NIMCAM: a compact multispectral instrument for detection of fugitive methane emissions at high spatial resolution

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Summary

NIMCAM: Near Infrared Multispectral Camera for Atmospheric Methane

PhD project 2017-2021, developing a **small, low-cost satellite instrument** for monitoring **fugitive methane emissions**, with potential for constellation deployment

Multispectral imaging for continuous monitoring and plume detection

Small number of **narrow bandwidth** thin film interference filters, isolating absorption features of methane and water vapour in the near infrared

Observation simulation with modelled plumes (gaussian) indicates plume detection at **leak rates around 400 kg/hr**, representing 95%+ of real world fugitive emission sources

ISS feasibility study (UKSA) 2020-2021

CEOI Pathfinder study KO April 2021

Methane: a potent greenhouse gas

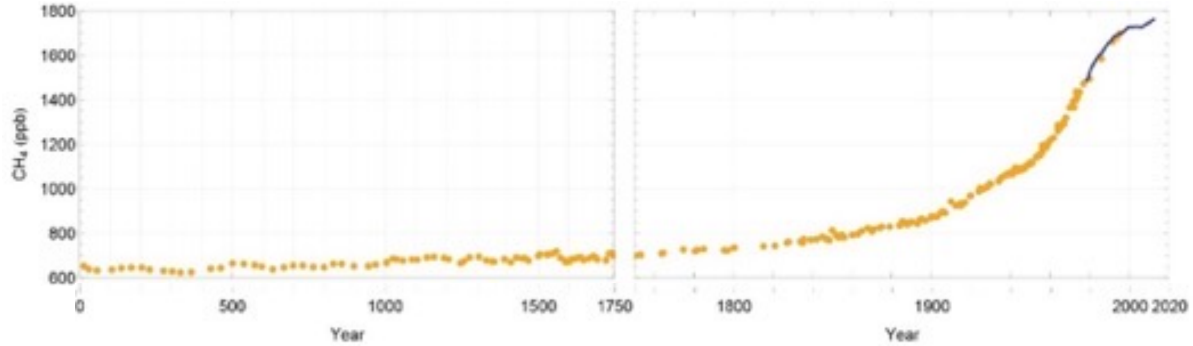
Methane has an **86-fold greenhouse efficiency** compared to CO2 (over 20 years).

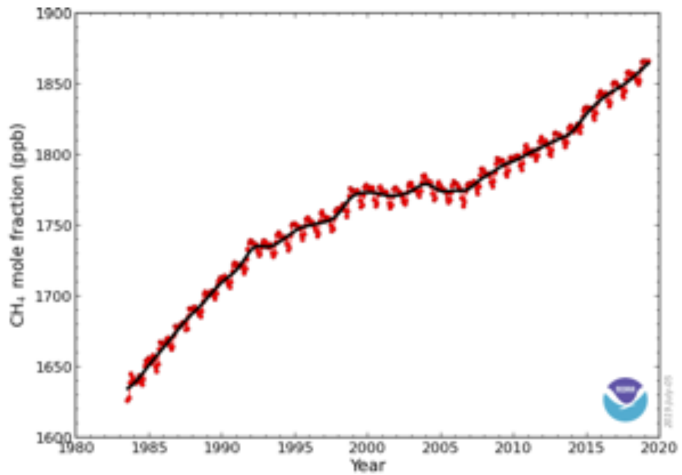
2.5 fold increase in atmospheric concentration since preindustrial era, driven by anthropogenic emissions.

Recent variations remain unexplained.

An appealing target for short term climate action:

- 10 year atmospheric lifetime.
- Heavy tailed distribution from oil, gas, coal industry: a few large sources make up majority of emissions.





