Deduction of Ice Layer-Thickness in Targeted Geographic Regions of Europa to Assess the Viability of Liquid Water Extraction

Abdul Moiz(HD), Rayaan Wasay, Muaaz Humayun, Zarar Haroon, Abdullah Khan

August 6, 2023

Abstract

Due to its possible underground liquid water reserves, Europa, one of Jupiter's fascinating moons, has piqued scientific curiosity and raised concerns regarding the existence of extraterrestrial life. Understanding the ice layer thickness, a crucial factor determining the viability of future missions for liquid water extraction, still has major uncertainty. To estimate the practicality of liquid water extraction, this paper presents a thorough investigation of cutting-edge remote sensing techniques to determine thickness of the ice cover in selected geographic regions of Europa. Through meticulously reviewing historical mission data, including Galileo and Voyager, and employing state-of-the-art modeling techniques.

Moreover, we elucidate the implications of our findings on the prospect of liquid water extraction by illuminating the ice layer's structural stability and potential water mobility. The results demonstrate regions with favorable conditions for future exploration and identify critical target areas for further in-site verification. As prior mentioned, this paper is about identifying the thickness of ice in targeted geographical zones on Europa, to determine the feasibility of extracting liquid water with different prospective drilling or any hypothetically plausible water extraction methods, limited solely to Europa, and Enceladus. .

CONTENTS

LIST OF FIGURES

CHAPTER 1

ACKNOWLEDGEMENTS

We are very thankful to the SPADES team for providing us with such a platform to research and experiment. We would also like to express our gratitude to the professors who conducted the workshops. The help they offered and the knowledge they passed on are of great benefit to us, and we are truly grateful for this experience.

CHAPTER 2

INTRODUCTION TO EUROPA AND ITS POTENTIAL FOR LIQUID WATER EXTRACTION

Europa possesses two of the few essential criteria for life: water, and energy. Europa contains 2x the water volume of Earth, and even the energy produced on it is a result of tides being 'tugged around' by Jupiter's gravitational force($24.79\,\mathrm{m/s^2}$), converting into heat energy. A major set point in our data, which deviates from NASA Galileo's data is the exclusion of Jupiter's radiation levels when comparing spectro-photometric data of the different H_2O variations currently found on Europa.

2.1 Analysing hypotheses of various astronomical studies

Europa has a core of silicate rock with an outer crust of liquid water and water ice that may only be approximately 20 km thick. [1]. The distance of Europa from the Earth and the Sun asks for autonomous analytical tools that maximize the scientific return at minimal resources, demanding new experimental concepts, which are mentioned within this study. A basis of many of our instruments is the electrical conductivity of the surface helps in any image detection upon the basis of energy perturbation. Furthermore, by utilizing tomographic data, those images provide only moderate- to high-resolution views of the moon's surface and are therefore a critical resource for scientific analysis and future mission planning. Unfortunately, uncertain knowledge of the spacecraft's position and pointing during image acquisition resulted in significant errors in the location of the images on the surface. (Bland, M. T., Weller, L. A., Archinal, B. A., Smith, E., and Wheeler, B. H. (2021). Improving the Usability of Galileo and Voyager Images of Jupiter's Moon Europa. Earth and Space Science, 8(12), e2021EA001935. https://doi.org/10.1029/2021EA001935) [2]

2.2 Identifying targeted geographic regions on Europa for potential liquid water extraction

Cryovolcanic zones within surface-level reach of quasi-symmetric double ridges will be the primary site in question, due to propagative variation in system energy as well as mass(through liquid excursion). The following is a cryo-volcanic zone that fits the aforementioned requirement

