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Ēngines of Ēternity: An Artistic Inquiry into Space Settlement Ideology Using Rotifer Experiments on Board the ISS

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Abstract

Ēngines of Ēternity is a transdisciplinary project that takes the biological phenomena of cloning and DNA repair as metaphorical departure points for an art installation about humanity's enthrallment with cultural immortality. Cultural immortality has long fascinated humankind, with such diverse examples as Ancient Egypt, the Roman Empire, Hindu kingdoms, and Mayan civilization, all assuming perpetuity through monumental works in art and architecture. This aspiration of cultural immortality is also deeply embedded in the imaginary of space exploration. Space settlements are often presented as the culmination of technological and cultural evolution. However, the quest for cultural immortality is often imbued with conflict because of convictions of superiority and impulses of colonialism, and this will be no different in outer space. Ēngines of Ēternity explores these human tendencies through the lens of the smallest animals on Earth, rotifers. On the surface, rotifers seem an unchanging biological culture, perfected through evolution, cloning itself endlessly, and surviving extreme conditions such as complete drying or freezing. However, during drying and rehydration, genetic material gets broken and repaired again, and in the process, diversity is generated. Moreover, DNA from totally different organisms such as fungi, bacteria and plants were discovered inside the rotifer's genome. This horizontal gene transfer is another mechanism through which rotifers seek out diversity. In Ēngines of Ēternity it's precisely this contrast between stasis and flux that is used as a metaphorical device to reflect critically on the aspirations of humankind in space. What concept of culture and identity will we develop in space? Who will have a say in this? And if we end up with a rich diversity of cultures and identities, how will we maintain cohesion? Ēngines of Ēternity is a joint effort between SEADS and the laboratory of Karine Van Doninck (UNamur/ULB). In a series of space biology experiments, rotifers were sent to the ISS in 2019 and 2020. SEADS sent a series of thumb-printed glyphs along with the rotifers. This code formed the algorithmic seed for an evolving artwork. After each space mission genetic data of the rotifers was used to parametrically evolve the art. As such, Ēngines of Ēternity engenders new forms of co-creation between humans, biological organisms, algorithms, and outer space. In this paper, the core concepts of the Ēngines of Ēternity project are presented, together with reflections on transdisciplinary research and the need for a more holistic perspective on our future in outer space.

1. Introduction

Cultural immortality has long fascinated humankind, with such diverse examples as ancient Egypt, the Roman Empire, Hindu kingdoms, and Mayan civilisation, all assuming perpetuity through monumental works in art and architecture [1,2,3]. This aspiration of cultural immortality is also deeply embedded in the imaginary of space exploration [4]. Space settlements are often presented as the culmination of technological and cultural evolution. The visions about life in space that are promoted by space entrepreneurs Elon Musk and Jeff Bezos are characteristic examples of this. Elon Musk talks about bootstrapping civilisation on Mars as a backup for humanity, but without oversight of any current government. He advocates for a direct democracy with simple laws instead—an extraterrestrial libertarian utopia [5]. Bezos talks about monumental free-floating space settlements, with the goal to transfer all heavy industry there, in order to let Earth regenerate itself [6]. Paradoxically, the images that are supposed to illustrate this do not show heavy industry but are idealized landscapes featuring corporate urbanism, Americana, and European exoticism [7]. Such ideas about space settlement have a long tradition, and go back, for example, to Gerard K. O'Neill and his visions of rotating space colonies in the 70s [8]. Further back in time, Cosmism was an influential 19th century Russian movement that believed that outer space was the territory of infinite resources and immortal life [9]. The spread of humanity throughout the Cosmos was considered an imperative to restructure all of humanity [10].

