Dr Nicola Black
Fraunhofer UK (Centre for Applied Photonics)

Impurity Detection in CCUS: Opportunities with Emerging Photonic Technologies

Measurement Focus Group
10/6/2026

Fraunhofer UK

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Fellowship Host & Partners

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What is Fraunhofer?

The largest organisation for applied research in Europe

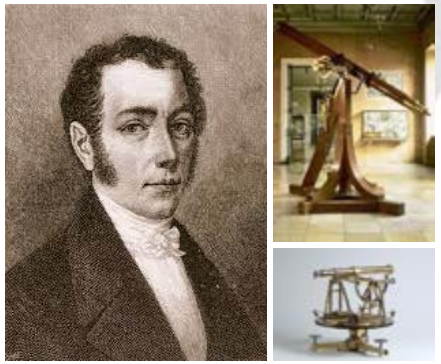
Established in 1949 and named for Joseph von Fraunhofer, instrument maker, astronomer and scientist (1787 – 1826)

76 institutes in Germany with 32,000 employees, increasingly international

Fraunhofer UK Research Ltd is a legally independent affiliate formed in 2012

€3.4 billion annual research budget (2023)

- Roughly 2/3 of this sum is generated through contract research on behalf of industry and publicly funded research projects
- Roughly 1/3 is contributed by government in the form of 'base funding'



Joseph von Fraunhofer

International profile and co-operation

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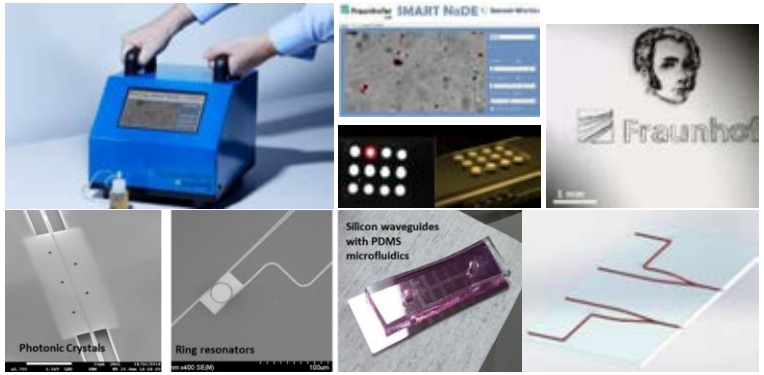
Activity areas and experience

Space, aerospace & defence

- Satellite, drone and aircraft communications
- Airborne inertial navigation
- Earth observation
- Handheld explosives detection

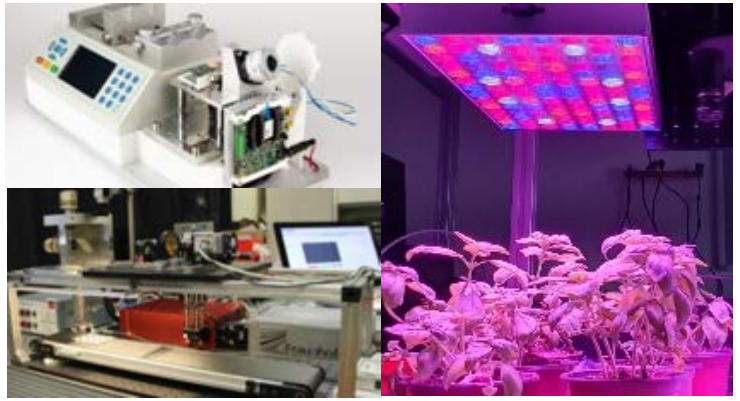
High-value manufacturing

- Particulate-in-oil monitoring
- Advanced lasers and sensors for manufacturing
- Manufacturing of advanced integrated photonics



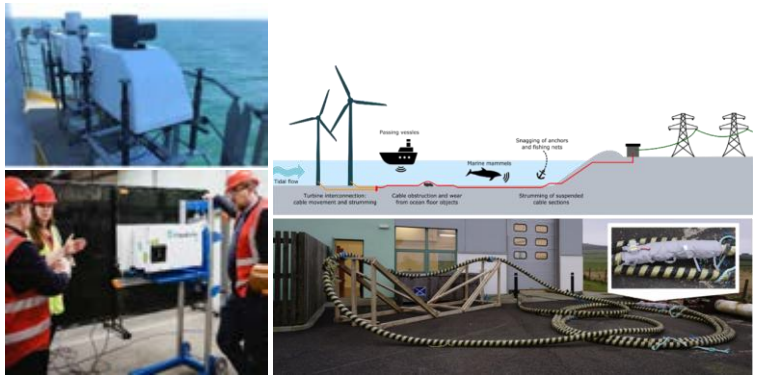
Health, pharma & agritech

- Optimised light for agritech
- Pharmaceutical content authentication
- Diagnosis, phototherapy, biochemical detection



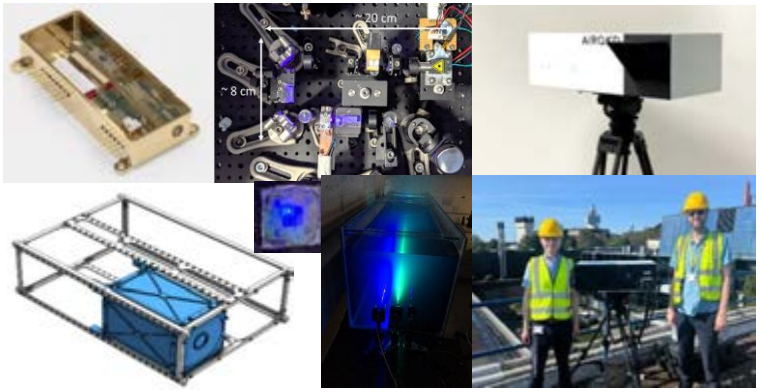
Net-zero

- Wind energy LIDAR
- Off-shore cable monitoring
- Hydrogen detection and imaging
- Satellite LIDAR vegetation monitoring



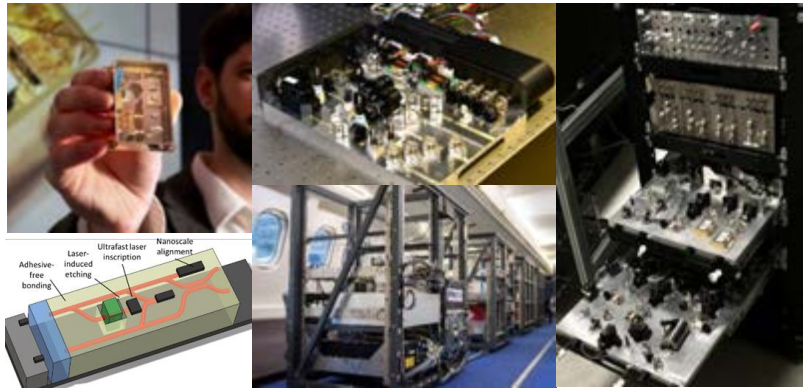
Communications

- Underwater communications and sensing
- Quantum secure comms
- Free-space optical
- Ground, air and space



Precision measurement & computing

- Quantum magnetic and gravitational field measurement
- Quantum inertial navigation and clocks
- Quantum computing
- Single-photon imaging



Fraunhofer CAP as a delivery partner

University

Fraunhofer CAP

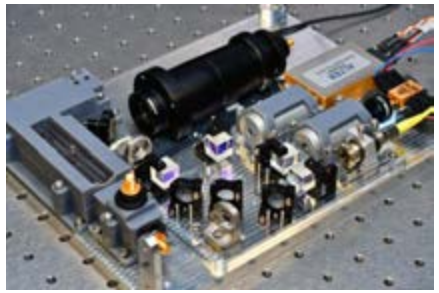
Professional R&D services for industry

Industry (UK)

*TRL indicative only

From laboratory bench-top

To engineered Proof of Concept



To Product

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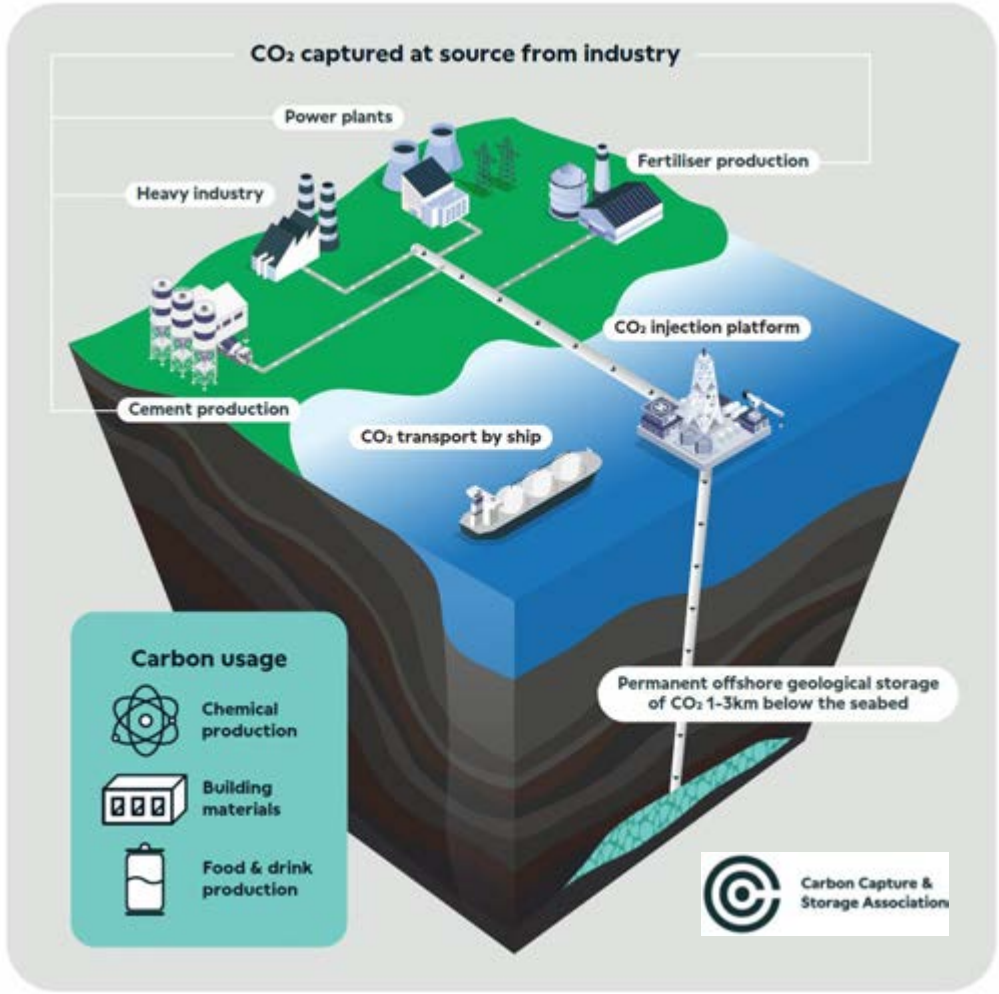
CCS and Pipeline Corrosion

