Atmospheric Research and Monitoring with a SATellite ARM-SAT

Proposal Submitted to H2020

LEIT-Space-Competitiveness of the European Space Sector-2015

Bottom up Technology at low TRL

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Abstract

- The objectives of this project are to design a small satellite able to fly one year at 250 km altitude, to optimise the pointing accuracy for synchronised solar and nadir observations, to set up the tools to manage the scientific output for this satellite, and to develop a breadboard for validation in laboratory environment. In order to design a small satellite bus that may be re-used to support many missions at low altitude, we wish to adapt several off-the shelf components already developed for space. The main scientific difficulties are to ensure the pointing stability and the thermal stability of the small satellite. Space is a harsh environment for optics with many physical interactions leading to potentially severe degradation of thermo-optical performances. Thermal control surfaces and payload optics are exposed to space environmental effects including contamination, atomic oxygen, ultraviolet radiation, and vacuum temperature cycling. Thus, the mastery of thermal control of a satellite represents a guarantee of success.

Outline

- 1. The team
- 2. Scientific Objectives
- 3. Technical Description
- 4. Implementation

1. The Team

Participant number	Participant organization name	Participant short name	Country
1 (Coordinator)	Laboratoire Atmosphères, Milieux, Observations Spatiales (**Cnrs**)	LATMOS	France
2	Byurakan Astrophysical Observatory/Armenian Space Agency (**Bao**)	BAO/ArSA	Armenia
3	Von Karman Institute (**Ivkdf**)	VKI	Belgium
4	Surrey Space Centre (**Surrey**)	SSC	United Kingdom
5	Royal Meteorological Institute of Belgium (**Irm/Kmi**)	RMIB	Belgium
6	SYSTHEIA (**Systheia Sas**)	SYSTHEIA	France

- LATMOS :large space laboratory with a strong background in atmospheric physics and Solar-Earth's relation and space instrumentation

- Royal Meteorological Institute of Belgium (**RMIB, Belgium**) with a strong background in space experimentation for total solar irradiance measurements

- Surrey Space Centre (**SSC, United Kingdom**) with a strong background with small satellite and electric propulsion design, manufacture, and operation

- Von Karman Institute (**VKI, Belgium**) with strong background in fluid dynamics for space applications

- SYSTEIA **(SYSTHEIA, France)**, a company with strong background in space miniaturised cameras

- Byurakan Astronomical Observatory (**BAO, Armenia**) with a strong background in astronomy and astrophysics, and now also part of the newly created Armenian space agency Armenian Space Agency (**ArSA**).

2. Scientific Objectives

We are going **to design a small satellite for atmospheric research and monitoring called ARM SAT** (Atmospheric Research and Monitoring with a SATellite).

The main scientific objectives of our satellite are:

- 1st: to extend Total Solar Irradiance (TSI) variability measurement and to improve the knowledge of the absolute value of the TSI,
- 2nd: to establish a radiation balance of the Earth with accuracy better than 5%,
- 3rd: to understand the relation between solar Ultra-Violet (UV) variability and stratospheric ozone,
- 4th: to monitor the hydroxyl radical OH ...

IMPACTS (general)

Ambitions :

- Earth observations
- Solar observations
- Sun-Earth simultaneous observations
- Sun-Earth Relationship
- Climate change

But also :

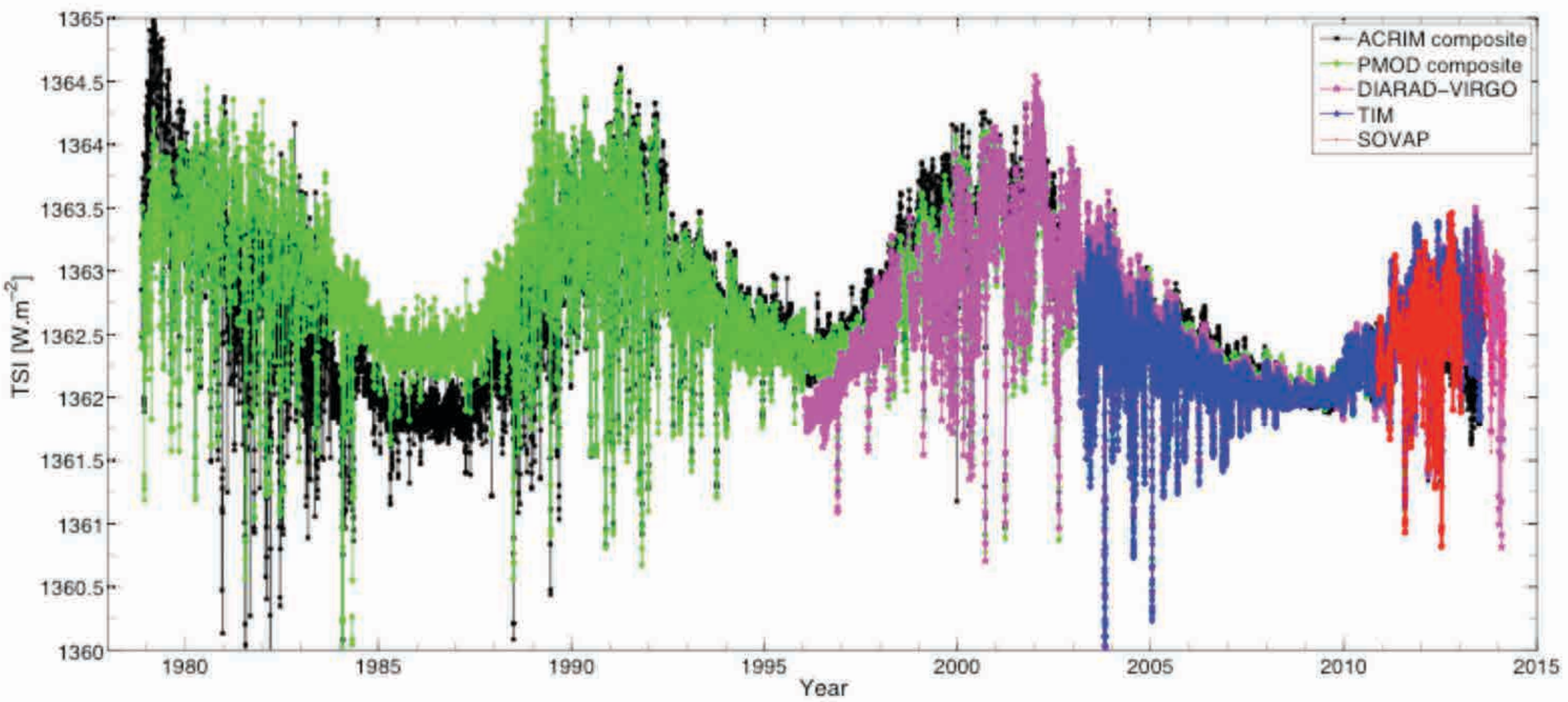
- Civilian protection
- Disaster monitoring (forest fire, etc…)
- Search and rescue (flight, etc…)

