Biological space experiments for the simulation of Martian conditions: UV radiation and Martian soil analogues

P. Rettberg a,*, E. Rabbow b, C. Panitz a, G. Horneck a

a DLR, Institute of Aerospace Medicine, Radiation Biology Section, Linder Höhe, 51147 Köln, Germany
b Medizinische Einrichtungen der RWTH Aachen, Lehrstuhl für Flugmedizin, Pauwelstr. 30, 52057 Aachen, Germany

Received 16 January 2003; received in revised form 5 March 2003; accepted 3 September 2003

Abstract

The survivability of resistant terrestrial microbes, bacterial spores of Bacillus subtilis, was investigated in the BIOPAN facility of the European Space Agency onboard of Russian Earth-orbiting FOTON satellites (BIOPAN I -III missions). The spores were exposed to different subsets of the extreme environmental parameters in space (vacuum, extraterrestrial solar UV, shielding by protecting materials like artificial meteorites). The results of the three space experiments confirmed the deleterious effects of extraterrestrial solar UV radiation which, in contrast to the UV radiation reaching the surface of the Earth, also contains the very energy-rich, short wavelength UVB and UVC radiation. Thin layers of clay, rock or meteorite material were shown to be only successful in UV-shielding, if they are in direct contact with the spores. On Mars the UV radiation climate is similar to that of the early Earth before the development of a protective ozone layer in the atmosphere by the appearance of the first aerobic photosynthetic bacteria. The interference of Martian soil components and the intense and nearly unfiltered Martian solar UV radiation with spores of B. subtilis will be tested with a new BIOPAN experiment, MARSTOX. Different types of Mars soil analogues will be used to determine on one hand their potential toxicity alone or in combination with solar UV (phototoxicity) and on the other hand their UV protection capability. Two sets of samples will be placed under different cut-off filters used to simulate the UV radiation climate of Mars and Earth. After exposure in space the survival of and mutation induction in the spores will be analyzed at the DLR, together with parallel samples from the corresponding ground control experiment performed in the laboratory. This experiment will provide new insights into the principal limits of life and its adaptation to environmental extremes on Earth or other planets which and will also have implications for the potential for the evolution and distribution of life.

© 2004 COSPAR. Published by Elsevier Ltd. All rights reserved.

Keywords: Astrobiology; Biological space experiments; Simulation of Martian conditions; UV radiation and Martian soil analogues; Mars

1. The environmental conditions on Mars

Mars is regarded as the most interesting planet in our solar system in a search for life beyond the Earth. This is mainly based on the fact that the early histories of Mars and Earth show similarities during the period when life emerged on Earth (Jakosky, 1998). Geological observations from Mars orbiting satellites suggest that liquid water was once stable on its surface, attesting the presence of a dense atmosphere and a warm and wet climate before about 3.5 Ga ago (Carr and Wänke, 1992). This is approximately the same time on Earth during the Archean era when the diversification of the early anaerobes took place and the first anaerobic photosynthetic bacteria appeared (Schopf, 1993; Westall et al., 2001). Since that time the climatic conditions on Mars have changed dramatically. For the last 1.5 Ga the temperatures on the surface of Mars have been low, between about −123 and +25 °C depending on season and geographical location. The atmospheric pressure is low as well, on average about 560 Pa, and the atmosphere consists mainly of CO₂. Under these conditions, near to its triple point, water cannot exist in the liquid state. However, recent observations from Mars Odyssey with a high energy neutron detector have clearly shown that large quantities of water, which is assumed to be an...
essential prerequisite for life, still exist on Mars, probably as ice beneath the surface (Mitrofanov et al., 2002). The environmental conditions of present Mars are summarized in Table 1 and compared to the limits of life on Earth, i.e., the environmental range allowing growth or survival of (micro)organisms (from Horneck, 2000).

The chemical composition and the low pressure of the Martian atmosphere result in an UV radiation climate which is quite different from that of the Earth. Oxygen is present only as a trace element in very low concentrations, therefore an UV-absorbing ozone layer cannot be formed as on Earth. The energy-rich short wavelengths of solar UV radiation can penetrate the Martian atmosphere and lead to high surface fluxes of UV radiation with wavelengths above 200 nm. Therefore, that fraction of UV radiation with a high biological efficiency in cell killing in terrestrial organisms, reaching the surface of Mars, is significantly larger than that reaching the surface of the present Earth, although the solar constant for Mars is only 43% of that for Earth. Due to absorption by CO₂ virtually no radiation of wavelengths below 200 nm reaches the Martian surface. Fig. 1 shows the present UV radiation climate on Mars derived from model calculations (M. Patel, personal communication).

