Air pollution: a public health problem then and now

Biological effects of emissions from ship diesel- and gasoline car-engines as well as from wood combustion compliances: Multi-omics characterization of aerosol-exposed lung cells and chemical profiles of the emissions

R.Zimmermann[1,11], T.G.Dittmar[2,11], T.Kanashova[2,11], J.Buters[3,11], S.Öder[3,11], H.Paur[4,11], M.Dilger[4,11], C. Weiß[4,11], H.Harndorf[5,11], B Stengel[5,11], K.Hiller[7,11], S.C.Sapcariu[7,11],K.A.BeruBe[8,11], A.J. Wlodarcyzk[8,11], B.Michalke[9], T.Krebs[10,11], M.Kelbg[5,11], T.Streibel[1], E.Karg[1], J.Schnelle-Kreis[1], M.Sklorz[1], J.Orasche[1,11], P.Richthammer[1,11], L. Müller[1,11], J.Passig[1,11], C. Radischat[1,11], S. Smita[5,11], J. Orasche[1,11], H. Lamberg[6], M.-R. Hirvonen[6,11], O. Sippula [6,11], J. Jokiniemi [6,11]

[1]Joint MS Centre, Rostock Univ./Analyt. Chemistry & Helmholtz Zentrum München (HMGU)/CMA, Germany; [2]Max Delbrück Ctr., Germany; [3]Technical Univ. Munich (ZAUM), Germany; [4]Karlsruhe Inst. Technol. (ITC/ITG), Germany; [5]Univ. of Rostock (Inst. of Piston Machines & Inst. of Physics & Systems Biology), Germany; [6]Univ. Eastern Finland, Finland; [7]Univ. Luxemburg, Luxemburg; [8]Cardiff Univ., UK; [9]HMGU, Germany; [10]Vitrocell GmbH, Germany; [11]HICE-Helmholtz Virtual Institute HICE (www.hice-vi.eu)

Emil Nolde, 1910, Tugboat on the Elbe (Kunsthalle Hamburg)

Health effects of ambient aerosols




„A Proper Pea-Souper - The Terrible London Smog of 1952“


Health effects of ambient aerosols

London smog 1952; Arsenal soccer match (canceled due to low visibility)

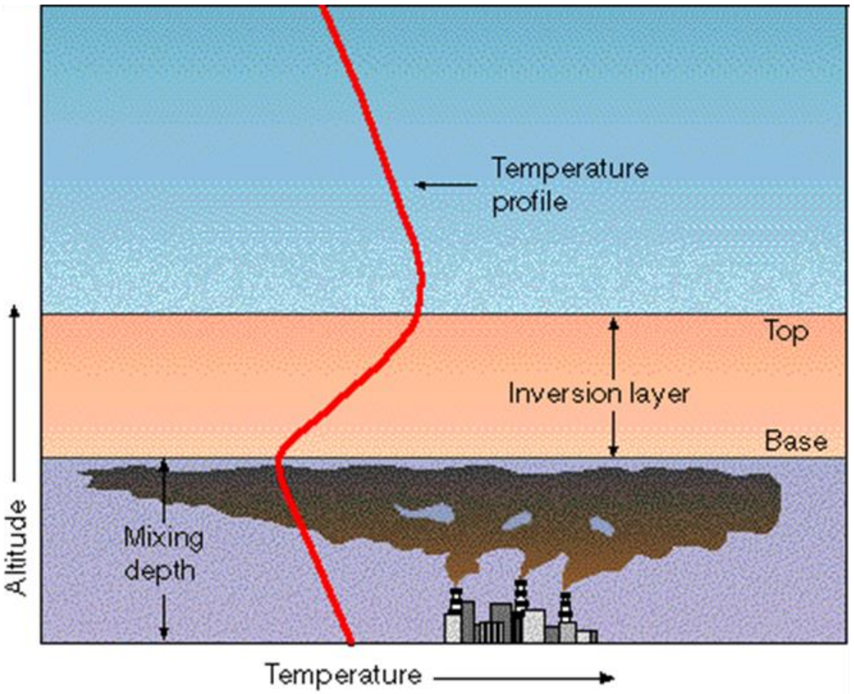
Health effects of ambient aerosols

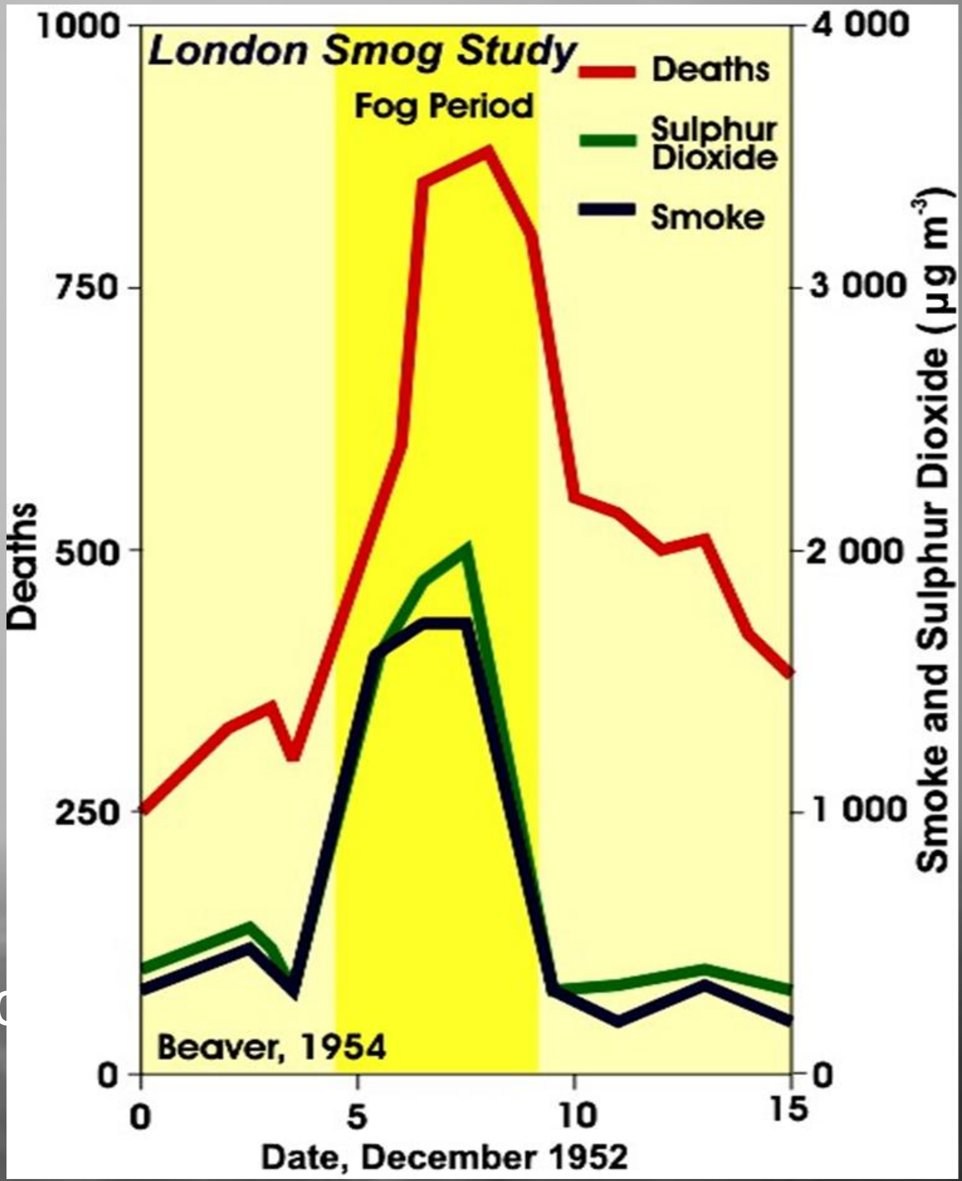
Reasons for London „Killer-Smog“ Episode 1952 :

➔ High emissions of combustion effluents (coal/industry/traffic)

&

➔ Weather (typ. winter inversion)



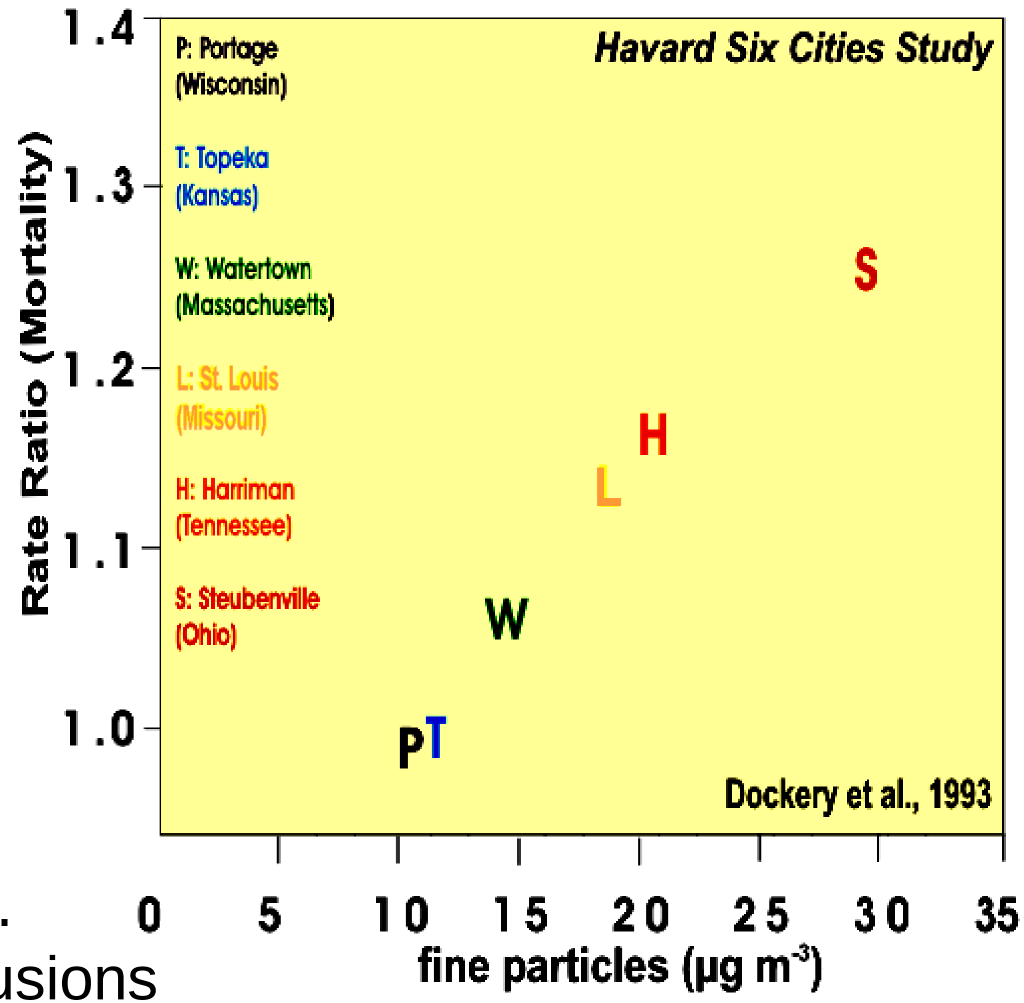


Health effects of ambient aerosols

Harvard-Six-Cities-Study

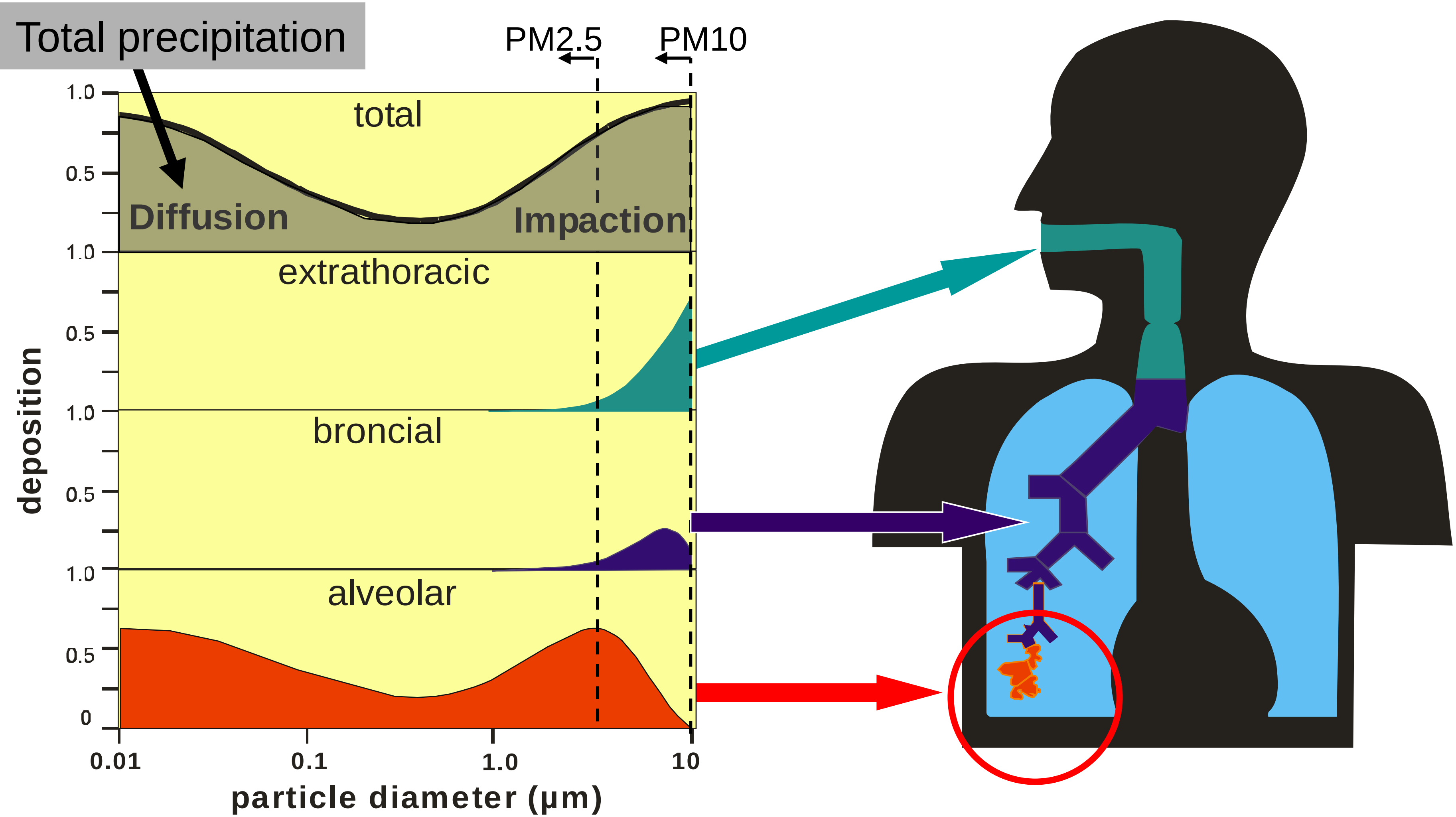
Dockery et al. (1993)

- cohort study (8111 Pers.)
- Six US cities with rather different PM10
- Study time: 16 years starting about 75.
- mortality in city with highest PM (~30 µg/m³) was 26% higher compared to cleanest city (~10 µg/m³)
- Re-analysis von Krewski et al. (2000) confirmend the consclusions

