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NASA Proposal Number

TBD on Submit

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SECTION I - Proposal Information

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Proposal Title : **Galileo PPR observations of Europa: Correlations of thermophysical properties with endogenic and exogenic processes**

Proposed Start Date	Proposed End Date	Total Budget	Year 1 Budget	Year 2 Budget	Year 3 Budget	Year 4 Budget
05 / 01 / 2015	**04 / 30 / 2017**	**59,410.00**	**28,607.00**	**30,803.00**	**0.00**	**0.00**

SECTION II - Application Information

NASA Program Announcement Number	NASA Program Announcement Title
NNH14ZDA001N-SSW	**Solar System Workings**

For Consideration By NASA Organization *(the soliciting organization, or the organization to which an unsolicited proposal is submitted)*
NASA , Headquarters , Science Mission Directorate , Planetary Science

Date Submitted	Submission Method	Grants.gov Application Identifier	Applicant Proposal Identifier
	Electronic Submission Only		

Type of Application	Predecessor Award Number	Other Federal Agencies to Which Proposal Has Been Submitted
New		

International Participation	Type of International Participation
No	

SECTION III - Submitting Organization Information

DUNS Number	CAGE Code	Employer Identification Number (EIN or TIN)	Organization Type
947710638	**368W3**	**330175263**	**8H**

Organization Name (Standard/Legal Name)	Company Division
Planetary Science Institute	

Organization DBA Name	Division Number

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SECTION V - Certification and Authorization

Certification of Compliance with Applicable Executive Orders and U.S. Code

By submitting the proposal identified in the Cover Sheet/Proposal Summary in response to this Research Announcement, the Authorizing Official of the proposing organization (or the individual proposer if there is no proposing organization) as identified below:

- certifies that the statements made in this proposal are true and complete to the best of his/her knowledge;
- agrees to accept the obligations to comply with NASA award terms and conditions if an award is made as a result of this proposal; and
- confirms compliance with all provisions, rules, and stipulations set forth in this solicitation.

Willful provision of false information in this proposal and/or its supporting documents, or in reports required under an ensuing award, is a criminal offense (U.S. Code, Title 18, Section 1001).

Authorized Organizational Representative (AOR) Name	AOR E-mail Address	Phone Number

AOR Signature *(Must have AOR's original signature. Do not sign "for" AOR.)*	**Date**

FORM NRESS-300 Version 3.0 Apr 09

PI Name : **Julie Rathbun**	**NASA Proposal Number** **TBD on Submit**
Organization Name : **Planetary Science Institute**	
Proposal Title : **Galileo PPR observations of Europa: Correlations of thermophysical properties with endogenic and exogenic processes**	

SECTION VI - Team Members

Team Member Role **PI**	Team Member Name **Julie Rathbun**	Contact Phone **909-215-8122**	E-mail Address **rathbun@psi.edu**
Organization/Business Relationship **Planetary Science Institute**		Cage Code **368W3**	DUNS# **947710638**
International Participation **No**	U.S. Government Agency		Total Funds Requested **0.00**
Team Member Role **Collaborator**	Team Member Name **Carly Howett**	Contact Phone **720-240-0120**	E-mail Address **howett@boulder.swri.edu**
Organization/Business Relationship **Southwest Research Institute**		Cage Code **26401**	DUNS# **007936842**
International Participation **No**	U.S. Government Agency		Total Funds Requested **0.00**
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International Participation **No**	U.S. Government Agency		Total Funds Requested **0.00**
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International Participation **No**	U.S. Government Agency		Total Funds Requested **0.00**

PI Name : **Julie Rathbun**	**NASA Proposal Number** **TBD on Submit**
Organization Name : **Planetary Science Institute**	
Proposal Title : **Galileo PPR observations of Europa: Correlations of thermophysical properties with endogenic and exogenic processes**	

SECTION VII - Project Summary

Little is known about how Europa's thermophysical properties vary across its surface. The goal of this work is to use Galileo Photopolarimeter-Radiometer (PPR) data to characterize those variations and determine if they are controlled by exogenic or endogenic processes. This will lay the groundwork for future spacecraft observations where passive and potentially active thermal emission will need to be disentangled.

Our methodology begins by dividing Europa's surface into bins approximately the same size as the resolution of Galileo PPR observations of surface emission. Rathbun et al. (2010) used the same methodology and 10° square bins. Next, we determine the diurnal temperature variation by determining which PPR observations have data within that bin, average the PPR temperatures for each observation in that bin, and determine the time of day for that bin in each observation. If the bin has a temperature measurement at night and another near midday, we fit the diurnal temperature variations to our thermal model to determine the albedo and thermal inertia in that bin.

We recently found that Rathbun et al. (2010) did not correctly account for the change in incident sunlight with latitude. In this study, we will correct that oversight and further extend their analysis by including 7 additional PPR observations, loosen the requirements on the times of observations, and reduce the size of surface bins from 10° to 9° square. This allows us to increase the surface coverage from 20% to nearly 50%. We will compare the results of this refined analysis with a geologic map (Dogett et al., 2009) and a map of electron bombardment (Patterson et al., 2012). However, such comparisons are hampered by presence of materials with different thermophysical properties within the same bin. Shrinking the bin size will reduce this problem, but not eliminate it.

