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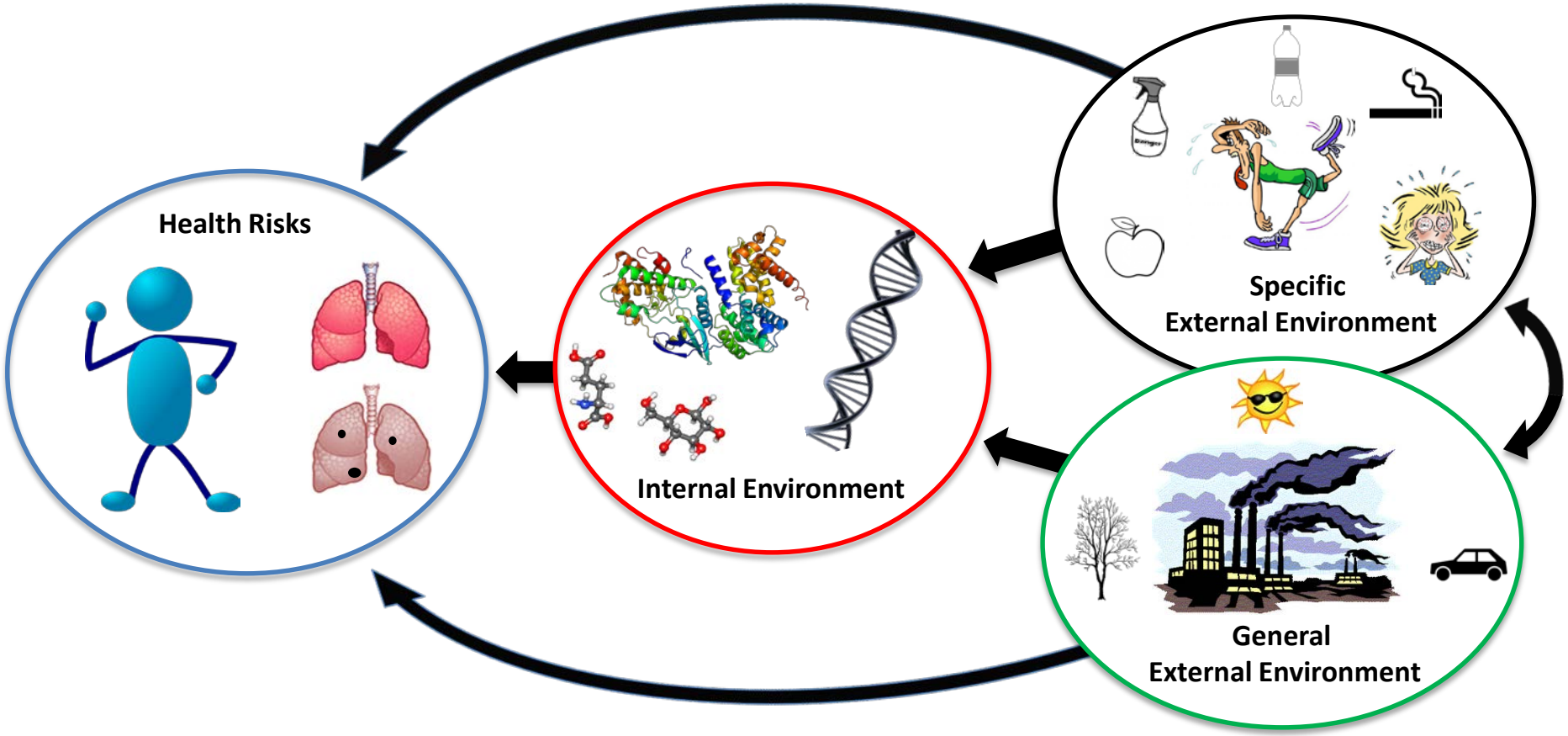
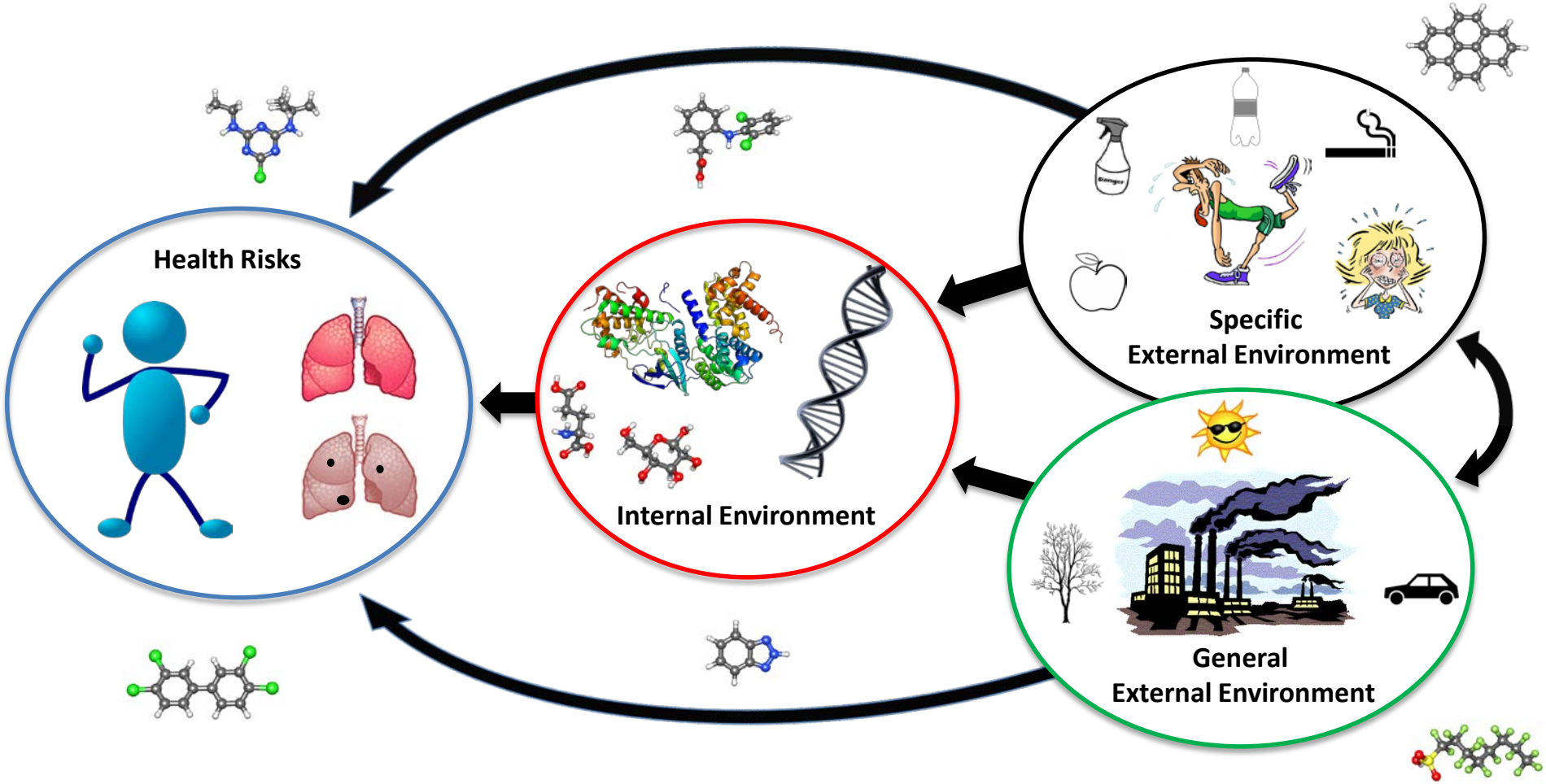
Rapid Metabolomic and Lipidomic Analyses Utilizing Ion Mobility Spectrometry

Erin Shammel Baker
Xueyun Zheng, Noor A. Aly, Vanessa L. Paurus, Yuxuan Zhou, Berwyck L. J. Poad*, Stephen J. Blanksby*, Richard D. Smith
Pacific Northwest National Laboratory
*Queensland University of Technology, Brisbane *Australia*

Understanding health risks



Understanding health risks



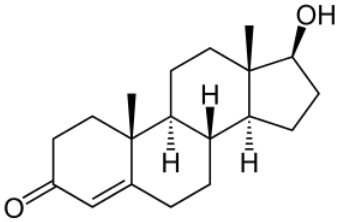
Main challenges with small molecule measurements

1. Small molecules of interest occur from very low to high concentrations (fM-mM) so measurements with high dynamic range and sensitivity are essential

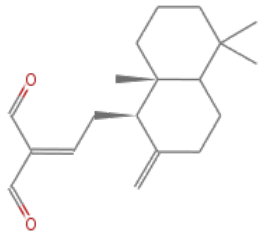
2. Biological changes are best understood when both endogenous metabolites and xenobiotics are analyzed

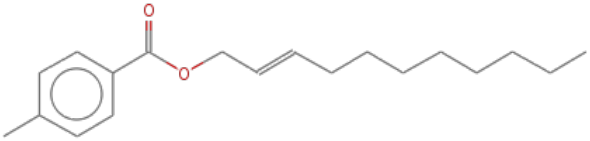
3. Untargeted measurements covering thousands of small molecules are desired to perform time course studies and analyze large cohorts

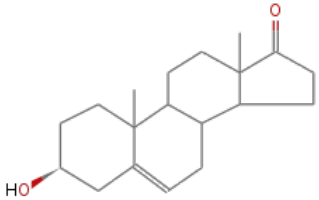
4. Many small molecules have the same masses but a different chemical makeup so distinguishing them with MS-based approaches can be difficult or impossible



Testosterone
Exact mass = 288.2089188

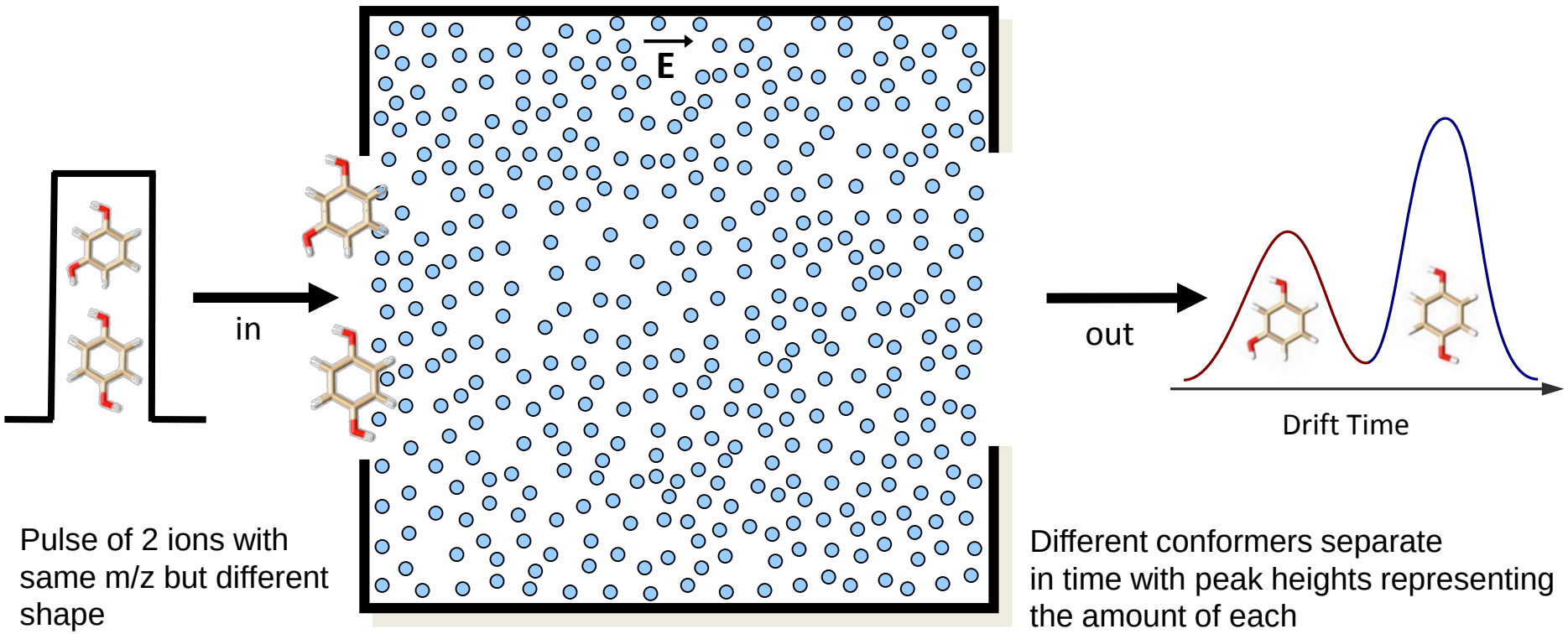






In the NIST database there are
18 different options with exact mass = 288.2089188

