THE PRISMA SYSTEM AND PAN/HYP INSTRUMENT

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ABSTRACT

In the framework of its activities in the field of Earth Observation, the Italian Space Agency (ASI) signed in 2007 a contract for the design, development and deployment of the PRISMA mission. PRISMA stands for "PRecursore IperSpettrale della Missione Applicativa"; the program is starting the C/D phase and has been completely funded by ASI until the completion of system on-orbit commissioning; the launch is planned for the second half of 2011 with VEGA.

PRISMA is conceived as a "public good" pre-operational and technology demonstrator mission, focused on the development and delivery of hyperspectral products and the qualification of the hyperspectral payload in space. PRISMA will focus on the needs of the Italian institutional and research entities, which will receive data spanning from raw (level 0) to fully calibrated standard products and including fully geo-coded image products (up to level 2). The Mission will provide worldwide access, with a specific area of interest covering the whole European and Mediterranean region. Hyperspectral data will help to efficiently address the selected applications, such as those related to quality and protection of the environment, sustainable development, climate change, strong economy.

The System will be based on a single satellite operating in sun-synchronous low Earth orbit (≈700km) for a 3+2 years lifetime, embarking a state-of-the-art hyperspectral and panchromatic payload. The satellite, weighting about 500kg, will primarily operate in a "user driven" targeting mode with a maximum 7 days re-look and a 14 days end-to-end response times; to fully exploit the available system capacity, a "data driven" background mission mode will be considered as well. The daily imaged area will exceed 100,000 km^2, with a generation and distribution capacity of more than 100 products. The ground stations, for TT&C and image data reception, will be located in the Italian territory; the quality of the images and products will be better than previous and competing systems concerning geometry (also thanks to fusion of panchromatic and hyperspectral data), spectral and radiometric resolution. To reduce the mission costs and risks, extensive re-use of elements already developed during previous contracts (e.g. satellite platform, ground infrastructures) will be pursued wherever possible.

The core of the space segment of the PRISMA mission is the HYP/PAN instrument. HYP/PAN is a combination of an hyperspectral camera working in the spectral range 0.4 - 2.5 µm (VNIR and SWIR channels) and a panchromatic camera working in the spectral range 0.4 - 0.7 µm. Both cameras use the same collecting optics based mainly on a TMA telescope with an entrance pupil of 21 cm., F#3.3 and a FOV of 2.45°. So large telescope is required to meet the very demanding SNR requirements. The telescope is realized in Zerodur glass. The separation of the PAN, VNIR and SWIR channels is obtained using field and dichroic separators, instead the dispersive elements of the VNIR and SWIR imaging spectrometers are prisms.

The resulting optical design is very compact and light weight. To assure an optimal reconstruction of the spectral signature of each observed pixel the VINIR and SWISR channels will overlap in the spectral zone between 920nm and 1010nm. The average spectral resolution is of less than10nm on all the spectral range, instead the GSD is 30m for a nominal orbit of 695 km of altitude. The cooling of the two FPAs is passive. An on board calibrator unit will assure that the data will be calibrated radiometrically, and spectrally very accurately. The PAN camera has the same swath , 30 km, of the hyperspectral cameras , and a GSD of 5m. The image quality is guaranteed by a very sophisticated design able to permit, at system level, a MTF at the Nyquist frequency larger than 0.3 for the two hyperspectral cameras and larger than 0.2 for the panchromatic camera. The fusion of the PAN data with the hyperspectral data will permit the development of very valuable data products.

The first part of the paper deals with the system engineering processes leading to the identification of system drivers and key requirements, in particular those related to the payload such as the number of bands (>200), the Image Quality, the SNR etc..

Then, the architecture and the main performance of the overall system will be described.

Finally, the payload concept design will be presented, also addressing specific elements of the design and involved technologies.