But also

- Space technology
- Constellations
- Flight at low altitude

• **First objective**: the extension of series of Total Solar Irradiance (TSI) measurement

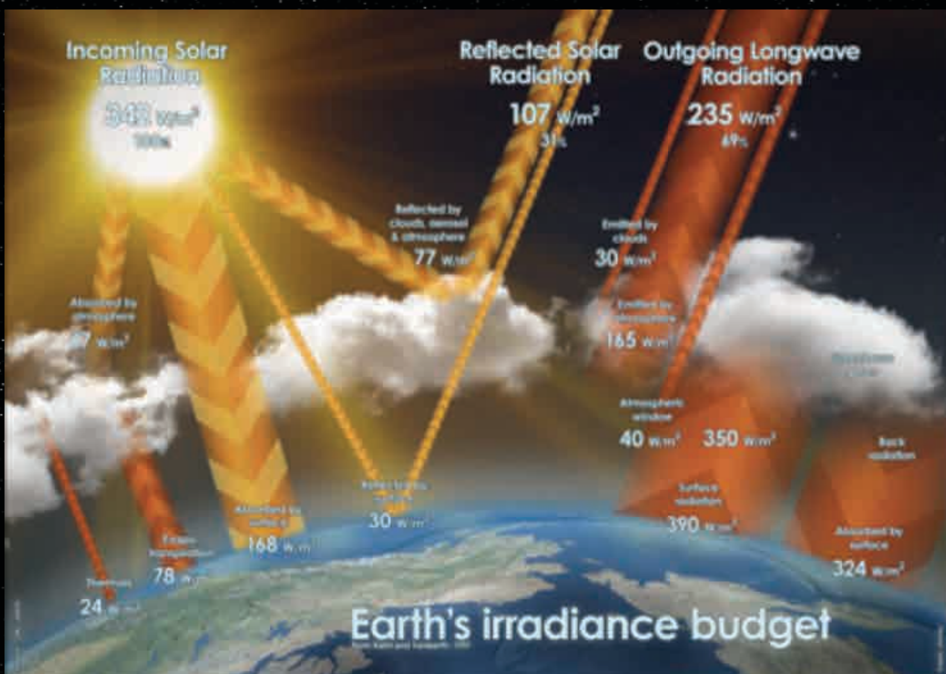
It's very important to continue to measure this essential climate variable with overlapping periods between instruments.



The TSI is measured to vary by approximately **+/-**0.05 % (over the last three 11-year sunspot cycles). Composite TSI time series (ACRIM and PMOD) or TSI space instruments highlighting differences for some solar minima.

• **Second objective**: the determination of the Earth radiation balance at global and regional scales

The total solar irradiance is the main external heat input into the Earth's climate system. The annual mean global energy balance for the Earth-atmosphere system is also very important to understand.



Irbah, Meftah, 2012 (SPIE)

Importance of the Earth radiative budget :

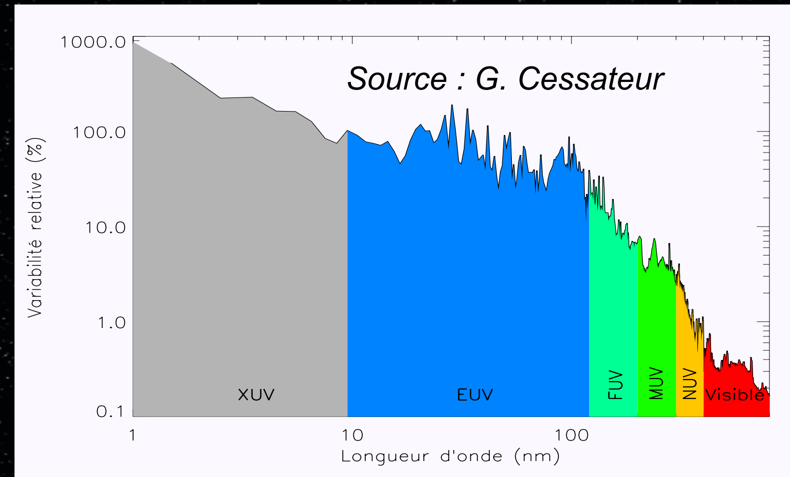
Radiation at "visible" and "NIR" wavelengths warms the lower atmosphere and the surface of the Earth. The TSI is a good proxy for solar energy reaching the ground.

Importance of the UV solar variability:

UV radiation photo-dissociates atmospheric molecules (including production of stratospheric ozone) and is the main source of heating in the stratosphere.

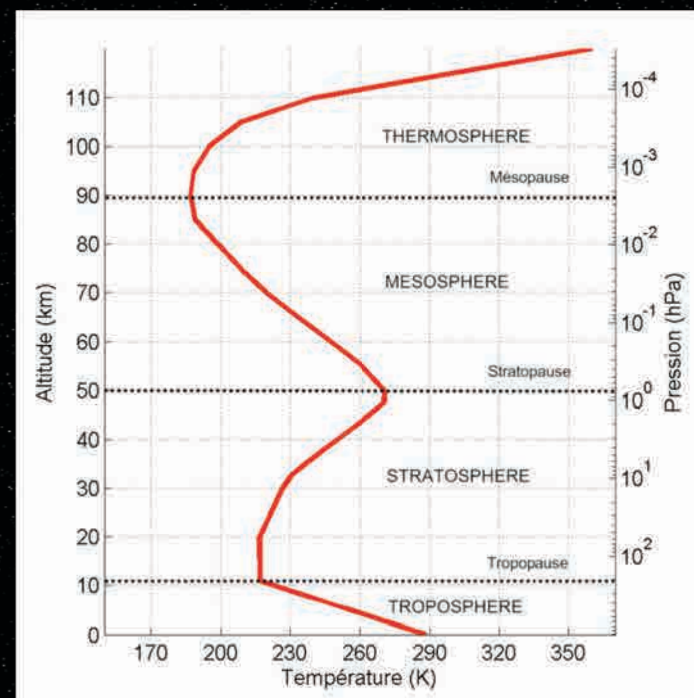
Atmospheric layers are dynamically and radiatively coupled

• **Third objective**: the understanding of the relation between solar Ultra-Violet (UV) variability and stratospheric ozone.



Solar UV:

In the UV, the variations of the solar spectral irradiance is more important: 1 to 20% of variability over a solar cycle (Cebula and Deland, 2012).