In 1976, two Viking spacecrafts landed on Mars with scientific instruments designed to detect the state of chemical evolution including the possible presence of living organisms on that planet (Klein et al., 1976). The experiments were based on the assumption that (i) Martian life, if it exists, would be carbonaceous; (ii) its chemical composition would be similar to that of terrestrial life; and (iii) it would metabolize simple organic compounds. All three Viking biology experiments gave results indicative of active processes when samples of Martian soil were subjected to incubation under the conditions that were imposed to them (reviewed in Horneck, 1995). When taking the data of all Viking results together, non-biological processes have generally been interpreted to be responsible for the observed reactions of Martian soil (Klein, 1979). The strongest argument against extant life was the complete lack of any organic residues in the Martian soil samples investigated by gas chromatography-mass spectrometry. So far, the mechanisms explaining the results of the Viking biology experiments are not known. Most hypotheses suggest the presence of highly reactive inorganic superoxides or peroxides produced in the Martian soil by the intense unfiltered solar UV radiation which could also be responsible for the lack of organics in the Martian soil samples (Chun et al., 1978; Oro and Holzer, 1979; Brenner et al., 2000). Recently Yen et al. (2000) showed that superoxide radical ions (O₂⁻) form directly on Mars analogue mineral surfaces exposed to UV radiation under a simulated Martian atmosphere.

In addition to the indirect determination of the composition of Martian soil by spectroscopic measurements from satellites and to the direct measurements on the Martian surface by analyzing instruments on landers, Martian meteorites found on Earth offer another

Table 1
Environmental range allowing growth or survival of microorganisms and environmental conditions at the Martian surface

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Martian conditions</th>
<th>Growth</th>
<th>Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>-123 to +25</td>
<td>-20 to +113</td>
<td>~262 to +113</td>
</tr>
<tr>
<td>Pressure (Pa)</td>
<td>560</td>
<td>10⁻⁸ to 10⁸</td>
<td>10⁻⁸ to 10⁸</td>
</tr>
<tr>
<td>Ionizing radiation (Gy)</td>
<td>≈0.2ᵃ</td>
<td>≈50</td>
<td>≈5000</td>
</tr>
<tr>
<td>UV radiation (nm)</td>
<td>≥ 200</td>
<td>Terrestrial (≥ 290)</td>
<td>≈Terrestrial (≥ 290)</td>
</tr>
<tr>
<td>Water stress (aᵥₜ)</td>
<td>7 × 10⁻⁶ᵇ</td>
<td>≥ 0.7</td>
<td>0-1.0</td>
</tr>
<tr>
<td>Salinity</td>
<td>Regional high(?)</td>
<td>³0%</td>
<td>Salt crystals</td>
</tr>
<tr>
<td>pH</td>
<td>(?)</td>
<td>1-11</td>
<td>0-12.5</td>
</tr>
<tr>
<td>Nutrients</td>
<td>(?)</td>
<td>High metabolic versatility, high starvation tolerance</td>
<td>Not required, better without oxygen</td>
</tr>
<tr>
<td>Gas composition</td>
<td>95.3% CO₂; 2.7% N₂; 0.13% O₂</td>
<td>Different requirements (oxic or anoxic)</td>
<td>Better without oxygen</td>
</tr>
<tr>
<td>Time (a)</td>
<td>(?)</td>
<td>≤ 0.5ᵇ</td>
<td>(25-40) × 10⁶</td>
</tr>
</tbody>
</table>

ᵃ Per year.
b ⁰g/cm³.
c Generation time.

Fig. 1. Extraterrestrial spectral irradiance (thin line) and calculated Martian spectral irradiance (thick line, Ls = 250, 15°S, noon, from M. Patel).
opportunity for investigation. In Table 2 the chemical composition of the Martian soil derived from the Viking experiments is compared to the chemical composition of one meteorite, Shergotty (Clark et al., 1976; Dreibus et al., 1982). Both show similarities in their major components, other Martian meteorites, however, differ considerably in their chemical compositions depending on the specific date and place of origin on Mars.

