様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科研費 KAKENHI

科学研究費助成事業　　研究成果報告書

令和　５年　５月２３日現在

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研究課題名（和文）The viability of Earth-life on other planets

研究課題名（英文）The viability of Earth-life on other planets

研究代表者
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交付決定額（研究期間全体）：（直接経費）　1,800,000円

研究成果の概要（和文）：私は2つのソフトウェアパッケージの開発を主導しました。これらのパッケージは、他の惑星における地球型生物の生存可能性を（その惑星で利用可能な化合物の観察に基づいて）決定する方法論の実用性を実証するために使用されました。この研究により、現在の知識では、調査した生物はいずれもエンケラドスで生存できないことが判明しました。

この方法は、初期地球の生命の起源と性質、および生命の初期進化に関する研究課題を調査するためにも使用されました。その結果、地球の代謝のほとんどは、シンプルな初期化合物のセットからアクセス可能であることがわかりました。

研究成果の学術的意義や社会的意義
This is one of the first systematically quantitative predictions on the viability of Earth-life on other planets. It even touches on explaining the Fermi paradox;perhaps colonizing other planets is hindered by the dependence of life on specific geochemistry.

研究成果の概要（英文）：I led development of two software packages related to 1) collecting and organizing biochemical data (package is called ecg, written in python), and 2) performing network expansion on biochemical data, including determining compounds necessary to make organisms viable in different environments (package is called BioXP, written in Julia). These packages were used to demonstrate the practicality of a methodology to determine the viability of Earth-organisms on other planets (based on observations of the compounds available on those planets). This work showed that none of the investigated organisms were viable on Enceladus given our current state of knowledge.

This methods were also used to investigate research questions to the origin and nature of life on early Earth, and early evolution of life. We found that most of Earth's metabolism is accessible from a simple set of initial compounds.

研究分野：Complex systems

キーワード：complex systems　biochemistry　networks　astrobiology　planetary science

様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９（共通）

１．研究開始当初の背景 (Background at the beginning of the study)

The concept of the origin of life implies that initially, life emerged from a nonliving medium. If this medium was Earth's geochemistry, then that would make life, by definition, a geochemical process. The extent to which life on Earth today could subsist outside of the geochemistry from which it is embedded is poorly quantified.

Despite the biosphere's apparent interminable coexistence with the geosphere, there remain many open questions on the matter of life persisting in Earth's absence. For example, visionaries dream of terraforming planets while program officers fret over "contaminating" them. While the terraformers tend to believe that seeding another planet would require careful human or robotic cultivation, planetary protection officers take the more conservative stance that a small, semi-sterilized spacecraft of Earth origin could cause life to spill onto a planet by accident. In both cases, there is the predominately implicit assumption that Earthlife would be viable outside of the Earth. To what extent, if any, is this true?

２．研究の目的 (Purpose of the study)

The purpose of this project (based on the key question: How viable is Earth-life on other planets?) was twofold: A) To identify the organisms and microbial communities which could be viable on other planets (based on their known geochemistry); or if none are viable, to identify the compounds necessary to make them so. And B) To develop robust and user-friendly software which can be used to answer these important research questions, as well as any follow-up questions which emerge from this project.

The results of this work are scientifically significant because it is one of the first systematically quantitative predictions on the viability of Earth-life on other planets. This has strong implications for addressing the hypothesis that life is intrinsically linked to its geosphere and cannot readily exist outside of it, and for addressing the hypothesis that Earth-life could accidentally contaminate Mars or an icy moon–both relevant to planetary protection and manned and unmanned space exploration. It even touches on explaining the Fermi paradox—perhaps colonizing other planets is hindered by the dependence of life on its parent planet's geochemistry.

３．研究の方法 (Methods of the study)

This study used computational "network expansion" models in conjunction with planetary observational data, and organismal genomic data. Network expansion models can make predictions on sets of compounds which can be produced given allowed reactions, and an initial starting set of compounds. For my research in exploring the viability of Earth-organisms on Enceladus, the set of initial compounds was based on observations of Enceladus, mainly from Cassini data. The allowed set of reactions was based on real observed biochemistry here on Earth, and differed depending on the organisms whose viability was being testing. This data came from integrating a variety of databases, such as KEGG (the Kyoto Encyclopedia of Genes and Genomes), JGI (the Joint Genome Institute), and PhyMet2.

Additional research extended these network expansion methodologies to investigating the origin and history of metabolism here on Earth, and relied on several additional databases with cofactor and enzyme data, including Expasy, PDBe, Uniprot, and NLDB.

