Questions for NASA about its mistakes in the Mars Sample Return Environmental Impact Statement submitted under NEPA - these make it not scientifically credible

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Preprint DOI …

[Many candidate microbes and even higher life like lichens have been proposed as Mars analogue organisms, some tested with promising results in Mars simulation chambers, so its biologically credible a species can have adaptations to live on both planets](#h_candidate_terrestrial_microbes_mars)

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(This version 1st March 2023)

Titles of sections are like mini-abstracts and summarize the details of the section. For a first overview of this paper read the section titles.

This focuses on the questions for NASA and the points of top priority for NASA to look at. It consists of sections from the larger review paper here:

…

Many of the internal links are to sections that expand on the points made here in the larger review paper and so don’t work in this page.

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# [Abstract](#h_Abstract)

JAXA can safely return unsterilized samples without any precautions, because any microbes already withstood ejection from Mars, most recently, 700,000 years ago. They then experienced conditions on the surface of Phobos similar to conditions inside martian meteorites arriving at Earth today from that ancient impact.

JAXA warned their meteorite argument is not valid for surface samples never ejected from Mars. NASA’s draft EIS incorrectly says any life from Jezero crater can get here faster and better protected in a meteorite than in a sample tube. Surface dirt and dust can’t get here at all.

NASA’s EIS also proposes to return its samples to a Biosafety Level 4 facility. However, the European Space Foundation study in 2012 set size limits well beyond capabilities of a BSL-4 and indeed beyond any current air filter capabilities.

There are numerous other mistakes in the draft EIS.

We can avoid all these issues and keep Earth 100% safe by sterilizing samples before they get here. with the equivalent of a few hundred million years of Mars surface ionizing radiation. This has virtually no effect on geology, while Perseverance’s forward contamination makes most astrobiology impossible.

We can greatly increase science value with bonus samples in a sterile container returned to a martian gravity centrifuge in an unmanned satellite above GEO, to start Sagan’s “vigorous program of unmanned exobiology”.

## [Questions for NASA](#h_questions_for_NASA)[Next section](#h_controversial_or_mistaken_statements) – [all sections](#h_titles_of_sections) – [previous section](#H_NEPA_say_to_contact)

#### 2012 ESF Mars Sample Return size limit review:

* Are you aware that the European Space Foundation (ESF) Mars Sample Return study in 2012 reduced the size limit from 0.2 microns to 0.01 microns for the 1 in a million threshold and required 100% containment at 0.05 microns? If so, why doesn’t the EIS mention this change?
[[details](#x_size_limit)]
* Are you aware that your recommendation to contain the samples in a Biosafety level 4 facility doesn’t comply with the size limit the ESF recommended in 2012, and that the ESF recommended that the size limit and level of assurance is reviewed regularly? If so, why isn’t the reader alerted to this discrepancy?
[[details](#x_size_limit_review)]

#### Meteorite argument for samples returned from the Mars surface

* Are you aware the JAXA cite you use says on page 4 not to use their meteorite argument for samples returned from the Mars surface? If so, why isn’t the reader alerted to this discrepancy?
[[details](#x_PHobos)]

#### 2015 MEPAG review:

* Are you aware of the 2015 MEPAG review that overturned all the findings you rely on to say that life couldn’t get to Gale crater? If so, why doesn’t the EIS cite it?
[[details](#x_MEPAG)]
* Are you aware that you used a cite about searches for current localized habitable regions on Mars to support a statement that conditions on Mars have not been amenable to supporting life as we know it for millions of years? If so, why isn’t the reader alerted to this discrepancy?
[[details](#x_RSL)]

#### Large scale effects

* Are you aware of warnings about large scale effects in the NRC study in 2009? If so, why isn’t this mentioned in the EIS?
[[details](#x_large_scale_effects)]
* Are you aware of warnings about the potential that we have no defences against alien life by Joshua Lederberg and others? If so, why doesn’t the EIS discuss them?
[[details](#x_no_defences)]

#### Mars microbes as pathogens of humans, these are questions for your sterilization working group about its report:

* Are you aware that Legionella pneumophila is a disease of biofilms that also opportunistically infects humans as Legionnaires’ disease, which is sometimes lethal, and is not adapted to multicellular life? If so why isn’t this disease mentioned in the discussion of whether pathogens have to coexist with humans to harm us?
[[details](#x_Legionella)]
* Are you aware that the fungus Aspergillus fumigatus is not adapted to any multicellular host and causes an estimated 200,000 life threatening cases of invasive aspergillosis a year, mainly in immunocompromised people, with a 30% to 95% mortality rate? If so, why isn’t this fungus mentioned in the discussion of Candidas yeast’s adaptations to humans?
[[details](#x_Aspergillus)]
* Are you aware of the example from the NRC sample return report of an independently evolved hydrothermal vent organism that shares many virulence genes with a human pathogen? If so why isn’t this included in the discussion of Shiga’s toxin?
[[details](#x_Shigia)]
* Are you aware that the toxin produced by Clostridium tetani is not a result of adaptation to humans and neonatal tetanus kills thousands of unvaccinated newborns every year? If so, why isn’t this mentioned in the discussion of Shiga’s toxin?
[[details](#x_tetanus)]

#### Potential for martian microbes to survive on Earth, more questions for your sterilization working group about its report:

* Are you aware that the extremophile paper you cited lists Planococcus Halocryophilus, a microbe isolated from permafrost at an ambient temperature of about -16 °C, which has an optimal growth temperature of 25 °C and can grow at temperatures up to 37 °C (temperature of human blood) and salinity 0% to 19%? If so why isn’t this microbe discussed in your suggestion that it’s plausible that life adjusted to Martian conditions such as temperatures and pressures would not be viable on Earth?
[[details](#x_extremophiles)]
* Did you have any examples of extreme conditions microbes face on Mars that could prevent them surviving on Earth? If you didn’t have specific examples, why doesn’t your report mention this limitation?
[[details](#x_extreme_conditions)]
* Are you aware that many Mars analogue terrestrial organisms such as chroococcidiopsis are thought to have some potential for living on present day Mars? If so, why isn’t the reader informed of this?
[[details](#x_analogue)]

#### Scoping and requirement for “safety testing”

* With your requirement of “Safety testing”, are you aware that the expected level of forward contamination of 0.7 nanograms per gram per biosignature means all samples will test positive and go to hold and critical review, which will make the safety testing pointless?
[[details](#x_safety)]
* Why wasn’t the option considered to sterilize samples before they reach Earth’s biosphere?
[[details](#x_sterilize)]

#### Procedure:

* As you surely know, NEPA requires agencies to ensure scientific integrity in an Environmental Impact Statement, so, do you know how the EIS come to have so many citing errors of central importance to your arguments, and can NASA ensure this won’t happen again in any future EIS?
[[details](#x_NEPA)]
* The Council for Environmental Quality says the first step is to contact the agency to resolve issues, so, can you respond to these questions?
[[details](#x_Council)]

The simplest answer is that it is all a big mistake, and they weren’t aware of any of those things. If so fine, we all make mistakes! But that means we need to start again with a scientifically credible EIS starting with a new size limit review etc .

At some point NASA are going to have to look at these questions and others like them. The public response to the EIS so far shows many will want answers. If these are indeed valid questions, the sooner NASA look at them the easier and less costly the solutions, and the fewer the complications.

### Reasons for these questions: mistakes in NASA's draft EIS and the report of the sterilizing subcommittee [Next section](#h_we_cant_actually_asseses) – [all sections](#h_titles_of_sections) – [previous section](#h_questions_for_NASA)

Here is a list of the mistakes in the EIS or the report of the sterilization working group which that list of questions is based on, with links to the sections of this paper that discuss them:

#### 2012 ESF Mars Sample Return size limit review:

**Are you aware that the European Space Foundation (ESF) Mars Sample Return study in 2012 reduced the size limit from 0.2 microns to 0.01 microns for the 1 in a million threshold and required 100% containment at 0.05 microns? If so, why doesn’t the EIS mention this change?**

[[summary](#xc_size_limit)]

Draft EIS ([NASA, 2022](#b_NASA_2022eis): S-4):

*“The material would remain contained until examined and confirmed safe or sterilized for distribution to terrestrial science laboratories. NASA and its partners would use many of the basic principles that Biosafety Level 4 (BSL-4) laboratories use today to contain, handle, and study materials that are known or suspected to be hazardous.”*

2012 ESF Mars sample return study: [(Ammann et al, 2012:48)](#qa4nethlmcdw):

*RECOMMENDATION 7:
The probability that a single unsterilised particle of 0.01 μm diameter or greater is released into the Earth’s environment shall be less than 10 -6 .*

*…*

*The release of a single unsterilized particle larger than 0.05 μm is not acceptable under any circumstances*

This is well beyond the capability of a BSL-4. See:

* [2012: The European Space Foundation study reduced the size of particle to contain from 0.2 microns to 0.01 microns at the one in a million threshold, and added that it is not acceptable to release a particle of 0.05 microns or larger in any circumstances – this is well beyond the capabilities of NASA’s proposed BSL-4](file:///C%3A%5CUsers%5Crober%5CDocuments%5Cbooklets%5CMSR_papers%5CWhy_we_must_be_able_to_protect_Earth_from_even_mirror_life_in_Martian_dirt.docx#h_the_ESF_study_in_2012)
[and following sections]

**Are you aware that your recommendation to contain the samples in a Biosafety level 4 facility doesn’t comply with the size limit the ESF recommended in 2012, and that the ESF recommended that the size limit and level of assurance is reviewed regularly? If so, why isn’t the reader alerted to this discrepancy?**[[summary](#xc_size_limit_review)]

2012 ESF Mars Sample Return Study [(Ammann et al, 2012:21)](#qa4nethlmcdw):

*RECOMMENDATION 8: Considering that (i) scientific knowledge as well as risk perception can evolve at a rapid pace over the time, and (ii) from design to curation, an MSR mission will last more than a decade, the ESF-ESSC Study Group recommends that values on level of assurance and maximum size of released particle are re-evaluated on a regular basis*

See:

* ESF study said values for required level of assurance and the size limit need to be revisited periodically based on changes in scientific knowledge and risk perception

#### Meteorite argument for samples returned from the Mars surface

**Are you aware that the Phobos sample return study you cite specifically says on page 4 not to use their meteorite argument for samples returned from the Mars surface? If so, why isn’t the reader alerted to this discrepancy?**

[[summary](#xc_PHobos)]

Draft EIS ([NASA, 2022](#b_NASA_2022eis): 3-3):

*“The natural delivery of Mars materials can provide better protection and faster transit than the current MSR mission concept.”*

2009 NRC Mars Sample Return Study ([SSB, 2009](#b_SSB_2009): [48](https://www.nap.edu/read/12576/chapter/7#48))

*The potential hazards posed for Earth by viable organisms surviving in samples [are] significantly greater with a Mars sample return than if the same organisms were brought to Earth via impact-mediated ejection from Mars*

*…*

*Thus it is not appropriate to argue that the existence of martian meteorites on Earth negate the need to treat as potentially hazardous any samples returned from Mars by robotic spacecraft.*

2019 study of planetary protection requirements for Japan’s Phobos sample return ([SSB, 2019](#b_Board_2019) : [43](https://nap.nationalacademies.org/read/25357/chapter/5)) (split the sentences into bullet points):

* *The material will be gently sampled and returned directly to Earth.*
* *The sample may well come from an environment that mechanically cannot become a Mars meteorite.*
* *The microbes may not be able to survive impact ejection and transport through space.*
* *Samples with current liquid water and recent ice seem especially fragile to natural transport to Earth.*

*Finding: The committee finds that the content of this report and, specifically, the recommendations in it do not apply to future sample return missions from Mars itself.*

See:

* [No, life on Mars can't get to Earth faster and better protected in meteorites than in a sample tube - the 2009 Mars sample return study warns against this argument as does the 2019 Phobos sample return study - indeed martian surface brines, ice, salts, dirt and dust can't get to Earth at all](#h_the_meteorite_argument)
[and following sections]

#### 2015 MEPAG review:

**Are you aware of the 2015 MEPAG review that overturned all the findings you rely on to say that life couldn’t get to Gale crater? If so, why doesn’t the EIS cite it?**

[[summary](#xc_MEPAG)]

Draft EIS ([NASA, 2022](#b_NASA_2022eis): 1-6):

*“Consensus opinion within the astrobiology scientific community supports a conclusion that the Martian surface is too inhospitable for life to survive there today, particularly at the location and shallow depth (6.4 centimeters [2.5 inches]) being sampled by the Perseverance rover in Jezero Crater, which was chosen as the sampling area because it could have had the right conditions to support life in the ancient past, billions of years ago.”*

MEPAG review ([SSB, 2015](#b_SSB_2015) :[28](https://nap.nationalacademies.org/read/21816/chapter/7)).

*Maps that illustrate the distribution of specific relevant landforms or other surface features can only represent the current (and incomplete) state of knowledge for a specific time—knowledge that will certainly be subject to change or be updated as new information is obtained*

MEPAG review ([SSB, 2015](#b_SSB_2015) : [12](https://nap.nationalacademies.org/read/21816/chapter/4?term=dust#12)).

*"The SR-SAG2 report does not adequately discuss the transport of material in the martian atmosphere. The issue is especially worthy of consideration because if survival is possible during atmospheric transport, the designation of Special Regions becomes more difficult, or even irrelevant."*

MEPAG review ([SSB, 2015](#b_SSB_2015) :[12](https://nap.nationalacademies.org/read/21816/chapter/4?term=dust#12)).

*Physical and chemical conditions in microenvironments can be substantially different from those of larger scales. Although the SR-SAG2 report considered the microenvironment (Finding 3-10), the implications of the lack of knowledge about microscale conditions was only briefly considered.*

See:

* [Jezero crater seems uninhabited from orbit – but so do terrestrial Mars analogue deserts – the 2015 MEPAG review which the EIS doesn’t cite overturned all the conclusions relevant to Jezero crater that NASA’s EIS relies on](#j_jezero_crater_uninhabited)
[And following sections]

**Are you aware that you used a cite about searches for current localized habitable regions on Mars to support a statement in the EIS that conditions on Mars have not been amenable to supporting life as we know it for millions of years? If so, why isn’t the reader alerted to this discrepancy?**

[[summary](#xc_RSL)]

Draft EIS ([NASA, 2022](#b_NASA_2022eis): 1-6):

*“Existing credible evidence suggests that conditions on Mars have not been amenable to supporting life as we know it for millions of years.”*

National Research Council, 2022 ([Smith et al, 2022](#b_Smith_et_al_2022): [393](https://nap.nationalacademies.org/read/26522/chapter/16#393))

*Section title: “Are There Chemical, Morphological and / or Physiologic / Metabolic or Other Biosignatures in* ***Currently Habitable Environments*** *in the Solar System*

*The exploration of … Mars (Curiosity, Perseverance) will help establish whether localised habitable regions* ***currently exist*** *within these seemingly uninhabitable worlds.*

[Emphasis on “currently” mine]

See:

* [NASA’s draft EIS argues that existing credible evidence suggests Mars has not been habitable to Earth life for millions of years –– yet their cite for this sentence is about a search for current localized habitable regions on Mars – another conclusion reached through a citing error](#h_NASA_credible_evidence)

See also:

* [2016: NASA discovered potential for current habitats for terrestrial life in Gale crater AFTER Curiosity’s landing](#h_NASA_current_habitats_Gale)

#### Large scale effects:

**Are you aware of the warnings about large scale effects in the NRC study in 2009? If so, why isn’t this mentioned in the EIS?**

[[summary](#xc_large_scale_effects)]

Draft EIS ([NASA, 2022](#b_NASA_2022eis): 3-3):

*“The relatively low probability of an inadvertent reentry combined with the assessment that samples are unlikely to pose a risk of significant ecological impact or other significant harmful effects support the judgement* ***that the potential environmental impacts would not be significant.”***

2009 NRC Mars Sample Return Study [(SSB, 2009](#kix.xed3c1hm3p4k) : [48](https://nap.nationalacademies.org/read/12576/chapter/7#48) )

The committee found that **the potential for large-scale negative effects on Earth’s inhabitants or environments by a returned martian life form appears to be low, but is not demonstrably zero**

… **it is not possible to assess past or future negative impacts caused by the delivery of putative extraterrestrial life**, based on current evidence.
…
… It follows that, since the potential risks of pathogenesis cannot be reduced to zero, a conservative approach to planetary protection will be essential, **with rigorous requirements for sample containment and testing protocols of life forms that are pathogenic to humans**

See:

* [The planetary protection literature warns of not demonstrably zero potential for even large scale harm to human health and the environment – NASA’s draft EIS conclusion of no significant risk of environmental effects seems a minority view amongst microbiologist and they don’t alert the reader to this discrepancy](#h_the_plnaetary_protection_literature)

**Are you aware of the warnings about the potential that we have no defences against alien life by Joshua Lederberg and others? If so, why doesn’t the EIS discuss them?**[[summary](#xc_no_defences)]

Draft EIS Sterilization Working Group report [(Craven et al., 2021:6)](#b_Craven_et_al_2021)

*“Since any putative Martian microorganism would not have experienced long-term evolutionary contact with humans (or other Earth host),* ***the presence of a direct pathogen on Mars is likely to have a near-zero probability.”***

Joshua Lederberg [(Lederberg, 1999b)](#kix.ar87fg72xwf2):

***Joshua Lederberg:*** *Whether a microorganism from Mars exists and could attack us is more conjectural. If so, it might be a zoonosis [infectious disease that jumps to humans] to beat all others*

See:

* [Warnings by some astrobiologists such as Sagan and Lederberg that in worst case we could be in effect immunocompromised to an entire exobiology from Mars](#h_warnings_by_some_astrobiologists)
[And previous sections]

#### Mars microbes as pathogens of humans, these are questions for your sterilization working group about its report:

**Are you aware that Legionella pneumophila is a disease of biofilms that also opportunistically infects humans as Legionnaires’ disease, which is sometimes lethal, and is not adapted to multicellular life? If so why isn’t this disease mentioned in the discussion of whether pathogens have to coexist with humans to harm us?**[[summary](#xc_Legionella)]

Draft EIS Sterilization Working Group report [(Craven et al., 2021:6)](#b_Craven_et_al_2021)

*Since any putative Martian microorganism would not have experienced long-term evolutionary contact with humans (or other Earth host),* ***the presence of a direct pathogen on Mars is likely to have a near-zero probability.***

Warmflash used Legionnaires’ disease to challenge whether there is a need for human pathogens to co-evolve with us [(Warmflash, 2007)](#inpazll45dhz):

*In essence, all that a potentially infectious human pathogen needs to emerge and persist is to grow and live naturally under conditions that are similar to those that it might later encounter in a human host. On Mars, these conditions might be met in a particular niche within the extracellular environment of a biofilm, or within the intracellular environment of another single-celled Martian organism.*

*…*

*To be sure, the genetic similarity between humans and protozoa is much greater than could be expected between humans and the Martian host of a Martian microbe.*

*Even in the context of a planetary biosphere that is limited to single-celled life, and even where there is unlikely to have been a co-evolution between agent and host organism, the possibility of infectious agents, even an invasive type, cannot be ruled out.*

See:

* [Argument that martian pathogens wouldn’t be adapted to humans or other Earth hosts misses a disease of biofilms that opportunistically infects human lungs - legionnaires’ disease](#h_argument_pathogens_not_adapted)

**Are you aware that the fungus Aspergillus fumigatus is not adapted to any multicellular host and causes an estimated 200,000 life threatening cases of invasive aspergillosis a year, mainly in immunocompromised people, with a 30% to 95% mortality rate? If so, why isn’t this fungus mentioned in the discussion of Candidas yeast’s adaptations to humans?**[[summary](#xc_Aspergillus)]

Draft EIS Sterilization Working Group report [(Craven et al., 2021:6)](#b_Craven_et_al_2021):

*Existing microorganisms that coexist with humans over long periods of time can also …

opportunistically infect a host with a weakened or compromised immune system such as candidiasis yeast infections*

From this list of the most common opportunistic invasive fungal diseases, Aspergillus is at the top alongside Candidiasis [(Brown et al, 2012:table 1)](#kix.jjb1r3cr4sax).



It’s not adapted to humans or indeed as a pathogen of any higher life ([McCormick et al, 2010](#b_McCormick_2010)).

*According to our current knowledge A. fumigatus lacks sophisticated virulence factors that are solely dedicated to permit a pathogenic lifestyle.*

See:

* [NEW: Sterilization working group’s report gives an example of an opportunistic fungal pathogen, Candidiasis, adapted to humans – the omission here is Aspergillus which is not adapted to humans and is invasive due to adaptations to survive rapid dehydration and rehydration, rapid changes of temperature etc. many of which may be shared by life adapted to Mars – with an estimated 200,000 life-threatening cases of invasive aspergillosis a year – with mortality 30% to 95%](#h_Aspergillus_not_adapted)

**Are you aware of the example from the NRC sample return report of an independently evolved hydrothermal vent organism that shares many virulence genes with a human pathogen? If so why isn’t this included in the discussion of Shiga’s toxin?**[[summary](#xc_Shigia)]

Draft EIS Sterilization Working Group report [(Craven et al., 2021:6)](#b_Craven_et_al_2021).

*Existing microorganisms that coexist with humans over long periods of time can also cause new diseases when the organism takes on new pathogenicity, such as the Escherichia coli strain 0157:H7 that acquired a gene for Shiga toxin, …*

2009 NRC Mars Sample Return Study ([SSB, 2009](#b_SSB_2009): [46](https://nap.nationalacademies.org/read/12576/chapter/7#46)):

*“****However****, it is worth noting in this context that interesting evolutionary connections between alpha proteobacteria and human pathogens have recently been demonstrated for natural hydrothermal environments on Earth … it follows that, since the potential risks of pathogenesis cannot be reduced to zero, a conservative approach to planetary protection will be essential, with rigorous requirements for sample containment and testing protocols of life forms that are pathogenic to humans’*

See:

* [The sterilization working group’s report mentions a strain of e. coli that they hypothesize became toxic by coexisting with humans – however the NRC sample return report gave an example of an independently evolved hydrothermal vent organism that shares many virulence genes with a human pathogen – martian microbes would continue to evolve on Earth – and this omits the suggestion by Łoś et al that e. coli developed Shiga’s toxin to deter protozoan grazing in biofilms and only uses it opportunistically in humans](#h_sterilizing_subc_accidental_toxins)

**Are you aware that the toxin produced by Clostridium tetani is not a result of adaptation to humans and neonatal tetanus kills thousands of unvaccinated newborns every year? If so, why isn’t this mentioned in the discussion of Shiga’s toxin?**[[summary](#xc_tetanus)]

Draft EIS Sterilization Working Group report [(Craven et al., 2021:6)](#b_Craven_et_al_2021).

*Existing microorganisms that coexist with humans over long periods of time can also cause new diseases when the organism takes on new pathogenicity, such as the Escherichia coli strain 0157:H7 that acquired a gene for Shiga toxin, …*

Warmflash et al give examples such as tetanus, locally infectious [(Warmflash, 2007)](#inpazll45dhz).

*Locally infectious organisms, which do not multiply systemically within a host but which produce a toxin which the host can absorb, perhaps through an infected wound, may also be possible on a planet that harbors single-celled life. Clostridia is an example of an anaerobic genus that often lives as spores in soils and some of its species are important human pathogens, including C. tetani and C. perfringens, which are locally infectious in wounds, where they release toxins that can be life-threatening through systemic effects (C. tetani) or local effects (C. perfringens)*

We can now protect babies with widely available tetanus vaccines, yet tetanus still kills thousands of newborns every year in weaker economies ([WHO, n.d.)](#b_WHO_ndt) .

See:

* [Sterilization working group’s report doesn’t mention clear examples of microbes which express accidental toxins without coevolution with humans or higher life, such as neonatal tetanus which kills thousands of unvaccinated newborns every year – and even the internal chemistry of an unfamiliar exobiology could be accidentally toxic](#b_Shigas_toxin_accidental_tetanus)

**Are you aware that the extremophile paper you cited lists Planococcus Halocryophilus, a microbe isolated from permafrost at an ambient temperature of about -16 °C, which shows activity down to the lowest temperature tested of -25 °C, and verified growth in the lab from -15 °C to 37 °C (temperature of human blood) and salinity 0% to 19%? If so why isn’t this microbe discussed in your report?**
[[summary](#xc_extremophiles)]

Draft EIS Sterilization Working Group report [(Craven et al., 2021:6-7)](#b_Craven_et_al_2021):

*There are many described extremophiles that may survive in environments that are extreme to human or animal life* ***(e.g. extremes of temperature or pressure)*** *but do not survive under conditions in our normal habitat* (Merino et al. 2019).

*… Thus, it is plausible that any Martian microbe, after it arrives on Earth, would not be viable on Earth due to a lack of its required Martian nutritional and environmental conditions.*

One of the extremophiles listed in their cite ([Merino et al, 2019](#b_Merino_2015): table 3) is Planococcus Halocryophilus with a temperature range -15 °C to 37 °C and optimal growth 25 °C which was actually isolated from permafrost soil, where it like inhabits cold brines in the soil ([Mykytczuk et al., 2013](#b_Mykytczuk_2913)) ([Mykytczuk, 2012](#b_Mykytczuk_2012)).



See:

* [NASA’s biological safety report agrees on the potential for an invasive Martian species to harm or displace terrestrial photosynthetic bacteria – but says life adapted to Martian conditions such as the temperatures and pressures plausibly wouldn’t be able to survive on Earth – their own cite mentions Planococcus Halocryophilus, a microbe which lives in Arctic permafrost soils and likely grows in sub zero brine veins down to at least -15 °C with an optimal growth temperature of 25°C and growth up to 37 °C (human blood temperature)](#h_argument_by_sterilizing_subcommittee)

**Did you have any examples of extreme conditions microbes face on Mars that could prevent them surviving on Earth? If you didn’t have specific examples, why doesn’t your report mention this limitation?**[[summary](#xc_extreme_conditions)]

Draft EIS Sterilization Working Group report [(Craven et al., 2021:6-7)](#b_Craven_et_al_2021)

*“There are many described extremophiles that may survive in environments that are extreme to human or animal life (e.g. extremes of temperature or pressure) but do not survive under conditions in our normal habitat … Thus, it is plausible that any Martian microbe, after it arrives on Earth, would not be viable on Earth due to a lack of its required Martian nutritional and environmental conditions.”*

See:

* [Microbes from near the surface in Jezero crater would withstand temperatures varying from below -70 °C to above 15 °C in a single day – and major changes in humidity and pressure – this is likely to favour polyextremophiles – while microbes able to resist stresses like UV, low humidity, vacuum, and ionizing radiation do not require a non-terrestrial biology and there is no reason for them to be dependent on these conditions to survive](#h_although_martian_life_is_likekly)
[And following sections]

**Are you aware that there are many Mars analogue terrestrial organisms such as chroococcidiopsis are thought to have some potential for living on present day Mars? If so, why isn’t the reader informed of this?**
[[summary](#xc_analogue)]

See:

* [Several candidate terrestrial microbes and even higher organisms such as lichens may be able to survive on Mars, with promising results in Mars simulation chambers, suggesting a possibility that their Mars analogues may be able to live on Earth](#h_candidate_terrestrial_microbes_mars)

#### Scoping and requirement for “safety testing”

**With your requirement of “Safety testing”, are you aware that the expected level of forward contamination of 0.7 nanograms per gram per biosignature means all samples will test positive and go to hold and critical review, which will make the safety testing pointless?**
[[summary](#xc_safety)]

Draft EIS ([NASA, 2022](#b_NASA_2022eis): 3-3)

*These same principles regarding the importance of using terrestrial laboratories to enable the best scientific return also apply to the care and attention to detail that would be required to conduct a proper and comprehensive sample safety assessment in a proposed SRF.*

See:

* [NEW: Sadly Perseverance’s permitted levels of 0.7 nanograms per gram for their most abundant biosignatures would overwhelm any faint signature of biosignatures from past life or even as many as thousands of cells per gram of present day life, even if viable](#h_sadly_perseverances_permitted)
* [So sterilization preserves virtually all geological interest with minimal impact on astrobiological impact – but NASA’s EIS doesn’t permit it due to a requirement for “safety testing”](#h_so_sterilization_presevers_virtually)
* [NEW: Even if samples are returned unsterilized this “safety testing” seems to serve no useful purpose – all the samples would be guaranteed false positives – with no available biosignature to distinguish terrestrial from potential martian life – and we can’t distinguish Martian life by gene sequences as nearly all terrestrial microbes are unsequenced – and we can’t test for martian life by trying to cultivate it as we can’t reliably cultivate even terrestrial life in a lab](#h_even_if_samples_are)
[And previous and following sections]

**Why wasn’t the option considered to sterilize samples before they return?**
[[summary](#xc_sterilize)]

See:

* [We can forestall all these issues and make the mission 100% safe by sterilizing samples before they reach Earth – NEW](#h_we_can_forestall)

#### Procedure:

**As you surely know, NEPA requires agencies to ensure scientific integrity in an Environmental Impact Statement, so, do you know how the EIS come to have so many citing errors of central importance to your arguments, and can NASA ensure this won’t happen again in any future EIS?**
[[summary](#xc_NEPA)]

*Agencies shall ensure* *the professional integrity, including scientific integrity, of the discussions and analyses in environmental impact statements*[§ 1502.23](https://www.ecfr.gov/current/title-40/chapter-V/subchapter-A/part-1502/section-1502.23)

* [NASA’s draft EIS fails NEPA requirement for a valid Environmental Impact Statement to ensure scientific integrity – with missing cites and cites that overturn the sentences they are cited to](#h_NASAS_draft_EIS_fails)

**The Council for Environmental Quality says the first step is to contact the agency to resolve issues, so, can you respond to these questions?**
[[summary](#cx_Council)]

Council of Environmental Quality ([COEQ, 2007](#b_COEQ_2007):28):

*Your first line of recourse should be with the individual that the agency has identified as being in charge of this particular process.*

* [The Council of Environmental Quality says the first step is to contact the agency to resolve issues, however NASA has not yet responded to attempts to contact them on this topic](#H_NEPA_say_to_contact)

## [NASA’s draft EIS fails NEPA requirement for a valid Environmental Impact Statement to ensure scientific integrity – with missing cites and cites that overturn the sentences they are cited to](#h_NASAS_draft_EIS_fails) [Next section](#h_NEPA_erasonable_alsternatives) – [all sections](#h_titles_of_sections) – [previous section](#h_many_legal_ramifications)[[question](#xc_NEPA)]

NASA’s draft fails several of NEPA’s central requirements for a valid EIS.

*Agencies shall ensure* *the professional integrity, including scientific integrity, of the discussions and analyses in environmental impact statements*[§ 1502.23](https://www.ecfr.gov/current/title-40/chapter-V/subchapter-A/part-1502/section-1502.23)

The EIS has major issues, mainly

* **Currency:** uses out of date research, with major omissions of later studies that overturn results it relies on.
* **Accuracy:** sentences in the EIS are contradicted by the cites attached to those sentences, and the reader isn’t alerted to this discrepancy
* **Accuracy:** doesn’t mention views opposed to their conclusions in their own sources or other sources with views that contradict the agency’s conclusions in the EIS.

A credible scientific report needs to be reviewed carefully to eliminate or minimize such errors ([Blakeslee, 2004](#b_Blakeslee_2004)) ([Tripp, n.d.)](#b_Tripp_nd) ([Nausman, n.d.](#b_Nausman_nd)). For a list of the main issues found in the draft EIS see:

* [Questions for NASA](#h_questions_for_NASA)
* [Reasons for these questions: controversial or mistaken statements in NASA's draft EIS and the report of the sterilizing subcommittee](#h_controversial_or_mistaken_statements)

On the last point of omissions of opposing views ([Feldman et al., n.d.](#b_Feldman_nd))

*An agency must address in an EIS “responsible opposing view[s].” Courts have
interpreted this regulation as requiring agencies to address opposing scientific viewpoints. In recent years, courts have given an agency’s response to opposing scientific viewpoints deferential treatment, so long as the agency addressed the opposing statements and differing opinions in a meaningful way during the decision-making process.*

So, for instance on the topic of environmental effects, it seems the courts would be able to pass it as a valid Environmental Impact Statement under NEPA based on NASA’s own statement that in their view there is no significant risk of environmental effects, so long as NASA alert the reader to the opposing views in sources such as the

* the NRC Mars sample return study in 2009
* the ESF Mars sample return study in 2012

and so long as NASA address these differences of view in a meaningful way in the EIS. Presumably NASA would need to discuss the reasons the ESF and the NRC gave for their views, and explain why they came to a different view.

However, the views in the ESF and NRC studies on environmental effects are simply not mentioned. So, it would seem to fail this requirement for a valid EIS. For a discussion of the views they omitted see:

* [The planetary protection literature warns the potential for even large scale harm to human health and the environment isn’t demonstrably zero – NASA’s draft EIS conclusion that there is no significant risk of environmental effects seems a minority view amongst microbiologist and they don’t alert the reader to the existence of any other view on the topic](#h_the_plnaetary_protection_literature)

For a list of the main issues found in the draft EIS see:

* [Questions for NASA](#h_questions_for_NASA)
* [Reasons for these questions: controversial or mistaken statements in NASA's draft EIS and the report of the sterilizing subcommittee](#h_controversial_or_mistaken_statements)

### [NASA’s draft EIS fails the NEPA’s requirement to consider reasonable alternatives in detail so that reviewers may evaluate their comparative merits – as it doesn’t examine the reasonable alternatives to sterilize samples in space first or to delay the mission until it can be done safely](#h_NEPA_erasonable_alsternatives)[Next section](#h_NASA_interdisciplinary) – [all sections](#h_titles_of_sections) – [previous section](#h_NASAS_draft_EIS_fails)

Another of the NEPA’s central requirements for a valid EIS.

*(a) Evaluate reasonable alternatives to the proposed action, and, for alternatives that the agency eliminated from detailed study, briefly discuss the reasons for their elimination.*

*(b) Discuss each alternative considered in detail, including the proposed action, so that reviewers may evaluate their comparative merits.*[§ 1502.14](https://www.ecfr.gov/current/title-40/chapter-V/subchapter-A/part-1502/section-1502.14)

NASA's EIS doesn't have rigorous analysis of ANY alternative except "no action". Reasonable alternatives include sterilizing samples in space before they approach humans or our biosphere or delaying the mission until it can be done safely.

### [NASA’s draft EIS fails the NEPA’s requirement to use an interdisciplinary approach including the social sciences, by failing to involve the public early on, not just in the USA but through fora open to representatives from all countries globally, as recommended in sample return studies – so the public weren’t given the opportunity to comment on a scientifically valid draft EIS](#h_NASA_interdisciplinary)[Next section](#h_other_commentators_raised) – [all sections](#h_titles_of_sections) – [previous section](#h_NEPA_erasonable_alsternatives)

Another of the NEPA’s central requirements for a valid EIS.

*Agencies shall prepare environmental impact statements using an interdisciplinary approach that will ensure the integrated use of the natural and social sciences and the environmental design arts*[§ 1507.2](https://www.ecfr.gov/current/title-40/chapter-V/subchapter-A/part-1502/section-1502.6)

Mars sample return studies emphasize the need to involve the public early on, not just in the USA, but through fora open to representatives from all countries globally because negative impacts could affect countries beyond the ones involved directly in the mission [(Ammann et al, 2012:59)](#qa4nethlmcdw)

*RECOMMENDATION 3*

*Potential risks from an MSR are characterised by their complexity, uncertainty and ambiguity, as defined by the International Risk Governance Committee’s risk governance framework. As a consequence, civil society, the key stakeholders, the scientific community and relevant agencies’ staff should be involved in the process of risk governance as soon as possible.*

*In this context, transparent communication covering the accountability, the benefits, the risks and the uncertainties related to an MSR is crucial throughout the whole process. Tools to effectively interact with individual groups should be developed (e.g. a risk map).*

*RECOMMENDATION 4*

*Potential negative consequences resulting from an unintended release could be borne by a larger set of countries than those involved in the programme. It is recommended that mechanisms and fora dedicated to ethical and social issues of the risks and benefits raised by an MSR are set up at the international level and are open to representatives of all countries*

The public weren’t involved early on in that way. Not only that, those in the public who did discover NASA’s request for public comment weren't given the opportunity to comment on a scientifically valid EIS.

