The Irish Atmospheric Simulation Chamber: a national facility for atmospheric sciences

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Introduction

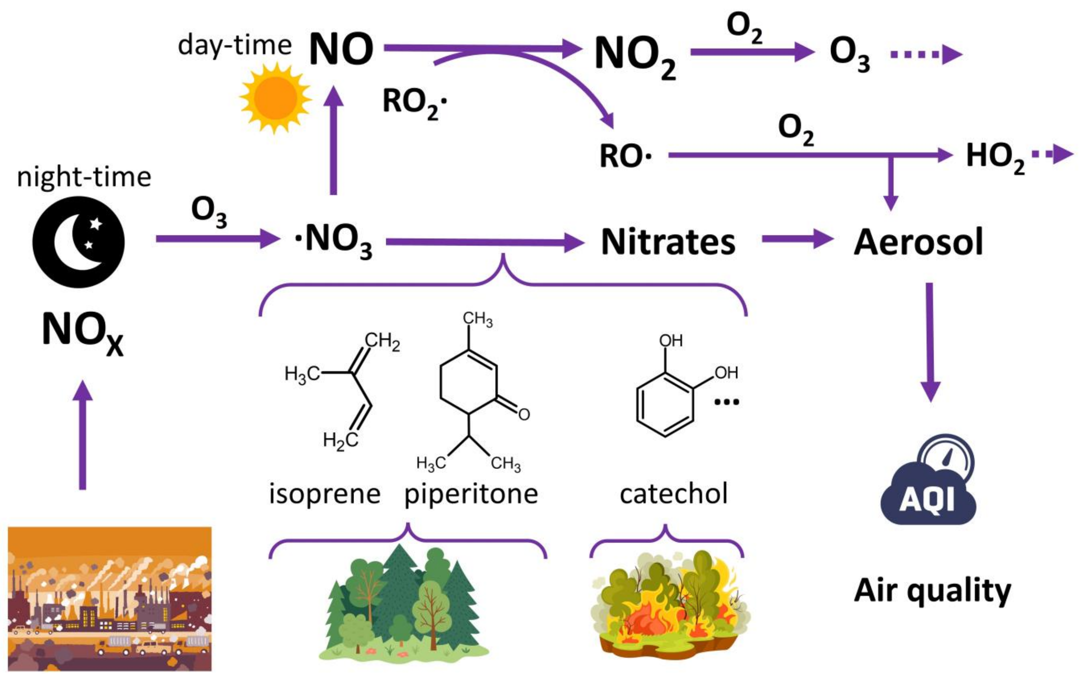

Figure 1: Schematics of atmospheric NO_x chemistry.

Atmospheric predictions use complex models that are underpinned by observations and a sound understanding of the underlying processes and interactions between atmospheric components and their environment. Atmospheric simulation chambers are the most advanced tools for studying and quantifying atmospheric processes and are used to provide many of the parameters incorporated in air quality and climate models [1]. The Irish Atmospheric Simulation Chamber (IASC) facility is a new new national infrastructure to support world-leading research activities in atmospheric science, sensor development and pollutant removal technologies. Based at University College Cork (UCC), the state-of-the-art research infrastructure consists of a large custom-built chamber equipped with cutting-edge instrumentation for continuous, real-time monitoring of gases and particles.

Irish Atmospheric Simulation Chamber (IASC)

