JUICE - JUpiter ICy moons Explorer
GIPER Ganymede Ice PEnetrating Radar
Part I: Instrument Scientific and Technical Plan

Instrument Consortia

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Prepared by:	**GIPER team**
Reference no.:	**GIPER-ScTch-01**
Revision:	**1**
Date of Issue:	**December 16, 2012**
Status:	**Draft**

Acronyms

AO: Announcement of Opportunity
EID-A: Experiment Interface Document - Part A
EGSE: Electronic Ground Support Equipment
EM: Engineering Model
FS: Flight Spare
GIPER: Ganymede Ice PEnetrating Radar
JUICE: JUpiter ICy moons Explorer
LEO: Letter of Endorsement
LFA: Lead Funding Agency
MOC: Mission Operations Centre
PFM: Proto-Flight Model
PI: Principal Investigator
SciRD: Science Requirements Document
SHARAD: Mars SHAllow RADar sounder
SOC: Science Operations Centre
STM: Structural and Thermal Model

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Document Change Record

Table 1 – *Document Change Record for GIPER Ganymede Ice PEnetrating Radar, Part I: Instrument Scientific and Technical Plan*

Doc. reference	Change date	Change Description
GIPER-ScTch-01	December 16, 2012	1st release

Contents

1. Introduction

The GIPER instrument consortium answer to the ESA Announcement of Opportunity (AO)[1] for the L1 class JUpiter ICy moons Explorer (JUICE) mission.

1.1. **JUICE Mission Overview.** ESA L1 mission selected May 2012 in Cosmic Vision programme. Expected launch date 2022. 7.5 year cruise to Jupiter. Orbit insertion 2030 around Jupiter including phase studies of Europa and Callisto. September 2032 orbit insertion around Ganymede. Nominal mission end 2033. Russian Ganymede lander.

2. Scientific Objectives

The scientific outcome of this instrument proposal is in accordance with ESA Science Requirements Document (SciRD)[2] and addresses many of the scientific investigations proposed in the ESA JUICE Assessment Study Report[3].

2.1. **Introduction .** Ganymede is the largest moon in the Jovian System and one of the four Galilean moon. It was discovered in 1610 by Galileo Galilei. With a mean radius of 2634 km Ganymede is the largest moon in the Solar System and even larger than the planet Mercury. It travels around Jupiter in an orbit with a semi-major axis of 1070400 km and an eccentricity of 0.00013. It is therefore the third of the Galilean moons[4].

It is believed that Ganymede consists mainly of 3 layers which are fully differentiated. The core consists of a hot iron alloy which is responsible for generating the intrinsic magnetic field. The second layer is made of heavier rocky material and the third layer consists mainly of water ice. The icy surface is expected to be around 800 km thick. On the boundary between the icy and the rocky layer large oceans of liquid water may be present[5].

2.1.1. *The surface composition of Ganymede.* The main understanding of the surface composition and the underlying processes of forming of Ganymede originates from the Galileo mission from 1989 to 2003 and partly from the flybys of Voyager 1 and 2. The objective of the Galileo mission was to investigate the Jupiter system. Therefore most instruments were focusing on imaging, measuring particles and fields and no subsurface measuring instrument was available. An image of the Ganymede surface taken from the Galileo orbiter is show in figure 1. It consists mainly of water ice and is basically separated into regions with a low albedo, often referred to as dark terrain, which covers about 34 % of the surface and regions of high albedo, named bright terrain respectively, which covers 66 %[5]. The boundaries between dark and bright terrain are mostly sharp and distinct. The dark terrain is covered with a much higher amount of impact craters. It is therefore believed to be much older than the bright terrain which could be as young as 1 billion years[6]. Stereo images suggests that the dark furrow terrain is generally higher than the grooved bright terrain. This leads to the idea that bright terrain has probably formed by tectonic processes of the (former) dark terrain together with transport processes of snow or water to the surface like cryo-volcanism (see also section 2.1.2) thereby smoothing the surface. Impact craters of meteoroids therefore show up as bright white spots on the white terrain[7, 8, 5, 9, 6].

