The Feasibility of Detecting Fluorescing Amino Acids in Near-Surface Ice on Europa Using Laser-induced UV Spectroscopy from Orbit

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Introduction

Europa is a prime candidate in the search for extraterrestrial life due to its subsurface ocean, believed to be in contact with a rocky mantle [1]. Potential hydrothermal activity on the ocean floor presents a plausible setting for synthesizing organic molecules from inorganic precursors [2].

Aromatic amino acids, namely phenylalanine, tyrosine and tryptophan, are essential for life as they play critical roles in cellular processes [3]. Their molecular structure enables them to fluoresce in the 200-400 nm range – suitable for detection and characterization. Their synthesis is unlikely to occur abiotically, making them compelling biosignatures [4].

The detection of salts and ocean-derived compounds on Europa's surface suggests that oceanic material, including organics, may be reaching the surface [5].

However, their longevity on the surface governed by degradation that is driven primarily by charged particles caught in Jupiter's magnetosphere and solar ultraviolet (UV) radiation [6, 7].

We modeled two key degradation mechanisms of aromatic amino acids on Europa's surface, depending on location, depth, and time: radiolysis and photolysis.

Fig. 1 Artistic rendering of internal and external processes affecting Europa's ocean and ice shell. Credit: NASA/JPL

Surface Degradation Mechanisms

Radiolysis: Using a particle physics code [8], we simulated the interaction of Europa's near-surface ice with energetic magnetospheric particles, namely electrons, which exhibit lens-like bombardment patterns that are hemisphere-dependent, and ions, which bombard the surface roughly uniformly [9, 10]. We then computed their energy deposition rates as a function of depth and derived radiolytic degradation rates of aromatic amino acids, based on experimental measurements [11, 12] (see Fig. 2).

Photolysis: Leveraging recently measured optical properties of vapor-deposited ice [13], we estimated them at- and post-deposition on Europa's surface, accounting for its thermal evolution, and amorphization by charged particles [14, 15]. Amorphous ice, which is prevalent at high latitudes due to slow crystallization [16], significantly scatters UV photons. We computed photolytic degradation rates for aromatic amino acids, which is significantly attenuated as a function of ice depth. These rates were derived from experimental measurements [6, 12] (see Fig. 2).

