Cambustion [1]
University of Alberta [2]
NRC · CNRC [3]

Automated Tandem Aerosol Classifier Experiments

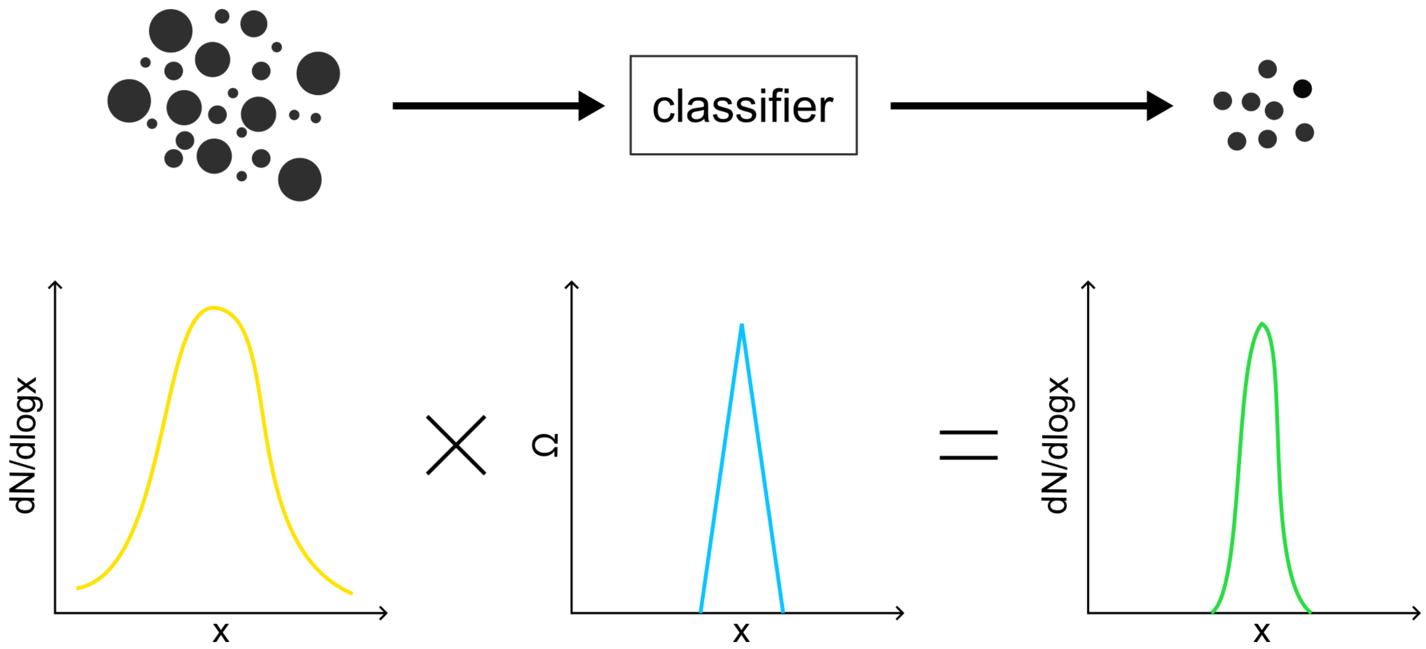
Exhibitor Showcase
AAAR 2023, Portland OR

Julie Pongetti[1], **Timothy Sipkens**[3], Morteza Kiasadegh[2], **Jason Olfert**[2], Jonathan Symonds[1]

Automated tandem aerosol classifier experiments

- A collaboration between Cambustion, University of Alberta, and NRC Canada
  - We also thank Aerosol Dynamics for providing the MAGIC CPC, and Particle Instruments for providing the ATM 226 nebulizer
- Demo: tandem CPMA – scanning AAC measurement of NaCl particles

Particle classification

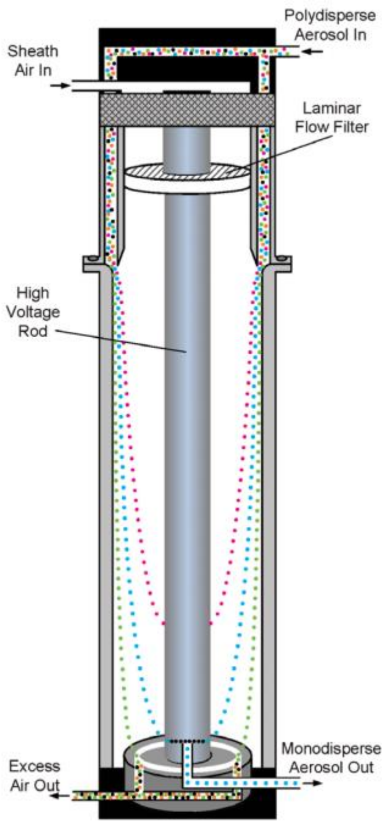


- Generate monodisperse aerosols
  - For calibration
  - For further analysis
- Obtain particle distributions

