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Advanced analytical techniques for industry

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Introduction to the Department

- The Department of chemistry is **115** years old this year!
- **24** academic and **4** research staff; **28** support staff.
- Approximately **130** post graduate students
- We house **3** Research Chairs (2 SARCHi Chairs and the SASOL Chair of Analytical Polymer Science)
- **75%** of our academic staff have a rating from the National Research Foundation (NRF):
  - **2 - A** rated (leading international researchers), **5 - B** rated, **7 – C** rated and **4 – Y** rated scientists

Stellenbosch 100 Chemie/Chemistry

2004

Offer undergraduate BSc degree in Chemistry and Polymer Science

- MSc (Chemistry)
- MSc (Polymer Science)
- PhD (Chemistry)
- PhD (Polymer Science)

115 years of chemistry at Stellenbosch….

The lecturers and third-year students of **1923** – the very first final-year class in the new De Beers building.

Staff and postgraduates in **2018**

Research Facilities

- **R48 Million** (about €3.8 Million) invested in physical infrastructure over the last 5 years
- Mostly on upgrading the research labs
- Department is spread over **5** buildings

Departmental Buildings

De Beers

Mike De Vries

Inorganic

Polymer Science

General Chemistry Building

Research Facilities

NMR Spectrometers

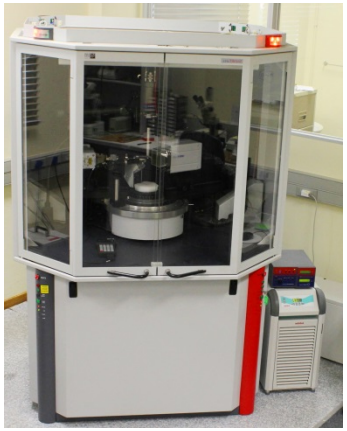
300, 400 & 600 MHz
500 MHz (Solid state)

X-Ray diffraction

BRUKER SMART APEX single crystal X-ray
BRUKER APEX DUO single crystal X-ray
BRUKER D8 VENTURE with a Photon II detector and I(mu)S 3 source
PANalytical X'pert Pro powder X-ray diffractometer, Cu source,
Multiple stages and Variable Temperature for Capillaries
BRUKER D2 desktop powder X-ray

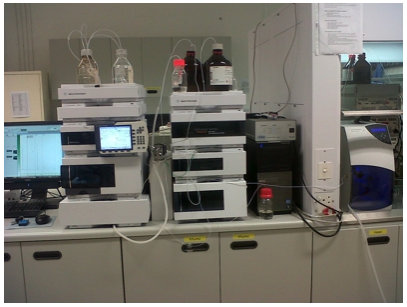
Thermal Analysis

DSC Q20
DSC Q100
TGA Q500



Other

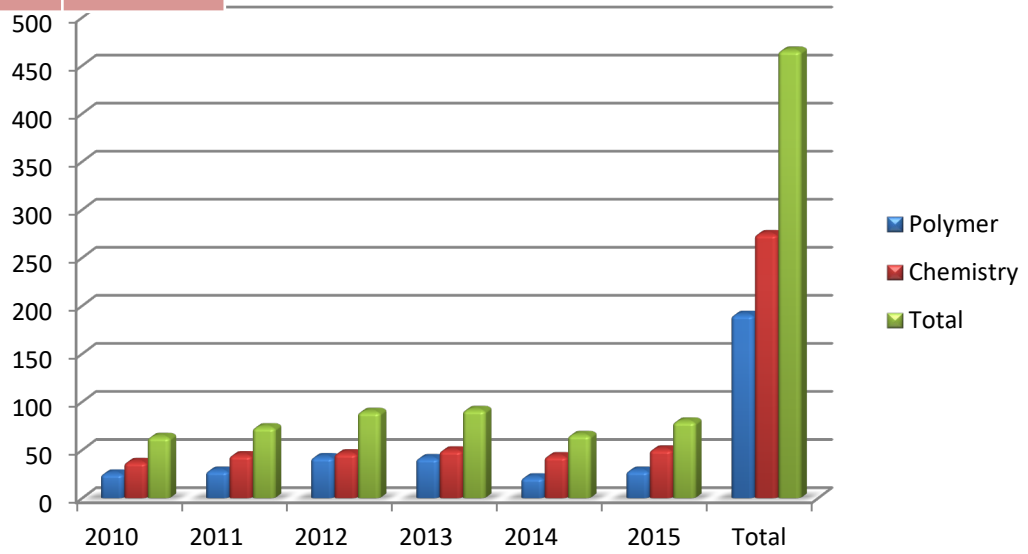
Leco Pegasus HRT GCxGC-MS
HPLC, 2D-LC, LC-MS
CRYSTAF
SEC, HT-GPC
FFF
FTIR, FTIR microscope
UV
PALS



Publication output 2010-2015

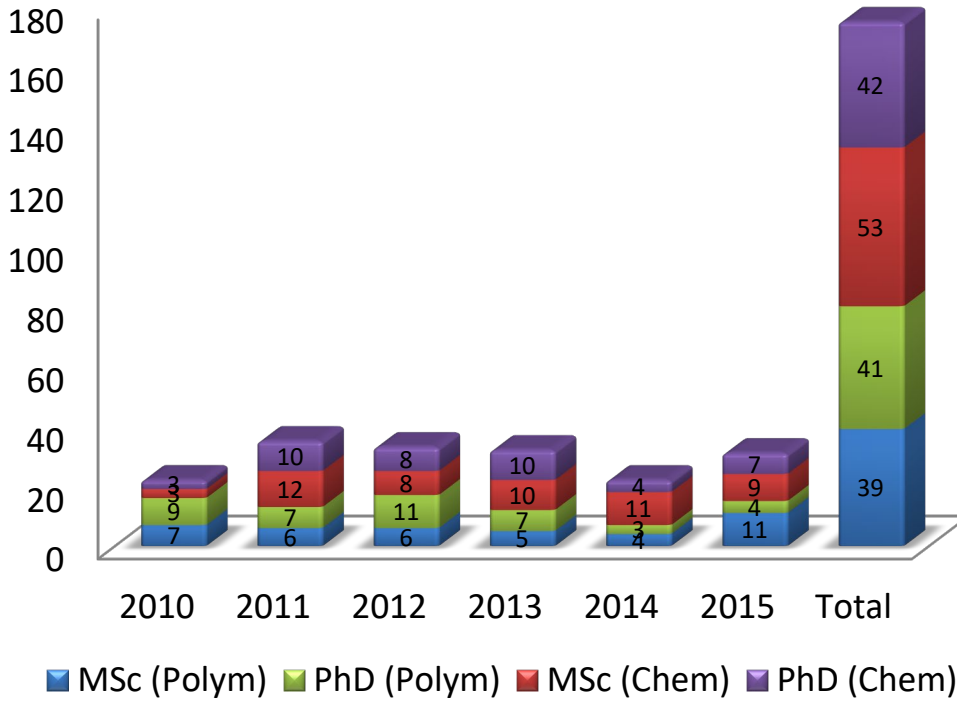
	Polymer Science	Chemistry	Total
2010	26	38	64
2011	29	45	74
2012	43	47	90
2013	42	50	92
2014	22	44	66
2015	29	51	80
Total	**191**	**275**	**466**

47% of publications are in the top 20% of journals in their field



Postgraduate degrees 2010-2015

	Polymer Science		Chemistry		Total	
	MSc	PhD	MSc	PhD	MSc	PhD
2010	7	9	3	3	10	12
2011	6	7	12	10	18	17
2012	6	11	8	8	14	19
2013	5	7	10	10	15	17
2014	4	3	11	4	15	7
2015	11	4	9	7	20	11
Total	**39**	**41**	**53**	**42**	**92**	**83**



Postgraduates students 2019:

	MSc	PhD	Hons
Chemistry	19	45	6
Polymer Science	20	20	7
Total	**39**	**65**	**13**

International research collaborations

Broad research strengths

- **Synthetic methodology** aimed at creating useful new compounds and materials (catalysts, polymers and supramolecular networks, with application potential in gas separation and storage, membranes and biologically active compounds)

- **Separation technology** and advanced analysis (NMR spectroscopy, electro-analysis, chromatographic separations, atomic force microscopy, diffraction techniques, MS, ICP, CRYSTAF, GPC, etc.)

- **Chemical structural modelling,** employing force fields and quantum mechanics.

Analytical Chemistry

Inorganic Chemistry

Chemical Biology

Physical Chemistry

Organic Chemistry

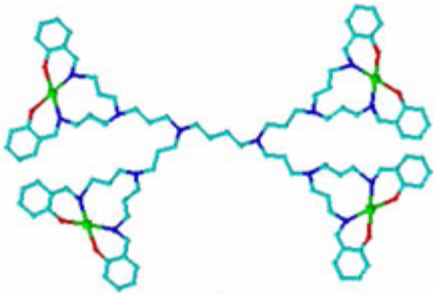
Polymer Science

Supramolecular Chemistry

Inorganic & Physical Chemistry

Selwyn Mapolie

Synthetic Organometallic Chemistry, Homogeneous Catalysis, Dendrimer Chemistry, Polymer Chemistry.



G2 Ni salicylaldimine complex

Robbie Luckay

Bulk liquid membranes, Transport, Extraction, Macrocycles, Stability Constants

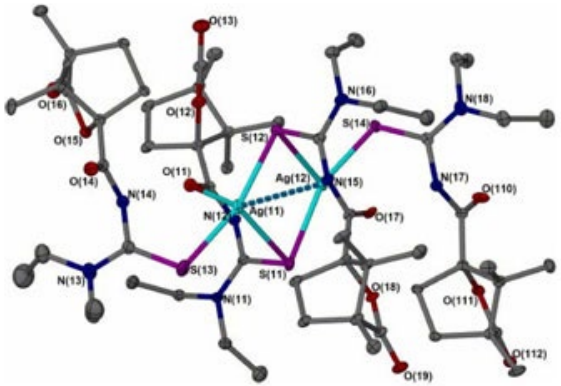
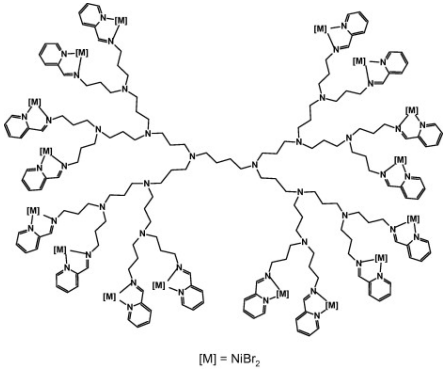


Fig. Ag(I) complex with camphanyl thiourea ligand.

Rehana Malgus-Enus

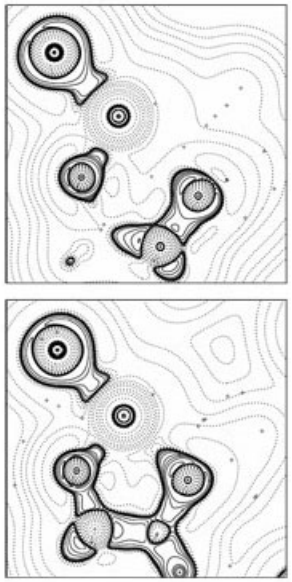
Inorganic Synthesis, nano-catalysis, homo-heterogeneous catalysis



[M] = $NiBr_2$

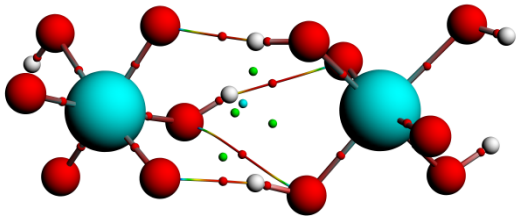
Jan Dillen

Structural chemistry, computational chemistry, molecular modelling, quantum mechanics, force fields, crystallography



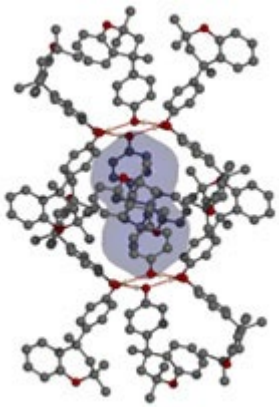
Willem Gerber

Kinetics, Thermodynamics and Quantum mechanics mechanistic studies of Inorganic redox reactions



Catharine Esterhuysen

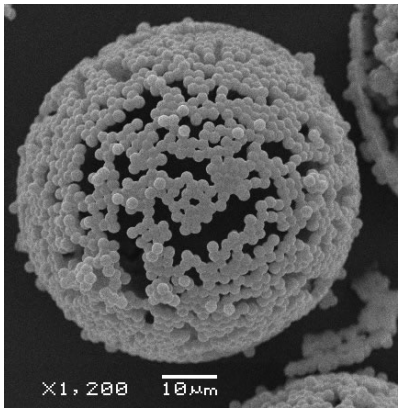
Structural chemistry, Computational Chemistry, Crystallography



Polymer, Organic & Medicinal Chemistry

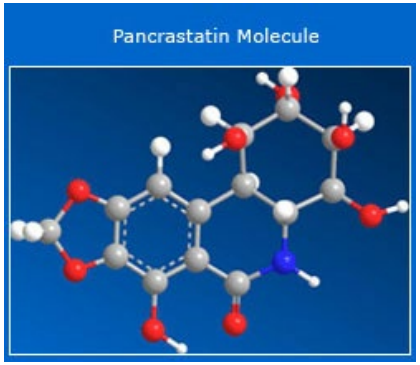
Bert Klumperman

Living Radical Polymerization, Advanced Macromolecular Architectures, Nanomedicine



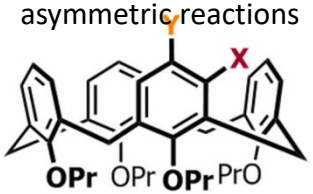
Willem van Otterlo

Organic synthesis, organometallic reagents, ring-closing metathesis, medicinal chemistry

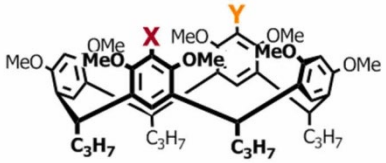


Gareth Arnott

Organic synthesis and methodology, calixarenes, resorcinarenes, new transition metal ligands, asymmetric reactions



An upper-rim inherently chiral calix[4]arene



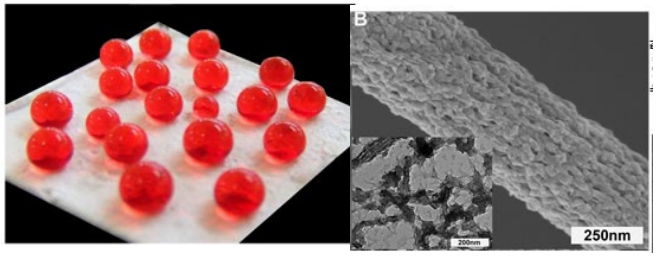
A bidentate resorcinarene ligand

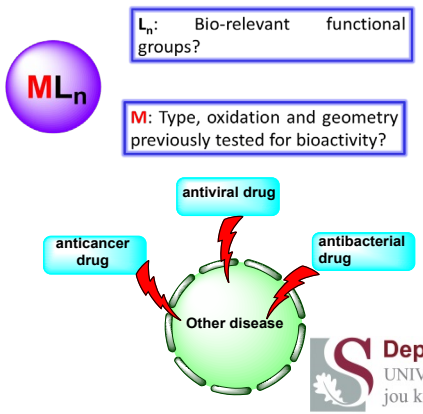
Prinessa Chellan

Organometallic Medicinal Chemistry, Synthesis, Infectious Diseases, Drug Design, Bioinorganic Chemical Biology

Peter Mallon

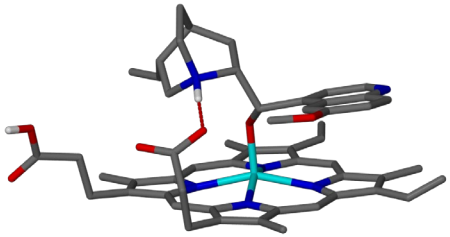
Polymer analysis, polymer structure property relationships and polymer hybrid materials, polymer nanocomposites and nanofibres





Katherine de Villiers

Bioinorganic/biophysical chemistry to elucidate structure-activity relationships for antimalarials



Supramolecular & Analytical Chemistry

Harald Pasch

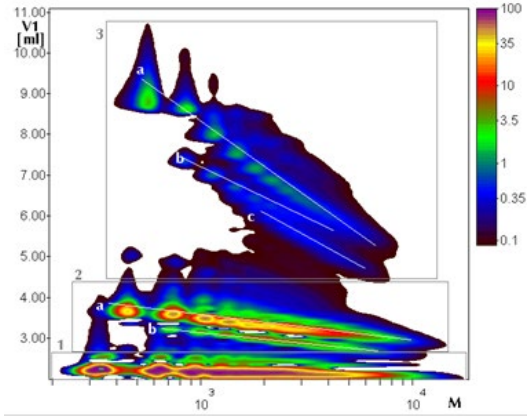
Novel multidimensional techniques for polymer characterization; field flow fractionation; polyolefins, structure-property relationships

