A Potential Mission Concept for the M3 2022 Launch: Investigation of MagnetoPause Activity using Longitudinally-Aligned Satellites (IMPALAS).

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Executive Summary: The dayside magnetopause is the primary site of energy transfer from the solar wind into the magnetosphere, and activity on this boundary modulates much of the activity observed within the magnetosphere itself (including 'Space Weather'), and indeed that propagating down into the ionosphere. Some specific plasma physical processes are already known to operate on the magnetopause, such as the occurrence of magnetic reconnection, the generation of boundary waves, the propagation of pressure-pulse induced deformations of the boundary, the formation of boundary layers and the generation of Alfven waves and field-aligned current systems that connect the boundary to the inner magnetosphere and ionosphere. However, many of the details of these processes, how they operate on the magnetopause and how they evolve are not fully understood. For example, magnetic reconnection is known to occur sporadically to produce flux transfer events, but how and where these arise, and their importance to the global dynamics of the magnetospheric system is still unresolved.

Many of the phenomena described above involve propagation of waves and other structures across the magnetopause surface. In many cases (e.g. magnetic reconnection, boundary waves), they are strongly influenced by the northward pointing direction of the terrestrial magnetic field. Understanding of these phenomena would be enhanced by measurements made at widely-spaced ($\Delta \sim 5\ R_E$) intervals along the direction of dayside terrestrial field lines at the magnetopause. We propose a mission involving deployment of a current state-of-the-art fields and plasmas payload package on 3 identical spacecraft. IMPALA 1 would be in a circular equatorial orbit of radius ~10.48 R_E, which has a period of exactly 2 days. Moreover, this orbit radius is also very close to the average location of the dayside magnetopause, such that the spacecraft would be expected to 'skim' along (and thus sample) this boundary over many hours during its dayside passage. The orbit should also be phased such that when the spacecraft was at local midday, northern European ground-based facilities were also at, or very near, local midday. IMPALA 2 and IMPALA 3 would be placed in orbits of +30 degrees and -30 degrees inclination, with slight eccentricity to increase their apogee to ~11 R_E, the typical position of the noon magnetopause at these inclinations, while maintaining the 2 day period and phase with respect to IMPALA 1. These spacecraft would thus skim the magnetopause ~5 R_E above and below IMPALA1 while all 3 spacecraft maintain common longitude and thus sample along the same magnetic field line. The 2 inclined orbit spacecraft should also carry an auroral imaging system aimed at remote sensing the foot-points of the magnetic field lines mapping through the 3 spacecraft locations. Moreover, appropriate phasing of the orbits could ensure that European ground-based facilities would also sample near the foot of that field line when the spacecraft are in their prime science locations.

1. Introduction and Background

In late July 2010 the European Space Agency issued a call for proposals (http://sci.esa.int/2010_M_Call) from the broad scientific community for the competitive selection of mission concepts to be candidates for the implementation of one medium-size (M-class) mission for launch in 2022. The deadline for submission of proposals is 3 December 2010, with an earlier deadline for a mandatory Letter of Intent (LOI) on 15

September 2010. The ceiling to the cost to ESA for an M-class mission is 470 MEuro, although a mix of smaller missions approximately equivalent, in terms of overall financial envelope and profile, to one M-class mission could also result from the present Call.

The NASA/THEMIS mission shows that significant progress on some of the major unanswered questions in magnetospheric physics can be made by tailoring a multi-spacecraft mission to make measurements in specific locations in the magnetosphere, and that this progress will be augmented if ground-based capability can be included as an extra measurement point. Moreover, lessons from the recent Cross-Scale experience include, perhaps, the understanding that the ESA M-Class budget is sufficient for only 2 or 3 ESA-sponsored spacecraft capable of making science quality *in situ* fields and plasma measurements, although clearly this is a function of orbit, payload mass, etc.

A further lesson from the Cross-Scale experience is that attempting to address very broad science goals makes it difficult to avoid mission resource creep, and difficult to make the descopes necessary if the mission concept is likely to push resource envelopes. This suggests that a mission proposal with a set of tightly focussed science goals and an equivalently focussed payload may be a sound approach, providing a sufficient members of the community will support it. Providing options for augmentations to a baseline may be more palatable to the community and more convincing to the assessors than descopes later in the program?

Under this philosophy, we broadly describe here a mission aimed at the Investigation of MagnetoPause Activity using Longitudinally-Aligned Satellites (IMPALAS).

