Annual Report of the Astrobiology Center, National Institutes of Natural Sciences

Volume 1, Fiscal 2015-2017

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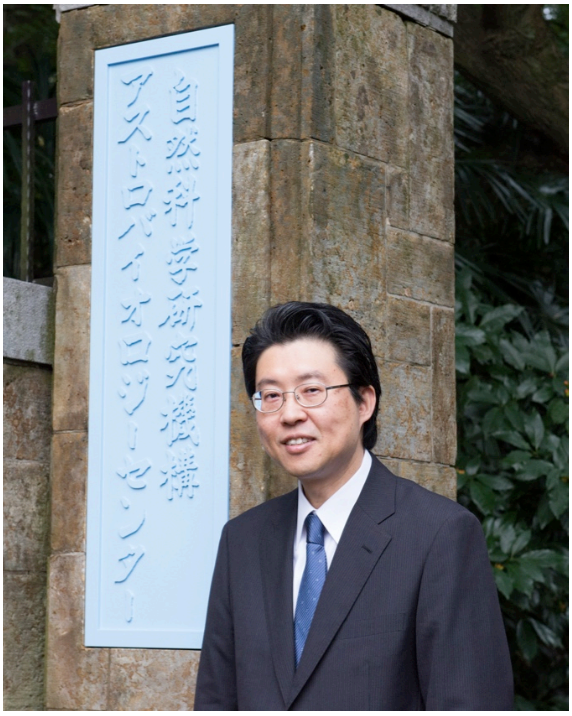
PREFACE



Astrobiology is a new discipline that searches for places in the universe that can accommodate life—in addition to the existence of life itself—and discusses the origins and evolution of life without fixating solely on the Earth. It is regarded as an extremely wide-ranging interdisciplinary subject, spanning fields including astronomy, planetary science, biology, biochemistry, earth science and engineering.

With the considerable progress over the last roughly 20 years in the search for planets existing outside of the solar system (exoplanets), the field has matured rapidly over the past 10 or so years, enabling the scientific discussion of life in the “New World” of exoplanets, of which a countless number exist in the universe. In fact, several thousand exoplanets have already been discovered and verified, and estimates based on the latest Kepler satellite data suggest the ratio of planets in the habitable zone around solar-type stars, where the existence of life is possible, to be as high as approximately 10%. As things stand, we can confidently say that the era of astrobiology has begun.

Amid these circumstances, the National Institutes of Natural Sciences established a new institute, the “Astrobiology Center” in April 2015, with the stated aim of developing the field of astrobiology, with a focus on exoplanet research. To fulfill its role as an inter-university research institute, the Astrobiology Center will encourage applications for satellite project studies for developing the diverse relevant sectors within Japan, expand the foundations and range of astrobiology and promote collaboration with organizations abroad, as well as take responsibility for efforts that are difficult to implement in a university laboratory, such as the development of large-scale equipment for astrobiology.

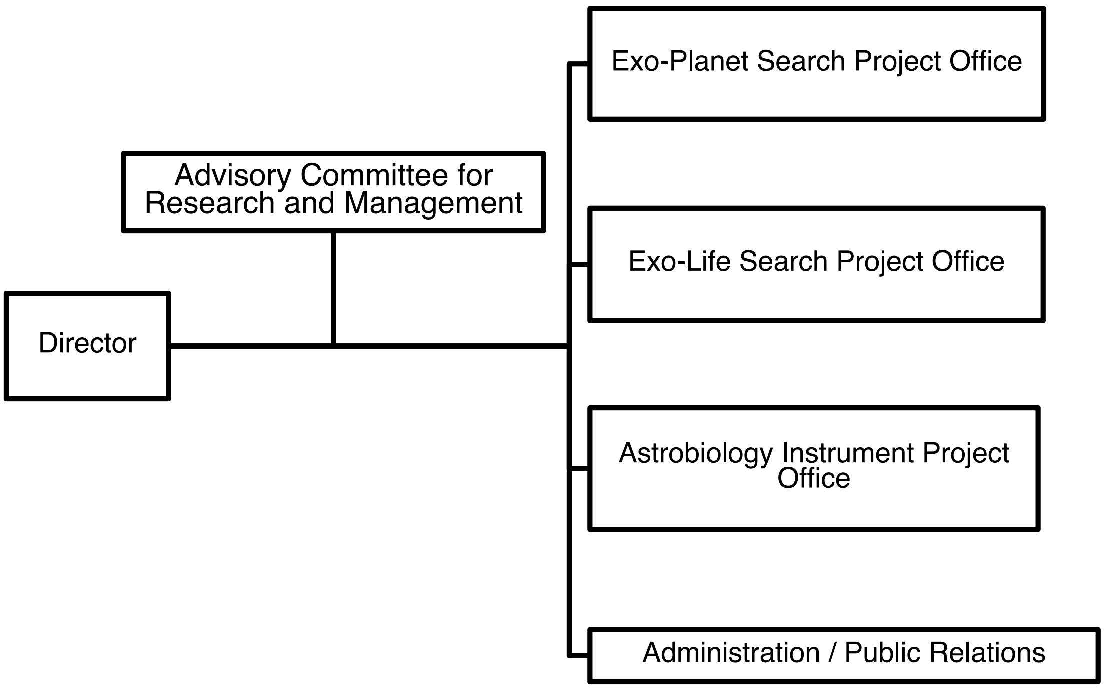
The Astrobiology Center is made up of three project laboratories: the Exoplanet Exploration Project Office, the Space Life Search Project Office and the Astrobiology Instrument

Development Office. It also plays a vital role in furthering development of the exoplanet research to date. The Strategic Explorations of Exoplanets and Disks with Subaru Telescope (SEEDS) Project that used the High Contrast Instrument for the Subaru Next Generation Adaptive Optics (HiCIAO) camera on the Subaru Telescope brought success in the direct imaging of "Second Jupiters" and many "planetary nurseries". In addition, it brought about the collaborative development and start of operations of the next-generation adaptive-optics-based instrument of the Subaru Coronagraphic Extreme Adaptive Optics (SCExAO), and the integral-field spectrometer for exoplanet observation, Coronagraphic High Angular Resolution Imaging Spectrograph (CHARIS). Both of these results served as proof of the core technology to refine the direct imaging and spectroscopy of earth analogs via similar methods with the forthcoming Thirty Meter Telescope (TMT). The design and development of equipment for this was an important challenge for the Center. In addition, plans are in progress to commence searching for Second Earths around lightweight stars (a different environment from stars like our Sun) very close by, using a new, high-precision infrared Doppler (IRD) spectrograph with the Subaru Telescope, which are not even clear yet with the Kepler satellite. What would life be like in a different environment such as this? One cannot fail to be intrigued.

Motohide Tamura
Director General
Astrobiology Center

1. Organization

1-1 Astrobiology Center



1-2 Number of Staff Members

FY2015

(2016.3.31)

Regular Employees	Director		1
	Executive Director		1
	Research and Academic Staff		2
		Assistant Professor	2
	Employees on Annual Salary System		5
		Special Professor	1
		Specially Appointed Assistant Professor	3
		Specially Appointed Senior Specialist	1
Fixed-term Employees	Part-time Contract Employees		2

2. Status Reports of Research Activities

In April 2015, Astrobiology Center (ABC) was established as international collaborative research base under the direct control of the National Institutes of Natural Sciences (NINS). This center is a mission to focus on “Astrobiology” aiming to confirm the existence of life in the universe with a view to the observations of the next generation ultra large telescope such as TMT. In addition to invite foreign researchers, we collaborate with relevant organizations and universities including National Institute for Basic Biology (NIBB), and promote international and advanced collaborative research. In November 2015, we held the opening ceremony.

In 2015, ABC started with two project office, Exo-Planet Search Project Office and Astrobiology Instrument Project Office. Exo-Life Search Project Office was started in 2016 and we promote research and development with three project offices. The outline of ABC’s activities from FY 2015 to 2017 is as follows.

a) Exo-Planet Search Project Office

This office promotes Exo-planet direct imaging using Subaru telescope and maintain/operate their instrument. They are also promoting observations of birthplace of planets using ALMA telescope. As a result of these observations, we published many refereed papers.

b) Astrobiology Instrument Project Office

Development of exoplanet instruments, IRD, MuSCAT, MuSCAT2, SCExAO and CHARIS.

c) Exo-Life Search Project Office

Research for photosynthesis of in exoplanets around red-dwarf’s habitable zone and promote cross-discipline workshop collaboration research.

d) ABC Grants

Single-year grants and Multi-year grants. These results were presented in the “Life in the Universe Workshop” on the end of fiscal year.

e) Cross-Appointment foreign researchers

Astrobiology Instrument Project Office:

Olivier Guyon, The University of Arizona (since 2016)

Exo-Life Search Project Office:

Victoria Meadows, University of Washington (since 2017)

f) International Collaborations

Consortium of Astrobiology Center and Earth-Life Science Institute

International partner with NASA Astrobiology Institute (NAI)

MOU with Instituto de Astrofisica de Canarias (IAC), Spain

g) Publications

"Collected Papers of the Subaru SEEDS Project" includes 57 papers.

h) Public relations

Open campus with National Astronomical Observatory of Japan and NINS

Symposiums.

3. Scientific Highlights

(2015.04 ～ 2018.03)

	Title	Author
1	Complete the SEEDS project main survey	Tamura, M.
2	New IR Instrument Searches for Habitable Planets	Kotani, T.
3	Red-edge position of habitable exoplanets around M-dwarfs	Takizawa, K.
4	Oxygen is not Definitive Evidence of Life on Habitable Extrasolar Planets	Narita, N.
5	Performance Evaluations of Subaru Telescope's Near-Infrared High-Precision Doppler Velocimeter, InfraRed Doppler (IRD)	Kuzuhara, M.
6	Planetary Systems in Clustered Environments	Hori, Y.
7	Theoretical search for photosynthetic pigments applicable around M dwarfs by quantum chemistry	Komatsu, Y.
8	The formation process of interstellar glycine	Suzuki, T.
9	Deconvolution with model-fitting in ALMA disk observations	Hashimoto, J.
10	Discovery of a Disk Gap Candidate at 20 AU in TW Hya	Akiyama, E.
11	A Substellar Companion to Pleiades HII 3441	Konishi, M.
12	Carbon-to-Oxygen Rations in M Dwarfs and Solar-type Stars	Nakajima, T.
13	Distortion of Magnetic Fields in a Starless Core III: Polarization--Extinction Relationship in FeSt 1-457	Kandori, R.

SEEDS Project Successfully Completed

Motohide Tamura (Astrobiology Center/The University of Tokyo/National Astronomical Observatory of Japan), and
The SEEDS Project Team

The SEEDS project (Strategic Exploration of Exoplanets and Disks with Subaru), which was first approved as the Subaru Strategic Program, started on a full scale in 2009. A total of 120 nights were allocated to the SEEDS project on Subaru/(Hi)CIAO. Over 120 people in 35 universities/institutions, 80 of which were Japanese researchers, were involved in the SEEDS project as part of an international collaboration project using Subaru telescope. This project was specifically designed to survey planets around ~ 500 relatively-young stars (Sun-like stars and more massive ones) aged < 1 Gyr. The SEEDS survey was successful in directly imaging four wide-orbit giant planets/candidate planets (see Figure 1): i) a 10–30 Jupiter-mass planet ($M_{\rm Jup}$) with an apparent semi-major axis of 29 au around GJ 758 (G9-type, $1\,M_{\odot}$), ii) a $12.8\,M_{\rm Jup}$ planet around an intermediate-mass star κ Andromedae (B9-type, $2.5\,M_{\odot}$), iii) a 3–$4.5\,M_{\rm Jup}$ planet orbiting a Sun-like star GJ 504 (G0-type, $1.2\,M_{\odot}$), and iv) a planetary/substellar-mass object with $< 15\,M_{\rm Jup}$ orbiting a 5-10 Myr-old Herbig Be star HD 100546.

Another important mission of the SEEDS project was to explore disk structures such as spiral patterns and gap structures around young stars, leading to a better understanding of the relationship between disk morphology and formation of distant planets. SEEDS observations using Subaru/(Hi)CIAO were capable of unveiling disk structures in an outer region where giant planets form around young stars. In fact, we got better results of disk images around nearby stars than disk observations using other 8m-class telescopes. We revealed detailed structures of protoplanetary/debris disks around T-Tauri stars and Herbig Ae/Be stars (see Figure 2).

The SEEDS project successfully finished in 2015 when Astrobiology Center was newly established as the 3rd research center of National Institutes of Natural Sciences. We completed planet surveys and disk exploration around ∼500 objects and published in total 57 refereed papers on SEEDS results (see also "Collected Papers of the Subaru SEEDS Project".)

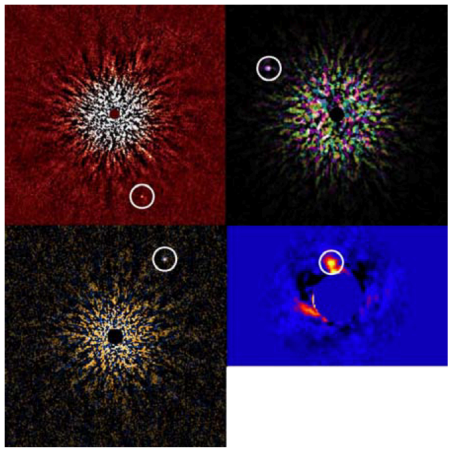


Figure 1: Planets/candidate planets directly imaged by the SEED project (the top-left:GJ 758b, top-right:κ And b, bottom-left:GJ 504b, and bottom-right:HD 100546b)

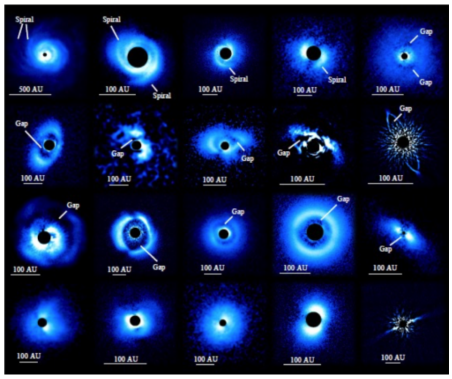


Figure 2: Polarized scattered light images of disks revealed by SEEDS direct-imaging surveys

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New IR Instrument Searches for Habitable Planets

Kotani,T., and IRD team

Astrobiology Center has developed a new instrument for exoplanet exploration, InfraRed Doppler (IRD), which is used on the Subaru Telescope. We needed 8 years in total, to design, develop, manufacture, test, and install IRD. Consequently, we had the first light of the IRD spectrometer on August 2017. Furthermore, it is capable to use the spectrometer together with the IRD ' s laser frequency comb since February 2018.

It has been ever challenging to perform precision Doppler velocimetry for late M-type stars, which however is now enabled by IRD. While a low probability of exoplanet detection using the transit technique makes it impractical to find a habitable exoplanet around nearby late M-type stars, the Doppler technique is less influenced by this problem, allowing us to effectively search for habitable planets in the solar neighborhood.

IRD has three advantages to detect small planets: (1) its stable spectrograph that can simultaneously covers a very wide wavelength range with a high wavelength resolution, (2) a laser frequency comb that works as a high-precision ruler to measure stellar velocities, and (3) mode scramblers that mimics the light fluctuation causing the velocimetry instability. In addition, the Subaru Telescope's large mirror is ideal to gather a number of photons even from late M-type stars that are faint compared with other main-sequence stars. Furthermore, infrared observation is the best for late M-type stars due to their low temperatures, two times cooler than sun-like stars. Accordingly, the use of IRD with the Subaru Telescope works as the most powerful choice for revealing habitable planets around late-M type stars with the Doppler technique.

In the first-light observations, we used IRD's high-dispersion spectrograph and laser frequency comb for velocity measurements. Both the spectra of an observed star and that of a laser frequency comb are simultaneously imaged as shown in Figure 2, where the dots correspond to the spectrum of laser frequency comb and the lines correspond to the observed star. The dots make a role as a precise and stable ruler to measure the movements of stellar spectra. This function has been rarely used and a new technology for high-precision Doppler velocimetry.

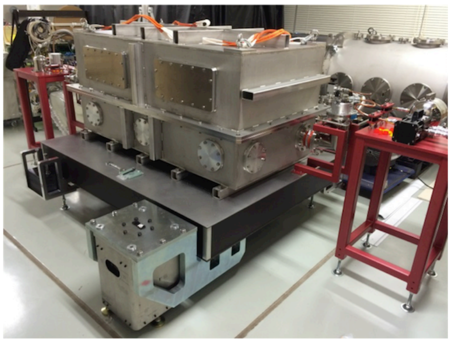

Figure 1: IRD.

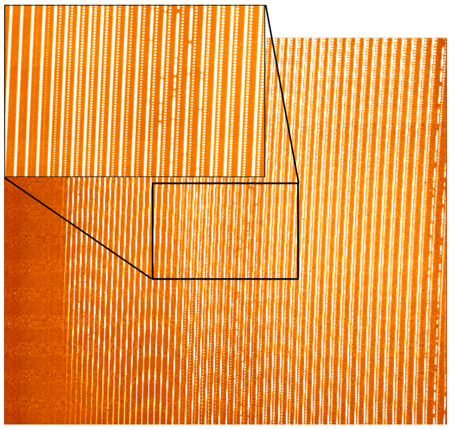

Figure 2: Test observation of a red dwarf. Comparing the star ' s spectrum (broken line) to the laser frequency comb (dots) allows researchers to calculate the motion of the star.

