

# THE SPACEBORNE IMAGING SPECTROMETER DESIS: DATA ACCESS AND SCIENTIFIC APPLICATIONS

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H. Lester<sup>b</sup>, U. Heiden<sup>a</sup>, S. Holzwarth<sup>a</sup>, U. Knodt<sup>a</sup>, D. Krutz<sup>a</sup>, D. Marshall<sup>a</sup>, M. Pato<sup>a</sup>, R. de los Reyes<sup>a</sup>,  
P. Reinartz<sup>a</sup>, M. Tegler<sup>a</sup>

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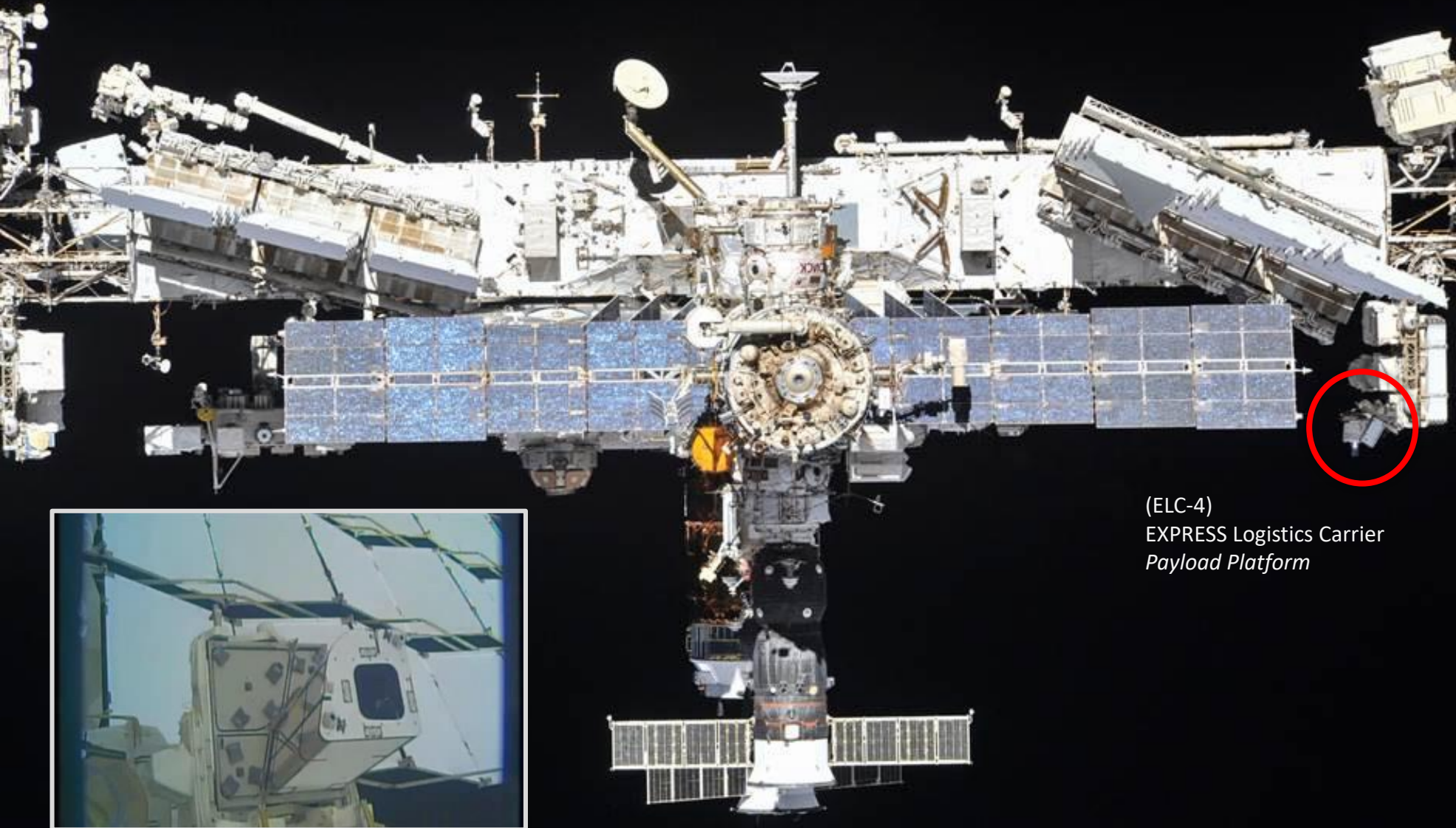
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<sup>c</sup> Innovative Imaging and Research, Corp. (I2R), Stennis Space Center Mississippi, USA



Knowledge for Tomorrow

# DESI, MUSES and ISS



(ELC-4)  
EXPRESS Logistics Carrier  
Payload Platform

Teledyne Brown Engineering (USA) and DLR (Germany) have partnered to build and operate the DLR Earth Sensing Imaging Spectrometer (DESI) from the Teledyne-owned Multi-User System for Earth Sensing (MUSES) Platform on the ISS

The imaging spectrometer DESI has been developed by DLR and is currently the first payload of MUSES.

DLR also established the Ground Segment @ DLR and licensed the SW processors to Teledyne running in an Amazon Cloud

# DESIS / MUSES TIMELINE



2014 / 2015

7. June 2017

29. June 2018

27.-28.08 2018

23 Oktober 2019

29.09.–01.10.2021

MUSES / DESIS  
Start Mission

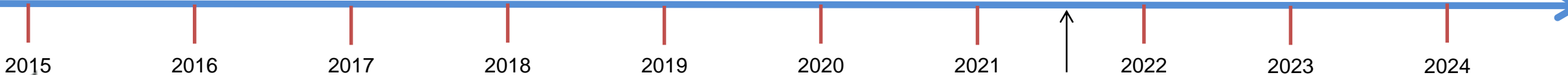
MUSES installation  
on ISS

DESIS launch from  
Cape Canaveral to ISS  
via SpaceX Dragon

Installation of DESIS  
in MUSES. Start  
Commissioning Phase

@ IAC Washington  
Start operationell  
Phase (official  
announcement)

1st DESIS User Workshop  
(online)

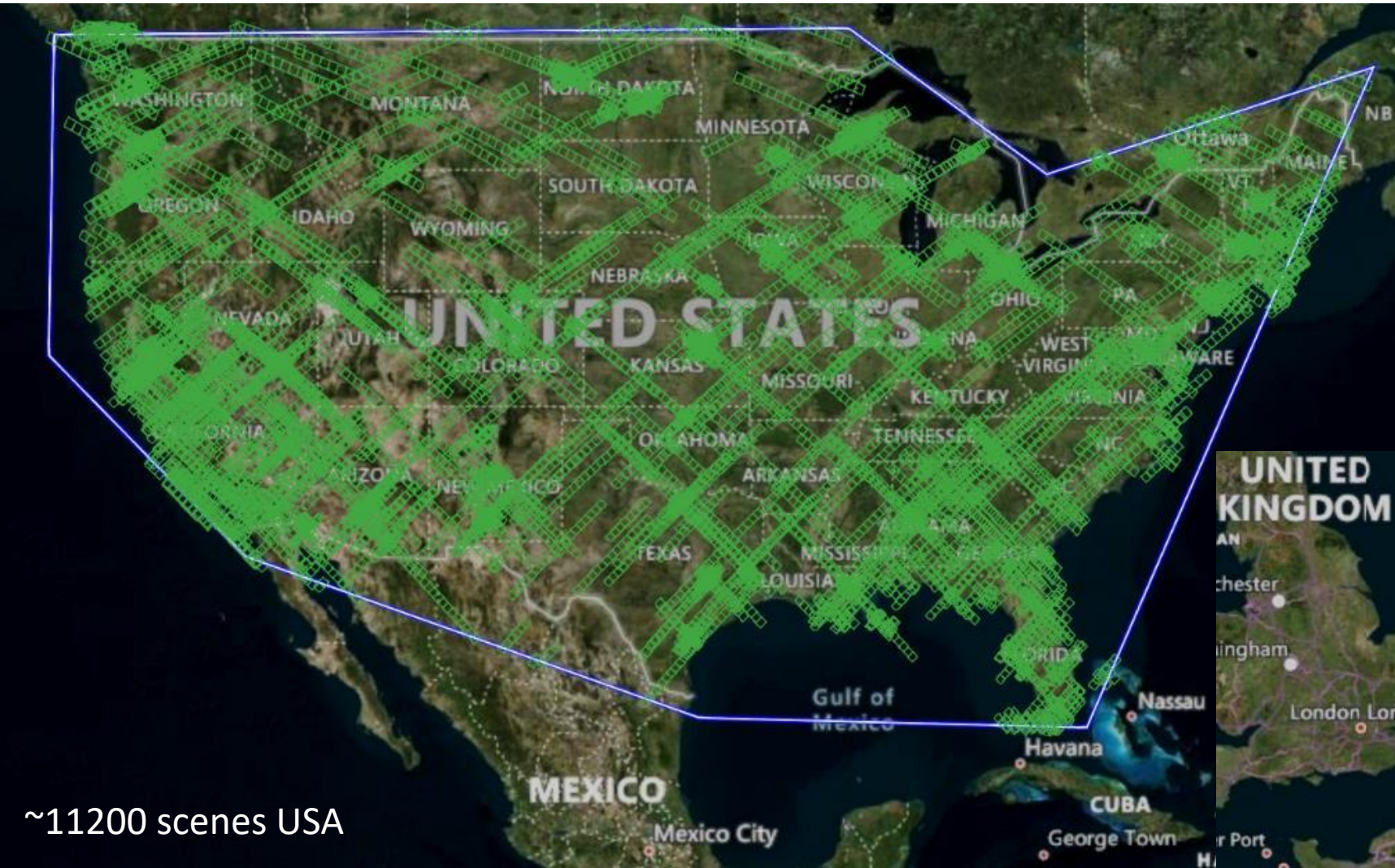


We are here

Nominell End



# Status Acquisitions (March 2021)



~11200 scenes USA

World  
~55.000 scenes processed  
<33% of the land surface of the Earth

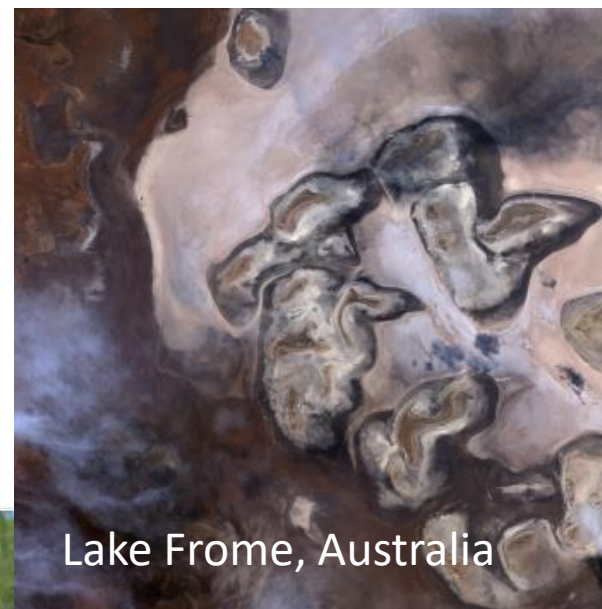
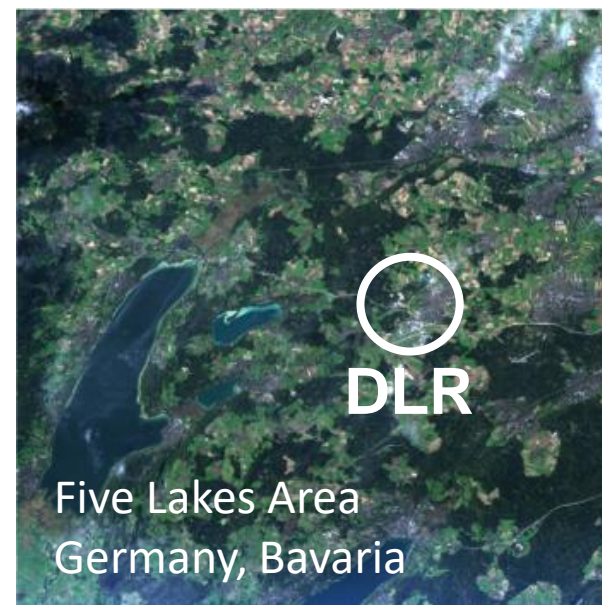
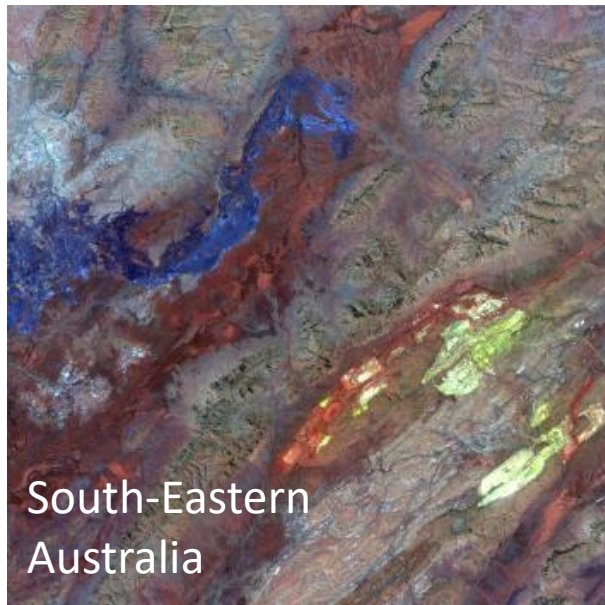
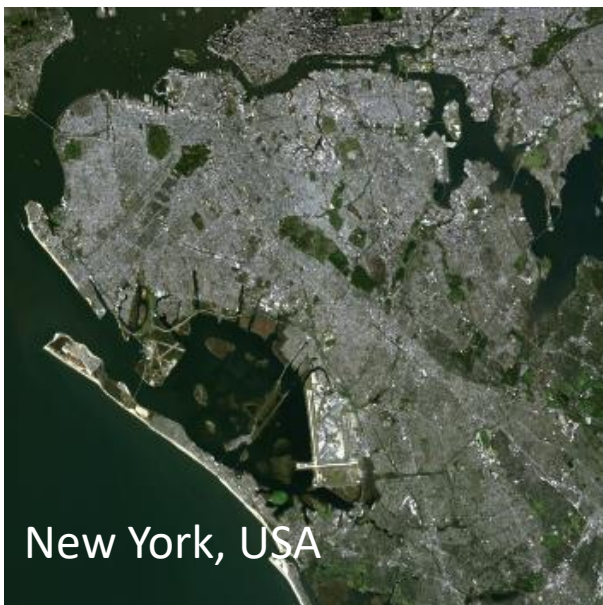
Note: DESIS is not a mapping mission



~1320 scenes Germany



# DESIS Image Impressions (see *official DESIS website*)



# DESIS Data Products



## Archive

L1A Raw Data  
(prepared for selection & ordering & processing)

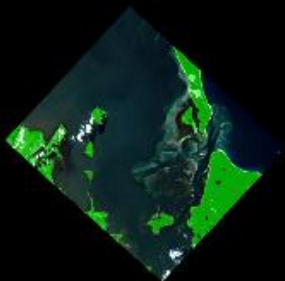
## Analysis Ready Data

L1B Top-Of-Atmosphere (TOA) Radiance

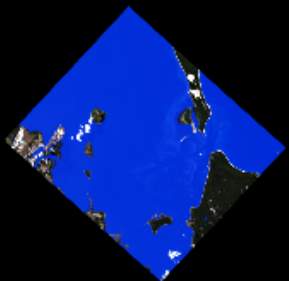
L1C Geocoded & Orthorectified

L2A Bottom-of-Atmosphere (BOA) Reflectance

Land Mask



Water Mask



Cloud Mask



Cloud Shadow  
over land



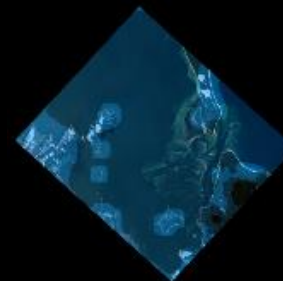
Haze over land



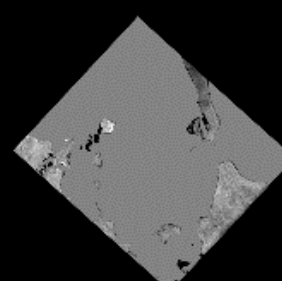
Haze over  
water



AOT Map



WV Map



# DESI Data Products - Quality

Absolute radiometric calibration is well within ~5% at the Top-of-Atmosphere (TOA) radiance and TOA reflectance level when validated against RadCalNet

