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MICROSCOPE SCIENCE MANAGEMENT PLAN

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Objectives of the document

The aim of the present document is to define the science management of the MICROSCOPE mission. The scientific objectives of the mission are recalled as well as the reference scenario of the in orbit experiment and the different types of data that will be available. The approach proposed for the organisation of the scientific community interested in the MICROSCOPE data processing and exploitation is described. The policy for the data access, use and dissemination is also defined.

1. Overview

2.1 Scientific objectives

The MICROSCOPE mission has been proposed by ONERA and the Observatoire de la Côte d'Azur (OCA); it has been selected in the frame of the CNES scientific programme in the field of Space Fundamental Physics. It aims at testing the Equivalence Principle through one of its major consequence, the Universality of Free Fall (UFF) that is to say the equivalence between the inertial mass and the gravitational mass, with an accuracy better than 10^{-15} i.e. more than two orders of magnitude better than the present on-ground experiments.

Recent laboratory experiments exploit the torsion pendulum technique and have to combat environmental instabilities, in particular the Earth gravity gradient fluctuations.

Earth-Moon laser ranging data have also been used lately to test the Equivalence Principle but the Sun gravity is more than one thousand times smaller than the Earth gravity in the vicinity of the Earth and an improvement of the experience better than 10 times is not expected in the near future. In addition, the material composition of the two celestial bodies may introduce difficulty for interpretation of the results.

Since the Equivalence Principle holds a central position in the theoretical formulation of gravitation and in the characterisation of our space-time frame, it is of prime importance to check its validity up to the extreme precision. Theoretical attempts to unify gravitation with the three other fundamental interactions (electromagnetic, weak and strong) such as the string theories lead to predict the possibility of a violation of the Equivalence Principle at a level just below the present experimental accuracy. Such predictions need to be challenged by experimental testing of Equivalence Principle with a better accuracy in space.

The first measurement of a violation of the Equivalence Principle might open the way to the demonstration of a new force or a new interaction (beside the electromagnetic, weak and strong interactions), the existence of which is predicted by many quantum theories of gravity. It would be the first signal of a new physics beyond the Standard Model of particles. It would thus bring into question our knowledge at the interface between the field quantum theory and the theories of gravitation as well as their application to astrophysics and cosmology. Present observation of dark matter and dark energy could be interpreted in conjunction with a potential violation measurement.

On the other hand, if the Equivalence Principle between the inertial mass and the gravitational mass were to be confirmed to an accuracy of one part in 10^{15}, this would provide an important verification of the relativistic theories of gravitation, which postulate this principle. A confirmation of the Equivalence Principle should further stimulate the interest in more accurate experimental or observational data on the Post Newtonian coefficients and would pose strong constraints on unified models of fundamental interactions.

MICROSCOPE would then be the first attempt in space to search for direct evidence of new gravitational phenomena before the realization of even more ambitious missions to complete the understanding of a violation or to look deeper into such a violation.

Description of the experiment :

The MICROSCOPE space experiment consists in testing very accurately the universality of free-fall of two masses made of different materials, on-board a drag-free satellite in low Earth orbit.

The core instrument is based on two ultra-sensitive, six-axis electrostatic differential accelerometers. These accelerometers employ electrostatic levitation and minute motion and attitude sensing of solid test masses in a precisely manufactured and thermally monitored instrument cage, at ambient temperature.

Each differential accelerometer includes two cylindrical and concentric test masses. The first differential accelerometer contains two masses made of different materials and is dedicated to test the Equivalence Principle (EP). The second one contains two masses of the same material Platinum and is used to assess the accuracy of the measurement and the level of systematic errors.

The experimental procedure consists for each couple of test masses in applying electrical potentials on electrodes surrounding them in order to nullify their relative motion on the same orbit. The fine measurements of the applied electrical potentials provide the dissymmetry of the acceleration on both test masses to follow the same trajectory while they are under the effect of the same Earth's gravity field.

The measurements are also used to perform the accurate control of the stability of the satellite attitude as well as of the orbit in such a way to guarantee the accuracy of the EP test. The applied non-gravitational forces on the satellite are compensated by the action of the eight cold gas micro-thrusters accommodated on two faces of the spacecraft.

Thus, this space experiment takes advantage of the undisturbed acceleration environment, on board the dedicated MICROSCOPE drag-free satellite and benefits from low fluctuations of the gravity gradients: on one hand the Earth's gravity field can be modelled with already existing static harmonic developments and on the other hand the satellite is designed to exhibit very weak mass deformations.

Thus, the success of the MICROSCOPE experiment relies first of all on performing the measurement of acceleration lower than 8. 10^{-15} ms^{-2} and on analysing very precisely the in orbit residual perturbations of the test mass motion to deduce any possible EP violation signal.

2.2 Technological objectives

MICROSCOPE will also test the limits of the technologies necessary to control the attitude and the orbit of a drag-free satellite which is shielding its payload from non-gravitational perturbations (Earth and Sun radiation pressures, atmospheric drag…).

These technologies are mainly based on:

- Cold gas micro thrusters providing the continuous dynamic force and torque necessary for the satellite control.
- Star sensors associated with ultra-sensitive accelerometers for the estimation of the residual drag and the estimation of the attitude pointing and motion,
- Estimators, command laws and software for the six servo-loops corresponding to the satellite degrees of freedom.

The production and the precise in-orbit testing of such a drag-free satellite are obviously necessary for the MICROSCOPE experiment but also mandatory for the preparation of future and more ambitious space missions, especially in the field of Fundamental Physics.

2.3 MICROSCOPE satellite and payload

The MICROSCOPE mission is developed in the frame of the CNES MYRIADE micro-satellite product line.

The payload needs to be protected from any external perturbation. So it is accommodated in the internal payload case at the centre of the cubic $1m^3$ satellite. The satellite is equipped with solar panels sufficiently rigid after their deployment; this configuration is well suited for the selected heliosynchronous orbit which is preferred for the thermal stability of the satellite and the payload and which also reduces the sizes of the solar panels to the benefit of their structural rigidity (see figure 1).

The same internal payload case supports on its top the sensor housings and at the middle the electronics units. It includes also the thermal control hardware and provides the centring of the proof masses with respect to the satellite spin axis. It exhibits a very high mechanical stability during the entire mission.

Beside the thermal stability, it includes a magnetic shielding for the masses.

The first stage supports the electronics units which are thermally linked to the outer radiator, and is insulated itself from the satellite structure by six titanium alloy blades. This anti-Sun radiator is protected from the Earth albedo by a cone so that the thermal conditions do not vary. The second stage which supports the two housings and the magnetic shielding is mechanically linked and thermally insulated from the first stage by six titanium alloy blades.

