ELECTRONIC LIFE-DETECTION INSTRUMENT FOR ENCELADUS/EUROPA (ELIE).

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Introduction: Habitable regions of Europa may include a subsurface ocean as well as transient liquid environments within its icy shell. Recent work suggests potential ocean-surface communication on 1–2 million-year (My) timescales [1]. Even more rapid communication may occur in chaos regions, which are thought to result from liquid exposure at the surface [2]. Current evidence is consistent with such events generating transient plumes [3], which could be observed by Europa Clipper, or past events inferred from remote sensing data.

On the basis of radiation-mediated bacterial killing models, organisms frozen into surface ice could remain viable at near-surface depths (10–100 cm) over 1–10 ky [4]. The Europa Lander will target samples at depths >10 cm [5], potentially enabling recovery of viable organisms if sampling conditions are ideal.

Any life on Europa would likely represent a separate genesis event from Earth life, based on low ($<10^{-5}$) probabilities of meteoritic transfer of viable organisms from Earth and Mars [6]. Life detection approaches should therefore not only target life *as we know it* (to detect forward contamination or test universality of biochemistry), but also *as we don't know it,* to lower the risk of false negatives. In the absence of extant life, detecting ancient life, or the extent to which prebiotic chemistry may be present, would remain invaluable.

ELIE Instrument: We propose to target prebiotic, ancient, or extant life at Europa using a novel fully-electronic single-molecule detection strategy. Now in early development (PICASSO), the Electronic Life-detection Instrument for Enceladus/Europa (ELIE) instrument will utilize quantum electron tunneling between nanogap electrodes to interrogate the electronic structure of single molecules (**Fig. 1A**).

Technology: Nanogaps are formed by breaking a gold nanowire embedded on a silicon chip (**Fig. 1B**). Bending is then used to control the gap size in the sub-nanometer regime (0.5-2.0 nm) to target a range of analyte sizes. A molecule can be identified by its characteristic conductance (or equivalently, current in picoamps at a given bias voltage, **Fig. 1C**) and interaction time as a function of gap size.

Prior work has demonstrated the ability to detect and distinguish among amino acids [7], and to detect RNA and DNA bases and short base sequences [8]. Chirally-specific detection may also be possible.

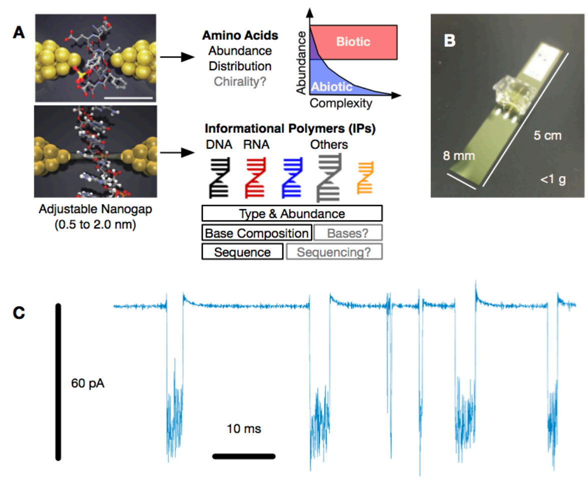

Figure 1. Instrument overview. A) ELIE will utilize an adjustable nanogap to measure at least two key biosignatures: 1) Amino acid abundance distribution, and 2) Presence of informational polymers, not limited to DNA and RNA. **B**) Nanogap chip. **C**) Single amino acid events (proline, 10 µM; 100 mV applied bias).

The extrapolated limit of detection (LOD) for single amino acids, without any preconcentration, is ~200 ppt after 5 min of sampling (~1 pMol/g). Integrating upfront separation methods will enhance specificity while further improving sensitivity.

Our lab-bench prototype integrates a nanogap chip, low-noise amplifier, and a laptop for data processing. Bandwidth requirements are around $\sim 10^3$ smaller than solid state nanopores. Even so, kHz to MHz sampling rates result in large data files that are reduced to events prior to classification. We target a ~1 kg flight instrument mass, including embedded data processing, suitable for Europa Lander or as part of other Ocean Worlds life detection missions.

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