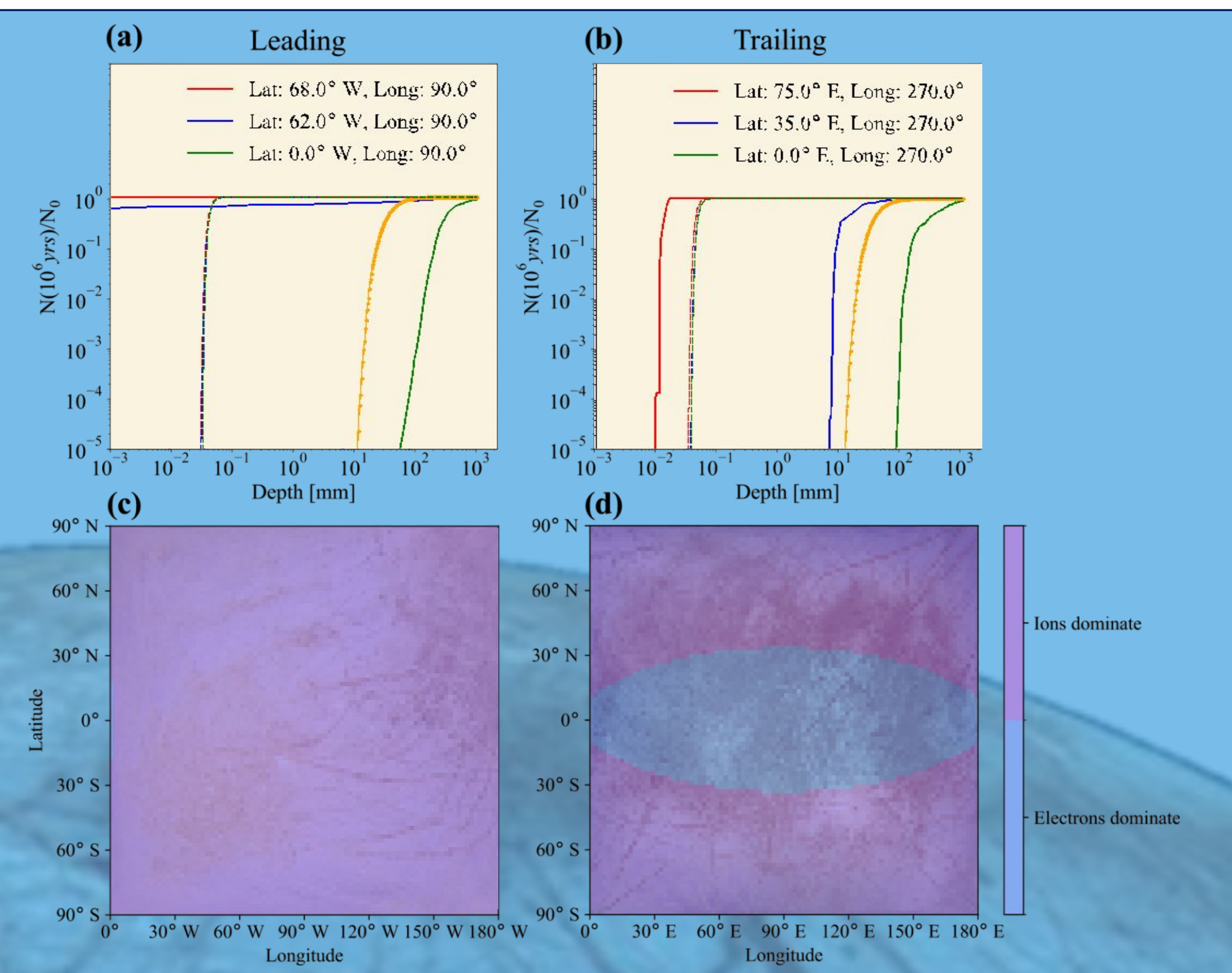

Fig. 2 Effectiveness of distinct degradation mechanisms on Europa. **(a)** and **(b)** Relative amino acid concentrations at select locations on the leading and trailing hemispheres, respectively, after being subjected to distinct degradation mechanisms for 10^6 years. **Dashed lines**: photolysis (photons). **Solid lines**: radiolysis (electrons). **Dotted orange line**: radiolysis (ions). **(c)** and **(d)** Most effective degradation mechanism at different locations of the trailing and leading hemispheres, respectively, after 10^6 years for a radiolytic constant of 0.034 Mgy^{-1}.

Estimating Fluorescence

We coupled the two degradation mechanisms to estimate the net longevity of aromatic amino acids as a function of location and depth in Europa's near-surface ice, assuming it is vapor-deposited.

Our findings indicate that such a laser can effectively penetrate the uppermost ~millimeter of vapor-deposited ice under Europan conditions, establishing this depth as the critical longevity depth scale of amino acids for significant fluorescence signal detection.

Assuming initial concentrations of 0.1, 3.6, and 6.6 ppb for try, tyr, and phe [17, 18], we estimated the permissible degradation of the effective upper layer of ice required to produce a statistically significant detection of aromatic amino acid fluorescence across Europa for two plausible detection strategies: A detection from the surface or during a flyby at a 10-kilometer altitude, for three considered radiolytic constants [11, 19] (see Fig. 3).

