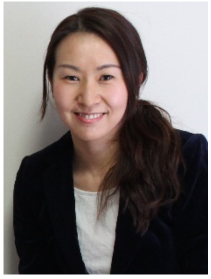
坂井星・惑星形成研究室
Star and Planet Formation Laboratory



主任研究員　坂井　南美（博士(理学)）
SAKAI, Nami (Ph. D.)

キーサイエンス：

1. 星間空間における物質進化の研究
2. 星・惑星系形成過程の研究
3. 分光実験による星間分子の回転遷移周波数の精密測定

キーワード：
星間化学、星間分子、電波観測、分光観測、電波干渉計、星形成、惑星系形成

研究概要
「太陽系のような環境はどれほど宇宙で普遍的に存在するのか？」。この問いに答えるには、母体となる星間分子雲から星や惑星がどのように作られるか、という物理進化の理解が不可欠である。同時に、星間分子雲で作られた様々な分子がどのように惑星系へもたらされるか、という化学進化の理解も原始地球環境との関連で非常に重要である。当研究室では、アルマ望遠鏡などの最先端電波望遠鏡を用いて、これらの両面から星と惑星の誕生過程を研究している。また、観測に必要な分子の回転遷移輝線の周波数を精密に測定する分子分光実験の準備も進めている。

Key Science:

A. Tracing chemical evolution from interstellar clouds to planets

B. Star and planet formation

C. Spectroscopy for molecules of astrochemical interests

Key Word :
Astrochemistry, Interstellar Medium, Molecular Cloud, Radio Observation, Spectroscopic Observation, Interferometric Observation, Star Formation, Plotoplanetary Disk, Microwave Spectroscopy

Outline
Star and planet formation is one of the most fundamental structure-formation processes in the universe. By use of the state-of-the-art radio telescopes including ALMA, we are investigating when a disk structure is formed around a solar-type protostar, and how it is evolved into a protoplanetary disk and eventually to a planetary system. This is an essential question deeply related to the origin of the Solar system. We particularly focus on a relation between physical evolution and chemical evolution. Star and planet formation is a process where interstellar matter is evolved into planets. Hence, chemical approach tells us not only chemical evolution itself but also novel information on physical processes of star and planet formation. Furthermore, such a chemical study is of fundamental importance in understanding an origin of the solar system, and eventually an origin of life on the Earth. With these in mind, we are studying star and planet formation by radio observations from chemical point of view. At the same time, we have started laboratory spectroscopy in millimeter band to tera-helz band to directly measure rest frequencies of rotational transitions of molecules with astronomical interest.

Overview

Project A： Tracing chemical evolution from interstellar clouds to planets

A comprehensive understanding of chemical evolution from protostellar cores to protoplanetary disks is important in relation to the origin of the Solar-System environment, which can eventually be related to origin of life. So far, it has been established that chemical composition of the protostellar cores shows significant chemical diversity. One distinct case is the hot corino chemistry, which is characterized by rich existence of saturated organic molecules. The other distinct case is the warm carbon-chain chemistry (WCCC), which is characterized by rich existence of unsaturated organic molecules such as carbon-chain molecules. It is proposed that a duration time of the starless core phase would cause this diversity. In this FY, we have analyzed spectral line survey data for the representative WCCC source, L1527, in order to reveal whole view of the WCCC source in the envelope scale (~1,000 au) [ref. 15]. For the disk forming scale (~100 au), we have found a new chemical type of source in Oph. region [ref. 3, 5]. In Oph region, some of the young stellar objects show extremely high abundance of Sulfur bearing species. We have also studied chemistry in the evolved (matured) system, revealing the origin of the gaseous component there [ref. 11]. This allows us to understand how molecules and chemical compounds are delivered to planetary system. As for the statistical study to reveal the chemical diversity in Perseus region (PEACHES project), complete datasets are delivered by ALMA. Calibration and basic analysis have been finished. In the next FY, we will investigate detailed chemistry of the disk forming regions in Perseus molecular cloud complex. We have also investigated chemical compositions of different-metallicity star-forming regions [ref. 2, 19]. This is a step toward revealing a whole story of chemical evolution in the Universe. In addition, we have investigated gas composition of the inner most part of the disk around a massive protostar candidate where dust grains are expected to be destroyed [ref. 1]. This tells us the history of interstellar dust, which is the building block of rocky-planets/comets.

