# HAPI BUSINESS CASE SUMMARY

# OUTLINE/SUMMARY DESCRIPTION

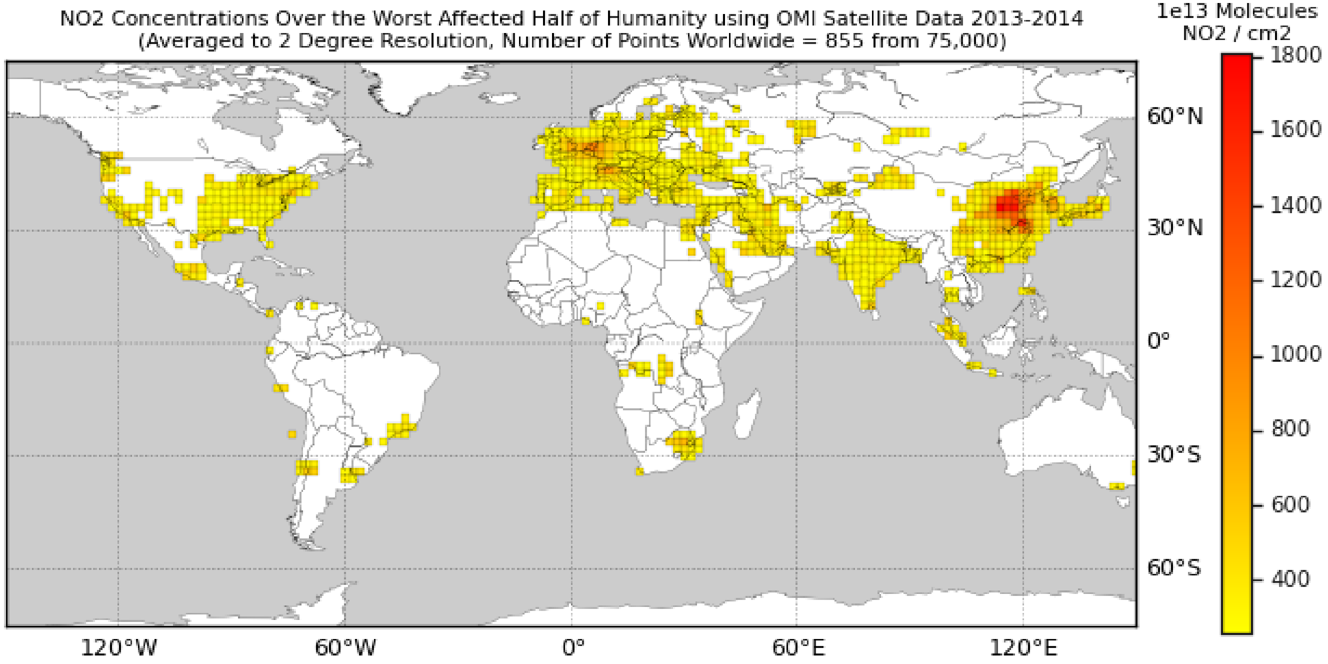
- /// MISSION/INSTRUMENT TITLE: **OmniSat HAPI**
- /// PRIMARY OBJECTIVE (*The Problem*): **to monitor urban air pollution globally at high spatial and temporal resolution** through a constellation of low cost, novel multispectral sensors
- /// THE MISSION (*The Solution*): will measure short wavelength visible radiances which will be used to retrieve **nitrogen dioxide** $NO_2$ column densities, and surface concentration maps at **600m surface resolution multiple times daily** through a constellation with population-exposure-weighted urban targeting
- /// OTHER MISSIONS: OmniSat HAPI has the highest resolution of any current missions or planned missions known to the team, however, the alternatives are based on more mature technology.
- /// COMPLEMENTARY MEASUREMENTS: OMI, TROPOMI
- /// TECHNICAL IMPLEMENTATION: The HAPI instrument is flown on the OmniSat bus. The lightweight low cost sensor mission requires a **constellation** in order to deliver a step change in data products

# THE MISSION: FOCUS ON NO2 EMISSION HOTSPOTS

/// NO 2 concentrations over the most polluted half of humanity.

