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DOCUMENT

EJSM/Laplace Cosmic Vision 2015/25 L-Mission Review Board Report - Part A

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1 INTRODUCTION

ESA's contribution to EJSM (Europa-Jupiter System Mission)/Laplace is the Jupiter Ganymede Orbiter (JGO), which is a proposed candidate mission for the first L-Class launch slot of the *Cosmic Vision 2015-2025* programme with a baseline launch date foreseen in 2020. At the time of this review the mission has completed a Phase 0/A industrial study with three Contractor teams.

The EJSM/Laplace mission consists of two spacecraft, the ESA-led Jupiter-Ganymede Orbiter (JGO) and the NASA-led Jupiter-Europa Orbiter (JEO).

This Review is intended to assist in the down-selection of two of the three candidate missions to be carried forward into the next study phase, which would be a Definition Study, aiming for completion of Phase B1. The Review focused on the technical issues of the mission, and an evaluation of the science return was excluded from the scope. The Review was conducted in accordance with the applicable Procedure (SRE-PA/2010/056 Issue 1 Rev. 1 dated 15 June 2010).

The major findings of the Review Board are summarized in this report.

2 MAJOR FINDINGS – TECHNICAL SYSTEM

2.1 Design & Definition

The collection of mission requirements that drive the mission design was found complete.

The following design drivers were identified and need to be revisited for the Definition Phase:

- The overall mission design and mission analysis with a focus on system mass.
- The required data volume to be returned by the mission, including the baseline architecture for providing radio-science and satellite-to-satellite link functionality.
- Various autonomy & operations issues related to operability and access to spacecraft.

The complete technical background available from the envelope of the industrial studies provides a good level of detail for an Assessment Study, including critical analysis (e.g. radiation analysis).

2.2 Resources: Mass and Power

The Industrial Studies declared an available System Margin in the order of 20%. However, the Board has identified a number of underestimated subsystem masses, specifically:

- The structural dry mass index presented is at about 17 – 20%. However, the JGO structural mass index is heavily influenced by the peculiar spacecraft configuration (very large propellant tanks). Hence a dry mass index of about 22 – 23% is considered more appropriate at this stage.
- The mass of various equipment items was underestimated, and/or discrepancies appear between assumptions in the different Industrial Studies (e.g. propellant tanks, magnetometer boom, PCDU, avionics, harness), resulting in an uncertainty on system margin.
- The power required by the platform varies by 15% between the Contractors, which also translates into an uncertainty on power subsystem mass.

A further impact on the system mass could result from the payload, which, once selected, could require increased resources (e.g. volume) than currently estimated.

The mass required for radiation shielding is also an area of uncertainty (see section 2.6), however it is estimated that with a proper design approach it can be maintained at the optimised level of 90 kg indicated by industry.

Concerning power aspects:

- The solar array mass efficiency (in terms of W/kg) assumed by the studies is deemed credible.
- The estimated power demand includes a 20% margin, which is deemed sufficient at this stage, also covering an ECSS-E-ST-20C requirement that a 5% margin be available on the supply side at FAR.
- However, consumers with large uncertainties on power demand were identified, including the communications system (in need of more detailed design, see specific discussion in section 2.4), the heaters (based on preliminary thermal design), and the payload. The power required by the platform must therefore be consolidated through a better definition of system modes.

With respect to the estimated propellant mass, it was found that the manoeuvre efficiency has not been fully analyzed yet. However, the Board expects that further detailed design and analysis will confirm the capability of performing navigation thrusts in any direction during most of the mission, as well as a force-free RCS layout as required for safe flyby manoeuvres, with small impact on propellant mass. At this point in time the estimated propellant was considered consistent and adequate for the specified mission profile.

The above findings led the Board to re-calculate a dry mass budget using other missions (BepiColombo, LISA Path Finder) as proxies, resulting in a reduced available System Margin of the order of 12%, based on the currently assumed Ariane 5 launcher capability. In addition, it is noticed that the launch mass is affected by a high wet-to-dry mass amplification factor, due to the large Δv. Therefore at the current mission definition level the system mass is regarded as **medium/high risk**.