The influence of Martian soil components on resistant microbial forms under the environmental conditions of Mars, especially the Martian UV radiation climate, has not yet been tested so far. Knowledge of the biocompatibility of the Martian surface will be required for future search for life studies on Mars, for establishing planetary protection guidelines, and in preparation for future human exploration of Mars.

2. Bacterial spores in space experiments as biological test systems for extreme environmental conditions

Certain bacteria with the ability to produce dormant stages, such as the Bacillus endospores, are capable of withstanding most of the parameters of the Martian environment (Nicholson et al., 2000) and of surviving very long periods of time. Recent reports suggest that spores of the genus Bacillus may remain intact over millions of years, if preserved in amber (Cano and Börucki, 1995) or in brine inclusions inside salt crystals (Vreeland et al., 2000). Because of their high resistance against different environmental extremes Bacillus subtilis spores are a biological model system which has been studied in several space experiments (Horneck et al., 1984, 1994) as well as in investigations using space simulation facilities. Among the parameters of space, solar UV radiation is the most deleterious one in killing bacterial spores. The incidence of the full spectrum of solar UV radiation (>170 nm) killed 99% of the spores within seconds (Rettberg et al., 1998; Rettberg and Horneck, 2000). Simultaneous action of solar UV and space vacuum even increased the UV-sensitivity (Rettberg et al., 2002). Photoproducts in the DNA which are difficult to repair, such as DNA protein cross-links, as well as high numbers of DNA strand breaks, are produced among others by solar UV radiation in spores when in space vacuum.

3. The experiments SURVIVAL on the ESA facility BIOPAN in FOTON missions

During three space missions, using the BIOPAN facility of the European Space Agency ESA on board of a Russian FOTON satellite, we investigated whether and to what extent natural soil, rock or meteorite material may protect bacterial spores against the harsh environment of space, especially against solar UV radiation, in the SURVIVAL experiments. For this purpose spores of B. subtilis were exposed to space either unprotected, or under a filter of clay, or mixed with different soil, rock or meteorite powders. These experiments are a preparatory step to the investigation of the biocompatibility of the Martian environment for terrestrial organisms and they will contribute to the definition of planetary protection requirements for lander missions on other solar system bodies.

3.1. Bacterial endospores

Spores of the following bacterial strains with different DNA repair capacities were used in the BIOPAN experiments in order to determine the role of DNA repair in survival after exposure to space: (i) B. subtilis HA 101 his B101 met B101 leuAS as a DNA repair wildtype strain, (ii) B. subtilis HA F polA as a strain with a defect in DNA polymerase required in DNA repair and (iii) B. subtilis 101 TKJ 6312 uvrA10 ssp-1 deficient in excision repair and spore photoproduct repair. The strains and their culture conditions are described in Rettberg et al. (1998).

3.2. Sample types, preparation and analysis

In order to test the protective effect of different soil or meteorite material against the space parameters B. subtilis spores were mixed with a powder made of the following materials: (i) clay from Adendorf, Germany, (ii) red sandstone from Heidelberg, Germany, (iii) the meteorite Millbillillie, probably from the asteroid Vesta, (iv) simulated Martian ‘soil’ MRTE, (v) the Martian meteorite Zagami. In addition, spores were mixed with glucose which has been found to support survival in space vacuum, probably by helping to prevent damage to DNA, membranes and proteins by replacing the water molecules during the desiccation process. The

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Comparison of the composition of Martian soil and the Shergotty meteorite (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mars soil</td>
</tr>
<tr>
<td>SiO₂</td>
<td>43.0</td>
</tr>
<tr>
<td>FeO</td>
<td>16.2</td>
</tr>
<tr>
<td>CaO</td>
<td>5.8</td>
</tr>
<tr>
<td>MgO</td>
<td>6.0</td>
</tr>
<tr>
<td>Al₂O₇</td>
<td>7.2</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.6</td>
</tr>
<tr>
<td>Na₂O</td>
<td>n.d.</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>n.d.</td>
</tr>
<tr>
<td>S</td>
<td>3.5</td>
</tr>
<tr>
<td>Cl</td>
<td>&lt;2</td>
</tr>
<tr>
<td>H₂O</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Sr (ppm)</td>
<td>58</td>
</tr>
</tbody>
</table>

