Habitable Planet Searches around Red Dwarfs: Ground and Space

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Red dwarfs or M-type stars are the most abundant stars in the Milky Way Galaxy. Therefore, the Earth-like small planet searches around red dwarfs, in particular the habitable Earth-like planet searches, are one of the most important topics in astrobiology. In this talk, I will introduce such searches with ground-based facilities like Subaru/IRD and those with space-based facilities like TESS mission. Then I will outline the future characterization plan of the targets discovered by these projects.

Keywords: exoplanet, IRD, TESS, habitable planet

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JpGU-AGU Joint Meeting 2017

Exploiting Modern Photoionization Tools to Untangle the Formation of Astrobiologically Relevant Molecules in Extraterrestrial Ices

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Astrobiologically relevant molecules such as the sugar glycolaldehyde are ubiquitous in the interstellar medium, but traditional gas phase astrochemical models cannot explain their formation routes. By systematically exploiting *on line* and *in situ* vacuum ultraviolet photoionization coupled with reflectron time of flight mass spectrometry (PI-ReTOF-MS) and combining these data within infrared spectroscopy (FTIR), we reveal that complex organic molecules - among them astrobiologically relevant species - can be synthesized within interstellar ices that are condensed on interstellar grains via non-equilibrium reactions at temperatures as low as 5K. By probing for the first time specific structural isomers withour their degradation (fragment-free), the incorporation of tunable vacuum ultraviolet photoionization allows for a much greater understanding of reaction mechanisms that exist in interstellar ices compared to traditional methods thus eliination the significant gap between observational and laboratory data that existed for the last decades. With the commisiton of the Atacama Large Millimeter/Submillimeter Array (ALMA), the detection of more complex organic molecules in space will continue to grow - including biorelevant molecules connected to the *Origins of Life* theme - and an understanding of these data will rely on future advances in hard core physical chemistry laboratory experiments.

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Keywords: photoionization, astrobiology, laboratory astrochemistry

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The influence of aqueous alteration in carbonaceous meteorites on its soluble organic content

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Carbonaceous meteorites are fragments from the asteroid belt that may be used as time capsules to understand the processes that happened in the early solar system. The analysis of these organic carbon-rich meteorites provide crucial information regarding the chemical reactions that occurred on the meteorite parent bodies, solar nebula or interstellar medium. They contain a rich inventory of extra-terrestrial molecules, present as insoluble organic matter (IOM) [1, 2], and as soluble organic compounds [3-5]. Bulk analysis of the soluble organic fraction of the Murchison meteorite has revealed a high molecular diversity of tens of thousands of different molecular compositions [6]. In addition, different carbonaceous meteorites show different abundances and distributions of their soluble organic content. The reason for this is not fully understood. Aqueous alteration on the meteorite parent body of carbonaceous chondrites may play a role as it is an important alteration process of their mineral, isotopic and volatile content [7-12]. In relation to the soluble organic content, a few studies show that the relative distribution of amino acids in carbonaceous chondrites seems to be influenced by the degree of aqueous alteration on the parent body [13-16]. In this talk I will present the organic inventory of different carbonaceous meteorites, and how the extension of aqueous alteration on the meteorite parent bodies may be related to this. For example, the least aqueously altered CM chondrites have smaller L-enantiomer excess (Lee) values of isovaline [17-19]. The Paris meteorite, one of the most primitive CM chondrites analysed to date has an isovaline Lee close to zero [17]. While aqueous alteration does not create an isovaline asymmetry by itself, it may amplify an L-enantiomeric excess that was originally created by other mechanisms (e.g. ultraviolet circularly polarized light (UV-CPL) photo-processing of interstellar/circumstellar ices [20-25]).

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First year report of the Tanpopo: Capture and Exposure Experiment of Micrometeorite and Microbes on Exposure Facility of International Space Station

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Purpose of Tanpopo mission
Tanpopo, a dandelion in Japanese, is a plant species whose seeds with floss are spread by wind. We proposed this mission to examine possible interplanetary migration of microbes, and organic compounds at the Exposure Facility of Japan Experimental Module (JEM: KIBO) of the International Space Station (ISS).
We are testing the panspermia hypothesis, which proposes the interplanetary transfer of life. We are also testing if the organic compound may be transferred from space before the origin of life on the earth.
The Tanpopo mission consists of six subthemes: Capture of microbes in space (Subtheme 1), exposure of microbes in space (Subtheme 2), analysis of organic compounds in interplanetary dust (Subtheme 3), exposure of organic compounds in space (Subtheme 4), measurement of space debris at the ISS orbit (Subtheme 5), and evaluation of ultra low-density aerogel developed for the Tanpopo mission (Subtheme 6).

