TRIAGE

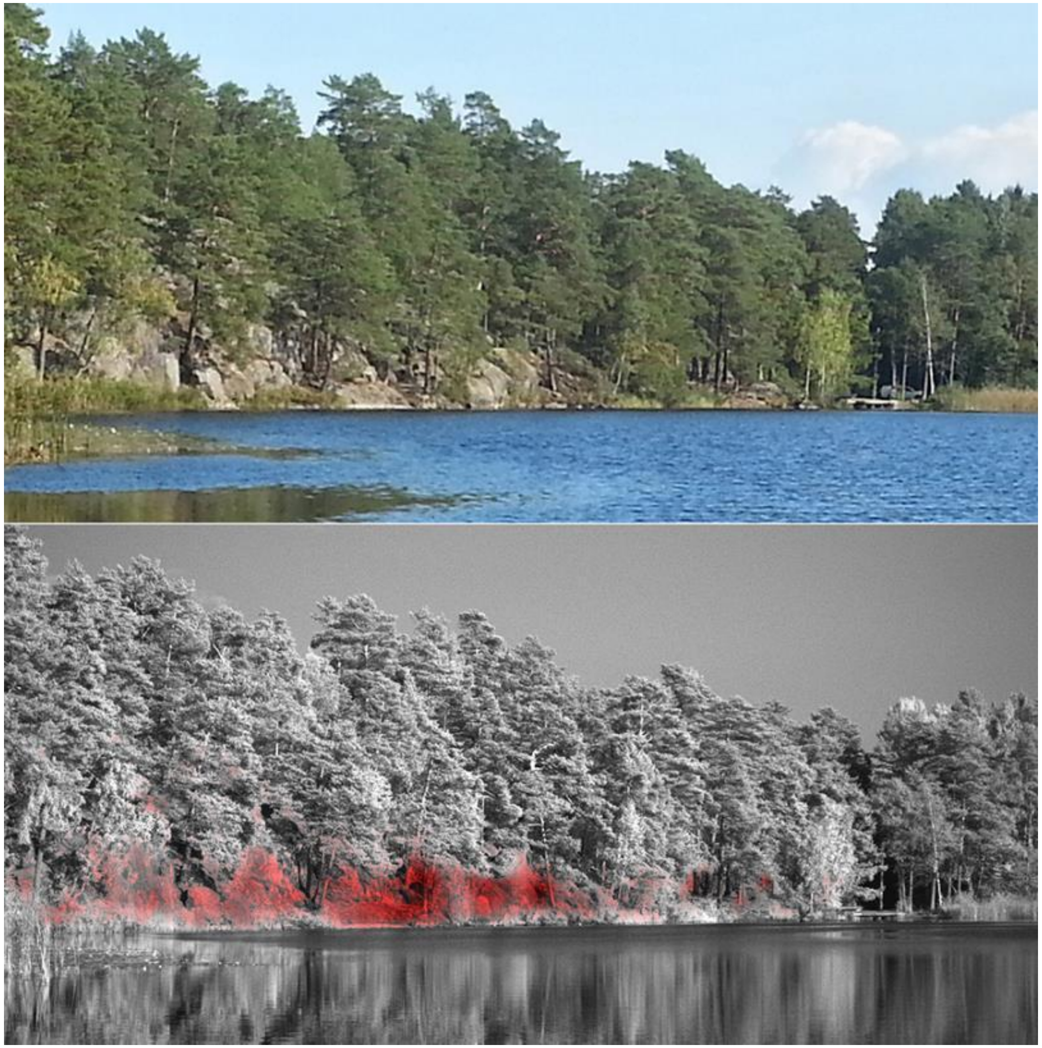
This project has received funding from Horizon 2020, the European Union’s Framework Programme for Research and Innovation, under grant agreement No. 101015825.

TRIAGE project presentation

Project overview; Mar-2022

Presentation outline

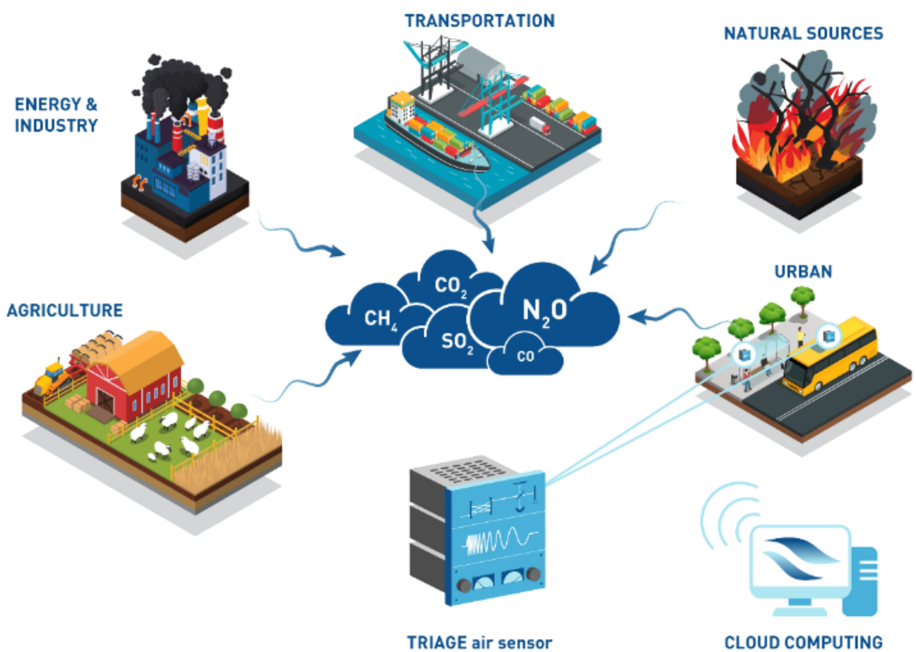
- **Objectives**
- Hardware
  - SO1-SO5
- Analysis and machine learning
  - SO6-SO7
- Measurements and demo
  - SO8-SO11



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

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

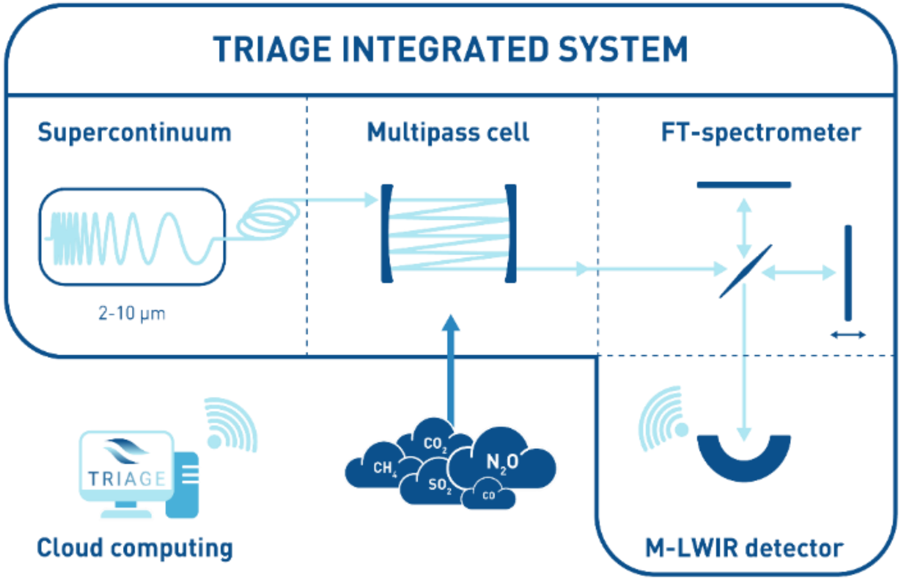
- Requirement for better sensors
  - Smart distributed networks
  - Community-based
  - Real-time monitoring and warnings

*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 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.

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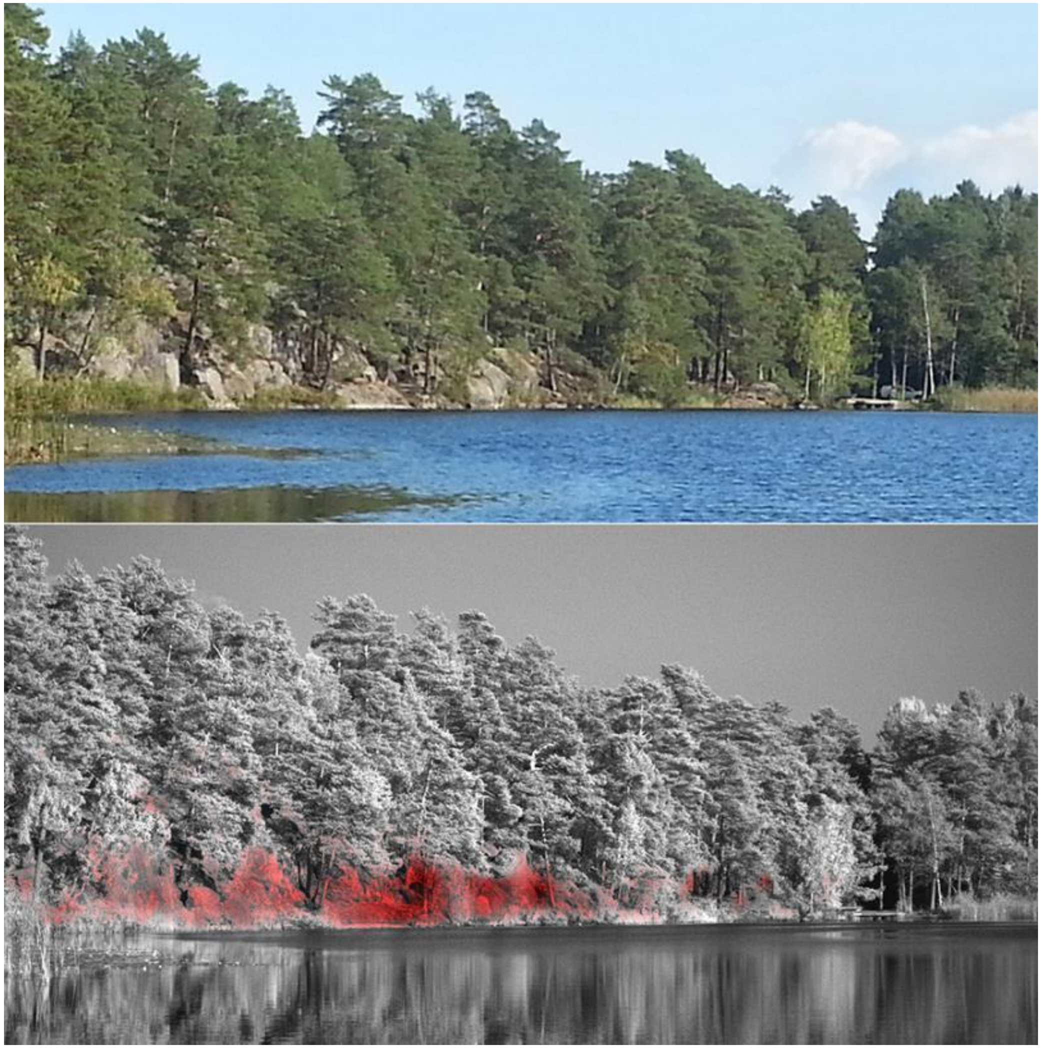