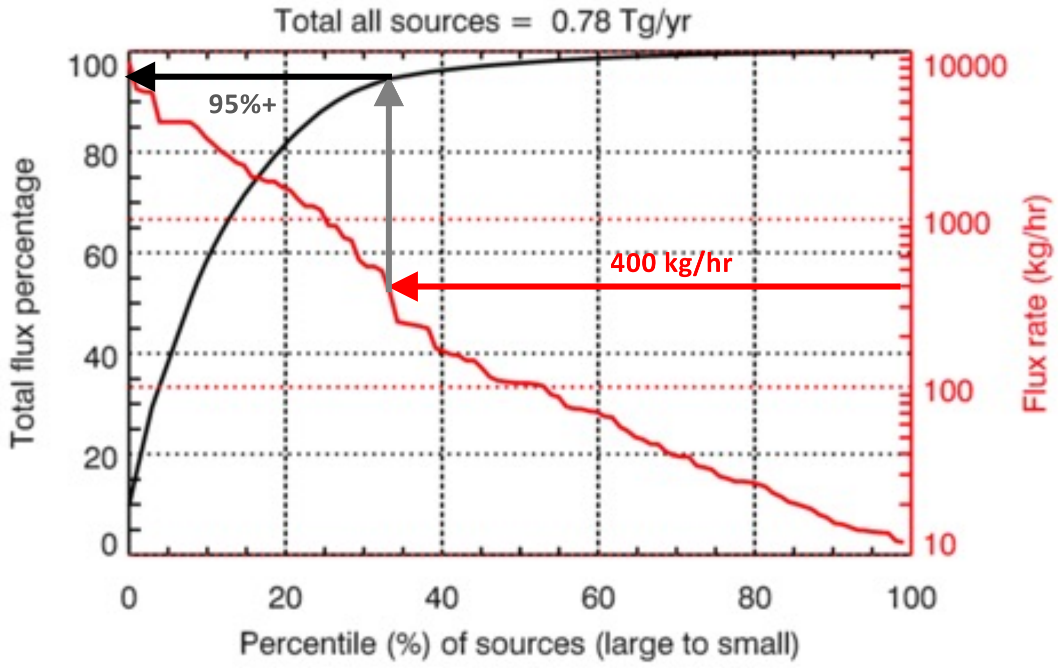
Fugitive methane emissions

Emissions from fossil fuel industry: around 30% of anthropogenic sources.

Point sources e.g. fracking well heads, pipeline compressor stations and gas processing plants.

Heavy tailed distribution: mitigating large point sources has a large net reduction effect.

Distribution of CH_4 point sources: European fossil fuel industry (E-PRTR)



(Original figure: Dominik Brunner, Empa / André Butz, Universität Heidelberg, used with permission)

Measurement gap

Large localised methane concentration enhancements due to point sources become small when averaged across kilometre scale pixels.

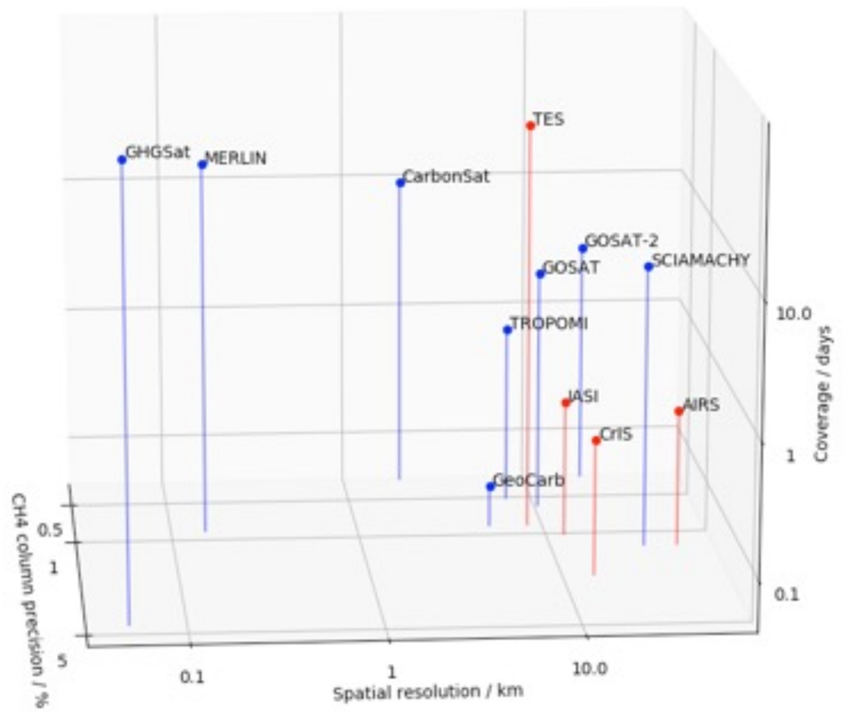
Most existing and planned satellite instruments **lack sufficient spatial resolution** to detect and quantify fugitive emissions.

