

Application of Mid-Infrared Distributed-Feedback Quantum-Cascade Lasers to Trace Gas Detection in the 8 μm Spectral Region

Anatoliy A. Kosterev, Robert F. Curl, and Frank K. Tittel

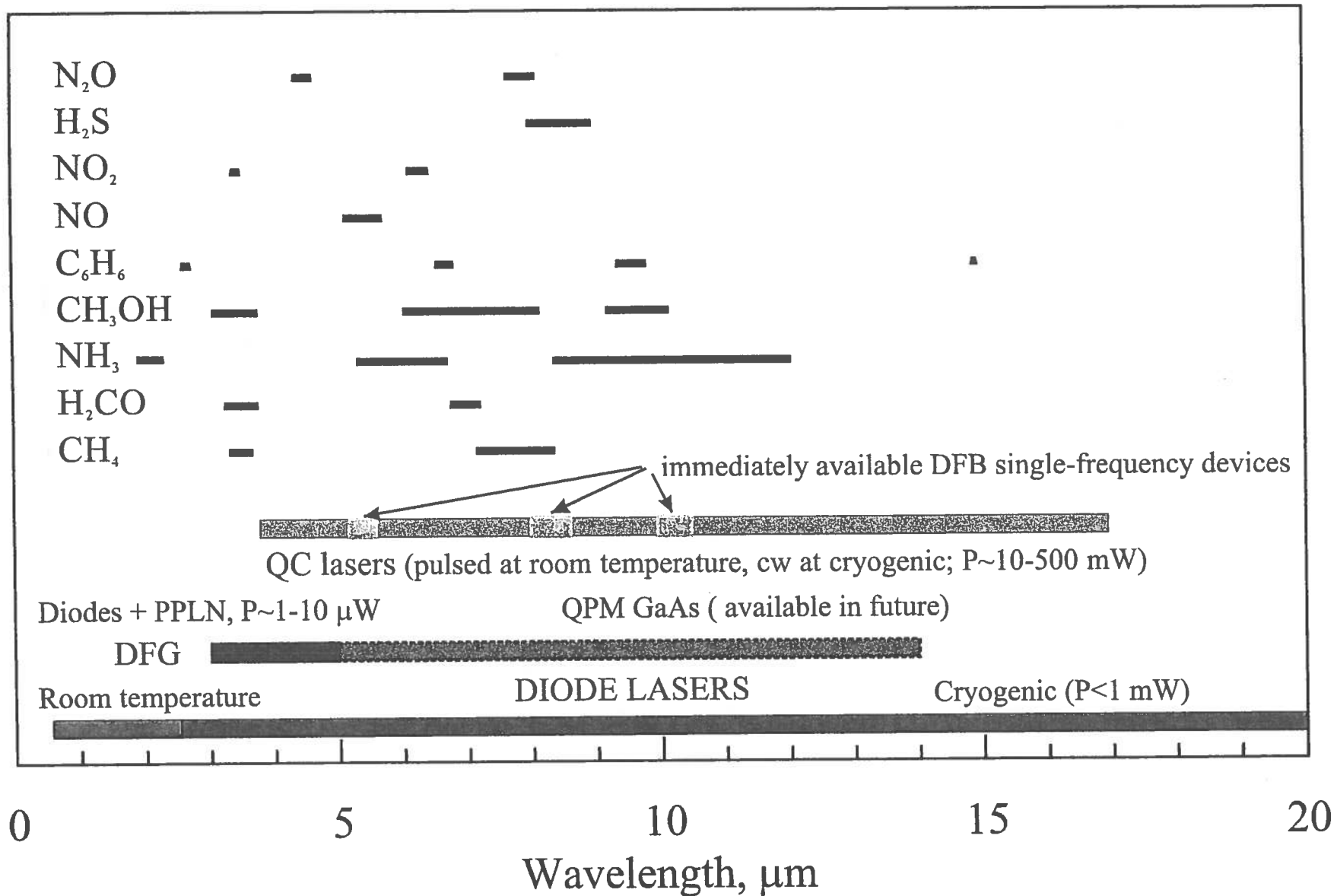
Rice Quantum Institute, Rice University, Houston, TX 77251-1892

C. Gmachl, F. Capasso, D.L. Sivco, J.N. Baillargeon, A.L. Hutchinson,
and A.Y. Cho

*Bell Laboratories, Lucent Technologies, 700 Mountain Avenue,
Murray Hill, NJ 07974*