n.d. – not determined.
mixtures (about $5 \times 10^7$ spores per sample) were exposed to space in sample containers covered with UV transparent quartz plates in the following arrangements: (i) so-called “artificial meteorites”: loose powder mixed with spores (280 mg dry powder per sample) in a volume of about 1 cm$^3$, (ii) “mixed layers”: dry layers of mixtures of spores and powder (different concentrations of powder) or spores and glucose (5%) mounted on quartz plates, (iii) “shadowed layers”: dry layers of spores mounted on quartz plates beneath a layer of powdered rock or soil (5.6 mg/0.8 cm$^2$) mounted on the inner side of the quartz window of the sample carrier, (iv) “inside layers”: dry layer of spores on quartz plates, (v) “outside layers”: dry layer of spores outside on quartz plates. All samples were exposed to space vacuum after launch by the opening of the BIOPAN. Details about the BIOPAN facility and the flight hardware for SURVIVAL are described in Burger (1995). After retrieval the colony forming ability was determined by plating diluted spore suspensions on nutrient broth (NB, Difco) agar plates. Surviving fractions were determined as $N/N_0$, where $N$ was the number of colony formers of the treated samples and $N_0$ the number of colony formers of the untreated controls.

3.3. Mission parameters

BIOPAN 1: 29/07/-17/08/94, 14.81 d (days of exposure), 39.3 s.c.h. (solar constant hours), 17.317 MJ m$^{-2}$ UV radiation $\geq 170$ nm, 74.0 mGy cosmic radiation for the sun exposed samples, 5.9 mGy for the dark samples, $-20 \, ^\circ\text{C} < T < +12 \, ^\circ\text{C}$.

BIOPAN 2: 09/10/-23/10/95, 9.95 d, 39.3 s.c.h., 12.030 MJ m$^{-2}$ UV radiation $\geq 170$ nm, 29.9 mGy cosmic radiation for the sun exposed samples, 4.0 mGy for the dark samples, $-38 \, ^\circ\text{C} < T < +10 \, ^\circ\text{C}$.

BIOPAN 3: 09/09/-24/09/99, 12.66 d, 26.1 s.c.h., 11.501 MJ m$^{-2}$ UV radiation $\geq 170$ nm, 28.2 mGy cosmic radiation for the sun exposed samples, 4.5 mGy for the dark samples, $-17 \, ^\circ\text{C} < T < +15 \, ^\circ\text{C}$.

4. Results and discussion

4.1. Survival of unprotected spores

During the BIOPAN 1 flight, for the first time bacterial spores were exposed to space without any shielding or protection. In the “outside layers”, dry layers of spores were mounted on that side of the quartz windows of the sample carriers that faced space. Apart from space vacuum, they received the full spectrum of extraterrestrial UV radiation, including the highly energetic vacuum-UV, at a total UV fluence of about 17 MJ m$^{-2}$. They were also exposed to a total dose of approximately 75 Gy of cosmic radiation due to the lack of any shielding. However, this cannot be the reason for the observed cell death, because the $D_{10}$ value (dose, causing 90% cell killing) was shown in the laboratory to be as high as about 1500 Gy for the DNA repair wildtype strain. The survival rate of the spores exposed unprotected to space was very low, about $1 \times 10^{-6}$ (see Fig. 2(a)). A similar low fraction of survivors ($10^{-6}$ or less) was obtained for those spores in dry layers, which were exposed inside the sample carrier beneath a UV-transparent quartz window (Fig. 2(b)) and which received nearly the same UV dose as the outside samples. In contrast, the dark flight samples survived very well: between 50% and 97% viable spores were recovered from those samples, which were exposed to all parameters of space except UV radiation. This survival rate coincides with that of the laboratory controls, stored at room temperature for the whole period, as well as of the ground controls, which were additionally exposed to vacuum. From these data it can be concluded that the energy-rich extraterrestrial solar UV radiation, which does not reach the surface of the Earth due to the absorption in the Earth’s atmosphere and to which the terrestrial organisms have not become adapted during evolution, is the most deleterious environmental factor for bacterial spores in space, whereas the other environmental factors investigated, vacuum and galactic cosmic radiation, do not play an important role for the survival of spores under these conditions.

