Mathematical Exploration of Life in Europa's Icy Shell

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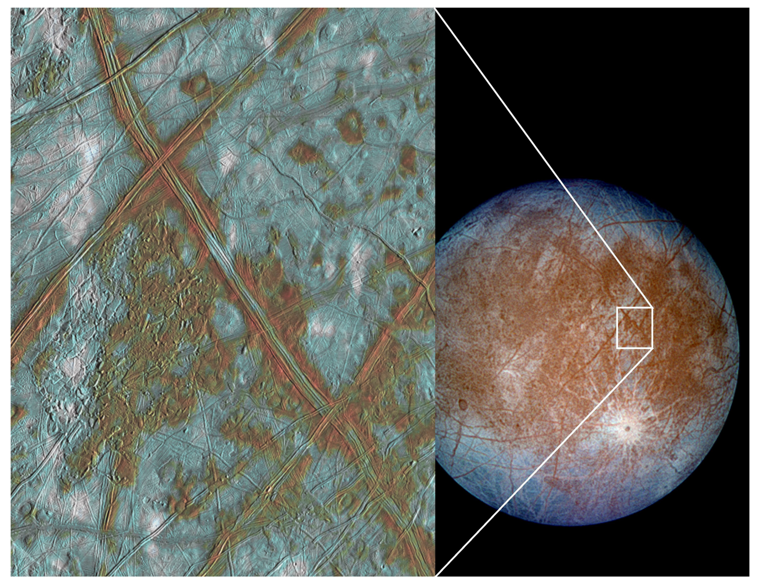
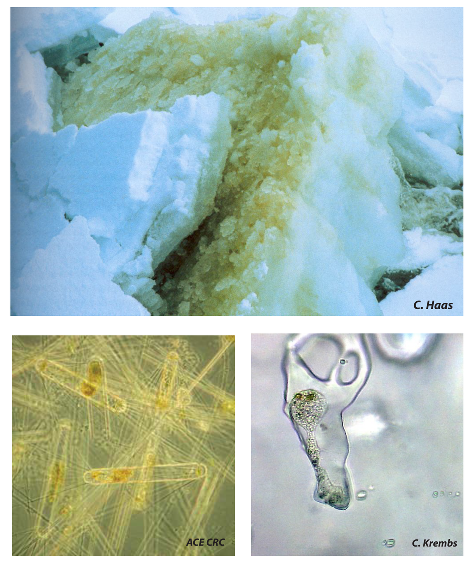
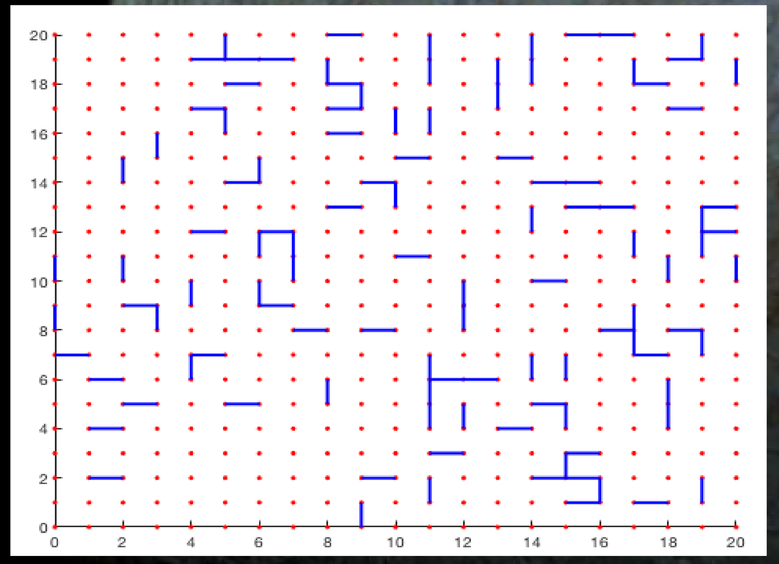
Introduction and Background