I hope NASA and other space agencies can ensure a mishap like this never happens again.

### [Other commentators raised significant issues – including one of the principle authors of NASA’s probabilistic risk assessment guide who said a better statement of options should include the possibility of delaying the return until the risks are better understood](#h_other_commentators_raised)[Next section](#H_NEPA_say_to_contact) – [all sections](#h_titles_of_sections) – [previous section](#h_NASA_interdisciplinary)

Several other commentators raised significant issues including some of the ones already mentioned as well as new ones ([Dehel, 2022](#b_Dehel_2022)) [(DiGregorio, 2022)](#b_DiGregorio_2022) ([Everline, 2022](#b_everline_2022)) .

Everline, a JPL employee and a principal author of NASA’s probabilistic risk assessment guide [(Stamatelatos, 2011)](#b_Stamatelatos_2011), made a detailed public comment which said ([Everline, 2022](#b_everline_2022))

***Chester Everline:*** *A better statement of options should include the possibility of delaying the return of Mars samples until the risks associated with their return are better understood*

### [The Council of Environmental Quality says the first step is to contact the agency to resolve issues, however NASA has not yet responded to attempts to contact them on this topic](#H_NEPA_say_to_contact)[Next section](#h_questions_for_NASA) – [all sections](#h_titles_of_sections) – [previous section](#h_other_commentators_raised)

[[question](#cx_Council)]

The Council of Environmental Quality say the first step is to contact the agency to resolve issues ([COEQ, 2007](#b_COEQ_2007):28):

*Your first line of recourse should be with the individual that the agency has identified as being in charge of this particular process.*

The natural point of contact is NASA’s planetary protection office. They haven’t responded to my email about the issues I raised after the draft EIS was published.

The comments section of the draft EIS didn’t include responses to substantial issues I raised in May [(Walker, 2022a)](#b_Walker_2022)

NEPA don’t mention the many significant issues I or anyone else raised with the draft EIS in their final letter to the public comments page on the last day of the public comments period, December 7th [(EPA, 2022)](#B_epa_2022).

It’s also not appropriate to try to work with other employees of NASA to resolve this issue when NASA’s planetary protection office aren’t responding.

There seems no way forward by way of dialog with NASA at this point in time. I encourage NASA to respond. I encourage any reviewers for this paper to ask NASA themselves.

## [We can’t actually assess the level of risk until we know more about Mars – it could be zero or it could be far higher than expected](#h_we_cant_actually_asseses)[Next section](#h_worst_case_scenarios) – [all sections](#h_titles_of_sections) – [previous section](#h_controversial_or_mistaken_statements)

This mission raises many novel ethical and legislative questions. First, as the NRC observed, we can’t actually assess the current level of risk [(Space Studies Board, 2009: 48).](#kix.xed3c1hm3p4k)

… **it is not possible to assess past or future negative impacts caused by the delivery of putative extraterrestrial life**, based on current evidence.

If later we find only prebiotic synthesis on Mars, or slowly and imperfectly reproducing life with a biochemistry compatible with terrestrial predators, our risk from an unsterilized sample return is zero. Our main risk is in the forward direction that we might lose the chance to discover and investigate early life or prebiotic synthesis on Mars.

However, if later we discover a mirror life analogue of chroococcidiopsis on Mars, our risk from an unsterilized sample return of even large scale harm is far higher than we currently assess it to be.

### [Worst case scenarios introduce novel ethical and legal questions – is a 1 in a million level of risk acceptable?](#h_worst_case_scenarios)[Next section](#h_synthetic_biologists_suggest) – [all sections](#h_titles_of_sections) – [previous section](#h_we_cant_actually_asseses)

The very worst case scenarios for martian life such as mirror life also introduce novel ethical and legal questions about the level of risk we are prepared to take.

Kelly has traced the 1 in a million figure back to a 1 in 100 million figure in a 1961 article, introduced by Mantel et al for the purpose of discussion ([Mantel et al, 1961](#b_Mantel_1961)). When asked why he chose this figure he replied ***"We just pulled it out of a hat"*** ([Kelly, 1991](#b_Kelly_1991)). The FDA adopted this in 1973 but it became 1 in a million when the final rule was issued. Graham [(Graham, 1993)](#b_Graham_1993) says in practice, EPA's air office tries to reduce the risk to as many people as possible to 1 in a million and the maximally exposed individual to 1 in 10,000. In other situations, EPA recommends a range of risk levels from 1 in 100,000 to 1 in 10 million, and sometimes approves at a level of 1 in 10,000.

This is an ad hoc ethical decision by regulators about levels of acceptable risk, which got accepted more widely by legislators and the general public.

It also doesn’t take account of human error. There are many examples, such as a SARS outbreak in 2003 in Taiwan which happened because a technician skipped the standard procedure after a spill, because it would make him late for a conference [(Demaneuf, 2020)](#b_Demaneuf_2020).

Other escapes could happen from equipment failure. During the Apollo sample returns, two technicians had to go into isolation after a leak was found in a sample handling glove for Apollo 11 [(Meltzer, 2012:485)](#kix.cewdeelxmotf), and 11 technicians in a similar incident for Apollo 12 [(Meltzer, 2012:241)](#kix.cewdeelxmotf).

All this needs especially close scrutiny once there’s potential for novel and even unprecedented larges scale harm – including other issues such as accidents, a fire at the facility or criminal actions.

### [Synthetic biologists suggest a safety mechanism for synthetic life should be many orders of magnitude safer than a BSL-4](#h_synthetic_biologists_suggest)[Next section](#h_society_places_very_high) – [all sections](#h_titles_of_sections) – [previous section](#h_worst_case_scenarios)

Synthetic biology already permits the creation of inheritable synthetic life such as life with hachimoji DNA [(Hoshika et al, 2019)](#kix.7yh9gckbgm8u). They make sure that this is safe by designing nucleotides that depend on chemicals only available in the laboratory.

Synthetic biologists have suggested that a safety mechanism to contain synthetic life should be many orders of magnitude safer than any contemporary biosafety device. Schmidt puts it like this [(Schmidt, 2010)](#kix.olm1b61u9vxl)

*The ultimate goal would be a safety device with a probability to fail below 10−40, which equals approximately the number of cells that ever lived on earth (and never produced a non-DNA non-RNA life form). Of course, 10−40 sounds utterly dystopic (and we could never test it in a life time), maybe 10−20 is more than enough. The probability also needs to reflect the potential impact, in our case the establishment of an XNA ecosystem in the environment, and how threatening we believe this is.*

*The most important aspect, however, is that the new safety mechanism should be several orders of magnitude safer than any contemporary biosafety mechanism.*

We can’t rely on the same risk-benefit calculus for release of SARS and for release of mirror life, without legislative / executive / public involvement to decide if this is what we should do.

### NEW: [Society places very high value on the environment and given the potential for large scale effects, we might require Earth is kept 100% safe for this mission – i.e. use the prohibitory precautionary principle](#h_society_places_very_high)[Next section](#h_carl_sagan_and_others) – [all sections](#h_titles_of_sections) – [previous section](#h_synthetic_biologists_suggest)

This mission also leads to novel questions about variations on the precautionary principle – principles to do with how we need to handle situations where the level of risk can't currently be assessed because the science is incomplete.

The ESF study considered variations on the precautionary principle [(Ammann et al, 2012:25)](#qa4nethlmcdw) based an analysis of the principle by Stewart [(Stewart, 2002)](#kix.i6axx1j5e276), including:

* **Best Available Technology Precautionary Principle**: Activities that present an uncertain potential for significant harm should be subject to best technology available requirements to minimise the risk of harm unless the proponent of the activity shows that they present no appreciable risk of harm.
* **Prohibitory Precautionary Principle**: Activities that present an uncertain potential for significant harm should be prohibited unless the proponent of the activity shows that they present no appreciable risk of harm

The ESF ruled out the Prohibitory Precautionary Principle on the basis that it would simply lead to cancellation of the mission [(Ammann et al, 2012:25)](#qa4nethlmcdw):

*It is not possible to demonstrate that the return of a Mars sample presents no appreciable risk of harm. Therefore, if applied, the Prohibitory Precautionary Principle approach would simply lead to the cancellation of the MSR mission.*

They did this as experts mandated to find the safest way to conduct the mission.

However Stewart, elsewhere in that same paper, suggests there may be situations where prohibition may be needed, since society places very high value on the environment and its protection [(Stewart, 2002:15)](#kix.i6axx1j5e276).

## [Carl Sagan and others warning we can’t take even a small risk with a billion lives – this could be formalized into law as a requirement to use the prohibitory precautionary principle whenever there is any appreciable risk for harm unprecedented in human history](#h_carl_sagan_and_others)[Next section](#h_the_decision_about) – [all sections](#h_titles_of_sections) – [previous section](#h_society_places_very_high)

Chester Everline in his comment said ([Everline, 2022](#b_everline_2022)):

*A possible consequence of unsuccessful containment is an ecological catastrophe. Although such an occurrence is unlikely, NASA should at least be clear regarding what level of risk it is willing to assume (for the biosphere of the entire planet)*

Is a sample return mission one where we should consider the prohibitory version of the principle?

Carl Sagan said we can’t take even a small risk – that’s the prohibitory version [(Sagan, 1973)](#kix.urfjjsuep509):

***Carl Sagan:*** *Because of the danger of back-contamination of Earth, I firmly believe that manned landings on Mars should be postponed until the beginning of the next century, after a vigorous program of unmanned Martian exobiology and terrestrial epidemiology.*

*…. I, myself, would love to be involved in the first manned expedition to Mars. But an exhaustive program of unmanned biological exploration of Mars is necessary first****. The likelihood that such pathogens exist is probably small, but we cannot take even a small risk with a billion lives.****.*

Gill Levin, who died shortly before the EIS, said the same, as recorded on video by Dehel and mentioned in his public comment ([Dehel, 2022](#b_Dehel_2022)).

***Gill Levin:*** *I believe people will realize, especially after the Covid-19 catastrophe, that even if there’s only a small chance that something could be contagious and pathogenic, coming from a foreign planet, I don’t think it’s worth taking that chance….you don’t take unnecessary chances where the risk-to-benefit ratio is almost infinite.”*

DiGreggorio in his public comment quotes from an interview he did with Dr Carl Woese who also expressed a similar sentiment [(DiGregorio, 2022)](#b_DiGregorio_2022)

***Carl Woese:*** *Unless you can rule out the chance that it might do harm, you should not embark on such a course*

One possible outcome of public debate on this topic is to formalize Woese, Levin and Sagan’s ethical views on this topic into legislation. The general public, and legislators, could decide that if an action has potential for unprecedented levels of harm to human health or the environment, the prohibitory version of the principle should always be used.

Perhaps it might be formulated something like this (for illustrative purposes only not a proposal):

*If it is impossible to show that there is no appreciable risk of unprecedented levels of harm to public health or the environment, the Prohibitory version of the Precautionary Principle must always be used*

Unprecedented here means unprecedented in human history (e.g. mass extinction level events).

There’s an interesting way of working with this mathematically derived by Nick Bostrom which may help others to understand the perspective of those who think a one in a million chance of a severe impact like this is unacceptable. His approach is to multiply the probability by the population to get the expected number impacted ([Bostrom, 2002](#b_Bostrom_2002))

Let’s apply his approach to this back contamination scenario. With a population of 7.7 billion and a 1 in a million chance of a severe impact, suppose that it affects half the population, that multiplies out to an expected 3,350 people that would be impacted by the sample return.

But if it is something that has long term future effects on our ecosystem, leaving Earth significantly less habitable to humans for all future time - the numbers become far greater. For instance, if you look forward a 100,000 years, or 3,000 generations, those 3,250 people become 9.75 million.

Nick Bostrom suggests that this can give a way to think about these existential risks, that take us out of our instinctual responses. His paper also looks at a way of calculating the impact for potential for human extinction, but in the back contamination scenarios arguably that’s not a risk as we could survive using space technology and paraterraforming Earth.

### [The decision about acceptable levels of risk for large scale harm is an ethical decision and can’t be decided on the basis of science or engineering](#h_the_decision_about)[Next section](#h_public_comments_on) – [all sections](#h_titles_of_sections) – [previous section](#h_carl_sagan_and_others)

This decision is something that needs global public debate.

NASA are likely to set a higher priority to completing the mission assigned to them than the general public, but we are all potentially affected in the worst case. It needs to be opened out to larger debate.

This is something we can’t decide on the basis of science or engineering. It is an ethical and legislative choice. As Randolph put it [(Randolph, 2009:292)](#xs0gwy1vf9ff).

*The risk of back contamination is not zero. There is always some risk. In this case, the problem of risk – even extremely low risk – is exacerbated because the consequences of back contamination could be quite severe.* ***Without being overly dramatic, the consequences might well include the extinction of species and the destruction of whole ecosystems****. Humans could also be threatened with death or a significant decrease in life prospects*

***In this situation, what is an ethically acceptable level of risk, even if it is quite low? This is not a technical question for scientists and engineers. Rather it is a moral question concerning accepting risk.***

### [Public comments on the EIS show that many members of the public have similar views to Carl Sagan that this is a qualitatively different situation from a human pathogen in a BSL-4 and that NASA shouldn’t take even a low level of risk with Earth’s biosphere](#h_public_comments_on)[Next section](#h_EPAs_letter) – [all sections](#h_titles_of_sections) – [previous section](#h_the_decision_about)

The public comments aren’t a poll, but they do show that many members of the public have similar views to Carl Sagan, Gill Levin, Carl Woese and others, that this is a qualitatively different situation from a known pathogen in a BSL-4 lab and that we shouldn’t take even a low level of risk.

Many specifically mention potential for unprecedented harm in one way or another. I think it is also reasonable to assume that all or nearly all the ones that say, test first, sterilize first or stop mission would support Carl Sagan’s quote [(Sagan, 1973)](#kix.urfjjsuep509):

***“The likelihood that such pathogens exist is probably small, but we cannot take even a small risk with a billion lives.”***

Here are the comments summarized, and I’ve shown in bold the ones that likely support Carl Sagan’s statement that we can’t take even a small risk with a billion lives.

As a rough estimate, 50 supporting some variation on Carl Sagan’s view out of a total of 63 separate people commenting (selected one only for duplicate entries). Some were anonymous and it’s not possible to know for sure if some of those were also duplicate. At any rate, several dozen distinct members of the public expressed views that suggest they would be in support of Sagan’s quote, on a not very widely publicised EIS.

* [**stop mission, unprecedented harm**](https://www.regulations.gov/comment/NASA-2022-0002-0177) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0178) **–** **[protect Earth](https://www.regulations.gov/comment/NASA-2022-0002-0179)** **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0180)**–** [**stop mission**](https://www.regulations.gov/comment/NASA-2022-0002-0181)
* [**stop mission**](https://www.regulations.gov/comment/NASA-2022-0002-0182) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0184) **–** [**test first, unprecedented harm**](https://www.regulations.gov/comment/NASA-2022-0002-0183) **–** [**keep Earth 100% safe**](https://www.regulations.gov/comment/NASA-2022-0002-0186) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0188)

* **[stop mission](https://www.regulations.gov/comment/NASA-2022-0002-0190)** – [need clarity about security measures](https://www.regulations.gov/comment/NASA-2022-0002-0187) – [off topic](https://www.regulations.gov/comment/NASA-2022-0002-0191) – [alternative design](https://www.regulations.gov/comment/NASA-2022-0002-0192)  - [**keep Earth 100% safe**](https://www.regulations.gov/comment/NASA-2022-0002-0189)
* [**unprecedented harm**](https://www.regulations.gov/comment/NASA-2022-0002-0194) **–** **[stop mission, unprecedented harm](https://www.regulations.gov/comment/NASA-2022-0002-0193)** – [alternative design](https://www.regulations.gov/comment/NASA-2022-0002-0196) – [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0202) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0207)
* [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0203) **–** [**unprecedented harm**](https://www.regulations.gov/comment/NASA-2022-0002-0206) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0204) **–** [**Test first**](https://www.regulations.gov/comment/NASA-2022-0002-0197) **–** [**Don’t return unless 100% safe – or sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0210)
* [**Don’t return**](https://www.regulations.gov/comment/NASA-2022-0002-0199) **–** [**don’t return until 100% safe**](https://www.regulations.gov/comment/NASA-2022-0002-0205) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0208) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0209) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0198)
* [**ISS first**](https://www.regulations.gov/comment/NASA-2022-0002-0200) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0201) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0213) **–** [**unknown risk, test first**](https://www.regulations.gov/comment/NASA-2022-0002-0214) **–** [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0218)
* [extra precautions for EES reentry](https://www.regulations.gov/comment/NASA-2022-0002-0215) - [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0216) **–** [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0217) **–** [**sterilize in space station first**](https://www.regulations.gov/comment/NASA-2022-0002-0222) **–** [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0220)

* [**do not return**](https://www.regulations.gov/comment/NASA-2022-0002-0221) **–** [**do not return**](https://www.regulations.gov/comment/NASA-2022-0002-0223) **–** [**do not return**](https://www.regulations.gov/comment/NASA-2022-0002-0219) – [send to Russia first](https://www.regulations.gov/comment/NASA-2022-0002-0226) **–** [issues with disinfection of earth entry site](https://www.regulations.gov/comment/NASA-2022-0002-0230)
* [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0229) **–** [support EIS](https://www.regulations.gov/comment/NASA-2022-0002-0231) **–** [**study in situ or space lab or sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0232) – [fully support, suggests more samples](https://www.regulations.gov/comment/NASA-2022-0002-0234) – [– [off topic (future missions need to be designed for reeuse)](https://www.regulations.gov/comment/NASA-2022-0002-0233)](https://www.regulations.gov/comment/NASA-2022-0002-0233)

* [multiple cautious measures](https://www.regulations.gov/comment/NASA-2022-0002-0236) – [support EIS](https://www.regulations.gov/comment/NASA-2022-0002-0240) – [support EIS](https://www.regulations.gov/comment/NASA-2022-0002-0241) **–** [**test or sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0251) **–** [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0246)
* [**test in situ or don’t return**](https://www.regulations.gov/comment/NASA-2022-0002-0248) **–** [**do**](https://www.regulations.gov/comment/NASA-2022-0002-0247) **not return –** [**unprecedented harm, test first**](https://www.regulations.gov/comment/NASA-2022-0002-0243) **–** [**unprecedented harm, return to space station**](https://www.regulations.gov/comment/NASA-2022-0002-0252)
* - and the four comments already mentioned by name [**(Walker, 2022a)**](#b_Walker_2022) **([Dehel, 2022](#b_Dehel_2022))** [**(DiGregorio, 2022)**](#b_DiGregorio_2022) **([Everline, 2022](#b_everline_2022))**

Also notice that 12 said sterilize first, even though it’s not listed as an alternative action in the EIS.

* [**Don’t return unless 100% safe – or sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0210) **–** [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0218) **–**  [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0216) **–** [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0217) **–** [**sterilize in space station first**](https://www.regulations.gov/comment/NASA-2022-0002-0222)
* [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0220) **–** [**test or sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0251) **–** [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0246) **–** [**study in situ or space lab or sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0232)
* Plus [(Walker, 2022a)](#b_Walker_2022) ([Dehel, 2022](#b_Dehel_2022)) [(DiGregorio, 2022)](#b_DiGregorio_2022)

### [EPA’s letter posted on the last day of public discussion says they didn’t identify significant environmental concerns in their review of the EIS – with no mention of all the public comments raising concerns similar to Carl Sagan’s](#h_EPAs_letter)[Next section](#h_this_doesnt_look) – [all sections](#h_titles_of_sections) – [previous section](#h_public_comments_on)

EPA posted on the last day of public comments. Their letter says it didn’t identify significant environmental concerns in its review of the EIS. It doesn’t say anything about a need for NASA to respond to new issues raised in the comments by the general public mentioned in the previous section [(EPA, 2022)](#B_epa_2022):

*We appreciate NASA addressing EPA’s concerns regarding water resources, unplanned releases and cultural/biological resources identified in the letter.*

*Based on the review of the draft PEIS, EPA did not identify significant environmental concerns to be addressed in the Final EIS.*

If Carl Sagan was still alive today he would surely have commented on the EIS raising the same concerns as many of the general public made.

### [This doesn’t look like the broad acceptance which Rummel et al said is essential for success of this mission – if NASA continues with this action, it is vulnerable to being stopped in the future](#h_this_doesnt_look)[Next section](#h_we_can_forestall) – [all sections](#h_titles_of_sections) – [previous section](#h_EPAs_letter)

Rummel at al wrote [(Rummel et al, 2002:96)](#B_rUMMEL_et_al_2002) :

*“Broad acceptance at both lay public and scientific levels is essential to the overall success of this research effort.”*

This doesn’t look like broad acceptance of NASA’s proposed action. It may be stopped at various points.

First NASA could withdraw the EIS, do the size limit review, do a scientifically rigorous EIS.

This seems far the best outcome for NASA. Not forced to do anything by a court decision. Not responding to public panic. They can decide in their own time how to proceed. For instance they can do a 100% safe mission using sterilize first, or they can work on other ideas, but it’s all done in coordination with the general public, legal experts, ethicists, social scientists etc.

Even a last minute conversion to a 100% safe mission could cause problems if NASA do it in response to panic from a distrustful public. Far better to get the public involved from the outset.

Assuming NASA continue with the EIS, it could be stopped by other agencies but this is unlikely as the draft EIS says that there are no significant environmental effects, so they’d have no reason to look at it closely.

The next point it can be stopped is by a court case. There is no provision for this within NEPA, so it is done through judicial review, usually on the basis that: ([Congressional Research Service, 2021](#b_CRS_2021)).

* the agency failed to consider some of the impacts
* the agency failed to properly consider the weight of the impacts under review

They can only be taken to the courts by someone with “standing”. For this, they need to take part in the public comments or debate in the NEPA process, and need to be directly affected by the proposed action.

There you have to show that you are particularly affected by it, which is normally understood to mean more so than by others. If the petitioner claims NASA overlooked a worst case risk of global effects NASA could try to block it on the basis that in their hypothetical scenario they wouldn’t be affected more than anyone else in the world and so don’t have standing.

In the past, environmental cases have gone either way based on subtle legal arguments about whether environmental effects give the petitioner “standing” for the case ([Birnbach, 1997](#b_Birnbach_1997)).

If it does get as far as the courts, the case is usually ([Congressional Research Service, 2021](#b_CRS_2021))

* referred back to the agency (such as NASA) for further proceedings HOWEVER
* the court can order the agency to stop the project going ahead or issue some other action (in this case perhaps order to sterilize the samples first?).

So if a case is taken out and it’s successful, that could lead to a justice asking NASA to either stop the mission or to sterilize the samples first.

If nobody takes them to court or NASA successfully block the case, the next step is the presidential directive NSC-25, which requires a review of large scale effects that could be reasonably expected to result in allegations of major or protracted effects. It has to be done even if the agency feels confident such allegations are false [(Whitehouse, 1977):](#b_WhiteHouse_1977). This happens after the NEPA process is completed [(Race, 1996)](#kix.7grd10futt6o).

If it gets past all those hurdles with little public awareness, it could be stopped at the last minute with samples already on their way back to Earth.

Mounting global public concern could lead to Congress and the president acting to tell NASA to divert the mission away from Earth. A worst case here might be an infodemic about Mars life similar to the COVID infodemic, junk science, problems for NASA’s credibility, and issues with eventual return of even 100% safe sterilized samples.

# [Conclusion and recommendations for space agencies generally – simplest solution to sterilize the sample before it reaches Earth with ionizing radiation – priority to return dust, dirt, atmosphere and salts – sterilization would have virtually no effect on geology and most likely no effect on astrobiology either](#h_conclusions_space_agencies) [Next section](#h_value_newly_formed_crater) – [all sections](#h_titles_of_sections) – [previous section](#h_we_can_explore)

It’s understandable that space agencies compete to be first to return a sample from Mars. The conclusion of this paper is that we don’t currently have the technology to contain an unsterilized sample that fulfils the size limit requirement of the ESF study in 2012. The cost of such a facility would likely to be high if it can be developed. The simplest solution, which also keeps Earth 100% safe, is to sterilize the sample before it reaches Earth.

The mission shouldn’t be presented as a way to decide central questions in astrobiology. We are unlikely to find present day or past life without in situ searches unless the Viking missions did detect life or life is very common in the dirt or dust on Mars. Any such mission should be presented as a first step in Carl Sagan’s vigorous program in unmanned exobiology. It should be part of a longer term plan to search for present day and past life in situ on Mars itself.

See:

* [We can’t expect samples returned from Mars at this stage to answer central questions in astrobiology even with bonus samples except with extraordinary luck – astrobiologists emphasize that we need to search in situ first – our aim instead is to find a way to turn this into a far more interesting first step for astrobiology](#h_with_more_ambition)

There’s one relatively easy way to return interesting microsamples from Mars that any space agency could do if it can send a mission to orbit around Mars. For instance it’s a possibility for India, Japan, or the UAE. That’s “SCIM”, a proposed mission to use aerogel collectors to skim the Martian atmosphere and return micron sized dust particles [(Leshing, 2002)](#b_Leshing_2002). The proposal is to dip into the Mars atmosphere during its dusty season, and pick up a sample of dusty air, to return to Earth. It would use a "free return" trajectory. As soon as it leaves Earth's vicinity, it's on a trajectory to skim the Mars atmosphere and return to Earth with only minor course corrections after that [(Leshin, 2002)](#b_Leshing_2002) [(Savage, 2002).](#Savage_2002)

Laurie Leshin, interviewed by Space.com, describes it like this [(Tillman, 2014)](#b_Tillman_2014)

"Think of it as a microscopic average rock collection from Mars"



Video: [SCIM Mission to Mars narrated](https://www.youtube.com/embed/7WorhUTyURg?feature=oembed)

A small sample like that could be sterilized during the journey back using nanoscale X-ray emitters or similar – which would have little effect on its science value as it is not likely to contain viable life.

The next step up is Chris McKay’s mission concept. Design the simplest lowest cost way to return a sample from Mars. No rover, just a lander like the Viking lander but with a Mars ascent stage. Just grab it and return [(David, 2015).](#b_David_L_2015)

"***The first thing is getting a mission that scoops up a bunch of loose dirt, puts it in a box and brings it back to Earth***.”

He motivates it by hazards for astronauts in the dirt such as the perchlorates. However the dirt is also of significant astrobiological interest as we saw.

This should be collected in a sterile container. Preferably it needs a sub compartment with a window so that part of the sample is kept in conditions resembling the Martian surface, ideally simulating day / night cycles.

If there are concerns that opening the sterile container would be mission critical, the mission could include a separate smaller container with permitted forward contamination which would return samples of geological interest but likely of little astrobiological interest:

This mission can be greatly enhanced in interest if it can also collect a compressed sample of atmosphere and of dust, and if possible it can also target a sample of salt from the Martian surface. It can also return some pebbles for a technical demo of a contamination free rock sample, and to return our first contamination free rocks from Mars.

See above:

* [NEW: We can transform this into a much more interesting first step for astrobiology with little change in the overall budget by adding bonus samples collected in a STERILE container sent on the ESF fetch rover – the aim is to return dust, dirt, ideally salts, compressed gas from the atmosphere – and some pebbles for a technology demo of a contamination free rock sample](#h_we_could_transform)

These samples again can be sterilized and returned directly to Earth and if sterilized carefully for instance using X-rays would still be of astrobiological interest. A small sample could be sterilized using nanoscale X-ray emitters during the journey back. A larger sample might need to be return to a sterilizing satellite. See:

* [NEW: Samples can be safely sterilized in a satellite similar to geostationary satellites, but positioned in a safe orbit tens of thousands of kilometers above GEO](#h_samaples_can_be_sterilized)

Or they could be returned to a Mars simulation chamber remotely operated in a satellite above GEO as described above in:

* [NEW: These clean samples will be studied above geostationary orbit in Mars simulation conditions with a Martian gravity centrifuge – they are not intended for safety testing - and humans never go near the satellite](#h_these_clean_samples)

Perhaps this sample receiving satellite above GEO could be operated internationally, similarly to the ISS but as a much smaller robotic facility rather than one staffed by humans. As it grows in complexity, it could use the same approach of docked modules, like the ISS in miniature, operated by different countries with the use of telerobotics to move samples and other equipment from one module to another.

A space agency can greatly increase the science value of demo rock samples returned from Mars by targeting pebbles from recently excavated craters on Mars. A new mission has the advantage that it could target one of the hundreds of craters which formed on Mars since we started photographing it from orbit.

If we can return a sample that’s been buried until just a few decades ago there’s a possibility that it’s had almost no exposure to cosmic radiation or solar storms since it was deposited.

See also:

* [Value of targeting a newly formed crater on Mars as an alternative to drilling meters below the surface – with example of a crater that excavated ice boulders from the Amazonis planitia in the equatorial regions in 2022 – also value of developing a 100% sterile marscopter, rover or complete lander](#h_value_newly_formed_crater)

[Conclusions and recommendations for NASA – need to restart the process with a scientifically credible EIS – simplest solution is to sterilize the samples before they are returned to Earth which retains virtually all the geology and most likely has no impact on astrobiology](#h_conclusions_NASA)
[Next section](#h_topcs_future_Mars_sample_return_study) – [all sections](#h_titles_of_sections) – [previous section](#h_value_newly_formed_crater)

First, the Environmental Impact Statement needs to be scientifically credible:

* [NASA’s draft EIS fails NEPA requirement for a valid Environmental Impact Statement to ensure scientific integrity – with missing cites and cites that overturn the sentences they are cited to](#h_NASAS_draft_EIS_fails)

At a minimum an independent reviewer needs to check cites are correctly summarized in the sentences they are attached to. Many of the errors found in the EIS would be spotted with this basic level of peer review.

Other errors were missed due to a limited literature review that didn’t pick up such things as the 2015 MEPAG review of the 2014 SR-SAG2, the 2012 size limit revision by the ESF, and many counter examples in the planetary protection literature to the examples in the sterilizing working group report. One way to avoid these issues is to rely on authors already familiar with the planetary protection literature and who have written extensively on the topic.

The former NASA planetary protection officers John Rummel and Cassie Conley wouldn’t be capable of such mistakes. John Rummel in particular is author, co-author or contributor to a significant fraction of the planetary protection literature on a Mars sample return. He is a co-author of the 2012 ESF Mars sample return study [(Ammann et al, 2012:19)](#qa4nethlmcdw) and is one of the individuals who gave advice or comments to the 2009 NRC study ([SSB, 2009](#b_SSB_2009) : [viii](https://nap.nationalacademies.org/read/12576/chapter/1?term=Rummel#viii)). He is principal author of the SR-SAG2 forward contamination study [(Rummel et al , 2014)](#kix.im73nfot8zt5), and one of the individuals who gave advice or comments to the MEPAG review ([SSB, 2015](#b_SSB_2015) :[xii](https://nap.nationalacademies.org/read/21816/chapter/1?term=Rummel#xii)).

Then a new EIS needs to consider reasonable alternatives such as sterilizing the samples before they are returned to Earth

* [NASA’s draft EIS fails the NEPA’s requirement to consider reasonable alternatives in detail so that reviewers may evaluate their comparative merits – as it doesn’t examine the reasonable alternatives to sterilize samples in space first or to delay the mission until it can be done safely](#h_NEPA_erasonable_alsternatives)

Indeed, the simplest solution is to sterilize all samples before they are returned to Earth. In this case all that’s needed is

* A review of methods for sterilization adequate to sterilize even unfamiliar life that may be hardier even than radiodurans while preserving astrobiological interest, including using ionizing radiation or x-rays

The rock samples could simply be sterilized before they reach Earth during the return journey, or they can be returned to a satellite for sterilization in a safe orbit above GEO.

Then even with the Earth kept 100% safe through sterilization, it’s important to engage with the public and get widespread agreement that the chosen method is effective and would keep Earth safe

* To set up fora and other ways to engage with the public and interested experts in countries around the world to make sure that all are in agreement that the method of sterilization will keep Earth 100% safe.

We need to avoid the situation where dozens of members of the public comment on a not well publicised draft EIS saying that the mission needs to be stopped.

See:

* [NASA’s draft EIS fails the NEPA’s requirement to use an interdisciplinary approach including the social sciences, by failing to involve the public early on, not just in the USA but through fora open to representatives from all countries globally, as recommended in sample return studies – so the public weren’t given the opportunity to comment on a scientifically valid draft EIS](#h_NASA_interdisciplinary)

As a bonus NASA could add on the capabilities suggested in the previous section for space agencies to make it a far more interesting mission for astrobiology. Even a pre-sterilized sample of dirt, gas and dust collected in a clean sample container would greatly add to the interest of the mission, and especially so if the unsterilized samples can be studied as suggested in a safe orbit remotely by telerobotics like studying samples on Mars but without the latency.

If NASA wish to continue with the proposed action in the draft EIS, much more is needed.

* The general public must be given the opportunity to comment on a scientifically credible environmental impact statement which must also examine reasonable alternatives such as to keep Earth 100% safe by sterilizing the samples before the return to Earth.

Even if the intention is to continue with the proposed action, the current EIS needs to be cancelled as the general public didn’t get the opportunity to comment on a valid EIS, which should make it invalid under NEPA.

Then before a new EIS:

* We need to follow the ESF study’s recommendation, to review the size limit of particle to be contained, and the level of assurance
* We also need a new Mars sample return planetary protection report to take account of the many advances in our understanding of Mars, of potential habitats on Mars, of Mars analogue terrestrial extremophiles, and of synthetic biology and the potential pathways for a second genesis of life.

The next section looks at some of the topics that a new Mars sample return planetary protection study would need to look at.

Some of the main points. We need to:

* Review the level of assurance and size limit.
* Allow for end of mission sterilization of any equipment or materials that could be contaminated in case the sample contains mirror life or some other form of life that can never be released to the terrestrial environment.
* We can’t rely on quarantine of technicians in case of a breach of containment, see:

[NEW: It is impossible to use quarantine to protect Earth’s biosphere if humans handle the samples in orbit – the Apollo quarantine procedures never had peer review and missed the issue of a symptomless superspreader – and this can’t keep out mirror life, or molds like the one that killed two plants on the ISS – keeping humans well away from the samples also avoids forward contamination for very sensitive measurements](#h_it_is_impossible_quarantine)

The facility most likely would need to use telerobotics.
* If the new proposal includes an air incinerator, we need to study the potential that Martian spores would be hardier than Aspergillus niger because of adaptations to the extreme Martian conditions

[Alternative of an air incinerator for the second HEPA filter – would need to be evaluated for containment of putative Martian life likely more resilient than standard test terrestrial spores – and for 100% containment](#he_alternative_HEPA_air_incinerator)

Also, any new valid EIS needs a proper comparison with reasonable alternatives including the ones outlined in this paper.

In more detail:

### Topics that need to be covered in a future Mars sample return backwards contamination study[Next section](#h_methods) – [all sections](#h_titles_of_sections) – [previous section](#h_conclusions_NASA)

Based on the new material found in this review a new sample return study should consider many topics not previously considered in planetary protection studies. This is not likely to be a complete list of all the topics they need to consider. It is just a list of the main ones that turned up so far in this review.

