GALILEO GALILEI (GG)

MISSION REQUIREMENTS DOCUMENT

DRL/DRD: DEL-018

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1. INTRODUCTION

1.1 Scope

This Mission Requirements Document (MRD) represents the reference set of mission-level requirements which shall enable, together with the other Applicable Documents, the assessment and definition studies by industrial contractors. It shall also be an evolving reference for all related mission definition activities, such as mission analysis and definition of interfaces with related mission elements or co-operation partners.

1.2 Issue schedule

This issue of the MRD has been established in support of the GG Phase A2 Study.

1.3 Requirements Categorisation

The statements in this document are classified according to the following categories.

R: Mandatory requirements to be complied with, and verified, by the Contractor using a verification method approved by ASI.

G: Performance goals, which are desirable in order to maximise the science return while keeping the impact on the cost and complexity to a minimum.

D: Descriptive text, providing supporting information/ background about a set of requirements or goals.

The whole of Chapter 4 consists of descriptive text, unmarked as such.

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2. ACRONYMS

AD	Applicable Document
AOCS	Attitude and Control Subsystem
ASI	Agenzia Spaziale Italiana
CCSDS	Consultative Committee for Space Data Systems
CNES	Centre National d'Etudes Spatiales
CPE	Control and Processing Electronics
ECE	Experiment Control Electronics
EP	Equivalence Principle
ERD	Experiment Requirements Document
ESA	European Space Agency
G/S	Ground Station
GG	Galileo Galilei
HK	Housekeeping
INFN	Istituto Nazionale di Fisica Nucleare
IRF	Inertial Reference Frame
LEOP	Launch and Early Orbit Phase
LLR	Lunar Laser Ranging
MRD	Mission Requirement Document
P/L	Payload
PA	Product Assurance
PCB	Pico Gravity Box
RD	Reference Document
SD	Standard Document
S/C	Spacecraft
S/S	Subsystem
SPoF	Single Point of Failures
TBC	To Be Controlled
TBD	To Be Defined
TC	Telecommand
TM	Telemetry

3. DOCUMENTS

The Applicable Documents listed below shall be complied with during the GG Phase A2 Study, unless conflicting with the MRD itself or where specifically stated. In such an event, ASI shall be notified and shall decide on course of action.

The Experiment Requirements Document ERD [AD 2] extends and complements the set of scientific requirements of the mission, defined in this document. The current version of the ERD is listed among the Phase A2 outputs [RD 6], until approval by ASI.

The published ECSS (European Cooperation for Space Standardisation) space standards documents quoted in the MRD are applicable throughout the GG Phase A2.

The Reference Documents listed below are given as complementary information and background data related to the GG Mission.

3.1 Applicable Documents

[AD 1] ASI, "Progetto Galileo Galilei-GG Fase A-2, Capitolato Tecnico", DC-IPC-2007-082, Rev. B, 10-10-2007 and applicable documents defined therein

[AD 2] GG Experiment Requirements Document, see preliminary version under [RD 6].

3.2 Standards

[SD 1] ECSS-M-00-02A, Space Project Management – Tailoring of Space Standards, 25 April 2000

[SD 2] ECSS-E-ST-10C, Space Engineering - System Engineering General Requirements, 6 March 2009

[SD 3] ECSS-E-10-02A, Space Engineering – Verification

[SD 4] ECSS-Q-00A, Space Product Assurance - Policy and Principles, and related Level 2 standards.

3.3 ASI Reference Documents

[RD 1] GG Phase A Study Report, Nov. 1998, revised Jan. 2000, available at: http://eotvos.dm.unipi.it/nobili/ggweb/phaseA/index.html

[RD 2] Supplement to GG Phase A Study (GG in sun-synchronous Orbit) "Galileo Galilei-GG": design, requirements, error budget and significance of the ground prototype", A.M. Nobili et al., Physics Letters A 318 (2003) 172–183, available at: http://eotvos.dm.unipi.it/nobili/documents/generalpapers/GG_PLA2003.pdf

[RD 3] A. Nobili, DEL001: GG Science Requirements, Pisa, September 2008

3.4 GG Phase A2 Study Notes

[RD 4] SD-RP-AI-0625, GG Final Report / Satellite Detailed Architecture Report, Issue 1