Geometric accuracy with respect to Landsat-8 reference is ~20 m (< 1 pixel) linear RMSE

Agreement of Bottom-of-Atmosphere (BOA) reflectance within ~5% to RadCalNet, Sentinel-2 and field campaign data from Pinnacles site (Australia)

## Analysis Ready Data

L1B Top-Of-Atmosphere (TOA) Radiance

L1C Geocoded & Orthorectified

L2A Bottom-of-Atmosphere (BOA) Reflectance

# Calibration & Validation – further information

## Successful **ECCOE** system characterization:



Article

### Data Products, Quality and Validation of the DLR Earth Sensing Imaging Spectrometer (DESI)

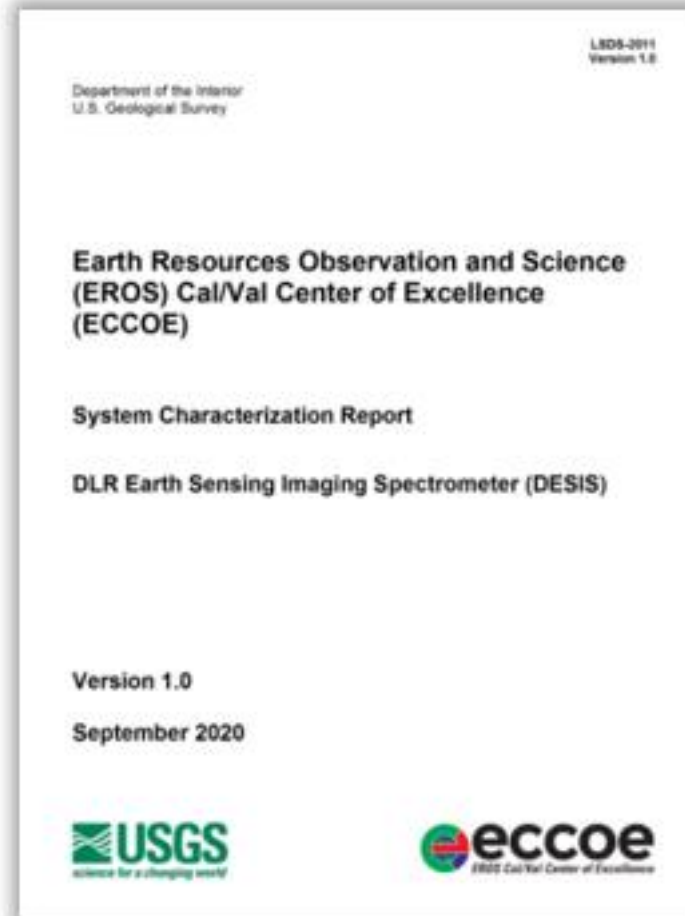
Kevin Alonso <sup>1</sup>, Martin Bachmann <sup>2</sup>, Kara Burch <sup>3</sup>, Emiliano Carmona <sup>1</sup>, Daniele Cerra <sup>1</sup>, Raquel de los Reyes <sup>1</sup>, Daniele Dietrich <sup>2</sup>, Uta Heiden <sup>2</sup>, Andreas Hölderlin <sup>4</sup>, Jack Ickes <sup>5</sup>, Uwe Knodt <sup>6</sup>, David Krutz <sup>7</sup>, Heath Lester <sup>5</sup>, Rupert Müller <sup>1\*</sup>, Mary Pagnutti <sup>3</sup>, Peter Reinartz <sup>1</sup>, Rudolf Richter <sup>1</sup>, Robert Ryan <sup>3</sup>, Ilse Sebastian <sup>7</sup> and Mirco Tegler <sup>2</sup>

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  - 6 Strategic services, DLR, Linder Höhe, 51147 Köln, Germany; Uwe.Knodt@dlr.de
  - 7 Institute of Optical Sensor Systems, DLR, Rutherfordstraße 2, 12489 Berlin, Germany; David.Krutz@dlr.de (D.K.); Ilse.Sebastian@dlr.de (I.S.)
- \* Correspondence: rupert.mueller@dlr.de

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**Abstract:** Imaging spectrometry from aerial or spaceborne platforms, also known as hyperspectral remote sensing, provides dense sampled and fine structured spectral information for each image pixel, allowing the user to identify and characterize Earth surface materials such as minerals in rocks and soils, vegetation types and stress indicators, and water constituents. The recently launched DLR Earth Sensing Imaging Spectrometer (DESI) installed on the International Space Station (ISS) closes the long-term gap of sparsely available spaceborne imaging spectrometry data and will be part of the upcoming fleet of such new instruments in orbit. DESI measures in the spectral range from 400 and 1000 nm with a spectral sampling distance of 2.55 nm and a Full Width Half Maximum (FWHM) of about 3.5 nm. The ground sample distance is 30 m with 1024 pixels across track. In this article, a detailed review is given on the applicability



For information about DESI calibration check **E. Carmona's** contribution:

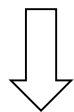
**TH4.O-17.3 - Vicarious Calibration of the DESI Imaging Spectrometer**



# Data Tasking and Access to Data Archive

## Tasking new DESIS data

A proposal is requested to understand the basic research question and the amount of data that will be ordered

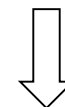


### Proposal Process

1. Proposal evaluation
2. **TBE TCloud portal**: Task L1A data
3. Get notification from Tcloud
4. Order your data via **DLR EOWEB Portal**
5. Download data (L1B, L1C, L2A) via EOWEB Portal

## Order archived data

Can be ordered without restrictions



Only DESIS EOWEB Portal account required

4. Order your data via **DLR EOWEB Portal**
5. Download data (L1B, L1C, L2A) via EOWEB Portal



# Scientific Exploitation

- DLR is responsible for the scientific data distribution
- Based on a proposal process
- Data available for scientists worldwide

| Topic  | Number of proposals |
|--|---------------------|
| Urban Thematic Exploitation & Material Composition | 2                   |
| Landcover & vegetation                             | 5                   |
| Water Resources                                    | 7                   |
| Ocean Applications                                 | 4                   |
| Coastal Applications                               | 5                   |
| Calibration  | 1                   |
| Natural Resources                                  | 8                   |
| Geology  | 3                   |
| Biodiversity                                       | 2                   |
| Others (e.g. methods development, data fusion)     | 4                   |

Currently ~50 international teams are using DLR's science access to DESIS data  
(plus additional commercial customers of TBE)

see next slide for the DESIS workshop





# 1st DESIS User Workshop

September 28<sup>th</sup> to October 1<sup>st</sup>, 2021

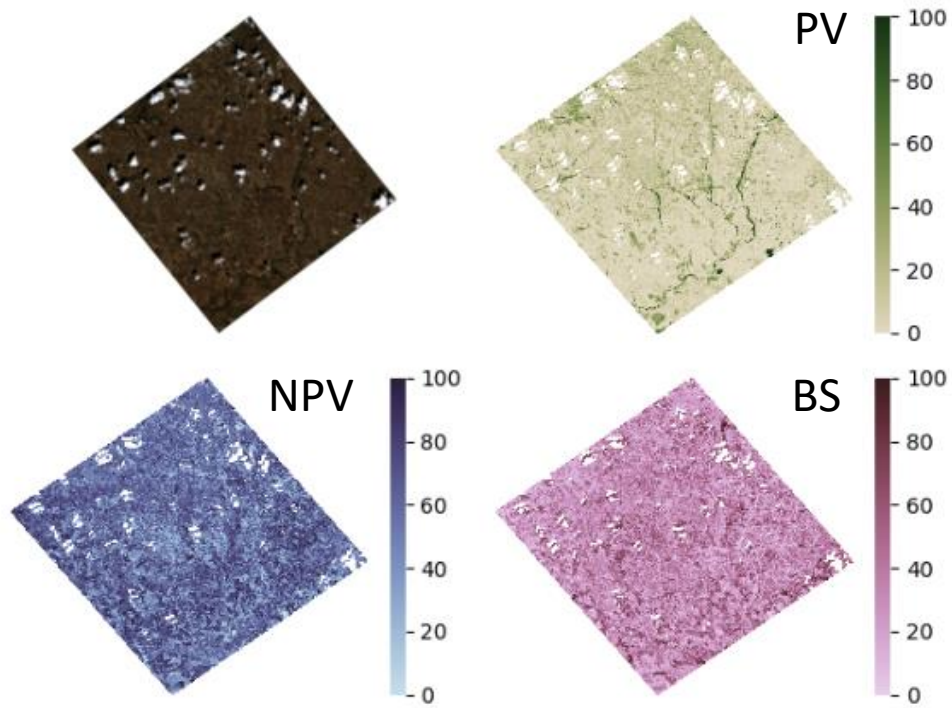
Virtual event

- Registration open 11th May 2021 till 17th September 2021
- Abstract Submission 1st July 2021 till 23th July 2021
- Notification of Acceptance until 17th August 2021
- Deadline for the Submission to the DESIS Best Image Award, 20th September 2021
- Online Workshop Tuesday, 28th of September to Friday, 1st of October 2021
- Deadline Full-Paper Submission 15th October 2021

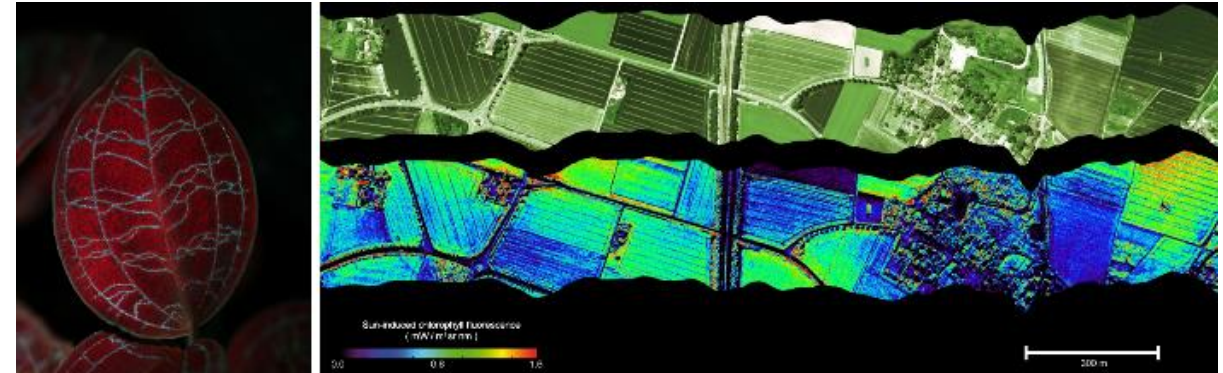
<https://desis2021.welcome-manager.de/>

# Scientific Exploitation at DLR (1)

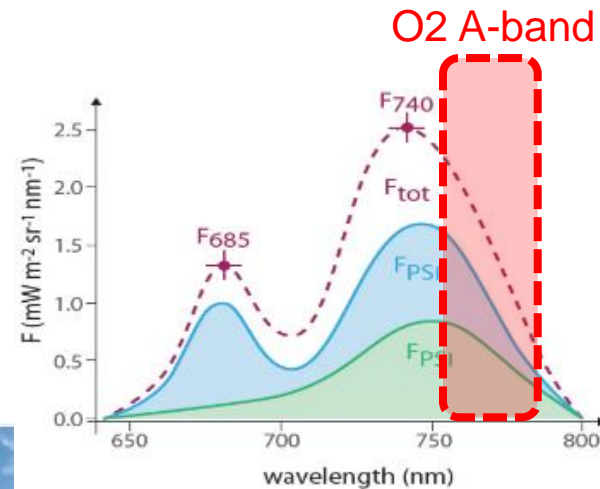
## Fractional vegetation cover for environmental modeling



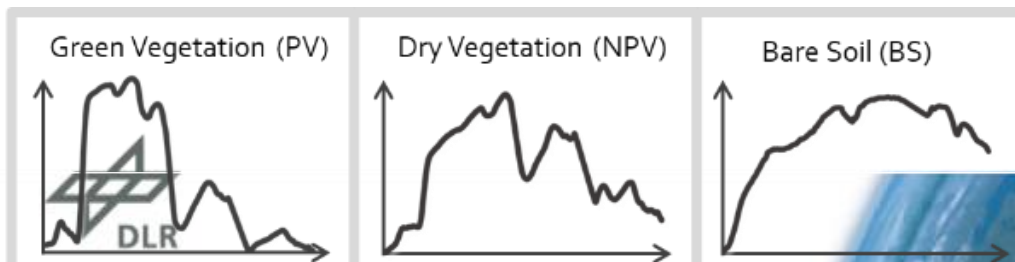
## Sun-induced fluorescence maps



Chlorophyll fluorescence of a single leaf and from an airborne HyPlant measurement (@FZJ)



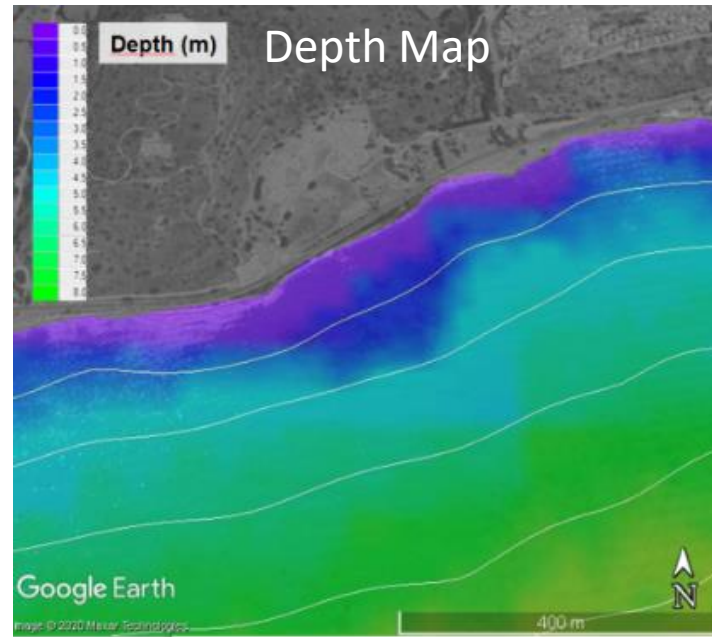
M. Drusch et al,  
IEEE TGRS, Vol.  
55, No. 3, 2017



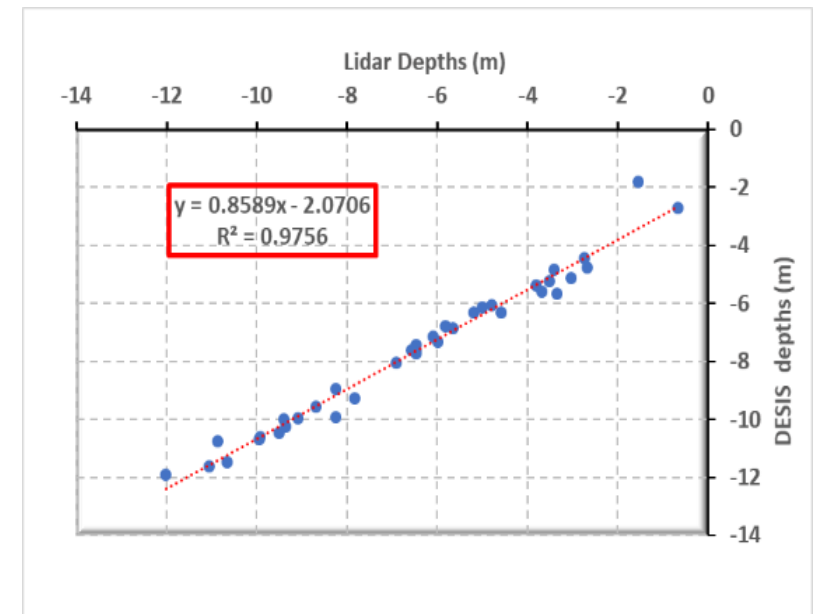
# Scientific Exploitation at DLR (2)

