AMTD - 2015-251: *Characterization of the mass dependent transmission efficiency of a CIMS*

by Heinritzi et al.

Author's reply to Anonymous Referee #2:

M. Heinritzi on behalf of all authors.

We thank the referee #2 for commenting on our manuscript. In this answer the referee's comments are shown in black Times New Roman Font, our replies are shown in blue Calibri Font.

This manuscript presents dedicated attempts to quantify the transmission of a chemical ionization mass spectrometer, the CI-APi-TOF. Due to the lack of easy-to-use calibration standards, especially for the newly discovered ELVOC, this transmission characterization is important for improving the quantification capabilities of the instrument.

The paper is mostly well written and clear, and well within the scope of AMT. While I can partly understand the reasoning of Referee # 1, I find this paper to provide very useful information for the (albeit not huge, though still large and quickly growing) CIMS, and especially CI-APi-TOF, scientific community, and therefore I recommend this paper for publication in AMT, following consideration of my comments below.

My only major comment relates to Fig. 5 and the interpretation of the transmission curves: The authors provide different fitted curves for the transmission, and seem to only look at those when doing the interpretation. By doing this, they find much worse agreement than the data actually suggests! For example, the authors state that the shapes of all measured transmission curves are different in Fig. 5, but in fact all the measurements peaks in the 500-600 Th range.

Based on the different aspects listed in the introduction that can influence transmission, I would not expect any combination of them to produce curves with the shapes of the fitted curves. For example, I doubt that anyone could tune such a bimodal transmission curve as in Fig. 5a, nor such a sharply changing curve at 600 Th as in Fig. 5b while still retaining a relatively broad overall transmission. I therefore suggest that the authors allow for larger uncertainty in the vertical direction instead of, as now is the case, assuming that the fits have to pass through every data point. In this way, they could allow for some more "reasonable" shapes for the transmission curves. For example, if doing this I think using a shape similar to that of Ehn et al. 2011, Fig 2, would fit the data relatively well, and in the end show a quite consistent shape of the transmission curve in all different experiments.

The reason for allowing variations in the vertical direction could come from the fact that there is fragmentation occurring in the mass spectrometer, which means that ions will have traveled some part through it with one mass, and some part with another. This will inevitably cause variability at the monomers, as they will depend on the transmission of the di/trimers in the initial parts of the instrument. This should in any case be discussed.

We agree that there could be fragmentation of larger molecules to smaller molecules inside the instrument. This could for example be fragmentation of a cluster composed of a perfluorinated acid monomer and NO_3^- to NO_3^-, or a dimer or trimer to a monomer. As fragmentation is assumed to be independent of specific concentrations, thus occurring always at a certain ratio of dimer/trimer/monomer signals, we can give an upper limit for fragmentation by looking at the measured data. E.g. if fragmentation from a cluster between a perfluorinated acid and NO_3^- back to NO_3^- would occur, there would always be some production of NO_3^- and it would not be possible to deplete NO_3^-

completely. If fragmentation occurs from a dimer to a monomer of perfluorinated acids, there would always be a certain signal for monomers. Fig. 1 and 2 show example measurements of primary ion depletion for perfluorinated heptanoic and nonanoic acid. In both cases we can see that the depletion of primary ions is rather complete. Comparing the primary ion level at 14:32 in Fig. 1 and 17:36 in Fig.2 to the undepleted levels of primary ions gives a ratio of <4% and <5% for heptanoic acid and nonanoic acid, respectively. It is likely that this percentage would go down even further for more intense heating. This leads to the assumption, that fragmentation from acid clusters to primary ions is relatively small.
Considering the fragmentation from dimers or trimers of perfluorinated acids to monomers of perfluorinated acids, we can use the same approach. However, dimers and trimers are only present at one main peak which does not contain an NO_3^- ion. So possible fragmentation of dimers/trimers cannot result in a monomer that includes NO_3^-, but only contribute to the left and middle peak of the three distinct monomer peaks (see Fig. 3 of the manuscript for spectra). Having this in mind, we have also plotted the sum of only the left and middle monomer peak in Fig. 1 and 2 (blue dotted line).

