TRIAGE

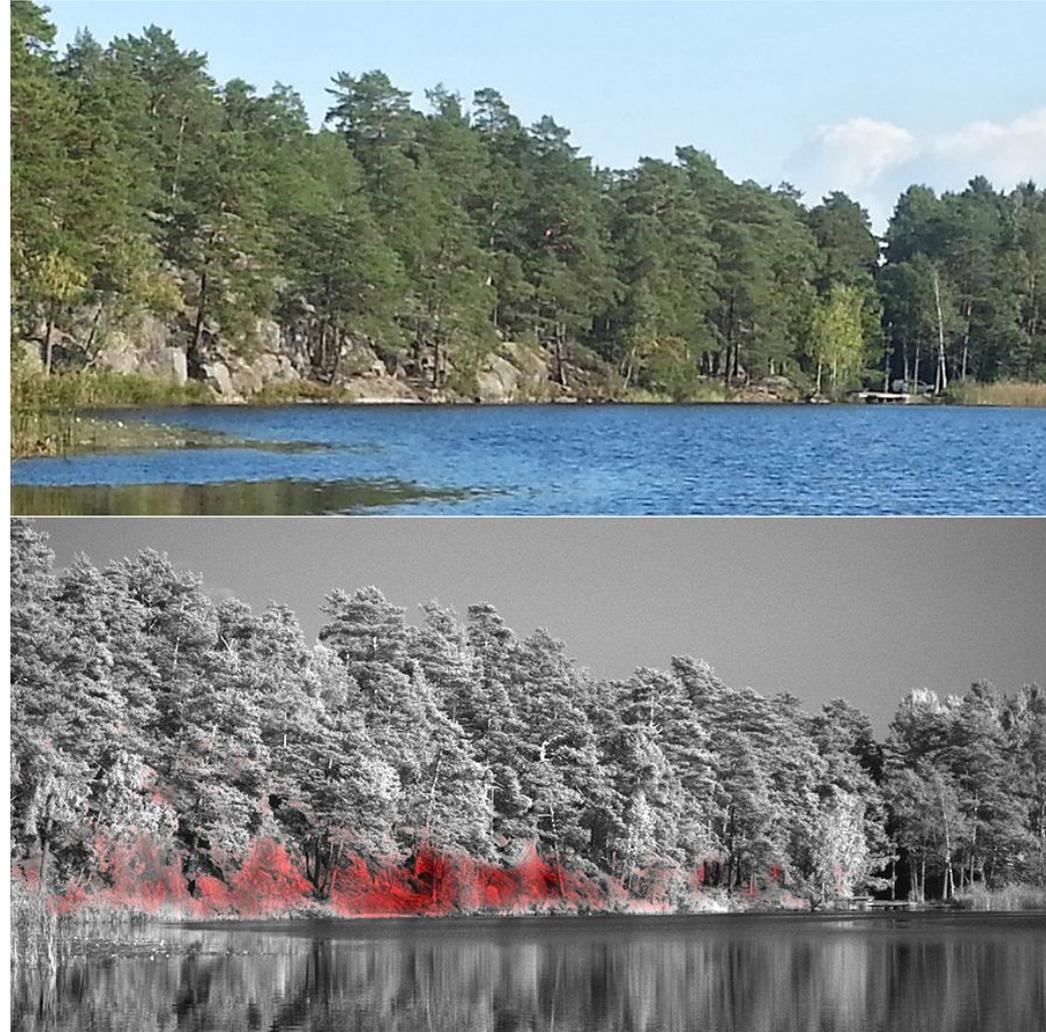# TRIAGE project presentation

Project overview; Jul-2021

- **Objectives**

- Hardware
  - SO1-SO5

- Analysis and machine learning
  - SO6-SO7

- Measurements and demo
  - SO8-SO11

[Image from: Gålfalk *et al.* 2016. Nature Climate Change **6**:426-430.]

TRIAGE

The need for TRIAGE

- Outdoor air pollution is a major health risk factor*
  - 4.2M premature deaths worldwide
  - Contributed to 7.6 % of all deaths

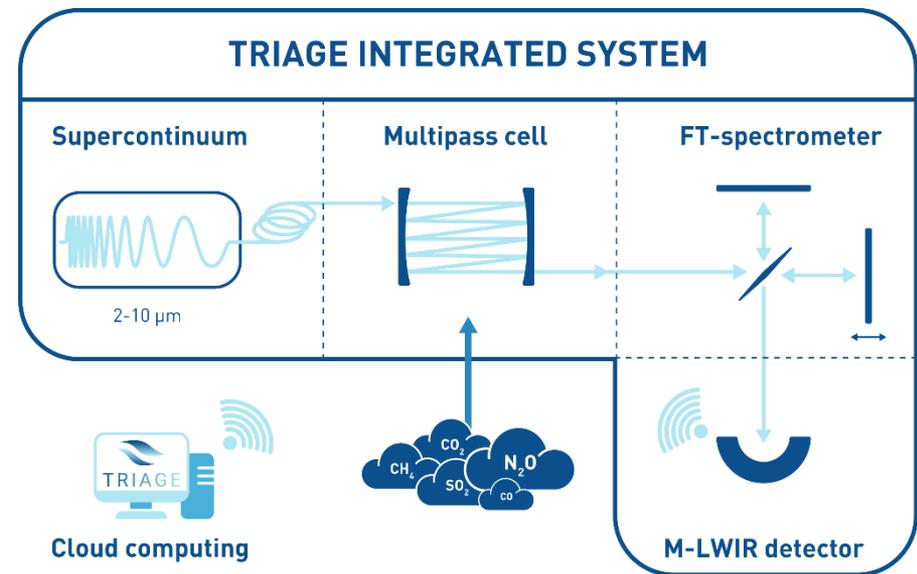- Legislation is rapidly increasing to tackle this problem

- Requirement for better sensors
  - Smart distributed networks
  - Community-based
  - Real-time monitoring and warnings
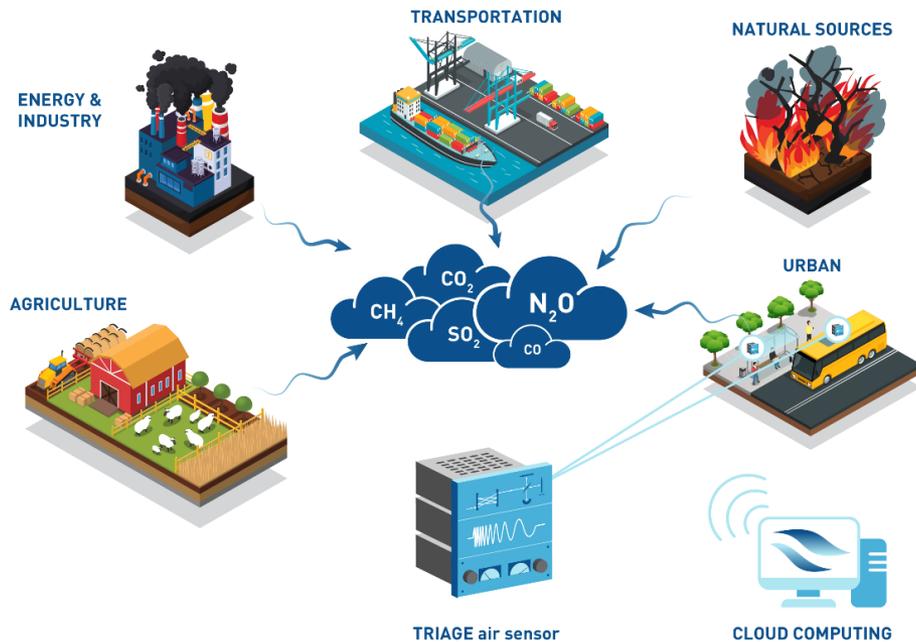
*WHO Fact Sheet, "Ambient (outdoor) air pollution" (2018); https://www.who.int/news-room/fact-sheets

TRIAGE objective O1

- O1 Beyond state-of-the-art real-time air pollution detection using the 2-10 µm wavelength region
- Sub-objectives (SO-)
  - SO1 Mid-IR supercontinuum 2-10 µm source
  - SO2 Multi-pass gas absorption cell
  - SO3 IR detector
  - SO4 Fourier Transform Spectrometer
  - SO5 System integration and validation
  - SO6 Deep learning algorithms for chemometric analysis
  - SO7 Cloud-based data management monitoring systems

TRIAGE INTEGRATED SYSTEM

Supercontinuum · Multipass cell · FT-spectrometer

2-10 µm

Cloud computing · M–LWIR detector

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TRIAGE objectives O2 + O3

- **O2 Field-tests for sensor**
  - SO8 On the rooftop of municipal buildings
  - SO9 On a public transport vehicle

- **O3 Long-term, pervasive air pollution monitoring**
  - SO10 Long-term sensing on the rooftop of municipal buildings
  - SO11 Long-term inventory of emitted pollutants

Rooftop station at Torkel Knutssonsgatan, Stockholm one of the TRIAGE demo sites.