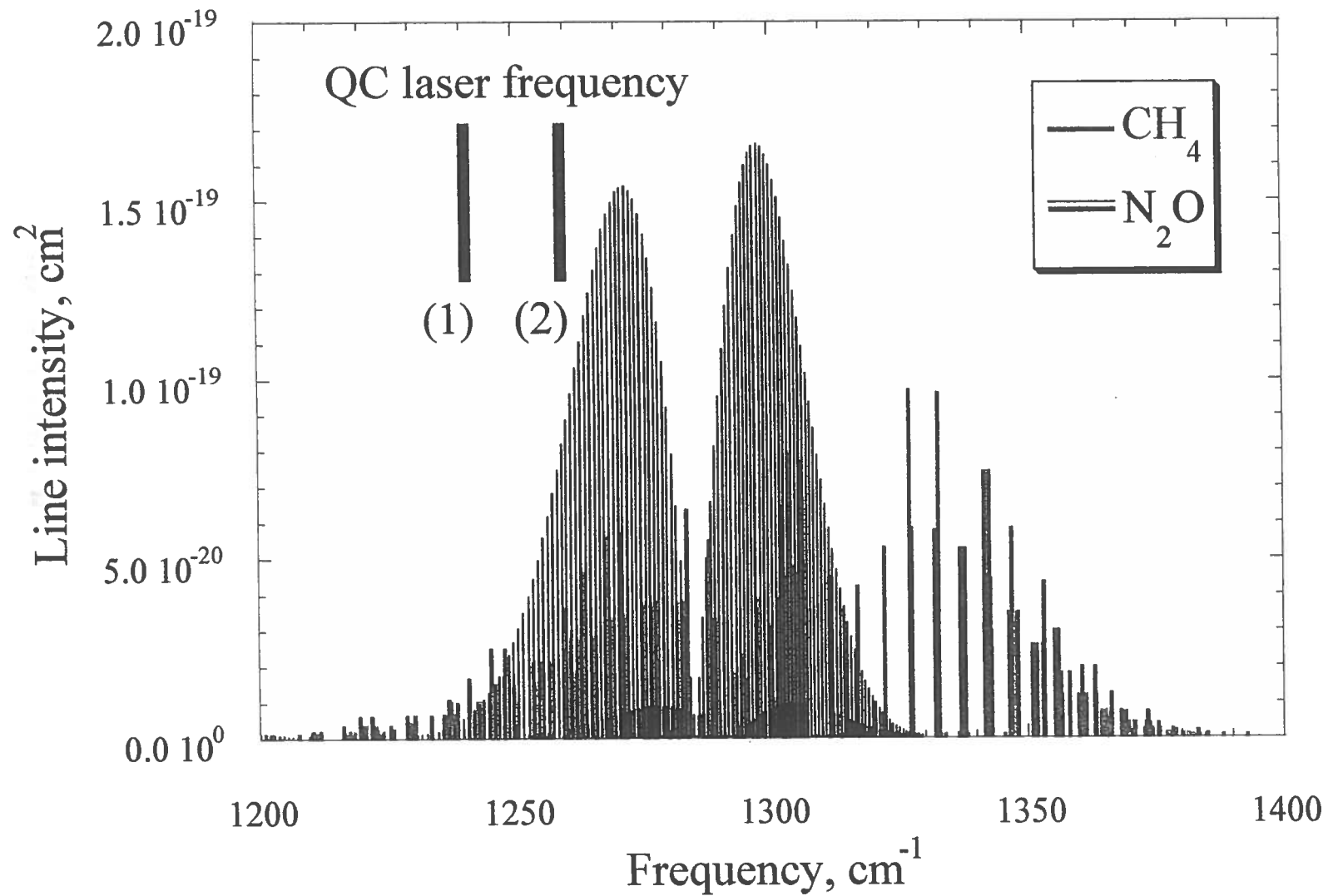
Spectral Coverage by Diode/QC Lasers



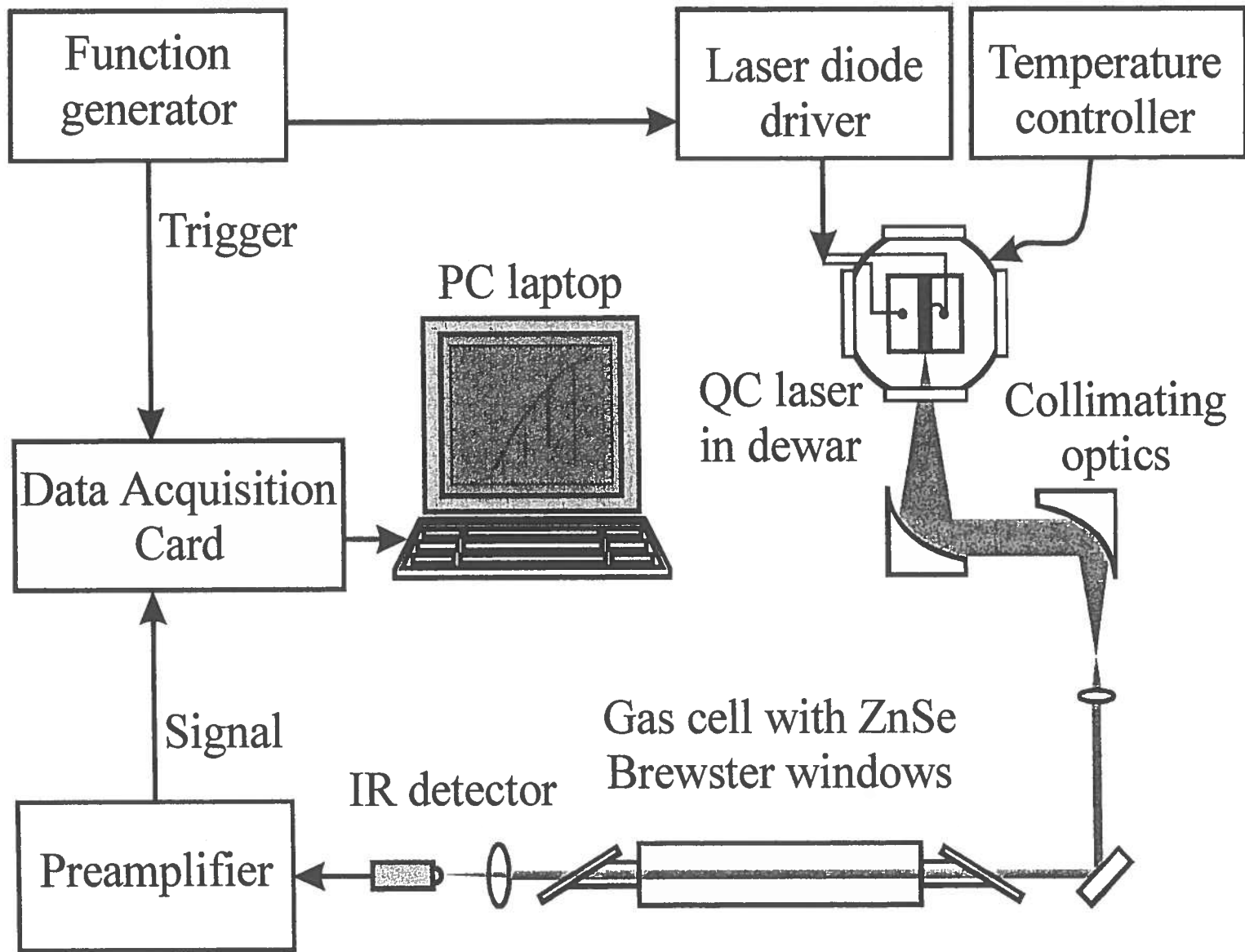
Motivation for CH₄ Detection

- Contributor to global warming
- Important in tropospheric and stratospheric chemistry
- Emitted by microorganisms
- Can leak from gas pipelines

