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Renewal of the FTIR platform at Jungfraujoch: first characterization of the performance of the new equipment

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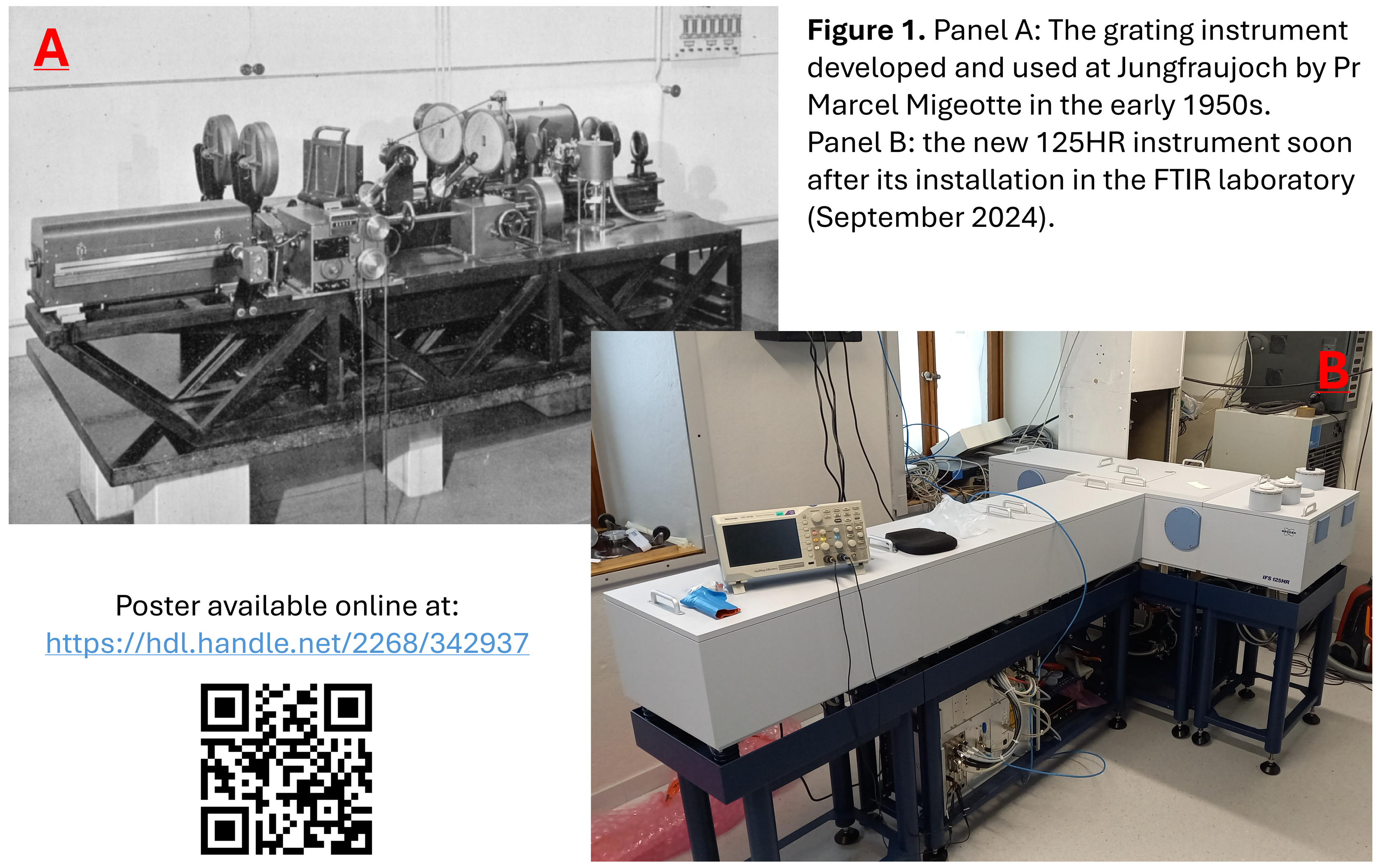

Figure 1. Panel A: The grating instrument developed and used at Jungfraujoch by Pr Marcel Migeotte in the early 1950s. Panel B: the new 125HR instrument soon after its installation in the FTIR laboratory (September 2024).