[RD 5] SD-RP-AI-0626, GG Phase A2 Study Executive Summary, Issue 1

[RD 6] SD-TN-AI-1163, GG Experiment Concept and Requirements Document, Issue 3

[RD 7] SD-RP-AI-0620, GG System Performance Report, Issue 2

[RD 8] SD-TN-AI-1167, GG Mission Requirements Document, Issue 2

[RD 9] SD-RP-AI-0590, GG System Concept Report (Mission Description Document), Issue 3

[RD 10] SD-SY-AI-0014, GG System Functional Specification and Preliminary System Technical Specification, Issue 1

[RD 11] SD-RP-AI-0631, GG Consolidated Mission Description Document, Issue 1

[RD 12] SD-TN-AI-1168, GG Mission Analysis Report, Issue 2

[RD 13] DTM, GG Structure Design and Analysis Report , Issue 1

[RD 14] SD-RP-AI-0627, GG Thermal Design and Analysis Report, Issue 1

[RD 15] SD-RP-AI-0268, GG System Budgets Report, Issue 1

[RD 16] SD-RP-AI-0621, Technical Report on Drag and Attitude Control, Issue 2

[RD 17] TL25033, Payload Architectures and Trade-Off Report, Issue 3

[RD 18] SD-RP-AI-0629, Technical Report on Simulators, Issue 1

[RD 19] ALTA, FEEP Thruster Design and Accommodation Report, Issue 1

[RD 20] TAS-I, Cold-Gas Thruster Design and Accommodation Report, Issue 1

[RD 21] SD-RP-AI-0630, Spin Sensor Design, Development and Test Report, Issue 1

[RD 22] SD-TN-AI-1169, GG Launcher Identification and Compatibility Analysis Report, Issue 1

[RD 23] ALTEC-AD-001, GG Ground Segment Architecture and Design Report, Issue 1

[RD 24] SD-TN-AI-1218, GG Preliminary Product Tree, Issue 1

[RD 25] SD-PL-AI-0227, GG System Engineering Plan (SEP), Issue 2

[RD 26] TAS-I, Payload Development and Verification Plan, Issue 1

[RD 27] SD-PL-AI-0228, GG System Verification and Validation Plan, Issue 1

[RD 28] SD-TN-AI-1219, Report on Frequency Management Issues, Issue 1

[RD 29] SD-RP-AI-0632, GG Mission Risk Assessment And Mitigation Strategies Report, Issue 1

[RD 30] SD-RP-AI-0633, Report on Mission Costs Estimates, Issue 1

4. MISSION DESCRIPTION

4.1 Scientific Objectives

The goal of GG is to test the "Equivalence Principle" (EP) to 1 part in 10^{17}, more than 4 orders of magnitude better than today's laboratory experiments. As a consequence of this "Principle" all bodies in the gravitational field of a source mass should fall the same (in vacuum), regardless of their mass and composition. This phenomenon goes under the name of "Universality of Free Fall" (UFF).

As the best theory of gravity to date, General Relativity is crucial to understand the Universe. The need for testing its foundations, hence the Equivalence Principle, is dictated by major current issues such as "dark" matter and "dark" energy, which together account for almost 95% of the Universe and as the word "dark" indicates, they are not understood.

The goal of GG to test the Equivalence Principle to 10^{-17} has to be compared with the current state of the art: 10^{-12} achieved with rotating torsion balances at the University of Washington in Seattle, US (recent improvement to about 10^{-13} announced). Lunar Laser Ranging (LLR) has provided a test (for the Earth and the Moon in the gravitational field of the Sun) to 10^{-13}, though it does not allow the sensitivity of the experiment to be tested with test masses of the same composition.

In both cases an intense research activity is carried out to further improve the sensitivity of the test. However, the difficulties of torsion balance tests explain the slow improvement of their results over the years and indicate that considerable progress beyond the current level is extremely hard to achieve. Only experiments designed to be performed inside a spacecraft to fly in low Earth orbit can aim at testing the Equivalence principle to very high accuracy.

As compared to test masses suspended on torsion balances in the lab, the driving signal in space is about 3 orders of magnitude stronger. As compared to free falling test masses on the ground, the experiment can last as long as the satellite keeps orbiting the Earth (in the conditions required by the experiment), certainly much longer than 1 second or less available on ground; in a 1 year measurement the statistical error would decrease by more than a factor 5000!

