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PAYLOAD DEFINITION DOCUMENT FOR THE JUPITER GANYMEDE ORBITER OF THE EUROPA JUPITER SYSTEM MISSION

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1 INTRODUCTION

The Jupiter Ganymede Orbiter Payload Definition Document is the reference document for all payload issues concerning the European contribution to the Europa Jupiter System Mission. This Payload Definition Document was compiled in close collaboration with the Joint EJSM SDT and the instrument contacts. This document is an update of a previous PDD for the Concurrent Design Facility study of the Jupiter Ganymede Orbiter performed in Q2 2008. In September 2008 during a week-long meeting the Joint EJSM SDT decided to change the payload definition to maximize the potential scientific output of the Jupiter mission. In March 2009 a revised JGO model payload was proposed by the Joint EJSM SDT and this is reflected in the issue 2 of this document. In the time frame between March 2009 and June 2009 the PDD will be updated with additional information requested from the instrument contacts.

The document is split up into two parts. In the first part the JGO model payload is described, which is basically the baseline instrumentation defined in March 2009. Finally, the fundamental physics instrument GAP is described. As it is not part of the scientific objectives of studying the Jupiter system it is given a special status and it will be reviewed in a later stage.

The payload and their related technological developments will be activities funded by the national agencies.

1.1 *Document Status*

This document is conceived to describe the model payload, the additional payload and the special payload for one of the proposed L-class missions within the Cosmic Vision 2015-2025 programme. The instruments described here shall not be seen as the final selection of the payload for the final mission. This PDD will be updated to be used as a living reference document in the coming parallel industrial studies to be started in the time-frame April-July 2009. The final payload selection for a potential Jupiter mission will be done through a joint ESA-NASA AO (Announcement of Opportunity) in 2010-2011 for instruments when the mission is selected to go into Industrial Definition Phase together with one other L-class mission in 2010-2011.

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2 ACRONYMS

ACE	Atmospheric Chemistry Explorer
AOTF	AcoustoOptic Tuneable Filter
APD	Avalanche Photo Diode
ASIC	Application Specific Integrated Circuit
CTS	Chirp Transform Spectrometer
DSI	Doppler Spectro-Imager
DoE	Department of Energy
ESA	European Space Agency
FOV	Field Of View
GAP	Gravity Advanced Package
GN2	Gaseous Nitrogen molecule
HRC	High Resolution Camera (identical to NAC)
INMS	Ion Neutral Mass Spectrometer
JEO	Jupiter Europa Orbiter
JGO	Jupiter Ganymede Orbiter
JMO	Jupiter Magnetospheric Orbiter
JRST	Júpiter Radio Science Transponder
LO	Local oscillator
MAG	Magnetometer instrument
MCP	MicroChannel Plate
MCT	Mercury Cadmium Telluride (HgCdTe)
MIRO	Microwave Instrument on the Rosetta Orbiter
MLA	Micro Laser Altimeter
MRC	Medium Resolution Camera (includes stereo capabilities)
NAC	Narrow Angle Camera (identical to HRC)
NASA	National Aeronautics and Space Administration
PLP	Plasma Package
RPWI	Radio & Plasma Waves Instrument
RF	Radio Frequency
ROSINA	Rosetta Orbiter Spectrometer for Ion and Neutral Analysis
RTOF	Reflectron Time-of-Flight
SSD	Solid State Detector
SSPA	Solid State Power Amplifier
SSR	SubSurface Radar
SWI	Submm wave sounder Instrument
TBC	To Be confirmed
TBD	To Be Determined
TM	Thermal Mapper
THEMIS	Thermal Emission Imaging System
USO	Ultra Stable Oscillator
UVIS	Ultraviolet Imaging Spectrometer

VIRHIS	Visible and InfraRed Hyperspectral imaging spectrometer
WAC	Wide Angle Camera

3 APPLICABLE AND REFERENCE DOCUMENTS

TBD

4 CONTACT PERSONS

Table 1 Contact persons per instrument.

Instrument	Acronym	Name	Address	Telephone	Fax	E-mail
High Resolution Camera, Medium Resolution Camera & Wide Angle Camera	NAC, MRC, WAC	Jürgen Oberst	German Aerospace Center, Institute for Planetary Research	+49 3067055336	+493067055402	Juergen.Oberst@dlr.de
Doppler Imager	DSI	Francois-Xavier Schmider	Université de Nice	+33492076341		schmider@unice.fr
Ion Neutral Mass Spectrometer	INMS	Peter Wurz	University of Bern Sidlerstrasse 5 3012 Bern, Switzerland	+41 31 631 44 26	+41 31 631 44 05	Peter.wurz@space.unibe.ch
Radio & Plasma Waves Instrument	RPWI	J-E. Wahlund	Box 537 SE-751 21 Uppsala, Sweden	+46-18-471 5946	+46-18-471 5905	jwe@irfu.se
Laser Altimeter	MLA	Hauke Hussmann	German Aerospace Center (DLR) Institute of Planetary Research Rutherfordstr. 2 12489 Berlin Germany	+49(0)3067055315		Hauke.hussmann@dlr.de
Magnetometer	MAG	Michele Dougherty	Imperial College			m.dougherty@imperial.ac.uk
Sub-Surface Radar	SSR	Lorenzo Bruzzone	Dipartimento di Ingegneria e Scienza dell'Informazione – University of Trento, Via Sommarive 14, I-38050 Trento, ITALY	+39-0461-883056	+39-0461-882093	lorenzo.bruzzone@ing.unitn.it
Radio Science Transponder	JRST	Paolo Tortora	University of Bologna II Facoltà di Ingegneria Via Fontanelle 40 I-47100 – Forlì ITALY	+39-0543-374456	+39-0543-374477	paolo.tortora@unibo.it
Ultrastable Oscillator	USO	Martin Pätzold	Rheinisches Institut für Umweltforschung, Abt. Planetenforschung, Universität zu Köln Aachener Strasse 209 50931 Köln Germany	+49-221-27781810	+49-221-4002320	martin.paetzold@uni-koeln.de
Submm Instrument	SWI	Paul Hartogh	Max-Planck-Institut für Sonnensystemforschung	+49-5556-979342	+49-5556-9796342	hartogh@mps.mpg.de

Thermal Mapper	TM	John Spencer	Southwest Resarch Institute, 1050 Walnut St Suite 300 Boulder CO 80304 USA	303-546-9674 (W), 303-929-0532 (M)	303-546-9687	spencer@boulder.swri.edu
Ultraviolet imaging spectrometer	UVIS	Marina Galand	Imperial College London	+44 20 7594 1771	+44 20 7594 7900	m.galand@imperial.ac.uk
Visible InfraRed Hyperspectral Imaging Spectrometer	VIRHIS	Filacchione Gianrico	INAF-IASF via del Fosso del Cavaliere, 100, 00133, Rome, Italy	+39-06-49934454		Gianrico.filacchione@iasf-roma.inaf.it
Plasma Package	PLP	S. Barabash	Swedish Ins. Of Space Physics, Box 812, Kiruna, Sweden	+46-980-79122	+46-980-79050	stas@irf.se
Special						
Gravity Advanced Package	GAP	C. Bruno	ONERA DMPH/IEA 29 av. Division Leclerc F-92322 Chatillon Cedex	+33 (0)1-46-73-49-35	+33 (0)1-46-73-48-24	bruno.christophe@onera.fr

5 PAYLOAD SUMMARY TABLES

Table 2 JGO Model Payload Instrument interface summary.

Instrument	Acronym	Mass [kg]	Size [cm]	Power [W]	TM [kbps]	TRL	Heritage
High Resolution Camera	HRC	<8 kg	50 x 20 x 20	15	75	6-8*	SRC @ Mars Express, PanCam @ ExoMars, DAWN camera
Medium-Res Camera	MRC	6	25 x5 x5 (2)	13	6250	6-8*	HRSC @ Mars Express
Wide-Angle Camera	WAC	1.5	10 x10 x10	3	5000	6-8*	SRC @ Mars Express
Micro Laser Altimeter	MLA	3.6	23x16x14 (tbc.)	26	24	3*	operational in terrestrial airborne applications
Magnetometer	MAG	1.5		1.5	7-70	9*	Cassini Double Star Venus Express
Sub-Surface Radar	SSR	10	37x25x13	20	300	*	MARSIS, SHARAD
Radio Science Transponder	JRST	3.5	10x20x15 (TBC)	35 (30 for SSPA)	TBD (very low)	>6-7*	Cassini, BepiColombo, Juno
Ultrastable Oscillator	USO		15.2x9.0x13.0		low HK only	9*	ERS, Rosetta, Venus Express
Submm Instrument	SWI	9.7	70x52x41	10-50	10	5-8*	Rosetta MIRO
Thermal Mapper	TM	5	25 x 25 x30	5	34-42	5*	THEMIS
UV imaging spectrometer	UVIS	6.5	30 x 30 x 20	3-12	30	4*	PHEBUS/ BepiColombo
Visible InfraRed Hyperspectral Imaging Spectrometer	VIRHIS	17	Optical Head: 50×40×30 ME: 30×25×20	20	5000	5*	Cassini/VIMS-V Rosetta/VIRTIS Etc.
Plasma Package	PLP	13.2		33	2-20	6-8*	MEX, VEX/ASPERA-3, 4 Chandrayaan-1/CENA, etc

Instrument	**Acronym**	**Mass [kg]**	**Size [cm]**	**Power [W]**	**TM [kbps]**	**TRL**	**Heritage**
Doppler Spectro-Imager	DSI	4	35x30x15	6	30 max	3-4*	SYMPA, MDI, LOI, Mars Express
Ion neutral mass spectrometer	INMS	4.9		10	1.5	*	ROSINA instrument on Rosetta
Radio and plasma wave instrument (RPWI)	RPWI-E	3.0[1]	15x15x8 cm	7+3[2]		8[3]*	
	LP-PWI	2.0[4]	4x 5cm probes on tip of 1-3m booms[5]		Min: 64 bps Max: Several kbps[6]	8*	Cassini RPWS Rosetta LAP Swarm CEFI Cluster EFW BepiColombo PWI
	RWI	1.5[7]	Triad of 50cm-1m antenna[8]		1-100 kbps[6]	8*	Cassini RPWS STEREO Waves Juno, RBSP BepiColombo PWI
	SCM	1.0[9]	11x11x11cm		See LP-PWI	8*	BepiColombo PWI Cassini RPWS
	QTN	3.7[10]	2x6m dipole		From 50 bps to 2kbps[6]	8*	Cassini RPWS BepiColombo PWI

***Important: The Technology Readiness Levels quoted in** Table 2 **and in the instrument summary tables are the TRLs given by the instrument teams. ESA has not reviewed these TRL numbers.**

Notes:
-: All instruments are without shielding mass and margin
-: The SSR instrument mass is without antenna system, which is assumed to be part of the spacecraft
-: The JRST uses 35 Watts of power due to the inclusion of its own SSPA. This power (30 W) can be subtracted from the telecom system of the S/C.

Additional notes:
1) Includes electronics box (1kg), DPU (400g), DC/DC converter (200g), three electronics cards (2x400g+1x600g)
2) Includes also heaters (3W, TBC)
3) Electronics design is flight proven. Interfaces to sensor elements and electronics box need be adapted (no problem).
4) Includes 4x spherical sensors (50g each), booms (450g each) incl. pre-amplifiers.
5) Boom design depends on possible accommodation configurations on S/C. The further the sensors are from the S/C main body the better.
6) Data rates are dependent on mode of operation choice. The duty cycle of data taking can be adjusted to comply with available TM rates at a particular time.
7) Includes antennas, pre-amplifiers and shielding
8) Includes triad of antennas with deployment mechanism. This triad should preferably be deployed on a boom (TBC) and depends on possible S/C accommodation configuration. The 1-2 m boom not included in mass estimate. Can be MAG boom.
9) Includes 3 SCM-sensors. Should be accommodated on a 1-2 m boom (e.g., MAG boom).
10) Optionally it is possible to use the RADAR antenna, in which case no sensor mass is needed (TBD)

Table 3: JGO Fundamental physics Payload Instrument interface summary.

Instrument	**Acronym**	**Mass [kg]**	**Size [cm]**	**Power [W]**	**TM [kbps]**	**TRL**	**Heritage**
Fundamental Physics							
Gravity Advanced Package	GAP	3		3	0.1	*	CHAMP, GRACE, GOCE

6 DESCRIPTION OF JGO MODEL PAYLOAD INSTRUMENTS

6.1 High Resolution Camera (HRC)

6.1.1 SCIENCE GOALS AND PERFORMANCE REQUIREMENTS

The orbiter camera will contribute to the characterization of the Satellites of the Iovian System, in particular in the areas of planetary geology, geodesy, and geophysics.

Science Goals

Satellites:

- Mapping of Callisto, Europa, and Io to complete or improve the coverage by previous missions
- Targetting of local areas of interest on Callisto, Europa, and Ganymede during flybys
- Study orbits, shapes, rotations, and characteristics of „irregular“ satellites, discover new satellites
- Io monitoring for volcanic activity
- Monitoring of the Iovian atmosphere

Ganymede:

- Target selected areas of interest at highest resolution, study surface morphology at ~1 m scale
- Search for past or present geologic activity, determine surface ages
- Search for candidate landing sites for future missions

Performance Requirements

- Derive high-resolution snapshots of distant targets
- Derive imaging swaths at highest resolution (swath width: ~ 1000 m, ~1 m/pix @ 200 km)
- Allow for stereo coverage by repeated passes over areas of interest with camera tilt
- Allow for astrometric measurements (high sensitivity and dynamics)
- High signal-to-noise
- Allow for geometric and radiometric calibration
- Lifetime: 2 years in Ganymede orbit

6.1.2 INSTRUMENT CONCEPT

Imaging experiments in the Jupiter environment are a challenge. The Jovian system is characterized by its large size and the very large distances between satellites. In addition, light levels are lower by a factory 25 compared to Earth environment. Also, radiation is harsh, and puts limits on the selection of instrument sensors or electronics. Hence, any satellite imaging during a Jupiter orbit mission requires a high-resolution camera, which is powerful but also robust.

The proposed instrument is intended for satellite imaging during Jupiter Tour, and during the Ganymede orbit phase. The camera will carry out observations of distant targets or will carry out high-resolution mapping of Ganymede in small selected areas.

As the orbiter moves fast over the surface of Ganymede, long exposures are prohibitive and imaging experiments require some strategy for motion compensation.

Hence, our proposed solution is a camera with an optical system of large focal length (f=3m) and an imaging array sensor, operated either conventionally (during the Jupiter orbit phase) or in a dedicated motion-compensation mode (during Ganymede orbit) to make long exposures possible. To accomplish motion compensation, the sensor is mounted on a small platform, which is moved in the direction of the spacecraft motion vector by piezo-control (piezo-motion compensated integration)

The spacecraft shall be tilted after the nominal Ganymede orbit mission to obtain stereo coverage.

6.1.3 INSTRUMENT DESCRIPTION

The instrument will consist essentially of 3 components, the optics, the sensor system, as well as a data processing unit.

The optics will be a reflecting telescope involving a primary mirror (20 cm Ø) and a secondary convex mirror, with a field corrector added. The focal length is 3 m.

The sensor will be a CMOS Star1000 1024 x 1024 array sensor (pixel size 15µ), which is known to be radiation-resistant, and for which much heritage is available.

6.1.4 ORBIT, OPERATIONS AND POINTING REQUIREMENTS

The instrument will operate during the Satellite tour as well as during the spacecraft orbit phase. The pointing prediction shall be sufficiently accurate to successfully keep the camera pointed at distant targets. The pointing shall be stable within the size of 1/3 of an image pixel during the typical exposure time of 0.5 s.

During orbit, the camera shall maintain nadir-pointing. The direction of the motion vector with respect to the spacecraft must be maintained throughout the orbit mission to allow for the mandatory motion compensation during imaging.

The instrument operation schedule should allow for geometric and radiometric calibration, instrument alignment cross-calibration and performance tests.

6.1.5 INTERFACE AND PHYSICAL RESOURCE REQUIREMENTS

- Instrument size: 50 x 20 x 20 cm^3
- Total mass not exceeding 8 kg, incl. DPU

6.1.6 CALIBRATION

- Measurements of instrument alignment wrt the spacecraft coordinate system using star observations
- Radiometric calibration of the camera using star observations

6.1.7 CLEANLINESS, PLANETARY PROTECTION AND PRE-LAUNCH ACTIVITIES

- tbd.

6.1.8 CRITICAL ISSUES

The Star1000 sensor is known to withstand high radiation levels and does not require additional shielding. The electronics will rely on radiation-resistant parts.

6.1.9 HERITAGE

The camera optics may be based on a modified design of the optics of the SRC on Mars Express. The Star1000 has been used on the ExoMars PanCam HRC, for which breadboards are already available. The required Piezo-controls are also being developed for ExoMars PanCam..

6.1.10 OPEN TECHNOLOGY ISSUES AND CRITICALITY

- tbd.

6.1.11 INSTRUMENT SUMMARY DATA SHEET

Table 4 HRC summary table.

Parameter	**Unit**	**Value/Description**	**Remarks**
Heritage	N/A	SRC on Mars Express, DAWN camera, PanCam on ExoMars	
Type of instrument	N/A	Camera	operating in framing mode as well as in a

			dedicated pushbroom mode during orbit involving motion compensation
Type of optics	N/A	Reflective	
Function mode	N/A	Passive	
Optics			
Spectral range	nm	350 - 1050	tbc.
FOV	deg	0.293	
Pixel IFOV	mrad	0.005	
Wavelength for diff. limit	nm		
Aperture	mm	200	
Focal length	mm	3000	very large f !
f/#	#		
Filters	#	1	panchromatic
Filter bandwidth	nm	700	
Detector			
Type of detector	N/A	CMOS Star1000	
Pixel lines in array	#	1024	
Pixels per array line	#	1024	
Pixel size	µm	15	
Exposure time	msec	1-2000	
Repeat time	msec		
Operating temperature	°C		
Operating temperature stability	°C/h		
A/D conversion	bit/pix	12	
Full well capacity	Ke^{-}		
Readout time	msec	1	
Swath and Resolution			
Swath width	km	1	from 200 km
Spectral sampling	nm		
Spatial pixel resolution	m	1 m	from 200 km
Thermal Control			
Total surface area	cm^2		
Non-isolated area	W		
Operating temperature	°C		
Operating temperature stability	°C/h		
Physical			
Preferred location	N/A	Nadir-pointed platform	
Mass, total	kg	< 8	Optics: 5 kg, Sensor: 1

			kg, Electronics: 1 kg (1 kg spare)
Power			
Total average power	W	<15	Sensor: 1 W, Piezo Drive: 1-2 W, DPU: 5-10 W, Thermal Control: 1-2 W
Detector + electronics	W	~6-13	
TE cooler	W	~1-2	
Data Rate & Volume			
Data volume (total)	Gbyte	200	= 300 000 images (2 Mb each)
Data rate (instantaneous)	kbyte/s	5000	5 images in 2 seconds max overall average of 25 kbits/s during cruise 75 kbits/s during 200 days of orbit phase, joint with WAC
Compression factor	#	3	(included in total volume estimate)

6.1.12 SUMMARY OF ALIGNMENT AND POINTING REQUIREMENTS

Table 5 Summary of instrument alignment and pointing requirements. Note that in case more than one angle is listed, the sequence is pitch, roll, yaw.

Instrument	Pixel size arcsec	FOV deg	Min. pixel readout time ms	APE arcmin	RPE arcsec/t	AMA arcsec	Pre-facto knowledge of co-alignment with reference arcsec	Co-alignment stability arcsec/t	Post facto knowledge of co-alignment with reference arcsec
HRC	1.03	0.293							

6.2 Medium Resolution Camera (MRC)

6.2.1 SCIENCE GOALS AND PERFORMANCE REQUIREMENTS

The orbiter camera will mainly contribute to the characterization of Ganymede in the areas of planetary geology, geodesy, and geophysics.

Science Goals

Satellites:
- Studies of Callisto, Europa, and Ganymede in areas along the flyby trajectory

Ganymede:
- Global geodetic studies (shape, rotation, librations)
- Cartographic mapping (topography, color orthoimage maps)
- Geologic mapping, search for past or present geologic activity, and processes, determine surface ages
- Constrain mineralogical/chemical constituents of the near-surface layers

Performance Requirements
- Derive long color stereo imaging swaths at medium resolution (swath width: ~ 50 km, 50 m/pix @ 200 km)
- Derive a global basemap at 50 m/pix in stereo
- Derive a global topographic model at an effective resolution of 100 – 150 m
- Derive global 4-color maps at 200 m/pix (using macropixel formation)
- Obtain 4-color coverage for selected large areas, up to 50 m/pix
- Multiphase coverage for measurements of surface physical properties
- Allow for stereo analysis in combination with the HRC camera
- Nighttime imaging (surface illuminated by Jupiter)
- Imaging of the Altimeter Laser spot
- High dynamic range
- High signal-to-noise
- Allow for geometric and radiometric calibration
- Lifetime: 2 years in Ganymede orbit

6.2.2 INSTRUMENT CONCEPT

In Ganymede orbit, the camera will be the prime instrument for surface mapping. The camera will aim at the complete global coverage at a resolution of 50 m in stereo and at a resolution of 200 m in 4 colors. The camera sensor consists of one imaging array, equipped with 5 different color filters (incl. 1 panchromatic), operated in the push-broom mode.

Two identical copies of the camera will be flown, one of which is pointed towards nadir ("prime" camera), the other tilted forward in the flight direction for obtain stereo coverage.

Alternatively, only one camera copy will be flown. The spacecraft has to be tilted after the nominal mission to obtain the required stereo coverage.

The instrument will also be used for satellite imaging during close flybys of the Jupiter Tour, where the push-broom mode can be applied meaningfully.

6.2.3 INSTRUMENT DESCRIPTION

Each of the two instruments will consist essentially of a separate optics and a sensor system. The data processing unit will be shared by both cameras.

6.2.4 ORBIT, OPERATIONS AND POINTING REQUIREMENTS

Although the instrument will operate during Satellite flybys of the tour, its most important contribution is during the spacecraft orbit phase. The pointing prediction shall be sufficiently accurate to successfully point the camera at the targets within 10 pixels. The pointing shall be stable within the size of 1/3 image pixel during the typical exposure time of 0.5 s.

During orbit, the "prime" camera shall maintain nadir-pointing, whereas the other one is pointed by 20° forward in flight direction. If only the "prime" camera component is flown, the camera (i.e., the spacecraft) shall be tilted with respect to nadir by approx. 20° after the first complete mapping cycle to accomplish stereo coverage. Orbit information must be made available to the camera in real-time to allow the camera to adjust scan rates according to orbit height.

The direction of the motion vector must be held throughout the orbit mission and known a priori (to allow for push-broom imaging)

The instrument operation schedule should allow for geometric and radiometric calibration, instrument alignment cross-calibration and performance tests.

6.2.5 INTERFACE AND PHYSICAL RESOURCE REQUIREMENTS

- Instrument size: two telescopes, incl. sensors, each: 25 x 5 x 5 cm^3
- Total mass not exceeding 6 kg for two cameras, incl. DPU

6.2.6 CALIBRATION

- Verification of the alignment of the camera with the Laser by imaging of the Laser spot

- Measurements of instrument alignment with respect to the spacecraft coordinate system using star observations
- Radiometric calibration of the camera using star observations

6.2.7 CLEANLINESS, PLANETARY PROTECTION AND PRE-LAUNCH ACTIVITIES

- tbd.

6.2.8 CRITICAL ISSUES

The Star1000 sensor is known to withstand high radiation levels and does not require additional shielding. The electronics will rely on radiation-resistant parts.

6.2.9 HERITAGE

The camera may be based on the design of the HRSC on Mars Express, or the Symbio-SYS stereo camera, being prepared for BepiColombo. A new modified version of HRSC is currently being prepared for the German Lunar mission LEO

6.2.10 OPEN TECHNOLOGY ISSUES AND CRITICALITY

- tbd.

6.2.11 INSTRUMENT SUMMARY DATA SHEET

Table 6 MRC summary table.

Parameter	**Unit**	**Value/Description**	**Remarks**
Heritage	N/A	HRSC on Mars Express, SymbioSYS on BepiColombo	
Type of instrument	N/A	Pushbroom Scanner	
Type of optics	N/A	Refractive	
Function mode	N/A	Passive	
Optics			
Spectral range	nm	350 - 1050	
FOV	deg	14.7°	across-track
Pixel IFOV	mrad	0.25	
Wavelength for diff. limit	nm		
Aperture	mm	50	tbd.

Focal length	mm	60	
f/#	#		
Filters	#	4	1 panchromatic, 4 color (346, 532, 670, 986 nm)
Filter bandwidth	nm	~50	
Detector			
Type of detector	N/A	CMOS Star1000	
Pixel lines in array	#	1024	Array separated into 5 sections, covered with color filters, 1 panchromatic, 4 color
Pixels per array line	#	1024	
Pixel size	µm	15	
Exposure time	msec	1-2000	
Repeat time	msec	1	max
Operating temperature	°C		
Operating temperature stability	°C/h		
A/D conversion	bit/pix	12	
Full well capacity	Ke⁻		
Readout time	msec	1	
Swath and Resolution			
Swath width	km	50	from 200 km
Spectral sampling	nm		
Spatial pixel resolution	m	50	from 200 km
Thermal Control			
Total surface area	cm^2		
Non-isolated area	W		
Operating temperature	°C		
Operating temperature stability	°C/h		
Physical			
Preferred location	N/A	Nadir-pointed platform	
Mass, total	kg	< 6	Optics and sensors: 2 x 2 kg, Electronics: 1 kg (1 kg spare)
Power			
Total average power	W	13	Sensor: 1 W, DPU: 5-10 W, Thermal Control: 1-2 W
Detector + electronics	W	6-11	
TE cooler	W	1-2	

Data Rate & Volume			
Data volume (total)	Gbyte	200	50 Gbyte for Jupiter Tour, 150 Gbyte for Ganymede (75 Gbyte for global map sets, 75 Gbyte for targeting), compression factor included
Data rate (instantaneous)	kbyte/s	6250	Absolute max rate: assume 2 km/s == > 40 exposures/s per image line at 50m/pix. With 10 image lines (5 per camera) and 1000 pixels per line: 400,000 pixels/s. With 16 bits per pixel: 6.4 Mio bits/s, or 6250 kbyte/s before any compression ===== Overall average of 75 kbits/s transmission rate during 200 orbit days to meet basic science requirements. During cruise: TBD
Compression factor	#	3	(included in total volume estimate)

6.2.12 SUMMARY OF ALIGNMENT AND POINTING REQUIREMENTS

Table 7 Summary of instrument alignment and pointing requirements. Note that in case more than one angle is listed, the sequence is pitch, roll, yaw.

Instrument	Pixel size arcsec	FOV deg	Min. pixel readout time Ms	APE arcmin	RPE arcsec/t	AMA arcsec	Pre-facto knowledge of co-alignment with reference arcsec	Co-alignment stability arcsec/t	Post facto knowledge of co-alignment with reference arcsec
MRC	52	14.7							

6.3 Wide Angle Camera (WAC)

6.3.1 SCIENCE GOALS AND PERFORMANCE REQUIREMENTS

The orbiter camera will contribute to the characterization of the Satellites of the Iovian System, in particular in the areas of planetary geology, geodesy, and geophysics.

Science Goals

Satellites:

- Global shape mapping of Callisto, Europa, Ganymede, and Io (Limb analysis)
- Multispectral mapping to help discern geological formations and constrain compositions
- Help in spacecraft navigation by astrometric imaging (optical navigation)

Ganymede

- Provide context images during Ganymede orbit
- Multispectral mapping to help discern geological formations and constrain compositions

Performance Requirements

- Derive wide-angle snapshots of close targets with multiple colors
- Derive snapshots at low resolution for context (400 m/pix @ 200 km)
- Allow for astrometric measurements (high sensitivity and dynamics)
- High signal-to-noise
- Allow for geometric and radiometric calibration
- Lifetime: 2 years in Ganymede orbit

6.3.2 INSTRUMENT CONCEPT

The instrument is intended for satellite imaging during flybys of the Jupiter Tour. The camera will carry out wide-angle imaging for context during the Ganymede orbit phase. The camera sensor consists of an imaging array, operated conventionally. The camera is equipped with a filter wheel with 12 filters.

6.3.3 INSTRUMENT DESCRIPTION

The instrument will consist essentially of 3 components, the optics, the sensor system including the filter wheel, as well as a data processing unit. The DPU may be shared with the other onboard cameras.

6.3.4 ORBIT, OPERATIONS AND POINTING REQUIREMENTS

The instrument will operate during the Satellite tour as well as during the spacecraft orbit phase. The pointing prediction shall be sufficiently accurate and is certainly not a crucial constraint in comparison to the MRC and HRC cameras. The pointing shall be stable within the size of 1/3 image pixel during the typical exposure time of 0.5 s.

During orbit, the camera shall maintain nadir-pointing.

The instrument operation schedule should allow for geometric and radiometric calibration, instrument alignment cross-calibration and performance tests.

6.3.5 INTERFACE AND PHYSICAL RESOURCE REQUIREMENTS

- Instrument size: 10 x 10 x 10 cm^3
- Total mass not exceeding 1.5 kg

6.3.6 CALIBRATION

- Measurements of instrument alignment wrt the spacecraft coordinate system using star observations
- Radiometric calibration of the camera using star observations

6.3.7 CLEANLINESS, PLANETARY PROTECTION AND PRE-LAUNCH ACTIVITIES

- tbd.

6.3.8 CRITICAL ISSUES

The Star1000 sensor is known to withstand high radiation levels and does not require additional shielding. The electronics will rely on radiation-resistant parts.

6.3.9 HERITAGE

The camera will be based on a modified design of the SRC on Mars Express

6.3.10 OPEN TECHNOLOGY ISSUES AND CRITICALITY

- tbd.

6.3.11 INSTRUMENT SUMMARY DATA SHEET

Table 8 WAC summary table.

Parameter	**Unit**	**Value/Description**	**Remarks**
Heritage	N/A	SRC on Mars Express	
Type of instrument	N/A	Framing Camera	
Type of optics	N/A		
Function mode	N/A	Passive	
Optics			
Spectral range	nm	350 - 1050	
FOV	deg	117	
Pixel IFOV	mrad	2	
Wavelength for diff. limit	nm		
Aperture	mm	30	tbd.
Focal length	mm	8	
f/#	#		
Filters	#		tbd.
Filter bandwidth	nm		tbd.
Detector			
Type of detector	N/A	CMOS Star1000	
Pixel lines in array	#	1024	
Pixels per array line	#	1024	
Pixel size	µm	15	
Exposure time	msec	1-2000	
Repeat time	msec		
Operating temperature	°C		
Operating temperature stability	°C/h		
A/D conversion	bit/pix		
Full well capacity	Ke^-		
Readout time	msec	1	
Swath and Resolution			
Swath width	km	400	from 200 km
Spectral sampling	nm		
Spatial pixel resolution	m	400	from 200 km
Thermal Control			
Total surface area	cm^2		
Non-isolated area	W		
Operating temperature	°C		
Operating temperature stability	°C/h		

Physical			
Preferred location	N/A	Nadir-pointed platform	
Mass, total	kg	< 1	
Power			
Total average power	W	3	Sensor: 1 W, Thermal Control: 1-2 W
Detector + electronics	W	1	assume that DPU is shared with other cameras
TE cooler	W	1-2	
Data Rate & Volume			
Data volume (total)	Gbyte	20	= 30 000 images (2 Mb each)
Data rate (instantaneous)	kbyte/s	5000	5 images in 2 seconds max overall average of 25 kbits/s during cruise 75 kbits/s during 200 days of orbit phase, joint with NAC
Compression factor	#	3	(included in total volume estimate)

6.3.12 SUMMARY OF ALIGNMENT AND POINTING REQUIREMENTS

Table 9 Summary of instrument alignment and pointing requirements. Note that in case more than one angle is listed, the sequence is pitch, roll, yaw.

Instrument	Pixel size arcsec	FOV deg	Min. pixel readout time ms	APE arcmin	RPE arcsec/t	AMA arcsec	Pre-facto knowledge of co-alignment with reference arcsec	Co-alignment stability arcsec/t	Post facto knowledge of co-alignment with reference arcsec
HRC	412.5	117							

6.4 Laser Altimeter (MLA/LA)

6.4.1 SCIENCE GOALS AND PERFORMANCE REQUIREMENTS

A Laser altimeter will contribute to the characterization of the mission target in the areas of geodesy and geophysics, and will also be crucial for studies of the spacecraft orbit in the gravity field of satellite by providing accurate range data.

Science Goals and Performance Requirements
- Derive topographic profiles
- Derive a global shape model of the satellite
- Determine tidal deformation
- Assist in studies of geodetic parameters (e.g., coordinate system, rotation, librations)
- Assist in orbit determination and gravity data modeling
- Measure surface roughness and albedo (at the Laser wavelength)

Performance:
- High signal-to-noise for reliable pulse detections during night and day from a typical range of 200 km and at least up to 400 km above Ganymede and 300 km above Callisto.
- Range accuracy: <0.2 m (TBC)
- Laser footprint (from 200 km): 10 m (tbd.)
- Allow for surface roughness modeling (classical case, fall-back solution: pulse shape modeling)
- Lifetime: 1 year (TBC, depends on requirements by the mission timeline)

(see performance spread sheet below for more details)

6.4.2 INSTRUMENT CONCEPT

The instrument will measure the two-way travel time of a Laser pulse traveling from the instrument to the reflecting surface and back. Travel time measurements, combined with additional information on pointing and location of the Laser at the time of each pulse, will be used to construct geo-referenced topographic profiles along the ground track of the spacecraft. By interpolation, a global shape model will be derived from satellite-wide range measurements. Much emphasis will be placed on measuring temporal changes in the global shape due to tidal forces. Moreover, Laser altimetry enables to characterize physical key properties of the target surface within the laser footprint. For example, measurements of pulse amplitude and shape will yield the reflectivity of the surface along with local slope and surface roughness.

6.4.3 INSTRUMENT DESCRIPTION

The instrument will consist essentially of three components, (1) a Laser transmitter, (2) a Laser receiver with a receiver optics of approx. 10 cm aperture (baseline) or 25 cm aperture (fall-back), respectively, and (3) a data processing unit. The receiver optics can possibly be shared with the camera.

6.4.4 ORBIT, OPERATIONS AND POINTING REQUIREMENTS

The instrument will operate during the Ganymede science phase and in some extend during the Ganymede elliptical orbit phase and during the Callisto fly-by orbits. At Ganymede, the instrument is capable to operate up to a range of at least 400 km, at Callisto up to a range of at least 300 km. Usable ranges are smaller at Callisto due to the satellite's lower albedo.

The different albedos of Ganymede (0.44) and Callisto (0.19) have an impact on the instrument design esp. the link budget calculations. The diameter of the receiver telescope and the laser output energy have to be selected carefully. For the operation at Callisto, approx. 50% more laser energy is required than for the operation during the Ganymede science phase. This temporarily increased laser energy is technically realizable.

During the Ganymede science phase, it will typically fire at a rate of 175 Hz (baseline) resp. 8 Hz (fall-back). Nighttime observations and daytime observations (which have to overcome the solar background noise) are equally possible. The pointing shall be accurate to within the size of the Laser footprint. The instrument should also be capable for 2-way (offline) range measurements to terrestrial Laser stations for instrument alignment calibration, performance tests, and also, for clock calibration and range measurements which will support the tracking of the spacecraft and gravity field modeling.

6.4.5 INTERFACE AND PHYSICAL RESOURCE REQUIREMENTS

Baseline:
- 10 x 5 x 5 cm (tbc.)
- Total mass not exceeding 3.6 kg (incl. DPU)
-

Classical case, fall-back solution:
- 23 x 16 x 14 cm
- Total mass not exceeding 10 kg (incl. DPU)

6.4.6 CALIBRATION

- Verification of the alignment of transmitter and receiver using Earth ranging during cruise phase to Jupiter, if the laser altimeter is not obscured by other parts of the S/C
- Measurements of instrument alignment with respect to the spacecraft coordinate system, in particular the camera using star observations
- Radiometric calibration of the Laser receiver using star observations

6.4.7 CLEANLINESS, PLANETARY PROTECTION AND PRE-LAUNCH ACTIVITIES

- tbd.

6.4.8 CRITICAL ISSUES

Including limit to radiation tolerance and list of least tolerant radiation component(s)

- Receiver diode, laser pump diodes, laser rod, Q-switch, optical coatings are rad-hard up to 75 krad (BELA design for Mercury environment).

6.4.9 HERITAGE

As optical receiver systems are standard for space applications, the proper choice of the optical system is not critical. In contrast, the choice of an appropriate Laser drives the complexity of the instrument.

As the baseline, we consider the development of a next-generation Laser altimeter system, which is based on a compact micro lasers firing at kHz rates and a silicon APD, operated as photon-counting device. Such Laser systems now become operational in terrestrial airborne applications, and have been studied by a DLR-lead consortium under ESA contract in 2002 (LAPE: Laser Altimeter for Planetary Exploration). Such a new system would have size, mass, and power requirements dramatically reduced over traditional Laser ranging systems. However, besides the development and space qualification of the Laser, dedicated pulse detection and processing schemes must be developed.

As a backup, it is conceivable to fly a laser altimeter which is derived from BELA (BepiColombo Laser Altimeter). The BepiColombo Laser Altimeter (BELA) has been selected for flight on board the European Space Agency's BepiColombo Mercury Planetary Orbiter (MPO). This will be Europe's first planetary laser altimeter system. BELA is currently developed jointly by the University Berne and the German Aerospace Center. For the mission, the space-qualified transmitter from BELA could be adopted, while the receiver optical system could be reduced in size to account for the closer range to the target and the high reflectivity of the surface. Radiation issues are already addressed by BELA as it operates in the Mercury environment. Radiation-hard parts and technologies used for BELA (designed for 75 krad) will relieve the development for the JGO Laser Altimeter.

6.4.10 OPEN TECHNOLOGY ISSUES AND CRITICALITY

- Radiation hardness, lifetime of laser pump diodes, space-qualified receiver diode in Geiger mode.

6.4.11 INSTRUMENT SUMMARY DATA SHEET

Table 10 Laser Altimeter summary table.

Parameter	Unit	Value/Description		Remarks
Heritage	N/A	Airborne applications, LAPE Study for ESA	BELA	
Type of instrument	N/A	Micro Laser Altimeter, baseline	Laser Altimeter classic case, fall-back	
Type of optics	N/A	Cassegrain (tbc) or Galilean telescope (receiver and transmitter)	Cassegrain (receiver) and beam expander (transmitter)	
Function mode	N/A	active	active	
Optics				
Spectral range	nm	532 or 1064 nm	532 or 1064 nm	
FOV	deg	0.00575	0.0115	Receiver FOV twice the Laser spot size
Pixel IFOV	mrad	0.1	0.2	Receiver FOV
Wavelength	nm	532 or 1064 nm	532 or 1064 nm	
Aperture	mm	100	250	
Focal length	mm	1250	1250	
f/#	#	N/A	5	
Filters	#	532 or 1064 nm	532 or 1064 nm	
Filter bandwidth	nm	≤1 nm	≤1 nm	
Detector				
Type of detector	N/A	Si Avalanche Photo Diode in Geiger mode	Si Avalanche Photo Diode	
Pixel lines in array	#	1	1	
Pixels per array line	#	1	1	
Pixel size	µm	100	100	
Exposure time	msec	n.a	N/A	Dependent on pulse length
Repeat time	msec	<0.6	100	
Operating temperature	°C	-1 to +1	-1 to +1	Will be controlled by the instrument. No requirement to the S/C

Operating temperature stability	°C/h	1	1	Margin: ± 0.1 °C (diodes), ± 2 °C (filter)
A/D conversion	bit/pix	1	10	
Full well capacity	Ke$^-$			
Readout time	msec	<1	1	
Swath and Resolution				
Swath width	km	0.01	0.05	Laser footprint from 400 km altitude
Spectral sampling	nm	N/A	N/A	
Spatial pixel resolution	m	10	50	Laser footprint
Thermal Control				
Total surface area	cm^2	~1500cm^3	~2000 cm^2	
Non-isolated area	W	4	600 cm^2	
Operating temperature	°C	-20 to +50	-30 to +50	
Operating temperature stability	°C/h	20	20	At thermal reference point
Physical				
Preferred location	N/A	Nadir-pointing	Nadir-pointing	
Mass, total	kg	<3.5	<10	
Power				
Total average power	W	26	50	Primary power from S/C including efficiency loss in power converter
Detector + electronics	W	11	18	Detector + DPU
Laser system	W	8	15	
TE cooler	W	2	2	
Data Rate & Volume				
Data volume (total)	Gbyte	>2.5 (tbc)	>2.5 (tbc.)	Dependent on duration of Ganymede orbital phase
Data rate (instantaneous)	kbyte/s	11 kbyte/s	10	For MLA: 0.5 kbit/pulse = 87 kbit/s =11 kbyte/s for assumed 175 Hz pulse rate; multiplied by 175 Hz pulse rate gives approx. 40 kbyte/s
Compression factor	#	1	2	

6.5 Magnetometer (MAG)

6.5.1 SCIENCE GOALS AND PERFORMANCE REQUIREMENTS

6.5.2 INSTRUMENT CONCEPT

The magnetometer will measure the magnetic field in the spacecraft vicinity in the bandwidth DC to 64Hz, depending on science requirements and available telemetry. Magnetometers have considerable space heritage. Efforts are currently underway at magnetometer labs across the world to further reduce the resource requirements.