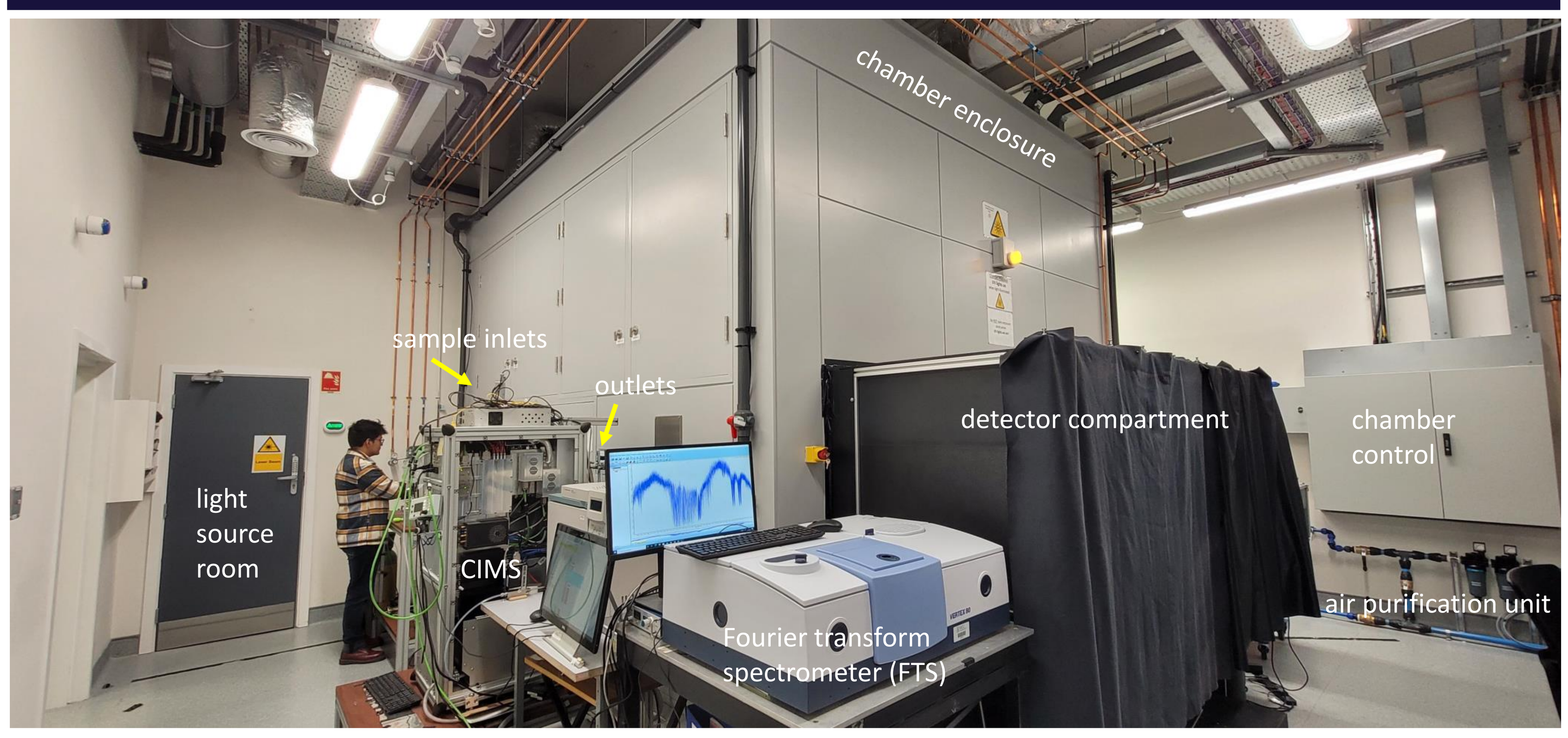

Figure 2: Photo of the Irish Atmospheric Simulation Chamber (IASC). Major components of the facility are labelled in yellow.

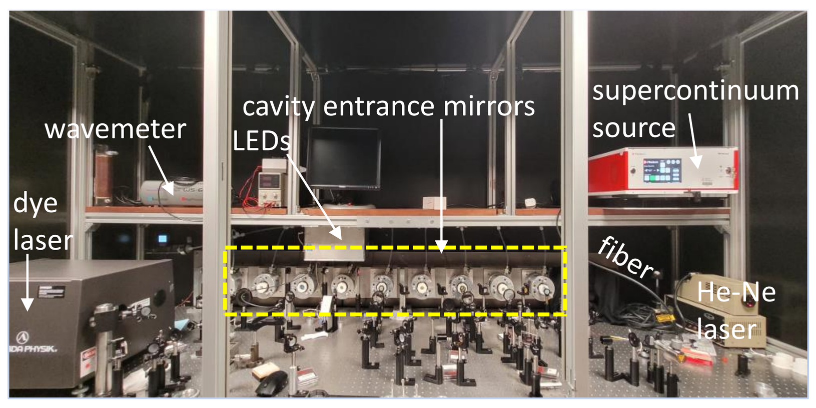

Figure 3: Photo of the light source compartment.

