Networking Event

Technology for Aeronomy

Ground-based instruments for the study of atmospheric composition

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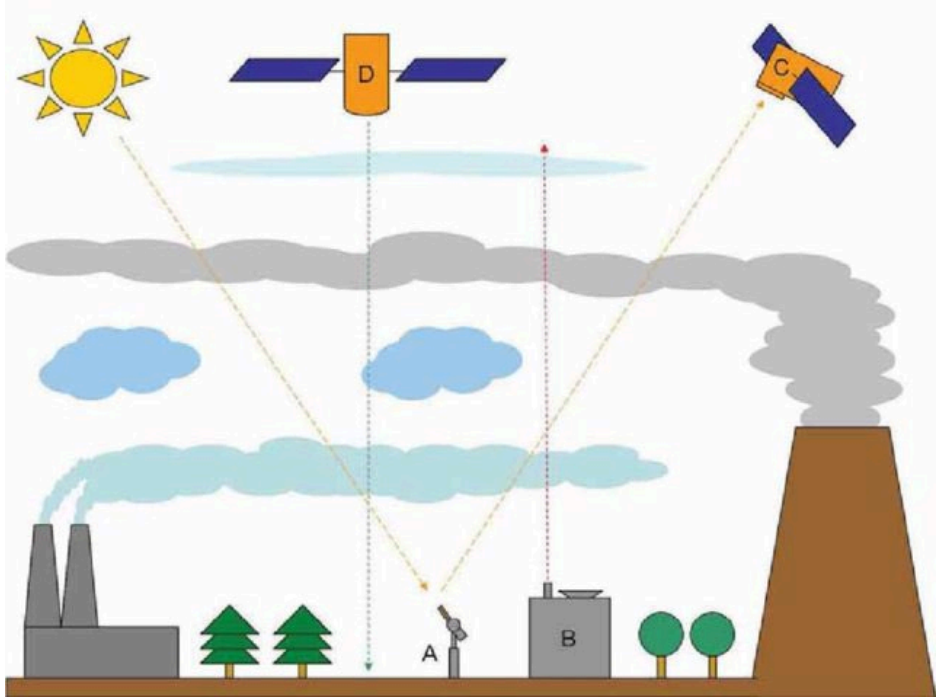
BIRA•IASB

Introduction

- Ground-based observations are complementary to satellite ones, e.g. they provide an essential source of **independent** information to **calibrate** or **validate** satellite measurements.
- Ground-based instruments can be deployed in **networks** (long-term static measurements) organised at local or global scale. E.g. the Network for the Detection of Atmospheric Composition Changes (**NDACC**).
- They can also be used in measurement **campaigns**, e.g. providing ground support for airborne measurements.
- Ground-based experiments used at BIRA-IASB are generally developed in-house with support from our **engineering department**. However due to limited resources, we are increasingly looking for **external support**.

Remote-sensing of atmospheric composition

- **General principle**: derive information on atmospheric gases or particles through analysis of how these species interact with incoming radiation
- The applications developed at BIRA mostly use the **sun as light source**, or the radiation thermally emitted by the earth → **passive** remote-sensing
- Instruments are based on **optical spectrometers** (grating spectrometers or interferometers)



Principle of atmospheric remote-sensing

Picture from Tero Mielonen (FMI)

Outline of this talk

- Develop a few **examples** of ongoing ground-based activities and realizations, with a focus on technological aspects:
  - Fourier transform infrared (**FTIR**) remote-sensing
  - UV-Visible differential optical absorption (**DOAS**) remote-sensing
  - **SWING** airborne mapping of air quality gases
  - **SEMPAS** project on the remote-sensing of ship emissions