6.5.3 INSTRUMENT DESCRIPTION

The magnetometer consists of two sensors, which would be preferably boom mounted to minimise magnetic interference, and associated electronics located on the main equipment platform. Two sensors are preferred to facilitate operation as a gradiometer in order to separate the very small target ambient field from any magnetic disturbance field due to the orbiter fields.

The sensors would be a miniaturised fluxgate, which would draw on considerable space heritage and currently has a high TRL. The sensor electronics would either be of a digital FPGA based design which is currently being developed, or of an ASIC based design which would require further specific development but offers considerable reductions in instrument power.

The electronics is composed of the sensor front end electronics (FEE), DC/DC converter and data processing and interface unit (DPU). A stand alone MAG box would contain cards for each of these functions with a total mass of around 1kg (depending on radiation shielding level). To reduce the overall mass and power of the instrument, the magnetometer design is consistent with a centralised DPU and centralised DC/DC conversion supplying the FEE with regulated secondary voltages (e.g. +8V, -8V and 3.3V). In this scenario the FEE would stream data to the central DPU using a standard serial protocol, e.g. RS422.

6.5.4 ORBIT, OPERATIONS AND POINTING REQUIREMENTS

The magnetometer has no particular orbital requirements.

The operational requirements on an orbiter MAG is minimal and can be limited to a simple power-on/power-off and data rate commands if required. The MAG electronics will feature the capability to auto-range and oversample with the MAG electronics, delivering telemetry to the main DPU. It is desirable that MAG be switched on before other payload so that any unwanted magnetic signature of other instruments may be characterised.

The magnetometer has no pointing or active alignment requirements; however accurate knowledge of the sensor orientation at all times is required to meet the science requirement of accurate knowledge of magnetic field direction. Stable alignment between the sensor mounting point and the nominal probe pointing axis is assumed. This can be achieved using a rigid boom.

Several data rates can be envisaged for the MAG instrument, some possible modes are summarised in the table below. The Total Bits per second figure includes a housekeeping allocation of 50 bits per second.

Mode Name	Magnetic Field Vectors per second		Total Bits per second
	Primary Sensor	Secondary Sensor	
Normal	16	1	900
Burst	128	1	6500
Low	1	1	150

Table 11 MAG science modes data rates

6.5.5 INTERFACE AND PHYSICAL RESOURCE REQUIREMENTS

The magnetometer can operate in different modes to allow for different sampling rates and in different ranges depending on the required measurement range. The magnetic sensors should be positioned away from the main sources of stray field or near ferromagnetic materials. Ideally this would be accomplished with a dedicated MAG boom.

The sensors should be positioned at the tip and inwards of the tip of a spacecraft supplied rigid boom. For the harness mass figures given below we assume a boom length of 5m with the inboard sensor positioned at 2.5m. However boom length requirement is dependent on strength of spacecraft magnetic signature and science measurement requirements.

The need for dedicated MAG sensor heaters is TBD depending on thermal models and sensor technology developments (see Critical Issues). Instrument power figures do not include those of the sensor heaters which are typically of order 0.5 to 1W per sensor.

6.5.6 CALIBRATION

The magnetometer would be calibrated on the ground prior to launch. In-flight calibration will determine the spacecraft induced field, verify the extent to which the ground calibration remains valid and to quantify changes in calibration parameters. Determination of the spacecraft induced field requires the use of two separate magnetometer sensors acting as a gradiometer. This is the reason two sensors are included in the instrument specification. The lack of an absolute field reference in the form of a scalar magnetometer (e.g. Cassini) means the requirement for a second MAG sensor is critical in order to achieve the required measurement accuracy.

6.5.7 CLEANLINESS, PLANETARY PROTECTION AND PRE-LAUNCH ACTIVITIES

The magnetometer has no particulate or molecular cleanliness requirements. To avoid contamination of other instruments, the qualification and flight model electronics can be built in a Class 10000 clean room.

Minimisation of the magnetic interference at the site of the magnetometer sensors is highly desirable to maximise the scientific return from the instrument. Whilst strict magnetic cleanliness requirements may not be realistic, the MAG team believes that through the use of best practice and the control of magnetic materials, the magnetic cleanliness goals can be met.

A magnetometer is currently being planned for the ExoMars mission. To date no issues have been found which will prevent the construction and calibration of a magnetometer within the strict planetary protection requirements for the mission.

6.5.8 CRITICAL ISSUES

Due to considerable space heritage in Europe, the US and Japan, the construction of a magnetometer capable of delivering the science for an orbiter spacecraft in the Jovian environment has no critical issues. However, depending on the orbital trajectory of JGO and therefore how severe the Jovian radiation environment will be for this spacecraft it may be critical to design radiation tolerant flight systems & instrumentation. Work has already begun on this topic and it will need to be part of the assessment study to ensure a sufficiently high radiation hard magnetometer instrument for a Jupiter mission.

There is always the need to optimise use of power, mass, volume, data storage and transmission capabilities. Towards this end studies will be carried out on the feasibility of cold sensor operation (removing the need for heaters) as well as resource sharing between instruments. A 45% savings in both mass and power is estimated compared to a stand-alone MAG design.

Radiation tolerance of current designs is 100kRad without spot shielding. Subject to the right technology developments (e.g. availability of rad-hard FPGAs and ASIC)s, the electronics radiation tolerance should have increased to between 300 kRad to 1 MRad in the timeframe of JGO.

6.5.9 HERITAGE

Fluxgate magnetometers have considerable heritage on orbiting spacecraft including Ulysses, Cassini, Double Star, Rosetta, Venus Express and on the Rosetta lander.

6.5.10 OPEN TECHNOLOGY ISSUES AND CRITICALITY

No major technology issues and criticality in terms of instrument function. The main challenge is the JGO radiation environment and very low mass and power resource. This will require some dedicated magnetometer development activities.

6.5.11 INSTRUMENT SUMMARY DATA SHEET

Table 12 Magnetometer summary table.

Parameter	**Unit**	**Value/Description**	**Remarks**
Heritage	N/A	Cassini, Double Star, Venus Express	
Type of instrument	N/A	Tri-axial fluxgate magnetometer	Fluxgate sensors have significant heritage as science instruments.
Type of optics	N/A	No optics	
Function mode	N/A	Different modes for different data rates	
Optics – N/A			
Spectral range	Nm		
FOV	Deg		
Pixel IFOV	Mrad		
Wavelength for diff. limit	Nm		
Aperture	mm		
Focal length	mm		
f/#	#		
Filters	#		
Filter bandwidth	nm		
Detector			
Type of detector	N/A	Fluxgate	
Pixel lines in array	#		
Pixels per array line	#		
Pixel size	µm		
Exposure time	msec		
Repeat time	msec		
Operating temperature	°C	Sensor: -80 to 70 Electronics: -20 to 50	Current qualified temperature range - work is planned to investigate sensor operation down to lower temperatures
Operating temperature stability	°C/h		

A/D conversion	bit/vector	50 bit / vector	16 bit/axis, 3 axes plus 2 range bits
Full well capacity	Ke$^-$		
Readout time	msec		
Resolution			
Field range and resolution		Fluxgate +/- 128 nT @ 4pT resolution +/- 512 @ 16pT resolution +/- 2048 @ 64pT resolution +/- 8192 @ 256pT resolution +/- 32768 nT @ 1nT resolution +/- 65536 nT @ 2nT resolution	Suggested ranges based on 16 bit precision per axis. Resolutions below 4pT (fluxgate) are not recommended due to the inherent noise level of the sensors. It is advisable to select 4 of the given ranges to limit the range bit code to 2 bits.
Spectral sampling	nm		
Spatial pixel resolution	m		
Thermal Control			
Total surface area	cm^2	Each Fluxgate Sensor: 9 x 5 x 5 = 230cm^2 Stand-alone Electronics Box 16 x 13x 10 cm = 996cm^2 FEE Box: 16 x 13 x 5 = 706cm^2	MAG instrument has two sensors. Stand-alone box is composed of the FEE, DC/DC and DPU cards. FEE box assumes centralised power conversion and data processing.
Non-isolated area	W		
Operating temperature	°C		
Operating temperature stability	°C/h		
Physical			
Preferred location	N/A	Sensors boom mounted with electronics located on the Main Equipment platform.	MAG harness length should be minimized by locating MAG Electronics close to the boom root position.
Mass, total	kg	Standalone Electronics Box: 1.5kg FEE Box: 1.1kg	Each Fluxgate Sensor: 0.1kg Stand-alone Electronics Box 1.0kg FEE Box: 0.6kg Sensor Harness 0.3kg Harness (40g/m)

			assumes boom length of 5m. There are two sensors.
Power			
Total average power	W	Standalone Electronics Box: 1.5W FEE Box: 1.0W	Power figures for continuous operation of both sensors.
Detector + electronics	W		
TE cooler	W		
Data Rate & Volume			
Data volume (total)	Gbyte		
Data rate (instantaneous)	Bits/sec	900 (Normal Mode 16/1) 6500 (Burst Mode 128/1) 150 (Mode 1/1)	Burst Mode 128/1: 128Hz data from primary sensor, 1Hz data from secondary sensor. Mode 16/1: 16Hz data from primary sensor, 1Hz data from secondary sensor. Mode 1/1: 1Hz data from primary and secondary sensors.
Compression factor	#		No compression included in these figures.

6.6 Subsurface Radar (SSR)

6.6.1 SCIENCE GOALS AND PERFORMANCE REQUIREMENTS

The analysis of the Ganymede subsurface (and partially of the Callisto sub-surface) with a radar sounder instrument can bring new and detailed data of an icy body that, matched with the Europa data, will provide evidences and clues on the genesis and behavior of this exotic type of planetary body.

The analysis of a single body cannot provide the general and large-scale picture. Therefore, Europa data will be not enough to understand the genesis and evolution of these bodies. The comparative and synergetic analysis of two similar data sets from two different icy bodies (Europa and Ganymede) will reveal the fundamental variables and processes active in these bodies of the external Solar System. This analysis, to be significant, should be based on a set of subsurface profiles associates with a large coverage of both Europa and Ganymede.

The detailed scientific goals related to SSR instrument on Ganymede are:

Identification of the stratigraphic and structural patterns of Ganymede – a) Reconstruct the stratigraphic geometries of the ice strata and bodies and their internal relations, define the unconformities and identify the detailed processes of formation; b) Recognition, analysis and mapping of the tectonic features; c) inference and analysis of the material present in the subsurface and heir metamorphism linked to the burial process

Crustal behaviour – a) Utilising the stratigraphic and structural data identify the mode of accretion of the crust and its consumption matched by the deformational processes; b) Estimation of the ice depositional rate; c) identification of evidences for degassing of the Ganymede’s interior.

Matching the surface geology with subsurface features – synergetic analysis of the surface and subsurface geology in order to understand the depositional and tectonic processes active in the uppermost icy crust and infer in areas without radar data the subsurface nature

Global tectonic setting and Ganymede’s geological evolution – a) Understanding the large scale geological processes active in the Ganymede at the global scale; b) Global map of the different geological realms based on the surface and subsurface geology; c) reconstruction of the geological evolution of Ganymede

Comparison between Ganymede and Europa – Definition of the differences and common geological patterns of the two planetary bodies leading to a better understanding of the general development of the icy bodies and the geological principles on which the icy bodies formation evolution are based.

Altimetry on Ganymede – The radar sounder is a low-frequency altimeter. Thus, such an instrument results in the acquisition of surface altimetry data at moderate resolution (vertical resolution of about 10 m, footprint of hundreds of meters depending on the specific radar design and frequency).

Some of the aforementioned goals (when pertinent) can be considered also for **Callisto** even if with minor emphasis due to the different acquisition conditions (non-circular orbit) and volume of data collected. In fact, it is expected that the SSR instrument will operate also during the Callisto flybys.

The main requirements on the measures are related to identify and locally characterize physical subsurface horizons by obtaining sounding profiles of subsurface thermal, compositional, or structural horizons at depths between 100 m and 3-4 km at relatively high vertical resolution (in the order of 10 m in free space).

The SSR instrument can achieve different tradeoff between penetration capability and vertical resolution by exchanging the vertical resolution with the gain of the system.

6.6.2 INSTRUMENT CONCEPT

The proposed instrument is a radar sounder system at low frequency (between 20 MHz and 50 MHz). The sounder system is based on a robust and mature technology that was already used successfully for two different Mars Missions (MARS Express, with the MARSIS instrument; NASA Reconnaissance Orbiter with SHARAD).

A radar sounder, thanks to the relatively low frequency of its pulse, has the capability to penetrate the surface and to perform a sub-surface analysis with a penetration ability of few kilometres (which depends on the specific selected central frequency of the pulse) with a vertical resolution in the order of some meters (this requirement mainly depends on the bandwidth of the signal).

The choice of the central frequency for the SSR on JGO should take into account the following parameters:

- A single frequency sounder is appropriate for Jupiter Ganymede Orbiter, since this represents a good tradeoff between possible scientific goals and complexity of the system (a dual frequency system will increase the complexity of the system and the mass).
- The radiation noise should not be critical at the Ganymede place and on other satellites far from Jupiter. Anyway it is sensibly higher at frequencies below 20 MHz. As a consequence, for the design of a relatively simple system (good SNR with limited DC power), a frequency between 20 MHz and 50 MHz should be used.
- A higher frequency results in less critical constraints for the design of the antenna than a lower frequency.

6.6.3 INSTRUMENT DESCRIPTION

The instrument has an architecture similar to that of the radar sounder SHARAD. It is made up of the antenna, the transmitter, the receiver, and the digital system.

The geometrical resolution in the across-track direction depends on the orbiter altitude. This means that we expect different resolutions when different operational mode are considered (circular orbit around Ganymede and flybys). In the along-track direction the antenna beamwidth is very broad thus resulting in much ambiguous energy being returned to the sensor. Nonetheless, these returns have slightly different Doppler shifts from those coming back from the nadir direction due to the motion of the satellite. Therefore a Doppler processing can be applied to sharpen the horizontal resolution and cut off along track clutter echoes. However, a high pulse repetition frequency (PRF) is required in that case to correctly sample the surface Doppler spectrum.

The sounder can range between different intervals of depths depending on the choice of the central frequency. We can expect to have a minimum depth of about 3 Km at about 50 MHz (with a range resolution of 10 m in the vacuum).

The dipole antenna would have a length of about 10 m in the assumption to use a central frequency of 20 MHz. This requires the development of proper mechanisms for antenna deployment. However, the length of the antenna is not critical also with respect to the available heritage (MARSIS antenna was much longer than the SSR one). The length of the antenna could be reduced by increasing the central frequency with respect to 20 MHz (estimated length 4 m at 50 MHz).

Table 13: Key characteristics of the Subsurface Radar

Orbiter altitude	200 Km (in the circular phase around Ganymede)
Transmitted central frequency	In the range 20-50 MHz
Transmitted bandwidth	10 MHz
Antenna dimension	< 10 m
Peak transmitted power	20 W
Along track resolution	<1 km
Across track resolution	< 5 Km
Penetration depth	< 5 Km
Vertical resolution	10 m (vacuum)
Data rate	300 kbps
Mass (without antenna)	10 kg
Pointing requirements	±5° for optimal measurements

The radar sounder can be used also in altimetry mode with a moderate resolution.

6.6.4 ORBIT, OPERATIONS AND POINTING REQUIREMENTS

The SSR instrument is nadir-looking radar sounder. The antenna should illuminate the surface according to a nadir view. The optimal conditions for the measurements are associated with a nadir pointing with an accuracy of ±5°.

It is expected that the SSR instrument does not operate continuously for limit data volume acquired. The acquisition strategy should be defined taking into account both the data rate of the other remote sensing instruments on the JGO and also the synergy with the sounder on board of the JEO (integrated and inter-calibrated analysis).

The SSR, being an active instrument, does not pose any constraint with the illumination conditions of Ganymede or Callisto.

The expected processed data rate is of about 300 Kbps.

6.6.5 INTERFACE AND PHYSICAL RESOURCE REQUIREMENTS

The sounder poses some configuration requirements related the accommodation of the radar antenna on the spacecraft. The risk of collision with any other instrument should be adequately investigated. Also the position of the antenna on the orbiter should be properly defined and the deployment issues evaluated in the entire mission.

The possibility to have external memory mass and external on-board raw data processing capability should be evaluated for compressing the volume of data acquired by the instrument.

6.6.6 CALIBRATION

No critical issues have been identified.

6.6.7 CLEANLINESS, PLANETARY PROTECTION AND PRE-LAUNCH ACTIVITIES

No critical issues have been identified.

6.6.8 CRITICAL ISSUES

The Jupiter radiation is a critical source of noise for the Jupiter Europa Orbiter. However, it seems less critical for the radar on the Jupiter Ganymede Orbiter. Nonetheless, a refined model of the Jupiter radiation noise should be defined for an adequate choice of the central frequency of the sounder capable to achieve a good signal to noise ratio (SNR).

6.6.9 HERITAGE

There are different experiences related to the use of a sounder from an orbiter, like MARSIS [1] and SHARAD [2] radar sounders orbiting around Mars. These experiences pointed out that the technology available, the signal processing capabilities, and the expertise gained in the scientific analysis of the data are more than mature to support such a possible mission to Europe. MARSIS is operative since July 2005 and SHARAD since November 2006. They are both continuously providing excellent data that have been used by the scientific community to make very important assessments on the subsurface of Mars and mainly on the polar layered deposits.

[1] R. Seu *et al.* "Performance and surface scattering models for the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS)", Planetary and Space Science 52 (2004) 149 – 156.
[2] R. Seu *et al.* "SHARAD: The MRO 2005 shallow radar", Planetary and Space Science 52 (2004) 157 – 166.

6.6.10 OPEN TECHNOLOGY ISSUES AND CRITICALITY

Technological developments are necessary for developing the antenna in Europe. No other open technology issues and criticality are identified.

6.6.11 INSTRUMENT SUMMARY DATA SHEET

Table 14 SSR summary table.

Parameter	**Unit**	**Value/Description**	**Remarks**
Heritage	N/A	SHARAD, MARSIS	
Type of instrument	N/A	Radar Sounder	
Type of optics	N/A	N/A	
Function mode	N/A	Active	
Optics			
Spectral range	Nm	20 MHz-50 MHz	
FOV	Deg	1 Km x 10 Km (TBC)	
Pixel IFOV	Mrad	N/A	
Wavelength for diff. limit	Nm	N/A	
Aperture	Mm	N/A	
Focal length	Mm	N/A	
f/#	#	N/A	
Filters	#	N/A	
Filter bandwidth	Nm	N/A	
Detector			
Type of detector	N/A	N/A	
Pixel lines in array	#	N/A	

Pixels per array line	#	N/A	
Pixel size	µm	N/A	
Exposure time	Msec	N/A	
Repeat time	Msec	N/A	
Operating temperature	°C	N/A	
Operating temperature stability	°C/h	N/A	
A/D conversion	bit/pix	N/A	
Full well capacity	Ke$^-$	N/A	
Readout time	Msec	N/A	
Swath and Resolution			
Swath width	Km	N/A	
Spectral sampling	Nm	N/A	
Spatial pixel resolution	M	N/A	
Thermal Control			
Total surface area	cm^2	N/A	
Non-isolated area	W	N/A	
Operating temperature	°C	N/A	
Operating temperature stability	°C/h	N/A	
Physical			
Preferred location	N/A	N/A	
Mass, total	Kg	10	
Power			
Total average power	W	20	
Detector + electronics	W	N/A	
TE cooler	W	N/A	
Data Rate & Volume			
Data volume (total)	Gbyte	TBD	
Data rate (instantaneous)	kbps	300	
Compression factor	#	TBD	

6.6.12 SUMMARY OF ALIGNMENT AND POINTING REQUIREMENTS

Table 15 Summary of instrument alignment and pointing requirements. Note that in case more than one angle is listed, the sequence is pitch, roll, yaw.

Instrument	Pixel size	FOV deg	Min. pixel	APE arcmin	RPE arcsec/t	AMA arcsec	Pre-facto knowledge	Co-alignment	Post facto knowledge

	arcsec		readout time Ms				of co-alignment with reference arcsec	stability arcsec/t	of co-alignment with reference arcsec
SSR	TBD								

6.7 Radio Science Transponder (JRST)

6.7.1 SCIENCE GOALS AND PERFORMANCE REQUIREMENTS

The science goals can be grouped in the following three areas:

1. **Galilean Satellites**: What is the interior structure and composition of the Galilean satellites? Our goal is to understand the different evolutionary paths of the Galilean Satellites.
2. **Life**: Do subsurface oceans exist in Ganymede and Callisto? We will search for physical conditions in the Jovian satellite system suitable for life to evolve and for evidence of life.
3. **System**: What is the role of interactions between the satellites and between Jupiter and its satellites on the dynamics and evolution of the Jupiter system? Characterize tides in the Jovian system. How did the small inner satellites, the ring system, and the small outer satellites evolve?

To achieve the above-listed science goals, a combination of different instrument measurements shall be needed. As far as the Radio Science payload is concerned, the following objectives were identified and ordered thematically (not by priority):

1. Objective: **Investigate the deep interior of the Galilean Satellites**

Analysis of the static gravity field

The degree-two static gravity field of the Galilean satellites has been determined with a precision of a few percent from a few close flybys by the Galileo mission. To separate zonal and sectorial gravity (J_2 and C_{22}) and estimate deviations from hydrostatic equilibrium, different flyby geometries (polar and equatorial) are needed for the JPO. This was only done for Io, by Galileo. With JRST, the gravity fields will be determined more precisely and extended to higher degree. Local mass anomalies, as observed on Ganymede by Galileo, could be detected and characterized from close flybys.

2. Objective: **Determine the existence and location of subsurface oceans of Ganymede and Callisto**

In the following we will focus on Ganymede and Callisto because Europa will be addressed by NASA Jupiter Europa Orbiter (JEO).

i) Measure the tidal response of Ganymede, and Callisto

Since the tides of a Galilean satellite with an ocean beneath an icy shell are at least five times larger than for the satellite without ocean, tidal observations are especially suited for proving the existence of subsurface oceans. The large, still undetected, tides of Ganymede and Callisto, with estimated amplitudes of about 7 m and 5 m if a subsurface ocean exists, will be measured from their gravitational perturbations on the spacecraft during flybys. An orbit accuracy of about 10 meters (TBC) will allow detection of such oceans. Characterization of the thickness of the icy shell requires meter-level accuracy of the relative orbit, which can be achieved by a combination of Doppler tracking and PN-ranging at Ka-band. As a minimum, two gravity-dedicated flybys for each body need to be planned at different tidal phases. Further flybys will improve the accuracy and are desirable. If an orbital phase is implemented (on Ganymede, for example, at S/C end of life), more accurate measurements of both the tidal gravitational perturbations and surface tidal displacements will be possible.

ii) Determination of the amplitude of forced libration and obliquity
The estimated 15 m and 11 m libration amplitudes of Ganymede and Callisto together with their obliquities can be characterized with an orbiter. This may require a high-resolution camera and a star-tracker, besides radio-tracking. Libration data give information on the existence of a subsurface ocean and the thickness of the icy shell. The knowledge of obliquity is essential for the determination of the degree of differentiation of the satellites.

3. Objective: **Characterize the effects on the Galileian satellites orbital evolution**

Jupiter's energy of rotation, which is transferred to the satellites mainly via tidal interaction between Jupiter and Io is an important energy source for the satellites. Due to the Laplace resonance energy and orbital angular momentum gained by Io is distributed among Io, Europa, and Ganymede. A part of the energy is dissipated in Io's interior (source for volcanic activity) and to a lesser degree also in Europa. The dissipation in Europa is crucial for the energy available for biological evolution inside a putative ocean. The Laplace resonance forces the orbital eccentricities and keeps dissipation within Io and Europa ongoing on geologic timescales (important for time being available for possible biological evolution in the ocean). Such an interaction between strong tidal forces and resonances, leading to volcanic activity (Io) and possibly subsurface oceans (Europa and Ganymede) is unique in the solar system.

i) Determine long-term changes of the orbits of the Galilean satellites
At present the rate at which the orbits change due to tides is not well determined. There is e.g. no consensus on whether Io's orbit is shrinking (due to dissipation within Io) or expanding (due to dissipation in Jupiter). The rate at which the orbits evolve will be determined to estimate the tidal dissipation in Io and Jupiter and to constrain the orbital history of the satellites in the Laplace resonance. This will be helpful to investigate the origin of the resonance (primordial, or tidal evolution after satellite formation). The combination of ranging data and Doppler tracking of JPO during flybys and in orbit helps constraining the ephemerides of the satellites.

Instrument rationale

The goal of the JRST is to provide a two-way coherent link from/to an Earth Deep Space antenna. The JRST will be able to generate both Doppler and ranging measurements. In particular the ranging measurement can be as accurate as 20-30 cm (two way) using the same transponder technology used for the BepiColombo Ka-band Radio Science payload. Two-way tracking of a planetary orbiter will provide an excellent tool to estimate, with very high accuracy, the mass and gravity field of Jupiter, Callisto and Ganymede. For atmospheric science, the Ka-band system can be used in one-way mode, provided a USO (Ultra Stable Oscillator) will be present on-board. See the following Section for details on the science goals and USO description for atmospheric science.

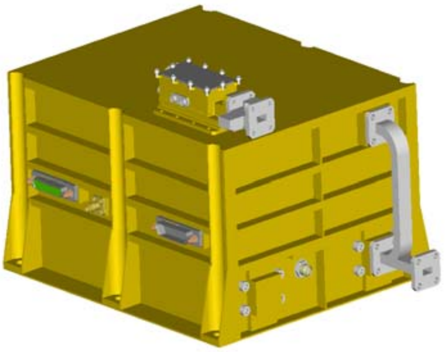
6.7.2 INSTRUMENT CONCEPT

The Ka-band JRST ensures the onboard reception of a Ka-band radio signal and its coherent retransmission to Earth. This instrument does not produce any telemetry (but a few housekeeping data), as the measurements are actually carried out by the ground station. The main observable quantities are the spacecraft range (accurate to about 30 cm, two-way) and range rate (to 1.5 microns/s at 1000 s integration times), exploiting the microwave radio links to and from the spacecraft. Range rate is measured from the Doppler shift of an electromagnetic wave transmitted from ground, received by the spacecraft and coherently retransmitted back to ground. Spacecraft range is obtained from the measurement of the time delay between transmission and reception of a known modulation of the carrier. In order to minimize measurement errors, all elements intervening in the generation, transmission and reception of the signal must preserve the coherence of the carrier and tone phases.

6.7.3 INSTRUMENT DESCRIPTION

The Ka-Band JRST specifications are very similar, if not identical, to those for the BepiColombo Ka-band transponder, summarized in the table below. The main differences between the BepiColombo KaT and the Ka-band JRST are in the mass and power consumption. New microelectronics technologies currently being developed in the EU allows significant reductions in the power consumption, , and in the total instrument mass. Current best estimates are ~ 2 kg for the mass and about 30W for the power consumption (including an internal Solid State Power Amplifier) based on a provisional link budget.

Table 16: Key characteristics of the BepiColombo Ka-band transponder

	**Objectives**	1) to support the mission objectives in geodesy, geophysics and fundamental physics 2) to coherently receive from and retransmit to ground a Ka-band carrier and a modulation tone up to 20 MHz 3) to enable high accuracy Doppler and ranging measurements
	General description	Coherent Ka/Ka Band frequency transponder enabling Doppler and ranging measurement
	Uplink frequency	34.38422 GHz (TBC)
	Downlink frequency	32.10085 GHz (TBC)
	Allan Deviation	< 10^{-15} (t=1000sec)
	Ranging Channel characteristics	PN Code with on-board calibration
	Chip rate	24 Mcps maximum (TBC)
	Group Delay calibration accuracy	better than ±0.2nSec (TBC)
	Group Delay stability (after calibration)	better than ±0.4nSec (TBC)
	DC power consumption	<40W
	Mass	<3.30Kg

- Receiver based on single-conversion approach with fixed IF @ 15F1 (~143.2 MHz):
  - Very compact implementation;
  - IF section phase shift vs. frequency does not affect the Allan Deviation performance;
  - SAW filter bandwidth: 4 MHz (centre frequency ~ 143.2 MHz)

- Transmitter based on direct Ka-Band frequency synthesis obtained by means of a X-Band PLL followed by x4 frequency multiplier:
  - Very compact implementation.
  - Optimum phase noise performance.

- Dedicated DC/DC Converter for Translator and SSPA functions

- The digital module is based on the KaT ASIC implemented in 0.18μ technology (ATMEL foundry)

A preliminary architecture for the Ka-band JRST is shown in the following Figure 1.

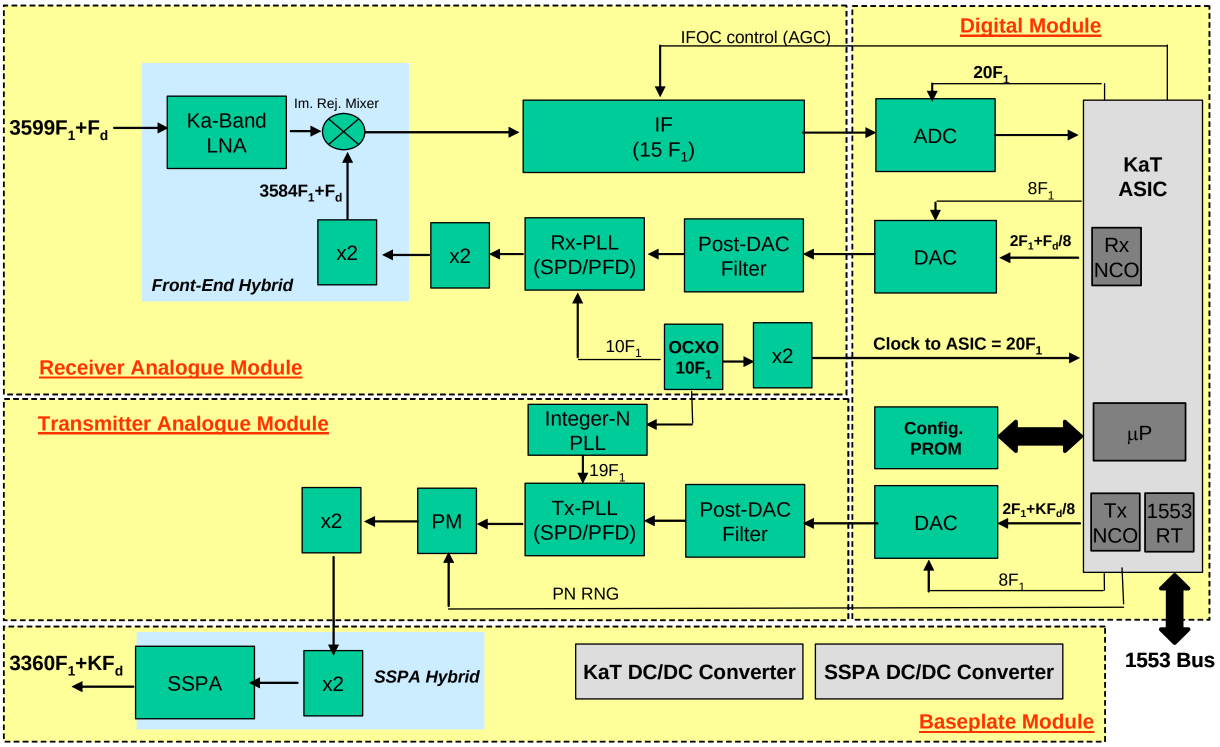


Figure 1: Architectural Design of the BepiColombo Ka-Band transponder

6.7.4 ORBIT, OPERATIONS AND POINTING REQUIREMENTS

6.7.4.1 Orbits:

For the estimation of Jupiter gravity field a high inclination orbit is highly desirable. For the estimation of the gravity field of Callisto and Ganymede, the current Mission Design foresees three phases (Callisto pseudo-orbits, Ganymede elliptical orbits and Ganymede circular orbits) which can guarantee a very accurate mapping of their gravity field, together with the determination of the existence and location of subsurface oceans.

6.7.4.2 Operations:

Data rate is a minor issue, as a Radio Science Transponder generates a very small amount of telemetry data corresponding to housekeeping information (temperature, status, lock, etc.) of the transponder.
The best performance of the Ka-band JRST is obtained when simultaneous transmission and reception both at X-band and Ka-band are carried out. In particular, the on-board S/C configuration should allow that a received X-band carrier is both retransmitted back to the Earth in phase-coherent mode and translated to Ka-band and transmitted to the Earth (Ka1 link) together with the Ka-band carried directly translated by the JRST (Ka2 link), as illustrated in the following Figure 2.

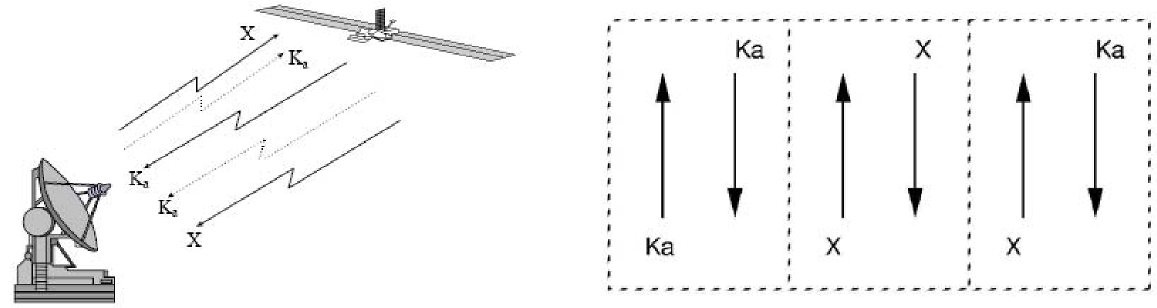


Figure 2: Triple link - X/X, X/Ka (Ka1) and Ka/Ka (Ka2) - operations proposed for the JGO

In order to allow the previous scheme to be implemented, the Ground Antennas must be capable of simultaneous transmission and reception at X- and Ka-band, both for the carrier and a modulated signal (for ranging measurements). Moreover, on-board the S/C, the following Communication system can be envisaged (in yellow, the JRST payload) (see Figure 3)

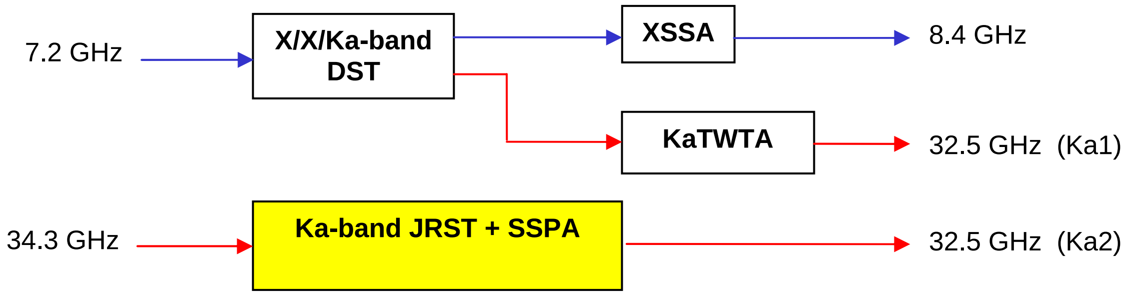


Figure 3: JGO proposed on-board Communication system configuration

6.7.4.3 *Pointing Requirements:*

During JGO two-way tracking for Doppler and ranging measurements, the following requirements apply:

- The S/C shall be three axis stabilized, controlled by momentum wheels (no thruster firings) in order to avoid introducing unmodeled ΔV on the S/C centre of mass;
- Momentum wheels unloading (desaturation) manoeuvres shall be executed outside tracking intervals dedicated to Radio Science;
- The High Gain Antenna shall be constantly pointed toward the Earth throughout the entire RS observations in order to guarantee continuous tracking;

The S/C angular speed around the HGA axis shall be controlled to zero angular velocity during RS observations in order to avoid introducing Doppler signatures due to circular polarization of the radio signals. There is no requirement on the (constant) attitude angle about the HGA antenna, so this can be optimized for other (power? remote sensing?) S/C requirements.

6.7.5 INTERFACE AND PHYSICAL RESOURCE REQUIREMENTS

Interfaces are:

1) Power connection
2) Antenna connection
3) On-board computer connection (for telecommands and telemetry data exchange)

6.7.6 CALIBRATION

Ground (pre-flight) calibration of the whole instrument and in-flight calibration of the ranging system.

6.7.7 CLEANLINESS, PLANETARY PROTECTION AND PRE-LAUNCH ACTIVITIES

None

6.7.8 CRITICAL ISSUES

None. Radiation tolerance for the JRST has been already assessed in the context of the JUNO studies. Additional work will be needed for radiation tolerance assessment, in the case where close flybys with satellites close to Jupiter will be performed (Io, Europa).

6.7.9 HERITAGE

Radio Science instrumentation onboard Cassini, BepiColombo and Juno. Ka-band transponders were developed (or are currently under development) for these missions. Thanks to new technology developments the mass and power needed for this instrument to work can be significantly reduced, leading to the values shown in the Table below.

6.7.10 OPEN TECHNOLOGY ISSUES AND CRITICALITY

The unit being designed in the context of the JUNO mission is tolerant to a total dose of 100 kRad, with a possible reduction to 75 kRad, during active life. Its duty cycle is however very low, as it is used only during the short Jupiter pericenter passes. In the case of the JUNO S/C, the (small) vault where the unit is hosted provides good protection.

6.7.11 INSTRUMENT SUMMARY DATA SHEET

Table 17 JRST summary table.

Parameter	Unit	Value/Description	Remarks
Heritage	N/A	Cassini, BepiColombo and Juno	
Type of instrument	N/A	Ka-band transponder with Doppler and Ranging capabilities	
Type of optics	N/A	N/A	
Function mode	N/A	N/A	
Optics			
Spectral range	nm	N/A	
FOV	deg	N/A	
Pixel IFOV	mrad	N/A	
Wavelength for diff. limit	nm	N/A	
Aperture	mm	N/A	
Focal length	mm	N/A	
f/#	#	N/A	
Filters	#	N/A	
Filter bandwidth	nm	N/A	
Detector			
Type of detector	N/A	N/A	
Pixel lines in array	#	N/A	

Pixels per array line	#	N/A	
Pixel size	µm	N/A	
Exposure time	msec	N/A	
Repeat time	msec	N/A	
Operating temperature	°C	N/A	
Operating temperature stability	°C/h	N/A	
A/D conversion	bit/pix	N/A	
Full well capacity	Ke$^-$	N/A	
Readout time	msec	N/A	
Swath and Resolution			
Swath width	km	N/A	
Spectral sampling	nm	N/A	
Spatial pixel resolution	m	N/A	
Thermal Control			
Total surface area	cm^2	TBD	
Non-isolated area	W	TBD	
Operating temperature	°C	-25 ÷ 60	
Operating temperature stability	°C/h	TBD	
Physical			
Preferred location	N/A	No preference	
Mass, total	kg	~ 2	
Power			
Total average power	W	30 (TBC)	
Detector + electronics	W	N/A	
TE cooler	W		
Data Rate & Volume			
Data volume (total)	Gbyte	TBD	
Data rate (instantaneous)	kbyte/s	TBD	
Compression factor	#	N/A	

6.8 Ultrastable Oscillator (USO)

6.8.1 SCIENCE GOALS AND PERFORMANCE REQUIREMENTS

The scientific goal is the sounding of the Jupiter atmosphere prior and after Earth occultations, that means when the spacecraft seems to disappear and reappear from behind the planetary disk as seen from the Earth.