In space, absence of weight allows the test masses to be suspended from the spacecraft much more gently than on ground, where suspension must withstand the local acceleration of gravity; in space they are close to free test masses, and therefore can be extremely sensitive to external effects.

Finally, the spacecraft in orbit around the Earth and enclosing the EP testing instrument is an isolated system. This is an extremely favourable condition when performing a small force experiment, and it is utterly impossible to achieve on ground where: a) the vacuum chamber enclosing the instrument is subjected to terrain tilts and seismic noise; b) any rotation of the apparatus (required to modulate the signal and reduce electronic noise, as in the best tests performed with rotating torsion balances) needs motor and bearings whose noise can be reduced but not eliminated altogether; c) nearby mass anomalies not rotating with the instrument would compete an EP violation signal from the Earth.

It is therefore no wonder that satellite experiments aiming at high accuracy tests of the Equivalence Principle have been proposed and studied by scientists both in the US and in Europe, with support and funding by major space agencies such as NASA, ESA, CNES and ASI.

CNES, with support from ESA, has approved and is completing construction of the MICROSCOPE satellite, to fly in the near future with the goal of performing an EP test to 10^{-15} (room temperature experiment, about 200 kg total mass at launch)

NASA has been the first space agency to investigate and support an experiment to test the Equivalence Principle in space proposed by Stanford University; the mission, still under investigation, is STEP (Satellite Test of the Equivalence Principle), has been studied also in Europe in collaboration with ESA , is a precursor of MICROSCOPE with a cryogenic payload, a large total mass (1 ton at launch) and the goal of reaching 10^{-18}.

GG, so far supported by ASI and INFN, has a conceptually different design with respect to STEP and MICROSCOPE, it does not require cryogenics, has a total mass comparable to that of MICROSCOPE (250 kg total mass at launch) and aims at an EP test to 10^{-17}.

4.2 Experiment Description

Two test masses of different composition form the GG **differential accelerometer**. The test masses are heavy (10 kg each) concentric, co-axial, hollow cylinders. The two masses are mechanically coupled by attaching them at their top and bottom to two ends of a coupling arm, using flexible lamellae. The coupling arm is made of two concentric tubes similarly attached at their midpoints to a single shaft. This assembly preserves the **overall symmetry** of the apparatus, when the two parts of the arm are taken together.

The masses are mechanically coupled through the balance arm such that they are free to move in the transverse (XY) plane. A differential acceleration acting on the masses gives rise to a displacement of the equilibrium position in the XY plane. The displacement of the test masses is sensed by two sets of capacitance plates located between the test cylinders, one set for each orthogonal direction (X and Y). Each set forms an **AC-bridge** so that a displacement of the masses causes an unbalance of the bridge and is converted into a voltage signal. When the physical system is mechanically well balanced, it is insensitive to `common-mode' accelerations. Moreover, the capacitance bridges are inherently sensitive to differential displacements. Thus, the differential nature of the accelerometer is ensured both by the dynamics of the physical system, and by the displacement transducer.

Testing the EP to 1 part in 10^{17} in the gravitational field of the Earth at 520 km altitude requires detection of a differential acceleration $\mathbf{a_{EP} \approx 8.4 \cdot 10^{-17}\ m/s^2}$. To achieve this sensitivity, the test masses must be very weakly coupled, otherwise the displacement signal resulting from such tiny acceleration is too small to detect. Moreover, the signal (at the orbital frequency) must be up-converted to higher frequency, the higher the better, to reduce 1/f noise.

In the GG accelerometer, the natural period of the differential mode will be designed to be about 545s. At that natural frequency, the EP acceleration signal a_{EP} will produce a displacement $\mathbf{\Delta x_{EP} \approx 0.6}$ **pm in the direction of the centre of the Earth**. By spinning the satellite and the accelerometer, with its displacement transducer, around their common symmetry axis, the EP violation displacement signal is **modulated at the spin frequency** of the system relative to the centre of the Earth.

Once the spacecraft has been given the required rate of rotation at the beginning of the mission (2 Hz with respect to the centre of the Earth), no motor or ball bearings are needed inside the satellite. In fact, all parts of the apparatus and the satellite co-rotate around a common symmetry axis. Since the satellite is not constrained to spin slowly, a spin speed which optimizes the stability of the experiment and satellite can be chosen.