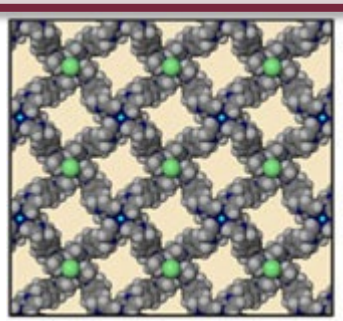
Len Barbour

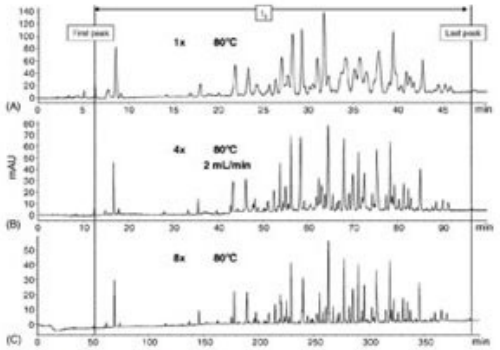
Physical, Inorganic, Organic, Materials, Solid-state, Gas Storage, Crystal Engineering

André de Villiers

Liquid chromatography, Gas chromatography, Wine chemistry, Mass spectrometry, Electrophoresis

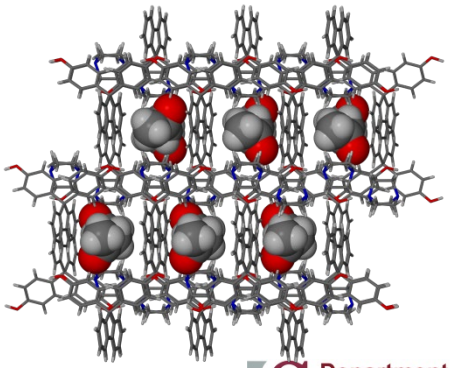


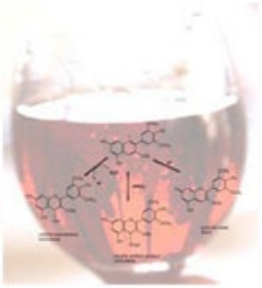




Tanya le Roex

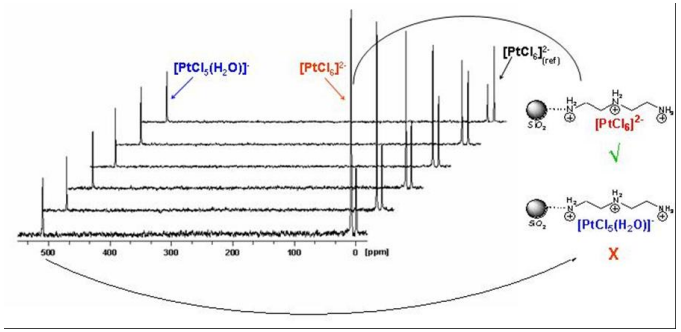
Supramolecular chemistry, crystal engineering, inclusion compounds, hydrogen-bonded organic frameworks





Klaus Koch

Platinum NMR, Acylaroylthiourea chemistry, PGM chemistry



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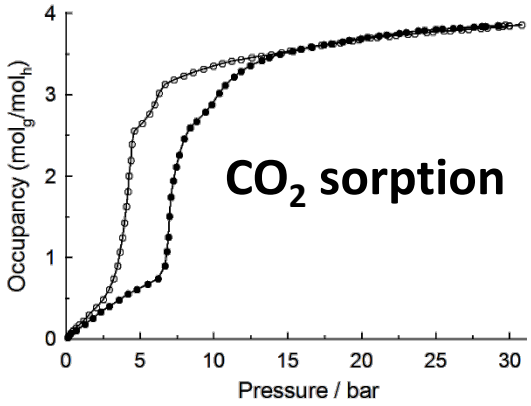
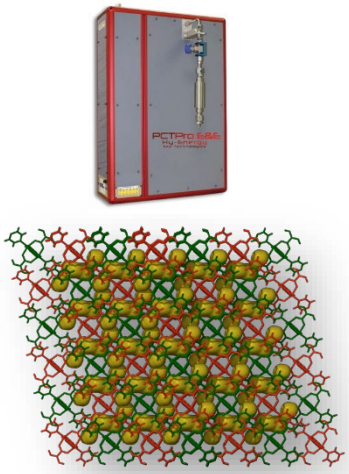
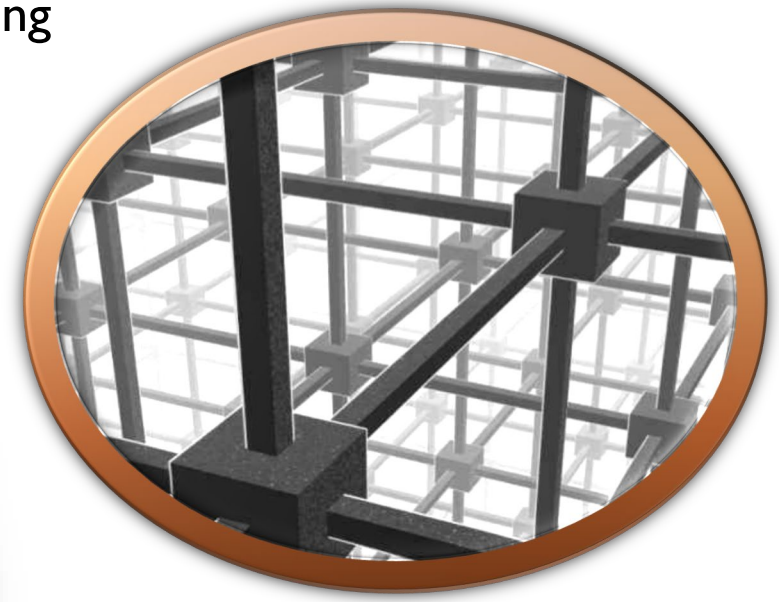
Len Barbour: Supramolecular Chemistry

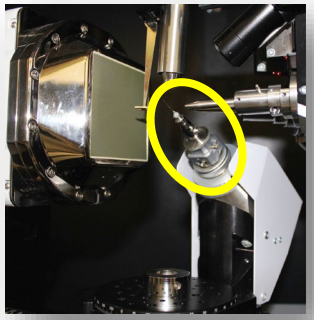
Study of structure-property relationships using supramolecular assemblies and MOFs



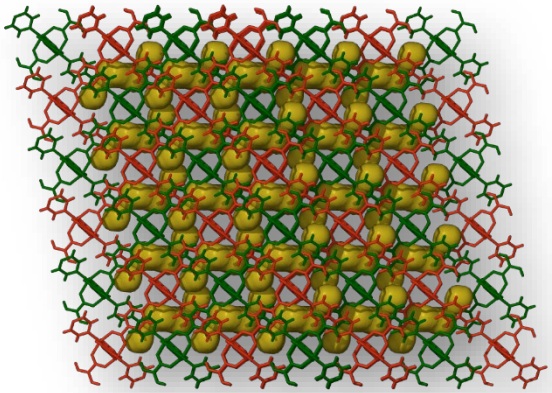


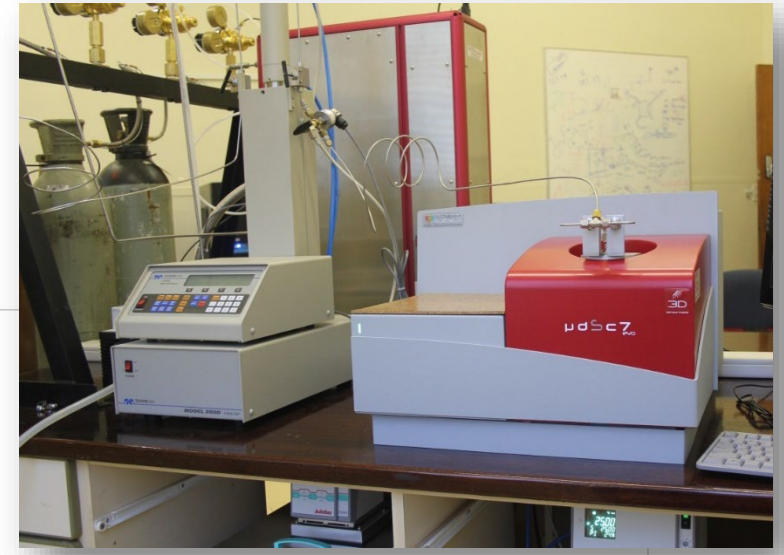


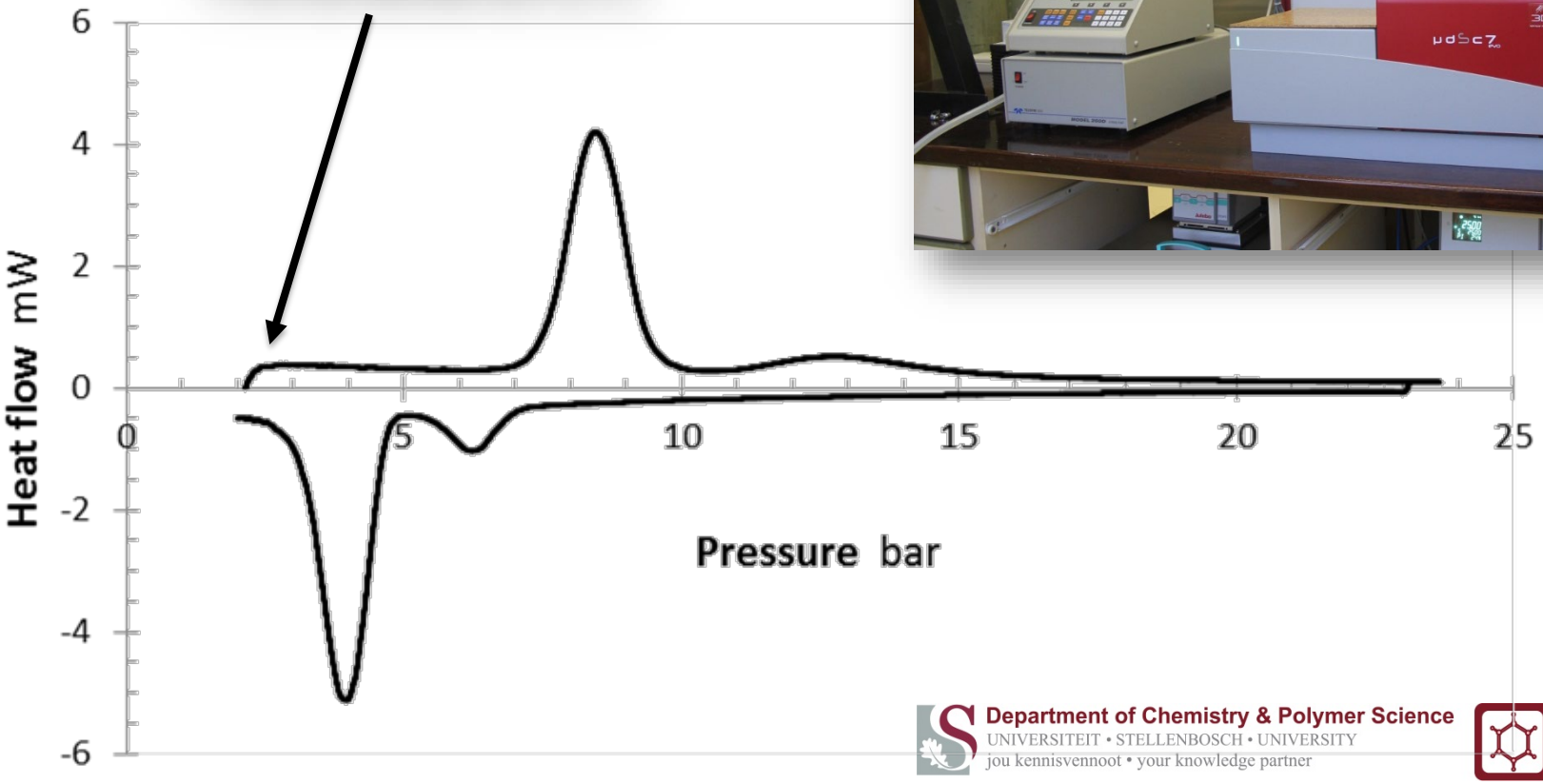
Study of the dynamic processes that occur in the porous solid state by developing and applying a range of complementary *in-situ* analytical methods.



