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November 28-30, 2013

JAXA/ISAS, Sagamihara, JAPAN

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International Astrobiology Workshop 2013

November 28–30, 2013 • Sagamihara, Kanagawa, Japan

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Preface

This volume contains abstracts that have been accepted for presentation at the International Astrobiology Workshop 2013, November 28–30, 2013, Sagamihara, Kanagawa, Japan.

Technical Guide to Sessions

Thursday, November 28, 2013

9:00 a.m.	ISAS Main Building 2F Conference Hall	Welcome and Introduction
9:30 a.m.	ISAS Main Building 2F Conference Hall	Meteoritics and Cosmochemistry
12:00 p.m.	ISAS Main Building 1F "Bidding Room" (Nyusatsu-Shitsu)	Lunch and Poster Viewing
1:30 p.m.	ISAS Main Building 2F Conference Hall	Special Lectures I
2:30 p.m.	ISAS Main Building 2F Conference Hall	Early Earth, Geochemistry, and Planetary Environment
4:30 p.m.	ISAS Main Building 2F Conference Hall	Group Photo
5:00 p.m.	ISAS Main Building 2F Conference Hall	Molecular Clouds and Planetary Formation Regions

Friday, November 29, 2013

9:00 a.m.	ISAS Main Building 2F Conference Hall	Webcast Presentation I
9:30 a.m.	ISAS Main Building 2F Conference Hall	Solar System Exploration and Experiments (Science, Mission Designs, Instruments, and Enabling Technology)
12:00 p.m.	ISAS Main Building 1F "Bidding Room" (Nyusatsu-Shitsu)	Lunch and Poster Viewing
1:30 p.m.	ISAS Main Building 2F Conference Hall	Special Lectures II
2:30 p.m.	ISAS Main Building 2F Conference Hall	Exoplanetary Systems and Exoplanets (Theories, Models, and Observations)
5:00 p.m.	ISAS Main Building 2F Conference Hall	Group Photo
5:30 p.m.	ISAS Main Building 1F "Bidding Room" (Nyusatsu-Shitsu)	Poster Session

Saturday, November 30, 2013

9:00 a.m.	ISAS Main Building 2F Conference Hall	Webcast Presentation II
9:30 a.m.	ISAS Main Building 2F Conference Hall	Panel Discussion: "Astrobiology vs. Space Experiments and Exploration"
11:15 a.m.	ISAS Main Building 2F Conference Hall	Life in Extreme Environments I
12:00 p.m.	ISAS Main Building 1F "Bidding Room" (Nyusatsu-Shitsu)	Lunch and Poster Viewing
2:00 p.m.	ISAS Main Building 2F Conference Hall	Life in Extreme Environments II
2:50 p.m.	ISAS Main Building 2F Conference Hall	Group Photo
3:20 p.m.	ISAS Main Building 2F Conference Hall	RNA and Molecular Biology
5:50 p.m.	ISAS Main Building 2F Conference Hall	Findings and Closing Remarks

Contents

Program

<div align="center">

Thursday, November 28, 2013
WELCOME AND INTRODUCTION
9:15 a.m.   ISAS Main Building 2F Conference Hall

</div>

Chair: **Akihiko Yamagishi**

9:15 a.m.   Yamagishi A. *
Opening Remarks by Japan Astrobiology Network (President, JABN)

9:25 a.m.   Tsuneta S. *
Welcome Address by the Host Institution (Director General, JAXA/ISAS)

9:35 a.m.   Yano H. *
Meeting Agenda and Logistics from the Local Organizing Committee

<div align="center">

METEORITICS AND COSMOCHEMISTRY
9:45 a.m.   ISAS Main Building 2F Conference Hall

</div>

Chairs: **Kensei Kobayashi**
Motoo Ito

9:45 a.m.   Krot A. N. * Doyle P. M. Nagashima K. Jogo K. Wakita S.
Ciesla F. J. Hutcheon I. D.
Aqueous Activity on Chondrite Parent Asteroids [#1052]

10:15 a.m.   Jogo K. * Krot A. N. Nagashima K.
Metamorphosed Clasts in the CV Carbonaceous Chondrite Breccias Mokoia and Yamato 86009:
Evidence for Strong Thermal Metamorphism on the CV Parent Asteroid [#1042]

10:30 a.m.   Kebukawa Y. * Cody G. D.
Deuterium-Hydrogen Exchange Between Organic Matter and Water: Implications for Chemical
Evolution During Asteroidal Processing [#1025]

10:45 a.m.   Mimura K. * Sugahara H.
Comet Impacts as a Driving Force of Glycine Oligomerization [#1012]

11:15 a.m.   Kobayashi K. * Kawamoto Y. El-Masry W. Eto M. Tokimura H. Kaneko T. Obayashi Y.
Mita H. Kanda K. Yoshida S. Fukuda H. Oguri Y.
Evolution of Interstellar Organics to Meteoritic and Cometary Organics: Approaches by
Laboratory Simulations [#1016]

11:30 a.m.   Ito M. *
Ultra High Spatial Resolution Ion Imaging with a NanoSIMS Ion Microprobe:
Applications to Astrobiology [#1044]

11:45 a.m.   Satoh T. * Kubota T. Fujita K. Okada T. Iwata T. Imamura T. Oyama A.
Ogawa N. Yamada K.
Overview of Japan's MELOS1 Mars Mission: Mars Exploration for
Life/Organism Search [#1049]

<div align="center">

LUNCH AND POSTER VIEWING
12:00 p.m.   ISAS Main Building 1F "Bidding Room" (Nyusatsu-Shitsu)

</div>

Thursday, November 28, 2013
SPECIAL LECTURES I
1:30 p.m.   ISAS Main Building 2F Conference Hall

Chair: **Akihiko Yamagishi**

1:30 p.m.   Oshima T. * [INVITED]
Puzzles of Biochemistry of Extraterrestrial Life **[#1043]**

2:00 p.m.   Maruyama S. * [INVITED]
From Origin of Life to Systematization to Astrobiology **[#1064]**

EARLY EARTH, GEOCHEMISTRY, AND PLANETARY ENVIRONMENT
2:30 p.m.   ISAS Main Building 2F Conference Hall

Chairs: **Yasuhito Sekine**
Yuichiro Ueno

2:30 p.m.   Tian F. * [INVITED]
The Faint Young Sun Problem — How Can Early Earth and Mars be Warmed? **[#1056]**

2:50 p.m.   Genda H. * Hamano K.   Abe Y.
Formation and Early Evolution of Atmosphere and Ocean on the Earth **[#1031]**

3:20 p.m.   Thomazo C. * [INVITED]
*Did Oceanic Biogenic Methane Cycling Regulate the Evolution of Early Earth
Atmospheric Chemistry?* **[#1063]**

3:40 p.m.   Ueno Y. * Danielache S. O.   Endo Y.
Unique Late Archean Atmosphere due to Enhunced Volcanic and Biological Activities **[#1010]**

4:10 p.m.   Sekine Y. * Shibuya T.   Postberg F.   Hsu S.   Suzuki K.   Masaki Y.
Kuwatani T.   Tachibana S.
Enceladus' Hydrothermal Activity: Another Habitable World? **[#1028]**

GROUP PHOTO AND COFFEE BREAK
4:30 p.m.   ISAS Main Building 2F Conference Hall

MOLECULAR CLOUDS AND PLANETARY FORMATION REGIONS
5:00 p.m.   ISAS Main Building 2F Conference Hall

Chairs: **Ohishi Masatoshi**
Aunaud Belloche

5:00 p.m.   Belloche A. * [INVITED]
Complex Organic Molecules in the Interstellar Medium in the Era of ALMA **[#1007]**

5:30 p.m.   Ohishi M. * Hirota T.   Kaifu N.   Suzuki T.   Motoki Y.   Ozeki H.
Absorption Features of CH_3NH_2 Towards SgrB2(M) **[#1009]**

5:50 p.m.   Kwon J. * Tamura M.
*Near-Infrared Circular Polarimetry in Star Forming Regions: Implication
for Astrobiology* **[#1023]**

6:10 p.m.   Ishihara D. * Kaneda H.   Oyabu S.   Kondo T.   Yamagishi M.   Yasuda A.
AKARI Observations of Interstellar Polycyclic Aromatic Hydrocarbons **[#1048]**

Friday, November 29, 2013
WEBCAST PRESENTATION I
9:00 a.m.   ISAS Main Building 2F Conference Hall

Chair: **Hajime Yano**

9:00 a.m.   C. Conley *
Planetary Protection for Astrobiology Missions (NASA-HQ): TBD

SOLAR SYSTEM EXPLORATION AND EXPERIMENTS
(SCIENCE, MISSION DESIGNS, INSTRUMENTS, AND ENABLING TECHNOLOGY)
9:30 a.m.   ISAS Main Building 2F Conference Hall

Chairs: **Hitoshi Kuninaka**
Masaki Fujimoto

9:30 a.m.   Horneck G. *   [INVITED]
Astrobiology Research on Board of the International Space Station as part of the European Space
Exploration Initiative **[#1026]**

10:00 a.m.   Yano H. * Yamagishi A. Hashimoto H. Yokobori S. Kobayashi K. Yabuta H. Mita H.
Tabata M. Kawai H. Higashide M. Okudaira K. Sasaki S. Imai E. Kawaguchi Y.
Uchibori Y. Kodaira S. Tanpopo Project Team
Tanpopo: Astrobiology Exposure and Micrometeoroid Capture, a Sample Return Experiment to
Test Quasi-Panspermia Hypothesis Onboard the ISS-Kibo Exposed Facility **[#1040]**

10:15 a.m.   Tsou P. *   [INVITED]
Intact Capture, Aerogel, SOCCER, Stardust and LIFE **[#1050]**

10:45 a.m.   Kuninaka H. *   Hayabusa 2 Project
Hayabusa Asteroid Sample Return Mission **[#1053]**

11:05 a.m.   Takano Y. * Yano H. Sekine Y. Funase R. Takai K.
A Strategy for Sample Retrieval and Possible Onboard Biosafety Controls: Perspectives **[#1054]**

11:20 a.m.   Kimura J. *
"Deep Habitat" in the Icy Moons: Structure and Evolution of the Internal Ocean **[#1062]**

11:40 a.m.   Vance S. *
TBD

LUNCH AND POSTER VIEWING
12:00 p.m.   ISAS Main Building 1F "Bidding Room" (Nyusatsu-Shitsu)

SPECIAL LECTURES II
1:30 p.m.   ISAS Main Building 2F Conference Hall

Chair: **Ken Takai**

1:30 p.m.   Kaifu N. *   [INVITED]
"Contact" with Extra-Terrestrial Life: An Astronomer's View **[#1014]**

2:00 p.m.   Hirose K. *   [INVITED]
Perspectives of ELSI Projects: The Origin of the Earth and the Origin of Life **[#1011]**

Friday, November 29, 2013
EXOPLANETARY SYSTEMS AND EXOPLANETS
(THEORIES, MODELS, AND OBSERVATIONS)
2:30 p.m.   ISAS Main Building 2F Conference Hall

Chairs: **Takao Nakagawa**
                Shigeru Ida

2:30 p.m.   Narita N. * [INVITED]
             Toward Detections and Characterization of Habitable Transiting Exoplanets

3:00 p.m.   Omiya M. * Sato B. Harakawa H. Kuzuhara M. Hirano T. Narita N. IRD Team
             *Search for Habitable Planets Around Low-Mass Stars Using the InfraRed
             Doppler Instrument* **[#1037]**

3:15 p.m.   Sorahana S. * Yamamura I. Suzuki T. K.
             Brown Dwarfs Atmospheres Revealed by 2.5–5.0 µm AKARI Spectra **[#1045]**

3:30 p.m.   Enya K. *
             Studies of Exoplanets with SPICA **[#1047]**

3:45 p.m.   Hut P. * [INVITED]
             Why Life? Origins of Life Elsewhere in the Universe **[#1055]**

4:15 p.m.   Fujii Y. *
             Toward Characterization of Exoplanetary Surface Environment **[#1020]**

4:30 p.m.   Takahashi J. * Itoh Y. Akitaya H. Okazaki A. Kawabata K. Oasa Y.
             Isogai M. Niwa T.
             Polarimetric Signatures of the Earth Extracted from Earthshine Observations **[#1034]**

4:45 p.m.   Ueta S. * Sasaki T.
             Conditions of Surface H_2O of Snowball Planets with High-Pressure Ice **[#1039]**

GROUP PHOTO AND COFFEE BREAK
5:00 p.m.   ISAS Main Building 2F Conference Hall

POSTER SESSION
5:30 p.m.   ISAS Main Building 1F "Bidding Room" (Nyusatsu-Shitsu)

Struck J.-T.
*Man Made Elements Periodic Table, Astronomical Periodic Table, Geographic Periodic Table-Dimitri
Mendeleev Imitation in the 21st Century* **[#1003]**

Takahashi J.
Polarized Space Radiation and Biological Homochirality **[#1030]**

Takano Y.
Abiogenic and Biogenic Chiral Amino Acids for Further Enantiomer-Specific Isotope Analysis (ESIA) **[#1046]**

Yuko Y. Yinjie Y. Narutoshi K. Keisuke S. Masako T. Issay N. Katsuya S. Hirofumi H. Kazumichi N.
Yoshiaki Y. Yoh-hei Y. Maiko T. Tomohiro S. Yuta Y. Yasuyuki S. Satoshi Y. Kensei K. Shin-ichi Y.
Yamagishi A.
*The Possible Interplanetary Transfer ofMmicrobes: Assessing the Viability of Deinococcus spp. Under the ISS
Environmental Conditions for Performing Exposure Experiments of Microbes in the Tanpopo Mission* **[#1013]**

Saturday, November 30, 2013
WEBCAST PRESENTATION II
9:00 a.m.   ISAS Main Building 2F Conference Hall

Chair: **Hajime Yano**

9:00 a.m.   C. McKay *
Astrobiology in USA (NASA Ames): TBD

PANEL DISCUSSION:
"ASTROBIOLOGY VS. SPACE EXPERIMENTS AND EXPLORATION"
9:30 a.m.   ISAS Main Building 2F Conference Hall

Moderator: **Hajime Yano**

Panel Members: **Gerda Horneck**
Hitoshi Kuninaka
Ken Takai
Akihiko Yamagishi
Hiroshi Yamakawa

LIFE IN EXTREME ENVIRONMENTS I
11:15 a.m.   ISAS Main Building 2F Conference Hall

Chairs: **Ken Takai**
Daiki Horikawa

11:15 a.m.   Nicholson W. L. *   [INVITED]
Can Terrestrial Microbes Grow on Mars? **[#1051]**

11:45 a.m.   Horikawa D. D. *
Astrobiological Research on Tardigrades: Implications for Extraterrestrial Life Forms **[#1035]**

12:00 p.m.   Gusev O. * Shagimardanova E. Bosch T. Okuda T. Kikawada T.
Interaction of the Sleeping Chironomid with Microorganisms: "Uchi-Soto" in the World
of Anhydrobiosis **[#1005]**

12:15 p.m.   Kitadai N. *
The Energetics of Amino Acid Synthesis and Polymerization as a Function of
Temperature and pH **[#1029]**

LUNCH AND POSTER VIEWING
12:30 p.m.   ISAS Main Building 1F "Bidding Room" (Nyusatsu-Shitsu)

LIFE IN EXTREME ENVIRONMENTS II
2:00 p.m.   ISAS Main Building 2F Conference Hall

Chairs: **Ken Takai**
Daiki Horikawa

2:00 p.m.   Inagaki F. * Hinrichs K.-U. Kubo Y. IODP Expedition 337 Scientists
Limits of Life in the Deep Subseafloor Biosphere: New Insights from IODP
Expedition 337 **[#1022]**

2:15 p.m.   Morono Y. *   Terada T.   Ito M.   Hoshino T.   Inagaki F.
Technological Challenges for the Advanced Study of Deep Subseafloor Life **[#1027]**

2:30 p.m.   Takai K. *   Shibuya T.   Sekine Y.   Russell M. J.
*Microbial Community Development in Deep-Sea Hydrothermal Vents in the Earth,
and the Enceladus* **[#1004]**

GROUP PHOTO AND COFFEE BREAK
2:50 p.m.   ISAS Main Building 2F Conference Hall

RNA AND MOLECULAR BIOLOGY
3:20 p.m.   ISAS Main Building 2F Conference Hall

Chairs: **Daisuke Kiga**
Yutetsu Kuruma

3:20 p.m.   Ueda T. *   [INVITED]
The Pure System for Artificial Cells **[#1057]**

3:45 p.m.   Ichihashi N. *   Usui K.   Yomo T.
*Darwinian Evolution in a Translation-Coupled RNA Replication System Within a Cell-
Like Compartment* **[#1060]**

4:10 p.m.   Kimoto M. *   Hirao I.
Variation of Genetic Alphabets of Nucleobases **[#1061]**

4:30 p.m.   Bessho Y. *
Bioimaging by X-Ray Laser Diffraction at SACLA **[#1036]**

4:45 p.m.   Becerra A. *   Islas S.   Hernandez-Morales R.   Lazcano A.   [INVITED]
RNA and the Nature of the Last Common Ancestor **[#1059]**

5:15 p.m.   Akanuma S. *   Nakajima Y.   Yokobori S.   Yamagishi A.
*Experimentally Testing the Hypothesis of a Limited Amino Acid Repertoire in
Primitive Proteins* **[#1015]**

5:35 p.m.   Amikura K. *   Kawahara-Kobayashi A.   Kiga D.
*Simplification of the Genetic Code: Restricted Diversity of Genetically Encoded
Amino Acids* **[#1058]**

FINDINGS AND CLOSING REMARKS
5:50 p.m.   ISAS Main Building 2F Conference Hall

Chair: **Ken Takai**

5:50 p.m.   Yano H. *
Workshop Findings

6:00 p.m.   Takai K. *
Closing Remarks

Experimentally testing the hypothesis of a limited amino acid repertoire in primitive proteins. S. Akanuma[1], Y. Nakajima[1], S. Yokobori[1] and A. Yamagishi[1], [1]Deptartment of Applied Life Sciences, Tokyo University of Pharmacy and Life Sciences, 1432-1 Horinouchi, Hachioji, Tokyo 192-0392, Japan.

Introduction: The genetic code is an essential element of life because it links genetic information to proteins that express biological functions. The modern genetic code, which encodes the standard 20 amino acids (and the termination signal) using 64 triplet codons, is shared by all of the extant organisms on the earth with a few exceptions. Therefore, the genetic code is thought to have been established at the age of the last universal common ancestor, which we call the Commonote (Fig. 1).

As to the origin and evolution of the genetic code, a number of theories have been proposed. Crick proposed the *frozen accident theory* [1] in which he suggested two things; i) The code is universal because, at the present time, any change would be lethal, or at least very strongly selected against; and ii) The shape of the genetic code table was entirely a matter of *chance*. Theories that rationalize the evolution of the genetic code have been also proposed: e.g. *Stereochemical interaction* [2], *Co-evolution with amino acid biosynthesis* [3, 4], *Error minimization*, and *Expanding codons theories* [5]. These theories all suggest that only a fewer amino acids were used in primitive proteins and later the amino acid repertoire gradually increased up to 20 through the course of evolution.

If it was the case, how many number of and which types of amino acids were involved in the earliest protein synthesis system? By comparing homologous amino acid sequences from different organisms or referring to various criteria for amino acid chronology, chronological order of appearance of amino acids in the early evolution have been predicted [6–8]. However, only limited experimental studies have partially tested these predictions [9–12].

Given simpler protein synthesis system, the primitive proteins**,** which might have comprised a reduced set of amino acids, must have had a sufficiently adequate structure for functional interactions and catalysis. To address this issue experimentally, we created reduced amino acid set proteins to examine whether a protein composed of less than 20 types of amino acids can form a stable structure and express a biological function. To this end, we first resurrected several ancestral proteins and then restricted the amino acid usage of a resurrected protein to reduced amino acid sets (Fig. 1).

Resurrection of ancient proteins: We targeted ancestral nucleoside diphosphate kinase (NDK) se-

quences for resurrection. The kinase catalyzes the transfer of a phosphate from a nucleoside triphosphate to a nucleoside diphosphate. The ancestral NDK may have arisen early because at least one gene that encodes NDK is present in most extant organisms. The first step in the reconstruction of ancestral NDK sequences is to prepare multiple amino acid sequence alignments using homologous sequences of NDK from extant species, which is then used to build phylogenetic trees. Then, ancestral sequences of NDK that seem to represent the last common ancestors of Archaea and of Bacteria were designed using the information contained in predictive phylogenetic trees. These ancestral kinases display extreme thermal stabilities, suggesting thermophilic ancestries for Archaea and Bacteria [13].

Experimentally testing the limited amino acid repertoire hypothesis: It is generally impossible to infer amino acid sequences that existed before the Commonote by currently well-used phylogenetic analysis. Instead, using the most thermally stable reconstructed NDK, Arc1 [13], as the starting molecule, we restricted its amino acid usage to several reduced sets. First, we followed the chronological order of appearance of amino acids proposed by Trifonov [7, 8]; Met, Gln, Lys, Tyr and Asn, which have been proposed to appear later, were replaced by other amino acids, thus
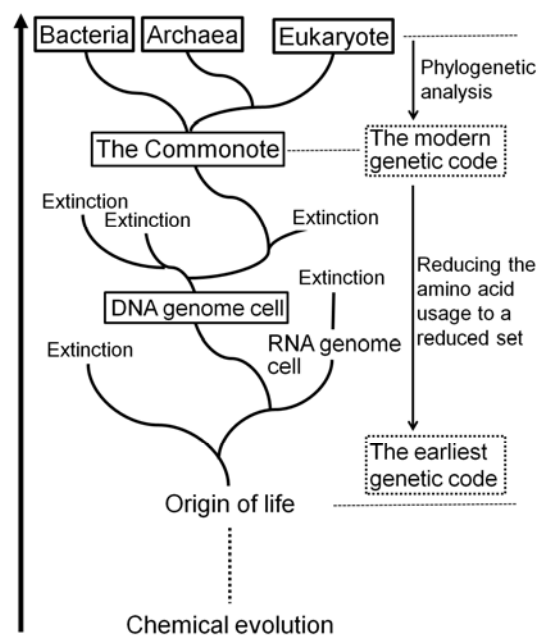
Fig. 1. A model for the history of life on the earth and our experimental strategy to address the limited amino acid repertoire hypothesis.

creating Arc1ΔKMNQY. Because Cys is absent from Arc1, Arc1ΔKMNQY consists of only 14 amino acid species. Arc1ΔKMNQY retains high thermal stability; whereas, no detectable level of catalytic activity was observed. Therefore, the fourteen amino acid types are sufficient to encode a thermally stable protein but more amino acid types would be required for its function.

In order to choose a reduced amino acid set more objectively and systematically, we evaluated the individual contributions of the 19 amino acid types to the stability and activity of Arc1. We reconstructed 19 Arc1 variants in which one of the 19 amino acid types was all replaced by other amino acids, thus creating proteins that consisted of 18 amino acid species. As the result, we found that some amino acid species would be easily lacked but others would be important for the NDK's structure and function. Based on the observation, we reconstructed two Arc1 variants, both of which consisted of respective 13 amino acid types. One of the variant is stable at up to 70°C and exhibits detectable level of catalytic activity. The other variant must be catalytically inactive because it lacks some catalytically important amino acids. However, the conformational stability of the variant is similar to that of a hyperthermophilic NDK.

Perspectives: In future, we will further restrict the amino acid usage to identify the minimum amino acid set that are required to encode a stable and catalytically active NDK. The result will provide an important insight into the amino acid usage in primitive proteins as well as the origin and evolution of the genetic code.

References: [1] Crick. F. H. C. (1968) *J. Mol. Biol.* 38, 367–379. [2] Woese C. R. (1967) The genetic code, Haper and Row, New York. [3] Wong J. T. (1975) *PNAS* 72, 1909–1912. [4] Wong J. T. (2005) *BioEssays* 27, 416–425. [5] Eigen M. and Schuster P. (1977) *Naturwissenshaften* 64, 541–565. [6] Jordan I. K. *et al.* (2005) *Nature* 433, 633–638. [7] Trifonov E. N. (2000) *Gene* 261, 139–151. [8] Trifonov E. N. (2004) *J. Biomol. Struct. Dyn.* 22, 1–11. [9] Akanuma S. *et al.* (2002) *PNAS* 99, 13549–13553. [10] Walter K. U. *et al.* (2005) *J. Biol. Chem.* 280, 37742–37746. [11] Doi N. et al. (2005) *Protein Eng. Des. Sel.* 18, 279–284. [12] Tanaka J. *et al.* (2011) *PLoS ONE* 6, e18034. [13] Akanuma S. et al. (2013) *PNAS* 110, 11067–11072.

Simplification of the Genetic Code: Restricted Diversity of Genetically Encoded Amino Acids. K Amikura[1,2],
A Kawahara-Kobayashi[2], and D. Kiga[1,2], [1]Department of computational intelligence and systems science, Interdisciplinary graduate school of science and engineering, Tokyo Institute of Technology, [2]Earth-Life Science Institute, Tokyo Institute of Technology. ffiliation (4259 Nagatsuta-cho, Midori-ku, YOKOHAMA, Japan, 226-8503. kiga@dis.titech.ac.jp).

At earlier stages in the evolution of the universal genetic code, fewer than 20 amino acids were considered to be used. Although this notion is supported by a wide range of data, the actual existence and function of the genetic codes with a limited set of canonical amino acids have not been addressed experimentally, in contrast to the successful development of the expanded codes. Recently, we constructed artificial genetic codes involving a reduced alphabet [1]. In one of the codes, a tRNA(Ala) variant with the Trp anticodon reassigns alanine to an unassigned UGG codon in the Escherichia coli S30 cell-free translation system lacking tryptophan. We confirmed that the efficiency and accuracy of protein synthesis by this Trp-lacking code were comparable to those by the universal genetic code, by an amino acid composition analysis, GFP fluorescence measurements and the crystal structure determination. We also showed that another code, in which UGU/UGC codons are assigned to Ser, synthesizes an active enzyme.

This method will provide not only new insights into primordial genetic codes, but also an essential protein engineering tool for the assessment of the early stages of protein evolution. To create a protein with improved activity relative to that of the wild-type, random mutagenesis by an error-prone polymerase chain reaction is widely used in a directed evolution process involving multiple rounds of mutagenesis and selection. For a simplified protein containing less than 20 amino acid species, however, efficient evolution with the random mutation strategy has been prevented by the reappearance of codons, generated by mutation, for the specific amino acids to be excluded. In this work, we showed that the simplified code completely excludes the specific amino acid from the genetic code. Therefore, even if the codon for the specific amino acid in the universal code appears in the sequence through a mutation, the amino acid to be excluded is not incorporated within the protein. As a result, the simplified codes will allow us to efficiently search the sequence space of simplified proteins.

In this presentation, we will show the generality of our method for the simplification, by constructing other types of further simplified codes including a 16-amino-acid code.

Reference: [1] Kawahara-Kobayashi A, et al. *Nucleic Acids Res.* 2012. 40(20):10576-84. (featured article, top 5% of papers)

RNA AND THE NATURE OF THE LAST COMMON ANCESTOR. A. Becerra S. Islas, R. Hernandez-Morales and A. Lazcano, Facultad de Ciencias, Universidad Nacional Autonoma de México, 04510 México, D.F., MEXICO; email: abb@ciencias.unam.mx.

Introduction: Based on the three-domain phylogeny proposed by Woese and Fox in the early 1970s [1] that all living beings can be classified on one of three main cellular lineages (Archaea, Bacteria, and Eukarya), it is possible to reconstruct some of the characteristics of the Last Universal Common Ancestor or cenancestor.

Comparative genomics of organisms from the three domains has shown that the cenancestor was not a direct descendant of the prebiotic soup nor a primitive cellular entity where the genotype and the phenotype had an imprecise relationship (i.e., a progenote), rather it was an organism similar in complexity to extant cells. Quantitative estimates of its gene complement, may be hindered by ancient horizontal gene transfer events as well as by biases in genome databases and methodological artifacts [2].

Nevertheless, a significant number of the highly conserved genes are sequences involved in the synthesis, degradation, and binding of RNA, including transcription and translation [3].

The extraordinary conservation of RNA-related sequences supports the hypothesis that the last common ancestor was an evolutionary outcome of the so-called RNA/protein world. However, the chemical nature of the first genetic polymers and the catalytic agents that may have formed the hypothetical RNA world can only be surmised and cannot be deduced from comparative genomics or deep phylogenetics [2,3].

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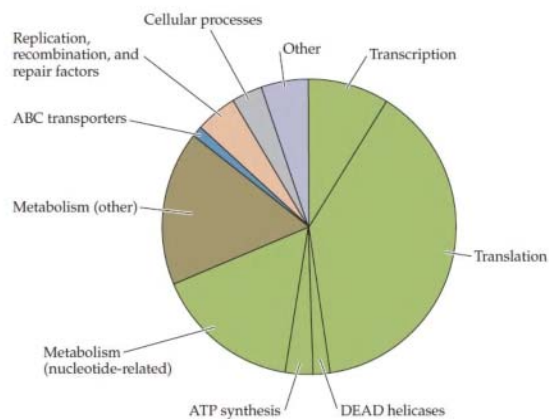
Highly conserved protein domains [3]

COMPLEX ORGANIC MOLECULES IN THE INTERSTELLAR MEDIUM IN THE ERA OF ALMA

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Amino acids were discovered in meteorites and glycine, the simplest of them, in samples returned from a comet to Earth. These discoveries strongly suggest that the chemistry of the interstellar medium (ISM) is capable of producing such complex organic molecules and that they may be widespread in our Galaxy. So far, about 180 different molecules have been discovered in the ISM or in circumstellar envelopes of late-type stars. However, these interstellar molecules still have a limited degree of chemical complexity and no amino acid has been detected in the ISM until now.

One of the key sites to search for new complex organic molecules in the ISM has turned out to be the star-forming hot molecular cloud core Sgr B2(N). I will describe the techniques used to decipher its molecular content based on a single-dish line survey of this source [1]. The analysis of this survey led to the detection of several new species [2,3,4] and will serve as a solid basis for the search for new complex organic molecules with the Atacama Large Millimeter/submillimeter Array (ALMA). I will discuss the perspectives offered by this new, powerful interferometer in this context.

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BIOIMAGING BY X-RAY LASER DIFFRACTION AT SACLA. Yoshitaka Bessho[1,2], [1]RIKEN SPring-8 Center, 1-1-1 Kouto, Sayo, Hyogo 679-5148 Japan, bessho@spring8.or.jp, [2]Academia Sinica, Institute of Physics, 128 Academia Rd. Sec. 2, Taipei 115 Taiwan, bessho@phys.sinica.edu.tw

In order to perform the biochemical analyses of the last universal common ancestor **LUCA** and the older proto life system, we have to elucidate the system pathways of extremophile microorganisms, as in *Thermus thermophilus*, which have deep phylogenetic branches. The maturation system of the tRNA molecule should be clarified on a structural basis, since it is the key molecule of the central dogma. Recent progress in structural biology, biochemistry, and molecular biology has encouraged us to elucidate the origin and evolution of fundamental molecular systems essential for the living cell.

Astrobiology can connect the origin and evolution of early life, and verify whether they are principles common to the universe from the characteristics of a substance. This is the voyage to search for our life spirit. The research will be shifted from "investigation of an individual life system", to "verification of the self-organization process of the life system". Finding the answer to the fundamental question of where we, and all of life, came from is essential for understanding and elucidating the life process.

