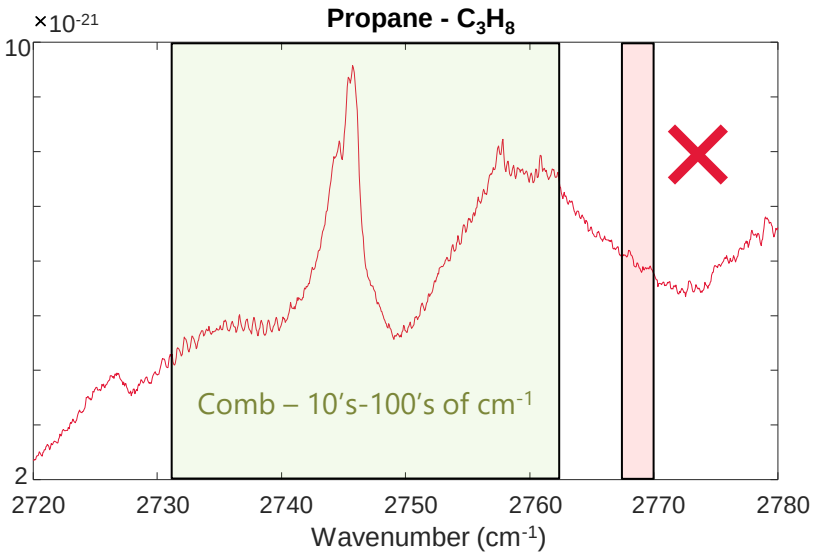


Why frequency combs if single-mode lasers work well?

Single-mode laser is sufficient – single line can be isolated (a few cm^{-1} tunability)

Comb becomes necessary – broad features would be difficult to probe with ~cm^{-1} tunability



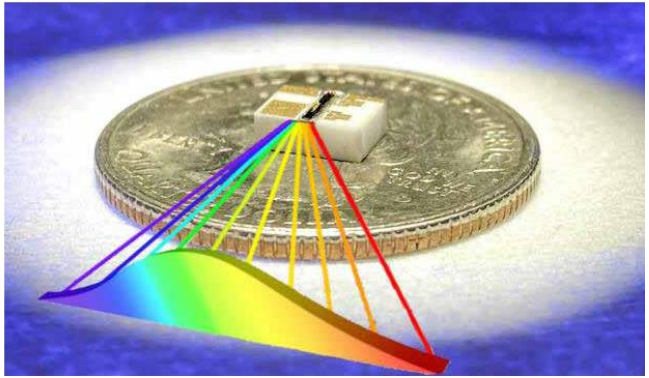


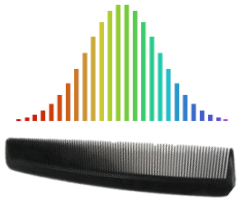
298.1 K, atmospheric pressure, HITRAN ABS 2019 database

Novel sources for comb spectroscopy

Type-I quantum well diode laser combs

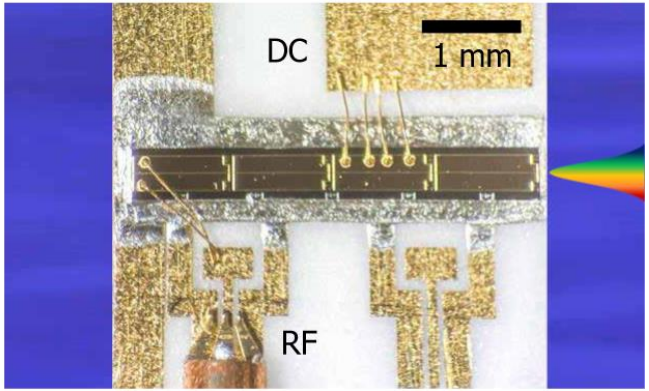
- Up to **20 mW** of CW power at <1 W of power consumption
- **~1 THz** spectral coverage, 10 GHz repetition rate
- Self-starting comb emission without any microwave generators
- Native emission in the 1.5-3 μm wavelength region
- Lockable to frequency standards



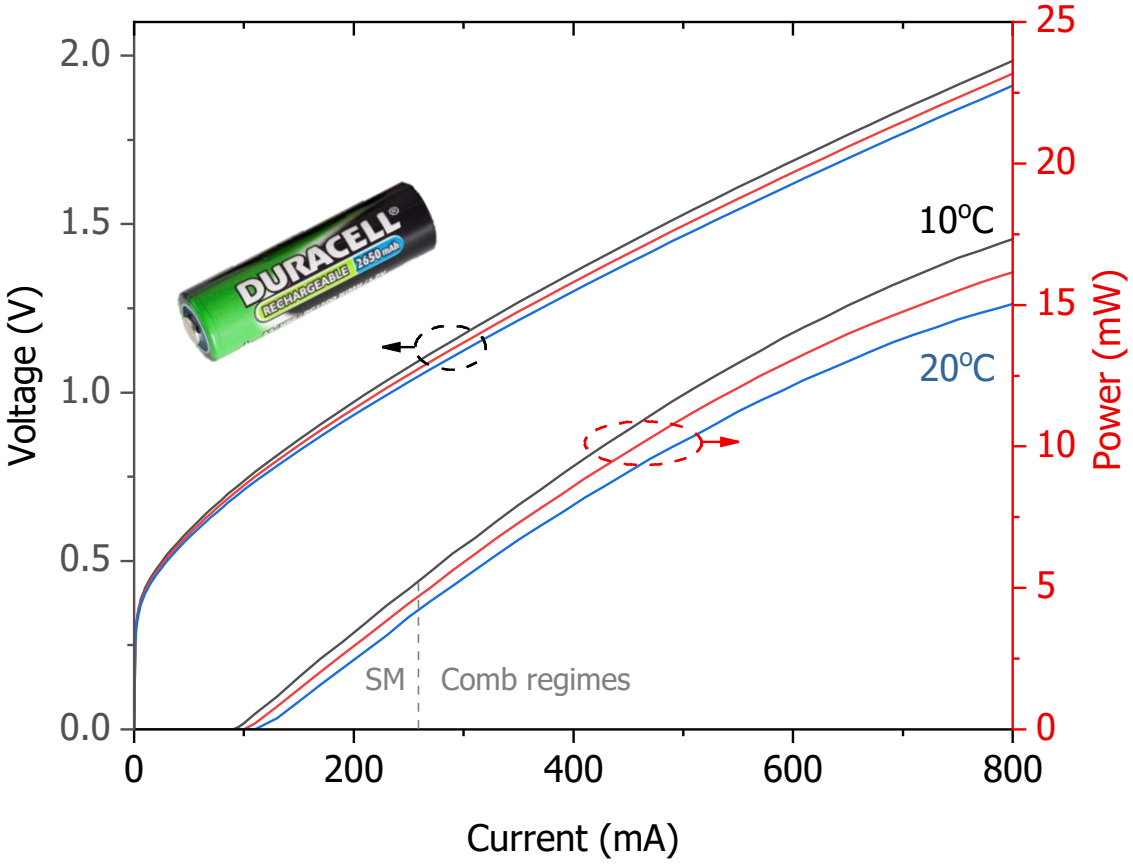


Inclusive frequency comb definition

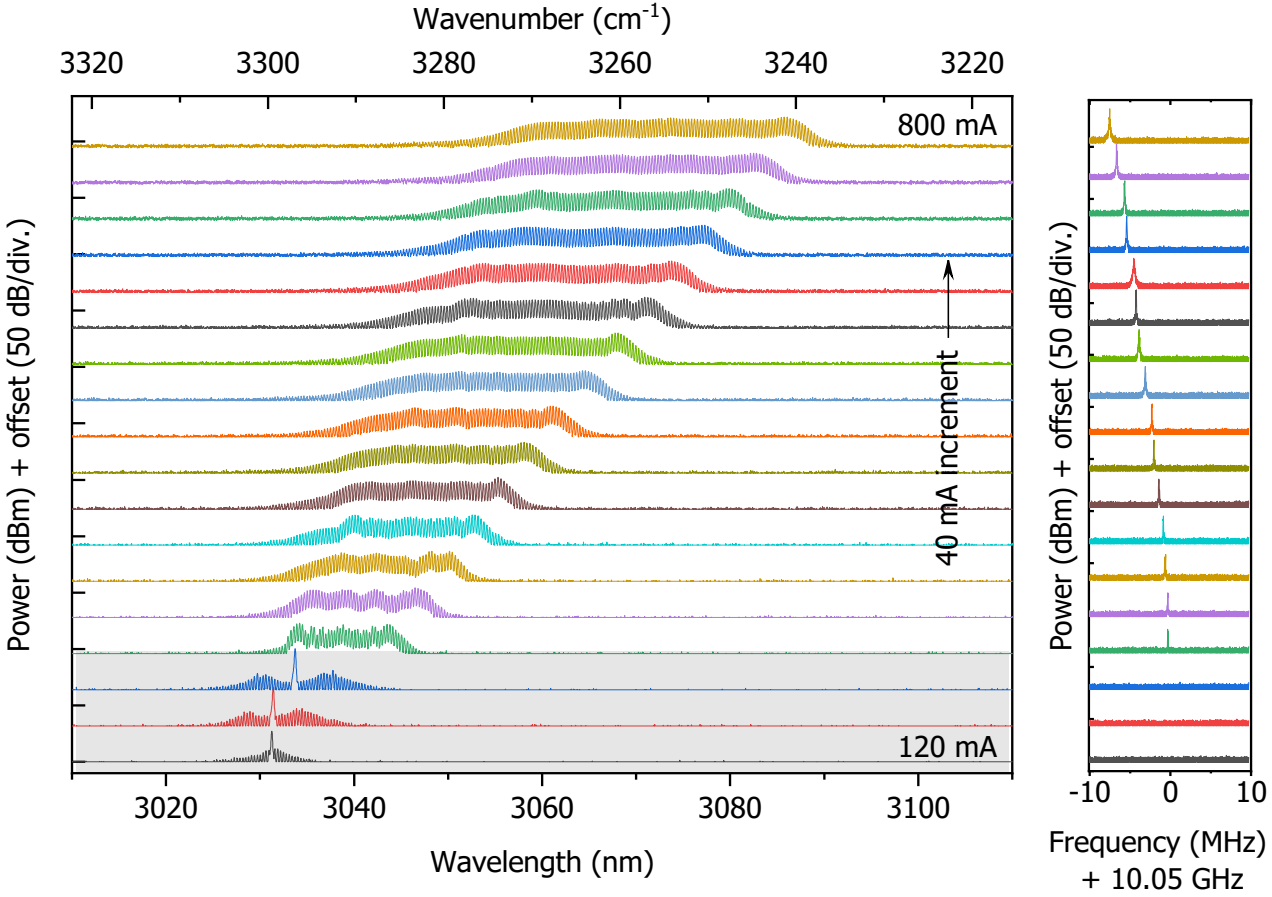
Frequency of each line defined by two parameters: global offset and repetition rate



