On the study of highly integrated payload architectures for future planetary missions

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ABSTRACT

Future planetary missions will require advanced, smart, low resource payloads and satellites to enable the exploration of our solar system in a more frequent, timely and multi-mission manner. A viable route towards low resource science instrumentation is the concept of Highly Integrated Payload Suites (HIPS), which was introduced during the re-assessment of the payload of the BepiColombo (BC) Mercury Planetary Orbiter (MPO). Considerable mass and power savings were demonstrated throughout the instrumentation by improved definition of the instrument design, a higher level of integration, and identification of resource drivers. The higher integration and associated synergy effects permitted optimisation of the payload performance at minimum investment while still meeting the demanding science requirements. For the specific example of the BepiColombo MPO, the mass reduction by designing the instruments towards a Highly Integrated Payload Suite was found to be about 60%. This has endorsed the acceptance of a number of additional instruments as core payload of the BC MPO thereby enhancing the scientific return. This promising strategic approach and concept is now applied to a set of planetary mission studies for future exploration of the solar system. Innovative technologies, miniaturised electronics and advanced remote sensing technologies are the baseline for a generic approach to payload integration, which is here investigated also in the context of largely differing mission requirements. A review of the approach and the implications to the generic concept as found from the applications to the mission studies are presented.

1. INTRODUCTION

For most recent European scientific missions, such as ROSETTTA, Mars Express, SOHO, and Herschel/Planck, individual instruments were developed usually on the basis of the heritage of instruments from former missions. In principle, this concept reduces development times and development costs to a minimum whilst allowing instrument capability and performance to mature through actual flight performance assessment. On the other hand, only a limited evolution through new technologies can be supported, and these have both cost and technical difficulties, which need to be solved in the usually tight schedules associated with payload (P/L) and spacecraft (S/C) developments. Additionally, the current approach of building a payload suite out of separate instruments is, in general, not the most mass-efficient approach. As an alternative, it might be possible to achieve drastic mass reductions, ultimately enabling the use of small spacecraft for planetary exploration, if both P/L and S/C are assessed on system level at the very beginning in the assessment or concept phase, before the start of the instrument design phase. The idea of a small S/C is not new and was addressed earlier [1,2,3] and several missions were initiated or developed in order to demonstrate the feasibility of the small satellite concept. A historical overview of the developments in the United States is given in [4]. Here the costs of microSats are compared to the costs of larger satellites with higher performance. Of course one obvious advantage of small satellites is that within the same budget, more satellites can be launched, which reduces the total risk of failure (at all mission levels). The main advantages of small satellites are:

I. Reduced mission preparation time
II. Smaller effective project & industrial teams
III. Easier interface reduction and standardisation
IV. System level aspects are addressed in a timely and multi-mission manner

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V. Reduced number of different components (space qualification facilitated)
VI. Reduced launch costs
VII. More frequent and faster launch possibilities (more recent technologies can be employed)

Although there is a general consensus on the potential for resource reduction through sharing and miniaturisation, there is still a debate about the effectiveness, and the associated risk, if new technologies need to be employed. The benefits from both mission and S/C point of view have been discussed in [5]. For example the Clementine mission to the Moon was built within 22 months according to a microSat concept and has cost only 2/3 of a conventional mission, although it has a rather complex payload [4]. It is also well known that the integration, testing and documentation of missions with payloads comprising discrete separate instruments is tremendous and that interface definition can take years; in fact the mass of the interface control documents exceeds sometimes that of the spacecraft. Since a change in this P/L concept influences the whole chain involving P/L and S/C development including technology issues as well as P/L procurement approaches, it is also highly desirable to understand the impacts of such a new approach. For this reason these aspects of such a system level P/L concept are studied by deriving a preliminary architecture of a Highly Integrated Payload Suite (HIPS) for the BepiColombo Mercury Planetary Orbiter (MPO) with a view to establishing the development, assembly and verification tasks required. This MPO payload serves as a typical example, which could be designed either in a classical manner or using a highly integrated (HIPS) approach and it is used here to mature the resource estimations of the payload of the other mission studies.

2. PAYLOADS OF PLANETARY TECHNOLOGY REFERENCE STUDIES

Technology Reference Studies are mission studies, that are not part of the ESA science program, but which have the purpose to identify the technical development requirements for potential future scientific missions. For planetary exploration, the primary objective is to explore ways to decrease cost and risk by studying the feasibility of small satellite missions, which would allow a phased and systematic approach to the exploration of the planetary bodies of the solar system. The studies were selected to address a wide range of challenging technologies for future exploration of the solar system. The following TRSs are currently under study:

1. **Jovian Minisat Explorer** – a mission to Jupiter's moon Europa
2. **Venus Entry Probe** – an Aerobot for in-situ exploration of the Venus atmosphere
3. **Interstellar Heliopause Probe** – a probe into the interstellar medium towards the bow shock
4. **Deimos Sample Return** – a zero gravity landing manoeuvre to bring back 1 kg from the moon of Mars
5. **MiniMarsExpress** – small sat mission comparative to Mars Express

This paper describes the aims of these missions with a particular view to the payload requirements and the identification of the pro and cons of the HIPS concept. More details on the complete mission scenario, including S/C, launch, cruise, communication, orbit and their feasibility, can be found in ref. [8,9,10,11]. Similarities of the payload requirements are investigated so as to derive a road map of technology developments which are required to enable the presented mission concepts, where all spacecrafts are to be launched as a single or double composite on-board a Soyuz-Fregat SF-2B launch from French Guyana.