Apparatus developed for Tanpopo mission
We have developed two types of apparatus used for Tanpopo mission: Capture Panels for aerogel to capture micro-particles and Exposure Panels for exposure of microbes and organic materials. Each Capture Panel contains a silica aerogel block in an aluminum mesh container. Silica aerogel, which is the lowest density solid material, is used to capture micro particles, which may include, micrometeorite, artificial space debris and earth-originated natural particles. We are going to analyze if the particles contain terrestrial microbial cells or not.
Exposure Panels have been developed to expose microbes and organic compounds to the space environment. Several microbial species including, *Deinococcus radiodurans, Deinococcus aerius, Deinococcus aetherius, Nostoc sp., Schizosaccharomyces pombe,* have been exposed to the space environment. These species are expected to be resistant against space environment, vacuum, desiccation, temperature-cycle, UV and ionization radiation. We are testing the survival of these species after one-, two- and three-year exposure in space. Organic compound such as amino acids and the precursors have also been exposed.

Schedule of Tanpopo mission
Tanpopo apparatus was launched on April 2015. The Panels were placed on the Exposed Experiment Handrail Attachment Mechanism (ExHAM) in the ISS. The ExHAM with Panels were placed on the Exposure Facility of KIBO (JEM) with the Japanese robotic arms through the airlock of KIBO on May 2015. The first set of Capture Panels and an Exposure Panel were retrieved on June 2016, contained in plastic bags, and stored in the pressurized area of the International Space Station. They have returned to the

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ground in the space capsule, and returned to JAXA, September 2016.
Exposure Panel was separated into each Exposure Unit, each harboring either microbe or organic compound was handed over to the scientist in charge of each microbe or organic compound. Some of the Units are dedicated to the UV or radiation dose measurement.
Each aerogel block of each Capture Panel was examined for the particles captured and the tracks made upon the impact, which were extracted from the aerogel block and handed over to the scientists. The analysis includes, fluorescence microscopic inspection to test if there are microbial cells or not. Particles and tracks will be used for the mineral analysis as well as the analysis of organic compounds.

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Keywords: International Space Station, Exposure Experiment, Microbes, Organic compounds, Aerogel, Micrometeorite

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Abiotic syntheses of organic matter and Fe-oxides in submarine hydrothermal plumes in a deep ocean ~3.45 Ga ago

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The evolutions of life and O_2 on the early Earth have long been debated among astrobiologists. Some have suggested that the life did not evolve until ~2.7 Ga, and that the organic matter (OM) in pre-2.7 Ga sedimentary rocks represent OM synthesized abiotically via Fischer-Tropsch-type reactions in submarine hydrothermal environments. The current paradigm for atmospheric evolution is that the atmosphere remained anoxic until ~2.5 Ga because of the presence of MIF-S signatures in pre-2.5 Ga sedimentary rocks. However, some researchers have suggested that the oxygenated atmosphere and the diverse biosphere, including anaerobic and aerobic microbes, have existed since at least ~3.5 Ga. Based largely on nano-scale investigations of the physical and chemical characteristics of OM and Fe-oxides in the Marble Bar Chert/Jasper (MBC) from Western Australia, here we suggest that abiotic hydrothermal synthesis of OM was important and that the diverse biosphere existed in the ~3.5 Ga oceans.

Our investigations of the MBC, utilizing state-of-the-art analytical instruments for nanomaterial sciences (e.g., HRTEM, STEM, EELS, TALOS), have recognized intimate associations of sub-nano- to nano-sized (<0.5 nm –100 nm) particles of Fe-oxides (FeNP) and organic matter (OM) in the every sample we have examined. Two modes of FeNP-OM associations were recognized. In the first mode, FeNP occurs abundantly both inside and outside of what appear to be "fossils of aerobic Fe-oxidizing microbes". This mode of FeNP-OM association typically occurs as microbial mats in chert beds formed by low-T hydrothermal fluids (see Watanabe et al., this session).