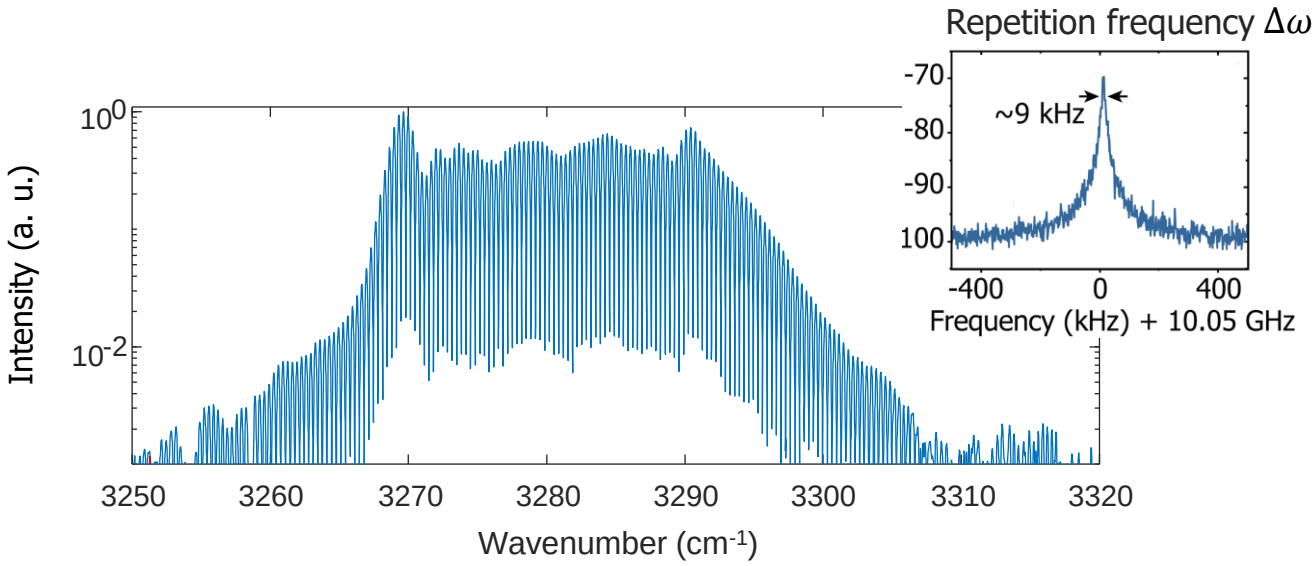
Diode laser combs - LIV



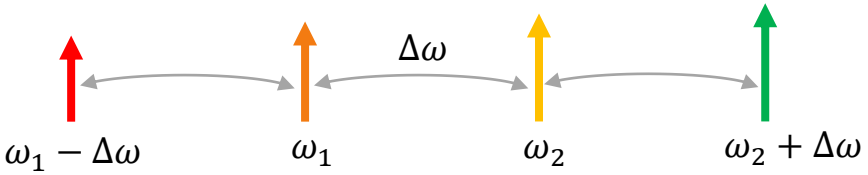
Diode laser combs – spectral characterization



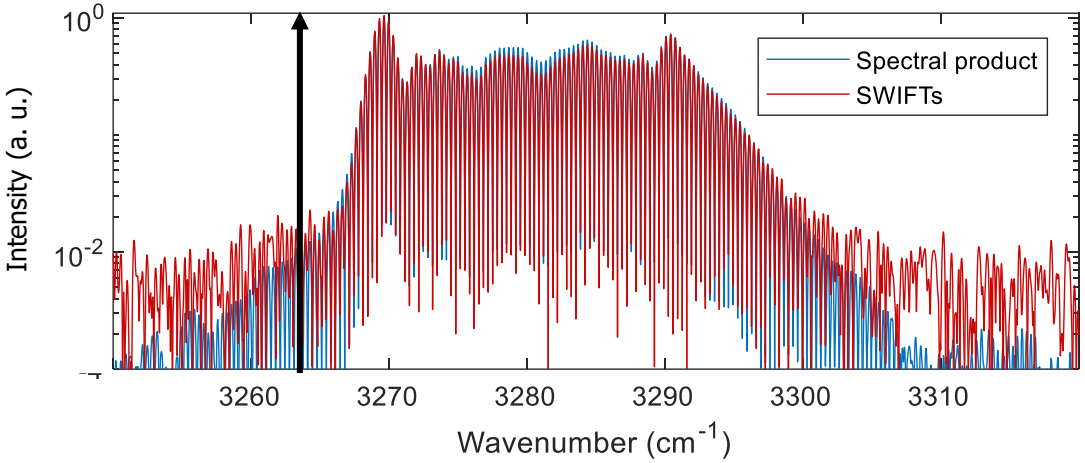
Semiconductor laser optical frequency combs

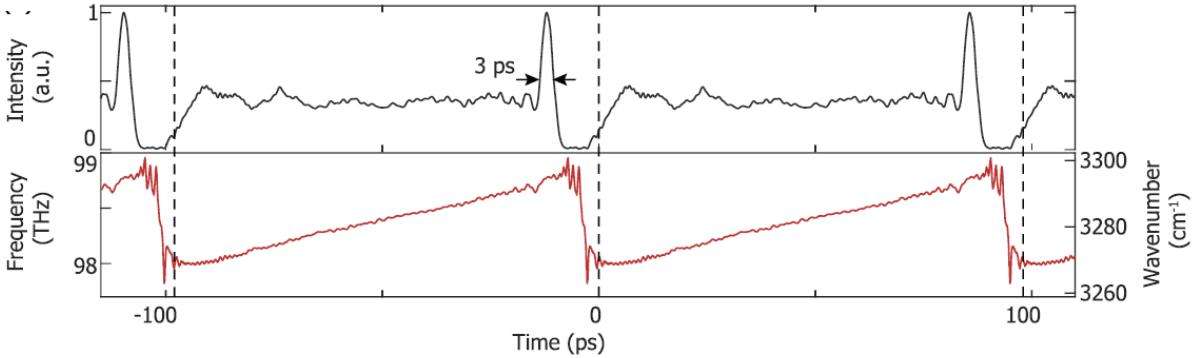


Comb operation enabled by multimode operation (spatial hole burning) + nonlinearity (four-wave mixing)

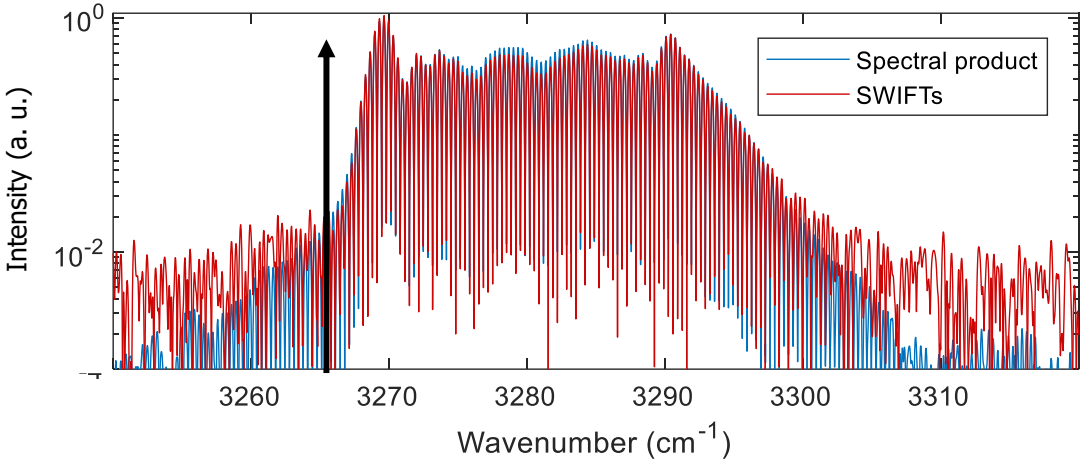


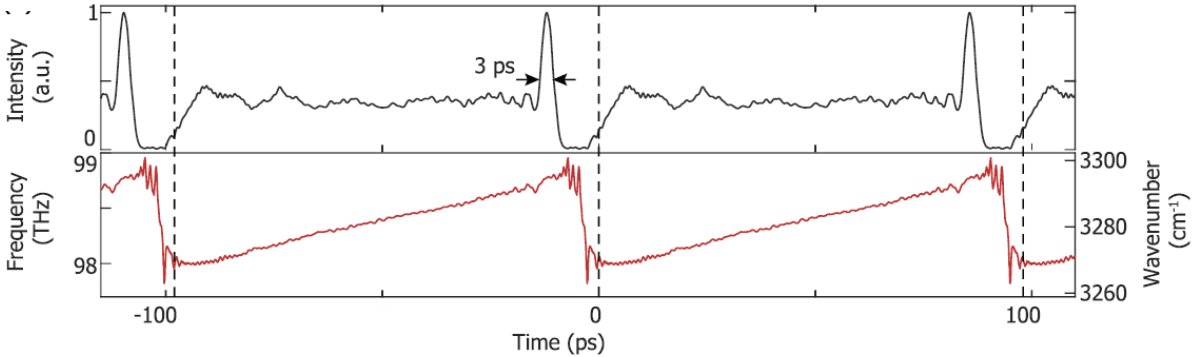
Linearly swept FM source - approximation