Due to the very weak coupling between the masses and rapid spin, the GG system is **a rotor in supercritical regime** and supercritical rotors are known to be self-centring even if fabrication and mounting errors give rise to departures from ideal cylindrical symmetry. Moreover, the spacecraft too is passively stabilized by rotation around its symmetry axis and no active attitude control is required for the entire duration of the space mission.

The only disadvantage of spinning at frequencies above the natural oscillation frequencies of the rotor is the onset of **whirl motions**. These occur at the natural frequencies of the system as “orbital” motion of the masses around their equilibrium position. Whirl arises due to energy losses in the suspensions: the smaller the losses, the slower the growth rate of whirl. It must be damped to prevent instability. Provided the **quality factor** Q of the suspensions is at least 20,000 (which laboratory tests have shown to be achievable), whirl growth is so slow that experiment runs can be performed between successive damping cycles, thus avoiding any disturbance from damping forces.

The largest disturbing accelerations experienced by the accelerometer are due to residual air drag and other non-gravitational forces such as sun and Earth radiation pressure. Such inertial accelerations act on the spacecraft and not on test masses suspended inside it, and are, in principle, the same on both the test bodies. Ideally, common mode effects do not produce any differential signal; in reality, they can only be partially rejected. The approach taken in GG calls for surface accelerations to be partially compensated by a **drag free control system**, and partially abated by the accelerometer’s own **common-mode rejection**. Drag compensation requires the spacecraft to be equipped with **proportional thrusters** and a control system to force the spacecraft to follow the motion of an undisturbed test mass inside it at (and close to) the frequency of the signal.

Another potential threat is due to temperature effects. **Temperature differences can give rise to differential accelerations** via (a) the “radiometer effect”, (b) differential elongation of the coupling arms, (c) differential changes in the stiffness of the suspensions, (d) expansion of the test masses leading to change of their position w.r.t. the capacitance sensors. The temperature requirements derived in the 1998-2000 study were as follows: 0.2°C/day test mass temperature stability; 1°C axial gradient across the test bodies and the coupling arms. Such performance, which was shown feasible by passive thermal insulation alone, allows 20 days of data taking before rebalancing the test bodies, and at least 15 days before rebalancing the read-out capacitance bridge.

4.3 System Description

4.3.1 System Elements

The GG system consists of the following segments:

- Space Segment, consisting of the GG satellite and its payload instruments
- Launch Service Segment
- Ground Segment.

4.3.2 Payload

The GG payload is constituted by the PGB (Pico Gravity Box) laboratory, enclosing

- The two cylindrical test masses
- Capacitance plates for “science-level” sensing of test mass relative displacements
- Small capacitance sensors/actuators for sensing relative displacements and damping the whirl motions
- Suspension springs and coupling gimbals
- Inchworms and piezo-ceramics for fine mechanical balancing and calibration
- Launch-lock mechanisms, associated to all suspended bodies.

The PGB also carries a small mirror, in correspondence of a photo-detector mounted on the inner surface of the spacecraft, for measuring small residual phase lags with respect to the spacecraft.

The payload electronics include:

- The PGB Control and Processing Electronics (CPE), located on the spacecraft platform, managing PGB motion control (whirl sensing, whirl damping and drag-free control) and processing of all signals coming from the test masses (motion control and EP sensing).
- The Experiment Control Electronics (ECE), housed inside the PGB, and communicating with the CPE via an optical link. The ECE locally manages whirl sensing and damper activation, under control by the CPE processor, and readout of the EP chain.

The payload apparatus further includes the necessary electrical harness and connectors and the thermal insulation.

4.4 Mission Design

4.4.1 Mission Overview

The GG mission has one single objective of outstanding scientific relevance i.e. the EP test at the required accuracy. Therefore the design and needs of measurement instrument totally drive the mission design in all its aspects. The spacecraft design shall minimise platform disturbances to the measurement while maximizing the platform services.

In the same way, the choice of the orbit is driven by the experiment needs and design constraints. An equatorial orbit has been selected as baseline for GG experiment. It allows naturally maintaining the attitude of the spin axis perpendicular to the orbit plane; a small residual inclination such as would result from a launcher injection would easily be tolerated too. This natural stability of the spin axis is an asset of the equatorial orbit, which was lost when SSO was considered (for reasons of launcher availability). The price to pay for the equatorial orbit is a less stable thermal environment. In the equatorial orbit, the satellite enters the Earth's shadow once per orbit, all year round. This is a source of severe thermal variations at orbit frequency, which affect the experiment and must be damped by design.