Ion mobility concept

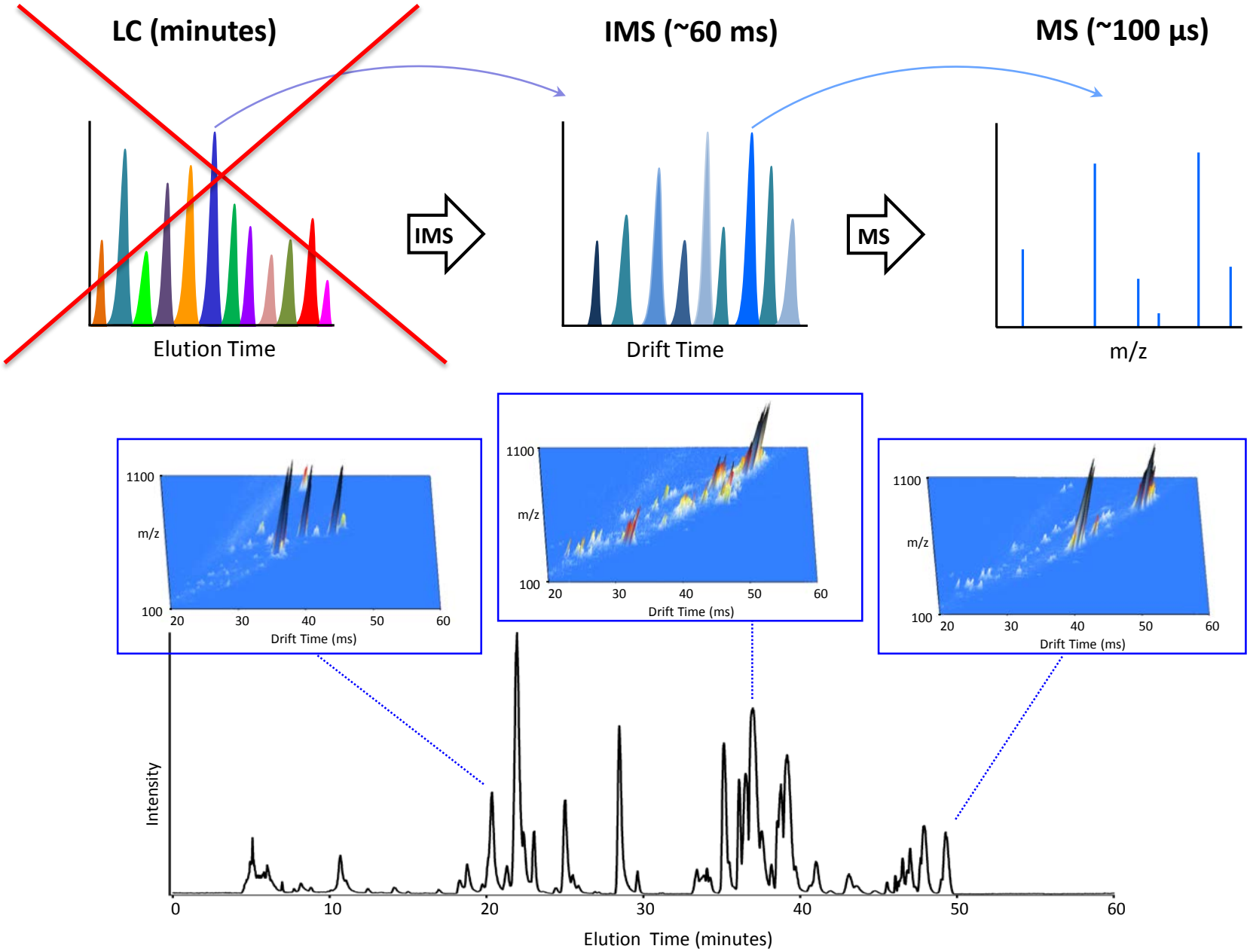


velocity is constant

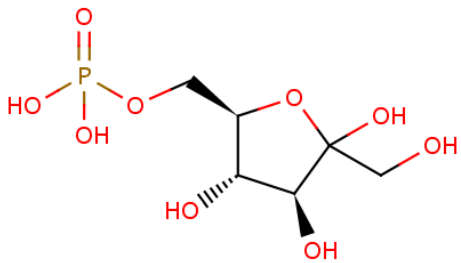
$$v = K \vec{E}$$

K = ion mobility

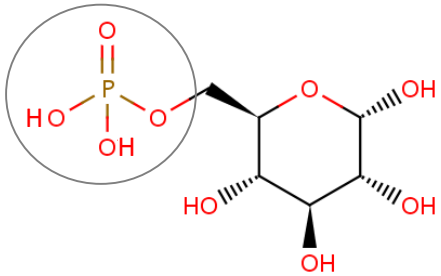
Ion mobility concept



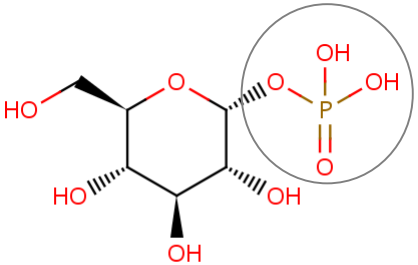
Isomers difficult to separate with hydrophobic interaction liquid chromatography (HILIC)



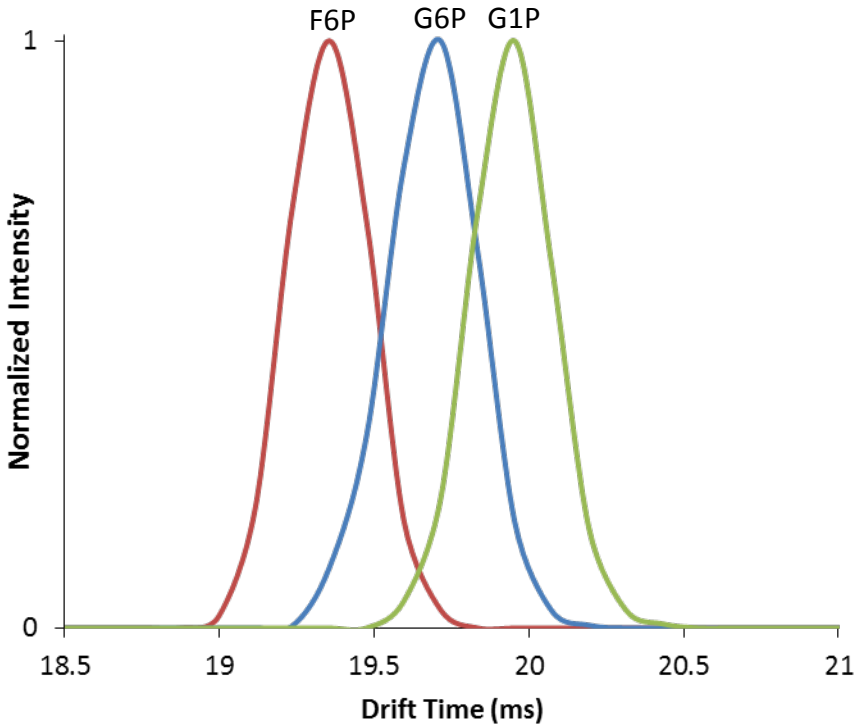
D-Fructose-6-phosphate (F6P)

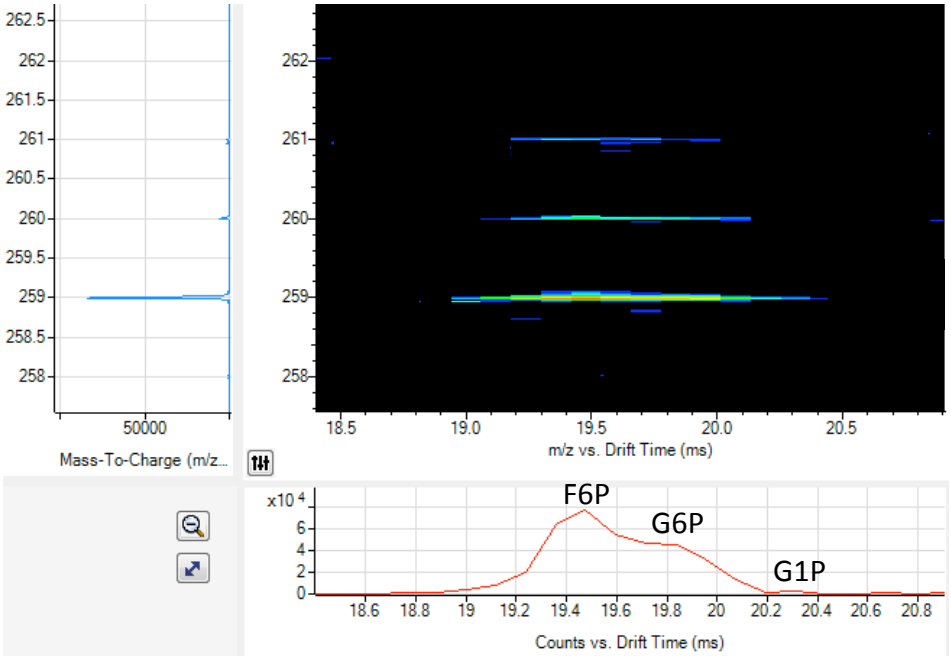


D-Glucose-6-phosphate (G6P)



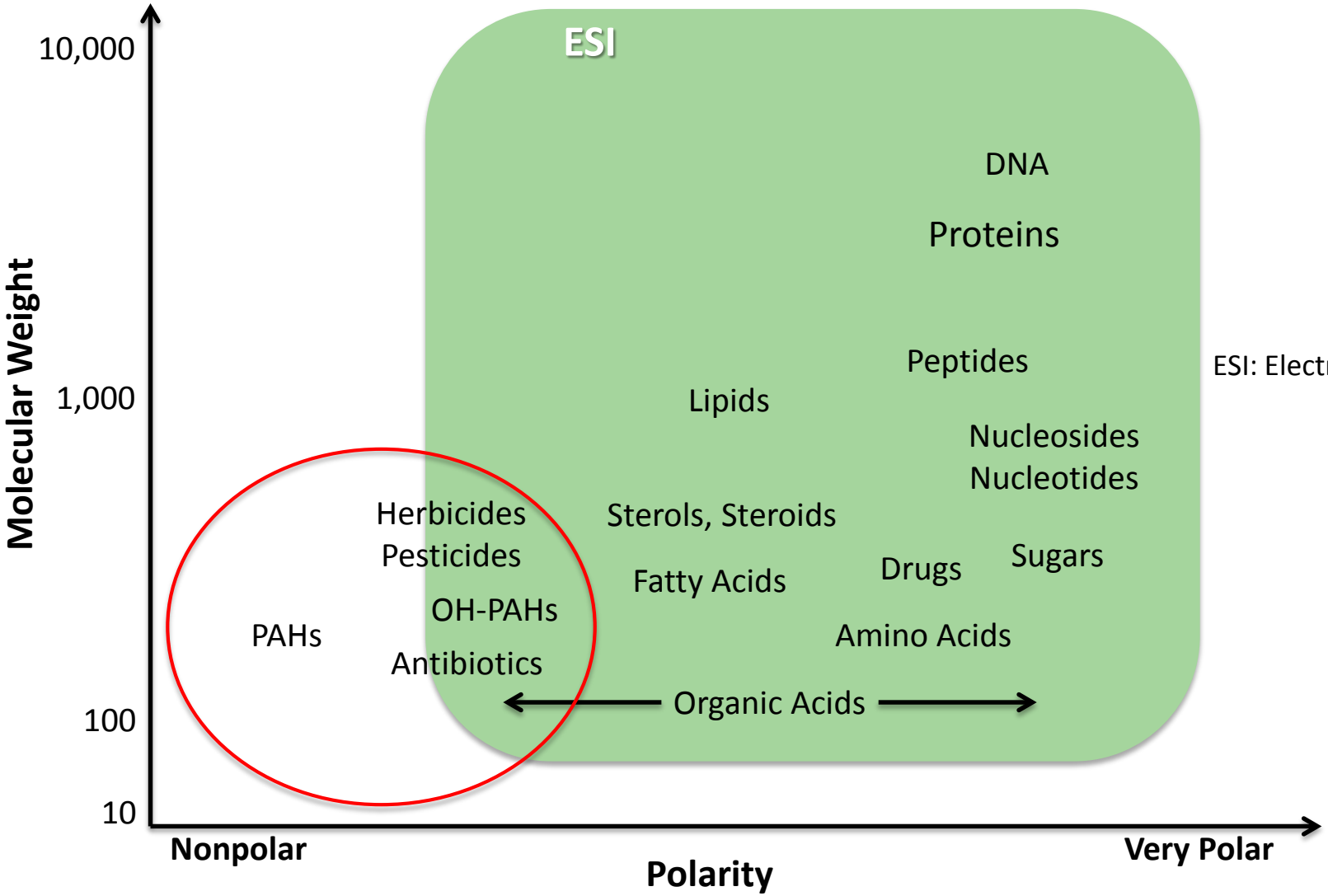
α-D-Glucose-1-phosphate (G1P)





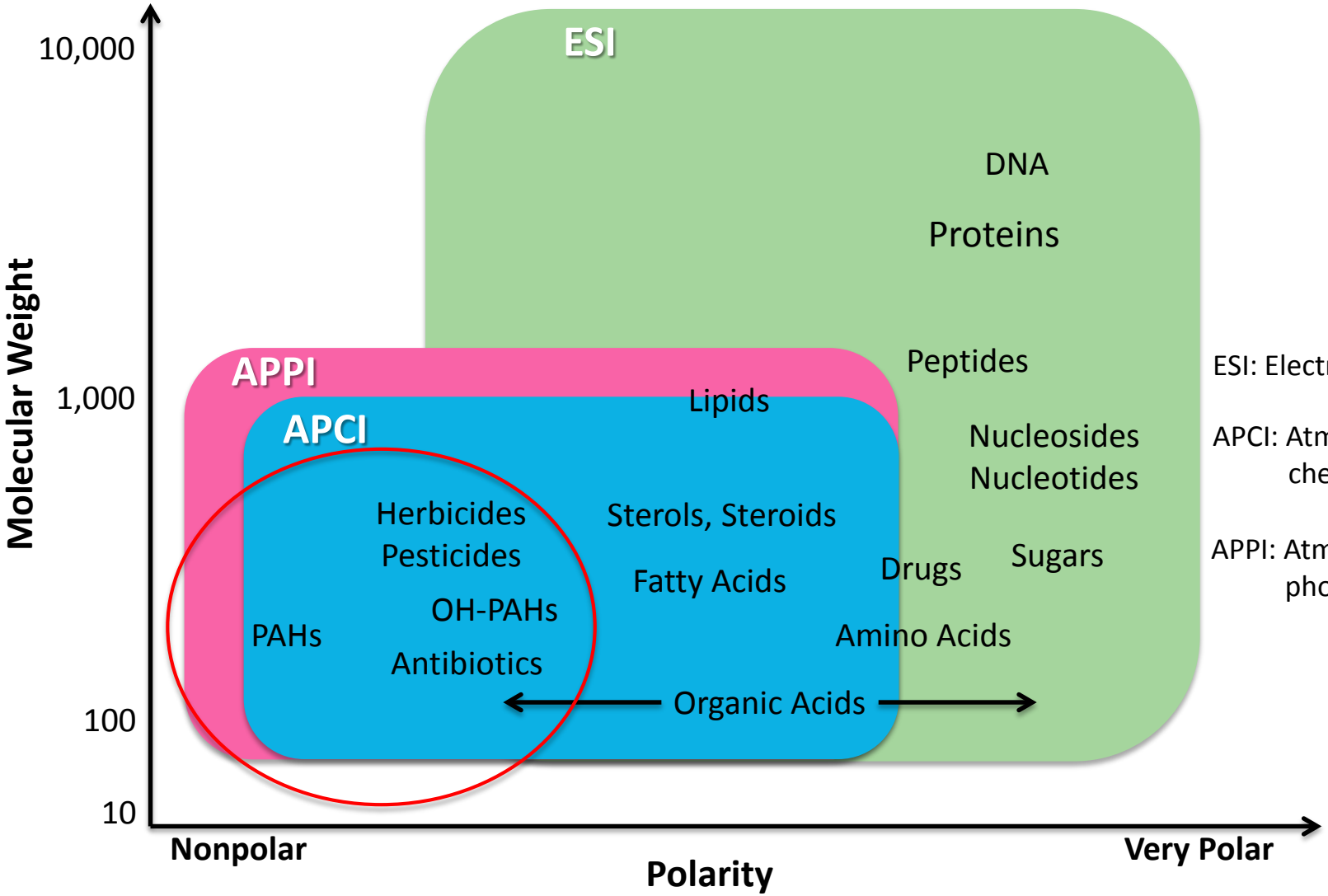
Deprotonated form $[M - H]^-$ m/z = 259.02

Different ionization methods



ESI: Electrospray ionization

Different ionization methods

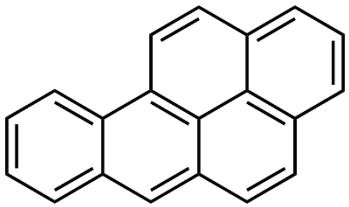


ESI: Electrospray ionization

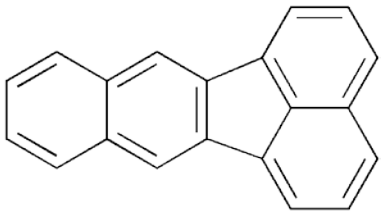
APCI: Atmospheric pressure chemical ionization