First, based on the 2012 ESF recommendation to review the size limit and level of assurance, it needs to review:

* The size limit, including reviewing new research on the potential for non terrestrial biology such as ribocells. See:
* [ESF study said values for required level of assurance and the size limit need to be revisited periodically based on changes in scientific knowledge and risk perception](#h_ESF_study_risk_size_limit)
* level of assurance, with a consideration of Carl Sagan’s view that we shouldn’t take even a small risk with a billion lives

On that last point, it needs to:

* examine whether or not to adopt the prohibitory version of the precautionary principle, based on wishes of the public rather than priorities of space agencies
* [Carl Sagan and others warning we can’t take even a small risk with a billion lives – this could be formalized into law as a requirement to use the prohibitory precautionary principle whenever there is any appreciable risk for harm unprecedented in human history](#h_carl_sagan_and_others)

The review of the potential for extraterrestrial pathogens of humans should consider examples such as:

* Aspergillus
	+ [NEW: Sterilizing subcommittee’s report gives an example of an opportunistic fungal pathogen, Candidiasis, adapted to humans – the omission here is Aspergillus which is not adapted to humans and is invasive due to adaptations to survive rapid dehydration and rehydration, rapid changes of temperature etc. many of which may be shared by life adapted to Mars – with an estimated 200,000 life threatening Aspergillus infections a year – mortality 30% to 95%](#h_Aspergillus_not_adapted)
* Tetanus

* + [Sterilizing subcommittee’s report doesn’t mention clear examples of microbes which express accidental toxins without coevolution with humans or higher life, such as neonatal tetanus which kills thousands of unvaccinated newborns every year](#b_Shigas_toxin_accidental_tetanus)
* Our immune response to a new genus of fungi as invasive as Aspergillus but with no pattern recognition capabilities to recognize it

* + [NEW: Our immune system responses are highly specific to each of the three genera of opportunistic human fungal pathogens – without the necessary pathogen associated molecular patterns (PAMPS) we might all be immunocompromised to a new genus of fungi from Mars](#h_new_our_immune_system_responses_fungi)
* Allergic reactions e.g. to fungi from Mars
	+ [NEW: Possibility of an allergic response to harmless alien life – or indeed a new genus of familiar life - if it is recognized by the immune system but not by the inflammation dampening Treg cells - allergic bronchopulmonary aspergillosis affects around 4.8 million people globally and chronic pulmonary aspergillosis, affects 400,000 globally – these figures could be higher if a normally functioning human immune system doesn’t recognize the need to dampen its response](#h_possibility_allergic_response)

The review of whether life from Mars could affect terrestrial ecosystems and the Earth’s biosphere should look at:

* Fungal parasites of microbes including parasites of photobionts
	+ [NEW: Microbes from Mars could have pathogens that can infect terrestrial microbes – example of fungal pathogens of phytoplankton and cyanobacteria – cyanobacteria depend on specific antifungal adaptations to protect against fungi in the chytrid phylum, so may have no adaptations to a novel fungal phylum from Mars](#h_microbes_Mars_pathogens)
* Example of permafrost microbe with optimal growth temperature 25 C and capable of growth at human blood temperature

* + [NASA’s biological safety report agrees on the potential for an invasive Martian species to harm or displace terrestrial photosynthetic bacteria – but says life adapted to Martian conditions such as the temperatures and pressures plausibly wouldn’t be able to survive on Earth – their own cite mentions Planococcus Halocryophilus, a microbe which lives in Arctic permafrost soils and likely grows in sub zero brine veins down to at least -15 °C, with an optimal growth temperature of 25°C and growth up to 37 °C (human blood temperature)](#h_argument_by_sterilizing_subcommittee)
* Species sorting which could lead to species adapted to higher temperatures than currently found in the environment life is returned from

* + [Mars surface temperatures can reach 35°C in the shade in summer – and possibility that some species of Martian surface life are pre-adapted to warmer, even hydrothermal conditions in geologically recent Mars – and may be present in small numbers in surface biofilms which might adapt to warmer conditions by species sorting](#b_Mars_surfacer_temperatures)
* Geobacillus paradox - the possibility that volcanic vents on Mars produce large numbers of hardy spores similarly to the geobacillus spores that then spread widely in the dust and may be found almost everywhere

* + [The geobacillus paradox and potential that present day Mars has abundant spores of life adapted to live in geothermal vents similarly to terrestrial Mars analogue deserts which may have been produced as recently as the last few million years or even be actively produced today](#h_geobacillus_paradox)

A new sample return study should look at possibilities with no terrestrial analogue such as:

* Joshua Lederberg's two papers looking at the possibility that terrestrial immune systems have no defences against alien biology - and Claudius Gros's similar suggestion

* + [Warnings by some astrobiologists such as Sagan and Lederberg that in worst case we could be in effect immunocompromised to an entire exobiology from Mars](#h_warnings_by_some_astrobiologists)
* and the possibility that this extends to even microbial terrestrial life with no defences against alien microbes

* + [Claudius Gros’s scenario extends Sagan and Lederberg’s hypothesis to all higher life, though in the forward direction only – could his scenario be applied in reverse – and could even terrestrial microbial life have no defences against pathogens from a completely alien biology?](#h_Claudius_GRos_scenario_forward)
* Effects of returning mirror life or other life with a radically different internal biology

* + [NEW: Example worst case scenario of a mirror life chroococcidiopsis analogue from Mars which could gradually convert organics in ecosystems into indigestible mirror organics](#h_worst_case_scenario_of_mirror_life)

* + [NEW: Closely related worst case scenario of a shadow biosphere of small mirror life nanobes that produce indigestible mirror life biofilms on Earth with small cells advantages that they take up nutrients faster and avoid protozoan grazing](#h_closely_related_worst_case)
* Life that might be better at photosynthesis than terrestrial life

* + [NEW: Martian life could be better at photosynthesis than terrestrial life since terrestrial photosynthesis works at well below its theoretical peak efficiency and the lower light levels on Mars might favour evolution of more efficient photosynthesis](#h_Martian_life_could_be_better)
* Life that might be better adapted that terrestrial life and spread rapidly
	+ [NEW: Worst case scenario - If a martian microbe can grow in the sea, soil, and fresh water like chroococcidiopsis, is adapted to spread in the wind in Martian dust storms, and outcompetes terrestrial biology, e.g. better at photosynthesis or nitrogen fixation, it could be found globally after introduction to Earth in weeks to months, and be one of the most common microbes in our soils and oceans in years to decades or sooner, far more common than nanoplastics or microplastics](#h_worst_case_outcompetes_terrestrial_lif)

When considering whether samples could contain life it should look at:

* Potential for Martian life to make the Curiosity brines habitable through adaptations such as biofilms, perhaps covered with surface mosses that use hair structures that swell when hydrated to block escape of water vapour and maybe even micropores that close at times of lower humidity or in response to daylight

* + [Martian life could be more capable of coping with Martian conditions than terrestrial life – e.g. survive better in dust storms or cope better with cold temperatures and temperature changes – and ways a martian biofilm could retain water in ultracold night time brines through to the midday warmth – fine hairs, pores that close in daytime like cactuses – chemicals that speed up metabolism, slow generation times and novel biochemistry](#b_Martian_life_more_capable)
* New studies on transport of biofilms in the dust

* + [2019: A thin (0.03 microns thick) fragment of desiccated biofilm of chroococcidiopsis would be still viable after blowing 100 km in moderate winds (5 meters per sec) in full Martian sunlight](#h_work_on_survival_dust_2015)
* suggestion that even if microbial life can't get started today, life on Mars could propagate via biofilm fragments

* + [2019: Curiosity found UV radiation fell by 97% at the start of the 2018 dust storm, which could increase Billi et al’s 100 km to 1000s of kilometers in Martian dust storms – and Mosca et al’s suggestion that biofilm fragments established in the past could continue to propagate even if Mars doesn’t have conditions to start a new biofilm today](#h_Curiosity_found)
* Potential for individual microbes to survive in cracks in dust spores

* + [2017: individual microbes can travel in dust storms imbedded in a dust grain for extra protection from UV](#potenial_for_transport)
* Potential for microbes to survive in cracks in bouncing grains of dust up to half a millimeter in size

* + [2019: Microbes can be protected by bouncing sand grains up to half a millimeter in diameter traveling meters in each bounce, and some (less than 1 in 1000) b. subtilis spores remain viable after hundreds to thousands of kilometers of travel in simulation experiments](#h_experiments_in_2019)
* Potential for Martian life to evolve propagules with hardened outer shells to survive bouncing and can be propagated similarly to bouncing grains

* + [New: Martian life could evolve new strategies for dust storm transport such as spores with extra layers to protect against UV, and fruiting bodies for higher life that are detached by strong winds and may be better protected against UV than terrestrial life](#h_potential_for_martian_life_to_evolve)
* Potential for microbial spores on Mars to develop extra layers to protect them from UV, chlorates, chlorites, hydrogen peroxide and desiccation
	+ [New: Martian life could evolve new strategies for dust storm transport such as spores with extra layers to protect against UV, and fruiting bodies for higher life that are detached by strong winds and may be better protected against UV than terrestrial life or protection from bounce impacts with biomaterials resembling chitin (used by lichens)](#h_potential_for_martian_life_to_evolve)
* The suggestion that Mars has fresh liquid water seasonally in the polar regions similarly to the subglacial melt in Antarctica which should happen at surface temperatures of -90 C because of the way ice lets light through but insulates the melt water and protects from evaporation in a vacuum which leads to ice melting at half a meter depth in Antarctica - in the different conditions on Mars it should melt at a depth of 5 cms
	+ [2009, 2014: Possible future surprise discovery of large quantities of fresh water on Mars: ice lets light through and traps heat, which melts ice half a meter below the surface in Antarctica -– if Martian ice is similar, its polar regions should have meltwater in summer, ~5 cms below the surface, even with surface temperatures below -90 °C – Mars may also have miniature melt ponds around sun warmed dust grains](#h_possible_future_surprise_discovery)

For the idea of testing samples before release it should consider:

* Testing can't protect Earth from life in a sample - that after 10,000 dust grains tested destructively you can't deduce that the 10,001th grain is safe

* + [NEW: Too early for any form of safety testing even for samples returned in sterile containers at the level of assurance needed for potential large scale harm – after destructively testing 10,000 grains of dust the 10,001th grain could have a viable microbe in it](#h_too_early_for_any)

For human quarantine:

* Human quarantine can't work to protect Earth or even humans - issue of life-long symptomless superspreader like Typhoid Mary and that technicians might happen to be immune to a new fungal pathogen which most of the population have no immunity to –
* if a technician got ill with a potentially life threatening disease, ethically you can't leave them to die in quarantine – they would be removed but that's the very time when they need to be kept in to protect Earth
Impossibility of keeping out a pathogen of crops or microbes with human quarantine - it can become part of the human microbiome as with the example of the crop pathogen brought to the ISS
* Impossibility of keeping out mirror life with human quarantine

These are all covered in

* [NEW: It is impossible to use quarantine to protect Earth’s biosphere if humans handle the samples in orbit – the Apollo quarantine procedures never had peer review and missed the issue of a symptomless superspreader – and this can’t keep out mirror life, or molds like the one that killed two plants on the ISS – keeping humans well away from the samples also avoids forward contamination for very sensitive measurements](#h_it_is_impossible_quarantine)

A Mars sample return study

* shouldn't be set up with a remit to find a way to return a sample safely
* should be tasked to evaluate whether or not current technology is not able to contain the samples to the required level of assurance, with “no” as a permissible answer

A Mars sample return back contamination study should be empowered to look at reasonable alternatives such as

* sterilizing all samples before they are returned to Earth,

* + [NEW: We can forestall all these issues and make the mission 100% safe by sterilizing samples before they reach Earth](#h_we_can_forestall)
* returning some samples of especial astrobiological interest to a satellite above GEO for study remotely, and sterilizing anything returned from that satellite to Earth. See:

* + [NEW: We can transform this into a much more interesting first step for astrobiology with little change in the overall budget by adding bonus samples collected in a STERILE container sent on the ESF fetch rover – the aim is to return dust, dirt, ideally salts, compressed gas from the atmosphere – and some pebbles for a technology demo of a contamination free rock sample](#h_we_could_transform)
	+ [NEW: These clean samples will be studied above geostationary orbit in Mars simulation conditions with a Martian gravity centrifuge – they are not intended for safety testing - and humans never go near the satellite](#h_these_clean_samples)

# [All sections – for an outline of this paper](#h_titles_of_sections)

Titles of sections are like mini-abstracts and summarize the details of the section. For a first overview of this paper read the section titles.

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[NASA’s draft EIS fails the NEPA’s requirement to consider reasonable alternatives in detail so that reviewers may evaluate their comparative merits – as it doesn’t examine the reasonable alternatives to sterilize samples in space first or to delay the mission until it can be done safely Next section – all sections – previous section 18](#_Toc129747299)

[NASA’s draft EIS fails the NEPA’s requirement to use an interdisciplinary approach including the social sciences, by failing to involve the public early on, not just in the USA but through fora open to representatives from all countries globally, as recommended in sample return studies – so the public weren’t given the opportunity to comment on a scientifically valid draft EIS Next section – all sections – previous section 19](#_Toc129747300)

[Other commentators raised significant issues – including one of the principle authors of NASA’s probabilistic risk assessment guide who said a better statement of options should include the possibility of delaying the return until the risks are better understood Next section – all sections – previous section 20](#_Toc129747301)

[The Council of Environmental Quality says the first step is to contact the agency to resolve issues, however NASA has not yet responded to attempts to contact them on this topic Next section – all sections – previous section 20](#_Toc129747302)

[We can’t actually assess the level of risk until we know more about Mars – it could be zero or it could be far higher than expected Next section – all sections – previous section 21](#_Toc129747303)

[Worst case scenarios introduce novel ethical and legal questions – is a 1 in a million level of risk acceptable? Next section – all sections – previous section 21](#_Toc129747304)

[Synthetic biologists suggest a safety mechanism for synthetic life should be many orders of magnitude safer than a BSL-4 Next section – all sections – previous section 22](#_Toc129747305)

[NEW: Society places very high value on the environment and given the potential for large scale effects, we might require Earth is kept 100% safe for this mission – i.e. use the prohibitory precautionary principle Next section – all sections – previous section 23](#_Toc129747306)

[Carl Sagan and others warning we can’t take even a small risk with a billion lives – this could be formalized into law as a requirement to use the prohibitory precautionary principle whenever there is any appreciable risk for harm unprecedented in human history Next section – all sections – previous section 24](#_Toc129747307)

[The decision about acceptable levels of risk for large scale harm is an ethical decision and can’t be decided on the basis of science or engineering Next section – all sections – previous section 25](#_Toc129747308)

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[EPA’s letter posted on the last day of public discussion says they didn’t identify significant environmental concerns in their review of the EIS – with no mention of all the public comments raising concerns similar to Carl Sagan’s Next section – all sections – previous section 27](#_Toc129747310)

[This doesn’t look like the broad acceptance which Rummel et al said is essential for success of this mission – if NASA continues with this action, it is vulnerable to being stopped in the future Next section – all sections – previous section 28](#_Toc129747311)

[Conclusion and recommendations for space agencies generally – simplest solution to sterilize the sample before it reaches Earth with ionizing radiation – priority to return dust, dirt, atmosphere and salts – sterilization would have virtually no effect on geology and most likely no effect on astrobiology either Next section – all sections – previous section 30](#_Toc129747312)

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# References

Some of the references have quotes to help the reader, and as part of the processes used to check the sources are cited accurately. This is usually for cites where it’s impossible to give page numbers, or where the source is quite technical.

7th Circuit, 1997, [Simmons v. U.S. Army Corps of Engineers](https://casetext.com/case/simmons-v-us-army-corps-of-engineers), 120 F.3d 664

Abbasi, J., 2021. [Researchers tie severe immunosuppression to chronic COVID-19 and virus variants](https://jamanetwork.com/journals/jama/fullarticle/2779850). *Jama*, *325*(20), pp.2033-2035.

Abdel-Razek, A.S., El-Naggar, M.E., Allam, A., Morsy, O.M. and Othman, S.I., 2020. [Microbial natural products in drug discovery](https://www.mdpi.com/2227-9717/8/4/470). *Processes*, *8*(4), p.470.

Abdo, J.M., Sopko, N.A. and Milner, S.M., 2020. [The applied anatomy of human skin: a model for regeneration](https://www.sciencedirect.com/science/article/pii/S2213909520300033#bib0020). Wound Medicine, 28, p.100179.

 *Skin is an active immunological organ, and dysfunctional innate defenses have serious clinical implications. Products of the stratum corneum, including free fatty acids, polar lipids, and glycosphingolipids accumulate in the intercellular spaces and horny layer, exhibiting antimicrobial properties, and functioning as a first line of defense. Antimicrobial peptides (AMPs) exhibit potent and targeted resistance against a wide spectrum of common pathogens. When this barrier is breached, second lines of protection are provided by inflammatory cascades in the subepithelial tissue. Approximately sixteen AMPs have been shown to be expressed in the skin (Table 1)*

Abe, S., 2001, [Can Liquid Water Exist on Present-Day Mars?](https://nai.nasa.gov/articles/2001/3/26/can-liquid-water-exist-on-present-day-mars/) NASA Astrobiology Institute

Abramov, O., Rathbun, J.A., Schmidt, B.E. and Spencer, J.R., 2013. [Detectability of thermal signatures associated with active formation of ‘chaos terrain’on Europa](https://www.lpl.arizona.edu/~abramovo/papers/Abramov_etal_2013.pdf). *Earth and Planetary Science Letters*, *384*, pp.37-41.

Abrevaya, X.C., Mauas, P.J. and Cortón, E., 2010. [Microbial fuel cells applied to the metabolically based detection of extraterrestrial life](https://arxiv.org/ftp/arxiv/papers/1006/1006.1585.pdf). *Astrobiology*, *10*(10), pp.965-971.

Adams, R.B., Alexander, R.A., Chapman, J.M., Fincher, S.S., Hopkins, R.C., Philips, A.D., Polsgrove, T.T., Litchford, R.J., Patton, B.W. and Statham, G., 2003. [Conceptual design of in-space vehicles for human exploration of the outer planets](https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20040010797.pdf).

Agha, R., Gross, A., Rohrlack, T. and Wolinska, J., 2018. [Adaptation of a chytrid parasite to its cyanobacterial host is hampered by host intraspecific diversity](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5952108/). *Frontiers in microbiology*, *9*, p.921.

*As with other chytrids,* R. megarrhizum *is characterized by presenting free-swimming infective stages in the form of flagellated zoospores that actively seek suitable hosts in the water column. Upon encystment, chytrids penetrate the host and extract nutrients from it, always leading to host death. Over the course of the infection, encysted zoospores develop into sporangia, reproductive structures that release asexually-produced zoospores upon maturation.*

Atri, D., Abdelmoneim, N., Dhuri, D.B. and Simoni, M., 2022. [Diurnal variation of the surface temperature of Mars with the Emirates Mars Mission: A comparison with Curiosity and Perseverance rover measurements](https://arxiv.org/pdf/2204.12850.pdf). *arXiv preprint arXiv:2204.12850*.

Afzal, I., Shinwari, Z.K., Sikandar, S. and Shahzad, S., 2019. [Plant beneficial endophytic bacteria: Mechanisms, diversity, host range and genetic determinants](https://www.sciencedirect.com/science/article/pii/S0944501318304592). Microbiological research, 221, pp.36-49

Alberts B, Johnson A, Lewis J, et al. Molecular Biology of the Cell. 4th edition,2002,

New York: Garland Science; .[Cell Biology of Infection](https://www.ncbi.nlm.nih.gov/books/NBK26833/)

Allen, C.C., Albert, F.G., Combie, J., Bodnar, R.J., Hamilton, V.E., Jolliff, B.L., Kuebler, K., Wang, A., Lindstrom, D.J. and Morris, P.A., 1999. [Biological sterilization of returned Mars samples](https://mars.nasa.gov/mgs/sci/fifthconf99/6161.pdf)

Allwood, A.C., Grotzinger, J.P., Knoll, A.H., Burch, I.W., Anderson, M.S., Coleman, M.L. and Kanik, I., 2009. [Controls on development and diversity of Early Archean stromatolites](https://www.pnas.org/content/106/24/9548). Proceedings of the National Academy of Sciences, 106(24), pp.9548-9555.

Almeida, M.P., Parteli, E.J., Andrade, J.S. and Herrmann, H.J., 2008. [Giant saltation on Mars](https://www.pnas.org/content/pnas/105/17/6222.full.pdf). *Proceedings of the National Academy of Sciences*, *105*(17), pp.6222-6226.

Alves, R., Barata-Antunes, C., Casal, M., Brown, A.J., Van Dijck, P. and Paiva, S., 2020. Adapting to survive: How Candida overcomes host-imposed constraints during human colonization. *PLoS Pathogens*, *16*(5), p.e1008478.

Ambrogelly, A., Palioura, S. and Söll, D., 2007. [Natural expansion of the genetic code](https://www.researchgate.net/profile/Dieter_Soll/publication/6627120_Natural_expansion_of_the_genetic_code_Nat/links/54d8bdc40cf25013d03efd4e/Natural-expansion-of-the-genetic-code-Nat.pdf). Nature chemical biology, 3(1), pp.29-35.

Ammann, W., Barros, J., Bennett, A., Bridges, J., Fragola, J., Kerrest, A., Marshall-Bowman, K., Raoul, H., Rettberg, P., Rummel, J. and Salminen, M., 2012. [Mars Sample Return backward contamination–Strategic advice and requirements](https://science.nasa.gov/science-red/s3fs-public/atoms/files/ESF_Mars_Sample_Return_backward_contamination_study.pdf) – Report from the ESF-ESSC Study Group on MSR Planetary Protection Requirements.

Anbar, A.D. and Levin, G.V., 2012, June. [A Chiral Labelled Release Instrument for In Situ Detection of Extant Life](https://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4319.pdf). In *Concepts and Approaches for Mars Exploration* (Vol. 1679, p.4319)

Anderson, A.W., 1956. Studies on a radio-resistant micrococcus. I. Isolation, morphology, cultural characteristics, and resistance to gamma radiation. *Food Technol*, *10*, pp.575-578.

Aron, S., 2016, [The History of the American West Gets a Much-Needed Rewrite](https://www.smithsonianmag.com/history/history-american-west-gets-much-needed-rewrite-180960149/), Smithsonian Magazine

Attias, M., Al-Aubodah, T. and Piccirillo, C.A., 2019. [Mechanisms of human FoxP3+ Treg cell development and function in health and disease](https://academic.oup.com/cei/article/197/1/36/6402553). *Clinical & experimental immunology*, *197*(1), pp.36-51.

Bada, J.L., Aubrey, A.D., Grunthaner, F.J., Hecht, M., Quinn, R., Mathies, R., Zent, A. and Chalmers, J.H., 2009. [Seeking signs of life on Mars: In situ investigations as prerequisites to a sample return mission](http://mepag.jpl.nasa.gov/reports/decadal/JeffreyLBada_URS211530.pdf). Planetary science decadal survey White Paper, Scripps Institution of Oceanography, USA.

Bahl, J., Lau, M.C., Smith, G.J., Vijaykrishna, D., Cary, S.C., Lacap, D.C., Lee, C.K., Papke, R.T., Warren-Rhodes, K.A., Wong, F.K. and McKay, C.P., 2011. [Ancient origins determine global biogeography of hot and cold desert cyanobacteria](https://www.nature.com/articles/ncomms1167). Nature communications, 2(1), pp.1-6.

Bains, W. and Schulze-Makuch, D., 2016. [The cosmic zoo: the (near) inevitability of the evolution of complex, macroscopic life](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5041001/). Life, 6(3), p.25.

Bak, E.N., Larsen, M.G., Jensen, S.K., Nørnberg, P., Moeller, R. and Finster, K., 2019. [Wind-driven saltation: an overlooked challenge for life on Mars.](https://www.researchgate.net/profile/Kai-Finster/publication/328837688_Wind-Driven_Saltation_An_Overlooked_Challenge_for_Life_on_Mars/links/5be5916fa6fdcc3a8dc8fc19/Wind-Driven-Saltation-An-Overlooked-Challenge-for-Life-on-Mars.pdf) Astrobiology, 19(4), pp.497-505.

*Spores in cavities will only be subjected to abrasion when the cavities crack open and the spores can get hit upon by a mineral particle. This process may be slow and explain the long tail of the number of surviving spores.The grain size of the regolith will likely affect the above-mentioned mechanisms and thus would have influence on the survival time of present microorganisms. We will address the effect of grain size in more detail in coming experiments.*

Ballard, E., Melchers, W.J., Zoll, J., Brown, A.J., Verweij, P.E. and Warris, A., 2018. [In-host microevolution of Aspergillus fumigatus: A phenotypic and genotypic analysis](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5883321/). *Fungal Genetics and Biology*, *113*, pp.1-13.

Batbander, K., 2020, [A Barn Swallow in Flight](https://commons.wikimedia.org/wiki/File%3AA_Barn_Swallow_in_Flight_%2850505960682%29.jpg), Wikimedia Commons

Baugh, R.F., 2017. [Murky Water: Cyanobacteria, BMAA and ALS](https://openaccesspub.org/jnrt/article/592). *Journal of Neurological Research and Therapy*, *2*(1), p.34.

Beaty, D.W., Grady, M.M., McSween, H.Y., Sefton‐Nash, E., Carrier, B.L., Altieri, F., Amelin, Y., Ammannito, E., Anand, M., Benning, L.G. and Bishop, J.L., 2019. [The potential science and engineering value of samples delivered to Earth by Mars sample return](https://onlinelibrary.wiley.com/doi/full/10.1111/maps.13242): International MSR Objectives and Samples Team (iMOST). Meteoritics & Planetary Science, 54, pp.S3-S152.

Beatty, J.T., Overmann, J., Lince, M.T., Manske, A.K., Lang, A.S., Blankenship, R.E., Van Dover, C.L., Martinson, T.A. and Plumley, F.G., 2005. [An obligately photosynthetic bacterial anaerobe from a deep-sea hydrothermal vent](https://www.pnas.org/doi/10.1073/pnas.0503674102). Proceedings of the National Academy of Sciences, 102(26), pp.9306-9310.

Beauchamp, P., 2012. [Assessment of planetary protection and contamination control technologies for future planetary science missions](https://web.archive.org/web/20170808152222/https%3A//solarsystem.nasa.gov/docs/PPCCTECHREPORT3.pdf)

Behera, B.C., 2020. [Citric acid from Aspergillus niger: a comprehensive overview](file:///C%3A%5CUsers%5Crober%5CDocuments%5Cbooklets%5CMSR_papers%5CBehera%2C%20B.C.%2C%202020.%20Citric%20acid%20from%20Aspergillus%20niger%3A%20a%20comprehensive%20overview.%20Critical%20Reviews%20in%20Microbiology%2C%2046%286%29%2C%20pp.727-749). *Critical Reviews in Microbiology*, *46*(6), pp.727-749.

.

Belbruno, E., 2018. [*Capture dynamics and chaotic motions in celestial mechanics: With applications to the construction of low energy transfers*](https://press.princeton.edu/books/hardcover/9780691094809/capture-dynamics-and-chaotic-motions-in-celestial-mechanics). Princeton University Press.

Benner, S. and Davies, P. , 2010,  [‘Towards a Theory of Life’](https://books.google.co.uk/books?id=OscgAwAAQBAJ&pg=PA27#v=onepage&q&f=false), in Impey, C., Lunine, J. and Funes, J. eds., *Frontiers of astrobiology*. Cambridge University Press.

Berad, A., 2022, [Traces of ancient ocean discovered on Mars](https://www.psu.edu/news/research/story/traces-ancient-ocean-discovered-mars/)

Bhullar, K., Waglechner, N., Pawlowski, A., Koteva, K., Banks, E.D., Johnston, M.D., Barton, H.A. and Wright, G.D., 2012. [Antibiotic resistance is prevalent in an isolated cave microbiome](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0034953). *PloS one*, *7*(4), p.e34953.

Bianciardi, G., Miller, J.D., Straat, P.A. and Levin, G.V., 2012. [Complexity analysis of the Viking labelled release experiments](http://central.oak.go.kr/repository/journal/11315/HGJHC0_2012_v13n1_14.pdf). International Journal of Aeronautical and Space Sciences, 13(1), pp.14-26.

Biersma, E.M., Convey, P., Wyber, R., Robinson, S.A., Dowton, M., Van de Vijver, B., Linse, K., Griffiths, H. and Jackson, J.A., 2020. [Latitudinal biogeographic structuring in the globally distributed moss Ceratodon purpureus](https://www.frontiersin.org/articles/10.3389/fpls.2020.502359/full%C2%A0%C2%A0). *Frontiers in Plant Science*, *11*, p.502359.

Billi, D., Staibano, C., Verseux, C., Fagliarone, C., Mosca, C., Baqué, M., Rabbow, E. and Rettberg, P., 2019a. [Dried biofilms of desert strains of Chroococcidiopsis survived prolonged exposure to space and Mars-like conditions in low Earth orbit](https://www.researchgate.net/profile/Cyprien-Verseux/publication/331027480_Dried_Biofilms_of_Desert_Strains_of_Chroococcidiopsis_Survived_Prolonged_Exposure_to_Space_and_Mars-like_Conditions_in_Low_Earth_Orbit/links/5ee9e56d299bf1faac5c948f/Dried-Biofilms-of-Desert-Strains-of-Chroococcidiopsis-Survived-Prolonged-Exposure-to-Space-and-Mars-like-Conditions-in-Low-Earth-Orbit.pdf). Astrobiology, 19(8), pp.1008-1017.

*Our results suggest that bacteria might indeed survive on Mars if shielded from UV, for instance by martian dust, since it is known that a few millimeters of soil is enough for UV protection (Mancinelli and Klovstad, 2000; Cockell and Raven, 2004). In view of the resistance of desert strain of Chroococcidiopsis to ionizing radiation (Billi et al., 2000; Verseux et al., 2017), the exposure in LEO to a total dose of 0.5 Gy of ionizing radiation did not affect biofilm survival. Hence, based on the dose of 76 mGy/year measured by the Curiosity rover at Gale Crater’s surface (Hassler et al., 2013), dried biofilms would survive on Mars more than half a decade. In addition, since the UV dose received in LEO corresponds to approximately 8 h under a Mars UV flux at the equator (Cockell et al., 2000), the speculated biofilm survival supports the possible dissemination of viable organisms. If carried, for instance, by winds at 5 m/sec (Gomez-Elvira et al., 2014) with the average flux mentioned above, they could travel more than 100km without dying. However, other factors found on Mars need to be taken into account so as to reduce the planetary protection risk, such as the presence of perchlorates that have been shown to be highly damaging to life (Wadsworth and Cockell, 2017)*

Billi, D., Verseux, C., Fagliarone, C., Napoli, A., Baqué, M. and de Vera, J.P., 2019b. [A desert cyanobacterium under simulated Mars-like conditions in low Earth orbit: implications for the habitability of Mars](https://www.researchgate.net/profile/Daniela-Billi/publication/331027480_Dried_Biofilms_of_Desert_Strains_of_Chroococcidiopsis_Survived_Prolonged_Exposure_to_Space_and_Mars-like_Conditions_in_Low_Earth_Orbit/links/5ca21364a6fdcc1ab5ba0613/Dried-Biofilms-of-Desert-Strains-of-Chroococcidiopsis-Survived-Prolonged-Exposure-to-Space-and-Mars-like-Conditions-in-Low-Earth-Orbit.pdf). *Astrobiology*, *19*(2), pp.158-169.

*In this experiment, survival of the Chroococcidiopsis strain occurred only with those cells that were mixed with martian regolith simulant and plated as thin layers (about 15–30 μm, corresponding to 4–5 cell layers).*

*… Our finding suggests that a putative microbial life-form at least as resistant to desiccation and radiation as the investigated desert cyanobacterium could withstand some exposure to UV on the martian surface.*

*… Our findings support the hypothesis that opportunistic colonization of protected niches on Mars, such as in fissures, cracks, and microcaves in rocks or soil, could have enabled life to remain viable while being transported to a new habitat*

Billi, D., Viaggiu, E., Cockell, C.S., Rabbow, E., Horneck, G. and Onofri, S., 2011. [Damage escape and repair in dried Chroococcidiopsis spp. from hot and cold deserts exposed to simulated space and Martian conditions](https://www.researchgate.net/profile/Charles-Cockell/publication/49810974_Damage_Escape_and_Repair_in_Dried_Chroococcidiopsis_spp_from_Hot_and_Cold_Deserts_Exposed_to_Simulated_Space_and_Martian_Conditions/links/0c960530543245cde9000000/Damage-Escape-and-Repair-in-Dried-Chroococcidiopsis-spp-from-Hot-and-Cold-Deserts-Exposed-to-Simulated-Space-and-Martian-Conditions.pdf). *Astrobiology*, *11*(1), pp.65-73.

*The survival of dried cells of strain CCMEE 123 when exposed to 21 days of simulated martian conditions further supports the employment of hot desert strains of Chroococcidiopsis in future approaches to mimic endolithic martian exposure. It was previously reported that the survival of dried cells of Chroococcidiopsis sp. CCMEE 029 (Negev Desert) under simulant martian soil or gneiss was not affected by a 4 h exposure to unattenuated martian UV flux. This shows that in theory such organisms could survive or even grow on Mars or Mars-like planets if they had a source of water and nutrients; thus they could be active in such environments (Cockell et al., 2005)*

Birnbach, I., 1997. [Newly Imposed Limitations on Citizens' Right to Sue for Standing in a Procedural Rights Case](https://ir.lawnet.fordham.edu/cgi/viewcontent.cgi?referer=&httpsredir=1&article=1496&context=elr). Fordham Envtl. LJ, 9, p.311.

Blackmond, D.G., 2019. [The origin of biological homochirality](https://cshperspectives.cshlp.org/content/11/3/a032540.full). *Cold Spring Harbor perspectives in biology*, *11*(3), p.a032540.

Blakeslee, S., 2004. [The CRAAP test](https://commons.emich.edu/cgi/viewcontent.cgi?article=1009&context=loexquarterly). *Loex Quarterly*, *31*(3), p.4.

Blankenship, R.E., Tiede, D.M., Barber, J., Brudvig, G.W., Fleming, G., Ghirardi, M., Gunner, M.R., Junge, W., Kramer, D.M., Melis, A. and Moore, T.A., 2011. [Comparing photosynthetic and photovoltaic efficiencies and recognizing the potential for improvement](https://www.researchgate.net/profile/Richard_Sayre/publication/51120946_Comparing_Photosynthetic_and_Photovoltaic_Efficiencies_and_Recognizing_the_Potential_for_Improvement/links/00463517eb44cd0891000000.pdf). *science*, *332*(6031), pp.805-809.

Boeder, P.A. and Soares, C.E., 2020. [Mars 2020: mission, science objectives and build. In Systems Contamination: Prediction, Control, and Performance 2020](https://www.researchgate.net/publication/343915302_Mars_2020_mission_science_objectives_and_build) (Vol. 11489, p. 1148903). International Society for Optics and Photonics

Bohannon, J., 2010. [Mirror-image cells could transform science-or kill us all.](https://web.archive.org/web/20151124042506/https%3A/www.wired.com/2010/11/ff_mirrorlife/) Wired

Borges, W.D.S., Borges, K.B., Bonato, P.S., Said, S. and Pupo, M.T., 2009. [Endophytic fungi: natural products, enzymes and biotransformation reactions](https://www.researchgate.net/profile/Warley_Borges/publication/233633077_Endophytic_Fungi_Natural_Products_Enzymes_and_Biotransformation_Reactions/links/550e1dbb0cf2ac2905aac539.pdf). Current Organic Chemistry, 13(12), pp.1137-1163.

Borojeni, I.A., Gajewski, G. and Riahi, R.A., 2022. [Application of Electrospun Nonwoven Fibers in Air Filters](https://www.mdpi.com/2079-6439/10/2/15/pdf?version=1644317375). Fibers, 10(2), p.15.

Boston, P.J., Hose, L.D., Northup, D.E. and Spilde, M.N., 2006. [The microbial communities of sulfur caves: a newly appreciated geologically driven system on Earth and potential model for Mars.](https://www.researchgate.net/publication/279870866_The_microbial_communities_of_sulfur_caves_A_newly_appreciated_geologically_driven_system_on_Earth_and_potential_model_for_Mars)

Boston, P.J., 2010. [Location, location, location! Lava caves on Mars for habitat, resources, and the search for life](https://web.archive.org/web/20101129032534/http%3A/journalofcosmology.com/Mars130.html). *Journal of Cosmology*, *12*, pp.3957-3979.

Bostrom, N., 2002. Existential risks: [Analyzing human extinction scenarios and related hazards](https://nickbostrom.com/existential/risks.html).

