Explosive Detection: An Overview

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Outline

- Threat
- Explosive Detection History
- Todays Detection Techniques
  - Bulk detection
  - Trace detection
  - Anomaly detection
  - Detection of visible amounts
- Emerging techniques
  - Anomaly detection
  - Bulk detection
  - Point detection, trace
  - Standoff detection, trace

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Commercial and military explosives

- Developed to suit certain criteria
  - High Performance
  - Low sensitivity (safety)
  - Good long term stability
- Requirements based on special application needs
- Limited number of substances have been found useful

Home Made Explosives (HME)

- Perfect performance is not an issue
  - As long as it kills a few people it is OK!
- Sensitivity (Safety) is not the biggest concern

Meaning: the explosives selection is endless

THREATS

Mines

The first modern mechanically-fused high explosive anti-personnel land mines were created by Confederate troops of Brigadier General Gabriel J. Rains during the Battle of Yorktown in 1862 (American Civil War)

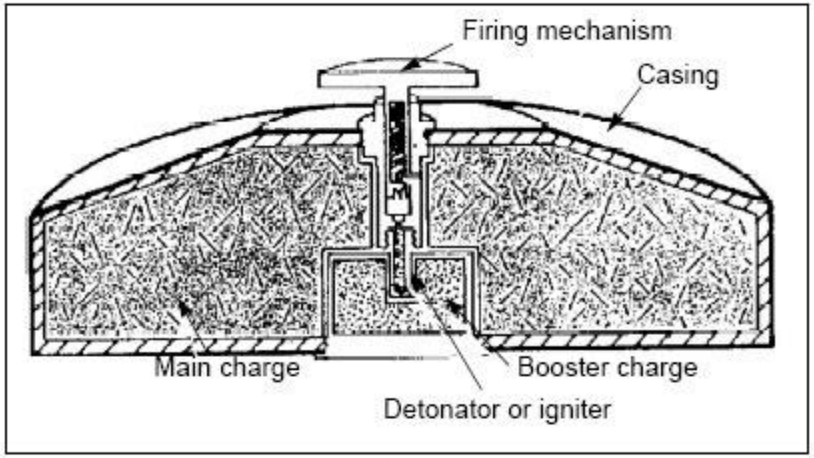


Figure 1-1. Mine components

Improved designs of mines were created in Imperial Germany, circa 1912, and were copied and manufactured by all major participants in the First World War

What is an IED?

- Improvised explosive device
- Unique – built *from whatever is available*
- Consists of:
    - Initiation system
        - Electronics
        - Detonator
        - Power source
    - Explosive (HME, commercial or military)
    - Container
- Could be a conventional warhead used in an improvised manner

Person Borne IEDs (PB-IED)

South-east asia

Israel

Leave-behind IEDs (LB-IED)

Road-side bomb

Vehicle Borne IEDs (VB-IED)

Explosive Detection History

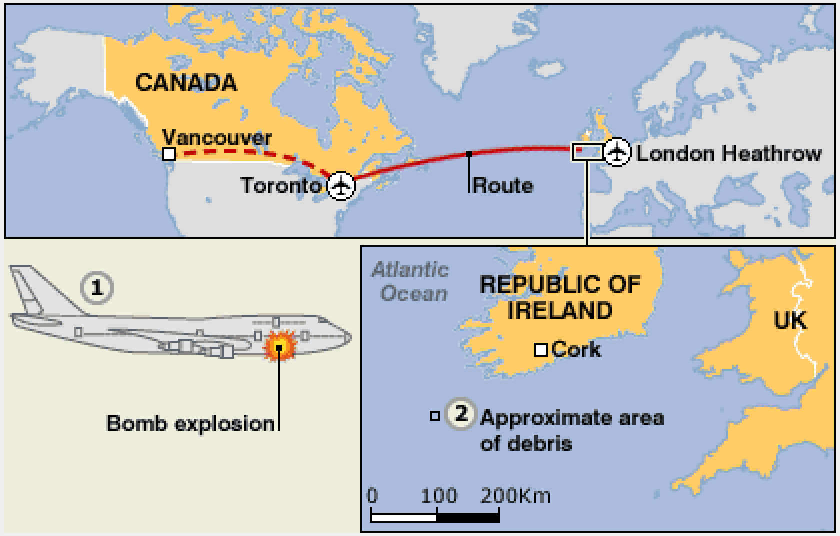
Early explosive detection

The British were the first to employ the talents of detection canines in WWI when they were trained to find land mines

Not: Under första världskriget använde man också minor som säppte ut giftgas istället för att explodera…

Air India Flight 182

- 747 from Montreal to Bombay via London Heathrow
- Bomb in suitcase destroyed the airplane 23 June 1985



Lockerbie 1988

- Pan Am Flight 103
- Approximately 400 g of plastic explosive in cargo bin
- Debris scattered over more than 100 km^2
- 270 people perished

En följd av attentatet var nya regler om screening av passagerare och bagage.

The historical main threat that has driven the development of explosives detection forward

- Commercial passenger air traffic
- Limited number of threat substances: EGDN, NG, DNT, TNT, PETN, RDX, ANFO (optional), and markers

2006 transatlantic aircraft plot

(Heathrow incident)

- 8 air craft targeted
- Liquid explosives were planned to be used (60% H_2O_2 + sports drink)
- New rules for liquids on airplanes

”A sugary drink powder, Tang, would be mixed with hydrogen peroxide”

Arrests were made on August 10, 2006

Oklahoma 1995

- Car bomb with home made explosives
- Fertilizer (ammonium nitrate) and nitromethane
- Approximately 2300 kg
- 180 people were killed

Madrid 2004: LBIED
Stolen ***dynamite*** (EGDN or NG) Electric blasting caps Cellular phones

London 2005: PBIED ***HME***-HP and fuel, HMTD in igniter

The needs – some scenarios

Check-point

Roadside bombs

Wide area surveillance

Point detection at safe distances

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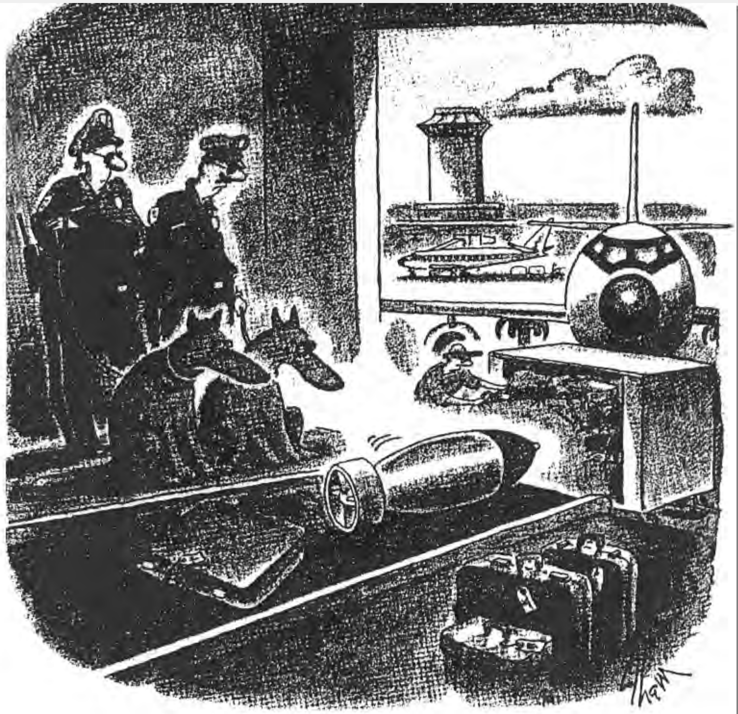
Extra demands on detection by HME

- Nearly endless number of threat substances
- Evolving threat
- Need to be one step ahead or at least keep up

Detection signatures

- Physical or chemical characteristics used to detect the explosive device
- More or less specific to
  - ***Explosives***
  - Other features of the device



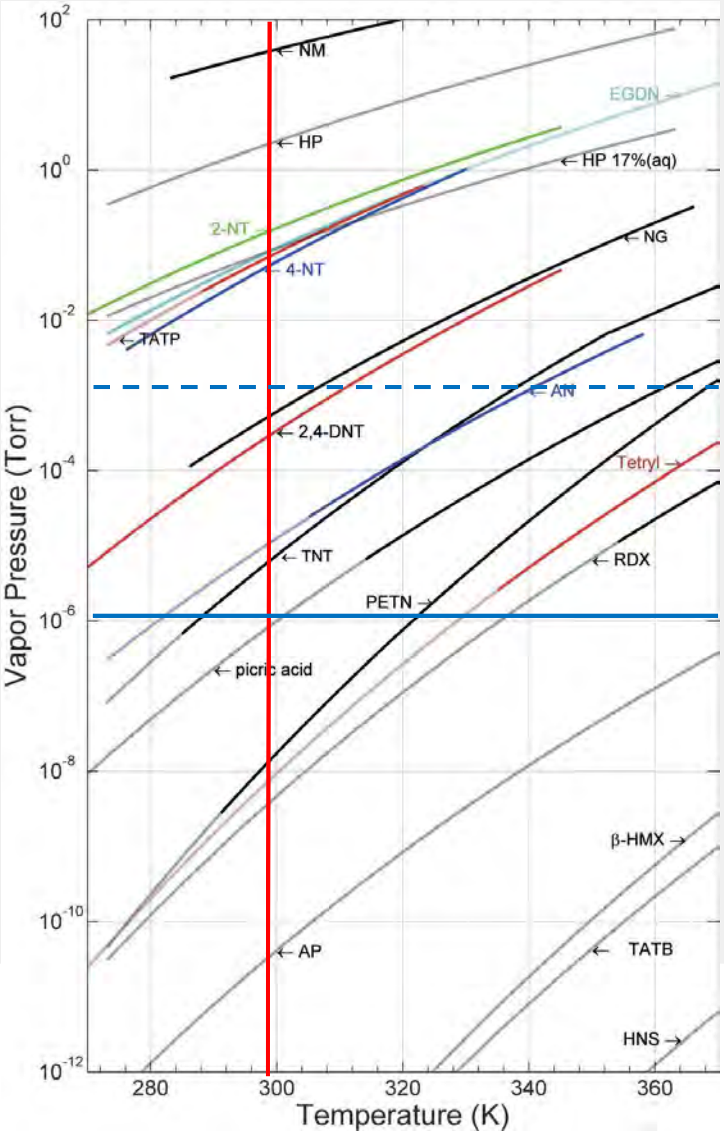
"Yeah, but it doesn't smell like a bomb!"

Figure 1 Drawing by Cotham; © 1997, The New Yorker Magazine, Inc.

Bulk detection

Detection of larger amount of explosives (>200g) - the explosive charge

Trace detection



- The handling of explosives will leave trace amounts on hands, cloth handles and packing material.
- Substances with low vapor pressure will remain as particles
- Substances with high vapor pressure will vaporize

Detection of this remnants gives a indication of the presence of explosives

Wide range of vapour pressures:

- TATP: 4.3 Pa @ 25 °C
- HMX: $5.9 \cdot 10^{-16}$ Pa @ 25 °C

n=1 Mass in the order of μg

n=50 Mass in the order of ng

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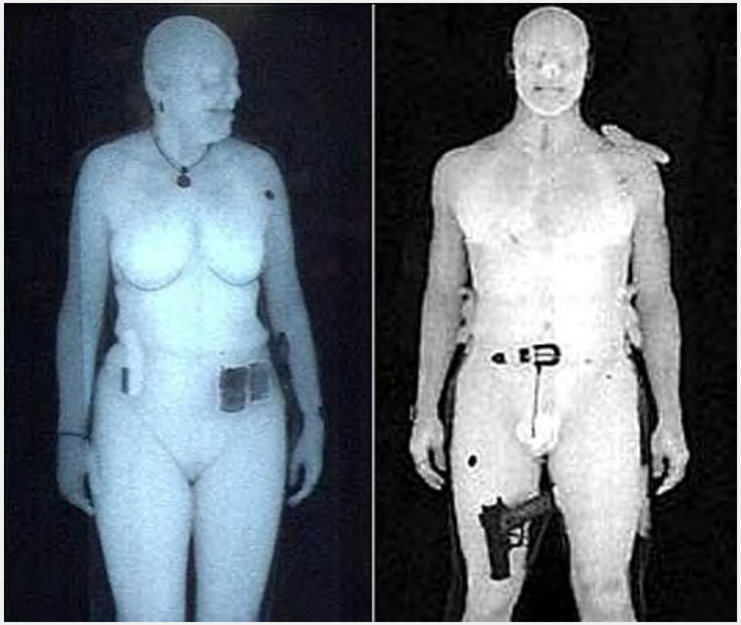
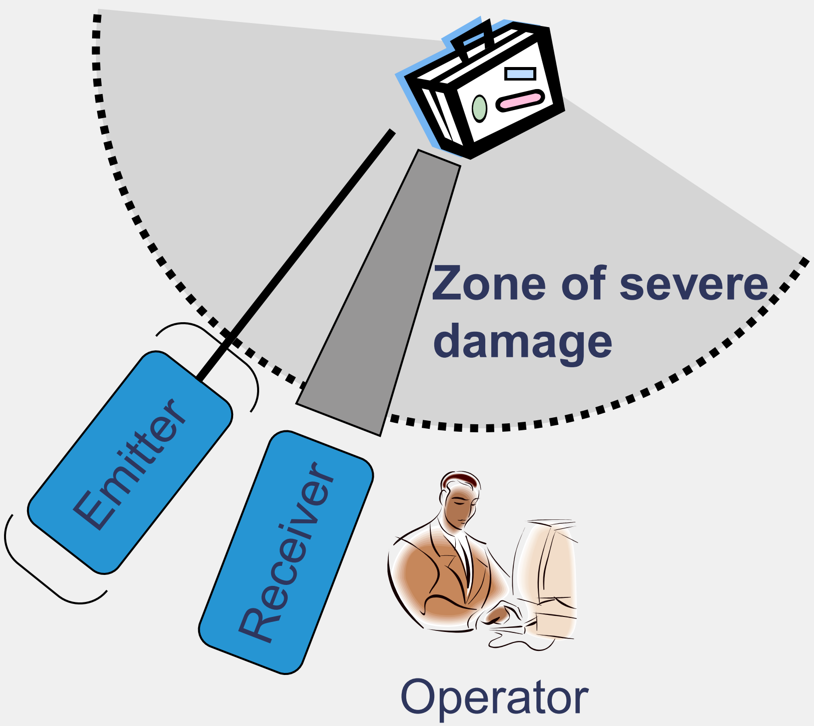
Anomaly detection

