HEALTH EFFECTS OF AIR POLLUTION IN PORT CITIES

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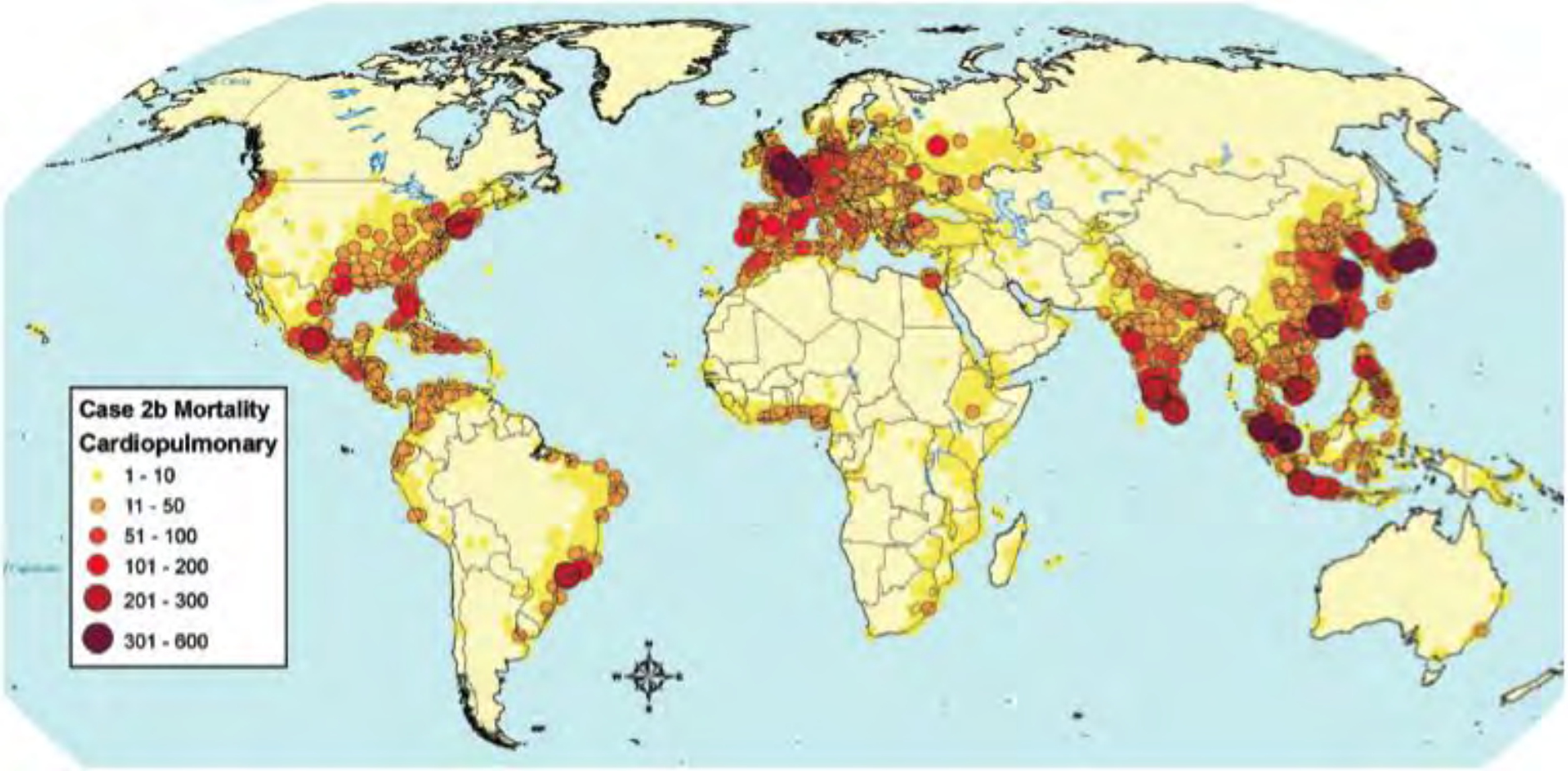
Technische Universität München

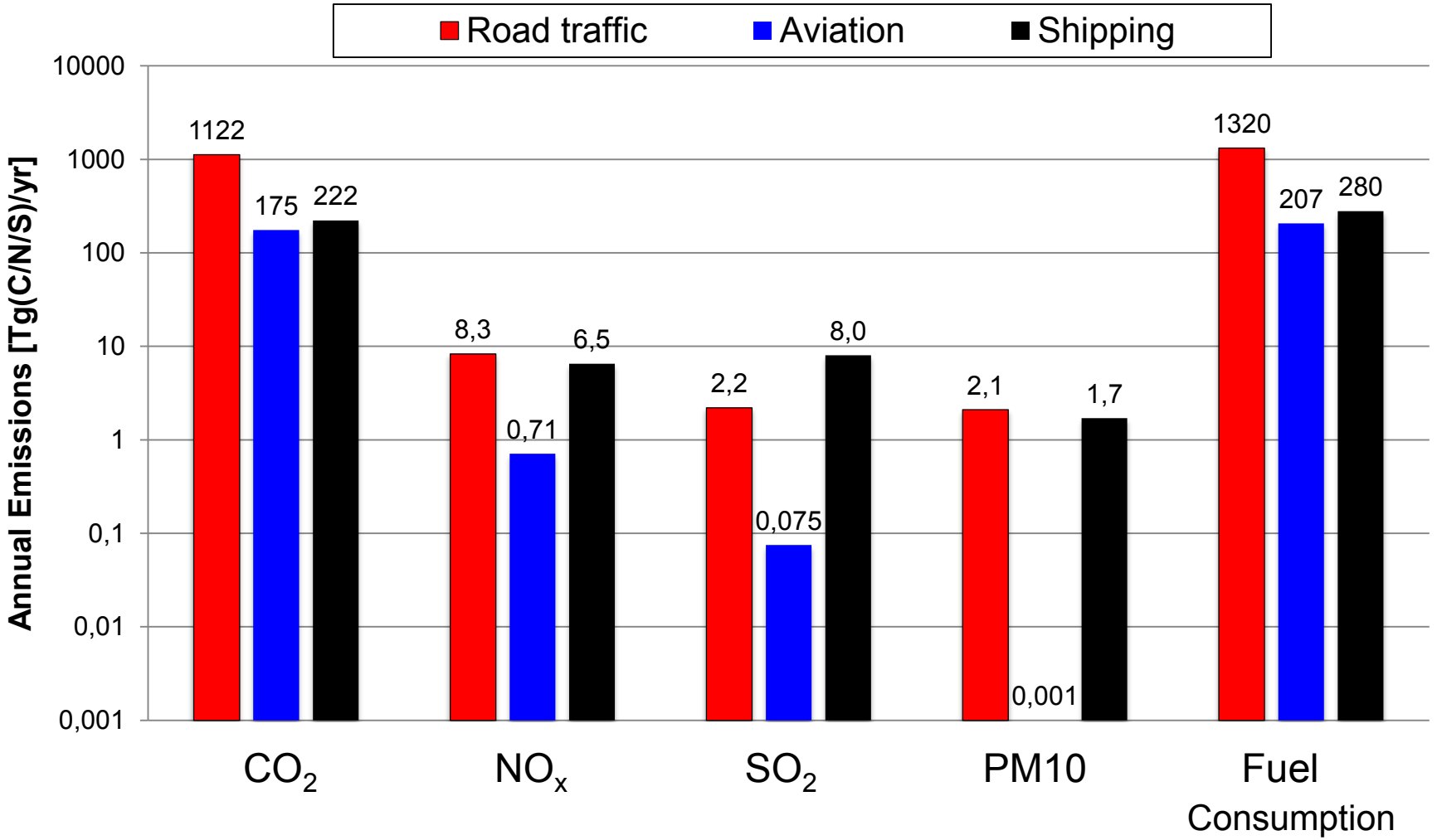
Ship emmissions and human health: a global problem

- Modelled cardiopulmonary mortality due to ship emmissions -



Corbett et al., ES&T 2007

Sources of pollution



Eyring, J Geophys Ter, 2005

Sulphur in ship emissions generates clouds

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.

http://www.isgtw.org/feature/clearing-cloudy-view-cloud-formation

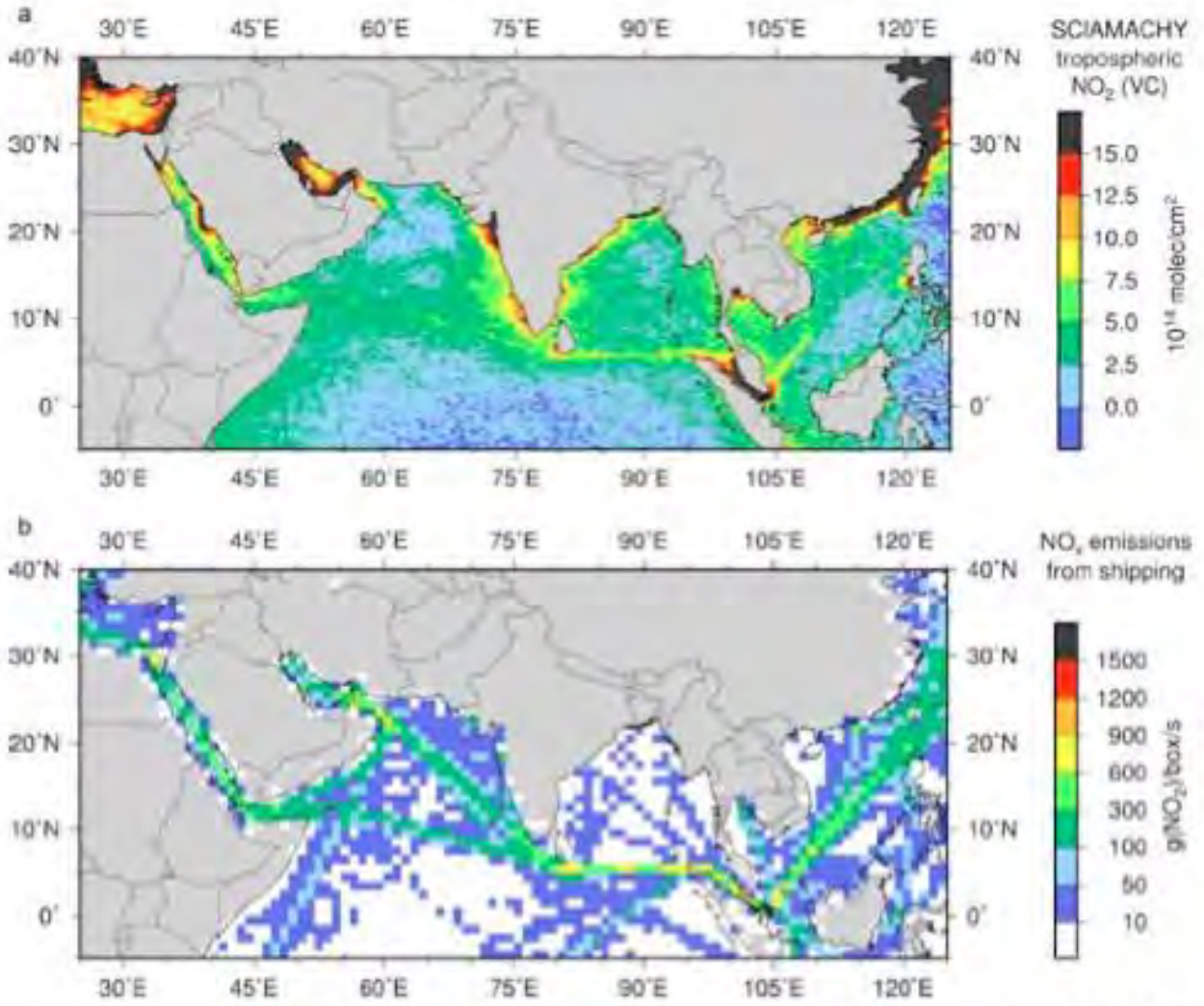
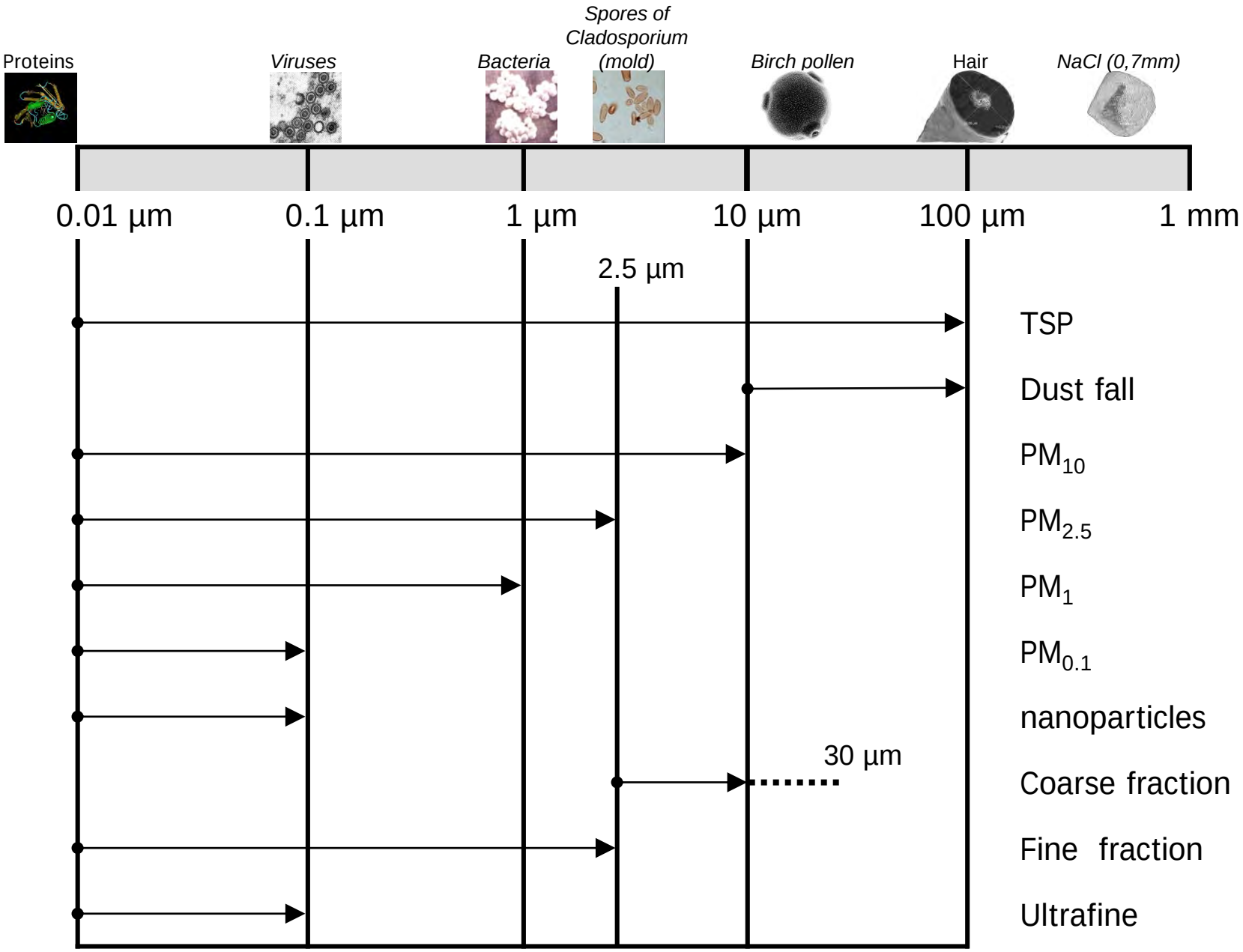
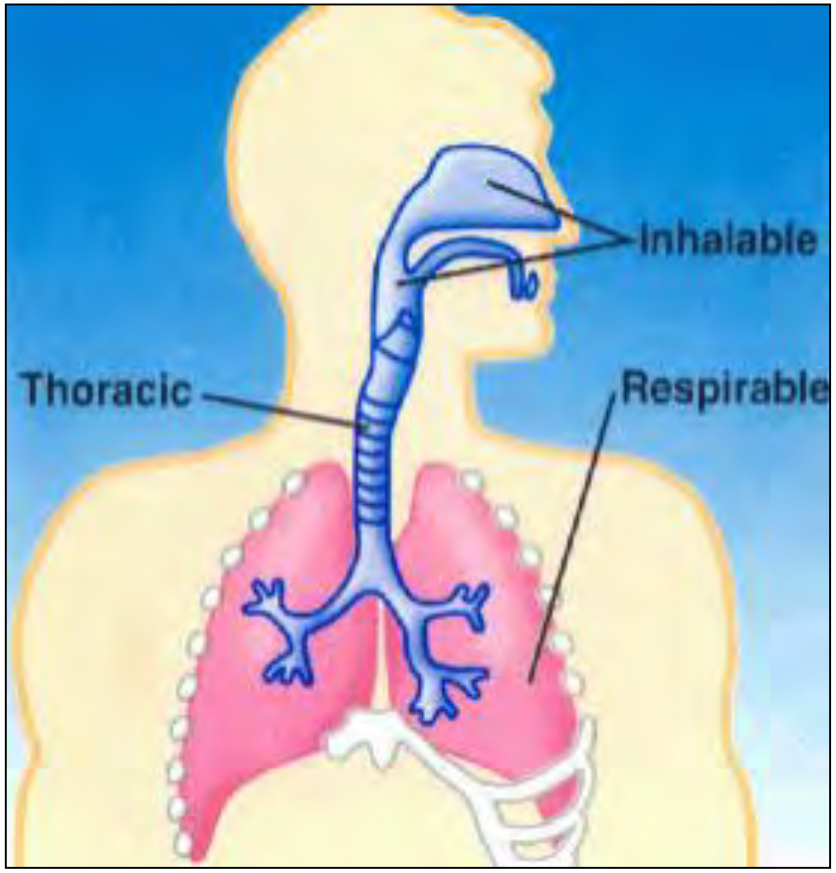
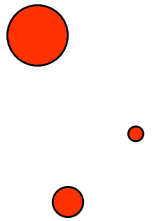


Figure 3. NO_X signature of shipping in the Indian Ocean, as detected by SCIAMACHY (a), and estimated from emission models (b). From *Richter et al., (2004)*.


Proteins
Viruses
Bacteria
Spores of Cladosporium (mold)
Birch pollen
Hair
NaCl (0,7mm)
0.01 µm
0.1 µm
1 µm
10 µm
100 µm
1 mm
2.5 µm
30 µm
TSP
Dust fall
PM10
PM2.5
PM1
PM0.1
nanoparticles
Coarse fraction
Fine fraction
Ultrafine

Particle deposition in the lung

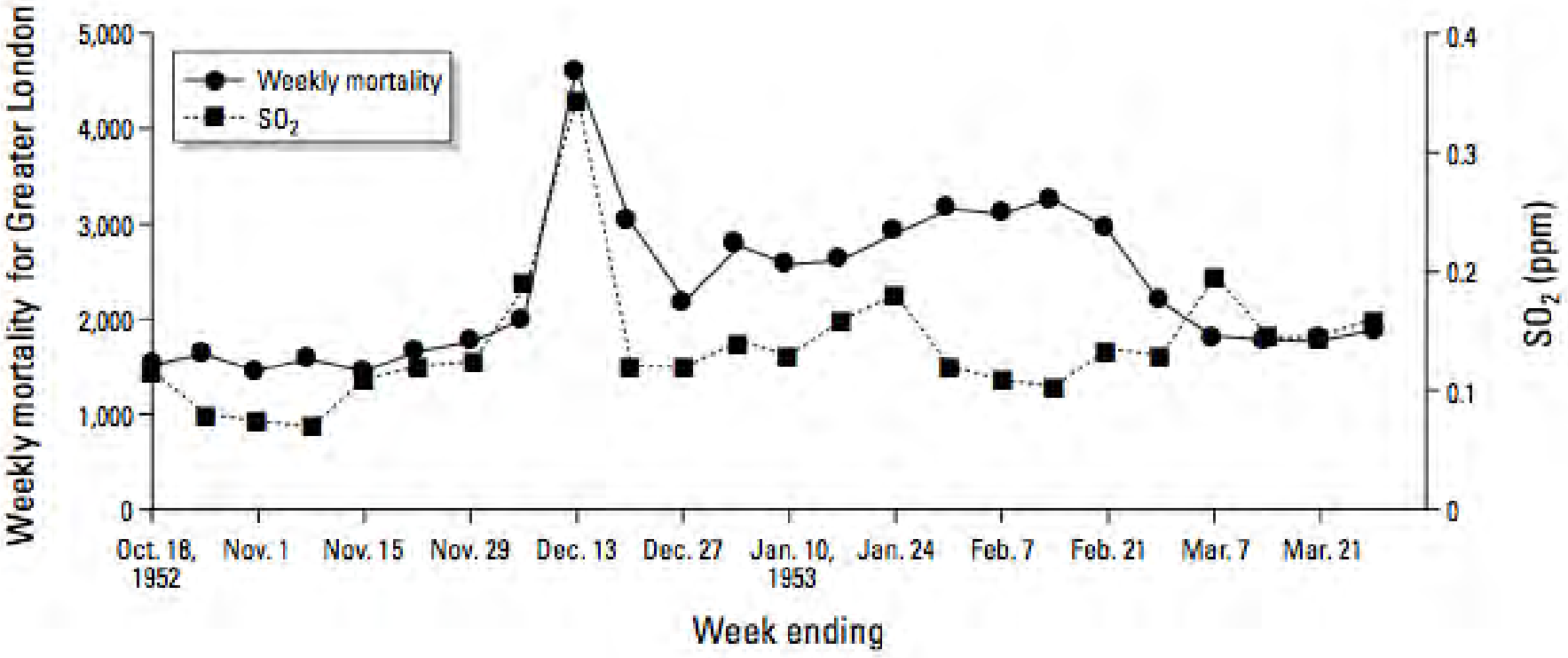




Morawska, 2009


London smog 1952
Ship diesel: 1600 mg sulphur/kg
<10mg Schwefel/kg ab Jan 2013 DIN EN 228: 2013-01, standard in Germany since 2003

London smog: lethality



Bell and Davis, Env Health Persp. 2001

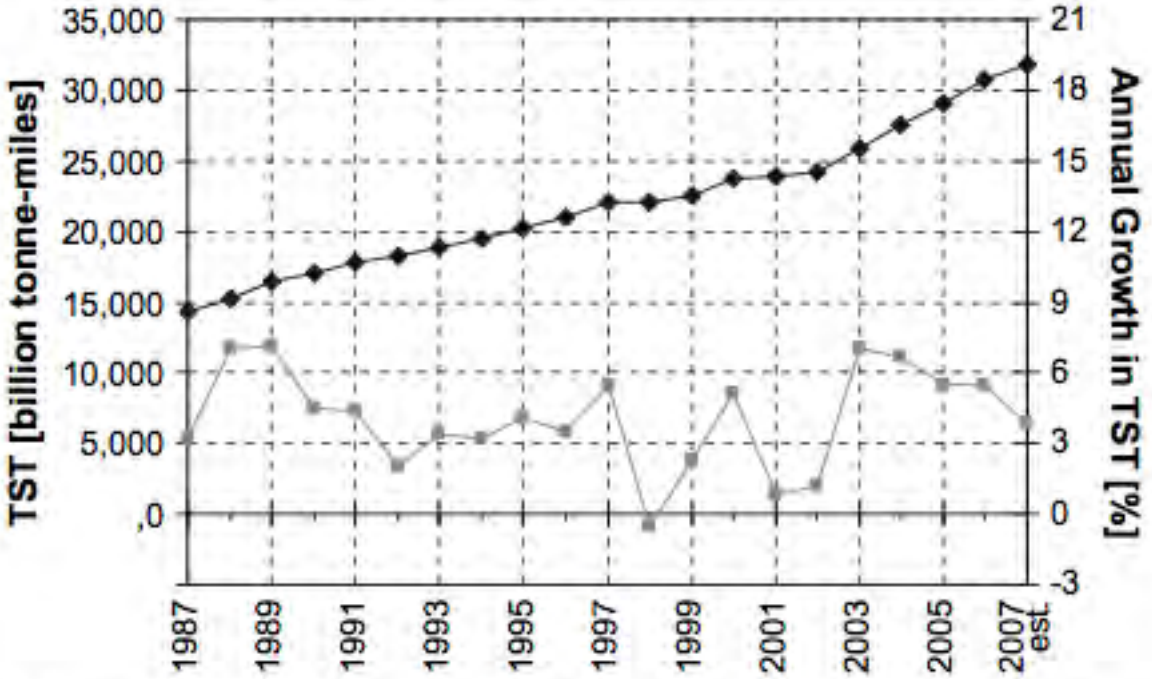


Fig. 4. World seaborne trade (TST) in billion ton-miles and corresponding annual growth rate from 1987 to 2007. Source: Fearnleys (2007).

