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# Lubricating Oil as a Major Constituent of Ship Exhaust Particles

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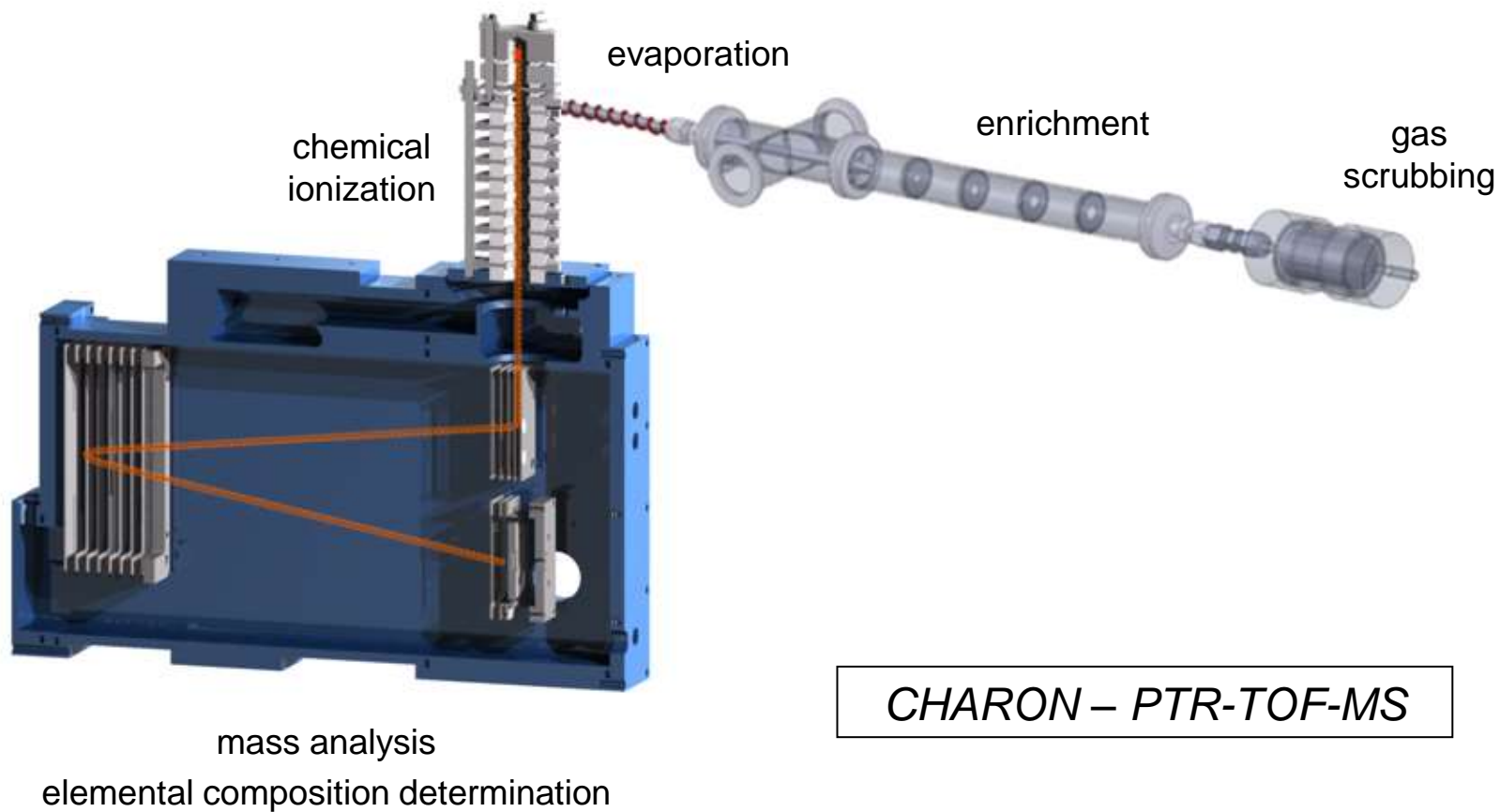
*SHIPPING AND THE ENVIRONMENT - From Regional to Global Perspectives*