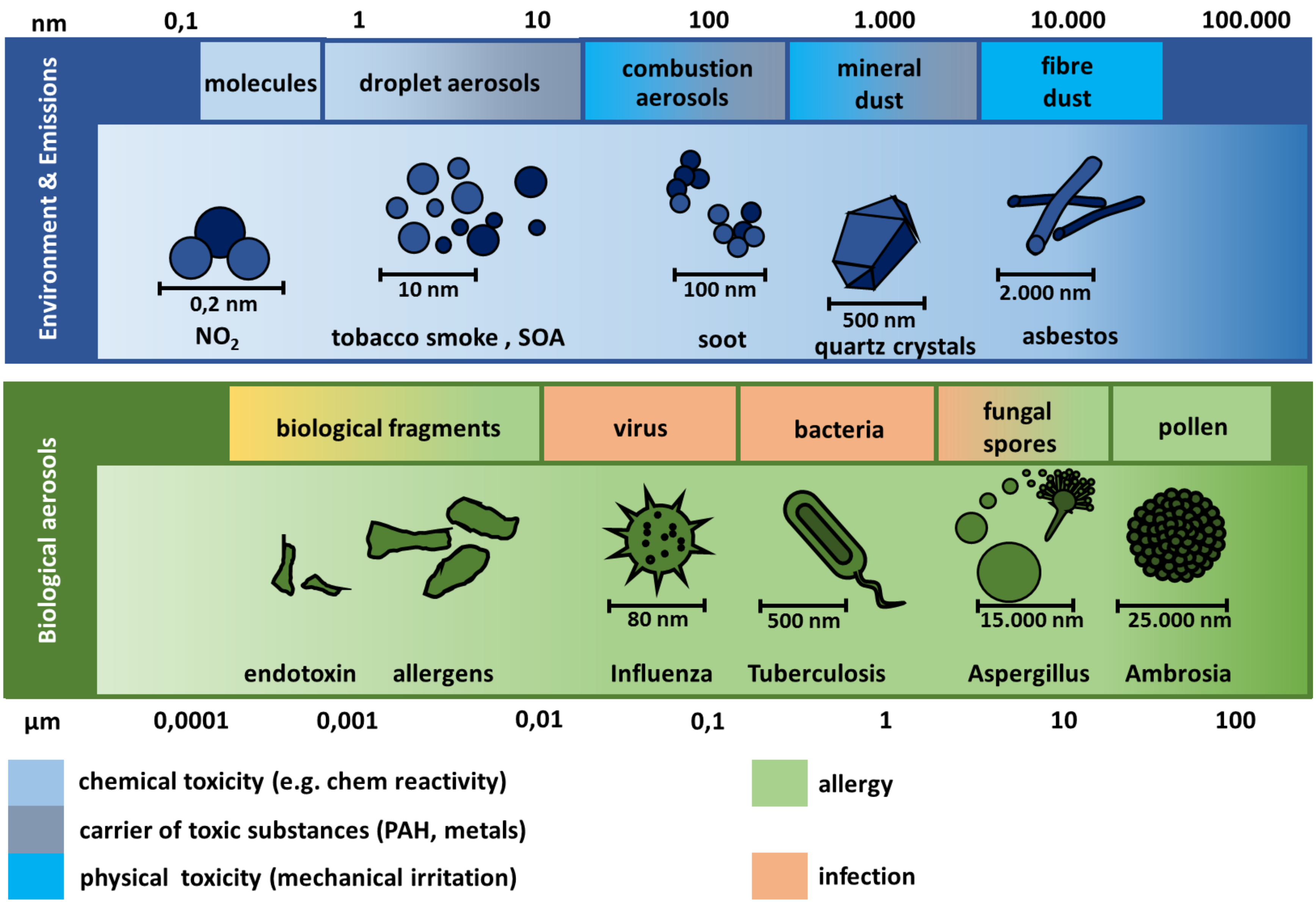


Health effects of ambient aerosols

Deposition of particles in the airways of healthy humans

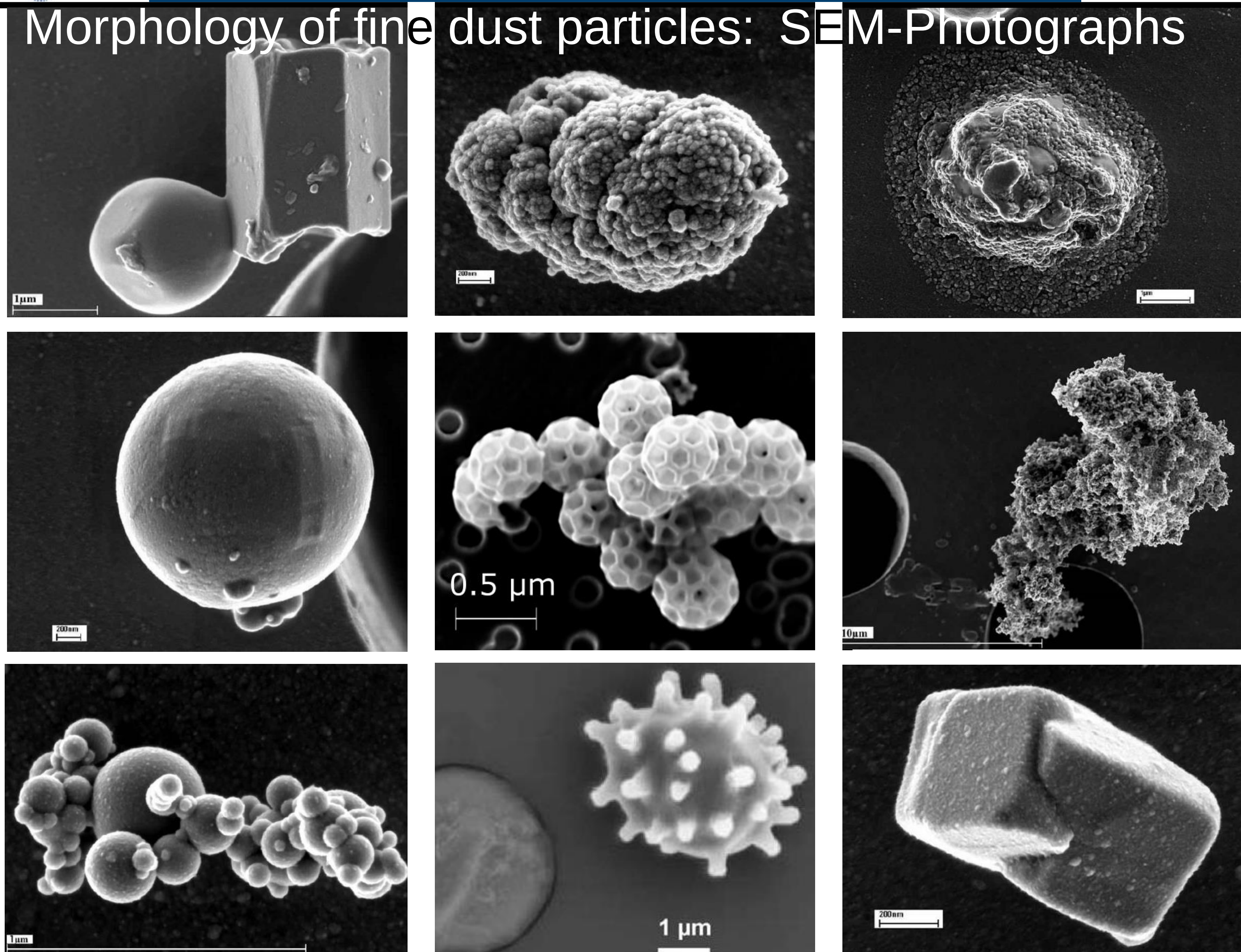


Health effects of ambient aerosols



Health effects of ambient aerosols

Morphology of fine dust particles: SEM-Photographs



Wittmaack et al., 2005 und http://www.mpch-mainz.mpg.de

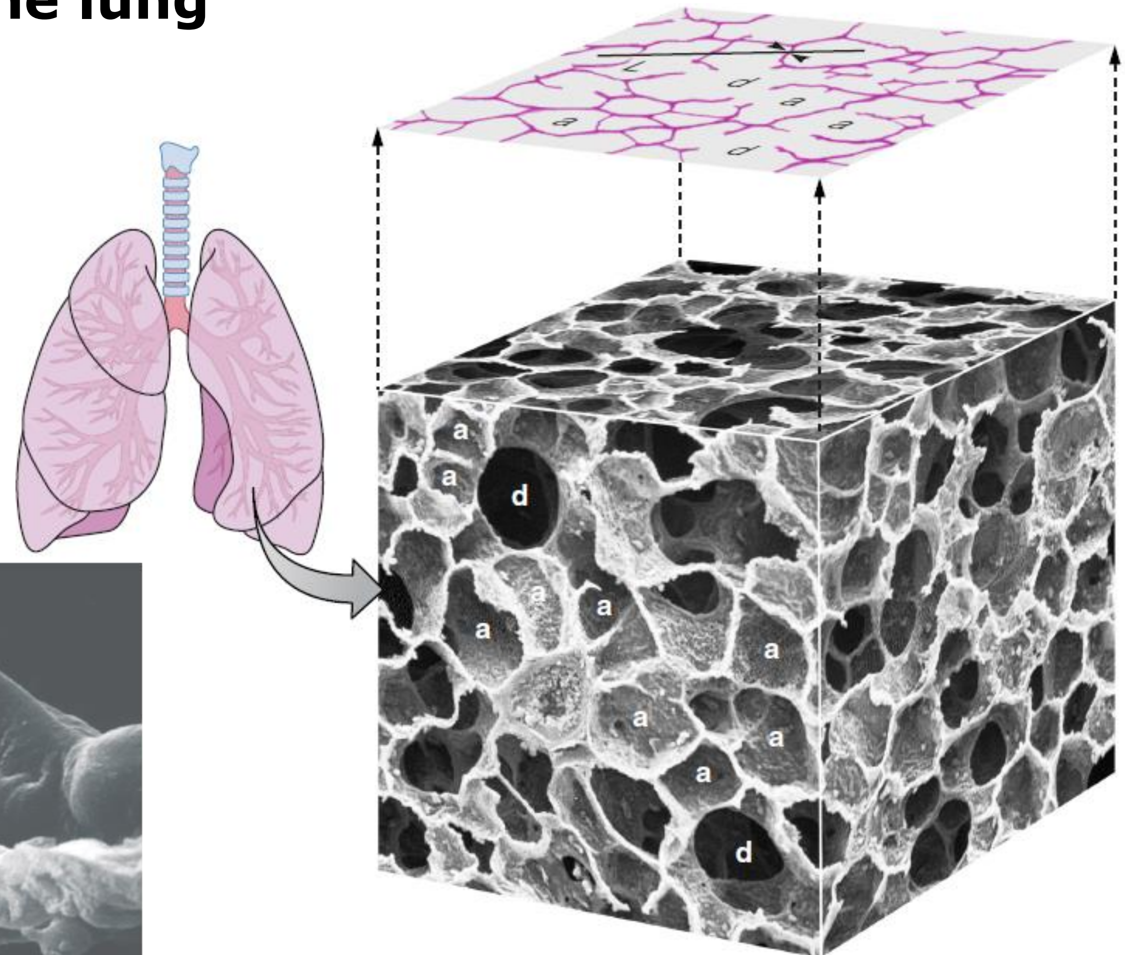
Sponge-like structure of the lung

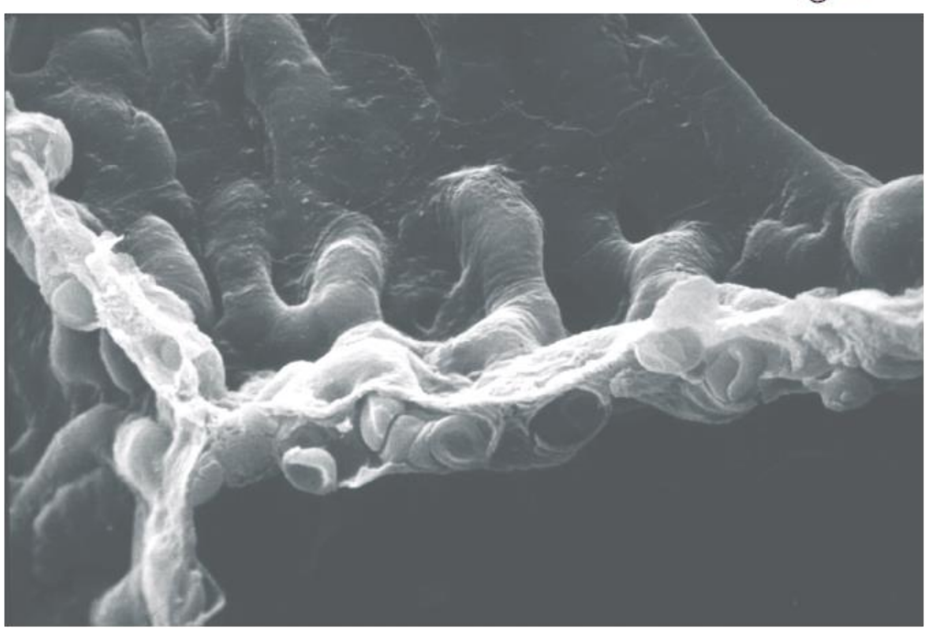
Lung surface: ca. 80 m²

Basal membrane thickness:
 ~0.1 µm

Number of alveoli:
 ca. 300 million

Size of alveoli: 50 – 250 µm





E. Weibel, 2013

Health effects of ambient aerosols

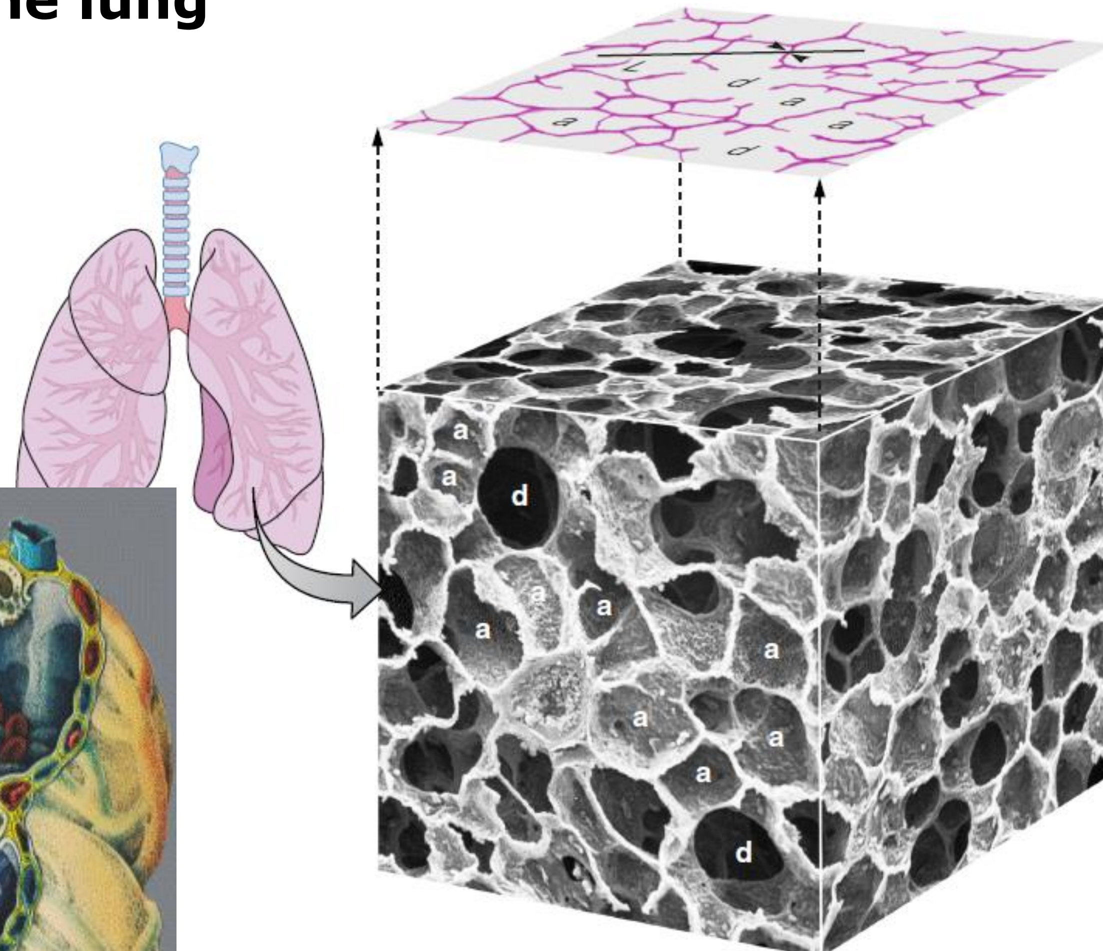
Sponge-like structure of the lung

Lung surface: ca. 80 m²

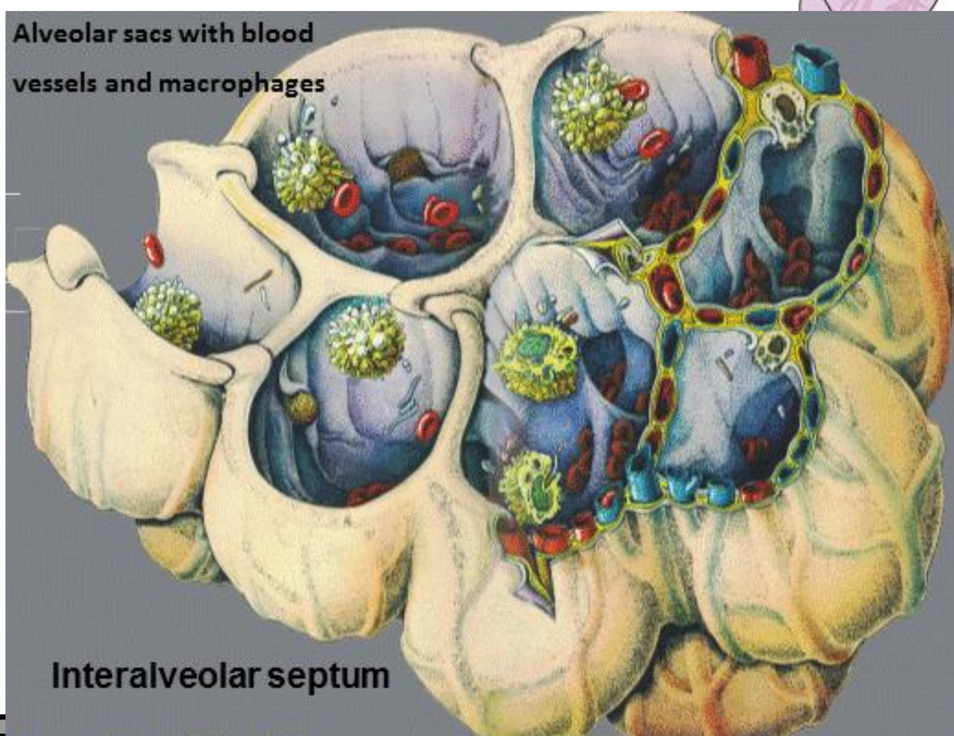
Basal membrane thickness:
~0.1 µm

Number of alveoli:
ca. 300 million

Size of alveoli: 50 – 250 µm

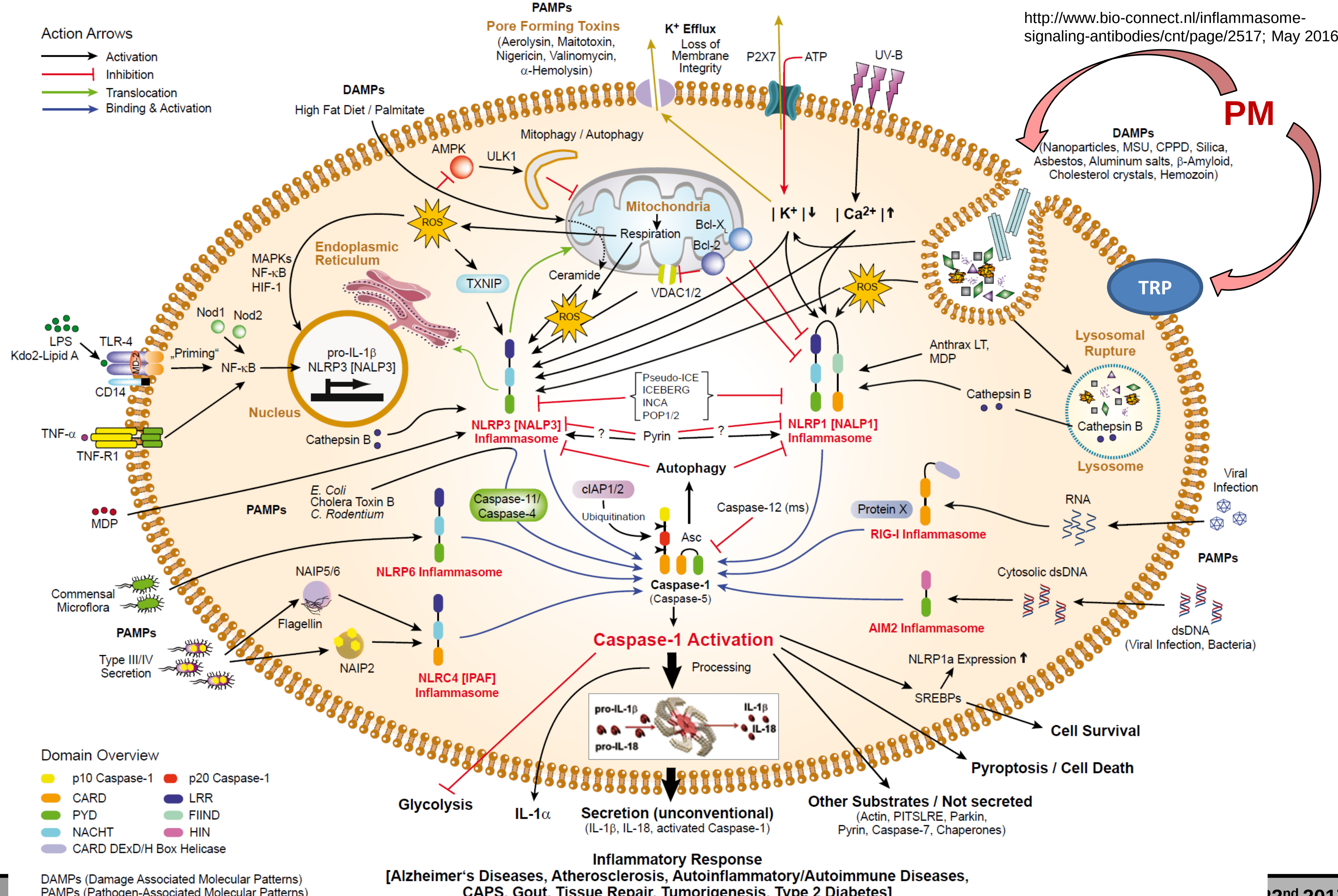


E. Weibel, 2013



Morgenroth and Nolte, 1988

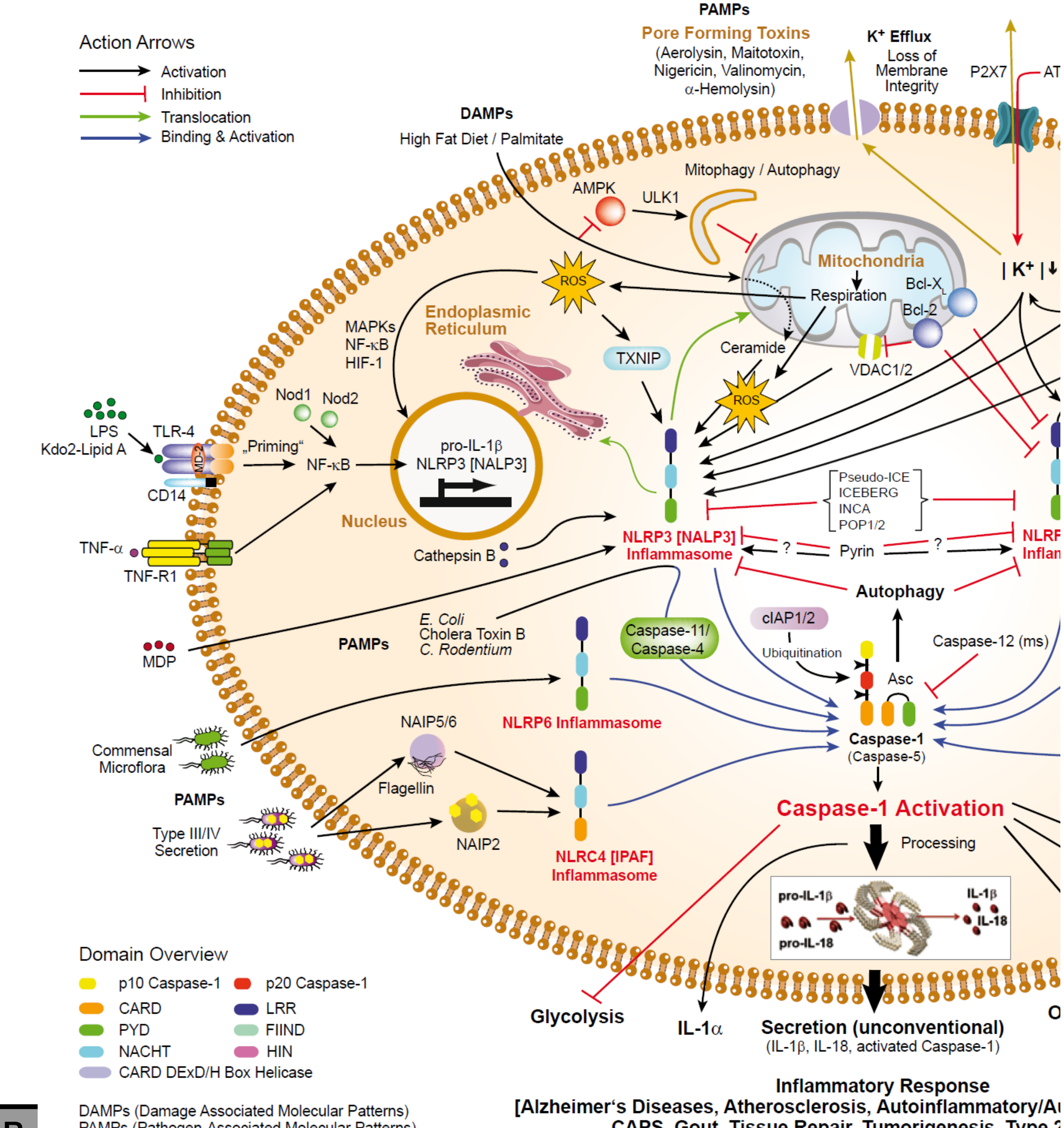
Health effects of ambient aerosols

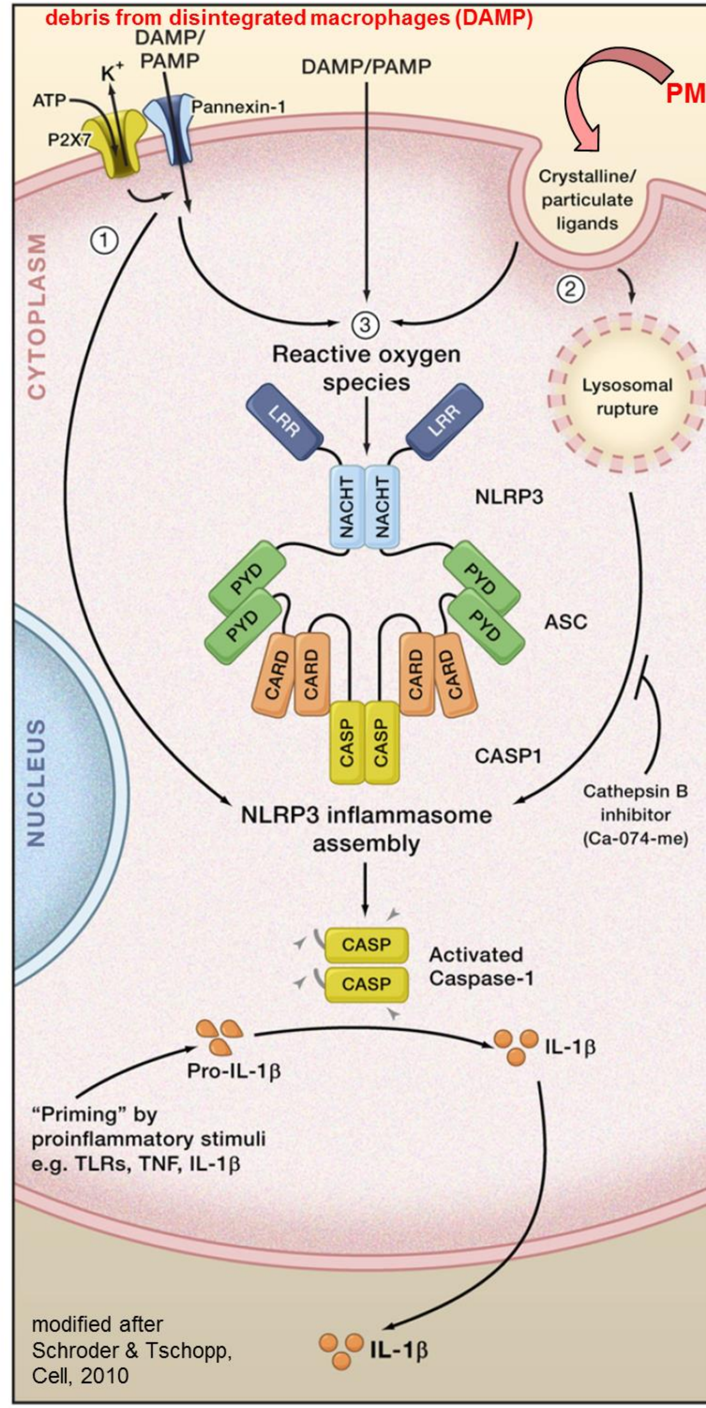


http://www.bio-connect.nl/inflammasome-signaling-antibodies/cnt/page/2517; May 2016

HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt
Mass Spectrometry Centre
Universität Rostock
Traditio et Innovatio

Health effects of ambien





R.