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1. Context of the renewal: a bit of history

- The atmospheric monitoring program of the University of Liège has started in the early 1950s, at the initiative of Pr Marcel Migeotte (Zander et al., 2008). At that time, a home built grating spectrometer has been deployed at the station for the systematic recording of the infrared spectrum between 2.8 and 23.7 µm (Migeotte et al., 1956; see panel A of Fig. 1). These historical observations available on paper-roll have recently been digitized and calibrated (Makkor et al., 2025) to allow their use with modern tools. A first successful study allowed to derive a mole fraction of (26.1 ± 18.5) ppt for CCl_2F_2, or CFC-12, for 1951 (Makkor et al., 2026), representing the earliest atmospheric CFC measurement.
- The instrumentation later evolved with the installation of a more powerful grating spectrometer which first focused on the study of the solar photosphere.
- In the mid-1970s, the team refocused its attention on the Earth's atmosphere, prompted by the Molina and Rowland (1974) hypothesis that chlorine atoms from the CFCs could efficiently destroy stratospheric ozone.
- It is in the early1980s that a Fourier Tranform Infrared (FTIR) homemade instrument was installed at the Jungfraujoch station. Its routine operation extended from 1984 until 2008, leading to the recording of nearly 10'000 high-resolution broadband solar absorption spectra, covering altogether the 650-4400 cm^{-1} range.
- A second FTIR instrument was installed at the Jungfraujoch station in the early 1990s, backing, then replacing, the homemade FTIR spectrometer. This commercial spectrometer, a IFS120HR instrument manufactured by Bruker Optics, was modified by the team before starting routine operation in 1991.
- The 120HR instrument has recorded more than 60'000 spectra spanning the 1991-2024 time period, during nearly 35 years.
- After such a long time into operation, its reliability became problematic, with a few first failures. Moreover, the support from the manufacturer ended, threatening the availability of spare parts. This motivated us to replace this instrument with a new 125HR, also manufactured by Bruker Optics.

2. Instrumental performance

The new spectrometer has been installed and set up in the Sphinx FTIR laboratory in early September 2024 (see panel B of Fig. 1). This instrument is equipped with two detectors (HgCdTe and InSb) and a set of six optical filters, covering altogether the 650-4400 cm^{-1} wavenumber range (see Fig. 2). Routine operation started after the installation in October 2024 of a liquid nitrogen (LN2) microdosing system from the Norhof company, needed to cool the detectors.

Since then, we have evaluated the performance of our new equipment. Its major advantages are:

- A recording speed three times faster than the 120HR, for the same spectral performance (typical maximum optical path differences in the 80-180 cm range; recording times between 2 and 7 minutes), allowing to cover quickly the six optical filters, critical on short sunny days, and to better capture the diurnal variations of short-lived target gases
- The signal-to-noise ratios (SNR) of the 125HR spectra show a significant improvement when compared to those obtained with the 120HR, using apertures of similar sizes. For the common optical filters, we note the following improvements of the SNRs:
  - Filter 1 (turquoise), from 1500 to 4000
  - Filter 2 (blue), from 1000 to 3300
  - Filter 3 (orange), from 1000 to 1600
  - Filter 4 (green), from 900 to 2900
  - Filter 6 (red), from 550 to 2000

