MEthane Remote sensing LIdar missioN

MERLIN Mission

EXECUTIVE SUMMARY

Atmospheric Methane Lidar Mission

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THE MERLIN MISSION

A mission which combines political and scientific backgrounds

The MERLIN (MEthane Remote sensing LIdar missioN) mission, more than a political opportunity for France and Germany to strengthen their cooperation in space activities through their space agencies (CNES and DLR), is a significant contribution for a better understanding of the climate change which is one of the greatest challenges mankind has to face.

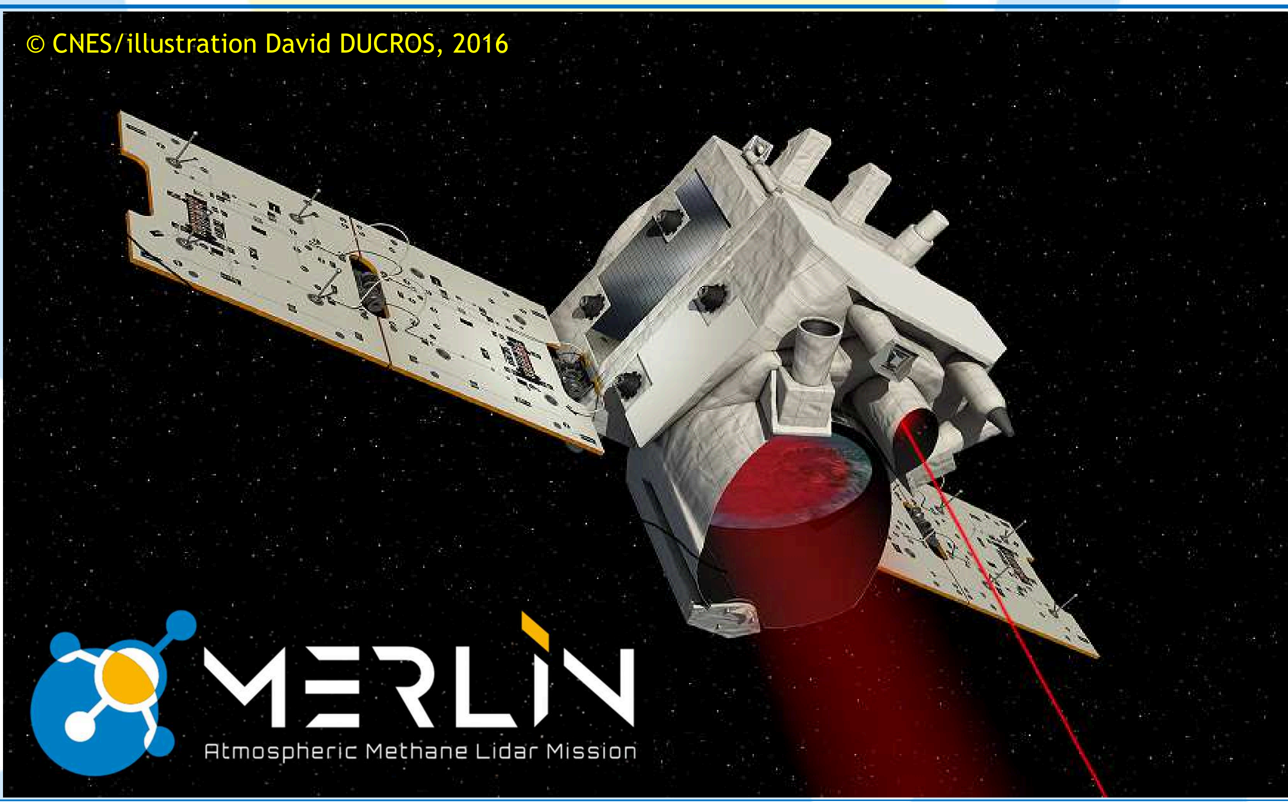
Methane is one of the most powerful greenhouse gases. MERLIN will precisely measure the methane concentration in the atmosphere thanks to an innovative satellite-based measurement concept developed and operated by CNES and DLR.

