In-situ and Standoff Gas Detection Using Laser Spectroscopy

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ARPA-E Workshop
Ubiquitous Methane Leak Detection Through Novel Sensors and Sensing Platforms

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TECHNOLOGY

Infrared Lasers

In situ sensors

Standoff sensors

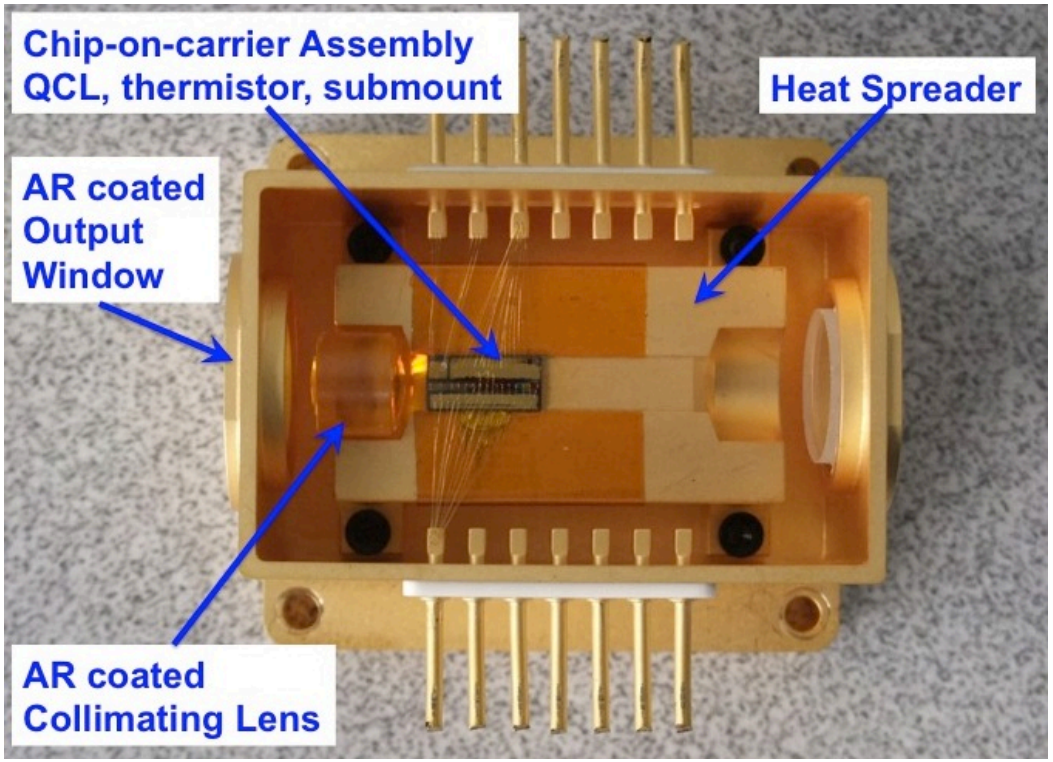
Why Optical Detection

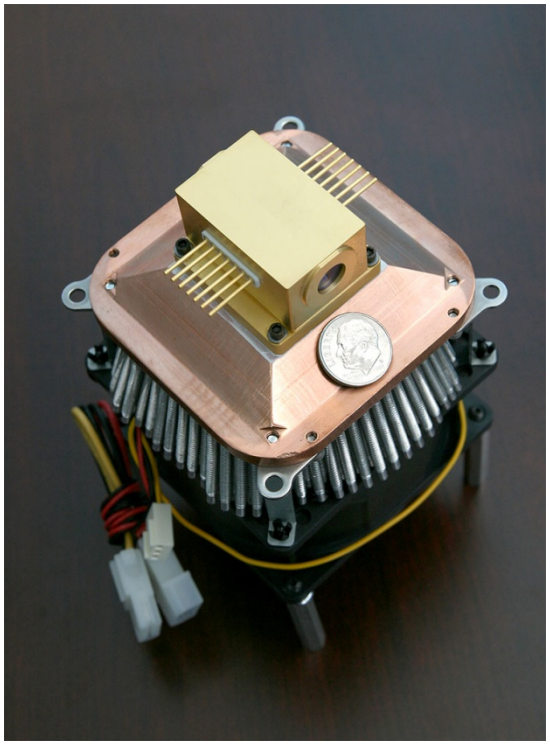
- Vast majority of molecules absorb light in the IR
- Unique spectral features
- Number of sensitive optical techniques developed for detection of many molecules
- A variety of lasers available
  - Mature technologies for deployment
    - Step tunable CO_2 lasers (9 μm to 11 μm)
    - Quantum cascade lasers (3.6 μm to >11 μm)
  - New technologies needing more development
    - Interband cascade lasers (3 μm-5 μm)

Quantum Cascade Lasers

- Unipolar semiconductor lasers for the infrared region
- Only lasers that operate continuously at room temperature in the midwave and longwave infrared
- Pranalytica pioneered new designs (several patents granted and pending) that made possible highest powers and highest efficiencies
- Quantum cascade lasers have completely changed the defense and homeland security applications
- At present, Pranalytica is the only vertically integrated supplier of high power quantum cascade laser systems in the world
- All manufacturing done in the USA