References

[1] ABC press release, http://abc-nins.jp/press/20180702/20180702_IRD_Abs.html.

Red-edge position of habitable exoplanets around M-dwarfs

Kenji Takizawa et. al.
(Astrobiology Center/National Institute for Basic Biology)

M-dwarfs have lower mass and lower surface temperatures than Sun, and the most abundant around neighboring stars. It is relatively easier to search for habitable planets and expected as the first candidate for discovering biosignatures from extraterrestrial life. One of the most important biosignatures on an exoplanet is a specific reflection pattern of vegetations named 'vegetation red-edge (VRE)'. On Earth, VRE appears between visible light, which is absorbed by photosynthetic pigments, and near infrared (NIR) radiation, which is reflected via leaf structure. In previous reports, it was predicted that VRE could be red-shifted around M-dwarfs since phototrophs on the exoplanet should use abundant NIR radiation (upper right graph in Figure 1), while the VRE wavelength positions is not obvious from the radiation spectrum of M-dwarfs.

We estimated the light conditions expected on habitable planets around an M-dwarf and predicted the most plausible photosynthetic wavelength. Assuming that an Earth-like planet is located in the habitable zone around AD Leo, light conditions on the land surface and under water were estimated and compared with solar irradiation on Earth. The land surface of the M-dwarf planet is illuminated by strong NIR-radiation, and phototrophs productivity can be maximized when they use NIR radiation up to 900 nm or 1,100 nm. On the other hand, Earth-like conditions are expected under water since only blue-green light can penetrate meters of water. If the origin of life and/or its evolution is placed underwater, Earth-type oxygenic photosynthesis can evolve on exoplanets around M-dwarfs.

The adaptive evolution of phototrophs from water to land can eventually use NIR radiation by one of the two photochemical reaction centers, with the other reaction center continuing to use visible light. These 'two-color' reaction centers can absorb more photons, but they will produce harmful reactive oxygen species when they are not equally exited. We examined intermediate lighting conditions in shallow water and how phototrophs might adapt to it. A seamless transition from water to land could be achieved if three factors were in place: a small difference in the radiation spectrum between land surface and underwater, a small difference in the light excitation spectra between the two reaction centers, and a flexible antenna regulation mechanism to balance light excitation of th

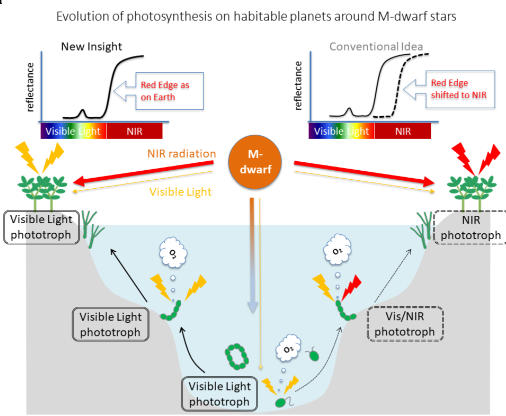

Figure 1: Conventional prediction of shifted red-edge (right half) and a novel concept of rigid red-edge (left half).

On Earth, environmental and biological conditions meet all factors. Although the difference in the radiation spectrum is larger on habitable exoplanets around M-dwarfs, the same evolutionary path may also occur if two reaction centers use only visible light and the antenna regulation mechanism is effective. 'Two-color' reaction centers will encounter difficulty in adapting to drastically changing light at the boundary between land and water. Thus, the first land plants on M-dwarf planets should use visible light and VRE position is similar to that on Earth (upper left graph in Figure 1). Our studies imply that VRE is a universal biosignature for life originated underwater.

References

[1] Takizawa, K., et al.: 2017, *Scientific Reports*, **7**, 7561.

Oxygen is not Definitive Evidence of Life on Habitable Extrasolar Planets

Narita, Norio[1,2], Enomoto, Takafumi[3], Masaoka, Shigeyuki[3], Kusakabe, Nobuhiko[1,2]

1:Astrobiology Center, 2:National Astronomical Observatory of Japan, 3:Institute for Molecular Science

The Earth's atmosphere contains oxygen because plants continuously produce it through photosynthesis. This abundant supply of oxygen allows life forms like animals to flourish. Therefore, oxygen had been thought to be an essential biomarker for life on extrasolar planets. However we have presented a novel hypothesis that it could be possible for planets to have large quantities of abiotic (non-biologically produced) oxygen. This study is a good example of interdisciplinary studies that combine knowledge from different fields of science to promote astrobiology in the search for life on extrasolar planets.

Until now, it had been thought that if a planet has oxygen atmosphere, that must mean that some form of plants are producing it through photosynthesis. Therefore, it had been assumed that when searching for signs of life on habitable extrasolar planets, the presence of oxygen in the atmosphere could be considered as a definitive biomarker. However, non-biological chemical reactions can also affect atmospheric compositions of extrasolar planets. In this work, the team has shown that, abiotic oxygen produced by the photocatalytic reaction of titanium oxide (TiO_2), which is known to be abundant on the surfaces of terrestrial planets, meteorolites, and the Moon in the Solar System, cannot be discounted.

For a planet with an environment similar to the Sun-Earth system, continuous photocatalytic reaction of titanium oxide on about 0.05 % of the planetary surface could produce the amount of oxygen found in the current Earth's atmosphere. In addition, the team estimated the amount of possible oxygen production for habitable planets around other types of host stars with various masses and temperatures. They found that even in the least efficient production case of a low-temperature star, the photocatalytic reaction of the titanium oxide on about 3% of the planetary surface could maintain the level of the current Earth's atmospheric oxygen through abiotic processes. In other words, it is possible that a habitable extrasolar planet could maintain an atmosphere with Earth-like oxygen, even without organisms to perform photosynthesis.

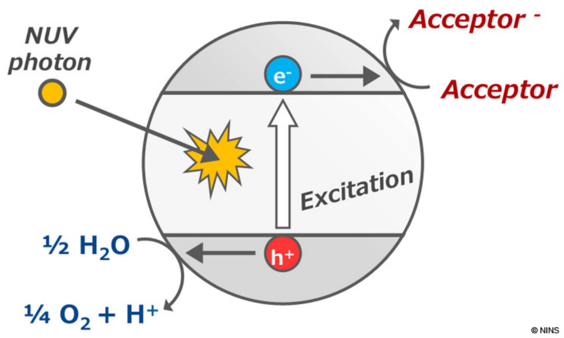

Figure 1: Photocatalytic Reaction of Titanium Oxide. Abiotic oxygen can be produced from water in the presence of titanium oxide and an electron acceptor under UV light. Our report suggests that this photocatalytic reaction can supply significant amount of abiotic oxygen on habitable extrasolar planets.

To search for life on extrasolar planets through astronomical observation, we need to combine the knowledge from various scientific fields and to promote astrobiology researches to establish the decisive signs of life. Although oxygen is still one of possible biomarkers, it becomes necessary to look for new biomarkers besides oxygen from the present result.

References

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[2] Ohno, T., et al.: 1997, *The Journal of Physical Chemistry B*, **101**, 10605.

Performance Evaluations of Subaru Telescope's Near-Infrared High-Precision Doppler Velocimetry Instrument, InfraRed Doppler (IRD)

KUZUHARA, M.[1,2], HIRANO, T.[3], KOTANI, T.[1,2,4], ISHIZUKA, M.[5], OMIYA, M.[1,2], KONISHI, M.[1,2], KUDO, T.[6], NISHIKAWA, J.[2,4,1], UEDA, A.[2,4], HOSOKAWA[2,4], K., KUSAKABE, N.[1,2], KUROKAWA, T.[1,2,7], KOKUBO, T.[7], MORI, T.[7], TANAKA, Y.[7], JACOBSON, S.[8], HODAPP, K.[8], TAMURA, M.[5,1,2],

1: NINS, Astrobiology Center, 2: NAOJ, 3: Tokyo Institute of Technology, 4: SOKENDAI, 5: University of Tokyo, 6: Subaru Telescope, 7: Tokyo University of Agriculture and Technology, 8: Institute for Astronomy, University of Hawaii

Exoplanet observations help us study the planet formation and evolution, as well as life on planets other than Earth. Especially, rocky planets around cool M-type stars are promising to better comprehend how low-mass planets such as Earth form and evolve, and their habitability. IRD[1] is available on Subaru Telescope since 2017. We have developed IRD to search for exoplanets orbiting cool M-type stars via the Doppler technique. The combination of Subaru Telescope's significant light-gathering power and IRD's high-precision Doppler-velocity measurements allows a great contribution on the planet survey for cool M-type stars.

Before we use IRD for on-sky observations on Subaru Telescope, we repeated the laboratory tests of IRD at IfA of Hawaii University and Subaru Telescope in 2016–2018, to verify its performance. The results of those tests were utilized as the fundamental resource to infer the outcomes of our planning planet survey with IRD. Also, those performance evaluations were reported with the IRD's early on-sky engineering observations at the SPIE's international conference and its proceedings[2].

Here we report a part of the performance tests that we carried out for IRD. Detector's noise is one of the sources that determine the precision of Doppler observations, and it is crucial to make the noise lower for the observations of faint objects like cool M-type stars. Accordingly, we attempted to estimate and decrease the noise produced by the IRD's infrared detectors. As a result, we found that it is possible to suppress the readout noise of IRD detectors to the level equal to 10–15 e^-, which is as low as the requirement for our planning planet survey. Furthermore, we tested the precision and stability of IRD Doppler-velocity measurements, by measuring the velocities of the spectra of IRD's laser frequency comb (LFC) over weeks. We use LFC to calibrate IRD velocity measurements; both an object spectrum and an LFC spectrum are simultaneously taken in one exposure to derive a relative velocity between those. We applied this calibration process to the velocity measurements of two simultaneously-observed LFC spectra, so the stability of those measurements were estimated to be about 1 m s^{-1} (see Fig. 1). In addition, we conducted the other tests to evaluate the error sources that are difficult to be examined by the above test; the total IRD's instrument stability can be expected to be 2 m s^{-1} or better (see [2] for detail). The laboratory tests are planned to be continued as well as the on-sky engineering observations to refine the IRD performance verifications.

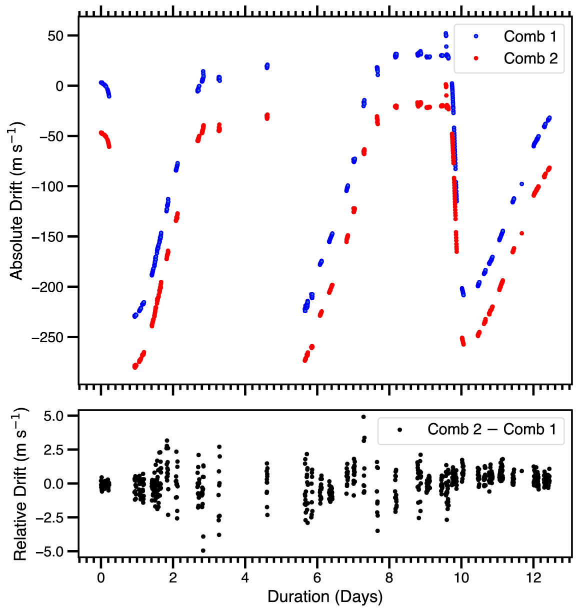

Figure 1: Results of the laboratory verifications based on the LFC spectra obtained in January, 2018. (Top panel) Absolute velocity variations of LFC spectra simultaneously obtained with two fibers over about 13 days are displayed. Artificial offset of -50 m s^{-1} were added to the original data of one fiber, to distinguish those from the ones with the other fiber. (Bottom panel) Relative velocity variations calculated by taking the differences of two-fiber measurements are shown. The similar calculations are applied to on-sky observations. The measurements in this figure are the same as in [2].

References

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Planetary Systems in Clustered Environments

Yasunori Hori
(Astrobiology Center)

An extremely low-temperature gaseous clump, the so-called molecular cloud, gravitationally collapses, leading to star formation. Most of stars are believed to form in a cluster environment [1]. Near-infrared surveys indicated that the majority of stars are born in embedded clusters inside molecular clouds, which are typically composed of a few hundred of stars. Stars, which are currently seen in the field, are likely to have resided in a star cluster. In fact, our Sun was also likely born in a star cluster. Records of radiogenic ^{60}Ni contained in chondritic meteorites prove the high initial abundance of a short-lived radionuclide (SLR), ^{60}Fe. This evidence requires injection of SLRs, including ^{26}Al, ^{36}Cl, ^{41}Ca, and ^{53}Mn, from nearby stellar sources before the birth of the Solar System and/or during the epoch of planet formation; for example, AGB stars, Wolf-Rayet stars, and Type II supernovae [2].

Advances in optical and infrared detection capabilities over the past 20 years have allowed us to find small planets with masses or radii comparable to the Earth and directly image giant planets in wide orbits beyond 10 au. Since the first discovery of an exoplanet in 1995, the existence of nearly 4,000 exoplanets has been reported. Almost all of the exoplanets that we discovered orbit around field stars. A number of surveys have monitored stars in young, metal-rich open clusters in order to explore the planet population in star clusters. However, the discovery of only ∼30 planets in five open clusters (the Hyades, Praesepe, M67, IC 4652, and NGC 6811) has been reported (e.g.[3]).

As a crucial difference between stars in the field and those in a star cluster, close encounters between a star and a planetary system frequently occur in a clustered environment. A stellar encounter event can perturbs orbital motion of planets (e.g.[4]) or liberate planets from their host stars; especially, a wide-orbit planet such as Uranus and Neptune in the solar system can be readily ejected from the system (e.g.[5]). We focus on gravitational interactions between a planet-hosting star and an intruding star in a star cluster, and examine how stellar encounters in a clustered environment can influence dynamical stability and detectability of planets in open clusters [6], using a series of N-body simulations.

Strong stellar encounters that can destroy a planetary system happen around a few Myr–10 Myr after a star cluster begins to evolve dynamically, as seen in Figure 1. Close-in planets within 1 au and planets with 1–10 au are rarely ejected by stellar encounters in clustered environments, whereas planets beyond 10 au get liberated through stellar encounters and eventually escape from a star cluster. The results obtained by microlensing surveys toward the Galactic Bulge suggest that the frequency of free-floating Jovian planets are less than 0.25 planets per main-sequence star [7]. The production rate of free-floating gas giant planets (FFPs) per star is estimated to be 0.0096–0.18 in our study. The expected frequency of FFPs is compatible with the upper limit on that of FFPs indicated by recent microlensing surveys.

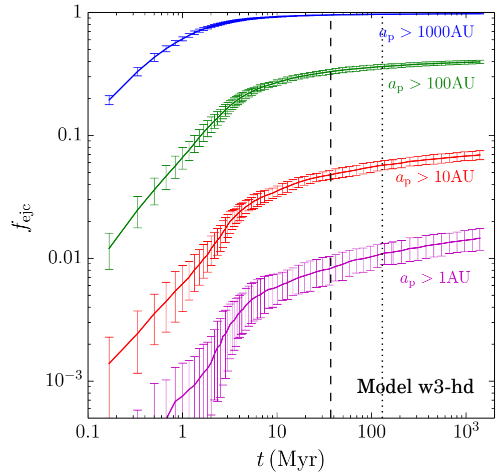

Figure 1: Ejection rates of planets that reside in a clustered environment as a function of time. Each curve represents ejection rates of planets that initially orbit beyond 1 au, 10 au, 100 au, and 1,000 au.

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Theoretical search for photosynthetic pigments applicable around M dwarfs by quantum chemistry

Yu Komatsu
(Astrobiology Center)

In order to discover planets which harbour lives, it will be a significant achievement to identify surface vegetation as a potential biosignature, which is a trace of life from planetary spectra. When we assume living organisms in an exoplanet, in term of gaining their essential energies, there is no reason why they don't utilize effectively the available light from the primal star. Planets around M dwarfs, which have lower effective temperatures than the Sun have been focused on current observations, and their vegetation would exhibit different spectral features from the Sun. Recently, an interesting example has been discovered that a cyanobacteria, which are categorized into oxygenic photosynthetic bacteria, becomes to utilize longer wavelength radiation for photochemistry than previously known, after grown under near infrared light (750 nm) [1]. Accumulating the knowledge from various points of view would lead to implications for future observations.

Photosynthetic pigments like chlorophylls play the central role to convert available light energies into chemical energies. Chlorophyll has a tetrapyrrole ring, which consists of four pyrroles. In the center of the ring, it posses a metal ion such as Mg.

In this study, we investigate thoroughly physical chemical properties of photosynthetic pigments and artificial pigments which may form on early Earth or other planets to unravel the red limit of the pigment. Using Gaussian 16, a quantum chemistry package, the electronic states of the pigments are evaluated at the density functional theory level. Starting with the tetrapyrrole, we search for the pigments which are applicable around M dwarfs by calculating their basic structures, functional groups, central metals and solvents to determine the absorption wavelength and other properties.

At first we focused on the central metal of the pigment. Having a tetrapyrrole ring is significant because it is considered to generate a diversity for its central metal. M={H2、Mg、Ca、Ni、Cu、Zn、Sr、Cd、Hg、Pb} are put in the center of the ring and are evaluated at the level of CAM-B3LYP/Def2TZVP//B3LYP-D3/Def2TZVP.