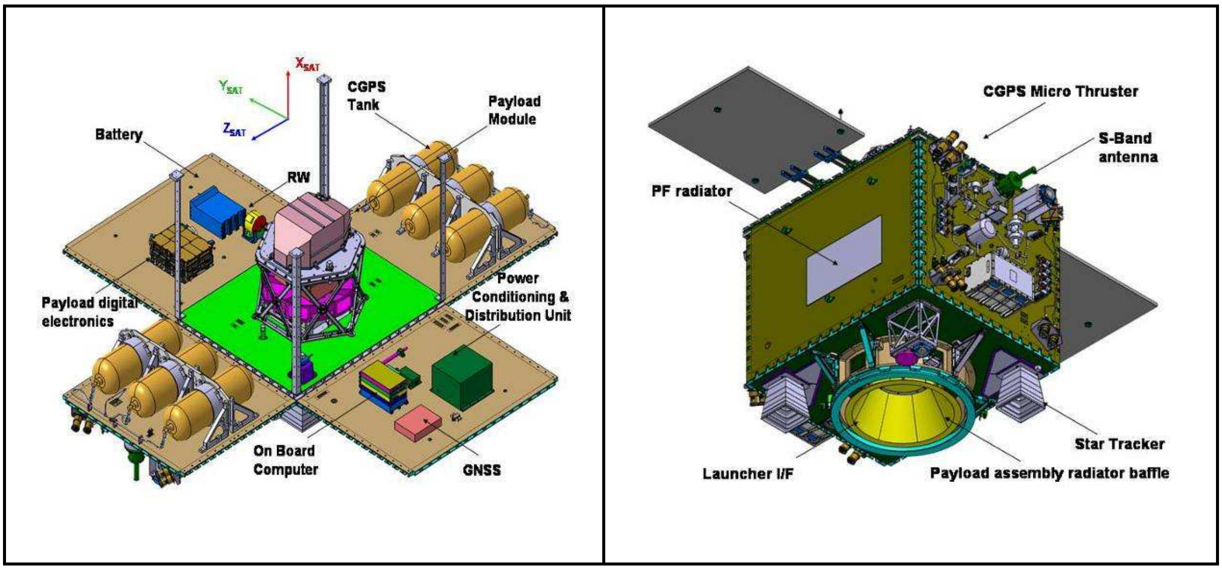

Figure 1. MICROSCOPE satellite internal Layout (left) and external Layout (right)

The satellite carries four pods of two thrusters for the attitude and the orbit control. They are mounted on two opposite faces of the satellite with the associated ensembles of three nitrogen reservoirs.

The satellite payload comprises four inertial sensors operating at finely stabilised ambient temperature. Those inertial sensors are associated by pairs.

One pair constitutes one differential accelerometer which is composed of three units:

- The Sensor Unit (SU) comprising two quasi cylindrical and co-axial masses and two silica instrument cores surrounding these masses, both being included in the same instrument tight housing (see figure 2),
- The Front End Electronic Unit (FEEU) including the capacitive sensing of both masses, the reference voltage sources and the analogue electronics to generate the electrical voltages applied on the electrodes,
- The Interface Control Unit (ICU) comprising the digital electronics associated to the FEEU for the control laws of the servo-loops and the interfaces to the data bus of the satellite. The ICU includes also the power converters and the interfaces.

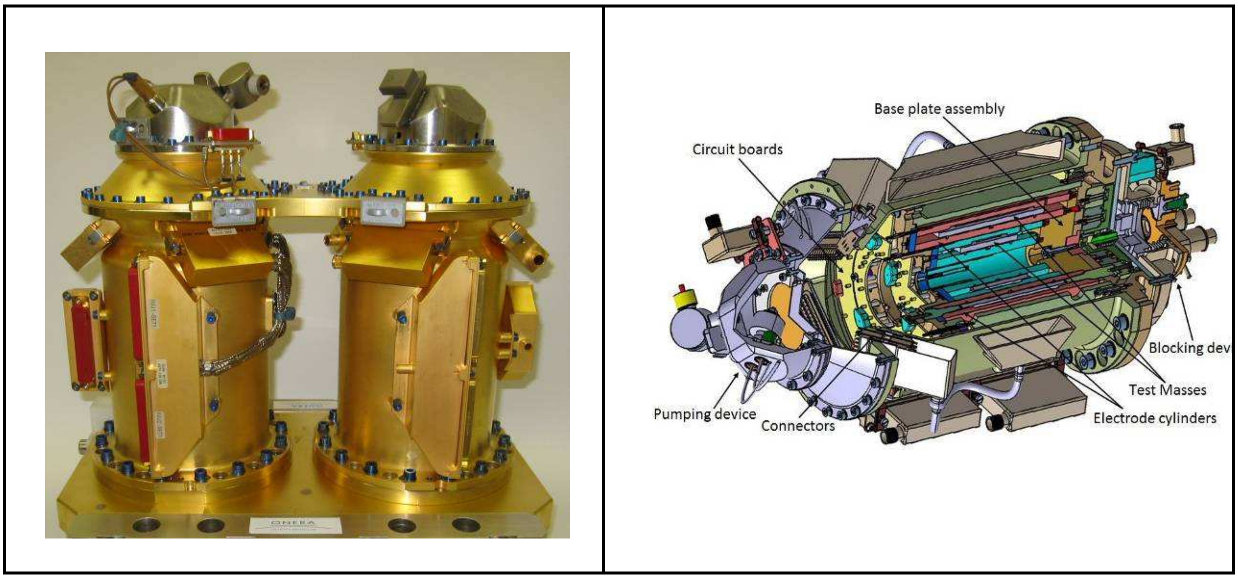

Figure 2. T-SAGE (Twin Space Accelerometer for Gravitation experiment) gold coated tight housings including two differential concentric inertial sensors (left); cutaway view of the concentric sensors with the two test masses -in violet- surrounded each by two silica electrode cylinders -in red- (right).

The sensors and their functional analogue electronics must be integrated inside the instrument highly stabilised thermal case. The electronics unit is less demanding and represents the only interface with the satellite buses (power, TM/TC).

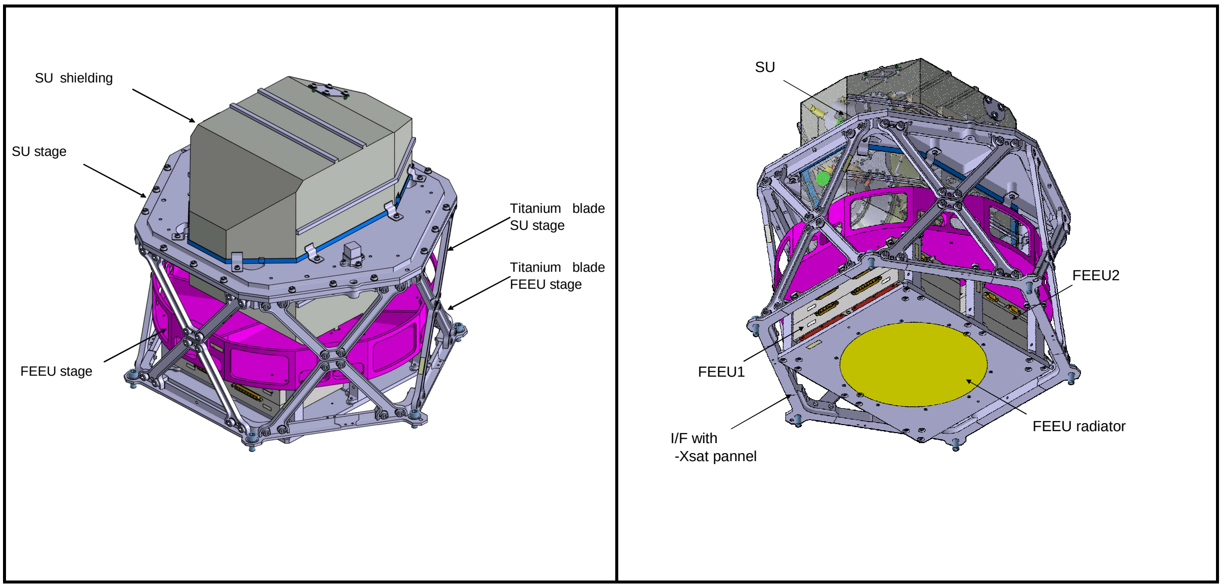

Figure 4: MICROSCOPE payload configuration with its magnetic shield (in grey, left figure); the two FEEUs are stacked and mounted on the bottom face of the payload case with the radiator on the external face; the SUs are very well insulated on the top.