Hermetically Sealed CW/RT 4.6 μm QCL on Air-Cooled Mount

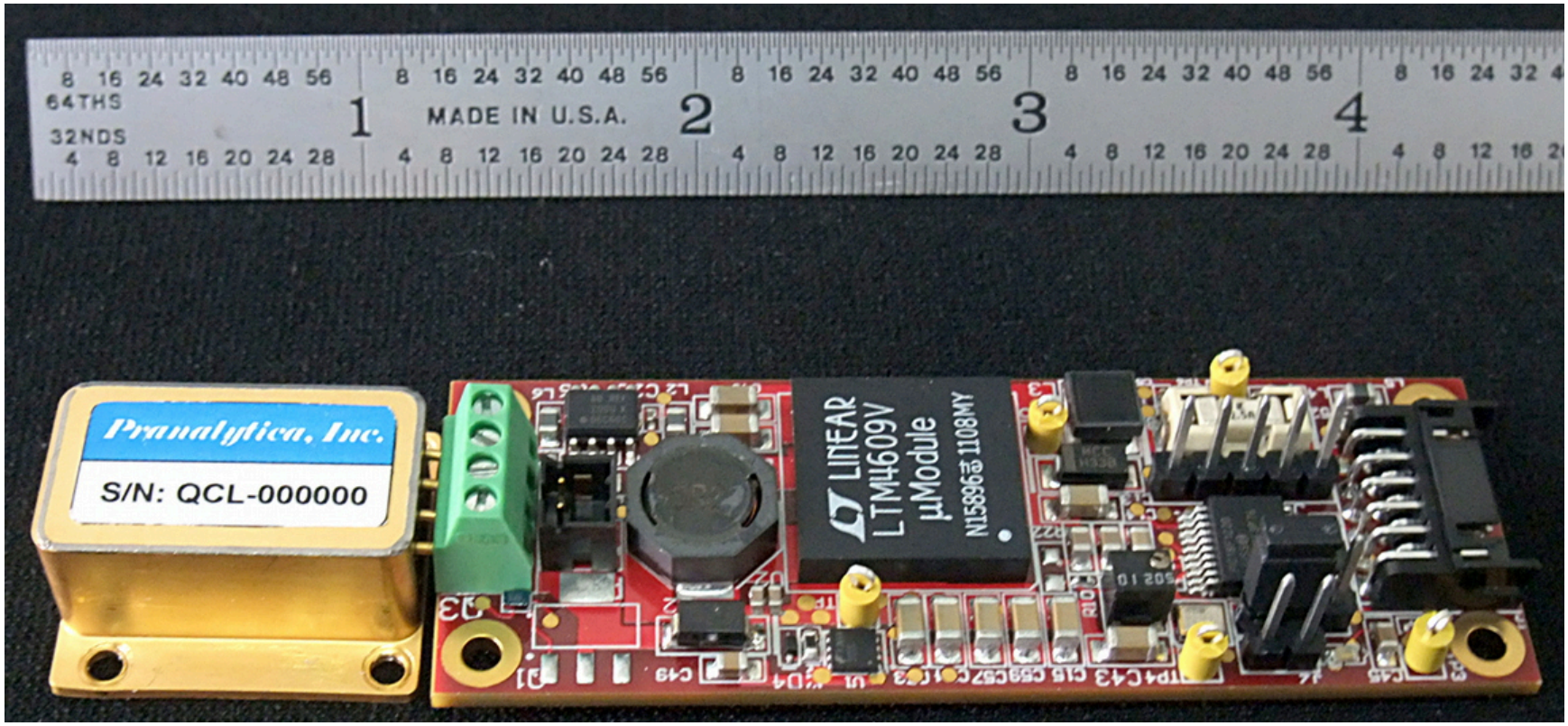




Utilize highly reliable, telecom grade materials and processes (conceptually consistent with Telecordia standards for reliability)