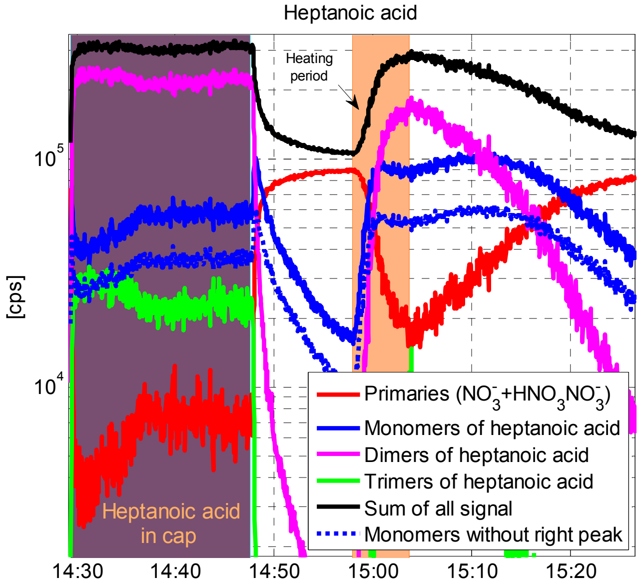

Figure 1: Timeseries of a depletion experiment with heptanoic acid. At the end of the first shaded period, the cap with heptanoic acid was replaced by a blank cap.

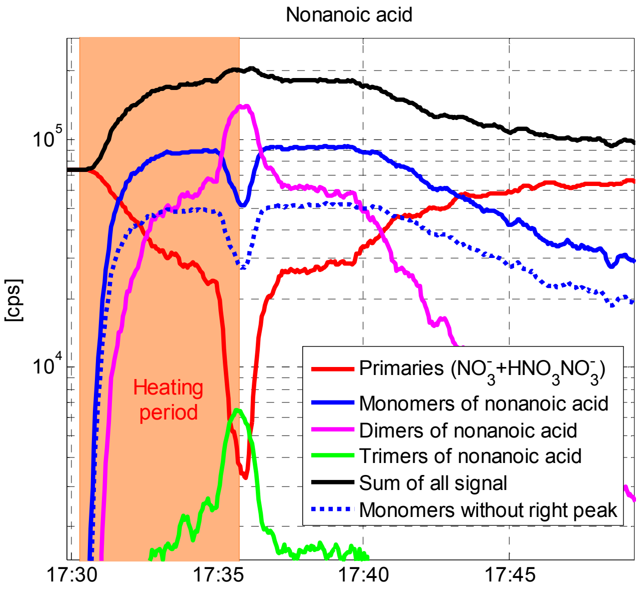

Figure 2: Timeseries of a depletion experiment with nonanoic acid.

We consider now the ratio of monomers (without the right peak) to dimers at the moment of highest dimer signal intensity (corresponds again to 14:32 in Fig. 1 and 17:36 in Fig.2). The minimal monomer to dimer ratio is around 12 % for heptanoic acid and 20 % for nonanoic acid. However, again these ratios might decrease even further for stronger heating. As these numbers are upper limits for the fragmentation ratios involved, we have added an additional uncertainty for primary ion signals of 5 % and for all the others of 15 %. The uncertainty of the primary ion signal adds in quadrature to the one of all other compounds as already described in the manuscript. Doing so leads to updated vertical error bars as shown in Fig. 3, which is also the updated Fig. 5 of the manuscript.
We have changed the sentence of the manuscript starting at l. 27 p. 11382 to:

"The relative uncertainty was estimated via the 95% confidence bonds of the regression analysis. Additional uncertainty for the relative transmission factors comes from possible fragmentation of larger clusters to primary or monomer ions. However, as fragmentation to primary ions implicates that their signal cannot be fully depleted and during the strongest heating the primary ion level goes e.g. below 4 and 5 % of the original level for heptanoic and nonanoic acid, respectively, we use 5 % as upper limit for fragmentation to primary ions. For fragmentation to monomer ions, we compare the highest dimer signal to the monomer signal at the same point of time (the right peak of the monomers can be excluded for this, as no dimer contains NO_3^- and thus cannot fragment to this peak). We find minimum monomer to dimer ratios of 12 and 20 % for heptanoic and nonanoic acid, respectively. These ratios might go down even further for stronger heating, so we have added an additional uncertainty for primary ion signals of 5 % and for all the others of 15 %. As the relative transmission of the primary ions was set to 1, their uncertainty was added in quadrature to the one of all other compounds involved."

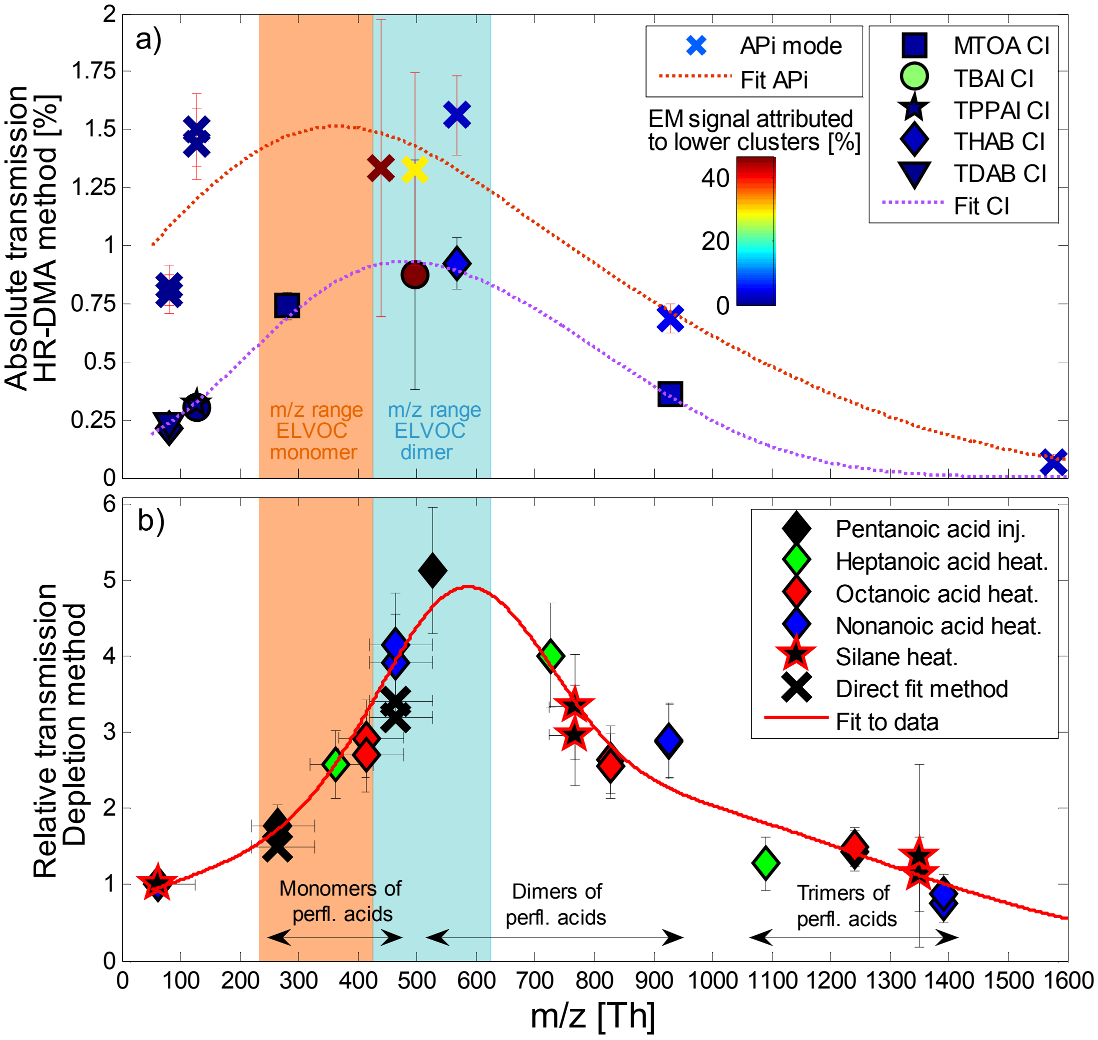

Figure 3 (updated Figure 5 of the manuscript): Changes made are: Updated transmission curves for APi- and CI-mode in panel a), updated fit for depletion method data in panel b) and increased vertical error bars in panel b) as described in the text. We added also annotations that indicate the regions of monomers, dimers and trimers of perfluorinated acids.

We can also provide additional proof that the depletion method works: If the time traces of Fig. 1 and 2 are corrected for their individual relative transmission efficiency and these corrected traces are summed up, the result should be a flat line, indicating constant ion production in the ion source of the instrument. In Fig. 4 we have plotted the same data as in Fig. 2, but with linear y-axis to see smaller changes and with the sum of the transmission corrected individual traces. The correction was done both with the mass dependent transmission factors given by the Gaussian fit in Fig. 3 as well as with the direct results of the nonanoic acid regression analysis. As especially the correction with the regression analysis results yields a flat line, we know that the depletion method works and that in our case there is no considerable disturbance by fragmentation.