2. PROGRAM OVERVIEW

2.1. Context

The Italian Space Agency has identified the “hyperspectral niche” as one of the fields of interest since about one decade. A dedicated roadmap is being established (see Fig.1), encompassing

- Definition of user needs, in cooperation with operational and scientific community
- Development and qualification of “critical technologies”
- System architecture and preliminary design
- System deployment and exploitation

Specific programmes (hyperspectral) undertaken so far are:

- Hypseo A/B phase (2002), in National context
- JHM A phase (2006-2007), as cooperation between Italy and Canada
- PRISMA B2/C/D/E1 phase (2008-2011), in National context

Wrt PRISMA follow-on, ASI is open to consider possible cooperation with other Countries.

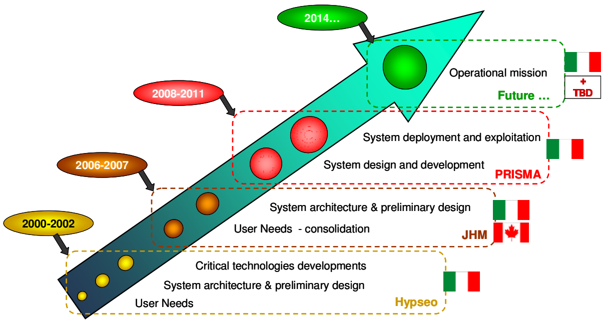

Fig. 1 – PRISMA Context

2.2. Actors

The prime contractor for the PRISMA mission is an industrial consortium formed by Carlo Gavazzi Space (CGS), Selex Galileo (GA) and Rheinmetall Italia (RHI), that form the industrial core team that coordinates the participation of other major Italian space companies, as subcontractors.

The responsibilities of the core team companies can be summarized as follows (see Fig.2):

- CGS: responsible for project management, overall system engineering, design, development and integration of the platform and system AIV activities. In the frame of the Ground Segment, CGS is responsible of the overall data processing in the IDHS

of the Level 2 standard products development.
- GA: responsible for design, development, integration, test and calibration of the complete hyperspectral instrument, PAN camera and of its test equipment (MGSE, EGSE and OGSE). For what concerns the platform GA will also supply solar panels, autonomous star tracker sensors for the attitude determination and the on-board power distribution unit (PCDU). In the frame of the Ground Segment, GA will be responsible for the overall Data Processing in the IDHS with direct responsibility of level 0 and level 1 standard products development.
- RHI: responsible for thermo-mechanical engineering of the satellite, development and integration of the structure and thermal subsystem of the platform, platform and payload structural model, launcher interface, satellite thermo-mechanical AIV/AIT including environmental qualification, satellite MGSE and launch campaign. RHI will also supply the solar panel mechanical substrate.

The industrial team also includes major Italian companies, such as Thales Alenia Space Italia (TAS-I), responsible for the PDHT, and Telespazio, responsible for the overall Ground Segment.

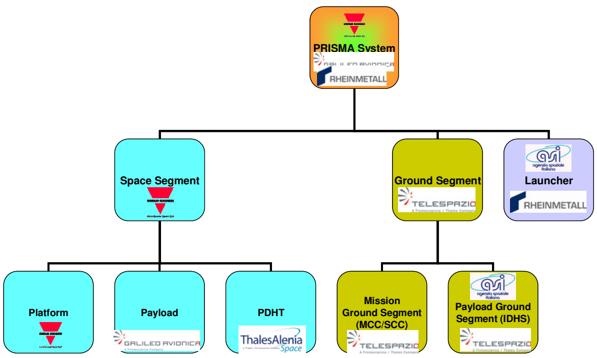

Fig. 2 – PRISMA Industrial Team

2.3. Planning and status

The program has been completely funded by ASI up to the system on-orbit commissioning

The Kick off meeting has taken place in January 2008 and the program is now starting the C/D phase; the launch is planned for the second half of 2011.

