Photoacoustic Sensing of Explosives (PHASE)

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DHS Workshop

16 November 2016

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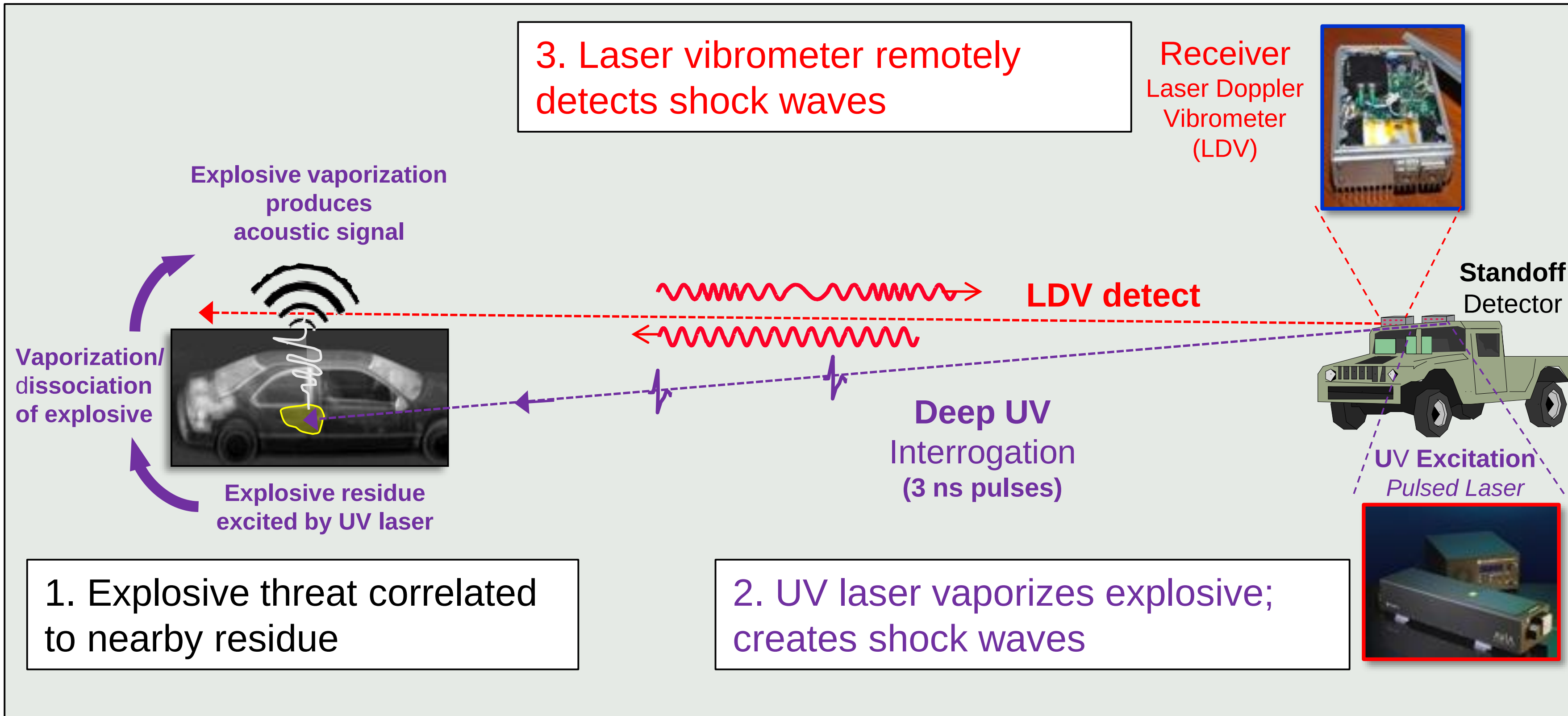
This work is funded by the Office of Naval Research (ONR), code 32 program: Brian Almquist under MIPR – N0001415MP00407 to Air Force contract AF2005

Photoacoustic Sensing of Explosives (PHASE) Concept

Utilize high energy of explosives to discriminate from ordinary materials



- **PHASE technique exploits large stored internal energy of explosives for detection**
  - Explosives' acoustic emissions depend critically on optical wavelength and material absorption
- **Laser vibrometry enables standoff detection (probes** explosive emission **within millimeters of source)**

PHASE Operational Concepts

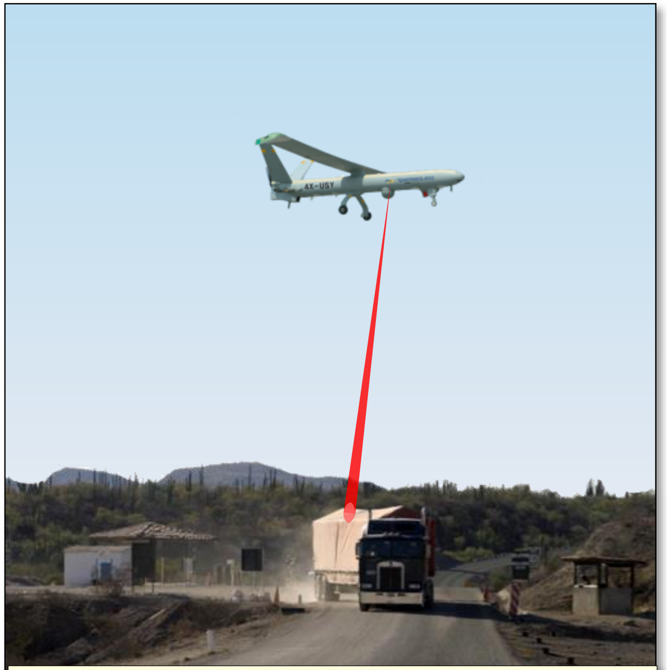
Rapid Development

Close Proximity Detection

Robotic – Standoff Cued Sensing

Long Term Development

Scanning from UAV Platform



CONOPS: Cued scans for explosive residue via low altitude airborne platform

- **PHASE system components well poised for rapid development for close proximity applications**
- **UAV platform system requires significant development**

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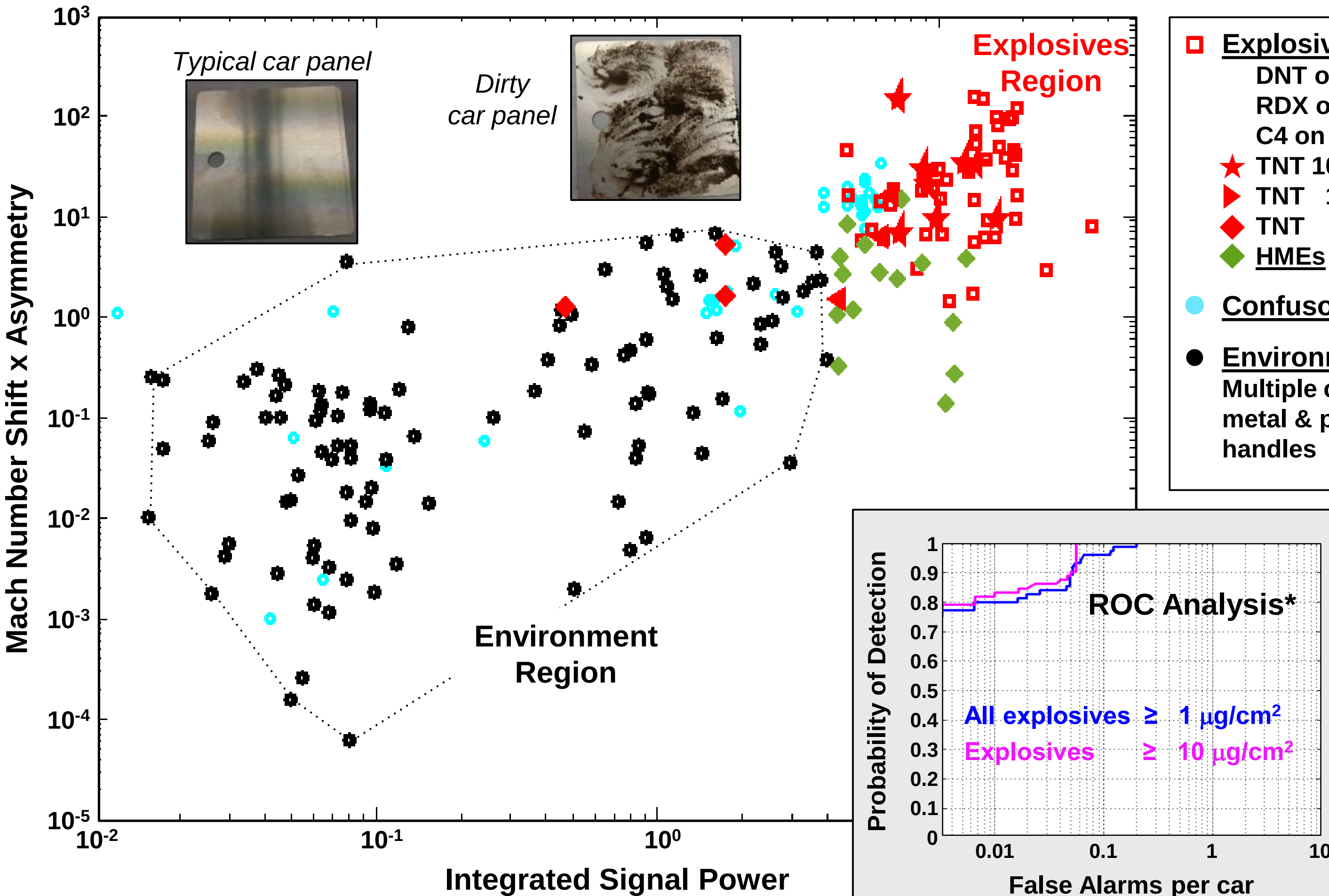
Estimated Performance for Vehicle Checkpoint Inspection