The facility is operated by SLB Analys on behalf of the City of Stockholm Environment and Health Protection Administration.
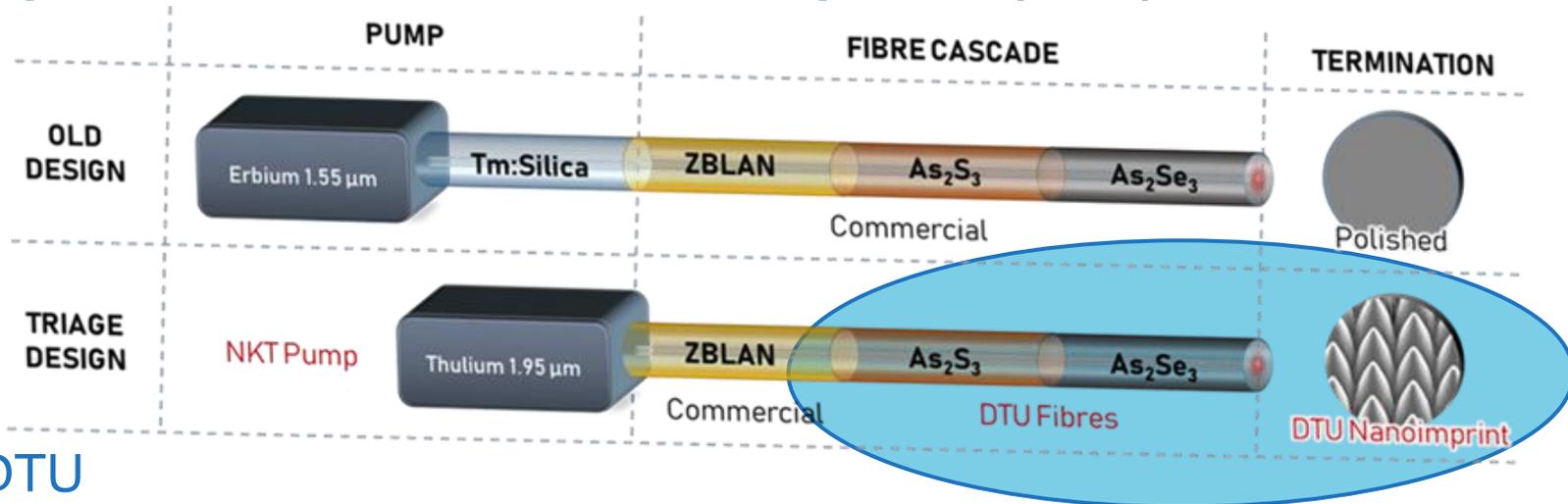
Presentation outline

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  - **SO1-SO5**

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[Image from: Gålfalk *et al.* 2016. Nature Climate Change **6**:426-430.]

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Supercontinuum source development (SO1)

- DTU
  - Chalcogenide fibre design and supercontinuum modelling
  - Chalcogenide fibre fabrication
  - Chalcogenide fibre termination
- NKT
  - Standard 2 μm pump system for initial testing
  - Optimized 2 μm pump for final TRIAGE system
- NORBLIS
  - Two standard laser systems for initial testing with TRIAGE sensor
  - Optimised version with DTU fibres + termination and NKT pump
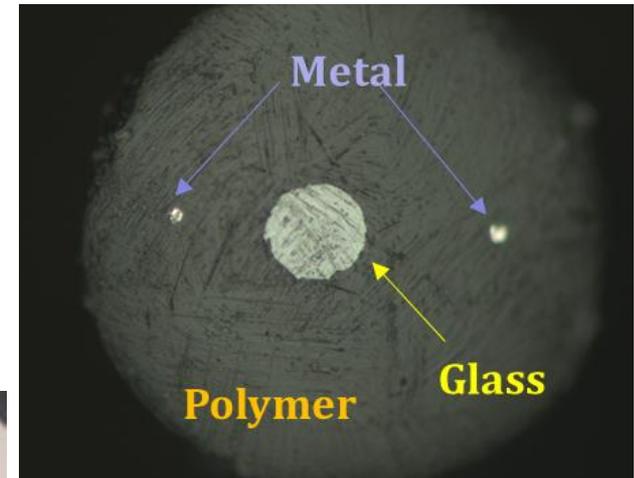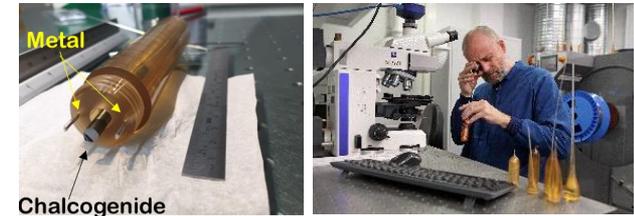
Custom glass and fibre fabrication

Dedicated DTU cleanroom laboratories
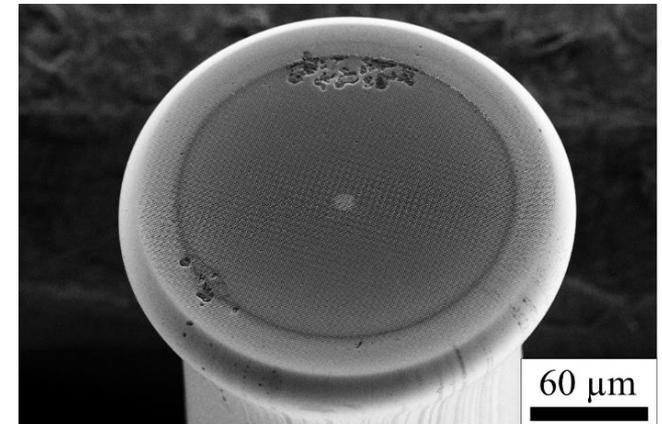
Glass synthesis from raw elements

Preform extrusion and fibre drawing

Metal

Chalcogenide

Metal

Polymer

Glass
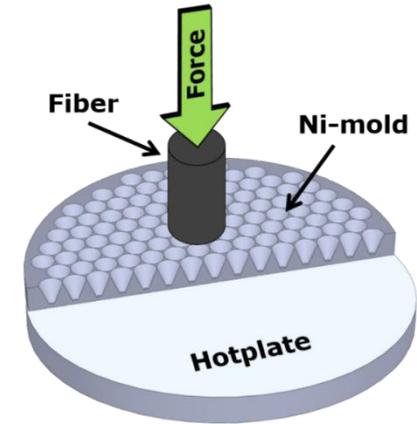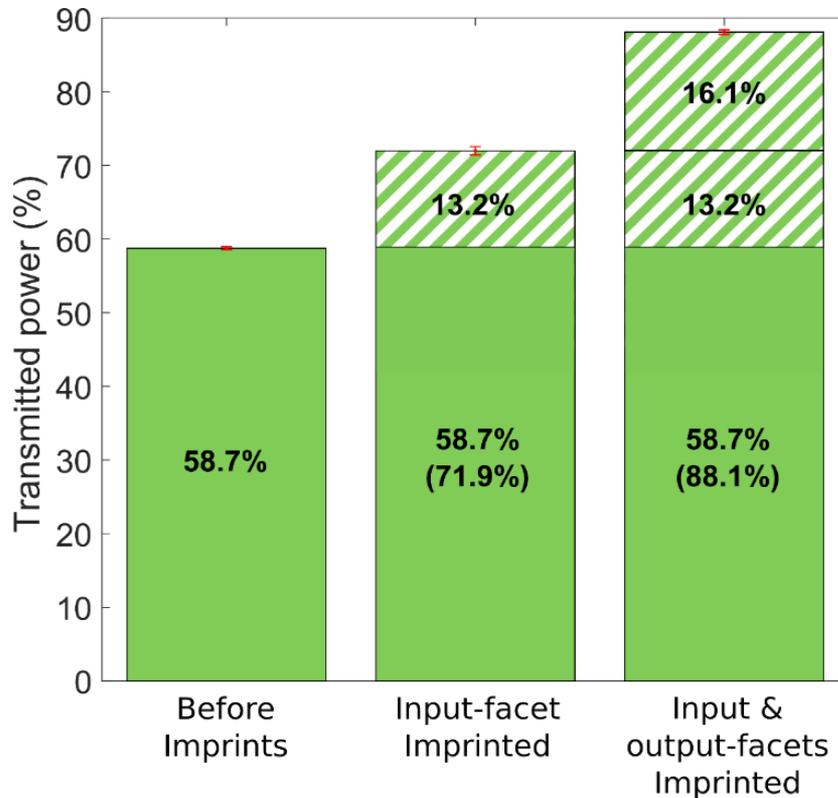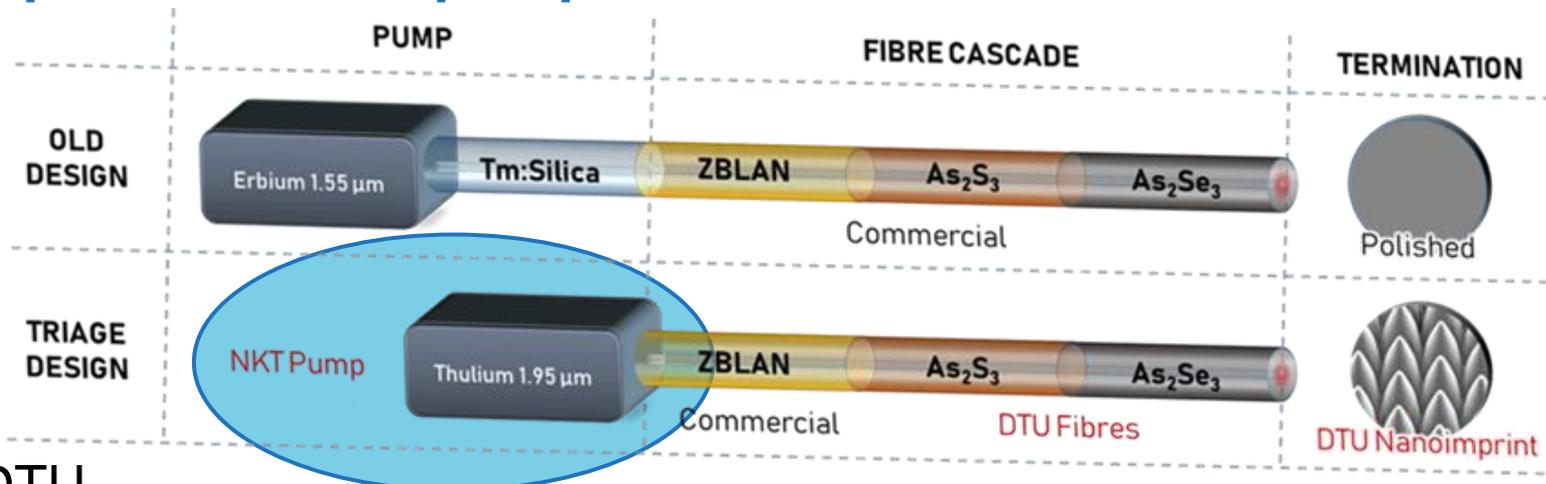
TRIAGE

