CHIME: A COPERNICUS HYPERSPECTRAL IMAGING MISSION FOR THE ENVIRONMENT

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Résumé
Une évolution de la Composante Spatiale de Copernicus (CSC) est prévue pendant la seconde moitié des années 2020 pour répondre aux besoins prioritaires des utilisateurs non couverts par l'infrastructure existante. La mission CHIME (Copernicus Hyperspectral Imaging Mission for the Environment) couvrira une partie de ces besoins en fournissant des mesures hyperspectrales pour des domaines applicatifs comme la sécurité alimentaire, l'agriculture et la gestion de matières premières. Cet article fournit une description de la mission CHIME et de son état de développement actuel.

Mots-clés : Observation de la Terre, Copernicus, hyperspectral, CHIME, Agence Spatiale Européenne, Thalès Alénia Space

Abstract
An evolution of the Copernicus space component (CSC) is planned for the second half of the 2020s to meet the priority of user needs that the existing infrastructure does not address. The Copernicus Hyperspectral Imaging mission for the Environment (CHIME) will cover part of these needs by providing hyperspectral measurements for application areas such as food safety, agriculture, and the management of raw materials. This article provides a description of CHIME mission and its current state of development.

Keywords: *Earth observation, Copernicus, hyperspectral, CHIME, European Space Agency, Thalès Alénia Space.*

1. Introduction

An evolution of the Copernicus space component (CSC) is planned for the second half of the 2020s to meet priority user needs that the existing infrastructure does not address. This evolution will allow for the reinforcement of Copernicus services' monitoring capabilities when it comes to monitoring CO_2, polar regions, and agriculture and forestry.
Growing expectations about the use of Earth observation data to support policy-making and monitoring are putting increasing pressure on technology to deliver proven and reliable information.
Hyperspectral imaging (also known as imaging spectroscopy) is a technology that allows for an accurate and reliable observation of the Earth surface's geobiophysical and geobiochemical variables. This observation is achieved through the contiguous, gapless spectral sampling from the visible to the shortwave infrared portion of the electromagnetic spectrum.
Hyperspectral imaging is a powerful remote sensing technology based on high spectral resolution measurements of light interacting with matter, thus allowing the characterisation and quantification of Earth surface materials.

Thanks to well-established spectroscopic techniques, optical hyperspectral remote sensing will significantly enhance quantitative value-added products, which will support the generation of a wide variety of new products and services in the areas of agriculture, food security, raw materials, soils, biodiversity, environmental degradation and hazards, inland and coastal waters, and forestry. These are relevant to various European Union policies that are currently not being followed or can be improved, but also to the private downstream sector.
The main objective of CHIME Mission is to provide routine hyperspectral observations through the Copernicus programme in support of European Union- and related policies for the management of natural resources, assets, and benefits. In particular, this unique visible-to-shortwave infrared spectroscopy-based observational capability will support new and enhanced services for food security, agriculture, and raw materials, including sustainable agricultural and biodiversity management, the characterisation of soil properties, sustainable mining practices, and environmental preservation.

In the areas of food security and agriculture, hyperspectral remote sensing allows for a more accurate determination of the main crop characteristics, their temporal changes, and the derivation of soil fertility (Asner and Heidebrecht, 2002). Innovative farm management options (smart farming) based on hyperspectral remote sensing have been used to predict temporal and spatial patterns of crop productivity and yield potential. Furthermore, after the harvesting period, the quantification of crop residues in the soil is an effective soil functionality measure that relies on organic matter and important attributes as input factors. In addition, the estimation of photosynthesis rate and metabolism provides detailed information about primary production. Overall, in agriculture, the main advantages of a hyperspectral imager over a conventional multispectral imaging radiometer lie in the diagnostic capability to distinguish photosynthetically active vegetation from non-photosynthetically active vegetation, the improvement in crop type classification, the simultaneous provision of nitrogen uptake and other nutrient content, as well as information on plant disease, yield quality, and quantitative crop damage (Apan, Datt *et al.*, 2005).

Hyperspectral imaging has shown itself to be a powerful technique for the direct and indirect determination and modelling of a range of soil properties, including soil organic carbon (SOC), moisture content, textural and structural information, pH, as well as other properties assigned to a soil quality parameter that are directly linked to crop production and fertility.