- **Explosives**
  - DNT on various substrates
  - RDX on various substrates
  - C4 on glass
  - TNT 100 μg/cm²
  - TNT 10 μg/cm²
  - TNT 1 μg/cm²
  - HMEs - ANFO, black powder
- **Confusors with Fuel Oil**
- **Environmental Materials**
  Multiple car panels – (clean and dirty; metal & painted), plastic moldings, handles

1 detection : Pd = 0.80
1 FA in 62 cars ≥ 1 μg/cm²
1 FA in 152 cars ≥ 10 μg/cm²

2 detections : Pd = 0.80
1 FA in 400 cars ≥ 1 μg/cm²
1 FA in 441 cars ≥ 10 μg/cm²

** 212 measurements per car*

- **Trace level explosives separate out from clutter and can be detected with reasonable confidence**
- **ROC analysis suggests very low fill trace detection is challenging against more false alarms**

Key Advantages of PHASE Technology

Industrial-Grade Organonitrates			Homemade Explosives (HMEs)	
Nitroaromatic ϕ-NO_2	*Nitramines* N-NO_2	*Nitrate Esters* O-NO_2	*Peroxides*	*Inorganics* NO_3^-, ClO_3^-
2,4-DNT 2,6-DNT DNB TNT TNB Tetryl	RDX HMX	PETN NG EGDN DNDMB	HMTD *TATP* *DADP* *H_2O_2 mixtures* *(i.e., airline liquid threats)*	NO_3^- Ammonium Nitrate / Fuel Oil Ammonium Nitrate / Nitromethane Urea Nitrate ClO_3^- *Chlorate/perchlorate variants* *Metal (Al, Mg) powders*

Current capability (266 nm excitation)

- *Either demonstrated or predicted based on similar photochemistry*

Potential capability (213nm excitation)

– *Based on known optical absorption at this wavelength*

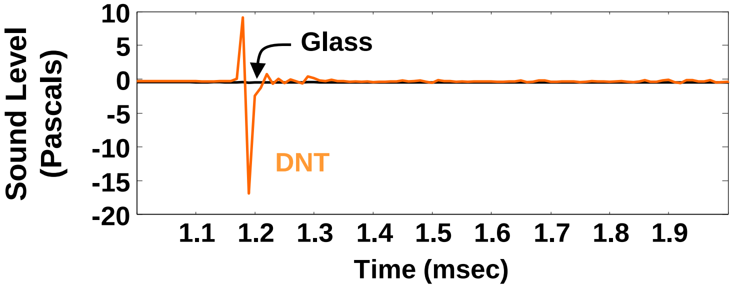
- **Potential for *significantly greater standoff* than other detection methods**
- **Noise-limited detection against realistic threat = *100 ng/cm²***
- **Exploits common factor of explosives – stored internal energy**
  - → ***Should be adaptable to evolving threat***
- **Acoustic clutter and interference are exceptionally limited**
- **Single-pulse detection enables potentially rapid area scan rate**
- **System components have potential to acquire signals from static or moving platforms**

PHASE Innovations

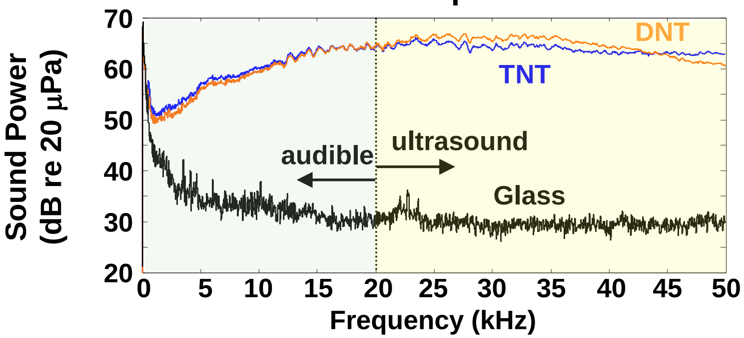
Audible signals observed from photoacoustic excitation of explosives