We will test multiple hypotheses. We first hypothesize that the thermophysical surface properties are dominated by geologic processes. We will define surface bins that lie entirely within a single geologic unit, which will eliminate the mixing problem. If the derived thermophysical properties are relatively constant across bins of the same geologic unit and vary between bins of different geologic units, then this hypothesis is correct. We will then test the competing hypothesis that the thermophysical properties are dominated by electron bombardment. We will define surface bins based on areas that receive similar amounts of bombardment, thus reducing mixing of different properties. If this hypothesis is correct, the derived thermophysical properties will be relatively constant across bins of similar bombardment and vary between bins with different levels of bombardment.

Because of its utility in detecting recent endogenic activity and determining surface characteristics and block abundances, the recent NASA call for proposals for Europa science investigations requiring spaceflight instrument development under the Stand Alone Missions of Opportunity Notice (SALMON-2) included a thermal instrument in the strawman payload (Solicitation: NNH12ZDA006O-EUROPA). The results of this proposed study would aid in designing a thermal instrument by predicting the maximum and minimum temperatures that will be found and by informing targeting of the instrument.

Table of Contents

1. Introduction & Significance

Europa is the second closest to Jupiter of the Galilean satellites. Its surface is primarily water ice and the lack of impact craters indicates its youth (Zahnle et al., 1998; Pappalardo et al., 1999; Schenk et al., 2004). Most work into Europa's surface has concentrated on its geology (Pappalardo et al., 1999; Figuerdo and Greeley, 2004; Doggett et al., 2009; Schmidt et al., 2011; Neish, et al., 2012) or chemistry (Carlson et al. 2009), and little into its thermophysical properties (Spencer et al., 1999; Rathbun et al., 2010). The surface composition appears to be controlled by plasma bombardment on a large scale (Paranicas et al., 2001; Grundy et al., 2007) and endogenic geology on a smaller scale (Carlson et al., 2009; Hendrix et al., 2011; Dalton et al., 2013). A recent analysis (Rathbun et al., 2010) has found no correlation between either of these processes and surface thermophyical properties. However, that analysis was subject to errors and can be greatly improved.

The detection of endogenic thermal emission on Enceladus in the infrared directly demonstrates the value of thermal observations of the icy satellites (Spencer et al., 2006). Cooling models of extruded warm material onto an icy surface have found that such features could be detected thermally for up to thousands of years, depending on the feature size and observational resolution (Abramov and Spencer, 2008; Abramov et al., 2013). Endogenic activity might therefore be detectable by its thermal signature longer than it might be seen directly, by, for example, plume activity. Rathbun et al. (2010) searched the Galileo Photo-Polarimeter Radiometer (PPR) data for such thermal signatures and found none, but they did determine the detection limits and found that 100 km^2 hotspots with temperatures of 116-1200 K could exist undetected on the surface, depending on the location. For these reasons, the recent NASA call for proposals for Europa science investigations requiring spaceflight instrument development under the Stand Alone Missions of Opportunity Notice (SALMON-2) included a thermal instrument in the strawman payload (Solicitation: NNH12ZDA006O-EUROPA). Furthermore, thermal measurements at two wavelengths with a spatial resolution of better than 250 m/pixel are recommended for landing site reconnaissance in order to determine surface characteristics and block abundances (Europa Study, 2012). In order to best design these instruments, we must first understand the data we currently have. For example, by determining the surface thermophysical properties, we can predict the maximum and minimum temperatures on Europa's surface, thus constraining future instrument designs. In addition, mapping global variations in surface properties and determining what process is responsible for variations can be used to inform targeting in future missions.

Here, we propose to determine whether the thermophysical properties of Europa's surface are dominated by endogenic or exogenic processes. We will use Galileo PPR data, which measures the surface brightness temperature, to determine the thermal inertia and bolometric albedo of different areas on Europa's surface and compare their variation with endogenic and exogenic processes. For endogenic processes, we will concentrate on one of the youngest geologic units on Europa, chaos, and compare its properties to the older background plains. For the exogenic process, we will examine correlations with patterns of bombardment by electrons and other charged particles. The previous analysis of Galileo PPR thermal data by Rathbun at al. (2010) is hampered by the poor spatial resolution, so materials with different thermophysical properties are likely present in the same bin. Defining bins based on a process that dominates thermophysical properties will remove this mixing. We will test two competing hypotheses for processes that control thermophysical properties: geologic unit and electron bombardment.

1.1 Previous work on thermophysical properties of Europa

Rathbun et al. (2010) examined Galileo PPR observations of Europa to search for endogenic activity, determine hot spot detection limits, and map thermophysical surface properties. While they found no thermal anomalies, they determined that 71% of the surface had not been mapped to a degree sufficient to detect 100 km^2 areas of surface liquid water. Using 15 PPR data sets, they found that 100 km^2 hotspots with temperatures of 116-1200 K could exist undetected on the surface, depending on the location.