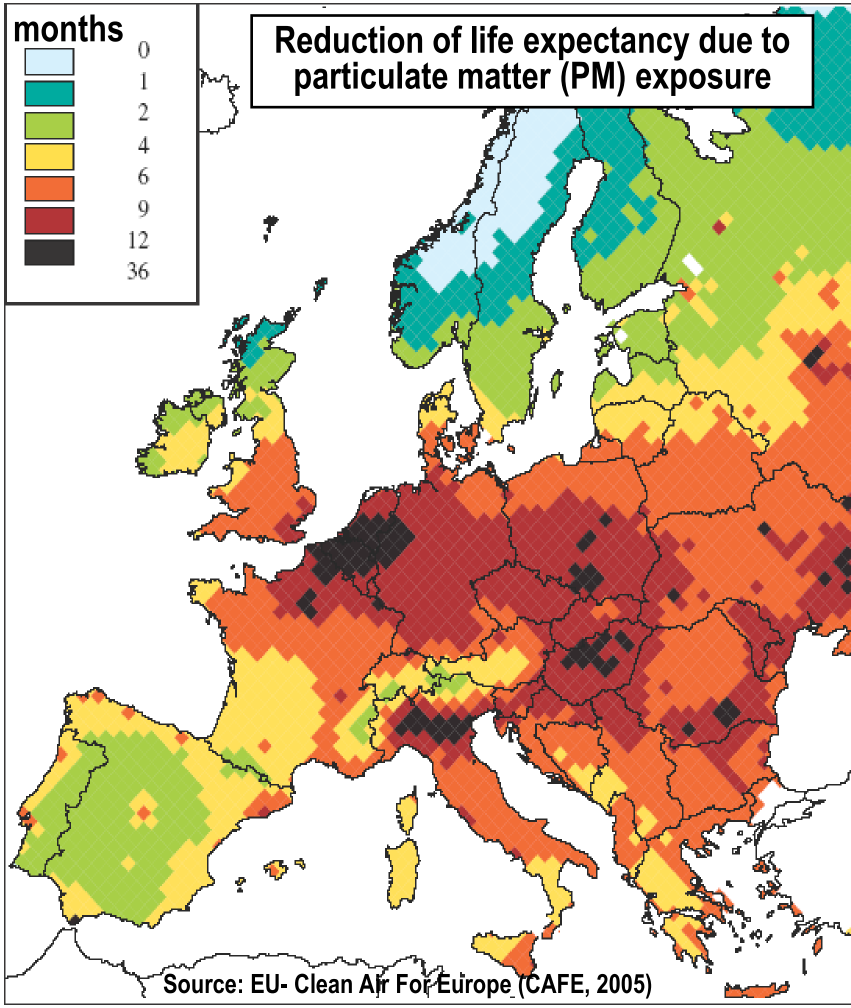
HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt
Mass Spectrometry Centre
Universität Rostock
Traditio et Innovatio

Health effects of ambient aerosols

HICE › Aerosols and Health
Helmholtz Virtual Institute of Complex Molecular Systems in Environmental Health

- Epidemiology: Today aerosols (air pollution) are the most relevant impact of environment on human health in EU
- Important for health effects (WHO): Combustion aerosols, organics, soot, transition metals, small particles
- Relevant sources: automobiles, trucks, house heating/ bio mass combustion, power stations, industry, ships

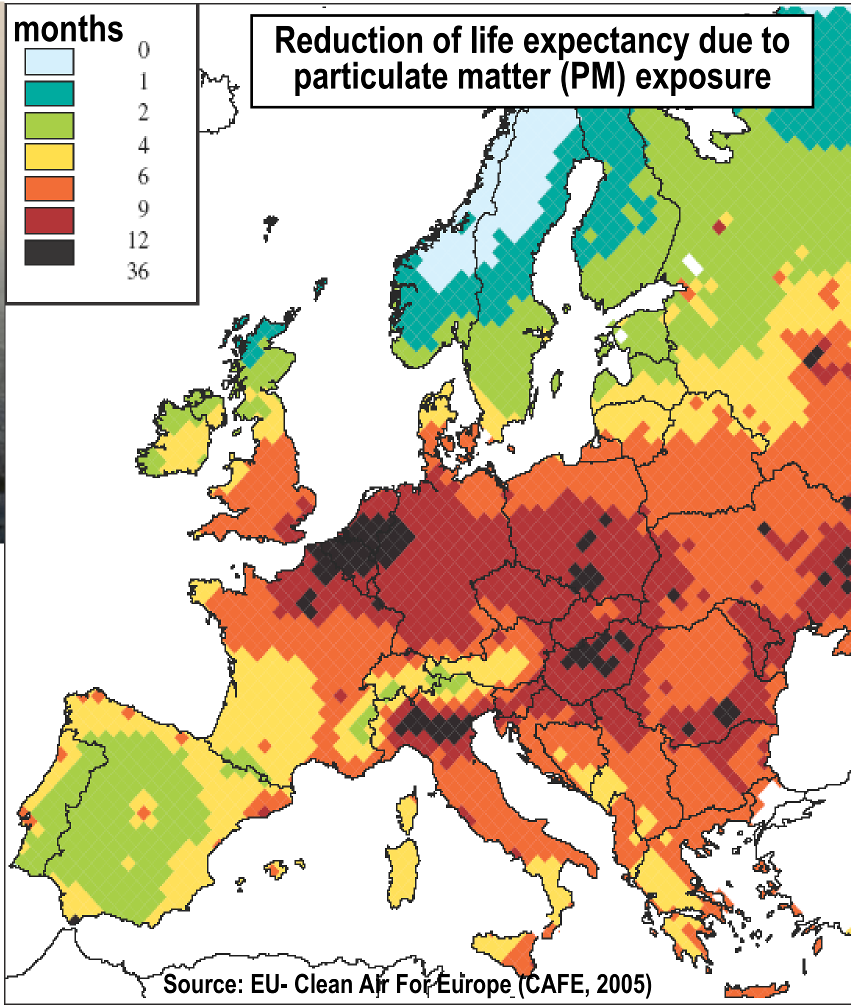
➔ **Why aerosols are so toxic and what causes the strong acute health effects of ambient particulate matter?**



➔ **What is the role of organic compounds, soot & carbonaceous fractions?**

Health effects of ambient aerosols

- Epidemiology: Today aerosols (air



- Relevant sources: automobiles, trucks, house heating/ bio mass combustion, power stations, industry, ships

➔ **Why aerosols are so toxic and what causes the strong acute health effects of ambient particulate matter?**

➔ **What is the role of organic compounds, soot & carbonaceous fractions?**

HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt
Mass Spectrometry Centre
Universität Rostock Traditio et Innovatio

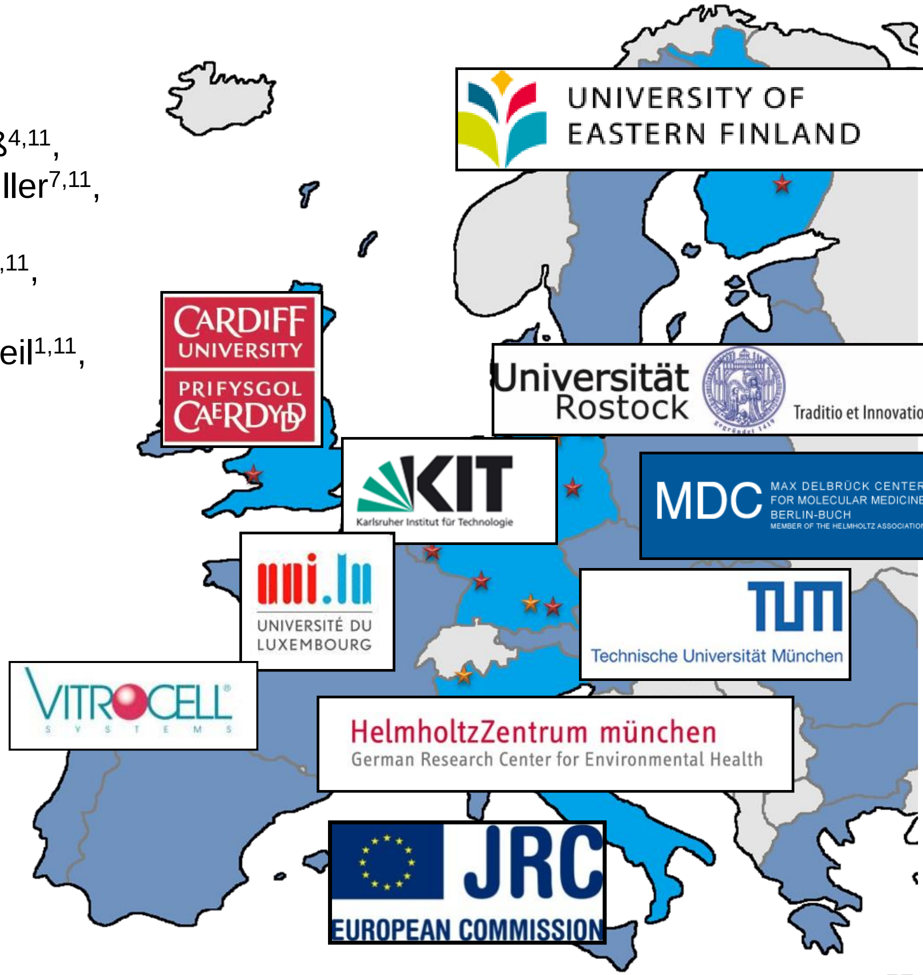
Helmholtz Virtual Institute - HICE: Research on Aerosol and Health

HICE › Aerosols and Health
Helmholtz Virtual Institute of Complex Molecular Systems in Environmental Health

HICE Konsortium (2012-2017):

T.G.Dittmar[2,11], T.Kanashova[2,11], J.Buters[3,11], S.Öder[3,11], H.Paur[4,11], C.Schlager[4], S.Mülhopt[4], M.Dilger[4,11], C.Weiß[4,11], S.Diabate[4], H.Harndorf[5,11], B Stengel[5,11], R. Rabe[5], K.Hiller[7,11], S.C.Sapccariu[7,11], K.A.BeruBe[8,11], A.J.Wlodarcyzk[8,11], B.Michalke[9], T.Krebs[10,11], M.Kelbg[5,11], J.Tiggesbäumker[5,11], T.Streibel[1], E.Karg[1], S.Scholtes[1,11], J.Schnelle-Kreis[1], J.Lintelmann[1], M.Sklorz[1], M. Arteaga Salas[1,11], S. Klingbeil[1,11], J.Orasche[1], L. Müller[1,11], A.Rheda[1], J.Passig[1,11], T. Gröger[1],G.Abbaszade[1], C.Radischat[1,11] , S.Smita[5,11], J.Orasche[1,11], T.Torvela[6], P.Tiitta[6], H.Lamberg[6], , [6], M.-R.Hirvonen[6,11], S.Kasurinen[6], P.Jalava[6], O.Sippula[6,11], J. Jokiniemi[6,11] R.Zimmermann

[1]Joint Mass Spectrometry Centre, Rostock University&Helmholtz Zentrum München), D
[2]MDC, Berlin, D;
[3]ZAUM, Technical University Munich, D;
[4]KIT (ITC/ITG), Karlsruhe, D;
[5]University of Rostock (Engineering/Physics), D
[6]University of Eastern Finland-Kuopio; FI
[7]University of Luxemburg; LUX
[8]University of Cardiff, UK;
[9] Helmholtz Zentrum München), D;
[10]Vitrocell GmbH, Waldkirch, D;
[11]HICE – Helmholtz Virtual Institute of Complex Molecular Systems in Environmental Health-Aerosols and Health



Health
Earth & Environment
Energy

Health relevance of combustion aerosols: Some scientific questions of HICE

- How is the **chemical composition** and **formation dynamics** of relevant combustion aerosols?
- What are the biological effects of **gas and particulate phase** of the aerosols?
- Why are combustion particles so dangerous and what are the underlying **biological mechanisms**?
- How does **atmospheric aging** impact health and environment?

Technological innovations:

- Realistic **on-line ALI cell exposure** & **comprehensive biological effect monitoring** (incl. multi-omics)
- **Comprehensive aerosol characterization** & **on-line monitoring** of the exposure by e.g. mass spectrometry

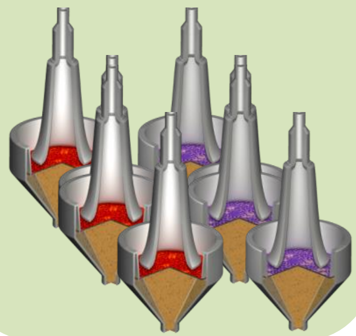
HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt
Mass Spectrometry Centre
Universität Rostock Traditio et Innovatio

HICE concept: Interdisciplinary research to address health effects of aerosols

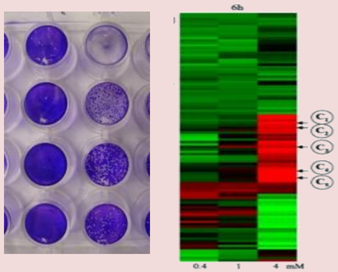
HICE › Aerosols and Health
Helmholtz Virtual Institute of Complex Molecular Systems in Environmental Health

Aerosol Sources

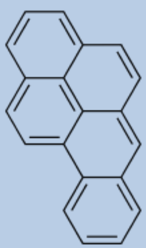
Advanced ALI lung cell culture & animal exposure

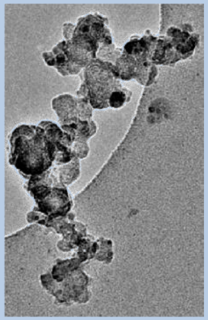


Multi-Omics, toxicol.-assays

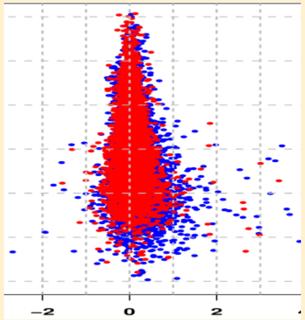


Comprehensive phys. & chem. aero-sol characterization





Biostatistics & Chemometry

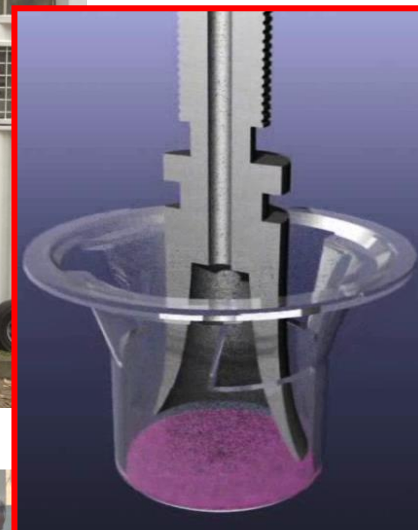


Characterization of biological effects of combustion aerosols: Exposure & Analyses

HICE-ALI-Exposure System (Vitrocell and KIT)

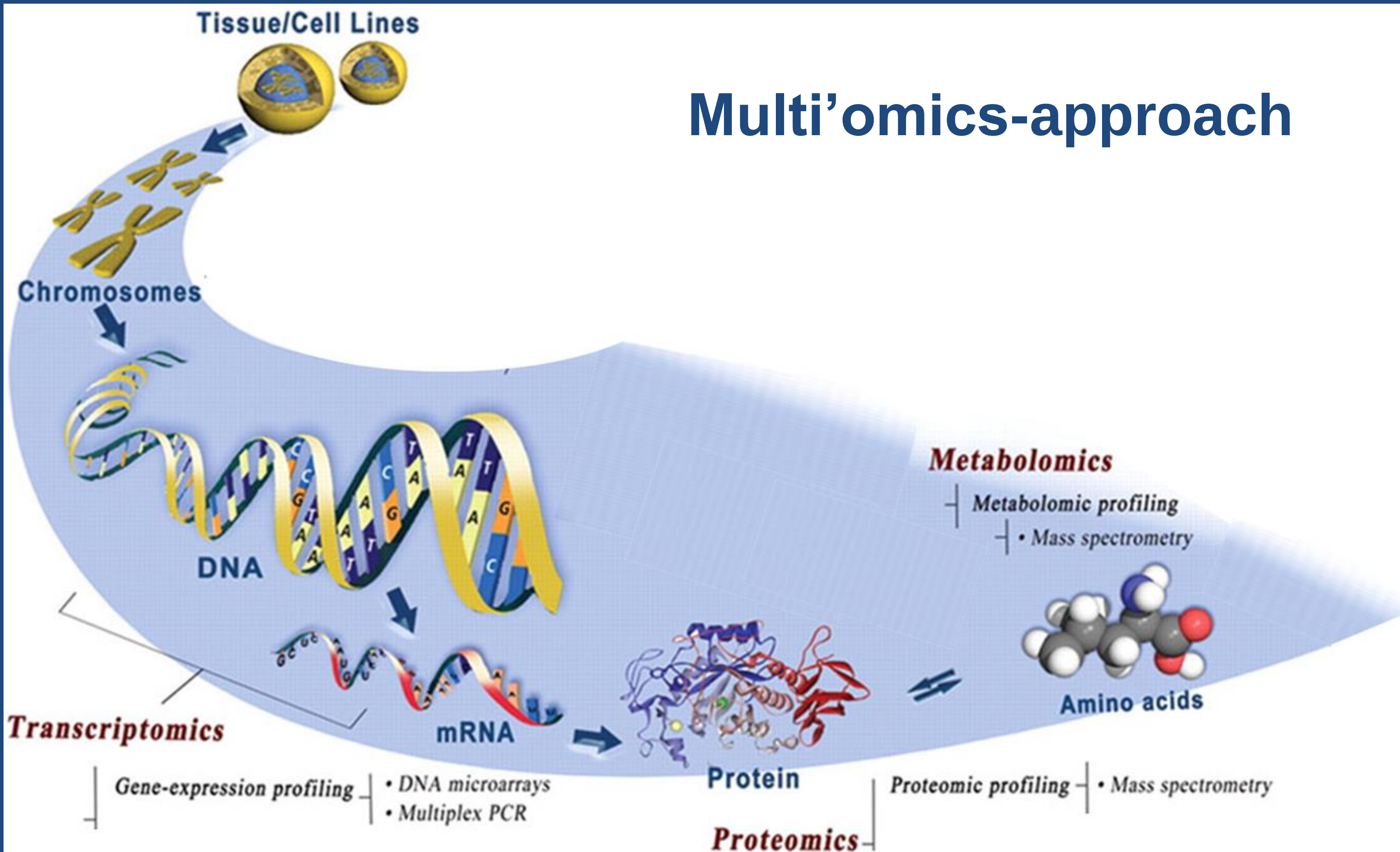
Characterization of biological effects of combustion aerosols: Exposure & Analyses

HICE-ALI-Exposure System (Vitrocell and KIT)



Characterization of biological effects of combustion aerosols: Exposure & Analyses

Multi'omics-approach



modified after :
Wu RQ, J Dent Res. 2011

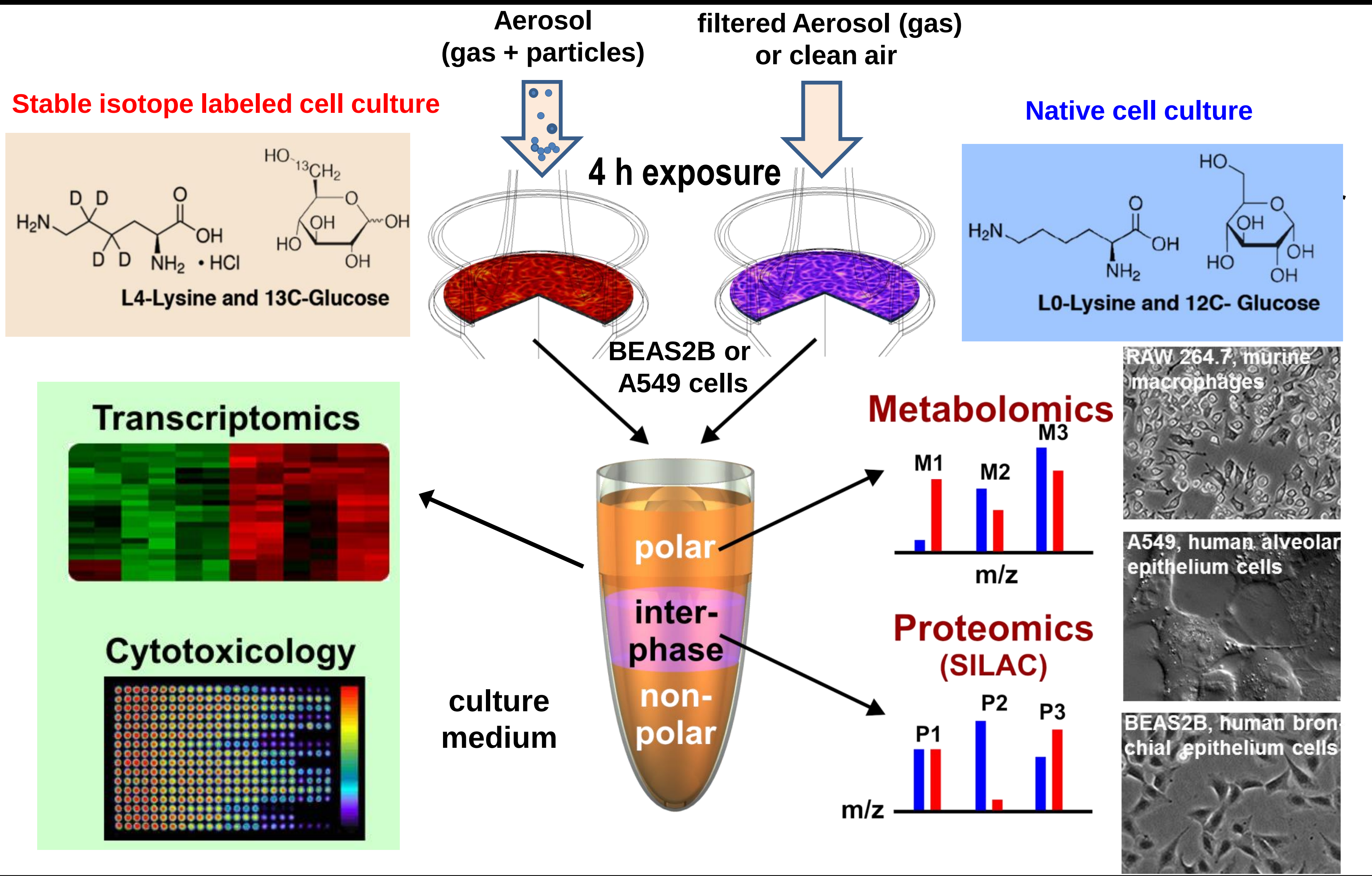
Characterization of biological effects of combustion aerosols: Exposure & Analyses