Microphone Measurement

Acoustic Time Signal



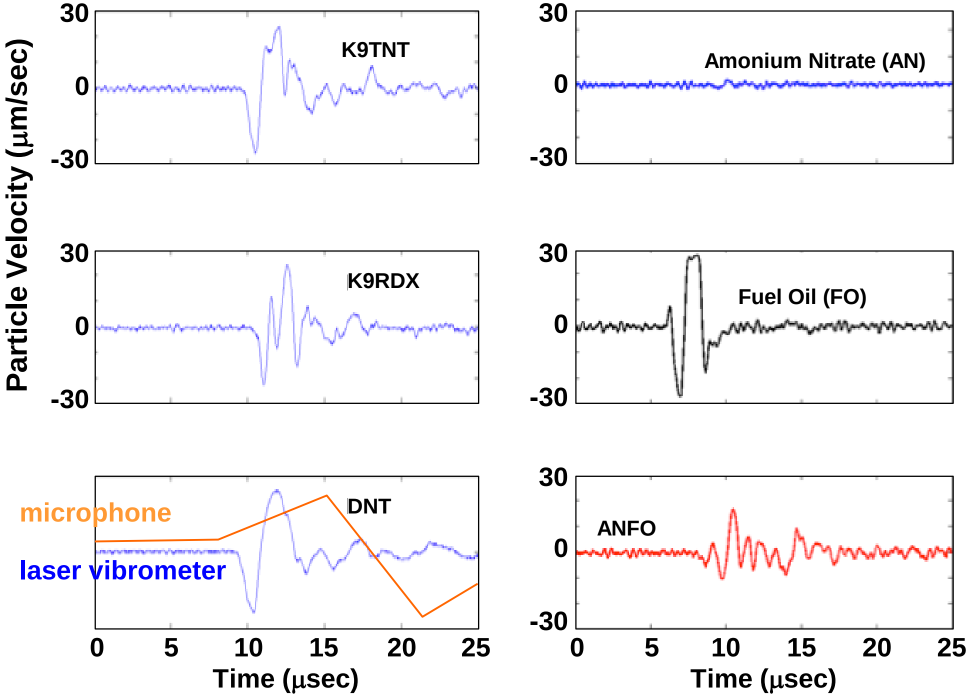
Acoustic Spectrum



High ultrasound (100 kHz – 2 MHz) enables explosives discrimination

Laser Vibrometer

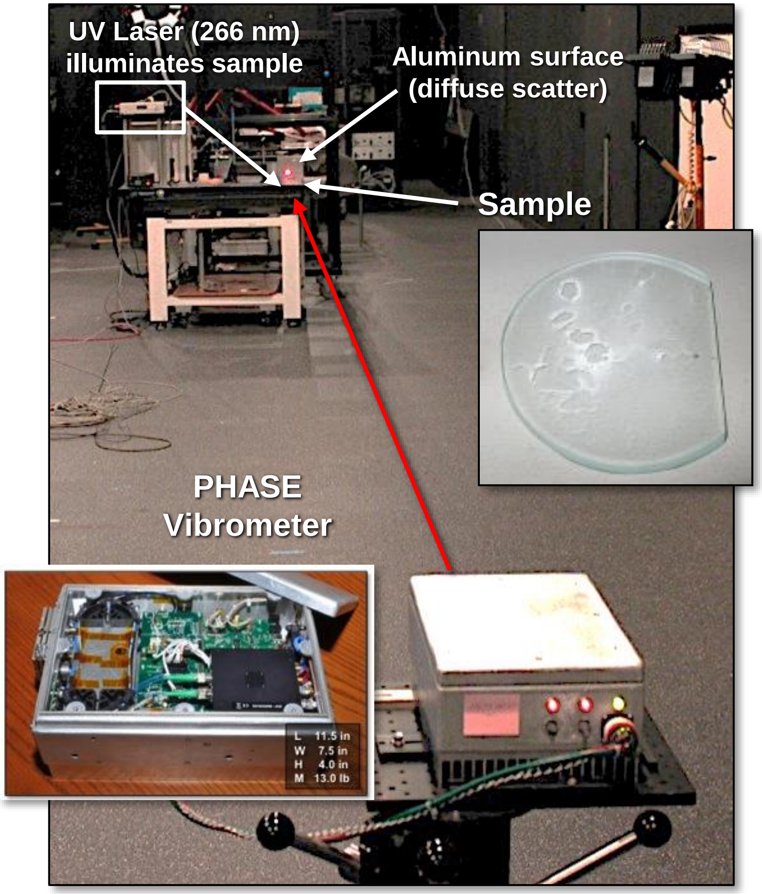
Measured Acoustic Time Signals



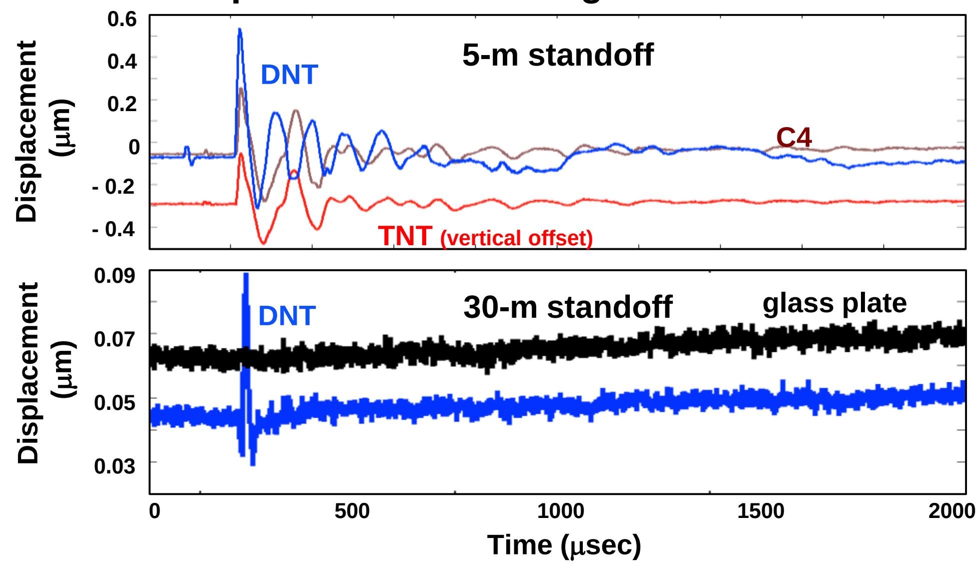
1) Discovery of unique explosives signatures in high ultrasound spectrum against very low clutter
2) Laser vibrometry senses and resolves high frequency ultrasound signals from standoff

PHASE Standoff Measurements

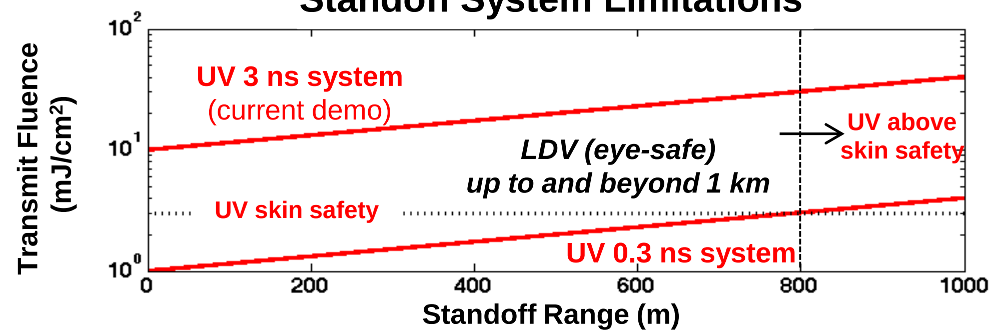
Measurement Setup
(Optical Systems Testing Facility)



Explosives Residue Signal Measurements



Standoff System Limitations

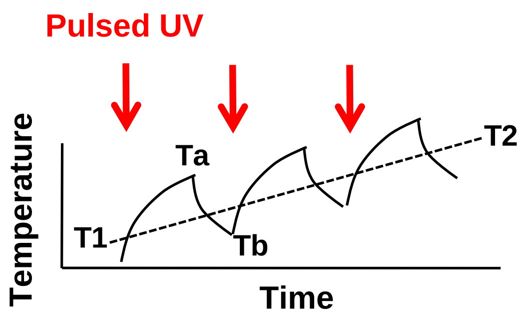


- Laser vibrometer developed at MIT Lincoln Lab detects explosive residue to 30 meter range
- System development possible to 1 km – UV challenging to keep below skin safety limits

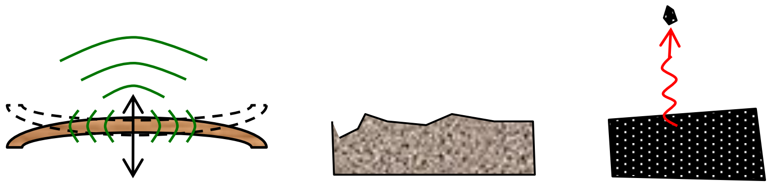
Technical Overview

Photo-Acoustic Excitation

Common Materials



Thin | **Thick** | **Man-made**

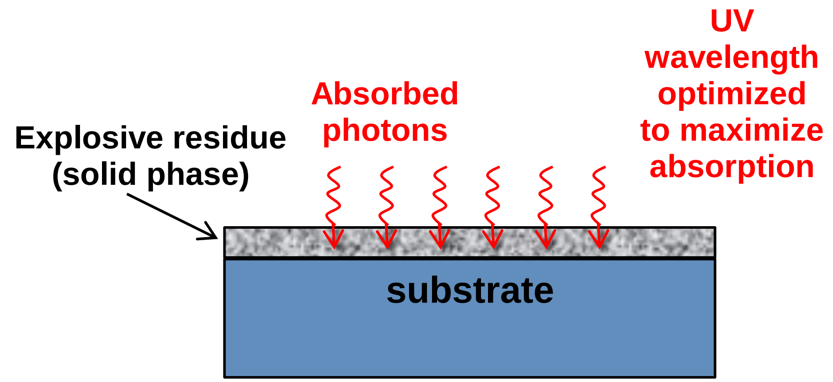


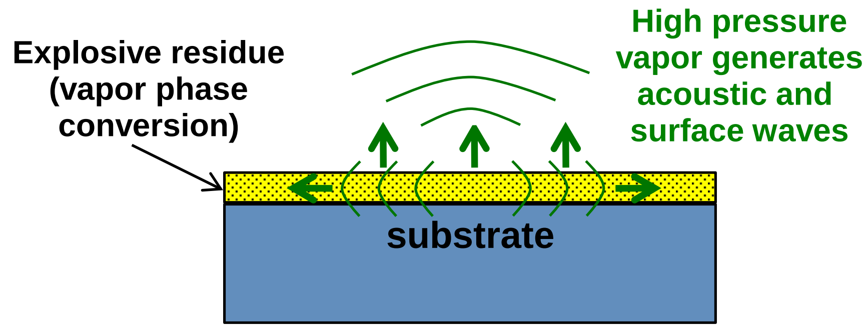
Flexing surface causes acoustic and elastic waves

