The Ganymede Laser Altimeter (GALA) on ESA's JUICE mission: Overview of the instrument design.

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Introduction: In 2012 the Jupiter Icy Moons Explorer (JUICE) has been selected as ESA's next L-class mission in the framework of the Cosmic Vision Program. JUICE is scheduled for launch in 2022 and it will arrive at Jupiter by the end of 2029. After several years in Jupiter-orbit investigating the giant planet and its magnetosphere as well as the Galilean Moons, the spacecraft will finally go in orbit around Ganymede, the largest satellite in the solar system. The Ganymede Laser Altimeter (GALA) is one of 11 instruments selected by ESA for the JUICE mission payload [1]. GALA will focus on geodetic and geophysical investigations of the icy satellites Europa, Callisto and, in particular, Ganymede.

The GALA science case: The icy moons of Jupiter – Europa, Ganymede, and Callisto – are believed to contain global subsurface water oceans underneath their icy crusts [2]. GALA is one of the instruments focusing on aspects related to the presence and characterization of subsurface water oceans by measuring Ganymede's tidal deformation. GALA will contribute to the exploration of the surface morphology and physical properties of Ganymede, Europa and Callisto, to the determination of their interior structures from a combination of shape, topography and gravitational field data, to the exploration of the satellites' physical surface properties, and to their formation and evolution especially with respect to subsurface water oceans.

By measuring the time-of-flight of a laser pulse transmitted from the instrument, backscattered at the moon's surface, and detected in the instrument's receiver telescope, height profiles can be obtained in along-track direction. Combining many of these tracks, the local, regional, and global topography of Ganymede can be obtained (Fig.1). From the pulse-spreading of the returned pulse the surface roughness on the scale of the laser footprint (order of a few tens of meters depending on S/C altitude) can be obtained. Additionally, information on the albedo at the laser wavelength (1064 nm) can be gained from the intensities of the transmitted and returned pulses.

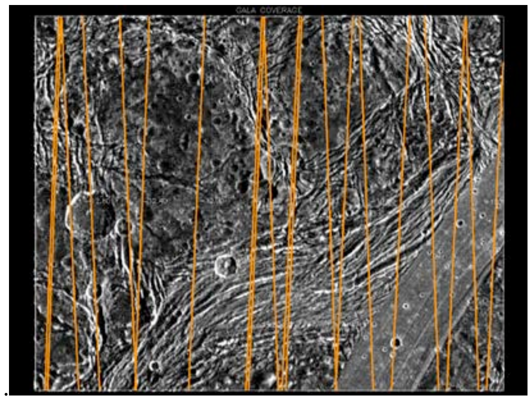

Figure 1: GALA ground-tracks across different geological units on Ganymede (Nicholson Regio: LAT=(-16°,-13.5°); LON=(-13.2°,-10°)).

By obtaining not only good spatial coverage but also temporal coverage with laser ground-tracks the tidal deformation of Ganymede's ice shell along the satellite's orbit around Jupiter will be measured. From the tidal signal (expressed in terms of the radial tidal Love number h_2), the presence of an ocean can be verified. While the tidal signal is expected to be on the order of several meters in case of a subsurface ocean (Fig. 2), without an ocean, the amplitude will be a few tens of centimeters only. To realize measurements of the tidal response, intersecting ground-tracks are analysed at different tidal phases. For the given performance model including statistical analyses of the expected surface slopes, errors of spacecraft orbit and pointing knowledge as well as the internal error budget of the instrument and operational constraints from the JUICE mission, a relative accuracy of the order of 1% is obtained for h_2. From h_2, the extension of Ganymede's ice shell can be constrained, especially when combined with measurements of the tidal potential by the radio science experiment (3GM). Global topography up to degree and order 20 to 44 (depending on operation scenario) will be obtained at Ganymede. This corresponds to grid sizes between 2° (degree 44) and 4.3°(degree 20). Due to the polar orbit, regional and local coverage will be best at high latitudes. Gaps in equatorial regions could be filled by targeted observations with off-nadir angles of a few degrees.