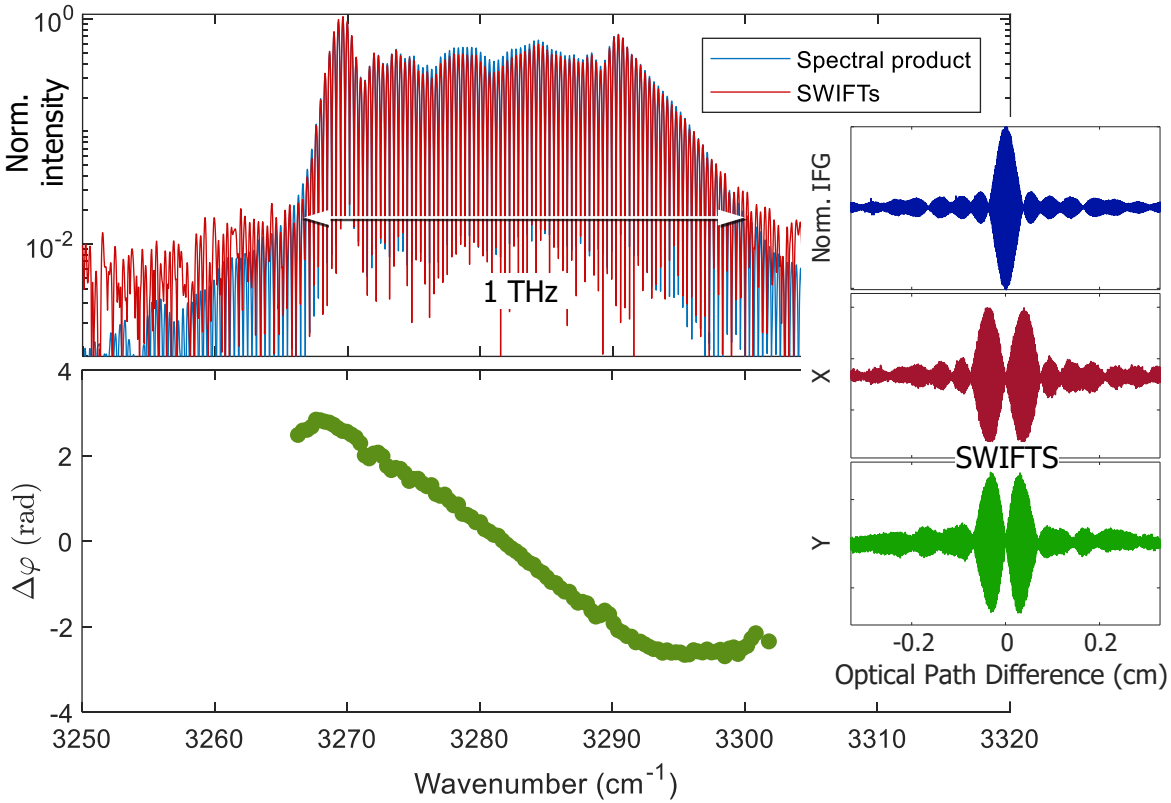


Linearly swept FM source – more accurate picture

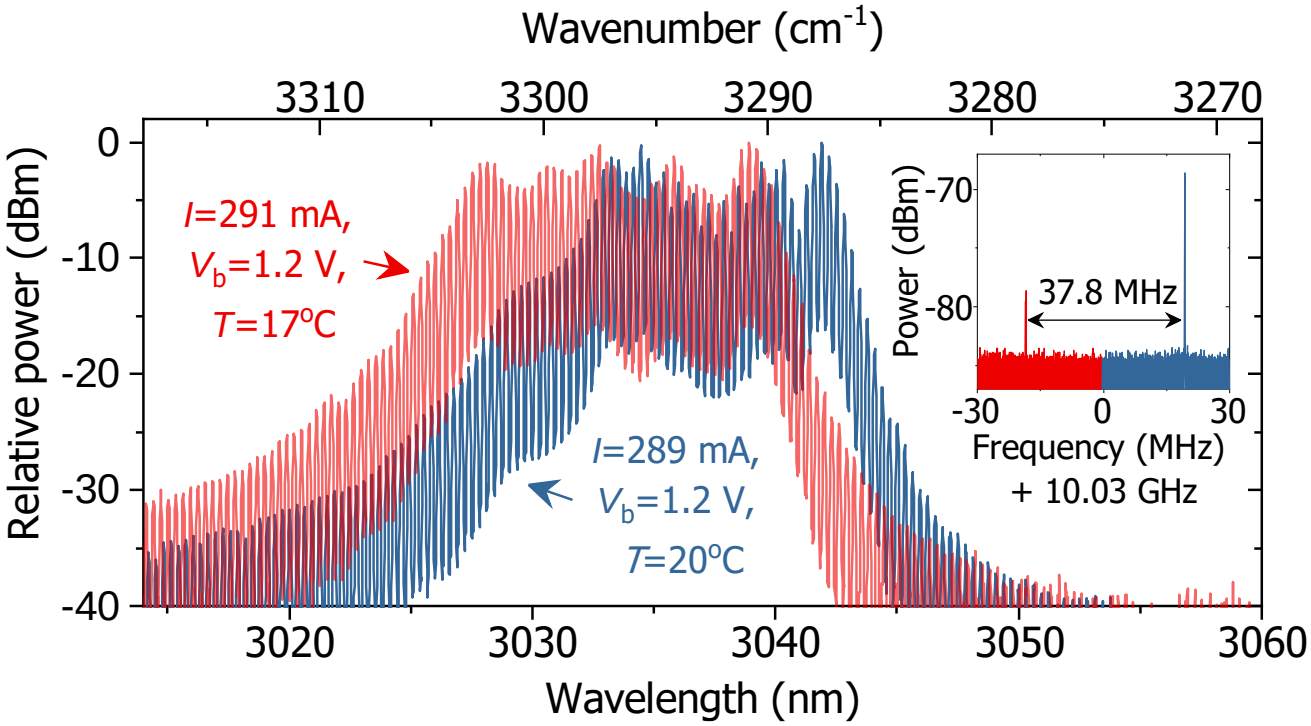




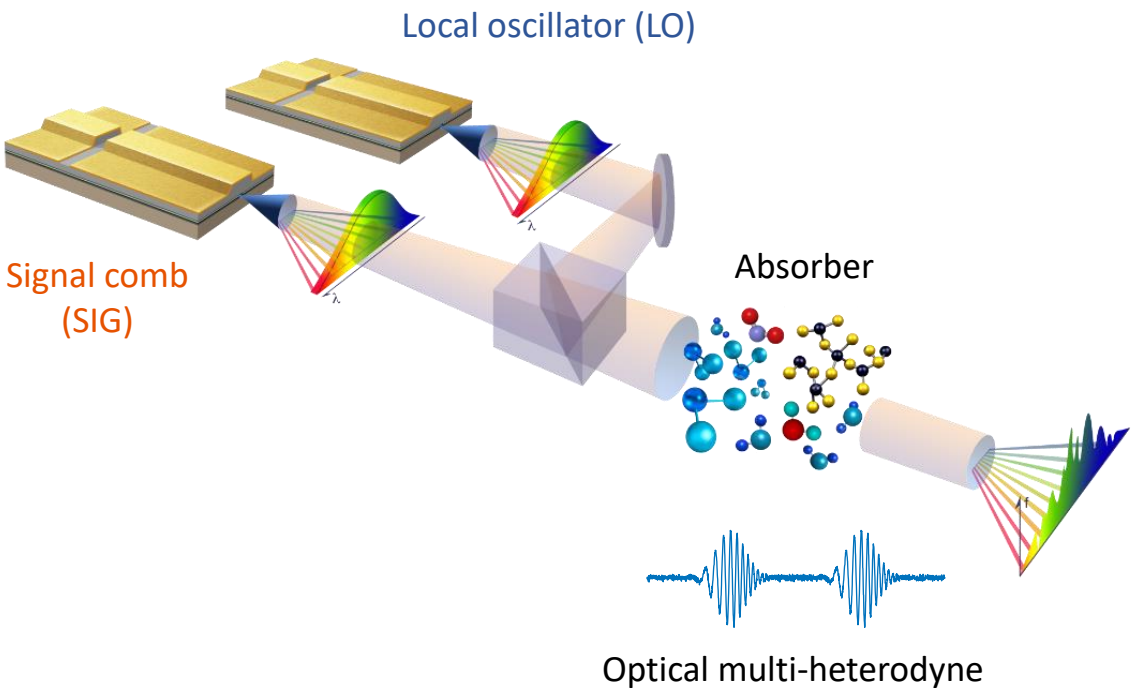
Original SWIFTS characteristics



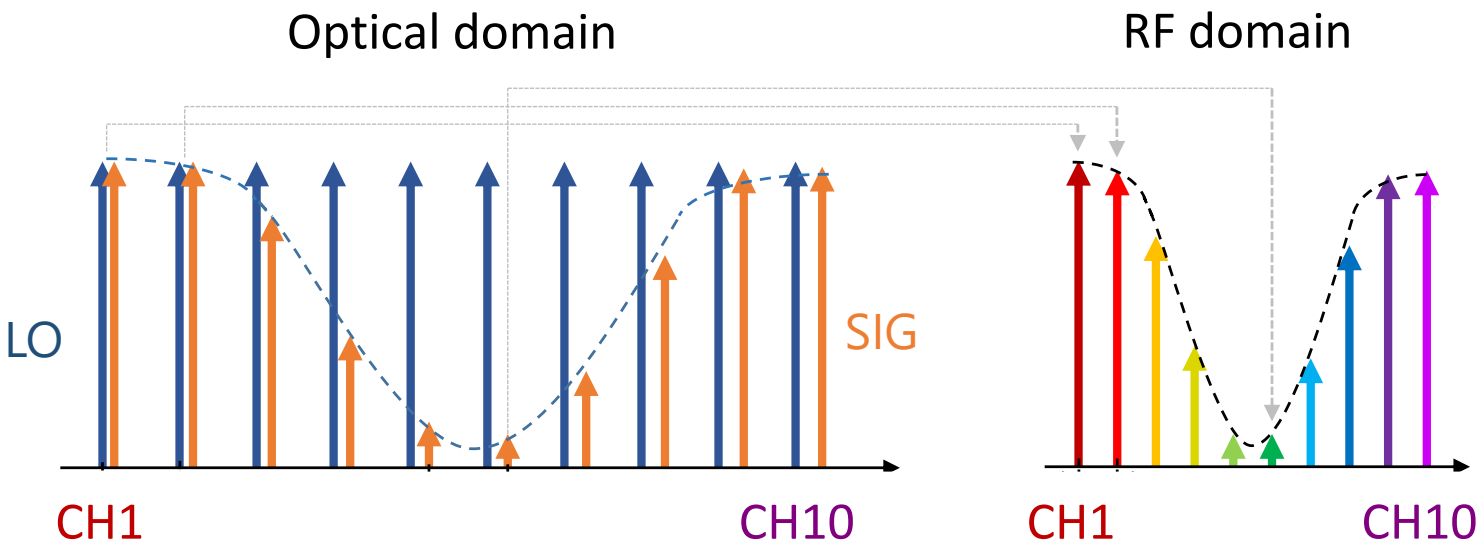
A pair of devices



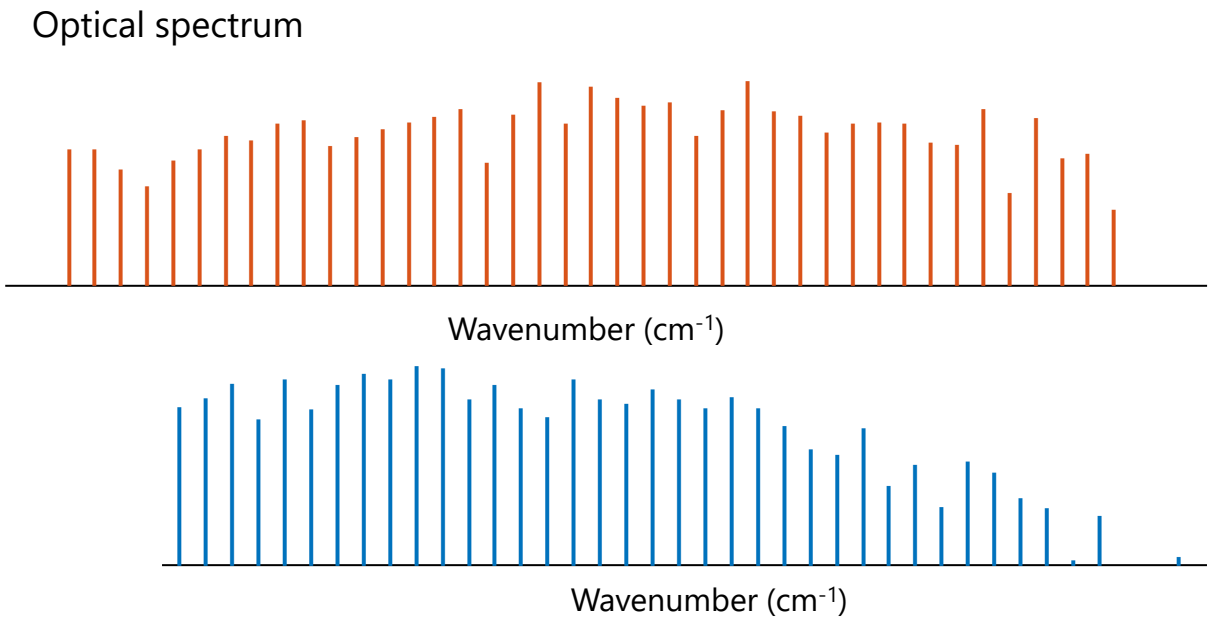
Dual-comb spectroscopy