## Bathymetry for archaeology

- Bathymetrical map from DESIS image using WAtER color SIMulator (WASI)



Submerged harbor of the ancient city of Amathus, Cyprus



Comparison with Sentinel-2  
(RMSE):

- S2: 0.72 m
- DESIS: 0.41 m

# Scientific Exploitation at DLR (3)

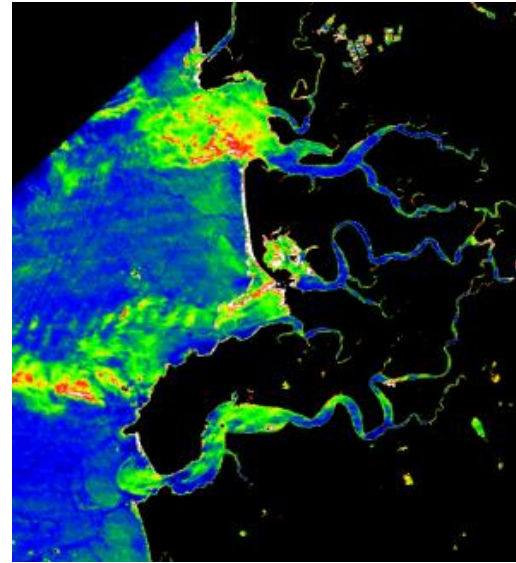
## Water constituents Costa Rica

### Inverse modeling of DESIS images using WASI

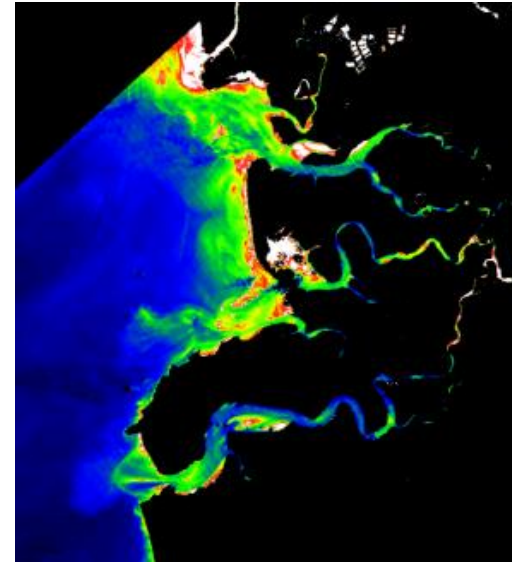
- Thin cloud correction
- Water constituents



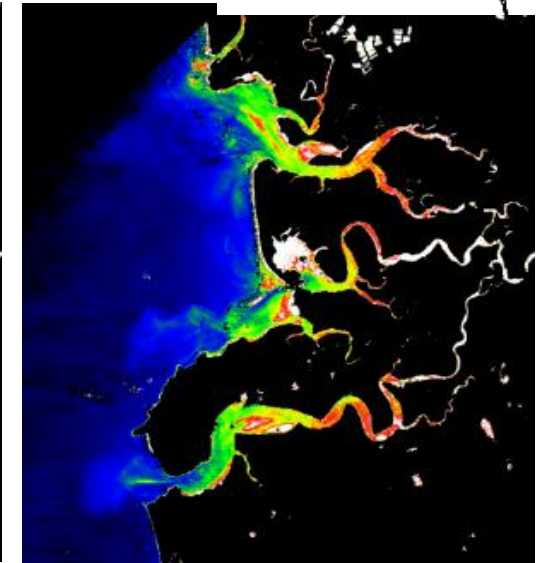
Terraba Sierpe NP, Costa Rica. DESIS image (04/03/2019)



0 0.7  
Cloud reflectance  
[sr<sup>-1</sup>]



0 5  
Total suspended matter  
[g m<sup>-3</sup>]



0 1  
CDOM absorption at 440 nm  
[m<sup>-1</sup>]



# Preparations for ESA's Chime Mission

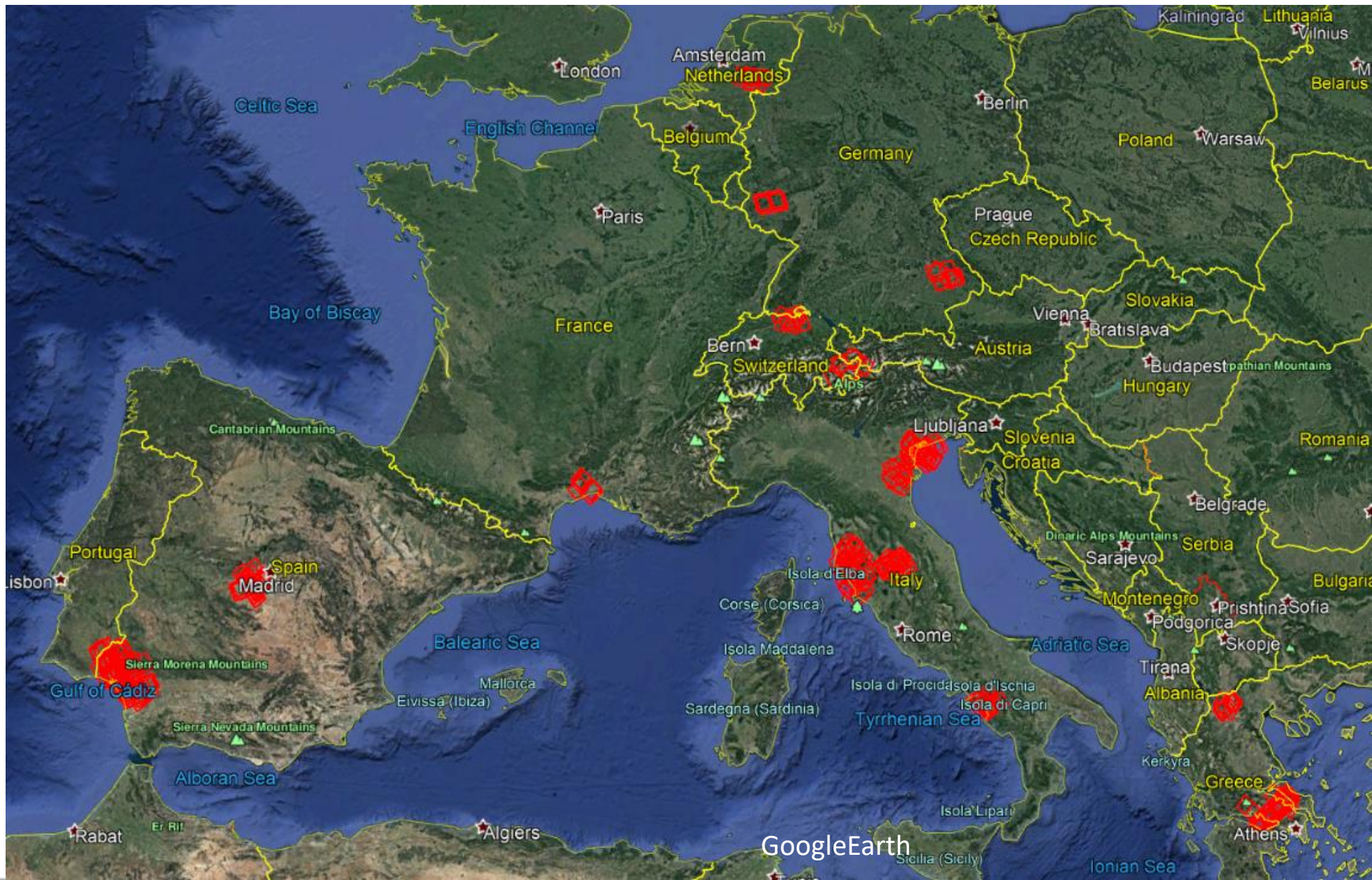
## DESIS Data for ESA's

future imaging

spectrometer spaceborne

CHIME mission

- More than 400 DESIS scenes acquired
- Multitemporal acquisitions for 2020
- New acquisitions in 2021



Thank you for your attention

Have a look at DESIS Website

<https://www.dlr.de/eoc/desktopdefault.aspx/tabid-13614/>

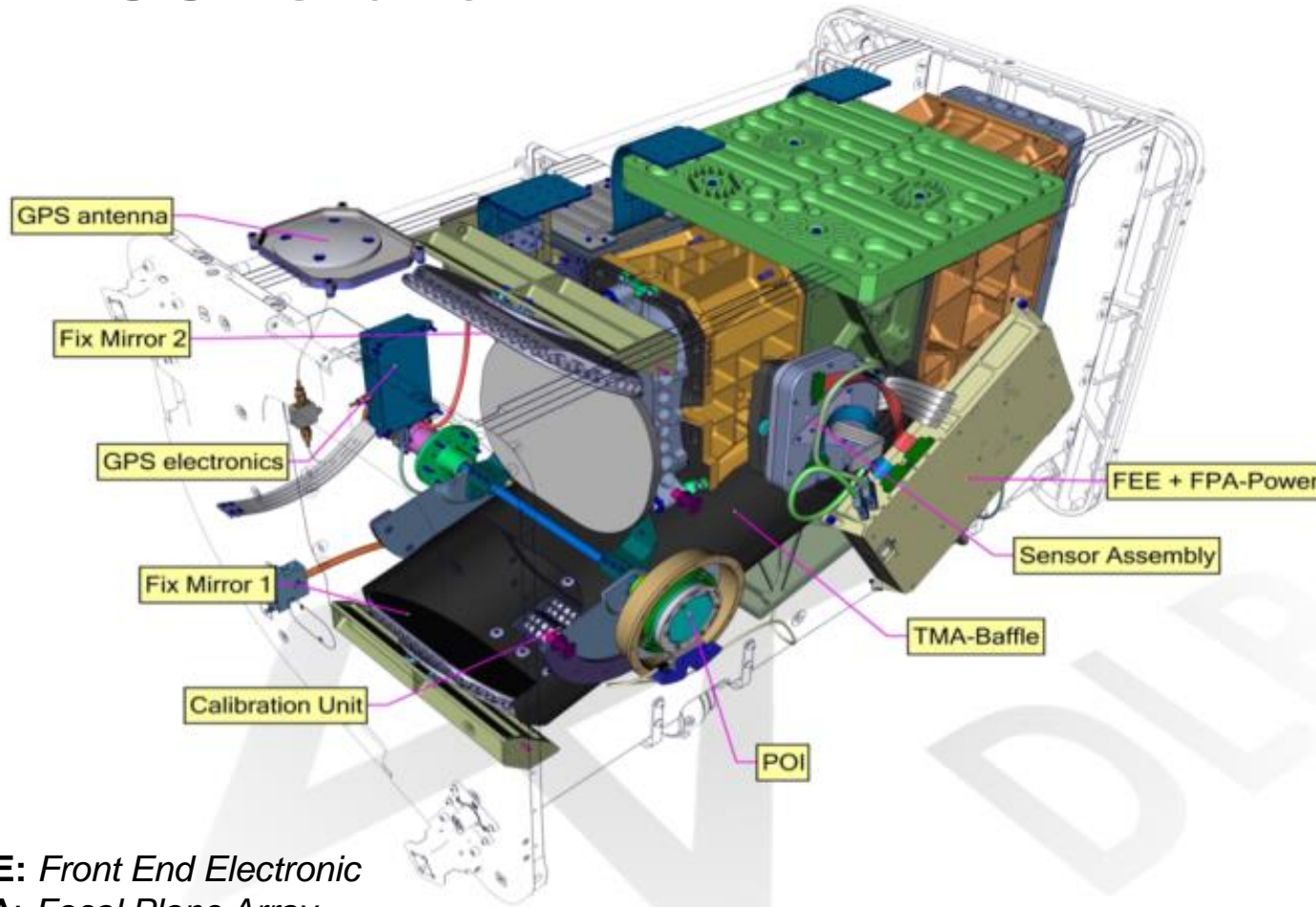


Space-X



Alex

# DESIIS Instrument



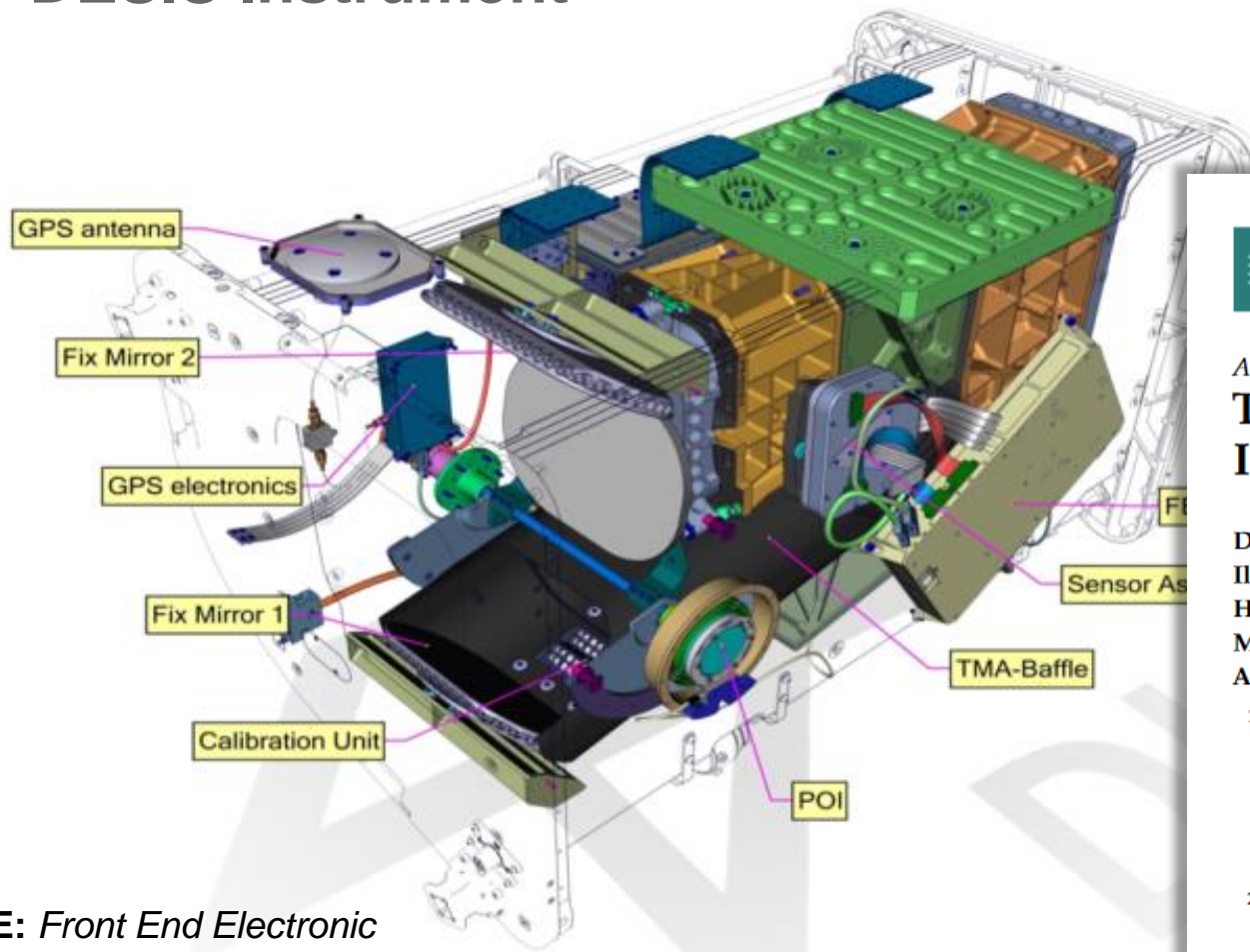
**FEE:** Front End Electronic  
**FPA:** Focal Plane Array  
**TMA:** Three Mirror Anastigmat  
**POI:** Pointing Unit

- Equipped with:
  - **Calibration Unit:** 2 banks with 9 (color+white) LED types. Allows for radiometric & spectral calibration/monitoring
  - **Pointing Unit:** Changes the instrument line of sight in the along-track direction between  $\pm 15^\circ$ . Allows for *angular observation mode* and *Forward Motion Compensation (FMC) mode*
  - **GPS receiver:** working as a time calibration unit for latency calibration and jitter measurement

- Telescope: Three-Mirror-Anastigmat (TMA)
- Spectrometer: Offner-type



# DESIS Instrument



**FEE:** Front End Electronic  
**FPA:** Focal Plane Array  
**TMA:** Three Mirror Anastigmat  
**POI:** Pointing Unit

| Mission / Instrument                       | MUSES/DESIS   |
|--|---|
| Target lifetime                            | 2018-2023   |
| Off-nadir tilting<br>(across-track, along- | -45° (backboard) to +5° (starboard), -40° to +40° (by |



Article

## The Instrument Design of the DLR Earth Sensing Imaging Spectrometer (DESIS)

David Krutz <sup>1,\*</sup>, Rupert Müller <sup>2</sup>, Uwe Knodt <sup>3</sup>, Burghardt Günther <sup>1</sup>, Ingo Walter <sup>1</sup>, Ilse Sebastian <sup>1</sup>, Thomas Säuberlich <sup>1</sup>, Ralf Reulke <sup>1</sup>, Emiliano Carmona <sup>2</sup>, Andreas Eckardt <sup>1</sup>, Holger Venus <sup>1</sup>, Christian Fischer <sup>1</sup>, Bernd Zender <sup>1</sup>, Simone Arloth <sup>1</sup>, Matthias Lieder <sup>1</sup>, Michael Neidhardt <sup>1</sup>, Ute Grote <sup>1</sup>, Friedrich Schrandt <sup>1</sup>, Samuele Gelmi <sup>1</sup> and Andreas Wojtkowiak <sup>1</sup>

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<sup>2</sup> Remote Sensing Technology Institute, DLR, Oberpfaffenhofen, 82234 Weßling, Germany; rupert.mueller@dlr.de (R.M.); emiliano.carmona@dlr.de (E.C.)