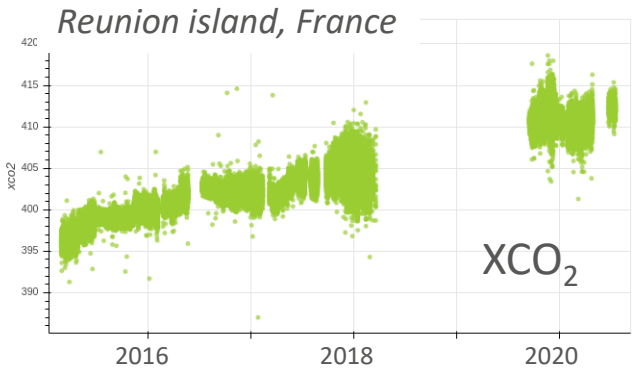
- There are more ground-based developments ongoing at BIRA (e.g. BRAMS, the NO_2 camera, etc), some of them are demonstrated around this tent

Permanent FTIR observatories

3 permanent observatories with a high-resolution FTIR spectrometer

Part of international networks that measure atmospheric composition using high-resolution FTIR
St. Denis & Maïdo at La Réunion, and Porto Velho in Brazil (Amazon)

- **BARCOS automation and remote control system including meteo station**
  fully autonomous operation with option of taking remote control
- **Solar tracker** with camera-based control software
- **Software** for operational and data management



TCCON data DOI: 10.14291/tccon.ggg2020.reunion01.R0

Martine De Mazière, Filip Desmet and FTIR team

Mobile compact spectrometers

Towards more affordable, compact spectrometers to increase global coverage

Enables participation in short-term campaigns and even mobile measurements

Enclosures for compact spectrometers: in development

- Compact, all-in-one easy to transport platform
- Compact innovative solar tracker
- Temperature-controlled enclosure
- Meteo station
- LN2-free operation
- Mobile FTIR measurements (car, ship) and remote / challenging locations complemented with low-cost sensors

Picture from Atmos. Meas. Tech., 14, 1111–1126, 2021

FTIR Perspectives

- **SEMPAS system** – Thermal infrared component: SO_2 and CO_2 monitoring (in development)
  - Combined FTIR and DOAS instrument to be placed on a platform in the North Sea
  - TIR measurements of ship exhaust plumes in the North Sea

- **Concepts for cubesat / nanosat / HAPS / aircraft / UAV payloads ready to respond to specific needs,**

  e.g., for measuring atmospheric hotspots of NH_3; for measuring vertical profiles of atmospheric species in troposphere; …

  - Looking for potential remote sensing IR (TIR or SWIR) techniques that fit the platform and the target requirements

    → Laser Heterodyne Spectroradiometry, Fabry-Pérot, else …?

Permanent MAX-DOAS observatories

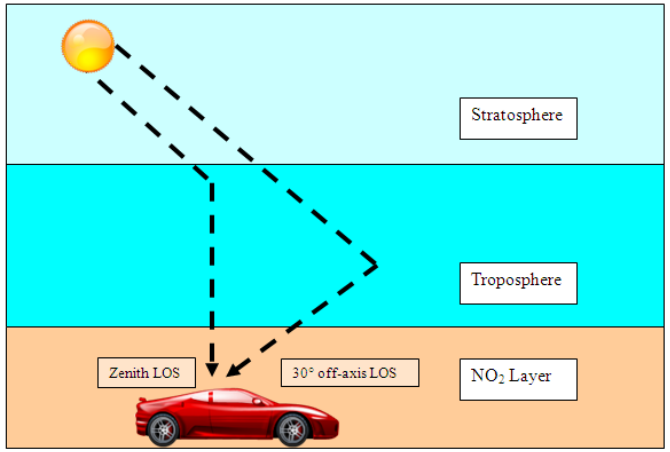
- **MAX-DOAS** = Multi-Axis Differential Optical Absorption Spectroscopy
- Systems **developed at BIRA** based on commercial components assembled with the support of the engineering department
- Operated **worldwide** in various sites, as part of international networks