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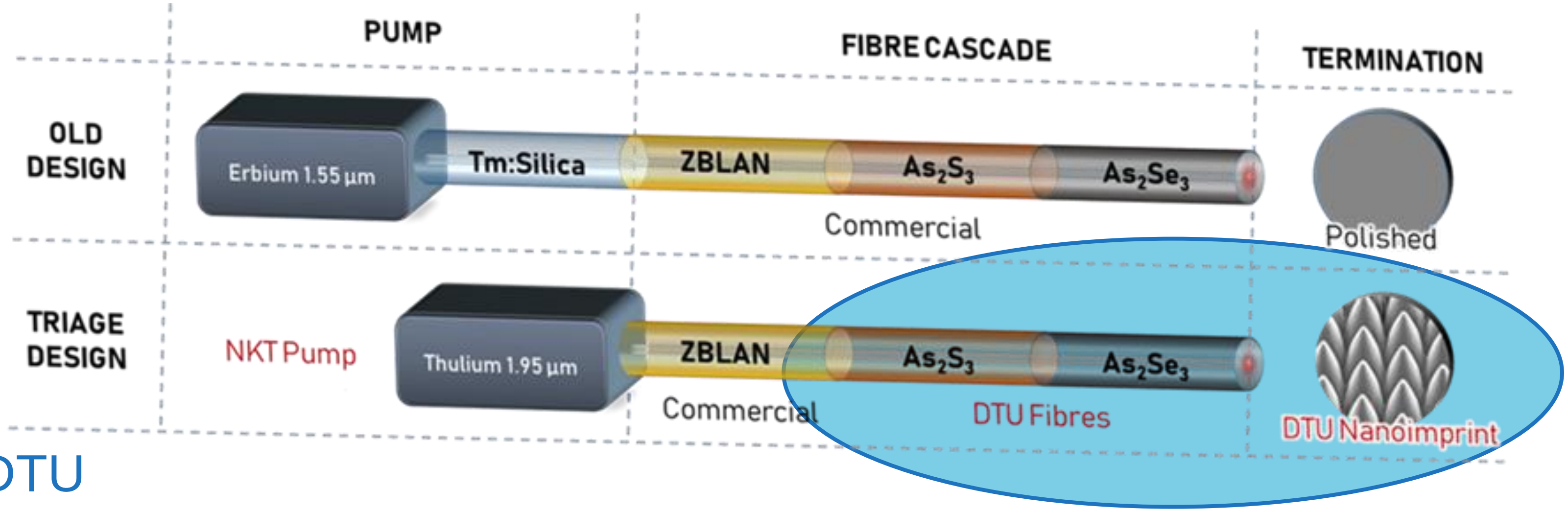
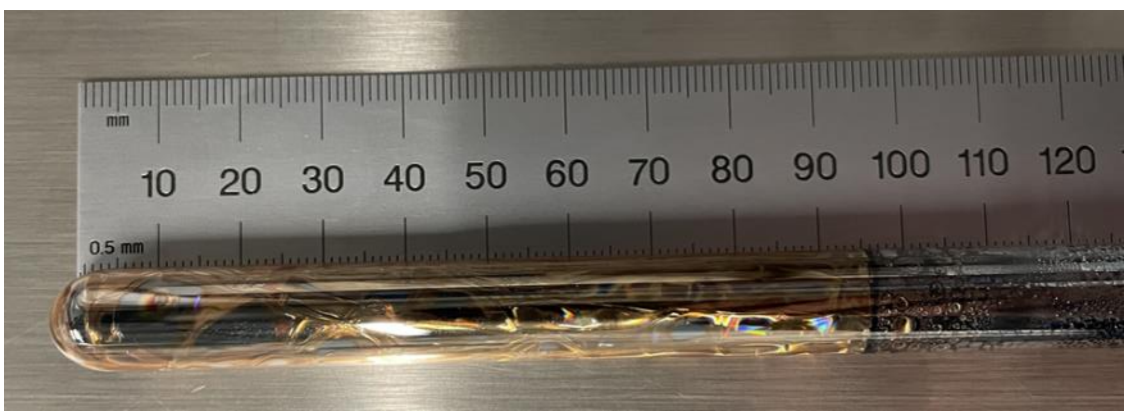
Supercontinuum source development (SO1)



- DTU
  - Chalcogenide fibre design and supercontinuum modelling
  - Chalcogenide fibre fabrication
  - Chalcogenide fibre termination
- NKT
  - Standard 2 µm pump system for initial testing
  - Optimised 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

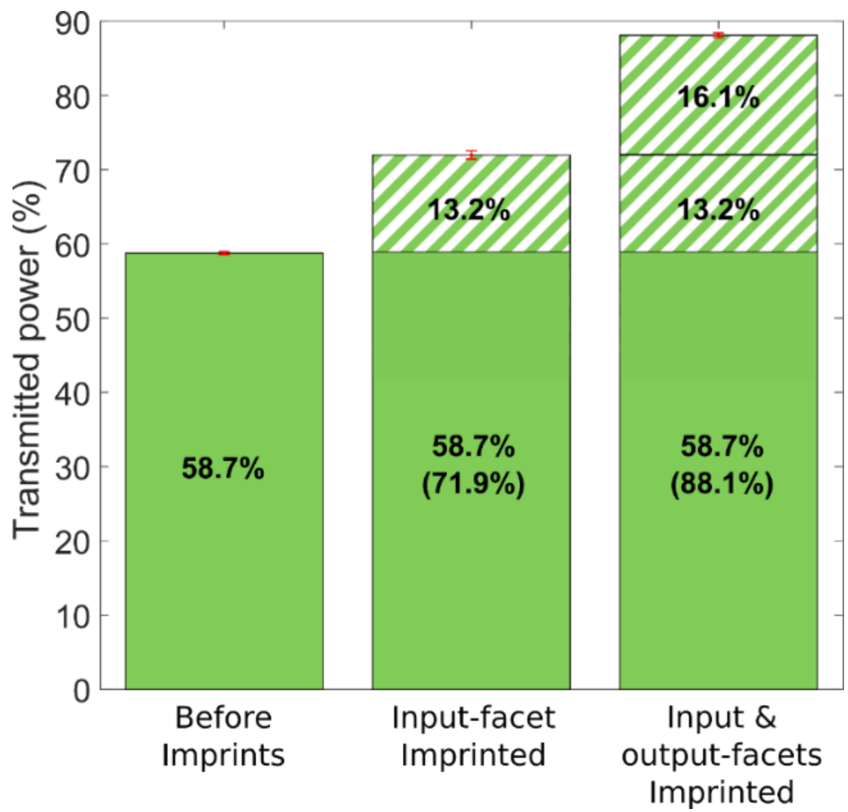
Custom glass and chalcogenide fibre fabrication

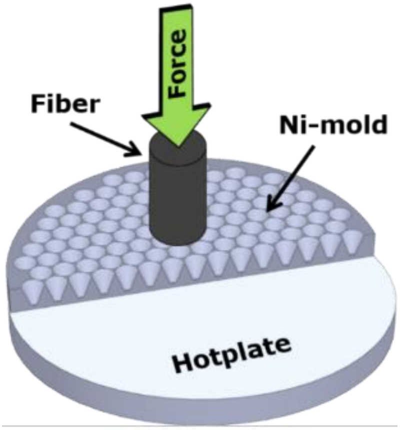
- Establishing a suitable fibre fabrication facility
  - Requisitioning/ integration of equipment and materials
  - Modification and optimisation of existing equipment
- Fabrication of glass preform
  - Precursor material successfully purified
    - Arsenic and selenium
    - Batched to the target composition
  - Materials were melted and rapidly quenched
    - Successfully formed a chalcogenide glass preform
- Next steps
  - Fibre drawing of preforms

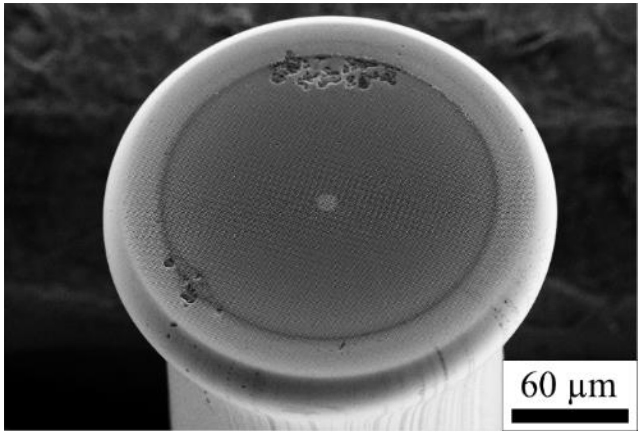


Nano-imprinting

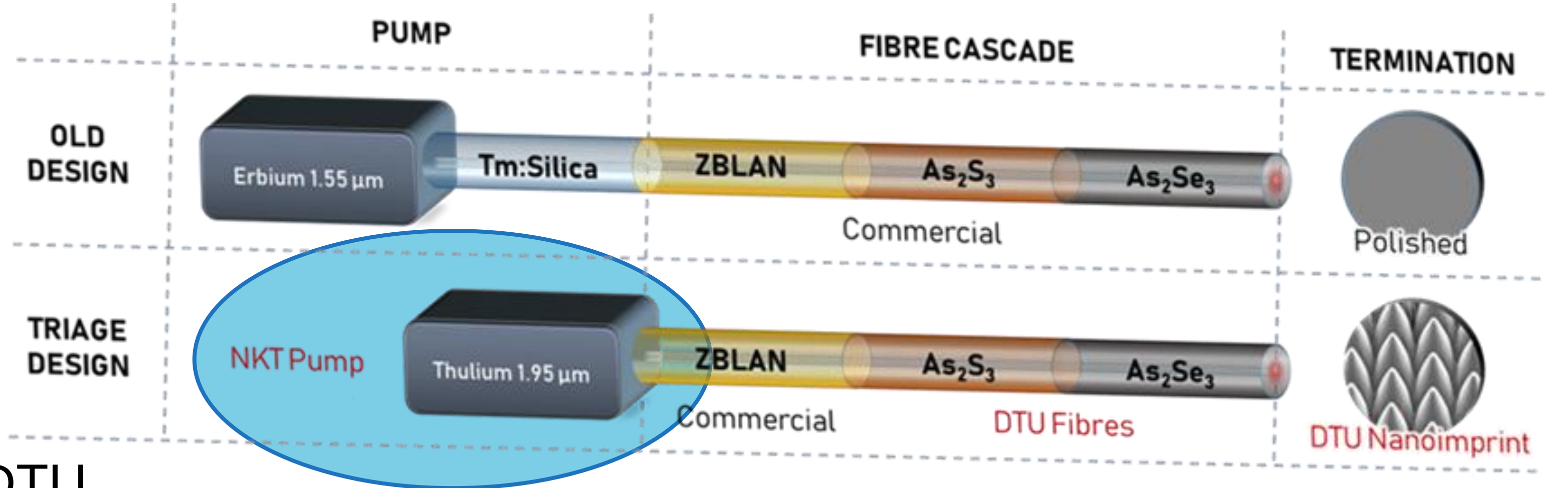
- DTU nano-imprinting technology
  - Modify fibre end facets with precision pattern
  - Transmission loss reduced by >70 %