The Impurity Problem



> "CCS is a necessity, not an option" [1]
>
> "We cannot see a route to Net Zero that does not include CCS" [2]
>
> **--Climate Change Committee** (2019 [1], 2025 [2])

- Global market worth £260bn by 2050
- Recycling existing O&G pipeline is the economic choice.
  - Constructing new ~£1bn/100km
  - 2050 corrosion could cost £1.7bn per annum

Trace impurities in CO_2 stream drives pipeline corrosion

State-of-the-art gas impurity analysers

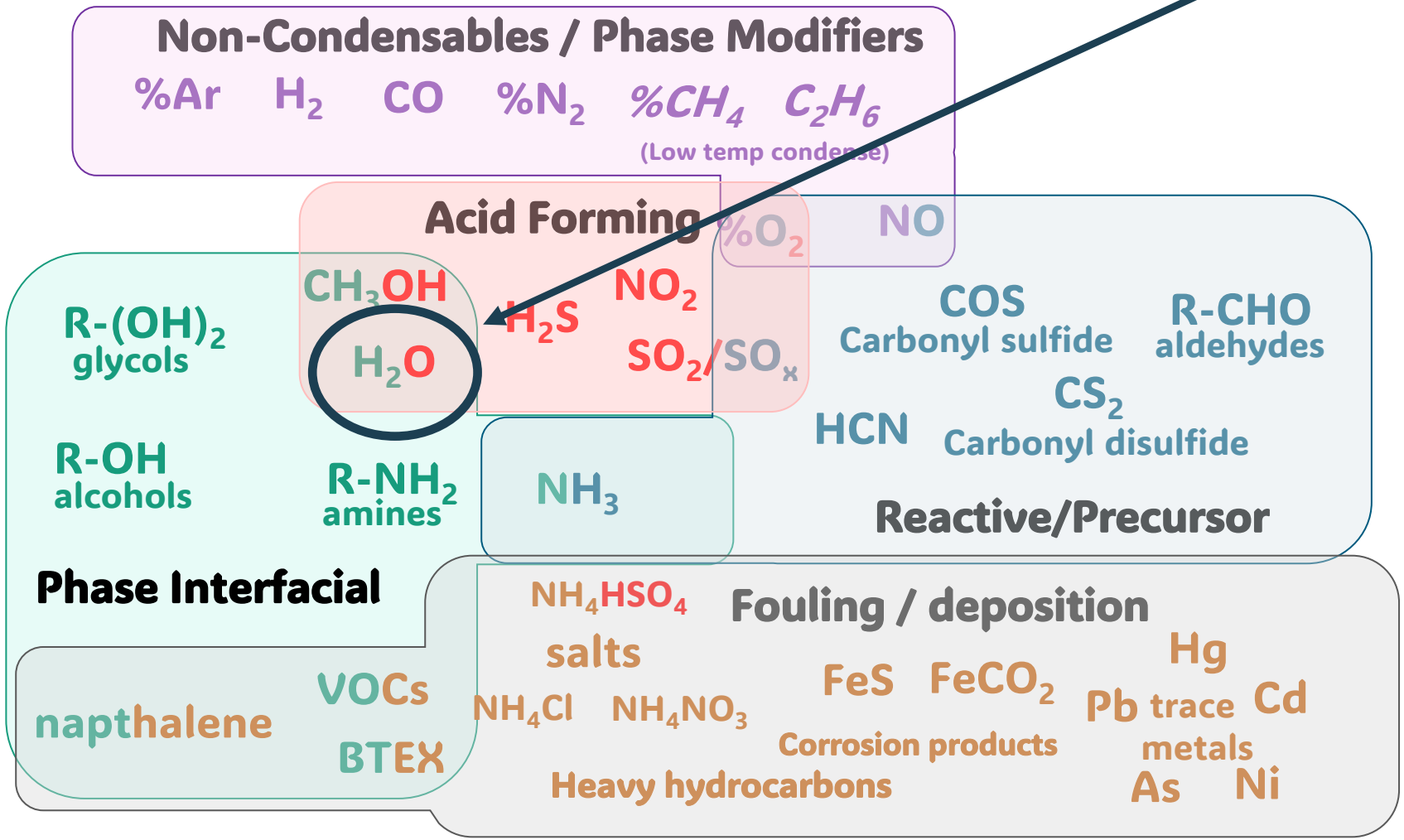
Process Insights		Baker Hughes	ABB	AMETEK	EMERSON	
TIGER[1]	*COSA XENTAUR[5]*	*AURORA[1]*	*OPTIMA[1]*	*5100 HD[1]*	*CT5100[1]*	
PCM 5000[2]	*EXTREL*	*OPTICA[3]*	*MB3000[2]*	*3050 OLV[4]*	Endress+Hauser	*J22[1]*
OPTIDEW[3]	*Max3000[7]*	*MISP2*	*PGC5000[5]*		SIEMENS	*Gasmet[2]*
					Thermo SCIENTIFIC	*MAX-Bev[2]*

Technology basis: *(1)TDLAS, (2)FTIR, (3)CMH, (4)QCM, (5)AlO2, (6)GC, (7)MS*

The CCUS Impurity Landscape

The complexity of impurity pathways

Water is a key contaminant!
Facilitates corrosive chemistry via the aqueous phase.