It is therefore recommended to adopt the following three measures:

- Investigation of options for reduction of dry mass. The review of the system dry mass shall include all subsystems, with emphasis on the communications and thermal subsystems. For this purpose, it is recommended to consider a dry mass performance incentive scheme with industry.
- Reassessment and further optimization of the required Δv with a view of possible reductions. Considering only the Δv, adequate system margin could be restored by a reduction of the required Δv by about 10% (equivalent of 270 m/s). The Science Team shall be closely integrated in such a process, in order to properly evaluate any consequences on scientific return.
- Improving the accuracy of the estimated launcher capability. Expected realistic increases of maximum available launch mass shall be investigated. It is also recommended oversizing the propellant tanks by 10%, in order to allow for exploitation of any future launcher performance increases.

2.3 Solar Arrays

The technology of the solar cells optimized for Low-Intensity-Low-Temperature (LILT) is regarded as **medium risk**. In case of an unsuccessful screening test, resulting in the inclusion of an estimated 25 – 30% of underperforming standard cells, the loss in power (due to the “flat spot” degradation phenomenon) would be about 6%. Therefore a development programme is being executed with the goal of improving the reliability of cells under LILT conditions, and specifically of the screening test at solar cell level. The successful conclusion of this development would allow downgrading the risk to low. The Board notices that the progress in solar cell development is expected to provide flight-qualified cells (3G32/33) with improved performance of about 14% by 2012, which would mitigate losses due to the “flat spot” phenomenon. The results of the design modifications for LILT conditions need to be confirmed for the new cell types.

Qualification of the solar array assembly for the Laplace extreme thermal environment (see section 2.7: low temperatures in the order of –230°C) shall be performed as part of the Implementation Phase, to verify that the composite materials withstand such low temperatures, and that the assembly remains intact after thermal cycling to such extreme conditions. No concerns were raised about the availability of suitable materials withstanding such conditions.

No specific concern was raised on the solar generator with respect to the radiation environment. The exposure to displacement damage is similar to GEO conditions, and solar protons are mainly encountered during the cruise phase only (not a Jupiter-specific issue).

2.4 Communications

The proposed layout of the communications subsystem appears overly complex, and heavily relies on BepiColombo heritage, lacking specific optimization. In fact, the use of two different frequency bands (X and Ka) for data downlink, and the close integration of the radio-science and the satellite-to-satellite link into the same Radio-Frequency Distribution Network (RFDN), are driving cost and complexity, and may limit telemetry data rates. Based on the established daily data downlink volume requirement of at least 1 Gb of science data, the Board finds that the use of X-band alone would be sufficient. This would allow for a segregation of the payload-related functions from the platform communication functional requirements, and avoid losses due to integration of other components in the essential telemetry RFDN. Some complexity would be shifted to the payload side.

The industrial studies assume that Radioscience could be carried out in parallel to telecommunications, however it is noted that this is not currently possible using ESA ground stations.

While the overall risk in this area is considered **low;** it is recommended to consolidate the data return requirements, and then to revisit and optimize the communications subsystem design.

2.5 Autonomy and Operations

The operational complexity of the baseline mission is considered comparable to other ESA interplanetary missions, such as Rosetta and BepiColombo.

Access to the spacecraft needs to be guaranteed during all mission phases, but it is complicated by the large distances involved (up to 6.4 AU) and by the fact that the pointing of the High-Gain Antenna (HGA) is compromised during the Venus gravity assist (GA), as it is used as sunshield. The duration of the non-availability of the HGA for communications needs to be minimized. A detailed thermal analysis shall be carried out to establish the duration during which the HGA is needed as a sun-shield, and this duration shall be minimized. In addition, in order to facilitate more efficient recovery from Safe Mode, a higher-level Safe Mode shall be developed providing an autonomous stable pointing of the HGA to the Earth.