According to calculations of electronic excited states, the wavelength of the first excited state is largest in M=Ni and it is a common tendency in chlorophylls *a* and *b* and bacteriochlorophylls *a* and *b*. For bateriochlorophyll *b* absorbing the longer wavelength radiation in the pigments, the calculated wavelength is 763.30 nm for M=Ni in vacuum (757.03 nm for M=Mg, 722.66 nm M=H2). Although the lowest excited states lie in redder wavelength in actual conditions, we can understand key tendencies. The properties in low-lying excited states connect to molecular orbitals around HOMO/LUMO (Highest Occupied Molecular Orbital / Lowest Unoccupied Molecular Orbital) (Figure 1), and it is an essence in searching for promising pigments to analyze the correlation further. Moreover, to evaluate the reactivity, ionization potential and electron affinity are calculated for each pigment.

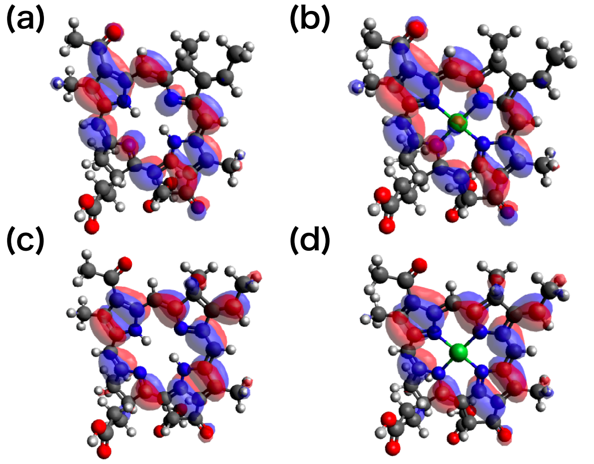

Figure 1: Molecular orbitals for low-lying excited states of M-bacteriochlorophyll b。(a)LUMO for M=H2, (b)LUMO for M=Ni, (c)HOMO for M=H2, (d)HOMO for M=Ni.

The accurate estimations for the redox potential and excited energy transfer rate are issues for this purpose. The theoretical estimation here must be a base for biological experiments and then astronomical observations. In addition, this attempt for photosynthesis beyond the Earth might contribute to the other research areas such as dye sensitized solar cell or bioimaging.

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The formation process of interstellar glycine

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As our body is composed of 20 amino acids, the amino acids are the essential blocks of our body. The amino acids are so important molecules that they are thought to have played an essential role in the Origin of Life. Then, how the amino acids have been provided to the early Earth? The various kinds of amino acids are detected in the meteorites, suggesting the possibility of extraterrestrial delivery to the early Earth after their formation in the interstellar medium.

However the formation mechanism of interstellar glycine is not well known and the proceeding studies are so limited. In this work, we expanded the previous chemical modeling [1] with the latest knowledge of the interstellar chemistry and investigated the formation process of glycine theoretically.

Is is widely accepted that the chemical compositions of comet and asteroids are the remnant of the parental dense cloud of the star. Therefore, we developed the chemical model assuming the physical evolution of the star-forming regions. First, the gravitational collapse of diffuse cloud makes the dense core. Then, the temperature is raised after the birth of a star. The chemical reactions were obtained from KIDA database, which is the database of chemical reactions and rate constants for interstellar condition developed by the experts of chemistry [2]. In addition, we included the latest chemical reactions for glycine reported by the quantum chemical calculations. Further, the evaporation temperature of glycine from the interstellar grains was updated based on an experiment [3].

The result of our chemical modeling is shown in Figure 1. In this figure, the fractional abundances of the gas phase, the grain surface, and the grain mantle are shown with black, blue, and red lines, respectively. The our interested molecule, glycine is built on grain surface through the reaction of "CH_2NH_2 + COOH" and stored in grain mantle. This formation process agrees well with the previous work [1]. However, we found that the peak abundance of glycine is lower than the previous work [1] by almost 10^{-3}. Since we employed higher evaporation temperature [3], glycine was destroyed on grains before evaporation. Although the evaporation temperature is not well determined, this result clearly shows the importance of accurate evaporation temperature to predict the gas phase abundance of glycine. Since the radio astronomers can only observe gas phase molecules, evaporation temperature of glycine would be very important to plan the future radio wave observation to achieve the first detection of interstellar glycine.

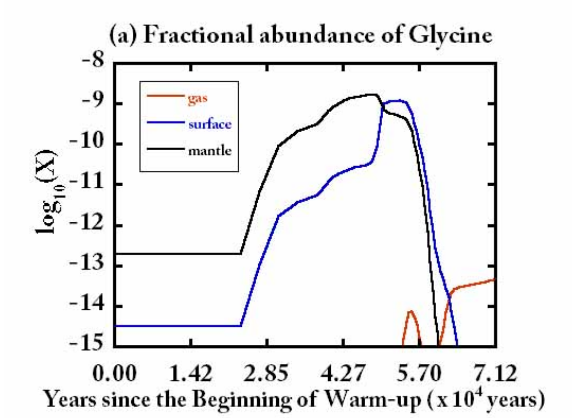

Figure 1: The predicted time evolution of the glycine abundance. The age of zero is corresponding to the birth of the star.

Another important suggestion of our work is regarding the suprathermal hydrogen (hereafter H*), which has extra kinetic energy given by UV photons. As suggested by a previous laboratory experiment, the extra kinetic energy of H* enable hydrogen atoms to penetrate the huge energy potential associated with "CO_2 + H", which usual hydrogen atoms cannot overcome. With H*, the formation of glycine is accelerated by enhancing its precursor, COOH radical. The further investigation of this process would be essential to understand glycine chemistry in the interstellar medium.

This work has been done in 2017 and published from ApJ in 2018[4].

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[3] Tzvetkov, G., Ramsey, M, G., & Netzer, F, P.: 2004, *Chemical Physics Letters*, **397**, 392.

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Deconvolution with model-fitting in ALMA disk observations

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The Atacama Large Millimeter/submillimeter Array (ALMA) have observed various structures in protoplanetary disks such as a ring structure (e.g., [1]). A high spatial resolution is essential to spatially resolve fine structures. However, since the fine structures correspond to high spatial frequency components on the uv-plane of object's visibilities, the widely used deconvolution method of the CLEAN algorithm[2] tends to result in a smeared image due to sparse sampling on the uv-plane.

Another deconvolution approach is model-fitting in the visibility domain. The advantage of this method is to make use of the full spatial frequency information. For instance, while there is a degeneracy in a narrow-deep and a wide-shallow gap in the image domain of the disk, their visilities are distinguishable at longer baselines. Figure 1 shows azimuthally averaged radial surface brightness of parametric axisymmetrical-disk with a narrow and a wide gap at $r = 200$ mas. A width and a brightness depth of a gap is described in table 1. With convolving these images by utilizing the CASA simobserve task, these gaps show similar structures with the CLEAN beam of 126 $\times$ 113 mas (Figure 1). Conversely, visibilities of these gapped disks show differences at longer uv-distance. Thus, model-fitting in the visibility domain could be a powerful tool of deconvolution.

Here I report the implementation of model-fitting method. The disk model has a simple power-law radial profile with an exponential taper at the outside (e.g., [3]):

$$I(r) \propto \alpha \left(\frac{r}{r_c}\right)^{-(q+\gamma)} \exp\left[-\left(\frac{r}{r_c}\right)^{2-\gamma}\right].$$

To convert a modeled disk image to complex visibilities with identical uv-coverages of observations, I utilize the public python code vis_sample[1]. The computed visibilities are deprojected in the uv-plane to calculate their azimuthal averages. For the fitting, I use the Markov Chain Monte Carlo (MCMC) method in the emcee package [4]. This implimentation was applied to CI Tau [5] and DM Tau [6] to deconvolve disk's structures.

Table 1: Gap property in modeled disk

Model	Position (mas)	Width (mas)	Depth
Narrow-deep gap	200	20	10^{-4}
Wide-shallow gap	200	90	0.75

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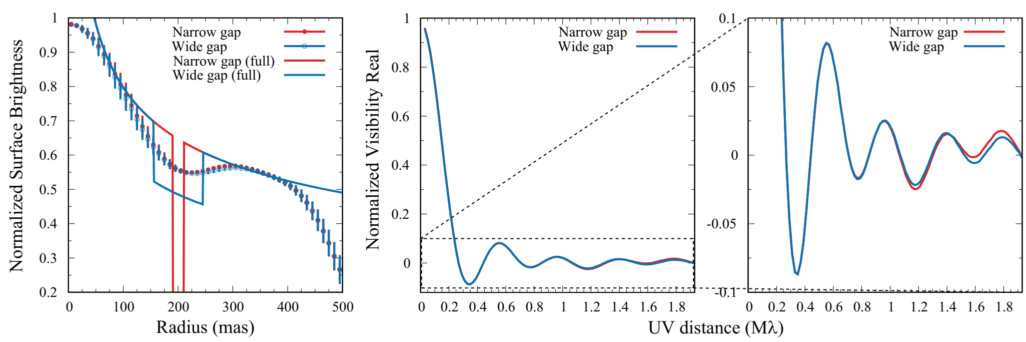

Figure 1: Radial surface brightness profile (left), real visibility (middle) and its zoomed-in view(right) of modeled disk. Full resolution image is convolved with CLEAN beam of 126 $\times$ 113 mas resolution. Red and blue represent narrow and wide gapped disk, respectively.

[1] vis_sample is publicly available at https://github.com/AstroChem/vis_sample or in the Anaconda Cloud at https://anaconda.org/rloomis/vis_sample

Discovery of a Disk Gap Candidate at 20 AU in TW Hya

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1: NAOJ, 2: Kogakuin University, 3: University of Heidelberg, 4: Ibaraki University, 5: The University of Tokyo, 6: Eureka Scientific,
7: Academia Sinica, 8: Stockholm University,9: Tokyo Institute of Technology, 10: Max Planck Institute for Astronomy,
11: Space Science Institute, 12: University of Cincinnati, 13: College of Charleston, 14: The Graduate University for Advanced Studies,
15: ETH Zurich, 16: The University of Oklahoma, 17: Universite de Nice Sophia-Antipolis, 18: Princeton University,
19:Universitäts-Sternwarte München, 20: University of Hawaii, 21: Kyoto University, 22: Goddard Space Flight Center,
23: Hiroshima University, 24: Space Telescope Science Institute, 25: Johns Hopkins University, 26: Jet Propulsion Laboratory,
27: Hokkaido University, 28: Tohoku University

Explorations and studies of protoplanetary disks reveal important physical processes that are fundamental to the formation and evolution of planetary systems. As part of the Strategic Explorations of Exoplanets and Disks with Subaru (SEEDS) project for exploring the circumstellar disk structure, TW Hya, an analog of the early solar nebula, was selected because it is particularly accommodating to investigations of its geometrical structure with high spatial resolution and sensitivity due to its close distance of 54 pc. As results of the observations, the scattered light from the disk was detected from 0.2 to 1.5 asec (11–81 AU) from the central star and the polarized image shows a ring-like depression, probably a gap at 20 AU from the central star as shown in Fig. 1 [1], similar to the 80 AU gap previously reported from the Hubble Space Telescope (HST) images [2]. Several gap formation mechanisms, such as disk–planet interaction, photoevapolation, grain growth, or dust filtration, has been proposed. Our observation suggests the possibilities of planet formation and grain growth because the observed radial profile can well be explained by the gap formation model by a planet [3] and the observed depression can also be reproduced by a change in dust scale height due to grain growth. In addition to the HST result, our observation revealed the multiple ring-like gap structure in TW Hya, implying that multiple planets are forming as a planetary system. In near future, ALMA and next-generation astronomical telescope, TMT, will provide convincing information about the origin of gaps and shed new light on planet formation.

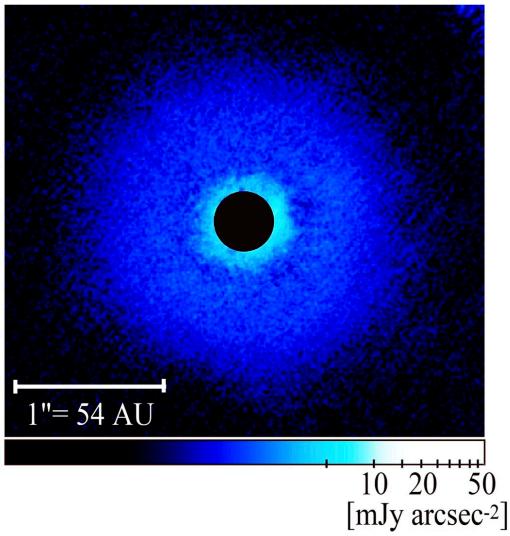

Figure 1: TH-band polarized intensity image of TW Hya. The dark filled circle at the center indicates a software mask with r = 0.2 asec.

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A Substellar Companion to Pleiades HII 3441

KONISHI, Mihoko (NAOJ), MATSUO, Taro (Osaka University), Yamamoto, Kodai (Kyoto University), SAMLAND, Matthias (MPIA), SUDO, Jun (Osaka University), SHIBAI, Hiroshi (Osaka University), ITOH Yoichi (Nishi-Harima Astronomical Observatory), FUKAGAWA, Misato (Nagoya University), SUMI, Takahiro (Osaka University), & SEEDS/HiCIAO/AO188 Team

The Pleiades has long been recognized as one of the nearest young open clusters (135 pc [1], 120 Myr [2]), and is the best target to study the low mass end of the initial mass function (e.g., 3]). Adaptive optics imaging surveys are also a good tool for detecting faint companions such as brown dwarfs. In Reference [4], they surveyed G and K dwarfs in the Pleiades, and revealed that the binary fraction with a separation range of 0.08 to 6.9 arcseconds is 28%±4% that is similar to that of G-type field dwarfs. However, the stellar multiplicity is still uncertain with respect to the low-mass and closely bound objects, due to the limited sensitivity to faint companions with small separations from the primary. Under the situation, previous studies discovered a brown dwarf companion around Pleiades HII 1348 and HD 23514 ([6], [7]). We report in this paper the discovery of a new substellar mass companion to the Pleiades member star, Pleiades HII 3441, and also show a fraction of close substellar companions in the Pleiades is consistent with those of the other open cluster and field stars.

This study was conducted as a part of the Subaru strategic program, SEEDS (Strategic Exploration of Exoplanet and Disks with Subaru, [9]) project. We used the Subaru high-contrast instrument HiCIAO [10] combined with the adaptive optics system AO188 [11]. Our data were obtained on September 2011 in the *H* band (1.6 μm) with the SDI (Simultaneous Spectral Differential Imaging, [12]) +ADI (Angular Differential Imaging, [13]) mode, on October 2014 in the *H* band with the ADI mode, and on January 2015 in the *J* (1.2 μm), *H*, K_S band (1.4 μm) with the DI (Direct Imaging) mode. After the post process that reduced halo of the primary star ([13], [14]), we found a point source with a projected separation of 0.49±0.02 arcseconds (66±2 au) and a position angle of 136.4±3.2 degrees. Its *J*-band magnitude was converted to 68±3 jupiter mass by using the stellar evolution model [15], which shows the brown dwarf mass. In addition, this object would be bounded to Pleiades HII 3441 by measuring the relative proper motion by using multiple-years data. This substellar companions has similar property to companions of Pleiades HII 1348 and HD 23514.

We have observed 21 Pleiades member stars to search companions and to elucidate the planet fraction [16]. The fraction of close substellar companions in the Pleiades is found to be $10^{+26.1}_{-8.8}$%, by using the unbiased sample from our Pleiades data. This value is consistent with the previous studies of the Pleiades and other clusters (e.g., [4], [17]). We note that all results of our planet search in the other moving group is also reported in our paper [8].

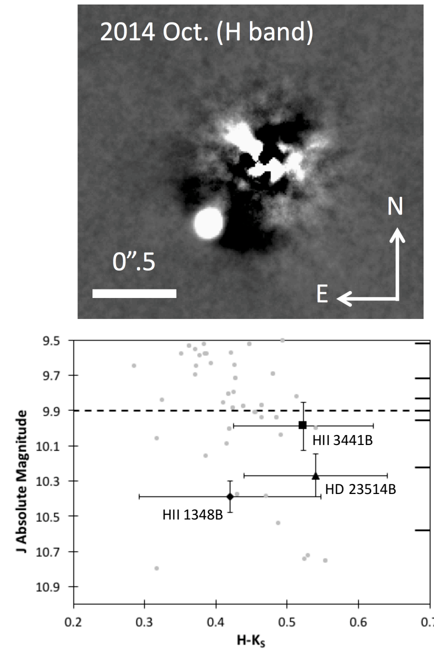

Figure 1: Upper Panle: Image of Pleiades HII 3441 after the image reduction. Bottom Panel: Color-magnitude diagram of Pleiades HII 3441b.

References

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CARBON-TO-OXYGEN RATIOS IN M DWARFS AND SOLAR-TYPE STARS

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and
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It has been suggested that high C/O ratios (>0.8) in circumstellar disks lead to the formation of carbon-dominated planets. Based on the expectation that elemental abundances in stellar photospheres give the initial abundances in the circumstellar disks, the frequency distributions of C/O ratios of solar-type stars have been obtained by several groups. The results of these investigations are mixed. Some find C/O $>$ 0.8 in more than 20% of stars, and C/O $>$ 1.0 in more than 6%. Others find C/O$>$ 0.8 in none of the sample stars. These works on solar-type stars are all differential abundance analysis with respect to the Sun and depend on the adopted C/O ratio in the Sun.

