MELISSA
MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

2022 MELISSA CONFERENCE
8-9-10 NOVEMBER 2022

CREATING A CIRCULAR FUTURE

Plastic recycling in space using microorganisms: a potential tool to close the loop

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UK Centre for Astrobiology

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THE UNIVERSITY OF EDINBURGH

The UK Centre for Astrobiology

LEVERHULME TRUST

Microorganisms could perform many tasks beyond Earth

- Generate food
- Generate oxygen
- Recycle waste
- Soil formation
- Bioindustries

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Microorganisms could perform many tasks beyond Earth

Generate food

Generate oxygen

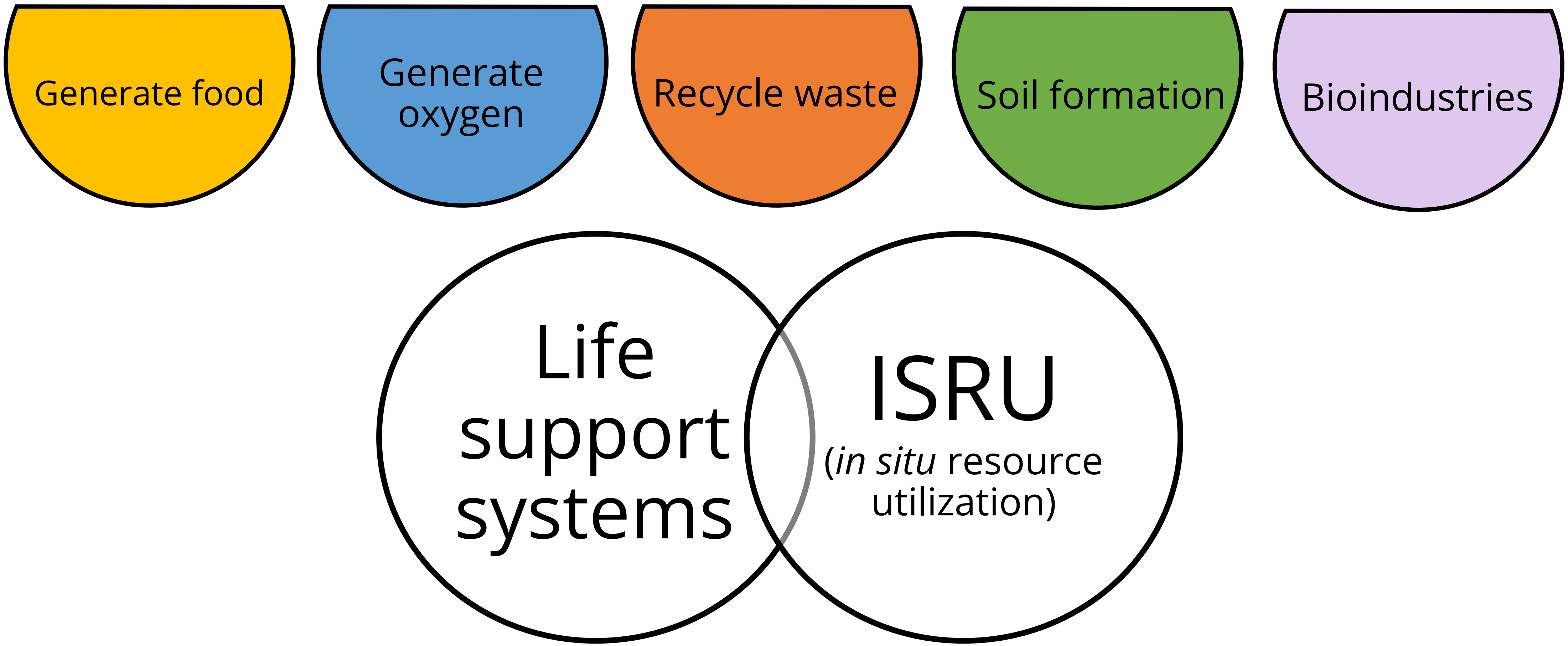
Recycle waste

Soil formation

Bioindustries

Life support systems

Microorganisms could perform many tasks beyond Earth



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Microorganisms could perform many tasks beyond Earth

- Generate food
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Recycling and reuse of materials (closed-loop system) = **self-sustainable human presence** in space:

- minimize the resupply of resources from Earth
- ethical considerations associated with space waste generated by the human presence

Microorganisms could perform many tasks beyond Earth

Generate food

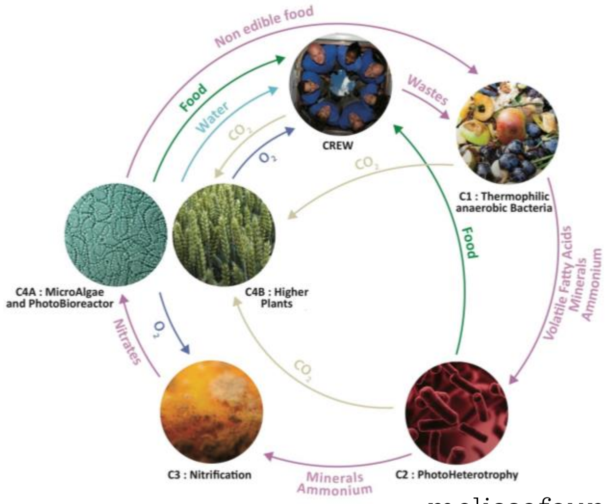
Generate oxygen

Recycle waste

Soil formation

Biondustries

Organic waste



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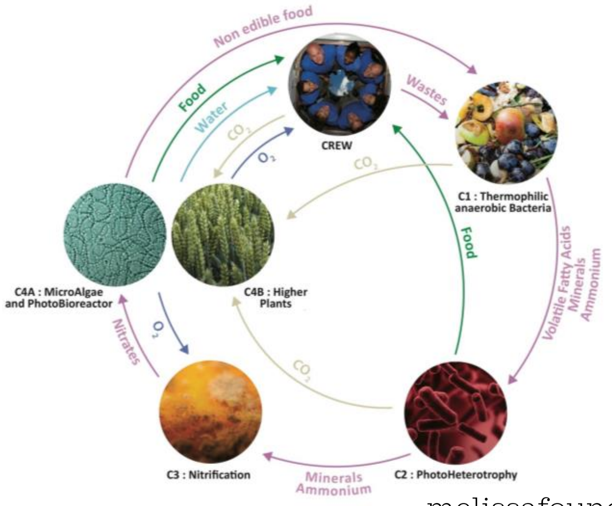
Microorganisms could perform many tasks beyond Earth

- Generate food
- Generate oxygen
- **Recycle waste**
- Soil formation
- Bioindustries

Organic waste



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Non-organic waste

- Metallic structures
- Electronic devices
- Clothes
- Consumables: **plastics**

pixta.jp - 15598514

Plastics

Wide range of synthetic or semi-synthetic polymeric materials, high durabile and adaptabile. Often derived from non-renewable fossil fuels.

A space perspective

- Will be indispensable in our everyday life in space, construction, food and pharmaceutical industries.
- Key role, due to their resistance and capacity to withstand harsh space conditions.