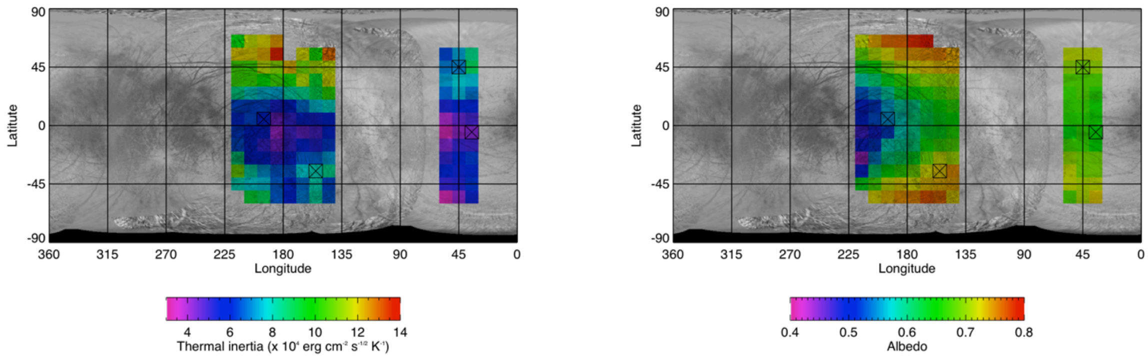

Figure 1: Thermal inertia and bolometric albedo derived from fits of a thermal model to the PPR data. From Rathbun et al. (2010).

Rathbun et al. (2010) also determined the thermal inertia and bolometric albedo of 20% of Europa's surface (figure 1). They chose 11 PPR data sets from Galileo orbits 6, 7, 14, 15, 17, and 25 based on high spatial resolution, low noise, and large areal coverage. They divided the surface into 10-degree square bins, searching each data set for measurements in that bin. Measurements within the bin were averaged to increase signal to noise, and the time of day of the measurement was determined. This results in a list of average temperature and time of day for each bin. Since thermophysical properties are best constrained by the maximum and minimum in the surface temperatures, they only applied a thermal model to determine the bolometric albedo and thermal inertia in a bin if at least one measurement in that bin was obtained at night and another within 30° of noon (although Rathbun et al., 2010 mistakenly states 20°).

The thermal inertias computed by Rathbun et al. (2010) generally ranged from 4 x 10^4 to 15 x 10^4 erg cm^{-2} s$^{-1/2}$ K^{-1} (40-150 J m^{-2} K^{-1} s$^{-1/2}$), too low for solid ice, indicating that the surface is composed of unconsolidated regolith. They found that the thermal inertia increased at higher latitudes, which could be explained by a more compacted surface. However, they could not correlate observed variations with geology, albedo, or other observables.

Rathbun et al. (2014) determined that Rathbun et al. (2010) paper did not correctly account for the change in incident sunlight in latitude, resulting in anomalously larger albedos at higher latitudes (figure 1).

1.2 Exogenic processes

Howett et al. (2011) showed that the main process affecting the thermophysical structure of Mimas' surface is electron bombardment. Using Cassini CIRS observations they determined

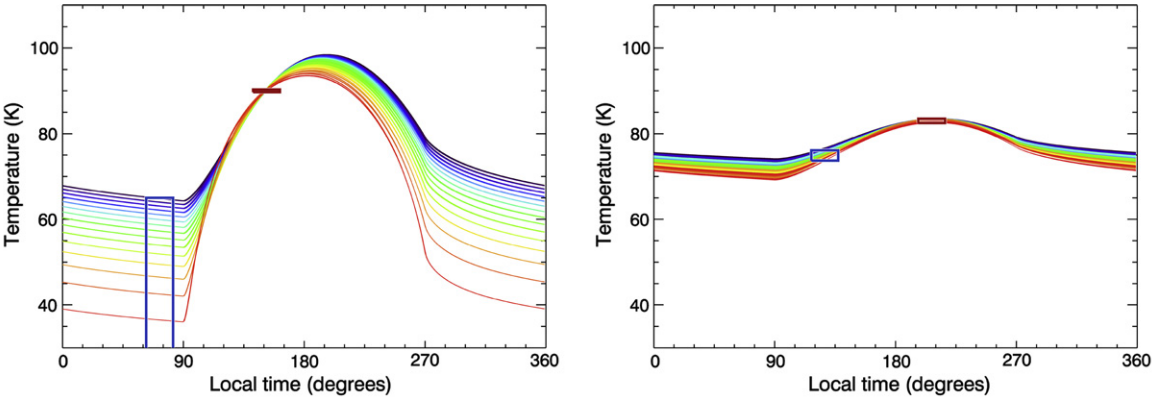

Figure 2: Diurnal curves that are able to fit both the observed daytime (red boxes) and nighttime/dawn (blue boxes) temperatures for regions outside and inside the anomaly. Bolometric albedos are 0.60 ± 0.11 and 0.59 ± 0.03 and thermal inertias are <16 and 66 ± 23 J m^{-2} K^{-1} $s^{-1/2}$ outside and inside the anomaly, respectively. From Howett et al. (2011).

the temperature of much of Mimas' surface and, using the same thermal model as Rathbun et al. (2010), derived the bolometric bond albedo and thermal inertia of two areas, one inside and one outside an observed thermal anomaly. They found that the location of the thermal anomaly roughly corresponds to the location of a region dark in IR/UV ratio (Schenk et al., 2011). Models of electron bombardment show that the lens of thermally anomalous material and the IR dark region correspond to the locations on Mimas where the electron energy deposition rate is greater than ~5.6×10^4 MeV/cm^2/s (Howett et al., 2011). While the effects of electron bombardment on thermal inertia are not understood in detail, Howett et al. (2011) discussed how increases in thermal inertia are a plausible consequence of irradiation. Overall, Saturnian satellites have a low thermal inertia (Howett et al., 2010), which may indicate a particulate surface with limited contact area between grains. Electron bombardment may compact the ice (Baragiola et al., 2008), thus increasing the conduction between the grains and resulting in higher thermal inertia. Similar anomalies have been observed on Tethys and Dione (Howett et al, 2012 and 2014). Howett et al. (2014) also found that the thermal inertia on Enceladus increases toward the south pole, which is surprising if the surface is covered in unconsolidated plume fallout, and may imply sintering of plume debris by condensed water vapor.