Differential Mobility Analyzer (DMA)

Most common classifier – has been around for a long time

- Electrical mobility classification
  - i.e. motion of charged particle in an *electrostatic* field (related to the number of **charges** on the particle, and its **drag**, which is a function of **size** & **shape**)
- Suffers from multiple-charging artefacts
  - i.e. smaller particles with one charge may have the same electrical mobility as a larger particle with two charges
- Less transmission due to charging efficiencies
  - i.e. limited proportion of total population has one and only one charge



Aerosol Mass Classifiers (CPMA / APM)

Mass classifiers have been commercially available for ~25 years

- Classification by mass:charge ratio
  - i.e. motion of charged particle in a *rotating electrostatic* field (related to the number of **charges** on the particle, and its **mass** – classification is independent on size and shape)

- Also suffers from multiple-charging artefacts but is easier to account for
  - i.e. charge and mass scale linearly for particles transmitted

- Improved transmission when cylinders rotate at different speeds

- Advantages: mass is a well-define property, classification is independent of shape

Aerodynamic Aerosol Classifier (AAC)

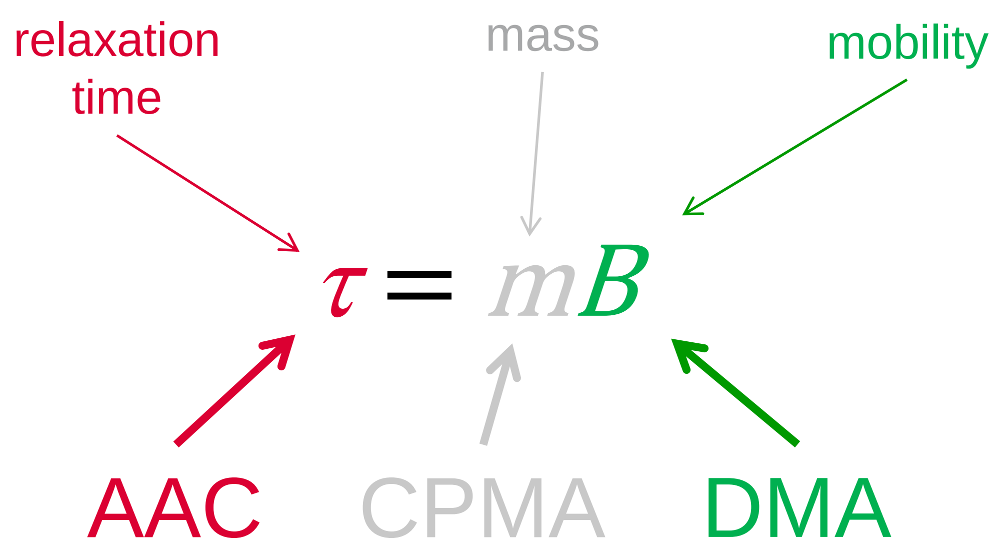
Most recent classifier – commercially available since 2016

- Classification by aerodynamic diameter (or relaxation time)
  - i.e. motion of particle in a *centrifugal* field (related to the **mass** of the particle, and its **drag**, which is a function of **size** & **shape**)

- Classification is independent of charge
  - i.e. all particles are classified equally regardless of their charging state

- Advantages: truly monodisperse aerosol and higher transmission as a result of not charging

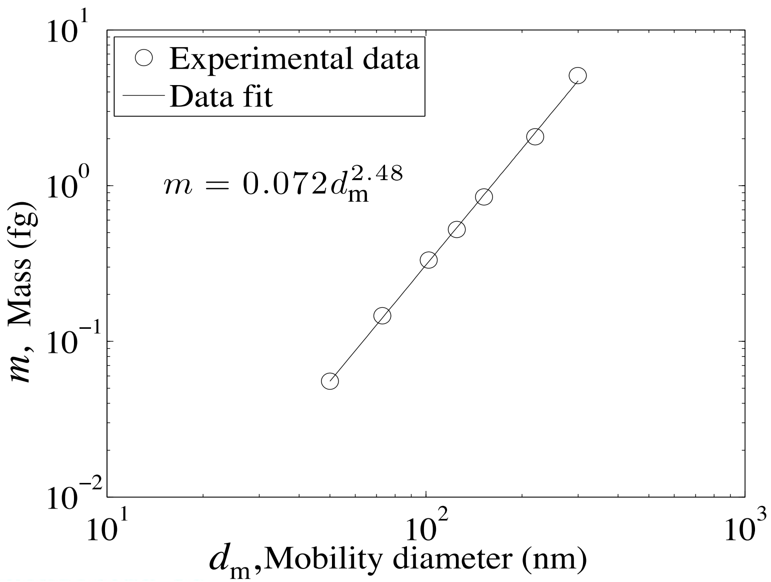
Tandem Classifier Experiments



- Combining any two of classifiers presented gives access to the same information