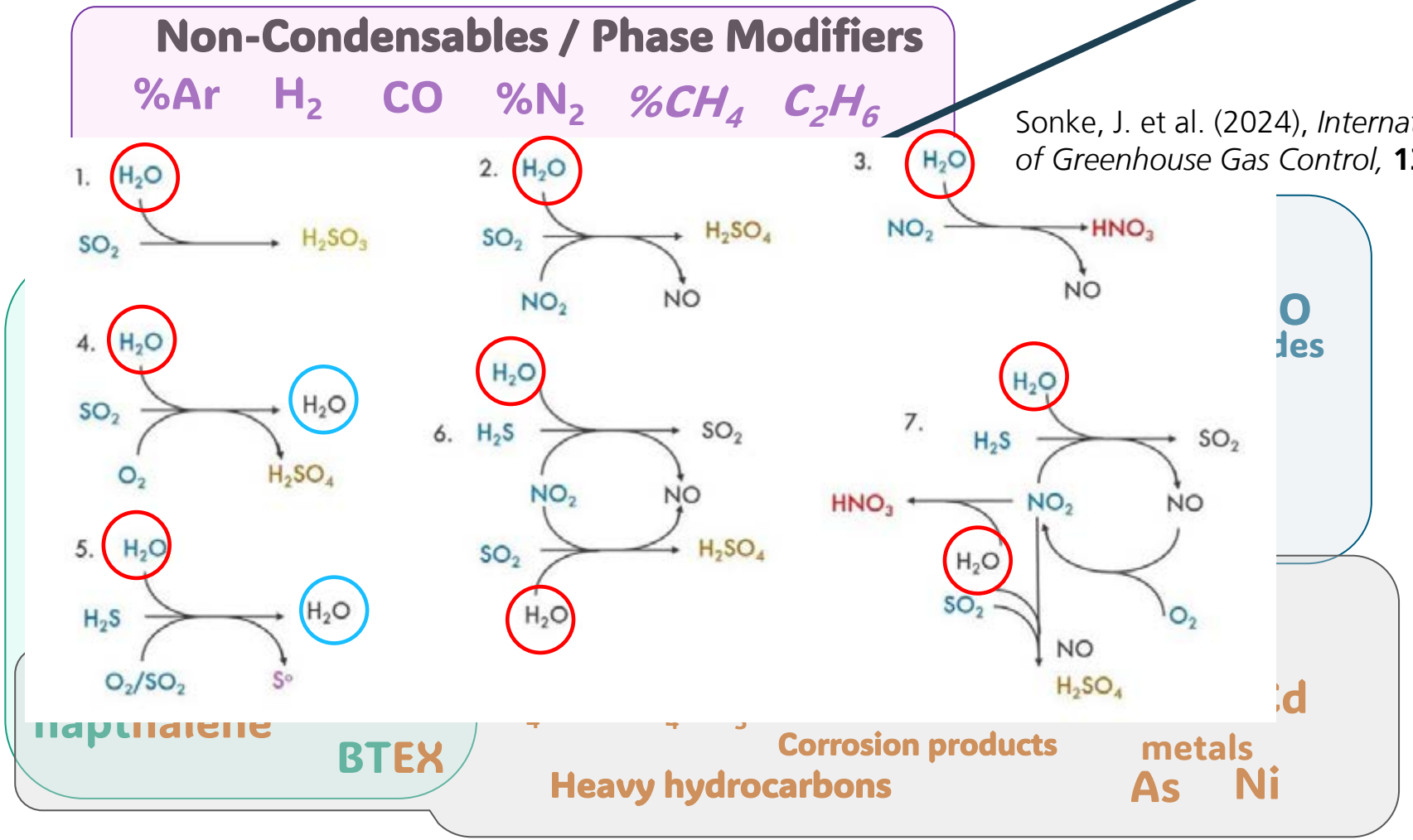


The CCUS Impurity Landscape

The complexity of impurity pathways

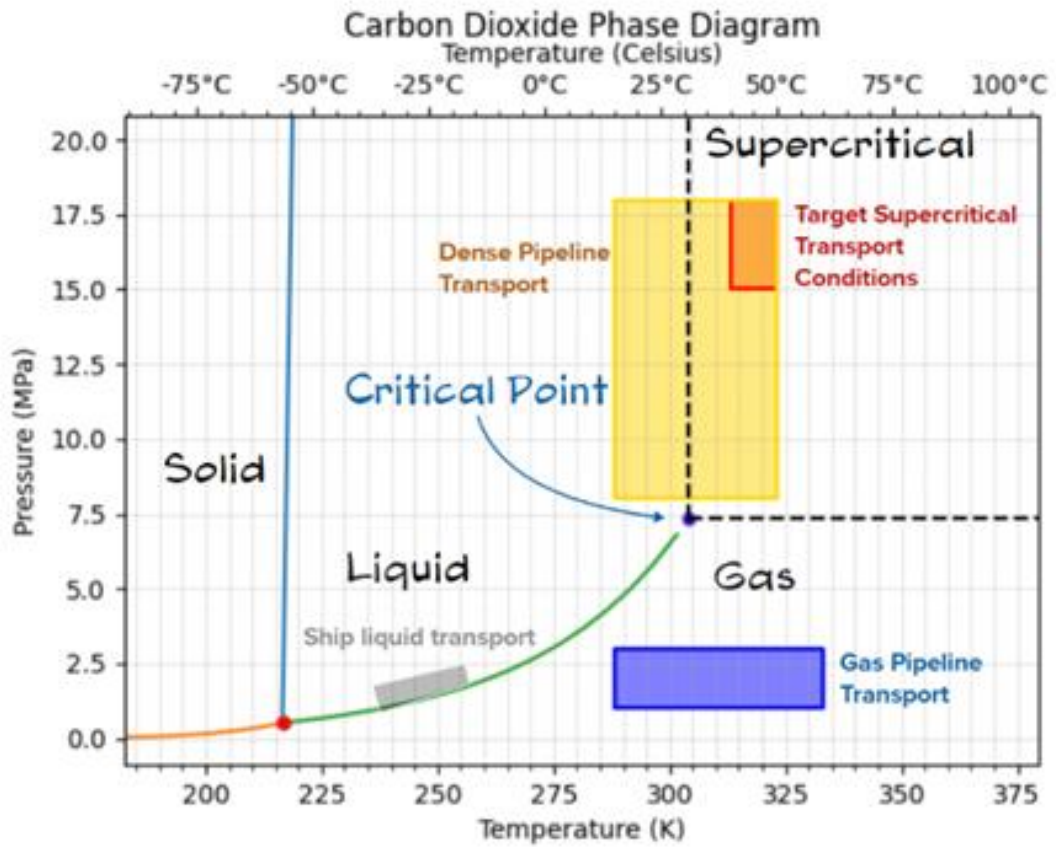
Water is a key contaminant!
Facilitates corrosive chemistry via the aqueous phase.

Sonke, J. et al. (2024), *International Journal of Greenhouse Gas Control,* **133**, 104075.



Thermodynamics and Impurities

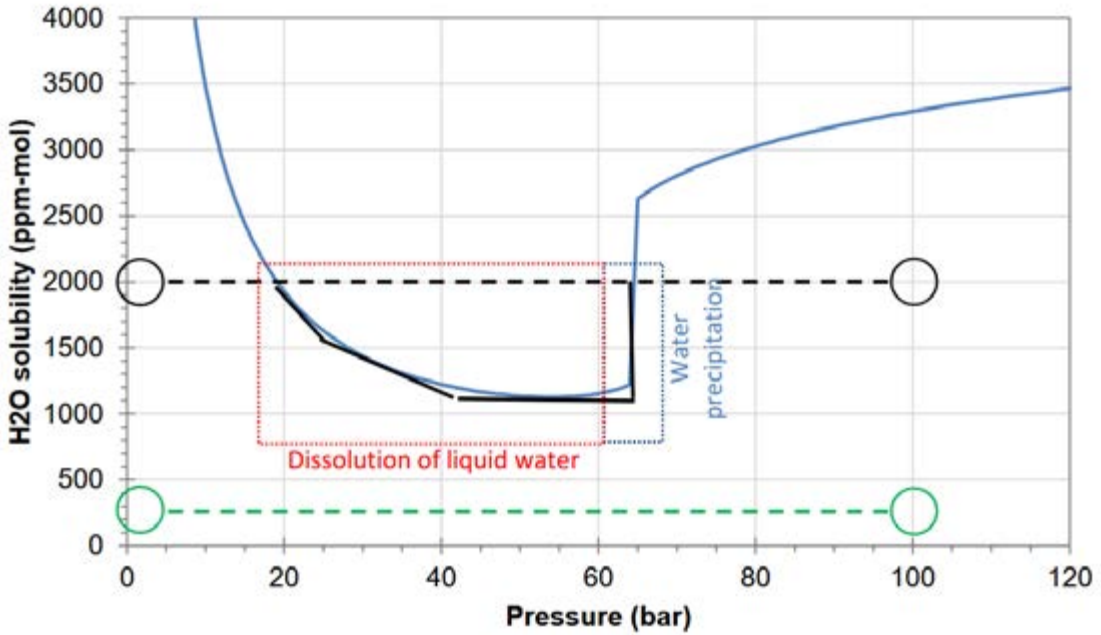
The context of acid-drop out



Solubility limit of water is dependent on

- the CO2 phase (PT)
- the concentration of other impurities present

Water interacts with other impurities that present many complex impurity pathways



Morland, B H., et al. (2021), *Processes* **9**, 4, 570.

Can we innovate analysers to measure impurities in the dense/ super-critical phase?

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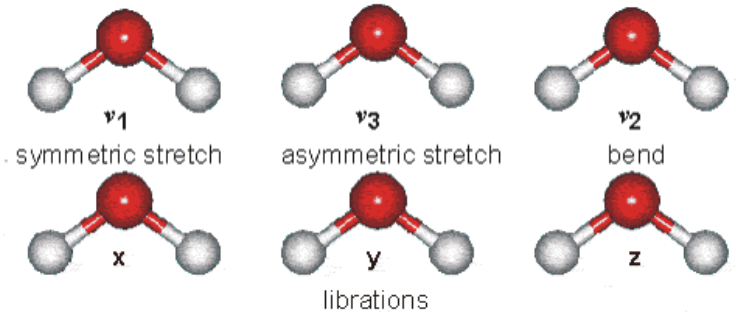
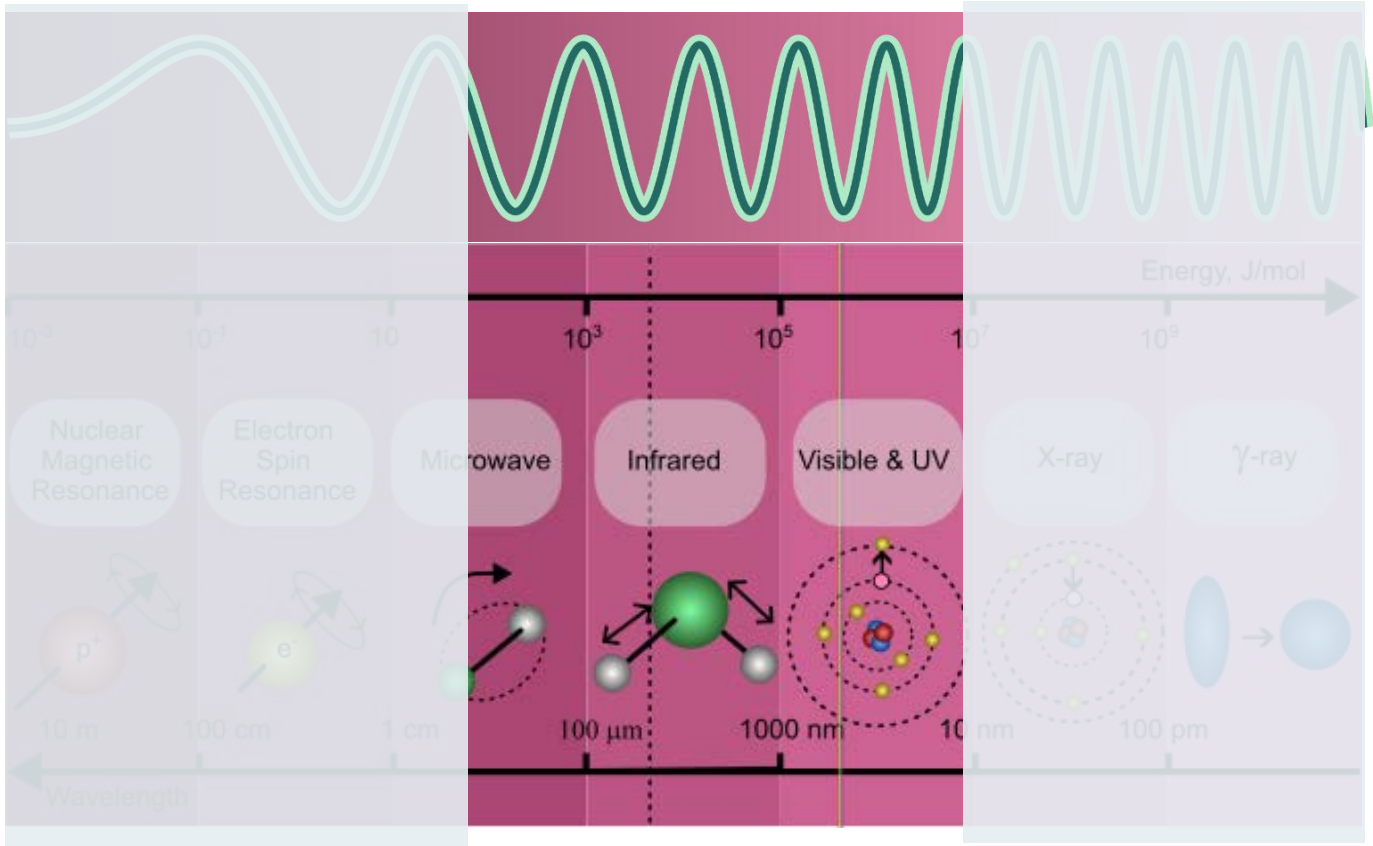
Photonics and Spectroscopy of Impurities