/// 2.27% of the Earth's total surface.

Alternative mission prioritisations are possible, for example, by including data sparsity and/or in the weighting, or projected urbanisation rates



# THE MISSION: FOCUS ON NO2 EMISSION HOTSPOTS

## Constellation Design Concept

/// Full operational constellation

/// 24 OmniSats

/// 8 OmniSats per plane

/// 3 planes in SSO (10AM, 12PM and 2PM)

/// 600m spatial resolution

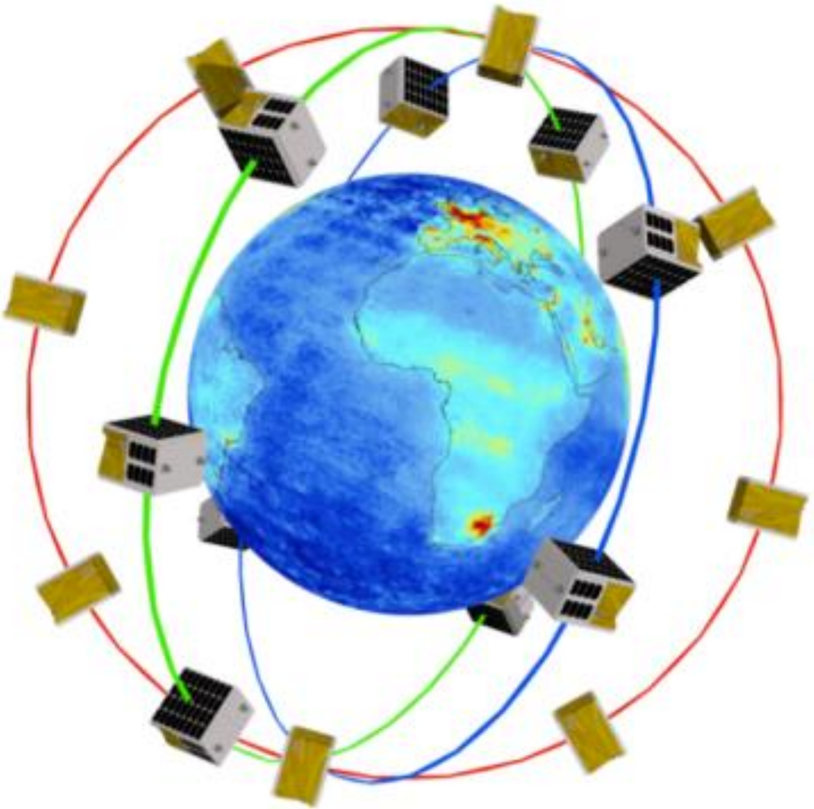
/// 200km swath

/// 600km orbit altitude

/// E.g. Ksat lite Ground Station

/// <2hr delay from capture to end user

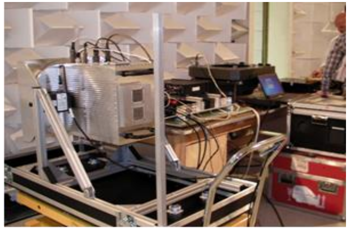
/// Data every 1.6 hours (average)



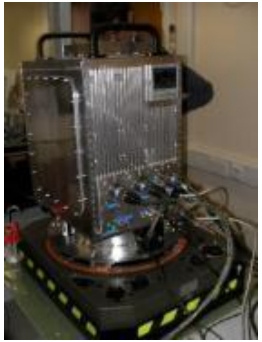
# TECHNICAL IMPLEMENTATION

- /// 3kg
- /// 500 – 600 m spatial resolution
- /// 10 channels centred at key wavelengths of the $NO_2$ absorption cross section (407-485 nm range)
- /// 10 individual 2-D detectors with optical filters – no complex optics!
- /// Simultaneous acquisition of data from all channels.
- /// Constellation giving 4+ observations per day at target locations under cloud free conditions