Bottos, E.M., Woo, A.C., Zawar-Reza, P., Pointing, S.B. and Cary, S.C., 2014. [Airborne bacterial populations above desert soils of the McMurdo Dry Valleys, Antarctica](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3907674/). *Microbial ecology*, *67*, pp.120-128.

*Many of the dominant sequences were found to group closely with known thermophilic genera. Sequences of OTU0.03 159 grouped within the Firmicutes to the genus* Thermaerobacter *and shared 99 % sequence identity with its closest BLAST match,* Thermaerobacter subterraneus*, an isolate from a hydrothermal system [*[*41*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3907674/#CR41)*]. Sequences of OTU0.03 238 were found to share 100 % sequence identity with isolate* Geobacillus tepidamans*, which has been recovered from highly disparate thermal environments, including geothermal systems and food processing facilities*

Boxe, C.S., Hand, K.P., Nealson, K.H., Yung, Y.L. and Saiz-Lopez, A., 2012. [An active nitrogen cycle on Mars sufficient to support a subsurface biosphere](https://authors.library.caltech.edu/30213/1/Boxe2012p17592Int_J_Astrobiol.pdf). *International Journal of Astrobiology*, *11*(2), pp.109-115.

Boyle, A., 2016, [Where does Jeff Bezos foresee putting space colonists? Inside O’Neill cylinders](https://www.geekwire.com/2016/jeff-bezos-space-colonies-oneill/), Geek wire. Video transcription from [12:40 into the interview](https://youtu.be/VNwE3sRWxHw?t=760).

Boyle, R., Rodriggs, L.M., Allton, C., Jennings, M. and Aitchison, L.T., 2013. [Suitport feasibility-human pressurized space suit donning tests with the marman clamp and pneumatic flipper suitport concepts](https://core.ac.uk/download/pdf/42736689.pdf). In *43rd International Conference on Environmental Systems* (p. 3399).

Brazil, R., 2015, [The origin of homochirality](https://www.chemistryworld.com/features/the-origin-of-homochirality/9073.article), Chemistry World.

Bristow, L.A., Mohr, W., Ahmerkamp, S. and Kuypers, M.M., 2017. [Nutrients that limit growth in the ocean](https://www.sciencedirect.com/science/article/pii/S0960982217303287). *Current Biology*, *27*(11), pp.R474-R478.

Brodribb, T.J., Sussmilch, F. and McAdam, S.A., 2020. [From reproduction to production, stomata are the master regulators](https://onlinelibrary.wiley.com/doi/full/10.1111/tpj.14561). The Plant Journal, 101(4), pp.756-767.

Brown, G.D., Denning, D.W., Gow, N.A., Levitz, S.M., Netea, M.G. and White, T.C., 2012. [Hidden killers: human fungal infections](https://knowthecause.com/wp-content/uploads/2015/09/Brown10121FungiGHiddenKillers.pdf). *Science translational medicine*, *4*(165), pp.165rv13-165rv13.

Brown, T., n.d. [Apple Search](https://applesearch.org/newsletter.html)

Brüggemann, H., Bäumer, S., Fricke, W.F., Wiezer, A., Liesegang, H., Decker, I., Herzberg, C., Martinez-Arias, R., Merkl, R., Henne, A. and Gottschalk, G., 2003. [The genome sequence of Clostridium tetani, the causative agent of tetanus disease](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC298770/). *Proceedings of the National Academy of Sciences*, *100*(3), pp.1316-1321.

The origin of pE88 remains unclear. Over 50% of all ORFs on pE88 are unique to C. tetani.

 BS, 2009, BS EN 1822-1:2009 [High efficiency air filters (EPA, HEPA and ULPA), Part 1: Classification, performance testing, marking](http://www.gttlab.com/uploads/soft/161025/EN1822-1-2009Highefficiencyairfilters%28EPA%2CHEPAandULPA%29Part1Classification%2Cperformance.pdf)

Butler, C., 1999, [NASA Johnson Space Center Oral History Project
Edited Oral History Transcript](https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/ErbRB/ErbRB_10-14-99.htm)

C4 Rice, n.d., [The C-4 rice project](https://c4rice.com/the-science/engineering-photosynthesis-what-we-are-doing/).

Cabrol, N.A., 2018. [The coevolution of life and environment on Mars: an ecosystem perspective on the robotic exploration of biosignatures](https://www.liebertpub.com/doi/pdf/10.1089/ast.2017.1756).

Preliminary results (e.g., Phillips et al., 2017) show that, to be effective and diag
nostic, the orbital resolution of a visible imager should reach \*1 cm/pixel to resolve fine-scaled geomorphic features in microbialites, spring mounds, and salt habitats, which is beyond the recommendation of \*10–15 cm/pixel for a future orbital visible imager (e.g., MEPAG NEX-SAG Report, 2015). HiRISE and a future orbiter with \*10–15 cm/pixel resolution could identify bulk geomorphic features that are consistent with a potential habitat (e.g., Suosaari et al., 2016), but might still not be diagnostic for many of them (e.g., Allen and Oehler, 2008) unless data sets can be improved through new super-resolution techniques (e.g., Tao and Muller, 2016).

Campanale, C., Massarelli, C., Savino, I., Locaputo, V. and Uricchio, V.F., 2020. [A detailed review study on potential effects of microplastics and additives of concern on human health](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7068600/). International Journal of Environmental Research and Public Health, 17(4), p.1212.

Capone, D.G., Popa, R., Flood, B. and Nealson, K.H., 2006. [Follow the nitrogen](https://www.researchgate.net/profile/Kenneth-Nealson/publication/7104708_Geochemistry_Follow_the_nitrogen/links/55db965508aed6a199ac63d2/Geochemistry-Follow-the-nitrogen.pdf). Science, 312(5774), pp.708-709.

Cardenas, B.T. and Lamb, M.P., 2022. [Paleogeographic reconstructions of an ocean margin on Mars based on deltaic sedimentology at Aeolis Dorsa](https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2022JE007390). *Journal of Geophysical Research: Planets*, *127*(10), p.e2022JE007390.

Caron, L., Douady, D., de Martino, A. and Quinet, M., 2001. [Light harvesting in brown algae](http://www.vliz.be/imisdocs/publications/289162.pdf). *Cah Biol Mar*, *42*, pp.109-124.

Carrier, B.L., Beaty, D.W., Meyer, M.A., Blank, J.G., Chou, L., DasSarma, S., Des Marais, D.J., Eigenbrode, J.L., Grefenstette, N., Lanza, N.L. and Schuerger, A.C., 2020. [Mars Extant Life: What's Next? Conference Report.](https://www.liebertpub.com/doi/pdfplus/10.1089/ast.2020.2237) ([html](https://www.liebertpub.com/doi/10.1089/ast.2020.2237))

Carroll, K.A., 2019. [The Early History of Canadian Planetary Exploration](https://www.researchgate.net/profile/Kieran-Carroll/publication/337992462_The_Early_History_of_Canadian_Planetary_Exploration/links/5e0baa5ea6fdcc28374d27ec/The-Early-History-of-Canadian-Planetary-Exploration.pdf).

Carter, J., 2022, [Why this Ceres mission could change the search for alien life](https://www.planetary.org/articles/ceres-sample-return-mission-alien-life)

Casadevall, A. and Pirofski, L.A., 2001. [Host‐pathogen interactions: the attributes of virulence](https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=476ab20775635c2456093efa381f7b430de7e999). The Journal of infectious diseases, 184(3), pp.337-344.

*“Aggressins” was a term used for substances produced by microorganisms that had*

*the power to inhibit or destroy the ability of the host to defend itself against microbes [10]. Although Bails’s “aggressins” were subsequently shown to be endotoxins [15], his “aggressin” theory can be regarded as the intellectual ancestor of today’s concept that pathogenic microbes have virulence factors that mediate their pathogenicity.*

Castillo-Rogez, J., and Brophy, J., 2022, [Ceres Exploration of Ceres' habitability](https://science.nasa.gov/science-red/s3fs-public/atoms/files/Exploration%20of%20Ceres%20Habitability.pdf?fbclid=IwAR3u1ws2Atwm_ZdQa1VIXKvdJ0dlaKTBYtbmvTC4P1VdAeGTqTfoFrFIrnM)

CDC, n.d., [Ebola](https://www.cdc.gov/vhf/ebola/index.html)

CDC, n.d., [HIV](https://www.cdc.gov/hiv/basics/whatishiv.html)

CDC, n.d., [Malaria](https://www.cdc.gov/malaria/about/biology/index.html%22%20%5Cl%20%22tabs-1-6)

CDC, n.d., [Schistosomiasis](https://www.cdc.gov/parasites/schistosomiasis/index.html)

CDC, n.d., [Yellow Fever virus](https://www.cdc.gov/yellowfever/transmission/index.html)

Cecere, E., Petrocelli, A. and Verlaque, M., 2011. [Vegetative reproduction by multicellular propagules in Rhodophyta: an overvie](https://d1wqtxts1xzle7.cloudfront.net/51137109/Vegetative_reproduction_by_multicellular20161231-29593-yau2q6.pdf?1483254010=&response-content-disposition=inline%3B+filename%3DVegetative_reproduction_by_multicellular.pdf&Expires=1614959639&Signature=A-9PiSVqRCkdtmTidDurz4Y2EZeFCLv3sD7S9REndyla-~tnC0Epg2abz5Brv8ycScZbsM9YYYBploNQkgnypZt-6afnZB-5JQbpQi14z60dKBZz7ysu4phZ3gPOpTq-al959S2U6HlAVD8gISKdxIzDYoE3BHYGzmyc9ZgZO0PJZSfoe74IyJIyuw9s7xgLPrwtEzWvf2mYPamkdKoqenG8B-QG5wEg3pX7-xQEBfjsFG2FvulWqAtYo6JP66obbKRN366ltOjW670koyuobHNNQ5jrv6B51A-6iukbB7azTAPk2uvSOMICM0LREnTf0Jd1rAL-6VcLJml4rioZ1A__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA)w. *Marine Ecology*, *32*(4), pp.419-437.

Center for Advanced Materials, n.d., [In situ resource utilization – Lunar Solar Cell Manufacturing](https://web.archive.org/web/20100622143653/http%3A/www.cam.uh.edu/SpaRC/ISRU%202p%20v1%20022007.pdf), University of Houston

Chang, E., 2015, [Mars Is Pretty Clean. Her Job at NASA Is to Keep It That Way](https://www.nytimes.com/2015/10/06/science/mars-catharine-conley-nasa-planetary-protection-officer.html).

Chappaz, L., Sood, R., Melosh, H.J., Howell, K.C., Blair, D.M., Milbury, C. and Zuber, M.T., 2017. [Evidence of large empty lava tubes on the Moon using GRAIL gravity](https://agupubs.onlinelibrary.wiley.com/doi/pdfdirect/10.1002/2016GL071588). *Geophysical Research Letters*, *44*(1), pp.105-112.

Chater, C., Kamisugi, Y., Movahedi, M., Fleming, A., Cuming, A.C., Gray, J.E. and Beerling, D.J., 2011. [Regulatory mechanism controlling stomatal behavior conserved across 400 million years of land plant evolution](https://www.sciencedirect.com/science/article/pii/S096098221100474X). Current Biology, 21(12), pp.1025-1029.

Chávez, R., Fierro, F., García-Rico, R.O. and Vaca, I., 2015[. Filamentous fungi from extreme environments as a promising source of novel bioactive secondary metabolites](https://www.frontiersin.org/articles/10.3389/fmicb.2015.00903/full). *Frontiers in Microbiology*, *6*, p.903.

Chevrier, V.F., Rivera-Valentín, E.G., Soto, A. and Altheide, T.S., 2020. [Global Temporal and Geographic Stability of Brines on Present-day Mars](https://iopscience.iop.org/article/10.3847/PSJ/abbc14/pdf). The Planetary Science Journal, 1(3), p.64.

Chivian, E. and Bernstein, A. eds., 2008. [Sustaining life: how human health depends on biodiversity](https://www.amazon.co.uk/Sustaining-Life-Health-Depends-Biodiversity-ebook/dp/B07R8WJ4JD/ref%3Dtmm_kin_swatch_0?_encoding=UTF8&qid=&sr=&asin=B07R8WJ4JD&revisionId=&format=4&depth=1). Oxford University Press.

*The stomachs of all vertebrate species, including frogs, contain cells that secrete acid and enzymes such as pepsin to begin the process of digesting food. There are also compounds that stimulate emptying of the stomach so that its contents can be moved along into the small intestine where further digestion takes place. The ingestion of food triggers release of these compounds.*

*Preliminary studies with gastric brooding frog tadpoles demonstrated that they secrete a substance, or substances, that both inhibits acid and pepsin secretions and prevents stomach emptying so that they do not end up being digested by heir mother. But these studies, which might have led to important new insights for treating human peptic ulcers, a disease that affects more than twenty-five million people in the United States, couldn't be completed because both species of Rhoebactrachus became extinct.*

Christidis, N., McCarthy, M. and Stott, P.A., 2020. [The increasing likelihood of temperatures above 30 to 40° C in the United Kingdom](https://www.nature.com/articles/s41467-020-16834-0/). *Nature communications*, *11*(1), p.3093.

Cichan, T., Bailey, S.A., Antonelli, T., Jolly, S.D., Chambers, R.P., Clark, B. and Ramm, S.J., 2017. [Mars Base Camp: An Architecture for Sending Humans to Mars](https://www.liebertpub.com/doi/full/10.1089/space.2017.0037). *New Space*, *5*(4), pp.203-218.

Clark, B., 2009, [Cultybraggan nuclear bunker](https://www.geograph.org.uk/photo/1483182)

Clark, R.A., 2010. [Skin-resident T cells: the ups and downs of on site immunity](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2922675/). *Journal of Investigative Dermatology*, *130*(2), pp.362-370Clark, S., 2018, [NOAA’s new GOES-17 weather satellite has degraded vision at night](https://spaceflightnow.com/2018/05/23/noaas-new-goes-17-weather-satellite-has-degraded-vision-at-night/)

Cleland, C.E., 2019. [The Quest for a Universal Theory of Life: Searching for Life as we don't know it](https://books.google.co.uk/books?id=eqCsDwAAQBAJ) (Vol. 11). Cambridge University Press.

Cockell, C.S., 2008. [The Interplanetary Exchange of Photosynthesis](https://www.researchgate.net/profile/Charles_Cockell/publication/5937888_The_Interplanetary_Exchange_of_Photosynthesis/links/0c960530632bf30e20000000.pdf). *Origins of Life and Evolution of Biospheres*, *38*(1), pp.87-104.

Cockell, C.S., 2014. [Trajectories of Martian habitability](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3929387/). Astrobiology, 14(2), pp.182-203.

Cockell, C.S. and McMahon, S., 2019b. [Lifeless Martian samples and their significance](https://www.researchgate.net/profile/Charles_Cockell/publication/333588068_Lifeless_Martian_samples_and_their_significance/links/5e6aa808458515e555763b87/Lifeless-Martian-samples-and-their-significance.pdf). Nature Astronomy, 3(6), pp.468-470.

Cockell, C.S., McMahon, S., Lim, D.S., Rummel, J., Stevens, A., Hughes, S.S., Nawotniak, S.E.K., Brady, A.L., Marteinsson, V., Martin-Torres, J. and Zorzano, M.P., 2019c. [Sample Collection and Return from Mars: Optimising Sample Collection Based on the Microbial Ecology of Terrestrial Volcanic Environments](https://link.springer.com/article/10.1007/s11214-019-0609-7). Space Science Reviews, 215(7), p.44.

Cortesão, M., Fuchs, F.M., Commichau, F.M., Eichenberger, P., Schuerger, A.C., Nicholson, W.L., Setlow, P. and Moeller, R., 2019. [Bacillus subtilis spore resistance to simulated Mars surface conditions](https://www.frontiersin.org/articles/10.3389/fmicb.2019.00333/full). Frontiers in microbiology, 10, p.333.

Cortesão, M., Siems, K., Koch, S., Beblo-Vranesevic, K., Rabbow, E., Berger, T., Lane, M., James, L., Johnson, P., Waters, S.M. and Verma, S.D., 2021. [MARSBOx: fungal and bacterial endurance from a balloon-flown analog mission in the stratosphere](https://www.frontiersin.org/articles/10.3389/fmicb.2021.601713/full). Frontiers in Microbiology, 12, p.601713.

*Fungal spores of Aspergillus niger and bacterial cells of Salinisphaera shabanensis, Staphylococcus capitis subsp. capitis, and Buttiauxella sp. MASE-IM-9 were launched inside the MARSBOx (Microbes in Atmosphere for Radiation, Survival, and Biological Outcomes Experiment) payload filled with an artificial martian atmosphere and pressure throughout the mission profile. The dried microorganisms were either exposed to full UV-VIS radiation (UV dose = 1148 kJ m−2) or were shielded from radiation. After the 5-h stratospheric exposure, samples were assayed for survival and metabolic changes. Spores from the fungus A. niger and cells from the Gram-(–) bacterium S. shabanensis were the most resistant with a 2- and 4-log reduction, respectively.*

*The fungus Aspergillus niger and the bacterium Staphylococcus capitis subsp. capitis were included in this study because they are human-associated and opportunistic pathogens, and have both been previously detected on the International Space Station (ISS). Thus, they are likely to travel to Mars in crewed space missions …. Moreover, spores from A. niger might resist space travel on the outside of a spacecraft; therefore, understanding their survival potential in a Mars-like environment is of interest to planetary protection.*

Council on Environmental Quality, 2007. [A citizen’s guide to the NEPA: Having your voice heard](https://ceq.doe.gov/docs/get-involved/Citizens_Guide_Dec07.pdf).

Congressional Research Service, 2021, [National Environmental Policy Act: Judicial Review and Remedies](https://crsreports.congress.gov/product/pdf/IF/IF11932)

Conley, °C (2016), interviewed by Straus, M., for National Geographic, [*Going to Mars Could Mess Up the Hunt for Alien Life*](http://news.nationalgeographic.com/2016/09/mars-journey-nasa-alien-life-protection-humans-planets-space/).

*From the perspective of planetary protection, Conley is also concerned about terrestrial organisms that can absorb water from the air. She recalls fieldwork she did in the Atacama Desert in Chile, which is one of the driest places on Earth, with less than 0.04 inch of rain a year.*

*Even in this dessicated place, she found life: photosynthetic bacteria that had made a home in tiny chambers within halite salt crystals. There’s a small amount of water retained inside the halite and, at night, it cools down and condenses both on the walls of the chambers and on the surface of the organisms that are sitting there.*

Comeau, A.M., Vincent, W.F., Bernier, L. and Lovejoy, C., 2016. [Novel chytrid lineages dominate fungal sequences in diverse marine and freshwater habitats](https://www.nature.com/articles/srep30120). *Scientific reports*, *6*(1), p.30120.

Comolli, L.R., Baker, B.J., Downing, K.H., Siegerist, C.E. and Banfield, J.F., 2009. [Three-dimensional analysis of the structure and ecology of a novel, ultra-small archaeon](https://www.nature.com/articles/ismej200899). *The ISME journal*, *3*(2), pp.159-167.

Cornelius, A.J., Chambers, S., Aitken, J., Brandt, S.M., Horn, B. and On, S.L., 2012. [Epsilonproteobacteria in humans](https://wwwnc.cdc.gov/eid/article/18/3/11-0875_article), New Zealand. *Emerging infectious diseases*, *18*(3), p.510.

COSPAR, 2011. [COSPAR Planetary Protection Policy, 20 October 2002, as amended to 24 March 2011](http://www.physics.rutgers.edu/~ajbaker/honors292/COSPAR_Planetary_Protection_Policy_v3-24-11.pdf), COSPAR/IAU Workshop on Planetary Protection.

Cowen, L.E., Sanglard, D., Howard, S.J., Rogers, P.D. and Perlin, D.S., 2015. [Mechanisms of antifungal drug resistance](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4484955/). Cold Spring Harbor perspectives in medicine, 5(7), p.a019752

Cox, P.A., Banack, S.A., Murch, S.J., Rasmussen, U., Tien, G., Bidigare, R.R., Metcalf, J.S., Morrison, L.F., Codd, G.A. and Bergman, B., 2005. [Diverse taxa of cyanobacteria produce β-N-methylamino-L-alanine, a neurotoxic amino acid](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC555964/). *Proceedings of the National Academy of Sciences*, *102*(14), pp.5074-5078.

Craven, E., Winters, M., Smith, A.L., Lalime, E., Mancinelli, R., Shirey, B., Schubert, W., Schuerger, A., Burgin, M., Seto, E.P. and Hendry, M., 2021. [Biological safety in the context of backward planetary protection and Mars Sample Return: conclusions from the Sterilization Working Group](https://web.archive.org/web/20210224111553id_/https%3A/www.cambridge.org/core/services/aop-cambridge-core/content/view/B541CA22933846952EC723FD2514B6F4/S1473550420000397a.pdf/div-class-title-biological-safety-in-the-context-of-backward-planetary-protection-and-mars-sample-return-conclusions-from-the-sterilization-working-group-div.pdf). *International Journal of Astrobiology*, *20*(1), pp.1-28.

Cronin, J.R. and Pizzarello, S., 1983. [Amino acids in meteorites](https://pubmed.ncbi.nlm.nih.gov/11542462/). Advances in Space Research, 3(9), pp.5-18.

Cunha, C., Carvalho, A., Esposito, A., Bistoni, F. and Romani, L., 2012. [DAMP signaling in fungal infections and diseases](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3437516/). *Frontiers in immunology*, *3*, p.286.

*It is now clear that several DAMPs are vital danger signals that alert the immune system to tissue damage upon fungal infections. However, PRR activation by DAMPs may initiate positive feedback loops where increasing tissue damage perpetuates pro-inflammatory responses leading to chronic inflammation.*

Dabravolski, S.A. and Isayenkov, S.V., 2022. [Metabolites Facilitating Adaptation of Desert Cyanobacteria to Extremely Arid Environments](https://www.mdpi.com/2223-7747/11/23/3225). *Plants*, *11*(23), p.3225.

*Apparently, EPSs synthesis is a slow process that could not quickly respond to fast-occurring dehydration and desiccation. However, during slow and gradual desiccation, cells have time to prepare for dehydration via up- or down-regulation of the necessary network of genes to facilitate quick revival.*

Daga, A.W., Allen, C., Battler, M.M., Burke, J.D., Crawford, I.A., Léveillé, R.J., Simon, S.B. and Tan, L.T., 2009, November. [Lunar and martian lava tube exploration as part of an overall scientific survey](https://www.lpi.usra.edu/decadal/leag/AndrewWDagaFINAL.pdf). In *Annual Meeting of the Lunar Exploration Analysis Group* (Vol. 1515, p. 15).

Dagenais, T.R. and Keller, N.P., 2009. [Pathogenesis of Aspergillus fumigatus in invasive aspergillosis](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2708386/). *Clinical microbiology reviews*, *22*(3), pp.447-465.

Dance, A., 2020, [The search for microbial dark matter](https://www.nature.com/articles/d41586-020-01684-z), Nature

Daubar, I.J., Atwood‐Stone, C., Byrne, S., McEwen, A.S. and Russell, P.S., 2014. [The morphology of small fresh craters on Mars and the Moon](https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014JE004671). *Journal of Geophysical Research: Planets*, *119*(12), pp.2620-2639.

David, L., 2015, [Q&A with Chris McKay, Senior Scientist at NASA Ames Research Center](https://spacenews.com/qa-with-chris-mckay-senior-scientist-at-nasa-ames-research-center/), SpaceNews

Davies, P., 2014, [The key to life on Mars may well be found in Chile](https://www.theguardian.com/commentisfree/2012/aug/03/life-mars-chile), The Guardian

Davila, A.F., Skidmore, M., Fairén, A.G., Cockell, C. and Schulze-Makuch, D., 2010. [New priorities in the robotic exploration of Mars: the case for in situ search for extant life](http://online.liebertpub.com/doi/abs/10.1089/ast.2010.0538?journalCode=ast). *Astrobiology*, *10*(7), pp.705-710

Davila, A.F., Willson, D., Coates, J.D. and McKay, C.P., 2013. [Perchlorate on Mars: a chemical hazard and a resource for humans](https://www.researchgate.net/publication/242525435_Perchlorate_on_Mars_A_chemical_hazard_and_a_resource_for_humans). *Int. J. Astrobiol*, *12*(04), pp.321-325.

Debus, A., 2004, April. [Planetary Protection: Organisation, Requirements and Needs for Future Planetary Exploration Missions](http://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query?db_key=AST&bibcode=2004ESASP.543..103D&letter=0&classic=YES&defaultprint=YES&whole_paper=YES&page=105&epage=105&send=Send+PDF&filetype=.pdf). In *Tools and Technologies for Future Planetary Exploration* (Vol. 543, pp. 103-114).

Deckers, J., Marsland, B.J. and von Mutius, E., 2021. Protection against allergies: Microbes, immunity, and the farming effect. *European Journal of Immunology*, *51*(10), pp.2387-2398.

Dehel, T., 2022.

* [Comment posted May 4th](https://www.regulations.gov/comment/NASA-2022-0002-0058)
* [Comment posted December 13th](https://www.regulations.gov/comment/NASA-2022-0002-0237)

Deighton B., 2016, [Life could exist on Mars today, bacteria tests show](https://ec.europa.eu/research-and-innovation/en/horizon-magazine/life-could-exist-mars-today-bacteria-tests-show), Horizon, EU research and Innovation Magazine

Demaneuf, G., 2020. The Good, the Bad and the Ugly: a review of SARS Lab Escapes

Desroches, T.C., McMullin, D.R. and Miller, J.D., 2014. [Extrolites of Wallemia sebi, a very common fungus in the built environment](https://onlinelibrary.wiley.com/doi/pdf/10.1111/ina.12100). Indoor air, 24(5), pp.533-542.

de Vera, J.P., Schulze-Makuch, D., Khan, A., Lorek, A., Koncz, A., Möhlmann, D. and Spohn, T., 2014. [*Adaptation of an Antarctic lichen to Martian niche conditions can occur within 34 days*](https://core.ac.uk/download/pdf/31019036.pdf). *Planetary and Space Science*, *98*, pp.182-190.

De Vera, J.P., Alawi, M., Backhaus, T., Baqué, M., Billi, D., Böttger, U., Berger, T., Bohmeier, M., Cockell, C., Demets, R. and De la Torre Noetzel, R., 2019. [Limits of life and the habitability of Mars: the ESA space experiment BIOMEX on the ISS](https://www.liebertpub.com/doi/pdf/10.1089/ast.2018.1897). *Astrobiology*, *19*(2), pp.145-157.

Devincenzi, D.L. and Bagby, J.R., 1981. [*Orbiting quarantine facility. The Antaeus report*](https://ntrs.nasa.gov/api/citations/19820012351/downloads/19820012351.pdf) (No. NASA-SP-454).

Dewi, I.M., Van de Veerdonk, F.L. and Gresnigt, M.S., 2017. [The multifaceted role of T-helper responses in host defense against Aspergillus fumigatus](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5753157/#B94-jof-03-00055). *Journal of Fungi*, *3*(4), p.55..

Denning, D.W., 1998. [Invasive aspergillosis](https://www.researchgate.net/profile/David-Denning/publication/277533431_Invasive_Aspergillosis/links/5cc08099a6fdcc1d49acb660/Invasive-Aspergillosis.pdf). *Clinical infectious diseases*, pp.781-803.

Denning, D.W., Pleuvry, A. and Cole, D.C., 2013. [Global burden of allergic bronchopulmonary aspergillosis with asthma and its complication chronic pulmonary aspergillosis in adults](https://fungalinfectiontrust.org/wp-content/uploads/2021/04/Global-burden-of-allergic-bronchopulmonary-aspergillosis-with-asthma-and-its-complication-chronic-pulmonary-aspergillosis-in-adults.pdf). *Medical mycology*, *51*(4), pp.361-370.

Dickson, M. n.d. [Requiem for a Cliché](https://diseasesofmodernlife.web.ox.ac.uk/article/requiem-for-a-cliche)

Dinan, F.J. and Yee, G.T., 2007. [An adventure in stereochemistry: Alice in mirror image land](https://static.nsta.org/case_study_docs/case_studies/alice.pdf). New York: National Center for Case Study Teaching in Science, University at Buffalo, State University of New York.

DiGregorio, B., 2022.

* [Comment posted April 28th](https://www.regulations.gov/comment/NASA-2022-0002-0005)
* [Comment posted May 7th](https://www.regulations.gov/comment/NASA-2022-0002-0173) [with attachment with detailed proposal]
* [Comment posted December 5th](https://www.regulations.gov/comment/NASA-2022-0002-0227)

Doyle, A., 2014, [Mapping Amino Acids to Understand Life's Origins](https://www.astrobio.net/origin-and-evolution-of-life/mapping-amino-acids-to-understand-lifes-origins/), NASA Astrobiology magazine.

Doytchinov, V.V. and Dimov, S.G., 2022. [Microbial community composition of the Antarctic ecosystems: Review of the bacteria, fungi, and archaea identified through an NGS-based metagenomics approach](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9228076/). *Life*, *12*(6), p.916.

Dundas, C.M. and McEwen, A.S., 2015. [Slope activity in Gale crater, Mars](https://www.unife.it/medicina/biotecnologie-mediche/insegnamenti/Biologia-Generale/materiale-didattico/biomed-papers-2k20/Dundas_McEwen_Icarus_2k15a.pdf#hs0035). *Icarus*, *254*, pp.213-218.

Dwyer, C., 2020, [Everest Gets A Growth Spurt As China, Nepal Revise Official Elevation Upward](https://www.npr.org/2020/12/08/944152693/everest-gets-a-growth-spurt-as-china-nepal-revise-official-elevation-upward), NPR

Elleman, D., 2014, [Path to Discovery](file:///C%3A%5CUsers%5Crober%5CDocuments%5Cbooklets%5Cautorecovered%5Chou.usra.edu%5Cmeetings%5Cipm2016%5Cpdf%5C4095.pdf)

Emerson, J.B., Adams, R.I., Román, C.M.B., Brooks, B., Coil, D.A., Dahlhausen, K., Ganz, H.H., Hartmann, E.M., Hsu, T., Justice, N.B. and Paulino-Lima, I.G., 2017. [Schrödinger’s microbes: tools for distinguishing the living from the dead in microbial ecosystems](https://microbiomejournal.biomedcentral.com/articles/10.1186/s40168-017-0285-3). Microbiome, 5(1), pp.1-23.

EMW, ISO 29463 - [New test standard for HEPA Filters](https://www.emw.de/en/filter-campus/iso29463.html) At: <https://www.emw.de/en/filter-campus/iso29463.html> Accessed on 7 July 2020

Engineering ToolBox, 2003. [Young's Modulus - Tensile and Yield Strength for common Materials](https://www.engineeringtoolbox.com/young-modulus-d_417.html) [online].

*In 1998* [*EN 1822*](https://www.emw.de/en/filter-campus/filter-classes.html) *came into effect. This was the first standard, which established a filter classification system for* [*HEPA filters*](https://www.emw.de/en/products/hepa-air-filters/) *based on filtration process theory. EN 1822 also introduced the evaluation criterion MPPS (Most Penetrating Particle Size). MPPS is the particle size at which the air filter has its lowest arrestance. Not just a whim of nature, MPPS relates directly to physical mechanisms in the* [*filtration process*](https://www.emw.de/en/filter-campus/theory-of-particle-filtration.html)*.*

*The U.S. takes a different approach for filter classification of HEPA filters. The mother of all test procedures for these filters in the U.S. is MIL-STD-282, which was introduced in 1956. Other test procedures include e.g. IEST-RP-CC001 and IEST-RP-CC007. Each test procedure specifies certain particle sizes at which efficiency is evaluated. Depending on the filter class evaluated, this is done at 0.3 µm, 0.1 - 0.2 µm or 0.2 - 0.3 µm.*

Eninger, R.M., Honda, T., Reponen, T., McKay, R. and Grinshpun, S.A., 2008. [What does respirator certification tell us about filtration of ultrafine particles?](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6800048/). Journal of occupational and environmental hygiene, 5(5), pp.286-295.

EPA, 2022, [Comment Submitted by the United States Environmental Protection Agency, December 7th, 2022](https://www.regulations.gov/comment/NASA-2022-0002-0235)

EPA, n.d., [Partnering with International Organizations](https://www.epa.gov/international-cooperation/partnering-international-organizations)

Erwin, D.H. and Davidson, E.H., 2002. [The last common bilaterian ancestor](https://authors.library.caltech.edu/12099/1/ERWdev02.pdf).

ESA, n.d., [Life Marker Chip](http://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/Life_marker_chip)

Eshleman, C., 2008. [Lectures on the Ice-Age Painted Caves of Southwestern France](http://labos.ulg.ac.be/cipa/wp-content/uploads/sites/22/2015/07/25_eshleman.pdf). *Interval (le) s*, pp.11-2.

Lascaux was discovered on September 12 th , 1940, primarily by 17 year old Marcel
Ravidat and 15 year old Jacques Marsal, both of whom—Marsal especially—became the caretakers and guides of Lascaux. Several days earlier, Ravidat and other friends had discovered a hole created by a toppled juniper. The boys dropped some stones into the hole and heard them hit far below. On the 12th , Ravidat returned with Marsal, equipped with a lamp made from an old oil-pump, and a big knife. He widened the hole so that he could squirm in five or six yards, at which point he tumbled to the cave’s floor into what is now known as the Rotunda. With Marsal and two other boys he explored the cave and discovered the paintings.

For many years a story was told in which it was said that Lascaux was discovered by
Ravidat’s dog, Robot. There is some basis for this, as during the first trip Ravidat had been drawn to the toppled pine hole by the barking of Robot who had become entangled in its brambly overgrowth. However, it appears that Robot was not around when the boys went down through the hole.

EU, 2001, [Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment](https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32001L0042&from=EN)

Everline, C., 2022. [Comment posted December 20th](https://www.regulations.gov/comment/NASA-2022-0002-0253)

Fajardo-Cavazos, Patricia, Lindsey Link, H. Jay Melosh, and Wayne L. Nicholson, 2005,. ["Bacillus subtilis spores on artificial meteorites survive hypervelocity atmospheric entry: implications for lithopanspermia."](https://pubmed.ncbi.nlm.nih.gov/16379527/) *Astrobiology* 5, no. ; 726-736.

Feldman, D.M. and Nichols, K.A., n.d. [NEPA’s Scientific and Information Standards—Taking the Harder Look](https://www.hollandhart.com/files/66008_RMMLF-NEPA_s-Scientific-and-Information-Standards--Taking.pdf)

Fenner, F., 2010. [Deliberate introduction of the European rabbit, Oryctolagus cuniculus, into Australia](https://pdfs.semanticscholar.org/2e75/f58839806ff4c5aaa89b1a0793dc87f49a2e.pdf). Revue scientifique et technique, 29(1), p.103.

Fischer, E., Martinez, G., Elliott, H.M., Borlina, C. and Renno, N.O., 2013, December. [The Michigan Mars Environmental Chamber: Preliminary Results and Capabilities](https://www.researchgate.net/publication/283504377_The_Michigan_Mars_Environmental_Chamber_Preliminary_Results_and_Capabilities). In AGU Fall Meeting Abstracts (Vol. 2013, pp. P41C-1928).

Fishbaugh, K.E., Poulet, F., Chevrier, V., Langevin, Y. and Bibring, J.P., 2007. [On the origin of gypsum in the Mars north polar region](https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2006JE002862). *Journal of Geophysical Research: Planets*, *112*(E7).

Fischer, E., Martínez, G.M., Elliott, H.M. and Rennó, N.O., 2014. [Experimental evidence for the formation of liquid saline water on Mars](https://agupubs.onlinelibrary.wiley.com/doi/pdfdirect/10.1002/2014GL060302). *Geophysical research letters*, *41*(13), pp.4456-4462.

Foing, B., 2005, [Peaks of Eternal Light](https://web.archive.org/web/20140903154604/http%3A/www.astrobio.net/news-exclusive/peaks-of-eternal-light/), NASA astrobiology magazine.