The surface of Europa may also be affected by electron bombardment. Paranicas et al. (2001) calculated how much energy is deposited by electrons at each location on Europa's surface. They also used Galileo NIMS spectra to determine the concentration of a hydrated material. They found that the global distribution of this material is associated with areas of high energy deposition and suggest that this component is created by radiolytic processing of surface materials. Johnson et al. (2004) compare the NIMS distribution of hydrated material to a UV/Violet Voyager ratio map and find a similar global distribution with a low ratio lens on the trailing hemisphere at the same region as the hydrated material. Grundy et al. (2007) used New Horizons LEISA data to determine the distribution of the hydrated material over more of Europa's surface than NIMS was able to cover. They find the same lens-shaped region, centered on the trailing apex, which has a high concentration of the hydrated material. The main deviation from symmetry is an area of cleaner ice south of the trailing apex associated with ejecta from the Pwyll impact crater. Hendrix et al. (2011) found a correlation between UV spectra of Europa and electron bombardment. However, like Carlson et al. (2009) they found that geology, as well as exogenic processes, appears to affect surface composition, particularly the SO_2 content. Cassidy et al. (2013) found a linear correlation between calculated sputtering rate on Europa's surface and ice grain size derived from NIMS spectra. Ice grain size may also affect the thermal inertia of a surface. Dalton et al. (2013) found correlations between both electron energy flux and sulfur ion flux with the observed abundance of sulfuric acid hydrate on Europa.

1.3 Geology of Europa

Rathbun et al. (2012) looked for correlations of thermophysical properties with surface geological features and found none. However, they were using the formulation of Rathbun et al. (2010), which did not correctly account for the change in incident sunlight with latitude. Furthermore, they used a preliminary geologic map of Europa (Doggett et al., 2009). Finally, their analysis was preliminary and considered only a small number of surface areas.

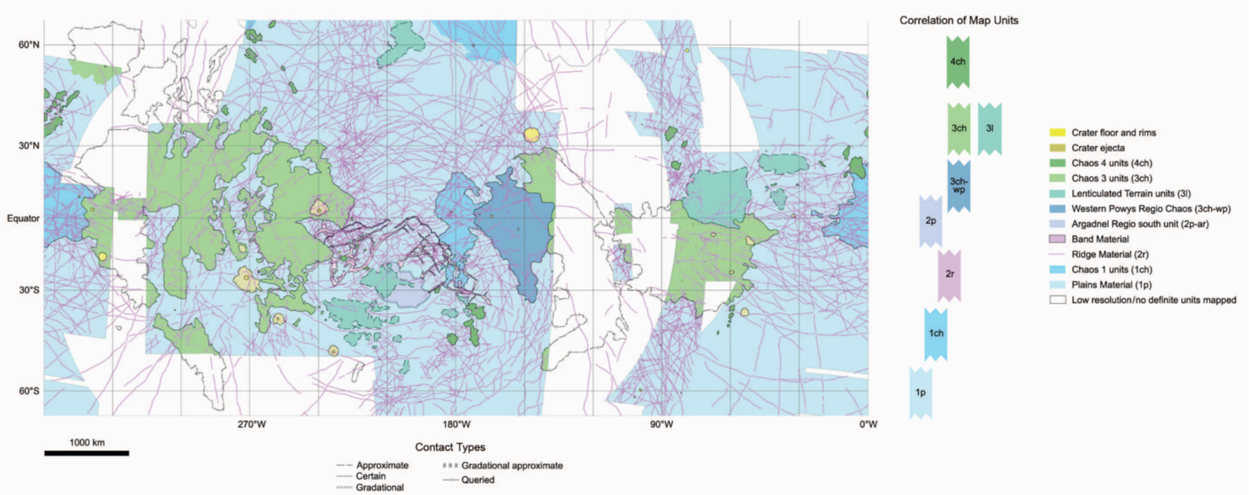

Figure 3: Geologic map and surface units from Doggett et al. (2009).

The global geologic map by Doggett et al. (2009) includes units for craters, chaos, lenticulated terrain, and band, ridge, and plain materials (figure 3). Figueredo and Greeley's (2004) pole-to-pole geologic map of Europa includes similar units with the exception of lenticulated terrain, which Figueredo and Greely (2004) and Neish et al. (2012) consider a subset of chaos terrain. The chaos units are interpreted to be among the youngest features on the surface of Europa, and some may currently be active (Schmidt et al., 2011). Riley et al. (2000) looked at the spatial and size distribution of chaos, but Neish et al. (2012) found that the global distribution was impossible to determine because of observational constraints on the identification of chaos.