Each inertial sensor includes one mass made of a selected material according to theoretical and practical criteria. The two masses of each differential accelerometer are monitored in order to have exactly the same orbit. The motion of each mass is finely measured by six capacitive position sensors with respect to the surrounding electrodes mounted on the very steady sensor structure. Each mass is then actively controlled by the electrostatic forces generated from the electronics servo loops.

The payload is composed of two differential accelerometers that can be separately switched ON/OFF.

Each of the four inertial sensors has three operating modes:

- Stand By Mode (SBy),
- Position Sensing Mode (PSM),
- Acceleration Sensing Mode (ASM), with two configurations Full Range (FR) or High Resolution (HR),

In the first mode (SBy), the sensor is powered but is not operating. No voltage is applied on the electrodes around the test mass but only on the test mass (Vp at DC and detection voltage Vd at 100kHz). No instrument science data are transmitted.

In the second mode (PSM), most of the sensor electronics is operating but the electrostatic loops (for the test mass levitation) are not closed; the position of the mass lying on stops is measured. All instrument data are transmitted.

In the last mode (ASM), the sensor is nominally operating and is delivering its data. Two configurations allow the modification of the instrument full range and the associated resolution by modifying Vp, Vd and the control laws (these changes can also be done in the previous mode).

Before the first in-orbit switch on (and so during the launch), the test-mass of each inertial sensor is clamped by the Test-Mass Blocking Mechanism. In this configuration, the sensors can sustain the launch accelerations and vibrations. The masses are released in orbit under telecommand.

2.4 Mission selection process

The MICROSCOPE project has been proposed by Pierre Touboul (ONERA) and Gilles Metris (OCA) in answer to the CNES call for proposals concerning scientific missions on small satellites, on July 1997.

The proposal was highly recommended by the Fundamental Physics Working Group (FPWG) of CNES. The Scientific Programme Committee of CNES (CPS, Comité des Programmes Scientifiques) then recommended to undertake a feasibility study on 13 October 1998 and confirmed the selection of the project on 9 December 1999.

On 12 January 2004, the Steering Committee of the phase A Review (Revue des Exigences Préliminaires, REP) recommended the start of the phase B.

On 24 June 2004, the CNES Board of Governors authorised the commitment of phases B/C/D/E.

Besides, the project was proposed for collaboration with ESA, by responding to the ESA flexible missions F2/F3 call for proposals in January 2000.

The involvement of ESA in the MICROSCOPE project was approved by the ESA Science Programme Committee on 11-12 October 2000 and the final ESA/CNES agreement was signed on 21 June 2001.

In this collaboration ESA was foreseen to provide the Field Emission Electric Propulsion (FEEP) proportional micro-thrusters.

In return, the project has been opened to European cooperation on the basis of the already defined technical and scientific specifications. A joint CNES/ESA announcement of opportunity for scientific contributions to the MICROSCOPE mission was released in January 2002.

A proposal from ZARM (Centre of Applied Space Technology and Microgravity, Bremen, Germany) was jointly selected. As a result, co-Is were selected : Hansjörg Dittus later joined by Claus Lammerzahl (see §2.5).

Two other proposals were submitted by M. Fehringer from ESA/ESTEC and by G. Balmino and R. Biancale from GRGS (Groupe de Recherche en Géodésie Spatiale, Toulouse, France).

The FEEP Extended Technology Experiment proposed by M. Ferhinger has been reconsidered in the framework of an eventual extended mission at the end of the nominal one.

Concerning the aeronomy proposal from G. Balmino and R. Biancale, no objection has been expressed by the scientific working groups (Earth Observation and Fundamental Physics) except for the additional requirement of an absolute positioning. It was not considered as a scientific priority by these groups and therefore it was not included in the nominal mission.

In February 2006, the preliminary design review of the satellite was performed followed by key points concerning the instrument, the mission performance and the satellite in January 2007.

The decision to enter the instrument in phase C/D was taken though difficulties with the satellite electrical propulsion system were faced. CNES, jointly with ESA, decided to study alternatives for the propulsion system and finally concluded to use the cold gas system such as in the Gaia ESA mission, instead of the ion propulsion system with FEEPs like in the Lisa Pathfinder ESA mission.

In 2010, the MICROSCOPE project was technically ready to be engaged in the implementation phase, after the additional study of the satellite definition needed by the new selection of the micropropulsion system provided by ESA (cold gas system).

The Design Review of the satellite was successfully held in April 2011 followed by a performance key point in November 2011 associated to a Delta System Design Review.

At that time, the satellite payload has been fixed, the satellite definition validated and the mission scenario frozen (see annex 1).

Since the decision of the Board of CNES made in 2004, major modifications concerning the space segment and the mission had occurred, mainly due to:

- Use of a European launcher,
- Addition of a desorbitation system (to avoid creating space debris)
- Change of the propulsion system and redefinition of the satellite,
- Delays on the payload and the satellite development,
- More careful consideration of the project risks.

The CNES Board validated this new configuration and approved the implementation phase on December the 8th , 2011, together with the corresponding cost increase.

The ESA Science Programme Committee approved its updated contribution on the cold gas micropropulsion system on June the 20th, 2012.

As for the situation in mid 2012, the payload is nearly at the end of its qualification and many flight model parts are already produced. The procurement of the satellite elements has started in CNES in January 2012.

2.5 Overall management and responsibilities

The MICROSCOPE project is developed in the frame of the CNES MYRIADE microsatellite series, in cooperation with ESA and DLR.

CNES is responsible for the overall management of the project that comprises both the ground segment and the development of the satellite.

The Principal Investigator (PI) is Pierre Touboul, Scientific Director of the Physics Branch in ONERA Palaiseau.

The co-PI is Gilles Metris, astronomer at the Observatoire de la Côte d'Azur OCA, in the Research Unit Geoazur in Sophia Antipolis.

Hansjörg Dittus, Member of the Executive Board, Space Research and Technology, DLR, is co-Investigator (co-I).

Claus Lämmerzahl, Director of the Center of Applied Space Technology and Microgravity ZARM located at the University of Bremen, is co-I.

The project is open to cooperation, including new co-Is. New co-Is will be selected by the SWG, on the basis of their answer to the international call for proposals that will be organised (see §4.2) .

ONERA is prime contractor for the payload and is responsible for the development of the ground segment of the Scientific Mission Centre (CMS).

ONERA and Observatoire de la Côte d'Azur (OCA) are responsible for the measurement process of the space experiment, for the mission data processing and analysis, for the data validation, archiving and distribution and for the mission scientific return.