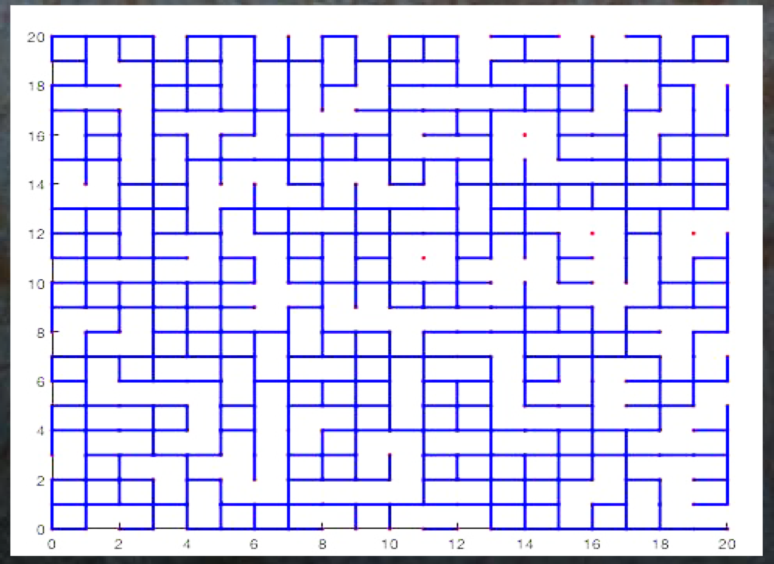


- Europa is one of Jupiter's icy moons, slightly smaller than Earth's.
- It is thought to be composed of a solid core surrounded by a large salt water ocean with an icy shell.
- Because it is one of the few bodies in our solar system with water, Europa is considered one of the best places in our solar system to search for simple extraterrestrial life.

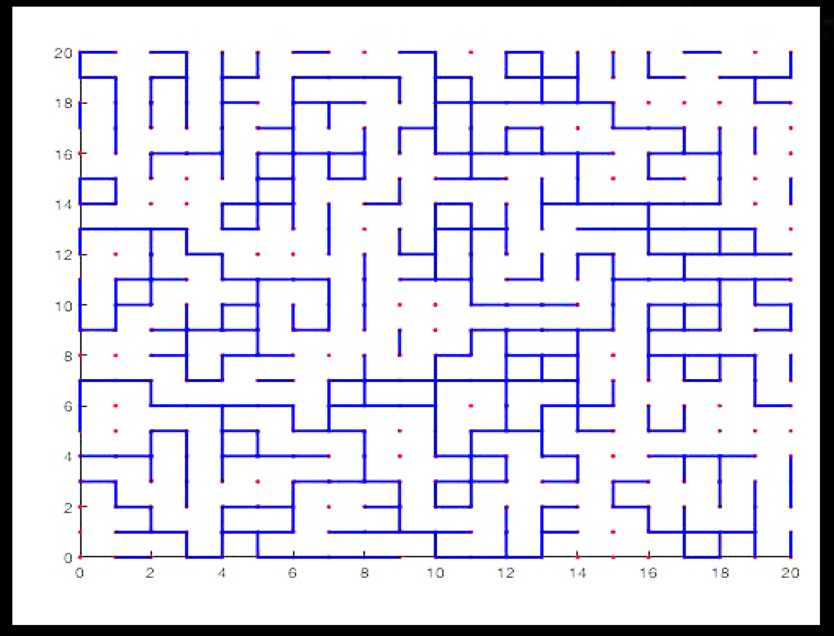
- Within sea ice on Earth, sections of non-frozen salt water create briny inclusions.
- Inclusions connect, creating channels that allow nutrients and other necessities for life to percolate through the salty ice.
- These channels allow certain extremophiles to thrive in permeable layers of Earth's ice.
- **Potential life on Europa could be similar to extremophiles in Earth's sea ice, living in a permeable layer of Europa's icy shell.**







Bond percolation models. Bonds are filled at a probability p. For low probabilities, the system will not percolate (upper left). Higher probabilities (upper right) are very likely to percolate.
The percolation threshold (lower left) is the lowest probability for which the system is still likely to percolate.



- Each bond represents a non-frozen channel in the ice that water is able to pass through.
- At the depth of the percolation threshold, the channels connect and water is able to freely percolate through the ice.
- The percolation threshold for Earth's sea ice occurs at -5 ° C.

Methods and Results

To determine the thickness of the layer of Europa's ice shell with salty inclusions, we use the heat equation:

$$D\nabla^2 U = \frac{\partial U}{\partial t}$$

One-dimensional form:

$$D\frac{\partial^2 U}{\partial x^2} = \frac{\partial U}{\partial t}$$

Assume temperature does not change as a function of time:

$$\frac{\partial}{\partial x}\left[D\frac{\partial U}{\partial x}\right] = 0$$

Simplifies to a linear function where U(x) is the temperature as a function of depth, D is the thermal conductivity of the ice, and the other variables are unknown constants.