All these visions share the same belief that outer space is the place where humanity will find its ultimate social and cultural destiny. However, quests for ultimate societies and cultural immortality are often imbued with conflict, because of competing convictions of superiority and impulses of colonialism, and this will be no different in outer space. In this paper, we describe how the Ēngines of Ēternity art project explores these human tendencies through the lens of the smallest animals on Earth, rotifers. We describe a series of space biology experiments with rotifers on board the International Space Station (ISS) and how SEADS—a transdisciplinary, cross-cultural collective of artists, scientists, designers, and activists—was invited to engage with these experiments. We describe the experimental, exploratory, speculative, and reflective processes that we undertook as part of this collaboration, and detail the artistic elements that resulted from these, consisting of photographs, drawings, abstracted diagrams, a video essay, sculptures, and objects. These are composed into varying large-scale installations. The elements of this installation—all of which take rotifers and the ISS experiments involving them as their departure points—bring together variety of scientific and creative processes that the Ēngines of Ēternity team has been developing over the past few years. We conclude by describing the unique contributions of Ēngines of Ēternity to the growing body of artworks that engage with space and the future of humankind in it.

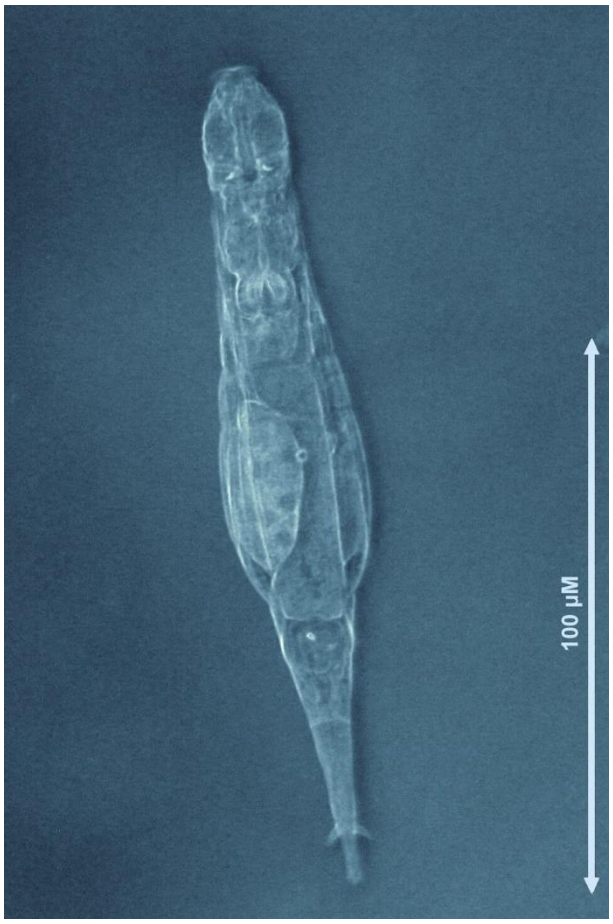

Fig. 1. Bdelloid rotifer *Adineta vaga*. Photo: Boris Hespeels.

2. Rotifers and the RISE project

Bdelloid rotifers are microscopic animals consisting of only females that have been cloning themselves for millions of years. They are cosmopolitan, live in limno-terrestrial environments such as mosses and lichens, and appear to be extremely stress tolerant. Their desiccation tolerance at any stage of their life cycle is known to confer tolerance to a variety of other stress factors, including high pressure, vacuum, freezing and large doses of ionizing radiation (such as X-rays, protons, Fe particles) [11]. It has been demonstrated that prolonged periods of desiccation induce DNA double-strand breaks in the bdelloid rotifer *Adineta vaga*, just like ionizing radiation does [12]. After rehydration or exposure to ionizing radiation, *A. vaga* individuals start