Recently, a method of molecular line spectroscopy of M dwarfs, in which carbon and oxygen abundances are derived respectively from CO and H_2O lines in the K band, has been developed ([1][2]). The telescope and instrument used for spectroscopic observations are Subaru and IRCS respectively. The resolution of the K-band spectrum is 20,000. Carbon and oxygen abundances of 46 M dwarfs have been obtained by this nondifferential abundance analysis. Carbon-to-oxygen ratios in M dwarfs derived by this method are more robust than those in solar-type stars derived from neutral carbon and oxygen lines in the visible spectra because of the difficulty in the treatment of neutral oxygen lines. We have compared the frequency distribution of C/O in M dwarfs with those of solar-type stars using the Kolmogorov-Smirnov test and have found that the low-frequency of high-C/O ratios is preferred ([3]).

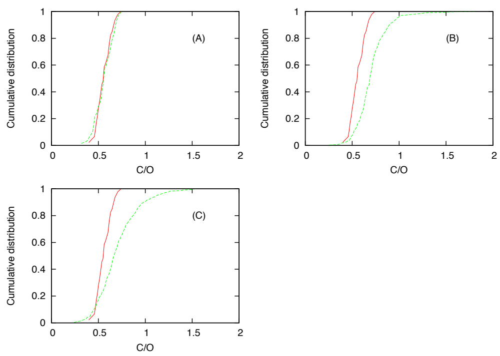

Figure 1: Comparisons of two cumulative distributions: (A) M dwarfs (red) and Nissen et al. 2014 (green). (B) M dwarfs (red) and Delgado Mena et al. 2010 (green). (C) M dwarfs (red) and Petigura & Marcy 2011 (green). M dwarf distribution is consistent with the solar-type star distribution by Nissen et al. who found no solar-type stars with C/O $>$ 0.8 in their sample.

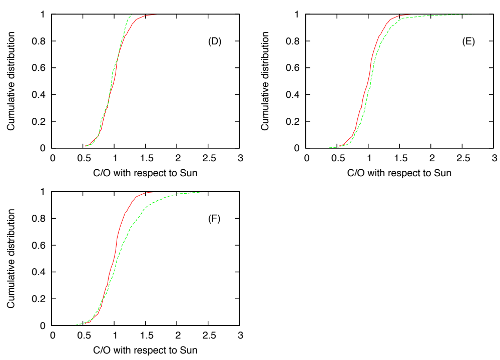

Figure 2: Comparison of two cumulative distributions obtained from differential abundance analyses of solar-type stars: (D) Takeda & Honda 2005 (red) and Nissen et al. 2014 (green). (E) Takeda & Honda 2005 (red) and Delgado Mena et al. 2010 (green). (F) Takeda & Honda 2005 (red) and Petigura & Marcy 2011 (green).

References

[1] Tsuji, T., Nakajima, T.: 2014, *PASJ*, **66**, 98.

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Distortion of Magnetic Fields in a Starless Core III: Polarization–Extinction Relationship in FeSt 1-457

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On the basis of the wide-field near-infrared (NIR) polarimetry of interstellar polarization of background stars, the hourglass-shaped magnetic field structure was discovered around the starless dense core FeSt 1-457 [1]. A three-dimensional (3D) hourglass model was developed in order to be compared with observations to determine the line of sight inclination angle of magnetic fields [2]. Since the distorted 3D magnetic field structure as well as its inclination angle can affect the polarization–extinction relationship, we correct it to derive the true polarization–extinction relationship in FeSt 1-457 [3].

The polarized light coming from the direction of the core consists of four components/effects. (1) the polarization produced by the core itself, (2) the polarization produced by the core's ambient medium, (3) the depolarization effect due to the distorted magnetic fields, (4) the effect due to inclined magnetic axis. On the basis of the analyses reported in the previous papers [1,2], the latter three effects can be corrected.

The result is shown in Figure 1. Figure 1(a) shows the original polarization–extinction relationship observed toward FeSt 1-457 (slope=2.43 % mag^{-1}). The polarization increases until $H - K_s \approx 0.9$ mag, and the relationship becomes flat. Figure 1(b) shows the polarization–extinction relationship after subtracting the ambient polarization component from the original data. The kink seen in Figure 1(a) disappeared in Figure 1(b), and the relationship becomes linear (slope=4.75 % mag^{-1}). Figure 1(c) shows the result of the further correction of the depolarization effect due to the distorted magnetic fields (slope=7.74 % mag^{-1}). The obtained correlation coefficient (0.79) is better than the original (0.71) and Figure 1(b) data (0.76), indicating that the correction improves the tightness in the relationship. Finally, Figure 1(d) shows the polarization–extinction relationship after the correction of the magnetic inclination angle (slope=11.00 % mag^{-1}). We obtained the linear relationship until the densest region ($A_V \approx 20$ mag) proved in our observations. The obtained slope is similar to the interstellar upper limit value ($P_H/E_{H-K} \approx 14$ % mag^{-1}).

The linearity of the polarization–extinction relationship can restrict the alignment theories of dust grains. In the simulation of the grain alignment by the radiative torque theory, the polarization efficiency starts to drop from A_V of several to 10 mag. This is in contrast to our result that reveals the linear polarization–extinction relationship at least until $A_V \approx 20$ mag. This indicates that the existence of large size grains in FeSt 1-457 and/or strong radiation fields.

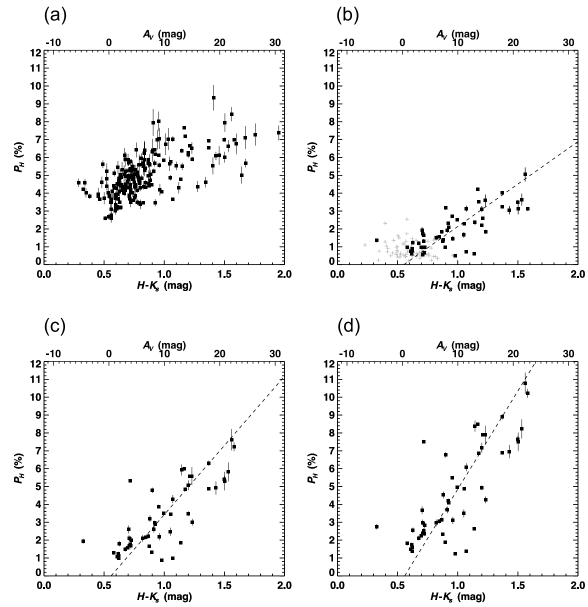

Figure 1: The relationships between the $H - K_s$ color and the H band polarization degree (P_H) toward the background stars of FeSt 1-457. The stars with $P_H/\delta P_H \geq 10$ located within the core radius (144″) are plotted. (a) the original polarization–extinction relationship. (b) the relationship after subtracting the ambient polarization component. (c) the relationship after the correction of the ambient polarization and the depolarization effect. (d) the relationship after the correction of the ambient polarization, the depolarization effect, and the magnetic inclination angle.

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4. Research Collaboration

Categories	Total Number	Comments
Project Research	73	25 organizations
Satellite Research	8	4 organizations, 3 continuations
Workshop, Conference, etc.	12	2 International workshops
Cross Appointment	3	University of Tokyo, University of Arizona, University of Washington

4-1 Astrobiology Grants

FY 2015 Project Research (Single-year Grants)

	Name	Affiliated Institute	Approved Budget Unit ¥1,000	Research Subject (in Japanese)
1	Kato, Masahiro	Institute for Molecular Science	1,200	実験・観測・計算シナジーによる自然界における生体分子の非対称性起源の解明
2	Masaoka, Shigeyuki	Institute for Molecular Science	1,200	低温度星まわりの生命居住可能惑星において起こり得る光合成反応の分子科学的考察
3	Kebukawa, Yoko	Yokohama National University	1,200	始原小天体から原始地球にわたる生命材料有機物の進化
4	Nakagawa, Hiromu	Tohoku University	1,100	ハワイ専用望遠鏡と国際連携による火星生命の痕跡を探る観測的研究
5	Kitadai, Norio	Earth-Life Science Institute	1,200	アルカリ熱水噴気孔環境におけるアミノ酸重合化

6	Kurihara, Kensuke	Okazaki Institute for Integrative Bioscience / Institute for Molecular Science	1,100	生命材料物質の組み立て場としてみた原始細胞膜の基礎的研究
7	Fukui, Akihiko	National Astronomical Observatory of Japan	1,100	ケプラー衛星の第二期探索で発見される太陽系近傍の地球型惑星の発見確認と詳細観測
8	Mita, Hajime	Fukuoka Institute of Technology	1,100	宇宙塵中のアミノ酸分析とホモキラリティーの起源
9	Akanuma, Satoshi	Waseda University	1,000	地球型生命におけるアミノ酸情報量の普遍性と特殊性の検証：遺伝暗号とアミノ酸レパートリーの進化
10	Yamamoto, Masahiro	Japan Agency for Marine-Earth Science and Technology	1,000	深海熱水噴出孔表面における電気的化学進化の検証
11	Kobayashi, Kensei	Yokohama National University	1,000	複合的アプローチによる星間およびタイタン大気中での超複雑有機物生成の検証
12	Hashizume, Hideo	National Institute for Materials Science	1,000	室温付近での蒸発乾固法を用いた核酸塩基とリボースからのヌクレオシド合成
13	Brasser, Ramon	Tokyo Institute of Technology	650	低質量な太陽系外惑星の形成とその組成について
14	Maeda, Taro	National Institute for Basic Biology	1,000	低温度星まわりの惑星における地球型光合成生物の成育可能性とその分子メカニズム
15	Kobayashi, Hiroshi	Nagoya University	1,000	原始惑星系円盤での H2O 大循環から探る地球型水惑星形成
16	Amikura, Kazuaki	The University of Tokyo	1,000	全ての生命が有する翻訳系の起源

17	Imai, Eiichi	Nagaoka University of Technology	900	海底熱水環境下における有機物ー鉱物ー熱水相互作用による化学進化過程
18	Ito, Motoo	Japan Agency for Marine-Earth Science and Technology	900	高空間分解能質量・同位体イメージングによる地球外有機物研究の新展開
19	Motoyama, Kazutaka	SOKENDAI	750	星間化学シミュレーションにおける最適な疎行列演算手法の開発
20	Yano, Hajime	Japan Aerospace Exploration Agency	800	エアロゲルに非破壊捕集された宇宙塵の初期分析用観察・摘出システムの開発 (3): ～衝突痕形状と捕集試料の三次元光学測定～

FY 2016 Project Research (Single-year Grants)

	Name	Affiliated Institute	Approved Budget Unit ¥1,000	Research Subject (in Japanese)
1	Mita, Hajime	Fukuoka Institute of Technology	2,100	宇宙塵中のアミノ酸分析とホモキラリティーの起源
2	Kiga, Daisuke	Waseda University	2,060	生命の初期進化において生体高分子の合成の正確さがその高分子の活性に与える影響の検証
3	Nakagawa, Hiromu	Tohoku University	1,960	火星生命の痕跡を探るための地上からの超高分解能赤外分光連続観測と国際連携観測
4	Kebukawa, Yoko	Yokohama National University	2,100	最先端イメージング分析で探る隕石有機物の起源と進化
5	Furukawa, Yoshihiro	Tohoku University	1,680	炭素質コンドライトおよび南極微小隕石の有機分子―鉱物イメージングによる地球外有機物の生成過程研究
6	Yamamoto, Shinji	Yokohama National University	1,740	ジルコンに保存された微小包有物から初期地球環境を読み解く
7	Amikura, Kazuaki	The University of Tokyo	1,800	全ての生命が普遍的に有する翻訳系の起源
8	Ohno, Sohsuke	Chiba Institute of Technology	1,680	成層圏微生物の高度分布観測の為の捕集・分析手法の開発
9	Yamada, Keita	Tokyo Institute of Technology	1,750	地球外アミノ酸の生成経路解明のための分子内炭素同位体分布分析法の確立
10	Kurihara, Kensuke	Okazaki Institute for Integrative Bioscience	2,100	リピッドワールド仮説に基づく原始細胞モデルの基礎研究
11	Noguchi, Takaaki	Kyushu University	2,070	太陽系始原有機物の物質進化から解明する彗星―含水小惑星の

				連続性 ～宇宙塵分析に基づく検討～
12	Fukui, Akihiko	National Astronomical Observatory of Japan	1,500	近傍地球型惑星の観測に向けた新多色カメラ MuSCAT-II の開発
13	Akiyama, Eiji	National Astronomical Observatory of Japan	1,330	原始惑星系円盤の水の分布に関する観測的研究
14	Shibuya, Takazo	Japan Agency for Marine-Earth Science and Technology	2,100	土星衛星エンセラダスの海底熱水活動域における岩石–水反応とアミノ酸重合
15	Kawahara, Hajime	The University of Tokyo	1,500	GPU ライトカーブ解析で探るクールな領域の惑星
16	Genda, Hidenori	Tokyo Institute of Technology	1,250	スーパーアースの平均密度多様性の起源:天体衝突侵食の影響
17	Hirano, Teruyuki	Tokyo Institute of Technology	1,500	K2 ミッションを利用した近傍の恒星周りの小型トランジット惑星の発見と特徴付け
18	Kobayashi, Hiroshi	Nagoya University	1,460	原始惑星系円盤での H2O 大循環から探る地球型水惑星形成
19	Arakawa, Kazuharu	Keio University	1,780	比較ゲノム解析による極限環境微生物の紫外線耐性関連遺伝子の網羅的探索
20	Yano, Hajime	Japan Aerospace Exploration Agency	1,200	氷天体内部海プリューム微粒子の試料捕集分析・惑星保護技術の研究
21	Hashizume, Hideo	National Institute for Materials Science	1,500	蒸発乾固法を用いた核酸塩基と 5 炭糖からのヌクレオシド合成
22	Danielache,	Sophia University	1,300	有機分子の近赤外スペクトルによ

	Sebastian			る大気系外惑星における新バイオマーカー特定
23	Nishizawa, Manabu	Japan Agency for Marine-Earth Science and Technology	1,250	初期地球海洋への隕石衝突による宇宙有機物の変質:海洋天体での生命誕生に果たす役割の解明
24	Honda, Mitsuhiko	Kurume University	1,250	原始惑星系円盤水氷分布観測のためのすばる IRCS への L-band 偏光観測機能の搭載
25	Kosugi, Makiko	Chuo University	1,250	恒星の光特性が惑星の生物進化に与える影響を光合成効率の波長依存性から予測する
26	Kurosawa, Kohsuke	Chiba Institute of Technology	950	二段式水素ガス銃を用いた無隔膜衝突有機開放系気相化学分析技術の確立: 氷天体上の衝突化学への応用
27	Kuruma, Yutetsu	Tokyo Institute of Technology	1,250	人工細胞構築による初期細胞生命の実証

FY 2016 Satellite Research (Multi-years Grants)

	Name	Affiliated Institute	Approved Buget Unit ¥1,000	Research Subject (in Japanese)	
1	Sekine, Yasuhito	The University of Tokyo	4,500	巨大ガス惑星周りのハビタビリティに関する研究基盤構築:衛星地下海の形成・進化・化学的多様性の解明	new
2	Kobayashi, Kensei	Yokohama National University	3,000	日本初のアストロバイオロジー宇宙実験「たんぽぽ計画」の試料分析をコアとする アストロバイオロジー研究拠点形成	new

3	Naganuma, Takeshi	Hiroshima University	4,500	ありえる地球外生物圏における「ありえる生物学」(アロバイオロジー)の実証的研究 Corroborative study on “allo-biology” in hypothetical extraterrestrial biospheres	new

FY 2017 Project Research (Single-year Grants)

	Name	Affiliated Institute	Approved Budget Unit ¥1,000	Research Subject (in Japanese)
1	Matsuo, Koichi	Hiroshima	2,700	円偏光ビーム照射による生体有機分子の光学活性発現の実験検証
2	Yamamoto, Masahiro	Japan Agency for Marine-Earth Science and Technology	2,700	宇宙における電気合成生態系の活動限界領域の提示
3	Kawahara, Hajime	The University of Tokyo	2,700	GPU ライトカーブ解析で探るクールな領域の惑星
4	Ikoma, Masahiro	The University of Tokyo	1,300	系外惑星の大気獲得過程の理論研究とトランジット観測への示唆
5	Kebukawa, Yoko	Yokohama National University	2,700	Ceres の化学:液体の水を伴う化学反応による有機物の形成
6	Kwon, Jungmi	Japan Aerospace eXploration Agency	1,250	生命のホモキラリティーと原始星形成領域における円偏光観測
7	Koga, Nobuyasu	Institute for Molecular Science	2,400	地球上に存在しないトポロジーを持つタンパク質分子の合理設計

