# Short Paper
## Subtitle

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**Abstract**

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*Keywords:* keyword1, keyword2

**Submission Note:** Paper prepared for the Microbiology (BT321IU) course, International University - VNU-HCM.

## 1. Introduction

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## 2. Microbes that Changed History

This section examines the all-encompassing influence of pathogenic microbes on human civilization, focusing on two specific agents that altered demographic, economic, and social structures globally.

### *2.1. The Black Death and* Yersinia pestis

The Black Death, a devastating pandemic caused by the bacterium *Y. pestis* that peaked between 1346 and 1353, serves as a primary example of microbial impact on human history. The disease is believed to have traveled along the Silk Road from Central Asia to Europe, facilitated by the expansion of trade routes and the movement of armies [1, 2]. Upon reaching Europe, the plague caused a demographic collapse of unprecedented scale, killing an estimated 50% of the population in affected regions of Europe and Asia [3, 4].

The massive loss of life triggered profound societal and economic shifts. The sudden scarcity of labor empowered the surviving peasantry, which led to the decline of the feudal system as workers demanded higher wages and better conditions [5, 6]. The psychological trauma of the pandemic also reshaped religious and social attitudes, manifesting in extreme movements such as the flagellants and the persecution of minority groups [7, 8].

The causative agent of the plague is the bacterium *Yersinia pestis*. The transmission cycle historically involved the black rat (*Rattus rattus*) and the rat flea (*Xenopsylla cheopis*) [9]. When the flea bites an infected host, the bacteria block the flea's digestive tract, causing it to regurgitate the pathogen into the bloodstream of a new host during subsequent feeding attempts [10]. While bubonic plague was the most common form, the pneumonic form allowed for direct person-to-person transmission—thereby accelerating the spread [11, 12]. Fig. 1 demonstrates in detail how the plague is spread.

### *2.2. Smallpox and Global Eradication*

Shifting focus to another microbial agent that fundamentally altered human history: Smallpox. Caused by the *Variola major* virus and carrying a fatality rate $\approx$ 30%, the disease played a decisive role in the colonization of the Americas. Following the arrival of Europeans, smallpox decimated indigenous populations, such as the Aztecs and Incas, who possessed no prior immunity [14]. This "virgin soil" epidemic killed tens of millions—perhaps up to 95% of

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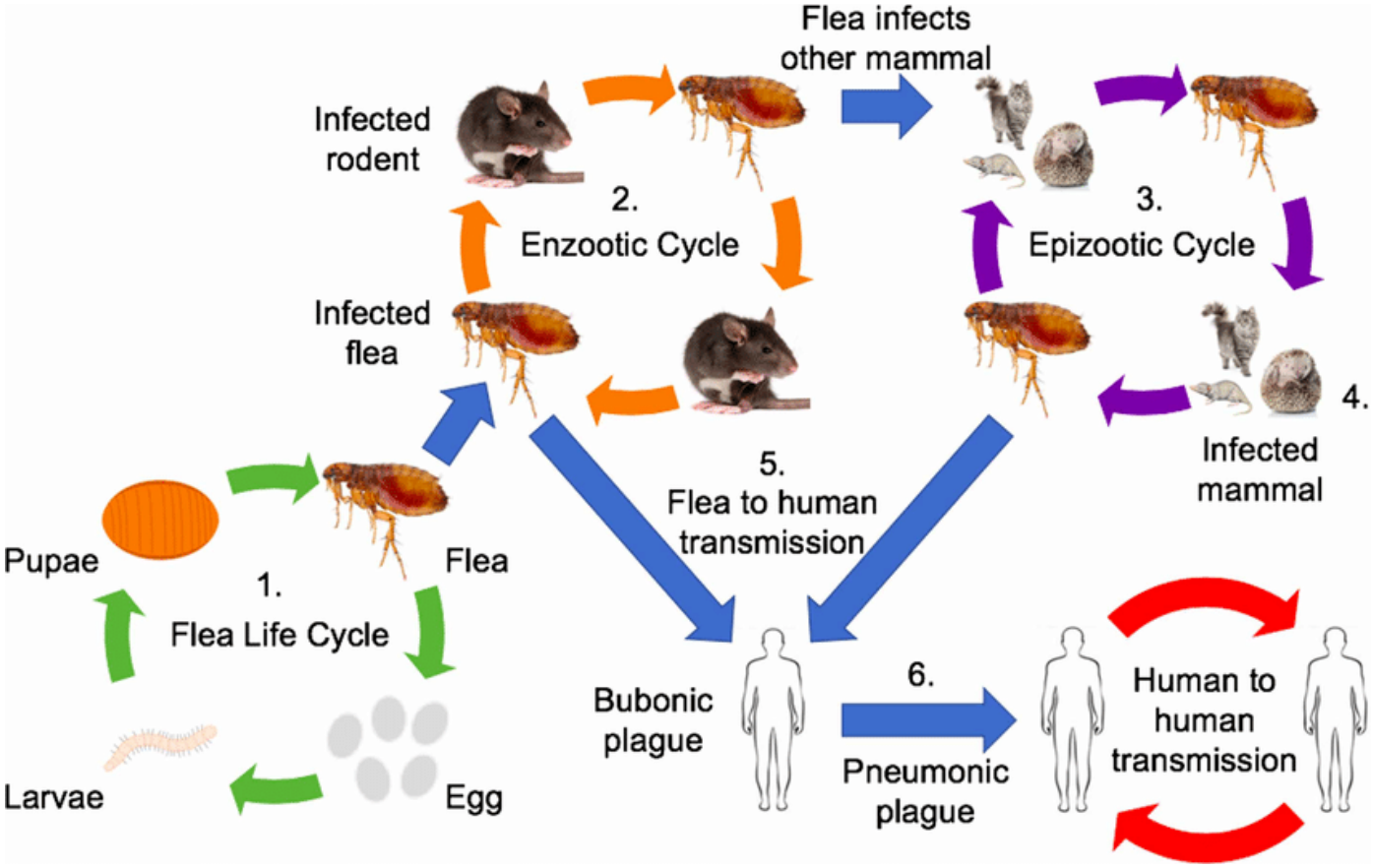



Fig. 1: Mechanisms of Plague (*Y. pestis*) Transmission and Disease Progression. The cycle begins with (1) the Flea Life Cycle: Eggs, laid in moist soil/burrows, hatch into larvae that feed on rodent feces and develop into pupae and adult fleas. Infected adult fleas parasitize rodents. (2) The Enzootic Cycle maintains *Y. pestis* among rodent hosts and reservoirs, primarily vectored by fleas (*X. cheopis*, *X. brasiliensis*, and *S. fonquerniei*). (3, 4) Epizootic Spills occur when fleas infect non-host mammals, which often lack resistance, rapidly succumb to the disease, and spread the plague geographically. (5) Human Zoonotic Transmission: Humans are typically infected via the bite of an infected flea from a rodent or secondary mammal host. (6) Human-to-Human Spread: Bubonic plague may progress to a highly contagious pneumonic plague via lung infection, enabling *Y. pestis* transmission through infectious respiratory droplets generated by coughing. Reproduced from Mackay-Alderson J, Quastel M, Wilson E, Bellamy D [13].

the indigenous population of the Americas—far exceeding deaths caused by warfare and facilitating the collapse of indigenous empires [15, 16]. Due to a lack of reliable data, historians continue to debate the true mortality rates and extent of casualties.