The accumulation of large quantities of protein structure information has enabled comparative examinations, toward the construction principles of a life system. In this research, the construction principle of the basic system of **the central dogma of life** will be clarified by structure-based analyses of nucleic acids, with synthetic biology knowledge, as the key elements for the genetic and protein composition systems, and their related enzymes, as in DNA replication and repair, and tRNA maturation and ribosomal translation. Some limited elements should be able to repeat diversification and integration spontaneously, and the life system must have thus materialized. This research should be able to verify the process by which a life system is formed.

The X-ray free electron laser (**XFEL**) facility, **SACLA**, at the RIKEN **SPring-8** campus, is soon expected to be useful for bioimaging with accuracy on the order of ten femto-seconds. The bioimaging of solution structures, using the SPring-8 and XFEL beamlines, should provide extraordinary information for the structural and system biology of proto life. Especially, our pulsed coherent X-ray solution scattering (PCXSS) method aims to achieve the high-resolution imaging of biological samples under close-to-natural cellular conditions. It does not require a lens for image formation, but instead numerically reconstructs object images from the coherent diffraction data.

We have successfully obtained genuine coherent X-ray speckle patterns from living bacterial cells, as well as from purified gigantic bio-molecules, such as ribosomes, by the PCXSS method. High-quality coherent X-ray diffraction (CXD) patterns were recorded from intact *Microbacterium lacticum* cells. An image reconstructed from the experimental CXD pattern revealed the natural nanoscale structures of live cells, thus providing clues toward understanding nucleoid structures, which are inaccessible by other methods. The technologies of this research will potentially create breakthroughs in whole cell biology, and contribute toward single-particle imaging in the future with XFEL.

We will discuss our recent results in this presentation.

STUDY OF EXOPLANET WITH SPICA

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SPICA: SPICA is the next-generation, space infrared observatory, following in the footsteps of IRAS,ISO, Spitzer, AKARI and Herschel. With its 3.2-meter telescope cryogenically cooled to 6 Kelvin, SPICA provides an extremely low background level environment. With its instrument suite, designed with state-of-the art detectors to fully exploit this low background, SPICA will provide high spatial resolution and unprecedented sensitivity in the mid- and far-infrared. These unique capabilities will bridge the gap between ALMA/large submm ground telescopes and JWST/large ground opt.-IR telescopes. Thus astronomers will be allowed to address key problems in present-day astronomy in many research areas, ranging from the formation of planets to the large scale star-formation history of the Universe. SPICA is proposed as a Japanese-led mission, with extensive international collaboration. The satellite is targeted for launch in the 2020s with a nominal mission lifetime of three years.

The SPICA Coronagraph Instrument (SCI): The SPICA Coronagraph Instrument (SCI) is proposed to SPICA for the purpose of studying small-scale structures surrounding bright stars and galactic nuclei, which specifically include exoplanets (not only detection but also characterization of the atmosphere), proto-planetary and debris disks, and dusty tori of active galactic nuclei. High contrast images of the SCI are produced by binary pupil-mask coronagraphs together with the image subtraction technique. The SCI is designed to have both functions of imaging (1' x 1' field of view) and spectroscopic capability (R=200). The SCI possesses the capability of low-background spectroscopic coronagraphy over the continuous wavelength range of 4 - 28 micron. These specifications make the SCI a unique instrument in functions of the high dynamicrange observation in the 2020s, including instruments of JWST and TMT.

Study of Exoplanet with the SCI: One of important science objectives is Planetary Formation Process Revealed by the Thermal History, including examination of the core-accretion model and the disk instability model for the formation of planetary systems. These models indicate different temperature of the exoplanet especially young phase of the planets. So, detail measurements of temperature of exoplanet atmosphere is important. The SCI is designed for high-dynamic range spectroscopy and imaging in the 4 to 28 microns wavelength range. The spectral features of atmospheric molecules are crucial indicators of the planetary temperature. Since there are several important molecular absorption lines within the wavelength coverage of the SCI, (CO (4.7 μm), CH_4 (6.5 μm, 7.7 μm), NH_3 (6.1 μm, 10.5 μm), and H_2O (6.2 μm)) the atmospheric temperature can be determined precisely by spectroscopic studies of the planetary atmosphere. CO and N_2 are stable at temperatures higher than 1500 K. As the temperature decreases, CO and N_2 react with H_2 to form CH_4 and NH_3. As a result, CH_4 and NH_3 become the dominant carbon- and nitrogen-bearing species at low temperatures, respectively. At a total gas pressure of 1 atmosphere, CH_4 and NH_3 mainly form at temperatures below 1000 K and 700 K, respectively. In addition, the mixing fraction of H_2O increases by releasing the oxygen tied up in CO. Thus, while CO is an indicator of high-temperature objects, CH_4, NH_3, and H_2O are indicators of low-temperature objects. Thus, combination of SPICA and the SCI is essentially useful for this study. Other science objectives of the SCI based on wide mid-infrared spectrum of the atmosphere of exoplanets are also important, of which studies will be possible thanks to unique capability of SPICA and the SCI.

TOWORD CHARCTERIZATION OF EXOPLANETARY SURFACE ENVIRONMENT

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Introduction: Recent astronomical observations have revealed an abundance of planetary systems outside the Solar system. Earth-size exoplanets in so-called habitable zones (HZ) have been already detected. The fraction of M-type stars hosting HZ Earth-size planets is estimated to be order of ten precent ([1][2]). These facts have motivated us for further investigations of these planets in terms of the presence of life as well as compositions of atmosphere and surface. In this context, direct photometry/spectroscopy of HZ planets is situated as an ultimate destination to go because of the potentially rich information it can provide, while it is technically challenging.

Observable features of Point-source Earth: In order to explore our potential to characterize rocky exoplanets with future direct imaging observations, a reasonable starting point is to consider how much we could determine Earth properties when it were observed from afar. To answer this question, disk-integrated spectra of the Earth have been studied at length. It has been shown that the major surface components may be indicated from scattered light of planets based on material-dependent reflectance spectra (e.g. [3]). Molecular absorption features in the spectra were also studied and a handful of biosignature molecules have been put forward e.g. oxygen, ozone, methane, nitrous oxide (e.g.[4]). On the other hand, given our ignorance of the environment there and that many parameters affect disk-integrated planetary spectra, it is not easy to decipher the planetary signal as an inverse problem. However, we may use the time variation of planetary light due to planetary spin rotation and orbital revolution as a probe of global inhomogeneity and localized features. Using the observational and simulation data of multi-photometry of Earth angalogs, we demonstrate the recovery of the major surface features including clouds/ice, continents, and vegetation ([5][6][7]; see also [8][9]). In addition, we discuss the variability of major molecular absorption bands and its applications to cloud coverage and hydrology on exoplanets ([10]).

Beyond Earth: Obviously, the diversity of rocky exoplanet surface environment should be much greater than presently expected. Seeking reasonable samples of various rocky planets, several studies have examined the possible spectra of the Earth during its evolutional development (e.g. [11][12][13]). Complementarily, we review the geologies of Solar system Earth-size bodies and survey their appearances as point sources for a comparative study of various rocky planets.

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FORMATION AND EARLY EVOLUTION OF ATMOSPHERE AND OCEAN ON THE EARTH.

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Introduction: The Earth is the only planet to harbor life, as we know so far. Adequate amount of water and atmosphere on the Earth has been thought to be essential for the emerge and evolution of life [1]. Therefore, investigating the origin and formation of ocean and atmosphere on the Earth is important, and it would answer the questions why we are here and whether or not another life exists in the universe.

We have a piece of geological and geochemical evidence that constrains the age of the ocean and atmosphere on the Earth. The existence of sediments implies that ocean already exist on the Earth at least 3.8 Gyr ago [2]. Moreover, the oxygen isotopes in very old zircon imply that a substantial amount of liquid water existed around 4.3 Gry ago [3]. According to isotopic compositions of the noble gases in the atmosphere and mantle, most of the atmospheric volatiles must have degassed to the surface by 4.0 Gyr ago [4]. Since the Earth was formed 4.5 Gry ago, volatile elements forming the ocean and atmosphere should be supplied during or just after the Earth's formation.

In this workshop, we would like to review mechanisms of supply and loss of volatiles on the terrestrial planets. We will discuss the effects of giant impacts on the formation of the ocean and atmosphere.

Supply and Loss of Volatiles on the Earth: Planets form in a protoplanetary disk composed of dust and gas. Terrestrial planets are made mainly from dust. It has been generally thought that the Earth's building blocks around 1 AU have no volatiles that compose the ocean and atmosphere. On the other hand, the objects beyond the asteroid belts (~ 2 AU) contain a significant fraction of volatiles [5]. Therefore, some mechanisms to supply or produce volatiles on the Earth are required for the Earth to possess the ocean and atmosphere. Supply process of volatile-rich objects from outside the terrestrial planet region is highly related to the planet formation theory. Recent planet formation theory suggests that the behavior of forming Jupiter have a great influence on this supply process [6]. For example, great migration of Jupiter called "The Grand Tack Model" would provide sufficient amount of water on the Earth [7].

Loss of volatile elements from planets has an influence on the volatile budget on the terrestrial planets. Several volatile loss mechanisms have been proposed so far, such as hydrodynamic escape [8], loss by giant impact [9, 10], and so on. Loss of water from Venus is important to the habitability of planets.

Cooling of Magma Ocean and Formation of Ocean: It is generally accepted that many giant impacts occur during the last stage of terrestrial planet formation. The energy released by a giant impact is huge, and it can raise the temperature of the whole proto-Earth by about 5000K in average. Therefore, the planet should be wholly molten just after a giant impact. Cooling process from molten Earth is important to formation of the ocean and atmosphere.

We have investigated the cooling process using coupled model of magma ocean, atmosphere, and space [11]. The Earth solidifies within several million years, and most of water is degassed but no escape occurs. In contrast, the magma ocean on the planet around Venus' orbit can be sustained until almost all water is lost to the space. In this case, the typical duration of magma ocean is about 100 million years. Planet formation theory suggests that water can be supplied on Venus as well as Earth. Therefore, drastic loss of water only on Venus is consistent with the present dry Venus.

Steam atmosphere fomed just after the solidification of magma ocean rapidly cools, and the ocean forms in 1000 years through the intense rainfall [12]. The rain drops is very hot (~ 300 ^{o}C) and the rain fall rate is very high (~ 500 cm/yr), which is ten times as high as that in tropical region on the present Earth.

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INTERACTION OF THE SLEEPING CHIRONOMID WITH MICROORGANISMS*: "UCHI-SOTO"* IN THE WORLD OF ANHYDROBIOSIS.

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Origin of anhydrobiosis in the larvae of the sleeping chironomid *Polypedilum vanderplanki* represents unique example of set of evolutionary events in a single species, resulted in acquiring new ability allowing survival in extremely changeable environment. Complex comparative analysis of the genome of *P. vanderplanki* resulted in discovery of a set of features, including existence of the set of unique clusters of genes contributing in desiccation resistance. Surprisingly, in several cases, the genes mainly contributing to the formation of the molecular shield in the larvae are sleeping chironomid-specific and have no homology with genes from other insects, including *P. nubifer* – a chironomid from the same genus. *Polypedilum* midges are active bacterial feeders and at least several genes (including intrinsically disordered proteins) are likely to be arisen from horizontal gene transfer (HTG) from soil and water microorganisms. The genome of *P. vanderplanki* has low number of transposable elements. We currently assume that the majority of the genomic rearrangements increasing the chance of HTG is a result of desiccation-driven nuclear DNA damage. In average, number of obvious HGT in *P. vanderplanki* genome is moderate, but in many cases, the corresponding genes are highly active in the process of anhydrobiosis and likely to contribute to the adaptive processes (eliminating of consequences of excessive oxidative stress, preventing denaturation of the proteins, nucleotides metabolism, etc.) associated with anhydrobiosis. Another set of data from recent experiments with artificially sterilized larvae of P. *vandeprlanki*, suggesting that associated microorganisms contribute to the resistance of the rehydrating larvae to exogenous parasite fungi. Finally, there is an evidence that association with the larvae of *P. vanderplanki* has a potential to provide protection against complete desiccation to at least several species of microorganisms otherwise sensitive to water loss.

INTERPLANETARY MIGRATION OF EUCARYOTIC CELL, SPORE OF *Schizosaccharomyces pombe*. N.

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Introduction: The TANPOPO mission to examine possible interplanetary migration of microbes, and organic compounds at the Exposure Faculty of Japan Experimental Module (JEM) of the International Space Station (ISS) is progressing [1]. Some microbes are considered as the exposed samples, and spore of *Schizosaccharomyces pombe* (*S.pombe*) is put on the list of the exposed eukaryotic cell because the spore is supposed to be one of the most tolerant organic form toward extreme environ-ments. *S.pombe* (Fig.1) is a kind of yeast isolated originally from beer ma-de in East Africa in 1980s. In this paper, re-sults of preliminary ex-periments for the expo-sure are shown.
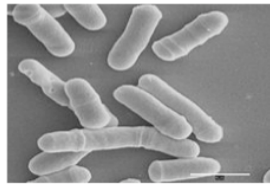
Fig.1 Microscopy of *S.pombe*

Materials and methods: Spores of *S.pombe* strain JY1 were prepared by the conventional and usual method.

Tolerance toward heat and vacume of *S.pombe* was examined on the assumption of severe temperature change in earth orbit. Under a pressure of 1.0 pascal, the temperature was heated to 80 degrees, and cooled to -80 degrees in 90 minutes.

Tolerance toward heavy particle irradiation was examined by argon beam.

Examination of γ ray irradiation was performed at JAEA, Japan.

UV tolerances were examined using ultraviolet light of wavelength 172 nm (1.01 mW/cm^2) and 254 nm (1.19 mW/cm^2),

Results: Spores of *S.pombe* showed tolerance for the thermal cycle under the vacume. Colony formation rate of the spore in exposure duration of 14 days (224 heat cycles)(95.8 %) was almost same as that of 1 cy-cle (97.8 %), and estimated at fewer decreasing in long term of one year.

Even in case of the heavy particle irradiation sup-posed to be extremely severer than that simulated for condition in earth orbit, the spores showed the strong resistance. After the irradiation of 538 Gy, 98.0 % of the spore survived.

As for the γ ray irradiation supposed to be extreme-ly severer than the condition in earth orbit (20 Gy), the survival rate (87.8 %) was also high enough to survive aftere the exposure in space. Nevertheless, stronger irradiation of γ ray (500 Gy) reduced the survival rate (51.5 %).

On the other hand, UV affected the survival rate severely. Although the spore showed tolerance toward UV irradiation of wavelength 172 nm (36.4 kJ/m^2) to some extent, UV irradiation of wavelength 254 nm (42.8 kJ/m^2) dramatically reduced the survival rate (1.0 %). This result showed that the spores can't sur-vive after one year under the UV condition in space.

Discussions: Besides UV irradiations, Spores of *S.pombe* showed tolerances for the survival after the exposure in space for one year. Biologically consider-ing, spores have their roles to bear sufferings and sur-vive. And, these results for spores of *S.pombe* this time showed the possible survival in space and the possibility of interplanetary migration.

Recently, it was found that spores of *S.pombe* are coated by Isp3, one of the unique gene products of *S.pombe*, and peculiar resistance of the spores toward extreme environments is assumed [2]. Results this time support the assumption, and the limit of protection ability of Isp3 is of great interest from the perspective of interplanetary migration.

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Perspectives of ELSI Projects: the Origin of the Earth and the Origin of Life

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Earth-Life Science Institute (ELSI) has been recently established at the Tokyo Institute of Technology based on the World Premier International Research Initiatives (WPI) program and is going to study the origins of the Earth and life. These two topics are indeed inseparable because life is a phenomenon that can exist only through the exchange of energies and matter with the surrounding environment. We will therefore integrate research on the Earth and life, and explore "how our life can originate and continue on this planet" through a detailed study focused on the early Earth. We will answer the following scientific questions: (A) How was the Earth formed within the solar system? (B) How was the earth's first ecosystem established, and (C) How can the earth and life evolve after the first state. Through the study of the Earth, we clarify universality and uniqueness of the planet Earth harboring life. Further, we utilize the outcomes of the research (D) to provide guidance for the search for life on other planets and moons. Each of those themes is performed under an interdisciplinary fusion of different fields such as astoronomy, planetary physics, geology, solid-Earth science, environmental biology, and microbial genome science.

Astrobiological Research on Tardigrades: Implications for Extraterrestrial Multicellular Life Forms.

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Tardigrades are microscopic (0.1-1.0 mm in length) invertebrate animals that are distributed in various environmental conditions in many areas from polar to tropical regions throughout the world. They have been considered as an appropriate model for astrobiological studies based on their high survival ability under various types of environmental stresses. So far, researches have shown that tardigrades have high tolerance to ionizing radiation, wide ranges of temperatures, vacuum, and high pressures in anhydrobiosis, a state that organisms lack free water in the body, and they resume activity when water is added. In addition, a short-term flight experiment demonstrated that tardigrades in an anhydrobiotic state survived open space environments at low Earth orbit. Results from those exposure experiments indicate that tardigrades are well tolerant of extremely low temperatures, vacuum, and high pressures. On the other hand, ionizing radiation, UV radiation, and high temperatures could be the critical factors to limit habitable environments for tardigrades. Future astrobiological research on tardigrades might provide important insight into the possibilities of existence of extraterrestrial multicellular life forms or interplanetary transfer of multicellular organisms in an inactivated-state like anhydrobiosis.

Short abstract:

Tardigrades have been considered as a model for astrobiological studies based on their tolerance to extreme environments. Future research on tardigrades might provide important insight into the possibilities of existence of multicellular life forms.

ASTROBIOLOGY RESEARCH ON BOARD OF THE INTERNATIONAL SPACE STATION AS PART OF THE EUROPEAN SPACE EXPLORATION INITIATIVE. G. Horneck, Deutsches Zentrum für Luft- und Raumfahrt DLR, Institut für Luft- und Raumfahrtmedizin, 51170 Köln, Germany, e-mail: gerda.horneck@dlr.de

Introduction: The environment of the International Space Station (ISS) comprises a complex spectrum of physical parameters that are not experienced on Earth and that are of high interest to Astrobiology. Exposure facilities on board of the ISS have provided unique opportunities to study biological and chemical processes in response to those parameters directly in Earth orbit [1]. From such studies a better understanding has been reached

- on the role of interstellar, cometary and planetary chemistry in the origin of life,
- on the role of the ozone layer in protecting our biosphere,
- on the likelihood of the interplanetary transfer of life via meteorites, i.e. the hypothesis of lithopanspermia,
- on the chances of survival of terrestrial microorganisms in outer space, e.g. on a trip to Mars, leading to the formulation of planetary protection requirements,
- on the habitability of Mars by exposing biological samples to simulated Martian conditions, providing support to "search for life" experiments.

ESA has developed a variety of astrobiology facilities (BIOPAN, STONE, EXPOSE-E, EXPOSE-R, EXPOSE-R2) to be attached to Earth orbiting satellites or the ISS [2]. For the next generation of test facilities on board of the ISS devices for *real-time in-situ* monitoring of the phenomena are recommended.

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Global census of microbial life in marine subsurface sediments.

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Introduction: Over the past decade, it has been demonstrated that nemerous microbial life are distributed in global marine subsurface sediments, and its total biomass is estimated to be 2.8 x 10^{28} cells, corresponding ~1% of biomass carbon on Earth [1]. To date, culture-independent molecular techniques have been dramatically improved, enabling us to provide detailed views of naturally occurring microbial communities, even for low biomass and cultivation-resistant microbial communities in a variety of geological habitats [2]. For example, using a newly developed hot-alkaline DNA extraction method [3] together with an improved cell separation technique [4], it is now possible to detect, enumerate and identify the deep sedimentary microbes more accurately and sensitively than before. Regarding quantification microbial genes in environmental DNA, the conventionally used real-time PCR assay is significantly hampered by the PCR inhibitors such as humic acids and polysaccharides, especially for organic-rich sedimentary habitats on ocean margins. However, a recently developed digital PCR using microfluidic devices is less affected by such inhibitory substances, providing absolute quantification of the target genes [5]. Using these technical advances on quantitative and qualitative molecular ecological approaches, one of the major scientific objectives on the deep subseafloor biosphere research is to understand the global census of subseafloor microbial population and its diversity.

Materials and Methods:

Sediment Samples.

Over 200 sediment samples were collected in 15 drilling sites; e.g., the eastern equatorial Pacific and Peru Margin (ODP Leg 201), Juan de Fuca ridge flank (IODP Exp. 301), South Pacific Gyre (IODP Exp. 329), Nankai Trough (IODP Exps. 315 and 316), off Shimokita of Japan (CK06-06, IODP Exp. 337), Gulf of Mexico (IODP 308), and Porcupine carbonate mound (IODP Exp. 307).

DNA extraction.

Five to ten grams of frozen sediments were used for the DNA extraction using a hot-alkaline method. Briefly, microbial cells were lysed in a warmed alkaline solution. After neutralization and centrifugation, DNA was extracted from supernatant using the phenol chloroform-isoamyl alcohol treatment. The bulk DNA extracts were purified by silica membrane columns.

Quantification of 16S rRNA gene by digital PCR.

The absolute number of bacterial and archaeal 16S rRNA gene in the extracted DNA was measured by digital PCR using BioMark[TM] HD system and pdPCR 37K IFC (Fluidigm, Tokyo, Japan).

Results and Discussions: Using less-biased digital PCR technique allowed us to evaluate the abundance of bacteria and archaea at various depths and oceanographic locations. The abundance of 16S rRNA genes was logarithmically decreased with increasing depth, which is in good agreement with previous observations. The number of bacterial 16S rRNA genes was generally higher than those of archaeal one. The current estimation of average ratio between archaeal and bacterial 16S rRNA genes was ~0.37. Since most bacteria have multiple copies of the 16S rRNA gene, our result indicates that archaeal population in the subseafloor environments is almost comparable to bacteria and significantly contributes to the global subseafloor microbial biomass. The ratio was found to be independent from the depth, whereas slightly different from site by site, potentially affected by some environmental factors such as geophysical, energetical, hydrological characteristics.

Our on-going effort of the global census of deep microbial life through the digital PCR has provided a new information of absolute quantify of the specific genes in the deep subseafloor biosphere. The next step will be to study the geographical distribution of microbial diversity and community structure by deep-sequencing of the genes on a global scale.

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Why Life? Origins of Life elsewhere in the Universe

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There is a thriving field of research studying the origins of life, as it occurred on Earth. Given life as we know it, we can ask the question how it originated, how the transition from chemistry to biology took place on our own planet. And in order to ask that question, we can try to characterize the life we know, by asking what are the most essential aspects of life. In 1944, this led Schroedinger to write his classic book "What is Life?", and since then several other authors have written books with the same title.

So far, nobody has been able to give a convincing answer. When we move our attention from the Earth to other planets, and especially to exoplanets, we encounter a second handicap. We don't know what forms life can take elsewhere, and whether it would have any resemblance to our carbon-based forms of life on Earth.

For exoplanets, a better question would be "Why Life?" to study the nature of the transition from relatively simple to truly complex systems. The question "how did chemistry give rise to biology?" is then seen as a specific example of the more universal question "what is the nature of the phase transition leading to complexity?" or simply "Why life?" which leads to the question "What can Life be?"

Darwinian evolution in a translation-coupled RNA replication system within a cell-like compartment. N. Ichihashi[1], K. Usui[2], and T. Yomo[3], [1]JST ERATO and Graduate School of Information Science and Technology, Osaka University, [2]JST ERATO, [3] JST ERATO, Graduate School of Information Science and Technology, Osaka University, and Graduate School of Frointier Bioscience, Osaka University (Yamadaoka 1-5, Suita-shi, Osaka-fu, Japan, ichihashi@ist.osaka-u.ac.jp).

Introduction: The construction of an artificial cell or model protocell is hypothesized to provide important insights into the emergence of life from an assembly of non-living molecules[1]. To date, various cellular functions have been reconstituted from purified biological polymers. However, the creation of an artificial cell that harbors the same level of evolutionary ability as natural organisms remains a major challenge.

The evolution of living organisms is a result of the error-prone replication processes of genetic material, either DNA or RNA, by the replication enzyme translated from its own information. In this study, we attempted to construct an artificial system that replicates and evolve in the same manner as natural organisms.

Result: *Translation-coupled RNA replication system.* To construct an artificial system that replicates in the same manner as natural organisms, through the translation of a replication enzyme, we combined an artificial genomic RNA that encodes an RNA-dependent RNA polymerase, the Qβ replicase, with a reconstituted translation system[2]. In this translation-coupled RNA replication system, the genomic plus-strand RNA (2125 nt) replicates using an RNA replicase translated from its own sequence via the synthesis of the complementary minus-strand. This type of replication requires a cell-like compartment to ensure interaction between the translated replicase and the original genomic RNA. In this study, we encapsulated the TcRR system into a micro-scale 1–6 μm cell-like compartment, a water-in-oil emulsion

Long-term replication. We perfomed a long-term continuous replication in the compartments[2]. First, the RNA amplification was assisted by reverse transcription and PCR due to the inefficient replication during the initial stage. We then simplified the cycle and performed the cycle through fusion-division cycle of nutrient emulsion containing the fresh translation system for another 100 rounds. Through all the long-term replication process, approximately 600 generations, the replication ability improved more than 100-fold.

Analysis of the evolved RNAs. To test whether the improvement in the replication ability is the consequence of evolution, we analyzed sequences of RNA clones during each round. The average number of mutations per clone increased constantly. We defined the mutations observed in more than half of the analyzed clones as "fixed." These fixed mutations increased intermittently and ultimately reached a total of 38 mutations, which included 34 point mutations, 1 insertion, and 3 deletions. These results (the increased replication ability, or fitness, and the successive fixation of the mutations) provide evidence of RNA evolution according to Darwinian principles.

We further characterized the biochemical properties of the evolved RNAs, such as the activity of the encoded replicase, the activity of the RNA as a template for replicase, the translation activity of the replicase, and so on. This biochemical analysis revealed that the RNA improved mainly the ability as a template for replication, and consequently the evolved RNA acquired the resistance against a parasitic replicator that spontaneously appear during the replication process through RNA recombination.

Discussion: This artificial cell-like system provide a useful platform to understand how an assembly of chemical molecules could become "alive" through an evolutionary process. In principle, the genomic RNA obtained in this study has an unlimited potential to acquire new functions and develop a more complex network by encoding additional genes, including translation factors, that are currently supplied externally. Examining whether the genomic RNA could (with additional replication cycles) evolve to create a system that resembles a natural living organism or whether the evolution would be halted by other obstacles such as an error catastrophe[3] would be of interest. The TcRR provides a novel platform for the experimental investigation of evolutionary scenarios that may lead to the emergence of a "living state" from the assembly of non-living molecules.

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Limits of Life in the Deep Subseafloor Biosphere: New Insights from IODP Expedition 337

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Introduction: Deep drilling of marine subsurface offers unique opportunities to explore how life persists and evolves in the Earth's interior ecosystems. There are very few natural environments on Earth's surface where life is absent; however, the limits to life are expected in the subsurface world. Processes that mediate genetic and functional evolutions of the deep life may be very different to those in the Earth's surface ecosystems. Previous studies of the subseafloor sediment have demonstrated that activity of microbial communities is generally extremely low, mainly because of the limit of nutrient and energy supply [1,2]. However, the limits to habitability in deep subseafloor sediments have still remained to be determined; which constraints involve a variety of geophysical and geochemical properties, such as temperature, pH, pressure, salinity, porosity, and availability of nutrient and energy. Understanding of these fundamental issues on Earth's deep biosphere may hold the clue to the mysteries of primordial microbial ecosystems on our planet or the life's habitability on other planetary bodies.

Integrated Ocean Drilling Program (IODP) Expedition 337: Expedition 337 was the first expedition dedicated to subseafloor microbiology that used riser drilling technology of the deep-sea drilling vessel *Chikyu* [3]. IODP drill Site C0020 is located in a fore-arc basin formed by the subduction of the Pacific plate off the Shimokita Peninsula, Japan, in the northwestern Pacific at a water depth of 1,180 m. Seismic profiles suggested the presence of deep, coal-bearing horizons at ~2 km subseafloor depth. Our primary objectives during Expedition 337 were to study the relationship between the deep microbial biosphere and the subseafloor coalbed and to explore the limits of life in horizons deeper than ever probed before by scientific ocean drilling. Among the questions that guided our research strategy was: Do deeply buried hydrocarbon reservoirs such as coalbeds act as geobiological reactors that sustain subsurface life by releasing nutrients and carbon substrates? To address this question and other objectives, we penetrated a 2,466 m deep sedimentary sequence with a series of coal layers at ~2 km below the seafloor. Hole C0020A is currently the deepest hole in the history of scientific ocean drilling,

and hence provided an unprecedented opportunity to study the limits of life in the subseafloor biosphere.

Preliminary results and perspective: During Expedition 337, over 1,700 microbiological and biogeochemical samples have successfully been obtained, for which rigorous contamination controls enable differentiation of contaminants from indigenous microbial communities. The estimated temperatures in 2 km-coalbed layers are ~50ºC and thus provide confortable conditions for microbial life. We conducted gas chemistry and isotopic analyses using a new real-time mud-gas monitoring during riser-drilling operation, which provided the first indication of biologically mediated CO_2 reduction to methane at the 2 km-deep coalbed layers. The numbers of microbial cells are generally notably lower than those expected based on the global regression line of sedimentary microbial biomass on the Pacific margins [4]. What are the constraints for the very low biomass in the deep sedimentary habitats? Interestingly, increase of microbial biomass was observed at the coal layers. This finding suggests possible contribution of microbial activity to the diagenetic process of organic matter, subsequently providing nutrient and energy substrates to the living biomass.

On-going efforts on the correlation between cell abundance and various physical properties, which were characterized by over 900 discreet samples and wireline logging, as well as cultivation-dependent and –independent molecular ecological and biogeochemical studies, will provide us some new insights into the limits of life and habitability in the deep subseafloor biosphere.

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AKARI OBSERVATIONS OF INTERSTELLAR POLYCICLIC AROMATIC HYDROCARBONS.

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Introduction: Polycyclic aromatic hydrocarbons (PAHs) are small organic matters found also in the interstellar space [1]. They are subjects of interest as distant ancestors of organic matters in our Solar system, in view of the life cycle of solid matters in space.

Data and analysis: AKARI, Japanese infrared astronomical satellite, surveyed all the sky in the 9, 18, 65, 90 and 160 micron bands. Among them, the 9um band map is the world-first all-sky PAH map efficiently tracing the emission features of PAHs at wavelengths of 6.2, 7.7, 8.2 and 11.2 micron [2]. Furthermore, from 2-5 micron spectra of various fields taken by AKARI, which cover 3.3 micron aromatic and 3.4 micron aliphatic features of PAHs, we can investigate local variations of aromatic/aliphatic ratios [3].

Results: From the all sky PAH map, we reveal that PAHs are widely distributed in the Galactic plane, showing good spatial correlation with other tracers of general interstellar medium such as CO, HI and far-IR dust emissions [4]. From the 2-5 micron spectra, we find that the variation of aromatic/aliphatic ratio reflects processing of carbonaceous grains in the local interstellar environments [5].