Biological effect analysis:

- Cytotoxicity & Viability (ATP/LDH assays)
- ‘Omics – regulation strength (Proteomics/Transcriptomics)
- ‘Omics pathway analysis (GO-Terms)
- Analysis of targets Proteins/RNA-Trans+crips

  (Cyp1A1, IL’s, JUN, TNFα etc.)
- Verification analysis via specific assays (genotoxicty etc.)
- Verification analysis via primary cell/animal exposure

Characterization of biological effects of combustion aerosols: Exposure & Analyses



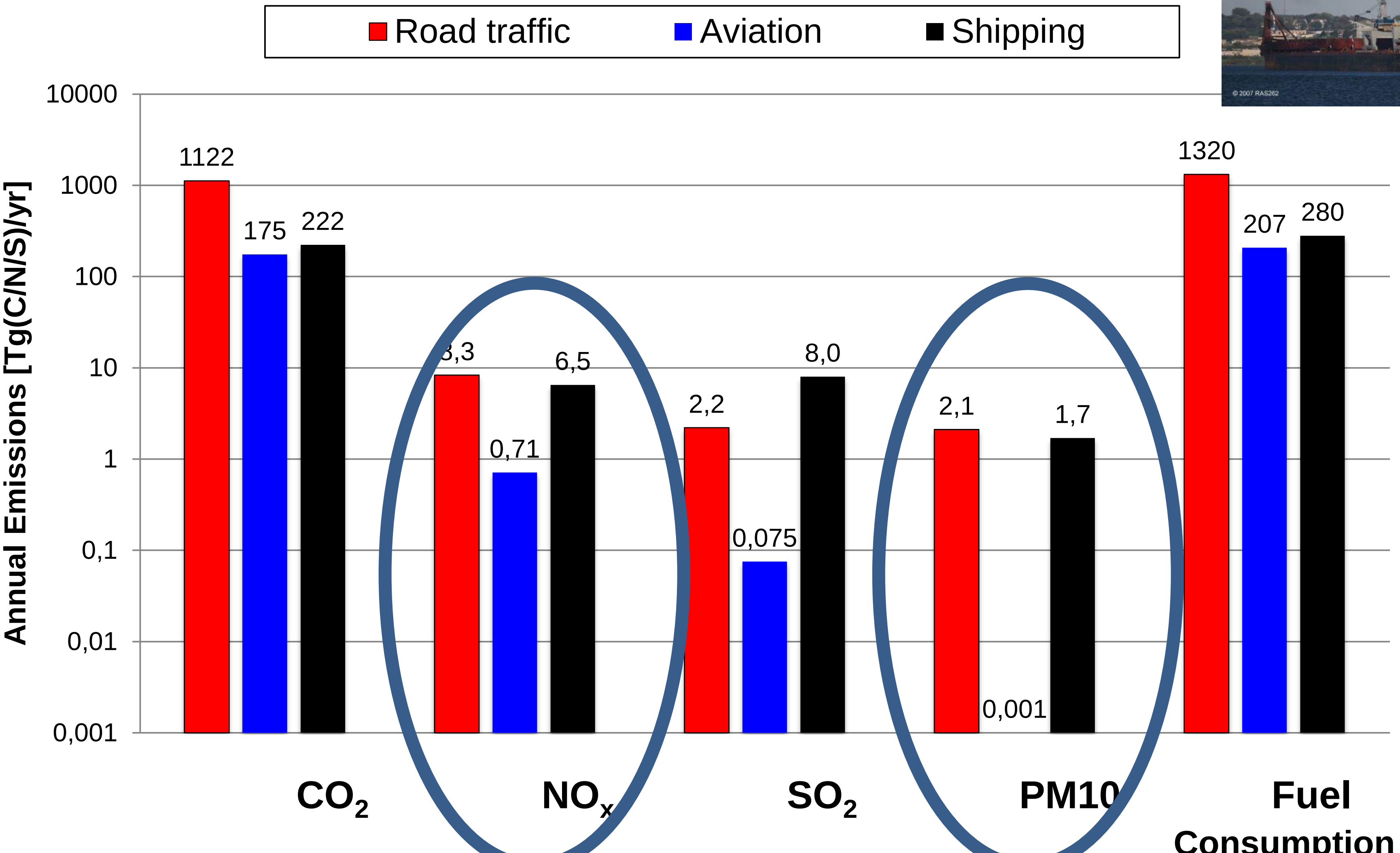
HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt
Mass Spectrometry Centre
Universität Rostock
Traditio et Innovatio

HICE-MOBILAB: Mobile biosafety class S2 cell culture & exposure Lab

HICE › Aerosols and Health
Helmholtz Virtual Institute of Complex Molecular Systems in Environmental Health

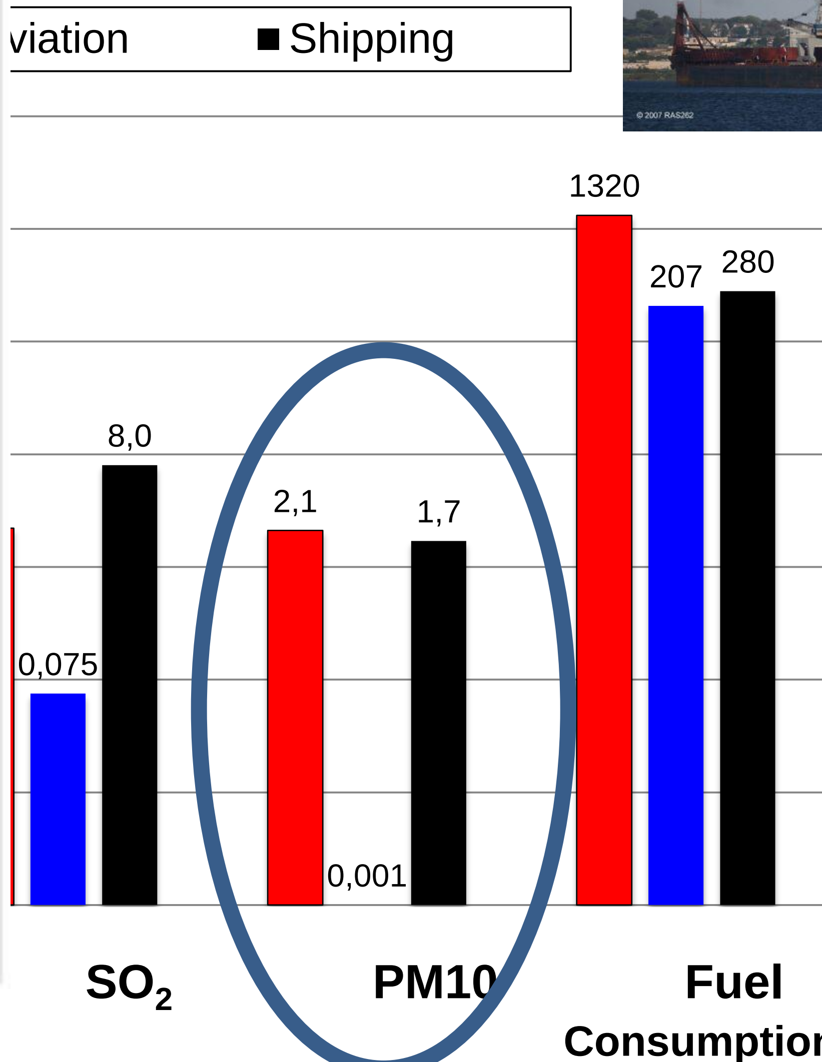
Air pollution by transportation sector

shipmanagementinternational.com/



Air pollution by transportation sector

A satellite image from 4 March 2009 showing ship tracks — the bright streaks of clouds that form around the particles in ship exhaust — over the northeast Pacific Ocean. The ship tracks are brighter than the natural marine clouds around them because they contain lots of small cloud droplets, which you can see in this zoomed-in image. NASA image by the LANCE/EOSDIS MODIS Rapid Response Team.

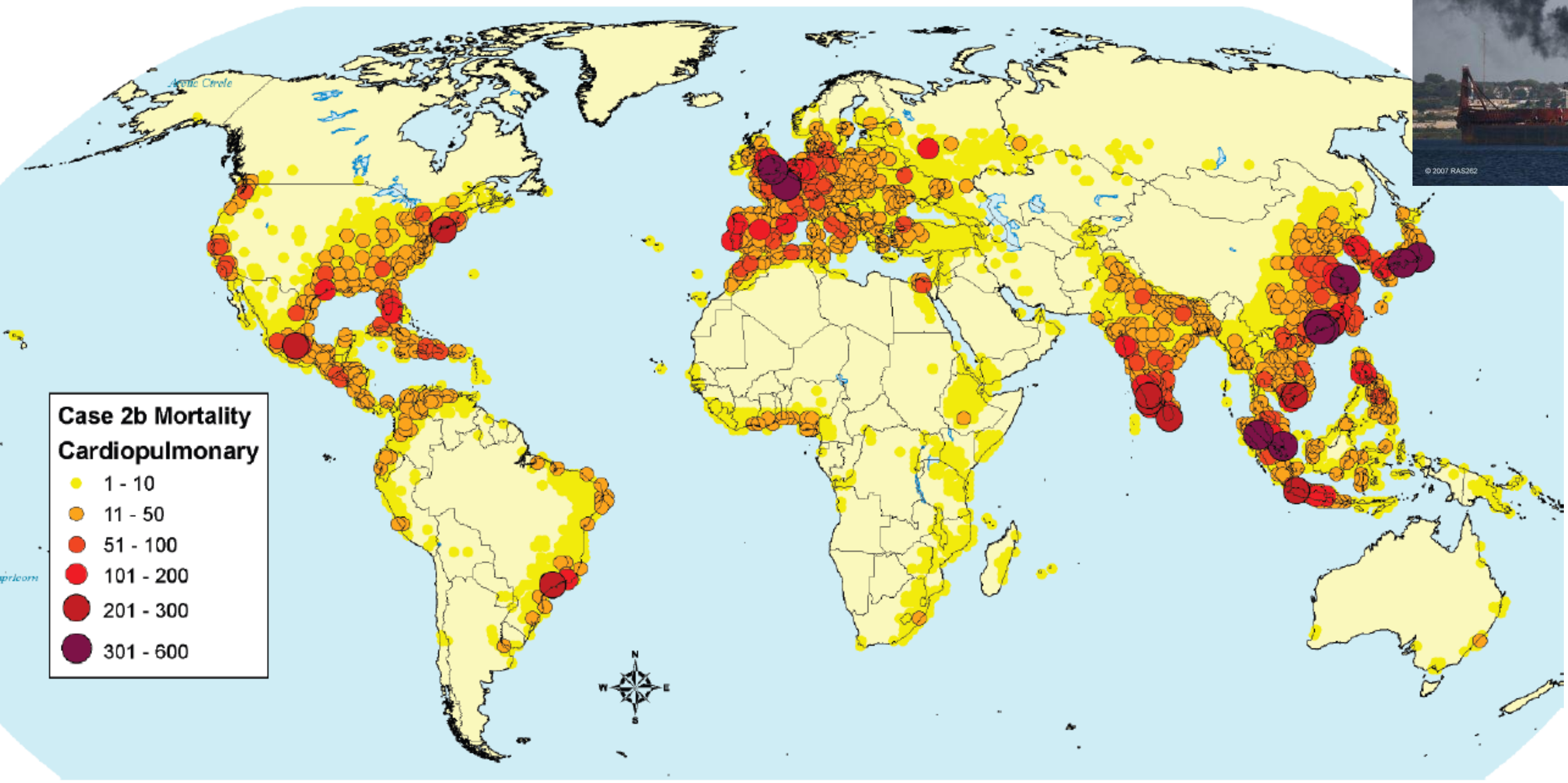


shipmanagementinternational.com/

Ship emissions & health effects

Ship emissions and human health: A global problem

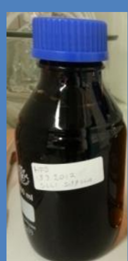
shipmanagementinternational.com/



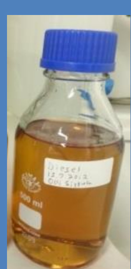
Corbett et al., ES&T 2007: Worldwide mortality cases due to pulmonary diseases attributable to ship pollution:~ 60.000 excess mortality cases/a

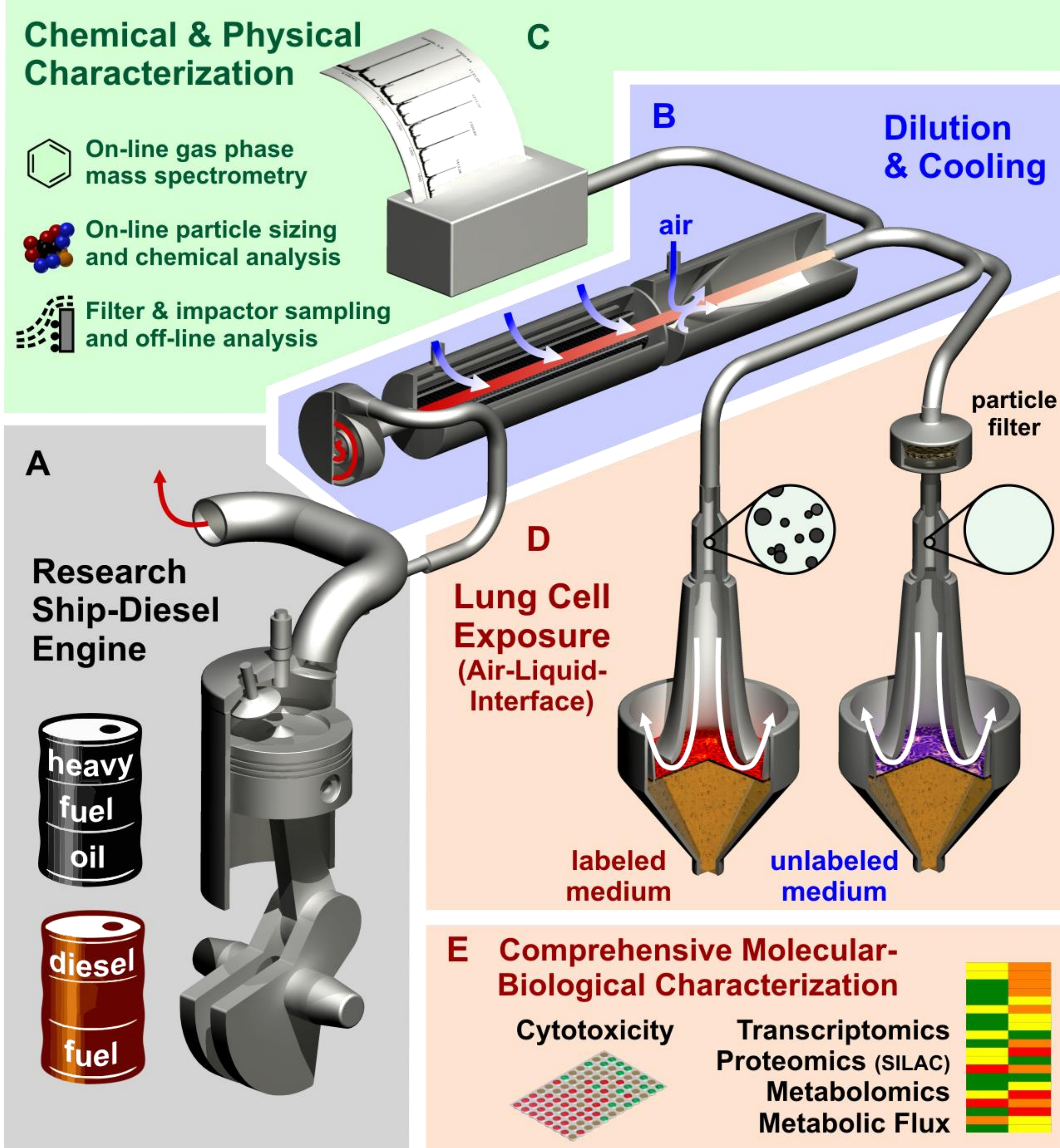
➔ ports /costal areas are in particular affected by (marine) shipping pollution

HFO

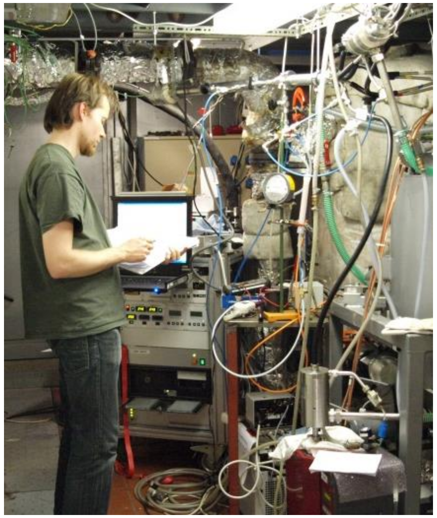


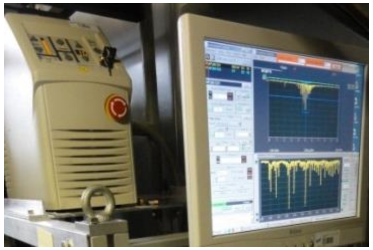
DF

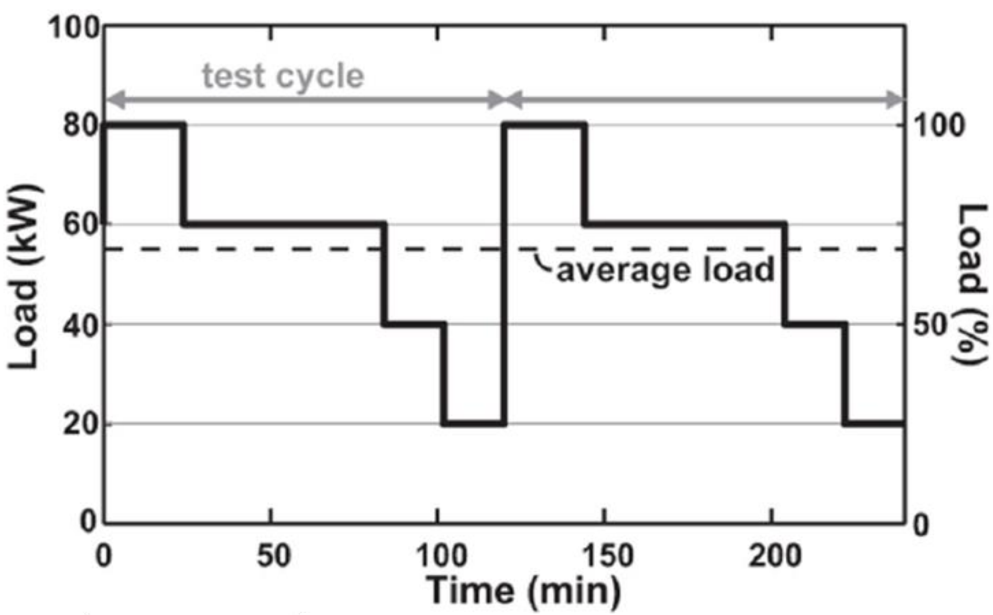


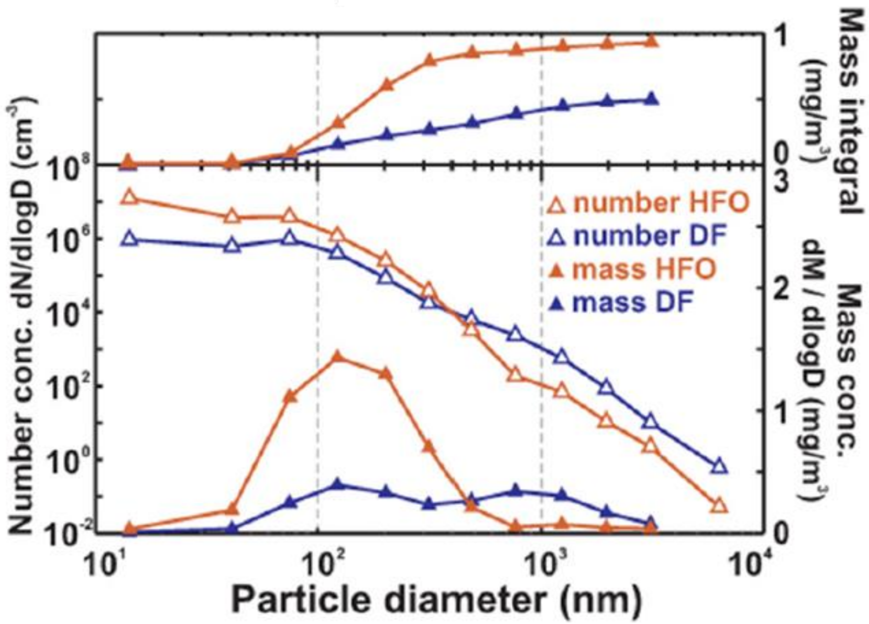

Chemical & Physical Characterization
C
On-line gas phase mass spectrometry
On-line particle sizing and chemical analysis
Filter & impactor sampling and off-line analysis
B
Dilution & Cooling
air
particle filter
A
Research Ship-Diesel Engine
heavy fuel oil
diesel fuel
D
Lung Cell Exposure (Air-Liquid-Interface)
labeled medium
unlabeled medium
E
Comprehensive Molecular-Biological Characterization
Cytotoxicity
Transcriptomics
Proteomics (SILAC)
Metabolomics
Metabolic Flux