reconstructing their genome, and up till radiation levels of 500 gray they can continue reproducing themselves [11]. This suggests the presence of an efficient DNA repair mechanism both in their somatic and germline nuclei [13] and, more importantly, a very efficient antioxidant system protecting the proteins (including the DNA repair proteins). Cosmic radiation is one of the greatest dangers faced by living organisms traveling in space and this type of radiation includes ionizing radiation causing DNA damage [14]. Therefore, having a model organism such as the bdelloid rotifers that can survive extreme radiation conditions by protecting their proteins and repairing the associated damage could help understand how organisms might adapt to survive beyond our planet. To study these notorious creatures, the RISE (Rotifer in Space) project has designed scientific experiments with *A. vaga* as model system on board of the ISS [15]. These experiments aim to contribute significantly to an understanding of microgravity and radiation effects on biological processes that are directly relevant to humans in space. The experiments are relevant to better understand resistance to space environments, and unravel the mechanisms involved in protein protection, DNA repair and oxidative stress processes, an essential component of aging.

In December 2019, hydrated *A. vaga* individuals were launched on the SpaceX CRS-19 mission and cultivated on board the International Space Station. This space-flight experiment—called RoB1—investigated the cumulative effect of microgravity and space radiation encountered by astronauts, on the biological pathways of *A. vaga*. Autonomous cultures of hydrated *A. vaga* individuals were successfully exposed to the ISS environment for 12 days. Back on Earth (January 2020), the RISE team performed a complete transcriptomic analysis, comparing *A. vaga* individuals maintained on Earth vs. the ISS (all coming from the same clone). One more spaceflight experiment was carried out in December 2020, and the third one is foreseen for 2024 or later.

3. Collaboration between RISE and SEADS

SEADS (Space Ecologies Art and Design) was invited by co-author and RISE principal investigator Karine Van Doninck to create an artwork inspired by the RISE experiments. SEADS is a transdisciplinary and cross-cultural collective of artists, scientists, engineers, and activists. Its members come from all corners of the world—from Belgium, the Netherlands, UK, Austria, Portugal, Iran, Afghanistan, the Philippines, Malaysia, Colombia, Brazil, and the US. SEADS actively

Fig. 2. Launch of the SpaceX CRS-19 resupply mission to the International Space Station on December 5th, 2019. The cargo contains the RoB1 experiment with the Ēngines of Ēternity art project. Photo: Angelo Vermeulen.

deconstructs dominant paradigms about the future and develops alternative models through a combination of critical inquiry and hands-on experimentation [16]. The collective had already created previous art projects related to the theme of space exploration, such as First Room for MELiSSA (2010), Seeker (2012-2018), and the Space Farming Project (2018) [17,18,19].

A concept was conceived and gradually developed by a team of a dozen SEADS members. It was decided to create an artwork that would travel to space, along with the rotifer space biology experiments. This became the starting point for a multimedial and multilayered art project that juxtaposes the characteristics of the rotifers with reflections on the future of humankind in outer space. The project was named Ēngines of Ēternity—as a reference to one of its core themes, cultural immortality. The current paper focuses on the contribution of SEADS to the first experiment on board the ISS (RoB1).

4. Ēngines of Ēternity

Ēngines of Ēternity (ĒoĒ) encapsulates the entirety of the processes (experiments, explorations, conversations) and outcomes (artifacts, media, texts) related to the collaborative engagement between SEADS and RISE. In order to communicate the results of this collaboration, we describe four general areas of exploration in ĒoĒ: (1) engaging with the launch of the rotifer samples to the International Space Station; (2) analyzing the impact of space on these samples and integrating the resulting transcriptomic data in the evolving art work, using custom-coded data visualization; (3) translating this into 3D printed sculptures using both data-scientific and data-aesthetic approaches, and (4) developing an integrative, critical, collaborative perspective on the broader themes of the project. We then describe how these processes each led to the creation of specific elements that are combined into varying art installations.

Fig. 3. Applying a thumb-printed glyph to one of the specimen bag labels at NASA Kennedy Space Center, right before the launch of the SpaceX CRS-19 mission. Photo: Angelo Vermeulen.