2. Science Rationale: Why target the dayside terrestrial magnetopause?

The magnetopause is the boundary between the solar and terrestrial plasma regimes. It is a critical interface in the field of solar-terrestrial relations, in that the coupling processes that ultimately control all magnetospheric dynamics occur there. These include some fundamental plasma processes, such as magnetic reconnection, particle acceleration and boundary wave generation. In the regions surrounding this interface other important processes, such as plasma turbulence and collisionless shocks can also be found. The magnetopause is also the key interface for defining the influence of 'space weather' on the Earth system, with the effects of, for example, Solar Particle Events (SPEs) and Coronal Mass Ejections (CMEs) mitigated by or transmitted through this boundary before they can effect near-Earth space. The magnetopause is also the most readily accessible analogue to other space and astrophysical plasma boundaries. There is considerable interest in the magnetopause, or the outer boundary of the sphere of influence, at the other planets. Generally speaking, telemetry constraints on missions to the other planets mean that this boundary

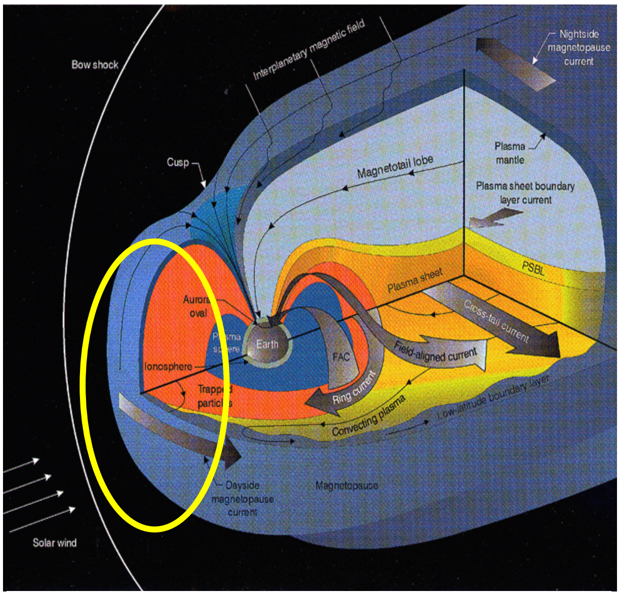

Figure 1. Schematic of the terrestrial magnetosphere, showing key regions. The dayside magnetopause, the prime target of the IMPALAS mission is highlighted towards the left of the figure.

is more poorly resolved and sampled than at the Earth, such that knowledge of the Earth system is crucial to put the more distant observations in context. Other plasma boundaries, for example the heliopause, which is the boundary between solar and interstellar plasma regimes, or those between other stellar and galactic spheres of influence, cannot be directly sampled. Thus understanding the interactions that occur at the terrestrial magnetopause can provide important ground truth for understanding these more remote interaction regions.

Over the last few decades we have assembled a fairly significant database of spacecraft encounters with the magnetopause. Early observations from a number of missions consisted of many brief single spacecraft traversals of the magnetopause, which occur when the boundary is swept past the spacecraft location as it rapidly moves in and out in response to changes in the solar wind pressure. These observations have certainly provided indications of the dynamic nature of this boundary, for example revealing the occurrence of reconnection associated flux transfer events and regions containing accelerated particle populations. More recently, multi-point measurements over a relatively small scale (compared to the extent of magnetopause) by Cluster have provided insights into the underlying physics of the interactions, for example revealing the detailed fields and currents in the vicinity of active reconnection regions. Further progress in our understanding of such plasma microphysics can be expected from the NASA Magnetospheric Multi-Scale Mission (MMS) to be launched in 2014. Conversely, we have only a few rare and fortuitous spacecraft conjunctions over larger scales, most recently, for example, those between the Cluster and Double Star missions. These sporadic observations are extremely useful in providing indications of the more global dynamics of the magnetopause, for example in tracking the motion of flux transfer events.