BUT…

- Fossil fuels, are not available in space.
- Bioplastic production potential solution, but could suffer limitations, e.g., when biomass is required to feed other LSS compartments.

Plastic recycling in space will be pivotal to:

- upcycle carbon
- obtain feedstock
- produce new consumables
- reduce space waste production


Metabolic Engineering 71 (2022) 77–98

Contents lists available at ScienceDirect

Metabolic Engineering

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

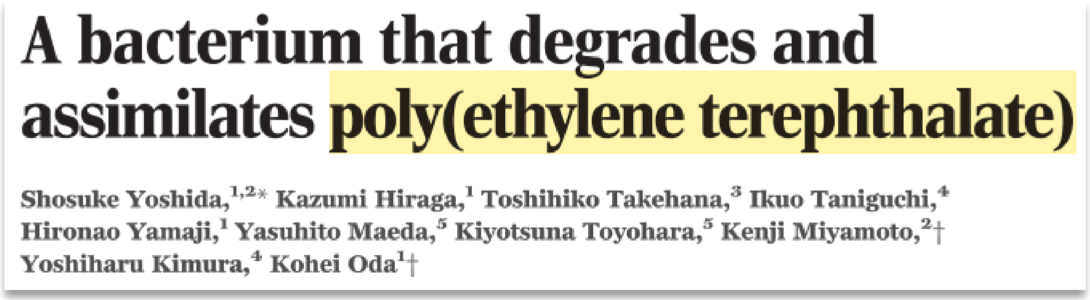
ELSEVIER

The metabolic potential of plastics as biotechnological carbon sources – Review and targets for the future

Till Tiso[a], Benedikt Winter[b,h], Ren Wei[c], Johann Hee[d], Jan de Witt[e], Nick Wierckx[e], Peter Quicker[d], Uwe T. Bornscheuer[c], André Bardow[b,h,i], Juan Nogales[f,g], Lars M. Blank[a,*]

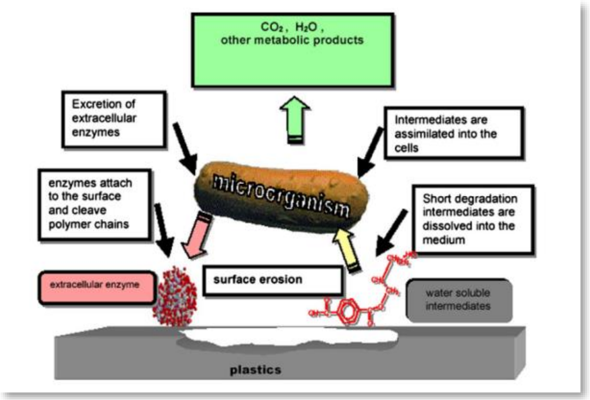
Plastic biodegrading microorganisms

- Microorganisms have been shown to break down microplastics (**biodegradation**) into organic nutrients to support growth**.**
- Synthetic biology approaches used to engineer microorganisms to **produce useful molecules starting from plastic waste**.

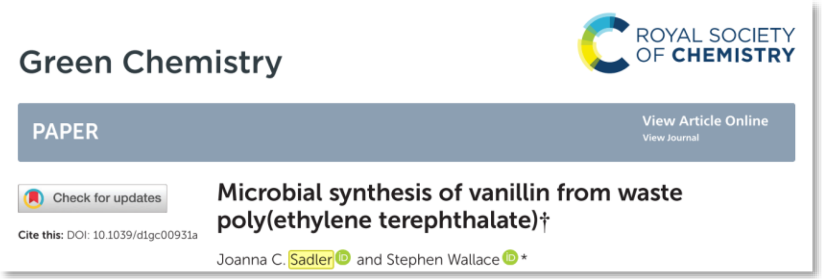

A bacterium that degrades and assimilates poly(ethylene terephthalate)

Shosuke Yoshida,[1,2*] Kazumi Hiraga,[1] Toshihiko Takehana,[3] Ikuo Taniguchi,[4] Hironao Yamaji,[1] Yasuhito Maeda,[5] Kiyotsuna Toyohara,[5] Kenji Miyamoto,[2]† Yoshiharu Kimura,[4] Kohei Oda[1]†

Yoshida et al. Science. 351, 5 (2016).



Shah et al., (2008) Biotechnol. Adv., vol. 26, pp. 246–265


Green Chemistry

ROYAL SOCIETY OF CHEMISTRY

PAPER

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View Journal

Check for updates

Cite this: DOI: 10.1039/d1gc00931a

Microbial synthesis of vanillin from waste poly(ethylene terephthalate)†

Joanna C. Sadler and Stephen Wallace *

Sadler & Wallace *Green Chem.* 23, (2021).

Plastic-biodegrading microorganisms could become promising components of extraterrestrial outposts.

Plastic biodegrading microorganisms

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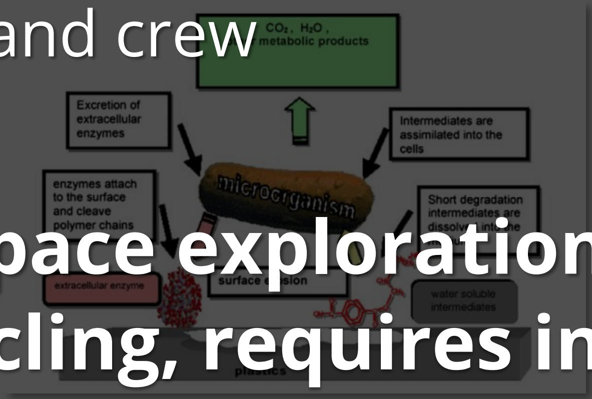

Shah et al. (2018)
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Green Chemistry
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PAPER
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Joanna C. Sadler and Stephen Wallace

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Green Chem. 23, (2021).

However microorganisms:

- respond unpredictably to space conditions
- can have deleterious effects on materials and crew

Their potential use in human space exploration for novel applications, such as plastic recycling, requires investigation.

Plastic-biodegrading microorganisms could become promising components of extraterrestrial outposts.

Plastic biodegrading microorganisms for a sustainable future on Earth and beyond

The project

To study the cellular and molecular mechanisms of microbe-mediated biodegradation under space conditions (e.g., simulated microgravity), which will be pivotal to **establish space biotechnologies**.