Fig. 4. Label with thumb-printed glyph, NASA Kennedy Space Center. Photo: Angelo Vermeulen.

4.1. Sending Ēngines of Ēternity to the ISS

SEADS decided to create an art project that could be sent along with the RISE experiments to the ISS. For the RoB1 experiment it was decided that this could be done via the specimen bags containing the rotifers. A very limited amount of space was made available– essentially a 1 by 1 centimeter square on the identification label of each bag. Because of the

Fig. 5. ESA astronaut Luca Parmitano handling the RoB1 experiment containing the Ēngines of Ēternity art project, on board the ISS. Photo: ESA.

restrictions of the experimental setup and space cargo in general, there were many constraints about what we could actually send. We had brainstormed a few ideas, including printing text in various languages. In the end, we decided to put an abstract glyph that references the infinity symbol and part of the DNA double helix, the archetypal symbol of life. The glyph was physically hand-printed by a SEADS member (and lead author of the paper) as a stenciled thumbprint (Figures 3 and 4). In this way, SEADS and the ĒoĒ project were sent to space in a material way, alongside the rotifer samples.

The printing was done at the Kennedy Space Center Payload Processing facilities, three days before launch, when the RISE team was filling the specimen bags with rotifer individuals. Because of the variability in inking and printing, each thumb-printed glyph was different, generating a series of unique identifiers. Each specimen bag, containing 10.000 rotifers and the ĒoĒ artwork, was placed inside one of two custom-made metal containers by Kaiser Italia. Once on board the ISS, an astronaut placed these containers in a temperature-controlled Kubik facility (Fig. 5). When the experiment was completed, the containers and their content were frozen before being sent back to Earth in January 2020. This was done with the same SpaceX CRS-19 cargo ship that brought the experiment to the ISS.

4.2. Analyzing the impact of space

The RISE team shared the experimental data with data with SEADS. The data represents the difference in gene expression of *A. vaga* rotifers on ISS compared to the ones on Earth. SEADS received transcriptomic data of sixteen rotifer specimen bags—eight that went to space and eight that remained on Earth. The processing of the raw transcriptomic data (i.e., aligning and performing differential expression analyses) uncovered how much each gene (the encoders of proteins) was expressed. We proceeded by aggregating the data of all rotifer bags that remained on Earth by taking the mean of those bags' values for each transcript. As such, we generated one single control. For each transcript, the value of the inferred control was subtracted from the value in each bag that went to space. In this way, it became clear which transcripts seemed to be a clear response to the space conditions. However, at that point, these were mere values without further meaning. In order to make sense of the observed differences, we turned to gene ontology (GO) [20]. GO allowed us to provide information on the functions of rotifer genes on three distinct levels: molecular functions, cellular components, and biological processes. The mapping of genes to GO was done using BioMart [21]. At this point we were able to arrange the variation between all transcripts in each bag, according to the ontology's hierarchy, ensuring that the approach didn't ignore