Frantseva, K., Mueller, M., ten Kate, I.L., van der Tak, F.F. and Greenstreet, S., 2018. [Delivery of organics to Mars through asteroid and comet impacts](https://arxiv.org/pdf/1803.03270.pdf). Icarus, 309, pp.125-133.

Franz, H.B., Mahaffy, P.R., Webster, C.R., Flesch, G.J., Raaen, E., Freissinet, C., Atreya, S.K., House, C.H., McAdam, A.C., Knudson, C.A. and Archer, P.D., 2020. [Indigenous and exogenous organics and surface–atmosphere cycling inferred from carbon and oxygen isotopes at Gale crater](http://www-personal.umich.edu/~atreya/Articles/indigenous.pdf). *Nature Astronomy*, *4*(5), pp.526-532.

Fraser, C.I., Terauds, A., Smellie, J., Convey, P. and Chown, S.L., 2014. [Geothermal activity helps life survive glacial cycles](https://www.pnas.org/content/111/15/5634#T1). Proceedings of the National Academy of Sciences, 111(15), pp.5634-5639. Press release [Volcanoes provided ice-age refuge for Antarctic biodiversity](https://www.antarctica.gov.au/magazine/issue-26-june-2014/science/volcanoes-provided-ice-age-refuge-for-antarctic-biodiversity/)

Freitas, R.A., and Zachary, W.B., 1981, May. [A self-replicating, growing lunar factory](http://www.rfreitas.com/Astro/GrowingLunarFactory1981.htm). In 4th Space manufacturing; Proceedings of the Fifth Conference (p. 3226).

Fuller, E.R. and Head III, J.W., 2002. Amazonis Planitia: [The role of geologically recent volcanism and sedimentation in the formation of the smoothest plains on Mars](https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2002JE001842). *Journal of Geophysical Research: Planets*, *107*(E10), pp.11-1.

*The geological environment and history of Amazonis Planitia also has astrobiological implications. The most recent of the lava flows associated with the emplacement of these plains have been dated as extremely young geologically (less than 24 million years old [*[*Hartmann and Berman, 2000*](https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2002JE001842#jgre1547-bib-0035)*]). If fossil or extant life existed at depth in the subsurface groundwater system at this time (a troglodytic fauna), it is highly likely that they would be among the material erupted to the surface during the cryosphere-cracking, dike-emplacement event (J. W. Head and L. Wilson, A model of simultaneous dike intrusion, cryospheric cracking, groundwater release and the eruption of lava: Examples from the Elysium Rise, Mars, manuscript in preparation, 2002), and washed down into Elysium and Amazonis Planitiae. The fate of such effluents under Mars conditions has recently been modeled [[Kreslavsky and Head, 2001](https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2002JE001842%22%20%5Cl%20%22jgre1547-bib-0054),* [*2002*](https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2002JE001842#jgre1547-bib-0055)*] and it has been shown that standing bodies of water at this scale would quickly freeze over and sublimate, leaving a sedimentary sublimation residue. Thus, Elysium and Amazonis Planitiae may be excellent locations to sample recently emplaced troglodytic faunal remains.*

Galletta, G., Bertoloni, G. and D'Alessandro, M., 2010. [Bacterial survival in Martian conditions](https://arxiv.org/abs/1002.4077). arXiv preprint arXiv:1002.4077.

Gannon, R., 1962. [Life in a Germfree World](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3477854/#f122). *Popular Science*, *90*.

Gaskin, J.A., Jerman, G., Gregory, D. and Sampson, A.R., 2012, March. [Miniature variable pressure scanning electron microscope for in-situ imaging & chemical analysis](https://ieeexplore.ieee.org/abstract/document/6187064/). In *Aerospace Conference, 2012 IEEE* (pp. 1-10). IEEE.

Georgiou, C.D., Zisimopoulos, D., Kalaitzopoulou, E. and Quinn, R.C., 2017. [Radiation-driven formation of reactive oxygen species in oxychlorine-containing Mars surface analogues](https://www.researchgate.net/profile/Christos-Georgiou-6/publication/316354998_Radiation-Driven_Formation_of_Reactive_Oxygen_Species_in_Oxychlorine-Containing_Mars_Surface_Analogues/links/592adae70f7e9b9979a9558e/Radiation-Driven-Formation-of-Reactive-Oxygen-Species-in-Oxychlorine-Containing-Mars-Surface-Analogues.pdf). *Astrobiology*, *17*(4), pp.319-336.

Gernhardt, M.L. and Abercromby, A.F., 2008. [Health and safety benefits of small pressurized suitport rovers as EVA surface support vehicles](https://web.archive.org/web/20100213221815/http%3A//ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080014281_2008013625.pdf).

Ghuneim, L.A.J., Jones, D.L., Golyshin, P.N. and Golyshina, O.V., 2018. [Nano-sized and filterable bacteria and archaea: biodiversity and function](https://www.frontiersin.org/articles/10.3389/fmicb.2018.01971/full). Frontiers in microbiology, 9, p.1971.

See section Selective Pressures for Small Size

Gibbons, J.G. and Rokas, A., 2013. [The function and evolution of the Aspergillus genome.](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/) *Trends in microbiology*, *21*(1), pp.14-22.

*Similarly, the top three most common human pathogens,* A. fumigatus, A. flavus *and* A. terreus*, do not group together in the* Aspergillus *family tree and all possess relatives that rarely, if ever, infect humans. This lack of association between lifestyle and evolutionary affinity is probably because many of the traits render fungi into potent pathogens, agricultural pests, or cell factories are likely features that are generally associated with the saprophytic lifestyle and selected for survival in conditions independent of their current roles in pathogenesis, pestilence, or biotechnology.*

*The advent of* Aspergillus *genomes has also augmented studies on understanding the regulation of SM gene clusters. One of the most interesting recent developments is the discovery that the velvet family of proteins, together with the global regulator* laeA *[*[*73*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R73)*], form a complex that links and coordinates SM production with morphological differentiation [*[*75*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R75)*,* [*76*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R76)*], which is in turn activated when a highly conserved signal transduction module receives the appropriate external environmental signals (*[*Figure 3*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/figure/F3/)*) [*[*77*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R77)*]. This coupling of SM with development presumably evolved because the protection offered by the deposition of SMs into the spores is vital to propagation [*[*76*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R76)*]. In line with this hypothesis,* A. nidulans *mutants deficient in the production of SMs are less toxic to their insect predators than the wild-type [*[*78*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R78)*]. However, SMs are not only important in predator avoidance; evidence that certain* Aspergillus *SM gene clusters are activated only when physically interacting with other microbes [*[*79*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R79)*], that SMs provide a competitive advantage [*[*80*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R80)*], as well as the discovery of self-protection genes nested within others [*[*81*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R81)*], suggest that SMs are also likely to be critical in interactions between* Aspergillus *and other microbes.*

*Additional support for the hypothesis that SMs are critical components of fungal–microbial interactions comes from a recent study aimed at identifying the molecular signature of domestication in* A. oryzae *[*[*7*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R7)*], one of the two fungi used in the making of sake in the last few millennia in the Far East. During sake making,* A. oryzae *is responsible for breaking down rice starch into simpler sugars, a process that occurs, to a large degree, in parallel with the conversion of sugars to alcohol by the brewer’s yeast* Saccharomyces cerevisiae*. In contrast to its wild relative* A. flavus*, the entire SM profile of* A. oryzae *is dramatically downregulated when grown on rice, including the gene clusters responsible for the synthesis of the mycotoxins aflatoxin and cyclopiazonic acid [*[*7*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R7)*]. Because aflatoxin, and presumably other SMs as well, is genotoxic to* S. cerevisiae *[*[*82*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R82)*] and its presence during fermentation would affect yeast survival and, consequently, sake making, the domestication process may have converted* A. oryzae *into a microbe that is ‘friendly’ to its other microbial co-inhabitants.*

*…*

*This dominance of* A. fumigatus *[as a human pathogen] is likely due to ecological traits, such as the high prevalence and buoyancy of its spores in the environment [*[*85*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R85)*], as well as genetic ones, such as the ability to grow well at 37°C and the coating of its spores with a hydrophobin that renders them immunologically inert [*[*86*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R86)*]*

Gilvarry, J.J., 1964a. [The possibility of a pristine lunar life](https://www.sciencedirect.com/science/article/abs/pii/0022519364900517). Journal of Theoretical Biology, 6(3), pp.325-346.

Gilvarry, J.J., 1964b. [The possibility of a primordial lunar life](https://books.google.co.uk/books?hl=en&lr=&id=t8zYBAAAQBAJ&oi=fnd&pg=PA179). in Mamikunian, G. and Briggs, M.H. eds., 2013. Current aspects of exobiology. Elsevier.

Glass, J.I., Assad-Garcia, N., Alperovich, N., Yooseph, S., Lewis, M.R., Maruf, M., Hutchison III, C.A., Smith, H.O. and Venter, J.C., 2006. [Essential genes of a minimal bacterium](https://www.pnas.org/doi/full/10.1073/pnas.0510013103). *Proceedings of the National Academy of Sciences*, *103*(2), pp.425-430.

Gleiser, M., Thorarinson, J. and Walker, S.I., 2008. [Punctuated chirality](https://arxiv.org/pdf/0802.1446.pdf). Origins of Life and Evolution of Biospheres, 38(6), pp.499-508.

Glenister, C. and Cameron, B., 2021. Paleoenvironmental Reconstruction of Glaciovolcanism in the Cascades of the Pacific Northwest: Implications of Potential Habitable Environments on Mars. In *Proceedings of the Wisconsin Space Conference* (Vol. 1, No. 1).

Goetz, W., Brinckerhoff, W.B., Arevalo, R., Freissinet, C., Getty, S., Glavin, D.P., Siljeström, S., Buch, A., Stalport, F., Grubisic, A. and Li, X., 2016. [MOMA: the challenge to search for organics and biosignatures on Mars. International Journal of Astrobiology](https://www.researchgate.net/publication/305311049_MOMA_The_challenge_to_search_for_organics_and_biosignatures_on_Mars), 15(3), pp.239-250

Gonçalves, D.D.S., Ferreira, M.D.S., Gomes, K.X., Rodríguez‐de La Noval, C., Liedke, S.C., da Costa, G.C.V., Albuquerque, P., Cortines, J.R., Saramago Peralta, R.H., Peralta, J.M. and Casadevall, A., 2019. [Unravelling the interactions of the environmental host Acanthamoeba castellanii with fungi through the recognition by mannose‐binding proteins](https://onlinelibrary.wiley.com/doi/full/10.1111/cmi.13066). *Cellular microbiology*, *21*(10), p.e13066.

Goodsell, D.S., 2004. [Catalase. Molecule of the Month](http://pdb101.rcsb.org/motm/57). RCSB Protein Data Bank. *Retrieved,(2007)-02-11*.

*Fortunately, cells make a variety of antioxidant enzymes to fight the dangerous side-effects of life with oxygen. Two important players are superoxide dismutase, which converts superoxide radicals into hydrogen peroxide, and catalase, which converts hydrogen peroxide into water and oxygen gas. The importance of these enzymes is demonstrated by their prevalence, ranging from about 0.1% of the protein in an Escherichia coli cell to upwards of a quarter of the protein in susceptible cell types. These many catalase molecules patrol the cell, counteracting the steady production of hydrogen peroxide and keeping it at a safe level.*

Gordon, E., Mouz, N., Duee, E. and Dideberg, O., 2000. [The crystal structure of the penicillin-binding protein 2x from Streptococcus pneumoniae and its acyl-enzyme form: implication in drug resistance](https://www.sciencedirect.com/science/article/pii/S0022283600937409). *Journal of molecular biology*, *299*(2), pp.477-485.

Gough, R.V., Rapin, W., Martínez, G.M., Meslin, P.Y., Gasnault, O., Schröder, S. and Wiens, R.C., 2020, March. [Possible Detection of Water Frost by the Curiosity Rover](https://www.hou.usra.edu/meetings/lpsc2020/pdf/2205.pdf). In Lunar and Planetary Science Conference (No. 2326, p. 2205).

Graham, J., 1993. [Risk in perespective: The legacy of one in a million](https://cdn1.sph.harvard.edu/wp-content/uploads/sites/1273/2013/06/The-Legacy-of-One-in-a-Million-March-1993.pdf). Harvard Center for Risk Analysis, Risk Perspective, 1, pp.1-2.

Greenberg, R. and Tufts, B.R., 2001. [Macroscope: Infecting Other Worlds](https://www.jstor.org/stable/27857494). *American Scientist*, *89*(4), pp.296-299.

Gronstall, A., 2014, [Liquid Water from Ice and Salt on Mars](https://www.astrobio.net/mars/liquid-water-ice-salt-mars/), NASA astrobiology magazine.

Gros, C., 2016. [Developing ecospheres on transiently habitable planets: the genesis project](https://link.springer.com/article/10.1007/s10509-016-2911-0). *Astrophysics and Space Science*, *361*(10), p.324.

Grotzinger, J.P., 2013. [Habitability, Taphonomy, and Curiosity's Hunt for Organic Carbon](https://www.planetary.org/blogs/guest-blogs/2013/20131221-habitability-taphonomy-and-curiositys-hunt-for-organic-carbon.html?referrer=http://www.quora.com/Is-Mars-worth-mining-for-Earth-purposes), Planetary Society.

Grotzinger, J.P., 2014. [Habitability, Organic Taphonomy, and the Sedimentary Record of Mars](https://www.hou.usra.edu/meetings/8thmars2014/pdf/1175.pdf). *LPICo*, *1791*, p.1175.

Groves, M., 2021, [A last-ditch attempt to find the Eungella gastric-brooding frog in the wild fails — but could they be cloned from extinction?](https://www.abc.net.au/news/rural/2021-11-15/eungella-gastric-brooding-frog-extinct-cloning-/100595258), ABC Rural

Hales, T.C., 1998. [An overview of the Kepler conjecture](https://arxiv.org/pdf/math/9811071.pdf). arXiv preprint math/9811071

Hales, T., Adams, M., Bauer, G., Dang, T.D., Harrison, J., Le Truong, H., Kaliszyk, C., Magron, V., McLaughlin, S., Nguyen, T.T. and Nguyen, Q.T., 2017. [A formal proof of the Kepler conjecture](https://www.cambridge.org/core/services/aop-cambridge-core/content/view/78FBD5E1A3D1BCCB8E0D5B0C463C9FBC/S2050508617000014a.pdf/a-formal-proof-of-the-kepler-conjecture.pdf). In *Forum of mathematics, Pi* (Vol. 5). Cambridge University Press.

Hamilton, C.W., Fagents, S.A. and Wilson, L., 2010. [Explosive lava‐water interactions in Elysium Planitia, Mars: Geologic and thermodynamic constraints on the formation of the Tartarus Colles cone groups](https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2009JE003546). *Journal of Geophysical Research: Planets*, *115*(E9).

Hancock, R.E. and Diamond, G., 2000. [The role of cationic antimicrobial peptides in innate host defences](http://www.cmdr.ubc.ca/bobh/wp-content/uploads/2016/10/227.-Hancock-2000.pdf). *Trends in microbiology*, *8*(9), pp.402-410.

Hancock, R.E. and Sahl, H.G., 2006. [Antimicrobial and host-defense peptides as new anti-infective therapeutic strategies](http://www.personal.psu.edu/kck11/blogs/bmb_498a_antibiotics_development_and_resistance/320_2006_NatureBiotech_24_p1551.pdf). *Nature biotechnology*, *24*(12), pp.1551-1557.

Hand, E., 2008, [Perchlorates found on Mars](https://doi.org/10.1038/news.2008.1016), Nature

Harris, D.R., Pollock, S.V., Wood, E.A., Goiffon, R.J., Klingele, A.J., Cabot, E.L., Schackwitz, W., Martin, J., Eggington, J., Durfee, T.J. and Middle, C.M., 2009. [Directed evolution of ionizing radiation resistance in Escherichia coli.](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2725583/) Journal of bacteriology, 191(16), pp.5240-5252.

*QUOTE We also examined the recovery of genomic DNA from CB1000 and CB2000 after exposure to 5,000 Gy of 137Cs (7.8 Gy/min) and compared this with the fate of genomic DNA in the founder strain. The acquired phenotype was evident in this experiment (Fig. ​(Fig.5).5). The DNA from the founder did not recover after this dose of radiation over a 9-hour time course. Even the fragmented DNA appeared to disappear with time, probably reflecting nuclease degradation. No growth of the irradiated cell culture was evident over a period of 9 h. In contrast, the genomic DNAs from CB1000 and CB2000 were repaired, with the normal NotI banding pattern clearly visible in the pulsed-field gel after 2 hours in both cases. Visible genome restoration appeared to peak after 3 to 4 h. The increase in genomic DNA was not due to growth of undamaged survivors. No increase in bacterial cell mass was evident in the cultures until 8 h and 5 h for CB1000 and CB2000, respectively. These results indicate that the genomic DNA was repaired well before the initiation of normal genome replication and cell division.*

*QUOTE One single colony isolate was taken from each of these populations, generating purified strains designated CB2000, CB3000, and CB4000. The founder, like other E. coli K-12 strains, is quite sensitive to IR; exposure to 3,000 Gy gamma radiation (60Co; 19 Gy/min) reduced the viability 4 orders of magnitude compared to that of the unirradiated culture (Fig. ​(Fig.2).2). The D37 value [37% survival] for CB1000 was 1,100 Gy, whereas the D37 value for CB2000 and CB3000 was 2,000 Gy—approximately threefold less than the D37 value measured for actively growing cultures of Deinococcus radiodurans R1 (41). The D37 value for the founder was 730 Gy. Higher doses of IR revealed a major improvement in resistance. CB1000, CB2000, and CB3000 exhibited 1,500- to 4,500-fold increases in survival relative to the founder after exposure to 3,000 Gy (Fig. ​(Fig.2).2). CB4000 was approximately 10-fold less radioresistant than the other isolates.*

*QUOTE 20 iterative cycles of irradiation and outgrowth. The length of each exposure was adjusted to kill >99% of the population, with this dose increasing from 2,000 Gy for the first cycle to 10,000 Gy on the last cycle*

Hartmann, W.K. and Daubar, I.J., 2017. Martian cratering 11. [Utilizing decameter scale crater populations to study Martian history.](https://onlinelibrary.wiley.com/doi/full/10.1111/maps.12807) *Meteoritics & Planetary Science*, *52*(3), pp.493-510.

Hassler, D.M., Zeitlin, C., Wimmer-Schweingruber, R.F., Ehresmann, B., Rafkin, S., Eigenbrode, J.L., Brinza, D.E., Weigle, G., Böttcher, S., Böhm, E. and Burmeister, S., 2014. [Mars’ surface radiation environment measured with the Mars Science Laboratory’s Curiosity rover](https://authors.library.caltech.edu/42648/1/RAD_Surface_Results_paper_SCIENCE_12nov13_FINAL.pdf). *science*, *343*(6169).

Hays, L.E., Graham, H.V., Des Marais, D.J., Hausrath, E.M., Horgan, B., McCollom, T.M., Parenteau, M.N., Potter-McIntyre, S.L., Williams, A.J. and Lynch, K.L., 2017. [Biosignature preservation and detection in Mars analog environments](https://www.liebertpub.com/doi/full/10.1089/ast.2016.1627). Astrobiology, 17(4), pp.363-400.

*Improved instrumentation on rovers that might detect and identify a diversity of potential in situ biosignatures, including ancient organic molecular biosignatures, designed with the ability to differentiate biotic and abiotic signals in micro- or macrostructures. Instrumentation could also be better attuned to the unique complications of biosignature preservation on Mars (e.g., deeper drilling to access potentially better preserved organics)*

*The fluorescence spectrometers on SHERLOC can detect condensed carbon and aromatic organics by deep UV-induced fluorescence, and SHERLOC's Raman spectrometer will allow classification of aromatic and aliphatic organics. Raman spectrometry can also be used to detect minerals relevant to aqueous chemistry. While these measurements would allow us to identify reduced carbon compounds, there may not be sufficient structural information to distinguish between a biological signal and extraterrestrial organic input.*

*A major knowledge gap that will directly impact our ability to choose an appropriate landing site is what terrestrial analog environments might look like—what the biosignature signals might be—if photosynthetic microorganisms had not evolved and instead the environments were only inhabited by chemosynthetic microorganisms*

*4.4. Strategies and priorities*

*In many of the environments discussed, there is a dichotomy between habitability and preservation—many of the conditions that make an environment more habitable are destructive to one or more of the biosignatures of interest. For example, fluid flow in the subsurface of hydrothermal environments helps create the redox gradients that support communities that inhabit the outflow channel. Fluids are also essential for lithification and the associated decrease in permeability essential for long-term preservation. Preservation is enhanced by rapid burial and mineral precipitation that encases and lithifies biological materials in less permeable matrices—in these cases, silica from hydrothermal environments, or silica-enriched aqueous environments, is an important material for preservation. However, these same fluids can degrade biosignatures such as mineralogy, chemistry, and micro- and macrostructures. One strategy for astrobiological exploration has to be to seek out a “sweet spot” where these two balance each other so that long-term preservation is possible. This sweet spot may occur as conditions change through time.*

Head, J.N., Melosh, H.J. and Ivanov, B.A., 2002. [Martian meteorite launch: High-speed ejecta from small craters](https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1945-5100.2002.tb01033.x). *Science*, *298*(5599), pp.1752-1756.

*Page 1355: Nishiizumi et al. (1986) found that all cosmogenic nuclide data indicate that the shergottites were ejected from>3 m depth. This conclusion was supported by Reedy (1989) stating that the Shergottite-Nakhdite-Chassignite group meteorites (SNCs), especially the shergottites, must have been buried >5 m in any previous parent object (corresponding to a shielding depth of >I500 glcm²)*

Hecht, M.H., Kounaves, S.P., Quinn, R.C., West, S.J., Young, S.M., Ming, D.W., Catling, D.C., Clark, B.C., Boynton, W.V., Hoffman, J. and DeFlores, L.P., 2009. [Detection of perchlorate and the soluble chemistry of martian soil at the Phoenix lander site](https://www.science.org/doi/abs/10.1126/science.1172466). *Science*, *325*(5936), pp.64-67.

Heim, N.A., Payne, J.L., Finnegan, S., Knope, M.L., Kowalewski, M., Lyons, S.K., McShea, D.W., Novack-Gottshall, P.M., Smith, F.A. and Wang, S.C., 2017. [Hierarchical complexity and the size limits of life](https://royalsocietypublishing.org/doi/full/10.1098/rspb.2017.1039). *Proceedings of the Royal Society B: Biological Sciences*, *284*(1857), p.20171039.

Heinz, P., Geslin\*, E. and Hemleben, C., 2005. [Laboratory observations of benthic foraminiferal cysts](https://www.researchgate.net/profile/Emmanuelle_Geslin/publication/235927029_Laboratory_observations_of_benthic_foraminiferal_cysts/links/55cb13f208aeca747d6a0083/Laboratory-observations-of-benthic-foraminiferal-cysts.pdf). *Marine Biology Research*, *1*(2), pp.149-159.

Hendrickson, R., Urbaniak, C., Minich, J.J., Aronson, H.S., Martino, C., Stepanauskas, R., Knight, R. and Venkateswaran, K., 2021. [Clean room microbiome complexity impacts planetary protection bioburden](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8643001/). *Microbiome*, *9*(1), pp.1-17.

Hendrix, A.R. and Yung, Y.L., 2017. [Energy Options for Future Humans on Tita](https://arxiv.org/ftp/arxiv/papers/1707/1707.00365.pdf)n. *arXiv preprint arXiv:1707.00365*.

Heppenheimer, T.A., 1977. [Colonies in Space](https://space.nss.org/colonies-in-space-chapter-2-our-life-in-space/).

Hoenigl, M., Seidel, D., Sprute, R., Cunha, C., Oliverio, M., Goldman, G.H., Ibrahim, A.S. and Carvalho, A., 2022. [COVID-19-associated fungal infections](https://www.nature.com/articles/s41564-022-01172-2). *Nature microbiology*, *7*(8), pp.1127-1140.

Specifically, clinical features and radiological findings of CAPA resemble those of severe COVID-19[2](https://www.nature.com/articles/s41564-022-01172-2#ref-CR2) and blood tests lack sensitivitydue to the invasive growth of *Aspergillus* in the airway and the clearance of *Aspergillus* galactomannan (GM) from systemic circulation by neutrophils in non-neutropenic patients

… *However, once CAPA becomes angioinvasive and produces positive serum GM, mortality is more than 80%, even if systemic antifungal therapy is provided*

*… Using these variable criteria, a median incidence of 20.1% (range 1.6–38%) was reported in patients with COVID-19 acute respiratory failure requiring invasive ventilation … bringing the prevalence of CAPA down to about 10% among invasively ventilated patients with COVID-19. However, incidence continues to vary widely between ICUs, due to non-uniform approaches to COVID-19 treatments, different burdens of Aspergillus exposure and differing diagnostic algorithms as well as genetic predisposing risk factors*

*… The combination of dexamethasone and tocilizumab, invasive ventilation and older age, have been reported as risk factors for developing CAPA*

*… Unlike influenza-associated pulmonary aspergillosis, CAPA develops later and is diagnosed a median of 8 days after ICU admission*

*… CAPA has been consistently associated with COVID-19 mortality rates of more than 50%*

Roh, J.S. and Sohn, D.H., 2018. [Damage-associated molecular patterns in inflammatory diseases](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6117512/). *Immune network*, *18*(4).

Hoff, B., Thomson, G. and Graham, K., 2007. [Ontario: Neurotoxic cyanobacterium (blue-green alga) toxicosis in Ontario](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1780230/). *The Canadian Veterinary Journal*, *48*(2), p.147.

Hogle, J.M., 2002. [Poliovirus cell entry: common structural themes in viral cell entry pathways](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1500891/). Annual Reviews in Microbiology, 56(1), pp.677-702.

Holson, D.A.. 2015, [Ackee Fruit Toxicity](https://emedicine.medscape.com/article/1008792-overview), Medscape - Emergency medicine

Holtcamp, W., 2012. [The emerging science of BMAA: do cyanobacteria contribute to neurodegenerative disease?.](https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.120-a110)*Environmental health perspectives*, *120*(3), pp.a110-a116.

Hopkins, J.B. and Pratt, W.D., 2011, September. [Comparison of Deimos and Phobos as destinations for human exploration, and identification of preferred landing sites](http://csc.caltech.edu/references/Hopkins-Phobos-Deimos-Paper.pdf). In *AIAA Space 2011 Conference & Exposition, Long Beach* (pp. 27-29).

Horvath, D.G., Moitra, P., Hamilton, C.W., Craddock, R.A. and Andrews-Hanna, J.C., 2021. [Evidence for geologically recent explosive volcanism in Elysium Planitia](https://arxiv.org/ftp/arxiv/papers/2011/2011.05956.pdf), Mars. Icarus, 365, p.114499.

*Stratigraphic relationships indicate a relative age younger than the surrounding volcanic plains and the Zunil impact crater (~0.1–1 Ma), with crater counting suggesting an absolute model age of 53 to 210 ka. This young age implies that if this deposit is of volcanic origin then the Cerberus Fossae region may not be extinct and Mars may still be volcanically active today.*

*…*

*Dike-induced melting of ground ice and hydrothermal circulation could generate favorable conditions for recent or even extant habitable environments in the subsurface. These environments would be analogous to locations on Earth where volcanic activity occurs in glacial environments such as Iceland, where chemotrophic and psychrophilic (i.e., cryophilic) bacteria thrive (Cousins & Crawford, 2011).*

Houtkooper, J.M. and Schulze-Makuch, D., 2006. [A possible biogenic origin for hydrogen peroxide on Mars: the Viking results reinterpreted](https://arxiv.org/ftp/physics/papers/0610/0610093.pdf). *arXiv preprint physics/0610093*.

Horne, W.H., Volpe, R.P., Korza, G., DePratti, S., Conze, I.H., Shuryak, I., Grebenc, T., Matrosova, V.Y., Gaidamakova, E.K., Tkavc, R. and Sharma, A., 2022. [Effects of Desiccation and Freezing on Microbial Ionizing Radiation Survivability: Considerations for Mars Sample Return.](https://www.liebertpub.com/doi/pdf/10.1089/AST.2022.0065?fbclid=IwAR3b2cGbAu_2Wu9bFHYTfUblARsZRIkFExalSwY5gSMDa2ubEGei7uNPobc) *Astrobiology*.

Hoshika, S., Leal, N.A., Kim, M.J., Kim, M.S., Karalkar, N.B., Kim, H.J., Bates, A.M., Watkins, N.E., SantaLucia, H.A., Meyer, A.J. and DasGupta, S., 2019. [Hachimoji DNA and RNA: A genetic system with eight building blocks](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6413494/). Science, 363(6429), pp.884-887

Hoyt, R.P. and Uphoff, C., 2000. [Cislunar tether transport system](http://www.niac.usra.edu/files/studies/final_report/7Hoyt.pdf). *Journal of Spacecraft and Rockets*, *37*(2), pp.177-186.

Hsu, J., 2009, [Keeping Mars Contained](https://web.archive.org/web/20200516104239/http%3A/www.astrobio.net/news-exclusive/keeping-mars-contained/), NASA Astrobiology Magazine.

Huesing, J., Sutherland, O., Geelen, K., Vijendran, S., Alves, J., Edwards Jr, C.D., Muirhead, B.K., Lock, R.E., Nicholas, A.K., Umland, J.W. and Nairouz, B., 2019. [Engineering the Earth Return Orbiter Concept for a potential Mars Sample Return Campaign](https://www.hou.usra.edu/meetings/ninthmars2019/pdf/6347.pdf). *LPICo*, *2089*, p.6347.)

Hussein, H.S. and Brasel, J.M., 2001. [Toxicity, metabolism, and impact of mycotoxins on humans and animals](http://higiene.unex.es/bibliogr/micotoxi/T1000101.pdf). *Toxicology*, *167*(2), pp.101-134.

*The worldwide contamination of foods and feeds with mycotoxins is a significant problem. Mycotoxins are secondary metabolites of molds that have adverse effects on humans, animals, and crops that result in illnesses and economic losses.*

*Aflatoxins, ochratoxins, trichothecenes, zearelenone, fumonisins, tremorgenic toxins, and ergot alkaloids are the mycotoxins of greatest agro-economic importance. … Mycotoxins have various acute and chronic effects on humans and animals (especially monogastrics) depending on species and susceptibility of an animal within a species.*

*…*

*Mycotoxins are secondary metabolites that have no biochemical significance in fungal growth and development*

*These toxins account for millions of dollars annually in losses world-wide in human health, animal health, and condemned agricultural products.*

Huwe, B., Fiedler, A., Moritz, S., Rabbow, E., de Vera, J.P. and Joshi, J., 2019. [Mosses in low Earth orbit: implications for the limits of life and the habitability of Mars](https://scholar.google.com/scholar?cluster=10502930596394515836&hl=en&as_sdt=0,5). *Astrobiology*, *19*(2), pp.221-232

Inmarsat, 2013, [Successful launch confirmed for Inmarsat’s first Global Xpress satellite (Inmarsat-5 F1)](https://www.inmarsat.com/en/news/latest-news/corporate/2013/successful-launch-confirmed-inmarsats-first-global-xpress-satellite-inmarsat-5-f1.html)

Jakosky, B.M. and Edwards, C.S., 2017, March. [Can Mars Be Terraformed?](https://www.hou.usra.edu/meetings/lpsc2017/pdf/1193.pdf). In *48th Annual Lunar and Planetary Science Conference* (No. 1964, p. 1193).

Jakosky, B., Amato, M., Atreya, S., Des Marais, D., Mahaffy, P., Mumma, M., Tolbert, M., Toon, B., Webster, C. and Zurek, R., 2021. [Scientific value of returning an atmospheric sample from Mars](https://assets.pubpub.org/fljl7iiz/51617915355905.pdf). Bulletin of the AAS, 53(4).

Jankovic, J., 2004. [Botulinum toxin in clinical practice](https://jnnp.bmj.com/content/75/7/951.share). *Journal of Neurology, Neurosurgery & Psychiatry*, *75*(7), pp.951-957.

Johansson, M., 2006. [Living in Space: A Comparative Study of one Conventional Life Support System and two Biological Systems](https://www.diva-portal.org/smash/get/diva2%3A460979/FULLTEXT01.pdf).

Johnson, R.D. and Holbrow, C.H. eds., 1977. *[Space settlements: A design study](https://books.google.co.uk/books?id=PGih0tcJb1MC&source=gbs_navlinks_s)* (Vol. 413). Scientific and Technical Information Office, National Aeronautics and Space Administ

*[Page 175:](https://books.google.co.uk/books?id=PGih0tcJb1MC&pg=PA175&source=gbs_selected_pages&cad=2" \l "v=onepage&q&f=false) "At all distances out to the orbit of Pluto and beyond, it is possible to obtain Earth-normal solar intensity with a concentrating mirror whose mass is small compared to that of the habitat.”*

Johnstone, J., 2017, [Starling](https://commons.wikimedia.org/wiki/File%3AStarling_-_Flickr_-_TrotterFechan.jpg), Wikimedia Commons

Joyce, G.F., 2007. [A glimpse of biology's first enzyme](https://science.sciencemag.org/content/315/5818/1507.full). Science, 315(5818), pp.1507-1508.

JPL, 2006, NASA Findings Suggest Jets Bursting From Martian Ice Cap

JPL, 2016, NASA Weighs Use of Rover to Image Potential Mars Water Sites

JPL, 2021, [SHERLOC’S view of Organics Within Garde Abrasion Patch](https://www.jpl.nasa.gov/images/pia25042-sherlocs-view-of-organics-within-garde-abrasion-patch)

JPL, 2022, [NASA’s InSight Lander Detects Stunning Meteoroid Impact on Mars](https://www.jpl.nasa.gov/news/nasas-insight-lander-detects-stunning-meteoroid-impact-on-mars)

Jung, P., Baumann, K., Lehnert, L.W., Samolov, E., Achilles, S., Schermer, M., Wraase, L.M., Eckhardt, K.U., Bader, M.Y., Leinweber, P. and Karsten, U., 2020. [Desert breath—How fog promotes a novel type of soil biocenosis, forming the coastal Atacama Desert’s living skin](https://onlinelibrary.wiley.com/doi/pdfdirect/10.1111/gbi.12368). *Geobiology*, *18*(1), pp.113-124.

Jung, P., Lehnert, L.W., Bendix, J., Lentendu, G., Grube, M., Alfaro, F.D., Del Río, C., Luis, J., Van Den Brink, L. and Lakatos, M., 2022. [The grit crust: A poly-extremotolerant microbial community from the Atacama Desert as a model for astrobiology](https://www.frontiersin.org/articles/10.3389/fspas.2022.1052278/full), *Frontiers in Astronomy and Space Sciences*, p.342.

Kakoi, M., Howell, K.C. and Folta, D., 2014. [Access to Mars from Earth–Moon libration point orbits: manifold and direct options](https://ntrs.nasa.gov/api/citations/20150000152/downloads/20150000152.pdf). *Acta Astronautica*, *102*, pp.269-286.

Kalil, 2014, [Bootstrapping a Solar System Civilization](https://obamawhitehouse.archives.gov/blog/2014/10/14/bootstrapping-solar-system-civilization), White House

Kapoor, G., Saigal, S. and Elongavan, A., 2017. [Action and resistance mechanisms of antibiotics: A guide for clinicians](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5672523/). *Journal of anaesthesiology, clinical pharmacology*, *33*(3), p.300

KEGG, n.d., [Metabolic pathways – Chroococcidiopsis thermalis](https://www.genome.jp/kegg-bin/show_pathway?cthe01100+Chro_2988), Kyoto Encyclopedia of Genes and Genomes*.*

Kelly, K.E. and Cardon, N.C., 1991. [The Myth of 10-6 as a Definition of Acceptable Risk: Or," in Hot Pursuit of Superfund's Holy Grail".](https://www.heartland.org/publications-resources/publications/the-myth-of-10-6-as-a-definition-of-acceptable-risk) Environmental Toxicology International, Incorporated.

Kerwick, T.B., 2012. [Colonizing Jupiter's Moons: An Assessment of Our Options and Alternatives](http://www.environmental-safety.webs.com/Galileo_WaS_Journal.pdf). *Journal of the Washington Academy of Sciences*, pp.15-26.