Focus on two aspects:

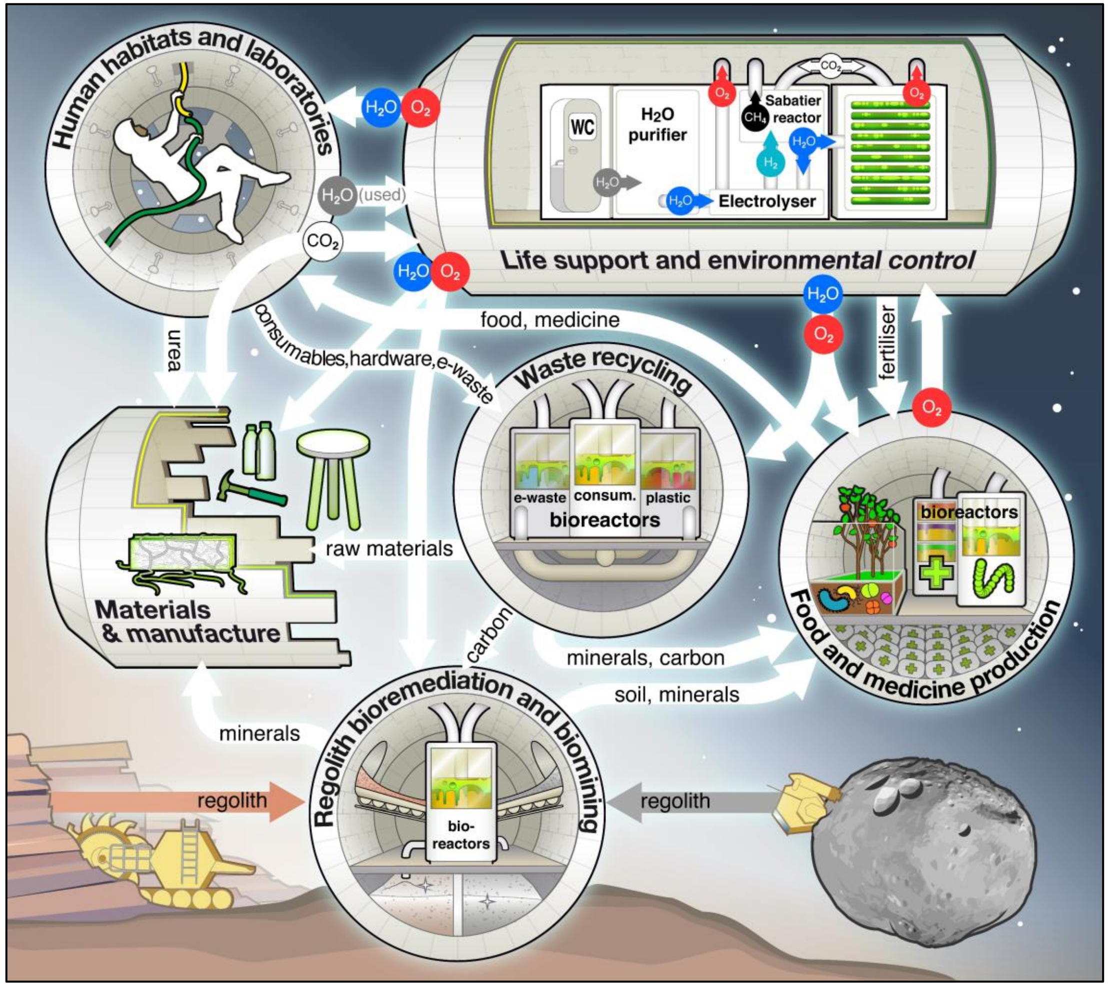
- advancing the knowledge on the molecular mechanisms of microbial plastic biodegradation, particularly under **space conditions**;
- applying the results to terrestrial and **space biotechnologies**

Plastic biodegrading microorganisms for a sustainable future on Earth and beyond

Toward loop closure

Space biotechnologies aimed to recycle **recycle non-organic waste** could produce primary and secondary products that could **sustain biological compartments** in LSS, and *vice versa*.

A potential new tool for **space ecology**?



(Santomartino et al., under revision)

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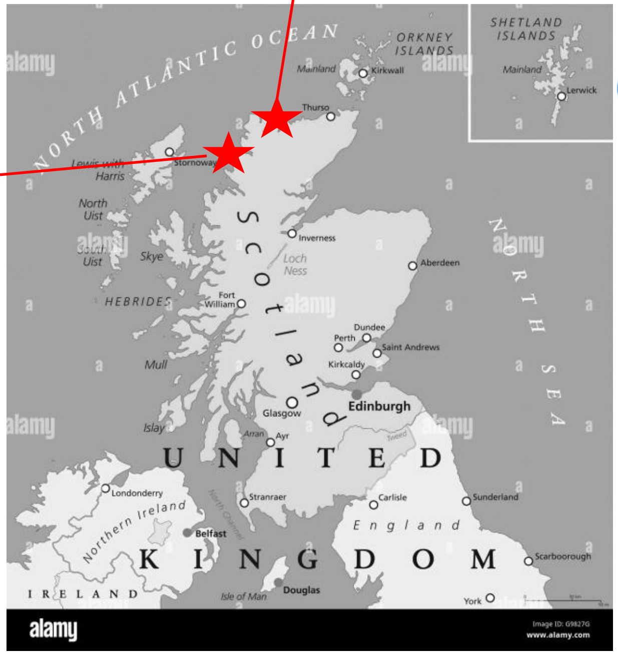
Plastic biodegrading microorganisms for a sustainable future on Earth and beyond

Microbial species selection

Isolation from Scottish plastic-polluted environments -> **sample collection in June 2022**

Durness

Scouriemore



Plastic@Bay

Plastic biodegrading microorganisms for a sustainable future on Earth and beyond

Microbial species selection

Test known plastic-degrading microorganisms under space conditions

i.e., *Penicillium simplicissimum*, *Sphingomonas* spp. etc.

Isolation from Scottish plastic-polluted environments -> **sample collection in June 2022**

Durness

Scouriemore

The first two biomining experiments on a space station

2019

2020-21

BioRock logo created by Hadrien Jouet and Mauro Manzo

BioAsteroid logo created by Dr Sean McMahon

The first two biomining experiments on a space station

2019

BioRock logo created by Hadrien Jouet and Mauro Manzo

2020-21

BioAsteroid logo created by Dr Sean McMahon

BioAsteroid – biomining meteorites in space

Microbial species:

Sphingomonas desiccabilis (bacterium)

Penicillium simplicissimum (fungus)

S. Desiccabilis + *P. simplicissimum*

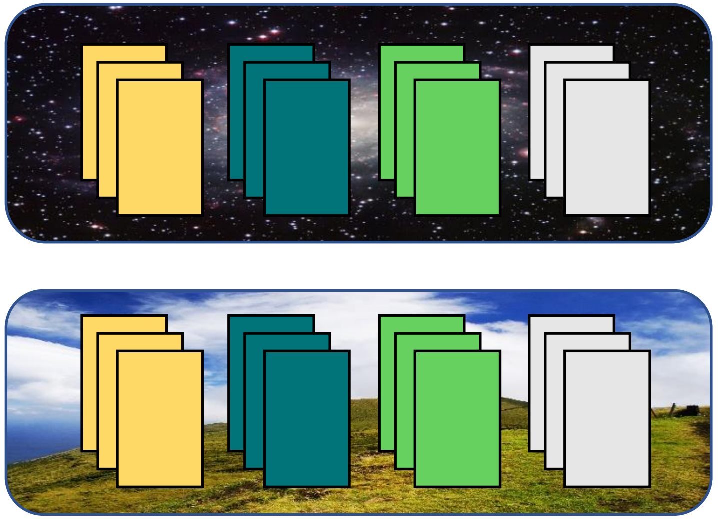
Non-biological control

Rock substrate:


Crushed L-chondrite

Gravity condition:

ISS



Microgravity (**μ*g***)

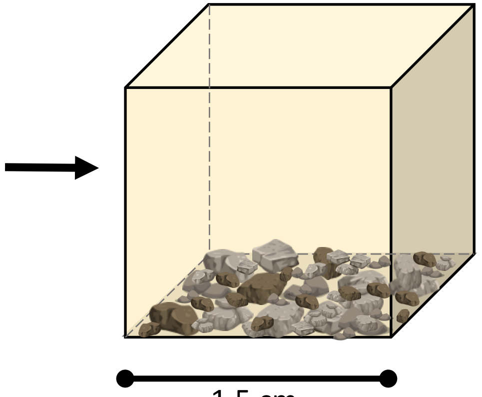
EARTH

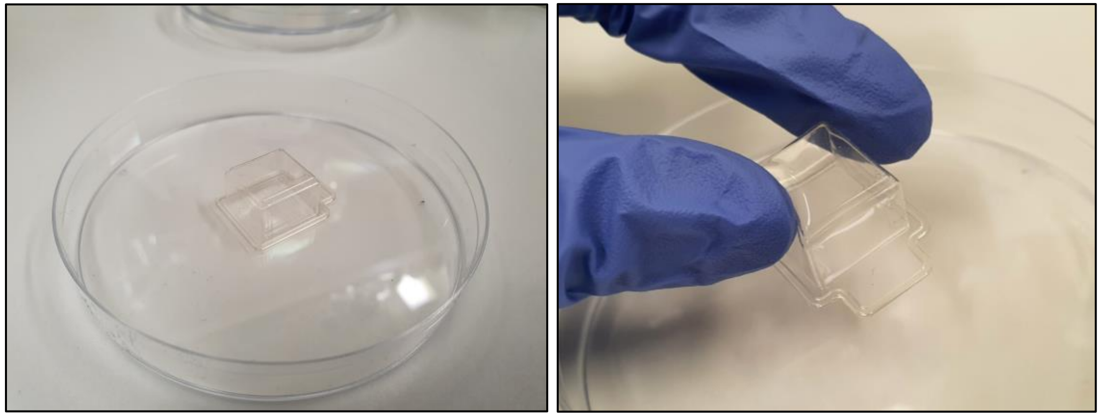
True terrestrial gravity (1 x *g*, **Ground control)**

Samples grew in liquid culture in the presence of the meteorite rock pieces for 19 days at 20°C

Medium: 50% R2A
Fixative: RNAlater

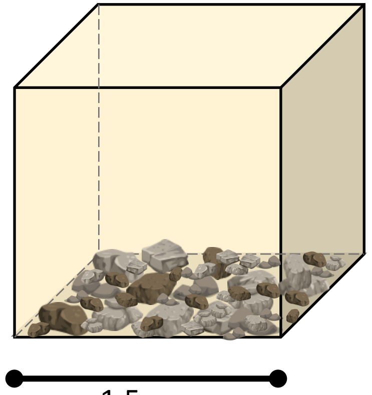
BioAsteroid – biomining meteorites in space

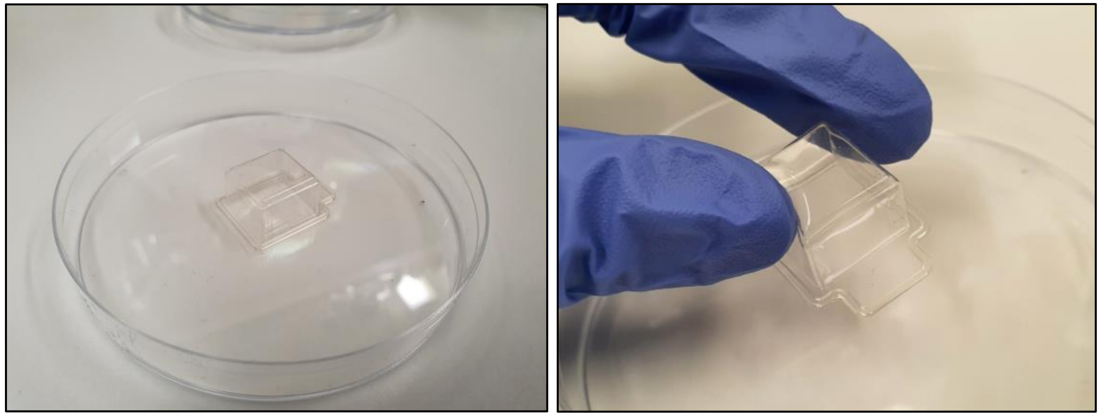




Silicone-rubber semipermeable membrane

BioAsteroid – biomining meteorites in space





Silicone-rubber semipermeable membrane

Vegetos (2021) 34:57–67
https://doi.org/10.1007/s42535-020-00176-9

RESEARCH ARTICLES

De-polymerization of LDPE plastic by *Penicillium simplicissimum* isolated from municipality garbage plastic and identified by ITSs locus of rDNA

Swapan Kumar Ghosh[1] · Sujoy Pal[1]

microorganisms MDPI

Article

***Sphingomonas* Relies on Chemotaxis to Degrade Polycyclic Aromatic Hydrocarbons and Maintain Dominance in Coking Sites**

Meng Zhou [1], Zishu Liu [1], Jiaqi Wang [1], Yuxiang Zhao [1] and Baolan Hu [1,2,3,*]

1 Department of Environmental Engineering, College of Environmental & Resources Sciences, Zhejiang University, Hangzhou 310058, China; 11914036@zju.edu.cn (M.Z.); liuzishu@zju.edu.cn (Z.L.); tudou@zju.edu.cn (J.W.); 21814091@zju.edu.cn (Y.Z.)
2 Zhejiang Province Key Laboratory for Water Pollution Control and Environmental Safety, Hangzhou 310058, China
3 Key Laboratory of Environment Remediation and Ecological Health, Ministry of Education, College of Environmental Resource Sciences, Zhejiang University, Hangzhou 310058, China
* Correspondence: blhu@zju.edu.cn; Tel.: +86-0571-8898-2340