Ship emissions will increase

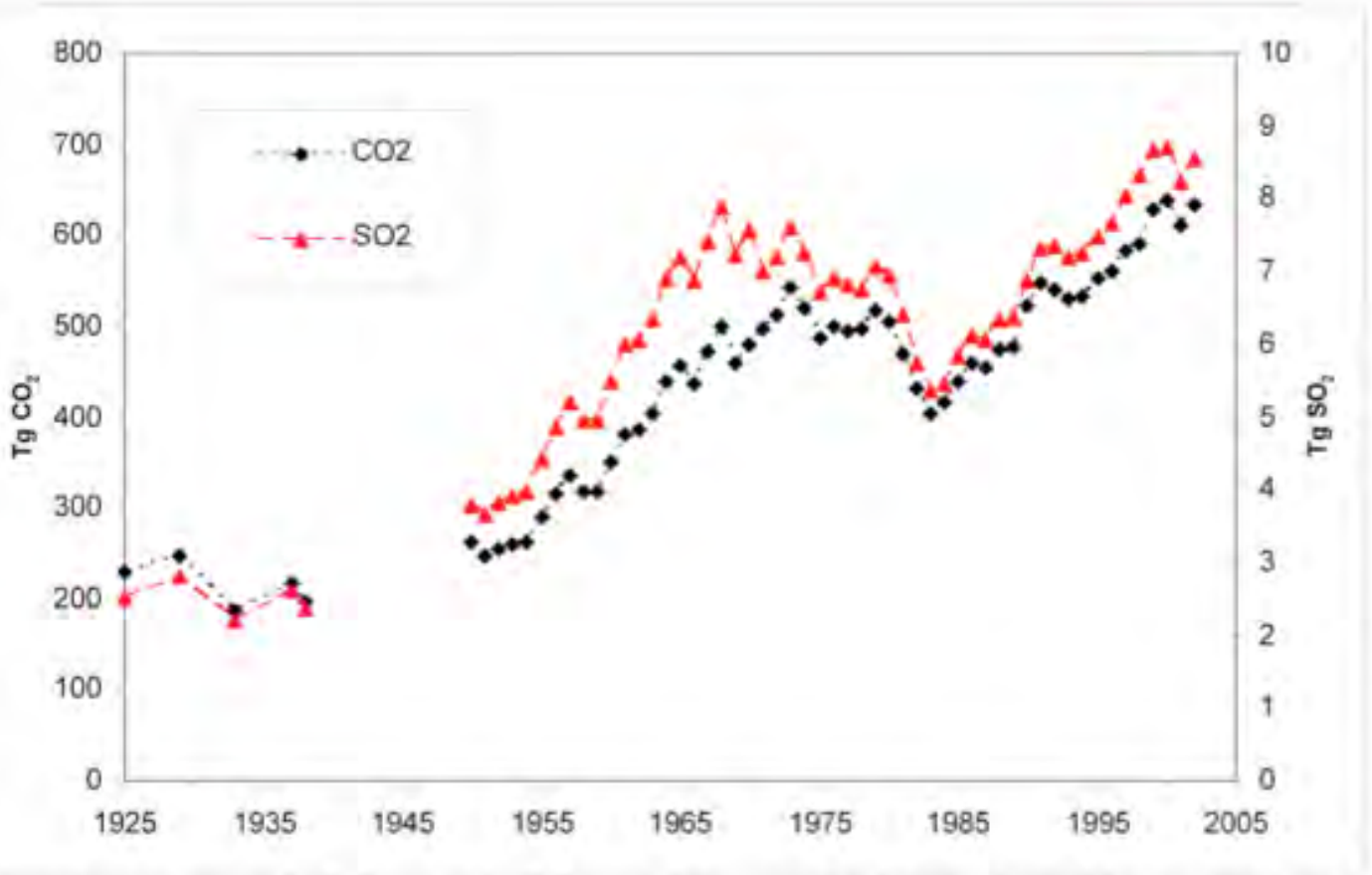


Figure 1. Development of CO_2 and SO_2 ships, emissions, based on estimated sales of marine fuel, 1925-2002. Note that no data are available for World War II (from *Endresen et al., 2007*).

Effect of sulphur removal from ship fuel

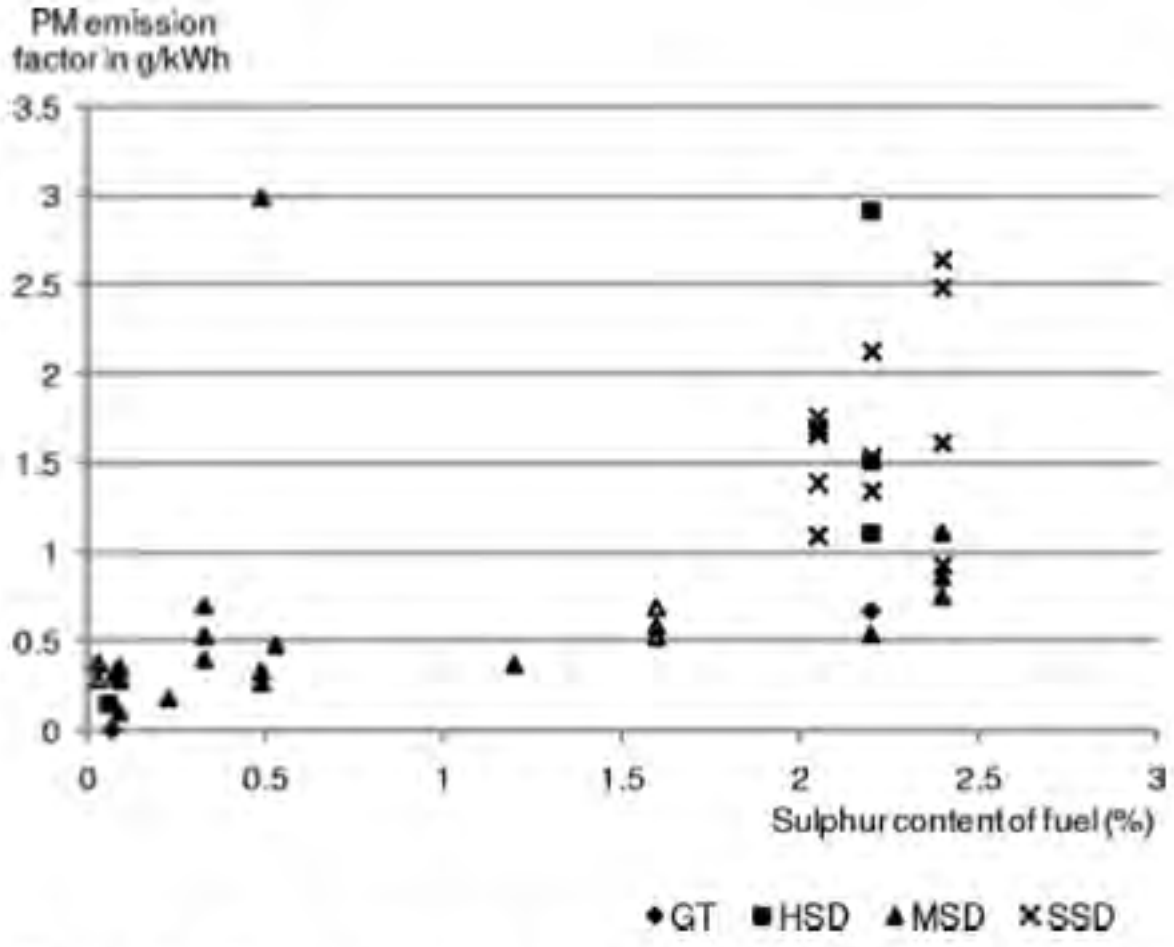


Figure 4. The variation of particle emissions with sulfur content of the fuel oil. GT = gas turbines, HSD = high-speed diesel, MSD = medium-speed diesel, SSD = slow-speed diesel.[7–9,23] The values from the presented measurements are indicated with open markers.

Effect of Sulfur in Ship Fuels on Mortality

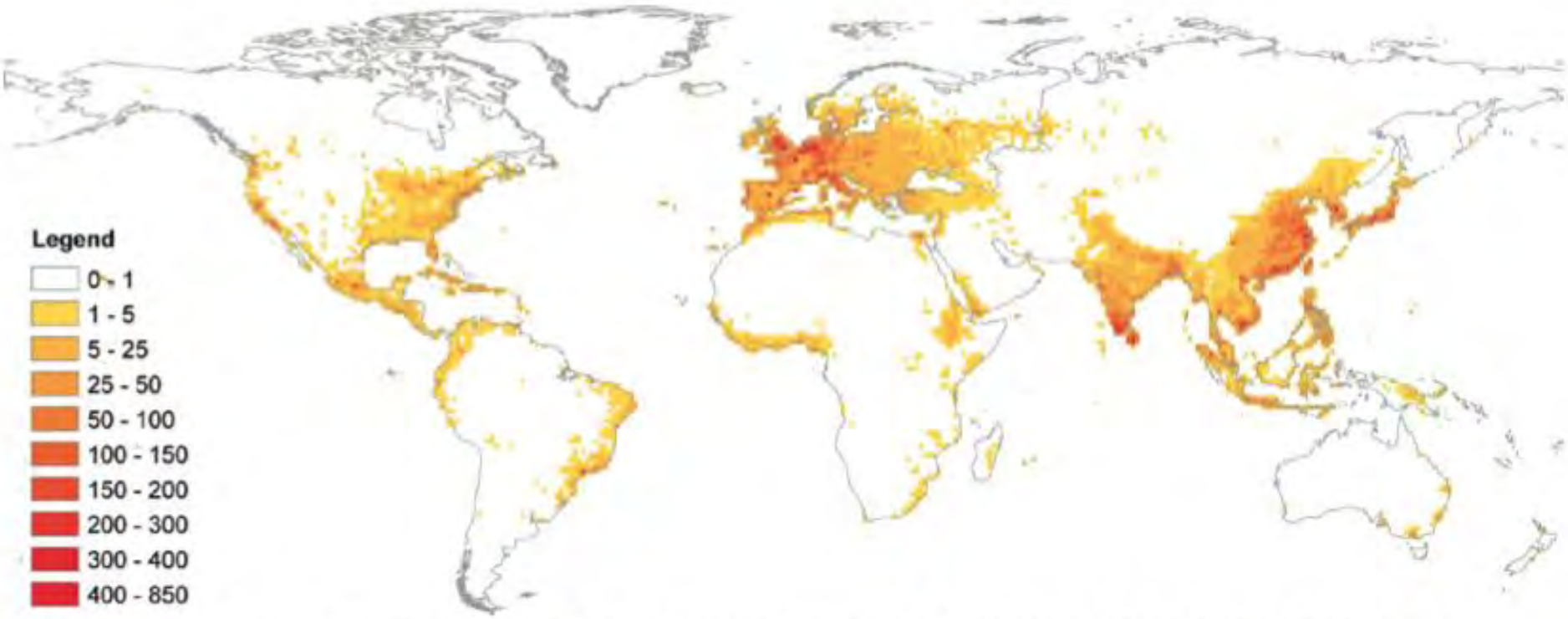


FIGURE 2. Annual premature mortality for the *No Control* scenario compared to a "no shipping" case using ICOADS data.

Winebrake et al., ES&T 2009

HFO DF

HICE

Testing toxicity of anthropogenic combustion:

ship diesel exhaust

Studying the causes of health effects of combustion-derived aerosols in the framework of the Virtual Helmholtz Institute HICE: Concep sols

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S.Mülhopt[4], M.Dilge[1], R. Rabe[5],
M.-R.Hirvonen[6,11], J. .A.BeruBe[8,11],
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T.Streibel[1], E.Karg[1],
M. Arteaga Salas[1,11], M. Elsasser[1],
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[5]University of Rost hysics), D
[6]University Eastern FI
[7]Uni Luxemburg; LUX
[8]Cardiff University,
[9]HMGU, D;
[10]Vitrocell GmbH, D;
[11]HICE – Helmholt nstitute ex Molecular Systems in Environmental Health-Aerosols a Health

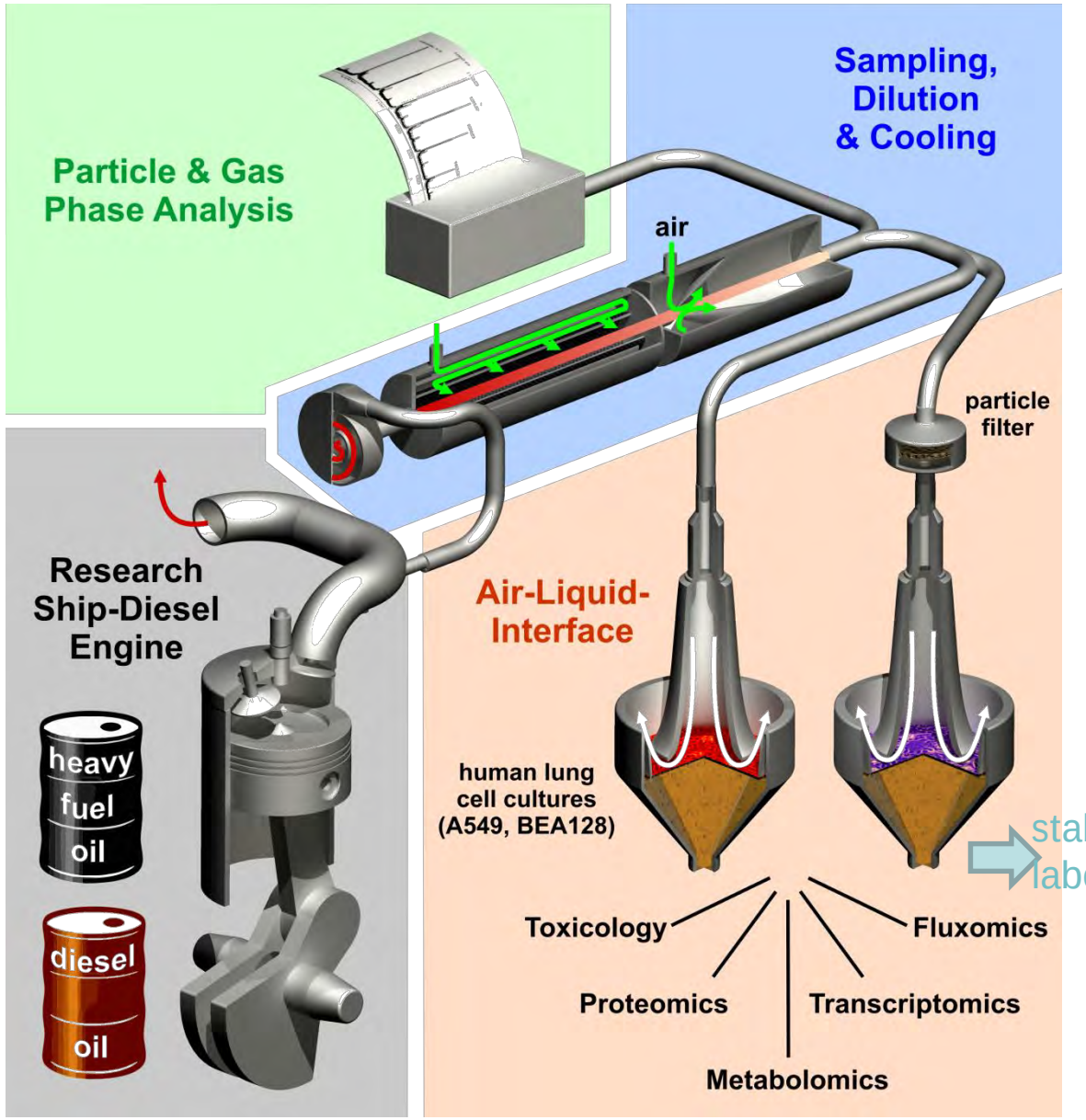
HICE › Aerosols and Health
Helmholtz Virtual Institute of Complex Molecular Systems in Environmental Health

On-line analysis:

- SMPS
- ATOFMS
- ELPI
- ELPI-MS/MS
- FTIR-MS
- SPOT-MS
- PTR-MS
- CPC
- Gases
- Sensors (FID..)

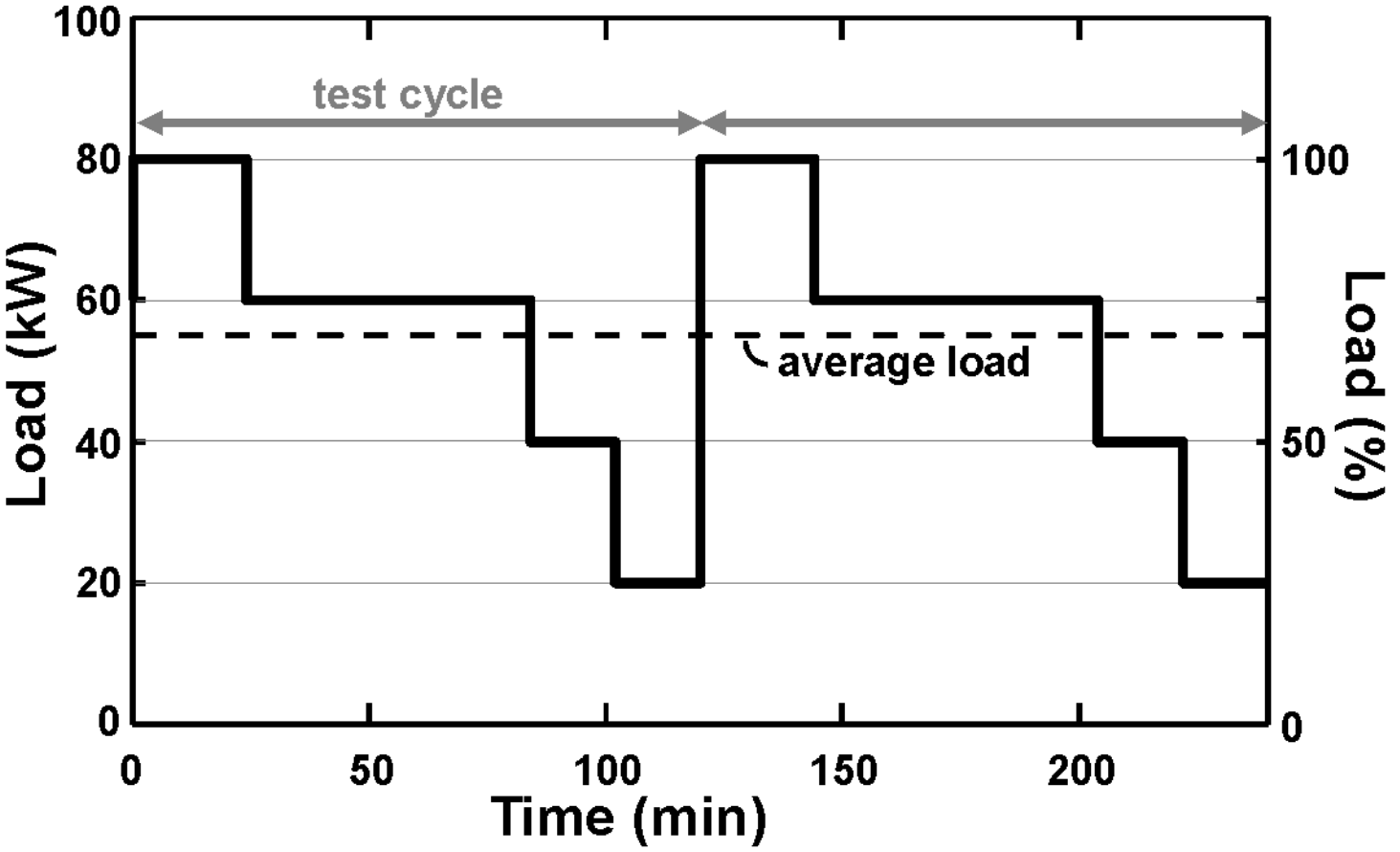
Off-line analysis:

- DMA
- GC-TOFMS
- LC-TOFMS
- Filters
- HPLC-MS/MS
- Denuder
- ESI-IMS
- EC/OC
- ICP-MS
- IC
- BC