*2<sup>nd</sup> BONUS Symposium*

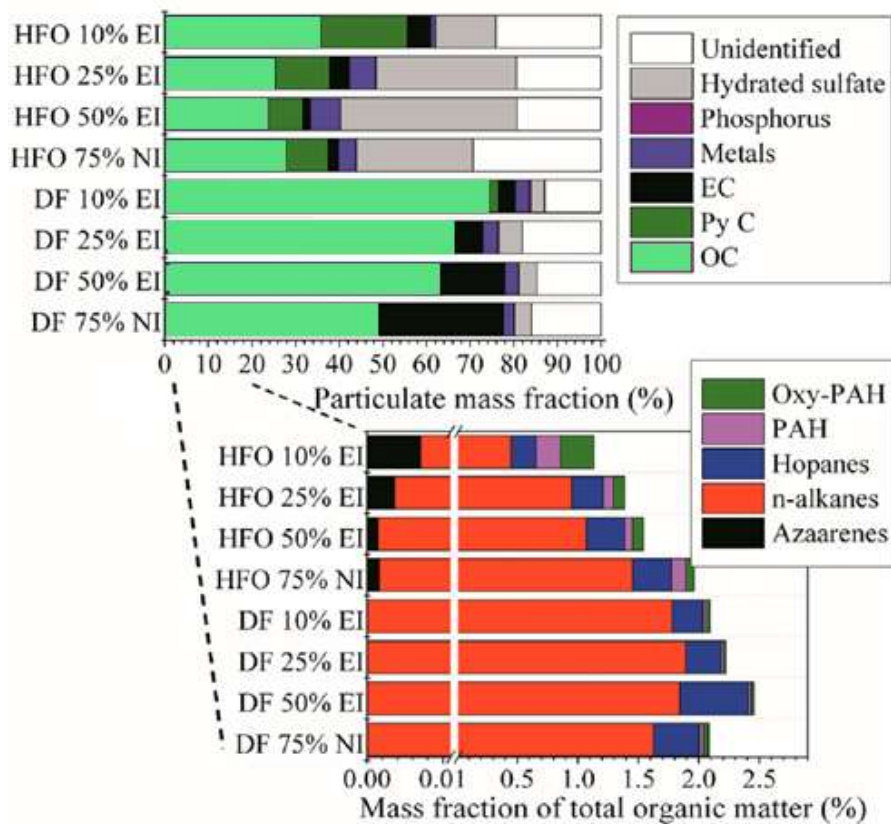
*October 24-25, 2017*

*Gothenburg, Sweden*

# Online organic analysis of particles



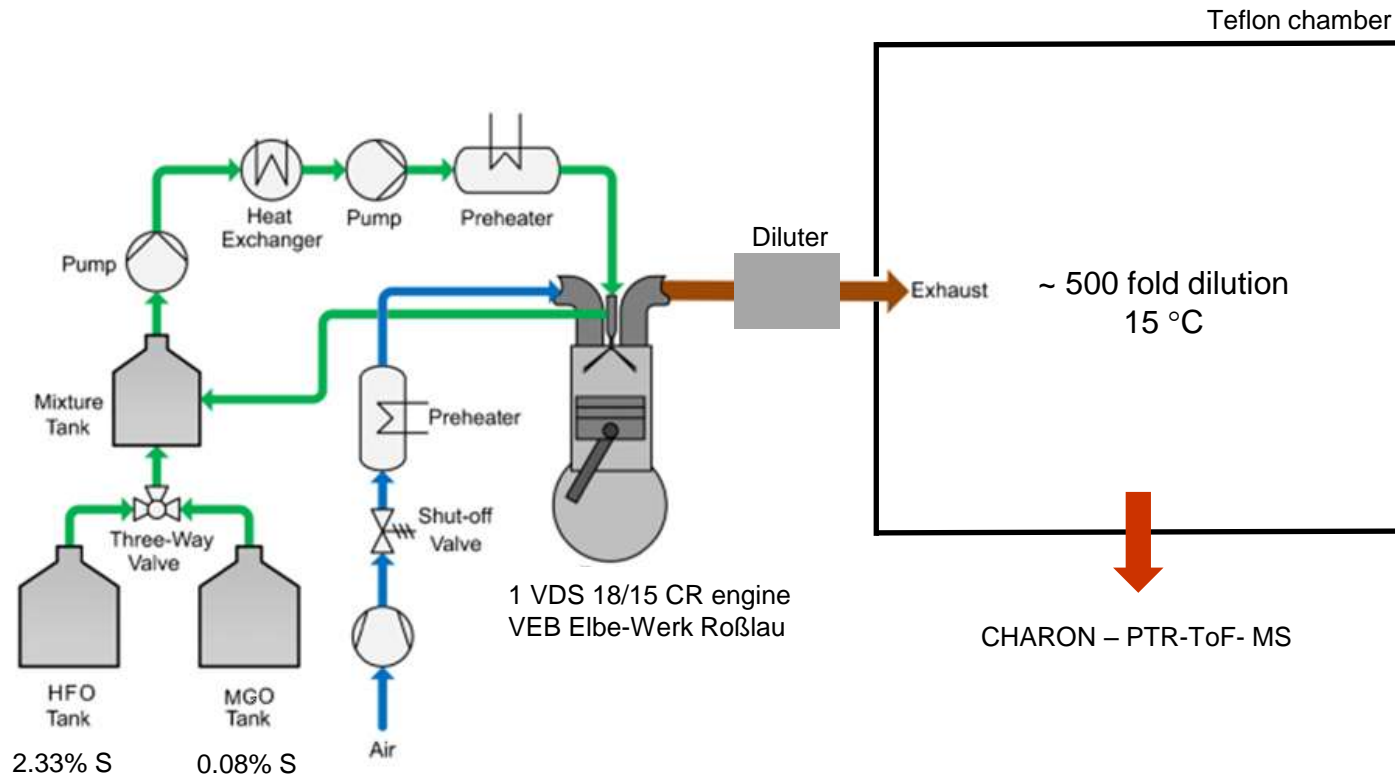
# Chemical composition of ship exhaust particles



Organic fraction is large and was poorly characterized by 2014.