The fight against smallpox marked the birth of immunology. In 1796, Edward Jenner observed that milkmaids who contracted cowpox, a mild disease, were immune to smallpox. He tested this hypothesis by inoculating a young boy with material from a cowpox lesion and subsequently exposing him to smallpox; the boy remained healthy [17, 18]. Jenner's work established the principle of vaccination, a term derived from *vacca* (Latin for cow), replacing the riskier practice of variolatio, an earlier technique that intentionally induced a mild smallpox infection to confer immunity [19].

Smallpox holds the distinction of being the first and only human infectious disease to be eradicated. Following a massive global campaign by the World Health Organization (WHO) involving vaccination, surveillance, and quarantine, the disease was declared eradicated in 1980 [20, 21]. This achievement stands as one of the greatest triumphs of public health and microbiology.

## 3. Famous Microbiologists and Groundbreaking Discoveries

This section highlights the contributions of three pivotal figures whose work transitioned medicine from superstition to the scientific germ theory of disease.

### *3.1. Louis Pasteur: The Father of Modern Microbiology*

#### *3.1.1. Germ Theory*

Louis Pasteur, a French chemist, fundamentally changed the understanding of biology by disproving the theory of spontaneous generation. Through his elegant experiments using swan-necked flasks, he demonstrated that microorganisms in the air, not a "vital force," caused contamination in sterile broth [22]. Fig. 11 shows the setup of

this experiment. Pasteur's work laid the foundation for the germ theory of disease, which establishes that specific invisible microbes are responsible for specific illnesses [23].

#### *3.1.2. Pasteurization*

In addition to establishing the germ theory, Pasteur applied his knowledge of fermentation to solve problems in the French wine and silk industries. He discovered that heating liquids to a specific temperature (60–90°C) killed the bacteria responsible for spoilage without destroying the product. This process, known as pasteurization, revolutionized food safety and is still widely used today for milk and other beverages [24].

#### *3.1.3. Vaccine Development*

Pasteur also pioneered the development of laboratory-attenuated vaccines. He created vaccines for chicken cholera and anthrax by using weakened strains of the bacteria [25]. His most famous medical achievement was the development of the rabies vaccine in 1885, which he successfully used to save the life of Joseph Meister, a boy bitten by a rabid dog [26, 27].

### *3.2. Alexander Fleming: The Serendipitous Discovery*

#### *3.2.1. Discovery of Penicillin*

In 1928, Scottish bacteriologist Alexander Fleming made a serendipitous discovery that launched the antibiotic era. Upon returning from a holiday, he noticed that a mold, *Penicillium notatum*, had contaminated a Petri dish of *Staphylococcus* bacteria. Crucially, he observed that the bacteria surrounding the mold had been destroyed [28].

#### *3.2.2. Impact on Medicine*

Fleming identified the mold's active substance as penicillin. Although mass production was later achieved by Howard Florey and Ernst Chain during World War II, Fleming's discovery provided the first effective treatment for bacterial infections that had previously been fatal [29, 30]. Penicillin was hailed as a "miracle drug," saving millions of lives from wound infections and diseases like syphilis and pneumonia, though Fleming himself warned early on about the potential for antibiotic resistance [31].

### *3.3. Robert Koch and Koch's Postulates*

#### *3.3.1. Methodological Rigor*

Robert Koch, a German physician, is often considered the father of medical bacteriology alongside Pasteur. He introduced rigorous scientific methods to the field, most notably "Koch's Postulates." This set of four criteria is used to establish a causal relationship between a specific microbe and a specific disease: (1) the microbe must be present in every case of the disease; (2) it must be isolated and grown in pure culture; (3) inoculation of the culture into a healthy host must reproduce the disease; and (4) the microbe must be recovered again from the experimentally infected host [32, 33].

#### *3.3.2. Key Discoveries*

Using these methods, Koch identified the specific causative agents of several deadly diseases, including *Bacillus anthracis* (anthrax), *Vibrio cholerae* (cholera), and *Mycobacterium tuberculosis* (tuberculosis) [34, 35, 36]. His work provided the definitive proof for the germ theory of disease and established the standards for diagnostic microbiology [37].

## 4. Microbes in Art and Culture

This section explores the scientific mechanisms underlying microbial involvement in aesthetic and cultural domains, focusing on bacterial pigment production as a medium for art and the role of fungi and yeasts in pigmentation for textiles and sustainable dyes.

### *4.1. Bacterial Art (Agar Art/Bio-Painting)*

Bacterial art is a form of art resulting from the special combination of microbiology with the power of visual expression by utilizing the Petri dish as a living canvas. This form of art relies entirely on the underlying biological mechanisms by which certain bacterial species synthesize brightly colored pigments [38].

The medium consists of nutrient-rich agar plates, where different bacterial strains are inoculated and cultured to grow into intricate images. The colors are generated by chromogenic bacterial secondary metabolites produced through distinct metabolic and biosynthetic pathways [source: 39]. The strong and visible colors of these pigments make it easier for scientists and artists to isolate and identify the strains that produce the compounds in sufficient amounts.

Two examples of bacterial species employed in biopainting are widely studied for their distinctive pigment production. The first is *Serratia marcescens*, a Gram-negative bacterium that is also a producer of prodigiosin. Prodigiosin is a red pigment belonging to the prodiginine group, characterized by a tripyrrole chemical structure, and has been successfully used in textile coloring processes [40]. The second example is *Chromobacterium violaceum*. This strain produces violacein, a distinctive bisindole-violet or blue pigment [41]. Violacein and prodigiosin are well-known hydrophobic bacterial chromogenic pigments, and these two are responsible for the purple and red color phenotype of the bacterial strain. Fig. 2 shows the chemical structure and the colored phenotypes of the bacterial strains that produce these compounds.

By integrating microbiological techniques with the principles of aesthetic design, bacterial art blurs the traditional boundaries between science and art. Fig. 3 shows the representation of various colors producing microorganisms on a Petri plate. Fig. 8 shows agar art from living microbes. Those are examples of colorful bacteria applied to agar in an artistic manner (A-C) ASM Agar Art Contest winners.

