Reply on RC2: 'Comment on amt-2021-133' by Anonymous Referee #2

We thank the reviewer for the positive assessment of our work and the recommendation for publication in AMT. In the following we answer (italic font) the minor comments (cited in roman font) and indicate manuscript modifications (bold font).

This is an excellent paper describing the advantages of using Fabry-Perots interferometers (FPI) in compact spectrographs for remote sensing measurements in the atmosphere. The authors emphasize that FPI-based instruments provide higher resolving power in comparison to conventional grating spectrographs (GS) of similar physical dimensions. The results are convincing and supported by an elegant prototype demonstration. The paper is very well written and certainly suits the scope of AMT. I have only minor suggestions to be addressed in the manuscript:

1. The authors limit their consideration to the geometrical dimensions of the instrument. However, more factors can and should be considered in the development of the mobile optical instrument. I would name mechanical and thermal stability, cost of production, and maintenance requirements. The paper would benefit if some of these points could be addressed by the authors.

We agree with the reviewer on the point that mechanical and thermal stability and low maintenance requirements are important aspects of mobility. In the abstract and in Sect. 1.3 (l. 115 original manuscript) we define 'mobility' as 'compact and stable'. 'Compact' refers to the geometrical dimensions of the instrument and 'stable' to mechanical/thermal stability that induces low maintenance requirements. Our argument is that FPI spectrographs maintain the high mobility of moderate resolution GS (which have proven their mobility, see Sect. 1.3) and, moreover, that modern FPI spectrograph designs exhibit excellent thermal stability, likely superior to most commercial GS designs. We refer to our answers to RC1 and the addition of the discussion of thermal stability to the revised manuscript (l. 181 of the original manuscript):

Generally, a static setup (without moving parts) has a high mechanical stability and low maintenance requirements. This is demonstrated by moderate resolution GS applications. Spectrographs using FPIs implemented with low thermal expansion glass (linear expansion coefficient $\gamma = 10^{-8}$/K) spacers further yield superior thermal stability. From Eqs. (1) and (2) follows that $d\lambda / \lambda \sim \gamma\, dT$. A rather extreme temperature change of 10K then induces a shift of the transmission spectrum by 10^{-7} λ. Even for a high resolving power of 10^5 this would hardly have an effect on the measurement. The issue of potentially varying air density within the etalon impacting the refractive index is solved by hermetically sealing the etalon. Further, the temperature impacts on FPIs, as well as that on the simple optics, can be accounted for in models of the instrument transmission. This is much more difficult for GSs, since there temperature also significantly affects the rather non-linear imaging of the slit. Thus, while GSs often require active temperature stabilisation (see Platt and Stutz, 2008), for FPI spectrographs it might be redundant for most applications. This substantially enhances their mobility through a simpler and smaller setup with lower power consumption.

2. Despite being essentially different in principle, laser spectroscopy offers high resolution and selective detection of trace gases and recent developments also show that the laser-based solutions can also be made compact and energy-efficient. The presented development could be put in the context of state-of-the-art mobile/compact laser systems.

We thank the reviewer for this valid remark. Laser light sources do exhibit high radiance and high spectral resolution. Therefore one might conclude that for active absorption spectroscopy (i.e. not using natural light sources like the sun) laser-based instruments should be superior to any other spectrometer. However, in practice lasers are frequently complicated, bulky, and expensive devices with limited spectral tuning range. Simple and compact designs, like diode lasers have only been available for very limited spectral ranges. It is probably because of these limitations that during the last decades their role in atmospheric remote sensing (i.e. open path measurements) was smaller than expected. For most applications, laser systems are not limited by photon statistics, which makes a comparison with a spectrograph system quite complex. A sound discussion of laser systems, potential future development and the comparison to techniques using incoherent light sources would be interesting, but quite a comprehensive task. It could be the topic of an independent review on atmospheric trace gas remote sensing. Here we limit our study to spectrograph measurements.
Despite of atmospheric remote sensing using laser technology being an emerging field (see e.g. Fiddler et al. 2009), we are convinced that it is worthwhile to further develop simple techniques using incoherent and natural light sources to study atmospheric trace gases.

(Marc N. Fiddler, Israel Begashaw, Matthew A. Mickens, Michael S. Collingwood, Zerihun Assefa, and Solomon Bililign: Laser Spectroscopy for Atmospheric and Environmental Sensing, Sensors 9, 10447-10512; doi:10.3390/s91210447,2009)

3. Line 448, the discussion on isotope detection is somewhat vague. Could you add what isotopes and in which compound you are aiming to detect?

In the Introduction (Sect 1.2, l. 102-104) we mentioned the example of water vapour isotope measurements, which are currently performed with lower resolution. The sensitivity could be substantially enhanced through a higher spectral resolution.
In the UV and visible wavelength range the difference in absorption cross sections of isotopologues of small trace gas molecules is often on a sub nm scale that cannot be resolved with moderate spectral resolution. High spectral resolution with comparable SNR might thus allow separating the absorption of different trace gas isotopologues as long as their abundance is high enough. For instance, in addition to water vapour isotopologues the measurement of the $^{34}SO_2$ in volcanic plumes could be possible.

We replace the sentence (l.448 original manuscript)

Consequently, also the feasibility of distinguishing trace gas isotopes is strongly enhanced and line broadening effects could add valuable information to retrievals of vertical atmospheric trace gas distributions.

by

Consequently, also line broadening effects could add valuable information to retrievals of vertical atmospheric trace gas distributions and the feasibility of distinguishing trace gas isotopologues is strongly improved. Besides improving water isotopologue quantifications (e.g. Frankenberg et al. 2009) the separation of $^{34}SO_2$ and $^{32}SO_2$ in volcanic emissions could be possible through the differences in the absorption cross section, which are on a sub nm scale (Danielache et al., 2008) and thus impossible to resolve with moderate spectral resolution.

With the additional reference:

Danielache, S. O., Eskebjerg, C., Johnson, M. S., Ueno, Y., and Yoshida, N.: High-precision spectroscopy of 32S, 33S, and 34S sulfur dioxide: Ultraviolet absorption cross sections and isotope effects, Journal of Geophysical Research, 113,https://doi.org/10.1029/2007jd009695, 2008.

4. Minor technical comment: Line 439 "... will be by **a factor of ... 0.04 lower** than that of ... " Please check if it is a correct statement.

We thank the reviewer for this remark. For clarification, we replaced "… will be by a factor of … 0.04 lower than that of common DOAS measurements with moderate spectral resolution" (l. 439 original manuscript) by

… will be reduced by a factor of … 0.04 compared to that of common, moderate spectral resolution DOAS measurements.

Again, this is an excellent paper that deserves publication!