Supercontinuum pump source



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DTU

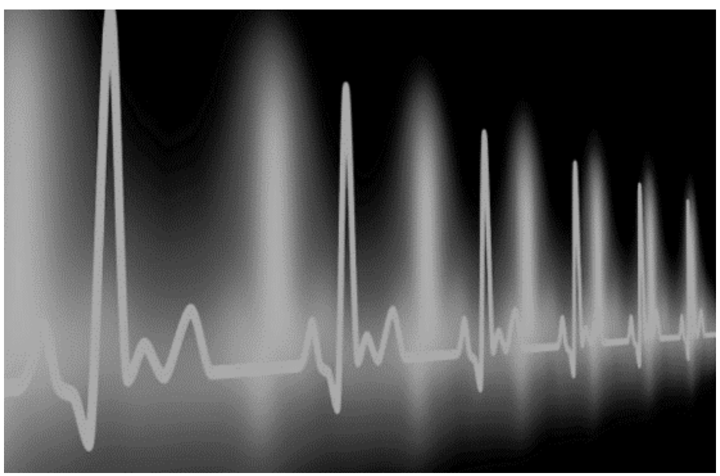
NKT Photonics the power of light

NORBLIS NORDIC BROADBAND LIGHT SOLUTIONS

Supercontinuum pump source

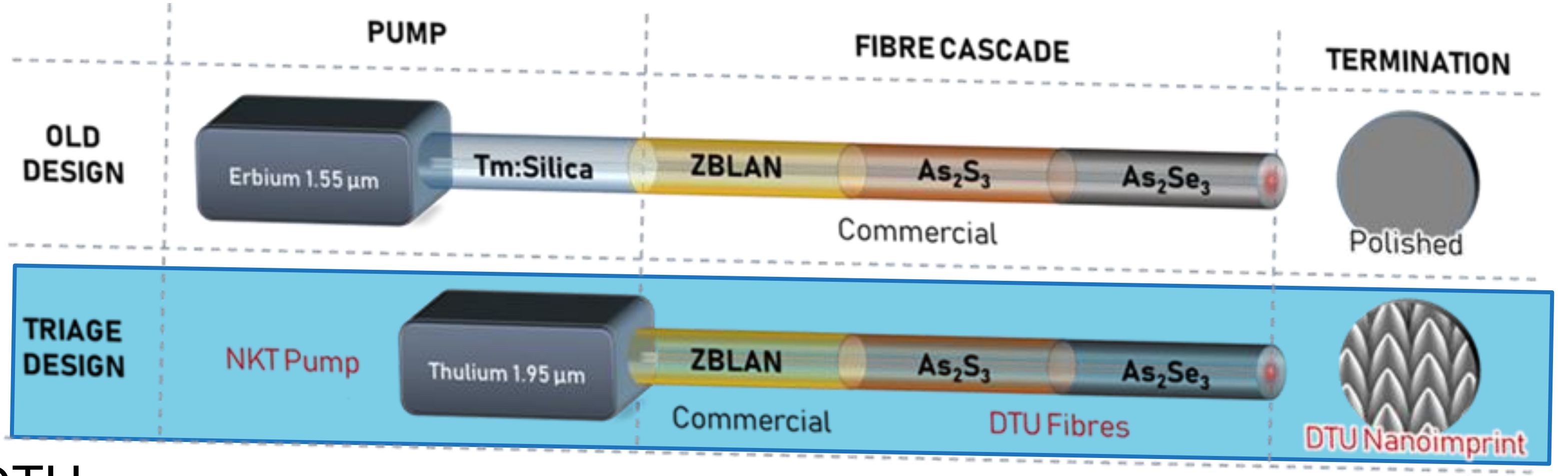
NKT Photonics
the power of light

- 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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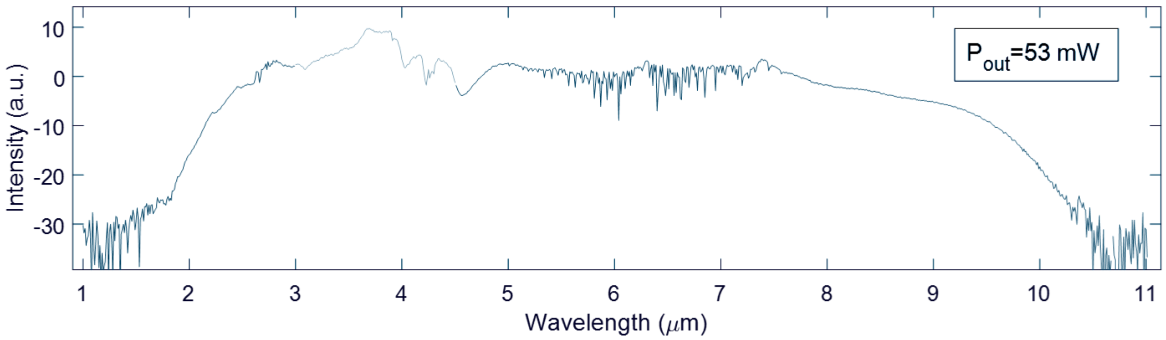
TRIAGE supercontinuum source

NORBLIS
NORDIC BROADBAND LIGHT SOLUTIONS

- 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

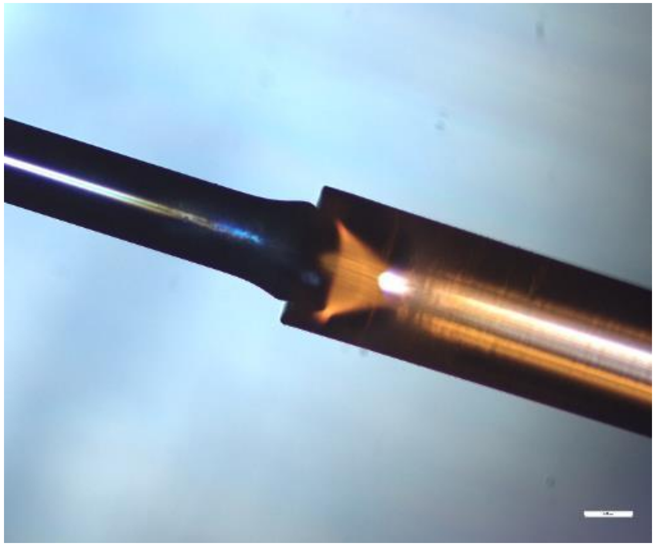


	Current world leader (NORBLIS Aurora)	TRIAGE
Ouput power/mW	50	100
Pump source	Non-EU 1550 nm	NKT 2 µm
Fibre type	Non-EU chalcogenide	DTU chalcogenide

TRIAGE SC source progress

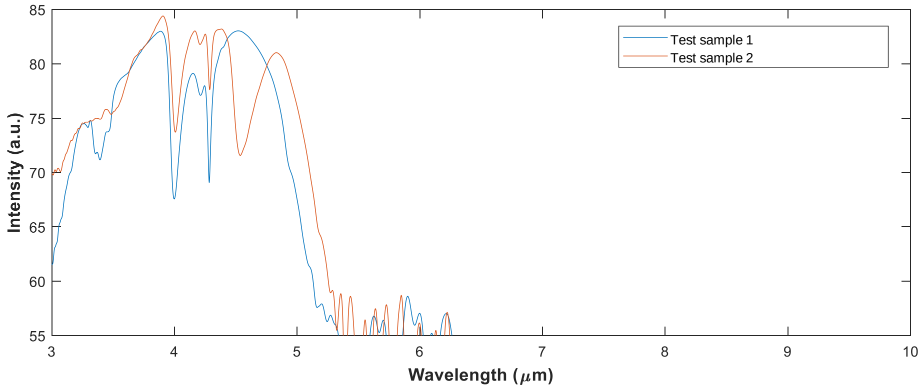
Sulphide-to-selenide splice

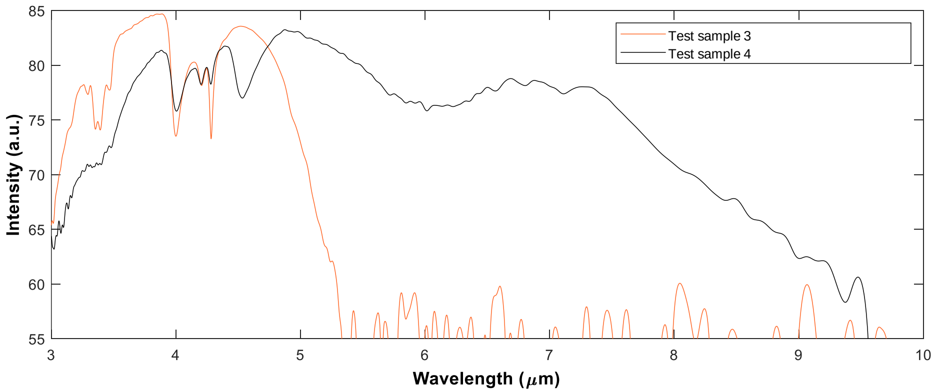
- Completely new splice process had to be developed due to large difference in fibre diameter (170 µm vs. 340 µm)
- Result is stable, and improves the transmission by up to 20 % compared with mechanical coupling



Alternative selenide fibre

- The high-NA selenide fibre originally used is also no longer available
- Low-NA version was tested having same core diameter of 12 µm
- Initial tests indicate that this fibre is unsuitable, since very little broadening is observed.