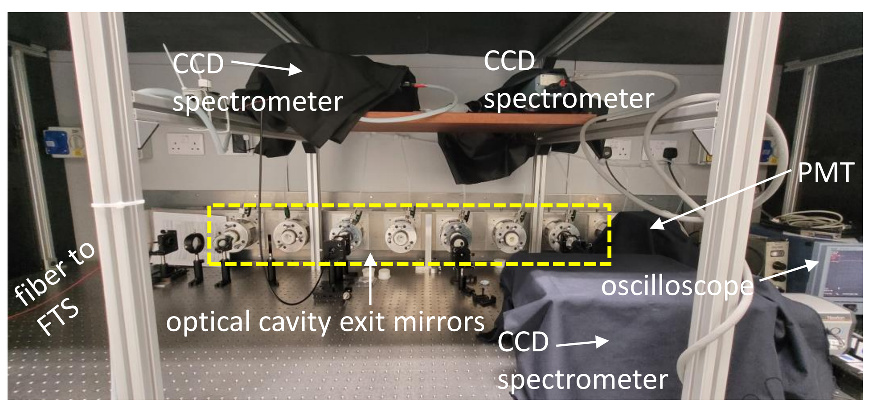

Figure 4: Photo of the detector compartment.

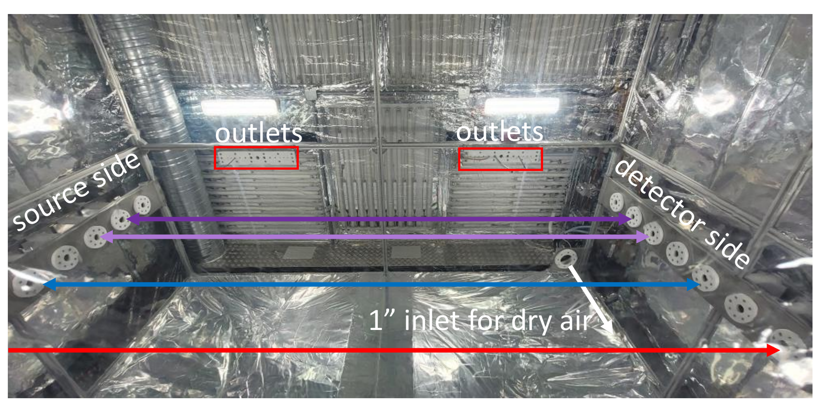

Figure 5: Inside view of the Teflon bag of IASC.

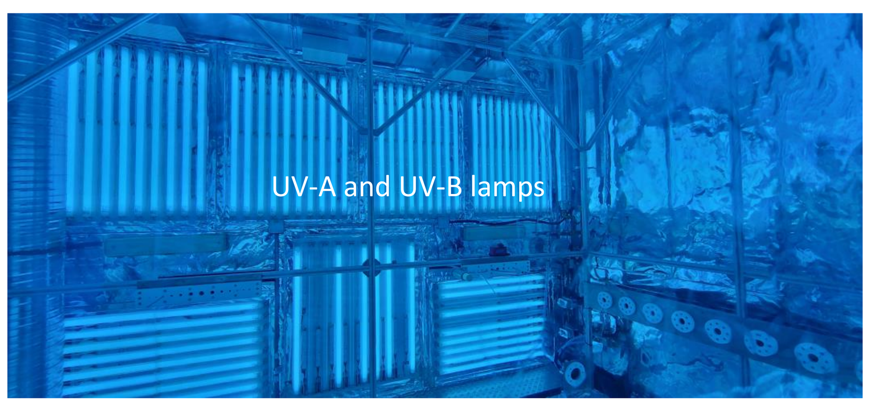

Figure 6: Inside view of the Teflon bag of IASC with UV lights on.

