Virtual Research Presentation Conference

Ice Penitente Modeling for Icy Worlds Surfaces

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Tutorial Introduction

Abstract

Penitentes are sharp, bladed ice structures found in high altitude equatorial regions on Earth. Their existence has been speculated on icy airless bodies including Europa. If they exist, it would make landing more difficult. At Europan temperatures, sublimation rates are very slow, meaning that lab experiments must run for ~1000 years to produce results. We therefore need a model, which can be validated with experiments at intermediate temperatures between Earth and Europa. Existing models rely on atmosphere and fluid dynamics relations, and this physics breaks down at the hard vacuum conditions of Europa, where molecules may travel 1000km before striking another particle.

Our newly-developed computational model simulates incoming sunlight interactions with snow under vacuum and resultant warming. Our second model uses this warming to predict molecular sublimation and surface shape change. We use a 2D photon Monte Carlo (PMC) approach to predict surface scattering and absorption, and penetration with multiple internal scattering. Heating from the PMC model feeds a heat transfer model to predict temperatures, which feed into a Free Molecular (FM) Monte Carlo code to predict sublimation. We validated the model against a JPL experiment, and find that penitents in vacuum tend to warm at the peaks and shrink.

Penitentes on Earth
https://www.everythingselectric.com/penitentes/

Problem Description

a) On Earth, meter-scale ice penitents form in cold, dry conditions

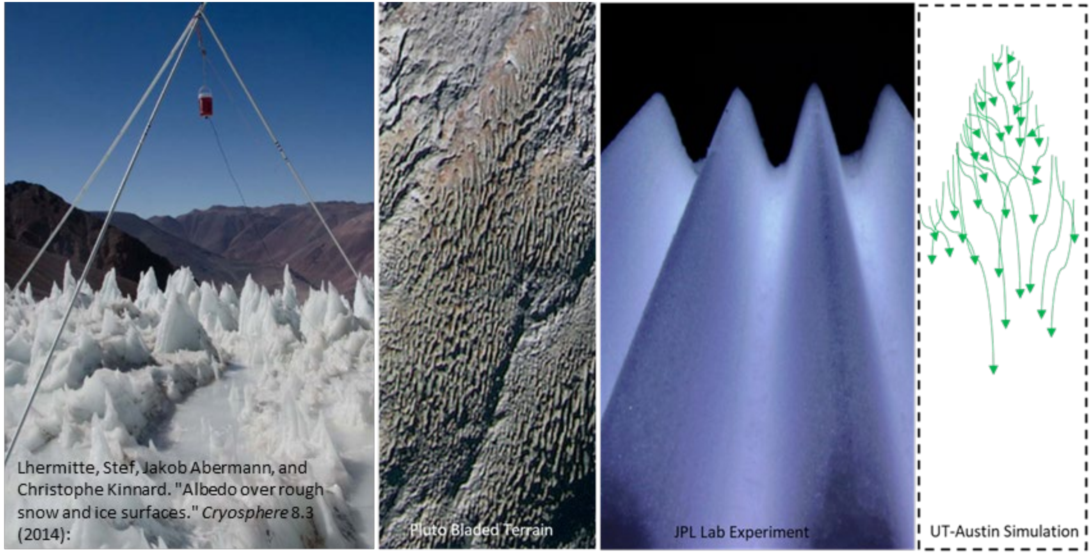
b) These are likely present on Pluto, which also has an atmosphere

c) Can they form on airless worlds such as Europa, where they would pose a landing challenge?