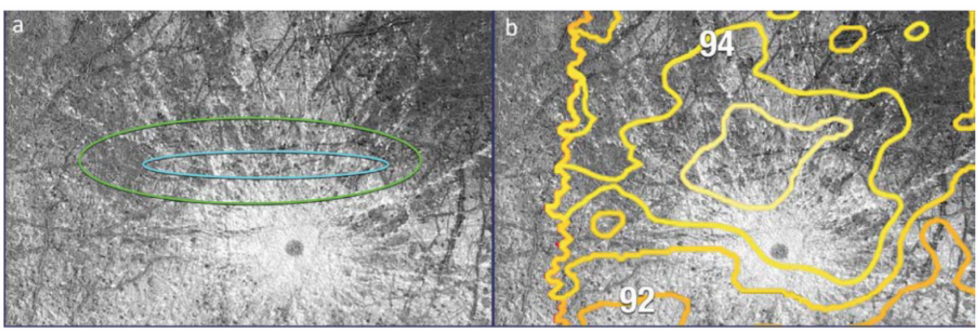

Figure 2.1: The yellow annotations in (b) shows contour heat maps of cryovolcanic zone areas. Upwelling in (a) is defined by green and cyan ellipses(cyan defines the region of higher plume activity based on old reports)

These domains manifest as dynamic locales where subsurface aqueous reservoirs, conceivably in the form of subsurface oceans, find proximal exposure to the moon's frigid surface via volcanic processes. These regions allude to recent or ongoing cryovolcanic activity, thus implicating the likelihood of renewed materials, including liquid water.

The geological and geophysical significance of cryovolcanic territories is unequivocal, offering unprecedented insights into Europa's intricate internal dynamics and potential habitability parameters. Deciphering the distribution of water and sundry constituents within these venerated locales augments our discernment of the moon's enigmatic ice-water interface, inspiring diligent efforts to address the daunting challenges of Europan exploration. Notwithstanding the rigorous environmental milieu characterized by harsh cryogenic temperatures and hazardous radiation flux, embarking upon concerted investigations within Europa's cryovolcanic precincts stands as an intellectual prerogative to unravel the enigmas of this glacial moon and discern its propensity for harboring conditions amenable to life.

2.3 Overview of ice layer-thickness deduction methods on Europa

First of all, thickness of the ice is important as it is an indirect measure of the total tidal heating europa is getting. It would also determine where and how material reaches the surface and goes back down. It would give us a direction on how to explore the satellite.

The images of craters on the surface of europa from the Galileo probe are compared to those on the surfaces of its sister satellites Ganymede and Callisto. This comparison is based on a comparison of the topography and morphology of impact craters on the respective satellites.

Pictures and Images from N.I.M.S of the Galileo Probe are used to deduce the thickness. N.I.M.S is A remote sensing instrument that makes measurements in the near-infrared region of the light spectrum, from which the chemical composition, structure, and temperature of planetary and satellite atmospheres can be determined, as well as the mineral composition and geochemistry of planetary and satellite surfaces. These images give us a clear view of the craters on the surface of Europa. These craters differ significantly from those on Ganymede and Callisto. The shape of the carters changes as their diameter exceeds 30 kilometres. Craters smaller than 30 kilometres have visible rims and central uplifts, features typical of an impact crater, but are surrounded by concentric rings, while craters larger than 30 kilometres seemingly have no rims or uplifts. This change indicates a change in the ice layer. The most viable explanation for this is that there is a change from solid to liquid. The rings are most probably caused by the collapse of the crater floor, and as the floor collapses and cracks, the material under it moves to fill in the gaps. Larger craters penetrate more deeply into the planet, and the crater size is determined by the property at the depth it goes to. Therefore, to determine the thickness, one must determine how big the crater is and how deep below the liquid layer must be before it can affect the shape of the crater. This is derived from numerical calculations and laboratory experiments into impact mechanisms. A crater collapse model is created, which is then used to convert the transitional diameter, in this case 30km, to the thickness of the layer, which is estimated to be 19–23 kilometres deep

2.4 Analyzing data from N.I.M.S of Galileo probe for ice layer-thickness estimates

By examining distinctive spectral signatures of ice, N.I.M.S data has provided crucial clues to set a specific estimate From a visual perspective ultimately, linea(trailing and leading hemisphere) patterns exhibit between 1.4μm and 2.0μm. Mirabilite, hexahydrate are hydrous vitreous salts, and will not be