Additionally, the use of hyperspectral imaging in support of sustainable raw material resource development has been shown to be one of the most compelling cases for a hyperspectral imaging mission (Goetz, 2009), since this technology can provide crucial mineralogical information, which is unobtainable from other exploration and mining tools, contributing towards improved exploration targeting and resource characterisation, thereby reducing environmental footprints as well as contributing towards more efficient and safer mining practices. Moreover, hyperspectral data provides quantitative and direct environmental information that is required for evidence-based decision-making and substantiating compliance with regulatory requirements.

Beyond the above applications, CHIME is also expected to support application areas such as biodiversity on land, forestry, hydrology and cryosphere study, the monitoring of inland and coastal waters, environmental degradation and hazards.

2. Mission requirements

The observational requirements of CHIME are driven by primary objectives (i.e., agriculture, soils, food security, and raw materials) and are based on experience, state-of-the-art technology, and the results of previous hyperspectral airborne and experimental spaceborne systems. here were established by an international group of experts and reflected in the Mission Requirement Document or MRD (Rast *et al.*, 2019). These baseline observational requirements consider trade-offs and dependencies between parameters, such as spectral resolution and radiometric performance.

The high-level requirements requirements are distinguishable in:

- Spatial coverage and geometry
- Observation Time
- Timeliness
- Revisit Time
- Spatial Requirements
- Spectral Requirements
- Radiometric Requirements
- Calibration Requirements

Details can be found directly in the Mission Requirement Document (Rast *et al.*, 2019).

Figure 1: Graphic rendering of CHIME satellite.

3. CHIME Development Phase B2/C/D/E1

For the development of the Space Segment Contract (Phase B2/C/D/E1) Thales Alenia Space (France) as Satellite Prime and OHB (Germany) as Instrument Prime were selected. The contract was signed in November 2020 and the corresponding Kick-Off released the start of Phase B2. The System Requirement Review (SRR) was conducted in July 2021 and the Preliminary Design Review (PDR) is planned for 2022.

The CHIME Space Segment will be confirmed by the end of the current phase B2. Currently there are 2 satellites foreseen and each of the satellites will embark a hyperspectral instrument, with a single telescope, and three single-channel spectrometers covering each one-third of the total swath of ~130 km. Each spectrometer has then a single detector covering the entire spectral range from 400 to 2500 nm.

The CHIME mission orbit is defined as:

- Type : LEO, sun-synchronous;
- LTDN 10:45 am (Mean Local Time of Descending Node).
- Repeat cycle: 22 (11) days with 1 (2) satellite(s);
- Mean altitude : 632 km;
- Inclination : 97.932°.

CHIME will embark a HyperSpectral Instrument (HSI) which is a pushbroom-type grating Imaging Spectrometer with high Signal-to-Noise Ratio (SNR) and data uniformity.

The generated hyperspectral data are already pre-processed onboard the satellite within the dedicated Data Processing Unit (DPU) allowing cloud detection and compression using artificial intelligence techniques (i.e. Support Vector Machine). Once the data are transmitted to the ground via Ka-Band antenna to the ground, the Data will be processed and disseminated through the Copernicus core Ground Segment (GS) allowing the generation of CHIME core products: L2A (surface reflectance in cartographic geometry), L1C (top-of-atmosphere reflectance in cartographic geometry) and L1B (top-of-atmosphere radiance in sensor geometry).

The CHIME instrument is a push-broom imaging spectrometer featuring a central, hollow, torus-like CFRP frame structure that provides all optomechanical stiffness to the single wide-field three-mirror anastigmat telescope (TMA) feeding three independent identical VISIR grating spectrographs in staggered slit configuration. The CHIME instrument employs spatial swath-splitting, i.e., the single wide field Three Mirror Anastigmat (TMA) telescope with a folding mirror feeds three independent identical full wavelength range VISIR grating spectrometer back ends in a staggered slit configuration with overlap. The offner-type spectrometers employ dual-blazed curved gratings delivering data in 10 nm Spectral Sampling Interval (SSI). More details about the instrument design can be retrieved from (Buschkamp *et al.* 2021).

In Figure 2, a summary of the CHIME system's main characteristics is provided.