Nano-imprinting

- ## DTU nano-imprinting technology
  - Modify fibre end facets with precision pattern
  - Transmission loss reduced by >70 %

60 μm

Supercontinuum pump source

- DTU
  - Chalcogenide fibre design and supercontinuum modelling
  - Chalcogenide fibre fabrication
  - Chalcogenide fibre termination
- NKT
  - Standard 2 µm pump system for initial testing
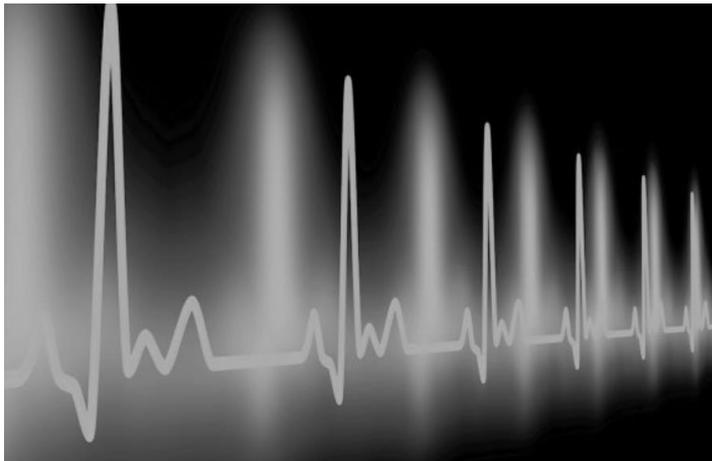 - Optimized 2 µm pump for final TRIAGE system
- NORBLIS
  - Two standard laser systems for initial testing with TRIAGE sensor
 - Optimized version with DTU fibres + termination and NKT pump

Supercontinuum pump source

- NKT's *Katana* laser is an amplified directly modulated diode
  - Pulse duration from 40 ps to 5 ns
- A new system at 2 µm will require:
  - New modulated diode and driver
  - Tm-doped amplifier chain/MOPA developed to reach watt-level power from the µW diode output

- A new ps-duration mode-locked laser will be developed for more stable and shorter pulsed source alternative
- A Tm amplifier will be adapted for short pulse amplification

Supercontinuum source integration
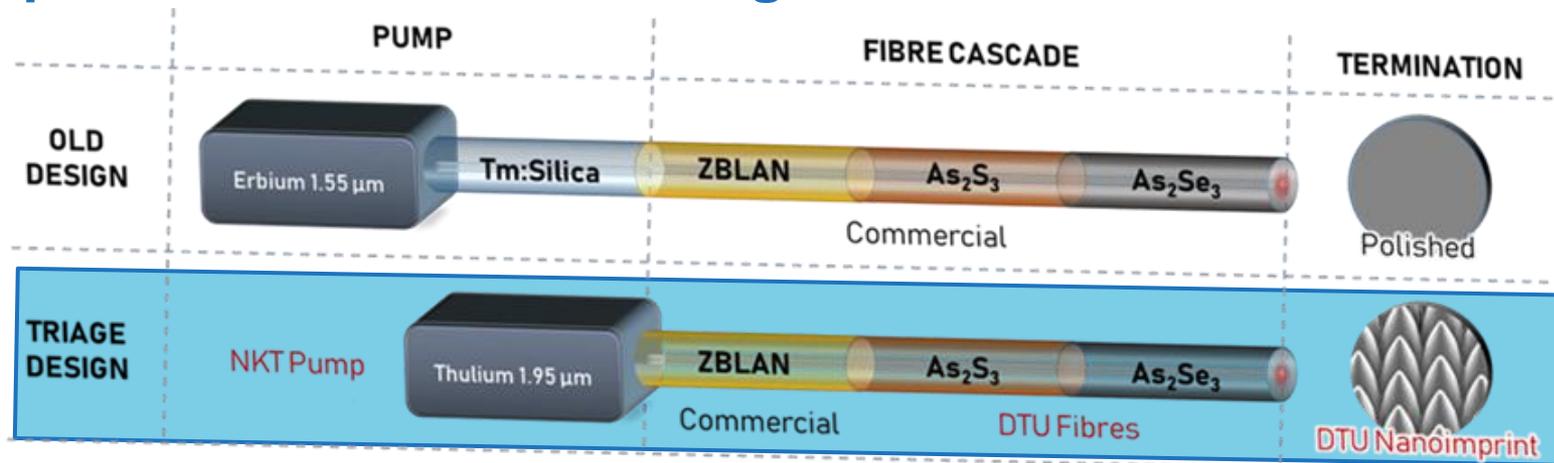
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TRIAGE supercontinuum source

- In TRIAGE, NORBLIS will develop its world-leading mid-IR supercontinuum lasers

- Current NORBLIS 2-10 µm *Aurora* source defines the state-of-the-art

- TRIAGE all-EU source will provide double the output power

	Current world leader (NORBLIS Aurora)	TRIAGE
Ouput power/mW	50	100
Pump source	Chinese 1550 nm	NKT 2 µm
Fibre type	US chalcogenide	DTU chalcogenide

Multipass cell (SO2)

In TRIAGE, Senseair will develop an optimised low-loss multipass cell (MPC)