Neish et al. (2012) mapped chaos in high-resolution regional scale images of Europa, artificially degraded the images to a lower resolution, and independently mapped chaos in the degraded images. They also verified the accuracy of their degradation techniques by comparing an artificially degraded image with an image originally acquired at the lower resolution, showing that albedo differences are enhanced in lower resolution images. They concluded that high incidence angle is more important than spatial resolution for identifying chaos regions. They found that chaos could be identified at resolutions as low as 1.5 km/pixel if the incidence angle were greater than 70 degrees. However, smaller incidence angle required spatial resolution better than 250 m/pixel to identify chaos. So, identification of chaos in geologic maps is only reliable in certain areas with the appropriate images.

2. Research Objectives and Technical Approach

The goal of this project is to determine whether the thermophysical properties of Europa's surface are controlled by endogenic or exogenic processes. To accomplish this goal we propose three tasks: 1. Complete the analysis of PPR data using 9 degree square surface bins, correcting for latitude, 2. Test the hypothesis that electron bombardment dominates thermophysical properties, and 3. Test the hypothesis that geologic unit dominates thermophysical properties.

Task 1: Complete analysis of 9 degree square bins

We will begin by completing the analysis presented by Rathbun et al. 2014. The resulting maps of surface geophysical properties will be free of assumptions and can, in the future, be compared to processes that are not currently recognized.

Rathbun et al. (2014) sought to improve the analysis of Rathbun et al. (2010) in 4 ways. First, they correctly accounted for the change in incident sunlight with latitude. Second, the original paper required at least one data point within 30° of noon. The shape of the diurnal phase curve is defined only by the thermal inertia and bolometric albedo. However, the complete shape of the curve can only be determined adequately when there is a data point near the peak (just after noon) and another near the minimum (just before sunrise). Rathbun et al. (2010) required at least one point at night and another point within 30° of noon. Rathbun et al. (2014) relaxed this second requirement to be within 60° of noon, although most of their bins do satisfy the stricter requirement. Furthermore, derivations of albedo and thermal inertia do not change abruptly in the regions with the relaxed requirement (figure 4). Thirdly, Rathbun et al. (2014) included 7 additional PPR data sets to increase the likelihood of data points at the required times of day. Together, these two changes resulted in increasing the percentage of the surface with model fits from just over 20% to nearly 50%. Finally, comparisons of the results of Rathbun et al. (2010) are hampered by the low spatial resolution of the thermal inertia

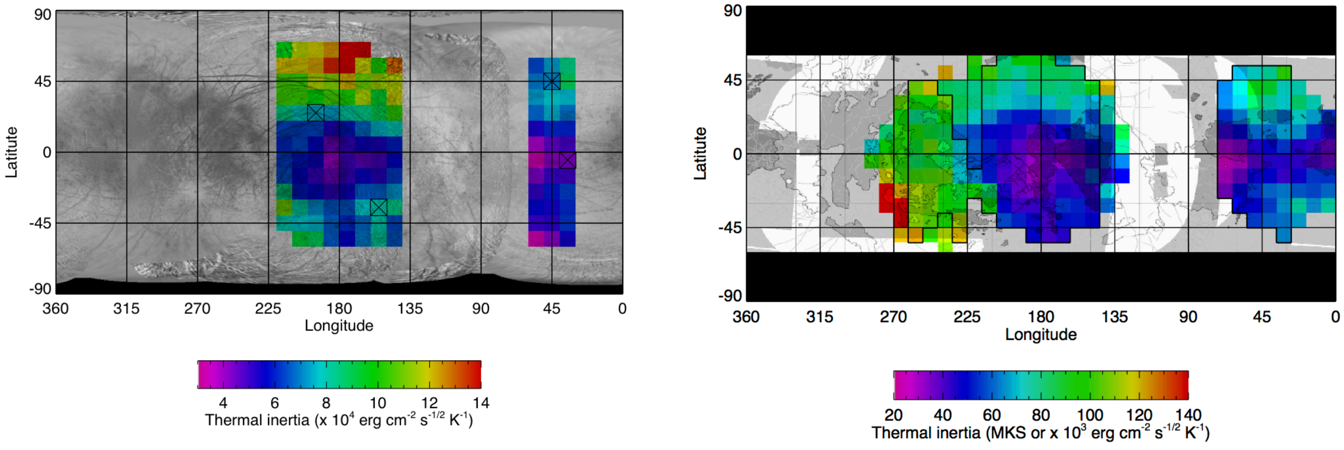

Figure 4: Thermal inertia derived from thermal models, from Rathbun et al. (2010), left, and from Rathbun et al. (2014), right. The derivation on the right covers more than twice the surface of the older derivation on the left. The background on the left is a Europa basemap, on the right is a black and white version of the geologic map from Doggett et al. (2009). . The solid line on the right encloses the areas where a midday temperature point was available, thus the thermal model was constrained by a stricter temporal requirement.

and bolometric albedo maps. By using 10 degree square bins, the resulting temperatures are averages of a large surface area (740 km^2 at the equator) which likely includes material of a variety of thermal properties. Rathbun et al. (2014) attempt to improve the spatial resolution, however, the resolution of the PPR data sets varies from 80 to more than 250 km, roughly equivalent to 3 to 9 degrees at the equator, so they used 9 degree square bins (600 km^2 at the equator).