<sup>3</sup> Department of Strategic Services, DLR, Linder, Höhe, 51147 Köln, Germany; uwe.knodt@dlr.de

\* Correspondence: david.krutz@dlr.de

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# Project DESIS / MUSES – Development Phases

## Operational Phase (~5 Jahre)



2014 / 2015  
MUSES / DESIS  
Start Mission



7. June 2017  
MUSES installation  
on ISS



29. June 2018  
DESIS launch from  
Cape Canaveral to ISS  
via SpaceX Dragon



27. - 28. August 2018  
Installation of DESIS  
in MUSES. Start  
Commissioning Phase



23 Oktober 2019  
@ IAC Washington  
Start operationell  
Phase  
(official announcement)

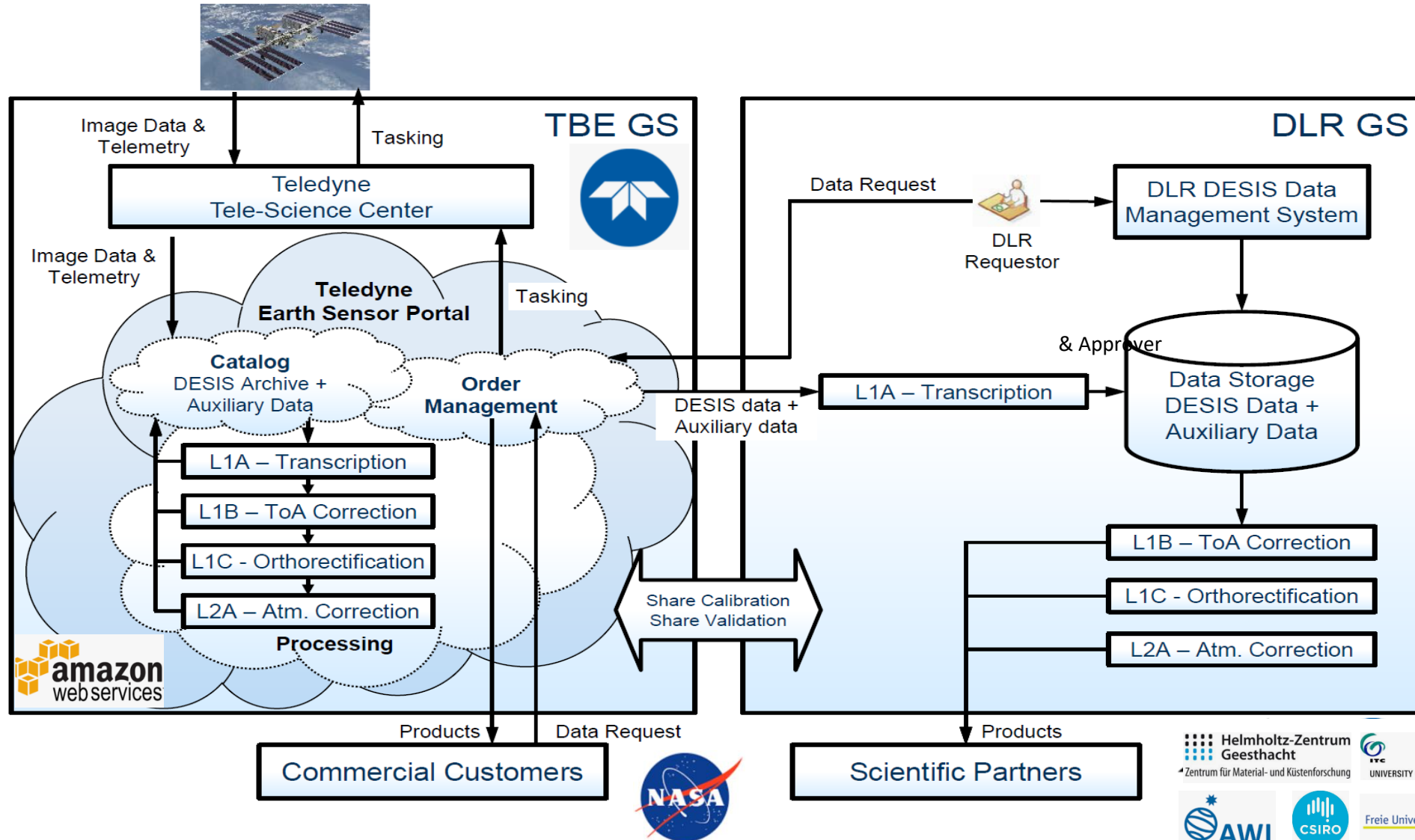


We are here



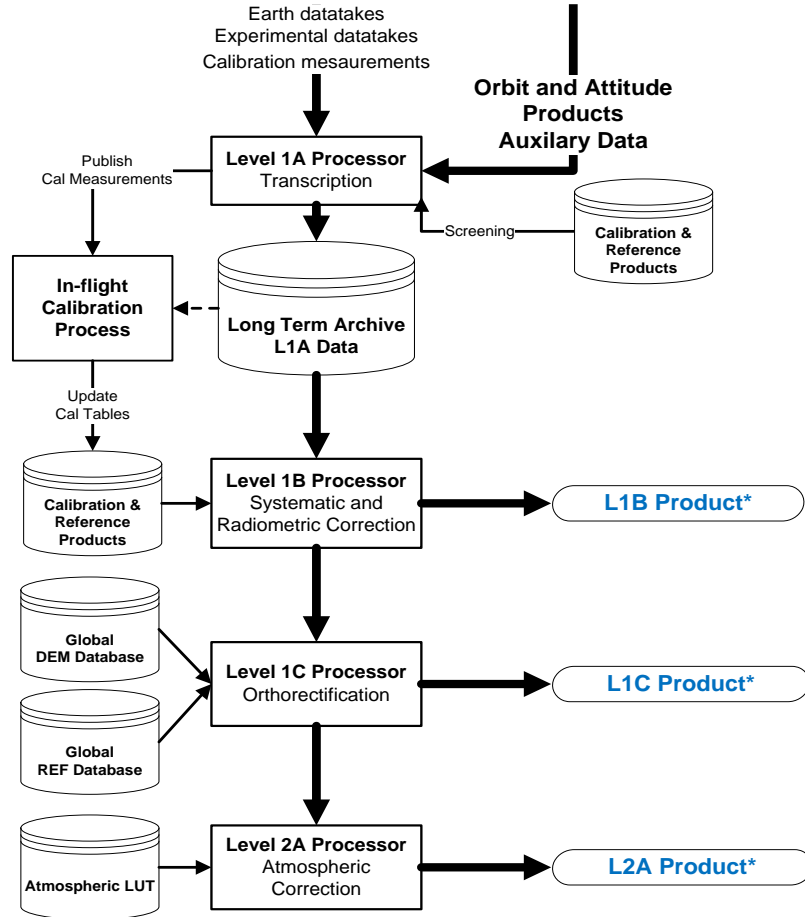
Nominell End

# 2x Ground Segments – from acquisition to distribution of Ready-to-Use products



# Data Processing

## Which products can a user get?



\*Delivery product

## Products

- **Level 0 (L0)**
  - Raw data (Datatakes up 100 tiles 30x30 km<sup>2</sup>, trajectory files, DC)
- **Level 1A (L1A)**
  - Tiled images, browse image, metadata, quality flags => archived
- **Level 1B (L1B)\***
  - Top-of-Atmosphere (TOA) radiance ( $W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$ )
  - Systematic and radiometric correction (rolling shutter, smile, suspicious and dead pixel interpolation,...)
  - **All metadata attached for further processing**
- **Level 1C (L1C)\***
  - Level 1B data ortho-rectified, re-sampled to a specified grid
  - Using a global DEM (SRTM, 1arcsec) for terrain distortions
  - Using a global reference (Landsat-8 PAN with acc. 18m CE90)
- **Level 2A (L2A)\***
  - Level 1C data atmospherically corrected. Ground surface reflectance / Bottom-of-Atmosphere (BOA) reflectance
  - With and w/o terrain correction

## Processors at the Ground Segments

- Fully automated
- Run 'on-request' over archived data
- Two instances: one at Teledyne (Amazon Cloud), one at DLR. Same processing

# Data Policy

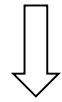
- DESIS is operated by Teledyne and data are distributed under NOAA License
  - TBE has the exclusive right to license or transfer image data for commercial use
  - For scientific purposes, DLR has the right to:
    - **Task 2000 minutes/year (~2200 km / day)**
    - Request archived data without restriction
- For scientific purposes only DLR can share DESIS 10.2 nm data with other scientific organizations within projects (data are free for the partners). Scientific use includes:
  - basic and application oriented research
  - projects by national and international educational or research institutions or by governmental institutions
  - development and demonstration of future applications for scientific and/or operational use and
  - preparation and execution of government-funded education, research and development programs
- Distribution of data with spectral sampling < 10 nm is subjected to NOAA approval
  - Currently these data are restricted to US governmental agencies and DLR (through waiver)
  - DLR Scientific partners willing to use 2.55 nm, 5.1 nm or 7.65 nm data require a waiver from NOAA



## DESIS Data Access for Scientific Purposes – Two Possibilities

### Tasking new DESIS data

- a proposal is requested to understand the basic research question and the amount of data that will be ordered



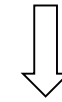
### Proposal Process

1. Proposal evaluation at **DLR**
2. Task L1A data via **TBE** – *Earth Sensor Portal*
3. Process and order your data via **DLR EOWEB** Portal
4. Download data (L1B, L1C, L2A) via **DLR EOWEB**

**Portal**

### Order archived data

- can be ordered without restrictions



### Only DESIS EOWEB Account required

3. Process and order your data via **DLR EOWEB** Portal
4. Download data (L1B, L1C, L2A) via **DLR EOWEB**

**Portal**



Detailed information on DESIS website: <https://www.dlr.de/eoc/desktopdefault.aspx/tabid-13614/>

## Product Example L1B

- Corrections applied:
  - Dark Current
  - Absolute Radiometric
  - Rolling Shutter
  - Smile correction
  - Relative radiometric (de-stripping)



## Product Example L1B

- Corrections applied:
  - Dark Current
  - Absolute Radiometric
  - Rolling Shutter
  - Smile correction
  - Relative radiometric (de-stripping)



