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Fingerprinting : the new frontier – breaking barriers to implementation

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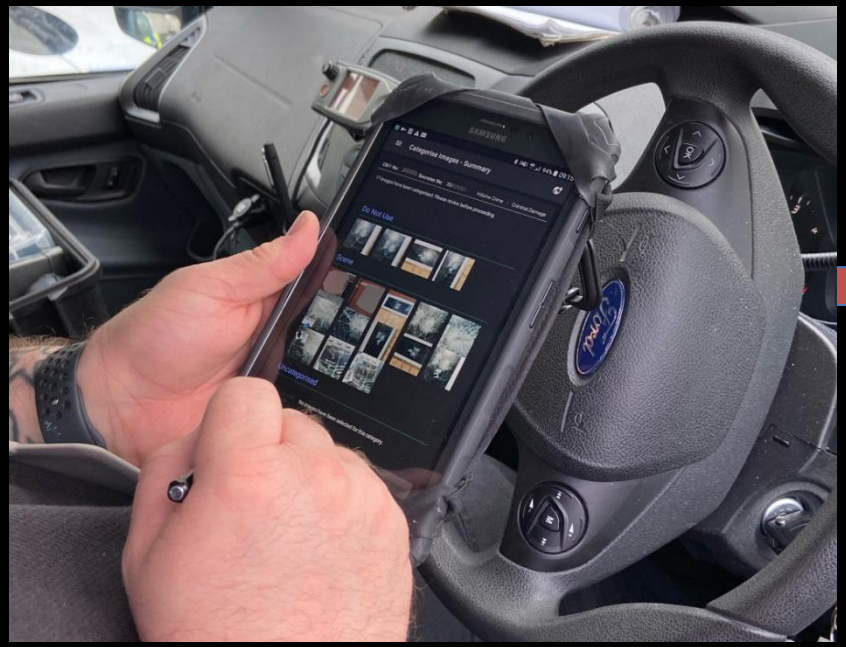
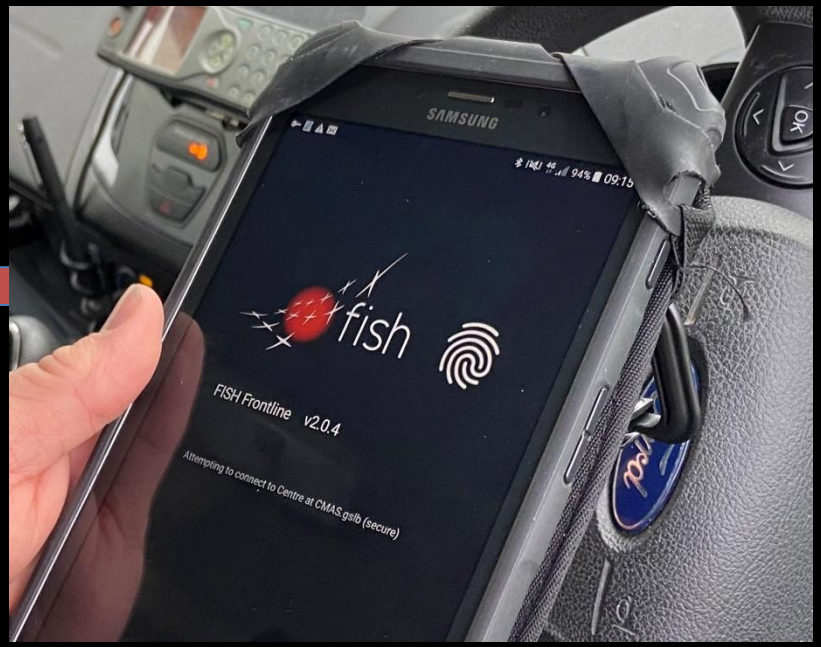
Fingerprinting





Yorkshire and Humber Regional Scientific Support Services

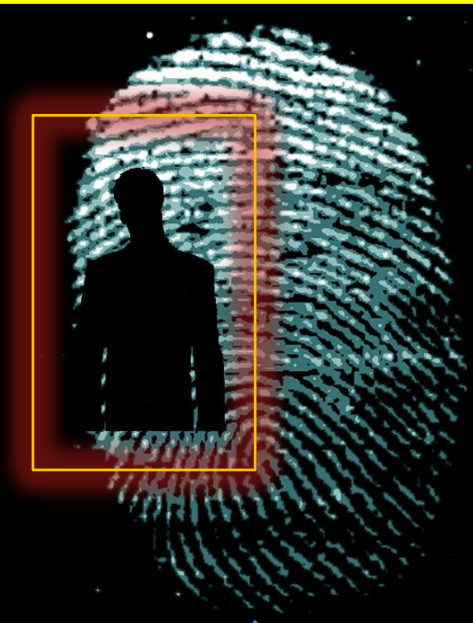
Courtesy of Peter Arnold Head of Operations YHRSSS

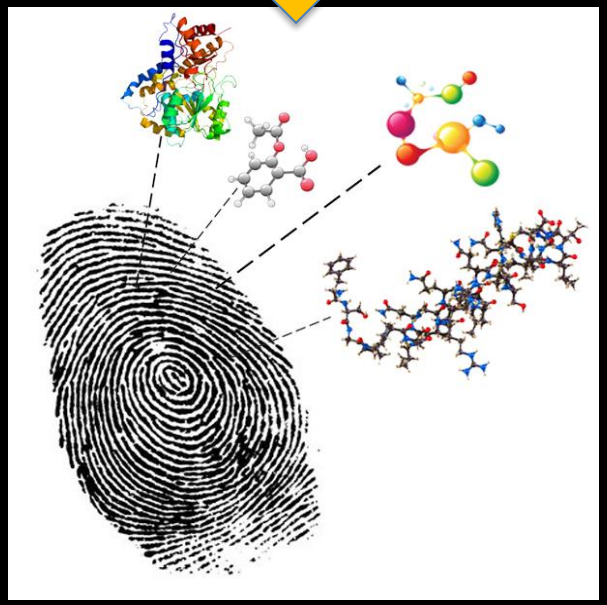
Conventional fingerprinting pitfalls

The “soul” of a fingerprint

Chemical criminal profiling

Francese S, et al. Analyst. 2013, 142(14):2518-46
Francese S et al. Analyst 2017, 138(15): 4215-28





Chemical criminal profiling

Mass Spectrometry
(and hyphenated techniques)

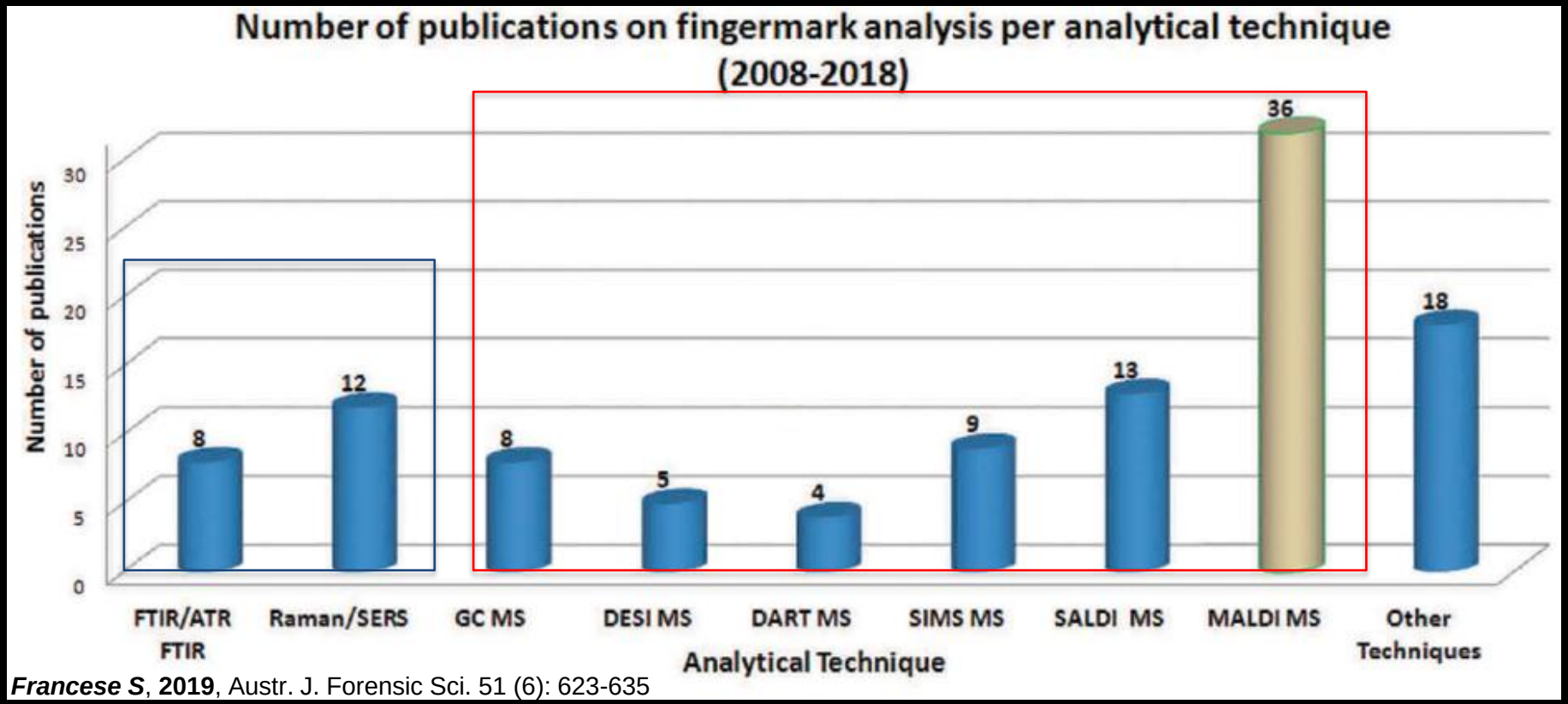
DESI
DART
MALDI
Ag LDI
Paper Spray
SALDI
SIMS

LC ESI MS
GC ESI MS

Spectroscopy

Raman
FT IR and ATR FT IR

Imaging and profiling capabilities



***Francese S*, 2019**, Austr. J. Forensic Sci. 51 (6): 623-635

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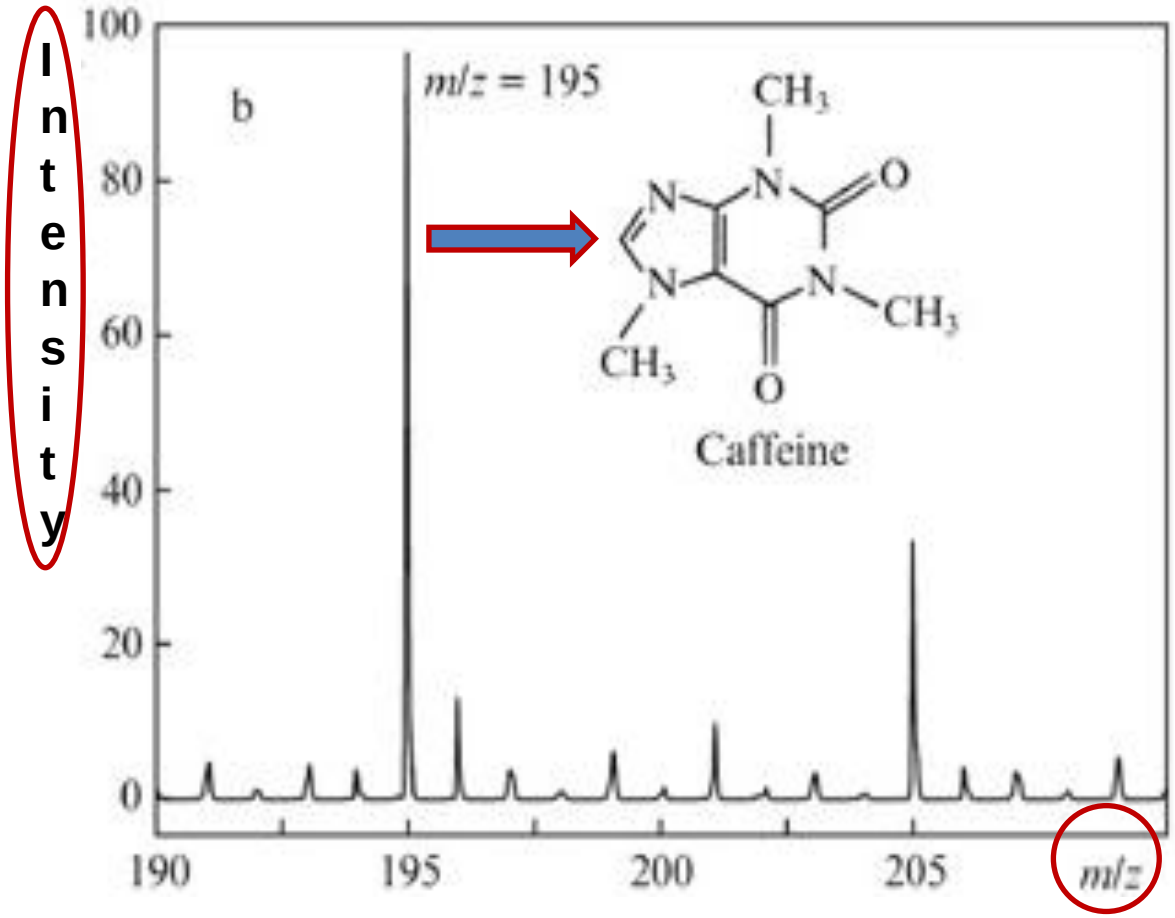
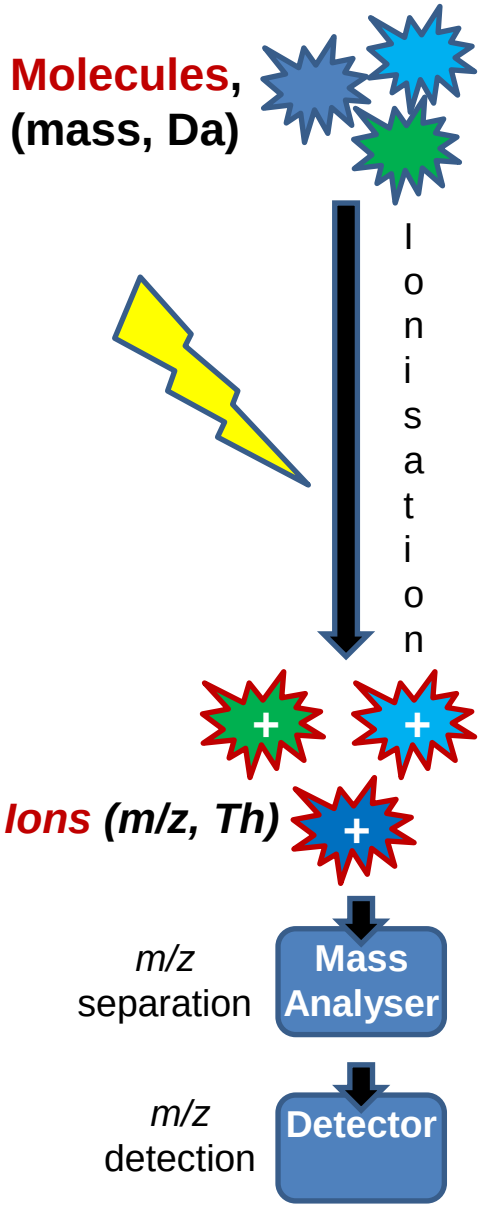
WHAT IS MASS SPECTROMETRY (MS)?