Raman and IR Spectroscopy

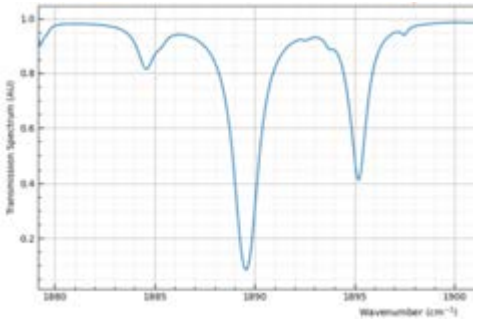


Electromagnetic Spectrum:

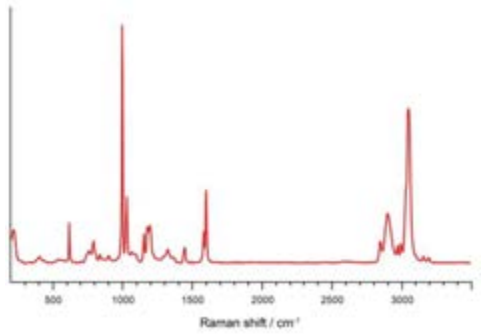


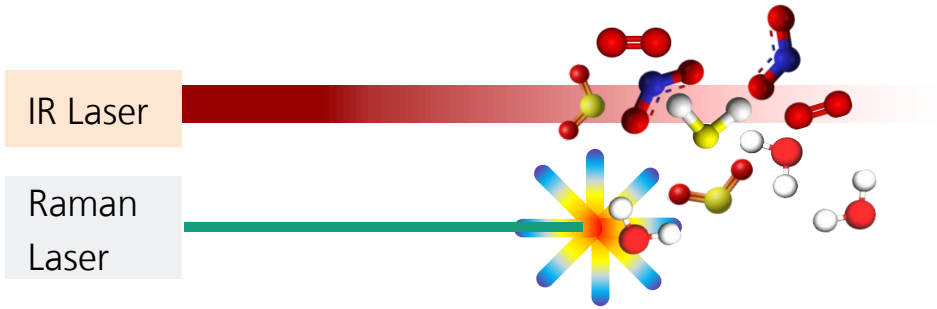
"Photonic Technology Window"

IR Transmission



Raman Scattering





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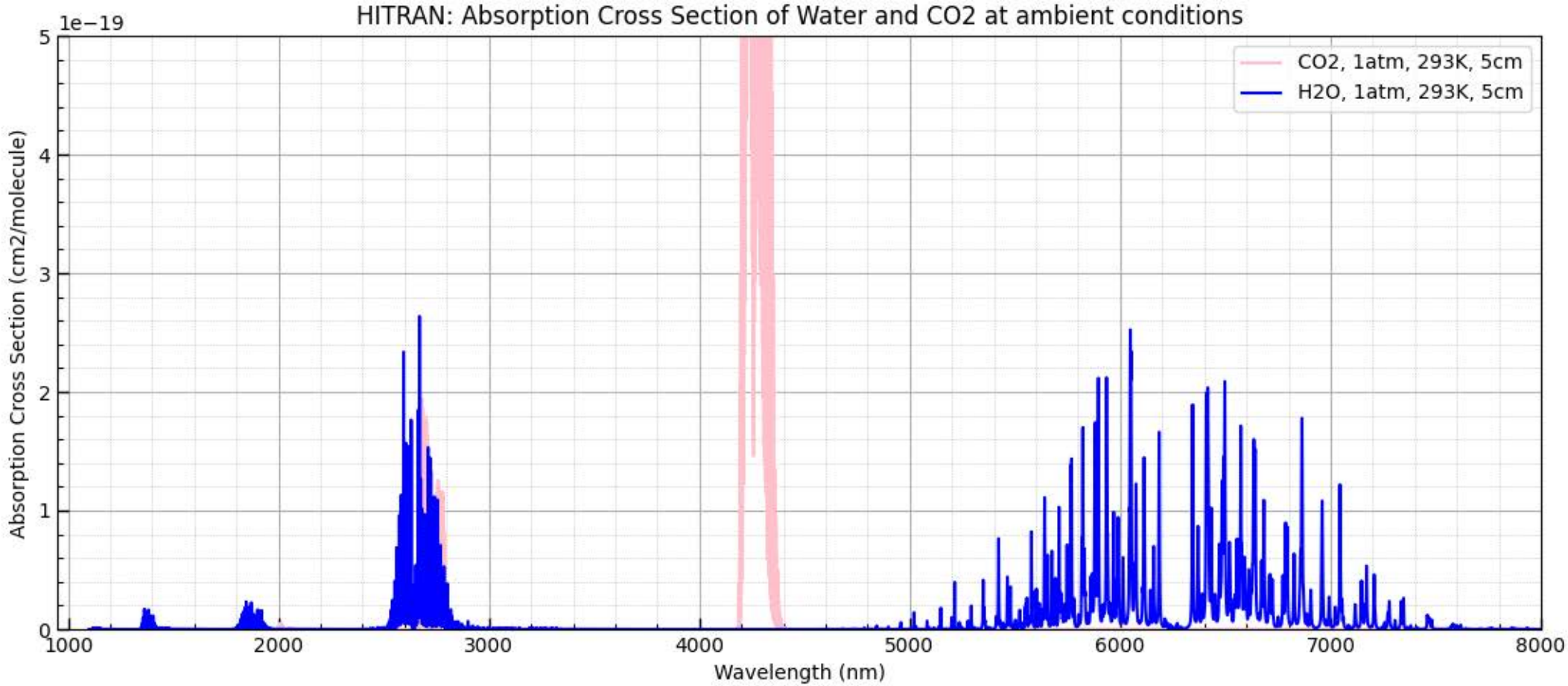
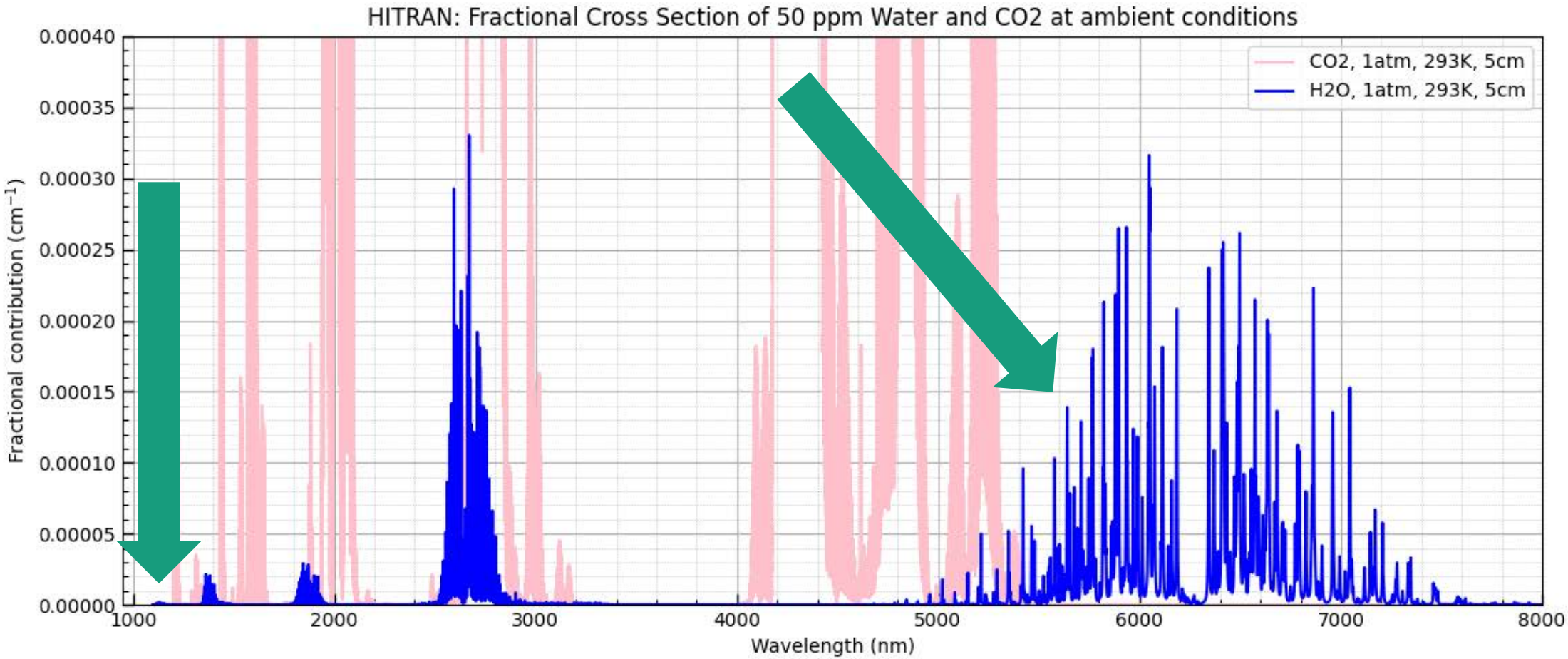
HITRAN: Ambient Conditions