APPI: Atmospheric pressure photoionization

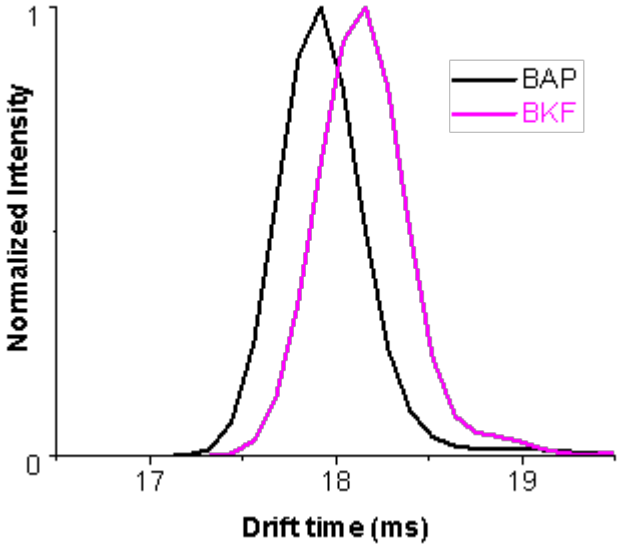
Isomeric xenobiotic separations



BAP:
Benzo(a)Pyrene



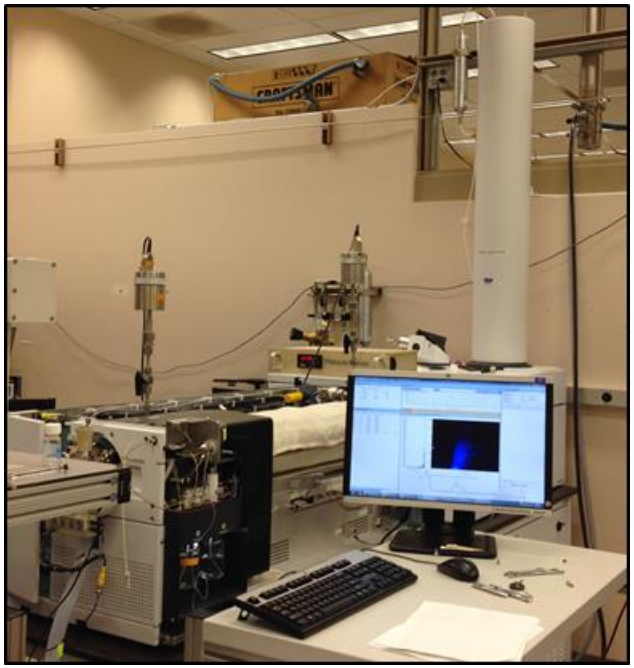
BKF:
Benzo(k)fluoranthene



Radical form $[M]^{\cdot+}$ m/z = 252.09

IMS collision cross section (CCS) precision

- Compare CCS accuracy across 4 international labs
- Analyze 80 molecules (metabolites, lipids, peptides and proteins) to determine CCS agreement

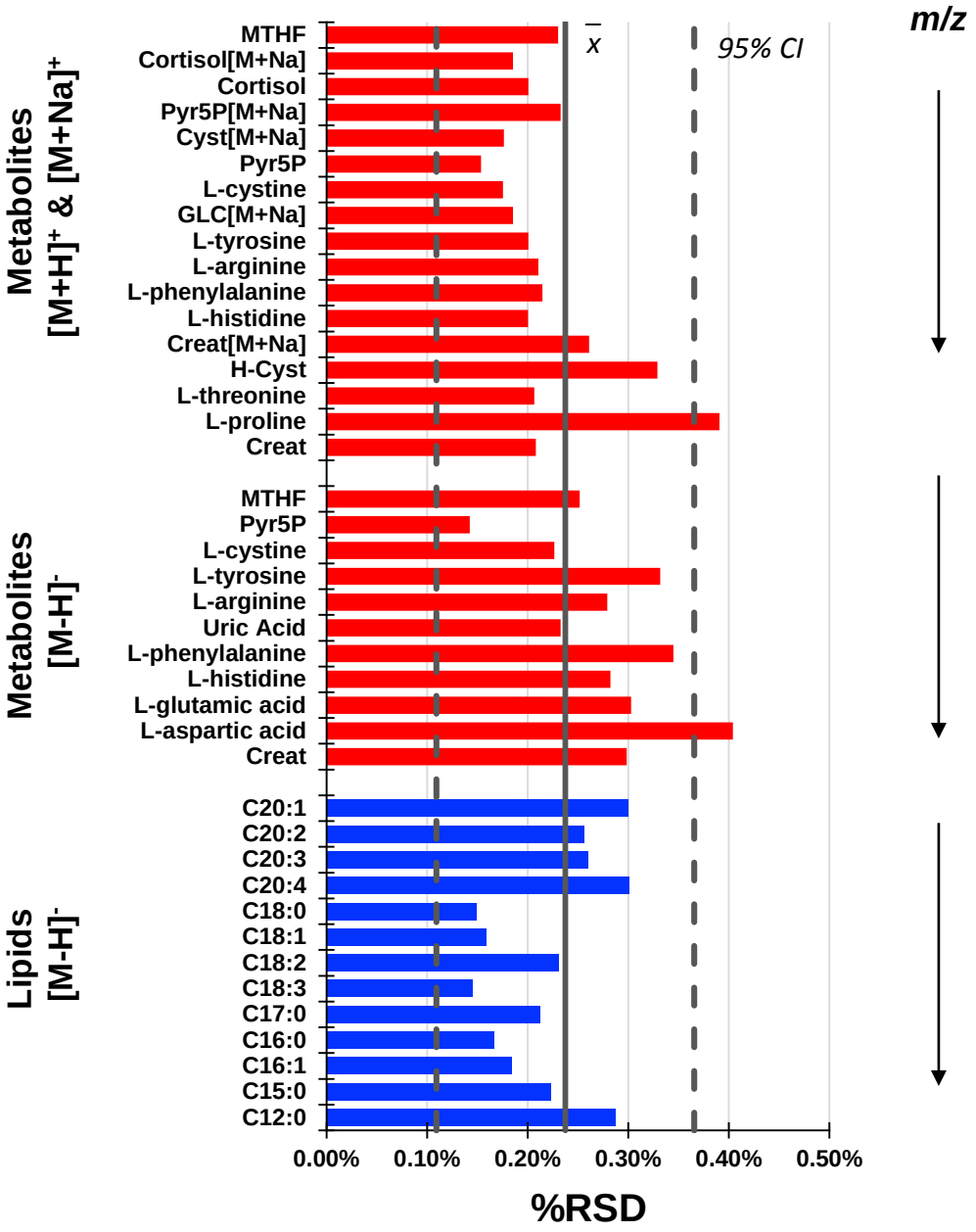


Pacific Northwest National Laboratory, Richland
Agilent Technologies, Inc., Santa Clara
Vanderbilt University, Nashville
BOKU – Univ. of Natural Resources and Life Sciences, Vienna

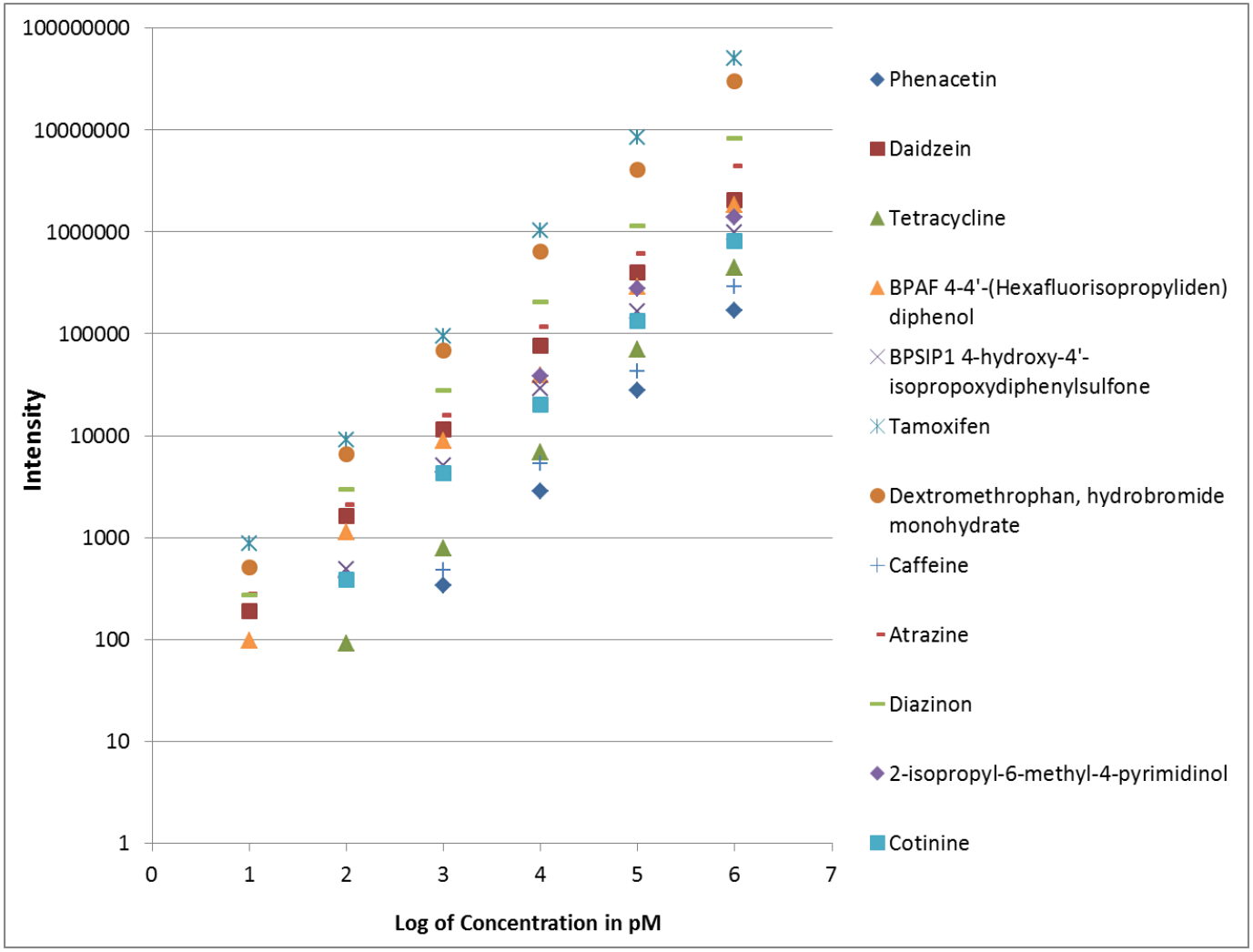
S. M. Stow, et al., *Anal. Chem.* **2017**, 89, 9048-9055.

Interlab comparison

- Ran triplicate injections at all 4 labs
- Analyzed in positive and negative ion mode
- Mean %RSD of 0.24%

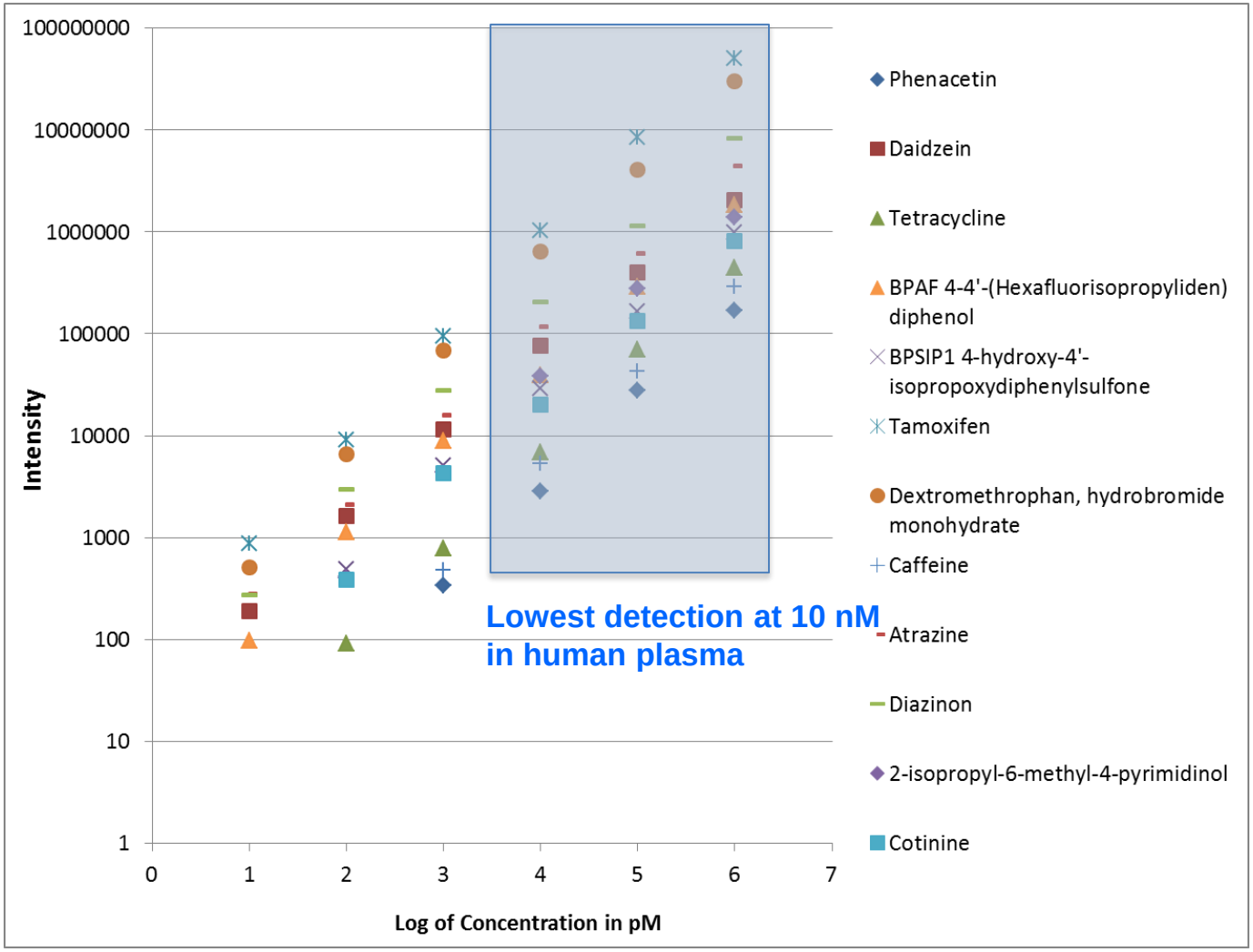


Limit of detection in water using IMS-MS



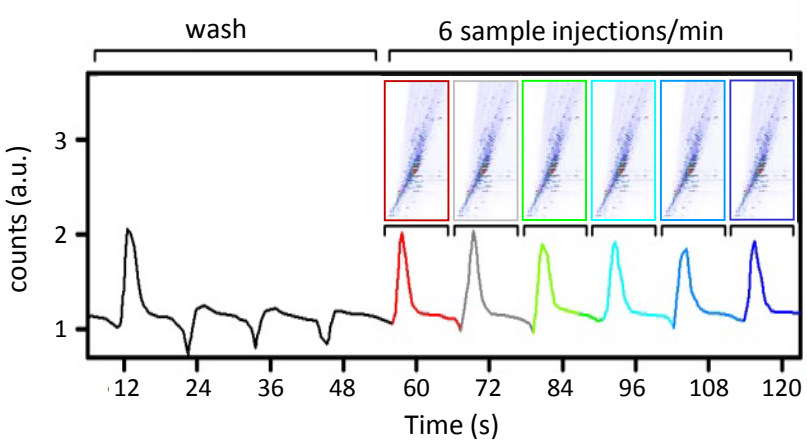
Lowest detection at 10 pM for standards in water
Linear concentration response