2.1.2. *Formation of the surface and sub-surface processes.* The processes causing the formation of the bright terrain from the ancient dark terrain are believed to be tectonics and cryo-volcanism although they are still not fully understood and part of active discussions[6, 7, 8]. Most models need a heat source strong enough to (partly) melt sub-surface layers. The current orbital parameters of Ganymede would not be sufficient to produce enough heat by tidal forces, orbital calculations suggest that Ganymede had a period where the eccentricity of its orbit reached as high as 0.03[9] which would cause enough tidal heating

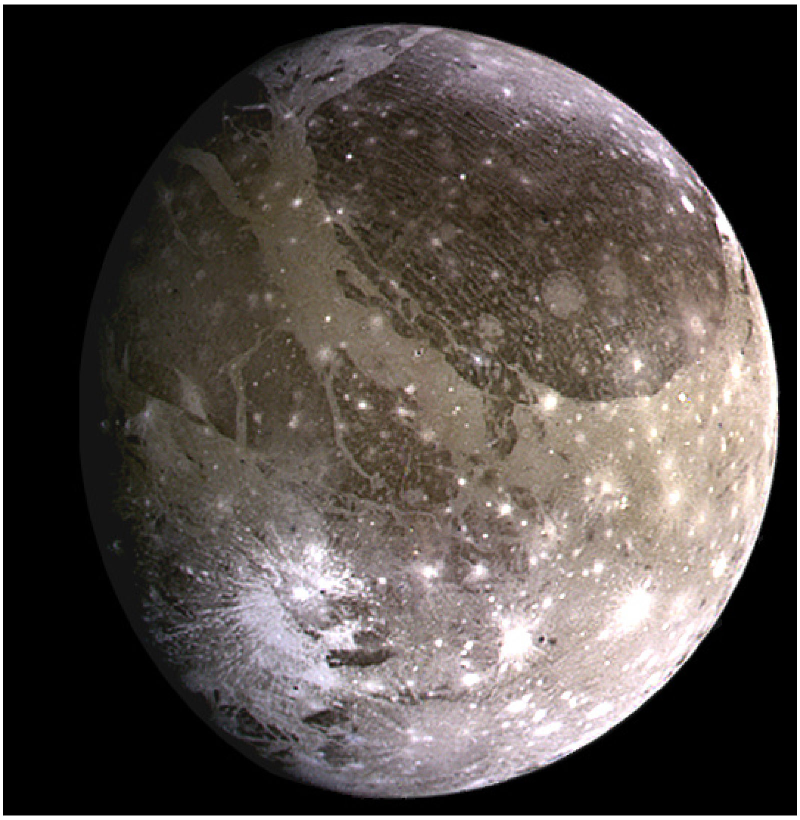

Figure 1 – *True color image of Ganymede's surface taken by the Galileo spacecraft.*

to melt parts of the icy interior up to an extend where the moon extends up to 1 % causing major tectonic movements and the formation of grabens[6].

Another unknown problem is the transport of the then (partly) molten ice or slush to the surface in order to fill graben. One proposition is that icy „volcanoes“ ejected low-viscous liquid water which then flooded the graben before freezing. So far no strong evidences for this volcanism like ejection centers or downstream patterns on the horsts have been found[8]. This may be because the resolution of the images obtained by the Galileo and Voyager missions do not have a high enough resolution, the areas for which high resolution pictures are available do not have pronounced enough evidences or there are just not existent[8, 7, 6]. Another problem is that water or slush have a higher density than ice, thus if tidal heating would melt ice, the water or slush would sink deeper instead of rising to the top.