Fine spatial resolution < 100 metres is required.

Private companies are testing concepts with higher spatial resolution (GHGSat, Bluefield).

Recently announced Carbon Mapper project (Planet, US).

Performance plot of current and proposed methane instruments, operating in SWIR and TIR



NIMCAM design drivers

Aiming to **detect and localise** methane plumes to **site scale without prior knowledge** (e.g. no targeting)

→ this requires high spatial resolution (and short integration times)

Maximise sensitivity to **boundary layer** methane enhancements

→ operating in SWIR to improve near surface sensitivity

Fugitive releases are often **intermittent**

→ revisit times should be low and spatial coverage broad to increase chances of observation; constellation deployment

Designing for **low cost** and deployment on a **small platform**

→ prefer optical and spectral design choices giving low size and complexity

Instrument spectral concept

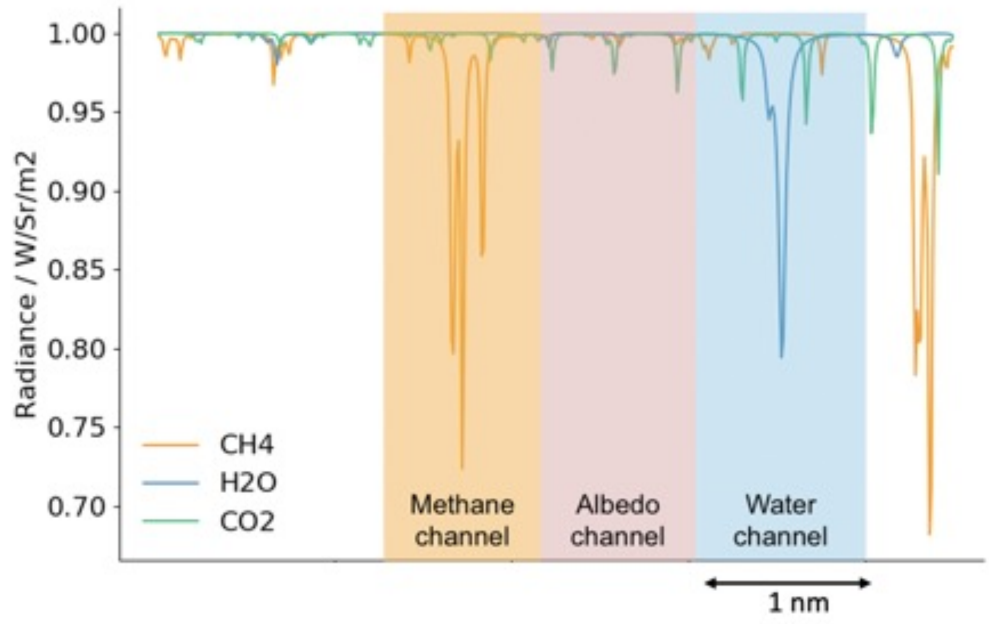
Three 1 nm FWHM channels located adjacent to each other close to 1640 nm (SWIR)

Channels tuned to a methane and water absorption feature, with a third channel to meaure surface reflectance

Modelling suggests good ability to reject the water and albedo signal and recover the methane enhancement information

Assumption that spectral characteristics of albedo (and aerosols) are effectively constant over the 3 nm interval