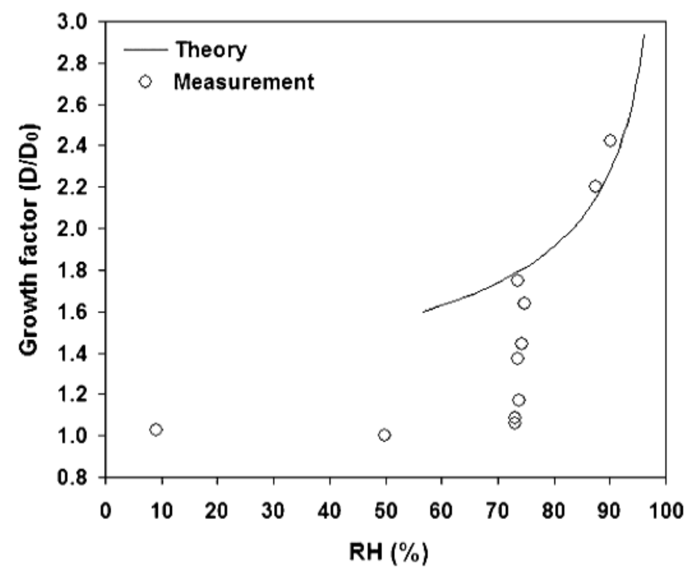
Examples of Tandem Classifier Experiments

Mass-mobility relation and effective density



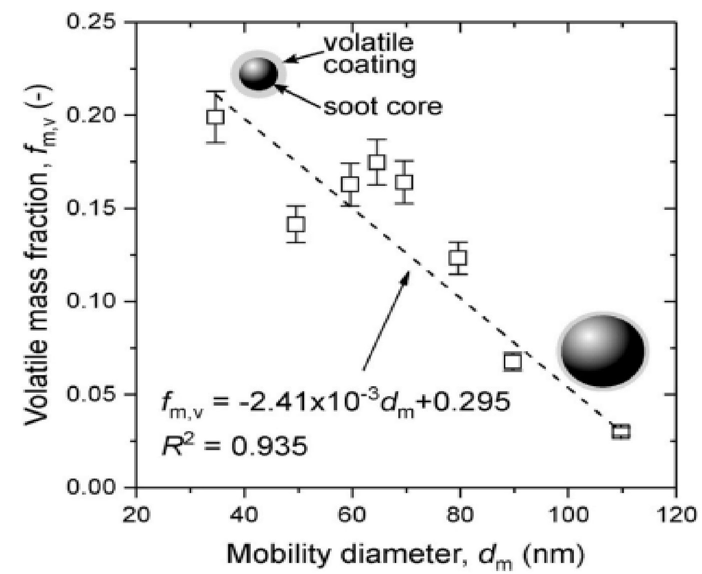
J. S. Olfert, J. P. R. Symonds, and N. Collings
Journal of Aerosol Science, 38:69-82, 2007

Hygroscopicity



P. Villani, D. Picard , V. Michaud , P. Laj
and A. Wiedensohler *Aerosol Science and Technology*, 42:9, 729-741, 2008

Volatile fraction



M. Kazemimanesh, Md M. Rahman, D. Duca, T. J. Johnson, A. Addad, G. Giannopoulos, C. Focsa, A. M. Boies *Journal of Aerosol Science*, 161, 2022

Limits of Tandem Classifier Experiments

- Slow:
  First instrument is fixed, second (step or continuously) scanned;
  then change setpoint of first and repeat

- Large amount of data:
  Difficult to handle and organise, including mismatched formats

- Inversion:
  CPMA and DMA transmit multiply-charged particles – need to correct raw data for that (assuming some charge distribution)