## Airborne Demonstrator

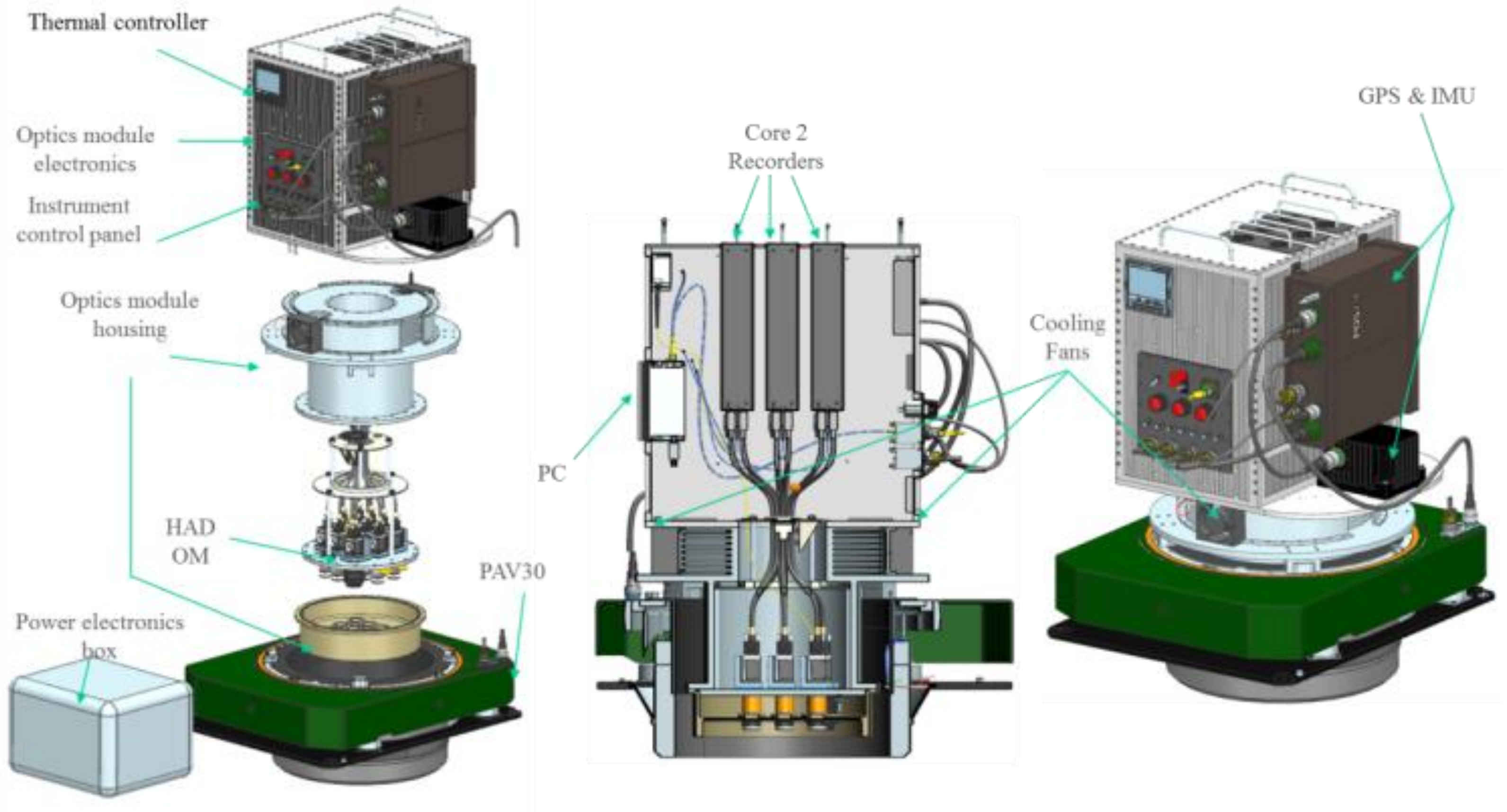


/// Lab testing



/// Instrument  as installed in aircraft

# TECHNICAL IMPLEMENTATION: AIRBORNE DEMO



# MULTIPLE USER NEEDS

/// Science Users

/// Local and National Governments (especially in data sparse regions)

/// Local and Global air quality data companies and environmental consultants

/// ESA, World Bank, WHO, philanthropy

/// Companies interested in monitoring their air quality footprint (large retail, logistics, etc.)