ZARM, at the University of Bremen in Germany, contributes to the payload development and to its qualification by i) developing specific test equipments dedicated to perform the operation of the MICROSCOPE accelerometer in the ZARM free fall tower, ii) participating to the tests and their interpretation and iii) preparing the data processing.

The German metrology laboratory PTB collaborates to the project by providing the test-mass material (platinum and titanium, under DLR funding), the ultra-fine machining, the accurate characterization and the metrology of the test-masses.

ESA provides the Cold Gas micro thrusters and electronics, while CNES provides the pressure regulation system.

CNES is in charge of developing the satellite platform and of conducting the integration and the tests. It is also in charge of the Command Control Centre (CCC) in CNES Toulouse and of the Expert Centre for Drag free control (CECT, Centre d'Expertise de la Compensation de Trainée).

The CNES Project Manager takes upon the technical responsibility of the project. He is supported in his tasks by a project team composed of:

- the MICROSCOPE project team for system and satellite (CNES),
- the Cold Gas project team (ESA),
- the payload team (ONERA),
- the Science Mission Centre team (ONERA in cooperation with OCA).

The overall supervision of the MICROSCOPE mission is under the responsibility of the MICROSCOPE Steering Committee which is the highest level body.

The Steering Committee meets on a regular basis to monitor the advancement of the project and to solve any issues that may have emerged. In particular, it concerns:

- topics related to mission specifications and scientific objectives,
- compromises between the scientific mission and the operational requirements,

- agreements concerning developments achieved in the laboratories (payload and mission centre), including cooperative agreements,
- agreements between funding agencies,
- organisation, funding, schedule.

The Steering Committee is composed of representatives of the funding agencies, CNES, ESA, DLR, and heads of the scientific institutes ONERA, OCA, ZARM.

It is chaired by the CNES Programme director or its representative.

The PI is invited to attend the Steering Committee meetings.

Scientists from cooperating laboratories or institutes may also be invited by the chairperson.

The Project Manager and the PI regularly report to the Steering Committee on the technical and scientific status of the mission.

The CNES Fundamental Physics programme coordinator does the secretarial work for the Steering Committee.

3 MICROSCOPE measurement principles

The success of the MICROSCOPE experiment relies on:

- the definition, the production and the in orbit operation of the dedicated instrument for the comparison of the inertial accelerations of two masses,
- the definition, the production and the operation of the specific satellite which controls the instrument environment during the experiment in term of local gravity and kinetic acceleration field, thermal field, electromagnetic field,
- the definition and the operation of the experiment procedures, not only to perform the scientific sessions of the mission but also the in orbit calibration and performance assessment sessions.

It also relies on:

- the validation of the in orbit instrument environment,
- the validation of the in orbit instrument performance,
- the validation of the observed signals, amplitude, fluctuations, error budget and confidence level according to the experiment conditions,
- the interpretations of the observed signals with respect to the present physics and the new theories.

The confidence on the final results depends on the number of measurements assessed in different experimental conditions.

Measurement sessions are already planed with an inertial pointing of the satellite (inertial mode, with two fixed orientations) or with rotations of the satellite pointing (spin mode, at two different frequencies) to modulate the Earth gravity in the instrument frame.

The scientific signals provided by the instrument consist, for each of the four inertial sensors, in the measurements of the six accelerations (forces and torques) delivered by the electrostatic actuators to maintain motionless the test mass with respect to the inertial sensor frame.

In particular, the three linear accelerations correspond to the difference of the absolute test mass kinetic acceleration minus the applied gravity field. If the gravity field acts identically on the two test masses of the two inertial sensors, then the instrument can provide the measurement of a possible difference of cinematic acceleration which would be induced by a non-nullity of the Eötvös parameter, i.e. $\delta_{12} = 2\frac{\frac{m_{g1}}{m_{i1}} - \frac{m_{g2}}{m_{i2}}}{\frac{m_{g1}}{m_{i1}} + \frac{m_{g2}}{m_{i2}}} \approx \frac{m_{g1}}{m_{i1}} - \frac{m_{g2}}{m_{i2}}$, m_g and m_i being the gravitational mass and the inertial mass respectively, for mass 1 and mass 2.

These scientific outputs cannot be correctly interpreted without a fine knowledge of the satellite orbital and attitude motion. So the measurements have to be associated to the star-sensor outputs and to the housekeeping data of the drag-free and attitude control system as well as to the *a posteriori* orbit determination.

In addition, the fine behaviour of the instrument and its sensitivity to the on board environment have to be accurately surveyed. Thus, all on board data concerning the instrument operation conditions have to be thoroughly analysed, understood and interpreted.

So, the parameters driving the operation of the instrument and of the satellite sub-systems are either calibrated or carefully surveyed in the different conditions. The objective is to assess the levels of the disturbances and the sensitivity of the instrument to these possible error sources.

That is why the MICROSCOPE mission scenario (see annex 1) includes:

- The nominal commissioning phase of the satellite and of the payload,
- Preliminary tests of performance and sensitivity to the environment,
- EP test sessions in different conditions,
- Calibration sessions separating the EP test sessions.

During these sessions, the perturbations have to be maintained at a sufficient low level or to be evaluated and subtracted from the measurements. The satellite with its sub-systems, the instrument and the in-orbit operation are thus controlled in such a way to limit the disturbing terms:

- Thermal fluctuations,
- Magnetic environment,

- Attitude pointing,
- Attitude motion,
- Orbit fluctuations and drag-free control residue,
- Thermo-elastic behaviour of the satellite and self gravity,
- ...

The drag free subsystem not only controls the outputs of the instrument to a null acceleration by acting the thrusters of the propulsion system in order to apply forces and torques, but also contributes to recover the instrument driving parameters during the in-flight calibration:

- Linear sensitivity matrix,
- Quadratic sensitivity,
- Test-mass miss-centring,
- Accelerometer alignments.

Obviously, the accuracy of this very important satellite sub-system must be demonstrated during the scientific data processing of both the measurement sessions and the calibration sessions.

Then, the acceleration measurements have to be *a posteriori* corrected in the ground data processing with the results of the calibration process and with the other environment characterisation.

For example, the Earth's gravity gradient acceleration must be subtracted in the data thanks to the accurate knowledge of the orbit position leading to the fine computation of the Earth gravity field and to the calibration of the two test-mass off-centring.

4 MICROSCOPE scientific organisation during development

4.1 Preparing the performances of the mission: the Performance Working Group

During the MICROSCOPE payload development associated to the mission analysis, a dedicated Performance Working Group (PWG) has been organized under the responsibility of the PI and the Co-PI and chaired by the CNES MICROSCOPE performance coordinator. This group oversees and validates the expected performance of the defined mission and components.

The PWG is responsible for defining the performance requirements of the systems and their justification with respect to the science mission objectives, for sharing these requirements over the various system elements, and for drawing up a complete balance of the evaluated performances and updating it as the development of the system components proceeds. The PWG presently validates the expected performances of the mission through error budgets, accepted by the MICROSCOPE teams and the different review committees of the mission development.

The PWG is helped in its activities by the analyses and results from all contributors to the project.

The PWG meets every month and reports on the progress of the performance evaluation to the CNES Project Manager.

All current members of the Science Working Group (SWG: see § 5.5) can participate to the PWG. In fact, the activities of the SWG are presently carried out during the monthly meetings of the PWG. This has led to a better efficiency in the trade-off between the scientific interest and the engineering constraints of this space mission, and to better relationships between the different actors.