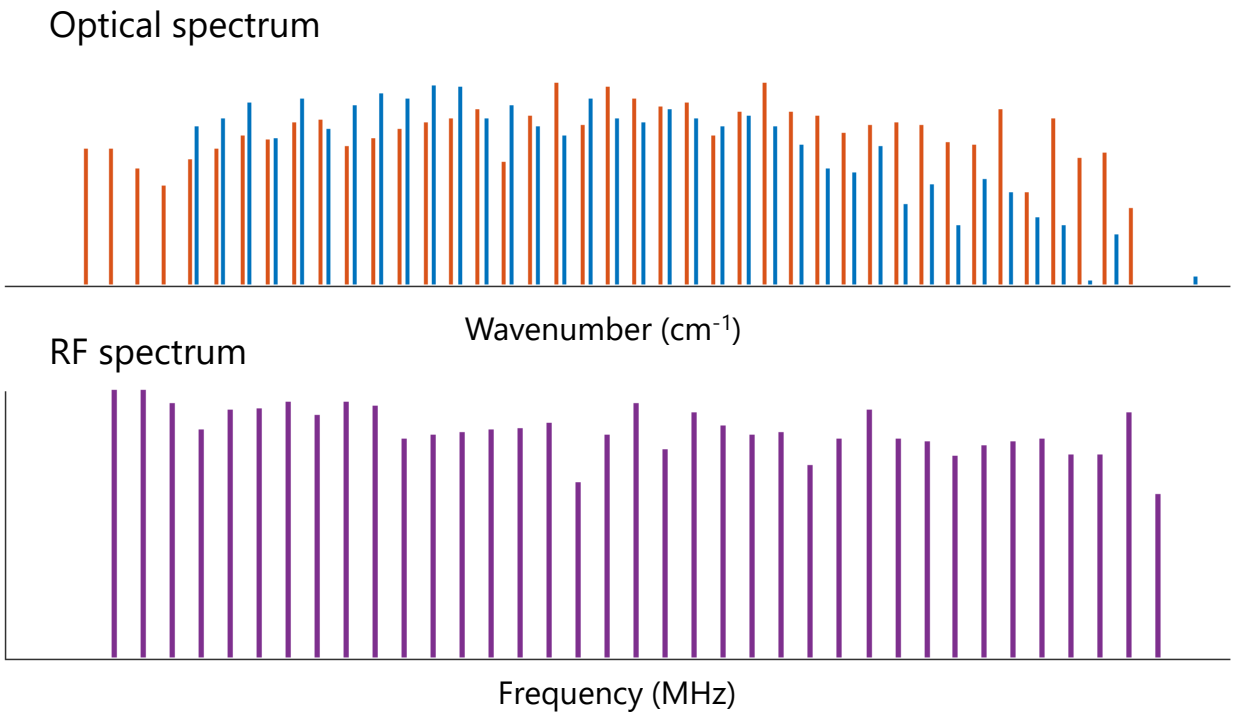
Dual-comb spectroscopy



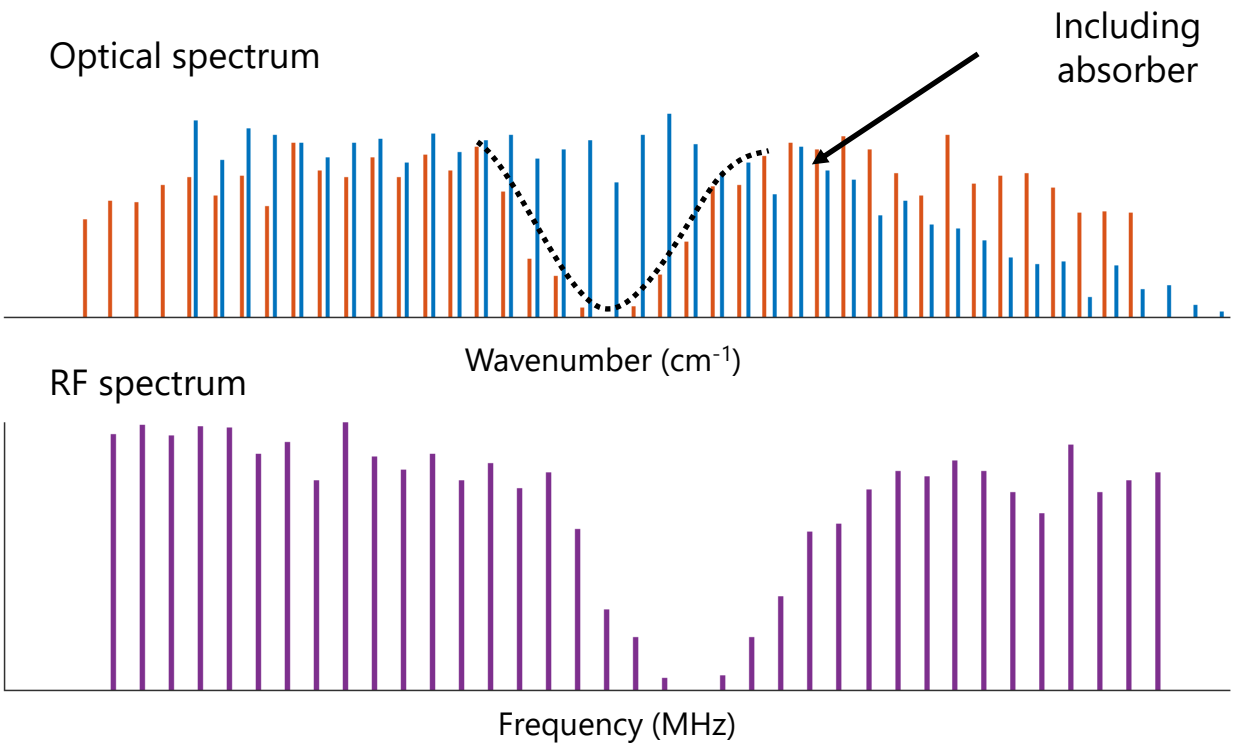
Optical multi-heterodyne



Optical multi-heterodyne

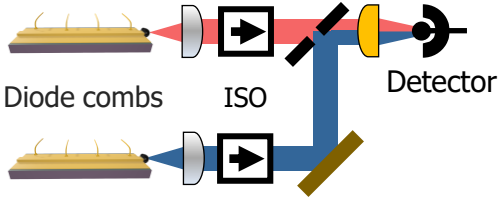


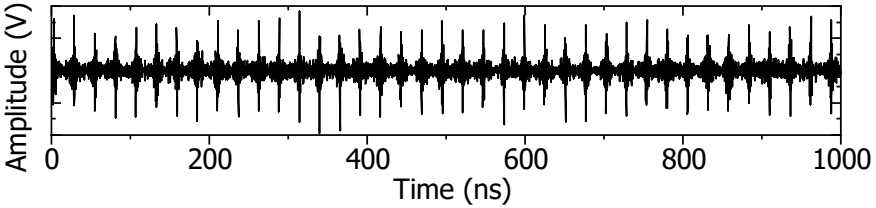
Optical multi-heterodyne

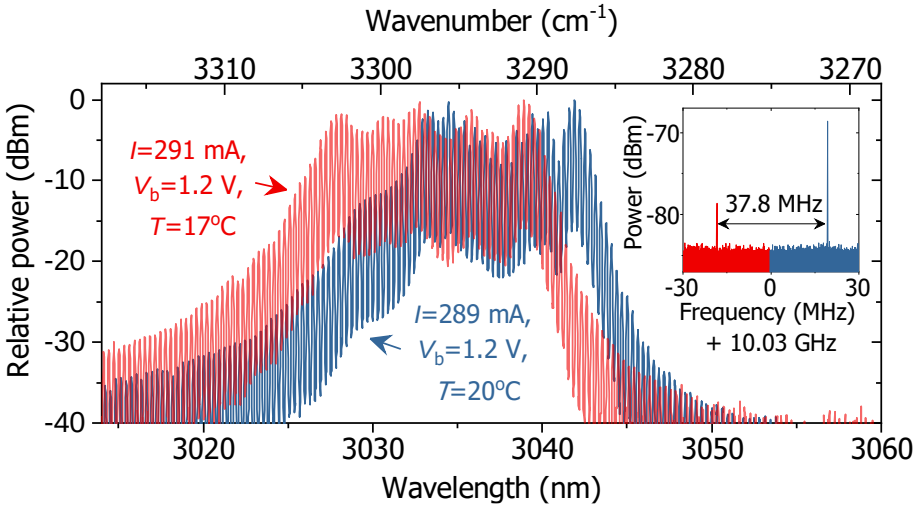


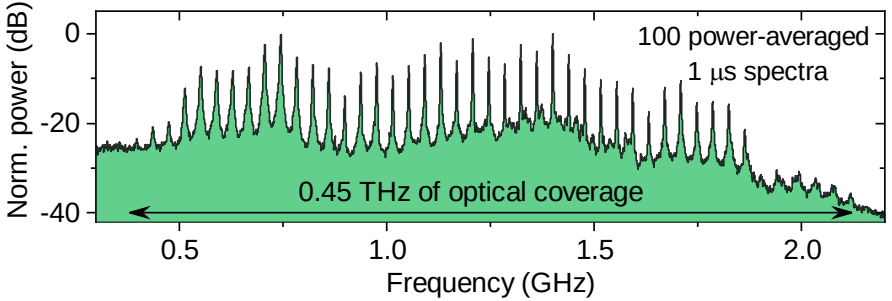
