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

Instrument Consortia

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Lead Funding Agency

Acme Space Agency

`http://home.roadrunner.com/~tuco/looney/acme.html`

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Acronyms

AO: Announcement of Opportunity
EID-A: Experiment Interface Document - Part A
EGSE: Electronic Ground Support Equipment
EM: Engineering Model
EMC: Electro-Magnetic Compatibility
ESA: European Space Agency
FS: Flight Spare
GIPER: Ganymede Ice PEnetrating Radar
IPR: Ice Penetrating Rader
IRF: Swedish Institute for Space Physics
JUICE: JUpiter ICy moons Explorer
LOE: Letter Of Endorsement
LFA: Lead Funding Agency
MOC: Mission Operations Centre
PFM: Proto-Flight Model
PI: Principal Investigator
QM: Qualification Model
SciRD: Science Requirements Document
SHARAD: Mars SHAllow RADar sounder
SMM: Structural and Mathematical Model
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

This is an answer to the European Space Agency (ESA) Announcement of Opportunity (AO)[1] for the JUpiter ICy moons Explorer (JUICE) mission. An Ice Penetrating Rader (IPR) is part of the Model payload suggested by ESA[2]. This document will show that the Ganymede Ice PEnetrating Radar (GIPER) instrument will be able to provide high profile scientific investigations that are within the scientific and technical requirements of the JUICE mission.

1.1. **JUICE Mission Overview.** The JUICE mission is an ESA L1 class science mission selected in May 2012 as part of the ESA "Cosmic Vision" programme. The JUICE mission originated from a reformulation of the EJSM-Laplace mission into a European-led mission. The mission is scheduled for a launch in 2022 and will arrive at Jupiter in 2030 where it will be inserted into a Jupiter orbit. It will the include numerous flybys of Callisto, two Europa flybys, insertion into circular Ganymede orbits of three different altitudes and eventually de-orbit onto the Ganymede surface.

2. Scientific Objectives

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

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.

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.

2.1.1. *The surface composition of Ganymede.* The main understanding of the surface composition and the underlying processes of forming Ganymede originates from the Galileo mission from 1989 to 2003. 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 35 % of the surface and regions of high albedo, named bright terrain respectively, which covers 65 %. The boundaries between dark and bright terrain are 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. 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.

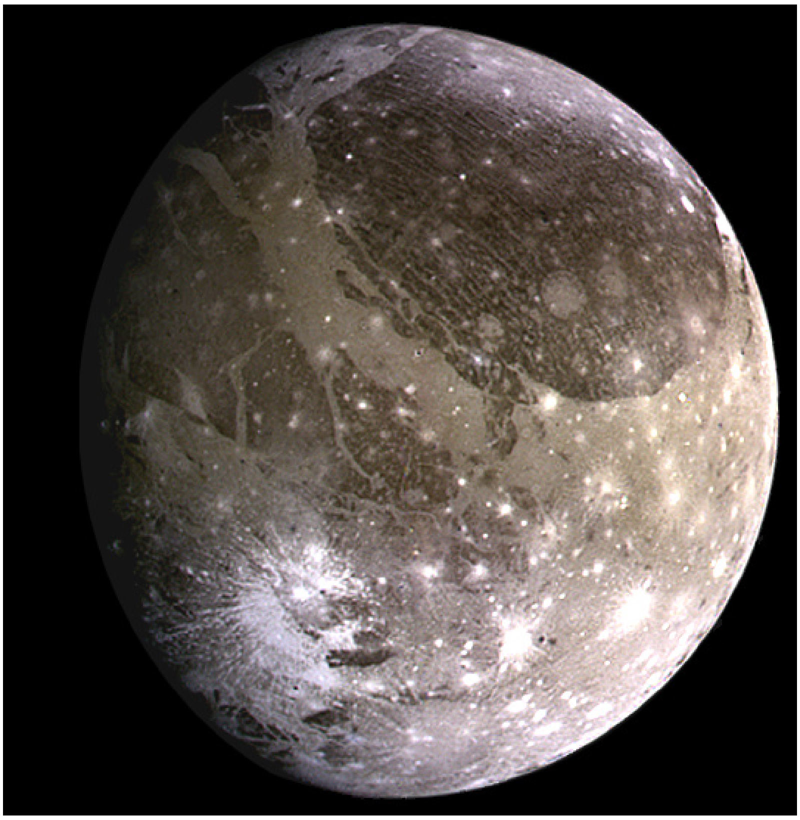

Figure 1

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. 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 which would cause enough tidal heating to melt parts of the icy interior.

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 downstream patterns on the horsts or ejection centers. 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. 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 which 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.

