Development of JUICE /Ganymede Laser Altimeter (GALA)

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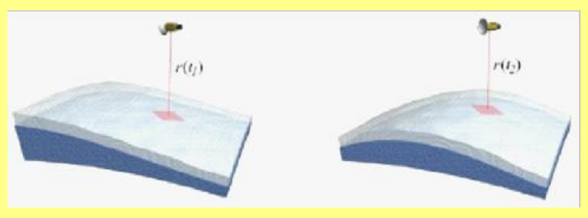
1. Overview of JUICE - 2022 Launch, 2030 Arrival at Jupiter, 2032 Orbit insertion around Ganymede -

"Is there a life elsewhere in the universe?" It is a fundamental question deeply rooted on intelligence of human beings. And a clue of this question may be found on Ganymede. For three icy satellites of Jupiter, Ganymede, Europa, and Callisto, an existence of thick liquid water layer, namely subsurface oceans under icy crust, has been implied. The evidence of ocean, however, is not widely accepted, because it depends on an inferences of electromagnetic observation and surface morphology. Looking for new evidences and clues for these important issues, a new mission to Jupiter system is planned by ESA. It is the Jupiter Icy Moon Explorer (JUICE)..

1. 1. Topographic measurement

GALA measures distance between the spacecraft and the surface of the satellite from time of flight of laser pulse. By taking positions of the spacecraft and mass center of the satellite, surface topography of the satellite is calculated from measured distances. The GALA data are particularly important for finding of internal ocean. if the ocean exists beneath icy crust, tidal deformation of the satellite is so large that temporal variation of the topography as great as several meters is expected. Thus accurate Love number will be calculated to infer internal density structure of the satellite.

Fig1.1 Principle of measuring the tidal deformation. Depending on the true anomaly of Ganymede, different heights are measured according to the tidal amplitude at different times



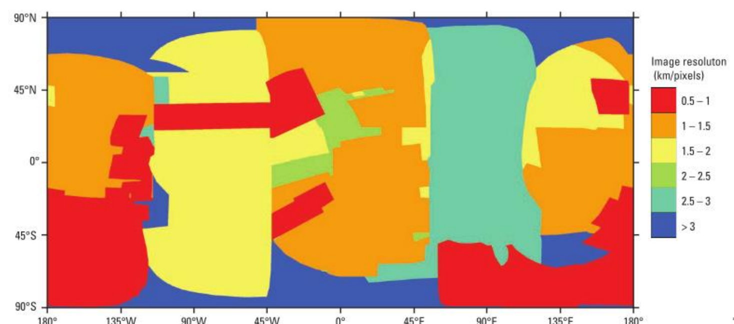
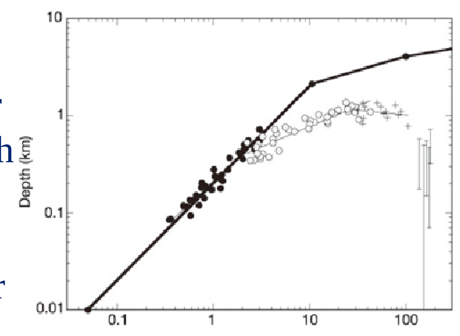


Fig 1.2 Spatial coverage and resolution of Galileo/SSI images of Ganymede (Collins+ 2013).

Fig 1.3 Depth/diameter for fresh impact craters on Ganymede. Heavy dark line lunar craters. Thin lines: least-squares fits through data (Schenk, 2002). Solid dots: simple crater, open circles: complex/central peak crater, crosses: central pit/dome craters, error bars: anomalous dome/multi-ring basins.



1.2. Scientific contributions of GALA to JUICE

(1) Global topographic data

No altimetry data for the icy moons so far and topographic database derived from stereo imaging from the Galileo & Voyager datasets is very limited. For example, GALA data can contribute to estimate global history for volume change to form tectonic features.

(2) Surface roughness and albedo

Slope & roughness (above few-m in height) information within the lase spot will affect optical pulse width. Relation between roughness and past tectonic activities would be clarified.

(3) Gravity and Love number

k_2 = 0.6 (ocean exists) and 0.06 (no ocean), changing with thickness and rigidity of the crust in the order of 0.01.

(4) Tidal deformation

Surface double amplitude will be 0.1-0.4 m (no ocean) and 5-7 m (ocean exists). Whether the ocean exists or not will be strong constraint to thermal history.