The PWG will pursue its activities up to the Flight Readiness Review (FRR). After the FRR, the PWG activities will be merged in the activities of the Science and Performances Group (SPG: see § 5.7) of the Scientific Mission Centre.

4.2 Preparing the scientific exploitation: MICROSCOPE colloquiums and calls

MICROSCOPE colloquiums will be organized on an annual basis to inform, promote and present the scientific developments of the MICROSCOPE mission.

The first MICROSCOPE colloquium has been held in ONERA Palaiseau on September the 19th, 2011. The objective of this Colloquium was to position the MICROSCOPE scientific return of the mission among the other present and envisaged accurate experiments in the fields of gravitation and meteorology, and in the context of the new extended theories of gravitation. It was also the opportunity for the scientific community to be informed of the status of the mission and to declare its interest.

The second MICROSCOPE Colloquium will be held on January 29-30, 2013.
The objectives are to present in details the mission, the instrumentation and the experiment and to describe the expected data as well as the organisation of the scientific mission centre. The scientific community will be invited to present their interest and their related know-how in the contribution to the data processing.

Before the third Colloquium in 2013/14, a call for ideas will be organised and sent to the scientific community in order to propose dedicated contributions. The resulting ideas will be presented and discussed during the Colloquium.

Before the fourth Colloquium in 2014/15, a call for proposals will be organised on the basis of the outcome of the 2013/14 Colloquium. The selected proposals will be presented and debated during the Colloquium. So, between Colloquium 3 and 4, the scientific community will have time to get organized and to coordinate the proposed projects efficiently.

Two other Colloquiums foreseen before the launch will be dedicated to the preparation of the data processing and expected results.

The two calls (for ideas and then for proposals) will be focused on the "scientific analysis of the MICROSCOPE data". They will be released under CNES and ESA responsibility.

The frame of these calls is extended to the theoretical interpretation of the results of the Equivalence Principle test. It will address French, European and international scientists. The Science Working Group (SWG, see § 4.5) will be deeply involved in the preparation of the calls and the evaluation of the scientific proposals.

5 MICROSCOPE scientific organisation during exploitation

N.B. This paragraph deals only with the scientific organisation. The project organisation during exploitation will be defined later.

5.1 Introduction

As previously mentioned, the test of the Equivalence Principle to the level of 10^{-15} requires a thorough and reliable validation of the measurements and of the overall performance of the experiment. The definition of the in orbit experimental procedures, of the satellite operations and of the instrument characteristics is now fixed. The reference mission scenario is also established to allow the realisation of the command and control centre and of the scientific mission centre.

The satellite will be operated by CNES during one year and a half, in relation with the CECT[1] satellite experts and the CMS[2] instrument experts and under the supervision of the CMS Science and Performance Group (SPG, see § 5.5, figure 1) which will be involved in the data processing and analysis.

Sessions of the scenario can be extended, replayed, postponed, modified or suppressed according to the already obtained results and when possible. Stringent rules must be respected before modification of the scenario but every week, the working scenario for the next month will be up-dated.

The operational procedures and the preliminary validation of the measurements will be made under the supervision of the Science Working Group (SWG, see § 5.4) in order to

[1] CECT : Centre d'Expertise de la Compensation de Trainée

[2] CMS : Centre de Mission Scientifique

progressively build up the data required to generate the final scientific products which will be used by the whole community.

The main logic of the scientific operations is the following:

- The result of the MICROSCOPE mission is based on experimental measurements which will need numerous and repetitive validation periods in different environmental conditions,
- The analysis of the measurements will require a complete understanding of the instrument operation, of the experimental procedures and of the operational conditions; in that way, subsystem data and instrument data will have to be considered in an integrated manner for the scientific interpretation,
- The reliability of the performances depends on the instrument characteristics as well as on the satellite and system and will have to be jointly approved by scientists and engineers,
- The experimental results will lead or not to a violation signal of the Equivalence Principle, measured with an accuracy finely characterized for each experimental conditions (10^{-15} and better is expected). These results will be discussed and approved by the Science Working Group; they can then give rise to various theoretical interpretations coming from different scientific communities.
- Phenomenological activities are needed to sustain the results with respect to various extended theories of gravitation and to envisage the perspectives of the MICROSCOPE experiment.

5.2 Scientific actors

The following persons and bodies are involved in the scientific part of the MICROSCOPE mission:

- the MICROSCOPE PI, co-PI and co-Is,
- the MICROSCOPE Science Working Group (SWG),
- the MICROSCOPE Performance Working Group (PWG) during development phase only.

5.3 The MICROSCOPE Principal Investigator, co Principal Investigator and co Investigators

The PI has the following responsibilities:

- He is responsible for the overall scientific performance of the MICROSCOPE mission,
- He gives the scientific constraints necessary to elaborate the mission scenario,
- He provides the inputs for the scientific programming of the MICROSCOPE mission to CNES,

- He exploits the scientific data of the mission together with the involved scientific groups,
- He checks and validates the quality of the scientific data products (N1 and N2, see section 7) before approval by the SWG for distribution to the science community,
- He co-chairs the SWG,
- He provides the necessary and pertinent information to support and stimulate the SWG activity,
- He reports to the scientific advisory bodies of CNES (Fundamental Physics Group, CERES, CPS) and of ESA (PSWG, SSAC),
- He reports to the Steering Committee,
- He supports CNES and ESA on public relations activities.

The co-PI assists the PI in all these activities.

The co-Is will bring their specific and pertinent expertise for the collaboration of their team to the MICROSCOPE data scientific exploitation.

The ZARM and DLR present co-Is are involved in the ground tests of the instrument and will contribute to the mission data analysis for the production of the N1 and N2 data in cooperation with the PI and Co-PI group.

New Co-Is will be selected by the SWG on the basis of their answer to the international call for proposals that will be organised.

Co-Is are responsible for their own funding which is guaranteed via their national funding agencies.

The MICROSCOPE Science Working Group

The SWG acts as a focus for the interest of the scientific community in order to maximize the scientific return. This structure promotes the debate between the scientists interested in the MICROSCOPE data analysis, allowing exchanges with the project team and discussion with other scientific users. It coordinates the different scientific contributions.

The Science Working Group (SWG) is responsible for:

- Supervising and approving the evaluation and the validation of the performance and of the calibration analysis of the instrument both on ground and in orbit,
- Selecting the proposals for the data processing in response to the calls,
- Selecting new Co-Is,
- Reviewing the scientific goals of the mission at regular intervals in the light of the results,
- Approving the final scientific data products to be distributed to the community (see §8 data policy),
- Reviewing the organisation of the data archive,
- Promoting diffusion of the information (colloquia…).

The members of the SWG are:

- The PI (ONERA) who is the Chairperson,
- The co-PI (OCA),
- The ZARM co-I ,
- The DLR co-I,
- Five scientific representatives of the already envisaged scientific themes, i.e. General Relativity and Gravitation, Fundamental Interactions, Interdisciplinary Physics, Earth gravity field, Aeronomy, one of them being proposed as co-Chairperson by CNES,
- One European scientist representative of similar space missions.

Permanent guests of the SWG are:

- The CNES Fundamental Physics coordinator,
- The CMS manager,
- The CNES project manager (CNES/DCT).