3. SYSTEM CONCEPT

<u>Mission Statement</u>

The statement summarizing the Mission objectives is: *“a pre-operative small Italian hyperspectral mission, aiming to qualify the technology, contribute to develop applications and provide products to institutional and scientific users for environmental observation and risk management …”*

<u>System overview</u>

PRISMA is system conceived for Earth observation having the following main objectives:

- in orbit demonstration and qualification of an Italian state-of-the-art hyperspectral camera;
- implementation of a pre-operative mission;
- validation of end-to-end data processing to be able to develop new application to manage the environmental risks and Earth observation based on high spectral resolution images.

The PRISMA satellite, placed in a sun synchronous orbit, will focus primarily on the European area of interest, enabling the download of the data on two ground stations located in Italy. Once the hyperspectral images are downloaded on ground, they are archived and processed up to level 2.

PRISMA System is articulated in the following integrated segments:

- A Space Segment, consisting in a single satellite placed in suitable LEO SSO orbit with an operational lifetime of at least 3+2 years. The satellite is made up of:

- a Platform, based on the Italian small satellites standard platform already used on MITA and AGILE missions
- a Payload, consisting in a Hyperspectral instrument and PAN camera
- a Payload Data Handling & Transmission (PDHT) recurrent from COSMO-SkyMed

- A Ground Segment, comprising various centres located in Italy and including:
  - a Mission Control Centre (MCC), in charge of mission planning and management
  - a Satellite Control Centre (SCC), in charge of satellite command and control
  - an Instrument Data Handling System (IDHS), in charge P/L data reception, archiving, processing and interface with users

A dedicated launcher will be used to directly inject the Satellite in its final orbit. The baseline is a VEGA launch, as alternative options, other small launchers such as Dnepr, Eurockot, etc. will be considered in the satellite design.

Orbit

The selected orbit for the area of interest (see Fig.5) in the baseline configuration is sun synchronous with repeat cycle of 25 days (364 orbits).

- Orbit altitude : ≈700 km
- Inclination : 98.19°
- Local Time of Descending Node: 10.30.
- Orbital period: about 99 minutes
- Average eclipse : 33.9 minutes

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Fig. 3 – Area of interest

Considering the selected orbit, the daily accesses to the area of interest are usually 6. The average duration of the access to the area of interest is about 8.5 minutes.

The daily imaging capability is about 108.000 km^2.

Ground stations visibility

The PRISMA satellite has two communication links:

- S band with Fucino ground station – providing telemetry and telecommand for satellite management
- X band with Matera ground station – providing telemetry link for image data download

Due to the small distance between the two ground stations the access are almost simultaneous therefore the satellite is designed to be able to manage both communication links at the same time, with a daily average contact duration of about 44 minutes.

The downlink capability for instrument data in X-band is 155Mbps.

Concept of Operations

The system operates in User Driven mode, since no systematic data take is performed.

Images acquisition, storage and download are made upon reception of commands from the Ground Segment to satellite.

The commands will be time tagged to the time of their required execution, for both Payload& PDHT (finer schedule) and platform (coarse schedule)

Background imaging will be done only for selected areas in the primary AoI (Area of Interest)

Specific users requests will have priority over background imaging.

The baseline plan, generated by the Mission Planner, will cover routine operations for satellite monitoring, control and maintenance, plus the operations to perform background acquisition activity.

User's requests will be then inserted in the operation plan modifying the original baseline plan.

4. SYSTEM ARCHITECTURE

4.1. The Payload

The core of PRISMA mission is the Hyperspectral/PAN instrument. The instrument will use the pushbroom scanning technique. It is made up of Hyperspectral imager, composed by two imaging spectrometers for the VNIR and SWIR spectral range respectively, able to take images in a continuum of spectral bands ranging from 400 to 1000 nm and from about 1000 to 2500 nm, and a Panchromatic camera (400 - 700 nm). The dispersive elements for the Hyperspectral imager are prisms.

The main features, considering the reference mission orbit are summarized in Table 1.