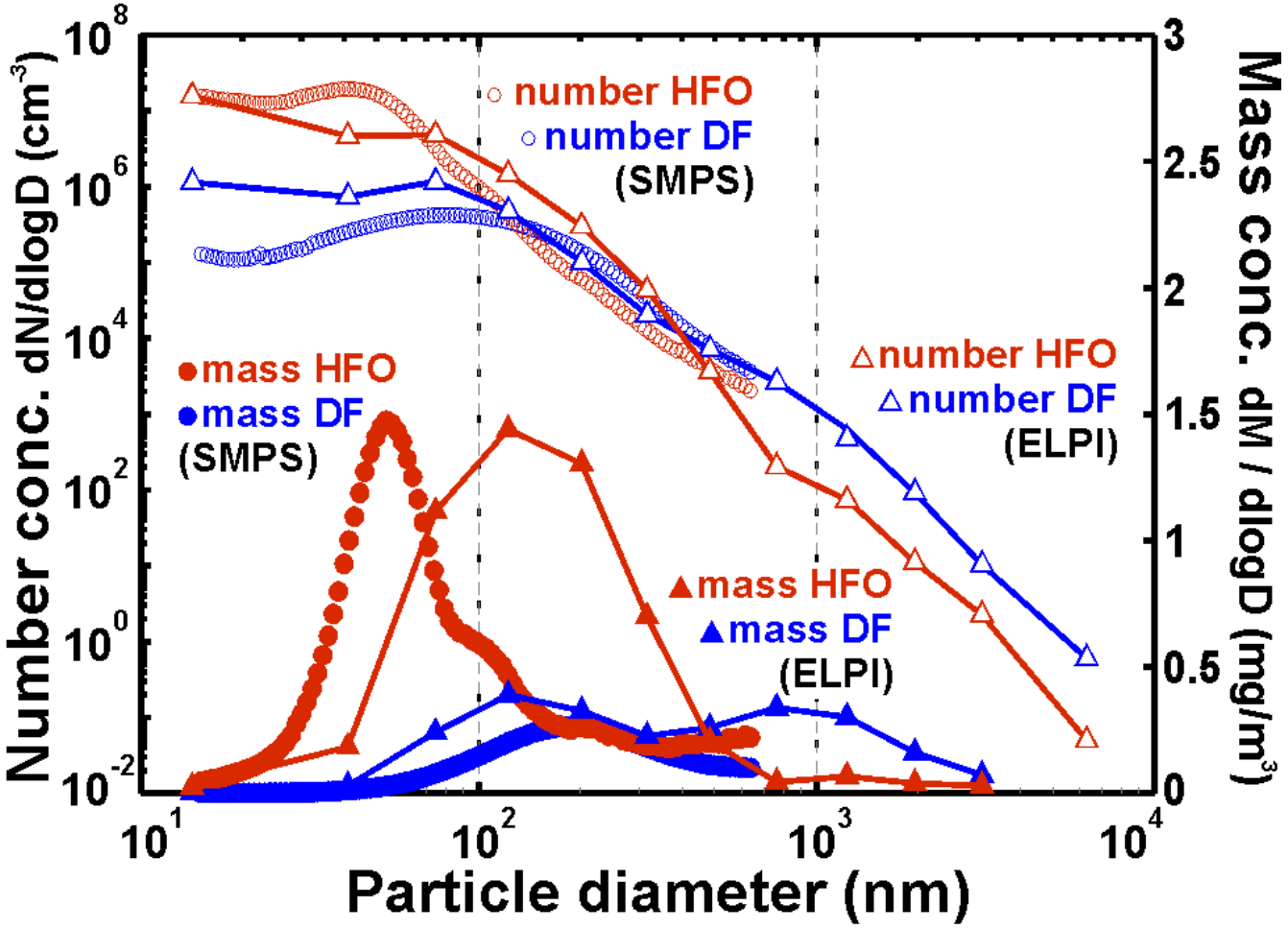


HFO DF

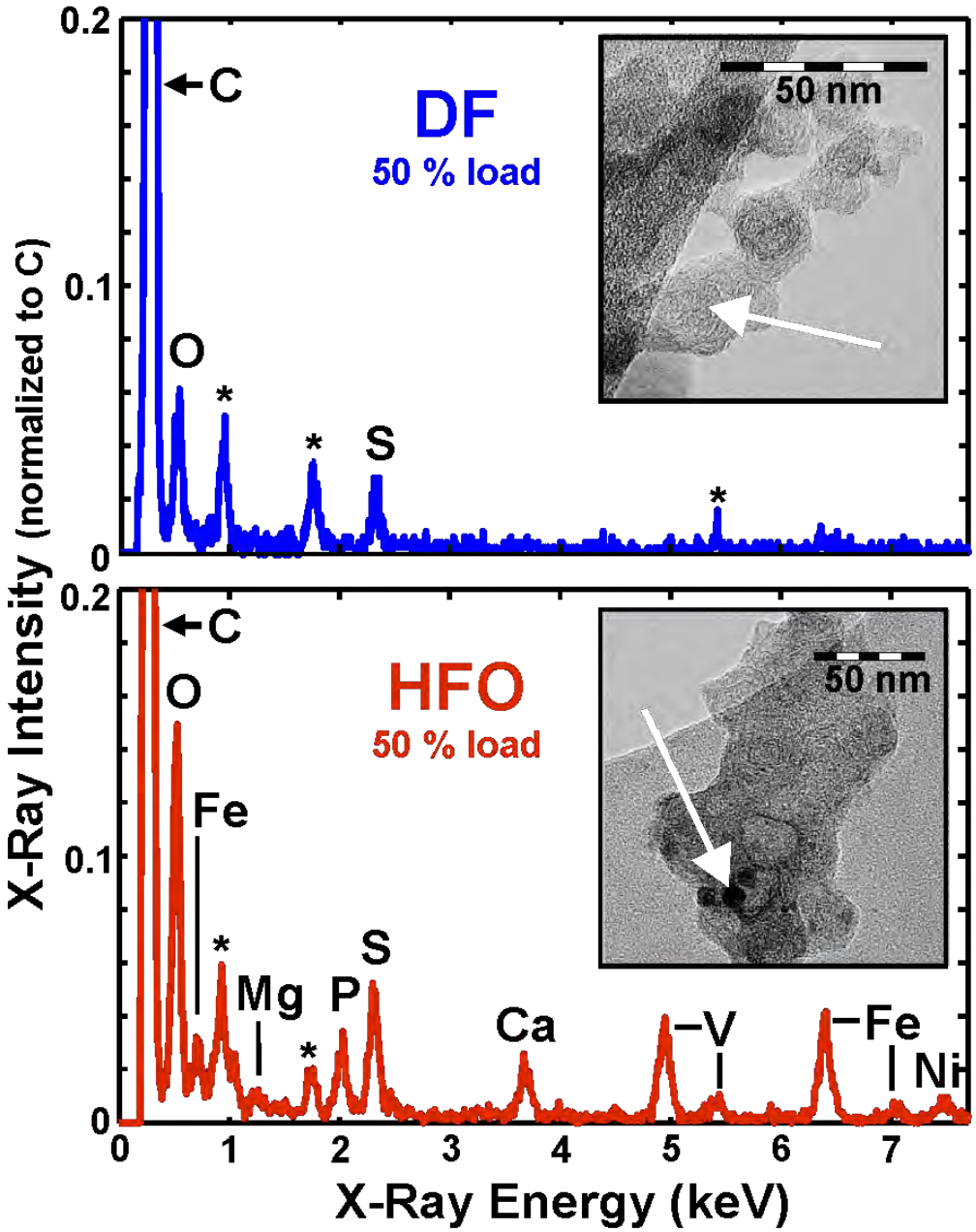
Harbour manouvering test cycle

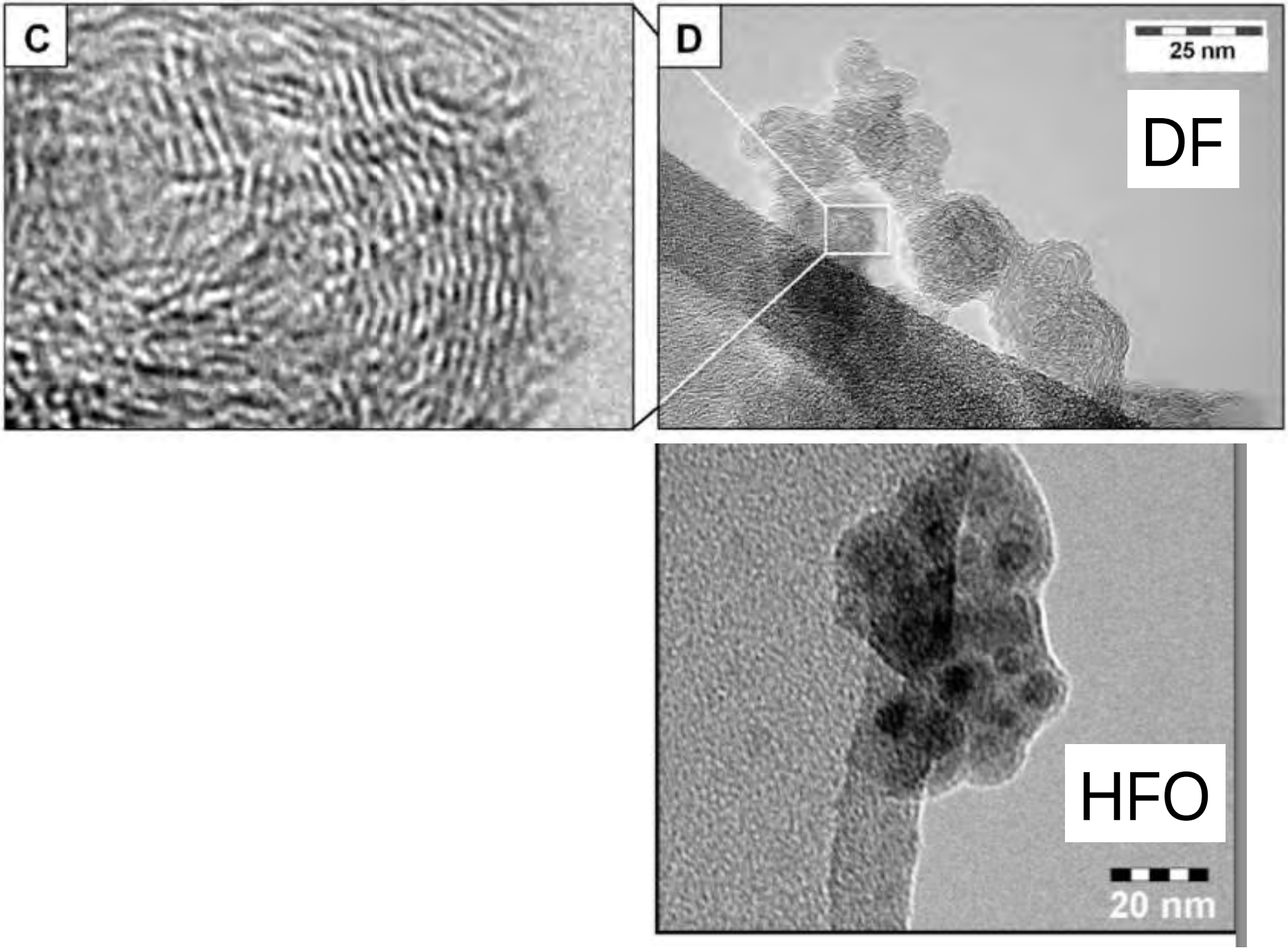


Particle size distribution

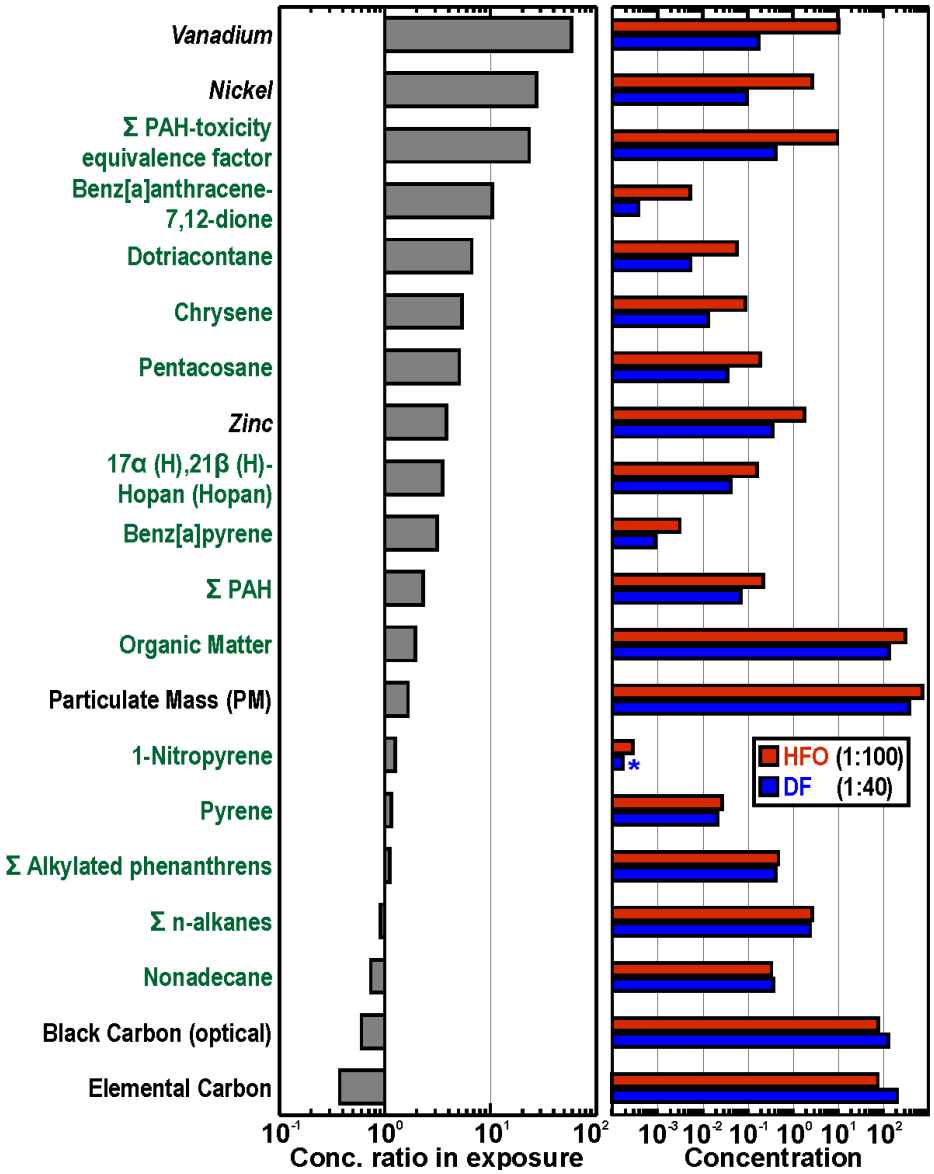


Anorganic composition of the exhaust particles

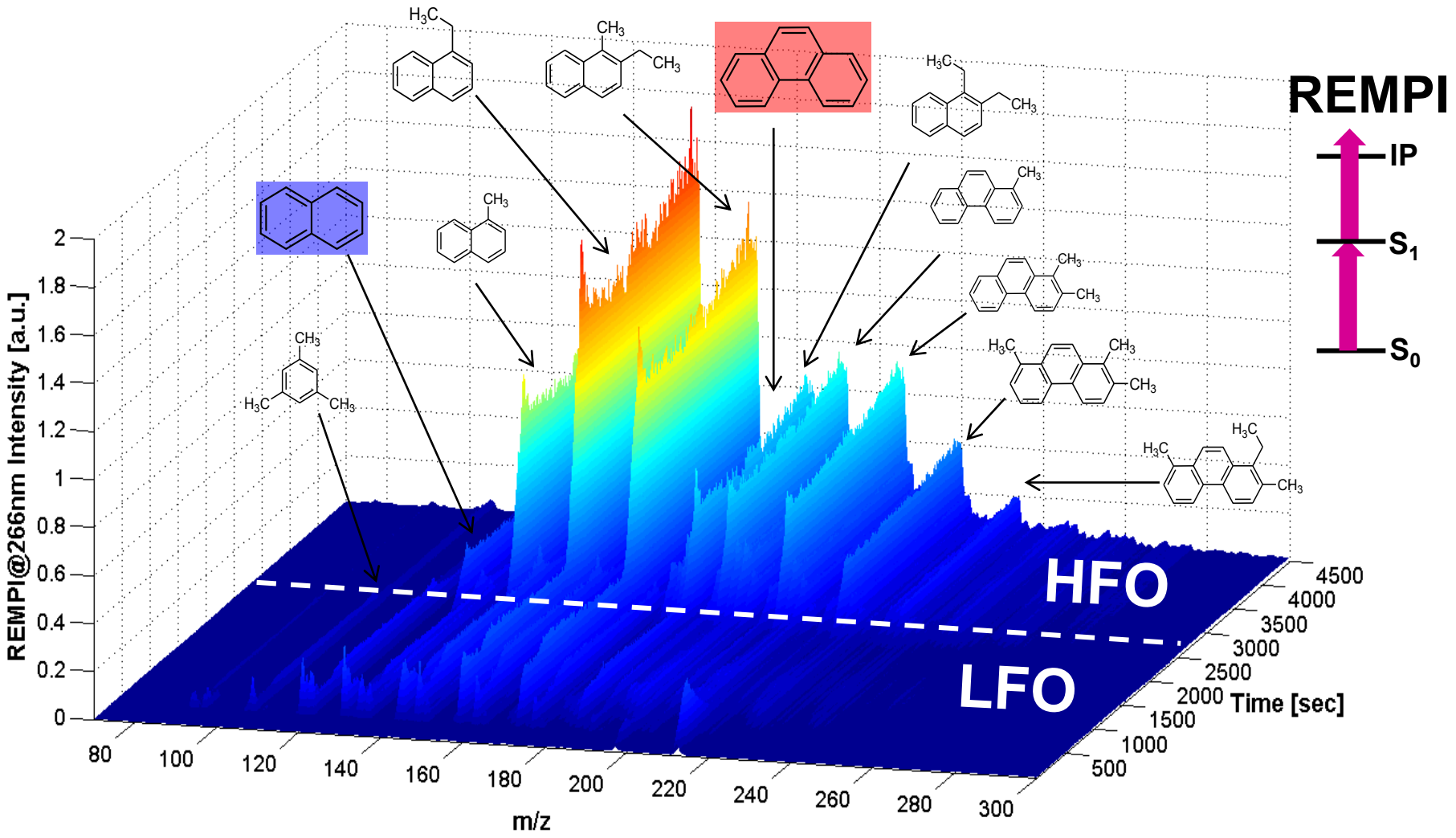



C
D
25 nm
DF
HFO
20 nm

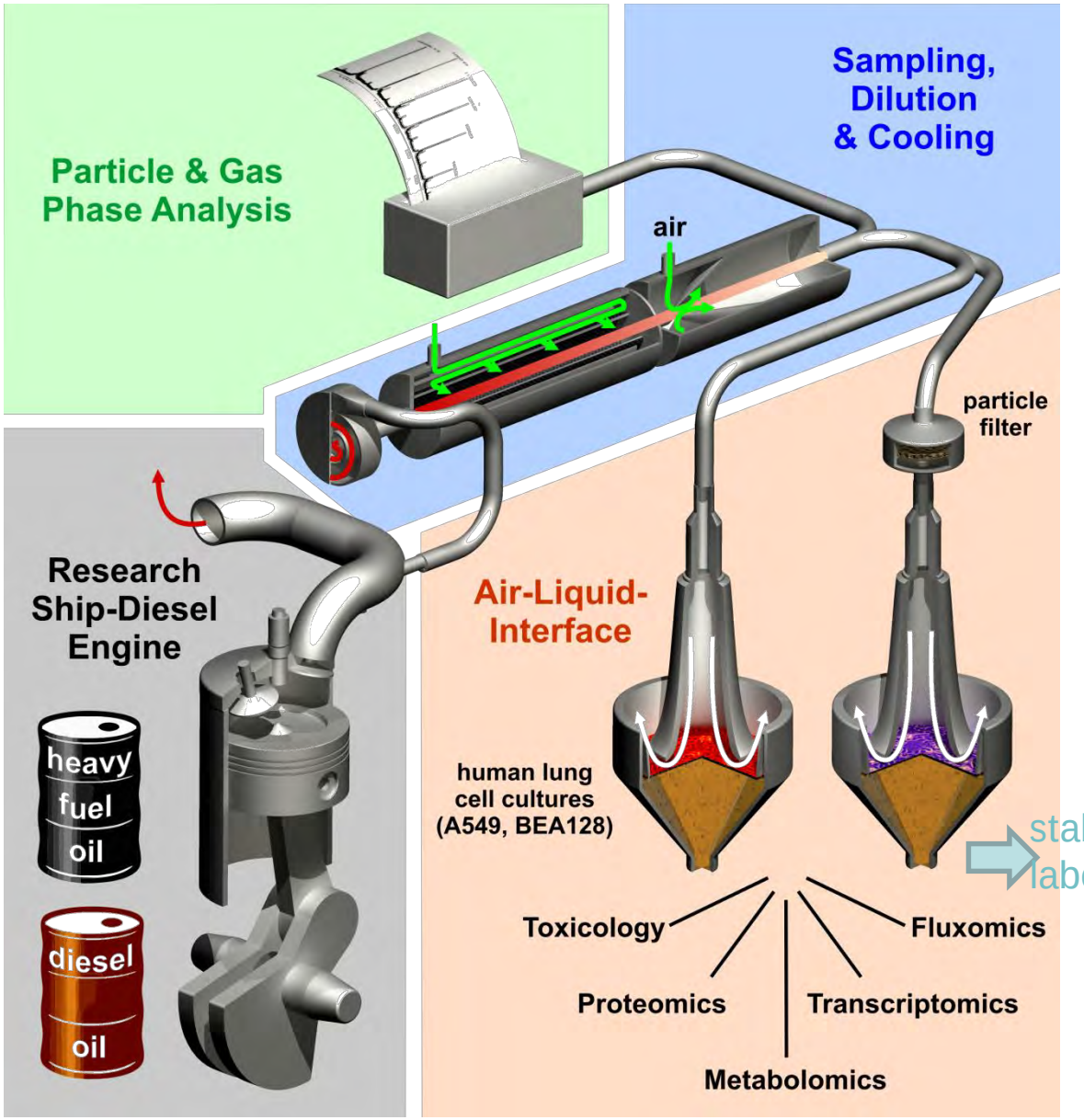
Organic composition of the exhaust particles



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

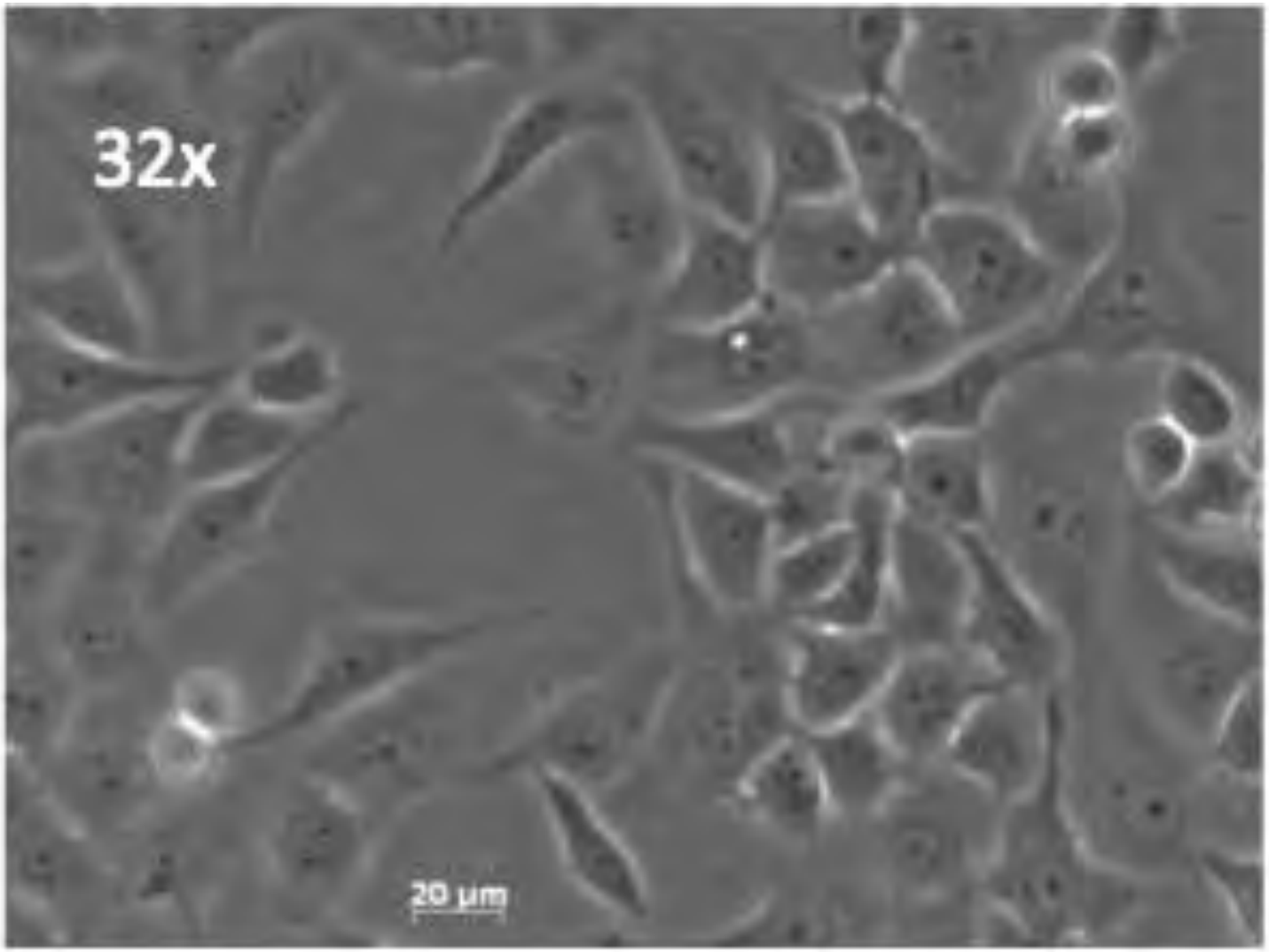



HFO
LFO

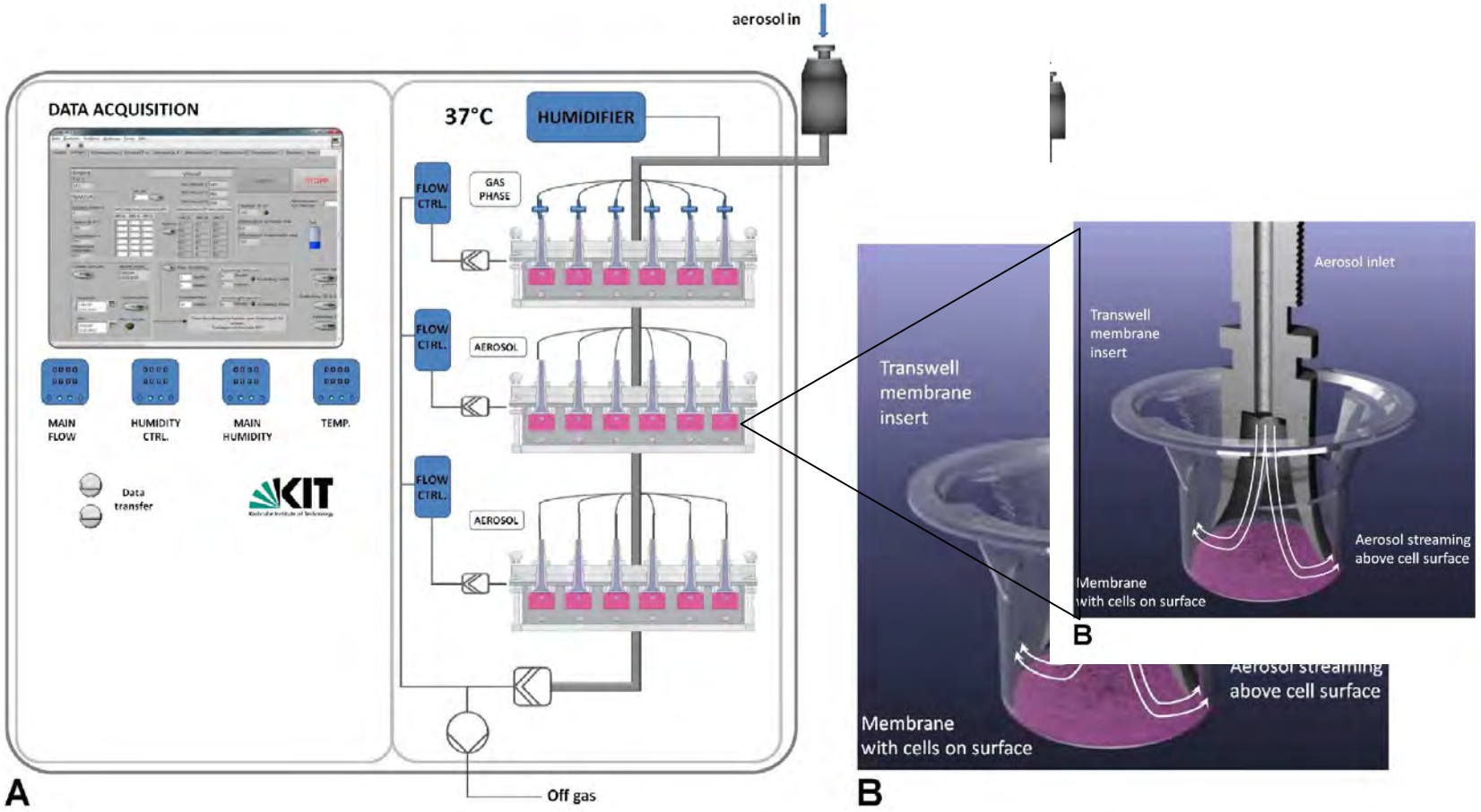

Particle & Gas Phase Analysis
Sampling, Dilution & Cooling
air
particle filter
Research Ship-Diesel Engine
heavy fuel oil
diesel oil
Air-Liquid-Interface
human lung cell cultures (A549, BEA128)
stable isotope labeling
Toxicology
Fluxomics
Proteomics
Transcriptomics
Metabolomics

Human bronchial epithelial cells

- BEAS-2B immortalized -



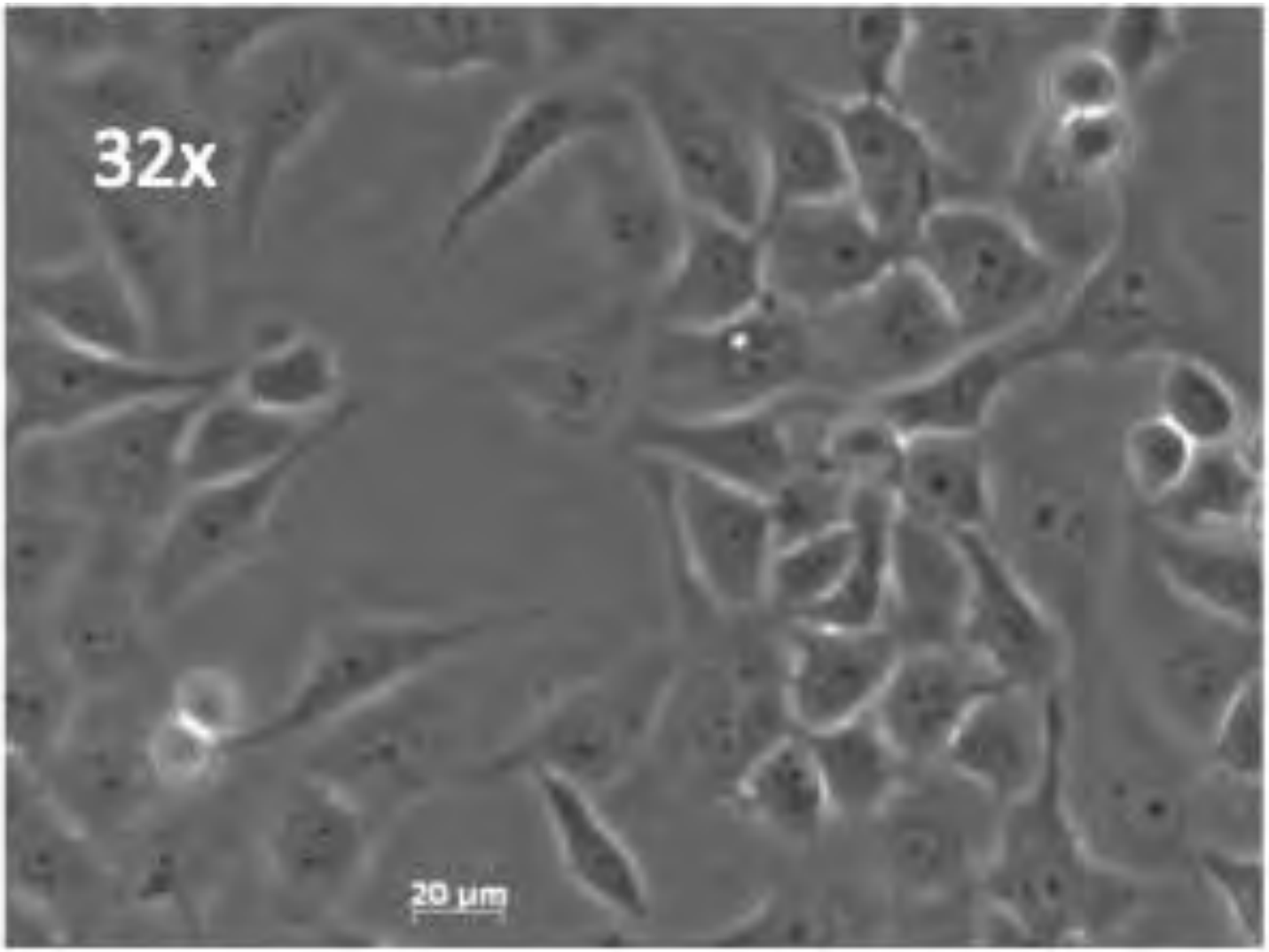
Exposing human cells at the air-liquid interface