Negligible response

Ablation common

Explosive Materials

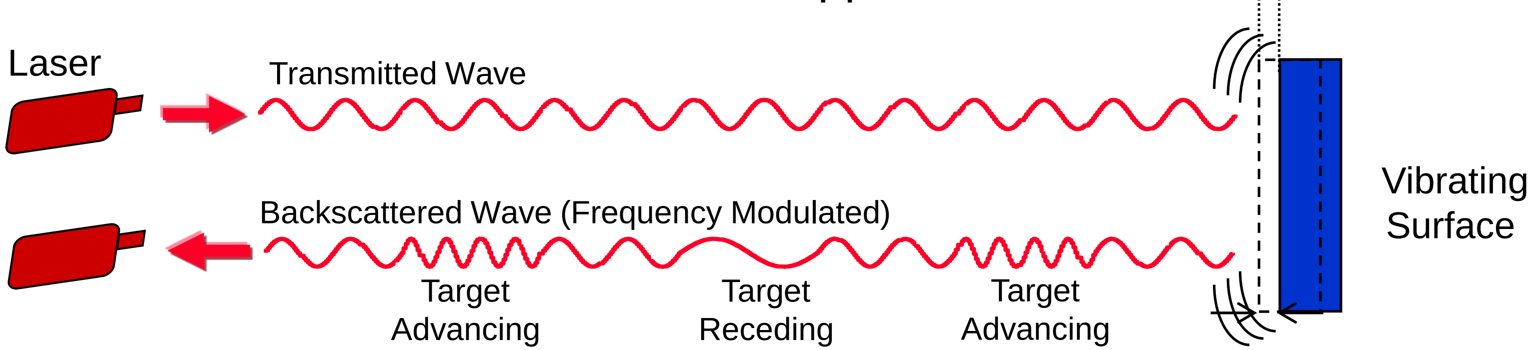




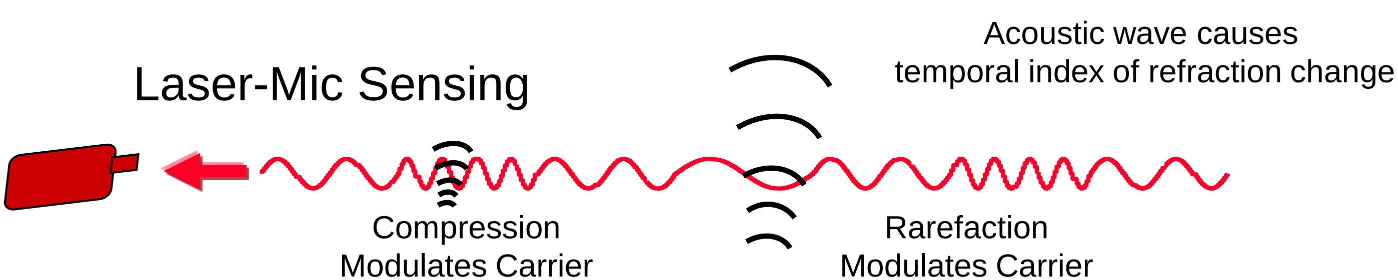
Explosives energy release much greater from pulsed UV excitation compared to common materials

Photo-Acoustic Sensing using Laser Vibrometry

Laser Vibrometer Measures Doppler Shift



Laser-Mic Sensing



Vibration Amplitude: Excursion distance on carrier

Vibration Frequency: Doppler side band

Laser vibrometer can measure surface vibrations and acoustic waves in the vicinity (near field) of explosives from significant standoff with fine location accuracy (~ 1 cm)

PHASE Demonstration System

Optical Excitation Source

(UV – photoacoustic generation)

Pulsed Laser 266 nm – Deep UV

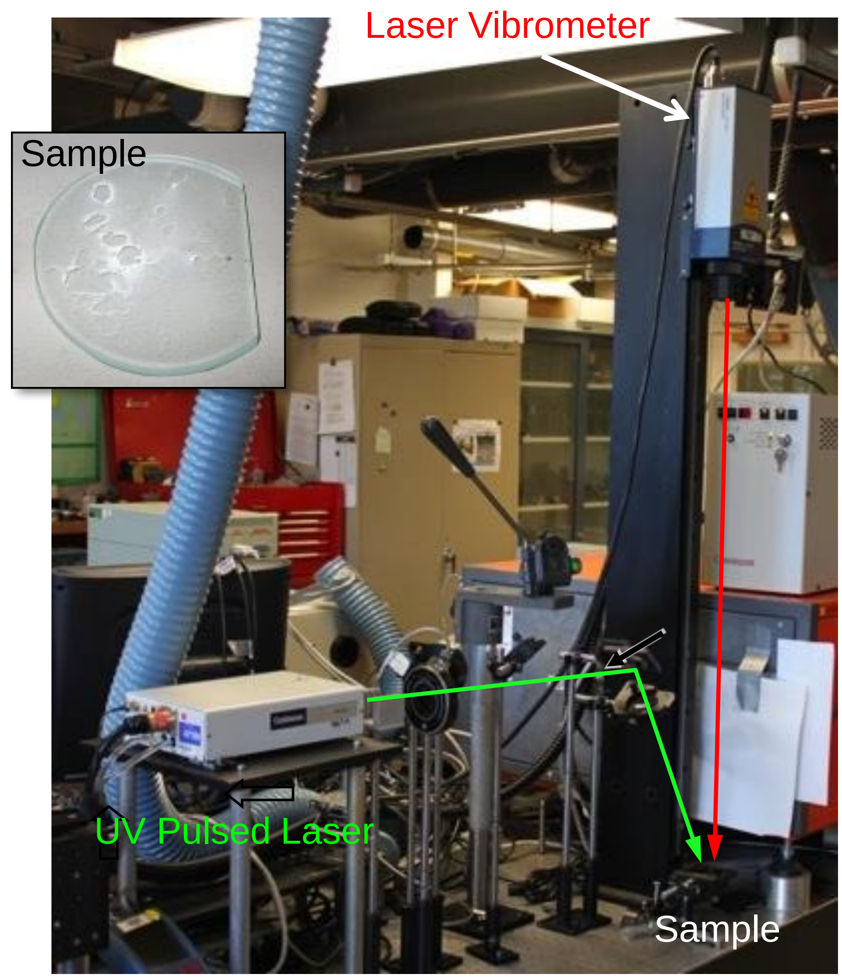
Laser Doppler Vibrometer (LDV)

(acoustic emission measurement)