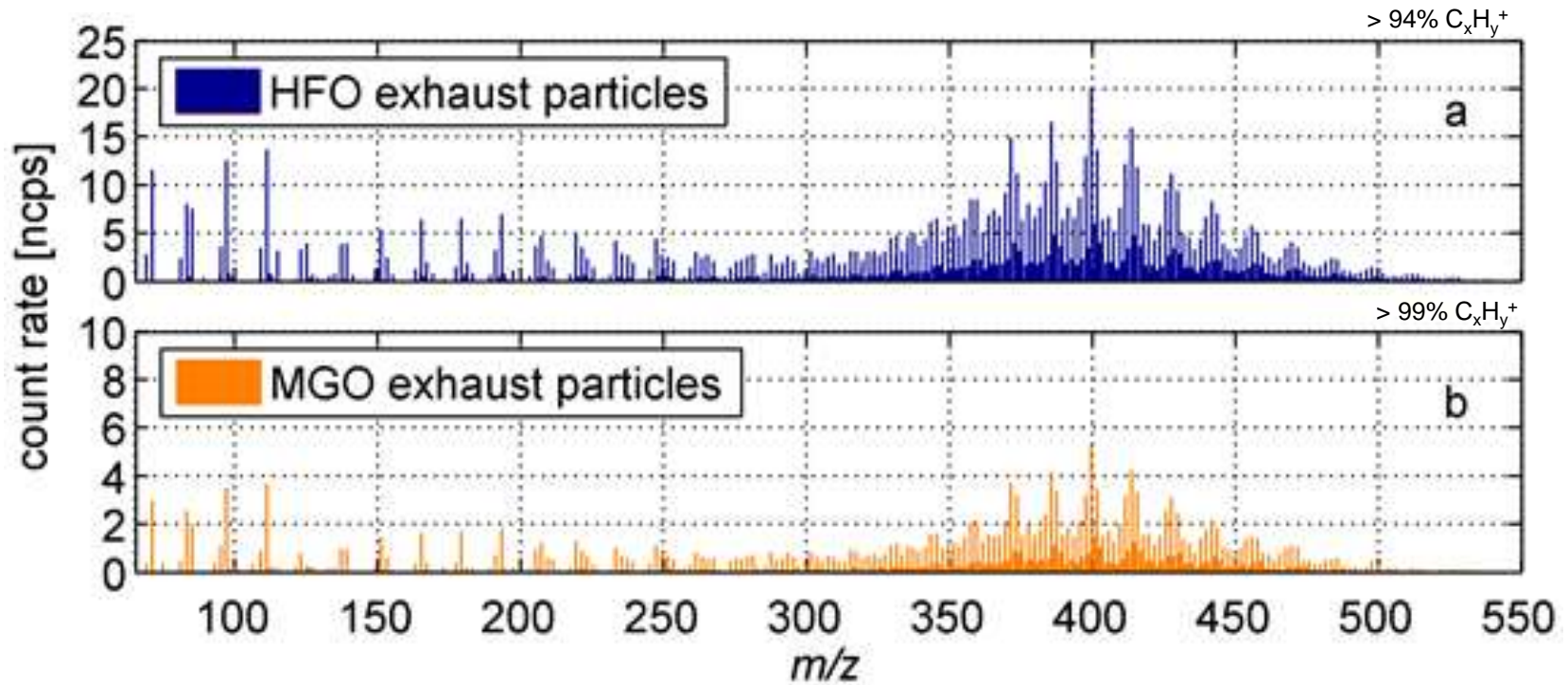
# Experimental set-up

Chair of Piston Machines and Internal Combustion Engines, University of Rostock