Recent Innovations in Chemical Engineering, 2020, *13*, 29-40

BENTHAM SCIENCE

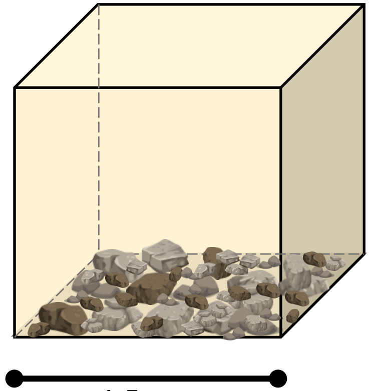
RESEARCH ARTICLE

Ecofriendly Degradation of Polyethylene Plastics Using Oil Degrading Microbes

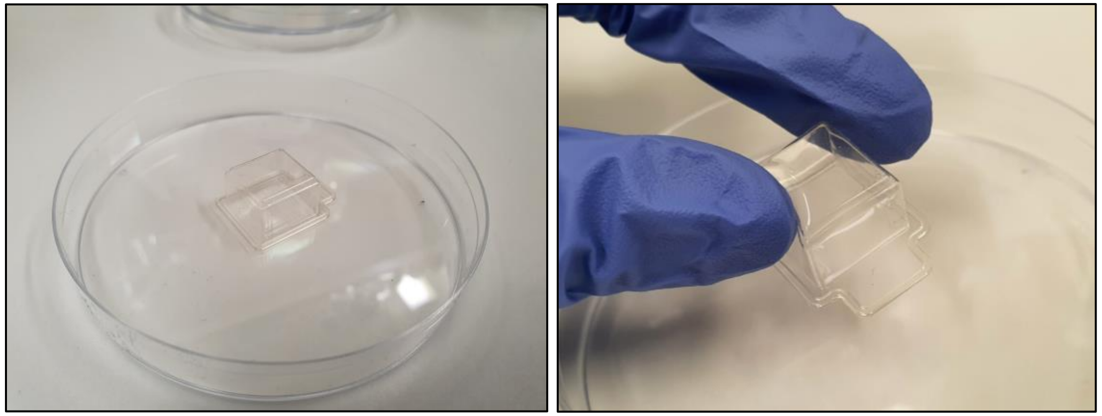
Liny Padmanabhan[1,*], Shreya Varghese[2], Raj Kumar Patil[2], H.M. Rajath[2], R.K. Krishnasree[2] and M. Ismail Shareef[1]

[1]*Acharya Institute of Technology, Soladevanahalli, Bangalore, India;* [2]*Shridevi Institute of Engineering & Technology, Tumkur, India*

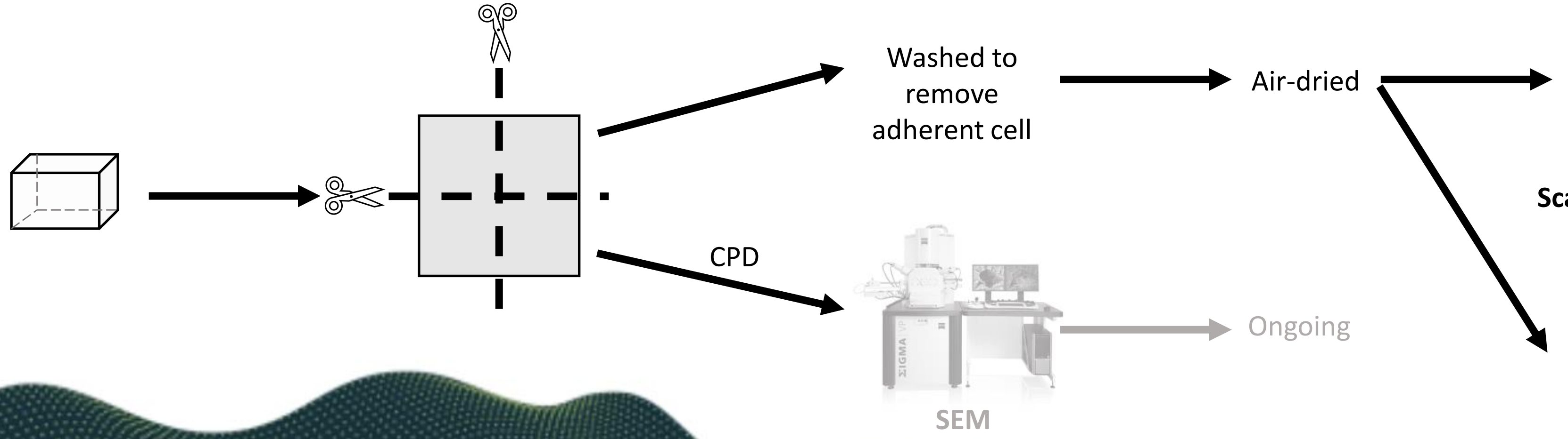
BioAsteroid – biomining meteorites in space



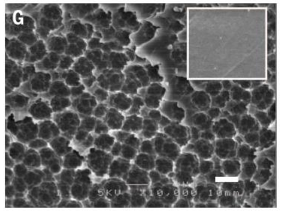
1.5 cm



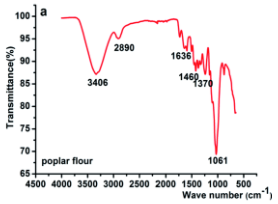
Silicone-rubber semipermeable membrane



Scanning Electron Microscopy (SEM)

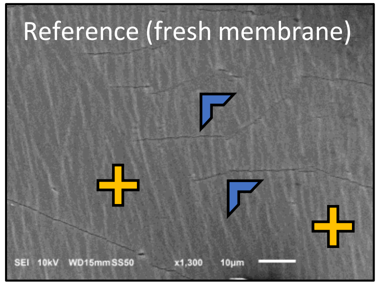


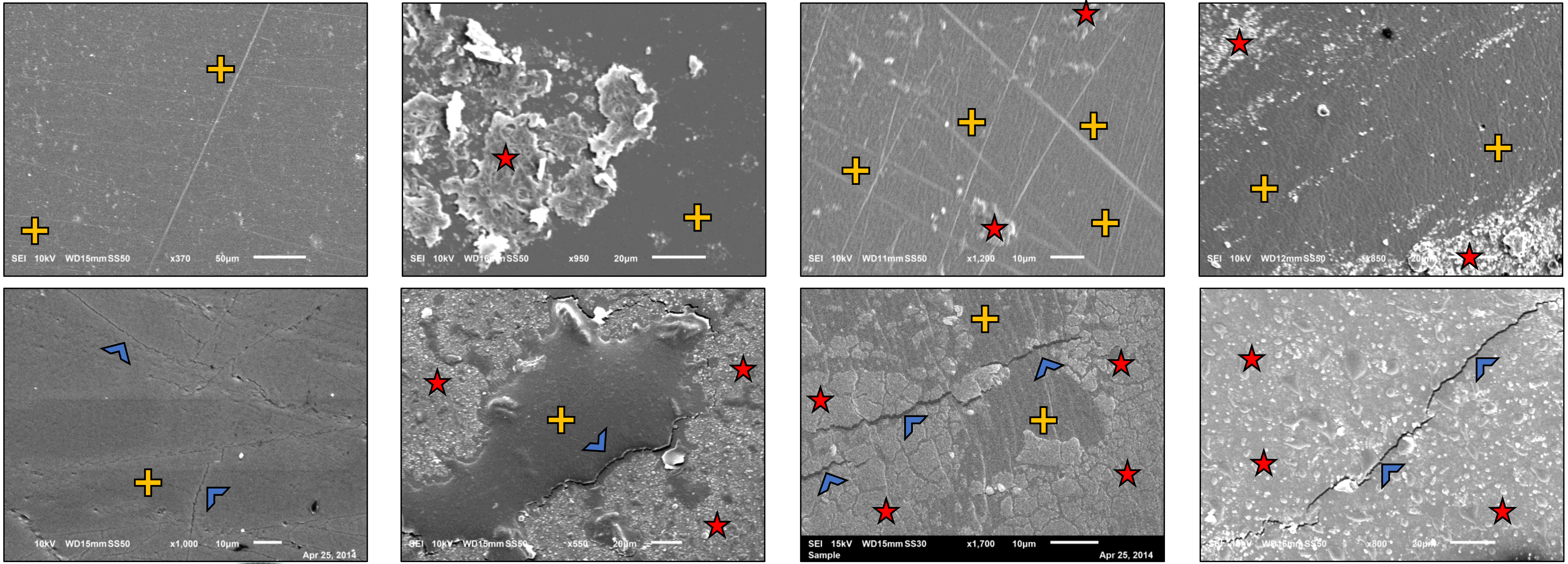
Yoshida et al., 2016



Fourier-transform infrared spectroscopy (FTIR)