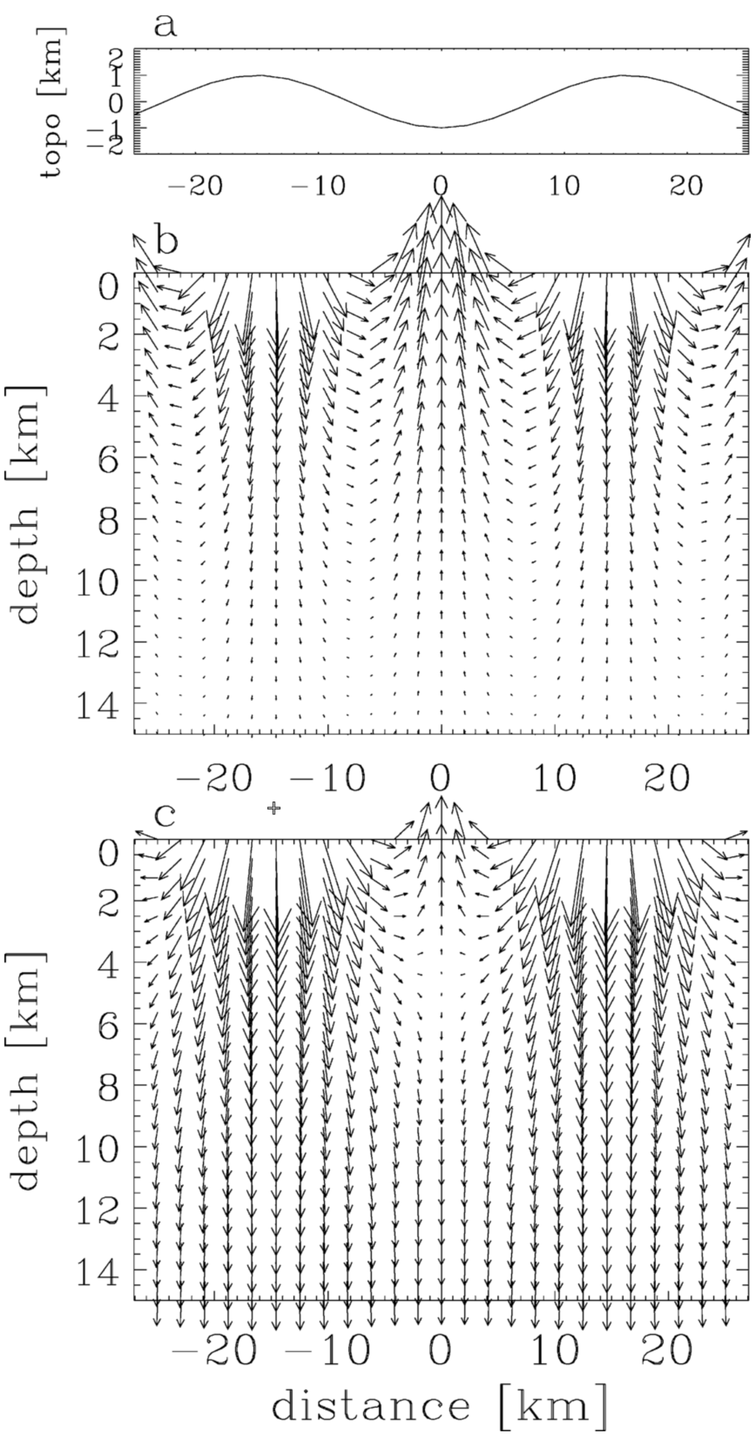

Figure 2

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 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.

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 .

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 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
- yada yada yada

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[4].

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

The GIPER instrument will undergo a series of development and qualification tests to ensure that the instrument functions correctly and that it will achieve its scientific objectives. The required test facilities include Electro-Magnetic Compatibility (EMC) lab, RF lab, Thermal-Vacuum chamber, vibration and shock testing and a GIPER raw signal simulator. Some test facilities are available within the instrument consortium, some will by provided by the Swedish space industry and consortium partners. The instrument will require tests at ESA's **RF!** (**RF!**) labs for testing of the GIPER antenna radiation characteristics. A complete instrument test overview is shown in Table 2.

5.1. **EGSE.** A GIPER raw signal simulator will be developed by the instrument consortia. This raw signal simulator will be similar to the one developed for the Mars SHAllow RADar sounder (SHARAD) instrument[5] as shown in Figure 3 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. After launch of the JUICE satellite, the GIPER Electronic Ground Support Equipment (EGSE) will be located at the JUICE Mission Operations Centre (MOC). A set of calibration files and algorithms will also be send to the JUICE Science Operations Centre (SOC) for processing of the raw instrument data into L1b data.