d) SOA models rely on fluid dynamics not valid for airless worlds

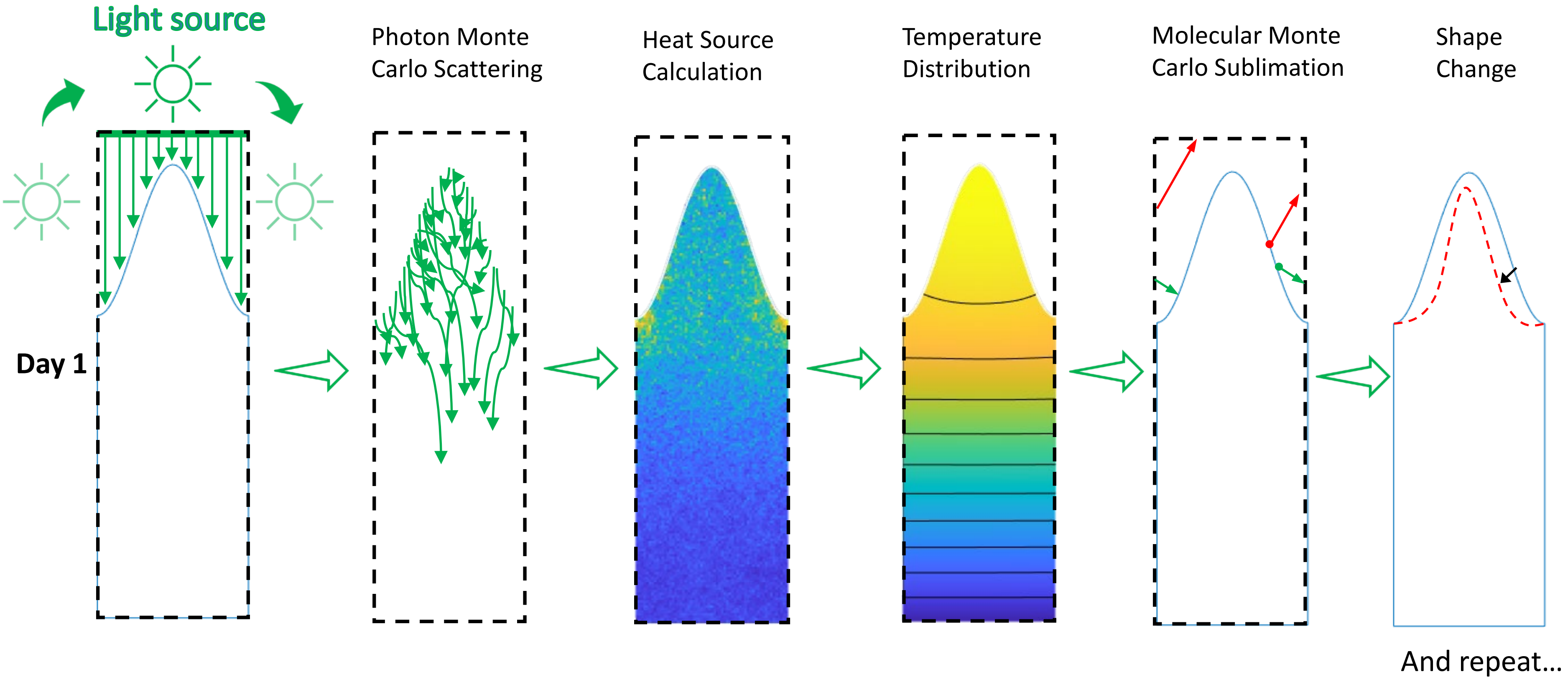
e) Experiments at Europa Temperature would take ~1000 years to see results

f) Our model works for these vacuum conditions and compares well with experiments at intermediate temperatures.