- **Optical head** mounted on suntracker
- Thermally stabilised **spectrometric** units
- **Acquisition** and **retrieval** software developed in house

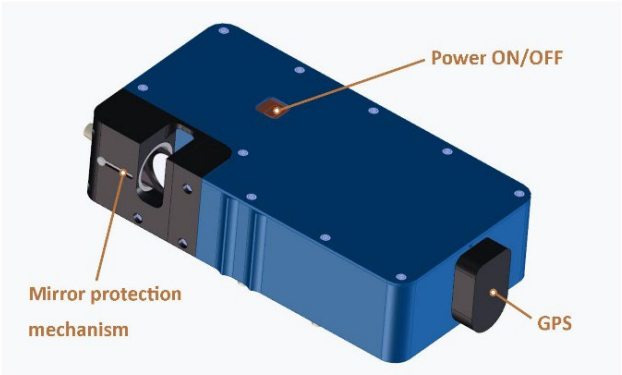
Michel Van Roozendael, Alexis Merlaud and the UV-Vis team

Mobile DOAS experiments

- **DOAS** experiments based on compact grating spectrometers operated on **mobile platforms** (e.g. car, bicycle) for local applications, campaigns, etc
- Systems developed at BIRA with support from engineering



Bike-DOAS experiment



AeroMobil

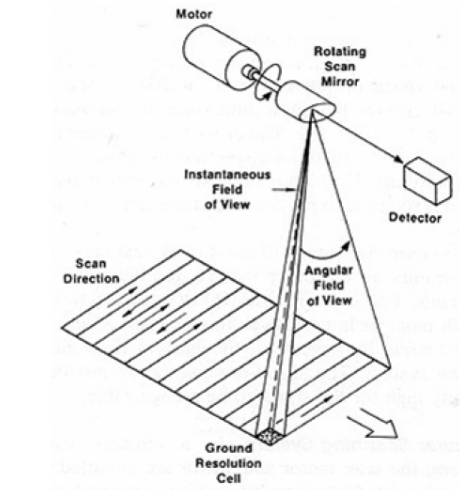
http://aeromobil.be/index.php/fr/

UV-Vis DOAS Perspectives

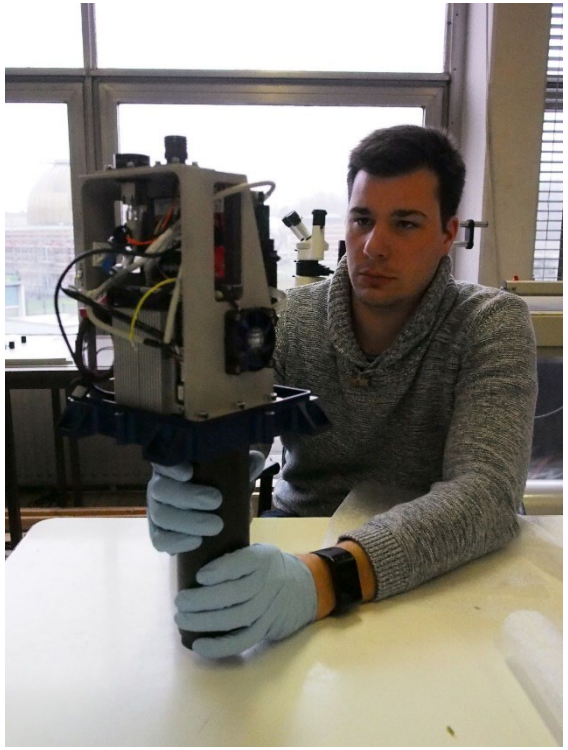
- Extend **measurement capabilities**, e.g. to include polarization channels
- Rationalise design for better **operationalisation** (current systems are build on purpose and do not share a common design)
- Develop **new measurement concepts**, e.g. trace gas imaging systems allowing to monitor pollution plumes (cf. AOTF-based NO_2 camera, see demos)