Hermetically Sealed CW/RT QCL Package on Air-Cooled Mount

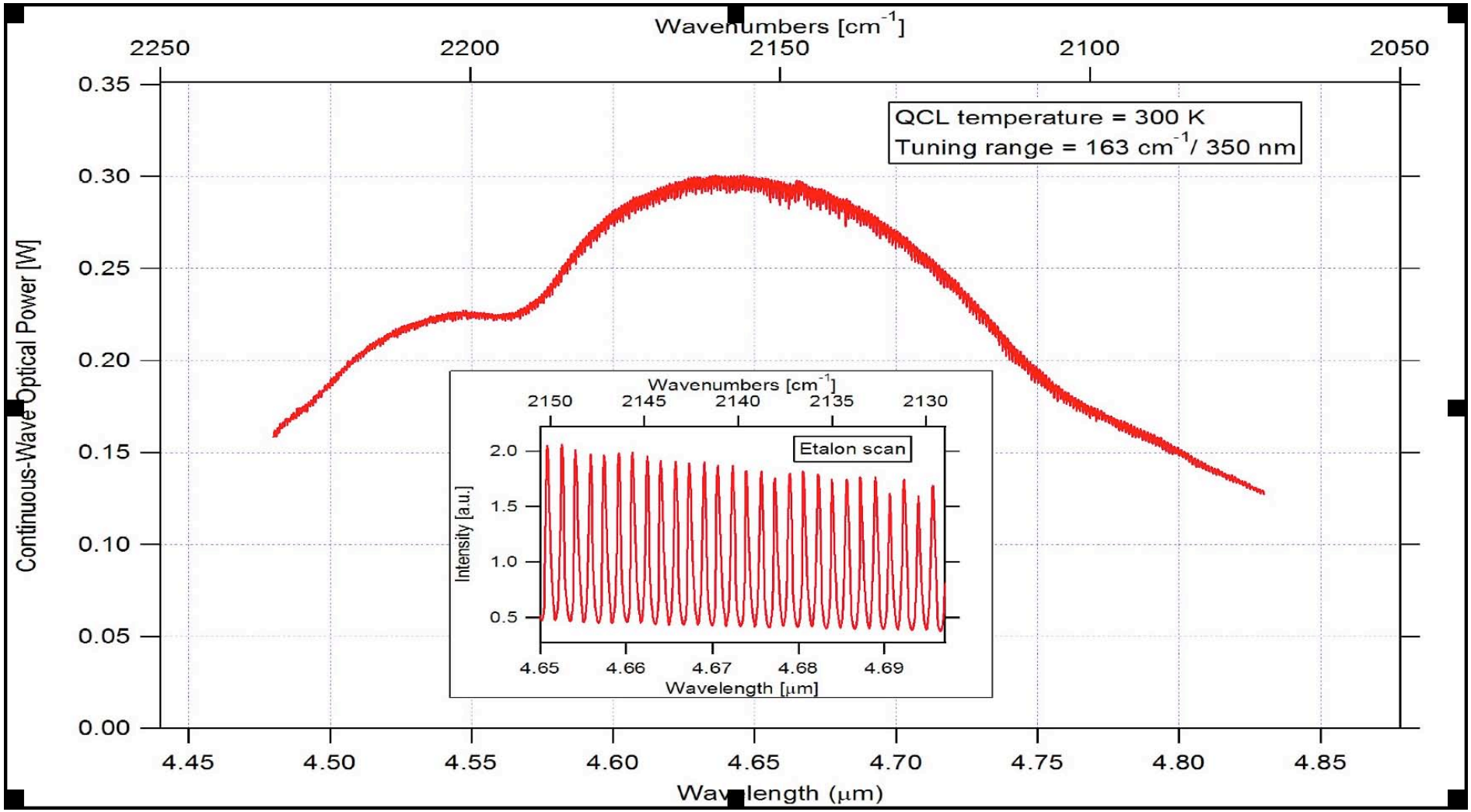
Ultra Small, Ultra Light QCL Package



Total weight < 2 Oz; WPE 10%

Meets MIL-STD VIB/SHOCK/TEMP requirements

EGC Spectral Output from 4.6 µm QCL

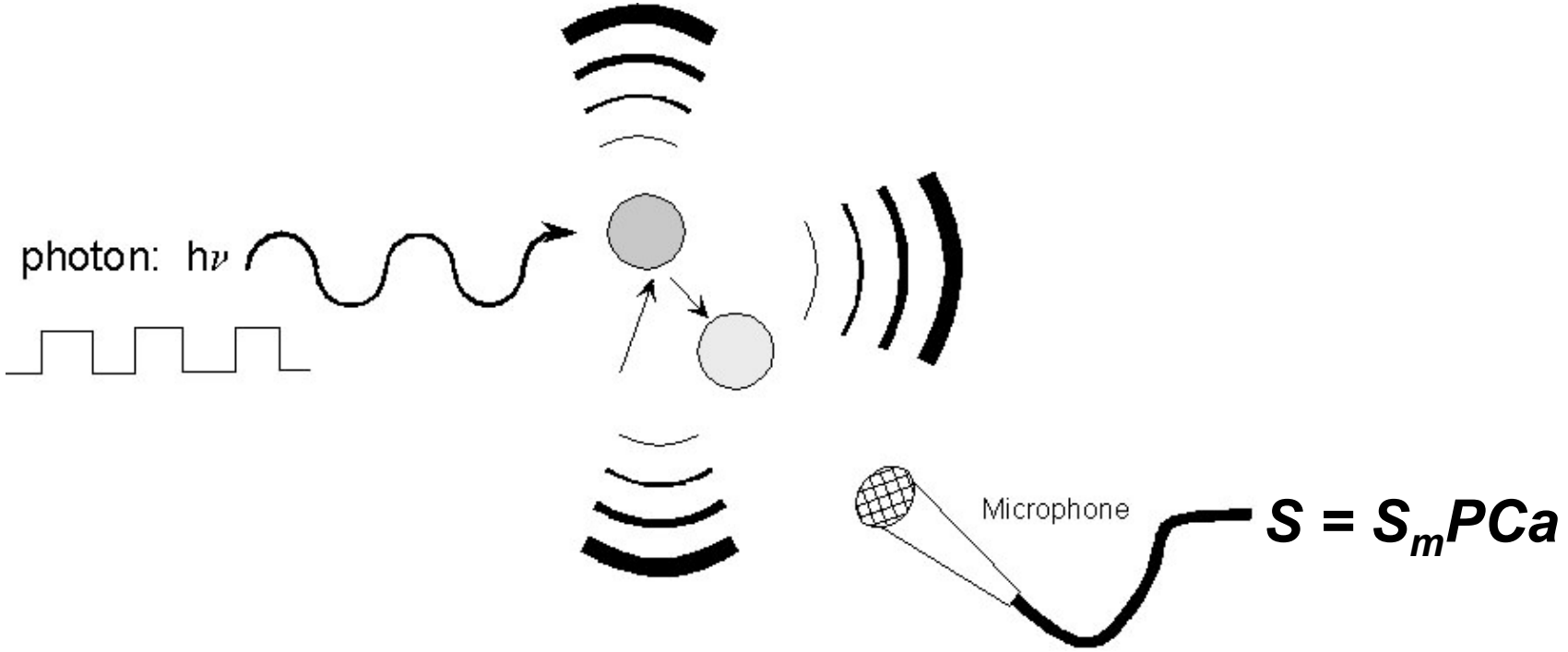


Currently Available Tunable High Power CW/RT QCLs (InGaAs/InAlAs System)