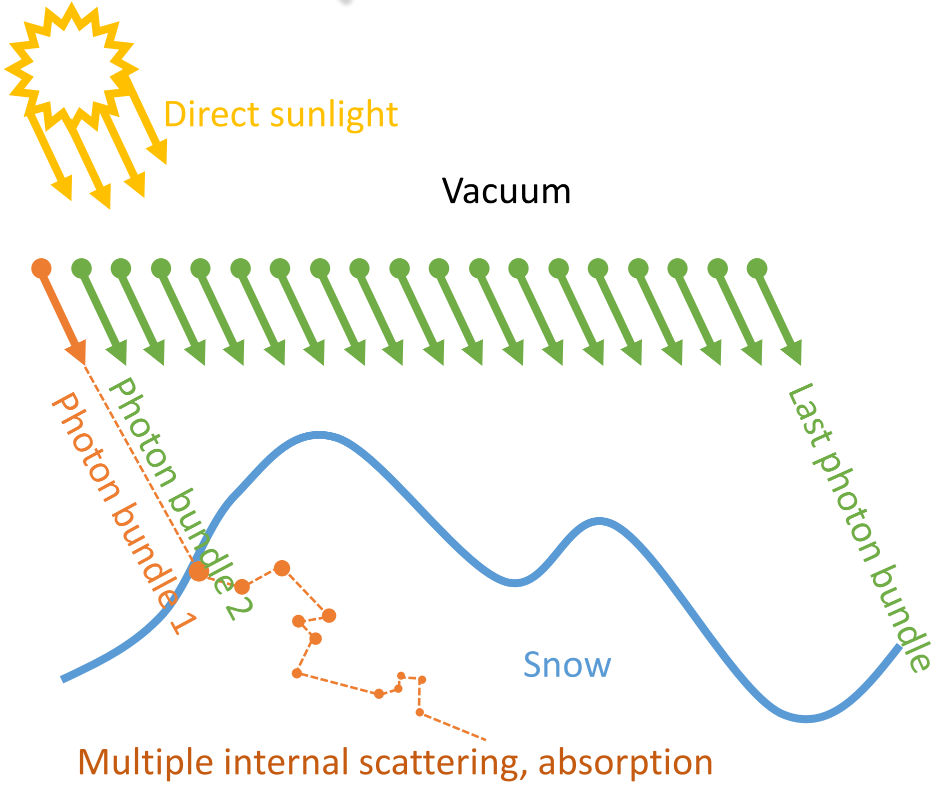
Earth Pluto Lab Model

Methodology



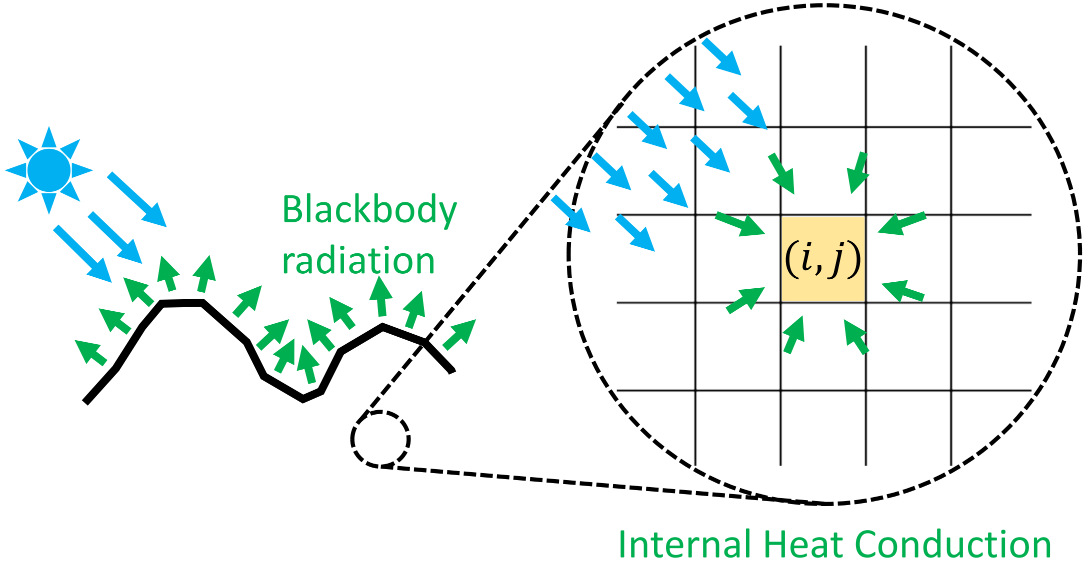
Photon Monte Carlo

- Incident sunlight onto surface with some shape
- Mie theory multiple internal scattering, reflection, absorption
- Sweep the sun angle for diurnal variation
- This produces a <u>spatial power deposition map</u> at each timestep



