Pollution and subcellular effects – the connection to non-communicable diseases

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Problem and Purpose

Air pollution is a large environmental risk factor for adverse health effects and approximately 99% of the world's population breathes air that contains high levels of pollutants, leading to 6.8 million premature deaths annually. Common sources of ambient air pollutants include both natural and anthropogenic emissions, the latter being caused by fossil fuel combustion, industrial activities, agriculture, and mining, amongst other sources (Maciejczyk et al., 2021). One of the main air pollutant constituents is particulate matter (PM), which is a diverse mixture of liquid and solid particles suspended in air, consisting of e.g. sulfates, nitrates, organic compounds and metals.

PM2.5 is associated with health issues such as an increased risk of cardiopulmonary and lung cancer mortality, cognitive dysfunction and Alzheimer's disease (Jung et al., 2015), as well as pregnancy complications and adverse birth outcomes (Song et al., 2023). In addition, the deposition of PM may lead to direct complications in the respiratory passageways such as asthma, chronic pulmonary disease and an increase the susceptibility of respiratory infections.

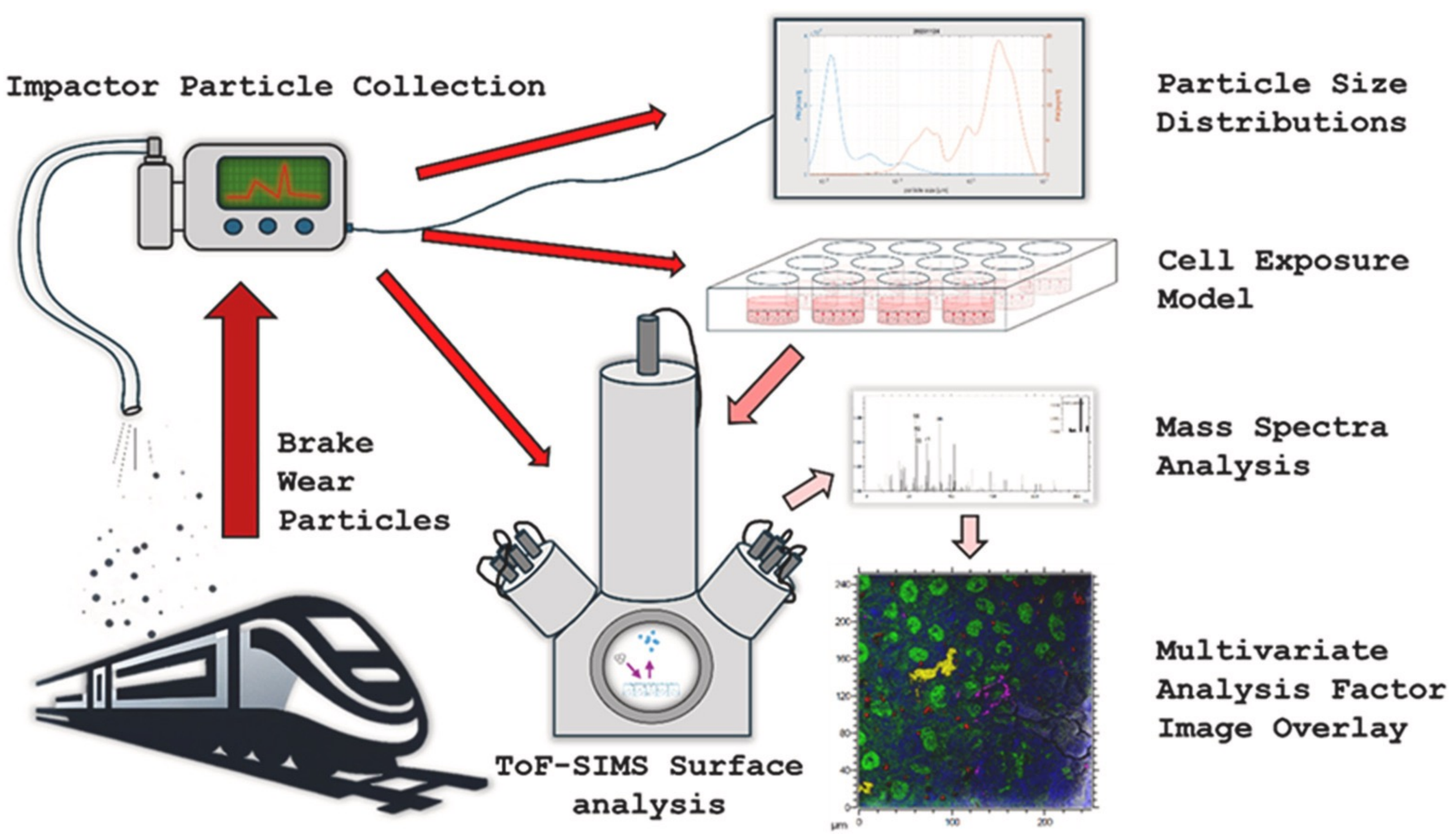

Figure 1: This study introduces a novel methodology that begins with in situ particulate pollution collection, proceeds to exposing non-animal human epithelial cell models which are then analyzed through high spatial resolution mass spectrometry imaging to differentiate the chemistry