More channels would be required to e.g. fit a polynomial characteristic



Channel positions and target variables

Optical design

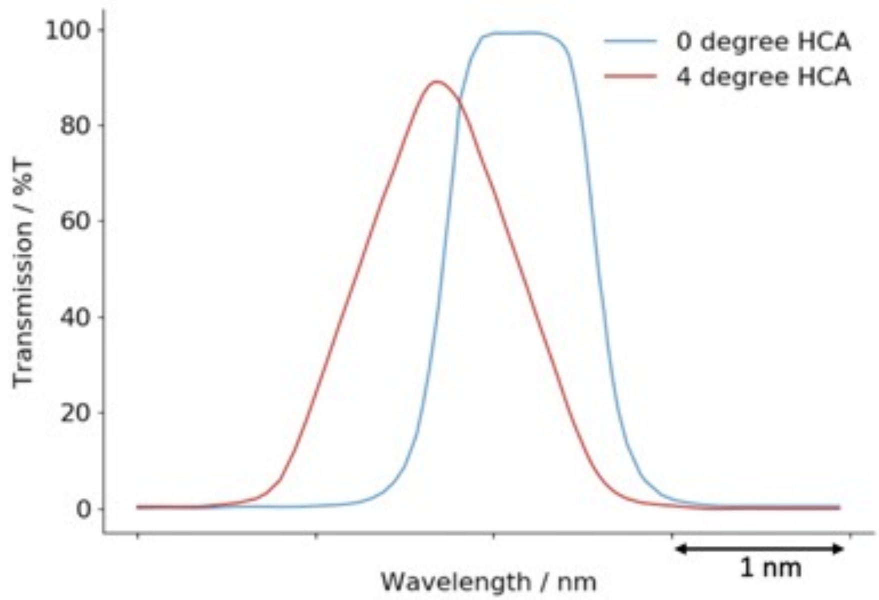
80 mm diameter primary aperture

Input field of view ±3.8˚

Narrowband filters at intermediate image, with telecentric relay lenses to produce parallel light cones through filter

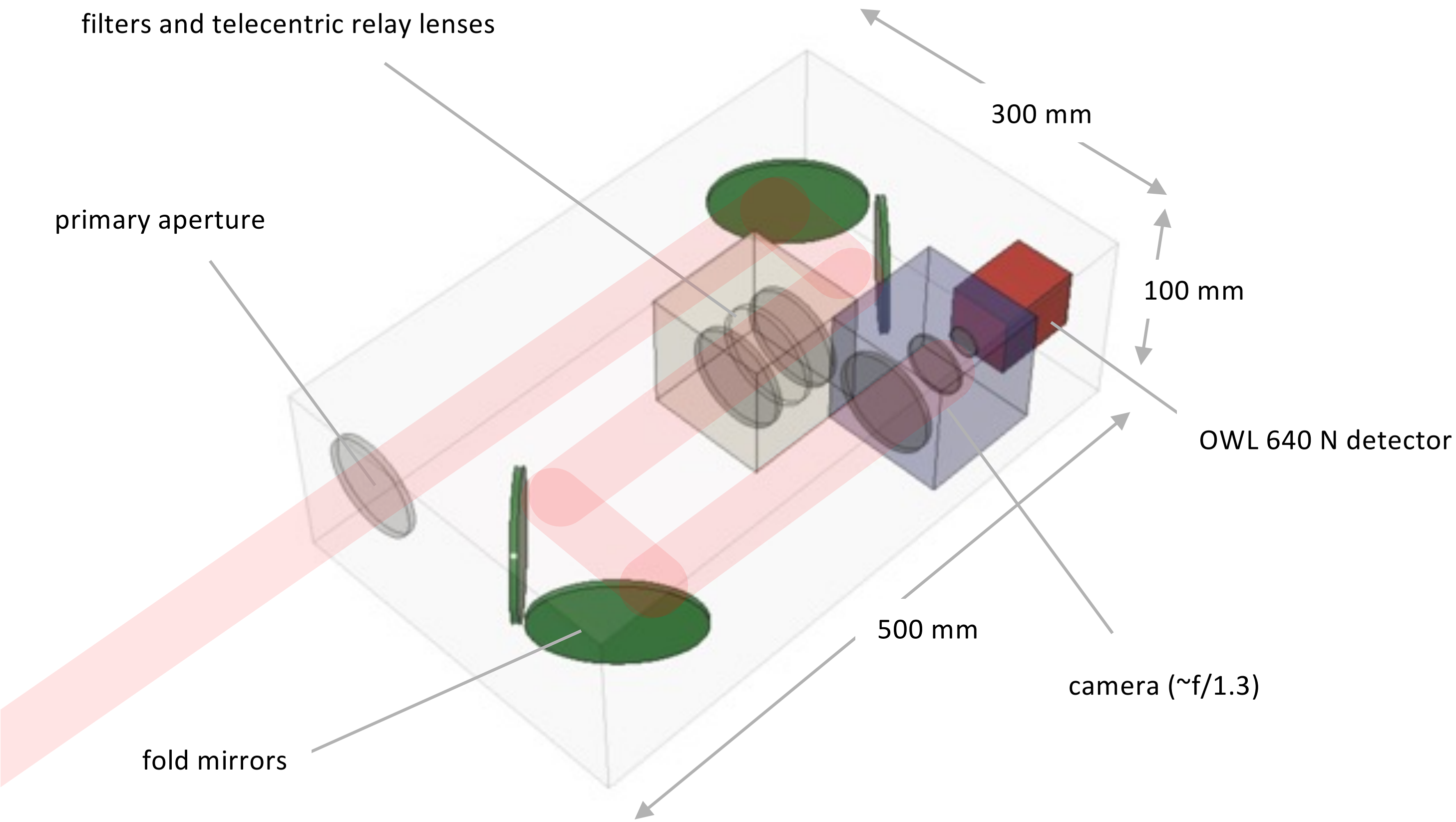
- Filter centre wavelength position has a strong dependence on incident ray angle
- Filter bandwidth has strong dependence on half cone angle (HCA) of beam
- Manufacturer (Materion) have provided simulated line shapes for 4˚ HCA filter