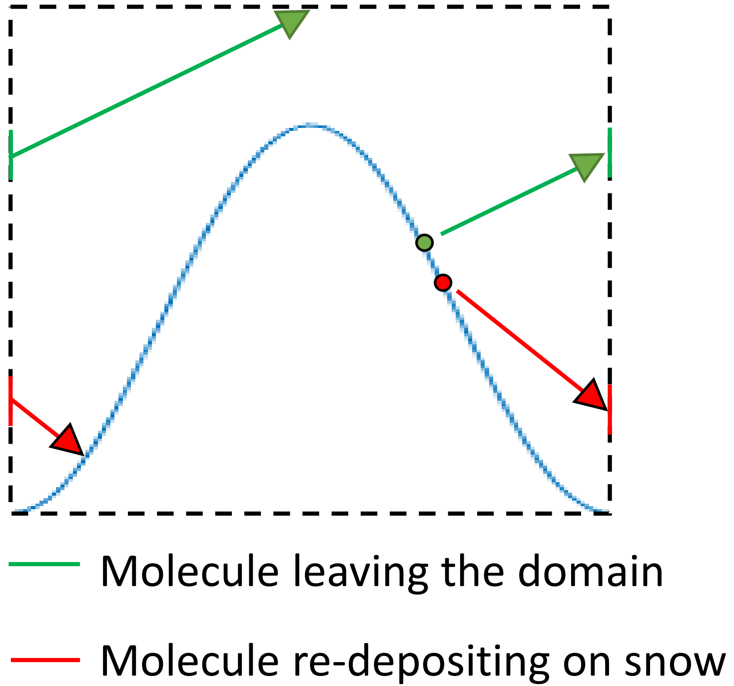
Heat Transfer

- Power deposition from PMC code feeds this bulk heat transfer model
- This produces a <u>temperature map</u> at each timestep.



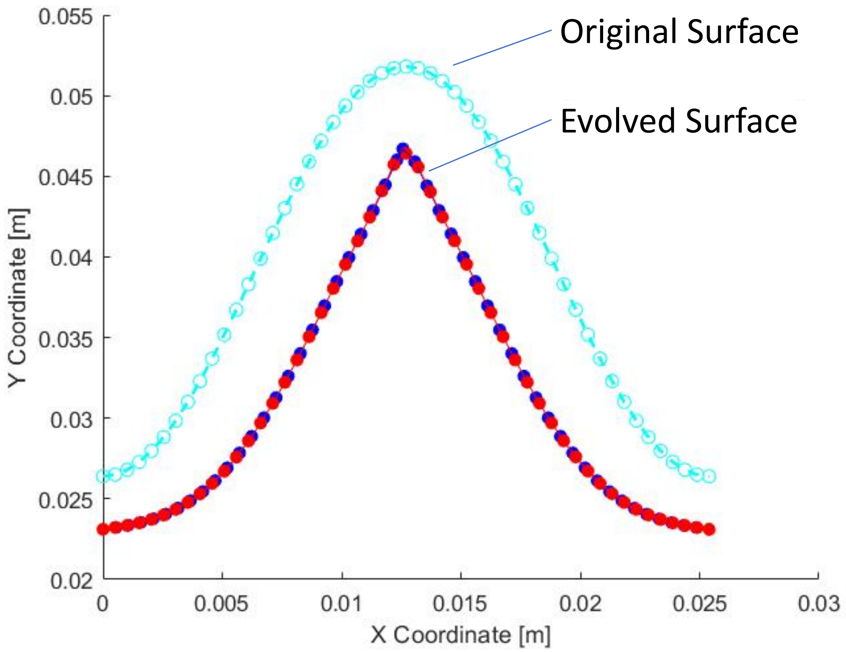
Molecular Monte Carlo

- Surface temperature map output from PMC/HT code feeds this model
- Sublimation rates from kinetic theory
- Trace molecule trajectories, including striking adjacent surfaces for redeposition.
- Track <u>mass loss and gain at each surface element</u>.



Surface Evolution

- Surface mass change from MMC code feeds this model
- Move each surface element up or down based on mass loss/gain
- Produce a new surface shape for the given timestep.
- Iterate all these codes to evolve the surface over long times.