Air Quality mapping with SWING

SWING: Small Whiskbroom Imager for Atmospheric compositioN monitorinG

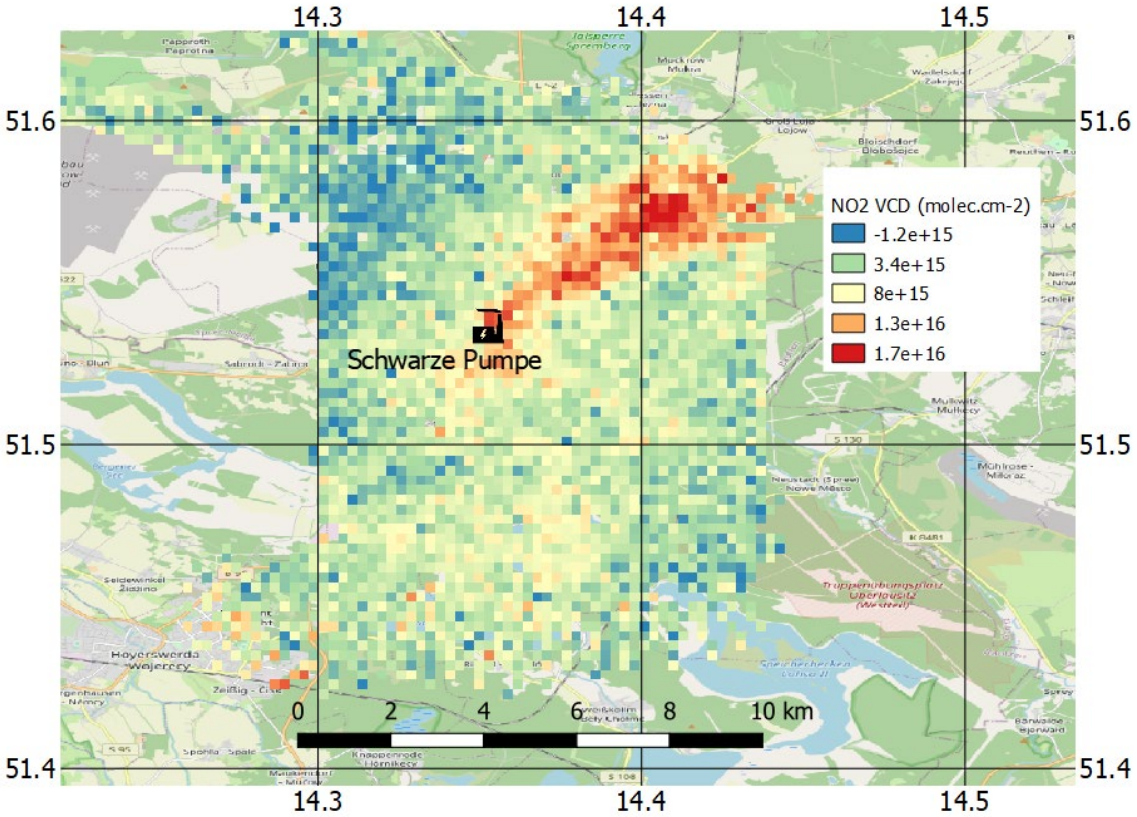


Whiskbroom set-up using a compact UV-Vis spectrometer



Several versions developed at BIRA-IASB in the context of air quality **satellite validation**

Produces maps of NO_2 and SO_2 above polluted areas (power plants, cities …)



SWING operations from various airborne platforms

UAV (Romania)

Cessa 307
(Gemany)

Motorglider
(Gemany)

BN-2
(Romania)