Scales...for molecules!!!!



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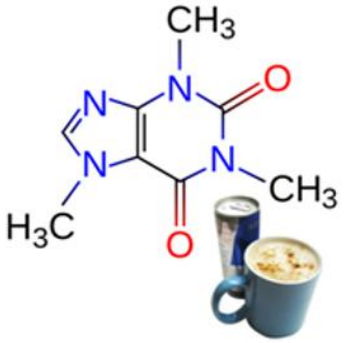
Mass Spectrometry as investigative analytical tool

Before Christmas

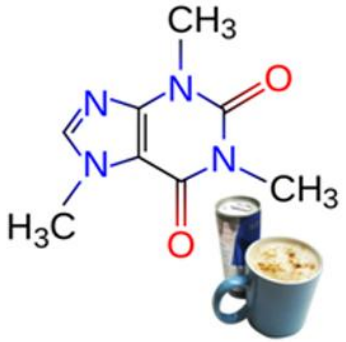
After Christmas



caffeine weighs = 194.1 Daltons

Before Christmas

After Christmas



caffeine weighs = 194.1 Daltons

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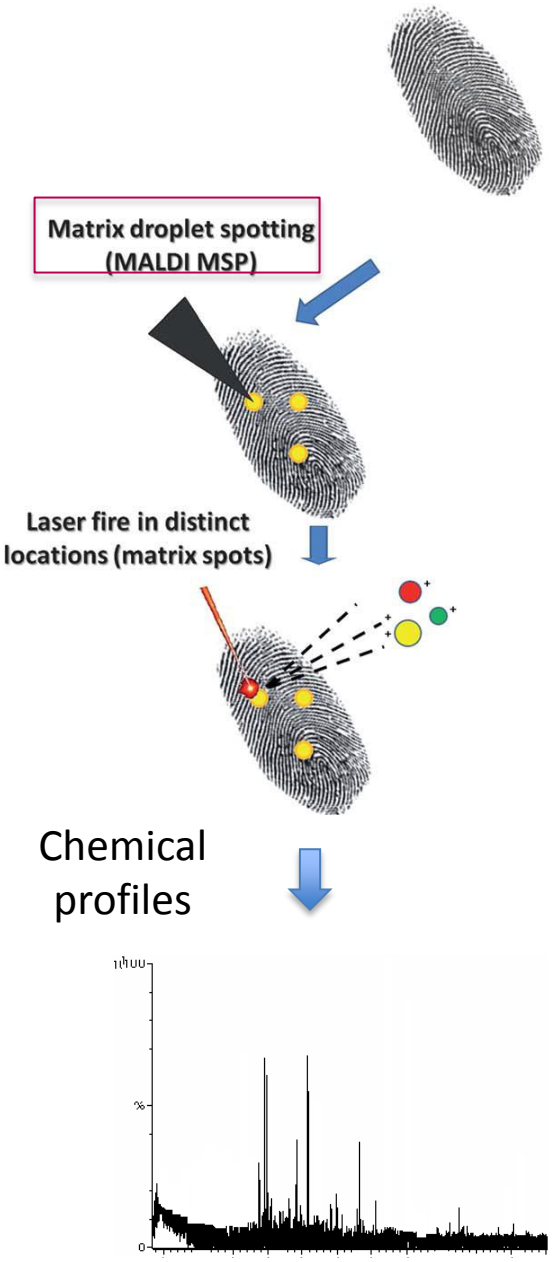
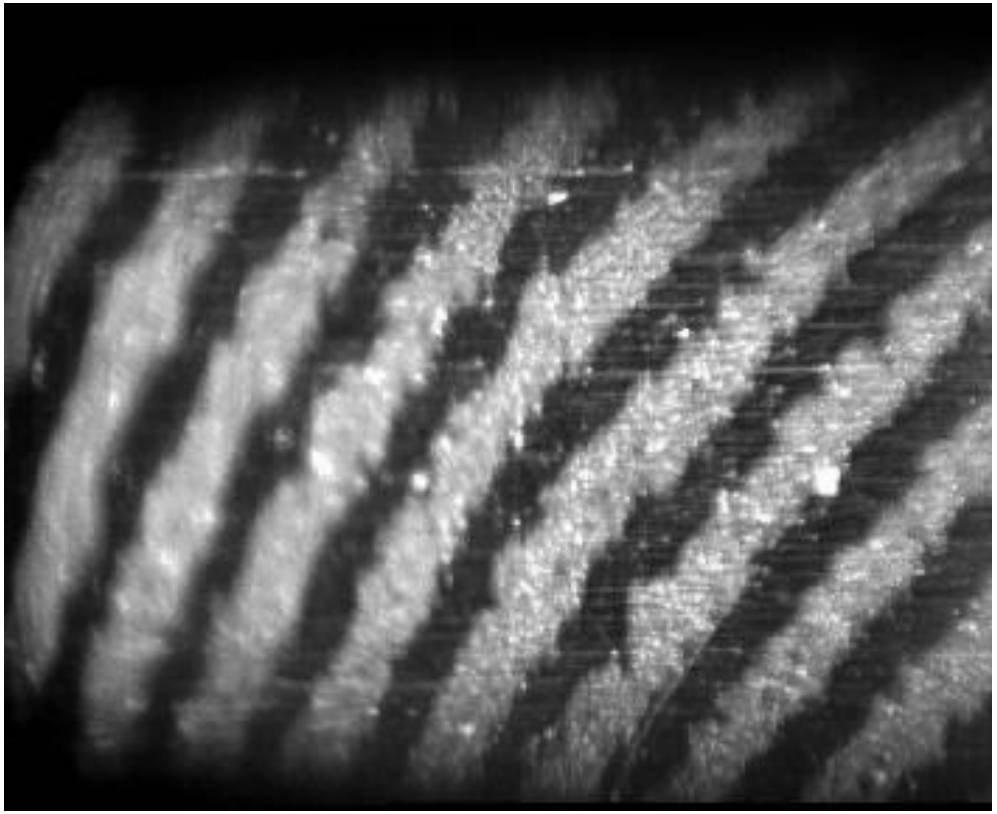
MALDI MS Profiling OF LATENT FINGERMARKS





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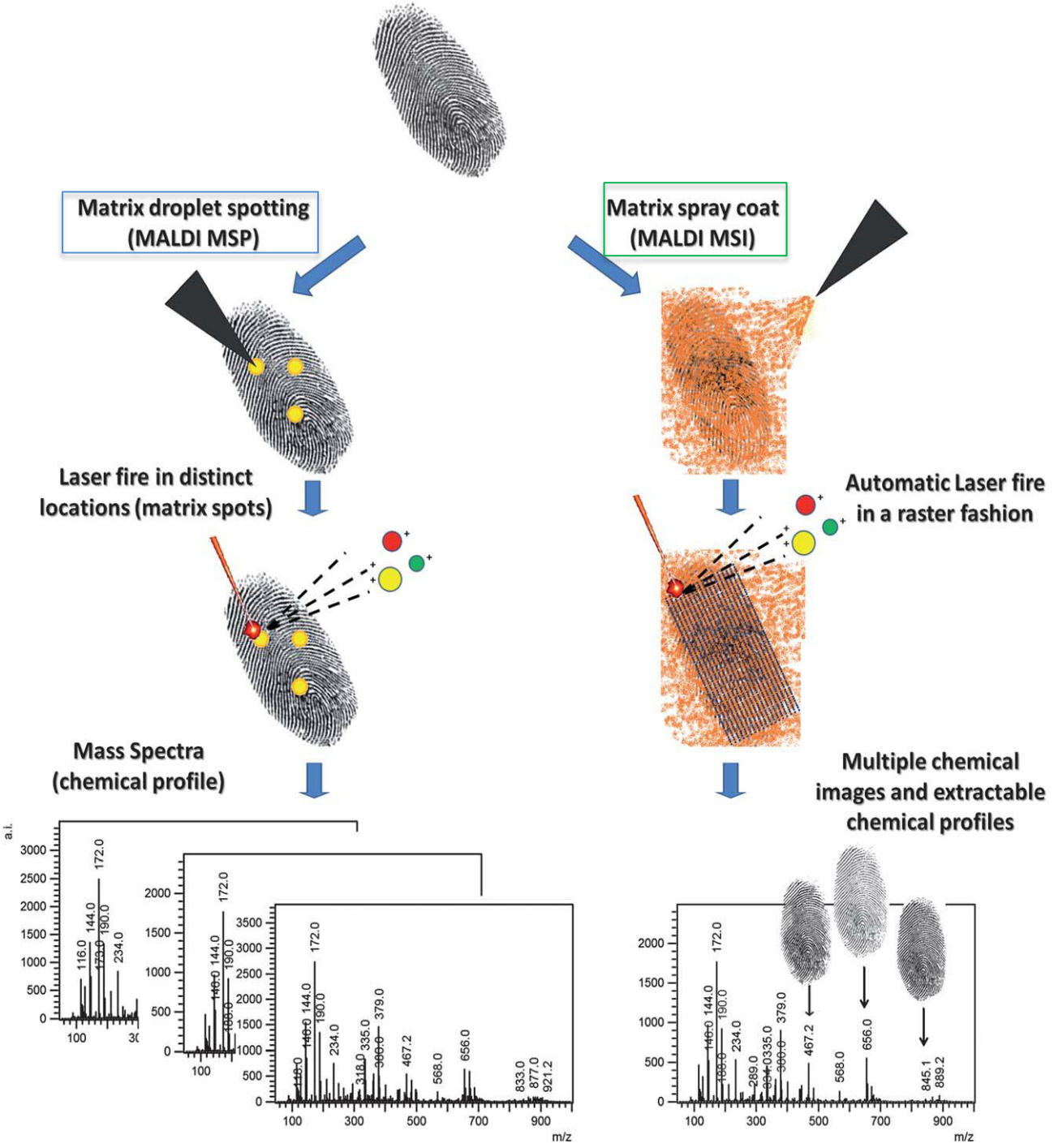
MALDI MSP and MALDI MSI OF LATENT FINGERMARKS