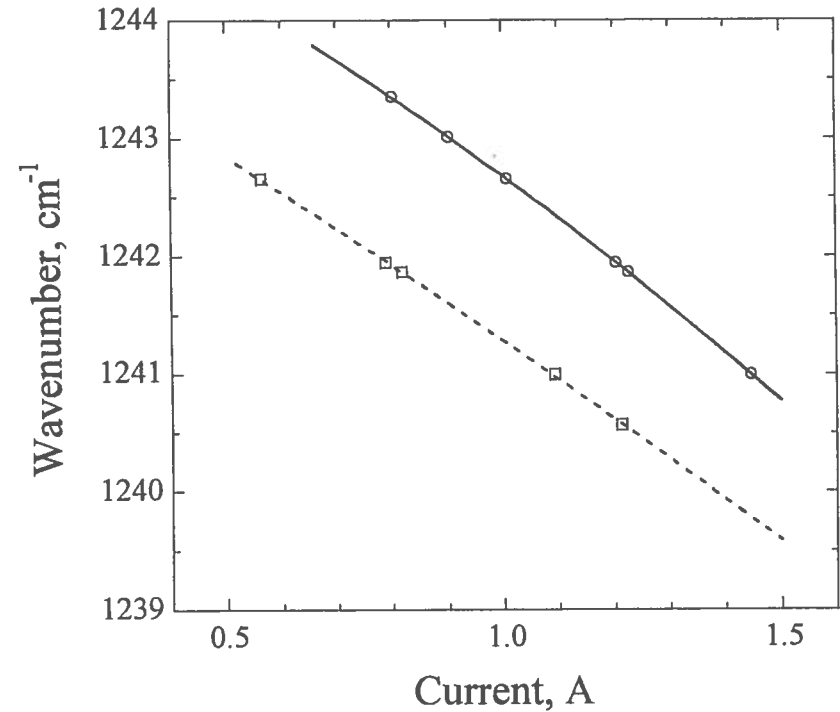
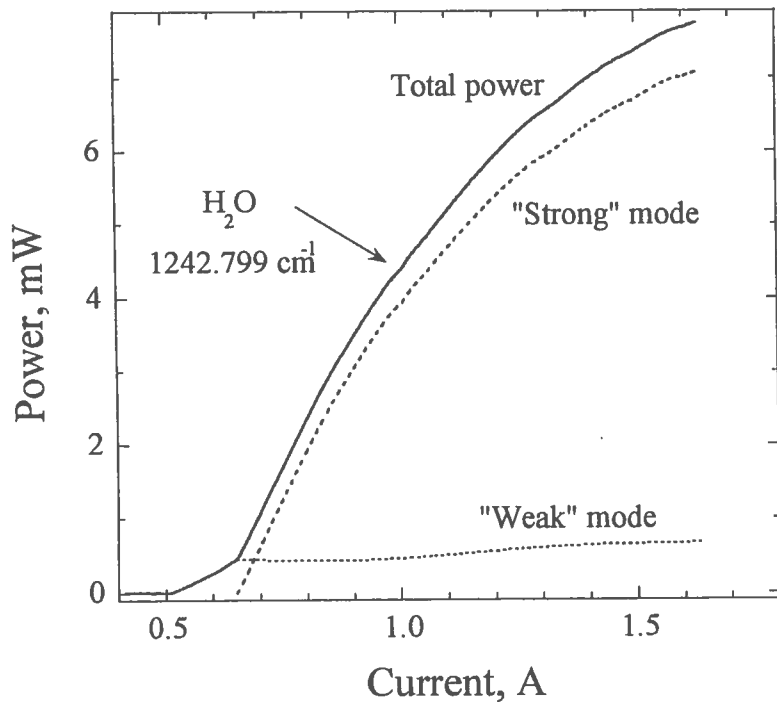
CH₄ and N₂O Absorption Spectra