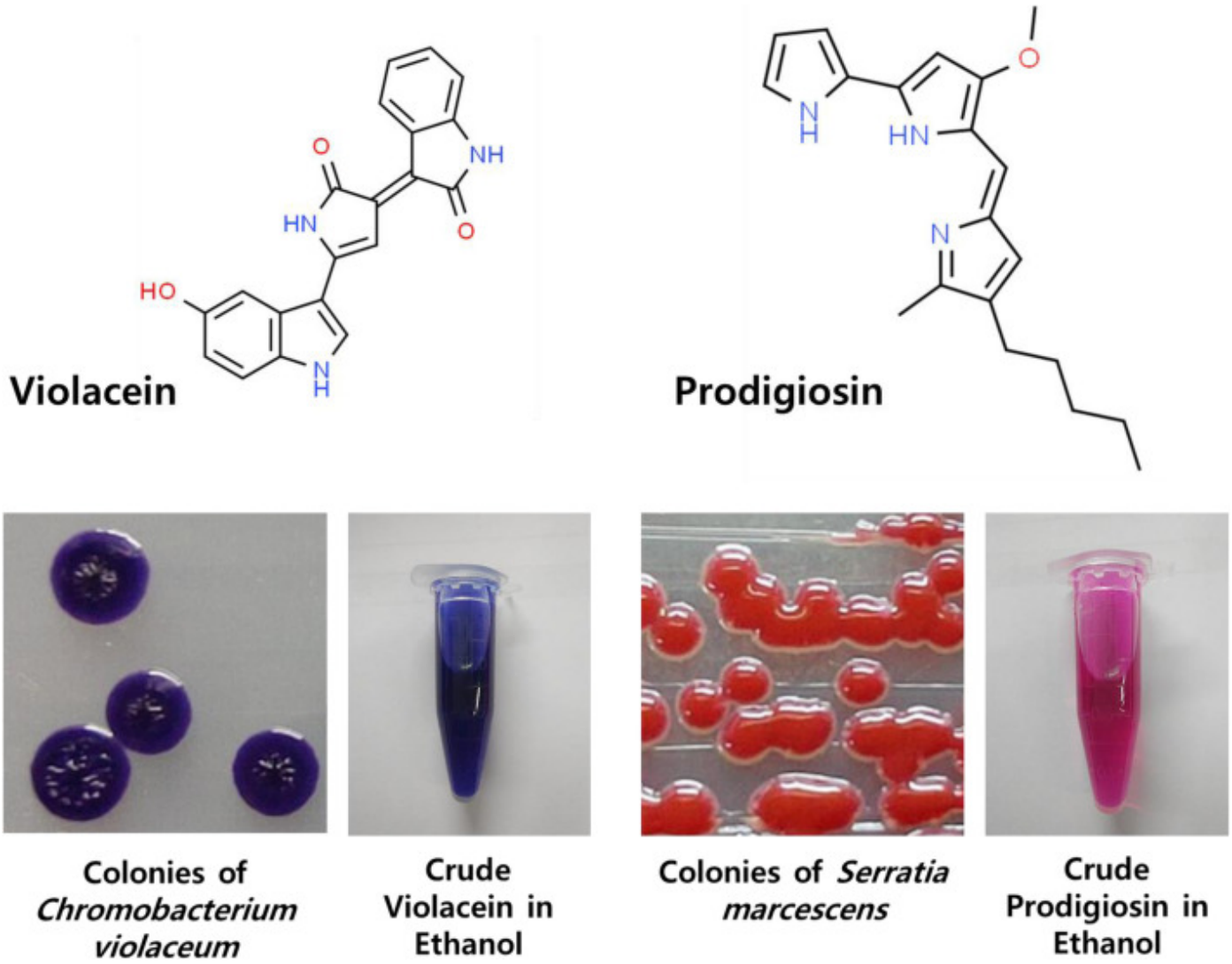



Fig. 2: Chemical structures of the bacterial pigments violacein (produced by *Chromobacterium violaceum*) and prodigiosin (produced by *Serratia marcescens*), shown alongside the respective colored phenotypes of the producing bacterial strains. Reproduced from Choi SY, Lim S, Yoon K, Lee JI, Mitchell RJ [39].

Fig. 9 shows The 2016 American Society for Microbiology Agar Art Contest winner, The First Race, illustrated fertilization using four pigment-producing bacterial species grown on selective agar. Created by Md Zohorul Islam (University of Copenhagen), the artwork used Staphylococcus aureus (red), S. xylosus (green), S. hyicus (white), and Corynebacterium glutamicum (yellow), with additional hues produced by mixing these microbes.

### *4.2. Fungi in Pigmentation and Textiles*

The rapid development of greener approaches in industrial processes, such as textile dyeing, has been driven by the environmental concern of synthetic dyes [42]. In this context, fungi have become a promising sources of natural pigments.

Fungi have shaped the history of natural dyes for centuries throughout history, with uses like ancient lichen dyes extracted from Roccella and Ochrolechia species for purples and violets. There were many traditional dyes made from lichens in the Scottish Highlands, including red dyes from the cudbear lichen (*Lecanoratartarea*), the common orange lichen (*Xanthoriaparietina*), and several species of leafy Parmelia lichens. During the 15th and 17th centuries, purple lichen dyes continued to play an important role in the European dyeing industry [43]. And today, the traditional practices have evolved into modern bio-dyes via fermentation to serve the demand of today's sustainable textile production demand [44].

From an industrial perspective, most fungal pigments are water-soluble, making production and extraction relatively straightforward. They can be easily cultivated and scaled up in industrial fermentation systems and can be harvested without the need for organic solvents, enhancing their sustainability and environmental compatibility (see Fig. 4).

Fig. 3: Representation of various colors producing microorganisms on a Petri plate. Reproduced from Tuli HS, Chaudhary P, Beniwal V, Sharma AK [40].

For reference, Table 1 shows List of fungal pigments produced on an industrial scale.

Fungal pigments cover a broad color spectrum, such as yellow, orange, red, purple, blue, brown, and black. Key producers are Monascus spp. (red, yellow, orange), Penicillium spp. (red, yellow, brown), Aspergillus spp. (yellow, brown), Fusarium spp. (pink, violet, red), and Blakeslea trispora ( -carotene) [43]. Numerous fungal genera have demonstrated efficient pigment production [46]. For instance, Penicillium brevicompactum can produce a mixture of yellow, orange, and red pigments [47]. While Penicillium purpurogenum generates red pigments with strong dyeing performance on fabrics such as wool, silk and polyester. Fig. 5 shows 3 effect of red pigment produced by Penicillium purpurogenum application on different fabrics (wool, silk, polyester, viscose). Furthermore, different fungal species with their active pigment for application in the textile industry are shown in Fig. 10. Fungal pigments have demonstrated successful dyeing performance on a wide range of textile materials, including cotton, linen, silk, and several synthetic fibers [48, 49].

### *4.3. Microbes in Fiction and Media (Optional)*

## 5. Bacteria in Space (Astromicrobiology)

Astromicrobiology investigates how microorganisms such as bacteria and archaea to survive, adapt, and behave under the extreme physical and chemical conditions found beyond Earth. This is crucial because many of Earth's microorganism, known as extremophiles already capable of thriving in hostile environments such as boiling hot springs, deep-sea hydrothermal vents, permafrost, acidic rivers, highly radioactive sites [50]. Their survival depend on their metabolisms and cellular structures evolved specifically for these extremes. Accurately simulating extraterrestrial ultraviolet (UV) radiation, which is significantly more intense and has a wider wavelength range than what reaches Earth's surface, is one of the main challenges in astromicrobiology [51]. The solar UV spectrum cannot be completely replicated in space by even the most powerful artificial UV generators on Earth. Simulation studies are nevertheless useful in spite of this drawback. As an illustration of how extremophiles might take advantage of the chemical environment of other planets, the acidophilic bacteria Acidithiobacillus ferrooxidans was found to grow successfully in simulated Martian regolith, even without additional nutrients. In true space conditions, however, the most informative results come from orbital experiments such as the ADAPT study, which exposed genetically UV-resistant Bacillus subtilis spores to space radiation in Low Earth Orbit (LEO) [52].

### *5.1. Extremophiles Defined*

Extremophiles are organisms, mostly bacteria and archaea, that not only survive but flourish in environments and conditions that were previously thought to be incompatible with life. The last point can be applied to a wide range of settings, including high pressure, temperature, pH, radiation, salinity, and nutrient availability, since they exist in severe habitats [53]. Extremophiles offer crucial insights about the boundaries of life on Earth and assist scientists in determining the potential habitability of alien settings since they live in such harsh circumstances.