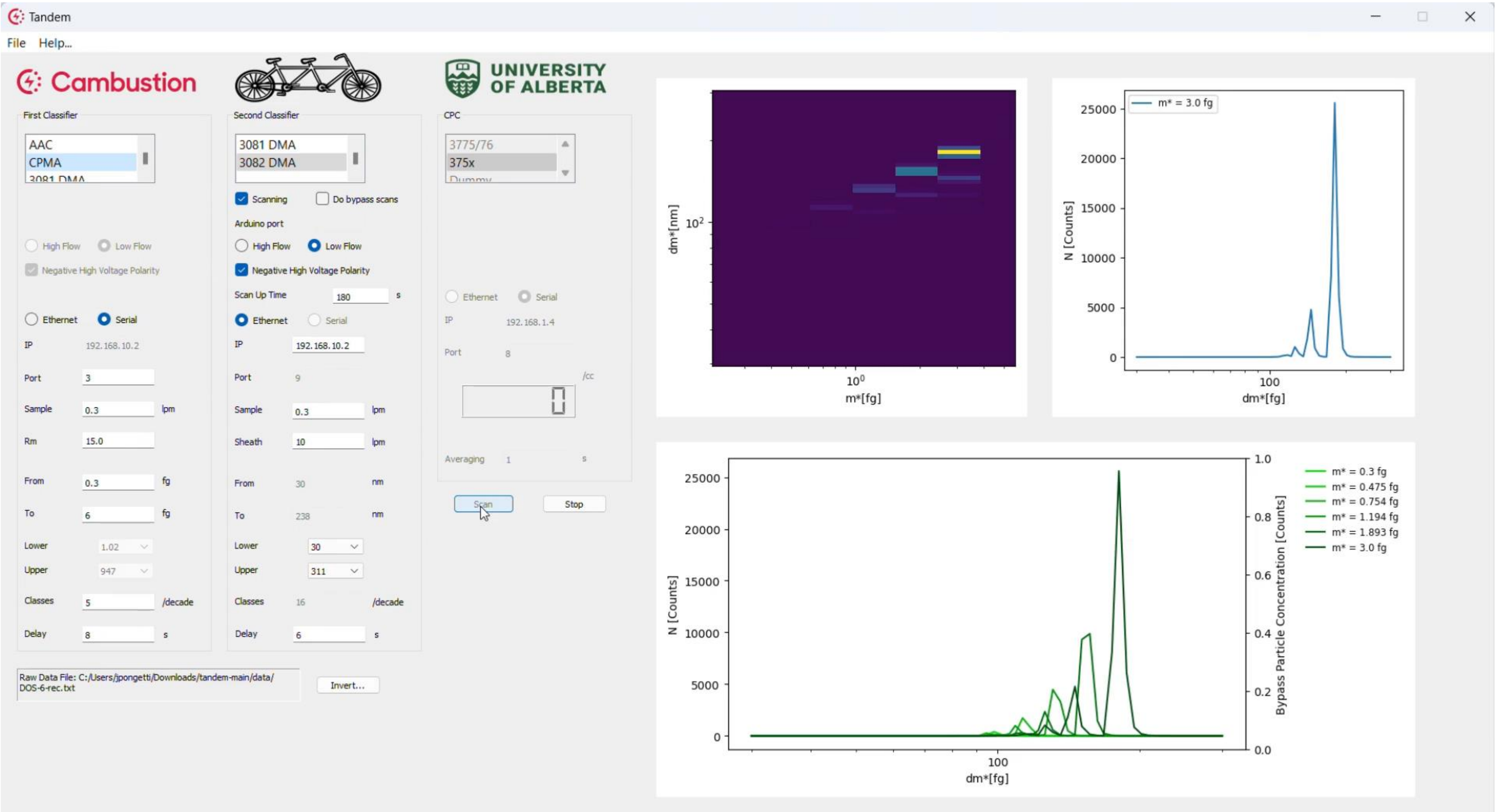
Automated Tandem Classifier Experiments

- New software capable of controlling any combination of 2 classifiers automatically, and perform the data inversion to automatically produce two-variable distributions
  - Will be available from GitHub in open-source beta release soon