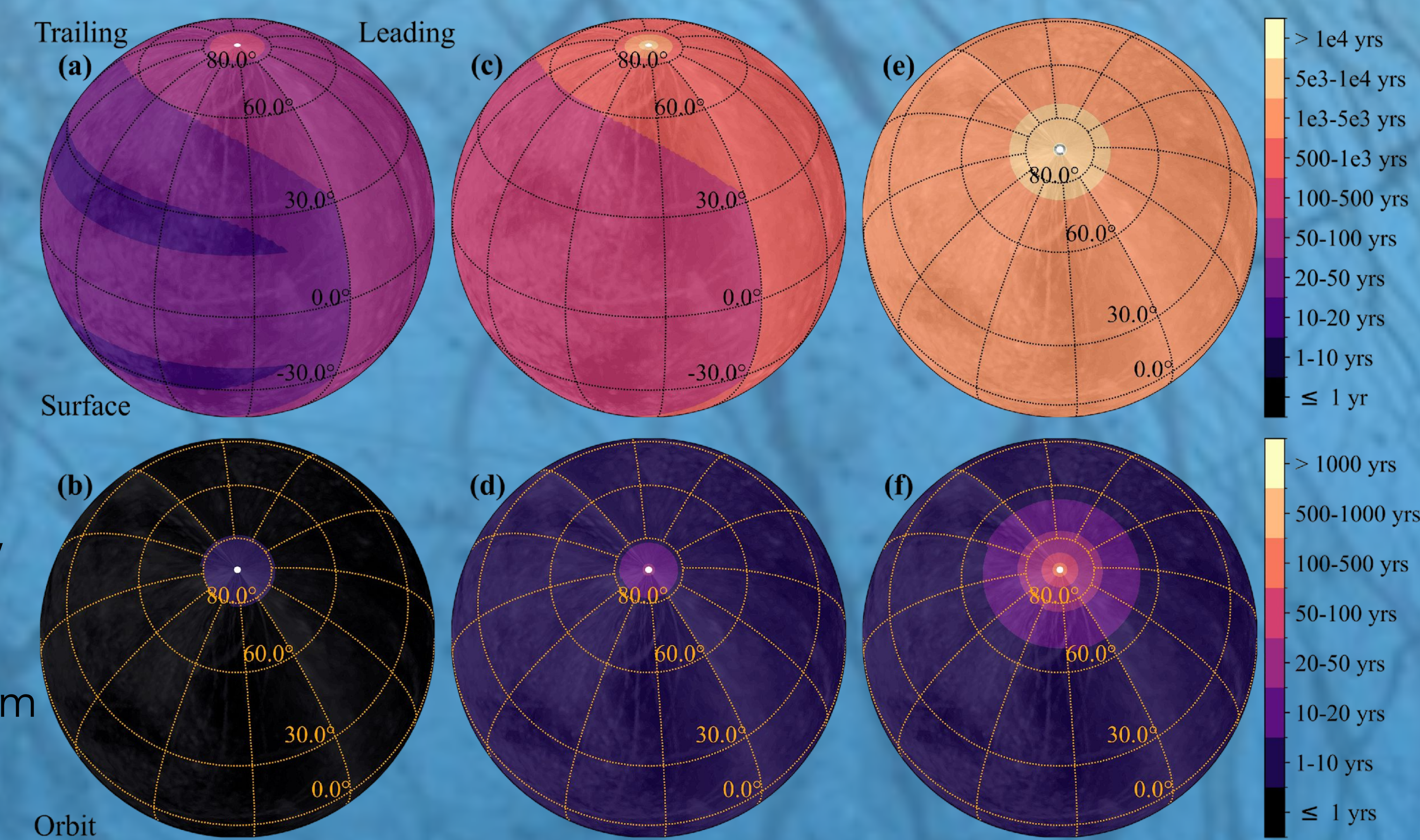

Fig. 3 Degradation timescales of aromatic amino acids in vapor-deposited ice, allowing for an SNR of 3 in laser-induced fluorescence detections, for three radiolytic constants: 0.034, 0.0034 0.00034 MGy^{-1} (**left to right**). **Top**: lander-based detection. **Bottom**: close-flyby detection.

Conclusions

We explore Europa's potential to preserve fluorescent biomolecules embedded in near-surface ice despite the harsh conditions on its surface, and the ability to detect these molecules.

The degradation rates of these molecules were found to vary significantly with latitude and depth, influenced by the intensity of charged particle bombardment and the phase of the ice.

We show that when embedded in freshly-deposited ice, laser-induced fluorescence spectroscopy can detect these biomolecules even from orbit.

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arXiv: https://tinyurl.com/biomoleculeseuropa