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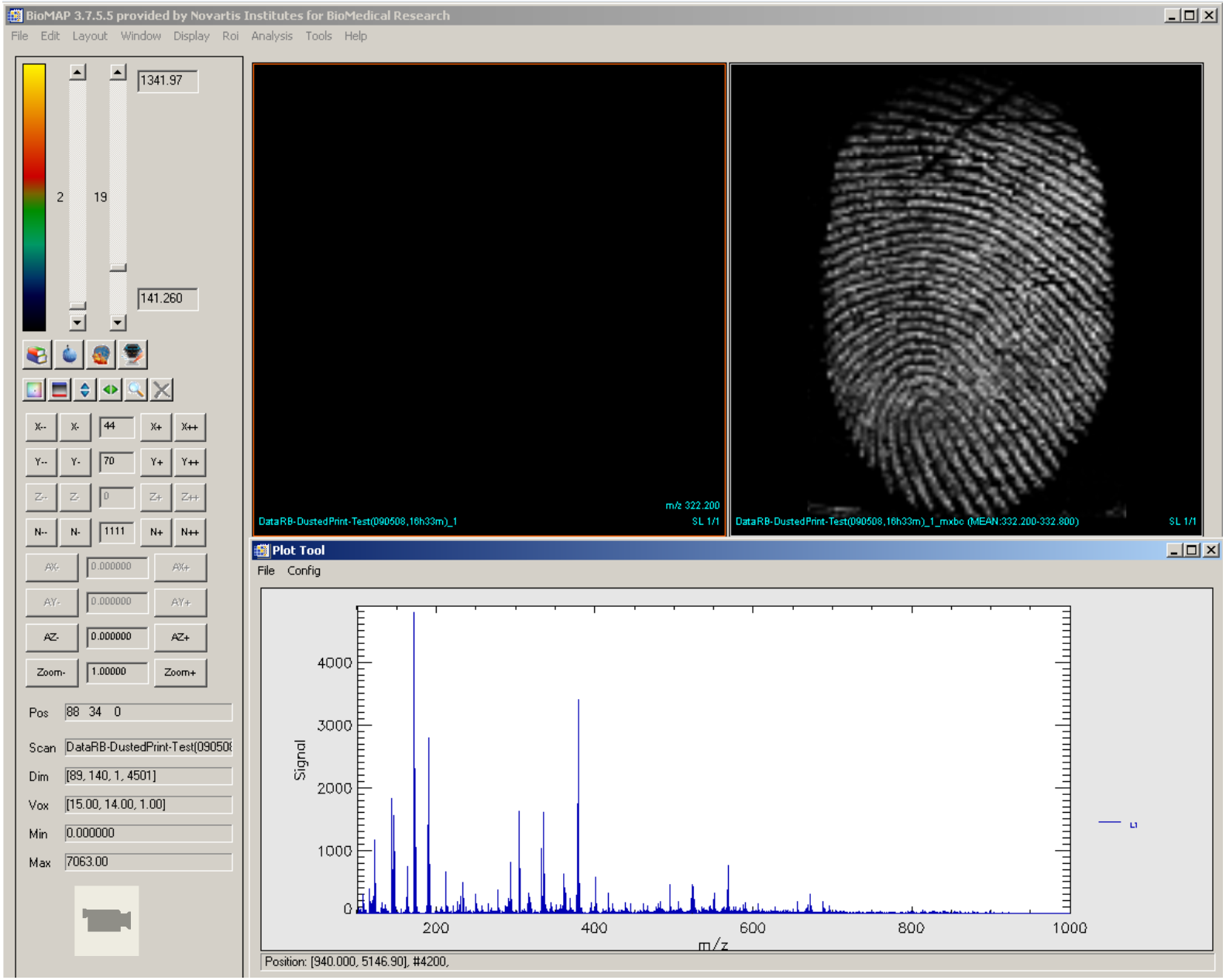
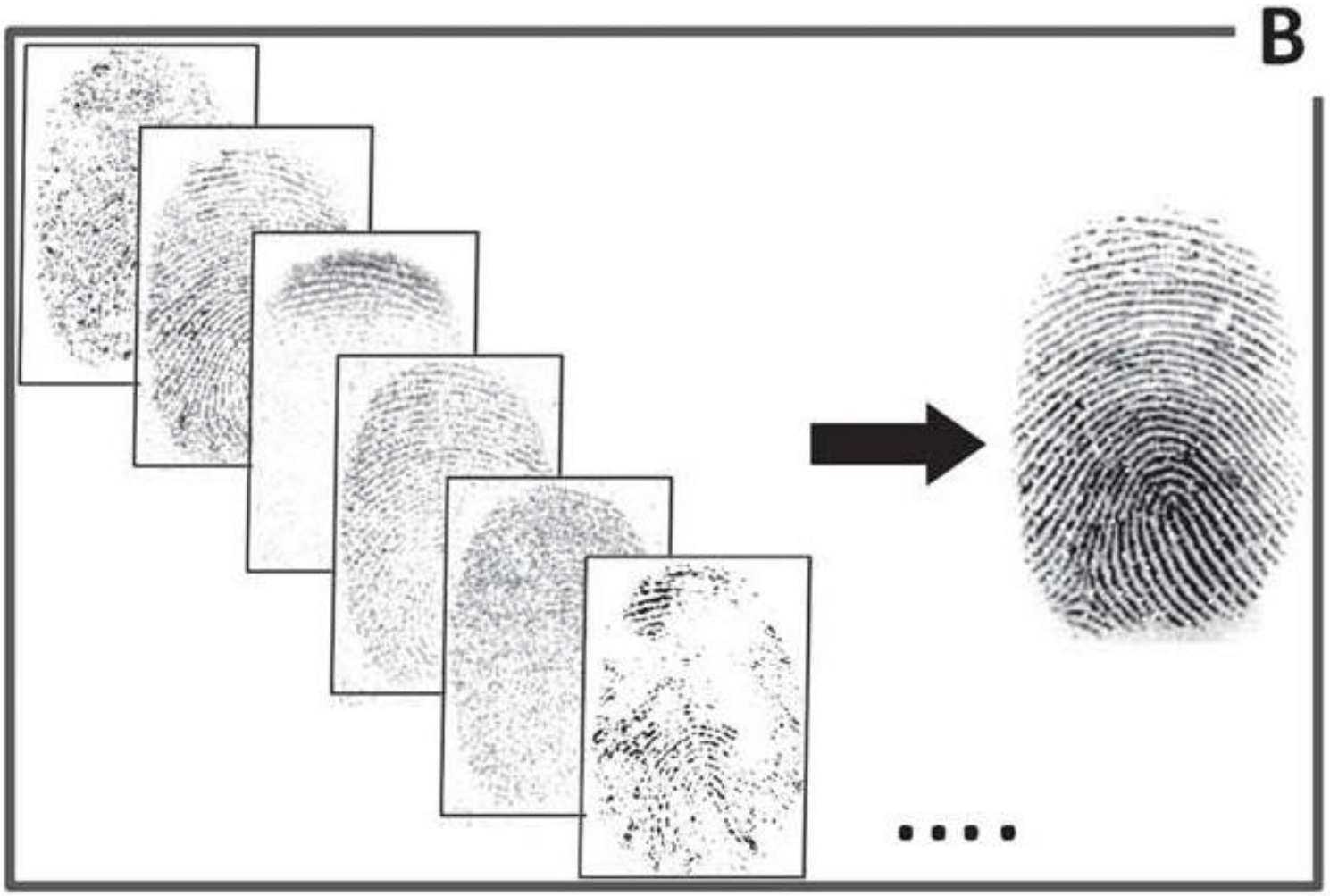
MALDI MSI OF LATENT FINGERMARKS

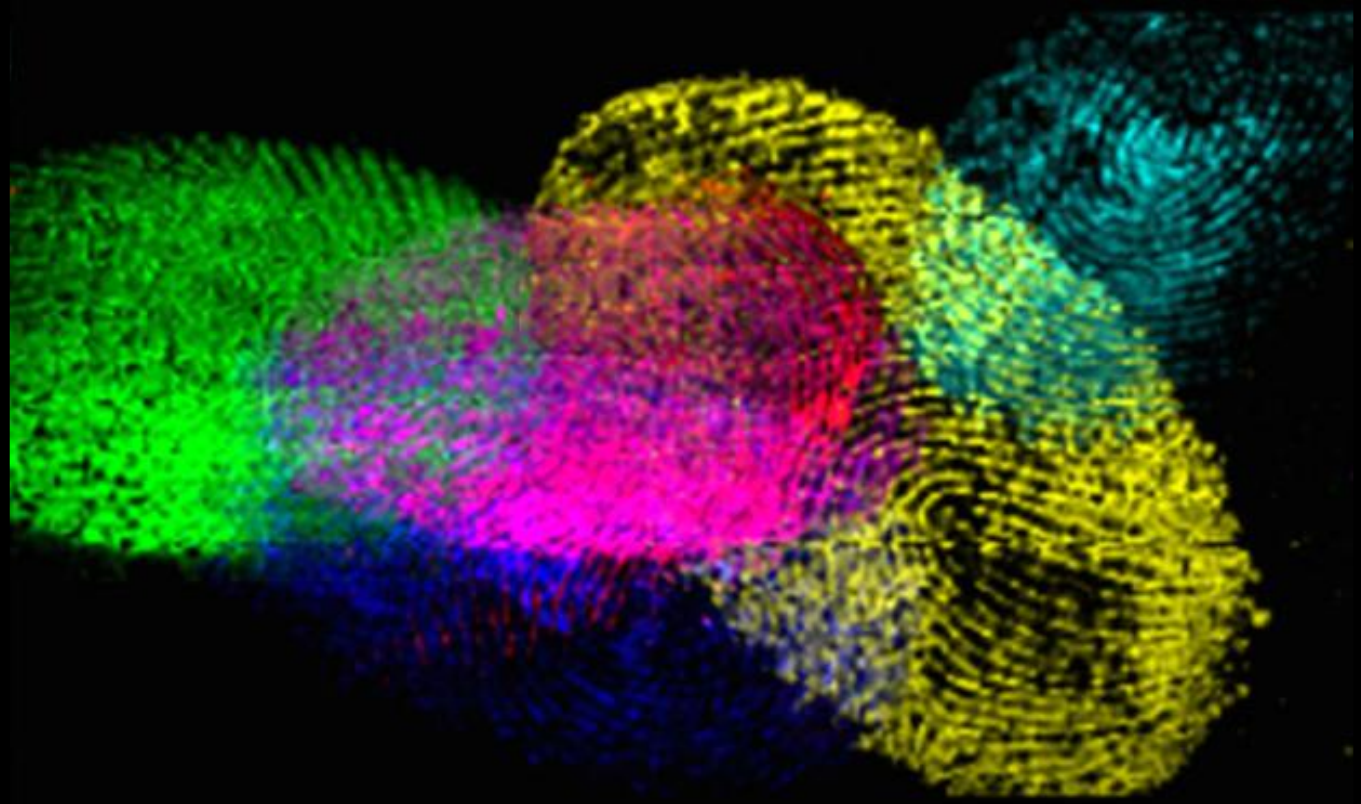


PHYSICAL INFORMATION

Improving the coverage of the ridge pattern



***Francese S**, Bradshaw R, Ferguson LS, Wolstenholme R, Clench MR, Bleay S. Analyst. 2013,* DOI: 10.1039/c3an36896c



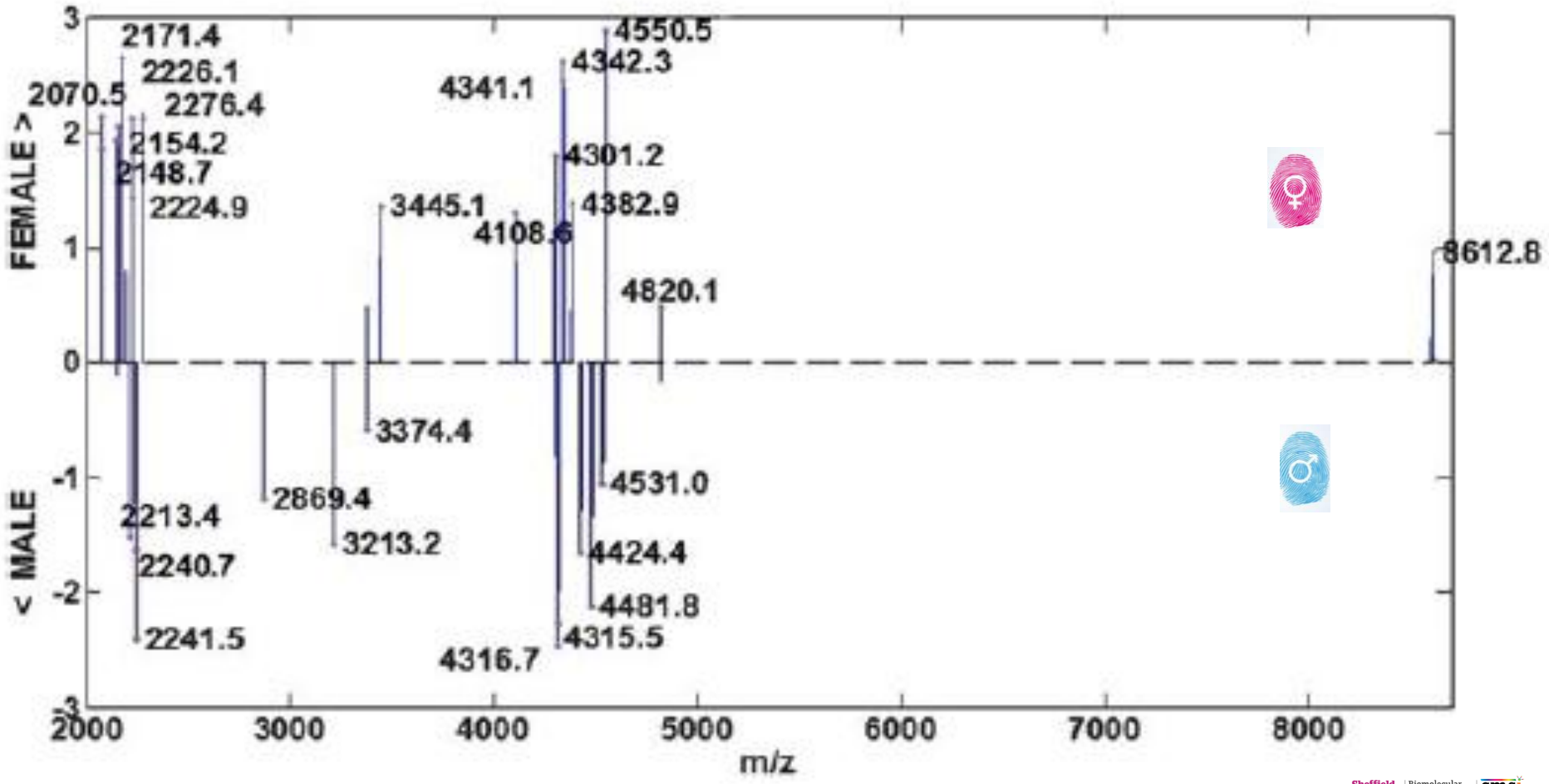
CHEMICAL INFORMATION

(very few examples)

Personal information (*endogenous molecules*)

CAN WE DETECT SEX FROM FINGERPRINTS?