Given the equatorial orbit, the candidate launch vehicles must either be launched from an equatorial site, or a plane-change manoeuvre must be introduced in the ascent flight plan. The preferred candidates are Vega and the Indian Space Agency's PSLV. Both can inject directly the satellite into a circular, low altitude, equatorial orbit. Given the low mass and small size of GG, a double or even triple launch can be envisaged, if the launchers possess this capability. Typical injection errors of launchers in this class have negligible effects on the GG mission.

The mission design assumes the near-equatorial ground station of San Marco (Malindi, Kenya). Contacts occur in a regular pattern with little variation over the lifetime. During the normal science mode, the data to be transmitted to ground are accumulated at a constant rate. With once per orbit downlink, the minimum required telemetry data rate is easily within the capability of a standard S-band station. All this scenario will be revisited with regard to ground station load and cost, and options for reducing the housekeeping data rates (hence the mass memory) will be addressed.

Mission lifetime of 1 year is considered as minimum nominal duration.

4.4.2 Mission Phases

4.4.2.1 General

Mission phases represent the time and logical sequence of mission implementation. Each phase corresponds to a different condition for both the spacecraft as a whole entity and the payload. The following phases are identified, in accordance to common approach for this kind of missions:

- Launch and Early Orbit phase (LEOP)

- Commissioning phase
- Normal Operation phase
- Disposal phase

4.4.2.2 Launch and Early Orbit Phase

The launch window shall be defined in order to be compatible to the orbital requirements. The power supply shall be provided by the battery. Activity of onboard equipments shall be minimal and limited to the necessary functions.

4.4.2.3 Orbit Phase

Orbit phase corresponds to the true operative phase of the mission. During this phase the instrument performs its measurements and science data are periodically downloaded to G/S station. The activity of the spacecraft, its attitude and position and its conditions are monitored by telemetry data that are regularly transmitted to ground.

4.4.2.4 Disposal Phase

Nominal operative life of the mission is 1 year. After the end of the mission the spacecraft will be useless and its permanence in orbit should be limited, according to common space debris mitigation policies. If the mission operation was stopped before the fuel is completely consumed, manoeuvres should be done to minimise the time in space of the spacecraft as much as possible. This result can be achieved by reducing the perigee of the satellite.

4.4.3 Orbit Parameters

The baseline orbit for the GG mission is near-circular, near-equatorial one. The altitude will be selected, as function of the epoch, so that the predicted maximum acceleration experienced by the spacecraft does not exceed a pre-defined value.

The analysis leading to the selection of a launch altitude in accordance with the above criterion will be performed basing on the assumed launch date and the corresponding solar flux / atmosphere density forecast.

5. PROGRAMMATIC REQUIREMENTS

5.1 Schedule

[MRD-1] (R) The GG satellite shall be compatible with launch in the time frame 2013-2020.

5.2 Cost Policy

[MRD-2] (R) The GG satellite shall be compatible with the cost policy of a small scientific satellite project of ASI.

5.3 Launch vehicle

[MRD-3] (R) The GG satellite shall be compatible with launch by VEGA.

[MRD-4] (R) Besides VEGA, the GG satellite shall be compatible with launch by at least one low-cost launch vehicle.

5.4 Launch mass

[MRD-5] (R) At launch, the total mass of the GG satellite, including the launch vehicle adapter, shall be less than 500 kg.

6. MISSION REQUIREMENTS

6.1 Orbit Requirements

[MRD-6] (R) The GG orbit shall be near circular, at a mean altitude such that [MRD-7] is met all through the mission lifetime.

[MRD-7] (R) The GG orbit shall be such that the maximum disturbing acceleration experienced by the satellite at any point of its orbit does not exceed 2×10^{-7} m/s^2.

[MRD-8] (R) The GG orbit shall be near-equatorial, with inclination at launcher release not exceeding 5.5°.

6.2 Mission Phases

[MRD-9] (D) The GG mission phases shall comprise:

- Launch and Early Orbit phase (LEOP)
- Commissioning phase
- Normal Operation phase
- Disposal phase.