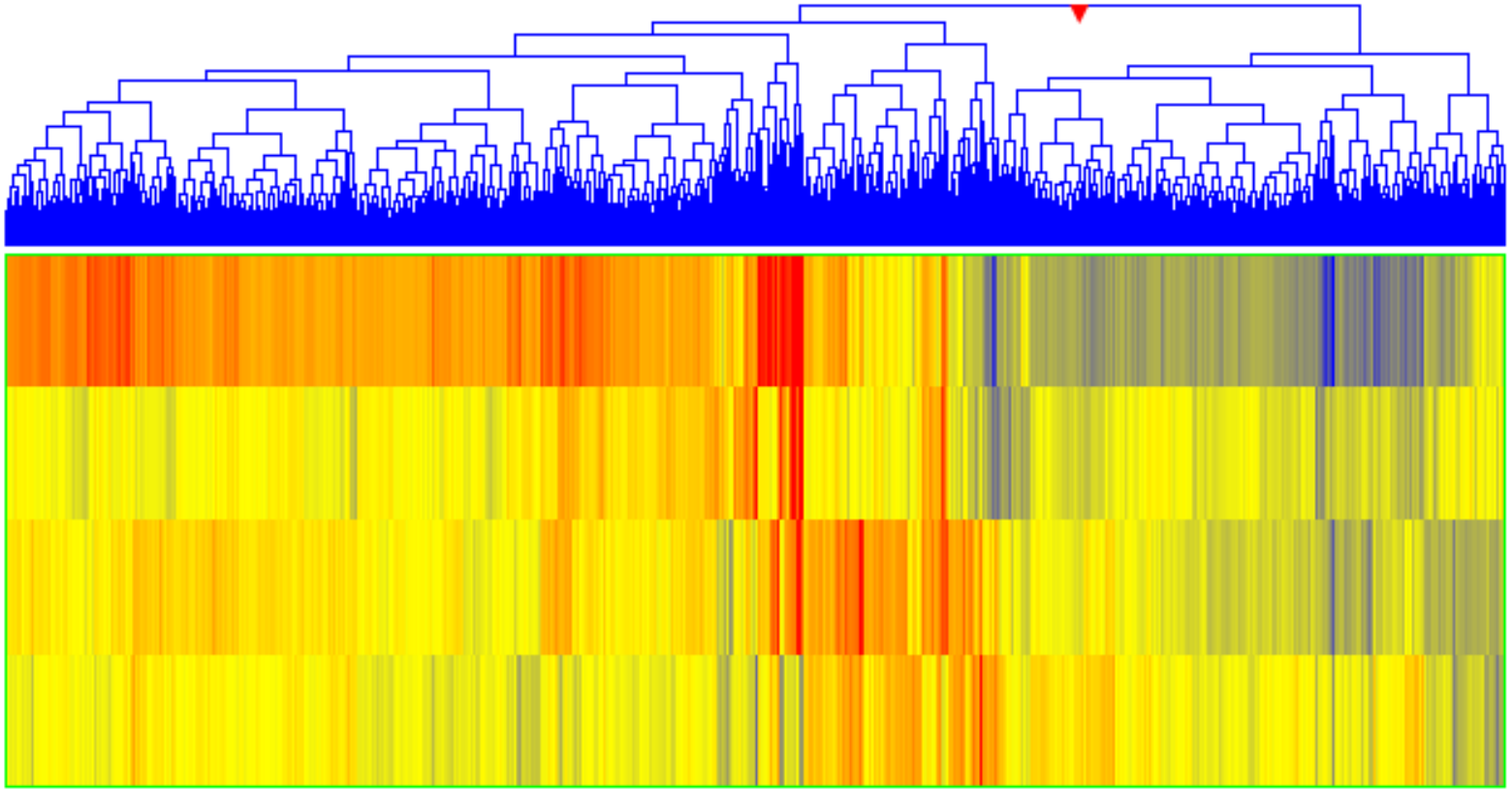

HICE › Aerosols and Health
Helmholtz Virtual Institute of Complex
Molecular Systems in Environmental Health

Human bronchial epithelial cells

- BEAS-2B immortalized -



Genome wide RNA target analysis *



DF aerosol

DF gas

HFO aerosol

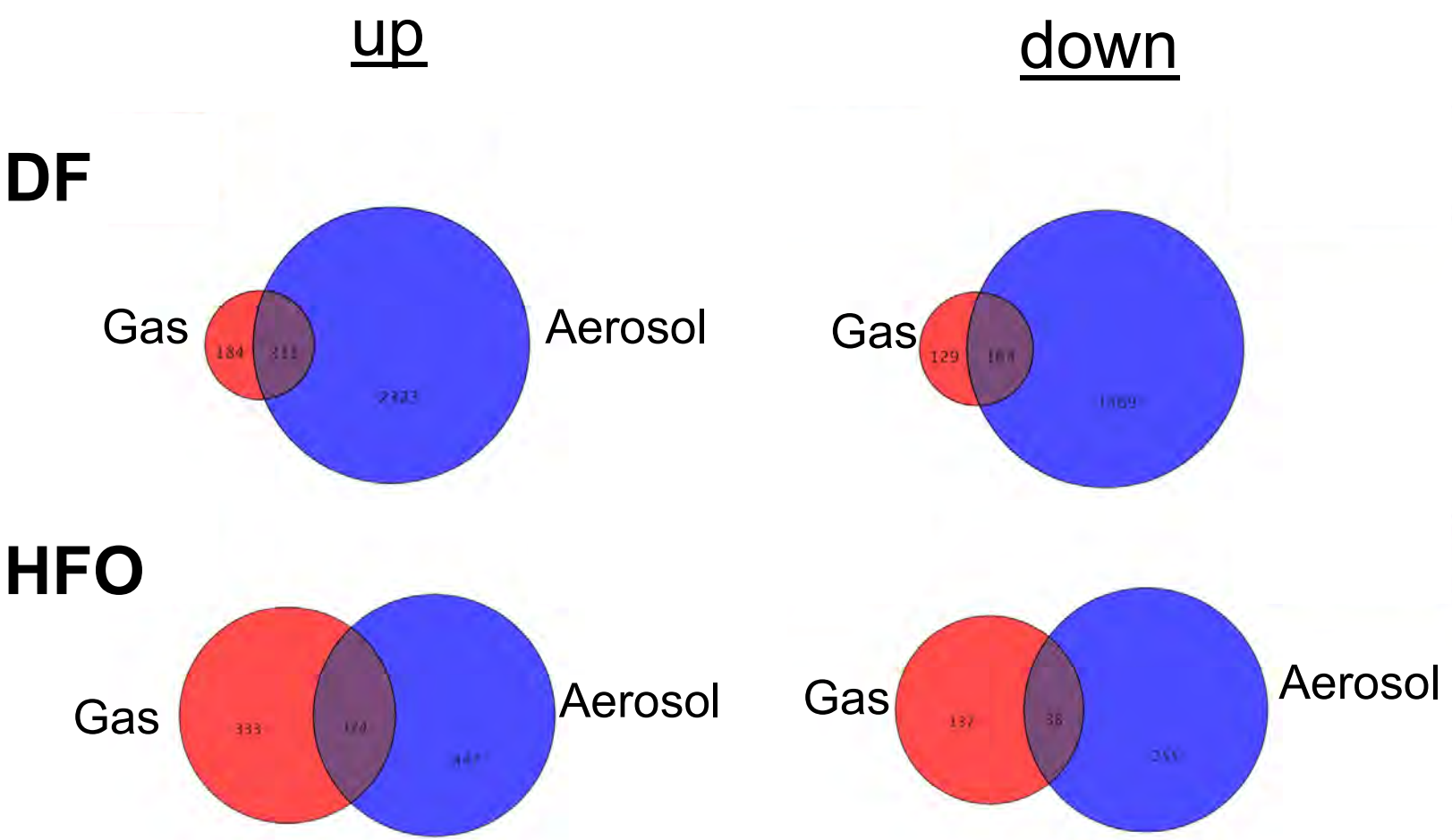
HFO gas

>1.5-fold Up-regulated genes

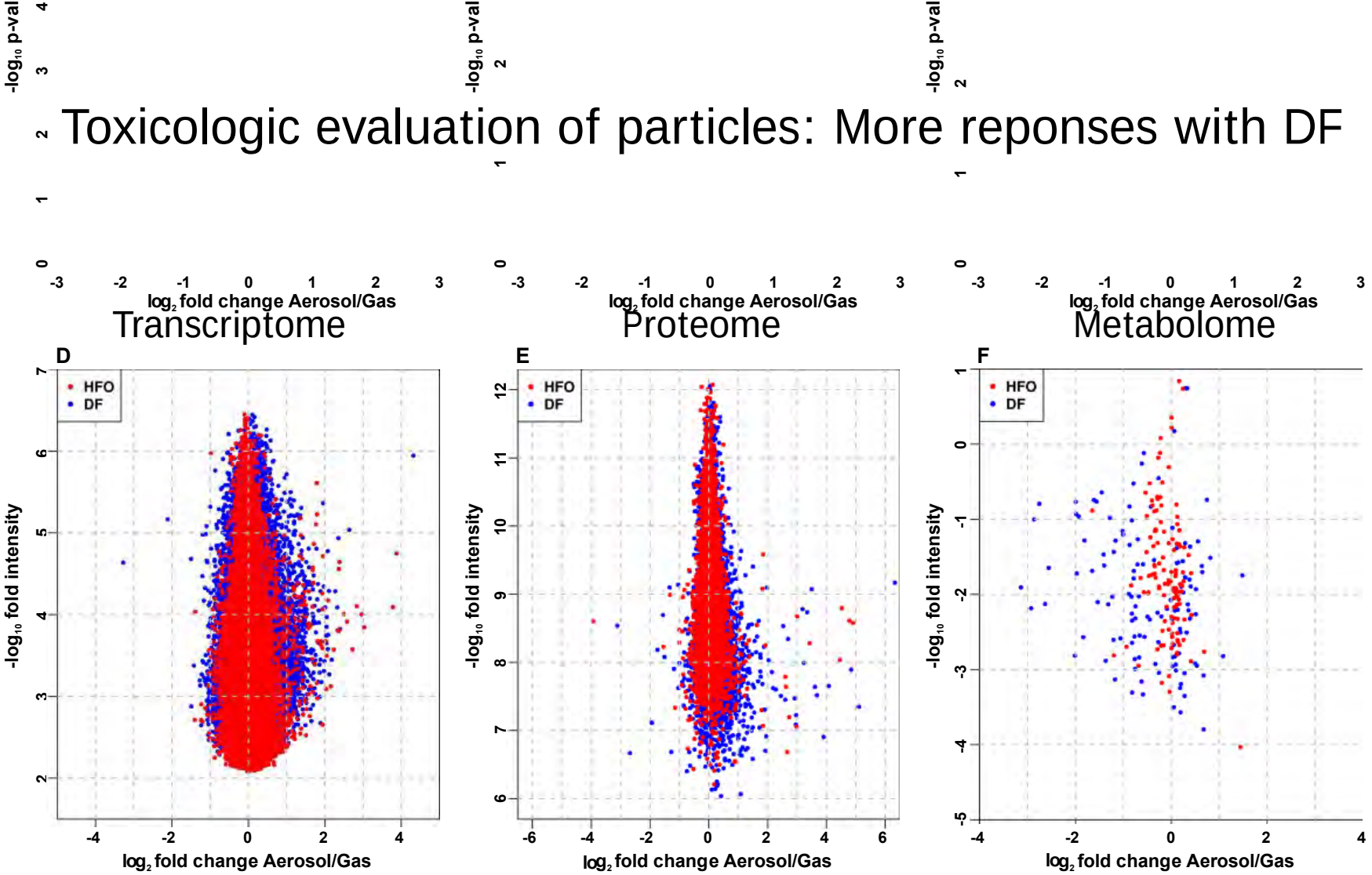
>1.5-fold Down-regulated genes

- about 42,000 genes, against clean air

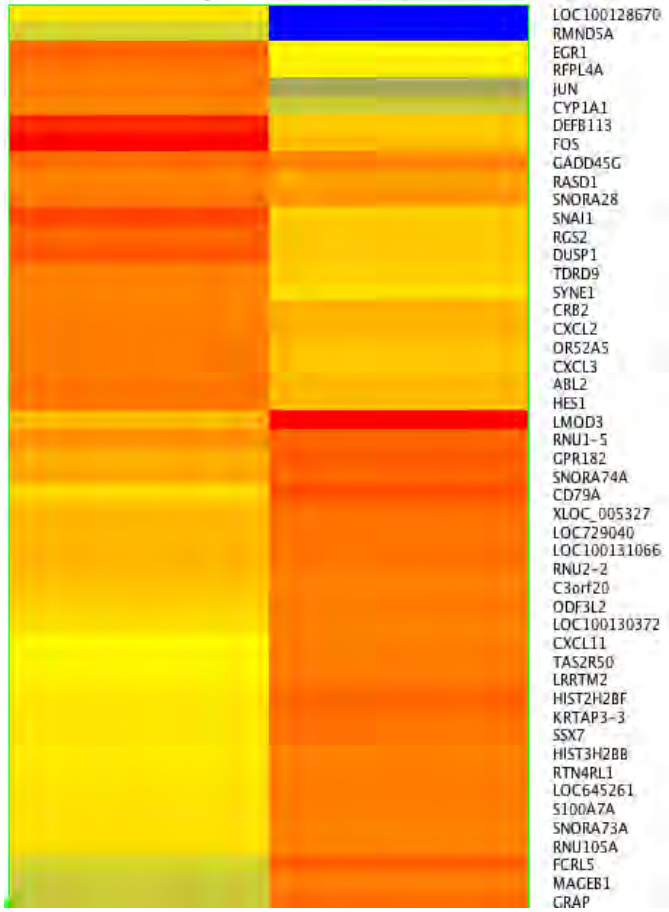
Number of regulated genes



Toxicologic evaluation of particles: More reponses with DF

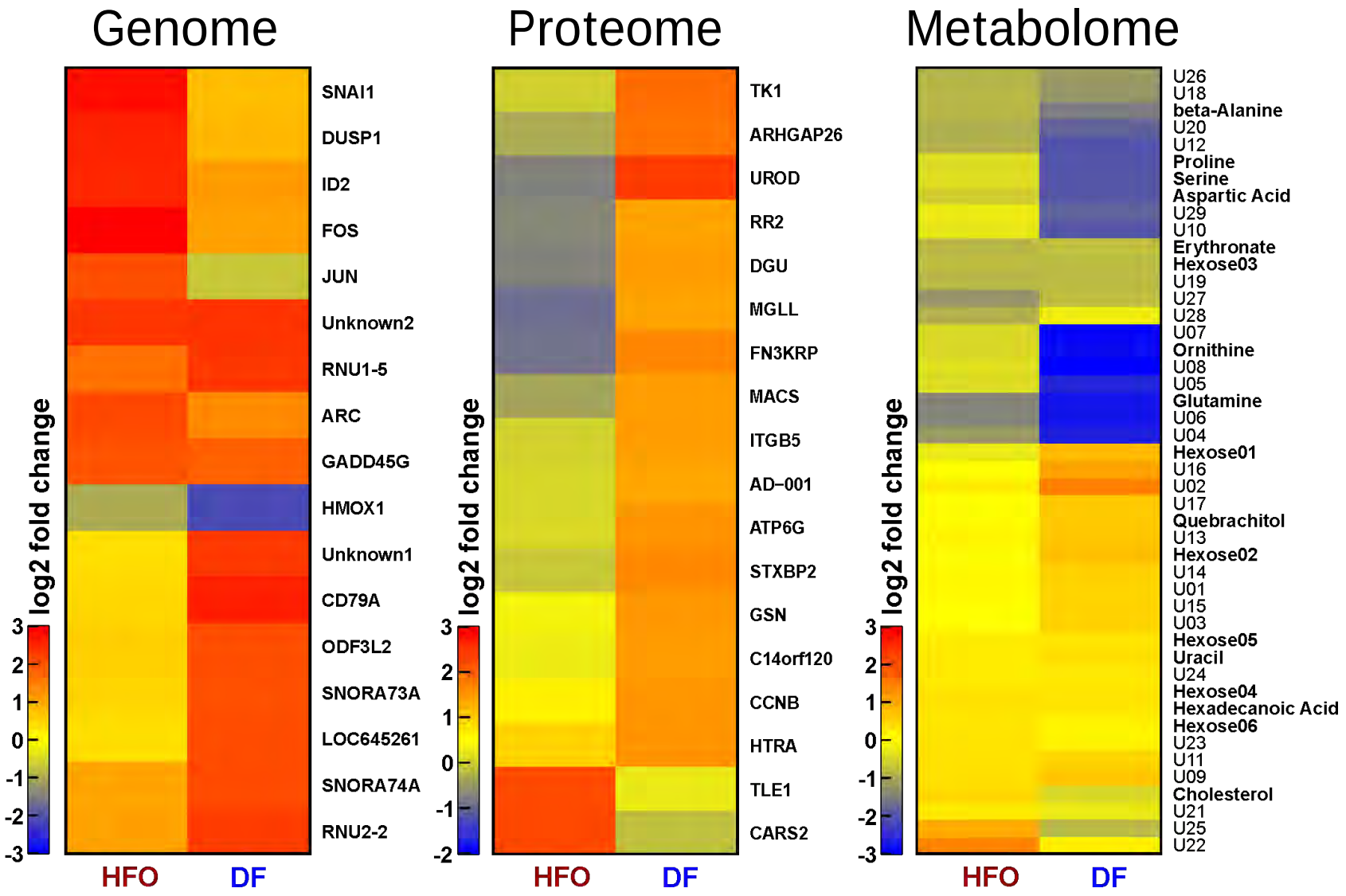


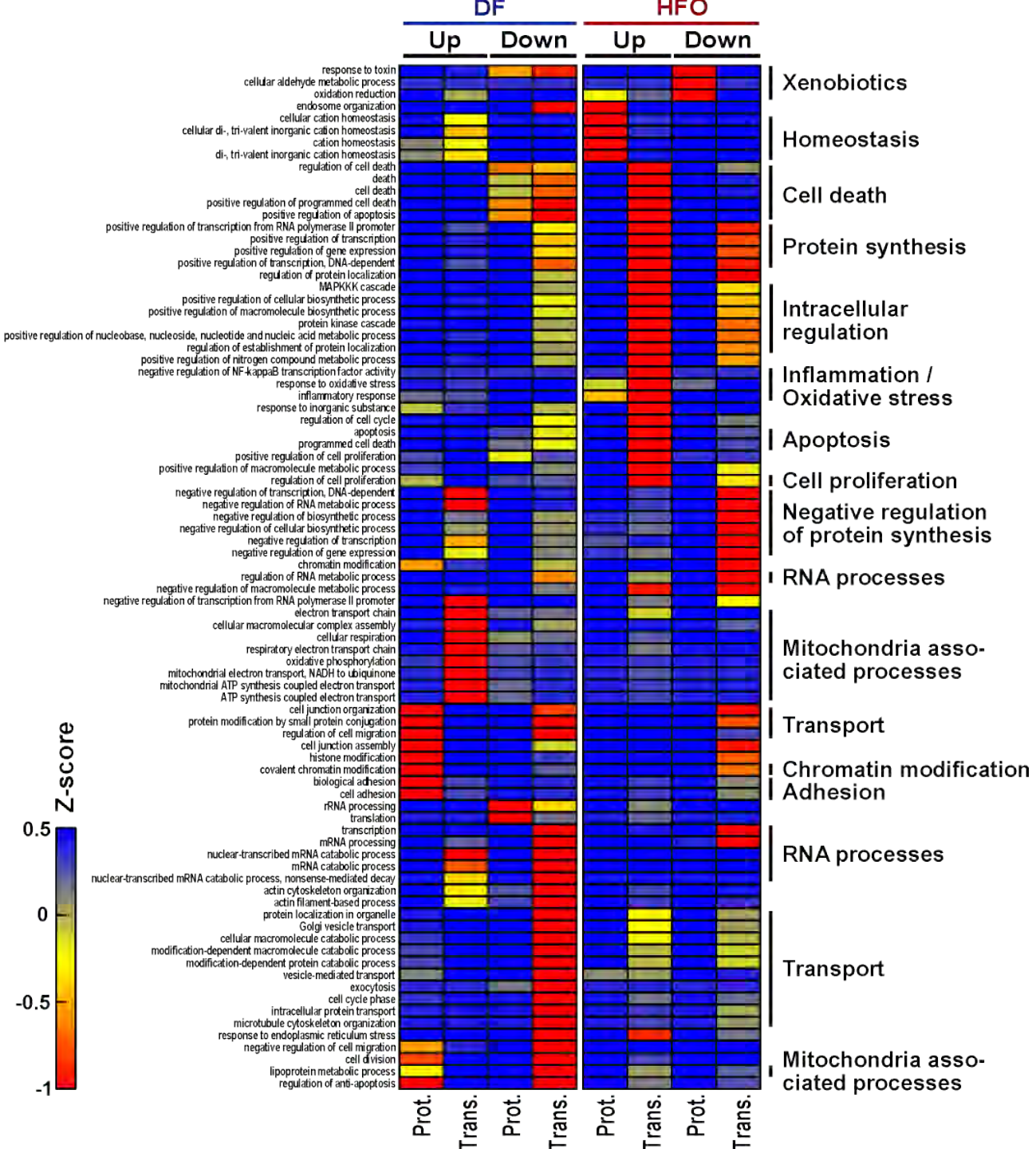
HFO ≠ DF- ≥4-fold regulated genes-



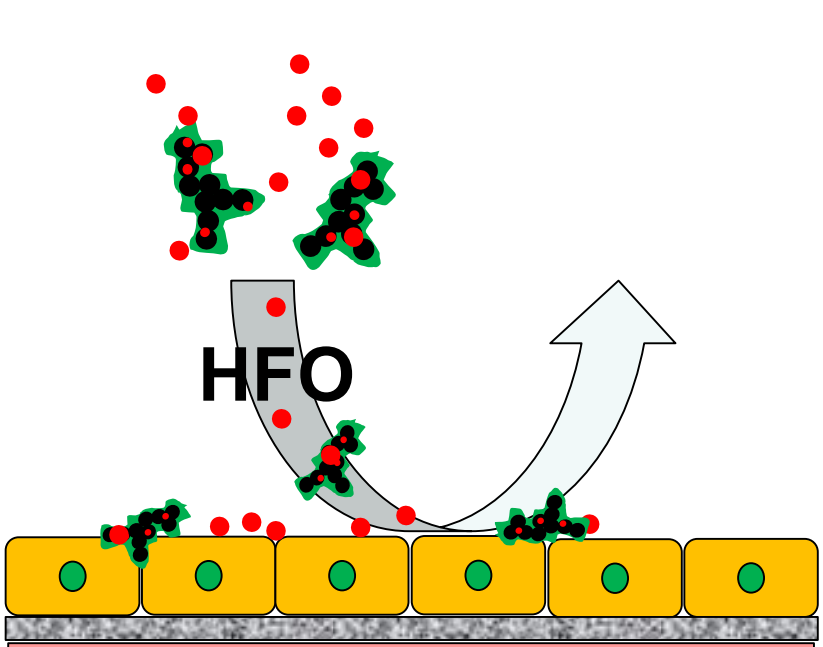
Gene	GO process/component
RMND5A	Unknown
EGR1	Response to mechanical stimulus, drug, isoquilonine alkaloid, hypoxia
RFPL4A	Unknown
JUN	Negative regulation of cell proliferation and transcription, innate immune response
CYP1A1	Xenobiotic metabolism
DEFB113	Immune defense
FOS	Response to oxidative stress, regulator of proliferation
GADD45G	DNA damage response
RASD1	Activator of G-protein signaling, negative regulator of transcription
SNORA28	(small nuclear RNA)
SNAI1	negative regulator of DNA damage response and transcription
RGS2	Negative regulation of G-Protein signaling
DUSP1	Oxidative/ heat stress, apoptosis
TDRD9	DNA methylation, gene silencing, cell differentiation
SYNE1	Cell death, cytoskeletal anchoring at nuclear membrane
CRB2	Calcium ion binding
CXCL2	Inflammation
OR52A5	Sensory perception of smell
CXCL3	Inflammation
ABL2	Regulator of cytoskeleton reorganization, autophagy, and endocytosis
HES1	Cell maturation
LMOD3	cytoskeleton
RNU1-5	unknown
GPR182	G-protein coupled receptor, vasodilation
SNORA74A	(small nuclear RNA)
CD79A	Transmembrane signaling
ODF3L2	unknown
CXCL11	Inflammation
TAS2R50	Sensory perception of taste (bitterness)
LRRTM2	Synapse organization
HIST2H2BF	Nucleosome assembly (histone)
KRTAP3-3	Keratin filament
SSX7	Regulation of transcription
HIST3H2BB	Nucleosome assembly (histone)
RTN4RL1	Cell surface
S100A7A	Inflammation (psoriasis), cell maturation, tumorigenesis
SNORA73A	(small nuclear RNA)
RNU105A	(small nuclear RNA)
FCRL5	Integral to membrane (Fc-receptor-like)
MAGEB1	Expressed in tumors
GRAP	Ras protein signal transduction
	Stronger induced by HFO
	Stronger induced by LFO

