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A Creativity-Cohesion-Contemplation modus for human space exploration

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Abstract

Humanity is exploring our mother planet underground, on the terrestrial surface and will explore outer space to develop the art of living together and living under extreme environmental conditions. New challenges are to build behavioral strategies and to exploit innovative technologies in process of social and individual adaptation to temporal dynamics. Humans in space will spend long periods of time in a Moon village then in Mars colonization. We analyzed ethological results, within interdisciplinary approaches, by the observation, description and quantification of isolated and confined groups' behavior in analog environments or experimental paradigms. The study applied scientific protocols during a 40-day expedition in a cave with no calendar time and no sunlight (DEEP TIME); during the crossing of hostile regions with changing climates, very hot or very cold temperatures (DEEP CLIMATE); during ground-based isolation and confinement campaigns of 180- and 240-day duration simulating interplanetary missions, greenhouses and extravehicular activities (DEEP SPACE). We address the question of what future solutions we could propose through behavioral observations and pictorial illustrations of social groups in human-like space exploration environments. We discuss results on creativity through evolution and exploration in DEEP TIME, cohesion through proxemics and temporality in DEEP CLIMATE, and contemplation through augmented reality and in the astral universe in DEEP SPACE. We conclude with a self-organized community under a Creativity-Cohesion-Contemplation modus to put humanity into perspective in other exploration fields on Earth and beyond.

Keywords: *behavior, art, adaptation, isolated and confined environment, spaceflight, ethology*

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1. Introduction

The modus vivendi of humans in space implies a different frame of references to that used on Earth. The gravitational force on the Moon is 0.16g and on Mars is 0.37g while on Earth it is 1g. Temperatures can reach +123°C on the lunar surface, -133°C on the Martian surface and we expect frequent +50°C on the terrestrial surface. New challenges for humanity are to develop processes of adaptation to changing environments on Earth such as extreme climates as well as for future exploration of the Moon and Mars such as unusual living conditions. Our previous works in ethology addressed this last issue, in parabolic flights, in orbital flights, in Arctic and Antarctic polar bases, in water immersion, in isolation and confinement campaigns, over several hours, several weeks, several months and several years (Tafforin et al., 2023). Salient results support the idea that adaptive strategies are related to contextual and temporal independent variables, and the increasing and decreasing values are considered as nominal in spaceflight scenarios. The relevant behavioral indicators (i.e. movements, postures, orientations, positions, actions, interactions, expressions, communications) are the dependent variables. For instance, in the very first weightlessness experience simulated in parabolic flight, the individual frees himself from bodily verticality along the gravitational axis to move indifferently head down or head up. This underlined new relationships between the body's references and those of the surroundings (x-y-z axes) towards a new cognitive image of the three-dimensional space. At the inter-individual level, we monitored a 520-day round trip to a distant planet, simulated over a 250-day journey from Earth to Mars, a 30-day orbital stay with Mars landing and a 240-day return journey of an isolated and confined group. We identified cyclic variations in personal actions and periodic oscillations in interpersonal actions duration. This confirmed the varying behaviors over three stages of polar wintering with a social organization, a social disorganization and a social reorganization such as revealed in our study at the Concordia station as an analog to space missions. By way of interpretation, the evolution of humankind in space and time would involve the transformation of its own universe, i.e. Umwelt defined by Von Uexküll (1934), which allows behaviors in a three-dimensional space and within a three-period time.

From the perspective of long-term interplanetary manned missions, environmental hazards (e.g. weightlessness, solar radiation, cold or hot temperatures, violent storms, landscape devoid of flora, fauna or people, physical confinement, social isolation) are as numerous as the factors (negative or positive) that impact the human being's multi-functional system (e.g. sensorial-motor, bio-medical, socio-psychological, neuro-cognitive and chrono-biological spheres). In this study, we have chosen to highlight beneficial effects and salutogenic responses on the behaviors that are the theoretical foundations of the ethological approach.

