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# A Diversity–Distraction–Dependency System as a Positive Human Factor in Crews' Interplanetary Missions

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**Abstract:** In successful scenarios of missions to the Moon and Mars, humans develop multi-factorial systems through adapted behaviors to build cohesive multi-national crews with their individual features. We assume that frequencies of social interactions, social orientations, and facial vs. collateral expressions change according to mixed-culture and mixed-gender crew characteristics and as a function of the crewmember's grouping at the same time and in the same place. The ethological method, with the phases of observation, description, and quantification of behavioral manifestations, was applied to the SIRIUS program and MARS-500 program. This involved simulating a 120-day confinement, a 240-day confinement, and a 520-day confinement in a multi-module facility. Focus was made on the meal area, sports area, and leisure area. We investigated the full nationality–gender-varied crew and the crewmember's attendance and localization for distractive or festive activities during their free time. Social optimization declined and then grew in a temporal dynamic. Global behavioral distribution showed differences according to the duration of experiments during collective time. As a result, a system based on crew diversity, crew distraction, and crewmembers' inter-dependence should be considered as a positive human factor in the process of adaptation with the goal of enhancing the well-being of future interplanetary crews.

**Keywords:** adaptation; behavior; ethology; isolated and confined environments; Moon and Mars missions; temporal dynamic; human space exploration; well-being

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## 1. Introduction

The next manned missions to the Moon and then to Mars are long-duration interplanetary trips that will require crews to build new systems in terms of human adaptation. Future living conditions will be an effective combination of environmental variables, social and individual variables, along with temporal variables. A short flight to the Moon should be of 4-day duration to reach the Lunar surface; a medium stay in Lunar orbit aboard the upcoming international station Gateway could be of 120-day duration to 240-day duration; extended time periods to journey to Mars and back to Earth should be under the conditional flight pattern of a 240-day duration to reach the planet, 30-day to stay on the surface—which could be extended to a 1000-day duration—and then a 250-day duration return trip. With such prolonged exploration missions, the multi-factorial profile of crews is changing while they adapt to their changed environment in space.

Human factors are the outcomes of physiological parameters, cognitive parameters, psychological parameters, social parameters, cultural parameters, operational parameters, and motivational parameters. Their synergic and homeostasic effects may act negatively or positively on behavioral manifestations. When considering interplanetary missions, an adequate crew composition is a prime solution by selecting compatible crewmembers for social cohesion in the tasks that need to be performed and in interpersonal relationships [1]. With increasingly long-stay scenarios on the Moon and on Mars, we must also consider the underlying mixed-gender and mixed-culture variables that have salutogenic effects on the behavioral adaptive process over time. Monotony could be mitigated, and autonomy

could be improved. In the literature, we found such salutogenesis about the different roles of women and men within the crews, as well as about the multi-national features of crews in terms of positive psychology [2]. In our previous ethological studies, results showed expressive and communicative behaviors in female crewmembers and less active but more interactive behaviors in male crewmembers during a simulated Moon mission [3]. There were also differences in the female astronauts who reported a slightly higher incidence of Space Adaptation Syndrome (SAS) upon transition to microgravity after arriving at the International Space Station (ISS). Conversely, more male astronauts experienced related symptoms upon return to Earth in terms of environment-impacted physiology [4].

Environmental factors are involved in positive human factors for the success of space missions. The physical environment is made of new frames of reference. The gravitational force no longer determines a vertical head-up orientation in microgravity. During oriented-body tasks in parabolic flights, we have observed three-dimensional behavior progression leading to a new cognitive image of space [5]. As a good platform for astronauts' training, reduced gravity short-slot effects represent a beneficial aspect for crew performance during long-term space missions [6]. Nevertheless, there are negative biological effects over time with a possible interaction between space radiation and microgravity [7]. Sensorimotor control is also modified with additional orientation cues that may increase spatial working memory ability [8]. It is reinforced by an adapted motor behavior. Extra Vehicular Activities (EVAs) generate physical fatigue but are of meaningful interest to the astronaut's well-being [9]. Inside the space habitat, the crewmembers develop a multi-system adaptation to confinement under the conditions of a Controlled Ecological Life Support System (CELSS) [10] as well as according to interior design with controlled habitability components [11].