4.2. Survival of spores shielded by rock or soil material

If solar UV radiation is the limiting factor in space for spores to survive, then a thin layer of dust or soil might provide sufficient shielding against the harmful extraterrestrial UV radiation. To test this, layers of spores were exposed to space beneath a thin layer of clay that covered the inner side of the quartz windows which was opaque for UV and visible light. Fig. 2(c) shows that in these “shadowed layers” none of the flight sun-exposed spores of the strains HA 101 and HA F and only a few spores of strain TKJ 6312 survived these conditions, whereas the survival rates of the flight dark controls were in the same range as those of the lab and ground controls. Hence, the filter of clay did not protect the spores against solar UV radiation. This unexpected lack of protection by the clay layer may be caused either by microscopic cracks in the clay layer which occurred during the mission and which allowed solar UV to reach the samples, or by toxic volatiles which were photochemically produced in the clay during insolation. To test these two alternatives, in the follow-on mission, the spores were brought in direct contact with soil or rock material when exposed to space. A much better survival (by more than five orders of magnitude) was achieved if the spores were exposed in “mixed layers” (Fig. 2(d)) than if exposed in “shadowed layers” under a filter of
clay (Fig. 2(c)). These data suggest that rock or soil material protects the spores against the solar UV radiation to certain extent, and that cracks in the clay filter were probably the reason for the killing of the spores in the “shadowed layers”. A comparable good protection was obtained in “mixed layers” prepared from powdered red sandstone or with powdered meteorites (Millbillillie, Zagami) or simulated Martian soil.
5. Conclusions

Our space studies in the BIOPAN facility provide experimental data on the efficiency of protection against energy-rich solar UV radiation by the uppermost layers of soil, rock or meteorite material in the μm to mm range. Although there was a large scattering between the colony formers of parallel samples, in some cases up to 10,000 spores survived full exposure to the sun (survival rates ranged between $10^{-4}$ and $<10^{-8}$). Probably, these survivors were located within clumps of spores where they might have been shadowed by the upper layers of dead spores. On the other hand, a thin layer of clay did not protect the spores at all, if it was placed at some distance (about 5 mm) from the spore layer. Probably, tiny cracks in the clay layer allowed solar UV to reach the spore layer. A certain degree of protection could be reached by mixing the spores in the layer directly with clay or other rock or meteorite material (survival rates ranged between $10^{-3}$ and $10^{-4}$). These results are consistent with observations during the PERSEUS mission on the MIR space station, where spores mixed with similar meteorite material were exposed to space for more than three months (Rettberg et al., 2002). Probably, soil or rock grains served as a shield against UV for those spores that were located beneath them. Maximum protection was achieved, if the spores were exposed to solar UV within a mixture of clay, rock or meteorite powder in a similar ratio as occurring in terrestrial soil. Within a column of 5 mm, sunlight was attenuated so efficiently that the same high survival rates were observed for both dark and sun-exposed flight samples. The results are also applicable for the discussion of the toxicity of the Martian regolith, because one of the minerals used (MRTE) served as simulated Martian soil and one was a Martian meteorite (Zagami). In layers mixed with MRTE or Zagami the spores survived sun exposure with a similar rate than in those layers mixed with clay or red sandstone. There was no indication of a photochemical production of toxic volatiles in the Martian meteorite analogue, when exposed to extraterrestrial UV radiation at $\lambda > 170$ nm, at least not within the short period of the BIOPAN missions. On the contrary, the Martian regolith may shield potential microbial inhabitants from solar UV. Mancinelli and Klovstad (2000) have shown that 1 mm of Martian analogue soil completely protects *B. subtilis* spores from UV radiation at doses comparable to those experienced during the BIOPAN flights, whereas unprotected spores were killed by 100%. These findings are also important for planetary protection considerations because potential terrestrial contaminants on the surface of spacecrafts could survive on the surface of Mars under a thin layer of Martian dust.

6. The future experiment MARSTOX

Based on the findings of the experiments SURVIVAL, the next experiment, MARSTOX, on BIOPAN on a future FOTON mission is designed to investigate in more detail the influence of the Martian UV radiation climate on bacterial spores in Martian soil analogues. The following environmental parameters will be investigated individually or in selected combinations in space and simulated in parallel on ground: (i) different types of Mars soil analogues, (ii) UV radiation conditions of the early Earth, (iii) UV radiation conditions of present Mars, (iv) temperature and (v) vacuum. As a biological assay system, the utilization of the well-characterized bacterial endospores of *B. subtilis* will be continued. The biological methods applied will be modified forms of those used in the previous SURVIVAL experiments (see above). As biological endpoints of their responses to the selected environmental parameters, the loss of viability and the mutation induction will be determined to investigate cyto- and genotoxicity, phototoxicity, as well as the protection provided by Martian soil components.