„top 10“ most regulated



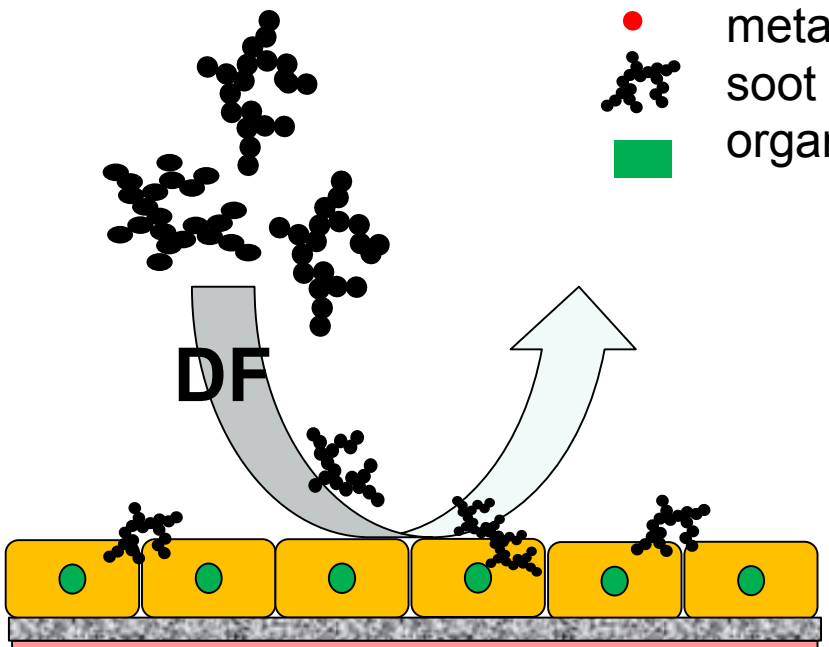

DF
HFO
Up
Down
Up
Down
response to toxin
cellular aldehyde metabolic process
oxidation reduction
endosome organization
cellular cation homeostasis
cellular di-, tri-valent inorganic cation homeostasis
cation homeostasis
di-, tri-valent inorganic cation homeostasis
regulation of cell death
death
cell death
positive regulation of programmed cell death
positive regulation of apoptosis
positive regulation of transcription from RNA polymerase II promoter
positive regulation of transcription
positive regulation of gene expression
positive regulation of transcription, DNA-dependent
regulation of protein localization
MAPKKK cascade
positive regulation of cellular biosynthetic process
positive regulation of macromolecule biosynthetic process
protein kinase cascade
positive regulation of nucleobase, nucleoside, nucleotide and nucleic acid metabolic process
regulation of establishment of protein localization
positive regulation of nitrogen compound metabolic process
negative regulation of NF-kappaB transcription factor activity
response to oxidative stress
inflammatory response
response to inorganic substance
regulation of cell cycle
apoptosis
programmed cell death
positive regulation of cell proliferation
positive regulation of macromolecule metabolic process
regulation of cell proliferation
negative regulation of transcription, DNA-dependent
negative regulation of RNA metabolic process
negative regulation of biosynthetic process
negative regulation of cellular biosynthetic process
negative regulation of transcription
negative regulation of gene expression
chromatin modification
regulation of RNA metabolic process
negative regulation of macromolecule metabolic process
negative regulation of transcription from RNA polymerase II promoter
electron transport chain
cellular macromolecular complex assembly
cellular respiration
respiratory electron transport chain
oxidative phosphorylation
mitochondrial electron transport, NADH to ubiquinone
mitochondrial ATP synthesis coupled electron transport
ATP synthesis coupled electron transport
cell junction organization
protein modification by small protein conjugation
regulation of cell migration
cell junction assembly
histone modification
covalent chromatin modification
biological adhesion
cell adhesion
rRNA processing
translation
transcription
mRNA processing
nuclear-transcribed mRNA catabolic process
mRNA catabolic process
nuclear-transcribed mRNA catabolic process, nonsense-mediated decay
actin cytoskeleton organization
actin filament-based process
protein localization in organelle
Golgi vesicle transport
cellular macromolecule catabolic process
modification-dependent macromolecule catabolic process
modification-dependent protein catabolic process
vesicle-mediated transport
exocytosis
cell cycle phase
intracellular protein transport
microtubule cytoskeleton organization
response to endoplasmic reticulum stress
negative regulation of cell migration
cell division
lipoprotein metabolic process
regulation of anti-apoptosis
Z-score
0.5
0
-0.5
-1
Prot.
Trans.
Prot.
Trans.
Prot.
Trans.
Prot.
Trans.
Xenobiotics
Homeostasis
Cell death
Protein synthesis
Intracellular regulation
Inflammation / Oxidative stress
Apoptosis
Cell proliferation
Negative regulation of protein synthesis
RNA processes
Mitochondria associated processes
Transport
Chromatin modification
Adhesion
RNA processes
Transport
Mitochondria associated processes

Summary of Effects



Rather specific pathways are activated, partially strong

- Cytokines (Inflammation)
- Xenobiotic metabolism
- Apoptosis
- Immune defence stimulation
- PAH metabolism (CYP1A1)



Rather general activation of (T genome wide)

- Inflammation (Cytokines)
- Xenobiotic metabolism
- Apoptosis

Conclusions

- To get approx. equal effects HFO was diluted 1:100; LFO 1:40
- Particles were more toxic than the gaseous phase
- HFO ≠ DF: HFO had more organics and less but stronger toxic effects, DF had more different effects
- Removing sulphur is not enough to eliminate the adverse health effects
- We expect particles to be the main culprit for the DF health effects. (Oeder *et al.*, PLOSone 2015 in press)

Zimmermann group @
Joint Mass Spectrometry Centre

Universität Rostock Traditio et Innovatio

HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt

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K. Lau

Funding

- Uni Rostc
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- Bundesm
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- Deutsche
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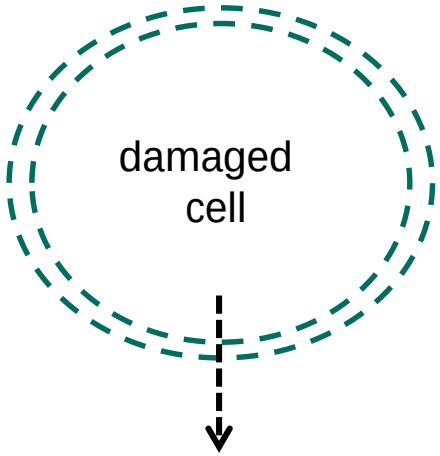
- Companie Airsense G
- Helmholtz HICE)

Rapid at-site assays for cytotoxicity: Determination of dilution-factor

LDH-Assay

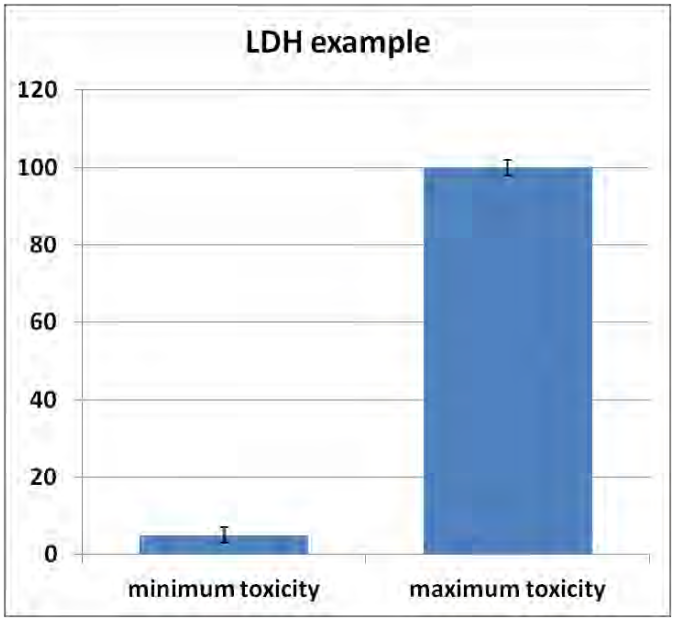


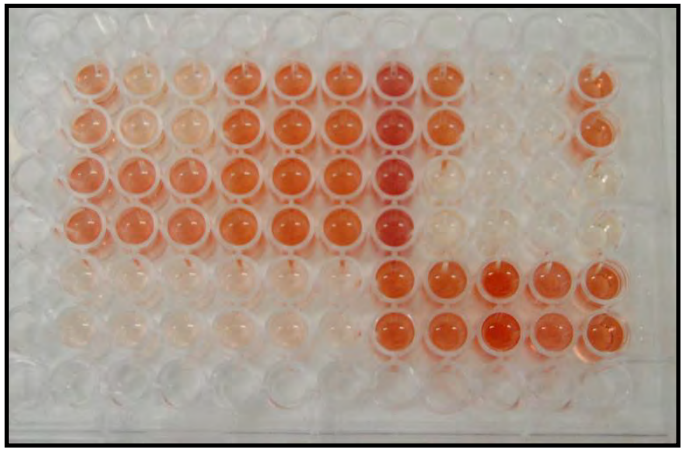
Lactate dehydrogenase (LDH)

↓

quantification with
enzymatic assay

➔ reflects amount of cells with damaged membrane (=dead)

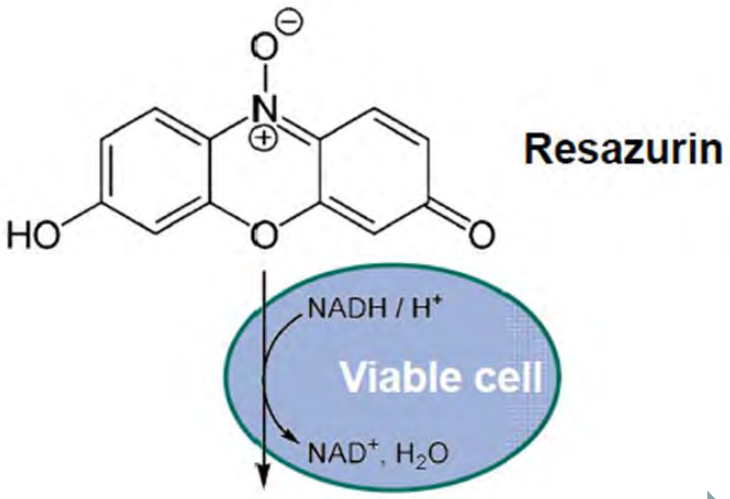


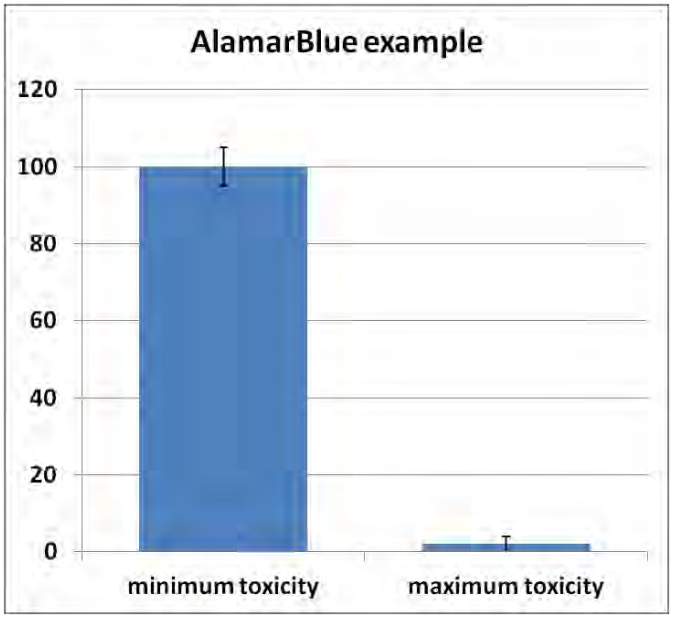


high red intensity = high LDH release

Rapid at-site assays for cytotoxicity: Determination of dilution-factor

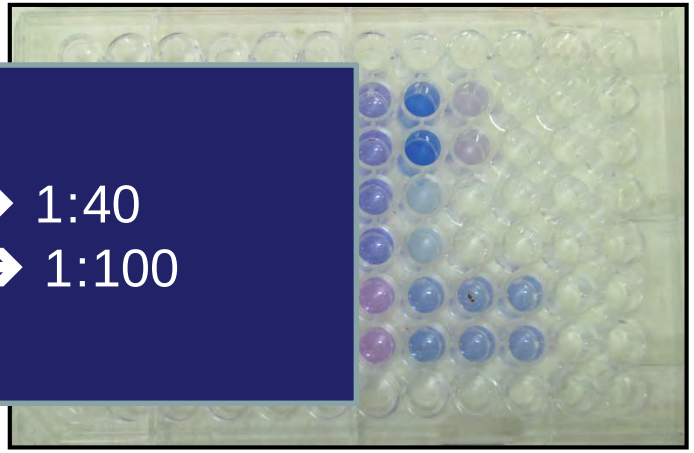
AlamarBlue Assay





AlamarBlue
LDH

LFO ➔ 1:40
HFO ➔ 1:100

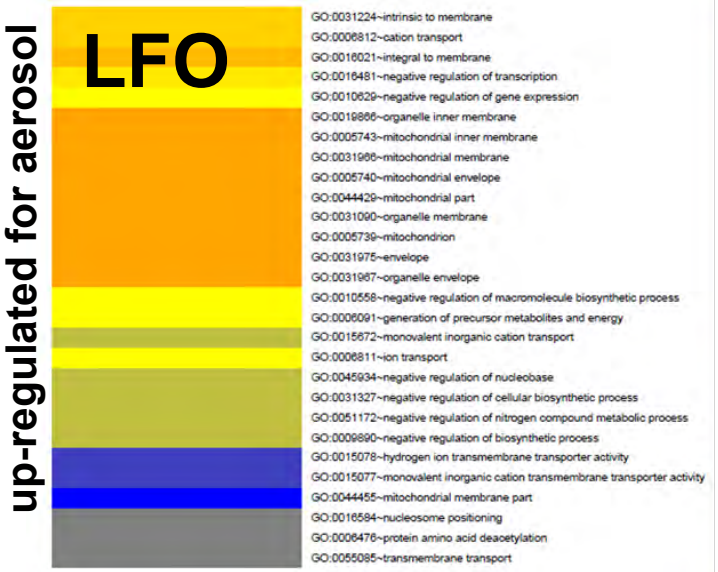


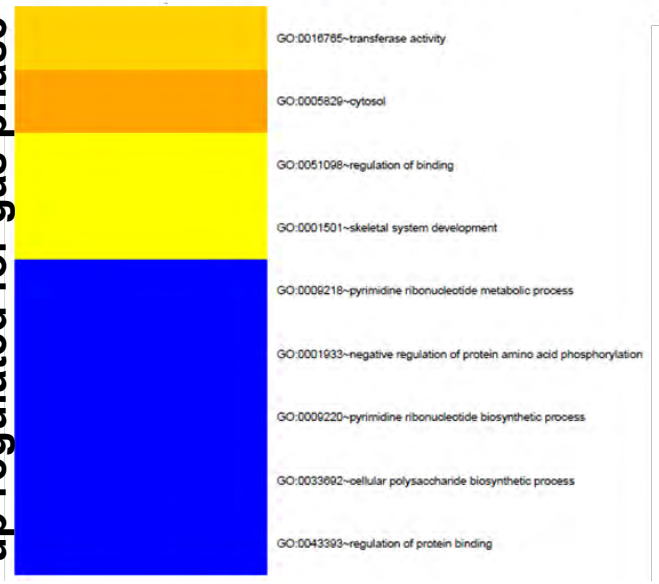
➔ **reflects metabolic activity … viabili…**

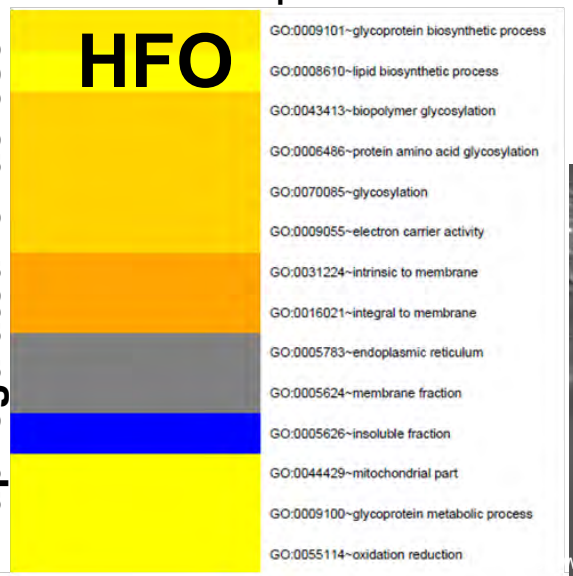
Low viability = high toxicity

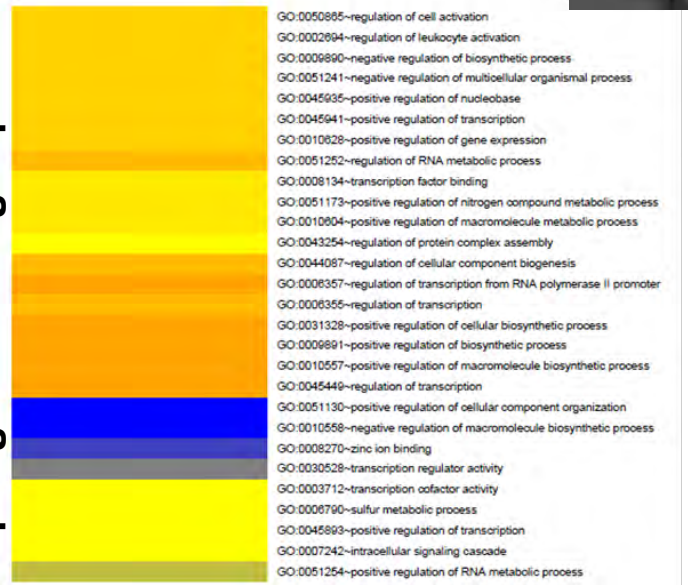
pink = high viability; blue = low viability

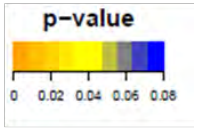
): A549 - adenocarcinomic human alveolar basal epithelial cells

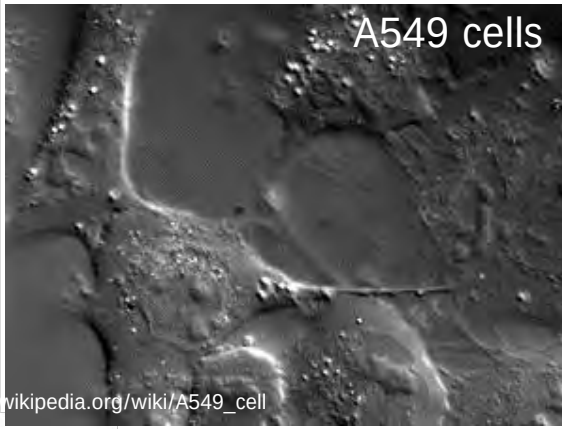




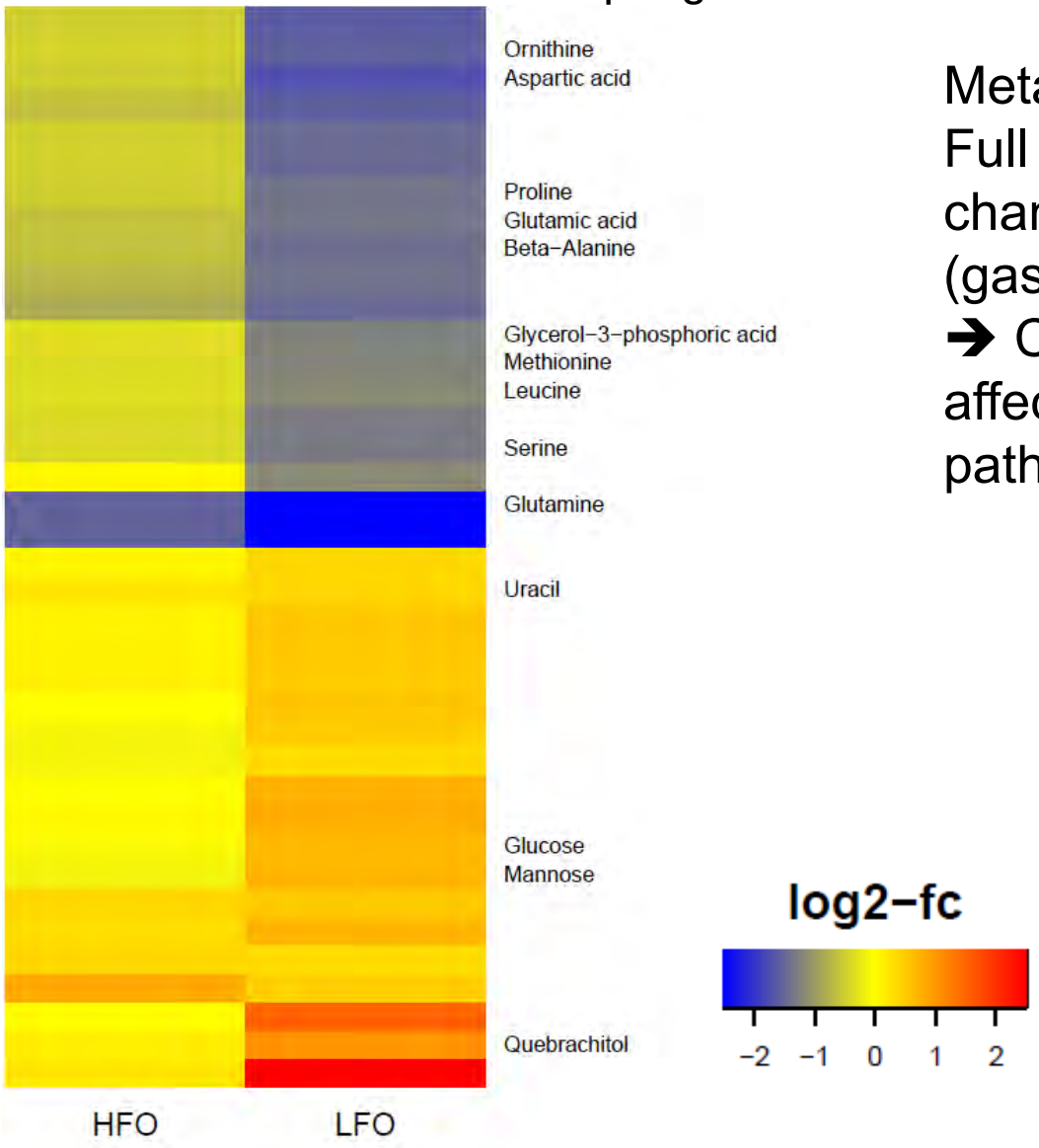




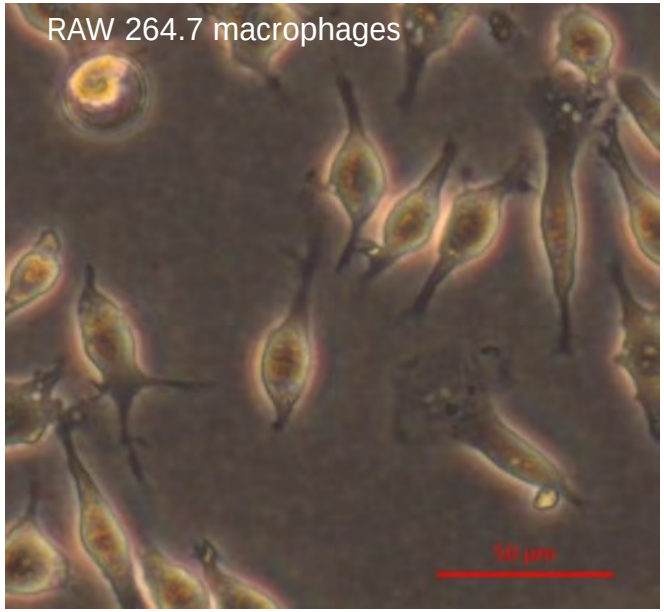




S 2B - RAW 264.7 murine macrophages

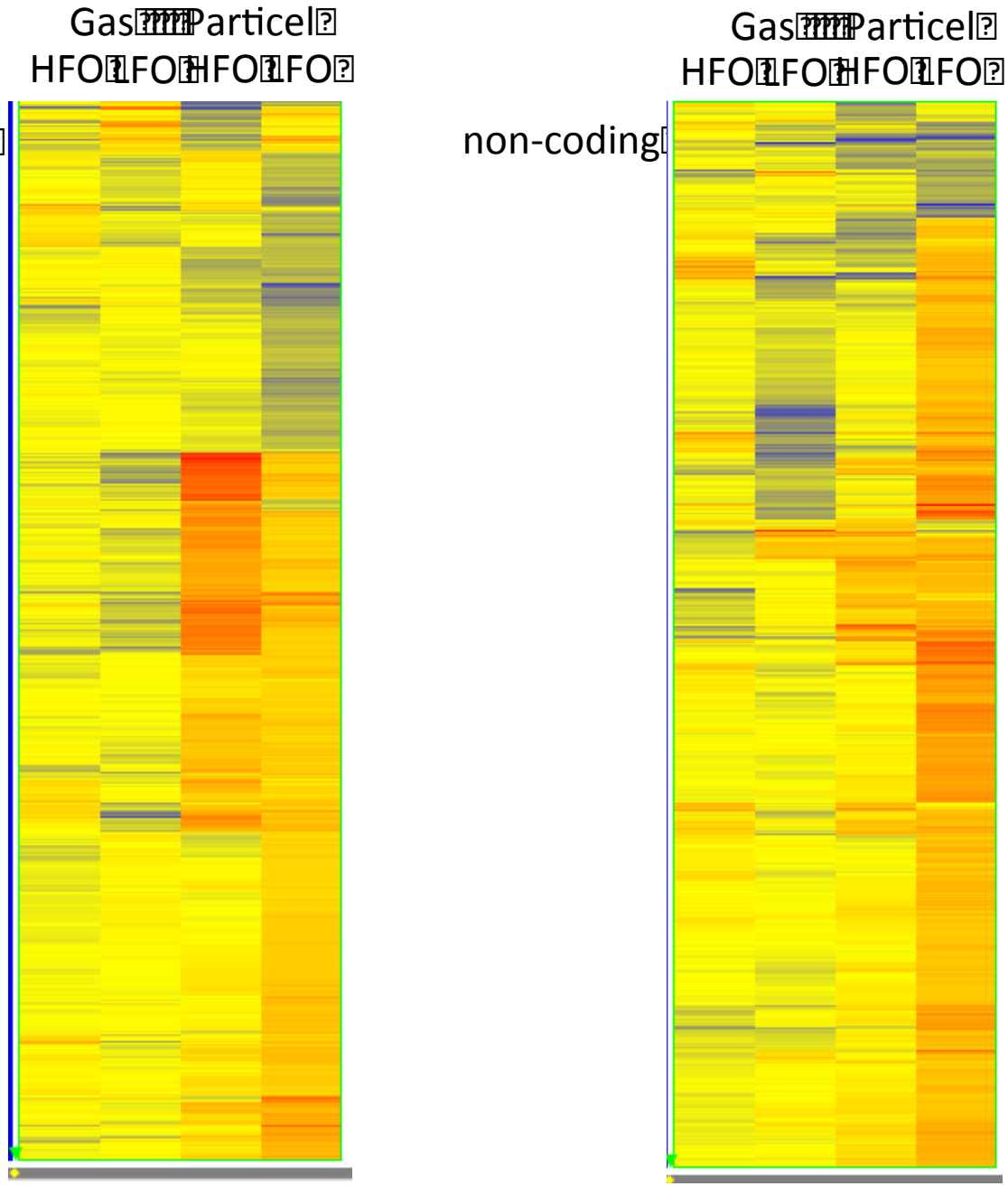


Metabolomics:
Full aerosol induces stronger changes than the filtered aerosol (gas phase).
➔ Central C-metabolism is not affected (labeling!) but other pathways are significantly regulated.