The present question is what are future solutions we could propose through behavioral observations and pictorial illustrations regarding social groups composed of mixed gender and multi-national members in the human-like space exploration environments? Elements of the answer are the qualities of creativity, cohesion and contemplation that are exacerbated in unusual, exotic or exceptional contexts. This might take shape as a model a human community would develop to put into perspective the art of living together and living on Earth and beyond.

Astronauts are heterogeneous in their spaceflight response patterns as far as Homo Sapiens are concerned and evolved under the boundary conditions of Earth (Hart, 2023). In the deep prehistory, there were form the first caves inhabited protecting themselves against dangers for survival. We have discovered traces of human settlements depicting scenes of daily life activities and testimony of creative abilities. In the deep space, the crew's ability to perform such conceptual tasks will be essential not only for thinking means of survival in unexpected situations but also for well-being in everyday life. In space analogs, studies have demonstrated that creative thinking and problem solving are associated with predictive shared mental models with nuanced shift in the third quarter of isolation and confinement campaigns (De Chruch et al., 2024). Conceptual performance was affected differently, and creative tasks declined over time (Larson et al., 2019). Nevertheless, creativity may reflect both brainstorming solution in the difficulty of things and the resulting emotion in the beauty of things. This is the case when exploration of the astral universe is inspired by imagination (De Vrie, 2021). Collective tasks of space crews could be to exploit the synergy of their creativity for the achievement and the success of missions. We give examples in the presented research protocols.

Increasing the fidelity of lunar and Martian analogs will help in understanding the influences of spaceflight on astronauts' behavioral health and mitigate potential adverse outcomes (Rahill et al. 2025). Among the extensive research that listed crew performance characteristics for the Artemis, Gateway and Mars habitats, we emphasize the importance of group cohesion. It increases with autonomy and distance from mission control center on ground (Vinokhodova et al., 2023). It has been shown that cohesive crews tend to sit closer to each other, pay more attention to each other and display coordinated patterns of behavior. Leadership may also play a role (NASA, 2009). Meta-analyses have shown that high cohesion or lack of cohesion is a predictor of reduced psychological distress or increased performance. Past and recent studies on small groups working under extreme conditions have focused on factors that are significant for a social functioning and determine group cohesion (Sandal et al., 2011; Gangeme et al., 2023). Group composition, group dynamics, group interaction, group communication and group cooperation are elements of such multi-factorial inferences about group cohesion. The temporal factor and proxemics (human use of space through inter-individual distances) in the group organization are to be considered. New observational data are presented in the research protocols.

Outside working time, astronauts on orbital missions like to practice Earth gazing during their free time. When they talk about their experiences, the language is often contemplative (White, 2021). These intense emotional reactions change the way they see the mother planet and humanity's place in the universe (Kanas, 2020). The philosopher Frank White has described this effect as the Overview phenomenon and related it to the creative performance of space explorers (2021). These are all positive effects of being in space. However, when moving away from Earth, real sights of cities, oceans and continents will disappear. Virtual or augmented realities landscapes could be valuable for maintaining the contemplation. As a behavioral health countermeasure, natural scene virtual reality was highly valued by most of the participants in several isolation and confinement expeditions (Anderson et al., 2023). The future potential of its use and perceived usefulness during long-duration space exploration is currently considered. Virtual leisure activities would facilitate positive emotional experiences (Thomas, 2023). The emerging behaviors that explore new visions of the world from Earth orbit or

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from the Mars surface are outcomes of this contemplative process. We provide examples in the presented research protocols.

Ethology, the science of behavior, is a part of the interdisciplinary approaches associating life sciences and social sciences, gathering biology, physiology, psychology, sociology and mainly anthropology when considering micro-societies with self-organization and own rules of living together against surrounding dangers and far from urban civilizations. Its specificity is first and foremost to consider what positive issues individuals can find in the resources offered by the environment. Finally, they act and interact with the purpose of well-being. In the present study as novel approach, we propose to illustrate our ethological analyses with artistic insights resulting from collective creations or technological innovations. Our field approach is to support the findings with behavioral occurrences from observational data regarding what is optimized in the human-environment interaction, be it social, ecological or spatial.