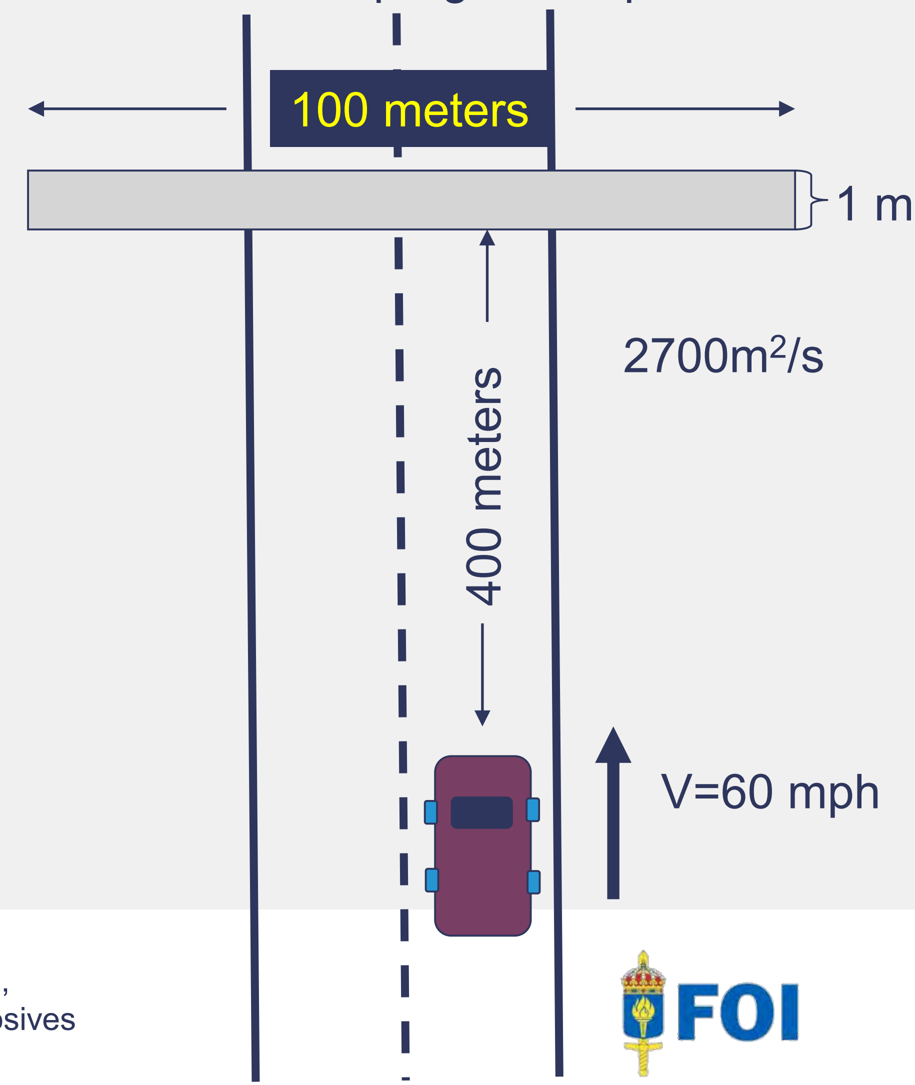
- "Detecting patterns in a given data set that do not conform to an established normal behavior"



Standoff detection



DARPA RIEDAR program requirements

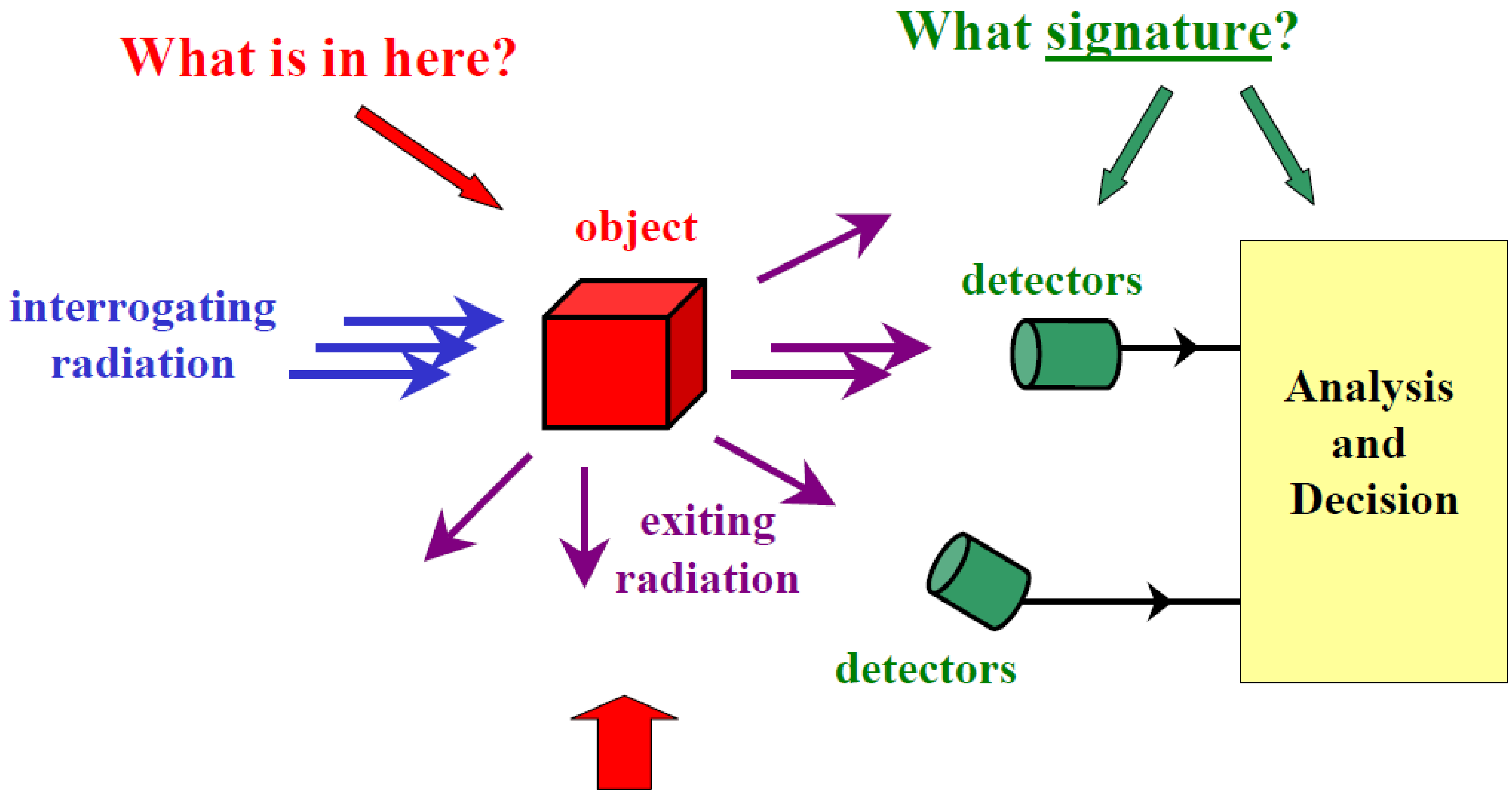


…individuals and vital assets [should be] outside the zone of severe damage… *

* Existing and Potential Standoff Explosives Detection Techniques, Committee on the Review of Existing and Potential Standoff Explosives Detection Techniques, 0-309-09130-6, Washington D.C., 2004

Todays detection Techniques

Bulk Detection



Do you want ... an **image** (regular or tomographic),

... or **elemental characterization**,

... or **both** (elemental image) ?

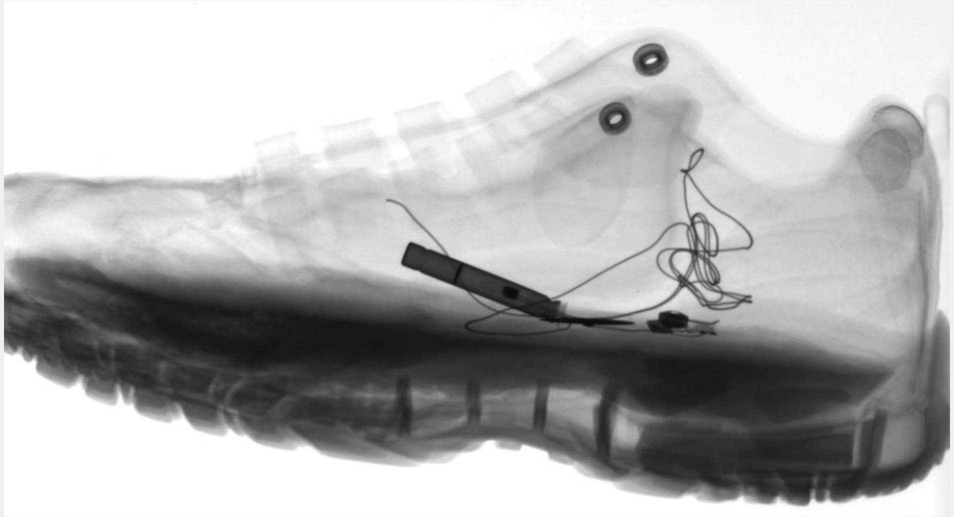
... the <u>context</u> of the problem is everything.

X-Ray absorption (single energy)

Larger absorption gives darker image.

Cannot differentiate a thin slab of a strong absorber from a thick slab of a weak absorber.