Pressure-ramped DSC

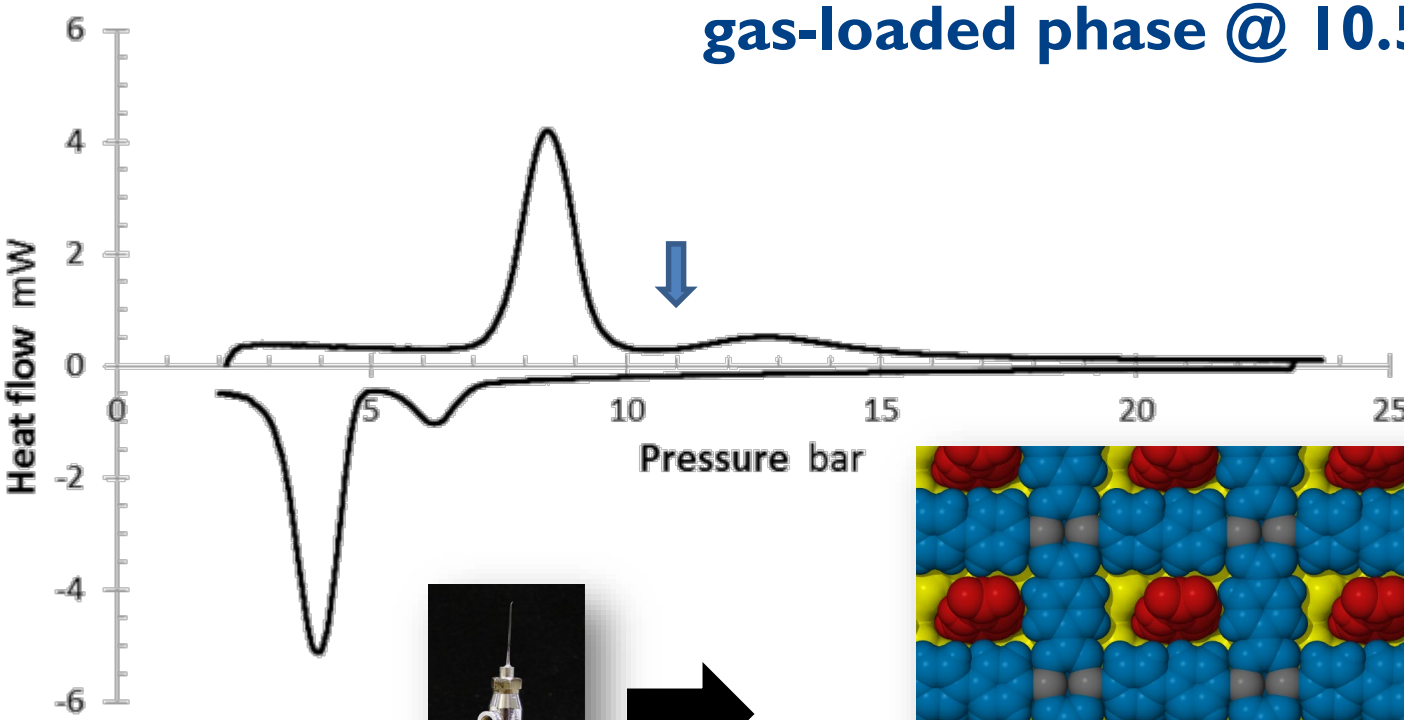


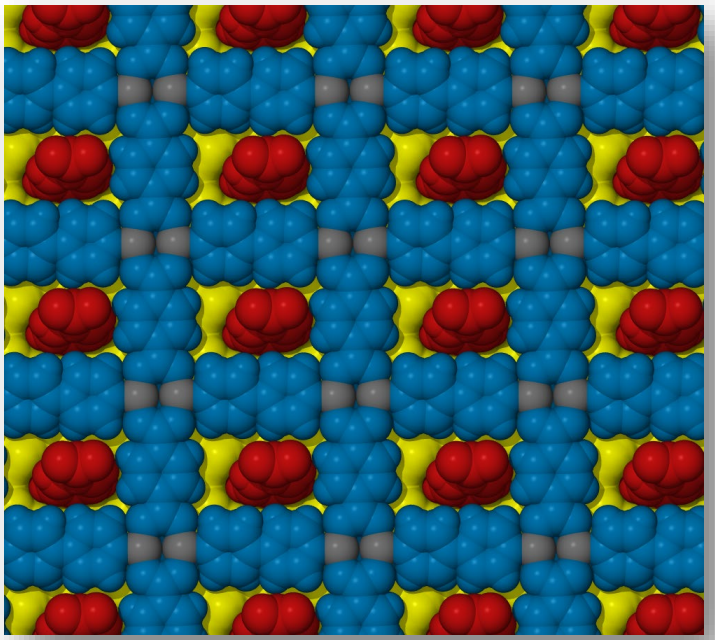




Pressure-ramped DSC

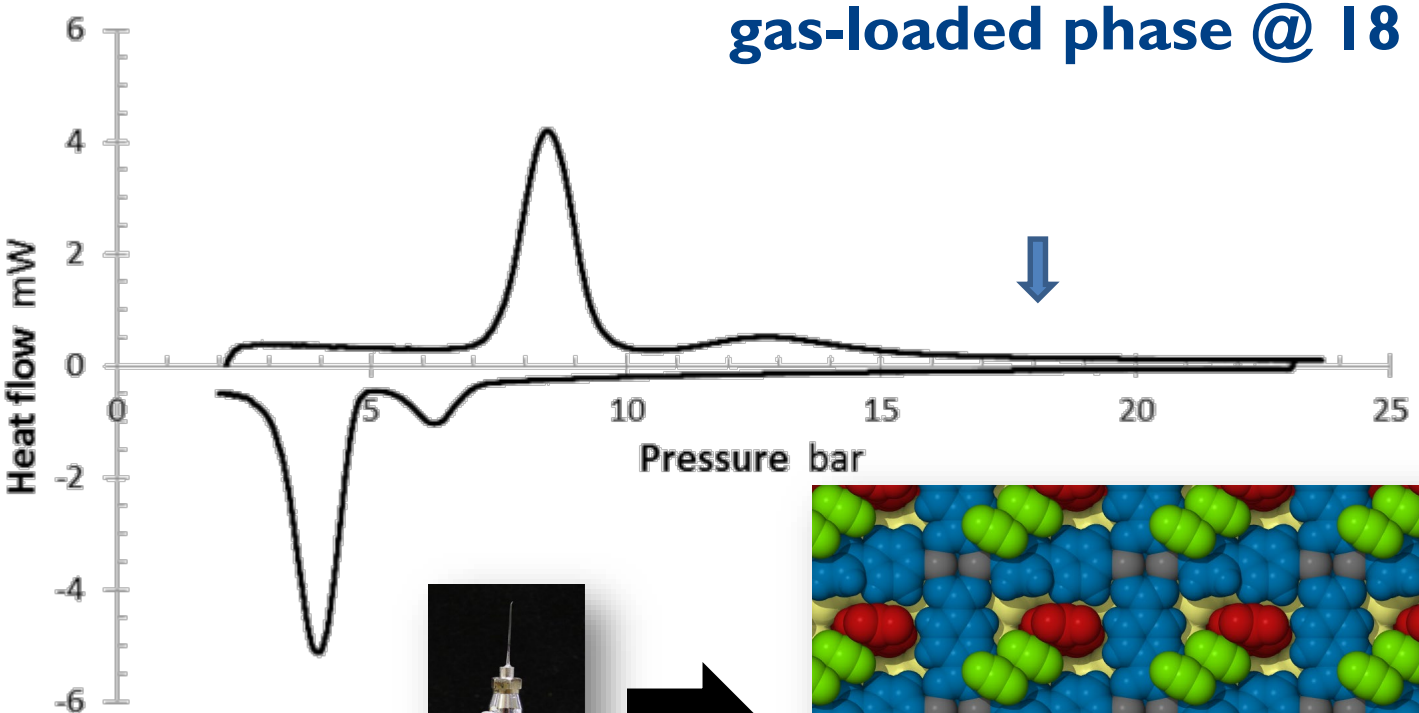
gas-loaded phase @ 10.5 bar

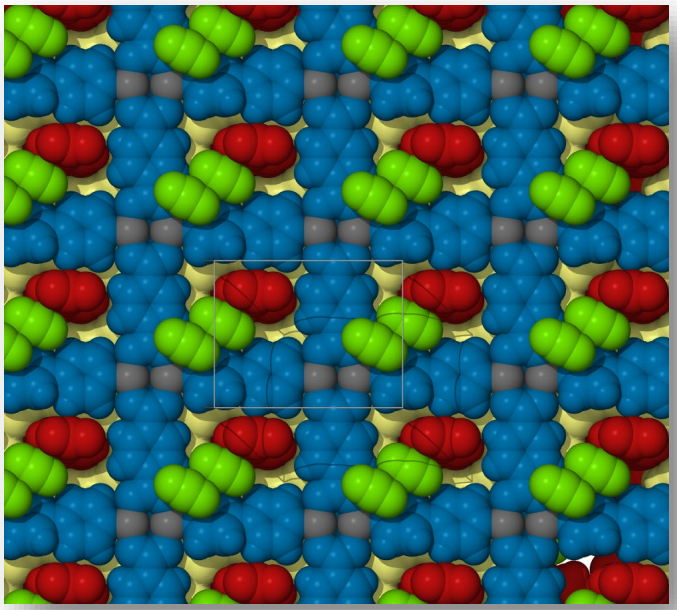




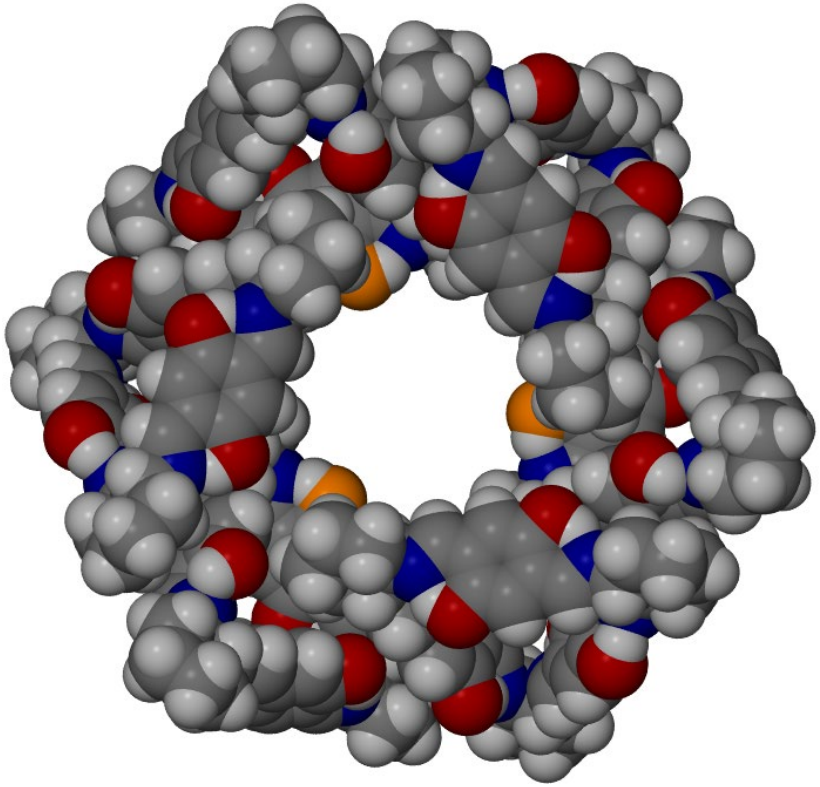
Pressure-ramped DSC

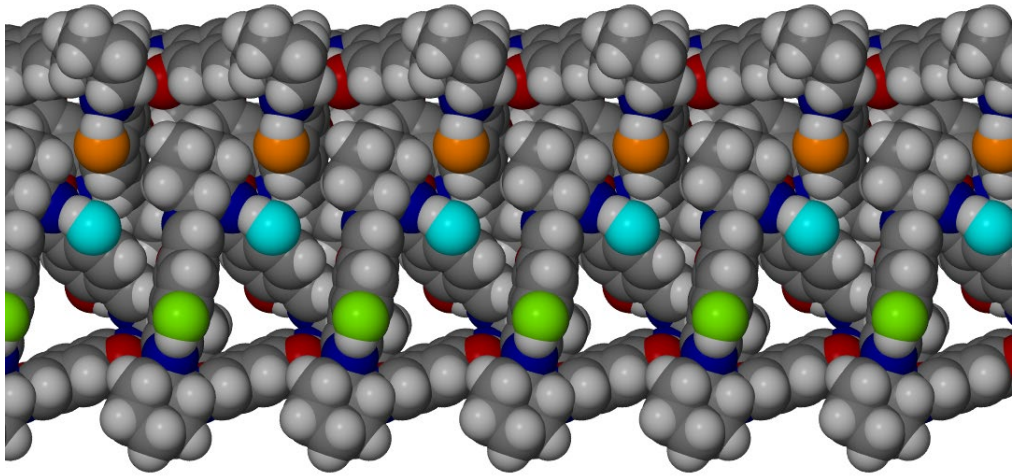
gas-loaded phase @ 18 bar

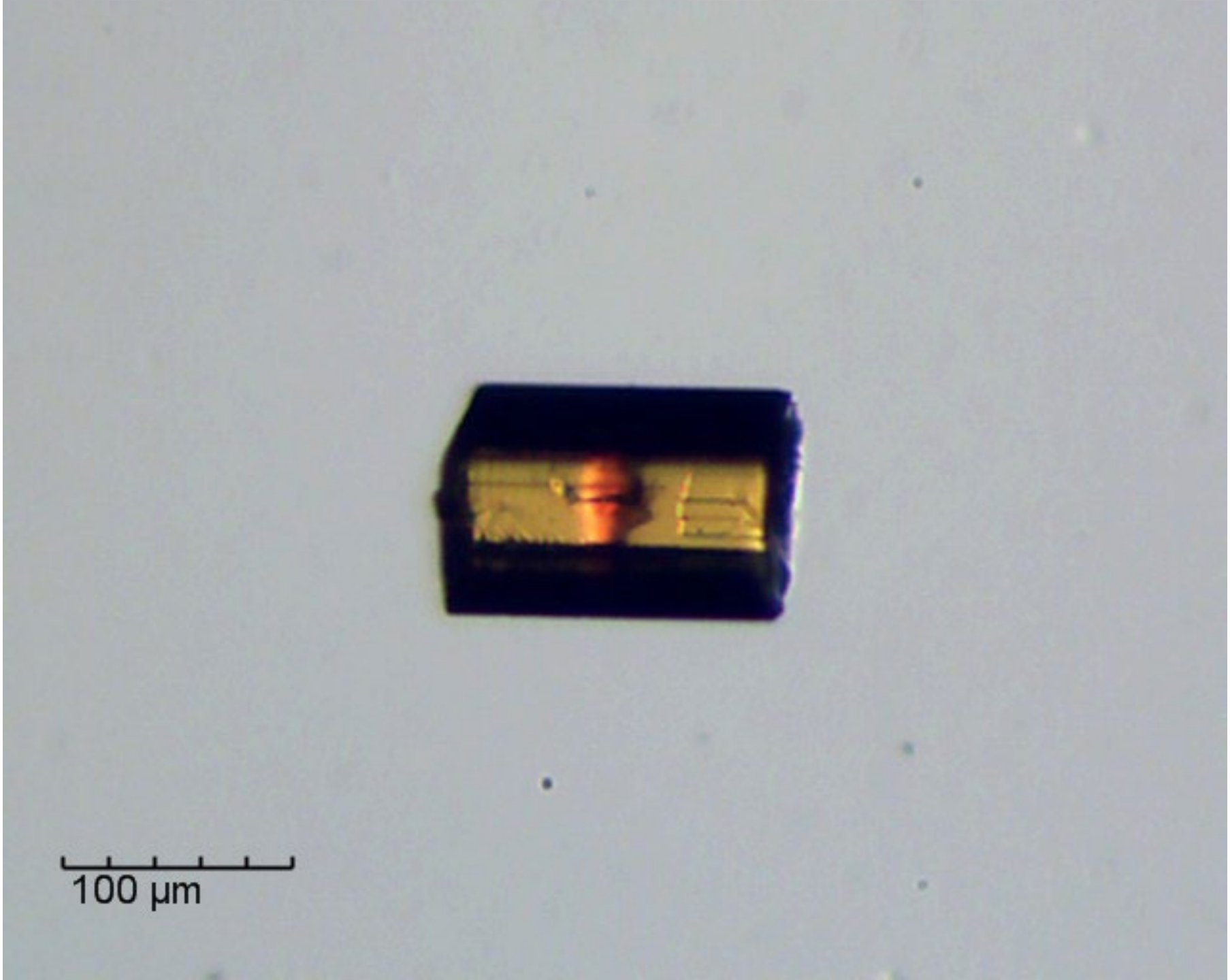




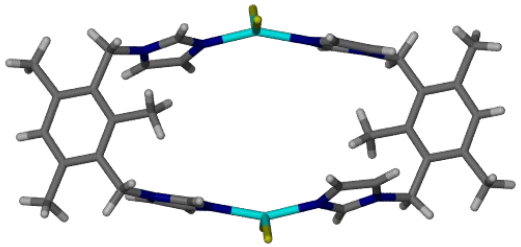
An organic humidity indicator

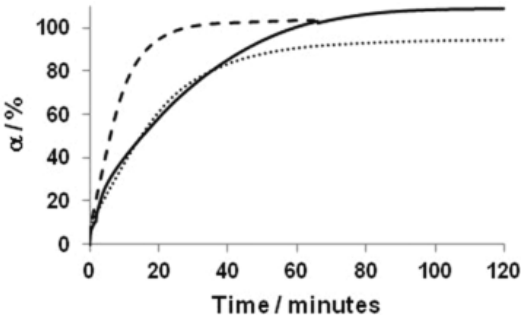




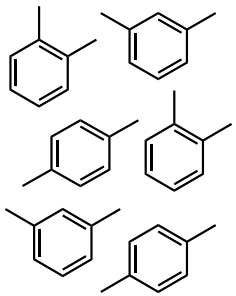

100 µm

Xylene separation

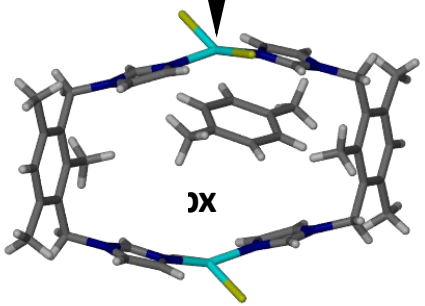


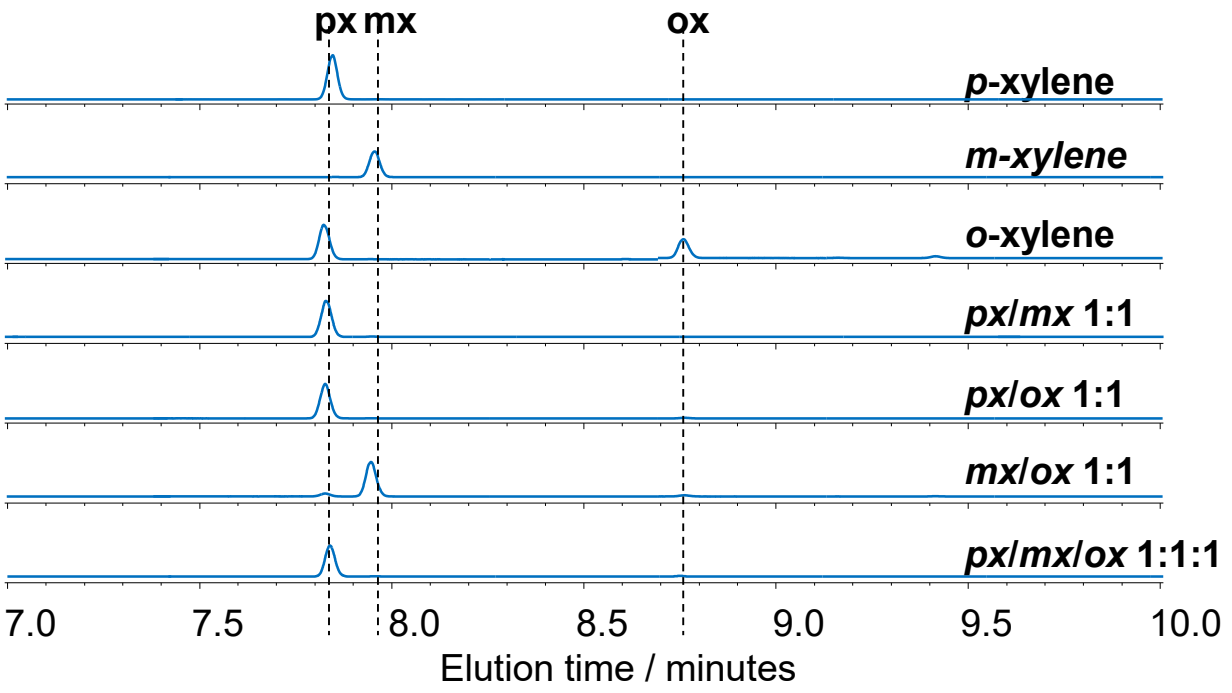


Sorption at 22 °C showing extent of reaction α as a function of time for the uptake of — o-xylene, - - - - m-xylene, •••• p-xylene).