Summary: In this talk, we review the results from AKARI observations of PAHs. We also discuss our future prospect for this study using the next Japan-led infrared space mission, SPICA.

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Ultra High Spatial Resolution Ion Imaging with a NanoSIMS Ion Microprobe: Applications to Astrobiology. M. Ito. Kochi Institute for Core Sample Research, JAMSTEC (B200 Monobe, Nankoku City, Kochi 783-8502 Japan).

Introduction: Ion imaging technique with secondary ion mass spectroscopy (SIMS) is a powerful tool to visualize the distributions of isotopes and/or elements in samples, and is becoming common to variety field of sciences including material science [1], cosmochemistry [2] and biology [3].

The CAMECA NanoSIMS 50L ion microprobe represents the *in-situ* microanalysis by SIMS, combining ultra high spatial resolution (minimum spot size of ~50 nm for Cs^+ and ~150 nm for O^-) with ultra-high sensitivity. Up to 7 elemental and/or isotopic images can be acquired simultaneously by 7 electron multipliers with sensitivity in the ppm. The capability for images of multiple elements and isotopes within a sample with per-mil precision and accuracy and nm scale spatial resolution is unique to the NanoSIMS. Because isotopic images can be acquired with extremely low primary beam currents (~ 1 pA), coordinated studies of morphological, structural, chemical and isotopic characteristics of materials at sub-μm scales by NanoSIMS, TEM, SEM, and FIB systems are becoming routine [4, 5].

Owing to these unique capabilities, the NanoSIMS has had a major impact in the field of cosmochemistry, leading to the discoveries of ancient silicate stardust and interstellar organic grains in meteorites and interplanetary dust [2, 6-8]. In both of these examples, the target materials are extremely small (0.2 - 1 μm), but have isotopic ratios in many elements that significantly differ (20-10,000 %) from materials formed in the Solar System. The NanoSIMS is particularly well suited to measuring large isotopic variations at small scales, and accordingly its use in cosmochemistry has been focused on the study of interstellar materials. More recently the NanoSIMS has been applied to high precision isotopic measurements that are required for many primitive Solar System materials (i.e., refractory inclusions in carbonaceous chondrites) that exhibit moderate isotopic variations (0.1-5 %) [9].

In last decade SIMS technique has been used to microbiology to match chemotaxonomic and phylogenetic signature of microbes [10]. Recently NanoSIMS ion imaging technique used to a stable isotope probing study (*i.e.*, ^{13}C, ^{15}N labeling) for a single cell to understand microbial metabolic activities, and combination with *in-situ* hybridization for phylogenetic identification [11-16].

Application to Astrobiology: The "Tanpopo Mission" is a space misstion on Japanese Experimental Module on the International Space Station for an interdisciplinary research of organic chemistry, microbiology and cosmochemistry [*i.e.,* 17] . The focuses of the mission are 1) to exam the survival of microbes and organic materials under space radiation and solar UV in space environment, 2) to capture organic materials and micrometeorites including interplanetary dust particles using an ultra low-density aerogel [17]. NanoSIMS ion imaging can be applied samples obtain by Tanpopo mission; i.e., microbes under space radiation and solar UV to understand microbial metabolic activities and phylogenetic signature, organic materials and micrometeorites to investigate their origins and formation processes in the solar system based on H, C, N and O isotopic signatures.

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METAMORPHOSED CLASTS IN THE CV CARBONACEOUS CHONDRITE BRECCIAS MOKOIA AND YAMATO 86009: EVIDENCE FOR STRONG THERMAL METAMORPHISM ON THE CV PARENT ASTEROID.

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Introduction: CV chondrites are a diverse group of meteorites currently subdivided into three subgroups, oxidized Allende-like (CV_{OxA}), oxidized Bali-like (CV_{OxB}), and reduced (CV_{Red}). These subgroups experienced different degrees of aqueous and/or metasomatic alteration and thermal metamorphism, and may represent different lithologies of a single CV parent asteroid [1]. Neither the size nor the thermal evolution of this asteroid are well-known. Allende is one of the most metamorphosed CV chondrites and appears to have reached peak metamorphic temperature of ~750–850 K [2]. The paleomagnetic records in Allende may imply a partially molten core in CV asteroid [3]. This interpretation, however, has been recently questioned by [4] who suggested that such magnetic records could have been induced by impact. Here, we describe the mineralogy, petrography, and O-isotope compositions of heavily-metamorphosed clasts in the CV chondrite breccias Mokoia and Yamato-86009 (Y-86009), which appear be genetically related to CV chondrites [e.g., 5, 6], and, therefore, provide important constraints on the the internal structure and thermal history of the CV parent asteroid.

Mineralogy and the O-isotope compositions of the clasts: The metamorphosed clasts in Mokoia and Y-86009 are coarse-grained, granular, polymineralic rocks composed of Ca-rich (up to 0.6 wt% CaO) ferroan olivine ($Fa_{34–39}$), ferroan Al-diopside ($Fs_{9–13}Wo_{47–50}$, ~2−7 wt% Al_2O_3), plagioclase ($An_{37–84}Ab_{63–17}$), Cr-spinel [$Cr/(Cr+Al)$ = 0.19−0.45, $Fe/(Fe+Mg)$ = 0.60−0.79], nepheline, pyrrhotite, pentlandite, Ca-phosphate, and rare grains of Ni-rich taenite; low-Ca pyroxene is absent. Most clasts have triple junctions between silicate grains, indicative of prolonged thermal annealing. Based on the olivine-spinel [7] and high-Ca pyroxene thermometry [8], the estimated metamorphic temperature recorded by the clasts is $\geq$1100 K.

On a three-isotope oxygen diagram (Fig. 1), the compositions of olivine in the clasts plot below the terrestrial fractionation (TF) line ($\Delta^{17}O$ ranges from −3.3‰ to −5.4‰, $2\sigma \sim 1$‰), along or near carbonaceous chondrite anhydrous mineral (CCAM) line and the Allende mass fractionation (AMF) line [9].

Comparison of clasts with known groups of chondrites and achondrites: The equilibrated textures of clasts are also found in ordinary and carbonaceous chondrites of high petrologic types (e.g., type 5−6 of H, L, LL, R, CK), CV metachondrites (possibly formed by the annealing of CV chondrites [10]), primitive and differentiated achondrites. However, a genetic relationship between the clasts and these meteorites is unlikely for following several reasons:

(*i*) The averaged bulk chemical compositions of the clasts obtained by defocused-beam EPMA show that compatible and plagiophile elements (e.g., Al, Na, K) are not as heavily depleted as in achondrites [11], and are similar to those in chondrites and primitive achondrites.

(*ii*) The absence of low-Ca pyroxene in the clasts is inconsistent with mineralogy of the metamorphosed chondrites, CV metachondrites and primitive achondrites [11]. Although brachinites contain high-Ca pyroxene and no or rare low-Ca pyroxene [12], they are much coarser grained (up to ~1 mm in size) than the clasts (up to ~50 µm in size), and have distinctly different O-isotope compositions [13] (Fig. 1).

(*iii*) Chemical compositions of olivine grains in the clasts ($Fa_{34–39}$) and their O-isotope compositions (below the TF line) are inconsistent with those in equilibrated ordinary chondrites ($Fa_{16–32}$; $\Delta^{17}O > 0$; [11]) and in CV metachondrites ($Fa_{~22}$; [14]). There are also differences in chemical compositions of spinel grains between the clasts and ordinary chondrites: $Cr/(Cr+Al)$ = 0.19−0.45 *vs.* 0.85−0.95, respectively [15].

(*iv*) Although the Fa contents, $Cr/(Cr+Al)$ ratio in spinel and O-isotope compositions of olivine grains in the clasts overlap with those in CK chondrites [11,16,17], the latter contain higher NiO contents (<0.3 *vs.* 0.3−0.7 wt%) [16]. In addition, plagioclase in clasts does not show bimodal distribution of An contents as observed in CK plagioclase [16]. The clasts also lack magnetite, which are rather common in CK chondrites [11].

Formation of the clasts by metamorphism of the CV-like chondritic precursors: A few clasts, which experienced metamorphism to a lower degree, have O-isotope heterogeneity (Fig. 1) and chondrule-like textures; some of them are surrounded by finer-grained mantle mineralogically similar to the enclosed objects. The re-crystallized texture of the mantle suggests that it formed by annealing of fine-grained materials. Based on high-Ca pyroxene thermometry [8], the estimated metamorphic temperature recorded by the mantle is $\geq$1100. The bulk chemical compositions and/or texture of the mantle are similar to those of the Allende matrix and coarse-grained igneous rims around Allende chondrules [18]. Thus, the clasts could have formed by prolonged thermal metamoprhism of the CV-like materials.

The absence of low-Ca pyroxene in the Mokoia and Y-86009 clasts may suggest that low-Ca pyroxene was replaced during the thermal metamoprhism. We note that in the CV_{OxA} chondrites and Allende dark inclusions, low-Ca pyroxene is commonly preferentially replaced by ferroan olivine [19]. These observations may suggest that the precursor materials of the clasts were heavily-altered CV chondrites. This hypothesis is supported by several similarities between the clasts and CV_{OxA}: (*i*) Al- and Ca-rich bulk chemical compositions of clasts and CV_{OxA} chondrites and Allende dark inclusions [20]. (*ii*)

The similar textures and bulk chemical compositions of the mantle in less-metamorphosed clast to those of coarse-grained igneous rims around Allende chondrules [18]. (*iii*) O-isotope compositions of olivine in metamorphosed clasts overlapping with those in Allende [21] (Fig. 1). (*iv*) Similar sizes of chondrule-like objects in the less-metamorphosed clasts (0.2−1 mm in diameter) and CV chondrules (0.09−2.5 mm in diameter [22]).

Alteration of the clasts prior to metamorphism: In most cases, O-isotope compositions of olivine grains within an individual clast are uniform, suggesting that their O-isotope compositions could have been homogenized during thermal metamorphism [6]. There are, however, variations in O-isotope compositions (mainly in $\delta^{18}O$) among the clasts (Fig. 1). E.g., the difference in $\delta^{18}O$ values of Y86#1 and M25#2 clasts is up to ~10‰.

Such $\delta^{18}O$ differences suggest that each clast's precursor had either different O-isotope compositions, or that O-isotopes of precursors were once homogenized and then mass-dependently re-distributed at different temperature during thermal metamorphism. Under the metamorphic temperature of clasts of 1100 K < T < 1570 K (1570 K is a melting point of the Fo-Di-An system [23]), expected $\delta^{18}O$ fractionation values in pyroxene and plagioclase relative to olivine are small as <1‰ and <3‰, respectively [24]. If we assume that O-isotope composition of each clast's precursor is between these major three minerals, possible ranges of O-isotope compositions of each clast's precursor are inconsistent. Therefore, precursor of each clast could have had different O-isotope compositions.

The observed spread in $\delta^{18}O$ values between the clasts may reflect various degrees of aqueous/metasomatic alteration they experienced prior to thermal metamorphism. Oxygen-isotope composition of water ice (most likely source of water) that accreted into CV chondrite parent asteroid appears to have had higher $\Delta^{17}O$ value than anhydrous silicates [21,25−27]. As a result of O-isotope exchange between aqueous solution and anhydrous silicates, the former evolved towards lower $\Delta^{17}O$ values. Aqueously produced minerals in CV chondrites (e.g., fayalite, magnetite, Ca,Fe-rich pyroxenes, andradite) appear to have recorded this fluid-rock interaction. On a three-isotope oxygen diagram, their compositions plot along mass-dependent fractionation line with $\Delta^{17}O \sim -3$‰ [21,25−27], close to the AMF line. The observed spread in $\delta^{18}O$ values between the aqueously produced minerals is up to 20‰. We suggest that the precursor materials of the Mokoia and Y-86009 experienced various degrees of aqueous alteration prior to metamorphism. For example, the precursor materials of clast Y86#1 with the highest $\delta^{17}O$ and $\delta^{18}O$ values may have experienced stronger degree of aqueous alteration and contain larger volumes of altered minerals compared to those of other clasts.

Implications for early accretion of the CV asteroid: Wakita et al. [28] performed numerical calculations of thermal evolution of a CV-like asteroid with various initial parameters (accretion time, size, and water/rock mass ratio). In order to reach 1100 K, which is the lower limit of metamorphic temperature experienced by the clasts, the CV asteroid with >50 km radius should accrete not later than ~2 Myr after formation of CAIs with the canonical $^{26}Al/^{27}Al$ ratio of 5×10^{-5}, consistent with Al-Mg ages of CV chondrules of ~ 1.5 Myr after CV CAIs [29].

Conclusions: We conclude that the Mokoia and Y-86009 clasts formed by thermal metamorphism of heavily-altered chondrites on the CV parent asteroid, which must have accreted within 2 Myr after CAI formation and experienced thermal metamorphism $\geq$ 1100 K. The presence of heavily-metamorphosed clasts and the lack of igneous clasts in CV chondrite breccias argue against the existence of a metal core on the CV parent asteroid.
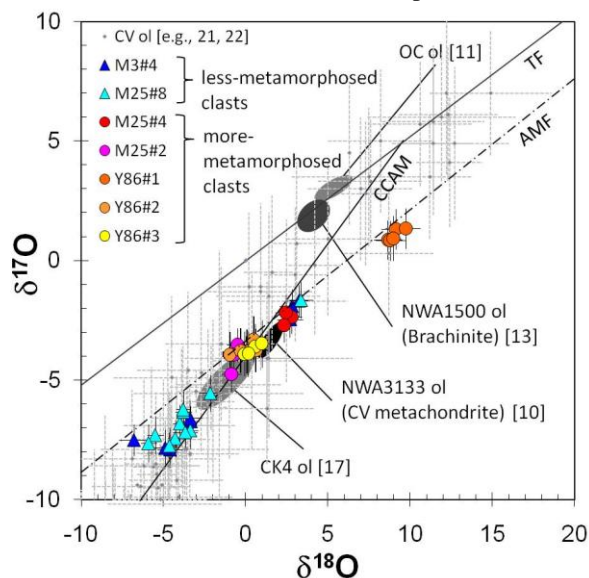
Fig. 1. O-isotope compositioins of olivine in Mokoia (M) and Y-86009 (Y) clasts which experienced different degrees of metamorphism. Errors are 2σ.

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Exploration of Jovian System by ESA-JUICE Mission: Participation of Japanese Teams.   JUICE JAPAN (Chief: Y. Saito[1] [saito@stp.isas.jaxa.jp], Associate scientists; M. Fujimoto[1], S. Sasaki[2], J. Kimura[3], Instrument chief Co-Is: N. Namiki[4], Y. Kasai[5], Y. Kasaba[6], K. Asamura[1], and more than 100 members), [1]The Institute of Space and Astronautical Science, JAXA, Sagamihara, Japan, [2]Deparent of Earth and Space Science, Osaka Univ., Toyonaka, Japan, [3]ELSI, Tokyo Institute of Technology, Meguro-ku, Tokyo, Japan, [4]PERC, Chiba Institute of Technology, Tsudanuma, Japan, [5]National Institute of Communications and Information Technology, Koganei, Japan, [6]Tohoku University, Sendai, Japan

Introduction: JUICE (Jupiter Icy Moon Explorer) is the ESA's first Large-class mission of Cosmic Vision 2015-2025 program. It will be launched in 2022 and will reach Jupiter in 2030 (Fig. 1). JUICE will continuously observe the atmosphere and magnetosphere of Jupiter. Using multi-flybys with Callisto, JUICE will not only map the whole surface of Callisto but also change orbital inclination. It will twice fly by Europa. JUICE will finally enter orbit around Ganymede in 2032, where it will study the icy surface and internal structure, especially its subsurface ocean, which is one of atrractive fields for astrobiology in the solar system. Ganymede would have molten metallic core generating intrinsic magnetic field. JUICE will observe the unique magnetic and plasma interactions of Ganymede with Jupiter's magnetosphere.

The discussion for the international collaboration for Jupiter mission between ESA and Japan (JAXA) started from 2006 and International Jupiter Mission Working Group started at JAXA in 2007. The initial plan was that JAXA will take a role on the magnetosphere spinner JMO (Jupiter Magnetosphere Orbiter) and JMO would be launched and transported together with ESA's main orbiter[1].   The original plan "Laplace" was similar to the framework of the Bepi-Colombo Mercury mission, where JAXA's magnetosphere orbiter (MMO: Mercury Magnetospheric Orbiter) is launched the ESA's main orbiter (MPO: Mercury Planetary Orbiter).

In October 2007, Laplace was selected as one of future ESA scientific missions Cosmic Vision (2015-2025). Then NASA which had been studied Europa mission (after JUNO) participated in the Jupiter mission planning. From 2008, JAXA will take a role on the magnetosphere spinner JMO (Jupiter Magnetosphere Orbiter). On the other hand, ESA will take charge of JGO (Jupiter Ganymede Orbiter) and NASA will be responsible for JEO (Jupiter Europa Orbiter). A Europa lander is also studied by Russian Space Agency. At this moment, EJSM and Titan Saturn System Mission (TSSM), are candidates for so-called Outer Planet Flagship Mission. In February 2009, NASA and ESA decided to continue the study of EJSM for the primary candidate of the Outer Planet Flagship Mission. Launches of EJSM spacecraft would be expected in 2020 (or early 2020's).

Following NASA's 2011 decadal survey and budget, a joint mission including Europa orbiter became unlikely to start in the proposed timeframe, unless JEO would be significantly descoped. Then JGO proposer group of ESA is investigating the possibility of a European-led mission, where two Europa flybys and high-inclination orbits are complimented prior to the insertion into the orbits around Ganymede. JGO was renamed with JUICE (Jupiter Icy Moon Explorer).

The model payload of JUICE consists of 10 state-of-the-art instruments plus one experiment that uses the spacecraft telecommunication system with ground-based receivers [2]. This set of instruments is capable can satisfy all of the mission's science goals, from in situ measurements of Jupiter's atmosphere and plasma environment, to remote observations of the surface and interior of the three icy moons, Ganymede, Europa and Callisto through flybys and orbits. The model payload of JUICE includes the following 11 instruments:

Remote sensing package
 − Narrow angle camera,
 − Wide angle camera,
 − Visible / IR hyper-spectral imaging spectrometer,
 − UV imaging spectrometer,
− Sub-mm wave instrument,
Geophysical package
− Laser altimeter,
− Ice penetrating radar,
− Magnetometer,
In situ observation package,
− Particle package – Ion neutral mass spectrometer,
− Radio and plasma wave instrument,
− Radio science instrument / Ultra-stable oscillator.
In addition to detailed seamless observation and characterization of a unique moon Ganymede, for more than two years between 2030 and 2032. On May 2, 2012, JUICE was selected as the first ESA cosmic vision L-class mission.

Participation of Japanese Groups: As for JMO plan by JAXA, it turned out that relatively low-cost solar power sail could not transport a magnetosphere orbiter with enough science payload in mass and size. Orbits around Jupiter would be restricted. Anyway it is difficult for JAXA to launch the outer planet mission by itself to meet the time constraint for co-operative ob-

servation with JUICE.Therefore direct collaboration with European groups/team should be necessary for Japanese scientists to participate in this attractive Jupiter system mission.

After the selection of JUICE in May 2012, six Japanese groups were invited to participate in the mission as Co-Is with instrument development for model payloads. There were also invited scientific Co-I candidates without instrument developments.

Following these invitations, on 25th June, the steering committee of ISAS/JAXA recommend the overall participation of Japanese scientist group with instrument developments should be supported by ISAS/JAXA after very careful examinations.

Six teams prepared their proposals to ISAS and also collaborated to submit AO proposals in October together with PI candidate teams. In total 31 proposals were submitted for AO (from Europe and US). The result of AO was announced on February 2013, and 11 proposals (10 PIs from Europe and 1 PI from US). And four of Japanese team partners were selected for the official JUICE instruments. These are GALA, SWI, PEP, and RPWI. Moreover three Japanese scientists are invited to participate in the initial scientific analysis as Co-Is of JANUS and J-MAG.

GALA is a laser altimeter for studying the tidal deformation of Ganymede and the morphology and topography of the surfaces of the icy moons. Detection of subsurface ocean is the important target.

SWI is a sub-millimeter wave instrument to investigate the temperature structure, composition and dynamics of Jupiter's stratosphere and troposphere, and the exospheres and surfaces of the icy moons.

PEP is a plasma package with sensors to characterize the plasma environment in the Jovian system.−PEP will measure density and fluxes of positive and negative ions, electrons, exospheric neutral gas, thermal plasma and energetic neutral atoms in the energy range from <0.001 eV to >1 MeV. The composition of exospheres of icy moons will be measured with a resolving power of more than 1000.

RPWI is a radio plasma wave instrument to characterize the radio emission and plasma environment of Jupiter and its icy moons.

JANUS is an optical camera to study global, regional and local morphology and processes on the moons, and to perform mapping of the clouds on Jupiter.

J-MAG is a magnetometer to characterize the Jovian magnetic field, its interaction with the internal magnetic field of Ganymede, and to study subsurface oceans of the icy moons.
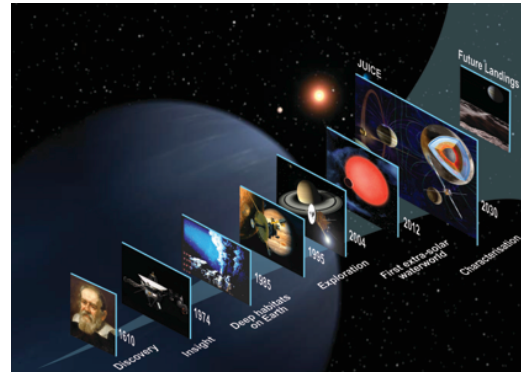
Fig. 1 Schematic picture of JUICE mission (ESA).

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"CONTACT" WITH EXTRA-TERRESTRIAL LIFE; AN ASTRONOMER'S VIEW. Norio Kaifu,
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From astronomical point of view contact with extra-terrestrial life (in whatever situation) may occur within the coming half century. In case of life on exo-solar planets the "contact" will happen by astronomical observations. Obviously it is role of young scientists to be eyewitnesses and be participants of such great scientific events, still I am excited as an old astronomer to be in this starting phase toward the great jump of human knowledge.

Since 2009 we have been organizing compact meetings to continuously discuss key issues relating to extraterrestrial life among some 20 Japanese scientists in broad area: biology, earth science, astronomy, and anthropology. Our main purpose is to understand steps of practical road map toward the "contact", and also to publish a textbook of "Life in Universe" for undergraduate student. The science in 21th century already has huge accumulation of new facts and data on evolution of terrestrial life, history of planet Earth, physical condition of solar system bodies, observational and theoretical outcome of exo-solar planets, and problems of civilization too. Taking the dramatic evolution of observational technology into account we can feel that we are actually getting the "contact" in our sight, though vast unknown problems are still waiting us.

In this talk I plan to discuss a few points among several issues which were identified through our discussion to be important to consider when we try to search for evidence of life on exo-solar planets. I put my emphasis on what we expect in future astronomical observations (optical/IR and radio waves) toward the exo-solar Earth-like planets.

EVOLUTION OF INTELLIGENCE IN A NETWORK OF CHAIN REACTIONS. S. Karasawa[1], [1]Affiliation

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Introduction: This paper describe a concept of network of chain reactions which represents activities. That is, the organism is a network of chain reactions. Principle of brain mechanism is possible to describe as systematic activities in a network of chain reactions. Concurrently activated portions in a network of neurons are able to link by intermolecular bond via thermal motion of molecules. The thermal motion is able to exchange neighboring atoms, and the electronic state is able to adapt to the surroundings. This mechanism creates a system of molecule. In such way, the first organism was born in soup of birth of organism. The generation of the first organism is a very small probability, but it increases via a reproduction system accompanied with. The mechanism of metabolism is able to maintain the body, and also to append functions. The metabolism and replicator must coexist at the birth of organism. The intelligence is a system to replay similar reaction. It makes possible to generate a system of replication.

Mechanism of intelligence in a brain: The mechanisms in a nerve system are helpful to understand the organization of a network of chain reactions. The nerve system sends an exited state of a plus impulse from sensor to actuator. Each neuron acts as representative of an action. The meaning of an impulse itself is excitation of the neuron.

The concurrently activated portions are able to link by intermolecular coupling. Remains of the activities has the effect of learning. The meaning of a sequence of voice sound depends on the experience of language use similarly to the bell for Pavlov's dog. Although eyes and ears are different, those concurrent excitations in a nerve system are able to link by an annex neuron. The layered networks are linked to the real world via sensors and actuators [1]. The intelligent system of representatives is an annex system in the brain. It makes possible to replay similar behavior.

Linkages in a network of chain reactions: An action makes change of a state. The result causes the next reaction. The route of reactions is possible to form the memory on a process of chain reactions. The concurrently activated portions of a chain reaction are able to link by intermolecular coupling. There is a possibility to make a loop of chain reactions. The excitation in a looped chain reaction is able to continue by circulation of reaction.

An equilibrium state can be kept by reaction of opposite directions. But a neuron is not possible to react opposite direction. In visual information processing of retina [2], there is combination of antagonized reaction. There is a checkered pattern of response called as ON-areas and OFF-areas. The antagonized change is carried out via abolishing of the activation [3]. The adjacent antagonistic region is derived from the relation of demand and supply in the biochemical reaction. The combination of antagonistic reaction makes possible to return to initial state easier.

The first system of replication: The replication takes place at the change of a generation. The organization of molecules that includes with organized parts contributes to the evolution of the chain reaction. Since intermolecular force is emphasized via the membrane, almost all the molecular arrangement will decompose at collapse of the membrane. Although most of chain reactions on the membrane will decompose at collapse of the membrane, some chain of reactions included on a part of membrane can be included in a renewed cell.

Synthesis of structural protein on a membrane: Protein is a chain of amino acids. Although amino acid is soluble in water, side chain of the amino acid attaches to a membrane. Thermal motion of these amino acids is suppressed by the connection. And it supresses decomposition of the connection. So, the binding of amino acids are continued.

There is the possibility that the intermolecular bond is changed to the chemical bond at interface of the membrane [4]. Although tremendous kinds of protein are possible to generate, there is natural selection. The membrane becomes robust by the structural protein. Moreover, the part of membrane with protein is able to have a special form and function. The thread of protein with membrane will be produced with linking to the same real world concurrently. The membrane with a series of amino acids is able to record the trace of series of reactions along a time progress.

Record of chain reaction by representative of activities: Operation of individual reaction in a chain reaction is transferred along the time progress. The elements of a chain reaction are located in space, and it is possible to link to other reactions to form a circuit.

It is known that DNA gene system consists of genetic code. In general, the code is a characteristic of representatives for information processing. A system of overlapped representatives is able to achieve reliable information processing. The layered system of representatives is able to economize the circuit. So,

evolved information processing becomes an overlapping layered system of representatives.

Memorizing of the serial data of a protein by a linear polymer of nucleotides: A system for replication of protein was formed as an annex system in a network of chain reactions. The record of reactions must have the circuit in which a series of activated states are aligned along time progress.

Phosphodiester bond of nucleotides, and peptide bond of amino acids are fairly different structure. The elements of nucleotide and amino acid are also different. But amino acid of a protein and an activated portion of the nucleotide chain are able to corresponded along the same time progress.

There exists a protein of a poly-ribo-nucleotide RNA chain. The linear polymer of nucleotide is available as a record for production of a protein, if the specified amino acid is linked to specified portion of nucleotides. That is messenger RNA (m-RNA). On the other hand, transfer RNA (t-RNA) binds at one end to a specific codon in the m-RNA and it binds at the other end to the amino acid specified by that codon. The size of t-RNA is small. The small size of t-RNA is convenient for transferring.

Establishment of DNA codon gene system [5]**:** Both DNA and RNA are linear polymers of nucleotides. RNA differs from DNA. It exists as a single strand rather than a double stranded helix [6].

DNA is very stable and it is able to replicate RNA easily. But DNA cannot be the template of protein. On the other hand, RNA is not so stable as DNA. But RNA has functions for processing of synthesis. m-RNA is used as an element of short-term memory. t-RNA is available to assign amino acid during protein synthesis. Francis Crick referred to this pathway as the central dogma [7]. That is, DNA functions as the template for RNA molecules. RNA determines the arrangement of amino acids within protein.

DNA and RNA consist of 4 kinds of building blocks. But the amino acids to be distinguished are over 20. So, combination of 3 pieces of bases is used for to assign one amino acid.

Control of overlapped network of chain-reactions: The structure of a network of representatives for behavior control is overlapping of layered structure. An approach for a mobile robot is layered control system [8]. The network of neuron in a brain is overlapping of layered structure. The f-MRI of a brain indicates concurrent existence of plural activations.

DNA system of central dogma requires an extensive array of chain reactions for production of protein. The evolutionary rate of the important part of gene is slow is, but evolutionary rate of the portion not impor-

tant is fast. This difference on change of gene indicates overlapping of layered structure.

Memory for a long series of amino acids will be divided to many elements. The system with segmentation has the merit that elements are available for the other part. An evolved intelligent system possesses with segmentation, and it needs the mechanism to control the other segments.

An annex system makes possible to control such network. That is, a representative in upper layer of the network must be activated during the period as needed. There are start codon and stop codon in DNA gene system. These signals are available to activate the representative of reaction that makes possible to suppress the other activation. In order to keep the activations in such layered structure of representatives, a loop of chain reactions is required. Organisms have the mechanism to maintain the chain of reactions.

If there are plural of candidates for an output, the decoder to select next reaction is necessary at the junction. A specific decoder is necessary for each situation.

Conclusion: The organism is a network of chain reactions. The first life was born by metabolism. It includes mechanism of replication and intelligence. Today's organism has been evolved extremely. DNA gene system of "central dogma" is an amazing system for evolution of innate intelligence. A signal processing concept of a network of representative of activities i.e. network of chain reactions is useful to describe evolution of intelligence, and it will provide guidance to explore the organism in the universe.

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DEUTERIUM-HYDROGEN EXCHANGE BETWEEN ORGANIC MATTER AND WATER: IMPLICATIONS FOR CHEMICAL EVOLUTION DURING ASTEROIDAL PROCESSING.

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Introduction: The high deuterium (D) enrichment in insoluble organic matter (IOM) in chondrites has largely been attributed to low temperature chemistry in the interstellar medium (ISM) or the early outer Solar System. Therefore, IOM is proposed to form in the icy mantles of interstellar dust grains through UV-induced photopolymerization of low molecular weight organic molecules [1]. Alternatively, a possible scenario of IOM formation has been proposed using interstellar formaldehyde (CH_2O) through the polymerization after planetesimal accretion, in the presence of liquid water [2]. Highly deuterated formaldehyde is observed in ISM, e.g., the $[CD_2O]/[CH_2O]$ abundant ratio in star forming region in ISM is 0.02-0.4 [3]. However, even among the highest D-enriched IOM has significantly lower (by a factor of ~2) D content compared with ISM molecules, e.g., a CR1 chondrite GRO95577 has a δD of 3303‰ [4]. While water in the solar system is much depleted in D, e.g., D/H ratio of water in comet 103P/Hartley 2 is 2.96×10^{-4} (close to the terrestrial water values) [5]. Thus, D-H exchange between D enriched IOM precursor and D depleted water could have occurred during and/or after the formation of IOM.

Here we report D-H exchange experiments between organic matter and water during and after IOM synthesis.