No material specificity

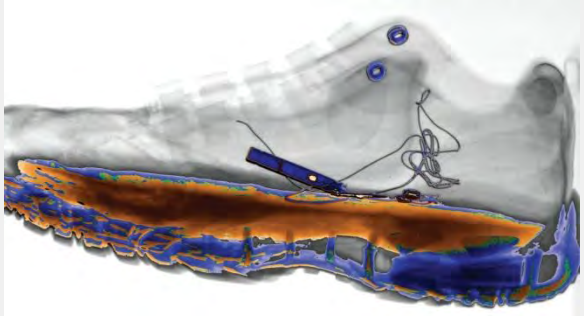


X-Ray absorption (dual energy)

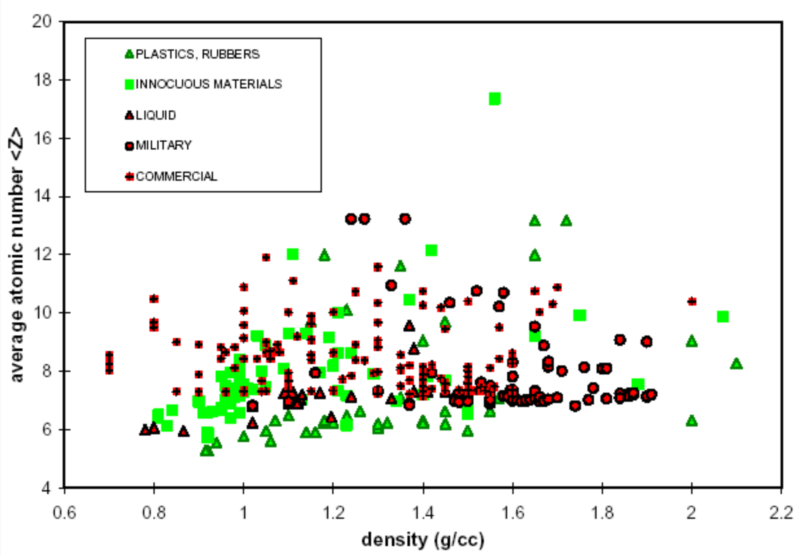
The method gives information on density an on average atomic number, <Z>

The result is normally shown to the operator as artificially colored pictures

Some degree of material specificity



+ Metals and other heavier elements tend to absorb more of the low X-ray energy radiation, while the lighter materials such as organic items, tend to absorb more of the higher X-ray energy
- Uncertainty in the determination of <Z>
- Very unspecific information of content

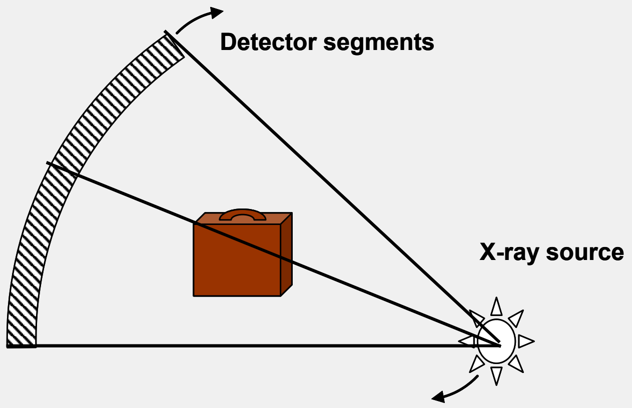


Emerging: X-Ray absorption using quadruple energy

Computer Tomography (CT)

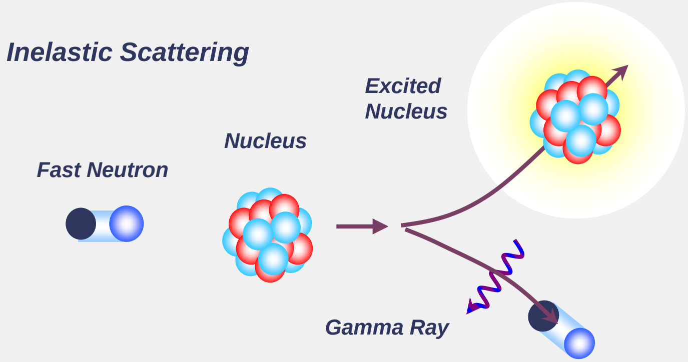
By taking images in several direction a 3D reconstructed image be acquired

- + Object hidden behind others in a pure 2D image can be identified.
- + More precise density measurements can be done.
- + The system is very complex and henceforth very expensive
- - A full 3D imaging is time consuming e
- - A high radiation dose is normal required

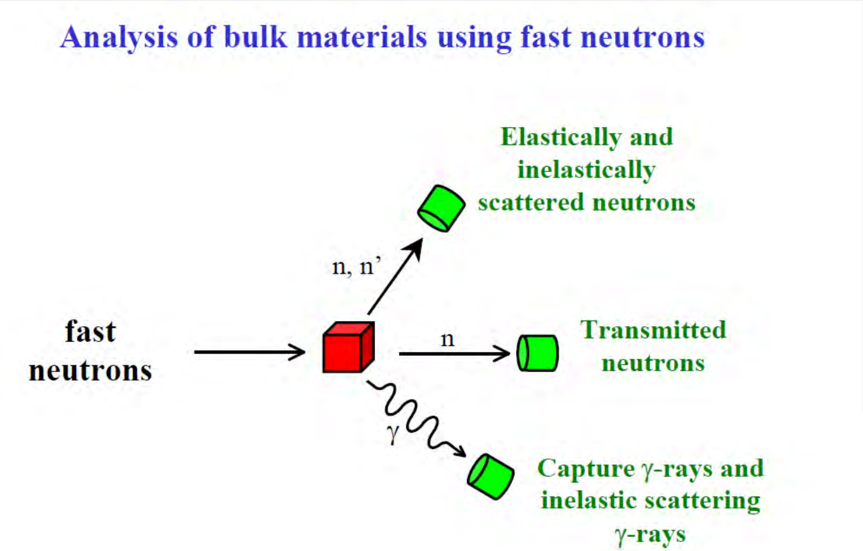


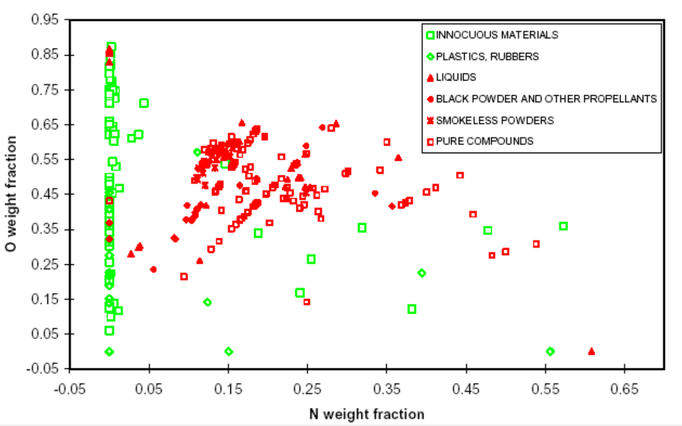
Pulsed Fast Neutron Analysis

Fast neutrons are scattered by the nucleus and a characteristic gamma photon is emitted



+ Information on several nucleus (e.g. O and N)
+ 3D information possibly
+ Complex and expensive system
- Ionizing radiation
- Not substance specific





NQR, Nuclear Quadruple Resonance

+ Do not use ionizing radiation.
+ Will give an **identification** of the explosives.
+ Low false alarm rate.
+ Do not require imaging analysis.
- The NQR-signal is weak and requires advanced signal analysis.
- NQR detection is normally slow
- NQR is near field detection system (less than 1 m)
- The signal is easily screened by a metal casing.
- NQR is only useful for nitrogen (and chlorine) containing explosive
- NQR do not work on liquids

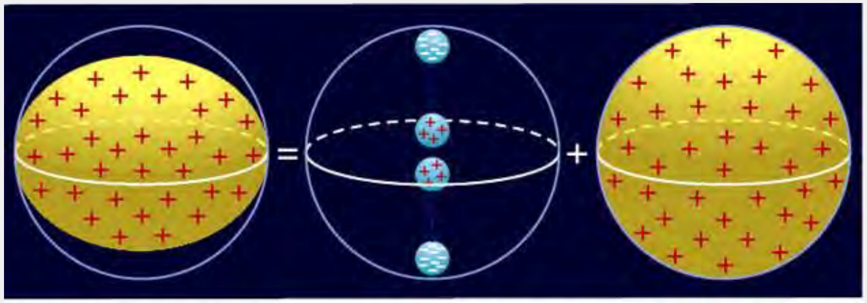
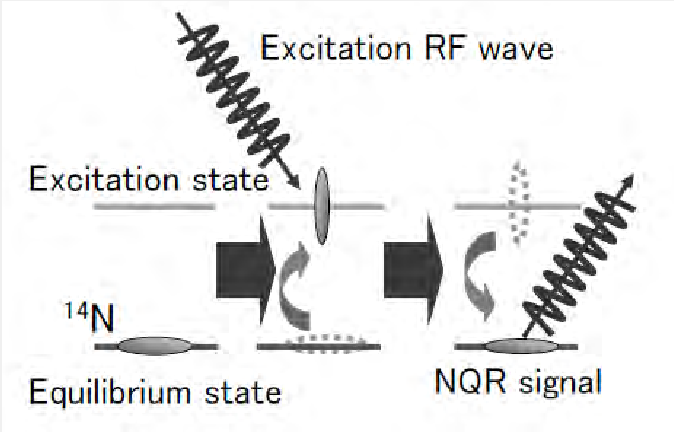


Figure 2. Nuclear quadrupole resonance requires that the nuclei under scrutiny display electric quadrupole moments. Such quadrupole moments arise when the distribution of positive electric charge in the nucleus is not perfectly spherical. For example, a slightly oblate (pumpkin-like) distribution of positive charge *(left)* can be thought of as the sum of a quadrupolar distribution *(center)* and a spherical distribution *(right)*.

E.g. Substances containing ^{14}N, ^{37}Cl or ^{127}I is NQR active



NQR frequencies: Explosives

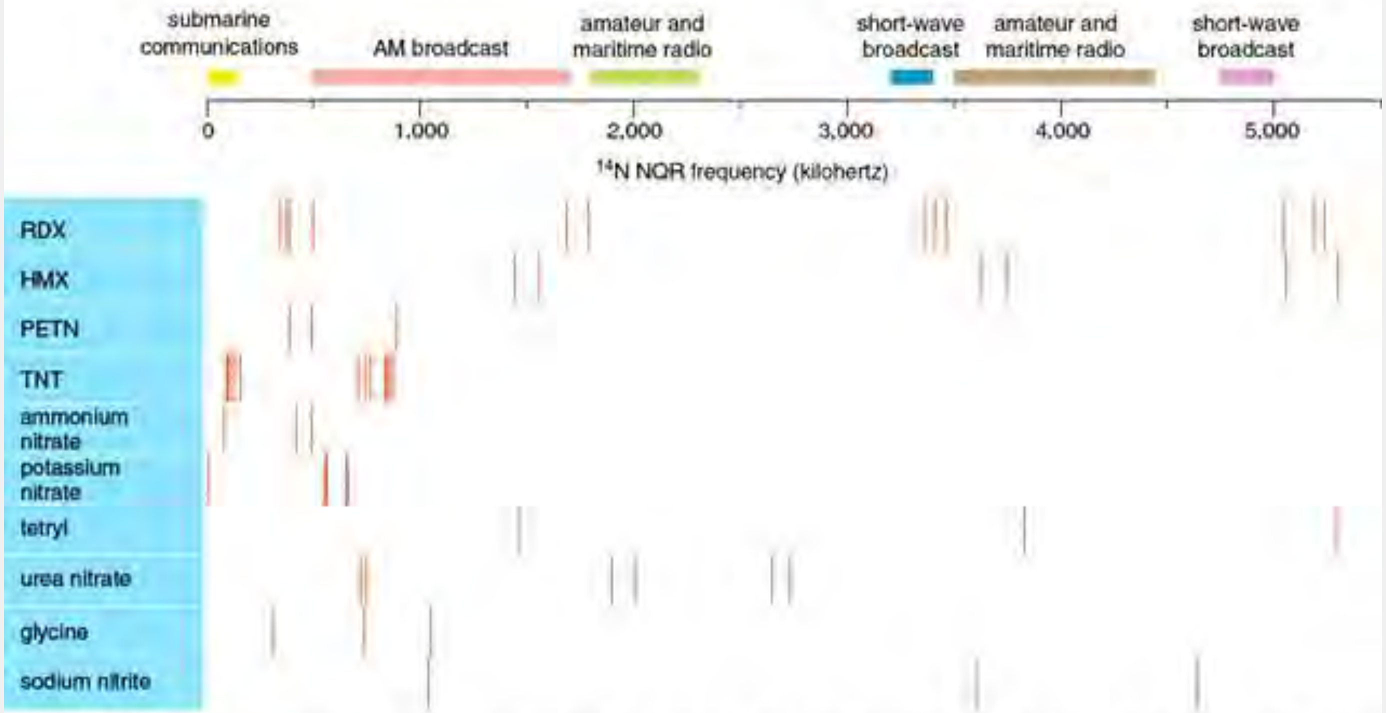
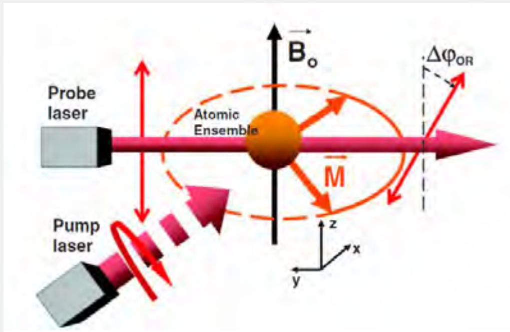
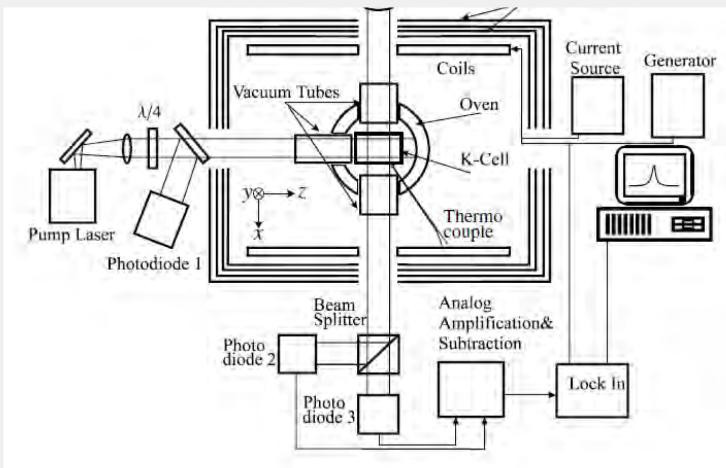
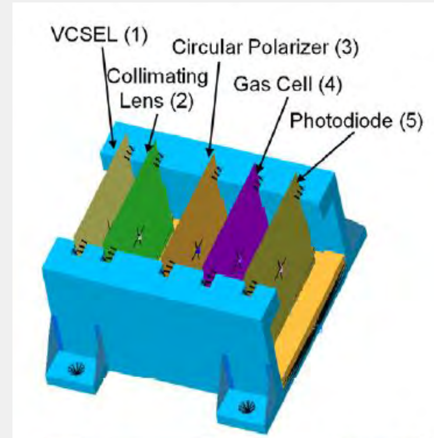


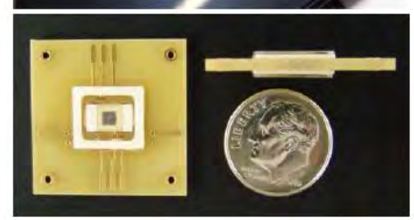
Figure 3. Common explosive compounds each produce a unique set of spectral lines when investigated for nuclear quadrupole resonance. The frequencies of almost all of those lines depend on the chemical environment of the nitrogen atoms contained in these compounds and on their crystalline arrangement. (The single purple line shown for potassium nitrate reflects a resonance of potassium-39.) Nitrogen-bearing compounds that are innocuous, such as glycine and sodium nitrite, also experience nuclear quadrupole resonance, but their spectral lines are distinct from those used in uncovering explosives. The resonances employed for detecting explosives do, however, overlap with various radio-communication bands *(top)*.