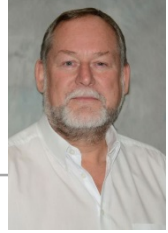


mixed
xylene isomers





Polymer analysis



Compositions

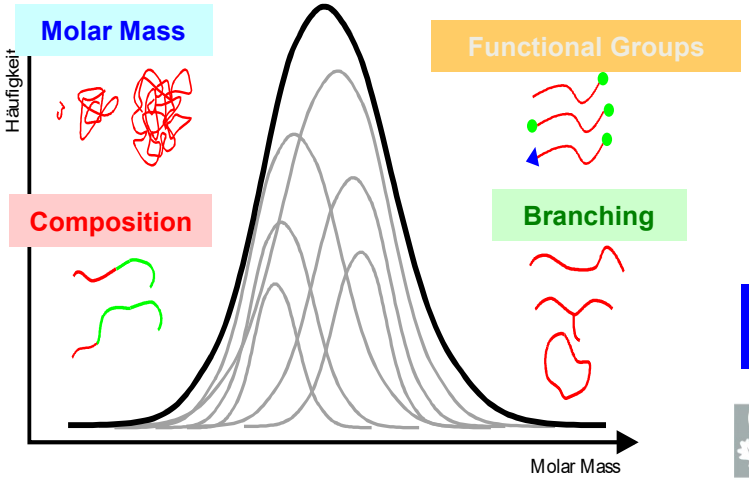
Homopolymers | Block Copolymers | Statistical Copolymers | Gradient Copolymers | Graft Copolymers

Architecture

Linear | Star / Multi - Armed | Comb Polymers | Networks | (Hyper)Branched

Functionality

X(Y)~~~X Homo/Hetero Telechelic | ~~~(X) Macromonomers | Star / Multi - Armed | Side Functional Groups | Hyperbranched / Multifunctional

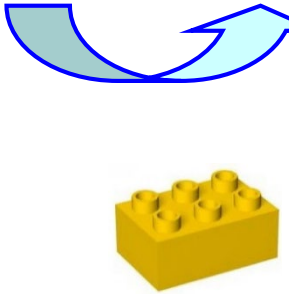


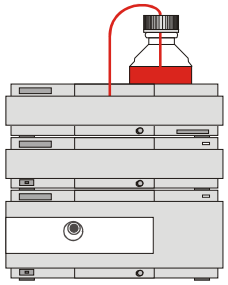
Mechanical strength
Thermal stability
Processability
Surface properties
Biocompatibility ….

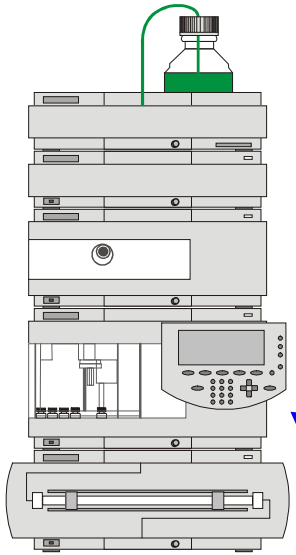
Structure-property correlations

Polymer analysis: Harald Pasch

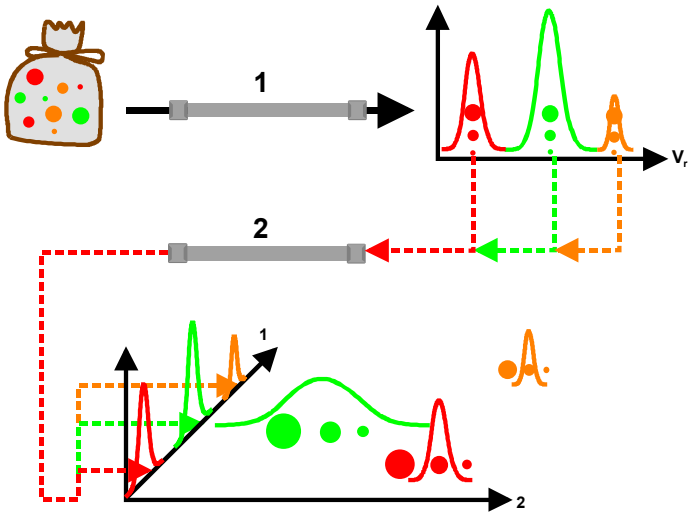
The LEGO Approach in Advanced Polymer Analysis

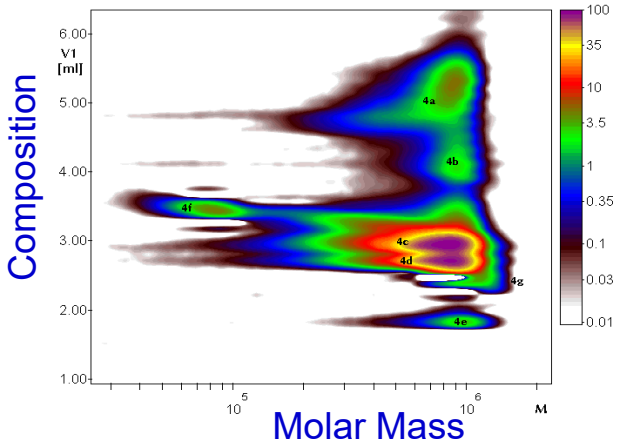






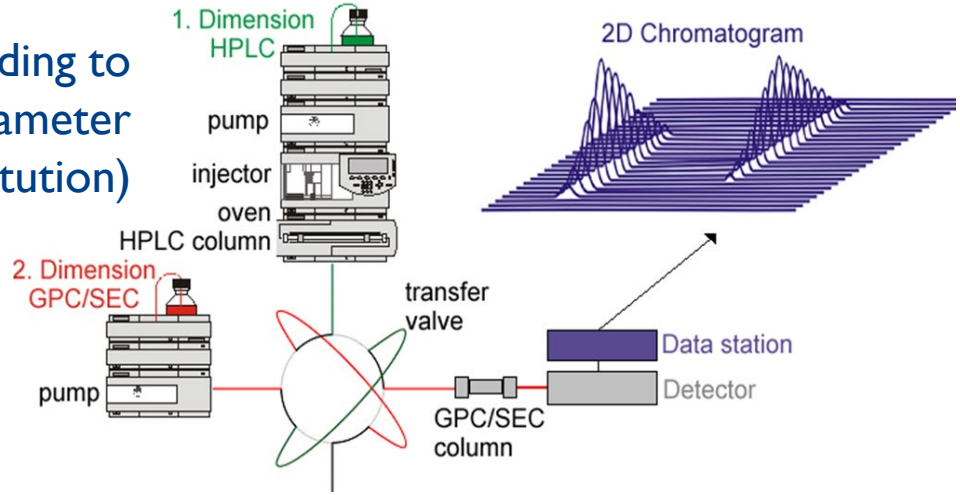
The LEGO Approach: Coupled techniques





Separation according to one structural parameter (degree of substitution)

Fractions subjected to another separation with respect to a different structural feature (molecular size)



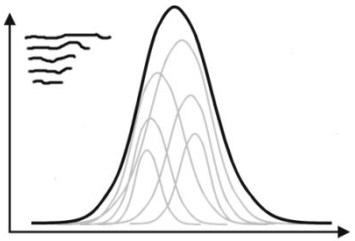
Analytical approach and suitable techniques

1. Suitable solvent/solvent system

1B. Bulk analysis of samples

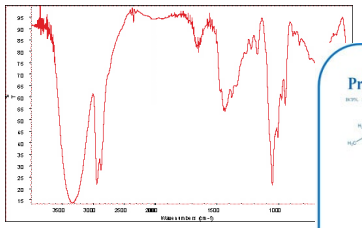
2. SEC

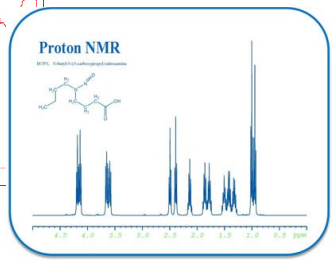
Chain length



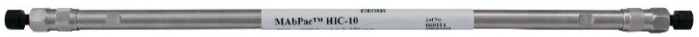
Molar mass

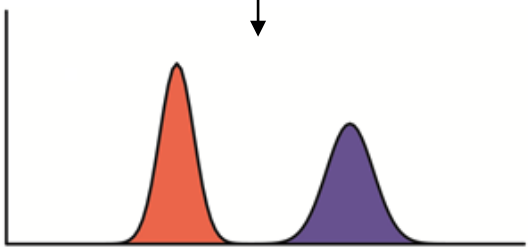
Information on chemical structure:





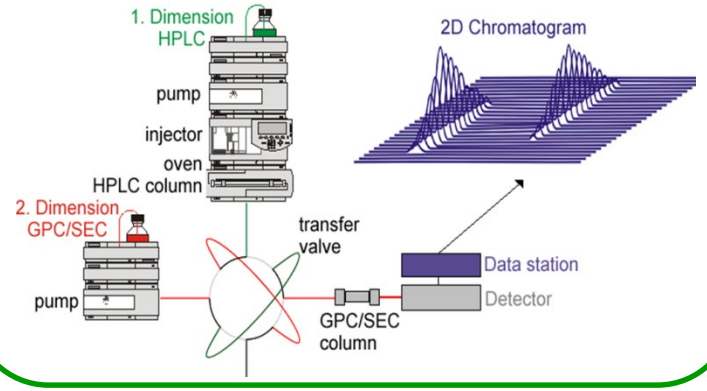
3. HPLC





Chemical composition

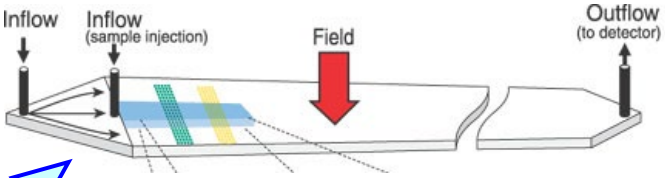
4. 2D-LC



The LEGO Approach in Field-Flow Fractionation

ICP-MS

NMR



AF4

SdFFF

ThFFF

FTIR

DLS

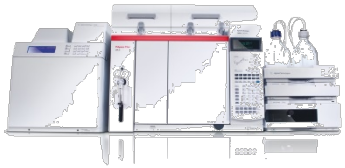
The LEGO Approach in Polyolefin Analysis

Molar mass
Molar mass dispersity

HT-SEC

Chromatography- based

Crystallization-based



HT-HPLC
HT-2D-LC

DSC, SSA

Branch types
Degree of branching

NMR

FTIR

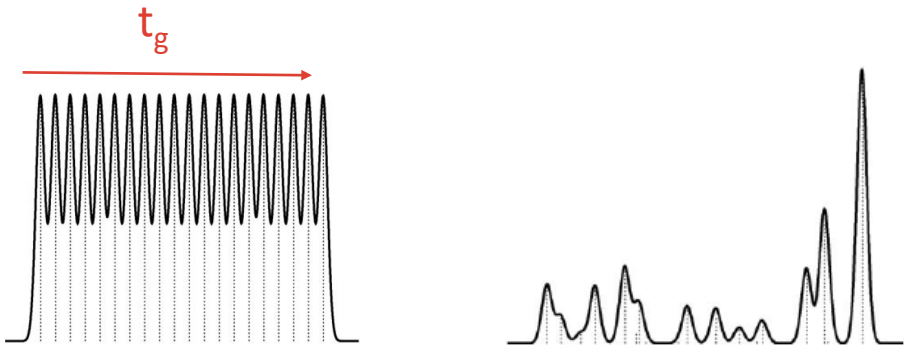
CRYSTAF, SCALLS, TREF

The limitations of chromatography

Limitations of 1-dimensional chromatography

Peak capacity (n_c): Number of compounds that can *theoretically* be separated.

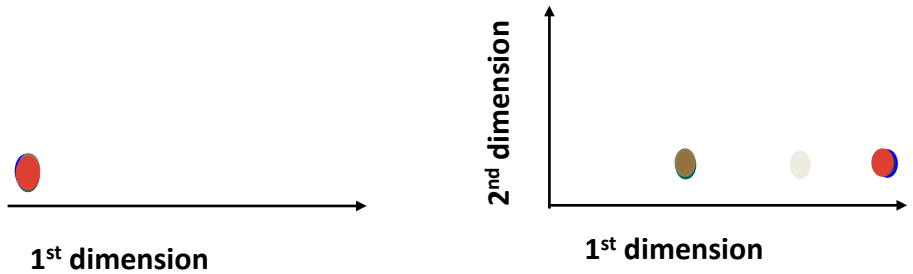
$$n_{c,1D} = 1 + \frac{t_g}{\frac{1}{n}\sum_1^n w_b}$$



A. Felinger, Data Analysis and Signal Processing in Chromatography, Elsevier, 1998

To resolve 98% of *n* randomly distributed components, n_c should be $n \times 100$

G(L)C×G(L)C: For *comprehensive* combination of orthogonal separations, $\boldsymbol{n_{c,2D}}$ is multiplicative

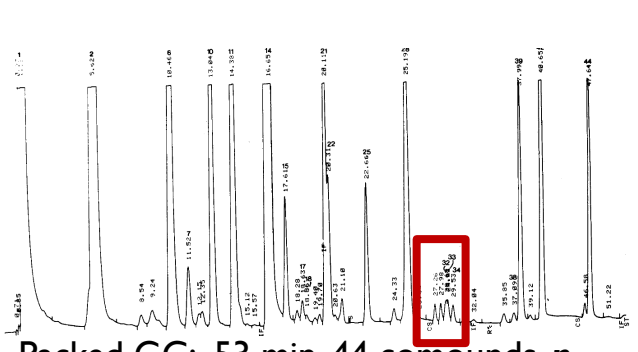


$$n_{c,2D} = {}^1n_c \times {}^2n_c$$

Karger, Snyder and Horvath, An Introduction to Separation Science, **1973**

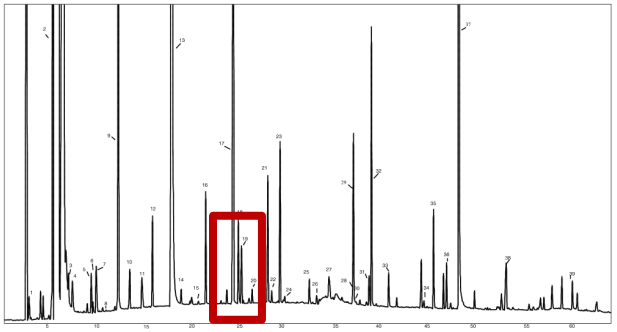
The challenges of complex sample analysis

Analysis of wine volatiles by GC



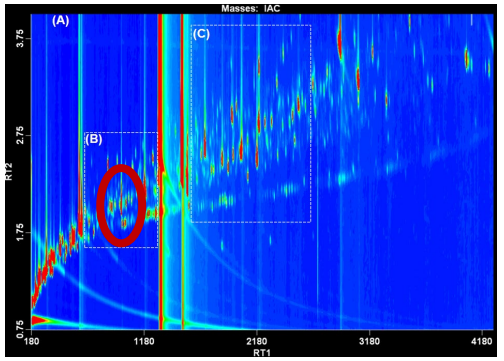
Packed GC: 53 min, 44 comounds, n_c ~ 92

Marais et al., S.Afr. J. Enol.Vitic. 2 **1981** 19



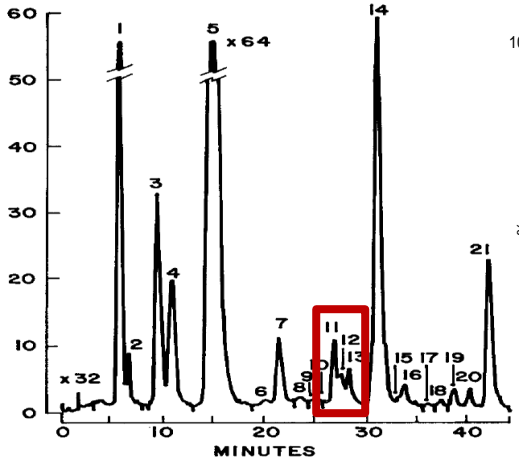
Capillary GC: 65 min, 37 compounds, n_c ~ 300

Ortega et al., J. Chromatogr.A 923 **2001** 205



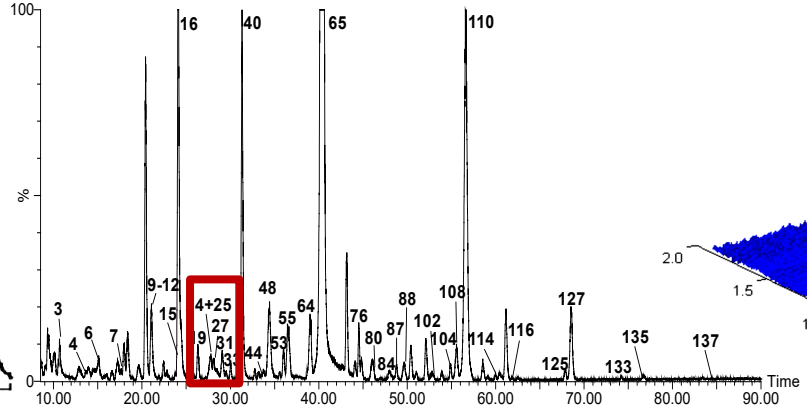
GC×GC: 84 min, 276 compounds, n_c ~ 6500