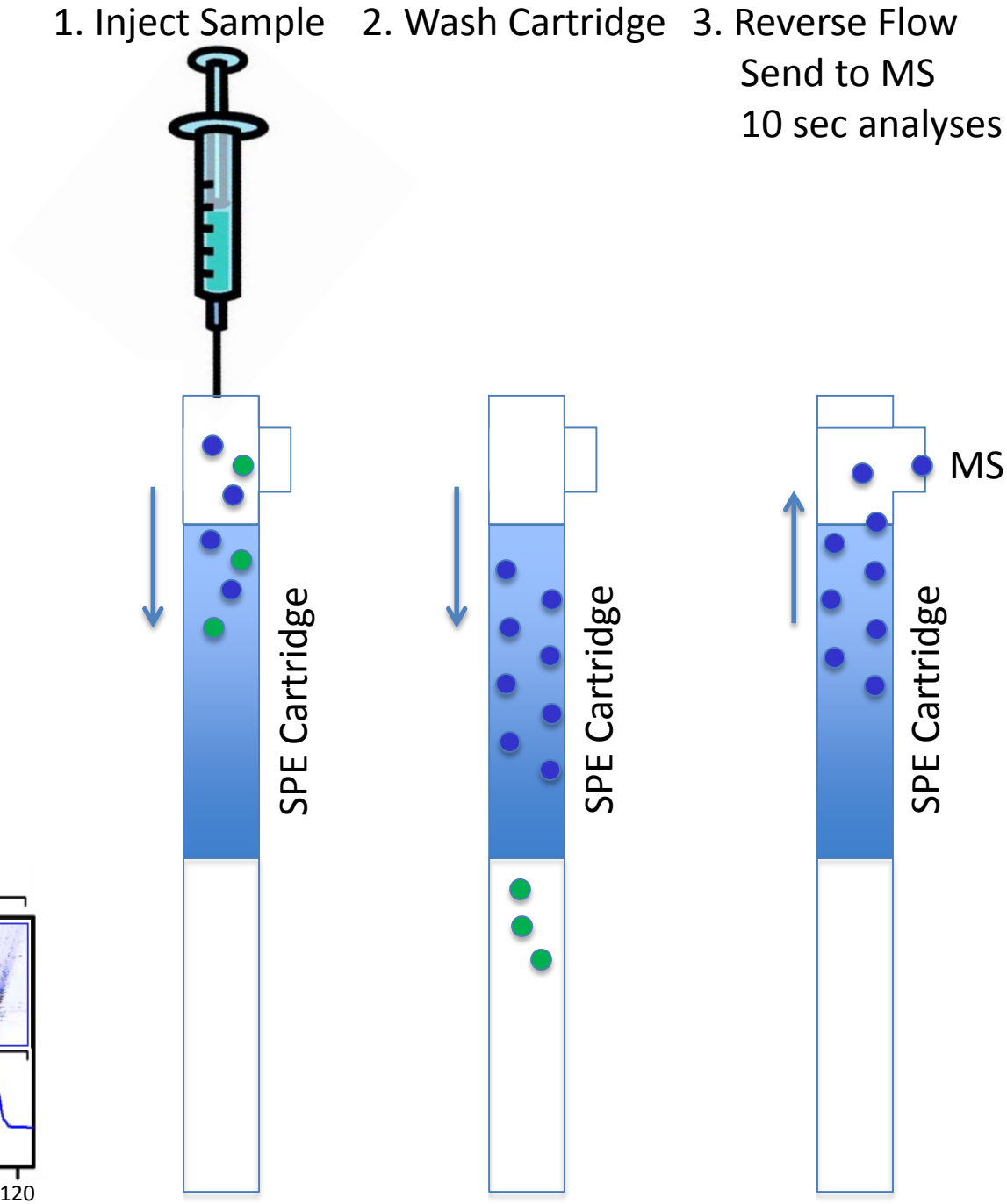
Limit of detection in human plasma with IMS-MS



Lowest detection at 10 pM for standards in water
Linear concentration response

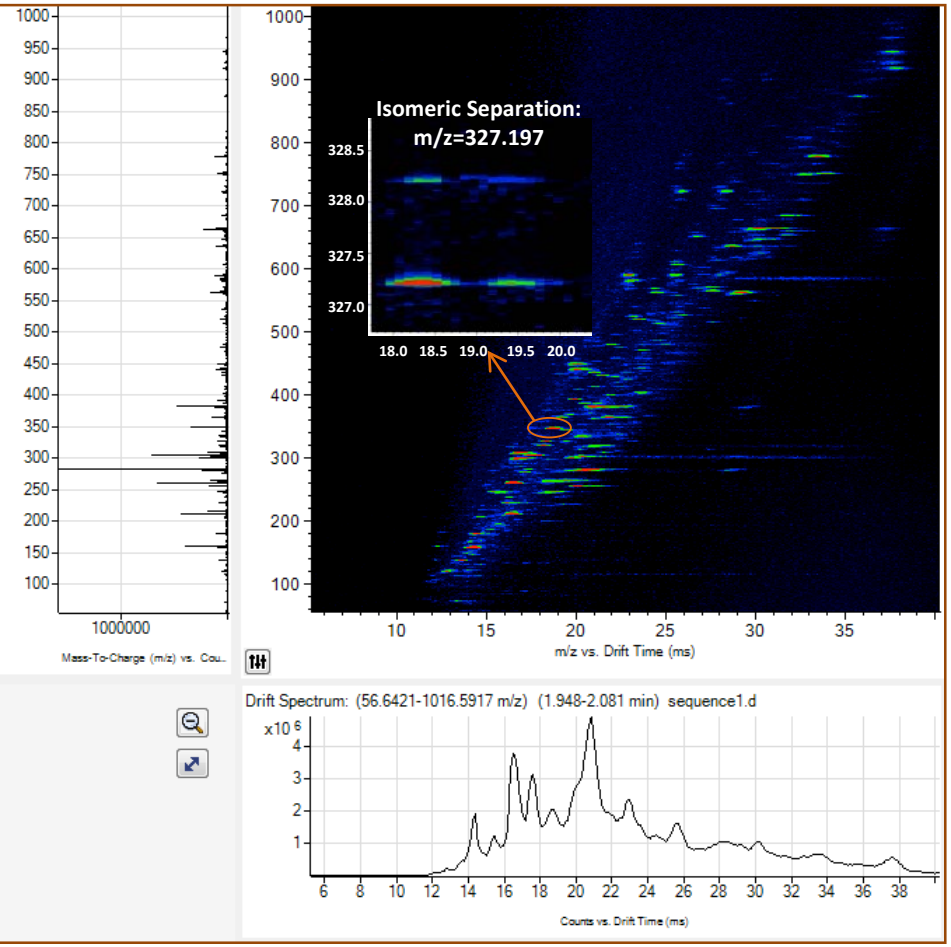
Automated SPE system





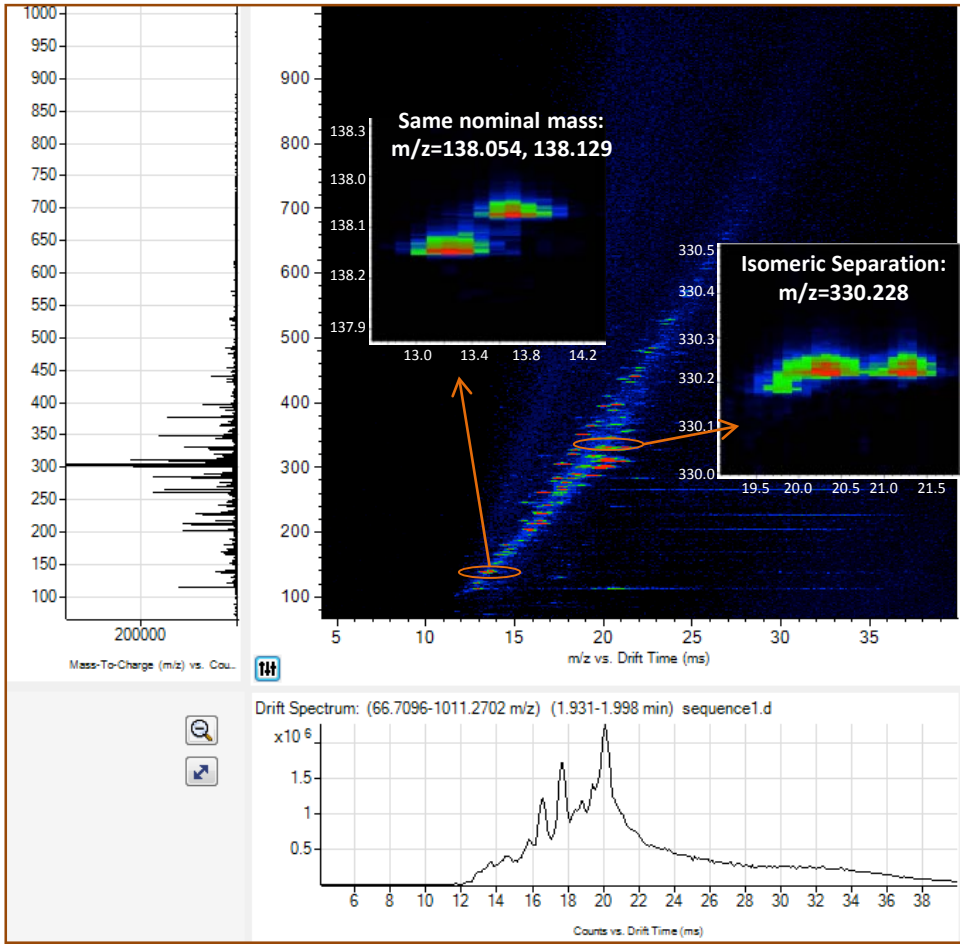
SPE-IMS-MS analyses of biological samples

Metabolites extracted from mouse plasma



~1400 features with S/N > 5

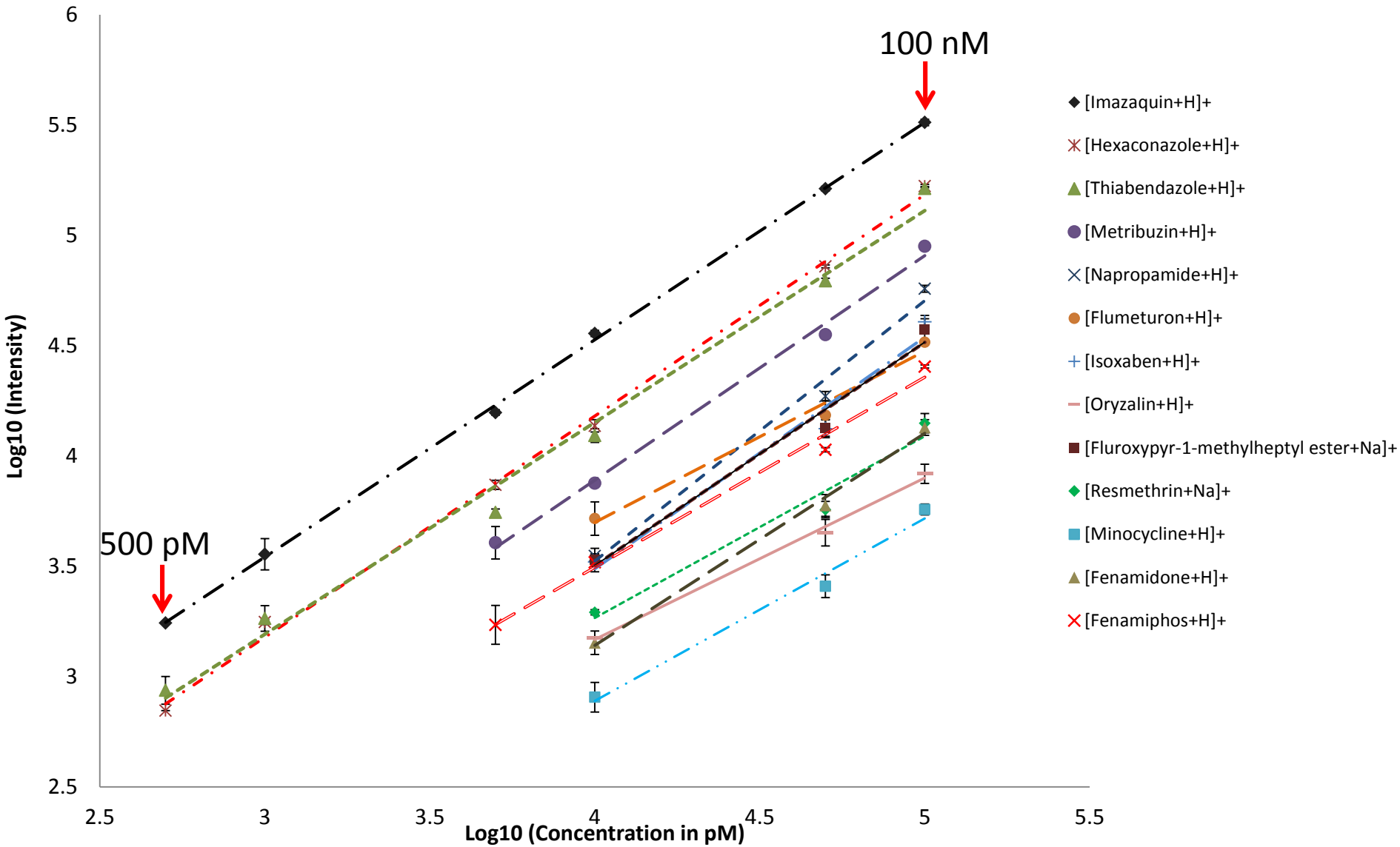
Metabolites extracted from human urine



~1000 features with S/N > 5

X. Zhang, et al., *Clin. Mass Spectrom.* **2016**, 2, 1-10.

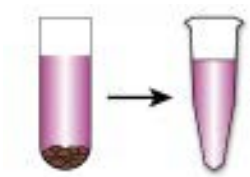
Calibration curve for xenobiotics in plasma



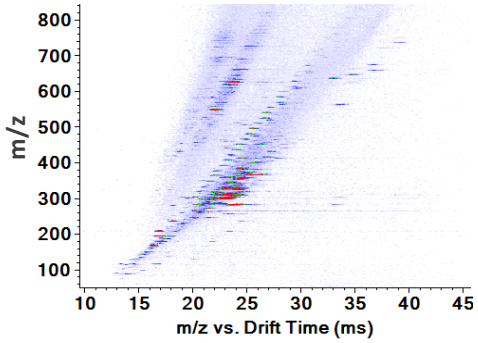
X. Zhang, et al., *Clin. Mass Spectrom.* **2016**, 2, 1-10.