OWL 640 N: 640x512 InGaAs detector with 15µm pixels

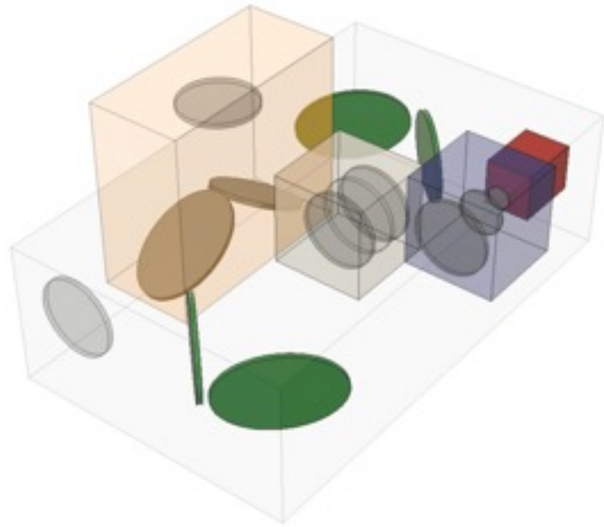


Modelled filter line shapes for 0˚ and 4˚ half cone angles, provided by Materion

Optical bench concept



ISS variant with K-mirror field de-rotator for platforms with reduced yaw stability