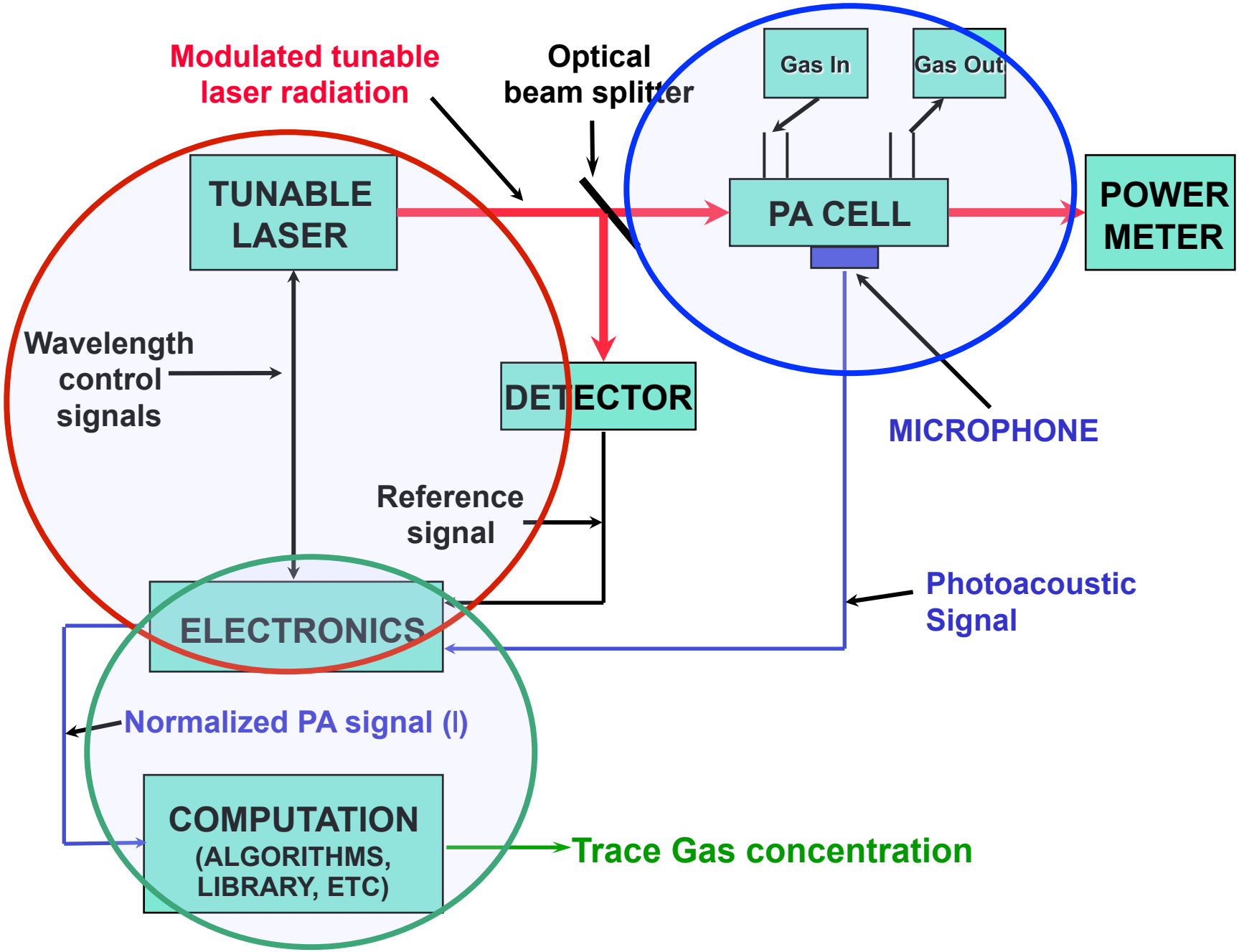
Center Wavelength	CW/RT Power (FP Geometry)	Tunability[1]
4.0 μm	> 2 W	3.8 μm-4.2 μm
4.6 μm	> 3.5 W	4.3 μm-5.0 μm
5.3 μm	~ 500 mW	5.0 μm-5.6 μm
6.2 μm	~ 500 mW	5.9 μm-6.5 μm
6.8 μm	~ 500 mW	6.5 μm-7.0 μm
7.2 μm	~ 1.4 W	7.0 μm-7.5 μm
8.2 μm	~ 1 W	8.0 μm-8.5 μm
9.2 μm	~ 1.5 mW	9.2 μm-9.6 μm
10.2 μm	~ 500 mW	9.6 μm-10.8 μm
10.6 μm	~ 500 mW	10.3 μm-11.0 μm
11.3 μm	~ 200 mW	10.9 μm-11.7 μm