Extreme settings can be either naturally occurring or man-made; these animals are just the result of evolution and the best adapted to their surroundings. Thousands of new species are found and named by scientists each year. Microorganisms have played a significant role in this massive expansion of species discoveries in recent years. Other terms that are used to categorize particular kinds of extremophiles include: Low pH acidophiles, high pH alkaliphiles, anaerobic extremophiles (anti-oxygen), cryophiles (thrive in cold temperatures), piezophiles (high pressure), psychrophiles (thrive in low temperatures), thermophiles (live in temperatures above 40°C), hyperthermophiles (above 80°C), xerophiles, methanogens, Toxitolerance Deep-sea hydrothermal vents, ice sheets and permafrost, volcanic systems and hot springs, salt pans and hypersaline lakes, and extremely acidic or alkaline waters are just a few examples of the various types of extreme conditions found in nature [54, 55]. According to National Geographic, around 1.2 million species have been identified around the planet, but some experts speculate that 8,7 million or more may exist [56].

By surviving in such environments, extremophiles reveal the true boundaries of Earth-based life. This helps astrobiologists evaluate the potential habitability of extraterrestrial environments such as Mars, Europa, Enceladus, or exoplanets, and understand the biochemical strategies that life might use elsewhere. Extremophilic habitats may occur naturally (e.g., hydrothermal vents, volcanoes, permafrost) or be produced by human activity (industrial

brines, highly acidic mining runoffs). Regardless of origin, extremophiles are the best-adapted products of evolution within these conditions [57].

### *5.2. Survival on the International Space Station (ISS)*

In the space experiment " Molecular adaption strategies of microorganisms to different space and planetary UV climate conditions" (ADAPT), bacterial endospores of the highly UV-resistant Bacillus subtilis strain MW01 were exposed to low-Earth orbit (LEO) and simulated martian surface conditions for 559 days on board the European Space Agency's exposure facility EXPOSE-E, mounted outside the International Space Station. These facilities allow biological samples to be exposed directly to Space vacuum, Full-spectrum solar UV radiation (>110 nm), Cosmic ionizing radiation, Rapid temperature cycling, Simulated Martian surface conditions [58].

One of the main goals of Mars exploration space missions is to find organic compounds on the planet's surface. Therefore, comprehending the preservation of organic matter in the Martian environment is a crucial step in interpreting future data obtained by these missions. The organic substances (glycine, serine, phthalic acid, phthalic acid in the presence of a mineral phase, and mellitic acid) completely degraded after a 1.5 year exposure to Mars-like surface UV radiation conditions in space. Under Martian surface conditions, their half-lives ranged from 50 to 150 hours. Amino acids and a dipeptide in pure form and embedded in meteorite powder were exposed to space conditions for eighteen months in order to study the chemical behavior of organic molecules in the space environment. The samples were then brought back to Earth and examined in a lab for reactions brought on by solar UV and cosmic radiation [59].

## 6. Conclusion

## 7. Abbreviations

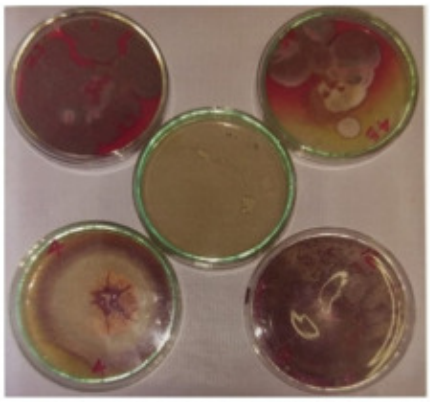
| Abbreviation | Full Term |
|---|---|
| PGx | Pharmacogenomic |
| DSA | Dolor sit amet |

## 8. Declaration of Competing Interest

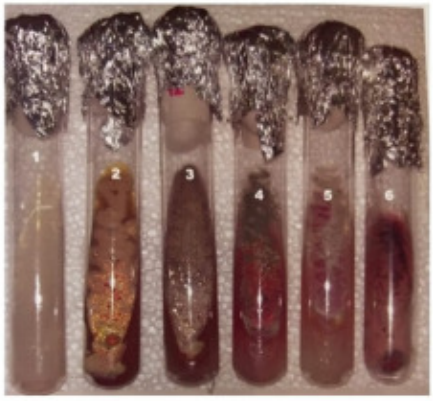
The authors declare no competing interests.

## 9. Data/Code Availability

The Quarto project underlying this paper—including the manuscript, figures, and bibliography—is available at https://github.com/ht2905/historical-microbes.



A) Growth of pigmented fungi in agar medium



B) Maintenance of pigmented fungi

1. Control
2. *Penicillium purpurogenum*
3. *Paecilomyces farinosus*
4. *Emericella nidulans*
5. *Fusarium moniliforme*
6. *Monascus purpureus*

C) Scale-up of pigment producing fungi in fermenter

Fig. 4: Scale-up process for pigment-producing fungi from laboratory culture to industrial fermentation. The process moves from initial isolation and growth in a Petri dish to larger-scale production. (A) Growth and visualization of pigmented fungi on solid agar medium (Petri dish). (B) Maintenance and preservation of the fungal strain for long-term use. (C) Scale-up of the culture in a liquid medium within a fermenter, which is a critical step for sustainable and high-volume industrial pigment production. Reproduced from Venil CK, Velmurugan P, Dufossé L, Renuka Devi P, Veera Ravi A [45].

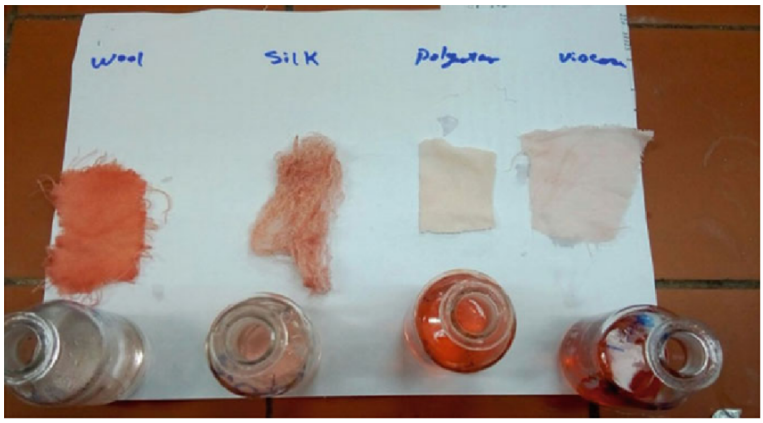



Fig. 5: 3 Effect of red pigment produced by *Penicillium purpurogenum* application on different fabrics (wool, silk, polyester, viscose). Reproduced from Elkhateeb W, Elnahas M, Daba G [49].