The ONERA payload manager and the GEX (Group of Experts, see paragraph 5.4) chairman, are invited to the SWG meetings when needed.

The list of the SWG members will be proposed by CNES to the Steering Committee.
The SWG remains in place until the final scientific products are delivered to the community.

5.4 The MICROSCOPE major operational groups

To ensure the operations of the MICROSCOPE mission, several groups are constituted. The organisation is represented in Figure 1.

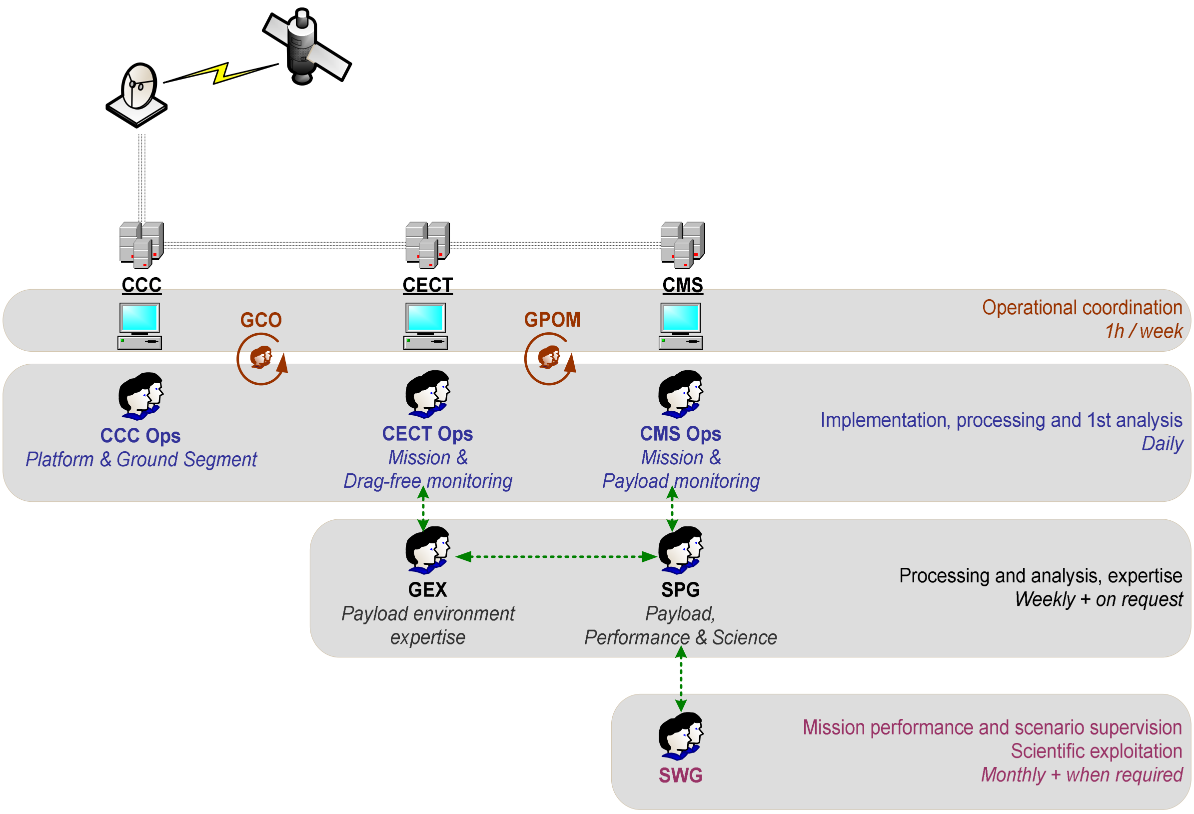

Figure 1 : The Science Working Group (SWG), the Science and Performance Group (SPG) and the operational organization

Some groups are usual, like the Command Control Centre (CCC) of the MYRIADE CNES missions.

Other groups are specific to the MICROSCOPE mission:

- The Group for Coordination of the Operations (GCO),
- The Group for Preparation of the Operations of the Mission (GPOM),
- The Group of Experts (GEX),
- The Science and Performance Group (SPG).

The ***Group for Coordination of the Operations (GCO)*** is set in place at CNES level to coordinate all the operational activities on the MICROSCOPE system. It does not interact with the SWG, but may occasionally require the participation of a CMS expert.

The role of the ***Group for Preparation of the Operations of the Mission (GPOM)*** is to define the programming task (working scenario) from the needs expressed by the SWG and the CMS. It validates and monitors the working scenario. It validates the updated flight software payload capacity and the operational procedures to be implemented. It validates the updated operational processing software of the CMS and its procedures. It insures the survey of in flight operation of the payload.

The GPOM is chaired by the head of the CECT in operation.

The GPOM participants are the manager for the MICROSCOPE operations, the head of the CECT, the head of the CMS, the CNES performance coordinator and the experts associated with the CECT if required (including AOCS), the representative of the SWG (the PI or his delegate).

The ***Group of Experts (GEX)*** is in charge of proposing and conducting all the actions to guarantee and improve the quality of the payload environment, in association with the ***Centre of Expertise for Compensation of Drag (CECT).*** The GEX, chaired by the CNES performance coordinator, is composed of CNES experts (SCAA, thermal…). The GEX benefits from the support of CNES operators for the routine tasks within the CECT such as data handling, regular processing for attitude and orbit restitution, drag-free monitoring. Payload expert from ONERA is invited to GEX when needed. Both GEX and CECT are specific to the MICROSCOPE mission because of the very strong links between the scientific instrument and the satellite operation performance. In particular, the drag compensation and the attitude control of the satellite require to be deeply surveyed during the mission as well as the recovery of the orbit position. Both are controlled in orbit through the data provided by the instrument itself.

CECT will be responsible for interfacing between the CCC and the CMS for the data exchanges, the management and the monitoring of the SCAA, and the performance monitoring of the system.

The role of the Science and Performance Group (SPG) is detailed in paragraph 5.5, as the SPG is closely related to the CMS (Centre de Mission Scientifique). The SPG benefits from the support of ONERA CMS operators and from CNES operational groups in charge of routine tasks within the CECT such as data handling, payload monitoring.

5.5 The MICROSCOPE Scientific Mission Centre (CMS)

The Scientific Mission Centre is operating under the supervision of the PI and the Co-PI.

It insures two functions: the payload operational functions during the mission on the one hand, the scientific data management, processing and archiving during and after the mission on the other hand.

The ***Scientific Mission Centre (CMS)*** is responsible for:

- Ensuring all the operational functions (exchanges of data, meetings, reporting…) in relation with the CECT to maximise the in flight operation of the MICROSCOPE instruments;
- Managing and monitoring the T-SAGE instrument during the mission;
- Proposing the actual mission scenario with respect to the reference scenario: the CMS proposes, under the supervision of the SWG, the optimized working scenario to achieve the best scientific objectives taking into account the operational constraints and the limited lifetime of the satellite;
- Defining the scientific data outputs and the associated processing for survey, automatic calibration and automatic analysis;
- Assessing the instrument operation, sensitivity to the environment and performances;
- Archiving and disseminating the different data to the scientific community through the process agreed on by all parties.

The scientific and technical team who is in charge of the CMS has the expertise of the instrument and develops, in collaboration with the OCA team, dedicated scientific tools for the data processing. For the operational aspects, the team relies also on the ONERA internal expertise in software engineering and control systems.