D-H exchange experiments: Our recent study revealed that IOM in primitive chondritic meteorites is predominantly derived from the polymerization of interstellar formaldehyde with incorporation of ammonia, evidenced by molecular spectroscopic characters [6]. We conducted two series of D-H exchange experiments based on the formaldehyde polymerization hypothesis; (1) D-H exchange between formaldehyde and water during formaldehyde polymer (FP) synthesis, and (2) D-H exchange between FP and water.

(1) D-H exchange between formaldehyde and water. The starting aqueous solution contained formaldehyde 2 mol/l and glycolaldehyde ($C_2H_4O_2$) 1 mol/l, $Ca(OH)_2$ 0.2 mol/l, NH_4OH 0.4 mol/l (N/C atomic ratio = 0.1). We prepared these solutions with (a) CD_2O (99 atom % D) and D_2O (D_2O/H_2O = 9/1, v/v), (b) CH_2O and D_2O, (c) CD_2O and H_2O, and (d) CH_2O and H_2O. The solutions were sealed in glass tubes and heated at 250ºC for 72 hours. After the heating, the supernatants were removed and the residues were washed with 2N HCl to remove bound calcium ions.

The FPs were then washed with deionized water and dried.

(2) D-H exchange between formaldehyde polymer (FP) and water. The most D-enriched FP $[CD_2O+D_2O]$ and the most D-depleted FP $[CH_2O+H_2O]$ which obtained from experiment #1 were selected as starting materials of D-H exchange experiments. The FP $[CD_2O+D_2O]$ was heated in H_2O, and the FP $[CH_2O+H_2O]$ was heated in D_2O (D_2O/H_2O = 9/1, v/v), at 150ºC, 200ºC and 250ºC for 1 hour up to 504 hours (21 days) in sealed glass tubes.
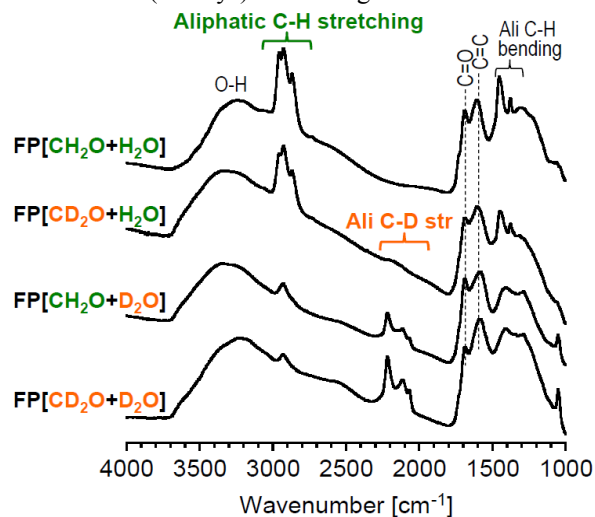
Fig.1: FTIR spectra of formaldehyde polymers (FPs).

Results and Discussion: *(1) D-H exchange between formaldehyde and water.* Fig. 1 shows Fourier transform infrared (FTIR) spectra of FPs. FPs synthesized with D_2O show large aliphatic C-D bands with small aliphatic C-H bands regardless of starting with CD_2O or CH_2O. FP with CD_2O and H_2O shows small aliphatic C-D bands and large aliphatic C-H bands. FP with CH_2O and H_2O shows aliphatic C-H bands and no C-D band was observed. The aliphatic C-D/C-H band area ratios obtained from IR spectra are shown in Fig. 2. These results indicate that most of the hydrogen in FPs is derived from water.

(2) D-H exchange between formaldehyde polymer (FP) and water. Fig. 2 shows the IR C-D/C-H band area ratio change with time. Three-dimensional diffusion was found to be the best fit for these D-H exchange profiles among the rate laws tested (fit curves are shown in Fig. 2).
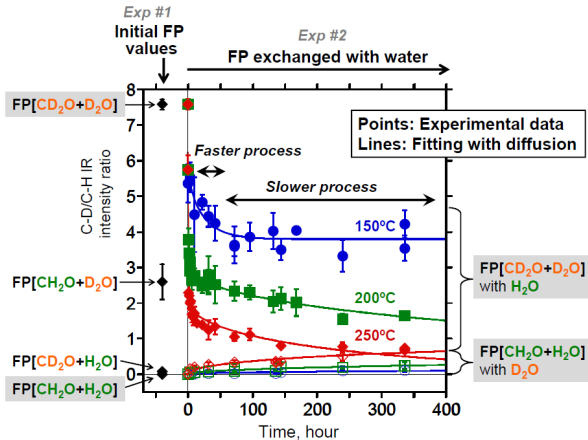
Fig. 2: The IR C-D/C-H band area ratios change with time. The C-D/C-H ratios of FPs obtained from experiment #1 are also shown.

For the D-poor FP exchanged with D_2O, the apparent reaction rate constants k were obtained by the fitting curves with the three-dimensional diffusion equation:

$$I_{D/H} = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp(-n^2 kt), \quad k = \frac{D\pi^2}{a^2} \quad (1)$$

where $I_{D/H}$ is the IR C-D/C-H band area ratio, t is the time, D is the diffusion coefficient, and a is the radius of the polymer particles. For the D-rich FP exchanged with H_2O, the apparent reaction rate constants k_1 (faster reaction) and k_2 (slower reaction) were obtained by the fitting curves with a combination of three-dimensional diffusion equations. Then the apparent activation energies E [kJ/mol] and the frequency factors A [s^{-1}] are obtained by the apparent rate constants k and the reaction temperatures T with the Arrhenius equation:

$$\ln k = \ln A - \frac{E}{RT} \quad (2)$$

where R is the gas constant, and T is the temperature. The kinetic parameters were obtained as $E = 80 \pm 5$, $\ln A = 3.5 \pm 1.2$ for the D-poor FP exchanged with D_2O, and as $E_1 = 53 \pm 11$, $\ln A_1 = 5.3 \pm 2.8$ (faster reaction), $E_2 = 67 \pm 7$ and $\ln A_2 = 1.4 \pm 1.7$ (slower reaction) for the D-rich FP exchanged with H_2O.

Now that the relationship between time t, temperature T and C-D/C-H band ratio $I_{D/H}$, with the equations 1 and 2, is established. Using obtained kinetic expressions, D-H exchange profiles can be estimated for a certain time and temperature, as shown in Fig. 3, based on the assumption that the kinetic rate low is invariance. These diagrams indicate that D-H exchange of polymers with D-rich water is slower than with D-poor water.

For primitive carbonaceous chondrites, it is possible to assume that D/H ratio of IOM decreased by exchanging with D-depleted water. For example, starting from the value of GRO 95577 ($\delta D=3303$‰, D/H=0.00067 [4]) down to the value of Murchison ($\delta D=811$‰, D/H=0.00028 [4]), the time scales of alteration are estimated as 5 years at 100°C, 100 years at 50°C, and 10^4 years at 0°C using the obtained kinetic expression. For ordinary chondrites, D/H ratio of IOM might have increased by exchanging with D-rich water [4]. For example, starting from the values of Murchison up to the values of WSG 95300 ($\delta D=11850$‰, D/H=0.002 [4]), the time scales of alteration can be estimated as 6 months at 200°C, and 100 years at 100°C.
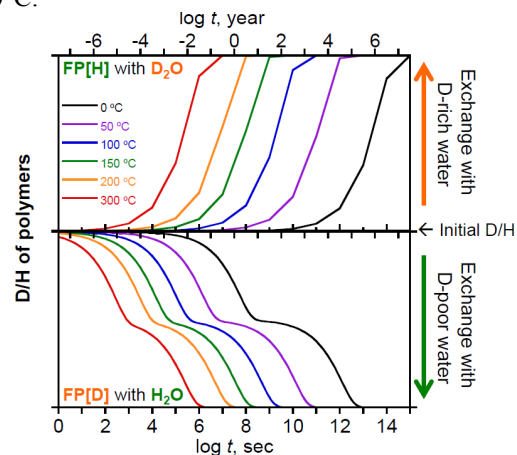
Fig. 3: D-H exchange profiles of polymers calculated by the experimental kinetic parameters.

Conclusions: Experimental simulations of D-H exchange between organic matter and water were conducted considering the following two processes; (1) IOM polymerization process starting with formaldehyde in the presence of water, and (2) D-H exchange between water and IOM. Most of the hydrogen in IOM might be derived from water during polymerization. The D-H exchange also occurs after polymerization. We obtained the kinetic expressions of D-H exchange between D-rich FP and D-poor water, and between D-poor FP and D-rich water. The estimated D-H exchange timescales between IOM and water may be determined experimentally.

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VARIATION OF GENETIC ALPHABETS OF NUCLEOBASES. M. Kimoto[1,2] and I. Hirao[1,2], [1]RIKEN Center for Life Science Technologies (CLST), 1-7-22 Suehiro-cho, Tsurumi-ku, Kanagawa, Yokohama, 230-0045, Japan, relies on[2]TagCyx Biotechnologies, 1-6-126 Suehiro-cho, Tsurumi-ku, Kanagawa, Yokohama, 230-0045, Japan.

Introduction: Nucleic acids are unique biopolymers, which work as both genetic information materials and functional molecules, such as a catalyst and ligands. The present DNA and RNA molecules are composed of four subunits called nucleotides, containing A, G, C, and T(U), as a nucleobase. Two sets of complementary base pairs, A–T(U) and G–C, play a critical role in storing genetic information and replicating genetic materials. Hypothetically, the number of subunits composing biopolymers might be associated with their replication competence and their funcional capability. Accordingly, the original material on the early Earth has been considered to contain fewer than four different subunits, like a precursor involving only a single base-pairing unit, such as adenine and inosine [1].

Through *in vitro* evolution experiments, Joyce and his colleagues demonstrated that ribozyme activities, which have been found in current life, can be also exhibited even with macromolecules comprising of three or only two different nuleotides [2–4]. Although the activities were much less than those of current RNA moleucls composing of four nucleotides, their results showed that the minimum number of distinct subunits allowing to develop functional informational macromolecules is two. With just only one subunit, it would be difficult to have information and basis for Darwinian evolutions [4], but it might be possible to retain the ability to replicate as a self pairing.

The expansion of the genetic alphabet by unnatural base pairs: Then, how about more than four nucleotides for nucleic acids, if not as much as 20, like amino acids for proteins? While several theoretical approaches have speculated that the optimized number of base types is four, for replicative genetic information storage, computational analysis also suggested the possibilities of six and eight under high-fidelity replicative conditions [5]. In addition, Alexander Rich already imagined a new base pair system including a third base pair as early as 1962 [6], and pioneering studies of unnatural base pairs were started in the late 1980s [7,8]. To date, three research groups, including our own, have reported their own unnatural base pairs, which can be replicable by DNA polymerases with appreciable fidelity as a third base pair [9–14].

To examine the hypothesis that increasing the number of bases augments nucleic acid functionality, we have been studying the development of unnatural base pairs. Recentrly, we developed a hydrophobic **Ds**–**Px** pair (**Ds**: 7-(2-thienyl)imidazo[4,5-b]pyridine; **Px**: 4-propynyl-2-nitropyrrole), which exhibits extremely high selectivity in replication: the **Ds**–**Px** pair retains more than 97% even after 100-cycle (10 times of 10-cycle) PCR amplification, allowing a practical use in further applications [11,12].

By using PCR involvings the **Ds**–**Px** pair, we designed a new method to generate high-affinity DNA aptamers containing a hydrophobic **Ds** base as a fifth base [15]. We obtained anti-VEGF165 aptamer (47-mer) containing two **Ds** bases and anti-IFNγ aptamer (49-mer) containing three **Ds** bases. Their binding affinities, the K_d values, to each target protein were 0.65 pM and 38 pM, respectively, which were more than one hundred times smaller than those of the existing DNA aptamers containing natural bases only. In addition, the binding abilities were largely dependent on the **Ds** bases: replacement of the **Ds** bases to the natural A bases in the aptamer significantly reduced their binding affinities, indicating the **Ds** bases actually involves their improved binding abilities. This was the first example that increasing the number of the components of nucleic acids, by adding the hydrophobic **Ds** bases to four natural bases, significantly augmented the functionalities of nucleic acids.

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"DEEP HABITAT" IN THE ICY MOONS: STRUCTURE AND EVOLUTION OF THE INTERNAL OCEAN.

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Introduction: Outer solar system may have a potential habitat of extra-terrestrial life. Most moons orbiting planets in the outer Solar System, at orbits beyond the snow-line, such as Jupiter or Saturn, are covered with water ice and they are called icy moons. Recent explorations (e.g., Galileo and Cassini spacecraft) have found direct or indirect evidences for that many icy moons may harbor an ocean underneath the icy surface. Internal oceans in the icy moons are speculated below the sold icy crust of the moons which means that the oceans exist independently of the stellar energy input and are located well outside the conventional habitable zone of the Sun. It may possess "a deep habitat", a different style of habitability from Earth-like biosphere. In this talk, observational facts and current understanding for the internal ocean in the icy moons provided by the spacecraft observations and theoretical models for the evolution will be reviewed.

Jovian icy moons and Galileo exploration: *Europa* is the smallest and second nearest of the four large Jovian moons, called Galilean moons, and its surface is mainly consists of water ice. The lack of large impact craters on the surface indicating relatively young (20-200 Myr [1]) implies that tectonic processes had erased old craters. Though Europa's surface appears to be extremely smooth from the images taken by spacecrafts, actually it is dominated by a cracked and ruptured features which need existence of the internal ocean for the formation of these surface features [e.g., 2, 3]. Also, disrupted terrain "Chaos" may be a sign of the subsurface lake of liquid water [4]. Moreover, magnetometer onboard Galileo spacecraft has detected a signal of electromagnetic induction during Europa flybys. It can be interpreted that a global electrically conducing layer, which means salty ocean, must lie within 200 km of the icy surface [5]. Europa's internal ocean must be directly contacted with underlying rocky mantle which means that an interaction between liquid water and rocks and associating various reactions can be sustained [6]. At the surface, sulfate and carbonate of magnesium and sodium considered to be a result of such seafloor interaction have been found [7].

Ganymede is the largest moon in the Solar System with a radius of 2,634 km, which is larger than the planet Mercury. Although Ganymede's surface is relatively older than Europa, signal of magnetic induction has been founded which means the existence of subsurface salty ocean. However, larger amount of water in Ganymede (half water and half rocks) than Europa would mean that the internal ocean would be sandwiched between an upper floating icy crust and lower layers of higher density ice polymorphs.

Callisto is farthest and second largest of the Galilean moons, and its surface is most heavily cratered in the solar system and no tectonic features suggesting that the surface is extremely ancient ($\sim$ 4 Gyr [1]). In addition, large value of the moment of inertial factor (0.3549 ± 0.0042) indicates that its interior is imperfectly differentiated [8], which means that it has never been heated well. However, Galileo spacecraft detected an electromagnetic signal implying an existence of the internal ocean like Europa and Ganymede.

Saturnian icy moons and Cassini exploration: *Titan* with a radius of 2575 km, is unique among the moons in having a thick atmosphere composing of mainly nitrogen ($\sim$95 %) and methane ($\sim$5%), and also having organic aerosols as minor components. At the surface, lakes and seas of liquid hydrocarbon exist and change with the seasons which implies Titan possibly has a circulation system and cycle of methane. In addition Titan has a possibility of the subsurface ocean which has been suggested by measurements of large periodic changes of Titan's quadrupole gravity exerted by tidal interaction with Saturn [9]. Such large response requires that Titan's interior is deformable, which is consistent with a global internal ocean.

Enceladus is actively erupting water-rich plumes from warm fractures near the south-pole region [10] though its radius is only 252 km. The plumes consist mainly of water vapor with large amounts of CO_2, NH_3, CH_4, and organics in a gaseous state, and H_2O ice, sodium salts, silicates, organics, and carbonates in a solid state [11, 12]. Although these activities need to have a subsurface water region, the structure of the ocean or the depth of a localized water reservoir is highly unclear.

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The Energetics of Amino Acid Synthesis and Polymerization as a Function of Temperature and pH.
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Introduction: Since their discovery in the late 1970s, submarine hydrothermal systems have been proposed as likely candidates for the origin and evolution of life on Earth [1]. In hydrothermal systems, seawater percolates into the oceanic crust and is heated, reacting with surrounding rocks. The resultant hot reductive fluid shows pH ranging from <1 to 11 and temperatures from 2 to 400 $^{\circ}$C. To evaluate the potential for abiotic organic synthesis under such hydrothermal conditions, thermodynamic calculations have been performed widely [2]. However, most of previous calculations have been performed assuming neutral pH. Reactivities of organic molecules under other pH conditions remain not well known. Therefore in this study, I performed thermodynamic calculatations for the synthesis and polymerization of amino acids (especially glycine (Gly)) under wide range of temperature (0-300 $^{\circ}$C) and pH (2-12) conditions.

Results and Discussion: Figure 1 shows the standard molal Gibbs energies ($\Delta_r G^o$) of formation ($2CO_2 + NH_3 + 3H_2 \rightarrow Gly + 2H_2O$; Fig. 1a) and dimerization ($Gly + Gly \rightarrow GlyGly + H_2O$; Fig. 1b) of Gly as a function of temperature and pH. In both the cases, strong temperature and pH dependences are observed. For instance at pH = 6, the values of $\Delta_r G^o$ for Gly formation increased with increasing temperature (Fig. 1a), whereas those of Gly dimerization decreased (Fig. 1b). These results indicate that favorable environments for the formation and polymerization of Gly are different; lower temperature and neutral pH condition is favorable for Gly formation whereas higher temperature and slightly alkaline (or slightly acidic) pH is favorable for Gly polymerization (neutral pH at 300 $^{\circ}$C is ~5.4). Therefore, formation and polymerization of amino acids might proceeded under different hydrothermal environments on the primitive Earth.

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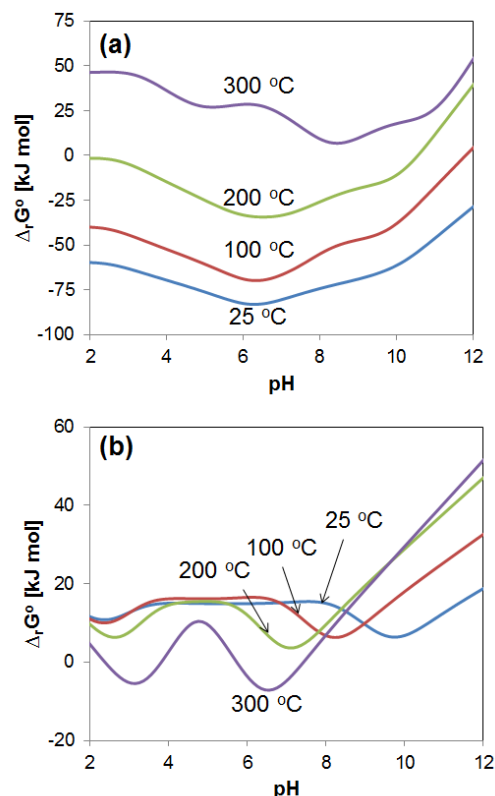
Figure 1. Standard molal Gibbs energies ($\Delta_r G^o$) of formation ($2CO_2 + NH_3 + 3H_2 \rightarrow Gly + 2H_2O$; Fig. 1a) and dimerization ($Gly + Gly \rightarrow GlyGly + H_2O$; Fig. 1b) of Gly as a function of temperature and pH.

METHOD FOR BIOLOGICAL CONTAMINATION MONITORING DURING AEROGEL CUTTING PROCESS IN TANPOPO PROJECT USING BIOLUMINESCENT BACTERIA *Photobacterium kishitanii*.

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Introduction: The Tanpopo mission is a Japanese astrobiological experiment which will be conducted on the Japanese Experiment Module (JEM) of the International Space Station (ISS) [1]. One of the goals of the Tanpopo mission is to capture microbes in space, possibly attached on the surfaces of micrometeoroids or space debris at the ISS orbit (approximately 400 km altitude). For this purpose, an excellent but fragile media called "silica aerogel" tiles will be used [2]. After the experiment, aerogel samples that possibly contain tracks with microbes/microbial DNA will be devided to regions using a device called "YOUKAN machine", and offered for PCR analysis. As PCR process amplifies any sort of microbial DNA, biological contamination of the returned sample in the curation laboratory must be strictly eliminated. To develop a suitable cutting method, biological contamination of returned aerogel during the proess should be monitored. In other words,
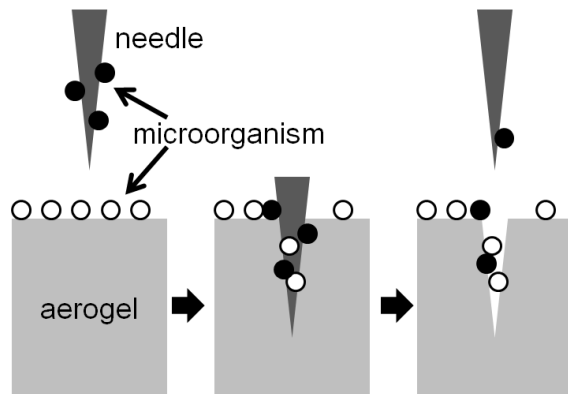
Fig. 2 Possible biological contamination.

sources (space or Earth) of microbes found in/on the returned aerogel sample should be clearly distinguished. In this report we focused on the measurement of microbes that should be dragged from the aerogel surface into the hole with the motion of the cutting needle. To measure only microbes from the aerogel surface (not those from the needle surface, etc.), here we report the use of bioluminescent bacteria, *Photobacterium kishitanii*.

Bioluminescent bacteria *Photobacterium kishitanii* : Among several bioluminescent bacteria, *P.*

kishitanii emits strongest light with the peak wavelength of 475 nm. Methods for the attachment of this bacteria on the glass surface were studied, and continuous measurement of the luminescence were performed [3]. Measurement of luminescence from one single cell was also possible [4]. Here in this report *P. kishitanii* cells will be used as models of microbe attached on the cutting needle of aerogel.
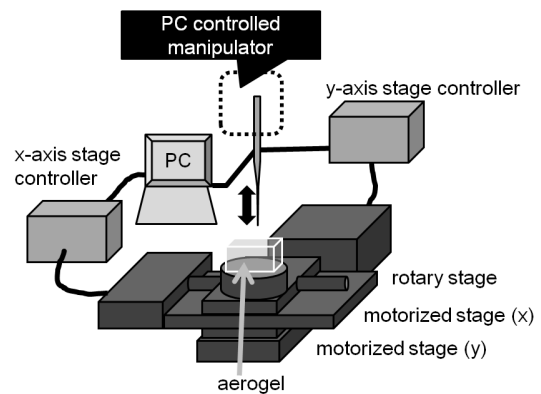
Fig. 1 Schematic illustration of YOUKAN machine.

YOUKAN machine BBM: We performed cutting experiment in a way similar to the one used in STARDUST mission by NASA [5], where the cutting needle vertically moved back and forth in z axis, together with the horizontal movement of aerogel fixed on x-y stage (Fig. 2).

Contamination measurement: Firstly, *P. kishitanii* suspension was attached on the top surface of the aerogel, followed by the repeated pricking. Secondly, the bacterial suspention was attached on the needle surface only. After the pricking the luminescence from the bacteria in holes was measured using a luminescence counter. Effect of the speed, shape and attached cell number on the contamination will be reported.

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Evolution of Interstellar Organics to Meteoritic and Cometary Organics: Approaches by Laboratory Simulations. K. Kobayashi[1,2], Y. Kawamoto[1], W. El-Masry[1], M. Eto[1], H. Tokimura[1], T. Kaneko[1], Y. Obayashi[1], H. Mita[3], K. Kanda[4], S. Yoshida[5], H. Fukuda[6] and Y. Oguri[6], [1]Yokohama National University, 79-5 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, Japan, kkensei@ynu.ac.jp, [2]National Institutes of Natural Sciences, 4-3-13 Toranomon, Minato-ku, Tokyo 105-0001, Japan, [3]Fukuoka Institute of Technology, [4]University of Hyogo, LASTI, 3-1-2 Koto, Kamigori-cho, Ako-gun 678-1205, Japan, [5]National Institute of Radiological Sciences, 4-9-1 Anagawa, Inage-ku, Chiba 263-8555, Japan, [6]Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8550, Japan.

Introduction: Wide variety of organic compounds including amino acid precursors have been detected in such extraterrestrial bodies as carbonaceous chondrites and comets, and their relevance to the origin of life on the Earth is discussed. Isotopic ratios of meteoritic and cometary organics has suggested that these organics were formed in extremely cold environments such as dense clouds. Laboratory experiments simulating possible reactions in ice mantles of interstellar dust particles (ISDs) indicated that amino acid precursors were easily formed in them [1]. Organic compounds formed in ISDs should have been altered after introduced to proto-solar nebula by high-energy photons and particles and/or thermal / hydrothermal reactions in parent bodies of meteorites. Here we examined possible formation of amino acids and nucleic acid bases (or their precursors) from possible interstellar media, and alteration with high-energy photons, particles and hydrothermal reactions.

Experimental: *Synthesis of possible interstellar organics.* Carbon monoxide (350 Torr), ammonia (350 Torr) and liquid water (5 mL) was put in a Pyrex tube, and the gas mixture was irradiated with 2.5 MeV protons from a Tandem accelerator (Tokyo Institute of Technology). Total electric quantity irradiated was 1 - 4 mC, and the products were hereafter referred to as CAW. Gas mixtures of carbon monoxide (350 Torr) and ammonia (87.5 – 350 Torr) were also irradiated with 2 mC of 2.5 MeV protons, and the products were referred to as CA. A mixture of methanol, ammonia and water (molar ratio was 1:1:2.8) was irradiated with heavy ions (290 MeV/u carbon ions, or 500 MeV/u argon ions) from HIMAC, NIRS, Japan. Total irradiation dose was 1.5 – 15 kGy, and the products were referred to as MeAW. All the irradiated products were acid-hydrolyzed and then were subjected to amino acid analysis by HPLC and/or GC/MS.

Alteration of amino acids and their precursors by high-energy photons. Five amino acid-related samples - Glycine (Gly), hydantoin (Hyd: precursor of glycine), isovaline (Ival), 5-Ethyl-5-methylhydantoin (EMHyd: precursor of isovaline) and complex organic compounds synthesized by proton irradiation of a mixture of CO, NH_3 and H_2O (referred to as CAW) - were irradiated with continuous light from soft X-rays to IR

(hereafter referred as to soft X-rays) at NewSUBARU BL-06 (University of Hyogo) under high vacuum condition. After collecting the irradiated sample with pure water, we measured the recovery ratio of each compound by using ion exchange or reversed-phase HPLC systems. In some cases, CaF_2 window was used to cut soft X-rays and EUV (referred as to VUV irradiation; cut-off wavelength is ca. 130 nm). Vacuum ultraviolet light at 172 nm from an eximer lamp (Ushio, Japan) was also used to test stability of amino acids and related compounds against VUV irradiation.

Alteration of amino acids and their precursors by high-energy particles. Amino acids, their precursors and nucleic acid bases were irradiated with high-energy heavy ions (*eg.,* carbon ion of 290 MeV/u) at HIMAC BIO, NIRS, Japan. The target molecules were irradiated either in aqueous solution or in dried phase.

Hydrothermal alteration. Aqueous solution of CAW in Pyrex glass tube was heated at 200 – 300°C for 2 hours in an autoclave after pressurized with a gas mixture of hydrogen (1%) and nitrogen (balance).

Analysis of the products. Amino acids were determined by ion-exchange HPLC and/or GC/MS after acid-hydrolysis. Nucleic acid bases were identified by HPLC and LC/MS after or without acid-hydrolysis. XANES spectra were measured at BL-5 of NewSUBARU, University of Hyogo, Japan.

Results and Discussion: *Formation of amino acid precursors and nucleic acid bases.* Wide variety of amino acids was detected in the hydrolysates of CAW, CA and MeAW. Glycine was always predominant among resulting amino acids, whose G-value was as high as 0.4 in the case of CAW. CAW was quite complex organic molecules whose molecular weights were thousands [2]. Several purines and pyrimidines were identified in unhydrolyzed portions of CAW and CA, though their G-values were much less than those of amino acids. It was suggested that amino acids were mainly formed in the forms of complex precursors in ISD environments, while free nucleic acid bases could be formed there.

Alteration of bioorganic compounds with high-energy particles and photons. Amino acid precursors were more stable against soft X-rays than free amino

acids. Water-insoluble products were formed after soft X-rays irradiation. XANES spectra before and after soft X-ray irradiation showed increase of C=C and decrease of C=O in the target molecules. Nucleic acid bases were more stable than amino acids and their precursors against the irradiation. Heavy ions were generally less effective than soft X-rays for decomposition or alteration of the molecules examined.

Suggested scenario of evolution of organic compounds in the proto-solar nebula and in the solar system. Most of meteoritic organics are so-called IOM (insoluble organic matter), and are quite hydrophobic. Cometary dusts sampled in the STARDUST mission were analyzed by XANES: Some of the particles were as hydrophobic as meteoritic organics while some others were much less hydrophobic. Laboratory simulation experiments suggested that ISD organics could be quite hydrophilic. Soft X-rays flax from young sun was much stronger than the present sun. Soft X-rays irradiation from young sun could hydrophobize organic compounds of interstellar origin. Formation of amphiphilic compounds from hydrophilic compounds by soft X-rays irradiation would have been important for the formation of organic structure or aggregates in prior to the generation of the first cell in primitive sea.

Alteration of organic compounds in parent bodies of meteorites. Differences in characteristics of meteoritic and cometary organics might be due to hydrothermal and thermal alteration in parent bodies of meteorites. Preliminary experiments suggested that hydrothermal reactions made organic compounds more hydrophobic. Further experiments are now in progress.

Delivery of extraterrestrial organics to the primitive Earth. It was suggested that more organic carbons were delivered to the early Earth by interplanetary dust particles (IDPs) than by meteorites or comets [3]. A demerit of IDPs for the carriers of extraterrestrial organics is that IDPs are so small that they are directly exposed to solar radiation that might decompose organics. Thus the presence of bioorganics in IDPs is expected, but it is difficult to judge it since IDPs (or micrometeorites) are so small and they have been collected in the terrestrial biosphere. Thus it would be of importance to study possible alteration of IDP organics in space environments, and to collect pristine IDPs out of the terrestrial biosphere. We are planning a novel astrobiology mission named *Tanpopo* by utilizing the Exposed Facility of Japan Experimental Module (JEM/EF) of the International Space Station (ISS). Two types of experiments will be done in the Tanpopo Mission: Capture experiments and exposure experiments [4].

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AQUEOUS ACTIVITY ON CHONDRITE PARENT ASTEROIDS. A. N. Krot[1,2], P. M. Doyle[1,2], K. Nagashima[1], K. Jogo[3], S. Wakita[3], F. J. Ciesla[4], and I. D. Hutcheon[5]. [1]HIGP, U. Hawai'i, USA. [2]U. Hawai'i NASA Astrobiology Institute, USA. [3]Tohoku U., Japan. [4]U. Chicago, USA. [5]Glenn Seaborg Institute, LLNL, USA.