Instrument Main Characteristics	
Swath / FOV	30 km / 2.45°
GSD	• Hyperspectral: 30 m • PAN: 5 m

Instrument Main Characteristics	
Field of Regards	± 15°
Spectral Range	VNIR: 400 – 1010 nm SWIR: 920 – 2505 nm
Spectral resolution	≤ 10 nm
Signal quantization	12 bit
VNIR SNR	> 200:1 on 400 – 1000 nm > 600:1 @ 650 nm
SWIR SNR	> 200:1 on 1000 – 1750 nm > 400:1 @ 1550 nm > 100:1 on 1950 – 2350 nm > 200:1 @ 2100 nm
PAN SNR	> 240:1
Abs. radiom. accuracy	Better than 5%
Polarization sensitivity	< 5%
Telescope type	TMA
Aperture Diameter	210 mm
MTF	VNIR @ Nyquist >0.3 SWIR @ Nyquist >0.3 PAN @ Nyquist >0.2
cooling system	Passive Radiator

Table 1 – Instrument main characteristics

As it is shown in the block diagram, the Instrument is composed of two units: the Hyperspectral/PAN Optical Head and the Main Electronics box(ME).

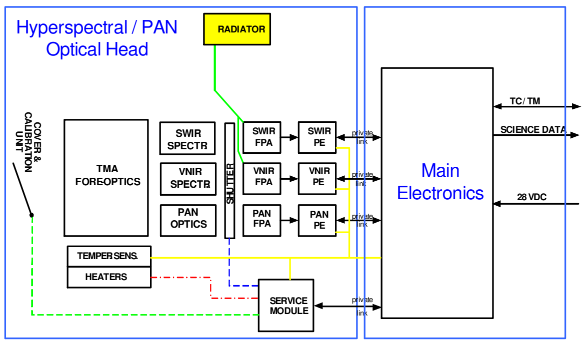

Fig. 4 – PRISMA Instrument block diagram

The Optical Head collects the radiation impinging by a common telescope. A Field separator will send the radiation in the PAN Channel and in the VNIR/SWIR channels. The VNIR and SWIR will be divided by a dichroic and dispersed in the two spectrometers. The photons will be converted in electrons by means of appropriate Focal Plane Arrays (FPA) and later on the electrical signal will be amplified and converted into digital data stream. The Optical Head has mechanical and thermal interfaces with the S/C.

The Main Electronics box has the function to control the Instrument and to handle, according to the agreed protocols, the bit stream representing the spectral images up to the interface with the S/C transmitter. It has mechanical, thermal and electrical interfaces with the S/C.

The cooling of the FPAs is obtained by means of a passive radiator facing the cold space.

The HYP/PAN Optical Head includes the following parts:

- optical systems,
- entrance covers,
- passive thermal control system,
- in-flight calibration units,
- Focal Plane Arrays (FPA),
- proximity electronics (PE),
- cover,
- shutter,
- internal calibration-unit.

In Table 2 are summarized the physical dimensions, mass and power consumption of the instrument and in Figure 8 a 3D layout of the Instrument..

Instrument Dimensions and Power	
Optical Head Dimensions (including PE boxes and baffle)	~ 700 mm width ~ 700 mm depth ~ 1100 mm Nadir
Main Electronics Box Dimensions	~ 400 x 300 x 250 mm
Optical Head Mass (including PE boxes)	< 80 kg
Main Electronics Box Mass	< 8 kg
Instrument Power Consumption	< 60 W (Acquisition mode) < 40 W (Standby mode)

Table 2– Instrument dimensions and power

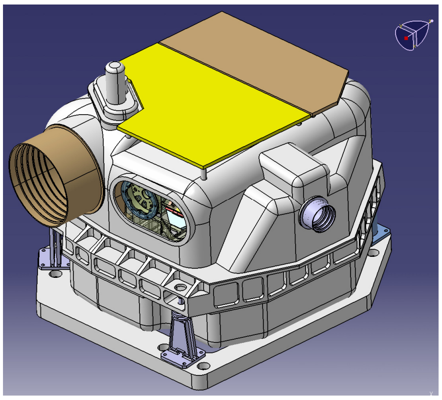

Fig. 5 – Hyperspectral / PAN Optical Head layout

The optical system consists of a common telescope two imaging spectrometers, operating in VNIR and SWIR bands, and a panchromatic camera. In Figure 9 the optical scheme of the system.