Absorption Cross Sections of Water and CO2



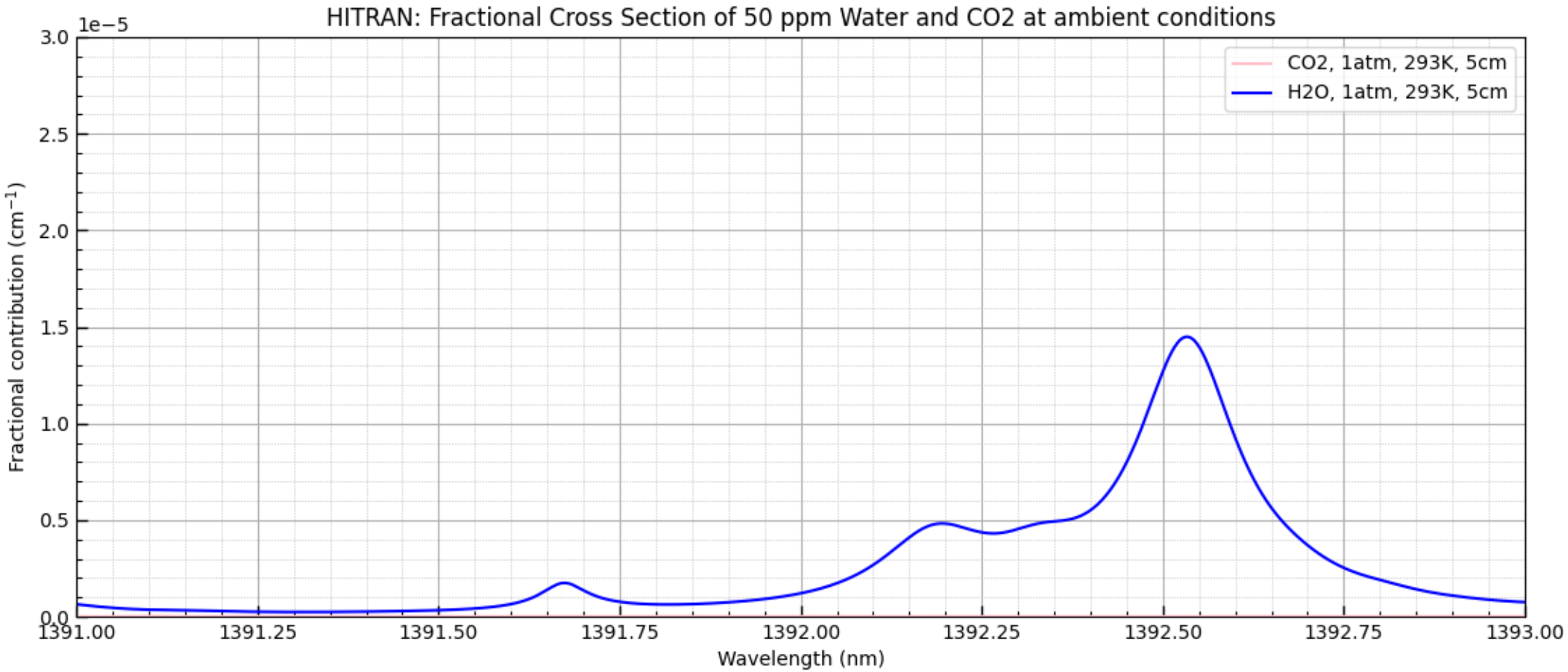
HITRAN: Ambient Conditions

Fractional Cross Sections of Water and CO2



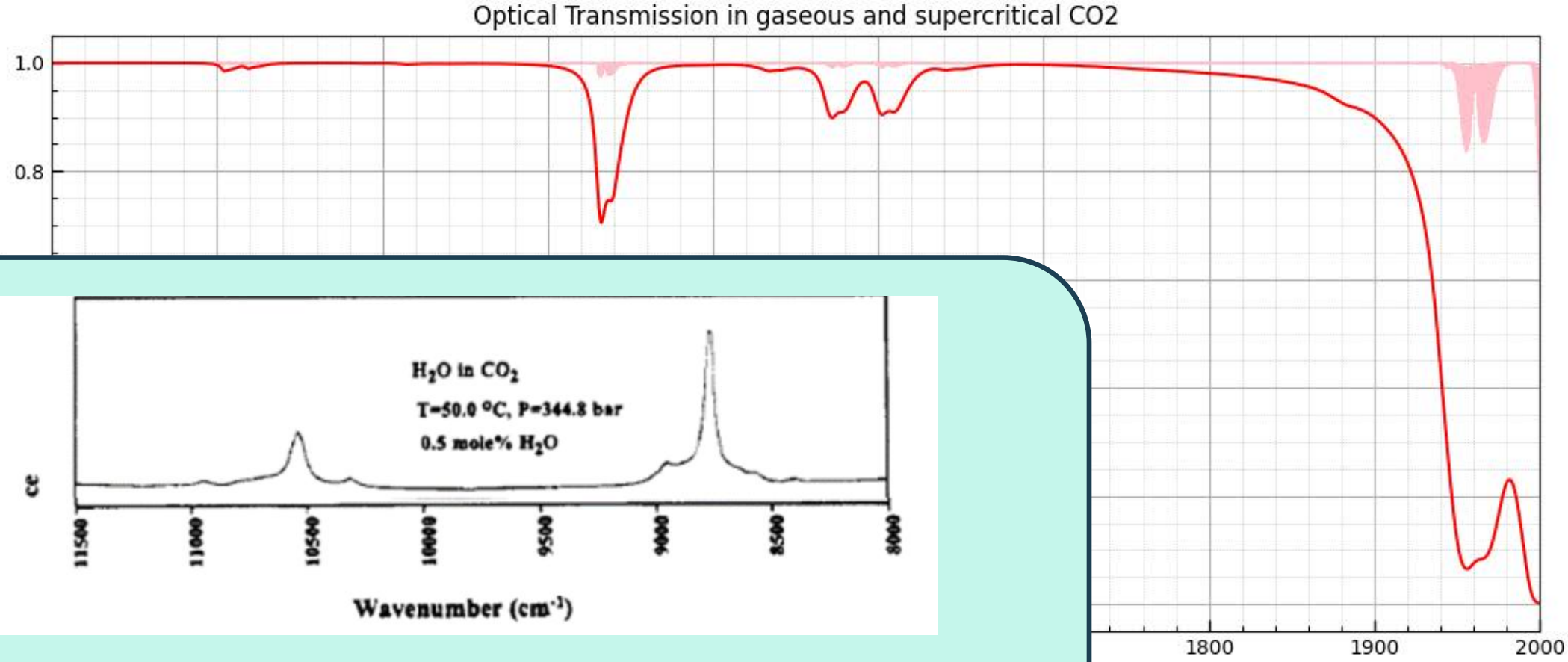
HITRAN: Ambient Conditions

Fractional Cross Sections of Water and CO2 of representative instrument



HITRAN: Supercritical

The transition from gas analysis to dense phase analysis



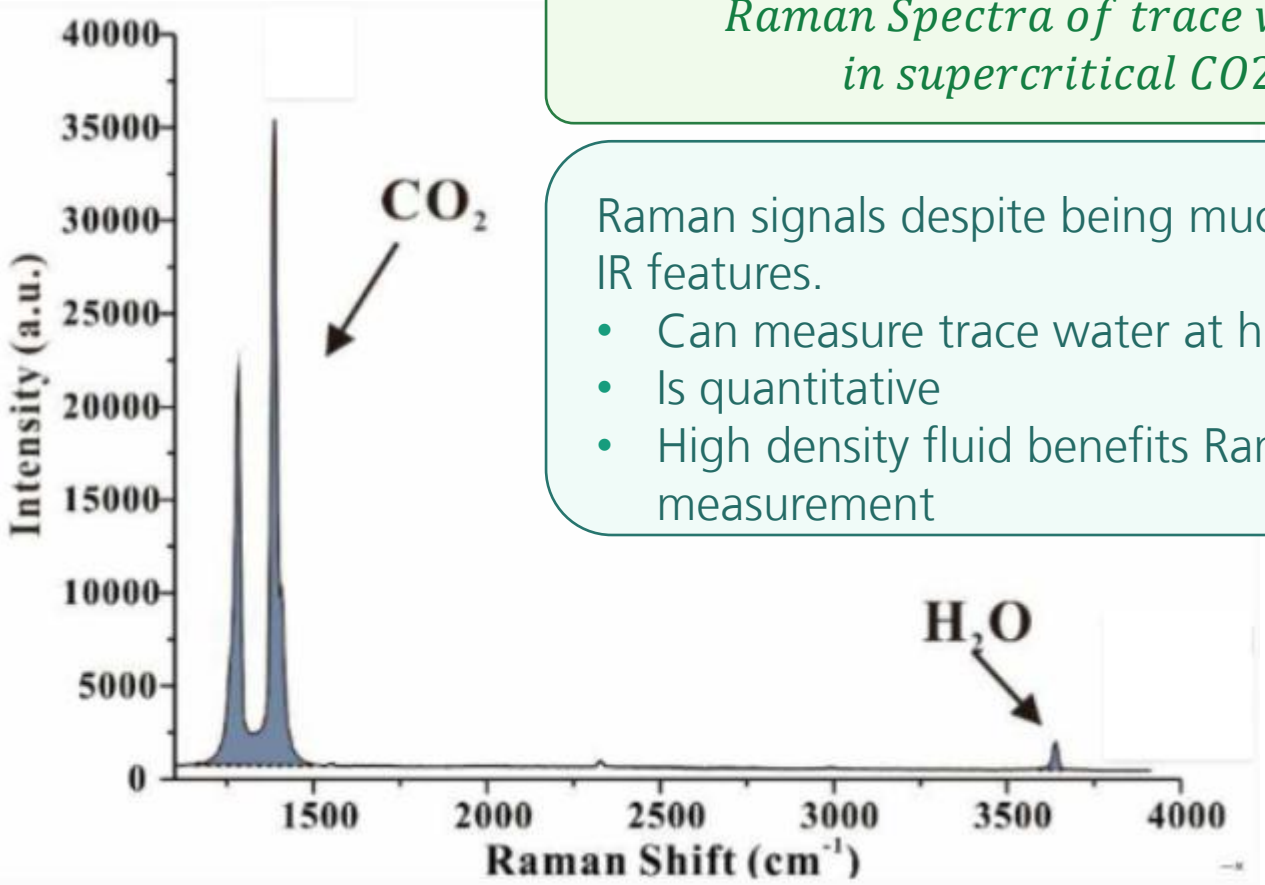
Jackson, K.,(1995) *Analytical Chemistry* **67**, no. 14): 2368–72. https://doi.org/10.1021/ac00110a007.