2. Materials and Method

The ethological method using observation tool, description tool and quantification tool was applied to emphasize the spontaneous motor and spatial behavior of the subjects in everyday situations, work tasks, leisure time or experimental paradigms with objective criteria. Scientific and technic details in the case of manned space missions were provided in Tafforin (2024). Such investigations are concerned not only with the result of the behavior (i.e. the performance) but also with the features of the behavior that underlie it (i.e. the multimodal quality). This can be studied as a function of time (hours, days, months) or in a chronology of selected events (periods, situations, contingencies) for longitudinal analysis such as in the DEEP TIME protocol. This can be studied as a function of environments (extreme living conditions and unusual living conditions) or individuals (gender, experience, function) such as in the DEEP CLIMATE protocol and DEEP SPACE protocols, for transversal analyses. The methodology, implemented in isolated and confined groups in environments similar to human space exploration, has demonstrated the full feasibility of the tools used in the designed protocols. All the participants have given a declared consent in the global scientific approaches.

DEEP TIME was an expedition in a natural environment, the Lombrives cave in Ussat-France which took place from March 14, 2021 at 20:00 to April 22, 2021 at 20:00, that was 960 hours without calendar time and without sunlight. The group of timonauts (n=15, 7α/8Ω, FR, aged between 30 and 50 years) was composed of members from a wide range of backgrounds (profession, experience, motivation, personality). The underground base, designed as a new type of mission analogous to lunar settlement (Clot et al., 2022), was divided into six zones. The living zone, illuminated by a light balloon, provided a collective space for daily tasks such as cooking, eating, relaxing, discussing and preparing for caving activities. The scientific measuring zone, in a closed cabin, housed the computer equipment. The sleeping area, a space of absolute silence, favored a rhythm specific to each individual. The speaking area favored isolation and personal expression filmed by a micro-camera. The exchange airlock allowed the deposit and evacuation of waste without contact with the outside. Dry toilets and cold-water lavatory completed the facilities. The ethological protocol consisted of filming the living area illuminated by the on and off light balloon and covered by two wide-angle cameras (24 hours a day and 7 days a week), totaling approximately 1900 hours of data collection. Sub-protocols of selected video recordings were designed in order to account for social activity including spare time in relation to time spent indoors. Supplementary data were pictures that captured relevant behaviors. We focused our analysis on the group-members' creativity mode.

DEEP CLIMATE ran from December 5, 2022 to June 30, 2023 and consisted of three 40-day expeditions in extreme climatic conditions in the equatorial forest of Guyana (98% humidity), Northern Lapland (-52°C) and the Saudi Arabian desert (+58°C), alternating with 30-day periods of team recovery (n=20, 10α/10Ω, FR, aged between 32 and 52 years). The climatonauts thus spent successive mobile days periods in versatile and extreme living conditions that presuppose future climate changes on Earth. This environmental immersion also represents new analogous situations in preparation for human life on other planets, with theoretical adaptation and practical training methods. The progress of the crossings, in complete autonomy (food, clothing, bivouac, medicine) and transportation (backpacks, canoes, pulkas), was conditioned by energy resources (sun to recharge batteries), water (minimal for human organisms) and shelters against torrential rains or bad weather from polar winds. The resting place for social bonding was inside a collective tent named Space Station Dome. The ethological protocol consisted of mapping and photographing the bivouacs each day when the living camp was set up on site. We focused our analysis on the group-members' cohesion mode.

DEEP SPACE included two experimental campaigns of social isolation and physical confinement for extended periods of time that simulating manned missions to the Moon and Mars.