Realization

After inhalation, PM primarily deposits in the respiratory airways. However, PM can reach as far as the gastrointestinal tract, through mucociliary transport as well as ingestion and inhalation. In the present study, we aimed to develop a novel analytical approach to study PM deposition of µm size on epithelial cells to be able to follow the PM interaction using ToF-SIMS and Multivariate Curve Resolution-Alternating Least Squares (MCR-ALS) (fig 1). PM was collected as per figure 2.

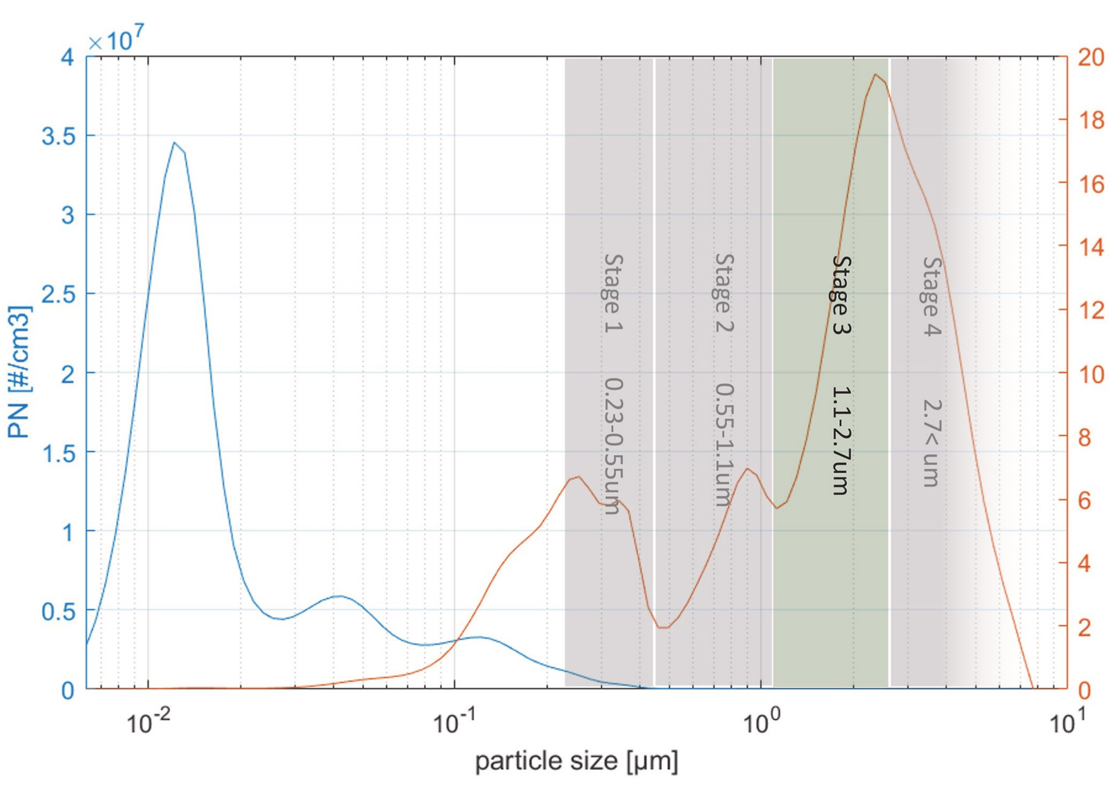

Figure 2: HR-ELPI+ & DGI measurements. HR-ELPI + measurement where the distribution of collected mass of particle size (orange, right) and collected count of particle size (blue, left) are shown on a logarithmic x-axis of particle size by diameter (µm). An overlay of the DGI collection ranges shows how the different DGI stages compared to the HR-ELPI + measurements.