Small molecule pipeline

Extraction



Instrumental Analysis



Data Processing & Analysis

ID	Mass	Intensity
----	----	----
----	----	----
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----	----	----
----	----	----

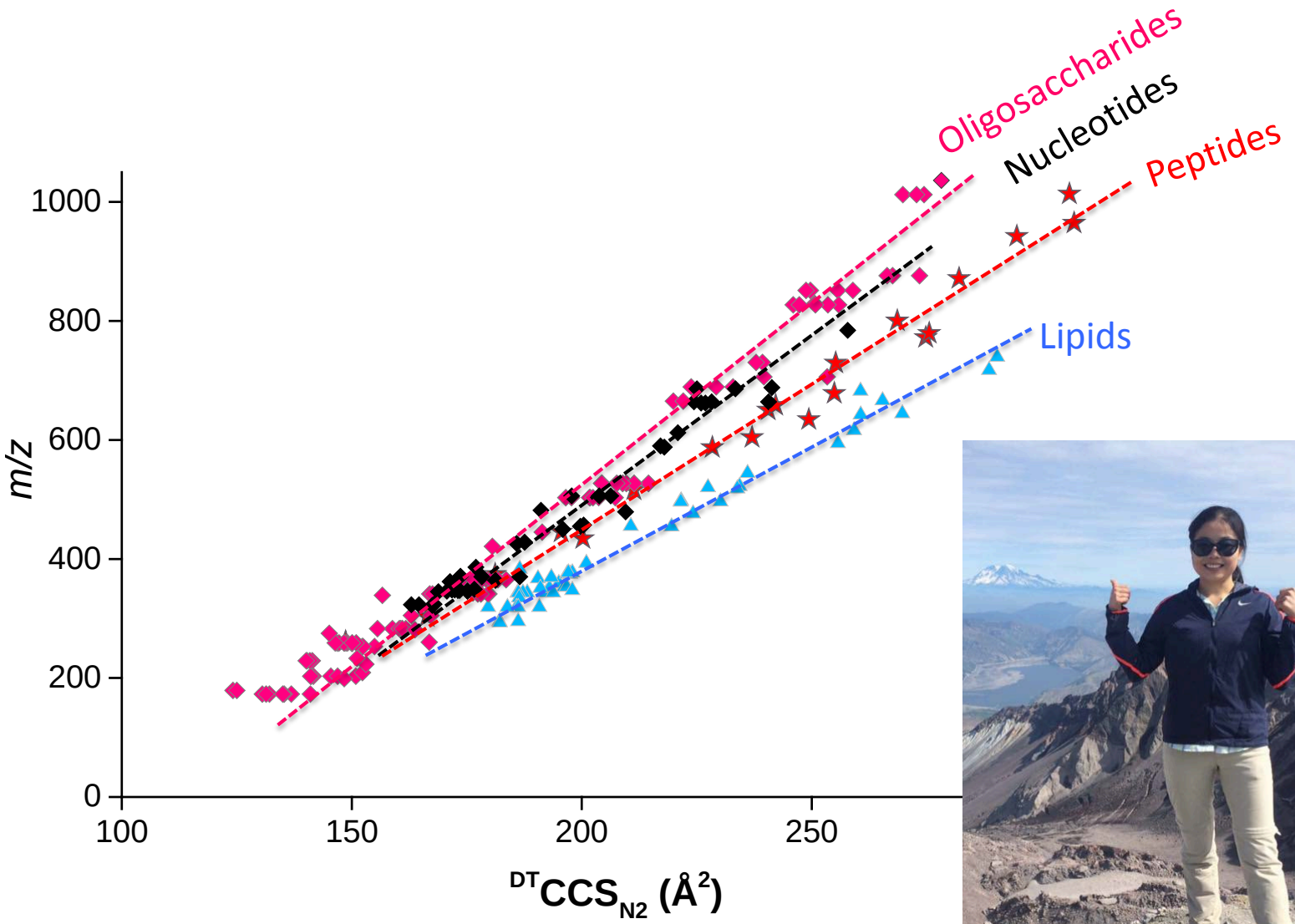
Methanol/Chloroform Extraction
(100 samples/day)

SPE-IMS-MS

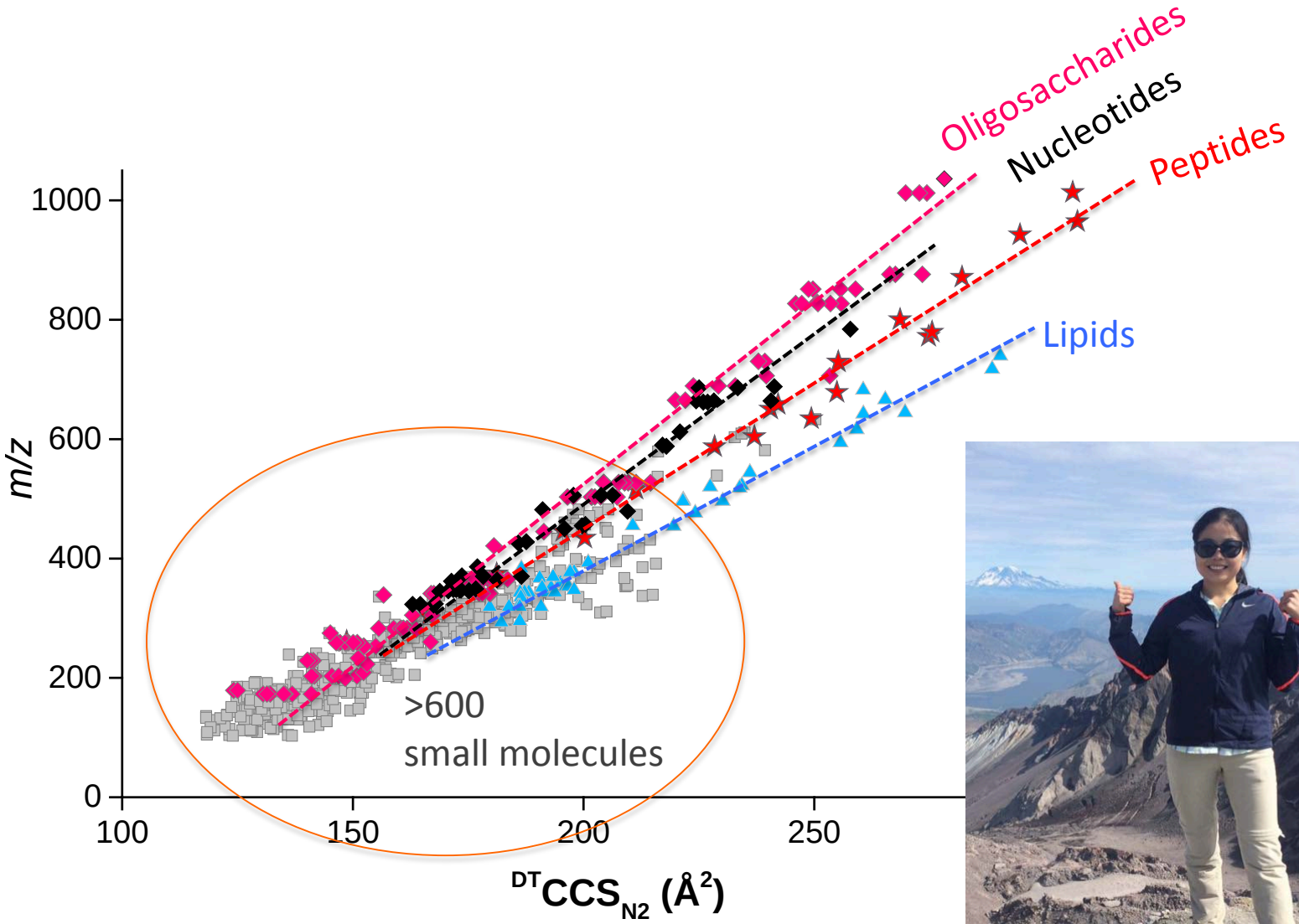
(8200 samples/day)

Database Matching & False Discovery Assessment
(? days)

Collision cross section database

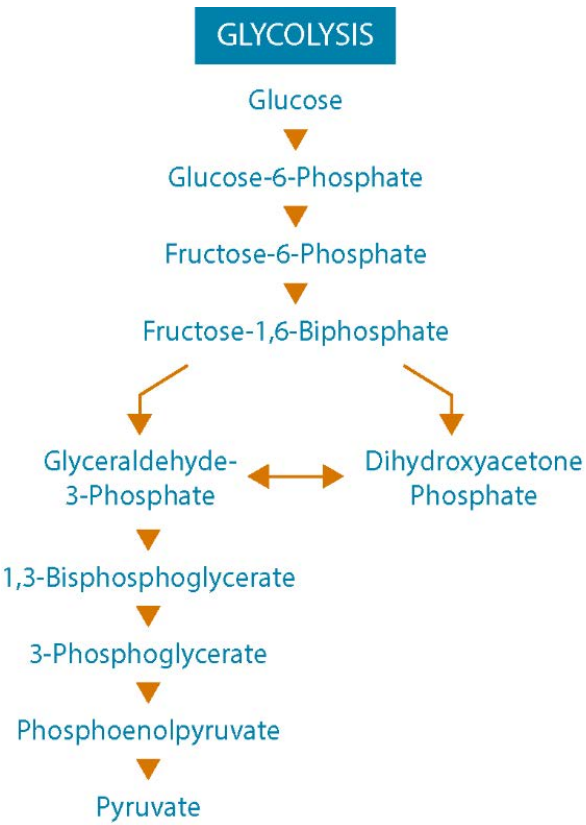


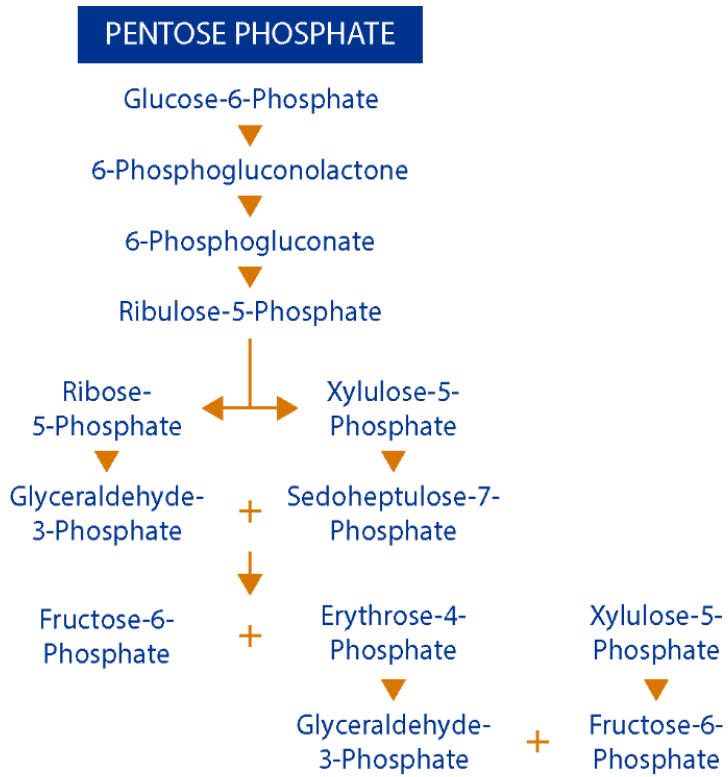
Collision cross section database

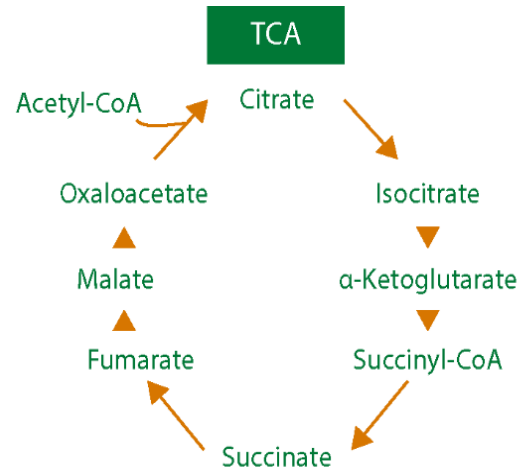


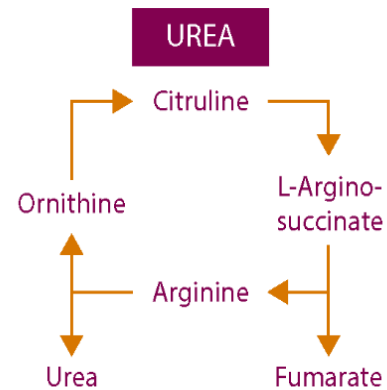
X. Zheng, et al., *Chem. Sci.* **2017**, ASAP.