The ground-based Controlled Ecological Life Support System (CELSS-180) campaign took place at the SISC in Shenzhen, South China, from June 17, 2016 to December 14, 2016, and lasted 180 days. It was an experimental platform with a total volume of 1340 m^3, comprising a life support module, a resource module, a low-pressure module, three greenhouse modules and a 2-chamber crew module. The group was of mixed composition (n=4, 1α/3Ω), of Chinese nationality and aged between 25 and 45 years. The technological principle was to simulate the key mechanisms of regenerative systems combining food production, atmospheric control and waste recycling, using plants and microorganisms as a central component, following a Mars mission scenario. The ethological protocol consisted of video recordings made once a month during collective meals (breakfast, lunch, dinner and preparation) for a total of 40 hours of data collected from a wide-angle camera positioned in the living area.

The Scientific International Research In Unique terrestrial Station (SIRIUS-21) ground-based campaign took place at the IBMP in Moscow, Russia, from November 4, 2021 to July 3, 2022, and lasted 240 days. The experimental facilities, with a total volume of 550 m^3, comprised a living module, a working module, a storage module including a greenhouse, a landing module and a planetary surface simulator. The group of six mixed and tri-cultural members (3 RUS, 2 USA, 1 UAE, aged between 31 and 43 years) had the definitive exit of one participant (RU) due to a medical incident (n=5, 3α/3Ω) on Day 33. The technological principle was to simulate the key stages of a mission to the Moon as follows: phase 1 launch, lunar orbit, docking with the Gateway station, search for the lunar landing zone; phase 2 remote observation, docking of transfer cargo, Extra-Vehicular Activities (EVAs) on the planet; phase 3 remote operations, undocking and return to Earth. The

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ethological protocol consisted in processing video recordings made twice a month during collective meals (preparation and breakfast) and every 40 days during free activities (20:30-21:30) for a total of 120 hours of data collected from 12 control cameras positioned in the modular infrastructure (living area, recreation area, sport area).

Exhaustive transversal and longitudinal analyses were made on the individual and inter-individual behaviors with the aim of revealing the adaptive strategies built by the isolated and confined group-members according to gender, culture and time. As a new analysis, we focused our interpretation of the results on the humanity contemplation mode.

3. Results and Discussion

3.1. Creativity

In DEEP TIME, by combining the three behavioral indicators (social orientations, social presences and social positions) during the 40-day expedition, we emphasized an "external social clock" within the framework of the internal circadian clock (Tafforin et al., 2023). Group-members adapted through visual cues (social orientations), presential cues (social presences) and collective reactivations (social positions) as behavioral strategies that compensated for the absence of temporal cues. They contributed to group functioning. Overall, considering that the balloon's activation (on) corresponded to a sunrise and its deactivation (off) to a sunset, we observed, described and quantified 70 social sunrises and sunsets indoors, while there were 40 real sunrises and sunsets outdoors. This showed an alternation of social light periods that no longer referred to the day/night rhythm of natural sunlight but to the voluntary human actions. The timonauts would then be immersed in this social sunshine for their collective activities in the living zone.

Figure 1. Creativity through evolution in DEEP TIME (image© Martin.Saumet)

No time information offered a sense of freedom in the group-member's activities. New luminous condition exacerbated power of imagination for artistic creativity within the group. This left time and openness not only to perform the assigned tasks for social and vital functioning but also to innovate art forms for recreational functioning. Figure 1 shows the result of the process. Together two explorers used their helmet light (loaded after pedaling on a bike as source of energy) by creating a beam of light as they moved. It illustrates an image of creativity as a new art in the technological evolution. Figure 2 shows the result of a handmade jewelry combining the creative ideas of several explorers during their leisure time in the cave. It looks like an astronomical image of galaxy as revealed by the Euclid telescope (ESA, 2023). This magnifies an object of creativity as future exploration in outer space, despite being in confinement.