Custom – standoff **MIT Lincoln Laboratory**

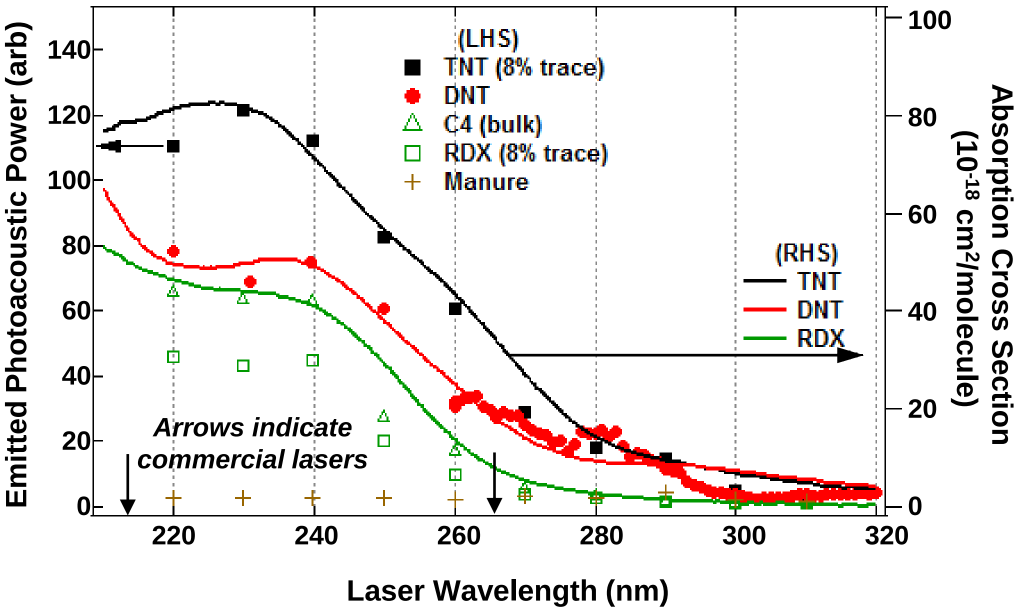
Commercial – lab Polytec

Laboratory Set-up

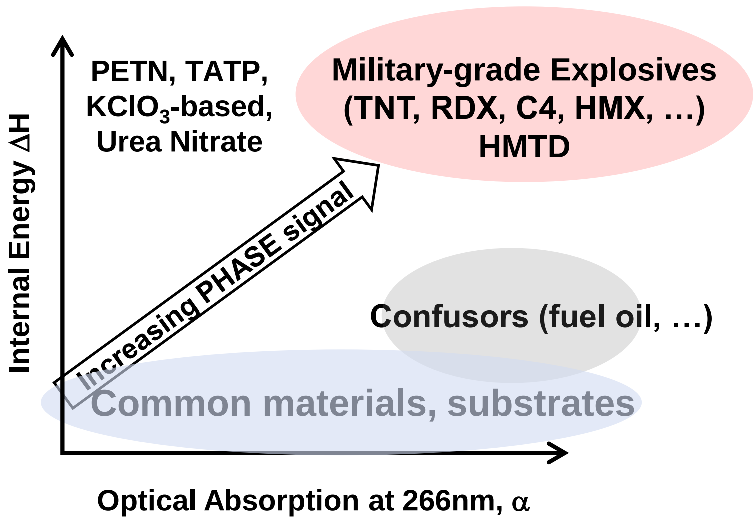


PHASE Signal Dependence on Optical Absorption and Explosives Energy

Effects of Optical Absorption / Wavelength on Photoacoustic Emission



PHASE Signal Dependence

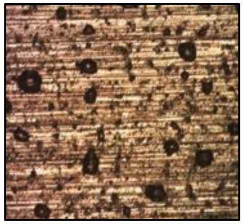


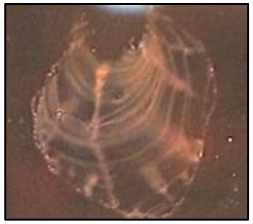
- Explosives possess high internal energy – Excitation laser wavelength chosen to match strong optical absorption of explosives
- PHASE acoustic emission signal scales directly with explosives optical absorption

PHASE Trace Explosives Sensing Capability

Sparse – Low Fill Samples

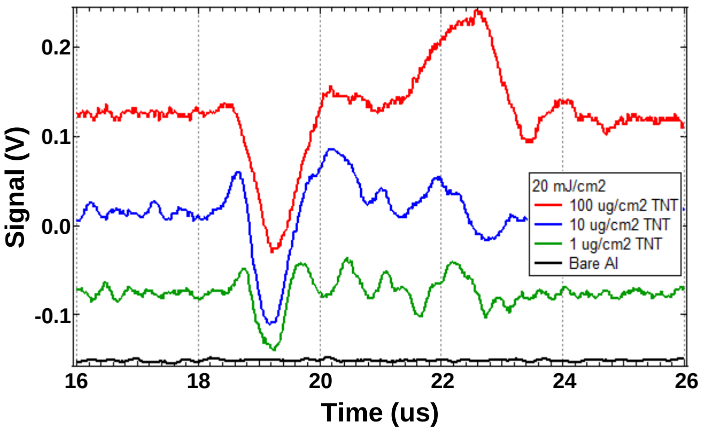
Finger Print | *Inkjet Print* | *Dropcast*