Quantum Cascade-DFB Based Gas Sensor

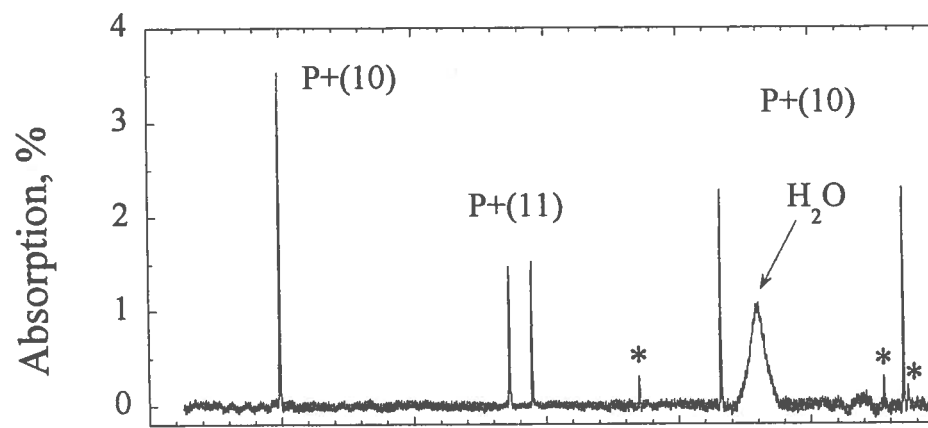


QC Laser (1) Characteristics

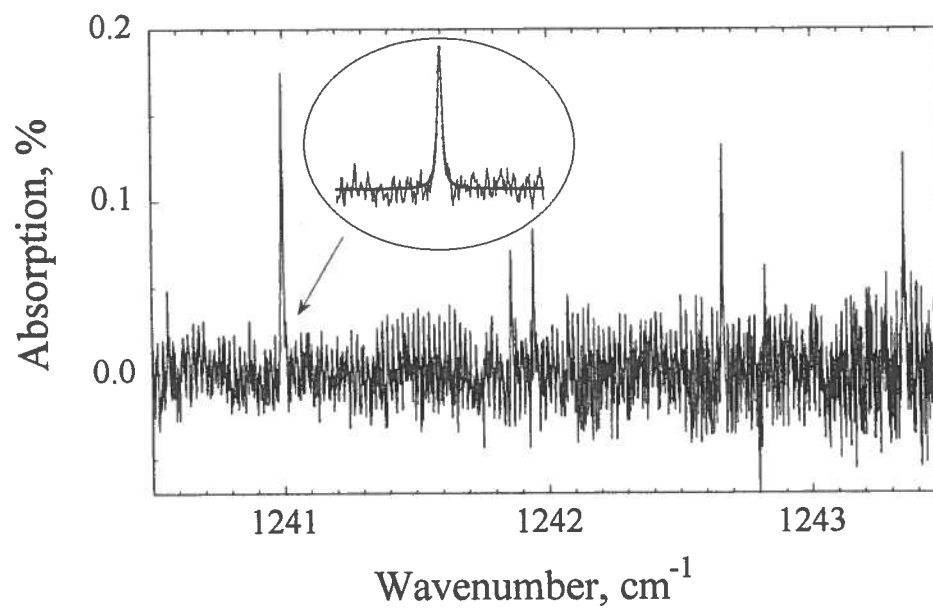


Detection of CH₄ Near 1241 cm⁻¹

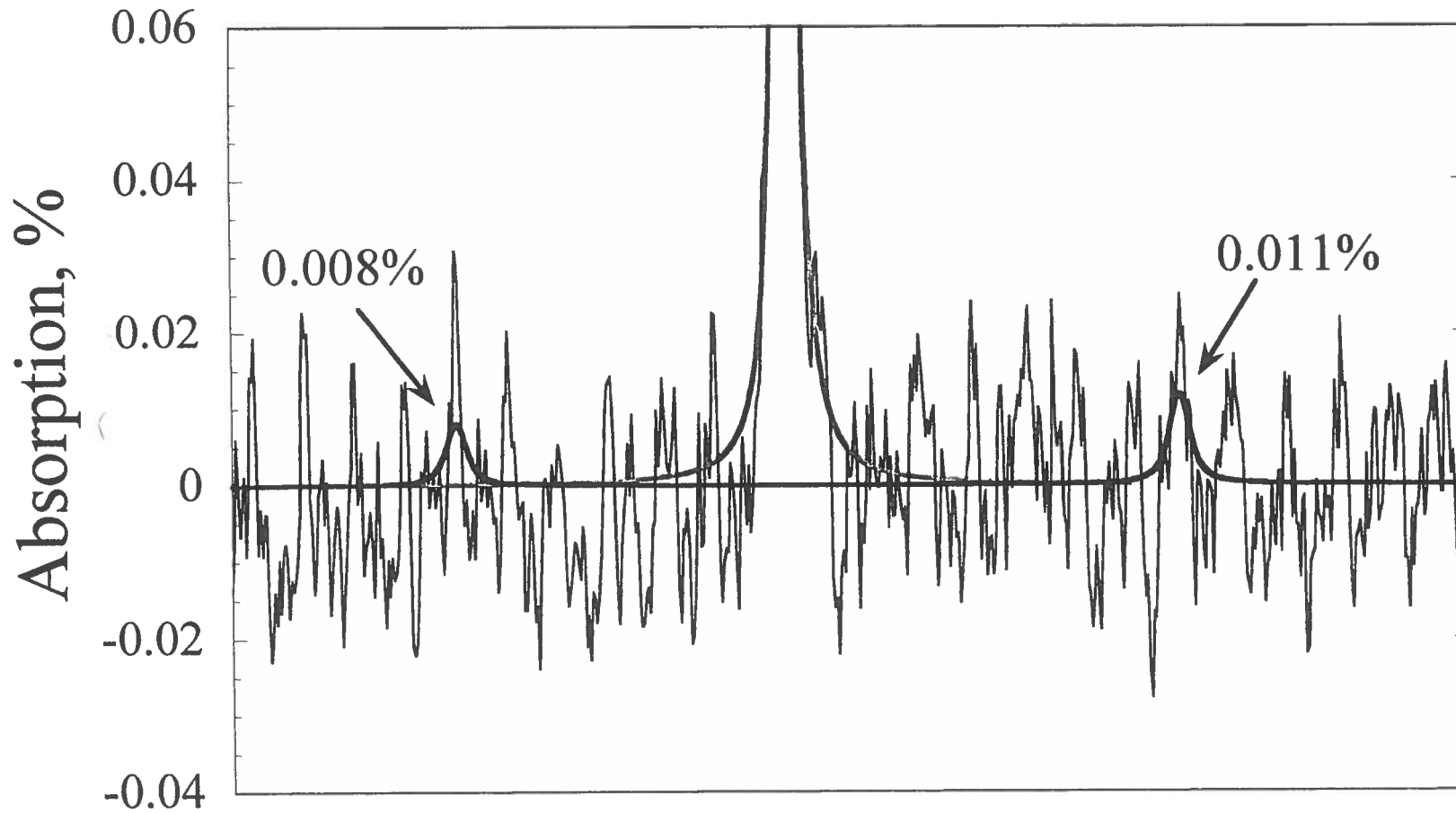
6.5 mTorr,
pure CH₄



16 ppm of CH₄
in 50 Torr of air



Estimate of Detection Sensitivity



Simulated false “lines” are always $\lesssim 0.01\%$