The French President, Nicolas Sarkozy, and the German Chancellor, Angela Merkel, jointly decided in 2009 to conduct a project on climate and greenhouse gases monitoring. The 12th Franco-German Council of Ministers in 2010 and the 15th one in 2013 confirmed the common will to develop a greenhouse gas mission dedicated to the methane measurement.

The United Nations Conference on the Climate Change (COP 21) held in Paris in 2015 was in particular the occasion to reaffirm the key contribution of the Franco-German MERLIN mission for a deeper understanding of the climate change and its mechanisms.

France and Germany confirmed their common interest in a mission able to measure methane emissions in accordance with the Kyoto Protocol and which will demonstrate a new generation of active optical sensors with a large application potential within the Global Climate Observing System.

Hence, the MERLIN mission is born from a political-scientific will for the overall public interest, for the protection of the environment, the plant and the animal kingdoms, and the mankind.



Artist view of the MERLIN satellite

THE MERLIN PROGRAMME

A French-German space mission for atmospheric methane measurement

Monitoring methane (CH_4) atmospheric concentrations from space is an important and challenging scientific problem.

It is important because human-induced emissions and land use changes make the global concentration of CH_4 increase and contribute to additional radiative forcing with other increasing greenhouse gases (GHG), ultimately leading to the rise of the global mean Earth surface temperature.

Methane emissions have various sources, partly anthropogenic, which can be grouped around three processes: the biogenic anaerobic degradation of organic matter by archaea (natural wetlands and inland waters, enteric fermentation and manure, rice cultivation, waste management, termites); the thermogenic formation in the Earth's crust under high temperatures and pressure (natural degassing of the Earth's crust, exploitation of fossil fuels); and the pyrogenic combustion of biomass under low-O_2 condition (biomass and biofuel burning). Even if total methane emissions are estimated with a global uncertainty of only 5-6% by atmospheric-based studies, this uncertainty increases to 20-30% for process-based estimates, and individual sources have uncertainties on the order of 30-40% for anthropogenic sources and larger than 100% for some natural sources (e.g., freshwater emissions).

The inversion systems inferring CH_4 emissions from CH_4 mole fractions are limited by the quality of the underlying atmospheric transport model used and by the uneven distribution of surface observations in space and time. Some key regions for the biogeochemical cycles of GHGs remain extremely difficult to access for long-term scientific activities because of their remote location or their political situation (e.g., the Arctic, tropical forests, some African countries). In addition, industrialized regions often have many different sources of CH_4 from, for example, livestock, fuel extraction and waste -some of them concentrated in hotspot regions- which requires high spatial density surface networks to separate and quantify those sources individually. Most of the emitted CH_4 is destroyed in the atmosphere by the chemical reaction with tropospheric OH, by photochemistry in the stratosphere (reaction with chlorine atoms, Cl) and by oxidation by soils.

In this context, measuring CH_4 from space becomes crucial, as it offers a drastic improvement in observational capacity to potentially provide either global coverage of CH_4 concentrations on a regular temporal basis (solar synchronous orbits), or regional coverage with continuous observations during daytime (geostationary orbits).

However, the monitoring of a trace gas such as CH_4 from space at a sufficient precision and accuracy to determine the changes in the plume resulting from changes in surface emissions is challenging. This is because the magnitude and variability of the absorption signal measurable at the top of the atmosphere for atmospherically relatively long-lived gases such as CH_4 is relatively small in comparison to the changes in reactive gases such as O_3 and CO, for example. Further, the accurate retrieval of these small changes is limited by the knowledge uncertainties of atmospheric parameters (as pressure and temperature profiles), spectroscopic CH_4 parameters, and other atmospheric species, which may have overlapping absorption lines in the profiled spectral region. CH_4 fluxes emitted from the surface result in small changes in the spatial distributions of the above CH_4 dry column mole fraction (e.g., typically a few part per billion (ppb)), and up to a few tens of ppb, on a day-to-day basis and at a typical model spatial resolution of 200 × 200 km, with most of the variation happening in the boundary layer. The level of measurement uncertainty that is required in this context to identify such changes above atmospheric background (~1800 ppb) is typically lower than ±2% for the total measurement error, with low systematic errors. The impact of methane on the Earth climate system is described in detail in [RD02].