Project B：Star and Planet Formation

By full use of chemical tools, we have revealed how dense cores are formed and how disks are formed inside the cores. Chemistry reflects not only history of physics, but also small changes in physical condition. It brings the breakthroughs to study physical evolution, such as disk formation, outflow launching, and planet formation. This FY, we focused on tracing rather simple atom and molecules to reveal outflow launch [ref. 1, 7, 13]. Toward understanding formation of planetary system, we have focused on dust size and disk substructure formation by full use of ALMA capabilities [ref. 11, 14]. Toward full understanding of star formation, we have also studied it not only in our Mikly Way galaxy but also in the early Universe. In the early Universe, a population of galaxies which are forming stars at a rate more than several 100 times higher than our Mikly Way galaxy. What causes and maintains the activity is yet unclear. Using ALMA, we identified unusual concentration of such starbursts at a proto-cluster core at a redshift of 3.1. All of the starbursts are embedded in filaments of cosmic web, which suggests that the violent star-forming activity is fueled by the gaseous network connecting galaxies [ref. 9].

Project C：Spectroscopy for molecules of astrochemical interests

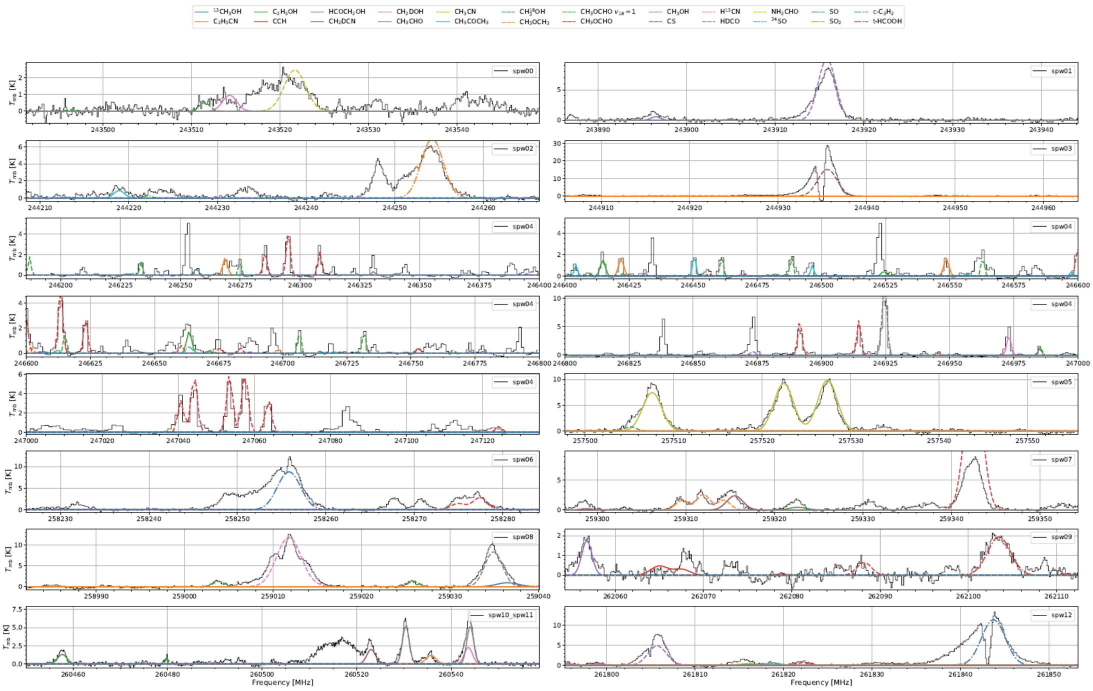
We have succeeded to launch the accurate and wide frequency band spectrometer (8 GHz at a time) by using radio-observation technique. After installing Rb clock, which gives 10^{-12} accuracy of the frequency, we have measured the rest frequencies of rotational transition line of N_2O to confirm the frequency accuracy. With the XFFTS spectrometer whose frequency resolution is 17.7 kHz, we could obtain the standard deviations of measured frequencies of 1-2 kHz for lines with enough signal to noise ratio. The line widths are ~0.3-0.4 km/s, which is comparable to or slightly larger than that of the Doppler broadening (0.28 km/s). Thus, the pressure broadening effect is not negligible but smaller contributor. Based on this success, we have started full scale operation of SUMIRE.

Highlights

Project A

A-1: Chemical Diversity in Perseus Molecular Cloud Complex: PEACHES-1 (led by Yao-lun Yang)

The Perseus ALMA Chemistry Survey (PEACHES) aims to provide the statistics on the occurrence of complex molecules at embedded protostars (Class0 and ClassI sources). This program unbiasedly observes 51 embedded protostars with ALMA around 260 GHz (34 field of view in total), covering the emission of simple molecules such as CS and SO as well as the emission of complex molecules including CH_3OH and CH_3OCHO. Our observations detect 50 unique continuum sources. Due to the overlap of the fields, 5 sources appear in multiple fields. The



continuum emission appears as compact circular or elliptical shape with no substructure. The spectra show various degrees of richness of emission lines (see Figure 1 for examples). We identified 24 molecules from the entire PEACHES spectra. We could also see the variety of chemistry among the samples. The detailed comparison among sources will be done in the next FY.