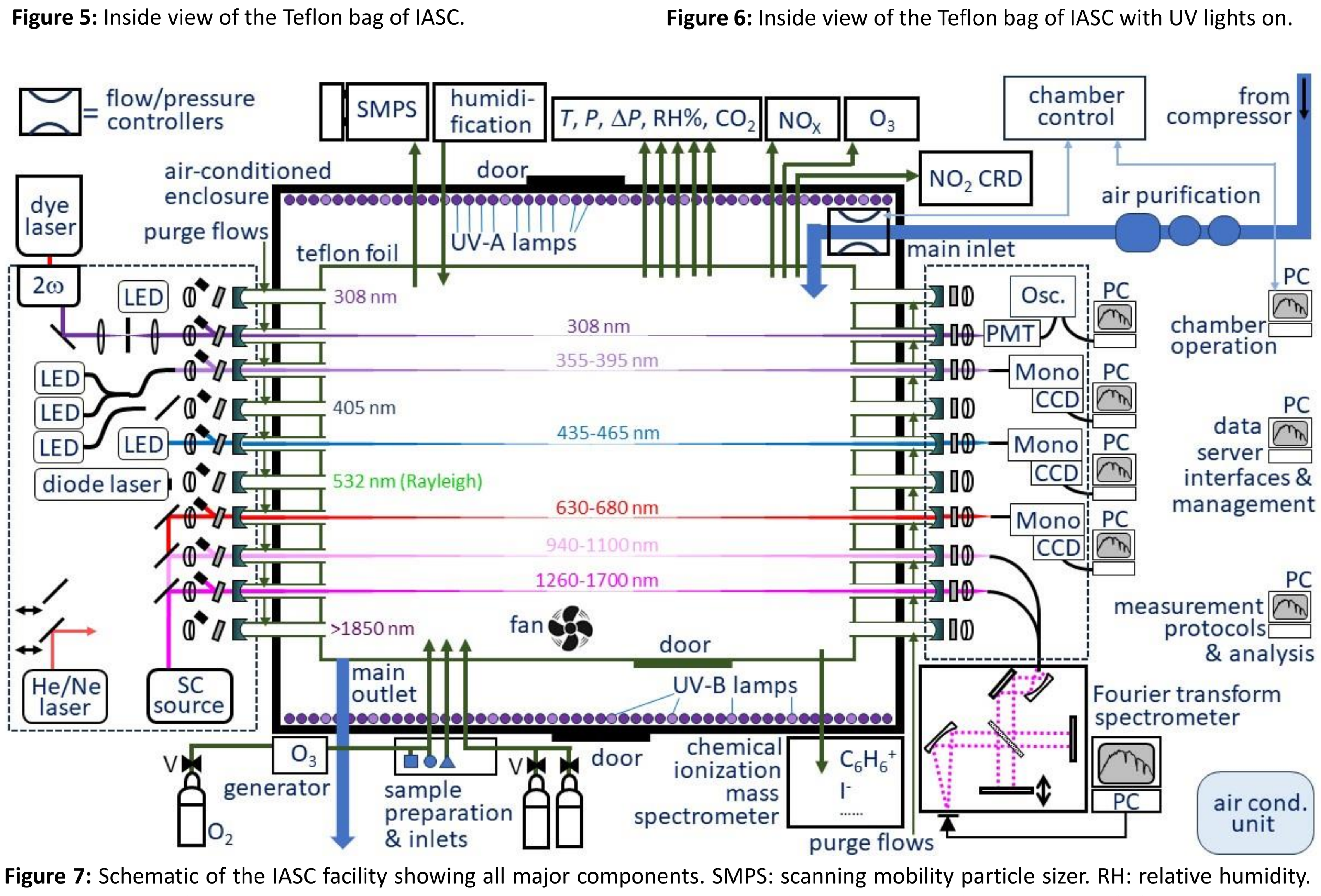

Figure 7: Schematic of the IASC facility showing all major components. SMPS: scanning mobility particle sizer. RH: relative humidity. CRD: cavity ring-down spectroscopy. PC: personal computer. Mono: Monochromator. CCD: charged coupled device. LED: light emitting diode. SC: supercontinuum. 2ω: frequency doubler. He-Ne: helium/neon alignment laser. ΔP: differential pressure. PMT: photomultiplier tube. Osc.: digital oscilloscope. UV: ultra-violet.

Chamber Instrumentation & Features

- Chemical Ionization Mass Spectrometer (CIMS; Aerodyne/TofWerk:-ToF-CIMS): Example for gas phase Limit of Detection (LoD): 4 pptv of formic acid in 15 s
- Scanning Mobility Particle Sizer (SMPS; TSI 3938 with a TSI 3082 Electrostatic Classifier and 3750 Condensation Particle Counter): Smallest particle size 10 nm in 2 min
- NO_X Monitor (Teledyne T200): 1 ppbv in 1 min (1σ LoD for NO_2)
  1 ppbv in 1 min (1σ LoD for NO)
- O_3 Monitor (Teledyne T400): 0.4 ppbv in 1 min (1σ LoD for O_3)
- Temperature Sensor (Vaisala PTU303): –40° C to +60° C, accuracy ± 0.2° C at +20° C in 1 min
- Humidity Sensor (Vaisala PTU303): 0% to 100% RH
- Differential Pressure Sensor (Vaisala PDT102): –50 to +50 Pa, accuracy ± 0.025 Pa at +10 Pa in 1 min
- Pressure Sensor (Vaisala PTU303): 500 to 1100 hPa, accuracy ± 0.20 hPa at 500 – 1100 hPa
- CO_2 monitor (Vaisala GMP 343): 0 to 5000 ppmv, accuracy ± 5 ppmv from 0 to 2000 ppmv in 1 min

Table 1: Custom-made cavity enhanced instruments attached to the IASC. #1 refers to an open-path cavity ring-down (CRD) setup using a tunable UV laser. #2 to #6 refer to open-path broadband cavity enhanced absorption setups with light beams going across the chamber (see Fig. 7). #7 refers to a custom-developed extractive CRD instrument.