THE MERLIN SYSTEM

A French-German responsibility sharing for development and exploitation phases

In order to strengthen their cooperation in space activities, CNES (Centre National d'Etudes Spatiales) and DLR (The German Aerospace Centre) have decided to jointly conduct a project on climate and greenhouse gases monitoring: the methane remote sensing LIDAR mission project dedicated to the measurement of atmospheric methane (CH_4) concentration is born from this common will. Its name is MERLIN.

The general MERLIN system design is classical:

- A dedicated space segment, namely the MERLIN satellite, encompassing: MYRIADE Evolutions platform, accommodated to the MERLIN payload, a payload, devoted to the MERLIN mission;
- A Control Ground Segment (CGS) function, encompassing elements shared with other missions: a command and control centre feature, by the use for the sake of MERLIN of the multi-mission MYRIADE Evolutions command and control centre;
- S-band and X-band features, by the use of the CNES 2 GHz and 8 GHz earth terminals multi-mission network;
- A PayLoad Operation Centre (PLOC), in charge of the instrument monitoring and control, as well as the monitoring of the radiometric corrections to apply on the science data;
- A PayLoad Data Processing centre (PLDP), in charge of the scientific product elaboration and dissemination;

- Scientific Product EXpertise (SPEX) subsystems in charge of the products quality monitoring;
- A numerical system simulator (TOMS - Training Operations and Maintenance Simulator) which is used to perform the system testing and qualifications;
- A position on a launcher.

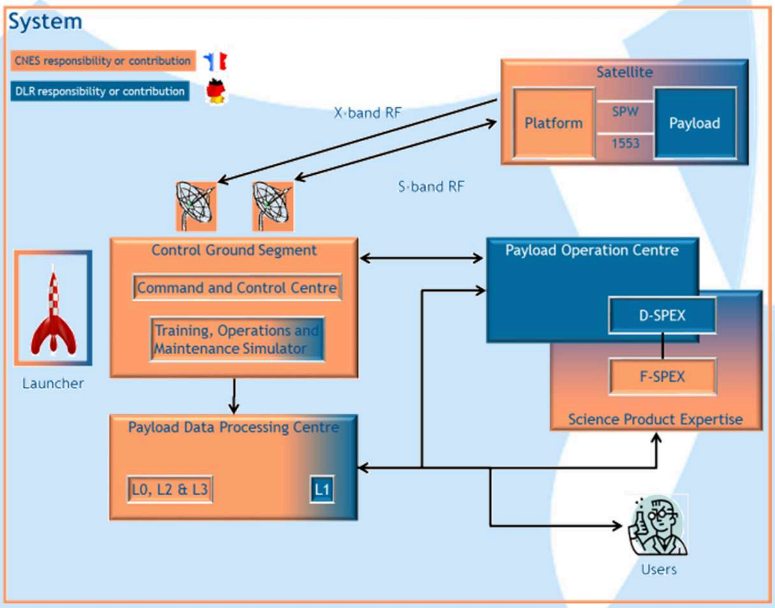
The following scheme gives an overall description of the system architecture.

Both Partners (CNES and DLR) defined the general responsibility sharing as follows:

- CNES, as system and satellite prime: To lead the system and the satellite level activities, including the system architecture definition, the final detailed satellite design and the satellite manufacturing, integration and test based on MYRIADE Evolutions platform and payload delivered by DLR; To develop and exploit the CGS; this CGS is based on the ISIS (Initiative for Space Innovative Standards) product line and uses the CNES Earth terminal network; To develop and exploit the system numerical simulator (TOMS) dedicated for system qualification testing; To develop and exploit the PLDP dedicated to product generation, archive and dissemination to the scientific community; To develop and exploit the French science product expertise function (F-SPEX);
- DLR, as payload prime: To lead the payload level activities, including IPDA (Integrated Path Differential Absorption) LIDAR (Light Detecting And Ranging) payload development, manufacturing, integration and test until its delivery to CNES; To develop and exploit the PLOC which consists in commanding and monitoring the payload; To develop and exploit the German science product expertise function (G-SPEX).