The main engine is proposed to be used for all major manoeuvres, being most efficient. However, the need for the autonomous on-board capability of continuing a burn in case of main engine failure is not fully assessed, in terms of probability of mission success. A switch-over from one main engine to a backup main engine has not been used on any ESA mission so far, and adds complexity and risk of mass increase, in case the main engines would need to be mounted with gimbals. Also the impact of a degraded mission using the RCS thrusters as backup has not yet been sufficiently analyzed.

The spacecraft needs to be capable of reliably performing time-critical manoeuvres. A more capable backup operating mode or a fast transition from a backup operating mode to an orbit control mode appears necessary. This has not been implemented on previous missions, but is not seen as a major new development.

The adoption of a redundant navigation camera specifically for the support of the earlier Jupiter moon flybys is recommended, in order to mitigate navigation errors due to the limited knowledge of the ephemerides of the moons. This results in a negligible mass increase and a very modest cost increase (no autonomous on-board navigation is required).

The risk entailed in the operations and autonomy aspects of the mission is regarded as **low**, although the complexity needs to be fully taken into account in the software development planning.

2.6 Radiation

The JGO radiation environment has similarities to the GEO environment (electron dominated), but is more severe (higher density and higher energies). The risk can be mitigated by careful application of shielding strategies similar to near-Earth missions (GEO/MEO). The industrial studies indicate that problems can be avoided with robust radiation hardness assurance and with component selection approaches. A layered defence with an optimised shielding approach is proposed, using:

- a thin "vault" (~1 mm Al shielding in addition to material of the structure) that enables a first reduction of the TID at the outside of the equipment to 50 krad.
- additional shielding of equipment housing (~2 mm Al) yields a typical exposure of 25 krad at component level
- spot-shielding with heavy materials (Pb/Ta/Cu) of critical parts or parts with lower tolerance.

Significant mass is allocated for shielding (in the order of 90 kg), and is assuming Al shielding. It is recognized that the shielding mass carries significant uncertainties due to early system design. The required accessibility to boxes inside a radiation protection vault, including access to harness and connectors may drive size & mass up. A mass reduction opportunity exists, however, by using higher Z materials for the shielding, allowing a reduction of the shielding thickness (25 – 30% more mass efficient).

The above optimised shielding approach is recommended, but it has to be underlined that it requires a critically early availability of detailed design models of spacecraft, platform equipment and instruments which are suitable for radiation shielding analysis.

As a practical measure, the radiation tolerance of components shall be 50 krad, i.e. double the expected TID to absorb uncertainties of the early modelling. No particular availability issue is expected for parts with TID tolerance ≥50 krad, however the majority of parts on GEO Comsats (80 – 90%) are US-sourced parts. This may raise a concern on procurement lead-time as ITAR clearance may be required.

In summary, the radiation risk is considered **medium**, requiring continued proper attention. Specifically, the Board recommends establishing tailored JGO Radiation Hardness Assurance requirements, and implementing iterative shielding analysis and shielding configuration control during the early design phases. The planned TDA's for characterization and screening of parts shall be pursued with high priority. Radiation characterizations shall also include effects on glasses, fibre optics and other optical and electro-optical components. A European radiation-tolerant Approved Parts and Materials List (APML) shall be established. The radiation shielding analysis shall be carried out with high priority in the Definition Phase.

The environment specification shall be updated with the results of the soon-to be finished TRP activity with the inclusion of the effect of the shielding by Ganymede. This additional reduction of radiation exposure has not yet been taken into account.

2.7 Materials

The spacecraft would be exposed to long eclipses during the Jupiter tour and the Callisto science phase, which could last as long as 7.5 hours. Consequently, surface materials and appendages will be exposed to extremely low temperatures, resulting in potential risk to structural integrity for solar arrays and antennae/masts, and require therefore qualification to the order of –230°C. In previous projects (e.g. XMM-Newton solar array) hardware was generally tested to –205°C only.