Parallel to these investigations, the HIPS concept and the related instrumentation for the BepiColombo mission is being studied further, thereby serving as a reference to prepare a realistic architecture of the P/L and to be able to compare HIPS to the conventionally implemented and distributed P/L. The status of the design case is beyond the scope of this paper and will be presented elsewhere.

2.1 Jovian Minisat Explorer (JME)

JME consists of two satellites, one of which is used as a relay station for data transmission and the observation of the Jovian system. The second orbiter shall map the moon Europa in a circular orbit at a distance of 200 km. The payload on the Jovian Relay Satellite (JRS), and especially on the Jovian Europa Orbiter (JEO) is constrained by the extreme radiation environment close to Jupiter (up to 5 Mrad after 4 mm Al). Since the instruments face a rather harsh radiation environment, it is recommended to apply radiation hard electronics and to shield sensitive components accordingly.

The main purpose of the JRS payload is the observation of the planet Jupiter and its surroundings during two years, provided the lifetime of the satellite and its payload is long enough. After the payload assessment the following instruments have been envisaged for **JRS:**

Table 1 Resource allocations and purpose of the JRS payload.

Instrument	Purpose	Mass (kg)	Power (W)	Data (kbit/s)
Jupiter Radiation Environment Monitor **(JuREM)**	Field mapping of the electron and proton activity and its distribution around Jupiter	1.5	1.70	1.1
Jupiter Plasma Wave Instrument **(JuPWI)**	Plasma wave environment, solar wind interaction with Jovian ionosphere	3.5	1.60	3.75
Jupiter Narrow Angle Camera **(JuNaCam)**	Imaging and spectroscopy of the surface with 10 different colours.	1.5	1.00	9.1
Jupiter Magnetometer **(JuMAG)**	Investigation of the Jovian magnetic field	1.15	0.95	0.25
Jupiter Dust Detector **(JuDustor)**	Measurement of dust present in the Jovian system	1	1.00	0.02
DPU + CPS	Data processing and power supply	2	3.25	-
Shielding (20%)	Shielding of the components	2.13	-	-
Structures	Optical bench and mounting structures	2	-	-
Margin (20%)		2.9	1.9	-
Total		**17.7**	**11.4**	**14.2**

It is intended that the payload shall be embedded in the satellite structure as much as possible. For the payload of JRS, this requirement is slightly relaxed compared to the Europa Orbiter, since the orbit is between 12.7 R_J and 27 R_J. The required effective shielding is only about 5 mm Al equivalent. Nevertheless, the assessment of the available resource revealed that less than 20 kg is available for the JRS payload, which is quite limited for the five instruments. Even more demanding than the low mass requirement is the low power consumption, which is imposed by the low solar flux at the large distance of the Jovian system from the Sun (~5 AU). Analysis has shown that a HIPS approach is the only viable - although still challenging- solution for the selected payload. The mass saving in electronics and the related support structures enables the installation of a payload fulfilling the required performance. One example for resource reduction is the installation of a filter wheel in front of the sensor of JuNaCam instead of in front of the aperture. This allows for a much smaller wheel, compared to a wheel in front of the much larger aperture.

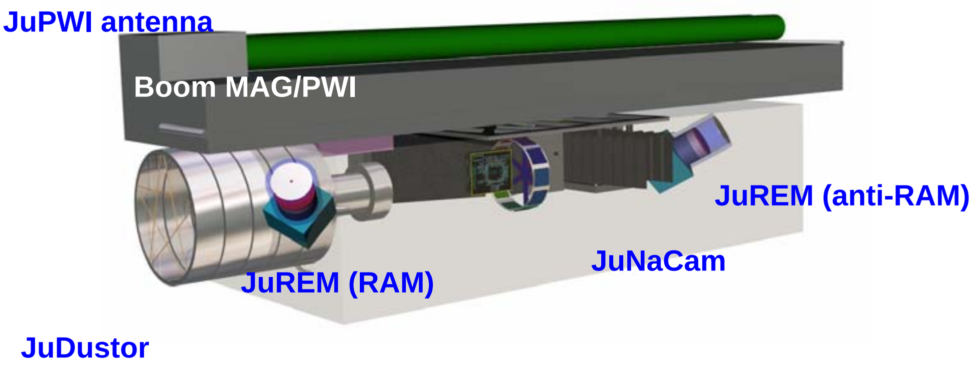


Figure 1 Visualisation of the payload suite. The instruments do not have any demanding requirements on pointing, co-alignment, or thermal requirements and can easily be operated by a central DPU.

The core science of the mission is addressed by the Jovian Europa Orbiter. The main purpose of its payload is the observation of Jupiter's moon Europa during a relatively short period of 60 days. The instruments face a rather harsh radiation environment (5 MRad), requiring a combination of radiation hardened electronics and external shielding to protect sensitive components accordingly. Also here the payload shall be embedded in the satellite structure as much as possible. The following instruments are envisaged for **JEO**:

Table 2 Resource allocations and purpose of the JEO payload.