Based on this breakdown structure, both Partners put in place an organisation consistent with:

- French Space Agency: Centre National d'Etudes Spatiales (CNES);
- German Space Administration within the German Aerospace Centre (DLR);
- French and German laboratories;
- French industry: French suppliers are involved for the development activities of the satellite, the control ground segment and the French part of the payload ground segment. The system activities are under the CNES responsibility. In addition, CNES uses supports with external technical actors for dedicated activities performed on CNES site in Toulouse;
- German industry: DLR Space Administration assigned Airbus Defence and Space GmbH as German industry prime contractor with the implementation of the German part of the MERLIN mission activities. For the phases E/F a formal selection process will be established to identify the industrial prime contractor for the German MERLIN contribution. The industry activities are controlled by DLR Space Administration using standard ECSS management regulations.



The MERLIN system architecture

THE MERLIN SATELLITE

A German payload embedded on a French platform

The MERLIN satellite is based on a platform and a payload developed respectively by France and Germany.

The MERLIN platform is based on the MYRIADE Evolutions product line. The MYRIADE Evolutions platform is based on two kinds of units:

- Units belonging to the so-named “common units”, specified, developed and qualified by the MYRIADE Evolutions partnership (CNES, Airbus Defence and Space and Thales Alenia Space);
- Units belonging to the so-named “avionic core units”, specified, developed and qualified by satellite prime contractor (Airbus Defence and Space and Thales Alenia Space).

Of course, the common units and the avionic core units are designed in order to guarantee a trans-compatibility in terms of functions and interfaces.

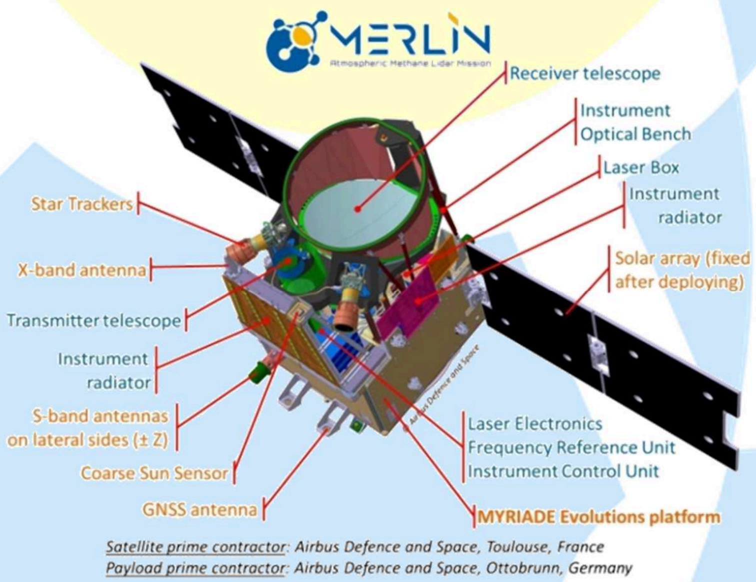
The payload consists of an IPDA LIDAR instrument with altimeter capability for the total CH_4 column and vegetation height distribution. The instrument measures the light scattered and reflected from the Earth’s surface and cloud tops, which are illuminated by laser pulses having slightly different wavelengths denoted as λ_{on} and λ_{off}.

The online wavelength λ_{on} is accurately positioned in the trough of one of the CH_4 absorption line multiplets in the 1.64 µm - 1.67 µm region, in order to relax the required laser frequency stability / knowledge. The measurement at λ_{off} serves as the reference measurement with negligible CH_4 absorption. From the ratio of the LIDAR echoes P_{on}/P_{off} (as mean values) the Differential Atmospheric Optical Depth (DAOD) and with that the column averaged CH_4 volume mixing ratio XCH_4 are calculated. From analysing the backscattered light strength vertical profile (vertical distribution of the illuminated targets), information on the vegetation height with respect to the ground, clouds, and strong aerosol layers can be derived with high vertical resolution.