The psychological environment that characterizes future interplanetary missions involves isolated and confined conditions with a demanding social context and security charge. Crew cohesion and crew survival depend on such factors. Mapping the communication within space crews [12] can help prevent interpersonal conflicts while optimizing behaviors in personal actions and collective tasks. Supporting crew through communications with the Mission Control Crew (MCC) can also help them cope with the operation-related workload and stress-related tension [13] for good mental health. As a result, safe crews for endurance missions depend on human system risk management [14].

The cognitive environment displays an exceptional paradigm for innovative studies from interdisciplinary approaches while considering ethology, the science of behavior, in interfaces. Away from Earth, the interplanetary crew experiences the Overview Effect that changes the way astronauts see Mother Earth and humanity's place in the universe [15] (Kanas, 2020). A new mode to cope with that effect is to consider virtual environments for maintaining behavioral health during long-duration space exploration [16]. They can also be considered as countermeasures to unfavorable factors, such as the disappearing Earth phenomenon, lack of personal area, and lack of social companionship [17]. The goal is to improve daily life activities and leisure activities for the best comfort and well-being of the crewmembers, both in usual conditions and unexplored fields.

In this multi-factorial analysis that takes into account the temporal factor, being in space becomes a new challenge. The human being must accordingly develop functional systems in the dynamic process of adaptation. Our theoretical hypothesis is that a system based on the crew's Diversity–Distraction–Dependency could be considered as a positive human factor in successful scenarios of interplanetary missions lasting 120 days and 240 days to 520 days. They are confinement experiments simulating two journeys around the Moon and one round trip to Mars, respectively. Our operational hypothesis is that the relative frequencies of observed social interactions, social orientations, and facial vs. collateral expressions change either according to mixed-culture crews and mixed-gender crew characteristics during the collective time (diversity), either according to areas of social activities during free time (distraction), or according to mission events and mission days (dependency).

## 2. Materials and Methods

Ground-based experiments in deep space are the proposed scenarios of the Scientific International Research in Unique Terrestrial Station (SIRIUS) program and the MARS-500 program. They used the controlled, isolated, and confined environment of the Institute for Biomedical Problems (IBMPs) in Moscow, Russia. They were designed to simulate interplanetary flights of a 120-day duration (SIRIUS-19), 240-day duration (SIRIUS-21), and 520-day duration (MARS-500). The environmental conditions and experimental facilities were structured as four hermetically sealed, interconnected modules. Module EU-50, with a total volume of 50 $m^3$, was meant for the simulation of the landing Martian module. Module EU-100, with a total volume of 100 $m^3$, was meant for the conduction of medical and psychological experiments. It included the living quarters used as the leisure area and the kitchen used as the meal area. Module EU-150, with a total volume of 150 $m^3$, was meant for the accommodation and living of six crewmembers. Module EU-250, with a total volume of 250 $m^3$, was meant for storing food, tending a greenhouse, and disposing of waste. It included fitness equipment used as a sports area. Moreover, a module PSS "Planetary Surface Simulator" connected to EU-50 was only opened for EVAs and remote operations.

Methodological tools applied to these experiments are the three phases of the ethological approach [18]. The phase of observation was to objectively look at the subjects' actions, interactions, expressions, orientations, and localization in daily life activities (collective mealtimes and personal free time). The phase of description was to encode these behavioral items (dependent variables) as a function of time (mission day), according to the individual–cultural background and to the activity area (independent variables). The phase of quantification was to measure the absolute occurrences (number) or relative frequency (percentage) among the behavioral flow. A software-based solution helped in organizing, filtering, processing, and visualizing observational and descriptive data [19].

Protocols of data collection were achieved from video recordings made every 15 days during collective times at breakfasts in the morning in SIRIUS-19, SIRIUS-21, and MARS-500. Focus was made on the SIRIUS-21 experiment with video recordings collected every 40 days during free time in the evening (20:30–21:30) inside the meal area, leisure area, and sports area.

Subjects were European, Emirati, Chinese, American or Russian, and female or male. They comprised different crews in SIRIUS-19 (n = 6, age $\approx$ 35), SIRIUS-21 (n = 5, age $\approx$ 35), and MARS-500 (n = 6, age $\approx$ 32). They provided her/his informed consent for participating in the distinctive experiments.