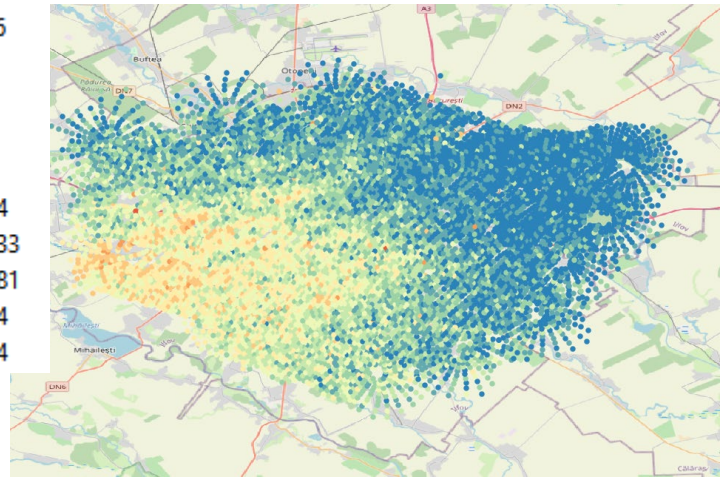
Thanks to our colleagues from Free Uni. Berlin and INCAS, Bucharest!

Exemple of SWING data: Spatio-temporal evolution of the NO_2 plume from Bucharest in 2021

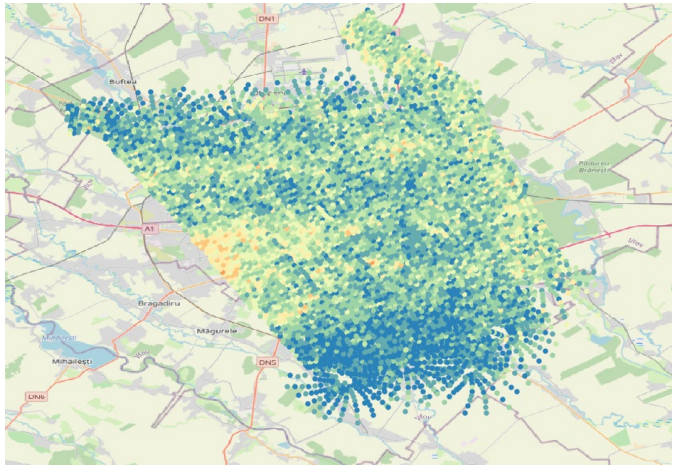
NO_2 Tropo (Pmolec.cm^{-2})

- -2.12 - 4.26
- 4.26 - 5.39
- 5.39 - 6.38
- 6.38 - 7.38
- 7.38 - 8.57
- 8.57 - 10.14
- 10.14 - 12.33
- 12.33 - 14.81
- 14.81 - 19.4
- 19.4 - 51.44