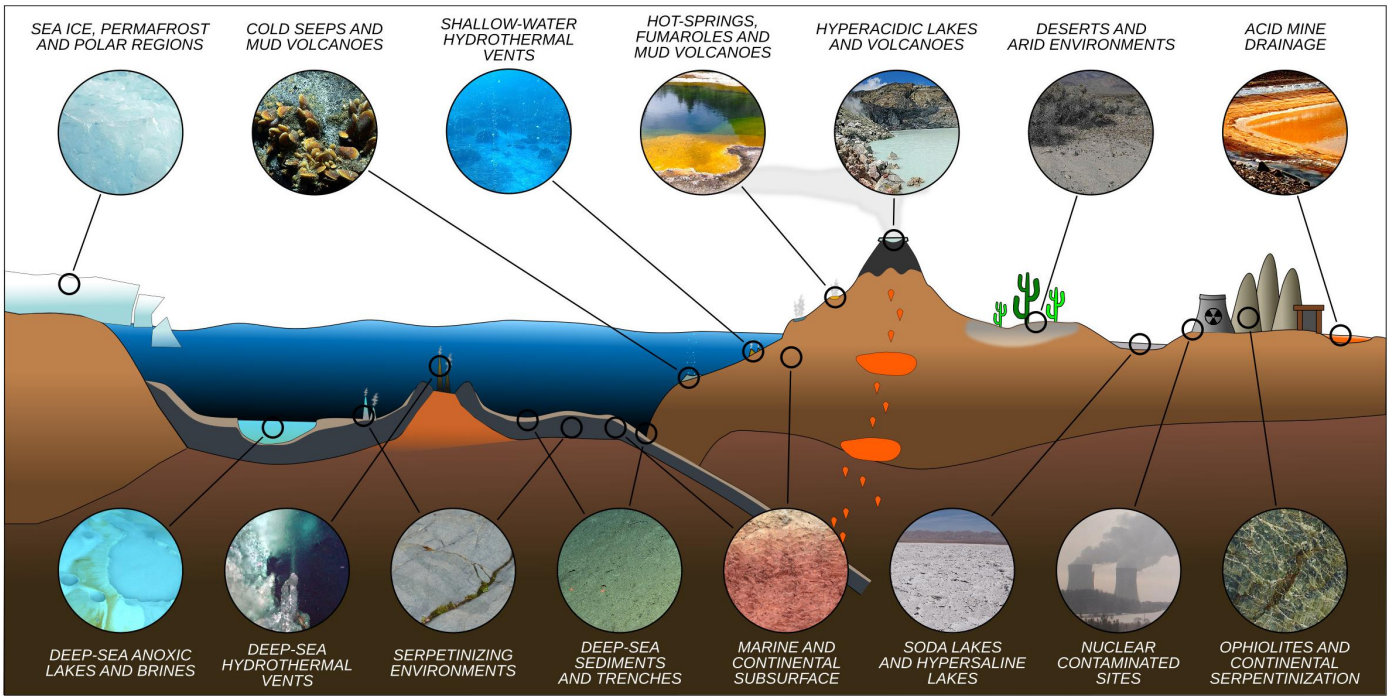



Fig. 6: Representative idealized cross section of Earth's crust showing the diversity of extreme environments and their approximate location. Reproduced from [54].

## 10. Appendix A: Supplementary Figures

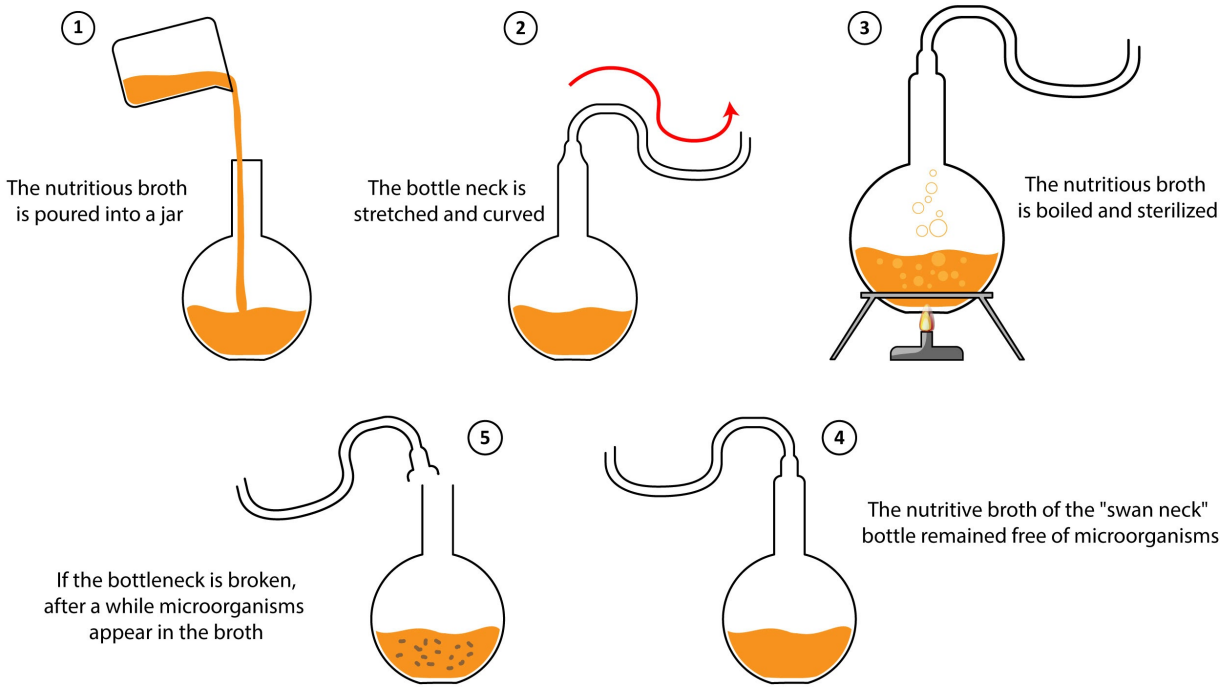



Fig. 7: Pasteur's swan-necked flask experiment illustrating how airborne microorganisms, rather than a "vital force," contaminate sterile broth. Reproduced from Shutterstock [60].

Table 1: List of fungal pigments produced on an industrial scale

| **Fungal species** | **Pigments** |
|---|---|
| *Monascus* species | Ankaflavin (yellow), monascorubramine (red), rubropunctatin (orange) |
| *Ophiocordyceps unilateralis* | Erythrostominone (red), 3,5,8-TMON (red) |
| *Blaskeslea tripora* | $\beta$-Carotene (yellow-orange), lycopene (red) |
| *Ashbya gossypii* | Riboflavin (yellow) |
| *Penicillium oxalicum* | Anthraquinone derivative (red), anthraquinones (red and other hues) |
| | Arpink red$^{TM}$, secalonic acid D (yellow) |

*Note. List of fungal pigments produced on an industrial scale, synthesized from Caro Y, Venkatachalam M, Lebeau J, Fouillaud M, Dufossé L [63].*