Instrument	Purpose	Mass (kg)	Power (W)	Data (kbit/s)
Europa Ground Penetrating Radar **(EuGPR)**	Mapping of the surface and subsurface properties of Europa down to ~20km depth	9.6	20	1.5
Europa Stereo Camera **(EuS-Cam)**	Stereographic imaging of the surface to derive full topography map	0.6	1.2	5
Europa Visible Near IR Mapping Spectrometer **(EuVN-IMS)**	Imaging and spectroscopy of the surface at a spatial and spectral resolution of up to 30m/px and 30 nm resp.	2	2	13
Europa Radiometer **(EuRad)**	Determination of the temperature profiles of Europa in particular at the equator	2	1	0.1
Europa Laser Altimeter **(EuLAT)**	Topography of the surface and measurement of tidal effects	2	2.5	3
Europa Magnetometer **(EuMAG)**	Investigation of the presence of a magnetic field of Europa and its interaction with Jupiter	1.4	0.5	0.25
Europa UV Spectrometer **(EuUVS)**	Mapping of interaction of the ionosphere of Jupiter with Europa	0.5	0.5	TBD
Europa Gamma-ray Spectrometer **(EuGS)**	Investigation of the elemental surface composition	3	1	TBD
Europa Radiation Environment Monitor **(EuREM)**	Field mapping of the electron and proton activity and its distribution around Europa	1.5	1	1.1
DPU + CPS	Data processing and power supply	2.5	4	-
Structures	Optical bench and mounting structures	2	-	-
Shielding (20%)	Shielding of the components	5.4	-	-
Margin (20%)		6.5	6.8	-
Total		**39**	**40.5**	**24**

Implementation of ground penetrating radar is particularly demanding. Further savings may be achieved by a light-weight antenna technology. The instrumentation relies on a micro-laser altimeter, a camera with a visible-NIR sensor with broad spectral range and low power requirements throughout, thereby asking for highly miniaturised and integrated electronics.

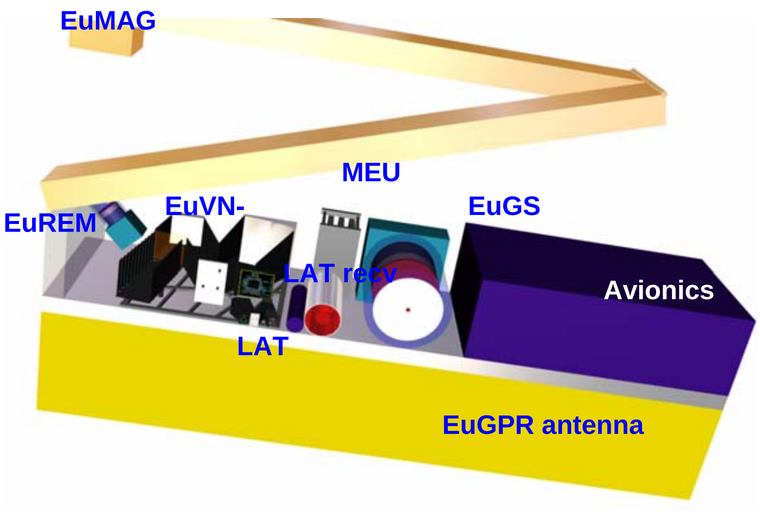
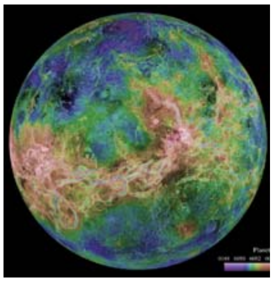


Figure 2 Conceptual layout of the JEO payload. The accommodation is preliminary and will be changed.

2.2 Venus Entry Probe (VEP)

The VEP mission study is designed to undertake the following science investigations:



1. The origin and evolution of the atmosphere by measuring the abundance and isotopic ratios of noble gases
2. Composition and chemistry of the lower atmosphere by determining the minor (<1%) constituents
3. Atmospheric dynamics by accurate measurements of vertical profiles of pressure, temperature and wind velocity
4. Aerosols in cloud layers by measuring the size distribution and temporal and spatial variability of the number density as well as chemical composition
5. Surface and subsurface investigations

These objectives can be summarized as the overall aim to fully understand the atmosphere of Venus in all its aspects and to explore the Venus surface and tectonic structure. The mission scenario that is able to fulfil these objectives consists of two small satellites: the Venus Elliptical Orbiter (VEO) and the Venus Polar Orbiter (VPO) and an Aerobot. The VPO, with the bulk of the atmospheric remote sensing payload, will operate in a polar orbit with altitude at perigee and apogee of about 2000 and 6000 km respectively. This orbit is selected for the study of atmospheric dynamics requiring high spatial and temporal resolution (the orbital period is about 3 hours).

The VEO primarily acts as a data relay station, but will also carry payload more suited to a highly elliptical orbit. The Aerobot will operate at an altitude of approximately 55 km within the Venusian middle cloud layer to derive *in situ* information. The Aerobot design is driven, in particular, by the need to operate in the harsh atmospheric environment of Venus and by a very tight mass budget. During flight, the Aerobot will release small probes which provide height profiles of pressure, temperature, solar flux levels and wind speed.

The VEO operates the following instruments:

Table 3 Resource allocations and purpose of the VEO payload.

Instrument	**Purpose**	**Mass (kg)**	**Power (W)**	**Data (kbit/s)**
Venus Surface & Subsurface Radar **(VSSR)**	Surface and subsurface study with high resolution.	12	40	14
UV/ visible camera	UV-CAM2 / tracking of UV features of cloud layers.	1	1	
DPU + CPS	Data processing and power supply	2	2	-
Margin (20%)		3	8.6	
Total		**18**	**51.6**	**21**

The VEO carries the radar instrumentation for (sub)surface investigations, which has a limited operational altitude, and a UV/visible camera for obtaining images of the complete globe at far distances. Though the topology has been completely and accurately mapped, the subsurface has never before been sounded.