HICE ship diesel engine campaign: Operation of engine and aerosol properties



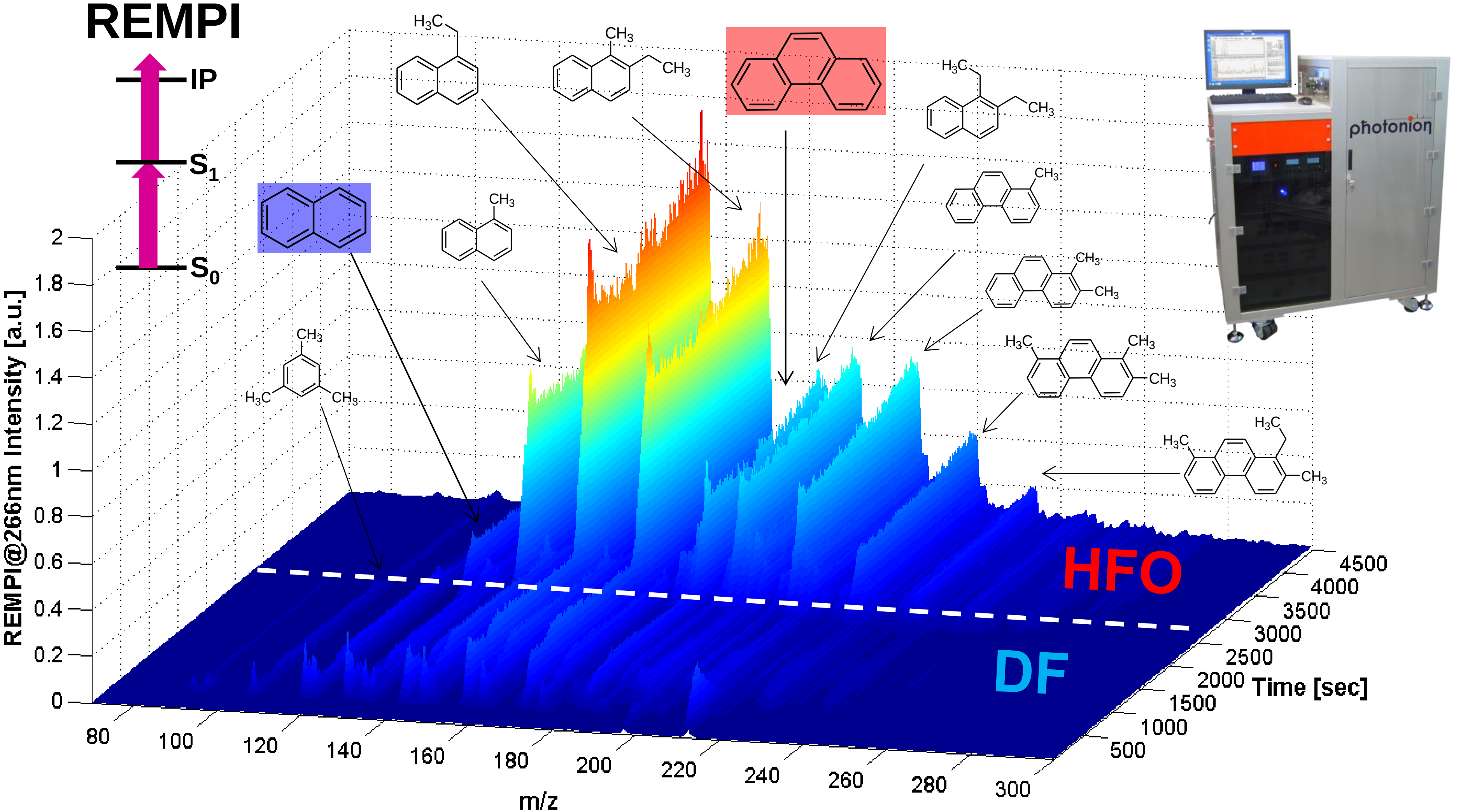




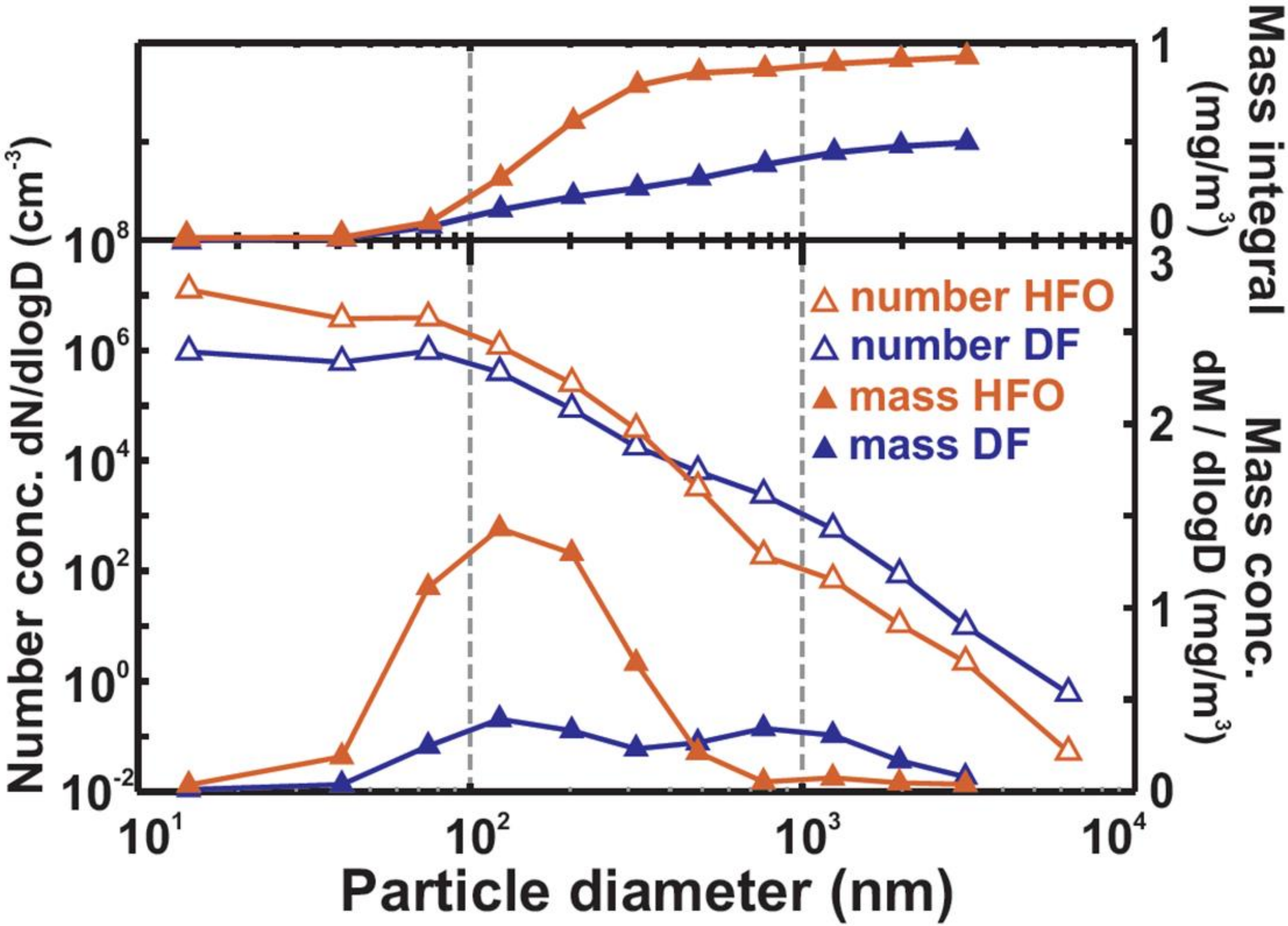


HICE ship diesel engine campaign: Characterization of the Aerosol

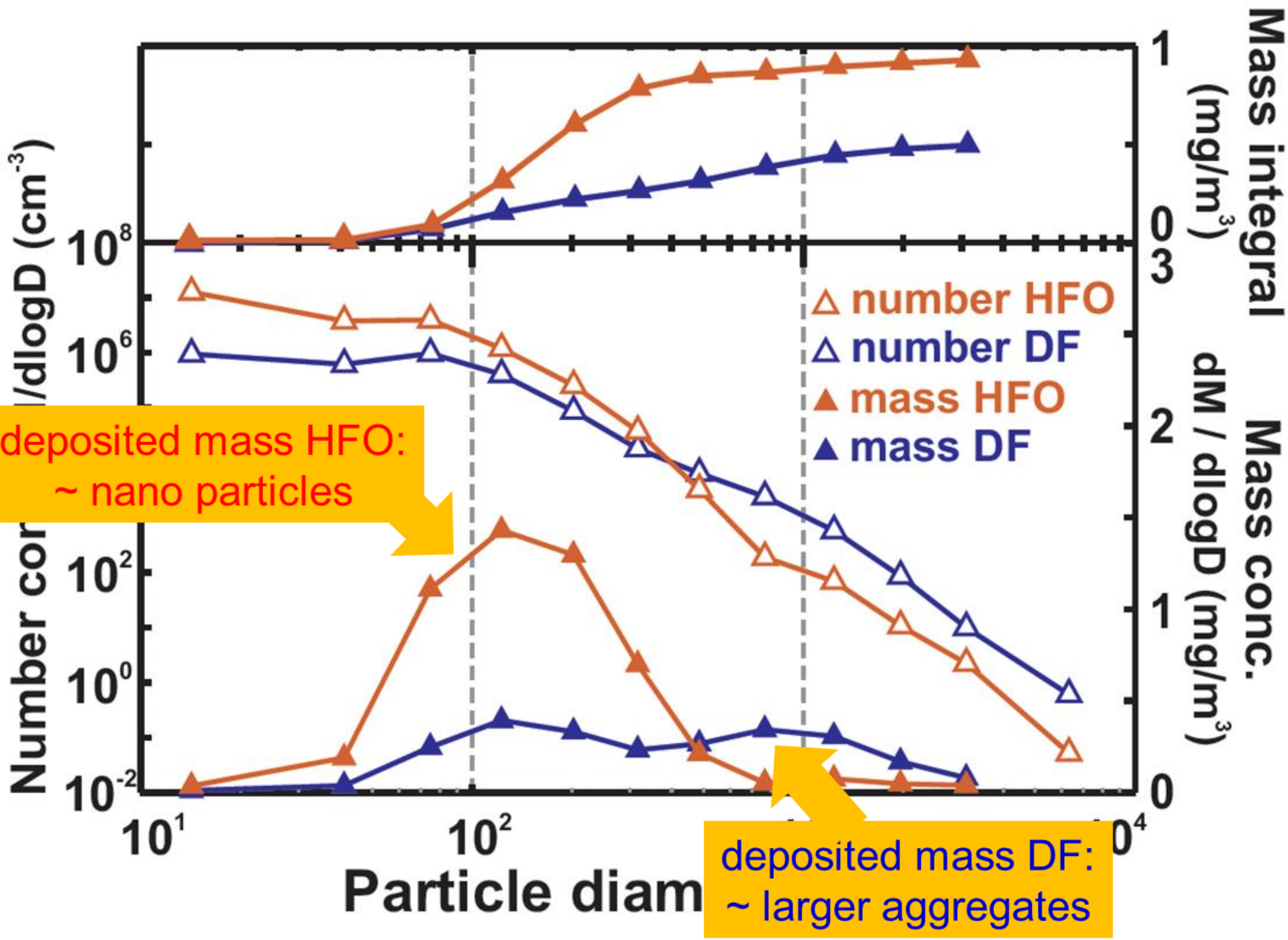
Switching from diesel fuel oil (DF) to heavy fuel oil (HFO) ➔ Increase of Polycyclic Aromatic Hydrocarbons (PAH) in exhaust gas



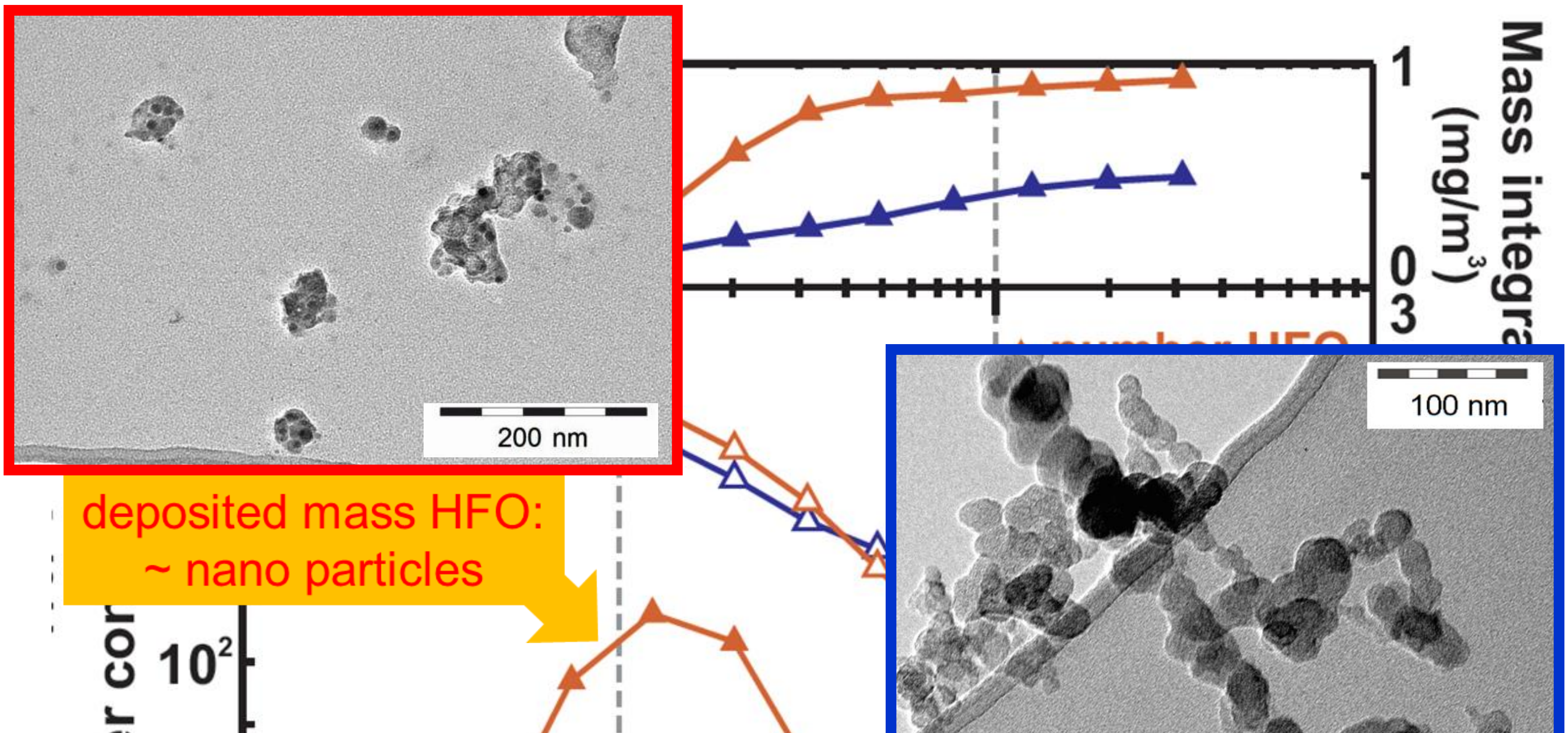
HICE ship diesel engine campaign: Characterization of the Aerosol



HICE ship diesel engine campaign: Characterization of the Aerosol



HICE ship diesel engine campaign: Characterization of the Aerosol



deposited mass HFO:
~ nano particles

ALI PM-deposition dose ship experiments:

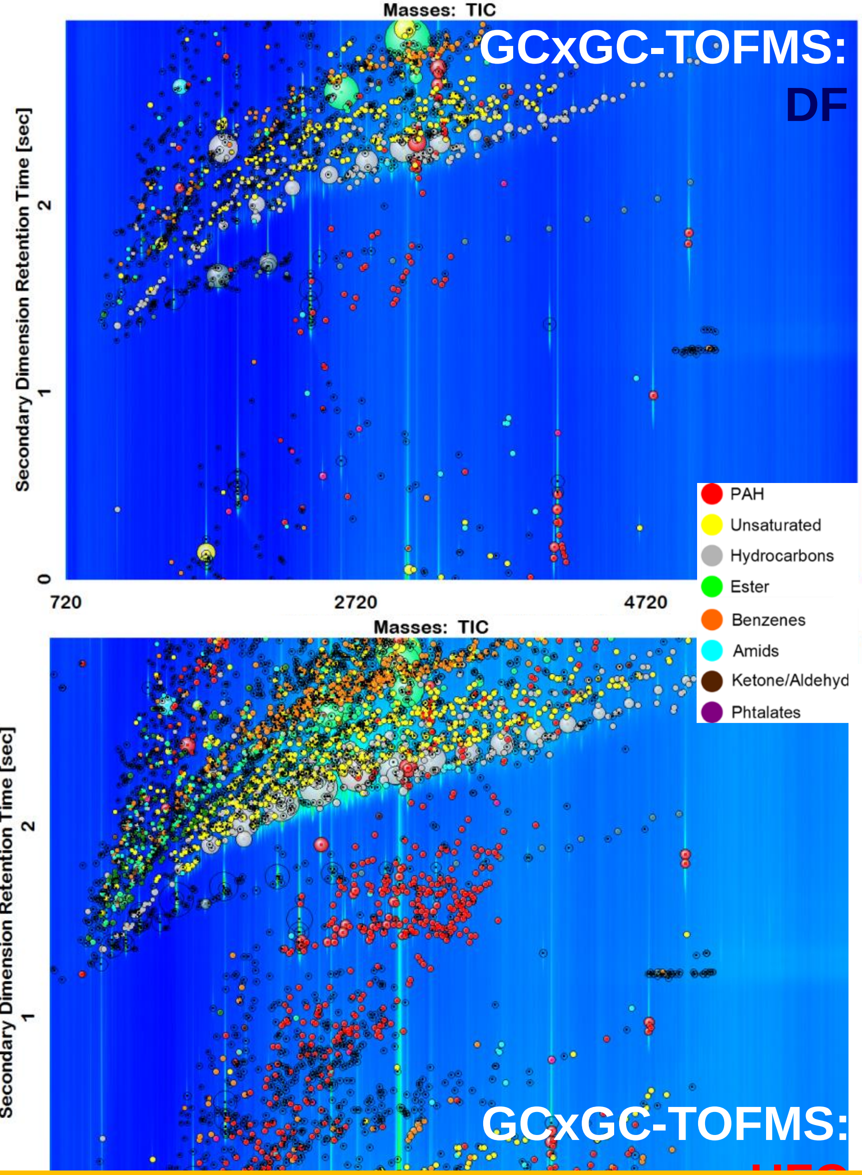
(estimation after Comouth et al., 2013, J Aerosol Sci)**:**

D_{HFO} ~ 56 ng PM/cm² and D_{DF} ~ 28 ng PM/cm²

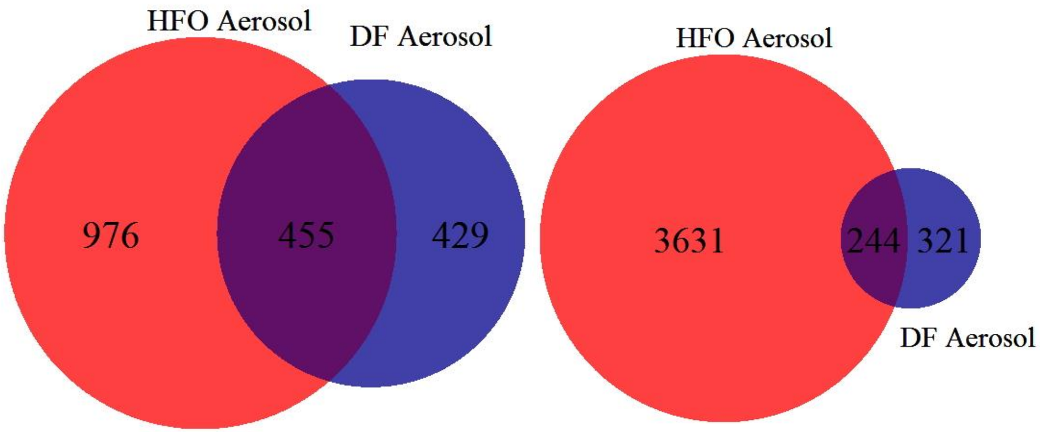
➔ Note: Higher dose for the HFO PM - deposition case!

