Physics Reports 713 (2017) 1–17

Contents lists available at ScienceDirect

Physics Reports

journal homepage: www.elsevier.com/locate/physrep

A review of exoplanetary biosignatures

John Lee Grenfell

Department of Extrasolar Planets and Atmospheres (EPA), Institute of Planetary Research, German Aerospace Centre (DLR), Rutherford Str. 2, 12489 Berlin, Germany

ARTICLE INFO

Article history:
Accepted 21 March 2017
Available online 10 October 2017
Editor: M.P. Kamionkowski

Keywords:
Exoplanet
Earth-like
Atmosphere
Biosignature

ABSTRACT

We review the field of exoplanetary biosignatures with a main focus upon atmospheric gas-phase species. Due to the paucity of data in Earth-like planetary atmospheres a common approach is to extrapolate knowledge from the Solar System and Early Earth to Earth-like exoplanets. We therefore review the main processes (e.g. atmospheric photochemistry and transport) affecting the most commonly-considered species (e.g. O_2, O_3, N_2O, CH_4 etc.) in the context of the modern Earth, Early Earth, the Solar System and Earth-like exoplanets. We consider thereby known abiotic sources for these species in the Solar System and beyond. We also discuss detectability issues related to atmospheric biosignature spectra such as band strength and uniqueness. Finally, we summarize current space agency roadmaps related to biosignature science in an exoplanet context.

Contents

E-mail address: lee.grenfell@dlr.de.

https://doi.org/10.1016/j.physrep.2017.08.003
0370-1573/

1. Introduction

The science of biosignatures i.e. signals which suggest the presence of life, is a wide and interdisciplinary field which is currently undergoing rapid expansion due in part to advances in exoplanet science. In this context, it is therefore convenient to split current biosignature methods into two groups, namely 'in-situ' and 'remote'. We define here in-situ biosignatures to include the study of fossil morphology and the direct examination of complex biotic molecules such as DNA and lipidic acids (see e.g. Horneck et al., [1] for a review). In-situ biosignatures are not our main focus here. We define remote biosignatures to refer to spectroscopic methods for detecting e.g. atmospheric species' abundance, (surface) reflectivity etc. In recent years there has been some cross-over from in-situ to remote methods e.g. for biosignatures involving isotopic ratios, surface pigments etc. as we will discuss.

This paper reviews the field of remote biosignatures in an exoplanetary context with a main focus on atmospheric species. Due to limited data in Earth-like exoplanetary science, a common approach when studying potential exoplanetary biosignatures is to consider what can be learned from the modern Earth, Early Earth and the Solar System. Based on these, one then extrapolates knowledge gained (together with theoretical model studies) to the study of Earth-like exoplanets.

Literature reviews which cover subjects related to exoplanetary biosignatures but which are not discussed in detail in this paper are cited throughout the manuscript. For conciseness however, we list here briefly some of the main review papers relevant to our subject. A review of conditions affecting potential habitability and biosignatures beyond the Solar System is provided in the Special Issue "Planetary Habitability and Life" edited by Spohn et al. [2] and references therein. The potential habitability of terrestrial planets orbiting in the Habitable Zone of M-dwarf stars (important targets in exoplanet science) was reviewed in [3] and more recently by Shields et al. [4]. These are central objects in exoplanetary science and are targets of interest for forthcoming space missions. This is because firstly, M-dwarf stars are numerous in the solar neighborhood; secondly, planets orbiting smaller, fainter stars have stronger (planet/star) contrast ratio signals and thirdly a fainter star suggests a closer HZ where planets have faster orbits meaning more rapid collection of data. There are however possible caveats regarding the habitability of these objects such as possible planetary tidal-locking due to the close proximity of the star. This could lead to slower planetary rotation and a possible weakening in the planet's magnetosphere hence potentially strong bombardment of the atmosphere with high energy particles as detailed in the Scalo and Shields reviews mentioned above. The extent to which these processes could be related however is generally not well-constrained. Lammer et al. [5] reviewed evolution of planetary environments towards habitable conditions. Regarding biosignatures, the recent NASA NExSS (**N**exus for **Ex**oplanet **S**ystem **S**cience) initiative has produced comprehensive reviews which discuss finding, assessing, detecting and planning observation programs for exoplanetary biosignatures, as detailed in [6–10]. Reviews by Seager [11,12] summarize responses of gas-phase species in biosignature science. A review of biosignature-related photochemical responses on modern Earth is provided by e.g. Wayne [13]. Reviews of potential biosignature species on Mars (and Venus) are provided by e.g. Krasnopolsky [14] and Atreya et al. [15].

The paper is organized as follows. Section 1 discusses current definitions of life (1.1) and the steps involved when searching for life remotely (1.2). Section 2 discusses biosignatures for vegetation and biological pigments. Section 3 deals