Figure 2. Creativity through exploration in DEEP TIME (image© Martin.Saumet)

3.2. Cohesion

In DEEP CLIMATE, the behavioral indicators were on inter-individual distances according to Hall's classification (1966). He defined the personal distances as less than 1.20 meters, social distances between 1.20 meters and 3.60 meters, and public distances as more than 3.60 meters. We extracted these data from the maps completed with photos on the sleeping place chosen by the climatonauts in the bivouac. The measurements were made in allocentric references, i.e. with respect to the position of the equipment, which varied according to the environment. In the equatorial forest of Guyana, the bivouac organization was based on hammocks attached to trees. In Northern Lapland, the sleeping equipment was 2-person tents and in the Saudi Arabian desert, it was 1-person tents. We quantified the distances between the tents' outer edges as a percentage of the observations to allow for adequate comparisons between the two climatic conditions, extreme cold vs. extreme heat regions. Data processing was based on 3610 observations (pairs of explorers) over 19 days in Lapland and on 7220 observations (single explorer) over the same 19 days in Saudi Arabia, with a measurement error of ±60 cm.

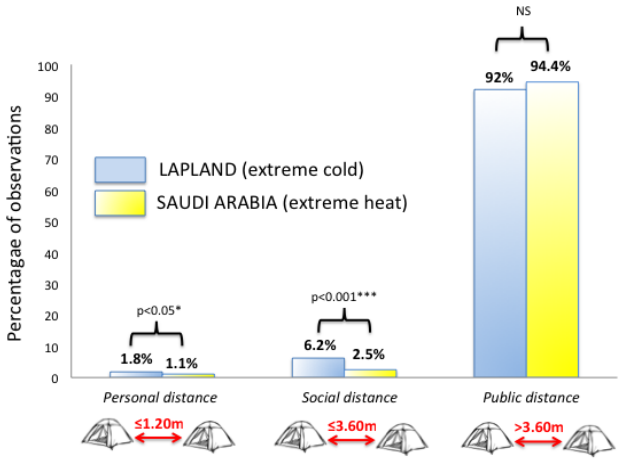

Figure 3. Cohesion via proxemics in DEEP CLIMATE

We first carried out a transversal analysis as shown in Figure 3. The results show highly significant ($p<0.001$) differences between the environments in one class of inter-individual distances. In Lapland (extreme cold), we observed 6.2% of social distances

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compared to 2.5% in Saudi Arabia (extreme heat). Personal distances are less significant (1.8% vs. 1.1%, $p<0.05$) and public distances not significantly different (92% vs. 94.4%, NS). As a result, climate change would affect social behavior such as group cohesion through new proxemics in extreme cold regions. We thus proceeded to a longitudinal analysis of the classified distances during the Lapland expedition. Figure 4 shows variations as a function of time. We observed an inflexion point of the social distances in the middle of a significant period from Day 6 to Day 12 ($p<0.001$). On Day 9, the lower level in the number of observations is related to the medical evacuation of the leader leaving the group with new leadership functionalities. Afterwards, in the last period, there was stability in the whole inter-individual distances, whether they were public, social or personal. The final expedition days hosted a few outside staff and the leader back on the field. This would be consistent with the Third Quarter Phenomenon in subpolar environments (Bechtel & Berning, 1991) and supports the hypothesis of group cohesion via temporality in extremely cold regions.