Mid-IR QCLs: Villares et al. *Nat. Comm.* **5** (2014)

Battery-operated MIR dual-comb source

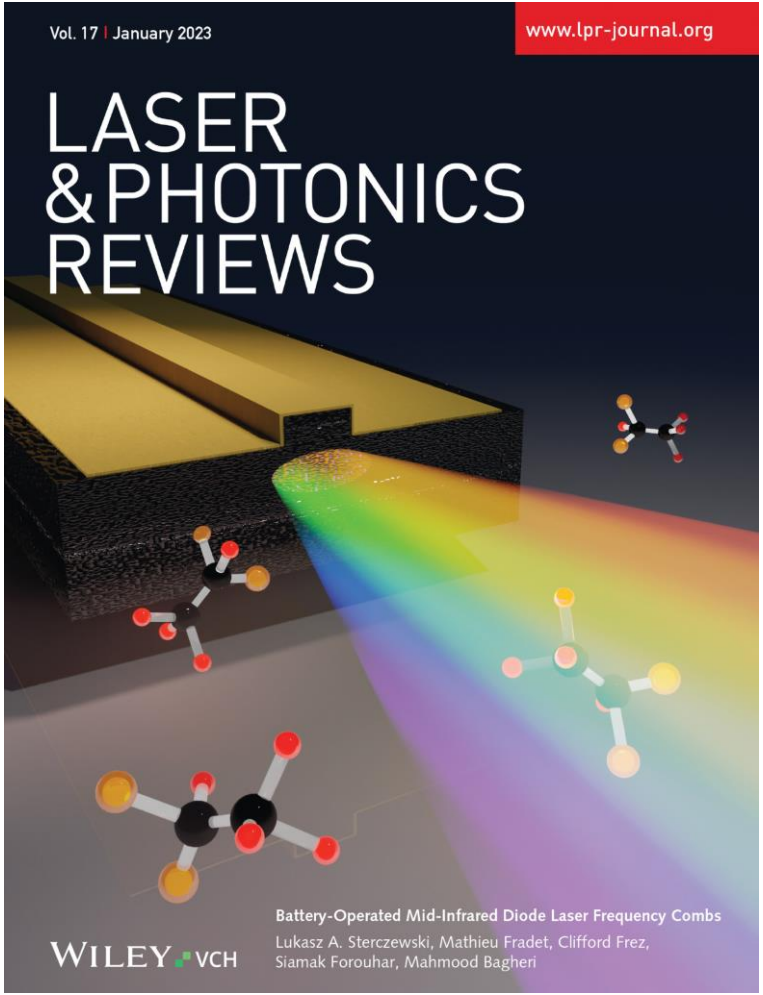






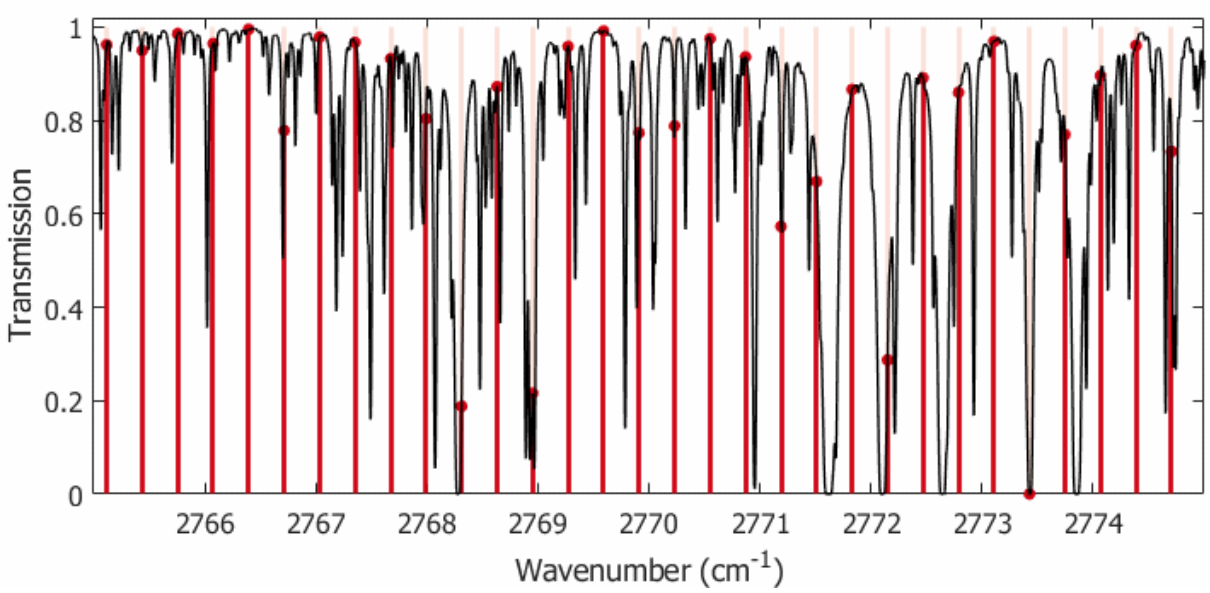


L. A. Sterczewski, et al., "Battery-operated mid-infrared diode laser frequency combs," *Laser & Photonics Reviews* **17**, 2200224 (2023).