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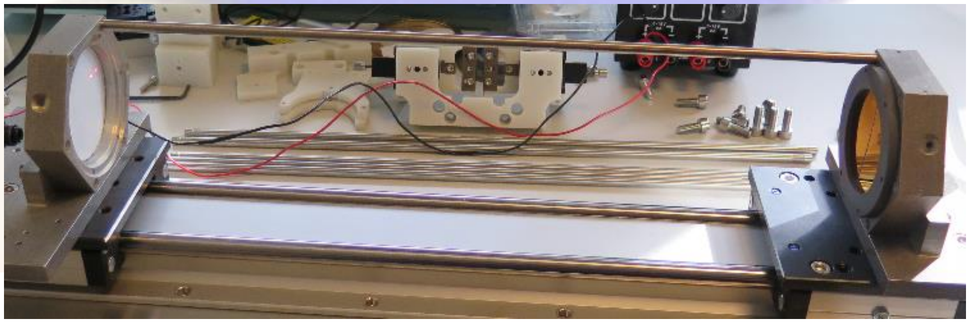
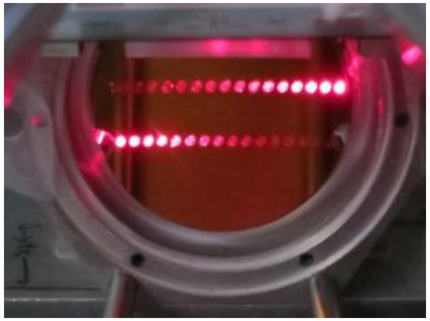
Multipass cell (SO2)

Senseair

- Senseair will develop a TRIAGE low-loss multipass cell (MPC)
- Design of high performance MPC is complete
  - 40 cm length, 1 litre internal volume
  - 76 passes results in 30 m path length
  - High transmission of >15 %
  - 98 % mirror reflectivity (simulation input parameter)
- Manufacturing of MPC-like test set-up for mirror qualification
  - Tests of mirror qualification ongoing
  - Optical Interfacing solutions finished

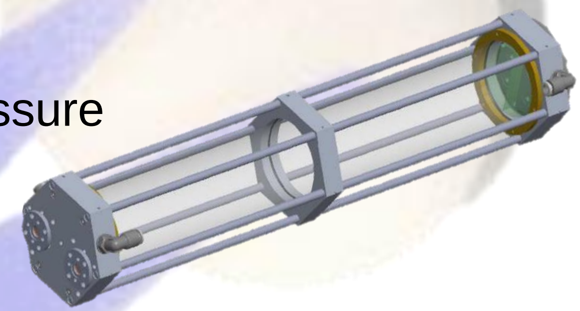




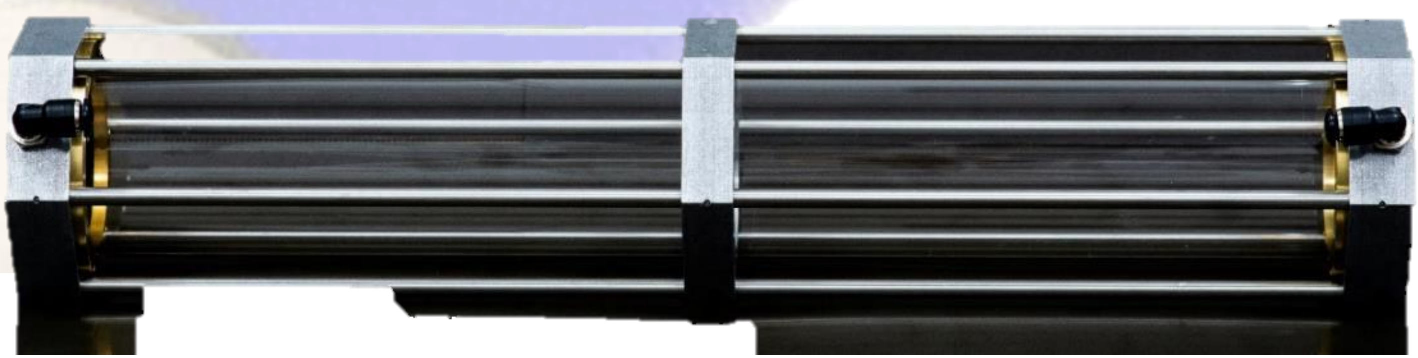
Multipass cell production

Senseair

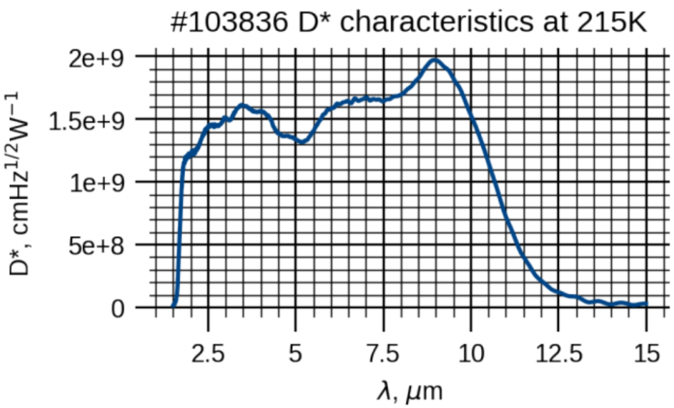
- Successful fabrication of first iteration TRIAGE MPC
  - Completed according to specification
  - Fabrication friendly design
  - Additional sensors for humidity, temperature and pressure
  - Operational in low and high pressure conditions



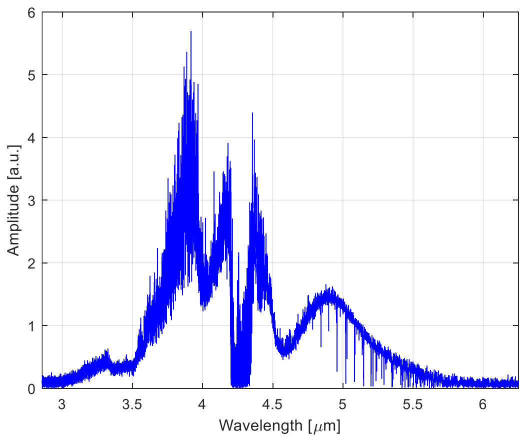
- Next generation improved design
  - Volume reduction by implementing a novel cell design
  - Heating and optional cooling functionality
  - Mirror optimisation
  - Low-cost in-house mirror fabrication process



IR detection advances (SO3)



Spectral detectivity of a PC detector used in the module developed in Stage 1



The measured background spectrum using the module developed in Stage 1 (results from FTS at RU)

Goal

Develop and test an auto-balanced detection module comprising of two IR photodetectors and dedicated electronics.

Stage 1 (completed Nov-2021)

Adaptation of existing analogue module for photoconductive (PC) long wavelength IR (LWIR) InAs/InAsSb Type 2 superlattice (T2SL) IR detectors and testing in FTS.

Stage 2 (in progress)

Development of photovoltaic (PV) LWIR T2SL IR detectors and the digital part of balanced detection module and testing in FTS.

Progress

- Parameters of the module determined
- Epitaxy of upgraded PV structures completed
- Processing of IR chips underway
- Design of PCBs for digital part underway

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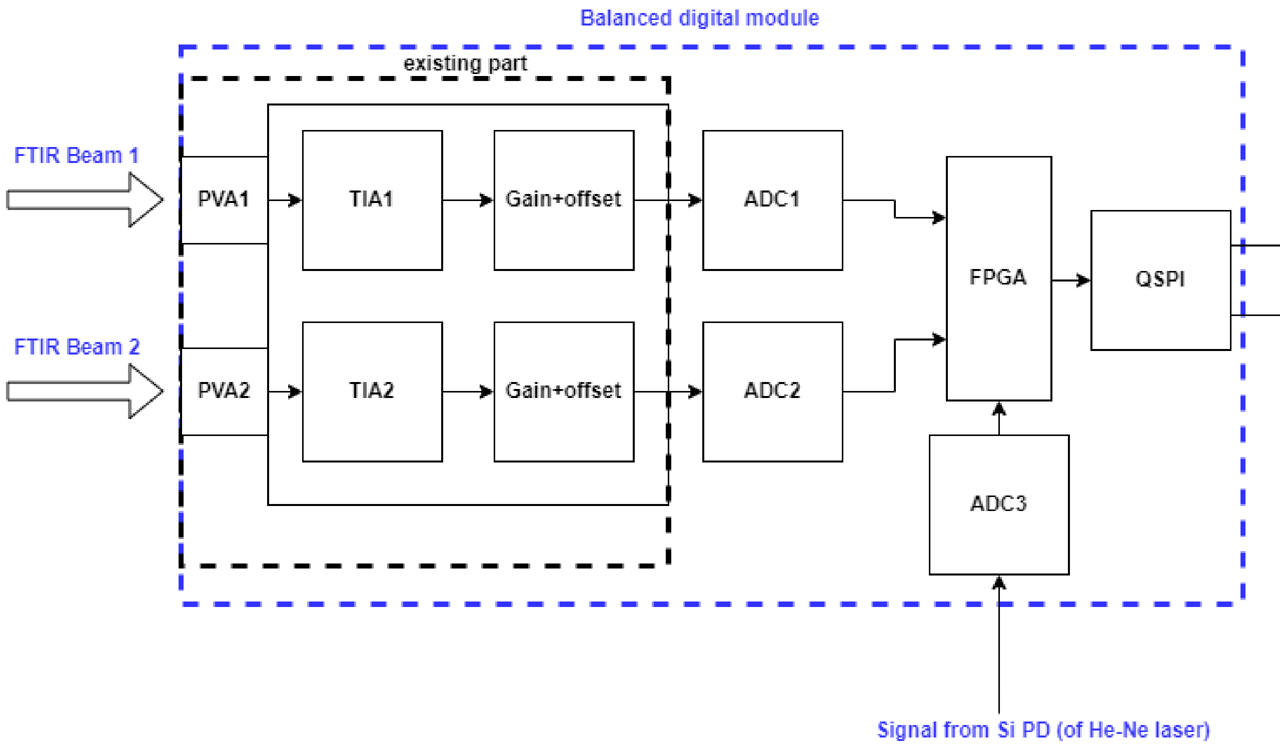
IR detection block diagram

Digital module block diagram



- Suggested parameters of ADC: 600 kSa/s; 14 bit – minimal
- FPGA for signal acquisition and signal processing
- Frequency limit (from FTS parameters):
  - f_{max} ≈ 250-500 kHz
  - f_{min} ≈ 0.8-1.6 kHz