A near-polar orbit to observe all latitude zones providing good samples of all climate zones is considered. Despite the fact that sampling of diurnal variations is limited, the choices of a sun-synchronous orbit, an orbit height in the range 500 km of altitude and a local time around 06:00 (preferred) and 18:00 (optional) is retained.

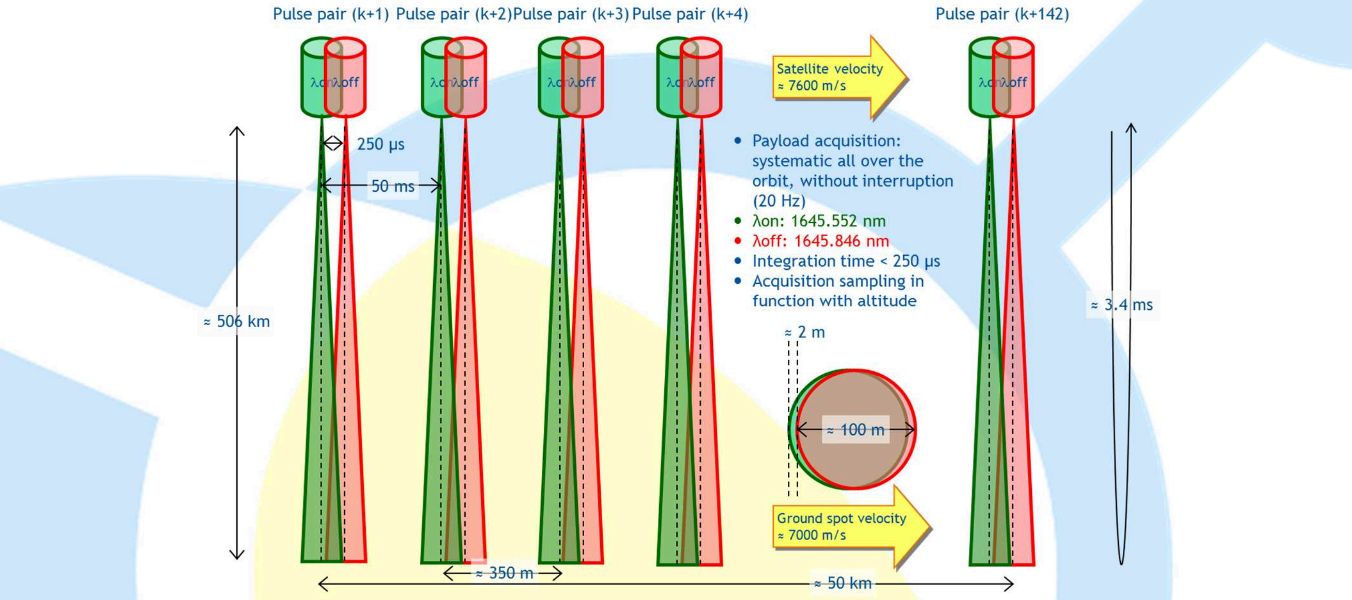
Power supply, on-board data storage and processing, and downlink capacity account for continuous operation of the IPDA LIDAR instrument at day and night time conditions.

The MERLIN mission is described in detail in [RD01].