Gene-Name	Gene-Function	accosciated with
IL1	Regulation of immune responses, inflammatory reactions, and hematopoiesis	Inflammation
CD4	Co-receptor assisting the T cell receptor (TCR) in communicating with an antigen-presenting cell, Inflammation	
GLYAT	Detoxification of a wide range of xenobiotic and endogenous metabolites	Xenobiotic metabolism
CYP1A1	Xenobiotic and drug metabolism, Metabolic activation of aromatic hydrocarbons (polycyclic aromatic hydrocarbons, PAH)	
CYP3A4	Catalyze many reactions involved in drug metabolism	
CYP26C1	Catabolism of all-trans- and 9-cis-retinoic acid, and thus contributes to the regulation of retinoic acid levels in cells and tissues	
CYP26A1	Regulates the cellular level of retinoic acid which is involved in regulation of gene expression in both embryonic and adult tissues	
CYP11B1	Involved in the conversion of 11-deoxycortisol to cortisol in the adrenal cortex	
SULT1E1	Catalyze the sulfate conjugation of many hormones, neurotransmitters, drugs, and xenobiotic compounds	
IGF1	Important role in childhood growth and continues to have anabolic effects in adults	Cancer induction
IGF2	Major fetal growth factor	
Jun	Cell cycle progression and anti-apoptotic activity	
Casp10	Execution-phase of cell apoptosis	Apoptosis
CRADD	Induction of cell apoptosis	
HRK	Activator of apoptosis	
CASP7	Apoptosis	
MAPK10	Regulatory roles in the signaling pathways during neuronal apoptosis	
NFKB	Immune response, Cell proliferation, Cell death	
CYCS	component of the electron transport chain in mitochondria, initiation of apoptosis	
CASP3	execution-phase of cell apoptosis	

Global analysis of regulated genes (≥1.5-fold)

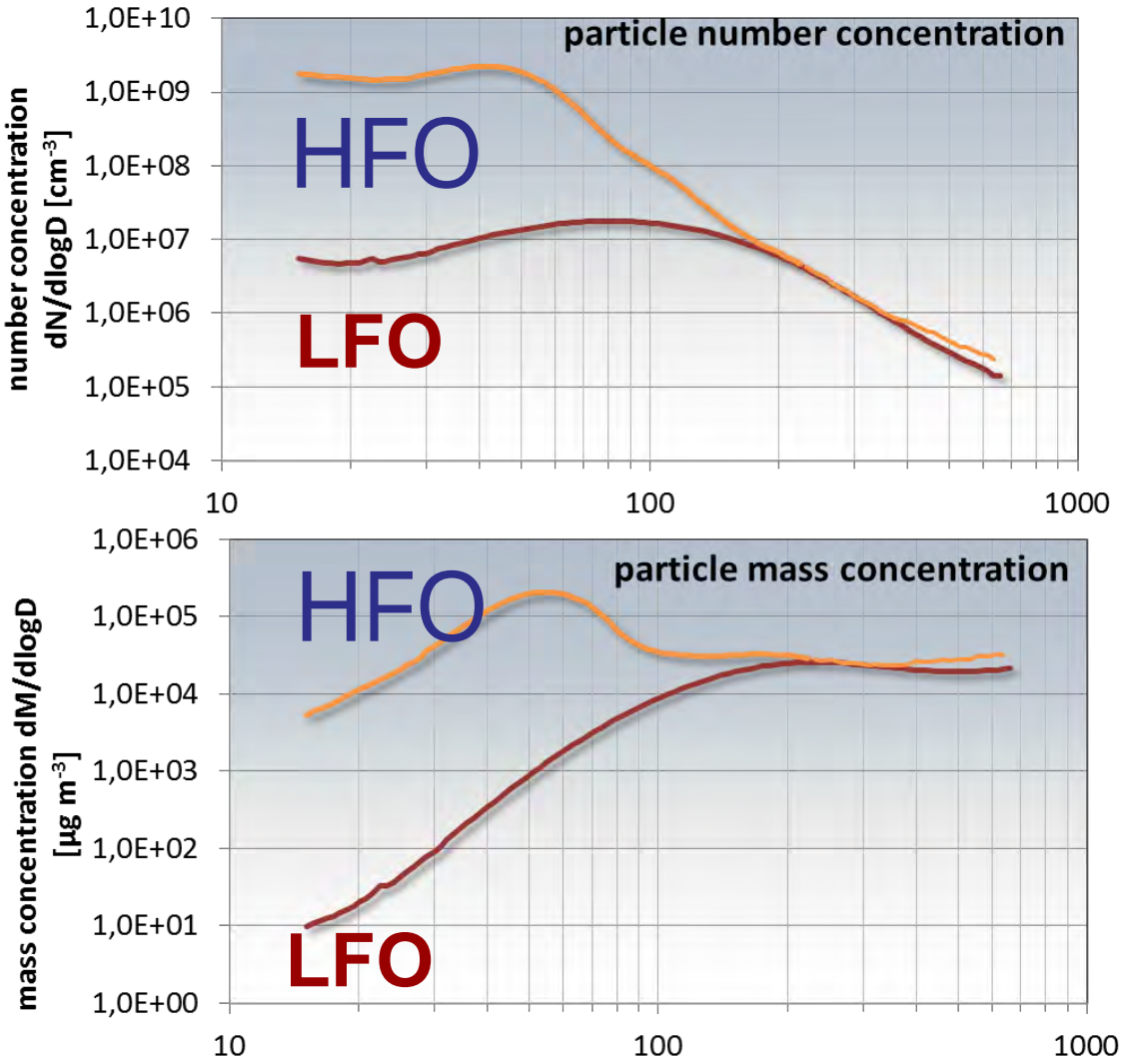


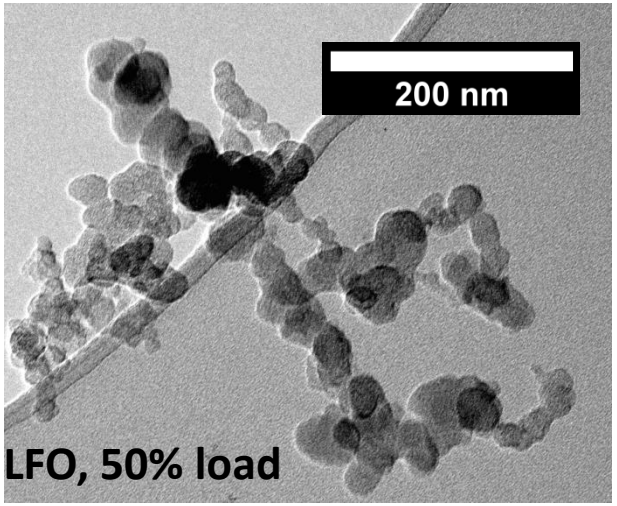
Gas refered to clean air;
Complete aerosol
refered to Gas
(=particle)

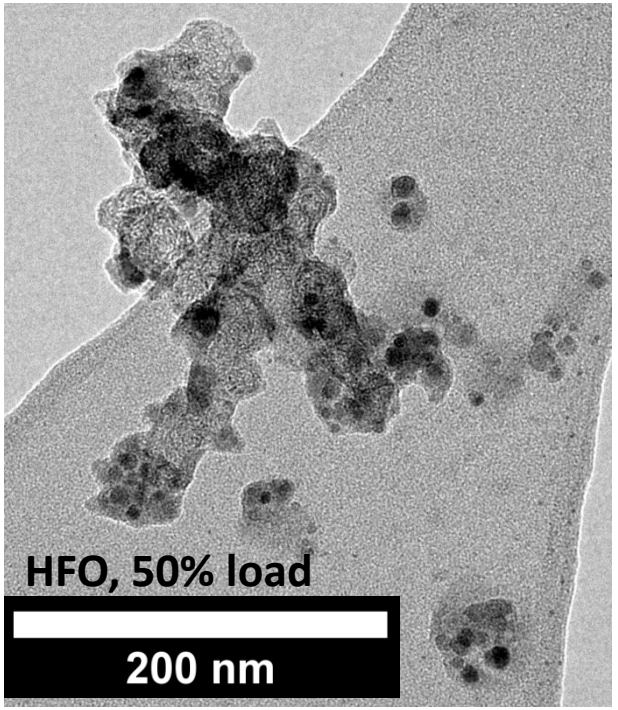
Particles: Measured Emissions

- at ALI-exposure system -

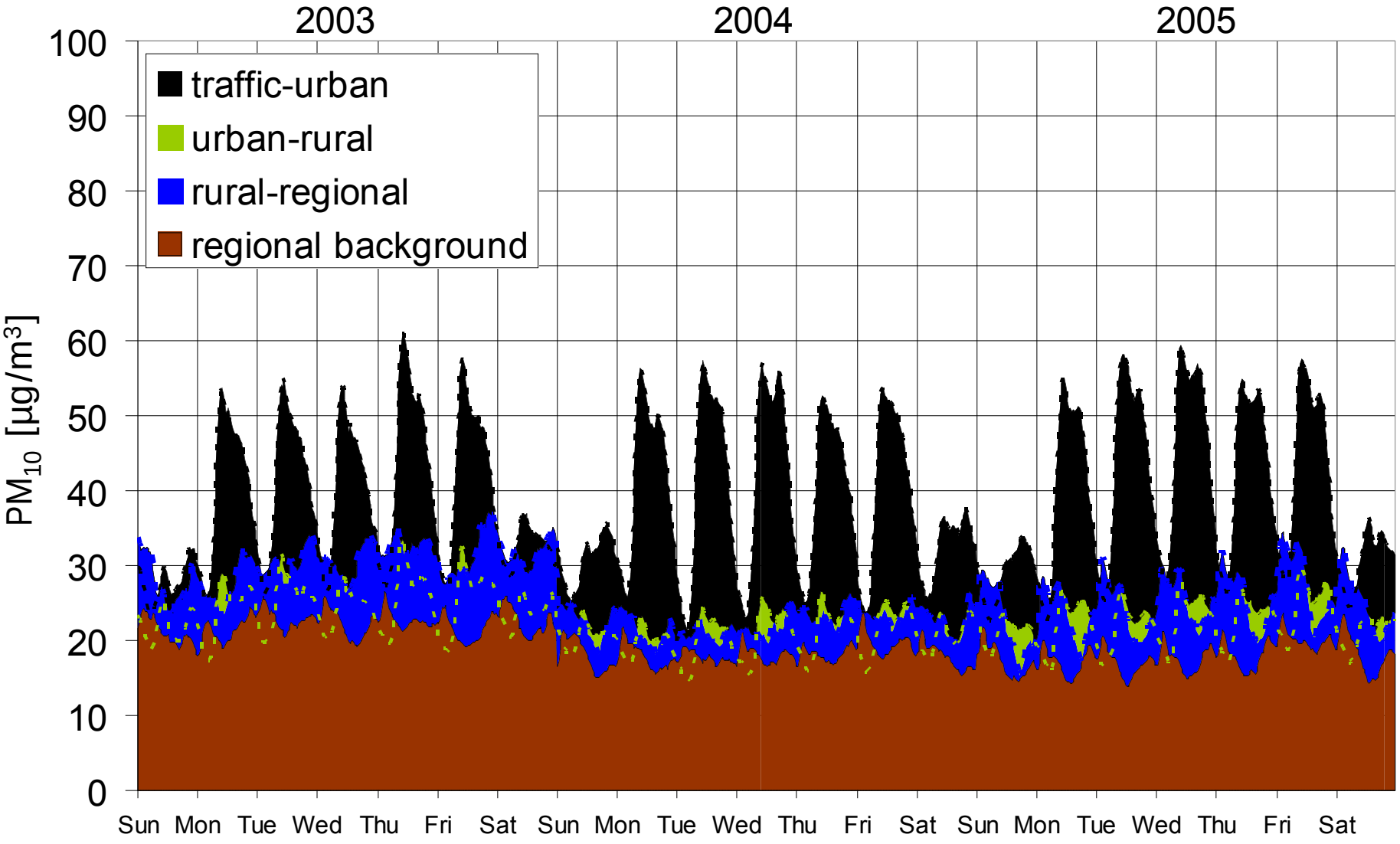
General parameters: Size distribution





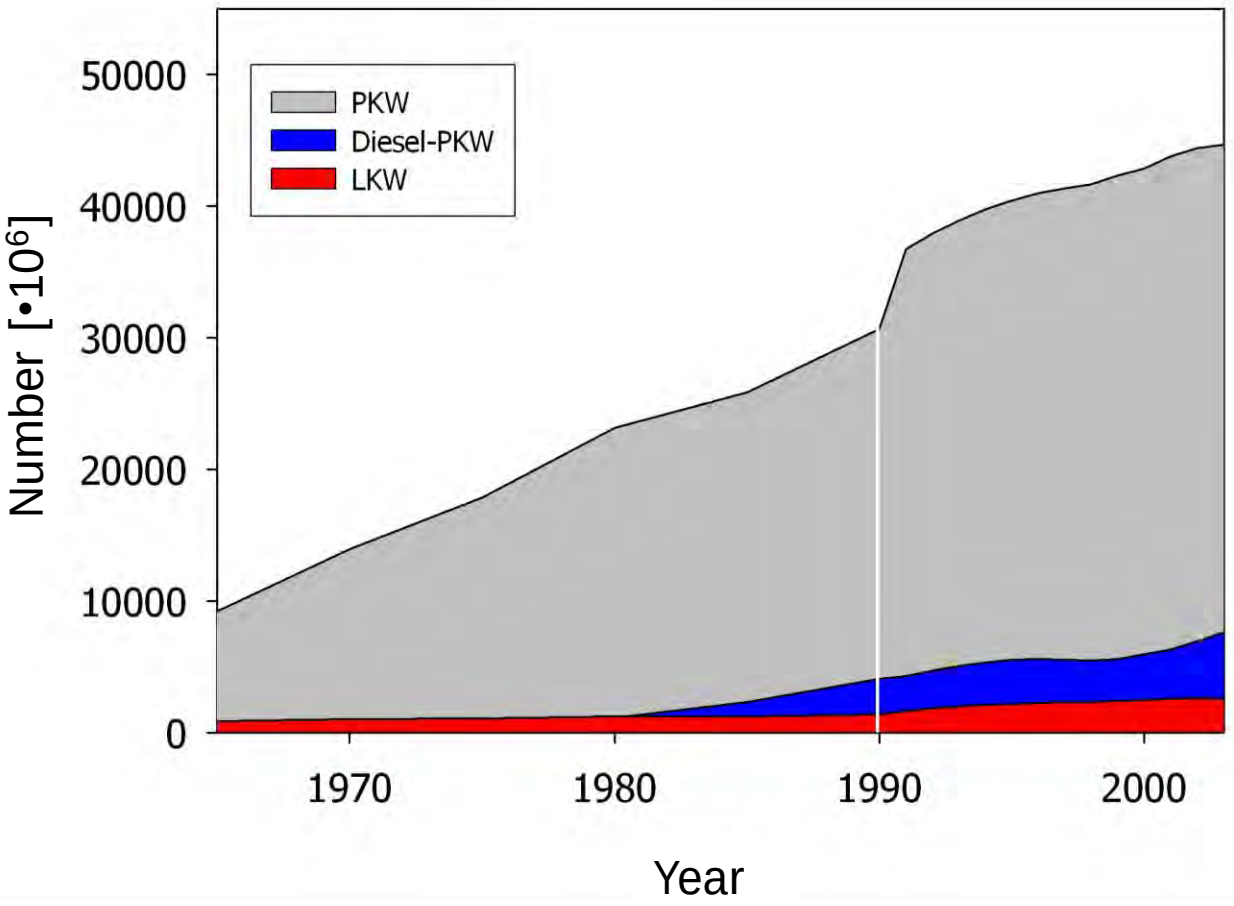


Diurnal Variation: Bremen (traffic site)



Quass et al., EAC Salzburg, 2007

Vehicle development in Germany



Statistisches Bundesamt, Verkehr in Zahlen 2006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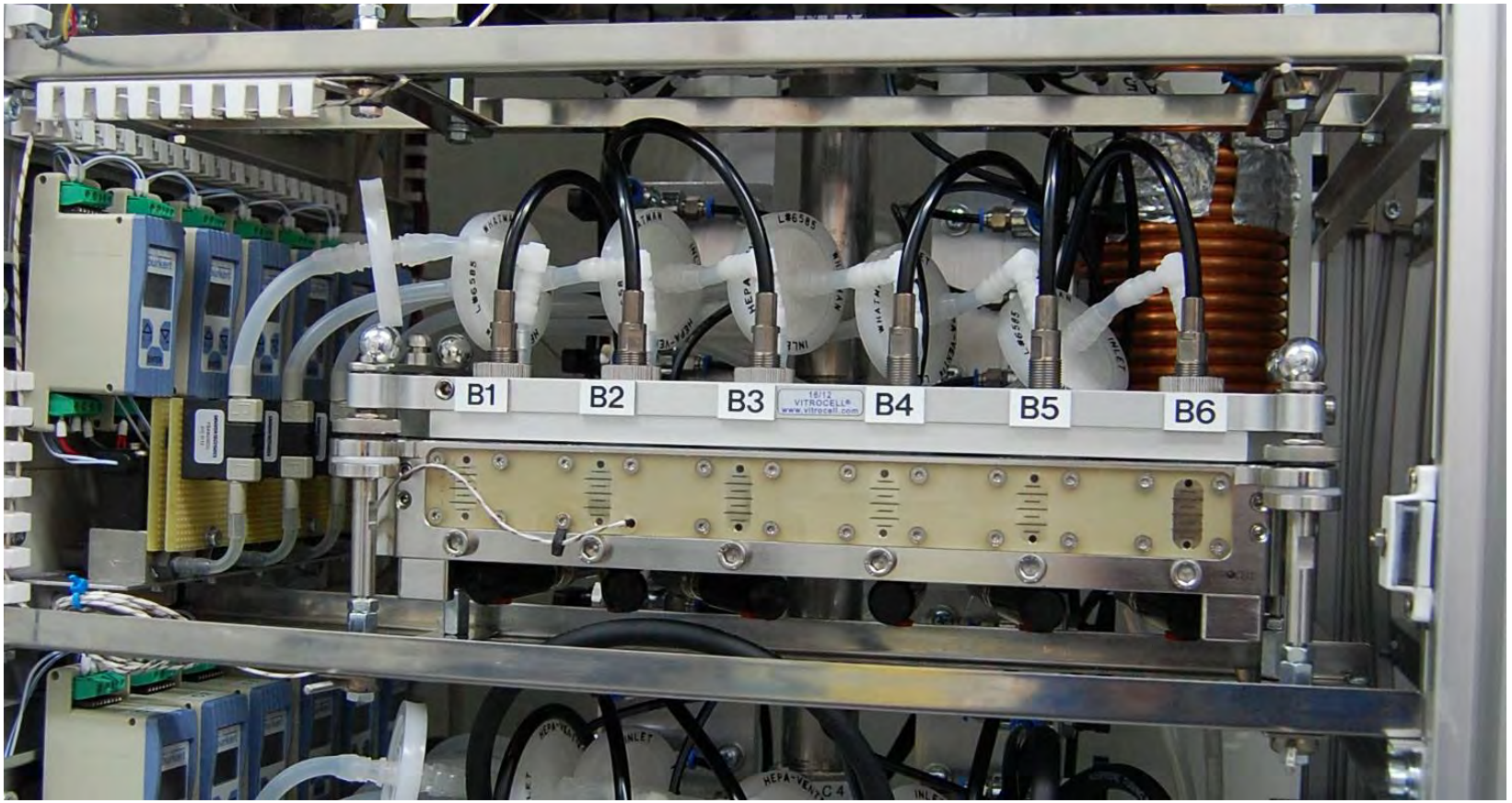
HICE › Aerosols and Health
Helmholtz Virtual Institute of Complex
Molecular Systems in Environmental Health
Universität
Rostock
KIT
Vorsicht!


Thermo
SCIENTIFIC


KIT


B1
B2
B3
B4
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B6
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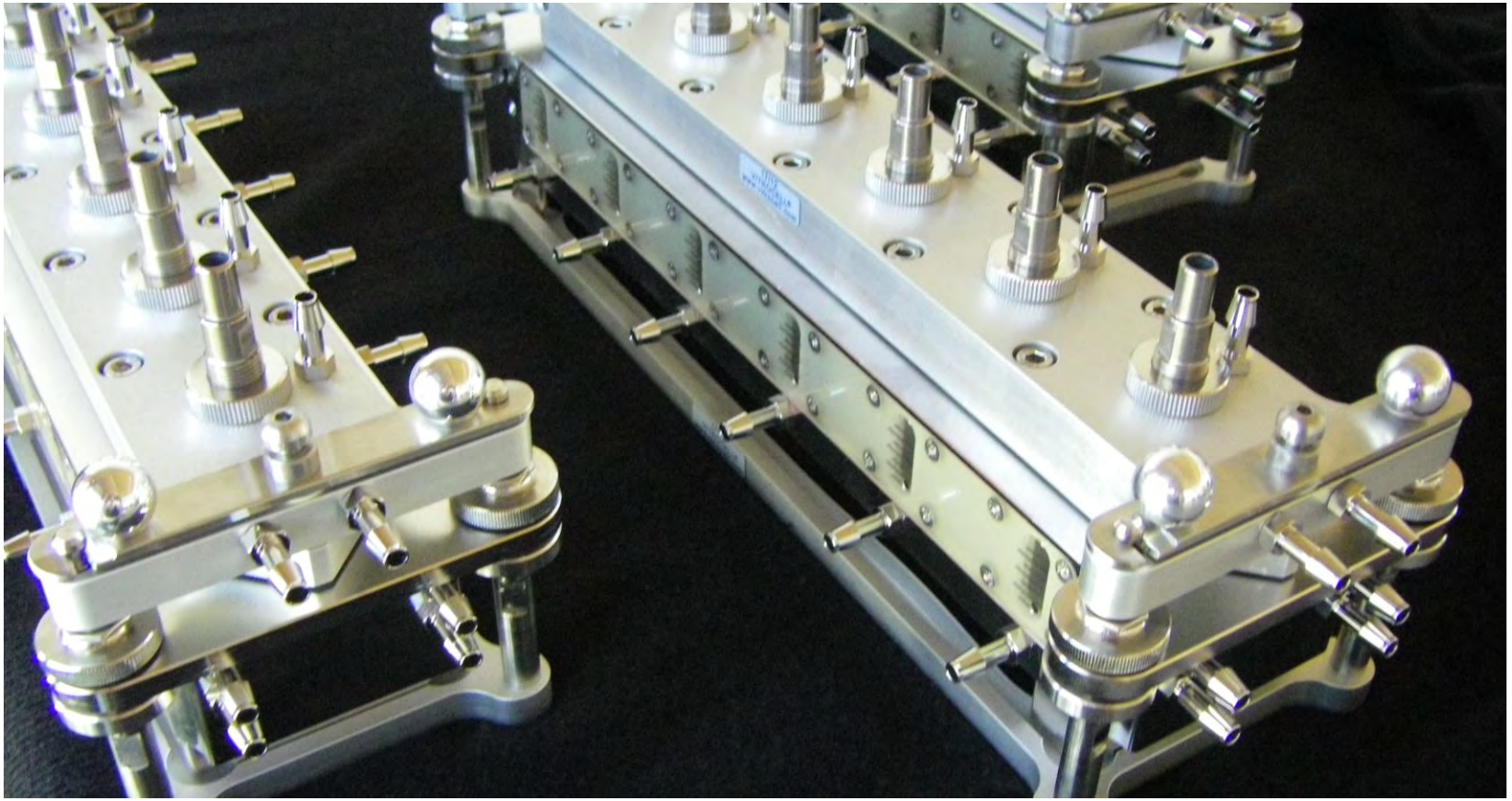
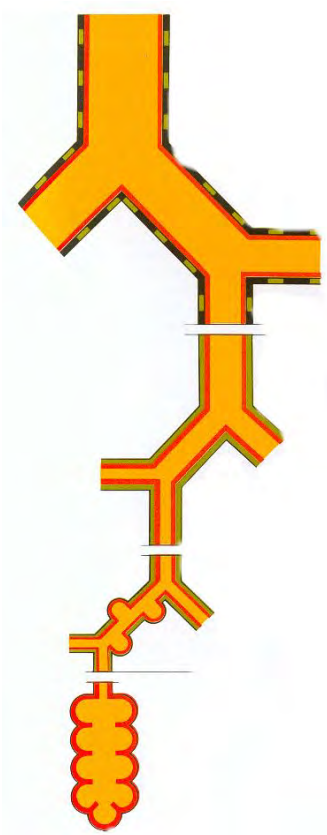
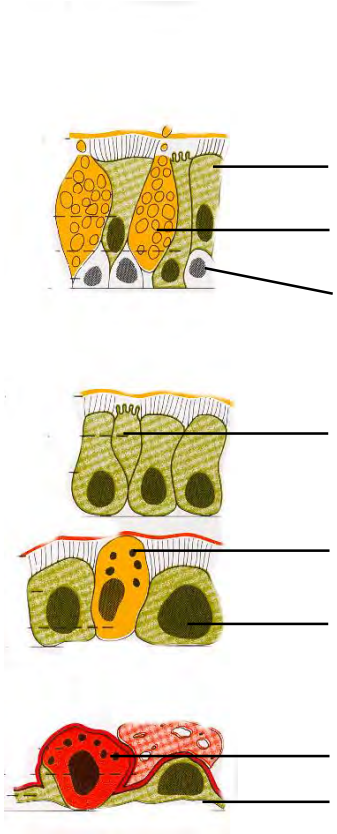