HICE ship diesel engine campaign at U Rostock: Characterization of the Aerosol

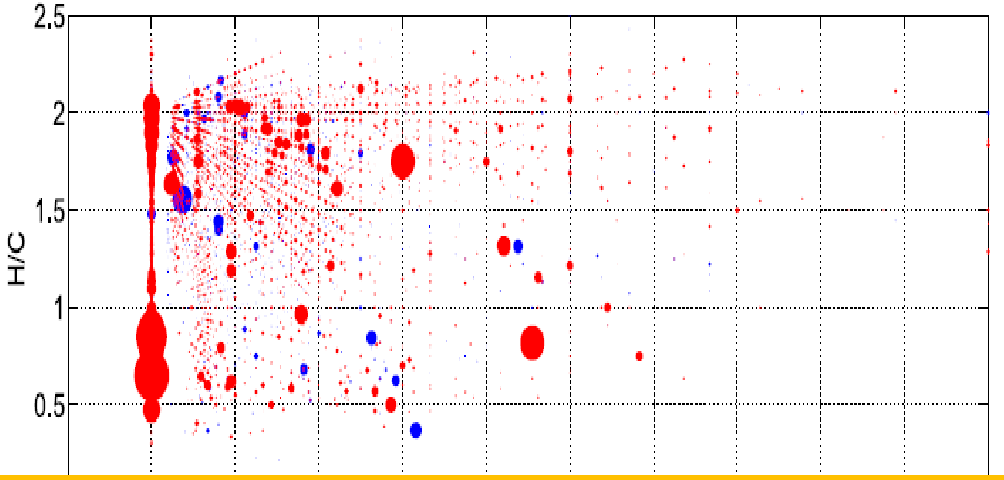
HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt
Mass Spectrometry Centre
Universität Rostock
Traditio et Innovatio
HICE Aerosols and Health
Helmholtz Virtual Institute of Complex Molecular Systems in Environmental Health



GC-APCI-FT-ICRMS and ESI-FT-ICRMS: HFO and DF



GC-APCI-FTICRMS: HFO and DF



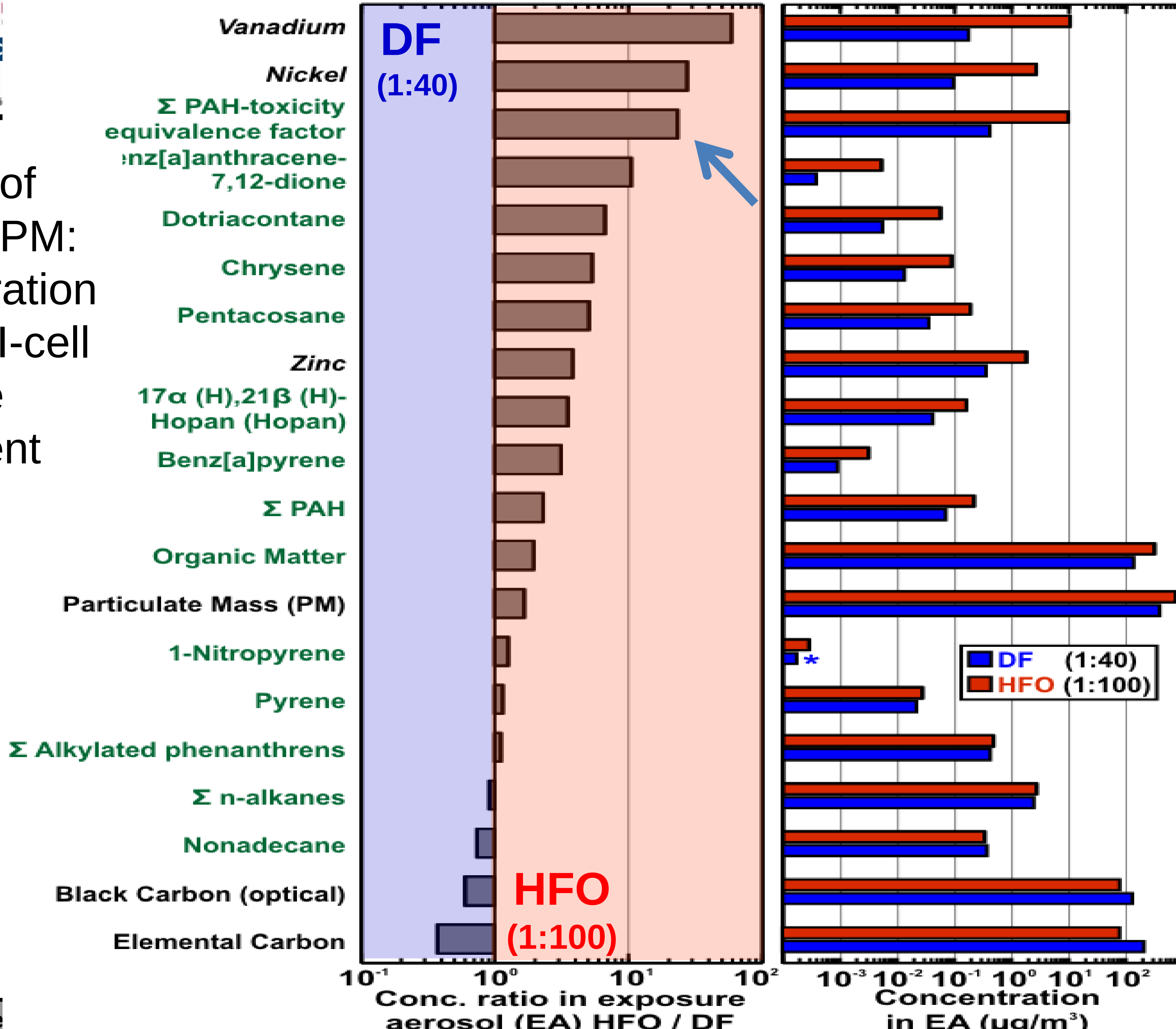
➔ Organic compounds: HFO PM much more complex than DF PM

HelmholtzZentrum mü
Deutsches Forschungszentrum für Gesundheit

Mass Spectrometry C

Universität Rostock

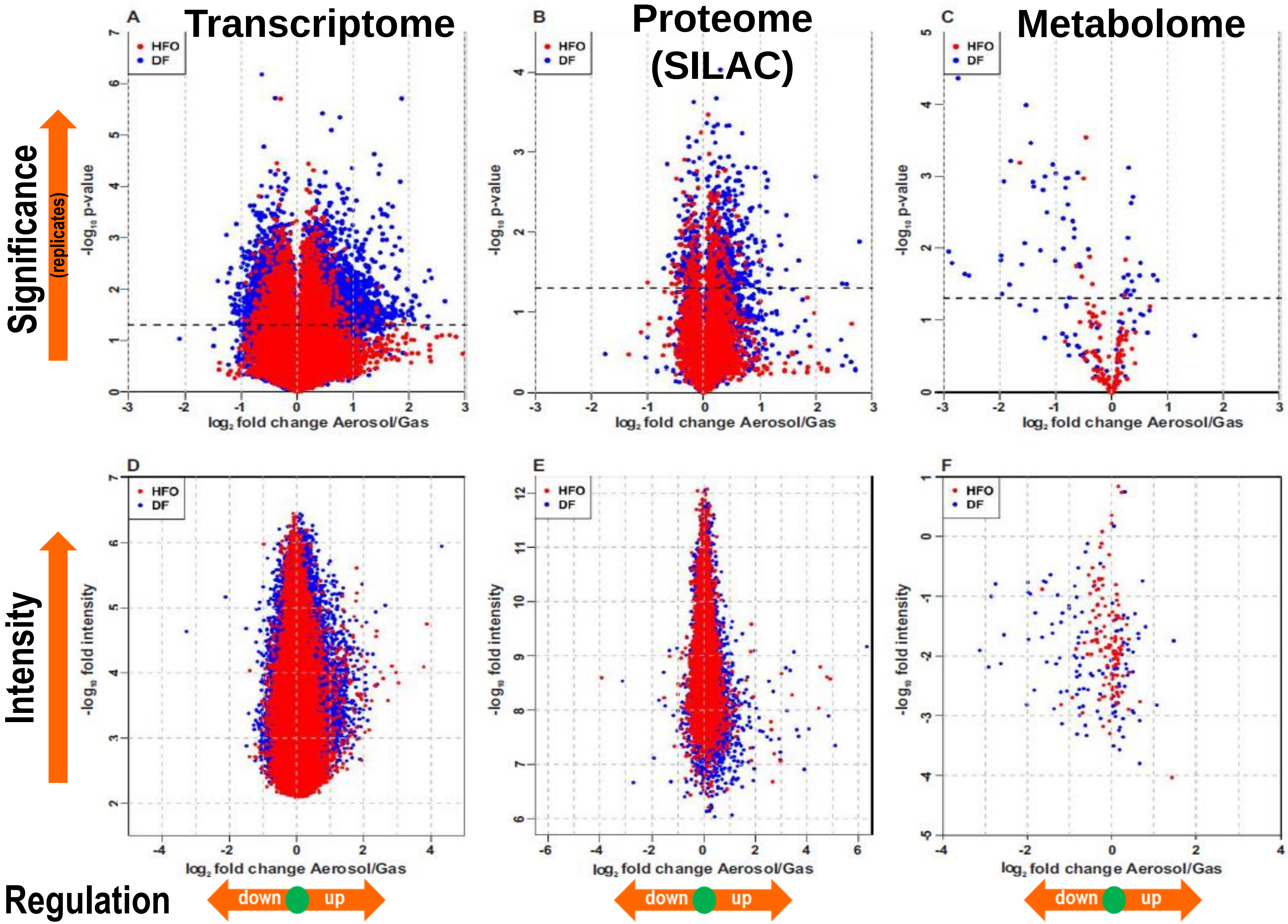
Analysis of shipping PM: Concentration at the ALI-cell exposure experiment



HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt
Mass Spectrometry Centre
Universität Rostock
Traditio et Innovatio

HICE ship diesel engine campaign: Biological effects on human lung cells

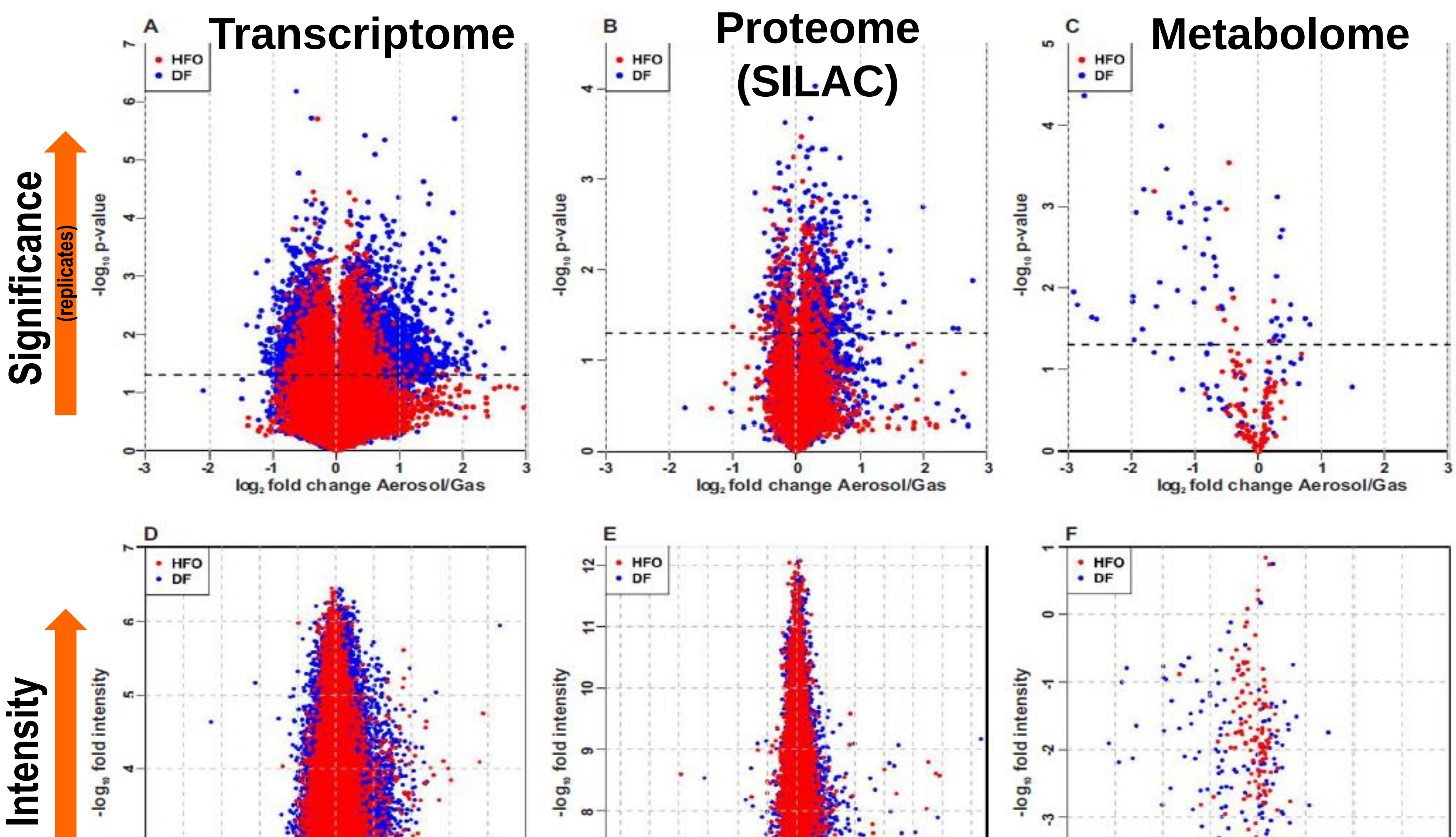
HICE › Aerosols and Health
Helmholtz Virtual Institute of Complex Molecular Systems in Environmental Health



HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt
Mass Spectrometry Centre
Universität Rostock
Traditio et Innovatio

HICE ship diesel engine campaign: Biological effects on human lung cells

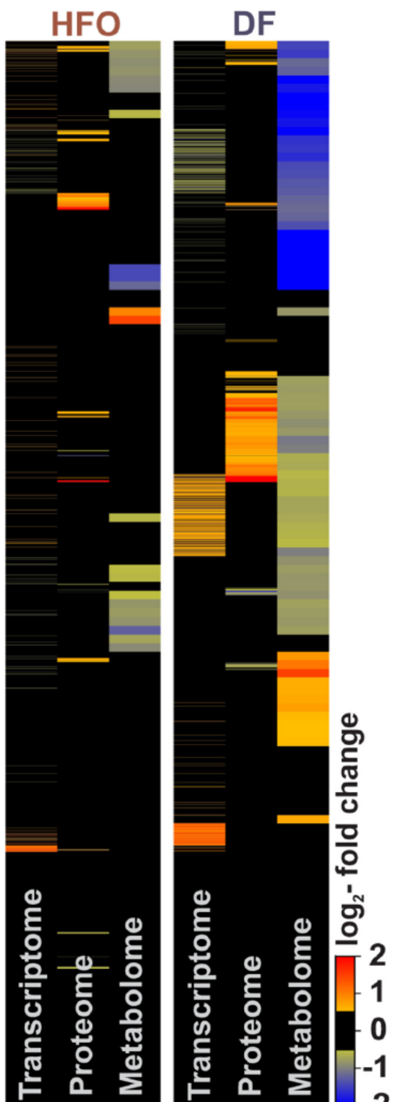
HICE › Aerosols and Health
Helmholtz Virtual Institute of Complex Molecular Systems in Environmental Health

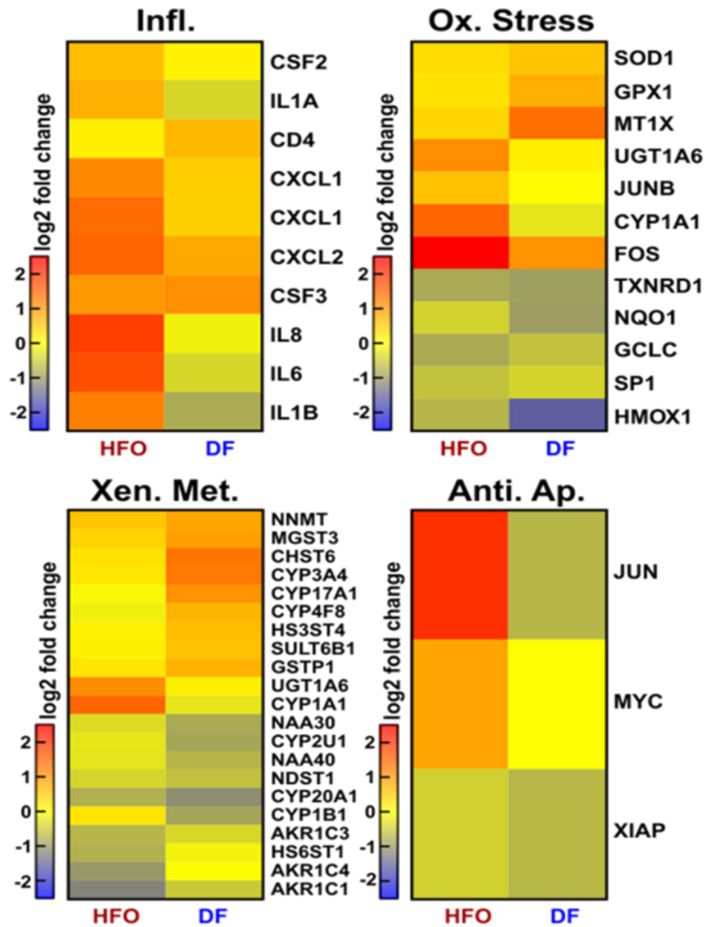


- Stronger biological activity (regulation strength) of DF-PM on all hierarchical biological levels (transcriptome, proteome, metabolome)
- Note: Dose of HFO-PM & content of toxic constituents is higher

HICE ship diesel engine campaign: Biological effects on human lung cells

regulation → selected markers → biological pathways

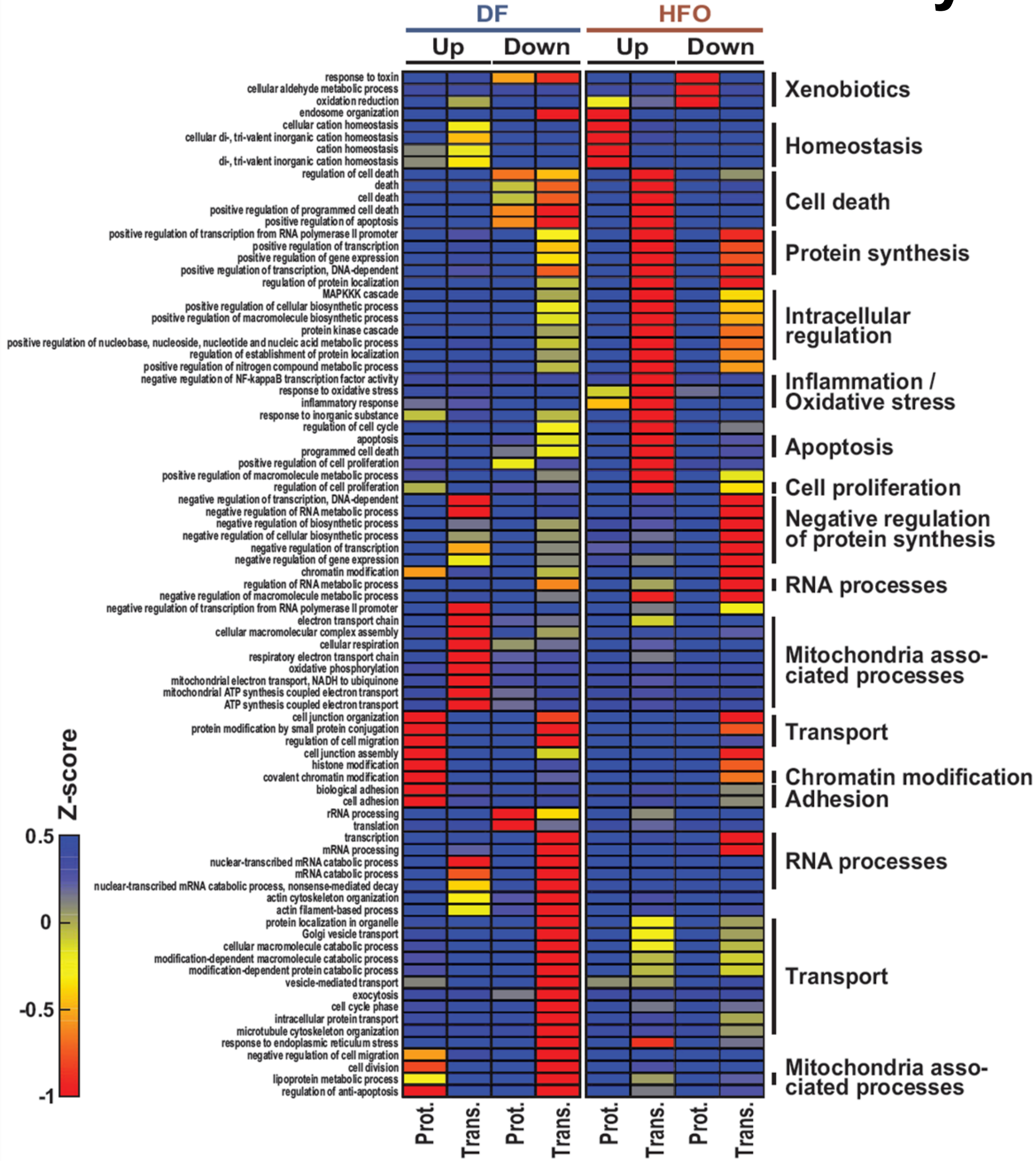




Effect	HFO	DF
Inflammation	↑	-
Oxidative Stress	↑	-
Cell homeostasis	↑	-
Response to chemicals	↑	↓↑
Cellular stress response	↑	↑
Motility	↑	↑
Endocytosis	↑	↑
Cellular signaling	MAPK, TGF beta, PDGF, EGF, GPCR	ID, kinase cascade
Energy metabolism	-	↑
Protein synthesis	-	↓
Protein degradation	-	↑
RNA metabolism	-	↓
Chromatin modifications	-	↑
Cell junction and adhesion	-	↓↑*