In the second mode, FeNP and OM occur as a ~30-50 nm-sized aggregate, which is comprised of a spherical- or tear-shaped Fe-rich core (~10-20 nm size) made of FeNP (hematite ±magnetite) with minor OM; the core is surrounded by a ~5 nm-thick ring of OM and then by a ~10-20 nm-thick outer zone comprised of mixtures of sub-nano-sized particles of Fe-oxides and OM. Such aggregates are typically coagulated to form larger clusters of Fe-oxides and OM. Considering the various geochemical data (e.g., Eu anomalies) of the jasper beds that host the FeNP-OM association, we interpret that the Fe-oxides and OM were synthesized abiotically during the mixing in hydrothermal plumes of high-T hydrothermal fluids and ocean bottom water. The abiotic reactions created colloidal Fe^{2+}-bearing proteins by utilizing CO_2 from the seawater and Fe^{2+} from the high-T hydrothermal fluids; the colloids were subsequently transformed into mixtures of sub-nano-sized particles of Fe-free OM and hematite (some to magnetite) through further reactions with seawater O_2 and hydrothermal Fe^{2+}. These chemical reactions are basically the same as those that produced the OM and Fe-oxides by aerobic Fe-oxidizing bacteria. The main difference is that one is promoted by biochemistry, while the other is promoted by heat.

The abiotic production of OM in the Archean oceans would have been much more important than today because the atmospheric pCO_2 was 100 PAL, the pO_2 was already ~1 PAL, and submarine hydrothermal activity was more extensive than today. The abiotically produced OM would have been more digestible to heterotrophic organisms and more reactive to chemical reactions than the OM produced by autotrophic organisms because of the absence of cell-wall lipids. Therefore, microbial activity would have flourished more during the Archean compared to later times. Thermochemical sulfate reduction by the reactive OM (rich in Fe-bearing proteins) would have generated MIF-S signatures. Decreasing submarine hydrothermal

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activity and decreasing atmospheric pCO_2 due to the increasing continental crust size since ~2.5 Ga would have decreased the productions of reactive OM and the MIF-S signatures. The disappearance of MIF-S at ~2.5 Ga does not indicate a change from an anoxic to oxic atmosphere.

Keywords: abiotic organic synthesis, early Earth, MIF-S, O2 evolution

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Syntheses of organic matter and Fe-oxides by aerobic Fe-oxidizing bacteria in a deep ocean ~3.45 Ga ago

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Previous researchers have postulated that anaerobic photoautotrophic Fe-oxidizing bacteria (FeOB) played a major role in the Fe geochemical cycle (especially in the formations of banded iron formations) in Archean. However, no fossil evidence for FeOB has been found in rocks older than ~2.4 Ga. Here we report the morphological, chemical, mineralogical, and isotopic characteristics of the remnants of microbial mats in the Marble Bar Chert/Jasper (MBC) in East Pilbara, Western Australia. We interpret that the mats were developed mostly by aerobic chemolithotrophic FeOB on a 2,000 m-deep ocean-floor during the influence of low-temperature submarine hydrothermal fluids at ~3.45 Ga. We will further discuss implications of our findings on the chemical and biological evolutions of the early Earth.

The major findings and their interpretations from this study include: (a) The intricate nano-scale features of the interface between the OM-rich layers and the underlying minerals suggest that the microbial mats were biochemically bonded to the minerals, rather than simply settling on the minerals; (b) The $d^{13}C$ values (-35 to -21‰) of the kerogens suggest that the kerogens were composed with two populations of primary producers: one that utilized CO_2 via the Calvin-Benson cycle for C-fixation (e.g., cyanobacteria, FeOB, sulfide-OB) and the other involved in the CH_4 related cycle (e.g., methanogens, methanotrophs); (c) Sub-nano- to nano-scale (<0.5 nm –100 μm) morphologies and chemistries of organic matter (OM) and associated Fe-oxides (mostly hematite) in the MBC closely resemble those of modern aerobic chemolithotrophic FeOB; (d) The close association of nano-crystals of barite with the "microfossils" of FeOB suggests the local production of SO_4 by sulfide-OB; and (e) The $d^{34}S$ values (-4 to +1‰) of pyrite crystals in the benthic mats suggest the activity of sulfate-reducing bacteria (SRB).