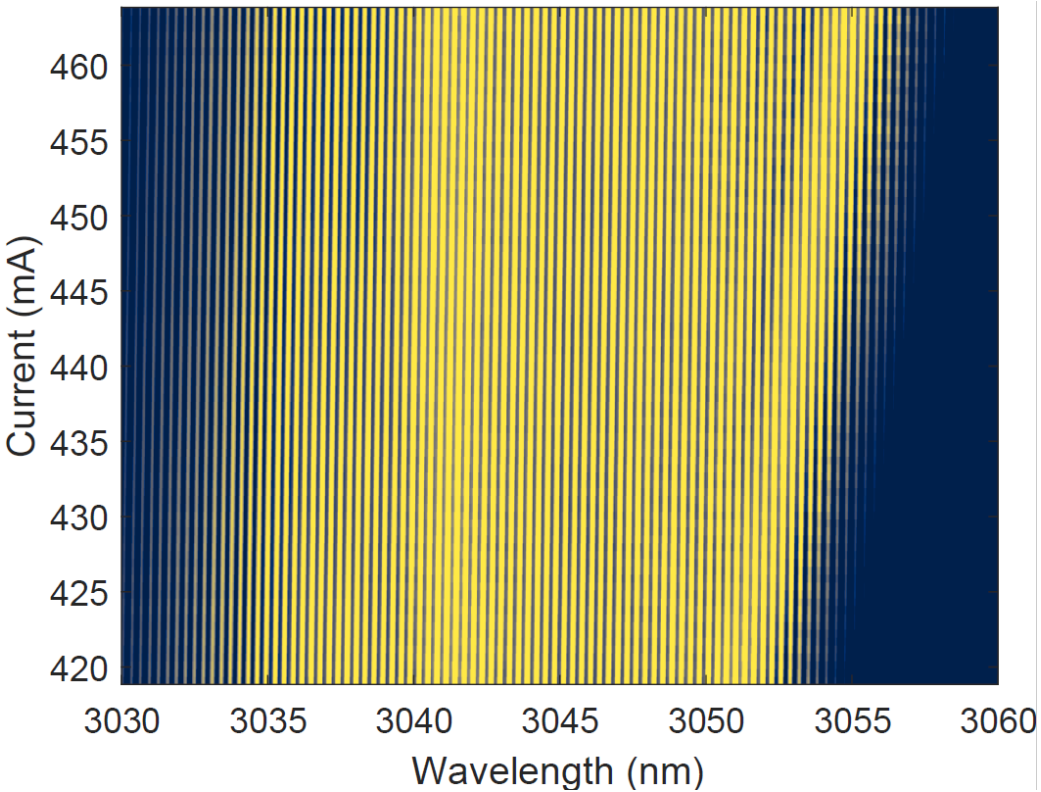


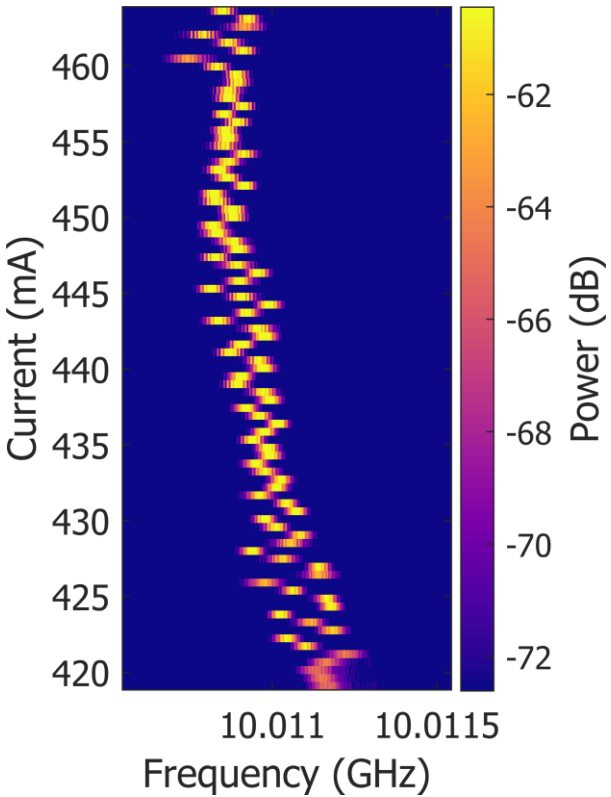
L. A. Sterczewski, et al., "Battery-operated mid-infrared diode laser frequency combs," *Laser & Photonics Reviews* **17**, 2200224 (2023).

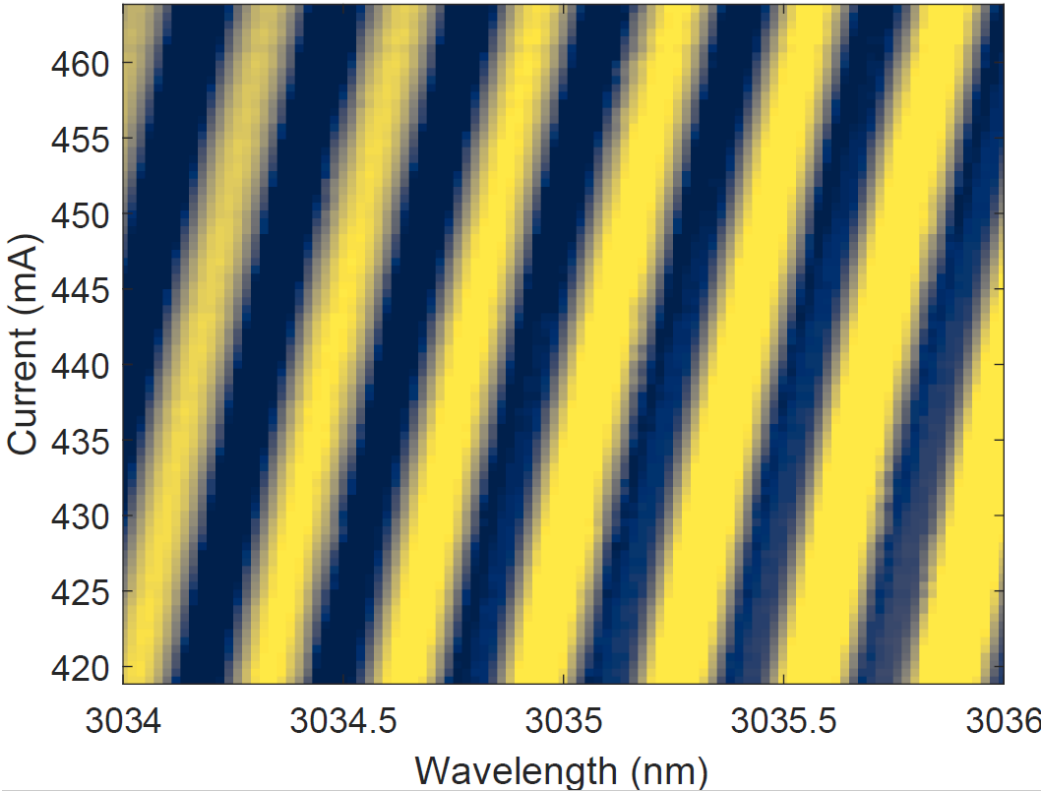
Multi-wavelength tunable laser spectroscopy

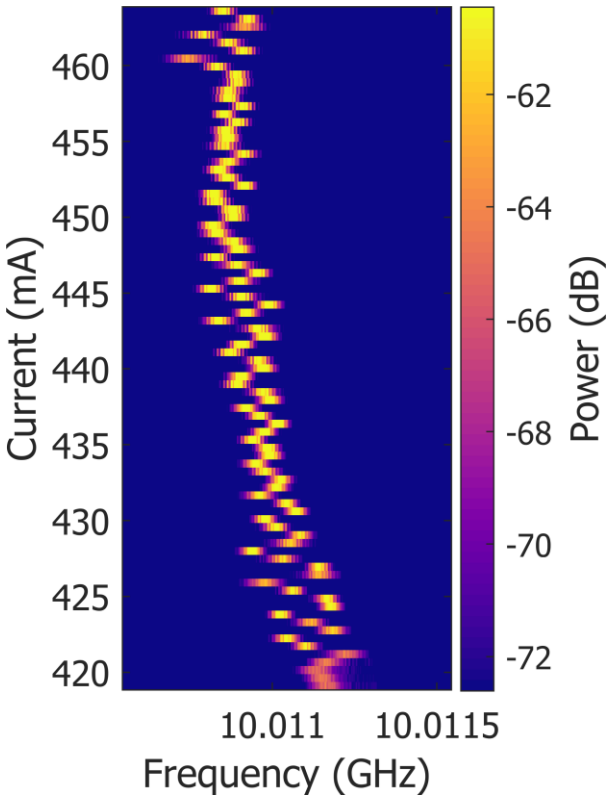


Pure CH_4, HITRAN simulation parameters *T*: 293 K, *P*: 0.1 atm (76 Torr) – for display visualization purposes