#	λ [nm]	Reflectivity of mirrors	Target species	Integration time [s]	Cavity length [cm]	1σ LoD
1	308	0.9995	OH	10	400	
2	355-395	0.9995	NO_2 HONO	60	400	~200 pptv ~250 pptv
3	435-465	0.99998	$(CHO)_2$	20	400	~40 pptv
4	630-680	0.999993	NO_3	10	400	~1 pptv
5	940-1100	0.999	H_2O ...	60	400	~340 ppbv
6	1260-1700	0.999	CO_2, H_2O ...	60	400	~3 ppmv, ~10 ppbv
7	405	0.99997	NO_2	3	45	~50 pptv

The IASC features a server (18 TB) plus network that creates a uniform time stamp for all workstations and devices, it collects and manages data centrally in the Centre for Research into Atmospheric Chemistry. It also stores data from an outdoor sun photometer and CRAC's weather mast. Work is in progress to consolidate all data into structured files (HDF5) for cloud storage and publication in open access repositories.

Examples of Trace Gas Detection

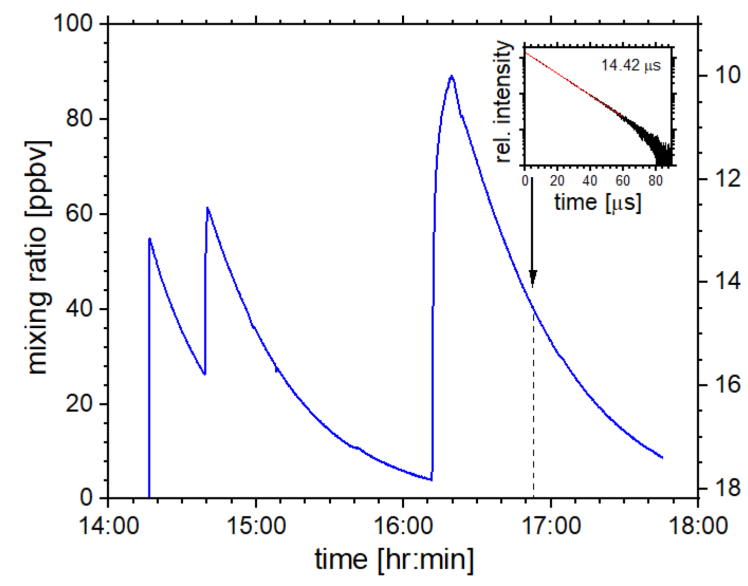

Figure 8: Temporal variation of NO_2 mixing ratios measured using a custom-developed extractive cavity ring-down spectrometer (#7). The inset shows a typical ring-down signal on a semi-logarithmic scale at 16:52 hrs (5 Sept 2023).