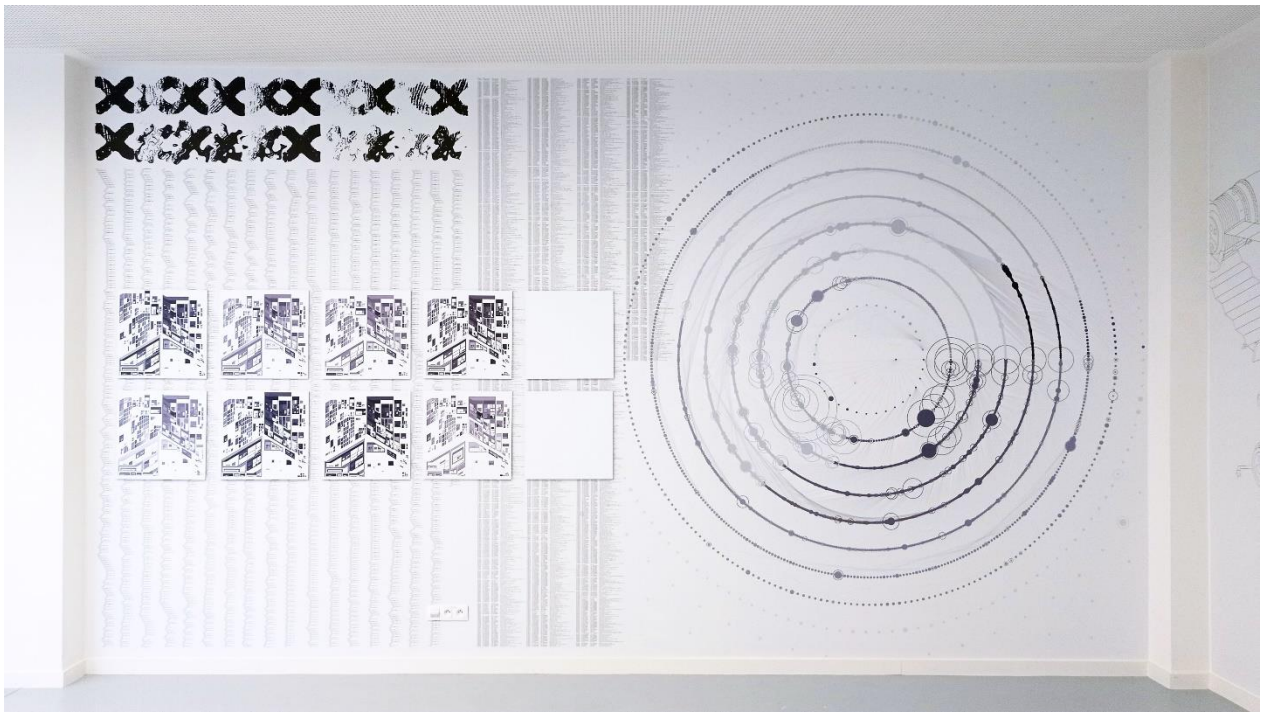

Fig. 6. SEADS, Ēngines of Ēternity, installation view at Pilar, Brussels, 2022. The wall print shows the various stages of the analysis of the transcriptomic data. Thumb-printed glyphs at the top left, tree maps on the square panels on the left, screenshot of the digital visualization tool on the right. Graphic design by Victor Steemans & Pieter Steyaert. Photo: Angelo Vermeulen.

biologically meaningful relations. The team then translated the data into a visual format for two distinct purposes. First, a series of exploratory visual representations was produced to gain a deeper understanding of the data and to detect patterns and relationships. This resulted in a series of graphics that showcases the underlying structure and interaction network topology of gene product attributes. The graphics also show differences between gene expressions of the rotifer organisms that went to space compared to the average gene expressions of the control group on Earth. The visualizations were put together in an interactive digital tool which allowed the user to explore the raw data in a structured format by means of a combination of a dendrogram and a multi-layered bubble chart. A selection of these exploratory visualizations, including a screenshot of the interactive tool, is shown in Fig. 6.

Based on the acquired understanding of the structure and the relationship between clusters of differences in gene expressions, a second series of visualizations was produced. These visualizations served as a vital tool to evolve the original thumb-printed glyphs, the artwork that was sent to space printed on the rotifer specimen bags. Considering that GO is organized in a hierarchical tree structure, a natural way to visualize the data is by representing it in treemaps. This is exactly the approach we took, by representing descendants in the hierarchy by contained surfaces. We could then easily display the differential expression values by using a color scheme; bigger differences are represented by darker surfaces, while small differences are brighter. As with the first series of data visualization experiments, this approach clusters gene expressed values that are functionally related to each other. The main difference between both series of visualizations is the intent. The first series is strictly exploratory in nature, the second series is designed to algorithmically evolve the artwork.