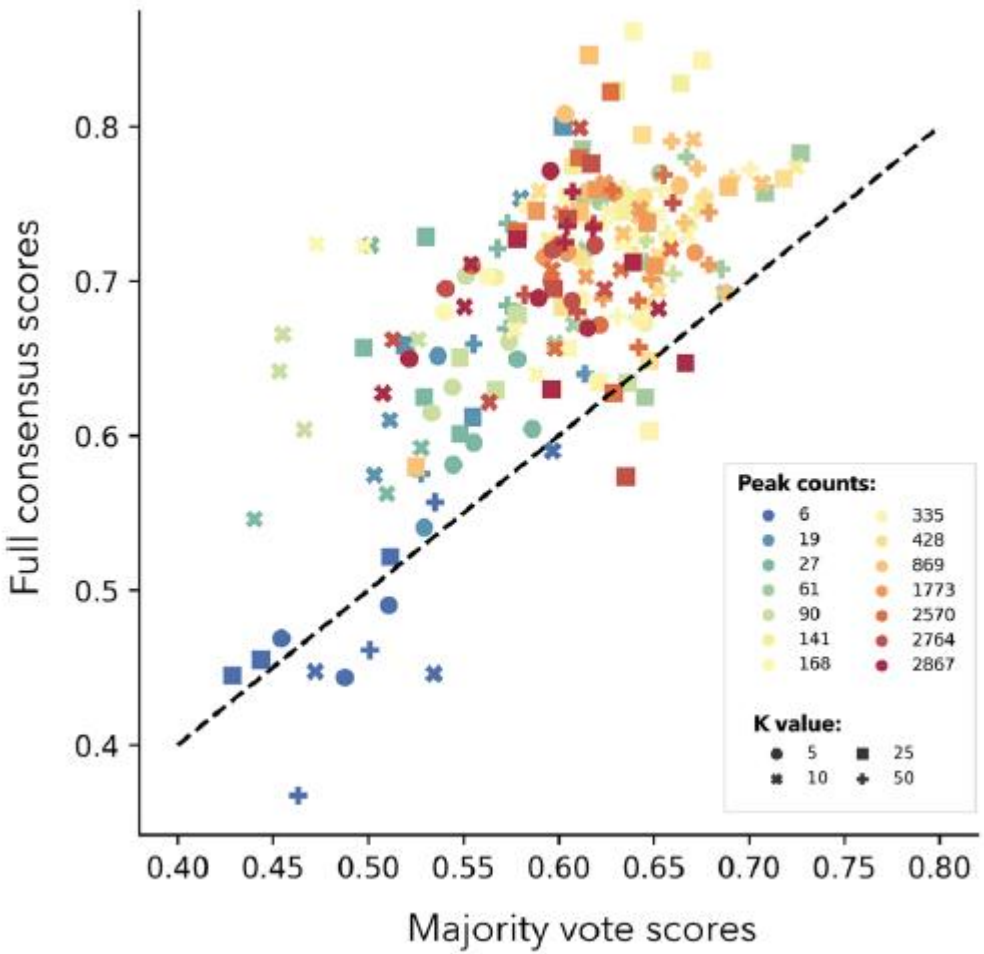
Males and Females are discriminated with the **75% of confidence** (85% if less harsh classification criteria were applied)



Ferguson L, Wulfert F, Wolstenholme R, Fonville J, Clench M, Carolan V, **Francese S**, Analyst, 2012, 137, 4686

Personal information (*endogenous molecules*)

XGBOOST classification with full consensus scoring



86% accuracy of prediction – considered by the Police viable for triaging crime scene marks

Application of "full consensus scoring" strategy. Correlation between calculated majority vote scores (*x-axis) and full consensus scoring* schemes (*y-axis), for the XGBOOST classifier.*

Each scatter point corresponds to the average cross-validation accuracy score for a specific peak picking strategy, and *k-fold, with each of the four feature selection strategies treated as separate scatter points. The* diagonal line *y = x is shown.*

Heaton C, Bury C., Patel E, Bradshaw R, Wulfert F, Heeren RM, Marchant L., Denison N, McColm R, Francese S. (2020) *Forensic Chemistry*, 20, 100271

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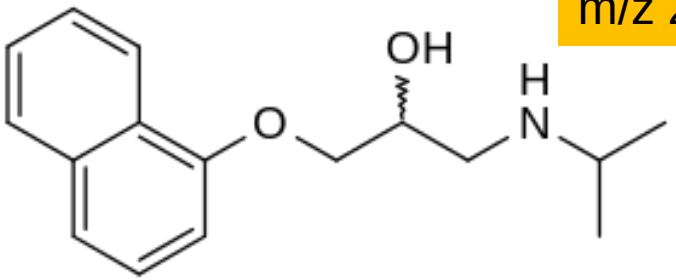
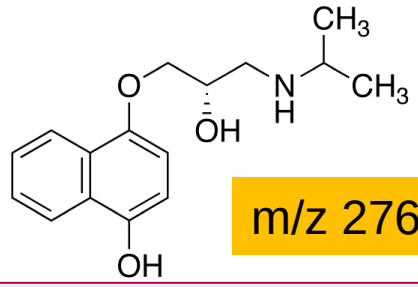
Pharmacological states (*semi-endogenous molecules*)

Propranolol

m/z 260.1650

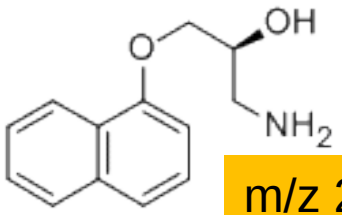


- **4- hydroxypropranolol**



m/z 276.1599

- N- desisopropylpropranolol



m/z 217.1103

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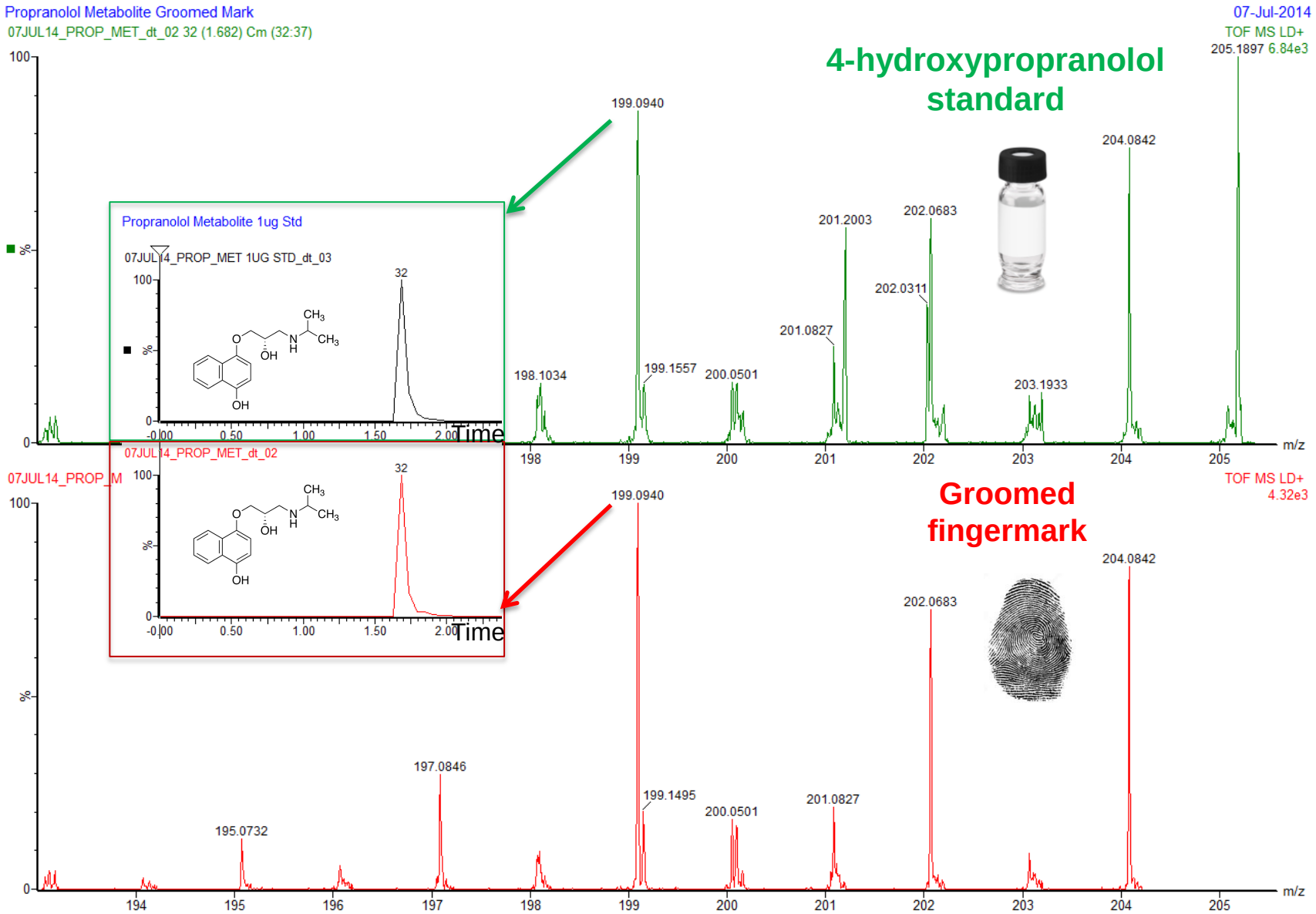
Confirmation of presence of 4-hydroxypropranolol in fingermark through drift time assessment of its product ion (*m/z* 199.0940)

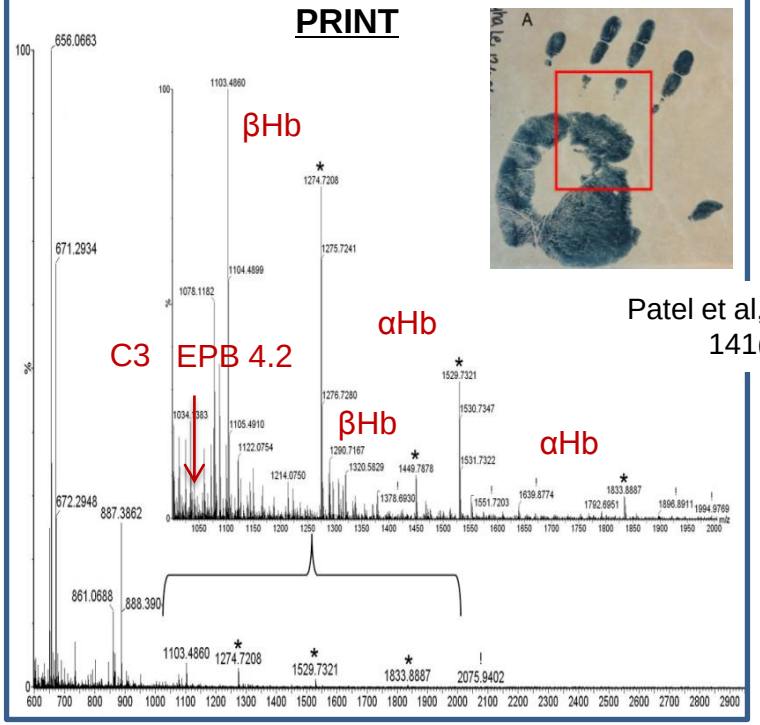


Patel et al, 2014 unpublished

Assessing crime dynamics (and not only) (*exogenous molecules*)

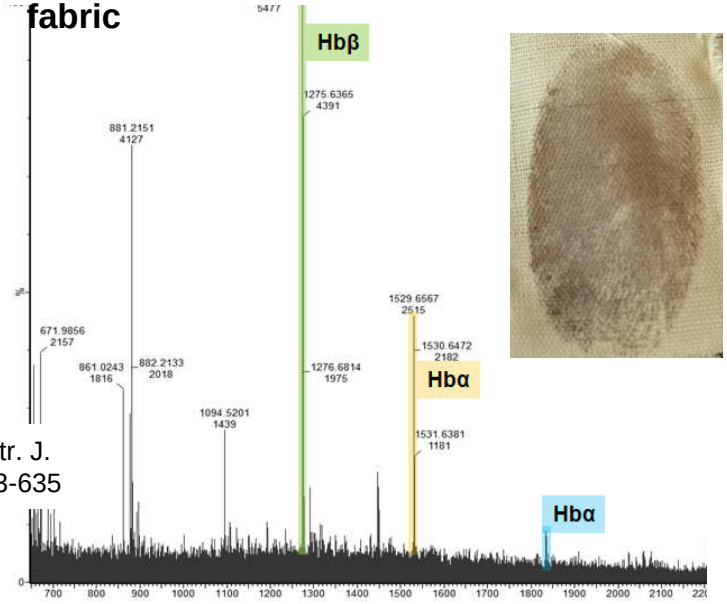
MALDI MSP/MSI combined proteomic approach for the specific, reliable and informative analysis of blood evidence