# Product Example L1C

two cases  
- with GCP  
- w/o GCP

using global  
reference L8

using global  
SRTM 1 arcsec  
DEM



# Product Example L1C

two cases  
- with GCP  
- w/o GCP

using global  
reference L8

using global  
SRTM 1 arcsec  
DEM



# Product Example L1C



DEGIS

Google Earth

DEGIS

DEGIS

Google Earth

DEGIS

Google Earth

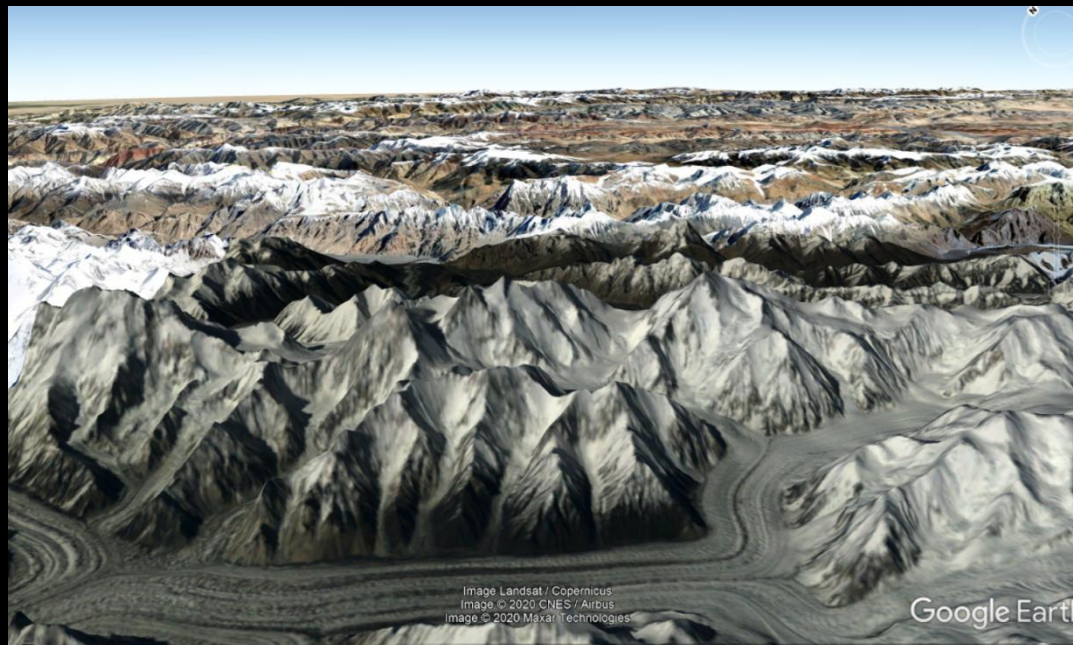


Google Earth

# Product Example L1C



**Venice, Italy**



**Gasherbrum massif  
Pakistan Karakoram**

# Product Example L2A



sensors



Article

## PACO: Python-Based Atmospheric Correction

Raquel de los Reyes <sup>1,\*</sup>, Maximilian Langheinrich <sup>1</sup>, Peter Schwind <sup>1</sup>, Rudolf Richter <sup>1</sup>,  
Bringfried Pflug <sup>2</sup>, Martin Bachmann <sup>3</sup>, Rupert Müller <sup>1</sup>, Emiliano Carmona <sup>1</sup>,  
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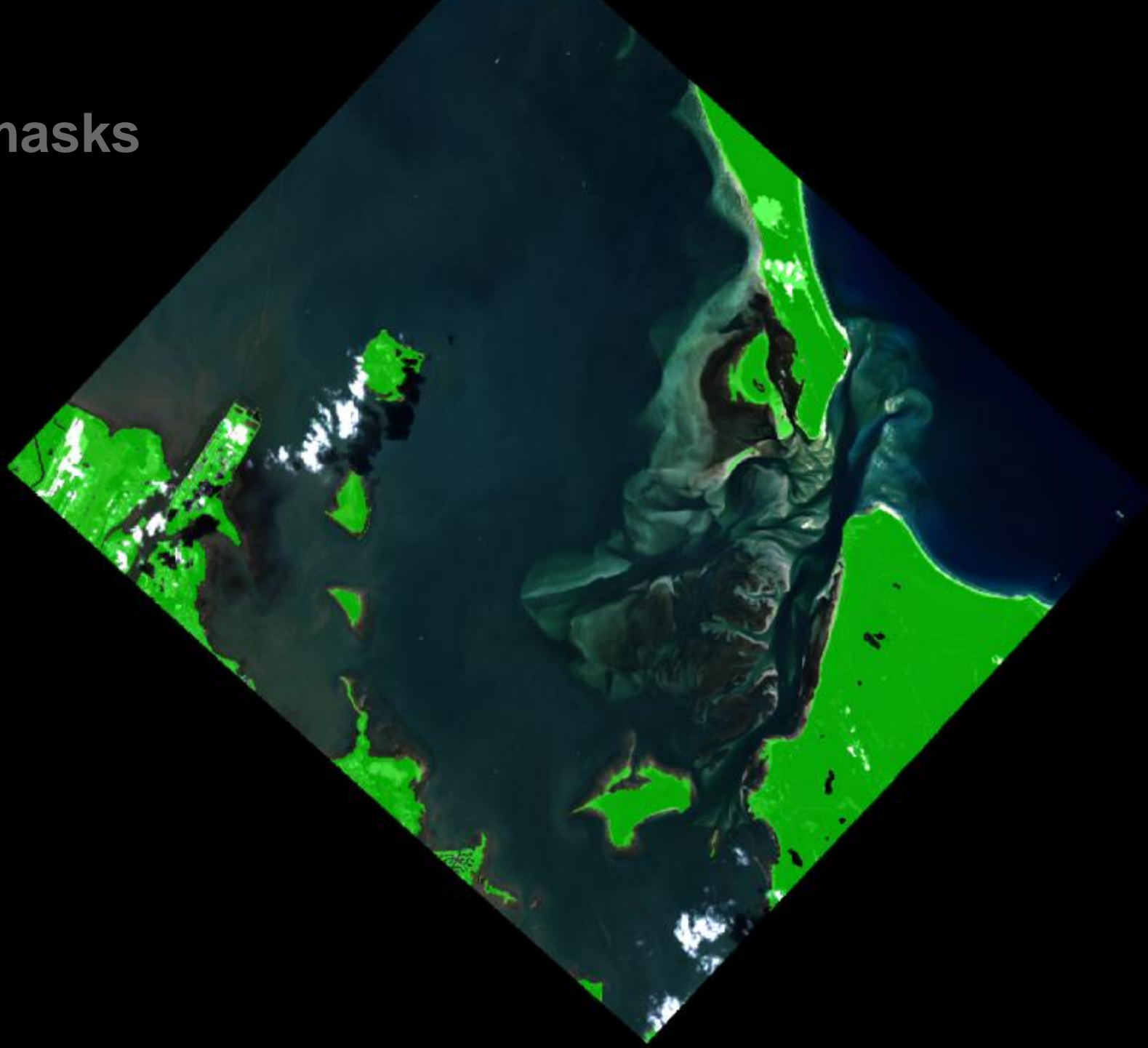
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# Product Example L2A masks