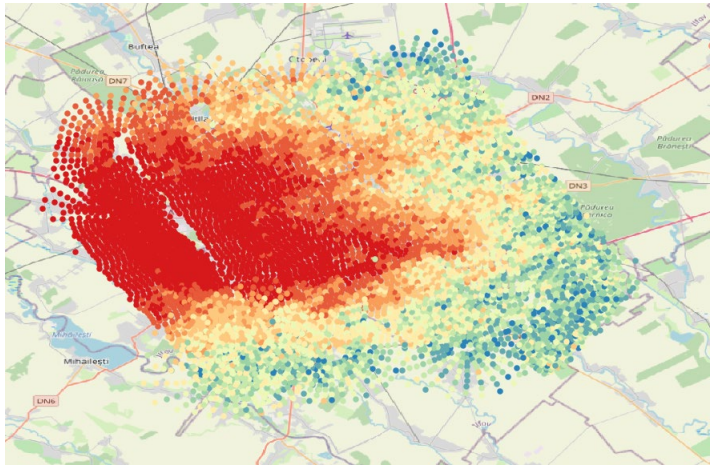
1 July 2021



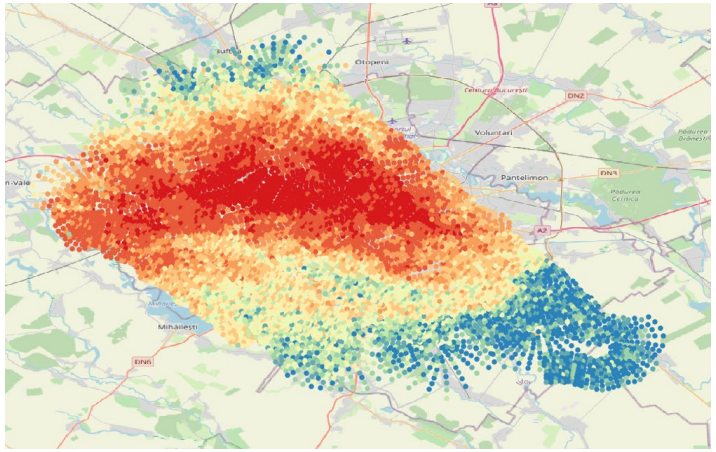
10 July 2021



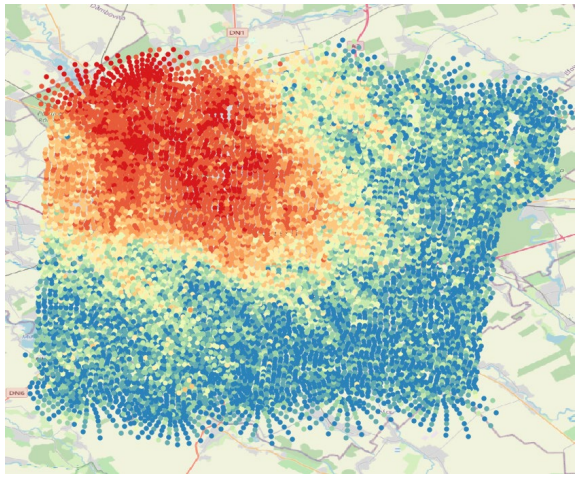
29 October 2021



4 November 2021



5 November 2021



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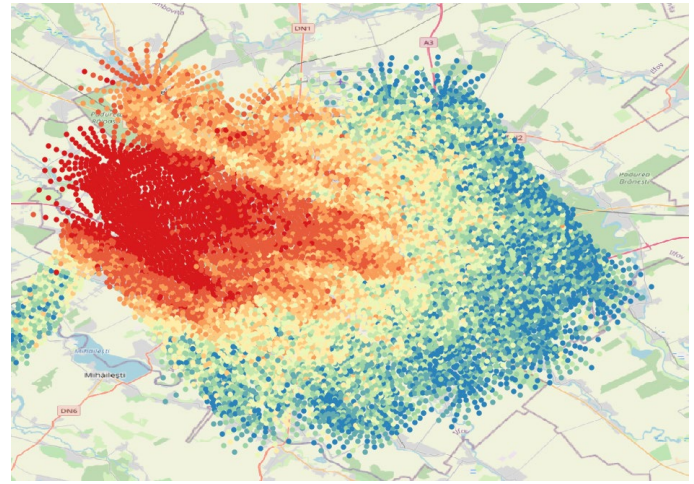


Larger NO_2 columns in winter due to larger emissions (heating) and longer lifetime of NO_2

Alexis Merlaud and UV-Vis team

SWING Perspectives

- SWING instrument **increasingly deployed** in various projects, in particular for **satellite validation**
- Current deployments take place in **Germany, Romania and Italy** with ESA funding
- Next to satellite validation, SWING airborne imaging can be used for **quantification of emissions** or atmospheric model validation
- SWING selected for the **ATMO-TECH proposal** (call HORIZON Europe), aimed to increase TRL of innovative scientific instruments for atmospheric monitoring
- SWING is **compact** and can potentially be adapted to **cubesat**, **stratospheric UAVs**...