Introduction: Aqueous alteration is a fundamental process in the early solar system that affected most groups of chondritic meteorites. Type 1 and 2 CI, CM, and CR carbonaceous chondrites experienced aqueous alteration at lower temperatures (T < 100°C) and higher water/rock ratios (W/R ~ 0.2–1) than type 3 ordinary (UOC), CO, and CV chondrites (T ~ 100–300°C, W/R ~0.1–0.2) [1]. As a result, these meteorites have different assemblages of aqueously-formed minerals: phyllosilicates (*phyl*), carbonates (*crb*), magnetite (*mgt*), and Fe,Ni-sulfides (*sf*) in CIs, CMs, and COs, and fayalite (*fa*), hedenbergite, andradite, *mgt*, *sf*, and *phyl* in UOCs, COs, and CVs (Figs. 1, 2). Mineralogical observations, isotopic data, and thermodynamic analysis suggest that the alteration resulted from interaction between a rock and an aqueous solution in an asteroidal setting [1,2]. The ages of aqueous alteration [3] and the sources of asteroidal water (inner *vs.* outer solar system) remain poorly-known [4]. In this talk, we will summarize recent results on the mineralogy, petrology, O and Cr-isotope compositions of aqueously formed minerals (*fa*, *crb*, and *mgt*) in UOCs and CCs.

Oxygen-isotope compositions of aqueously-formed minerals: On a three-isotope oxygen diagram, compositions of *fa* and *mgt* in UOCs and CCs measured *in situ* by SIMS, plot along mass-dependent fractionation lines with a slope of ~0.5 and $\Delta^{17}O$ values of +4.5‰ and −1‰, respectively; they are in disequilibrium with chondrule olivines and bulk compositions of their host meteorites (Fig. 3a). Because $\Delta^{17}O$ values of *fa* and *mgt* are equal to $\Delta^{17}O$ of a fluid, we infer that during formation of *mgt* and *fa* the fluid experienced insignificant exchange with ^{16}O-enriched anhydrous silicates. In CMs and CIs, O-isotope compositions of *crb* and *mgt* plot close to the terrestrial fractionation line ($\Delta^{17}O$ ~ ±1.5‰); with increasing degree of aqueous alteration, and the $\Delta^{17}O$ values of *crb* approach those of bulk meteorites. We suggest that $\Delta^{17}O$ values of *fa* and *mgt* in UOCs, CVs, and COs, and *mgt* and *crb* in CIs and CMs, can be used as a proxy for $\Delta^{17}O$ values of water ices that accreted into their parent asteroids. We note, however, that $\Delta^{17}O$ of water prior to the formation of *mgt* and *fa* is not known.

Mn-Cr isotope systematics of fayalite and carbonates. ^{53}Mn-^{53}Cr ages of fayalite formation, anchored to D'Orbigny angrite [9,10] and compared with the U-corrected Pb-Pb age of CV CAIs [11], are 4.6 and 5.1 Myr after CAIs, respectively [12]. These ages are indistinguishable from ^{53}Mn-^{53}Cr ages of calcite and dolomite formation in CI and CM chondrites reported by

[13-15]. These observations indicate that aqueous alteration on several carbonaceous chondrite asteroids occurred nearly contemporaneously.

The CO and CV chondrites define metamorphic sequences of petrologic subtypes between 3.0 and 3.7 with a peak metamorphic temperature of about 600°C [16]. ^{26}Al is the major heating source of asteroids. The initial $^{26}Al/^{27}Al$ ratio in the protoplanetary disk is unknown, but after epoch of CAI formation could have been uniform at ~5×10^{-5} level [17]. Therefore, peak metamorphic temperatures experienced by CV and CO chondrites can be used to constrain accretion ages of their parent asteroids. Numerical modeling of thermal history of the CV and CO-like asteroids with radius of 50 km, water/rock ratio of 0.2, and peak metamorphic temperature of 600°C suggests that these asteroids must have accreted within < 2.6 Myr after CAIs. Fayalite could have precipitated < 5 Myr after CAIs in the outer portions of these asteroids, which have never been heated above 300°C. For a comparison, the inferred accretion ages of the CI and CM parent bodies are 3–4 Myr after CAIs [13,14].

Sources of water in chondrite asteroids: In the CO self-shielding models of [18,19], water ice in the outer disk is highly-enriched in ^{17}O and ^{18}O relative to solids in the inner disk. This is consistent with heavy O-isotope compositions of iron oxides in Acfer 094 reported by [20]. In contrast, the inferred $\Delta^{17}O$ values of the chondrite water ices are close to the terrestrial value, i.e., very different from the suggested $\Delta^{17}O$ values of water ices in the outer Solar System. We conclude that chondrite water ices had a local, inner Solar System origin, which is consistent with the inferred D/H ratio of chondritic water that is different from the isotopically heavy water in the Oort Cloud comets [4].

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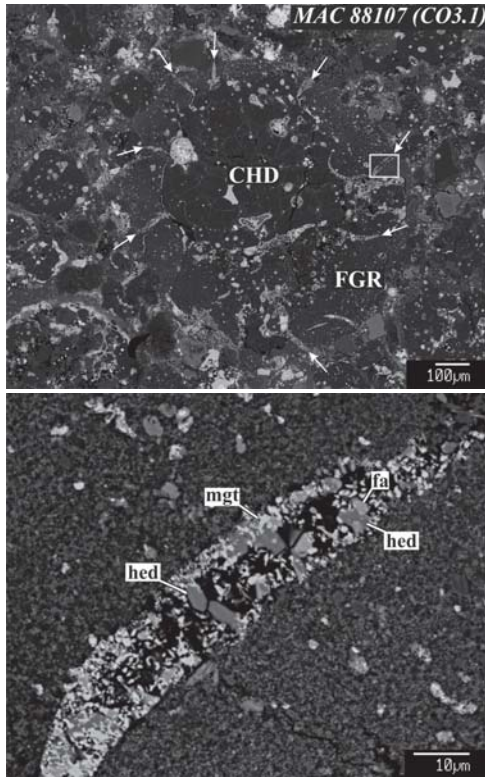
Fig. 1. Fayalite (fa) – magnetite (mgt) - hedenbergite (hed) veins crosscutting fine-grained rim around chondrule in MAC 88107 (CO3.1).
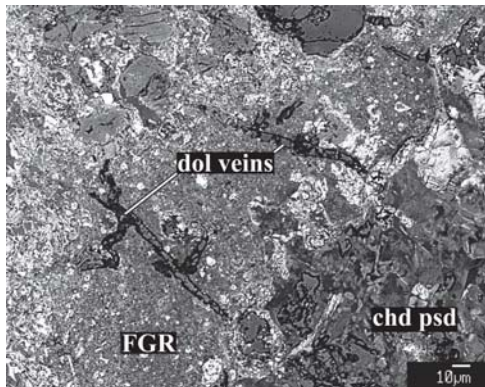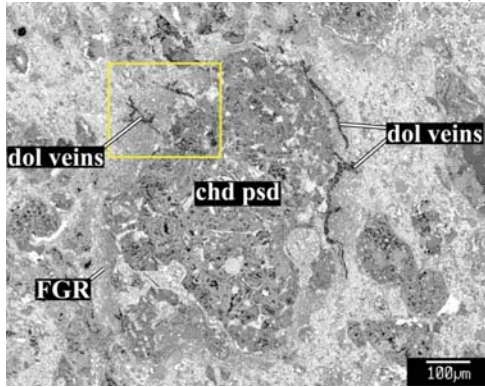
Fig. 2. Dolomite (dol) veins crosscutting fine-grained rim around chondrule pseudomorph (chd psd) in Sutter's Mill (CM2.0).
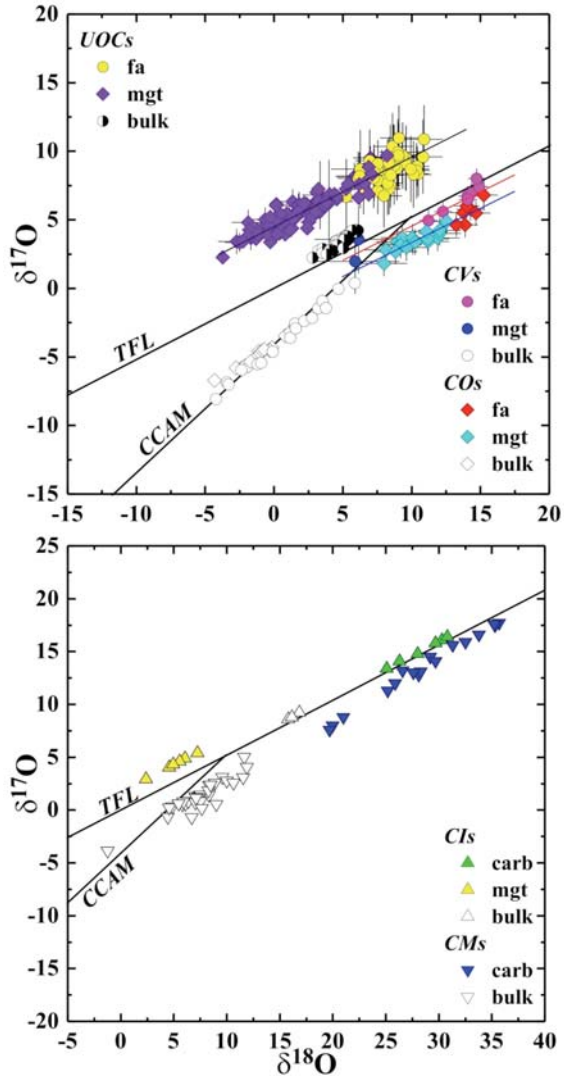
Fig. 3. Whole-rock O-isotope compositions of UOCs and CCs and aqueously-formed fayalite, magnetite, and carbonates in these meteorites (data from [5–8]).
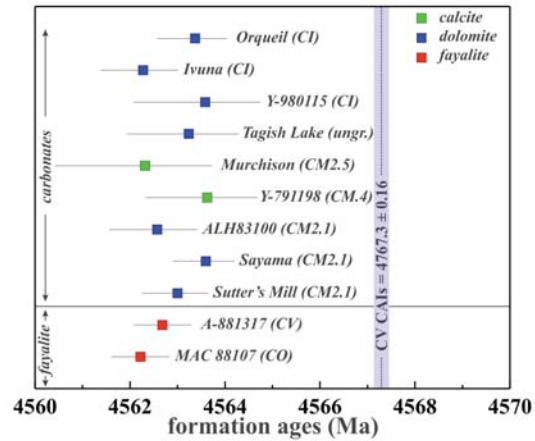
Fig. 4. ^{53}Mn-^{53}Cr relative ages of aqueously formed fayalite, calcite and dolomite in CI, CM, CO, and CV chondrites (data from [12–14]).

HAYABUSA ASTEROID SAMPLE RETURN MISSION

H. Kuninaka and Hayabusa 2 Project, JSPEC/JAXA, Yoshinodai Chuo Sagamihara Kanagawa JAPAN

Hayabusa asteroid explorer was launched by M-V rocket on May 9th 2003. It cruised in deep space using the novel ion engines and arrived at the asteroid Itokawa on September 12th 2005. Hayabusa executed the scientific observation staying around the asteroid in September and October 2005. And in November it succeeded twice touchdowns on it. Just after the lift-off so many troubles damaged the spacecraft. Innovative and dedicative engineering efforts solved these malfunctions and made Hayabusa on the return way to Earth. It dropped a reentry capsule to Earth and disappeared in the atmosphere above Woomera Australia on June 13th 2013. The reentry capsule was successfully retrieved and transported to the ISAS curation center. A lot of particles originated from Itokawa were found in the canister and devoted to precision scientific analysis to resolve the solar science.

Figure 1 shows the progress on resolution to observe asteroids. The telescopes indicate an asteroid as a luminous point. The ground radar may show dim image on an asteroid. Hayabusa brought us lot of complete images on Itokawa with meter-class resolution at the moment of rendezvous. At instant of landing it reveled the surface configuration as rubble pile structure with millimeter-class resolution. At the complete of Earth return the asteroid material showed itself in the microscope with micrometer-class resolution. And they are now devoted to the electron microscope, X-ray tomography isotope analysis and so on. The observation resolution has reached angstroms. This is the newest observation technique "Asteroid Sample Return" to elucidate the nature of the universe.

Hayabusa 2 space mission is under development using the design philosophy and heritage succeeded from Hayabusa mission for the purposes of investigating the C-type asteroid by in-situ observations and the sample return techniques and realizing the space system with robustness and reliability. The spacecraft of 600 kg aims to retrieve surface material of the asteroid 1999JU3 to Earth as a final goal. Its artist image under the powered flight by ion engines in deep space toward an asteroid is seen in Fig. 2. The near-infrared spectrometer, the thermal infrared camera, the wide/telescope cameras and the laser altitude meter will play important roles on remote sensing at the rendezvous phase. Especially the former two devices are turned to C-type asteroid in order to detect hydrate mineral. Four separation robots will challenge tangible observations. Material sampling in several opportunities will be performed using the sampling mechanism, the target makers, the flash the laser range finders and

the navigation camera. A copper bullet of the impacting device accelerated by pyrotechnics will make a new crater, which moment will be observed by the deployment camera. Flesh material scattered from inside around the new crater will be collected. At the final moment the reentry capsule will dive from the heliocentric space into Earth atmosphere and bring us the asteroid samples. In the present plan it will be launched by H-2A rocket in 2014, arrive at 1999JU3 in 2018, and return to Earth in 2020.

Figure 3 shows the assembled spacecraft and the staff members of Hayabusa 2 project, who are very able, active and reliable. Hayabusa 2 space mission will open not only the era of space exploration but also the interdisciplinary science.
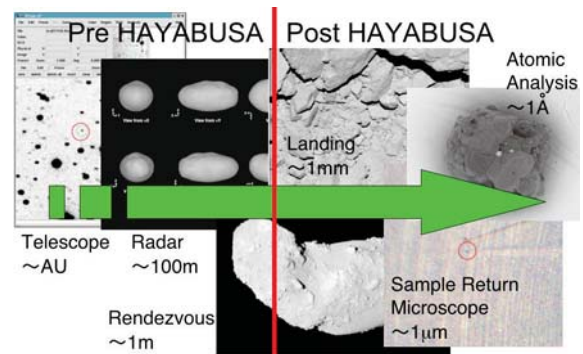
Fig.1 Progress on resolution for asteroid observation.

Fig.2 Artist image of Hayabusa 2 cruising.

Fig. 3 Hayabusa 2 spacecraft and project members.

NEAR-INFRARED CIRCULAR POLARIMETRY: IMPLICATION FOR ASTROBIOLOGY. J. Kwon[1] and

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Magnetic fields have been thought for many years to play a crucial role in regulating accretion onto protostars, both in powering and shaping outflows and removing angular momentum from disk material. However, the precise role of the magnetic field is poorly understood and evidence for the shape and structure of the magnetic fields near the outflow regions has been difficult to obtain, although polarimetry is a technique that can certainly help. In this presentation, we show results from deep imaging linear and circular polarimetry of the NGC 6334 massive star-formation complex [1]. These observations show high degrees of circular polarization (CP), as much as 22%, ever observed. The CP has an asymmetric positive/negative pattern and is very extended (˜80" or 0.65 pc). Both the high CP and its extended size are larger than those seen in the Orion CP region [2]. By using 3-D Monte Carlo light-scattering models, we present the origin of high CP: the high CP may be produced by scattering from the infrared nebula followed by dust grains aligned with the magnetic field (dichroic extinction). Our results show not only the magnetic field orientation of around young stellar objects, but also the structure of circumstellar matter. This is the second case to support the large CP in scattering protostellar nebulae as a possible explanation for the extraterrestrial origin of homochirality of life on Earth. In addition, we present our first CP survey results in star forming regions, also supporting the extraterrestrial origin. We have found that (1) the CP is ubiquitous in star forming regions, (2) the CP degrees are very high (>~20 %) in massive star forming regions, (3) the CP extent is extensive (~0.1 pc) in massive star forming regions, (4) there is a clear trend between the CP degrees and the masses of young stellar stellar objects, (5) the dichroic polarization of scattered light is most likely the origin of large CP, and (6) these may support the CP in star forming regions as an origin of the biological homochirality on Earth, as proposed for the Orion nebular.

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From Origin of life to systematization of Astrobiology

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Abstract: Our proposed research, "Origin and evolution of life", which is one of the biggest mysteries in science, was adopted under WPI (World Premier International Research Center Initiative) project in 2012, and Earth-Life Science Institute (ELSI) was newly established.

Our final goal is synthesis of life in laboratory. Since the experiment by Miller (1953), numerous kinds of experiments have been conducted; however, life could not be synthesized. The point is reproduction of primordial surface environment on Earth where first life was born. Another key is the presence of three components such as ocean, atmosphere, and landmass (called "Habitable Trinity") under the driving force, Sun.

Present biology is accumulated on researches of Earth life. Therefore it is not a universal biology applicable to whole Universe, but biology only applicable to Earth. To systematize Astrobiology, how we do it? I will introduce how to make it.

For successful multi-disciplinary research, each researcher needs to recognize self-implementation of multi-disciplinary research. It means an astronomer must write a paper of biology, and vice versa, which requires preparedness and courage. This is critical condition to be met by multi-disciplinary researchers.

Comet impacts as a driving force of glycine oligomerization.

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Introduction: Abiotic peptide synthesis is a key step in the chemical evolution that led to the emergence of life. Peptides are not only building blocks of life but probably also played an important role as a catalyst to form biomolecules on the primitive Earth. Several studies have proposed plausible energy sources for abiotic peptide synthesis on the early Earth, such as heating by volcanic activity [1] and ultraviolet radiation [2]. An alternative approach has been to examine peptide synthesis using condensation reagents [3] or from other starting materials such as amino acid amides [4].

In this study, we examine the process of comet collision as a source of peptides on the early Earth. Comets are known to contain abundant organic materials including amino acids [5] and impact shock can cause reactions that transform these simple organic materials into more complicated ones [6]. These features suggest the formation of peptides could be associated with comet impact shocks [7]. However, this process has been largely overlooked in previous literature concerning peptide synthesis on the early Earth.

Here we report the results of shock experiments using frozen mixture of glycine, water ice, and silicate at cryogenic conditions that successfully reproduce the conditions in comet impacts.

Experimental: We used a mixture of glycine, water ice, and olivine as a starting material. Glycine is one of protein amino acids and abundant in carbonaceous chondrites. The mixing ratio was amino acid/water ice/olivine = 0.1/0.8/1.0 (wt/wt/wt). A container carrying the starting material was placed in liquid nitrogen (77 K) and subjected to shock using a vertical propellant gun. After shocked samples were recovered from containers, peptides were extracted from the samples and separated into a linear peptide (dipeptides and tripeptides) fraction and a cyclic peptide (diketopiperazines) fraction using a cation exchange column. After derivatization, the samples were analyzed by gas chromatograph-mass spectrometer.

Results and Discussions: Diglycine, triglycine, and glycine-diketopiperazine were identified in the shocked glycine samples by comparison of their retention times and mass fragmental patterns with those of purchased standard materials. No peptide was detected in shocked samples below 4.8 GPa, indicating that the detected peptides were not contaminated during the experimental process. The yields of diglycine and triglycine show an initial increase with increasing shock shock pressure up to values of 3% and 0.3%, respectively, at 20.6 GPa. This increase is followed by a decline to 1% and 0.2% at 26.3 GPa. The yield of glycine-diketopiperazine increases with increasing shock pressure up to a value of 0.1% at 26.3 GPa.

The yields of linear peptides were higher than those of cyclic peptide in the pressure range of this study. The formation of linear peptides is extremely important to produce long chains promoting chemical evolution. In contrast, the formation of cyclic peptides retards further growth of peptide chains due to their lower reactivity [8]. Where peptides are formed by intermolecular condensation, the formation of linear peptides is thermodynamically less favored compared to cyclic peptides [9]. Thus, heating solutions of amino acids leads to the synthesis of large amounts of cyclic diketopiperazines [1]. In contrast, shock reactions of glycine in cryogenic conditions disfavor intramolecular condensation and lead to preferential synthesis of linear peptides that can combine to form more complex organic compounds. This result of our study is in contrast with the result of shock experiments on aqueous amino acids at room temperature by Blank *et al*. (2001) [7]. They reported that the amount of synthesized cyclic peptides was comparable to that of linear peptides. Thus, the cryogenic condition at impact shock might be a key for the predominant synthesis of linear peptides.

Our study suggests that comet impacts can readily account for the oligomerization of glycine to form the precursors of life on the early Earth. Furthermore, since comet impacts are ubiquitous phenomenon in the solar system, they probably play an important role in organic chemical evolution on other extraterrestrial bodies, especially icy satellites.

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Exposure experiments of organic compounds on the JEM, ISS, in the TANPOPO mission.

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Introduction: The Tanpopo mission is a Japanese astrobiological experiment which will be conducted on the Japanese Experiment Module (JEM) of the International Space Station (ISS). The Tanpopo mission consists of six subthemes: 1) capture of microbes in space, 2) exposure of microbes in space, 3) exposure of organic compounds in space, 4) capture of organic compounds in micrometeoroids in space, 5) evaluation of ultra low-density aerogel developed for the Tanpopo mission, and 6) capture of space debris at the ISS orbit (approximately 400 km altitude).

Here, we overview the exposure experiment of organic compound in space environment (Subtheme 3). Since many kinds of organic compounds, especially, amino acids which are ones of most important organic compounds in living organisms, are found from extraterrestrial materials, extraterrestrial and outer-solar environments are thought as the place for the prebiotic organic compound synthesis. Then, it is proposed that the first organisms on the earth was born from the prebiotic organic compounds delivered from extraterrestrail environments into the early earth on meteorites, micrometeorites and/or comets. In order to discuss the possibility of this hypothesis, alteration of prebiotic compounds in space environments should be clear. Therefore, we will expose some prebiotic organic compounds on the exposure facility at ISS-JEM.

Exposure sample: Glycine, isovaline, hydantoin, ethylmethylhydantoin and complex organics (CAW) are chosen for the exposure. Glycine is the most primitive and common amino acid detected from meteorites and isovaline is a relatively abundant non-protein amino acid whose chirality in meteorites were nonracemic. Since free amino acids were rare in meteorites, amino acids detected from meteorites were existed as their precursors. There are two plausible amino acids precursors; low molecular weight precursors and high molecular weight ones. Hydantoin and ethylmethylhydantoin are ones of plausible low molecular weight precursors for glycine and isovaline, respectively. CAW which is a simulated material of interstellar medium prepared by proton radiation into mixture of CO, NH_3 and H_2O is a high molecular weight precursors for amino acids, and is a complex organics that means a dificult to identified its chemical structure.

Simulation experiments: In the space environments, uv-light and cosmic rays (heavy ions and γ-ray) will cause the alteration of organic compounds. Therefore, simulation experiments were studied using Xe-excimer lamp (uv 172 nm), synchrotron radiation at NewSUBARU BL06 (uv > 130 nm), ^{60}Co γ-ray radiation (Ouantum Beam, JAEA) and carbon ion beam (290MeV, NIRS). γ-Ray and heavy ion beam irradiation with dose of ISS environment for one year induced little decomposition of organic compounds. However, uv irradiation was critical for organic compounds. Although almost all glycine and isovaline would be decomposed, approximately 29 % and 72% of hydantoin and ehtylmethyl hydantoin, respectively, would remain after one year uv irradiation at ISS environment. Furthermore, 36% of CAW would remain after one year uv irradiation at the environment. In those experiments, free amino acids would be difficult sto survive in space environments, and amino acids precursors were more stable than free amino acids. Therefore, extraterrestrial amino acids precursors would be effective source for origins of life on the earth.

Experimental design: In order to demonstrate above conclusions on the ISS-JEM, five compounds will put into the holes on the small aluminum plates. The plates covered with MgF or quartz windows will expose into space at ISS orbit for one to three years.

Peptide formation in space environment: In addition, Nakagawa and his colleagues were found that dialanine was formed from alanine films by uv-irradiation. Then, we will demonstrate a peptide synthesis with uv-irradiation in the space environment. This experiments will show the possibility of peptide formation in space.

EVOLUTION AND ADAPTATION OF THE RNA COUPLED WITH AN ARTIFICIAL LIFE-LIKE SELF-REPLICATION SYSTEM TO A SEVERE TRANSLATIONAL ENVIRONMENT

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Introduction: To understand how the early life appeared and started evolving by overcoming various difficulties, many groups are attempting to construct artificial life-like components or systems early life could have from nonliving molecules [1][2]. In our laboratory, we have created in vitro translation-coupled RNA self-replication system which can allow Darwinian evolution by means of one artificial RNA and some chemical components [3]. Self-replication and Darwinian evolution is considered one of the key characteristics that must have been necessary for early life-like system to flourish as life [4].

In our system, the RNA encodes the replicase protein (RNA-dependent RNA polymerase) so that once the RNA is translated and replicase is synthesized, it replicates the original (plus) RNA and produce the complementary (minus) RNA. Then the minus RNA is replicated to produce the plus RNA in the same way. In this system, the RNA exhibits the ability of Darwinian evolution if encapsulated into a small compartment [3].

However, to obtain the knowledge about far earlier life, there is still a matter to be solved. Although this simple system enables efficient gene self-replication, it occurs only in a particular optimized environment in which the translation and following replicase synthesis well occurs. And it is doubtful that the translation in the early era could have functioned efficiently like our system because of its complicated reaction sets. Therefore the next step is making this system well function in the severer translational environment. Hence, we made the translational environment hostile (by decreasing in the concentration of the pivotal factor, ribosome), and then tried to make RNA adapt to that severer condition through Darwinian evolution by the repetitive self-replication reactions described above.

Results: Through experimental Darwinian evolution coupled with life-like self-replication system, some mutations have been spontaneously introduced into the RNA by replication error, and the highly adapted one has been condensed. As a result, we obtained a variant RNA which self-replicates completely (plus RNA to minus RNA to plus RNA) with more than 10-fold efficiency comparing to the original RNA at the harsh, lower ribosome condition. This adaptation mainly seems to result from increasing in the translation efficiency by changing the RNA secondary structure of the specific site to stimulate the easier interactions between the RNA and translation factors.

On the other hand, there were also some detrimental effects. We observed the trade-off between the increase in the translation efficiency and the decrease in the template activity (how easily the RNA is replicated by replicase). Also, the variant RNA no longer well self-replicates in the original higher ribosome environment.

Discussion: This time, we examined whether RNA coupled with artificial life-like self-replication system evolved, adapted and thereby well functioned in the severer translational environment, and we found that the RNA actually adapted to the new environment. This result demonstrates the evolutional capacity of our self-replication system and how powerful and robust the capability of evolution and self-replication is. Through this evolution, we also confronted with the trade-off between the translation and the replication, both of which are central features for life. Although we did not know the precise mechanism of this effect, this may result from the fact that both the translation and the replication concurrently occur on the same RNA in the opposite direction [5]. What ways improve this effect and allow further evolution may be the switching mechanism between those two phenomena [5] or the non-canonical translation [6], as seen in some viruses.

Our result offers various interpretations about life in terms of evolution and adaptation. Of course the environment we constructed may not reflect the specific one that led to the evolution of early life, but it is to provide useful knowledge to uncover plausible pathways and scenarios [4].

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Technological challenges for the advanced study of deep subseafloor life.
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Introduction: During the past decades, scientific ocean drilling has explored the subseafloor biosphere at some representative drilling sites: on the ocean margins, organic-rich anaerobic sedimentary habitats (e.g., Shimokita coalbeds) harbor sizable numbers of microbial cells at least over 1,000 meters below the seafloor whereas microbial populations in ultra-oligotrophic aerobic sedimentary habitats of the oceanic gyre (e.g., South Pacific Gyre) are several orders of magnitude lower. Previous molecular ecological studies have demonstrated that microbial communities in deep sedimenary habitats consist largely of phylogenetically diverse microbes, which are distinct from previously known isolates. Hence the metabolic functions of individual microbial components, as well as the strategy for long-term survival under the energetically and geophysically severe condition, have remained largely unknown. To tackle these significant questions, technological development for the advanced microbiological and biogeochemical analyses is of our essential challenges.

Discriminative detection of microbial cells: One of the most fundamentally significant techniques is the precise detection and enumeration of indigenous subseafloor life. We established a highly efficient and discriminative detection and enumeration technique for microbial life in sediments using automated image analysis after staining microbial cells with DNA specific dye SYBR Green I (SYBR-I)[1]. Acid wash treatment of sediment slurry with hydrofluoric acid significantly reduced non-biological fluorescent signals and enhanced the efficiency of cell detachment from the sediment particles. We found that cell-derived SYBR-I signals can be distinguished from non-biological backgrounds by dividing green fluorescence (band-pass filter: 528/38 nm [center-wavelength/bandwidth]) by red (617/73 nm) on images. A newly developed automated microscope system could take a wide range of high-resolution image in a short time, and subsequently enumerate the absolute number of cell-derived signals by the image calculation [2].

Quantitative cell separation and combination with flow cytometry: The methodological constrain on cell detection and enumeration is the limitation of sediment amount that can be placed on observation membrane for microscope. One of the clues to solve this problem is to separate microbial cells from geological matrix. We have standardized an improved cell separation method, which effectively detached the cells from mineral grains of the sedimentary habitat, by applying multiple density gradient layers [3]. Similar to the microscopic detection, we could discriminatively recognize cell-derived fluorescence, and the separated cells can be enumerated without a significant deviation between automated fluorescent microscopic system and flow cytometry.

The combined use of these new techniques allows us to separate the cells for single cell genomics and secondary ion mass spectrometry (e.g., an ion imaging by NanoSIMS ion microprobe). We also established clean sample prepration procedures, which are capable of very low biomass sample down to 10^1~10^2 cells cm^{-3}. The systematic analytical scheme currently applies to some representative deep-biosphere samples such as the South Pacific Gyre and Shimokita coalbeds (i.e., IODP Expeditions 329 and 337, respectively).

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Toward Detections and Characterization of Habitable Transiting Exoplanets. Norio Narita[1], [1]National Astronomical Observatory of Japan (2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan).

The *Kepler* mission [1] led by NASA has discovered dozens of possible habitable exoplanets by the transit survey method. The transit survey method monitors brightness of hundreds of thousands of stars to detect a periodic slight dimming which is caused by a transit of a planet in front of a host star. The *Kepler* has demonstrated that habitable exoplanets indeed exist around other stars than the Sun.

A big problem for *Kepler*'s candidates of habitable transiting exoplanets is their host stars are far away, say over 1000 light years. It is difficult to characterize such distant exoplanets with the current telescopes or even with next generation extremely large telescopes (ELTs). Thus the next step for astronomical studies of habitable exoplanets is to detect such planets around the Solar neighborhood, say within 100 light years from the Sun.

The next breakthrough for detections of habitable transiting exoplanets will come from the Transiting Exoplanet Survey Satellite (TESS) mission [2] led by MIT/NASA, which is expected to be launched in 2017. The TESS will search for nearby transiting exoplanets in almost the whole sky for 2 years.

Thus a time for observations to characterize habitable transiting exoplanets will come in 2020s. For transiting exoplanets, it is known that one can observe their atmospheres by transmission spectroscopy.

Transmission spectroscopy can be done using some observing methods, including multi-colar photometry, multi-object spectroscopy, and high dispersion spectroscopy. The multi-color photometry and multi-object spectroscopy methods can characterize wavelength dependence of transit depths for transiting exoplanets, and can reveal whether the planetary atmosphere is dominated by primitive compositions (hydrogen dominated) or not, and possible presence of clouds or haze. While the high dispersion spectroscopy method may be able to detect alkali metal lines (e.g., Na and K) and molecular lines (e.g., H_2O, CH_4, CO, CO_2, O_2). Those observations will reveal characteristics of habitable transiting exoplanets in the future.