HICE ship diesel engine campaign: Biological effects on human lung cells

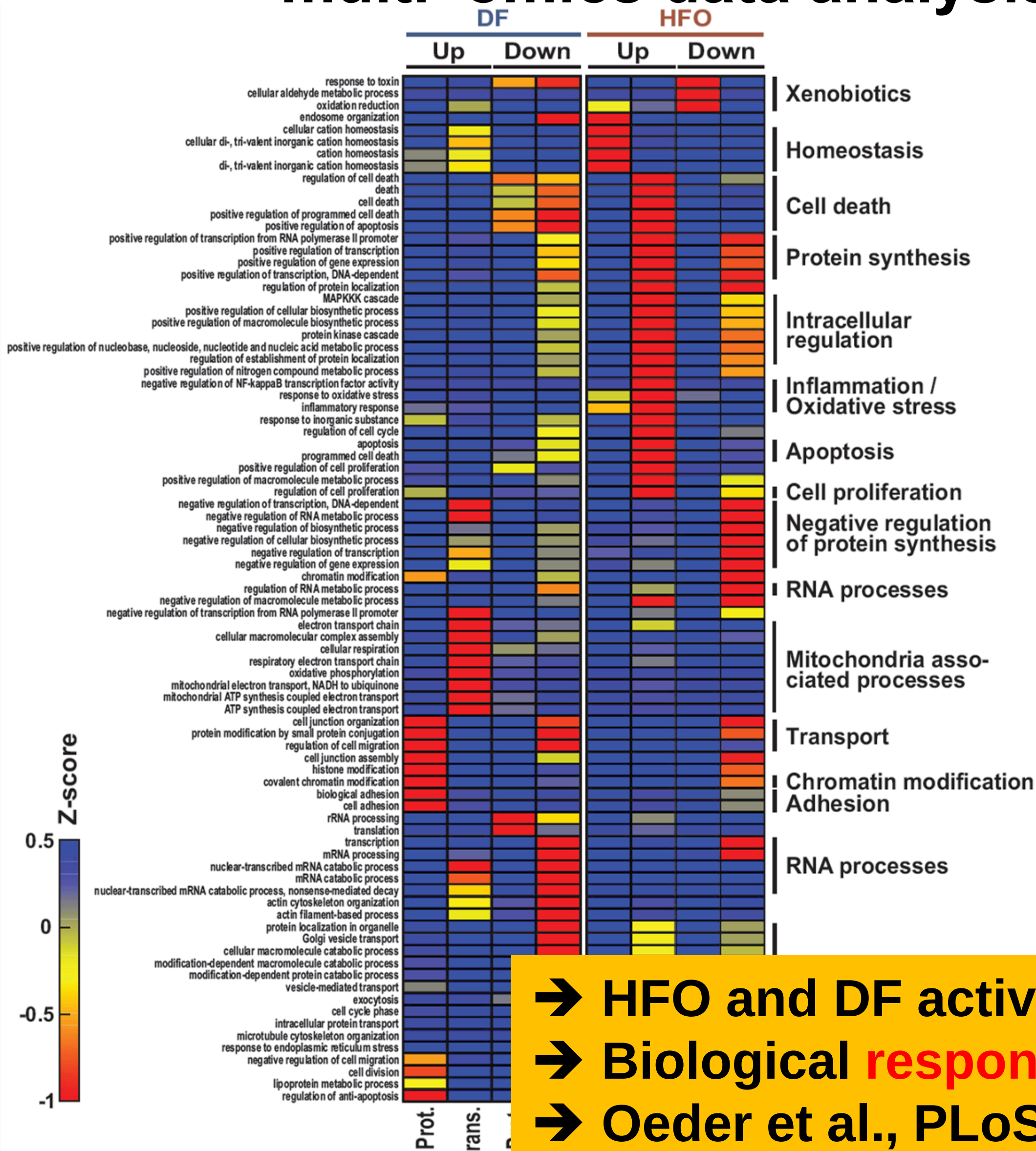
multi 'omics data analysis ➔ biological pathways



Effect	HFO	DF
Inflammation	↑	-
Oxidative Stress	↑	-
Cell homeostasis	↑	-
Response to chemicals	↑	↓↑
Cellular stress response	↑	↑
Motility	↑	↑
Endocytosis	↑	↑
Cellular signaling	MAPK, TGF beta, PDGF, EGF, GPCR	ID, kinase cascade
Energy metabolism	-	↑
Protein synthesis	-	↓
Protein degradation	-	↑
RNA metabolism	-	↓
Chromatin modifications	-	↑
Cell junction and adhesion	-	↓↑*

HICE ship diesel engine campaign: Biological effects on human lung cells

multi ‘omics data analysis ➔ biological pathways



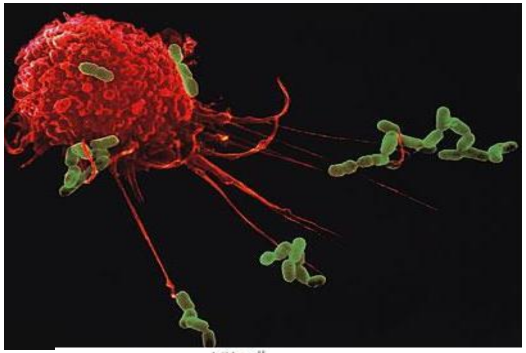
Effect	HFO	DF
Inflammation	↑	-
Oxidative Stress	↑	-
Cell homeostasis	↑	-
Response to chemicals	↑	↓↑
Cellular stress response	↑	↑
Motility	↑	↑
Endocytosis	↑	↑
Cellular signaling	MAPK, TGF beta, PDGF, EGF, GPCR	ID, kinase cascade
Energy metabolism	-	↑
Protein synthesis	-	↓
Protein degradation	-	↑
RNA metabolism	-	↓
Chromatin modifications	-	↑
Cell junction and adhesion	-	↓↑*

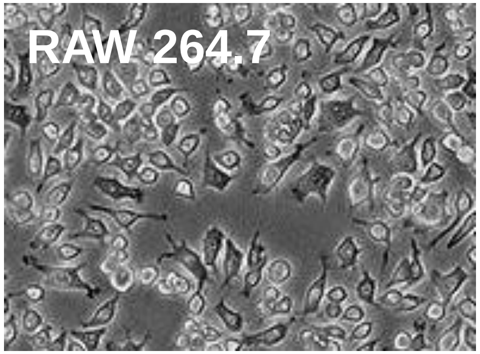
➔ HFO and DF activate different adverse pathways
➔ Biological response of DF stronger than HFO!
➔ Oeder et al., PLoS one, 2015

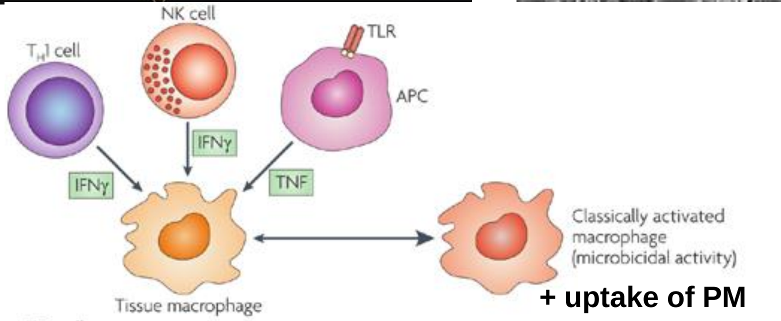
Validation of ship diesel results: Ship diesel exposure of RAW macrophages

Validation with Macrophage cell model (RAW 264.7, murine M.) Macrophages are phagocytotic innate immune cells heavily involved in inflammatory response

➔ Same exposure experiment as with the epithelial cells (DF, HFO)



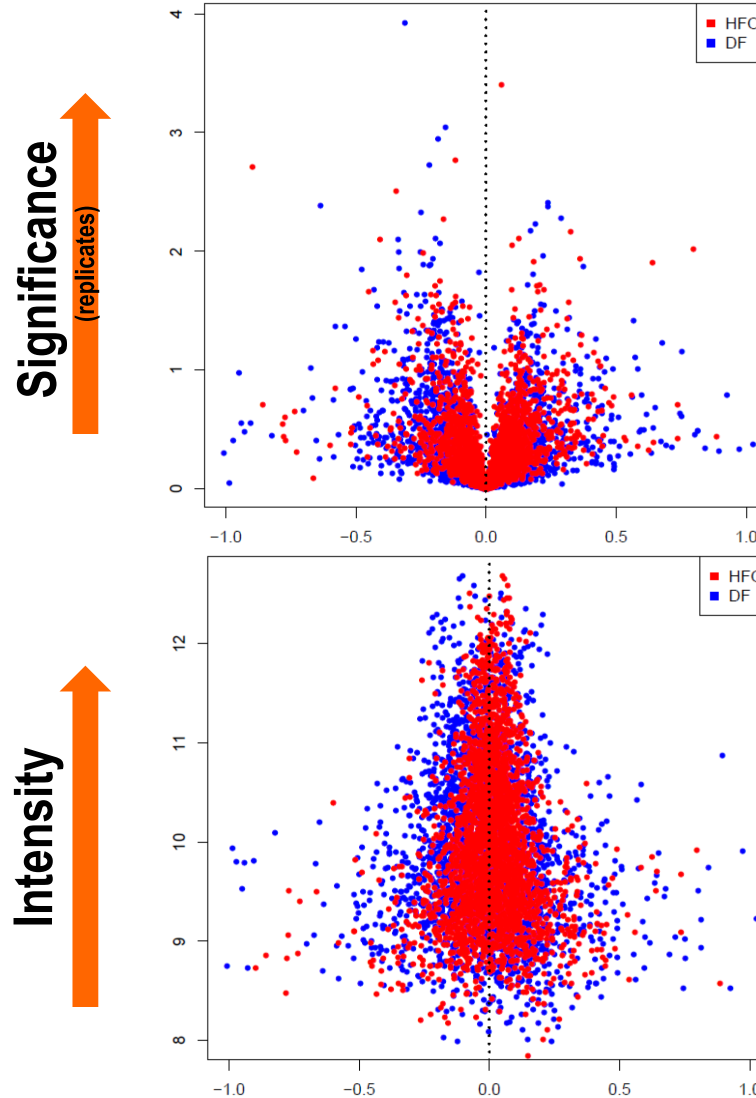




+ uptake of PM

Mosser and Edwards, *Nature Reviews Immunology* 2008 Nature Reviews | Immunology

Proteome (SILAC)

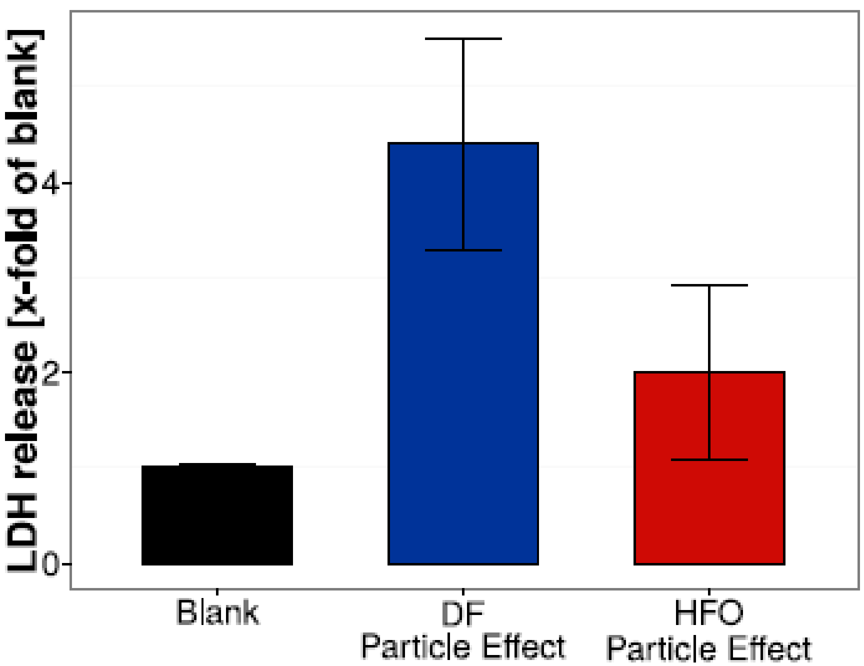


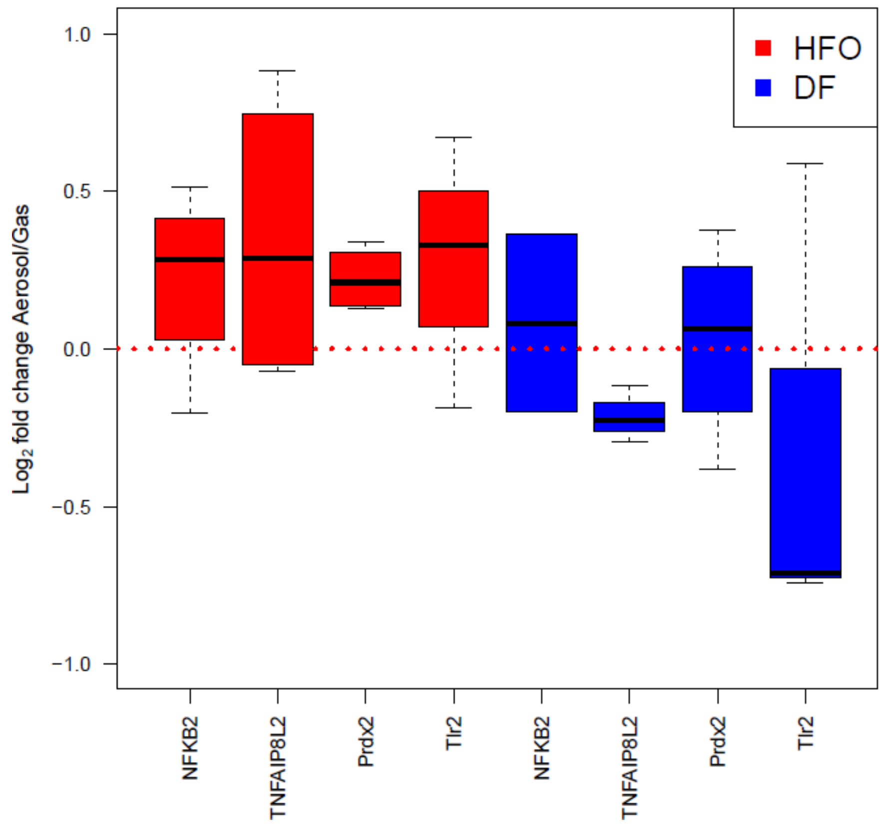
• RAW exp. confirms stronger regulation strength by DF-PM on proteomic level

Validation of ship diesel results: Ship diesel exposure of RAW macrophages

LDH assay for acute cytotoxicity
➔ Higher acute cytotoxicity of DF particles for macrophages!

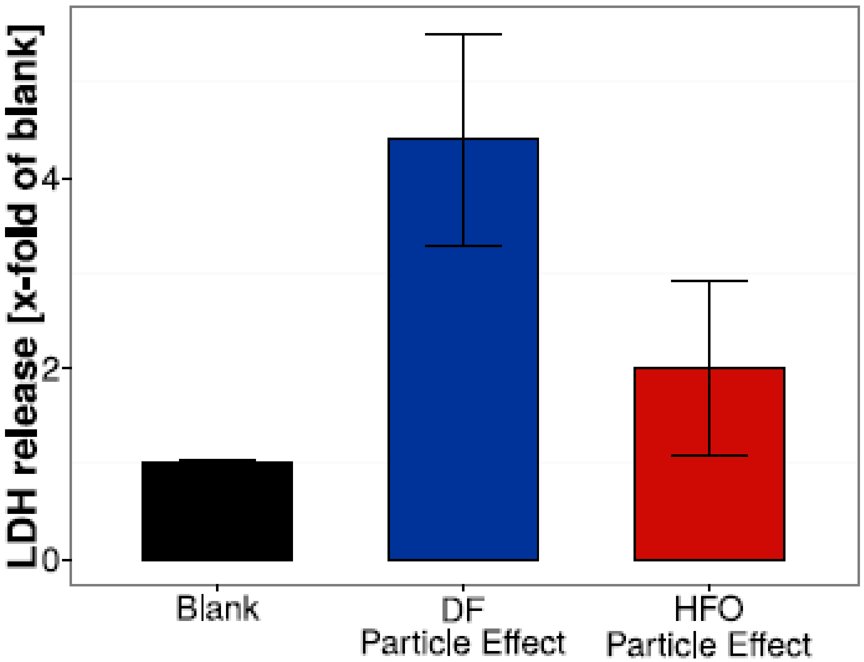
Proteomics ➔ Inflammatory pathways stronger activated by HFO particles for macrophages!



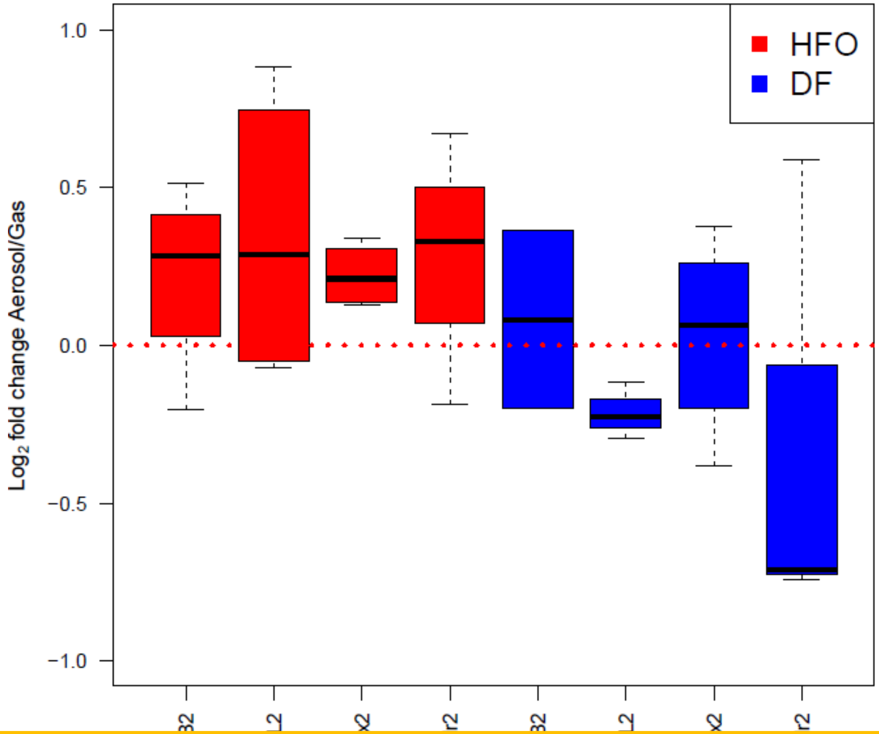


Validation of ship diesel results: Ship diesel exposure of RAW macrophages

LDH assay for acute cytotoxicity
➔ Higher acute cytotoxicity of DF particles for macrophages!



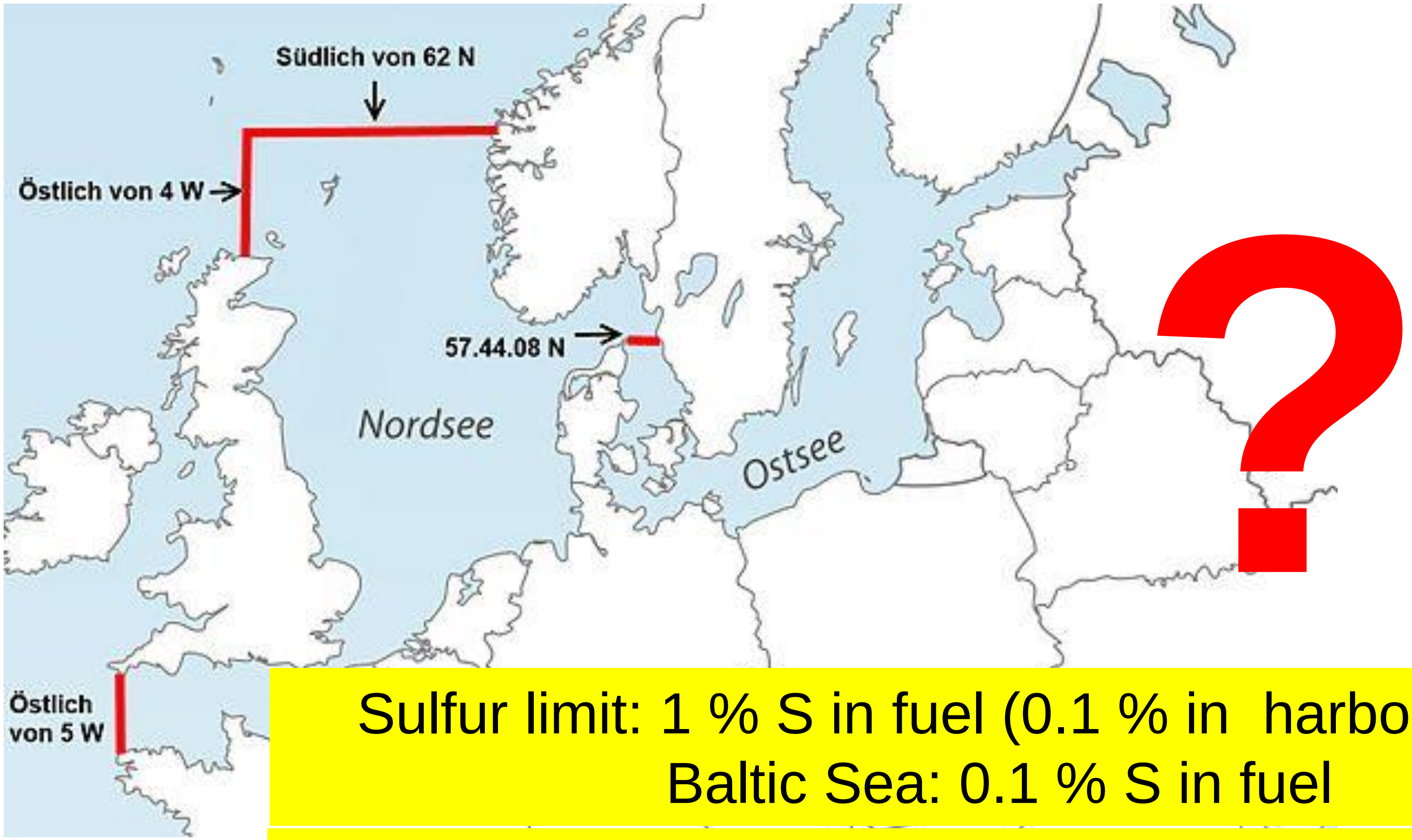
Proteomics ➔ Inflammatory pathways stronger activated by HFO particles for macrophages!