# POLICY ALIGNMENT I

Alignment with UK policy goals—DEFRA[1]:

- **The most immediate air quality challenge is tackling the problem of nitrogen dioxide ($NO_2$) concentrations around roads** - the only statutory air quality obligation that the UK is currently failing to meet.
- There is considerable uncertainty on the real world impact of speed limits on $NO_2$ concentrations and there is limited data available showing the impact of speed limit changes. Given this, there is a need to collect data from further monitoring in real world conditions…
- Access to information is essential to enable the public to make informed choices to help tackle the sources of, and to avoid exposure to, air pollution
- The UK Government and the devolved administrations also publish near real-time air pollution monitoring and forecasting information, with social and other media used to communicate actual or forecast episodes of high pollution.
- Local authorities, non-government organisations and other stakeholders play a key role in disseminating advice and guidance to those affected by poor air quality.

**[1] Improving air quality in the UK: tackling nitrogen dioxide in our towns and cities Draft UK Air Quality Plan for tackling nitrogen dioxide May 2017, DEFRA**

# POLICY ALIGNMENT II

Alignment with Industrial Strategy:

- /// **Clean Growth**: We want everyone to feel the benefits of clean growth, so we will work to create a future where our cities benefit from cleaner air, our businesses from enhanced resource security and our countryside from regenerated natural capital.

- /// The UK is already one of the most successful countries at growing our economy while **reducing emissions**. We have cut emissions by more than 40 per cent since 1990, while our economy has grown by two thirds. Our recently-published Clean Growth Strategy sets out our ambitious proposals for continuing this progress through the 2020s.

- /// Clean Growth: An important benefit of a cleaner economy is cleaner air. We are determined to tackle air pollution and support affected areas, given the significant negative impact it has on public health, the economy and the environment. We will provide £220m for a new Clean Air Fund that will allow local authorities in England with the most challenging pollution problems to help individuals and businesses adapt as measures to improve air quality are implemented. This new fund is in addition to the £255m provided to implement the **Air Quality plan** earlier this year, and takes the total amount invested in cleaner air since 2010 to £3.2bn.

- /// We will explore ways to use data to accelerate development of **new mobility services** and enable the more effective operation of our transport system

- /// We will leverage our health data to improve **health outcomes**

- /// Our country has world-class data, from the highest quality **geospatial and climatic analysis** to company information. We are committed to making this data available to innovators and businesses throughout the UK to create products and services that will transform our economy and society.

# POLICY ALIGNMENT III

## Alignment with EO Technology Strategy:

- **OBJECTIVE 2—INNOVATION, AND**
- **OBJECTIVE 3—CAPABILITY, IN UK STRENGTH AREA AND MARKET GROWTH TECHNOLOGY AREA OPTICAL SPECTROSCOPY**

/// Institutional EO science and operational missions

/// driven by challenging science requirement, are a major driver of innovation, usually demanding new sensor types or greatly improved performance from existing sensor configurations.

/// driven by societal need... It is possible to target technology development for operational missions as the requirements are often well known in advance, and government funding can be crucial to allow UK consortia to bring instrumentation to a sufficient level of maturity to gain access… A unifying technology theme for all these mission types is miniaturization.