## 3. Results

### *3.1. Collective Time (Breakfast in the Meal Area)*

A quantitative description of the whole behavior observed during a collective activity gives an overview of the expressions, interactions, and actions of the crew. Collateral expressions are any short act that has no manifest function in the current action but expresses stress, fatigue or discomfort, such as "scratches the noise", "rubs eyes", or "chews a pencil". Facial expressions are positive manifestations, such as "smiles" or "laughs" that are indicators of well-being or good spirit. Body interactions are any contact between two crewmembers, such as "taps on the shoulder of subject B" or "touches the arm of subject C". Object interactions are any manipulation from one crewmember to another one, such as "gives spoon to subject D" or "points food at subject E". Visual interactions include a long gaze toward a crewmember, such as "looks at subject A" or "looks at all subjects". Figure 1 presents the behavioral distribution of each category of behavior in the SIRIUS-19, SIRIUS-21, and MARS-500 experiments. The results show significant variations ($p < 0.001$) in the percentage of observations through the missions. During the 520-day confinement, collateral expressions were the most frequent (13%) compared to those during the 120-day (10%) and 240-day (7%) confinements. The longest mission duration appeared to be the most stressful. Considering crew composition, facial expressions were more frequent in both mixed-culture and mixed-gender crews (SIRIUS-19 = 26%;

SIRIUS-21 = 24%) compared to only the mixed-culture crew (MARS-500 = 18%). There is an emphasis on the most multi-varied crew, whose collateral expressions had the lowest number of observed manifestations compared to the other crews. Indeed, the SIRIUS-21 crew was composed of one Russian-female subject, one American-female subject, one Russian-male subject, one American-male subject, and one Emirati-male subject considering the full nationality–gender-varied characteristics.

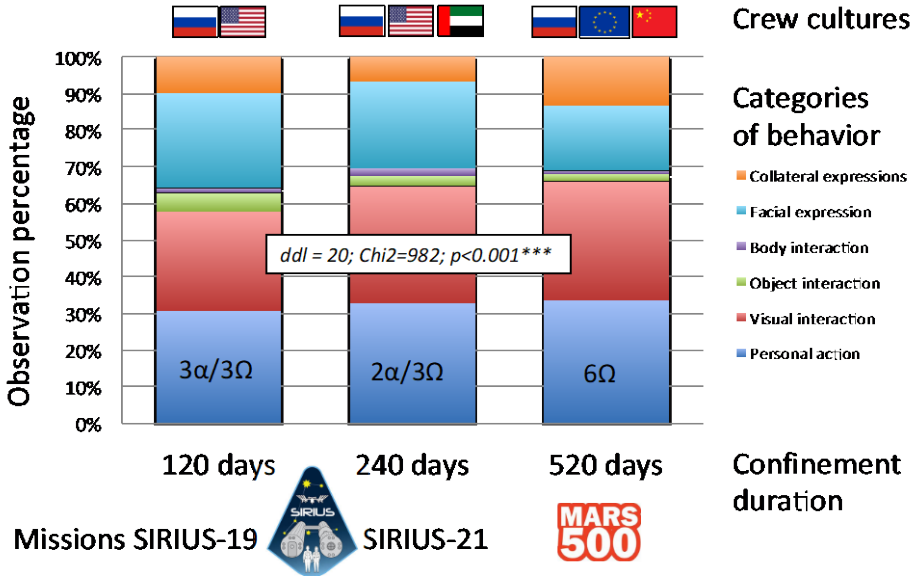



**Figure 1.** Comparison of behavioral distribution between SIRIUS-19, SIRIUS-21, and MARS-500, according to crew composition as a function of time, during collective time (breakfast). *** High significance level.

Over the respective missions from 120 days to 250 days, there were slight increases in personal actions vs. a slight decrease in object interactions. As a result, the time variable had a negative impact on the crews' behavioral profile, whereas gender variables and culture variables had a positive impact. So, we highlight the crew's diversity.