The payload selection for **VPO** is driven by the penetration characteristics of radiation through the atmosphere. TIR and UV radiation can only provide information on the upper part of the atmosphere and part of the cloud layer. Through NIR radiation, it is possible to observe down to the ground in several NIR window regions. Imaging of the lower atmosphere therefore relies on several of these NIR spectral windows; different spectral channels may probe different atmospheric layers. NIR radiation is also suited to the study of dynamics by monitoring the motion of the cloud layers: while the lower atmosphere is sounded spectrally, cloud opacity can be spatially resolved because the clouds are highly, but conservatively, scattering. The microwave instrument has the attractive features of being able to measure temperature down to around 50 km and to resolve individual spectral lines from which Doppler shifts and hence velocities may be inferred.

Table 4 Resource allocations and purpose of the VPO payload.

Instrument	Purpose	Mass (kg)	Power (W)	Data (kbit/s)
Venus Ultraviolet Spectrometer **(VUVS)**	Spectroscopy of H_2O, SO_2, COS, CO, noble gases and unknown UV absorbers; study and mapping of night glow emissions as dynamics tracers; EUV spectroscopy.	4	4	10
Venus UV-Camera **(VUVCam)**	Tracking of UV features of cloud layers.	1	1	3
Venus Visible Near IR Mapping Spectrometer **(VN-IMS)**	Tracking of NIR cloud features to study dynamics, esp. super-rotation; monitoring of the O_2 airglow at 1.27 µm; study of the cloud opacity and its variations; spectroscopy of NIR windows, including search for volcanic activity and study of surface temperature.	4	14	10
Venus IR radiometer **(VRad)**	Tracking of cloud IR features (especially at poles); H_2O mixing ratio; heat transfer; measurements of the outgoing thermal spectral fluxes (radiative balance); temperature/pressure sounding	4	3	10
Venus Micro Wave Sounder **(VMS)**	CO and H_2O mixing ratios, temperature/pressure and wind speed profile from Doppler shifts in limb and nadir views.	6	20	10
DPU + CPS	Data processing and power supply	2	4	-
Margin (20%)		4.2	9.2	8.6
Total		**25.2**	**55.2**	**51.6**

The remote sensing payload will provide new studies in the form of microwave and subsurface exploration and improve upon former studies. The orbit of the VPO offers the possibility of complete global coverage of the upper atmosphere over the length of a super-rotation period (4 days) and a temporal resolution of 3 hours, invaluable for study of the polar vortices for example. Most of the instruments can be miniaturised and well integrated into HIPS, with the exception of the radar instrumentation, largely due to the large antenna. For this reason and the requirement of a low altitude perigee, the ground-penetrating radar is accommodated on the VEO.

The remote sensing measurements of VPO are primarily dedicated to support and enrich the Aerobot investigations. The tentative payload that be integrated into the **Aerobot** and its purpose are given in Table 5:

Table 5 Resource allocations and purpose of the Aerobot payload.

Instrument	Purpose	Mass (kg)	Power (W)	Data (kbit/s)
Gas Chromatograph/Mass Spectrometer **(GCMS)**	Abundance and isotopic ratios of noble gases, minor gases (e.g., SO_2, COS, HCl, H_2S and H_2O)	0.8	5	TBD
Aerosol analysis package **(AAP)**	Analysis of particles of Venus' atmosphere	0.3	2	TBD
Solar and IR Flux radiometers **(FR)**	Measure the radiation transport and heat transfer properties of the atmosphere	0.2	1	TBD
Meteorological package **(MP)**	Pressure, temperature, light level, flux, acceleration	0.5	1	0.3
Inertial package **(IP)**	Measure acceleration and changes in attitude	0.05	1.2	
Radar altimeter **(RALT)**	Determine the position of the Aerobot	0.9	10	
DPU	Data processing	0.25	0.25	-
Structures	Optical bench and mounting structures	0.3	-	-
Margin (20%)		0.7	4.09	
Total		4.0	24.95	TBD
Total (incl. duty cycle)		**4.0**	**5.15**	TBD

For reasons such as mass distribution and to be able to keep the option to observe the atmosphere on both sides of the Aerobot, the payload has been split into two HIPS, which are fully integrated into the gondola. Here the resources are extremely low, therefore requiring extremely high miniaturisation and integration of the instruments.

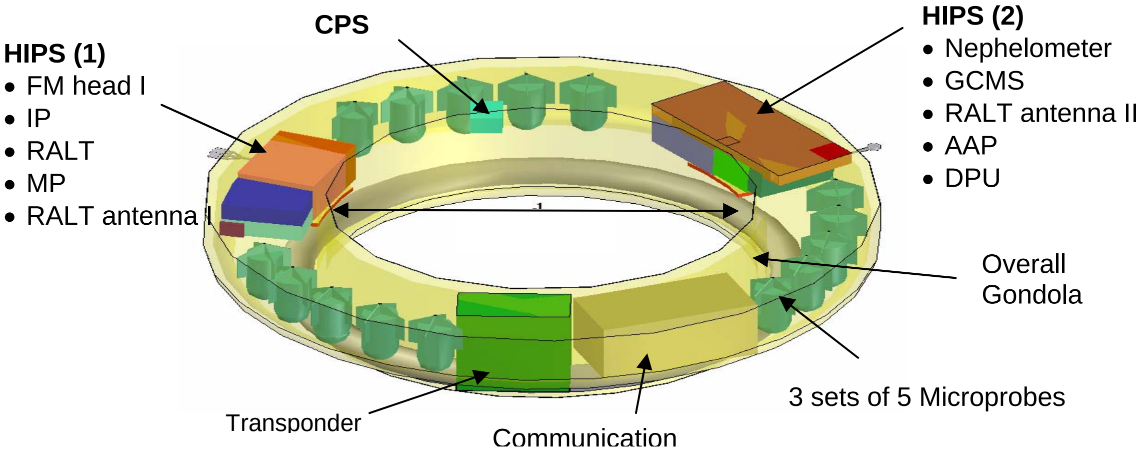
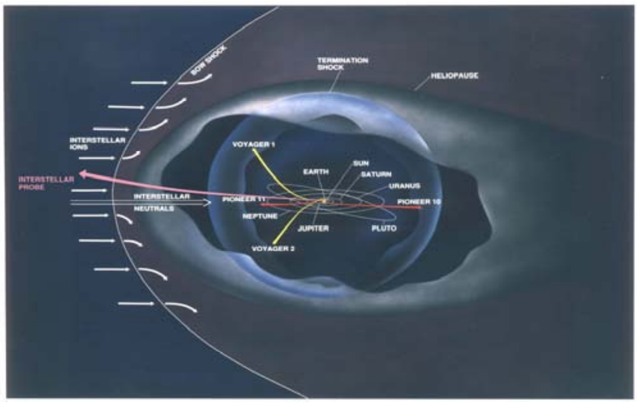