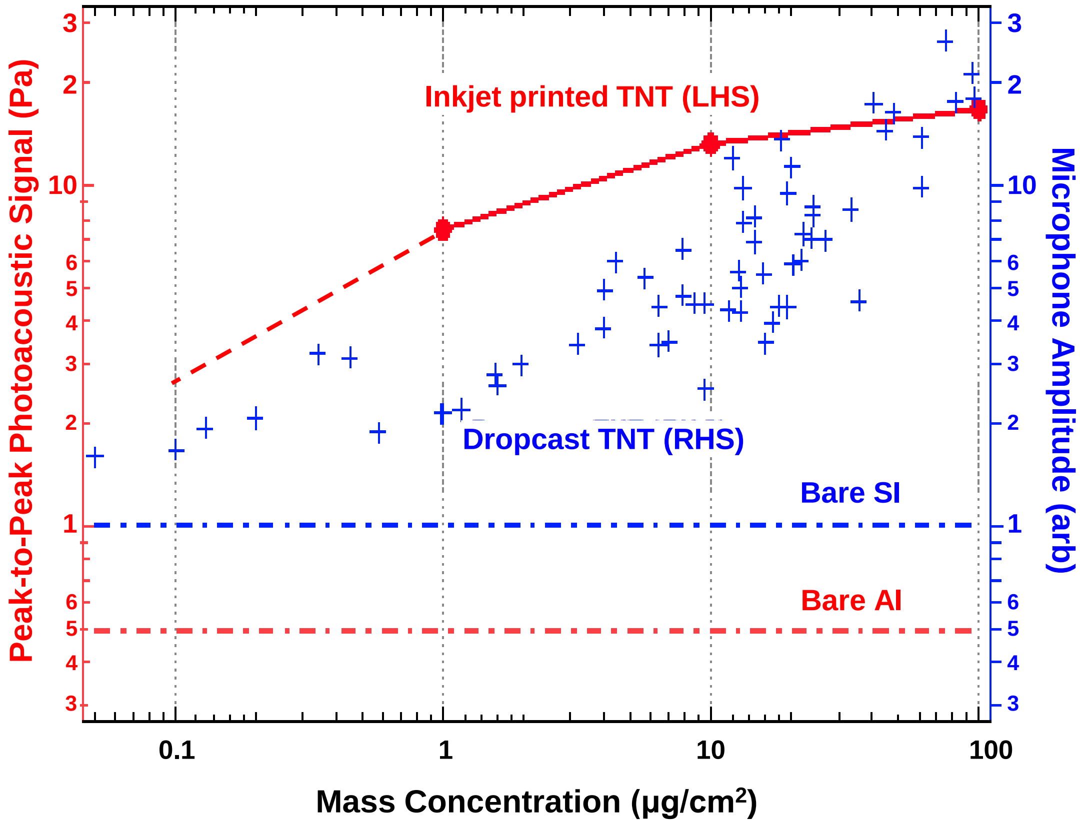


← 1 mm → ← 100 μm → ← 1 cm →

Trace Time Series Signatures

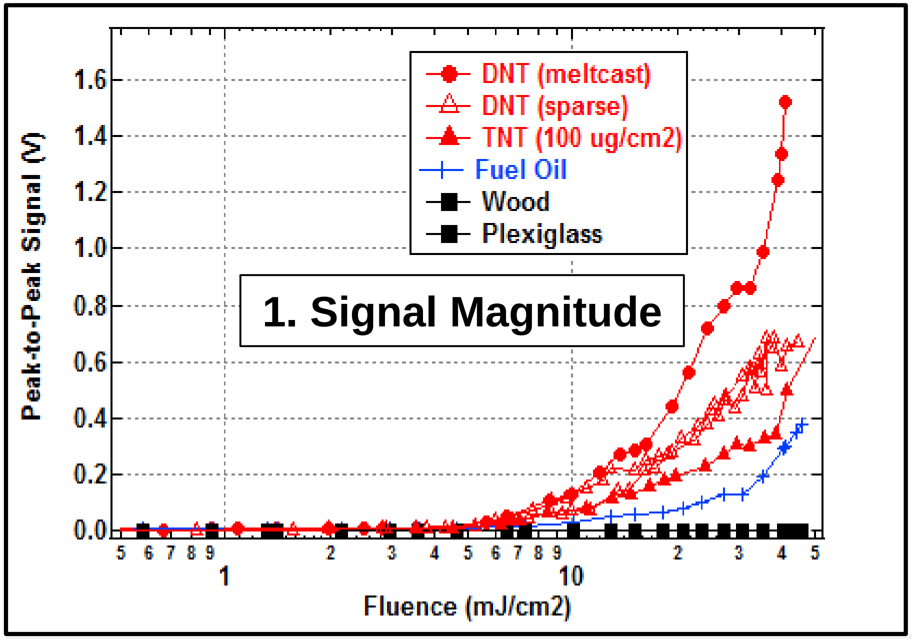


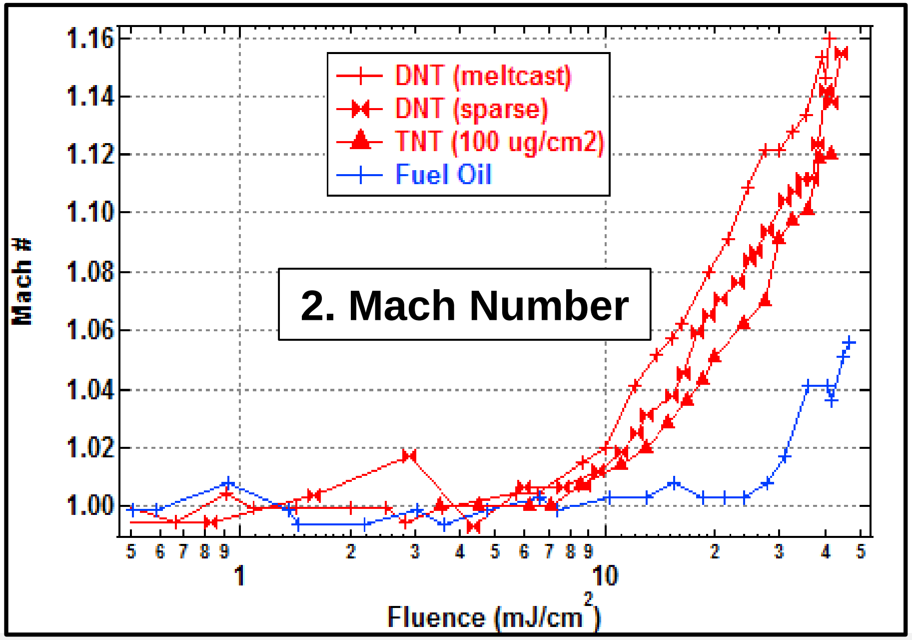
Explosive Trace Signal Above Environment



PHASE demonstrates detection capability down to100 ng/cm² (5th generation fingerprint)

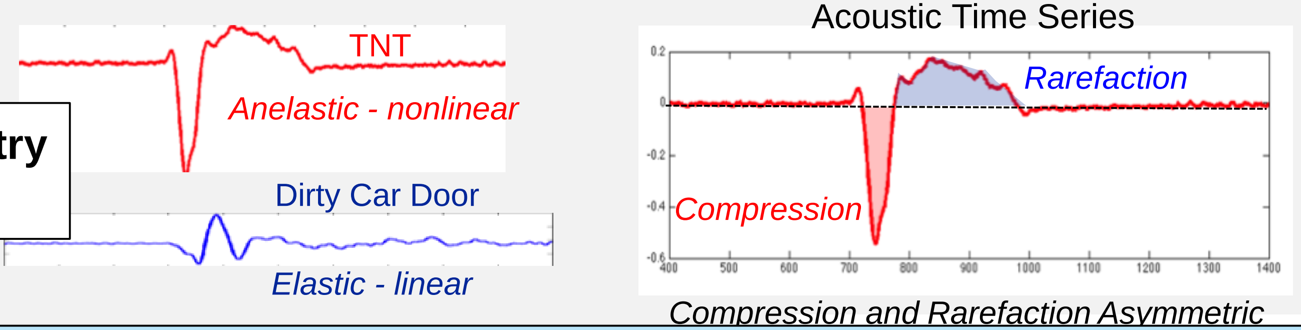
Trace Explosives Signature Discriminants





3. Waveform Asymmetry

metric of non-linearity



Multiple metrics aid in discrimination of explosives from ordinary materials
- More metrics being investigated via statistical analysis of waveforms

Summary

- **Urgent need to develop standoff sensing capabilities to detect explosives that target civilians and military staff**
  - Detecting trace level explosives key to finding device
- **PHASE innovations include**
  - Discovery of high ultrasonic frequency signals resulting from UV excitation
  - Laser vibrometry able to sense and resolve resultant signals
- **PHASE demonstrated high sensitivity and long standoff sensing capabilities**
  - Signals measured from 100 ng/cm^2 concentration of TNT
  - 30-m standoff measurement achieved with estimates to 100-m reasonable
  - Detection capability demonstration shows potential for screening sensor
- **PHASE has potential for commercial platform**
  - Light weight, portable, low power, covert, safe system capabilities possible
  - Applications for homeland security and overseas activities

Backup

Diversity of Explosives Threats

Industrial-Grade Organonitrates*			Homemade Explosives (HMEs)*	
Nitroaromatic ϕ-NO_2	*Nitramines* N-NO_2	*Nitrate Esters* O-NO_2	*Peroxides*	*Inorganics* NO_3^-, ClO_3^-
2,4-DNT 2,6-DNT DNB TNT TNB Tetryl	RDX HMX	PETN NG EGDN DNDMB	HMTD *TATP* *DADP* *H_2O_2 mixtures* *(i.e., airline liquid threats)*	NO_3^- Ammonium Nitrate / Fuel Oil Ammonium Nitrate / Nitromethane Urea Nitrate ClO_3^- *Chlorate/perchlorate variants* *Metal (Al, Mg) powders*

Military Use

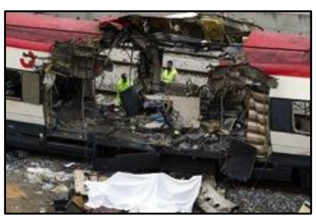
Landmines – anti-personnel and vehicles, artillery rounds