6.3 Lifetime

[MRD-10] (R) The in-orbit lifetime of the GG spacecraft shall be 1 year after the end of the initial commissioning.

[MRD-11] (G) The in-orbit lifetime of the GG spacecraft shall be at least 2 years after the end of the initial commissioning.

6.4 Attitude Profile

[MRD-12] (R) After commissioning, the GG satellite shall be spin-stabilized.

[MRD-13] (R) The nominal spin rate of the GG satellite shall be 1 Hz.

[MRD-14] (R) The nominal attitude of the spin axis of the GG satellite shall be orthogonal to the mean orbit plane at beginning of life.

7. SYSTEM FUNCTIONAL REQUIREMENTS

7.1 Preparation and programming of the measurements

[MRD-15] (R) To prepare the measurements the GG system shall perform the following functions:

- scientific and operational management of the measurements being part of the scientific mission,
- preparation of the measurement sequences according to the scientific operations plan (parameter optimisation, calibration).

[MRD-16] (R) To prepare and upload the work plan the GG system shall perform the following functions:

- generation of payload work plan,
- generation of the satellite guidance,
- generation and validation of the platform and payload TCs,
- transmission of the TC sequences to the ground station.

7.2 Recording, downloading and transmission of the data

[MRD-17] (R) The payload telemetry data shall be recorded on-board by the on-board mass memory in a continuous way. The mass memory capacity shall be sized to record 7 days (TBC) of mission before rollover.

[MRD-18] (R) The system design shall be compatible with a science daily telemetry volume of 2.5 Gbit/day.

[MRD-19] (R) The command and control uplink and downlink communications shall be performed in S-band, with a data rate able to handle all necessary TM/TC for housekeeping operations.

[MRD-20] (R) Payload data downlink shall be done in S-Band.

[MRD-21] (R) Link shall be established for an elevation angle equal or higher than 10° (TBC).

[MRD-22] (R) The availability of the link shall be greater than 95%.

[MRD-23] (R) TM and TC shall be compliant to the CCSDS standards for data coding in space-ground communications.

[MRD-24] (R) P/L and HK telemetry data shall be separated through virtual channels in such a way that the ground station can immediately separate the telemetry flow into science data and functional housekeeping telemetry.

[MRD-25] (R) During the scientific mission phase, a ground station availability of 90% (TBC) maximum shall be assumed.

[MRD-26] (R) The transmission of the HK data to the Mission Operations Centre shall be completed in less than 1 day after the end of a communication slot with the satellite.

[MRD-27] (R) The transmission of the P/L data to the Science Operations Centre shall be completed in less than 1 week after the end of a communication slot with the satellite.

7.3 Processing, calibration and distribution of the scientific data

[MRD-28] (R) The GG system shall perform the following functions:

- acquisition of the scientific data in P/L telemetry and pre-processing,
- systematic checks on the data validity and quality,
- instrument performances follow-up,
- instrument calibration and optimisation,
- processing of the scientific telemetry up to level 1,
- archiving and cataloguing of the data delivered to final users.

These functions shall be performed by the Science Operations Centre.

8. SCIENTIFIC PERFORMANCE AND PAYLOAD REQUIREMENTS

8.1 Experiment Performance Requirements

[MRD-29] (R) The science objective of GG is to test the "Equivalence Principle" (EP) to 1 part in 10^{17}.

[MRD-30] (R) The GG differential capacitance readout shall be able to detect a test mass differential acceleration, with period Tdiff, and smaller than aEP = 10E-17× g(h) m/s², over the fundamental measurement interval Tint.

[MRD-31] (R) After calibration, the capacitance read-out shall be able to detect the displacement ΔxEP (in the test masses XY plane) in one fundamental science integration time slot Tint.

[MRD-32] (R) The overall noise affecting the science measurement shall be such that in one fundamental science integration time slot Tint the Signal to Noise Ratio is SNR > 2.

[MRD-33] (R) In the IRF, the residual (due to limited rejection of common mode) external non-gravitational acceleration sensed from each test mass in the XY plane shall cause no differential acceleration of the proof masses greater than $0.5 \times a_{EP}$ m/s² at the orbit frequency, and 3×10^{-15} m/s^2/$\sqrt{\text{Hz}}$ in a bandwidth of 2×10^{-4} Hz around the orbit frequency.