9 YEAR OLD AB-1 treated BLOOD PALM PRINT

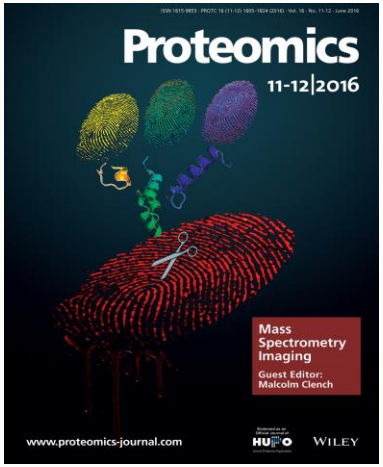


Patel et al, **2015**, *Analyst,* 141(1):191-8

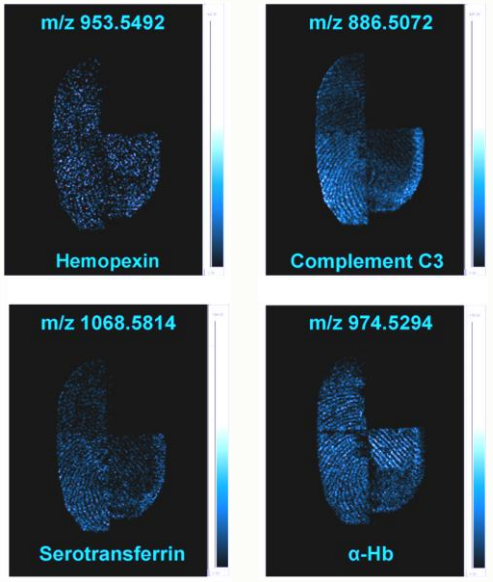
37 YEAR OLD NIN treated blood mark on fabric



Francese S. **2019**, Austr. J. Forensic Sci. 51 (6): 623-635



Deininger et al, **2016**, *Proteomics* 16(11-12):1707-17



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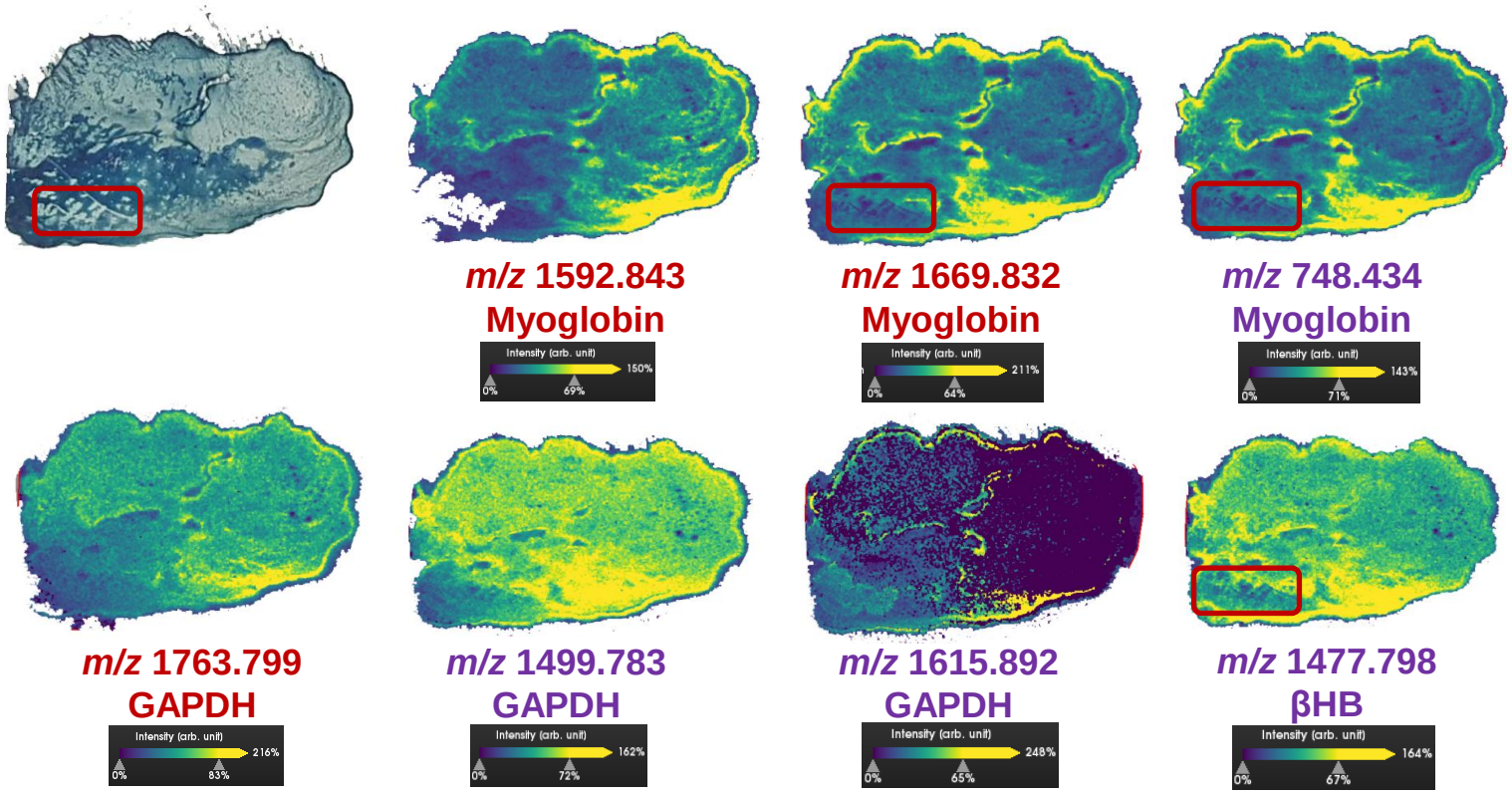
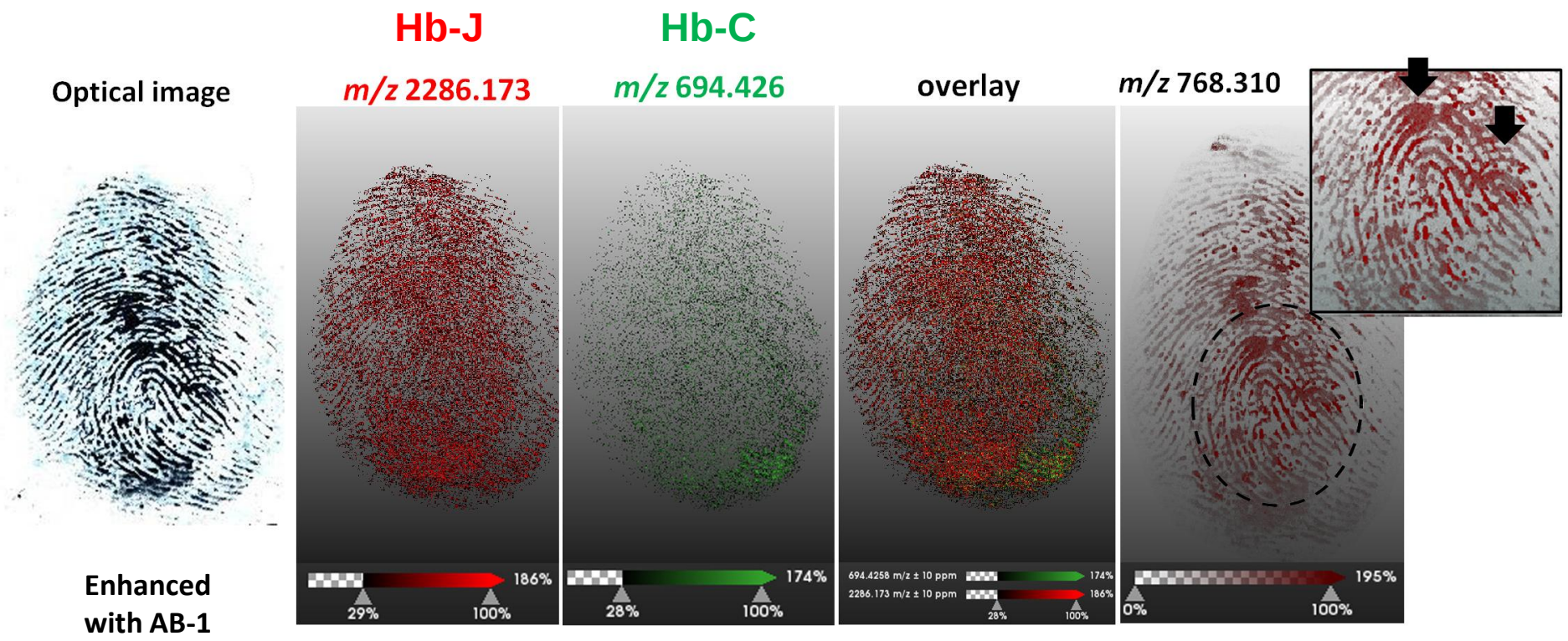
MALDI MSI of animal blood signatures

4 YEAR OLD AB-1 treated bovine blood mark



Particularly the images of the ions at *m/z* 1669.832, 784.434 and 1477.798 depict the partial ridge detail that was observed in the optical images (red rectangle)

MALDI MSI of overlapping pre-enhanced fingerprints contaminated with HbC and HbJ-Baltimore blood variants



Breaking barriers to implementation

Understanding the use and limitations of the technology

Understanding end user needs

Walking in the right direction to break barriers to implementation

Disseminate/increase awareness

Make research borderless

Actively involve end users in the developments

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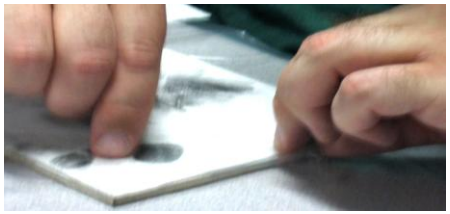
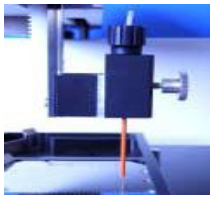
To use MALDI…..the fingermark needs to be visualised first….Duh!!!

MALDI matrix

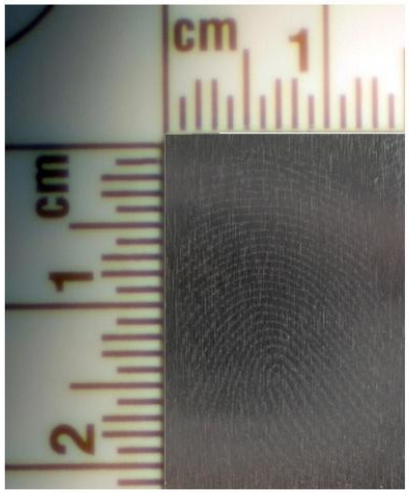


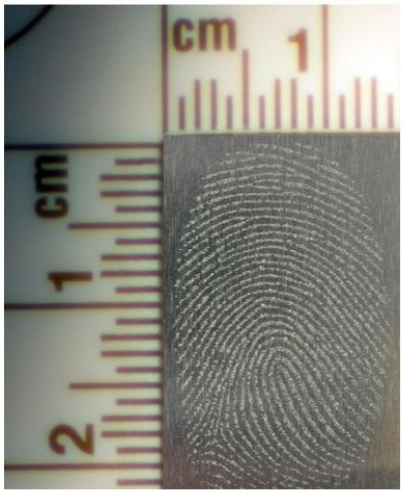


The dry-wet method

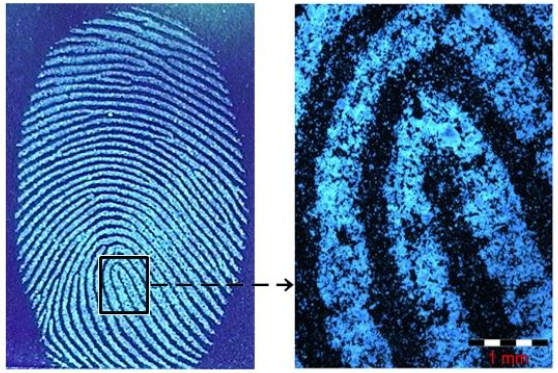
Patent no. GB2489215; EU application (EP268401A1); Granted HK patent (HK1169854A1); Granted US patent (US9261438B)

LS Ferguson, R Wolstenholme, ***S. Francese***





mark enhancement by matrix powdering



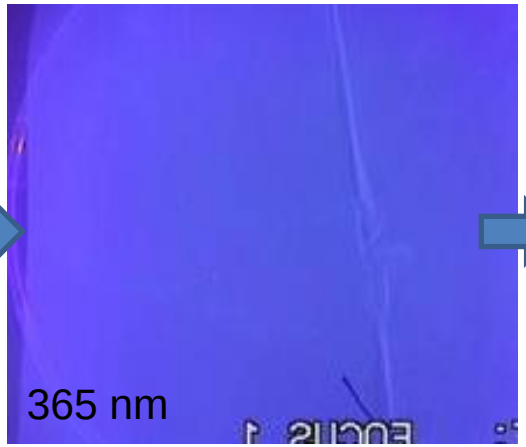
UV image

fluorescent microscope image

MALDI MSI image

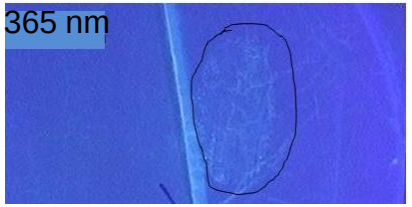
The dry wet method adaptation – ENFSI collaborative exercise 2020