Based on the above data we suggest that: (1) Microbial mats in the MBC developed at the interface between CO_2- and O_2-rich bottom ocean water and the underlying unconsolidated cherts which were invaded by low-temperature, Fe^{2+}- and H_2S-bearing hydrothermal fluids; (2) Although oxygenic photoautotrophs (cyanobacteria) had evolved by ~3.45 Ga, the involvement of cyanobacteria in the formation of benthic mats in the MBC is unlikely. This is because cyanobacteria could not have been active in the deep (dark) ocean, and the remnants of cyanobacteria in the photic zone could not have accumulated on the deep seafloor (>2,000m) with widely variable thickness in centimeter to meter scales; and (3) The microbial mats were comprised of various autotrophs (primary producers) and heterotrophs. The primary producers were mostly aerobic chemolithotrophic FeOB with minor sulfide-oxidizing bacteria (sulfide-OB) and methanotrophs, and the heterotrophs were mostly Fe-reducing bacteria (FeRB), sulfate-reducing bacteria (SRB), and methanogens. They imply that the global oceans and the atmosphere were already fully oxidized at ~3.45 Ga and the diverse microbial world had evolved by ~3.5 Ga. Our findings of the presence of negative- and positive Ce anomalies and the Y/Ho ratios (up to ~120) of the host cherts also support these implications.

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The oldest terrestrial material with life-forming elements

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Besides amino acid detected in meteorites, terrestrial material that preserves information on the Earth’s earliest life is extremely poor. The oldest C-isotope record for life has been tracked back to ca. 3.9 Ga (Eoarchean), whereas the oldest solid material (zircon) from the Earth to ca. 4.4 Ga (Hadean). The latter represents a potential target to check evidence for life; nonetheless, total amount of the oldest zircon is highly limited; 3 grains out of 100 thousands dated ones. Despite the recent development in radiometric dating techniques, mineral separation still remains as a major obstacle, particularly in the search for the oldest zircon of the Earth. To improve the efficiency in zircon separation, we newly designed and developed a new machinery, i.e. automatic zircon separator (AZS) that operates in three functions; 1) image processing to choose target individual zircon grains out of all heavy mineral fraction, and 2) automatic capturing of individual zircon grains with micro-tweezers, and 3) placing them one-by-one in a coordinate alignment. A new software for automatic and continuous capturing was also designed/created for continuous mineral picking without human attendance for long hours. We tested the practical efficiency of AZS, by analyzing the Archean Jack Hills conglomerate of the Mt. Narryer complex in Western Australia, i.e. the oldest zircon-beqaring rock. Preliminary results are quite positive; we could obtain more than 42 zircons of over 4.0 Ga out of ca. 1,400 checked grains with 4 zircons of over 4,300 Ma with the oldest one of 4,371.1 +- 6.7 Ma. This new AZS system guarantees much higher gain in hunting older zircons. As to the origin of life, we identifiied tiny mineral inclusions in the oldest zircons, apatite, by Raman spectroscopy. These apatite inclusions naturally contain one of the bioessential element P, halogens (F and Cl), and possibly OH. These indicate that early Earth, at least at 4.37 Ga, has prepared inevitable elements and water potentially for generating the first life in near-surface crust.

Keywords: Hadean, life, zircon, automatic separator, apatite

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Microbial nitrogen cycle enhanced by the continental input recorded in the Paleoproterozoic Gunflint Formation

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We report the heterogeneity of nitrogen isotope compositions ($\delta^{15}N$) observed in the kerogen, to know the complex origins of organic components sealed in a single kerogen of the Gunflint Formation, together with corresponding geochemical data of sedimentary rocks. The Gunflint Formation has been recognized as one of the best geological sections to understand the microbial activity and ocean environments in the Paleoproterozoic era. During the sedimentation of the Gunflint Formation, a significant orogeny event, so-called Penokean orogeny, has occurred which should affect on the change of environment in the sedimentary basin. However, the correlation between the microbial activity and change of the sedimentary environment triggered by the tectonics has not been understood.
The stepwise combustion method was performed on 13 kerogen samples to know the heterogeneities of $\delta^{15}N$. In this method, components hosted by different carriers that are intimately mixed in a sample and cannot be separated by other physical methods can be resolved based on the combustion temperature. A preliminary study suggested that the temperature dependent $\delta^{15}N$ heterogeneities were exist in the single kerogen (Ishida *et al.*, 2012, *Geochem. J.*). In the present study, the same isotope heterogeneity was observed among examined kerogen samples. The occurrences of minerals, and major and trace elemental concentrations of bulk rock samples were evaluated to understand the transition of ocean chemistry triggered by the active tectonics in this region.
A positive correlation between $\delta^{15}N$ values of subset of kerogen, and Pr/Sm ratios of bulk rock was obtained. This relationship indicates that when the terrestrial input increased, the nitrogen isotope composition recorded in the kerogen would become heavy, suggesting the biological nitrogen cycle under the oxic environment was promoted. It is inferred that the increase of terrestrial input promoted the higher productivity of cyanobacteria, making dense-microbial zone in the surface of the ocean. This organic-rich zone secondarily induces the sub-oxic zone beneath it because of consumption of oxygen by decomposing organic matter. As a result, biological nitrogen cycle including nitrification and denitrification was promoted in this zone, resulting to the heavier nitrogen isotope compositions in organic matter.
Our study suggests that the transition of ocean environment can be recorded as unique isotope heterogeneities of nitrogen in kerogen, in the relation to the specific trace elemental concentrations left in the sedimentary rocks. The techniques and evaluation procedures in this study will be largely beneficial to the future research on Precambrian geology.