Metabolic pathways



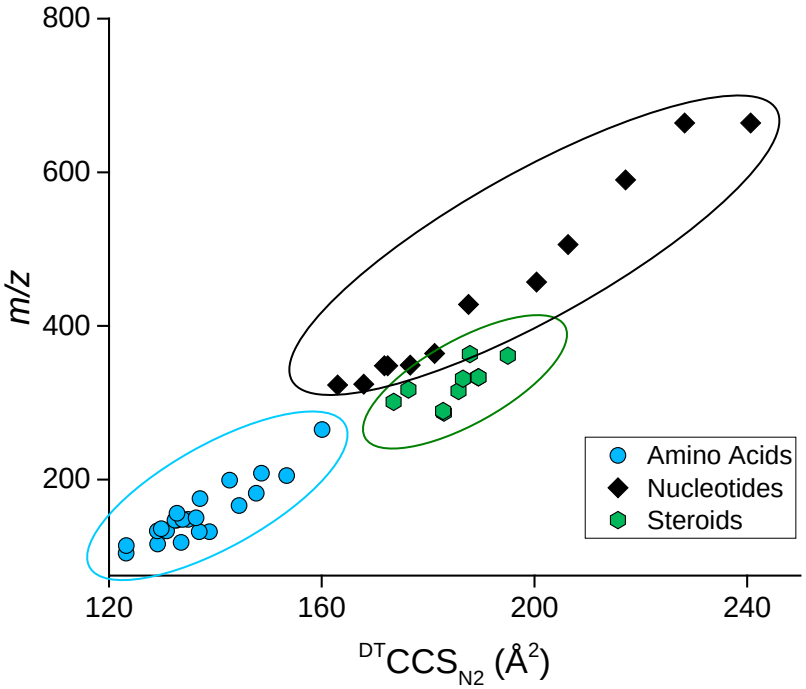






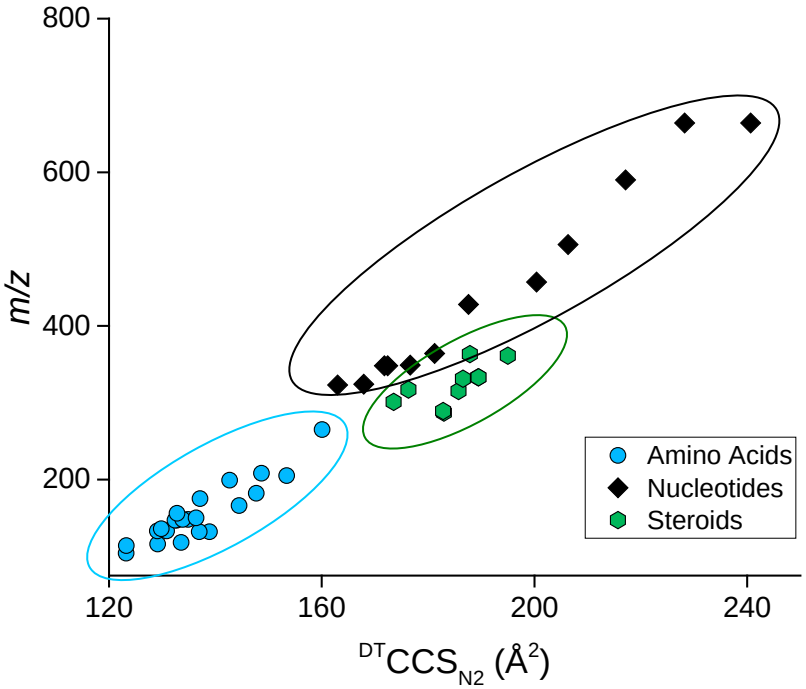
Primary metabolite trend lines

Protonated form

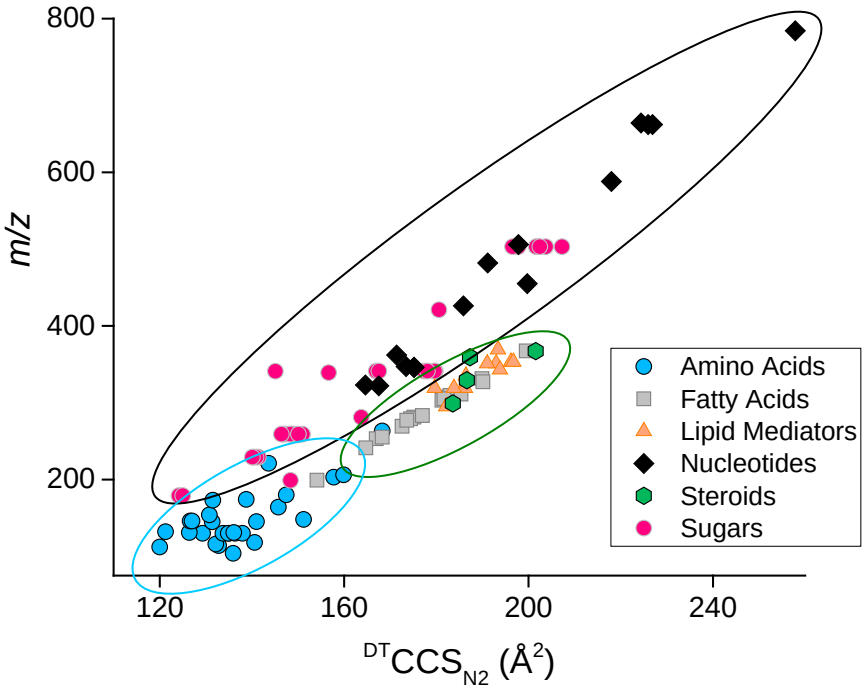


Primary metabolite trend lines

Protonated form



Deprotonated form



Website - http://panomics.pnnl.gov/metabolites/

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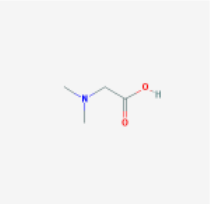
Home About Download Data ?

Results from manuscript "A Structural Examination and Collision Cross Section Database for Over 500 Metabolites and Xenobiotics Using Drift Tube Ion Mobility Spectrometry"

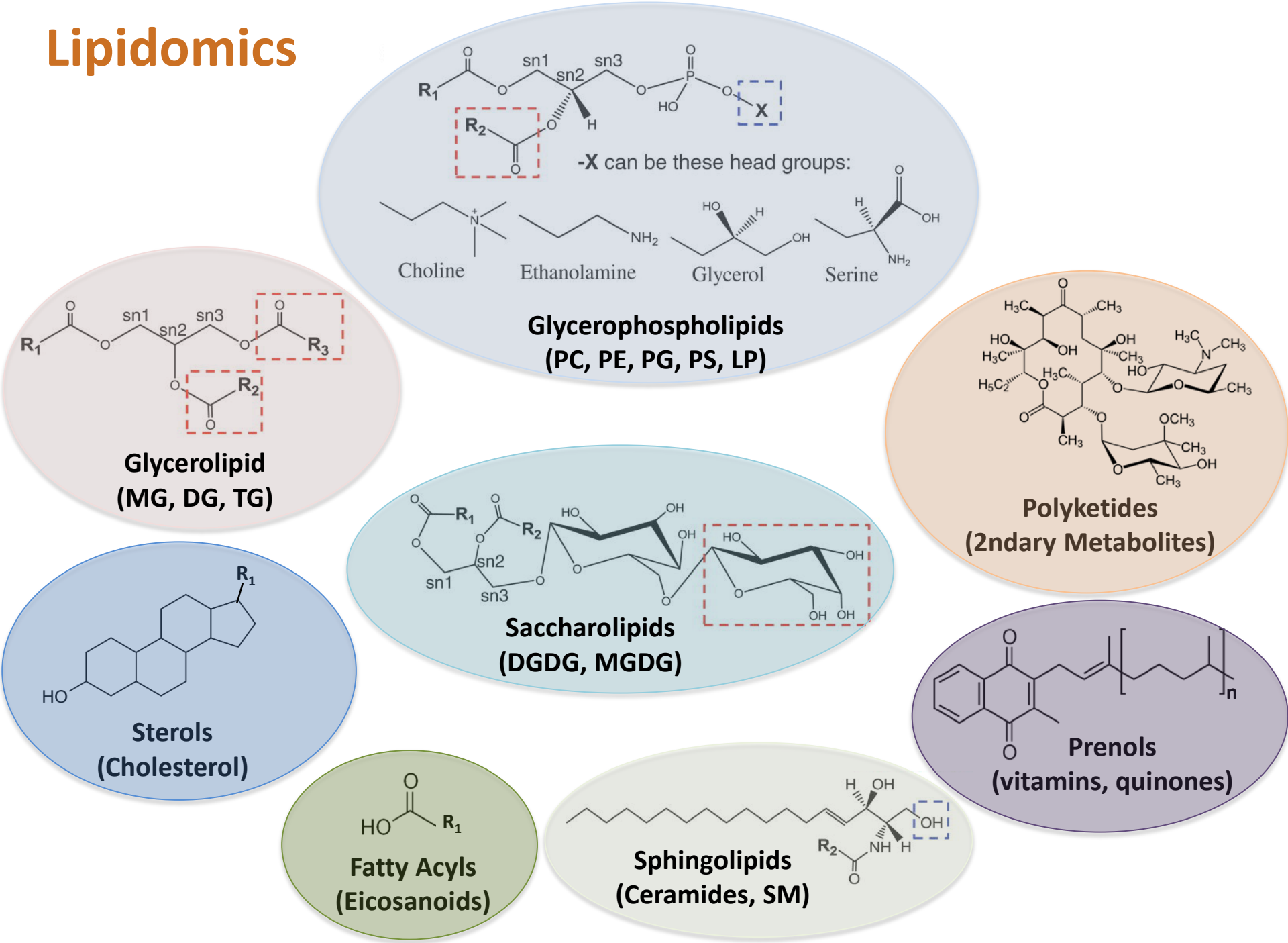
No Pathway Filter Show Pathway

Primary Metabolite × Subclass Search:

Name	CAS Number	Formula	Structure	Exact Mass	$^{DT}CCS_{N_2}$ (Å^2)
Class Primary Metabolites					
Subclass Amino Acids					
N,N-Dimethylglycine	1118-68-9	C4H9NO2		103.120336	$[M+H]^+$: 123.90

X. Zheng, et al., *Chem. Sci.* **2017**.

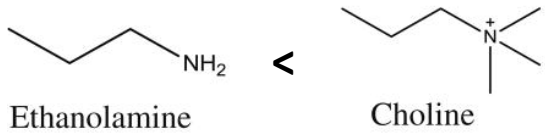
Lipidomics


sn1
sn2
sn3
R1
R2
X
-X can be these head groups:
Choline
Ethanolamine
Glycerol
Serine
Glycerophospholipids
(PC, PE, PG, PS, LP)
R3
Glycerolipid
(MG, DG, TG)
Polyketides
(2ndary Metabolites)
Saccharolipids
(DGDG, MGDG)
Sterols
(Cholesterol)
Prenols
(vitamins, quinones)
Fatty Acyls
(Eicosanoids)
Sphingolipids
(Ceramides, SM)

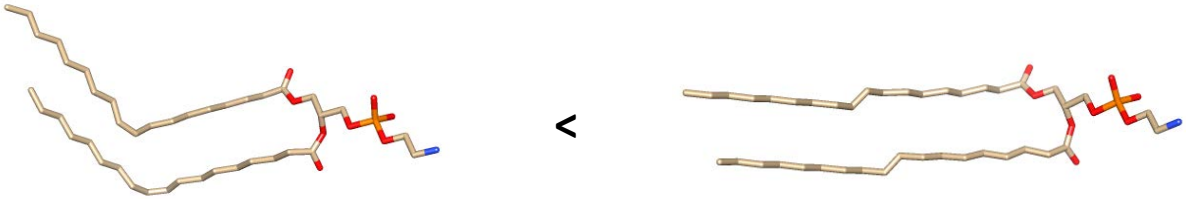
Lipid isomers

1. Class isomers (PC and PE)

PE 36:2 < PC 33:2 but has the same elemental composition, $C_{41}H_{78}NO_8P$



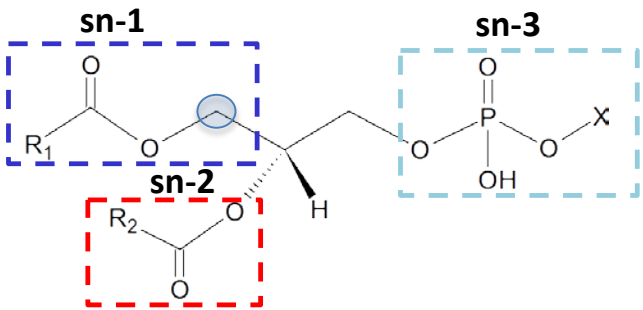
2. cis/trans double bond orientations



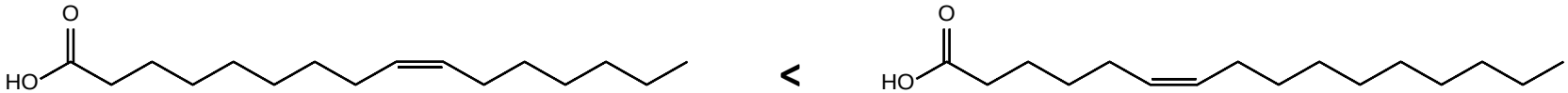
PE(18:1/18:1) (cis-Δ^9) **PE(18:1/18:1) (trans-Δ^9)**

3. sn-1/sn-2/sn-3 fatty acyl positions

PC(14:0/<u>16:0</u>) < PC(<u>16:0</u>/14:0)