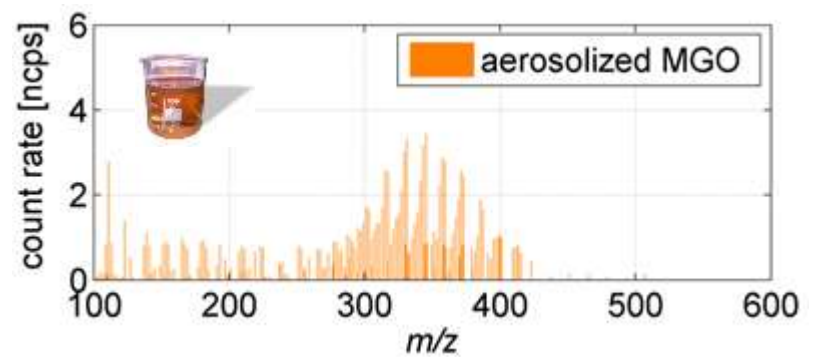
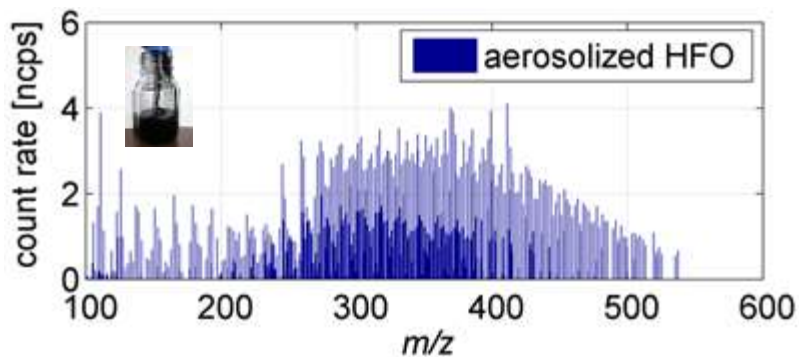
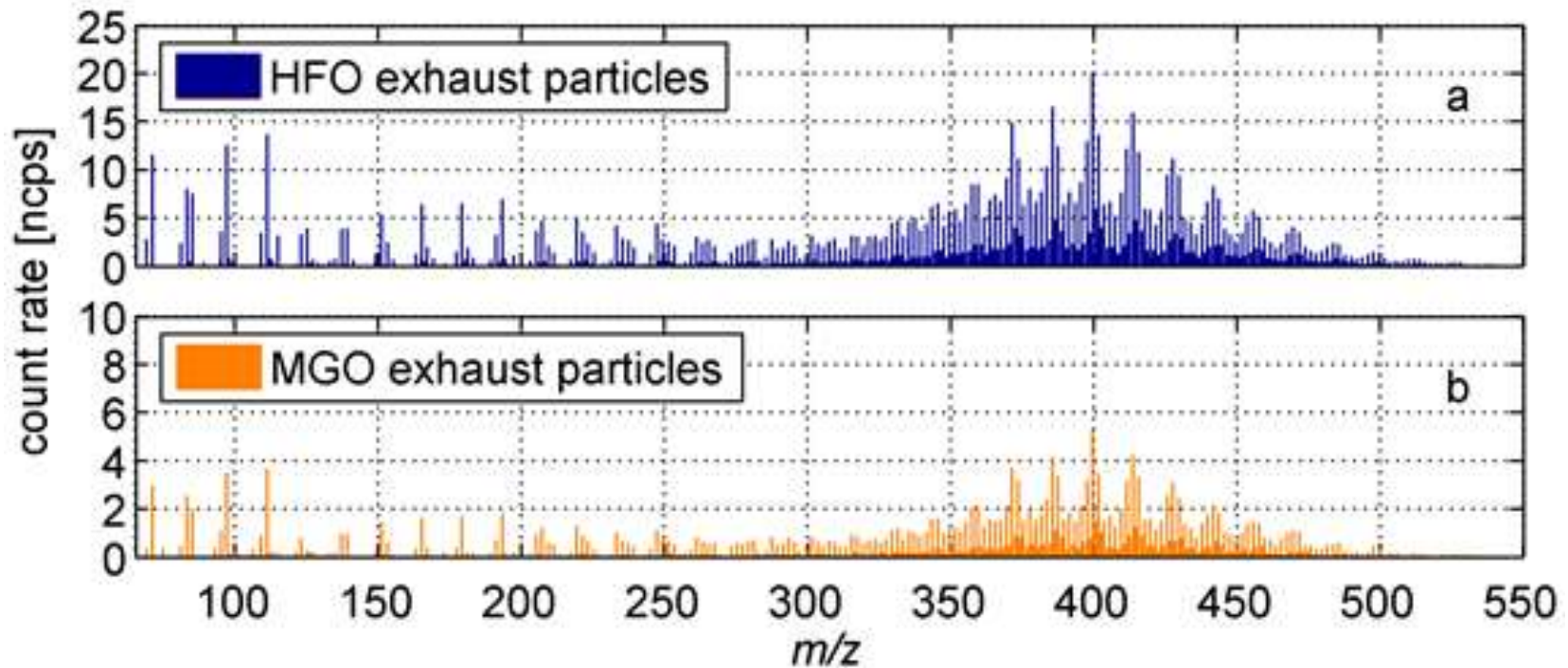