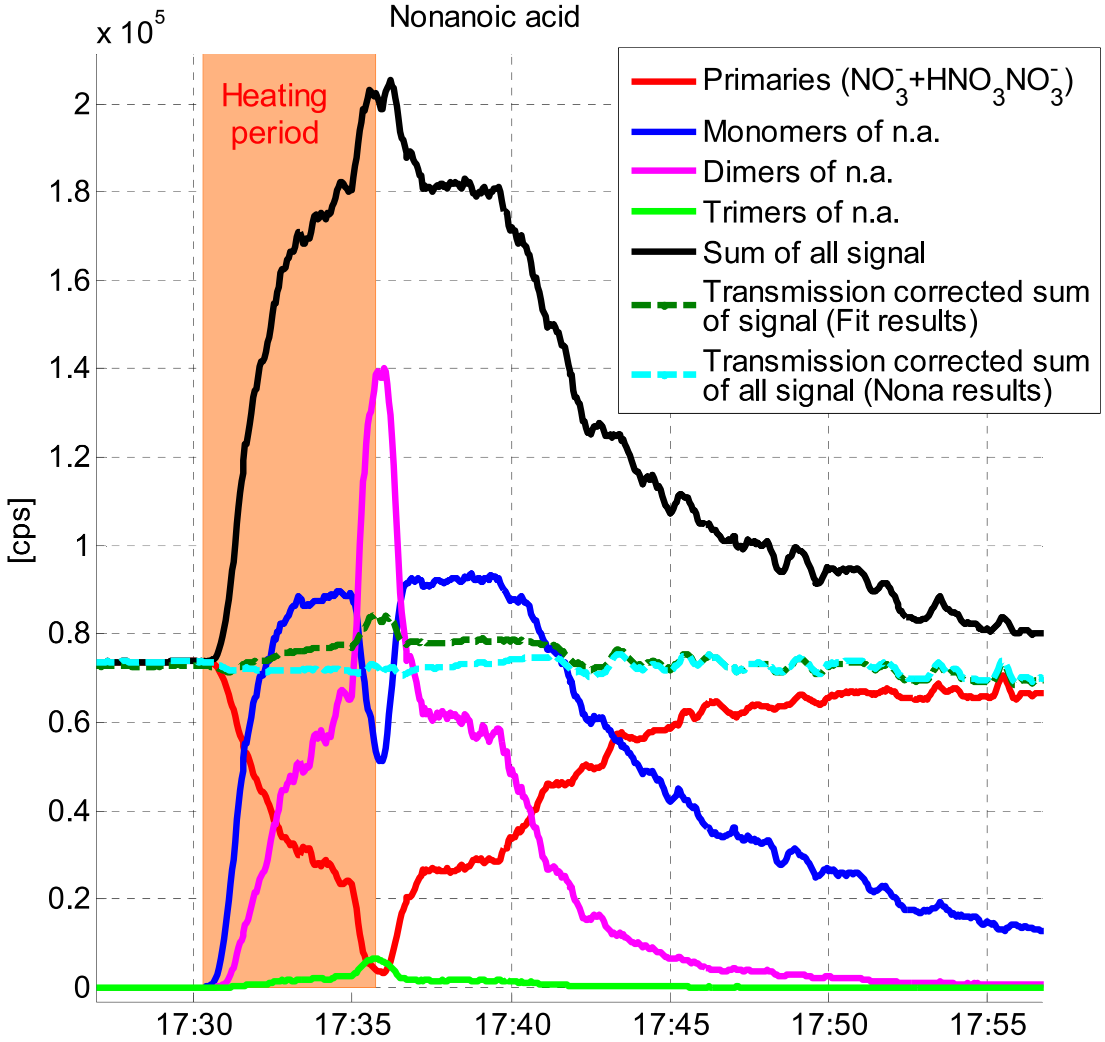

Figure 4: The transmission corrected sum of all individual traces should yield a constant level during the time of the experiment. The dashed dark green line shows the correction made with the transmission curve of the instrument (Fit in Fig. 3b); the dashed light blue line shows the correction that was done with the direct results of the nonanoic acid regression analysis, which gives a flat line.

We have added the transmission corrected sum of all signals to Fig. 4 of the manuscript (see Fig. 5 of this text). For the correction the direct results of the regression analysis of the corresponding acid was used.

In both cases we get a constant sum of corrected signal. To mention this also in the results section of the manuscript, we have added the following sentence at l. 2 p. 11385 of the manuscript:

"If we use the results of the regression analysis for the individual acids and correct the corresponding time traces in Fig. 4 for transmission, their sum should yield a constant level over the time of the experiment. This is the case for both acids shown in Fig. 4 (light blue line). The constant signal confirms our method and represents now the constant ion production in the CI-source. It also means that there is no considerable fragmentation occurring, which would lead to biased results of the regression analysis."

