Mid-Infrared Laser Heterodyne Systems
From Earth Observation to Security and Defence

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Outline

- Laser Heterodyne Radiometer (LHR)
  - Earth Observation rationale
  - Principles and capabilities
  - Hollow waveguide miniaturization

- Security & Defence applications
  - Capability Gap
  - Adapting LHR to the problem
  - Early demonstration
  - Prospects
Earth Observation Needs
LHR capabilities well aligned

- Atmospheric composition measurements
  - Finer geographical coverage
  - Better vertical resolution
  - Improved sensitivity
  - From light and compact platforms

- Laser heterodyne radiometer (LHR)
  - High sensitivity in the thermal and far IR
  - Ultra-high spectral resolution -> vertical profiling
  - Ultra-high spatial resolution (< mrad)
Laser Heterodyne Radiometer
Passive - Laser is only local oscillator

Collects thermal radiation from the scene contains unique spectral signatures from atmospheric constituents

![Diagram of Laser Heterodyne Radiometer components]

- **QCL chip on submount**: 3 mm
- **Photodiode**: 15 mm
- **RF analysis**
- **Focusing optics**
- **Beam combining**
- **LO**
- **Mid IR Laser**

**Graph**
- **Transmission**
- **Wavenumbers (cm⁻¹)**
- **1160 - 1180**
Vertical Profile Measurements
Solar occultation ground based

- Ozone
- Water vapour
- Freon 12
- Nitrous oxide
- Methane
Miniaturization
Hollow waveguide integration

Bench top 75x75cm
Hollow waveguide channels
Passive component integration

Fully integrated LHR

Active component integration
Trace Chemical Remote Sensing
EO vs. Terrestrial (Security & Defence)

- EO from space
  - Long paths
  - Thermal contrast

- Terrestrial S&D
  - Short plume
  - Highly localized
  - No thermal contrast
  - Low vapour pressure
Remote Sensing of Explosives

Requirements

- Strict performance criteria
- Multi-species identification and quantification
- High sensitivity (ppb)
- Detection ranges > 50 m
- Rapid response times (seconds to minutes)
- Eye-safe operation
- Compact and portable design
- Cost effectiveness

SOLUTION: CREATE THE CONTRAST -> MAKE THE LHR ACTIVE

LHR becomes ACLaS
Typical Detection Scenario

Active Coherent Laser Spectrometer

- Analyse spectral signatures
- Fraction of the backscattered light collected by the ACLaS
- Backscattering from obstacle OR aerosols

Active Coherent Laser Spectrometer

Mid IR (2-20 μm) laser illumination (eye-safe)
Benefits of ACLaS
Inherit advantages of LHR + new ones

High detection sensitivity (femtoWatts)

Ultra high spectral resolution: ~1MHz !!! (0.00003 cm\(^{-1}\))
- Can match the 1 MHz laser linewidth
- Immune to laser frequency noise
- Full profile information

High spatial resolution (narrow FoV)
- Identification of highly localized releases before dispersion
- Potential for high resolution imaging

Dual Wavelength (DIAL, ideal)

Dual Wavelength (DIAL, non-ideal)

ACLaS full profile
First System - First Spectrum

Nitrous Oxide

COLLECTION OPTICS
TRANSMISSION OPTICS
TARGET 6 m away

N$_2$O (1000 ppm)
Atmospheric
Beam blocked

Heterodyne signal (V)

Relative Wavenumber (cm$^{-1}$)

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Long Range Tests (up to 50 m)
Hydrogen Peroxide and Nitrous Oxide

H₂O₂
- 20 cm plume
- 252 ± 17 ppm
- 10 seconds
- 10 meters

N₂O
- 20 cm plume
- 3588 ± 29 ppm
- 8 seconds
- 40 meters
Current Normalised Detection Limits

Sensitivity normalised to:
- 1 m path length
- 1 s acquisition time

Explosives still ~10^4 above ultimate noise limit

Only 20 mW of laser power
Conclusions & Prospects

- Adapting EO oriented instrumental development into terrestrial sector for standoff detection

- Most sensitive Standoff detection/identification system fulfilling operational requirements
  - Several orders of magnitudes to gain in sensitivity
  - Miniaturization under way (field deployment)
    - Direct benefits from CEOI programme
  - Increased spectral agility
  - Range resolution

- Further spinning out in environmental monitoring
  - What and how much is getting out of this chimney stack?
  - Urban tomography
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