While Rathbun et al. (2014) presented the preliminary results of the improved model fits, little scientific analysis has been completed. In this project, we will complete the analysis by testing and improving the model fit code to make sure it is now correctly accounting for the change in incident sunlight. We will compare the resulting bolometric albedos to visible albedos obtained by other methods, which will ensure that the correction is working correctly. We will also experiment with using selected data sets with higher spatial resolution to determine if we can improve the spatial resolution in some areas of the thermal inertia and albedo maps. Next, we will compare these maps to geologic maps and calculations of electron flux. We will also search for variations in thermal inertia with latitude, which might be due to a current or ancient plume on Europa. Since variations were found on Enceladus (Howett et al., 2010), we might expect to find increasing thermal inertia toward the south pole, though this would depend on how recently the plume was active and how geology and electron bombardment have subsequently affected the surface. We will search for such variations here, and also in subsequent tasks, particularly in task 3 by looking for variations in the thermal inertia within the older plains units. Finally, we will put the calculated thermal inertias in context of those found for other icy bodies in the Jovian and Saturnian systems (Howett et al., 2010).

Task 2: Test if electron bombardment dominates thermophysical properties

Even with the improved spatial resolution obtained in task 1, surface bins in which we are averaging observed temperatures would still include different surface units. Here, we hypothesize that electron bombardment is the primary factor determining thermophysical properties. Thus, to avoid mixing different properties, we will define bins that lie entirely within regions defined by its electron bombardment. Patterson et al (2012) have determined where on the surface electrons of certain energies will fall, the depth to which these electrons penetrate, and the integrated flux of electrons into the surface. They also found that the albedo and color pattern on Europa is observed on the surface for an integrated flux above $10^{6.7}$ MeV cm^{-2} s^{-1} and not the $10^{4.5}$ MeV cm^{-2} s^{-1} observed on Mimas and Tethys. From this, they suggested that the energies of the bombarding electrons may be more significant than the integrated flux. Using the results of their analysis, figure 5 shows a sketch of some of the bins in one possible binning scheme. Note that there are multiple bins with electron bombardment from electrons with the same energy. Once the bins have been determined, we will use the same thermal model, PPR data sets, and methodology to determine the thermal properties of each bin. If bins with the same electron bombardment have similar thermophysical properties and those with different electron bombardment have different thermophysical properties, then electron bombardment is

Electron bombardment controls thermophysical surface properties on the saturnian satellites Mimas, Tethys, and Dione. We will create bins that lie within areas of the same electron bombardment to determine if this exogenic process is also dominant on Europa.

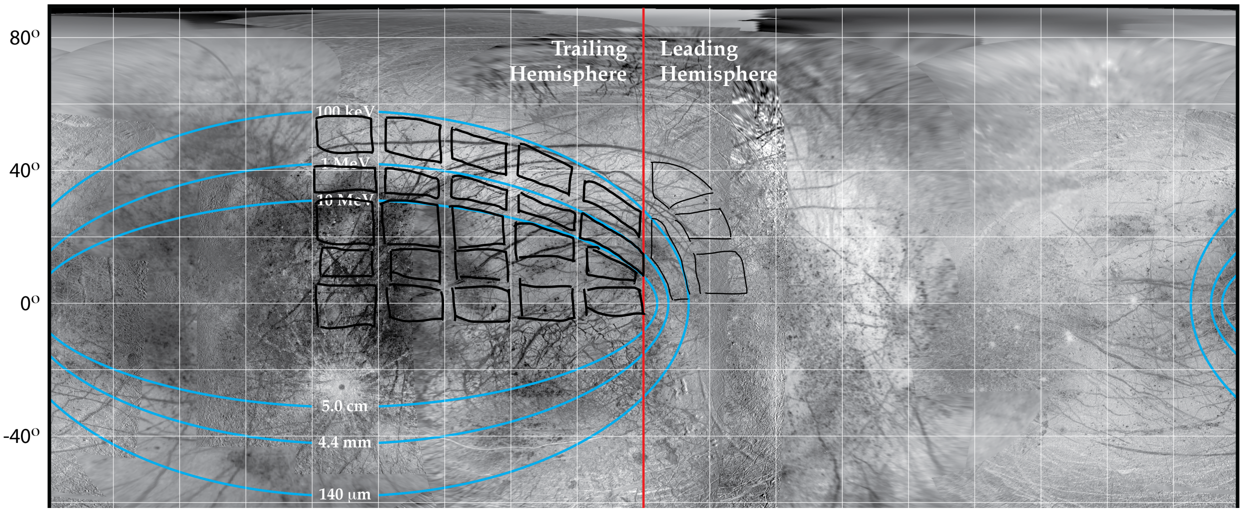

Figure 5: Contour plot of the energies and penetration depths for electrons bombarding the surface of Europa from Patterson et al. (2012). Boxes in black are a sketch of some possible bins to use for the thermal properties derivation.

dominating Europa's surface thermal properties.

Task 3: Test if geology dominates thermophysical properties

Chaos is likely the youngest geologic unit on Europa, so we expect that it might have different thermophysical properties than the surrounding plains material. Here, we hypothesize that surface areas within the same geologic unit have similar theromophysical properties and those in different units have different thermophysical properties. In particular, we care about chaos units versus plains units, so we define surface bins that lie entirely within one unit or the other. However, as discussed earlier, reliable determinations of geologic unit are complicated by observational biases.