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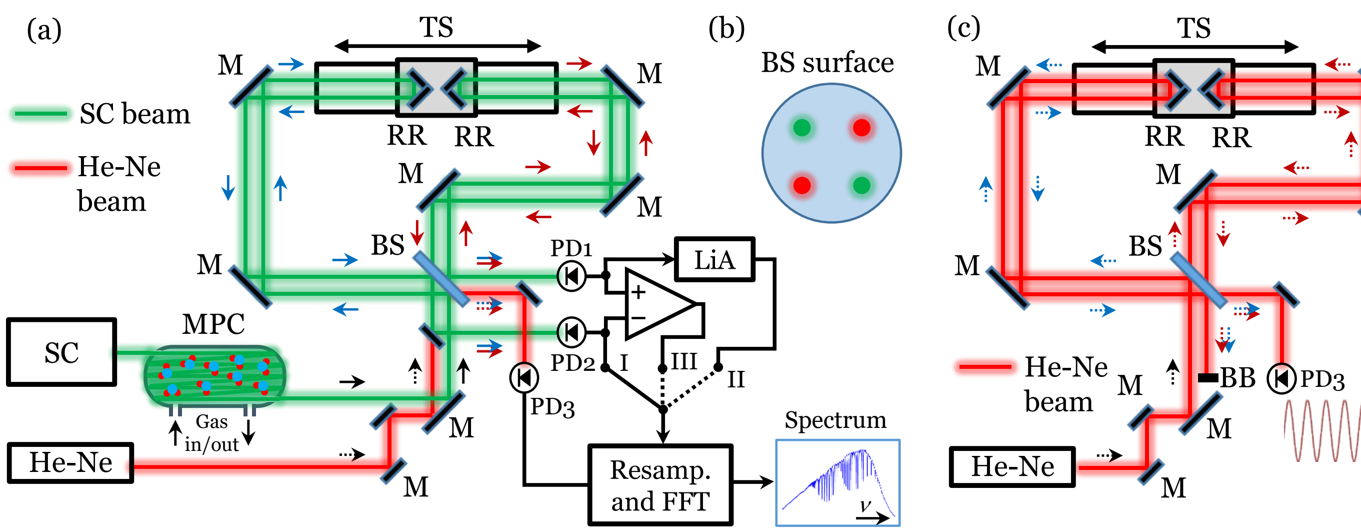
Fourier transform spectrophotometer (SO4)

Radboud University

Leader: Radboud University

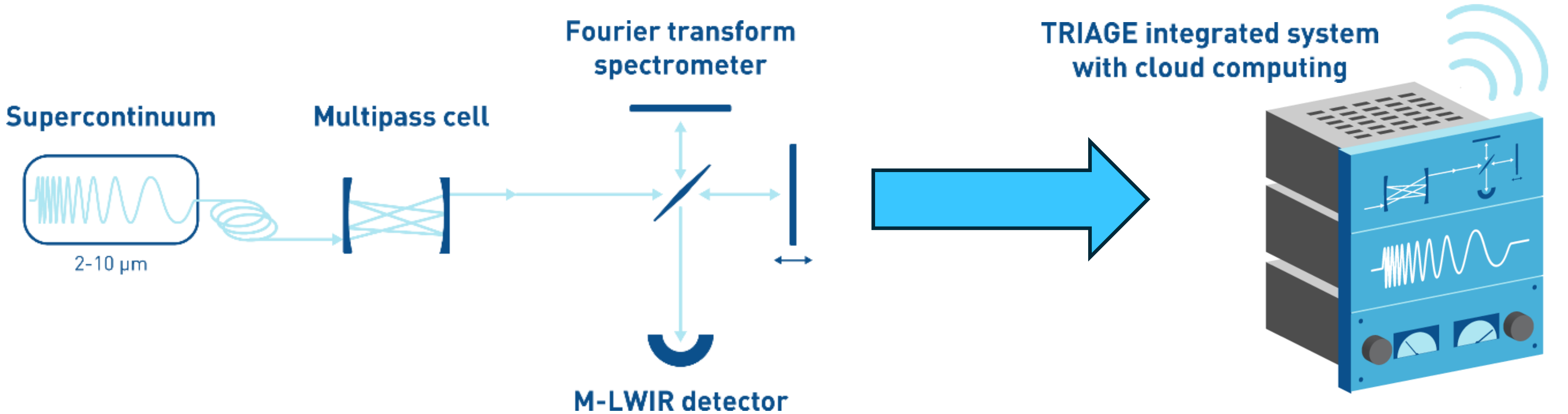
- Design and development of the first prototype
- FTS evaluation with multipass cell and free-path measurement
- FTS optimisation, using developed auto-balanced detector and multipass cell



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

System integration (SO5)

- Integrate all sub-systems as a single device
  - Unique user interface

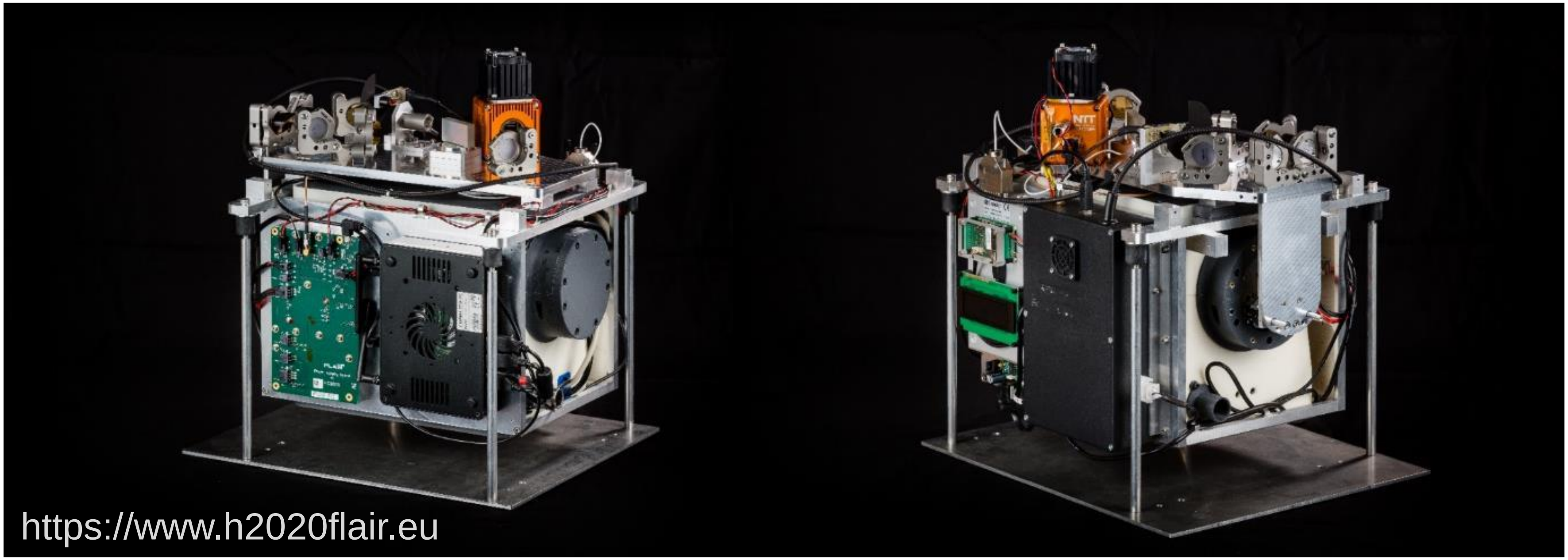


- Three prototypes will be developed and tested *in situ*

2× first generation prototype

1 × improved final prototype

Building on FLAIR



- 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

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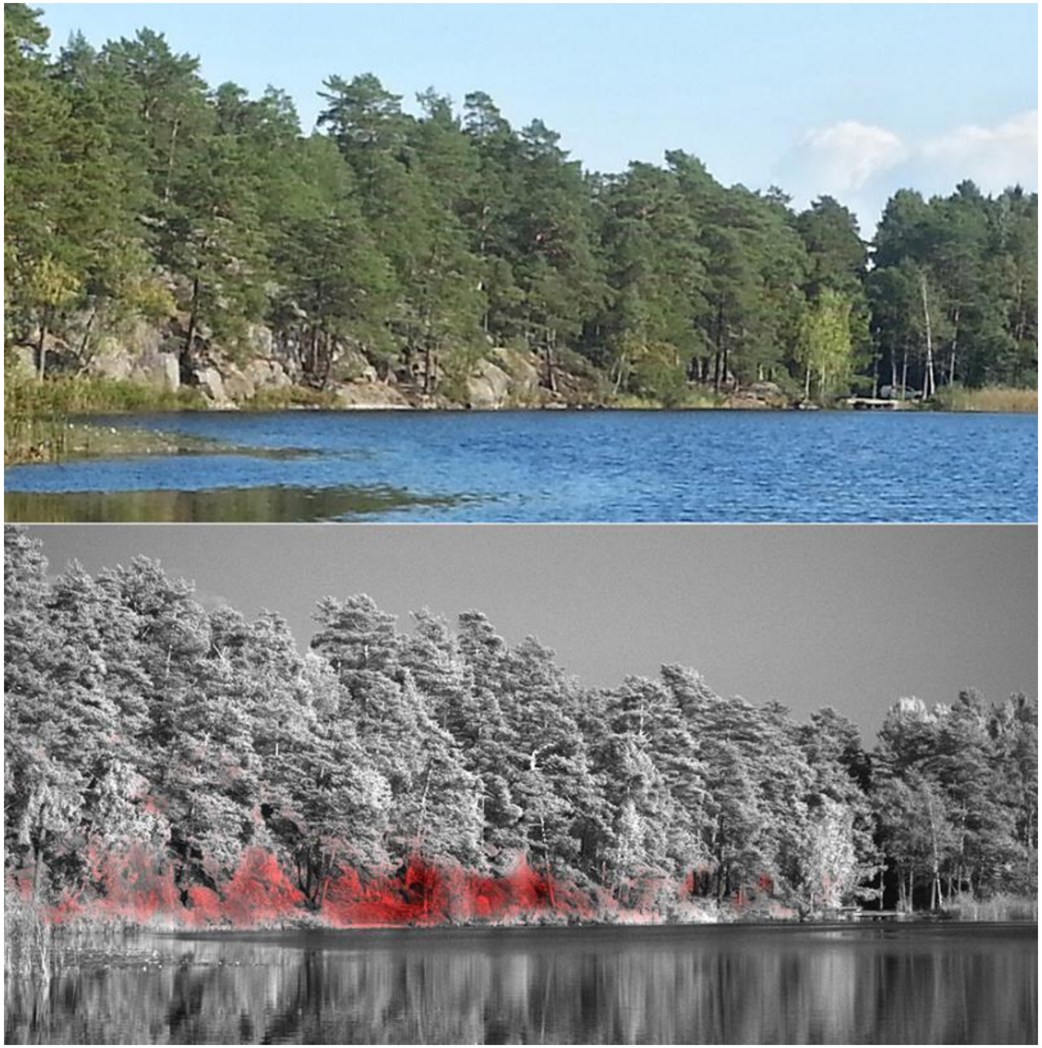
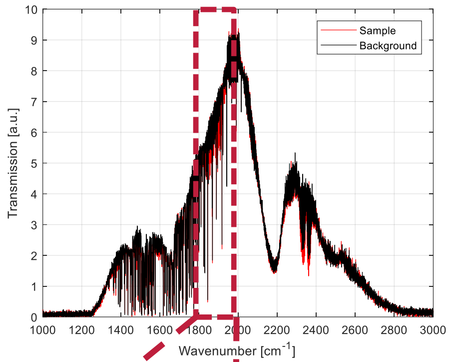


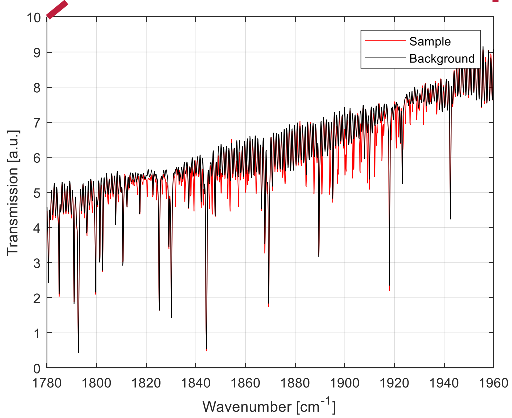
[Image from: Gålfalk *et al.* 2016. Nature Climate Change **6**:426-430.]