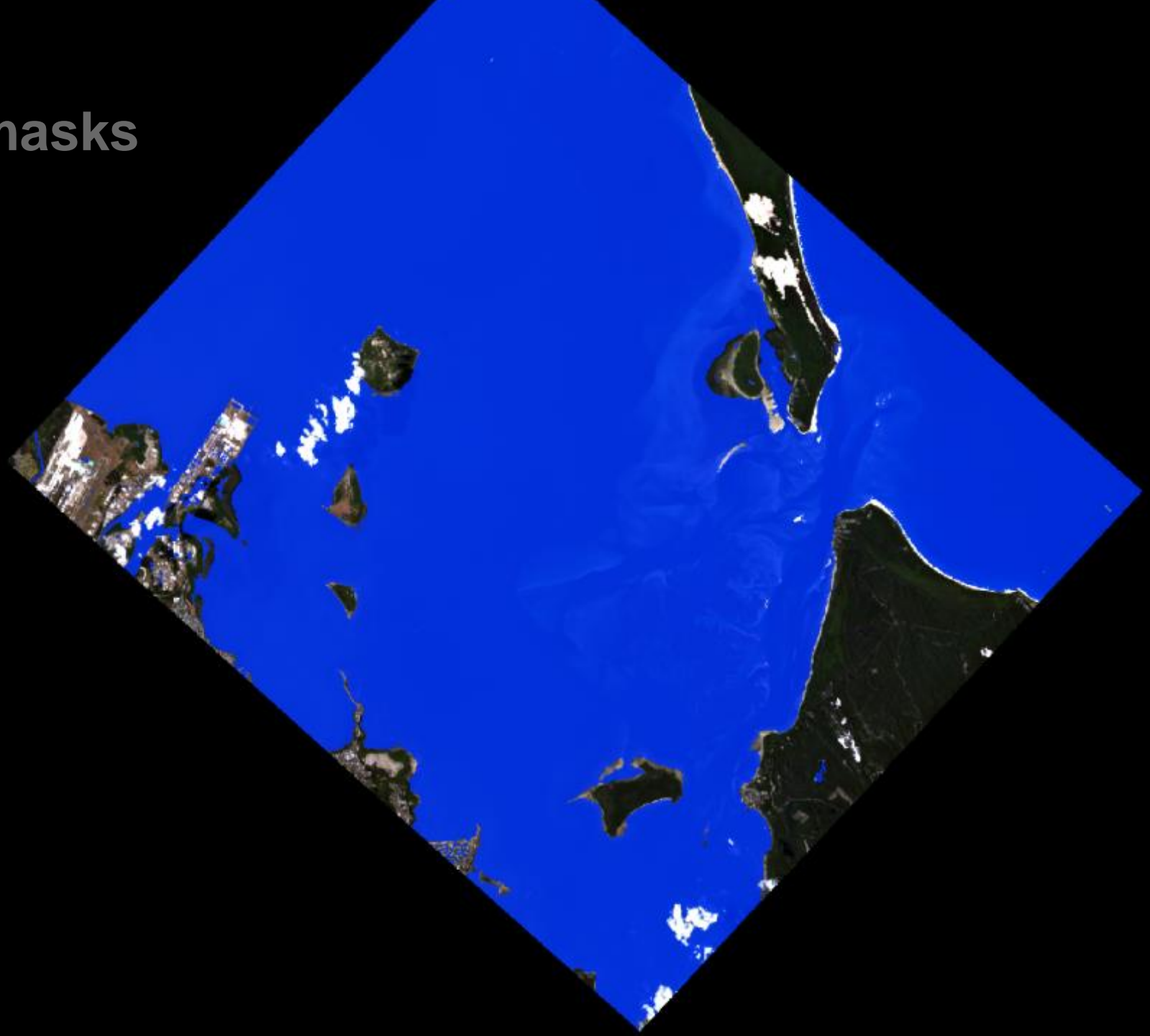
Land Mask



# Product Example L2A masks

Land Mask

Water Mask

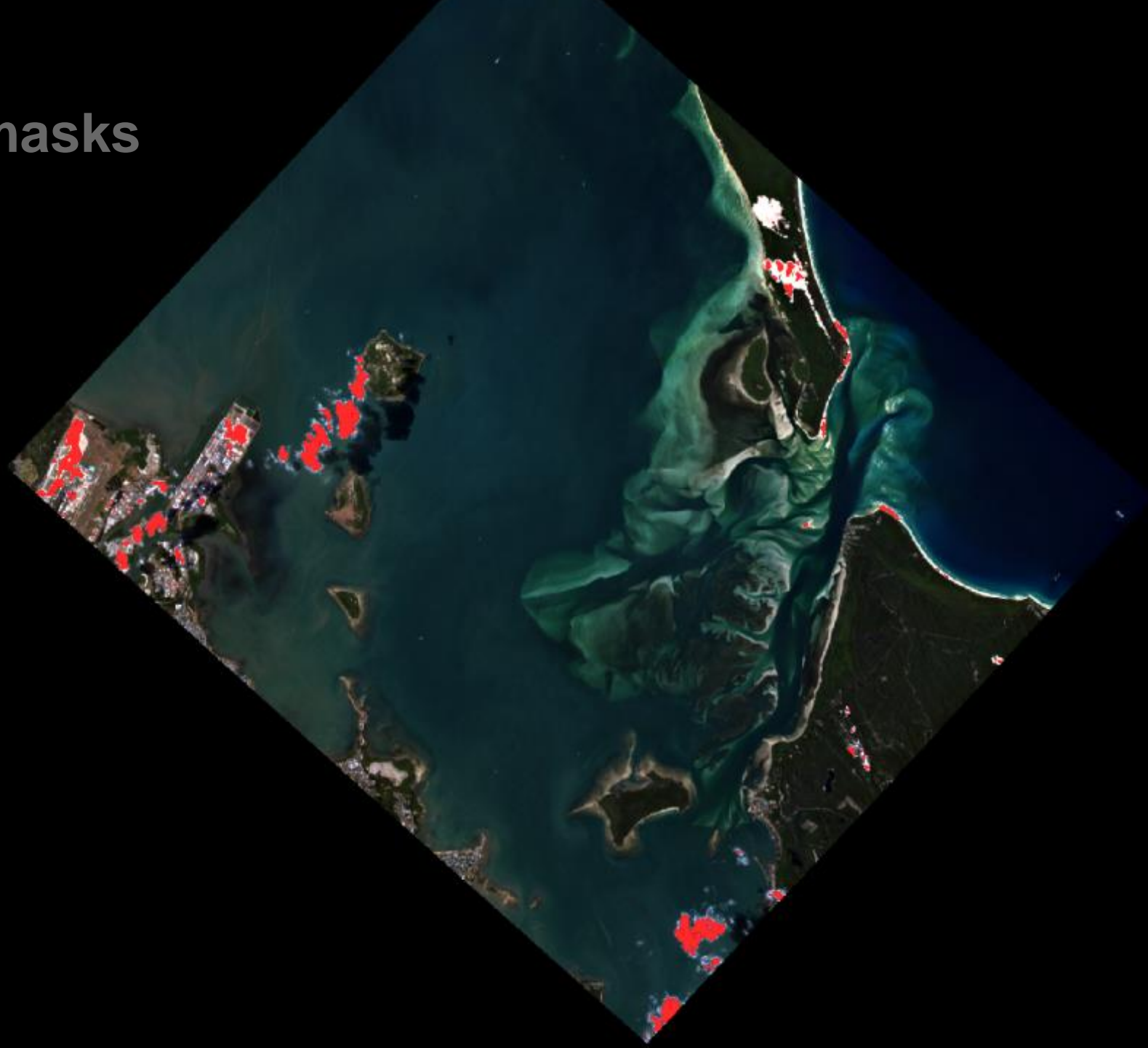


# Product Example L2A masks

Land Mask

Water Mask

Cloud Mask



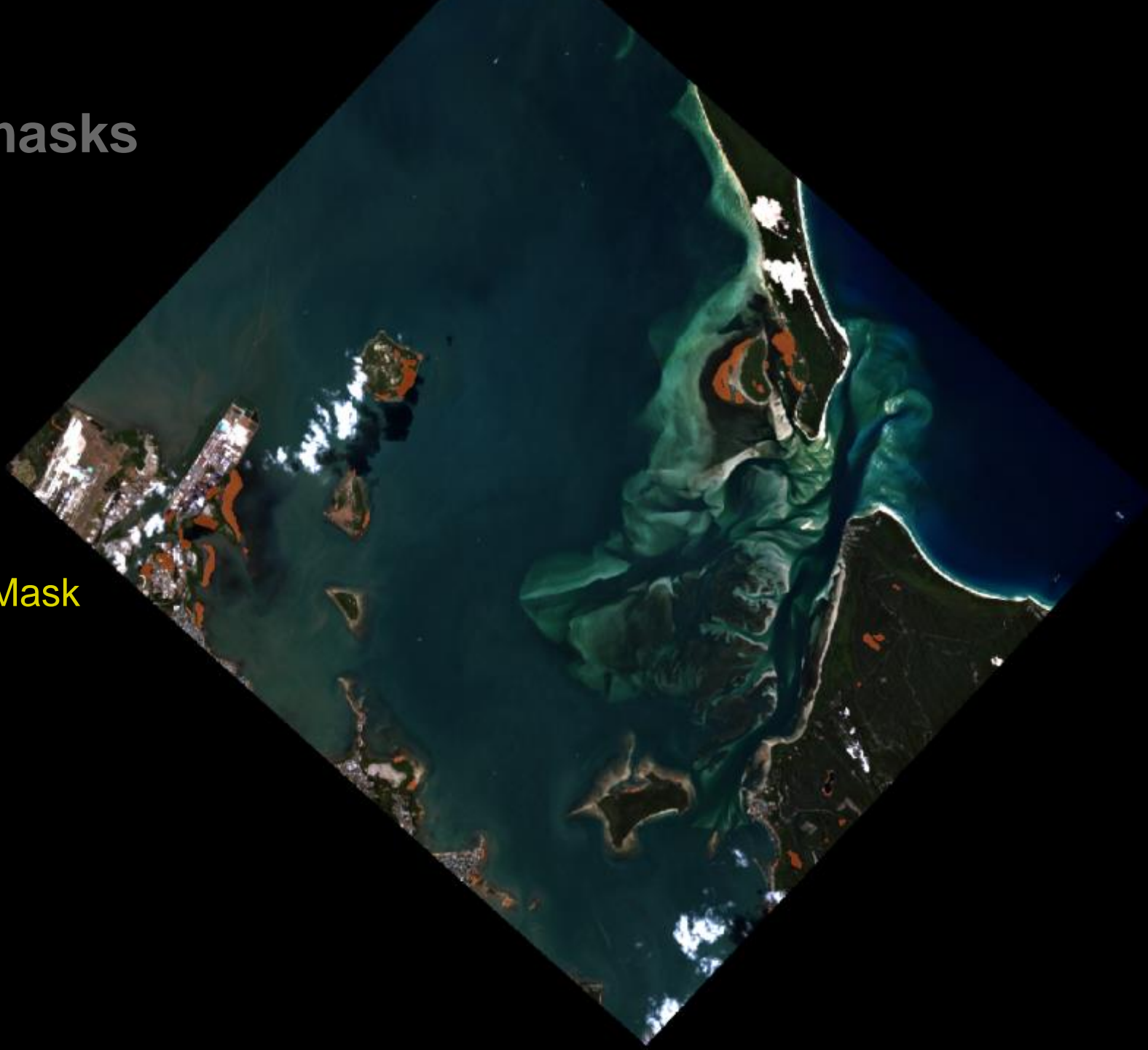
# Product Example L2A masks

Land Mask

Water Mask

Cloud Mask

Cloud Shadow over land Mask



# Product Example L2A masks

Land Mask

Water Mask

Cloud Mask

Cloud Shadow over land Mask

Haze over land Mask



# Product Example L2A masks

Land Mask

Water Mask

Cloud Mask

Cloud Shadow over land Mask

Haze over land Mask

**Haze over water Mask**



# Product Example L2A masks

Land Mask

Water Mask

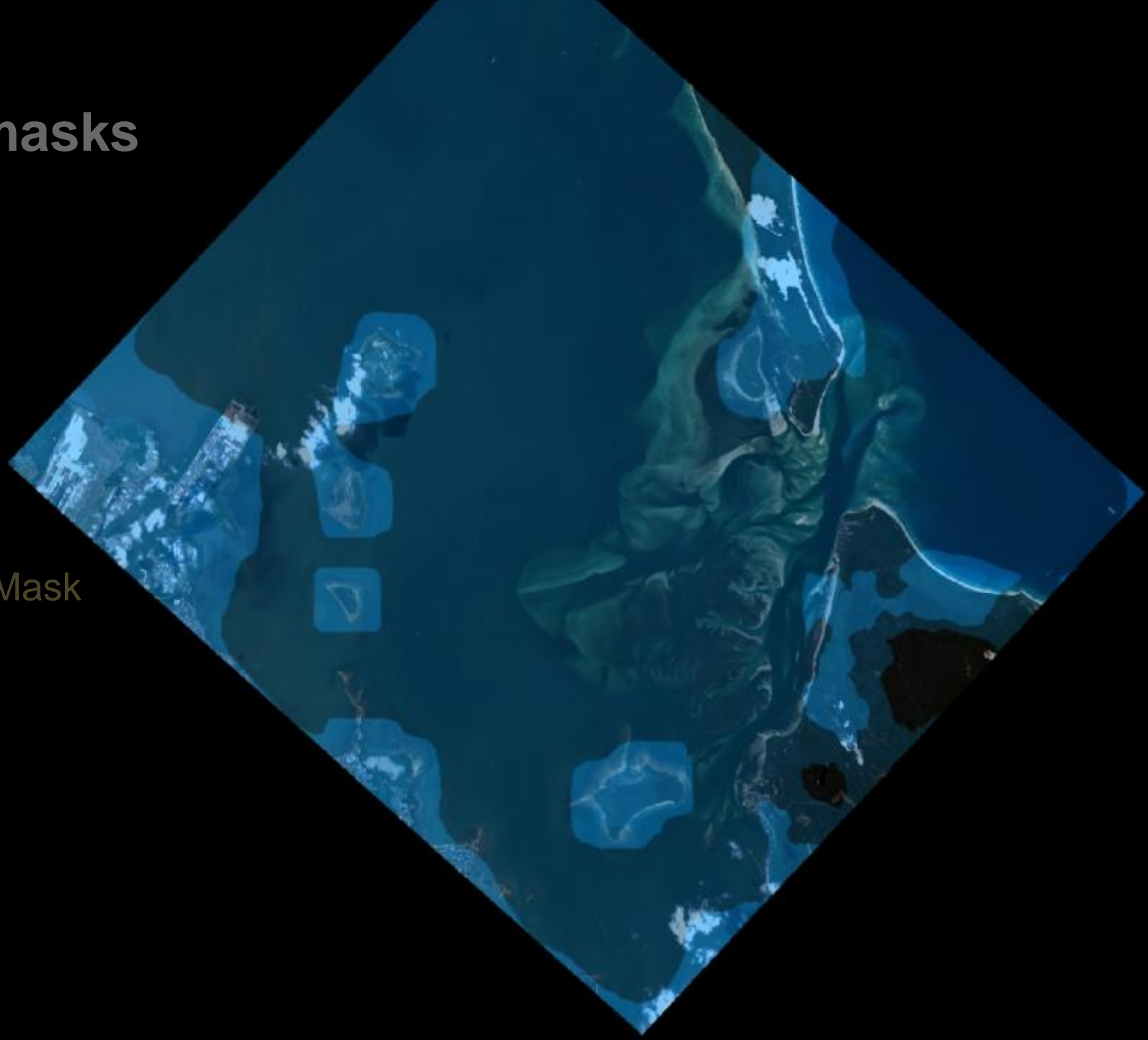
Cloud Mask

Cloud Shadow over land Mask

Haze over land Mask

Haze over water Mask

**AOT Map**



# Product Example L2A masks

Land Mask

Water Mask

Cloud Mask

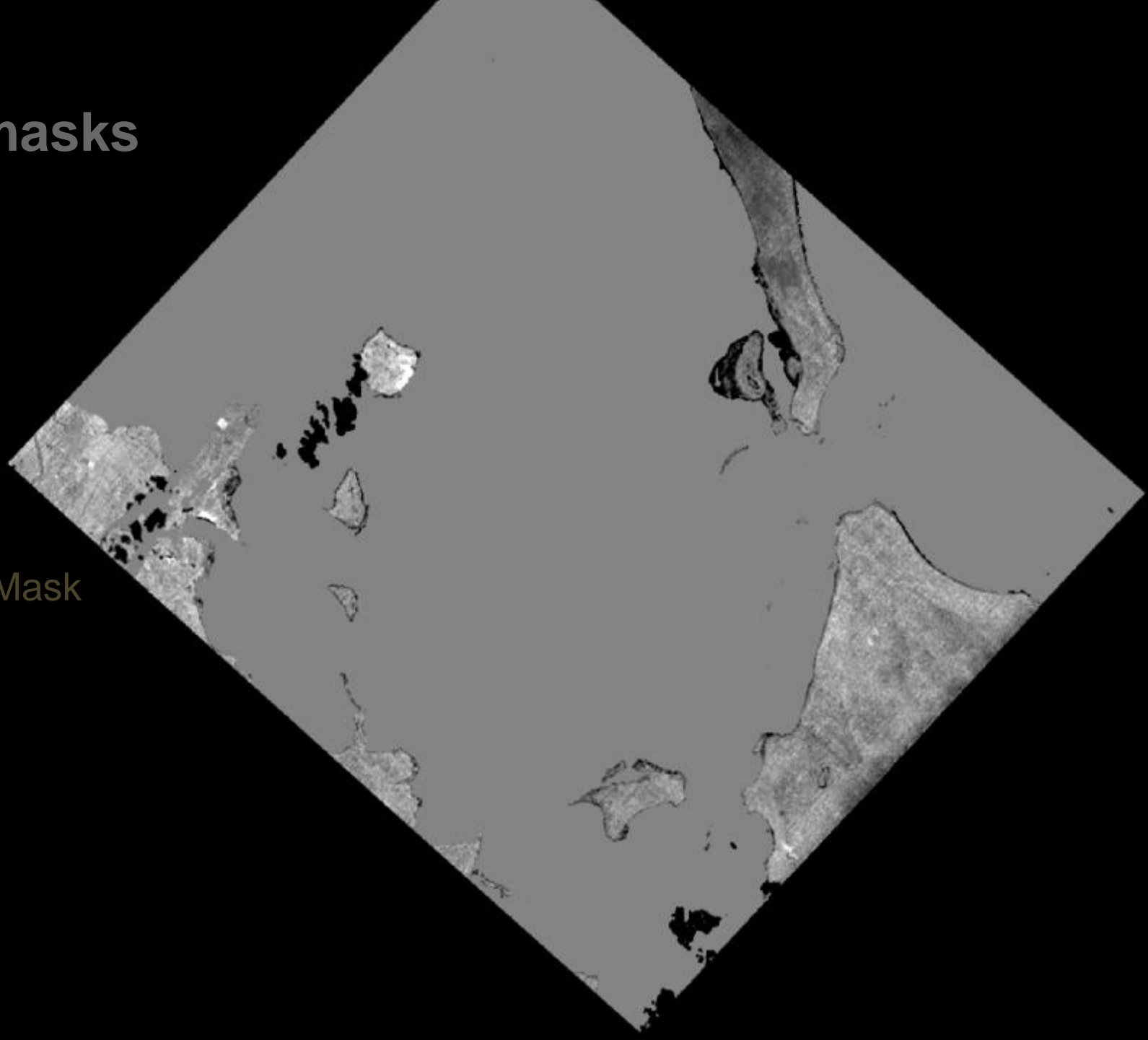
Cloud Shadow over land Mask

Haze over land Mask

Haze over water Mask

AOT Map Mask

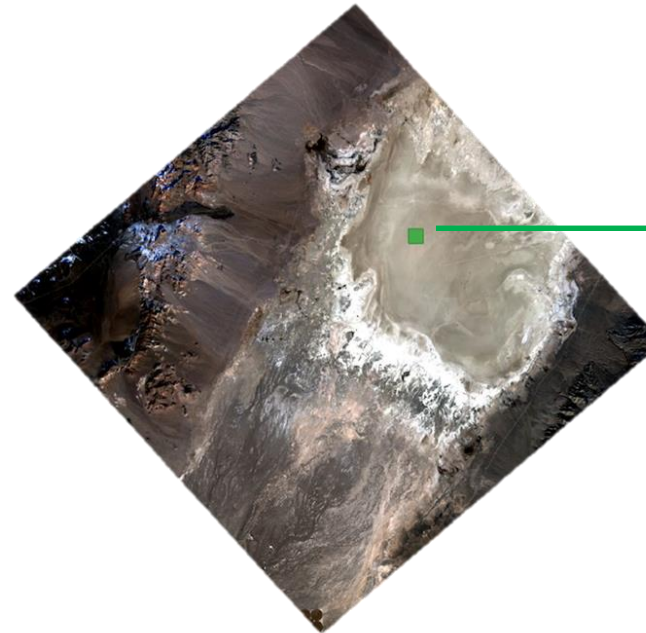
**WV Map Mask**



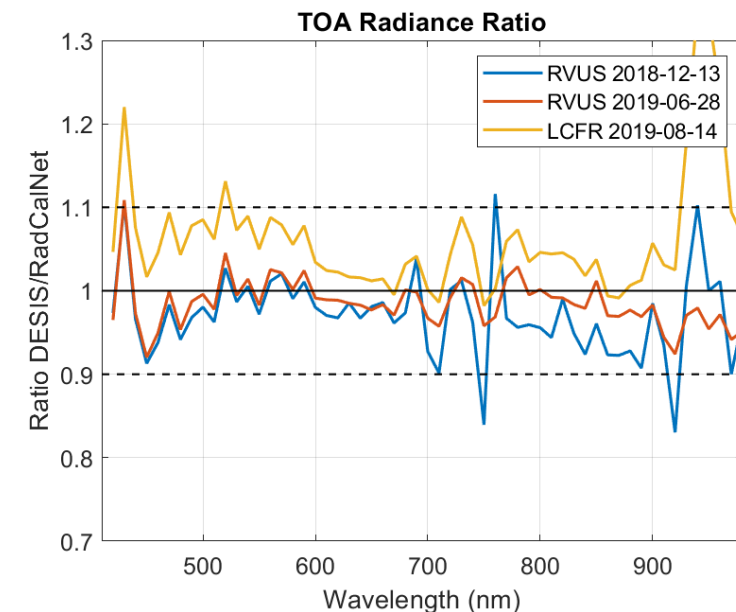
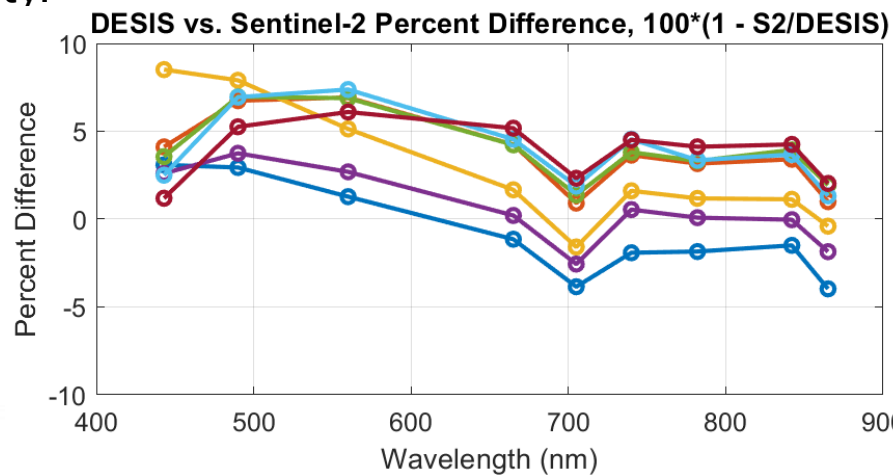
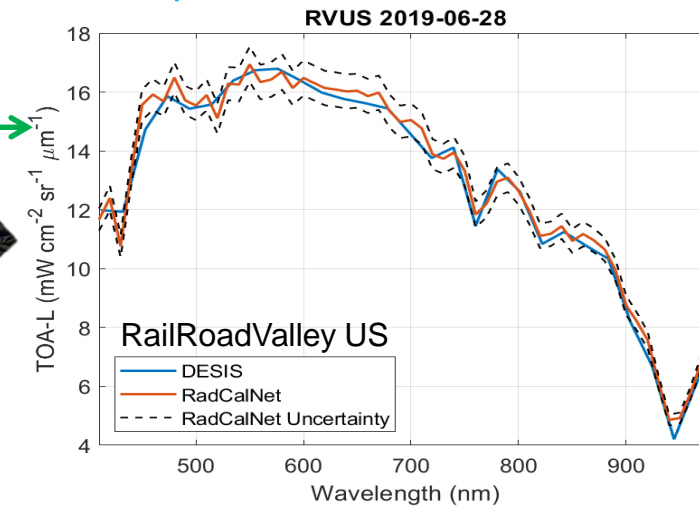
# Product Quality

## Top-of-Atmosphere Radiance (TOA)

- Absolute radiometric calibration of the TOA radiance using RadCalNet (RVUS, GONA)
- Comparison of DESIS with RadCalNet is <10% (mostly < 5%)
- Comparison of DESIS with Sentinel-2 and Landsat-8 show differences of <10%
- Spectral calibration (after smile corr.) better than 0,5 nm.
- SNR is greater than 200 in the green spectral region for a 30% albedo, 45 degree solar elevation, 23 km visibility.



### Comparison DESIS & RadCalNet



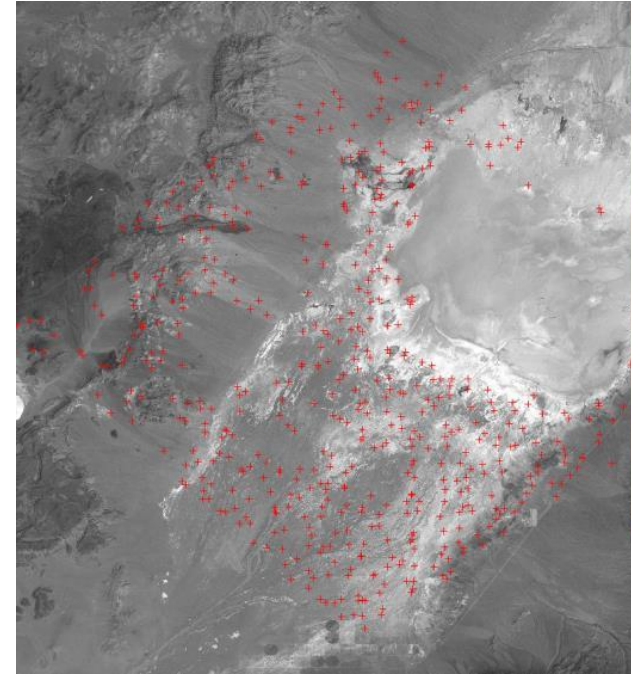
# Product Quality

## Geolocation Accuracy

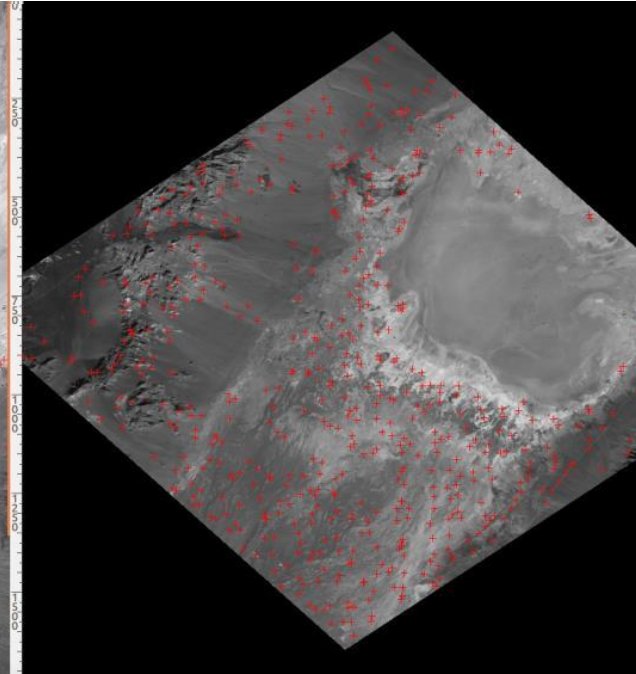
177 scenes investigated

- #GCP: average 282 per scene for calibration
- #Control Points: average 1357 per scene for QA
- MTF@Nyquist (across track) is about 0.3–0.4.
- Geometric accuracy with respect to reference is 20 m (<1 pixel) linear RMSE in the case that GCPs can be derived from image-to-image matching; otherwise, RMSE is 300–500 m

Reference Image  
(Landsat 8 Pan, ~18 m CE90)



DESIIS Image  
(after coarse rectification)



Cascade of matching

- BRISK (Binary Robust Invariant Scalable Keypoints)
- LLSQ (Local Least Squares)
- SIFT (Scale-Invariant Feature Transform)