Kiang, 2007, [The Color of Life, on Earth and on Extrasolar Planets](https://web.archive.org/web/20160118212625/https%3A//www.giss.nasa.gov/research/briefs/kiang_01/), NASA science briefs

Kieffer, H.H., Christensen, P.R. and Titus, T.N., 2006. [CO2 jets formed by sublimation beneath translucent slab ice in Mars' seasonal south polar ice cap](https://www.researchgate.net/profile/Timothy-Titus/publication/6873114_CO2_jets_formed_by_sublimation_beneath_translucent_slab_ice_in_Mars%27_South_Seasonal_Polar_Ice_Cap/links/0046351f41835f0bef000000/CO2-jets-formed-by-sublimation-beneath-translucent-slab-ice-in-Mars-South-Seasonal-Polar-Ice-Cap.pdf). *Nature*, *442*(7104), pp.793-796.

Kim, H.J., Kim, H.N., Raza, H.S., Park, H.B. and Cho, S.O., 2016. [An intraoral miniature X-ray tube based on carbon nanotubes for dental radiography.](https://www.sciencedirect.com/science/article/pii/S1738573316000437) *Nuclear Engineering and Technology*, *48*(3), pp.799-804.*,*

The dose rate of the X-ray at 3-cm apart from the miniature X-ray tube in air was 8.19 Gy/min at 0° when the X-ray tube was operated at 50 kV with the emission beam current of 140 μA.*.*

*[This corresponds to 7 watts of power output]*

X-rays are almost perfectly blocked when the thickness of the copper collimator is 3 mm

Kim, J.P., Kim, J.H., Kim, J., Lee, S.N. and Park, H.O., 2016. [A nanofilter composed of carbon nanotube-silver composites for virus removal and antibacterial activity improvement.](https://www.sciencedirect.com/science/article/abs/pii/S1001074215004180) Journal of Environmental Sciences, 42, pp.275-283.

King, G.M., 2015. [Carbon monoxide as a metabolic energy source for extremely halophilic microbes: implications for microbial activity in Mars regolith](https://www.pnas.org/doi/full/10.1073/pnas.1424989112). *Proceedings of the National Academy of Sciences*, *112*(14), pp.4465-4470.

King, H., n.d., [Mohs Hardness Scale](https://geology.com/minerals/mohs-hardness-scale.shtml), Geology.com

Kirst, H., Formighieri, C. and Melis, A., 2014. [Maximizing photosynthetic efficiency and culture productivity in cyanobacteria upon minimizing the phycobilisome light-harvesting antenna size](https://www.sciencedirect.com/science/article/pii/S0005272814005362). *Biochimica et Biophysica Acta (BBA)-Bioenergetics*, *1837*(10), pp.1653-1664.

Kleidon, A., 2002. [Testing the effect of life on Earth's functioning: how Gaian is the Earth system?](https://link.springer.com/content/pdf/10.1023/A%3A1014213811518.pdf). *Climatic Change*, *52*(4), pp.383-389.

Klingler, J.M., Mancinelli, R.L. and White, M.R., 1989. [Biological nitrogen fixation under primordial Martian partial pressures of dinitrogen](http://www.ncbi.nlm.nih.gov/pubmed/11537369). *Advances in Space Research*, *9*(6), pp.173-176.

Kminek, G. and Bada, J.L., 2006. [The effect of ionizing radiation on the preservation of amino acids on Mars](https://www.researchgate.net/profile/Jeffrey_Bada/publication/222819214_The_effect_of_ionizing_radiation_on_the_preservation_of_amino_acids_on_Mars/links/5c1c0f61299bf12be38eedf5/The-effect-of-ionizing-radiation-on-the-preservation-of-amino-acids-on-Mars.pdf). *Earth and Planetary Science Letters*, *245*(1-2), pp.1-5.

Kminek, G., Benardini, J.N., Brenker, F.E., Brooks, T., Burton, A.S., Dhaniyala, S., Dworkin, J.P., Fortman, J.L., Glamoclija, M., Grady, M.M. and Graham, H.V., 2022. [COSPAR Sample Safety Assessment Framework (SSAF)](https://doi.org/10.1089/ast.2022.0017).

Kok, J.F., 2010. [Difference in the wind speeds required for initiation versus continuation of sand transport on Mars: Implications for dunes and dust storms.](https://arxiv.org/ftp/arxiv/papers/1002/1002.1346.pdf) Physical Review Letters, 104(7), p.074502.

Korr, M., 2020. [Mary Mallon: First Asymptomatic Carrier of Typhoid Fever](https://search.proquest.com/openview/b536a8e243370d01edfceccee5aab225/1?pq-origsite=gscholar&cbl=24126). Rhode Island Medical Journal, 103(4), pp.73-73.

Kosaka, T., Nakajima, Y., Ishii, A., Yamashita, M., Yoshida, S., Murata, M., Kato, K., Shiromaru, Y., Kato, S., Kanasaki, Y. and Yoshikawa, H., 2019. [Capacity for survival in global warming: adaptation of mesophiles to the temperature upper limit](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0215614#pone-0215614-t001). *PLoS One*, *14*(5), p.e0215614.

Kremic, T. and Hunter, G.W., 2021. [Long-lived in-Situ solar system explorer (LLISSE) Potential Contributions to solar system Exploration](https://assets.pubpub.org/fhm6bv7l/21617915343249.pdf). Bulletin of the American Astronomical Society, 53(4), p.151.

Krisko, A. and Radman, M., 2013. [Biology of extreme radiation resistance: the way of Deinococcus radiodurans](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3685888/). *Cold Spring Harbor perspectives in biology*, *5*(7), p.a012765.

Kronstad, J., Saikia, S., Nielson, E.D., Kretschmer, M., Jung, W., Hu, G., Geddes, J.M., Griffiths, E.J., Choi, J., Cadieux, B. and Caza, M., 2012. [Adaptation of Cryptococcus neoformans to mammalian hosts: integrated regulation of metabolism and virulence](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3272904/). *Eukaryotic cell*, *11*(2), pp.109-118.

Kumar, V., van de Veerdonk, F.L. and Netea, M.G., 2018. [Antifungal immune responses: emerging host–pathogen interactions and translational implications](https://link.springer.com/article/10.1186/s13073-018-0553-2). Genome medicine, 10(1), pp.1-3.

Kun, Á., 2021. [Maintenance of Genetic Information in the First Ribocell](http://real.mtak.hu/139999/1/RibozymeBook-AdamKun-05.pdf). Ribozymes, 1, pp.387-417.

Kunzig, R., 2010, [Making Mars the New Earth](https://web.archive.org/web/20100128104618/http%3A/ngm.nationalgeographic.com/big-idea/07/mars)

Kurokawa, H., Kuroda, T., Aoki, S. and Nakagawa, H., 2022. [Can we constrain the origin of Mars' recurring slope lineae using atmospheric observations?.](https://www.sciencedirect.com/science/article/pii/S0019103521003444) *Icarus*, *371*, p.114688.

Kwong, J., Norris, S.D., Hopkins, J.B., Buxton, C.J., Pratt, W.D. and Jones, M.R., 2011, September. [Stepping stones: exploring a series of increasingly challenging destinations on the way to mars](https://arc.aiaa.org/doi/abs/10.2514/6.2011-7216). In *AIAA Space 2011 Conference, Long Beach, CA* (pp. 27-29).

Lackey, K.A., Williams, J.E., Meehan, C.L., Zachek, J.A., Benda, E.D., Price, W.J., Foster, J.A., Sellen, D.W., Kamau-Mbuthia, E.W., Kamundia, E.W. and Mbugua, S., 2019. [What's normal? Microbiomes in human milk and infant feces are related to each other but vary geographically: the INSPIRE study](https://www.frontiersin.org/articles/10.3389/fnut.2019.00045/full). Frontiers in nutrition, 6, p.45.

Lanagan, P.D., McEwen, A.S., Keszthelyi, L.P. and Thordarson, T., 2001. [Rootless cones on Mars indicating the presence of shallow equatorial ground ice in recent times](https://agupubs.onlinelibrary.wiley.com/doi/pdfdirect/10.1029/2001GL012932). *Geophysical Research Letters*, *28*(12), pp.2365-2367.

Landis, G.A., 2003, January. [Colonization of Venus](http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20030022668_2003025525.pdf). In *AIP conference proceedings* (Vol. 654, No. 1, pp. 1193-1198). American Institute of Physics.

Latgé, J.P., 1999. [Aspergillus fumigatus and aspergillosis](https://scholar.google.com/scholar_url?url=http://cmr.asm.org/content/12/2/310.full&hl=en&sa=T&oi=gsb-gga&ct=res&cd=0&ei=0sS-WovXCMK1mAGjh5LQBw&scisig=AAGBfm1LpPRudw3-i5PXvXsD6H1BB4pWpQ). *Clinical microbiology reviews*, *12*(2), pp.310-350.

Lederberg, J., 1999a. [Paradoxes of the host-parasite relationship](https://profiles.nlm.nih.gov/spotlight/bb/catalog/nlm%3Anlmuid-101584906X19509-doc). *ASM News*, *65*(12).

Lederberg, J., 1999b. [Parasites face a perpetual dilemma](https://profiles.nlm.nih.gov/spotlight/bb/catalog/nlm%3Anlmuid-101584906X19508-doc). *ASM News*, *65*(2).

Lenardon, M.D., Munro, C.A. and Gow, N.A., 2010. [Chitin synthesis and fungal pathogenesis](https://www.sciencedirect.com/science/article/pii/S1369527410000639). *Current opinion in microbiology*, *13*(4), pp.416-423.

Lerner, L, 2019, [Salt deposits on Mars hold clues to sources of ancient water](https://news.uchicago.edu/story/salt-deposits-mars-hold-clues-sources-ancient-water), University of Chicago news.

Lesage, E., Massol, H., Howell, S.M. and Schmidt, F., 2022. [Simulation of Freezing Cryomagma Reservoirs in Viscoelastic Ice Shells](https://iopscience.iop.org/article/10.3847/PSJ/ac75bf/meta). *The Planetary Science Journal*, *3*(7), p.170.

Leshin, L.A., 2002, May. Sample Collection for Investigation of Mars (SCIM): [Mars Sample Return Within This Decade](https://ui.adsabs.harvard.edu/abs/2002AGUSM.P51A..11L/abstract). In AGU Spring Meeting Abstracts (Vol. 2002, pp. P51A-11).

Levin, G.V. and Ann Straat, P., 1976. [Labeled release—an experiment in radiorespirometry](https://web.archive.org/web/20110925190951/http%3A/www.gillevin.com%3A80/Mars/Reprint78-labelrel-files/Reprint78-labrelea.htm). *Origins of Life*, *7*(3), pp.293-311.

Levin, G.V. and Straat, P.A., 2016. [The case for extant life on Mars and its possible detection by the Viking labelled release experiment](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6445182/). *Astrobiology*, *16*(10), pp.798-810.

Levine, J.S., 2020. [Lunar Dust and Its Impact on Human Exploration: Identifying the Problems.](https://www.lpi.usra.edu/announcements/artemis/whitepapers/2012.pdf) *The Impact of Lunar Dust on Human Exploration*, *2141*, p.5007. .

Levy, M. and Miller, S.L., 1998. [The stability of the RNA bases: implications for the origin of life](http://www.pnas.org/content/pnas/95/14/7933.full.pdf). *Proceedings of the National Academy of Sciences*, *95*(14), pp.7933-7938.

Li, C., Zhang, X., Ye, T., Li, X. and Wang, G., 2022. [Protection and Damage Repair Mechanisms Contributed To the Survival of Chroococcidiopsis sp. Exposed To a Mars-Like Near Space Environment](https://journals.asm.org/doi/pdf/10.1128/spectrum.03440-22). Microbiology Spectrum, 10(6), pp.e03440-22.

Li, J., Mara, P., Schubotz, F., Sylvan, J.B., Burgaud, G., Klein, F., Beaudoin, D., Wee, S.Y., Dick, H.J., Lott, S. and Cox, R., 2020. [Recycling and metabolic flexibility dictate life in the lower oceanic crust](https://par.nsf.gov/servlets/purl/10149187). *Nature*, *579*(7798), pp.250-255.

Lindensmith, C.A., Rider, S., Bedrossian, M., Wallace, J.K., Serabyn, E., Showalter, G.M., Deming, J.W. and Nadeau, J.L., 2016. [A submersible, off-axis holographic microscope for detection of microbial motility and morphology in aqueous and icy environments](http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0147700). *PloS one*, *11*(1), p.e0147700.

Lingam, M., 2021. [Theoretical constraints imposed by gradient detection and dispersal on microbial size in astrobiological environments](https://arxiv.org/pdf/2102.05009.pdf). *Astrobiology*, *21*(7), pp.813-830.

Lippincott, M., n.d., [Solar Thermal Atmospheric Research Station (STARS) Proposals, 1978-1982](https://www.headfullofair.com/post/stars/)

Liston, G.E. and Winther, J.G., 2005. [Antarctic surface and subsurface snow and ice melt fluxes](https://brage.npolar.no/npolar-xmlui/bitstream/handle/11250/174146/2005%20liston%20JCLIM.pdf?sequence=1). *Journal of Climate*, *18*(10), pp.1469-1481.

Liu, J., Li, B., Wang, Y., Zhang, G., Jiang, X. and Li, X., 2019. [Passage and community changes of filterable bacteria during microfiltration of a surface water supply](https://www.sciencedirect.com/science/article/pii/S016041201930772X). *Environment international*, *131*, p.104998

Liu K., 2016, [Dendritic Cells](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7148618/). Encyclopedia of Cell Biology

Liu, J., Michalski, J.R. and Zhou, M.F., 2021. [Intense subaerial weathering of eolian sediments in Gale crater](https://www.science.org/doi/10.1126/sciadv.abh2687), Mars. *Science Advances*, *7*(32), p.eabh2687.

Lock, R.E., Bailey, Z.J., Kowalkowski, T.D., Nilsen, E.L. and Mattingly, R.L., 2014, March. [Mars Sample Return Orbiter Concepts Using Solar Electric Propulsion for the Post-Mars 2020 Decade](https://www.researchgate.net/profile/Zachary_Bailey/publication/269300438_Mars_Sample_Return_Orbiter_concepts_using_Solar_Electric_Propulsion_for_the_post-Mars2020_decade/links/55955d6708ae21086d206431.pdf). In *2014 IEEE Aerospace Conference* (pp. 1-10). IEEE.

Los Angeles Fire Department, 2018, [*“Smoke alarm saves residents of a Bel Air home”*](https://www.flickr.com/photos/lafd/40194010602)

Łoś, J.M., Łoś, M., Węgrzyn, A. and Węgrzyn, G., 2013. [Altruism of Shiga toxin-producing Escherichia coli: recent hypothesis versus experimental results](file://C:\\Users\\rober\\Documents\\booklets\\autorecovered\\Łoś, J.M., Łoś, M., Węgrzyn, A. and Węgrzyn, G., 2013. Altruism of Shiga toxin-producing Escherichia coli: recent hypothesis versus experimental results. Frontiers in cellular and infection microbiology, 2, p.166.). *Frontiers in cellular and infection microbiology*, *2*, p.166.

*Although STEC strains produce virulence factors and cause severe symptoms in infected humans, they might be assessed as non-classical human pathogens. This is because human-to-human transmission of STEC is relatively rare outside of an outbreak situation and therefore is probably insufficient to sustain populations of these bacteria*

Losiak, A. and Velbel, M.A., 2011. [Evaporite formation during weathering of Antarctic meteorites––A weathering census analysis based on the ANSMET database](https://onlinelibrary.wiley.com/doi/full/10.1111/j.1945-5100.2010.01166.x). *Meteoritics & Planetary Science*, *46*(3), pp.443-458.

Losiak, A., Czechowski, L. and Velbel, M.A., 2014, September. [Ice Melting by Radiantly Heated Dust Grains on the Martian Northern Pole](https://www.hou.usra.edu/meetings/metsoc2014/pdf/5314.pdf). In *77th Annual Meeting of the Meteoritical Society* (Vol. 77, No. 1800, p. 5314).

Madariaga-Mazón, A., Hernández-Alvarado, R.B., Noriega-Colima, K.O., Osnaya-Hernández, A. and Martinez-Mayorga, K., 2019. [Toxicity of secondary metabolites](https://www.researchgate.net/publication/335275132_Toxicity_of_secondary_metabolites/link/5e2b37fc92851c3aadd7bcbf/download). *Physical Sciences Reviews*, *4*(12).

Magana-Arachchi, D.N. and Wanigatunge, R.P., 2013. [First report of genus Chroococcidiopsis (cyanobacteria) from Sri Lanka: a potential threat to human health](https://scholar.google.com/scholar?cluster=7725054431080211508). *Journal of the national science foundation of Sri Lanka*, *41*(1).

Maki, T., Lee, K.C., Kawai, K., Onishi, K., Hong, C.S., Kurosaki, Y., Shinoda, M., Kai, K., Iwasaka, Y., Archer, S.D. and Lacap‐Bugler, D.C., 2019. [Aeolian dispersal of bacteria associated with desert dust and anthropogenic particles over continental and oceanic surfaces](https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018JD029597). Journal of Geophysical Research: Atmospheres, 124(10), pp.5579-5588.

Mancinelli, R.L., 1993, personal communication with D. Thomas at NASA Ames Research center, cited in Thomas, D., 1995, [Biological aspects of the ecopoesis and terraformation of Mars: Current perspectives and research](https://s3.amazonaws.com/academia.edu.documents/5281196/1995_Thomas_48_415-418.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1522874944&Signature=G4jffUdXqwiHPq6YNKyAxkSWANg%3D&response-content-disposition=inline%3B%20filename%3DBiological_aspects_of_the_ecopoeisis_and.pdf), Journal of the British Interplanetary Society, vol 48, pp 415 – 418,

*“Additional unpublished research revealed nitrogen fixation by a variety of microorganisms at pN of 0.2 mbar – the current partial pressure of nitrogen in the Mars atmosphere.”*

Mangus, S. and Larsen, W., 2004. [*Lunar Receiving Laboratory Project History*](http://tomrchambers.com/CR-2004-208938.pdf) (No. NASA/CR-2004-208938).

Mann, A., 2012, [Almost Being There: Why the Future of Space Exploration Is Not What You Think](https://www.wired.com/2012/11/telerobotic-exploration/), Wired

Mantel, N. and Bryan, W.R., 1961[. “Safety” testing of carcinogenic agents](https://academic.oup.com/jnci/article-abstract/27/2/455/907154?redirectedFrom=PDF). Journal of the National Cancer Institute, 27(2), pp.455-470.

Marinova, M.M., McKay, C.P. and Hashimoto, H., 2005. [Radiative‐convective model of warming Mars with artificial greenhouse gases](https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2004JE002306). *Journal of Geophysical Research: Planets*, *110*(E3).

Martínez, J.L., 2012[. Natural antibiotic resistance and contamination by antibiotic resistance determinants: the two ages in the evolution of resistance to antimicrobials](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3257838/). Frontiers in microbiology, 3, p.1.

Martínez, G.M. and Renno, N.O., 2013. [Water and brines on Mars: current evidence and implications for MSL](https://link.springer.com/article/10.1007/s11214-012-9956-3). *Space Science Reviews*, *175*(1-4), pp.29-51. Section numbers refer to the pdf rather than the online html version of the article.

Martín-Torres, F.J., Zorzano, M.P., Valentín-Serrano, P., Harri, A.M., Genzer, M., Kemppinen, O., Rivera-Valentin, E.G., Jun, I., Wray, J., Madsen, M.B. and Goetz, W., 2015. [Transient liquid water and water activity at Gale crater on Mars.](https://www.nature.com/articles/ngeo2412) Nature Geoscience, 8(5), p.357. Summary:  ["Evidence of liquid water found on Mars (BBC)](http://www.bbc.co.uk/news/science-environment-32287609). NASA press release: [NASA Mars Rover's Weather Data Bolster Case for Brine](https://www.nasa.gov/jpl/msl/nasa-mars-rovers-weather-data-bolster-case-for-brine) and University of Copenhagen press release, [Mars might have liquid water](https://www.nbi.ku.dk/english/news/news15/mars-might-have-liquid-water/)

Mattingly, R, 2010, [Mission Concept Study, Planetary Science Decadal Survey, MSR Orbiter Mission (Including Mars Returned Sample Handling)](https://www.nap.edu/resource/13117/App%20G%2008_Mars-Sample-Return-Orbiter.pdf)

Maus, D., Heinz, J., Schirmack, J., Airo, A., Kounaves, S.P., Wagner, D. and Schulze-Makuch, D., 2020. [Methanogenic archaea can produce methane in deliquescence-driven Mars analog environments](https://www.nature.com/articles/s41598-019-56267-4). *Scientific Reports*, *10*(1), p.6.

*Our results show that M. soligelidi is an especially suitable model organism for studying how microbial life could thrive in Martian environments that are subject to deliquescence producing conditions. Considering the UV radiation and freeze-thawing tolerance of M. soligelidi, this organism is in principle well adapted to conditions expected to be prevalent within the salty shallow subsurface at RSL locations on Mars. Although UV radiation tolerance would not be necessary within the shallow subsurface, it would be crucial for aeolian-driven dispersion. Other studies have shown that methanogenic archaea can also withstand Mars-like conditions such as pressures of 50 to 400 mbar or three weeks of simulated Martian thermal conditions*

Maxmen, A., 2010. [Virus-like particles speed bacterial evolution](https://www.nature.com/news/2010/100930/full/news.2010.507.html). *Nature doi*:*10.1038/news.2010.507*

Mayo clinic, n.d., [Kaposi Sarcoma](https://www.mayoclinic.org/diseases-conditions/kaposis-sarcoma/cdc-20387726)

McCormick, A., Loeffler, J. and Ebel, F., 2010. [Aspergillus fumigatus: contours of an opportunistic human pathogen](https://onlinelibrary.wiley.com/doi/full/10.1111/j.1462-5822.2010.01517.x). *Cellular microbiology*, *12*(11), pp.1535-1543

McDaniel, L.D., Young, E., Delaney, J., Ruhnau, F., Ritchie, K.B. and Paul, J.H., 2010. [High frequency of horizontal gene transfer in the oceans](https://www.researchgate.net/profile/Kim-Ritchie/publication/47369923_High_Frequency_of_Horizontal_Gene_Transfer_in_the_Oceans/links/5578554908ae752158703436/High-Frequency-of-Horizontal-Gene-Transfer-in-the-Oceans.pdf). *Science*, *330*(6000), pp.50-50.

McDonald, M.J., 2019. [Microbial experimental evolution–a proving ground for evolutionary theory and a tool for discovery](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6680118/). EMBO reports, 20(8), p.e46992.

McKay, C.P., 2009. [Planetary ecosynthesis on Mars: restoration ecology and environmental ethics. *Exploring the origin, extent, and future of life*](https://esseacourses.strategies.org/EcosynthesisMcKay2008ReviewAAAS.pdf)*: Philosophical, ethical, and theological perspectives*, pp.245-260.

McEwen, A.S., Ojha, L., Dundas, C.M., Mattson, S.S., Byrne, S., Wray, J.J., Cull, S.C., Murchie, S.L., Thomas, N. and Gulick, V.C., 2011. [Seasonal flows on warm Martian slopes](http://science.sciencemag.org/content/333/6043/740). *Science*, *333*(6043), pp.740-743.

McEwen, A.S., Schaefer, E.I., Dundas, C.M., Sutton, S.S., Tamppari, L.K. and Chojnacki, M., 2021. [Mars: Abundant recurring slope lineae (RSL) following the Planet‐Encircling Dust Event (PEDE) of 2018](https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020JE006575). *Journal of Geophysical Research: Planets*, *126*(4), p.e2020JE006575.

MacGregor, D.G. and Race, M., 2001. [Microbiologists’ Perceptions of Planetary Protection](https://scholarsbank.uoregon.edu/xmlui/bitstream/handle/1794/20638/458.pdf?sequence=1).

McGuire, M.L., Borowski, S.K., Mason, L.M. and Gilland, J., 2003. [High power MPD nuclear electric propulsion (NEP) for artificial gravity HOPE missions to Callisto](https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20040005901.pdf).

McKay, C.P. and Marinova, M.M., 2001. The physics, biology, and environmental ethics of making Mars habitable. *Astrobiology*, *1*(1), pp.89-109.

McMahon, S., Bosak, T., Grotzinger, J.P., Milliken, R.E., Summons, R.E., Daye, M., Newman, S.A., Fraeman, A., Williford, K.H. and Briggs, D.E.G., 2018. [A field guide to finding fossils on Mars](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6049883/#jgre20942-sec-0011title). Journal of Geophysical Research: Planets, 123(5), pp.1012-1040.

McSween, H.Y., 1997. [Evidence for life in a Martian meteorite?](https://www.geosociety.org/gsatoday/archive/7/7/pdf/i1052-5173-7-7-1.pdf). Geological Society of America.

Mégarbane, B., Borron, S.W. and Baud, F.J., 2005. [Current recommendations for treatment of severe toxic alcohol poisonings.](https://www.semanticscholar.org/paper/Current-recommendations-for-treatment-of-severe-M%C3%A9garbane-Borron/2634afbfda7553fb76f78b5dd827145bebe9fcba) Intensive care medicine, 31(2), pp.189-195.

Melis, A., 2009. [Solar energy conversion efficiencies in photosynthesis: minimizing the chlorophyll antennae to maximize efficiency](https://ehsanzadeh.iut.ac.ir/sites/ehsanzadeh.iut.ac.ir/files/files_course/rue-antennae2009.pdf). *Plant science*, *177*(4), pp.272-280.

Meltzer, M., 2007. [Mission to Jupiter: a history of the Galileo project](https://history.nasa.gov/sp4231.pdf). *NASA STI/Recon Technical Report N*, *7*.

Meltzer, M., 2012. [When Biospheres Collide: A History of NASA's Planetary Protection Programs](https://www.nasa.gov/pdf/607072main_WhenBiospheresCollide-ebook.pdf). Government Printing Office, After Splashdown: Plans To Safely Transport the Apollo Astronauts, Command Module, and Samples to the Recovery Ship, Page 217 and following

Meringer, M., Cleaves, H.J. and Freeland, S.J., 2013. [Beyond terrestrial biology: Charting the chemical universe of α-amino acid structures](https://pubs.acs.org/doi/abs/10.1021/ci400209n). Journal of chemical information and modeling, 53(11), pp.2851-2862.

Merino, N., Aronson, H.S., Bojanova, D.P., Feyhl-Buska, J., Wong, M.L., Zhang, S. and Giovannelli, D., 2019. [Living at the extremes: extremophiles and the limits of life in a planetary context](https://www.frontiersin.org/articles/10.3389/fmicb.2019.00780/full#T4). *Frontiers in microbiology*, *10*, p.780.

Metzger, P.T., Muscatello, A., Mueller, R.P. and Mantovani, J., 2013. Affordable, rapid bootstrapping of the space industry and solar system civilization. *Journal of Aerospace Engineering*, *26*(1), pp.18-29.

Meyer, E.L., Jenkins, C. and Rengarajan, K., 2019. [NIH guidelines April 2019](https://www.liebertpub.com/doi/pdf/10.1177/1535676019871146). *Applied Biosafety*, *24*(4), pp.179-181.

*If an air incinerator is used in lieu of the second high efficiency particulate air/HEPA filter, it shall be biologically challenged to prove all viable test agents are sterilized. The biological challenge must be minimally 1x108 organisms per cubic foot of airflow through the incinerator. . Test spores meeting this criterion are Bacillus subtilis var. niger or Bacillus stearothermophilus. The operating temperature of the incinerator shall be continuously monitored and recorded during use*

Michalski, J., 2021, [Curious results from the Mars stratigraphy rover](https://astronomycommunity.nature.com/posts/curious-results-from-the-mars-stratigraphy-rover), Nature Portfolio Astronomy community

Miedaner, T. and Geiger, H.H., 2015. [Biology, genetics, and management of ergot (Claviceps spp.) in rye, sorghum, and pearl millet](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379517/). *Toxins*, *7*(3), pp.659-678.

Miller, J.D., Straat, P.A. and Levin, G.V., 2002, February. [Periodic analysis of the Viking lander Labelled Release experiment](http://www.gillevin.com/Mars/Reprint119-Miller-Straat-Levin-FINAL_files/Reprint119-Miller-Straat-Levin-FINAL.htm). In *Instruments, Methods, and Missions for Astrobiology IV* (Vol. 4495, pp. 96-108). International Society for Optics and Photonics.

Miller, R., 2006, [PIA08660: Sand-Laden Jets (Artist's Concept), JPL](https://photojournal.jpl.nasa.gov/catalog/PIA08660)

Ming, X. and Shijie, X., 2009. [Exploration of distant retrograde orbits around Moon](http://ming). *Acta Astronautica*, *65*(5-6), pp.853-860.

Minton, K.W., 1994. [DNA repair in the extremely radioresistant bacterium Deinococcus radiodurans](https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1365-2958.1994.tb00397.x). Molecular microbiology, 13(1), pp.9-15.

Miteva, V.I. and Brenchley, J.E., 2005. [Detection and isolation of ultrasmall microorganisms from a 120,000-year-old Greenland glacier ice core](https://aem.asm.org/content/aem/71/12/7806.full.pdf). *Applied and Environmental Microbiology*, *71*(12), pp.7806-7818.

Möhlmann, D., 2005. [Adsorption water-related potential chemical and biological processes in the upper Martian surface](https://www.researchgate.net/publication/7390930_Adsorption_Water-Related_Potential_Chemical_and_Biological_Processes_in_the_Upper_Martian_Surface#pf3). *Astrobiology*, *5*(6), pp.770-777.

Möhlmann, D.T.F., 2009, June. [Liquid Interfacial and Melt-Water in the Upper Sub-Surface of Mars](https://www.lpi.usra.edu/meetings/hydrous2009/pdf/4001.pdf). In Workshop on Modeling Martian Hydrous Environments (Vol. 1482, p. 48).

Möhlmann, D.T., 2010. [Temporary liquid water in upper snow/ice sub-surfaces on Mars](https://www.sciencedirect.com/science/article/abs/pii/S0019103509004539?via%3Dihub)?. *Icarus*, *207*(1), pp.140-148. New Scientist story [Watery niche may foster life on Mars](https://www.newscientist.com/article/mg20427373-700-watery-niche-may-foster-life-on-mars/)

Mojarro, A., Hachey, J., Tani, J., Smith, A., Bhattaru, S., Pontefract, A., Doebler, R., Brown, M., Ruvkun, G., Zuber, M.T. and Carr, C.E., 2016, October. [SETG: nucleic acid extraction and sequencing for in situ life detection on Mars](https://www.hou.usra.edu/meetings/ipm2016/pdf/4095.pdf). In *3rd International Workshop on Instrumentation for Planetary Mission* (Vol. 1980).

Mosca, C., Rothschild, L.J., Napoli, A., Ferré, F., Pietrosanto, M., Fagliarone, C., Baqué, M., Rabbow, E., Rettberg, P. and Billi, D., 2019. [Over-expression of UV-damage DNA repair genes and ribonucleic acid persistence contribute to the resilience of dried biofilms of the desert cyanobacetrium Chroococcidiopsis exposed to Mars-like UV flux and long-term desiccation](https://www.frontiersin.org/articles/10.3389/fmicb.2019.02312/full#ref51). Frontiers in microbiology, 10, p.2312.

*Dried-rewetted biofilms and dried-UV-irradiated-rewetted biofilms were tested for respiration by monitoring the INT reduction by dehydrogenases after 72 h of rehydration. The INT staining revealed 30 and 10% of alive cells with insoluble red formazan spots in the cytoplasm of dried-rewetted biofilms and dried-UV-irradiated-rewetted biofilms, respectively,*

*After 7 years of air-drying, Chroococcidiopsis not only avoided genome degradation but preserved at least a sub-set of mRNAs and 16S ribosomal RNA.*

*... In the present work, the occurrence of survivors in dried biofilms and dried-UV-irradiated biofilms was proved by growth after transfer into liquid BG-11 medium (not shown) and by INT reduction after 72 h of rewetting.*

*Reshaping the boundaries of Chroococcidiopsis desiccation and UV tolerance has implications in the search for extra-terrestrial life since it contributes to defining the habitability of Mars and planets orbiting other stars. In fact, the UV dose used here corresponds to that of a few hours at Mars’s equator (Cockell et al., 2000). Hence, considering that survivors occurred in the bottom layers of the biofilms (Baqué et al., 2013), it might be hypothesized that if a biofilm life form ever appeared during Mars’s climatic history, it might have been transported in a dried state under UV radiation, from niches that had become unfavorable to niches that were inhabitable (Westall et al., 2013). The reported survival also suggests that intense UV radiation fluxes would not prevent the presence of phototrophic biofilms or their colonizing of the landmass of other planets.*

Moskalenko, G. , 1981, [Airship for Venus](https://epizodyspace-ru.translate.goog/bibl/n_i_j/1981/9/9-dir.html?_x_tr_sch=http&_x_tr_sl=auto&_x_tr_tl=en&_x_tr_hl=en-US&_x_tr_pto=wapp), Science and life, No. 9, pp85-87

Moyer, C.L. and Morita, R.Y., 2007. [Psychrophiles and psychrotrophs](https://fire.biol.wwu.edu/cmoyer/research/Moyer%20etal%20psychrophiles_rmls17.pdf). *Encyclopedia of life sciences*, *1*(6).

Mulkidjanian A.Y. (2015) [Abiotic Photosynthesis](https://link.springer.com/referenceworkentry/10.1007/978-3-662-44185-5_4). In: Gargaud, M., Amils, R. and Cleaves, H.J. eds., 2011. Encyclopedia of astrobiology (Vol. 1). Springer Science & Business Media.

Muñoz-Dorado, J., Marcos-Torres, F.J., García-Bravo, E., Moraleda-Muñoz, A. and Pérez, J., 2016. [Myxobacteria: moving, killing, feeding, and surviving together](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4880591/). *Frontiers in microbiology*, *7*, p.781.

Murray, D.H., Pilmanis, A.A., Blue, R.S., Pattarini, J.M., Law, J., Bayne, C.G., Turney, M.W. and Clark, J.B., 2013. [Pathophysiology, prevention, and treatment of ebullism](https://www.researchgate.net/profile/Jonathan-Clark-10/publication/235754706_Pathophysiology_Prevention_and_Treatment_of_Ebullism/links/57cf6ffb08ae057987ac0dcc/Pathophysiology-Prevention-and-Treatment-of-Ebullism.pdf). Aviation, space, and environmental medicine, 84(2), pp.89-96.

Mykytczuk, N.C., Wilhelm, R.C. and Whyte, L.G., 2012. Planococcus halocryophilus sp. nov., an extreme sub-zero species from high Arctic permafrost. *International journal of systematic and evolutionary microbiology*, *62*(Pt\_8), pp.1937-1944.

Mykytczuk, N., Foote, S.J., Omelon, C.R., Southam, G., Greer, C.W. and Whyte, L.G., 2013. [Bacterial growth at− 15 C; molecular insights from the permafrost bacterium Planococcus halocryophilus Or1](https://www.nature.com/articles/ismej20138#Fig2). *The ISME journal*, *7*(6), pp.1211-1226.

Nakagawa, S., Takaki, Y., Shimamura, S., Reysenbach, A.L., Takai, K. and Horikoshi, K., 2007. [Deep-sea vent ε-proteobacterial genomes provide insights into emergence of pathogens](https://pubmed.ncbi.nlm.nih.gov/17615243/). Proceedings of the National Academy of Sciences, 104(29), pp.12146-12150.

Nanjaraj Urs, A.N., Hu, Y., Li, P., Yuchi, Z., Chen, Y. and Zhang, Y., 2018. [Cloning and expression of a nonribosomal peptide synthetase to generate blue rose](https://pubs.acs.org/doi/abs/10.1021/acssynbio.8b00187). ACS Synthetic Biology, 8(8), pp.1698-1704

NASA, 1967, [Comprehensive Biological Protocol for the Lunar Sample Receiving Laboratory](https://ntrs.nasa.gov/citations/19680021536)

NASA, 1995, photograph [AS11-40-5927](https://www.history.nasa.gov/alsj/a11/AS11-40-5927HR.jpg) from [Apollo 11 image library](https://www.history.nasa.gov/alsj/a11/images11.html).