Results

ToF-SIMS and SEM provided detailed visual and chemical insights into the particle-cell interface. SEM images confirmed a high degree of confluency of the Caco-2 cell epithelia and a successful freeze drying and washing process, as well as deposition of agglomerated BWP on the cell surface. ToF-SIMS measurements on only BWP identified 64 ions with high confidence, of which metal ions for Fe+, Mg+, Cu+, Ca+, Si+, Al+ were some of the elements found (Rydbergh et al. 2025).

DEEX measurement images with contrast of cell structures with the particles established the presence of partially agglomerated BWP particles deposited on top of the Caco-2 epithelia (fig 3 and 4).

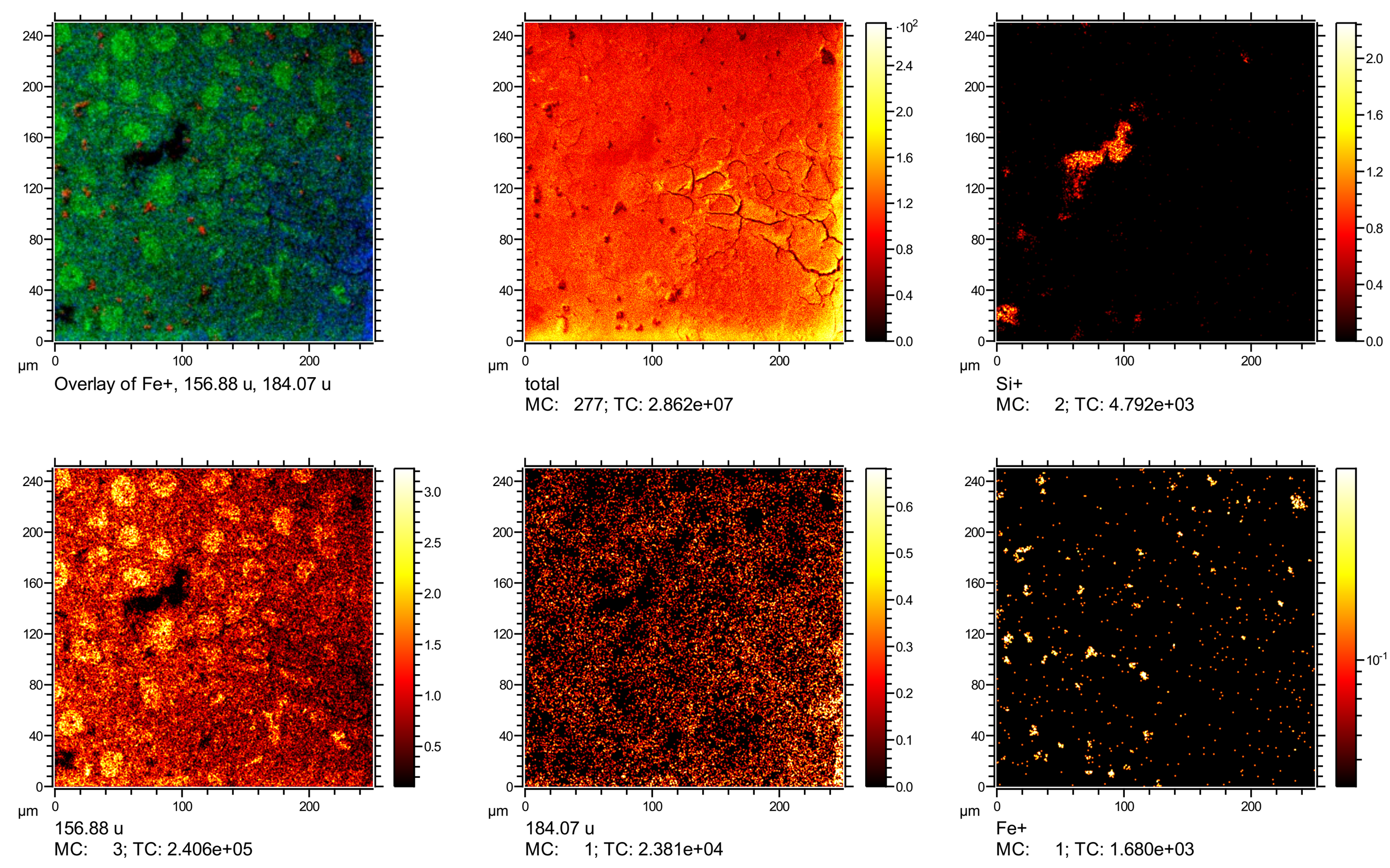

Figure 3: . ToF-SIMS ion images of measurements conducted BWP treated Caco-2 cells. A RGB color overlay (A), total ion signal image (B), identified Si+ ion signal image (C), undocumented fragment m/z 156.88 ion signal image (D), PC ion signal image (E) and identified Fe+ ion signal image (F). All images are shown with the Average 2 filter.