[1]Measured linewidth < 4 MHz

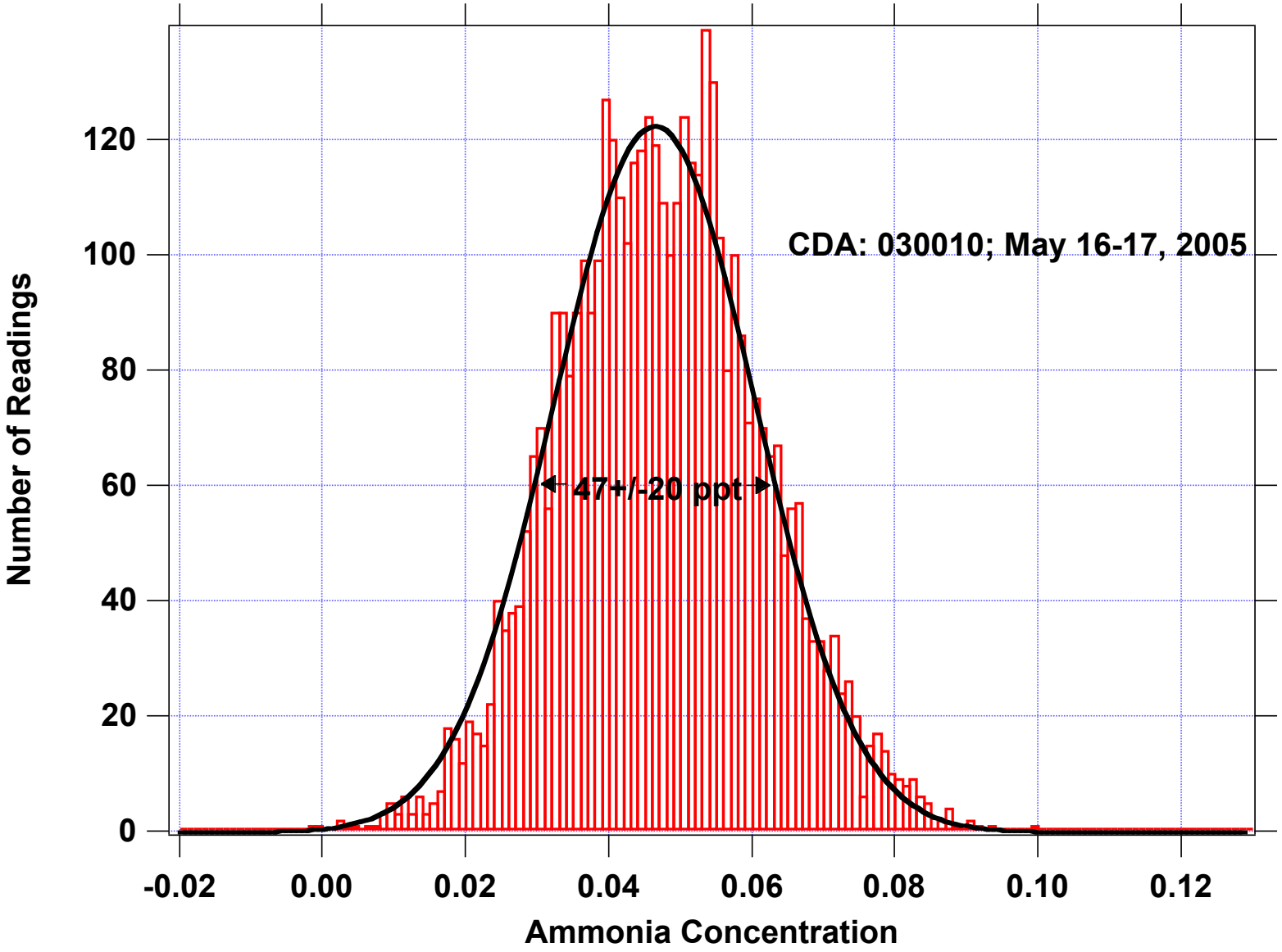
Photoacoustic Spectroscopy for *in situ Sensors*



- Incoming photon excites target molecule
- Collisional de-excitation converts absorbed energy into local heating and pressure waves


Modulated tunable laser radiation
Optical beam splitter
Gas In
Gas Out
TUNABLE LASER
PA CELL
POWER METER
Wavelength control signals
DETECTOR
MICROPHONE
Reference signal
Photoacoustic Signal
ELECTRONICS
Normalized PA signal (I)
COMPUTATION (ALGORITHMS, LIBRARY, ETC)
Trace Gas concentration

48 Hour Statistical Analysis of Clean Air Data



O-Nose™ Technology: Ammonia Status

- Ammonia sensor based on tunable CO_2 laser
- "World Record" sensitivity for laser-based gas detection systems
- 20 ppt sensitivity for NH_3 (14 ng/m^3)
- The only TRUE stable guaranteed 100 ppt sensor for ammonia that is not affected by interferences
- Portable
- Real-time (10±2 second measurement time)
- Continuous & autonomous
- Multiplexing capability
- No disposables or consumables
- Push-button operation; no operator intervention needed

O-Nose™ Technology: Detection of Other Gases

- Same platform
- Change the wavelength of the laser to match the absorption wavelength of the target gas
- Use different types of lasers for different gases
  - CO_2 laser: Detection of ammonia, arsine, 1,3-butadiene, DMF, benzene, toluene, xylene, SF_6, SO_2, HNO_3, NO_2, ...
  - Near IR semiconductor laser: Detection of NH_3
  - Quantum cascade lasers: Detection of CWAs, explosives, many other TICs, Methane
- Can custom design a sensor for almost any target gas
- Detection sensitivity from 10 ppt to 1 ppb depending on the target gas (most gases at <100 ppt)

Pranalytica *In-Situ* Gas Sensors

GAS	SENSITIVITY	GAS	SENSITIVITY
Acetic acid	200 ppt	Nitric acid	1 ppb
Acrolein	500 ppt	Nitric oxide	1 ppb
Ammonia	100 ppt	NO_2	0.5 ppb
Arsine	1 ppb	Ozone	500 ppt
1,3-butadiene	500 ppt	Phosphine	1 ppb
DMMF	500 ppt	Silane	200 ppt
Ethylene	200 ppt	SF_6	1 ppt
Formaldehyde	1 ppb	Toluene	1 ppb
Methane	100 ppt	Xylene	1 ppb