4-stroke single cylinder trunk piston engine  
40 kW / 1500 rpm - 50% load

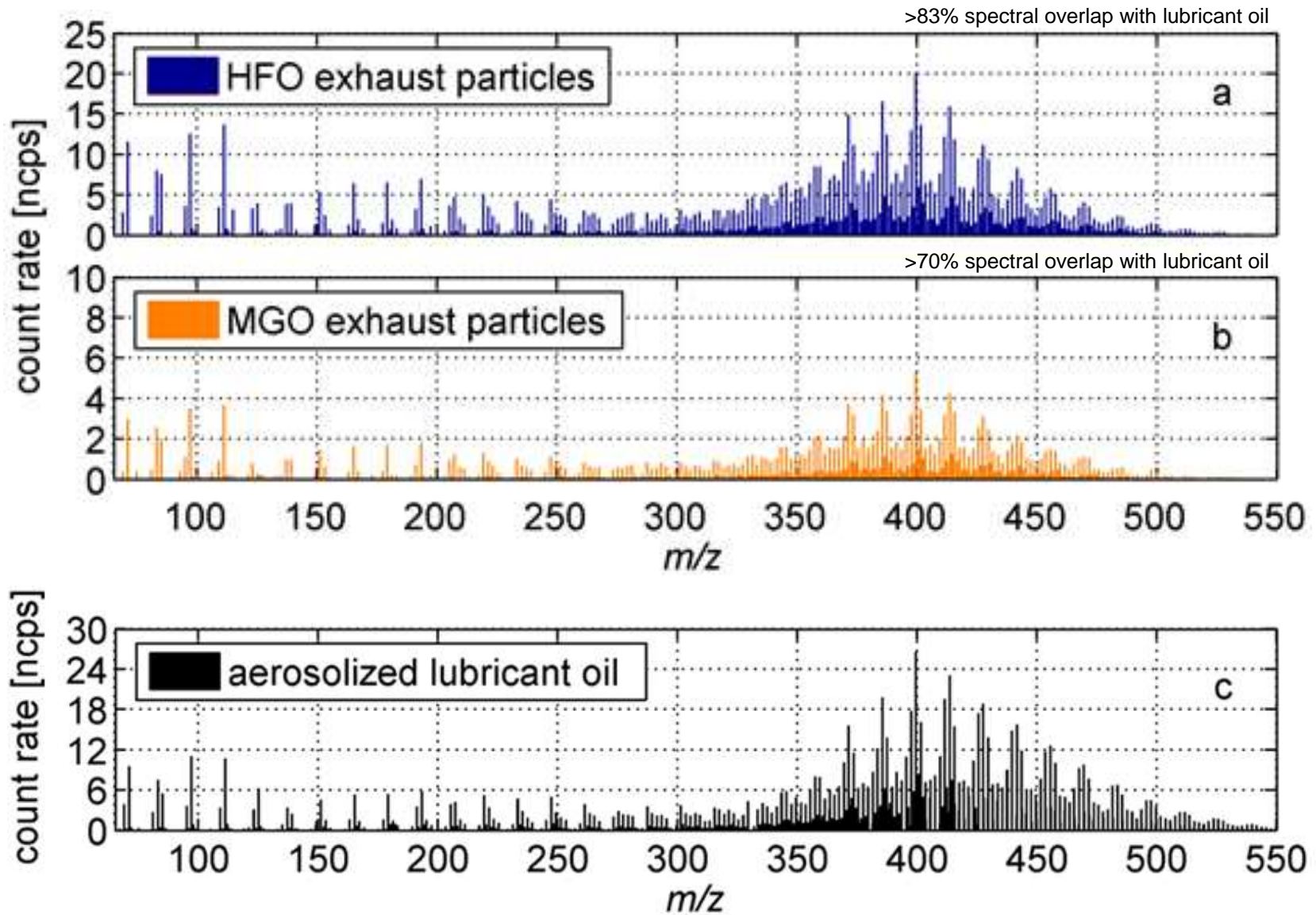
# Organic mass spectra



# Organic mass spectra



# Organic mass spectra



# Key role of lubricating oil in PM emissions

**ENVIRONMENTAL**  
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## Lubricating Oil Dominates Primary Organic Aerosol Emissions from Motor Vehicles