Scanning Electron Microscopy (SEM)





Sinéad Corbett, SH student

Fourier-transform infrared spectroscopy (FTIR) to monitor plastic biodegradation

Degradation of Biomedical Polydimethylsiloxanes During Exposure to *In Vivo* Biofilm Environment Monitored by FE-SEM, ATR-FTIR, and MALDI-TOF MS

Peter Kaali,[1,2] Dane Momcilovic,[1] Agneta Markström,[3] Ragnhild Aune,[4] Gyorgy Czel,[2] Sigbritt Karlsson[1]

[1]School of Chemical Science and Engineering, Department of Fibre and Polymer Technology, Division of Polymeric Materials, Royal Institute of Technology (KTH), Stockholm SE-100 44, Sweden
[2]Department of Polymer Engineering, University of Miskolc, Miskolc HU-3515, Hungary
[3]Department of Clinical Sciences, Danderyd Hospital, Karolinska Institutet, National Respiratory Centre, Stockholm SE-18 288, Sweden
[4]School of Industrial Engineering and Management, Department of Material Science and Engineering, Division of Materials Process Science Royal Institute of Technology (KTH), Stockholm SE-100 44, Sweden

Received 30 March 2009; accepted 13 July 2009
DOI 10.1002/app.31119
Published online 10 September 2009 in Wiley InterScience (www.interscience.wiley.com).

- new peak between 3200 cm^{-1} and 3600 cm^{-1}. This corresponds to the stretching vibration of the **Si-OH bond**.
- **-CH3** functional group peak increased during exposure.
- hydroxyl compounds were formed: this confirms **degradation by hydrolysis**.

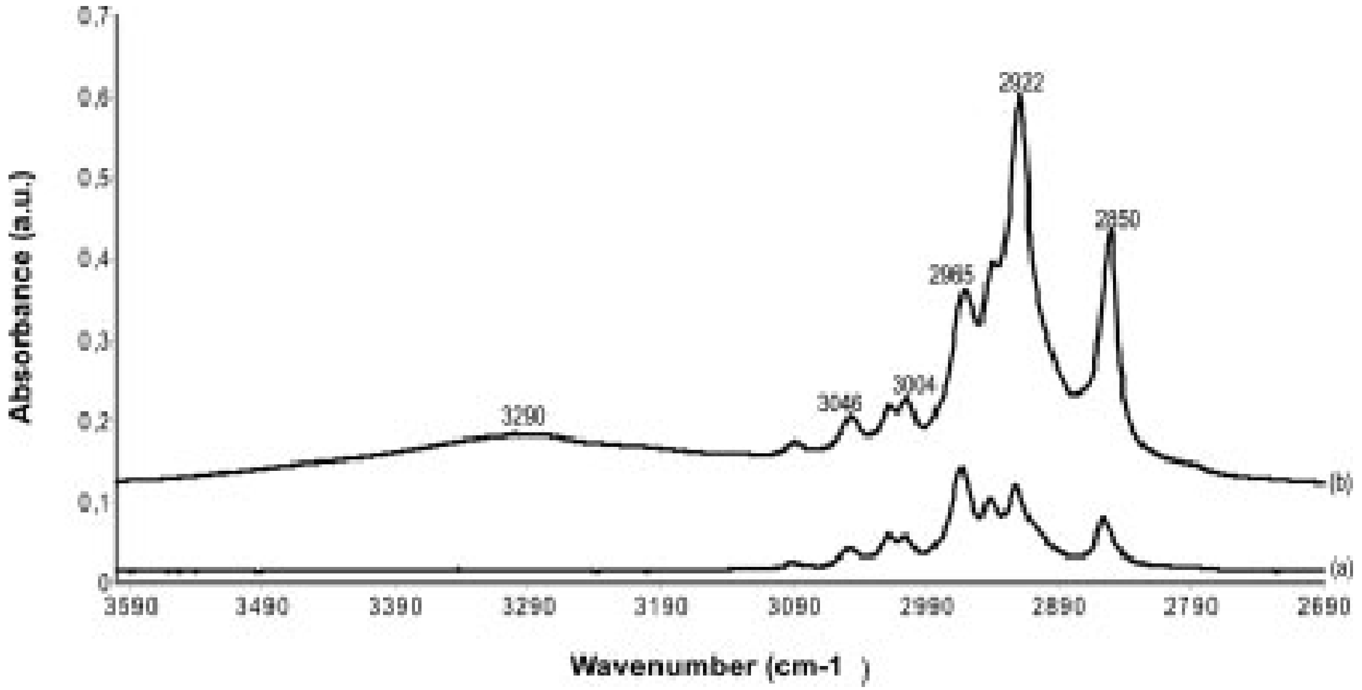
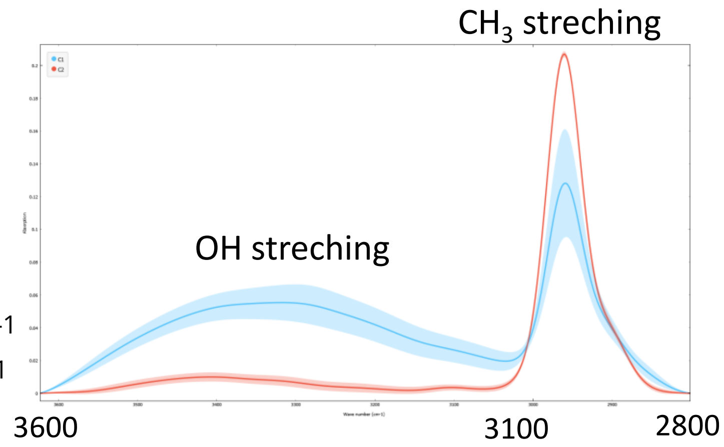


Figure 6 Comparison of ATR-FTIR test results of an unexposed reference (a) and *in vivo* used silicone rubber tracheostomy tube (b) in region 2690–3590 cm^{-1}.