Pranalytica's Commercial *In-Situ* Gas Sensors

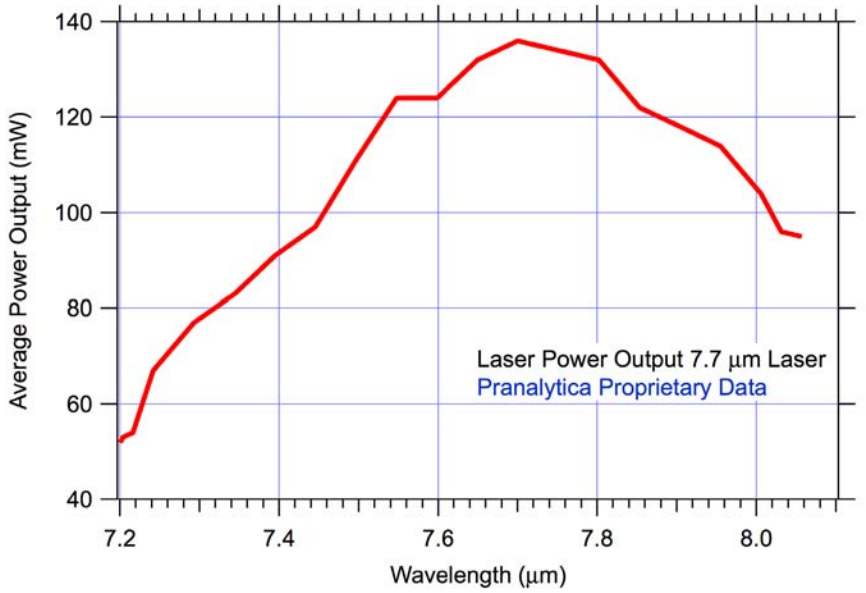
Nitrolux-100 (20 ppt) for semiconductor fabline applications (over 50 sensors already deployed)

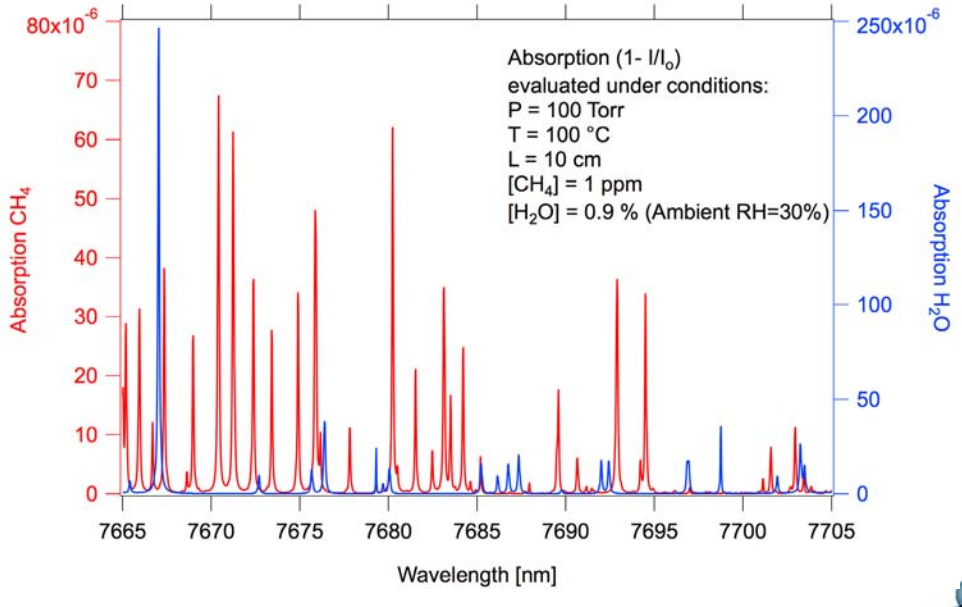
Gas Sensing System with sensors for ammonia and SO_2 and 32-point sequential switch

Nitrolux-S (40 ppb) for agricultural applications

Methane Detection: Pranalytica

- Use tunable LWIR quantum cascade lasers with PA spectroscopy at ~7.7 µm
- Select appropriate wavelength scan region
- Can detect ~100 ppt level of methane in urban and other contaminated environment in ~ 10 seconds