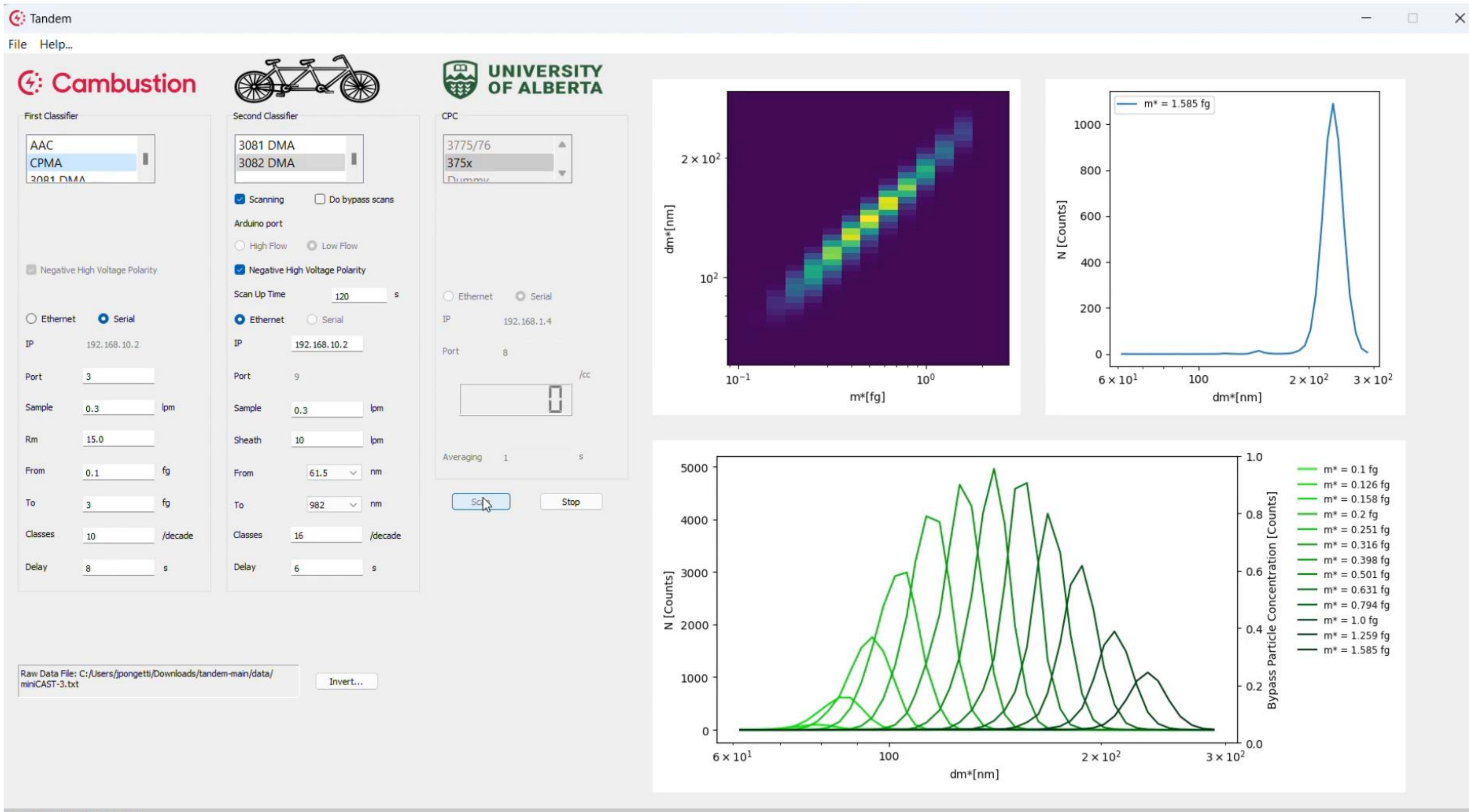
- Current supported classifiers:
  - TSI 3082 (scanning or stepping), TSI 3080 (stepping), Cambustion CPMA (stepping), Cambustion AAC (scanning or stepping)

- Current supported CPCs when 2nd classifier is stepping:
  - Aerosol Dynamics MAGIC, TSI 302x, TSI 3775/3776, TSI 375x