Stratospheric Ozone:

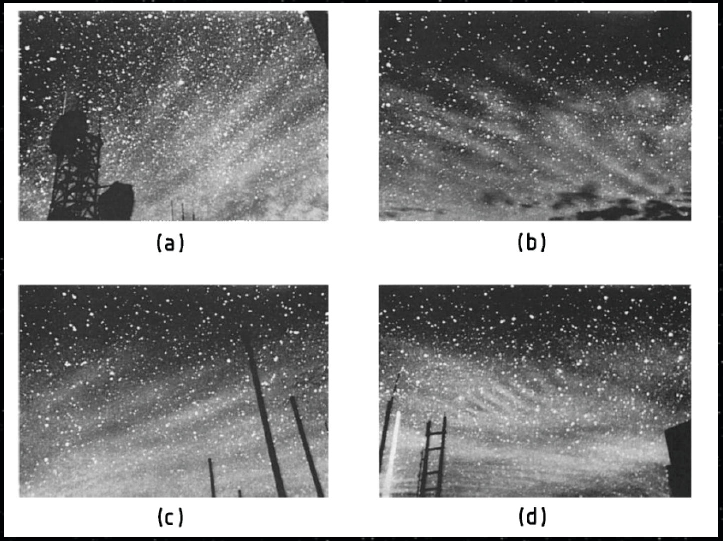
The measurement of the vertical column of ozone is very important.

It will be performed using a differential absorption method at two wavelengths (310 nm and 340 nm).

• **Fourth objective:** to monitor the hydroxyl radical OH.

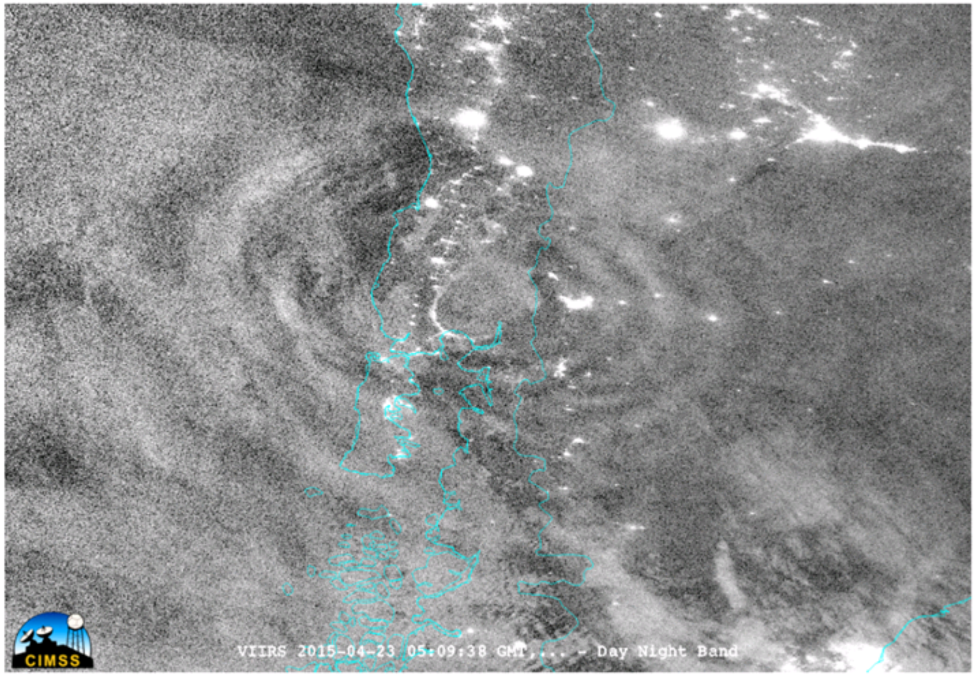
- Thus, through the study we propose, we will develop an instrumental tool in order to better understand the physics of the upper mesosphere.
- Indeed, in the near infrared (IR) radiation mesospheric night mainly takes its source in the photochemical emission lines produced by "hydroxyl" radical (OH), atmospheric bands of the O2, and oxygen Atomic.

Gravity wave structures observed in the OH emission layer to the Haute-Provence Observatory in April 2014 (Simoneau et al., 2014, private communication).



Examples of structures or waves can be observed (OH). Images taken during the ALOHA-90 campaign.

M.J. Taylor and M.J. Hill, Geophysical research letter, Vol. 18, N°7, Pages 1333-1336 (July 1991).



OH band observation of the gravity wave generated by the eruption of volcano Cabulco. (Source : University of Wisconsin's Cooperative Institute for Meteorological Satellite Studies (CIMSS, http://cimss.ssec.wisc.edu/).

3. Technical Description

The main technical objectives are :

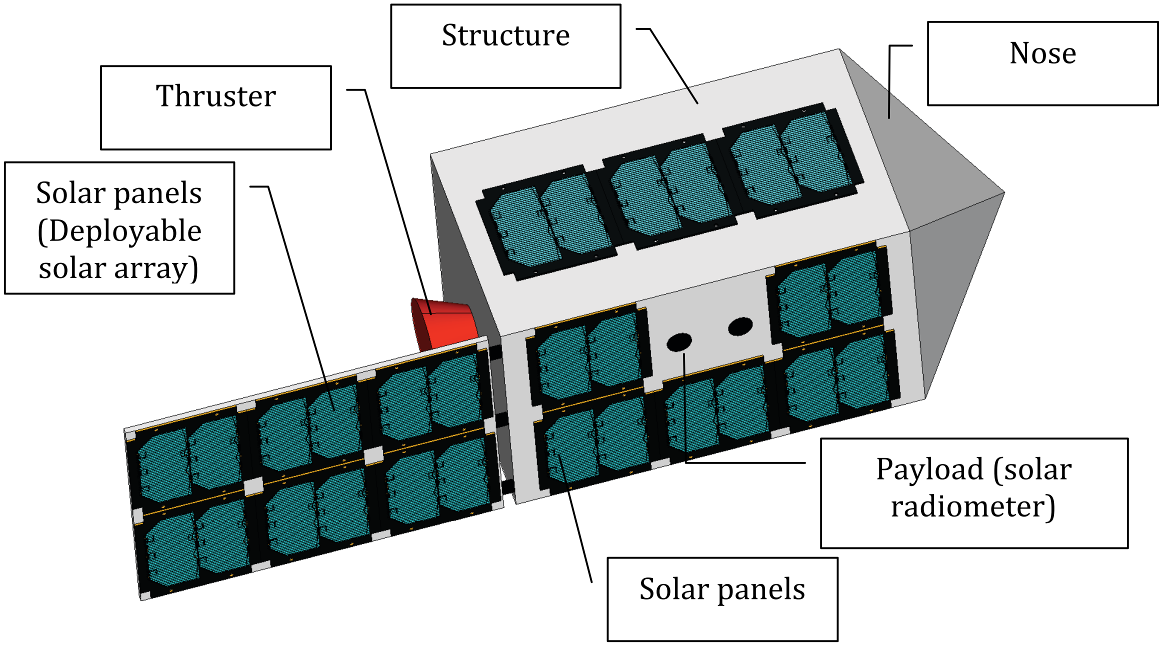
- **1. Design of a miniaturized versatile satellite that can orbit at a low altitude of 250 km for at least one year with the help of**
  - a. Passive aeronautics means such as an aerodynamic shape and a high ballistic parameter
  - b. Active means such as an atmospheric drag compensation electric propulsion unit
  - c. High accuracy pointing technology for Sun and Earth observations