David R. Worton,<sup>\*,†,‡</sup> Gabriel Isaacman,<sup>†</sup> Drew R. Gentner,<sup>§</sup> Timothy R. Dallmann,<sup>§,#</sup>  
Arthur W. H. Chan,<sup>†,∇</sup> Christopher Ruehl,<sup>||</sup> Thomas W. Kirchstetter,<sup>§,⊥</sup> Kevin R. Wilson,<sup>||</sup>  
Robert A. Harley,<sup>§</sup> and Allen H. Goldstein<sup>†,§</sup>

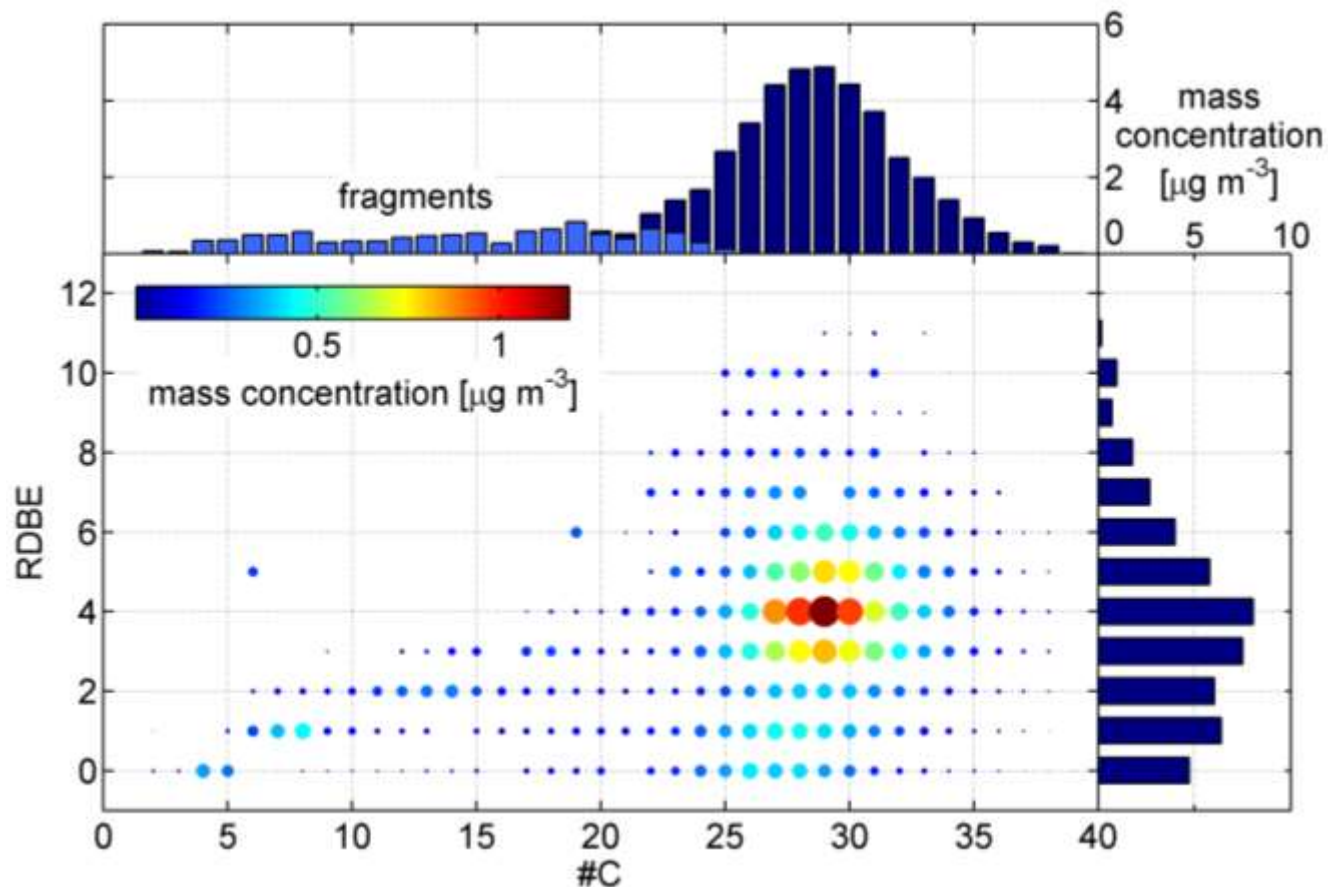
*Worton et al., Environ. Sci. Technol., 2014*