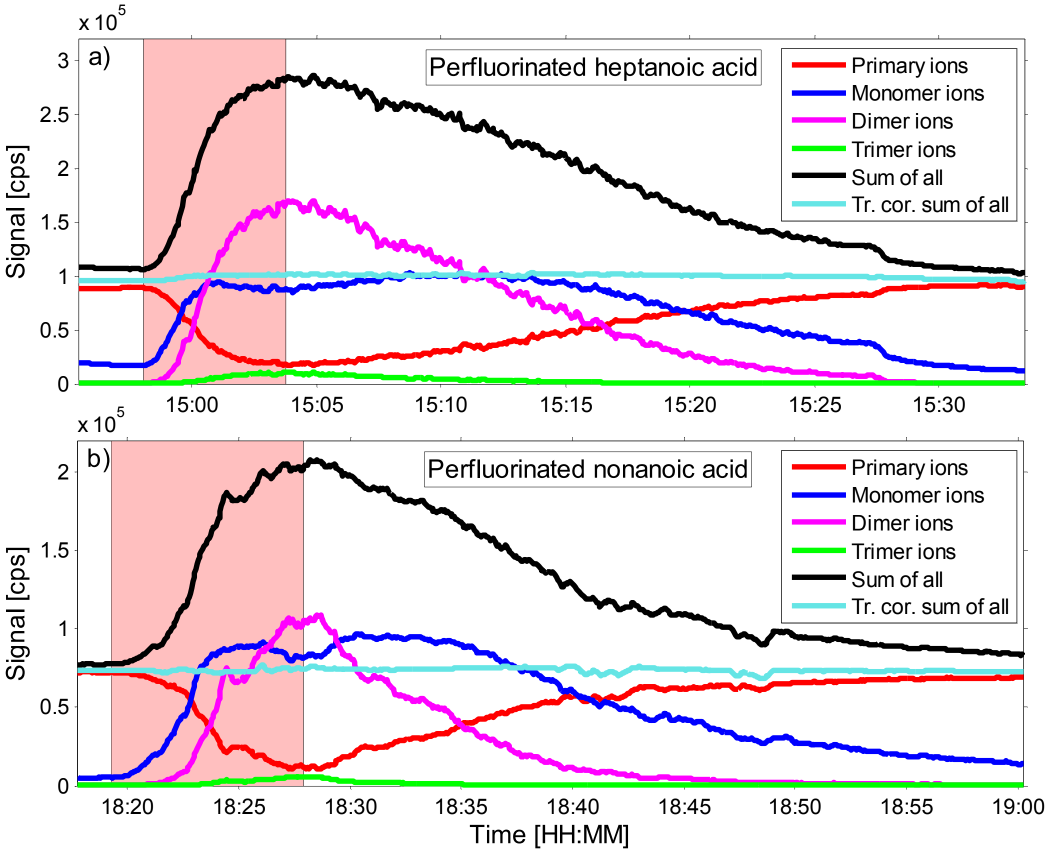

Figure 5: Same as Fig. 4 of the manuscript, but with added transmission corrected sum of all signals.

Another point the referee mentioned was the shape of our fitted curves. We have updated all three fits in Fig. 5 in the manuscript (see Fig. 3 of this text). The basic fit model for all three fits is now a twofold Gaussian distribution. However, to ensure reasonable well representation of the measured data, we had to set lower limits for the two parameters in the denominator of the exponent (200 for the CI-mode and depletion method fit and 350 and 500 for the APi-mode fit). By doing so, we could apply the same fit model to all measured datasets. We now don't have any bimodality in the APi-mode fit, but especially the data points corresponding to m/z 79 and 127 Th suggest a steeper increase in transmission efficiency than the actual fit.

However, as we discuss in the manuscript, the data comparison between APi-mode and depletion method suggests non-negligible transmission effects of the ion source itself. For that reason only the fit of the depletion method (that uses a setup similar to standard measurement conditions) was used as actual transmission curve of the instrument to e.g. correct data sets from other experiments performed under the same conditions. The fit lines in the upper panel of Fig. 5 in the manuscript act rather as “to guide the eye”-lines lines and have a large uncertainty, especially in the APi-mode in the lower mass range (m/z 0-400 Th). A more detailed investigation of the HR-DMA-method in the APi-mode would be necessary but is beyond the scope of this paper.

The referee also mentioned the sharply changing curve in Fig. 5b. With the updated fit, we now have a smoother change of the curve and the maximum of the curve does also not any more exceed the maximum of the measured data points. We have also added annotations indicating the regions of monomers, dimers and trimers of the perfluorinated acids used.

We have changed the manuscript to reflect these points. The sentence in l. 15-17 on p. 11383 was replaced by:
“The curves were obtained by applying least-squares fits to a twofold Gaussian distribution for the APi-, CI-mode and depletion data. To ensure reasonable well representation of the measured data we had to set lower limits for the two parameters in the denominator of the exponent (200 for the CI-mode and depletion method and 350 and 500 for the APi-mode fit).”