- **2. Design of sensors with high performance thermal control management systems for the observation of**
  - OH radiation originating from the mesosphere
  - Total solar irradiance
  - UV solar spectral irradiance
  - Visible imaging of the Earth surface

- **3. Demonstration of the technology maturity through the manufacturing of a breadboard for validation in laboratory environment**

These achievements (leading ultimately to a small satellite manufacture) will have their technology readiness level (TRL) increased from the levels of 1 to 4-5 in 23 months.

Solar Metrology Meeting : Picture of the Day


Structure
Nose
Thruster
Solar panels (Deployable solar array)
Payload (solar radiometer)
Solar panels

General parameters

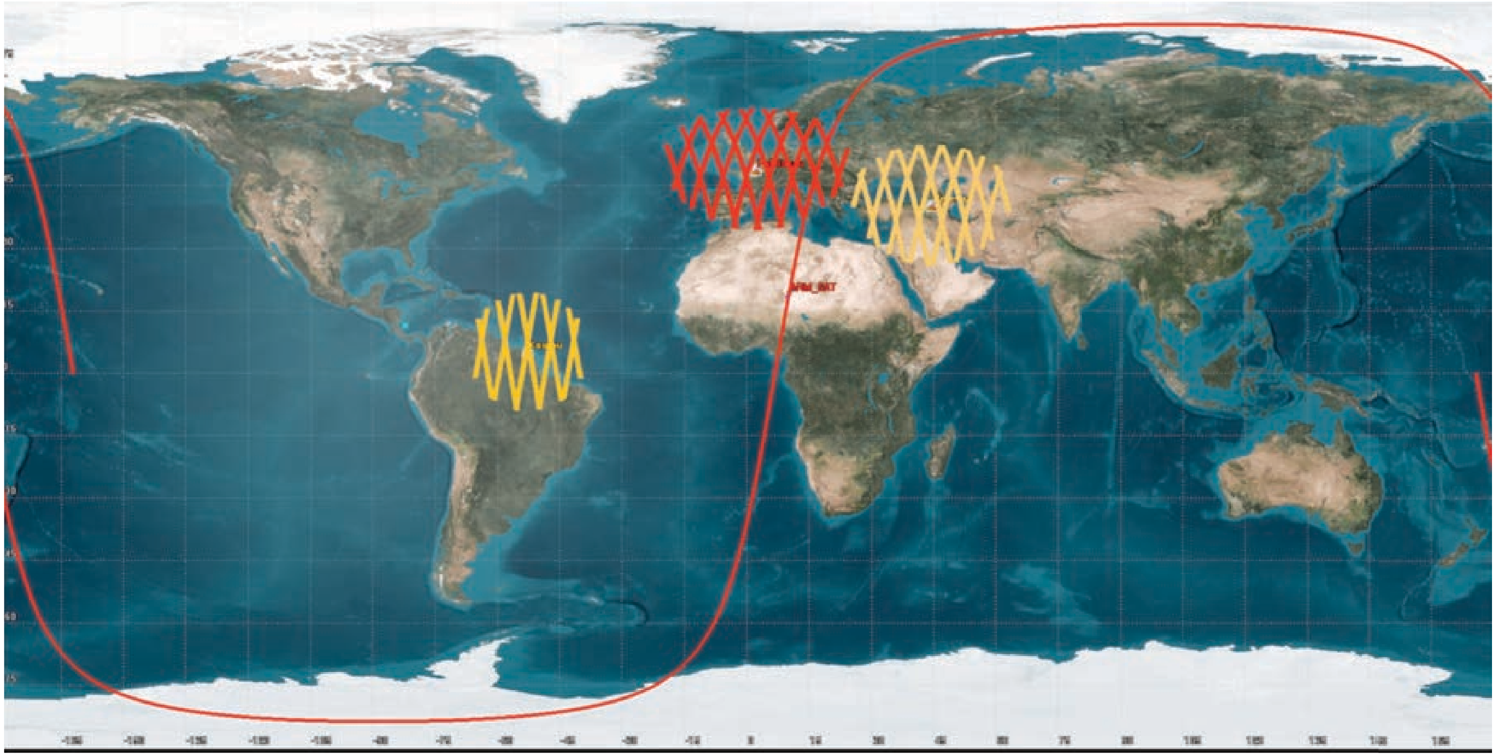
Parameter	Values (remarks)
Volume (un-deployed)	20 (d) × 20 (w) × 33 (h) cm^3
Mass	20 kg (maximum with a margin of 20%)
Power	22 W (without eclipses)
Drag coefficient	Cd = 2.2 (at 250 km)
Total drag force	< 0.5 mN
Power/Thrust (electrical propulsion)	12.1 W/mN (QCT-40)
Field of view (payload)	180°
Data storage (flash)	128 Gbyte (with NINANO board)
Downlink speed (S-band option)	115.0 kbps - **8.0 Mbps**
Uplink speed (VHF)	1.2 kbps
Ground station contact time	< 7 minutes
Downlink volume (S-band option)	**2.7 Gbytes per day**
Uplink volume	0.3 Mbytes per day
Mission modes	Sun pointing, Nadir pointing, and stars pointing
Mission lifetime	One year
Solar pointing	0.1°
Nadir pointing	0.4°

- Power
    - Solar arrays
    - Solar arrays deployment mechanism
    - Electronic power supply
    - Power switch board
    - Batteries
- Command and data handling
    - On board computer (OBC)
    - Hardware interfaces between satellite and electronic ground support equipment
- Attitude and Orbit Control System (AOCS):
    - Attitude, Determination, and Control System (ADCS)
        - CubeControl/CubeSense/CubeComputer/CubeStar
            - Momentum Wheel (x 3)
            - Digital Sun Sensor
            - Digital Nadir Sensor
            - GPS interface (the GPS receiver is a restricted technology)
            - 3-Axis Magnetometer
            - CubeComputer ADCS Processor
            - CubeStar Star Camera for precision attitude sensing
    - Electric Propulsion (EP)
        - QCT-40 Thuster
- Telemetry & Telecommands
    - S-band downlink transmitters
    - S-band patch antenna
- Structure and interface modules
- Harness and connectors
    - Solar array and sun sensor harness
    - Micro-switch harness
    - S-Band antenna harness
    - GPS harness
    - Ground Support Equipment (GSE) harness
    - ADCS harness
- Payload
    - UV sensor that require thermal management control (**thermal stability to reduce contamination kinetics**)
    - Imaging system that require thermal management control (**CCD temperature around -20°C**)
    - Solar radiometer that require thermal management control (**thermal stability**)
    - IR camera system that require thermal management control (**cryo-cooler to obtain a temperature around 100K**).