Prevention of Air Pollution from Ships: Diesel Engine Particulate  
Emission Reduction via Lube-Oil-Consumption Control

*Miller et al., ASNE Environmental Symposium, 1997*

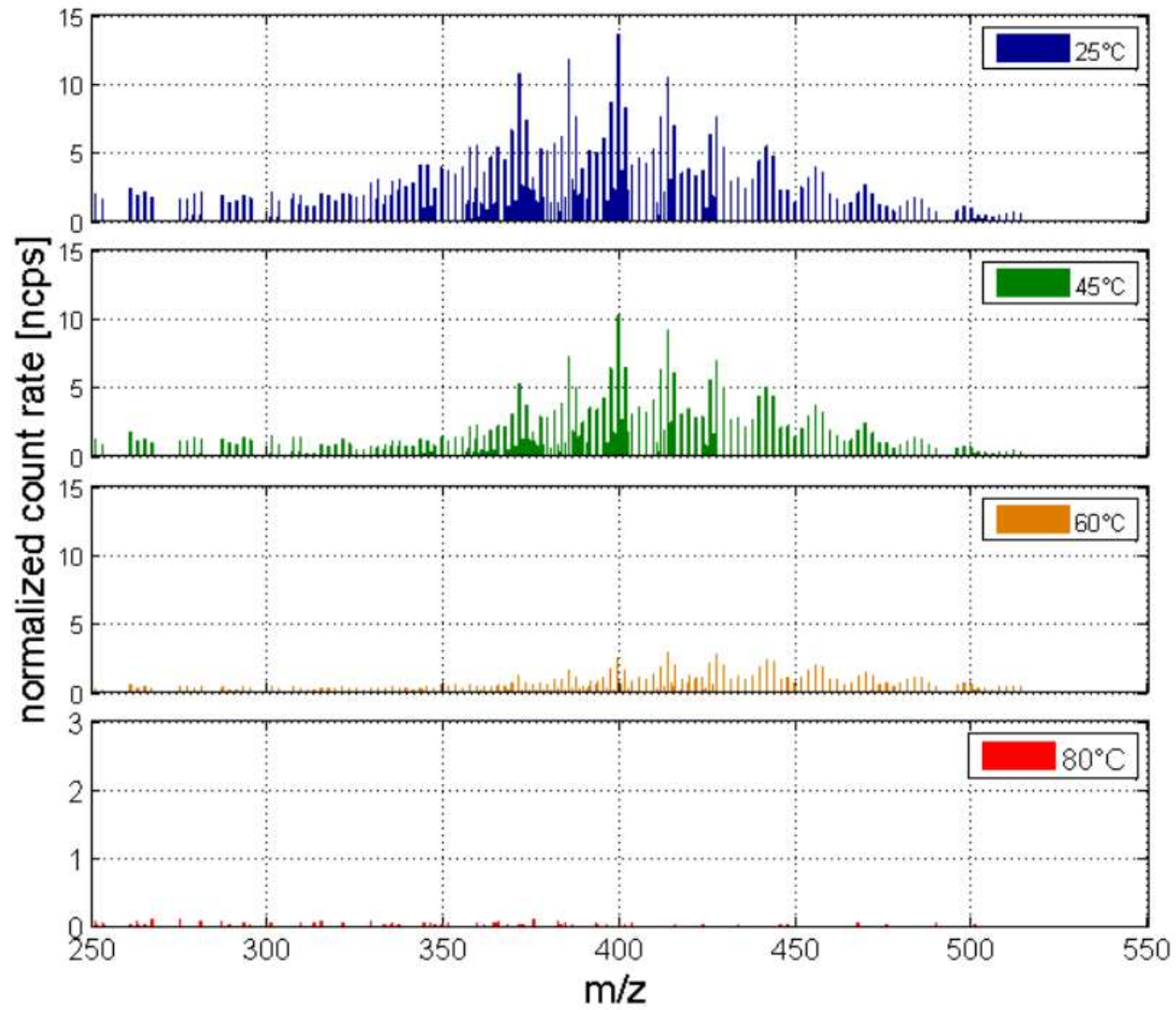


# Organic composition of ship exhaust particles

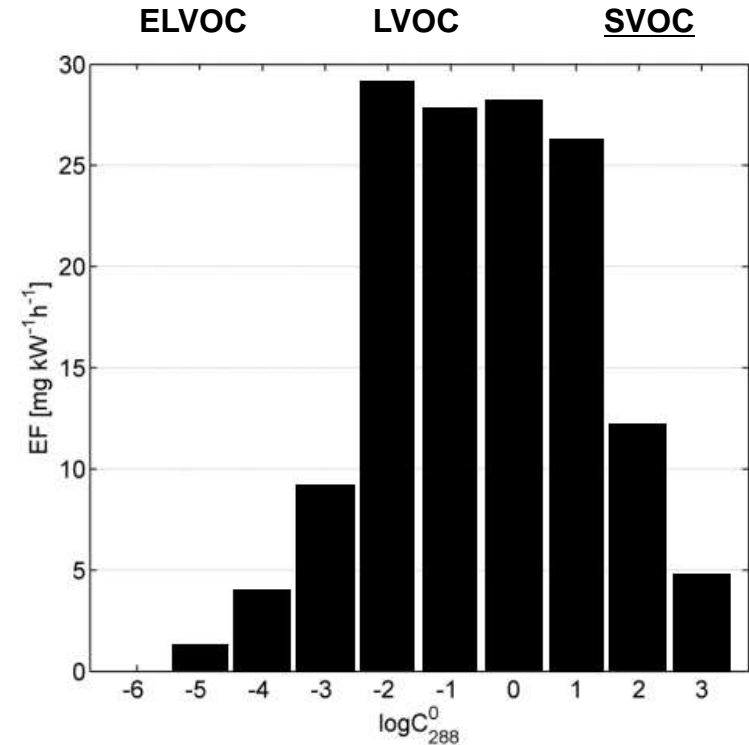
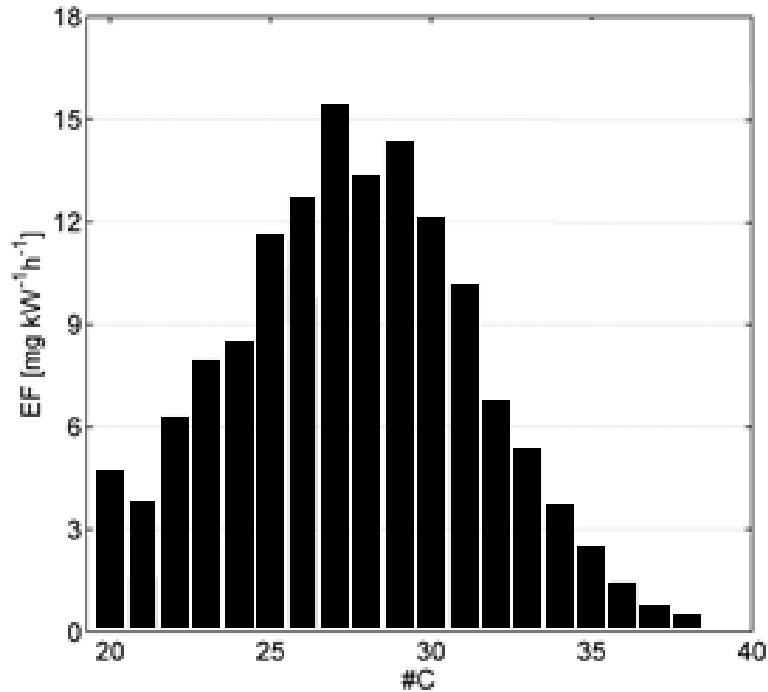


Polycycloalkanes are the dominant organic constituents.