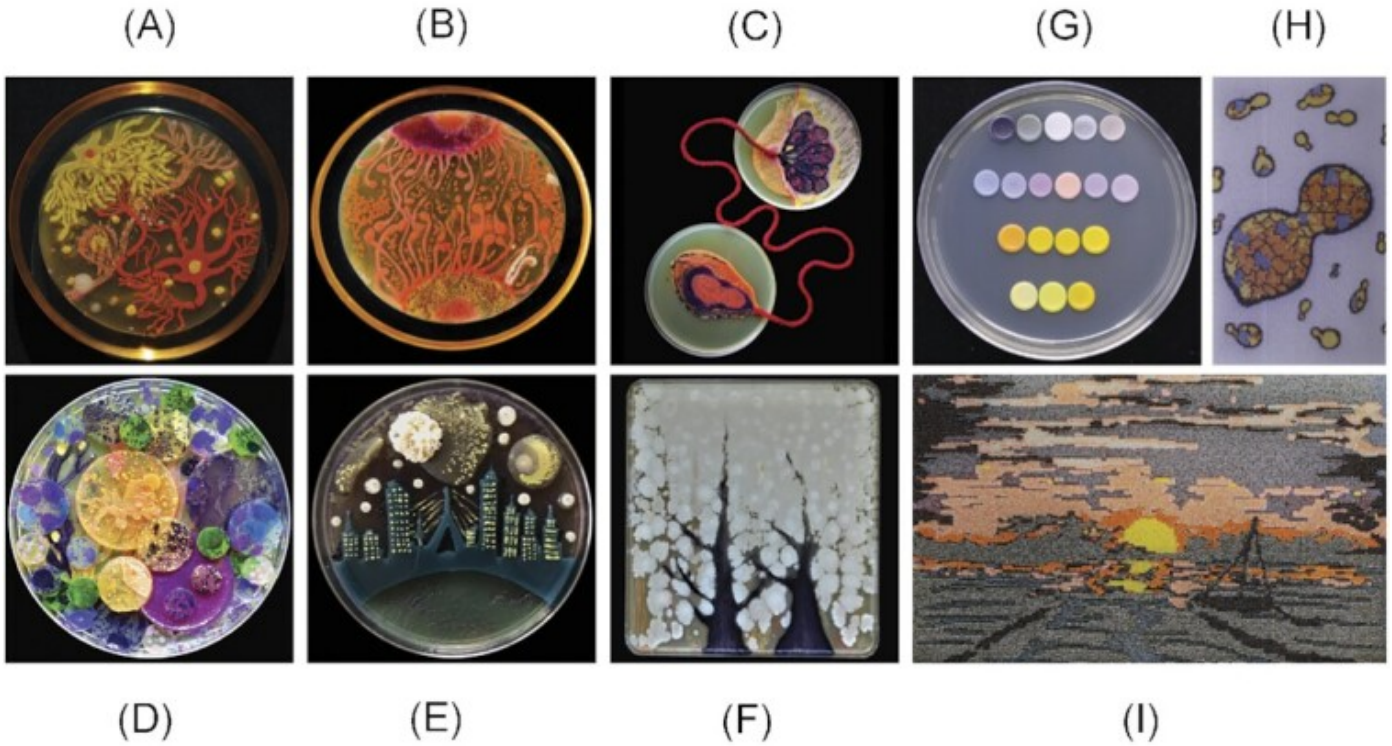



Fig. 8: Examples of Agar Art from Living Microbes. Panels (A-C) display winning entries from the ASM Agar Art Contest. (A) "Cell to cell" (2015) using yellow *Nesterenkonia*, orange *Deinococcus*, and *Sphingomonas*. (B) "Neurons" (2015) using red *Serratia*, yellow *Nesterenkonia*, orange *Deinococcus*, and *Sphingomonas*. (C) "Sustenance" (2018): (Top) pink colonies, orange *Nesterenkonia*, and *Deinococcus radiodurans*. (Bottom) Dark-violet recombinant *E. coli* (violacein pathway), red *Serratia marcescens*, and white *Bacillus*. (D) "Remainders": microbial paintings on food-colored agar plugs. (E) "Boston skyline" (2019): sculpted and collaged agar and bacteria. (F) "Bacillus surprise": dark-violet recombinant *E. coli* and white *Bacillus*. (G) A palette of colored recombinant yeast (*Saccharomyces cerevisiae*) expressing chromogenic proteins (black/grey/purple from violacein, blue from anemone gene, pink from RFP, and various yellows/oranges from beta-carotene). (H) "Puzzle Pieces" (2017) and (I) "Sunset at the End" (2016): patterns printed using engineered *S. cerevisiae*. Reproduced from Frankel E, Temple J, Dikener E, Berkmen M [61].

Table 2: Fungal pigments and their application in the textile industry

| **Fungi** | **Pigment** | **Color** | **Fabrics** |
|---|---|---|---|
| *Alternaria alternata* | Anthraquinones | Reddish-brown | Cotton |
| *Penicillium Oxalium* | Anthraquinones | Arpink red | Wool |
| *Chlorociboria aeruginosa* | Quinones | Green | Bleached cotton, spun polyacrylic, |
| *Scytalidium cuboideum* | | Red | spun polyamide, spun polyester, |
| *Scytalidium ganodermophthorum* | | Yellow | worsted wool |
| *Aspergillus* sp. | Quinones | Brown cotton | Silk, silk cotton |
| *Acrostalagmus* (NRC 90) | Quinones | Brown | Wool |
| *Alternaria alternata* (NRC17) | Quinones | Reddish-brown | Wool |
| *Alternaria* sp. (NRC 97) | Quinones | Brown | Wool |
| *Aspergillus niger* (NRC 95) | Quinones | Brown | Wool |
| *Bisporomyces* sp. (NRC 63) | Quinones | Deep brown | Wool |
| *Penicillium murcianum* | Cartenoids | Yellow | Wool |
| *Talaromyces australis* | 2,4-Di-tert-butylphenol | Red | Cotton fabric |
| *Phoma harbarum* | Magenta pigment | Magenta | Nylon |
| *Talaromyces verruculosus* | Polyketide | Red | Cotton fabric |
| *Monascus purpureus* | Rubropunctamine | Red | Wool |

*Note. Fungal pigments and their application in the textile industry. Adapted from Elkhateeb W, Elnahas M, Daba G [49].*

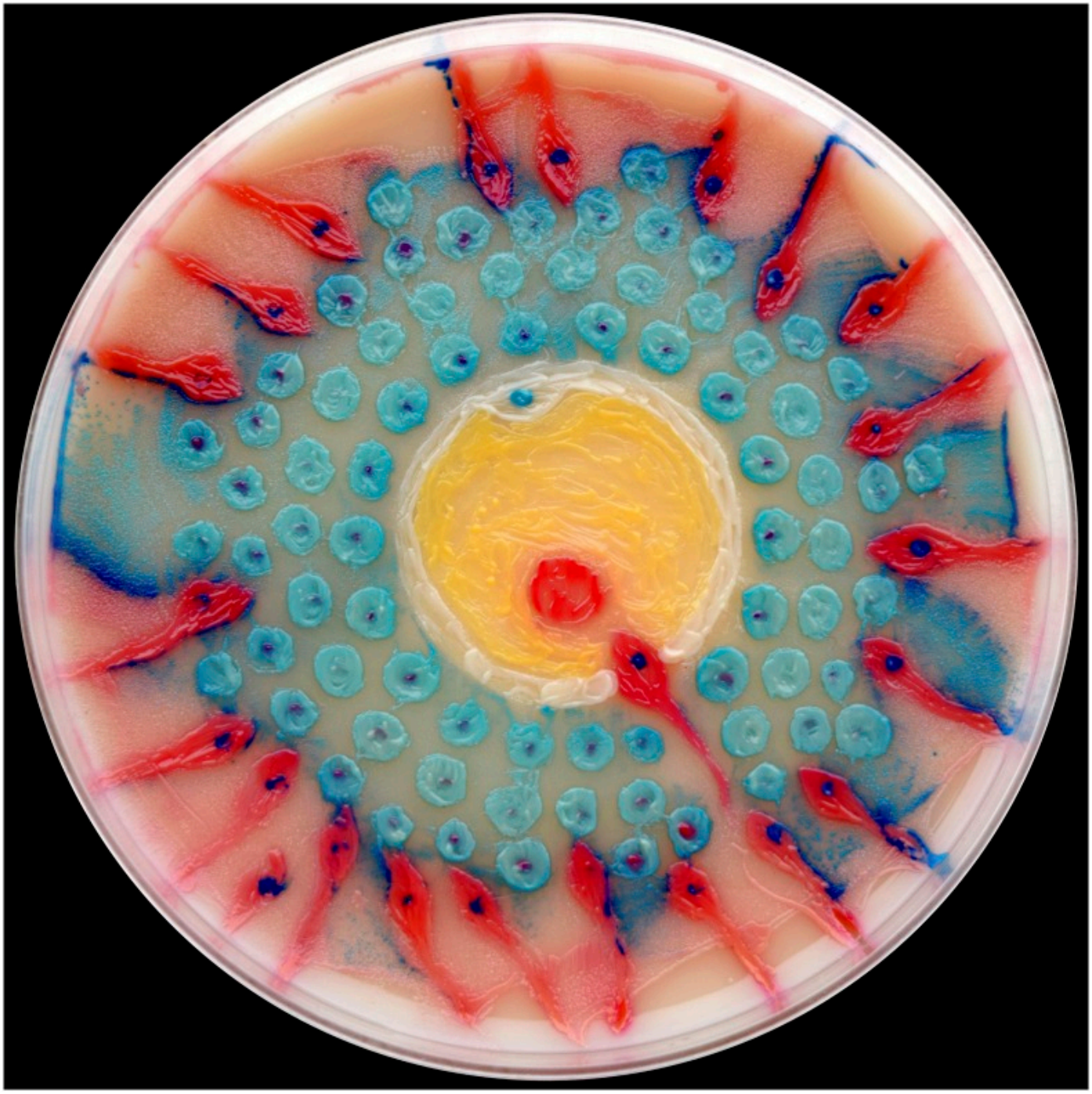
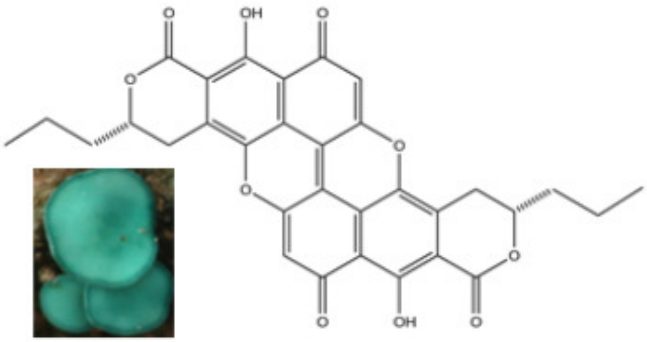