This will allow air sample paths of >10 m

Optical ray tracing simulations for optimised performance and lowest losses
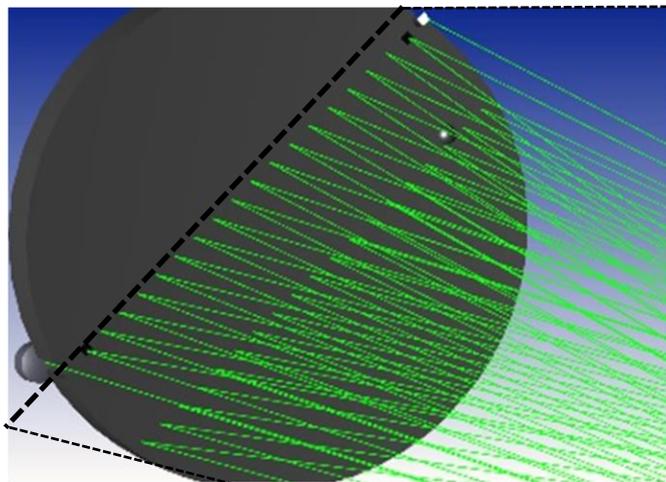
Mirror design for application-specific requirements
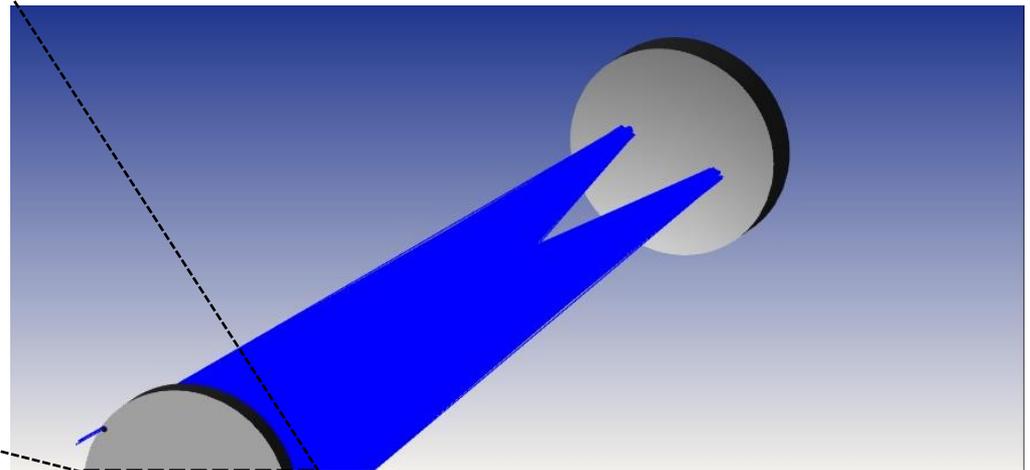
TRIAGE

Multipass cell production

Leader: Senseair

- Development & fabrication of mass-production-friendly multipass absorption cells for TRIAGE

  - Advanced mirror manufacturing capabilities

  - Precision moulding of polymer components
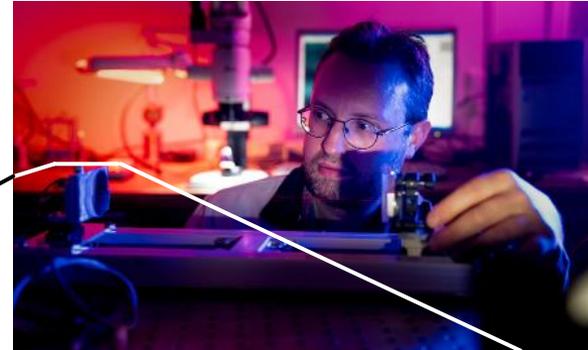
Alignment of mirrors during prototyping phase for MPC fabrication
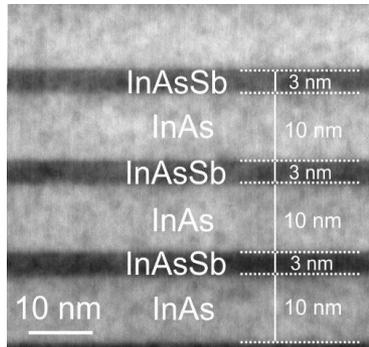
TRIAGE

IR detection advances (SO3)

- Improved signal-to-noise (SNR) using auto-balanced detection mode
  - Two independent IR detectors
  - Dedicated electronics perform signal amplification, subtraction and further processing

- Detector features
  - InAs/InAsSb superlattice as active material
  - Responsivity in MWIR and LWIR ranges
  - Thermoelectrically (Peltier) cooled (TEC)
  - Operating temperature ~210 K
  - Optically immersed – improved SNR
  - Resistance >100 Ω
  - RoHS compliant

Typical spectral responsivity of LWIR SL detector
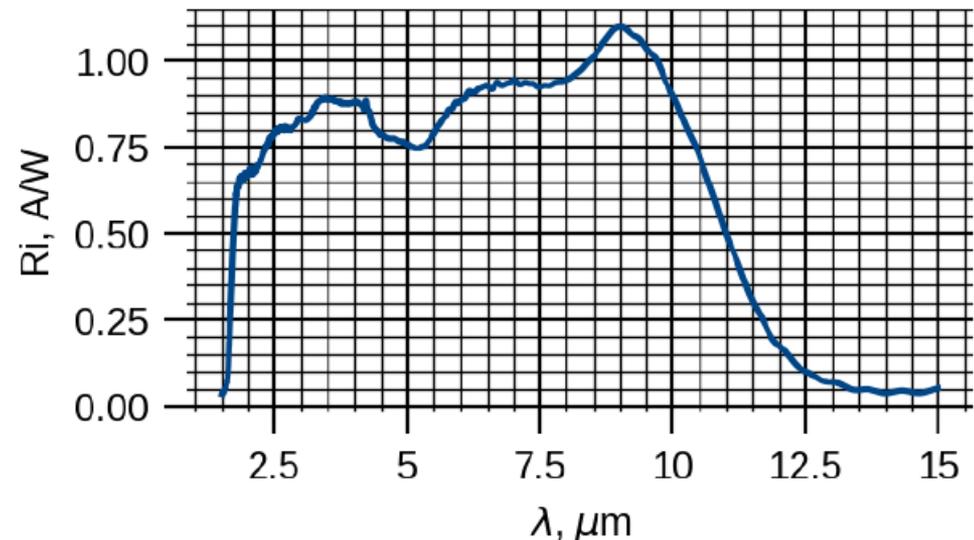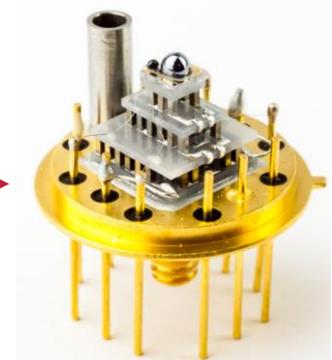
IR module fabrication

1-Epitaxy
InAs/InAsSb superlattice active material

InAsSb | 3 nm
InAs | 10 nm
InAsSb | 3 nm
InAs | 10 nm
InAsSb | 3 nm
InAs | 10 nm
10 nm
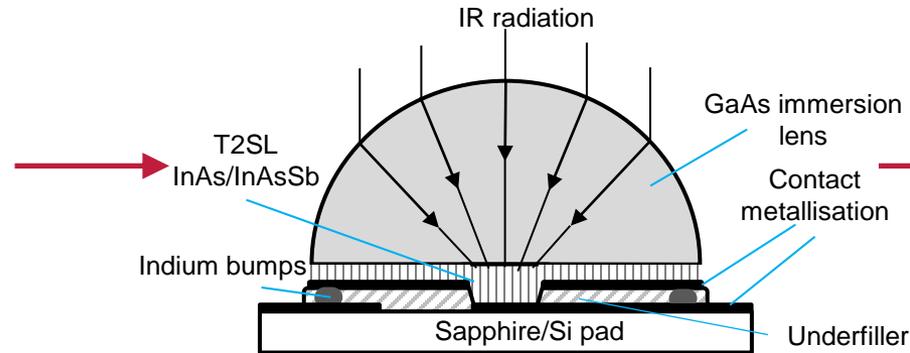
2-Processing
IR chip monolithically integrated with lens

IR radiation

T2SL InAs/InAsSb
GaAs immersion lens
Contact metallisation
Indium bumps
Underfiller
Sapphire/Si pad

3-Assembly
IR chip on TEC

5-Dedicated electronics and integration
TRIAGE auto-balanced IR detection module

REF   SIG

4-Hermetisation
IR detector

Fourier transform spectrophotometer (SO4)