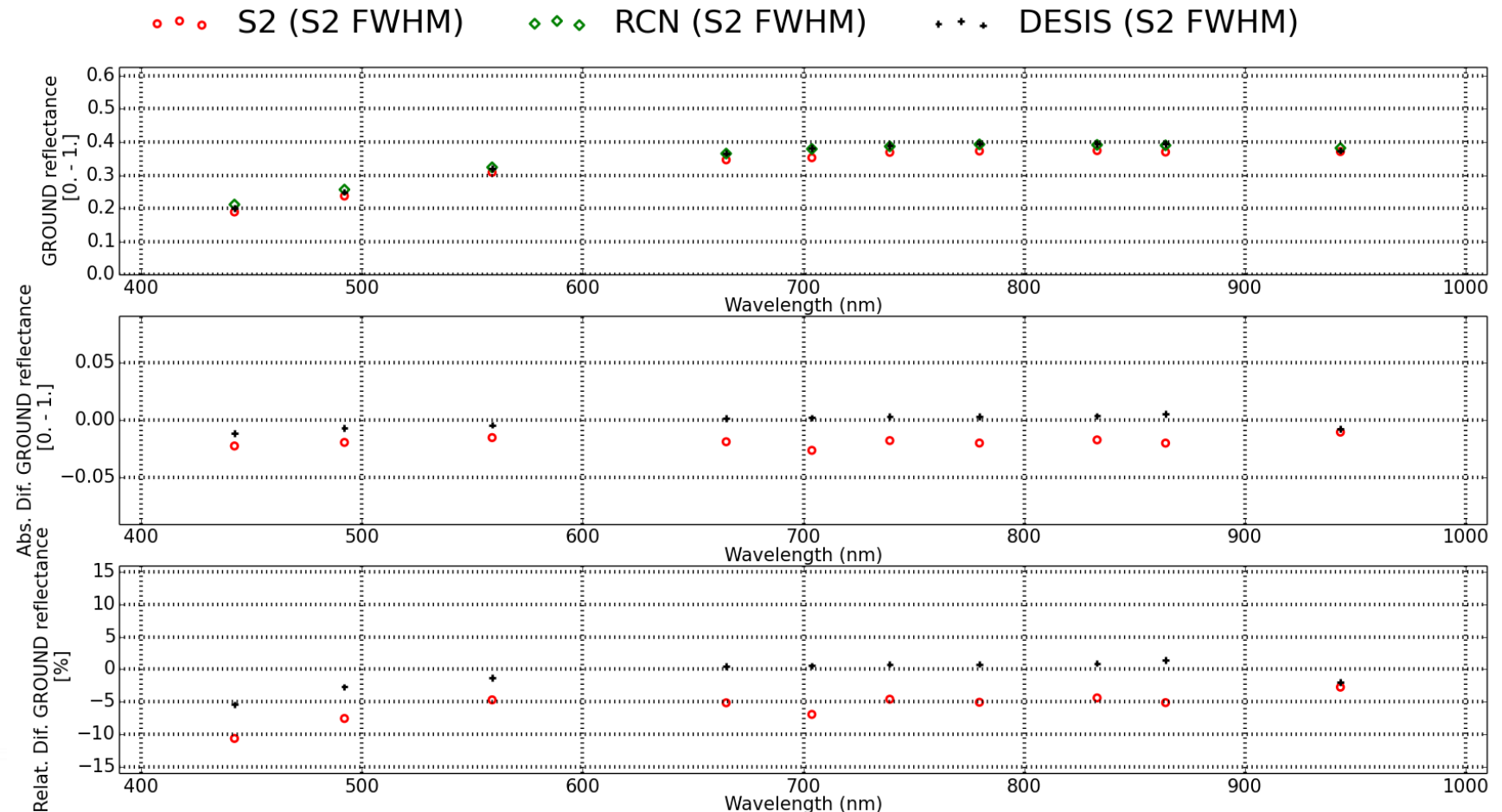


# Product Quality

## Bottom-of-Atmosphere Reflectance (BOA)

- Comparison of BOA using a scene of RVUS (20° sun zenith angle, time difference 25 min, both processed with the same atm. correction program)
- BOA reflectance differences is < 5% based on RadCalNet
- BOA reflectance difference is < 10% compared to Sentinel-2

Cross Validation:  
BOA for Sentinel-2B, DESIS and  
Railroad Valley Playa RadCalNet  
(RCN)



# Where you can find more information on data quality

- Absolute radiometric calibration of TOA-Radiance <10% (mostly < 5%) in comparison to RadCalNet and cross-calibration with Sentinel-2 and Landsat-8.
- Spectral calibration better than 0,5 nm (1/5 pixel)
- SNR better than 200 at 550 nm at an albedo of 30%, 45° sun elevation, 23 km visibility.
- MTF@Nyquist (across) is about 0,3-0,4.
- Geometric accuracy w.r.t. Reference is ~20 m (<1 Pixel) linear RMSE with GCPs; otherwise RMSE 300-500 m with peak values up to 1 km.
- BOA-reflectance <10% in comparison to RadCalNet and Sentinel-2.



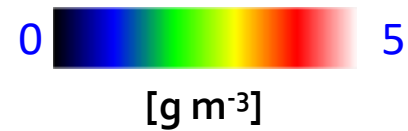
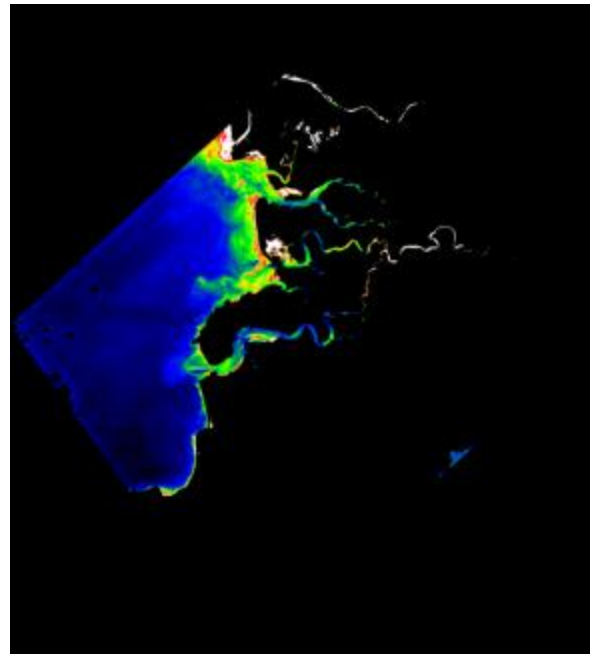
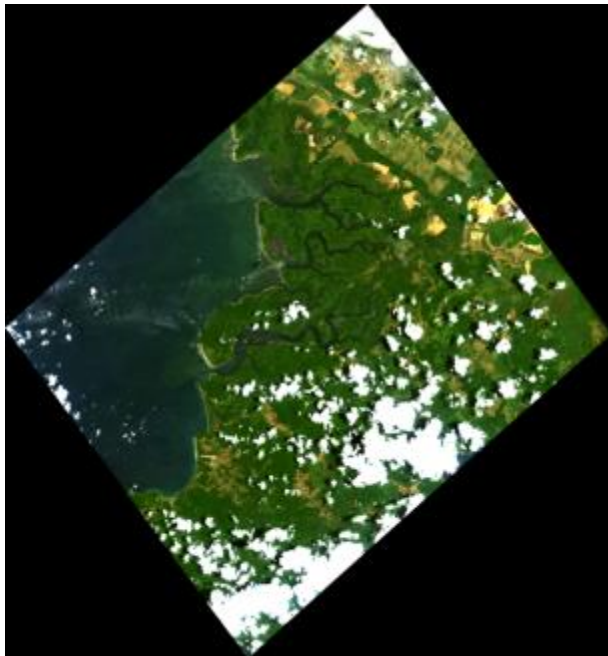
The image shows the cover of a scientific article. At the top left is the 'sensors' logo, and at the top right is the MDPI logo. The title is 'Data Products, Quality and Validation of the DLR Earth Sensing Imaging Spectrometer (DESI)'. Below the title are the authors: Kevin Alonso, Martin Bachmann, Kara Burch, Emiliano Carmona, Daniele Cerra, Raquel de los Reyes, Daniele Dietrich, Uta Heiden, Andreas Hölderlin, Jack Ickes, Uwe Knodt, David Krutz, Heath Lester, Rupert Müller, Mary Pagnutti, Peter Reinartz, Rudolf Richter, Robert Ryan, Ilse Sebastian, and Mirco Tegler. The article is from the 'sensors' journal, published by MDPI. The cover also includes a 'check for updates' button and the publication date: Received: 23 September 2019; Accepted: 9 October 2019; Published: 15 October 2019.

Ongoing sensor monitoring, calibration and SW improvements

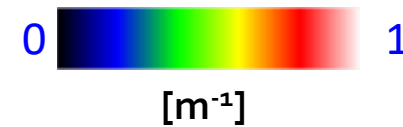
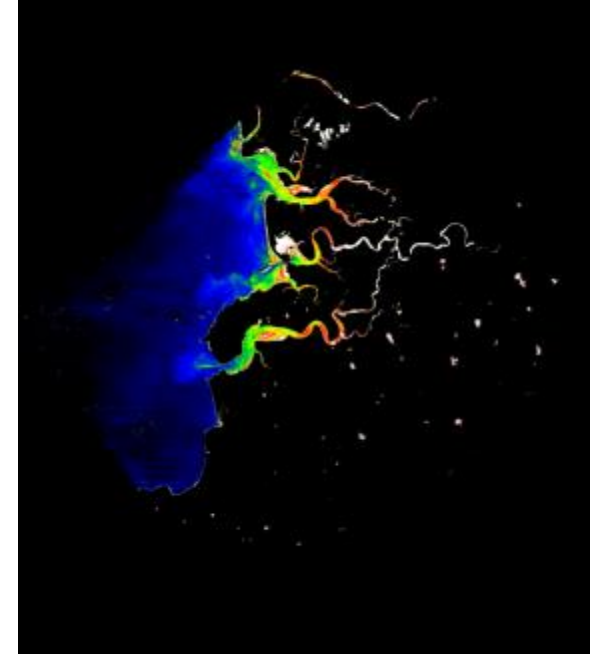


## Application examples

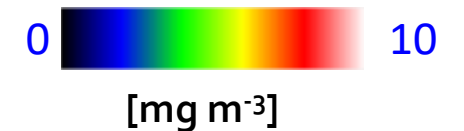
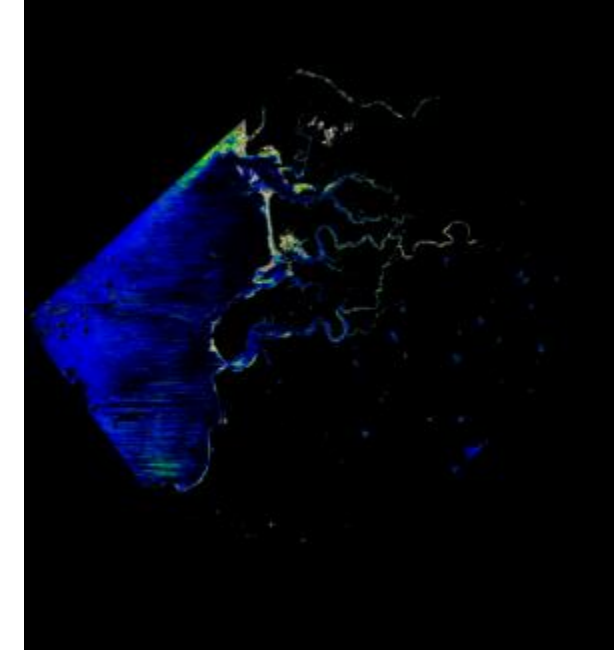
- Hyperspectral imagery for water quality studies related to agricultural activities within the National Wetland Térraba Sierpe, Costa Rica



Total suspended matter  
concentration

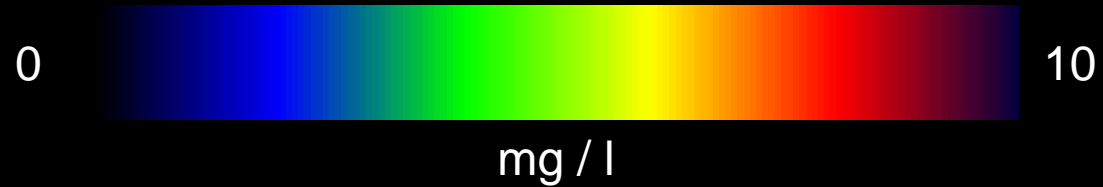
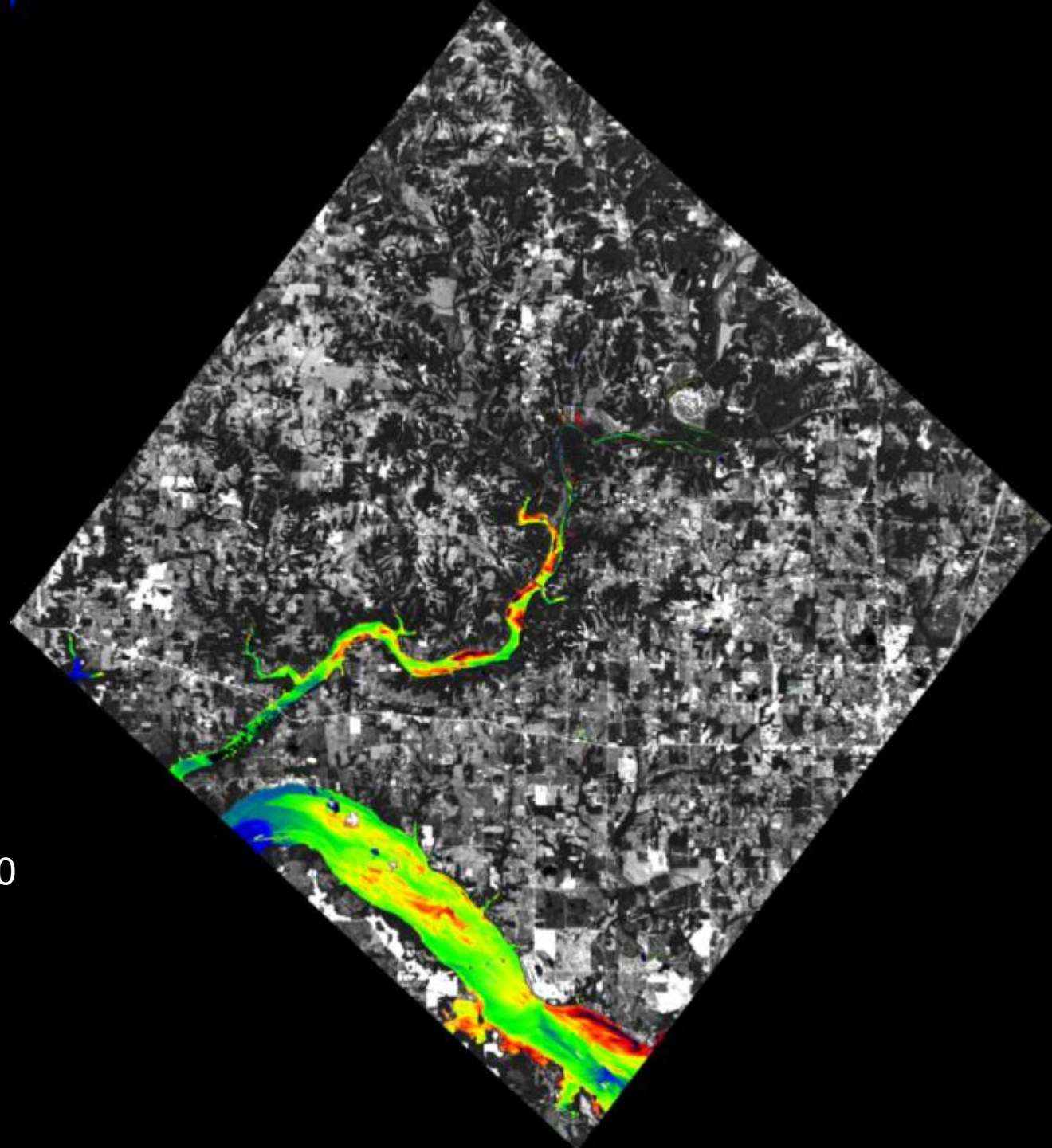