Raman Spectroscopy in Supercritical CO2

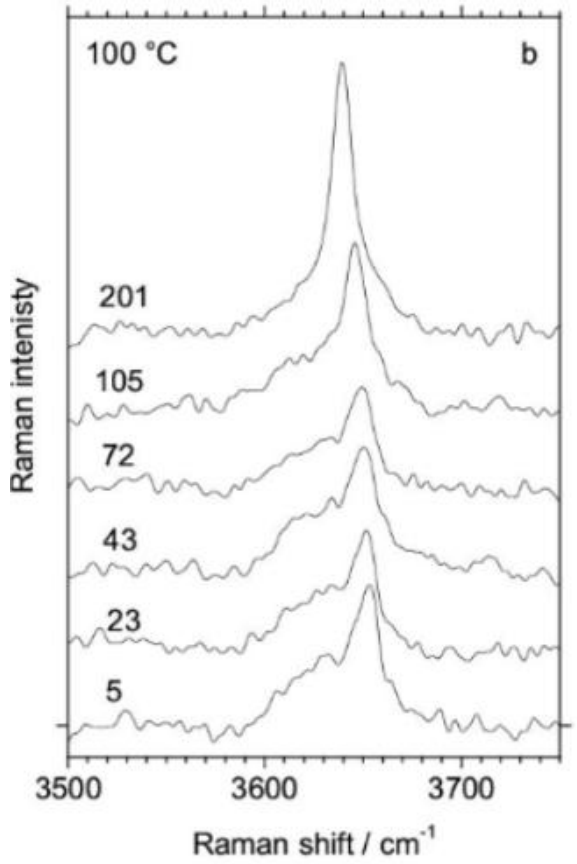
Raman Spectra of trace water in supercritical CO2

Raman signals despite being much weaker than IR features.

- Can measure trace water at high pressure
- Is quantitative
- High density fluid benefits Raman measurement



Wang, Z., (2018) *Fluid Phase Equilibria* **476**: 170–78. https://doi.org/10.1016/j.fluid.2018.08.006.



Caumon, M., (2016), *International Journal of Greenhouse Gas Control* **47,** 63–70. https://doi.org/10.1016/j.ijggc.2016.01.034.

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Innovating Impurity Analysers

Future Leader's Fellowship Road Map

Commissioning High Pressure Optical Measurement Lab

- 200 bar, 100C
- Impurity concentration control (ppm range now, ppb future)
- Corrosion Resistant Materials

Work Packages

2026 | 2027 | 2028 | 2029 | 2030

1. Moisture Analyser Development
   - Design Phase
   - Gas Phase Analyser
   - Dense Phase Analyser
2. Analyser Validation
   - Impurity Rig
   - Internal & External Validations
3. EOS & Chemistry
   - Impurity-EOS model validation
4. Smart Infrastructure
   - Dashboard Demo
5. Multicomponent Monitoring
   - Design Phase
   - Validation

- Prototype Moisture Analyser
- Digital twin and EOS corrosion chemistry model
- Breadboard multi-component impurity analyser

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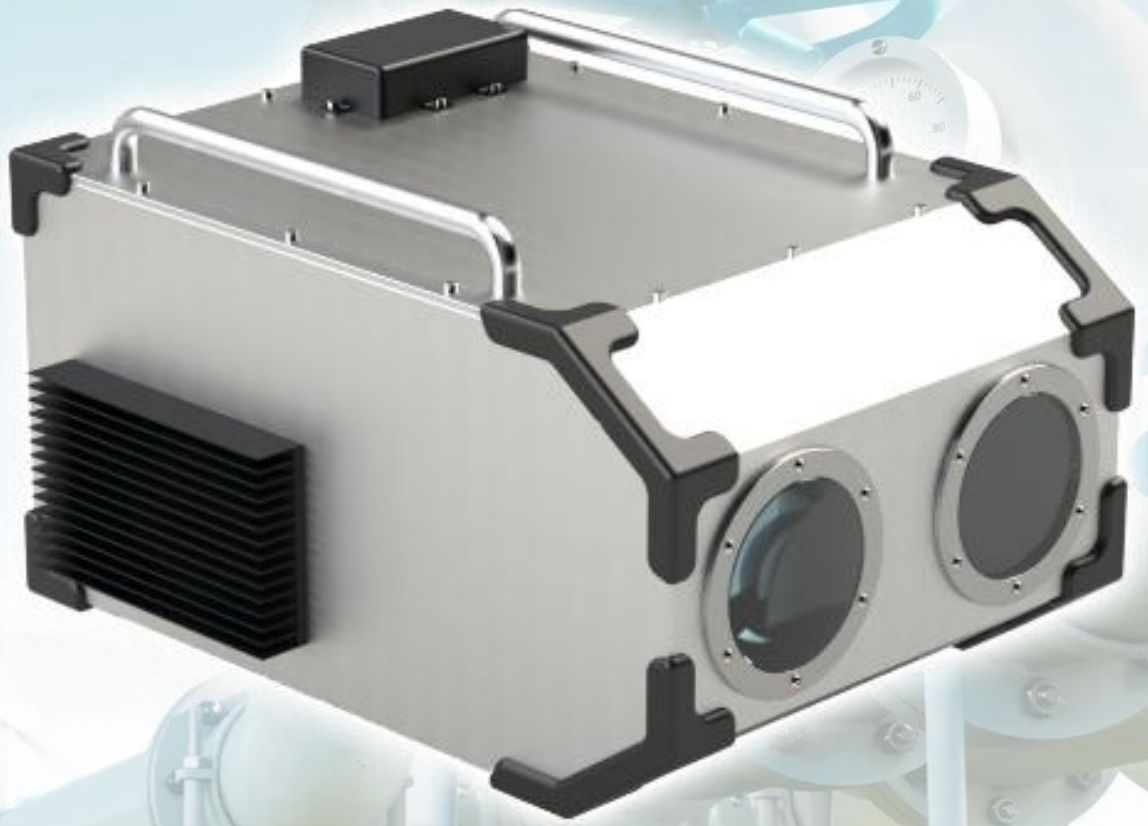
HYDRI: Enabling the H_2 supply chain



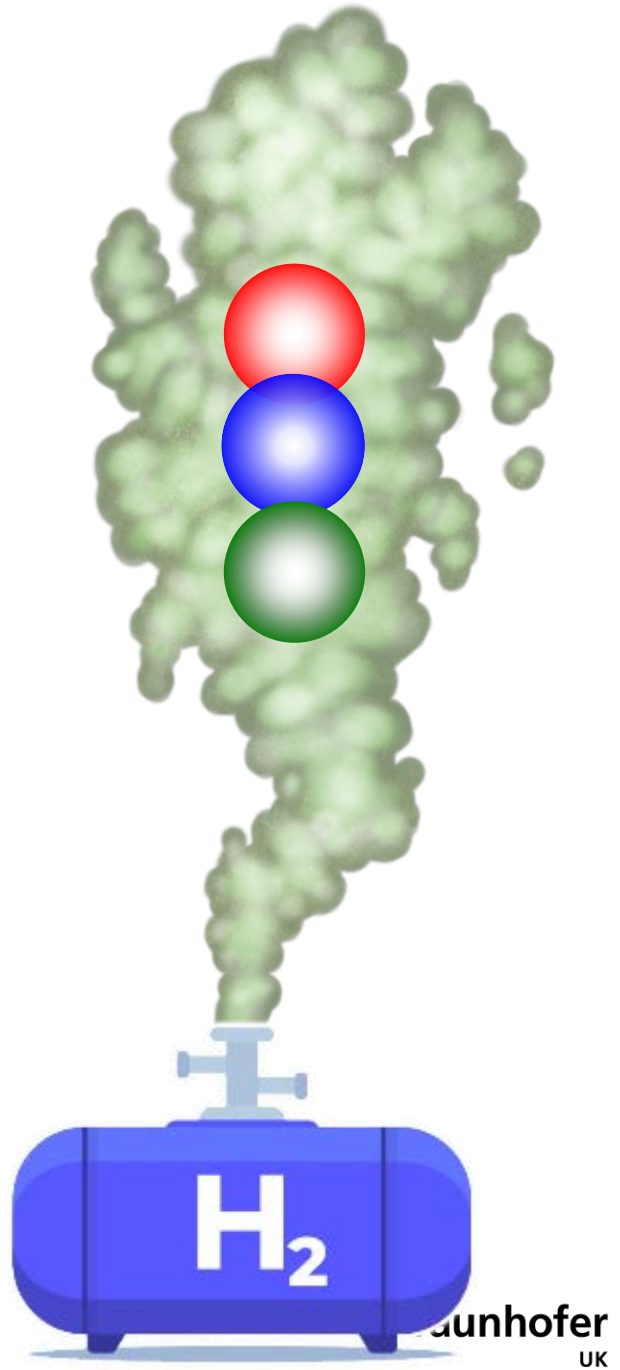
Roman Spesyvtsev, Stuart Bennett, Craig Hunter, Anthony Ojo, John Leck, Andrew Gardner & David Stothard