Covert operations *(< 10 kg)*

No military applications

Terrorist Events

Madrid Train



Brussels Attack

London 7/7

Boston Marathon

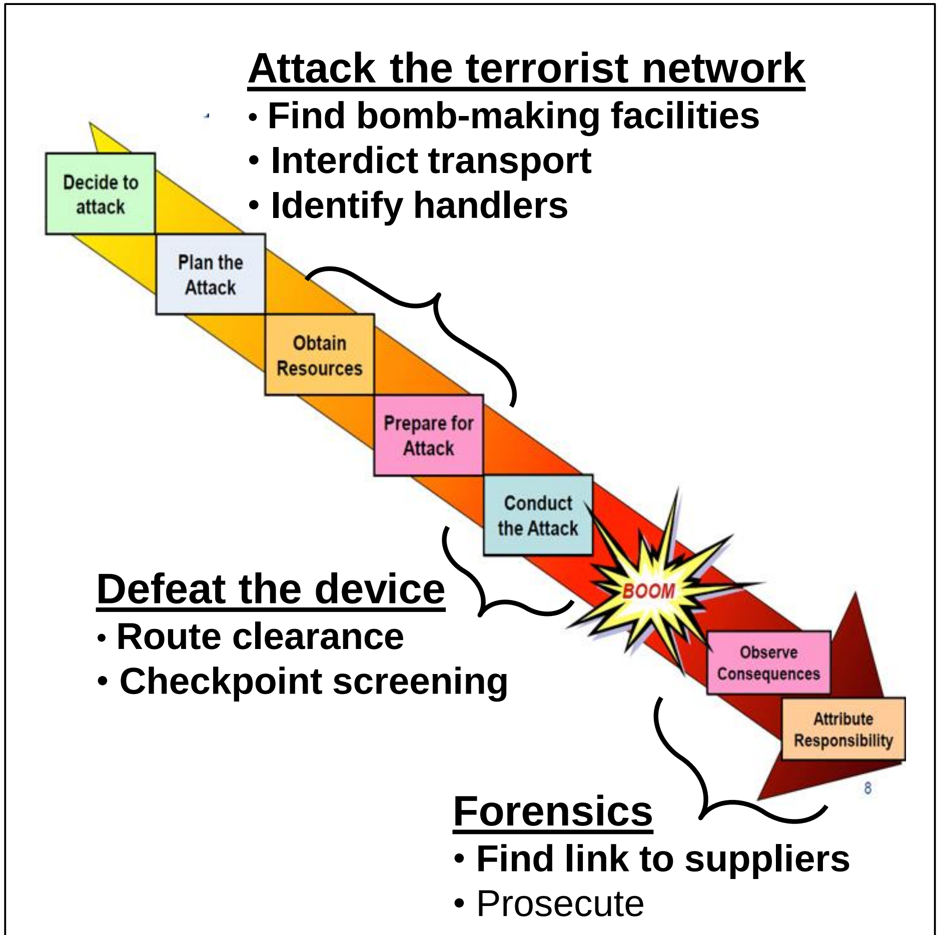
Oklahoma City

African Embassy

Common Explosives feature – they yield high pressure and temperature release upon detonation

*C. Wynn (MIT LL) – Laser Based Optical Detection of Explosives CRC Press

Role of Explosives Detection



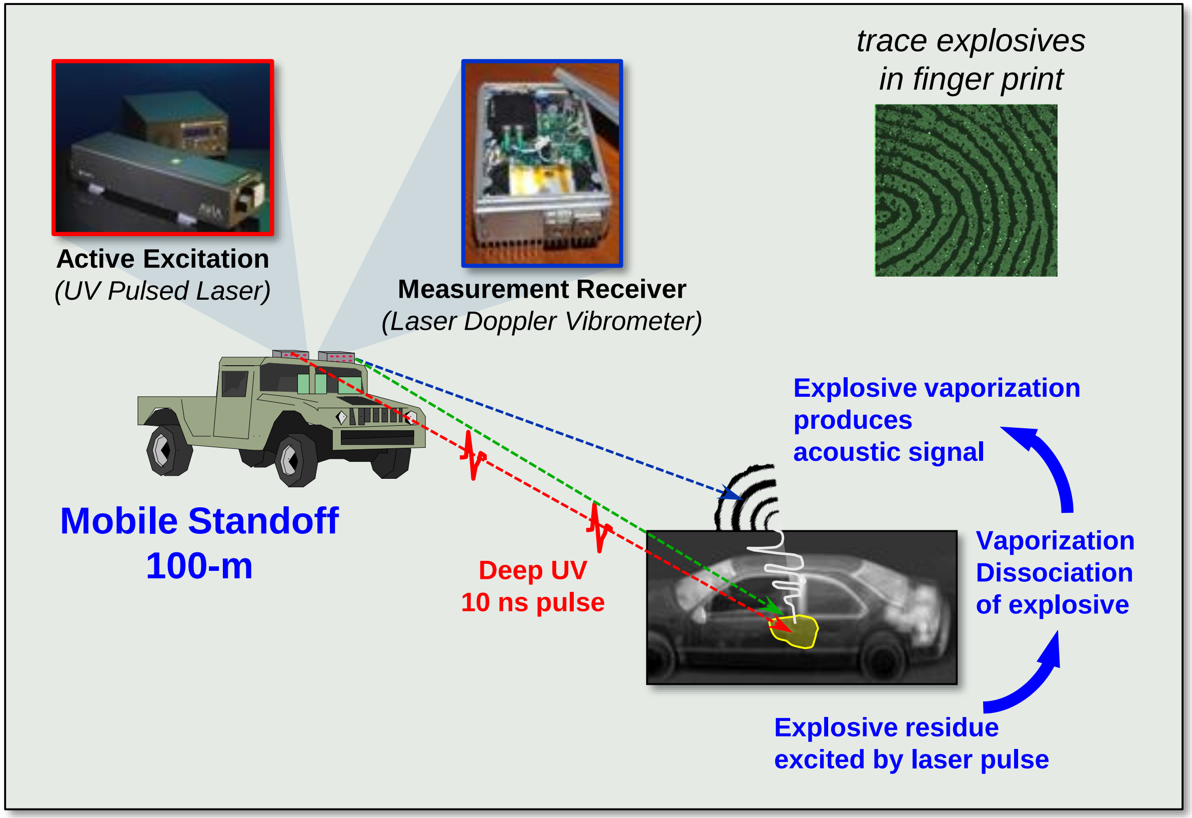
Detection Modalities

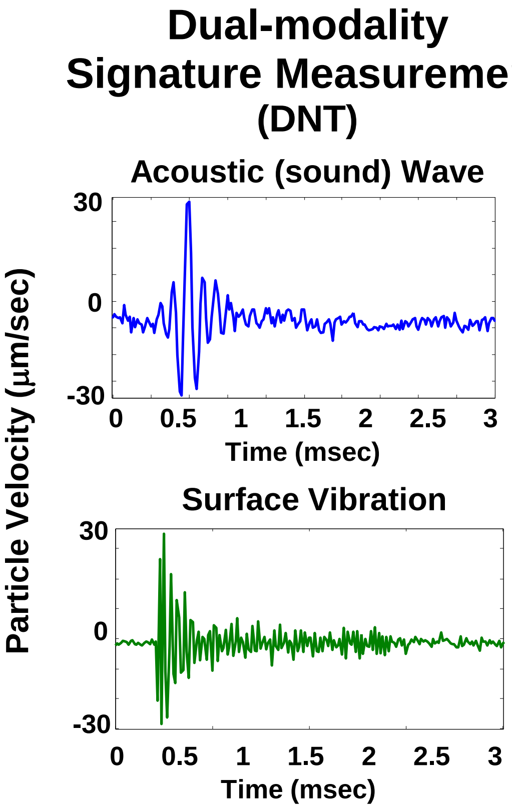
- **Point**
  - Measure and analyze explosives particulates
  - Ion mass and mobility
  - Well established techniques
  - Trace quantity sensing < 1 ng/cm^2
- **Standoff (< 1 m)**
  - Laser based measurement approach
  - Spectrographic features
  - Limited techniques
  - Bulk and trace quantity sensing
- **PHASE Standoff (>> 1 m)**
  - Laser based measurement approach
  - Exploits acoustic emissions from explosives
  - Path to detect trace deposits and bulk from significant range

Standoff explosives detection role suffers greatly from threat variations, composition, phenomenology, coverage rate, and difficulty in observing small trace explosive quantity levels