Respiratores Epithelium





zyl. Flimmerzelle

Becherzelle

Basalzelle

Bürstenzelle

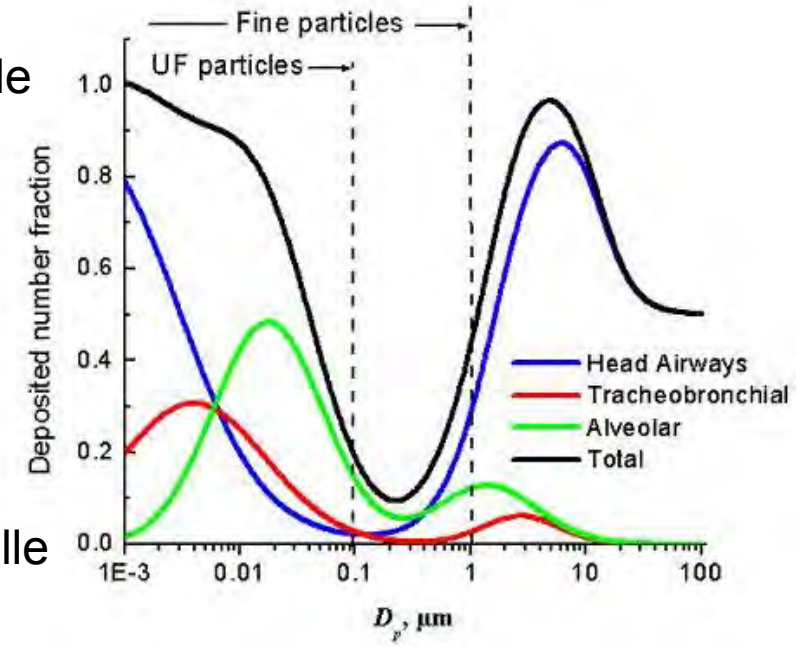
Clara-Zelle

kub. Flimmerzelle

Typ II - Zelle

Typ I - Zelle

Deposition von Partikeln



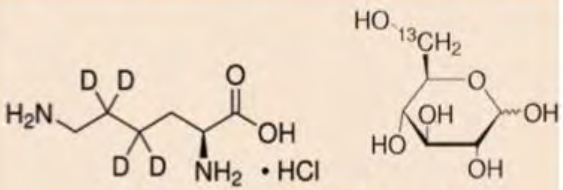
Quelle Figur: Prof. N. Krug, pers. Mitteilung

D=Diameter, UF=Ultrafeinstaub

aerosol

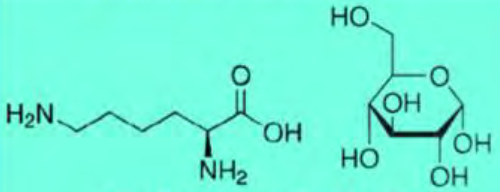
filtered aerosol (gas)

Stable isotope labeled cell culture

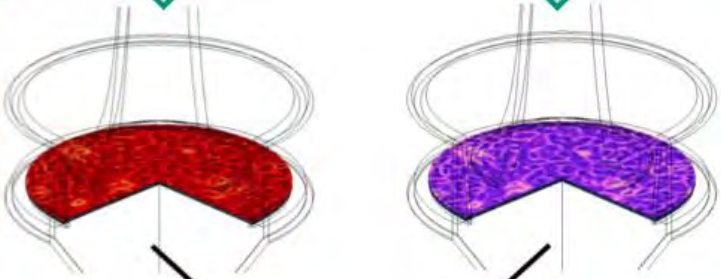


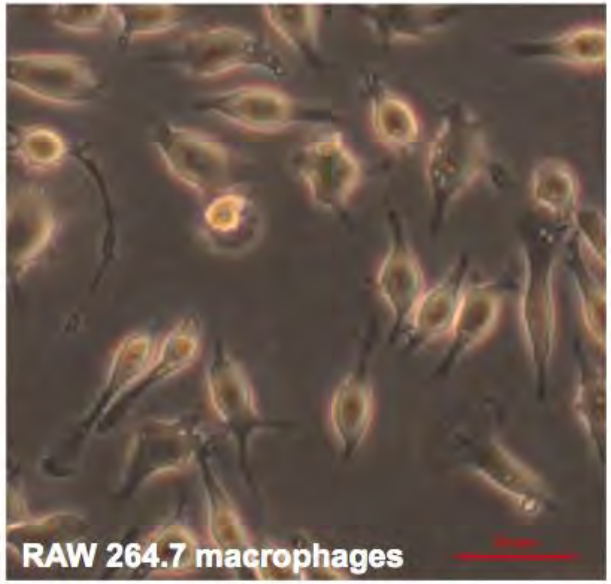
L4-Lysine and 13C-Glucose

Native cell culture

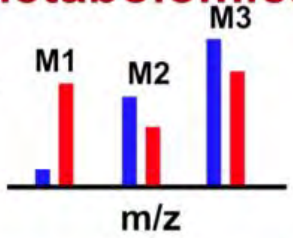


L0-Lysine and 12C- Glucose

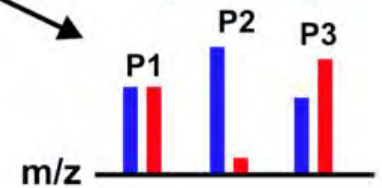




Metabolomics



Proteomics (SILAC)

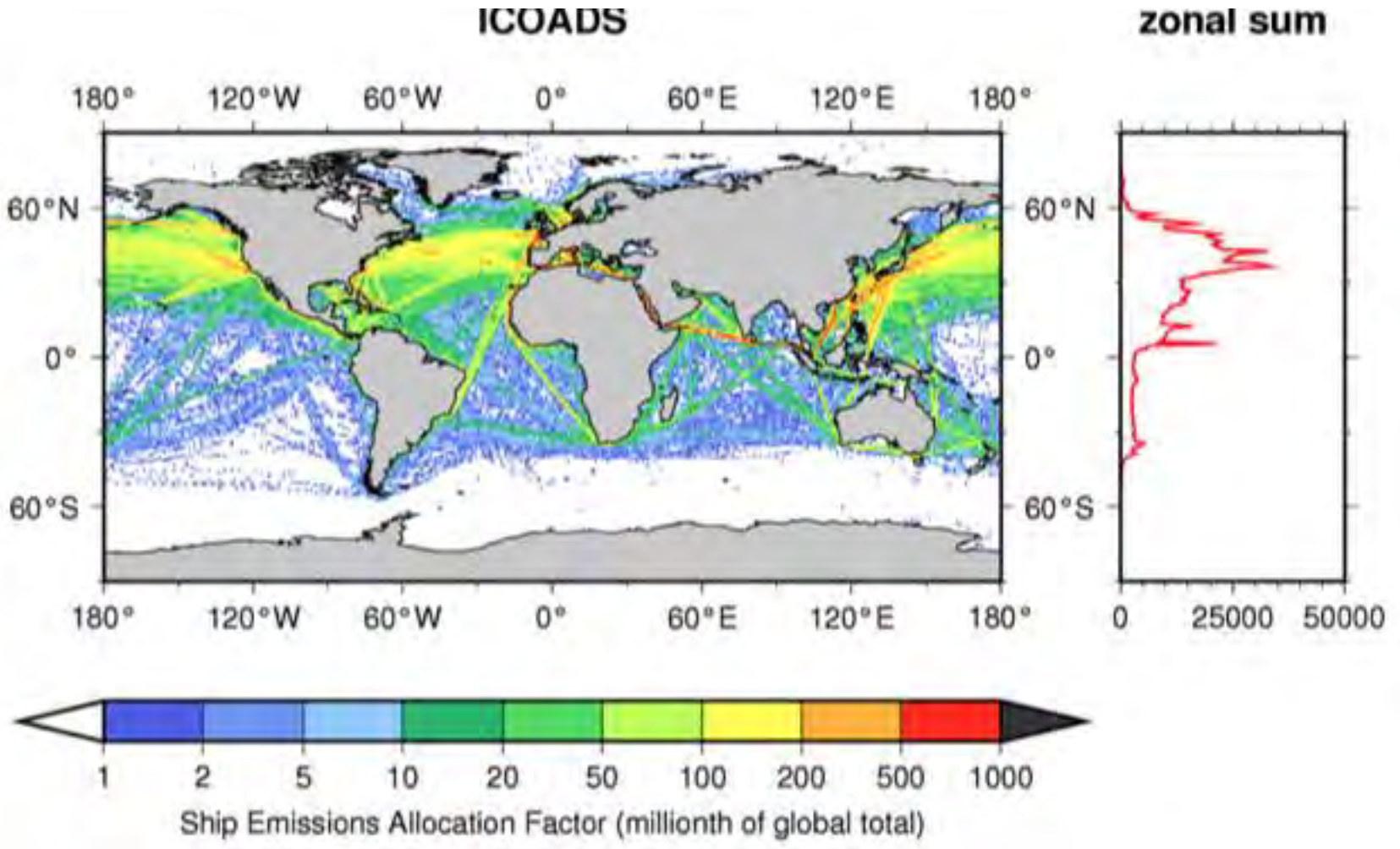


Ship diesel exhaust components

Component	Heavy Fuel *	Diesel**
SO_2	400-550ppm	1-10 ppm
NO_2	1-10 ppm	61-50ppm
CO	50-300 ppm	70-550 ppm
NO_x	600-750 ppm	600-700 ppm
PM (TSP)	665.0 µg/m^3	14.4 µg/m^3
THC	150-270 ppm	200-350 ppm

* 1.6% Sulphur (world average 2.7%, max. 4.5%)

** Diesel according DIN EN 590: <10 ppm Sulphur

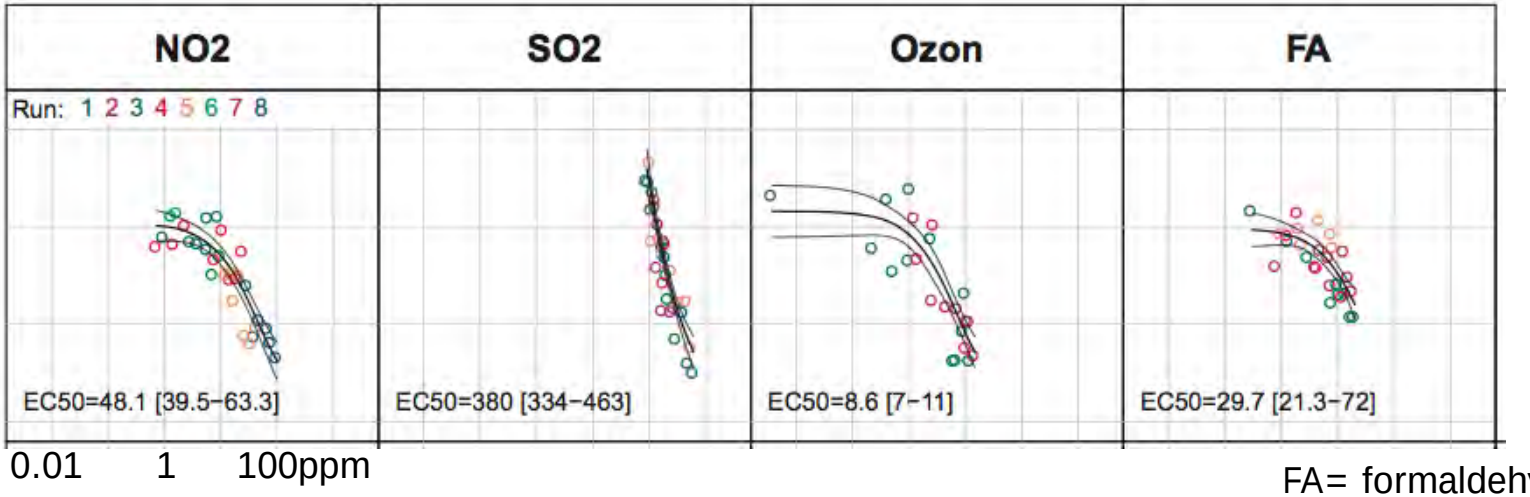

ICOADS
zonal sum
180°
120°W
60°W
0°
60°E
120°E
180°
60°N
0°
60°S
0
25000
50000
1
2
5
10
20
50
100
200
500
1000
Ship Emissions Allocation Factor (millionth of global total)

Eyring 2010

Toxicity in at the Air Liquid Interface

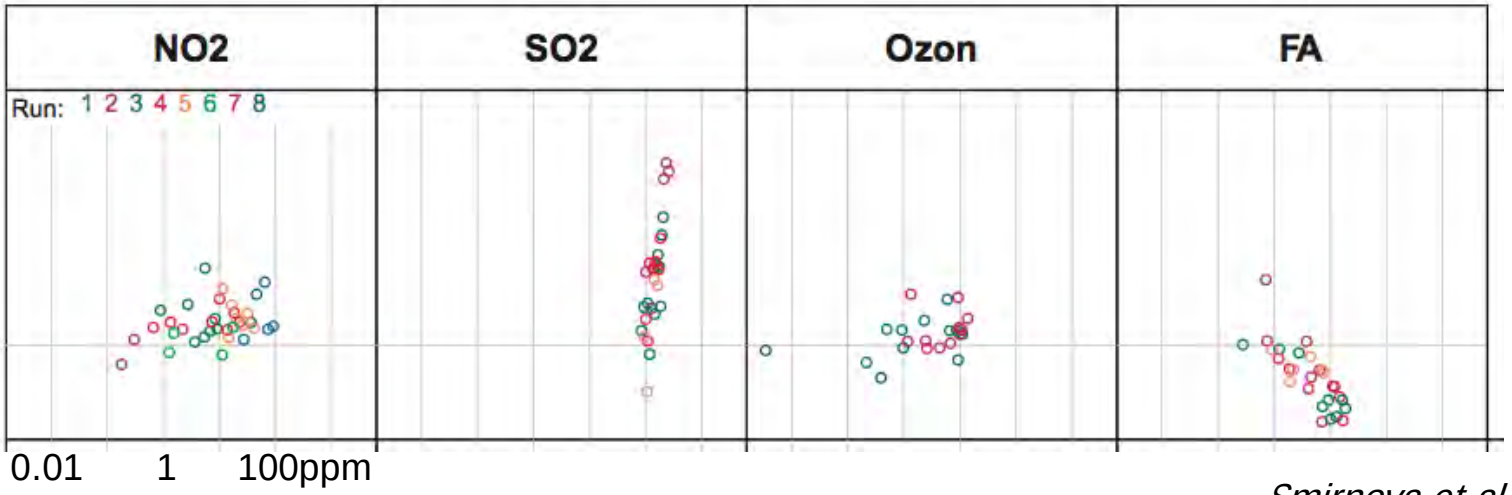
- 1hr exposure, BfRA -

Current Exclusion Method



FA= formaldehyde

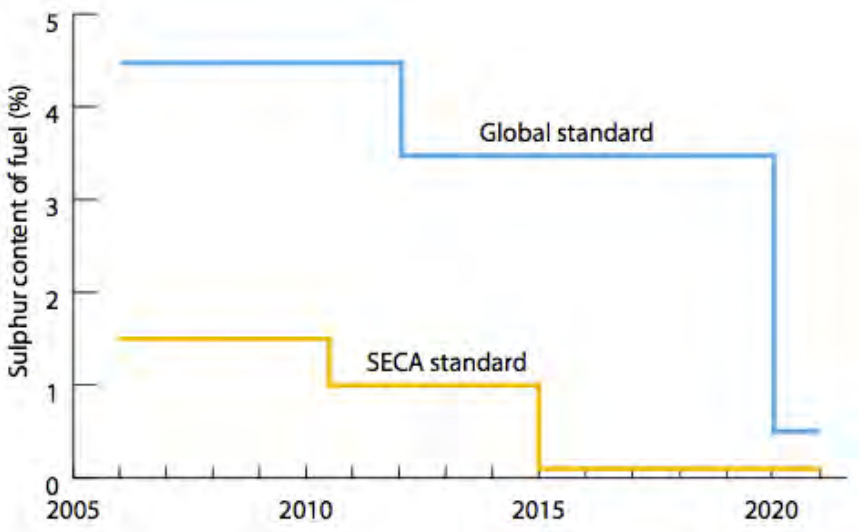
Comet Assay



Smirnova et al, BfRA 2012

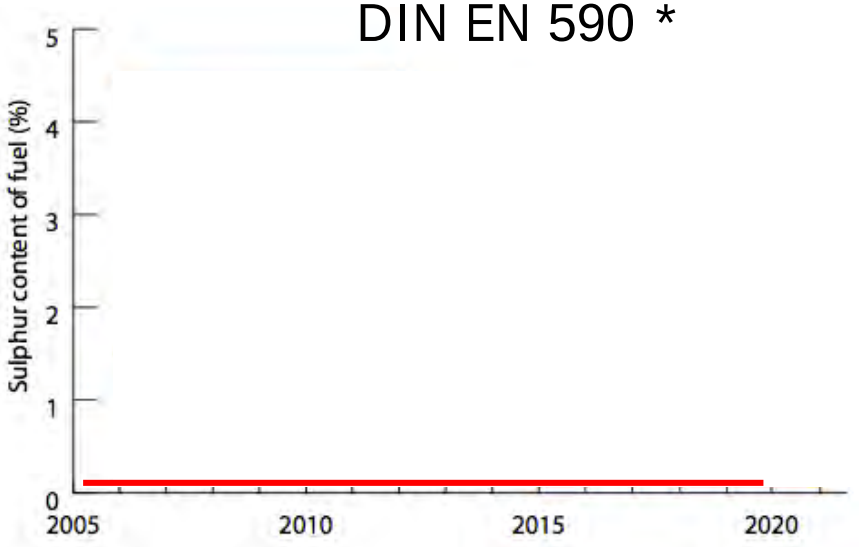
Regulations of fuels

Ship-fuel



Automotive-fuel

DIN EN 590 *



Abgasnorm	spätestens	Schwefelgehalt	Cetanzahl
Euro 1	1. Januar 1993	max. 0,200 %	min. 49
Euro 2	1. Januar 1996	max. 0,050 %	min. 49
Euro 3	1. Januar 2001	max. 0,035 %	min. 51
Euro 4	1. Januar 2006	max. 0,005 %	min. 51
Euro 5	1. Januar 2009	max. 0,001 %	min. 51
Euro 6	1. Januar 2014		

*<10ppm Sulphur

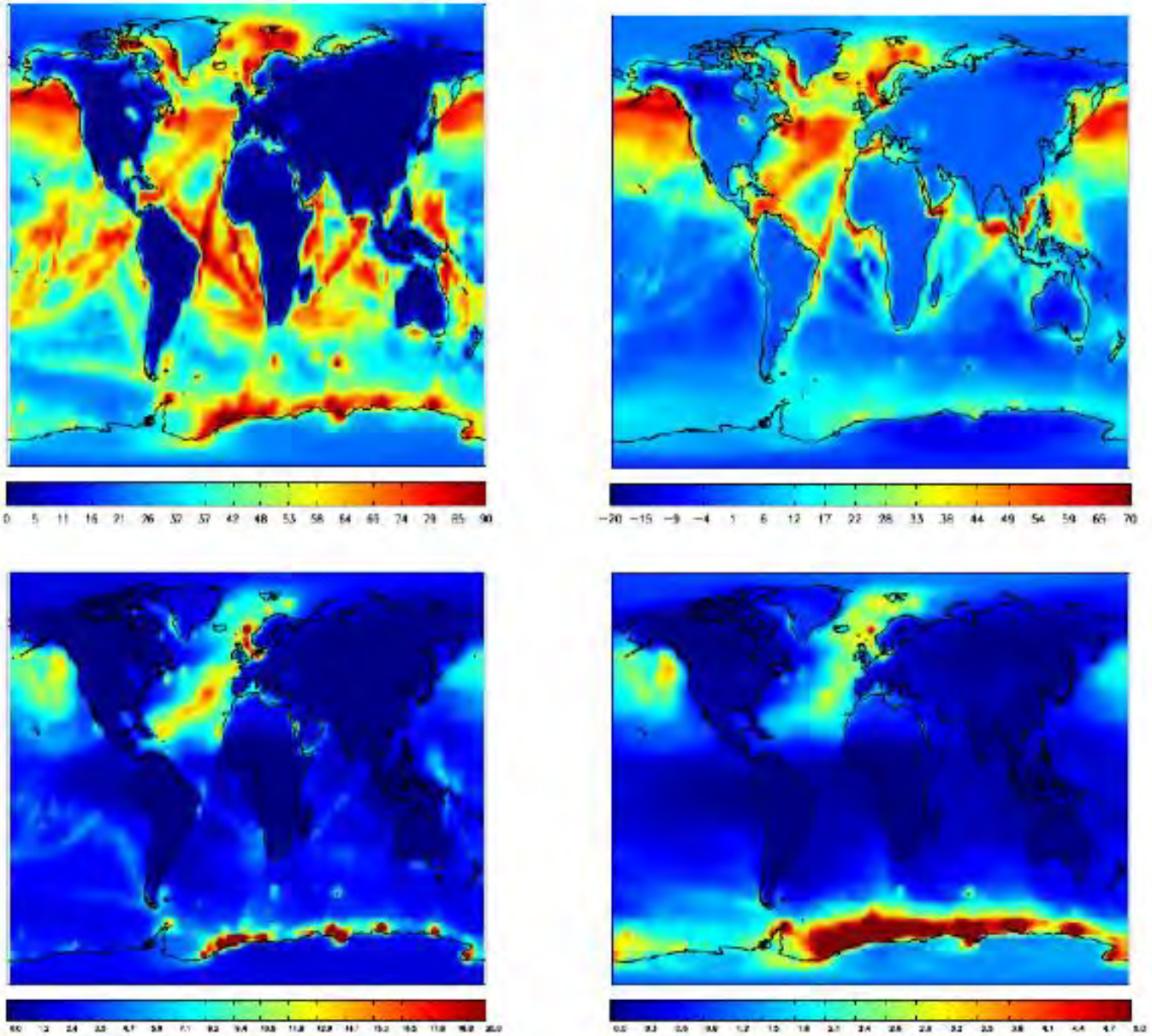
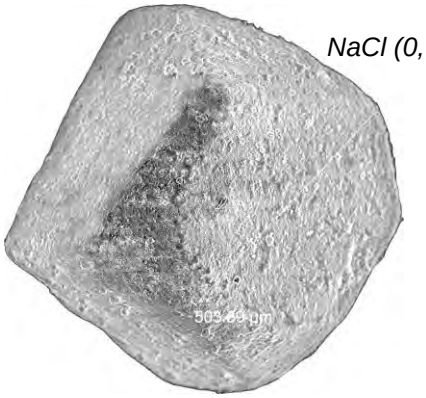
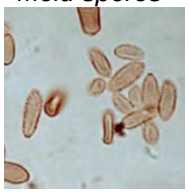


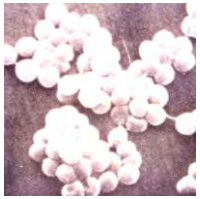
Fig. 7. Yearly average contribution (%) from all ships+ports to NO_2 (upper left) SO_2 (upper right), hydrophobic organic carbon (lower left) and hydrophilic organic carbon (lower right).


NaCl (0,7mm)

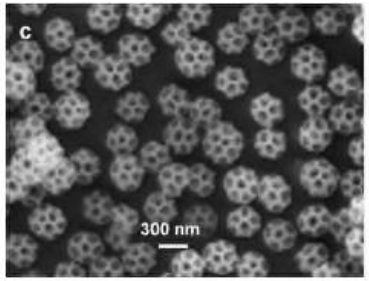
Sources of particles

Biogenic

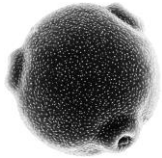

Mold spores


Bacteria

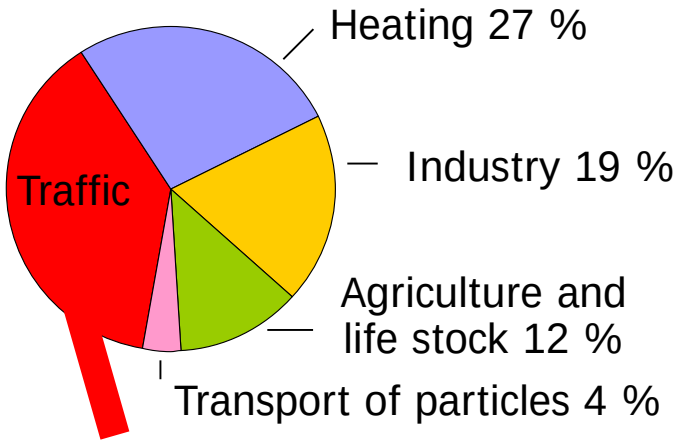
- Spores
- Bacteria
- Sea salt
- Bronchosomes
- Crustal materiall (Sand etc.)
- Combustion of vegetable Material
- Pollen



Bronchosomes


Birch pollen

Anthropogenic



Source: Emissionskataster Bayern, 2004

Traffic:
- 26% Off-road Diesel
- 63% On-road vehicles (of those ca. 70 % Dieselfahrzeuge)

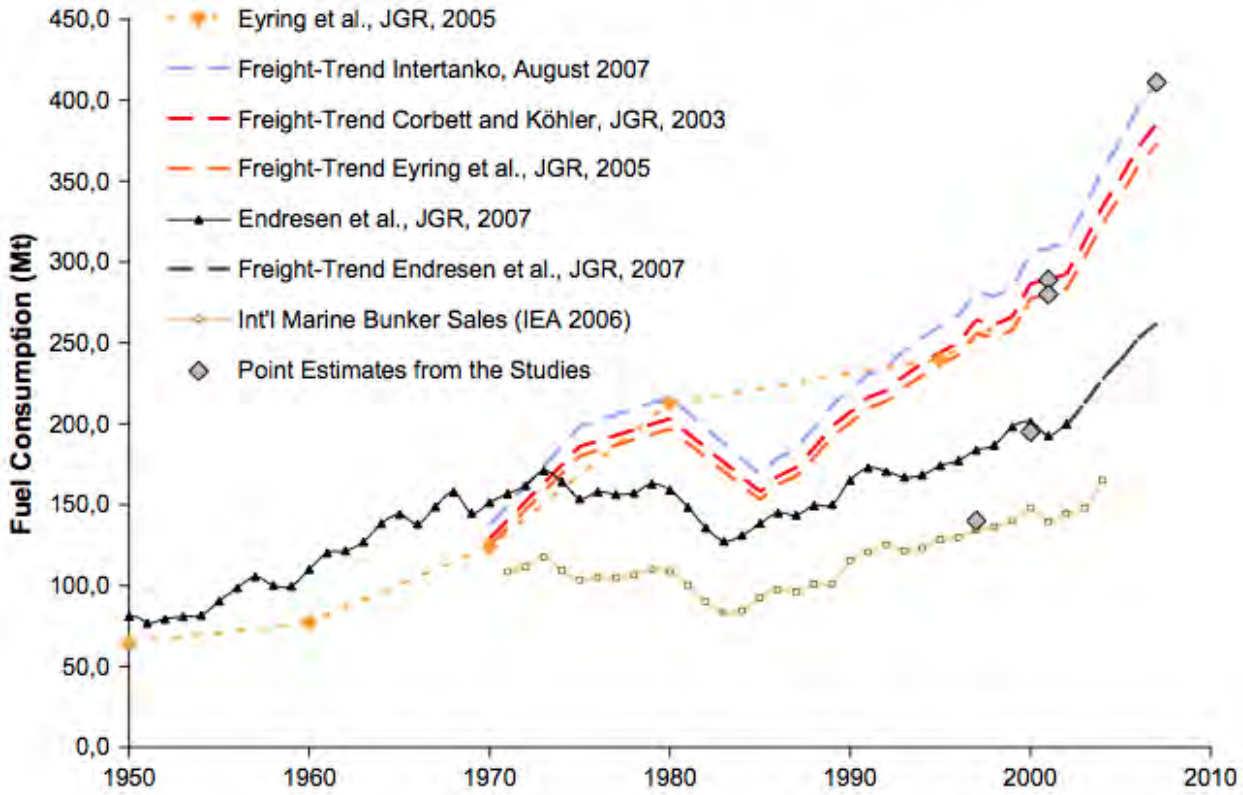


Fig. 5. World fleet fuel consumption (civilian, military, and auxiliary) and international marine bunker fuel statistics in Mt from different estimates. The symbols indicate the original estimates for individual years and the solid lines show the original trend estimates from these studies. The dashed lines show the back- and forecast calculated from the time evolution of freight ton-miles with the point estimates from 2001 (Corbett and Köhler, 2003; Eyring et al., 2005a), 2000 (Endresen et al., 2007), 2007 (Gunner, 2007), and 1997 (IEA, 2006) taken as the reference year.