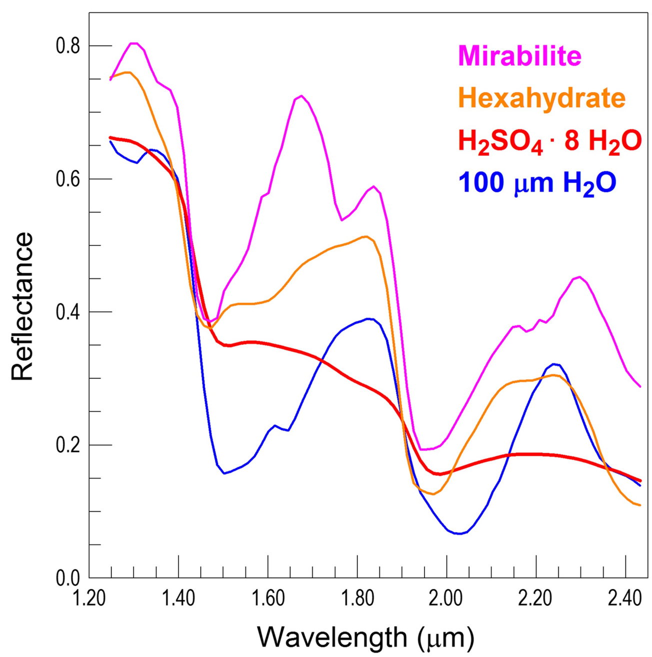

Figure 2.2: Convergence of reflectance for surface composites displays a preference to the theorization of bonds between water and hydrated salts at 1.4μm

deduced by plain observations

We will also be employing linear mixing, which is most appropriate for situations where the exact imaged surface is made up of separate subsurfaces - perfect for Europa's chaotic terrain patterns, as well as cryovolcanic fluxes resulting in leading hemispheric surface patterns to be distinctly visible from space. During this procedure, reflectance spectra of suspected surface materials are combined linearly, to replicate the radiative properties individually, and are used most visibly in compositional mapping using MCMC modeling. [1]A secondary method of radiative transfer calculations can be employed, which may be collectively diverse since it describes the behavior of incident photons with particles present on the surface. [1]

2.5 Analyzing spectroscopic datasets from Galileo Solid-State Imaging Camera for layer thickness estimates

The near-I.R observations of N.I.M.S have a primary flaw: Jupiter exerts high energy radiation, mid-infrared, and the visible light spectrum falls within this limit. This displays the minorly-superfluous variation in spectroscopic readings of salty water and the observable minerals beneath the ice layer. (Klaasen, K.P., M.C. Clary, James R. Janesick, Charge-Coupled Device Television Camera for Nasa's Galileo Mission To Jupiter, 23(3). p. 334- 342, Optical Engineering, May 1984.) These results depict ice-layer thickness between 16 and 18km, followed by an unknown depth of salty-ocean water(extraneous to research and specify)

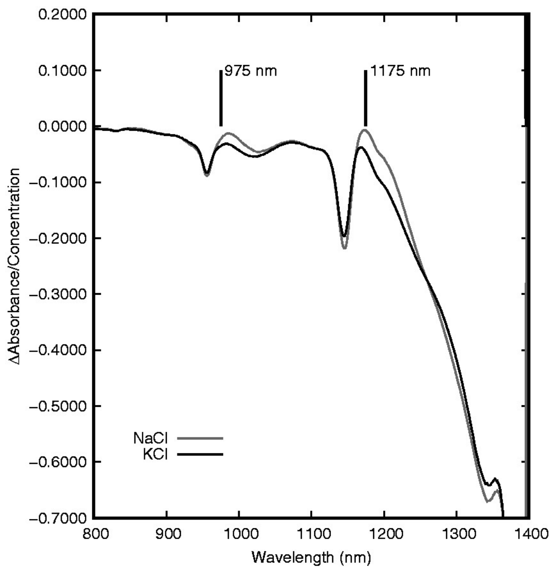

Figure 2.3: The aforementioned graph shows composite spectroscopic data of salt-water samples taken from Earth's oceans. There is bound to be variance, primarily minimal