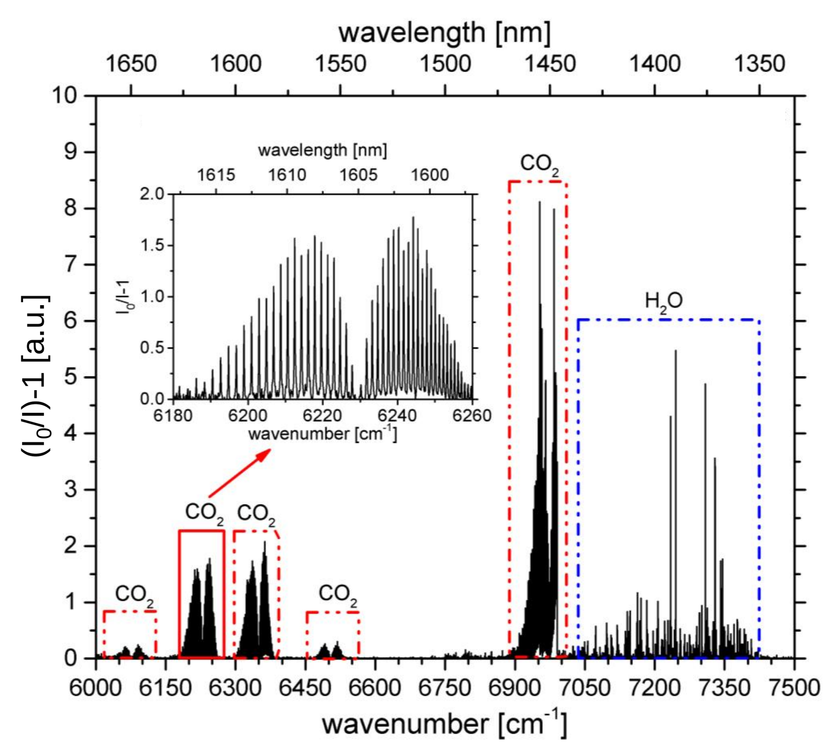

Figure 9: Absorption spectrum in the region between 6000 and 7500 cm^{-1} using a Fourier Transform Incoherent Broad-Band Cavity Enhanced Absorption Spectroscopy (FT-IBBCEAS) setup (channel #6). Ro-vibrational absorption features of CO_2 and H_2O are shown in the red and blue dashed rectangles respectively. The inset shows a magnified view of the CO_2 band in the limits of the red solid rectangle. Measured on 9 Mar 2023 (10:35 hrs). Spectral resolution 0.08 cm^{-1}.

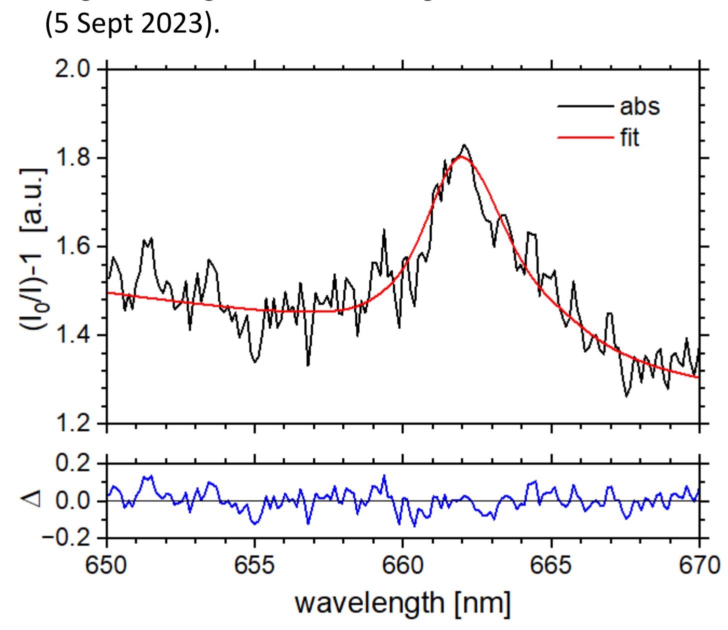

Figure 10: Absorption spectrum (black trace) of NO_3 measured using Incoherent Broadband Cavity Enhanced Absorption Spectroscopy (IBBCEAS) (channel #4). A fit to the data (red trace) is based on singular value decomposition. The absolute fit residuals (blue trace) are shown in the lower panel. The absorption is based on ~2 pptv of NO_3 measured in 10 s. Measured on 5 Sept 2023.

Conclusion

The Irish Atmospheric Simulation Chamber (IASC) [2], initially funded through an SFI research infrastructure grant (15/RI/3209), has been further developed as part of the Research Frontier Award (21/FFP-A/8973) "Ultra-sensitive cavity-enhanced trace gas detection for new atmospheric science and socio-economic impacts" in the Centre for Research into Atmospheric Chemistry (CRAC) at UCC. It enables detailed investigations of a wide range of atmospheric processes including chemical reactions of radicals, volatile organic compound (VOC) oxidation, secondary pollutant formation, as well as aerosol formation and ageing in day and night cycles. The IASC is an internationally recognized facility and enables involvement in European research and training networks such as EUROCHAMP-2020, ATMO-ACCESS and the ESFRI ACTRIS. The facility has unique capabilities which make it attractive to the international research community as well as private sector users. The versatile and highly instrumented nature of the infrastructure makes it an ideal test bed for the development, testing and benchmarking of new atmospheric monitoring technologies and sensors under controlled (not field) conditions. Collaborations with industry and high profile international atmospheric scientists has been established and is further envisaged.

References

[1] A. Leskinen et al., Characterization and testing of a new environmental chamber, Atmos. Meas. Tech. **2015**, 8, 2267-2278.
[2] J.F. Doussin et al., A practical guide to atmospheric simulation chambers, Springer **2023.**

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