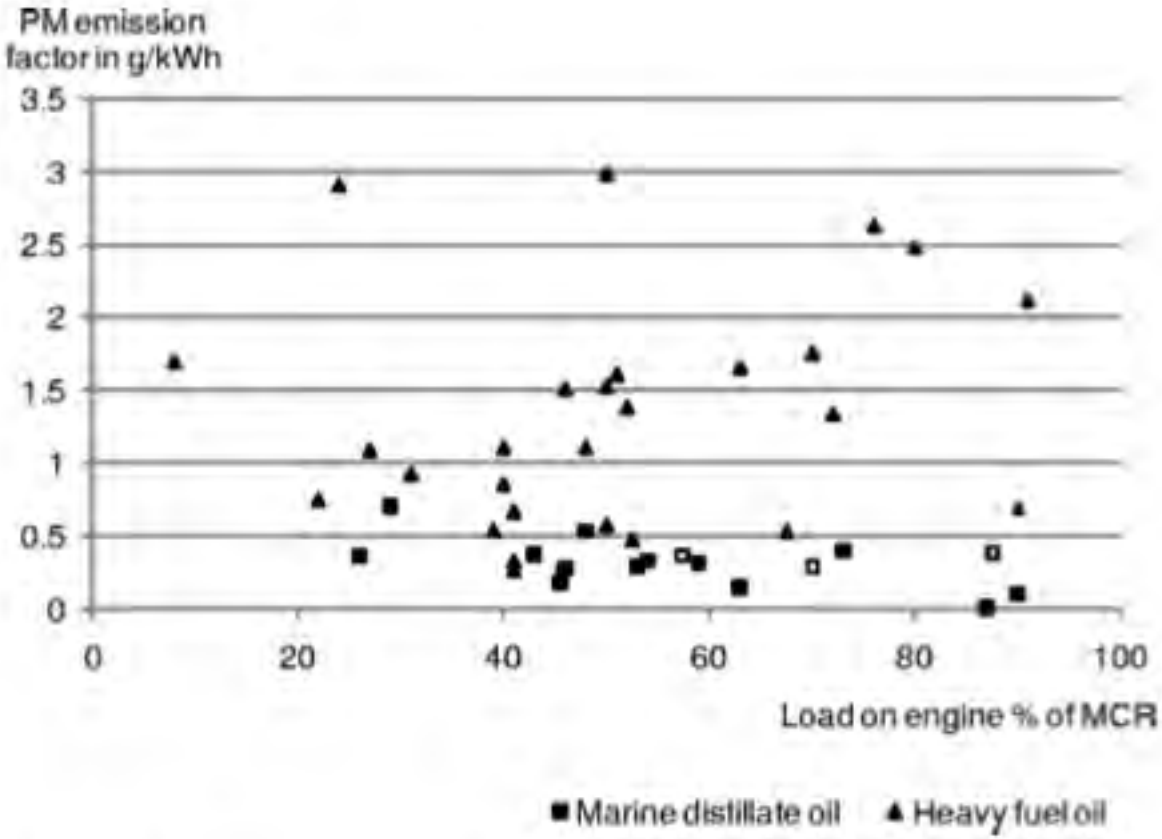
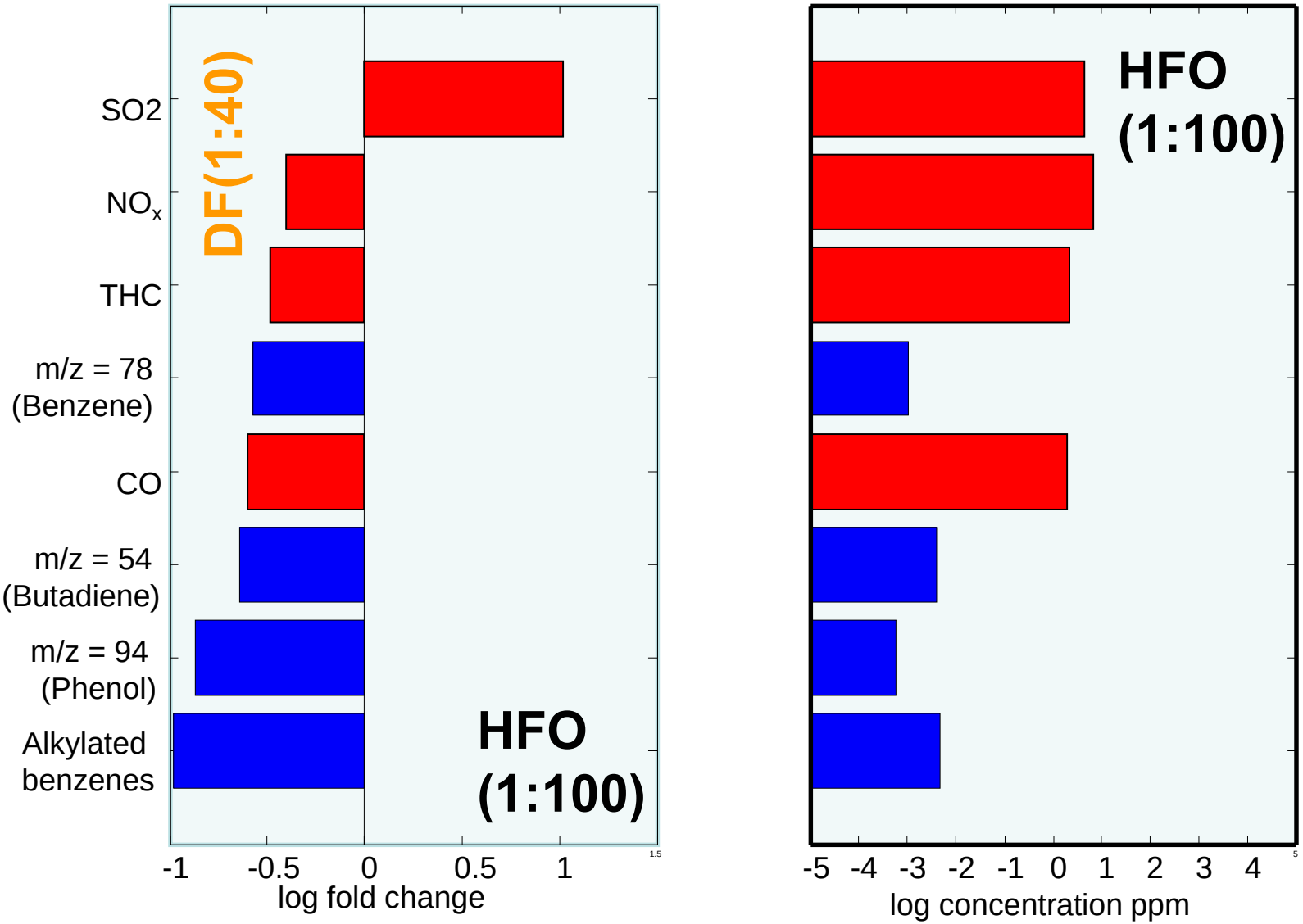


Figure 3. PM emission factor as a function of engine load. Results from four prior studies and the presented measurements. The values from the presented measurements are indicated with open markers.

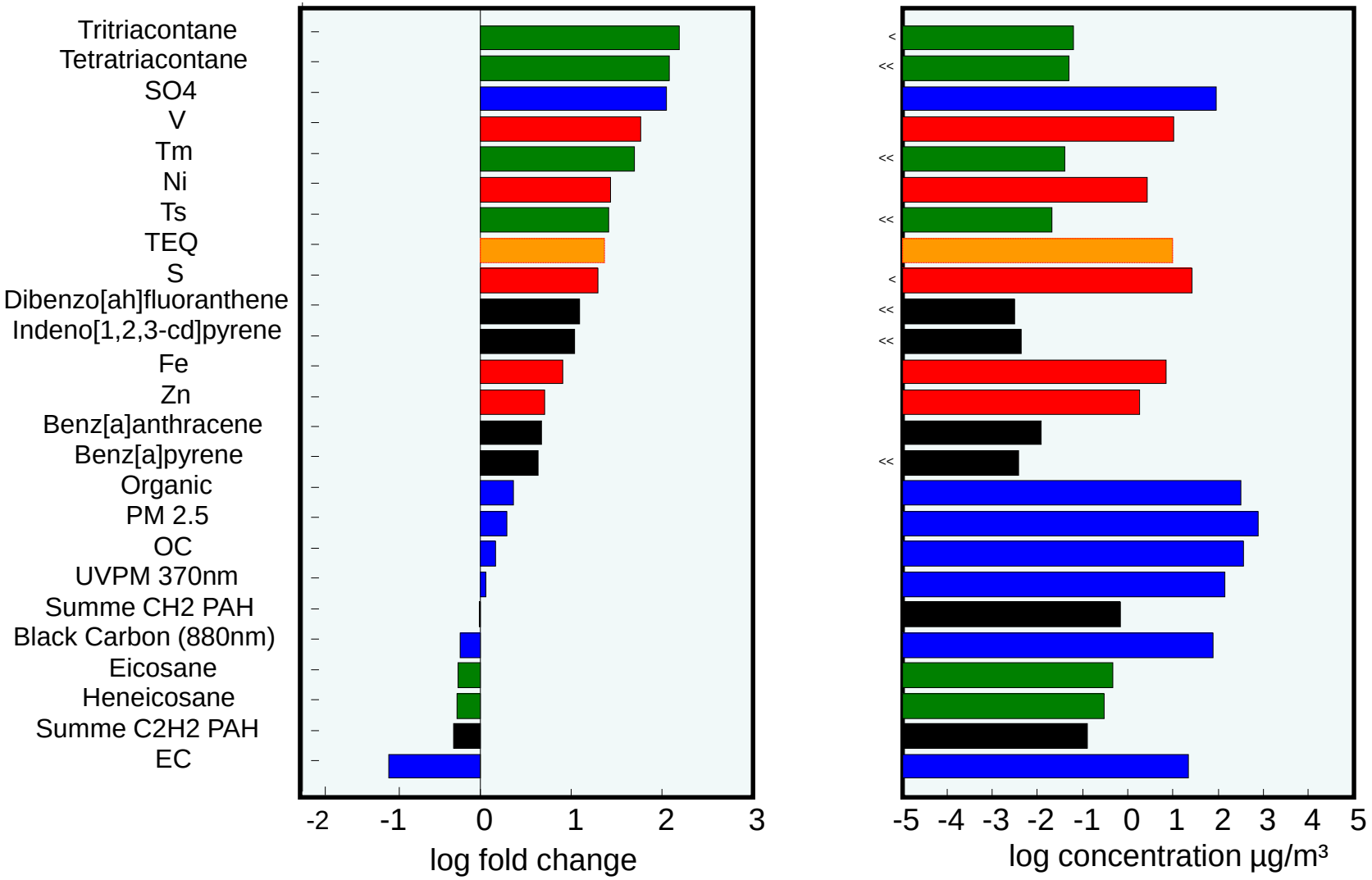
Measured Emissions

- at ALI-exposure system -



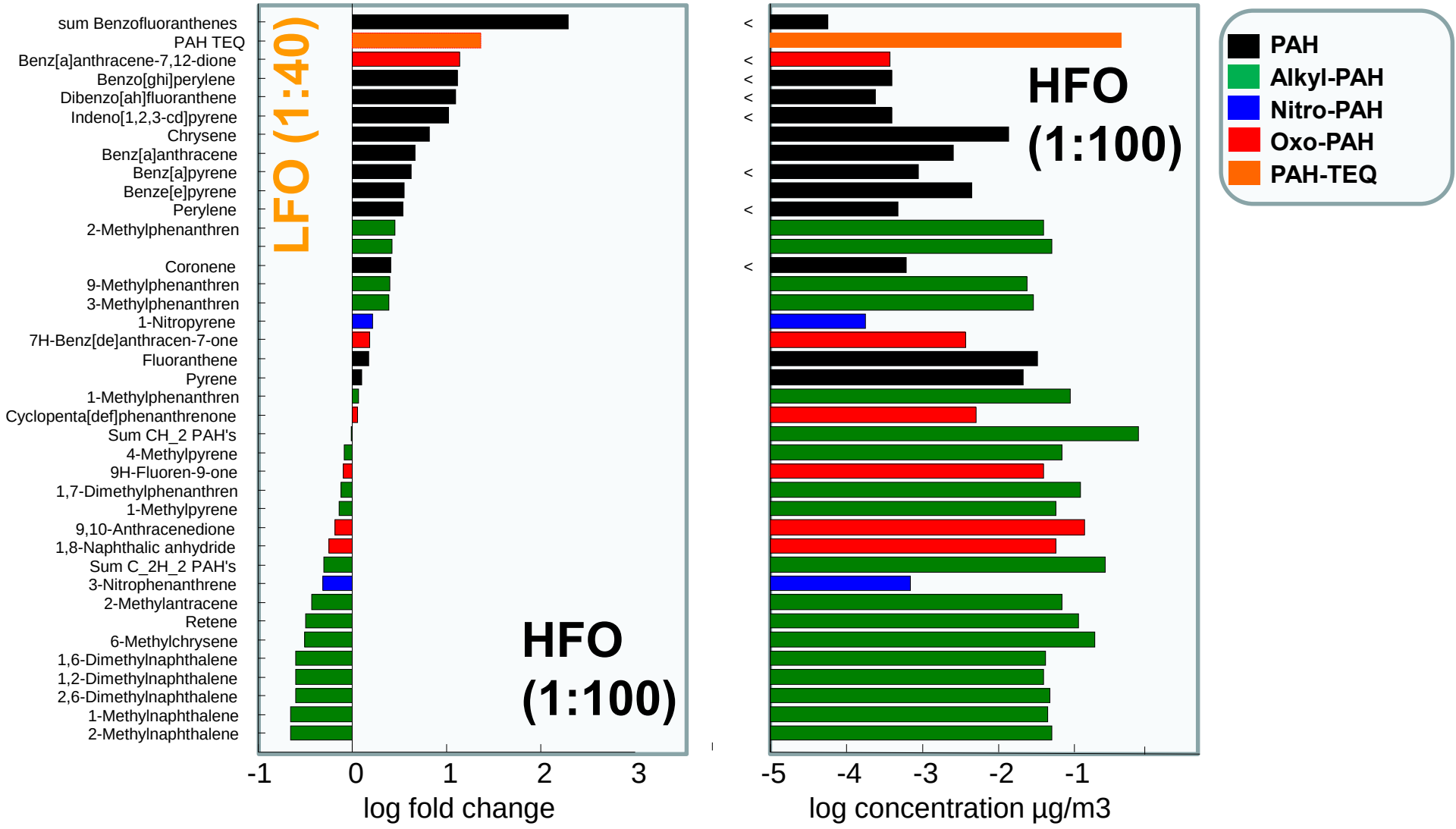
Measured Emissions

- at ALI-exposure system -



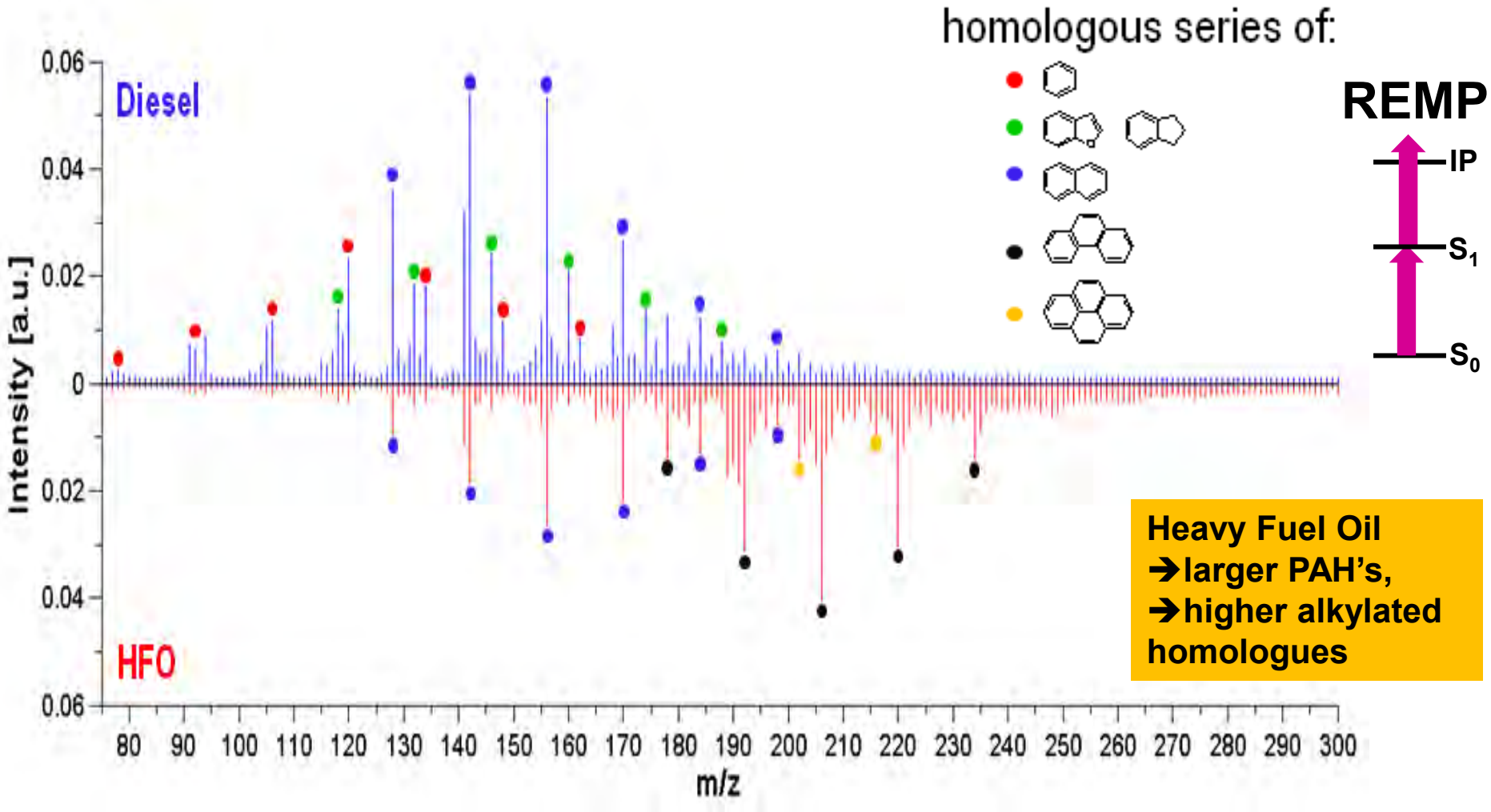
Measured Emissions

- at ALI-exposure system -



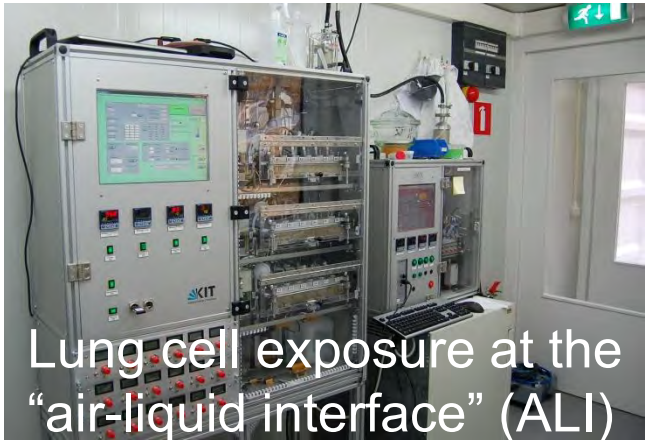
Measured Emissions

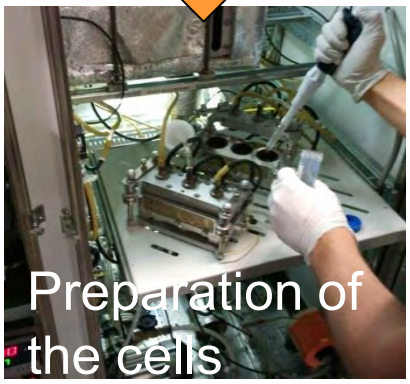
- at ALI-exposure system -



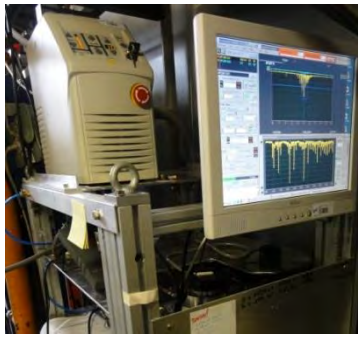
Heavy Fuel Oil
➔larger PAH's,
➔higher alkylated homologues

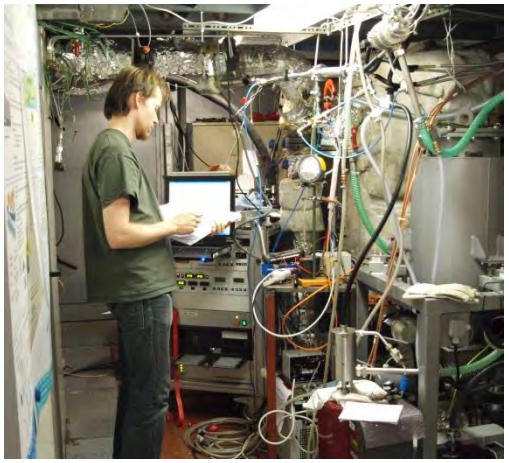
HICE ship diesel engine campaign: Exposure of human lung cell assays

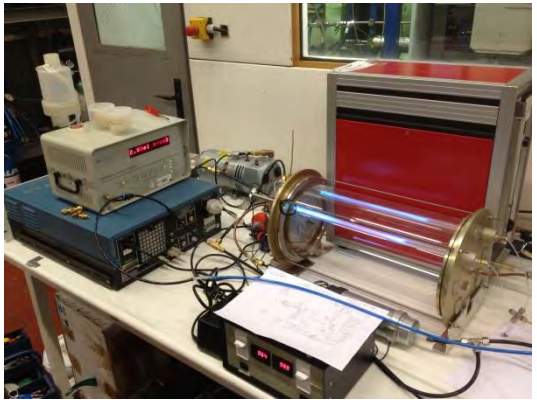




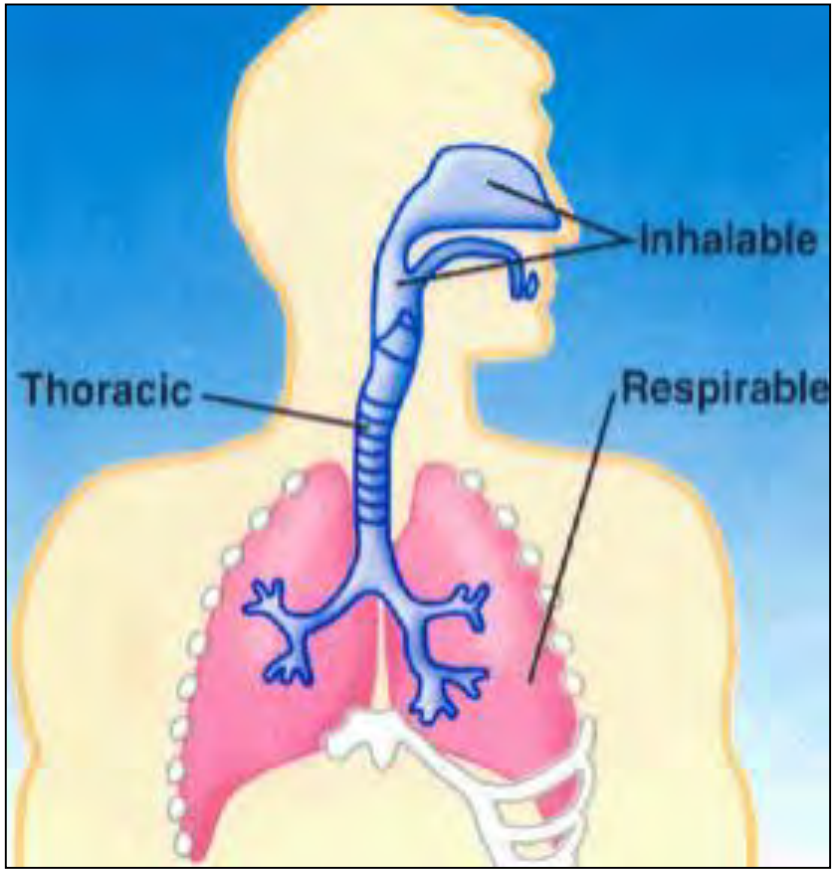
HICE ship diesel engine campaign: Aerosol characterization

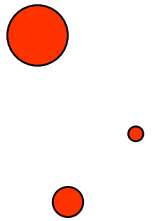






Particle deposition in the lung





Morawska, 2009