４．研究成果（Research Results）

I published a paper in the journal Astrobiology titled "Seeding Biochemistry on Other Worlds: Enceladus as a Case Study", in which I found that no Earth organisms investigated in my study were viable using the compounds which have been heretofore observed on Enceladus.

Another paper is in revision at the journal BioEssays which highlights current issues in

Astrobiology research related to life detection. This research was also done in collaboration with a collaborator at Arizona State University. This work extends my research to thinking about exoplanets, and the viable methodology which could be used to assess whether or not life can be reliably detected on such worlds. It will hopefully help exoplanet astrobiologists better assess life detection methods.

The other main paper related to this grant that I've been working on extends the network expansion codebase development to python, and the research questions to the origin and nature of life on early Earth, and early evolution of life. This development has been supporting another research project with collaborators at ELSI and Caltech. The paper corresponding to this project is currently under revision at Nature Ecology and Evolution.

As mentioned in my original purpose and goals of this project, one of the major goals was to build a software package that could be used to answer these kinds of research questions more generally. I was successful in this regard, as both software packages that I led development of (BioXP and ecg), with help from collaborators at Arizona State University and ELSI, are being used for future research related to understanding universal features of life, and applied microbial ecology research.

５．主な発表論文等

〔雑誌論文〕　計3件（うち査読付論文　3件／うち国際共著　3件／うちオープンアクセス　1件）

１．著者名 Harrison Smith, Cole Mathis	４．巻 -
２．論文標題 Life Detection in a Universe of False Positives	５．発行年 2023年
３．雑誌名 BioEssays (in-revision)	６．最初と最後の頁 -
掲載論文のDOI（デジタルオブジェクト識別子） なし	査読の有無 有
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１．著者名 Harrison B. Smith, Alexa Drew, John F. Malloy, Sara I. Walker	４．巻 21
２．論文標題 Seeding Biochemistry on Other Worlds: Enceladus as a Case Study	５．発行年 2021年
３．雑誌名 Astrobiology	６．最初と最後の頁 177-190
掲載論文のDOI（デジタルオブジェクト識別子） 10.1089/ast.2019.2197	査読の有無 有
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１．著者名 Joshua E. Goldford, Harrison B. Smith, Liam M. Longo, Boswell Wing, Shawn E. McGlynn	４．巻 -
２．論文標題 Primitive purine biosynthesis connects ancient geochemistry to modern metabolism	５．発行年 2023年
３．雑誌名 Nature Ecology and Evolution	６．最初と最後の頁 -
掲載論文のDOI（デジタルオブジェクト識別子） なし	査読の有無 有
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〔学会発表〕　計8件（うち招待講演　6件／うち国際学会　1件）

１．発表者名 Harrison Smith
２．発表標題 Seeding Biochemistry on Other Worlds: Enceladus as a Case Study
３．学会等名 Astrobiology Graduate Conference
４．発表年 2021年

1．発表者名 Harrison Smith
2．発表標題 (untitled)
3．学会等名 NAS Committee on Planetary Protection Meeting No. 4 on Planetary Protection for Missions to Small Bodies Astrobiology and Astrochemistry Contamination Concerns for Small Bodies Science（招待講演）（国際学会）
4．発表年 2022年

1．発表者名 Harrison Smith
2．発表標題 What are we actually looking for when we look for life
3．学会等名 Earth-Life Science Institute 10th International Symposium（招待講演）
4．発表年 2022年

1．発表者名 Smith, Harrison
2．発表標題 Habitability in terms of complex biochemical networks
3．学会等名 Re-conceptualizing panspermia（招待講演）
4．発表年 2020年

1．発表者名 Smith, Harrison
2．発表標題 Computationally assessing the viability of biochemical networks on Enceladus
3．学会等名 2nd international symposium of aquaplanetology（招待講演）
4．発表年 2020年

１．発表者名 Smith, Harrison
２．発表標題 Computationally assessing the viability of biochemical networks across environments
３．学会等名 Interdisciplinary origin of life virtual workshop（招待講演）
４．発表年 2020年

１．発表者名 Harrison Smith, Cole Mathis
２．発表標題 The Futility of Exoplanet Biosignatures
３．学会等名 Astrobiology Science Conference 2022
４．発表年 2022年

１．発表者名 Joshua E. Goldford, Harrison B. Smith, Liam M. Longo, Boswell Wing, Shawn E. McGlynn
２．発表標題 Primitive purine biosynthesis connects ancient geochemistry to modern metabolism
３．学会等名 Astrobiology Science Conference 2022（招待講演）
４．発表年 2022年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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６．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関