The ionospheric electron density profile and the temperature, pressure and neutral density profiles in the neutral atmosphere can be derived from the bending of the radio ray path. The sensitivity of this method is < 1000 10^6 el/m^3 in the ionosphere (tbc) and the altitude coverage in the neutral atmosphere may start from a few pascals down to approximately 3000 hPa as experienced in the Venus atmosphere by Venus Express. At Jupiter, however, radio signals at X-band may already be extinguished at the 660 hPa level, potentially by ammonia (Lindal et al., 1981).

In order to assess the above sensitivities, a USO stability of $\boxed{\frac{\delta f}{f_0} \square 10^{-13}}$ is required and achieved by the USOs on Rosetta and Venus Express.

6.8.2 INSTRUMENT CONCEPT

The USO is connected to the spacecraft transponders. The purpose of the Ultrastable Oscillator is to provide a highly stable reference source for the transmission of radio signals by the spacecraft transponder in the one-way mode. The radio signal(s) is (are) recorded on the Earth.

6.8.3 INSTRUMENT DESCRIPTION

TBD

6.8.4 ORBIT, OPERATIONS AND POINTING REQUIREMENTS

The one-way mode transmission allows observing the ingress into as well as the egress from occultation. An inclined orbit will lead to occultation ingress and egress locations on opposite hemispheres. The High Gain Antenna needs to be pointed toward the Earth. The observation starts and ends a sufficient time before (after) the ionosphere/atmosphere has a sensible influence on the radio propagation. For Mars and Venus this is typically 20 minutes, for Jupiter this is tbd.

The receiver settings (sample rates, loop band width, etc.) in the ground station need to be properly addressed.

6.8.5 INTERFACE AND PHYSICAL RESOURCE REQUIREMENTS

Interfaces are:

Power connection
Transponder connection

HK data port

6.8.6 CALIBRATION

Phase noise and stability of the USO have to be determined on unit, subsystem and system level during ground tests. Stability and frequency drift have to be regularly determined during cruise (typically every six months).

6.8.7 CLEANLINESS, PLANETARY PROTECTION AND PRE-LAUNCH ACTIVITIES

n/a

6.8.8 CRITICAL ISSUES

Radiation tolerance may be a critical topic. This needs to be assessed.

6.8.9 HERITAGE

The USO is currently flying and is in operation with Rosetta and Venus Express. The same USO will also be part of the payload of the Japanese Planet-C spacecraft to Venus.

6.8.10 OPEN TECHNOLOGY ISSUES AND CRITICALITY

According to the radiation tolerance analysis performed for the VEX mission, a total dose of 30kRad is considered tolerable for the crystal. This analysis was done for the VEX mission assuming a S/C shielding of 1 mm Al equivalent. A similar assessment could be done for a typical orbit about Jupiter with the typical shielding assumed for all other instruments.

6.8.11 INSTRUMENT SUMMARY DATA SHEET

Table 18 USO summary table.

Parameter	**Unit**	**Value/Description**	**Remarks**
Heritage	N/A	ERS Rosetta Venus Express	
Type of instrument	N/A	Ultrastable Oscillator	
Type of optics	N/A	N/A	
Function mode	N/A		
Optics			
Spectral range	nm	N/A	
FOV	deg	N/A	
Pixel IFOV	mrad	N/A	
Wavelength for diff. limit	nm	N/A	
Aperture	mm	N/A	

Focal length	mm	N/A	
f/#	#	N/A	
Filters	#	N/A	
Filter bandwidth	nm	N/A	
Detector			
Type of detector	N/A	N/A	
Pixel lines in array	#	N/A	
Pixels per array line	#	N/A	
Pixel size	µm	N/A	
Exposure time	msec	N/A	
Repeat time	msec	N/A	
Operating temperature	°C	N/A	
Operating temperature stability	°C/h	N/A	
A/D conversion	bit/pix	N/A	
Full well capacity	Ke⁻	N/A	
Readout time	msec	N/A	
Swath and Resolution			
Swath width	km	N/A	
Spectral sampling	nm	N/A	
Spatial pixel resolution	m	N/A	
Thermal Control			
Total surface area	cm^2	TBD	
Non-isolated area	W	TBD	
Operating temperature	°C	-20 ÷ +50	
Switch-on temperature	°C	-30 ÷ +50	
Non-operating temperature	°C	-40 ÷ +70	
Operating temperature stability	°C/h	USO has its own temperature stabilization	
Physical			
Preferred location	N/A	Away from TWTA	
Mass, total	kg	1.5	
Power			
Total average power	W	operating temperature: -20 °C: 5.5 operating temperature: 50 °C: 4.5	
Detector + electronics	W	N/A	
TE cooler	W	N/A	

Data Rate & Volume			
Data volume (total)	Gbyte	Negligible, only few HK	
Data rate (instantaneous)	kbyte/s	Negligible, only few HK	
Compression factor	#	N/A	

6.9 Submm Instrument (SWI)

6.9.1 SCIENCE GOALS AND PERFORMANCE REQUIREMENTS

The main focus of the Submm Wave Instrument (SWI) proposed for the JGO orbiter of EJSM is the stratosphere of Jupiter. The stratosphere couples the deeper layers of the troposphere to the upper atmosphere. Its structure, circulation and composition are still poorly determined. Direct estimation of winds is not possible with conventional observation methods, since there are no discrete clouds. However, knowledge of the stratospheric circulation is vital in understanding the transport of hazes and minor species. Temperature fields are known from Voyager/Cassini and ground observations, but temporal variations are organized along many different time scales, the longer known being the quasi-quadriennal oscillation, and recently the semi-annual oscillation observed from the ground. Wind measurements in the stratosphere are known only from thermal wind equation retrieval, which unfortunately excludes the equatorial regions where important phenomena take place, and from the dispersion of dust and chemical elements since the Shoemaker-Levy 9 collision in 1994. Missing elements are, to date, clues on the meridional and equatorial circulations and the vertical structure of the winds. Moreover, the question of the origin of stratospheric water is still open, and has implication on the origin of water in the Solar System: latitudinal variations of H2O would provide important clues on this origin. Finally, the remnants of the Shoemaker-Levy 9 collision (CS, HCN, CO) are still observed 13 years later and used as tracers of stratospheric mixing. JGO in general and SWI in special will follow up these observations, in relation with ground-based or space-borne observations (ALMA, Herschel).

SWI provides for the first time the possibility to directly measure vertical profiles of winds with scale height resolution from Doppler shifts of molecular species in the Jupiter stratosphere simultaneous with vertical profiles of the temperature which allows distinguishing between the different mechanisms forcing its circulation, i.e. investigating the role of thermal versus mechanical forcing from below. The expected results will also help to understand the high temperatures measured in the upper atmosphere. Furthermore SWI will provide information constraining the hydrocarbon chemistry of Jupiter’s stratosphere and provide 3-d pictures of the evolution of SL-9 impact molecules. One of the unique features of SWI is that it will provide vertical profiles even from distances as large as 15 RJ, since it exactly resolves the spectral line shapes. Their opacity and pressure broadened features bear the vertical information.

To summarize the scientific objectives concerning Jupiter’s stratosphere:

Determination of important parameters constraining the general circulation of Jupiter’s stratosphere: vertical profiles of wind and temperature.

Determination of the origin of water in the stratosphere and its role in atmospheric chemistry and dynamics

Characterization of latitudinal variations of stratospheric water to constrain its origin

Determination of the composition of the primordial material from which Jupiter was formed

Observations of the dispersion of HCN in the atmosphere following the SL-9 impacts

Characterization of the strength of the vertical mixing in the stratosphere.

The secondary scientific objectives concern the Galilean satellites:

SWI may have the chance to investigate IO's atmosphere even from large distance. The atmosphere is dominated by active volcanism that directly injects species like SO_2, SO, NaCl into the atmosphere. This atmosphere shows unique spatial and temporal variability, which remains poorly characterized. SWI can map the detected species, and measure the Doppler shifts that are due to planetary-wide circulation regimes or to plasma interactions and search for many new potential atmospheric molecules (OCS, S2O, KCl, Cl0, SiO...) as well as determine chlorine and sulfur isotopic ratios. All this bears implications on the composition of ionian lavae, magmas and the interior.

SWI may also have the capability to provide by large distance observations information about the structure and composition of Europa's surface bounded atmosphere with focus on water vapour. The atmosphere is produced mainly by sputtering processes. Considerable amounts of water vapour are also produced by sublimation in the equatorial region. Other sources of water may be caused by thermal flexing or cryovolcanism.

The science objectives are not only limited to atmospheric science. Properties of the surface and subsurface of the Galilean satellites (mainly Ganymede) can be derived by radiometric observation of the surface in the two bands. Depending on the properties of the surfaces / sub-surfaces the penetration depth of the submm waves are between several and several ten wavelengths, so that two different wavelengths will most likely detect different brightness temperatures. The interpretation of these together with a thermophysical model will provide information about the thermal and electrical properties of the surface / sub-surface. A dual-polarization detection will furthermore provide information about its dielectric constants.

In order to achieve the scientific requirements SWI will observe the stratosphere in 2 bands around 557 GHz (400 – 600 GHz) and 1200 GHz. In an optimum case the detector of the instrument should be cooled. Basically 2 concepts should be investigated, a) cooling down to about 150 K in case a Schottky mixer is used (baseline) or b) 4 K in case of a superconductive mixer. In case one the instrument will also operate without any cooling. The instrument requires two spectrometer back-ends (e.g. Chirp Transform Spectrometers as used for Rosetta MIRO) with 1 GHz bandwidth and a spectral resolution of 100 KHz. For determination of wind and temperature the instrument will observe water and methane lines. The vertical extension of theses parameters will be about 50 to 250 km above the 1 bar level with a vertical resolution of about a scale height (~ 20 km).

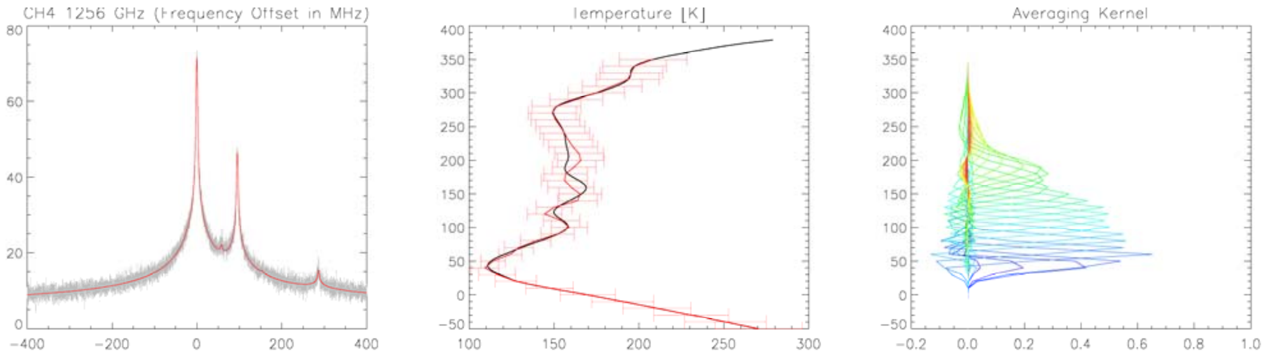


Figure 4: Spectrum of methane at 1256 GHz observed from 6 RJ in limb geometry and derived temperature profile. The averaging kernels indicate the altitude coverage above the 1 bar level and the vertical resolution

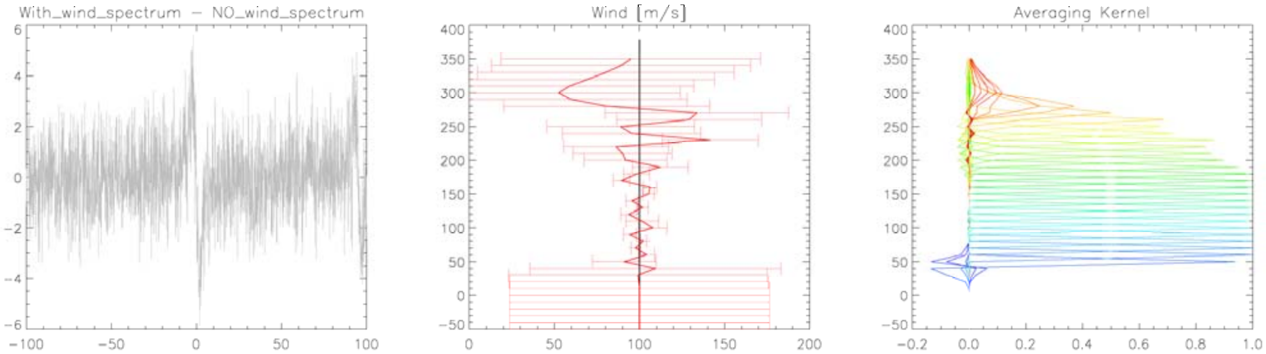


Figure 5: Residual of methane spectrum after fit of Doppler winds with velocity zero for typical observing conditions. Averaging kernels provide information about altitude coverage of measurements and vertical resolution. Simulation of observation from 6 RJ

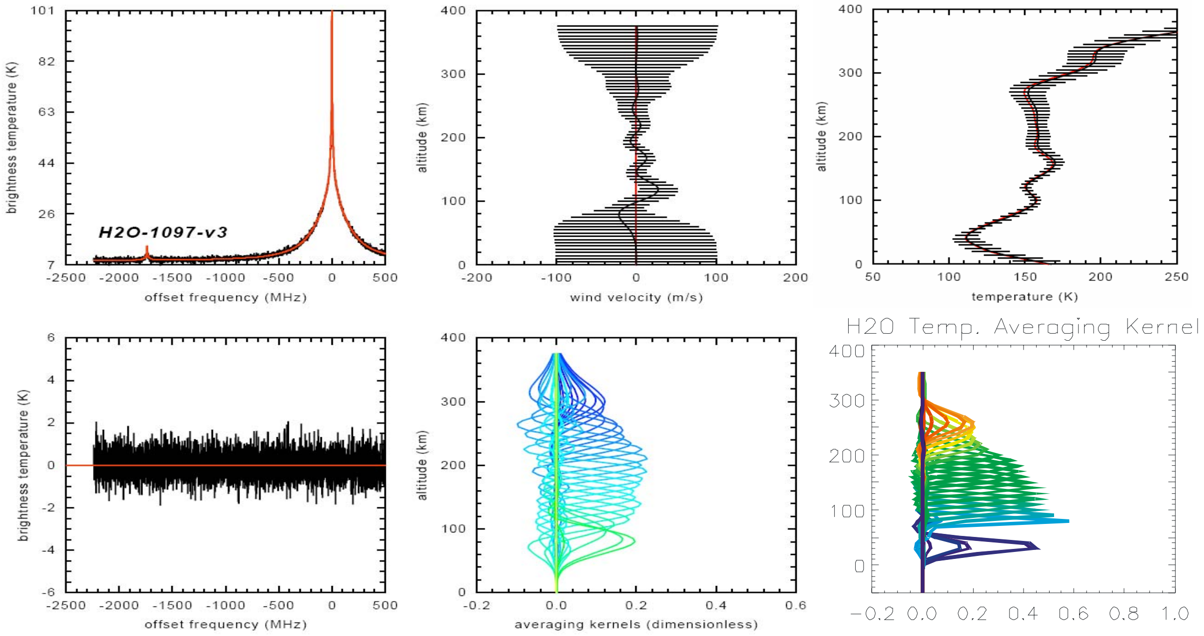
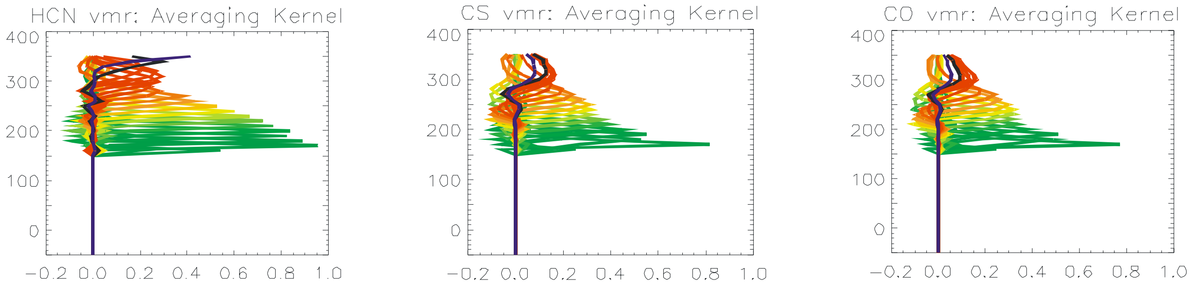


Figure 6: Spectrum of water vapour at 1256 GHz observed from 6 RJ in limb geometry and derived temperature profile. The averaging kernels indicate the altitude coverage above the 1 bar level and the vertical resolution



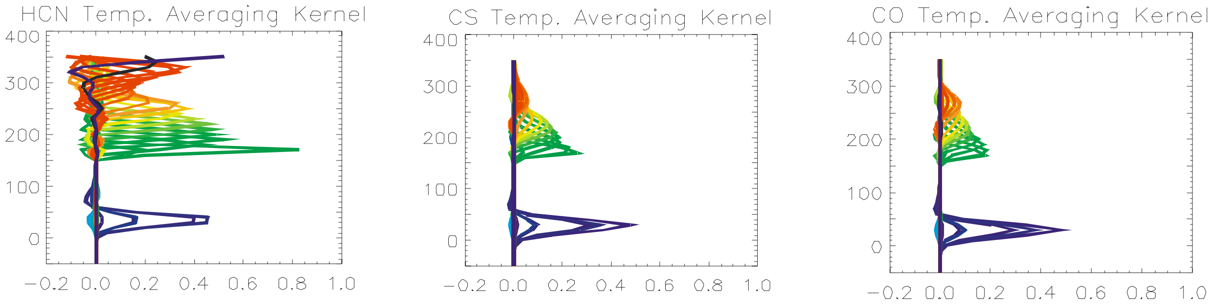


Figure 7: Averaging kernels of the volume mixing ratio (vmr) and temperature for HCN, CS and CO. With these molecules the vertical extension of the temperature retrieval can be extended to altitudes of about 350 km.

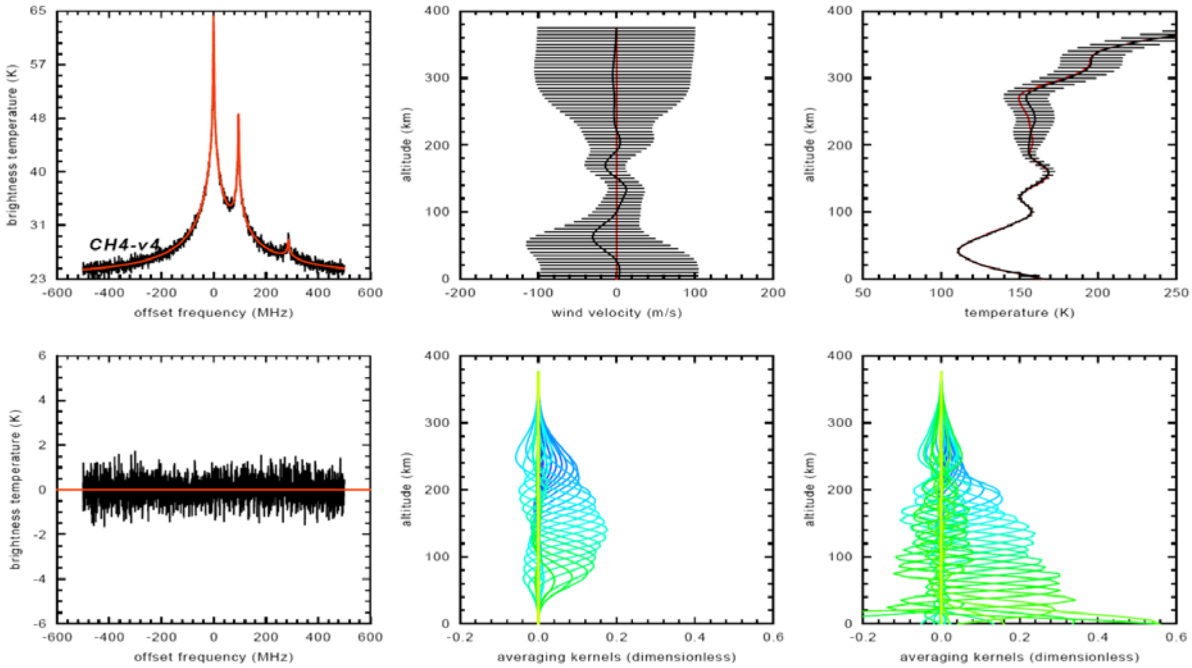
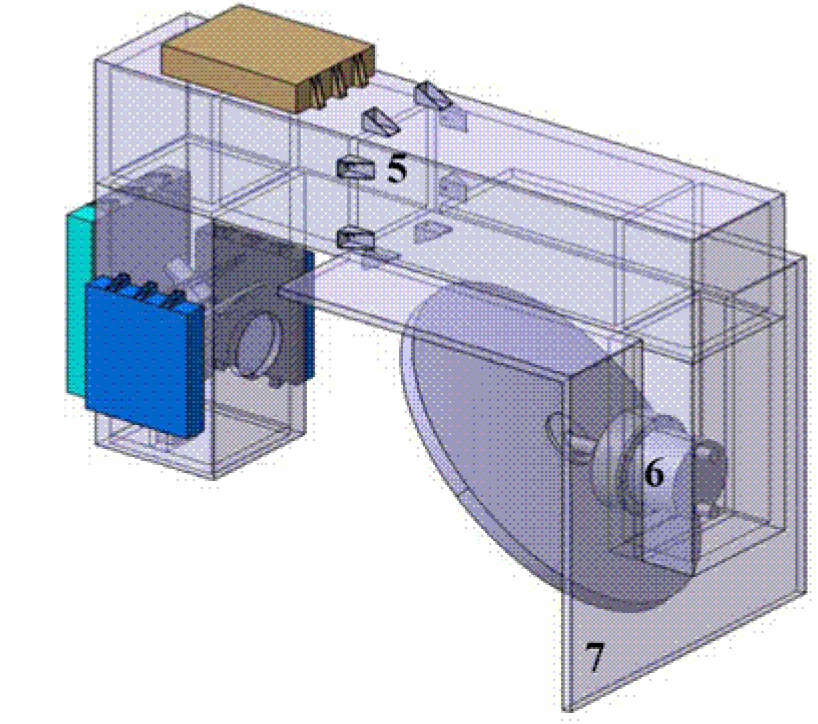


Figure 8: Spectrum of methane at 1256 GHz observed from 15 RJ in limb geometry and derived temperature profile. The averaging kernels indicate the altitude coverage above the 1 bar level and the vertical resolution

6.9.2 INSTRUMENT CONCEPT

Heterodyne spectrometer with 2 submm bands around 557 and 1200 GHz. Movable mirror for limb and nadir sounding capabilities. High resolution, large bandwidth spectrometer backends. Tunable local oscillator unit, solid state (baseline).

Figure 9: schematic view of the submm wave sounder



6.9.3 INSTRUMENT DESCRIPTION

The instrument constists of 2 submm heterodyne spectrometers covering the frequency bands around 557 GHz and 1200 GHz. Baseline are subharmonically pumped Schottky mixers and a tunable solid state local oscillator system. Two wide band spectrometers with 1 GHz bandwidth and 100 KHz spectral resolution are required

6.9.4 ORBIT, OPERATIONS AND POINTING REQUIREMENTS

TBD, see summary tables

6.9.5 INTERFACE AND PHYSICAL RESOURCE REQUIREMENTS

See summary tables

6.9.6 CALIBRATION

Hot load calibration and cold space calibrations

6.9.7 CLEANLINESS, PLANETARY PROTECTION AND PRE-LAUNCH ACTIVITIES

TBD

6.9.8 CRITICAL ISSUES

Some of the electronical components have been qualified up to about 50 kRad total dose only. Further developments adapting to the harsh radiation environment required.

6.9.9 HERITAGE

Rosetta-MIRO, Herschel.

6.9.10 OPEN TECHNOLOGY ISSUES AND CRITICALITY

Antenna/telescope: the size of the telescope determines the SNR of the observation. Especially at large distances (e.g. during the time in the Ganymede orbit) beam dilution plays a role in that part of the beam will look into cold space and another part gets signals from the upper troposphere. That leads to a decrease of the maximum line amplitude of the molecules to be observed and an increase of the continuum radiation caused by the collisional induced absorption of helium/hydrogen. For this situation the above mentioned 60 cm telescope is desirable. In the CDF-34(A) study the mass of the CFRP-telecope has been estimated to 450 g. The open question is into what mass this would translate for a 60 cm dish.

Local oscillators (LO): the anticipated LO baseline design will be based on the solid state design which has been developed for Herschel/HIFI. This kind of oscillator has the advantage that it is tunable. Therefore large number of molecular lines can be detected. The difference of the proposed instrument compared to HIFI is that the mixers are not superconductive, but as baseline operating at ambient temperature, i.e. they need a larger LO-power. Especially for the 1.2 THz band the presently available LO power leaves space for improvement and developments should be started. In increased LO power translates into a more sensitive receiver and a better SNR.

Mixers: mixers for the spectral bands proposed for the SWI have been manufactured in the past and are available. However recent developments have not been focused on improvements of the mixer insertion loss, or in general the reduction of the mixer noise. For instance the mixer performance has only marginally improved since begin of the millennium when the MIRO mixers have been manufactured. Therefore improvement of the functional performance of this technology is highly desirable

Spectrometers: SWI requires a wide band spectrometer. More precisely 1 spectrometer per receiver is required with a bandwidth of 1 to 1.5 GHz and about 100 KHz spectral resolution. The use of ASICs could help to considerably reduce the mass and power consumption of the spectrometers. Therefore developments into this direction are highly desirable

More information on mixers, spectrometers. Radiation. TBD

6.9.11 INSTRUMENT SUMMARY DATA SHEET

Table 19 SWI summary table.

Parameter	**Unit**	**Value/Description**	**Remarks**
Heritage	N/A	Rosetta-MIRO, Herschel	
Type of instrument	N/A	Submm spectrometers	
Type of optics	N/A	quasi-optics	
Function mode	N/A	TBD	
Optics			
Spectral range	µm	550-230	
FOV	deg	0.15 – 0.065 (baseline)	0.07 – 0.03 (goal)
Pixel IFOV	mrad	3 – 1.3 (baseline)	1.5 –0. 6 (goal)
Wavelength for diff. limit	nm	N/A	
Aperture	mm	270 (baseline)	600 (goal)
Focal length	mm	420 (TBC)	
f/#	#	10[7]	
Filters	#	CTS	
Filter bandwidth	kHz	100	
Detector			
Type of detector	N/A	Schottky	
Pixel lines in array	#	N/A	
Pixels per array line	#	N/A	
Pixel size	µm	N/A	
Exposure time	sec	1 - 300	
Repeat time	sec	1 - 300	
Operating temperature	°C	-20 to 20 (baseline)	-150 (goal)
Operating temperature stability	°C/h	1 to 3	
A/D conversion	bit/pix	8	
Full well capacity	Ke$^-$	N/A	
Readout time	msec	0.01	
Swath and Resolution			
Swath width	km	550 – 1200 km (@6RJ)	275 – 600 (@ 6RJ)
Spectral sampling	kHz	100	
Spatial pixel resolution	m	like swath width	
Thermal Control			
Total surface area	cm^2	6000	

Non-isolated area	cm^2	729	
Operating temperature	°C	-20 to 50	
Operating temperature stability	°C/h	1 to 6	
Physical			
Preferred location	N/A	Nadir/limb viewing	
Mass, total	kg	9.7	
Power			
Total average power	W	50	
Detector + electronics	W	45	
TE cooler	W	TBD	
Data Rate & Volume			
Data volume (total)	Gbyte	5/year	
Data rate (instantaneous)	kbyte/s	1.375	
Compression factor	#	average by 20 %	

6.9.12 SUMMARY OF ALIGNMENT AND POINTING REQUIREMENTS

Table 20: Summary of instrument alignment and pointing requirements. Note that in case more than one angle is listed, the sequence is pitch, roll, yaw.

Instrument	Pixel size arcsec	FOV deg	Min. pixel readout time ms	APE arcmin	RPE arcsec/t	AMA arcsec	Pre-facto knowledge of co-alignment with reference arcsec	Co-alignment stability arcsec/t	Post facto knowledge of co-alignment with reference arcsec
SWI	> 100	0.15-0.065	0.01	1	10 (TBC)	30 (TBC)	<10	<10	<10

6.10 Thermal Mapper (TM)

6.10.1 SCIENCE GOALS AND PERFORMANCE REQUIREMENTS

The main objective of the Thermal mapper instrument is to characterize the dynamics and structure of Jupiter's shallow atmosphere (above the cloud level, 3—400 hPa). The second objective aims at detecting and understanding endogenic and volcanic activity on Io and icy satellites.

The four narrowband filters are centered at specific wavenumbers to retrieve the vertical temperature profile of Jupiter's atmosphere between 400 and 3 hPa (mbar), from the upper troposphere up to the middle stratosphere :

- CH_4 ν_4 band (1250 - 1350 cm^{-1}, or 7.41 – 8.00 μm) probes around 3 hPa
- Collision-induced H_2 continuum 565 - 635 cm^{-1} (15.7 -17.7 μm) probes around 200 hPa
- Collision-induced H_2 continuum 650 - 700 cm^{-1} (14.3 -15.4 μm) probes around 300 hPa
- Collision-induced H_2 continuum 460-490 cm^{-1} (20.4 – 21.7 μm) probes around 400 hPa

These measurements will be used to:

- Retrieve the vertical temperature profile and global maps of the temperature field for comparison with NIR images at different levels (lower troposphere at 5 micron and upper troposphere from 2 micron continuum, lower stratosphere from 3.5 micron), to infer a fundamental dynamic quantity: the Ertel potential vorticity (Read et al. 2006), allowing to trace motions and mixing of air masses. This requires spatial resolution of 250—1000 km/pixel, hence 0.25 – 1.0 mrad/pixel.
- Map the wave activity in the atmosphere of Jupiter at short and long time scales (hours to years). Waves are the prime responsible for the transport of energy and momentum in the upper troposphere and stratosphere.
- Measure and map the vertical wind shear and its temporal evolution following on the Cassini study (Flasar et al, 2004).
- Monitor the evolution of the quasi-quadriennal oscillation (QQO, Leovy et al. 1991), a wave-induced phenomenon and search for its influence on general circulation.
- Monitor the thermal response of Jupiter to changes in insolation (meridional and seasonal) to understand how the general circulation and the radiative balance determine the thermal structure.

The filters, although designed primarily for thermal imaging of Jupiter's atmosphere, will also address questions regarding Jupiter's satellites:

- Map thermal inertias on Ganymede and Callisto by comparing daytime and nighttime temperatures, to follow up on surprising nighttime thermal anomalies seen on Europa and Ganymede by Galileo (Spencer et al. 1999). Require daytime and nighttime global mapping of the satellites with spatial resolution better than 30 km, in one or more broadband filters, and sufficient sensitivity to detect typical low-latitude nighttime temperatures of 85 – 90 K.

- Map Io's total heat flow. Require full-disk observations at 2-3 wavelengths between 8 and 21 µm with a resolution of a few pixels, and over a wide variety of longitudes and local times. Frequent observations, once per day if possible, to detect and characterize large volcanic outbursts, would be desireable.
- Search for thermal emission produced by endogenic activity on Ganymede. As is demonstrated by Enceladus (Spencer et al. 2006), thermal emission is powerful way to detect and understand endogenic activity on icy satellites. Activity on Ganymede is not likely given its cratered surface. However the magnetic evidence for internal activity means that isolated surface activity cannot be ruled out, and would be of enormous importance if discovered. Requires spatial resolution better than 1 km/pixel, at least two broadband wavelengths between 8 and 21 µm, daytime and nighttime coverage of a large fraction of Ganymede.

> Note that the NASA Europa Orbiter plans to include a thermal infrared instrument in its core payload. Its filters will be designed to probe mostly icy satellites and the troposphere of Jupiter. The complementarity between the two instruments increases the value of a thermal mapper on the ESA spacecraft.

6.10.2 INSTRUMENT CONCEPT

The instrument is a 7.7 – 21 µm imager using filters for spectral discrimination. The most important choice is the detector to be used. Bolometer arrays, as used on THEMIS, are uncooled, which simplifies spacecraft accommodation and saves mass, and can probably be used to at least 21 µm wavelength. They are also relatively radiation-hard. Greater sensitivity can be achieved with cooled arrays (HgCdTe or QWIPs), which run at 65 – 75 K and thus require either a radiator, which adds mass, cost, and spacecraft accommodation complexity, or an active cooler which requires significant power and possible reliability concerns. For this initial document we assume the simplest option of an uncooled bolometer array, which can probably meet the required sensitivity goal for the selected filters (based on calculations done for the 1999 Europa Orbiter Ball Aerospace proposal). Estimated S/N ratio with the list of filters specified above for a Jupiter nominal radiance are for a 100sec integration time :

- Filter 1 : 3.5
- Filter 2 : 45
- Filter 3 : 26
- Filter 4 : 48

Based on the CIRS expertise, the temperature profile can be inverted with typical error bars of +/-1 K in the troposphere and +/- 3K in the stratosphere, hence smaller than a typical meridional gradient induced by the QQO phenomenon in the stratosphere.

6.10.3 INSTRUMENT DESCRIPTION

The strawman design is based on an instrument proposed by Ball Aerospace for the 1999 Europa orbiter proposal, using a Raytheon bolometer array with 320 x 240 pixels. It is also similar to THEMIS which uses a similar array and has flown successfully on Mars Odyssey. The array is read out many times per second and the frames are coadded by the instrument electronics. The design has an IFOV of 0.5 mrad/pixel, which will give 500 km resolution on Jupiter from the orbit of Ganymede, 300 km resolution on Io, and 100 m resolution for satellite orbital observations from 200 km altitude. Filters are placed directly over the array and for distant targets are selected by moving the spacecraft to position the target over the filter of interest. The instrument can also be operated in "pushbroom" mode for scanning observations: images are shifted in memory within the instrument electronics after readout and before coadding, to compensate for the motion of the scene across the array.

We estimate an approximate instrument mass of 5 kg, including shielding, and a power of 5 W, values which are intermediate between the mass and power estimates for the 1999 Ball Aerospace Europa Orbiter proposal, and the values for THEMIS.

6.10.4 ORBIT, OPERATIONS AND POINTING REQUIREMENTS

The thermal structure of Jupiter is relatively smooth and can be observed with high enough spatial resolution from Ganymede orbit, a IFOV of 0.5 mrad/pixel giving ~500 km/pixel. In framing mode, with small spacecraft offsets from the initial pointing to place the target on each of the filters, and to scan the planet, each 4-color observation would take about 4 Mbit uncompressed. Jupiter science will require

1. global temperature maps, reobserved over timescale of 1-2 days for fast changes, 3-4 weeks for slow evolution of features, and over longer periods to look for periodicity such as the QQO;
2. feature tracks from centre-to-limb of vortices and other storms to characterize the vertical T(p) and (maybe) aerosol effects;
3. concurrent imaging with the other instruments for contextual studies

For satellites observations in orbital operations, or high-resolution nadir coverage during close flybys, raw data rate in "pushbroom" mode (assuming coadding in the instrument), at 200 km altitude would be 100 Mbits per 1000 km along-track. No special spacecraft maneuvers would be needed in this mode. At a typical orbital speed of 1.5 km/sec, data rate would be 160 kilobits/sec.

For Io monitoring, we require frequent observations with useful spatial resolution (<400 km)- if possible several times per day (minimum once per day) when we are close enough to Io for this resolution and the spacecraft is not busy with other observations. For a small target like Io that occupies a small fraction of the chip, onboard dark-sky editing could greatly reduce this volume.

In framing mode, an absolute pointing accuracy of about 24 mrad and pointing stability of about 50 µrad/sec (for long exposures (~20 seconds) on the night side) would be preferred, though pointing stability requirements could perhaps be relaxed if motion compensation could be done in software.

Assuming a circular 200 km altitude orbit at Ganymede, day and night global coverage of the moon at full spatial resolution of 100 m/pixel in three spectral channels would require an unrealistic data volume of 1000 Gbits (120 Gbytes). We propose 10x10 pixel binning of most of the orbital data, which still provides an acceptable 1000 m spatial resolution, will improve signal-to-noise, and results in a 100x data volume reduction.

6.10.5 INTERFACE AND PHYSICAL RESOURCE REQUIREMENTS

The physical size of THEMIS, which has twice the spatial resolution as our instrument concept and includes a visible channel, is 39 x 37 x 55 cm, so we expect a significantly smaller design, with half the focal length of THEMIS: a rough estimate is thus a little over half the size of THEMIS, or 25 x 25 x 30 cm. The instrument would be bore-sighted with other remote sensing instruments. THEMIS is an un-cooled instrument that does not require a radiator. Cooled instrument concepts would require a radiator with a sky view.

6.10.6 CALIBRATION

In all operations, the instrument would require occasional turns to view the sky to measure the background radiation. Absolute calibration would be done with pre-launch measurements coupled with in flight observations of Jupiter and Callisto's day side, which has well-understood thermal radiation.

6.10.7 CLEANLINESS, PLANETARY PROTECTION AND PRE-LAUNCH ACTIVITIES

TBD

6.10.8 CRITICAL ISSUES

Detailed signal-to-noise calculations will depend on the choice of detector array. A conservative approach on un-cooled bolometers has been used in this description. Trades between cooled and un-cooled detector arrays need to be explored further.

6.10.9 HERITAGE

THEMIS, Ball instrument proposal for the 1999 Europa Orbiter.

6.10.10 OPEN TECHNOLOGY ISSUES AND CRITICALITY

Radiation hardness of readout electronics. Long-wavelength sensitivity of microbolometer array.

6.10.11 INSTRUMENT SUMMARY DATA SHEET

Table 21 TM summary table.

Parameter	Unit	Value/Description	Remarks
Heritage	N/A	THEMIS, 1999 Ball Aerospace Europa Orbiter proposal	
Type of instrument	N/A	Thermal Infrared Imager	
Type of optics	N/A	TBD	Both refractive optics (Ball proposal) and reflective optics

			(THEMIS) are possible
Function mode	N/A		
Optics			
Spectral range	nm	7,400 – 21,700	
FOV	deg	6.9 degrees	
Pixel IFOV	mrad	0.5	
Wavelength for diff. limit	nm	20,000	
Aperture	mm	50	
Focal length	mm	100	
f/#	#	2	
Filters	#	4	
Filter bandwidth	nm	Between 600 and 2000	
Detector			
Type of detector	N/A	Uncooled microbolometer array	Cooled arrays are also an option
Pixel lines in array	#	320	
Pixels per array line	#	240	
Pixel size	µm	50	
Exposure time	msec	100000 (for Jupiter)	
Repeat time	msec		
Operating temperature	°C	300	
Operating temperature stability	°C/h		
A/D conversion	bit/pix	12	
Full well capacity	Ke^{-}		
Readout time	msec		
Swath and Resolution			
Swath width	km	120,000 (Jupiter) 20 (Ganymede)	From Ganymede orbit From 200 km altitude
Spectral sampling	nm		
Spatial pixel resolution	m	500 km for Jupiter 100, or 1000 with 10x10 binning for global coverage of Ganymede	From Ganymede orbit From 200 km altitude
Thermal Control			
Total surface area	cm^2		No radiator needed for microbolometer array-would be needed for cooled arrays
Non-isolated area	W		
Operating temperature	°C		
Operating temperature stability	°C/h		

Physical			
Preferred location	N/A	Nadir-Pointing	
Mass, total	kg	5	
Power			
Total average power	W	5	
Detector + electronics	W		
TE cooler	W		
Data Rate & Volume			
Data volume (total)	Gbyte	0.112 for 1 period (4weeks of Jupiter observation) – 1.2 for complete cycle 0.25 for 10 satellite flybys, 0.025 for Io monitoring, 1.2 for complete Ganymede coverage	Assumes 200 Io monitoring visits, 10x10 binning of global Ganymede coverage
Data rate (instantaneous)	kbyte/s	20	Based on 1.5 km/sec groundtrack speed
Compression factor	#	2 (lossless)	High compression factors with lossy compression

6.10.12 SUMMARY OF ALIGNMENT AND POINTING REQUIREMENTS

Table 22 Summary of instrument alignment and pointing requirements. Note that in case more than one angle is listed, the sequence is pitch, roll, yaw.