The MERLIN satellite

Mission Duration	3 years (+1 year)	**Payload**	
Mission Orbit	Quasi circular sun-synchronous (LTAN = 06:00 or 18:00) ≈ 500 km, ≈ 97.4°, 28 days	Type	Integrated Path Differential Absorption Light Detecting And Ranging for methane column density measurements
Satellite		Mass	≈ 150 kg
Dimensions	≈ 1600 mm × 4500 mm × 1600 mm	Power	≈ 150 W
Mass	≈ 430 kg	**Performances**	
Power	≈ 400 W	Random error	< 22 ppb*
Platform		Systematic error	< 3 ppb*
Type	MYRIADE Evolutions product line	Horizontal sampling	≈ 50 km
Mass	≈ 260 kg	Objectives	Seasonal and annual budgets on country scale
Power	≈ 200 W	*: part per billion	



Measurement principle of space borne CH_4 IPDA LIDAR

THE MERLIN PERFORMANCES

A mission designed to meet the demanding measurement performance

The challenging performances required for MERLIN Level 2 Products are detailed below. They will enable MERLIN to deliver XCH_4 products of unprecedented quality to the scientific community.

Parameter	Threshold	Breakthrough	Target
Geophysical product	XCH_4		
Random error	36 ppb	18 ppb	8 ppb
Systematic error	3 ppb	2 ppb	1 ppb
Spatial coverage	Global	Global	Global
Horizontal resolution	50 km	50 km	50 km
Vertical resolution	Total column	Total column	Total column

To reach these figures, a careful evaluation of all system contributors to the performance is made: this includes payload characteristics which are a major contributor, but also platform capacity, algorithms performance, spectroscopy measurements, external data accuracy, etc.

Each contributor is analysed to derive its impact on the MERLIN scientific data and products, with a specific focus on XCH4. This is done through analysis, tests and extensive simulations using prototypes of the processor chains.

To ensure that the target scientific performances will be reached by the mission, a dedicated working group including French and German engineers and scientists has been set up, and three performance key points are included in the MERLIN development logic after major System milestones: Payload and Satellite Preliminary Design Reviews and Critical Design Reviews, and Payload Delivery.

THE MERLIN VALIDATION

A mission validation which requires a worldwide scientific contribution

Validation is an important part of a space mission. Before the scientific product dissemination, the scientific product quality has to be assessed by comparing the MERLIN products to data from other sensors which are regarded as a reference for MERLIN.

In this context, the central questions of the MERLIN space mission validation are:

- How representative are the retrieved satellite products for the actual atmospheric state?
- What are the systematic and random errors?
- How well are the temporal variations of CH_4 captured, with regards to fluctuations and trends?
- How well are spatial structures captured, from regional emission sources to global features?

Prerequisite are comparisons to temporally and spatially coincident measurements performed by independent instrumentation from various platforms (i.e. ground-based, aircraft, ship, balloon) from a variety of locations around the globe are considered to be of high priority. Continental scale projects such as European Copernicus or North American Carbon Project, in connection with modelling and interpretation activities, can help to cope with representativeness errors of both the MERLIN observations itself as well as the measurements taken from validating instruments. To infer data quality over the mission lifetime, both long-term and campaign mode validation activities are needed. In principle, the full suite of existing, high accuracy and reliable techniques used for CH_4 measurements on an operational basis shall be considered, including flask samples, in situ, and remote sensors.

The MERLIN mission validation requires different infrastructures and missions, as preliminary listed below:

- Ground-based network, towers network (TCCON - Total Carbon Column Observing Network);
- Balloon campaigns;
- Airborne campaigns;
- Satellite missions;
- Solar backscatter sensors;
- Thermal infrared sensors.

The means are not considered on an exclusive way, but their combined contributions bring a relevant answer to the validation question. The product validation requires to federate the worldwide scientific community to benefit of the various competences.

The MERLIN validation concept is described in [RD02].

THE MERLIN LAUNCH

A European launcher for a European mission

Because the MERLIN mission is developed thanks to a Franco-German cooperation, it has been decided by both Partners that the MERLIN launcher shall be a European one.

To be consistent with the MERLIN mission schedule, the programmatic launch aspects are as follows: The launch interval is defined from mid-2024 till mid-2027, with a dead line for the taking up of the contractual option in June 2022.

For the satellite configuration, two eligible launchers are considered:

- Vega C considered as the preferred and nominal launcher; two satellite positions are suitable: lower and inner positions using the launch system VESPAC (Vega-C Secondary Passenger Adapter), or the upper position with the launch system SSMS (Small Satellite Mission Service);
- Ariane 62 as back up launcher, the MERLIN satellite is set up in central position using the launch system MLS (Multi Launch System).