It is recommended to identify available LHe (20 – 40 K) facilities and to perform conclusive tests of representative samples at lowest temperatures before the Implementation Phase ITT. This needs to be added to the Technology Development Plan. It is not anticipated that full-scale Acceptance Tests at LHe temperature would be required for the PFM solar arrays, however a test and qualification approach shall be established for the whole mission.

The overall risk is regarded as **medium/low**.

2.8 Electrostatic Charging

The environment is similar to GEO/MEO. Special measures for avoiding electrostatic charging will have to be taken, including standard mitigations such as early attention to surface finishes, using ITO Kapton on MLI on the back of the solar array, and standard anti-reflective coating with MgF_2 on the solar cells. The material properties for the JGO environment shall be studied with respect to the charging and low temperature exposure (resistivity, SEE yields, cold conditions).

In particular the proposed material for the Sub-Surface Radar antenna structure (S glass/Kevlar composite) was flagged as being highly susceptible to surface and internal charging; less resistive options shall be investigated. The plasma environment specification (including secondary electrons from surfaces) needs to be provided.

The risk is regarded as **low** if the standard design measures, including those specified above, are systematically adhered to.

2.9 Magnetic Cleanliness

The magnetic cleanliness requirements (measurement background <0.2 nT) are regarded as ambitious and are similar to typical magnetosphere missions, and are two orders of magnitude more stringent than for BepiColombo, however only slightly lower than those achieved for Rosetta. The Board recommends applying best practices for reducing the spacecraft field and providing knowledge by measurement, to a similar level as was performed with Rosetta and LISA PF, avoiding the involvement of a specific magnetic measurement facility (with the associated planning and cost impact). The recommended best practices should include:

- Early detailed magnetic cleanliness analysis.
- Application of magnetic cleanliness guidelines for design and procurement minimising the use of magnetic materials.
- The magnetic moment of all units being characterised, and a magnetic budget being maintained at system level.
- Application of local compensation, where needed.
- spacecraft harness routing being laid out such that the magnetic field is minimized/reduced.
- A magnetic test being carried out at spacecraft level in a standard cleanroom, similar to what was performed for Rosetta.

Following these steps Rosetta achieved a DC magnetic field level of 43 nT at the tip of a 1.5 m boom. Based on a scaling of these results, it is expected that a resulting field of the order of 1 nT at the tip of a 5 m boom (current baseline length) could be achieved, or 0.2 nT , if the boom was extended to ~8.4 m (to be confirmed by further analysis).

If the above design measures are systematically taken, and if the performance similar to Rosetta and Lisa PF is deemed acceptable, the risk is regarded as **low**.

2.10 Planetary Protection

The JGO mission is classified as Category II plus additional requirements, which are at the level of analysis and documentation only, and include a bioburden assessment at launch. At this point in time, no impact on the spacecraft design and minimal contribution to the AIV schedule is expected, and this is therefore not considered a programmatic driver. Therefore the risk is estimated as **low**. Should, however, either the planetary protection classification of the JGO mission be changed (by COSPAR), or should the analysis not be confirmed achieving the required levels, then significant impacts on AIV, schedule, and cost are expected, which were not included in the baseline evaluated by the review.

3 MAJOR FINDINGS – TECHNICAL PAYLOAD

The review focused on the status of instruments, which were listed in the JGO model payload as per the Payload Definition Document (PDD). The preliminary instrument study reports that were made available (Declaration of Interest [DOI] reports) covered all instruments but one (radio-science experiment), with several model payload instruments being addressed by more than one study/team. No assessment of the science performance was carried out by the review.

3.1 Payload Resources and Redundancy

The content of the PDD, which was used as reference in the Industrial Studies, was frozen in February 2010 to ensure a consistent design of the spacecraft. In August 2010 the DOI reports of the instrument studies became available. The comparison between the two sets of documents indicates an increase in power and mass assumed for the individual instruments (the increased resources are taken into account in section 2.2 above); this trend needs to be monitored carefully.