NASA, 1997, PIA00571: [Ice on Mars Utopia Planitia Again](https://photojournal.jpl.nasa.gov/catalog/PIA00571)

NASA, 2004, [The Vision for Space Exploration](https://www.nasa.gov/pdf/55583main_vision_space_exploration2.pdf)

NASA, 2007, [Extreme Planet Takes Its Toll](https://mars.nasa.gov/mer/spotlight/20070612.html)

*Temperatures in the shade for Spirit ranged from highs of about 35 degrees C. (95 degrees F.) in summer to lows of -90 degrees C. (-130 degrees F.) in winter.*

NASA, 2008, [Morning Frost on the Surface of Mars](https://www.nasa.gov/multimedia/imagegallery/image_feature_1160.html)

NASA, 2011, [Are Water Plumes Spraying From Europa? NASA's Europa Clipper Is on the Case](https://europa.nasa.gov/news/40/are-water-plumes-spraying-from-europa-nasas-europa-clipper-is-on-the-case/)

NASA, 2012, [Telerobotics Could vHelp Humanity Explore Space](https://sservi.nasa.gov/articles/telerobotics-could-help-humanity-explore-space/)

NASA, 2014, [A Spectacular New Martian Impact Crater](https://www.nasa.gov/jpl/mro/martian-impact-crater-pia17932)

*The crater is at 3.7 degrees north latitude, 53.4 degrees east longitude on Mars.  Before-and-after imaging that brackets appearance dates of fresh craters on Mars has indicated that impacts producing craters at least 12.8 feet (3.9 meters) in diameter occur at a rate exceeding 200 per year globally. Few of the scars are as dramatic in appearance as this one.*

NASA, 2016hmossf, [How Mold on Space Station Flowers is Helping Get Us to Mars](https://www.nasa.gov/mission_pages/station/research/news/flowers)

NASA, 2017rgc, [Remembering Gene Cernan](https://www.nasa.gov/astronautprofiles/cernan/).

NASA, 2016, [NASA Rover's Sand-Dune Studies Yield Surprise](https://www.jpl.nasa.gov/news/nasa-rovers-sand-dune-studies-yield-surprise)

NASA, 2022, [Mars Perseverance Sol 361: Left Navigation Camera (Navcam)](https://mars.nasa.gov/mars2020/multimedia/raw-images/NLG_0361_0698997520_847ECM_N0110000NCAM00527_00_2I4J)

NASA, 2022, [NASA Study Suggests Shallow Lakes in Europa's Icy Crust Could Erupt](file:///C%3A%5CUsers%5Crober%5CDocuments%5Cbooklets%5Cautorecovered%5CNASA%20Study%20Suggests%20Shallow%20Lakes%20in%20Europa%27s%20Icy%20Crust%20Could%20Erupt)

NASA, 2019, [Moon’s South Pole in NASA’s Landing Sites](https://www.nasa.gov/feature/moon-s-south-pole-in-nasa-s-landing-sites)

NASA, 2022, [MSR Campaign Programmatic EIS, DRAFT Mars Sample Return (MSR) Campaign Programmatic Environmental Impact Statement](https://www.regulations.gov/document/NASA-2022-0002-0176)

NASA, 2022, [Mars Lander Missions](https://www.giss.nasa.gov/tools/mars24/help/landers.html)

NASA, 2022, [Perseverance's First 2 Regolith Samples](https://mars.nasa.gov/resources/27161/perseverances-first-2-regolith-samples/)

NASA, n.d.ame, [Atmosphere](https://marsed.asu.edu/mep/atmosphere), Mars Education

NASA, n.d.cm, [Chris McKay, at NASA Ames](https://www.nasa.gov/content/chris-mckay/)

NASA, n.d., [Centrifuge Rotor](https://iss.jaxa.jp/iss/contribution/issjpdoc3_2_e.html) [biology experiment on the ISS]

NASA, n.d., [HOTTech](https://www1.grc.nasa.gov/space/pesto/space-vehicle-technologies-current/high-operating-temperature-technology-hottech/)

NASA, n.d., [Health Stabilization Program V1 4.4.2.4](https://www.nasa.gov/sites/default/files/atoms/files/health_stabilization_program_technical_brief_ochmo_021020.pdf)

NASA, n.d., Mars fact sheet

NASA, n.d., [Martian seasons and solar longitude](http://www-mars.lmd.jussieu.fr/mars/time/solar_longitude.html)

NASA, n.d., [Perseverance Sample Tube 266](https://mars.nasa.gov/resources/26218/perseverance-sample-tube-266/)

NASA, n.d. [Searching for Frost at Jezero Crater](https://mars.nasa.gov/mars2020/mission/status/404/searching-for-frost-at-jezero-crater/)

NASA, n.d., [Starting HAVOC for a Venus Exploration Concept, featuring Dale Arney and Chris Jones](https://sacd.larc.nasa.gov/smab/havoc/)

NASA, n.d., [Where is Curiosity](https://mars.nasa.gov/msl/mission/where-is-the-rover/)

Nausman, R., n.d., [Source Evaluation, a quick guide to CRAAP](https://hundreddayinitiative.files.wordpress.com/2021/05/craap-guide.pdf)

National Center for Biotechnology Information., n.d. PubChem Compound Summary for CID 2724488, L-Glucose. <https://pubchem.ncbi.nlm.nih.gov/compound/L-Glucose>. Accessed Jan. 27, 2023.

Navale, V., Vamkudoth, K.R., Ajmera, S. and Dhuri, V., 2021. [Aspergillus derived mycotoxins in food and the environment: Prevalence, detection, and toxicity](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8363598/). *Toxicology reports*, *8*, pp.1008-1030.

Navarro‐González, R., Vargas, E., de La Rosa, J., Raga, A.C. and McKay, C.P., 2010. [Reanalysis of the Viking results suggests perchlorate and organics at midlatitudes on Mars](https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2010JE003599). *Journal of Geophysical Research: Planets*, *115*(E12).

Negi, S., Perrine, Z., Friedland, N., Kumar, A., Tokutsu, R., Minagawa, J., Berg, H., Barry, A.N., Govindjee, G. and Sayre, R., 2020. [Light regulation of light‐harvesting antenna size substantially enhances photosynthetic efficiency and biomass yield in green algae](https://lodgbot.com/wp-content/uploads/2020/05/13May20-The-Plant-Journal-Algae-photosynthesis-improvement.pdf). *The Plant Journal*.

Neveu, M., Anbar, A.D., Davila, A.F., Glavin, D.P., MacKenzie, S.M., Phillips-Lander, C.M., Sherwood, B., Takano, Y., Williams, P. and Yano, H., 2020. [Returning samples from Enceladus for life detection](https://www.frontiersin.org/articles/10.3389/fspas.2020.00026/full). *Frontiers in Astronomy and Space Sciences*, *7*, p.26.

Newman, C.E., De La Torre Juarez, M., Pla-García, J., Wilson, R.J., Lewis, S.R., Neary, L., Kahre, M.A., Forget, F., Spiga, A., Richardson, M.I. and Daerden, F., 2021. [Multi-model meteorological and aeolian predictions for Mars 2020 and the Jezero crater region](https://link.springer.com/article/10.1007/s11214-020-00788-2). *Space science reviews*, *217*, pp.1-68.

NOAA, n.d.  [Can we clean up, stop, or end harmful algal blooms?](https://oceanservice.noaa.gov/facts/hab-solutions.html)

Noell, A.C., Fisher, A.M., Takano, N., Fors-Francis, K., Sherrit, S. and Grunthaner, F., 2016, October. Astrobionibbler: [In Situ Microfluidic Subcritical Water Extraction of Amino Acids](https://www.hou.usra.edu/meetings/ipm2016/pdf/4059.pdf). In *3rd International Workshop on Instrumentation for Planetary Mission* (Vol. 1980).

*anets*, *106*(E10), pp.23317-23326.

Nott, J., 2009. [Titan: a distant but enticing destination for human visitor](https://www.researchgate.net/publication/26883114_Titan_A_Distant_But_Enticing_Destination_for_Human_Visitors)s. *Aviation, space, and environmental medicine*, *80*(10), pp.900-901.

Oleson, S.R., Landis, G.A., McGuire, M.L. and Schmidt, G.R., 2013. [HERRO mission to Mars using telerobotic surface exploration from orbit](https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20130011281.pdf)

Ort, D.R., Merchant, S.S., Alric, J., Barkan, A., Blankenship, R.E., Bock, R., Croce, R., Hanson, M.R., Hibberd, J.M., Long, S.P. and Moore, T.A., 2015. [Redesigning photosynthesis to sustainably meet global food and bioenergy demand](https://www.pnas.org/content/pnas/112/28/8529.full.pdf). *Proceedings of the national academy of sciences*, *112*(28), pp.8529-8536.

*page 8530: A principal limitation of efficient photosynthesis is that organisms absorb more light in full sunlight than they can use productively. The reason seems clear: high absorptivity provides effective capture at low light intensities, such as at dawn and dusk and on cloudy days, and it obviates competition from other phototrophs by absorbing the light before they do.*

Osman, S., Peeters, Z., La Duc, M.T., Mancinelli, R., Ehrenfreund, P. and Venkateswaran, K., 2008. [Effect of shadowing on survival of bacteria under conditions simulating the Martian atmosphere and UV radiation](http://aem.asm.org/content/74/4/959.full). *Applied and Environmental Microbiology*, *74*(4), pp.959-970.

Pacelli, C., Selbmann, L., Zucconi, L., De Vera, J.P., Rabbow, E., Horneck, G., de la Torre, R. and Onofri, S., 2017. [BIOMEX experiment: ultrastructural alterations, molecular damage and survival of the fungus Cryomyces antarcticus after the experiment verification tests](https://www.researchgate.net/publication/299542317_BIOMEX_Experiment_Ultrastructural_Alterations_Molecular_Damage_and_Survival_of_the_Fungus_Cryomyces_antarcticus_after_the_Experiment_Verification_Tests). Origins of Life and Evolution of Biospheres, 47(2), pp.187-202.

Paige, D.A., 2000, July. [Mars exploration strategies: Forget about sample return](http://www.lpi.usra.edu/meetings/robomars/pdf/6199.pdf). In *Concepts and Approaches for Mars Exploration* (p. 243)

Pan, Z., Pitt, W.G., Zhang, Y., Wu, N., Tao, Y. and Truscott, T.T., 2016. [The upside-down water collection system of Syntrichia caninervis](https://www.researchgate.net/profile/Ye-Tao/publication/303828699_The_upside-down_water_collection_system_of_Syntrichia_caninervis/links/584e5ec208aecb6bd8cb8833/The-upside-down-water-collection-system-of-Syntrichia-caninervis.pdf). *Nature plants*, *2*(7), pp.1-5. See [Supplementary Information](https://www.nature.com/articles/nplants201676#Sec7) for the videos.

Parro, V., de Diego-Castilla, G., Moreno-Paz, M., Blanco, Y., Cruz-Gil, P., Rodríguez-Manfredi, J.A., Fernández-Remolar, D., Gómez, F., Gómez, M.J., Rivas, L.A. and Demergasso, C., 2011. [A microbial oasis in the hypersaline Atacama subsurface discovered by a life detector chip: implications for the search for life on Mars](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3242637/). *Astrobiology*, *11*(10), pp.969-996.

Paulussen, C., Hallsworth, J.E., Álvarez‐Pérez, S., Nierman, W.C., Hamill, P.G., Blain, D., Rediers, H. and Lievens, B., 2017. [Ecology of aspergillosis: insights into the pathogenic potency of Aspergillus fumigatus and some other Aspergillus species](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5328810/table/mbt212367-tbl-0002/). *Microbial biotechnology*, *10*(2), pp.296-322.

Peplow, M., 2016. [Mirror-image enzyme copies looking-glass DNA](https://www.nature.com/articles/nature.2016.19918). *Nature News*, *533*(7603), p.303.

Peschel, A. and Sahl, H.G., 2006. [The co-evolution of host cationic antimicrobial peptides and microbial resistance](https://www.nature.com/articles/nrmicro1441). *Nature Reviews Microbiology*, *4*(7), pp.529-536.

*Several bacterial pathogens can resist certain CAMPs to some extent by, for example, proteolytic cleavage, CAMP-specific binding or extrusion mechanisms, or by modifications to the bacterial surface that reduce the affinity for CAMPs.*

Pfliegler, W.P., Pócsi, I., Győri, Z. and Pusztahelyi, T., 2020. [The Aspergilli and their mycotoxins: Metabolic interactions with plants and the soil biota](https://www.frontiersin.org/articles/10.3389/fmicb.2019.02921/full). *Frontiers in microbiology*, *10*, p.2921.

Pla-García, J., Rafkin, S.C.R., Martinez, G.M., Vicente-Retortillo, Á., Newman, C.E., Savijärvi, H., de la Torre, M., Rodriguez-Manfredi, J.A., Gómez, F., Molina, A. and Viúdez-Moreiras, D., 2020. [Meteorological predictions for Mars 2020 Perseverance rover landing site at Jezero crater](https://link.springer.com/article/10.1007/s11214-020-00763-x). *Space science reviews*, *216*(8), pp.1-21..

Planetary Society, n.d., [Mars calendar](https://www.planetary.org/articles/mars-calendar)

Pikuta, E.V., Menes, R.J., Bruce, A.M., Lyu, Z., Patel, N.B., Liu, Y., Hoover, R.B., Busse, H.J., Lawson, P.A. and Whitman, W.B., 2016. [Raineyella antarctica gen. nov., sp. nov., a psychrotolerant, d-amino-acid-utilizing anaerobe isolated from two geographic locations of the Southern Hemisphere](http://riquim.fq.edu.uy/archive/files/6dc14dcd6641d2e6d706d6f3e5923446.pdf). *International journal of systematic and evolutionary microbiology*, *66*(12), pp.5529-5536.

Pires, F. 2015, [“Mars liquid water: Curiosity confirms favorable conditions”](http://ns.umich.edu/new/releases/22815-mars-liquid-water-curiosity-confirms-favorable-conditions), Michigan news.

*"Life as we know it needs liquid water to survive. While the new study interprets Curiosity's results to show that microorganisms from Earth would not be able to survive and replicate in the subsurface of Mars, Rennó sees the findings as inconclusive. He points to biofilms—colonies of tiny organisms that can make their own microenvironment.*

Preston, L., Grady, M. and Barber, S., 2013. [CAFE-Concepts for Activities in the Field for Exploration– TN2: The Catalogue of Planetary Analogues](https://esamultimedia.esa.int/docs/gsp/The_Catalogue_of_Planetary_Analogues.pdf).

Priya, M., Haridas, A. and Manilal, V.B., 2008. [Anaerobic protozoa and their growth in biomethanation systems](https://www.researchgate.net/profile/Manilal-Vattackatt/publication/6340284_Anaerobic_protozoa_and_their_growth_in_biomethanation_systems/links/5434d7e30cf2dc341daf542d/Anaerobic-protozoa-and-their-growth-in-biomethanation-systems.pdf). *Biodegradation*, *19*(2), pp.179-185.

Puente-Sánchez, F., Arce-Rodríguez, A., Oggerin, M., García-Villadangos, M., Moreno-Paz, M., Blanco, Y., Rodríguez, N., Bird, L., Lincoln, S.A., Tornos, F. and Prieto-Ballesteros, O., 2018. [Viable cyanobacteria in the deep continental subsurface](https://www.pnas.org/doi/full/10.1073/pnas.1808176115). *Proceedings of the National Academy of Sciences*, *115*(42), pp.10702-10707.

[Pusey, C., 2012,](https://commons.wikimedia.org/wiki/File%3A1DNA.gif) DNA groove animation based on PDB [1DNH](http://www.rcsb.org/structure/1DNH)

Quinn, R.C., Martucci, H.F., Miller, S.R., Bryson, C.E., Grunthaner, F.J. and Grunthaner, P.J., 2013. [Perchlorate radiolysis on Mars and the origin of Martian soil reactivity](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3691774/). *Astrobiology*, *13*(6), pp.515-520

Race, M. S., 1996, [Planetary Protection, Legal Ambiguity, and the Decision Making Process for Mars Sample Return](https://web.archive.org/web/20100619123320/http%3A//salegos-scar.montana.edu/docs/Planetary%20Protection/AdvSpaceResVol18%281-2%29.pdf) Adv. Space Res. vol 18 no 1/2 pp (1/2)345-(1/2)350.

Raffensperger, C., 1998, [The Wingspread Consensus Statement on the Precautionary Principle](https://web.archive.org/web/20010622225811/http%3A/www.sehn.org/wing.html)

Ramachandran, A.V., Zorzano, M.P. and Martín-Torres, J., 2021. [Experimental Investigation of the Atmosphere-Regolith Water Cycle on Present-Day Mars](https://aura.abdn.ac.uk/bitstream/handle/2164/17597/Ramachandran_etal_MDPI_Experimental_Investigation_Of_VoR.pdf?sequence=1). *Sensors*, *21*(21), p.7421.

Randolph, R. 2009, [Chapter 10, A Christian Perspective](https://books.google.co.uk/books?id=TljowmgtdcYC&pg=PA292), in Bertka, C.M. ed., 2009. Exploring the Origin, Extent, and Future of Life: Philosophical, Ethical and Theological Perspectives (Vol. 4),. Cambridge University Press.

Rennó, N.O., Bos, B.J., Catling, D., Clark, B.C., Drube, L., Fisher, D., Goetz, W., Hviid, S.F., Keller, H.U., Kok, J.F. and Kounaves, S.P., 2009. [Possible physical and thermodynamical evidence for liquid water at the Phoenix landing site](https://agupubs.onlinelibrary.wiley.com/doi/pdfdirect/10.1029/2009JE003362). *Journal of Geophysical Research: Planets*, *114*(E1).

See also first announcement before the paper was published: Michigan Engineering, 2009 (March 25), [Liquid saltwater is likely present on Mars, new analysis shows](https://news.umich.edu/liquid-saltwater-is-likely-present-on-mars-new-analysis-shows/) and earlier in Astronomy magazine on March 17th. [Liquid saltwater is likely present on Mars](https://astronomy.com/news/2009/03/liquid-saltwater-is-likely-present-on-mars), Astronomy magazine

Renno, N., 2014, [How liquid water forms on Mars](https://www.youtube.com/watch?v=iLWv9UGwjdE), YouTube video, [University of Michigan Engineering](https://www.youtube.com/channel/UCSvOdBJgMnTYsK-cZIGZSYQ) (transcript from [1:48 onwards](https://youtu.be/iLWv9UGwjdE?t=108))

Richmond, J.Y. and McKinney, R.W., 2000. [Primary containment for biohazards: selection, installation and use of biological safety cabinets](https://www.who.int/ihr/training/laboratory_quality/3_cd_rom_bsc_selection_use_cdc_manual.pdf).

Rodriguez, J.A.P., Fairén, A.G., Tanaka, K.L., Zarroca, M., Linares, R., Platz, T., Komatsu, G., Miyamoto, H., Kargel, J.S., Yan, J. and Gulick, V., 2016. [Tsunami waves extensively resurfaced the shorelines of an early Martian ocean](https://www.nature.com/articles/srep25106). *Scientific reports*, *6*(1), pp.1-8.

Rodriguez-Manfredi, J.A., De la Torre Juárez, M., Alonso, A., Apéstigue, V., Arruego, I., Atienza, T., Banfield, D., Boland, J., Carrera, M.A., Castañer, L. and Ceballos, J., 2021. [The Mars Environmental Dynamics Analyzer, MEDA. A suite of environmental sensors for the Mars 2020 mission](https://link.springer.com/article/10.1007/s11214-021-00816-9). *Space science reviews*, *217*(3), pp.1-86.

Roehl, T., 2016 [Characteristics of Phylum Chytridiomycota](https://www.fungusfactfriday.com/014-characteristics-of-phylum-chytridiomycota/)

Rohrlack, T., Christiansen, G. and Kurmayer, R., 2013. [Putative antiparasite defensive system involving ribosomal and nonribosomal oligopeptides in cyanobacteria of the genus Planktothrix](https://drive.google.com/file/d/138tv9P-Ywj-Mb5B2MNghLqrTDlS0_Coa/view). *Applied and environmental microbiology*, *79*(8), pp.2642-2647.

Rothschild, A., 2017, [Meet the Gastric Brooding Frog](https://www.youtube.com/watch?v=9xfX_NTrFRM), [PBS](https://www.pbs.org/video/meet-gastric-brooding-frog-ombnou/)

Rowland, M.L., 2010, [Role-playing in the worlds of Stanley Q. Weinbaum's 1930s science fiction](https://www.forgottenfutures.com/game/ff11/html/ffxi.htm)

Rookmelder, 2007*[Smoke detector.JPG – Wikimedia Commons](https://commons.wikimedia.org/wiki/File%3ASmoke_detector.JPG)*

Rucker, M., 2017. [Dust storm impacts on human Mars mission equipment and operations.](https://core.ac.uk/download/pdf/84914099.pdf)

Rummel, J., Race, M., Nealson, K., 2000. ["No Threat? No Way"](https://www.planetary.org/planetary-report/tpr-2000-6), The Planetary Report Nov/Dec. Contains:

* ***A Case for Caution*** by John Rummel, NASA'S planetary protection officer at the time, and previously, NASA senior scientist for Astrobiology
* ***Hazardous Until Proven Otherwise***, by Margaret Race, a biologist working on planetary protection and Mars sample return for the SETI Institute and specialist in environment impact analysis

***Practical Safe Science*** by Kenneth Nealson, Director of the Center of Life Detection at NASA's JPL at the time.

Rummel, J.D., Race, M.S., DeVinenzi, D.L., Schad, P.J., Stabekis, P.D., Viso, M. and Acevedo, S.E., 2002. [A draft test protocol for detecting possible biohazards in Martian samples returned to Earth](https://explorers.larc.nasa.gov/HPMIDEX/pdf_files/07_MSRDraftTestProtocol.pdf)

Rummel, J.D., Beaty, D.W., Jones, M.A., Bakermans, C., Barlow, N.G., Boston, P.J., Chevrier, V.F., Clark, B.C., de Vera, J.P.P., Gough, R.V. and Hallsworth, J.E., 2014.A [new analysis of Mars “special regions”: findings of the second MEPAG Special Regions Science Analysis Group (SR-SAG2)](https://mepag.jpl.nasa.gov/reports/Rummel_et_al_Astrobiology_14-SR-SAG2.pdf)

Rosengren, A.J., Scheeres, D.J. and McMahon, J.W., 2013. [Long-term dynamics and stability of GEO orbits: the primacy of the Laplace plane](https://www.researchgate.net/profile/Aaron_Rosengren/publication/287471546_Long-term_dynamics_and_stability_of_GEO_orbits_The_primacy_of_the_laplace_plane/links/56795cf308ae0d45249b34ab.pdf). In Proceedings of the AAS/AIAA Astrodynamics Specialist Conference, Hilton Head, South Carolina, Paper AAS (pp. 13-865).

Also as Rosengren, A.J., Scheeres, D.J. and McMahon, J.W., 2014. [The classical Laplace plane as a stable disposal orbit for geostationary satellites](http://commercialspace.pbworks.com/w/file/fetch/88916768/Rosengren%2C%20Scheeres%202014.pdf). Advances in Space Research, 53(8), pp.1219-1228.

Sabater, S., Timoner, X., Borrego, C. and Acuña, V., 2016. [Stream biofilm responses to flow intermittency: from cells to ecosystems](https://www.frontiersin.org/articles/10.3389/fenvs.2016.00014/full). Frontiers in Environmental Science, 4, p.14.

Sagan, C, 1961. [Organic matter and the Moon](https://www.nap.edu/download/18476)., National Academy of Sciences.

[*Page 23*](https://www.nap.edu/read/18476/chapter/5#23)*: It is remarkable that the depth at which surviving lunar organic matter is expected to be localized (section II) is just the depth at which temperatures appear to be optimum for familiar organisms (section IV). At such temperatures and depths, some moisture should be expected, arising from meteoritic and organic bound water. Watson, Murray and Brown (1961) have recently pointed out that ice could have been retained on permanently shaded areas of the Moon. These circumstances provide all the survival requirements of many terrestrial organisms - water and their metabolites, appropriate temperature, and negligible radiation. That autochthons evolving with the changing environment could also survive under these conditions is far from inconceivable.*

Sagan, C., Levinthal, E.C. and Lederberg, J., 1967. [Contamination of Mars](https://profiles.nlm.nih.gov/ps/access/BBABJH.ocr). *Science*, *159*(3820), pp.1191-1196.

*"The prominent dust storms and high wind velocities previously referred to imply that aerial transport of contaminants will occur on Mars. While it is probably true that a single unshielded terrestrial microorganism on the Martian surface ... would rapidly be enervated and killed by the ultraviolet flux, ... The Martian surface material certainly contains a substantial fraction of ferric oxides, which are extremely strongly absorbing in the near ultraviolet. ... A terrestrial microorganism imbedded in such a particle can be shielded from ultraviolet light and still be transported about the planet."*

*…*

*"A single terrestrial microorganism reproducing as slowly as once a month on Mars would, in the absence of other ecological limitations, result in less than a decade in a microbial population of the Martian soil comparable to that of the Earth's. This is an example of heuristic interest only, but it does indicate that the errors in problems of planetary contamination may be extremely serious."*

Sagan, C., 1973, [*The Cosmic Connection – an Extraterrestrial Perspective*](https://www.e-reading.life/bookreader.php/148581/Sagan_-_The_Cosmic_Connection___An_Extraterrestrial_Perspective.pdf)

Sagan, C., 1997. [Pale blue dot: A vision of the human future in space](http://www.planetary.org/explore/space-topics/earth/pale-blue-dot.html). Random House Digital, Inc..

Sahara Forest Project, 2020, [Enabling restorative growth](https://www.saharaforestproject.com/wp-content/uploads/2019/12/Folder_liggende-A5_2019_v2_TE.pdf)

Sakon, J.J. and Burnap, R.L., 2005, March. [A Further Analysis of Potential Photosynthetic Life on Mars](https://www.lpi.usra.edu/meetings/lpsc2005/pdf/2120.pdf). In *36th Annual Lunar and Planetary Science Conference* (Vol. 36).

Sakon, J.J. and Burnap, R.L., 2006. [An analysis of potential photosynthetic life on Mars. *International Journal of Astrobiology*](https://www.cambridge.org/core/journals/international-journal-of-astrobiology/article/an-analysis-of-potential-photosynthetic-life-on-mars/7E87D8A6D505F4055573F1FDA7F38F39), *5*(2), pp.171-180.

Salisbury, F.B., Gitelson, J.I. and Lisovsky, G.M., 1997. [Bios-3: Siberian experiments in bioregenerative life support](https://academic.oup.com/bioscience/article/47/9/575/222647?login=false). *BioScience*, *47*(9), pp.575-585.

Sanders, W.B. and Masumoto, H., 2021. [Lichen algae: the photosynthetic partners in lichen symbioses](https://www.cambridge.org/core/journals/lichenologist/article/lichen-algae-the-photosynthetic-partners-in-lichen-symbioses/A4808B98986967A742EF0DCFF187A937). *The Lichenologist*, *53*(5), pp.347-393.

Sarmiento, F., Peralta, R. and Blamey, J.M., 2015. [Cold and hot extremozymes: industrial relevance and current trends](https://www.frontiersin.org/articles/10.3389/fbioe.2015.00148/full). *Frontiers in bioengineering and biotechnology*, *3*, p.148.

Sauder, J., Hilgemann, E., Johnson, M., Parness, A., Hall, J., Kawata, J. and Stack, K., 2017. [Automation Rover for Extreme Environments](https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170002798.pdf).

Savage, D., 2002, [NASA selects four Mars scout mission concepts for study](https://www.nasa.gov/home/hqnews/2002/02-238.txt)

Scanlon, K.E., Head, J.W., Wilson, L. and Marchant, D.R., 2014. Volcano–ice interactions in the Arsia Mons tropical mountain glacier deposits. *Icarus*, *237*, pp.315-339. Press release [“A habitable environment on Martin volcano?”](https://news.brown.edu/articles/2014/05/mars)

Scharf, C., 2016, [How the Cold War Created Astrobiology, Life, death, and Sputnik](http://nautil.us/issue/32/space/how-the-cold-war-created-astrobiology-rp), Nautilus Magazine.

Scheller, E.L., Hollis, J.R., Cardarelli, E.L., Steele, A., Beegle, L.W., Bhartia, R., Conrad, P., Uckert, K., Sharma, S., Ehlmann, B. and Asher, S., 2022. [First-results from the Perseverance SHERLOC Investigation: Aqueous Alteration Processes and Implications for Organic Geochemistry in Jezero Crater](https://ntrs.nasa.gov/api/citations/20220003568/downloads/Scheller_SHERLOC_LPSC%202022_submitted.pdf), Mars. In *LPSC 2022*.

Schenk, P.M., Thomas-Hall, S.R., Stephens, E., Marx, U.C., Mussgnug, J.H., Posten, C., Kruse, O. and Hankamer, B., 2008. [Second generation biofuels: high-efficiency microalgae for biodiesel production](https://www.researchgate.net/profile/Ben_Hankamer/publication/43498856_Second_Generation_Biofuels_High-Efficiency_Microalgae_for_Biodiesel_Production/links/0c96051cc124e949e7000000.pdf). *Bioenergy research*, *1*(1), pp.20-43.

Schlaepfer, M.A., Sax, D.F. and Olden, J.D., 2011. [The potential conservation value of non‐native species](http://depts.washington.edu/oldenlab/wordpress/wp-content/uploads/2013/03/ConservationBiology_2011b_replies.pdf). *Conservation Biology*, *25*(3), pp.428-437.

Schirber, M, 2013 [Searching for Organics in a Nibble of Soil](https://web.archive.org/web/20130221043653/http%3A/www.astrobio.net/exclusive/5325/searching-for-organics-in-a-nibble-of-soil) NASA Astrobiology Magazine

Schmidt, B.E., Blankenship, D.D., Patterson, G.W. and Schenk, P.M., 2011. [Active formation of ‘chaos terrain’over shallow subsurface water on Europa](http://lunar.earth.northwestern.edu/courses/450/europachaos.pdf). *Nature*, *479*(7374), pp.502-505.

Schmidt, M., 2010. [Xenobiology: a new form of life as the ultimate biosafety tool](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2909387/). *Bioessays*, *32*(4), pp.322-331.

Schmidt, M., n.d. [Species Profile – Didymosphenia geminata](https://nas.er.usgs.gov/queries/greatLakes/FactSheet.aspx?Species_ID=2856&Potential=N&Type=0&HUCNumber=DGreatLakes) , aquatic non indigenous species, Great Lakes Information system

Schrunk, D., Sharpe, B., Cooper, B.L. and Thangavelu, M., 2007. [*The moon: Resources, future development and settlement*](https://books.google.co.uk/books?id=oxLBa_8tLHAC&source=gbs_navlinks_s). Springer Science & Business Media.

Schulze-Makuch, D. and Houtkooper, J.M., 2010a. [A perchlorate strategy for extreme xerophilic life on Mars.](https://meetingorganizer.copernicus.org/EPSC2010/EPSC2010-308.pdf) *EPSC Abstracts*, *5*, pp.EPSC2010-308.

Schuyler, A., Warner, N.H., Derick, B., Rogers, A.D. and Golombek, M.P., 2020, March. [Crater Morphometry on the Dark-Toned Mafic Floor Unit at Jezero Crater, Mars: Comparisons to a Known Basaltic Lava Plain at the InSight Landing Site](https://www.hou.usra.edu/meetings/lpsc2020/pdf/1608.pd). In Lunar and Planetary Science Conference (No. 2326, p. 1608).

Sczepanski, J.T. and Joyce, G.F., 2014. [A cross-chiral RNA polymerase ribozyme](https://www.nature.com/articles/nature13900). Nature, 515(7527), pp.440-442.

Seckbach, J. and Rampelotto, P.H., 2015. [Polyextremophiles. *Microbial Evolution under Extreme Conditions*](https://www.researchgate.net/publication/279948825_Polyextremophiles)*; Bakermans, C., Ed.; De Gruyter Editorial: Berlin, Germany*, pp.153-170.

Selbmann, L., Zucconi, L., Isola, D. and Onofri, S., 2015. [Rock black fungi: excellence in the extremes, from the Antarctic to space](https://scholar.google.com/scholar?start=0&hl=en&as_sdt=0,5&cluster=13685363864875790259&authuser=1). Current Genetics, 61(3), pp.335-345.

Sella, S.R., Vandenberghe, L.P. and Soccol, C.R., 2014. [Life cycle and spore resistance of spore-forming Bacillus atrophaeus](http://www.sciencedirect.com/science/article/pii/S0944501314000597). Microbiological research, 169(12), pp.931-939.

Serrano, P., Alawi, M., de Vera, J.P. and Wagner, D., 2019. [Response of methanogenic archaea from Siberian permafrost and non-permafrost environments to simulated Mars-like desiccation and the presence of perchlorate](https://www.liebertpub.com/doi/full/10.1089/ast.2018.1877). *Astrobiology*, *19*(2), pp.197-208.

Service, R. 2022, [A big step towards mirror-image ribosomes](https://zhu.lab.westlake.edu.cn/wp-content/uploads/Service_2022.pdf), Science, Vol 378, Issue 6618.

Sharnoff, S, 1989, [*Pleopsidium chlorophanum*](https://lichenportal.org/cnalh/collections/individual/index.php?occid=4932677)

Shekhtman, L., 2019, [With Mars methane mystery unsolved, Curiosity serves scientists a new one: Oxygen](https://www.nasa.gov/feature/goddard/2019/with-mars-methane-mystery-unsolved-curiosity-serves-scientists-a-new-one-oxygen/)

Shirley, J.H., 2015. [Solar System dynamics and global-scale dust storms on Mars](https://www.researchgate.net/publication/273398220_Solar_System_dynamics_and_global-scale_dust_storms_on_Mars). *Icarus*, *251*, pp.128-144.

Sielaff, C.A. and Smith, S.A., 2019. [Habitability of Mars: How Welcoming Are the Surface and Subsurface to Life on the Red Planet?](https://www.mdpi.com/2076-3263/9/9/361). Geosciences, 9(9), p.361.

Singer, E., 2014, [New Twist Found in the Story of Life’s Start](https://www.quantamagazine.org/chiral-key-found-to-origin-of-life-20141126), Quanta Magazine

Singh, R., Bhadouria, R., Singh, P., Kumar, A., Pandey, S. and Singh, V.K., 2020. [Nanofiltration technology for removal of pathogens present in drinking water](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7173494/). In Waterborne Pathogens (pp. 463-489). Butterworth-Heinemann.

Smith, M.D. and Guzewich, S.D., 2019. [The Mars Global Dust Storm of 2018](https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20190027303.pdf).

Smith, T.P., Mombrikotb, S., Ransome, E., Kontopoulos, D.G., Pawar, S. and Bell, T., 2022. [Latent functional diversity may accelerate microbial community responses to temperature fluctuations](https://elifesciences.org/articles/80867). *Elife*, *11*, p.e80867

Smith, D.H., Canup, R.M. and Christensen, P.R., 2022, May. [Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology](https://nap.nationalacademies.org/catalog/26522/origins-worlds-and-life-a-decadal-strategy-for-planetary-science?fbclid=IwAR0UORtHg6ZQjVb8dUZeM3XZXSZCpdDoKmN_3gP6b48BwirYEEhqIXid2cw)

. In *2022 Astrobiology Science Conference*. AGU.

Solden, L., Lloyd, K. and Wrighton, K., 2016. [The bright side of microbial dark matter: lessons learned from the uncultivated majority](https://www.sciencedirect.com/science/article/pii/S1369527416300558#bib0345). *Current opinion in microbiology*, *31*, pp.217-226.