The spectrometer is based on a prism solution. This prism system has high efficiency and low polarization sensitivity. The good efficiency allows to reduce the instrument dimension and mass with less demanding resources to the S/C and less criticalities for the optics design.

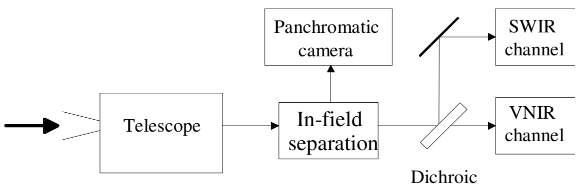

Fig. 6 – Block diagram of optics

The configuration was studied in order to match a detector with a pixel size of 30 µm for both VNIR and SWIR channels, and 6.5 µm for the PAN. The detection chain involves three focal planes (FPA) which are physically accommodated on the optical bench.

Due to the demanding requirements on the radiometric accuracy an in-flight internal calibration unit (ICU) has been designed so to allow operations of absolute and relative radiometric calibration and spectral calibration.

4.2. PRISMA Satellite

The PRISMA spacecraft can be divided into the following elements:

- a Platform
- a Payload, consisting in a Hyperspectral / Panchromatic instrument
- a Payload Data Handling and Transmission subsystem (PDHT)

The PRISMA platform will provide all the functionalities to guarantee the operation of the Satellite and in particular it is in charge to provide to the PRISMA payload the required services for its operation.

The satellite configuration is shown in the Figure below.

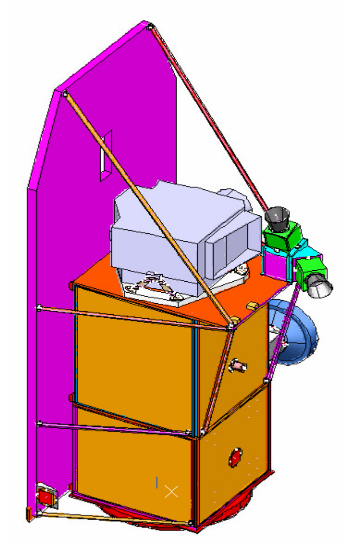

Fig. 7 – PRISMA satellite configuration

The proposed satellite configuration results in a total wet mass around 500 kg with margins. The calculated average power of the satellite is about 325 Watts with a peak of 720 Watts during acquisition and download

The main satellite elements are described in the following, with emphasis on the payload instrument, that is the real core of the space segment.

4.2.1 PRISMA platform

The PRISMA platform represents a significant evolution of the MITA/AGILE platform. In particular it will include an enhanced attitude control system with pointing agility, a propulsion subsystem for orbit control and final disposal, and a power control electronics that makes maximum use of the competences in this domain at national level.

The resulting key performances of the proposed PRISMA platform are in line with the current European state-of-art platforms used in first class remote sensing missions.

The on board operative and control functions of the satellite are performed by the On Board Data Handling (OBDH) Subsystem, which is in charge of on board telemetry and telecommand management, ground generated commands execution, AOCS, power management, monitoring of main platform H/K parameters, payload monitoring and image downloading during ground contacts.

The Attitude and Orbit Control Subsystem is based on qualified and flight-proven equipment. The AOCS will be designed using a standard development plan that, starting from system requirements, will be divided in the following consecutive principal steps: Design, Algorithm Validation, Processor in the loop test, Hardware in the loop test, Sensors and Actuators test, Final test.

The S band TM/TC subsystem carries out the telecommunications tasks. It is composed of two transmitters, two receivers and three antennas, managed in order to guarantee global coverage with every attitude condition.