Weldegergis et al., Anal. Chim. Acta 701 **2011** 98



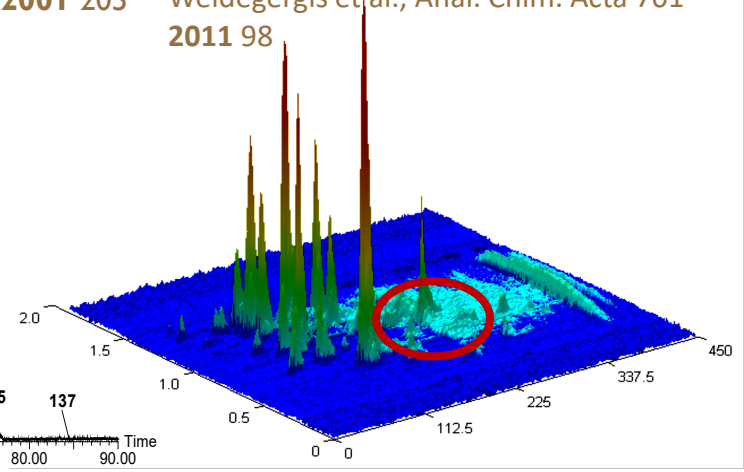
HPLC: 45 min, 21 compounds, n_c ~ 45

Wulf et al, Am. J. Enol.Vitic. 29 **1978** 42



UHPLC: 1.7 mm, 90 min, 101 compounds n_c ~ 290

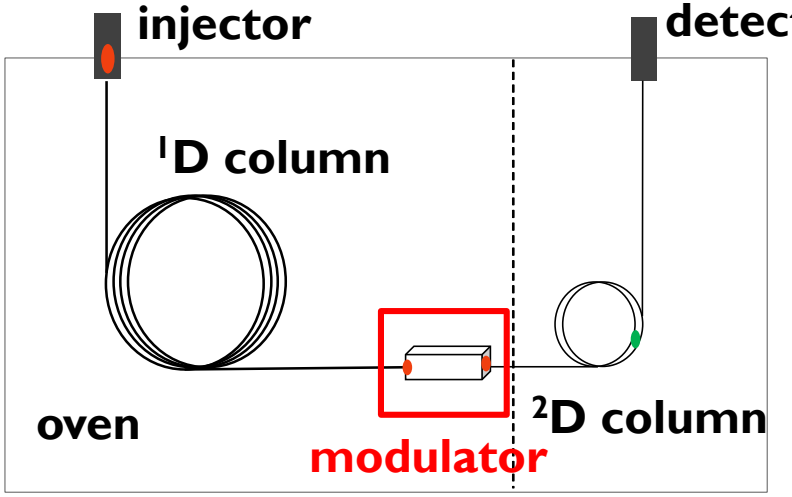
de Villiers et al, J. Chromatogr.A 1218 **2011** 4660



HILICxRP-LC: 450 min, 94 compounds, n_c ~ 900

Willemse et al, Anal. Chem. 87 **2015** 12006

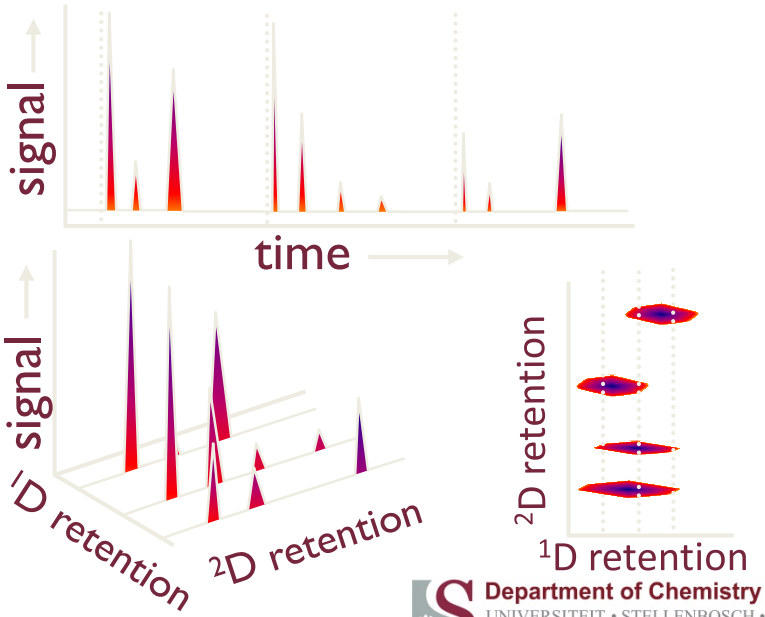
GC×GC: Principles and instrumentation



^{1}D column: conventional
^{2}D column: short, high speed
Modulation: 2-10 seconds
Detection: > 100 Hz (FID, TOF-MS)

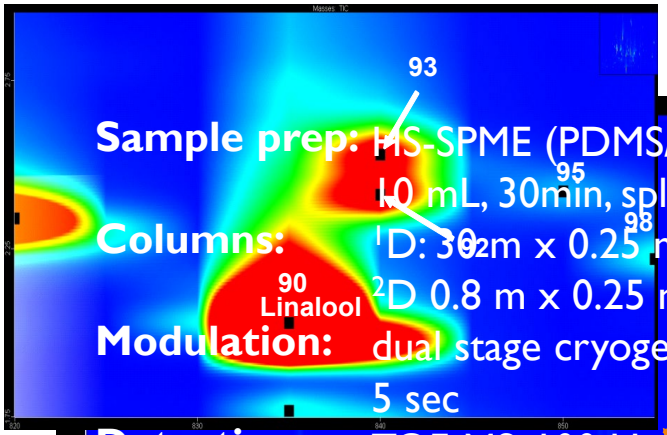
Orthogonal separations obtained using apolar and (mid)-polar columns

Data representation



Animation courtesy of T. Gorecki

GC×GC-TOF-MS analysis of honeybush tea

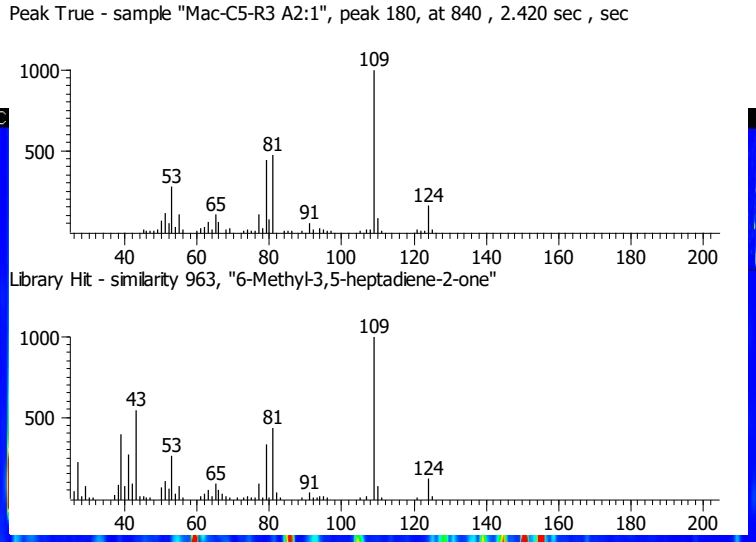


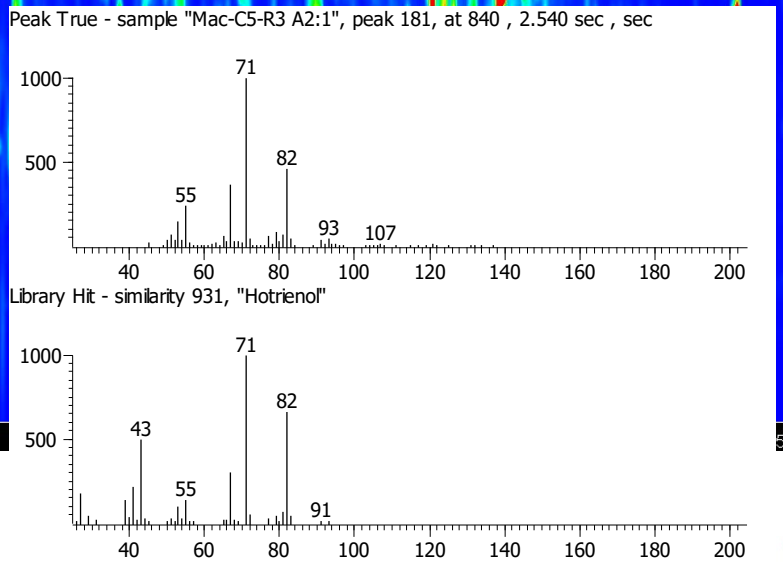
Sample prep: HS-SPME (PDMS/DVB), 10 mL, 30min, split inj.

Columns: ^{1}D: 30m x 0.25 mm Rxi
^{2}D 0.8 m x 0.25 mm Wax

Modulation: dual stage cryogenic (N_2) 5 sec

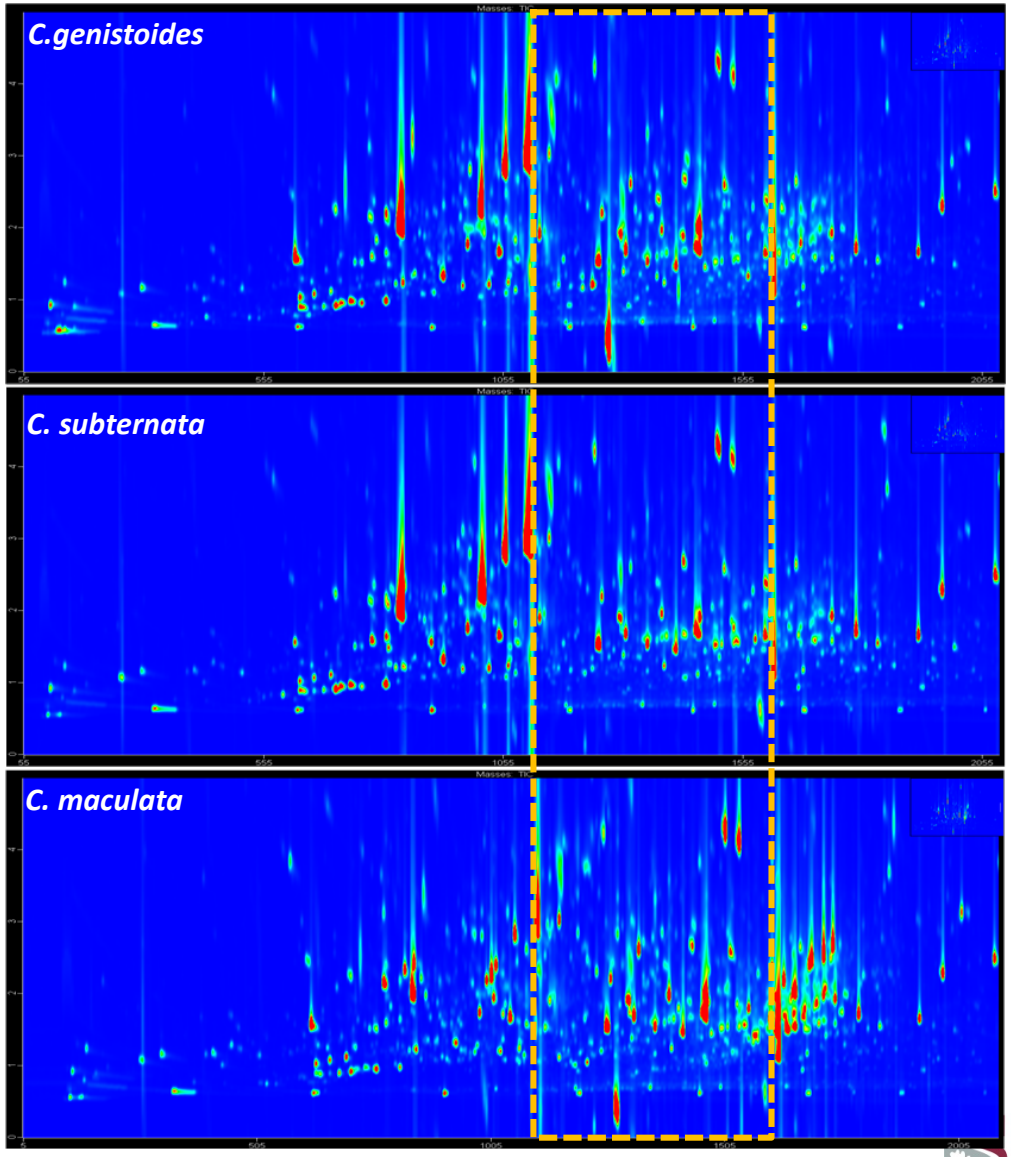
Detection: TOF-MS, 100 Hz





G. E. Ntlhokwe et al., J. Chromatogr. A 1536 **2018** 137

GC×GC-TOF-MS analysis of honeybush tea



232 compounds

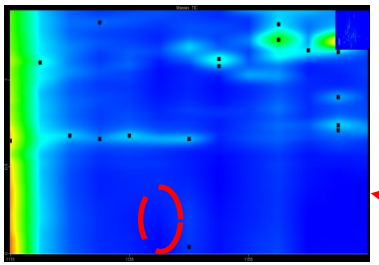
- Total of 274 identified
  - 161 new compounds

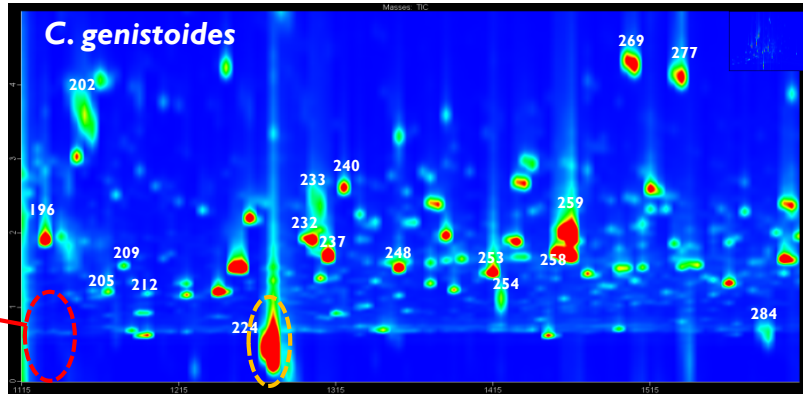
182 compounds

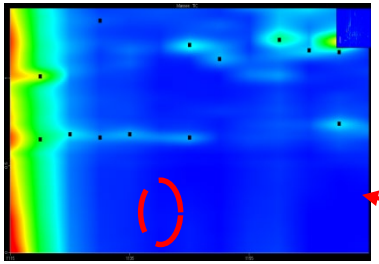
218 compounds

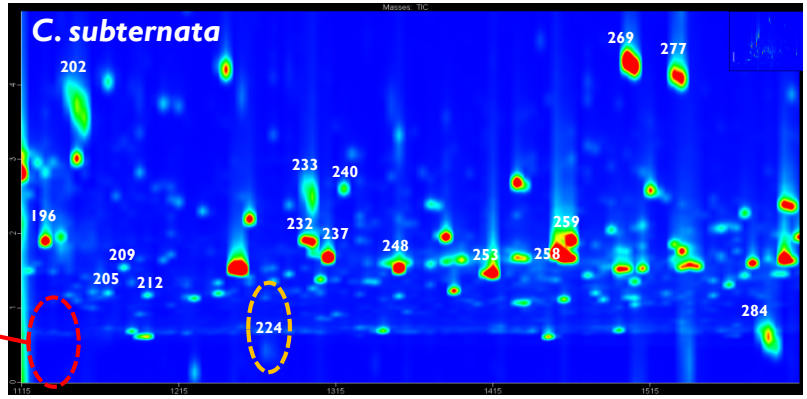
G. E. Ntlhokwe et al., J. Chromatogr. A 1536 **2018** 137