From spectrum to concentration

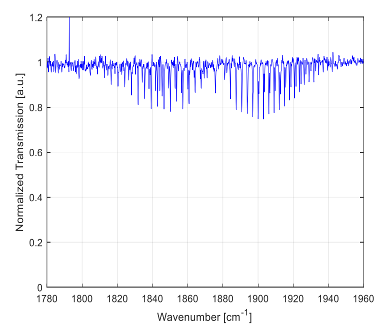
1-Measure spectrum on FTIR



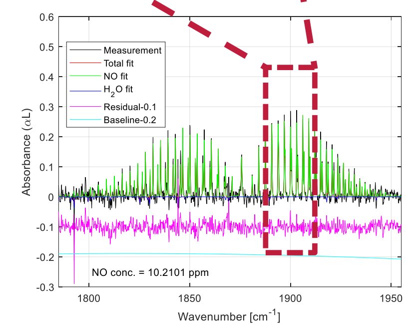
2-Select region of interest (ROI)

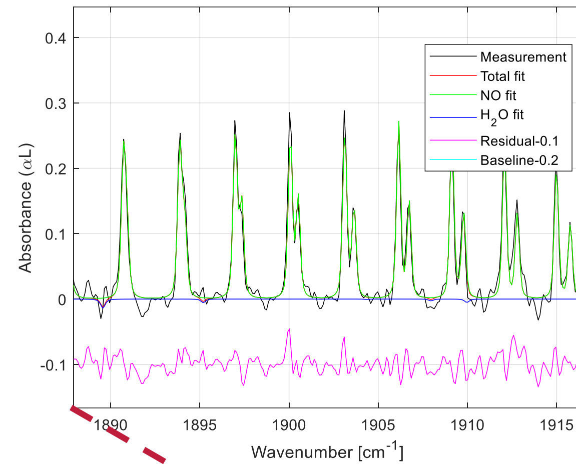


3-Normalise vs. background



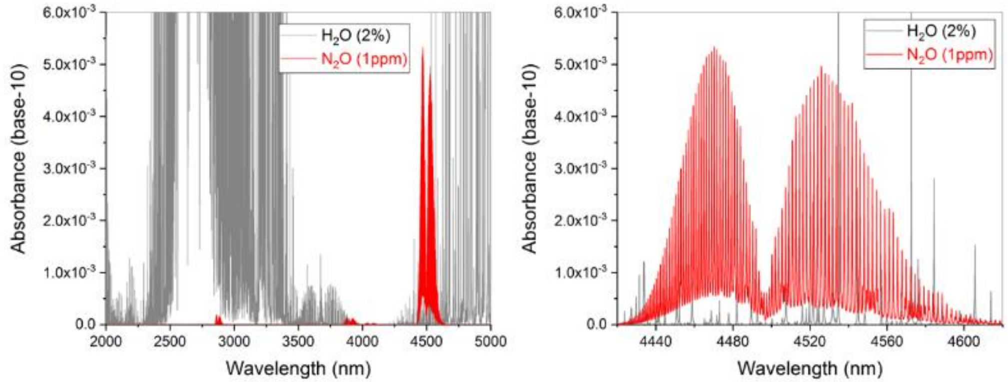
4-Spectral fitting to model and concentration retrieval



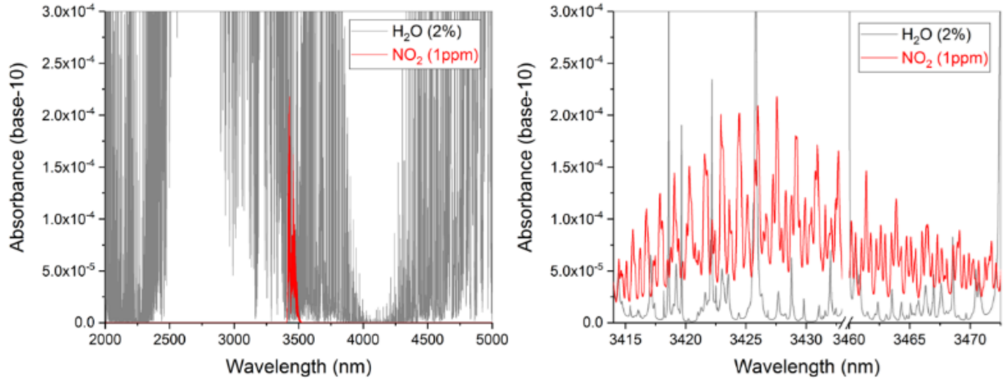


Reference database

- Constructing a reference database for the spectra of the target species
  - Development of a reference database for absorption spectral fingerprints



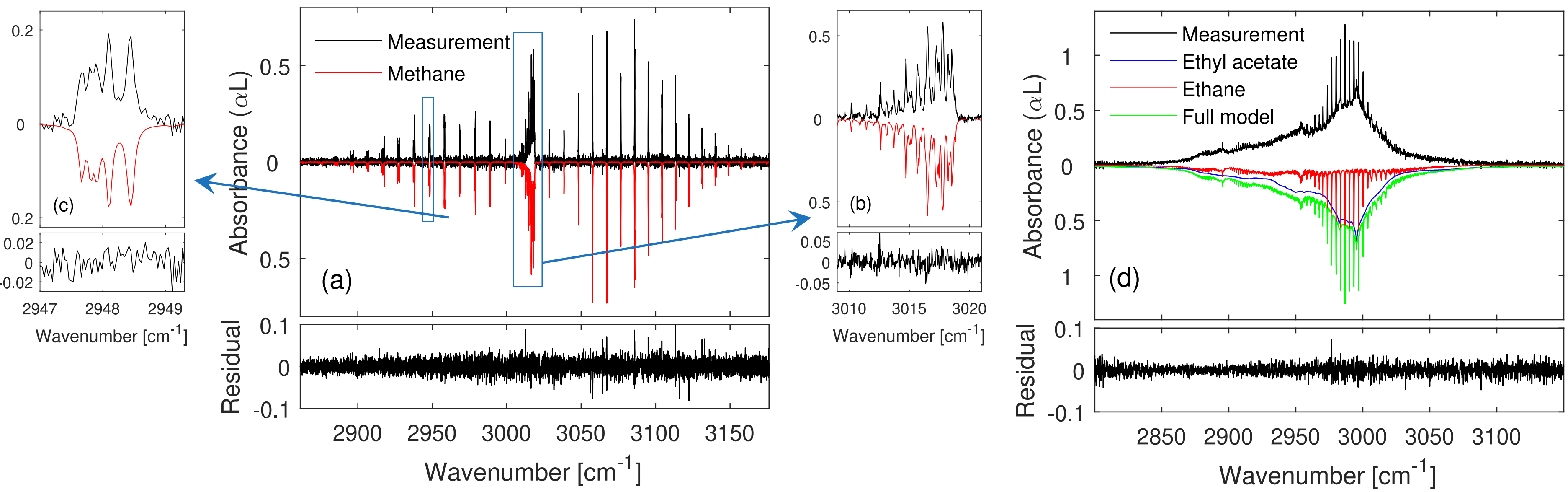
  - Effect of the interfering atmospheric species



Conventional fitting evaluation

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



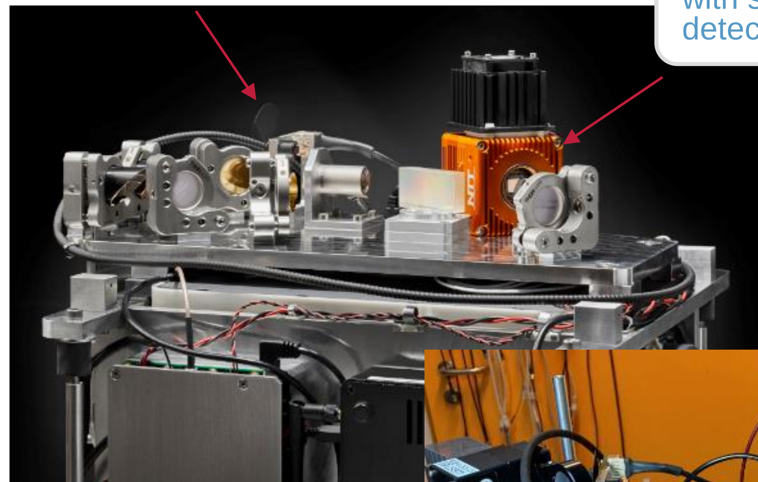
FLAIR adaptation for 24/7 operation

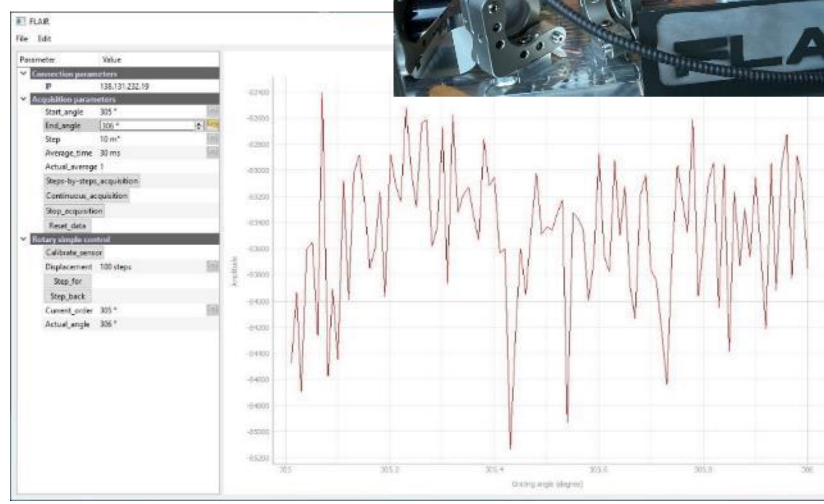
csem

- NIT IR camera replaced with single pixel MTC detector
- Lock-in detection on SC rep rate (200 kHz) on first four harmonics by a dedicated FPGA
- Provides data for ML training and big data implementation and validation
- GUI implementations for sub-systems and data management (readily adaptable for TRIAGE prototypes)