8	Noguchi, Takaaki	Kyushu University	2,303	太陽系始原有機物の物質進化から解明する彗星―含水小惑星の連続性 ～宇宙塵分析に基づく検討～
9	Yano, Hajime	Japan Aerospace Exploration Agency	1,952	氷天体内部海プリューム微粒子の試料捕集分析・惑星保護技術の研究(2) --捕集微粒子その場分析機構の開発と汚染管理技術の確立--
10	Furukawa, Yoshihiro	Tohoku University	2,240	炭素質コンドライトの有機分子―鉱物イメージングによる地球外有機物の生成過程研究
11	Genda, Hidenori	Tokyo Institute of Technology	1,500	巨大天体衝突による連惑星形成の可能性について
12	Nakagawa, Mayuko	Tokyo Institute of Technology	1,800	多様な環境条件下の生態系から放出される VOC の大気系外惑星バイオマーカー可能性探索
13	Tanaka, Yosuke	Tokyo University of Agriculture and Technology	1,800	地球型系外惑星の探査を汎用化する分光集積回路の研究
14	Iino, Takahiro	Tokyo University of Agriculture and Technology	980	ALMA モニタリング観測によるハビタブル個体天体における地表面温度の時空間変動の解明
15	Nakagawa, Hiromu	Tohoku University	1,260	火星生命の痕跡を探るための地上からの超高分解能赤外分光連続観測と国際連携観測
16	Murakami, Naoshi	Hokkaido University	1,800	3層波長板にもとづく広帯域コロナグラフマスクの開発
17	Kuruma, Yutetsu	Tokyo Institute of Technology	1,800	地球型・宇宙型生物に普遍的と考えられる生物特徴の再構築
18	Hashizume, Hideo	National Institute for Materials Science	1,500	粘土存在下でのヌクレオシド、または核酸塩基と糖、とリン酸からのヌクレオチド合成
19	Kurihara,	Okazaki Institute	1,800	原始的なタンパク質を内包する原始

	Kensuke	for Integrative Bioscience		細胞モデルの創成とその挙動解析
20	Arakawa, Kazuharu	Keio University	1,794	比較ゲノム解析による極限環境微生物の紫外線耐性関連遺伝子の網羅的探索
21	Hernlund, John	Tokyo Institute of Technology	810	Possibility of Terrestrial Exoplanet Magnetic Fields in Light of New Discoveries
22	Yamamoto, Kodai	Kyoto University	1,200	巨大ガス惑星の直接撮像観測を目指した極限補償光学系用光学系の開発
23	Niihara, Takafumi	The University of Tokyo	1,015	火星隕石の水–岩石反応から探る火星表層の古環境
24	Kawaguchi, Yuko	Tokyo University of Pharmacy and Life Sciences	1,500	乾燥耐性に寄与する新規カロテノイドの代謝機構の解明
25	Kiga, Daisuke	Waseda University	1,176	生命の初期進化において生体高分子の合成の正確さがその高分子の活性に与える影響の検証
26	Motoyama, Kazutaka	SOKENDAI	735	反応性輻射流体シミュレーションで探る星形成領域の化学進化の多様性

FY 2017 Satellite Research (Multi-years Grants)

	Name	Affiliated Institute	Approved Budget Unit ¥1,000	Research Subject (in Japanese)	
1	Sekine, Yasuhito	The University of Tokyo	4,500	巨大ガス惑星周りのハビタビリティに関する研究基盤構築:衛星地下海の形成・進化・化学的多様性の解明	Cont.
2	Kobayashi, Kensei	Yokohama National University	3,000	日本初のアストロバイオロジー宇宙実験「たんぽぽ計画」の試料分析をコアとする アストロバイオロジー研究拠点形成	Cont.
3	Naganuma, Takeshi	Hiroshima University	4,500	ありえる地球外生物圏における「ありえる生物学」(アロバイオロジー)の実証的研究 Corroborative study on “allo-biology” in hypothetical extraterrestrial biospheres	Cont.
4	Kitadai, Norio	Tokyo Institute of Technology	5,000	電気化学進化モデルから探る宇宙における生命の起源	New
5	Sato, Bunei	Tokyo Institute of Technology	5,000	高精度ドップラー観測で探る太陽型星周りのハビタブル惑星	New

4-2 Round Table Conference on Life and the Universe

Date	Name	Affiliated Institute	Title (in Japanese)
28th January, 2016	Hori, Yasunori	ABC	系外惑星大気のこれまでとこれから
27th June, 2016	Harada, Mariko	Tokyo University of Pharmacy and Life Sciences	シアノバクテリアのプロモーター配列解析による抗酸化酵素の発現量の進化
18th October, 2016	Sekine, Yasuhito	The University of Tokyo	太陽系における”海”の多様性

＊After FY2017, the Round Table Conference and the Astrobiology Center Symposium were merged.

4-3 Workshop

	Organizer	Affiliated Institute	Workshop name	Participants
1.	Agata, Hidehiko	NAOJ	The 11th Workshop for Popularizing Cutting the Edge Astronomy" Astrobiology - Habitability inside and outside of the Solar System"	68
2.	Omiya, Masashi	ABC	Workshop of Near-Infrared High-Resolution Spectroscopy: Earth-like Planet Hunting and Its Expansion in Science	40
3.	Narita, Norio	ABC	Astrobiology Center Mini-Workshop: Photosynthesis in Extreme Environments	11
4.	Tamura, Motohide	ABC	Post SEEDS workshop	30

5.	Tamura, Motohide	ABC	The 4th Life in the Universe workshop by Astrobiology Center, NINS (FY-H27 Project Research Results)	85
6.	Tamura, Motohide	ABC	The 5th Life in the Universe workshop by Astrobiology Center, NINS (FY-H28 Project/Satellite Results)	70
7.	Tamura, Motohide	ABC	Astrobiology Center International Workshop 2017	41
8.	Tamura, Motohide	ABC	Astrobiology Center Symposium 2018	60
9.	Tamura, Motohide	ABC	The 6th Life in the Universe Workshop by Astrobiology Center, NINS (FY-H29 Project/Satellite Results)	80

＊Each program is shown on the next pages.

The 11th Workshop for Popularizing Cutting the Edge Astronomy "Astrobiology - Habitability inside and outside of the Solar System"

Date and Place

November 15th (Sun) – 17th (Tue), 2015
National Astronomical Observatory of Japan Mitaka campus,
Japan Agency for Marine-Earth Science and Technology

Speakers

Tamura, Motohide (Astrobiology Center / National Astronomical Observatory of Japan / The University of Tokyo)
Yamagishi, Akihiko (Tokyo University of Pharmacy and Life Sciences)
Tajika, Eiichi (The University of Tokyo)
Sekine, Yasuhito (The University of Tokyo)
Hori, Yasunori (Astrobiology Center / National Astronomical Observatory of Japan)
Watanabe, Jun-ichi (National Astronomical Observatory of Japan)
Ohishi, Masatoshi (National Astronomical Observatory of Japan)
Kobayashi, Kensei (Yokohama National University)
Naganuma, Tsuyoshi (Hiroshima University)
Maruyama, Shigetoku (Tokyo Institute of Technology / Earth-Life Science Institute)
Takai, Ken (Japan Agency for Marine-Earth Science and Technology)

Workshop of Near-Infrared High-Resolution Spectroscopy: Earth-like Planet Hunting and Its Expansion in Science

Date and Place

November 24th (Tue) – 26th (Thu), 2015
National Astronomical Observatory of Japan Mitaka campus

Speakers

Sato, Bun′ei (Tokyo Institute of Technology)
Kotani, Takayuki (Astrobiology Center / National Astronomical Observatory of Japan)
Iwamuro, Fumihide (Kyoto University)
Kurokawa, Takashi (Tokyo Institute of Technology)
Hirano, Teruyuki (Tokyo Institute of Technology)
Omiya, Masashi (National Astronomical Observatory of Japan)
Oshino, Shoich (National Astronomical Observatory of Japan)
Narita, Norio (Astrobiology Center / National Astronomical Observatory of Japan)
Kondo, Sohei (Kyoto Sangyo University)
Otsubo, Shogo (Kyoto Sangyo University)
Motohara, Kentaro (The University of Tokyo)
Ebizuka, Noboru (Institute of Physical and Chemical Research)
Aoki, Wako (National Astronomical Observatory of Japan)
Kawahara, Hajime (The University of Tokyo)
Nugroho, Stevanus Kristianto (Tohoku University)
Nakajima, Tadashi (National Astronomical Observatory of Japan)
Baba, Haruka (SOKENDAI)
Kuzuhara, Masayuki (Tokyo Institute of Technology)
Takagi, Yuhei (University of Hyogo)
Nishiyama, Shogo (Miyagi University of Education)
Takeda, Yoichi (National Astronomical Observatory of Japan)
Notsu, Yuta (Kyoto University)
Hashimoto, Osamu (Gunma Astronomical Observertory)
Moritani, Yuki (The University of Tokyo)
Tamura, Motohide (Astrobiology Center / National Astronomical Observatory of Japan / The University of Tokyo)

Posters

Ishizuka, Masato (The University of Tokyo)
Dogasaki, Chisei (個人研究事業　町田系外惑星天文学研究所)
Ohno, Kazumasa (Tokyo Institute of Technology Earth-Life Science Institute)
Komatsu, Yu (University of Tsukuba)

Astrobiology Center Mini-Workshop:
Photosynthesis in Extreme Environments

Date and Place

February 6th (Sat) – 7th (Sun)
Tachikawa Grand Hotel

Speakers

Narita, Norio (Astrobiology Center)
Kusakabe, Nobuhiko (Astrobiology Center)
Komatsu, Yu (University of Tsukuba)
Kudoh, Sakae (National Institute of Polar Research)
Natsume, Yuno (Japan Wumen's University)
Kurihara, Kensuke (Okazaki Institute for Integrative Bioscience / Institute for Molecular Science)
Takizawa, Kenji (National Institute for Basic Biology)
Masaoka, Shigeyuki (Institute for Molecular Science)
Enomoto, Takafumi (Institute for Molecular Science)
Maeda, Taro (National Institute for Basic Biology)
Kosugi, Makiko (Chuo University)
Hori, Yasunori (Astrobiology Center)

Post SEEDS Workshop

Date and Place

February 26th (Fri), 2018

National Astronomical Observatory of Japan Mitaka campus

Program

time	content
10:20	CHARIS status hardware (Tyler via TVorSKYPE)
10:40	CHARIS commissioning (Tim/Tyler/Nem)
11:00	SEEDS/HiCIAO status
11:30	Future SEEDS paper plans (contributed talks welcome)
12:00	SCExAO status (incl. VAMPIRE) and notes for current and future proposals
12:00	SCExAO status (incl. VAMPIRE) and notes for current and future proposals
12:30	LUNCH
14:00	CHARIS and notes for future proposals
14:30	SCExAO intensive plan
15:00	CHARIS intensive plan
15:30	Other observation plans (contributed talks welcome)
16:00	Discussion and Q&A to instrument teams from users
18:00	Dinner near National Astronomical Observatory of Japan

The 4th Life in the Universe workshop by Astrobiology Center, NINS (FY-H27 Project Research Results)

Date and Place

March 7th (Mon) – 8th (Tue), 2016
Hitotsubashi Hall

Speakers

Tamura, Motohide (Astrobiology Center / National Astronomical Observatory of Japan / The University of Tokyo)
Fukui, Akihiko (National Astronomical Observatory of Japan)
Masaoka, Shigeyuki (Institute for Molecular Science)
Maeda, Taro (National Institute for Basic Biology)
Kobayashi, Kensei (Yokohama National University)
Imai, Eiichi (Nagaoka University of Technology)
Gaidos, Eric (University of Hawaii at Manoa)
Kebukawa, Yoko (Yokohama National University)
Kato, Masahiro (Institute for Molecular Science)
Yamamoto, Masahiro (Japan Agency for Marine-Earth Science and Technology)
Amikura, Kazuaki (The University of Tokyo)
Nakagawa, Hiromu (Tohoku University)
Ito, Motoo (Japan Agency for Marine-Earth Science and Technology)
Hashizume, Hideo (National Institute for Materials Science)
Kurihara, Kensuke (Okazaki Institute for Integrative Bioscience / Institute for Molecular Science)
Akanuma, Satoshi (Waseda University)
Mita, Hajime (Fukuoka Institute of Technology)
Motoyama, Kazutaka (SOKENDAI)
Kobayashi, Hiroshi (Nagoya University)
Yano, Hajime (Japan Aerospace eXploration Agency / Institute of Space and Astronautical Science)
Kitadai, Norio (Earth-Life Science Institute)
Miyama, Shoken (Hiroshima University)

The 5th Life in the Universe workshop by Astrobiology Center, NINS (FY-H28 Project/Satellite Results)

Date and Place

March 6th (Mon), 2017 9:50〜17:30
March 7th (Tue), 2017 9:30〜16:00
Hitotsubashi Hall

Speakers

Furukawa, Yoshihiro (Tohoku University)
Shibuya, Takazo (Japan Agency for Marine-Earth Science and Technology)
Naganuma, Tsuyoshi (Hiroshima University)
Yamamoto, Shinji (Yokohama National University)
Hashizume, Hideo (National Institute for Materials Science)
Yamada, Keita (Tokyo Institute of Technology)
Ohno, Sohsuke (Chiba Institute of Technology)
Kurihara, Kensuke (Okazaki Institute for Integrative Bioscience / Institute for Molecular Science)
Amikura, Kazuaki (The University of Tokyo)
Nishizawa, Manabu (Japan Agency for Marine-Earth Science and Technology)
Kebukawa, Yoko (Yokohama National University)
Mita, Hajime (Fukuoka Institute of Technology)
Sekine, Yasuhito (The University of Tokyo)
Kawahara, Hajime (The University of Tokyo)
Nakagawa, Hiromu (Tohoku University)
Fukui, Akihiko (National Astronomical Observatory of Japan)
Genda, Hidenori (Tokyo Institute of Technology / Earth-Life Science Institute)
Kobayashi, Hiroshi (Nagoya University)
Akiyama, Eiji (National Astronomical Observatory of Japan)
Honda, Mitsuhiko (Kuruma University)
Kiga, Daisuke (Waseda University)
Kuruma, Yutetsu (Tokyo Institute of Technology)
Arakawa, Kazuharu (Keio University)
Hirano, Teruyuki (Tokyo Institute of Technology)
Danielache, Sebastian (Sophia University)
Kosugi, Makiko (Chuo University)
Kobayashi, Kensei (Yokohama National University)
Kurosawa, Kohsuke (Chiba Institute of Technology)
Noguchi, Takaaki (Kyushu University)
Yano, Hajime (Japan Aerospace eXploration Agency / Institute of Space and Astronautical Science)

Astrobiology Center International Workshop 2017

Date and Place

March 21th (Tue) – 23th (Thu), 2017

21th (Tue)：Hiroshima University Higashi-Hiroshima campus

22th (Wed)：Hiroshima City Bunka Koryu Kaikan

23th (Thu)：Hiroshima University Higashi-Hiroshima campus

Program

21-Mar

time	speaker	affiliation	title
10:50	Tamura, Motohide	The University of Tokyo / Astrobiology Center National Astronomical Observatory of Japan	Opening Remark
11:10	Yamashiki, Yosuke	Kyoto University	Development of Exoplanetary database "ExoKyoto" aiming for inter-comparison with different criteria of Goldilocks zones
11:30	Yabuta, Hikaru	Hiroshima University	Hayabusa2 mission and Chemical Compounds in the Solar System Evolution of Organic
12:00	Lunch		
13:20	Yamagishi, Akihiko	Tokyo University of Pharmacy and Life sciences	The first result of Tanpopo: Micrometeorite capture and microbe exposure experiments
13:50	Kobayashi, Kensei	Yokohama National University	High-Energy Particles-Induced Formation of Bioorganics and Its Relevance to Habitability of Exoplanets
14:20	Worden, Pete	Breakthrough Initiatives	BT Initiatives
15:20	Break		
15:50	Ida, Shigeru	Tokyo Institute of Technology	Planet formation and Proxima b
16:30	Tajika, Eiichi	The University of Tokyo	Life-span of habitable planets around main sequence stars
17:10	Naganuma, Takeshi	Hiroshima University	Driving energies of exo-life - light, tidal heating and radiation
18:00	Banquet		

22-Mar

time	speaker	affiliations	title
9:10	Anglada-Escude, Guillem	University of London	Proxima b
10:00	Kupler, Pete	Breakthrough Initiatives	BT Starshot technology
10:45	Barnes, Rory	University of Washington	Proxima b biosignatures
11:45	Lunch		
13:00	Guyon, Olivier	University of Arizona / Astrobiology Center	Imaging Proxima b
14:00	Kameda, Shingo	Rikkyo University	UV spectroscopy Pro. b
14:30	Break		
15:10	Saar, Steven	Harverd-Smisonian University	Proxima activity observations

23-Mar

time	speaker	affiliation	title
10:20	Kitazawa, Yuya	University of Tsukuba	Theoretical investigation of a mechanism of chiral induction for amino acid by circular polarized light
10:40	Shoji, Mitsuo	University of Tsukuba	A quantum chemical study of the glycine formation reactions in interstellar medium
11:00	Takizawa, Kenji	Astrobiology Center	Photosynthesis on M stars
11:30	Narita, Norio	Astrobiology Center / The University of Tokyo	TRAPPIST-1 and Future Surveys of Habitable Transiting Earth-like Planets
12:00	Lunch		
13:00	Omiya, Masashi	National Astronomical Observatory of Japan	IRD/Subaru search for Earth-like planets around M dwarf stars
13:20	Hori, Yasunori	Astrobiology Center / National Astronomical Observatory of Japan	The Primordial Atmosphere on a Terrestrial Planet in a Habitable Zone
13:40	Miura, Yasunori	Yamaguchi University	Experiments for model of possible air-water-bearing solid-remnants applied for the habitable planets
14:00	Hashizume, Hideo	National Institute for Material Science	Formation of nucleosides by nucleobases and sugars in the presence of clay minerals
14:20	Danielache, Sebastian	Sophia University	NIR spectra of Isoprene and its atmospheric stability, applications for biomarkers