Song, C., Weichbrodt, C., Salnikov, E.S., Dynowski, M., Forsberg, B.O., Bechinger, B., Steinem, C., De Groot, B.L., Zachariae, U. and Zeth, K., 2013. [Crystal structure and functional mechanism of a human antimicrobial membrane channel](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3607029/). *Proceedings of the National Academy of Sciences*, *110*(12), pp.4586-4591.

Space Studies Board and National Research Council, 1999. [*Size limits of very small microorganisms: proceedings of a workshop*](https://nap.nationalacademies.org/read/9638/chapter/1). National Academies Press.

Space Studies Board and National Research Council, 2002a. [*Safe on Mars: Precursor measurements necessary to support human operations on the Martian surface*](https://books.google.co.uk/books?hl=en&lr=&id=OOs3oDSKj4oC). National Academies Press.

Space Studies Board and National Research Council, 2009. [*Assessment of planetary protection requirements for Mars sample return missions*](https://nap.nationalacademies.org/read/12576/chapter/1). National Academies Press

Space Studies Board and National Research Council, 2012. [*Vision and voyages for planetary science in the decade 2013-2022*](https://solarsystem.nasa.gov/resources/598/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022/). National Academies Press.

Space Studies Board, European Space Sciences Committee and National Academies of Sciences, Engineering, and Medicine, 2015. [Review of the MEPAG report on Mars special regions](https://www.nap.edu/catalog/21816/review-of-the-mepag-report-on-mars-special-regions). National Academies Press.

Space Studies Board, 2019. [Planetary protection classification of sample return missions from the Martian moons](https://nap.nationalacademies.org/catalog/25357/planetary-protection-classification-of-sample-return-missions-from-the-martian-moons),

SpaceX, 2016, [Interplanetary Transport System](https://www.flickr.com/photos/spacex/29343905184/), Official SpaceX Photos, Flickr

Spaulding, S.A., Kilroy, C.A.T.H.Y. and Edlund, M.B., 2010. [Diatoms as non-native species](https://www.researchgate.net/profile/Sarah_Spaulding/publication/232666319_Species_within_the_Genus_Encyonema_Kutzing_Including_Two_New_Species_Encyonema_reimeri_sp_nov_and_E_nicafei_sp_nov_and_E_stoermeri_nom_nov_stat_nov/links/02e7e51ddd414216aa000000/Species-within-the-Genus-Encyonema-Kuetzing-Including-Two-New-Species-Encyonema-reimeri-sp-nov-and-E-nicafei-sp-nov-and-E-stoermeri-nom-nov-stat-nov.pdf). *The diatoms: applications for the environmental and earth sciences*, pp.560-569.

Stacey, K.N., 2019. [Interactions between Athabasca Valles Flood Lavas and the Medusae Fossae Formation (Mars): Implications for Lava Emplacement Mechanisms and the Triggering of Steam Explosions](https://utd-ir.tdl.org/bitstream/handle/10735.1/8687/ETD-5608-014T-261607.88.pdf?sequence=7&isAllowed=y). The University of Texas at Dallas.

Page 29:

*Volcanic rootless cones throughout southern Cerberus Palus and the Aeolis Trough indicate the presence of near surface volatiles at the time of lava emplacement, perhaps ≤20 Ma. The form of these volatiles is unclear, with pore ice, bulk ice lenses, ephemerally stable liquid water, adsorbed water, and hydrous minerals all being possible to various degrees. Multiple mechanisms allowed for steam eruptions, resulting in landforms of varying scale and morphology:*

Stamatelatos, M., Dezfuli, H., Apostolakis, G., Everline, C., Guarro, S., Mathias, D., Mosleh, A., Paulos, T., Riha, D., Smith, C. and Vesely, W., 2011. [*Probabilistic risk assessment procedures guide for NASA managers and practitioners*](file:///C%3A%5CUsers%5Crober%5CDocuments%5Cbooklets%5Cautorecovered%5CNASA%E2%80%99s%20draft%20EIS%20does%20NOT%20establish%20that%20life%20from%20Mars%20can%20get%20to%20Earth%20faster%20and%20better%20protected%20in%20a%20meteorite%20.docx) (No. HQ-STI-11-213).

Stamenković, V., Ward, L. M., Mischna. M., Fischer. W. W.. "[O2 solubility in Martian near-surface environments and implications for aerobic life](https://www.nature.com/articles/s41561-018-0243-0)" — [*Nature*](https://en.wikipedia.org/wiki/Nature), October 22, 2018 – see also "[Origins of Life & Habitability – authors website with bibliography – and author shared link to the article](http://habilabs.com/life/)", sharing is via [Nature Sharedit](https://www.springernature.com/gp/researchers/sharedit) — [*Habilabs*](https://en.wikipedia.org/wiki/Habilabs)

Stern, S.A., 1999. [The lunar atmosphere: History, status, current problems, and context.](https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/1999RG900005) Reviews of Geophysics, 37(4), pp.453-491.

Stewart, R.B., 2002. [Environmental regulatory decision making under uncertainty](http://www.cserge.ucl.ac.uk/Stewart.pdf). Research in Law and Economics, 20, pp.71-126.

Stillman, E, 2018, Chapter 2 – [Unraveling the Mysteries of Recurring Slope Lineae](https://books.google.co.uk/books?id=2aRBDwAAQBAJ&pg=PA69&lpg=PA69&) in Soare, R.J., Conway, S.J. and Clifford, S.M. eds., 2018. *Dynamic Mars: Recent and Current Landscape Evolution of the Red Planet*. Elsevier.

[*Page 81*](https://books.google.co.uk/books?id=2aRBDwAAQBAJ&pg=PA81#v=onepage&q&f=false)*: “No proposed RSL mechanism can adequately describe all the observations … We suggest RSLs that are scored excellent and very good and sites that do not typographically preclude aquifer fed springs are likely caused by a wet-dominated mechanism while numerous other sites are caused by dry granular flow”*

Stillman, D.E., Michaels, T.I., Hoover, R.H., Barth, E.L., Primm, K.M., Egan, A.F. and Grimm, R.E., 2021. [Evaluation of grainflow mechanisms for martian recurring slope lineae (RSL)](https://www.sciencedirect.com/science/article/abs/pii/S0019103521003080). *Icarus*, *369*, p.114648.

*Nonetheless, we suggest that the mixed success of the external sediment transport model is still quantitatively better than any competitor (including water), and that we simply lack the model and data resolution to treat RSL at the required meter scales.*

*…*

*Overall, neither frost nor deliquesced brines correlate with RSL activity except for the absence of frost when RSL at Palikir crater are active. Note the RH [Relative Humidity] in the near surface is also poorly constrained as additional in-situ measurements are needed to better calibrate the mesoscale models.*

*We hypothesize that the rough correspondence of RSL activity with warmer parts of the year at most sites may actually be due to seasonal variations of wind speed, direction, and turbulence. Our MRAMS modeling does not show a clear correlation between upslope potential sediment transport and RSL seasonality. However, it is possible that more detailed modeling (higher resolution, varying surface roughness, better PDF evaluation for wind gusts) could find a better correlation.*

*…*

*We also conclude that if the dry RSL mechanism is correct then locations with favorable RSL geomorphology that lack RSL may lack a combination of strong winds and sand grains that can easily saltate on Mars (~100 μm in diameter).*

*…*

*We found that at two of the three RSL sites deliquescence never occurs, and at the third site (Rauna crater) the stability of brines does not correlate with RSL activity. The existence of small amounts of surface brines that could possibly trigger RSL grain flows via efflorescence and associated changes in cohesion appears to be unlikely. Likewise, the absence of frost is only correlated with RSL activity at Palikir crater, thus frost is likely not affecting RSL triggering.*

St. Leger, R.J., Screen, S.E. and Shams-Pirzadeh, B., 2000. [Lack of host specialization in Aspergillus flavus](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC91824/). *Applied and Environmental Microbiology*, *66*(1), pp.320-324.

Stout, J.D., n.d., [Protozoa and the Soil](https://nzetc.victoria.ac.nz/tm/scholarly/tei-Bio04Tuat03-t1-body-d3.html)

Stubbs, T.J., Vondrak, R.R. and Farrell, W.M., 2007. [Impact of dust on lunar exploration](https://www.nasa.gov/centers/johnson/pdf/486014main_StubbsImpactOnExploration.4075.pdf)

Shannon, D.M., 2006[. Elemental analysis as a first step towards “following the nitrogen” on Mars](http://sites.google.com/site/derekshannon/DShannon_Thesis_Full.pdf). University of Southern California.

Summons, R.E., Amend, J.P., Bish, D., Buick, R., Cody, G.D., Des Marais, D.J., Dromart, G., Eigenbrode, J.L., Knoll, A.H. and Sumner, D.Y., 2011. [Preservation of martian organic and environmental records: final report of the Mars Biosignature Working Group](https://dash.harvard.edu/bitstream/handle/1/13041033/66876195.pdf?sequence=2&isAllowed=y). Astrobiology, 11(2), pp.157-181.

Sun, H.J. and Friedmann, E.I., 1999. [Growth on geological time scales in the Antarctic cryptoendolithic microbial community](https://www.tandfonline.com/doi/abs/10.1080/014904599270686). Geomicrobiology Journal, 16(2), pp.193-202.

Sun, S., Noorian, P. and McDougald, D., 2018. [Dual role of mechanisms involved in resistance to predation by protozoa and virulence to humans](https://www.frontiersin.org/articles/10.3389/fmicb.2018.01017/full). *Frontiers in microbiology*, *9*, p.1017.

Tao, Y. and Zhang, Y.M., 2012. [Effects of leaf hair points of a desert moss on water retention and dew formation: implications for desiccation tolerance](https://www.researchgate.net/profile/Ye-Tao/publication/51804317_Effects_of_leaf_hair_points_of_a_desert_moss_on_water_retention_and_dew_formation_Implications_for_desiccation_tolerance/links/5ab347b5a6fdcc1bc0c1f9e9/Effects-of-leaf-hair-points-of-a-desert-moss-on-water-retention-and-dew-formation-Implications-for-desiccation-tolerance.pdf). *Journal of plant research*, *125*, pp.351-360.

Taylor, L., Schmitt, H., Carrier, W. and Nakagawa, M., 2005, January. [Lunar dust problem: From liability to asset](https://www.nasa.gov/centers/johnson/pdf/486017main_Taylor.pdf). In *1st space exploration conference: continuing the voyage of discovery* (p. 2510).

Tenaillon, O., Rodríguez-Verdugo, A., Gaut, R.L., McDonald, P., Bennett, A.F., Long, A.D. and Gaut, B.S., 2012. [The molecular diversity of adaptive convergence](https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=1dd954a6d6cfc4620f0b17df9054340ed56ab5d6). Science, 335(6067), pp.457-461.

Thammahong, A., 2021. Aspergillus-Human Interactions: From the Environment to Clinical Significance. In *The Genus Aspergillus-Pathogenicity, Mycotoxin Production and Industrial Applications*. IntechOpen

Tennyson, A., 2003. [Ulysses](https://www.gutenberg.org/files/8601/8601-h/8601-h.htm%22%20%5Cl%20%22chap62).” 1842. T*he Early Poems of Alfred, Lord Tennyson*, Project Gutenburg

Thorney¿?, 2006, [Didymo signage on Waiau river](https://en.wikipedia.org/wiki/File%3ADidymo_signage_on_Waiau_river.jpg) , Wikipedia

Tillman, N.T., 2014, [Incredible Technology: Private Mars Mission Could Return Samples by 2020](https://www.space.com/26255-private-mars-sample-return-mission-2020.html), Space.com

Todea, A.M., Schmidt, F., Schuldt, T. and Asbach, C., 2020. [Development of a method to determine the fractional deposition efficiency of full-scale HVAC and HEPA filter cassettes for nanoparticles≥ 3.5 nm](https://www.mdpi.com/2073-4433/11/11/1191). *Atmosphere*, *11*(11), p.1191.

Toll-Riera, M., Olombrada, M., Castro-Giner, F. and Wagner, A., 2022. [A limit on the evolutionary rescue of an Antarctic bacterium from rising temperatures](https://www.science.org/doi/full/10.1126/sciadv.abk3511?utm_campaign=Daily%20Briefing&utm_content=20220821&utm_medium=email&utm_source=Revue%20newsletter). *Science Advances*, *8*(28), p.eabk3511.

Toner, J.D., Sletten, R.S., Liu, L., Catling, D.C., Ming, D.W., Mushkin, A. and Lin, P.C., 2022. [Wet streaks in the McMurdo Dry Valleys, Antarctica: Implications for Recurring Slope Lineae on Mars](https://www.sciencedirect.com/science/article/abs/pii/S0012821X22002187). *Earth and Planetary Science Letters*, *589*, p.117582.

*To determine if RSL are consistent with brine flows, we investigated Mars analog wet streaks in Wright Valley Antarctica using new chemical analyses of soils and waters, time-lapse photography, and satellite images.*

*…*

*Applied to Mars, wet streaks are inconsistent with the surface expression and dynamics of RSL. Wet streaks propagate and fade over multiple years, drain onto low angled slopes, and have a characteristic pattern of dark downhill and lateral edges. In contrast, RSL are seasonal features, terminate on angle-of-repose slopes, and typically appear monochromatic. These inconsistencies provide evidence against brine flow hypotheses of RSL formation.*

Topputo, F. and Belbruno, E., 2015. [Earth–Mars transfers with ballistic capture](https://arxiv.org/pdf/1410.8856.pdf). *Celestial Mechanics and Dynamical Astronomy*, *121*(4), pp.329-346

Tornabene, L.L., Moersch, J.E., McSween Jr, H.Y., McEwen, A.S., Piatek, J.L., Milam, K.A. and Christensen, P.R., 2006. [Identification of large (2–10 km) rayed craters on Mars in THEMIS thermal infrared images](https://agupubs.onlinelibrary.wiley.com/doi/pdfdirect/10.1029/2005JE002600): Implications for possible Martian meteorite source regions. *Journal of Geophysical Research: Planets*, *111*(E10)

Trainer, M.G., Wong, M.H., Mcconnochie, T.H., Franz, H.B., Atreya, S.K., Conrad, P.G., Lefèvre, F., Mahaffy, P.R., Malespin, C.A., Manning, H.L. and Martín‐Torres, J., 2019. [Seasonal variations in atmospheric composition as measured in Gale Crater](https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2019JE006175), Mars. *Journal of Geophysical Research: Planets*, *124*(11), pp.3000-3024. See also [Supporting information](https://agupubs.onlinelibrary.wiley.com/action/downloadSupplement?doi=10.1029%2F2019JE006175&file=jgre21250-sup-0001-2019JE006175-SI.pdf)

Tripp, H.C., n.d.,[CRAA(M)P Test](https://guides.lib.utexas.edu/c.php?g=961624&p=6944629) , [Biology – Research basics](https://guides.lib.utexas.edu/biology_researchbasics), University of Texas Libraries

Turbet, M. and Forget, F., 2019. [The paradoxes of the Late Hesperian Mars ocean](https://www.nature.com/articles/s41598-019-42030-2). Scientific reports, 9(1), pp.1-5.

UNHabitat, 2022 [UN-Habitat and partners unveil OCEANIX Busan, the world’s first prototype floating city](https://unhabitat.org/news/27-apr-2022/un-habitat-and-partners-unveil-oceanix-busan-the-worlds-first-prototype-floating)

University of Arizona, n.d., [Under the Glass Systems](https://biosphere2.org/research/under-glass-systems)

Udry, A., Howarth, G.H., Herd, C.D.K., Day, J.M., Lapen, T.J. and Filiberto, J., 2020. [What martian meteorites reveal about the interior and surface of Mars.](https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020JE006523)

Uhran, B., Conley, C. and Spry, J.A., 2019. [Updating Planetary Protection Considerations and Policies for Mars Sample Return](https://www.sciencedirect.com/science/article/abs/pii/S0265964618300833). Space Policy, 49, p.101322.

UNECE, n.d. [Espoo Convention](https://unece.org/environment-policy/environmental-assessment)

Urbaniak, C., Massa, G., Hummerick, M., Khodadad, C., Schuerger, A. and Venkateswaran, K., 2018. [Draft genome sequences of two Fusarium oxysporum isolates cultured from infected Zinnia hybrida plants grown on the international space station](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5958250/). Genome announcements, 6(20).

. MSystems, 4(2).

Urbaniak, C., van Dam, P., Zaborin, A., Zaborina, O., Gilbert, J.A., Torok, T., Wang, C.C. and Venkateswaran, K., 2019. [Genomic Characterization and Virulence Potential of Two Fusarium oxysporum Isolates Cultured from the International Space Station](https://msystems.asm.org/content/msys/4/2/e00345-18.full.pdf). MSystems, 4(2).

US DOA, 2017, [European Starling](https://www.aphis.usda.gov/wildlife_damage/reports/Wildlife%20Damage%20Management%20Technical%20Series/European-Starlings-WDM-Technical-Series.pdf).

Vago, J.L., Westall, F., Coates, A.J., Jaumann, R., Korablev, O., Ciarletti, V., Mitrofanov, I., Josset, J.L., De Sanctis, M.C., Bibring, J.P. and Rull, F., 2017. [Habitability on early Mars and the search for biosignatures with the ExoMars Rover](https://www.liebertpub.com/doi/full/10.1089/ast.2016.1533). Astrobiology, 17(6-7), pp.471-510.

*However, the likelihood of a cold surface scenario does not constitute a serious obstacle for the possible appearance of life, as extensive subglacial, submerged, and emerged volcanic/hydrothermal activity would have resulted in numerous liquid water-rich settings. The right mixture of ingredients, temperature and chemical gradients, organic molecule transport, concentration, and fixation processes could have been found just as well in a plethora of terrestrial submarine vents as in a multitude of vents under (maybe) top-frozen martian bodies of water.*

Valinia, A., Garvin, J.B., Vondrak, R., Thronson, H., Lester, D., Schmidt, G., Fong, T., Wilcox, B., Sellers, P. and White, N., 2012. [Low-Latency Telerobotics from Mars Orbit: The Case for Synergy Between Science and Human Exploration](https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120013068.pdf).

van der Giezen, M., 2002. [Strange fungi with even stranger insides](http://davidmoore.org.uk/21st_Century_Guidebook_to_Fungi_PLATINUM/REPRINT_collection/vanderGiezen_rumen_chytrids.pdf). *Mycologist*, *16*(3), pp.129-131.

van Heereveld, L., Merrison, J., Nørnberg, P. and Finster, K., 2017. [Assessment of the Forward Contamination Risk of Mars by Clean Room Isolates from Space-Craft Assembly Facilities through Aeolian Transport-a Model Study](https://www.researchgate.net/publication/305656209_Assessment_of_the_Forward_Contamination_Risk_of_Mars_by_Clean_Room_Isolates_from_Space-Craft_Assembly_Facilities_through_Aeolian_Transport_-_a_Model_Study). *Origins of Life and Evolution of Biospheres*, *47*(2), pp.203-21*.*

Vasaveda, 2015, [Gale Crater Observations of Relevance to Planetary Protection](https://science.nasa.gov/science-pink/s3fs-public/atoms/files/Vasavada_-_Mars_Science_Laboratory_Gale_Crater_observations.pdf)

Ventero, M.P., Moreno-Perez, O., Molina-Pardines, C., Paytuví-Gallart, A., Boix, V., Escribano, I., Galan, I., González-delaAleja, P., López-Pérez, M., Sánchez-Martínez, R. and Merino, E., 2022. [Nasopharyngeal Microbiota as an early severity biomarker in COVID-19 hospitalised patients](https://www.sciencedirect.com/science/article/pii/S0163445321006472). Journal of Infection, 84(3), pp.329-336.

Verne, J., 1897. [A Journey to the Center of the Earth](https://etc.usf.edu/lit2go/222/the-journey-to-the-center-of-the-earth/).

Vesper, S.J., Wong, W., Kuo, C.M. and Pierson, D.L., 2008. [Mold species in dust from the International Space Station identified and quantified by mold-specific quantitative PCR](https://ntrs.nasa.gov/api/citations/20080014829/downloads/20080014829.pdf). *Research in microbiology*, *159*(6), pp.432-435.

Vincent, J.F. and Wegst, U.G., 2004. [Design and mechanical properties of insect cuticle](https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1090.7026&rep=rep1&type=pdf). *Arthropod structure & development*, *33*(3), pp.187-199.

Vítek, P., Edwards, H.G.M., Jehlička, J., Ascaso, C., De los Ríos, A., Valea, S., Jorge-Villar, S.E., Davila, A.F. and Wierzchos, J., 2010. [Microbial colonization of halite from the hyper-arid Atacama Desert studied by Raman spectroscopy](http://rsta.royalsocietypublishing.org/content/368/1922/3205#ref-36). *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, *368*(1922), pp.3205-3221.

Viúdez‐Moreiras, D., Newman, C.E., Forget, F., Lemmon, M., Banfield, D., Spiga, A., Lepinette, A., Rodriguez‐Manfredi, J.A., Gómez‐Elvira, J., Pla‐García, J. and Muller, N., 2020. [Effects of a large dust storm in the near‐surface atmosphere as measured by InSight in Elysium Planitia, Mars](https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020JE006493). Comparison with contemporaneous measurements by Mars Science Laboratory. *Journal of Geophysical Research: Planets*, *125*(9), p.e2020JE006493.

Volpe Chaves, C.E., do Valle Leone de Oliveira, S.M., Venturini, J., Grande, A.J., Sylvestre, T.F., Poncio Mendes, R. and Mello Miranda Paniago, A., 2020. [Accuracy of serological tests for diagnosis of chronic pulmonary aspergillosis: A systematic review and meta-analysis](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7287442/). *PloS one*, *15*(3), p.e0222738.

Wadsworth, J. and Cockell, C.S., 2017. [Perchlorates on Mars enhance the bacteriocidal effects of UV light](https://www.nature.com/articles/s41598-017-04910-3%29). *Scientific reports*, *7*(1), pp.1-8.

Waite, D.W., Vanwonterghem, I., Rinke, C., Parks, D.H., Zhang, Y., Takai, K., Sievert, S.M., Simon, J., Campbell, B.J., Hanson, T.E. and Woyke, T., 2017. [Comparative genomic analysis of the class Epsilonproteobacteria and proposed reclassification to Epsilonbacteraeota (phyl. nov.)](https://www.frontiersin.org/articles/10.3389/fmicb.2017.00682/full). *Frontiers in microbiology*, *8*, p.682.

Walker, R., 2022a, [Comment posted on May 15th by Robert Walker to NASA’s first request for comments on their plans](https://www.regulations.gov/comment/NASA-2022-0002-0170).

Later updated with:

* [Comment posted on November 28h by Robert Walker to NASA’s second request for comments on their draft EIS.](https://www.regulations.gov/comment/NASA-2022-0002-0195)
* [Comment posted December 5](https://www.regulations.gov/comment/NASA-2022-0002-0228)[th](https://www.regulations.gov/comment/NASA-2022-0002-0228)
* [Comment posted December 13th](https://www.regulations.gov/comment/NASA-2022-0002-0238)
* [Comment posted December 20th](https://www.regulations.gov/comment/NASA-2022-0002-0254)

Walker, R., 2022b, [NASA and ESA are likely to be legally required to sterilize Mars samples to protect the environment until proven safe – technology doesn't yet exist to comply with ESF study's requirement to contain viable starved ultramicrobacteria that are proven to pass through 0.1 micron nanopores – proposal to study samples remotely in a safe high orbit above GEO with miniature life detection instruments – and immediately return sterilized subsamples to Earth,](https://osf.io/rk2gd/) (preprint, not peer reviewed)

Walker, R., n.d., [Are you an orang utan or a chimpanzee? Common misunderstandings when talking about doomsday fears with people who are autistic, Aspergers, or very empathic and imaginative](https://debunkingdoomsday.quora.com/Are-you-an-orang-utan-or-a-chimpanzee-Common-misunderstandings-when-talking-about-doomsday-fears-with-people-who-are-au%22%20%5Ct%20%22_blank)

Walker, n.d., [Calculator to find the delta V to get from LEO to GEO, or from LEO to a higher orbit, and calculate the difference between the two delta v's.](https://robertinventor.online/booklets/Orbit_calculator_for_transfer_to_above_GEO.htm)

Walker, R., n.d. [Our pale blue dot-are there other homes for us in our galaxy?](https://osf.io/634mw)

Wall, M., 2018, ["Salty Martian Water Could Have Enough Oxygen to Support Life"](https://www.space.com/42210-mars-brines-oxygen-support-life.html)

— [*Space.com*,](https://en.wikipedia.org/wiki/Space.com)

Wang, Y., Hammes, F., Boon, N. and Egli, T., 2007. [Quantification of the filterability of freshwater bacteria through 0.45, 0.22, and 0.1 μm pore size filters and shape-dependent enrichment of filterable bacterial communities](https://scholar.google.com/scholar?start=0&hl=en&as_sdt=0,5&cluster=4410388950891671370). Environmental science & technology, 41(20), pp.7080-7086.

Warmflash, D., Larios-Sanz, M., Jones, J., Fox, G.E. and McKay, D.S., 2007. [Assessing the Biohazard Potential of Putative Martian Organisms for Exploration Class Human Space Missions](https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20070030011.pdf).

*Indeed, not even all infectious human pathogens—let alone non-infectious pathogens— on Earth require a multicellular, macroscopic host to evolve harmful capabilities.*

*July, 1976, the month that VL1 [Viking Lander 1] landed on the Martian surface, was also the month of the outbreak of Legionnaires’ disease at the American Legion convention in Philadelphia.*

*The cause, Legionella pneumophila, is a facultative, Gram-negative rod that is one of several human pathogens now known to be carried in the intracellular environments of protozoan hosts. L. pneumophila can also persist, even outside of any host, as part of biofilms.*

*In essence, all that a potentially infectious human pathogen needs to emerge and persist is to grow and live naturally under conditions that are similar to those that it might later encounter in a human host. On Mars, these conditions might be met in a particular niche within the extracellular environment of a biofilm, or within the intracellular environment of another single-celled Martian organism. It is important to note the numerous biofilms observed aboard the Mir space station, which were found on surfaces and within water plumbing. These films were often multi-species and included bacteria, fungi, and protozoa.*

*To be sure, the genetic similarity between humans and protozoa is much greater than could be expected between humans and the Martian host of a Martian microbe.*

*However, the L. pneumophila example does bring into question the rationale of the need for host-pathogen coevolution. Even in the context of a planetary bio-sphere that is limited to single-celled life, and even where there is unlikely to have been a co-evolution between agent and host organism, the possibility of infectious agents, even an invasive type, cannot be ruled out.*

Welcome Foundation, n.d., [Why is it so hard to develop new antibiotics?](https://wellcome.org/news/why-is-it-so-hard-develop-new-antibiotics)

Weinbaum, S.G., 1945. [*A Martian Odyssey*](https://www.gutenberg.org/files/23731/23731-h/23731-h.htm). Project Gutenberg e-book.

Wiens, R.C., Udry, A., Beyssac, O., Quantin-Nataf, C., Mangold, N., Cousin, A., Mandon, L., Bosak, T., Forni, O., Mclennan, S.M. and Sautter, V., 2022. [Compositionally and density stratified igneous terrain in Jezero crater, Mars](https://www.science.org/doi/full/10.1126/sciadv.abo3399?et_rid=558517217&utm_campaign=TrendMD_1&af=R&et_cid=4371577&utm_medium=cpc&utm_content=alert&utm_source=TrendMD). *Science advances*, *8*(34), p.eabo3399.

Weiss, I.M., Muth, C., Drumm, R. and Kirchner, H.O., 2018. [Thermal decomposition of the amino acids glycine, cysteine, aspartic acid, asparagine, glutamic acid, glutamine, arginine and histidine](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5807855/). *BMC biophysics*, *11*(1), p.2. For the decomposition temperatures see [Table 1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5807855/table/Tab1/?report=objectonly)

Wells, H.G., 1898. [*The war of the worlds*](https://www.gutenberg.org/files/36/36-h/36-h.htm#chap17). Project Gutenburg

Westall, F., Loizeau, D., Foucher, F., Bost, N., Betrand, M., Vago, J. and Kminek, G., 2013. [Habitability on Mars from a microbial point of view](https://hal-insu.archives-ouvertes.fr/file/index/docid/866015/filename/ast.2013.1000-1.pdf). Astrobiology, 13(9), pp.887-897.

Westall, F., Foucher, F., Bost, N., Bertrand, M., Loizeau, D., Vago, J.L., Kminek, G., Gaboyer, F., Campbell, K.A., Bréhéret, J.G. and Gautret, P., 2015. [Biosignatures on Mars: what, where, and how? Implications for the search for Martian life](https://www.liebertpub.com/doi/pdfplus/10.1089/ast.2015.1374). *Astrobiology*, *15*(11), pp.998-1029.

Whitehouse, 1977, [NSC-25: Scientific or Technological EXperiments with Possible Large-Scale Adverse Environmental Effects and Launch of Nuclear Systems into Space](https://irp.fas.org/offdocs/pd/pd25.pdf)

WHO, 2003, [Laboratory Biosafety Manual Second Edition (Revised)](https://www.who.int/csr/resources/publications/biosafety/Labbiosafety.pdf)

WHO, 2019, [Leprosy, Key facts](https://www.who.int/news-room/fact-sheets/detail/leprosy),

WHO, n.d., [Tetanus](https://www.who.int/news-room/fact-sheets/detail/tetanus)

Wierzchos, J., Cámara, B., de Los Rios, A., Davila, A.F., Sánchez Almazo, I.M., Artieda, O., Wierzchos, K., Gomez‐Silva, B., McKay, C. and Ascaso, C., 2011. [Microbial colonization of Ca‐sulfate crusts in the hyperarid core of the Atacama Desert: implications for the search for life on Mars](https://scholar.google.com/scholar?cluster=7084099818676232737&hl=en&as_sdt=0,5&authuser=1). *Geobiology*, *9*(1), pp.44-60.

*Abstract: “Our data shows that the threshold for colonization is crossed within the dry core, with abundant colonization in gypsum crusts at one study site, while crusts at a drier site are virtually devoid of life. We show that the cumulative time in 1 year of relative humidity (RH) above 60% is the best parameter to explain the difference in colonization between both sites.*

Wierzchos, J., Davila, A.F., Sánchez-Almazo, I.M., Hajnos, M., Swieboda, R. and Ascaso, C., 2012. [Novel water source for endolithic life in the hyperarid core of the Atacama Desert](https://bg.copernicus.org/articles/9/2275/2012/bg-9-2275-2012.pdf). *Biogeosciences*, *9*(6), pp.2275-2286

Witze, A., 2016. [Mars contamination fear could divert Curiosity rover](https://www.nature.com/articles/537145a). *Nature*, *537*(7619), pp.145-147.

Woese, C.R., 2002. [On the evolution of cells](http://www.pnas.org/content/99/13/8742). *Proceedings of the National Academy of Sciences*, *99*(13), pp.8742-8747.

*“Aboriginal cell designs are taken to be simple and loosely organized enough that all cellular componentry can be altered and/or displaced through HGT [Horizontal Gene Transfer], making HGT the principal driving force in early cellular evolution. Primitive cells did not carry a stable organismal genealogical trace. Primitive cellular evolution is basically communal. The high level of novelty required to evolve cell designs is a product of communal invention, of the universal HGT field, not intralineage variation. It is the community as a whole, the ecosystem, which evolves. The individual cell designs that evolved in this way are nevertheless fundamentally distinct, because the initial conditions in each case are somewhat different. As a cell design becomes more complex and interconnected a critical point is reached where a more integrated cellular organization emerges, and vertically generated novelty can and does assume greater importance.”*

Wohlforth, C., Hendrix, A.R., 2016a, [Let’s Colonize Titan](https://blogs.scientificamerican.com/guest-blog/lets-colonize-titan/), Scientific American

Wohlforth, C., Hendrix, A.R., 2016b, [Beyond Earth: Our Path to a New Home in the Planets](https://books.google.co.uk/books?id=WBycCwAAQBAJ&dq), Knopf Doubleday Publishing Group

Xu, Z., Chen, Y., Meng, X., Wang, F. and Zheng, Z., 2016. [Phytoplankton community diversity is influenced by environmental factors in the coastal East China Sea](https://www.tandfonline.com/doi/pdf/10.1080/09670262.2015.1107138). *European Journal of Phycology*, *51*(1), pp.107-118.

*Abstract: Surface seawater was collected in four different seasons in the coastal East China Sea adjacent to the Yangtze River Estuary and phytoplankton community diversity was analysed using rbc L genetic markers.*
*page 111: The cyanobacterium Chroococcidiopsis sp. was widely represented in the tree, accounting for 14%, 7%, 3% and 7% of total clones in spring, summer, autumn and winter, respectively*

Yocum, R.R., Rasmussen, J.R. and Strominger, J.L., 1980. [The mechanism of action of penicillin. Penicillin acylates the active site of Bacillus stearothermophilus D-alanine carboxypeptidase.](https://www.ncbi.nlm.nih.gov/pubmed/7372662) *Journal of Biological Chemistry*, *255*(9), pp.3977-3986.

Young, R.M., Millour, E., Forget, F., Smith, M.D., Aljaberi, M., Edwards, C.S., Smith, N., Anwar, S., Christensen, P.R. and Wolff, M.J., 2022. [First Assimilation of Atmospheric Temperatures From the Emirates Mars InfraRed Spectrometer](https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2022GL099656). *Geophysical Research Letters*, *49*(21), p.e2022GL099656.

Zakharova, K., Marzban, G., de Vera, J.P., Lorek, A. and Sterflinger, K., 2014. [Protein patterns of black fungi under simulated Mars-like conditions](https://www.nature.com/articles/srep05114). *Scientific reports*, *4*, p.5114.

Zhang, Y., Lu, L., Chang, X., Jiang, F., Gao, X., Yao, Y., Li, C., Cao, S., Zhou, Q. and Peng, F., 2018. [Small-scale soil microbial community heterogeneity linked to landform historical events on King George island, maritime Antarctica](https://www.frontiersin.org/articles/10.3389/fmicb.2018.03065/full). *Frontiers in Microbiology*, *9*, p.3065.

Zeigler, D.R., 2013. Review [The Geobacillus paradox: why is a thermophilic bacterial genus so prevalent on a mesophilic planet?.](https://www.microbiologyresearch.org/content/journal/micro/10.1099/mic.0.071696-0) *Microbiology*, *159*, pp.000-000.

Zeth, K., 2013. [Dermcidin: what is its antibiotic potential?.](https://www.researchgate.net/profile/Kornelius-Zeth/publication/248395579_Dermcidin_What_is_its_antibiotic_potential/links/0c9605228b3f40f7a7000000/Dermcidin-What-is-its-antibiotic-potential.pdf) *Future Microbiology*, *8*(7), pp.817-819.

Zhang, F., Lee, J., Liang, S. and Shum, C.K., 2015. [Cyanobacteria blooms and non-alcoholic liver disease: evidence from a county level ecological study in the United States](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4428243/). *Environmental Health*, *14*(1), pp.1-11.

Zhang, N. and Cao, H., 2020. [Enhancement of the antibacterial activity of natural rubber latex foam by blending It with chitin](https://www.mdpi.com/1996-1944/13/5/1039/htm). *Materials*, *13*(5), p.1039.

Zhou, B. and Shen, J., 2007. Comparison Of HEPA/ULPA Filter Test Standards Between America And Europe. In *Proceedings of Clima*

Zifa, A., 2016, [Opening and closing of stoma](https://commons.wikimedia.org/wiki/File%3AOpening_and_Closing_of_Stoma.svg)

Zubrin, R.M., 1996. [The significance of the Martian frontier](https://space.nss.org/the-significance-of-the-martian-frontier-by-robert-zubrin/). *Strategies for Mars: A Guide to Human Exploration*, *86*, p.13.

Zubrin, R. ["Contamination From Mars: No Threat"](http://www.freerepublic.com/focus/f-news/516795/posts), The Planetary Report July/Aug. 2000, P.4–5

Zubrin, R., 2016 starring in [episode 0 (making of) of season 1 of the National Geographic series Mars](http://channel.nationalgeographic.com/mars/episodes/making-mars/)