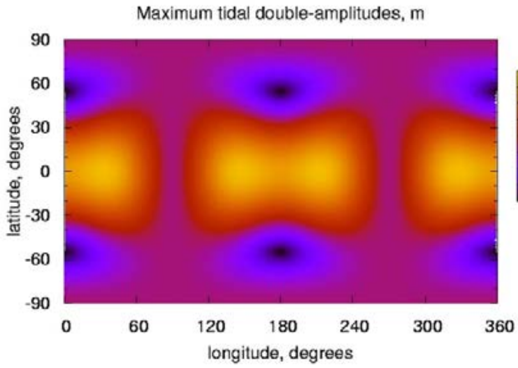

Figure 2: Expected pattern of maximum tidal amplitudes on Ganymede's surface.

During flybys GALA will acquire data at closest approaches at Europa and Callisto. These data will mainly be used for geological characterization of surface features in combination with imaging and subsurface radar data and for constraining the global shape of the satellites.
The instrument can be operated from ranges smaller than about 1000 to 1300 km (depending on the different albedo values of Europa, Ganymede and Callisto) during flybys and orbital pericenter passages. The main phase for acquiring data at Ganymede is the final circular orbit phase with an altitude of 500 km, where continuous operation is possible.

Instrument Performance: GALA uses the "direct-detection" (classical) approach of laser altimetry. Laser pulses are emitted at a wavelength of 1064 nm by using an actively Q-switched Nd:Yag laser. The pulse energy and pulse repetition frequency is set to 25 mJ at 30 Hz. The emission time of each pulse is measured by the detector inside the receiver. The beam is reflected from the surface of the moon (surface spot size = 20 to 50 m) and received at a 25 cm diameter F/1 telescope. The returning laser pulse is refocused onto a silicon avalanche photodiode (APD) through back-end optics including a narrow bandpass interference filter for isolating the 1064 nm wavelength. The APD-signal is then amplified, sampled and fed to a digital range finder. The minimum acceptable SNR is approx. 1.2. This system determines the time of flight (and therefore range), the integrated pulse intensity, its width and full shape. The data is passed to a digital processing unit which controls the operation of the complete instrument and communicates with the spacecraft. GALA will provide <1 ns time resolution (<15 cm range, <8 cm under optimal conditions). Fig. 3 depicts the described working principle. In the Ganymede orbit phases, samples will be acquired without gap along-track on ground-tracks separated by a few kilometers on average (better coverage at the high latitudes in the near-polar orbit). The experiment will provide return pulse intensity and wave-form analysis allowing an assessment of surface albedo and surface roughness at tens of meters scale – a remote sensing capability not depending on sunlight.

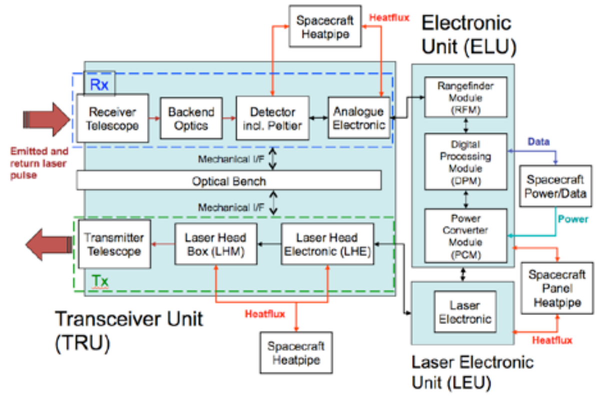

Figure 3: GALA block diagram

The electron-dominated radiation environment in the Jovian system is very demanding and has a strong impact on selection of parts and materials for the instrument.
The GALA consortium responsible for hardware development consists of institutes and industry from Germany, Japan, Switzerland and Spain.

Instrument Design: The GALA instrument consist of three units which incorporate several sub-assemblies in order to provide the measurement data (see Fig.4):
The *Transceiver Unit* (TRU) houses the laser optics (Laser Head Module, LHM) and the appropriate electronics (Laser Head Electronics, LHE). The laser emits the laser pulse through the collimating transmitter telescope. The return laser pulse is received by the receiver telescope and focused on the detector by the backend optics. The analogue electronics pre-amplifies the detector output before it is directed to the Range Finder Module inside the Electronic Unit.
The *Electronic Unit* (ELU) houses the digital Rangefinder Module (RFM), which analyzes detector signal and computes range, surface slope and roughness etc. The Digital Processing Module (DPM) is the 'main computer' of the instrument and controls all instrument functions as well the interface to the spacecraft. The Power Converter Module (PCM) provides power in different voltages for all instrument sub-assemblies.
The *Laser Electronic Unit* (LEU) contains the laser control electronics for powering and controlling the laser incl. capacitors, high voltage supply, power driver for the laser pump diodes etc.