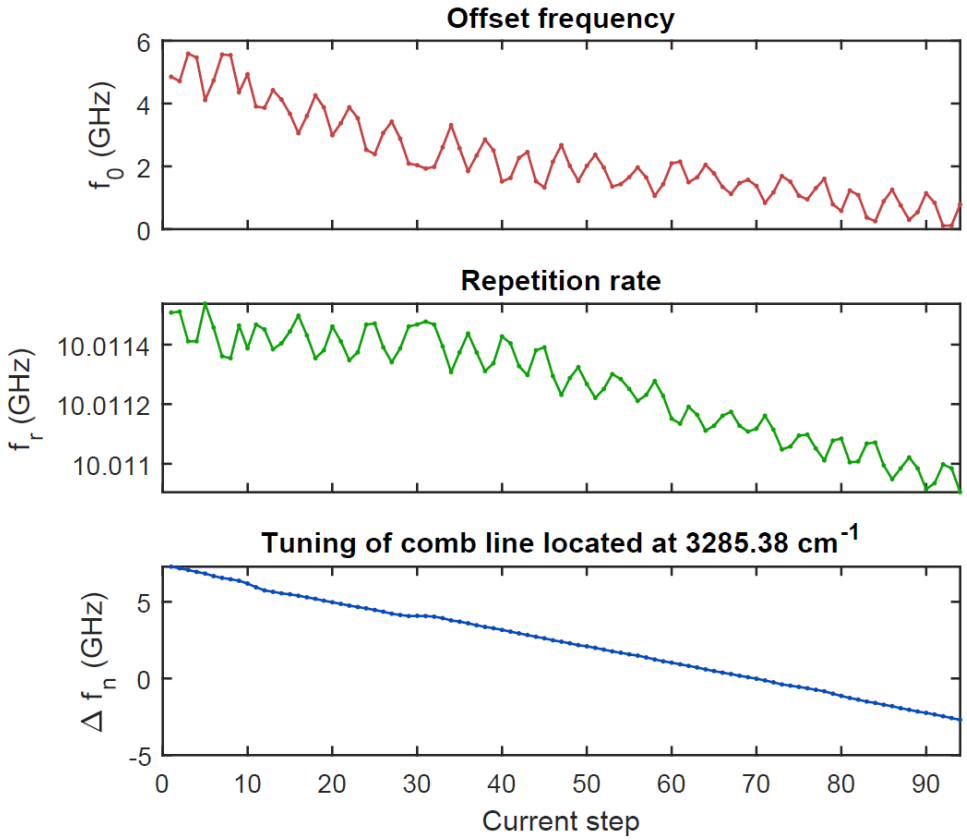

460
455
450
445
440
435
430
425
420
Current (mA)
3030
3035
3040
3045
3050
3055
3060
Wavelength (nm)

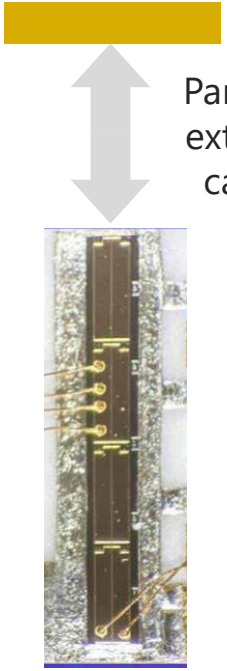

460
455
450
445
440
435
430
425
420
Current (mA)
10.011
10.0115
Frequency (GHz)
-62
-64
-66
-68
-70
-72
Power (dB)


460
455
450
445
440
435
430
425
420
Current (mA)
3034
3034.5
3035
3035.5
3036
Wavelength (nm)

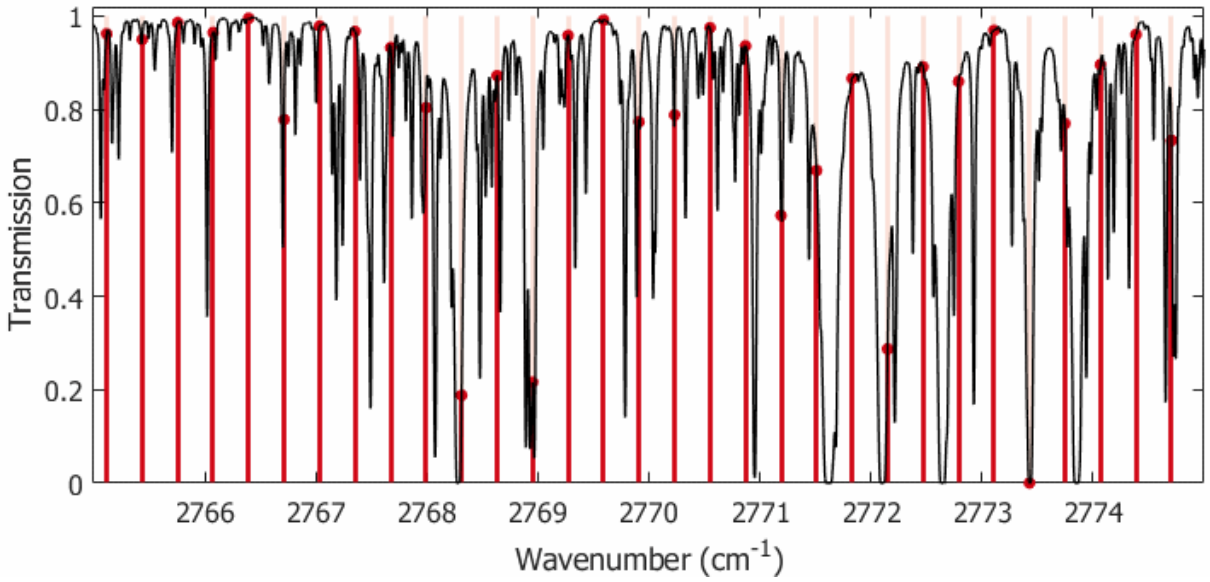

460
455
450
445
440
435
430
425
420
Current (mA)
10.011
10.0115
Frequency (GHz)
-62
-64
-66
-68
-70
-72
Power (dB)

Tuning over a full free spectral range





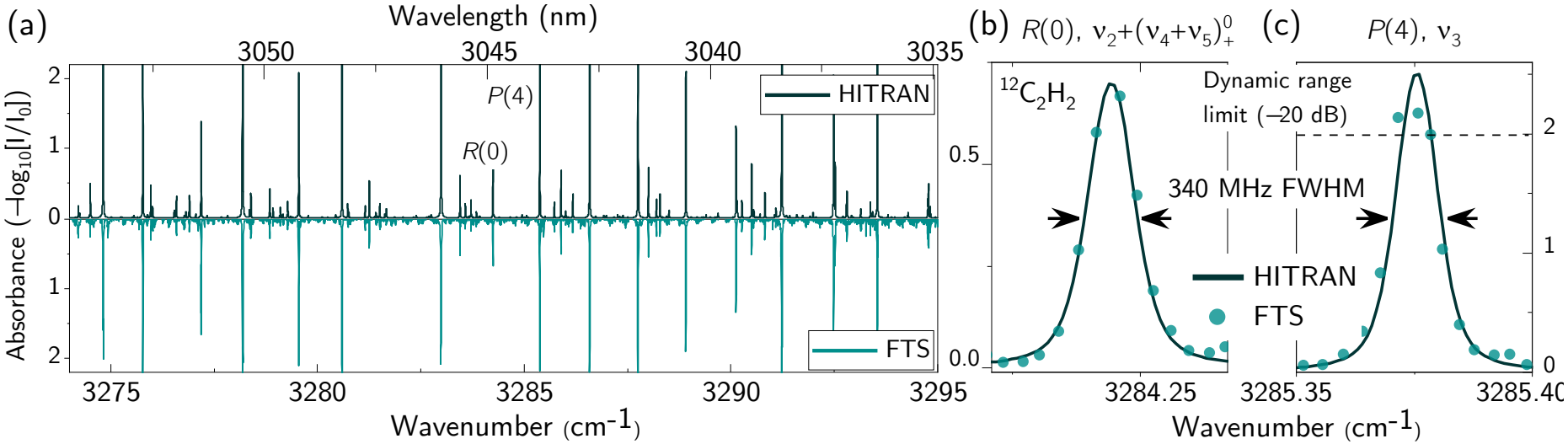
Multi-wavelength tunable laser spectroscopy



Pure CH_4, HITRAN simulation parameters *T*: 293 K, *P*: 0.1 atm (76 Torr) – for display visualization purposes

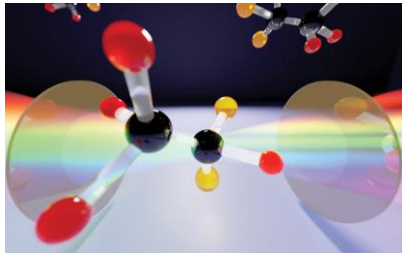
High resolution spectroscopy at 3 µm – C_2H_2

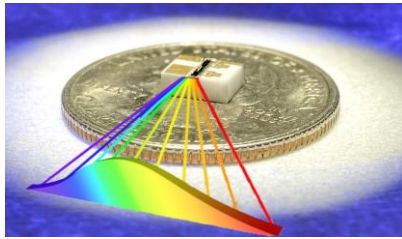
$^{12}C_2H_2$, 10 Torr



Summary

- First mid-infrared (3 μm) diode laser frequency combs. Ultra-low power consumption enables battery-operated dual-comb spectrometers.
- Suitability for mechanical high-resolution Fourier transform spectrometers.
- Future exploitation of intracavity nonlinearities for frequency conversion.





Acknowledgments

Jet Propulsion Laboratory
California Institute of Technology

This work was supported under National Aeronautics and Space Agency's (NASA) PICASSO program & PDRDF program. It was in part performed at the Jet Propulsion Laboratory (JPL), California Institute of Technology, under contract with the NASA.

USRA
Universities Space Research Association

L. A. Sterczewski's research was supported by an appointment to the NASA Postdoctoral Program at JPL, administered by Universities Space Research Association under contract with NASA.

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 101027721.