THE MERLIN DEVELOPMENT SCHEDULE

A challenging schedule driven by the payload development

The MERLIN development is scheduled in order to have a system fully qualified for the launch date. All system components follow their own development and qualification processes and cycles. Today, the mission schedule (including the space and the ground segments) is driven by the satellite development activities. In particular, the critical path of the mission schedule is made by the payload development, while the platform development is definitively subcritical.

Indeed, the platform activities shall be anticipated at maximum, to complete the MYRIADE Evolutions qualification activities at the "earliest". On the other hand, the LIDAR payload is an extremely ambitious instrument; the payload delivery date implies a platform storage phase until the payload delivery.

At the end, the availability of a launch slot as an auxiliary passenger needs to be confirmed.

The development of the ground segments has to be managed to declare their qualification prior to the launch date.

The mission schedule has to be robust and optimised thanks to ad-hoc margins and contingencies at different levels and steps of the development.

The mission schedule is monitored, and the adherence between the reality of the development and the theory is checked on a frequent and regular basis by the Agency managements. Decision points are foreseen in order to cope with the uncertainties inherent to the MERLIN programme (payload delivery date, launcher availability, etc.), and to jointly decide either to proceed with the project developments or to freeze momentarily the activities until the situation comes back on a relevant track.

Except for the payload development, flexibility is implemented within the mission schedule in order to guarantee a certain level of robustness.

Spring 2020:	Payload Critical Design Review	Spri. 2024 - Sum. 2025:	Satellite Assembling Integration & Test
Summer 2020:	Satellite Critical Design Review	**Spring 2025:**	**Launch Readiness**
Spring 2024:	Payload delivery	Summer 2025:	Satellite In Orbit Verification Review

REFERENCES

[RD01] Ehret et al., MERLIN: A French-German Space Lidar Mission Dedicated to Atmospheric Methane, Remote Sensing 2017, 9, 1052

[RD02] The MERLIN validation plan, MLN-SYS-PL-90003-PI

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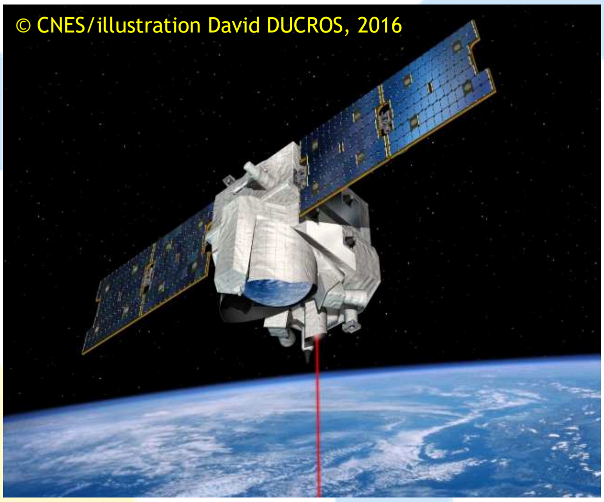
MERLIN at a glance

Measurements of atmospheric methane from space

Climate change is one of the greatest challenges mankind has to face. Methane is one of the most powerful greenhouse gases. For a better understanding of climate change, it is necessary to apply precise space-based measurement techniques in order to obtain a global view on the complex processes that control the methane concentration in the atmosphere.

CNES and DLR cooperate to develop and operate a space system dedicated to the measurements of methane sources and sinks. The name of the mission is MERLIN (Methane Remote Sensing Lidar Mission). It is planned to launch the satellite in the time frame of 2025 with at least 3 years of operation in space.