Question:	How solved:
What is the location of the MP reconnection site for given conditions?	Large number of measurements of particle dispersions/cut-offs on the same reconnected field line
What is the importance of Flux Transfer Events (FTEs) in global dynamics of the magnetosphere?	Determine if FTEs appear in only one or in both hemispheres simultaneously (adding open flux or not?)
How do boundary waves evolve as they propagate across the magnetopause?	Regular multi-point observations of boundary deformations at different distances from their origin.
Which mechanisms form boundary layers at the MP and how do they vary or evolve with position?	Regular and simultaneous multi-point observations of boundary layers across the dayside MP.
How do disturbances, discontinuities and waves propagate within the magnetosheath and how and where can they impact the MP?	Widely spaced measurements within the magnetosheath at times when the magnetosphere is compressed and MP is located below average position.
How do MP disturbances propagate along field lines and into the ionosphere?	Multi-point measurements of Alfvenic disturbances and field aligned currents along the same field line, combined with regular observations of those field line foot-points by ground-based facilities.

Table 1: Examples of top level science objectives to be addressed with the IMPALAS mission concept.

Significant progress could be made in the latter area, the global dynamics of the magnetopause, if we could generate a statistically significant number of ‘controlled’ conjunctions with multiple spacecraft taking simultaneous *in situ* measurements at the magnetopause and spread widely ($\Delta s \sim 5\ R_E$) along, say, a reconnecting field line. These *in* *situ* measurements could be considerably enhanced if they were made in association with measurements of the ionosphere at or near the foot-points of the terrestrial field lines magnetic field lines that lie immediately inside the dayside magnetopause. Such complementary measurements could be made by remote sensing of the auroral emissions at or near these footpoints and/or by designing a mission which has additional conjunctions with European (or other) ground-based facilities located in these regions. Some examples of top level science goals that could be addressed by such measurements are listed in Table 1.

3. A possible IMPALAS Mission Scenario

With the science questions listed above in mind, together with similar investigations into the global dynamics of the magnetopause, we put forward here an example implementation of the IMPALAS mission concept.

3.1. Orbit

An example of the kind of orbit envisioned for the IMPALAS mission is shown in Figure 2.

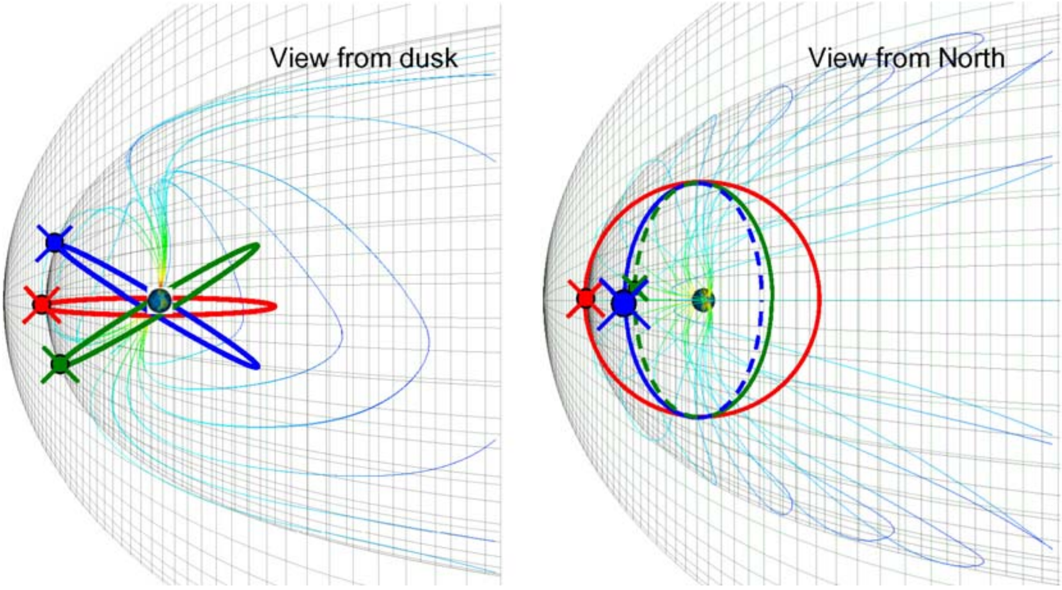

Figure 2. Schematic illustrations of the orbits of the 3 IMPALAS spacecraft. The left hand panel shows the view from dusk, with the 3 spacecraft located at the magnetopause boundary. The right hand panel shows the view from the north, and illustrates how the 3 spacecraft skim along the dayside magnetopause boundary for many hours during their 2-day orbit.

