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Persistence of Raman biosignatures in the Martian radiation environment

L.R. Dartnell (1,2,3), Kristian Page (4), Susana E. Jorge-Villar (5), Gary Wright (6), Howell G. M. Edwards (7)

(1) UCL Institute for Origins, University College London, UK
(2) The Centre for Planetary Sciences at UCL/Birkbeck, Earth Sciences, University College London, London, UK
(3) Space Research Centre, Physics & Astronomy, University of Leicester, Leicester, UK
(4) Division of Chemical and Forensic Sciences, University of Bradford, Bradford BD7 1DP, UK
(5) Área de Geodinámica Interna, Facultad de Humanidades y Educación, C/ Villadiego s/n, 09001 Burgos, Spain
(6) Department of Engineering and Applied Science, Cranfield University, Shrivenham, Swindon, UK
(7) Centre for Astrobiology and Extremophiles Research, School of Life Sciences, University of Bradford, Bradford, UK

Abstract

Model organisms were exposed to increasing doses of ionizing radiation to track the degradation of detectable biosignatures by Raman spectroscopy, which is of direct relevance to the ExoMars mission and cosmic radiation environment of the martian surface.

1. Introduction

The martian surface represents a very hostile environment for both the survival of microbial life and the persistence of organic molecules or biosignatures of possible past life. One major hazard of the surface environment is the flux of ionising radiation delivered by cosmic rays [1,2,3]. Unlike Earth, Mars no longer possesses a global dipolar magnetic field or substantial atmosphere, and the surface is essentially unshielded from this harmful radiation. Particle cascades triggered by these energetic primaries penetrate metres underground, and so even the 2 m drill proposed for the ESA-Roscosmos ExoMars rover, due for launch in 2018, will be sampling material that has been bathed in ionising radiation throughout martian history. The crucial question, therefore, is what is the effect of this long-term irradiation on the detectability of potential biosignatures - what is the window of opportunity before these signs of life have become erased, or at least modified and distorted to no longer be unambiguously indicative of past biological action?

Raman spectroscopy has proven to be a very effective approach for the detection of microorganisms colonising hostile environments on Earth [4]. The ExoMars rover will be the first space mission to carry a Raman laser spectrometer, to analyse samples of the martian subsurface collected by the probe's 2m drill in a search for similar biosignatures.

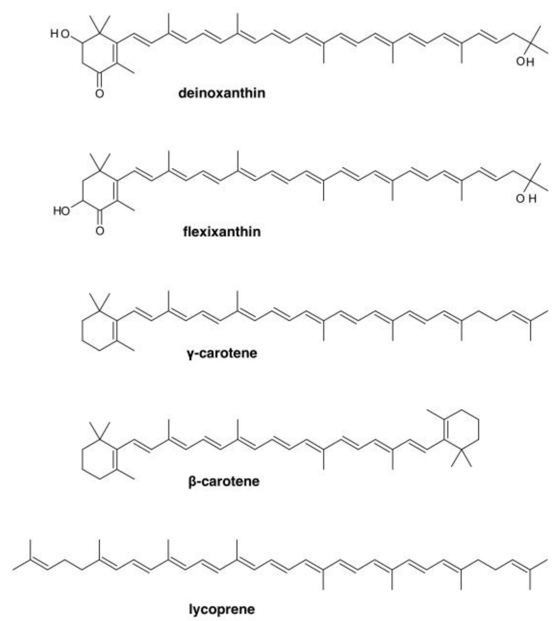

Figure 1. Molecular structures of cellular carotenoids. Synechocystis expresses the common β-carotene, whereas deinoxanthin is unique to D. radiodurans, although structurally related to flexixanthin. All yield distinctive Raman spectra.

2. Methods

We employed Raman spectroscopy to analyse samples of two model organisms, the cyanobacterium Synechocystis sp. PCC 6803 and the extremely radiation resistant polyextremophile Deinococcus radiodurans. The three most prominent peaks in the Raman spectra from these bacteria are cellular carotenoids: deinoxanthin in D. radiodurans and β-carotene in Synechocystis (Figure 1). Carotenoids are used by photosynthetic cells, such as Synechocystis, to enhance light collection, but are also very widely distributed amongst terrestrial microorganisms to provide ultraviolet screening and act as scavengers of reactive oxygen species. Samples of these model organisms were exposed to increasing doses of ionising radiation from a cobalt-60 gamma-ray source, and then reanalysed by Raman spectroscopy to track the loss of detectable signal (Figure 2).

3. Results and Conclusions

The degradative effect of ionising radiation was clearly seen, with significant diminishment of carotenoid spectral peak heights after 15 kGy and complete erasure of Raman biosignatures by 150 kGy of ionising radiation. The Raman signal of carotenoid in D. radiodurans diminishes more rapidly than that of Synechocystis, believed to be due to deinoxanthin acting as a superior scavenger of radiolytically produced reactive oxygen species, and so being destroyed more quickly than the less efficient antioxidant β-carotene.

This study highlights the necessity for further experimental work on the manner and rate of degradation of Raman biosignatures by ionising radiation, as this is of prime importance for the successful detection of microbial life in the martian near subsurface [5].

Acknowledgements

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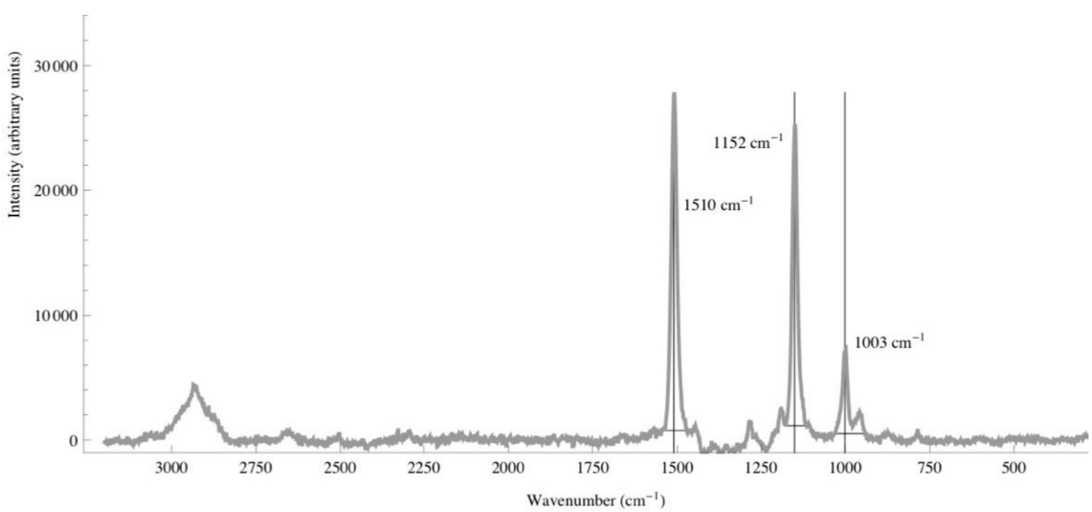

Figure 2. Raman spectrum (532 nm laser) of D. radiodurans showing prominent peaks at labeled wavenumbers from the carotenoid deinoxanthin. These peaks, a detectable biosignature, diminished with ionising radiation due to radiolysis of the molecule.