NQR and EFNMR Emerging Techniques: Optical Megnetometers







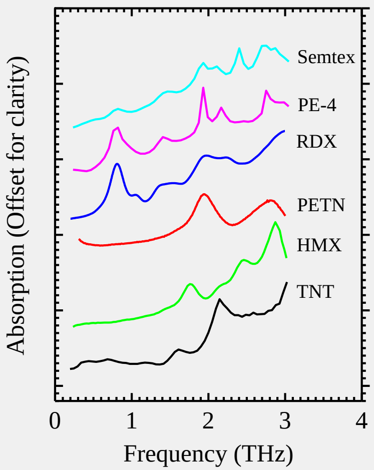


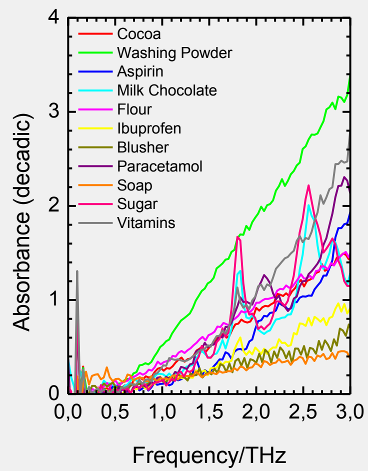
Emerging technologies

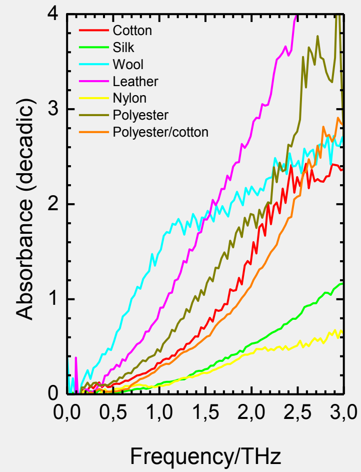
Bulk detection

THz spectroscopy

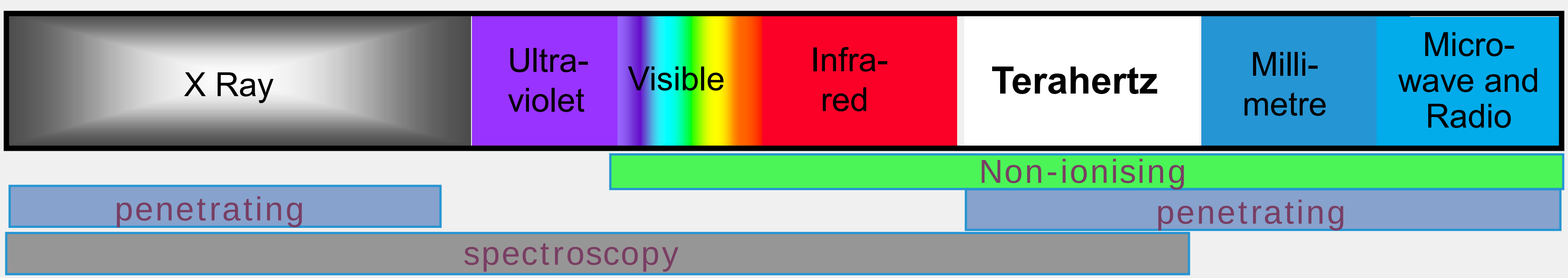
- Materials identification using characteristic Terahertz spectra



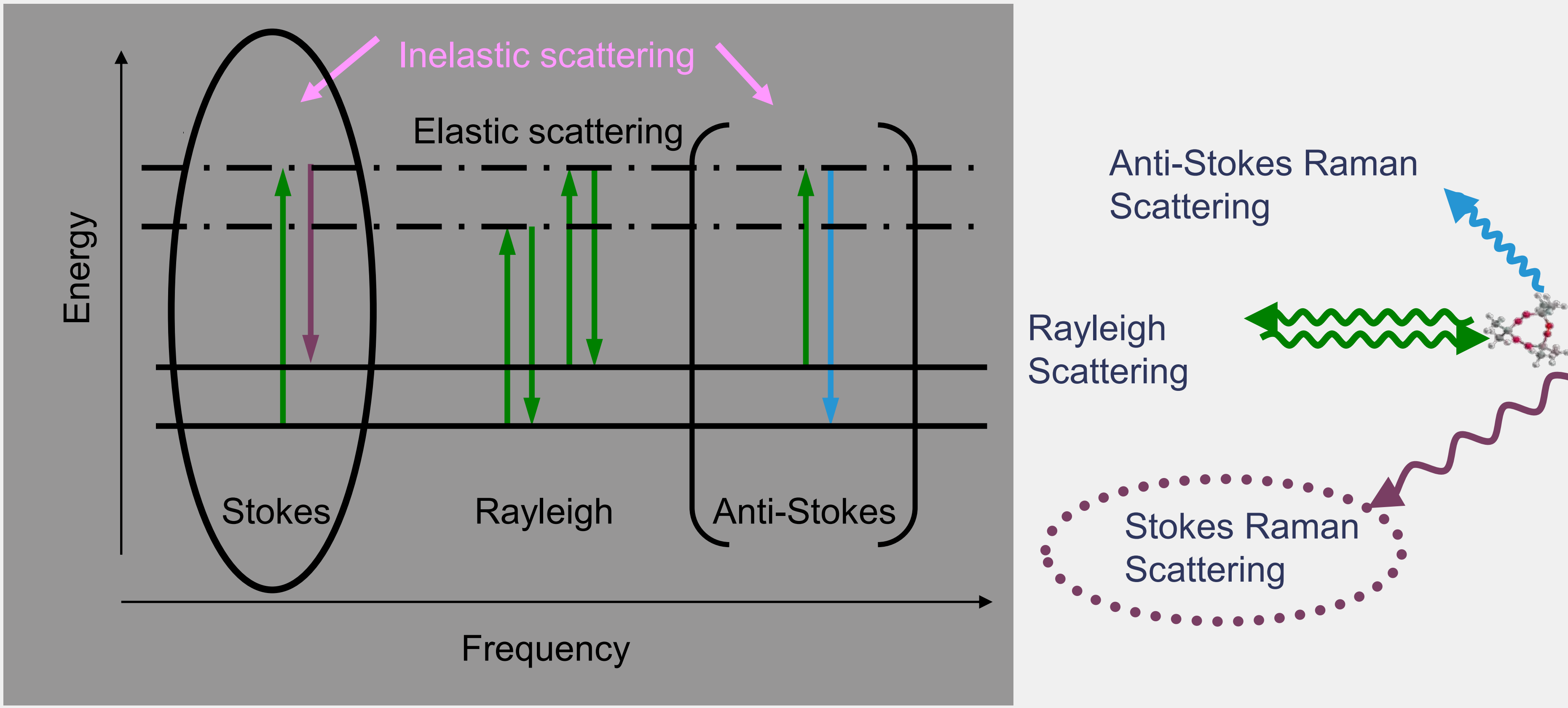




- Too slow
- Water absorbs above 2-3 THz
- Competition between region with most spectroscopic information and atmospheric window



Raman spectroscopy – scattering of light



+ **Molecule specific information**
– **Weak signal**

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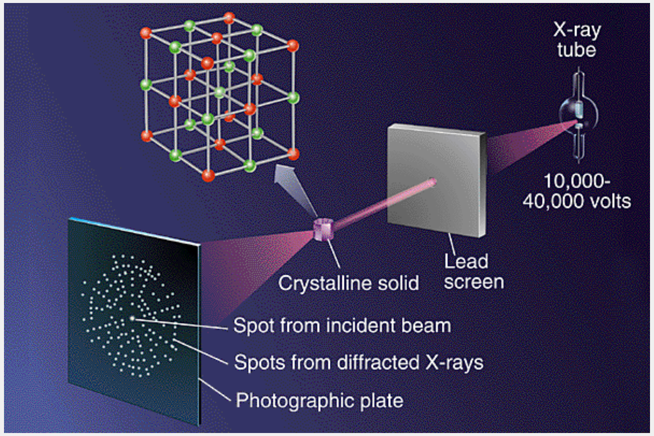
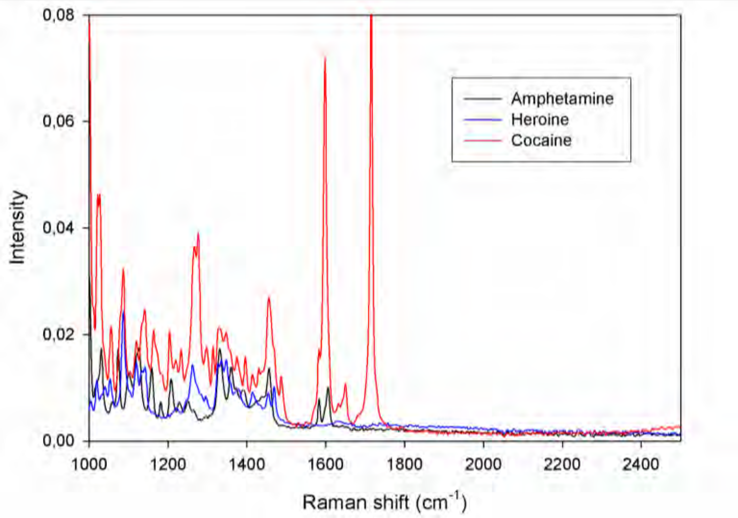
X-ray Diffraction

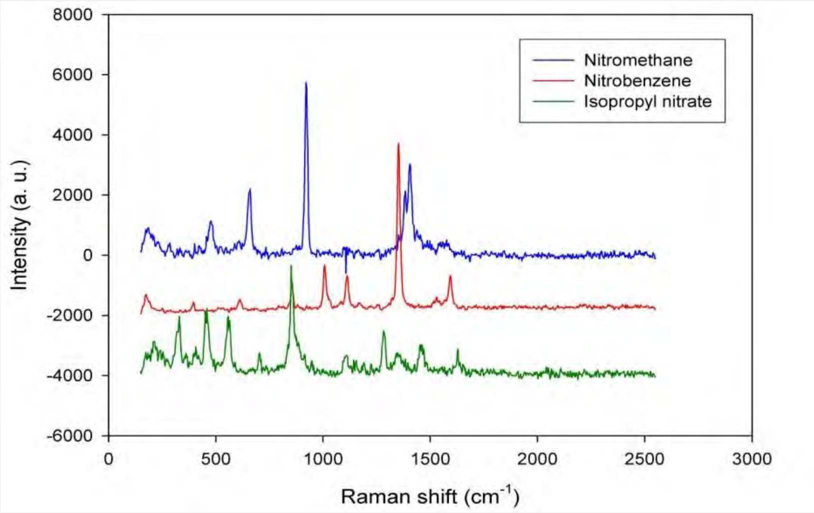


Raman spectroscopy as an analytical tool

- Gives detailed molecular specific information
- Has been used as a standard analytical tool for identification of chemical substances for many years.
- Well suited for use on many different substances, eg. explosives and drugs.