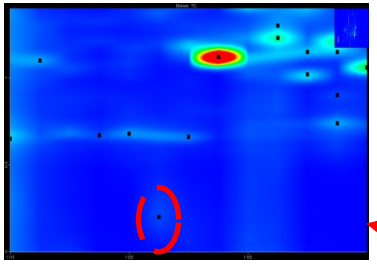
GC×GC-TOF-MS analysis of honeybush tea

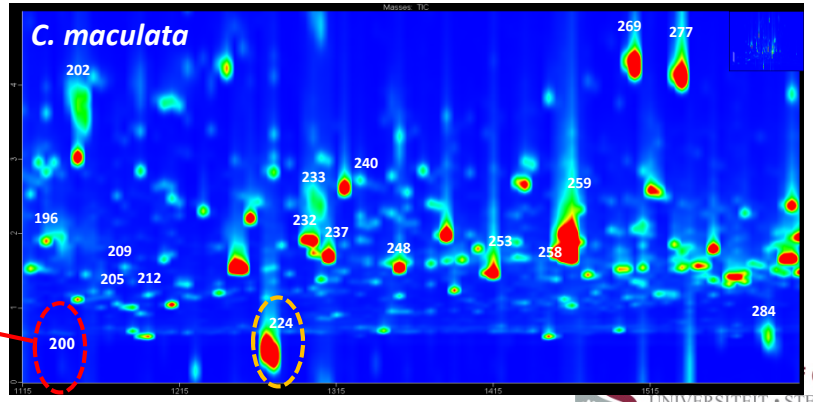


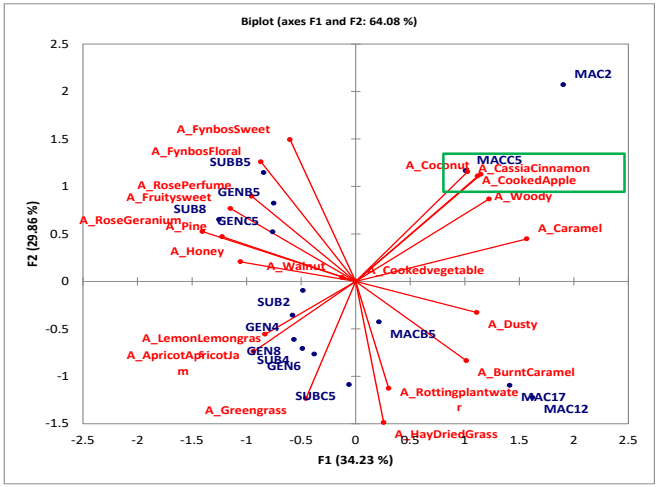




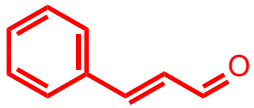








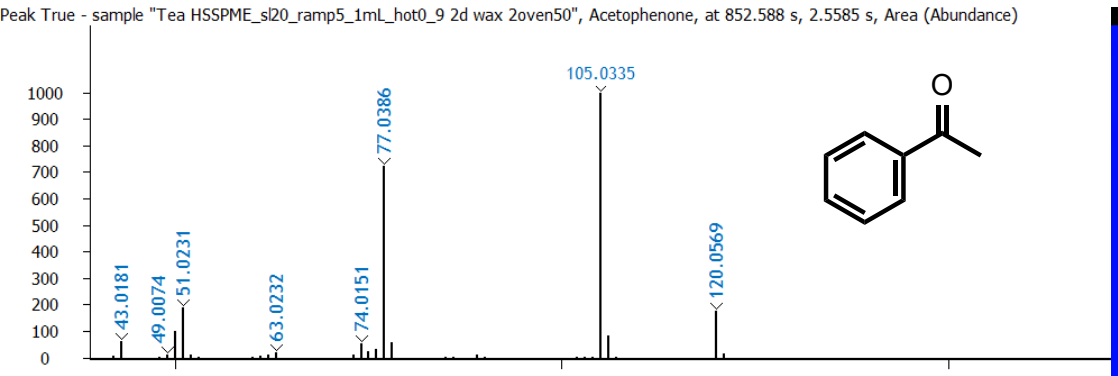
Likely responsible for the characteristic cassia/cinnamon aroma of this species

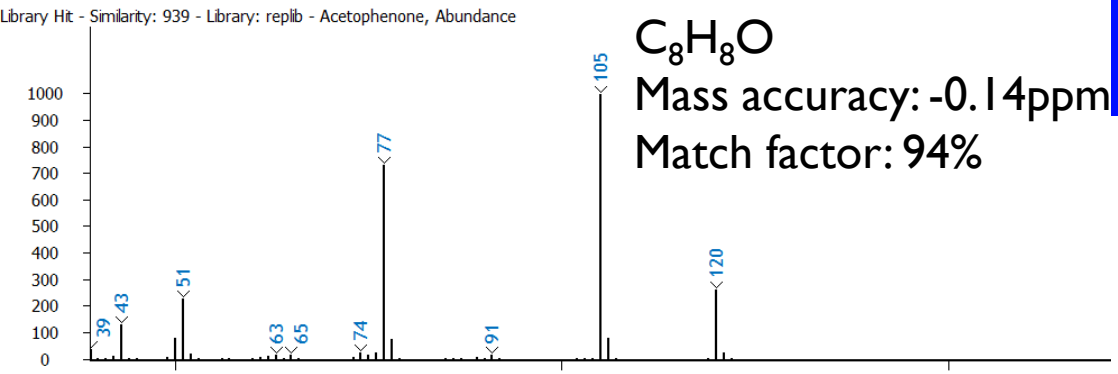


cinnamaldehyde uniquely detected in ***C. maculata*** - cassia cinnamon aroma.

G. E. Ntlhokwe et al., J. Chromatogr. A 1536 **2018** 137

GC×GC-high speed *high resolution* TOF-MS

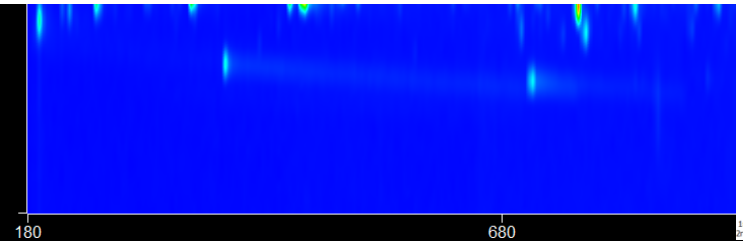


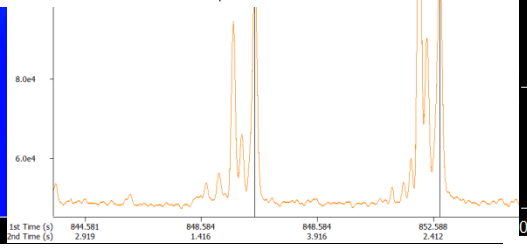


C_8H_8O

Mass accuracy: -0.14ppm

Match factor: 94%





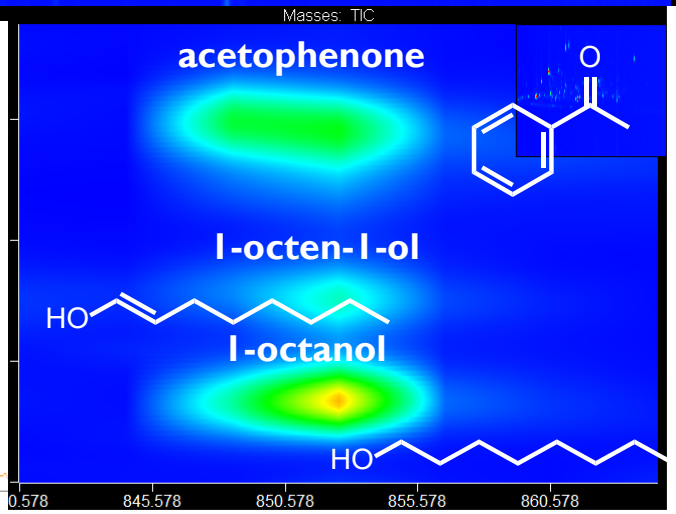
Sample prep: HS-SPME (PDMS/DVB), 10 mL, 30min, split inj.

Columns: ^{1}D: 30 m x 0.25 mm Rxi

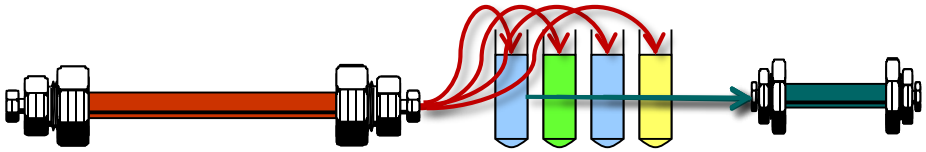
^{2}D 2 m x 0.25 mm Wax

Modulation: dual stage cryogenic (N_2) 4 sec

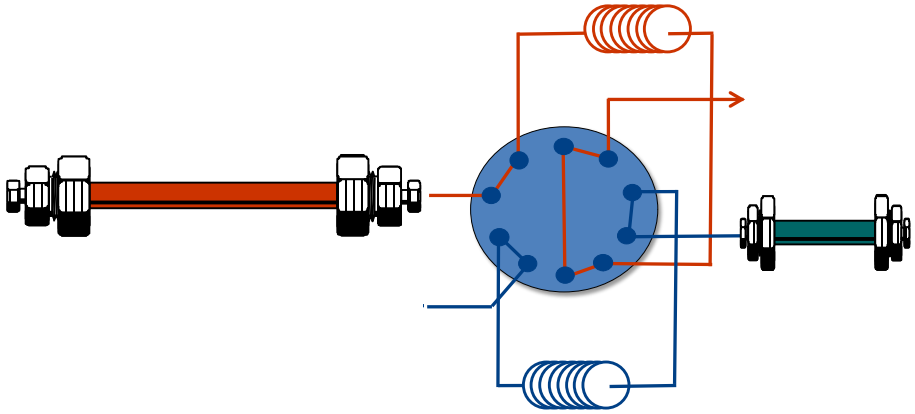
Detection: TOF-MS, 120 Hz



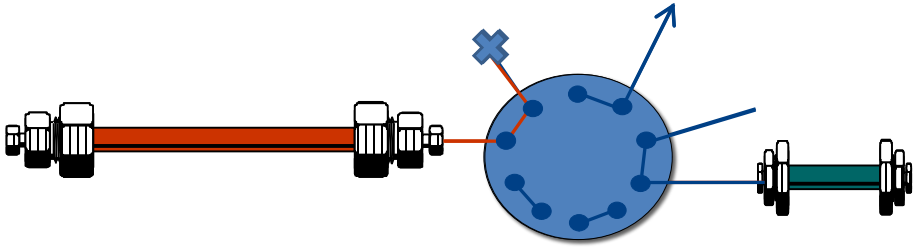
LC×LC: Principles and instrumentation



Two dimensions operated independently

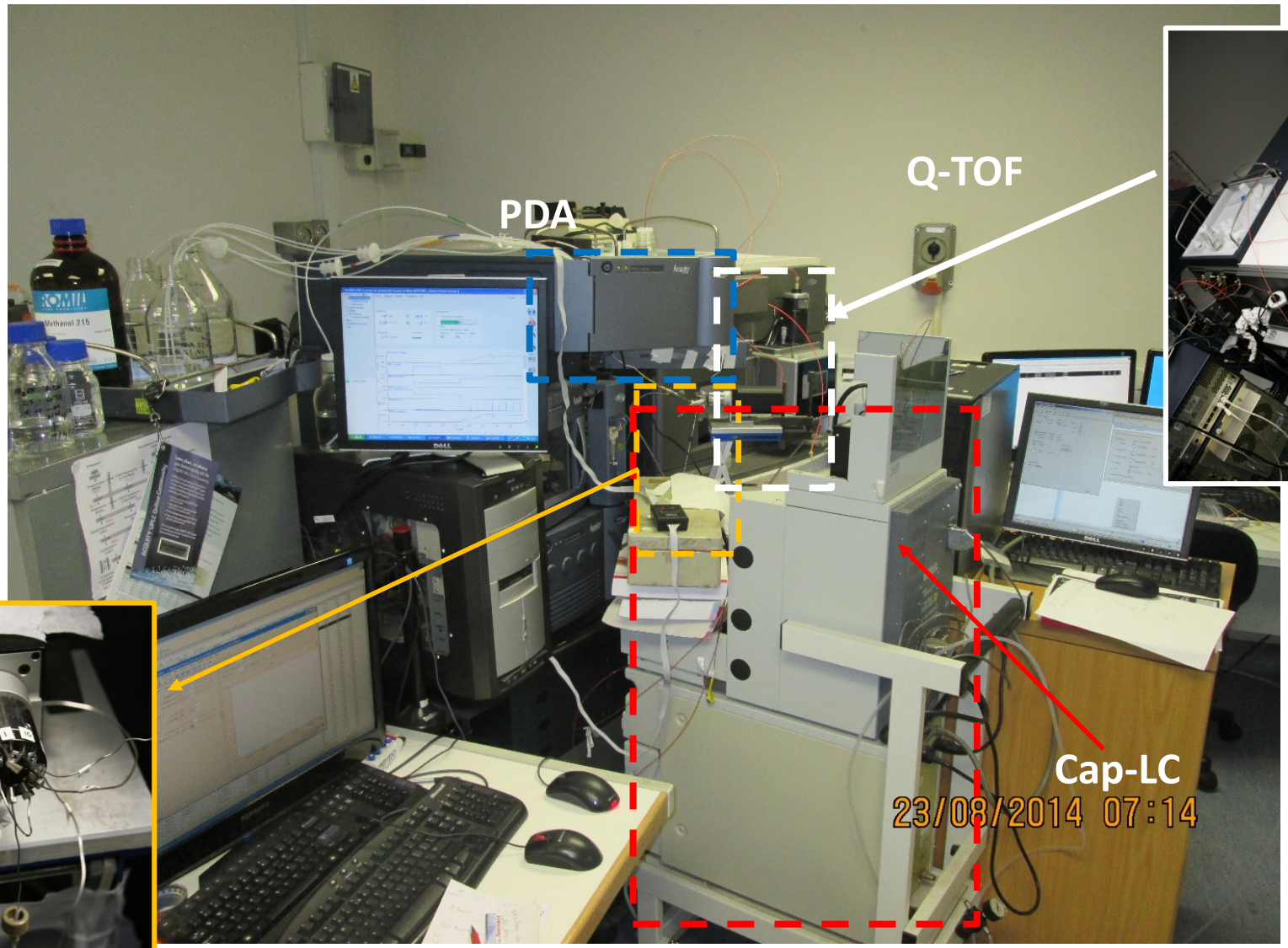


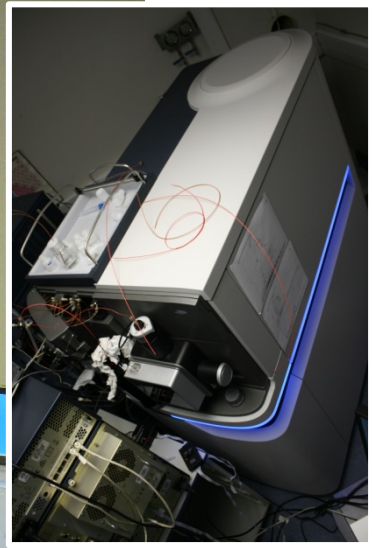
Second dimension separation completed during fraction collection