Observation concept

LEO, sun synchronous, small satellite platform, nadir pointing

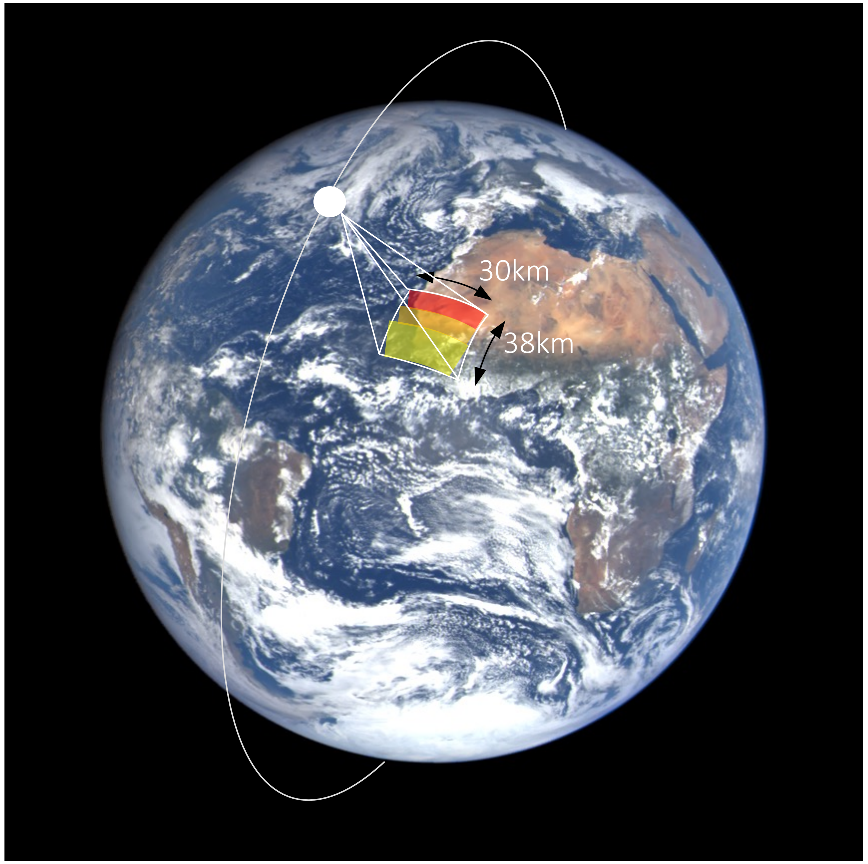
SWIR: daytime land observations

Roughly 30 km swath width with 60 metre ground pixel side

Single telescope and detector with filters arranged in strips perpendicular to ground track direction

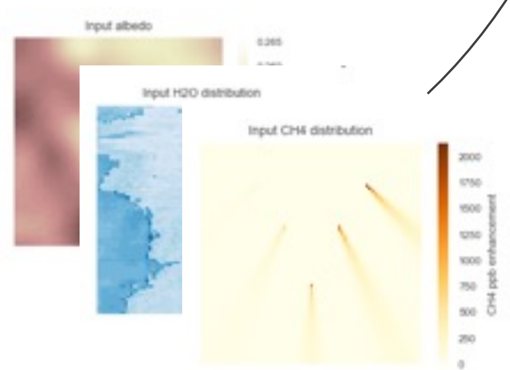
Co-addition of along-track pixels within each filter band by synchronising frame rate with ground velocity at ~60 Hz

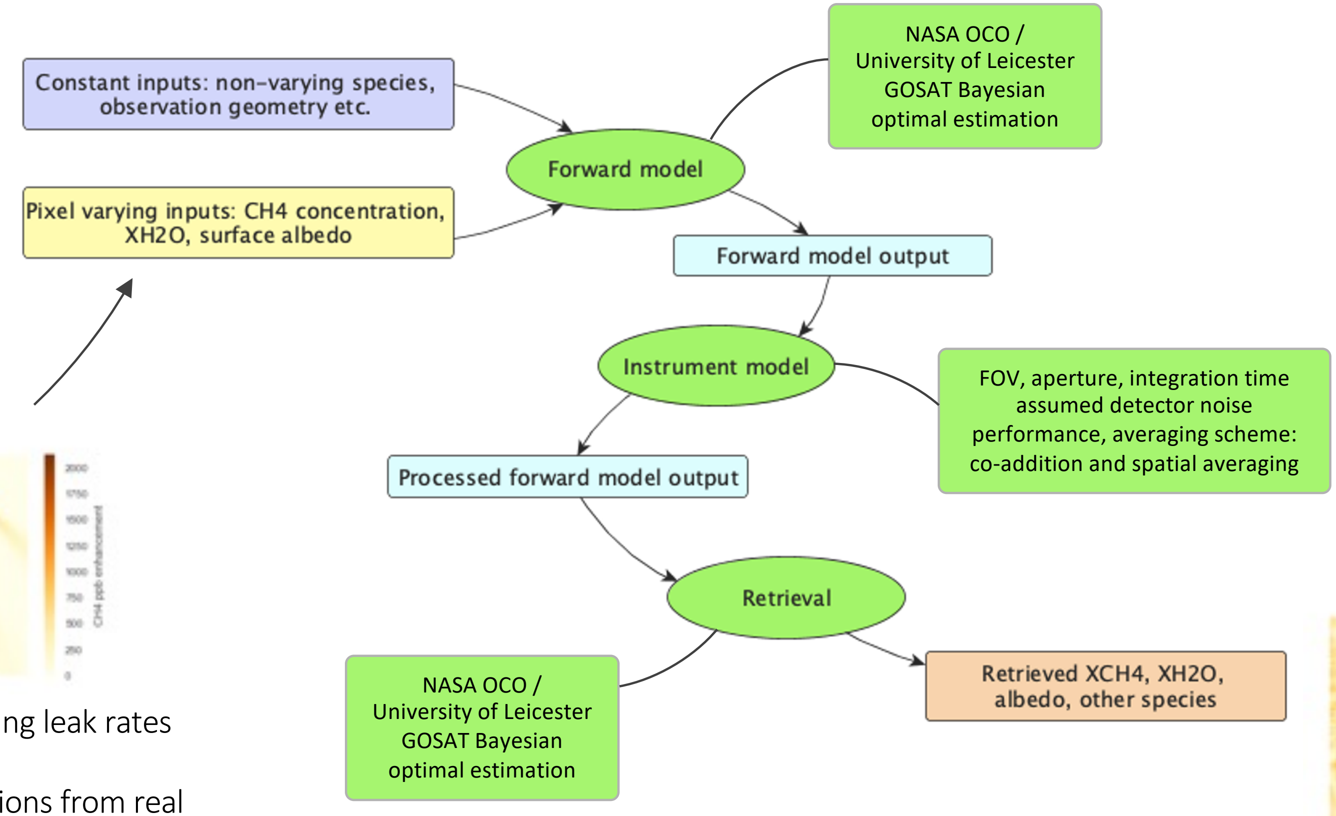
May benefit from visible light camera to aid with frame registration, not investigated yet