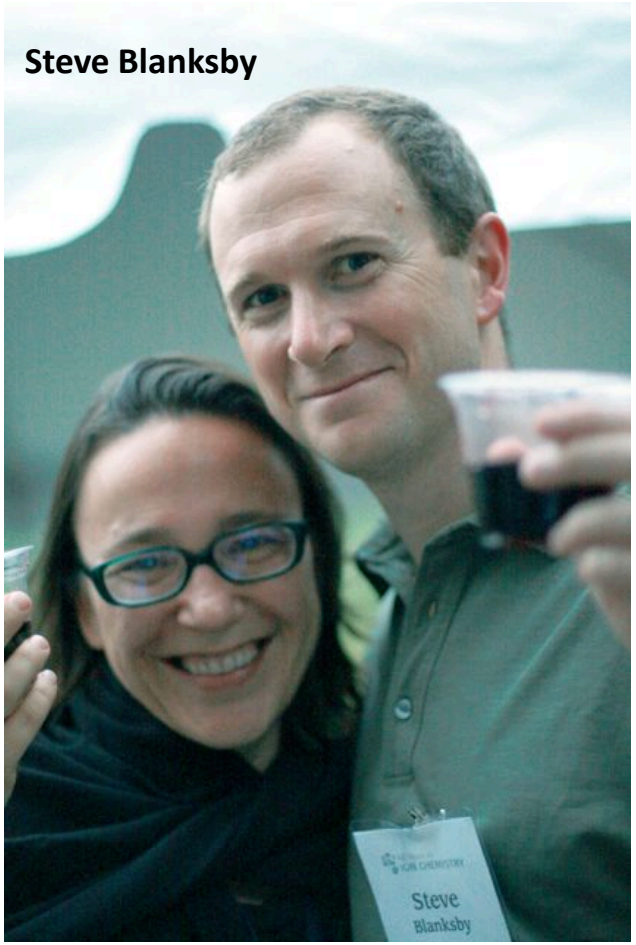
4. double bond locations

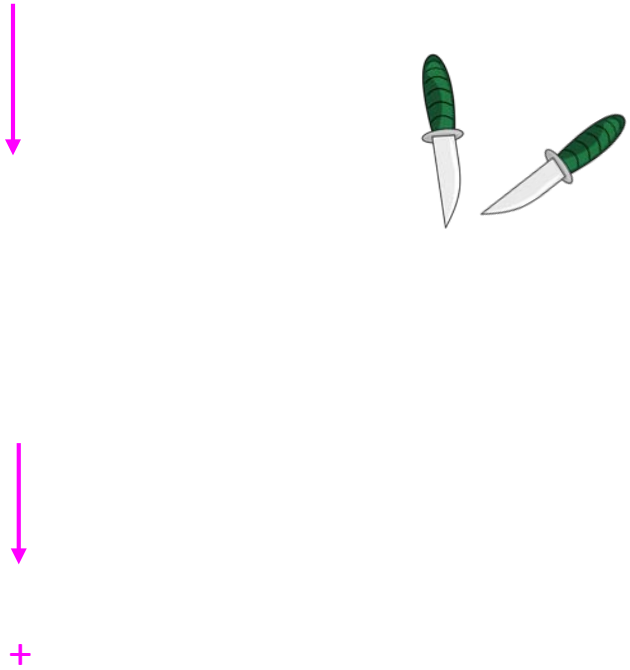


cis-Δ9 **cis-Δ6**

Ozonolysis or OzID

Parent Lipid

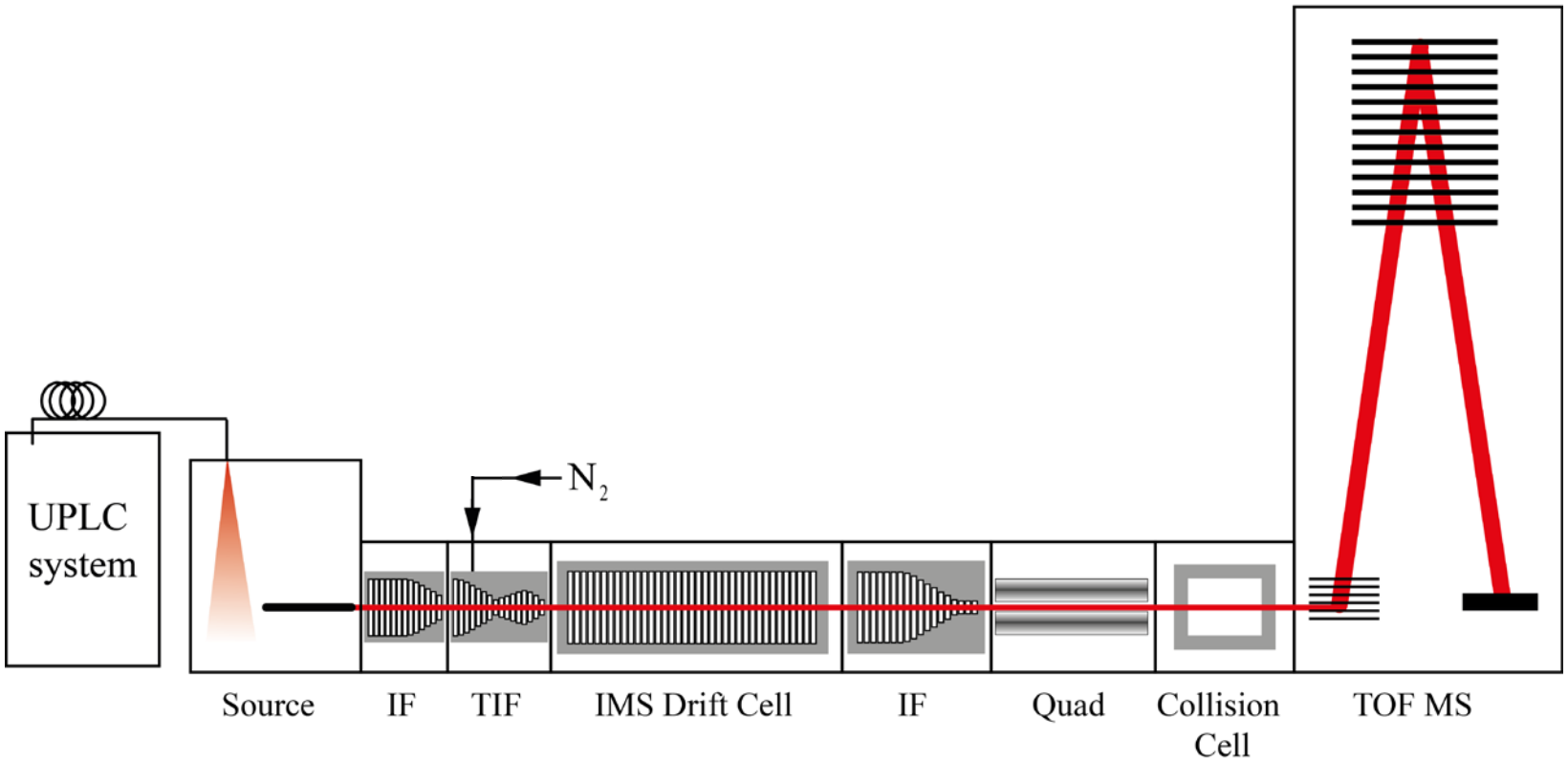




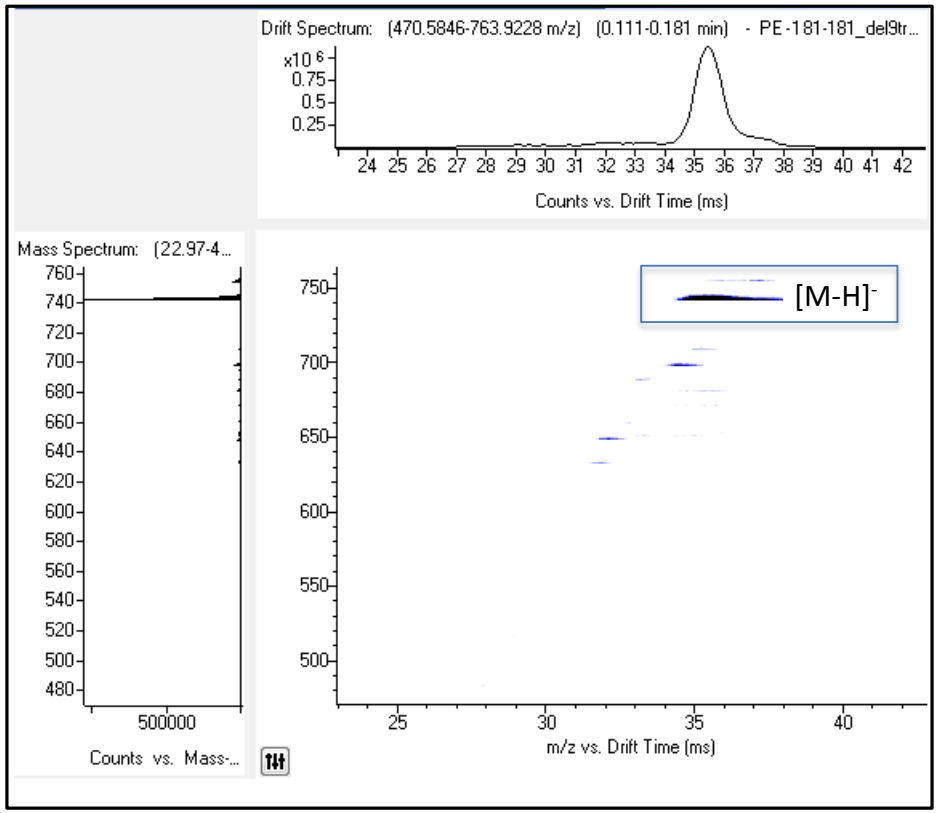
Diagnostic Ions
Δmass = 16 Da

Criegee

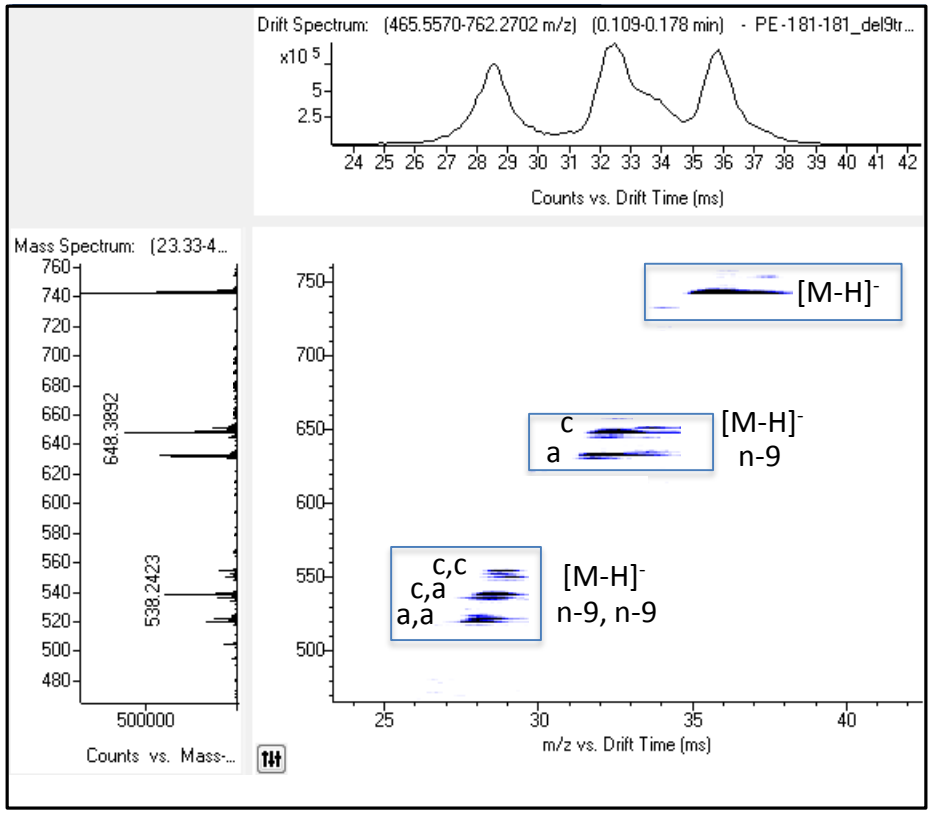
Ozonolysis on IMS instrument



ESI-OzID-IMS-MS of [PE(18:1/18:1)-H]$^-$



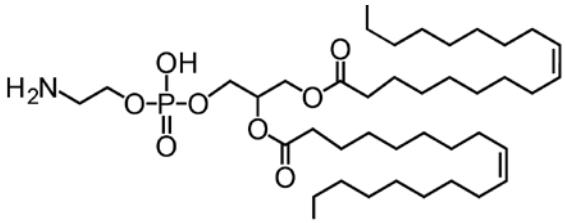
No Ozone



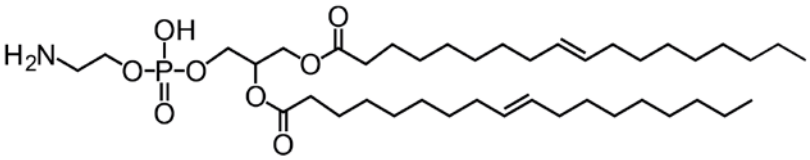
Ozone

Both double bonds trans-Δ9

ESI-OzID-IMS-MS of PE(18:1/18:1)