Single-point failures (SPF's) were identified in a number of instrument designs, mostly related to mechanisms. In most cases only a small effort was made to study alternatives avoiding such SPF's or limiting their effect, e.g. through introduction of alternative solutions. It is recommended for the next phase to focus on these SPF's and to devise proper strategies minimising the impact of such failures.

Attention shall also be given to optimized instrument redundancy concepts (including optimization of redundancy, e.g. by sharing data processing, with a view at minimising the required resources).

3.2 Radiation and Plasma

The Jovian radiation environment is properly addressed by the DOI studies, although radiation shielding guidelines need to be established at system level (see section 2.6 above).

The integrated radiation analysis approach, suggested by the industrial studies for an optimized allocation of shielding mass, requires that a reasonably detailed level of instrument design becomes available at an early stage. It is therefore recommended that instrument development starts immediately after instrument selection.

A number of detector systems proposed by the DOI instrument studies are rather sensitive to relatively high-energetic electrons, which are present with high fluence in the Jovian radiation environment, and which can generate a large background signal. It is therefore recommended to carry out an analysis of the scientific performance of critical detector systems in the Jovian radiation environment as one of the highest priorities by the instrument teams. The consequences of the plasma environment on the electrostatic cleanliness requirements need to be addressed in more detail.

3.3 Yaw Steering

The spacecraft will continuously rotate around its yaw axis (nadir-direction) in the baseline operating mode during science measurements while in Ganymede orbit due to the need of having the solar panels continuously illuminated. This is referred to as *Yaw Steering* and has a direct impact on the instruments. Some of the instrument studies address the effects of yaw steering and discuss how to avoid loss of performance, , or how to benefit from it. In the DOI reports, however the discussions mostly remain at a high level and more detailed analysis is needed to evaluate the impact on the scientific performances.

3.4 Payload Development Status

Significant instrument heritage is available, albeit specific issues on performance and sensitivity need addressing, mainly due to the environment of the Laplace mission. For JGO, the overall risk was deemed **low** for instrument developments relying on proven technology, and **medium** for new developments. One instrument study appears to rely on a new sensor with low TRL and is therefore viewed as **high risk**, however an alternative instrument design has also been investigated and could be considered for the mission.

Several instrument teams envisage mechanisms, including a scanning platform, shutters and covers of optical systems, filter wheels, etc. The application of scanning mechanisms should be traded against optimized accommodations and/or additional sensor heads to ensure the required FOV.

It was noted that the selection of materials for lenses based on radiation hard glasses makes it more difficult to achieve achromatisation (cameras). Care must be taken with the assumed suppliers, as some radiation hard glasses are no longer in routine manufacture/stock.

3.5 JEO Instruments

European instruments contributed to JEO will be exposed to much higher radiation doses, which are more difficult to shield, and to more complex surface charging conditions. Provisions to JEO will have to comply with the NASA APML, with associated limited-detailed technical information available due to ITAR restrictions. A preliminary APML is available in restricted and unrestricted versions. Some European teams have gained relevant experience by providing instrumentation to the JUNO mission.

The JEO spacecraft is classified as planetary protection Category III, which is considered an additional cost driver also for instruments, having an impact on the design and choice of materials/processes available.

Pure European contributions to JEO are therefore regarded as **medium/high risk**.

4 MAJOR FINDINGS – PROGRAMMATIC ASPECTS

4.1 Overall Technology Assessment

No technology showstopper has been identified by the review. Overall, the mission does not appear particularly technology-intensive, and could be designed with current technologies, with the exception of the LILT solar cells (see discussion in section 2.3 above).

No specific development is required to enhance the radiation tolerance of parts and materials, but an early start of characterisation and screening is recommended, which realistically is expected to continue until 2013, and reserves for later testing shall be provided.