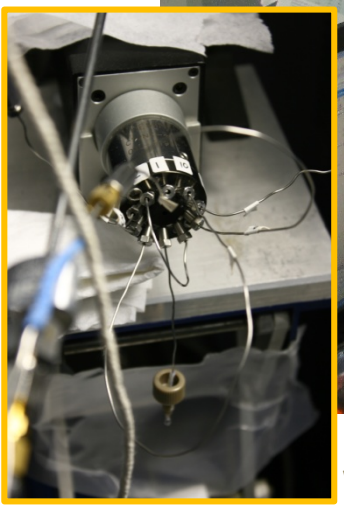


First dimension flow stopped during second dimension separation

On-line HILIC×RP-LC-UV-Q-TOF-MS analysis of red wine pigments



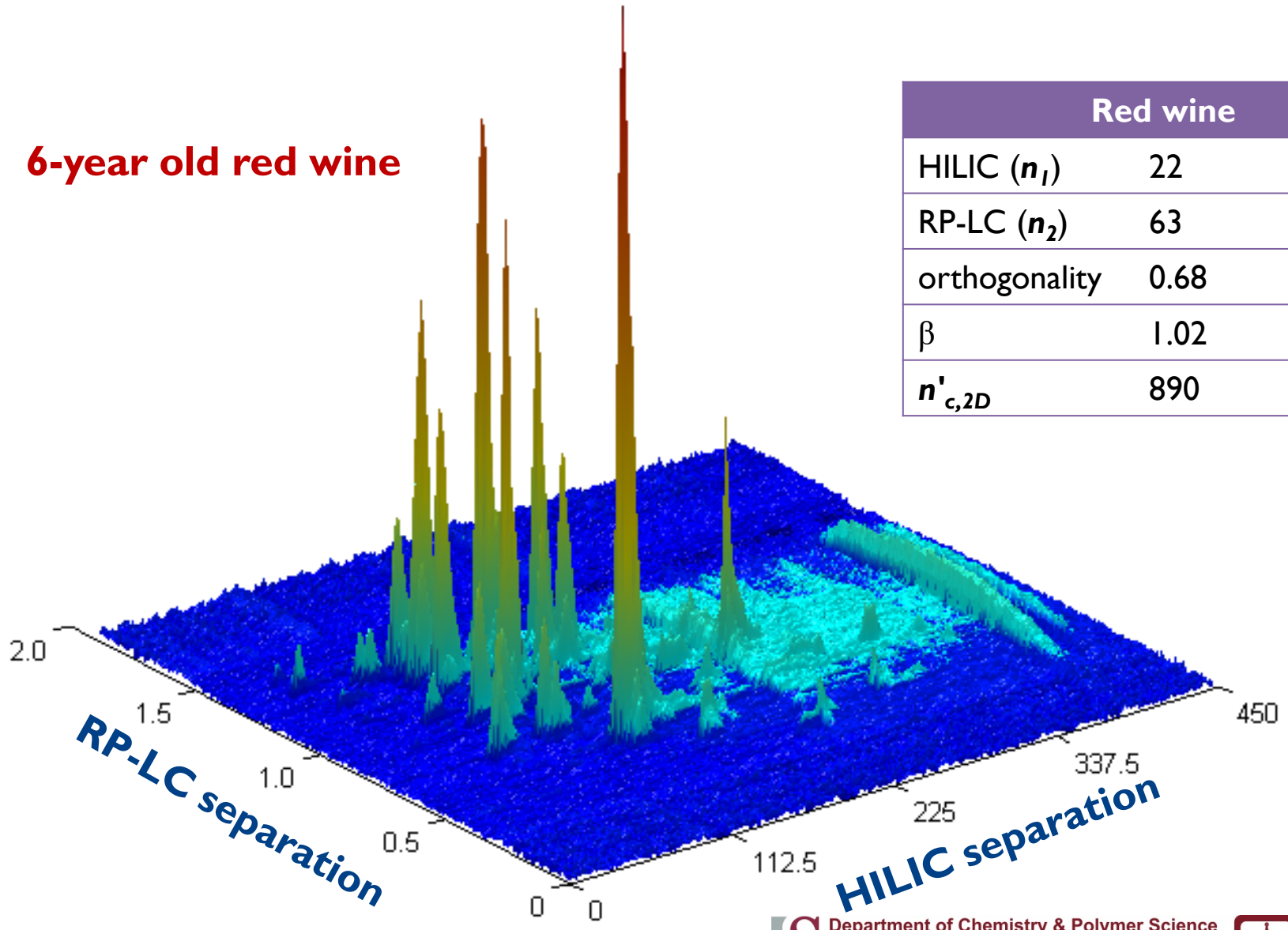




Willemse et al., Anal. Chem. 87 **2015** 12006

On-line HILIC×RP-LC analysis if wine pigments

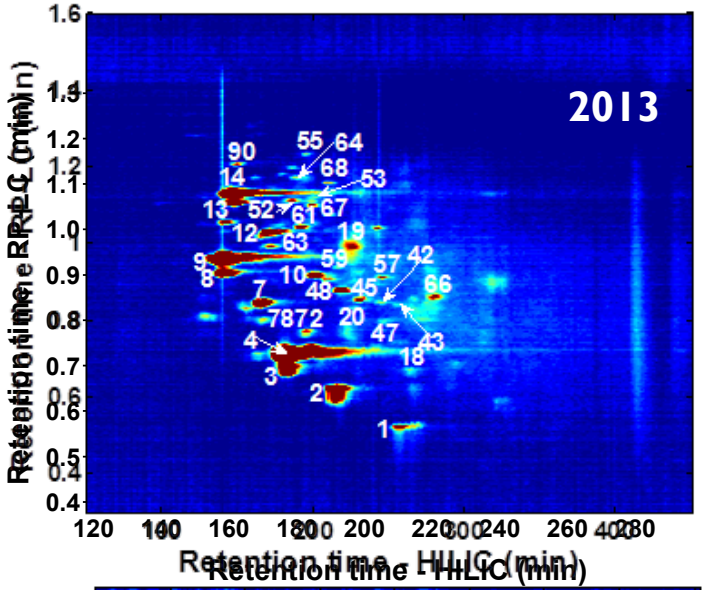
6-year old red wine

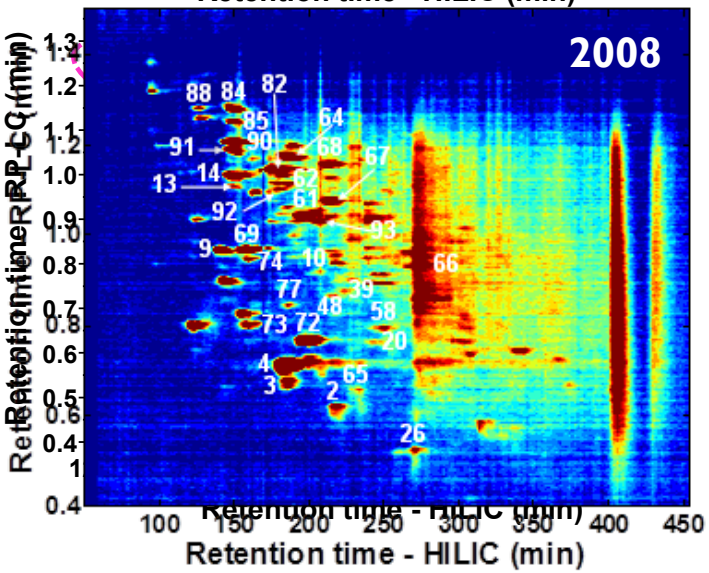


Red wine	
HILIC (n_1)	22
RP-LC (n_2)	63
orthogonality	0.68
β	1.02
$n'_{c,2D}$	890

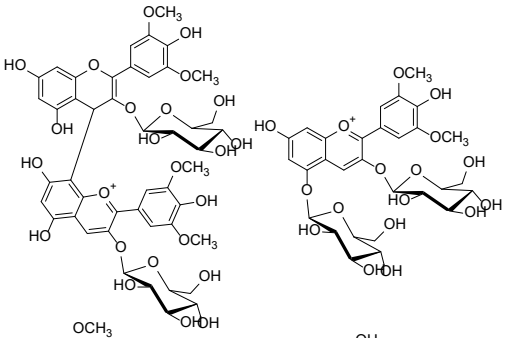
C.M. Willemse et al., Anal. Chem. 87 **2015** 12006

Comparison of pigment profiles

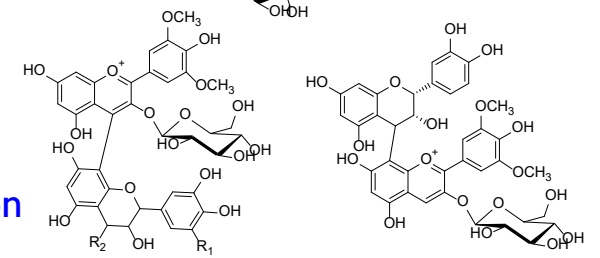




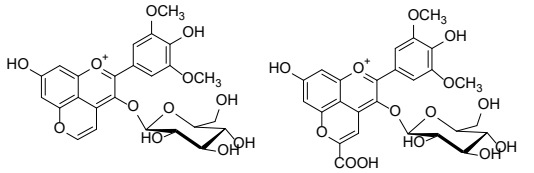
□ Anthocyanin-glucosides (15)
○ Anthocyanin-di-glucosides (5)
Δ Oligomeric Anthocyanins (5)



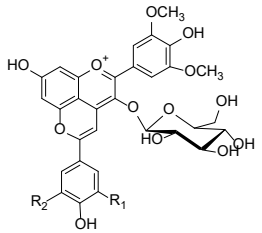
□ Anthocyanin-tannin adducts (15)
○ Acetaldehyde-mediated tannin adducts (16)
Δ Vinylflavanol condensation products (12)



□ Oxovitisins (3)
○ Pyruvic acid derivatives (6)
Δ Acetaldehyde derivatives (4)

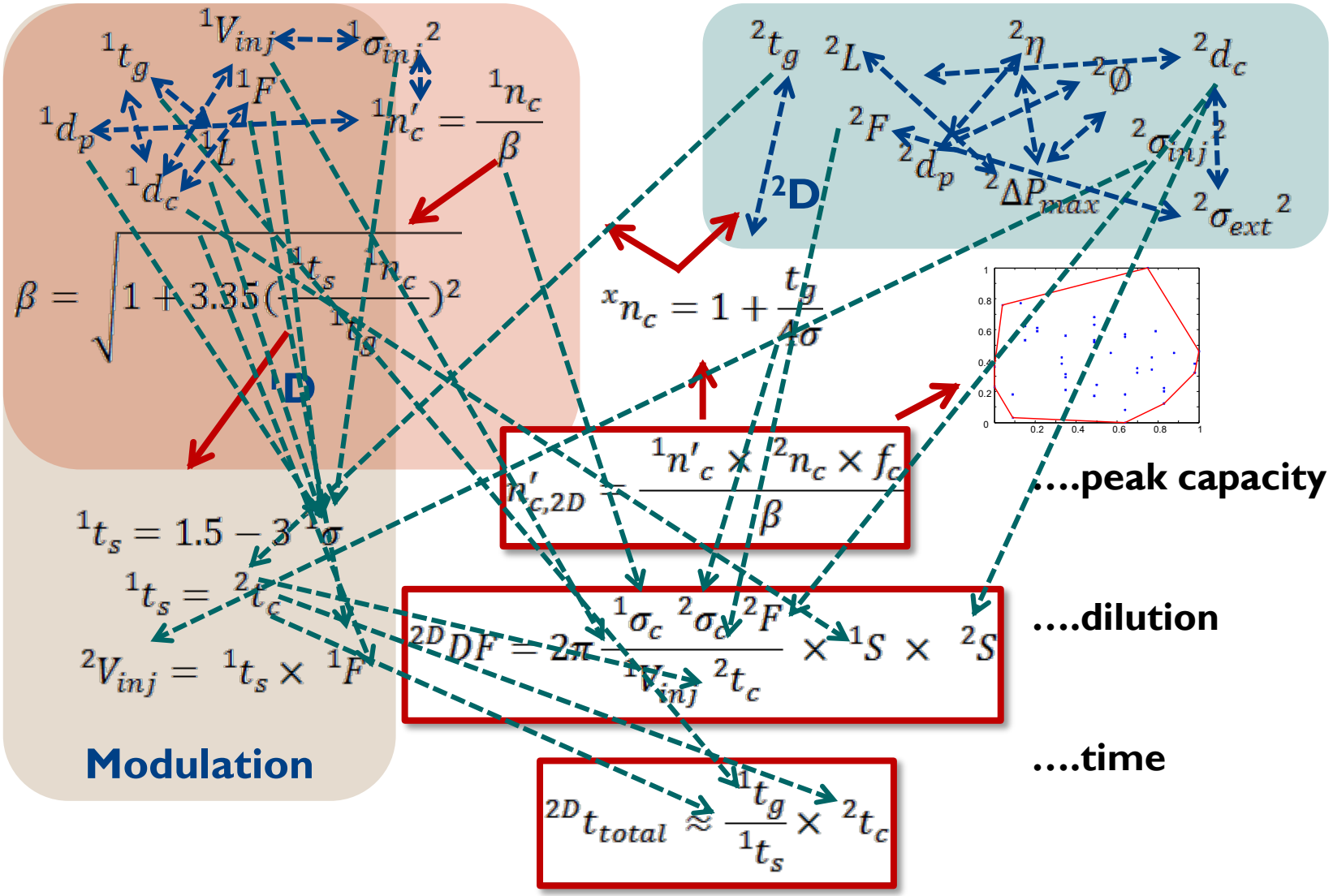


□ Anthocyanin-catechol derivatives (5)
○ Anthocyanin-phenol derivatives (3)
Δ Anthocyanin-guaicol derivatives (4)
◊ Anthocyanin-syringol derivative (1)