Leader: Radboud University

- Design and development of the first prototype

- FTS evaluation with multipass cell and free-path measurement

- FTS optimization, using developed auto-balanced detector and multipass cell

M. Abbas *et al*. https://doi.org/10.1364/OE.425995 Optics Express (2021).

Building on FLAIR

https://www.h2020flair.eu
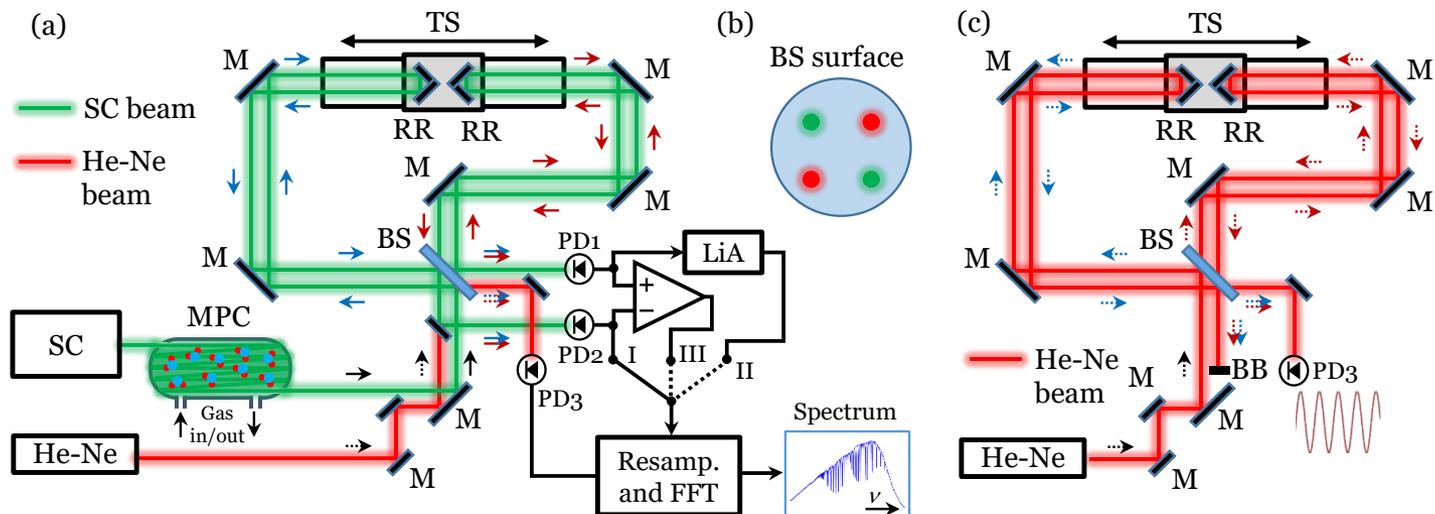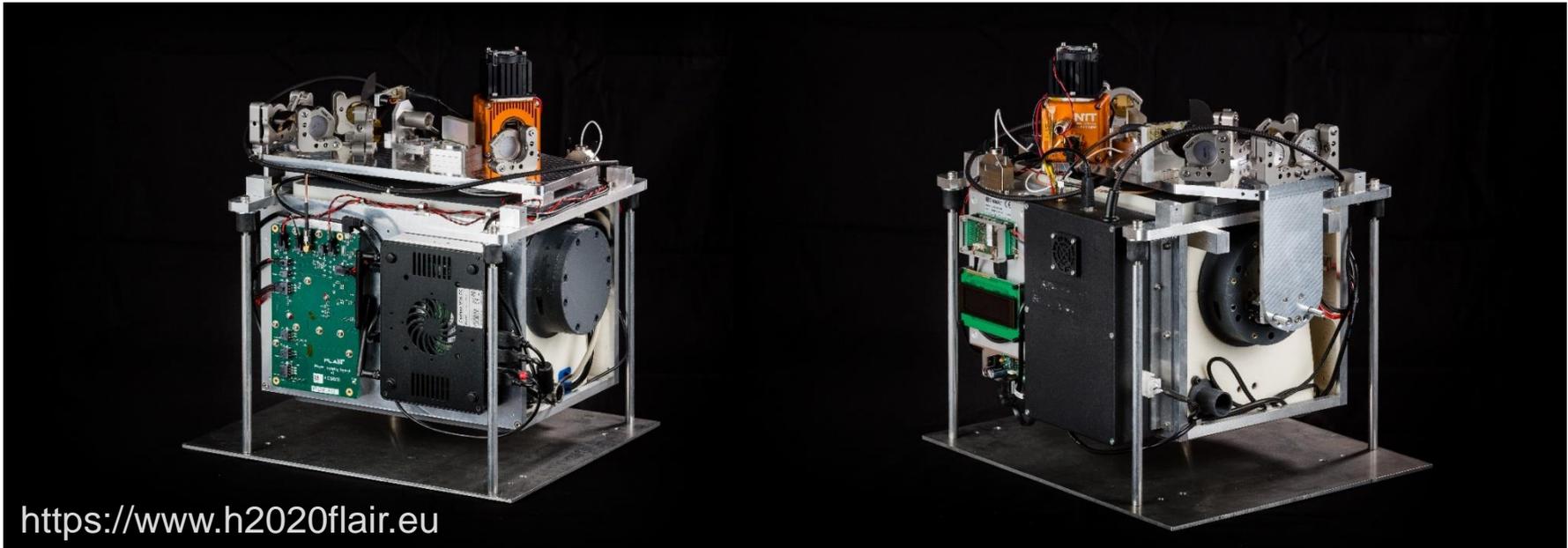
- A comparable prototype system was built for the FLAIR project
  - 2-5 µm supercontinuum based infrared spectrometer
  - Successful measurement campaign onboard a helicopter to inspect shipping
- In TRIAGE this will be adapted for 24/7 operation
  - Software adaptation and upgrade for long-term environmental testing
  - Gain experience on real measurement conditions
  - Trials in municipality air quality monitoring installation

System integration (SO5)

- Integrate all sub-systems as a single device
  - Unique user interface
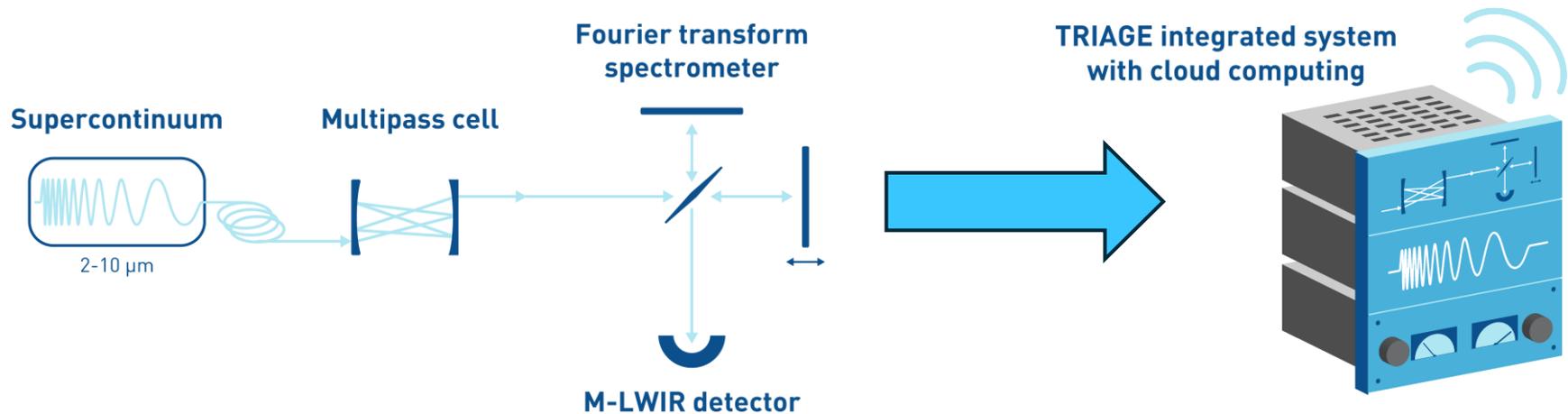
- Three prototypes will be developed and tested *in situ*

2× first generation prototype

1 × improved final prototype

Presentation outline

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- **Analysis and machine learning**
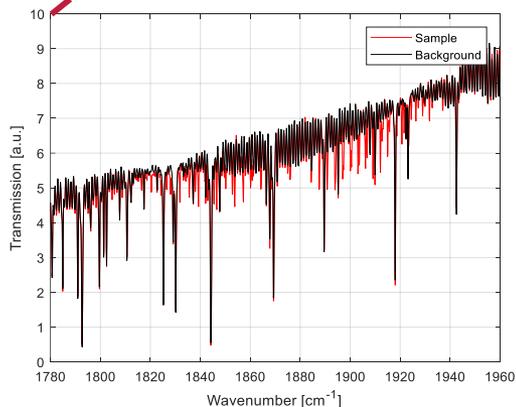 - **SO6-SO7**

- Measurements and demo
  - SO8-SO11

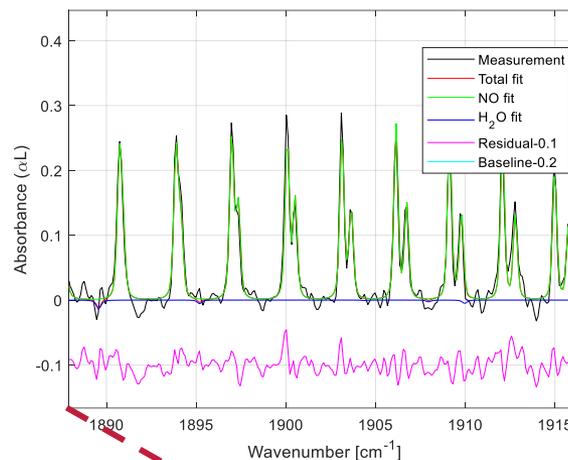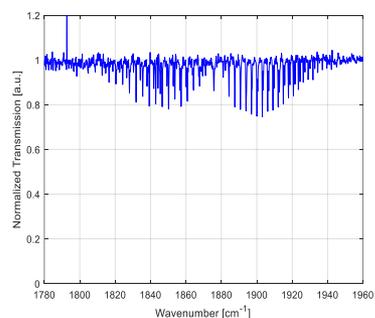[Image from: Gålfalk *et al.* 2016. Nature Climate Change **6**:426-430.]