The data visualizations were at a later stage graphically adapted to be included in a large-scale composite mural, in combination with an export of the raw data in structured format (Fig. 6 and Fig. 9). This offers the visitor an impression of the underlying science and interconnectedness of the data, and provides a window on some aspects of the artistic research process. What is particularly interesting about this data is that they represent the immediate effects of the space environment on genetic information, which is then translated into an artistic outcome. Or, put differently, in

Fig. 7. SEADS, Ēngines of Ēternity: Data Monument, Pilar, Brussels, 2022. The Data Monument consists of two 3D printed sculptures that represent the interaction between rotifers, genetic transcription, spaceflight, and algorithms. Photo: Angelo Vermeulen.

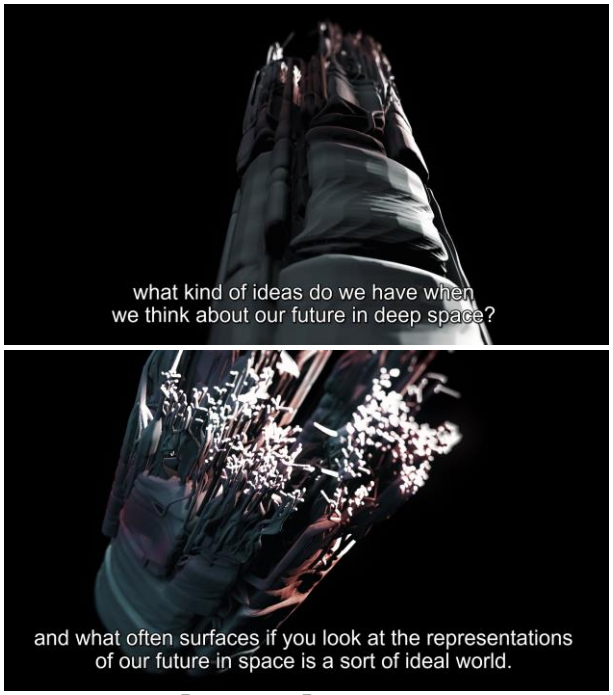

Fig. 8. SEADS, Ēngines of Ēternity: Eagerness for the Alien, 2022, digital video, color, sound, 24 minutes 7 seconds. Video stills.

creating art that is based on altered gene expression in space, we are inviting space itself as a co-creation agent.

4.3. Evolving Data Monument

The next step was to use the data from the space experiment to re-shape the original artwork (the thumb-printed glyph) by both the space environment and the rotifers. Eight out of ten glyphs were matched with their corresponding transcriptomic datasets (the rotifers of two specimen bags were not analyzed because of redundancy). The higher the impact of space on gene expression, the more the glyphs would be morphed. This was done by overlaying each glyph with its corresponding visual gene ontology map. The genes that showed a stronger difference in expression in space in comparison to Earth were dark colored on the gene ontology map. Through a gravity-inspired algorithm, these areas would excerpt a pulling force on the underlying area of the glyph.

Both the original set of glyphs and the 'evolved' ones were then used to generate two 3D sculptures, conceived together as the 'Data Monument'. One sculpture represents the reference before launch, the other sculpture incorporates the effects from space. This was achieved by laying out each string of 10 glyphs in a circular fashion and then vertically extruding the resulting pattern using a custom-coded algorithm. Consequently, ĒoĒ became an artwork *de facto* co-created by humans, rotifers, algorithms, and outer space.

4.4. Critical, cross-cultural dialogue

Ēngines of Ēternity: Eagerness for the Alien, written and directed by SEADS, is a video essay that takes the unusual biological characteristics of rotifers as the start of a meditation on ideological conflict, cultural exceptionalism, and contested visions of human civilization in space. Featuring digitally generated visuals, Eagerness for the Alien reflects on the competing impulses for stability and change, and how this tension might subsequently shape the future of human societies.