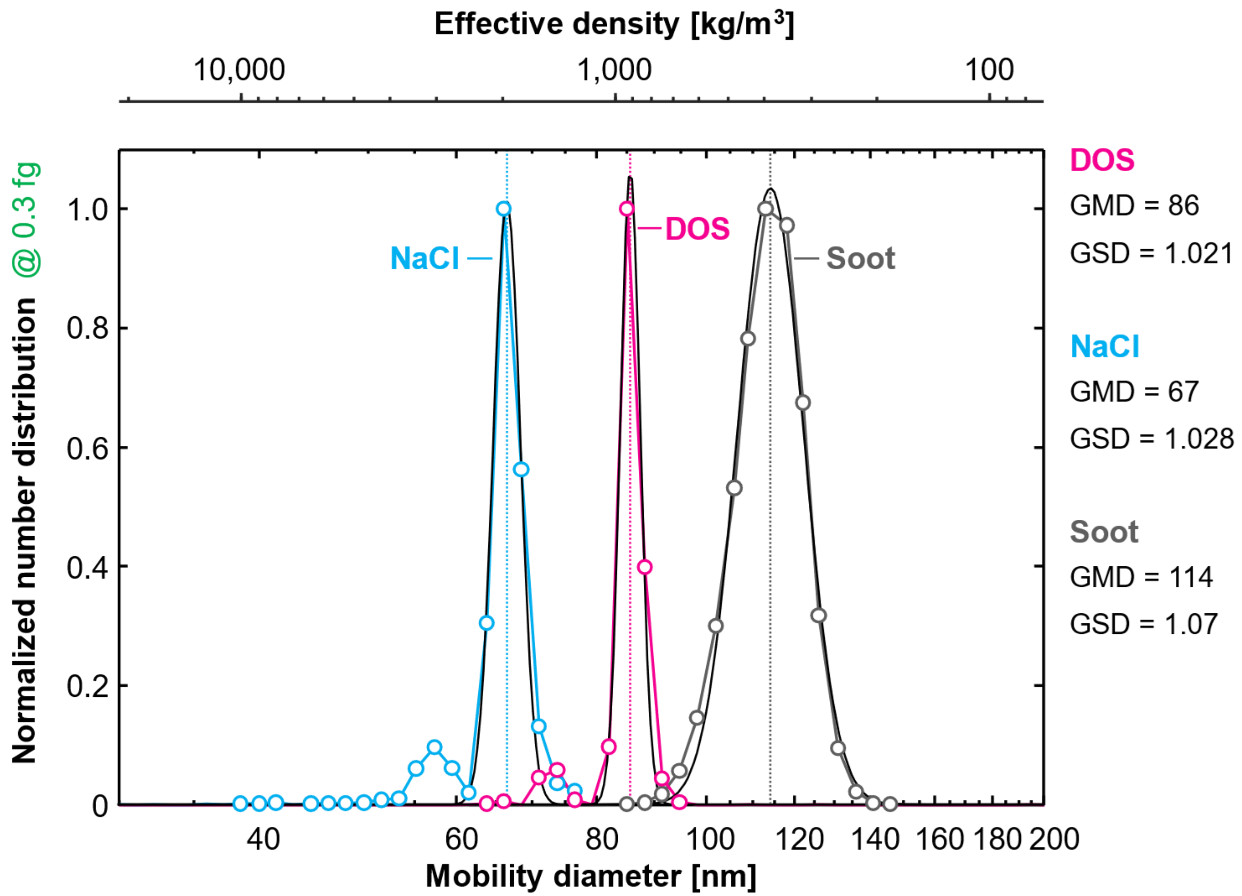
Tandem CPMA – SMPS: DOS



Tandem CPMA – SMPS: soot

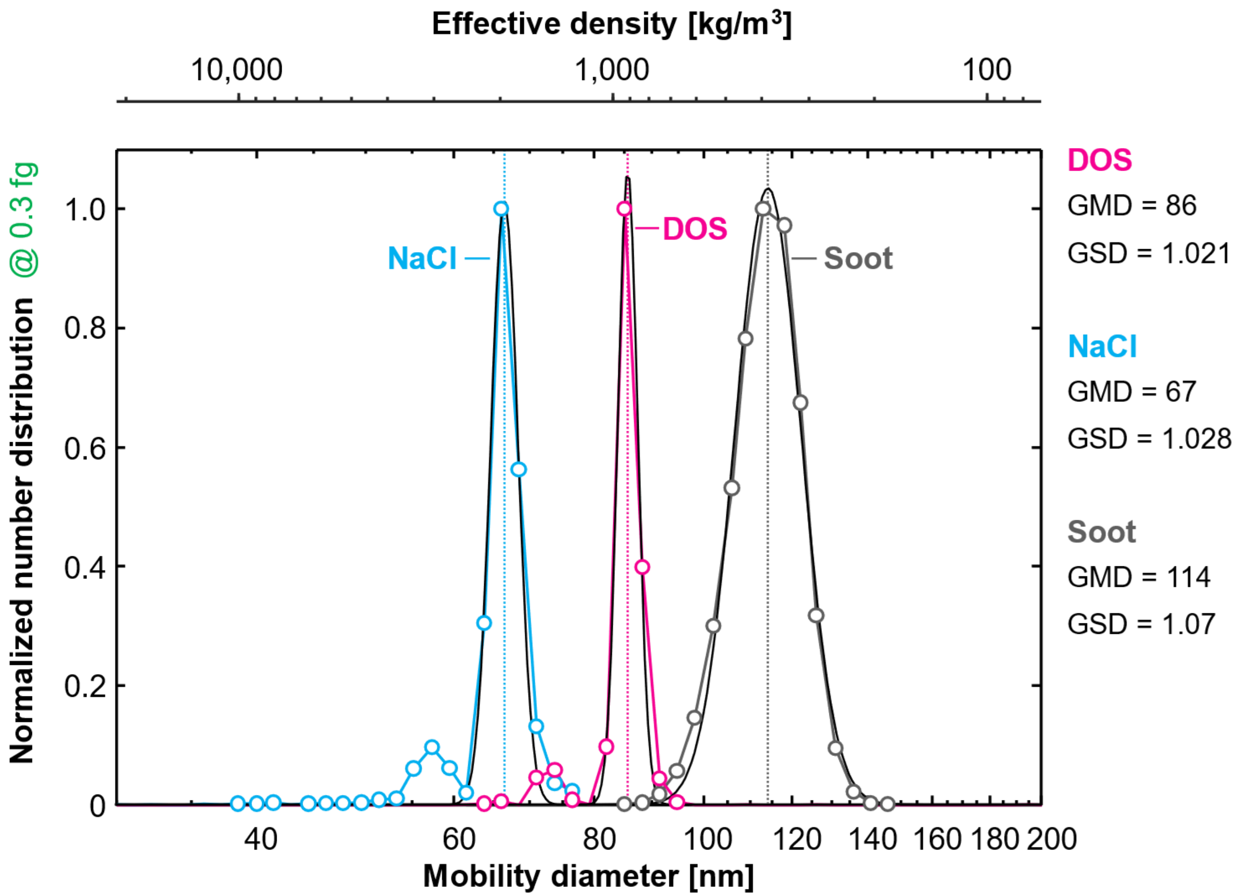


Example Data: CPMA-SMPS with CPMA set to 0.3 fg



- In traditional analysis, the distribution is fit to find the peak. The peak diameter and mass set point are used to calculate the ***average*** effective density.
- Note that spheres (DOS) only have one possible morphology, so the mobility distribution is narrow.
- NaCl and soot can have a range of morphologies for a given mass, thus the mobility distributions become broader. The peak only represents a central value of the ***effective density distribution***.

Example Data: CPMA-SMPS with CPMA set to 0.3 fg



- Also, for narrow distributions (DOS, NaCl) it is easy to distinguish multiply-charged particles and remove them from the analysis.
- For soot, the single and multiply-charged peaks overlap and cannot be distinguished.
- Therefore, data inversion is needed to find the ***distribution*** of effective densities which accounts for multiple charges.

Bivariate data inversion

- Show mass-mobility plot and effective density-mobility plot

$$R = \int_{-\infty}^{\infty} \frac{\partial N}{\partial \ln d_m} \cdot K(d_m, R_m) \cdot \mathrm{d}\ln d_m$$

Response of system

Scary, but just **collects** or **sums** all possible particles that …

1. Exist in the real population

2. The classifier lets **escape** with some **efficiency**

Bivariate data inversion

- Data inversion is similar to that for a single classifier.

$$R=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\frac{\partial N}{\partial \ln d_{\mathrm{m}}\,\partial \ln m_{\mathrm{p}}}\cdot K\left(d_{\mathrm{m}},m_{\mathrm{p}},R_{\mathrm{m},1},R_{\mathrm{m},2}\right)\cdot \mathrm{d}\ln m_{\mathrm{p}}\cdot \mathrm{d}\ln d_{\mathrm{m}}$$