6.1. Martian soil analogues

Different terrestrial soil samples will be scored for their suitability as Martian soil analogue. Candidates are *Palagonite*: Palagonite is the main amorphous hydrolysis product of basaltic lava and/or tuff. It is very likely that palagonite is a substantial component of Martian regolith, as deduced from IR spectroscopic data. Palagonite PA-2-5 from Hawaii, Pahala District, has the following composition: SiO$_2$ (42.1%), TiO$_2$ (2.31%), Al$_2$O$_3$ (12.6%), FeO (11.91%), MnO (0.19%), MgO (7.40%), CaO (8.40%), Na$_2$O (2.57%), K$_2$O (0.68%),
P2O5 (0.18%), CO2 (5.2%), H2O(+) (6.2%). A sample with a grain size <63 μm is available and has been used in preliminary compatibility test with B. subtilis spores.

**Bentonite:** Bentonite is another terrestrial weathering product, which consists mainly of crystallized secondary mineral phases. It originates from tuff or crystallized primary rock material. From the results of the Viking experiments, crystalline weathering products, such as the Fe-rich Montmorillonites are thought to exist in the Martian regolith. Bentonite Sol I/80 from Hainwalde (Sachsen) has the following chemical composition: SiO2 (43.8%), TiO2 (3.90%), Al2O3 (22.2%), FeO (15.38%), MnO (0.18%), MgO (1.72%), Na2O (0.13%), K2O (0.83%), P2O5 (0.62%), CO2 (0.9%), H2O(+) (9.1%). It consists of 74% Montmorillonit-Illit, 5% Kaolinit, 5% Mica (Muscovite), 3% quartz, 5% feldspar, 5% hematite (Goethite) and 3% Anastase. A sample with a grain size <63 μm is available and has been used in preliminary tests.

**JSCMars-1:** JSC Mars-1 is a widely used Martian soil analogue (Allen et al., 1998, kindly provided by NASA). It is mainly a Ca-feldspar and originates from Mauna Kea, Hawai/C213. It has the following composition: SiO2 (43.5%), Fe2O3 (15.60%), TiO2 (3.80%), Al2O3 (23.30%), MnO (0.30%), MgO (3.40%), CaO (6.20%), Na2O (2.40%), K2O (0.60%), P2O5 (0.90%). A samples with grain sizes of 75 wt% >149 μm is available and has been used in preliminary tests.

The above mentioned soil preparations are all natural terrestrial soils. The possibility to artificially modify the soils by adding certain substances, e.g., powdered hematite (Fe2O3) and the use of solid material samples in form of discs cut from different minerals on top of the spore layers will also be considered.

### 6.2. Simulated Martian UV radiation climate

The whole spectrum of the Martian UV radiation climate, i.e., all wavelengths above 200 nm, will be simulated as realistic as possible for early Earth and for present Mars by using the energy-rich extraterrestrial solar UV radiation in space and appropriate cut-off filter systems on top of the samples. Fig. 3 shows an example of how the simulation of the UV conditions on Mars can be performed in space.

### 6.3. Mission parameters

Originally the experiment MARSTOX together with other physical, chemical and biological experiments in the ESA facility BIOPAN was scheduled for the FOTON M-1 mission in October 2002. However, because of a launch failure it will be performed on the next available FOTON mission, presumably in 2004. Table 3 shows the expected mission parameters derived from the experiences of the previous BIOPAN flights.

### 7. Outlook

Future research in the field of exo/astrobiology in Earth orbit, and on other solar system bodies like Mars, requires an external platform for studying processes under the conditions of free space and for simulating selected space or planetary parameters. Derived from existing facilities for exobiology in Earth orbit, ESA has developed the exposure facility EXPOSE, to be mounted outside of the ISS. To study the Responses of Organisms to the Space Environment (ROSE), a consortium of scientists has formed to study photobiological processes in the simulated UV radiation climate of planets (like early Earth, Mars, the role of the ozone layer in protecting the biosphere from harmful UVB radiation), and the probabilities and limitations for life to be distributed among the bodies of our solar system. The EXPOSE facility will be mounted outside on the COLUMBUS module and the launch is scheduled for 2004/5.

### References