Colored Dissolved Organic Matter  
CDOM Absorption at 440 nm



Phytoplankton concentration

# Product Example L3 Suspended Matter in Water

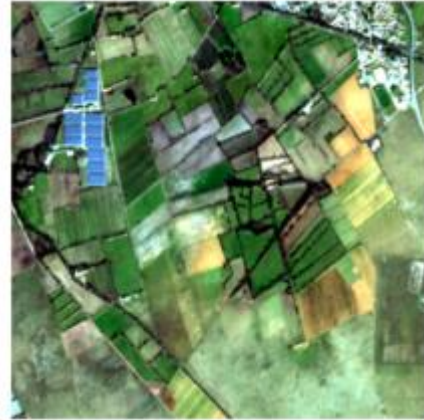


# Application examples

- Data Fusion: Enhance Ground Sampling Distance (GSD) of DESIS using Sentinel 2



DESIS, 30 m GSD



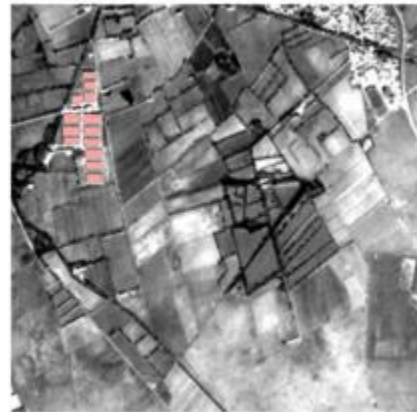
Sentinel 2, 10 m GSD



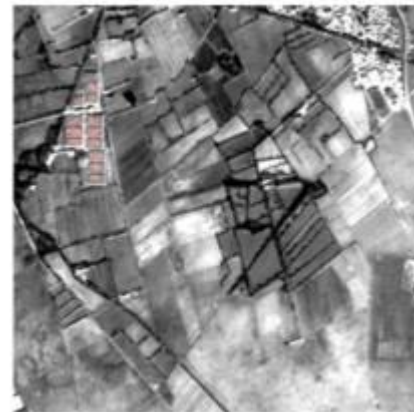
Fusion results, 10 m GSD

## Better Target Detection

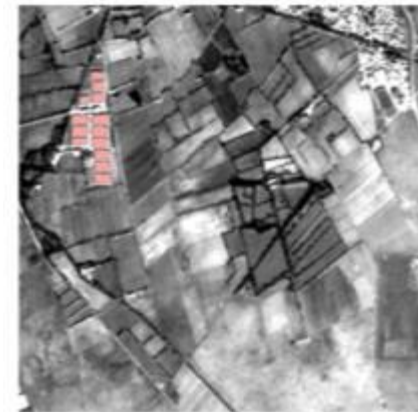
Solar panels by spectral similarity



Solar panels locations



Detection Sentinel 2

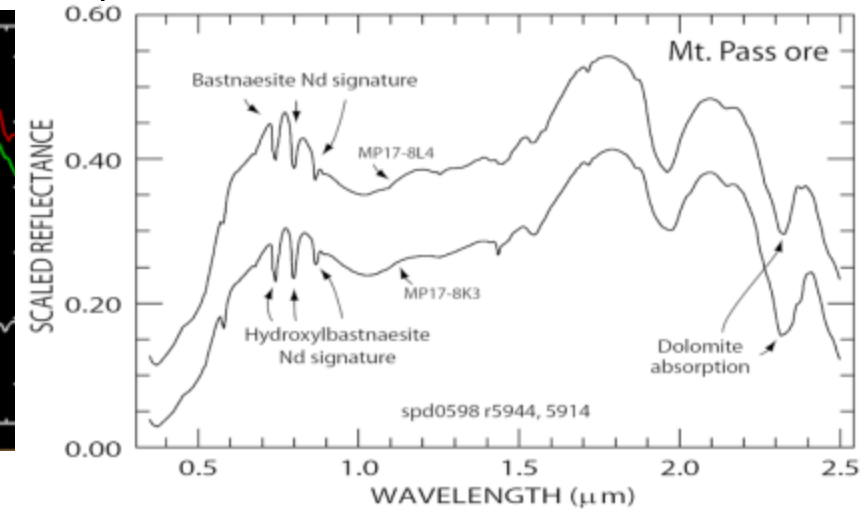
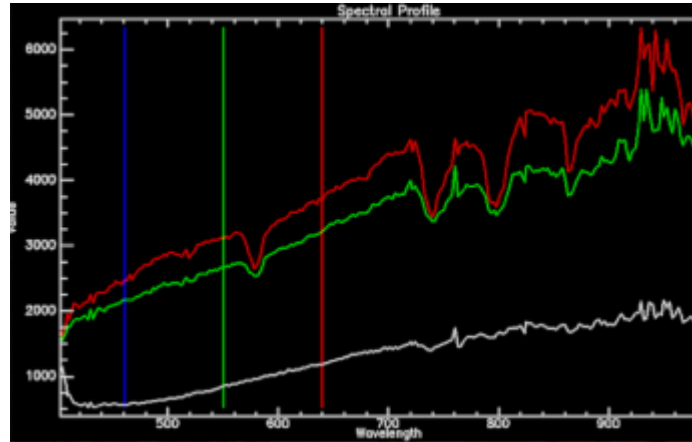
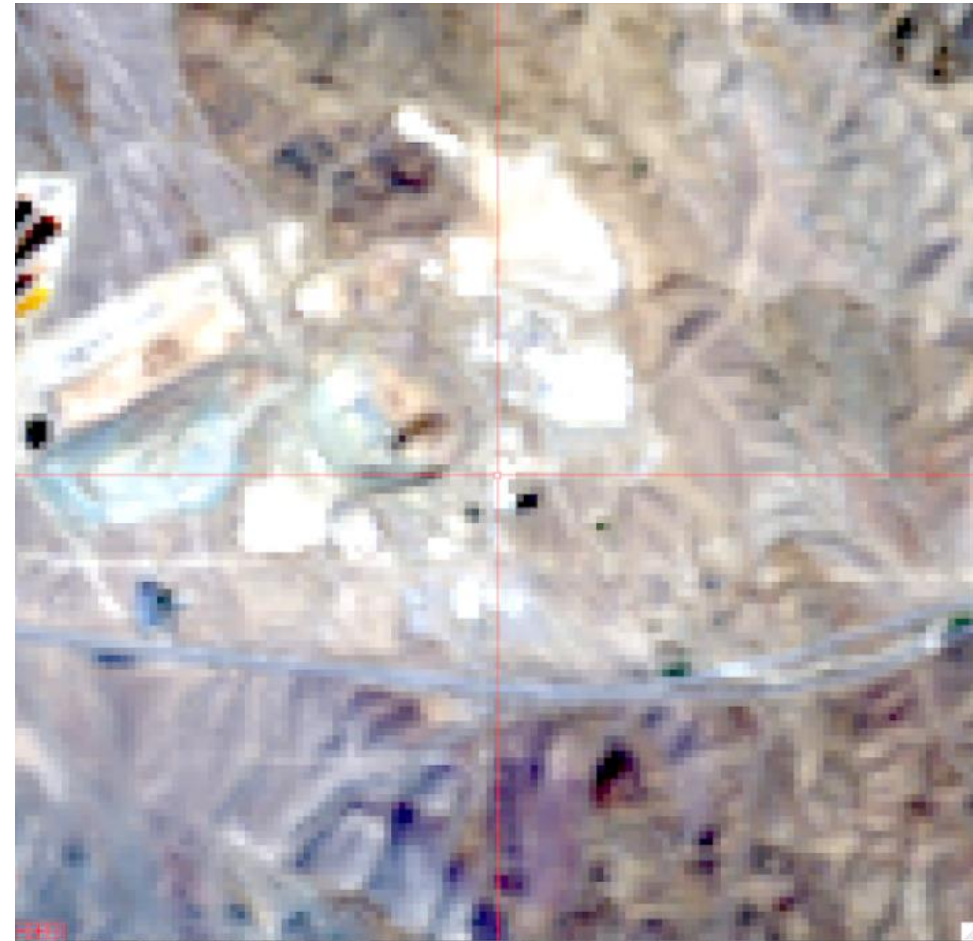


Detection  
(fused product)



# Application examples

- Rare Earth Elements (REE) @ Mt. Pass mine (USA / California)



Gregg Swayze from USGS Spec Lab

“So this may be the first demonstration of REE detection from space but may also have high enough resolution and SNR to allow differentiation of individual REE minerals”

Element: Neodymium (Nd); Class: Lanthanoide

Usage: Magnets, Laser, Glas,...

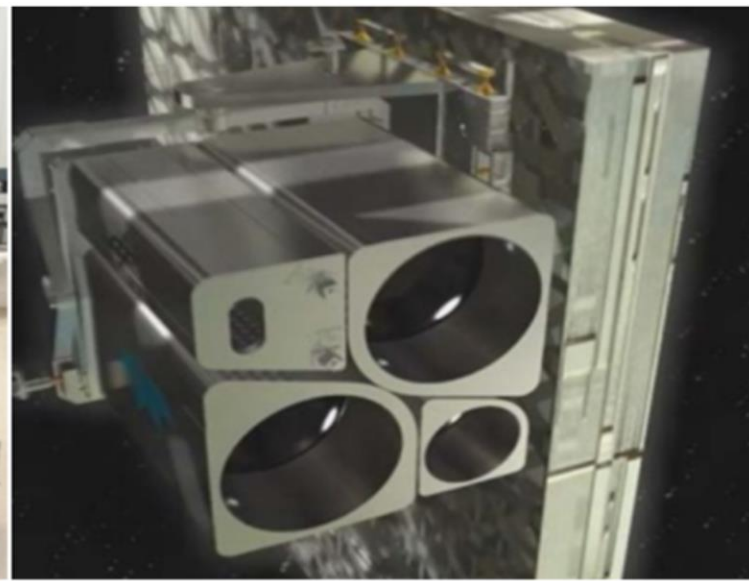
# DESI, MUSES and ISS



Teledyne Brown Engineering (USA) and DLR have partnered to build and operate the DLR Earth Sensing Imaging Spectrometer (**DESI**) attached to Multi-User System for Earth Sensing (**MUSES**) Platform on the ISS

**MUSES** provides accommodations for two large and two small hosted payloads and provides **core services** for the instruments like

- **Position** via GPS (1 Hz)
- **Attitude** via Startracker + MIMU (10 Hz)
- **Master time** (acc. <150 μsec)
- **2 Gimbals** ±25° for/back; 45° backboard; 5° starboard
- **Downlink** 225 Gbit / day Ku band

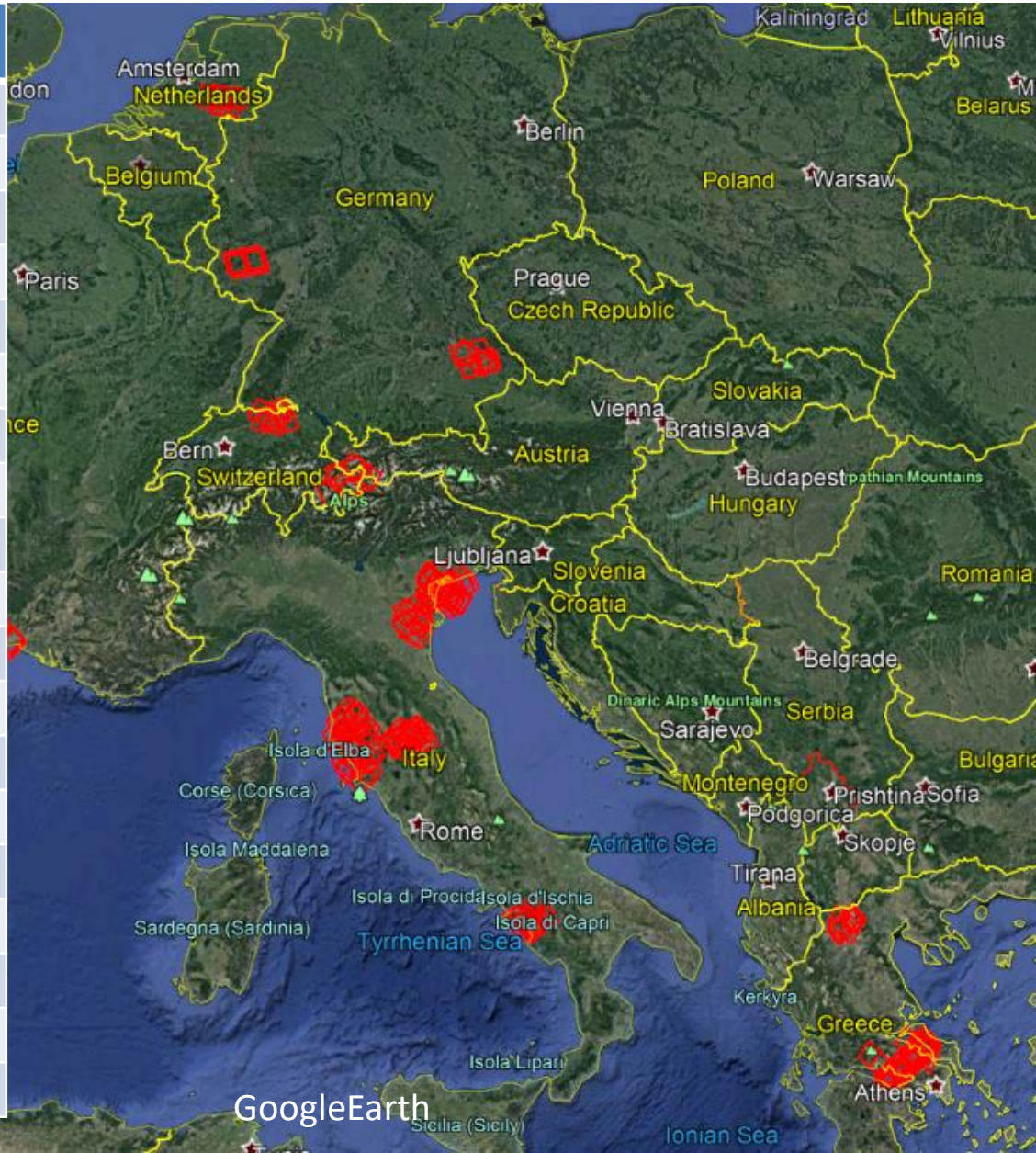


(ELC-4)  
EXPRESS Logistics Carrier  
Payload Platform

DESIS Data for ESA's  
spaceborne hyperspectral  
CHIME mission

- More than 400 DESIS scenes acquired
- Multitemporal acquisitions for 2020
- New acquisitions in 2021

| CHIME Test Site    | No. of DESIS scenes |
|--------------------|---------------------|
| Braccagni          | 21                  |
| Camarena           | 41                  |
| Campania           | 24                  |
| Desfina            | 22                  |
| HogeVeluwe         | 8                   |
| Irlbach            | 13                  |
| JolandaDiSavoia    | 13                  |
| Kokino             | 33                  |
| Laegern            | 9                   |
| LakeTrasimeno      | 33                  |
| LakeZazari         | 15                  |
| Natuurmonumenten   | 12                  |
| NPHH               | 6                   |
| ParcoBiancane      | 22                  |
| Puechabon          | 9                   |
| SNP                | 12                  |
| Venice             | 41                  |
| IberiaPyritBelt I  | 75                  |
| IberiaPyritBelt II | 32                  |



# Calibration / Validation Summary

## • Status October 2019

- Absolute radiometric calibration is well within  $\sim 10\%$  at the Top-of-Atmosphere (TOA) radiance and TOA reflectance level when validated against RadCalNet [9], Sentinel-2 and Landsat-8 - most of wavelength range better 5%
- Spectral calibration after smile correction is typically better than  $\sim 0.5$  nm, and always within  $1/3$  of a spectral pixel.
- SNR is greater than 200 at 0.3 albedo, mid-latitude summer,  $45^\circ$  solar elevation, rural aerosol and 23 km visibility (investigated at five bands at 443 nm, 482 nm, 562 nm, 655 nm, 865 nm) and agrees with groundbased measurements
- MTF@Nyquist (across track) is about 0.3 - 0.4
- Geometric accuracy with respect to reference is  $\sim 20$  m ( $< 1$  pixel) linear RMSE in the case that GCPs can be derived from image-to-image matching; otherwise RMSE is 300 - 500 m.
- Agreement of Bottom-of-Atmosphere (BOA) reflectance within  $\sim 10\%$  to RadCalNet [9], Sentinel-2 and field campaign data from Pinnacles site (Australia)