Figure 3 Conceptual design of the payload core of the gondola of the Aerobot with the two envisaged HIPS.

With the exception of the Aerobot, the VEP mission is not particularly constrained by power nor are the mass requirements particularly demanding, although lowering the mass of the VPO payload allows a less eccentric orbit, more suited to the type of global mapping that can unravel the mystery of the Venusian dynamics. Thus in this case, the introduction of the HIPS concept mainly allows an enhancement of the instrument performance and thereby the scientific objectives through resource savings.

2.3 Interstellar Heliopause Probe (IHP)

IHP is to perform chemical and plasma measurements in the heliosphere, the interstellar medium and the interface region between them. The vehicle shall reach a distance of 200 AU from the sun within 25 years. In order to explore the interstellar medium in the shortest time possible the spacecraft shall travel in the direction of the Heliosphere nose, which is located at 7.5° latitude and 254.5° longitude in ecliptic coordinates. In order to minimize the attitude manoeuvring a spinning spacecraft is envisaged. IHP will be the first spacecraft designed to leave the solar system and to enter the interstellar medium. No direct observations of this region exist today. Hence the main objectives of the IHP will be to:



1. explore and investigate the interface between the local interstellar medium (LISM) and the heliosphere,
2. to investigate the influence of the interstellar medium on the solar system,
3. to investigate the influence of the solar system on the interstellar medium, and
4. to explore the nature of the interstellar medium and the outer solar system and the heliosphere.

Additionally a secondary objective might be to observe Trans-Neptunian Objects (TNO) during cruise.

The main purpose of this payload is therefore the study of plasma, energetic particles, magnetic fields, and dust in the outer heliosphere and nearby interstellar medium with a focus to the investigation of the conditions close to the termination shock. The 3-dimensional characteristic of the heliopause requires in principle observations from multiple sides. Since only one S/C is available it is at least tried to have a large coverage of the observations asking for large field of views of the instruments.

Observations aim at the determination of the composition of the plasma and the determination of particle energies and travelling directions of the plasma. The rather broad range of energies from suprathermal to high energetic GeV particles and even neutral atoms requires a whole suite of instruments. The dust grain composition and directional information shall be investigated in-situ. Remote sensing of the dust and the interstellar clouds shall be enabled by UV, VIS-NIR and FIR measurements. The strawman payload is limited in mass and power to 20 kg and 20 W, respectively. This requires a high degree of miniaturisation, integration and demands resource sharing among all instruments. The limited time for communication and lack of interaction requires highly autonomous instruments and a high degree of data compression. The total mass that can be shipped by solar sailing transportation is less than 20 kg.

Table 6 Resource allocations and purpose of the IHP payload.

Instrument	**Purpose**	**Mass (kg)**	**Power (W)**	**Data (bit/s)**
Interstellar Plasma Analyser **(IPA)**	Determine the elemental and isotopic composition of plasma and the associated energy levels at temporal composition	2	1	10
Interstellar Plasma Wave and Experiment **(IPWE)**	Determine the plasma and radio wave environment in outer space CO	5.5	2.5	23
Interstellar Magnetometer **(IMAG)**	Magnetic field measurements in very low fields	3.2	2.5	8
Interstellar Neutral and Charged Atom Detector and Imager **(INCADI)**	Energy levels, composition, mass, angular and energy distribution of neutral atoms	0.5	1	16
Interstellar Energetic Particle Detector **(IEPD)**	Measure supra-thermal, and energetic ions and electrons energy distributions	1.8	1.2	14
Interstellar Dust analyzer **(IDA)**	Determine the energy levels of cosmic rays	1	0.5	1
Interstellar UV photometer **(IUVP)**	Surface and subsurface topology with high resolution, altimetry	0.3	0.3	10
Interstellar Visible NIR Imager **(IVI)**	Determine the radial distribution of Small Kuiper belt objects and TNO	1	0.5	10
Interstellar FIR Radiometer **(IFIR)**	Measurement of the radial distribution of dust and the cosmic infrared background	0.3	0.2	1
DPU + CPS	Data processing and power supply	2	3.5	-
Structures	Optical bench and mounting structures	2	-	-
Margin (20%)		3.92	2.64	18.6
Total		**23.52**	**15.84**	**111.6**