Neish et al. (2012) determined that chaos terrain can only be reliably identified in images with an incidence angle great than 70 degrees. While they also find that chaos can be identified at lower incidence angles, it requires image resolutions of better than ~250 m/pixel and few images at this resolution are available. We have taken the map of incidence angle from Neish et al. (2012) and superimpoesed the areas where Rathbun et al. (2014) were able to determine surface thermophysical properties (figure 6). There are two bands of areas that have both high incidence angle imaging and temperature data to use to determine thermophysical properties, one near 230 W and another near 140 W. We will use existing geologic maps to define regions within these bands that lie completely within chaos or plains material. Using our thermal model, we will determine the average bolometric bond albedo and thermal inertia in each region. If bins within chaos units have similar thermophysical properties and those properties are substantially different from those within plains units, then geologic unit dominates

Geologic surface units have different formation processes and ages, which affect thermal inertia and albedo. We will create bins that lie within the same geologic unit to determine if these endogenic processes are controlling the thermophysical properties on Europa's surface.

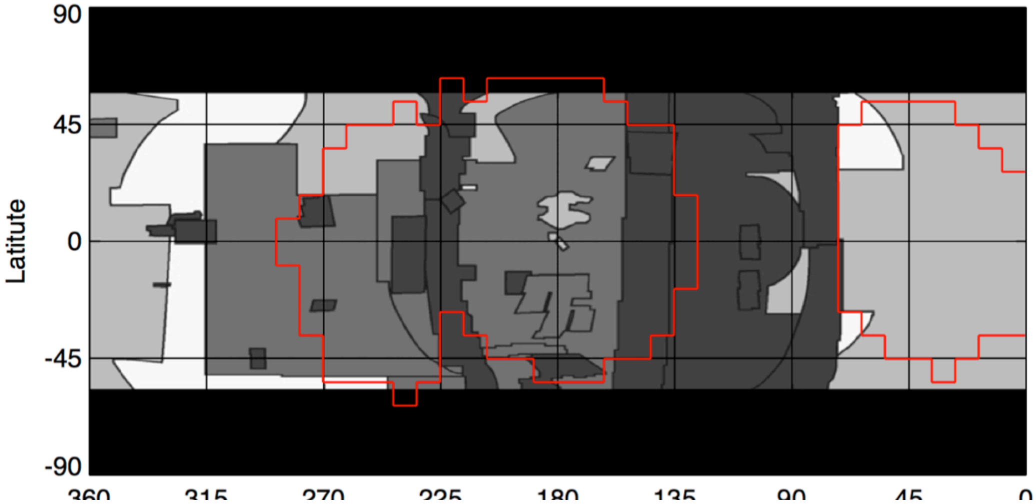

Figure 6: Europa observations suitable for thermal mapping (red outline) overlaid on incidence angle of observations (based on Neish et al., 2012). Only the darkest regions in the background map are appropriate for mapping of chaos units. There are two places where that unit overlaps the thermal mapping observations: a north-south swath near 230 W and another near 140W.

thermophysical surface properties. The band near 140 W is located on the leading hemisphere and should experience very little electron bombardment which the band near 230 W is off center on the trailing hemisphere and experiences large amounts of bombardment, especially near the equator. So, similar geologic units in each band will experience large differences in electron bombardment, allowing us to distinguish effectively between the two as the controlling factor in thermophysical surface properties.

4. Work Plan

Table 1 shows the anticipated breakdown of tasks by year. In year one, we will complete tasks 1 and 2. We will begin by thoroughly testing the model and methodology, and comparing the results for bolometric albedo to other albedo analyses (McEwen, 1986). Collaborators Spencer and Howett will advise based on their experience with the thermal model. The PI will determine the number of observations with smaller spatial resolutions and the time of day of those observations to see if a significant amount of the surface can be analyzed at smaller scales. Collaborators Spencer and Howett will also assist with putting the resulting thermal inertias into context of other icy bodies. The PI will present the results at the annual Lunar and Planetary Science Conference (LPSC). Collaborator Patterson will assist with the definition of bins based on electron flux. The PI will write the computer code necessary to define the bins, search the PPR data sets, and fit the thermal model.

During year 2, we will complete task 3 and publish the results of this study. The PI will meet with Collaborator Patterson to determine bins that lie entirely within a single geologic unit. Once these bins are determined, the PI will again write and implement the computer code to determine the thermophysical properties in each bin. The PI and all collaborators will work on the resulting publication.

The thermal model is already written and has already been successfully used by the PI and collaborators Spencer and Howett (Rathbun et al., 2010; Howett et al., 2010; Rathbun et al., 2014). The PI has experience defining bins of different shapes and sizes and has demonstrated expertise in writing computer programs (Rathbun et al., 2010; Rathbun et al., 2012; Rathbun et al., 2014).

Table 1: Anticipated breakdown of tasks by year.

Year	**Task**	**JAR**	**Total /year**
1	1: Complete analysis of 9 degree square bins	.04	.12
	2: Bins based on electron flux	.08	
2	3: Bins based on geologic unit	.08	.12
	Write publication	.04	

5. Relevance to NASA Objectives

This work is relevant to the objectives of the Solar System Workings (SSW) program. As requested in the Announcement of Opportunity (AO), we will “characterize and understand the … physical features of planetary surfaces”. In this proposal we “seek to understand processes that occur throughout the solar system” and how those processes, cryovolcanism and electron bombardment, affect planetary surfaces. We further seek to “understand the … physical processes that [plasma interactions] may drive”. Our derived surface thermophysical properties of Europa will be particularly useful for planning of instruments on the Europa Clipper and future missions to Europa.