(5) Rotational state

Ice crust is decoupled from deeper mantle if the ocean exists. -Libration amplitude depends on the thickness of ice crust (15-355 m for 0-400 kg/m^3 of density difference between crust and ocean).crustal thickness 500 m-25 km).

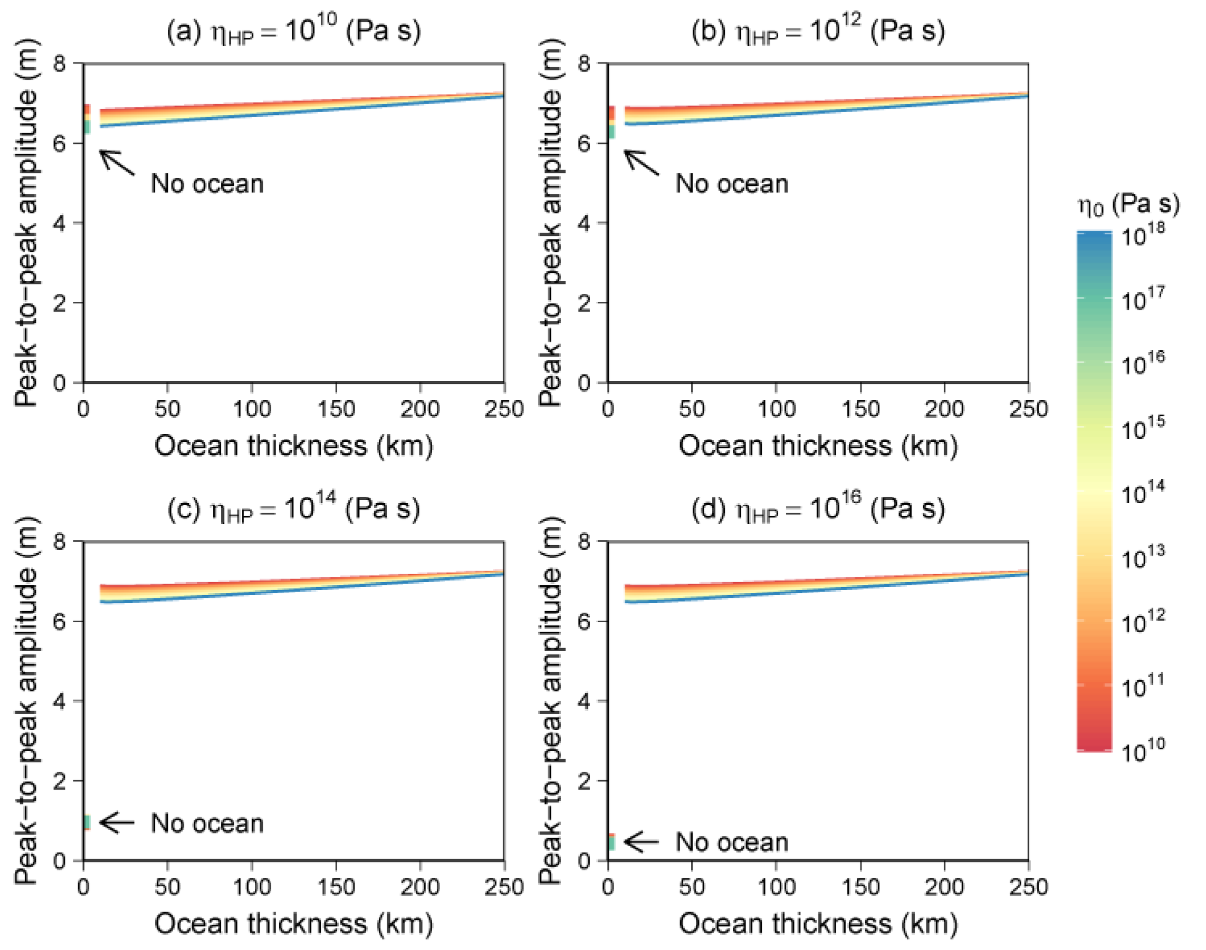


Fig 1.4 Examples of tidal deformation of Ganymede (*Kamata et al*., in prep). Constant thermal gradient, 145-kmdepth of the subsurface ocean at the mid-plane, rigidity of ice crust of 3 GPa, and rheology of pure ice are assumed. Viscosity of ice of high pressure phase, η_{HP}, is varied from 10^{10} Pa s to 10^{16} Pa s for comparison.