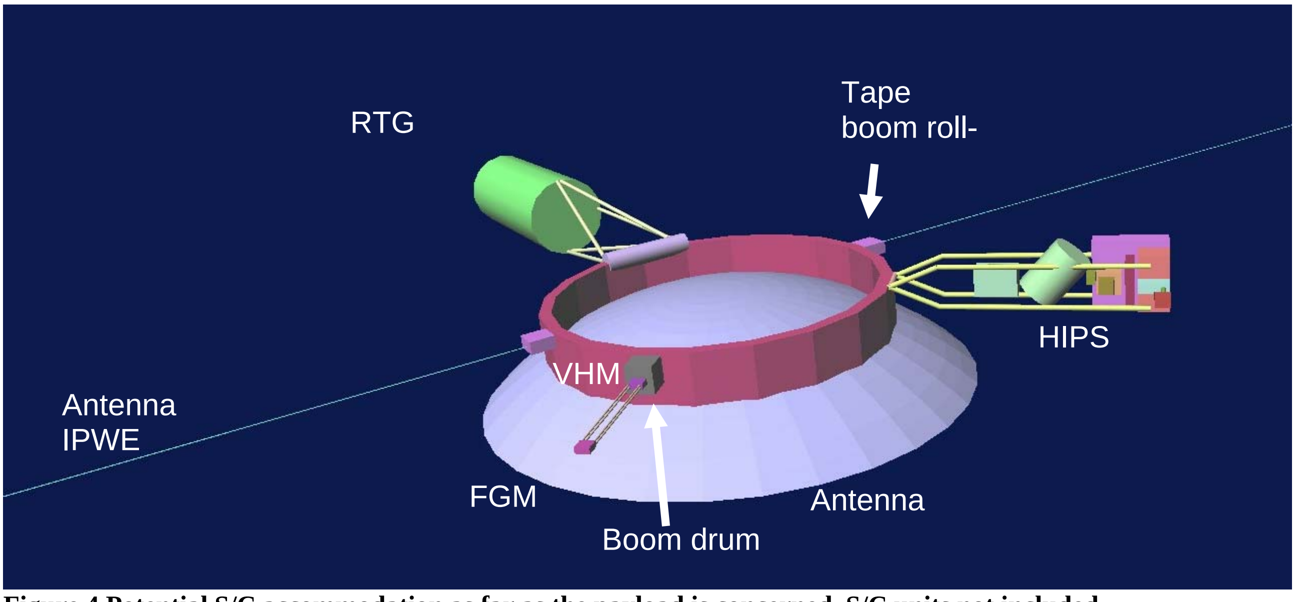


Figure 4 Potential S/C accommodation as far as the payload is concerned. S/C units not included.

2.4 Deimos Sample Return

Two MicroSats launched as a single composite from a Soyuz-Fregat SF-2B shall be inserted into Mars Orbit. One MicroSat acts as a Data Relay Satellite and return vehicle for a Deimos sample and return capsule. The second MicroSat will rendezvous with Deimos to perform a 1 kg sample capture and return to the data relay satellite, which will then leave Mars orbit for a return to Earth, where the capsule will perform a direct re-entry. In the intended single MicroSat scenario, the operations of both satellites are combined aboard one spacecraft. The payload consists as a minimum of a landing system, which allows imaging of Deimos and a distance measurement with the aim to derive landing coordinates and terrain information. Other scientific objectives are the determination of Deimos' size, shape, orbit, gravitational field, rotational properties, surface features and composition. A sufficiently small landing system would allow implementing also some scientific instruments, which could be beside the camera a NIR spectrometer, a UV spectrometer and a scanning system which allows the topographical mapping of the moon. The payload is still under assessment; therefore Table 7 is only indicative.

Table 7 Resource allocations and purpose of the DSR payload.

Instrument	**Purpose**	**Mass (kg)**	**Power (W)**	**Data (kbit/s)**
µ Stereo Imaging Laser Altimeter (**µSILAT**)	Landing coordination, surface topography, shape, size; measure mineralogical composition of the surface (NIR spectroscopy); measure distance during landing and approach	2	3.5	30
Radio Science Experiment **(RSE)**	Measure Doppler shift during approach	2	6	1
Magnetometer **(MAG)**	Search for and map intrinsic magnetic fields	0.5	0.5	1
UV photometer **(UVP)**	Investigate halo and potential exosphere	0.3	0.5	1
DPU + CPS	Data processing and power supply	1	1	-
Structures	Optical bench and mounting structures	1	-	-
Margin (20%)		1.2	2.3	-
Total		**8.2**	**13.8**	**33**

2.5 MiniMarsExpress

The MarsExpress mission is well known and is taken as reference in order to compare the conventional mission with the same mission instrumentation performance implemented in an advanced highly integrated manner. The resources of the instruments of both mission payload concepts are compared in the following table:

Table 8 Resource allocations and purpose of the MEX(*) and MiniMEX(**) payload – still preliminary.