\Rightarrow The detection limit is 10^{-4} absorption
for absorption



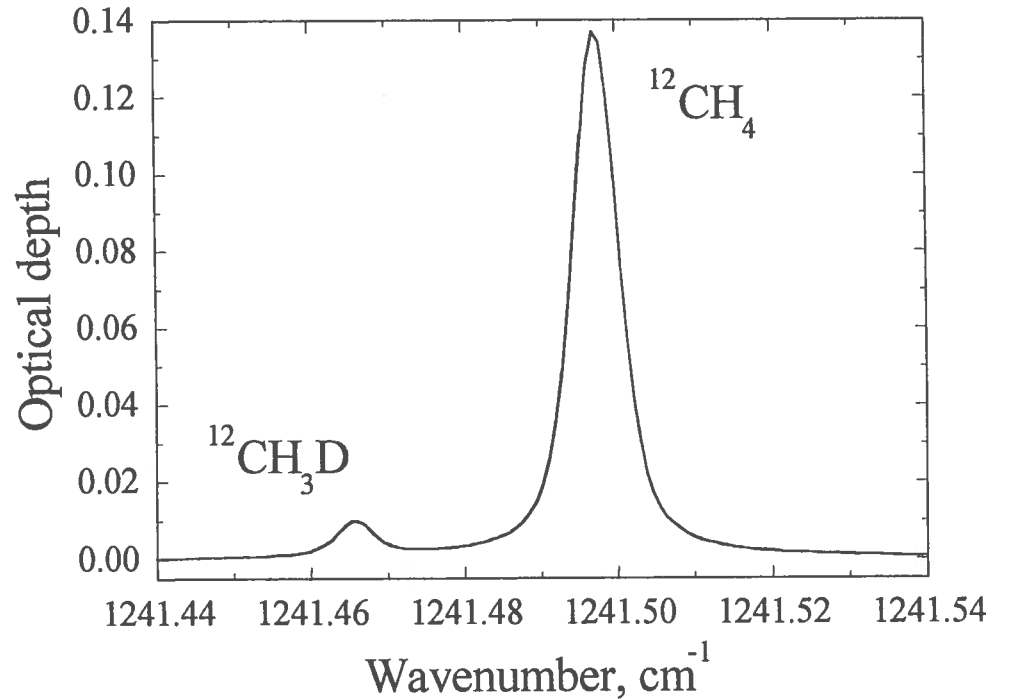
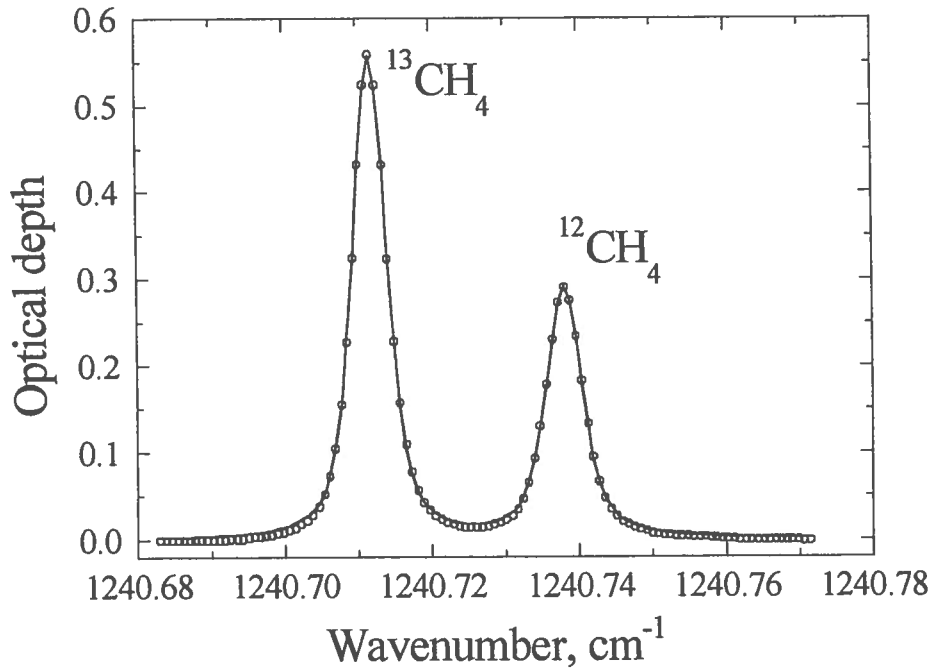
Importance of Isotopic Measurements

Different sources of methane
(or other trace air components)
have different isotopic signatures



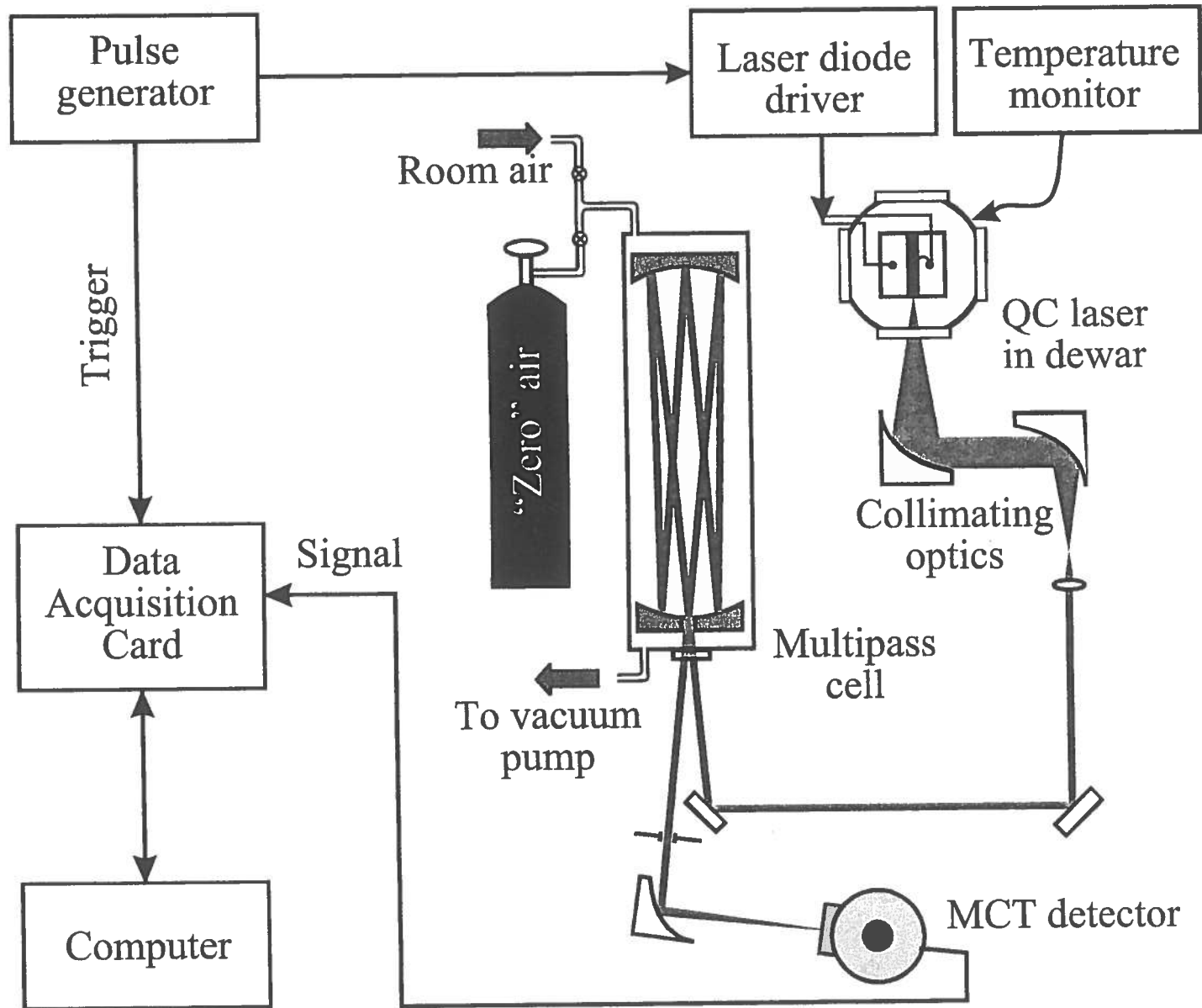
Knowledge of isotopic composition helps to
identify sources and sinks of trace gases