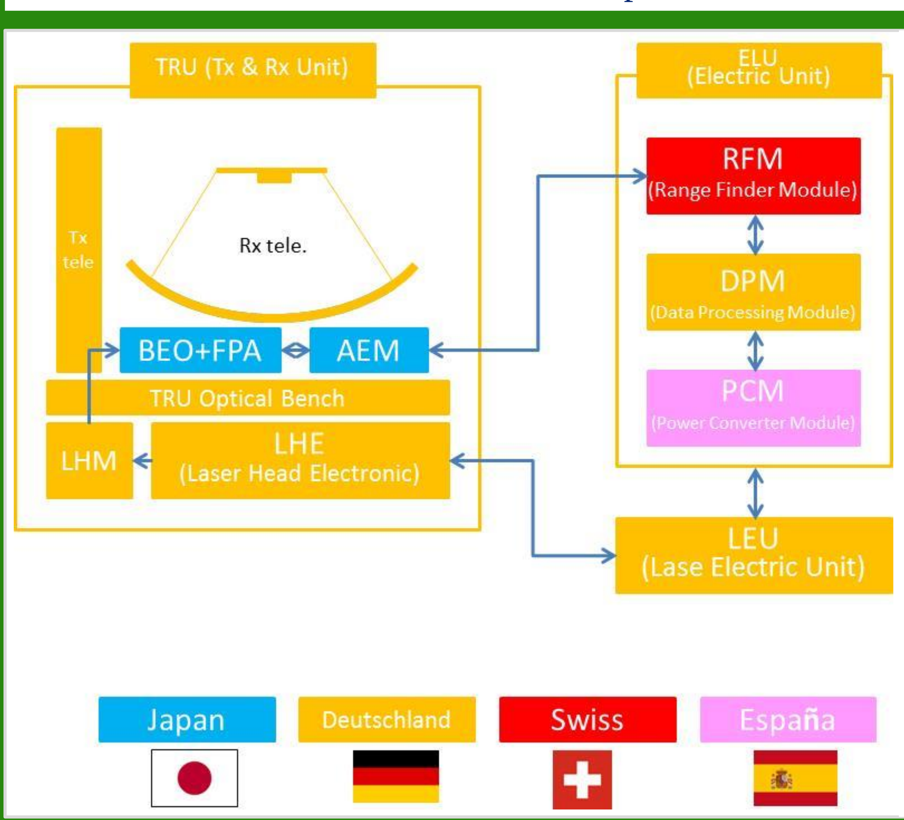


Fig 2.1 Assignment of modules among Germany, Japan, Switzerland , and Spain.

2. Performance model

GALA development is an international collaboration by Germany, Japanese, Switzerland, and Spanish teams. Modules will be manufactured respective country, and will be assembled at DLR in Germany. Scientific achievement is, of course, dependent on the integrated performance of the instrument. For the purpose to clarify requirement to each module and interface conditions between modules, we developed the performance model of GALA based on the model of BELA (*Thomas et al*., 2007; *Gunderson et al*., 2006; *Gunderson and Thomas*, 2007). The performance model quantifies the link budget, range accuracy, albedo measurement accuracy, and probability of false detection.

2.1. System requirement

Scientific requirements of GALA performance is listed in *JUICE Science Requirements Document: [AD1]*, however, necessary minimum conditions are not explicitly described in *JUICE Science Requirements Document*. Therefore the Japanese team summarized the requirements into the following five criteria.

2.1.1 For Europa fly-by, PFD is less than 0.2 from an altitude of 1300 km or lower.

2.1.2 Under the worst obs. condition of GCO500 (the lowest albedo, and the steepest surface slope), the accuracy of the ranging is less than 10 m and PFD is less than 0.2.

2.1.3 Under the nominal obs. condition of GCO500 (the average albedo, and the average surface slope), the accuracy of the ranging is less than 2 m and PFD is less than 0.1.

2.1.4 Under the best obs. condition of GCO500 (the highest albedo, and the zero surface slope), the accuracy of the ranging is less than 1 m and PFD is less than 0.1.