Ref for SWING: Merlaud et al., 2018, AMT, Tack et al., 2019 AMT, Merlaud et al., 2020, AMT

SEMPAS project

SEMPAS – Ship Emission Monitoring using Passive Absorption Spectroscopy

- Instrument to remotely measure **NO_2, SO_2 and CO_2 emissions** from ship plumes, from which the fuel sulfur content (FSC) can be quantified
- Dedicated to **verify compliance** of ships with limits set in MARPOL Annex VI regulations
- Based on a combination of remote sensing instruments in **UV-Vis** and **thermal infrared** (TIR) range
- To be operated off-shore from a windmill farm
- Funded by DG Environment and Nationale Loterij

Federale Overheidsdienst Mobiliteit en Vervoer DG Scheepvaart

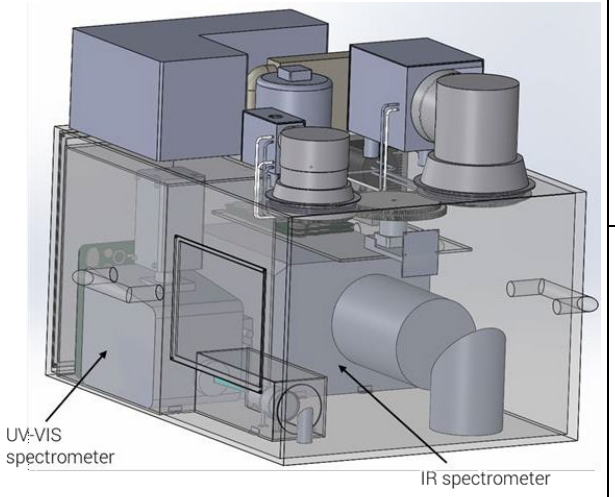
federal public service HEALTH, FOOD CHAIN SAFETY AND ENVIRONMENT

nationale loterij

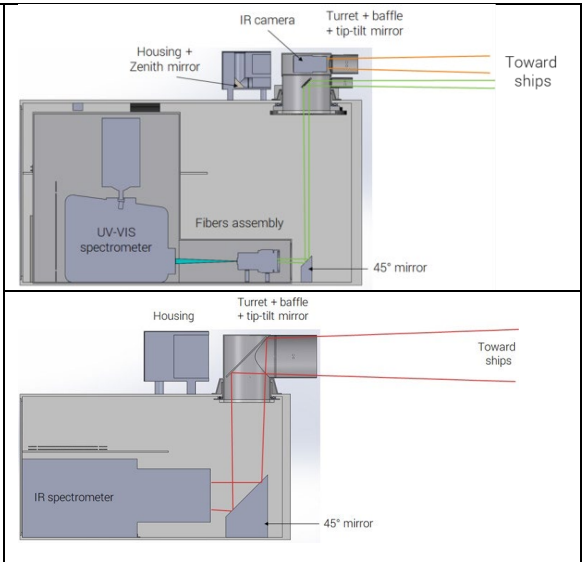
Status and development plan

- Instrument **concept design** realized with the support of Lambda-X

- **Next steps** (2022-2024):
  - De-risking phase (ongoing)
  - Alpha prototype
  - Beta prototype (final instrument)
  - Tests and optimisation from coastal site
  - Operation off-shore on transformer platform for a 1-year demonstration



3D CAD conceptual design



Section views for VIS and IR xspectrometers

Summary

- Ground-based instruments **mostly developed in-house**, based on commercially available components and with the support of the BIRA engineering department for integration
- **Strengths**: agility, low costs, direct interaction between scientists and engineers
- **Limitations**: internal resources limited to small/medium size projects

- **Increasing need** for external support (e.g. SEMPAS project) in order to address **larger scale** projects
- Look for **expertise addressing specifics needs**, e.g. on compact remote sensing IR (TIR or SWIR) techniques suitable for operation on small airborne or satellite platforms

THANK YOU!

MORE INFO?

www.aeronomie.be