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Academic Record

January 2000: PhD - Cornell University: Astronomy (Defended September, 1999)
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August 1997: M.S. - Cornell University: Astronomy
May 1994: B.S. - State University of New York at Buffalo: Physics (magna cum laude)

Professional Experience

2010-present Senior Scientist, Planetary Science Institute
2007-present Associate Professor of Physics: University of Redlands
2001-2007 Assistant Professor of Physics: University of Redlands
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Grants Awarded:

Quantitative measurements of active Ionian volcanoes: Global distribution and temporal variability using Galileo NIMS, PPR, ground-based, and New Horizons data; NASA Outer Planets Research Program 2013-2016; Julie Rathbun, PI

The Ins and Outs of the Io Plasma Torus: A Comparison of Two Decades of Io Plasma Torus and Io Volcanic Data; NASA Outer Planets Research Program 2013-2016; Jeffrey Morgenthaler, PI

Io in the Near Infrared: observations from New Horizons and comparison to Galileo PPR and NIMS; NASA Jupiter Data Analysis Program 2009-2012; Julie Rathbun, PI

Geologic Mapping of Io: GIS Database & Regional mapping; NASA Outer Planets Research program 2008-2011; David Williams, PI

Studying the Galilean satellites with Galileo and ground-based data: Io's volcanoes from the ground and incorporating Galileo PPR data into ArcGIS; NASA Outer Planets Research program 2008-2010; Julie Rathbun, PI

Io Volcanism, and Galilean Satellite Surface Temperatures; NASA Planetary Geology and Geophysics Program 2007-2010; John Spencer, PI

Modeling volcanism on Io using groundbased and Galileo data; NASA Outer Planets Research Program 2006-2009; Julie Rathbun, PI

Io Volcanism, and Galilean Satellite Surface Temperatures; NASA Planetary Geology and Geophysics Program 2004-2007; John Spencer, PI

Mutual occultations between the Galilean satellites: Two-dimensional imaging of Ionian volcanoes, particularly Loki which may erupt predictably; NASA Planetary Astronomy Program 2002-2005; Julie Rathbun, PI

Selected Publications:

Rathbun, J.A., Spencer, J.R., Lopes, R.M., Howell, R.R. Io's active volcanoes during the New Horizons era: Insights from New Horizons imaging, Icarus, **231**, *261-272*, 2014.

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Current and Pending Support

Julie Rathbun

A. Current Support

Quantitative measurements of active Ionian volcanoes: Global distribution and temporal variability using Galileo NIMS, PPR, ground-based, and New Horizons data; NASA Outer Planets Research Program, Terry Hurford (terry.a.hurford@nasa.gov); Julie Rathbun, PI; 2013 September 1 to 2016 August 31, $157K; 0.16 FTE

B. Pending Support

Synoptic monitoring of Io volcanic activity and the Io plasma torus during the Juno mission; NASA Solar System Observations Program; Jeffrey Morgenthaler, PI; 2015 January 6 to 2018 January 5, $590K; 0.12 FTE

Researchers at the Planetary Science Institute, a non-profit organization, support their salaries and research and travel expenses entirely from funding received from grants and contracts. There are no institutional funds available to subsidize research projects. Therefore, each scientist writes proposals to cover 12 person-months (2080 hours) each year. Once the funding level reaches a full person-year, any remaining pending proposal(s) will be withdrawn or, if subsequently awarded, managed through the appropriate allocation of effort and personnel needed to achieve the funded objectives on the timescales proposed.

Budget Justification

Salary

For each year of the proposal (2 years total), salary is included for PI Rathbun in the amount of 0.12% FTE (1.5 months). These amounts are based on the time required to reduce all data and perform all the scientific analyses. Details and breakdown of tasks and time dedicated to each is given in Table 1. No salary support is requested for collaborators Spencer, Howett, and Patterson. Collaborator Spencer has extensive experience studying Europa and using multiple data sets and will contribute several days to discussing the project with the PI and advising on data sets and analysis tools. Collaborator Howett has extensive experience analyzing theromophysical data on the Saturnian satellites. She will contribute several days each year to discussing results and placing in a greater context. Collaborator Patterson has experience with Europa's surface geology and electron bombardment. He will advise on shapes of bins to use.

Operations and Publications

Funds are requested for operations to support this research project. The software required for the analysis may include VICAR, ISIS, IDL, and Arc GIS. The PI has access to all of these software packages. This project will result in the publication of at least one peer-reviewed article, funds are therefore necessary for page charges by the journals (30 publication units at $30 per publication unit for JGR). The PI will travel to the Lunar and Planetary Science Conference (LPSC) each year to present results and updates from this project.

Personnel and Work Effort

	2013	2014	2015
Julie Rathbun, PI	0.12 yr	0.12 yr	0.12 yr
John Spencer, Collaborator	0.01 yr	0.01 yr	0.01 yr
Carly Howett, Collaborator	0.01 yr	0.01 yr	0.01 yr
Wes Patterson, Collaborator	0.01 yr	0.01 yr	0.01 yr

Facilities and Equipment

The only required equipment for this project is a computer running the software mentioned in the proposal. A computer and the software is already accessible to the PI.

The cognizant government audit agency is the Office of Naval Research.
The administrative contracting officer is Linda Shipp, Department of the Navy, 875 N. Randolph St., Suite 1425, Arlington VA 22203-1995.