TRIAGE
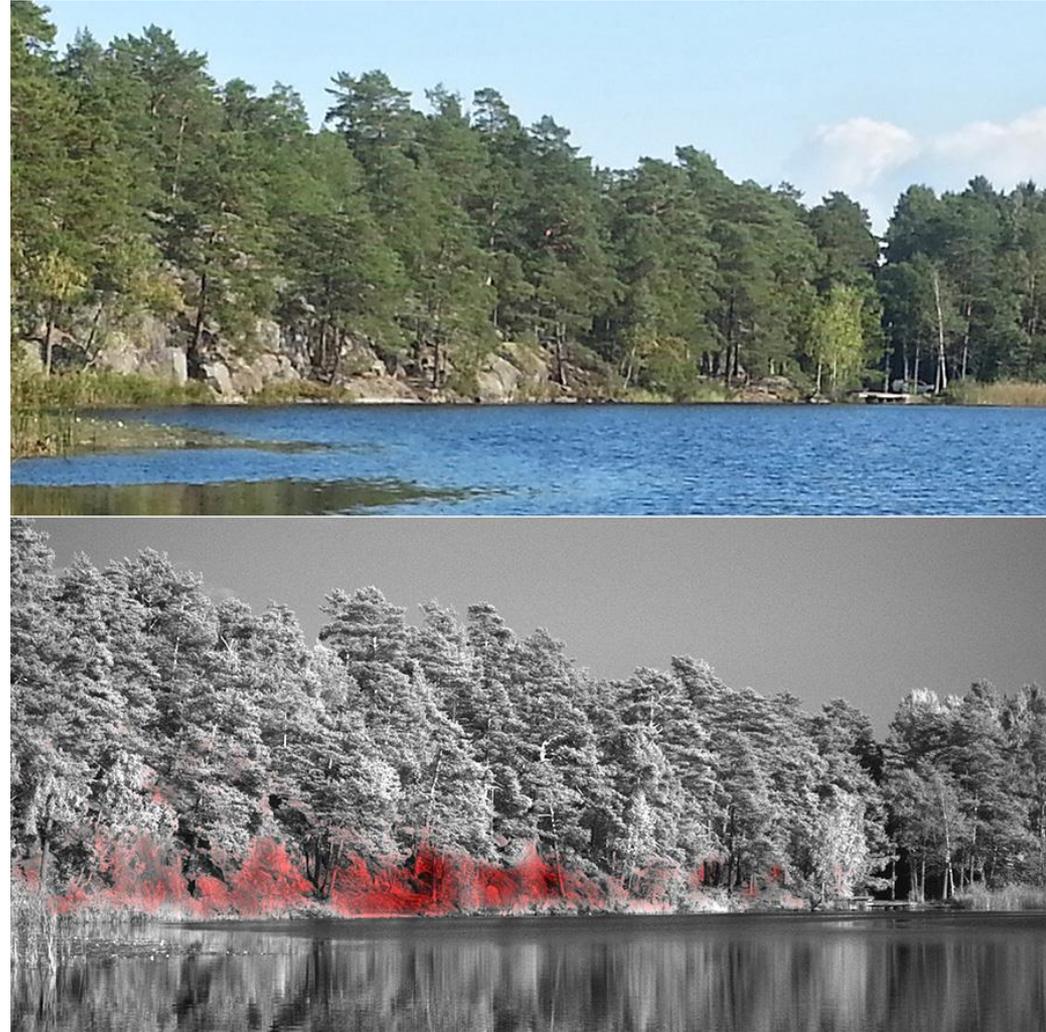
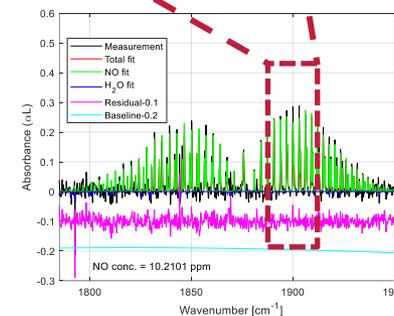# From spectrum to concentration

1-Measure spectrum on FTIR
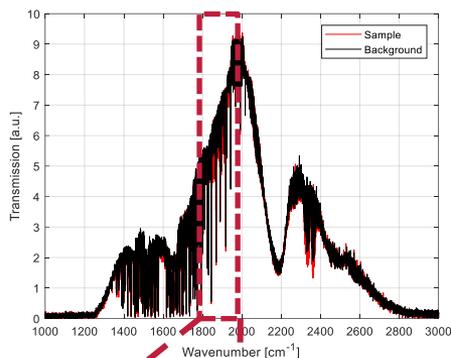
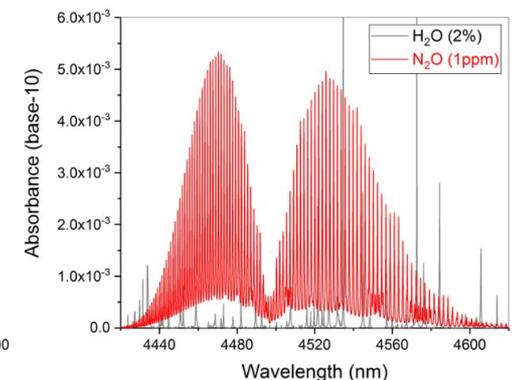2-Select region of interest (ROI)

3-Normalise vs. background

4-Spectral fitting to model and concentration retrieval
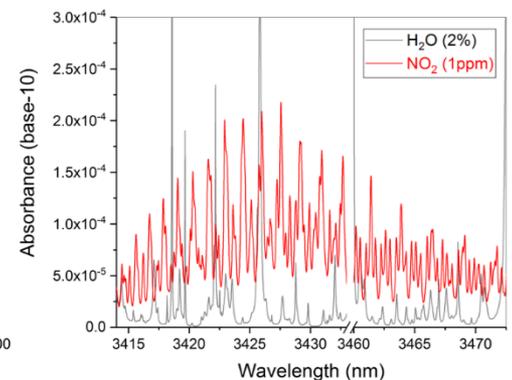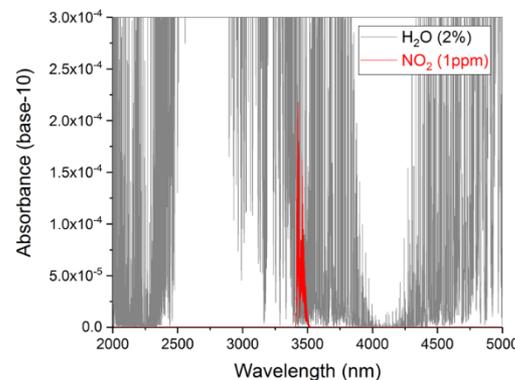
Reference database

- Constructing a reference database for the spectra of the target species

 - Development of a reference database for absorption spectral fingerprints
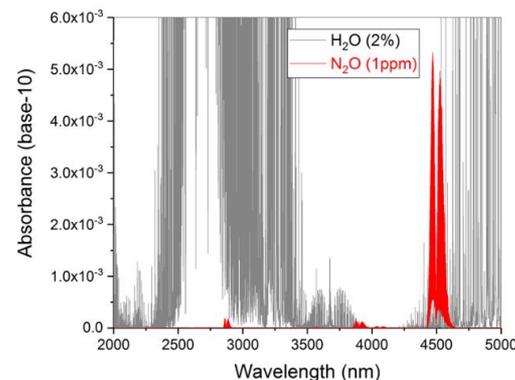
  - Effect of the interfering atmospheric species

Radboud University

- Developing and evaluating conventional fitting routines for the concentration retrieval

  - Least square fitting for concentration retrieval
  - Effects of interfering species with high concentration and unknown gases
 - Feedback for deep-learning algorithm