C.M. Willemse et al., Anal. Chem. 87 **2015** 12006

Method development in LC×LC



M. Muller et al., J. Chromatogr. A 1571 **2018** 107

Method development in LC×LC

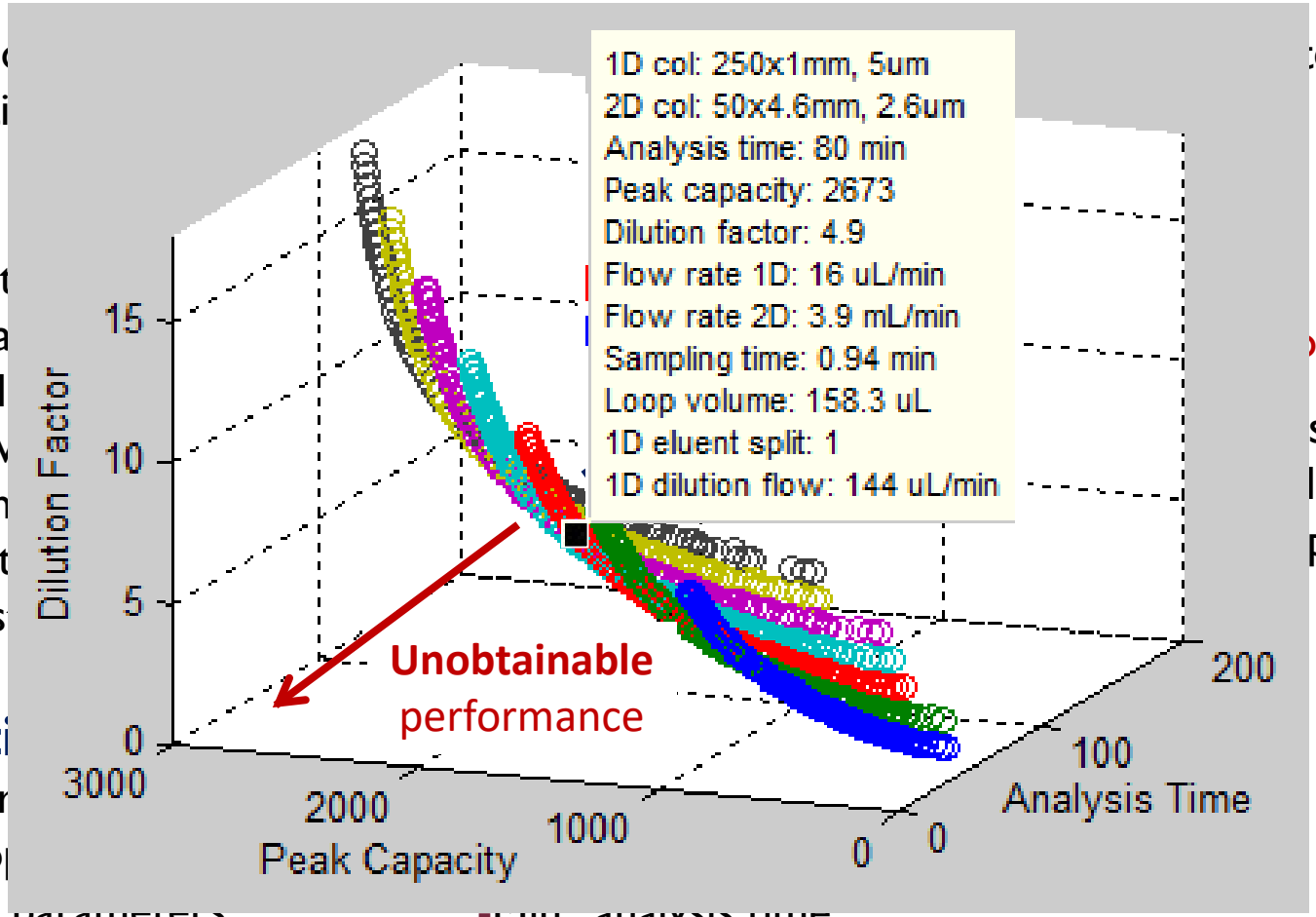
Use the
properti

Input

-Opt
-Ana
-Col
-Solv
-Tim
-Syst
-Res

Opti

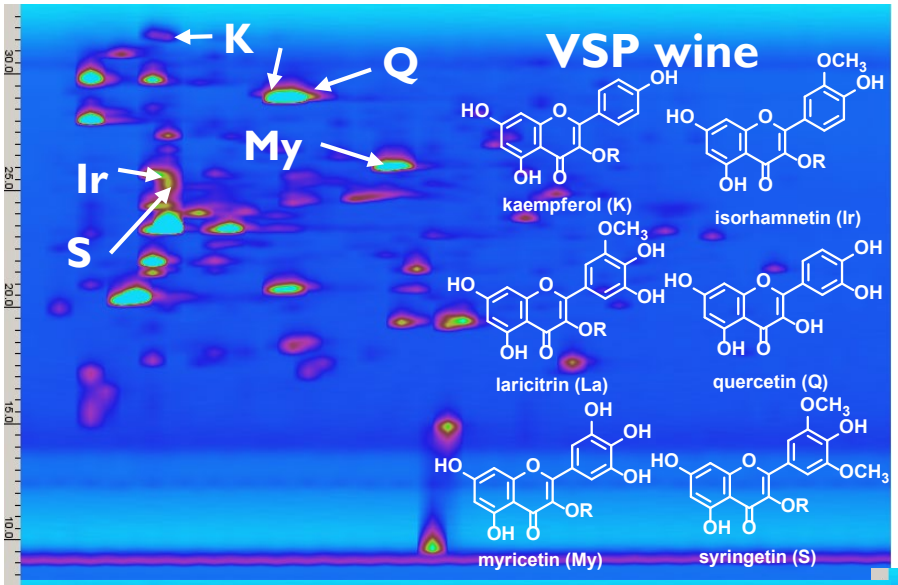
The Par
set of o



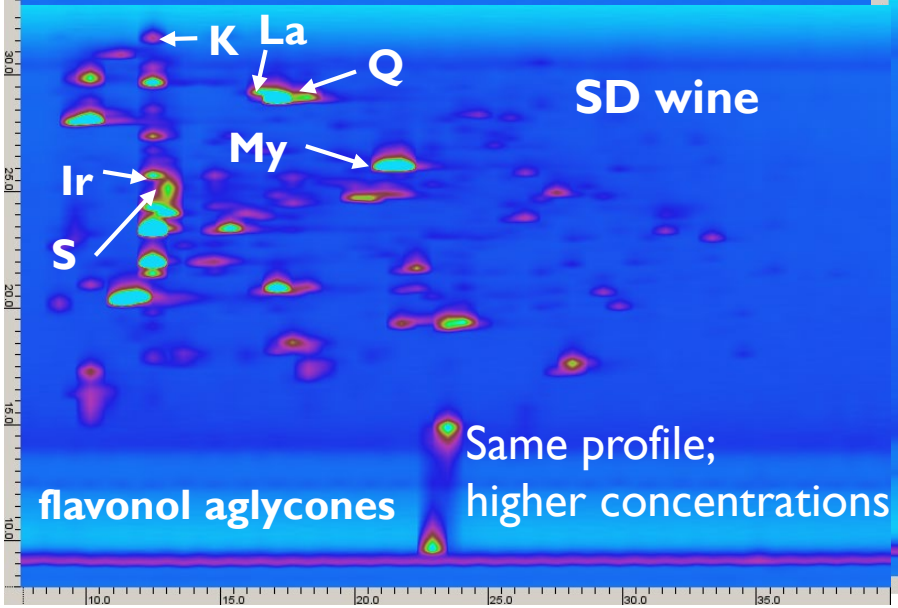
parameters

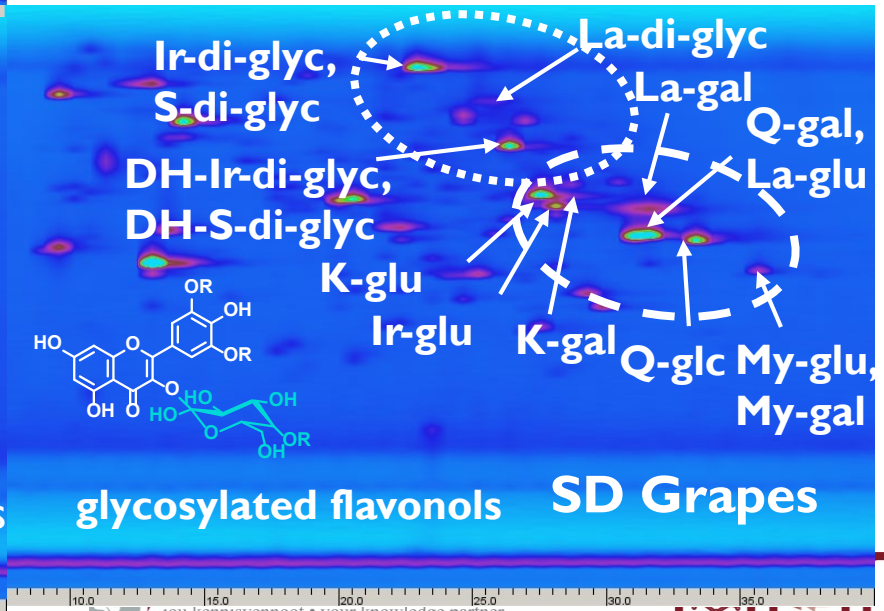
-Min. analysis time
-Min. dilution

HILIC×RP-LC-Q-TOFMS: Wine flavonols



Vertical Shoot Position (VSP) trellis



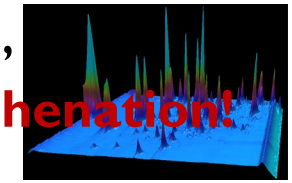


The future…

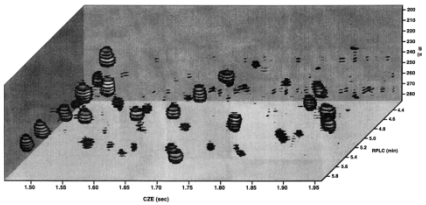
The incentive for improved separation methods provided by demands of fields such as proteomics, metabolomics and natural product analysis

1D (U)HPLC does not provide adequate performance…..**MS^n hyphenation!**

LC×LC offers higher performance, but remains insufficient….**MS^n hyphenation!**



Comprehensive 3-dimensional separations?



A.W. Moore, J.W. Jorgenson, Anal. Chem. 67 **1995** 3456

- Time-based (^{t}LC×^{t}LC×^{t}LC)
- Space-based (^{x}LC×^{x}LC×^{x}LC)
- Combination (^{t}LC×^{t}LC×^{x}LC)

E. Davydova et al., J. Chromatogr. A 1271 **2013** 137

….**MS^n hyphenation!**

Peak capacity

$$n_{components} > 10^2 - 10^3$$

$$n_{c,required} \gg n_{components}$$

$$n_{c,1D} \sim 10^2 - 10^3$$

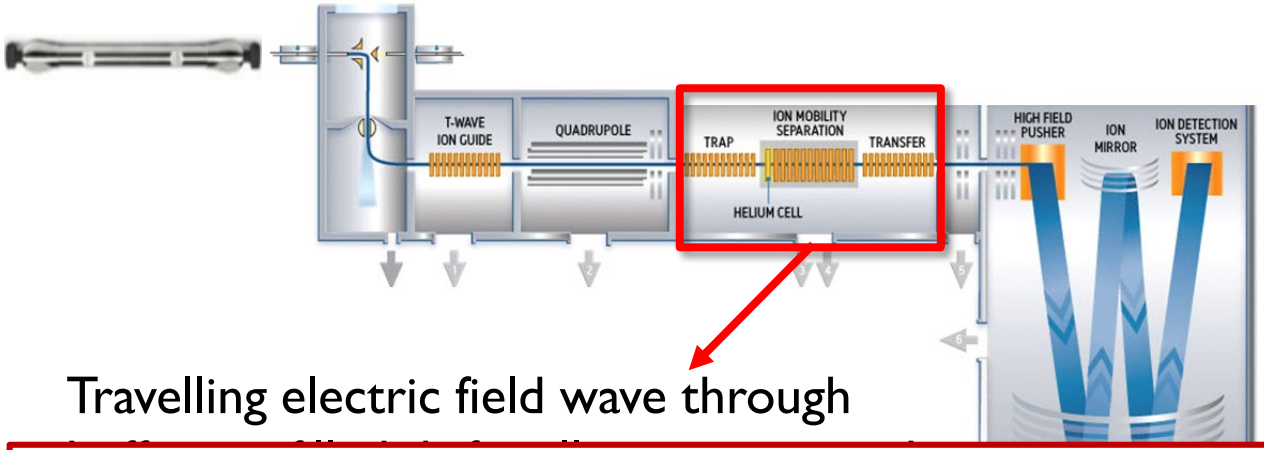
$$n_{c,2D} \sim 10^3 - 10^4$$

$$n_{c,3D(t)} \sim 10^3$$

$$n_{c,3D(t)} \sim 10^4$$

$$n_{c,3D(t,s)} \sim 10^5$$

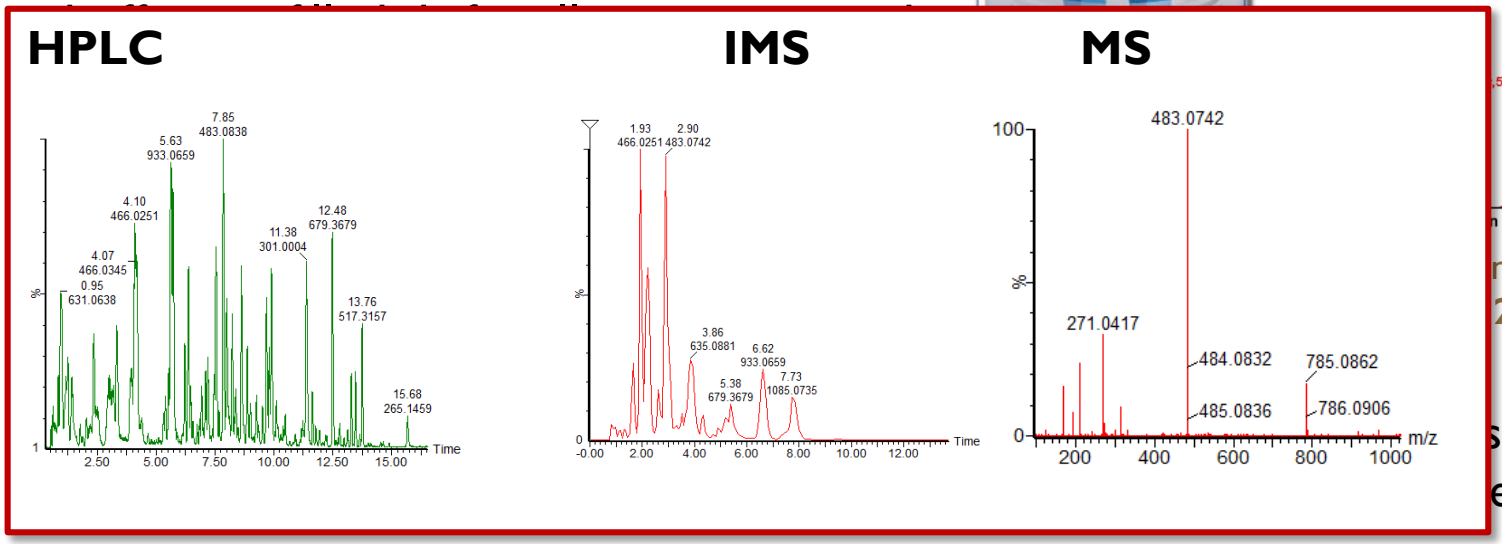
Ion mobility-Mass spectrometry (IMS-MS)

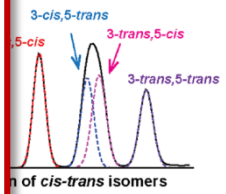


Travelling electric field wave through

e.g. Q-TOF instruments:

- High scan speeds (5-100 Hz)
- High mass ranges
- High resolving power (RP = 10-60 000)
- MS/MS or MS^E operation





ng et al., J. Phys. Chem. **2017** 1381

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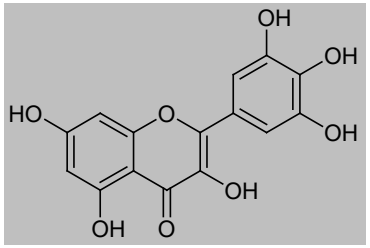
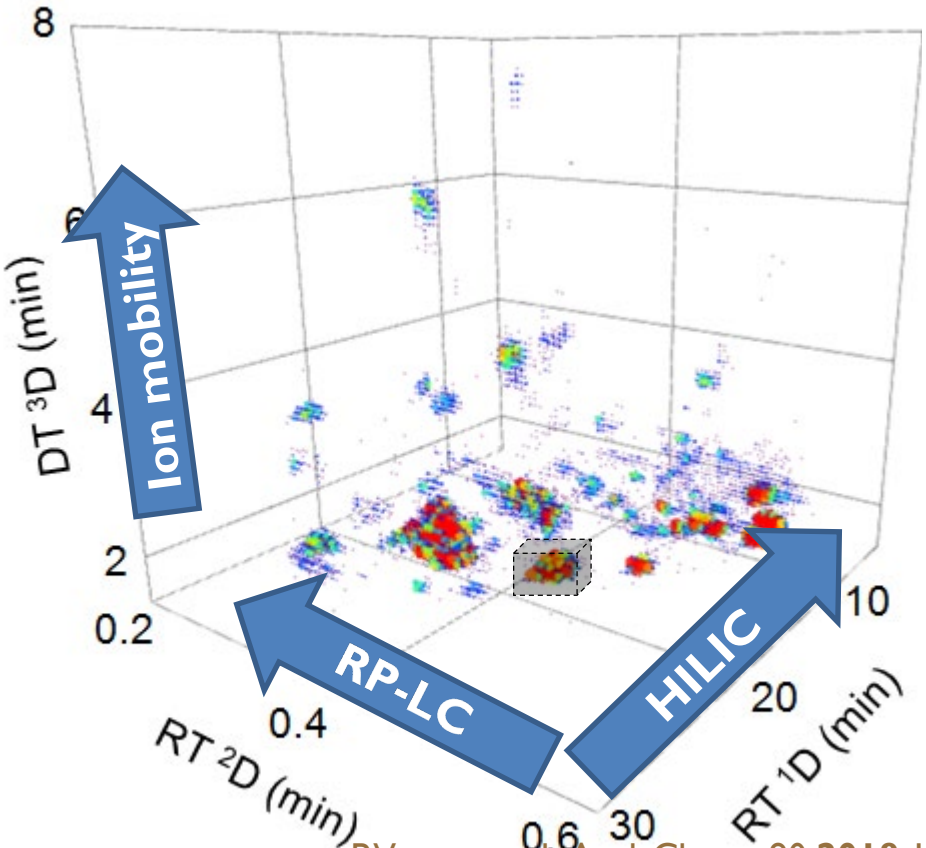
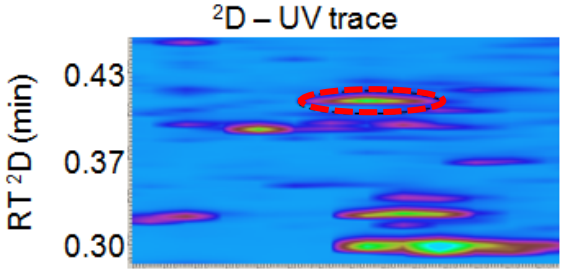
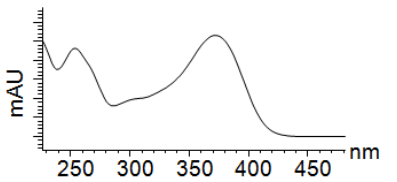
LC×LC×IMS-MS analysis of wine phenolics

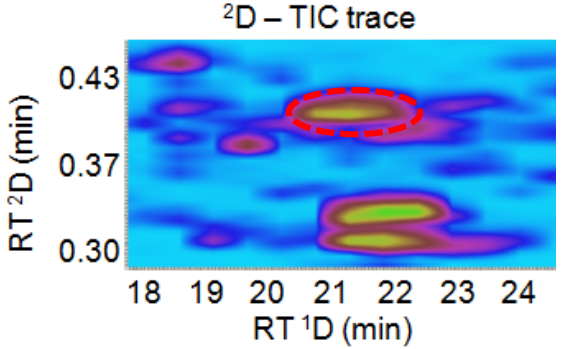
Myricetin
Mol. formula: $C_{15}H_{10}O_8$
^{12}C mass: 318.0376
Δ_{mass}: 0.1 ppm

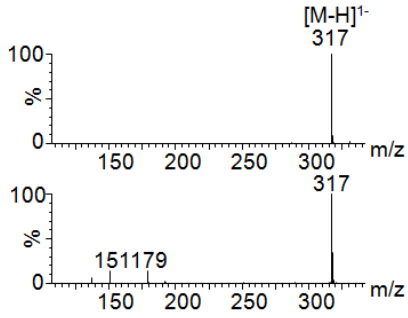


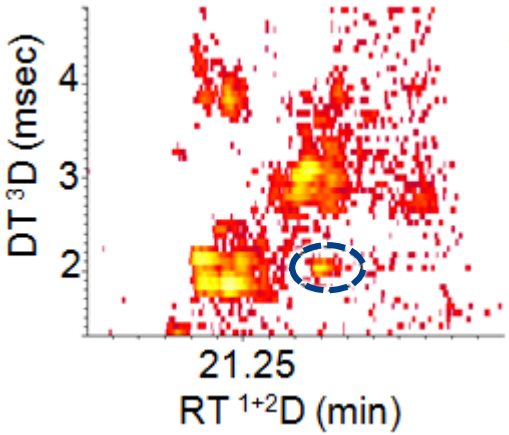


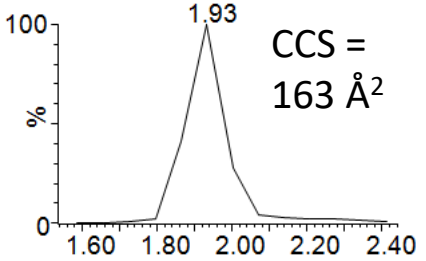












CCS = 163 Å^2

P.Venter et al.,Anal. Chem. 90 **2018** 11643

Concluding remarks

Advanced analysis has become indispensable in chemical research and manucturing.

- Quality control, safety
- Structure-property relationships
- Improving product quality
- Enabling research progress

New developments continuously improving on established techniques

- Improved sensitivity, resolving power, hyphenation possibilities
- But, these advanced techniques are often complex and require dedicated expertise to exploit their benefits

The Department of Chemistry at Stellenbosch is very well equipped in terms of both instrumentation and expertise to make a significant contribution in this field in SA

Thank you for your attention

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