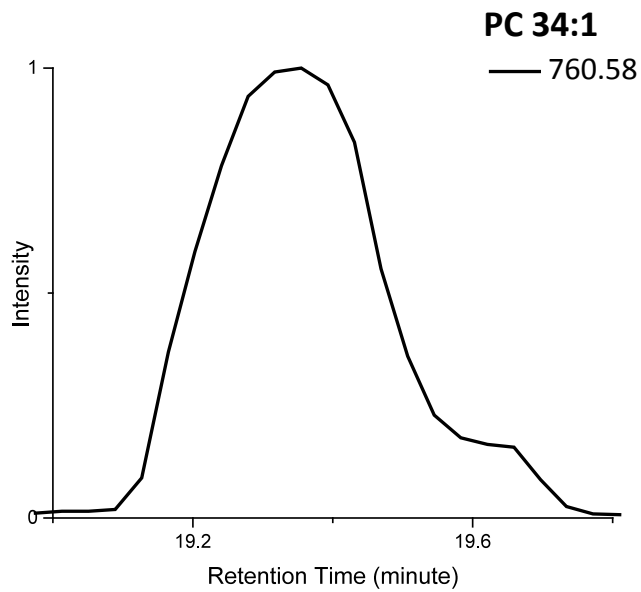


cis, cis

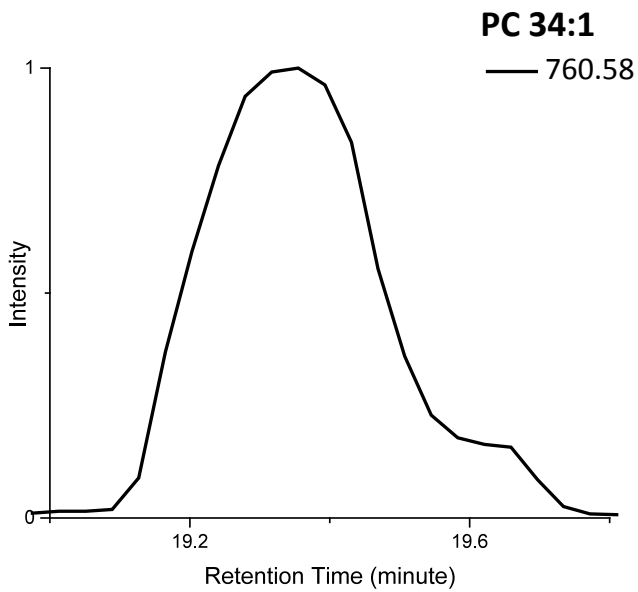


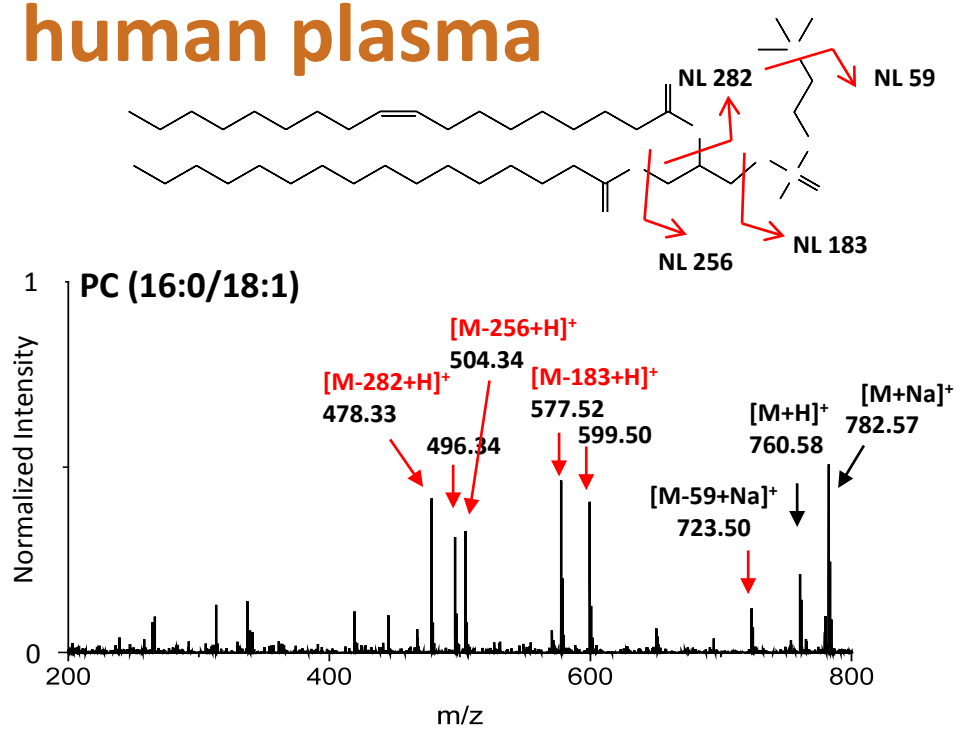
trans, trans

LC-OzID-IMS-CID-MS in human plasma

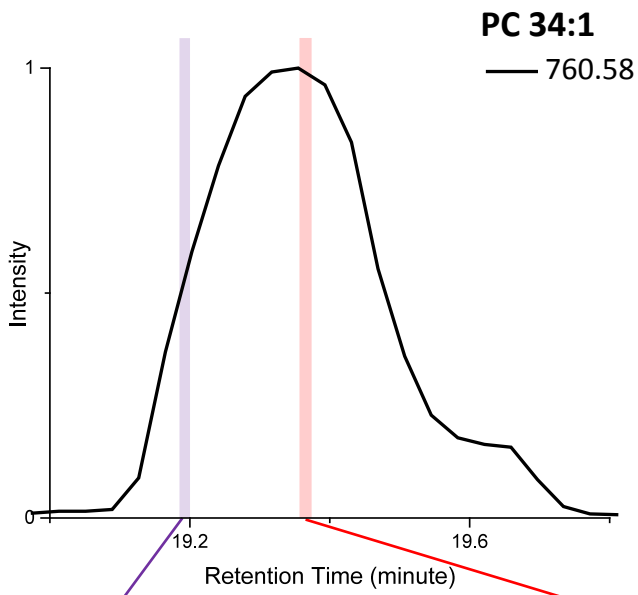


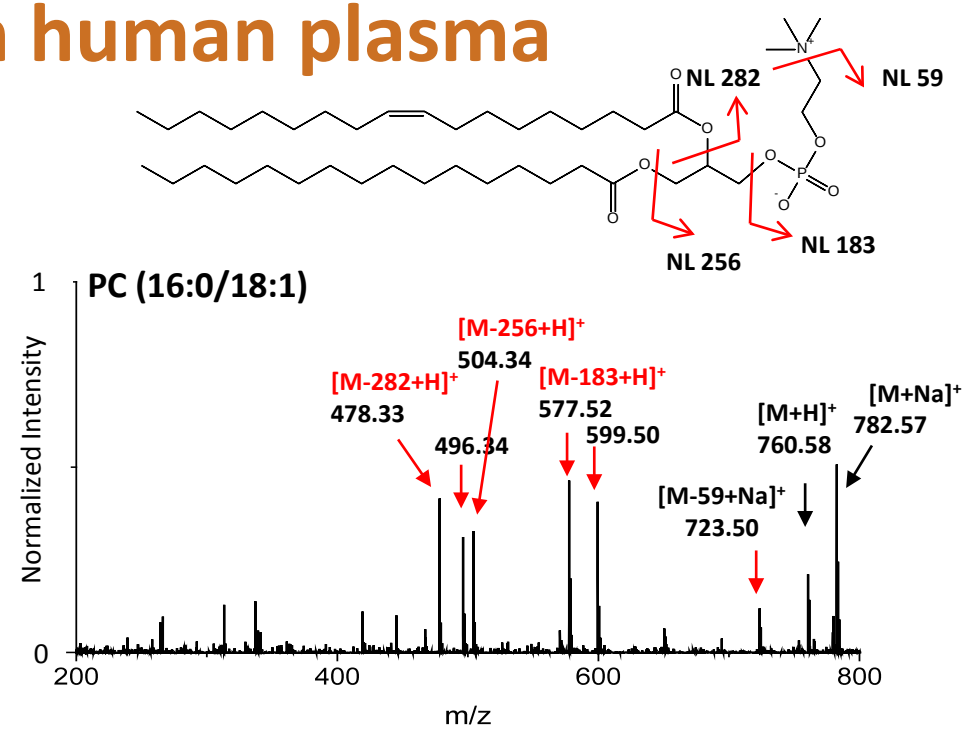
LC-OzID-IMS-CID-MS in human plasma



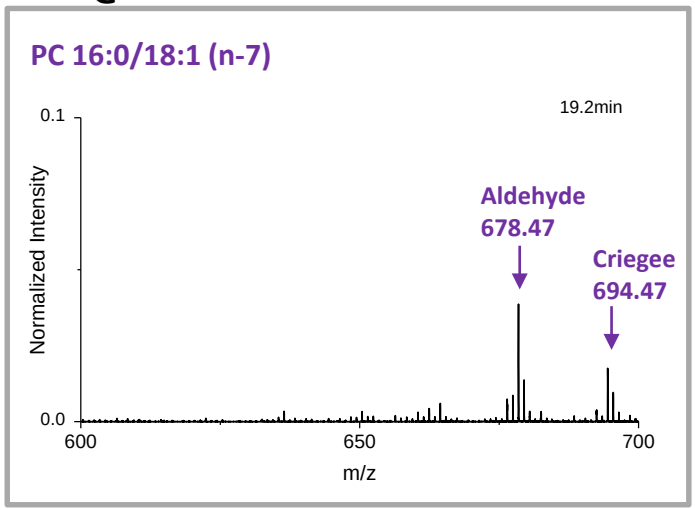


LC-OzID-IMS-CID-MS in human plasma

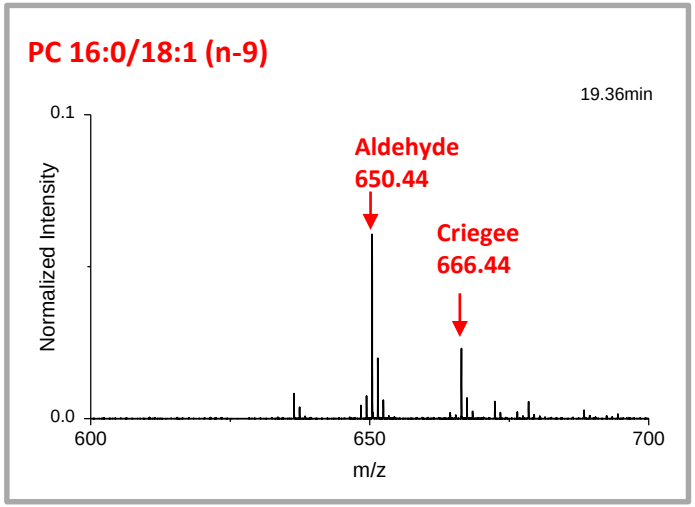




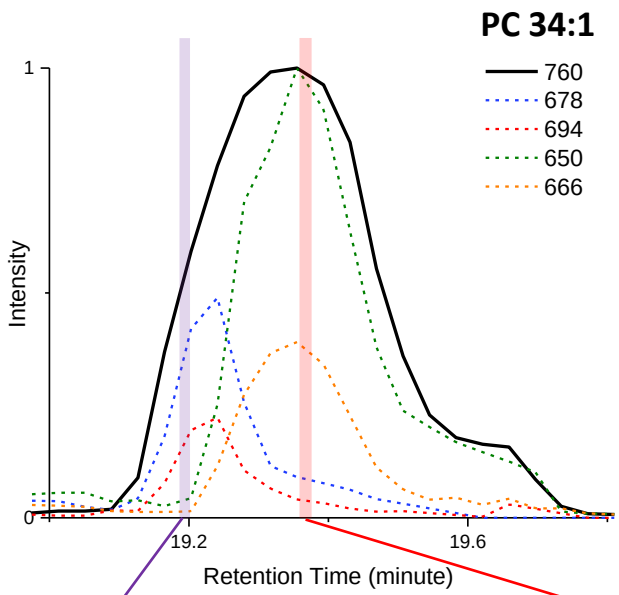
OzID @ RT 19.2 min

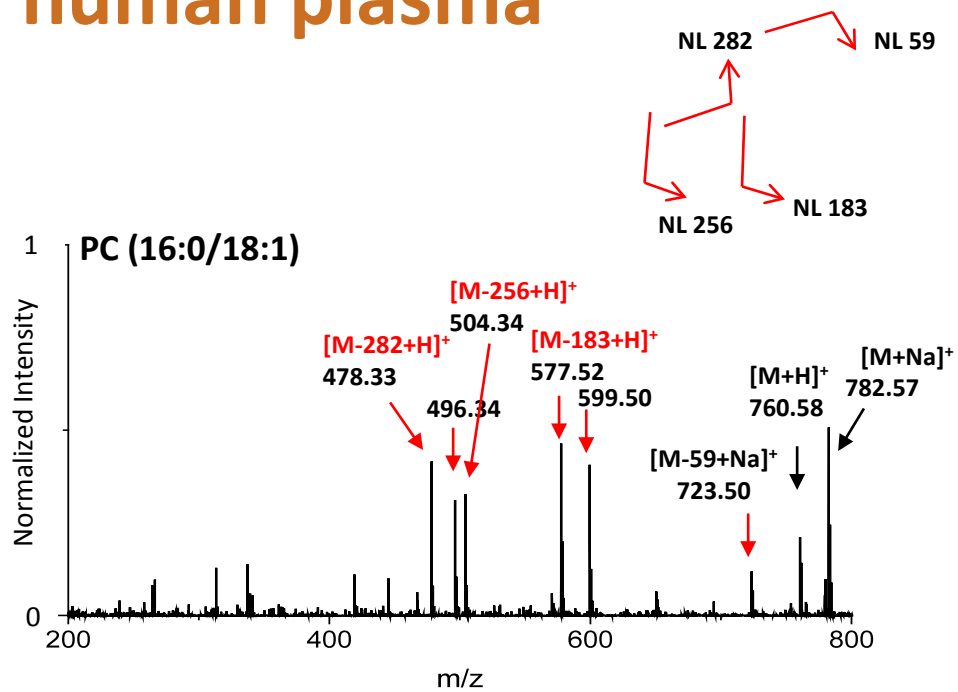


OzID @ RT 19.36 min

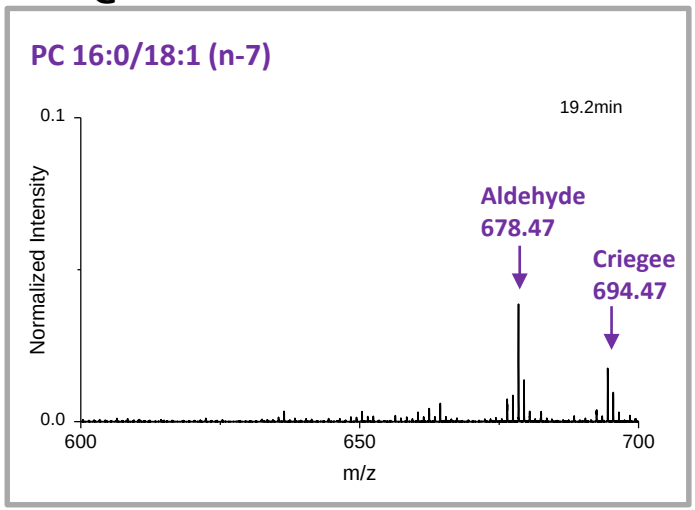


LC-OzID-IMS-CID-MS in human plasma

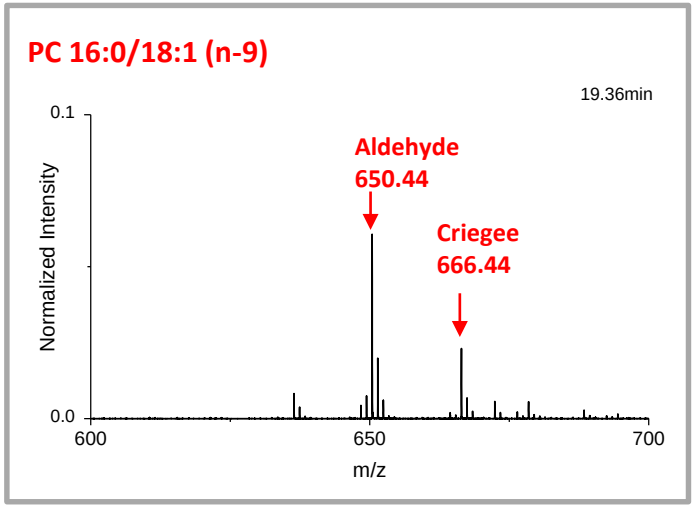




OzID @ RT 19.2 min

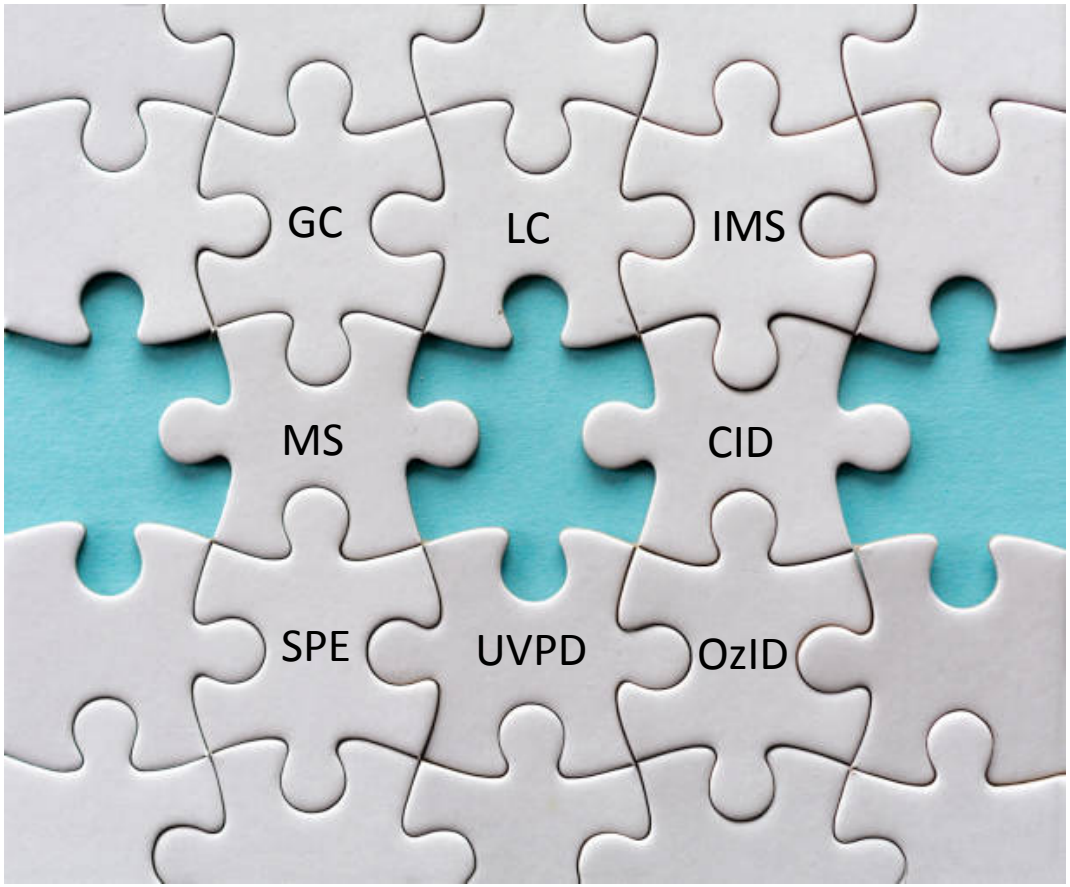


OzID @ RT 19.36 min



Summary

- Combining multiple separations and methods enables faster and better small molecule identifications as demonstrated with SPE-IMS-MS and LC-OzID-IMS-CID-MS analyses



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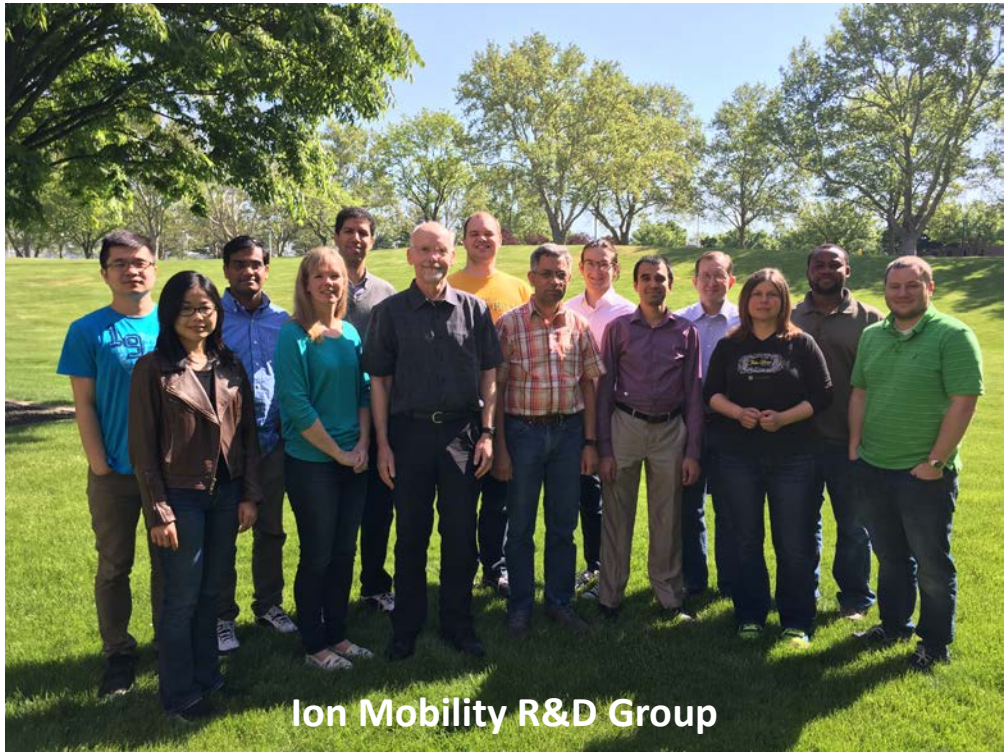
- Environmental Molecular Sciences Laboratory



Noor Aly