Characterisation and screening of materials for low temperatures shall be added to the Technology Plan.

Specific developments that need to be started include:

- Sub-Surface Radar antenna structure (MARSIS heritage is judged unsuitable for extremely low temperatures and high charging radiation environment).
- 100 W Ka-band TWTA (only if current downlink telemetry approach is confirmed).

Several instrument study reports (DOI reports) indicate on-going or planned developments. Their planning must however be tuned with the available schedule resources. It is noted that viable backup options essentially appear to exist for all instruments. No ESA-funded TDA's are planned for instruments, with the exception of radiation-related characterizations and two ASIC developments, all of which are of general application.

4.2 Schedule

The schedule provided by the Contractors appears optimistic, taking what is viewed as considerable risk already at this early stage. A more realistic schedule, including key Agency milestones, was established by the Board, based on the following assumptions:

- Assuming a downselection in June 2011, followed by a definition phase for 18 months.
- An instrument AO would also be issued shortly after the downselection, and is expected to be released in summer 2011.
- Assuming a mission adoption by the SPC in June 2013, and typical ITT process duration, the kick-off (KO) of Implementation Phase (B2/C/D) nominally takes place in June 2014.
- 12 months for the build-up of the industrial consortium (Subsystem- and Equipment-level Subcontractors), through lower-level ITT's and selections; this is judged slightly optimistic and incompressible.
- 24 months for the procurement of LLI's; while considered adequate in duration, an optimistic start date of the parts procurement with respect to the finalisation of the electronic units design was assumed.
- 24 months for qualification of LILT solar cells; no schedule risk needs be considered for this, as the solar array design would be frozen earlier, independently on the outcome of the development.
- A classical 3-model approach (STM/EM/PFM) is assumed, without relying on h/w links between models.
- 36 months are assumed from PDR to start of PFM spacecraft AIT; this is considered challenging for s/w development and validation, due to the complexity of spacecraft autonomy and operations, requiring early definition of s/w requirements baseline.
- Radiation shielding and magnetic cleanliness are not considered to be schedule drivers, assuming that the outlined approaches (c.f. sections 2.6 and 2.9) are implemented.
- 32 months are assumed for the total PFM campaign, which is deemed adequate. However, procurement of PFM structure, thermal control, propulsion, harness and other equipment is assumed to occur prior to System CDR, which is considered a risk, especially with regards to the procurement of PFM/FM electrical units.
- For the development of the instruments, a total duration of 4 and 5 years from start to PFM delivery is assumed, respectively, for instruments with significant heritage and for new developments.

Based on the above assumptions, it is noted that the schedule is driven by the industrial team build-up, the procurement of the LLI, the electrical systems, and the flight s/w development. The Implementation Phase, including 6 months contingency and a 4-month launch campaign, was found to last 6.2 years from KO to launch. No meaningful de-scoping options were identified that would allow significantly shortening the schedule.

The resulting earliest launch date (August 2020) is 5 months later than the available launch window (March 2020), or, conversely, the schedule contingency is effectively reduced to only 1 month. However, considering that JGO is a pure ESA spacecraft development, it is reasonable to envisage an adoption procedure similar to that achieved for the M1 & M2 missions. In such case, the mission selection could take place towards the end of the Definition Phase (February 2013) recovering the schedule margin to 5 – 6 months.

The instrument development times (4 or 5 years, see above) imply that the starting date of the instrument development must be soon after instrument selection, following the Announcement of Opportunity (AO) for JGO. Currently the AO is assumed to be released as soon as EJSM/Laplace is selected for Definition Phase, which would be in July 2011. This constrains the possibilities for instrument (pre-) development.