(Bruker 55 FT-IR / FRA 106)



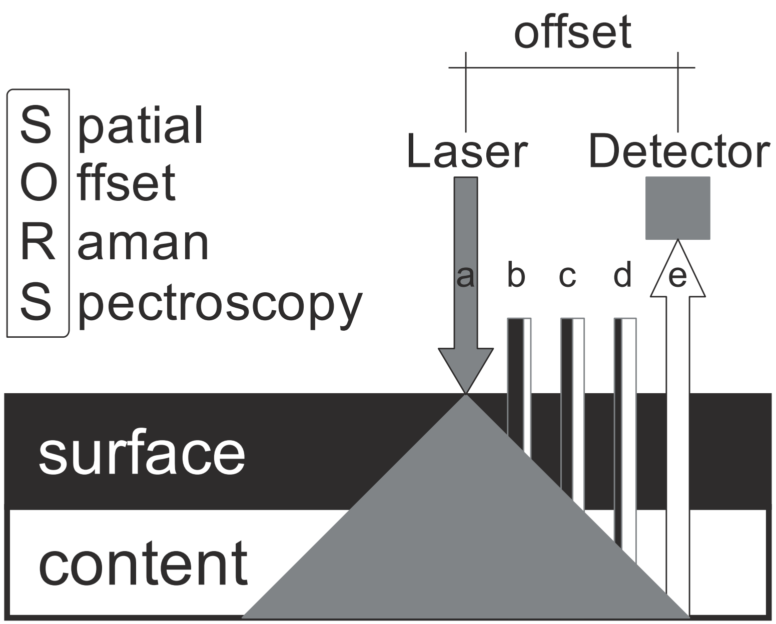
(Standoff setup @55 m)

S O R S

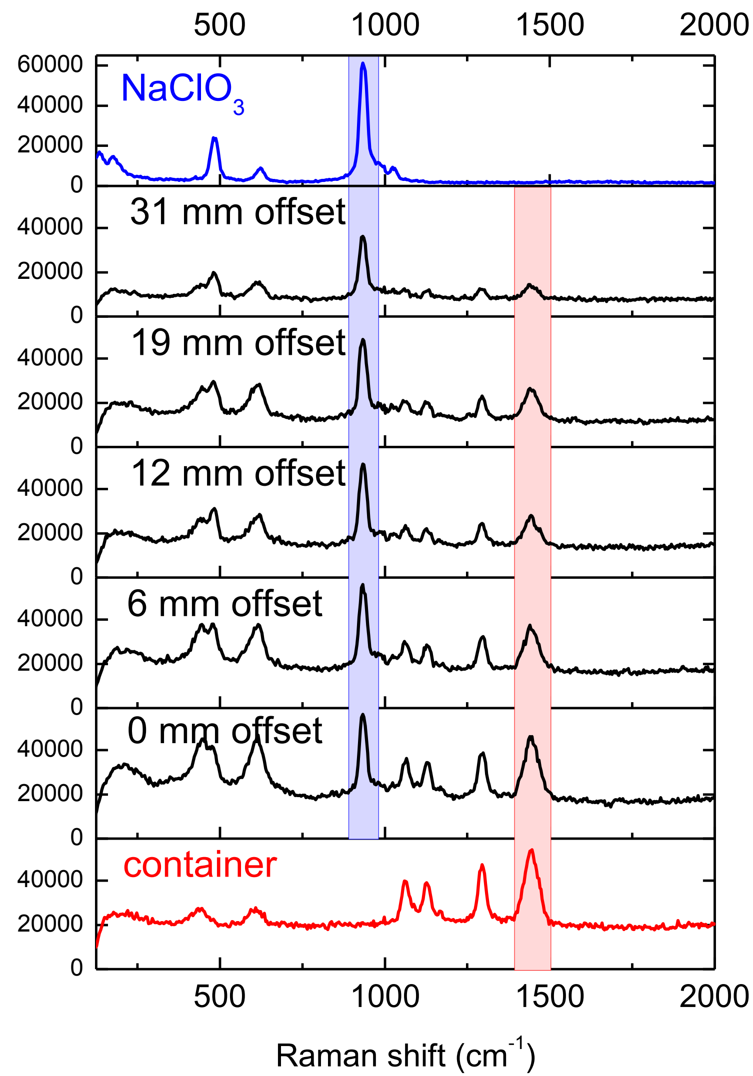
Spectra of container content

Spatial offset changes relative band intensity

A distant look behind the scenes



Stand-off SORS: Zachhuber et al. Anal. Chem. 83, 2011



Solid $NaClO_3$ through 1.5mm white HDPE bottle at 12m; 532nm laser excitation, 51mJ, 5ns, 10Hz; ICCD gate 5ns; summation of 250 laser pulses

Todays detection Techniques

Trace Detection

Dogs (Canine detection)

- \+ Best today
- \+ Unsurpassed mobility
- \+ Can search for the source
- \- Can not communicate the result
- \- Can only be used for a limited time
- \- Demand large amount of continuous training
- \- Costly, even when not used

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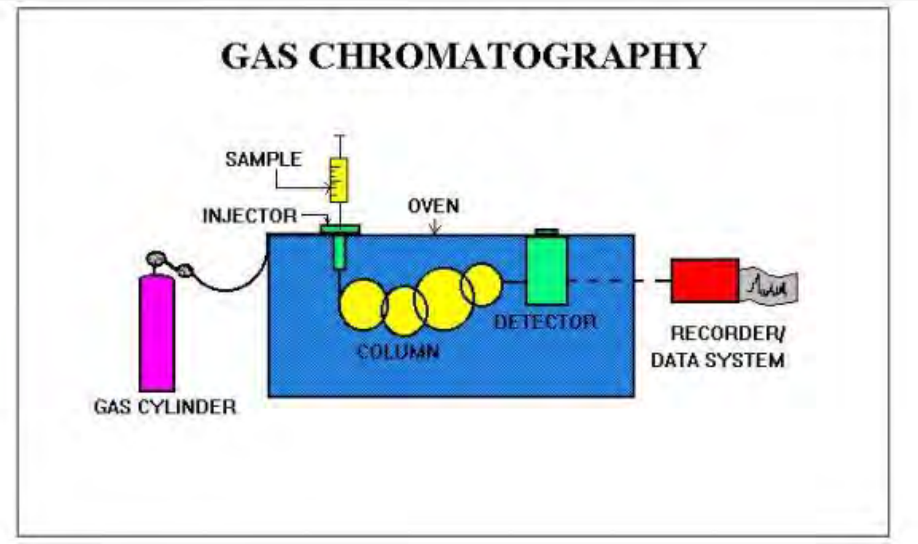
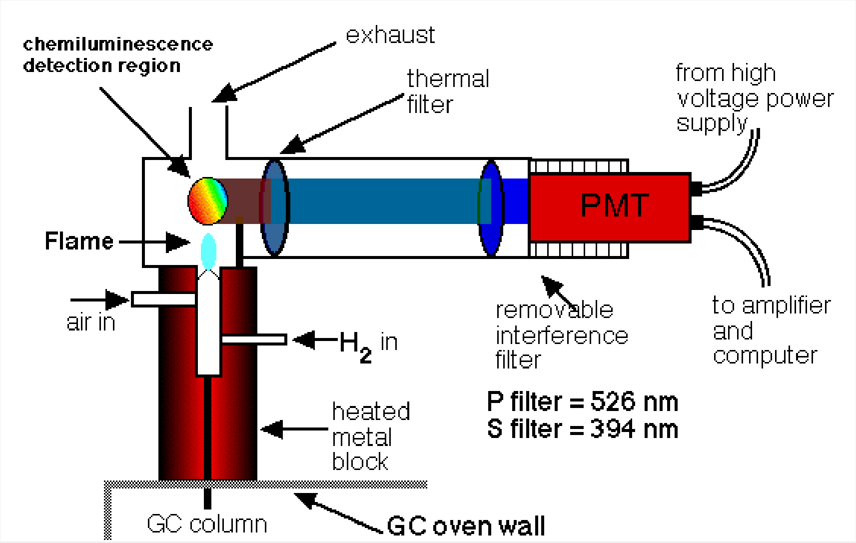
GC-CLD

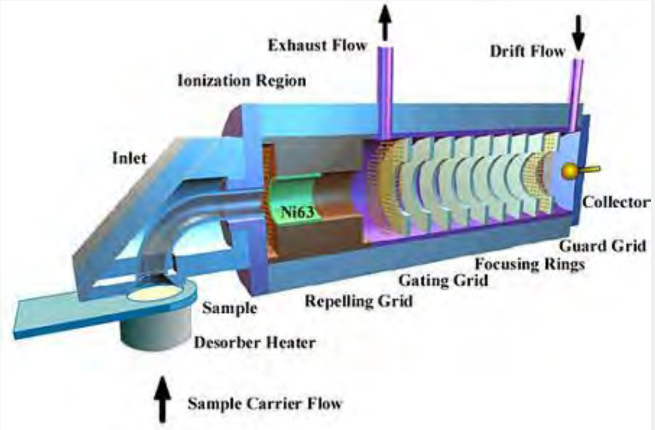
- Gas Chromatography – Chemo Luminescence Detector
- Still used in some equipment today
- Separation of the different gases in a colon
- Works only for NO_2- explosives!
- $NO + O_3 \rightarrow NO^*_2 + O_2$ $NO^*_2 \rightarrow NO_2$ + IR photone

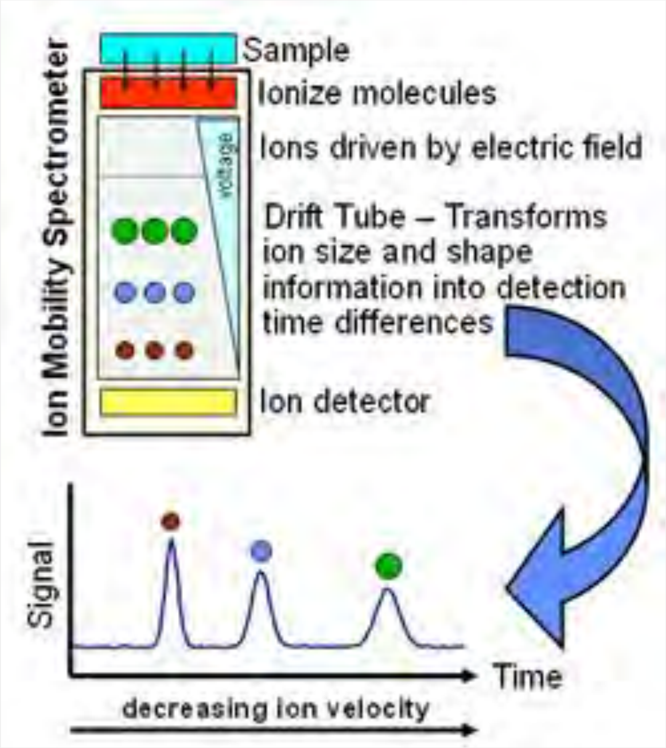




IMS

- Ion Mobility Spectrometry
- Most common trace detecting method today
- Ions are separated by their drift time in a electric field in a carrier gas
- Poor selectivity (6-10 substances)





Particle collection, Swipes

Example from Smiths Detection, IonScan 400B

- Time consuming
- Contact required (privacy issues)
- Operator dependent
    - Particle transfer depends on eg. applied pressure
    - Sampling location
    - Bad day

Particle collection, Portal

- Quick
- Non-contact
- Have been tested in many airports
- Now decommissioned…

Bees

- The bees are gently restrained in a fixed position
- Trained by Pavlovian conditioning to recognize an odor eg. Explosives
- When they encounter this smell the bees extend their tongue
- A beam of light is broken which in turn triggers an electronic signal.