Chopper removed

Camera replaced with single pixel detector

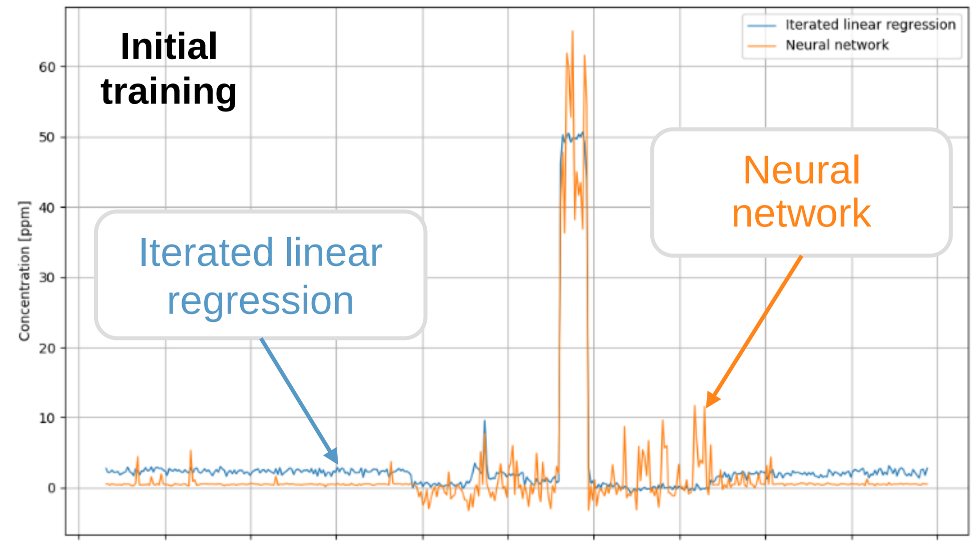


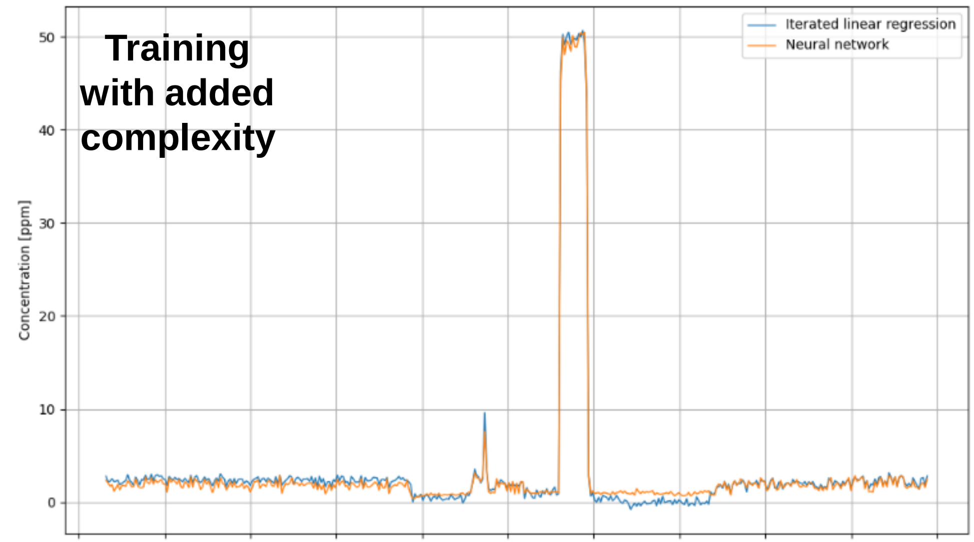


Deep learning algorithms (SO6)

- Machine learning (ML) algorithms for gas concentration estimates
- Neural network trained on synthetic data
- Added training data complexity
  - Random baselines
  - Random noise
  - Wavelength random shifts
- Benchmarking on data acquired by FLAIR

- Next steps:
  - Different neural network architectures
  - Fine-tune on TRIAGE real data

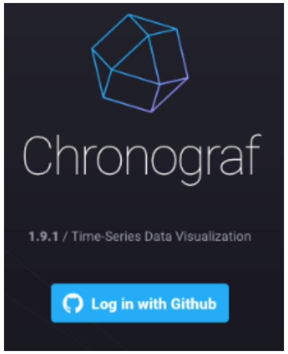


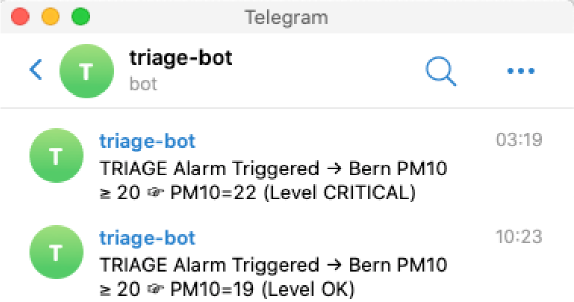


Big data management (SO7)

- Challenges
  - Integrate TRIAGE with other databases
  - Define data flows suitable for ML algorithms
  - Develop interfaces between ML and cloud platform(s)

- Progress
  - Migrated Air Quality DB and backend/frontend
    - Uses Swiss provider (exoscale.ch)
  - Dashboard at https://triage.tk
    - Accessible with *github* account
  - Air quality sends alarms via Telegram BOT
    - Try it! https://t.me/triager_bot
  - Set-up a file-based *Data Lake* (or *Data Store*)
    - On wasabi.com
    - Compatible with Amazon S3.
- Synchronised FLAIR data generator to wasabi in preparation for TRIAGE (Win10)





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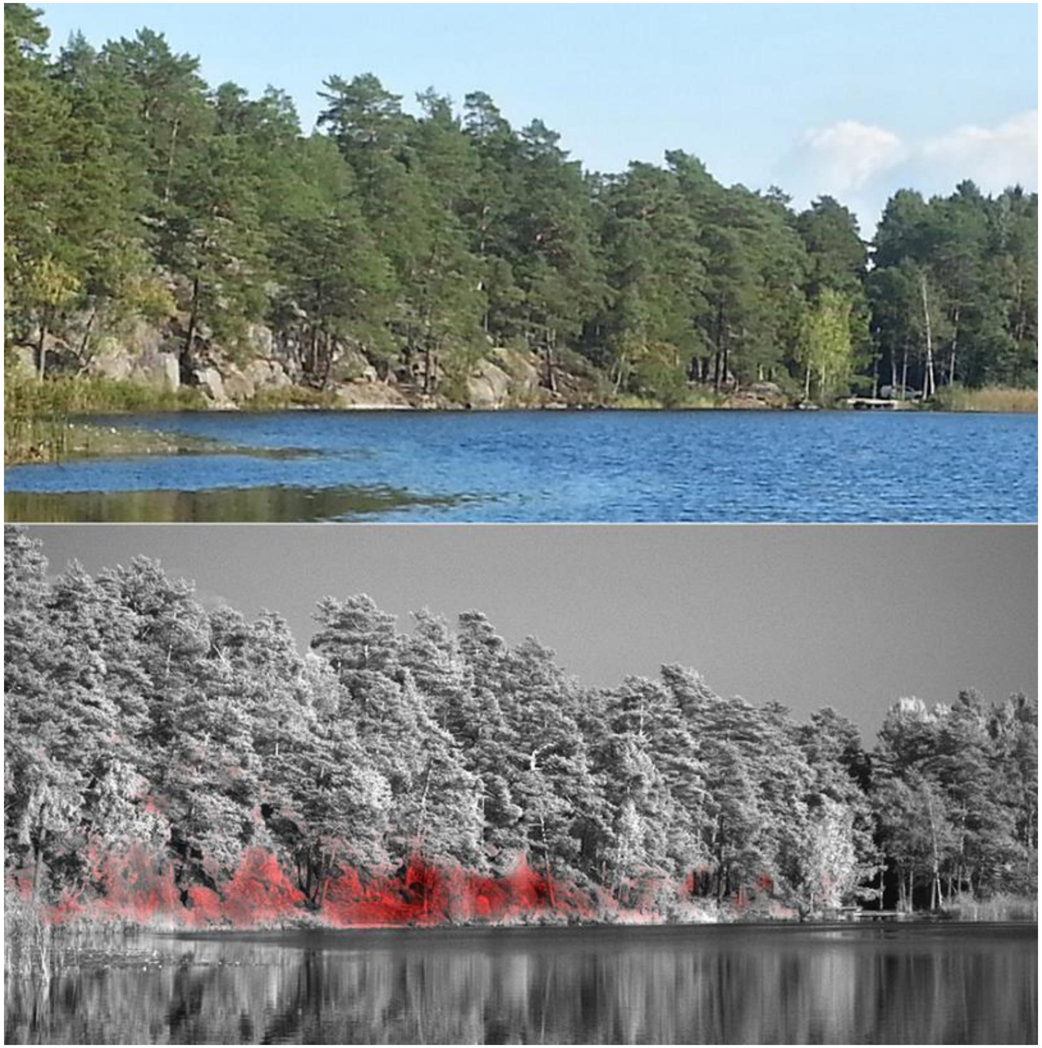

[Image from: Gålfalk *et al.* 2016. Nature Climate Change **6**:426-430.]

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

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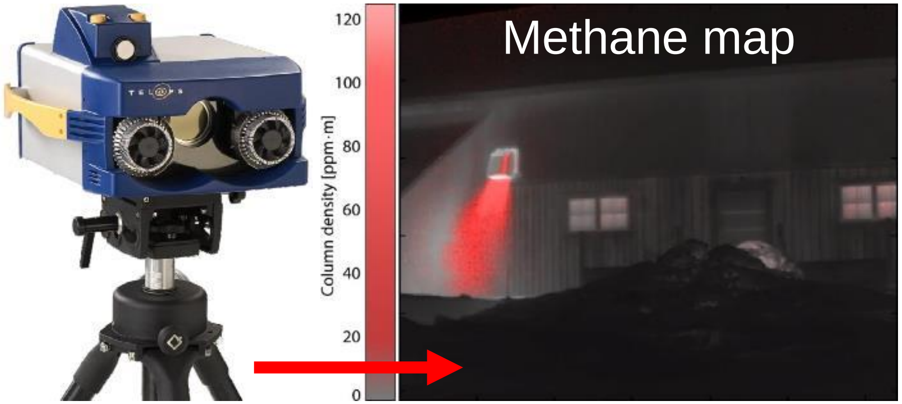
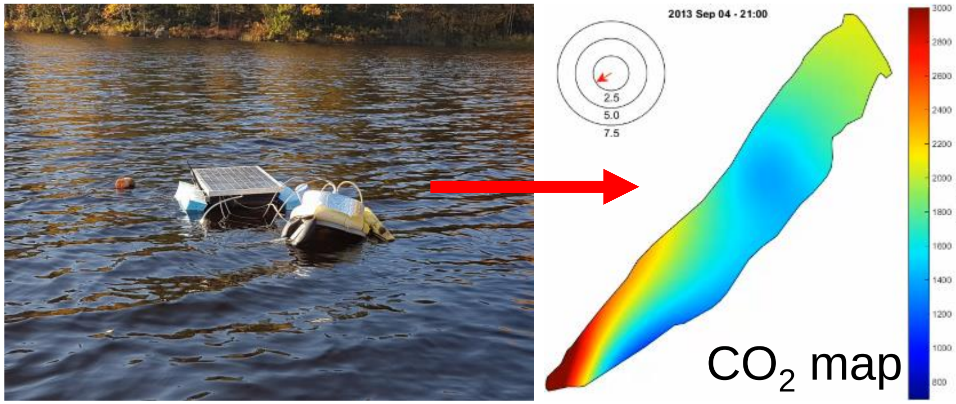
Trace gas method development