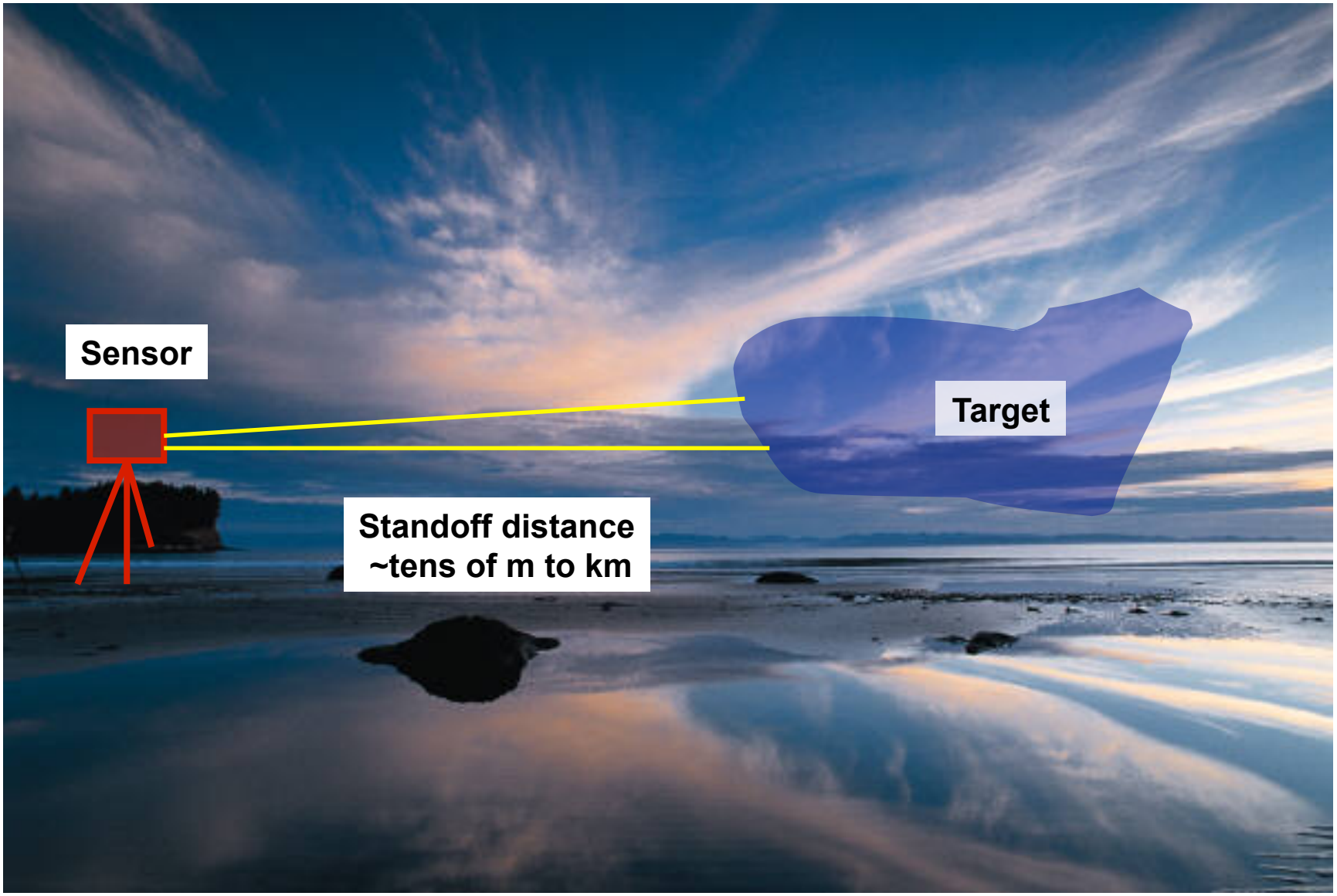




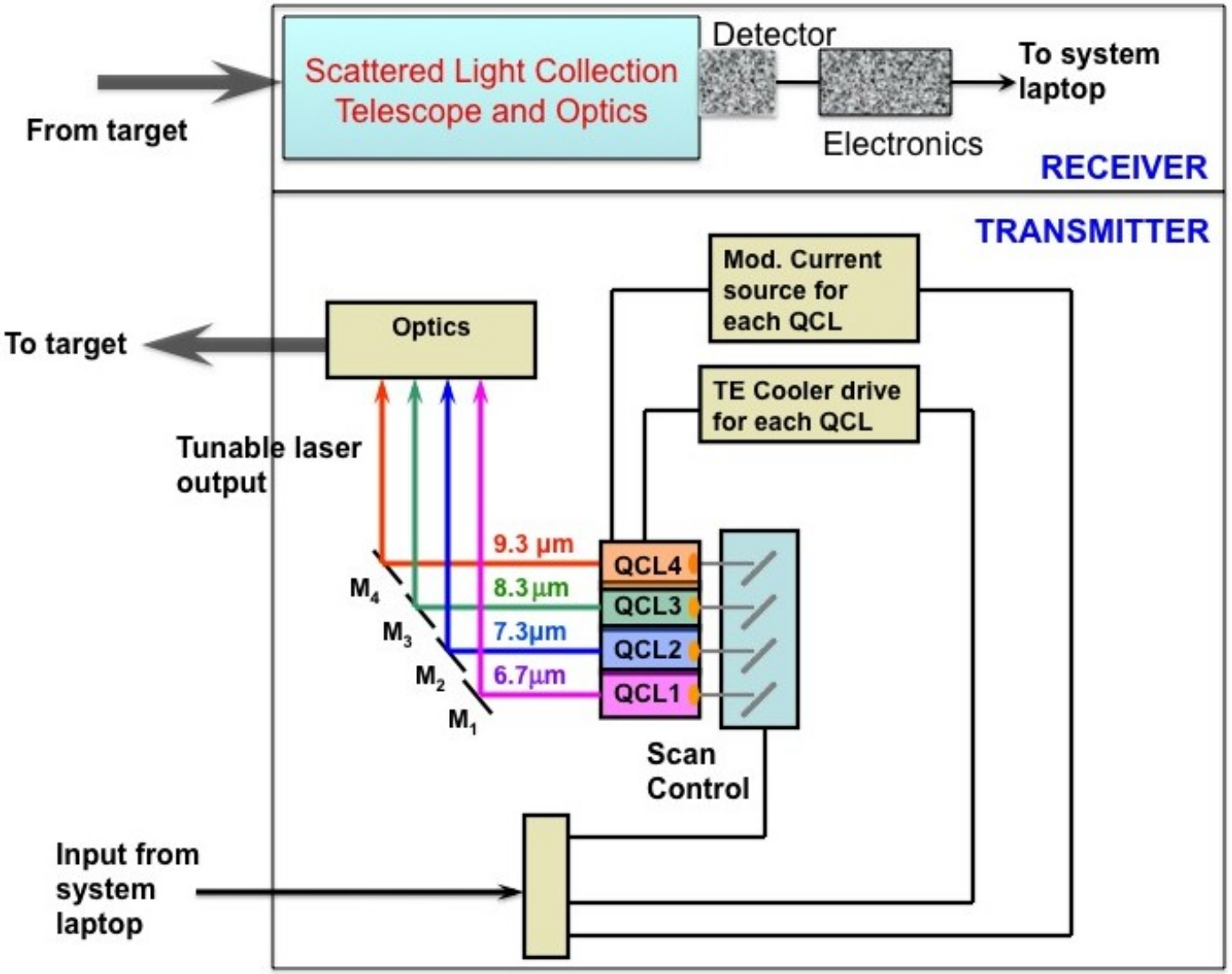
Standoff Detection of Gases

- Use tunable QCL radiation for looking at scattered light from remote objects
- Use wavelength dependent scan signal to determine absorption features
- Very successful in determining surface contamination on distant objects (e.g., IEDs)