Instrument	**Purpose**	**Mass* (kg)**	**Power* (W)**	**Mass** (kg)**	**Power** (W)**
High Resolution Stereo Camera **(HRSC)**	Stereo mapping of Mars with different colours	21.4	40.4	6	2
NIR spectral imager **(OMEGA)**	Observatoire pour la Mineralogie, l'Eau, Glace, l'Activite	28.8	47.6	5	15
Planetary Fourier Spectrometer **(PFS)**	Investigation of the atmosphere of Mars	31.2	45	5	3
UV/NIR spectrometer **(SPICAM)**	Spectroscopy for the Investigation of Characteristics of the Atmosphere of Mars	4.9	25	1.5	3
Plasma Analyser **(ASPERA 3)**	Analyser of Space Plasmas and EneRgetic Atoms	5.95	6.4	4	4
Subsurface Radar **(MARSIS)**	Radar (Subsurface & Ionospheric Sounding)	15	59	10	15
DPU + CPS	Data processing and power supply	-	-	2	4
Structures	Optical bench and mounting structures	-	-	1	-
Margin (20%)		-	-	6.9	9.2
Total		**107.25**	**223.4**	**39.7**	**55.2**

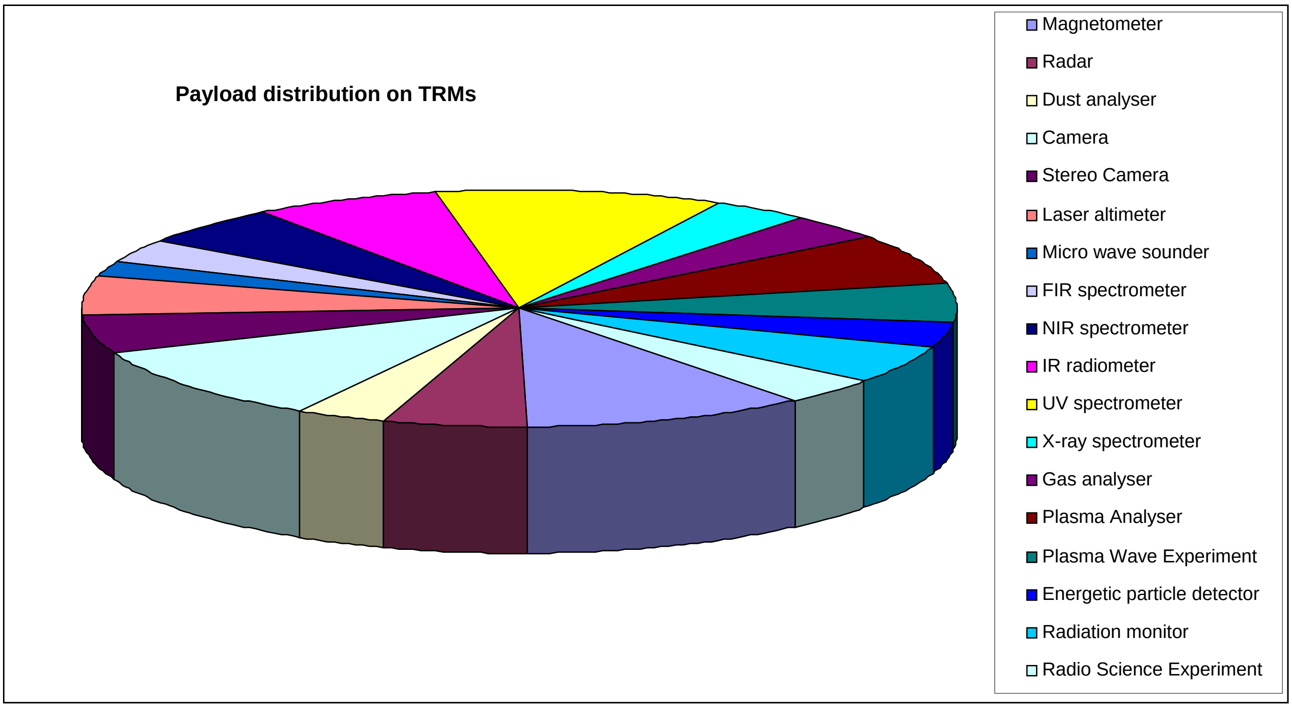
The given resources are preliminary and are still under assessment. The main gain of resources results from the provision of a high performance and centralised DPU, which serves the instruments HRSC, OMEGA, PFS and MARSIS, and from the use of common resources. Instrument concepts and detector technologies are mature for most of the instruments, but must be revisited in the frame of recent developments. It can however already be seen that a saving of about 50% is expected in mass and even 70% in power. Including the snowball effect (multiplication factor of satellite weight for a given increase of payload mass) which is usually ~3, this means that a modern MiniMEX mission would give room for a second S/C being launched with the same rocket and at the same time it would even endorse more or better performing science payload. A new mission to Mars would most likely shift the scope of the scientific instruments, but would still be within the here given resource envelope.

3. GENERIC PAYLOAD

3.1 Instruments

An overview of the payload for all mentioned missions including the payload for the BepiColombo mission shows clearly the need of future technology developments. 18 types of instruments are required in total to cover the scientific demands of the presented 8 orbiters having a total of 52 instruments as strawman payload.

Figure 5 Statistical visualization of the amount of payload types assessed in the technology reference studies.



The highest demand is obviously on magnetometers, cameras and UV spectrometers, and it seems to be feasible that all these instruments can be built from generic components. The ranking of instrument developments according to that chart is the following:

1. Generic fluxgate magnetometers with optional vector Helium magnetometer and miniaturised electronics
2. Cameras being flexible to be changed in aperture size, sensor adaptation and filtering concept with an option of integrating a stereo channel and a laser altimeter
3. UV spectrometers with scalable aperture (photometry is an additional demand)
4. IR radiometer with optional spectrometric capability and broad band spectral range
5. Plasma analyser with possible accommodation of field-of-view

A limited amount of instrument concepts and technologies is needed to realise the observed instrument requirements. The conducted study gives a great insight into the feasibility of building generic instruments or components for scientific space instrumentation, and it allows proposing a roadmap into the future.