Date

March 22th (Wed),2017 18:00 20:00　　Hiroshima City Bunka Koryu Kaikan

Program

Tamura, Motohide	Professor, The University of Tokyo / Director, Astrobiology Center
Worden, Pete	Executive Director, Breakthrough Initiatives
Klupar, Pete	Director of Engineering, Breakthrough Initiatives

【Chairman】Miyama, Shoken (Hiroshima University)

Astrobiology Center Symposium 2018

Date

January 15th (Mon), 2018 9:45

January 16th (Tue), 2018 17:30

National Astronomical Observatory of Japan Mitaka campus

Program

Day 1: Jan. 15

time	speaker	affiliation	title
9:45	Tamura, Motohide	Astrobiology Center	
10:00	Usui, Tomohiro	Tokyo Institute of Technology / Earth-Life Science Institute	The Martian surface and missions in the world to search for life
11:00	Yabuta, Hikaru	University of Hiroshima	Organic matter in the solar system (Extraterrestrial organic matter)
12:00	Break		
13:00	Takizawa, Kenji	Astrobiology Center	Photosynthesis
14:00	Bott, Kim	Washington University	Polarization of extrasolar planets
15:00	Break		
15:20	Suzuki, Taiki	Astrobiology Center	The review of the search for amino acids in the universe
16:20	Guided tour of 4D2U Dome Theater		
17:30	social gathering		

Day 2: Jan. 16

time	speaker	affiliation	title
10:00	Akanuma, Satoshi	Waseda University	Commonote / LUCA
11:00	Yokobori, Shin-ichi	Tokyo University of Pharmacy and Life Sciences	Eukaryote
12:00	Break		
13:00	Ikegami, Takashi	The University of Tokyo	Complex system
14:00	Ayukawa, Shotaro	Waseda University	Synthetic biology, Synthetic gene networks
15:00	Break		
15:20	Narita, Norio	The University of Tokyo	The review of extrasolar planets
16:20	Fujii, Yuka	Tokyo Institute of Technology	Extrasolar planets, Potential biosignatures

The 6th Life in the Universe Workshop by Astrobiology Center, NINS (FY-H29 Project/Satellite Results)

Date and Place

February 19th (Mon), 2018 February 20th (Tue), 2018
Hitotsubashi Hall

Speakers

Genda, Hidenori (Tokyo Institute of Technology / Earth-Life Science Institute)
Kawahara, Hajime (The University of Tokyo)
Kwon, Jungmi (Japan Aerospace eXploration Agency)
Hernlund, John (Tokyo Institute of Technology)
Sekine, Yasuhito (The University of Tokyo)
Iino, Takahiro (Tokyo University of Agriculture and Technology)
Niihara, Takafumi (The University of Tokyo)
Yano, Hajime (Japan Aerospace eXploration Agency / Institute of Space and Astronautical Science)
Yamamoto, Masahiro (Japan Agency for Marine-Earth Science and Technology)
Kobayashi, Kensei (Yokohama National University)
Kawaguchi, Yuko (Tokyo University of Pharmacy and Life Sciences)
Matsuo, Koichi (Hiroshima University)
Koga, Nobuyasu (Institute for Molecular Science)
Kurihara, Kensuke (Okazaki Institute for Integrative Bioscience)
Sato, Bun′ei (Tokyo Institute of Technology)
Kiga, Daisuke (Waseda University)
Noguchi, Takaaki (Kyushu University)
Kebukawa, Yoko (Yokohama National University)
Kuruma, Yutetsu (Tokyo Institute of Technology)
Kitadai, Norio (Earth-Life Science Institute)
Hashizume, Hideo (National Institute for Materials Science)
Furukawa, Yoshihiro (Tohoku University)
Motoyama, Kazutaka (SOKENDAI)
Tanaka, Yosuke (Tokyo University of Agriculture and Technology)
Murakami, Naoshi (Hokkaido University)
Yamamoto, Kodai (Kyoto University)
Nakagawa, Mayuko (Tokyo Institute of Technology)
Nakagawa, Hiromu (Tohoku University)
Ikoma, Masahiro (The University of Tokyo)
Yabuta, Hikaru【PI: Naganuma, Tsuyoshi】 (Hiroshima University)

5. Publications, Presentations

5-1 Refereed Publications

Akiyama, E., et al. including **Hashimoto, J.**, **Kusakabe, N.**, **Kuzuhara, M.**, **Guyon, O.**, **Suto, H.**, **Tamura, M.**: 2016, SPIRAL STRUCTURE AND DIFFERENTIAL DUST SIZE DISTRIBUTION IN THE LkH alpha 330 DISK, *Astron. J.*, **152**, 222.

Akiyama, E., et al. including **Kusakabe, N.**, **Hashimoto, J.**, **Suto**, **H.**, **Tamura, M.**: 2015, Discovery of a Disk Gap Candidate at 20 AU in TW Hydrae, *ApJ*, **802**, L17.

Asensio-Torres, R. et al. including **Hashimoto, J.**, **Kuzuhara, M.**, **Kusakabe, N.**, **Guyon, O.**, **Suto, H.**, **Tamura, M.**: 2016, Polarimetry and flux distribution in the debris disk around HD 32297, *A&A*, **593**, A73.

Chen, Z. W., Zhang, S. B., Zhang, M. M., Jiang, Z. B., **Tamura, M.**, Kwon, J.: 2016, COEVAL INTERMEDIATE-MASS STAR FORMATION IN N4W, *ApJ*, **822**, 114.

Currie, T. et al. including **Guyon, O.**, **Kuzuhara, M.**: 2017, Subaru/SCExAO First-light Direct Imaging of a Young Debris Disk around HD 36546, *ApJL*, **836**, L15.

Dai, F. et al. including **Narita, N.**: 2016, DOPPLER MONITORING OF FIVE K2 TRANSITING PLANETARY SYSTEMS, *ApJ*, **823**, 115.

De Leon, J. including **Hashimoto, J.**, **Kusakabe, N.**, **Suto, H.**, **Tamura, M**.: 2015, Near-IR High-resolution Imaging Polarimetry of the SU Aur Disk: Clues for Tidal Tails?, *ApJ*, **806**, L10.

Dong, R. B. et al. including **Hashimoto, J.**, **Tamura, M.**: 2017, The Sizes and Depletions of the Dust and Gas Cavities in the Transitional Disk J160421.7-213028, *ApJ*, **836**, 201.

Fukui, A. et al. including **Narita, N.**, **Kusakabe, N.**: 2016, Demonstrating High-precision, Multi-band Transit Photometry with MuSCAT: A Case for HAT-P-14b, *ApJ*, **819**, 27.

Fukui, A. et al. including **Narita, N.**, **Kusakabe, N.**: 2016, GROUND-BASED TRANSIT OBSERVATION OF THE HABITABLE-ZONE SUPER-EARTH K2-3D, *Astron. J.*, **152**, 171.

Gaidos, E. et al. including **Narita, N.**: 2017, Zodiacal exoplanets in time (ZEIT) - II. A 'super-Earth' orbiting a young K dwarf in the Pleiades Neighbourhood, *MNRAS*, **464**, 850-862.

Garcia, E. V. et al. including **Guyon, O.**, **Kuzuhara, M.**, **Hashimoto, J.**, **Kusakabe, N.**, **Tamura, M**.: 2017, SCExAO AND GPI Y JH BAND PHOTOMETRY AND INTEGRAL

FIELD SPECTROSCOPY OF THE YOUNG BROWN DWARF COMPANION TO HD 1160, *ApJ*, **834**, 162.

Garcia, E. V. et al. including **Guyon, O.**, **Kuzuhara, M.**, **Hashimoto, J.**, **Kusakabe, N.**, **Suto, H.**, **Tamura, M.**: 2017, SCExAO and GPI Y JHBand Photometry and Integral Field Spectroscopy of the Young Brown Dwarf Companion to HD 1160, *ApJ*, **834**, 162.

Harakawa, H. et al. including **Omiya, M.**, **Hori, Y.**: 2015, Five New Exoplanets Orbiting Three Metal-rich, Massive Stars: Two-planet Systems Including Long-period Planets and an Eccentric Planet, *ApJ*, **806**, 5.

Helminiak, K. et al. including **Kuzuhara, M.**, **Kusakabe, N.**, **Narita, N.**, **Hashimoto, J.**, **Guyon, O.**, **Suto, H.**, **Tamura, M.**: 2016, SEEDS DIRECT IMAGING OF THE RV-DETECTED COMPANION TO V450 ANDROMEDAE, AND CHARACTERIZATION OF THE SYSTEM, *ApJ*, **832**, 33.

Henderson, C. B. et al. including **Tamura, M.**: 2016, Campaign 9 of the K2 Mission: Observational Parameters, Scientific Drivers, and Community Involvement for a Simultaneous Space- and Ground-based Microlensing Survey, *PASP*, **128**, 124401-124422.

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Hirano, T. et al. including **Narita, N.**, **Kusakabe, N.**, **Kuzuhara, M.**, **Tamura, M.**: 2016, The K2-ESPRINT Project III: A Close-in Super-Earth around a Metal-rich Mid-M Dwarf, *ApJ*, **820**, 41.

Honda, M. et al. including **Tamura, M.**: 2016, WATER ICE AT THE SURFACE OF THE HD 100546 DISK, *ApJ*, **821**, 2.

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Jovanovic, N., Schwab, C., Cvetojevic, N., **Guyon, O.**, Martinache, F.: 2016, Enhancing Stellar Spectroscopy with Extreme Adaptive Optics and Photonics, *PASP*, **128**, 121001-121015.

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Kwon, J. et al. including **Tamura, M.**, **Kusakabe, N.**: 2015, Wide-field Infrared Polarimetry of the ρ Ophiuchi Cloud Core, *ApJS*, **220**, 17.

Kwon, J., **Tamura, M.**, Hough, J.H., Nagata, T., **Kusakabe, N.**, Saito, H.: 2016, NEAR-INFRARED IMAGING POLARIMETRY OF GGD 27: CIRCULAR POLARIZATION AND MAGNETIC FIELD STRUCTURES, *Astron. J.*, **824**, 95.

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Long, Z. C. et al. including **Hashimoto, J.**, **Tamura, M.**: 2017, The Shadow Knows: Using Shadows to Investigate the Structure of the Pretransitional Disk of HD 10045, *ApJ*, **838**, 62.

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Newman, K.; Conway, J., Belikov, R., **Guyon, O.**: 2016, Focal Plane Phase Masks for PIAA: Design and Manufacturing, *PASP*, **128**, 055003-055009.

Ninan, J. P. et al. including **Tamura, M.**: 2015, V899 Mon: An Outbursting Protostar with a Peculiar Light Curve, and Its Transition Phases, *ApJ*, **815**, 4.

Nishiyama, S., Schodel, R., Yoshikawa, T., Nagata, T., Minowa, Y., **Tamura, M.**: 2016, Spectroscopically identified intermediate age stars at 0.5-3 pc distance from Sagittarius A*, *A&A*, **588**, A49.

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Shashkova, I. et al. including **Nishikawa, J.**: 2015, Extremely unbalanced interferometer for precise wavefront control in stellar coronagraphy, *J. Astron. Telesc. Instrum. Syst.*, **2**, 011011.

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5-2 Non-Refereed Publications, Proceedings

Ammons, S. M. et al. including **Guyon, O.**: (07/2016), Precision astrometry with adaptive optics: constraints on the mutual orbit of Luhman 16AB from GeMS, SPIE, Volume 9909, id. 99095T 9 pp.

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Newman, K., Sirbu, D., Belikov, R., **Guyon, O.**: (07/2016), Development of PIAA Complex Mask Coronagraphs for large aperture ground-based telescopes, SPIE, Volume 9912, id. 99126L 8 pp.

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Pathak, Prashant; **Guyon, O.** et al.: (07/2016), First on-sky closed loop measurement and correction of atmospheric dispersion, SPIE, Volume 9909, id. 990956 11 pp.

Rains, A. D. et al. including **Guyon, O.**: (08/2016), Precision single mode fibre integral field spectroscopy with the RHEA spectrograph, SPIE, Volume 9908, id. 990876 12 pp.

Rezaei, M. et al. including **Guyon, O.**: (07/2016), New progress in electron-injection detectors for NIR imagers with low noise and high frame rates, SPIE, Volume 9915, id. 99150P 8 pp.

Schwab, C. et al. including **Guyon, O.**: (07/2016), Adaptive optics fed single-mode spectrograph for high-precision Doppler measurements in the near-infrared, SPIE, Volume 9912, id. 991274 7 pp.

Singh, G. et al. including **Guyon, O.**: (07/2016), PSF calibration using the Lyot-based low order wavefront sensor telemetry: first simulations, SPIE, Volume 9909, id. 99097K 10 pp.

Sirbu, D. et al. including **Guyon, O.**: (09/2015), EXCEDE technology development IV: demonstration of polychromatic contrast in vacuum at 1.2 λ/D, SPIE, Volume 9605, id. 96050J 13 pp.

Soam, A., Kwon, J., Maheswar, G., **Tamura, M.**, Lee, C. W.: (12/2015), Optical and NIR Polarimetry of a Core L328 with Proto-Brown Dwarf, Revolution in Astronomy with ALMA: The Third Year. Proc. a Conf., Eds. D. Iono, K.-I. Tatematsu, A. Wootten, L. Testi, 293.

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Yoneta, K. et al. including **Kotani, T.**, **Tamura, M.**: (07/2016), Development of speckle nulling technique for the Savart-plate lateral-shearing interferometric nuller for exoplanets (SPLINE), SPIE, Volume 9912, id. 99126I 8 pp.

5-3 Conference Presentations

Currie, T. M., **Guyon, O.**, Jovanovic, N., Lozi, J., Tamura, M., Kudo, T., Uyama, T., Garcia, E.: 2017, SEEDS: Direct Imaging of Exoplanets and Their Forming Disks with the Subaru Telescope, AAS Meeting #229 id.303.04, (Grapevine, TX, USA, Jan. 3-7, 2017).

Grady, C. A., et al. including **Tamura, M.**: 2016, Decoding Debris System Substructures: Imprints of Planets/Planetesimals and Signatures of Extrinsic Influences on Material in Ring-Like Disks, AAS Meeting #227, (Kissimmee, FL, USA, Jan. 4-8, 2016).

Guyon, O., Jovanovic, N., Lozi, J.: 2015, Direct imaging and spectroscopic characterization of habitable planets with ELTs, Extreme Solar Systems III, (Waikoloa, HI, USA, Nov. 29-Dec. 4, 2015).

Hori, Y., Iwasawa, M., Oshino, S., Fujii, M.S.: 2016, Towards High-resolution N-body Simulations for Planet Formation, Japan-Germany Planet and Disk Workshop, (Okinawa, Japan, Sept. 25-30, 2016).

Hori, Y., Liu, S-F., Lin, D. N. C., Asphaug, E.: 2015, A Collisional Origin for the Coexistence of Volatile-poor Super-Earths and Mini- Neptunes in the Proximity of Stars, Exoplanetary Atmospheres and Habitability: Thermodynamics, Disequilibrium, and Evolution Focus Group, (Nice, France, Oct. 12-16, 2015).

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Hori, Y.: 2015, Can ExoEarths be Habitable?: Origin and Evolution of Planetary Atmospheres, Astrobiology: A Japanese-German Colloquium, (Kiel, Germany, Dec. 8-10, 2015).

Hori, Y.: 2015, Peer into a Nutshell: The Interior of Jupiter, Science Workshop for the Giant Planet System, (Ookayama, Tokyo, Japan, Apr. 14, 2015).

Hori, Y.: 2015, Recent Developments in Planetary Interiors under High Pressure, International Workshop on Warm Dense Matter 2015, (Kurashiki, Okayama, Japan, Aug. 8-13, 2015).

Hori, Y.: 2015, The Interior Structure of Jupiter Towards Future Missions of the Jovian System, 48th ISAS Lunar and Planetary Symp., (Sagamihara, Kanagawa, Japan, Jul. 29-31, 2015).

Hori, Y.: 2016, The Atmospheres and Water on Our Terrestrial Planets and Other Planets, Symposium on Hierarchy and Holism in Natural Sciences, (Mitaka, Tokyo, Japan, Feb. 5-6, 2016).

Hori, Y.: 2017, The Primordial Atmosphere on a Terrestrial Planet in a Habitable Zone, Astrobiology Center International Workshop, (Hiroshima, Japan, Mar. 22-24, 2017).

Kokubo, T. et al. including **Kotani, T.**, **Nishikawa, J.**, **Tamura, M.**: 2016, 12.5-GHz-spaced laser frequency comb covering Y,J, and H bands for infrared Doppler instrument, SPIE Astronomical Telescope + Instrumentation, (Edinburgh, Scotland, UK, Jun. 26 - Jul. 1, 2016).

Kusakabe, N., **Tamura, M.**: 2016, SEEDS direct imaging survey of exoplanet and disks, and next steps (I), EAMA10, (Seoul, Korea, Sep. 26-30, 2016).