CHIME Mission and System Summary	
Satellite heritage	• Platform: MILA (under development) • Instrument: HyperSpectral Instrument (HSI)
Payload	• On-ground swath: ~130km (at equator), composite of 3 identical spectrometers with 3 overlapping staggered sub swaths) • Spatial Sampling Distance (SSD): 30m • MTF: >0.25 ALT (along track); >0.4 ACT (across track) • > 200 spectr. channels within 400-2500nm, Spectral Sampling Interval (SSI) <10nm • Single channel solution offering excellent spatial co-registration across FoV • Spatial/Spectral co-registration at 0.1 SSD/SSI • Compliant with NEDL requirements • Radiometric accuracy < 4%; stability < 0.5% at Level 1
Satellite mass / power	• ~1.6 ton (Payload: 526kg) • ~1.4 kW (Payload: ~360 W)
AOCS	• Star Tracker optical heads interface directly to optical bench • Gyroless nominal operating mode • Safe Mode (w. magnetometer, sun sensors, reaction wheels and magnetic actuators) • Thrusters for orbit control • Autonomous LEOP sequence and simple NOM recovery
Payload data Tx	• Ka-Bands single polarisation: from 2 x 1.85 Gbps
Ground Segment	• Flight Operations Segment (FOS) • Core Ground Segment (GS) • High latitude stations (e.g., Svalbard) for Payload data downlink
Launcher	• VEGA-C (Vampire 1194 adaptor) in single launch configuration from CSG. • Compatibility with back-up launcher (e.g., Ariane 62) required until PDR

Figure 2: Copernicus Hyperspectral Imaging Mission for the Environment, CHIME Mission and System Summary.

4. Complementary Activities

In parallel to the ongoing Space Segment activity, three complementary studies were being conducted (Rast *et al* 2021): a) End to End Simulator under the lead on the Helmholtz-Zentrum Postdam Deutsches GeoForschungsZentrum (GFZ) (DE), b) Requirements Consolidation Study under the lead of Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA, IT) and c) CHIME Campaign under the lead of University of Zurich (CH) and in cooperation with the NASA – JPL making use of the NASA's airborne imaging Spectrometer AVIRIS-NG.

5. Synergies and International Context

In terms of potential for synergies with other optical imaging missions, a hyperspectral mission would be especially complementary to Sentinel-2 for many fields of applications, in particular for vegetation-related applications and raw materials. Additionally, there are other hyperspectral missions planned with similar mission requirements, e.g. a moderate spatial resolution in the range of ~ 30 m and a 10 nm spectral sampling interval over the spectral range between 400 and 2500 nm.

The PRISMA mission (Loizzo *et al*, 2018) is a hyperspectral Italian Space Agency program with 30 m spatial resolution, 30 km swath with a 5-year life (http://www.asi.it/en/flash/observing-earth/prisma), and was successfully launched in March 2019. A cooperation between CHIME and PRISMA was set up in 2020, to support the so called *"PRISMA for CHIME"* 2020 Space-borne campaign. This dedicated campaign combined both field and space-borne PRISMA data to simulate CHIME-like High Priority Prototype Products, further develop novel retrieval techniques and provide data for the consolidation of CHIME mission requirements.

The recent NASA Decadal Survey selected a hyperspectral mission SBG (Surface Biology and Geology) as "designated" mission to perform observations considered essential to the overall NASA programme. Following the workshop on International Cooperation in Imaging Spectroscopy from Space in July 2019, a NASA-ESA cooperation on imaging spectroscopy space missions is seen as a priority for collaboration, specifically given the complementarity of mission objectives and measurement targets of CHIME and SBG and defining key data products essential for the mission requirements for both concepts. As such, a collaboration was formalised by the set up of three Working Groups (WGs), to address collaboration in terms of a) Calibration and Validation, b) Data Product Harmonisation and c) Modelling and End-to-End Simulation.

Further, ENMAP the Environmental Mapping and Analysis Program (Guanter et al, 2015) for an imaging spectrometer mission with 30 m pixel resolution and 30 km swath is in Phase D for a 2022 launch by the DLR with a five-year mission (www.enmap.org). In parallel, DESIS, the DLR Earth Sensing Imaging Spectrometer (Düller *et al*, 2016) and HISUI, Japanese Hyperspectral Imager Suite (Matsunaga *et al*, 2017) are deployed in a non-sun synchronous orbit aboard the International Space Station.

All of these complementary missions provide excellent opportunities for preparing CHIME mission and defining the synergies with CHIME in view of delivering high-fidelity imaging spectroscopy data on a regular, operational, and global basis to governmental, scientific, and commercial communities.

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