'Quantum' Raman Spectroscopy

PHOTON ARRIVAL TIME → **POSITION**

PHOTON COLOUR → **COMPOSITION**

PHOTON NUMBER → **CONCENTRATION**



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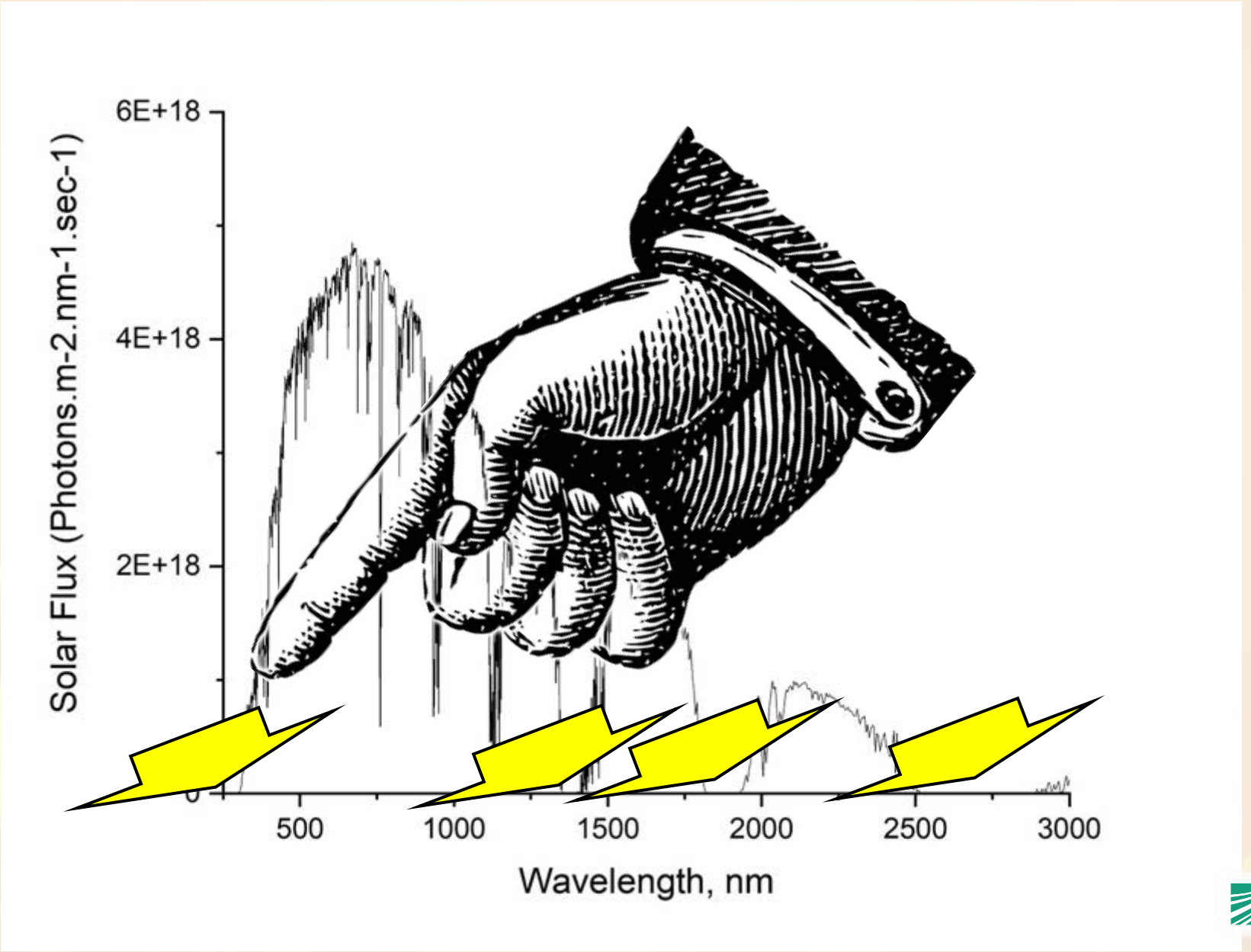
The issue of ambient light