A tentative schedule of the main milestones would be:

	Industry	**Instrument Teams**	**SPC**
June 2011			Approval of draft SMP[1]
July 2011	ITT for Definition Phase	Instrumentation AO	
October 2011	KO of Definition Phase		
February 2013			Mission selection
April 2013	End of Definition Phase	MLA[2] signed	Mission adoption
May 2013	ITT for Implementation Phase		
Q1/2014	KO Implementation Phase		

Although this schedule is following in broad lines the approach for M1/M2 and is considered as feasible, it remains tight and as a consequence, the overall schedule for a 2020 launch is judged a **medium/high risk**. The review board stresses the need to approve a draft SMP in June 2011, such that the instrument AO can proceed. It is also noted that the currently assumed backup launch is only in May 2022, providing comfortable margins. Therefore the review board also recommends a revisit of the mission profile for identifying as possible options leading to a viable launch in 2021.

5 ACHIEVEMENT OF REVIEW OBJECTIVES

The major objectives of the review (stipulated in the Procedure) are briefly summarized in the following sections, together with a statement about the status of the mission.

5.1 Technical Feasibility of the EJSM/Laplace Mission

The proposed mission was evaluated as feasible, without major concerns on the required technology. A risk on mass increase was identified. This shall be urgently addressed by the Study Team.

5.2 Compatibility of Overall Development Risk with the Applicable Schedule

The schedule was re-worked by the Board, and a realistic duration established, resulting in marginal contingency with respect to the nominal 2020 launch window.

5.3 Compatibility of the Estimated ESA Cost at Completion with L-Class Mission Budget Allocation

This objective is addressed in Part B of this Board Report.

5.4 Completeness of the Proposed Technology Developments

The current technology development plan was found to be adequate. Two additional items were identified by the Board, and shall be added:

- Low temperature verification of materials to –230°C.
- An investigation on adequate materials for the Sub-Surface Radar antenna structure to withstand the combination of low temperatures and high charging radiation environment.

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[1] Science Management Plan

[2] Multi-Lateral Agreement

6 CONCLUSIONS AND RECOMMENDATIONS

The Board finds that the establishment of mission requirements for EJSM/Laplace is complete, that the level of system definition is adequate at this stage of the development, and that the design approach is sufficiently robust with regards to the main technical challenges posed by the mission (namely: power availability and radiation at Jupiter).

The following technical risk items were identified:
- **Medium/high risk**: overall mass, JEO Payload elements to be provided by European institutes.
- **Medium risk**: solar array, radiation tolerance, new developments for JGO payload instrumentation (specifically in the domain of sensors and optics).
- **Medium/low risk**: exposure of external appendices to extremely low temperatures, including payload mast/antennae.
- **Low risk**: the overall mission, as it could be implemented with a minimum of new technologies.

A realistic schedule, established by the Board including key Agency milestones, results in a **medium/high risk** of not meeting the nominal March 2020 launch opportunity.

In summary and based on the discussion above, the following recommendations are made:
1. An **increase of mass margin** adequate of this type of mission and this stage of the system definition shall be urgently implemented, before the Definition Phase. An incentive scheme with industry could help controlling the depletion of the mass margin for the Implementation Phase.
2. The **Technology Development Plan** focusing on **solar cells** and **radiation** is endorsed and shall be carried out timely, with two specific additions (extreme low temperature characterization of solar array composite and of materials for deployable antennae/mast structures).
3. Radiation **shielding analysis** shall be carried out as soon as possible and a major effort shall be spent on shielding simulations in order to reduce uncertainty of this contribution to the system mass.
4. Tailored **Radiation Hardness Assurance** requirements shall be compiled, and a radiation-tolerant Approved Parts and Materials List shall be established, specifically in support to payload instruments development.
5. **Instrument development** activities shall be started as soon as possible after selection by the AO, commensurate with the envisaged level of new developments, but specifically focusing on Jovian environmental issues at sensor and optics level.
6. **Data return** requirements, and interfaces to **radio-science** and **satellite-to-satellite link experiments**, shall be consolidated before the Definition Phase.
7. Best practice approach on **magnetic cleanliness** shall be implemented from an early stage.