An approach to solve this issue proposed by Showman and Mosqueira would also explain why there is no ice on top on the horsts and the lack of flooding tracks is that tectonics resurfaced the dark terrain to contain horsts and grabens. These apply different pressure to the underlying terrain. These pressure gradients could actually lead to the circumstance that material with a negative buoyancy like water or slush could move upwards but only below the grabens. When the graben are filled with ice, the process automatically stops because the necessary pressure imbalance from the terrain disappears hence no ice could reach the high horsts[6].

In figure 2 an example calculation for the gradients due to terrain imbalance is presented. The terrain was modeled as a sine wave with 30 km wavelength and an amplitude of 1 km (2 km peak-to-peak) as shown in the top graphic of figure 2. The vector plot in the middle shows the resulting pressure gradients. As can be seen underneath the graben they are directed upwards but decrease exponentially with depth. The lower vector plot

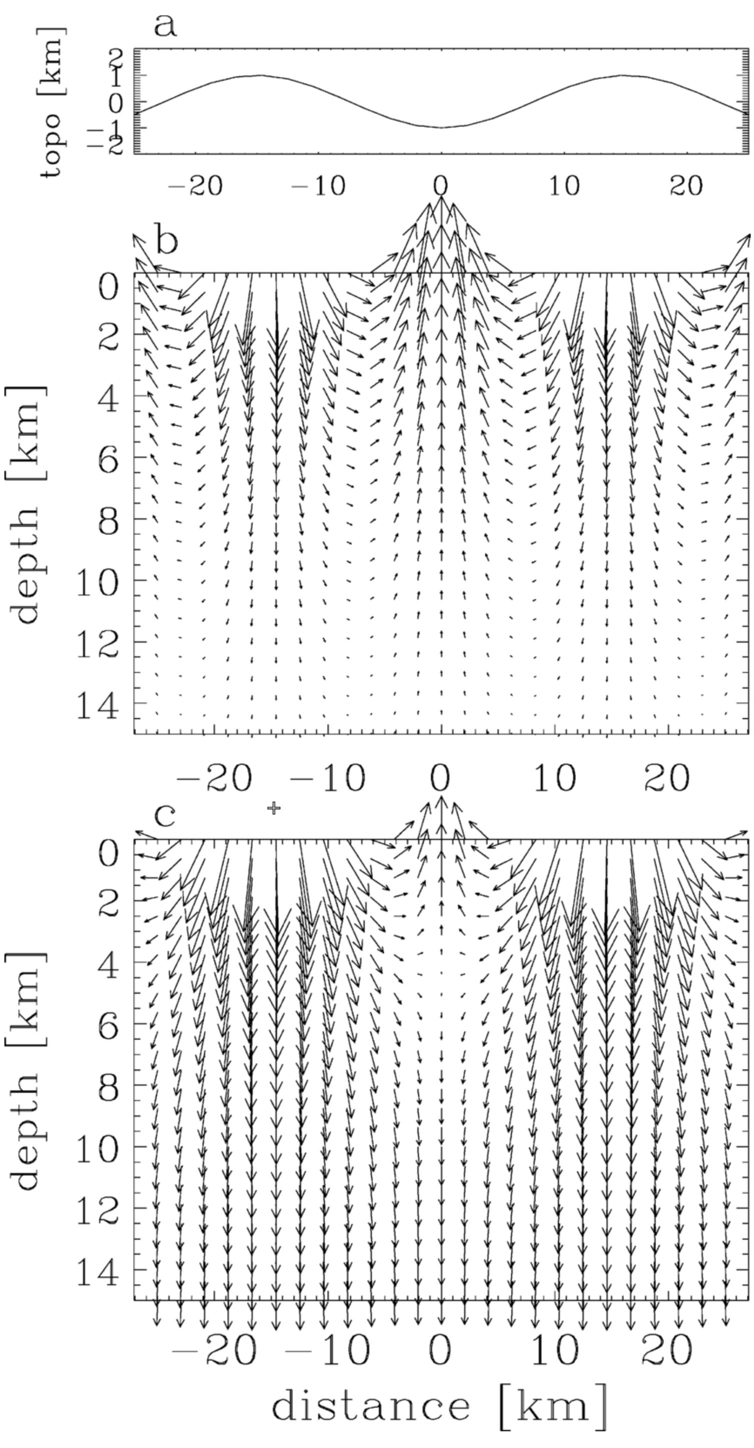

Figure 2 – *Example calculation for **(a)** a sinusodial terrain with an amplitude of 1 km and a wavelength of 30 km. The **(b)** pressure gradient from the tectonic imbalance can compensate the negative byuoancy of water in lower surface areas up to 5 km **(c)**. Figure taken from [6]*

shows the resulting gradients when considering water with a negative buoyancy. As can be seen water could only move up to the surface when it is created in a depth below 5 km. Further calculations performed by Showman, Mosqueira et al. estimate that depth from where water or slush can rise to the surface ranges from 5 km to 10 km. A possible problem with this model may be that is would need at lease 1 million years to transport enough water to the surface in order to fill grabens, but the graben could relax gravitationally earlier and thus stop the upward flow[6].

In order to find the dominant processes for the resurfacing of Ganymede's dark terrain it would be essential to acquire measurements from the subsurface interior additionally to (new) surface pictures. Ganymede can be seen as a prototype for an icy body. Therefore investigating the tectonic processes of Ganymede and its surface evolution will not only provide more information about the formation of Ganymede but also of its siblings Europa and Callisto as well as icy bodies in general [5].