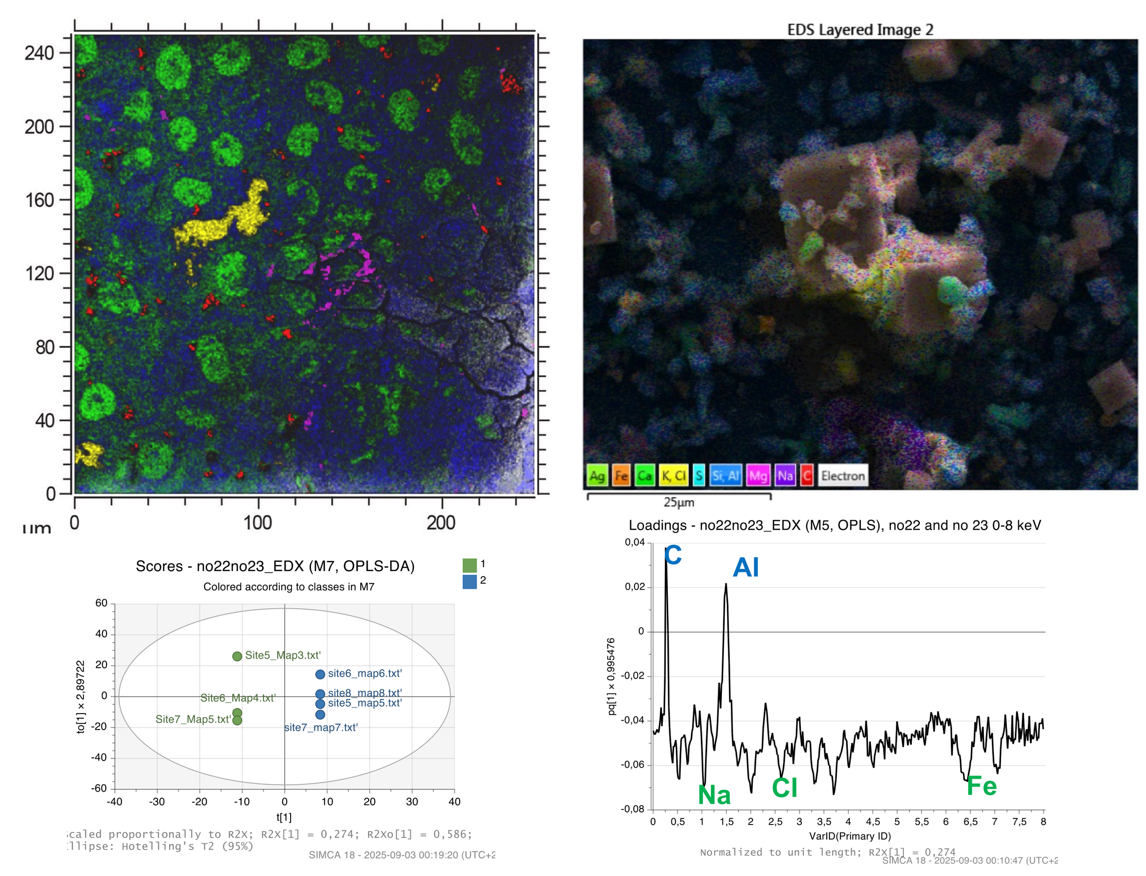

Figure 4: a, ToF-SIMS MCR-ALS factor overlay image. The following observation can be made; confluent Caco-2 cell epithelium (green) with partially agglomerated BWP (red) scattered across its surface. B, SEM-EDS map of Tyre and road wear Particles, c-d MVA anlysis of differences between PM1 and PM2.5 (Sjöblom, 2025)

Conclusions and ongoing work

ToF-SIMS, combined with MCR-ALS, is a viable option in distinguishing and characterizing in situ collected, chemically complex BWP interactions with epithelial cells. This will be combined with new cell experiments that evaluates inflammatory markers in response to BWP and PM.

Tyre and road wear Particles from HD truck was sampled on-road and size-separated using impactor, SEM-EDX data was interpreted using MVA to model the differences between PM1 and PM2.5 with similar model performance for EDX and ToF-SIMS

The more sensitive ToF-SIMS can characterize e.g. the carbon and molecular content in particles

The methodology used is hoped to allow a better understanding of the mechanisms by which air pollutants affect human health, which ultimately could act as basis for more effective legislation and regulation of particle emissions.

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