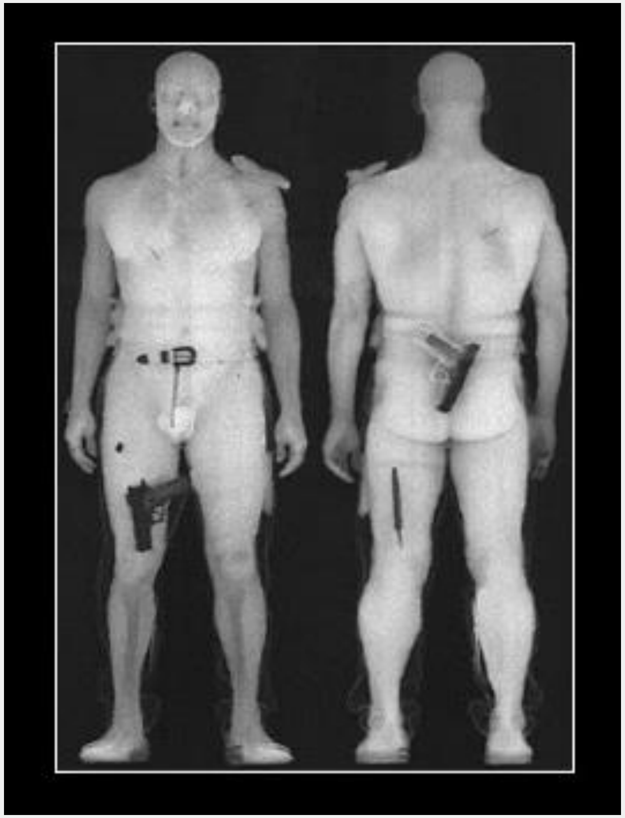
Todays detection Techniques

Anomaly Detection

X-ray backscatter

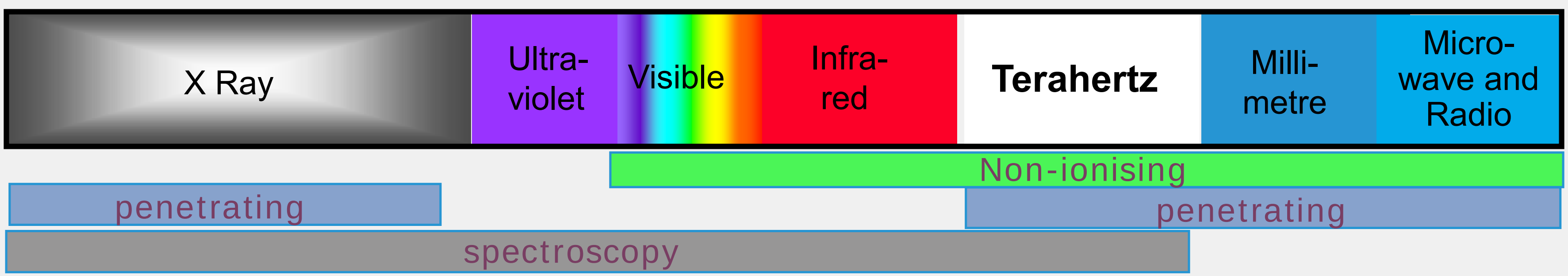
The radiation source and the detector is on the same side of the examined object.

- The combination of traditional transmittance X-ray and backscattered x-ray will give extra information.
- If a low dosage is used the technique can be applied to scanning humans for hiden objects under the cloths Material with high density will hide other material.



Millimeter Wave Imaging

- Clothes and many other materials is nearly transparent in the mm wave region.
- Passive millimeter wave imaging uses the body's natural emitted radiation. Dense object bocks this emission and gives clear images of the object.
- Active millimeter wave imaging utilize a millimeter wave radiation source and illuminate the target and use the reflected radiation to produce an images.



Todays detection Techniques

(Detection/)Identification of Visibly Amounts

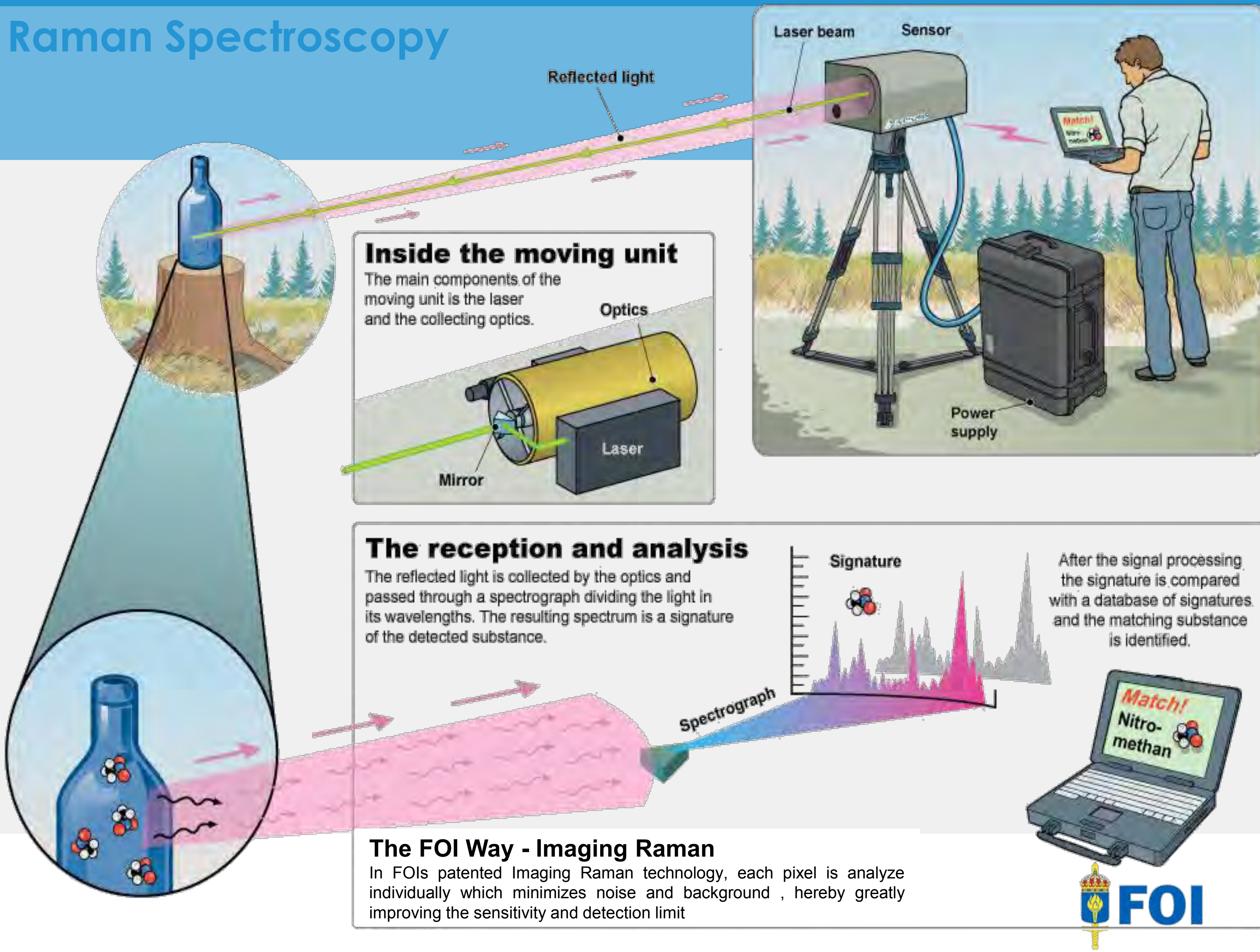
Identification of visible amounts

- Spot tests
- For field detection

- Ramanspektroskopi
- För identifiering av synliga mängder material, t.ex. pulver
- Ger god identifiering

Emerging Trace Detection: Standoff

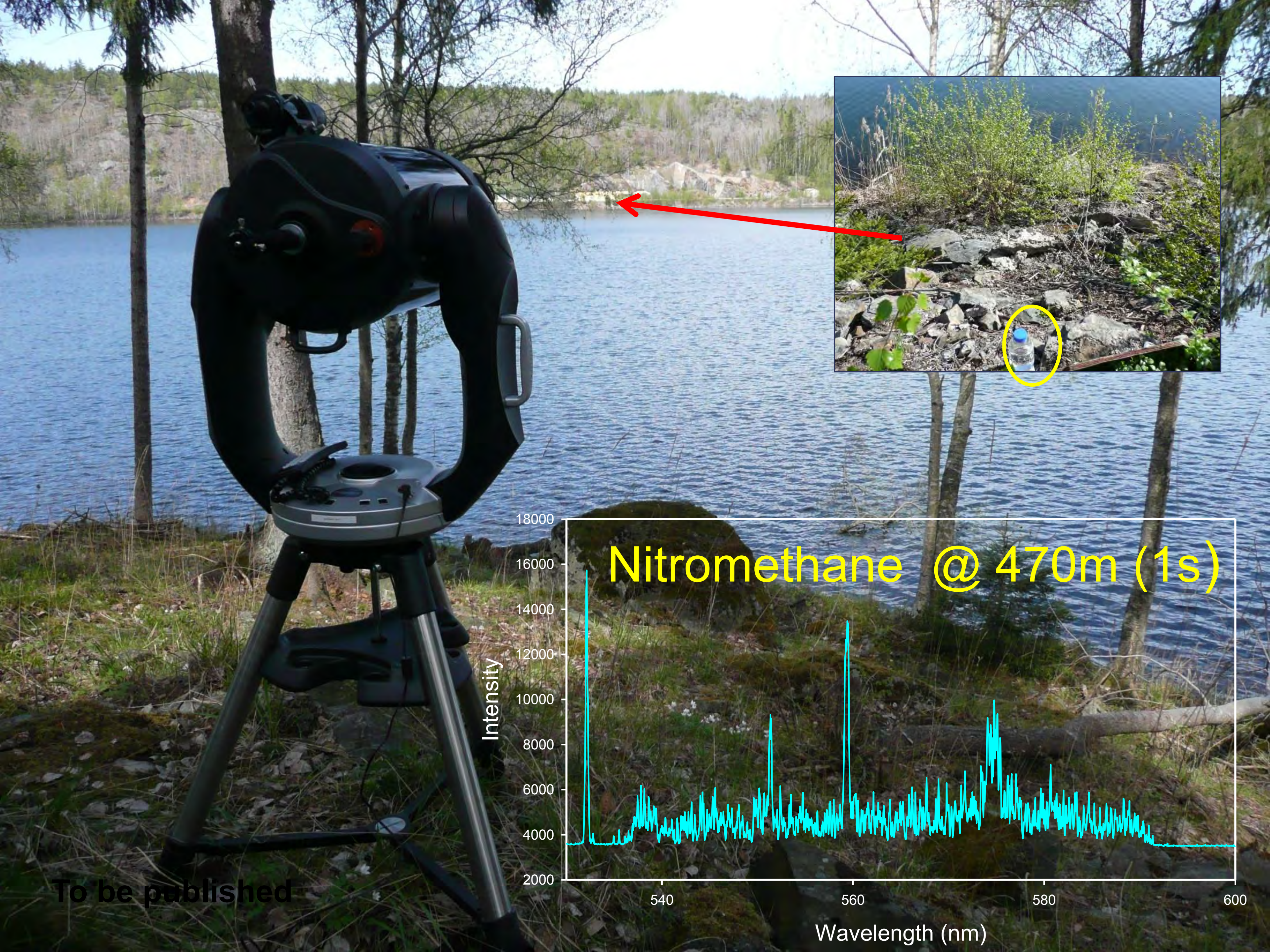
Raman Spectroscopy



The FOI Way - Imaging Raman

In FOIs patented Imaging Raman technology, each pixel is analyze individually which minimizes noise and background , hereby greatly improving the sensitivity and detection limit


UFT 424
470m Mobile setup


Nitromethane @ 470m (1s)
18000
16000
14000
12000
10000
8000
6000
4000
2000
Intensity
540
560
580
600
Wavelength (nm)
To be published

Detection limits for spontaneous Raman

Detection limits:
30 meters, 5s

Ammonium nitrate ~250 µg
TNT ~500 µg
DNT ~ 375 µg

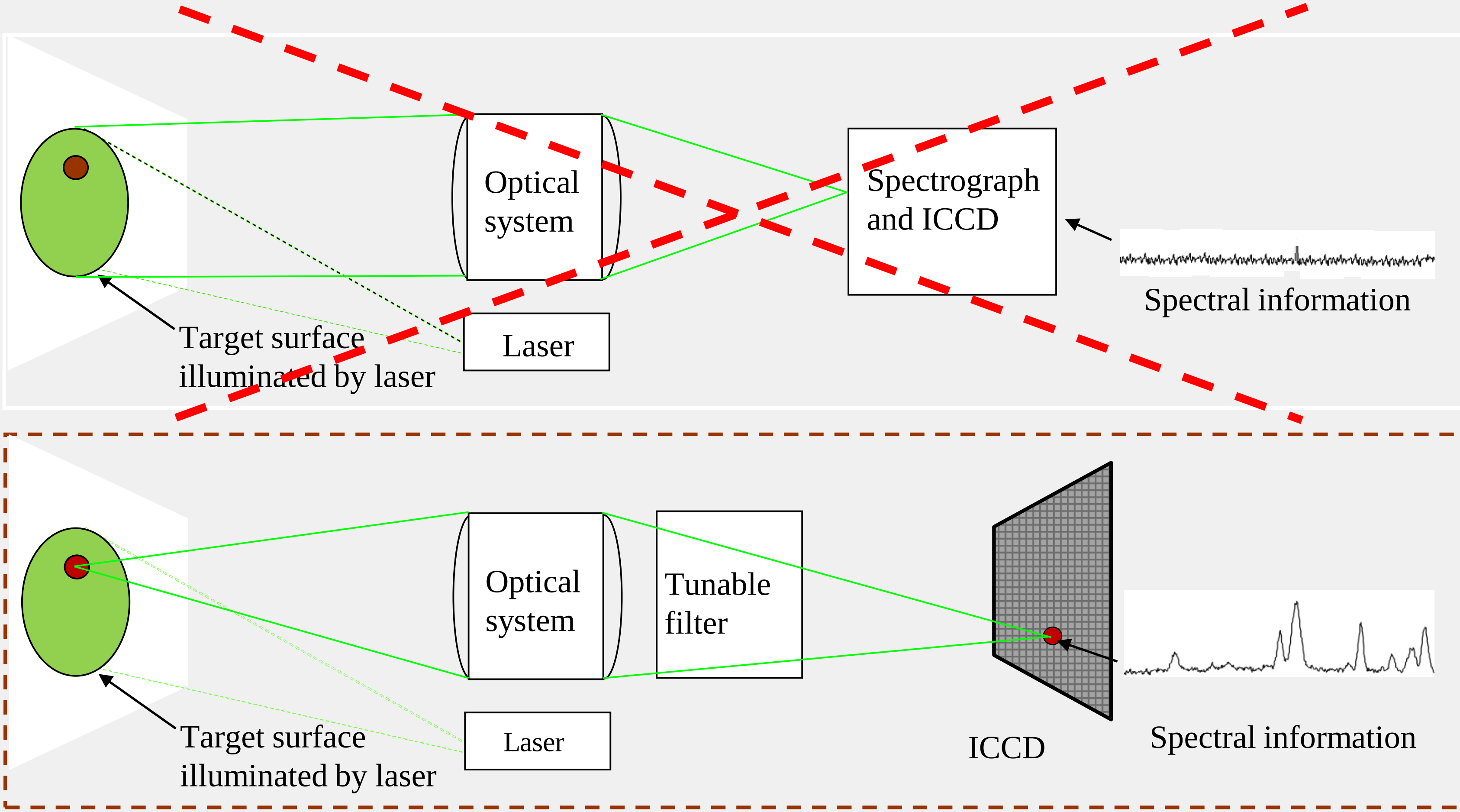
What do we need?