Compostable bag

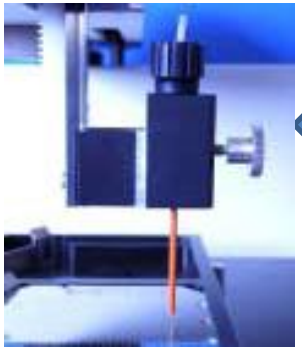


Illumination at 365 nm

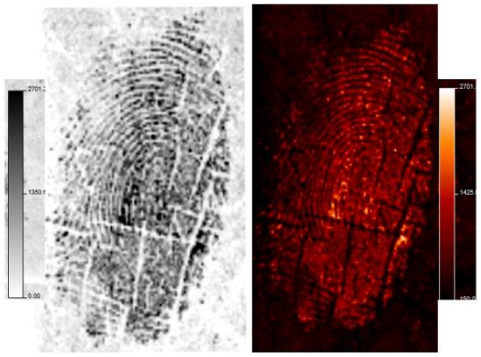
Powdering with MALDI Matrix



Illumination at 365 nm



MALDI Matrix solution spray



m/z 460.8

MALDI MS image

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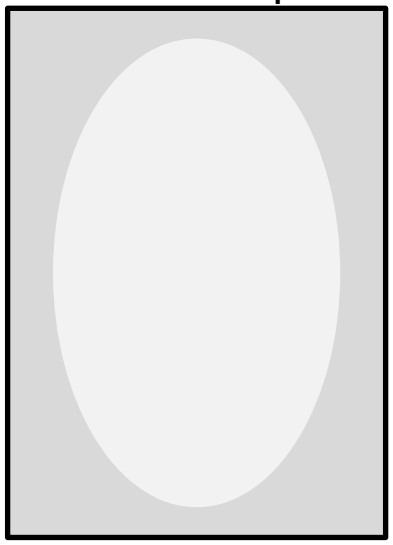
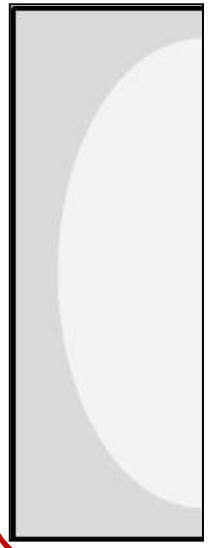
CSI place lifts on acetate for transport…would MALDI still work when the lift is peeled off???

Deposition of fingermark onto aluminium plate

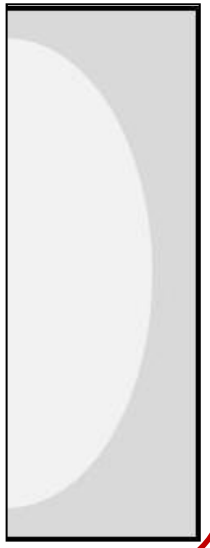


Aluminium powder

Primary lift



Primary lift pealed from acetate



Triacylglyceride
m/z 664.6

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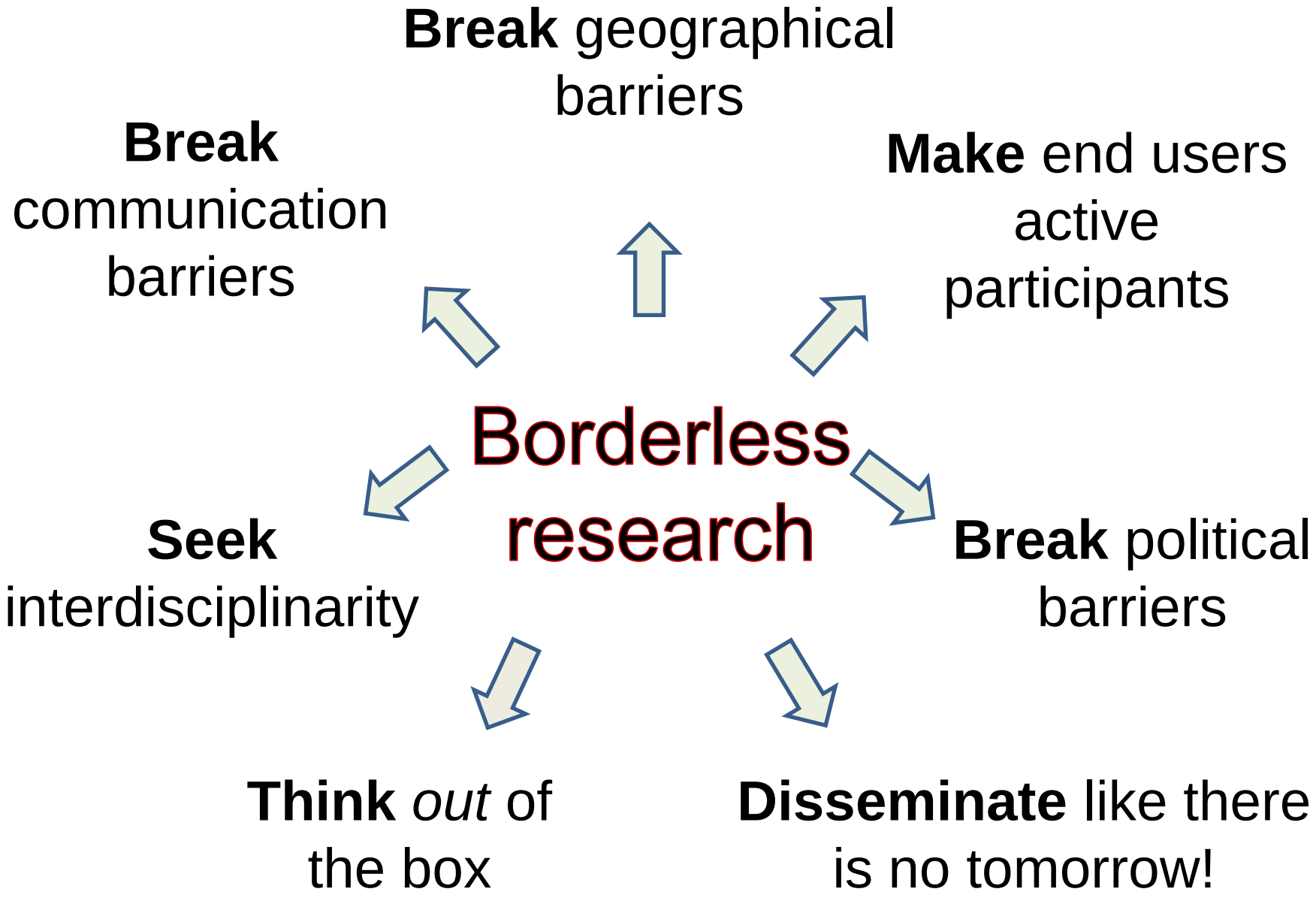
Break geographical barriers
Make end users active participants
Break political barriers
Disseminate like there is no tomorrow!
Think *out* of the box
Seek interdisciplinarity
Break communication barriers
Borderless research

Breaking barriers to implementation

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641 Share

Fingerprint breakthrough offers new forensic evidence

A technology to extract fingerprints from a crime scene could show if a criminal suspect has taken drugs or been in contact with explosives.

Researchers at Sheffield Hallam University have developed a way to capture fingerprints that can identify substances touched, and secretions from a person's body.

This could provide new information about a suspect's actions and habits.

April 2014

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28 March 2014 Last updated at 01:16

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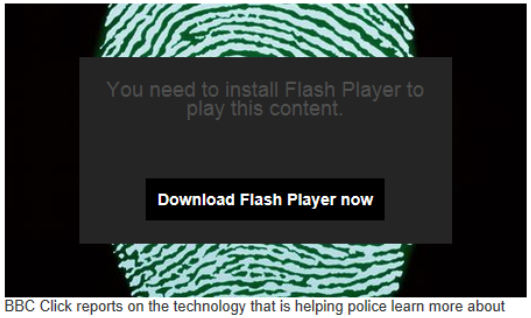
Fingerprints give police new clues for solving crime

By Rebecca Morelle
Science reporter, BBC World Service

Mar 2014



BBC Click reports on the technology that is helping police learn more about people from their fingerprints.

Sept 2018

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Aug 2021

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At the frontier of fingermarks: Prof Simona Francese on 13 years of research into molecular fingerprinting

Traditional fingerprint analysis can help police forces match a mark left at a crime scene to a person – but molecular fingerprinting can go further – from identifying if the person has been in contact with drugs or explosive products or other materials, to revealing their lifestyle habits, such as if they've been taking drugs or have traces of blood.

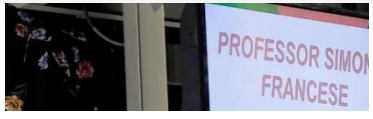
Professor Simona Francese, an expert in forensic science and bioanalytical mass spectrometry, has been researching fingermarks for 13 years.

Fingermarks left at a crime scene can be used for identification. Investigators take an impression of the ridges and whorls or wider pattern of the skin. Molecules – a

, so why is a lies in its

ANZFSS 2018 + Follow

ANZFSS18 - Conference - 13th Sept 2018



Oct 2017

June 2014

June 2018

Breaking barriers to implementation.....

Understanding the use and limitations of the technology

Understanding end user needs

Disseminate/increase awareness

Walking in the right direction to break barriers to implementation

Make research borderless

Actively involve end users in the developments

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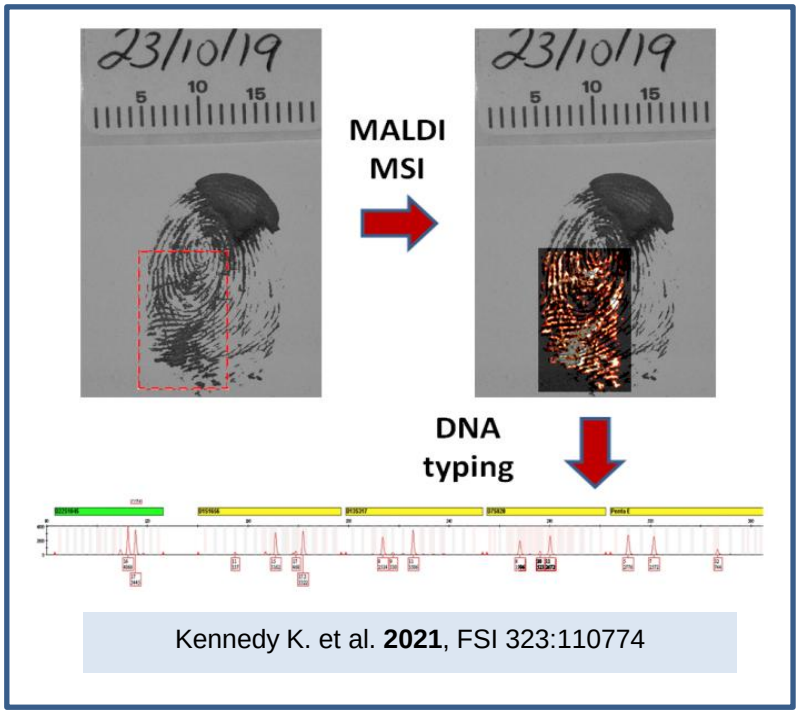
Home Office funding 2011-2014 "*Integration of MALDI MSI into the Home Office operational fingermark examination workflow"*

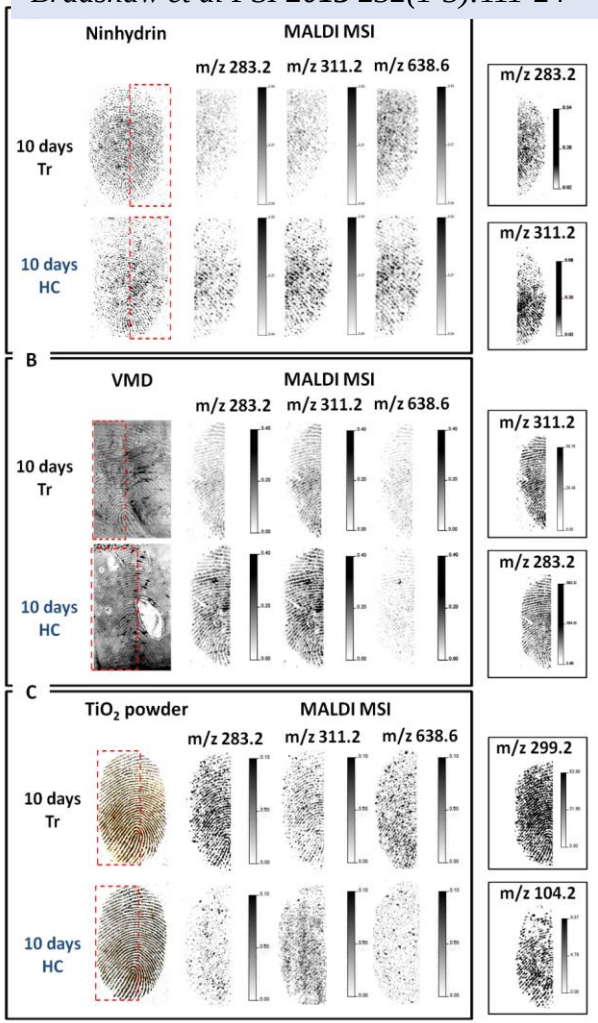
2013 - Attendance to crime scenes with West Yorkshire Police

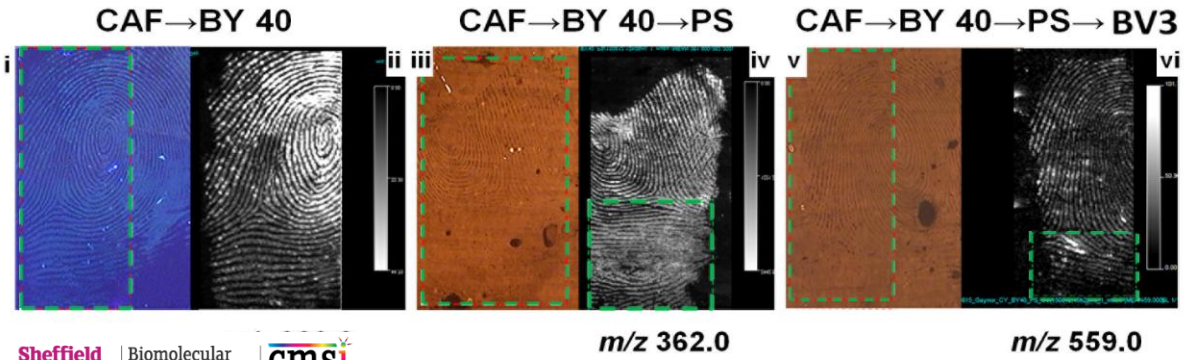
- Understanding CSI requirements for collection of marks
- Understanding optimal storing of marks
- **Developing compatibility between fingermark visualisation processing and MALDI**



Kennedy K. et al. **2021**, FSI 323:110774

*Bradshaw et al FSI **2013** 232(1-3):111-24*





*Bradshaw et al FSI **2021** , 319, 110643,*

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What Police thought in 2015.....