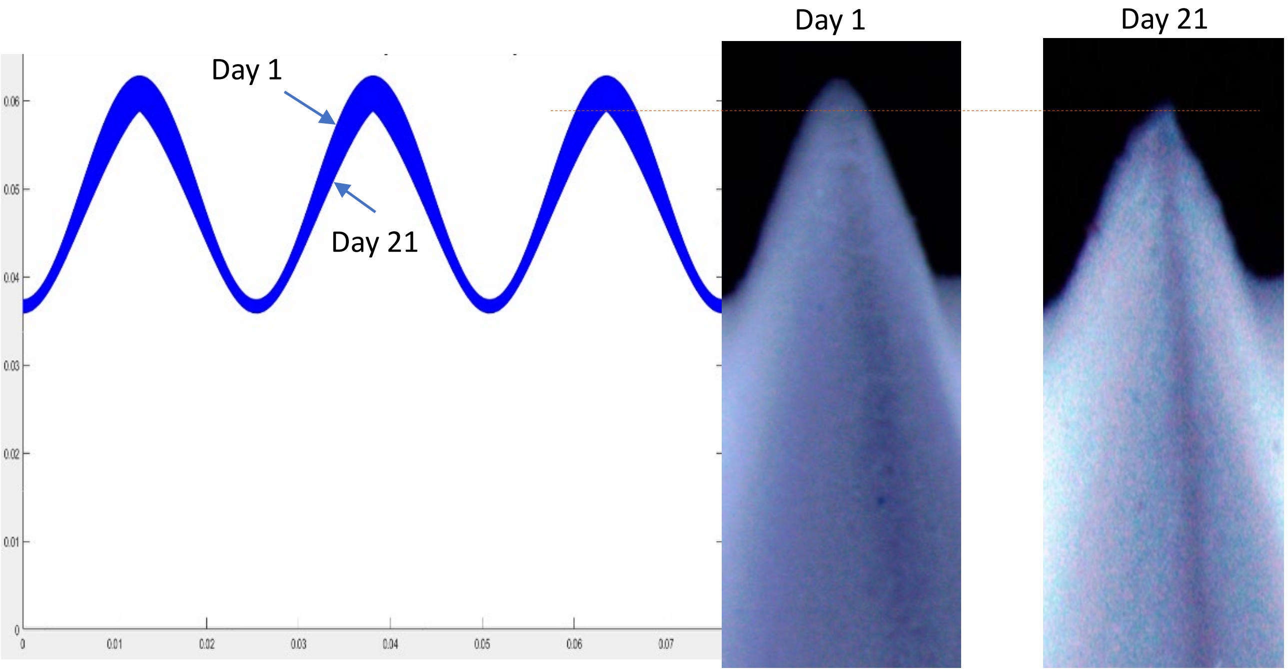
Results

JPL Simulation Comparison with Experiment

a) Working model for surface shape change
   a) Validated with JPL test

b) Penitentes shrink at these conditions
   a) May be good news for lander

c) Next steps
   a) Simulate range of conditions likely found on Europa
   b) Snow/Ice Properties
   c) Aspect ratios, size effects, random noise



Publications and References

Journal publication draft, to be submitted to Icarus before Oct. 1

Additional References:

- Claudin, P., Andreotti, B., Plapp, M. Vignoles, G., Jarry, H. Physical processes causing the formation of penitentes. Physical Review, E 92, 033015 (2015).
- Hobley, D. E. J., Moore, J. M., Howard, A. D., Umurhan, O. M. Formation of meter-scale bladed roughness on Europa's surface by ablation of ice., Nature Geoscience, Vol. 11, pp. 901-904 (2018).
- Hand, K. P., Berisford, D., Daimaru, T., Foster, J., Hofmann, A. E., Furst, B., Penitente formation is unlikely on Europa. Nature Geoscience, Vol 13 (2020).
- Moores, J. E., Smith, C. L., Toigo, A. D., & Guzewich, S. D. Penitentes as the origin of the bladed terrain of Tartarus dorsa on Pluto. Nature, 541(7636), 188–190 (2017).

Simulating Radiative Heat Transfer for Penitente Formation on Europa

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Abstract

Penitentes are sharp, bladed snow structures found in equatorial regions on Earth. Their existence has been speculated on icy airless bodies including Europa. We have developed a computational model to simulate radiative transfer and penitente warming in a vacuum environment. We use a 2D photon Monte Carlo (PMC) approach to predict surface scattering and absorption, as well as penetration and multiple internal scattering within the granular snow medium. Power absorption distributions from the PMC model feed into a heat transfer model to predict temperature distributions. After validating the model with experimental results, we simulate the sun irradiating a sinusoidal penitente field on Europa in a diurnal cycle. Our results show that crests reach higher temperatures than troughs by $10\ K$ to $50\ K$, despite higher energy absorption in the troughs. This temperature difference suggests that penitente fields sublimate faster at the crests and are therefore unsustainable on Europa.

1. Introduction

Sharp, bladed snow structures known as penitentes have long been observed in cool, dry regions with high sun exposure (Betterton et al., 2006). Their general growth derives from ablative processes driven by radiative solar heating of the snow's surface. Penitentes have been observed on Earth primarily near the equator, especially the Andes mountains and Mt. Kilimanjaro in Africa. These structures are also theorized to exist on Pluto (Moores et al. 2017) and Mars (Svitek et al., 1988; Nguyen et al., 2019) and within equatorial regions on Jupiter's moon Europa (Hobley et al., 2018). The presence of these surface