- Very successful in measuring distant column of gases (field demonstration at China Lake for detection of SF_6 column at 450 meters)

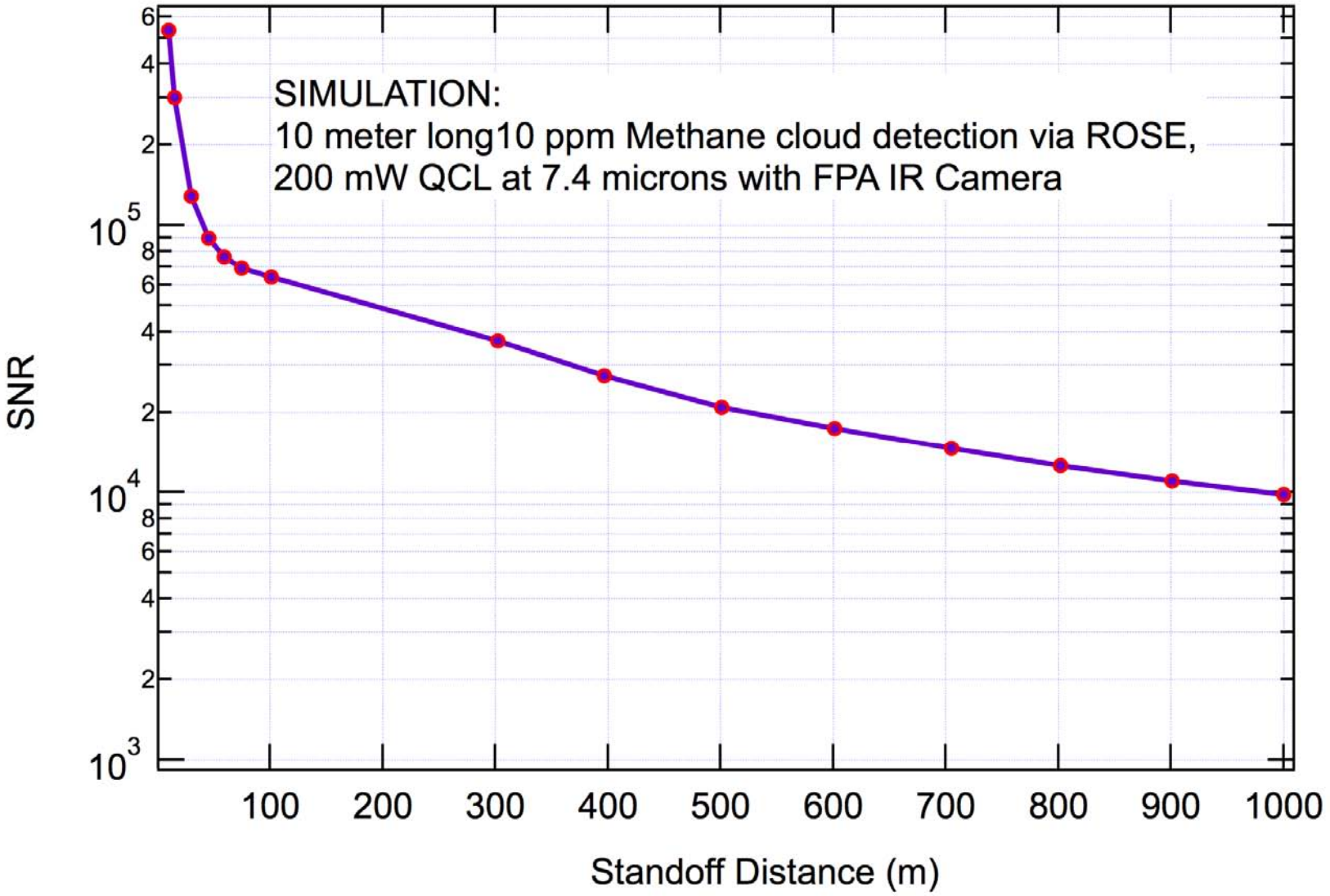
Standoff Detection (ROSE)



Standoff Infrared Detection of Gases



Standoff Detection Methane (Simulation)



Standoff Sensor

Standoff Sensor

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