VURP Research Proposal
Surface Temperatures of Icy Galilean Satellites

YILUO LI[1] and MICHAEL E. BROWN[2]

[1]University of California, Santa Barbara
[2]Division of Geological and Planetary Sciences, California Institute of Technology

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1 Introduction

The outer three satellites of Jupiter(Europa, Ganymede, and Callisto) are often referred to as the "Icy Galilean Satellites" for their spectroscopically detectable quantities of surface water ice [1]. Galileo orbiter was launched to study Jupiter and the Jovian satellites. It arrived in 1995, and since then, data were sent back to further support the hypothesis of a subsurface ocean on Europa at the current epoch [2] [3].

Based on the Galileo Photopolarimeter-Radiometer (PPR) data and later the Atacama Large Millimeter Array (ALMA) observations, thermal models were developed to study Europa specifically. To build upon that, in this proposed research we will take the current thermal model for Europa and extend it to analyze the diurnal surface temperature on Ganymede and Callisto.

2 Significance

By evaluating criteria for origins of life, at least three conditions must be satisfied: organic compound, sufficient heat to support biomass, and water, possibly required to be in the liquid form [2]. With these constraints, Europa is one of the few targets in the Solar System to meet these conditions [2], and the other two icy satellites, from models including trace quantities of ammonia, are also suspected to have subsurface ocean [7] [4] [5]. Therefore, we find it a good reason to further investigate the behavior of these icy satellites.

With our extended thermal model from Europa [6], we would like to characterize other thermal anomalies on icy satellites that display similar traits as the regions we are studying. All three icy satellites are hypothesized to host oceans, so the identified regions may allow us to construct an initial picture for icy satellites' geological and thermal identities. This understanding may possibly provide evidences for future research into their habitability [8], since water plumes are also reasons for thermal anomalies, and such activity has detectable signature for a lifetime of up to a thousand years [3].

In addition, from previous work, there were one-layer, two-layer(vertically homogenous), and two-component(laterally homogenous) models fitted to the Voyager and ground based cooling data during solar eclipses on satellites [1]. However, the PPR temperature data for Ganymede is 10K higher than all three models [9], so further investigation is required for Ganymede. Possible sources of this discrepancy will be discussed in the Methodology section of this research proposal.

Finally, while all three icy satellites are interesting astrobiological targets for in-depth examination, the understanding for diurnal temperature performance would assist with designing the infrared detection instruments and planning corresponding probing missions in the future [3] such as the NASA Europa Clipper spacecraft that is planned for in the 2020s.

3 Objective

The overall goal of this project is to analyze the surface temperatures of the icy satellites. The criteria of success can be categorized into the following three:

1. Study the differences and similarities of three icy satellites, and propose different modifications to be made for the current Europa model;
2. Extend the Europa model [6] to fit to Galileo PPR data and ALMA observations for Ganymede and Callisto;
3. Analyze the temperate maps with the developed models and potentially identify other similarly anomalous regions.

There might be places with high internal heat flow if water is close to the surface as previous works have suggested about water plumes on Europa [3] [8], so we would like to explore this possibility for other icy satellites as well.

4 Methodology

This research will start with retrieving data for Ganymede and Callisto from the Galileo PPR and ALMA observations and generating temperature maps based on these data. Each observation needs specific processing before they are usable. The ALMA data will require calibration as noted in previous work [6] in order to obtain the deconvolved images. The Galileo PPR obtained a large amount of observation data, but only a portion has high spatial resolution, low noise, and covers a large area (15 sets out of more than 100 observations for Europa) [3].

With the temperature maps, we will extend the Europa model [6], which invoked variation in thermal inertia and local albedo change within uncertainties of measurements. This would be a good starting point when proposing sources of thermal anomalies on Ganymede and Callisto, but it is also worth having in mind that the homogeneous model failed to capture the local discrepancies on Europa [6], so we might want to look into the two-component model [1] and treat that as a possible starting point as well. Neither model should work well for Ganymede initially [9], but should both offer insight into extending the existing models. A further note is that, when developing the Europa model, adding volcanic heat flow and excess heat flow would not match daytime and nighttime brightness temperature near the Pwyll Crater [6]. However, these two possibilities should not be ruled out when fitting the models to observations of Ganymede and Callisto.

Concerning the assumptions made for Europa, sunlight could penetrate a significant depth into regions of high albedo on Europa, and the Europa model took this into account, but the result does not show improvement in fitting the data. Therefore the Europa model stays with the assumption that absorbed sunlight is stored in the topmost layer [6]. As seen from Figure 1, the geometric albedo is relatively low on Callisto, so when extending model for Callisto, it would be also valid to stay with the same assumption as for the Europa. However, for Ganymede, the overall albedo is relatively high, so it might pose a difference in fitting the data, and we should take into account that sunlight might be stored in deeper layers in Ganymede to see if this will alter the data.