5.2. **In-Flight Calibration.** As was done for the SHARAD instrument[7], two types of in-flight calibrations are planned. An internal calibration is performed by directly looping a transmitted signal to the receiver and sending the raw unprocessed data to ground. An external calibration is performed by transmitting signals onto a flat surface region of Ganymede, receiving the echo and sending the unprocessed data to ground.

Figure 3 – *Mars Echo Generation System used on the SHARAD instrument[6]*

6. System Level Assembly, Integration and Verification

Verification by testing will be the main method of verification for the GIPER instrument. Other means of verification will be by analyses and mathematical models.

6.1. **Requirements.** Of special concern to the GIPER instrument performance and degradation is the intense radiation of high energy electrons which may affect the instrument electronics and the Heavy Ion Non-Ionsing Dose which might degrade the antenna surface material. Testing and verification must ensure that the instrument will meet is full operational performance when it enters its primary scientific operation phase at the spacecraft Ganymede orbit insertion ten years after launch.

6.2. **Deliverable Models.** Three instrument models will be delivered to ESA:

- Structural and Thermal Model (STM) - For testing of the instrument structural and thermal interface to the spacecraft
- Engineering Model (EM) - To test and verify that the instrument meets the functional and technical requirements.

- Proto-Flight Model (PFM) - will be build using full flight standard components and tested at qualification levels and at acceptance durations. This will ensure that the specified instrument performance is met in accordance to the space environment found around Jupiter.

Before building of the PFM is initiated, a dedicated Qualification Model (QM) will be build and tested at qualification level. This unit can then later be refurbished as a Flight Spare (FS) in case this deems necessary.

6.3. **System Level Testing.** Table 2 shown the test plan for each instrument model and the applied testing levels.

Table 2 – *Instrument test levels for different instrument models (D=Development, Q=Qualification, P=Proto-flight)*

Test	STM	EM	QM	PFM	Facility
Mechanical Interface, Inspection, Alignment	-	-	-	P	LTU Rymdcampus
Mechanisms lifetime testing	Q	-	-	-	Swedish Institute for Space Physics (IRF)
Functional and Performance Test	-	D	Q	P	IRF
Sine and Random Vibrations Test	Q	-	-	P	IRF
Shock Test	Q	-	-	P	Chalmers University of Technology[8]
Thermal Vacuum Test	-	D	Q	P	IRF
EMC Conducted/Susceptibility	-	D	-	P	
RF Test	-	-	Q	-	ESA ESTEC
DC Magnetic Test	-	D	Q	P	IRF

7. Flight Operations Concept

The instrument modes are inherited from the SHARAD instrument[7].

7.1. **Nominal Operations.** Four nominal operation modes are defined:

- Low data rate
- High data rate
- Calibration
- Receive only

7.2. **Other Modes.** Two silent modes are defined:

- Off - all equipments turned off
- Heating - only heaters are powered on

Additionally, four support modes are defined:

- Check/init
- Standby
- Warm-up
- Idle

The instrument consortia will provide expert support to the JUICE MOC and SOC during the GIPER instrument 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 science data will be sent from the JUICE MOC, via internet, to the instrument team in LTU, Kiruna. Here data will be reduced, archived and distributed to other science teams including the JUICE science data archive. To correctly remove surface clutter signals, it is required to have simultaneously data from the altimeter instrument. A Quick-Look data analyser software will be developed, to optimise efficiency and scientific return of instrument operations. A software tool to analyse L1b raw data values (un-calibrated science data) will also be developed.

10. Organization

The GIPER instrument consortium team is led by three SpaceMaster students from round 7. LTU and IRF are supporting institutions.

10.1. Management Structure. Jan Sommer is the instrument Principal Investigator (PI). With a background in Physics and numerous courses and Space Science, he has a strong knowledge a Planetary Sciences and understanding of the underlying physics which will ensure that the GIPER instrument will meet the scientific requirements.

Morten Olsen is the project manager. With experience as project manager for previous space projects including CanSat and U-SPACE, he will manage the GIPER project to ensure that deliverables are ready on schedule and within budget.

Omair Sarwar is the technical manager. With a background in Aeronautical Engineering, experience with telecommunication systems and having studied radar courses, he will ensure that the GIPER 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 (LOE) has been issued ensuring funding for the project during the instrument development phase, in-flight operations and post operations activities.

References

[1] *Announcement of Opportunity for the JUICE Payload.* ESA/SRE(2012)4. 2012.

[2] *JUICE Exploring the emergence of habitable worlds around gas giants, Assessment Study Report.* ESA/SRE(2011)18. 2011.

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[5] A. Giovanni and S. Giuseppe. "Raw signal simulator for SHARAD". In: *Remote Sensing in Transition.* European Association of Remote Sensing Laboratories. 2004.

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Appendix A. Some Appendix