3.2 Components

Within the scope of this paper, the particular needs towards generic instrumentation cannot be addressed sufficiently. However, a short list of some of the identified key technologies is given here:

1. Deployable large antennae (subsurface radar)
2. Deployable booms with flexible length for spinning and non-spinning S/Cs (magnetometers)
3. Advanced instrument structures and materials (plastics and lightweight alloys with similar stiffness and thermal conductivity as Aluminium) and their qualification
4. Smart baffles (reflecting thermal heat)
5. Filter technologies (interference filters); perhaps even integrated onto the sensors
6. Optical fibres, and micro-collimators
7. Linear variable and patched filters
8. Sensors being coupled to a passive cooler (radiator)
9. Sensors with low power consumption (CMOS technology)
10. Room temperature bolometers
11. Field Programmable Gate Arrays (FPGAs) and Application Specific Integrated circuits (ASICs)
12. Highly miniaturised Data Processing Unit (DPU) and bus system

3.3 Electronics

The DPU performance handling different requirements for different missions must be very flexible or scalable. One way to achieve this is to use a scalable processor paradigm such as SPARC (Scalable Processor ARChitecture). This type of system is designed for use in a multiprocessor system and supports the concept well. With the latest advancements in the LEON core design, this is particularly well suited to a space qualified multiprocessor system approach. There are many approaches to multiprocessor systems, although since recommendations have already been made towards the use of the LEON SPARC-V8 architecture (see Figure 6), which is now followed as baseline. The SPARC concept directly supports the SMP (Symmetrical MultiProcessor) idea which itself has a number of approaches. Two of these approaches include the shared memory multiprocessor, and the distributed memory model. The LEON architecture supports the shared memory model and the SPARC standard supports this directly in its memory model. Specific instructions for multiprocessing are also supported within the SPARC concept, which include atomic load-store operations. IP cores for the implementation of the different functions are made available mostly and considered as generic components.

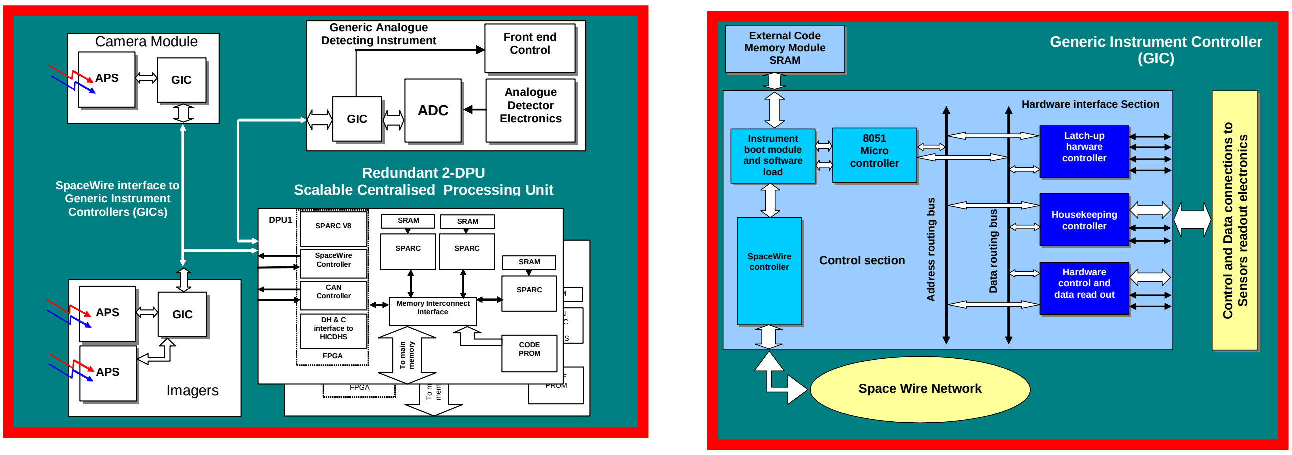


Figure 6 Single Chip Multiprocessor system using LEON SPARC architecture (left) and conceptual layout of the generic instrument controller (right).

The Concept of the Generic Instrument Controller (GIC), allows the central DPU to be able to communicate with all surrounding instruments in the same way. With only minor modifications to the sensor interface, a standard set of functions in the GIC will enable the DPU to "talk" to many differing types of instrument. This will reduce development efforts, not only at the instrument end, but also in the centralised data processing unit. With only one type of interface for communication, the DPU can be highly standardised, and scalable. Many of these system modules can be realised using FPGA technology. Some generic ASICs shall be developed. This also has advantages in mass, size and power consumption. In some cases, whole circuit boards can be replaced by a single programmable component with inter-module connections being simply handled within the device. The processing performance can be adapted from some up to several hundred MIPS while consuming only a few hundred mW.

4. CONCLUSION

Technology Reference Studies are a tool to identify enabling technologies and to provide a reference for mid-term technology developments that are of relevance for potential future scientific missions. Early development of strategic technologies will reduce mission costs and shorten the mission implementation time. As the enabling technologies mature and mission costs reduce, the scientific community will benefit by an increased capability to perform major science missions possible at an increased frequency. The presented technology reference studies have been taken as a showcase for the investigation of the needs on advanced instrumentation for future highly miniaturised and integrated payloads. The term highly integrated is used here not in a literal sense, and is meant more in the sense to provide the basis for a symbiosis being able to benefit from the synergy effects. Instruments can still be distributed and are only combined in case this is subject to a clear advantage. The autonomy of each instrument can still be high, although the 'central brain' may observe and command executive payloads. For the presented approach the total payload mass of a satellite is typically around 30kg and weighs therefore as much as single instruments aboard former conventional missions. This might open a new road towards many science driven missions and a future approach for the exploration of the solar system and beyond.

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