Possible explanation for thermal anomalies on Ganymede and Callisto include:

1. Local change of albedo
2. Variation of thermal inertia
3. Internal heat flow due to subsurface liquid and cryovolcanism
4. Volcanic heat flow
5. Other endogenic activities

When we compare our model to Galileo PPR and ALMA data, it is worth noticing that the thermal behaviors observed by Galileo might have cooled down to a point that the detectable lifetimes have expired for these features 17 years later during ALMA observations. Therefore, discrepancy is possible if our models don't converge for Galileo and ALMA data.

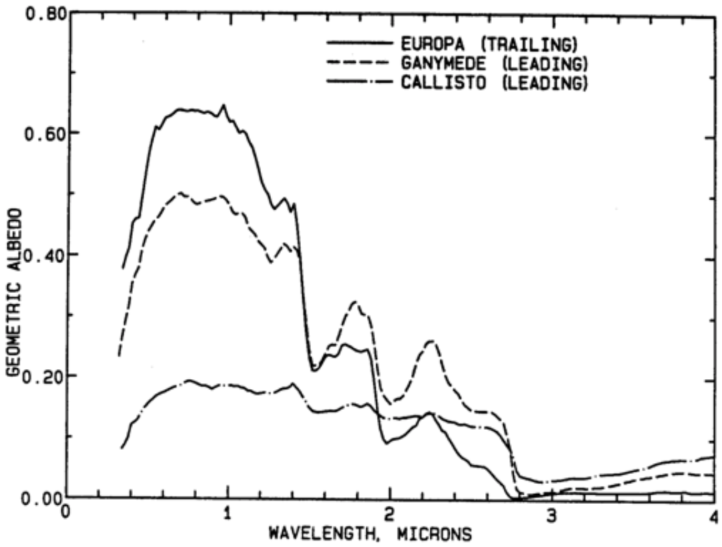

Figure 1: Geometric albedo for Europa, Ganymede, and Callisto with data from multiple sources [10] [11] [12] and image from a previous work [1].The Europa spectrum is of the trailing hemisphere only, while the Ganymede and Callisto spectra are leading hemisphere up to 2.5 microns and at longer wavelengths contain data from various orbital phases [1].

5 Proposed Research Timeline

Research Timeline	
Week	Description
1	Develop required skills to work with instruments and software for this proposed research; obtain Galileo PPR and ALMA data for Ganymede and Callisto
2 - 4	Generate temperature maps for Ganymede and Callisto at multiple local times with the Galileo PPR and ALMA data
4 - 7	Extend the model developed for Europa [6] to the temperature maps of Ganymede and Callisto
8	Analyze the temperature maps of Ganymede and Callisto's and relate to their thermal/geological properties; identify other similarly anomalous regions
9 - 10	Refine details and analysis for the temperature map and model; write up results and conclusions

6 Conclusion

In this proposed research, we are looking to analyze the surface temperatures of Ganymede and Callisto based on current model established for Europa. Using our developed model, we should be able to identify other similar thermal anomalies, and this proposed research will help us further our understanding for the behavior of icy satellites and potentially contribute to the conjectures of their habitability.

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References

[1] J. R. Spencer, Thesis (PH.D.) – THE UNIVERSITY OF ARIZONA, 1987. Source: Dissertation Abstracts International, Volume: 48-03, Section: B, page: 0793. (1987).

[2] R. T. Pappalardo et al., Journal of Geophysical Research: Planets **104**, 24015 (1999).

[3] J. A. Rathbun, N. J. Rodriguez, and J. R. Spencer, Icarus **210**, 763 (2010).

[4] J. I. Lunine and D. J. Stevenson, Icarus **52**, 14 (1982).

[5] R. Kirk and D. Stevenson, Icarus **69**, 91 (1987).

[6] S. K. Trumbo, M. E. Brown, and B. J. Butler, page 1 (2017).

[7] A. P. Showman and R. Malhotra, Science **286**, 77 (1999).

[8] W. B. Sparks et al., The Astrophysical Journal **839**, L18 (2017).

[9] G. S. Orton, J. R. Spencer, L. D. Travis, T. Z. Martin, and L. K. Tamppari, Science **274**, 389 (1996).

[10] L. Mc Fadden, J. Bell, and T. Mc Cord, Icarus **44**, 410 (1980).

[11] R. N. Clark, Icarus **44**, 388 (1980).

[12] J. B. Pollack et al., Icarus **36**, 271 (1978).