Instrument	Pixel size arcsec	FOV deg	Min. pixel readout time ms	APE arcmin	RPE arcsec/t	AMA arcsec	Pre-facto knowledge of co-alignment with reference arcsec	Co-alignment stability arcsec/t	Post facto knowledge of co-alignment with reference arcsec
TM	100	6.9	30	80	10 arcsec/sec		2000		

6.11 Ultraviolet Imaging Spectrometer (UVIS)

6.11.1 SCIENCE GOALS AND PERFORMANCE REQUIREMENTS

Science goals include:

- *Jupiter atmosphere (IV.J3.1, 3.2, 3.6) and aurorae (IV.J3.3):*
  - study of dynamical coupling between atmospheric layers and energy sources in the upper atmosphere.
  - study of the origin of the bulge and to assess the possibility of its connection with the auroral activity or with with thermospheric/exospheric circulation.
  - assessment of the atmospheric composition, in particular hydrocarbons. The combination of UV and IR solar occultations is a powerful means to characterize Jupiter's atmospheric vertical structure and composition.
  - assessment of the global variation of the homopause, by multiple stellar occulations using hydrocarbon tangential column densities to infer homopause heights.
  - study of processes produced by the electromagnetic coupling between the solar wind, the rotating magnetosphere/plasma environment and the ionosphere/ thermosphere, mediated through the magnetic field (UV spectral imaging complementary to X-ray spectral observations of the jovian aurora).

- *Jupiter magnetosphere (III.M2 and III.M3):*
  - characterization of the magnetosphere/ionosphere/thermosphere coupling processes and response to solar wind variability (UV spectral imaging complementary to X-ray spectral observations of the jovian aurora).

- *Io torus (II.S3.3 and III.M3.3):*
  - assessment of the basic characteristics of the torus and its variability.

- *Io atmosphere, surface and aurorae (II.S2, II.S3, III.M3.4):*
  - study of the interaction between Io's volcanic activity and its atmosphere.
  - study of the horizontal and vertical spatial distribution of the atmosphere, by direct mapping and stellar occultations.
  - study of the generation of Io's aurora.

- *Europa, Ganymede, and Callisto surface and atmosphere and, for Ganymede, aurorae (II.S2, II.S3, III.M3.4):*
  - identification of key chemical elements and compounds at the surface or in the atmosphere of the icy moons (e.g., O_3, H_2O_2, SO_2). This is crucial for assessing the past and present geologic activity and the atmospheric evolution of the satellite.

- mapping emissions of trace species in the atmosphere as they are potentially markers of geologic activities (e.g., Na in MUV at Europa).
- study of the horizontal and vertical distribution of the atmosphere, by direct mapping and stellar occultations.
- study of the interactions between the intrinsic magnetosphere of Ganymede and the moon's exosphere and surface.

Performance requirements:

- **Jovian atmosphere and aurora** (H_2 bands, H Ly a, CH_4, acetylene): 90-170 nm with a 0.5 nm resolution (at least) and a temporal resolution of 1 s for occultations; solar occultations (if possible) in the EUV for H_2 density; in the auroral regions: 110-170 nm required for estimating the hard electron component and 90-110 nm, for the soft electron component)

- **Satellites**:
  - *Io torus* (numerous spectral features, requires a high spectral resolution, low temporal resolution of the order of the hour and low spatial resolution): 50-100 nm with a spectral resolution of 0.3 nm at least. Note that the lowest boundary is driven by the mirror reflectivity (which becomes small below 50 nm) but this cutoff does not significantly affect our ability to address the Io torus objectives.
  - *Io* (SO_2, S_2, SO, chlorine (absorption and emission features), O, S, and Cl emissions in the FUV): 100-300 nm with a spectral resolution of 0.5 nm at least in FUV
  - *Icy moons* (Ganymede and Europa [O_2 atmosphere], Callisto [O_2 and CO_2 atmosphere], Emissions: e.g., OI emissions by O_2 dissociation (all icy moons), HLy α (Ganymede); Absorption: e.g., water, CO_2 (Callisto), O_2: 100-320 nm with a spectral resolution of 0.5 nm at least in FUV (300-320 nm for OH emissions not yet detected at icy moons; note however that it may be difficult to detect as the solar light scattered on the surface might mask the relatively weaker OH emission when the spectral resolution is low (>0.1 nm).

1. *FUV measurement requirements:*

- Spectral range: 110-230 nm [jovian atmosphere and aurora (e.g., H_2 Lyman and Werner bands and H Ly α emissions; acetylene in absorption), moon's atmospheres (e.g., oxygen (OI 130.4 nm, OI 135.6 nm) (all moons), H Ly α (Ganymede), chlorine and sulfur (Io) emissions, strong SO_2 (Io – 200-230 nm) as well as O_2 (Icy moons), CO_2 (Callisto), SO (Io), and water (icy moons) absorption bands)], Io torus (H Ly α, sulfur ion emissions)

- Spectral resolution: 0.5 nm (for stellar occultations (water, oxygen, CO_2 bands), for oxygen emissions, to resolve and differentiate between absorption bands)
- Temporal resolution: 1s (for stellar occultations (e.g., H_2 density in the lower atmosphere and temperatures, Io SO_2 atmosphere) to minutes (e.g., moon's aurorae)
- Spatial resolution: sufficient to spatially-resolved Io and icy moons
- Sensitivity: 0.2 count/s/R for extended source

2. *EUV measurement requirements:*

- Spectral range: 50-110 nm [Io torus (e.g., strong O and S ion emissions), jovian atmosphere (H_2 absorption features), jovian aurora (soft electron component through H_2 band emission)]
- Spectral resolution: 0.3 nm at least (to be able to resolve as much as possible the spectral features in Io torus)
- Temporal resolution: 1s (for solar occultations, especially to derive H_2 density) [otherwise, a few minutes (aurora) to the hour (Io)]
- Spatial resolution: low resolution
- Sensitivity: 0.3 count/s/R for extended source

Note that for including the possibility of *solar occultations* which would primarily provide H2 density over the whole thermosphere, one needs an angular size for a pixel, of the order of an atmospheric scale height or less. This is a very strong constraint. We keep solar occultation as a secondary, non-critical requirement, even though of great interest.

3. *MUV measurement requirements:*

- Spectral range: 230-320 nm (moons: ozone, H_2O_2, SO_2 in the surface; trace species in the atmosphere (e.g., Na, Ca, Fe, Mg, OH (not yet detected at moons), N_2); SO_2 and strong S_2 absorption features in Io atmosphere)
- Spectral resolution: $\leq$ 1 nm
- Temporal resolution: 1 s (for stellar occultations to probe the atmosphere of Io or to detect plumes above volcanoes) [otherwise, days].
- Spatial resolution: sufficient to spatially-resolved Io and icy moons
- Sensitivity: 0.05 count/s/R for extended source

4. *H Lyman alpha measurement requirements:*

While H Lyman alpha line (121.6 nm) is included in the FUV channel (1. above), a high spectral resolution channel dedicated to H Lyman alpha is of great relevance for addressing objectives related to the jovian atmosphere and aurora.
Spectral resolution: ~0.001 nm

Table 23: Overview of the atmospheric and surface constituents which can be probed in the different spectral windows selected for UVIS illustrating the rationale for a spectral coverage from 50 to 320 nm. "Abs" and "Emi" stand for absorption and emission lines or bands. "ND" means that the species has not yet been detected

but could be as it has a spectral feature in this window. A species is underlined when it has strong emission or absorption features.

UVIS on JGO	EUV 50-110 nm	FUV 110-230 nm	MUV 230-320 nm
Jovian atmosphere	H_2 (abs) + Tn (z)	Abs: Hydrocarbons Emi: H_2, H Ly α	Abs: Hydrocarbons, NH_3
Jovian aurora	H_2 Rydberg (emi) → e-: 20-200 eV (compl. to FUV)	H_2 Lyman and Werner bands (emi) → e-: 5-200 keV	
Icy moon's atmosphere	*Discovery (not yet looked at)*	Emi: OI, CO_2, C(ND), CO(ND); Abs:O_2, CO_2, O_3, H_2O	Emi: CO_2(compl. to FUV), trace species (Na, Ca, OH(?), Mg, …)
Icy moon's surface		Abs: H_2O, CO_2, NH_3 ice	Abs: Weathering products (e.g., O_3, H_2O_2, SO_2 frost)
Ganymede aurora		H Ly α; OI (critical channel)	
Io atmosphere, aurora, surface		Abs: $\underline{SO_2}$, SO Emi: S, O, Cl	Abs: $\underline{S_2}$, SO_2 (atm), SO_2 frost (surface)
Io torus	$\underline{S}$, O and Cl ion emissions + Te (critical channel)	Emi: O & S ions (weaker cp with EUV), OI & SI (worth having but more complementary to EUV)	

6.11.2 INSTRUMENT CONCEPT

**** Rationale for an imaging spectrometer:***

- Can address the majority of the scientific objectives set for the UV instrument
- Crucial for satellites (e.g., identification of component in surface and atmosphere) and jovian atmosphere (e.g., density and temperature profiles through occultations);
- Relevance for magnetosphere (lower temporal/spatial resolutions compared with those achieved with bandpass imager, but quantitative analysis significantly improved)
- Allows science which is not redundant with Juno

- Complementary to IR, X-ray, and sub-millimetre spectrometers (e.g., combination with IR and sub-millimetre observations for characterizing Jupiter atmospheric vertical structure and composition; observations of the aurora combined UV and X-rays for identifying and characterizing auroral particle inputs and auroral drivers).

Imaging spectrometer versus narrow-band interference filter imager:

- a narrow-band filter imager is temperature sensitive and angle dependent (if incoming light comes at a different angle, this will shift the spectral band of the filter).

CONCEPT:
The UV imaging spectrometer provides 2D spectral-spatial images. The 2D spatial images are built over time. Alternatively, the images are directly provided at high spectral resolution within selected narrow windows. Heritage: Phebus/BepiColombo.

**** Rationale for a high spectral resolution H Lyman alpha channel:***

- A line profile is a richer source of information than unresolved emission lines. The H Lyman alpha line profile would provide the density, temperature and wind velocity of the emitting H atoms, which is of great relevance for addressing the objectives related to the jovian atmosphere. It would also allow the quantitative analysis of the self-reversal in the auroral regions for assessing the characteristics of the incoming, auroral particles.

CONCEPT:
The use of H absorption cell allows to achieve high spectral resolution measurements of H Lyman alpha line, provided the same target may be observed at different Doppler shifts, that is, from different locations along the orbit. Further studies need to be done to assess the potential of this method for achieving the objectives. The typical mass of a cell is 300 g. Heritage: Cassini/UVIS/SWAN.

**** Rationale for a polarimeter*** *(e.g., Chwirot et al., Appl. Optics, 1993; Bartelemy et al., Europa-Jupiter International Workshop, Frascati, Italy, April 21-22, 2008):*

- Would provide key information regarding the energetic particles contributing to the Jovian auroral observations in terms of type, energy, and pitch angles
- Would be a new type of instrument (providing unique auroral information) never flown to Jupiter
- Would focus on H Ly α, best candidate for such a study, as it is the most intense auroral line and is relatively easy to interpret.

A specific study needs to be done to assess the potential of this method for achieving the objectives as well as for an optimum design.

6.11.3 INSTRUMENT DESCRIPTION

**** Overview:***
1 telescope
2 detectors (1 for FUV-MUV; 1 for EUV)
Note regarding the FUV-MUV detector: in order to eliminate at best the reflected light from bright objects (esp. in the MUV) when looking at faint emissions, a baffle must be used.

The UV imaging spectrometer experiment is made up by a detector unit and by an electronics unit. The ***detector unit*** includes a telescope, a spectrograph, two 2D detectors and associated high voltage detector power supply. The ***electronics unit*** includes the data acquisition, processing and buffering electronics and the power, command and data interface with the JGO systems. It consists of two cards, one being a power converter.

The ***optics*** includes one entrance slit, a telescope, which focuses the light from the slit onto a grating. The grating disperses the radiation onto the focal plane, where an UV-sensitive microchannel plate detector records the spectrum.

The optics consists of a clear aperture off-axis paraboloidal mirror (OAP). The OAP collects the incoming light (from limb and/or nadir) and directs it toward the entrance slit of a imaging spectrograph with a reflective holographic diffraction grating. The grating disperses the radiation onto the focal plane, where an UV-sensitive microchannel plate detector records the spectrum. The electronics unit includes the data processing and buffering electronics and the power, command and data I/F to the JGO systems.

The instrument has a 0.1° x 2° FOV and operates in the 50 – 320 nm band with one detector covering the EUV range and the other, the spectral range longward of 110 nm. Spectral resolution is 0.2 nm in the EUV range and optimized to 0.5 nm in the FUV reaching up to 2 nm in the MUV.

The ***telescope*** has the following characteristics:

- shape: parabolic
- layout: off-axis
- main aperture: 25 x 25 mm (same as grating)
- focal length: 170 mm
- focal number: TBD
- material: Al
- reflective coating: MgF_2 reflective coating (adopted for the grating as well).

The EUV and the FUV/MUV detectors are 2D imaging photon counting microchannel plates (MCP) z-stack, with a solar-blind photocathode of KBr (50-120 nm), CsI (120-200 nm), or Cs_2Te (200-330 nm). It makes use of a 3-channel wedge and strip readout array and requires 4 kV powers supply voltage (not exposed to the outside). The size of the detector's active area is ~ 70 x 20 mm^2. In order to prevent sensitivity losses which are critical in UV ranges, a minimum of reflexion is guaranteed inside the instrument using only an off-axis parabola and a set of holographic gratings.

The average exposure time is 1s in nadir mode, in the range from 1 s to 1000 s in limb mode (selectable from ground through command order). The total image is estimated to be about 4 Mbits.

The ***electronics*** unit contains a microprocessor that can be programmed to perform lossless data compression by a factor 2 or similar. The data compression S/W is integrated in and controlled by the spectrometer itself.

An internal time reference is generated with millisecond accuracy.

**** Scanning device:***

A scanning device is necessary for good sampling and coverage, especially for performing occultations and look at a variety of targets in the jovian system, in particular satellites.
The optimum solution would be to a 2D scanning platform provided by the spacecraft as a facility (e.g., Voyager) and shared with other remote-sending instruments, such as the IR and X-rays spectrometers. However, if this is not possible, we will select a 1D scanning mechanism, which will give less flexibility though allowing us to observe the major targets some of the time thanks to the spacecraft pointing.

The heritage is based on Phebus/BepiColombo (1 degree of freedom: periscope-like as illustrated in the Figure 10 below; note that the baffle will be shorter for the present experiment) and Soho/Swan (2 degrees of freedom; (See http://www.ias.u-psud.fr/swan/SWAN_instr.html)).

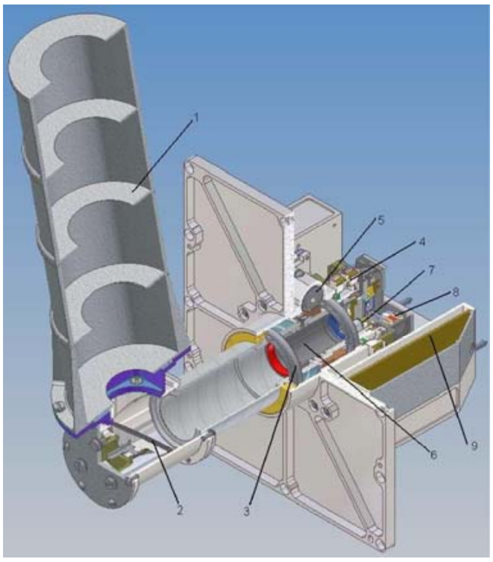


Figure 10: Illustration of the scanning device based on the heritage instrument. Note that for the present experiment, the length of the baffle will be reduced as the scattered light environment is different.

6.11.4 ORBIT, OPERATIONS AND POINTING REQUIREMENTS

**** Orbit:*** TBD

**** Operations:***

The UVIS instrument requires operating:

- during the interplanetary trajectory coasting phases, for instrument and alignment stability calibrations
- during the envisaged planetary flybys, for calibration and remote sensing
- during the operational mission on orbit around Jupiter and then Ganymede.

The first two requirements apply on a non-interference basis with system operations, while the third one is an operational driver.

During the operational mission, the UVIS instrument will be operating through four modes:

- nadir-pointing mode for direct measurement of the total column abundance of atmospheric components (Jupiter, moons) and detection of surface components (moons)

- limb-pointing mode for inferring vertical profiles of atmospheric emissions

- stellar-occultation mode for the derivation of vertical density profiles of atmospheric components from absorbed stellar light by the atmosphere

- solar-occultation mode, similar to stellar occultation but with a bright, extended source.

These modes translate into two types of attitude control for the spacecraft:

- nadir mode (for nadir and limb observations
- internal mode (fixed in reference to the stars) for stellar and solar occultation.

**** Pointing requirements:***

The constraint on pointing accuracy and stability is driven by the angular width of the slit (0.1°) and by the angular size of a pixel (0.1 (without) to 0.01° (with the option of solar occultation)) during an acquisition time from 1 s up to a few tens of second. This provides a stability constraint of ~0.01°/s in the most conservative case.

The UVIS instrument is expected to provide complementary measurements for the imaging instruments observing in other spectral range spectrometers, in particular the IR and the X-ray instruments (e.g., stellar occultations, jovian aurora, satellites). It is therefore crucial that all these instruments have the same pointing.

**** Illumination constraints:***

The Sun should be at least 30° away from the field of view of the instrument. This value is conservative, and may be reduced once the dimension of the baffle is decided.

6.11.5 INTERFACE AND PHYSICAL RESOURCE REQUIREMENTS

Mass, volume, temperature range requirements

6.11.6 CALIBRATION

Flight calibration is based on the observation of:

- the interplanetary medium (extended source) in H Ly α,
- stars (point source)

6.11.7 CLEANLINESS, PLANETARY PROTECTION AND PRE-LAUNCH ACTIVITIES

For the general need to keep the optical surfaces free of contamination. Standard practice and procedures (e.g. from SOHO - UVCS) are in place to this end. They include:

- regular heating of holographic grating
- flexible shutter for radiation protection

6.11.8 CRITICAL ISSUES

Including limit to radiation tolerance and list of least tolerant radiation component(s)

Among various subsystems of the UVIS (baffle, telescope, slit and grating, detector
and electronics), the subsystems the most sensitive to **radiation** are:

(a) the ***detector***: there are several options to try to minimize the radiation impact:
- choice of an Active Pixel Sensor (APS) which has a high radiation hardness
- intensified MCP at several levels with one level inversed to remove part of the contribution by radiation
- discrimination of the signature of the sprays to eliminate part of those due to radiation

(b) the ***electronics***: they may be wrapped some of the electronic components individually and choose the components carefully.

In addition, we are planning an aluminium box of 3-mm thick with a mass estimated roughly to 600 g, value not included in the total mass of the instrument given in the present document.
Below the 8 mm shielding of aluminium already planned, we expect 1 Mrad accumulated over 66 days with an estimate up to 3 Mrad with margin. Most of components can undergo up to 100 krad. We therefore need to reduce the radiation on the detector and electronics by a factor 30. This yields

protection boxes of 3-mm thick box of aluminium. This means a total of 600 g to protect the detector.

In order to reduce the impact on the total mass of each instrument, we would like to encourage the availability of a similar box for the electronics of groups of instruments.

6.11.9 HERITAGE

* Heritage of the imaging spectrometer: PHEBUS/BepiColombo, SPICAM/ Mars Express, SPICAV/ Venus Express.

6.11.10 OPEN TECHNOLOGY ISSUES AND CRITICALITY

- The most critical issue is radiation exposure with a careful analysis of the choice of material, components, detector type (see 5.1.8).

- In order to fulfill the mass constraint, we will need a full study to derive a compact design for the instrument.

- Regarding the high spectral resolution H Lyman alpha channel, the way to accommodate absorption cells has to be studied.

- Regarding the polarimeter, further studies need to be undertaken in order to optimize this additional capability (dedicated to the observations of the jovian atmosphere) in terms of optimum design (including a moving part), mirror type, and possible interaction with the spectrometer.

6.11.11 INSTRUMENT SUMMARY DATA SHEET

Table 24 UVIS summary table.

Parameter	**Unit**	**Value/Description**	**Remarks**
Heritage	N/A	PHEBUS / BepiColombo SPICAM / Mars Express SPICAV/ Venus Express	
Type of instrument	N/A	EUV/FUV/MUV imaging spectrometer	
Type of optics	N/A	Off-axis parabolic mirror/ slit/ grating/detector	
Function mode	N/A	TBD	
Optics			
Spectral range	nm	1. 110-230 nm 2. 50-110 nm	2 detectors : EUV : 50-110 nm

		3. 230-320 nm	FUV : 110-320 nm
FOV	deg x deg	0.1 x 2	0.1 deg (spectral direction) 2 deg (spatial direction)
Pixel IFOV	deg	> 0.01	0.1 if no solar occultation
Wavelength for diff. limit	nm	N/A	
Aperture	mm	25 x 25	
Focal length	mm	170	
f/# (focal number)	#	TBD	
Filters	#	N/A	
Filter bandwidth	nm	N/A	
Detector			
Type of detector	N/A	Microchannel plate (MCP) + Position sensitive anode (Resistive Anode Encoder : RAE)	Additional options discussed in 5.1.8
Pixel lines in array	#	512	
Pixels per array line	#	512	
Pixel size	µm	80	
Exposure time	msec	1000	
Repeat time	msec	2000	
Operating temperature	°C	-20°C/+40°C	
Operating temperature stability	°C/h	TBD	
A/D conversion	bit/pix	16	
Full well capacity	Ke^-	TBD	
Readout time	msec	<1000	
Swath and Resolution			
Swath width	km	TBD	
Spectral sampling	nm	TBD	
Spatial pixel resolution	m	TBD	
Thermal Control			
Total surface area	cm^2	TBD	
Non-isolated area	W	TBD	
Operating temperature	°C	TBD	
Operating temperature stability	°C/h	TBD	
Physical			
Preferred location	N/A	(1) If 2D scanning device: at a corner, in such a way to cover the maximum angular field with the scanner* (2π solid angle	(1) to be able to look at different objects of interest (2) for simultaneous

		in Jupiter's direction, significant solid angle in anti-Jupiter direction) (2) Same face of the spacecraft as other spectrometers (IR, X-rays, sub-millimetre) and cameras	observations (e.g., stellar occultations, jovian aurora) * 1 degree of freedom scanning device by default (Phebus/BepiColombo heritage).
Mass, total	kg	6.5 (without shielding)	Without radiation shielding
Power			
Total average power	W	3-12	3W: average with strict restriction (only one detector working at a given time and instrument working only part of the time; 12W upper limit relaxing these constraints.
Detector + electronics	W	12 (peak, including scanner)	
TE cooler	W	NA	
Data Rate & Volume			
Data volume (total)	Gbyte	40 per year	
Data rate (instantaneous)	kbyte/s	30 (imagery), 4 (spectroscopy)	Imagery: nadir pointing; Spectroscopy: limb, occultations
Compression factor	#	TBD	

6.11.12 SUMMARY OF ALIGNMENT AND POINTING REQUIREMENTS

The ***constraint on pointing accuracy*** and stability is driven by the angular width of the slit (0.1°) and by the angular size of a pixel (0.1 (without) to 0.01° (with the option of solar occultation) during an acquisition time from 1 s up to a few tens of second. This provides a stability constraint of ~0.01°/s in the most conservative case.

The UVIS instrument is also expected to provide ***complementary measurements*** to the observations by instruments observing in other spectral ranges, in particular IR, X-ray, and the sub-millimetre, for addressing objectives relevant to, for instance, the jovian atmosphere and aurora and the satellites. It is therefore crucial that all these instruments have the **same pointing**.

Table 25 Summary of instrument alignment and pointing requirements. Note that in case more than one angle is listed, the sequence is pitch, roll, yaw.

Instrument	Pixel size arcsec	FOV deg	Min. pixel readout time ms	APE arcmin	RPE arcsec/t	AMA arcsec	Pre-facto knowledge of co-alignment with reference arcsec	Co-alignment stability arcsec/t	Post facto knowledge of co-alignment with reference arcsec
UVIS	> 36	0.1 x 5	TBD	TBD	TBD	TBD	TBD	> 36 arcsec/s	TBD

6.12 VIRHIS (Visible InfraRed Hyperspectral Imaging Spectrometer)

6.12.1 SCIENCE GOALS AND PERFORMANCE REQUIREMENTS

The VIRHIS capabilities and performances allow acquiring an integrated picture of the Jovian system by combining information on the Galilean satellites, Jupiter atmosphere, ring system and irregular satellites. The level of details and the expected extended mapping capabilities will unveil crucial characteristics of the Jovian system, allowing the reconstruction of the overall evolution and current state of the planet.
The main scientific objectives of the experiment are summarized in the following paragraphs.

Scientific objectives for the Galilean Satellites: study the Jovian satellites system and their connection to the population of minor bodies in the Solar System

- Surface composition of the Galilean Satellites, in particular Ganymede and Callisto, in relation to geologic and tectonic features;
- Characterization of the non-icy components and search for new components (organic compounds, altered products,…);
- Mapping surface space weathering due to radiation environment and impacts;
- Monitoring of Io’s volcanic and thermal activity on day and night sides;
- Identification of possible thermal spots and plumes related to internal processes;
- Monitoring exospheres with limb scans and stellar occultations;
- Characterization of the irregular satellites composition;
- Characterization of composition, grain size and 3D spatial distribution of the Jupiter’s rings system.

Scientific objectives for Jupiter atmosphere and interior: study the stratospheric and thermospheric structure, circulation dynamics and composition

- Determination of the general circulation and composition of the atmosphere;
- Observation of the auroral emissions (mainly due to H_3^+);
- Monitoring clouds and thermal hot spots;
- Characterization of the nature of CH_4;
- Determination of the composition of the primordial material from which Jupiter formed;

6.12.2 INSTRUMENT CONCEPT

The Visible and InfraRed Hyperspectral Imager (VIRHIS) onboard JGO is an innovative and performancing imaging spectrometer, operating in the 0.4-5.2 μm spectral range, able to detect and identify the compositional units of the Ganymede and Callisto surfaces as well as to study the Jupiter atmosphere composition and dynamics.

The instrument operates in pushbroom mode by using a scanning/pointing mirror located inside the telescope or by using the platform's relative motion respect to the different targets.

VIRHIS is sensitive to a broad spectral range (0.4-5.2 μm) thanks to an optical layout using reflecting optics and two HgCdTe detectors: the first devoted to the VIS-NIR range (0.4-2.2 μm) and the second to the IR range (2.0-5.2 μm). Both detectors have an active area of 480 × 640 pixels aligned along the sample × bands orthogonal directions, respectively.

Instrument geometrical performances allow to observe in detail the different objects of the Jovian system thanks to an angular resolution (IFOV) of 125 μrad and a large 3.4° FOV; these values correspond to a spatial scale of about 62 m/pixel and a swath width of 30 km from an altitude of 500 km.

Identification of compositional units is possible thanks to a very high spectral sampling equal to 2.8 nm/band in the VIS-NIR (0.4-2.2 μm) range and 5.0 nm/band in the IR range (2.0-5.2 μm).

As an option, it is possible to extend the spectral range of the IR channel beyond 5.2 μm up to 6.0 μm by reducing the spectral sampling at 6.25 nm / band; this could be interesting for the detection of some organic materials on the icy surfaces as well as for the study of the Jupiter's atmosphere. However, this option will require a more demanding thermal control and cooling both on the optics and on the IR detector.

Another possible option is to add a spectrograph channel optically co-aligned to VIRHIS which will be able to perform single point - high resolution spectroscopy (at resolution $\Delta\lambda/\lambda > 2000$) at infrared wavelengths; in this case the two instruments can easily share the same Main Electronics unit for data handling, processing and compression. Such configuration will introduce an increase in resources (mainly mass and power) but will also boost the overall scientific return of the experiment as VIRTIS demonstrated onboard Rosetta and Venus Express missions.

6.12.3 INSTRUMENT DESCRIPTION

VIRHIS is an imaging spectrometer that allows inferring the surface/atmosphere composition of a target by measuring the emitted spectral radiance ($W\ m^{-2}\ \mu m^{-1}\ sr^{-1}$).

The instrumental concept is based on a Three Mirrors Anastigmatic (TMA) telescope joined at the entrance slit of an Offner spectrometer. The instrument uses a single slit and a dual region reflecting convex grating to split the diffracted optical beam on the two focal planes.

Since the system is telecentric, it is possible to collect the image of the slit diffracted by the convex grating on two bidimensional sensors optimized for the VIS-NIR and IR spectral ranges. Thus, the instantaneous acquisition on the bidimensional focal planes consists of a frame of slit images dispersed across the selected spectral range (pushbroom concept).

The VIRHIS payload architecture is based on three main components: an Optical Head (OH), a Proximity Electronics Module (PEM) and a Main Electronics/Data Processing Unit (ME-DPU).

The OH consists of an external deployable cover, a Three Mirrors Anastigmatic (TMA) telescope, a scanning/pointing unit, a slit with integrated shutter, an Offner spectrometer, a VIS-NIR and IR focal planes, two passive radiators and an internal calibration unit. The OH has an electrical interface provided by the PEM and power/telecommand/telemetry/data bidirectional link with the ME-DPU.

The Main Electronics/Data Processing Unit (ME-DPU), located in an internal position of the spacecraft which allows a suitable radiation protection, is devoted to the control of the whole experiment by commanding the switch-on and switch-off of the two focal planes; receiving and interpreting telecommands; formatting and transmitting telemetry and data packets to the spacecraft mass memory; assuring the power distribution to each subsystem. The harness connecting OH/PEM and ME/DPU must be limited below 1 m in length to avoid degradation of the electrical signals.

The functionalities of each single instrument subsystem are schematized in Figure 11, and described in the next paragraphs.

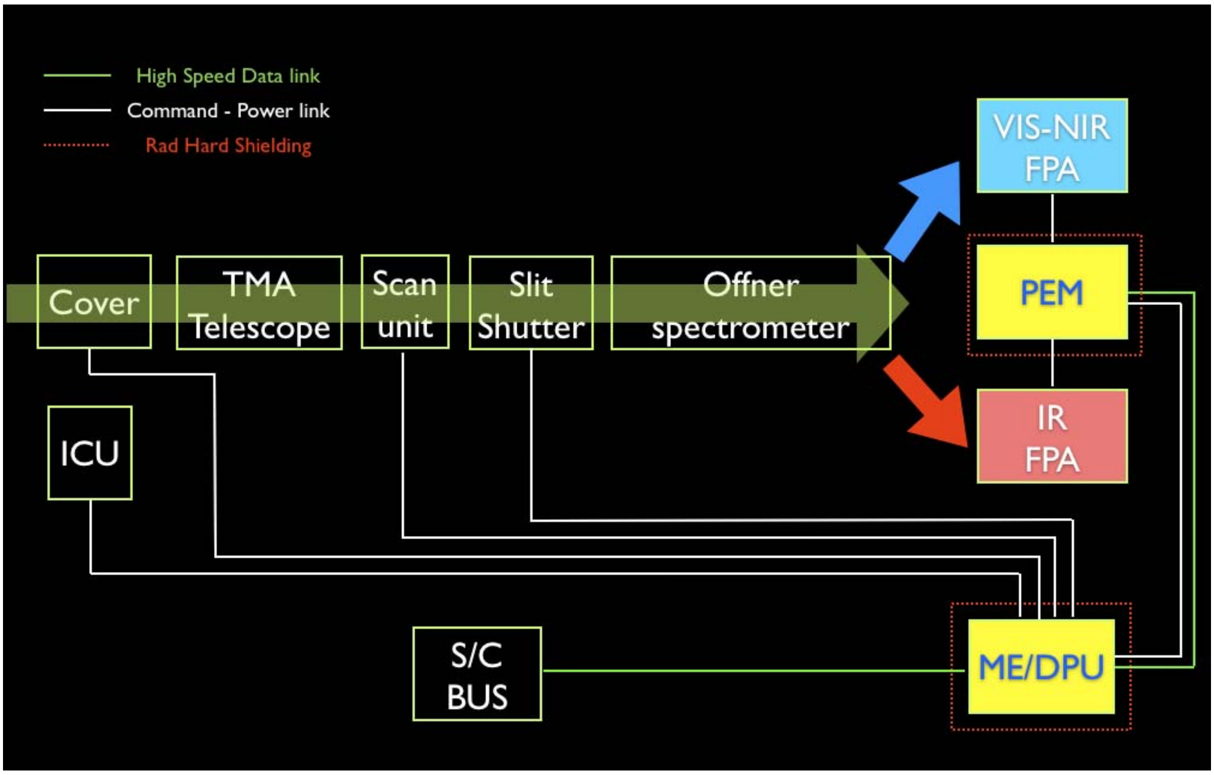


Figure 11. Block diagram of the VIRHIS concept.

COVER: the external deployable cover is used to protect the telescope's entrance pupil in critical phases of the mission (passage of the S/C through the Jupiter rings and S/C maneuvers during which the Sun enters the instrument's FOV). It can be commanded in two fixed positions (open vs close) according to the operations running on board. Cover's controller is housed in a dedicated circuit board of the ME/DPU. This device is also used to perform internal calibrations with a joined use of the internal calibration unit and shutter (see next point).

INTERNAL CALIBRATION UNIT (ICU): this device consists of a couple of calibrated sources (lamp and blackbody) which can be switched on to illuminate the internal side of the cover, allowing both focal planes to acquire a reference signal in flight conditions. Both sources are housed on the internal side of the telescope and are equipped with specific filters to introduce well characterized absorption bands, over which the spectral response of the instrument can be periodically checked. Moreover, because the cover is placed in front of the telescope's entrance pupil, the internal sources spots are able to illuminate the whole FOV: in this way it is possible to do a relative check of the overall instrument performances (flat field, defective/damaged pixels, spectro-radiometric responses) during the whole operative lifetime, monitoring in particular possible changes induced by radiations.

TELESCOPE: the instrument uses a Three Mirrors Anastigmatic (TMA) Telescope with a VIS-NIR pupil of 34 mm operating at f/# 5.6 and an IR pupil of 60 mm at f/# 3.2. The equivalent focal length is 192 mm. This compact design assures outstanding spatial performances as well as a good optical transmission in the 0.4-5.2 μm spectral range.

SCAN UNIT: the scan unit consists of a mirror mounted on a stepping motor, which allows a rotation of ± 1.7° (optical angle) with respect to the boresight, at steps of 125 μrad. The scan unit performs 480 steps to acquire a full 3.4° FOV at high spatial resolution (TELE). Inside this range it is possible to use it as a pointing unit respect to the S/C pointing direction. The scan unit position is controlled by a dedicated circuit board of the ME/DPU.

SLIT and SHUTTER: are placed at the focus of the telescope and correspond to the entrance of the spectrometer. The slit is the instrumental field-stop which defines the IFOV (3.4° × 125 μrad; slit width 27 μm). The slit is equipped with an electromechanical shutter necessary to interrupt the optical beam during the periodic measurement of the dark current.

SPECTROMETER: it is based on an Offner design, which allows to separate and disperse the optical beam in the two VIS-NIR and IR ranges. The spectrometer's design consists of a spherical Offner relay mirror coupled to a convex reflecting grating. The grating uses two diffraction zones (Airy design) optimized for the two spectral channels. To reduce thermal backgrounds, the spectrometer mount and walls are passively cooled down to 120 K.

VIS-NIR AND IR FOCAL PLANE ARRAYS: they both consist of a 640×480 pixels HgCdTe (mercury-cadmium-telluride) sensors with CMOS multiplexer; the VIS-NIR detector has the HgCdZn substrate removed to extend performances in the VIS range. For both, the pixel pitch is equal to 27×27 μm, the typical dark current is < 10 fA at 70 K and the full well capacity is 2E6 e^- (TBC, due to in-run developments in sensors technology). The sensors are housed in a thermo-mechanical structure that assures optical alignment, thermal coupling with the external passive radiators and electrical connections; an optical window maintains the detector in a protected environment and houses the order sorting filters and thermal rejection filters (Linear Variable Filters design). The operative temperatures of the focal planes are 180 K for the VIS-NIR and 70 K for the IR channels.

THERMAL CONTROL: consists of a couple of dissipating radiators, which allow to maintain the optics and focal planes at the operative temperatures. The spectrometer's optics are passively cooled at 120 K by means of a first external radiator oriented towards the deep sky (to reduce internal thermal background). The VIS-NIR focal plane is passively cooled <180 K by means of a thermal strap connected to a second dedicated OH radiator. The IR focal plane is passively cooled at 70 K by using a S/C provided coldfinger. The availability of a S/C provided coldfinger will help to simplify the thermal design as well as to reduce mass.
The OH is housed inside a thermomechanical structure that allows isolating it from the warm S/C interface as well as to maintain stable the optical boresight respect to the S/C.
Several standard techniques are foreseen to be used to reduce temperature impacts at various levels: new MLI materials and mounting techniques, detectors mechanical structures, thermal straps and radiators design, clever baffling of thermal background and proper user of optical filtering.

PROXIMITY ELECTRONICS MODULE (PEM): provides the timing, acquisition, pre-processing and digitization of the focal planes data; the PEM is connected to the ME/DPU with two high velocity data links, one for each focal plane. The PEM is housed close to the OH in a mechanical structure with a radiation shielding able to guarantee a total dose <70 krad on the electronics components at the EOM.

MAIN ELECTRONICS / DIGITAL PROCESSING UNIT (ME/DPU): provides the data/handling and the instrument control functions. The main tasks of the ME/DPU are:

- compression and formatting of the science data from both VIS-NIR and IR channels;
- control of the whole system, including all electro-mechanical devices (cover, scanning mirror, shutter, ICU's sources);
- control and monitoring of the down-link of the scientific data and housekeeping to the S/C bus through a high velocity link;
- calibration and health check of the instrument;
- interpretation and execution of the telecommands;
- timing and synchronization of the instrument activities with the S/C events;
- providing status information of VIRHIS to the S/C;
- providing the power supply for all components of the experiment.

The ME/DPU is housed in a mechanical structure with a shielding adapt to guarantee a total dose <70 krad on the electronics components at the EOM; in order to optimize the configuration it should be preferentially placed inside a S/C vault (together with other electronic units) to reach a high level of protection from radiations. The ME box heat is exchanged through the S/C interface.
In Figure 12 the block diagram of the PEM and ME/DPU functionalities are shown.
A possible option to reduce mass and optimize the payload configuration could be to realize a ME/DPU shared between VIRHIS and other spectrometers (like for VIRTIS-M and VIRTIS-H in the Rosetta and Venus Express configurations). In this case, it will be necessary to negotiate mass and power resources between the spectrometers and the S/C.