Response of system

Scary, but just **collects** or **sums** all possible particles that …

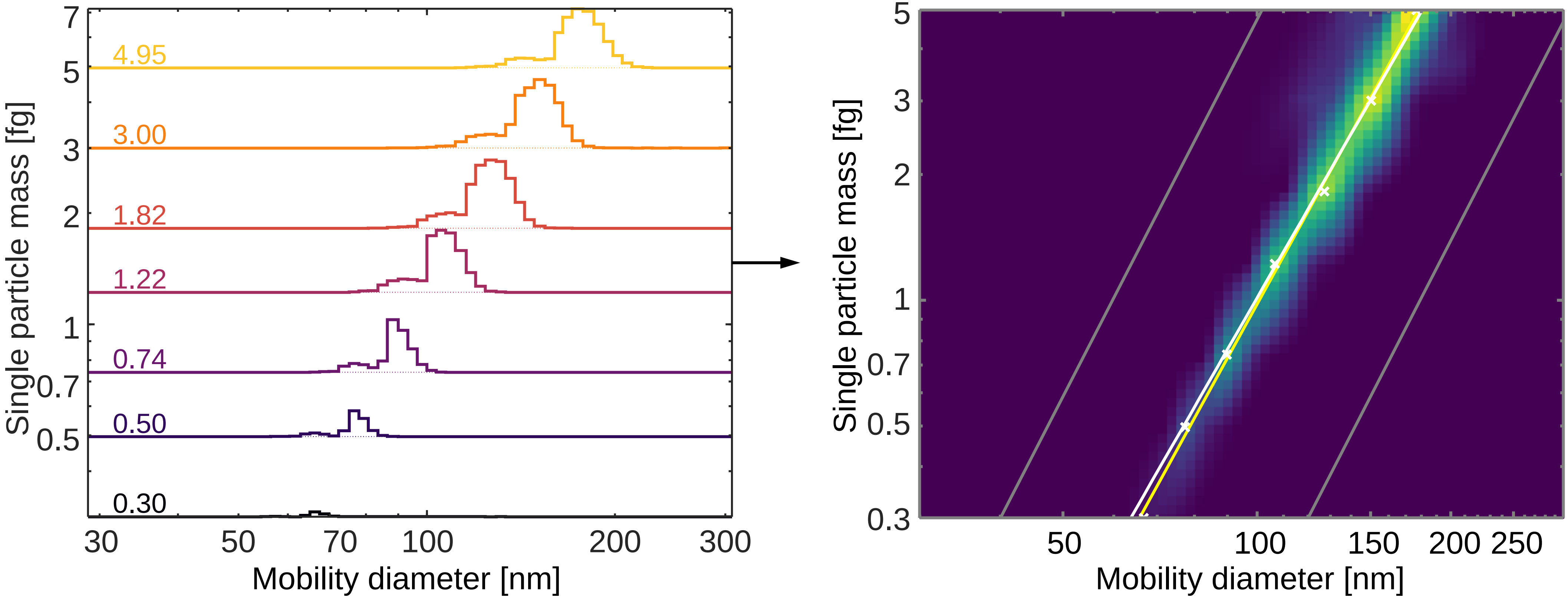
1. Exist in the real population

2. The classifier lets **escape** with some **efficiency**

- The process of inversion seeks to get the **distribution** from the response. This is hard given noise amplification.

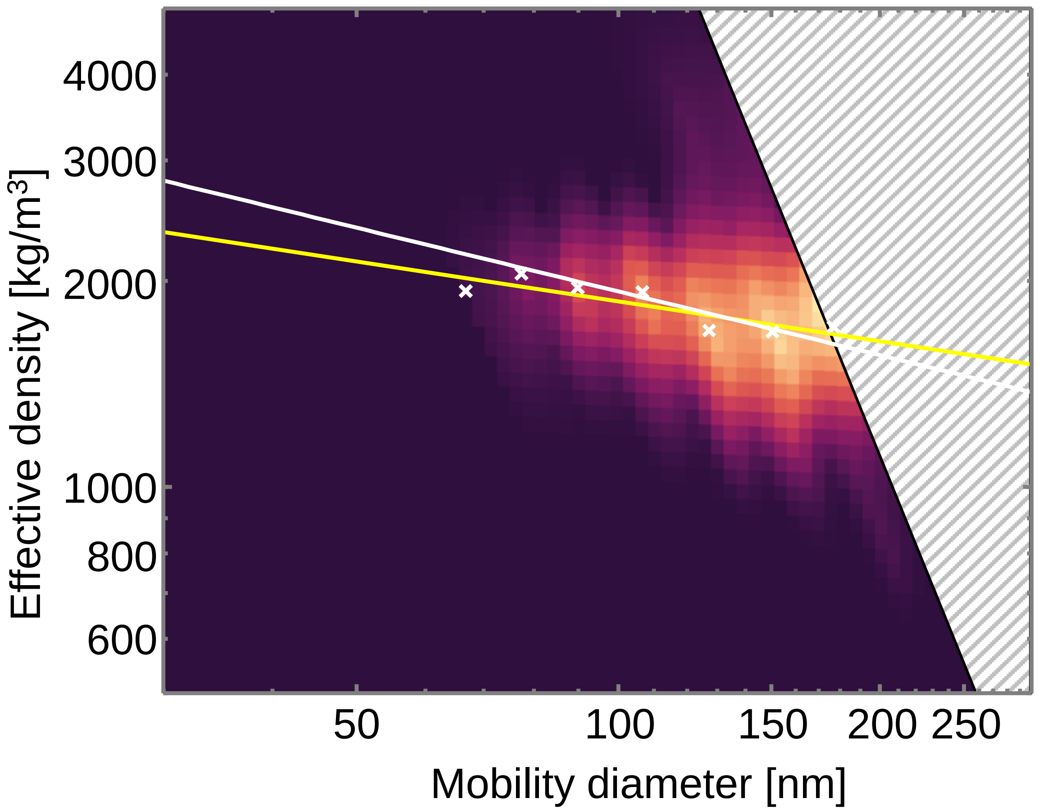
Bivariate data inversion

- Data inversion is similar to that for a single classifier.



Bivariate data inversion

- Data inversion is similar to that for a single classifier.



Future features

- Build inversion into the GUI
- AAC-SMPS inversion
- CPMA/DMA-scanning AAC inversion
- Calibration methods for determining effective density (particles of known shape (spheres) and known density) can be used to calibration tandem systems
- Improve the inversion for very narrow mass-mobility distributions

Thank you!