## Alignment with UKSA Strategy:

/// to grow the **knowledge base**

/// to meet **societal needs**

/// to support growth of commercial space markets such that the contribution of UK industry to the economy is increased… **new technologies for EO and miniaturisation**

# BENEFITS

- /// Obtain **improved understanding of NOx chemistry and sources**
- /// Routinely **monitor air quality in data sparse regions**
- /// Improve air pollution early warning systems
- /// **Evaluate existing emission inventories** (as NO2 is short-lived and collocated with its sources)
- /// Critically evaluate air quality models that are used to inform air quality policy
- /// Assess the impact of air pollution on the health of inhabitants of a city
- /// **Evaluate the effect of air pollution mitigation strategies** and demographic changes on air quality

BENEFITS FOR UK EO

- /// **Unique UK capability extending a core capability area**
- /// **UK-based hardware supply chain**
- /// **UK-based novel science and retrieval technology**
- /// **UK-based downstream service improvement**
- /// **UK benefits of improved monitoring**

# INNOVATION

/// First of its kind **multispectral DOAS-like** space system

/// Scattered-light, **discrete-wavelength imaging** instrument for remote sensing of NO2.

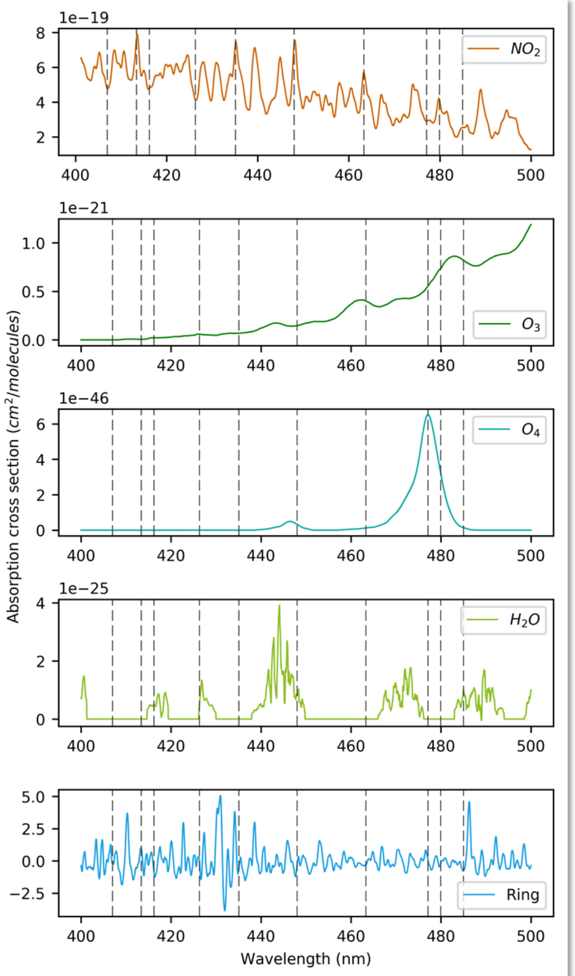
/// **10 channels** centred at key wavelengths of the NO2 absorption cross section (407-485 nm range)

/// 10 individual 2-D detectors with optical filters – **no complex optics**!

/// Simultaneous acquisition of data from all channels.

/// **Small and light** – potential for **low-cost** constellations of small satellites

/// **GLOBALLY UNIQUE**, and the mission will give building leading capability in the UK on high resolution multispectral gas retrieval



# COSTS

/// £100-250 M for full 24 satellite constellation-EXTREMELY Cost Effective

/// Operational costs likely funded through government/ESA/philanthropic development funding

/// However, supplemental commercial models are being developed and tested

/// Broad scope for bilateral missions:

/ **SOUTH AFRICA, KENYA, NIGERIA, INDIA, BRAZIL, CHINA…**

/// Main risk is around the novelty of the retrieval science and technology

/ **BEING ADDRESSED THROUGH INTENSIVE R&D**

/ **OPTIMIZED RETRIEVAL COULD REVOLUTIONIZE ATMOSPHERIC SENSING FROM SPACE**

# PROGRESS ON HAPI SINCE FLAGSHIP—EFFORTS

/// Intensive Testing and Analysis of OMI and TROPOMI Data

- SELECTING BEST PERFORMING NO2 FITTING WINDOW
- SELECTING BEST PERFORMING 10 CHANNELS
- INVESTIGATING CHANNEL FWHM IMPACT ON RETRIEVAL