### *3.2. Free Time (Meal Area, Leisure Area, Sports Area)*

The result of positive behaviors as indicators of crewmembers' well-being during collective time in SIRIUS-21 led us to choose this experiment for further analyses during free time. Subjects' localization was checked every minute in the meal area, the leisure area, and the sports area within 40-day intervals (Mission Day 40, MD80, MD120, MD160, MD200, and MD240). In a recent study, we observed behavioral changes after 40 days in an analog environment [20].

Figure 2 presents the percentage of subjects located in social areas during the whole mission. The results show significant differences ($p < 0.001$) in observation percentage between the sports area (18%), meal area (37%) and leisure area (45%). During free time, the crew would privilege distractive social activities such as watching a movie together or playing a video game with two crewmembers in the leisure area. Figure 3 presents the dynamic changes over the mission days. The results show significant variations ($p < 0.001$) with an emphasis on MD200. On this mission day, there was a festive social event when the crew celebrated a crewmember's birthday. All the crewmembers gathered in the meal area for this special time. So, we highlight the crew's distraction.

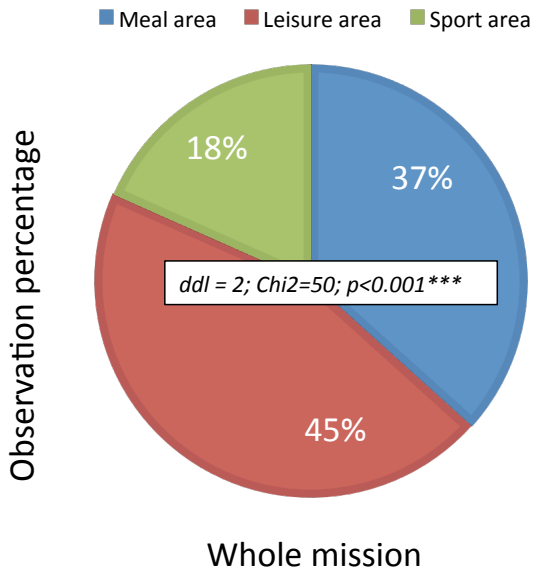



**Figure 2.** SIRIUS-21 crewmembers' localization during free time in three collective areas (meal area, leisure area, and sports area). We checked 61 observations × 5 subjects × 6 days = 1830 measurements per area. *** High significance level.

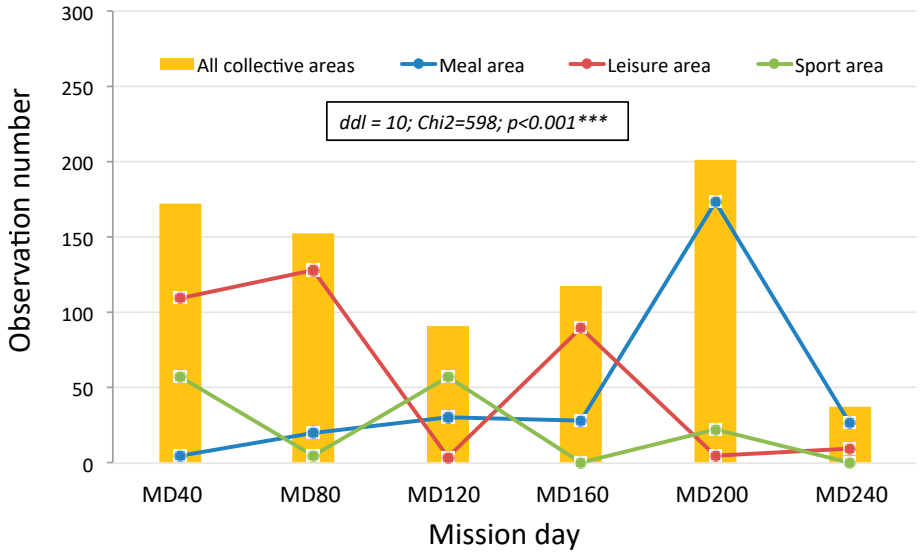



**Figure 3.** SIRIUS-21 crewmembers' attendance and localization during free time according to collective areas and as a function of mission day. We checked 61 observations × 5 subjects = 305 measurements per day. *** High significance level.