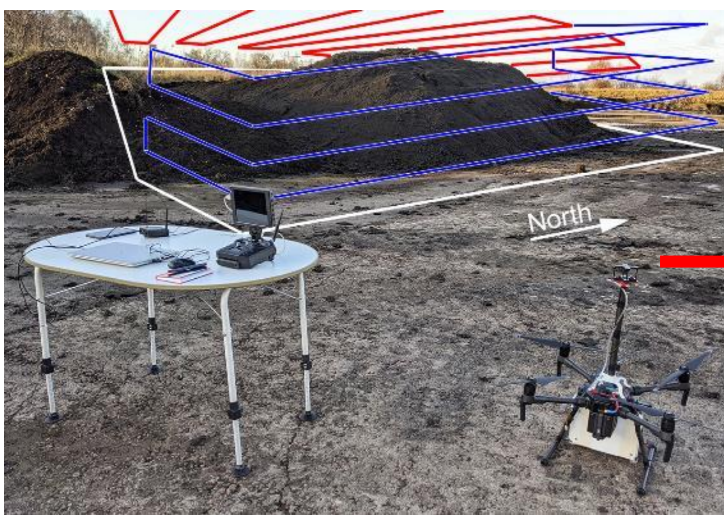


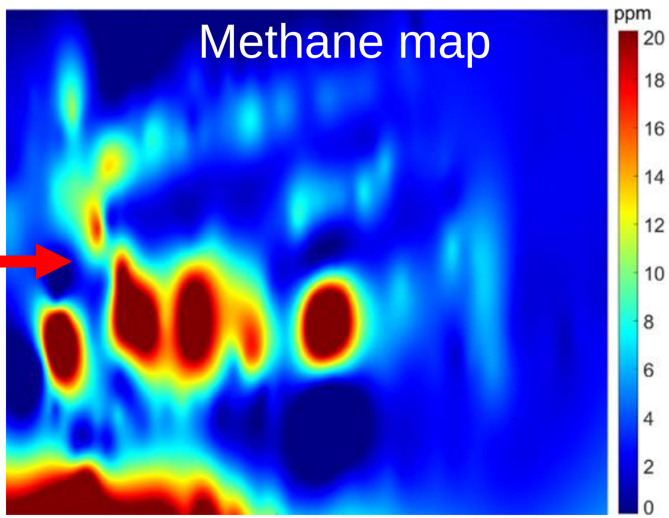
Hyperspectral imaging and quantification
(CH_4, N_2O, H_2O)



Automatic flux chambers
(CH_4, CO_2)

Drone system (CH_4, C_2H_6, H_2O)





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

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Examples of environments for field tests

- Laboratory tests
  - Initial tests can be performed in a controlled environment
  - *E.g*. short-term drift, response time, gas interference, voltage
- Waste incineration
  - Test of instrument robustness in tough conditions
- Wastewater treatment and biogas plant
  - Temporal emission variations and unexpectedly high levels (alarm)
- Sensor validation in an urban environment
  - Air pollution monitoring on a rooftop in Stockholm
  - Source attribution test using tracer gas flux measurements
  - Long-term testing, real-time citizen alerts on pollution levels
- Natural emissions
  - Greenhouse gas (CO_2, CH_4, N_2O) emissions from wetlands

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Wastewater treatment plant (Linköping, Sweden)

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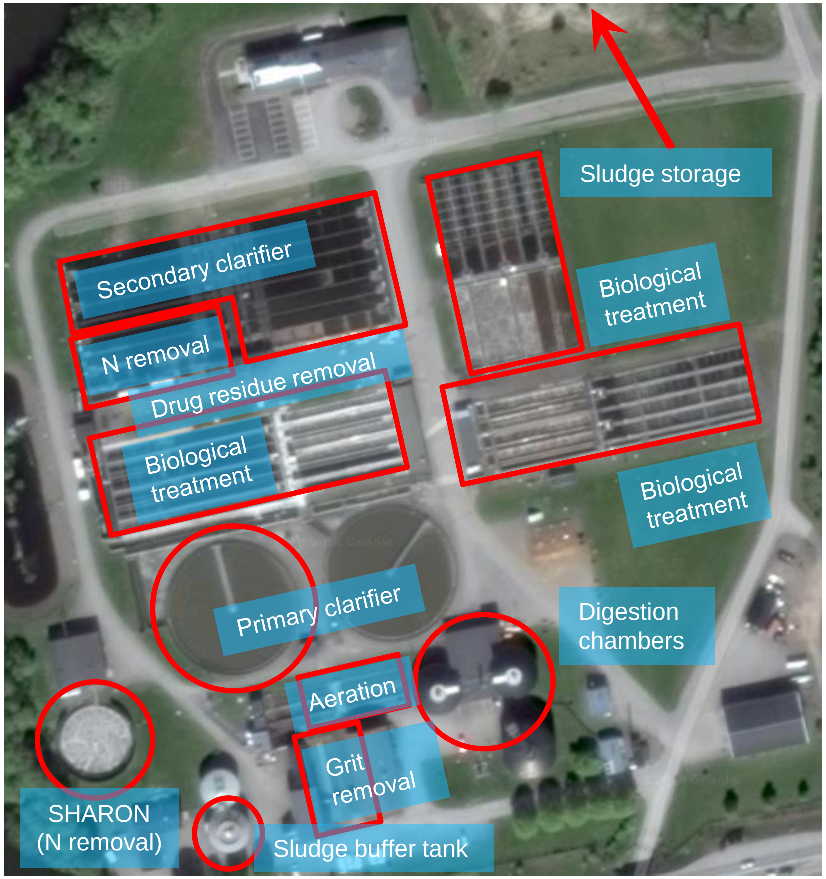

- Greenhouse gas emissions were mapped across different parts of a wastewater treatment plant over a one year period
- This provided important baseline information for planning potential future TRIAGE tests in this environment
- Results showed high temporal variability and identified clear emission hotspots
- This was also the case for a nearby biogas plant.
- For more information see reference below.

Gålfalk M., Nilsson Påledal S., Sehlén R., Bastviken D.
Ground-based remote sensing of CH_4 and N_2O fluxes from a wastewater treatment plant and nearby biogas production with discoveries of unexpected sources.
Environmental Research. 2022, **204**, Part B, 111978.

Skogaryd catchment (Sweden)
Natural greenhouse gas emissions test site

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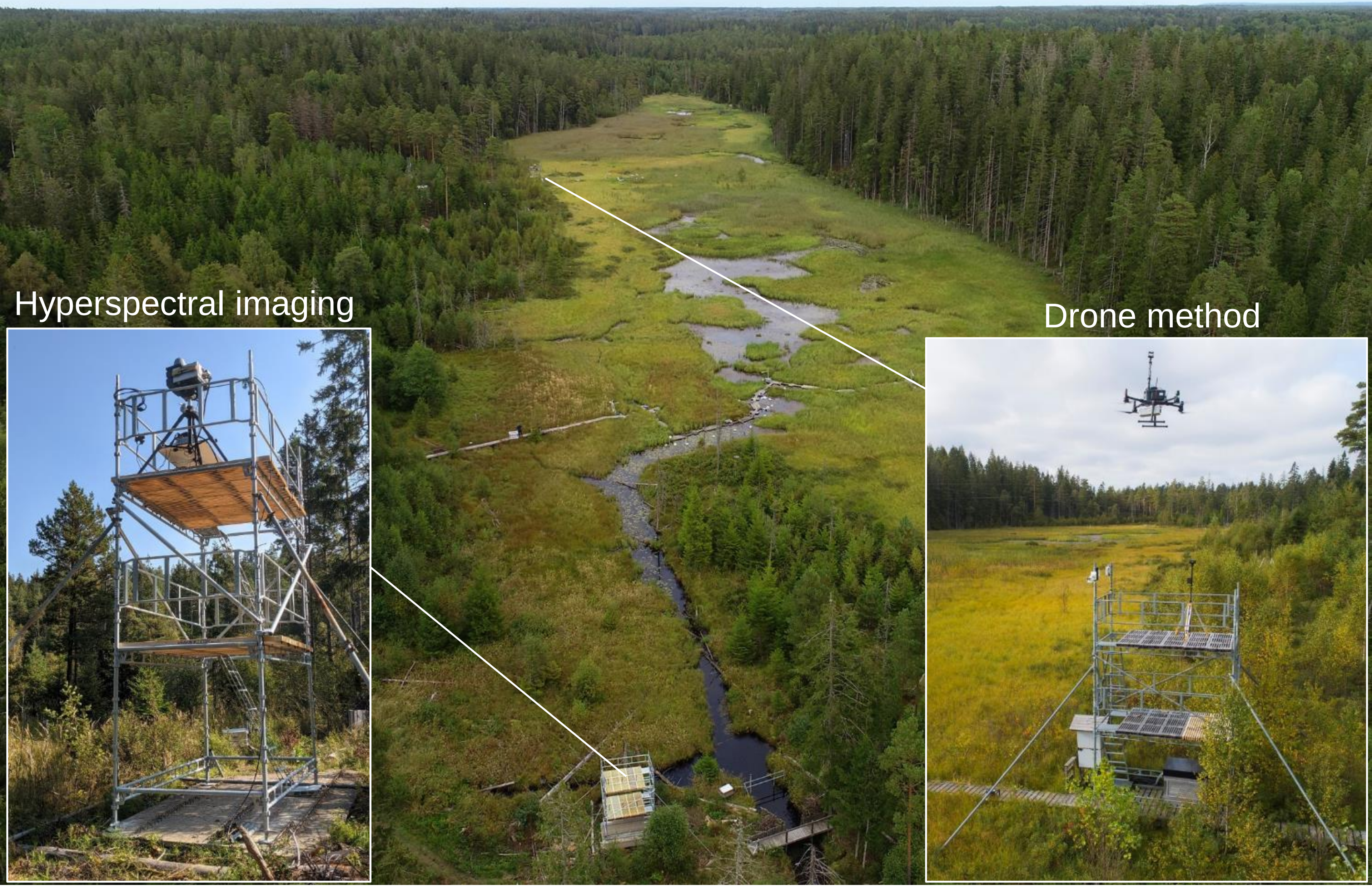

Thank you for your attention!

Dissemination lead

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