In this talk, I will present such prospects of future detections and characterization of habitable transiting exoplanets.

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CAN TERRESTRIAL MICROBES GROW ON MARS? W. L. Nicholson, Dept. of Microbiology & Cell Science, University of Florida, Space Life Sciences Laboratory, 505 Odyssey Way, Merritt Island, FL USA 32953. E-mail: WLN@ufl.edu.

Introduction: A central goal of Astrobiology is to explore the limits at which life can occur and to search for life and habitable locations outside Earth. Mars is currently an active target in the search for life due to its relative proximity and similarity to Earth, coupled with increasing evidence pointing to the past and present existence of liquid water at the surface and near subsurface [1]. Exchange of rocky impact ejecta between Mars and Earth has been known for at least two decades [2], and evidence has accumulated supporting the hypothesis that living microorganisms embedded in rocks could survive the transfer process [3]. Understanding the ability of terrestrial microorganisms to grow in the near-surface martian environment is of prime importance both for life detection and for protection of Mars from forward contamination by human or robotic exploration [4].

The surface environment of Mars presents formidable challenges to life, such as: harsh solar radiation; a scarcity of liquid water and nutrients; extreme low temperatures; and a low-pressure, CO_2-dominated anoxic atmosphere [5]. Recent work in our laboratory has concentrated on investigating the possibility that prokaryotes from Earth could either (i) live on Mars in their current form, or (ii) evolve the ability to live under Mars conditions. Our experiments have involved environmental chambers that can simulate Mars atmospheric conditions of low pressure (P; 0.7 kPa), temperature (T; 0˚C), and a CO_2-dominated anoxic atmosphere (A), called here collectively low-PTA conditions.

Growth of permafrost bacteria under low-PTA conditions: Because much of the water on present-day Mars exists in a permanently frozen state mixed with mineral matrix, terrestrial permafrosts are considered to be analogs of the martian environment [6]. We therefore screened Siberian permafrost soils for microbes capable of growing under low-PTA conditions. Using this approach we reported the isolation of 6 *Carnobacterium* spp. isolates from Siberian permafrost that were capable of low-PTA growth [7]. In addition, a laboratory strain of *Serratia liquefaciens* was also found to grow under low-PTA conditions [8].

Evolution of *Bacillus subtilis* to growth at low-P: Previous work had indicated that most bacteria, including the common laboratory strain of *B. subtilis*, were unable to grow at pressures lower than ~2.5 kPa [9]. To investigate if *B. subtilis* could evolve the ability to grow at low-P, we cultivated strain WN624 at the near-inhibitory pressure of 5 kPa for 1,000 generations, and isolated a low-P adapted strain designated WN1106 [10]. In competition experiments the low-P adapted strain showed higher relative fitness than the ancestor at 5 kPa, but not at normal Earth pressure (~101 kPa) [10]. Transcription microarray analyses indicated that exposure to low-P induced both the *sigB*-mediated General Stress Response and the anaerobic response in both the ancestral and low-P adapted strains [11]. Whole genome sequencing revealed that low-P adapted strain WN1106 had accumulated 12 mutations not present in the ancestral strain. The significance of these mutations to low-P adaptation in *B. subtilis* is currently being explored.

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FLUORESCENT DYE HANDLING SYSTEM FOR MELOS1 LIFE DETECTION MICROSCOPE M.

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Introduction: Unlike other missions [1], one of the goals of the MELOS1 mission is to find life directly on Mars. To fulfill this purpose, observation of potentially existing cell images will be performed using a microscope. To distinguish 1 micro-m sized cells from sand particles, fluorescent dyes are planned to be used together with an excellent fluorescent microscope. Use of different types of dyes that can stain nucleic acid, cell membrane, or protein-like molecules will be used. Detection of a wide variety of organic compounds would be able using the same method.To operate unmanned microscopic observation on Mars, one bottleneck would be the handling of dye solution. Concerning the temperature and pressure on Mars, choice of dye solvent and the way of its supply to the collected sample sand should be carefully performed. Here we report the method of dye solution supply onto the sampled sands. Effect of material property (wettability) on solution dropping will also be reported.

Solvent for dyes: Ethyleneglycol and methanol are widely used material to promote antifreezing property of a water-based solution. As measurement of enzymatic activity is planned in MELOS1 mission, they are not suitable because they might cause denaturation of some proteins. Choice of biochemically friendly materials was selected.
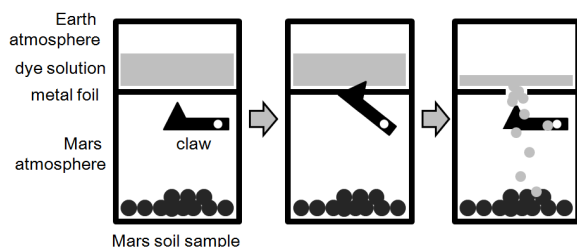
Fig. 1 Schematic illustration of dye solution handling method..

Dye solution handling method: After sampling the Mars sample sands by the use of robot arm of the rover, sample cuvette will be sealed. The cuvette will then separated by the metal foil with the dye solution-capsule that contains Earth atmosphere (100 kPa). A claw will rip the foil and the solution will drop over the sampled sands (Fig. 1). Drop behavior of the solution depends on the foil wettability, surface tention of the solution, thickness of the solution, of the pressure difference between the two spaces.
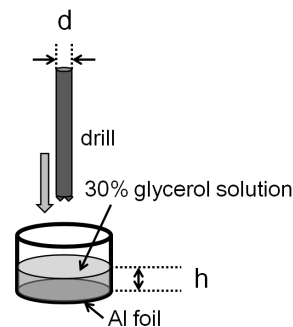
Fig. 2 Experimental setup   Fig. 3 Microscope
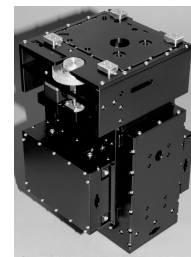
Experiment: As a first step, we examined the effect of foil wettability and the hole size on the drop behavior. A cuvette with an Al foil at the bottom that contained a 30% glycerol solution of fixed thickness was used (Fig. 2). Drills with different diameter were used to make a hole into the foil. Al foil was used with and without the boehmite treatment [2]. As a result, behavior of the 30% glycerol solution was almost the same with water. Boehmite treatment worked effectively from the solution dropiing viewpoint. Together with the behavior of water on aluminum surface under a reduced pressure [3], an optimal method for the dye handling will be discussed.   Design and performance of a newly designed microscope system (Fig. 3) will also be reported.

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Discovery of Absorption Features of CH$_3$NH$_2$ towards SgrB2(M)

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Abstract

There is a wide agreement that complex organic molecules (COMs), such as amino acids, are crucial material for life. There has been a hot debate where such COMs were formed, on the Earth or in the Universe. Ehrenfreund et al. (2002) suggested that exogenous delivery of COMs to the primitive Earth would be much larger by three orders of magnitude than terrestrial formation of COMs. Thus it would be crucial to study what and how much COMs exist in star and planet forming regions.
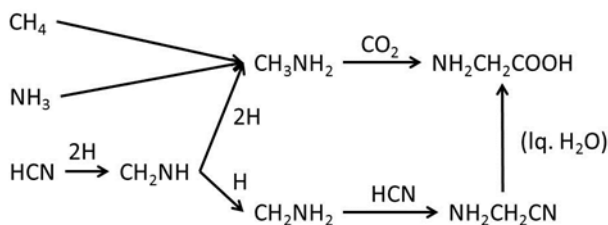
Figure 1. Possible Formation Paths to Glycine

Methyl amine (CH$_3$NH$_2$) has been proposed as a precursor to glycine through reaction with CO$_2$ under UV irradiation (Holtom et al. 2005; Kim & Kaiser, 2011). Bases on such laboratory studies it is possible to assume possible formation paths from simple and rich molecular species (CH$_4$, NH$_3$, CO$_2$ and HCN) to glycine (Figure 1).

Since there are a very small number of studies on interstellar CH$_3$NH$_2$ since its detection by Kaifu et al. (1974), we conducted survey observations of CH$_3$NH$_2$ towards several star-forming regions by using the Nobeyama 45m radio telescope in April 2013. During this survey we discovered three low-energy CH$_3$NH$_2$ lines in clear absorption against the radio continuum emission towards SgrB2(M). An example spectrum is shown in Figure 2. Our detection may suggest that CH$_3$NH$_2$ would be widely distributed even in cold molecular clouds.
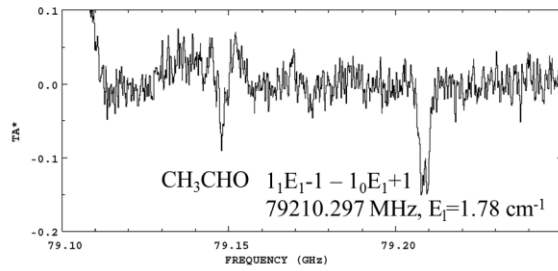
Figure 2. Example of absorption line of
CH_3NH_2 towards SgrB2(M)

In the workshop, we will report details on the detected features and comparison results with simulations by using a chemical reaction model.

Key word: Origin of Life; Methyl amine; Glycine formation; Precursor to Glycine

Search for Habitable Planets Around Low-Mass Stars Using the InfraRed Doppler Instrument
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Detecting low-mass planets in the habitable zone around low-mass stars is one of the milestones to understand the habitable planets outside the solar system. Several new planet search programs will thus start in the near future to search for low-mass planets around low-mass stars (e.g. CARMENES, SPIRou, TESS).

Now, we are also planning a Doppler (radial velocity, RV) exoplanet survey of low-mass stars by using a new near-infrared instrument, the InfraRed Doppler instrument (IRD) to be installed to the Subaru 8.2m telescope in 2014. Aims of the survey are to find Earth-mass planets in the habitable zone and uncover the statistical properties of the planetary systems around low-mass stars. Observation targets of the RV survey are about 300 M dwarf stars that have masses with 0.1-0.6 times solar masses and a flux peak in the near-infrared wavelength region. IRD is an exoplanet hunting instrument with a laser frequency comb and a near infrared high-resolution spectrograph, and suitable for the search for low-mass planets around M dwarfs. The RV measurements of M dwarfs with IRD would active the high precision of about 1 m/s by producing extremely stable references for accurate wavelength calibration by using the laser frequency comb. Therefore, we expect to detect a few Earth-mass planets in habitable zone and some rocky planets in close-in orbits around low-mass stars (Figure1). In the IRD project, we also have plans to perform the photometric (Transit) and spectroscopic (RV) follow-up observations of planet candidates detected by IRD using Japanese facilities.

In this presentation, we introduce the IRD and the Doppler exoplanet surveys of low-mass stars, and discuss observational strategies and the expected results of the IRD project.

Figure 1: Detectability of planets (Contour, simulation) for the IRD survey and results of population synthesis (Dots, Y. Hori et al. 2013). In an observation strategy, we would expect to detect some Earth-mass rocky planets around very low-mass stars by the IRD survey.
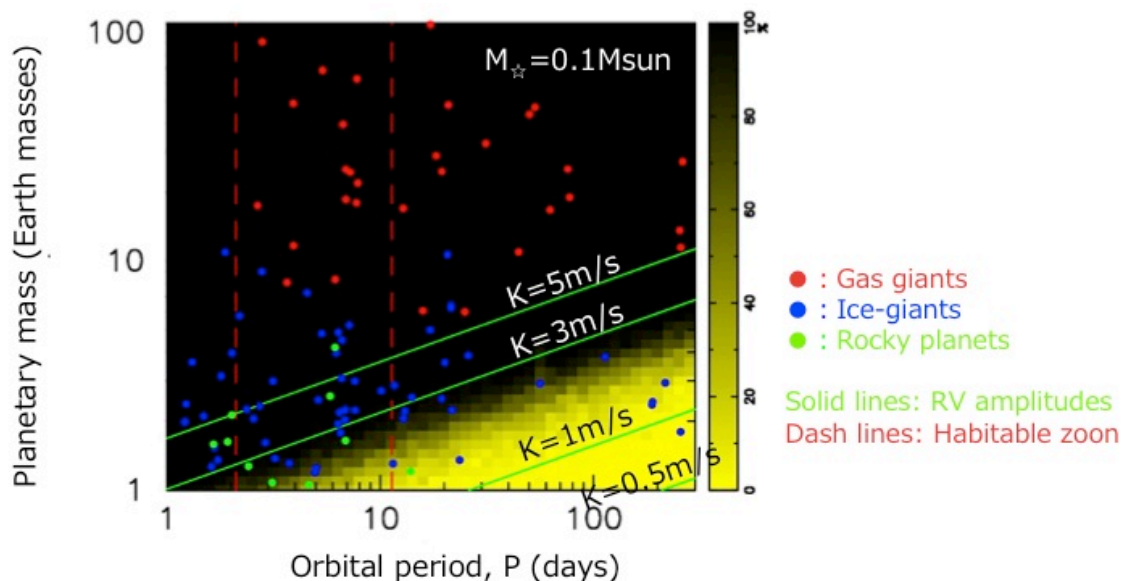
PUZZLES OF BIOCHEMISTRY OF EXTRATERRESTRIAL LIFE.   Tairo Oshima, Institute of Environmental Microbiology, Kyowa-kako Co., Machida, Tokyo 194-0035, Japan; tairo.oshima@kyowa-kako.co.jp

Biochemical Exclusion Principle: Chemical structures of biological molecules are strictly restricted by "biological exclusion principles". The author would like to discuss whether or not the exclusion principle can also be applied on biochemistry and molecular biology of extraterrestrial life.

Magic 20: Amino acids incorporated into proteins during translation processes are limited to 20 amino acids. This set of amino acids is often called "magic 20" (This term is originally used by Crick in the late 50'). Proteins in terrestrial organisms consist of many different amino acids in addition to the members of magic 20 due to post translational modifications (one example is hydroxyproline residues in collagens which were converted form proline residues by post translational modifications), and in exceptional cases other amino acids than the members of magic 20 are directly coded by mRNA; one example is selenosystein in formate dehydrogenase. When, how and why the members of magic 20 are selected is fundamental enigma. Members of magic 20 are alpha-amino acids; gamma aminobutyric acid is an important amino acid in brain function, but not the member of magic 20. Amino acids which possess straight hydrocarbon chain, such as normal-leucine are excluded, but no rational explanation has been presented so far. It seems that the members of magic 20 are determined by chance or impulse or whim rather than by necessity or reason. Functional protein can be produced omitting some amino acids from magic 20; one example is proteins produced by aerobic thermophiles. Often enzyme proteins produced by extreme thermophiles lack cystein (a member of magic 20) since cystein residue is unstable under high temperatures. Extraterrestrial organisms may use a different set of amino acids to make proteins.

Nucleic Acids: Our DNA and RNA consist of D-ribose (or its derivatives), four nucleic acid bases and phosphate. Again no rational explanations have been given for fundamental questions such as why ribose and phosphate are chosen. Why 4 bases? As a coding language, binary system may be better than quaternary like in our computers. Extraterrestrial life may use binary as genetic language. It seems that the most rational genetic system is binary consisting of adenosine and inosine; This idea was also proposed by Crick long time ago.

Chirality: The members of magic 20 are L-amino acids, and deoxyribose used in DNA and ribose used in RNA are D-sugars. Origin of the chirality of biological molecules is another fundamental enigma in biochemistry of terrestrial life. In this context, another serious puzzle is chirality of membrane lipids; glycerol moiety of major membrane lipids of domain Archaea is d-form whereas Bacteria and Eukarya use l-form glycerol residues.

OVERVIEW OF JAPAN'S MELOS1 MARS MISSION: MARS EXPLORATION FOR LIFE/ORGANISM SEARCH. T. Satoh[1], T. Kubota, K. Fujita, T. Okada, T. Iwata, T. Imamura, A. Oyama, N. Ogawa, K. Yamada (Japan Aerospace Exploration Agency), H. Miyamoto (University of Tokyo), A. Yamagishi (Tokyo University of Life and Pharmacy), G. Komatsu (IRSPS), T. Usui (Tokyo Institute of Technology), G. L. Hashimoto (Okayama University), H. Demura (Aizu University), H. Senshu (Chiba Institute of Technology), S. Sasaki (Osaka University), and G. Ishigami (Keio University). [1]ISAS/JAXA, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa 252-5210, Japan (satoh@stp.isas.jaxa.jp).

Introduction: Mars is an attractive object for explorations (scientific, robotic, or human in coming decades). Japan had a Mars exploration mission, NOZOMI (launched 1998), of which primary scientific objectives was escaping atmosphere from Mars. NOZOMI was unsuccessful (sad to say) and we did not have a chance to visit the red planet since then. After having our first Venus mission, AKATSUKI (launched 2010), there have been planning activities for "next" Mars missions. Through intensive discussion among researches of various areas, we have recently reached a conclusion about the aim of our MELOS1 mission [1]. It is "Life/Organism Search" which can be compared to what Americans or Europeans will do in upcoming missions (ESA's ExoMars [2] or NASA's Mars2020 [3]). "MELOS" in MELOS1 is an acronym of "Mars Exploration for Life/Organism Search".

When and How: ESA will launch a series of ExoMars missions: an orbiter in 2016 and a rover in 2018. NASA, on the other hand, will search for signs of "past" lives with a rover, Mars 2020, build based on successful (in engineering aspects, at least) Curiosity rover [4]. Because the area of Mars is about the same as the earth's continents, too wide to cover with just a handful of landing probes, it is necessary that as many places as possible should be visited via international collaboration. Japan should play a role in this and the best way to do so is to send a rover equipped with a high-sensitivity life and organism detector. The timing should not be too far from ExoMars or Mars2020, of course.

We, therefore, propose a rover mission for early 2020's. The launch vehicle is assumed to be H-IIA 202. The entire system consists of an entry-descent-langind (EDL) module and a cruise stage, weighing some 800 kg or so. After departing from the earth, the cruise stager will generate necessary electric power with its solar-array panels. The power covers communication to the earth and data handling, the attitude control system, the heat-managing system, and the trajectory control maneuvers. When approaching Mars, the EDL module will be detached and enter the Mars atmosphere [5].

To efficiently search for life or organism, the probe should land on very specific place where remote observations strongly indicate there should be something. This requires a "high-precision" landing that can be done by active-guided descent under speed of supersonic or sub-sonic, an engineering challenge. The Martian atmosphere is sometimes saide to be "too thin to be useful but too thick to ignore". MELOS1's engineering team members are working hard to overcome this problem with high confidence.

The system is currently so designed that we can land a 60-kg rover on the Martian surface.

On Mars: The rover's nominal life time, though still TBD, may be 60 to 120 Martian days during which she performs life and organism detection experiments. The 60-kg rover will host 6 to 7 kg of science payload. The main instrument, of course, is Life Detection Microscope (LDM) [7]. To best utilize 8 sample containers of LDM, the rover will traverse for 5 to 6 days to a new location. At one place, the onboard instruments will be used to decide from where we pick up the sample (may take a few days for this). Then, scoop and test will be performed for one full day. This cycle requires up to 10 days per sample. During the mission's life time of 90 days, we can utilize all 8 sample containers.

More Future: It is imaginable that the entire world will be shocked and changed if ANY sign of life on Mars is discovered. After MELOS1, if successful, we should then plan missions that give us more detailed data to study what kind of lives they are on Mars and probably on othe worlds in the universe. This should be the dawn of "generalized" biology.

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ENCELADUS' HYDROTHERMAL ACTIVITY: ANOTHER HABITABLE WORLD?.   Y. Sekine[1], T.

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A plume of vapour and water ice particles rich in sodium salts erupting from warm fractures near the south pole of Saturn's icy moon Enceladus suggest the presence of a liquid-water reservoir in the interior[1,2], which is or has been in contact with the moon's rocky core. The findings of silica nanoparticles in the E-ring originating from the plumes imply active geochemistry involving water-rock interactions[3,4]. However, the particular conditions of temperature and mineral compositions are yet unconstrained. Here we report laboratory experiments and calculations of hydrothermal reactions simulating Enceladus' interior. To achieve high silica concentrations in the fluids, which are sufficient for the formation of silica, hydrous silicates involving the water-rock interactions would be composed mainly of serpentine and saponite/talc, consistent with the rock components similar to carbonaceous chondrites. Fluid temperature needs to reach ≥ 100–$200°C$, suggesting hydrothermal activity in Enceladus. In contrast to previous reports[5,6], the lack of N_2 in the plumes[7] may be in good agreement with a warm interior because decomposition of NH_3 to N_2 would be kinetically inhibited even at $300°C$. Our results support the idea that deep hydrothermal circulation in a warm core of Enceladus[5,8–10] drives hotspots in the H_2O mantle, possibly contributing large tidal dissipation and anomalous heat flow at the south pole[11,12]. To achieve such high temperatures in geologically recent past or today, Enceladus might have formed in ~4 Myrs after the formation of the solar system.

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Brown Dwarf Atmospheres Revealed by 2.5-5.0 μm *AKARI* Spectra S. Sorahana[1], [1]Department of Physics, Nagoya University, Nagoya, Aichi 464-8602, Japan

Introduction: Brown dwarfs play an important role as a bridge between stars and planets. The first detection of brown dwarf was reported by Nakajima et al. [1]. Since they are not sufficiently massive for core hydrogen burning, they simply cool off after deuterium burning ends [2]. The physical and chemical structures of brown dwarf atmospheres are complicated and cannot be understood with a simple extension of stellar atmospheres. Theoretical studies of brown dwarf atmospheres predict that such low temperature atmospheres are dominated by molecules and dust [3][4][5], and can be determined by simple radiative equilibrium under local thermodynamic equilibrium [6]. However, many previous observations in the near-infrared wavelength range find that the actual physical and chemical structures of brown dwarf atmospheres are more complicated and differ from such simple predictions [7][8][9][10].

By understanding brown dwarf atmospheres we will be able to investigate exoplanet atmospheres so that we can finally gain a comprehensive understanding of atmospheres from stars to planets.

***AKARI* Spectra of Brown Dwarfs:** We observed 27 brown dwarfs with *AKARI,* a Japanese infrared astronomical satellite [11], and for the first time obtained good continuous spectra with moderate-resolution (R~120) between 2.5 and 5.0 μm for 16 sources (Figure 1).

Analysis of *AKARI* Spectra: We investigate the appearance of the CH_4 (3.3 μm), CO_2 (4.2 μm) and CO (4.6 μm) molecular absorption bands in this new wavelength range along their spectral types, and attempt to interpret these results with the Unified Cloudy Model (UCM), a theoretical brown dwarf atmosphere model.

We find that the physical and chemical structures in the brown dwarf atmospheres deviate from theoretical predictions for local thermodynamic equilibrium (LTE) with solar metallicity [10].

Elemental Abundances of Brown Dwarfs: We discuss possible elemental abundance variations among brown dwarfs using model atmospheres and *AKARI* data to explain the deviations. We construct a set of models with various elemental abundances as a first trial, and investigate the variation of the molecular composition and atmospheric structure. From the results, we suggest that a possible reason for the CO_2 4.2 μm absorption feature in the late-L and T type spectra is the C and O elemental abundances being higher or lower than the solar values used in previous studies

(Figure 1; see also [12]; [13]). Investigation of elemental abundances is important for exoplanets to understand their origin of formation.
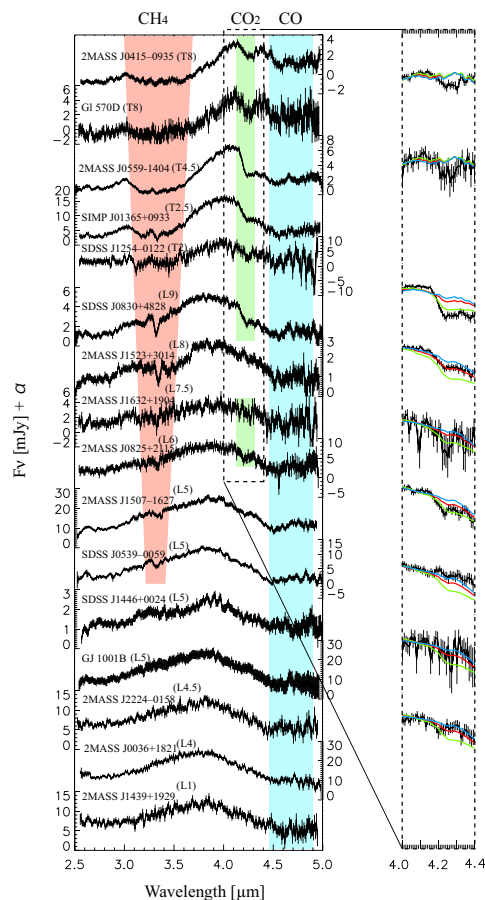
Figure.1 *AKARI* spectra of brown dwarfs with errors shown in black. 11 L dwarfs and 5 T dwarfs are successfully observed. The 3.3 μm CH_4, 4.2 μm CO_2 and 4.6 μm CO absorption bands are shown in red, green and blue, respectively in the left panel. We also enlarge the CO_2 absorption band region and show a comparison between observation and models with varying elemental abundances. We pick up 9 sources of our sample. They show the 4.2 μm CO_2 band, except for 2MASS J1523+3014. Three objects are better explained by the model with increased C and O elemental abundances (green), one object is well reproduced by the model with decreased abundances (blue), and the spectra of the other three sources are best explained by the solar abundance model (red). We are not yet able to explain the other two latest T-type sources that the CO_2 band appears.

Chromospheric activity in Brown Dwarfs: No previous brown dwarf atmosphere models have considered chromospheric activity. However, the deviations between theoretical model spectra and observed spectra in the wavelength range 2.5-5.0 μm indicate that there is additional heating in the upper atmosphere. If a brown dwarf has a chromosphere, the temperature in the upper atmosphere should be higher. We construct a simple model that includes heating due to chromospheric activity. With this additional heating, we find that the chemical structure of the atmosphere changes dramatically, and the heating model spectra of early-type brown dwarfs can be considerably improved to match the observed spectra. Our result suggests that chromospheric activity is essential to understand the near-infrared spectra of brown dwarfs [14].

Our results are important for searching for signs of life in exoplanets orbiting brown dwarfs. NASA's Kepler space telescope has detected more than 1000 Earth-mass exoplanet candidates, and it is now estimated that at least 17 billion Earth-sized exoplanets reside in the Milky Way Galaxy. Since less massive, rocky planets tend to orbit around low mass stars, planets resembling our Earth are more likely to be discovered around brown dwarfs. Understanding chromospheric activity, such as flares, in brown dwarfs and its effects on the atmospheric structure of orbiting planets will be very important for investigating the potential for life on exoplanets.

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Man Made Elements Periodic Table, Astronomical Periodic Table, Geographic Periodic Table-Dimitri Mendeleev Imitation in the 21st Century

A Man Made Elements Periodic Table, including every single current element not just synthetic elements, can be built differently than the naturally occurring element periodic table. Every element can be produced not just the regular synthetic elements.Naturally occurring elements can be seen as different Elements than man made elements related to differences in chemical properties. For example, the man made elements have origins from protons, neutrons, electrons, particle colliders, accelerators. The naturally occurring elements occur in many places/environments like Carbon with Oxygen, plutonium occurs with Uranium, Helium in places like the Sun, Hydrogen in most stars, Carbon occurs in places like trees, oxygen and nitrogen occurs in air, Phosphorus/Sulfur in our bodies.

 Man made elements are different than naturally occurring elements and Man Made Elements Periodic Table different than natural periodic table too. The Man Made Elements Periodic Table can have the same structure as Mendeleev's Table, but include man made elements.

 I previously had shown how square, linear, circular, solar system, galaxy atomic configurations can be made, and these Man Made Elements Can take all these different atomic configurations like linear, galaxy, solar system or square atoms too!

Dimitri Mendeleev and me then both were involved in inventions of Periodic Tables. My periodic table inventions include Man Made Periodic Table, Astronomical Periodic Table where the element exists in space/Universe, Geographic Periodic Table where the element exists on the Earth.

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SILICA AEROGEL FOR USE IN COSMIC DUST COLLECTORS UTILIZED IN THE TANPOPO MISSION. M. Tabata[1,2,*], H. Yano[1], H. Kawai[2], E. Imai[3], H. Hashimoto[1], S. Yokobori[4], and A. Yamagishi[4], on behalf of the Tanpopo WG[1], [1]Japan Aerospace Exploration Agency (JAXA), Sagamihara, Japan, [2]Chiba University, Chiba, Japan, [3]Nagaoka University of Technology, Nagaoka, Japan, [4]Tokyo University of Pharmacy and Life Sciences, Hachioji, Japan ([*] Corresponding author: makoto@hepburn.s.chiba-u.ac.jp).

Introduction: The Tanpopo mission is an astrobiological experiment to be conducted on the Japanese Experiment Module (JEM) on the International Space Station (ISS) [1]. The primary goal of the mission is to determine whether terrestrial microbes in dusts ejected by events such as volcanic eruptions can reach the low Earth orbit and whether interplanetary dust particles containing prebiotic organic compounds can migrate among solar system objects. In this mission, we will collect cosmic dusts using silica aerogels. After a one-year sampling period, the returned samples will be biochemically analyzed in our ground laboratories.

We developed an ultralow-density (0.01 g/cm^3) silica aerogel for capturing hypervelocity microparticles [2], which realizes an almost intact collection of cosmic dusts. Silica aerogel, a colloidal form of quartz (SiO_2), is an eminently suitable medium for cosmic dust sampling because of its light weight and optical transparency. Aerogel sample tiles were especially developed for the Tanpopo mission and were not contaminated by bacterial deoxyribonucleic acids (DNA) [3]. The aerogel material is formed as an integrated monolithic tile with different density layers and box-framing structures [4]. Being hydrophobic, it also suppresses age-related degradation caused by moisture absorption [5].

Because the aerogel-based cosmic dust collector will be mounted on the Exposed Experiment Handrail Attachment Mechanism (ExHAM), newly developed by the Japan Aerospace Exploration Agency, and equipped to the Exposed Facility using a robotic arm and airlock on the JEM, we developed a special aerogel holder [6]. The aerogel loaded in the holder must pass a vibration test for launch and a pressure test. We plan to expose multiple aerogels to several different sides of the ISS, both parallel and perpendicular to its direction of travel (i.e., the East, which is the direction of the ISS orbit, North, and zenith direction) in three-time annual exposures.

Development of Silica Aerogel for Capturing Cosmic Dusts: As a bread bode model, we first developed a simple two-layer aerogel with different densities at Chiba University. The aerogel consists of a 10.5 mm thick top layer of density 0.01 g/cm^3 and a 10 mm thick base layer of density 0.03 g/cm^3. The two layers are chemically combined as a monolithic tile in a wet-gel synthesis process [3], [4]. The low-density top aerogel layer is helpful for capturing cosmic dusts more or less intact. The higher density base layer funcions to increase the strength of the whole aerogel tile and to surely capture high-energy cosmic dusts as well. In 2011, we conducted a mass production test of the two-layer aerogels in contamination-controlled environments. A total of 126 aerogel tiles were manufactured, and as a result, 106 undamaged aerogels were successfully obtained (i.e., a 84% yield) [6].