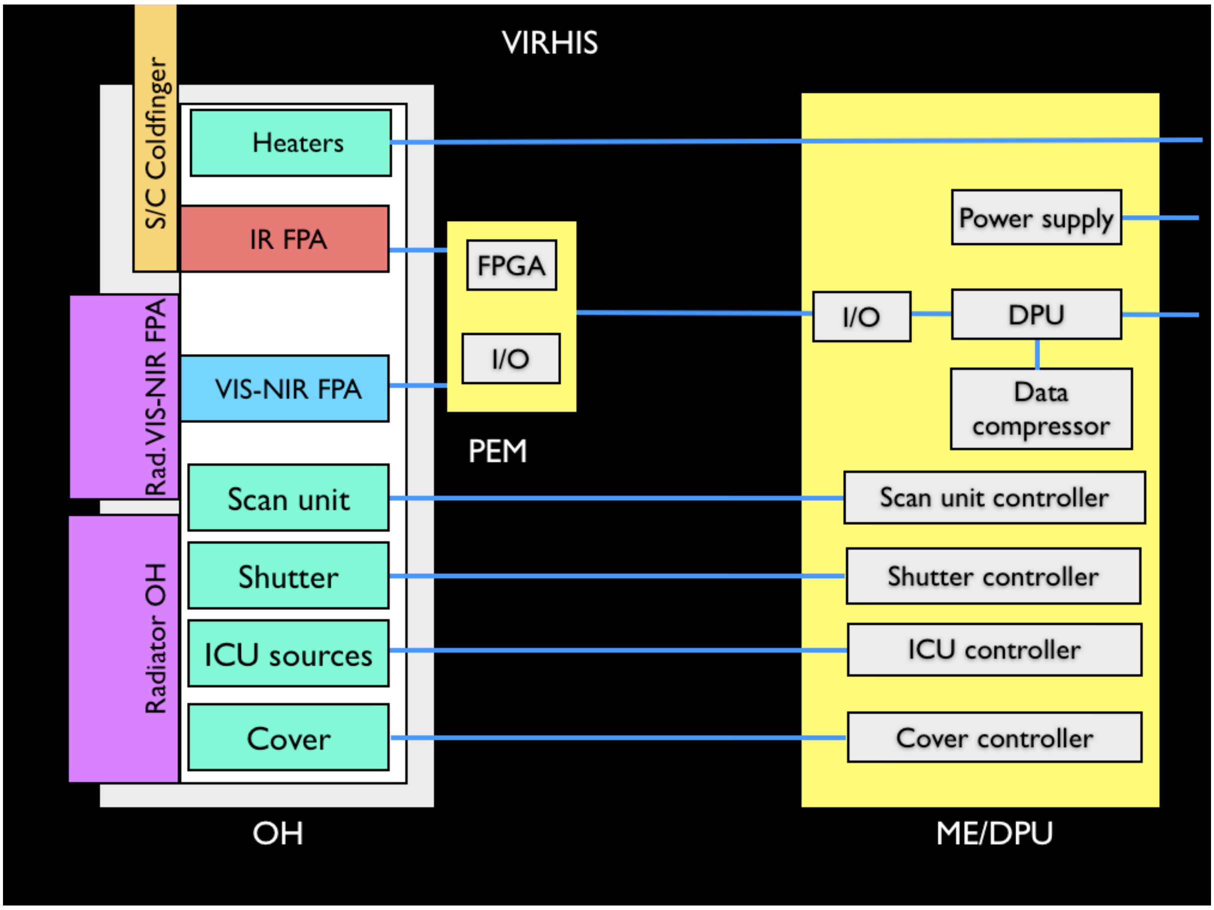


Figure 12. Block diagram of the OH and ME/DPU units.

6.12.4 ORBIT, OPERATIONS AND POINTING REQUIREMENTS

The hyperspectral image of the observed scene is reconstructed in time by subsequent acquisitions of the two focal planes; two operative acquisition modes are possible according to the different phases of the mission:

1- for close encounters with the targets, or to perform large angular scans, it is possible to match the dwell time with the integration time (pushbroom mode);
2- for targeted observations from far distances, the instrument uses the internal scanning mirror mechanism to move the projection of the slit across the scene (scan mode). A full square FOV is collected with 480 or 240 steps scan (see next Table 26).

In both cases, the final acquisition collected on ground is a three-dimensional hyperspectral cube which contains a full 0.4-5.2 μm radiance spectrum associated to each pixel of the image.
The large focal planes' dimension allows implementation of several instrumental operative modes: this flexibility is needed to optimize the scientific return during the different phases of the mission.
The instrument can operate both in TELE mode (high spatial resolution, corresponding to a 125

µrad IFOV) or in WIDE mode (250 µrad IFOV) in both HI and LOW SPECTRAL resolutions according to the following Table 26. Other possible operative modes can be implemented in the flight software to add flexibility during the different phases of the mission..

	HI SPECTRAL *VIS spectral resolution:* *2.8 nm/band @ 640 bands* *IR spectral resolution:* *5.0 nm/band @ 640 bands*	**LOW SPECTRAL** *VIS spectral resolution:* *5.6 nm/band @ 640 bands* *IR spectral resolution:* *10.0 nm/band @ 640 bands*
TELE *IFOV* *125* *µrad*	Scale: 62 m/pixel@500 km Observed region: 30×30 km @ 500 km altitude (480 samples × 480 lines)	Scale: 62 m/pixel@500 km Observed region: 30×30 km @ 500 km altitude (480 samples × 480 lines)
WIDE *IFOV* *250* *µrad*	Scale: 125 m/pixel@500 km Observed region: 30×30 km @ 500 km altitude (240 samples × 240 lines)	Scale: 125 m/pixel@500 km Observed region: 30×30 km @ 500 km altitude (240 samples × 240 lines)

Table 26. VIRHIS operative modes summary.

The resulting data volume for the two channels on one single line and for a full cube is tabulated in Table 27. When the target's angular size is smaller than the instrumental FOV, it will be possible to reduce by telecommands the acquired data region (windowing mode).

		Data Volume @ 16 bit	**Data Volume @ 14 bit**
TELE 480 samples	HI SPECTRAL - 640 bands	Line: 2.0 Mbit Cube: 960 Mbit	Line: 1.75 Mbit Cube: 840 Mbit
	LOW SPECTRAL - 320 bands	Line: 1.0 Mbit Cube: 480 Mbit	Line: 0.88 Mbit Cube: 282 Mbit
WIDE 240 samples	HI SPECTRAL - 640 bands	Line: 1.0 Mbit Cube: 240 Mbit	Line: 0.88 Mbit Cube: 211 Mbit
	LOW SPECTRAL - 320 bands	Line: 0.5 Mbit Cube: 120 Mbit	Line: 0.44 Mbit Cube: 106 Mbit

Table 27. VIRHIS data volume evaluated for a single line and a full cube for both VIS-NIR and IR channels. Values calculated for the different operative modes at 16 and 14 bit resolutions including a compression factor of 5 and a 2% telemetry margin.

The instrument capabilities allow to fulfill JGO scientific objectives from many different orbits and distances from the targets. In Table 28 is summarized a possible observation strategy for the three orbital phases of JGO mission (Callisto pseudo-orbit, Ganymede elliptical orbit and Ganymede circular orbit).

Orbital	**Observation**	**Pointing**	**Solar phase angle**

phase			
Callisto pseudo-orbit	***Jupiter full-disk observations*** from 30 RJ (both dayside and nightside): tele mode, IFOV 125 μrad/pixel, scale 260 km/pixel; full disk imaged with 480×1280×534 (samples × bands x lines) cube; total data volume 1,09 Gbit/observation - total data rate: 600Kbit/sec	Nadir pointing	0°-180° on both the dayside and nightside for exophere and aurora observations
	Callisto observations: we can assume a strategy similar to the Ganymede elliptical orbit: 1) North-South scan from a distance of about 6000 km corresponds to 7 Gbit/orbit; data rate 3Mbit/sec; 2) dayside high resolution pushbroom scan corresponds to about 8.8 Gbit/orbit; data rate 2Mbit/sec	North-South scan and/or nadir pointing	0°-100° (TBC)
Ganymede elliptical orbit (6000×200 km)	***High spatial resolution scan from the apocenter (6000 km):*** high resolution mosaic built by using scanning mirror and S/C repointing along the North-South central meridian. Mosaic of 480×1280×7016 (samples × bands × lines); tele mode, IFOV 125 μrad/pixel, scale 0.75 km/pixel; acquisition in about 1 hour with a repetition time of 0.5 sec (TBD); total data volume: 14 Gbit/orbit - total data rate 4Mbit/sec	North-South scan with 8 different pointings of the S/C at step of 3.4° for mosaics; otherwise nadir pointing	0°-100° (TBC)
	Medium spatial resolution scan from the apocenter (6000 km): medium resolution mosaic built by using scanning mirror and S/C repointing along the North-South central meridian. Mosaic of 240×1280×3508 (samples × bands × lines); wide mode, IFOV 250 μrad/pixel, scale 1.5 km/pixel; acquisition in about 30-40 minutes with a repetition time of 0.5 sec (TBD); total data volume: 7 Gbit/orbit - total data rate: 3Mbit/sec	North-South scan with 8 different pointings of the S/C at step of 3.4° for mosaics; otherwise nadir pointing	0°-100° (TBC)
	Limb scan at nightside: observation of the limb to characterize the atmosphere at heights between 0-300 km; 100	Limb pointing and scanning up to 300 km	150°-180° (TBC)

	frames in high resolution; total data volume: 200 Mbit/orbit - total data rate 170kbit/sec (duration 20 min)	(TBC)	
Ganymede circular orbit (200 km)	***High spatial resolution scan on dayside:*** scan at nadir with a repetition of about 30 slits/sec in pushbroom mode; 480 samples × 1280 bands; tele mode, IFOV 125 μrad/pixel, corresponding to a scale of about 25 m/pixel; acquisitions only on dayside (about 75 min/orbit); total data volume: 270 Gbit/orbit - Total data rate during acquisition: 60Mbit/sec NOTE: due to data volume/rate limitations, this mode can be operated only for a very limited period of time	Nadir pointing	0°-100° (TBC)
	Low spatial resolution scan on dayside: scan at nadir with a repetition of about 8 slits/sec in pushbroom mode; 120 samples × 1280 bands; ultrawide mode, IFOV 1000 μrad/pixel, corresponding to a scale of about 200x225 m/pixel (across × along track); acquisitions only on dayside (about 75 min/orbit); total data volume: 17.6 Gbit/orbit - Total data rate: 4Mbit/sec	Nadir pointing	0°-100° (TBC)

Table 28. A possible observation strategy for VIRHIS during the three orbital phases of the JGO mission: Callisto pseudo orbit, Ganymede elliptical orbit and Ganymede circular orbit.

Furthermore, we can consider here also some general case studies for the observation of Jupiter and the Galilean satellites. In Table 29 are reported the S/C distances at which VIRHIS can acquire the full-disk of the target in one FOV (3.4° × 3.4°) and the corresponding spatial resolution.

Target	Distance (km)	Spatial Scale (TELE-WIDE) (km/pixel)
Jupiter	2.400.000	300 – 600
Io	60.000	7.5 – 15
Europa	50.000	6.3 – 12.6
Ganymede	85.000	10.6 – 21.2
Callisto	82.000	10.3 – 20.6

Table 29. S/C distances corresponding to a full-disk cube acquisition (480 × 480 pixels in TELE and 240 × 240 in WIDE modes).

Moreover, assuming the S/C is moving around Jupiter at the distance of the Ganymede's orbit (1.070.400 km from Jupiter), VIRHIS has the capabilities to obtain disk-integrated spectra for some of the small inner moons (Table 30).

Target	Distance from Jupiter (km)	Radius (km)	Spatial Scale (TELE-WIDE) (km/pixel)
J5 Amalthea	181.400	83.45	111 – 222
J14 Thebe	221.900	49.3	106 – 212

Table 30. Spatial resolution for typical VIRHIS pointed observations of some of the small inner satellites.

Finally, some considerations about the outer irregular satellites: the far distances of these objects from Jupiter (> 10.000.000 km) generally prevents VIRHIS acquisitions from the region of Ganymede and Callisto. However, if the S/C will have the chance of a close flyby with one of these bodies during the Jupiter Orbit Insertion phase (like for Phoebe during the Cassini-Huygens approach to Saturn), VIRHIS will be able to obtain hyperspectral data of the surface. As an alternative if a close flyby is not feasible, it will be anyway possible to obtain long-duration exposure spectra of these bodies from a ~1.000.000 km distance (in this case, they will appear as subpixel, i.e. spatially unresolved or dot-like sources).

6.12.5 INTERFACE AND PHYSICAL RESOURCE REQUIREMENTS

The Optical Head, containing the telescope and the two spectral channels (VIS-NIR and IR) must be considered an Instrument Front End (IFE) as identified and sketched in Figure 12.

The OH is externally mounted to the –Y side of the S/C with the VIRHIS boresight aligned to the +X direction. The spectrometer slit is parallel to the +Z axis allowing to point and scan along the ±Y axis.

The instrument OH will be mounted and aligned in a thermomechanical structure. The mechanical interface with the S/C is a rectangular Pallet (50×40 cm) via eight mounting feet (two per side). The optical module must be considered as a cold box, thermally isolated from the S/C and passively cooled down <130 K through a flat radiator mounted on the –Y plane. A second radiator is necessary to dissipate heat generated by the VIS-NIR detector. The VIS-NIR FPA is thermally connected with the external radiator through a thermal strap. The IR FPA is cooled down at about 70 K by a S/C provided coldfinger.

The PEM and ME/DPU units contains electronic circuit boards which generate a mean power of about 20 W; both must be maintained below 50°C and therefore must be thermally connected to the S/C mechanical interface to dissipate power without interfere with the thermal balance of the OH and of the two FPAs.

At now we assume both PEM and ME/DPU boxes housed inside a radiation hardened vault of the S/C bus; PEM and ME/DPU boxes and electrically connected through the following lines:

- 2 Command links;
- 2 Engineering links;
- 2 Science data links, one for each FPA and/or for redundancy (high velocity, i.e. spacewire interface).

The ME/DPU unit is interfaced with the S/C PDDU through the following lines:

- Primary/secondary power;
- Electronics primary/secondary heaters line;
- OH primary/secondary decontamination heater;
- OH primary/secondary survival heater.

The ME/DPU unit is connected to the S/C C&DH through:

- 2 Command links;
- 2 Engineering links;
- 2 Science data links, one for each FPA and/or for redundancy (high velocity, i.e. spacewire interface);
- 2 Timing signals;
- ME/DPU temperature monitoring (2 lines).

Finally the OH is interfaced with the S/C C&DH through:

- OH temperature monitoring (2 lines);
- Cover emergency closure.

6.12.6 CALIBRATION

Critical components of sub-assemblies, such as the detectors, internal calibration sources and the diffraction grating, will be independently tested and calibrated prior to system integration. Subsequently, the instrument will be tested to a specified acceptance level. These measurements will both verify the baseline performance checks and ensure proper instrument function prior to integration. The integrated VIRHIS instrument is delivered to the science and technical teams to allow a full calibration of the payload before the flight. This is one of the more important steps necessary to be completed before launch because allow to verify, understand and characterize the instrumental responses.

The following calibration definition should be considered to understand the importance of this activity:

“Comparison of a measurements standard or instrument of known accuracy with another standard of instrument to detect, correlate, report or eliminate by adjustment, any variation in the accuracy of the item being compared” (MIL-STD-4566A).

The scope of the calibration activity, which is asymptotically achieved through the whole life of the payload, is to evaluate the conversion values necessary to transform the engineering quantities supplied by the instrument (Digital Number coming from the readout stage circuits) in physical units of spectral radiance (W m^{-2} μm^{-1} sr^{-1}).

The calibration of VIRHIS will require the following characterizations to be done during on-ground measurements:

- Boresight and reference system misalignment;
- Spectral response (spectral range, sampling and resolution);
- Geometrical response (IFOV, FOV) and image quality;
- Spatial uniformity (flat-field);
- Detector's response linearity (with different fluxes and exposure times) and defective pixels;
- Polarization response (induced by the instrument and measured on polarized sources);
- Radiometric response;
- Straylight contamination;
- Internal calibration unit characterization.

- The instrument key parameters obtained during on-ground calibrations will be updated and checked during the whole instrument lifetime by using the internal calibration unit and observing celestial reference targets.

The instrument key parameters obtained during on-ground calibrations will be updated and checked during the whole instrument lifetime by using the internal calibration unit and observing celestial reference targets.

All components and materials used to assemble the instrument will respect the following rules necessary for cleanliness:

- Metallic materials shall be corrosion resistant;
- Metals that can sublimate in vacuum or that can generate particles (cadmium, zinc and unfused electro-deposited tin) shall not be used;
- Organic material selection shall be guided by consideration on their outgassing rates, location and amount;
- Unless easily cleanable afterwards, all special parts/components shall be procured through dedicated specifications evidencing, case by case, the acceptable incoming cleanliness levels (MIL-STD-1246C TBD)
- The choice of manufacturing sequences, techniques and processes shall be governed by considerations concerning compatibility with cleanliness requirements; operations that imply high risk of contamination (soldering, painting, extensive bonding, conformal

coatings etc) shall be performed under vapor hoods in restricted area separated from Assembly and Integration Clean Rooms (class 100.000).

The instrument OH will be equipped with several heaters necessary to accelerate the outgassing process soon after the launch. The final configuration of the heaters and venting holes will be defined during the thermomechanic project.

Planetary Protection rules: TBD (depending on mission scenario).

Pre-launch activities: VIRHIS team needs that the following activities on the assembled instrument must be completed before launch:

- full scientific on-ground calibration;
- measurement of the optical boresight w.r.t to external reference cubic mirror;
- functional tests of the instrument on board the S/C bus.

6.12.7 CRITICAL ISSUES

- Overall Mass: must be optimized by adapting the telescope pupil diameter respect to the throughput necessary to have a satisfactory SNR (>128);
- Radiation hardening for both Focal planes and ME/DPU;
- Thermal design: availability of S/C supplied coldfingers reduces instrumental mass and dimension of the external radiators;
- DPU performances: become critical for repetition times < 0.5 sec (which could be necessary during close encounters or for low orbit acquisitions); in this case a more detailed mission scenario is needed; technological developments of electronics components and design;
- Data Volume: the necessity and capacity of an instrumental mass memory can be better estimated only when a more detailed mission scenario will be available.

6.12.8 HERITAGE

VIRHIS design and development relies on the following heritage coming from these in-flight experiments (in preparation experiments are indicated by *):

- Cover: Rosetta/VIRTIS-M, VenusExpress/VIRTIS-M, Dawn/VIR-MS;
- Internal calibration unit, shutter: Rosetta/VIRTIS-M, VenusExpress/VIRTIS-M, Dawn/VIR-MS, Juno/JIRAM*, BepiColombo/VIHI(SYMBIO-SYS*);
- Offner relay spectrometer and grating: Cassini/VIMS-V, Rosetta/VIRTIS-M, VenusExpress/VIRTIS-M, Dawn/VIR-MS;
- Scan mirror unit: Cassini/VIMS-V, Rosetta/VIRTIS-M, VenusExpress/VIRTIS-M, Dawn/VIR-MS, Juno/JIRAM*;
- HgCdTe focal planes: Rosetta/VIRTIS-M, VenusExpress/VIRTIS-M, Dawn/VIR-MS, Juno/JIRAM*, BepiColombo/VIHI(SYMBIO-SYS*);
- Thermal design: Cassini/VIMS-V, Rosetta/VIRTIS-M, VenusExpress/VIRTIS-M, Dawn/VIR-MS, Juno/JIRAM*, BepiColombo/SYMBIO-SYS*;

- ME/DPU: Cassini/VIMS-V, Rosetta/VIRTIS-M, VenusExpress/VIRTIS-M, Dawn/VIR-MS, Juno/JIRAM*, BepiColombo/SYMBIO-SYS*;
- Radiation hardening: Juno/JIRAM*, BepiColombo/SYMBIO-SYS*;

6.12.9 OPEN TECHNOLOGY ISSUES AND CRITICALITY

See 5.1.8

6.12.10 INSTRUMENT SUMMARY DATA SHEET

Table 31 VIRHIS summary table.

Parameter	**Unit**	**Value/Description**	**Remarks**
Heritage	N/A	Cassini/VIMS-V Mars Express/OMEGA Rosetta/VIRTIS VenusExpress/VIRTIS Dawn/VIR-MS Juno/JIRAM* BepiColombo/VIHI (SIMBIO-SYS)*	(* indicate in preparation payloads)
Type of instrument	N/A	Pushbroom imaging spectrometer with scanning-pointing mirror	
Type of optics	N/A	Three Mirrors Anastigmatic (TMA) telescope; Offner spectrometer	
Function mode	N/A	Pushbroom, scanning mode	
Optics			
Spectral range	nm	400-5200 VIS-NIR channel: 400-2200 IR channel: 2000-5200	Possibility to increase the IR spectral range up to 6000 nm
FOV	deg	3.4°	
Pixel IFOV	mrad	0.125 – 0.250	TELE - WIDE
Wavelength for diff. limit	nm	800	
Aperture	mm	34 VIS-NIR 60 IR	Concentric apertures
Focal length	mm	192	Equivalent
f/#	#	5.6 VIS-NIR 3.2 IR	
Filters	#	2	One order sorting filter for each focal plane
Filter bandwidth	nm	<100	Linear Variable Filters for grating orders

			suppression and thermal shielding
Detector			
Type of detector	N/A	*VIS-NIR FPA:* HgCdTe with HgCdZn substrate removed, CMOS multiplexer *IR FPA:* HgCdTe, CMOS multiplexer	
Pixel lines in array	#	640	
Pixels per array line	#	480	
Pixel size	µm	27	
Exposure time	msec	From 0 (readout) to 60000 (TBC)	
Repeat time	msec	From 30 to 30000 (TBC)	
Operating temperature	°C	VIS-NIR detector: < -93°C (180 K) IR detector: < -203°C (70 K)	
Operating temperature stability	°C/h	2	
A/D conversion	bit/pix	14 floor – 16 optimal	
Full well capacity	Ke$^-$	2000	
Readout time	msec	30 msec with A/D converter @10 Mpixel/sec	For each FPA
Swath and Resolution			
Swath width	km	30	480 spatial pixels (samples) from 500 km altitude in TELE mode; 240 samples in WIDE mode.
Spectral sampling	nm	*VIS-NIR range:* 2.8 nm/band *IR range:* 5.0 nm/band	
Spatial pixel resolution	m	62 – 125	From 500 km altitude (TELE – WIDE mode)
Thermal Control			
Total surface area	cm^2	2500	Radiator area
Non-isolated area	cm^2	5000	Walls area
Operating temperature	°C	Optical Head: < -143°C (130 K)	
Operating temperature stability	°C/h	4	
Physical			
Preferred location	N/A	Co-aligned with other remote sensing instruments boresights;	

		radiators placed on antisolar direction	
Mass, total	kg	17	Excluding harness
Power			
Total average power	W	20	Assuming S/C provided coldfingers
Detector + electronics	W	20	
TE cooler	W	N/A	
Data Rate & Volume			
Data volume (total)	Gbyte	TBD	Depends on mission scenario
Data rate (instantaneous)	Mbit/s	5	Max burst, compressed
Compression factor	#	>5	

6.12.11 SUMMARY OF ALIGNMENT AND POINTING REQUIREMENTS

Table 32 Summary of instrument alignment and pointing requirements. Note that in case more than one angle is listed, the sequence is pitch, roll, yaw.

Instrument	Pixel size arcsec	FOV deg	Min. pixel readout time ms	APE arcmin	RPE arcsec/t	AMA arcsec	Pre-facto knowledge of co-alignment with reference arcsec	Co-alignment stability arcsec/t	Post facto knowledge of co-alignment with reference arcsec
VIRHIS	25.8	3.4	1000 (both focal planes)	0.5	6.5 arcsec/ 0.5 sec	5	13.0	TBD	26

6.13 Radio and Plasma Waves Instrument

6.13.1 SCIENCE GOALS AND PERFORMANCE REQUIREMENTS

General RPWI:

We present a full state-of-the-art plasma waves and radio instrument (RPWI) for the ESA Jupiter Ganymede Orbiter (JGO). RPWI consists of a set of sensors that measures the near dc electric field (LP-PWI), electric component of waves (LP-PWI), magnetic component of electromagnetic waves (SCM), radio emissions (RWI) as well as detailed characteristics of the thermal plasma (LP-PWI and QTN). Most of the measurements have never been carried out before around Jupiter and its moons, and only this type of instrumentation can address fully the scientific objectives stated below. The main science topic for the investigation is the Jupiter moons - magnetosphere interaction. The secondary topic is the Jupiter magnetosphere.

Expected Plasma Regimes:

As discussed in *Blomberg et al.* [2005] and *Wahlund et al.* [2005], the JGO will encounter a wide range of space plasma conditions. The most relevant statements from these reports will be repeated here.

Near Ganymede and Callisto the nearly co-rotating magnetospheric plasma (130-230 km/s) have number densities in the range from 0.1 cm^{-3} to several cm^{-3}. Typical cyclotron and plasma frequencies range from 0.01 Hz to 30 kHz. JGO will most probably also encounter the upper parts of the ionospheres of Ganymede and Callisto. These ionospheres are controversial, and in Callisto's case it is highly variable with time. At Callisto the estimated ionospheric peak densities of 7000-17000 cm^{-3} with a scale height of 30-50 km suggest that substantial plasma will be encountered by JGO. In situ measurements of the upper hybrid line revealed densities over 100 cm^{-3} at 600-700 km. On Ganymede the predicted ionospheric peak densities are somewhat less (400 – 2500 cm^{-3}) but scale heights are larger (up to 1000 km). In-situ upper hybrid emission lines revealed 50 cm^{-3} at 600-700 km. Since Ganymede also have a strong intrinsic magnetic field the dense plasma is bound on closed field lines at polar latitudes. JGO will most probably encounter significantly enhanced plasma densities around 1000 cm^{-3} (plasma frequencies near 300 kHz) depending on flyby and orbit choices. Langmuir probes voltage sweeps (part of LP-PWI) and QTN measurements make therefore perfect sense, while particle measurements (both ions and electrons) will not gain complete information and requires the determination of the spacecraft potential provided by LP-PWI.

NOTE: Except for the electron and ion temperature measurements, RPWI provides full information in any space plasma as described in 6.2.3.

Common Science Goals for RPWI:

Some of the science goals that RPWI addresses can be found in the JGO traceability matrix. A more detailed description follows below.

LP-PWI & SCM:

Plasma Measurements

- Characterize the interaction of the flowing Jovian magnetosphere with the Galilean moons
  - Study the induced magnetosphere of Callisto
  - Study the thermal plasma within the intrinsic magnetosphere of Ganymede
  - Study the escape of plasma through the torus/wake of Callisto and Ganymede
  - Study plasma/surface sputtering processes
- Determine the *in situ* plasma characteristics (n_e, v_i, $<m_i>$) of Jupiter's nearly co-rotating magnetosphere (see further 5.1.3)
  - Study of pick-up & charge-exchange processes in plasma/neutral tori
  - Study the magnetodisk structure, dissipation of rotational energy, transfer of angular momentum
  - Study of pick-up & charge-exchange processes in plasma/neutral tori
  - Response to mass loading variability
  - Determine the sources of plasma from moons inside the magnetosphere
- Determine the *in situ* plasma characteristics (n_e, v_i, $<m_i>$, T_e) of the ionised exospheres around the Galilean moons. From these characteristics it is possible to monitor:
  - Heating sources/cooling sinks
  - Dynamics
    - Processes arising from the interaction of Jupiter's flowing magnetosphere with the Galilean ionospheres
    - Exospheric erosion (ionospheric escape) from the Galilean moons
  - Ionisation sources (particles, UV, charge-exchange)
  - Energy transfer by plasma waves ($\delta n/n$, δE)
- Determine the electrical conductivities of the ionised exospheres of the Galilean moons and their role in supporting *MHD*-dynamo generated current systems (and associated magnetic field disturbances) induced by the co-rotating magnetosphere.

Electric & Magnetic Field Measurements

- Determine the wave electric & magnetic fields (e.g., Alfvén waves) in the magnetosphere of Jupiter
- Characterize the interaction of the flowing Jovian magnetosphere with the Galilean moons
- Contribute to the understanding of possibly conducting sub-surface oceans on the Galilean moons by determining the current systems generated in the ionised exo-ionospheres by the *MHD*-dynamo induced by the co-rotating magnetosphere
- Determine the *in situ* electric & magnetic fields in the magnetosphere of Jupiter in the frequency range from near DC to 3 MHz, in particular study how a plasma flow – (magnetised) solid body interaction occurs
  - Jupiter's magnetospheric response on the variable solar wind flow

- Jupiter's nearly co-rotating magnetospheric flow interacts with the Galilean moons
- Determine sub-or trans-Alfvénic interactions (Callisto sometimes has Mach ~1)
- Determine directly the electric & magnetic fields associated with the *MHD*-dynamo induced by the co-rotating magnetosphere
- Determine the magnetospheric large scale convection electric fields and co-rotation breakdown
  - dissipation of rotational energy, transfer of angular momentum
- Determine parallel electric fields and their relationship to charged particle acceleration, aurora and auroral current systems in both Ganymede's and Jupiter's magnetospheres
- Determine ionospheric plasma escape/acceleration from the Galilean moons
- Study reconnection processes at Ganymede

- Determine energy transfer processes by EM & plasma waves ($\delta\mathbf{E}$, $\delta\mathbf{B}$)
  - Alfvén waves to Jupiter footprints (along magnetic flux tubes)
  - Ion Cyclotron waves in ion pick-up regions
- Characterise the ULF pulsations and their importance

RWI:

Planetary Radio Measurements

- Determine the full polarization and Poynting flux characteristics of radio waves
- Determine the source locations of radio emissions. This includes
  - determination of the morphology and modulation of (auroral) radio emissions (multi- λ)
  - magnetospheric mapping of radio emissions
- Determine the dynamics of radio emission sources and the magnetospheric response to solar wind variability (Jovian space weather)
- Microphysics of Auroral radio emissions
- Observations of the moons auroral magnetic footprints
- Characterization of Jupiters magnetosphere/ionosphere/thermosphere coupling processes

QTN:

Plasma Measurements

- Characterize the interaction of the flowing Jovian magnetosphere with the Galilean moons
  - Study the induced magnetosphere of Callisto
  - Study the thermal plasma within the intrinsic magnetosphere of Ganymede
  - Study the escape of plasma through the torus/wake of Callisto and Ganymede
  - Study plasma/surface sputtering processes
- Determine the *in situ* plasma characteristics (n_e, T_e) of Jupiter's nearly co-rotating magnetosphere (see further 5.1.3)
  - Study of pick-up & charge-exchange processes in plasma/neutral tori
  - Study the magnetodisk structure
  - Study of pick-up & charge-exchange processes in plasma/neutral tori
  - Determine the sources of plasma from moons inside the magnetosphere

- Determine the *in situ* electron number density and temperature characteristics of the ionised exospheres around the Galilean moons.
    - Heating sources/cooling sinks
    - Determine sources and sinks of plasma

6.13.2 INSTRUMENT CONCEPT

LP-PWI:

A Langmuir probe and plasma waves experiment consists of a small conducting spherical sensor of a few cm diameter mounted on a boom extending from the spacecraft. The length of the booms should optimally be longer than the local Debye length (λ_{De}) and the probes situated in the ram plasma flow. In practice, the boom length and placement is often subject to considerations of what is technically feasible on the spacecraft. On Cassini and Rosetta the solid boom length used was 1.5 m and 3 m respectively.

A Langmuir probe is in theory a simple experiment, where the probes are set to a specific bias potential (or swept in bias potential) and the electrical current from the surrounding plasma is sampled. When the probe is negatively biased the current is dominated by ions attracted to the probe or by photoelectrons emitted from a sunlit probe. When the probe is positively biased attracted electrons dominate the current. From a Langmuir probe experiment it is possible to derive a fair range of information from the plasma. See instrument capabilities under 6.2.3.

The basic principle of a multiple-probe instrument for electric fields and plasma waves is identical to that of a voltmeter: the potential difference between two sensors is measured, and the electric field component along the direction of the sensors is obtained as the potential difference divided by the separation distance of the sensors. In order to bring the probes outside the region that is electrostatically perturbed by the spacecraft, it is desirable to have long booms. From an electric field and plasma waves instrument it is possible to derive the electric fields associated with waves in a broad frequency range (up to 3 MHz). By using four booms it is most often possible to do interferometry, infer the propagation, wave-vector, polarization and Poynting flux of these waves.

RWI:

The 3-axis radio antenna measures the 3 components of the wave electric field. More specifically, the RWI measures auto- and cross-correlations from three non-coplanar antennas to estimate the four Stokes parameters (flux and polarization) as well as the direction of arrival of the radio waves in the frequency range from 1 kHz to 45 MHz. This enables also wave normal and Poynting flux determinations (e.g. for whistler mode waves). These goniopolarimetric measurements require a triad of short electrical antennas (~1m).

The possibility of embarking the same radio experiment on 2 spacecraft would enable stereoscopic analysis of the radio emissions. This is very valuable for the microphysics of the radio emissions as their beaming pattern is usually highly anisotropic.

SCM:

A tri-axial search coil magnetometer measures the 3 components of the waves magnetic field. Usual bandwidth is 0.1 Hz-10 kHz. Using bi-band antennas (two magnetic antennas arranged in a compact configuration), the bandwidth can be extended up to hundreds of kHz, with no loss of sensitivity at lower frequencies. However, based on Galileo results it is usually not required to reach more than 20-30 kHz. The simultaneous measurement of the 3 magnetic field and at least 2 electric field components of the electromagnetic waves allows the full determination of the wave characteristics from the calculation of the associated spectral matrices.

QTN:

A quasi-thermal noise antenna samples the thermal noise of the antenna. Local plasma parameters (density and temperature) are derived from the Quasi-Thermal Noise (QTN) spectroscopy. This requires antennas longer than the local plasma Debye length. The 2x 5m dipole-antennas would facilitate this.

The method is based on the spectral analysis of the electric potential induced by the plasma particles as they pass by the antennas, and/or impact them or the spacecraft. The QTN technique has a great advantage over usual electron detectors: its cross section for detection is much larger than the surface of the detector itself, ensuring a great sensitivity and quasi-immunity to spacecraft perturbations (including effects due to negative spacecraft potential). In particular, that may allow the detection of a genuine population of thermal cold electrons (for example, < 0.5eV in the inner magnetosphere of Saturn) even if the photoelectrons surrounding the spacecraft have a comparable temperature. Because it provides electron density with the best accuracy, QTN is then a powerful tool for other electron sensors calibration. The main limitation of QTN spectroscopy is that requires antennas longer than the local plasma Debye length, in order to catch and bracket the resonance around the plasma frequency or upper hybrid frequency (which thus defines the frequency range of our receiver). The radar antenna (10 to 20m dipole) could be used for QTN analysis anywhere in the magnetosphere. Nevertheless a 2x 5m electric dipole provides good compromise and allows the plasma measurements and scientific objectives as described in 6.2.1.

6.13.3 INSTRUMENT DESCRIPTION

RPWI-E:

RPWI-E is the common integrated electronics box that operates the four different sensor systems, LP-PWI, RWI, SCM and QTN. It includes electronics box, DPU, DC/DC converters and three electronics cards. The receiver channels are fully digital and is the latest (and flight proven) state-of-the-art electronics design. The electronics enables the onboard computation of spectral matrices and wave parameters, but can also produce raw (compressed) waveforms and simple spectra.

LP-PWI:

The instrument consists of four 1-3 m long thin light-mass deployable booms, with 5 cm diameter TiN coated spherical sensors at the tips of the booms.

Table 33: LP-PWI Instrument Capabilities

Measured Quantity	Range
Electron density (n_e, δn/n)	0.001 – 10^6 cm^{-3}, 0(dc)-10 kHz
Electron temperature	0.01 – 20 eV, <100 Hz
Ion drift speed	0.1-200 km/s, <1 Hz
Ion temperature	0.01 – 20 eV, <1 Hz
Spacecraft potential	±50 V, <100 Hz
Electric field vector, δ**E**(f)	0(dc) – 3 MHz (waveform), ±1 V/m Bit resolution: 0.015 mV/m
Integrated solar EUV flux	Resolution 0.05 Gphotons/cm^2/s

The electron number density (n_e) is determined through several independent techniques:

- Through potential bias sweeps (for densities > 10 cm^{-3})
- Through monitoring the upper hybrid emissions (f_{uh})
- Through monitoring the spacecraft potential (U_{SC}) and calibrating toward f_{uh} (or possibly an electron spectrometer on board S/C). This gives a time resolution of up to several kHz.

At best the electron density can be sampled at ms resolution.

NOTE: The electron and ion temperatures determination is restricted to a dense plasma condition (> 10 cm^{-3}). All other listed parameters are available for all plasma conditions encountered by LP-PWI. Thus, it is possible to monitor the e.g. electron density, spacecraft potential and electric field vector everywhere (also in the magnetosphere).

The electric field vector and δn/n measurements allows for determination of

- Wave polarization
- Wave vectors
- Wave Poynting flux/vector (together with MAG or SCM measurements)
- Density and electric field spectrum in frequency range from near dc to 3 MHz
- Interferometry and determination of wave group speeds and plasma drift speeds
- Convection electric fields (**E**×**B** drift)
- Waveform determination
- Electric fields of structures and waves responsible for accelerating charged particles

The LP-PWI is therefore a complete and modern electric field and plasma wave instrument as well as having full Langmuir probe capabilities.

RWI:

Table 34: RWI Instrument Capabilities

Measured Quantity	Range
Electric field vector, δ**E**(f)	1 kHz – 45 MHz

The measurement allows for determination of:

- Electric field vector spectrum in the frequency range 1 kHz to 45 MHz
- Polarization
- Direction finding
- Radio flux

SCM:

A search coil magnetometer consist of a core in a high permeability material on which are wound a main coil and a secondary coil. The second coil is used as a feedback to flatten the frequency response on a bandwidth, which is centered on the resonance frequency of the main coil. A tri-axial search coil magnetometer is thus composed of 3 couples of coils or 6, if bi-band antennas are used.

Table 35:SCM Instrument Capabilities:

Measured Quantity	Range
Magnetic field vector, $\delta\mathbf{B}(f)$	0.1 Hz – 20 kHz

The measurement allows for determination of:

- Magnetic field vector spectrum in the frequency range 0.1 Hz to 20 kHz

Together with simultaneous capture of the electric waveforms by LP-PWI and RWI it allows for the calculation of spectral matrices required for the determination of wave normal angles, Poynting flux, polarization, and other wave parameters.

QTN:

The QTN (quasi-thermal noise) spectroscopy capability enables determination of the local plasma parameters (electron number density, electron temperature), which complements the Langmuir probe measurements in LP-PWI, as described above.

The performance of the QTN spectroscopy requires very sensitive preamps and low noise high dynamic receivers with AGC, as provided in LESIA (see heritage below). So, with a 2x5m dipole (3.7 kg including deployment mechanisms and preamps) and using the radio receiver we propose with RWI, the instrument capabilities are given in Table 36.

Table 36: QTN instrument capabilities

Measured Quantity	Range
Electron density	$0.1– 10^5$ cm^{-3} ($\Delta n/n < 1\%$)
Electron temperature (core and halo, or non-Maxwellian distrib.)	0.1 – 100 eV ($\Delta Tc/Tc < 10\%$)
Waves spectrum (QTN range only)	10kHz-2.5MHz ($\Delta f/f \sim 4\%$) (dynamic 120dB, sensitivity <7nV/√Hz)

Note : The duration to sample a whole spectrum (and so the time resolution of the electron density and temperatures) will be about 0.5s.

6.13.4 ORBIT, OPERATIONS AND POINTING REQUIREMENTS

Orbit:
The RPWI will fulfill its scientific objectives operating on very wide class of orbits around the moons. The preferable orbits are polar, elliptical 100-300 km x 3-5Rm (Rm the moon radius).
Occasional close flybys (<100 km) would greatly enhance the understanding of the ionospheres of Callisto and Ganymde and their contribution to near surface or sub-surface electrical currents.

Pointing:
The four 5 cm spherical probe sensors of LP-PWI should be in the plasma-ram hemisphere of the spacecraft and not “shadowed” (from incoming plasma) by other structures. The preferable configuration would be to place the four LP-PWI probes in a plane and place the two QTN dipole antennas orthogonal to this plane. Other RPWI sensors have no pointing requirements.

The RPWI main electronics can be placed in the spacecraft bus, but preamplifiers for all sensors must be located near the sensors.

6.13.5 INTERFACE AND PHYSICAL RESOURCE REQUIREMENTS

Mechanical Interface:
The LP-PWI sensors should be at least 2 m from each other, as well as not be close to a propulsion exhaust system. The booms should preferably be deployed on opposite sides of the S/C in a cross-like configuration. The 1 m to 3 m long stiff booms can be used to facilitate this. The booms can be deployable.

Electronics box: 15x15x8 cm.

Table 37: Instrument interface summary.