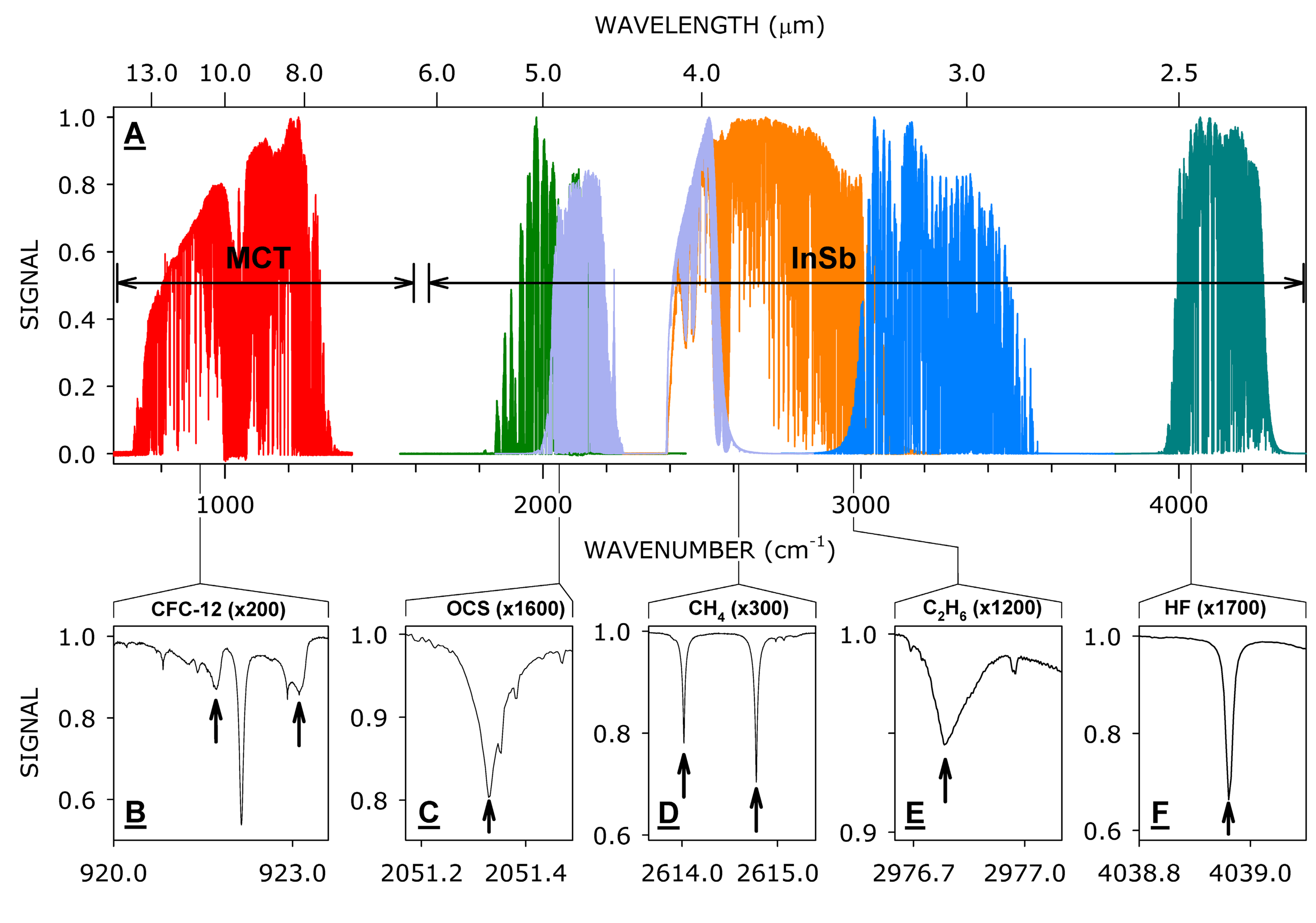

Figure 2. Panel A: the spectral range covered by the 125HR instrumental setup, involving two cooled detectors. The six optical filter band-paths are color-coded. Panels B-F show, after scaling the horizontal axis by 200 to 1700, a selection of spectral micro-windows that include absorption bands of several target molecules. Mind the different vertical scales.

3. Time series consistency

As running the 120HR and 125 HR instruments in parallel was not possible due to space limitations in the FTIR laboratory, a Vertex80V moderate resolution FTIR spectrometer (Bruker Optics) lent by Universität Bremen was installed on the second floor of the Sphinx building, to adhere as much as possible to the GCOS principle #3. This instrument shared the solar beam of the 120 and 125HR. It was operated from May 2024 until May 2025. It recorded spectra in parallel with the 120 HR, until July 19, 2024, and in parallel with the 125HR instrument, from September 2024 until May 2025. In between, it was operated alone, recording observations which will be useful to bridge the gap between the HR instruments.

Observations obtained simultaneously have now been analyzed for a suite of FTIR targets, namely ozone, methane, nitrous oxide, carbon monoxide and ethane, hence including long- and short-lived species with strong or moderate/weak absorptions.