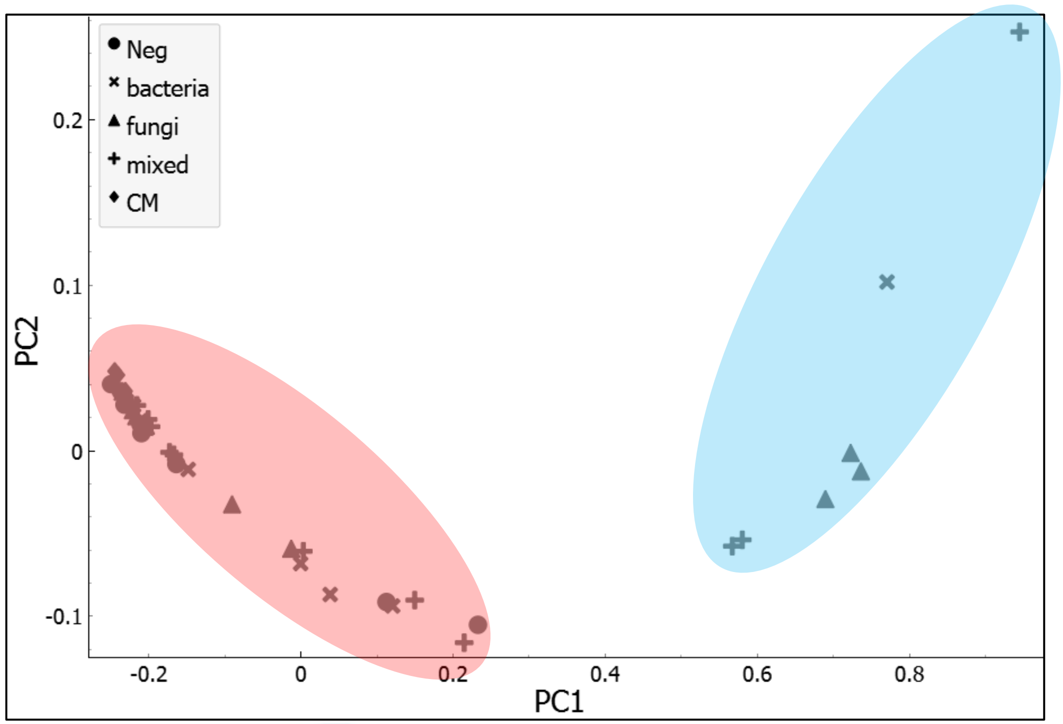
Fourier-transform infrared spectroscopy (FTIR)

Dr Corentin Loron

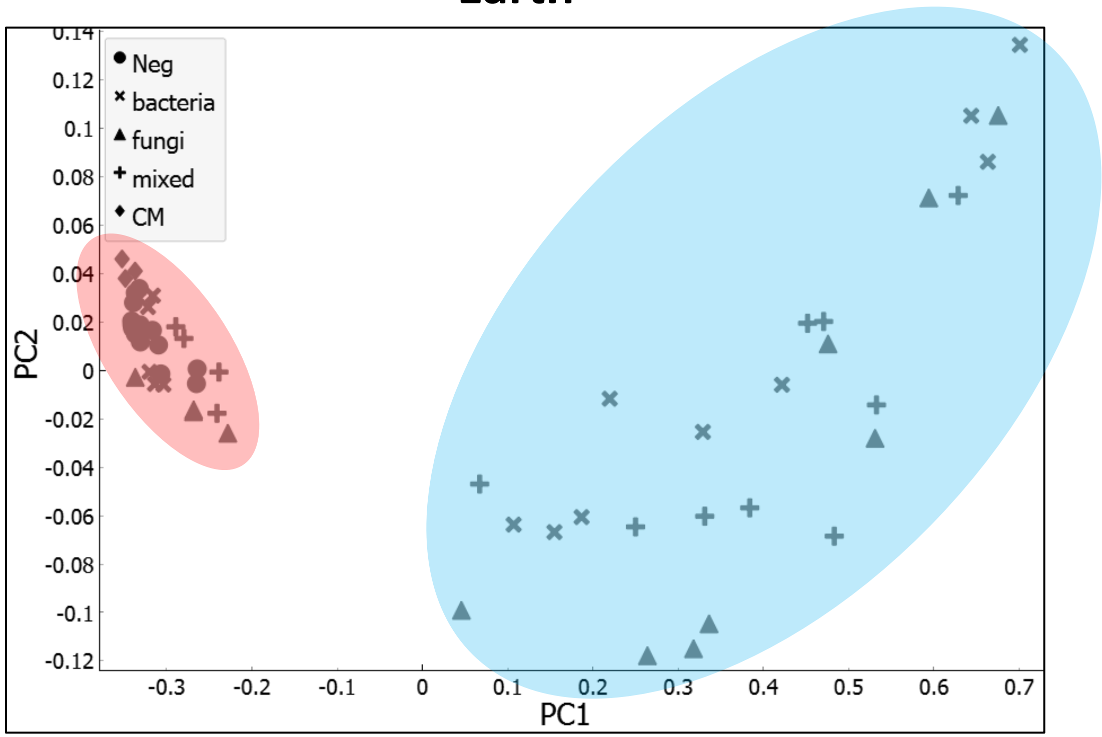
CH_3 stretching: 2800 cm^{-1}-3100 cm^{-1}
OH stretching: 3200 cm^{-1}-3600 cm^{-1}