Instrument	Acronym	Mass [kg]	Size [cm]	Power [W]	TM [kbps]	TRL	Heritage

RPWI Common Electronics	RPWI-E	3.0[1]	15x15x8 cm	7+3[2]		8[3]	
Langmuir Probe & Plasma Waves Instrument	LP-PWI	2.0[4]	4x 5cm probes on tip of 1-3m booms[5]		Min: 64 bps Max: Several kbps[6]	8	Cassini RPWS Rosetta LAP Swarm CEFI Cluster EFW BepiColombo PWI
Radio Wave Instrument	RWI	1.5[7]	Triad of 50cm-1m antenna[8]		1-100 kbps[6]	8	Cassini RPWS STEREO Waves Juno, RBSP BepiColombo PWI
Tri-axial Search Coil Magnetometer	SCM	1.0[9]	11x11x11cm		See LP-PWI	8	BepiColombo PWI Cassini RPWS
Quasi-thermal noise	QTN	3.7[10]	2x6m dipole		From 50 bps to 2kbps[6]	8	Cassini RPWS BepiColombo PWI

1) Includes electronics box (1kg), DPU (400g), DC/DC converter (200g), three electronics cards (2x400g+1x600g)
2) Includes also heaters (3W, TBC)
3) Electronics design is flight proven. Interfaces to sensor elements and electronics box need be adapted (no problem).
4) Includes 4x spherical sensors (50g each), booms (450g each) incl. pre-amplifiers.
5) Boom design depends on possible accommodation configurations on S/C. The further the sensors are from the S/C main body the better.
6) Data rates are dependent on mode of operation choice. The duty cycle of data taking can be adjusted to comply with available TM rates at a particular time.
7) Includes antennas, pre-amplifiers and shielding
8) Includes triad of antennas with deployment mechanism. This triad should preferably be deployed on a boom (TBC) and depends on possible S/C accommodation configuration. The 1-2 m boom not included in mass estimate. Can be MAG boom.
9) Includes 3 SCM-sensors. Should be accommodated on a 1-2 m boom (e.g., MAG boom).
10) Optionally it is possible to use the RADAR antenna, in which case no sensor mass is needed (TBD).

6.13.6 CALIBRATION

On-ground laboratory calibrations at a PI institute.
In-flight calibration of effective electrical antenna lengths and directions, using a known radio source.

6.13.7 CLEANLINESS, PLANETARY PROTECTION AND PRE-LAUNCH ACTIVITIES

EM cleanliness: < 50 dBμV/m below 45 MHz, but needs interactive testing to reduce EMC problems.

Planetary protection restrictions are not applicable, no lander.

6.13.8 CRITICAL ISSUES

Including limit to radiation tolerance and list of least tolerant radiation component(s).

The electronics have a tolerance threshold of 100 krad, and the most sensitive part is the FPGA. XLink FPGA can be used with 300 krad tolerance. In order to manage up to 3 Mrad, the electronics box need have 3 mm thickness of Aluminium. Spot-protection of certain electronics components can be used as well.

LP-PWI sensors are made of Titanium, and no radiation protection is needed.

6.13.9 HERITAGE

Cassini RPWS (NASA), STEREO Waves (NASA), Rosetta LAP (ESA), Juno (NASA), RBSP, Swarm CEFI-LP (ESA), Cluster EFW (ESA), BepiColombo PWI (JAXA/ESA), Freja F1 and F4 (Swedish).

QTN heritage : The technique has been applied in the interplanetary medium, cometary's plasma and dust tails, plasma environments of the Earth, Venus, Jupiter (including the Io plasma torus), Saturn (including the plasma torus and the E ring), with antennas of various shape aboard a number of spacecraft. The technique is in the course of use on Cassini and STEREO (NASA), is selected on MMO/Bepi-Colombo (JAXA-ESA) for in situ plasma measurements at Mercury (PWI/SORBET experiment), and planned on the Solar Orbiter (ESA). These two last receivers are using ASIC technology.

The required instrumentation requires only new interface adaption development (TRL = 8).
Development time from P/L-selection to FM delivery is 4 years.

6.13.10 OPEN TECHNOLOGY ISSUES AND CRITICALITY

No open technology issue, except that the boom design and interface need be defined.
All sensors and subsystems have flying heritage.

6.13.11 INSTRUMENT SUMMARY DATA SHEET

Table 38 RPWI summary table.

Parameter	**Unit**	**Value/Description**	**Remarks**
Heritage	N/A	Cassini RPWS STEREO Waves Rosetta LAP Swarm CEFI Cluster EFW Juno, RBSP BepiColombo PWI Freja F1 & F4	
Type of instrument	N/A	Thermal plasma measurements, Plasma & EM waves instrument, Radio astronomy, Plasma physics	
Type of optics	N/A	N/A	Sensors have ~4-pi FOVs
Spectral range	Hz	B: 0.1 Hz – 20 kHz E: near DC – 45 MHz	
FOV (instantaneous)	rad	E: ~ 4-pi B: ~ 4-pi	Ram hemisphere
Spectral resolution	%	Programmable, depends on data rate, typically 20 channels/decade of frequency	
Amplitude resolution/accuracy	dB	RWI: 2 LP-PWI bit resolution: 0.015 mV/m SCM Sensitivity: 2 pT/√Hz@10 Hz 0.2 pT/√Hz@100 Hz 0.02 pT/√Hz@1 kHz 0.007 pT/√Hz@100 kHz (optional)	
Dynamic range	dB	~90	
Temporal resolution	s	0.001	Waveform
Detector			
Type of detector	N/A	4x 5cm spheres (LP-PWI) 3x 1m antennas (RWI) 2x 6m dipoles (QTN) 3x 10cm sensors (SCM)	Titanium with TiN coating
A/D conversion	bits	16	
Thermal Control			
Total surface area	cm^2	TBD	
Non-isolated area	W	TBD	

Operating temperature	°C	-20°C to +50°C (electronics) <300°C (sensors)	
Operating temperature stability	°C/h	<20	
Physical			
Preferred location	N/A	Prefer 4 LP-PWI sensors in one plane & the 2x 6m dipoles antenna orthogonal to this plane Prefer 3 orthogonal RWI antenna on 1-2m boom fr S/C MSC on boom 1-2 m fr S/C (can be same as RWI boom)	
Mass, total	kg	3.0 + 2.0 + 1.5 + 1.0 + 3.7	
Power			
Total average power	W	7.0 (max average) Heaters: +3W (TBC)	Use of heaters depends on electronics box accommodation on S/C
Data Rate & Volume			
Data volume (total)	Mbits	Up to 100 Mb/day	Data rate is highly flexible and can be adapted to availability, adjusting spectral and temporal resolutions and amount of waveform data.
Data rate (instantaneous)	kbyte/s	Min: 0.064, Max: 100 kbps	Operation mode dependent
Compression factor	#	3 for waveforms	Included in data rate

6.13.12 SUMMARY OF ALIGNMENT AND POINTING REQUIREMENTS

The four LP-PWI 5 cm spherical probe sensors should both be in the ram hemisphere (up to 180° from ram) of the spacecraft and not “shadowed” (from incoming plasma) by other structures.

Table 39 Summary of instrument alignment and pointing requirements. Note that in case more than one angle is listed, the sequence is pitch, roll, yaw.

Instrument	Pixel size arcsec	FOV deg	Min. pixel readout time ms	APE arcmin	RPE arcsec/t	AMA arcsec	Pre-facto knowledge of co-alignment with reference arcsec	Co-alignment stability arcsec/t	Post facto knowledge of co-alignment with reference arcsec
RPWI	N/A	360[1]	N/A	<1° [2]	<1° [2]	<1° [2]	N/A	N/A	N/A

1) The LP-PWI sensors should be at least 2 m from each other, as well as not be close to a propulsion exhaust system. The booms should preferably be deployed on opposite sides of the S/C in a cross-like plane configuration. The 1 m to 3 m long stiff booms can be used to facilitate this. The booms can be deployable. The QTN 2x 5m dipole-antennas should be orthogonal to this plane.

2) RPWI needs reconstructed attitude knowledge of ~ 1 degree and assumes mounting knowledge of sensors to ~ 1 degree.

References

Blomberg et al., Electric Field Diagnostics in the Jovian system: Brief scientific case and instrumentation overview, *Proceedings of the 6th IAA International Conference on Low-Cost planetary Missions*, Kyoto, Japan, 2005.

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Cecconi et al., A radioastronomy experiment for the Europa-Jupiter System Mission, part I: Goniopolarimetric remote sensing and plasma wave analysis, *OPFM workshop*, Monrovia, California, USA, 2008.

Moncuquet et al., A radioastronomy experiment for the Europa-Jupiter System Mission, part II:
Passive electric antennas as in situ detectors of plasmas, *OPFM workshop*, Monrovia, California, USA, 2008.

6.14 Plasma Package (PLP)

PLP (Plasma Package) is an analyzer of space plasmas and energetic atoms. It shall be noted that the PLP is the full plasma package, which covers the complete plasma environment around Jupiter and its moons.

6.14.1 SCIENCE GOALS AND PERFORMANCE REQUIREMENTS

The Plasma Package (PLP) addresses the following top – level scientific objectives within two main goals of EJSM (Ref: EJSM science requirement document)

- Goal 1: How does the Jupiter System works?
    - Understand the evolution and environment of Ganymede
    - Study the Jupiter magnetodisk and magnetosphere
    - Investigate interactions of the moons in the Jovian system (Callisto)
- Goal 2: Does the Jupiter system harbor a habitable world?
    - Study the impact of the environment on the Jupiter moons

These four objectives are grouped into two main topics
Topic 1 The magnetosphere/moon interactions and the magnetospheric impact on moon (‘habitability’ and ‘binary system’ themes),
Topic 2 The Jupiter magnetosphere (‘fast rotator’ and “Jupiter as a ‘giant accelerator’ theme).

These two primary topics cover the following questions:

Q1: How Jovian magnetosphere interacts with the moons?

- *Characterization of the plasma dynamics around the moons*
- *Structure of the interaction region and global energy budget*
- *Ion and electron acceleration processes*
- *Aurora on Ganymede*
- *Structure of exospheres and ionospheres*
- *Moons as plasma sources for the Jovian magnetosphere and dynamics of tori.*
- *The specific case of Ganymede’s magnetosphere. Does the magnetic field offer a shielding?*

Q2: What are the effects of the magnetosphere interaction on the moons ?

- *Loss of volatiles due to plasma interactions and radiation*
- *Effects on the surface (space weathering) and sputtering processes*
- *Role of intense radiation on possible elaborated chemical compounds*
- *What are the effects of the intense radiation on moon habitability?*

Q3: Dynamics of Jupiter’s magnetosphere: what are the fundamental dynamic processes and instabilities of a magnetodisc in fast rotation?

- *What is the 3D structure of the disc?*
- *What are the key dynamical processes in a magnetosdisc ?*
- *What is the origin of the Quasi-Periodic energy releases?*

- *How are they related to the problem of radial mass transport and loss of rotational energy?*
- *How is co-rotation enforced?*
- *What is the energy budget of fast rotating system?*
- *How is it coupled to acceleration and radiation in Jupiter's auroral regions?*
- *What is the relative part of internal processes and magnetosphere/solar wind coupling?*

Q4: Why is Jupiter's magnetosphere a so efficient particle accelerator?

- *Structure and dynamics of the Jupiter radiation belts and*

To address these questions, the set of detectors of PLP has to measure the distribution functions of the electrons and dominant ion species (from Hydrogen to Sulfur), from a few eV to a few MeV energies (see Table 1). Coverage of the whole sphere (4π) is highly desirable in general. It is required for plasma measurements (ions and electrons) at low energy (below typically 10 keV) and around moons since no preferable direction exists in the spacecraft frame due to pointing variations. The characterization of very cold plasma (moon exosphere and ionosphere) are required to characterize moon's ionosphere and provide spacecraft potential needed to correctly interpret electron and ion measurements at low energies, few eV. Table 40 below shows the measurement requirements

Table 40: Measurement requirements

Objectives	Cold plasma (<10eV)	Medium Energy (~few eV* - 50 keV)	High Energy (up to few MeV)	Neutrals (10 eV - 10 KeV)
Topic 1: Magnetosphere/moons interaction and impact on the moons (habitability' and 'binary' theme)	Density, temperature, velocity, s/c potential	Electron and ion distributions, with mass composition	Electron and ion distributions, with mass composition	Neutral flux distribution with composition, both charge – exchange and sputtered neutrrals
Topic 2 Jupiter magnetosphere ('fast rotator' and "Jupiter as a 'giant accelerator' theme		Electron and ion distributions, with mass composition	Electron and ion distributions, with mass composition	Neutral flux distribution, with composition only charge – exchange

* down to the spacecraft potential

Global imaging (via energetic neutral atoms (ENA)) is required to image the whole moon - magnetosphere interaction region at once to separate time and spatial variations of the plasma population. This is a critical requirement for observations limited by fly-bys because no comprehensive statistics can be accumulated. The ENA imaging also provides patterns of ion precipitation onto the moon's surface to understand surface albedo variations and particle surface release processes. Also coverage of the whole sphere (4π) is required for plasma measurements (ions and electrons) for no preferable direction exists in the spacecraft frame due to pointing variations.

INSTRUMENT CONCEPT

To cover the measurement requirements PLP would consist of six sensors, dedicated to the measurement of specific species - electrons, ions and neutrals - in different energy ranges. From low to high energy, a possible arrangement could be – see table 2:

1) A Langmuir probe (LAP), to measure plasma density and temperature down to very energy (E<10 eV).
2) An Electron Spectrometer (ELS), to measure electron distribution function from a few eV to 30 keV.
3) A Hot Plasma Spectrometer (HPS), to measure ion distribution functions, with composition (up to sulfur ions), from a few eV to a few keV/q.
4) A Medium energy Plasma Spectrometer (MPS), to measure ion distribution functions, with composition (up to sulfur ions), from a few 100 eV to 50 keV/q.
5) An Energetic Plasma Spectrometer (EPS), to measure ion and electron distribution functions, from a few 10 keV to a few MeV.
6) An Energetic Neutral Analyzer (ENA), to characterize the neutrals from a few eV to a few 10 keV.

To save resources, in mass and power, it is desirable to adopt a highly integrated architecture. Common DPU and power converters are anticipated. If possible, sensible electronic parts would be protected by the same shielded box.

The instrument comprises the following sensors and subsystems given in Table 41.

Table 41: PLP sensors and subsystems

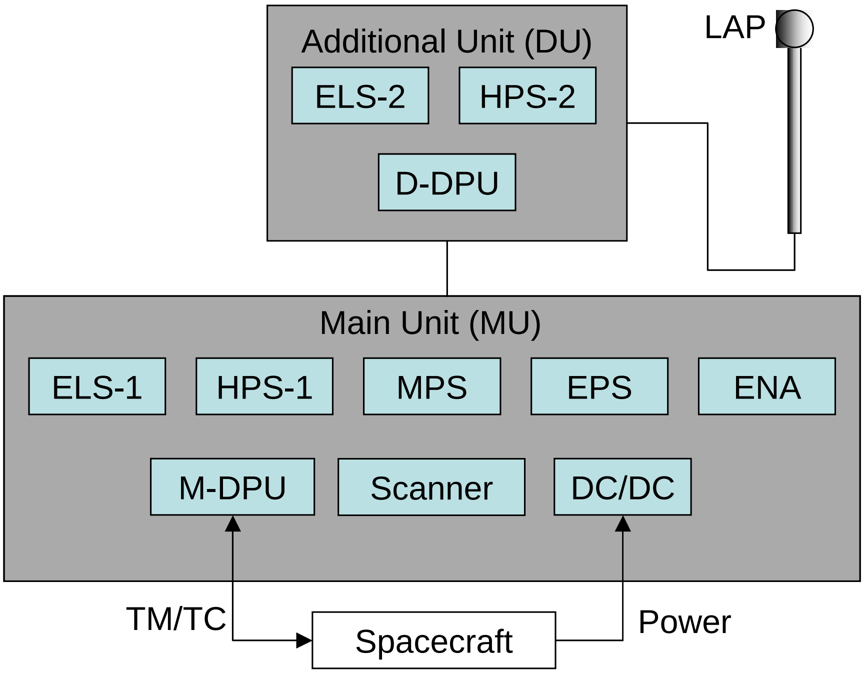
Sensor	Name	Function
Langmuir probe	LAP	Cold (Te < 10 eV) plasma
Electron spectrometer	ELS	Electron distribution function, 1 eV – 20 keV
Hot plasma spectrometer	HPS	Ion measurements, 1 eV – 10 keV with mass resolution
Medium plasma spectrometer	MPS	Ion measurements, 1 keV – 50 keV with mass resolution
Energetic charge particle spectrometer	EPS	Ion measurements, 3 keV – 5 MeV with mass resolution) Electron measurements, 15 keV – 1 MeV
Energetic neutrals analyzer	ENA	ENA imaging, 10 eV – 10 keV
Digital Processing Unit	DPU	Data processing, power control
Scanner	SCN	Scanning over azimuth angle
Radiation shield	SHD	Radiation protection

The JGO equatorial orbit over the science phases (Callisto fly-bys and Ganymede orbit) is not suitable for high energy ENA imaging of the Jupiter magnetosphere because of proximity to the emission region, the radiation belt. No coverage suitable for the inversion can be achieved. The high energy ENA sensor could be useful during cruise phase (approaching the Jupiter system) and far from the radiation belt. It is not included in the package.

PLP is highly integrated instrument with high degree of sharing resources. This approach allows reducing the overall mass using mutual shielding of the sensors, common radiation shielding, data processing power, and DC/DC converters. Sharing the scanning platform allows to reach maximum possible coverage (ideally 2π sr) for all sensors that is an important aspect of plasma/neutral measurements is their angular coverage. Ideally, 4π sr total FOV is required to adequately characterize the fluid and kinetic properties of plasma environments measuring the co-rotating plasma and the field-aligned components. On a non-spinning spacecraft, this can be achieved by (1) multiplying the number of sensors head on opposite sides of the spacecraft (2) using electrostatic deflectors and/or (3) scanning platforms. We implement all three methods.

The PLP would consist of two units, Main Unit (MU) and additional Unit (DU). The MU would include a mechanical scanner which carries HPS-1, MPS, EPS, ELS-1, ENA, and a main digital processing unit (M-DPU) and DC/DC converters. The possibility to consider the ENA sensor as a separate unit may be also considered. DU is a separate unit accommodated on the plane opposite to the plane where MU is accommodated. DU includes HPS-2 and ELS-2 and an additional digital processing unit (D-DPU) for the DU sensor data pre-processing before sending to M-DPU. This configuration allows achieving full 4π sr coverage for the hot plasma energy range including ions and electrons critical for understand the moon – magnetosphere interaction (from eV to ~ 10 keV). Ideally, MPS (ions from 1 keV/q to 50 keV/q) and EPS (ions and electrons up to 5 MeV) need also be duplicated to widen the angular coverage. Both MPS and EPS are essential to characterize the dynamics of the disc and understand acceleration/radiation processes. During the ‘Jupiter’ phase of the mission (the phase preceding the proper ‘moon’ orbital phase), it is critical that the spacecraft attitude is such that the FOV of MPS and EPS contain the direction of co-rotation. With this requirement, it is possible to perform all the critical ion and energetic particle measurements needed to solve theme 2 questions (the ‘fast rotator’ theme). LAP sensor is accommodated on a boom. LAP interfaces DU and DU interfaces Main Unit. Electrically PLP interfaces the spacecraft only via MU. The block diagram in Figure 13 shows the overall architecture.

Figure 13: Block diagram of the PLP configuration



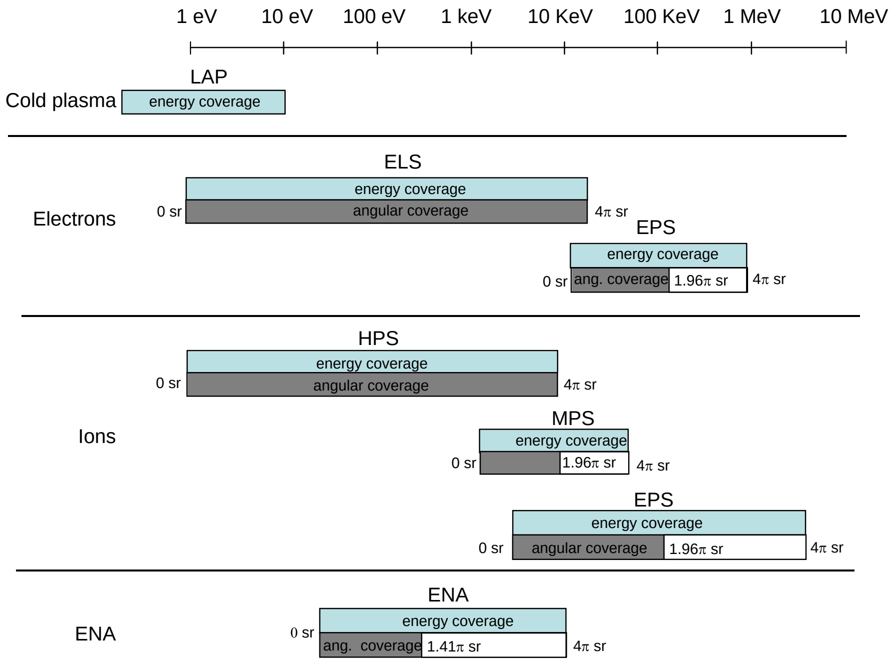
The traceability matrix below demonstrates the coverage of the scientific objectives

Table 42: Part of the traceability matrix of JGO focusing on PLP

	LAP	ELS	HPS	MPS	EPS	ENA
Q1: How Jovian magnetosphere interacts with the moons?	▨	▨	▨	▨	▨	▨
Q2: What are the effects of the magnetosphere interaction on the moons?	▨	▨	▨	▨	▨	▨
Q3: Dynamics of Jupiter's magnetosphere		▨	▨	▨	▨	▨
Q4: Why is Jupiter's magnetosphere a so efficient particle accelerator?					▨	

The diagram in Figure 14 gives an overview of the energy and angular coverage of the PLP.

Figure 14: Coverage of PLP-B in energy and angular coverage



6.14.2 INSTRUMENT DESCRIPTION

The majority of the sensors mentioned in Table 41 have considerable heritage (see also table in Section Heritage). ELS is a top-hat analyzer in a very compact design with electrostatic deflector providing 2π coverage. HPS consists of an entrance electrostatic deflector to provide 2π coverage followed by an electrostatic cylindrical analyzer which in turn is followed by a time-of-flight cell (TOF) with a reflecting surface. The electrostatic analyzer provides energy and the TOF cell velocity and thus ion mass. MPS includes a top-hat analyzer followed by a TOF section using the reflection surface for start signal generation similarly to HPS. This instrument significantly improves measurements in the critical energy range of tens keV which is usually difficult to cover with hot plasma and energetic particle spectrometers. The energy ranges of the three ion instruments, HPS, MPS, and EPS, overlap ensuring precise reconstruction of the distribution function over the energy range from 1 eV to few MeV. EPS is a foil-based TOF instrument with solid-state detectors. ENA also uses reflection surface and TOF technique for neutral's velocity and mass measurements. It also equipped with a shuttering system, based on coupled moving slits of nanometric dimension, operating either as an UV suppressor (high sensitivity mode) or a beam chopper for TOF measurements. LAP is a well known instrument that have flown on many missions, including CASSINI and the plasma package on ROSETTA. This instrument has to be mounted on a short boom (the magnetometer boom for example).

The DU HPS-2 and ELS-2 sensors provides inherent the 2π coverage. The MU scanner provides a close to 2π coverage for MPS and EPS sensors because it is not feasible to use electrostatic deflection for these high energy range. A close to 2π coverage can be also provided for the ENA sensor for operations outside nadir pointing. Scanner in non-scanning mode can be used to point the MU sensors in any desirable direction.

The instrument configuration is based on highly integrated architecture. The feasibility of such architecture has been demonstrated in the ASPERA-type of instruments onboard ESA Mars and Venus Express. Each sensor consists of a sensor mechanics with no active components, point shielded detectors, and separate electronics boards. All sensor's electronics boards and common PLP electronics (DC/DC, spacecraft interface electronics, processor) are integrated in a single electronic box with required shielding. Programmatically it is more difficult but the approach provides large mass saving. The similar ASPERA architecture demonstrated that this approach is doable. Shielding plates may be a separate mechanical element and are attached to the MU and DU after completion of all electrical tests on the sensor level. This approach allows changing shielding at a very late stage of the project, simplifies mass budget control and the package management.

6.14.3 ORBIT, OPERATIONS AND POINTING REQUIREMENTS

During the 'Jupiter' phase, the wider local time and radial distance coverage of the magnetosphere is desired. Initial 'tour' designs suggest that this requirement will be fulfilled easily given the large apojove distance of the insertion orbit and the multiple moon flybys needed for final capture by Ganymede. In case of a multiple spacecraft mission (JEO+JGO), the inter-spacecraft separation should cover both short distances (less than 1 Rj and 1 MLT) and large distances (more than 20 Rj and 6 MLT).

The FOV of the instruments (especially, ELS, MPS and EPS) must cover the co-rotation direction. This could require that the scanner direction points towards the co-rotation direction for the longest possible time periods. Continuous operations are required.

During the 'moon' phase, the plasma package will fulfill its scientific objectives by operating on a very wide class of orbits around the moons. The preferable orbits are polar, elliptical 100-300 km x 5Rm (Rm the moon radius). The instrument requires continues operation.

The scanner axis should point to nadir. Blocking of viewing directions in the scanner spin axis hemisphere must be minimized. Blocking the DU sensor hemisphere must be also minimized.

LAP is installed on the magnetometer boom (preferable). It may also be installed on its own boom at least 50 cm length (not considered currently). During the spacecraft nadir pointing, LAP must be in the ram direction.

6.14.4 INTERFACE AND PHYSICAL RESOURCE REQUIREMENTS

Figure 15 and Figure 16 give the PLP/ Main Unit and PLP/HPS-2 envelops, and the PLP overall configuration including all three units. Table 43 provides mass breakdown per sensor/subunit.

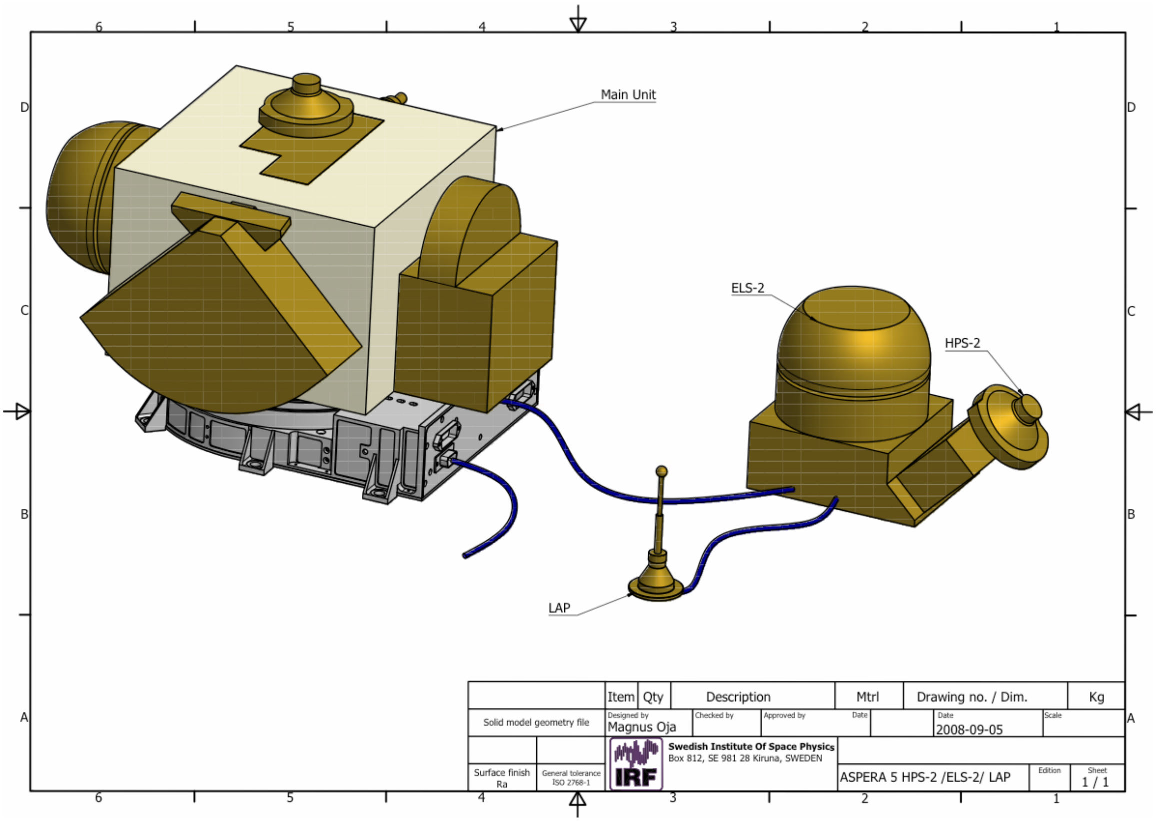


Figure 15: Overview of PLP sensors

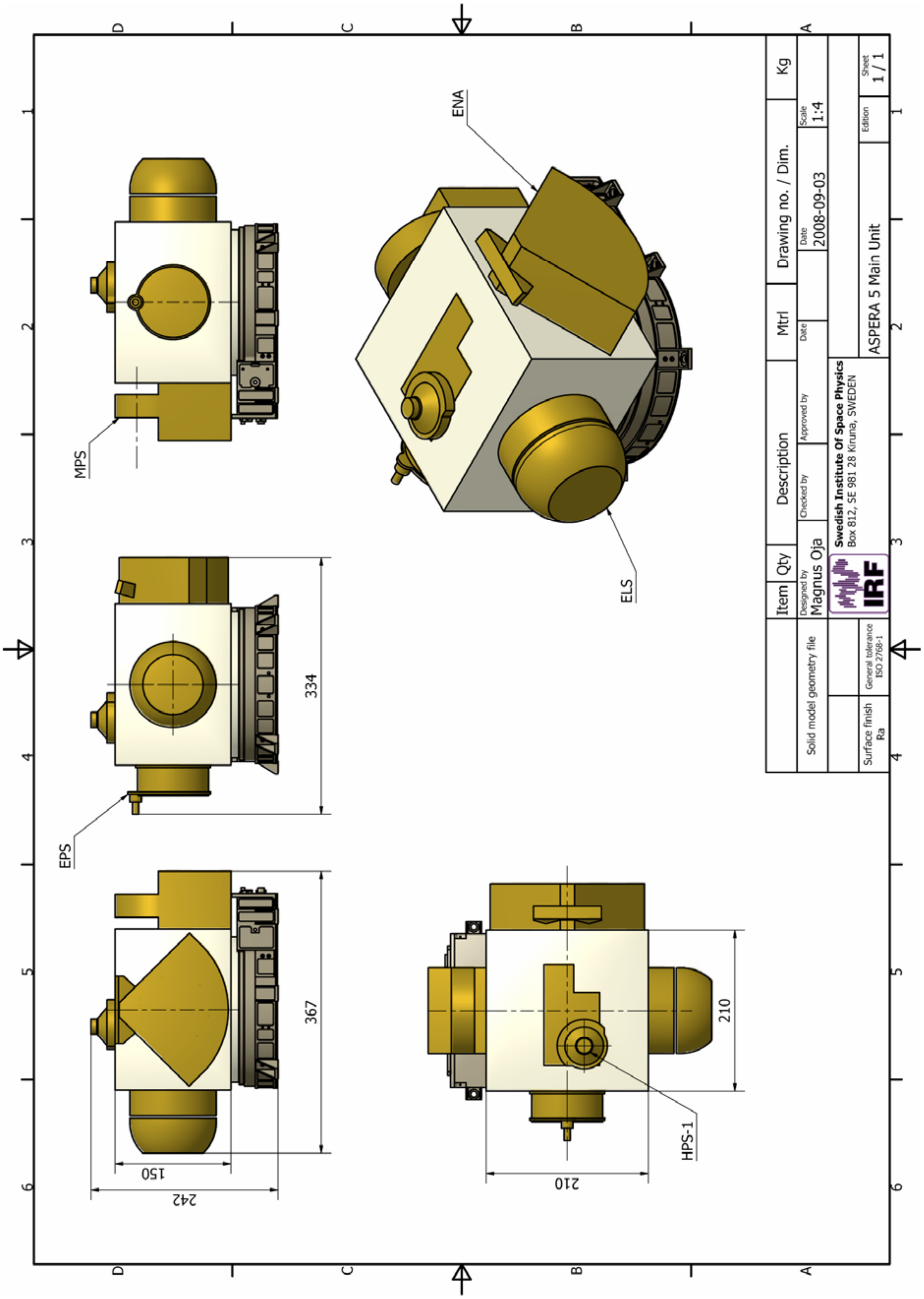


Figure 16: Concept design for the PLP subsystems and sensors

Table 43: PLP overview of subsystems and the associated masses

Unit	Mass, kg	Comment
Main Unit (MU)		
ELS-1	0.7	Derived from MEX / VEX, Stereo
HPS-1	0.8	As built for Phobos-Grunt
MPS	2.5	Estimated
EPS	1.5	Based on New Horizon
ENA	1.4	Based on MEX / VEX / ASPERA-3/4/ NPD and BC/SERENA/ELENA
Scanner	1.5	As built
DPU	1.8	Estimated
Add. Unit (DU)		
ELS-2	0.7	As ELS-1
HPS-2	0.8	As HPS-1
LAP	0.5	As built for Rosetta (sensors and electronics)
D-DPU	1.0	
Total MU	10.0	
Total DU	3.2	
Total	13.2	
SHD-MU	< 4.00	Not included in the PLP mass
SHD-DU	<1.5	Not included in the PLP mass

6.14.5 CALIBRATION

Only on-ground laboratory calibrations at a PI institute.

6.14.6 CLEANLINESS, PLANETARY PROTECTION AND PRE-LAUNCH ACTIVITIES

MU and DU require continues GN2 purging during AIV and until red-tagged covers removed. Centralized purging system is preferable for DU. For MU it may be difficult to implement because all MU sensors are installed on a movable platform.
Planetary protection restrictions are not applicable (not a lander).

6.14.7 CRITICAL ISSUES

Not identified. The radiation hardness for electronics 100 kRad.

6.14.8 HERITAGE

Table 44 provides the heritage for different sensors / subunits and estimated TRP for each sensor. The PLP TRP level is estimate as 6.

Table 44: PLP technology readiness levels for all sensors and subsystems

	Heritage	TRP
ELS	MEX, VEX (ASPERA-3/4), CLUSTER, Cassini, STEREO	7
HPS1/2	Chandrayaan (launch Oct. 2008), Phobos-Grunt (Oct. 2009, QM is available, FM under manufacturing)	8
MPS	Cluster / CORDIF, Prototype tested	5
EPS	New Horizons / PEPSSI	8
LAP	Rosetta, Cassini, Swarm	8
ENA	MEX, VEX (ASPERA-3/4), BC/SERENA	7
DPU	MEX, VEX (ASPERA-3/4)	6
SCN	MEX, VEX (ASPERA-3/4)	8
SHD		N/A

6.14.9 OPEN TECHNOLOGY ISSUES AND CRITICALITY

No open technology issues. All sensors and subsystems have flying heritage.

6.14.10 INSTRUMENT SUMMARY DATA SHEET

Table 45 Plasma Package summary table.

Parameter	**Unit**	**Value/Description**	**Remarks**
Heritage	N/A	MEX, VEX, Chandrayaan, Phobos-Grunt, Rosetta, Cassini, Cluster, Stereo, New Horizon	
Type of instrument	N/A	Plasma physics, particle measurements	
Type of optics	N/A	Electrostatics, geometrical	
Function mode	N/A		
Optics			
Spectral range		ELS: 1 eV – 20 keV HPS: 1 eV – 10 keV MPS: 1 keV – 60 keV EPS: 3 keV- 5 MeV (i) EPS: 15 keV – 1 MeV (e) ENA: 10 eV – 10 keV LAP: < 10 eV	Low energy limit 1 eV depends on the s/c potential to be measured by LAP
FOV (instantaneous)	deg	ELS: 90° x 360° HPS: 90° x 360° MPS: 10° x 160° EPS: 12° x 160° ENA: 5° x 90° LAP: hemisphere	
Coverage	deg	ELS: full sphere HPS:full sphere MPS: 160° cone EPS: 160° cone	Full coverage for ELS and HPS is provided by two sensors, ELS1&2 and HPS1&2.

		ENA: 90° cone or 5°x 90° (in stand-along configuration)	Coverage for MPS, EPS, ENA is provided by scanning over ±180°. The blocking must be minimized.
Pixel IFOV (angular resolution)	deg	ELS: 10° x 22.5° HPS1/2: 20° x 45° MPS: 5° x 20° EPS: 12° x 25° ENA: 5° x 5°	
Wavelength for diff. limit	nm	N/A	
Aperture	mm^2	N/A	
Focal length	mm	N/A	
f/#	#	N/A	
Filters	#	N/A	
Filter bandwidth	nm	N/A	
Detector			
Type of detector	N/A	MCP, CCEM, SSD	CCEM: Ceramic Channel Electron Multiplier
Pixel lines in array	#	N/A	
Pixels per array line	#	N/A	
Pixel size	µm	N/A	
Exposure time	msec	N/A	
Repeat time	msec	N/A	
Operating temperature	°C	-30…+50 (MCP) -30…+70 (CCEM) -30…+25 (SSD)	
Operating temperature stability	°C/h	Not critical	
A/D conversion	bit/pix	N/A	
Full well capacity	Ke^-	N/A	
Readout time	msec	N/A	
Swath and Resolution			
Swath width	km	N/A	
Spectral sampling	nm	N/A	
Spatial pixel resolution	m	N/A	
Thermal Control			
Total surface area	cm^2	TBD	
Non-isolated area	W	TBD	
Operating temperature	°C	-20…+50 (MU except EPS) -30…+25 (EPS) -20..+50 (DU) -100…+300 (LAP sensor)	
Operating temperature stability	°C/h	Not required	
Physical			

Preferred location	N/A	MU: nadir plane DU: antinadir plane LAP sensor: ram direction for nadir pointing	Cables: LAP sensor–HPS2: < 3m MU-HPS2: < 2 m
Mass, total	kg	PLP: 13.2	Main unit: 10.1 kg Add. Unit: 3.1 kg
Power			
Total average power	W	33W (max) Heaters: 15W (TBC)	Losses in DC/DC converters are NOT included
Detector + electronics	W	N/A	
TE cooler	W	N/A	
Data Rate & Volume			
Data volume (total)	Gbyte	54	20 kbps at 4 h/day for 4 years
Data rate (instantaneous)	kbyte/s	2-20 kbps	Mode dependent
Compression factor	#	2 (max)	Included in the data rate

6.14.11 SUMMARY OF ALIGNMENT AND POINTING REQUIREMENTS

Table 46 Summary of instrument alignment and pointing requirements. Note that in case more than one angle is listed, the sequence is pitch, roll, yaw.