Much as a journey into the harsh conditions of outer space might alter the genetic composition of rotifers, so might long-term travel to and settlement in space shape human societies. The jumping-off point for the discussion is rotifers' capacity for horizontal gene transfer. When rotifers are desiccated, their genetic material breaks. However, when rehydrated, rotifers manage not only to repair their own DNA; during the repair process, they seem to assimilate genetic material from foreign organisms (such as fungi, bacteria, and plants) [22]. Thus, while rotifers are able to endlessly 'preserve' copies of their genetic material through cloning, they also appear to take advantage of horizontal

Fig. 9. SEADS, Ēngines of Ēternity, installation view at Pilar, Brussels, 2022. Photo: Ulrike Kuchner.

gene transfer to breed diversity and adapt. Eagerness for the Alien reflects precisely on this contrast between stasis and flux as a metaphorical device to reflect critically on the aspirations of humankind in space. What concept of culture and identity will we develop in space, and who will have a say in this? If we end up with a rich diversity of cultures and identities, how will we maintain cohesion? What foreign 'Other' might we have to incorporate and integrate in order to create stability? In other words, what insights might rotifers reveal about evolving and maintaining a sustainable future for human habitation in space? The dialogic format of the video essay allows for an exploration of such questions. Eagerness for the Alien integrates the various ideas that had been constructed throughout the project, even as it charts new directions for multidisciplinary exploration.

One of the central concepts that is explored in the project is the human yearning for cultural immortality—an enduring importance and often superiority of one's own culture—and how outer space is characteristically used to create a futurist imaginary around this. The belief that the concept of cultural immortality even exists can be traced back to the individual experience of temporal continuity. Temporal continuity is inherent to the human self. The perception that we are temporally enduring as an individual, but also as communities allows us to make sense of our (social) identity and connect our past, present and future [23]. It has also become increasingly clear that the sense of collective continuity one experiences provides us with existential security [2]. Despite the awareness of our transience, collective continuity somehow ensures that the part of the self that is defined by one's group membership has transgenerational endurance and forms an eternal us [3]. The longing for eternal relevance is deeply engrained in all human activities but is continuously challenged by the fundamental transitory nature of the world.

4.5. Presentation

Artifacts resulting from the above-described artistic processes are combined in various configurations and lead to large-scale installations. From 21 April to 21 June 2022, Ēngines of Ēternity was set up at the Pilar art-science gallery in Brussels, as part of the 'Bemande Vlucht/Vol Habité/Manned Flight' exhibition curated by Ive Stevenheydens and Karine Van Doninck. The data visualization was abstracted into large wall prints, accompanied by both the original glyphs that went to space and photo enlargements of the glyphs (Fig. 9). The Eagerness for the Alien video essay, created with digital renders of the Data Monument, was juxtaposed with the Data Monument itself. A large hand illustrated drawing, used as preparatory study for the sculptures, completed the installation. Subsequent exhibitions are planned at the Motorenhalle in Dresden (curated by riesa efau), and at ESA ESTEC in Noordwijk (for the ESA Open Day).

5. Conclusion

Ēngines of Ēternity is one of few artworks in which outer space is not merely used as a gallery in which art is passively exhibited, but instead is actively mobilized as an artistic co-creator. ĒoĒ is a deeply integrated transdisciplinary project with the involvement of many different disciplines such as visual art, graphic design, photography, data visualization, computer science, 3D modelling, genetics, bioinformatics, and space science. The transdisciplinary processes were enhanced by the fact that many of the project team members had backgrounds in both art and science. This facilitated dialogue between SEADS and RISE and within the team. It also ensured that the artists could take their engagement with the involved science to a higher level, which is not a widespread practice in art-science collaborations [26,27]. The project also highlights the need to open up the discussion about humanity's future and the threat of monolithic thinking [18]. It uses unique space biology experiments to start a much larger critical conversation on the ethics and politics of space settlement, and problematic fantasies and misconceptions of 'space colonization' [28].

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