Possible Nature and Detectability of Endogenic
Thermal Anomalies on Europa

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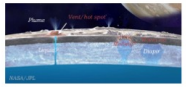
Background/Motivation:

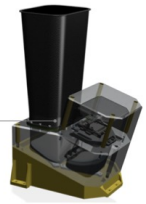
How active is Europa at the present time?



What types of thermal anomalies do models of Europa's ice shell and interior predict?

Previous Work:
Endogenic activity is likely [1] given Europa's young surface age of < 100 Myr [2]. Tidal heating may drive ongoing activity [3, 4]. Temperature is a fundamental indicator of activity [5]. Previous studies have investigated the cooling behavior [6] and detectability [7] of some possible thermal anomalies on Europa, which could be associated with geologic features such as **lenticulae, chaos, ridges and bands**.

The Europa Thermal Emission Imaging System (**E-THEMIS**) is a multi-wavelength infrared instrument designed to search for thermal anomalies as part of NASA's planned Europa Clipper ("multiple flyby") mission. It is based on the highly successful THEMIS investigation at Mars [8].



E-THEMIS rendering (Credit: ASU)

Methods:

We ran Monte Carlo simulations using a discrete probabilistic model for resurfacing, incorporating temperatures and lifetimes based on numerical thermal models for four feature types: Ridges, Bands, Chaos, Lenticulae.

Likelihood of hot spot occurrence:

- Global average resurfacing rate:

$$\langle \dot{A} \rangle = A / t_{surf} \sim 1 \text{ km}^2 \text{ yr}^{-1}$$

- Average occurrence rate for feature i with area A_i (= L_i^2) whose total population occupies a fraction of Europa's surface f_i:

$$\langle R_i \rangle = f_i \langle \dot{A} \rangle / A_i$$

- Average time between events $\dot{t}$:

$$\tilde{t}_i = \langle R_i \rangle^{-1} = \frac{A_i}{f_i \langle \dot{A} \rangle}$$

- Probability of N events during interval Δt, assuming events are independent:

$$P(\Delta t, N) = \left(\frac{\Delta t}{\tilde{t}_i} \right)^N \frac{e^{-\Delta t / \tilde{t}_i}}{N!}$$

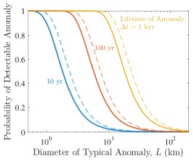


Figure (above): *Probability of at least one event occurring during the specified time interval Δt, representing the detectable lifetime for a given thermal anomaly size. Solid lines indicate f_i = 0.3; dashed lines indicate f_i = 0.5.*

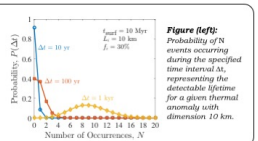


Figure (left): *Probability of N events occurring during the specified time interval Δt, representing the detectable lifetime for a given thermal anomaly with dimension 10 km.*

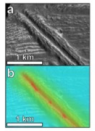
Temperatures and lifetimes:

- Buried liquid layer with temperature T_l produces surface anomaly:

$$\delta T \sim k \frac{T_l - T_s}{4 \sigma T_s^3 z}$$

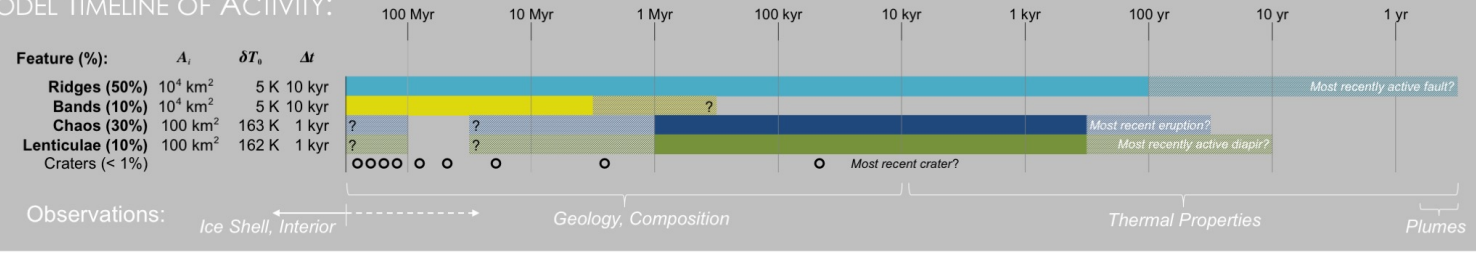
➢ **Maximum detectable depth: ~0.1 – 1 km**