Instrument	Pixel size arcsec	FOV deg	Min. pixel readout time ms	APE arcmin	RPE arcsec/t	AMA arcsec	Pre-facto knowledge of co-alignment with reference arcsec	Co-alignment stability arcsec/t	Post facto knowledge of co-alignment with reference arcsec
PLP/MU PLP/HPS2 PLP/LAP	N/A	90 x 360	N/A	< 1°	< 1°	< 1°	No required	No required	No required

6.15 Ion Neutral Mass Spectrometer (INMS)

The science goal of the Ion and Neutral Mass Spectrometer (INMS) is the determination of the extended atmosphere of Ganymede and Callisto, in particular the neutral and the ionised component. The main scientific goals are:

- The composition of regular atmosphere produced by energetic particle and photon interaction with the surface
- The ion composition of the ionosphere
- Chemical analysis of geysers (if encountered) and their temporal evolution
- Isotopic analysis of $^{1}H/^{2}D$, $^{12}C/^{13}C$, $^{14}N/^{15}N$, $^{16}O/^{18}O$, $^{32}S/^{34}S$, … and others when signal levels are sufficiently high.
- Assist in the identification of the chemical nature various surface elements

Neutral Mode: The total gas pressure at an JGO spacecraft altitude during the flybys and Ganymede orbit is expected to be rather low, down to 10^2 #/cm^3 and lower based on modelling by Marconi [2007, and references therein]. Based on species confirmed to be present, the predicted neutral densities near Ganymede are [Marconi, 2007]:

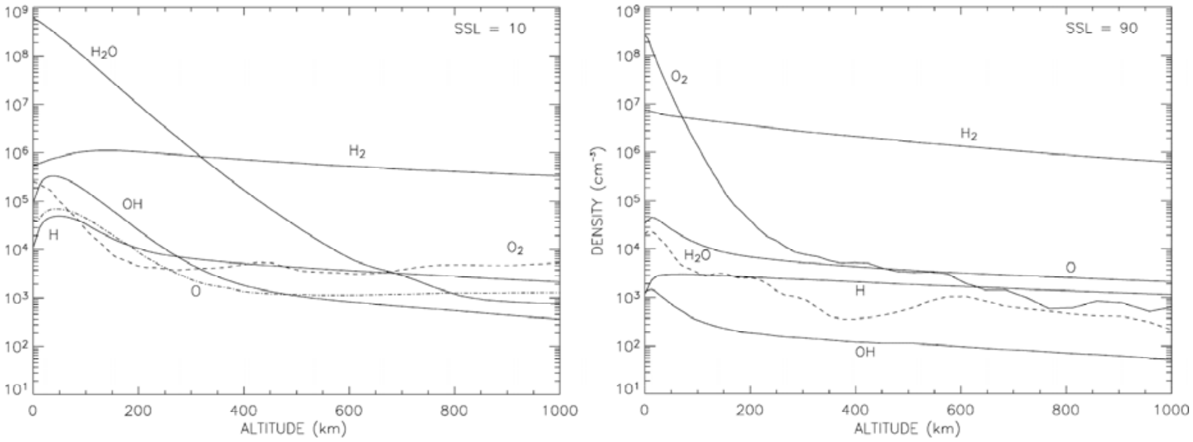


Figure 17: Radial density profiles at 10º and 90º Sub-Solar Longitude (SSL), from Marconi, 2007. The fluctuations in the O2 density reflect statistics. The data are averaged over a 6º latitude range.

Thus a high sensitivity instrument for neutral gas measurements is necessary to measure a full mass spectrum in 1 minute with the smallest identified peaks at the 10^{-14} mbar or better. Note that the present detection threshold of INMS for neutral particles is 10^2 #/cm^3 (for 1-minute integration), thus all expected species (see figure above) can be detected during flyby and in orbit of Ganymede. The time resolution arises from the spatial resolution together with the spacecraft speed in orbit. Spatial resolution is of advantage to identify geysers and their chemical composition.

Ion Mode: Ion densities in Europa's ionosphere at 200 km altitude are expected in the range from 3000 to 0.1 ions/cm^{-3} based on a similarity to the situation at Europa [Johnson et al., 1998]. Again, the instrument sensitivity for these ionospheric ions should be commensurate with these expectations, e.g. record a full mass spectrum with a dynamic range from 10^{-1} to 10^4 ions/cm^3 in one minute. The detection threshold of RTOF/ROSINA for is 10^{-2} #/cm^3. INMS for JGO will have a similar performance.

Mass resolution should be at least M/ΔM = 1000, however larger mass resolutions would be helpful to remove some mass interferences for the more complicated hydrocarbons, in case they exist.

6.15.1 INSTRUMENT CONCEPT

INMS is a time-of-flight mass spectrometer using an ion mirror (reflectron). Ions are either generated in a storage ion source (neutral mode) or collected from the ambient plasma (ion mode). With the pulsed ion optics of the ion source ion packets are produced, accelerated, shaped and sent into the TOF structure. After passing the first leg of a field-free drift path ions a reflected in an ion mirror, which allows for energy and spatial focussing of ions, and directed onto a fast micro-channel plate detector. The charge signal versus time is recorded on the detector and converted into mass spectrum.

6.15.2 INSTRUMENT DESCRIPTION

A drawing of the RTOF sensor is shown in Figure 18. The INMS for JGO will have the same outline and mounting pattern, but there will not be the recloseable cover.

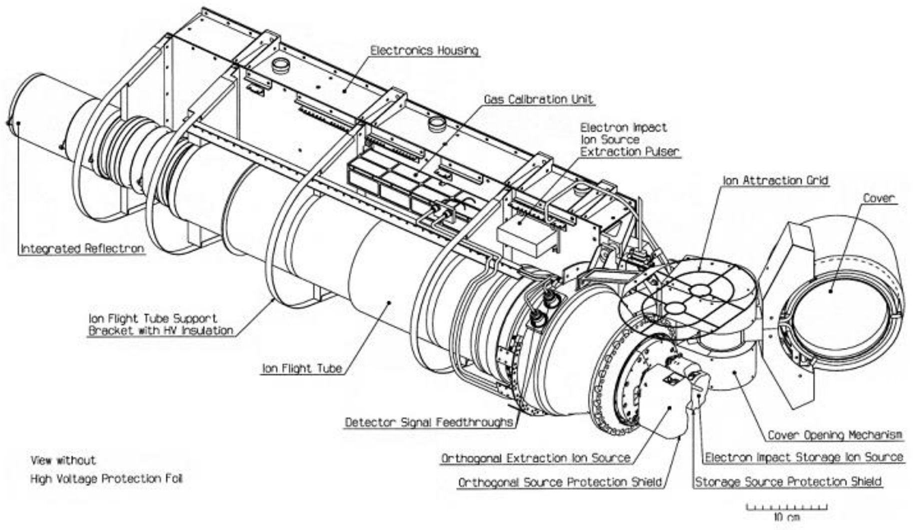


Figure 18: RTOF sensor of the INMS

The field-of-view is pointing upward in Figure 18, which is the ram direction of the spacecraft movement. The ion sources are meant to be flow-through, thus there should not only be an unobstructed field-of-view (which is twice the nominal field-of-view) but also at the exit of the ion sources (anti-ram direction) there should not be any hardware.

6.15.3 ORBIT, OPERATIONS AND POINTING REQUIREMENTS

The entrance of INMS has to point approximately into the ram direction of the spacecraft movement around Ganymede and Callisto. Actual pointing is not that critical, since the field of view is large enough to accommodate deviations of a circular orbit.

6.15.4 INTERFACE AND PHYSICAL RESOURCE REQUIREMENTS

MLI around and in the vicinity of INMS has to be conductive, to allow for ion measurements.

Thruster placement may not interfere with the field-of-view, possible shimming might be necessary.

Accommodation of the INMS instrument can be inside the spacecraft, if that is of advantage to the spacecraft design, with the sensor head protruding the spacecraft envelope. This is the way RTOF sensor of the ROSINA instrument was accommodated on the Rosetta spacecraft.

6.15.5 CALIBRATION

Neutral and ion calibration will be performed before launch. In-flight calibration sources for the neutral gas channel will be part of the INMS instrument.

6.15.6 CLEANLINESS, PLANETARY PROTECTION AND PRE-LAUNCH ACTIVITIES

INMS is sensitive to chemical and particulate contamination at a high level. Continuous nitrogen purging in the pre-launch operations is required, preferably all the way to launch.

Red-tag covers will be installed for spacecraft manipulations during pre-launch campaign.

Since neutral and ion populations are measured by INMS in space at a very low level, outgasing of the spacecraft has to be minimised. Venting of internal volumes of the spacecraft is important, but venting holes of the spacecraft should be placed sufficiently far away from INMS.

Thruster placement should be far away from INMS, if they are inside the FOV appropriate shielding is necessary (e.g. collars around the thrusters).

6.15.7 CRITICAL ISSUES

Including limit to radiation tolerance and list of least tolerant radiation component(s)

Present radiation tolerance is 100 krad (Rosetta design).

6.15.8 HERITAGE

The INMS is a further development of the RTOF sensor of the ROSINA mass spectrometer suite [Balsiger et al., 2007] on the Rosetta mission of ESA.

6.15.9 OPEN TECHNOLOGY ISSUES AND CRITICALITY

Increasing radiation tolerance.

6.15.10 INSTRUMENT SUMMARY DATA SHEET

Table 47 INMS summary table.

Parameter	**Unit**	**Value/Description**	**Remarks**
Heritage	N/A	Reflectron Time-of-Flight (RTOF) sensors of the ROSINA instrument on Rosetta	
Type of instrument	N/A	Time-of-flight mass spectrometer	
Type of optics	N/A	Ion optics	
Function mode	N/A		
Optics			
Mass range	Amu	1 – 300	Can be extended in flight to 1000 amu if necessary
FOV	Deg	20 x 5	Wide angle in plane of orbit. FOV can be extended to larger range if necessary.
Pixel IFOV	Mrad	N/A	
Wavelength for diff. limit	Nm	N/A	
Aperture	Mm	10 x 2	
Focal length	Mm	N/A	
f/#	#	N/A	
Filters	#	N/A	
Filter bandwidth	Nm	N/A	
Detector			
Type of detector	N/A	Microchannel plates	
Pixel lines in array	#		
Pixels per array line	#		
Pixel size	µm		
Exposure time	Msec	1 sec – 1 min	Typical integration times
Repeat time	Msec		
Operating temperature	°C	–20 … +50	
Operating temperature stability	°C/h	2	
A/D conversion	bit/pix	8 bit/channel	
Full well capacity	Ke$^-$		
Readout time	Msec		
Swath and Resolution			
Swath width	Km		
Spectral sampling	Nm		
Spatial pixel resolution	M		

Thermal Control			
Total surface area	cm^2		
Non-isolated area	W		
Operating temperature	°C		
Operating temperature stability	°C/h		
Physical			
Preferred location	N/A	Instrument mounted that head reaches over corner	
Mass, total	Kg	4.9	
Power			
Total average power	W	10	
Detector + electronics	W	10	
TE cooler	W	N/A	
Data Rate & Volume			
Data volume (total)	Gbyte		
Data rate (instantaneous)	kbyte/s	1.5 kbit/s	
Compression factor	#	3	

H. Balsiger, K. Altwegg, P. Bochsler, P. Eberhardt, J. Fischer, S. Graf, A. Jäckel, E. Kopp, U. Langer, M. Mildner, J. Müller, T. Riesen, M. Rubin, S. Scherer, P. Wurz, S. Wüthrich, E. Arijs, S. Delanoye, J. De Keyser, E. Neefs, D. Nevejans, H. Rème, C. Aoustin, C. Mazelle, J.-L. Médale, J.A. Sauvaud, J.-J. Berthelier, J.-L. Bertaux, L. Duvet, J.-M. Illiano, S.A. Fuselier, A.G. Ghielmetti, T. Magoncelli, E.G. Shelley, A. Korth, K. Heerlein, H. Lauche, S. Livi, A. Loose, U. Mall, B. Wilken, F. Gliem, B. Fiethe, T.I. Gombosi, B. Block, G.R. Carignan, L.A. Fisk, J.H. Waite, D.T. Young, and H. Wollnik, "ROSINA - Rosetta Orbiter Spectrometer for Ion and Neutral Analysis," Space Science Review 128 (2007), 745–801.

R. Johnson, R. Killen, H. Waite, W. Lewis, “Europa’s surface composition and sputter-probed ionosphere”, Geophys. Res. Lett. 25 (1998) 3257–3260.

M.L. Marconi, A kinetic model of Ganymede’s atmosphere, Icarus 190 (2007) 155–174.

6.16 Doppler Spectro-Imager (DSI)

6.16.1 SCIENCE GOALS AND PERFORMANCE REQUIREMENTS

The DSI instrument covers two scientific objectives: seismological studies of Jupiter's internal structure, and atmospheric studies.

Two scenarios are generally proposed for the formation of giant planets: the first scenario, the "nucleated instability" approach, assumes that cores are formed first by accumulation of planetesimals, in a mechanism similar to the one generally accepted for the formation of the terrestrial planets. Then, the nebular gas was captured, leading to a phase of hydrodynamic gas accretion, during which the central body was formed; this rapid accretion stage is followed by a phase of slow accretion, during which a disk was "emerged" from the planet atmosphere (Magni and Coradini, 2004). This phase is important for satellite formation (Magni and Coradini, 2004; Alibert et al. 2005). This scenario has been shown to be compatible with the present day knowledge of Jupiter's internal structure (and the existence of a large solid core), its atmospheric composition and the overall characteristics of regular satellites, particularly of Jupiter, where weak density gradient are present.

The second scenario assumes that giant planets are formed by gravitational instabilities in the massive proto-Solar Nebula (see e.g. Boss, 1998; Mayer et al., 2002), leading rapidly to formation of density enhancements - or clumps - with solar chemical compositions and masses probably larger than the present masses of the giant planets. A key issue in this model is the *a posteriori* formation of a core. Moreover, this model hardly explains the large amount of heavy elements suspected in Jupiter and Saturn (Guillot et al., 2004).

On the basis of the previous discussion, the nucleated instability approach seems to be favored, provided that the existence and the size of the central core are confirmed. However, the final answer to the question of giant planets formation mode can only be given by knowing the size and mass of Jupiter's core and its heavy elements and volatiles content.

In order to determine Jupiter's internal structure, two approaches have been proposed. In the framework of JUNO, the NASA/New Frontiers mission giving new insight to this problem, the determination of Jupiter's internal structure will rely on the determination of the planet's gravitational moments. However, the interpretation in terms of density structure and the presence or absence of a core is non-unique, and relies in particular on the correct knowledge of H and He equations of state: uncertainties in the EOS will limit the resolution with which the density structure can be determined. Moreover, the higher order gravitational moments essentially depend on the structure of Jupiter's external shells, and not too strongly on Jupiter's deep interior.

Another way to obtain information on Jupiter's interior is the seismology approach, namely the study of the spatially resolved oscillations of the planet. Observations aimed at detecting oscillation modes of Jupiter have shown promising results (Schmider et al., 1991, 2007; Gaulme et al., 2008), but so far they have been limited by instrumental and 'windowing' effects (i.e., daily interruptions in the observations), and by the complex nature of the atmosphere (Guillot et al., 2004). This method, combined with gravitational moment data, has however the potential of determining the whole internal density profile of Jupiter, thus giving the mass of its internal core and amount of heavy elements. It can also constrain the level of

homogeneity of Jupiter's envelope, essential information in order to interpret Galileo's measurement of volatile species in a global context.
Combining gravitational moment seismologic and data thus represents a unique opportunity to decipher both the mystery of Jupiter's origin, and the formation of planets as a whole. Moreover, it could also be used to give constraints on the state of matter in the planet's center, thus improving our knowledge of matter under extreme conditions. Jupiter, and the Jupiter-Europa mission, is at the crossroad of fundamental physics and understanding of planet formation.

Seismic measurements requires a monitoring of the velocity field of the planet with a spatial resolution of 100 to 200 in order to reach modes of degree l=50 (goal). The goal is to reach a velocity noise level of 0.3 cm/s for the detection of oscillations, and a precision on the frequency measurements better than 0.5 μHz. The latter supposes almost continuous (duty cycle > 70 %) observations for at least 20 days of the full field of the planet. The same precision can be achieved by combining two or more shorter runs, not shorter than 10 days.

Atmospheric studies

The troposphere will be the deepest level sounded by LAPLACE: its meteorology in a global sense is poorly understood. In particular, the exact origin of the global circulation of Jupiter, the structure of the band system, its relation to differential rotation and the connection of this meteorological system with deep and outer layers are unknown. One way of progressing in this field is to constrain models by direct measurements of the quantities involved in meteorological equations, such as velocities, thermodynamics quantities and the "potential vorticity", which is conserved in nondissipative flows like a passive tracer, and which is directly calculated in the models. This latter quantity can be deduced from observations of the wind field, together with temperature profiles of the atmosphere. Moreover, long term monitoring of Jupiter at medium scales (300 km) with potential vorticity retrieval at different time scales would constrain the evolution of waves, of atmospheric structure and of winds from the models. The distribution of lightning storms on Jupiter, detected by Galileo with a non-uniform density, is still mysterious. The importance of local convection as a source term for global circulation remains to be proven at a global scale. These convective cells can also be a source of strong gravity waves propagating up to the thermosphere, and contributing to upper atmosphere heating. Finally, internal waves already described connect the troposphere to the interior of Jupiter and complete the picture that LAPLACE could give of the Jupiter atmosphere from the uppermost layers to the deep interior.

An instrument monitoring the velocity radial velocity in the visible domain would complete the measurements in the NIR domain at higher altitude and the cloud following. The goal is to reach a level of a few m/s with a resolution of 200 km. This can be achieved with the same instrument from Ganymede orbit.

6.16.2 INSTRUMENT CONCEPT

The instrument is designed to provide Doppler-shift instantaneous velocity map, with spatial resolution only limited by the pixel size. The instrument is based on the principle of the Fourier Transform Spectrograph, with a fixed Optical Path Difference. The central part of the instrument is a compact interferometer of Mach-Zehnder design, calculated to have a maximum sensitivity to Doppler shift of solar spectral lines reflected at the surface of Jupiter. It is made of a several prisms all glued together in a single compact ensemble. A prototype of this instrument, SYMPA (Schmider et al, 2007, Gaulme et al, 2008), has been used for observations of Jupiter, and has proved to achieve the expected performances.

This instrument could share its entrance optical beam, shielding and electronics with a NIR imaging spectrometer, in the scope of a fully integrated instrument for atmospheric studies, in order to reduce the total mass of the payload.

6.16.3 INSTRUMENT DESCRIPTION

The instrument consists in three modules: the entrance telescope followed by a tuning mirror to feed the optic consisting in a collimator, an entrance filter, a polarizer, the interferometer itself and a recombining output optic, and finally the detector. The collimator and the objective have focal length of 50 mm. The choice of the pupil diameter and focal length depends of the distance of Jupiter at the period of the observations. Here, we present the optimal solution for observations at 0.1 AU: the pupil size is 6.5 cm, and the focal length is 340 mm. The telescope could be either a two mirror configuration telescope, or a refractor. The entrance filter is a 20Å interferential filter. The detector is either a CCD or a CMOS APS detector.

The core of the instrument is the interferometer (Mach-Zehnder design) able to produce four images of the planet at the output, after separation of the polarisations. The four images I1, I2, I3, I4 present interferometric fringes with a phase shift 0, Pi/2, Pi, 3Pi/2. The combination of the four outputs produces a phase map, which is directly related to the velocity on the line of sight. The choice of the glass of the interferometer is optimised to minimize thermal drift of the OPD. Therefore a passive insulation of the interferometer is sufficient to guarantee the required stability of the OPD.

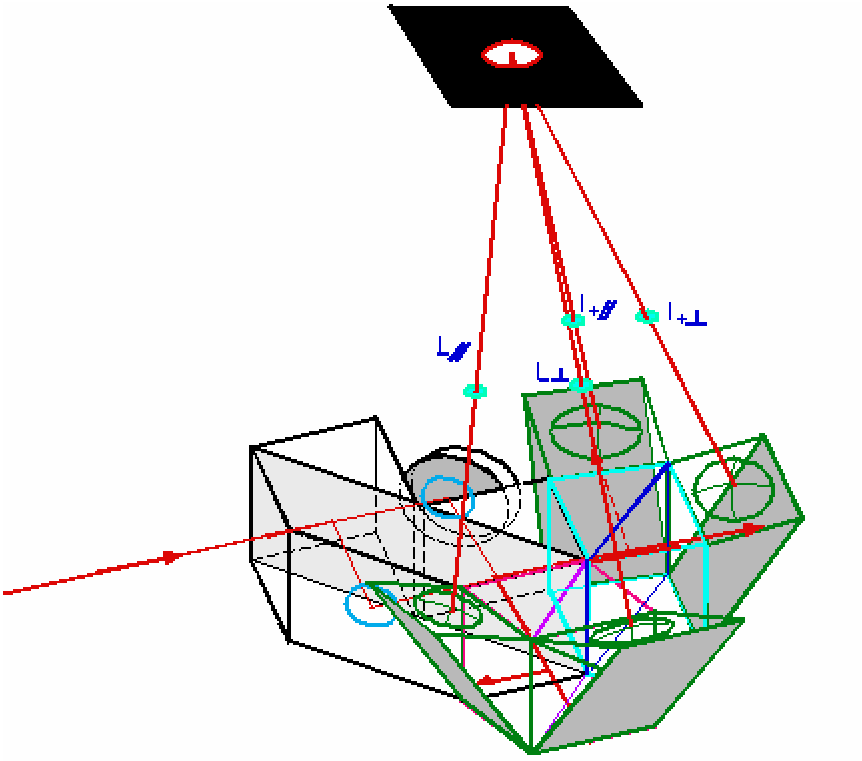


Figure 19 Schematic view of Mach-Zehnder interferometric optical block with its four outputs optic and polarization separation. All optical elements are sealed together. The overall dimension is 9x7x2 cm

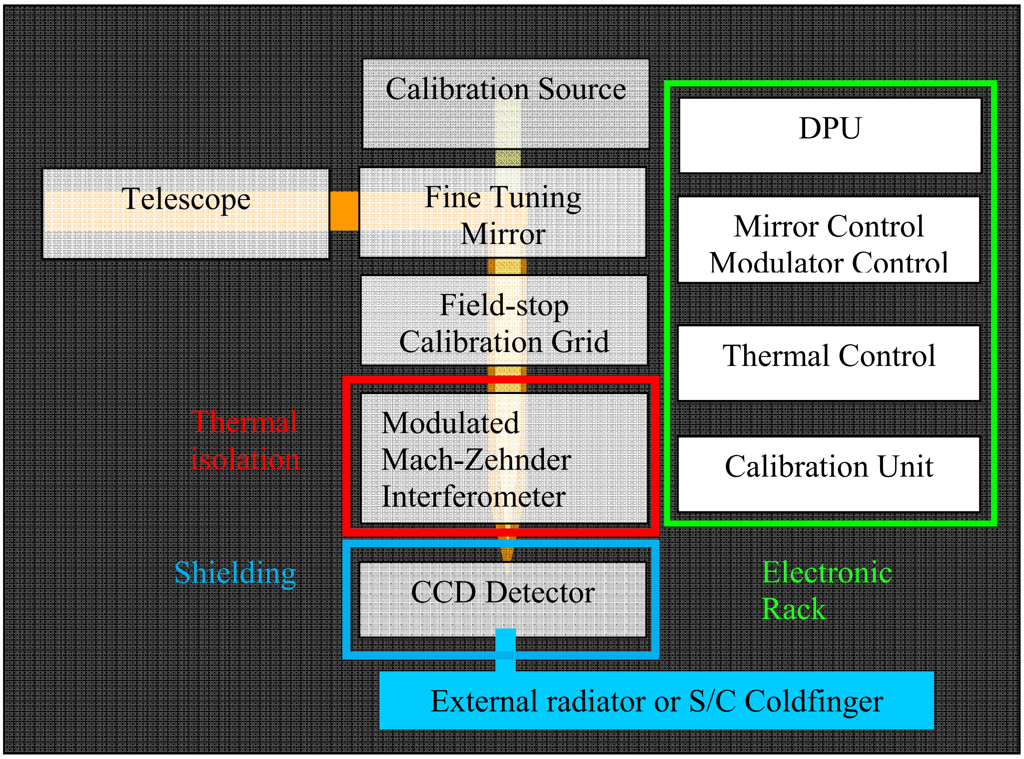


Figure 20: Block diagram of DSI

6.16.4 ORBIT, OPERATIONS AND POINTING REQUIREMENTS

The best periods for seismic observations are apojove of the orbits during the insertion phase. They offer long periods (>20 days) for observing Jupiter daily face. Different scenarios are envisioned for the orbital insertion of the JGO. Following thus scenarios, different instrumental design can be envisioned, mainly dependant of the distance to Jupiter at the time of the observations.

Generally, apocenters closer than 0.01 AU only permit observing periods shorter than 7 days, insufficient for the required precision on the frequencies.

Our best scenario is the use of the first long elliptic orbit after JOI (225-12.5 R_J), allowing almost 100 days of continuous observations.

The values of pupil size, spatial resolution and optical length given in this document have been calculated to fulfil the requirements of seismic observations between 0.1 and 0.05 AU, but this could be changed if another scenario is chosen. The calculation takes into account the phase angle of Jupiter.

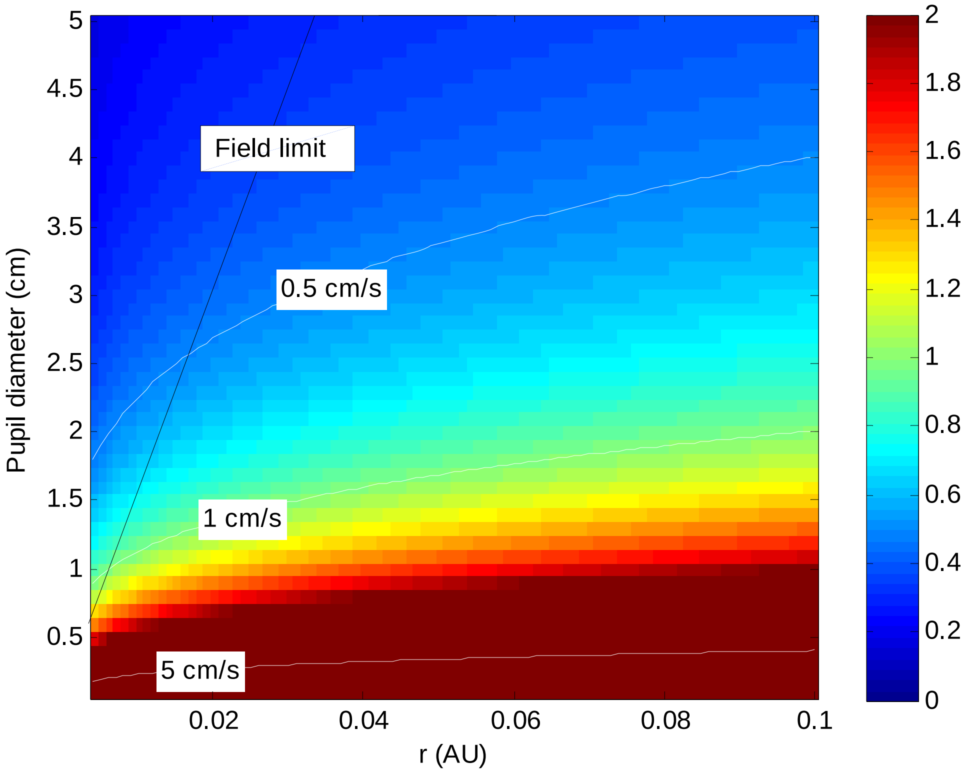


Figure 21: Noise level achieved during apocentre phase observations, as a function of the apocentre distance and of the entrance pupil diameter. The black line indicates the diameter limit to accommodate the full planet in the field of the instrument. Here the OPD has been set to 0.23 cm at 589 nm providing 6 % fringe contrast with a 1nm filter.

The instrument should be pointed permanently to Jupiter. Due to the large field of the instrument, an accurate prepointing is not required. However, the pointing stability is a critical point of the measurement. For observation at 0.03 AU, a precise knowledge of the pointing at 2-3 arcsec (1/10 pixel) in 30 s is required. The Cassini spacecraft has shown a pointing stability better than 6 µrad (~1.2 arcsec) over a 32 seconds integration time. This perfectly suits the requirements. However, if this stability cannot be achieved by JGO, a fine-pointing mirror, derived from LOI, should be used.

6.16.5 INTERFACE AND PHYSICAL RESOURCE REQUIREMENTS

The front end of the instrument is oriented permanently to Jupiter during the observing run, i.e. the apojove of insertion orbits. A small lens located on the enlightened face of the S/C provides solar light to the instrument for calibration purpose.

The optical bench is submitted to environment temperature of the satellite. However, the interferometer itself should have a temperature stability of 0.05°C per hour. The interferometer is placed in an enclosure that isolates it from the thermal variations (MLI) and is connected to the optical bench through non-conducting material. A small heater (2W) will maintain the temperature to 20°C.

The detector is passively cooled to a temperature of -60°C through an external radiator. This radiator is placed not far from the instrument, on the shadow side of the spacecraft. If cold finger is provided by the S/C, the weight of the radiator and physical interface can be avoided.

The images coded on 8 bits are taken every 1 s, and accumulated onboard for 30 seconds periods, before compression and transfer to Earth (without binning). The accumulated images will be coded on 13 bits. This corresponds to a datarate of 3 kbps, with an estimated compression factor of 3 at least, during the whole observing run (i.e. 100 days during first orbit). Shorter periods are foreseen during the Callisto and Ganymede phase for atmospheric studies. There requires less time, but with higher precision, Typically, an observing run of 20 hours during the Ganymede phase will produce 20 Gb of data to be transmitted with a datarate of 15kb/s. If the transmission is not available at the moment of the observation, the data should be recorded onboard and transmitted whenever possible, with an increased datarate.

6.16.6 CALIBRATION

OPD Modulation

The DSI provides fringed images that have to be converted into velocity field. This process requires a very accurate knowledge of the instrumental phase on each of the sub images, as well as a very precise geometric positioning of the sub images on each other. The instrumental phase recovery can be obtained through a redundant calibration process. A modulation of the OPD is obtained by a scanning mirror with a precision of a fraction of nm. This modulation allows to invert the sub images in the field and to remove any geometrical distortion effects. It will allow knowing the variation of the instrumental phase along the field. However, the absolute phase cannot be obtained by this way, and long term drift could occur. This is not annoying for seismic measurement, where only velocity variations are sought.

However, atmospheric studies require the knowledge of the absolute velocity at each point of the planet. In order to recover an absolute velocity value, a calibration of the phase with solar light is necessary.

Solar Light Calibration

The instrument will be fed by solar light, simultaneously with jovian observations, through an optical fibre. A small hemispheric lens, located on the enlightened face of the satellite, ensure a correct illumination of the fibre entrance with solar light, with an angle of acceptance of 60°.

Geometrical calibration

The data processing requires a very good knowledge of the optical path, which has to be calibrated at the laboratory prior to launch. However the response of the detector may vary during the flight due to exposition to radiation. This response should be monitored periodically thanks to a calibration white source illuminating uniformly the field. A shutter is also necessary to measure the dark current and offset. The stability of the optical distortion can be monitored either by pointing a bright stellar source at different places in the field, or by looking to an internal calibration grid to be placed in the field.

The present instrumental configuration includes all the redundant calibration configurations. If the first temporal modulation proves to work well and to pass the assessment study, then the other calibration might be avoided, conducting to a reduction of the total weight.

6.16.7 CLEANLINESS, PLANETARY PROTECTION AND PRE-LAUNCH ACTIVITIES

All components and materials used to assemble the instrument will respect the following rules necessary for cleanliness:

- Metallic materials shall be corrosion resistant;
- Metals that can sublimate in vacuum or that can generate particles (cadmium, zinc and unfused electro-deposited tin) shall not be used;
- Organic material selection shall be guided by consideration on their outgassing rates, location and amount;
- Unless easily cleanable afterwards, all special parts/components shall be procured through dedicated specifications evidencing, case by case, the acceptable incoming cleanliness levels (MIL-STD-1246C TBD);
- The choice of manufacturing sequences, techniques and processes shall be governed by considerations concerning compatibility with cleanliness requirements; operations that imply high risk of contamination (soldering, painting, extensive bonding, conformal coatings etc) shall be performed under vapor hoods in restricted area separated from Assembly and Integration Clean Rooms (class 100.000).

The instrument OH will be equipped with several heaters necessary to accelerate the outgassing process soon after the launch. The final configuration of the heaters and venting holes will be defined during the thermomechanic project.

Planetary Protection rules: TBD (depending on mission scenario).

Pre-launch activities: DSI team needs that the following activities on the assembled instrument must be completed before launch:

- full scientific on-ground calibration;
- measurement of the optical boresight w.r.t to external reference cubic mirror;

functional tests of the instrument on board the S/C bus.

6.16.8 CRITICAL ISSUES

Although the knowledge of the spacecraft trajectory is critical to determine the best possible instrumental configuration and observing schedule, the scientific objectives should not impose any a priori constraints on the trajectory, but rather be adapted from the mission scenario.

The level of acceptable radiation is fixed at a level of 40 to 50 krad (TBC) for the whole instrument. If this level is exceeded despite the shielding of the spacecraft, sensible elements could be protected by a dedicated shielding. The sensible electronic part should be placed in a dedicated vault, which could be shared with other instruments. The detector and close electronic will be protected from radiation by their own shielding (4 mm AU).

DSI has a large field of view and therefore does not require an absolute pointing accuracy. Pointing relative stability is a critical point of the measurement. An internal fine pointing mirror will compensate the pointing drift at a frequency of one Hz, thus eliminating any movement at lower frequency. The low frequency position can be deduced from the scientific measurement of DSI. If the spacecraft cannot guarantee the required level of stability for higher frequencies (<1’’ in 1 s, see below), the relative position of the S/C should be used as an input signal for the pointing mirror. If the star tracker signal provided by the S/C has sensitivity better than 1’’ at 10 Hz, it can be used for that goal; otherwise DSI will use his own measurement on Jupiter for precise pointing.

6.16.9 HERITAGE

The ground-based instrument SYMPA is a prototype for DSI. It demonstrated the validity of the concept and it has proved to achieve the theoretical noise level, both at the laboratory and on Jupiter.

MDI, on board of SOHO, is based on the same principle. It has produced velocity maps of the Sun for more than 10 years. However, this instrument is rather complex. Both technology improvement and a simplified optical design will allow the same functionality with a much more compact design. Moreover, the OPD modulation, originally made by motors, will be provided by small PZT actuator, much lighter and reliable.

Several components can be inherited from previous space experiment. The fine pointing mirror (if required) can be inherited from LOI. The CCD detector and controller could be derived from Mars Express.
Fine pointing and OPD modulation will benefit from R&T already achieved on PZT actuators in the frame of Solar Orbiter studies. Other alternative concepts aiming at the same type of measurements are under studies at LESIA and could be considered at the phase A study.

6.16.10 OPEN TECHNOLOGY ISSUES AND CRITICALITY

PZT actuators have been extensively used in space research. Recent improvement in accuracy and stability make them particularly suitable for OPD modulation. However, a full study of long term stability and thermal drift of these devices has to be achieved. Such a study has already been started in the frame of Solar Orbiter studies (Appourchaux et al), but it needs to be pursued for the present instrument proposal.

6.16.11 INSTRUMENT SUMMARY DATA SHEET

Table 48 DSI summary table.

Parameter	**Unit**	**Value/Description**	**Remarks**
Heritage	N/A	MDI, LOI, SYMPA	Solar Orbiter studies
Type of instrument	N/A	Compact interferometer	
Type of optics	N/A	TBD	
Function mode	N/A	Image	
Optics			
Spectral range	Nm	590	
FOV	Deg	1.095	For an optimum at 0.1 AU
Pixel IFOV	Mrad	0.075	
Wavelength for diff. limit	Nm	589	
Aperture	Mm	65	
Focal length	Mm	347	
f/#	#	5.33	
Filters	#	1	Interferential filter
Filter bandwidth	Nm	1	
Detector			
Type of detector	N/A	CCD or APS	Mars Express heritage or R&D
Pixel lines in array	#	512	
Pixels per array line	#	512	
Pixel size	µm	25	
Exposure time	Msec	500	
Repeat time	Msec	500	
Operating temperature	°C	-60	
Operating temperature stability	°C/h	0.5	
A/D conversion	bit/pix	10	

Full well capacity	Ke^-	100 (TBC)	
Readout time	Msec	10 (TBC)	
Swath and Resolution			
Swath width	Km	N/A	
Spectral sampling	Nm	N/A	
Spatial pixel resolution	M	$750\ 10^3$	from 0.1 AU
Thermal Control			
Total surface area	cm^2	4000	
Non-isolated area	cm^2	500	
Operating temperature	°C	-20 +40	
Operating temperature stability	°C/h	2	
Physical			
Preferred location	N/A		
Mass, total	Kg	4	Without electronic shielding
Power			
Total average power	W	6	
Detector + electronics	W	4	
TE cooler	W	N/A	
Data Rate & Volume			
Data volume (total)	Gbyte	30 (TBC)	For a 90 days (70 % duty cycle) run (depending on mission scenario)
Data rate (instantaneous)	kbyte/s	3	Rate for continuous transfer (compressed)
Compression factor	#	>3	

6.16.12 SUMMARY OF ALIGNMENT AND POINTING REQUIREMENTS

Table 49 Summary of instrument alignment and pointing requirements. Note that in case more than one angle is listed, the sequence is pitch, roll, yaw.

Instrument	Pixel size arcsec	FOV deg	Min. pixel readout time Ms	APE arcmin	RPE arcsec/t	AMA arcsec	Pre-facto knowledge of co-alignment with reference arcsec	Co-alignment stability arcsec/t	Post facto knowledge of co-alignment with reference arcsec
DSI	26	1.1	1	1	30 arcsec/s	30	TBD	TBD	T

7 DESCRIPTION OF FUNDAMENTAL PHYSICS INSTRUMENT

7.1 Gravity Advanced Package (GAP)

7.1.1 SCIENCE GOALS AND PERFORMANCE REQUIREMENTS

The main objectives of the Gravity Advanced Package are the following fundamental physics tests during the cruise up to the planet:

- test of the gravity in the Solar system,
- verification of the fly-by anomaly,

During the cruise, the payload can be used for the following secondary objectives:

- improvement of the knowledge of solar aeronomy

After arrival at the planet, the following secondary objectives can be achieved:

- measurement of the planet or moon atmospheric drag
- determination of the planet or moon gravity,

The payload, as it is described in the following paragraphs, is defined to reach these objectives during the cruise up to the planet. For taking advantage of this payload at arrival on the planet, some adaptations should be necessary (as the specific radiation protection), this is not presented hereafter.

The more demanding scientific goal is for the instrument the test of the gravity in the Solar System for which an accuracy of the non-gravitational acceleration measurement is required at 5.10^{-11} m/s^2 in the low-frequency bandwidth ($0–10^{-4}$ Hz). This accuracy has to be achieved while the coupling in the data of the angular and linear motion of the spacecraft is sufficiently rejected.
For the other scientific objectives, a measurement accuracy of the non-gravitational acceleration at $10^{-9}–10^{-10}$ m/s^2 is sufficient in the same low-frequency range ($0\text{-}10^{-4}$ Hz).

For the test of gravity in the Solar system, the measurements of the non-gravitational forces applied to the spacecraft, performed by the accelerometer, will be used in the orbit determination and interpretation process in complement of the radio-science currently done measurement (ranging and Doppler, plus eventually VLBI). A discrepancy in the two types of measurement signifies an error of the model used for the orbit determination (at the level of accuracy of the measurement) and consequently a possible discrepancy of the gravity law.

7.1.2 INSTRUMENT CONCEPT

The Gravity Advanced Package consists in a three axis accelerometer exhibiting 3 orthogonal sensitive axes with null bias (in orbit evaluated and rejected) along 2 axes in the orbit plane.

The package is composed of three units: the electrostatic accelerometer, with its specific analog electronics, the bias rejection system and the interface and control unit.

The core of the instrument is an inertial mass electrostatically controlled at the center of a high accurate silica gold coated cage; this configuration is based on the Onera expertise in the field of space accelerometry and gravimetry developed in the frame of the CHAMP, GRACE, and GOCE missions. Ready-to-fly concept and technology are used with dedicated improvements aimed at reducing power consumption, size and weight.

One bias rejection system is integrated in the package with the accelerometer in order to ensure the high performance at the very low frequencies. This system consists of a flip mechanism to create a ± 180° rotation of the accelerometer sensitive axes with respect to the satellite ones at regularly spaced times. As a consequence, the resulting modulation of the measured accelerations projected on the instrument sensitive axes allows distinguishing the applied acceleration on the satellite from the accelerometer bias, the latter staying at DC while the first is transposed at the modulation frequency.