'This technology shows real potential to be the next step change in developing fingerprint technology for the 21st century.'

Neil Denison
West Yorkshire Police

"This new fingerprinting technology has the potential to be a real step change in forensic work. This technology will allow us to gain significantly enhanced information from prints to build a picture of an offender's prior movements, and is now being trialled at crime scenes"
(Yorkshire Post Aug 2015)

Assistant Chief Constable, Russ Foster
West Yorkshire Police

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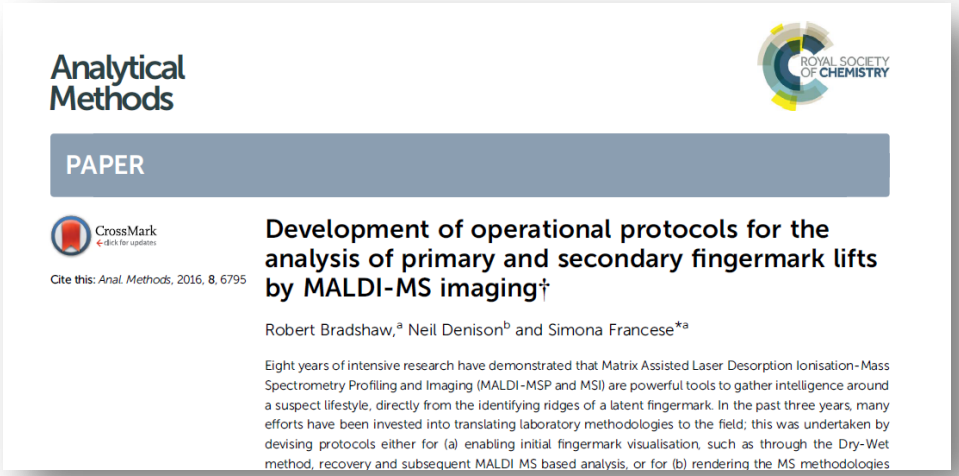
Home Office Innovation Grant co-funded by West Yorkshire Police, UK 2014-2016

"Chemical Profiling of fingermarks : MALDI MSP and MALDI MSI method refinement for operational deployment in casework"



Analytical Methods

ROYAL SOCIETY OF CHEMISTRY

PAPER

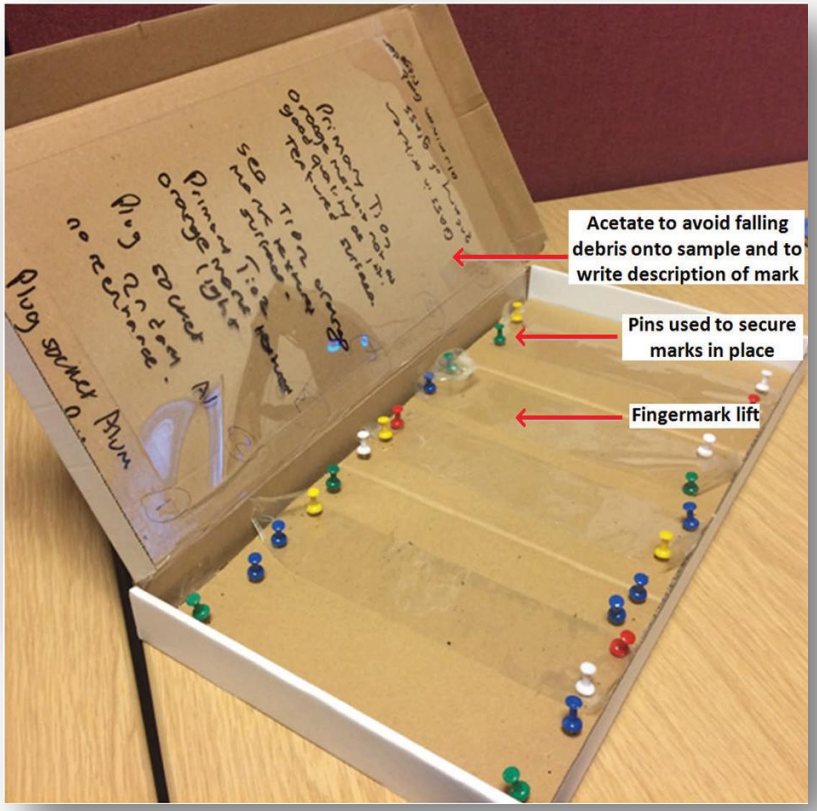
CrossMark click for updates

Cite this: *Anal. Methods*, 2016, **8**, 6795

Development of operational protocols for the analysis of primary and secondary fingermark lifts by MALDI-MS imaging†

Robert Bradshaw,[a] Neil Denison[b] and Simona Francese*[a]

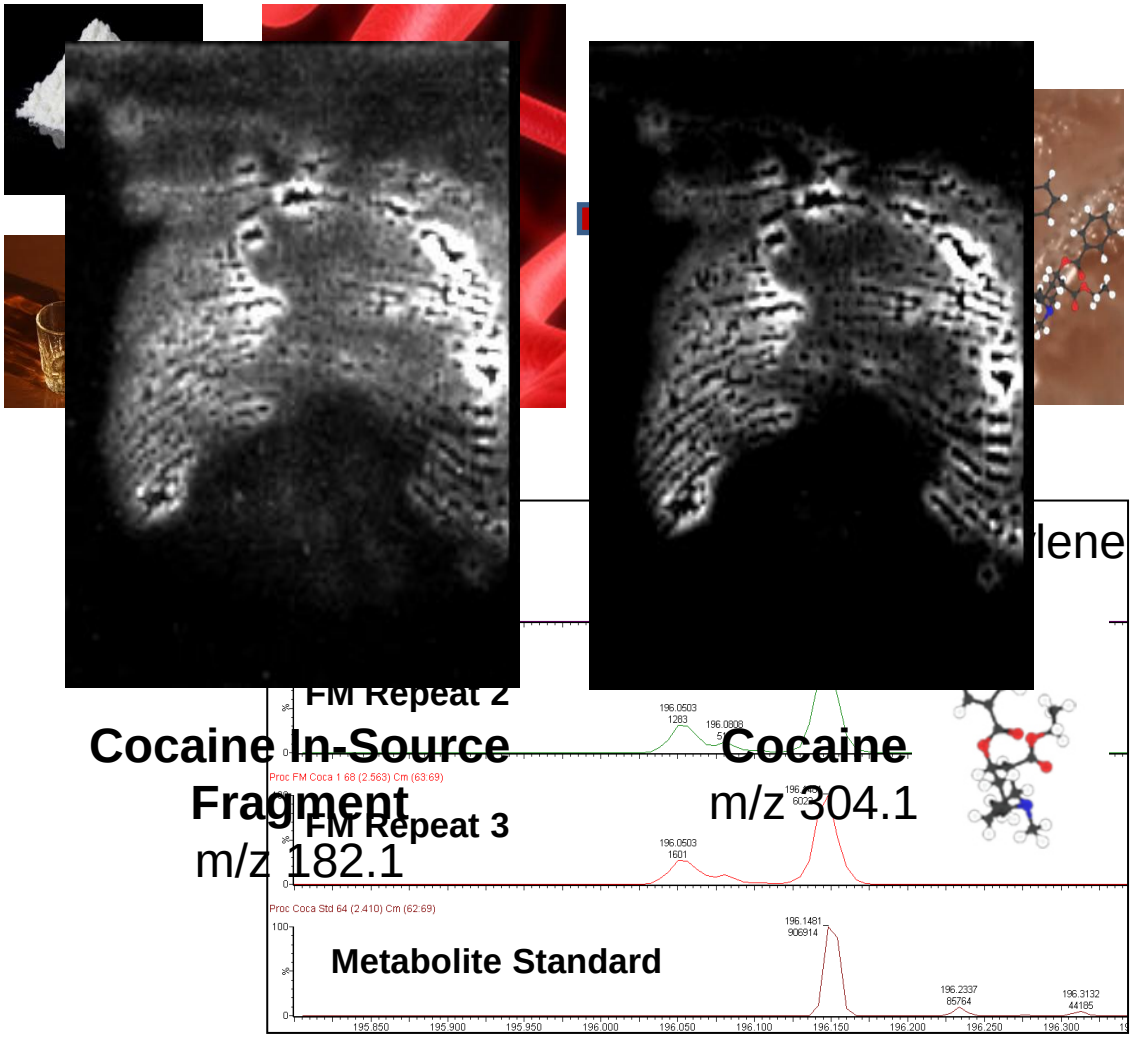
Eight years of intensive research have demonstrated that Matrix Assisted Laser Desorption Ionisation-Mass Spectrometry Profiling and Imaging (MALDI-MSP and MSI) are powerful tools to gather intelligence around a suspect lifestyle, directly from the identifying ridges of a latent fingermark. In the past three years, many efforts have been invested into translating laboratory methodologies to the field; this was undertaken by devising protocols either for (a) enabling initial fingermark visualisation, such as through the Dry-Wet method, recovery and subsequent MALDI MS based analysis, or for (b) rendering the MS methodologies



John Dixon, WYP

Operational casework (UK 2015)- harassment crime scene

Carbon Black
Lifted mark sealed in acetate

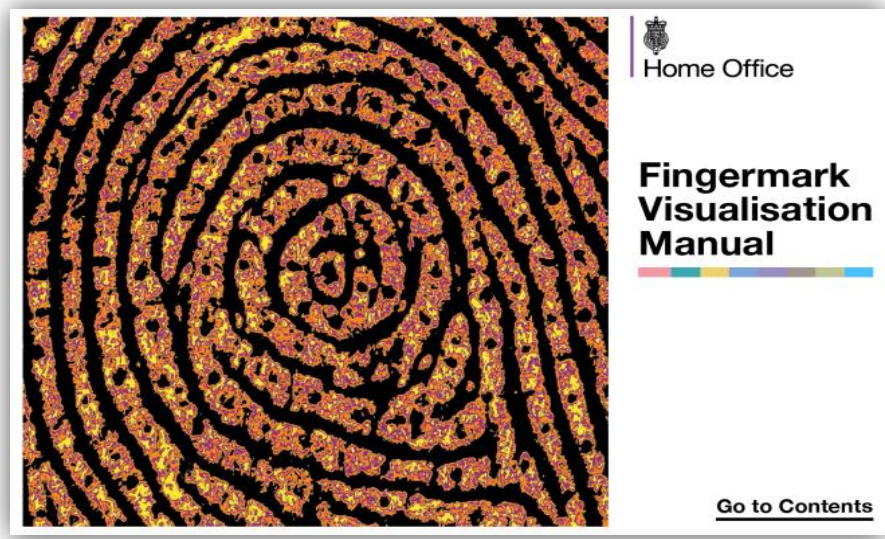


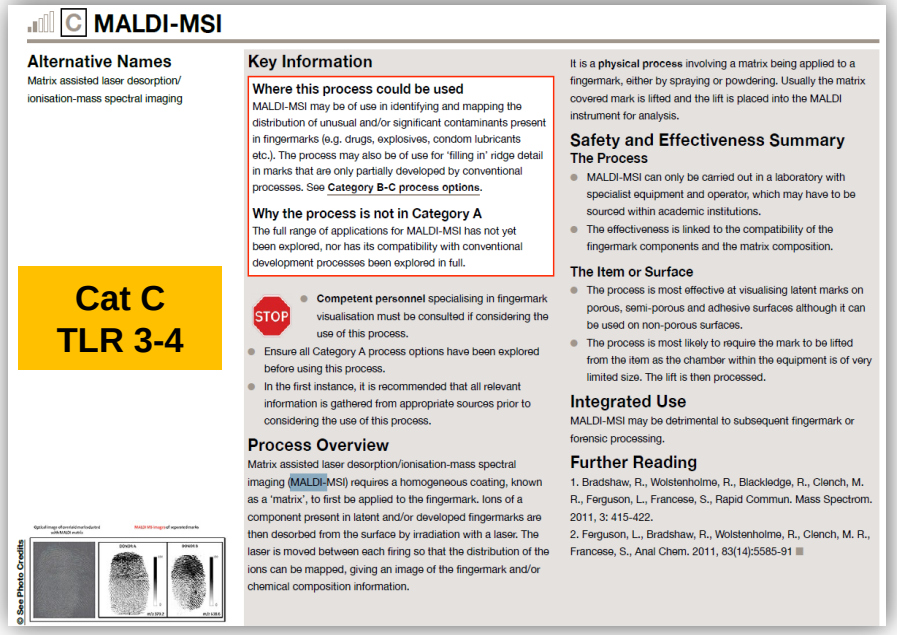
Cocaine In-Source Fragment
m/z 182.1

Cocaine
m/z 304.1

R. Bradshaw, 2017, DOI: 10.1039/C7AN00218A, *Analyst*

Home Office Recognition of the technology





C MALDI-MSI

Alternative Names

Matrix assisted laser desorption/ ionisation-mass spectral imaging

Cat C
TLR 3-4

Key Information

Where this process could be used

MALDI-MSI may be of use in identifying and mapping the distribution of unusual and/or significant contaminants present in fingermarks (e.g. drugs, explosives, condom lubricants etc.). The process may also be of use for 'filling in' ridge detail in marks that are only partially developed by conventional processes. See Category B-C process options.