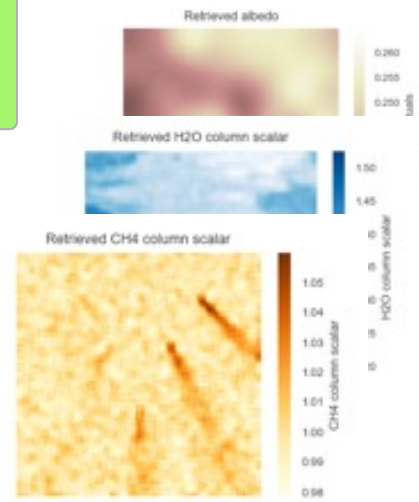


Observation simulation

74˚ SZA
400km altitude
Nadir viewing
Filter parameters

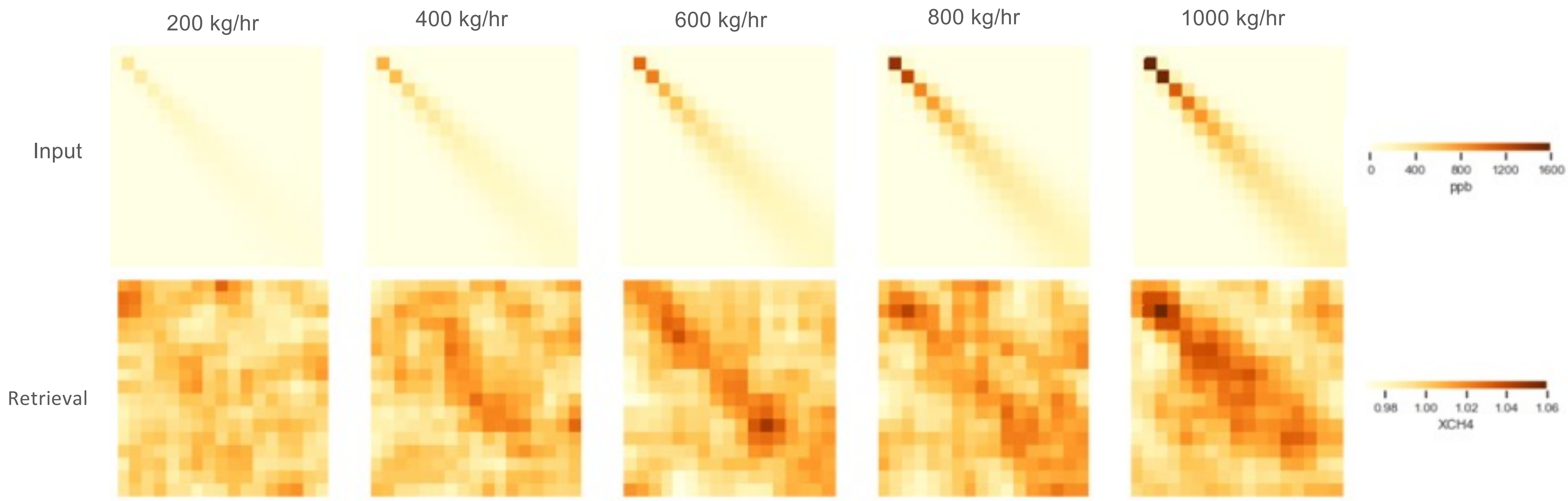






Gaussian plumes with varying leak rates from 100-1000 kg/hr
Albedo and water distributions from real world data (Texan fracking sites)