Mission Goals:

- Global information on atmospheric methane (CH_4) concentration (methane column density) with accuracy better than 2% and with a spatial resolution of 50 km along track also under cloudy and variable sun illumination conditions.
- The main data product will be column-weighted dry-air mixing ratio of CH_4.
- Improved knowledge on contribution to the atmospheric methane amount from energy production, wild fires, wetland changes due to climate change such as melting of permafrost soils and ocean sediments (gas hydrates).
- Improved understanding of CH_4 sources and sinks and their interactions with Earth climate.
- Improved data quality concerning anthropogenic and natural methane emissions.
- Contribution to computation of methane fluxes estimations.
- Significant contribution to climate change prediction.
- Contribution to control of the Kyoto protocol aims on methane emission regulation.
- Demonstrator for future satellite-based Integrated Path Differential Absorption (IPDA) LIDAR missions (LIDAR stands for Light Detecting and Ranging or “Laser Radar”.).
- Compliant with GCOS (Global Climate Observing System) monitoring principles.

Mission Schedule:

Launch: in the time frame of 2025.

Minimum mission duration: 3 years.

Orbit:

Polar, quasi circular sun-synchronous Earth orbit, with a mean orbit altitude of approximatively 500 km and a Local Time of Ascending Node (LTAN) of 06:00 or 18:00.

IPDA LIDAR Principle:

An IPDA LIDAR (light detecting and ranging) is an instrument that is able to determine the total methane column density between satellite and Earth surface or cloud top height. The methane amount is calculated from different absorptions at two laser wavelengths (on-line and off-line), reflected on Earth surface or cloud tops. Earth surface or cloud top reflected laser light is used because this is much more intense than backscattered light from aerosol particles in the atmosphere. The attenuation due to atmospheric methane absorption is strong at the on-line wavelength. The off-line “reference” wavelength is selected to be only marginally affected by methane absorption.

Instrument concept:

MERLIN will be the first space-based integrated path differential absorption LIDAR instrument. It consists of a frequency stabilized high-power laser (20 Hz double pulse approximatively 9 mJ pulse energy, wavelengths around 1.645 µm) as transmitter, and a receiver section consisting of an off-axis telescope (ø 690 mm) and a sensitive signal chain (baseline: InGaAs APD detector).

Satellite:

Satellite platform: MYRIADE Evolutions

Satellite dimensions:

≈ 160×120×160 cm^3 with stowed solar panels

≈ 160×450×160 cm^3 with deployed solar panels

Satellite mass:	≈ 430 kg
Satellite power consumption:	≈ 400 W
Payload mass allocation:	≈ 150 kg
Payload power allocation:	≈ 150 W

Launcher:

Auxiliary passenger on VegaC or Ariane 62 launcher from Kourou in French Guiana.

Mission Operation:

CNES satellite control centre with CNES ground station network for S-Band downlink for housekeeping data, S-Band uplink for commanding, and X-Band downlink for scientific data.

Mission organisation:

The MERLIN climate mission is a joint French-German cooperation, performed by the national space agencies, CNES and DLR Space Administration.

Germany provides the IPDA LIDAR instrument. France provides its MYRIADE Evolutions satellite platform and its satellite control centre. CNES is mission prime and operates the satellite.

The system numerical simulator (Training Operation and Maintenance Simulator) is developed by CNES with DLR contribution and operated by CNES in Toulouse (France).

The Payload data processing centre is developed and will be exploited by CNES Toulouse space centre; Germany contributes with the development of the processor (Level 1) in charge of the instrument corrections.

Two Science Product EXpertise centres (SPEX) are developed; one in France and the other one in Germany.

Science activities are led by two Co-Principle-Investigators from the French laboratory from CNRS and the German Institute for Atmospheric Physics from DLR, with additional support of several French and German Research Institutes.

The satellite is developed by Airbus Defence & Space SAS (France), which will provide the MYRIADE Evolutions platform. Airbus Defence & Space GmbH (Germany), with contributions from German and French industries and German research institutes, will build the methane IPDA LIDAR instrument. The industries are under contracts by CNES and DLR Space Administration, respectively.

Mission Status:

The preliminary design phase has been finished successfully in 2016. The mission is now in the detailed design phase. Both CNES and DLR Space Administration have established industry contracts to build in particular the MERLIN satellite and payload. A contract with Arianespace has been signed to launch the MERLIN satellite.