The ARM-SAT consortium is composed of partners with complementary expertise in all field related to our proposal:

- Leadership and PI-ship (LATMOS),
- Power (SSC, LATMOS),
- Thermo-aerodynamic (VKI),
- Propulsion (SSC),
- Attitude determination and control (SSC),
- Structures (LATMOS)
- Materials and mechanisms (LATMOS),
- Thermal control management (VKI, LATMOS),
- Radiometry (RMIB),
- UV, visible, and IR observations (SYSTHEIA, RMIB, LATMOS),
- Command and data handling (LATMOS),
- Communications (LATMOS),
- Integration (LATMOS, RMIB),
- Launch and deployment (French ground support CNES, and ESA),
- Ground data systems and operations (BAO/ArSA and LATMOS),
- Astronomy and astrophysics (BAO/ArSA and LATMOS),
- Scientific (Earth and Sun scientific studies) and technological Data analysis (LATMOS),
- Analysis of the scientific outputs of the various space experiments (BAO/ArSA),
- Data Management Tools for scientific data interpretation with virtual observatory (BAO/ArSA and LATMOS).

The orbit and terrestrial relays



3. Technical description : selection

Attitude Determination and Control Systems:

Attitude Determination and Control (ADCS) for small spacecrafts relies on miniaturized technology without significant performance degradation. Miniaturizations are achieved with advanced technologies such as new imaging devices, materials, peripheral circuits, and algorithms. Overall attitude-pointing accuracy of typical mini- and microsatellite Earth observation missions is of the order of 0.1°. Higher accuracy below 0.1° can be achieved using a mission related sensor (i.e. a total solar irradiance radiometer of the payload instrument) in the attitude control loop. The desired performances are:

- Sun pointing: the platform is three-axes stabilized. The **attitude and orbit control subsystem (AOCS)** is required to provide a pointing accuracy of 0.1°.
- Nadir pointing: the ARM-SAT satellite is pointed towards the Earth (payload line of sight) with accuracy better than 1°.

The Stellanbosh/Surrey Space Centre ADCS will provide attitude sensing and control capabilities to ARM-SAT in order to meet the system requirements and science unit requirements. The ARM-SAT mission requires attitude control in order to:

- Minimize the influence of drag,
- Allow more atmospheric data to be gathered (the orbital life of the satellite will be prolonged if the effect of drag is minimized),
- Ensure that science payloads point towards the desired direction.

SSC will carry out this study.

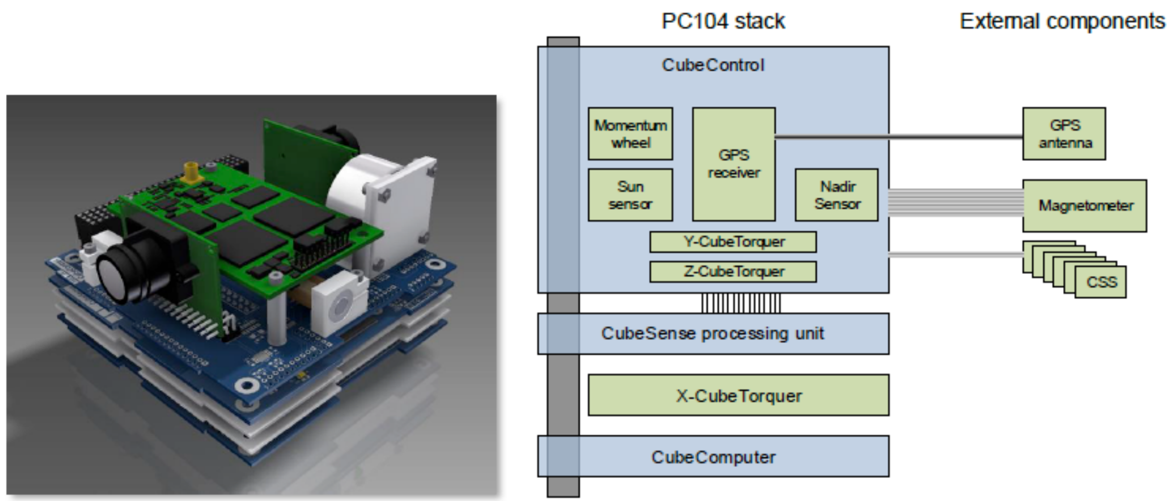


Figure 9: ARM-SAT AOCS architecture.

In order to stay at a constant altitude, an **electric propulsion (EP) system** will be used. EP

Propulsion system to be carried out by SSTL

- Net specific impulse: 250 seconds,
- Thrust: 3.3 mN,
- Net thrust efficiency: 10%,
- Power/Thrust: 12.3 W/mN.

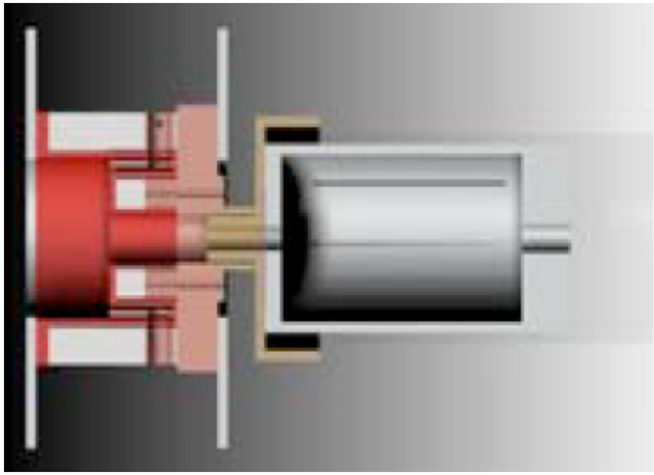
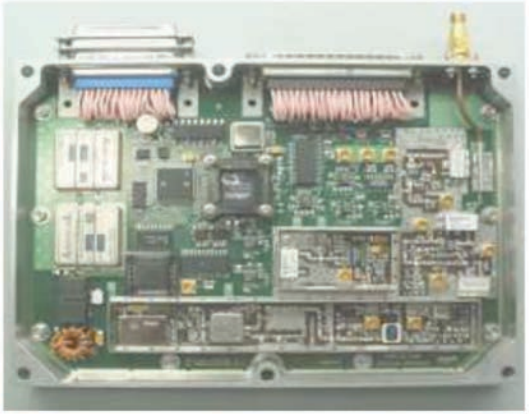


Figure 10: ARM-SAT EP design.