Kusakabe, N.: 2015, SEEDS : Review of direct imaging explorations of exoplanets/disks with Subaru, 3rd DTA Symposium: The Origins of Planetary Systems: from the Current View to New Horizons, (Mitaka, Japan, Jun. 1-4, 2015).

Kusakabe, N.: 2016, Exoplanet to Lives in the Universe, Asian Astronomical Forum, (Chiang Mai, Thai, Nov. 11, 2016).

Kuzuhara, M. et al. including **Tamura, M.**, **Kusakabe, N.**, **Hashimoto, J.**: 2015, The SEEDS High-Contrast Imaging Survey: Exoplanet and Brown Dwarf Survey for Nearby Young Stars Dated with Gyrochronology and Activity Age Indicators, Extreme Solar Systems III, (Waikoloa, HI, USA, Nov. 29-Dec. 4, 2015).

Kuzuhara, M.: 2017, Exploring Exoplanet and Disk with Telescope, from SEEDS to Next, Subaru International Partnership Science and Instrumentation Workshop, (Mitaka, Japan, Mar. 22-24, 2017).

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Mendillo, C. B. et al. including **Guyon, O.**: 2015, The low-order wavefront sensor for the PICTURE-C mission, SPIE Optics + Photonics, (San Diego, CA, USA, Aug. 9-13, 2015).

Narita, N., Enomoto, T., Masaoka, S., Kusakabe, N.: 2016, Titania may produce abiotic oxygen atmospheres on habitable exoplanets, Extreme Solar Systems III, (Waikoloa, HI, USA, Nov. 29-Dec. 4, 2015).

Narita, N.: 2015, Exoplanet ISDT Activity Report: TMT's Prospects for Exoplanets, TMT Science Forum 2015, (Washington D.C., USA, Jun. 23-25, 2015).

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Narita, N.: 2015, Introduction of Japanese Facilities for K2 Follow-up Observations and Latest Results, The first K2 Science Conference, (Santa Barbara, USA, Nov. 2-5, 2015).

Narita, N.: 2015, Possible Contribution of the Subaru telescope to TESS follow-up, Subaru-Keck synergy workshop, (Sendai, Miyagi, Japan, Sep. 1-2, 2015).

Narita, N.: 2016, Introduction of Subaru IRD and Okayama MuSCAT, TESS Science Team Meeting, (Cambridge, MA, MIT, May 19, 2016).

Narita, N.: 2016, MuSCAT and MuSCAT2 / IRD, TESS Science Team Meeting/TFOP splinter session (Cambridge, MA, MIT, Dec. 8-9, 2016).

Narita, N.: 2016, Possible Subaru-TESS Synergy Campaign, Subaru Users Meeting FY2015, (Atami, Japan, Jan. 19-21, 2016).

Narita, N.: 2016, Toward detections of habitable terrestrial planets around the Solar neighborhood, Symposium on Hierarchy and Holism in Natural Sciences, (Mitaka, Tokyo, Japan, Feb. 5-6, 2016).

Narita, N.: 2017, MuSCAT and MuSCAT2 for Detection and Characterization of Transiting Exoplanets, Formation and Dynamical Evolution of Exoplanets, (Aspen, USA, Mar. 26-Apr. 1, 2017).

Narita, N.: 2017, TRAPPIST-1 and Future Surveys of Habitable Transiting Earth-like Planets, AstroBiology Center, NINS International Workshop 2017, (Hiroshima, Japan, Mar. 22-24, 2017).

Nishikawa, J., Oya, M., Murakami, N., **Tamura, M.**, Kurokawa, T., Tanaka, K.: 2015, Imperfect Pre-coronagraph for additional contrast, Pathways 2015: Pathways Towards Habitable Planets, (Bern, Schweizerische, Jul. 13-17, 2015).

Nishikawa, J., Oya, M., Murakami, N., **Tamura, M.**, Kurokawa, T., Tanaka, K.: 2015, Imperfect Pre-coronagraph for contrast enhancement with speckle area nulling control, In the spirit of Bernard Lyot, (Montréal, USA, Jun. 22-26, 2015).

Nishikawa, J., Oya, M., Murakami, N., **Tamura, M.**, Kurokawa, T.: 2015, Contrast enhancement with pre-coronagraph and dark-hole, IAU XXIX General Assembly, (Honolulu, HI, USA, Aug. 3-14, 2015).

Omiya, M, Takada-Hidai, M., Sato, B., Izumiura, H., Okayama planet search team, Korean-Japanese planet search team: 2015, Occurrence rate of giant planets around massive stars, OHP 2015: Twenty years of giant exoplanets, (La Chapelle-Saint-Jean, France, Oct. 5-9, 2015).

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Omiya, M., Takada-Hidai, M., Sato, B., Izumiura, H.: 2015, Occurrence rate of giant planets around massive stars, 3rd DTA Symposium: The Origins of Planetary Systems: from the Current View to New Horizons, (Mitaka, Japan, Jun. 1-4, 2015).

Omiya, M.: 2015, Search for extrasolar Earth-like planes in the habitable zone using InfraRed Doppler and the Subaru, Japan Geoscience Union Meeting 2015, (Chiba, Japan, May 24-28, 2015).

Omiya, M.: 2016, Observations of exoplanets and stellar activity, Superflares on Solar-type Stars and Solar Flares, and Their Impacts on Exoplanets and the Earth, (Kyoto, Japan, Mar. 1-4, 2016).

Rich, E. A., Wisniewski, J. P., **Hashimoto, J.**, Brandt, T., **Tamura, M.**: 2015, Discovery of Low Mass Binary with Super Jupiter Companion, American Astronomical Society, ESS meeting #3, (Hawaii, USA, Nov. 29-Dec. 4, 2015).

Sirbu, D. et al. including **Guyon, O.**: 2015, EXCEDE technology development IV: demonstration of polychromatic contrast in vacuum at 1.2 λ/D, SPIE Optics + Photonics, (San Diego, CA, USA, Aug. 9-13, 2015).

Tamura, M. et al.: 2016, Five Years of SEEDS: Strategic Exploration of Exoplanets and Disks with Subaru, Subaru Users Meeting FY2015, (Atami, Japan, Jan. 19-21, 2016).

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Tamura, M.: 2015, Development of Astrobiology with Exoplanet Explorations, Japan Geoscience Union Meeting 2015, (Chiba, Japan, May 24-28, 2015).

Tamura, M.: 2015, NINS Astrobiology Center: Development of Astrobiology with Exoplanet Explorations, NAI/EC and International Partner In-person Meeting, (Chicago, USA, Jun. 19-20, 2015).

Tamura, M.: 2015, Subaru Direct Imaging Survey of Wide-Orbit Exoplanets and Solar-System-Scale Disks, IAU XXIX General Assembly, (Honolulu, HI, USA, Aug. 3-14, 2015).

Tamura, M.: 2015, Subaru Observations of Exoplanets and Toward TMT: A Role of the New Astrobiology Center at NINS, Astrobiology Workshop, (Kiel, Germany, Dec. 9, 2015).

Tamura, M.: 2016, Astrobiology Center (ABC) of NINS, EANA, (Athens, Greece, Sep. 27-30, 2016).

Tamura, M.: 2016, Exoplanet exploration with IRSF/SIRIUS and future, IRSF Workshop 2016, (Cape Town, South Africa, Mar. 3, 2016).

Tamura, M.: 2016, Workshop summary, Post-SEEDS Workshop, (Mitaka, Japan, Feb. 21, 2016).

Uyama, T., **Tamura, M.**, **Hashimoto, J.**: 2015, Search for Exoplanets around Young Stellar Objects by Direct Imaging, American Astronomical Society, ESS meeting #3, (Hawaii, USA, Nov. 29-Dec. 4, 2015).

5-4 Research Collaboration Refereed Publications

Akanuma, S., Yamagishi, A.: 2016, A Strategy for Designing Thermostable Enzymes by Reconstructing Ancestral Sequences Possessed by Ancient Life, Biotechnology of Extremophiles, Ed: Rampelotto P. H., 581-596, Springer International Publishing.

Aoki, S., et al. including Nakagawa, H.: 2018, Stringent upper limit of CH4 on Mars based on SOFIA/EXES observations., *Astron. Astrophys.* 610, A78.

Brasser, R., Matsumura, S., Ida, S., Mojzsis, S. J., Werner, S. C.: 2016, Analysis of terrestrial planet formation by the Grand Tack model: System architecture and tack location, *ApJ* 821, 75.

Chan, Q. H. S. et al. including Kebukawa, Y.: 2018, Heating experiments of the Tagish Lake meteorite: Investigation of the effects of short‐term heating on chondritic organics., *Meteorit. Planet. Sci.* 54.1, 104-125.

Chan, Q. H. S. including Kebukawa, Y.: 2018, Organic matter in extraterrestrial water-bearing salt crystals, *Sci. Adv.* 4.1, eaao3521.

Hirano, T. et al.: 2016, The K2-ESPRINT Project III: A Close-in Super-Earth around a Metal-rich Mid-M Dwarf, *ApJ* 820, 41.

Hyodo, R., Genda, H.: 2018, Implantation of Martian materials in the inner solar system by a mega impact on Mars., *ApJL* 856.2, L36.

Iino, T., Yamada, T.: 2018, Spatially Resolved Sub-millimeter Continuum Imaging of Neptune with ALMA, *ApJ* 155.2, 92.

Ikoma, M., Elkins-Tanton, L., Hamano, K., Suckale, J.: 2018, Water Partitioning in Planetary Embryos and Protoplanets with Magma Oceans, *Space Sci. Rev.* 214.4, 76.

Kashiwagi, K. et al. including Kurokawa, T.: 2016, Direct generation of 12.5-GHz-spaced optical frequency comb with ultrabroad coverage in near-infrared region by cascaded fiber configuration, *Opt. Exp.*, 24, 8120.

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Kobayashi, H., Tanaka, H., Okuzumi, S.: 2016, From Planetesimals to Planets in Turbulent Protoplanetary Disks. I. Onset of Runaway Growth, *ApJ* 817, 105.

Long, Z. C., et al. including Akiyama, E.: 2018, Differences in the gas and dust distribution in the transitional disk of a sun-like young star, PDS 70, *ApJ* 858.2, 112.

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Naganuma, T., Iinuma, Y., Nishiwaki, H., Murase, R., Masaki, K., Nakai, R.: 2018, Enhanced bacterial growth and gene expression of D-amino acid dehydrogenase with D-glutamate as the sole carbon source, *Front. Microbiol.* 9, 2097.

Nakashima, S., Kebukawa, Y., Kitadai, N., Igisu, M., & Matsuoka, N.: 2018, Geochemistry and the Origin of Life: From Extraterrestrial Processes, Chemical Evolution on Earth, Fossilized Life’s Records, to Natures of the Extant Life, Life 8.4, 39.

Narita, N. et al. including Fukui, A.: 2015, Characterization of the K2-19 Multiple-transiting Planetary System via High-dispersion Spectroscopy, AO Imaging, and Transit Timing Variations, *ApJ* 815, 47.

Notsu, S., Nomura, H., Walsh, C., Honda, M., Hirota, T., Akiyama, E., Millar, T. J.: 2018, Candidate Water Vapor Lines to Locate the H2O Snowline through High-dispersion Spectroscopic Observations. III. Submillimeter H2 16O and H2 18O Lines, *ApJ* 855.1, 62.

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Sheng, L., Kurihara. K.: 2016, Generation of Catalytic Amphiphiles in a Self-reproducing Giant Vesicle, *Chem. Lett.* 45, 598-600.

Shibue, R., Sasamoto, T., Shimada, M., Zhang, B., Yamagishi, A., Akanuma, S.: 2018, Comprehensive reduction of amino acid set in a protein suggests the importance of prebiotic amino acids for stable proteins, *Sci. Rep.*, 8.1, 1227.

Yamagishi, A., et al.: 2018, Environmental Data and Survival Data of Deinococcus aetherius from the Exposure Facility of the Japan Experimental Module of the International Space Station Obtained by the Tanpopo Mission, *Astrobiology* 18.11, 1369-1374.

5-5 Research Collaboration Conference Presentations

Abe, H. et al including Kobayashi, K.: 2016, Laboratory simulations of Titan tholins formed by cosmic rays, Japan Geoscience Union Meeting 2016, (Chiba, Japan, May 22-26, 2016).

Akanuma, S., Bessho, M., Sasamoto, T., Yokobori, S., Yamagishi, A., reverification of the thermophilicity of ancient life, 8th Astrobiology Workshop, (Tokyo, Japan, Nov. 27, 2015).

Amikura K., Aoyama R., Tamaru D., Shimizu Y., Ueda T.: 2016, In vitro reconstitution of 30S ribosomal subunit in the presence of ribosome biogenesis factors, EMBO Conference on Ribosome structure and function 2016, (Strasbourg, France, Jul. 6-10, 2016).

Aoki, R. et al. including Kobayashi, K.: 2016, Amino acid formation from simulated midly-reducing primitive atmospheres by spark discharges, UV irradiation and proton irradiation, Japan Geoscience Union Meeting 2016, (Chiba, Japan, May 22-26, 2016).

Hashizume, H.: 2015, Reaction of adenine and ribose by repeated wetting and drying in the presence of montmorillonite, 8th Astrobiology Workshop, (Tokyo, Japan, Nov. 27, 2015).

Kobayashi, H., Tanaka, H., Okuzumi, S.: 2016, From Planetesimals to Planets in Turbulent Protoplanetary Disks. I. Onset of Runaway Growth, International Workshop on "Exoplanets and Disks: Their Formation and Diversity III", (Ishigaki, Japan, Feb. 21-24, 2016).

Kobayashi, K. et al., Astrobiology Experiments in Earth Orbit WG, 2015, Chemical Astrobiology Experiments in Earth Orbit: The Tanpopo Mission and Beyond, International Chemical Congress of Pacific Basin Societies 2015, (Honolulu, USA, Dec. 15-20, 2015).

Kobayashi, K. et al.: 2015, Abiotic Synthesis of Nucleic Acid Bases from Possible Interstellar Media by Particles Irradiation, International Chemical Congress of Pacific Basin Societies 2015, (Honolulu, USA, Dec. 15-20, 2015).

Kobayashi, K. et al.: 2015, Cosmic-rays induced synthesis of complex amino acid precursors in planetary atmospheres and in interstellar ices, 8th Astrobiology Workshop, (Tokyo, Japan, Nov. 27, 2015).

Kobayashi, K. et al.: 2016, Astrobiology Experiments in Earth Orbit to Test Formation, Alteration and Delivery of Organic Compounds: From the Tanpopo Mission to Future Plans, 41th COSPAR Scientific Assembly 2016, (Istanbul, Turkey, Jul. 30-Aug. 7, 2016).

Kobayashi, K. et al.: 2016, Energetics of Amino Acid Formation in Slightly Reducing Atmospheres of Primitive Earth and Titan, 26th Goldschmidt Conference, (Yokohama, Japan, Jun. 26-Jul. 1, 2016).

Kobayashi, K. et al.: 2016, Formation of Amino Acid Precursors by Bombardment of Interstellar Ice Analogs with High Energy Heavy Ions, 41th COSPAR Scientific Assembly 2016, (Istanbul, Turkey, Jul. 30-Aug. 7, 2016).

Kobayashi, K. et al.: 2016, Formation of Super-complex Amino Acid Precursors in Interstellar Ice Analogues by Particles Irradiation, Japan Geoscience Union Meeting 2016, (Chiba, Japan, May 22-26, 2016).

Kobayashi, K.: 2015, Cosmic Ray-Induced Formation of Bioorganic Compoundsin Planetary Atmospheres and in Interstellar Dusts, 12th German-Japanese Colloquium, (Kiel, Germany, Dec. 9-10, 2015).

Kurihara, K.: 2015, A chemical approach to primitive cell, The 6th Yonsei-IMS Joint Workshop, (Seoul, Korea, Mar. 13-15, 2016).

Masaoka, S.: 2015, Possible photosynthetic reactions on habitable exoplanets, 12th German-Japanese Colloquium, (Kiel, Germany, Dec. 8-10, 2015).

Matsuda, T. et al. including Kobayashi, K.: 2015, Formation of Complex Amino Acid Precursors from Possible Interstellar Media by Particles Irradiation, International Chemical Congress of Pacific Basin Societies 2015, (Honolulu, USA, Dec. 15-20, 2015).

Nakagawa, H. et al.: 2015, Complementary studies to TGO/ACS, TGO-ACS SWT, Second ACS (Atmospheric Chemistry Suite) SWT, (Moscow, Russia, Oct. 29-30, 2015).

Nakagawa, H. et al.: 2016, Regional coupling between lower and upper atmosphere revealed by MAVEN/IUVS and complementary study by Earth-based observation, GEMSIS WS, (Nagoya, Japan, Mar. 24, 2016).

Yamamoto, M. et al.: 2015, Electrochemical evolution of primordial metabolic core on deep -sea hydrothermal vent, 8th Astrobiology Workshop, (Tokyo, Japan, Nov. 27, 2015).

Yamamoto, M. et al.: 2015, Reproduction of primitive metabolic pathways on the iron sulfide surface with electricity, 25th Goldschmidt Conference, (Prague, Czech, Aug. 16-21, 2015).