We have calculated the absorbance by first, calculating transmittance through

$$T = l/l_0$$

. After this, we calculate absorbance (A) with the equation:

$$A = -log_{10}T$$

T=Transmittance l= Final reading l_0 = Blank reading

CHAPTER 3

EXPERIMENTAL ANALYSIS AND METHODOLOGY OUTLINE

3.1 Gathering relevant datasets and imagery from past missions to Europa, as well as from Earth-based observations and simulation

3.1.1 Simulating temperature

From December 2017 to August 2018, JPL simulated the conditions on Europa on 'Project Ark'. It utilized a pump-driven vacuum chamber, that would 'pump' kinetically energized particles, of various low kinetic energies, into the chamber to simulate an average of$129.12K$. Towards the end of the timelapse, the ice appears to expand as water molecules accrete in colder sections of the ice, growing new ice patterns. Various light patterns applied display the diurnal cycle present on Europa.

3.1.2 Simulating terrain

Chaos terrains are a very prominent terrain class on Europa henceforth analysis of the simulation of such terrains assists us in deducing the prominence and frequency of quasi-symmetric ridge-like, and cryovolcanic geographical structures, most commonly found in the trailing hemisphere region: Chaos

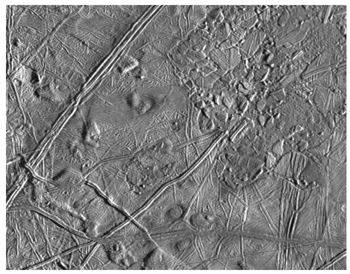

Figure 3.1: The visible lines are quasi-symmetric ridge patterns. The complex ridge crossing the picture in the upper left corner is part of a feature that can be traced hundreds of miles

terrains, also contain dark bands, disruptions, and perturbative patterns, which are present alongside criss-cross bands in regions like Agenor Linea. Such chaos patterns are influenced by various gravitational parameters, primarily the result of Jupiter's strong gravitational influence affecting the icy crust on Europa, across all band patterns under chaos terrain categorization.

3.2 Applying different methods, such as tilt series tomography, thermal imaging, to estimate ice layer-thickness in targeted regions of Europa.

3.2.1 Tilt-series tomography

Tilt series tomography, a technique commonly employed in electron microscopy has the potential to minorly deduce the ice-layer thickness, but with immense limitations, mentioned below in chapter 3. By capturing multiple satellite images at a 30° angle, it is possible to create 3D constructions of a surface.

3.2.2 Thermal imaging

By utilizing a laser-scanning method, and directing a thermal laser at the ice, due to the surface-affected deformation of the laser, it projects a contour-curve shape. Laser altimeters would be employed alongside the introduction of high-speed optical cameras, which would take images of the ice layers. [2] from multiple angles in a similar magnitude shift as tilt-series tomography. Thermal imaging through the aforementioned method would not be affected by spectral problems, due to its use of thermal radiation, as opposed to visible light. Furthermore, infrared thermography identifies targets through discrepancies in thermal conductivity characteristics

3.3 Comparing the results obtained from various methods and validating them against known features on Europa to ensure accuracy.

To measure the exact thickness of the ice, we would take sample of Europan ice from a quasi-symmetric ridge area, to coalesce previous result data. After that we would utilize the sample thickness and absorbance and transmittance readings to compare with a larger scale. Such an accuracy would requir prospective-onsite probes, and could be greatly assisted by N.A.S.A Clipper. Fig.1.2 displayed the wavelength and reflect of surface composite substances present in double-ridge trailing hemispheric zones values.Reflectance variation is prominent in mirabillites observed at a various number of wavelengths ranging from 1.2 to 2.4 micrometres.Water-bound salts and water experienced relatively less reflectance variation. [4] .Moving to Fig.1.3, the reason N.A.S.A used Galileo N.I.M.S to observe layer depth and water depth was due to mid-infrared range being reached at higher wavelengths, resulting in major decrease of absorbance readings, proving reverse-linearity when tested from near-infrared (800nm to 2500nm) to mid-infrared (3μm to 50μm)