Keywords: nitrogen, Paleoproterozoic, kerogen

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Interaction of Methanogens and Early Earth Environment

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The luminosity of the Sun was 20-25% lower during the Archean (3.8˜2.5 Ga) but geological records indicate a generally warmer climate than those of today. The common consensus is that the Archean warm climate was supported by greenhouse effect from CO_2, CH_4, and/or H_2-N_2 collision-induced absorption. It is generally accepted that H_2-using methanogens evolved early. In this work we developed a coupled ecosystem model to study the dynamic relationship between methanogens and their environment on early Earth.

The model shows prior to the development of biological nitrogen fixation, the methanogens biosphere would have little impact on the environment because of limited Net Primary productivity (NPP). After the invention of biological nitrogen fixation, there could be 2 types of interaction patterns. In the case of low hydrogen escape efficiency and high CO_2 weathering rate, both the biomass of methanogens and the environmental variables (temperature, greenhouse gas concentrations, etc.) show cyclic variations around the freezing point. Activities of methanogens are limited by environmental temperature in this case, which is in turn regulated by atmospheric CO_2 and H_2. In the case of high hydrogen escape efficiency and high CO_2 weathering rate, low hydrogen escape efficiency and low CO_2 weathering rate and high H_2 escape efficiency and low CO_2 weathering rate, both the biomass of methanogens and the environmental variables are stable, with the activities of methanogens limited by the availability of H_2, which does not directly influence environmental temperature. We will compare the NPP and atmospheric concentrations of greenhouse gases in the coupled model with results in previous works (Kharecha et al. 2005, Canfield et al. 2006, Wordsworth et al. 2013). We will also discuss the impact of biological nitrogen fixation on the interactions of methanogens and the Archean environment.

Keywords: Early Earth, Methanogens, biological nitrogen fixation

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UNKNOWN WIDELY-SPREAD Fe REDOX CYCLING BACTERIA BENEATH THE EAST ANTARCTIC ICE SHEET