Telemetry & Telecommands:

The Surrey Satellite Technology Ltd (SSTL) S-band downlink transmitters provide a flexible high-speed downlink solution for LEO missions, offering rates between 9.6 kbps (2 W transmitter) and 8.0 Mbps (4 W transmitter). We will use this technology. The main characteristics are:

- S-band,
- Up to 4WRF power using additional power amplifier,
- 28 V unregulated supply, < 38 W,
- 200x191x80mm(4W, 8Mbps),
- < 2kg.



Structure and ARM-SAT nose definition:

The drag reduction device (DRD) is aimed at enlarging the lifetime of ARM-SAT by reducing drag. This will be achieved by attaching a smooth surface conical/pyramidal nose to it. Since both weight and volume are limited (similar to any other space vehicles), we propose that the design complies with the following guidelines:

- Rapid prototyping will be applied by employing 3D printing techniques for the main DRD assembly parts and for as many secondary pieces as possible. This will help reducing weight.
- A layer will be deposited on the windward surface, which then will be polished.
- The stow volume will be reduced splitting the nose into parts and will be positioned during deployment.
- **Temperature knowledge and thermal management in space.**

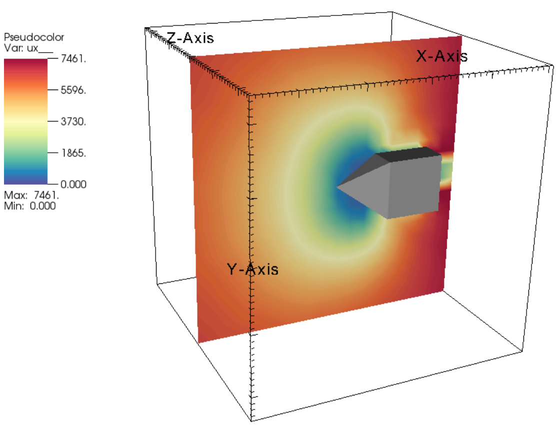
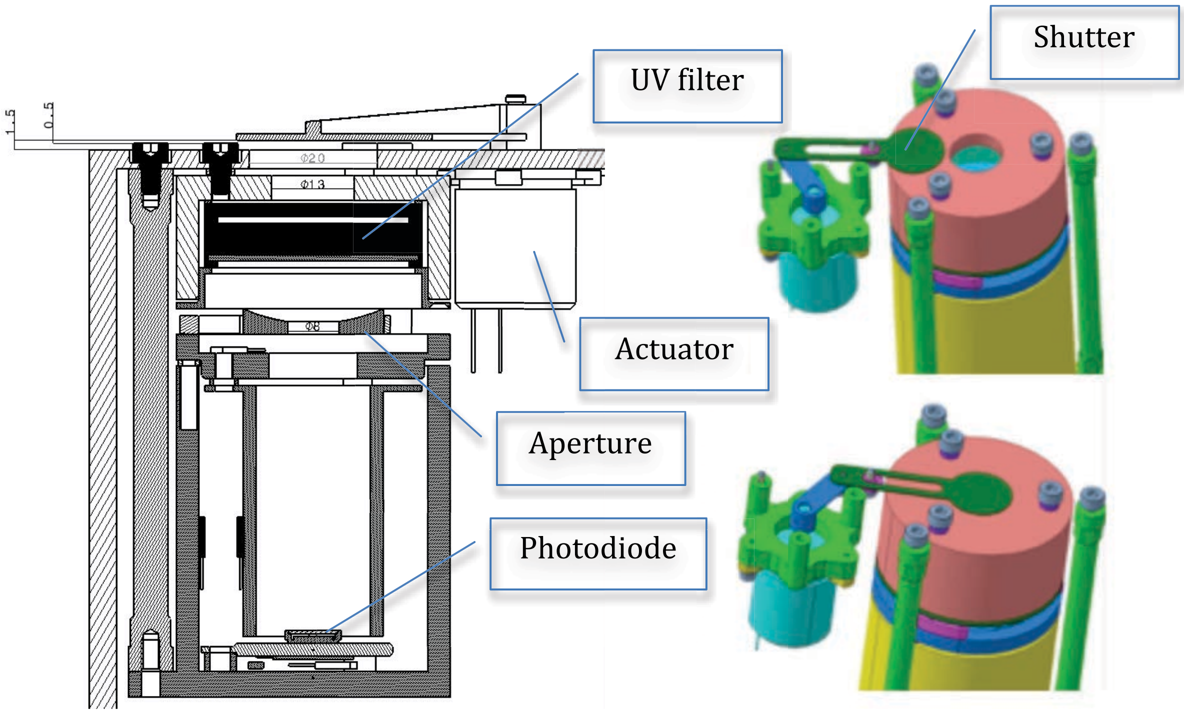


Figure 12: X-axis velocity component contour map in the mid-plane.

For our specific application (ARM-SAT), additional simulations are needed to improve the design and to find the optimum geometry of the drag reduction device. VKI will carry out this study.

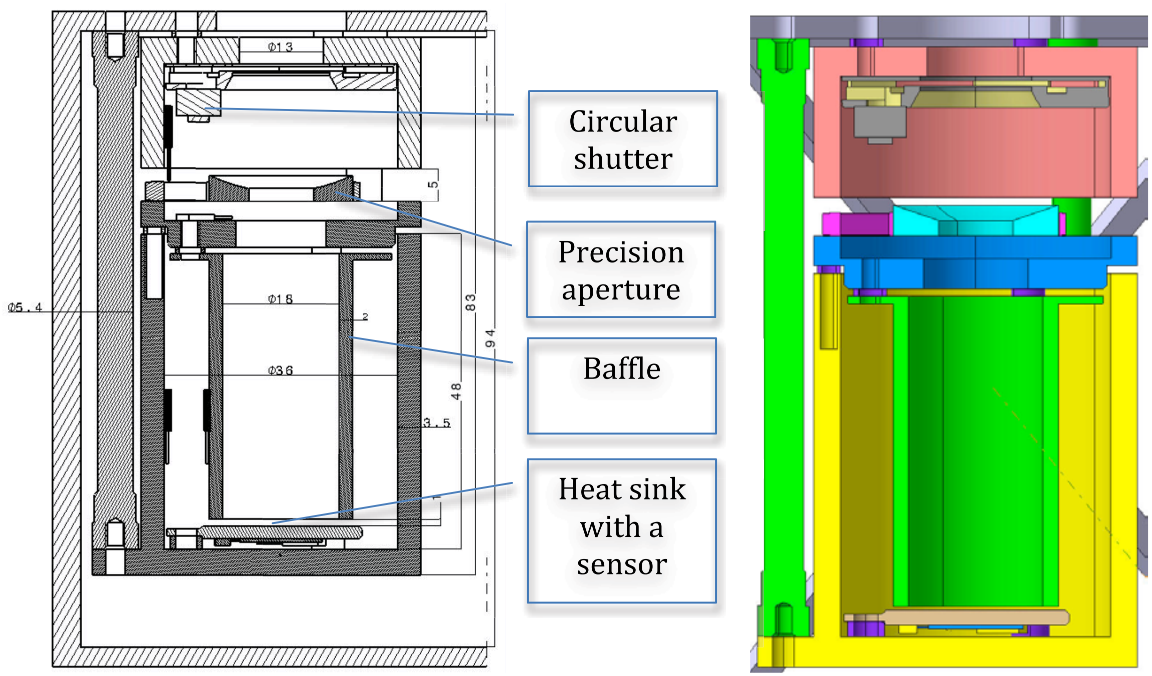
- UV sensor:

ARM-SAT will use a small photometer whose mass will be less than 300 g. This technology will be based on the experience of LATMOS and RMIB. The UV sensor (photometer) is based on a simple principle, which is inexpensive. The main components are: a UV interferential filter (200-220 nm), a photodiode, a precision aperture, a shutter, and a stepper motor (Thales AEM actuator). **This sensor requires a high thermal stability.**



- Solar radiometer:

The ARM-SAT radiometer is a new design based on RMIB's 34 years of space experience in radiometry. The new design intends to fix the issues of dynamic non-equivalence identified in the DIARAD type radiometers. The design described below will lead to a faster time response of the electrical substitution radiometer (ESR). By using both analog and digital electronics, we will combine the advantages of both technologies to reduce the static error of the feedback loop in view to have better accuracy performances than TIM type radiometer. A careful thermal design will lead to a better knowledge of the different terms in the instrumental equation. We expect to operate the radiometer with cycles of ten seconds close shutter operation and twenty seconds open operation. During both cycles the sampling rate will achieve one electrical measurement per second. The resolution of the measurements will be of 31 bits each second; to achieve this, we will use 24 bits converters sampling at 500 samples / second and summing the results on 128 samples. The integration time of the measurements will thus be of 0,256 sec each second. In order to reduce the electrical power needed, we will use apertures of 7 mm to maintain the electrical power dissipated in the sensor below 70 mW.



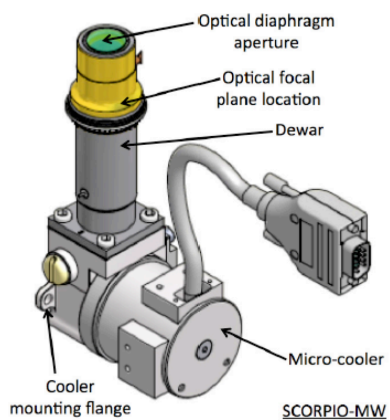
- Visible imaging system:

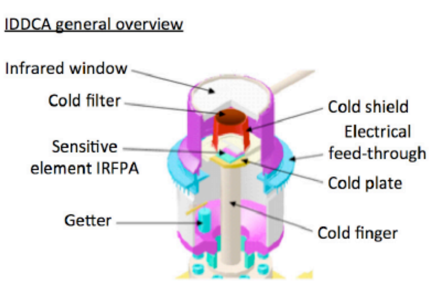
The system is based on technologies developed over the last 20 years for micro-cameras in space exploration, with extended operation in extreme environments and advanced miniaturization. The micro-cameras previously developed have been flown on numerous space missions. It is proposed to derive from these successful developments a new system being able to provide additional measurements, yet keeping the benefits of miniaturization and operation in the extreme environment encountered in space, allowing proper operation and reliability with full performance. The imaging system for visible observations proposed is based on a micro-camera design used in several space missions (Rosetta, SMART-1, MSL NASA Curiosity rover, Beagle2, Proba 1 & 2, Sentinel-1A, etc.). The miniaturization relies on expertise and technologies developed over the last 20 years for space applications, allowing very high integration and extreme robustness. The cameras are able to operate in extreme conditions, beyond the space standard range (temperatures down to -120°C, radiations, vacuum, shocks, and vibrations). This digital imager aims to be used, amongst others, for Earth observation, planetary missions or any applications needing low storage & operation temperatures, resistance to vibrations and low power consumption. It integrates compression capability, single or burst image(s) acquisition and storage of up to 64 images and gives 8 or 16 bits digital output images with integration times between 1ms & 9 hours. Its lightness and compactness is a valuable asset for tight payload mass & volume requirements. The main characteristics of the camera are the following:

- 1024x1024 pixels charge coupled device (CCD),
- 8-16 bit/pixel resolution,
- 10 Mbit/s Input/Output,
- Integrated Electronics including: sequencer, converter, internal buffer for up to 32/64 images, internal clock,
- On-board image compression, auto-exposure,
- Power consumption: 1.6 W,
- Operating range: −120°C to +30°C (+60°C with SNR reduction),
- Storage: −150°C to +70°C,
- Mass: 110 g including 70° FOV rad-hard optics (85 g without optics),
- Dimensions: 65 x 52.5 x 36 mm with 70°FOV rad-hard optics,
- Easy operation and data acquisition.