Why the process is not in Category A

The full range of applications for MALDI-MSI has not yet been explored, nor has its compatibility with conventional development processes been explored in full.

STOP

- **Competent personnel** specialising in fingermark visualisation must be consulted if considering the use of this process.
- Ensure all Category A process options have been explored before using this process.
- In the first instance, it is recommended that all relevant information is gathered from appropriate sources prior to considering the use of this process.

Process Overview

Matrix assisted laser desorption/ionisation-mass spectral imaging (MALDI-MSI) requires a homogeneous coating, known as a 'matrix', to first be applied to the fingermark. Ions of a component present in latent and/or developed fingermarks are then desorbed from the surface by irradiation with a laser. The laser is moved between each firing so that the distribution of the ions can be mapped, giving an image of the fingermark and/or chemical composition information.

It is a **physical process** involving a matrix being applied to a fingermark, either by spraying or powdering. Usually the matrix covered mark is lifted and the lift is placed into the MALDI instrument for analysis.

Safety and Effectiveness Summary

The Process

- MALDI-MSI can only be carried out in a laboratory with specialist equipment and operator, which may have to be sourced within academic institutions.
- The effectiveness is linked to the compatibility of the fingermark components and the matrix composition.

The Item or Surface

- The process is most effective at visualising latent marks on porous, semi-porous and adhesive surfaces although it can be used on non-porous surfaces.
- The process is most likely to require the mark to be lifted from the item as the chamber within the equipment is of very limited size. The lift is then processed.

Integrated Use

MALDI-MSI may be detrimental to subsequent fingermark or forensic processing.

Further Reading

1. Bradshaw, R., Wolstenholme, R., Blackledge, R., Clench, M. R., Ferguson, L., Francese, S., Rapid Commun. Mass Spectrom. 2011, 3: 415-422.
2. Ferguson, L., Bradshaw, R., Wolstenholme, R., Clench, M. R., Francese, S., Anal Chem. 2011, 83(14):5585-91

© See Photo Credits

Currently included as a Cat C process in the Fingermark Visualisation Manual

promoted to Cat B in the next DSTL edition

Assessing Technology Readiness Levels

TRL	Description
1	Published papers reporting a technology or data potentially relevant to the area being considered
2	Published papers reporting a technology or data relevant to the area of application being considered
3	Initial application of technology being assessed to samples of forensic relevance in experimental settings
4	Focussed studies showing feasibility of technology for the proposed application
5	Focussed studies, assessing factors such as sensitivity and repeatability for the proposed application
6	Critical mass studies showing clear potential for operational use
7	Pseudo-operational trials, analysis of evidence under pseudo-operational conditions.
8	Operational trials on evidence obtained from casework
9	Publication of data from live casework
10	Publication of data showing the application of the technology in casework over several years

TRL scale combined from FVM, Dstl, EPSRC

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Assessing Technology Readiness Levels

Application of MALDI MSI to fingermarks	TRL	TRL description	Application of MALDI MS Profiling to fingermarks	TRL	TRL description	Recommendation
Visualisation of the ridge detail	**9**	Publication of data from live casework	NA	NA	NA	**High Priority**
Mapping of blood	**7**	Pseudo-operational trials, analysis of evidence under pseudo-operational conditions.	Detection and provenance of blood	**8**	Operational trials on evidence obtained from casework	**High Priority**
Mapping of drugs and metabolites	**8**	Operational trials on evidence obtained from casework	Detection and Identification of drugs and metabolites	**8**	Operational trials on evidence obtained from casework	**High Priority**
NA	NA	NA	Determination of sex from fingermarks	**6**	Critical mass studies showing clear potential for operational use	**Medium priority**
Mapping of condom lubricants	**5**	Focussed studies, assessing factors such as sensitivity and repeatability for the proposed application	Detection and identification of condom lubricants	**8**	Operational trials on evidence obtained from casework	**Low priority**
Mapping of pharmaceuticals and metabolites	**2**	Published papers reporting a technology or data relevant to the area of application being considered	Detection and identification of pharmaceuticals and metabolites	**2**	Published papers reporting a technology or data relevant to the area of application being considered	**Low priority**
Mapping of explosives	**2**	Published papers reporting a technology or data relevant to the area of application being considered	Detection and Identification of explosives	2	Published papers reporting a technology or data relevant to the area of application being considered	**Low priority**

So why isn't the technology used more often in major crimes?

1. Many Forensic providers and Major crime Managers lack of awareness of capabilities (and forgetfulness) despite major dissemination

- No other way than keeping at it as much as possible!!
- Round table with policing and new technologies/products representative discussing (non live) casework would be helpful (CAST used to organise this)

2. Live cases and backlogs don't lend themselves to decisions to explore new approaches

- Tough one. Structured Programmes of CPD would help. This is also raised in the HoL report

3. Some confusion on exploitation

- Are validation (and accreditation) obstacles to implementation? NOT AT AN INVESTIGATIVE LEVEL. Your thoughts in a court environment?

So why isn't the technology used more often in major crimes?

4. Innovation improves turnaround and employee satisfaction but may negate benefits of emerging capabilities

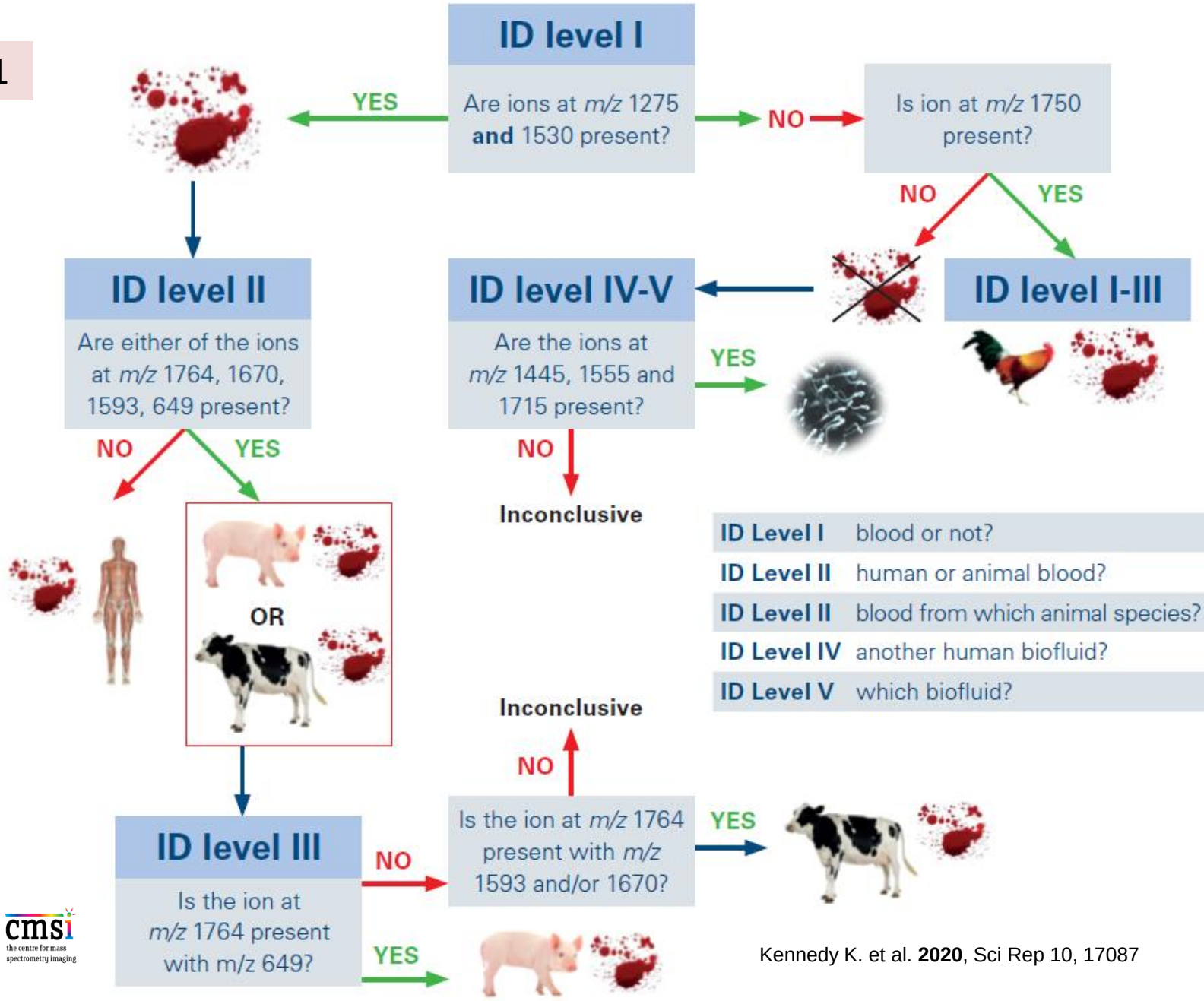
- NO quick fix. Keep raising the issue at a management level. IN MAJOR CRIMES, If lifts are taken at the time, opportunity for additional intelligence will be maximised

5. Scepticism towards an emerging approach and fear to "burn" evidence.

- Continue to offer evidence of operationally feasible technology

Pre-validation of MALDI MSP for the detection of blood and its provenance

Example 1



ID Level I	blood or not?
ID Level II	human or animal blood?
ID Level II	blood from which animal species?
ID Level IV	another human biofluid?
ID Level V	which biofluid?

Kennedy K. et al. **2020**, Sci Rep 10, 17087

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Rate of success of MALDI?

- **Access to at least hundreds of crime scene marks (non live cases) to establish the impact of :**

  - Fingermark molecular composition variability
  - Fingermark age
  - Environmental factors
  - Fingermark visualisation processes
  - Cross talk of the above factors

  ON THE:

  Success rate of this technology for the provision of profiling and biometric information

Research Councils…these mythological creatures..

Sheffield Hallam University 2008-2009
"Chemical Analysis of Fingermarks"

1 UG student

Erasmus 2015 (5 months)"*Detection and Visualisation of drugs by MALDI MSP/MSI"*

Sheffield Hallam University 2009-2012
"Analysis of composition of latent fingerprints by MS and spectroscopic imaging techniques"

1 PhD student

GSK-BBSRC 2012-2016 "*"Using ion mobility mass spectrometry to investigate the distribution and affect of dosed compounds on endogenous molecules"*

Home Office funding 2011-2014 "*Integration of MALDI MSI into the Home Office operational fingermark examination workflow"*

1 PhD student

EU Action CA16101 2017-2021 STSM bursary

Home Office Innovation Grant co-funded by West Yorkshire Police, UK 2014-2016
"Chemical Profiling of fingermarks : MALDI MSP and MALDI MSI method refinement for operational deployment in casework"

1 Post doctoral Researcher

SHU-UoS-MRC 2019-2020 "*"Non-invasive screening of breast cancer in fingertip smears"*

DSTL funding 2014-2017 *"Multi-informative and specific detection of blood in fingermarks via MALDI MS based strategies"*

1 PhD student

DSTL funding 2017-2020 *"Human identification through advanced forensic mass spectrometry of blood and fingermarks"*

1 PhD student

DSTL funding 2019-2022 *"Method refinement and validation for the operational non presumptive and informative detection of blood in stains and fingermarks "*

1 PhD student

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Research Contributors and Funding

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Dr. R. Wolstenholme (Sheffield Hallam University)
Prof. M.R. Clench (Sheffield Hallam University)
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Dr H. Bandey, Mr Mark Seale, Dr R. McColm (Dstl)
Mr Neil Denison (Yorkshire and Humber RSSS)
Prof. M. de Puit (NFI, The Netherlands)
Dr G. Langenburg (Elite Forensic Services, US)
Michal Levin and Dr Ravell Bengiat (Israel Police)
Prof. Marcel dePuit (NFI)
Dr Charlie Bury, Catapult Medicine Discovery

Sheffield Hallam University | Home Office | West Yorkshire Police | [dstl] | BMSS British Mass Spectrometry Society | gsk | Analytical Chemistry Trust Fund | cost European Cooperation in Science & Technology