Isotopic Composition of CH₄

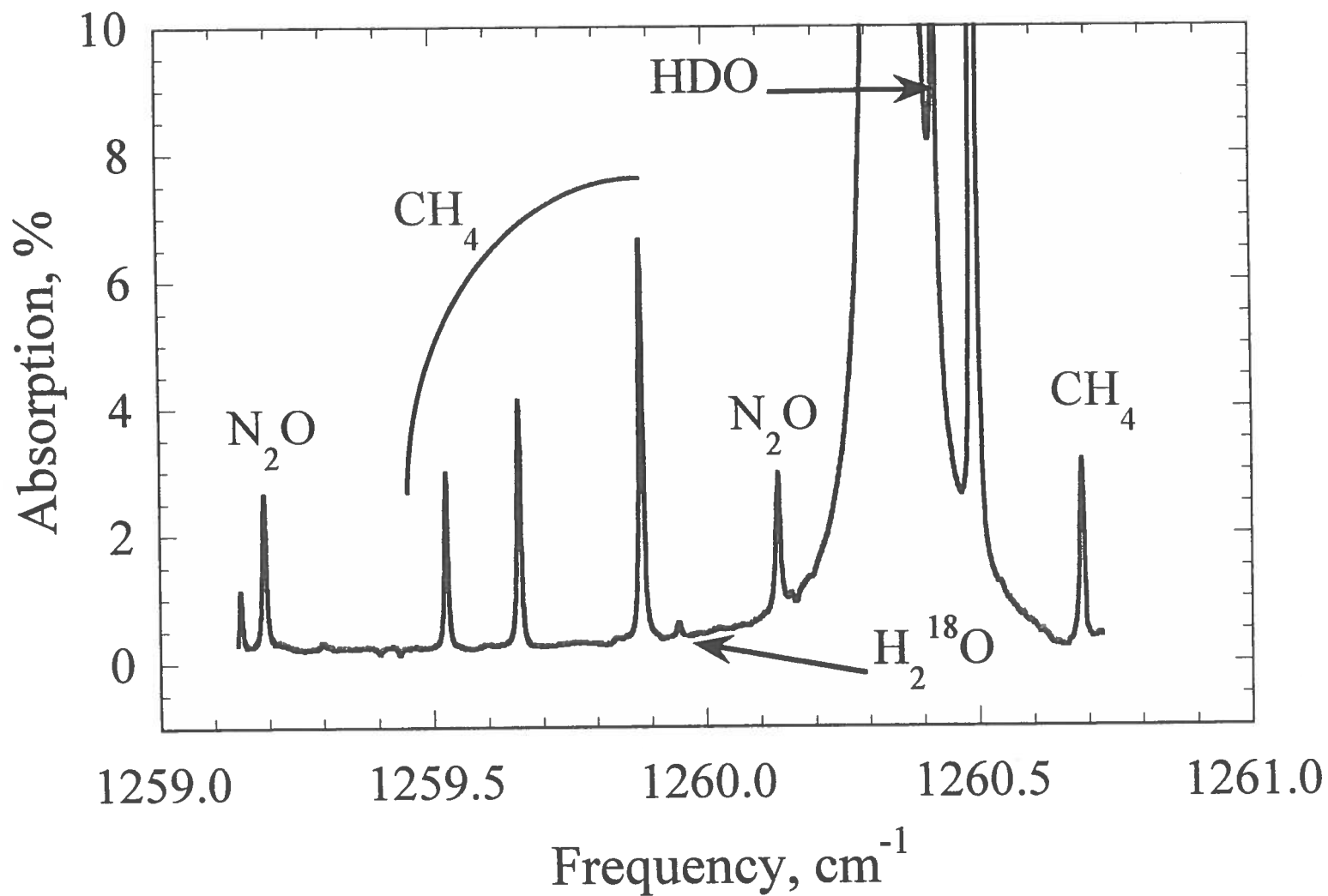


pressure.
path length

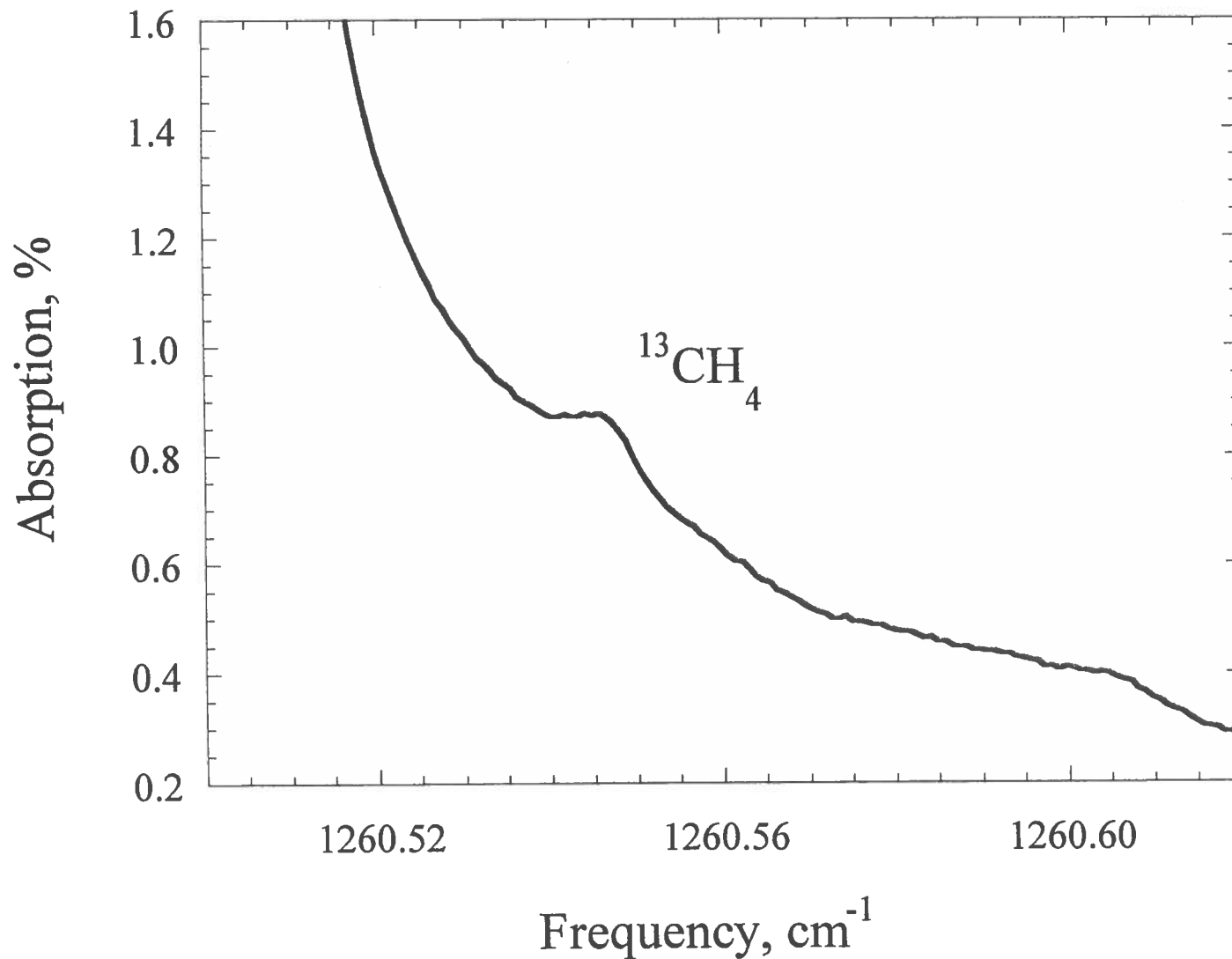
Trace Gas Detection with a Multipass Cell



Absorption Spectrum of Room Air



Detection of $^{13}\text{CH}_4$ in Ambient Air



Summary and Future Outlook

- A ^{CW} QC-DFB laser based gas sensor ^{@ 8 μm was} ~~is~~ designed and tested for methane and nitrous oxide detection
- A detection limit of ^{10⁻⁴} ~~10⁻⁴~~ ^{min} ~~for absorption~~ ^{was obtained} ~~is reached~~ ^{for}
- Isotopic composition measurements ^{were} ~~are~~ demonstrated

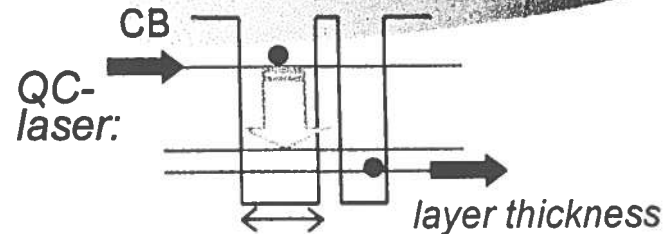
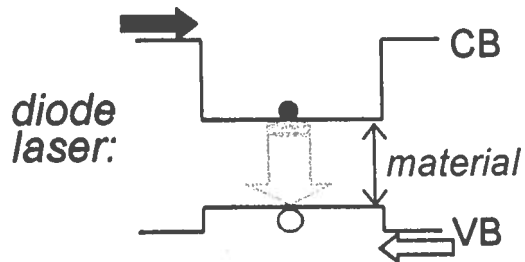
Future development

- ◆ More efficient suppression of optical interference fringes
- ◆ Detection of more complex organic molecules
- ◆ Room-temperature operation

Quantum Cascade Lasers

- Laser wavelengths cover entire range from 3.4 to 17 μ m determined by layer thickness of same materials
- Intrinsically high power lasers (determined by number of stages)
 - CW: 0.2W @ 80 °K, ~100 mW single frequency
 - Pulsed: 0.5W peak, ~15 mW avg. @ 300 °K
- High Spectral purity (single frequency with DFB structure)
- Continuous tuning by temperature or current
- High reliability: low failure rate, long lifetime and robust fabrication

unipolar quantum-cascade (QC) laser



- ◆ “materials by design”: band structure engineering and MBE population inversion, matrix elements, scattering times, and transport are designed for optimum performance
- ◆ tailor wavelength throughout mid-IR via thickness control:
 - » 3 - 17 μm
- ◆ N laser photons per injected electron through cascading:
 - » very high power: 0.5 - 1 W
- ◆ wide range of sensor applications:
 - » environmental, automotive, medical, military, ...