During the mission and before the release of the data to the community, ***the Science and Performance Group (SPG)*** will carry out the following activities for the CMS with the help of the GEX:

- The supervision and the optimization of the mission operation programme, both during the calibration sessions and the science measurement sessions; the SPG informs and exchanges with the SWG,
- The scientific analysis of the data and the preparation for the processing,
- The scientific expertise of the experiment, of the instrument, of its environment and its sensitivity,
- The processing of the data from level 0 to 1, and level 1 to 2, leading to the EP test results,
- The validation (in regard to the claimed accuracy) of the exploited data, of the experiment environment, of the operation of all the involved systems and of the needed assumptions and the methods used in the processing.

The SPG interacts with the SWG to stimulate the exploitation of the data. On request of the SWG, the SPG may complete the delivered data of the instruments to fit with dedicated scientific objectives.

The SPG is co-chaired by the PI and the Co-PI, and coordinated by the CMS manager. It includes experts from ONERA, OCA and ZARM as well as the CNES GEX chairman; scientific members working continuously in the data processing, from the PWG or other teams, can be added to the SPG.

6 Data products

Various types of data products will be generated by the project:

- Technical and scientific data products: these are the deliverables resulting from the mission which will be made available to the community at large and which will form the basis for scientific research and publications. Their nature and delivery schedule are described in more detail in section 7,
- Scientific publications which are intended to appear in the scientific literature, having undergone scientific validation and peer review,
- Public relation materials whose purpose is to maintain the public at large informed of the progress and scientific results of the mission, and which are normally distributed through the written and visual media (e.g. newspaper, magazines, TV..).

7 MICROSCOPE technical and scientific data

All along the orbit, each of the four inertial sensors will provide six scientific measurements corresponding to the electrostatic forces and torques applied to each test mass. In addition, many other data will provide information on the environment of the masses, on the instrument operation and on the satellite behaviour.

All these data will be processed to different levels: raw data, level 0, level 1 and level 2 data. They are defined on the following way:

Raw data are TM data coming from the satellite to the ground segment without any processing.

Level 0 data (N0) are obtained though re-formatting of the raw data; they are presented in documented files, where each provided parameter is expressed in physical unit and is dated. Complementary information coming from other elements of the system is delivered.

This will in particular include:

- The electrostatic forces and torques applied on each mass,
- The driving parameters of the instrument (electronics configuration, geometrical configuration…),
- The thermal environment,
- The instrument position along the orbit and its attitude,

- The AOCS data from the attitude sensors and actuators, in particular from the cold gas thrusters and the magneto-torquers,

All data will be properly dated.

The data will be differently organised according to N0a, N0b or N0c:

- The N0a data contain the entire formatted TM. They are obtained about two hours after each pass over an operating ground station: there are no additional data packets to TM. The N0a are not nominally transferred to the CMS, but may exceptionally be required in case of urgency;
- The N0b data contain the formatted N0 data, organized and delivered to the CMS for a period of 24H. Complementary data are also provided to further help the mission analysis (orbit restitution, orbit event file, list of measuring lack). The N0b are delivered every day;
- The N0c data contain the formatted N0 data, organized and delivered by session with data to further help the mission analysis (fine orbit restitution, fine attitude restitution, list of measuring lack). The N0c are delivered weekly.

Level 1 data (N1) are derived from level 0 data after pre-processing with *a priori* known characteristics of the space experiment and with the needed instrumental parameters. They are either instrumental data (when they are derived from level 0 data coming from the payload) or technological data when they are derived from data coming from other elements of the satellite or of the system. They are both produced during the calibration periods and the EP measurements periods.

N1 data are obtained from CMS software to generate data that could take into account inputs from multiple sessions (N0c) and from matrices of sensitivities and orientations corresponding to each inertial sensor. N1 data include calibration parameters, acceleration and sensitivity matrices used to produce these accelerations.

N1a data are obtained from N0c with the matrices of sensitivities and orientations of each inertial sensor which are established just after the commissioning phase.

These matrices are kept fixed throughout the mission: each matrix is defined on the ground before the launch, and they can be updated after the in-orbit commissioning and, possibly, after the pre-testing phase if necessary. They are not intended to be changed according to the different phases of calibration or of the EP measurements.

N1a data cover all the sessions for which the acceleration measurements are validated; they are defined in order to be delivered to the scientific community as initial data which have not undergone specific corrections that may give rise to discussion.

They are intended to be used for independent analysis or for processing that would be biased by the data processing made later in N1b or N1c.

The distances between the masses are also provided; they are deduced from measurements made during the integration before launch.

The N1b data are similar to the N1a data but include matrices of sensitivities and orientations corresponding to the latest validated calibration session that has been performed before the considered session. These data are therefore dependent on the quality and confidence attached to the conducted calibration sessions.

N1c data are obtained from N1a data corrected with matrices of sensitivities and orientations of each inertial sensor, which is determined from the results obtained during all the calibration sessions, from the estimated environmental variations and from the understanding of the evolution of each inertial sensor parameters.

N1b and N1c are used for the production of N2 data.

When validated, N1a, N1b and N1c data will also be available to the scientific community.

Level 2 data (N2) are derived from level 1 data by applying scientific algorithms taking into account the fine analysis of the instrument operation and environment. They can be used for publications in scientific newspapers.

To reach the level 2, the first step will be to analyse the six accelerations of each inertial sensor around the specific frequency Fep of the EP test, corresponding to the modulation frequency of the Earth's gravity fields along the sensitive axes of the instrument and to characterise the noises and corrections to be made.

The perturbing accelerations will be correlated to various environmental conditions (thermal, drag-free, magnetic..).

In fact, since the expected signals will be at well known frequencies and phases, long periods (days or weeks) of measurements will enable the rejection of most of the stochastic noises.

By selecting inertial mode or rotating mode of the satellite about the normal to the orbital plane, the frequency and phase of the signal can be changed.

N2 data include measurements known as "differential" corresponding to differences in acceleration fields seen at the two considered test masses. These data require the estimate of the distance between the two masses and the correction of the effect of the Earth's gravity gradient tensor. They may also require other corrections depending on the data level.

N2a data are obtained with the CMS software from N1a data for each session and from the estimated pre-flight distances between the masses.

N2b data are derived from N1b data and from the estimated distances between the test masses: these estimations come either from specific calibration sessions or from the analyse of gravity gradient signal during the considered EP session. The differential measurements corrected from the gravity gradients are provided for each of the two accelerometers.

N2c data are derived from N1c data, from the estimation of the distances between the test masses considered as optimal, from the models of gravity gradient signals and from the understanding of the behaviour of the instrument with respect to the changes in its environment.

The results of the commissioning sessions and of the performance sessions of the instrument are both exploited.

Assessments of all interfering signals considered in the measurement equation are given with their uncertainties.

The residual signal corresponding to a possible violation of the Equivalence Principle is provided for each session with its statistic characteristics, taking into account comparisons between the two accelerometers.

When validated, N2a, N2b and N2c data will also be available to the scientific community.

In summary, all validated data N1 and N2 will be provided to the scientific community with the tools and auxiliary data to transform the N1a data to the different levels of data.