Figure 1. An example spectra: The entire spectra toward one of the PEACHES sources.

A-2: Whole Chemical View of the WCCC source, L1527 (led by Kento Yoshida)

An unbiased spectral line survey toward a solar-type Class 0/I protostar, IRAS04368+2557, in L1527 has been carried out in the 3 mm band with the Nobeyama 45 m telescope. L1527 is known as a warm carbon-chain chemistry (WCCC) source, which harbors abundant unsaturated organic species such as C_nH (n = 3,4,5, . . .) in a warm and dense region near the protostar. The observation covers the frequency range from 80 to 116 GHz. A supplementary observation has also been conducted in the 70 GHz band to observe fundamental transitions of deuterated species. In total, 69 molecular species are identified, among which 27 species are carbon-chain species and their isomers, including their minor isotopologues. This spectral line survey provides us with a good template of the chemical composition of the WCCC source. The high dynamic range of the column density ratios shown in figure 2 further confirms that the hot corinos such as IRAS 16293−2422 and the WCCC sources such as L1527 are the two distinct cases in chemical composition.

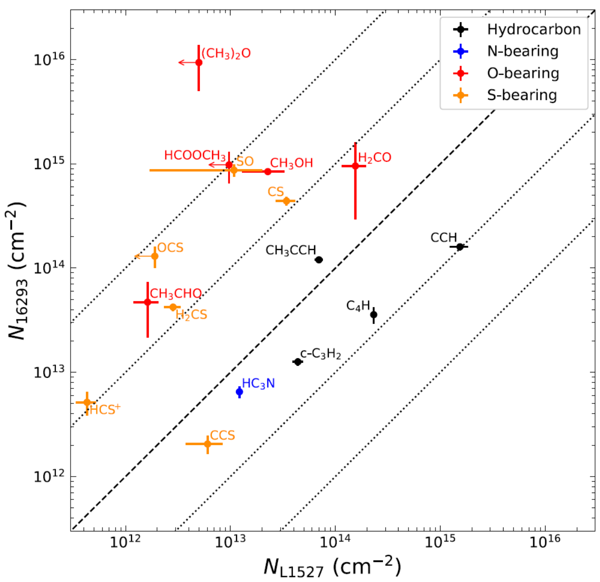


Figure 2. Comparison of column densities between L1527 and IRAS16293-2422

A-3: Aluminum Oxide found a massive protostar candidate Orion KL Source I (Ref. paper 1)

High-temperature molecular gas containing metallic elements is potentially a good probe to trace the kinematics/dynamics of circumstellar disks, and its presence in circumstellar disks around young stellar objects (YSOs) may also give some insights into formation processes of high-temperature meteoritic components formed in the Sun's protoplanetary disk. The Orion Kleimann–Low (KL) region is the most famous and nearest massive star formation site, and has been extensively studied since the 1970s. The KL region harbors a candidate high-mass YSO, Source I, which has a hot circumstellar rotating gas disk emanating a magnetocentrifugal wind of SiO. In this study, we spatially resolved distributions of aluminum monoxide (AlO) emission lines at 497 and 650 GHz in the rotating outflow of Orion Source I based on subarcsecond observations obtained by the ALMA for the first time in star-forming regions. These AlO emissions are detected only at the base of the outflow as the high excitation line of H2O in spite of their low excitation temperatures. The limited distribution of AlO to the launching point of the outflow indicates that AlO is not in the gas phase in the outer part of the outflow lobes away from the disk surface, which could be attributed to recondensation of AlO as dust due to its refractory nature. Aluminum rich inclusions found in meteorites are some of the oldest solid objects formed in the Solar System. This result is a good step toward understanding their formation process and stage. (Collaboration with Prof. Tachibana in the University of Tokyo. See press release.)

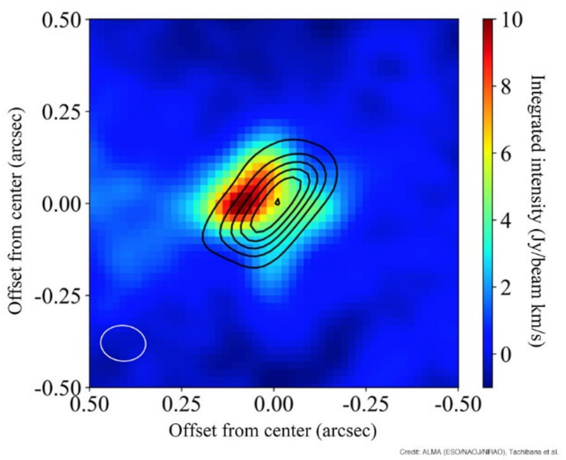


Figure 3. Integrated intensity map of the AlO lines (color)