Deep learning algorithms (SO6)
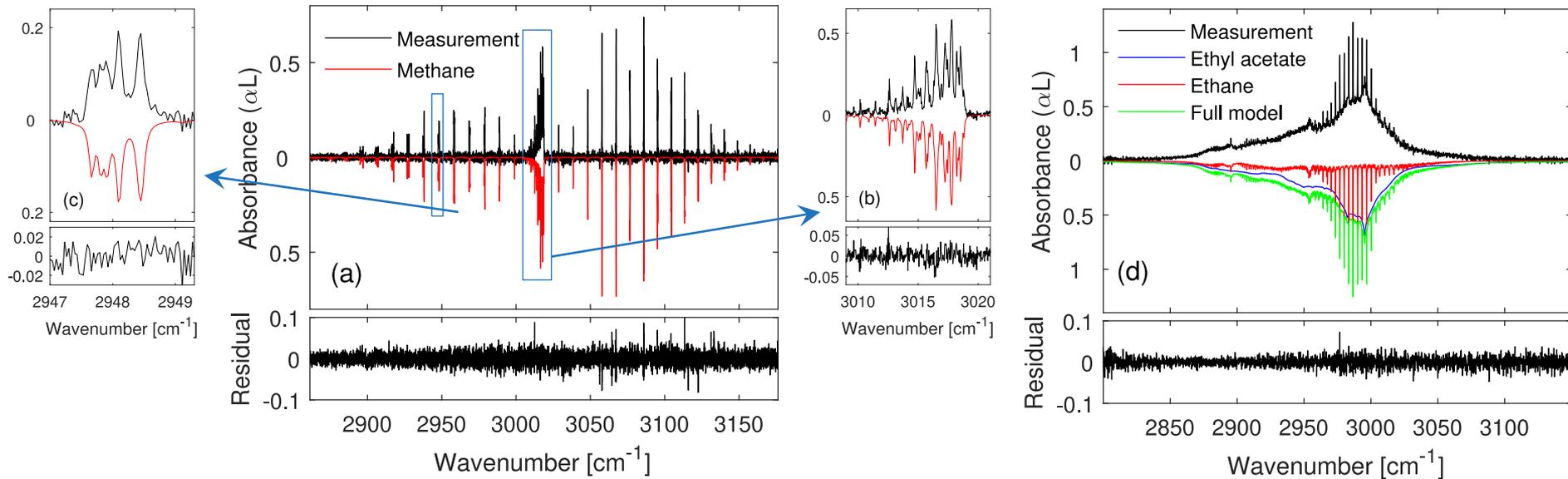
- Machine learning (ML) algorithms for gas concentration estimates

Fourier interferogram

ML algorithm

Gas concentration estimation
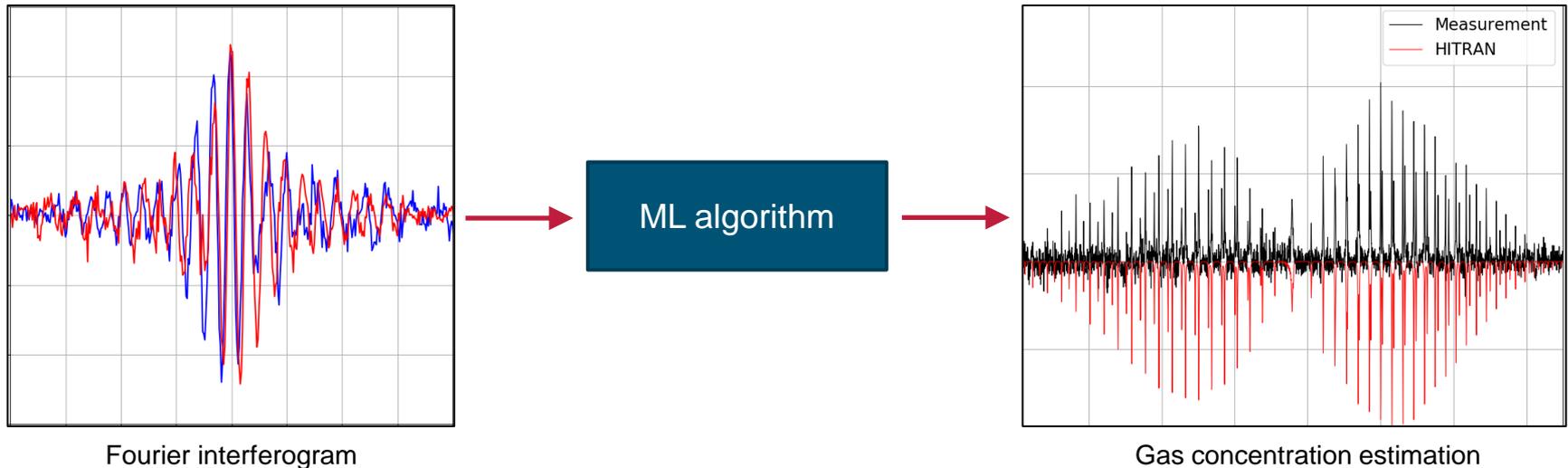
- Machine learning for air pollution monitoring
  - Gaussian processes
    - Provide an estimate and variance at any location
    - Build on previous relevant applications
   - E.g. rainfall estimation
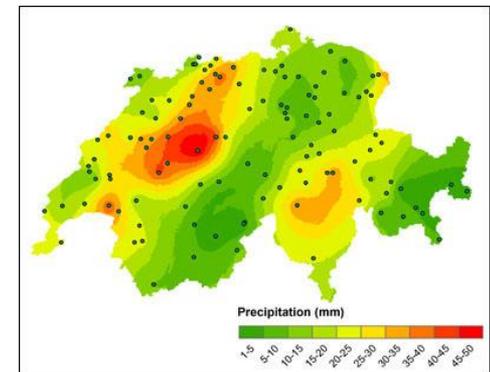
TRIAGE

Big data management (SO7)

- Integrate TRIAGE with other databases
    - E.g. Copernicus atmospheric data store

- Define data flows suitable for machine learning algorithms

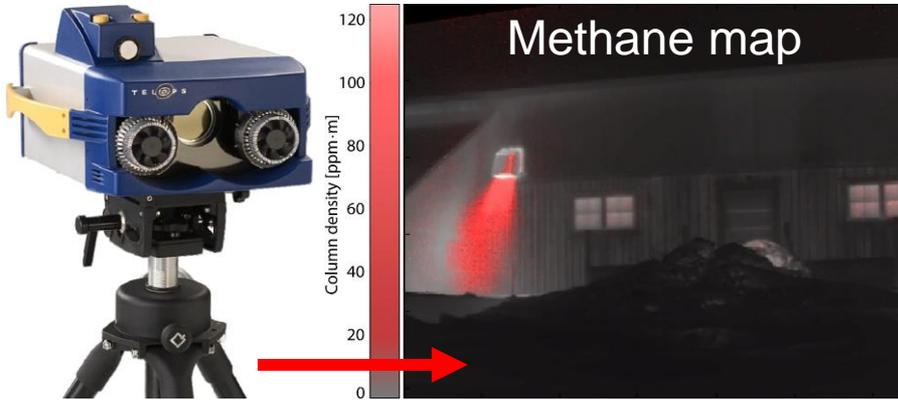- Develop interfaces between the machine learning and cloud platform(s)
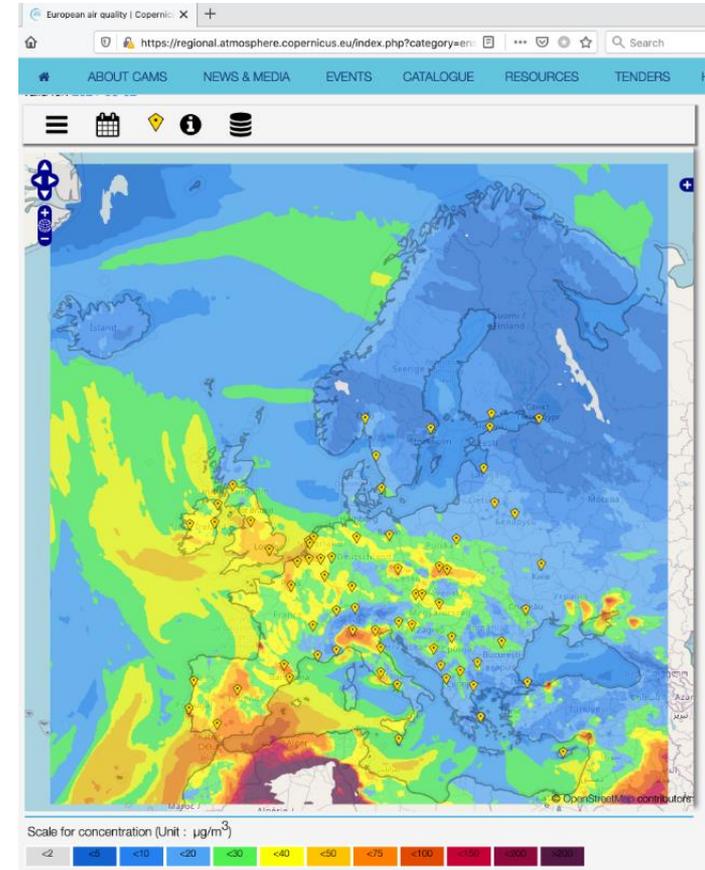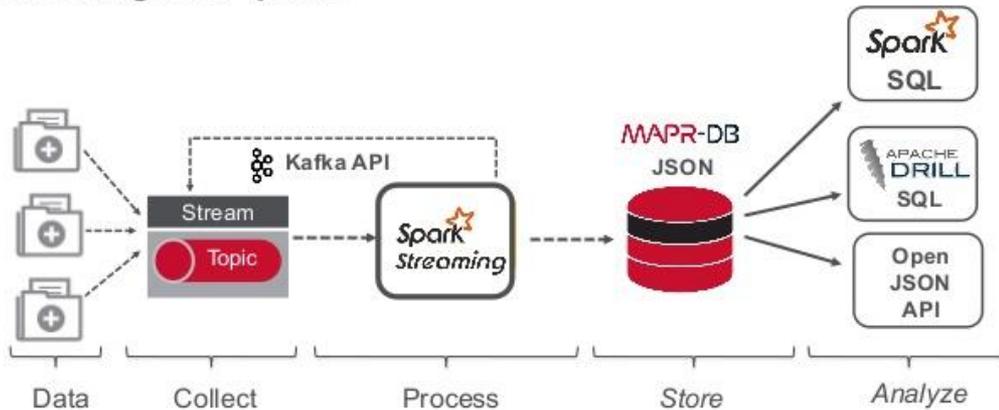
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- **Measurements and demo**
  - **SO8-SO11**