In the ethological repertoire, social orientations correspond to the number of crewmembers in the visual field of one crewmember. This is counted for each subject in each area. Figure 4 presents the percentage per mission day. The results show significant differences ($p < 0.001$) in the distribution of 0 subjects, 1 subject, 2 subjects, 3 subjects, and 4 subjects, with nearly none (number = 0) for MD120 and a maximum rating for MD200 (number = 4). It confirms the above results on that particular day. We can interpret these changes in social behavior by the mid-term period as a result of the exacerbated monotony of living conditions. Nevertheless, over an extended time period, we can interpret increasing social orientations as the crew's autonomy is a precursor of crewmembers' interdependence. Figure 5 presents this temporal dynamic of social orientations upon social attendance as an observation index of social optimization. The results show a significantly declining trend,

then a growing trend ($R^2$ = 0.5108) with a critical temporal point in the second quarter of the experiment. It appears that social optimization could depend on the grouping of subjects in the same place and at the same time. So, we highlight the crew's dependency.

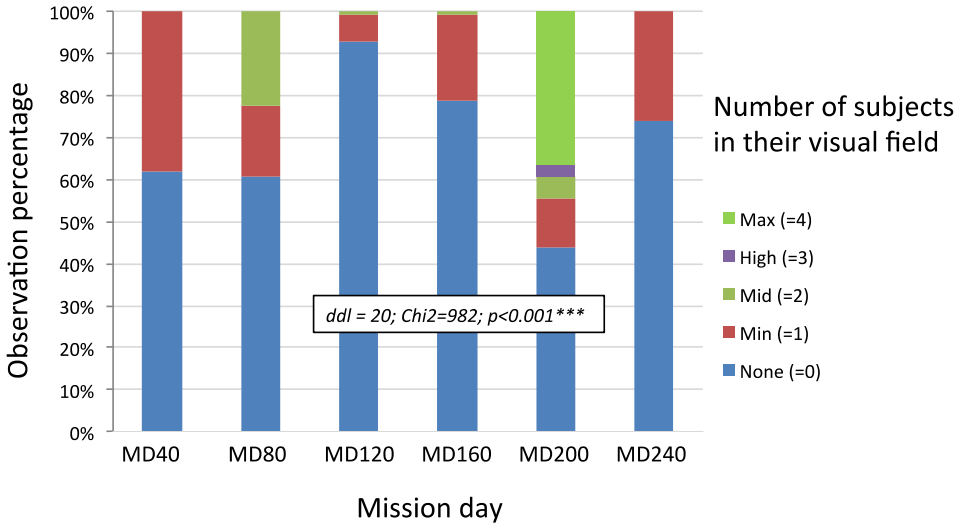



**Figure 4.** SIRIUS-21 crewmembers' social orientations during free time as a function of mission day. We checked 61 observations × 5 subjects = 305 measurements per day. *** High significance level.

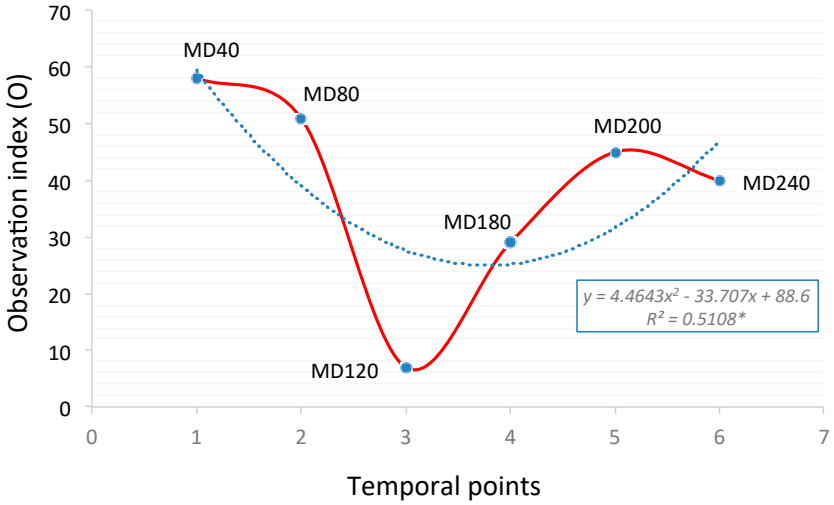



**Figure 5.** SIRIUS-21 crewmembers' social optimization based on the observation index (O) during free time over temporal points during the experiment. (O) = N Social orientation ÷ N Social attendance. Blue line = linear trend. * Low significance level.