We propose that the mission should consist of a baseline of 3 spacecraft, which we will designate I1, I2 and I3. I1 should be placed in a circular orbit with a 10.48 R_E radius (1 RE = 1 Earth Radius = 6371 km) an a 0º inclination. I2 should be place in a slightly eccentric orbit with apogee ~11 R_E and +30º inclination. Finally I3 should be placed in a similarly eccentric orbit as I2 but with -30º inclination. The point of these orbits is that each spacecraft should then have an exactly 2 day period which ‘skims’ dawn-to-dusk very close to the average position of the dayside magnetopause. In addition, each of the 3 orbits should be phased so as to remain in longitudinal (magnetic) alignment with other 2, but separated by about 5 R_E, and further phased so that the foot-point of the field line connecting the spacecraft is over European ground-based facilities when the spacecraft are at local mid-day.

3.2 Strawman Payload

The payload for the IMPALAS spacecraft should be a relatively simple set of in situ instruments, supplemented by an auroral imaging system on I2 and I3. The payload and some optional elements, which could be included if resources allow, are listed in Table 2 below:

Required Instruments	Required for:
Magnetometer	Identification of MP crossings plasma waves and FTEs, Walen tests…..
Ion & Electron Spectrometers	MP crossing, particle cut-offs to locate reconnection site, Walen tests…….
Energetic Particle Detectors	Determine boundary motions, particle acceleration signatures…..
Auroral Zone Imager	Provides context and additional link between MP and ground-based measurements…….
Desirable Instruments	
Electric field booms	Identification of plasma waves,
Ion Mass Spectrometer	Plasma composition for correct analyses, tracers of particle origins within boundary layers;

Table 2: Strawman payload for the IMPALAS mission concept.

This baseline payload largely consists of high heritage instruments which should be flown in their current state-of-the-art format, or where appropriate technology development plans exist, in their next generation configuration, allowing the mission to benefit from resource savings achieved, for example, by planned miniaturization of these sensors. The fields and plasma packages should be identical and flown on all 3 spacecraft, while the nadir pointing auroral imager would fly only on the 2 spacecraft in inclined orbits. A snapshot from a simulation of

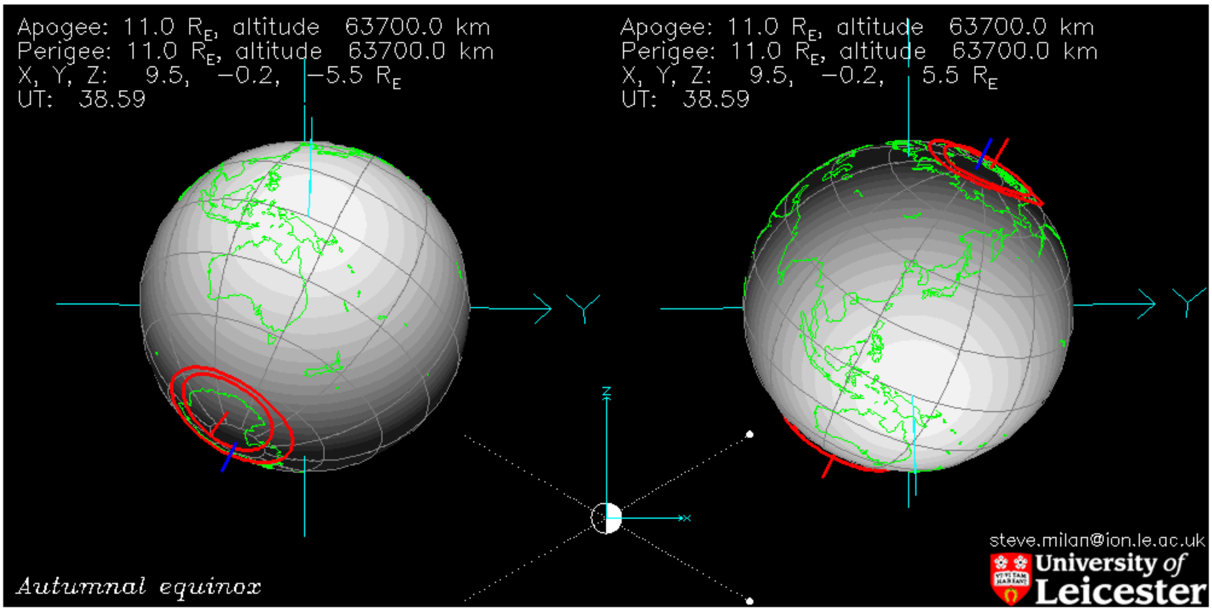

Figure 3. A snapshot of a simulation of the view of the dayside auroral oval (contained nominally within the red rings) that would be obtained from the IMPALAS 2 and 3 spacecraft in inclined orbits. The simulation shows that the footpoint of the field lines threading the spacecraft location would be clearly visible in both northern and southern hemisphere.

the view of the auroral ovals from the I2 and I3 spacecraft is shown in Figure 3 (courtesy S. Milan, University of Leicester).