2.1.5 Requirement of albedo and roughness obs. is not specified.

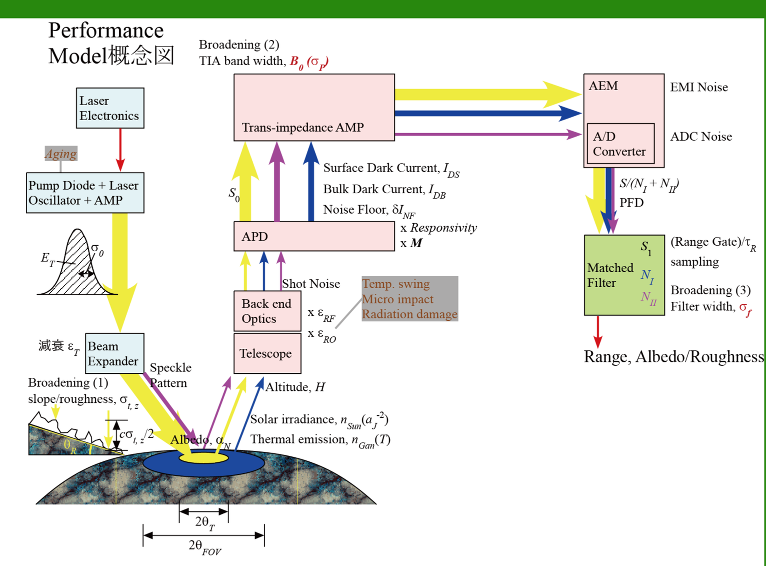


Fig 2.3 Schematics of the performance model.

2.3. Signal and noises

In the performance model, the signal is assumed to have a Gaussian form in both spatial and time domain. The width of transmitted laser pulse is 5.5 nsec, however, the broadening occurs on a reflection at the Ganymede surface and filtering processes in AEM and RFM. Background noise from scattered sunlight from the Ganymede surface, surface and bulk dark currents of APD, noise floor of APD-TIA, shot noise, and speckle noise are taken into consideration. Black-body emission from the Ganymede surface is also taken into account while its influence to *SNR* is negligible compared with other noises. EMI noise shall be included after the evaluation of the verification model.

Parameters	Symbol [Unit]	2.1.1	2.1.2	2.1.3	2.1.4
Surface temperature	T [K]	103	113	←	←
S/C altitude	H [km]	1300	550	500	450
Ganymede albedo	α_N	0.67	0.2	0.44	0.7
Ganymede surface slope	θ_R [deg]	5	20	3	0
Ganymede surface roughness	$Var(\Delta\xi)$ [m]	3	10	1	0
Solar emission @1064nm	W_{sun} [W/m^2/m]	3.09E+07	3.09E+07	3.09E+07	0

Table 2.2 Observation conditions.

Parameters	Symbol [Unit]	2.1.1	2.1.2	2.1.3	2.1.4
Energy input to APD	[J]	7.13E-17	1.12E-16	3.18E-16	6.24E-16
Power input to APD	P_r [W]	1.03E-09	6.00E-10	1.52E-8	1.07E-07
Number of photons to APD	n_{γ_in} [個数]	382	601	1700	3344
Output level of APD-HIC	V_1 [mV]	3.14	1.81	50.1	272
Signal power	S_1 [A^2]	1.43E-15	4.67E-16	1.57E-13	8.54E-13
Background noise	N_I [A^2]	3.19E-17	9.12E-18	5.10E-17	4.16E-17
Shot noise and speckle noise	N_{II} [A^2]	2.70E-17	5.69E-18	7.78E-16	2.50E-15
Matched filter width	s_f [nsec]	2.00E-08	6.00E-08	1.00E-08	1.00E-08
Calculated SNR	***SNR***	15.1	8.3	184	308
SNR requirement (Table 2.1)		>1.8	>1.8	>11.2	>20.7

Table 2.3 Model results.

2.2. Matched filter simulation

Analogue signal processed in Japanese AEM (Analogue Electric Module) is converted to digital signal and transferred to Swiss RFM (Range Finder Module). RFM applies matched filtering to the digital signal to determine the range as accurately as possible. The signal processing in RFM constrains the performance of Japanese modules, therefore GALA-JP developed its own matched filter simulation aiming to specify signal-to-noise ratio (SNR) requirement.

The matched filtering in RFM is a convolution of signal and Gaussian filter whose width in time domain is adjustable. The filtering is thus equivalent to moving average weighted by Gaussian filter in time domain. In this simulation, the length of range gate is 8192 and the sampling frequency is 66.7 MHz which is lower than the current design of ADC of 80 MHz. The band-pass filtering by trans-impedance amplifier of APD (APD-TIA) is taken into account by filtering the return pulse and APD noise by 30 MHz. By changing input SNR and width of the Gaussian filter, the lower bounds of the output SNR that satisfy the system requirements 2.1.1-2.1.4 are investigated.