/// Radiative Transfer Modelling for Instrument Performance Simulation

- EVALUATING SNR IMPACT ON SIMULATED ALGORITHM PERFORMANCE
- EVALUATING IMPACT OF CHANNEL WAVELENGTH BAND SHIFTING
- SIMULATING IMPACT OF LAND SURFACE TYPE ON ALGORITHM

/// Presenting scientific results at three international conferences (EGU, AGU, ESA ATMOS) and engaging with the space NO2 science community

/// Preparing manuscript for publication

# PROGRESS ON HAPI SINCE FLAGSHIP--FINDINGS

/// Understanding that a critical issue affecting the airborne demonstrator was the large fitting window*

/// Strong evidence towards proof of concept from measured OMI and TROPOMI data that with a small fitting window and optimised wavelength selection, running the HAPI algorithm on only 10 wavelengths provides NO2 SCDs within acceptable deviations near the target error (generally < +/- 10^15 molecules per cm^2) from the operational OMI and TROPOMI retrievals**

/// Development of a scientific plan to quantify differences in performance and outline theoretical issues with using data from existing platforms to simulate HAPI performance

/// The HAPI retrieval is performing similarly over a range of swaths in different regions.

/// Our assessment is that HAPI would provide useable data for some applications even at 10^15 molecules cm^2

*The HAPI instrument concept is very sensitive to broadband effects such as surface reflectance, hence the HAPI airborne demonstrator as originally designed is unsuitable for the remote sensing of $NO_2$. This not because of the number of channels or the filter width, but rather because the fitting window was too large (wavelengths too far apart).

**Theoretically, the HAPI airborne demonstrator would be able to measure $NO_2$ SCDs with ~10% error if the filters were replaced with narrower filters (FWHM = 1.25-1.50 nm) centred at a new set of wavelengths comprising the peaks and troughs of the $NO_2$ absorption cross section between 425 - 450 nm.

# NEXT DEVELOPMENT STEPS OF HAPI

- Reach and document SRL 3 and hold HAPI scientific review panel
- In depth characterization of demonstrator optical channel response
- Replace filters with refined channel selection centre wavelengths
- Validate with airborne demonstrator integrated field campaign (including surface sensing, current space platforms, and atmospheric modelling)

# THE ADDED VALUE FOR THE SCIENTIFIC COMMUNITIES

/// Spatial resolution always makes a difference as features previously not resolvable from face become apparent.  This happened in the shift from OMI (30km) to TROPOMI (7km) and will happen again when we move to 1km, providing **a step change in our understanding of distributions of emission sources and pollution transportation and chemistry**.

/// In all conversations with the science community the temporal resolution (4 overpasses per day) is hugely valued; **the constellation would provide radically new understanding of the diurnal cycle of nitrogen dioxide**.

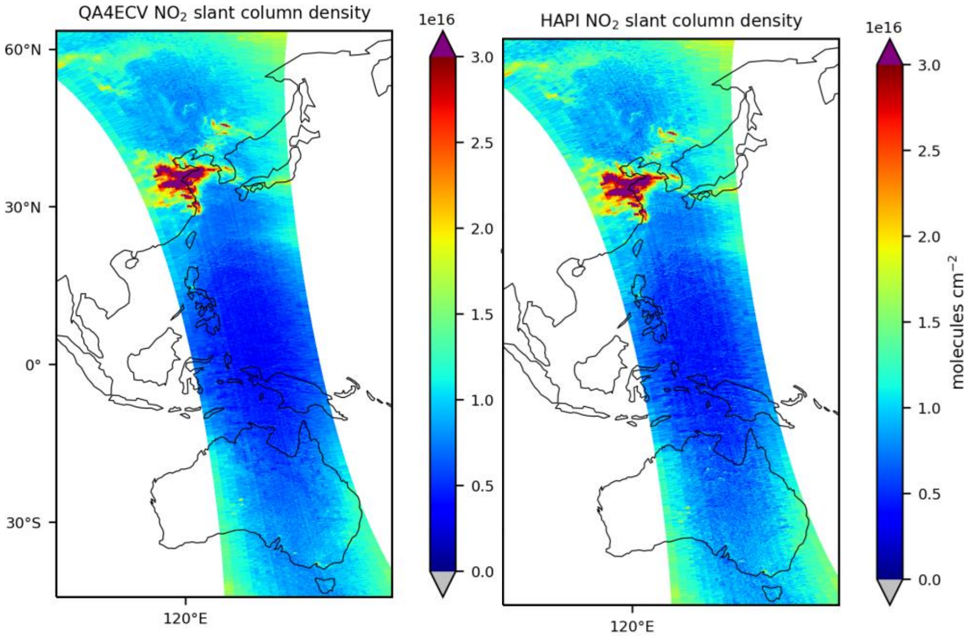
/// New data for scientific understanding of air pollution management interventions such as **fast fine-scale feedback on local, regional, and national emissions reduction interventions**