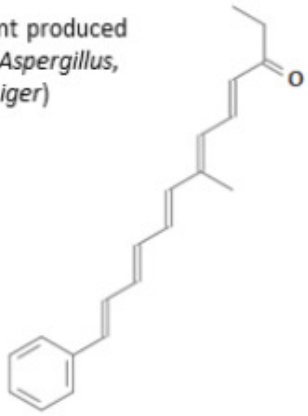
Fig. 9: The 2016 winner of the American Society of Microbiology's Agar Contest, titled The First Race, depicted fertilization. Graduate student Md Zohorul Islam of the University of Copenhagen "painted" with four bacteria on a selective agar canvas. The red was *Staphylococcus aureus*, a pathogen in both humans and animals. *Staphylococcus xylosus*, a commensal organism in human skin, generated green. The white was *Staphylococcus hyicus*, an animal pathogen responsible for grassy pig disease. And yellow came from *Corynebacterium glutamicum*, a bacterium used to produce amino acids, such as L-glutamate and L-lysine. Other colors came from mixing two or more of these microbes. Artwork by Md Zohorul Islam (University of Copenhagen, Copenhagen). Image courtesy of American Society for Microbiology. Reproduced from Madhusoodanan Y [62].

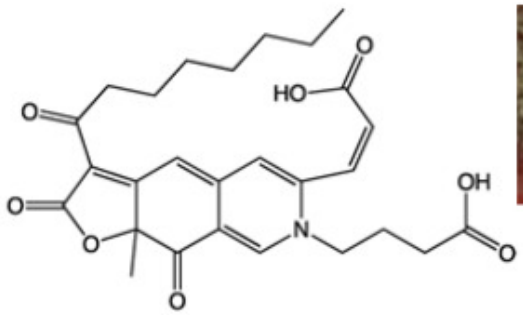




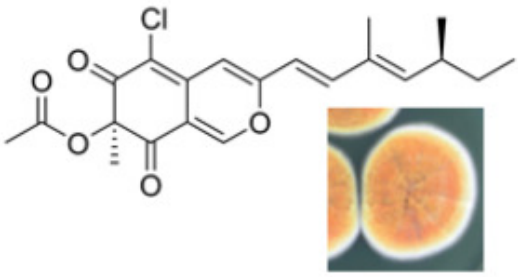
Xylindein (quinone pigment, dimeric naphthoquinone derivative, produced by fungi from genus *Chlorociboria*)

Asperyellone (pigment produced by fungi from genus *Aspergillus*, e.g. *A. awamori, A. niger*)



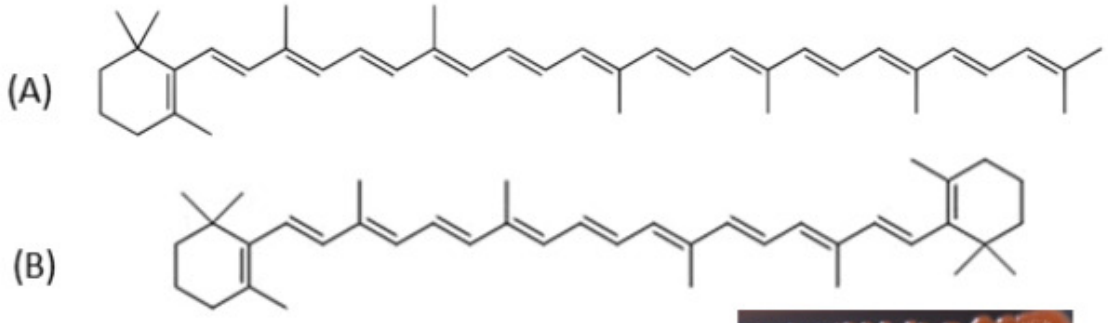


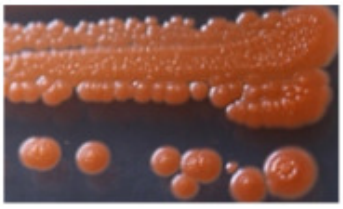
6-[(Z)-2-Carboxyvinyl]-N-gamma Aminobutyric Acid-PP-V (azaphilone pigment, produced by the fungus *Talaromyces albobiverticillius*)





Sclerotiorin (orange azaphilone pigment produced by fungi such as *Penicillium sclerotiorum*)





Torulene (A) and β-carotene (B) (carotenoid pigments, produced by the yeast *Sporidiobolus pararoseus*)

Fig. 10: Chemical structures of fungal pigments with potential coloring properties that could be used in textile dyeing. Reproduced from Venil CK, Velmurugan P, Dufossé L, Renuka Devi P, Veera Ravi A [45].