# Volatility of the organic fraction



# Emission factors

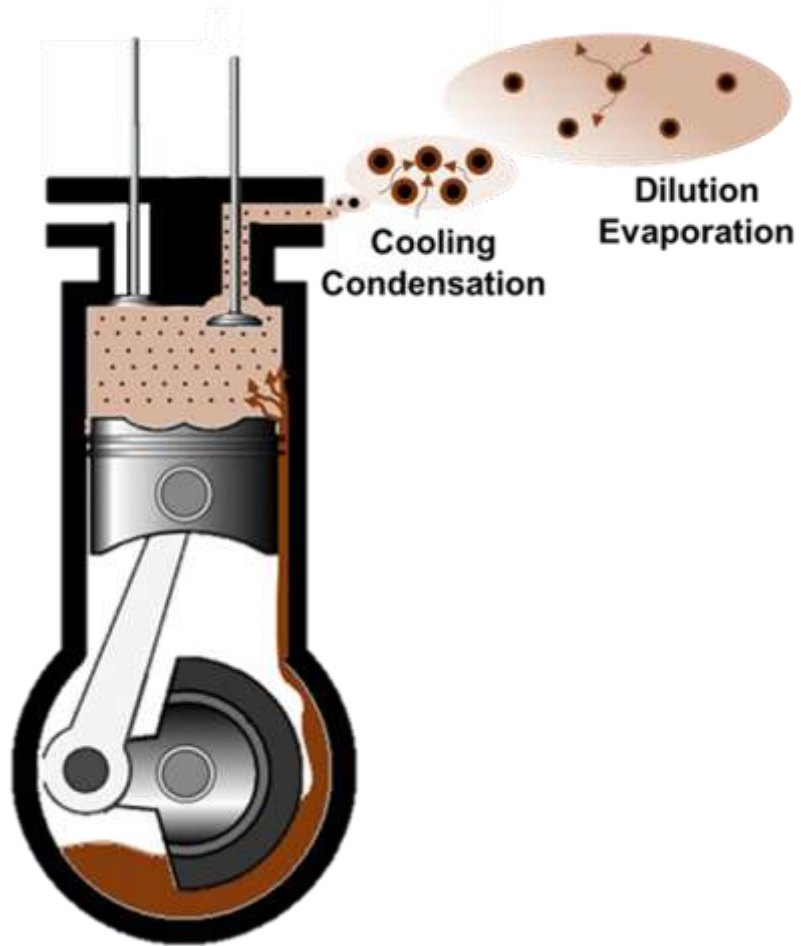


Total emissions:

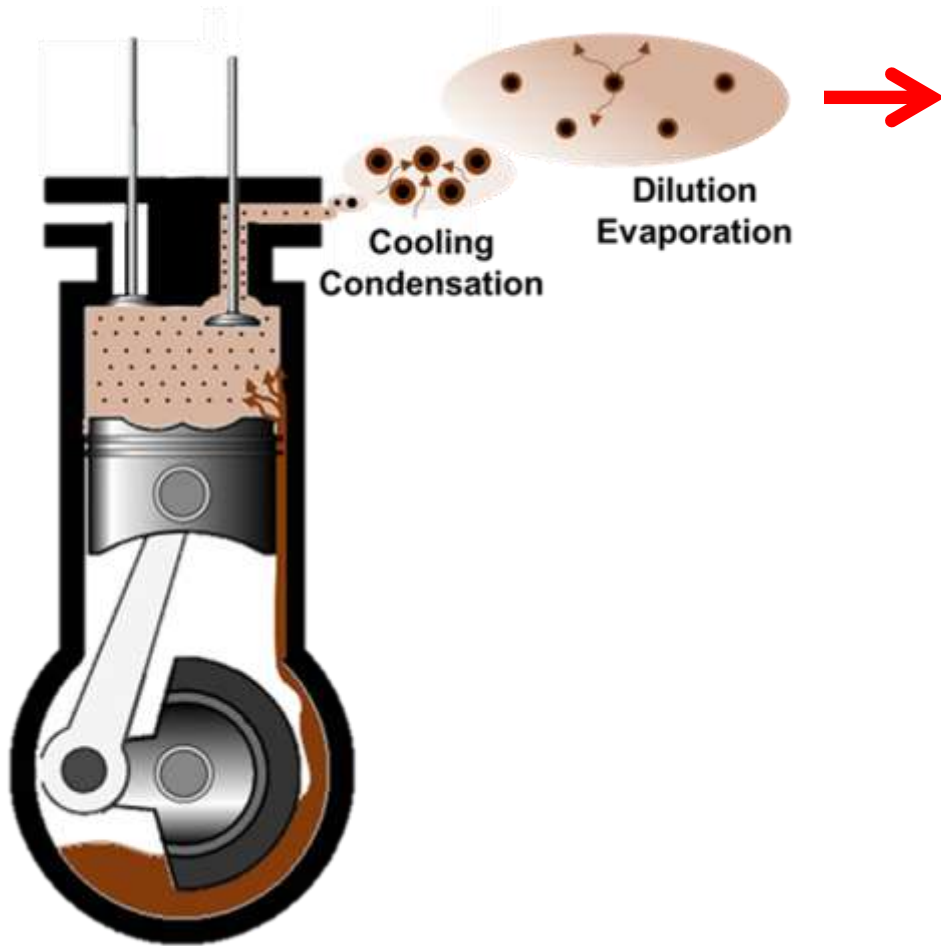
HFO: 183 mg kW<sup>-1</sup>h<sup>-1</sup>

MGO: 74 mg kW<sup>-1</sup>h<sup>-1</sup> (to be explained)

# Conceptual picture



# Next step: plume chemistry



**oxidation  
in the gas-phase**

**condensation of  
oxidized hydrocarbons**

# Generalizability of results, conclusion

- Lubricant oil consumption of marine engines:
  - four-stroke trunk piston engines: 0.3 – 0.5 g/kWh
  - two-stroke crosshead engines: 0.7 – 1.6 g/kWh
    - 0.4 – 1.0% of fuel consumption
    - 200-300 t/yr for a 6500 TEU container vessel
- Lubricant oil is primarily lost through the combustion chamber.
- Use of alternative fuels may not reduce emissions of organic particle mass.

# Reference and Acknowledgements



Letter

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WOOD combustion and SHIPPING – primary aerosol emissions  
and secondary aerosol formation potential (WOOSHI)

S. Pieber, I. El Haddad