Photo-Acoustic Sensing of Explosives (PHASE) Concept

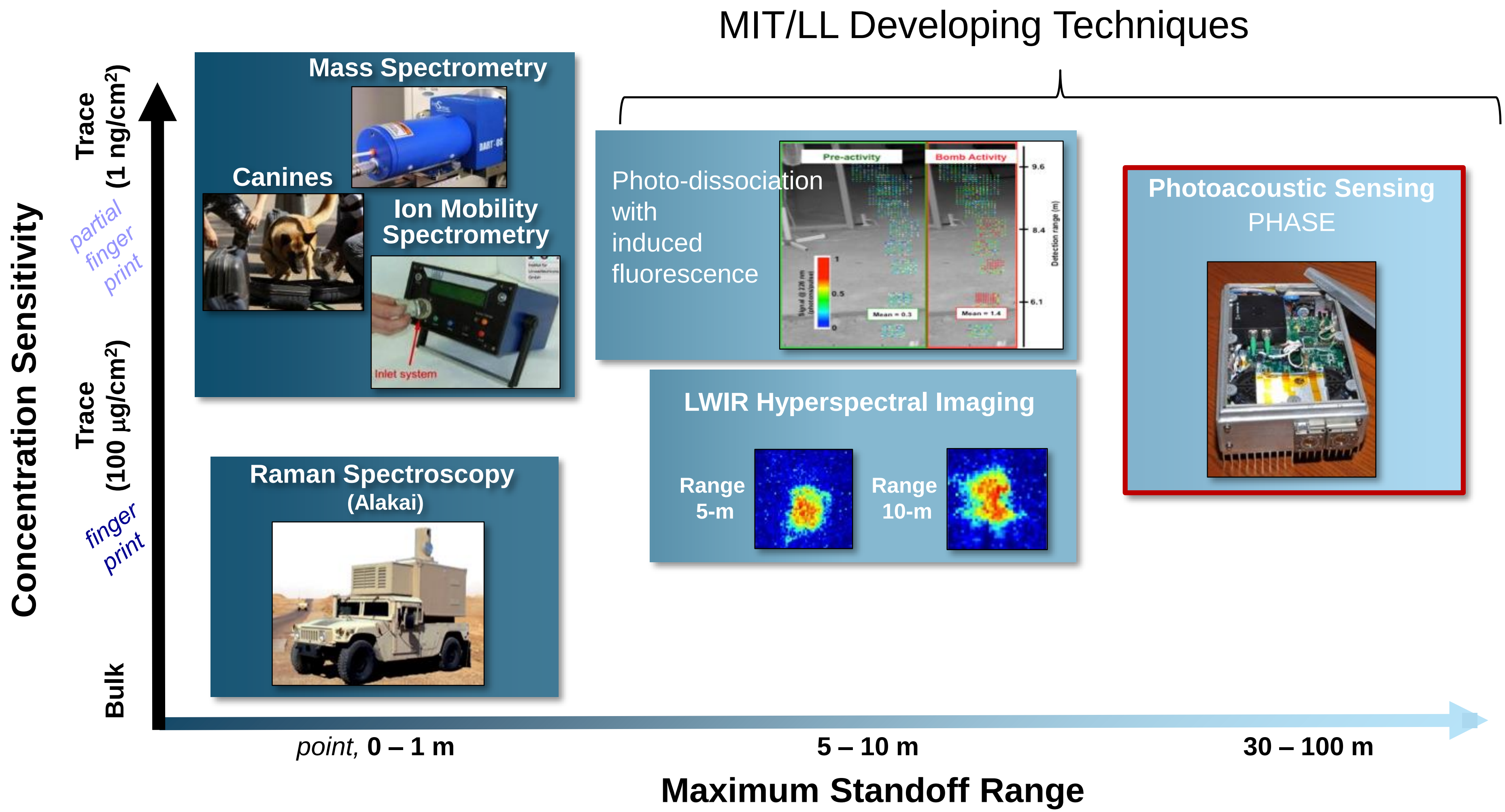
Utilize high energy of explosives to achieve detection





- **PHASE laser technique exploits large stored internal energy of explosives as detection mechanism**
- **Explosives acoustic – vibrational emissions critically depend on optical wavelength and absorption**
- **Laser vibrometry enables explosives standoff signature measurement to within millimeters of source**

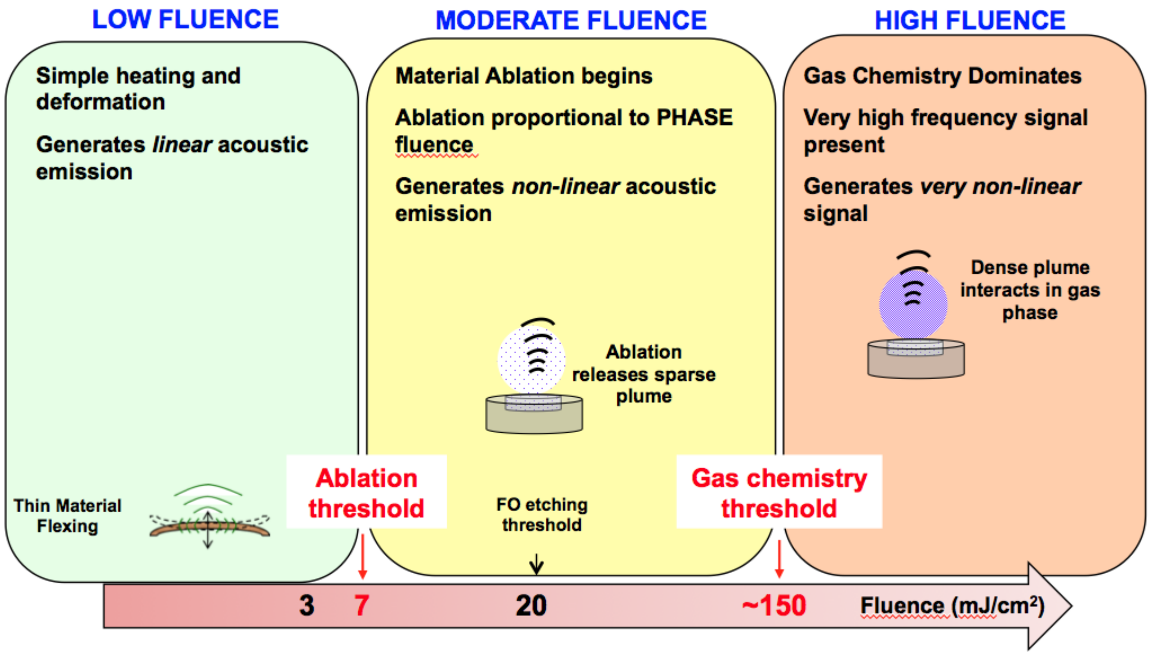
Explosives Detection Techniques



PHASE utilizes MIT Lincoln laser technologies to provide longer standoff while achieving sensitivity

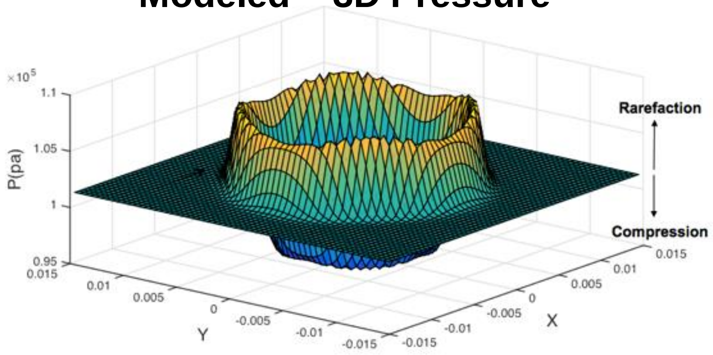
*Additional techniques exist, e.g., LIBS (now generally considered not useful) and CARS (still being investigated)

Theoretical Modeling of Photoacoustic Emissions from Explosives

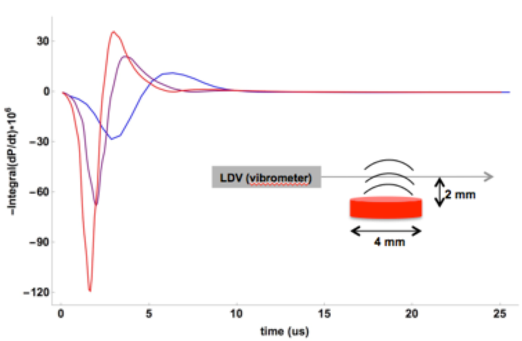


- Developed physical model (photo-ablation) and its functionality on experimental parameters (laser fluence)
- Potential for eye-safe system via micropchip laser – 0.3 ns pulse

Modeled - 3D Pressure



Modeled - Waveforms



Modeled -Behavior