The sentence in l. 22-24 on p. 11383 was replaced by:
“The data points of the APi setup are systematically higher than for the CI setup, with a larger difference for smaller masses. This difference is due to a combined effect of the CI ion source as well as the discussed voltage step of -500 V in front of the ion source. The result is a stronger suppression of lighter ions in the CI setup and a shift of the maximum of the curve towards higher masses.”

We have also changed the two sentences in p. 11384, l.13-17 to:
“The above mentioned fit to the twofold Gaussian distribution of the results of the regression analysis was used as transmission curve of the instrument and to correct datasets from other experiments obtained under similar conditions.”

Minor comments:
- At the end of the introduction there should typically be a paragraph discussing what the aims/methods/ approach of this particular study.

We have added a short paragraph at the end of the introduction that describes the aims and methods of our study:
“In this study we show the application of the method of depleting primary ions to the nitrate based CI-APi-TOF for obtaining transmission curves. We describe the measurement setup and the used compounds as well as the statistical analysis that became necessary due to the high level of clustering of compounds inside the CI-APi-TOF. Additionally we compare this method with a second approach for transmission estimations that uses a High-Resolution Differential Mobility Analyzer and an electrometer.”

- 11375, line 1: ” larger spatial spread” I do not feel that this effect is described as well as many of the others. At least it is my impression that the point here is that a larger fraction of the small ions will have already exited the extraction region when the next extraction takes place. This should be stated more concretely.

The larger spatial spread of lighter ions leads directly to the effect the referee describes here. We have updated our formulation in the manuscript to express this more clearly:
"So as a larger fraction of lighter ions has already left the extraction region compared to heavier ions, fewer of the lighter ions are accelerated orthogonally to the detector."

- Section 3.1. and Fig 2c: I had to read it several times to understand that the EM correction factor still has nothing directly to do with the transmission, but is only used to account for the different positions of the TOF and EM. Please state this explicitly and clearly somewhere, as this whole (long) section is now a bit hard to follow.

To clarify this passage we have updated the sentence starting in l. 18 on p. 11377: "We have made additional measurements to obtain mass dependent EM correction factors that account for the different tubing lengths and flows (see Fig. 2). By doing so, we can estimate the ion concentration not only at the position of the EM, but directly in front of the mass spectrometer which is the important measure for the transmission estimation. For that we placed the EM at the position of the TOF and applied equal flows as during the standard measurements."

- 11381, line 7: "permanently depleted completely", what exactly does this mean? The aim is to deplete the primary ions. . .

It is correct that it is the goal of our method to deplete the primary ions, but not to do this completely. In fact we need a varying degree of depletion to perform the statistical analysis. If the amount of an added substance is too large, the primary ions will be depleted completely more or less instantaneously after connection of the cap without any chance of a recovery within reasonable time. Then this data is not useful for estimating transmission curves. It is actually very easy to add a too large amount to the system, so as we point out only tiny amounts (a very small grain) of substance should be used as well as a longer/thinner vertical tube in the inlet system.

To clarify this a bit more, we have changed the sentence on p. 11381 l. 6-9 as follows:
"If the amount of a compound in the cap is too large, a permanent complete depletion of all primary ions can occur. As will be described below, we need however varying degrees of depletion to deliver meaningful transmission curves; a complete and permanent depletion of the primary ions is not useful. To avoid this, it is important to only use a small grain/drop of the respective compound and/or to install a longer and/or thinner vertical diffusion tube in the inlet setup (see Fig. 1c)."

- 11383, lines 21-22. "Here" vs "this study"?

We have reformulated our sentence: "The shape of the transmission curve is in agreement with earlier estimates for an APi-TOF using a similar method by Ehn et al. (2011), however, in our study we found around a factor of two higher transmission levels than Ehn et al. (2011)."