# HAPI SRL—AS ALIGNED WITH ESA SCIENTIFIC READINESS LEVELS (SRL)

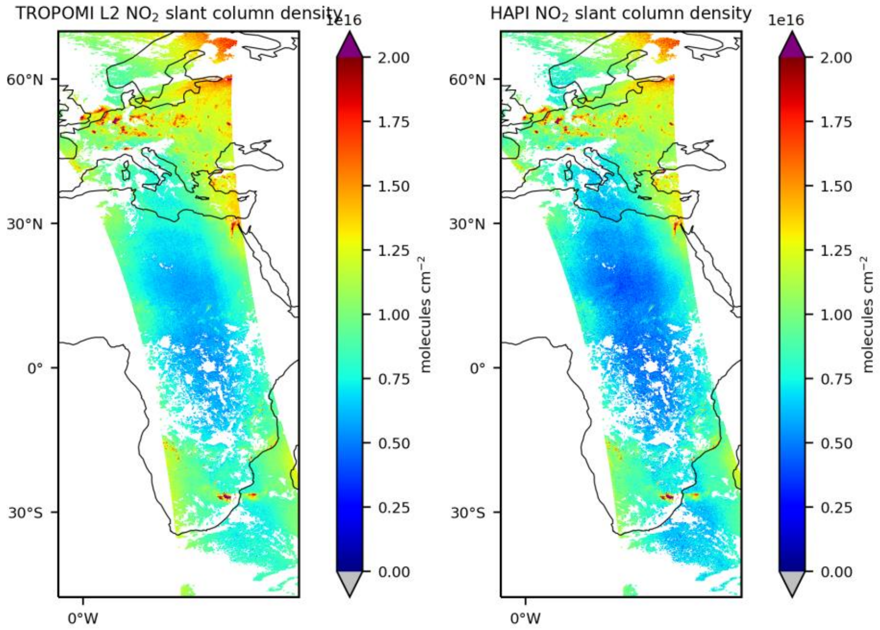
/// The $NO_2$ product generation is at approximately SRL2, and would probably be at SRL 3 when we progress to "scientific objective confirmed and approved," which the peer-reviewed journal paper being written (submission target date Q2 2019) would go a way towards, possibly followed by a formal scientific review of the mission conducted with an expert panel. We are still gathering scientific evidence in a theoretical study to consolidate the scientific concept and have only partially characterized the retrieval uncertainty, but we have a clear scientific strategy. We anticipate that from SRL 3, SRL 4 can be achieved if we iterate the current demonstrator by updating the filters as re-specified through the theoretical study, and then apply the retrieval to this new ground and flight data collected through a carefully designed field campaign (ground validation, OMI/TropOMI overpass, and atmospheric modelling). This would get the mission to scientific proof of concept / SRL 4