2.2. **Scientific Goals.** Based on the short scientific introduction of Ganymede from section 2.1 the following scientific goals can be identified:

- Map the interior below the surface of Ganymede to get more insight about different layers and their composition.
- Find evidences for the tectonic processes which created the horsts and grabens of the grooved terrain
- Find out how did the dark and bright terrain evolve over time.
- Find evidences for or against different cryo-volcanism scenarios
- Get a more detailed map of the surface terrain compared to stereoscopic imaging
- Possibility to find habitable zones

2.3. **Scientific Performance Requirements.** In order to achieve the goals described in section 2.2 the instrument should be able to penetrate the surface to at least 5 km. Attenuation of radar waves in the lower MHz spectrum in ice is quite small which is beneficial for a high penetration depth, but although it is quite certain that the upper surface mainly consists of water ice there might be significant amounts of rocky material at some parts due to the many meteoroid impacts after the accretion phase of Ganymede. Therefore an appropriate margin for the penetration depths should be considered.

The vertical resolution should be in the range of 10 m – 35 m to give the chance to resolve the position and offset of the identified layers with high accuracy. A typical width for the groves of the terrain is 10 km, thus the horizontal resolution should not exceed this value in order to correlate different vertical layers to the surface terrain.

As the goal is to create a map of the whole surface of Ganymede it is expected that even after preprocessing and compression a large amount of data will be collected. An appropriate downlink capacity should be reserved for the mission.

3. Technical Description and Design

The proposed instrument has been designed in accordance to ESA Experiment Interface Document - Part A (EID-A) for the JUICE mission[10].

3.1. **Design Overview.**

3.2. **Instrument Design Elements.**

3.3. **Technical Resources.**

3.4. **Instrument Spacecraft Requirements.** This mission assumes that an altimeter instrument is included in the JUICE mission scientific instrument package. Altimeter is needed to estimate the surface clutter and surface slope. The instrument consortia will provide an Instrument Operation Manual.