We developed a box-framing aerogel by redesigning density configuration and tile size so that it passes vibration tests for rocket launching. The outer size of an aerogel holder called as a capture panel was determined to be $100 \times 100 \times 20$ mm^3, and a prototype panel was fabricated. The panel lid has grids to prevent the aerogel from escaping the panel and to ensure the safety of the ISS crew. Vibration tests revealed that the simple two-layer aerogel was seriously damaged by the panel grids. To resolve this, we designed the box-framing aerogel as an engineering model (Fig. 1). The top layer of density 0.01 g/cm^3 is surrounded by the base frame of density 0.03 g/cm^3 on not only the bottom surface but also the four sides. The box-framing aerogel is fixed in the panel by compressing only the base frame edges with the lid. The thickness of the 0.01 g/cm^3 top layer is designed not to touch the grids. The box-framing aerogel passed vibration tests for rocket launching and a depressurization and repressurization test [6].
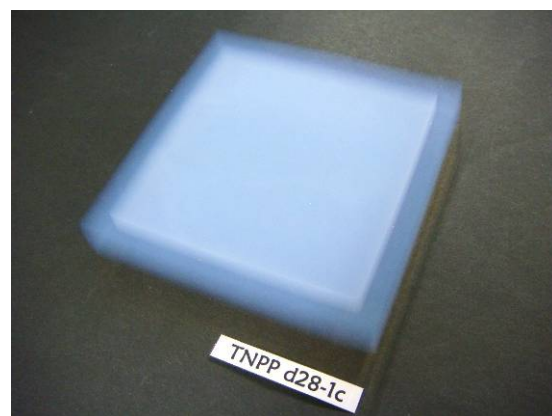
Fig. 1: Prototype of the box-framing aerogel, consisting of a 0.03 g/cm^3 base frame and a 0.01 g/cm^3 top layer.

We have conducted mass production of box-framing aerogels in 2013. A special polystyrene case was made for molding the base frame in the wet-gel synthesis process. It has taken 3 months to produce a total of 72 aerogel tiles. 60 out of 72 aerogels were manufactured strictly in contamination-controlled environments. The others were not treated in contamination-controlled environments; however, they can be used in laboratory tests. At present, measurements of the produced box-framing aerogels are ongoing.

Conclusion: We are developing silica aerogels for use in the cosmic dust collectors utilized in the Tanpopo mission. A procedure for manufacturing aerogels in contamination-controlled environments was established. A box-framing aerogels was designed to withstand vibrations during rocket launching. Mass production of box-framing aerogels has been performed in 2013. In this paper, we present the recent development of aerogels for the Tanpopo cosmic dust collectors.

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POLARIZED SPACE RADIATION AND BIOLOGICAL HOMOCHIRALITY

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Introduction: The origin of biological homochirality in terrestrial organisms (proteinogenic amino acids with L-form enatiomar dominant and sugars in DNA and RNA with D-form enatiomar dominant) is one of the most important but unsresolved problems in astrobiology. A most attractive scenario by the astrobiological contexts is that the single-handedness phenomenon was originated by asymmetric chemical reactions under asymmetric interstellar/circumstellar conditions stimulated by polarized space radiation.

Typical polarized radiation sources in space which can induce asymmetric chemical reactions is circularly polarized light (CPL) [1]. This CPL scenario is supported by the occurrence of L-enantiomer-enriched amino acids in carbonaceous meteorites [2], and the observation of CPL of the same helicity (left- or right-handed circular polarization) over large distance scales in the massive star-forming region of Orion [3] and NGC 6334-V [4] nebulae.

One of the serious drawbacks of the CPL hypothesis above is that polarization direction (left- or right-handed) depends on relative position to radiation sources. Another possible hypothesis is based on the radiation source with absolutely determined polarization direction. It is well known that electrons from beta-decay radiation are spin-polarized, that is, the spin angular momentum is polarized to the direction of motion due to parity non-conservation law in the weak interaction. The helicity (the projection of the spin angular momentum onto the direction of kinetic momentum) of beta-ray electrons is universally negative (left-handed). Spin polarized electrons (SPE) can be emitted as beta-decay electrons from radioactive nuclei or from neutron fireballs in supernova explosion [5].

Experiments: Ground simulation experiments for the extraterrestrial homochirality scenario have been conducted by using CPL from synchrotron radiation (SR) facilities. Solid films of achiral hydantoin (a precursor molecule of achiral glycine) were irradiated with CPL at 215 nm from a free electron laser (FEL) of UVSOR-II (IMS, Japan). As the results of the circular dichroism (CD) spectra measurement of the CPL irradiated hydantoin, opposite CD spectra depending on the polarization direction was observed ilike as DL-amino acid experiments [6].

The same kind of ground simulation experiments by using SPE from beta-decay radioactive nuclei have also being conducted. DL-Isovaline (Iva) films were irradiated the with a flux of SPE from high-dose beta-decay radioactive isotope source (^{90}Sr - ^{90}Y) of the Russian Federal Nuclear Center. In the CD measurements using beamline-15 of HiSOR, the samples were set so that the film-deposited surface of them faced to the source of the CD-probe SR beam. The samples were rotated around the axis of CD-probe SR beam. Furthermore, linear dichroism (LD) spectra of the samples also simultaneously measured by using a laboratory spectropolarimeter including LD measuring equipment. As the results of these measurements, the prospective emergence of optical anisotropy in the irradiated DL-Iva films was successfully detected [7]. The experiments by using SPE from spin-polarized electron accelerators, by which the polarization direction of SPE can be well-controlled, are also planning.

Summary: The measured CD spectra of our CPL- and SPE-irradiated amino acid films showed apparent emergence of optical anisotropy presenting the irradiation effects of polarized spase radiation. Present results can be important for the solution of biological homochirality problems.

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POLARIMETRIC SIGNATURES OF THE EARTH EXTRACTED FROM EARTHSHINE OBSERVATIONS.
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Introduction: Growing number of exoplanets including those in the habitable zone have been discovered [e.g., 1]. However, a planet in the habitable zone does not necessarily mean that the planet is habitable. Thus, we need to make continuous efforts to characterize the planet as habitable. Polarimetric observations may be able to play an important role to approach the goal. Light emitted from a host star is virtually unpolarized, whereas reflection on a planet produces polarization. Degree and position angle of polarization are dependent with the planet's geometry and physical properties with regard to reflection. Therefore, polarimetric measurements can be used to characterize exoplanets in a coming age when direct polarimetry of exoplanets has been put into practical use.

In this presentation, we focus on potential of polarimetry for searching (1) planetary atmosphere with Earth-like optical thickness, and (2) liquid surface on planets, both of which are important information to discuss habitability of planets. To investigate the potential, we have carried out polarimetric observations of Earthshine on the Moon. Earthshine is Earthlight reflected from the lunar surface. It is commonly used by ground-based observers to obtain disk-integrated Earthlight and to extract observational signatures of the Earth.

Atmosphere with Earth-Like Thickness: Firstly, we summarize our optical spectropolarimetry of Earthshine for Earth phase angles ranging from 49° to 96°. Full description of this project can be found in [2]. This project aims to derive the phase variation of polarization spectra of the Earth to find a signature pointing toward a distinctive characteristic of the Earth. The observations were conducted on March 9-13, 2011 (UT). We utilized the spectropolarimeter HBS mounted on the 1.88 m telescope at the Okayama Astrophysical Observatory located in Okayama, Japan. The wavelength coverage is 450-850 nm with a resolution of 6 nm. We have found that the phase dependence differed with the wavelengths; the maximum polarization for the *V* band wavelengths occurred at a phase angle of near 90°, whereas that for longer wavelengths is reached at larger phase angles. This is interpreted as indicating that Earthshine polarization at shorter wavelengths is dominated by atmospheric Rayleigh scattering, whereas that at longer wavelengths has an increasingly effective contribution from the Earth surface reflection. The observed wavelength dependence in the phase angles of the maximum polarization for the Earth is suggested to be different from the other rocky planetary objects in the Solar System. Therefore our observational result might be a signature pointing toward atmosphere with Earth-like optical thickness: the atmosphere is scattering in the shorter wavelengths but transparent in the longer wavelengths.

Liquid Surface: Secondly, we describe our ongoing project of comparing polarization between Earthshine from land-dominant surface and that from ocean–dominant surface. Polarimetry may be a method to search a planet with a liquid surface because specular reflection from a liquid surface is expected to produce a greater polarization degree than reflection from a rough surface does [3]. This project aims to evaluate the difference between Earthshine polarization contributed by reflection at a land-dominant surface and that by an ocean-dominant surface. As viewing from Japan, we can observe Earthshine with contribution from a land-dominant surface in waxing phases of the Moon, whereas we can study that from an ocean-dominant surface in the waning phases. We utilized the 60 cm reflecting telescope at the Nishi-Harima Astronomical Observatory located in Hyogo, Japan and the simultaneous imaging/spectrometric polarimeter. In a series of observations from May 2010 to March 2012, twelve data sets were obtained for the waxing phases and seven data sets for the waning. The observations were conducted in *V* band. The measured polarization degrees increased as the Earth phase approaches a quadrature phase. The maximum polarization degree was roughly ~8 % for the both phases. Fitting with a function for Rayleigh scattering have yielded the polarization maximum of 7.7±0.4% and 8.4±0.7% for the waxing and waning phases, respectively. Although a larger value has been derived for the waning phases when the Earthshine is contributed by an ocean-dominant surface, the difference is not significant considering uncertainty of the result. Refinement of our observational system is currently underway.

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Microbial community development in deep-sea hydrothermal vents in the Earth, and the Enceladus

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Over the past 35 years, researchers have explored seafloor deep-sea hydrothermal vent environments around the globe and studied a number of microbial ecosystems. Bioinformatics and interdisciplinary geochemistry-microbiology approaches have provided new ideas on the diversity and community composition of microbial life living in deep-sea vents. In particular, recent investigations have revealed that the community structure and productivity of chemolithotrophic microbial communities in the deep-sea hydrothermal environments are controlled primarily by variations in the geochemical composition of hydrothermal fluids (Takai and Nakamura, 2010; 2011). This was originally predicted by a thermodynamic calculation of energy yield potential of various chemolithotrophic metabolisms in a simulated hydrothermal mixing zone (McCollom and Shock, 1997). The prediction has been finally justified by the relatively quantitative geomicrobiological characterizations in various deep-sea hydrothermal vent environments all over the world (Takai and Nakamura, 2010; 2011).

Thus, there should be a possible principle that the thermodynamic estimation of chemolithotrophic energy yield potentials could predict the realistic chemolithotrophic living community in any of the deep-sea hydrothermal vent environments in this planet.

In 2005, a spacecraft Cassini discovered a water vapour jet plume from the sole pole area of the Saturnian moon Enceladus. (Hansen et al., 2008; Waite et al., 2009). The chemical composition analyses of Cassini's mass spectrometer strongly suggested that the Enceladus could host certain extent of extraterrestrial ocean beneath the surface ice sheet and possible ocean-rock hydrothermal systems. In addition, a recent research has suggests that there is silica nanoparticles in Saturn's E-ring derived from the Enceladus plume. An experimental study simulating the reaction between chondritic material and alkaline seawater reveals that the formation of silica nanoparticles requires hydrothermal reaction at high temperatures. Based on these findings, we attempt to build a model of possible hydrothermal fluid/rock reactions and bioavailable energy composition in the mixing zones between the hydrothermal fluid and the seawater in the Enceladus subsurface ocean. The results indicate that the pH of fluid should be highly alkaline and H_2 concentration in the fluid is elevated up to several tens mM through the water/rock reaction. The physical and chemical condition of the extraterrestrial ocean environments points that the abundant bioavailable energy is obtained maximally from redox reactions based on CO_2 and H_2 but not from with other electron accepters such as sulfate and nitrate. Our model strongly suggests that the abundant living ecosystem sustained by hydrogenotrophic methanogensis and acetogenesis using planetary inorganic energy sources should be present in the Enceladus hydrothermal vent systems and the ocean.

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Abiogenic and biogenic chiral amino acids for further enantiomer-specific isotope analysis (ESIA)

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Introduction:

Since the time of Pasteur, the development of biomolecular chirality has remained one of the most important problems with regard to our knowledge concerning chemical evolution. The homochiral amino acids and sugars are essential to the formation, structure, and function of biopolymers and are a defining molecular trait of life on the Earth [1] (cf. asymmetric photochemical processes from amino acid precursors in complex organics [2]). Meteorites, specifically carbonaceous chondrites, carry pristine abiotic signatures of molecular chirality in the solar system. Enantiomeric excesses of L-form α-methyl amino acids are found in the CM meteorite Murchison and the CI meteorite Orgueil with the correlation of hydro-alteration processes in the parent body [3]. For further information of compound-specific and enantiomer-specific nitrogen isotopic composition, here we developed the analytical optimization for achiral and chiral amino acids.

Results and Discussion:

The precise determination of amino acids in calcareous, siliceous, geological samples (including mineral matrix in C-type meteorites) is troublesome, since extracts of these samples often contain a significant amount of interfering organic and inorganic substances. To overcome this critical issues, at first we employed cation-exchange chromatography of protein and non-protein amino acids prior to derivatization for gas chromatographic separation, including gas chromatograph/ combustion/ isotope ratio mass spectrometry (GC/C/IRMS) [4,5]. Among the wet chemical treatment, we confirmed that the average recovery of amino acids was better than 94% and there was no nitrogen isotopic fractionation [5]. Pre-treatment of an extract has two advantages: (i) Separation from complex hydrophilic compounds, including sugars and organic acids, which consume derivatization reagents during esterification, (ii) desalting of inorganic compounds derived from matrix minerals, thereby preventing damage to the combustion and reduction furnaces in the system. We occasionally use ion-pair liquid chromatography combined with electro-spray ionization mass spectrometry (LC/ESI-MS) for further compound isolation [unpulished].

A remarkable feature of the nitrogen isotopic compositions of bulk organics from various carbonaceous chondrites is that they are significantly higher than those of terrestrial materials, up to +3200‰ (vs. Air) [6]. We successfully applied the present optimized procedure to representative carbonaceous meteorites [7], including wide variety of geological samples. We believe that application of compound-specific nitrogen isotopic analysis will reveal the role of indivisual amino acids and open up our knowledge of the abiotic chemical processes [8].

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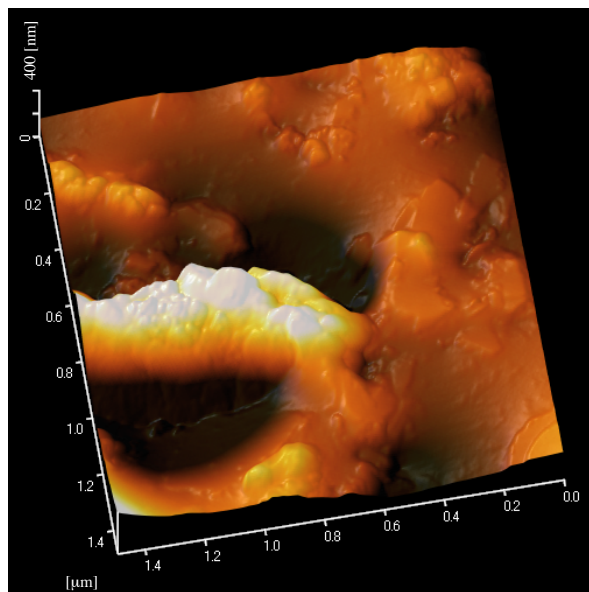

Figure 1.
Three-dimensional atomic force microscopy (AFM) images of aggregated high-molecular-weight complex organic materials synthesized by proton irradiation with CO-NH3-H2O (vapor) gas mixture.

A strategy for sample retrieval and possible onboard biosafety controls: Perspectives

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Issues of planetary protection are generally handled by the space community, although these issues often come to the attention of various academic communities and the public (e.g., [1, 2]). Since the establishment of the Panel on Plantary Protection (PPP) and the Committee on Space Rsearch (COSPAR), an international consensus has emerged regarding the development and promulgation of planetary protection knowledge and policies, and regarding plans for mitigating the harmful effects of biological contamination on Earth. The investigation of biological quarantine for planetary protection against both forward and back-contamination has been discussed from the viewpoint of risk management and public consensus, in the context of further planetary exploration. However, selection of a candidate location for initial quarantine, especially for materials with high biosafety levels, is problematic due to the potential risk of biological back-contamination and the difficulty of obtaining public consensus in the host countries of the sample recovery site.

To resolve key issues related to extraterrestrial sample-return projects, we suggest that international waters (i.e., areas of oceans, seas, and waters outside of national jurisdiction; Figure 1) are a meaningful option for the location of sample retrieval, likewise the pioneering Apollo missions in 1960's. To conduct an initial investigation of onboard biological control, we propose application of a BSL laboratory on a developed research vessel operating in international waters. According to the United Nations Convention on the Law of the Sea (UNCLOS), international waters are defined as all waters beyond national boundaries with freedom of navigation and also freedom of scientific research (see, Article 87: Freedom of the High Seas). We think that the international waters are the most likely place for the future public consensus of onboard quarantine because of the potentially minimum risk of back-contamination in the ocean environments and the most rapid and convincing processing of the subsequent scientific research. On this basis, we propose potential onboard protocols for the initial biological control of future sample-return missions (e.g., [3], [4]).

Acknowledgements:

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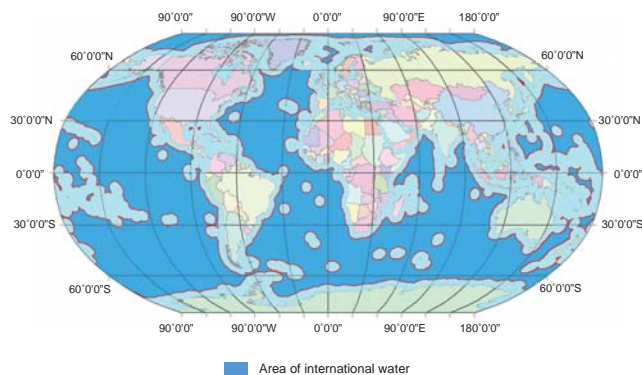
Figure 1. Global distribution of international waters.

Did oceanic biogenic methane cycling regulate the evolution of Early Earth atmospheric chemistry? C. Thomazo, UMR-CNRS 6282 Biogéosciences, Université de Bourgogne, Dijon, France (correspondence: christophe.thomazo@u-bourgogne.fr).

One of the most remarkable changes in the Earth surface chemistry of our planet history was the biologically induced pervasive oxygenation of the ocean and atmosphere between around 2.45 to 2.32 Ga. This event, namely the Great Oxidation Event (GOE, [1]), is underlined in the sedimentary record by the disappearance of mass independent fractionation of sulfur isotopes which is a robust geochemical signature of a low oxygen level ($<10^{-5}$ times the present atmospheric level; [2]) in Earth's atmosphere and surface environments.

In the last decade, a growing number of studies using geochemical proxies capable of tracing atmosphere and ocean paleo-redox conditions suggests localized and transient oxygenation of the marine environment as early as 300 Ma before the GOE [3-4]. The idea of a pre-GOE "whiff" of oxygen in terrestrial environment is in line with molecular biomarkers evidence for an early rise of oxygenic photosynthetic bacteria at around 2.7 Ga [5]. However, strong uncertainties remain regarding the extend of di-oxygen production and its consequences onto the oceanic and atmospheric redox balance at that time.

In order to explore atmospheric and oceanic chemistry before the transition toward an oxidizing Earth, we report the results of a detailed carbon (^{12}C, ^{13}C), sulfur (^{34}S, ^{33}S, ^{36}S) and nitrogen (^{14}N, ^{15}N) isotopic study of well preserved Neaorchean (2.7 to 2.6 Ga) sediments from the Pilbara craton (Australia), the Belingwe Greenstone Belt (Zimbabwe) and the Superior carton (Canada).

We suggest that a protracted oceanic oxygenation starting at around 2.7 Ga might have widely impacted marine biogeochemical cycles and triggered the evolution of methane oxidizing bacteria (methanotrophs) but that Neoarchean atmospheric chemistry remained weakly reducing at that time. In particular, paired carbon isotopes of carbonate and organic matter coupled with mass independent fractionation of sulfur isotopes record suggest that biogenic methane fluxes between ocean and atmosphere might have strongly influenced the magnitude and signs of mass independent fractionation of sulfur isotopes and the overall atmospheric sulfur chemistry on the Early Earth. We propose that geochemical signatures of biologically induced changes in atmospheric chemistry could thus be recorded before oxygen rise using multiple isotopic studies including for instance carbon, sulfur and nitrogen.

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The Faint Young Sun Problem – how can early Earth and Mars be warmed? F. Tian, Center for Earth System Science, Tsinghua University, Beijing, China (correspondence: tianfengco@tsinghua.edu.cn).

Based on current understanding of star evolution, the Sun was much fainter in the past than it is now. If the atmosphere of early Earth were the same as it is today, the Earth would have been frozen prior to ~2 billion years ago (2Ga). However, the lack of geological evidence for glaciation suggests that the Earth was at least as warm as it is today during the Archean (3.8~2.4 Ga) except for short periods of time.

There are three types of solutions to this faint young sun problem: 1) the Sun was different from other stars; 2) there was glaciations but we have not found the geological record yet; and 3) the Earth's atmosphere was much different from that of today and therefore could have provided much stroner greenhouse warming to the surface.

Similar to the early Earth, there is also a faint young sun problem on early Mars. There are many geomorphological and geochemical evidence that water once flew on the planet's surface. However how long time it would have taken for liquid water environment to form these features is still open to debate. Nevertheless the intriguing perspective of life on our sister planet requires a warmer and wetter early Mars. How could such a climate have been maintained given the faint young Sun?

In the past two decades, more than 900 exoplanets have been discovered, and some of them are potentially habitable planets based on the traditional definition of the liquid water habitable zone. However, water is not the sole requirement of life as we know it. Could there be other considerations which would further constrain the habitability of exoplanets?

In this talk we will review the new progress related to the faint young sun problem of Earth/Mars and link it to the habitability of known exoplanets.

DRIED COLONY IN CYANOBACTERIUM, *NOSTOC* SP. HK-01 - SEVERAL HIGH SPACE ENVIRONMENT TOLERANCES FOR "TANPOPO" MISSION

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Introduction:

Habitation in outer space is one of our challenges. We have been studying future space agriculture to provide food and oxygen for the habitation area in the space environment, in the craft and/or on Mars[1]. A cyanobacterium, *Nostoc* sp. HK-01, has high several space environmental tolerance. Arai et al. already reported that *Nostoc* sp.HK-01 had an ability to grow for over several years on the Martian regolith simulant in a laboratory experiment[1]. *Nostoc* sp HK-01[2] would have high contribution for the "TANPOPO" mission in Japan Experimental Module (JEM) of the International Space Station (ISS) [3]. Here, we will show the importance of this material for TANPOPO Project and further utilization and important aims for future using them as a food after its growing on Mars.

Material and Method:

Cyanobacterium, *Nostoc* sp.HK-01, was used in this all experiments. The dried colony as material, *Nostoc* sp. HK-01, was exposed to high temperature (100°C:3h, 4h, 5h, 6h, 7h, 24h), UV (253.7nm:24h, 48h), gamma-ray (5KGy), heavy particle beam. After the exposure, they incubated in water for 2 days. Fluorescein diacetate, FDA, was used for the staining of *Nostoc* sp. in this study. The detailed method was described previously. The stained cells were observed under a fluorescent microscope (BX50 type, OLYMPUS, Japan).

Results and disscussion:

All or a part of the tested cells in the colony could survive under the exposed serious environments, 100°C (1~7h), UV (24h, 48h), gamma-ray (5kGy), heavy particle beam (5, 20, 40, 80min). In the high temperature, 100°C in 24h, the percentages of survived cells were decreased. According to these results, *Nostoc* sp. would have survival limit temperature within 24h at 100°C.

On the other hand, the easy cell separation method was examined. The optimum conditions were ascertained. The dry material, *Nostoc* sp. HK-01, was incubated at 37 °C for 30 minutes with water. After their shaking for 15 minutes, cells could be cultured on ager in cell culture plate for 2-3the days.

The increased cells were re-incubated for screening a high tolerance material for future space utilization. The screened material would be used in the several evolutional experiments. In the heat exposure experiment, even the cells without EPS has also had a high tolerance. These results, in the case of high temperature tolerance, it has a possibility that the contribution of their tolerance would be a little relation to extracellular polysaccharides (EPS), although several reports suggested the relation to EPS on the cyanobacteria tolerances[4,5]. We are studying the identification of functional substances related to their tolerance in their cells.

We are trying to determine the best conditions and evolution for high space environment tolerance of *Nostoc* sp.HK-01 and studying the proposal of utilization of cyanobacteria, *Nostoc* sp HK-01, for the variation of total utilization as space agriculture [6].

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Intact Capture, Aerogel, SOCCER, STARDUST & LIFE Peter Tsou, Sample Exploration System, P. O. Box 831 La Canada CA 91012, tsou.peter@gmail.com

Intact Capture: In order to determine if comets brought the Earth's ocean water and early life seedlings, we needed to bring samples of comets to terrestrial laboratories for detailed analyses. The concept of landing on a comet, excavating the surface, then returning the samples back to Earth (Comet Nucleus Sample Return) has been studied for decades, but unimplemented due to lack of necessary technologies and very high cost. Comets, however, expel their surface material as they approach the Sun, making conceivable a low cost flyby sample return missions. There was a catch, though - flybys are at hypervelocity encounter speeds that atomize the samples, destroying the sample morphology and causing fractionations and losing astrobiological value. To solve this problem, an "intact capture" technology was developed in 1984, utilizing a technique that captures and preserves intact a portion of the sample at hypervelocity flyby speeds.

SOCCER NEARER STARDUST: With intact capture technology and the adaptation of transparent silica aerogel as a capture medium, in 1987 NASA/ISAS began to develop a comet coma sample return mission, Figure 1. 1992 a joint NASA/ISAS SOCCER mission concept was proposed, Figure 2. The final outcome was a NASA STARDUST Discovery mission and a NEARER (later Hayabusa) mission both of 1994. Detailed analyses of samples from comet Wild 2 have revolutionized our understanding of comets, revealing for the first time elements formed at the formation of our Solar System. Comets have principally a Solar composition, containing both fire (Solar core material) and ice (Kuiper belt and beyond accretions).

LIFE: In 2005, Cassini discovered that water being jetted from the south pole of Enceladus. Its instruments returned data showed that Enceladus is habitable; that is, it has liquid water, a heat source to maintain water as a liquid, organic nutrients and nitrogen. These discoveries make Enceladus the second Solar System body with a proven existence of these factors (besides Earth). Everywhere there is water on Earth, there is life. Enceladus can help us determine if we are alone in the Solar System. To answer this question, we need to return intact samples from Enceladus to terrestrial laboratories for detailed analyses to determine if it once had life and if not at what stage of development of life. LIFE (Life Investigation For Enceladus) proposes once again a joint NASA/JAXA-ISAS mission to acquire and return the first samples from Enceladus. The 1st joint LIFE Workshop was held in Los Angeles 2013 Figure 3
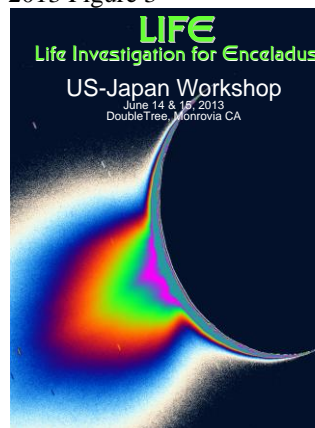

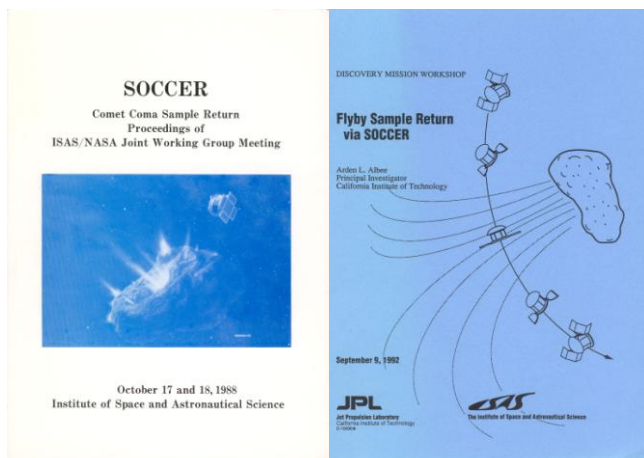Figure 3. First Joint LIFE Workshop was held in June 2013.

Figure 1 SOCCER   Figure 2 Joint NASA/ISAS Proposal

THE PURE SYSTEM FOR ARTIFICIAL CELLS. Takuya Ueda, Department of Medical Genome Sciences, Graduate School of Frontier Sciences, The University of Tokyo, FSB-401, 5-1-5 Kashiwanoha, Kashiwa, Chiba Prefecture, 277-8562 Japan, ueda@k.u-tokyo.ac.jp
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Introduction: The ultimate goal of biology is to obtain the answer to the question, "what is life?" We have two approaches to reach the goal, analytical and synthetic approaches. In the last century molecular biology had afforded a number of powerful tools to analyze molecular mechanism occurring in living organisms and is still extending our vast knowledge on life. One of outcomes achieved through the approach of reductionism is undoubtedly the huge database of genome sequences of various species. The accumulating blue-prints of life will allow us to proceed the other approach, synthetic biology. Based on the gene information, we could synthesize a set of proteins encoded on a particular genome. Such possibility leads us to challenge the synthesis of cell or life.

Experimentals Results and Discussion: To address this objective we first reconstituted cell-free translation system from translation factors individually purified from over-expressed *E. coli* cell and named the system PURE system[1]. We are addressing to create cell-like system in test tube by combining PURE system with lipid-bilayer. In addition to DNA, RNA and protein, lipid is indispensable for the cell, due to several properties, such as compartmentalizing ability, substance exchange, DNA replication, energy production, etc. Thus, cell-like system should be comprised of gene expression machinery and functional membrane. Whereas the development of gene expression system had been realized by the PURE system, the creation of biologically active membrane *in vitro* has not been established so far.

We first made an attempt to create energy-generating liposome by expressing the genes corresponding to ATPase subunits onto lipid membrane using the PURE system supplemented with liposome. We succeeded in construction of membrane insertion system using the PURE system and membrane fraction and efficient integration of membrane protein into lipid bilayer was observed [2]. Furthermore, preliminary results indicate that Fo subunit of ATPase can be synthesized onto the proteoliposome as active form and F_1 assembly can be fulfilled simply by adding a set of ATPase genes. Through this approach, complete synthesis of ATPase on liposome from template DNA by PURE system was focused and efficient ATP generation system derived by the proton gradient across the liposome membrane was achieved.

The reproduction of gene-expression system *in vitro* is also necessary to generate an artificial cell. To address this objective, the reconstitution of ribosome has been challenged and we succeeded in the efficient assemble of 30S ribosomal subunit in the presence of the factors involved in biosynthesis of ribosome. The reconstitution of ribosome will be discussed.

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Unique Late Archean Atmosphere due to Enhunced Volcanic and Biological Activities

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Late Arcehan may be characterized by increasing continental volume and large igneous provinces as well as by onset of oxygenic photosynthesis [1,2]. Enhanced biological production at that time may not have readily resulted in oxidizing atmosphere, and rather caused increasing biological methane in the atmosphere [3,4], that is supported by anomalously ^{13}C-depleted organic carbon recorded in the Late Archean sequence [5]. The large volcanic input into CH_4-bearing very reducing atmosphere may cause unique atmosphere of habitable planet.