- Shear heating [13] (*upper figure*): detectable lifetime Δt ~ 10 kyr, δT ~ 5 K
- Freezing and cooling of liquid water ~10 – 100 m thick: detectable lifetime Δt ~ 0.01 – 1 kyr [6]
- Chaos model: Δt ~ 1 – 10 kyr, δT ~ 163 K (melting) [6]



***Lower figure**: melting/warm ice model for a thick layer (> 100 m)*

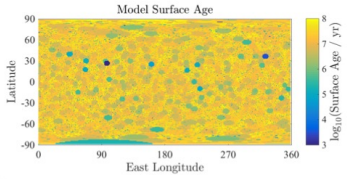
Model Timeline of Activity:

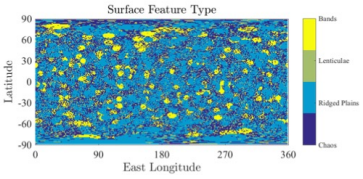


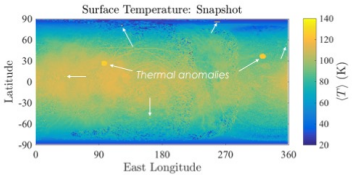
Results:

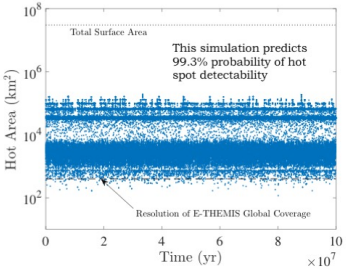
Panels at right show example simulation using model parameters above, for a total duration 200 Myr.

The surface temperature "snapshot" is the diurnal mean temperature map at an arbitrary instant in time.









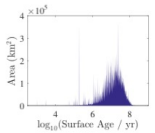


Figure (above): At the end of the simulation, the surface is composed of units of various ages, with an average of ~60 Myr.

***Figure (left)**: Each point represents one instant in time; points above the dashed line are detectable.*

Predictions for E-THEMIS:

- Thermal anomalies expected for modeled styles of resurfacing: emplacement of warm ice or liquid water, or shear heating on faults with sufficient dissipation [13]
- Subsurface heat sources (e.g., liquid water) detectable within ~100 m to 1 km
- Daytime and nighttime measurements needed; also visible albedo (*right figure*)
- Background heat flow could be measured if >200 mW m^{-2} at the equator, or >100 mW m^{-2} at the pole

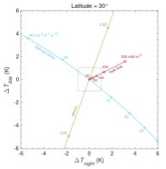


Figure (left): *Temperature differences ΔT during the day and night, relative to the background. Error bars indicate uncertainties on individual E-THEMIS measurements. Each point shows expected ΔT values for the given variations in thermal inertia, albedo, and heat flow.*

Conclusions:

Models of Europa's ice shell and interior can be tested by the presence or absence of thermal anomalies:

1. Thermal anomalies **are likely to be present on Europa today**, if resurfacing occurs via warm ice or liquid water, and is either continuous or episodic with recurrence interval < 10 kyr
2. Expected **thermal anomalies are detectable** by E-THEMIS with >99% likelihood for the model above
3. Smaller, more frequent thermal anomalies are more likely to be detected, even if they are sub-pixel hot spots

Detection depends critically on accurate measurements of both daytime and nighttime temperature, and visible albedo. NASA's planned Europa Clipper mission and E-THEMIS are being designed to achieve these objectives.

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Pre-decisional information – for planning and discussion purposes only