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The main objective was to recover bacterial life existing beneath the thick East Antarctic Ice Sheet (EAIS) using the sequencing of bacterial 16S rRNA genes recovered in the ice samples containing bedrock source mineral inclusions. The samples included the accretion (lake water source) ice of the Vostok ice core (the Russian intra-continental station Vostok) containing small numerous mineral inclusions (ice type I). Three ice samples from the same depth horizon (3607-3608 m deep; age about 16 kyr) were obtained from 3 parallel boreholes (5G-1, 5G-2 and 5G-3). Another sample was the glacier ice segment containing numerous big in size reddish rock sediments of moraine source from the D10 ice core (East Antarctic coastal area, nearby the French station Dumont d’Urville. The sample was recovered from 230 m depth and aged by about 20 kyr. The samples were strictly decontaminated and treated under ‘clean room’ conditions (IGE, CNRS-University Grenoble Alpes).
The comprehensive DNA analyses (constrained by Ancient DNA research criteria) of three Vostok accretion ice samples have confidently revealed three phylotypes of iron-oxidizing beta-proteobacteria belonging to Gallionellaceae. Two related phylotypes from boreholes 5G-2 and 5G-3 samples have had the closest relative at the genus level Sideroxydans lithotrophicus, while the remaining phylotype from the borehole 5G-3 sample - Ferriphaselus amnicola. The 3rd ice sample originated from the borehole 5G-1 has gave only contaminants.
The similar analysis of the D10 ice core sample has confidently recovered also three phylotypes. The 1st phylotype has proved to be the same bacterium already detected in the Vostok ice core (borehole 5G-3 sample) –the iron-oxidizing bacterium of Gallionellaceae with the closest relative at the genus level Sideroxydans lithotrophicus. Two other related phylotypes have showed rather low family level similarity (92%) with the acidophilic thermotolerant facultative anaerobic Fe- and S-oxidizing gamma-proteobacterium Acidiferrobacter thiooxydans. However, due to status ‘unidentified’ they were removed from the further discussion on their possible involvement in the Fe redox cycling.
Thus, three confident phylotypes of iron-oxidizing beta-proteobacteria of Gallionellaceae related to Sideroxydans lithotrophicus and Ferriphaselus amnicola were revealed in Vostok and D10 ice cores meaning that unknown bacterial Fe redox cycling communities widely exist beneath the EAIS.
Of them, one phylotype (population) related to Sideroxydans lithotrophicus was surprisingly found out in both Russian Vostok 5G-3 and French D10 ice cores. The age of both ice sample types is nearly the same while their origin is evidently different - Vostok accretion (lake water source) ice vs. Dumont d’Urville glacier ice. The storage time periods for ice samples (before to be treated in a laboratory) are quite different (0.5 year for Vostok ice samples vs. 40 years for D10 ice sample) as well as the time frame for the ice treatment (in a range of 1-5 years –D10 ice core sample was treated in a year after the last Vostok 5G-3 ice sample) meaning no cross-contamination could happen. The ice coring sites (Vostok and Dumont d’Urville) are far away (more than 1000 km) with no evident hydrological links beneath the EAIS meaning no bacterium ‘flow’ could occur. How to explain such a coincidence in findings? It seems that the presence of bedrock minerals containing Fe(II) under similar physical-chemical conditions featured by the existence of unfrozen water might provide the plausible scenario.

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Keywords: East Antarctic Ice Sheet, Bedrock-originating mineral inclusions, Vostok ice core, D10 ice core, 16S rRNA genes, Iron-oxidizing bacteria

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500 μm cell-aggregation of *Deinococcus* spp. was enough thickness to survive after 384 days exposure at ISS orbit in Tanpopo mission

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The concept of panspermia hypnosis is interplanetary transfer of life prospered by solar radio-pressure (Arrhenius, 1903). Previous exposure experiment of microbes in space reveals microbes inside of shielding (*e.g.* small fragments of rock, mixture of sugar or clay) with efficient thickness to protect from UV irradiation survive in space for a long period (*e.g.* Onofuri et al., 2012). On the other hand, we proposed interplanetary transfer of cell-aggregation in sub-millimeter to survive at hash space environment (Kawaguchi et al., 2013). The hypothesis is named massapanspermia. For the investigation of microbial survival and their DNA damage induced in space, dried cells of the radioresistant bacteria *Deinococcus* spp. put in wells of aluminum plates in Exposure Panels (EPs) were exposed in space at the outside of International Space Station (ISS) in Tanpopo mission since May 2015 (Yamagishi et al., 2007; Kawaguchi et al., 2016). EPs are going to be exposed for one, two and three years. The first year’s EPs were retrieved into the ISS pressurized room in June 2016 and returned to the ground laboratory in September 2016. Dried-deinococcal cell-aggregations with various thickness from single layer to about 1500 μm were used to expose in space. Dried-deinococcal cells with 100 μm-thickness were dead. However, cell-aggregations with 500 μm-thickness were alive. Intact DNA (%) with 100 μm-thickness was less 1% according to an analysis by quantitative-PCR. The results indicated that a lethal dose of UV reached inside of cell-aggregation in the case of the 100 μm-thickness samples. For 500 μm-thickness samples, UV reached only the surface of cell-aggregation, and the surface of dead cells protected inside of living dried-cells. No remarkable difference was observed in surviving fractions between space exposed samples and laboratory controls in the case of cell-aggregation over 1000 μm-thickness. These results highlight the importance of microbial cell-aggregates as an ark for interplanetary transfer of microbes as we hypothesized in our previous study (Kawaguchi et al., 2013). Global-shaped cell-aggregation of *Deinococcus* spp. with 1 mm-thickness is possible to survive during the interplanetary journey and propagate if water exists in landing planets.

Keywords: panspermia, cell-aggregation, Tanpopo mission

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