System requirement	Lower bound of SNR
2.1.1 Europa fly-by	1.8
2.1.2 GCO500 worst condition	1.8
2.1.3 GCO500 nominal condition	11.2*
2.1.4 GCO500 best condition	20.7*

Table 2.1 *SNR* requirements.

* Calculated for 25-MHz TIA and 80 MHz sampling.

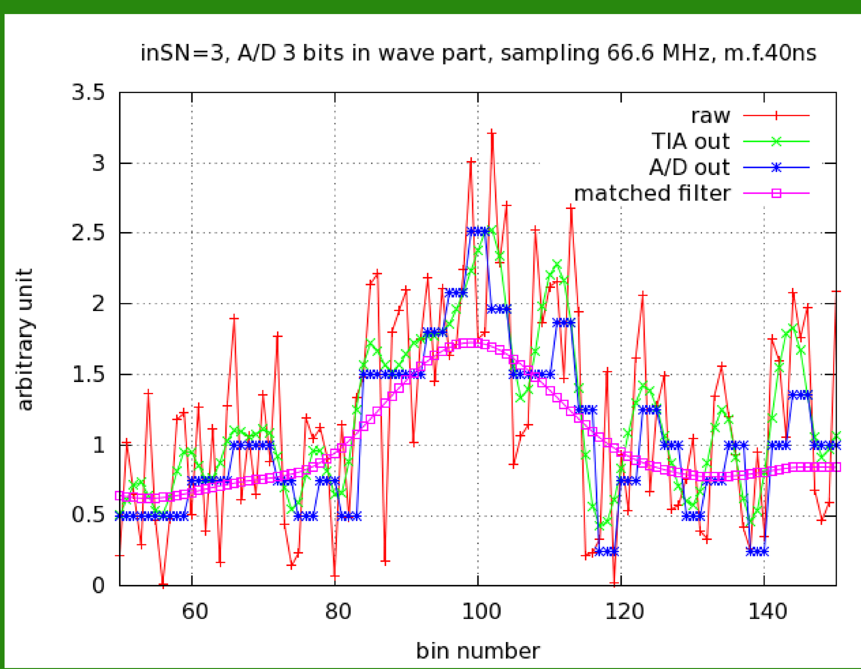


Fig 2.2 An example of the matched filtering in RFM. Red line is an input signal to RFM which is sum of the return pulse and white noise. Green line is an output from 66.6 MHz TIA. Blue line is a simulated output from 3-digit ADC. And green line is a filtered signal. *SNR* of the red line is 3.

Function	Symbol [Unit]	Specification
Pulse energy	E_T [J]	0.017
Pulse width	FWHM [sec]	5.50E-09
Wavelength	λ [m]	1.06E-06
Beam divergence (1/e^2)	θ_T [rad]	5.00E-05
Collimator efficiency	ε_T	1.0

Table 2.4 GALA laser specification.

Function	Symbol [Unit]	Specification
Aperture radius	r_R [m]	0.125
Field of view	θ_{FOV} [rad]	2.75E-04
Telescope efficiency	ε_{RO}	0.85
Filter transmission	ε_{RF}	0.8
Filter band pass	R_F [m]	2.00E-09
APD responsivity	$Res(M)$ [V/W]	M/150×2.25E+06

Table 2.5 GALA receiver specification.

2.4. Results and Summary

Current design of GALA satisfies the system requirements from 2.1.1-2.1.4. Conceptual design will start once the ISAS management review will be finished.

References

Thomas, N. et al., The BepiColombo laser altimeter (BELA): Concept and baseline design, *Planet. Space Sci*., **55**, 1398-1413, 2007.
Gunderson, K. et al., A laser altimeter performance model and its application to BELA, IEEE Trans. *Geosci. Remote Sens*., **44**, 3308-3319, 2006.
Santovito, M. R. et al., A laser altimeter for BepiColombo mission: Instrument design and performance model, *Planet. Space Sci*., **54**, 645-660, 2006.
Gunderson, K. and N. Thomas, BELA receiver performance modeling over the BepiColombo mission lifetime, *Planet. Space Sci*., **58**, 309-318, 2010.
JUICE Science Requirements Document: [AD1]: SciRD (JUI-EST-SGS-RS-001, Issue 2, revision 5