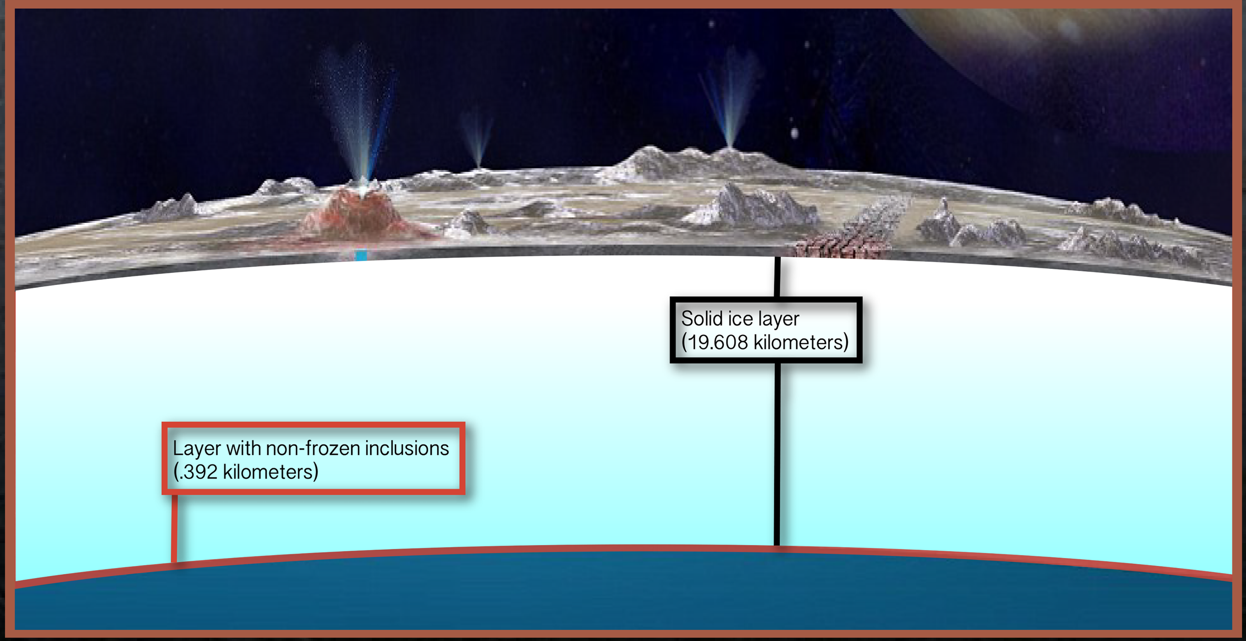
$$U(x) = \frac{C}{D}x + \beta$$

Assumptions:

Composition: Water with 1% $MgSO_4$ concentration
Surface Temperature: -173.15 ° C (100 K)
Depth: 20 km
Melting Point: -0.31 ° C (272.84 K)
Thermal Conductivity: 2.3 W/mK

Using known initial conditions, we derive a linear model of temperature as a function of depth:

$$U(x) = 8.642x + 100$$



Estimated thickness of the layer of Europa's shell with non-frozen inclusions.

- The eutectic temperature of the water + $MgSO_4$ system is -3.7 ° C (269.45 K). At temperatures higher than the eutectic, non-frozen inclusions will exist in the ice.

$$269.45 = 8.642x + 100$$

$$x = 19.608$$

- Depth of frozen solid ice on Europa: 19.608 km.

Discussion and Future Work

- Because the eutectic point of the $MgSO_4$ and water system is so close to its melting point, the layer with non-frozen inclusions has an extremely narrow temperature range.
- Europa's ice shell is deep enough that this layer could still be hundreds of meters thick, including a percolating layer through which liquid could be transported.
- The thickness of both layers would likely be highly sensitive to slight changes in temperature.
- Any potential life in Europa's ice shell must be able to survive in these delicate conditions.

- Currently, this model is limited by the amount of available knowledge of Europa.
- The temperature distribution in Europa's ice is unlikely to be linear and one-dimensional, as we assume in this model. Future models should use more complex versions of the heat equation to reflect the complex conditions on Europa.
- We would like to determine the percolation threshold of Europa's ice and approximate the thickness of its permeable layer.

References

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