1:st fingerprint
mass in the order of µg *

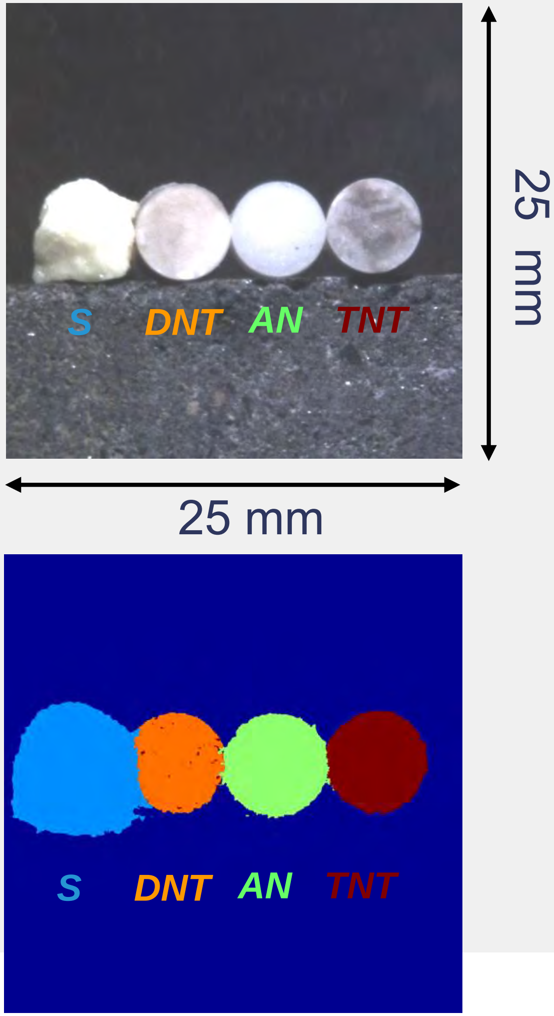
50:th fingerprint
mass in the order of ng *

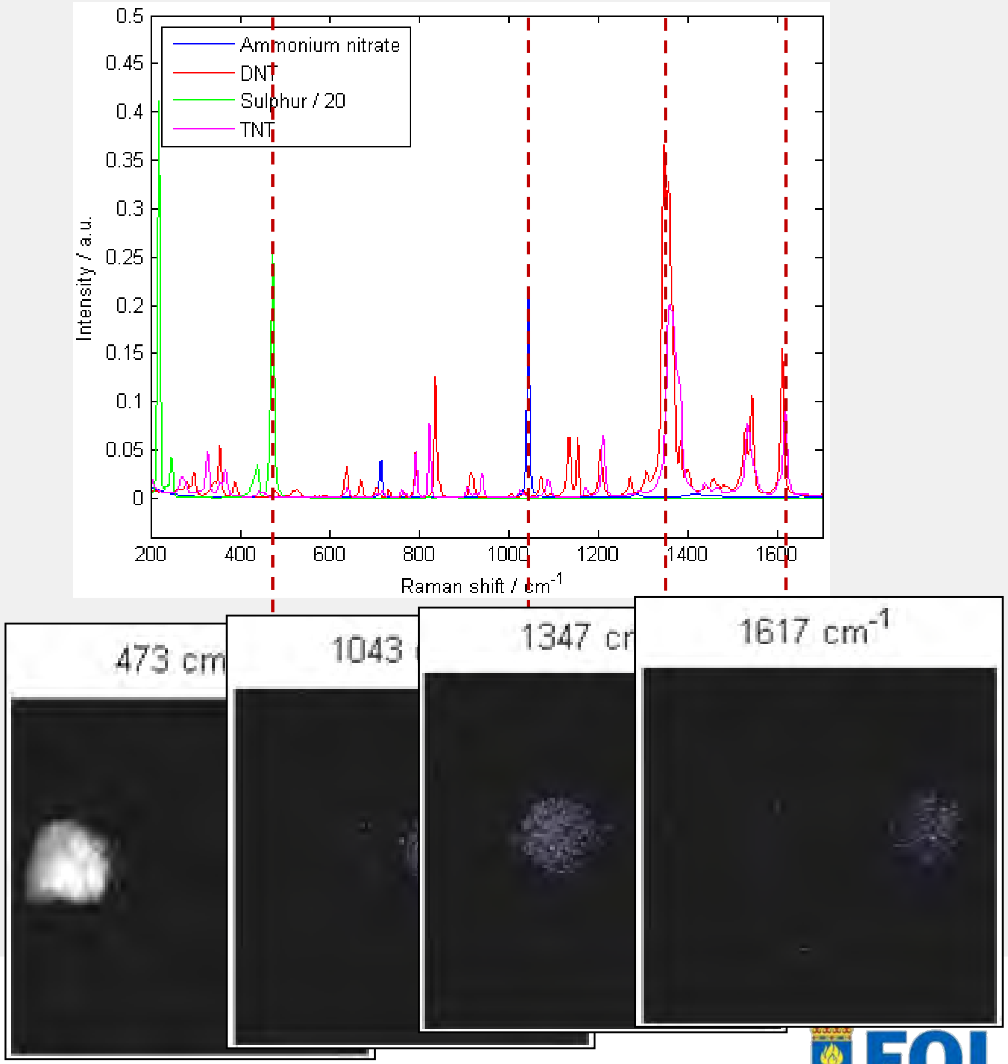
Mass of a TNT particle	100 µm ~ 1 µg 50 µm ~ 100 ng 20 µm ~ 10 ng

Imaging Raman Spectroscopy



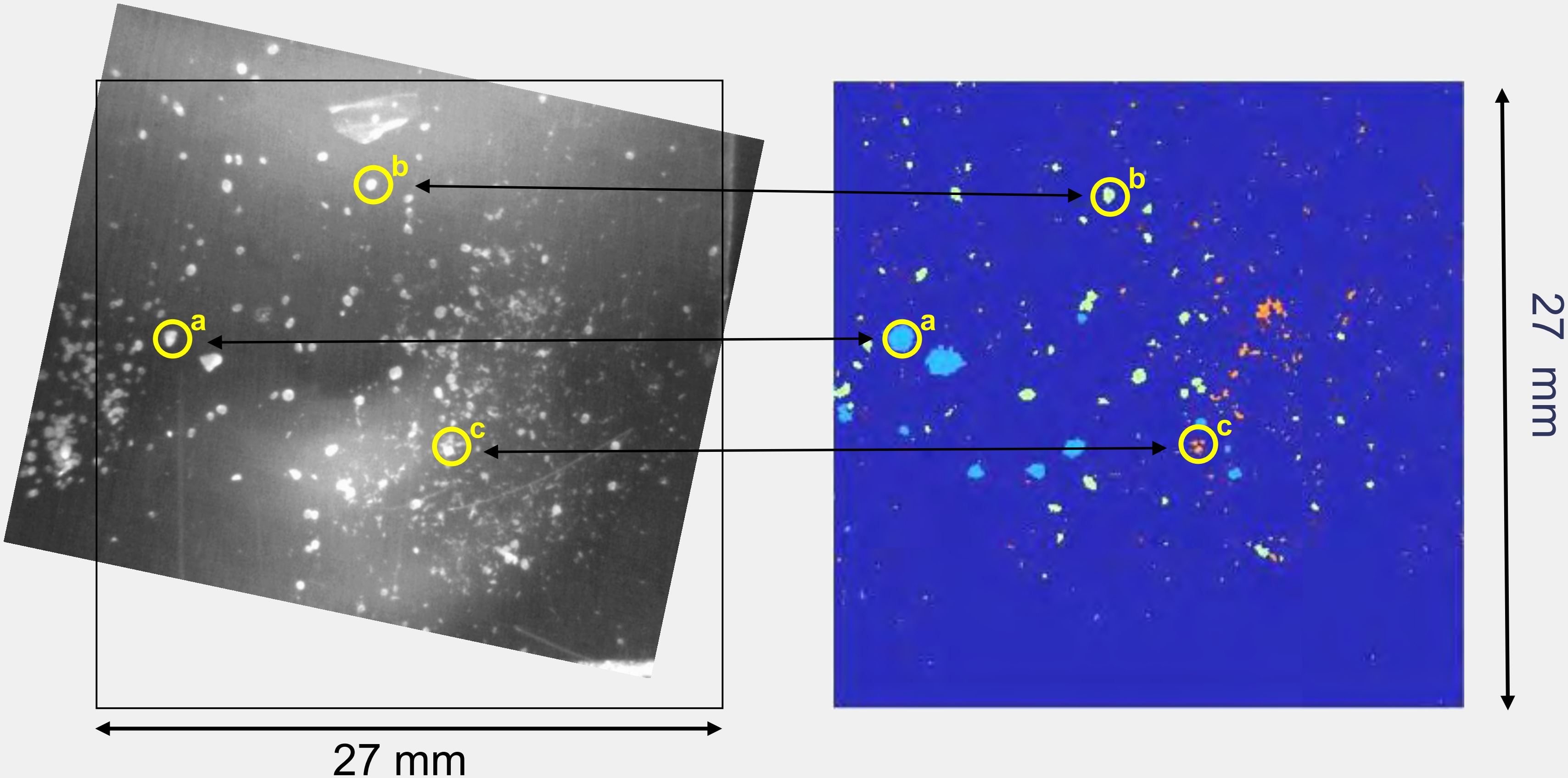
Multispectral Imaging Raman



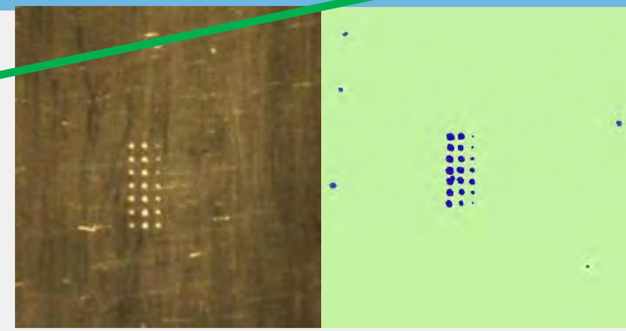


Mixed Particles in Fingerprint

Sulfur(a), ammonium nitrate(b) and DNT(c) particles at 10 m



Stand Of Detection by Raman Imaging – trace residues



Present Capability:
TNT Limit of Detection << 400 ng
@ 10 m distance and 30 sec for 25x25 mm
Eye Safe *(2014-10-01, but needs to be improved)*

Future Capability:
- *Improved* Eye Safety *(planed for 2016-)*
- Faster <1s *(planed for 2016-)*
- Moving Target (TBD)
- Longer distance (TBD)
- Higher sensitivity *(planed for 2016-)*

Example on Requirements

First fingerprint: µg
Fingerprint #50: ng

Mass of a TNT particle
100 µm ~1 µg
50 µm ~100 ng
20 µm ~10 ng

FOI

Tunable filter based hyperspectral Raman imaging

Previous systems for trace detection of explosives are mostly based on tunable filters. Example: UV-HLIN (8-20m).

Pros:

- This type of imaging has the potential to measure each point on the object independently, reducing the influence of fluorescence.

Cons:

- Filters, especially in the UV have low transmission, bad blocking and can be very sensitive to changes in the environment/alignment. (cost)
- A lot of light lost when scanning the wavelength bands

Possible improvements include a ~380 nm laser to keep in the eye-safe region while avoiding getting to close to absorption bands.