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RAMAN SCATTER

1

RAYLEIGH / MIE SCATTER

BACK-CATTER

~10^3

FLUORESCENCE

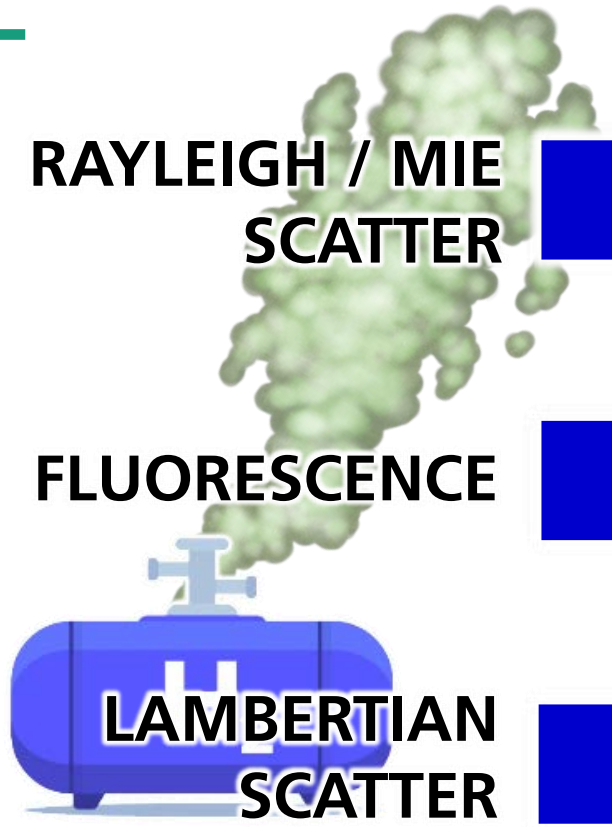
~10^6

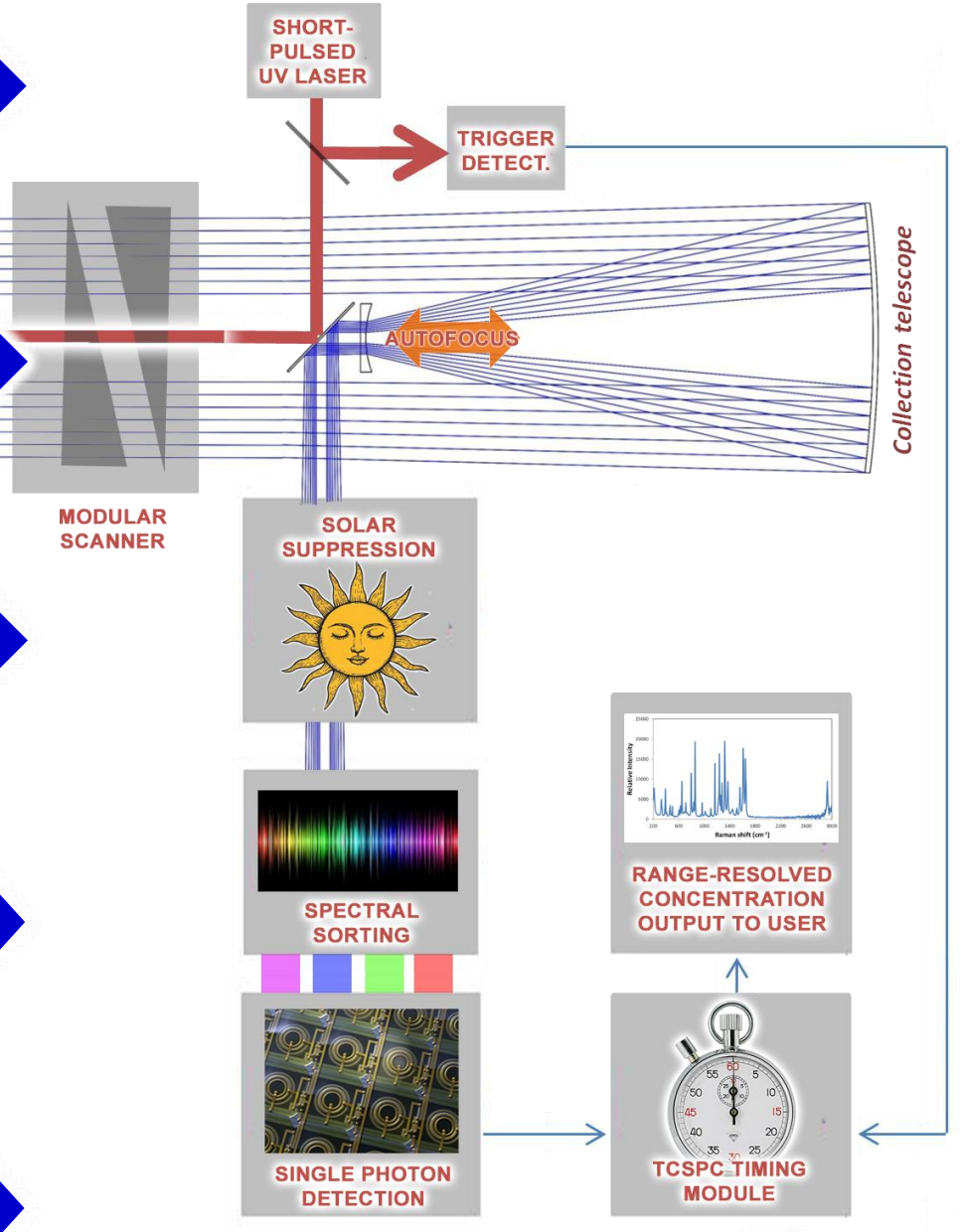
LAMBERTIAN SCATTER

~10^9

SOLAR BACKGROUND

~10^{18}





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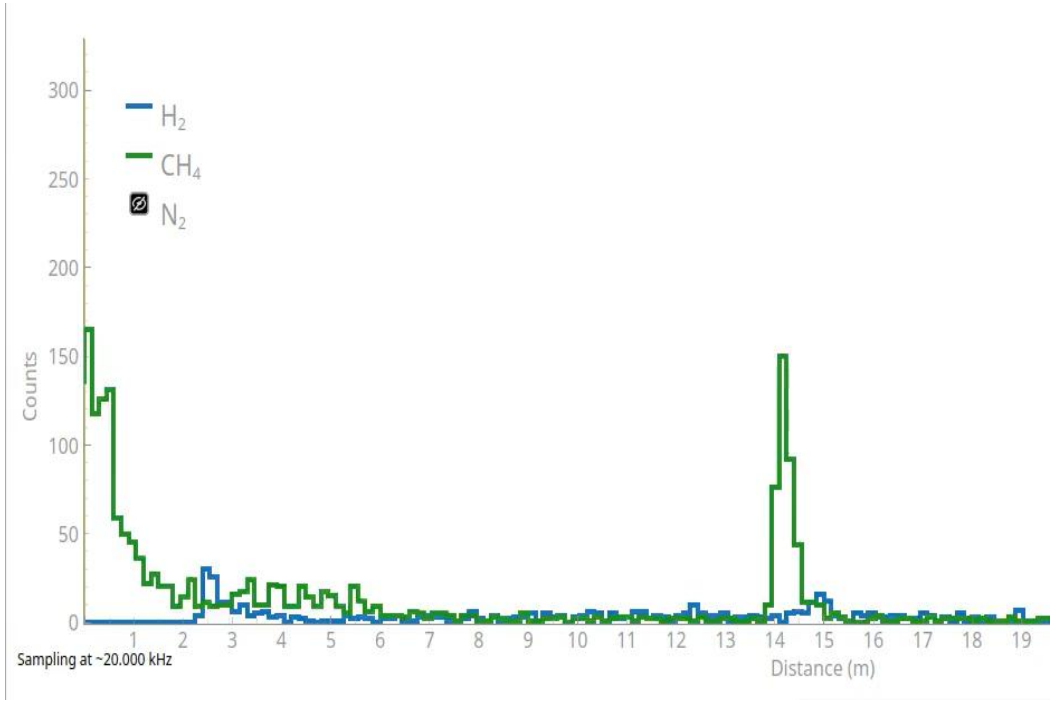
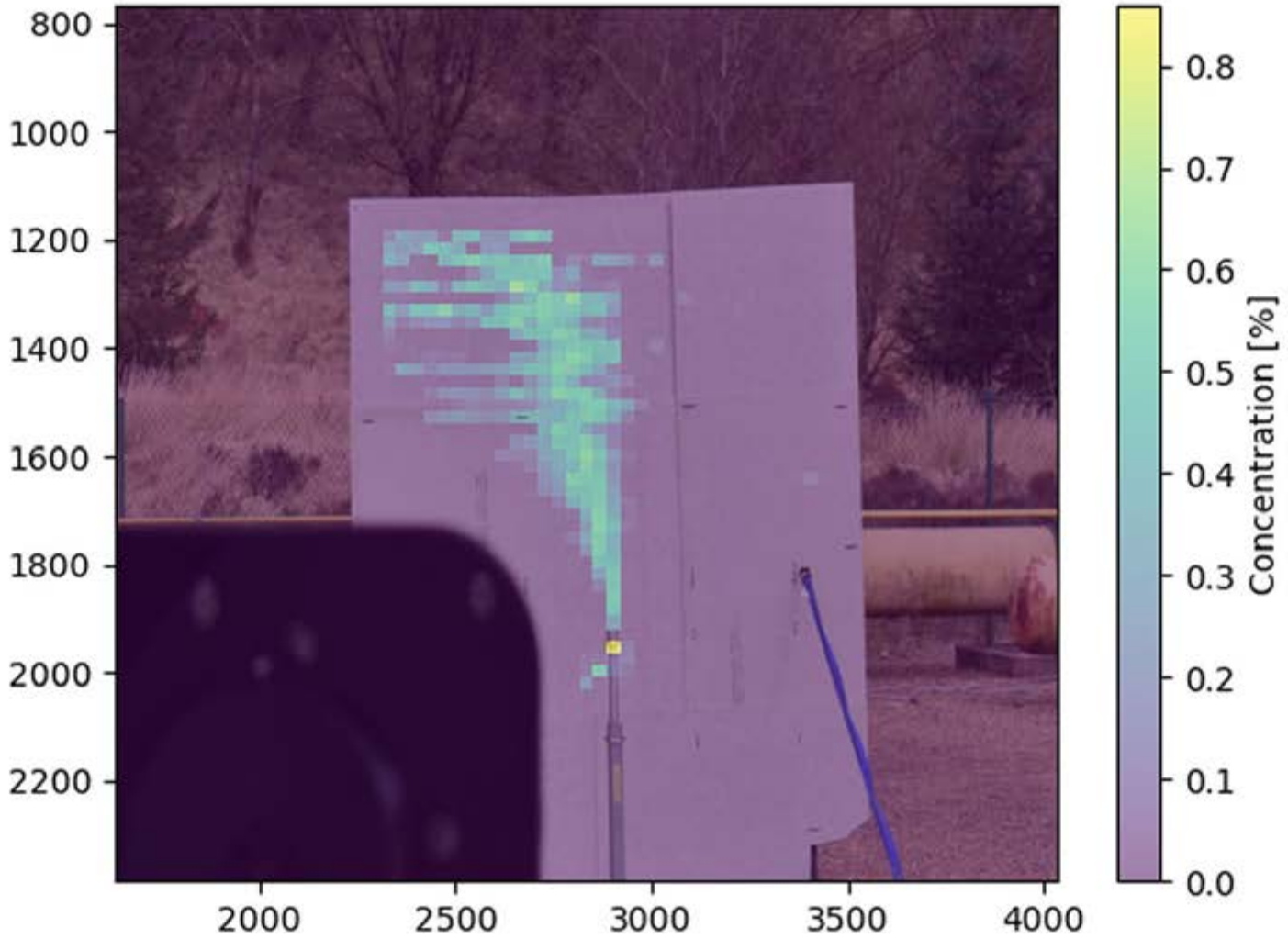
Data overlay





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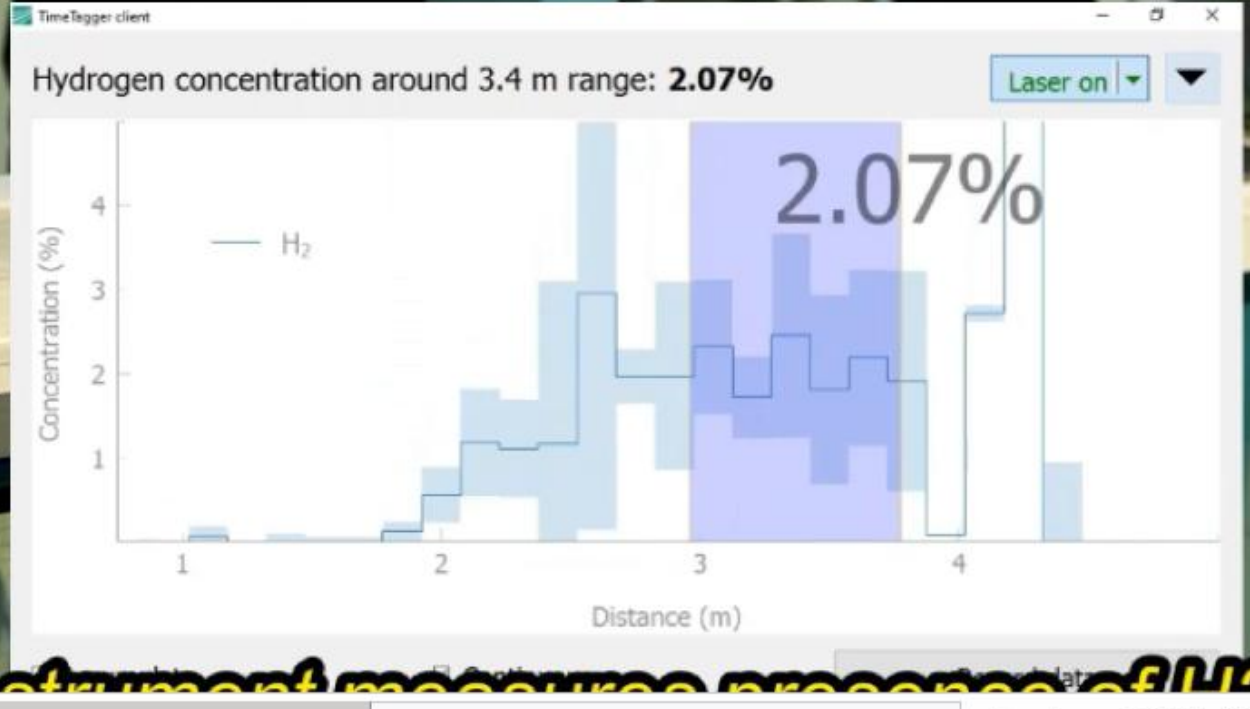
The hand-held concept demonstrator in use

Instrument measuring in H2-rich (2%) environment



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Instrument measures presence of H2

00:15.86

Thank you!
Any Questions