The power to the Satellite is provided by fixed solar panels and by two Lithium-Ion battery packs during eclipse periods and during the attitude acquisition phase. The satellite attitude will be nominally kept Sun pointing while the fine nadir pointing attitude will be applied only during images acquisition and download. The electronics to convert and distribute the power to the satellite users is included in the Power Control and Distribution Unit (PCDU) and managed by the OBDH.

The PRISMA bus software will run on the OBDH and will be based on an Operating System kernel with Real Time and Multitasking features, so it will consists in a set of task working in parallel.

The sensors used to satisfy the payload needs are two star sensors, two GPS receivers, a set of gyros; two magnetometers, and a set of coarse Sun sensors. Four reaction wheels and three redundant magnetic-torquers constitute the actuators set of the ACS which is completed by ACS software running on OBDH.

The orbit control will be guaranteed by an hydrazine blow-down propulsion subsystem. Initial orbit correction and periodic orbit maintenance tasks will be calculated and planned by MCC, and uploaded to the satellite by the SCC. The satellite will then execute the required attitude manoeuvres and the thrusters firing according to the uploaded command sequence.

The satellite thermal control is mainly passive and it is realised by placing the most dissipating devices on radiating surfaces. Dedicated thermal control will be implemented for Li-Ion battery, for payload detectors and for the propulsion subsystem.

The satellite structure consists in a frame made of tubes and reinforcing side made up by Aluminium - Aluminium honeycombs and which supports internal sub-systems hardware.

4.2.2 PDHT

The PDHT is a payload embarked on scientific satellite that includes all the necessary functions to interface different sources at different data rate, for the Payload data acquisition, data storage, downlink data formatting, encryption and RF transmission (X-Band communication equipment) to Ground Stations.

The architecture of PDHT is composed by three major assemblies:

- Data Storage and Handling Assembly (DSHA): this Assembly is used to store, to format and to encrypt the Science Data acquired from Payload Instrument (depending on the specific application the DSHA will two Mass Memory & Storage Unit MMSU)
- X-Band Transmission Assembly (TXA): used to perform Modulation and Power Amplification of modulated carriers up to the required level for transmission;
- X-Band Antenna Assembly (XBAA): used for the transmission of the X-Band signals to ground according to the required performance (gain, coverage, etc.)

4.3. Ground segment

The PRISMA mission scope is to demonstrate an Hyperspectral payload and at the same time it shall perform as a preoperative mission. The system and its components, including the Ground Segment, are defined, designed, developed, qualified, integrated, tested and validated to be able to support and to exploit the satellite, after the Commissioning, during its entire lifetime.

The PRISMA Ground Segment includes the two main centers:

- the Matera IDHS (Image Data Handling System) based on the reuse and improvement of the existing “Centro Nazionale Multimissione”, that will be dedicated to remote sensing data acquisition, processing, archiving and distribution, as well as to the PRISMA users interfacing

- the Satellite and Mission Control Centre at Fucino, currently operating with Agile satellite, that will be the evolution and customization, according to PRISMA mission requirements, of the existing Control and Mission Centre and that is devoted to the satellite control, mission control and flight dynamics.

During the PRISMA missions, the two centers will work in close coordination exchanging data such as satellite tracking information (based upon orbit determination data) and payload observations planning (based upon the users' orders) to be uploaded to the satellite during the entire mission life.

Image Data Handling System (DHS)

One of the most important functions of the IDHS is the Users interfacing. PRISMA Users are organized into various classes (e.g. institutional, scientific, commercial, organizations, members of the CALVAL Working Group, etc) characterized by specific roles and privileges. They are allowed to:

- Access the PRISMA system on a worldwide basis, by mean of a web-based portal
- Browse the products catalogue
- Order acquired images processing or new image acquisitions
- Download mission products
- Get general mission info & help

The support of users with such services asks IDHS for the following capacities:

- Maintain a interoperable catalogue of the archived Level-0 products, their quicklook images and associated metadata, allowing users to browse it and to perform complex queries based on space, time, allowed cloud coverage and selected spectral shape
- Assist users in the creation of requests for existing or new acquisitions, allowing them to specify the space, time, acquisition constraints / parameters of the desidered image
- Validate the user request against its technical acquisition feasibility as well as PRISMA data policy constraints
- Receive the raw data downlinked by the PRISMA satellite and process them into Level-0, Level-1 or Level-2 products, in a fully automated fashion
- Receive, archive and update the auxiliary data repository, containing Digital Elevation Models (DEM), Calibration data, Atmospheric models, Ground Control Points (GCP) used during the Level 1 / 2 processing
- Give a feedback to the users notifying the success / failure / delay of their acquisition or processing requests
- Handle special orders, as those with very high priorities (e.g. in case of emergency) or outside the primary area of interest
- Support the Value-added Application Product Segment with the PRISMA standard products to be used for the generation of the Level 3 and Level 4 Products
- Assists users in case of anomalies of the system (failed login into portal, lost of ordered products, etc)
- Disseminate worldwide general info & specific documentation about PRISMA

Such services will be supplied to the user community ensuring the following performances and capacities:

- Archive the data downloaded daily from the satellite, corresponding to 108000 km2 of Hyp+Pan image data
- Process daily all the Hyp+Pan data downloaded in the day (i.e. 120 images, 30x30 km^2 each), with at least 30 Hyp scenes processed up to level 2d (i.e. geocoded at surface reflectance, Hyp and Pan)
- Allow a product generation and delivery latency (in case of level 2d products) below than 4.5 days from their acquisition on-board the spacecraft

- Geocode images (using ground control points and a Level-2 DEM) with an accuracy of 0.5 GSD (90% radial error)
- Maintain the mission vital data (acquired raw data plus associated ancillary / auxiliary data, e.g. calibration coefficients, orbits, DEM, etc) for a minimum of 10 years, following commissioning of the system
- Maintain capacity and throughput with operations based on 2-shift/day, 7 day/week

Mission Ground Segment (MGS)

The Fucino part of the Ground Segment shall be devoted to the control of the spacecraft (Mission Control Centre – MCC) and to the control of the payload (Mission Control Centre – MCC).

MCC is composed by the SCS (Satellite Control System), the FDS (Flight Dynamic System) and by the TT&C antenna.

In particular, SCS shall be capable to ensure the following main functions:

- Satellite telemetry acquisition from TT&C ground station, TM processing, display and archiving;
- Satellite database handling and maintenance
- Satellite sub-systems and payload health monitoring;
- Real time or time-tagged telecommand preparation;

The Flight Dynamics System (FDS) is in charge of the satellite orbit determination and prediction.

Orbit determination shall be based on data coming by the GPS receiver installed on the spacecraft.

Moreover, FDS is in charge of the satellite attitude dynamics determination (based on the observations of the relevant sensors, such as star sensors, sun sensors, gyroscopes, etc.).

TT&C subsystem represents the RF interface between the spacecraft and the Ground Segment devoted to the M&C of the spacecraft and the payload.

It is based on a S-Band Tx/Rx antenna.

Signals are received and demodulated: information relevant to the spacecraft are extracted (telemetry);

Commands to be sent are modulated and transmitted to the spacecraft.

MCC receives the requests for new acquisitions coming from the IDHS and generates the acquisition plan to be transmitted to the SCC

Main functions of the MCC are the following:

- Geometric feasibility analysis;
- Generation of the long term acquisition plan;
- Generation of the short term acquisition plan (taking into account availability of the system and weather forecast);
- “Translation” of the acquisition plan into the commands ready to be transmitted to the spacecraft (through the SCC);
- Generation of the acquisition schedule (done on the basis of the priorities assigned to the acquisition requests and after the resolution of the conflicts between the requests).
- Optimization of the resources through the implementation of a “background mission”.

4.4. Launch Compatibility

PRISMA will be compatible with a wide range of small-class launchers, in particular with the ones in the class of up to 1000-1500 kg of payload mass. The baseline launch provider is assumed to be VEGA. Other possible launch providers for PRISMA are Dnepr, PSLV and Eurorockot.