Line scan Raman spectroscopy for hand luggage

Example: XP-DITE/SAFEPOST system (built into X-ray cabinet).

Pros:

- Single shot measurements possible (LOD>10ug)

Cons:

- Full image readout -> repetition rate limited by FPA detector (current system limit 20 Hz) -> low coverage

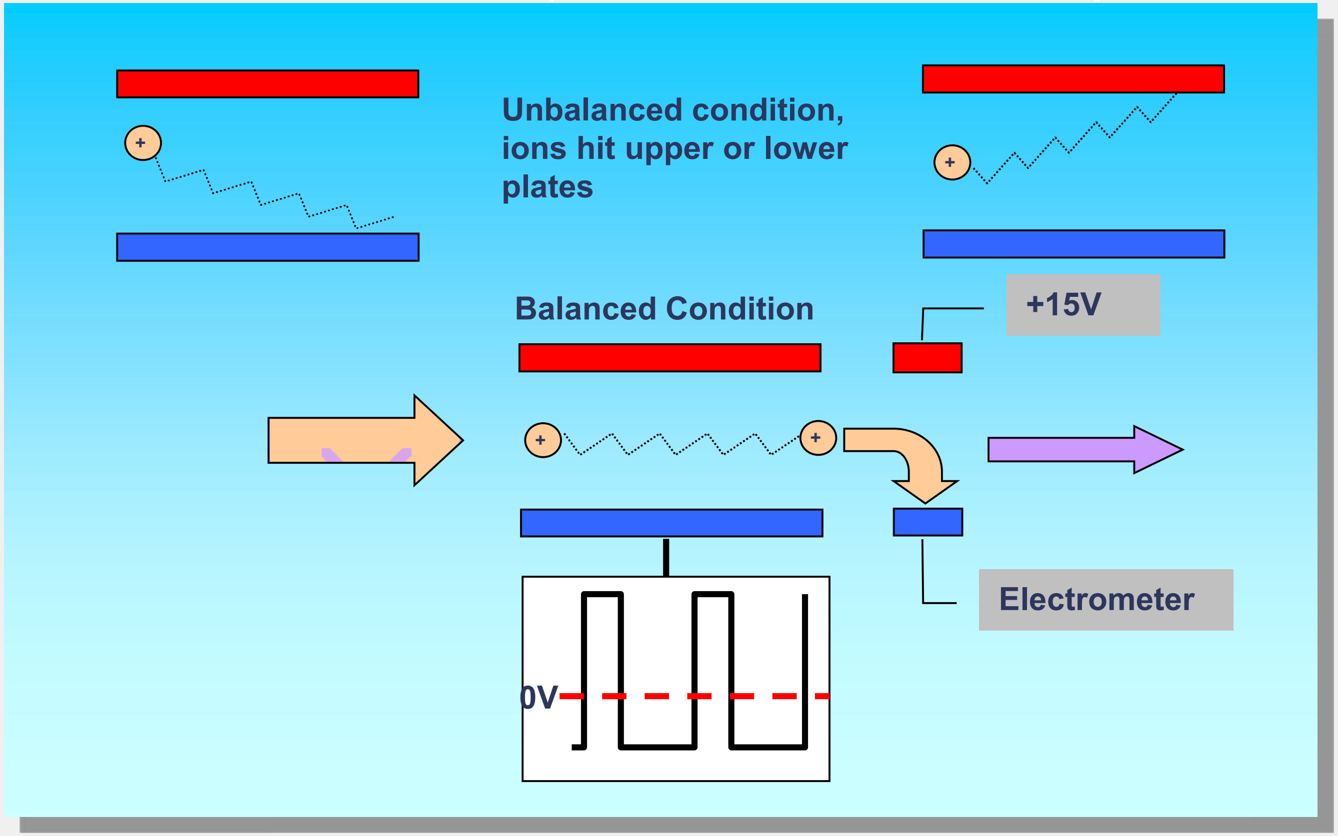
FOI

Emerging technologies

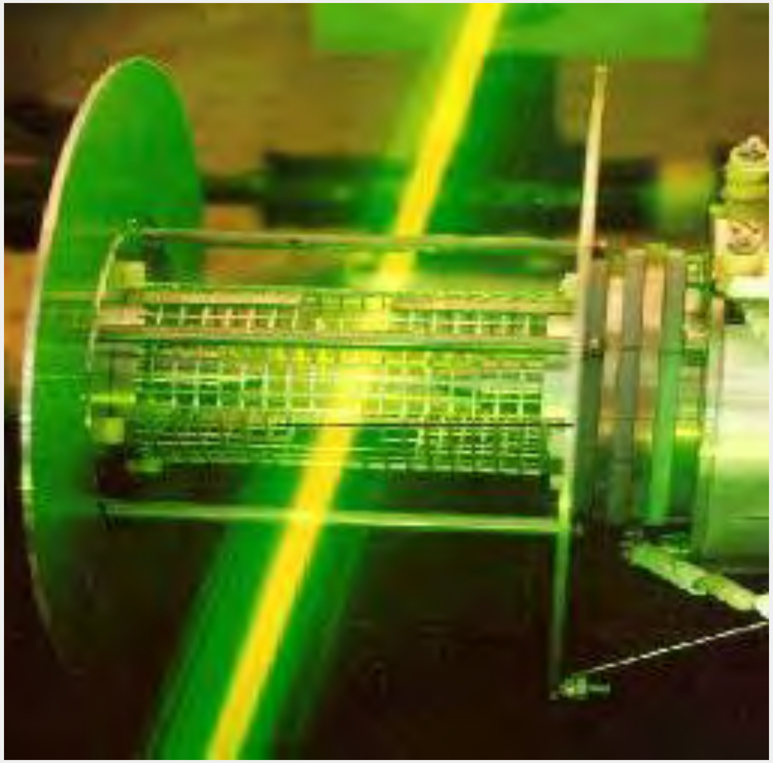
Point detection, trace

DMS (Differential Mobility Spectrometry)

- Improvement of IMS, better selectivity

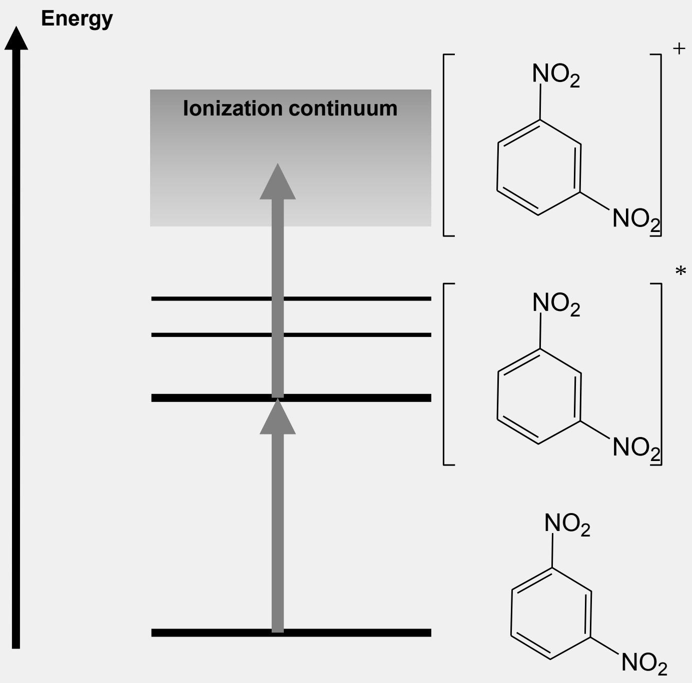


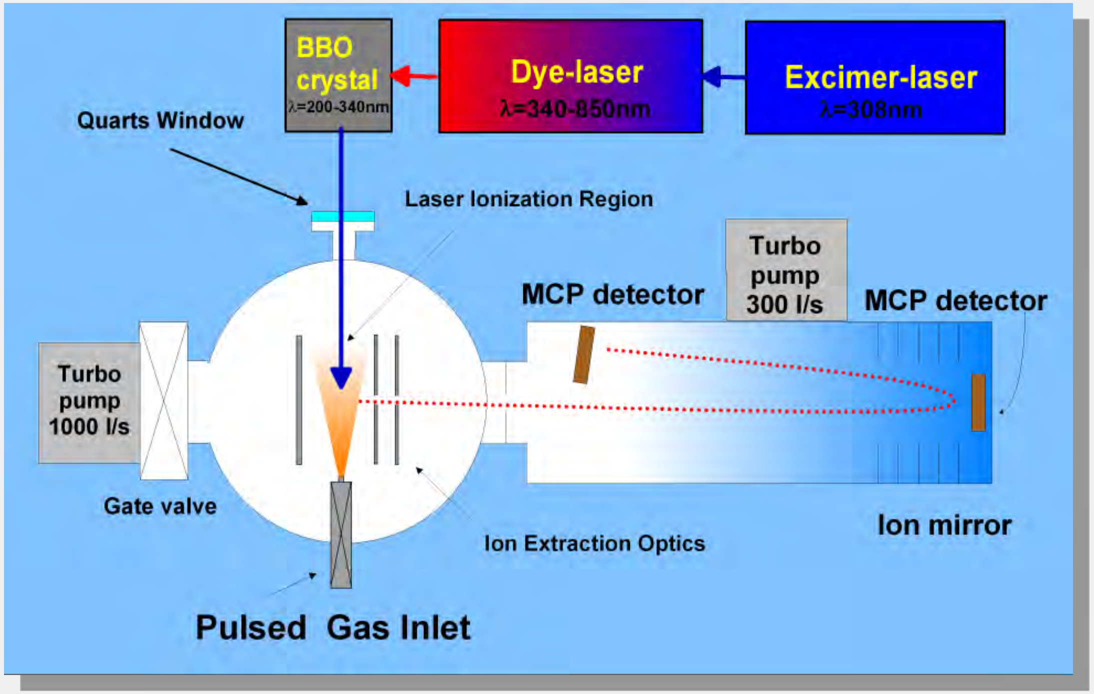
Jet- REMPI-MS



- Combines laser and mass spectrometer
- Measures ***two*** molecule specific parameters
- Very selective
- Very sensitive
- Very rapid measurement

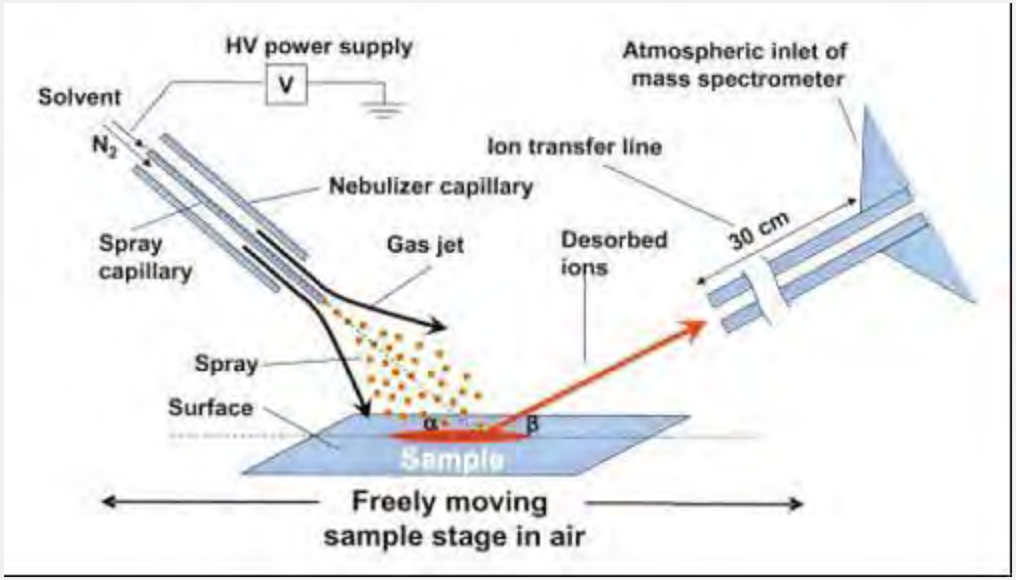
REMPI-MS


Energy
Ionization continuum
NO2
NO2
+
*


BBO crystal
λ=200-340nm
Dye-laser
λ=340-850nm
Excimer-laser
λ=308nm
Quarts Window
Laser Ionization Region
Turbo pump 300 l/s
MCP detector
MCP detector
Turbo pump 1000 l/s
Gate valve
Ion Extraction Optics
Ion mirror
Pulsed Gas Inlet

DESI

DESI=Desorption Electrospray Ionization



- Direct ionization from surface
  - Clothes
  - Skin
  - Paper
- Charged microdroplets used for ionization
- Works at ambient pressure
- Subnanogram (RDX, HMX, PETN, TNT, Comp C4, Semtex-H, Detasheet), subpicogram (TNT)
- < 5 s total analysis time

Questions?