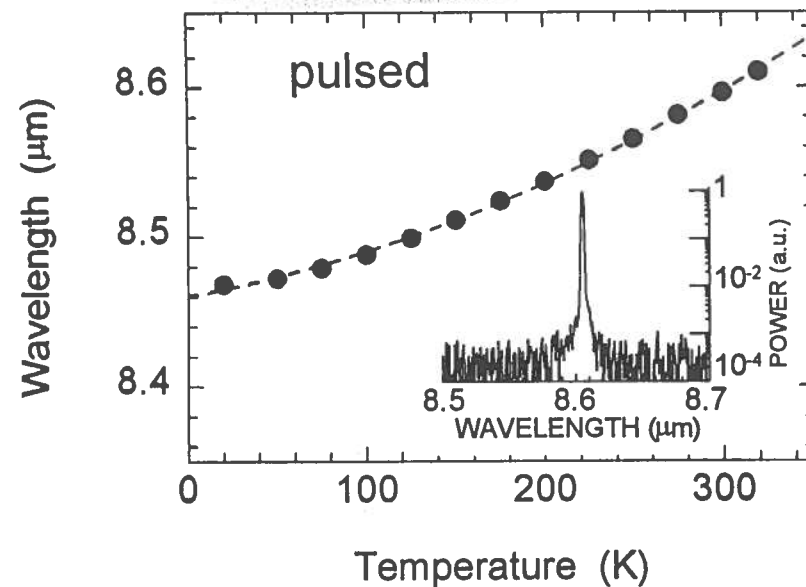
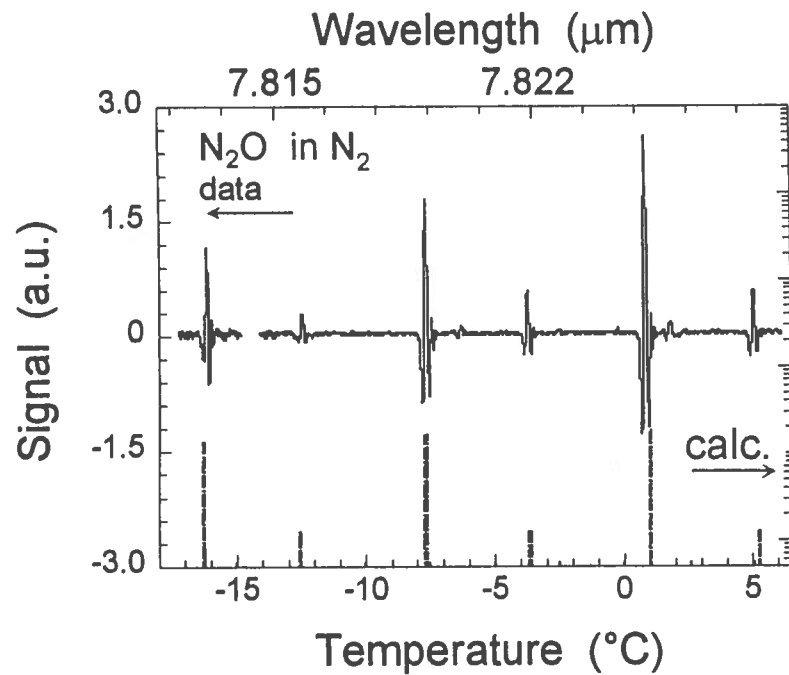


quantum cascade laser: milestones

- ◆ tailored wavelength from 3.4 - 17 μm
- ◆ high-power operation ($\lambda \approx 8 \mu\text{m}$)
 - cw: 200 mW @ 80 K, 20 mW @ 145 K
 - pulsed: 520 mW peak, 14 mW average @ 300 K
- ◆ tunable single-mode QC-DFB laser
 - *demonstration of gas sensing capability (cw and pulsed)*
- ◆ multi-wavelength operation: 6.6 μm , 7.3 μm , 8 μm
 - from intrinsic, finite superlattices with tailored phonon bottle-neck
- ◆ quantum cascade “bow-tie” lasers



DFB performance: single-mode and widely tunable



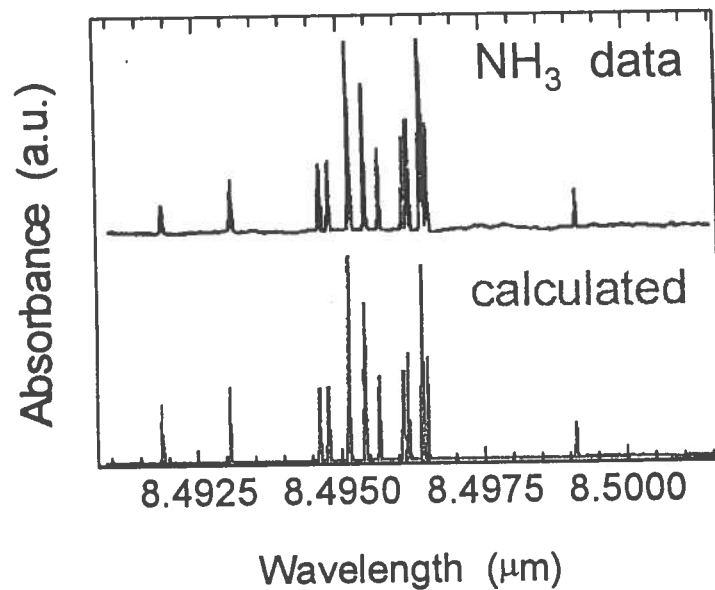
- ◆ unprecedented single-mode tuning range
- ◆ side mode suppression ratio > 30 dB
- ◆ room temperature trace gas sensors: $250 \text{ ppb-m/Hz}^{0.5}$

collaboration with: Stevens Institute, NJ

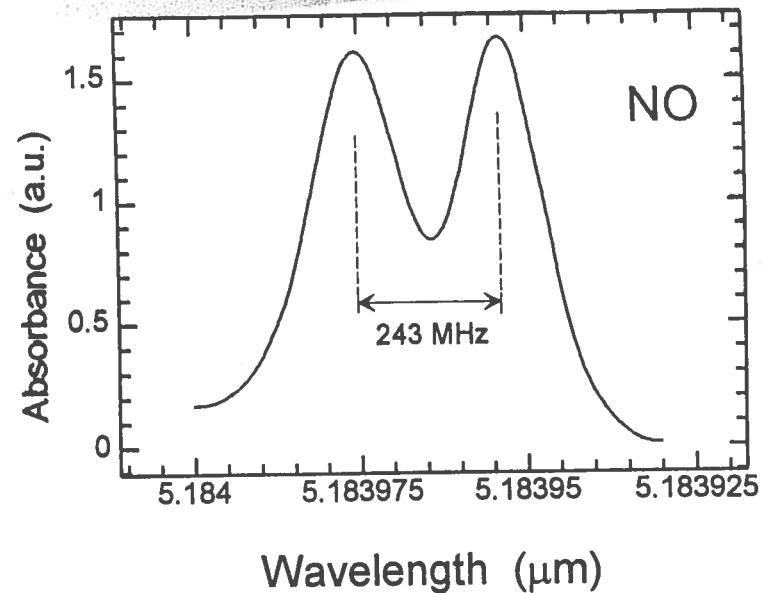
Lucent Technologies
Bell Labs Innovations



Doppler limited, high resolution spectroscopy



cooled (LN₂) continuous wave lasers:
sensitivity limit: 2×10^{-5} absorbance



narrow cw linewidths:
~ few MHz, technical noise-limited

collaboration with: Pacific Northwest National Lab.

Lucent Technologies
Bell Labs Innovations



Spectral Coverage by Diode/QC Lasers