[MRD-34] (R) In the IRF, the product of the DFC rejection χ_{DFCxy} and of the mechanical suspension Common Mode Rejection Ratio χ_{CMRRxy} shall be such that in the test masses XY plane and at the orbit frequency, $\chi_{DFCxy} \times \chi_{CMRRxy} = 0.5\times a_{EP} / a^{ext}_{NG\,xy} = 2\times10^{-10}$.

8.2 Fundamental Payload Design and Performance Requirements

[MRD-35] (R) In order to maximise the EP violating signal, the test masses material shall be chosen in order to maximise the difference between the ratio of atomic number (number of atom protons) over mass number (atomic number + number of atom neutrons).

[MRD-36] (R) The quality factor Q of the mechanical springs connecting the PGB to the spacecraft, measured at the s/c spin frequency, shall be $Q_{PGB}(@\nu'\ \text{Hz}) \approx 90$.

[MRD-37] (R) The quality factor Q of the test masses mechanical suspension, measured at the s/c spin frequency shall be be $Q_{TM}(@\nu'\ \text{Hz}) \approx 20000$.

[MRD-38] (R) The residual pressure acting on the test masses shall be $\leq 10^{-5}$ torr, in order to avoid air damping in between test masses and science capacitance plates.

8.3 Derived Payload Design and Performance Requirements

[MRD-39] (R) The GG system shall be compliant with the requirements specified in the ERD [AD 2].

8.4 Payload Interface Requirements

[MRD-40] (R) The GG system shall be compliant with the interfaces specified in the ERD [AD 2].

9. SATELLITE PHYSICAL REQUIREMENTS

9.1 Launcher Compatibility Requirements

[MRD-41] (R) The GG spacecraft total length and diameter shall fit within the fairing of the selected launcher.

[MRD-42] (R) The GG spacecraft shall fit with a standard launch adapter of the selected launcher.

[MRD-43] (R) The GG spacecraft shall comply with fundamental lateral and longitudinal frequencies of the launch vehicle.

[MRD-44] (R) Total mass budget in launch configuration shall be compliant with the launcher capability, referred to selected orbit.

[MRD-45] (R) The GG spacecraft shall be compatible with a launch window of at least 30 consecutive days.

[MRD-46] (R) During combined operations with the launcher, the GG spacecraft shall comply with the launcher operations and attitude.

[MRD-47] (R) During all phases of the launcher mission, the GG spacecraft shall comply with the attitude profile of the launcher.

9.2 Environmental Requirements

[MRD-48] (R) The maximum level of particulate contamination shall be TBD.

[MRD-49] (R) The maximum level of chemical contamination shall be TBD.

[MRD-50] (R) The spacecraft shall be compatible with the radiation environment of the selected orbit.

9.3 Design Requirements

[MRD-51] (R) The design margin philosophy shall comply with [SD 2].

[MRD-52] (R) All consumables (cold gas, propellant…) shall be sized from launch until the end of the nominal mission.

[MRD-53] (G) All consumables (cold gas, propellant…) shall be sized from launch until the end of the extended mission. Margins are not applied to the extended lifetime.

[MRD-54] (R) All radiation sensitive units shall be selected and sized from launch until the end of the nominal mission

[MRD-55] (G) All radiation sensitive units shall be selected and sized from launch until the end of the extended mission. Margins are not applied to the extended lifetime.

10. SATELLITE FUNCTIONAL REQUIREMENTS

10.1 Payload and System Functional Requirements

[MRD-56] (R) The spacecraft shall support and provide mechanical interface to the science instrument. Interface shall be compliant to experiment specific needs.

[MRD-57] (R) The spacecraft electrical power S/S shall provide sufficient power to the payload during all mission phases.

[MRD-58] (R) An adequate thermal environment shall be granted to all the subsystems, as well as to the scientific payload, so that it can operate nominally.

[MRD-59] (R) The spacecraft shall host the communication S/S for all uplink and downlink communications (science payload and housekeeping).

[MRD-60] (R) The spacecraft shall have the capability to handle all the telecommands received from ground, transmit them to the payload instrument and send back all acknowledgments for ground control.

[MRD-61] (R) The spacecraft shall have the capability to enter and exit from all the functional modes and to emit in real time the current hardware and software status for diagnostic purposes.

[MRD-62] (R) The AOCS shall enable the spacecraft to perform all the orbital manoeuvres that may be necessary for the performance of the mission and the achievement of the science objectives.