4. Summary of Instrument Interfaces

5. On-ground and In-flight Test and Calibration

Functional, EMC, Thermal-Vacuum, Vibration. For Electronic Ground Support Equipment (EGSE) a Ganymede Ice PEnetrating Radar (GIPER) raw signal simulator will be developed by the instrument consortia. The raw signal simulator will be similar to the one developed for the Mars SHAllow RADar sounder (SHARAD) instrument[11] and allow testing of the signal processing chain and to develop a Ganymede transfer function considering the orbit altitude and surface clutter and sub-surface dielectric interfaces. A set of calibration files and algorithms will be send to the JUICE Science Operations Centre (SOC) for the raw to L1b data processing.
In-flight internal calibration (transmitted signal looped to receiver and data sent to ground) In-flight external calibration (unprocessed data of reflected signals from a flat surface region of Ganymede is sent to ground)

Figure 3 – *Mars Echo Generation System used on the SHARAD instrument[12]*

6. System Level Assembly, Integration and Verification

Verification by test will be the main method of verification.

Vibration and thermal vacuum tests will be done at IRF in Kiruna. Shock tests may be performed at Chalmers University of Technology[13].

Table 2 – *Instrument testing for different instrument models*

Test	STM	EM	PFM	Facility
Mechanical Interface, Mass Inspection	-	-	-	
Electrical Performance	-	-	-	
Functional Test	-	-	-	
Strength Test	-	-	-	
Sine and Random Vibrations Test	-	-	-	
Shock Test	-	-	-	
Thermal Vacuum Test	-	-	-	
EMC Conducted and Radiated	-	-	-	
DC Magnetic Test	-	-	-	

6.1. Requirements.

6.2. Deliverable Models.

In appliance with EIDA-R005590[10], three instrument models will be developed:

- Structural and Thermal Model (STM) - For testing of the instrument structural and thermal interface to the spacecraft

- Engineering Model (EM) - To test and verify the instruments functional and technical requirements as well as the instrument performance. If required, this unit will be refurbished as an Flight Spare (FS).

- Proto-Flight Model (PFM) - will be build using full flight standard components and tested for qualification and acceptance levels.

6.3. **System Level Testing.**

7. Flight Operations Concept

The instrument modes are inherited from the SHARAD instrument[14].

7.1. **Nominal Operations.** Operation modes: Low data rate, high data rate, calibration, receive only

7.2. **Other Modes.** Silent Modes: Off, Heating Support modes: Check/init, standby, warm-up, idle The instrument consortia will provide expert support to the JUICE Mission Operations Centre (MOC) and SOC during the payload commissioning phase and at critical operations.

8. Science Ground Segment Concept

ESA ESTRACK will be used as ground station network. A JUICE MOC established at ESOC and SOC at ESAC.

8.1. **Implementation concept for the Science Ground Segment.**

8.2. **Planning of payload operations.** During the ??? mission phases, the instrument consortia will submit science operations plans and perform maintenance and optimizations as required.

8.3. **On-Board Software Maintenance.**

9. Data Reduction, Scientific Analysis and Archival Plans

It is expected that housekeeping data and raw science data will be sent from the JUICE MOC, over internet, to the instrument team in LTU, Kiruna. To correctly remove surface clutter signals, it is required to simultaneously receive the data from the altimeter instrument. Quick-Look data analyser - to optimise efficiency and scientific return of instrument operations. L1b raw data (un-calibrated science data) analyser Data will be archived at LTU and also sent to JUICE science data archive.

10. Organization

10.1. **Management Structure.** (Please note, some of the contents in this section are fictive and should not be taken literally.)

Jan Sommer is the instrument Principal Investigator (PI). He has an extensive background studying planet geology, especially on Mars. This study will enhance our knowledge of planet inner structures, geology and provide better understanding of planet formations and evolution.

Morten Olsen is the project manager. With experience as project manager for previous successful space instruments, he will manage the project schedules and budgets.

Omair Sarwar is the technical manager. With extended engineering experience in radar systems, he will ensure that the instrument meets the performance requirements, proper instrument verification and qualification in accordance with ESA space standards.

10.2. **Budget.** ACME Space Agency is the Lead Funding Agency (LFA) for this instrument proposal. A Letter of Endorsement (LEO) has been issued ensuring funding for the project during the instrument development phase, in-flight operations and post operations activities.

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Appendix A. Some Appendix