➔ RAW exposure show: DF PM indeed more toxic (acute) than HFO PM
➔ Pathway analysis also confirm results on epithelial cells
➔ Conclusion: Higher overall regulation strengths ➔ higher toxicity!
➔ Sapcariu et al., PLoS one, 2016

Introduction: IMO regulation to reduce Sulfur in shipping fuels – does it help?

Sulphur Emission Control Areas (SECA) by the International Maritime Organization (IMO)

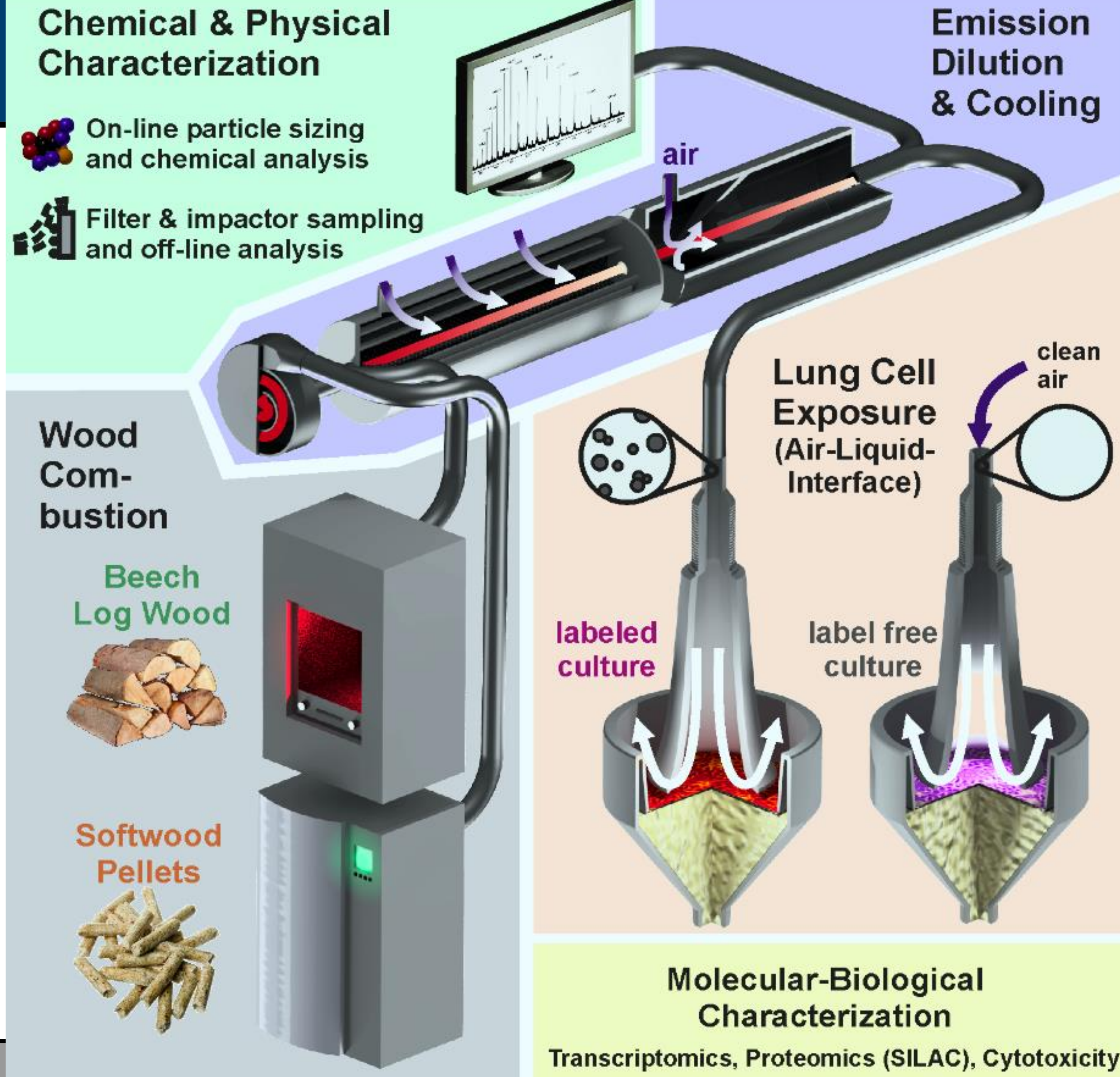


Sulfur limit: 1 % S in fuel (0.1 % in harbor)
Baltic Sea: 0.1 % S in fuel

Suggestion: Don’t play with fuel or engines but filtrate the inhalable particles !

HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt
Mass Spectrometry Centre
Universität Rostock
Traditio et Innovatio

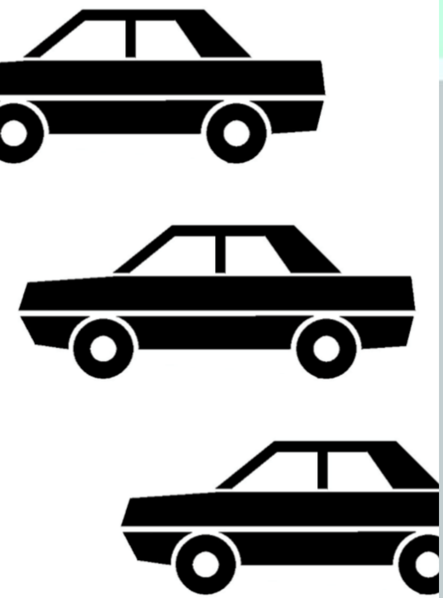
UNIVERSITY OF EASTERN FINLAND

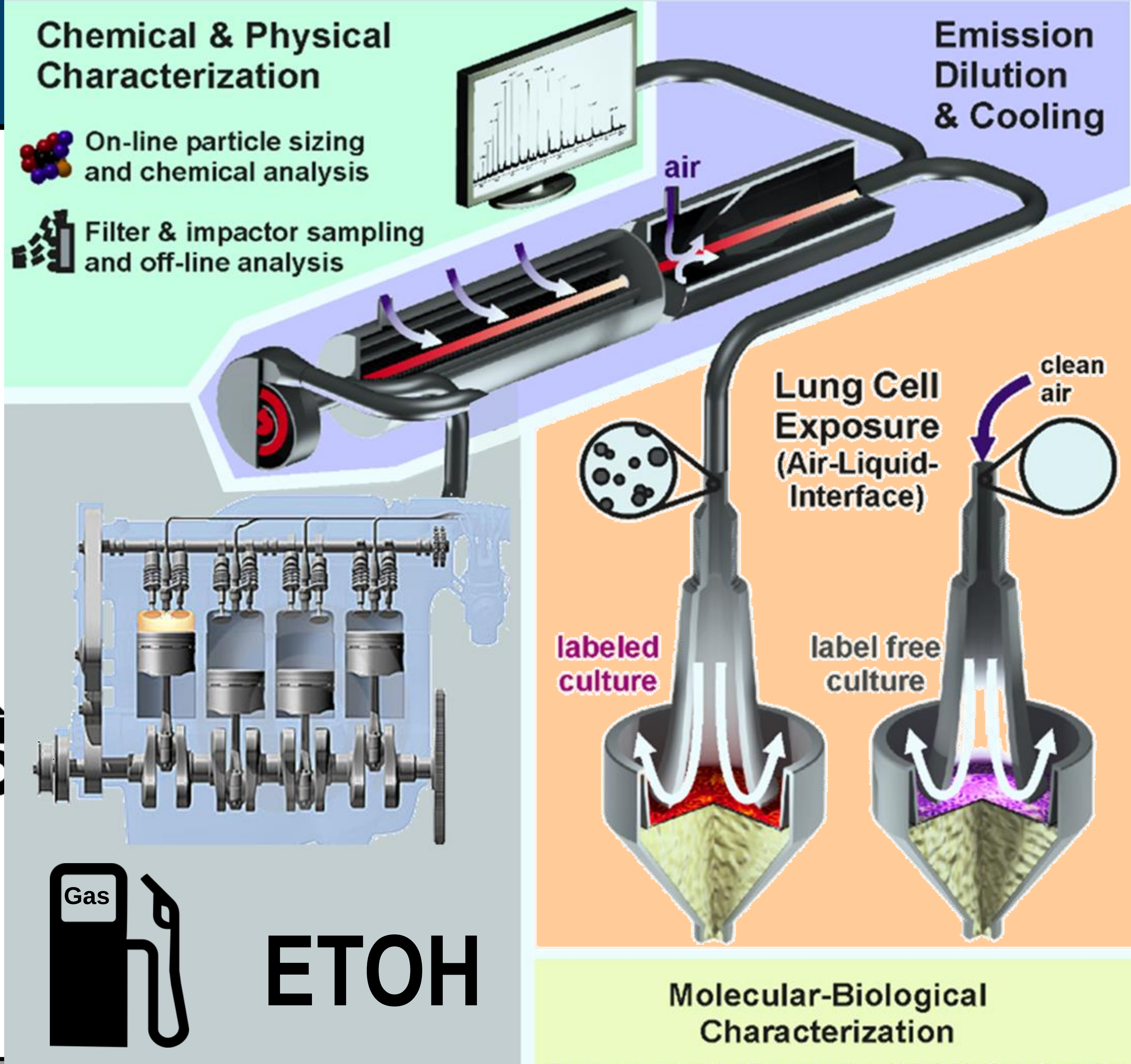


R. Zimmermann et al.

HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt
Mass Spectrometry Centre
Universität Rostock
Traditio et Innovatio

LKV ROSTOCK





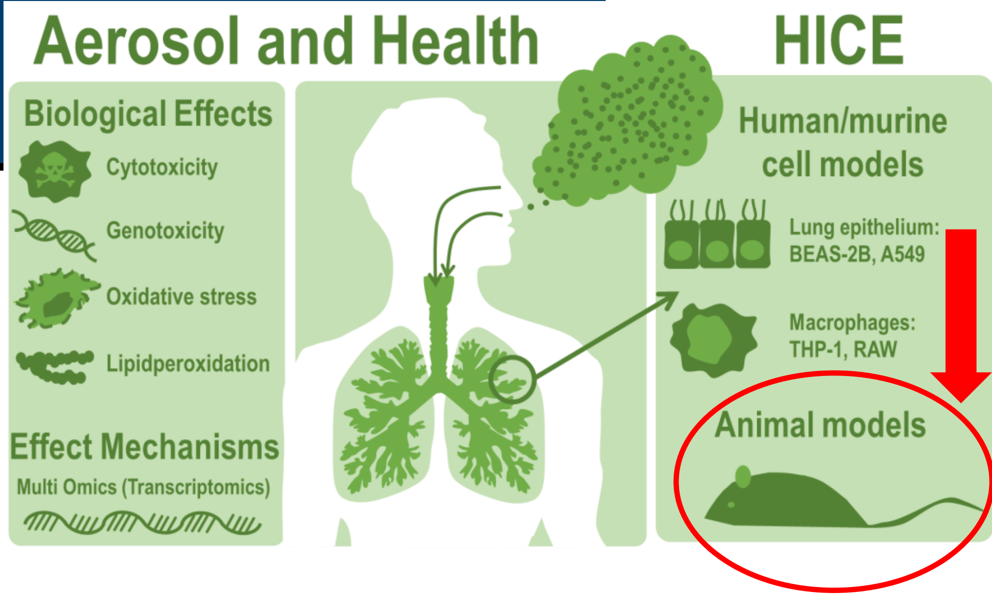
R. Zimmermann et al.

http://nl.dreamstime.com, https://pixabay.com

Summary

- Successful HICE ship diesel, wood combustion and car exhaust ALI cell and animal exposure field campaigns.
  ➔comprehensive analysis: Aerosol properties and biological response on human lung cells on the molecular biological level
- Composition/properties of combustion aerosol emissions of the different combustion sources are extremely different
- Biological activity and acute toxicity differs largely as well. Partly unexpected behavior – aerosol components cold be adverse or protective, synergistic effects are likely
- First validation of ALI approach with animal exposure successful
- ***→ Diesel PM highly adverse – Shipping emission problematic!***
  → Pellet burners w/o PM precipitation questionable
  → Log wood burner/HFO ships: High PAH emission – genotoxicity
  → Car emissions: Strong contribution of gas phase (in part. ETOH!)

Outlook ….



Validation of ALI-cell exposures with **animal exposures (mice)** and analysis of cells in BALF (Broncho-Alveolar Lavage Fluid), i.e. mainly macrophages

➔ HICE-Measurement campaign Nov. 2016:
Joint exposure of cell lines (ALI) and animals at the ILMARI facility at University of Eastern Finland (UEF) (with Jokiniemi and Hirvonen research groups)

➔ 12 h exposure (3x4 h) of healthy male C57BL/6J mice with 1:15 diluted diesel exhaust: Transcriptomic analysis of BALF of macrophages in BALF ➔ Clear effects (Cytotox, Genotox and Transcrptomics) visisble

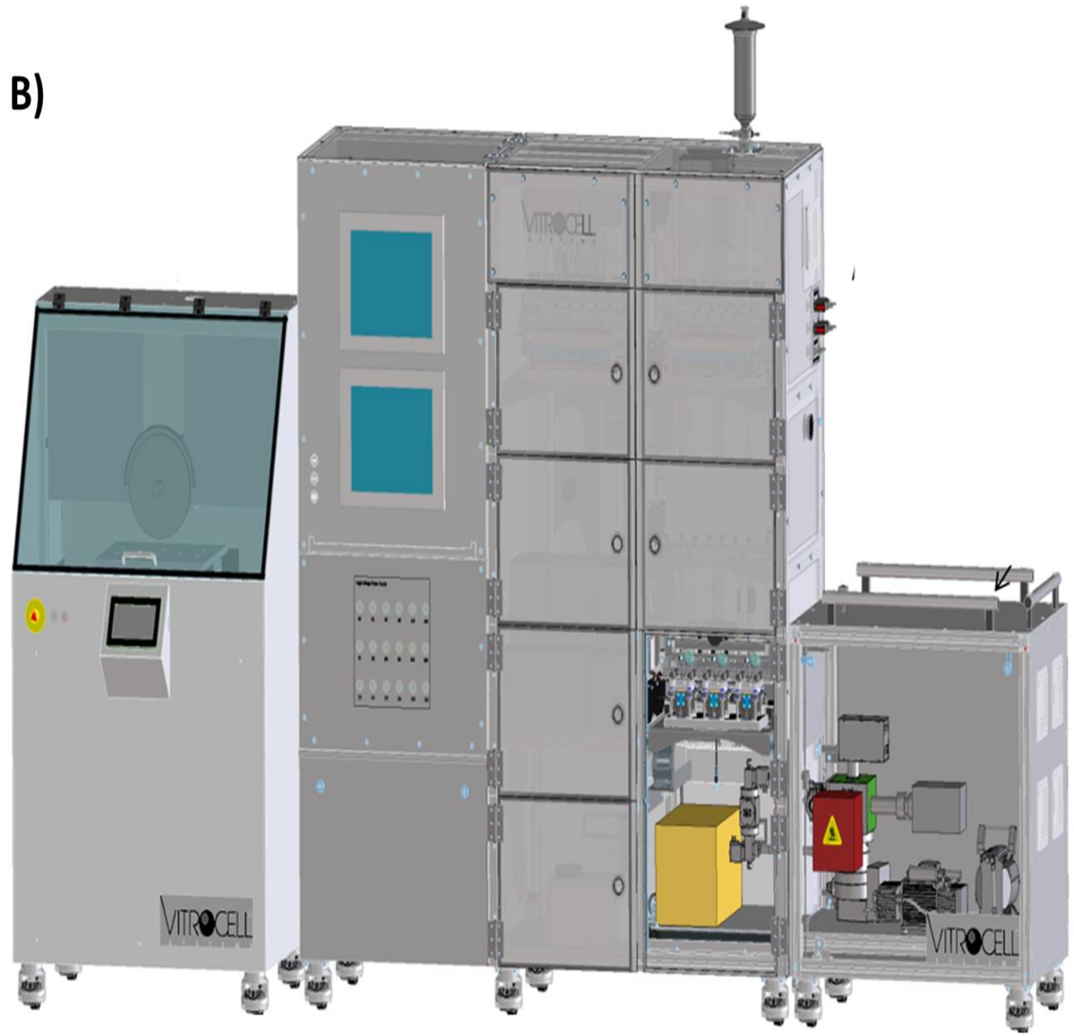
➔ Validation of animal results via murine macrophage (RAW) and human cell lines (THP1/A549/Beas2B) under progress

M. Happo (UEF), S.Öder (HMGU) et al.

Outlook ….

A)

B)



➔ New improved ALI-exposure technology (B) for lung cell exposure with mechanically generated dust (concrete dust, break-/clutch-wear etc.), C3-BMBF 2020 Project

HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt
Mass Spectrometry Centre
Universität Rostock
Traditio et Innovatio

Acknowledgements: HICE-measurement campaigns

HICE › Aerosols and Health
Helmholtz Virtual Institute of Complex Molecular Systems in Environmental Health

Car campaign (gasoline, ethanol), Rostock

Diesel, wood and ageing campaign w. animals, Kuopio

Ship campaign (diesel, heavy fuel oil), Rostock

Wood campaign (pellet, log wood, wood types), Kuopio

Zimmermann Group @ Joint Mass Spectrometry Centre

Universität Rostock Traditio et Innovatio

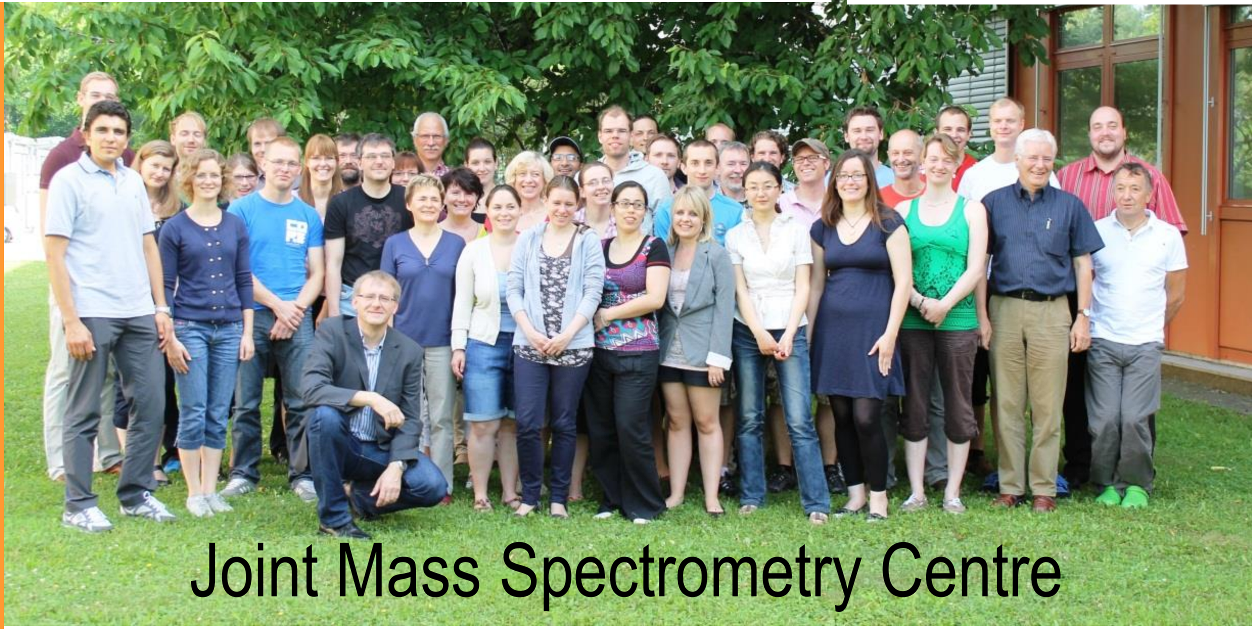
HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt

JOINT MASS SPECTROMETRY CENTRE

HICE › Aerosols and Health
Helmholtz Virtual Institute of Complex Molecular Systems in Environmental Health

Dr. T. Streibel
Dr. J. Schnelle-Kreis
Dr. M. Sklorz
Dr. J. Lintelmann
Dr. J. Passig
Dr. G. Jakobi
Dr. S. Smita
Dr. J. Orasche
Dr. S. Haack
Dr. S. Ehlert
Dr.. S. Öder
E. Hübner
T. Gröger
T. Miersch
A. Sutherland
C. Rüger
T. Schwemer
G. Dragan
H. Czech
V. Kohlmeier

S. Erdmann
B. Weggler
P. Sattler
G. Abbazade
E. Karg
B. Gruber
M. Jennerwein
F. Li
L. Müller
X. Wu
L. Müller
M. Hahn
Y. Huang
J.Varga
S. Scholtes
C. Kühl
R. Reiss
A. Hoffmann
A. Ulbrich
C. Grimmer



Funding:

- Uni Rostock and State of Mecklenburg Vorpommern
- Helmholtz Zentrum München
- **Deutsche Forschungsgemeinschaft (DFG)**
- Bundesministerien für Bildung &Forschung/Wirtschaft (BMBF, BWM)
- **Bayerische Forschungsstiftung (BFS**)
- Deutsche Gesetzl. Unfallversich. (DGUV)
- Bundeskriminalamt (BKA)
- Companies (SASOL Ltd., Netzsch GmbH, Photonion GmbH, LECO, Airsense GmbH, Borgwaldt KC, SABIC Inc., Shimadzu etc.)
- Helmholtz-Impulse and Networking- Fonds (Virtual Helmholtz Institute - HICE)

HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt
Mass Spectrometry Centre
Universität Rostock
Traditio et Innovatio

photonion: The Photo Ionisation Mass Spectromtry Company

HICE › Aerosols and Health
Helmholtz Virtual Institute of Complex Molecular Systems in Environmental Health

Multi-Component Trace Gas and Aerosol Analysers


Dr. S.Ehlert


Dr. M. Bente


Dr. M. Saraji

Instrumental Solutions and Applications

- Custom-made **PIMS-Systems** for Research and Industry:
- Photonion Photo-TOF **process gas** analyzer
- Photonion **aerosol** TOF-mass spectrometer
- Evolved Gas Analysis in **TA**
- **Cigarette** smoke analyzers
- **Fast GC** PIMS

Contact:
walte@photonion.de