8 The MICROSCOPE data policy

The MICROSCOPE data policy that is defined in the present paragraph applies to:

- The PI,
- The co-PI,
- The Co-Is,
- all the MICROSCOPE Science and Performance Group (SPG) members
- all the MICROSCOPE Science Working Group (SWG) members

unless specified otherwise by a MICROSCOPE Steering Committee decision.

The representatives of the cooperating groups, members of the SWG, will be responsible for applying the same rules to the members of their group.

The rules will then be followed by all scientists having access to the MICROSCOPE data.

The MICROSCOPE data policy concerning access, use and dissemination of the data shall reflect the wish:

- To deliver to the scientific community scientific results of the highest quality within the shortest possible delay,
- To encourage the exploitation of the data by the scientific community at large and the publication of results as early as possible, in peer review publications.

The SWG ensures that all calibrated science data and appropriate housekeeping data will be distributed to the public after completion of the instrument calibration and validation of the measured accelerations under different flight conditions, no later than one year after the availability of the N2c calibrated science data.

The SPG is in charge of producing the data files, to be archived and distributed by the CMS.

The terms of reference of SPG and SWG (including confidentiality of the data and restrictions on publications during the validation phase) will be given in a Letter of Agreement to be agreed by the members of the groups.

8.1 Validation period

The validation period starts with the reception on Earth of the first MICROSCOPE data and ends when the first coherent set of data usable to perform scientific analysis has been properly calibrated and its meaning has been confirmed.

The validation of the data is pronounced by the SWG and the PI after reporting by the SPG.

During the validation period the data are not released outside the SPG and the SWG.

During the validation period, publications are possible under approval by the PI and in compliance with the data rights described in the Letter of Agreement.

8.2 Diffusion period

The diffusion period starts once the validation of the MICROSCOPE data has been pronounced.

The MICROSCOPE scientific data are made available to the science community at large within a reasonable delay, less than one year.

The Scientific Mission Centre will archive and distribute all the data and processing algorithms at least during five years after the end of the mission.

8.3 Data rights and publication policy

The liable data are those defined in paragraph 7.

CNES, as the satellite provider, and ONERA, as the payload provider, have rights to use and distribute data from the MICROSCOPE mission.

The data distribution is made in agreement with the ESA/CNES document concerning participation of ESA in the MICROSCOPE mission and with the rules previously expressed in this document.

Scientific results obtained with MICROSCOPE data are made available to the scientific community in general through publication in appropriate refereed journals or other established channels of communication.

Any publication and reports using MICROSCOPE data shall include a suitable acknowledgement of the services afforded by the MICROSCOPE partners.

The general policy for publication is the following:

- The PI shall publish within the shortest possible delay the mission results concerning the main mission objective, the EP test,
- During the validation period, preliminary results can be published by the PI or the SWG members after formal approval by the PI,
- Any report or publication of results obtained from the use of MICROSCOPE data, or any other information from the MICROSCOPE mission shall indicate that the results were obtained from the CNES-ESA-ONERA-CNRS/OCA MICROSCOPE mission. In particular, any scientific publication must at least mention in the acknowledgements «This work was supported by the Centre National d'Etudes Spatiales (CNES). It is based on observations made with T-SAGE instrument embarked on MICROSCOPE satellite». In the abstract, the words MICROSCOPE and T-SAGE must be used.

9 Public and Educational Outreach Policy

The use of the MICROSCOPE data for Public and Educational Outreach purposes is strongly encouraged.

CNES has the overall responsibility for planning and carrying out outreach and public relations activities related to the MICROSCOPE mission.

The MICROSCOPE Steering Committee members coordinate among themselves in advance concerning public information activities related to their responsibilities.

The MICROSCOPE Steering Committee members retain the right to release public information on the portion of the activities they entirely fund and manage.

The MICROSCOPE PI and SWG members shall actively contribute to outreach and public relations activities. Material suitable for release to the public or participation in media events shall also be made available upon CNES or ONERA request and shall be at the disposal of the MICROSCOPE Steering Committee members in order to support their respective communication plan.

In addition, the PI and the SWG members shall provide the MICROSCOPE Steering Committee members with a copy of all their Public Outreach product.

10 Applicable Documents

DA1 Mission Specification MIC-SP-S-7-5005-ONE issue 4 revision 3 of June 10th 2004

DR1 Convention CNES-ONERA 03/1332/00 du 6 septembre 2004

DR2 Agreement between CNES and ESA concerning the ESA participation to the MICROSCOPE mission signed on 21st ,June, 2011 and following SPC revision (ESA/SPC(2012)22).

Annex 1

Objective reference mission scenario
(September 2012, may be updated)

sessions	orbits	days	orbits propu ON
Satellite commissionning & verif.	51	3	0
TSAGE commissionning & verif.	87	6	0
Propulsion commissioning & verif.	73	5	20
Drag-free SCAO verification	667	46	522
Preliminary Test EPI SUEP & SUREF	250	17	250
Preliminary Test EPR SUEP & SUREF	110	8	110
Performance Test	436	30	436
Calibration SUEP	138	9	138
Calibration SUREF	138	9	138
Test EPI-SUEP	250	17	250
Test EPI-SUREF	250	17	250
Test EPR-SUREF	284	20	284
Test EPR-SUREF	284	20	284
Calibration SUEP	138	9	138
Calibration SUREF	138	9	138
Test EPI-SUEP TM centered	125	9	125
Test EPI-SUREF TM centered	125	9	125
Test EPR-SUREF TM centered	142	10	142
Test EPR-SUEP TM centered	142	10	142
Test EPR-EP consolidation	284	20	284
Test EPR-SUREF consolidation	284	20	284
Calibration SUEP	138	9	138
Calibration SUREF	138	9	138
Test EPI SUEP consolidation	125	9	125
Test EPI SUREF consolidation phase 90	125	9	125
Total (only full operation sessions)	**4921**	**339**	**4586**

This scenario is considered by the operational ground segment for the implementation of the needed tools and procedures. It will be implemented in the CNES Control Centre and revised during the mission when needed and according to the request of the Scientific Mission Centre.

Annex 2: Acronyms

AOCS: Attitude and Orbit Control System
CCC: Command Control Centre
CECT: Centre of Expertise for drag compensation system (Centre d'Expertise pour la Compensation de Trainée);
CNES: Centre National d'Etudes Spatiales
CERES: CNES Committee for Universe Science Program
CMS: Scientific Mission Centre (Centre de Mission Scientifique)
CPS: CNES Committee for Scientific Program
ESA: European Space Agency
FEEU: Front End Electronics Unit (element of T-SAGE)
FEEP : Field Electric Emission Propulsion
GCO: Group for Coordination of the Operations
GEX: Group of Experts related to the CECT
GPOM: Group for Preparation of the Operations of the Mission
ICU: Interface Control Unit (element of T-SAGE)
MICROSCOPE : MICRO Satellite à Compensation de traînée pour l'Observation du Principe d'Equivalence
OCA: Observatoire de la Côte d'Azur
ONERA: The French Aerospace Lab
PI: Principal Investigator
PWG: Performance Working Group
SPG: Science and Performance Group
SSAC: ESA Space Science Advisory Committee
SU: Sensor Unit
SU EP: Sensor Unit for the Equivalence Principle
SU REF: Sensor Unit for Reference
SWG: Science Working Group
TM/TC: Telemeasure/Telecommand
T-SAGE: Twin Space Accelerometer for Gravitation experiment