4. Technological and Programmatic Issues

Since the required payload listed above currently exists in a form that would meet the measurement requirements likely to be imposed by the flow-down from the science goals, there are no significant technical issues likely to arise from the payload. However, the mission could be seen as providing a flight opportunity for next generation instruments, such that some technology development should be accommodated in this area (c.f. Figure 4.). A proper optimisation of the orbit parameters is required, together with a study of the options for launch and delivery of the spacecraft to their 3 distinct operational orbits from a single launch. The cost of the mission will of course be an issue, but we note in comparison to the most recent ESA study of a plasma physics mission, that of Cross-Scale, that the IMPALAS baseline payload and the number of spacecraft are both only a of the Cross-Scale hardware and therefore hopefully this mission would fall well within the M-Class budget. Indeed it might be hoped that there could be options for augmentation of the payload should spacecraft resources allow. Finally there is the issue of community support for the mission which needs to be built up if the mission is to be considered ‘politically’ viable. This briefing document, which will be circulated to potentially interested parties within Europe, is intended to be the first step in that process.

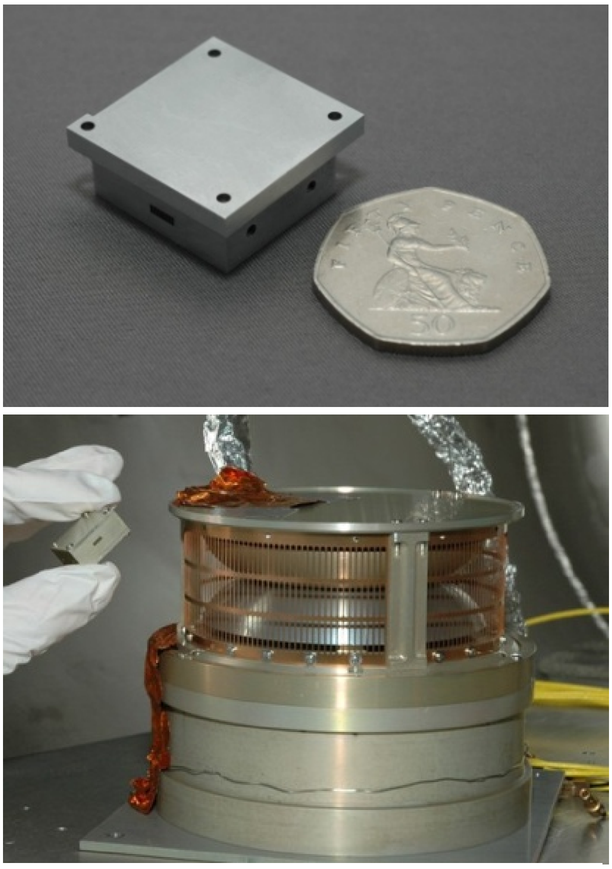

Figure 4. Example of the sensor technology advancements that could be employed on the IMPALAS mission to reduce required resources. The photographs show a prototype miniaturised plasma analyser, roughly the size of a coin, in comparison to current state-of-the-art analysers that will be flown, for example, on Solar Orbiter.

5. Summary

We believe IMPALAS, the mission described briefly in this document is a modest (affordable) mission with focussed and achievable science goals. The baseline (and possible augmented) payload is high heritage and provides significant opportunities for European hardware groups. The baseline mission described above could support many options, depending on available resources. It may be possible to plan for a later phase of the mission in which the apogee of all 3 spacecraft is boosted to bow shock altitudes, such that cross-surface studies of the shock dynamics could be undertaken. If resources allow, further spacecraft could be deployed to increase longitudinal, latitudinal and/or radial coverage. The feasibility of the baseline mission, together with these and other options, need to be the subject of a more comprehensive assessment study, and we suggest that the Cosmic Vision M3 opportunity may well be appropriate for that study.