[MRD-63] (R) The AOCS shall enable the spacecraft to perform attitude control in all the mission phases, compliant with the pointing requirements of the scientific payload.

10.2 Autonomy and Safe Mode

[MRD-64] (R) The spacecraft shall respond to on-board critical failures (endangering the mission) by switching to safe mode, independently from ground control.

[MRD-65] (R) The spacecraft shall remain in safe mode conditions for at least 7 days (TBC) without ground intervention.

[MRD-66] (R) In safe mode the system shall provide enough power to maintain the thermal conditions within the prescribed qualification limits for the on-board equipments.

[MRD-67] (R) Safe mode shall be recovered from ground.

11. DATA PRODUCT REQUIREMENTS

11.1 Overview

In this section the requested characteristics of the level-1 products provided by the system after calibration and application of the instrumental corrections performed on ground (whatever the component in charge of this task) are summarised.

A first set of requirements shall be defined and iterated during the phase A2/B, intended for identifying and compiling the auxiliary data to be produced by the space segment and its mission control.

The definition and structure of the products will be elaborated at a later stage of the development.

11.2 GG Payload

[MRD-68] (R) The level-1 product shall contain:

- a header, with the context used to generate the product
- the following science extracted data (TBC):
    - Position of test masses relative to each other
    - Position of test masses relative to PGB
    - Spin reference signal
    - Temperature
    - Spin axis attitude
    - Phase difference between PGB and spacecraft
    - tbd
- the following quality data flag: TBD

12. OPERATIONAL REQUIREMENTS

12.1 Normal Operations

[MRD-69] (R) All operations shall be autonomous, executed on the basis of time-tagged operation sequences that shall be loaded at least one day in advance.

[MRD-70] (R) The satellite shall autonomously detect its status, basing on automatic self-check procedures and programmable decision tables.

[MRD-71] (R) On detection of an anomaly, the satellite shall suspend the scientific operations.

[MRD-72] (R) Resumption of the scientific operations shall be commanded by the ground.

[MRD-73] (R) In normal operations, the satellite shall receive commands and transmit telemetry from/to its dedicated Ground Station located at TBD.

12.2 LEOP Operations

[MRD-74] (D) During LEOP, extended coverage of the spacecraft is required in order to:

- observe the on-board status after separation,
- guarantee the spacecraft command and control link during all critical operations,
- perform orbit determination (Doppler and ranging).

[MRD-75] (R) During LEOP, additional ground stations shall be employed to achieve TBD% coverage of the orbit.

13. VERIFICATION REQUIREMENTS

[MRD-76] [SD 3] shall apply.

14. PRODUCT ASSURANCE REQUIREMENTS

[MRD-77] (R) Product Assurance (PA) requirements provided by ECSS-Q series and the detailed requirements provided by lower level standards defined in ECSS-Q- 00A [SD 4] for each of the PA disciplines shall apply.

[MRD-78] (R) Detailed requirements from the applicable Level 2 and Level 3 ECSS standards shall be tailored according to the characteristics of the mission and the input required to perform an effective risk assessment process.

[MRD-79] (R) Tailoring of PA requirements standards shall be performed according to [SD 1].

[MRD-80] (R) Tailoring of detailed requirements with regard to risk assessment shall assure that all PA tasks necessary to provide the required qualitative and quantitative input for the risk assessment process are provided.

[MRD-81] (R) Single Point Failures (SPF) with catastrophic and critical consequences as defined in ECSS-Q-40A and ECSS-Q-30A are a subset of critical items to be identified in the scope of the risk assessment process.

[MRD-82] (R) Risk assessment and control shall be performed in compliance with ECSS-Q-00A [SD 4], clause 3.3.5.

[MRD-83] (R) Risk assessment according to ECSS-Q-00A contributes to the overall project risk management process according to ECSS-M-00-03b. In particular safety and dependability critical items identification and control shall comply with:

- ECSS-Q-30B, clause 5.3 (dependability critical items)
- ECSS-Q-40B, clause 5.4 (functions)
- Launch site Safety Regulations

[MRD-84] (R) Identification and control of SPFs as defined above applies to: all interfaces between payload instruments and the spacecraft module, including mechanical, thermal, electrical (power, data, EMC/EMI, pyrotechnics), radiation, as far as applicable.

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