## 4. Discussion

In this panel of ground-based experiments simulating missions to the Moon (SIRIUS-19, SIRIUS-21) and to Mars (MARS-500), we observed the negative impact of a 520-day confinement with increasing collateral expressions that are indicators of stress. A 120-day confinement is less impacted. We observed the positive impact of a full nationality–gender-varied crew over a 240-day period of confinement. This complements our data in previous studies on group self-organization [21], cultural influences, and individual differences in isolated and confined environments [22,23]. During the SIRIUS-21 experiment, the crew privileged distractive social activities in the leisure area and social festive events in the meal area of the multi-module facility. Social optimization, which depends on the number of social orientations and social attendance in all these areas, tends to decline at the

mid-period. Afterwards, it tends to grow. With regard to previous scenarios, we found ascending and descending curves of behavioral flow related to mission days and major events in a positive way [24]. The context of behavioral occurrences is obviously to be regarded in these case studies. We emphasized that landing and on-surface operations, then transit and reaching near-Earth orbit, were high-behavior-impacted periods and key days in the milestones simulated. Social context, shaped by the unique nature of the space crew, also needs to be considered. Individual differences are implicit. Despite the small number of observed subjects, data are representative of real human crew missions. The present quantitative description supports our operational hypothesis that the relative frequencies of social interactions, social orientations, and facial vs. collateral expressions change either according to mixed-culture crews and mixed-gender crews characteristics (diversity), according to areas of social activities (distraction) or according to mission events and mission days (dependency).

A high level of occurrences in the category of social behaviors could be an indicator of social cohesion as a result of crewmembers' interdependence. The greatest positive influence of diversity could also mean a more cohesive crew. We observed visual interactions, object interactions, and body interactions at breakfast from this viewpoint. This meets the requirements of developing countermeasures for mental health and cognitive demand on long-duration spaceflights. In an exhaustive list of salutogenic means, we point out the need to purposely give time for crew meals to build cohesion [25]. This ethological approach deals with indicator-based methods by applying the objective observation, description, and quantification of behavioral manifestations in daily life activities, during collective time, or during free time. While taking into account multi-national features, the detection of common values in a cohesive space crew is important from a psychological approach [26]. Sociomapping methods are also appropriate from a sociological approach [27]. The ultimate interdisciplinary goal is to investigate multiple factors that can determine manned mission success in deep space.

New progress is being made on human factors over a long journey, such as designing systems to mitigate the hazard of reduced gravity, which affects physical fitness [28]. Being confined and isolated on Mars are decoupled environmental variables, affecting psychological comfort with distance from Mother Earth and the explored planet along with the exacerbating temporal variable. Feeling closer to Earth while looking at it far away from the Moon has a more beneficial effect by building a new cognitive image. These missions are not exactly the same. The SIRIUS program and MARS-500 program illustrated these specificities like remote operations on the Lunar surface and EVAs on the Martian surface. This gives another explanation of the resulting behavioral profiles related to activity areas. However, the foundations of individual and social adaptation might be the same during a human crew mission. Orchestrating physical, psychological, and cognitive functions requires further advances in several fields. For instance, continuous Antarctic expeditions (Concordia station), recent Human Exploration Research Analog (HERA) campaigns, and recurrent Hawaii Space Exploration Analog and Simulation (HI-SEAS) expeditions in terrestrial settings are relevant for improving knowledge of efficient and endurant interplanetary crewmembers. Again, with the aim of salutogenesis, it becomes interesting to include analyses on mindfulness dispositions as a protective factor [29], shared mental models as predictive effects [30], natural scenes in virtual reality for behavioral health [31], and creative performance in safety solutions [32]. The next step would be to promote creativity, cooperation, and contemplation modes as examples of human skills.

In conclusion, a $D^3$-system, Diversity–Distraction–Dependency, should be considered as a positive human factor in the dynamic process of adaptation to physical environments, psychological environments, and cognitive environments. Along with temporal factors, enhancing crews' well-being and good spirit in the synergy of these impacting environmental factors leads to a key research direction in aerospace topics. Interplanetary flights are the current challenge. Exploring other planets will be the future human experience.

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