The mechanical design of the TRU focuses on opto-mechanical stability and mitigation of the radiation environment. The stiff optical bench in the center of the unit guarantees the opto-mechanical stability.

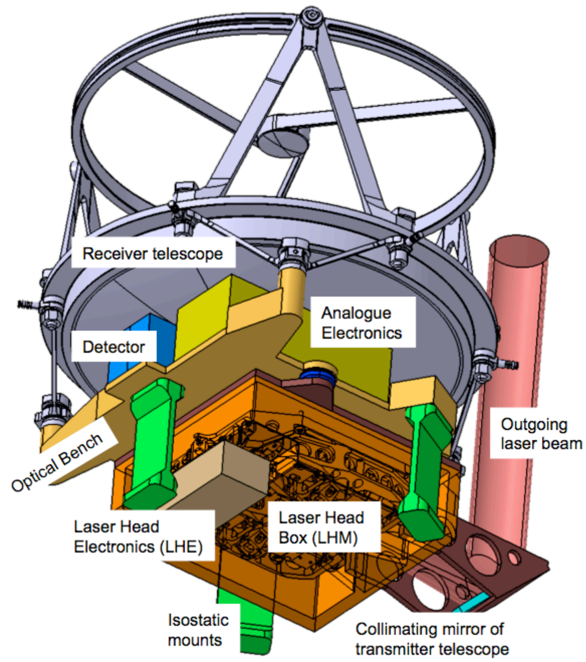

Figure 4: Preliminary Design of the Transceiver Unit (TRU)

The stacking of receiver, optical bench and laser optimizes the surface-to-volume ratio of the TRU, which is very beneficial for radiation mitigation. The housings of all sub-assemblies of the TRU have variable wall thicknesses and materials depending on their allocation on the TRU. The telescope e.g. shields the whole unit from one side, which leads to small wall thicknesses for other subassemblies pointing in that direction.

The laser sub-assembly with a large volume is allocated below telescope and optical bench and requires therefore only a thin shielding. Receiver sub-assemblies with small volumes are located between telescope and optical bench.

The TRU will be isostatically mounted on the S/C panel. The thermal interfaces are mainly flexible thermal straps connected to the S/C heat pipes.

The design of the *Electronics Unit* (ELU) (Fig.5) is similar to design of the electronics unit of BELA, the BepiColombo Laser Altimeter. The design fulfills all electrical, thermal and mechanical requirements for GALA. The five modules (RFM, main & redundant DPM, main & redundant PCM) are mounted in frames, which are mated together to form the ELU

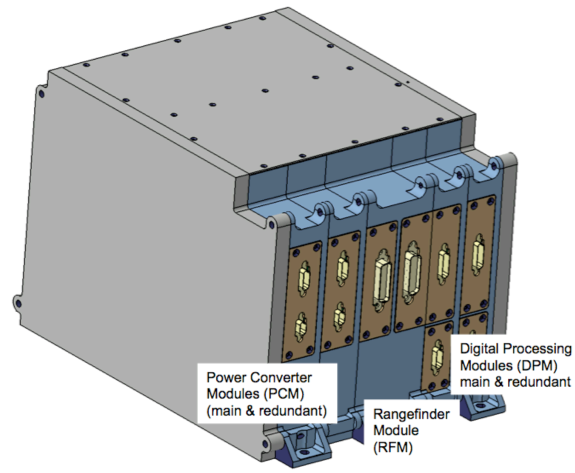

Figure 5: Preliminary design of the Electronics Unit (ELU)

References:

[1]: Grasset, O. et al. (2013) JUpiter ICy moons Explorer (JUICE): an ESA mission to orbit Ganymede and to characterise the Jupiter system. Planet. Space Sci. 78, 1 – 21.

[2] Hussmann, H., C. Sotin, and J.I. Lunine (2007) Interiors and Evolution of Icy Satellites. Schubert, G. (ed.) Treatise on Geophysics, Vol. 10, pp. 509-540, Oxford: Elsevier Ltd.