Note that these results are still preliminary, requiring some further refinements. Table 1 lists the statistics derived from all comparisons, involving morning and afternoon averages. The uncertainty ranges are provided at the 2-σ level. Example scatter plots are displayed for ethane in Fig. 3.

Target	120HR vs V80	125HR vs V80
Ozone	-8.2 ± 5.0 %	-2.9 ± 4.9 %
Carbon monoxide	-0.7 ± 3.9 %	-1.4 ± 2.7 %
Ethane	-0.1 ± 12 %	-0.6 ± 7.7 %
Methane	-0.7 ± 1.9 %	-0.2 ± 0.8 %
Nitrous oxide	-0.8 ± 1.5 %	-1.7 ± 0.9 %

Table 1. Average morning (AM) and afternoon (PM) fractional differences (V80-12xHR/mean) computed for the parallel observations. All cases indicate consistent results for the 120HR and 125HR at the 2-σ uncertainty level. In the case of N_2O, dissimilar microwindows have been used for the HR instruments and the Vertex, potentially leading to a systematic bias of spectroscopic origin.

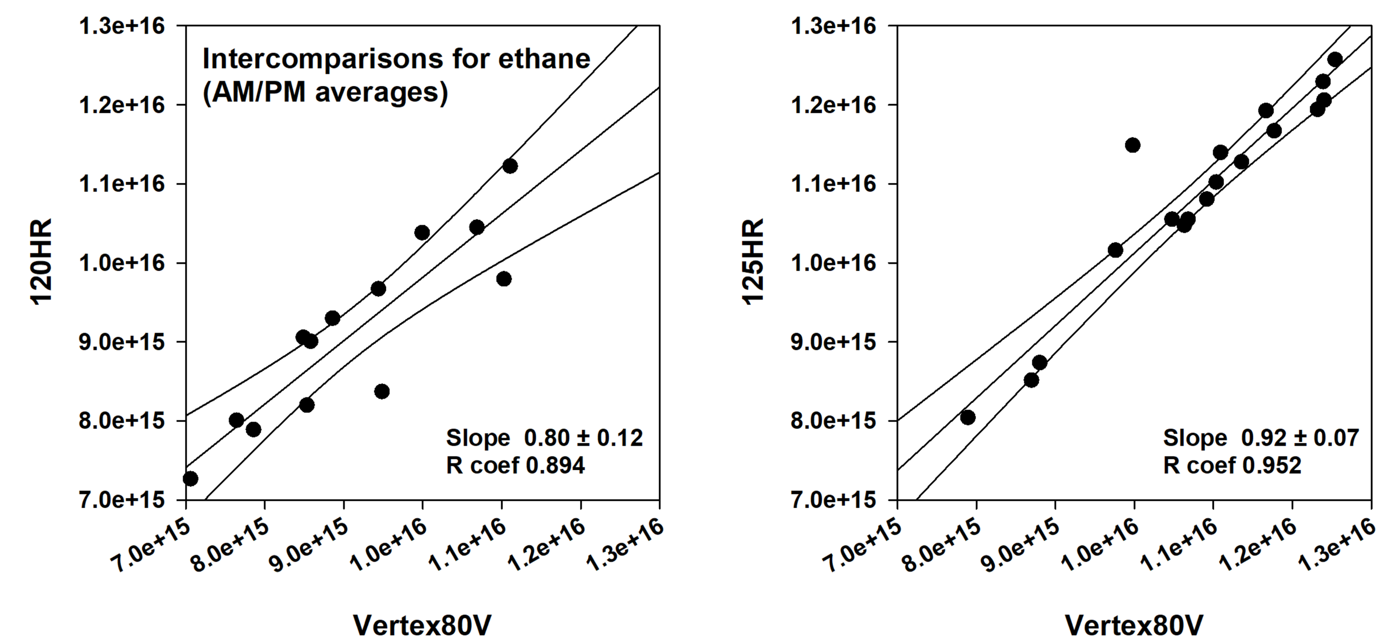

Figure 3. Scatter plots showing the 120HR vs Vertex and 125HR vs Vertex intercomparisons for ethane, considering AM/PM averages.

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