New chapter

European Research Council

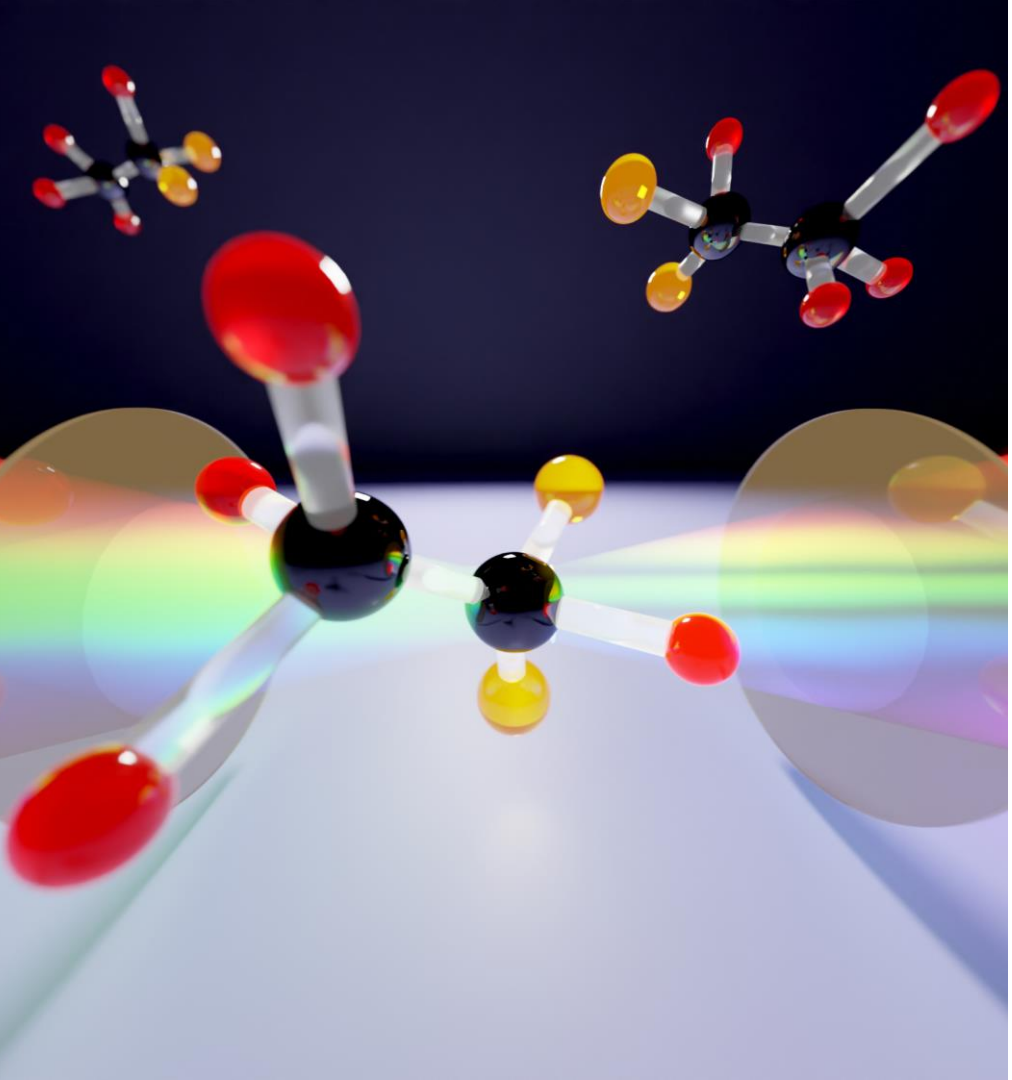
Established by the European Commission

TeraERC

Chip-based room-temperature terahertz frequency comb spectrometers (1 500 000 EUR).

lukasz.sterczewski@pwr.edu.pl

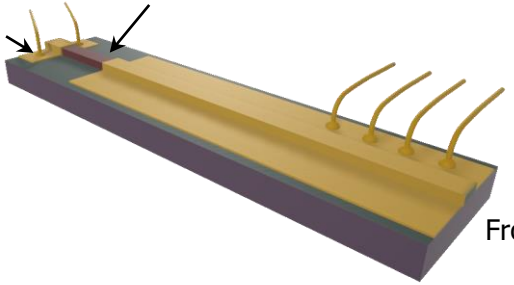
We are hiring!

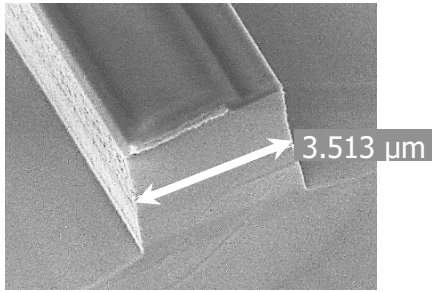


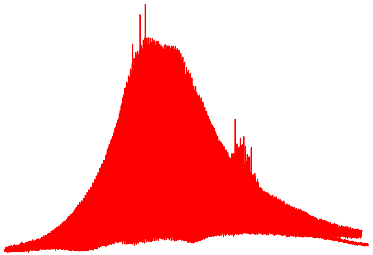
Wrocław University
of Science and Technology

lukasz.sterczewski@pwr.edu.pl
sterczewski.com

Modal leakage – well known challenge for GaSb devices

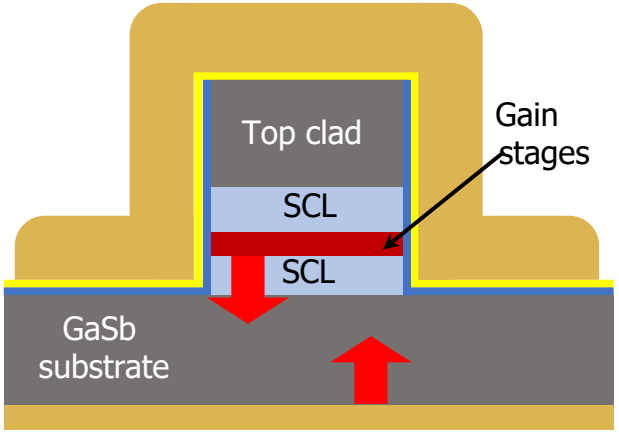




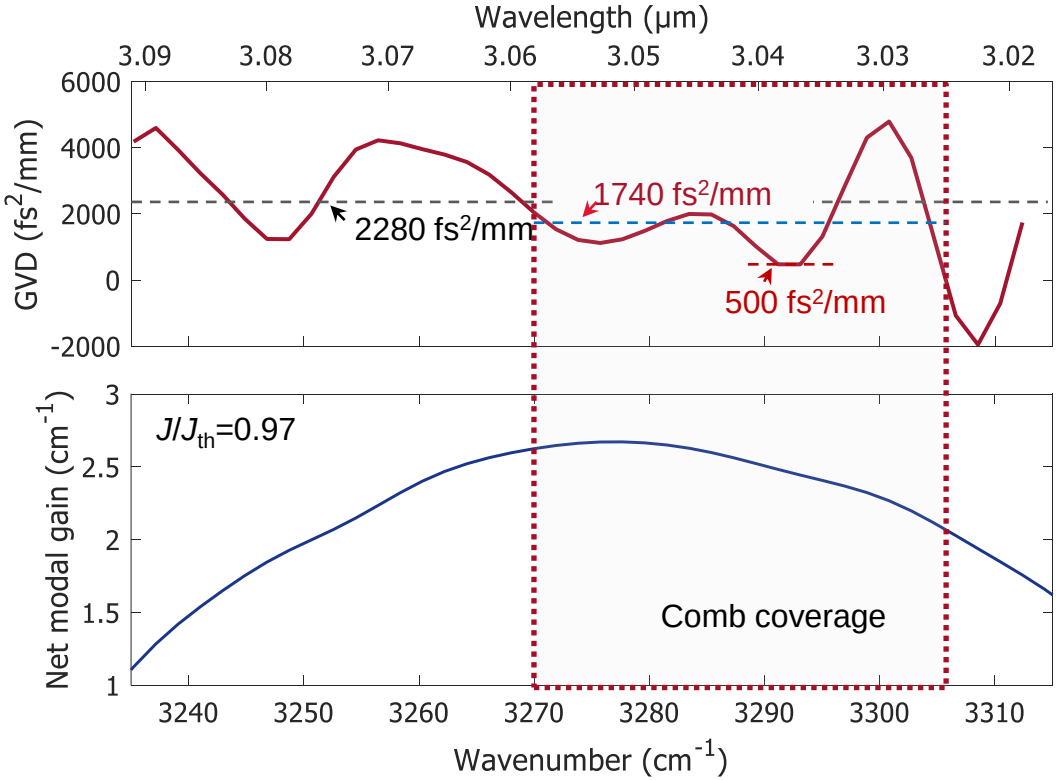


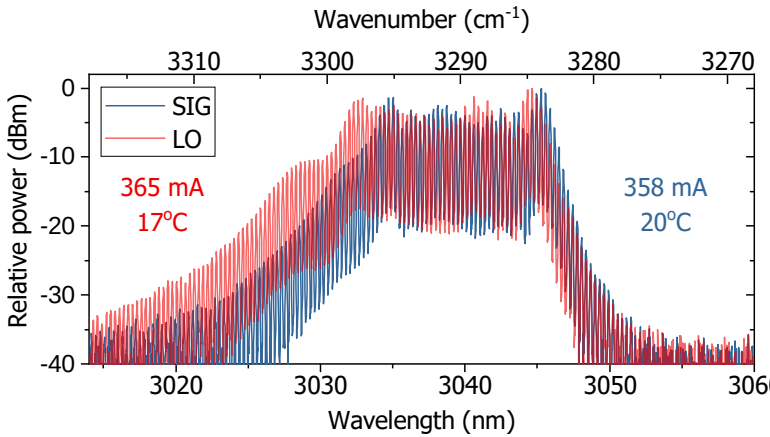
Amplified spontaneous emission

Front facet view



Gain and dispersion





Weak modal leakage acts as vertical dispersion compensation (local)