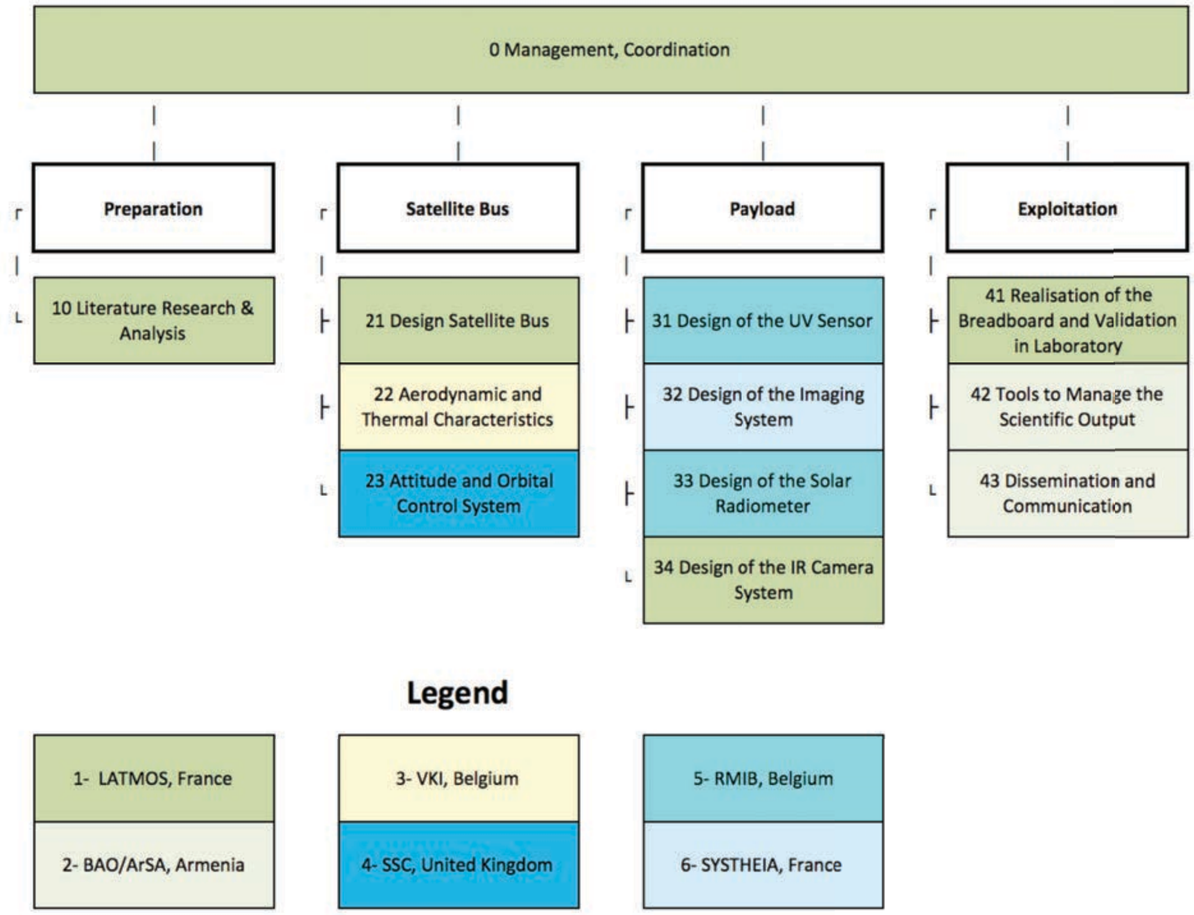
- IR camera system:

The system is based on technologies developed over the last 2 years by LATMOS for High-resolution IR detectors in space exploration, with extended operation in extreme environments and advanced miniaturization. High-resolution infrared (IR) detectors are used in many space applications: IR detectors are being used to observe deep space, observe the Earth, monitor the environment, observe planets of the solar system, study the atmosphere of planets, and provide data on meteorological phenomena. SCORPIO-MW infrared detector (Sofradir) will be used as part of an instrument of the ARM-SAT payload. The infrared opto-electronic device is a high performance, small and lightweight, low input power integrated Dewar device cooler assembly (IDDCA) adapted for high resolution thermal imaging applications (forward looking infrared radiometer (FLIR), etc.), and for civilian applications (spectrometry, non destructive test, etc.) in the mid-wave band. In the frame of the ARM-SAT mission, the SCORPIO-MW IR detector (**Figure 17**) will be adapted to suit the need of this space application. In particular, the standard product is sensitive to infrared radiation in the mid-wave band (3-5µm) but will be adapted with spectral range optimized in band 1.1-5µm.





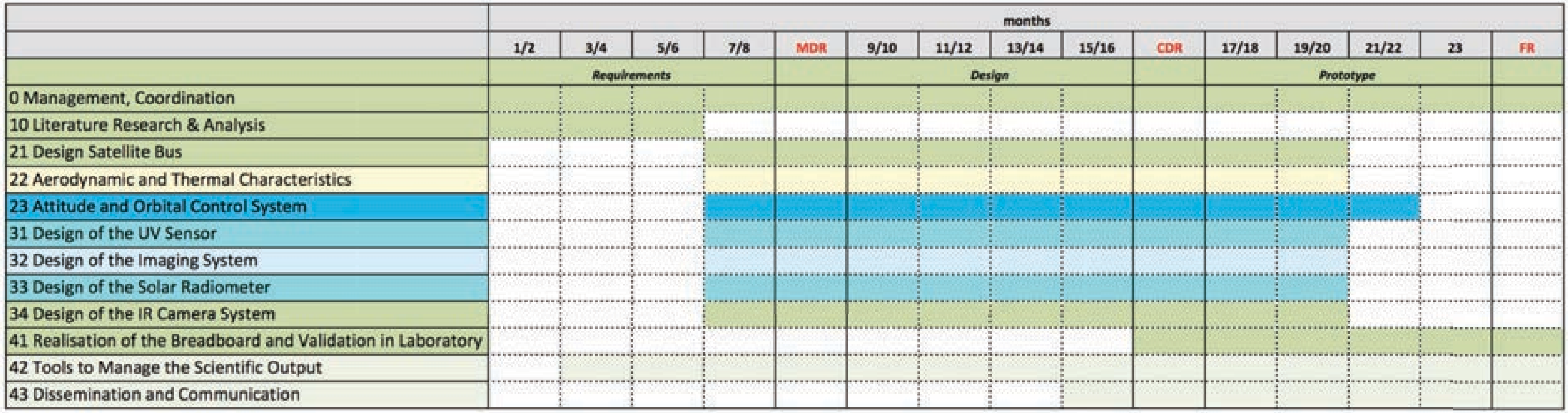
4. Implementation



The ARM-SAT objectives will be reached following the work described in the following Work Packages:

- **WP21: Design Satellite Bus,**
- **WP22: Aerodynamic and Thermal Characteristics,**
- **WP23: Attitude and Orbital Control System,**
- **WP31: Design of the UV Sensor,**
- **WP32: Design of the Imaging System,**
- **WP33: Design of the Solar Radiometer,**
- **WP34: Design of the IR Camera System,**
- **WP41: Realisation of the Breadboard and Validation in Laboratory.**

Duration of the program and tasks



List of work packages

WP N°	Work Package Title	Lead Participant No	Lead Participant Short Name	Person-Months	Start Month	End month
0	**Management, Coordination**	**1**	**LAT**	**16.5**	**1**	**23**
10	Literature Research & Analysis	1	LAT	5.7	1	6
21	Design Satellite Bus	3	LAT	16.75	7	20
22	Aerodynamic and Thermal Characteristics	4	VKI	18.2	7	20
23	Attitude and Orbital Control System	5	SSC	18.2	7	22
31	Design of the UV Sensor	5	RMIB & LAT	7	7	20
32	Design of the Imaging System	6	SYS	10.9	7	20
33	Design of the Solar Radiometer	7	RMIB	7.9	7	20
34	Design of the IR Camera System	8	LAT	7	7	20
41	Realisation of the Breadboard and Validation in Laboratory	1	LAT	8.4	17	23
42	Tools to Manage the Scientific Output	2	BAO	33.6	3	23
43	Dissemination and Communication	1	BAO & LAT	30.6	15	23
				180.75		

Merci !!!!