ISS



Earth



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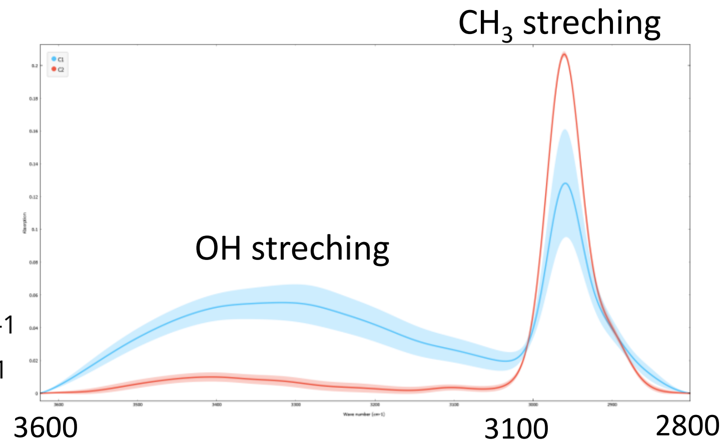
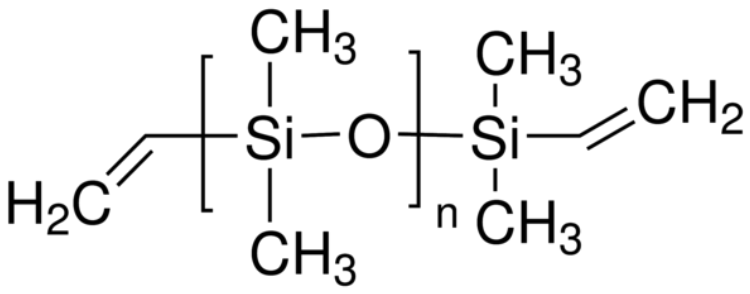
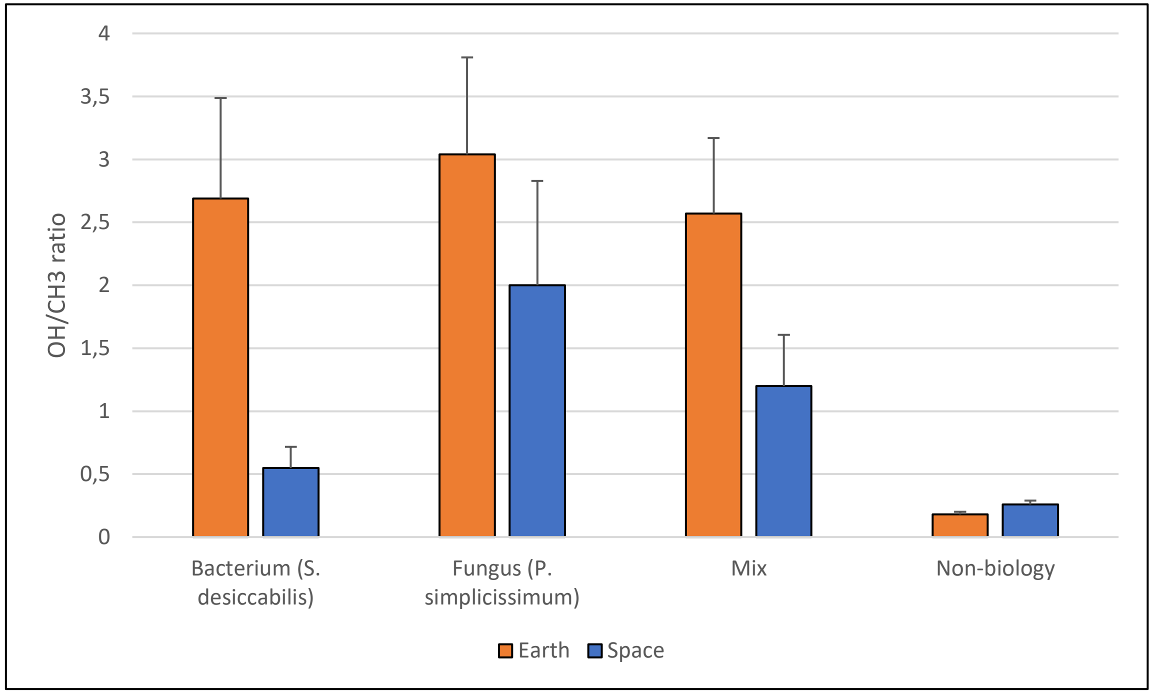




Polydimethylsiloxane, vinyl terminated

Chemometric OH/CH_3 ratio to reflect the degradation gradient



Microgravity seems to have a stronger effect on reducing bacterial rather than fungal biodegradation

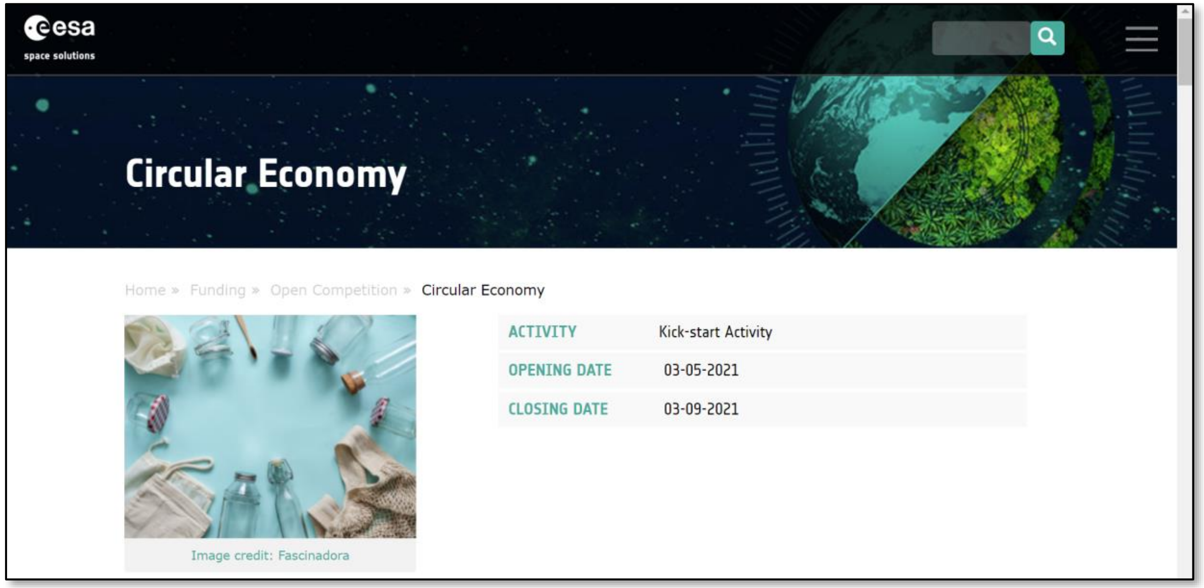
Take home messages

- Plastic waste represents a valuable resource for extraterrestrial outposts
- Although not providing products traditionally included in regenerative LSS (e.g., food, oxygen, water), non-organic waste recycling (i.e., plastic) compartments would produce primary and secondary products that could sustain biological LSS compartments, and *vice versa*
- Plastic-biodegrading microorganisms could therefore become **promising components of extraterrestrial outposts: a potential tool to close the loop.**
- Preliminary side results from a space microbiology experiment (on biomining) provided the first evidence that microbial biodegradation could be possible, but **potentially less efficient**, under space conditions – **research is required to test/improve the process for space application!**

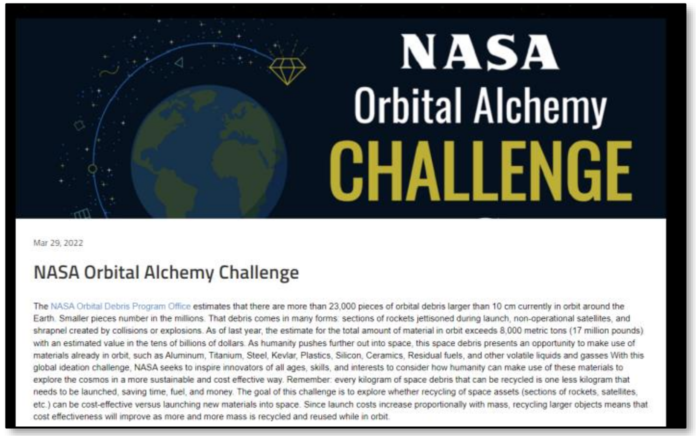
How can microbial biotechnologies support sustainable space exploration, contributing to the establishment of a space circular economy?

How can advancement in this research be transferred to Earth, to address crucial environmental issues?

Can advancement in this research be transferred to Earth, to address crucial environmental issues?



Space agencies, included ESA, and companies believe this is possible!



Looking forward to collaborate!

Prof Charles S. Cockell
Dr Corentin Loron
Dr Andrei Gromov
Sinéad Corbett
Scott McLaughlin

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THANK YOU.

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