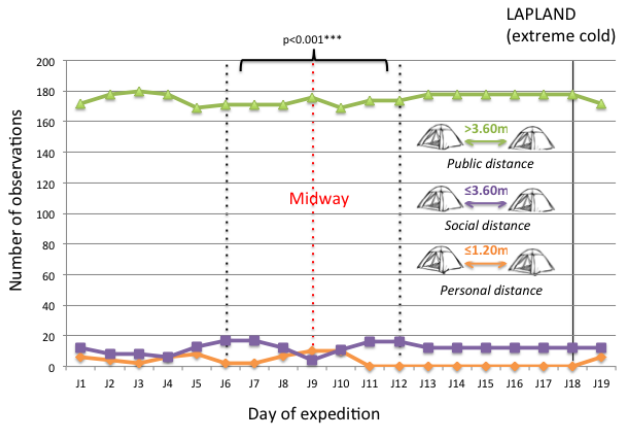

Figure 4. Cohesion via temporality in DEEP CLIMATE

3.3. Contemplation

In CELSS-180, ethological observations showed that the behavioral flow reflecting global activity diminished after the first month of confinement. Psychological questionnaires revealed a decrease in hostility and negative emotions but an increase in emotional adaptation suggesting boredom and monotony. Physiological parameters were impacted with increased intima media thickness and endothelial deconditioning. This experiment was unique in its design as it included a biological closed-loop system with the aim to study an integrated multi-system adaptation to impacting psycho-physiological conditions in healthy volunteers (Yuan et al., 2019). The overall results converged on the need for countermeasures to prevent these negative effects. We analyzed the behavioral results (facial expressions such as smiling and laughing) that showed beneficial effects of the crew's food production from the greenhouses and the sharing of fresh dishes during the collective meals (Tafforin & Tamponnet, 2025). In the confined habitat, we came to the idea of a broad space ecosystem composed of three overlapping spheres that together represent ecological, physiological and psychological life-support systems. It draws a colored 3-petal flower inside a virtual natural landscape as hypothesis of countermeasure responding to new needs and innovative techniques towards the well-being of spationauts.

Figure 5 gives a photographic representation of the city of Toulouse in France such as Thomas Pesquet (2017) might have perceived it during the Proxima space mission from the Cupola. It is a panoramic observation dome aboard the International Space Station (ISS). This is both an artistic real view and a pictorial group of people superimposed on the image. We assume that the spationaut would look thoughtfully at the terrestrial city dwellers and, through a cognitive shift, look virtually at this distant view with wellness or fullness. This may help the contemplation of augmented reality in DEEP SPACE against social isolation.

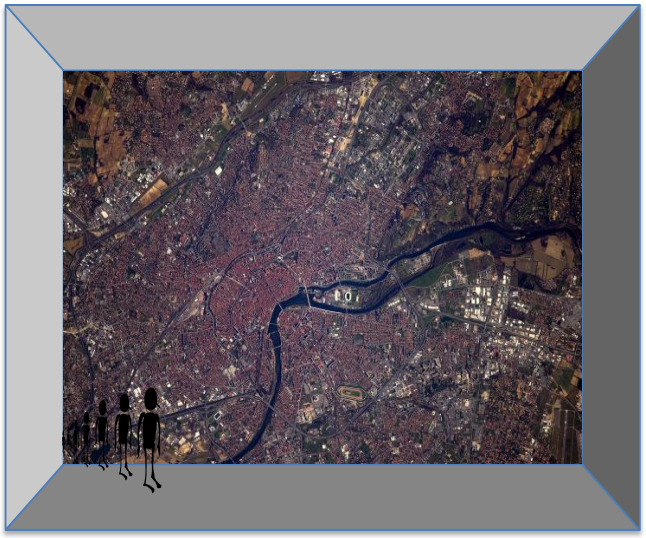

Figure 5. Contemplation by augmented reality in DEEP SPACE (Image© ESA/NASA, open access in the CNES picture library)

The Overview phenomenon can thus be related to positive effects on the behavioral health of humans in space. Innovative countermeasures using Artificial Intelligence (IA) are relevant in isolated habitats. For instance, robotic companions participating in recreational activities indoors or outdoors (EVAs) could also be beneficial solutions to compensate for personal discomfort with loneliness. In SIRIUS-21, we observed that social interactions, social orientations, and facial vs. collateral expressions changed as a function of crewmember grouping in the dining, sport and recreation areas of the multi-module facility (Tafforin, 2024). The results showed attendance and localization for distractive or festive activities during free time as adaptive strategies. Similarly, on board the ISS, contemplative activities might include watching the sixteen sunrises every 24 hours. The astral universe provides this opportunity. It can be an imaginative function, like the little prince contemplating forty-three sunsets on his asteroid B612 (Saint Exupéry, 1943) or a restorative function to mitigate the effects of the disappearing Earth (Kanas, 2020) while traveling beyond low orbit. On the planet Mars, the interplanetary travelers will move away from the alternating sunrise/sunset to find out a period of revolution of 24 hours 39 minutes and 35 seconds. During EVAs, they will become astronomer, pulling out a long chair and scouring the sky, the stars and the sun as Hubert Reaves (1984) used to do on ground.