# PERFORMANCE SIMULATION EXAMPLE DATA

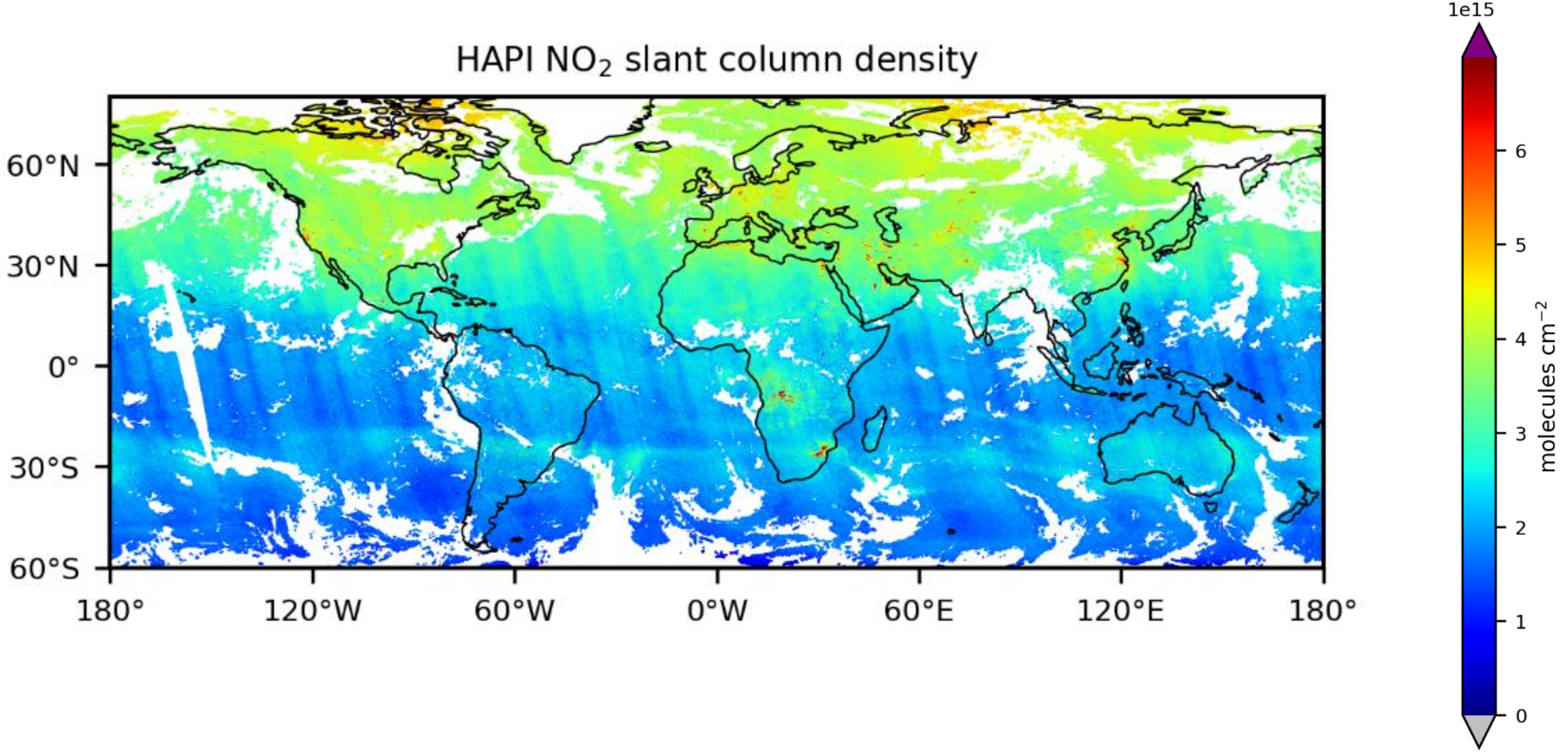
## OMI QA4ECV VS HAPI
## 10 WAVELENGTHS (425-450 NM), FWHM = 1 NM




## TROPOMI VS HAPI
## 10 WAVELENGTHS (425-450 NM), FWHM = 1 NM



# TROPOMI 30-07-2018 PROCESSED WITH HAPI ALGORITHM USING ONLY HAPI WAVELENGTHS



# THE PATH TO SRL 4