

EUROPA

Biosignature hide and seek

A new model predicts locations on the surface of radiation-blasted Europa, the ocean moon of Jupiter, where biochemical signatures of life emergent from the subsurface ocean might survive long enough for detection on the moon's changing surface.

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Put it the dangerous and predictably short lives of alien microbes on the surface of the ocean moon Europa. As they emerge from the protection of the more benign environments of Europa's subsurface ocean and ice crust to the irradiated lands of the moon's surface, they might be able to run but could they hide, and possibly be detected by a future Europa lander¹, as envisaged by NASA? And if found, where might they be most recognizable after varying levels of irradiation? In this issue of *Nature Astronomy*, Tom Nordheim et al.² model the surface irradiation by Jovian magnetospheric electrons and protons to show that high latitudes offer the greatest promise for detection of minimally irradiated organisms at accessible surface depths below 1 cm.

The charged energetic particles of Jupiter's magnetosphere execute a complicated ballet as they periodically encounter Europa³ in their motions within the planetary magnetic field around Jupiter. First, as the field rotates with Jupiter at a ten-hour period, it drags all trapped charged particles inexorably towards the moon. Second, some particles can escape impact at the surface by spiralling up and down along the local magnetic line of force. If their timing is just right, they can then ably pirouette past the moon into the downstream field and plasma wake. Third, the spatial gradients and line curvature of the dipolar magnetic field induce additional drift motions for particles of opposite charge. Like good soldiers, the positively charged protons and heavier ions march along with the co-rotating magnetic field towards Europa. But energetic electrons are more reluctant soldiers and want to drift in the opposite direction to that of co-rotation. The higher the energy of the particles, the faster they drift in these respectively opposite directions.

The results of all this dancing and marching are different patterns of surface irradiation by the different particle types, which are tracked by the computational algorithm of Nordheim and colleagues.

The trailing apex, a surface location 90° eastward of the sub-Jovian point at Europa's equator, is the centre of a bullseye pattern for irradiation by electrons below 20 MeV. A similar pattern is predicted at the leading apex, 180° opposite to the trailing apex, for electrons above 20 MeV. In both cases the surface energy fluxes fall off with increasing energy and with increasing distance from the two apex points in all directions, including towards the north and south poles of the moon. Although the higher energy electrons around the leading apex have lower fluxes, such electrons are more penetrating. As a consequence, the most inhospitable radiation environments for biochemical signatures within ten centimetres of the surface are around and between both apexes along the moon's equator.

In contrast, the protons and heavier ions are less tightly bound to the local magnetic field lines and can execute larger pirouettes in their gyrating movements within the magnetic field near the moon. For this reason, their surface energy fluxes are globally uniform instead of being concentrated around the leading and trailing apexes like in the case of electrons. According to the Nordheim et al. model, the regions of lowest total energy flux for electrons and protons lie at middle to high latitudes. It is in these less irradiated regions that we might expect the best chance of finding recognizable biosignatures of life.

As proxies for biosignatures at Europa, Nordheim et al. employ selected amino acids (glycine, alanine and phenylalanine) that are the building blocks of chemical proteins for all living organisms that we know of. These amino acids have previously been irradiated in laboratory experiments to measure the survival fraction as a function of radiation dosage deposited in matter by the energy losses of the charged particles. The dosage unit of one gray (Gy) represents an energy deposition of 100 ergs (10^{-5} J) by atomic ionization and nuclear interactions in one gram of material. In these units the authors find that a cumulative dose of 74 million

grays would result in a significant reduction in survival probability for amino acids in water ice near the moon's surface.

In the most inhospitable regions near the moon's equator the doses are higher than this within a few centimetres of the surface, so there is little chance of finding unprocessed organic molecules there as signs of life. We can also forget about finding living organisms — one of the most radiation-resistant Earth bacteria, *Deinococcus radiodurans*⁴, survives at dosages up to 5,000 Gy. The most resistant multi-cellular organisms, for example, a certain type of wasp⁵, would not survive at even lower dosages above several thousand grays. It is often said that cockroaches could survive a nuclear war better than humans but even they would not do as well as the wasps in the near-surface radiation environment of Europa. The best we could expect to find would be biochemical fragments of past life mixed into the surface ice at the centimetre depths that could be accessible to a lander.

At metre to kilometre depths the radiation dosages diminish to much lower but still significant levels from highly penetrating cosmic rays and the decay of natural radioisotopes, for example, ⁴⁰K (ref. 6), but we shouldn't have to dig so deep to find the fragments of life. Where and how deep should we look? Nordheim et al. remarkably find that at least ten per cent of an initial concentration survives at 10-cm depths everywhere, including in the most irradiated equatorial regions, in regions with geologic ages up to ten million years. The same survival fraction is predicted at 0.6 cm in the trailing high latitude region, the most benign location to search for biosignatures, and at 8 cm for the same latitudes on the leading side. The trailing location, the highest-value real estate for migratory microbes, is uniquely benign because only the less-penetrating low-energy electrons impact there.

There is one qualifier to this optimistic assessment, however. The authors assume that the surface is not disturbed by

meteoritic impacts over a ten-million year timescale, otherwise there would be vertical mixing of materials from shallower depths exposed to more intense irradiation with material from greater depths exposed to less irradiation. Even a relatively short time spent close to the surface during the impact gardening process could degrade the biochemical signatures. In my own work⁷ I argued for a metre-thick impact regolith that could have this effect, but later work from cratering models³ gave a regolith depth of about one centimetre. This difference cannot yet definitely be resolved, as Nordheim et al. note, since surface imaging from the Galileo Orbiter mission could not see surface details at these size scales. The Europa Clipper multi-flyby mission⁹ will resolve surface features no smaller than one metre, so the burden of final proof will fall on the Europa lander mission¹ from images taken during the descent to, and at, the surface.

The Nordheim et al. study tells us that a lander should either probe deeper than ten centimetres wherever it lands or else do shallower measurements at high-latitude sites, but there are other considerations that could determine the most promising landing site. Any location of recently emergent material on 10³ year timescales — for example, from subsurface plumes^{10,11} — could have fully pristine biosignatures with negligible loss to irradiation at depths below a few millimetres. Local topography and roughness of the site could produce a wide range of position-dependent lifetimes for biosignatures. The lander itself would be the final judge of whether we have been clever or lucky enough to find a biosignature, perhaps one taking refuge from radiation within reach under a small block of ice, a sign of life we might most probably recognize as coming from our closest extraterrestrial cousin in the Universe of life. □

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