Modelling results



- Detection limit around 400 kg/hr, equivalent to 95% of EU sources by total flux

Key challenges and opportunities

Filter coating development

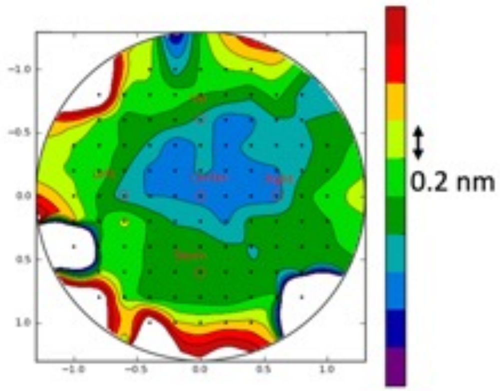
- Spectral performance at wider HCAs
- Coating uniformity at larger diameters

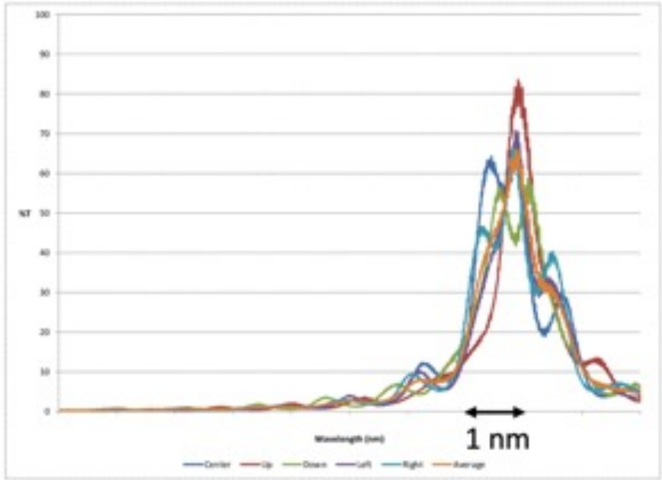
Data collection and processing algorithm

Platform stability: stabilisation vs software

Calibration/validation strategies

Laboratory and field testing





NIMCAM represents an important new UK methane measurement capability

Growing market for methane data: industry, finance, insurance, policy, scientists

Leveraging expertise in data analysis at University of Edinburgh and engineering capabilities at UK ATC

Small satellite deployment with excellent potential for constellation building in future

UKSA funded ISS feasibility study

6 month study investigating feasibility of ISS deployment for NIMCAM

Airbus Bartolomeo platform ideal payload hosting option

Important considerations include:

- Compensating for ISS altitude and attitude changes – solutions identified
- Accurate platform position measurement – solutions identified
- On-board data processing needs – area for development
- Long revisit time (unavoidable aspect of ISS deployment)

Modelling showed plume detection limits of around 400 kg/hr with 60 metre pixels

NIMCAM compatible with the smallest, cheapest hosting option, ArgUS

Excellent opportunity for **on-orbit demonstration** as well as rapid deployment of instrument able to provide **valuable high spatial resolution methane data**

Science & Technology Facilities Council
UK Research and Innovation
UK SPACE AGENCY
Centre for EO Instrumentation

CEOI Pathfinder study

9 month study kicking off late April 2021

Further developing the satellite specific concept for NIMCAM

- Refining mission and instrument **requirements**
- Performing initial engineering concept design of a **field demonstrator instrument**, including **optical and mechanical design** in collaboration with UK Astronomy Technology Centre
- Undertaking initial **laboratory trials** of the core spectral concept
- Working with Materion to **develop narrow bandpass filter coatings** able to maintain the required spectral performance at larger cone angles

Thank you for your attention!

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