6. Finance

6-1 Revenues and Expenses (FY2017)

(Unit: ¥)

Revenues	Budget	Final Account	Budget – Final Account
Management Expenses Grants	87,566,000	194,285,433	-106,719,433
Total	87,566,000	194,285,433	-106,719,433

Expenses	Budget	Final Account	Budget – Final Account
Management Expenses: Research and Education Expenses	87,566,000	194,285,433	-106,719,433
Total	87,566,000	194,285,433	-106,719,433

Revenues-Expenses	Budget	Final Account	Budget – Final Account
	0	0	0

6-2 Revenues and Expenses (FY2018)

(Unit: ¥)

Revenues	Budget	Final Account	Budget – Final Account
Management Expenses Grants	284,960,000	279,560,000	5,400,000
Total	284,960,000	279,560,000	5,400,000

Expenses	Budget	Final Account	Budget – Final Account
Management Expenses: Research and Education Expenses	284,960,000	271,671,226	13,288,774
Total	284,960,000	271,671,226	13,288,774

Revenues-Expenses	Budget	Final Account	Budget – Final Account
	0	7,888,774	-7,888,774

6-3 Revenues and Expenses (FY2019) (Unit: ¥)

Revenues	Budget	Final Account	Budget – Final Account
Management Expenses Grants	147,413,000	182,501,774	-35,088,774
Subsidy Income	163,429,000	163,429,000	0
Miscellaneous Income	0	10,260	-10,260
Total	310,842,000	345,941,034	-35,099,034

Expenses	Budget	Final Account	Budget – Final Account
Management Expenses: Research and Education Expenses	147,413,000	155,183,228	-7,770,228-
Subsidy Expenses	163,429,000	163,429,000	0
Total	310,842,000	318,612,228	-7,770,228

Revenues-Expenses	Budget	Final Account	Budget – Final Account
	0	27,328,806	-27,328,806

7. KAKENHI (Grants-in-Aid for Scientific Research)

The grants below were operated by researchers who have dual appointments with NAOJ through the Financial Affairs Division in NAOJ, because, from FY2015 to FY2017, there was no system for accepting grants including KAKENHI as Astrobiology Center.

7-1 Series of Single-year Grants

Research Term	Research Categories	Principal Investigator	Budget (Unit: ¥1,000)		
			Direct Funding	Indirect Funding	Total
FY2014-FY2015	Scientific Research on Innovative Areas (Research in a proposed research area)	Takayuki Kotani	6,000	1,800	7,800
FY2014-FY2015	Scientific Research on Innovative Areas (Research in a proposed research area)	Yasunori Hori	1,700	510	2,210
FY2013-FY2016	Scientific Research (A)	Norio Narita	33,000	9,900	42,900

7-2 Multi-year Fund

Research Term	Research Categories	Principal Investigator	Budget (Unit: ¥1,000)		
			Direct Funding	Indirect Funding	Total
FY2015-FY2017	Challenging Exploratory Research	Takayuki Kotani	2,900	870	3,770
FY2014-FY2015	Challenging Exploratory Research	Nobuhiko Kusakabe	2,800	840	3,640

7-3 Partial Multi-year Fund

Research Term	Research Categories	Principal Investigator	Budget (Unit: ¥1,000)		
			Direct Funding	Indirect Funding	Total
FY2013-FY2015	Scientific Research (B)	Takayuki Kotani	12,800	3,840	16,640

8. Graduate Course Education

From FY2015 to FY 2017, the Astrobiology Center had not directly taken charge of the graduate education in SOKENDAI (The Graduate University for Advanced Studies), because it is not a parent institute for SOKENDAI. However, the center has contributed to the education in SOKENDAI, due to the joint appointment system with NAOJ.

From FY2018, it became possible to accept graduate students by cooperating with School of Physical Sciences and School of Life Science of SOKENDAI.

FY2015：

3rd year

Graduate Student	Supervisor	Research Theme
Baba, Haruka	Aoki, Wako （NAOJ）	Development of infrared instruments and observational research for exploring Earth-like exoplanets
Ryu, Tsuguru	Hayashi, Saeko （NAOJ）	High-Contrast Imaging for Intermediate-Mass Giants with Long-Term Radial Velocity Trends

4th year

Graduate Student	Supervisor	Research Theme
Yang, Yi	Hayashi, Saeko （NAOJ）	Direct Imaging of Circumstellar Disks and Planets in Binary Systems
Onitsuka, Masahiro	Usuda, Tomonori （NAOJ）	Observational Studies of the Structure and Evolution of Exoplanets

FY2016：

1st year

Graduate Student	Supervisor	Research Theme
Ishikawa, Hiroyuki	Usuda, Tomonori (NAOJ)	Detailed study of the habitable exoplanets as candidates where actual life can be found
Hosokawa, Ko	Kotani, Takayuki	Development of a new high-resolution spectrograph with a spatial resolution and study of an exoplanet characterization
Watanabe, Noriharu	Usuda, Tomonori (NAOJ)	Observational Studies of Orbital Evolution of Various Exoplanets System

4th year

Graduate Student	Supervisor	Research Theme
Baba, Haruka	Aoki, Wako (NAOJ)	Development of infrared instruments and observational research for exploring Earth-like exoplanets
Ryu, Tsuguru	Hayashi, Saeko (NAOJ)	High-Contrast Imaging for Intermediate-Mass Giants with Long-Term Radial Velocity Trends

5th year

Graduate Student	Supervisor	Research Theme
YANG, Yi	Hayashi, Saeko (NAOJ)	Direct Imaging of Circumstellar Disks and Planets in Binary Systems
Onitsuka, Masahiro	Usuda, Tomonori (NAOJ)	Observational Studies of the Structure and Evolution of Exoplanets

FY2017：

2nd year

Graduate Student	Supervisor	Research Theme
Ishikawa, Hiroyuki	Usuda, Tomonori （NAOJ）	Detailed study of the habitable exoplanets as candidates where actual life can be found
Hosokawa, Ko	Kotani, Takayuki	Development of a new high-resolution spectrograph with a spatial resolution and study of an exoplanet characterization
Watanabe, Noriharu	Usuda, Tomonori （NAOJ）	Observational Studies of Orbital Evolution of Various Exoplanets System

5th year

Graduate Student	Supervisor	Research Theme
Baba, Haruka	Aoki, Wako （NAOJ）	Development of infrared instruments and observational research for exploring Earth-like exoplanets
Ryu, Tsuguru	Hayashi, Saeko （NAOJ）	High-Contrast Imaging for Intermediate-Mass Giants with Long-Term Radial Velocity Trends
Yang, Yi	Hayashi, Saeko （NAOJ）	Direct Imaging of Circumstellar Disks and Planets in Binary Systems

9. Public Access to Facilities

date	name	place	visitors
23-24th, October, 2015	[Special Open-House Event] Mitaka Open House Day 2015 Topic: The Challenges Awaiting Astrobiology	NAOJ Mitaka campus	5,036
21-22th, October, 2016	[Special Open-House Event] Mitaka Open House Day 2016 Topic: Gravitational Waves, a new Frontier of Astronomy	NAOJ Mitaka campus	4,534
13th, March, 2016	The 20th NINS symposium「生命の起源と進化～地球から系外水惑星へ～」	Hitotsubashi Hall	413
13-14th, October, 2017	[Special Open-House Event] Mitaka Open House Day 2017 Topic: Cold Universe, Hot Universe	NAOJ Mitaka campus	5,026

10. Overseas Travel

FY2015：Research and Academic Staff Overseas Travel

country/area	business trip
Hawai`i	9
U.S.A.	1
Canada	1
South Korea	1
Germany	3
France	1
Switzerland	1
Spain	1
Republic of South Africa	1

FY2016：Research and Academic Staff Overseas Travel

country/area	business trip
Hawai`i	24
U.S.A.	1

FY2017：Research and Academic Staff Overseas Travel

country/area	business trip
Hawai`i	28
U.S.A.	3
Chile	3
Australia	2
Republic of South Africa	1

11. Important Dates

April 1, 2015 – March 31, 2016

April 1	Astrobiology Center（ABC）is newly inaugurated.
June 19	NASA Astrobiology Institute (NAI) steering committee（Tamura, Kobayashi, Hirose（TV）；Chicago）
July 13～ August 8	FY2015 Grants-in-Aid of AstroBiology Center Project open.
August	Joining an International partnership of NASA Astrobiology Institute (NAI) as the Japan AstroBiology Consortium together with ELSI
September 7	The 1st steering committee（at Research Organization of Information and Systems conference room）
October 23～ October 24	Mitaka Open House Day 2015 (at NOAJ Mitaka campus，Sponsors：NAOJ, ABC, Univ. of Tokyo, SOKENDAI) Topic: The Challenges Awaiting Astrobiology
November 15～ November 17	The 11th Workshop for Popularizing Cutting the Edge Astronomy" Astrobiology - Habitability inside and outside of the Solar System"（at NAOJ Mitaka，JAMSTEC，Sponsors：NAOJ, ABC）
November 19	Astrobiology Center HP open.　http://abc-nins.jp
November 20	Astrobiology Center opening ceremony and the social gathering（at NAOJ）
November 24～ November 26	Workshop of Near-Infrared High-Resolution Spectroscopy: Earth-like Planet Hunting and Its Expansion in Science（at NAOJ Mitaka）
December 8～ December 10	JSPS Japanese-German science colloquium（at University of Kiel）
January 28	The 2nd steering committee and the Round Table Conference on Life and the Universe（at NAOJ Mitaka）provided by: Yasunori Hori (ABC)「系外惑星大気のこれまでとこれから」（Video Conference from Mizusawa）Topic: Exoplanetary Atmosphere
February 6～ February 7	Astrobiology Center Mini-Workshop: Photosynthesis in Extreme Environments（at Tachikawa Grand Hotel）
February 26	Post SEEDS Workshop（at NAOJ Mitaka）

March 6～ March 28	FY2016 Grants-in-Aid of AstroBiology Center Project open.
March 7～ March 8	The 4th Life in the Universe workshop by Astrobiology Center, NINS （FY-H27 Project Research Results)
March 13	NINS symposium「生命の起源と進化～地球から系外水惑星へ～」（at Hitotsubashi Hall）Topic: Origins and Evolution of Life – from the Earth to Exoplanets
End of March	ABC new building is completed（an extension in the ALMA building at NOAJ）

April 1, 2016 – March 31, 2017

May 9	The 3rd steering committee（at Research Organization of Information and Systems conference room）
June 3	The 4th steering committee（at Tokyo Tech. ELSI ELSI-2 1F room 106）
June 27	the Round Table Conference on Life and the Universe（at NINS conference room）provided by: Makiko Harada (Tokyo Univ. of Pharmacy and Life Sciences)「シアノバクテリアのプロモーター配列解析による抗酸化酵素の発現量の進化」Topic: Evolution of Cyanobacteria by Genome Analysis
October 18	The Round Table Conference on Life and the Universe（at NINS conference room）provided by: Yasuhito Sekine (Univ. of Tokyo)｢太陽系における“海”の多様性」Topic: Diversity of Ocean in the Solar system
October 21～ October 22	Mitaka Open House Day 2016 (at NOAJ Mitaka campus, Sponsors：NAOJ, ABC, Univ. of Tokyo, SOKENDAI) Topic: Gravitational Waves, a new Frontier of Astronomy
January 25	The 5th steering committee（at NINS conference room）
March 6～ March 7	The 5th Life in the Universe workshop by Astrobiology Center, NINS （FY-H28 Project/Satellite Results)
March 21～ March 23	Astrobiology Center International Workshop 2017（at Hiroshima University Higashi-Hiroshima campus, Hiroshima City Bunka Koryu Kaikan）

March 22	Public Lecture “隣の星に生命を探せ！　系外惑星とブレイクスルー･イニシアチブ”（at Hiroshima City Bunka Koryu Kaikan）Topic: Exoplanets and Breakthrough Initiatives

April 1, 2017 – March 31, 2018

May 22	The 6th steering committee（at TKP Shimbashi Business center room 604）
September 8	The 7th steering committee（at TKP Tokyo Station Central Conference Center 4M）
October 13～ October 14	Mitaka Open House Day 2017 (at NOAJ Mitaka campus，Sponsors：NAOJ, ABC, Univ. of Tokyo, SOKENDAI) Topic: Cold Universe, Hot Universe
January 15～ January 16	Astrobiology Center Symposium 2018 （at NAOJ Mitaka）
February 15～ February 19	The 8th steering committee（e-mail deliberations）
February 19～ February 20	The 6th Life in the Universe Workshop by Astrobiology Center, NINS (FY-H29 Project/Satellite Results)
March 12	The 9th steering committee（at NINS conference room）

Location：

address：

Astrobiology Center, NINS.

National Astronomical Observatory of Japan (NAOJ),

2-21-1 Osawa, Mitaka, Tokyo,

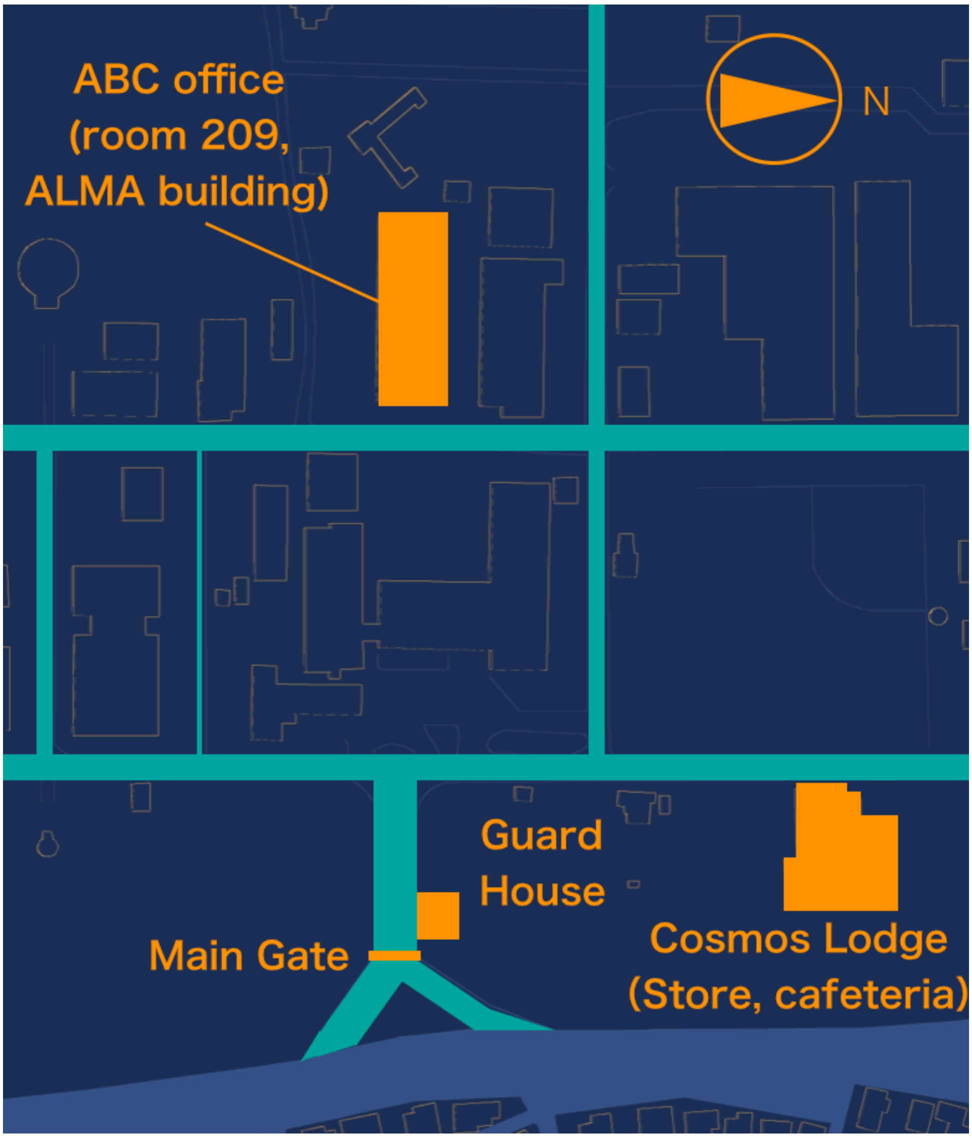
181-8588, JAPAN

Tel: (0422) 34-4066 (ABC office)

e-mail: abc-office@nao.ac.jp

URL: http://abc-nins.jp

Map in NAOJ:



How to access:

From JR Musashi-sakai station

Odakyu bus Sakai 91

bus stop “Musashisakai Eki Minamiguchi No. 3”

→“Tenmondai Mae”

（cash ¥220 / IC ¥216, around 15 min）

taxi （¥1.500, around 15 min）

From Keio Chofu station

Odakyu bus Sakai 91 / Taka51

bus stop “Chofu Eki Kitaguchi No. 11”

→“Tenmondai Mae”

（cash ¥220 / IC ¥216, around 15 min）

Keio bus Mu 91

bus stop “Chofu Eki Kitaguchi No. 12”

→“Tenmondai Mae”

（cash ¥210 / IC ¥206, around 15 min）

taxi （¥1.500, around 10 min）

*Buses from Mitaka station（Taka 51 toward Chofu Eki Kitaguchi）, Musashi-koganei station（Mu 91 toward Chofu Eki Kitaguchi） and Komae station（Sakai 91 toward Musashisakai Eki Minamiguchi） are also available.