Figure 6 gives a new dimension of what the spationaut could look outside the space habitat depicted by the illustrative flower of the life-support multi-system along with a teammate-like robot. This may help human being to feel good against its physical confinement, which can be resolved by the contemplation of astral universe. Man and woman are endowed with Human Intelligence (HI) as the sum of collective intelligence, individual intelligence and emotional intelligence. We assumed that augmented reality scene conceived by IA and real natural scene perceived by HI

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would provide the space explorer with positive emotion sources captured in an optimal way.

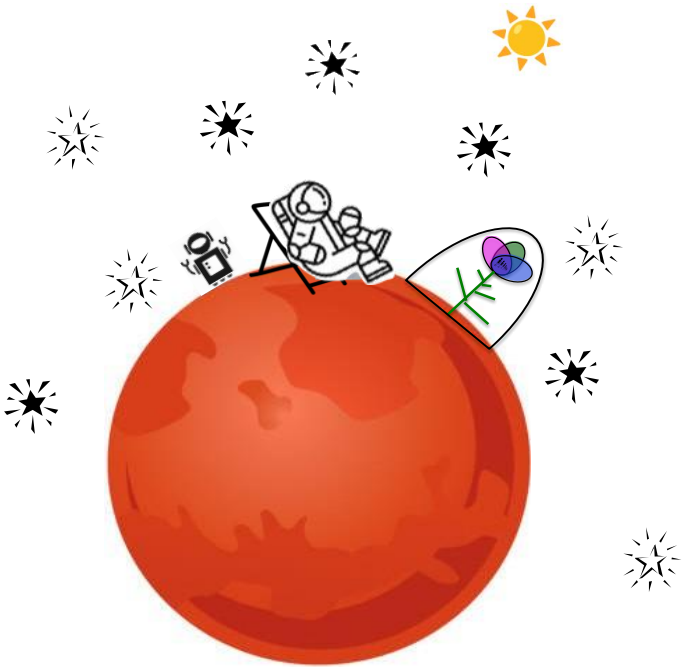

Figure 6. Contemplation of astral universe in DEEP SPACE

4. Conclusion

In future paradigms for human space exploration, extreme confined and isolated crews' behavioral adaptation is the main objective. A prospective view on underground living could be done with the design of lunar habitat under domes to protect against external environmental hazards. A prospective view on living in hostile regions on the terrestrial surface could be done with the concept of Moon village to deploy solutions through own organizations and dynamics (e.g. appropriate inter-individual distances, efficient leadership relay, nominal and critical periods). A prospective view on living on remote planets could be done with the idea of Mars colonization to explore another area of freedom (e.g. innovative management of space and time, human being in the astral universe, free body movements in reduced gravity).

The timonauts, climatonauts and spationauts adapted their behavior in relation with their environment under a salutogenic form as observed in DEEP TIME, DEEP CLIMATE and DEEP SPACE. From an ethological viewpoint this relationship is considered to be optimal because the adaptive strategies for well-being are developed with interrelated components of life-support systems. They lead to successful manned missions. The intrinsic qualities of mission crews in meeting new demands in order to maintain cohesive profiles have also been key factors. Crewmembers are enriched by their diversity, made up of men, women, different experiences and specific activities, against conflicts. Crewmembers would find opportunities for interpersonal and personal development in the artistic innovation and contemplative enjoyment of the explored environment, against monotony. Crewmembers would ensure their safety and vital tasks in mutual dependence and preferential proxemics, for autonomy. Social functioning and living are thus achieved with missing temporal cues, without sunshine, under changing climates, as well as during extended periods of time in isolation and confinement.

A self-organized community would thus be under a Creativity-Cohesion-Contemplation modus (three-quality model) to put humanity into perspective in other exploration fields on Earth and beyond to the Moon and Mars.

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