3.4 Integrating information on potential geothermal heat sources to understand their influence

Many locations exhibit geothermal activity, which is characterized by localized heat dissipation and thermal upwelling, which produce thermal gradients that rise above the frozen lithosphere. The different geothermal signals show a complex interaction between latent primordial energy stores, radiogenic heating, and tidal forces. These energy details, which control the distribution of heat sources below the surface, produce heterogeneous ice-layer formations. Different geothermal zones have different impacts. These effects can include localized thinning of the ice, mobility of subsurface meltwater, and even remnant cryovolcanic resurgences.

The ability to distinguish between these geothermal heterogeneities has been made possible by recent developments in theoretical thermal models and remote sensing and imaging techniques. Through thermal mapping and the analysis of the spectral properties of individual surface features, researchers attempt to infer the subtle effects of geothermal dynamics on the thickness of the ice cover. [3]

CHAPTER 4

DISCUSSION

After analyzing the Spectroscopic and tomographic data, we reach an indirect conclusion of the absolute experimental analysis. Firstly, the targeted zones for data analysis have been deduced based on energy-based variation, that ultimately make the sites analyzed in this area active zones, affecting the increase in analyzed datasets available. Using a technique of electron-microscopy(tilt-series tomography) in large-scale topographic imaging presents innumerable challenges. Firstly, tilt-series tomography is used for smooth, or microscopic terrain. Europa possesses a challenging and intricate class of terrain, which makes scanning accurately difficult, to the point of major experimental uncertainty.

We would experience limitations for geothermal heat patterns as well. Radiative variation would be prominent due to the immense thermal energy perturbations occuring on Europa, causing unknown variance within ice thickness.

CHAPTER 5

CONCLUSION

5.1 Conclusion

Ultimately, the effort that has been made to infer the thickness of the ice layer in particular geographic areas of Europa, based on a thorough combination of geophysical modeling, remote sensing techniques, and careful data analysis, represents a significant advancement in our understanding of the complex dynamics present on this mysterious moon of Jupiter. By combining radar sounding, thermal imaging, and gravity data, underlying ice stratigraphy has been quantified, which has made stratified interpretation of Europa's cryospheric architecture possible. Iterative analysis based on meticulous empirical measurements and computer simulations provides a more sophisticated understanding of the temporal variability and spatial distribution of ice-layer properties.

From these conclusions, we can draw important conclusions about how to better comprehend how habitable Europa might be in light of the planned extraction of liquid water resources. The specific places that have been targeted and identified through this empirical discourse could serve as future exploration missions' focal points when combined with the identification of subsurface heat gradients and geothermal activity. This work clearly represents a significant breakthrough in our capacity to assess the viability of liquid water extraction projects on Europa, skillfully combining scientific investigation with practical exploration goals.

BIBLIOGRAPHY

[1] Oliver King, Leigh N. Fletcher, and Nicolas Ligier. Compositional mapping of europa using MCMC modeling of near-IR VLT/SPHERE and galileo/NIMS observations. *The Planetary Science Journal*, 3(3):72, mar 2022.

[2] SG Pavlov, EK Jessberger, H-W Hübers, S Schröder, I Rauschenbach, S Florek, J Neumann, H Henkel, and S Klinkner. Miniaturized laser-induced plasma spectrometry for planetary in situ analysis–the case for jupiter's moon europa. *Advances in space research*, 48(4):764–778, 2011.

[3] Louise M. Prockter and Robert T. Pappalardo. Chapter 36 - europa. In Tilman Spohn, Doris Breuer, and Torrence V. Johnson, editors, *Encyclopedia of the Solar System (Third Edition)*, pages 793–811. Elsevier, Boston, third edition edition, 2014.

[4] Huai-Ruo Zhang, Ray F. Egerton, and Marek Malac. Local thickness measurement through scattering contrast and electron energy-loss spectroscopy. *Micron*, 43(1):8–15, 2012. Applications of EELS in Materials and Physics Research.