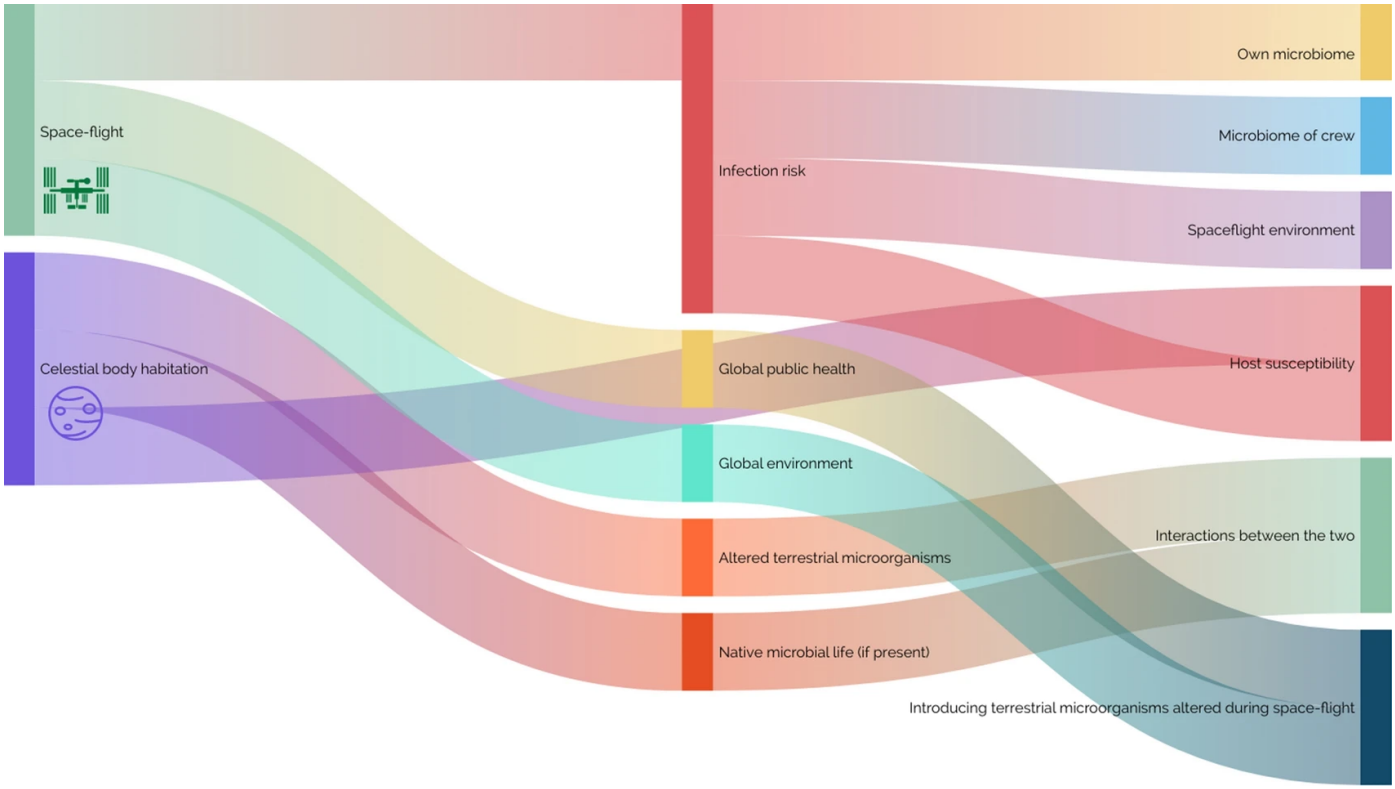



Fig. 11: A sankey diagram visualising the key medical astro-microbiology considerations relating to spaceflight and celestial body habitation. Reproduced from McDonagh et al. [64].

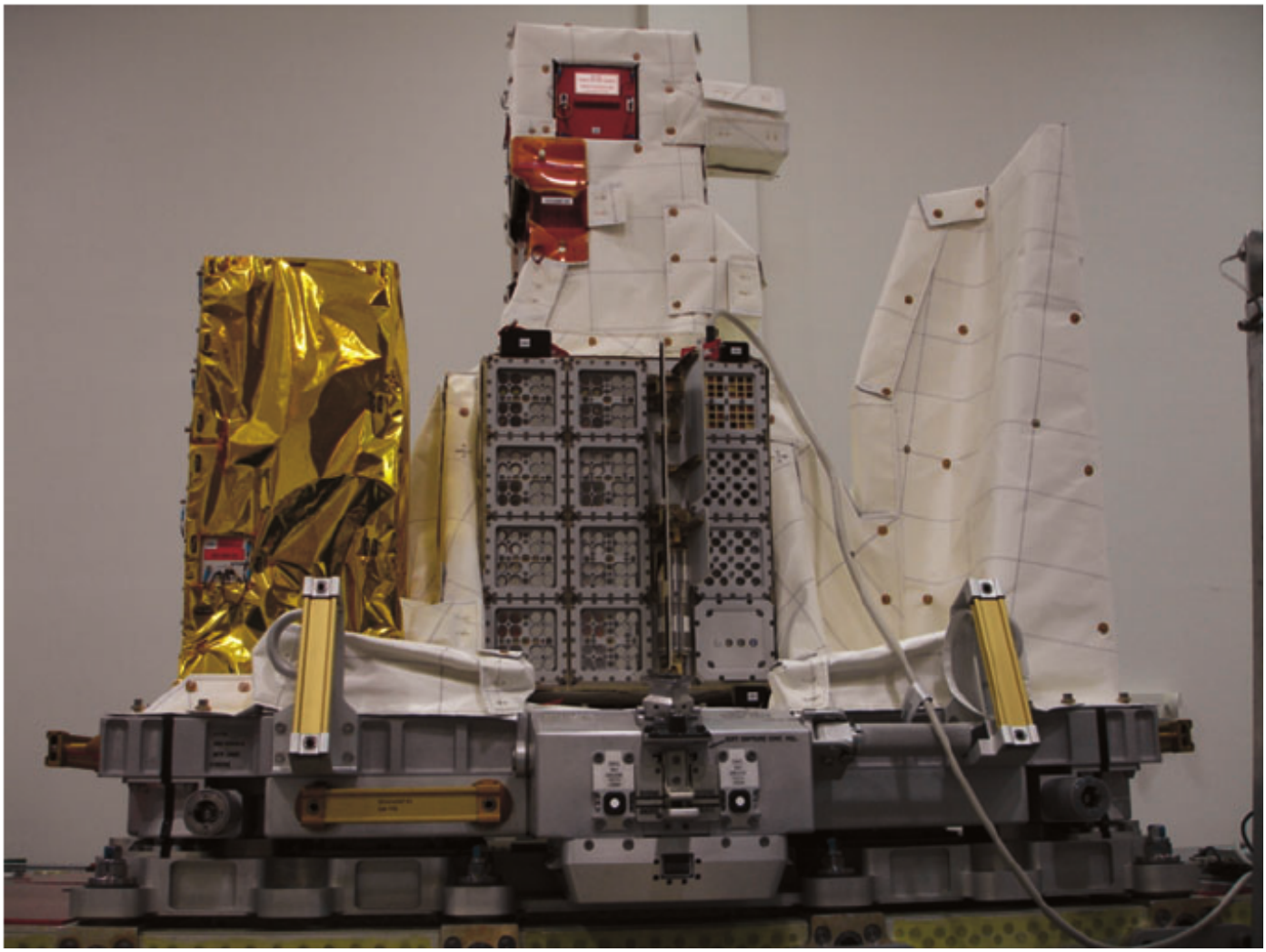


Fig. 12: EXPOSE-E payload, fully integrated and accommodated onto EuTEF at Kennedy Space Center, USA. Arranged vertically from left to right are tray 1 and tray 2—experiments in the four compartments of both trays from bottom compartment to top are ADAPT, PROTECT, $\frac{1}{2}$ ADAPT, and $\frac{1}{2}$ PROTECT sharing the third compartment and LIFE in the top compartment; on the right, separated from tray 2 by the three open lids and their motor drives, is tray 3 with R3DE in the bottom compartment, two compartments with PROCESS, and the top compartment with SEEDS. On the right half of each compartment of trays 1 and 2 the mirroring effect of the 0.1% ND filters can be seen. On the left side of EXPOSE-E, the experiment MEDET (wrapped in golden multilayer insulation) is located. Reproduced from Rabbow E et al. [58].

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