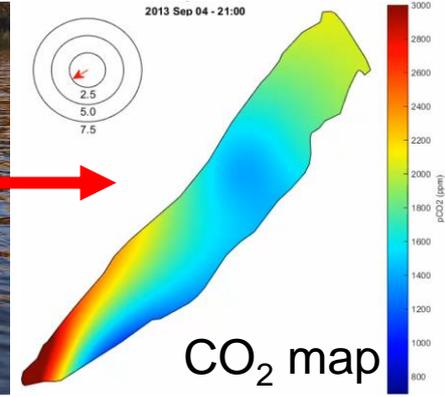[Image from: Gålfalk *et al.* 2016. Nature Climate Change **6**:426-430.]
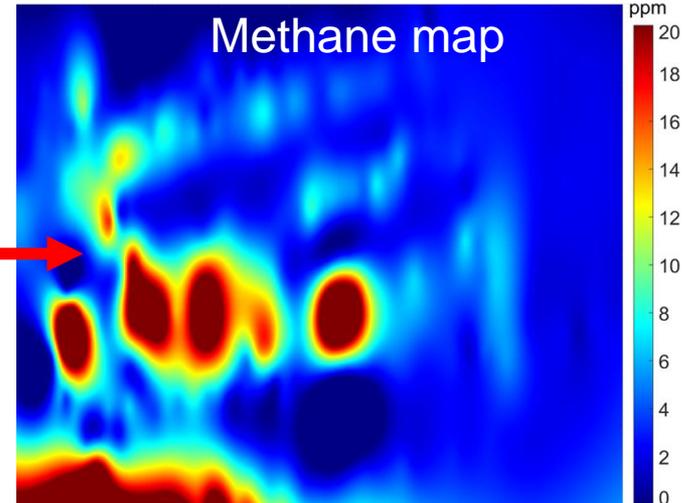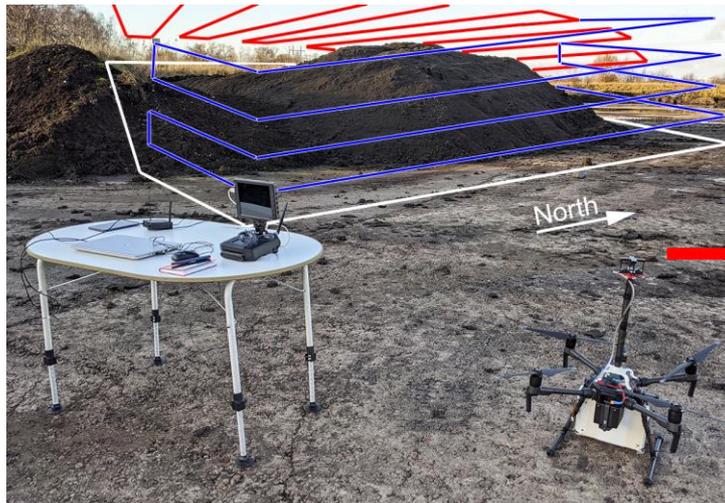
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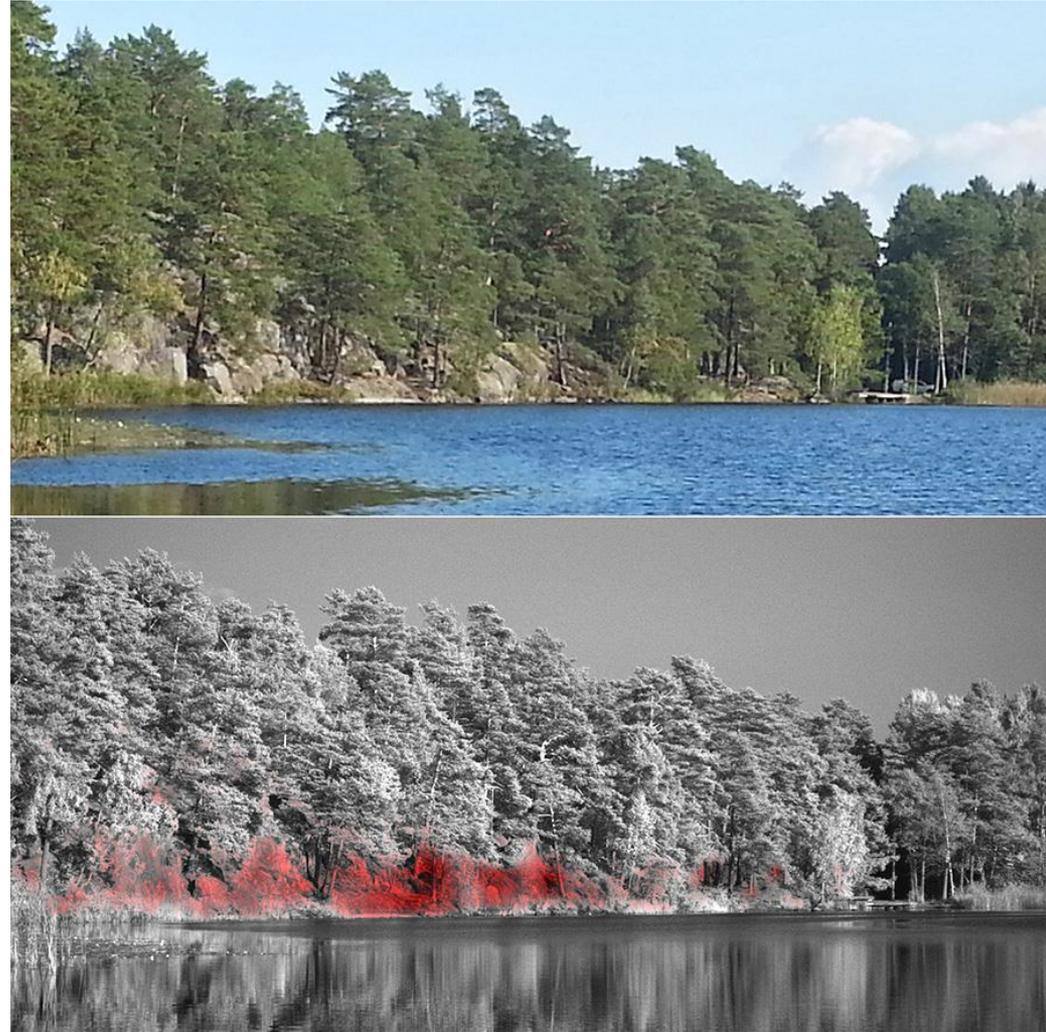
Trace gas method development

Methane map

CO_2 map

Hyperspectral imaging and quantification
(CH_4, N_2O, H_2O)

Automatic flux chambers
(CH_4, CO_2)

Drone system (CH_4, C_2H_6, H_2O)

Methane map

TRIAGE

Validation and demonstration (SO8 + SO9)

- Sensitivity and measurement performance evaluation
  - Short-term drift tests
  - System response time for target gases
  - Effects from different averaging times for different gases

- User interface and functionality
  - Evaluation of user interface, user settings, troubleshooting, data transfer *etc*.
  - Tests of reporting system for high concentrations (alarm function)

- Validation in different environments
  - Influence of environmental variables on sensor performance
  - Field tests at TRIAGE-NET sites (urban, industrial, natural)
  - Comparison with simultaneous reference measurements

Air pollution monitoring (SO10 + SO11)

- Long-term tests for air pollution monitoring
  - At least three months
    - Field tests with simultaneous reference measurements to check drift
    - Evaluation of system performance and maintenance needs
    - Daily, weekly, seasonal changes in pollution levels

- Operational demonstration *in situ*
  - Set-up and data collection on rooftops
  - Ethane trace gas release experiments + site specific source attribution
  - Source and flux modelling

- Evaluation and recommendations
  - Evaluation of experiments and discussions with TRIAGE-NET
  - Recommendations for users

Thank you for your attention!

Dissemination lead

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