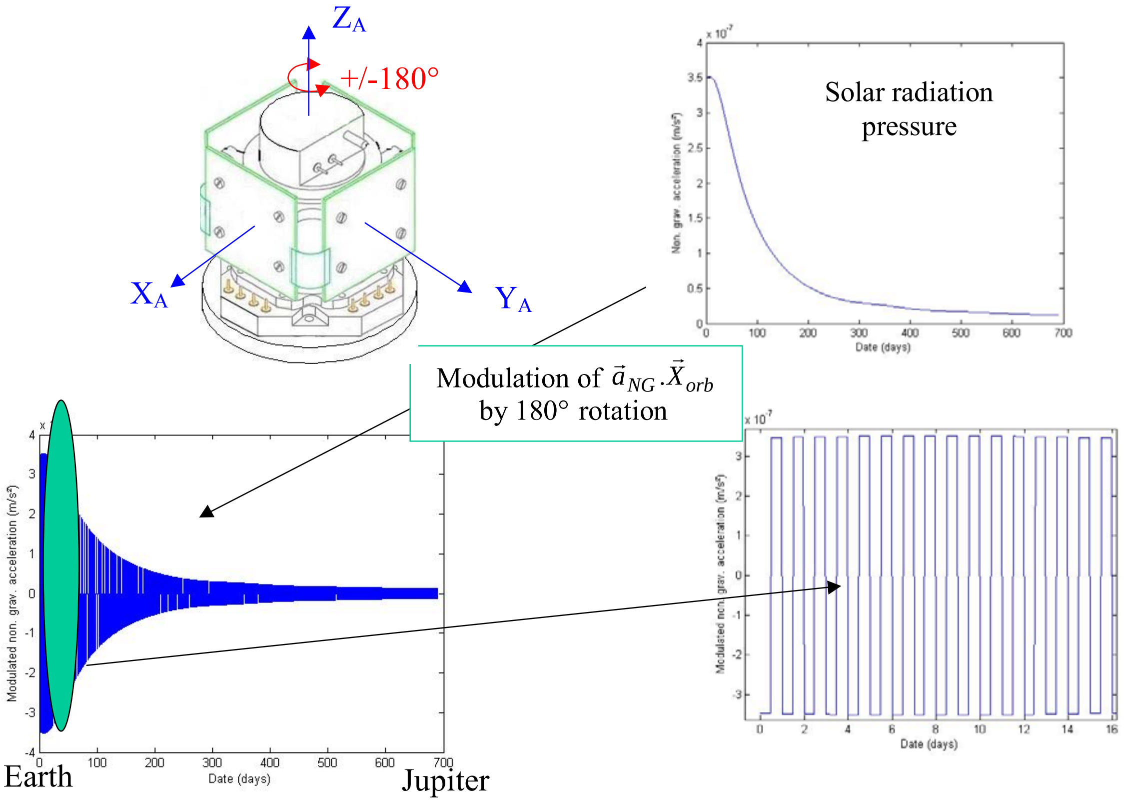


Figure 22 : Principle of the bias rejection system. The graphs show simulated data under the assumption of a trajectory to Jupiter.

7.1.3 INSTRUMENT DESCRIPTION

7.1.3.1 Accelerometer sensor

Three axis electrostatic accelerometers developed at ONERA are based on the electrostatic levitation of the instrument inertial mass with almost no mechanical contact with the instrument frame. Measurements of the electrostatic forces and torques, which result from the six servo-loops necessary to maintain the mass motionless with respect to the sensor cage, provide the six outputs of the accelerometer. The relative motion of the proof-mass (6 degrees of freedom) is in fact finely measured by capacitive sensors with respect to the sensor silica core selected for its very high geometric stability. The proof-mass is then actually controlled by electrostatic forces and torques generated by six servo loops applying well measured opposite voltages on symmetric electrodes. Whatever is along the orbit the charged particles radiation, the electrical potential of the mass is maintained at a constant level to linearize the actuators.

Figure 23 shows the mechanical core of the accelerometer, which is composed of a silica cubic proof-mass of 18 g, with 3 pairs of similar electrode plates, each pair controlling two degrees of freedom.

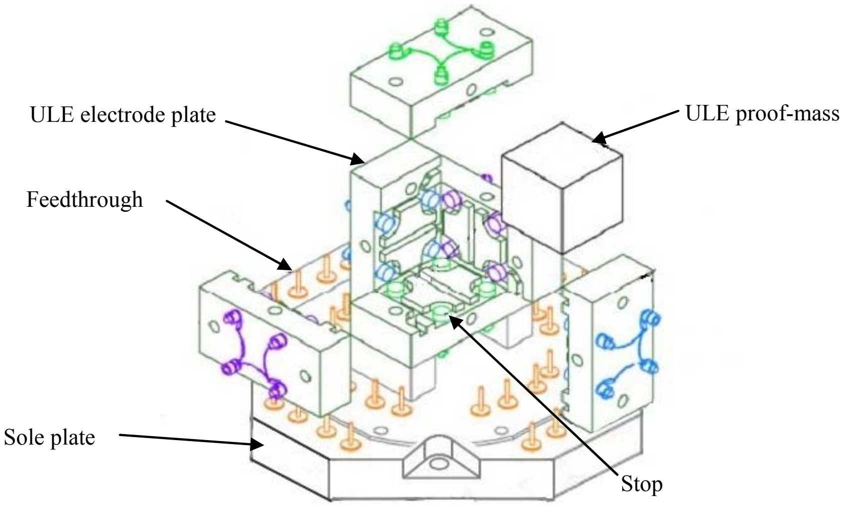


Figure 23 : Mechanical core of the µSTAR accelerometer

Figure 24 is a complete view of the accelerometer with its mechanical core inside the tight housing and the electronic boards implemented around the housing. The control of the proof-mass is performed by low consumption analogue functions. The outputs of the accelerometer, which are the applied voltages on the electrodes to control the proof-mass, are sent to an Interface Control Unit.
The size of the accelerometer is 10x10x10 cm^3.

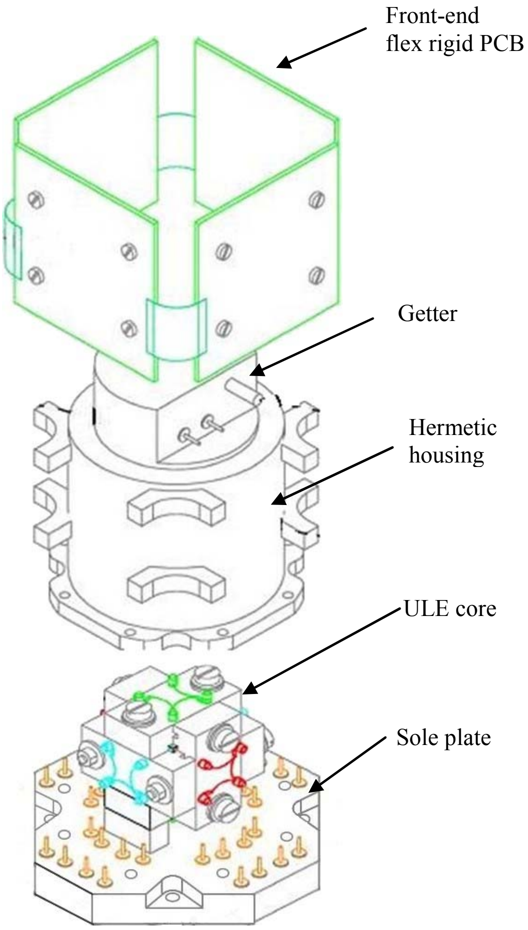


Figure 24: µSTAR accelerometer with the analog electronic board

7.1.3.2 *Bias rejection system*

The bias rejection system is similar to rotating stage existing on the shelf, but optimized in order to reduce the mass and the consumption. This reduction is possible due to the limited requirement: only 4 angles (0°, 90°, 180° and 270°) are required with accuracy of about 0.005°, load charge is reduced due to the space conditions.

The rotation is obtained either with a stepper motor or a piezoelectric motor. The principle of the rotation stage is presented in Figure 25. The rotation of the accelerometer on the stage is obtained by the worm gear system. A worm preloading system ensures that the worm and the gear are in a perfect contact.

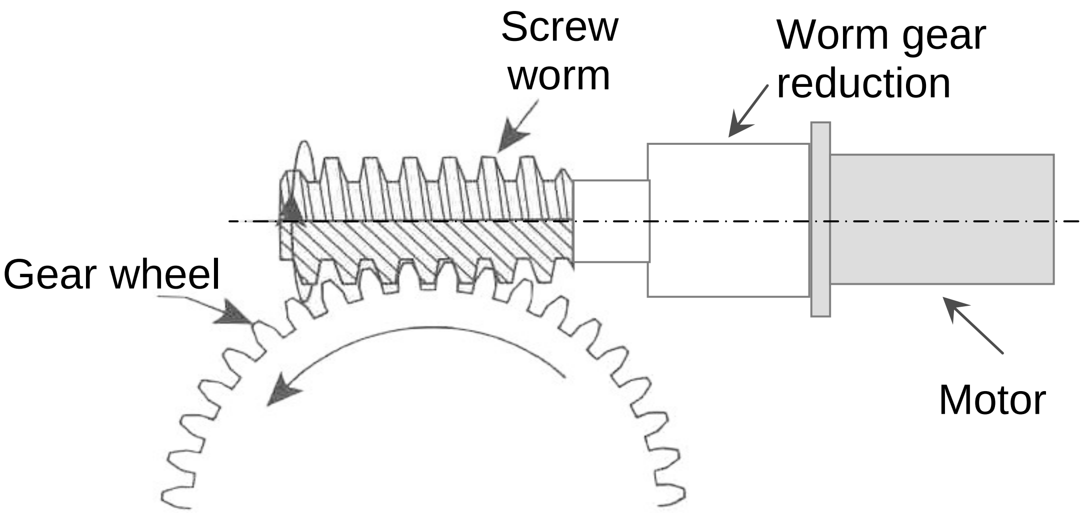


Figure 25: principle of the rotation stage

Figure 26 shows the implementation of the different mechanism of the rejection system. An angular positioning measurement is included allowing the correct positioning for the 4 privileged angular positions (0°, 90°, 180°, 270°).

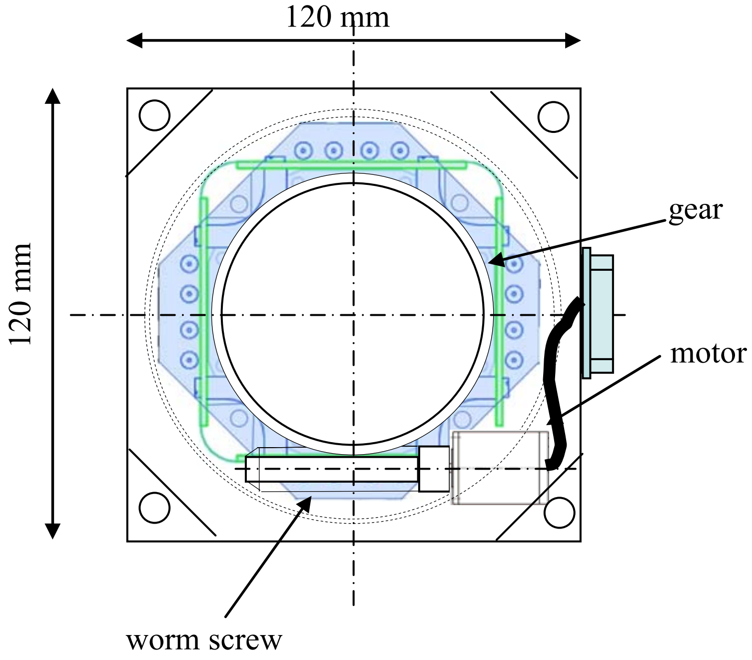


Figure 26: Rejection system box, with the gear, the worm scerw and the stepper motor

The size of the rejection system box is 12x12x5 cm^3.
The electronic of control/command of the rotation stage is included in the ICU.

7.1.3.3 *Interface Control Unit*

The ICU includes:

- the DC/DC converter to pass from the primary voltage of the non-regulated 28 V of the satellite power bus to the secondary voltage needed for the instrument operation, ±15V;

- the interface RS422 function with the satellite data bus and the necessary data formatting operation;
- the electronics of the bias rejection system (micro control processor).

The size of the ICU is 12x12x5 cm^3.
Figure 27 presents the 3 units composing the gravity advanced package. The ICU can be either in a separate electronics unit (as presented) and located even far from the accelerometer or placed side by side with the rejection system unit, depending of the satellite integration constraints.

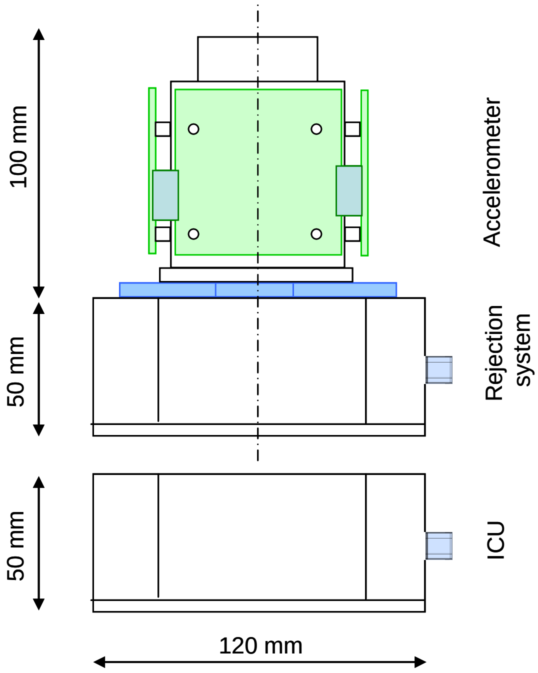


Figure 27: Gravity Advanced Package Assembly

7.1.3.4 Instrument performance

The total error budget of the instrument package includes the following main limitation sources:
-the noise of the accelerometer,
-the error in the rejection of the accelerometer bias,
-the misalignment of the accelerometer sensitive axes with the reference axes of the spacecraft given by the star trackers,
-the angular motion of the spacecraft affecting the data in presence of accelerometer mis-positioning with respect to the centre of gravity of the spacecraft,
-the self-gravity of the spacecraft applied to the accelerometer mass.

Accelerometer noise:
Taking advantage of the previous instrument development and models, the instrument characteristics can be evaluated on the basis of the selected configuration for the sensor core and the electronics functions. Figure 28 presents the expected noise level along one sensitive axis with a light proof-mass (18 g) when considering a thermal stability of 1°C/$Hz^{1/2}$ at

0.01 mHz (obtained with passive insulation of the sensor environment). Over one day, the integrated noise, assuming a data rate of 10 s, is 1x10^{-11} m/s^2 rms.

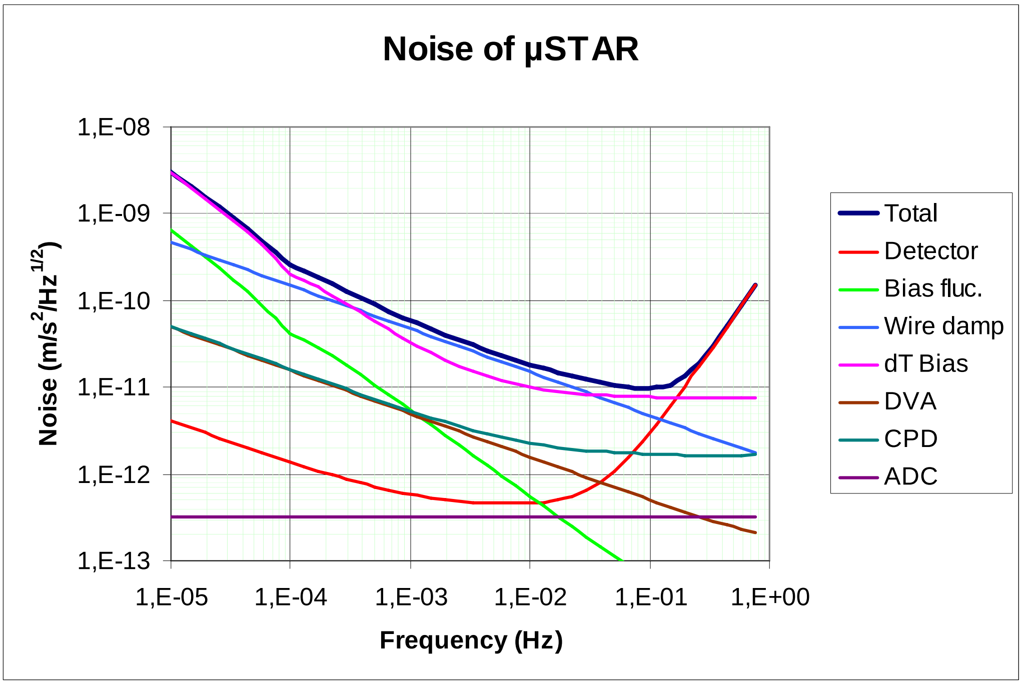


Figure 28: Evaluated acceleration noise density versus signal frequency. The considered noise sources are: the capacitive positioning thermal noise (Detector), the time and thermal fluctuations of the accelerometer bias (Bias fluc. and dT Bias), the Nyquist fluctuation dissipation of the mass motion due to the gold wire (Wire damp.), the electrostatic actuation noise (DVA), the contact potential differences between the conductors of the core (CPD), the analog to digital conversion noise (ADC)

In this configuration, the accelerometer range is 2x10^{-5} m/s^2 and the maximum bias level before calibration is 5x10^{-6} m/s^2, with a thermal stability of 3x10^{-9} m/s^2/°C with respect to the temperature of the mechanical sensor (due mainly to the stiffness variation of the gold wire) – this bias stability is taken into account in the noise performance.

Misalignment of accelerometer axes

The misalignments of the accelerometer axes with respect to the ones of the spacecraft, given by the star tracker lead to errors proportional to the maximal non-gravitational acceleration applied on the spacecraft. Considering a one ton spacecraft, with a 30 m^2 surface of solar panel, Table 50 gives the requirements to be met on these misalignments in order to limit their impact on the measurement accuracy to less than 10^{-11} m/s^2.

Table 50 : Aligment accuracy for rejection system

Distance to sun	Solar pressure radiation	Alignment for impact less than 10^{-11} m/s^2
1 AU (Earth)	2.0 10^{-7} m/s^2	50 µrad
1.52 AU(Mars)	8.8 10^{-8} m/s^2	114 µrad
2 AU	5.0 10^{-8} m/s^2	200 µrad
3 AU	2.3 10^{-8} m/s^2	444 µrad
4 AU	1.3 10^{-8} m/s^2	790 µrad
5.2 AU (Jupiter)	7.5 10^{-9} m/s^2	1.3 mrad

These alignment matching accuracies are limited by several sources of errors:
-the accuracy of the rotating system,
-the knowledge of the accelerometer sensitive axes,
-the alignment of the gravity advanced package with respect to the satellite axes after integration
.

Nota: the experiment requires the alignment of the acceleration delivered by the accelerometer and the velocity delivered by the Doppler measurement. In addition, corrections of the satellite attitude motion effects should require the star trackers data. The alignment global approach could be to consider all alignment accuracies with respect to the axes defined by the star sensor quaternions transmitted to ground.

For the test of gravity in the Solar system, the performance will be achieved from 2 AU, leading to a requirement of misalignment less than 0.2 mrad. If the electric generation is done with RTG, the maximal acceleration is due to the RTG radiation (with a level less than 3 10^{-9} m/s^2 – from Cassini) and the alignment requirement is relaxed to 3.3 mrad.

Error of bias rejection

The bias rejection is performed by the modulation of the measured non-gravitational acceleration at a frequency of about 10^{-3} Hz, by flipping the accelerometer of ±180° every 500 s. The velocity of the flip is 18°/s. The modulated signal and the bias are evaluated over 10 periods of 10^3s. The10^4s period has to be selected according to the instrument stability and thus the possible thermal stability of the instrument on board the satellite. The flip-flop period is then selected in consequence.
Figure 29 presents the shift of the different signals in the frequency domain allowing the separation of the signals linked to the instrument orientation (in particular its bias) and to the satellite one..

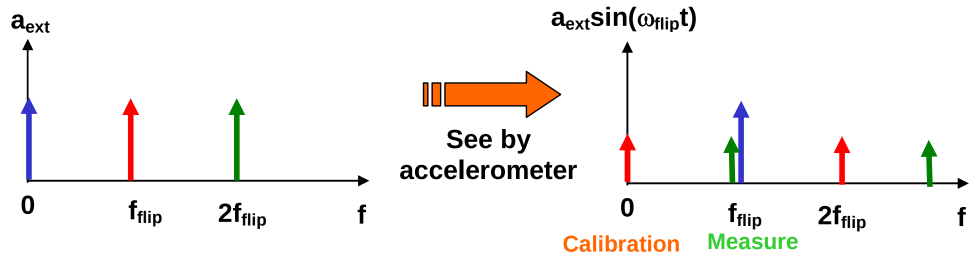


Figure 29: Effect of the modulation of the external acceleration

The error of the bias evaluation and rejection comes from the non perfect rotation of the instrument with respect to the considered one in the processing, the post-processing limitation; the evolution of the bias and non-gravitational acceleration during the processing period and the effect of the external acceleration signals at harmonics of the flip frequency.
The total error due to the bias rejection system and the post-processing should be less than 2 10^{-11} m/s^2.

Coupling with spacecraft angular motion

As the sensitive center of the accelerometer (center of gravity of the proof-mass) will not be perfectly co-localized with the center of gravity of the spacecraft, a coupling term with the angular motion of the spacecraft will perturb the linear acceleration measurement:

$$\vec{\Omega}\wedge\left(\vec{\Omega}\wedge\vec{GO}\right)+\overset{o}{\vec{\Omega}}\wedge\vec{GO}$$

where O is the center of the mass and G the center of mass (of gravity for a uniform field) of the satellite.

This term could be corrected according to the knowledge of the relative position of the accelerometer with respect to the center of gravity of the spacecraft and to the estimate of the angular motion of the spacecraft from the star tracker quaternions.

This coupling should be the main source of error for a non-dedicated spacecraft. Requirement on the residue of this term evaluation has been considered to 4.1×10^{-11} m/s^2. From this level, the requirements on the accuracy of the a posteriori knowledge of the satellite attitude deduced from the star tracker measurements can be deduced in regard to the satellite attitude control performance and to the accuracy of the accelerometer position versus the satellite center of gravity that may vary during the mission but which displacements can be evaluated according to the fuel consumption in the tanks for instance (see §7.1.4.2).

Spacecraft self-gravity

All the masses around the accelerometer will attract the proof-mass and creates a parasitic acceleration, the satellite self-gravity: this acceleration cannot be rejected by the rejection system as its direction is linked to the spacecraft and not to the accelerometer. If too large, it can be estimated according to the satellite design but nevertheless has to be limited either by a good symmetric architecture or by a good knowledge of the steady mass repartition of the components around the accelerometer in order to reduce the estimation residue.

The requirement of 10^{-11} m/s^2 corresponds about to the gravity field of one 150 g mass source at 1 m or a distance error of 7.5 cm over 1 m for one mass source of 1 kg.

Total error

Table 51 gives the established error budget of the gravity advanced package. A supplementary 10^{-11} m/s^2 error is added for all other error sources, not detailed here above.

Table 51: Performance breakdown of the Gravity Advanced Package

Source of errors	Impact on performance between 0–10^{-4} Hz
Noise of the accelerometer	10^{-11} m/s^2
Error of bias rejection	2 10^{-11} m/s^2
Misalignment of accelerometer axis	10^{-11} m/s^2
Coupling with spacecraft angular motion	4.1 10^{-11} m/s^2
Spacecraft self-gravity	10^{-11} m/s^2
Other source of errors	10^{-11} m/s^2
Total (quadratic sum)	**5 10^{-11} m/s^2**

Nota: for fly-by anomaly objectives, the performance requirements is an order of magnitude less severe, allowing to relax , for example, the requirement on the coupling with spacecraft angular motion by a factor 10.

7.1.4 ORBIT, OPERATIONS AND POINTING REQUIREMENTS

7.1.4.1 Orbit requirement

No requirement on the orbit, except that some fly-by will occurred.

7.1.4.2 Pointing requirement

The major operation requirement is linked to the integration of the accelerometer inside the spacecraft. The accelerometer should ideally be placed at the centre of gravity of the spacecraft, in order to nullify in the linear acceleration measurement, the effect of the spacecraft angular rate and angular acceleration. This effect is proportional to the distance between the satellite and the accelerometer centers. In case of an off-centered integration of the package, attitude control may be specified or more easily, evaluation of this disturbing term is specified according to:

- the off centering distance and the knowledge accuracy,
- the attitude motion of the satellite and its knowledge accuracy

The satellite center of gravity may move during the mission due to the fuel consumption, therefore it may be necessary to correct the measurement from this coupling term accordingly. This correction is done thanks to the star tracker measurement and the model of the satellite center of gravity motion according to the thruster actuations.
Then, the error of the disturbing term estimate is evaluated by:

$$\delta\vec{a}_{AOCS} \approx \delta\vec{\Omega} \wedge \left(\vec{\Omega} \wedge \vec{GO}\right) + \vec{\Omega} \wedge \left(\delta\vec{\Omega} \wedge \vec{GO}\right) + \vec{\Omega} \wedge \left(\vec{\Omega} \wedge \delta\vec{GO}\right) + \delta\overset{o}{\vec{\Omega}} \wedge \vec{GO} + \overset{o}{\vec{\Omega}} \wedge \delta\vec{GO},$$

where $\delta\vec{\Omega}$ is the knowledge a posteriori angular rate,

$\delta\overset{o}{\vec{\Omega}}$ is the knowledge a posteriori angular acceleration,

$\delta\vec{GO}$ is the knowledge a posteriori of the accelerometer position with respect to the centre of gravity.
For worst case analysis, the same order of magnitude of each term can be considered for all axes, which leads to the following worst case error along one axis:

$$\delta a_{AOCS} \leq \left(4\Omega^2 + 2\dot{\Omega}\right)\delta R + \left(8\delta\Omega.\Omega + 2\delta\dot{\Omega}\right)R$$

As the evaluation of this error has to be done from DC to to10^{-4} Hz, it is easier to express the angular rate and acceleration terms with respect to attitude measurement or control, by:

$$\Omega = \omega\theta; \qquad \dot{\Omega} = \omega^2\theta; \qquad \delta\Omega = \omega\delta\theta; \qquad \delta\dot{\Omega} = \omega^2\delta\theta;$$

where ω corresponds to the highest angular frequency of the bandwidth (10^{-4} Hz).
The disturbing term is then less than:

$$\delta a_{AOCS} \leq \omega^2\left[\left(4\theta^2 + 2\theta\right)\delta R + \left(8\theta\delta\theta + 2\delta\theta\right)R\right]$$

For small attitude control performance, the error can be written by:

$$\delta a_{AOCS} \leq 2\omega^2\theta.R\left[\frac{\delta R}{R} + \frac{\delta\theta}{\theta}\right]$$

Figure 30 presents the relation between the needed accuracy of the accelerometer position evaluation versus the satellite attitude control performance considering a star tracker accuracy of 10 arcsec from DC to 10^{-4} Hz for different accelerometer off-centering along the 3 directions in order to achieve the requirement of 4.1×10^{-11} m/s^2 with respect to the spacecraft angular motion.

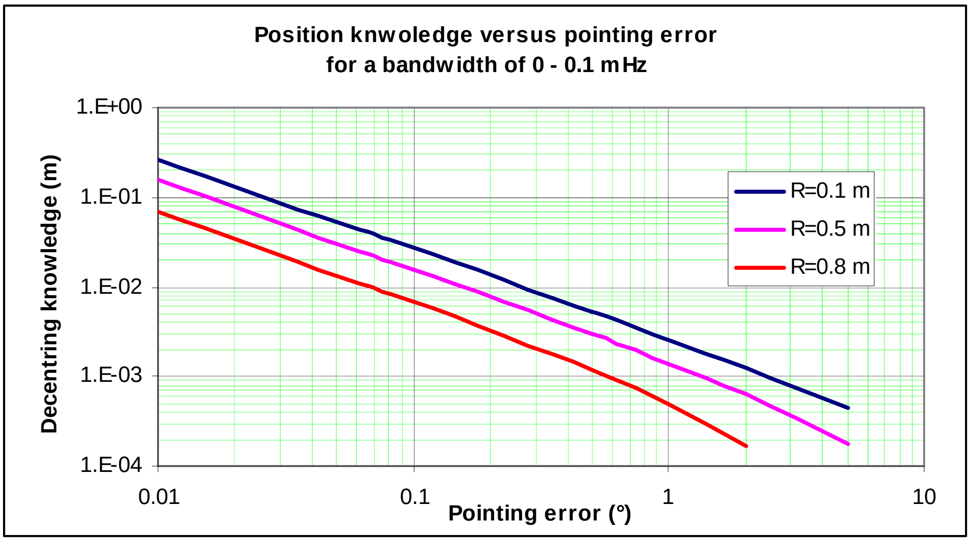


Figure 30: Position knowledge needed to achieve the requirement with respect to the s/c angular motion

Assuming a 50 cm off-centering, known all over the mission with 1 cm accuracy, the satellite pointing accuracy, θ, has to be better than 0.15° to meet the requirement of $4.1\ 10^{-11}$m/s^2 error. This leads to an angular velocity of $1.7\ 10^{-6}$ rd/s at the considered frequency of 10^{-4} Hz. These specifications on the attitude control can be even relaxed if the accelerometer is nearer the centre of gravity along some axes or for better star tracker accuracy.

In case of such requirements are not achievable for nominal operation mode of the spacecraft, a specific measurement mode for s/c operation may be necessary.

Nota: for fly-by anomaly objectives, the performance requirements is an order of magnitude less severe, leading to relax the requirement on spacecraft angular motion requirement.

7.1.4.3 Thermal requirement

There is no constraint on the operating temperature.
In fact, for the accelerometer core, the material used (ULE) has a thermal expansion of 3×10^{-8}m/m/K for proof-mass and electrode plates. Only the stops (in Arcap) have a higher thermal expansion of 1.6×10^{-5} m/m/K, leading to a variation of 3.2 µm over 100 K. This variation is taken into account in the free motion of the proof-mass to not break it (during its integration, the accelerometer is heated at 100°C for out-gassing).
The electronic components operate between -55°C and +125°C, with their performance guaranteed between -40°C and +85°C. The variation of their characteristics with the temperature leads to modification of the accelerometer bias (but it is calibrated) and scale factor (about 10^{-5} ppm/K). This scale factor thermal sensitivity shall be characterized on ground to be corrected in the ground data processing.

Concerning the thermal stability of the units, the noise and the bias stability of the instrument depend also on the accelerometer temperature fluctuations on board. In Figure 28, a 1/f

frequency dependence of the thermal stability has been considered with a value of 1°K/Hz$^{1/2}$ at 0.01 mHz, the 1/f cut-off frequency being 0.1 mHz, where the density is assumed constant for higher frequencies. It corresponds to a peak-peak variation of the temperature of 0.4°K over 10 s and 0.6°K peak-peak over one day.
This thermal stability is supposed to be obtained passively by the insulation of the accelerometer. The ICU electronics unit can support higher thermal variations.

7.1.4.4 Operations requirement

The main objectives of the payload occur during the cruise phase of the trajectory (including fly-by). Considering that the other instruments are OFF during this phase of the mission, the accelerometer could work continuously.

Nevertheless, for achieving the requirements of the gravity test in the Solar system, it could be necessary to have specific measurement mode of the spacecraft characterised by a quiet angular motion environment (see §7.1.4.2). This quiet angular environment could be achieved by switch off the angular control of the spacecraft during a limited period (but keeping the angular measurement through the star tracker). This has obviously to be analysed during the satellite definition phase in term of interest, necessity and impact.
In such case, the measurement mode will occur at a sun distance of 2 AU, for one day (or one navigation sequence of 8 hours), once every week. This would achieve 52 days of accurate measurements per year, in order to determine annual or semi-annual period in the science measurement. During this measurement period, continuous ranging and Doppler tracking of the spacecraft shall be performed.

7.1.5 INTERFACE AND PHYSICAL RESOURCE REQUIREMENTS

7.1.5.1 Mass

Table 52 gives the mass budget of the Gravity Advanced Package in case of a different box for the ICU. A margin of about 10% is taken into account. In case of co-location of the ICU and the rejection system in the same box, the total mass is reduced of about 200g (a part of the sole-plate).

Table 52: Mass budget of the Gravity Advanced Package

Functions	Item	Material	u. mass (g)	Qty	Mass (g)
Accelerometer	Proof-mass	Gold Coated Zerodur	20	1	20
	Electrodes plates	Gold Coated Zerodur	18,7	6	112,2
	Stops	Arcap	0,7	24	16,8
	Base plate	Ti alloy (Ta6V)	170	1	170
	Hermetic housing	Ti alloy (Ta6V)	145	1	145
	Getter	/	22	1	22
	Core screws	Ti alloy (Ta6V)	3,3	6	19,8
	Cabled PCBs+ flex links	/	40	4	160
	Internal cabling	CuAg/PTFE	/	/	50
	PCB screws	Ti alloy (Ta6V)	1,5	16	24
	Other items	/	/	/	25
				Sub-total	**744,8**
Rejection system	Rotative stage		400	1	400
	Stepper motor		100	1	100
	Chassis (3 mm) + screws + connectors	Al alloy (2017A)	300	1	300
	Base plate	Ti alloy (Ta6V)	260	1	260
	Other items	/	/	/	25
				Sub-total	**1085**
ICU	Base plate	Ti alloy (Ta6V)	260	1	260
	Connectors	/	50	2	100
	Cabled PCBs	/	50	3	150
	Specific EEE (DC/DC)	/	50	1	50
	Chassis (3 mm) + screws + connectors	Al alloy (2017A)	300	1	300
	Other items (screws, columns)	/	/	/	50
				Sub-total	**910**
				TOTAL	**2739,8**
				Margin	**260,2**
				TOTAL with margin	**3000**

7.1.5.2 Consumption

Table 53 gives the mean power consumption of the Gravity Advanced Package, assuming that the motor is operated for only 2% of the time. The maximum peak power is obtained during motor operations, and is 13 W.

Table 53: Consumption budget of the Gravity Advanced Package

Function	Sub-function	Power per sub-function (W)	Nb of sub-function	Power (W)
FEEU	Position Sensor	0.05	6	0.3
	PID	0.1	6	0.6
	Polarisation and pumping voltage sources	0.4	1	0.4
	Temperature monitoring	0.1	1	0.1
	sub-total			**1.4**
ICU	DC/DC losses (80% of efficiency for 2,5 W max)			0.5
	µC + peripherals			0.4
	RS 422 interface			0.5
	sub-total			**1.4**
Rejection system	Stepper motor	0.2	1	0.2
	sub-total			**0.2**
Total				**3**

7.1.5.3 TM/TC

No TC except switch on/off of the instrument is required. The operation is fully automatic. The calibration is done continuously.

The telemetry package is available to the satellite computer every 10 s, with each data of 24 bits. A reduction of the number of bits as well as the rate can be considered according to the satellite data system demand, but shall be sufficient for rejection of the bias in the ground processing. The different provided signals are:
- the 6 voltages applied on the electrodes;
- the 6 detector outputs,
- the polarisation and detection voltages,
- the house-keeping data (stabilised voltage, temperature, …),
- the data of the rejection system,
- the status of the accelerometer.

The total TM rate is 100 bit/s.

7.1.6 CALIBRATION

No specific calibration phase or mode.
The operation of the bias calibration system is the nominal mode of the accelerometer.

7.1.7 CLEANLINESS, PLANETARY PROTECTION AND PRE-LAUNCH ACTIVITIES

The cleanliness of the core (class 100) is ensured by the hermetic housing. The pre-launch activity is only the re-activation of the getter 1 or 2 months before the launch.

7.1.8 CRITICAL ISSUES

The critical issues for such package may be related to the integration inside the spacecraft:
- Implementation of the payload not to far from the centre of gravity of the spacecraft, with impact on the attitude control performance;
- Alignment of the accelerometer axes with respect to the star tracker ones.

In addition and as an advantage, the instrument does not need any outside view.

As the main scientific objectives of GAP are achieved during the interplanetary cruise, no specific radiation protection was considered in the design of the instrument against the radiative environment around Jupiter. The electronic can support up to 15 krads (proved by previous mission). The rejection and ICU subsystems mass budget already includes a 3mm shielding of Aluminium.

7.1.9 HERITAGE

The accelerometer (sensor core and electronics) is based on the same concept and technology than those used for the accelerometers of the CHAMP, GRACE and GOCE missions.

The rejection system is based on laboratory existing technology, with components space-qualified for the motor. Similar system is also used on OARE acceleration measurement system on-board the space shuttle.

7.1.10 OPEN TECHNOLOGY ISSUES AND CRITICALITY

No open technology

7.1.11 INSTRUMENT SUMMARY DATA SHEET

Table 54 GAP summary table.

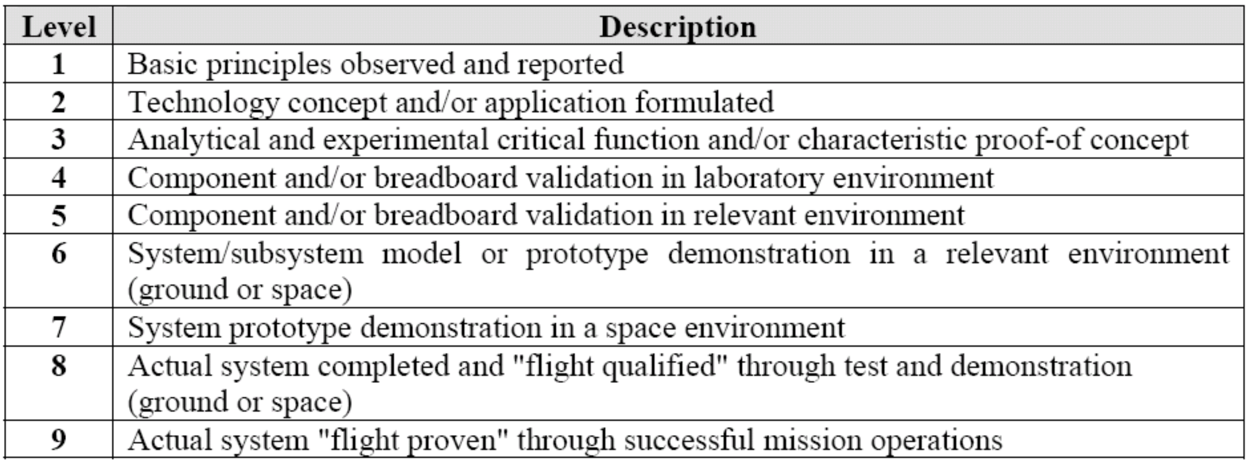
Parameter	**Unit**	**Value/Description**	**Remarks**
Heritage	N/A	CHAMP, GRACE, GOCE	
Type of instrument	N/A	Electrostatic accelerometer	
Type of optics	N/A	No	
Function mode	N/A	On/Off	
Detector			
Type of detector	N/A	Gravity sensor	
Acceleration range	m/s^2	$2\ 10^{-5}$	Loss of proof-mass control for higher acceleration, but automatically acquired as soon as the acceleration decreases
Acquisition time	sec	5	Time to acquire the proof-mass at the center of the cage after switch ON.
Operating temperature	°C	-40°C / +85°C	
Operating temperature stability	°C/h	0.6	During measurement period (1 day)
Readout time	msec	No	

Thermal Control			
Total surface area	cm^2	1248	But only 624 cm^2 need accurate thermal control (accelerometer subsystem)
Non-isolated area	W		
Operating temperature	°C	-40°C / +85°C	
Operating temperature stability	°C/h	0.6	During measurement period (1 day) on
Physical			
Preferred location	N/A	s/c COM	See §7.1.4.2 for impact of decentring
Mass, total	kg	3	
Power			
Total average power	W	3	
Detector + electronics	W	2.8	
TE cooler	W	-	
Data Rate & Volume			
Data volume	Gbyte	0.56	Assuming 10 years, 52 days/yr
Data rate (instantaneous)	kbyte/s	0.0125	
Compression factor	#	N/A	

7.1.12 SUMMARY OF ALIGNMENT AND POINTING REQUIREMENTS

See 7.1.4.2

8 TRL LEVELS



Level	Description
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof-of concept
4	Component and/or breadboard validation in laboratory environment
5	Component and/or breadboard validation in relevant environment
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
7	System prototype demonstration in a space environment
8	Actual system completed and "flight qualified" through test and demonstration (ground or space)
9	Actual system "flight proven" through successful mission operations

9 RELEVANT TECHNOLOGY DEVELOPMENT ACTIVITIES

This section gives a list of all the technology developments related to the instruments. In the next update of the PDD expected in the Summer of 2009 more relevant technology development activities will be described.

An activity relevant to the Subsurface Radar has been defined in which a deployable dipole antenna of 10 meters in total length will be developed being able to operate in the Jovian environment.

HILDRA: Demonstration of the deployment of a highly integrated low power ice penetrating radar antenna