In order to test the scenario, we have developed a sulfur isotopic model by improving our atmospheric reaction model [6,7]. The improvements to our model includes the addition of hydrocarbon chemistry, chemical formation and deposition of organic sulfur haze, together with newly determined high-accuracy ultraviolet absorption cross sections of SO_2 isotopologues for reproducing the geological record. The "Sulfur Mass-Independent Fractionation" (S-MIF) has been useful to monitor chemistry of the Earth's early atmosphere. Sedimentary sulfides exhibit exceptionally large variation of $\Delta^{33}S$ values in the latest Archean, from 2.7 to 2.5 Ga, compared to older period. The maximum scatter of S-MIF may indicate anomalous chemistry of atmosphere or climatic system of the late Archean Earth, though the primary cause of the large MIF is still poorly understand.

Our model results suggest that after a volcanic injection of SO_2 into the Archean atmosphere, a significant fraction of the sulfur is converted into carbonyl sulfide (OCS) and could be accumulated in an atmosphere over a timescale of 10 years, if background atmosphere is reducing enough to yield hydrocarbon haze and volcanic sulfur input is large and episodic. Such model could explain the large $\Delta^{33}S$ scatter observed in the Late Archean sedimentary rocks. Moreover, isotopically fractionated two reservoirs (i.e. atmosphere and ocean) can be mixed episodically and thus possible to explain the observed small scale heterogeneity of S-MIF even within a hand specimen level. Combined greenhouse effect by the CH_4 and OCS could have resulted in warm Late Archean climate. Furthermore, subsequent oxidation event of this highly reducing atmosphere may have been more significant for cooling than previously thought, thus could have been the triger of global-scale glaciation at around the earliest Proterozoic.

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CONDITIONS OF SURFACE H2O OF SNOWBALL PLANETS WITH HIGH-PRESSURE ICE S. Ueta[1] and T. Sasaki[1], [1]Earth and Planetary Sciences, Tokyo Institute of Technology (2-12-1 Ookayama, Meguro-ku, Tokyo 152-8551, Japan; ueta@geo.titech.ac.jp, takanori@geo.titech.ac.jp)

Introduction: Since the first extrasolar planet was discovered in 1995 [1], more than 800 exoplanets have been detected as of 2013 March. Although most known exoplanets are gas giants, Earth-like planets have indeed been discovered. Moreover, space telescopes (e.g., Kepler) have now released observational data about many terrestrial planet candidates. Whether terrestrial planets with liquid water exist is an important question to consider because it lays the groundwork for the consideration of habitability.

The orbital range around a star for which liquid water can exist on a planetary surface is called the habitable zone (HZ; e.g., [2]). Planets with plentiful water on the surface but outside the outer edge of the HZ would be globally covered with ice and no liquid water would exist on the surface. These planets are called "snowball planets" [3]. Moreover, an ocean planet could be ice-covered even within the HZ because multiple climate modes are possible, including ice-free, partially ice-covered, and globally ice-covered states (e.g., [3]). Although such planets would be globally ice-covered, liquid water could exist beneath the surface ice shell if sufficient geothermal heat flows up from the planetary interior to melt the interior ice. In this scenario, only a few kilometers of ice would form at the surface of the ocean [4] and life could exist in the liquid water under the surface ice shell (e.g., [5]).

Considering geothermal heat from the planetary interior, Tajika (2008) [3] discusses the theoretical restrictions for ice-covered extrasolar terrestrial planets that, on the timescale of planetary evolution, have an internal ocean. In this paper, we extend the analysis of [3] and vary the parameter values such as the abundance of radiogenic heat sources and the H_2O abundance on the surface. We also check whether ice appears under H_2O layers under high-pressure conditions (high-pressure ice). Therefore, in this work, we consider the effect of high-pressure ice under an internal ocean and discuss its implications for habitability (see Discussion). Finally, we investigate the structure of surface H_2O layers of ice-covered planets by taking into account the effects of high-pressure ice.

Method: *Numerical model.* The planetary surfaces are assumed to consist of frozen H_2O and to have no continental crust. We define the planetary radius as $R = dw + l$, where dw is the H_2O thickness and l is the mantle-core radius. The mass of H_2O on the planetary surface is given by

$$M_{sw} = (4/3)\pi\rho_w[(dw + l)^3 - l^3], \qquad (1)$$

where ρ_w is the density of H_2O. We vary M_{sw} from 0.1 M_{sw0} to 100 M_{sw0}, where $M_{sw0} = 0.00023M$ and M is the planetary mass, with the coefficient being the H_2O abundance of Earth (0.023% by weight). Assuming that a heat flux q is transferred from the planetary interior through the surface ice shell by thermal conduction, the ice thickness dh can be calculated as

$$dh = k_i(T_{ib} - T_s)/q, \qquad (2)$$

where k_i is the thermal conductivity of ice, T_{ib} is the temperature at the bottom of the ice, and T_s is the temperature at the surface. From these models, we can obtain the H_2O thickness dw and the ice thickness dh. The condition for terrestrial planets having an internal ocean is

$$dw > dh. \qquad (3)$$

To estimate the geothermal heat flux q through planetary evolution, we investigate the thermal evolution of terrestrial planets using a parameterized convection model (e.g., [6]). We assume E, which is the initial heat generation per unit time and volume, to be $0.1E_0$–$10E_0$, where the constant E_0 is the initial heat generation estimated from the present heat flux of the Earth.

High-pressure ice. Ice undergoes a phase transition at high pressure. Unlike ice Ih, the other phases are more dense than liquid H_2O. We call the denser ice "high-pressure ice." Because Tajika (2008) [3] assumes that the amount of H_2O on the planetary surface is the same as that on the Earth's surface M_{sw0} (= $0.00023M$), the only possible conditions on the planetary surface are those labeled 1, 2, and 3 in Figure 1. However, because we consider herein that H_2O mass may range from 0.1 M_{sw0} to 100 M_{sw0}, the H_2O–rock boundary could move to higher pressure, so we should account for the effect of high-pressure ice (Figure 1(a)). Therefore, types 4, 5, and 6 of Figure 1(b) are added as possible surface conditions. Type 2 and type 5 planets both have an internal ocean, but high-pressure ice exists in type 5 planets between the internal ocean and the underlying rock.

Results: Figures 2(a) and (b) show the surface conditions for planets with masses from 0.1 $M_\oplus$ to 10 $M_\oplus$ 4.6 billion yr after planetary formation, with varying H_2O masses on their surfaces or initial radiogenic heat sources. All of the planets are located 1 AU from thier central star. We assumed $E/E_0 = 1$ for Figure 2(a) and $M_{sw}/M_{sw0} = 1$ for Figure 2(b). Because larger planets have larger geothermal heat fluxes and thicker H_2O layers, these objects could have an internal ocean with

a smaller H_2O mass on the planetary surface (Figure 2(a)) and a weaker initial radiogenic heat source (Figure 2(b)). However, larger planets also have larger gravitational accelerations. Thus, on those planets, high-pressure ice tends to appear under the internal ocean with a smaller H_2O mass on the surface (Figure 2(a)). For example, if a planet of mass $1M_\oplus$ has an H_2O mass of 0.6 M_{sw0}–25 M_{sw0}, it could have an internal ocean. However, if a planet has an H_2O mass > $25M_{sw0}$, high-pressure ice should exist under the ocean (Figure 2(a)). Note, however, that an internal ocean can exist on a planet having a mass of $1M_\oplus$ if the initial radiogenic heat source exceeds $0.4E_0$ (Figure 2(b)).

Figures 3(a) and (b) show the surface conditions for free- floating planets ($L = 0$) with masses from 0.1 $M_\oplus$ to 10 $M_\oplus$ 4.6 billion yr after planetary formation. The incident flux from the central star affects the surface temperature, thereby affecting the condition on the surface. Therefore, the conditions, and in particular those shown in Figure 3(a), are different from those shown in Figures 3(a) and (b). The results of Figure 3(a) show that, regardless of the amount of H_2O a $1M_\oplus$ planet has, an internal ocean cannot exist under the ice shell. An internal ocean could exist on free-floating planets under certain conditions, but the planetary size and water abundance strongly constrain these conditions (see Figure 3(a)). For instance, if a free-floating planet has an initial radiogenic heat source greater than $7E_0$, it can have an internal ocean (Figure 3(b)).

Discussion: For genesis and sustenance of life, we need at least (1) liquid water and (2) nutrient salts because these substances are required to synthesize the body of life [7]. Because nutrient salts are supplied from rocks, it is necessary that liquid water be in contact with rock to liberate the salts. A type 5 planet (Figure 1(b)) is thus not likely to be habitable because the internal ocean does not come in contract with rocks. However, it is possible for a type 2 planet to meet this requirement. We presume that only type 2 planets have an internal ocean that is possibly habitable. Therefore, the results of this study indicate that only a planet with the appropriate planetary mass and H_2O mass can have an internal ocean that is possibly habitable.

Conclusions: Herein, we discuss the conditions that must be satisfied for ice-covered bound and un-bound terrestrial planets to have an internal ocean on the timescale of planetary evolution. Geothermal heat flow from the planetary interior is considered as the heat source at the origin of the internal ocean. By applying and improving the model of Tajika (2008), we also examine how the amount of radiogenic heat and H_2O mass affect these conditions. Moreover, we investigate the structures of surface H_2O layers of snowball planets by considering the effects of high-pressure

ice. The results indicate that planetary mass and surface H_2O mass strongly constrain the conditions under which an extrasolar terrestrial planet might have an internal ocean without high-pressure ice existing under the internal ocean.

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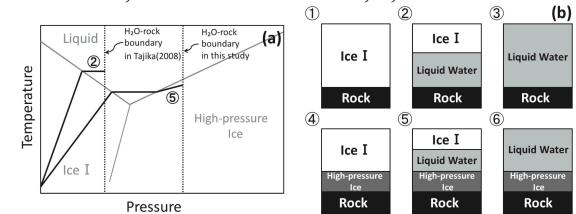

Figure 1. (a) Schematic phase diagram of H_2O (gray lines), temperature gradient (black lines), and H_2O–rock boundaries (dashed lines). (b) Types of planets that have H_2O on their surfaces.
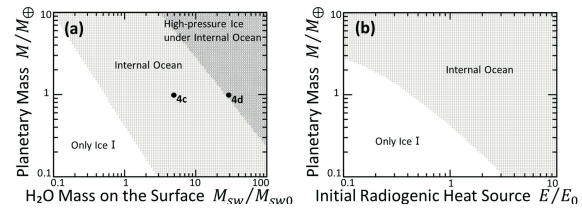
Figure 2. Surface conditions for a planet at 1 AU around a central star ($L = L_0$; the present luminosity of our Sun). (a) The x axis is the surface H_2O mass and the y axis is planetary mass normalized by the Earth's mass, assuming $E/E_0 = 1$. (b) The x axis is initial radiogenic heat, and the y axis is the planetary mass normalized by the Earth's mass, assuming $M_{sw}/M_{sw0} = 1$.

Figure 3. Same as Figure 2, but for a free-floating planet ($L = 0$).

POSSIBILITY OF ELECTRO-ECOSYSTEM AROUND DEEP-SEA HYDROTHERMAL VENTS.

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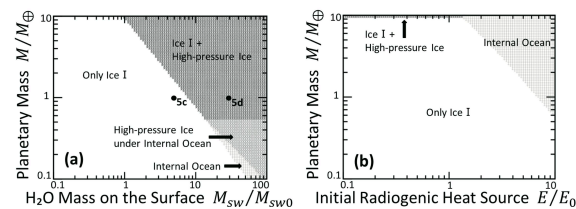
Introduction: A Deep-sea hydrothermal vents discharge subseafloor hot and reductive fluids into cool and oxidative seawater. The inter-fluidal oxidation-reduction potential substantially drives various abiotic and biotic oxidation-reduction reactions and supports chemosynthetic ecosystems in the mixing zones. It has been predicted that an electric current will be generated if the two solutions are connected by a conductor with electrodes. Here, we used in situ electrochemical analyses and installation of a fuel cell on the vents to demonstrate that deep-sea hydrothermal vents have the ability to generate electricity [1]. We successfully measured the oxidation-reduction potential (ORP) at high temperatures of approximately 309°C in deep-sea hydrothermal fluids (i.e., approximately -39 mV versus standard hydrogen electrode). Deffernce of ORP between the hydrothermal fluid and ambient seawater bridged was 0.52 V. We have provided the first evidence of in situ generation of electricity in a newly developed fuel cell installed in deep-sea hydrothermal vents and witnessed the illumination of a light emitting diode (LED) lamp in a dark deep-sea environment. Moreover, we have shown that sulfide minerals of chimney wall formed around the deep-sea hydrothermal vents have high electric conductivity and electro-catalytic activities [2]. These results suggest that hydrothermal vent chimney walls can generate a continuual flow of electrons from inside hydrothermal fluid to outside seawater. This implies that at least a portion of the chemolithotrophic microbial components living in chimney habitats may directly utilize the electrons transported from the hydrothermal fluids via the sulfide crystal network as not only the reductive electron donors but also an energy source. In addition, the potential electron transfer may be associated with the prebiotic synthesis of organic compounds in ancient deep-sea hydrothermal environments. This expectation of the electroecosystems will provide important insights into understanding of microbial ecosystems and chemical processes in the present and ancient deep ocean.
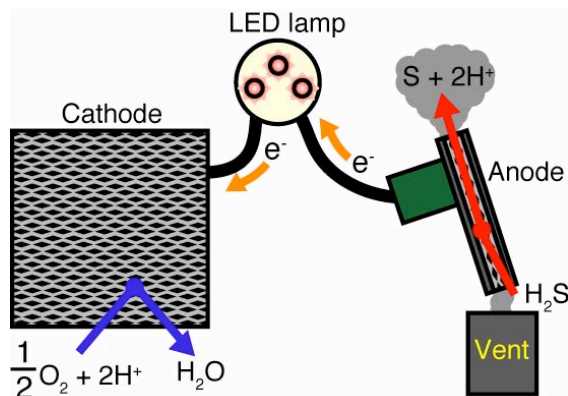
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TANPOPO: ASTROBIOLOGY EXPOSURE AND MICROMETEOROID CAPTURE, A SAMPLE RETURN EXPERIMENT TO TEST QUASI-PANSEPERMIA HYPOTHESIS ONBOARD THE ISS-KIBO EXPOSED FACILITY.

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Introduction and Mission Design: The origin of life is one of the most profound scientific quests to be challenged in this century. Yet we don't know if terrestrial life has been originated on the earth or in other parts of the solar system yet. On the other hand, it is known that "life precursors" or complex organic compounds are discovered both in molecular clouds nearby young stars and inside meteorites and cosmic dust, reaching to the earth from asteroids and comets.

Named after dandelion, a grass whose seeds with floss are spread by the wind, the TANPOPO is the first astrobiology experiment to be performed on a small pallet called "ExHAM" on the handrail of the ISS-Kibo Exposed Facility (EF) in the duration of 1-3 years starting from the 2014-5 timeframe, in order to test key questions consisted of the "quasi-panspermia" hypothesis, a theory for exogenesis origin of life and their transports among celestial bodies (Fig. 1) [1].

System Description: The TANPOPO employs blocks of uktra-low dense aerogels [2] on the Capture Panels (CP) that will be exposed and retrieved to capture impacting solid microparticles such as organic-bearing micrometeoroids and possible terrestrial particles in the low Earth orbit, for assessing the possibility of interplanetary transport of life and its precursors. By analyzing captured micrometeoroids in the aerogels, one can lear what kinds of extraterrestrial organic compounds in the pristine states inside micrometeoroids can be transported to the earth from primitive bodies and how they will be altered in outer space .

Once impacting microparticles of terrestrial origin impacted into the CPs, one can test if terrestrial microbes (e.g., aerosols embedding microbial colonies) may be present, even temporarily and in "freezed dry" form in the low earth orbit altitudes. Also by evaluating retrieved samples of exposed terrestrial microbes and astronomical organic analogs on the Exposure Pan-

els (EP), one can investigate their survivals and alterations in the duration of interplanetary transport.

Six Sub-Themes: The TANPOPO experiment consists of following six sub-themes (ST): 1) capture of microbes in space, 2) exposure of microbes in space, 3) exposure of organic compounds in space, 4) capture of organic compounds in micrometeoroids in space, 5) evaluation of ultra low-density aerogel developed for the Tanpopo mission, and 6) capture of space debris at the ISS orbit. Each will utlize one or more CP and EP samples from various pointing faces onboard the Ex-HAM as the ISS is a earth gravity gradient three-axis stabilized satellite (Fig. 2 and Table 1).:

(ST1:Terrestrial Life-bearing Aerosols Capture) Some research groups have conducted aerosol collections at high altitudes using balloons and aircraft. Microbes were isolated, suggesting their possible migration from ground to high altitudes. There has also been an unsolved discussion of how terrestrial microbial colonies embedded inside aerosols can escape to outer space. Potential candidates of the delivery mechanisms are energetic volcanic eruption, cloud-to-space electromagnetic discharges such as sprites, combined with the electromagnetic field around the earth, and occasional, large meteorite impacts. Microparticles captured in aerogels mainly on the leading and north faces will be microbiologically analyzed in order to test if the microbes may reach to the ISS orbit altitude. They will be observed under a fluorescence microscope in the presence of the DNA specific fluorescence pigment [3].

(ST2: Terrestrial Microbe Exposure) We will also expose UV-resistant and other terrestrial extremephile microbes on EPs and see how well they will survive in the low-earth orbit in a few years. We will analyze the survival of these microbes after transferring the exposed samples back to the ground laboratory.

(ST3: Astronomical Organic Analog Exposure) Life has evolved on the earth for ~4 billion years. Be-

fore the evolution of life, organic compounds were needed to accumulate on the terrestrial surface. One of the major sources of the organic compounds on the earth is micrometeoroids. Thus analogs of organic compounds known to exist in molecular clouds and meteorites will be exposed on EPs in order to see how much these organic compounds may be modified by the space environment. In order to assess properly synergy effects of the space environmental factors, both radiometers and thermometers will be exposed together with the EPs and identical blank samples will be kept in the Kibo Pressurized Facility (PF) in the same duration as the TANPOPO exposure.

(ST4: Organic-bearing Micrometeoroid Capture) This sub-theme will try to detect organic compounds in micrometeoroids in space to discuss whether IDPs containing prebiotic organic compounds migrate among solar system bodies. Captured particles and their penetration tracks in the aerogels will be offered for various analyses after retrieval to Earth. Samples will be analyzed for mineralogical and organic characteristics. [4].

(ST5: Lowest Density Space-borne Aerogel Verification) The aerogel to be used in the TANPOPO experiment is uniquely designed to capture microparticles at hypervelocity at the least alteration, in order to protect for organic and biological signatures as much as possible. Thus the bulk density of the upper part of this "double-layered" aerogel is ~0.01g/cc. The lower part of the aerogel is ~0.03g/cc. The upper layer is expected to capture microparticles at the least peak heat, while the lower layer should withstand shock and vibration during the launch a rocket and landing a return capsule. Ground impact calibration tests have been performed but the TANPOPO flight will be its first space proven opportunity.

(ST6: Orbital Debris Flux Evaluation) Space debris is a real, existing threat to the sustainable space program. The CPs will also capture sub-mm sized space debris in the ISS orbit, which are impossible to be observed by remote sensing, in the entire duration of its exposure operation. Mainly from the leading face capture, post-retrieval analysis will allow one to study flux, sizes, impact direction, approximate velocities of such micro-scale debris in the low earth orbit.

Initial Sample Analysis and Curation Plan: The TANPOPO-Initial Sample Analysis and Curation (ISAC) is planned and will be conducted by its Preliminary Examination Team (PET). The ISAC plan for CPs covers the receipt of retrieved samples, their initial inspection and documentation, processing and distribution of the samples for detailed analyses of each sub-themes, cataloging for data archiving and sample storage. For initial inspection and documentation, they will map and measure aerogel penetration tracks and cap-

tured particles (e.g., incoming angle, track depth and track volume). Then they will process keystones or quickstones containing microparticles to be inspected further and their penetration tracks for allocation to respective sub-theme researchers, in accordance with their requests for the subsequent detailed analyses.

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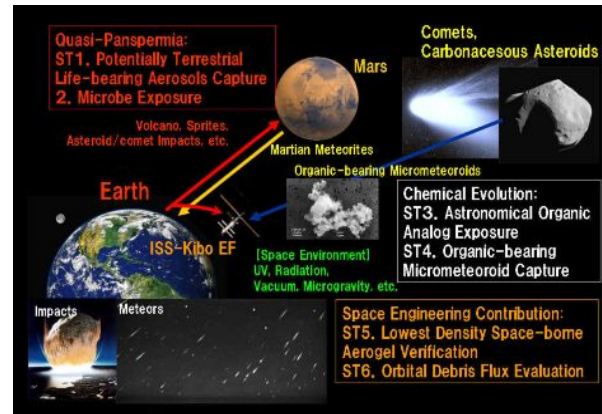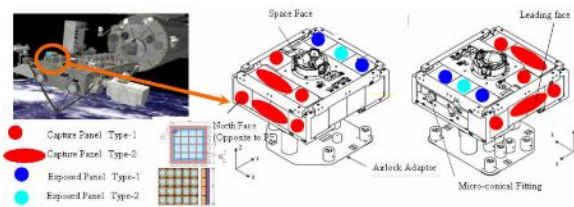

Fig.1 Concept of the Tanpopo Experiment

Fig.2. Tanpopo Configuration onboard the ExHAM attched to the ISS-Kibo ExFosed facility

Table 1. Tanpopo Sub-themes and Experiment Conditions (*= Anti-Pressurized Facility face)

Sub-themes	Main Exposed Faces	Panels	Exchange frequency
ST1: Potentially Terrestrial Life-bearing Aerosols Capture	Leading, North*	Capture	Every year, x3 times
ST2: Terrestrial Microbe Exposure	Space	Exposure	1 tray after 1st, 2nd, 3rd years
ST3: Astronomical Organic Analog Exposure	Space	Exposure	1 tray after 1st, 2nd, 3rd years
ST4: Organic-bearing Micrometeoroid Capture	Space, North*	Capture	Every year, x3 times
ST5: Lowest Density Space-borne Aerogel Verification	Space, Leading, North*	Capture	Every year, x3 times
ST6: Orbital Debris Flux Evaluation	Leading, North*	Capture	Every year, x3 times

Moelcular Phylogenetic Analyses of G1P Dehydrogenase and G3P Dehydrogenase Suggest the Late Origin of Archaea-Type Membrane

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Introduction: All extant terrestrial life is classified into three domains, Bacteria, Archaea, and Eukarya, although the relationship among three domains is still under debate [1-3]. The membrane component before the appearance of Bacteria and Archaea is one of the foci of the argument, because membrane lipids that divide inside and outside of the cell are essential for life [4-5].

Various lipid structures are found in the three domains. However, all cellular organisims have a glycerol backbone as the common structure, with the exception of the stereostructure. The stereostructure of the glycerol backbone in polar lipids of Bacteria and Eukarya is *sn*-glycerol-3-phosphate (G3P), while in polar lipids of Archaea, it is *sn*-glycerol-1-phosphate (G1P) [5-6]. G3P and G1P are generated from dihydroxyacetone phosphate (DHAP) by different enzymes: G3P dehydrogenase (G3PDH) and G1P dehydrogenase (G1PDH), respectively. There is no sequence similarity between G3PDH and G1PDH at gene and protein levels. It was proposed that division of Bacteria and Archaea have been caused by the cellularization with different type of membrance lipids synthesized by G3PDH and G1PDH with different origins [6].

Wächtershäuser proposed a model [7] that incorporated the Koga model [6] and the precell theory [8]. In his hypothesis, in the earliest stage, precell had heterochiral membrane lipids. Under the assumption that the homochiral membrane is more stable than heterochiral membrane, the heterochiral membrane is thought to have evolved toward homochiral membrane. After invention of G3PDH in the cells with G3P-rich membrane, Bacteria was thought to have appeared. After invention of G1PDH in the cells with G1P-rich membrane, Archaea was thought to have appeared. However, Shimada and Yamagishi suggested that the membrane with heterochiral lipids is stable as that with homochiral lipids [9]. This suggests that the cells with the membrance with heterochiral lipids could have existed not only in the earliest cellular stage but also in later stages. For example, the replacement of the membrane with G1P by that with G3P, or the replacement of the membrane with G3P by that with G1P, could occurred during the evolution of cellular cells, and could directly been related to the origin of either of Bacteria and Archaea.

Proteins with G1PDH activity have been reported from certain bacterial lineage [10-11]. If they were not originated by the horizontal gene transfer from arachaeal species after the separation of Bacteria and Archaea, the common ancestor of Bacteria and Archaea (or LUCA/Commonote) could have had G1P in its membrane. Proteins with G3PDH activity have also been reported from certain archaeal lineage [12]. If they were not originated by the horizontal gene transfer from bacterial species after the separation of Bacteria and Archaea, the common ancestor of Bacteria and Archaea (or LUCA/Commonote) could have had G3P in its membrane.

To understand the early evolution of cellular membrane, we reconstructed the molecular phylogenetic trees of G1PDH and G3PDH separately. First, we collected G1PDH and G3PDH sequences from Bacteria and Archaea together with the sequences of their homolog proteins. G1PDH and its homolog protein sequences were aligned carefully, and then used for the maximum likelihood (ML) analysis and Bayesian (BI) analysis. G3PDH and its homolog protein sequences were also used for similar phylogenetic analyses.

Results and Discussion: The ML and BI analyses suggested that the bacterial G1PDHs were originated from crenarchaeal G1PDHs by the horizontal gene transfer. However, archaeal G3PDHs form the separate group from bacterial G3PDHs.

Our phylogenetic analyses of G1PDH and G3PDH suggested that the common ancestor of Bacteria and Archaea (or LUCA/Commonote) had cellular membrane with G3P that were formed by G3PDH. During the appearance of Archaea, G1PDH was acquired by the archaeal ancestry, and then the membrane with G3P was replaced with that with G1P. Since the heterochiral membrane may not be unstable [9], the period with heterochiral membrane might have existed during the establishment of Arcahea, even though Arcaeal common ancestor is thought to have been thermophile/hyperthermophile [13].

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The possible interplanetary transfer of microbes: Assessing the viability of *Deinococcus* spp. under the ISS environmental conditions for performing exposure experiments of microbes in the Tanpopo mission.

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Introduction: The possibility of transfer of life between the Earth and exterrestrial has been proposed by Arrenius in 1908 [1]. The transfer prosess is called "panspermia". To investigate the panspermia hypothesis, numerous exposure experiments have been carried out on various some organisms e.g., spores of *Bacillus* spp. and the lichens, in space since 1960's [2]. The results suggested that some organisms might survive for a long period if the organisms are shielded from intense solar radiation [3, 4]. We have proposed to carry out the experiments on capture and space exposure of microbes at the Exposure Facility of Japanese Experimental Moduke of International Space Station (ISS) — Tanpopo mission [5]. Microbial candidates for the exposure experiments in space include *Deinococcus radiodurans*, *D. aerius* and *D. aetherius*. We have examined the survivability of *Deinococcus* spp. under the environmental conditions on ISS in orbit (i.e., long exposure to heavy-ion beams, temperature cycles, vacuum and UV irradiation).

Results and Discussion:

Among the space environmental factors, the solar UV is most lethal to microbes, and this UV correlated with this absorption wavelength of DNA. In this report, we examined the effect of solar UV radiation (172 nm, 254 nm respectively) on the deinococcal cell aggregates with different thicknesses to determine whether the size of the cell aggregate influences the cell survivability. Though the cells in thin layers of aggregates were killed by UV $_{172\ nm}$ radiation, large number of cells survived the radiation when the cell layer was thick (Fig. 1). The similar trend of survivability was observed for UV $_{254\ nm}$. Considering with these results, the submillimeter-sized aggregate cells that are sufficient to shield the cells in the inner layer from solar UV radiation after one-year exposure.

A One-year dose of heavy-ion beam irradiation (< 1 Gy) did not affect the viability of *Deinococcus* spp.
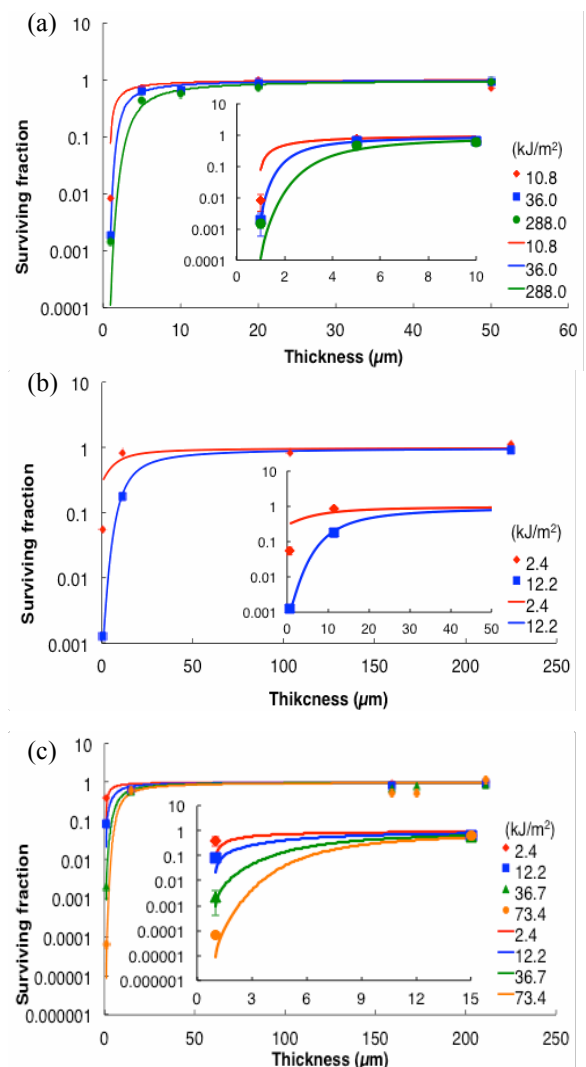

Fig. 1. Survival curves of *D. radiodurans* (a), *D. aerius* (b) and *D. aetherius* (c) following exposure to different doses of VUV$_{172}$ nm radiarion ubder vacuum.

within the detection limit. Vacuum (10^{-1} Pa) also had little effect on the cell viability. Experiments to test the effects of changes in temperature from 80 $^{\circ}$C to –80 $^{\circ}$C in 90 min (± 80 $^{\circ}$C/90 min cycle) or from 60 $^{\circ}$C to –60 $^{\circ}$C in 90 min (± 60 $^{\circ}$C/90 min cycle) on cell viability revealed that the survival rate decreased severely by the ± 80 $^{\circ}$C/90 min temperature cycle.

The survivability of *Deinococcus* spp. after one-year in space was estimated by multiplying the survival rates after one-year exposure of heavy-ions, γ ray, temperature changes, vacuum and UV radiation. *D. aerius* cells will be killed when the temperature fluction is ± 80 $^{\circ}$C/90 min cycle, but the would survive if the temperature fluctuation is less than ± 60 $^{\circ}$C/90 min cycle. Based on our results, *Deinococcus* spp. could be suitable candidate microes for ecposure experiment in Tanpopo mission.

Conclusion:

From our results, we would like to emphasize the importance of microbial cell-aggregates as an ark for interplanetary transfer of microbes. We call this consept 'massapanspermia' [6]. The proposed experiment for the Tanpopo mission enhances the possibility that this massapanspermia concept might be true.

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