Project B

B-1: Radial variations of grain sizes and dust scale heights of the protoplanetary disk (Ref. paper 14, led by Satoshi Ohashi)

The disk of HD 163296 is one of the representative source showing ring and gap substructures. In observations with ALMA, the rings and gaps are spatially resolved in millimeter-wave polarization measurements. Our radiative transfer modeling that includes self-scattering polarization constrained the grain size and its distribution. We found that the grain size and dust scale height are the key parameters for reproducing the radial and azimuthal distributions of the observed polarization signature. Radial variation is mainly determined by grain size. The polarization fraction is high if the particle size is $\sim\lambda/2\pi$ it is low if the particle size is larger or smaller than this. In contrast, azimuthal variation in polarization is enhanced if the dust scale height is increased. Based on detailed modeling of the polarization of HD 163296, we found the following radial variations in the grain size and dust scale height. The maximum grain size was 140 μm in the gaps and significantly larger or smaller in the rings. The dust scale height is less than one-third of the gas scale height inside the 70 au ring, and two-thirds of it outside. Furthermore, we constrained the gas turbulence to be $\alpha \lesssim 1.5 \times 10^{-3}$ in the 50 au gap and $\alpha \sim 0.015$–0.3 in the 90 au gap. The transition in the turbulence strength at the boundary of the 70 au ring indicates the existence of a dead zone. This study clearly shows that polarization millimeter-wave polarization measurements are very powerful tool to study behavior and properties of dust grains in protoplanetary disks. Understanding disk turbulence(scale height evolution) is also important issue to reveal disk evolution.

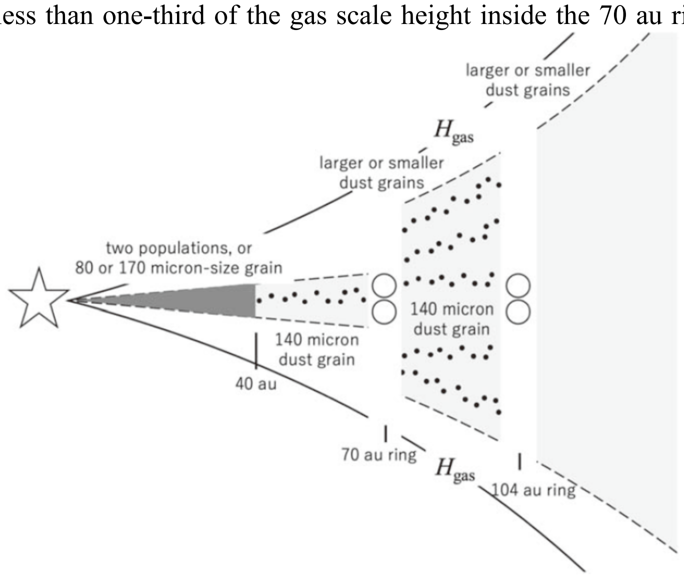
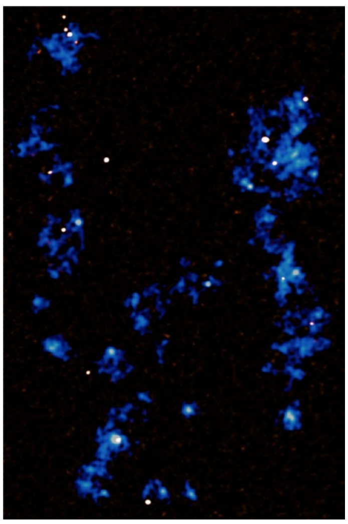


Figure 4. Schematic illustration HD163296 disk

B-2 Massive filaments fuel the growth of galaxies and supermassive black holes (Ref. paper9, led by Hideki Umehata)



The SSA22 proto-cluster at z=3.1 is a remarkable cosmic structure with an extent of 30 comoving Mpc, which provides a unique laboratory to investigate the co-evolution of galaxies and large-scale structures. Utilizing a series of ALMA observations, we detected numerous dust continuum and molecular emission lines from galaxies at z=3.1, which results in discovery of extreme overabundance of starbursts at the proto-cluster core. On the basis of observations using an integral field unit at optical wavelength, we also identified extended Lyman-alpha filaments, connecting the starbursts on 1 Mpc scale. The filaments are considered to be parts of massive gaseous network which harbors a plentiful amount of hydrogen gas. These results suggest that we are witnessing violent star-forming phase of galaxies in the proto-cluster, associated with high level of gas accretion from the cosmic web.

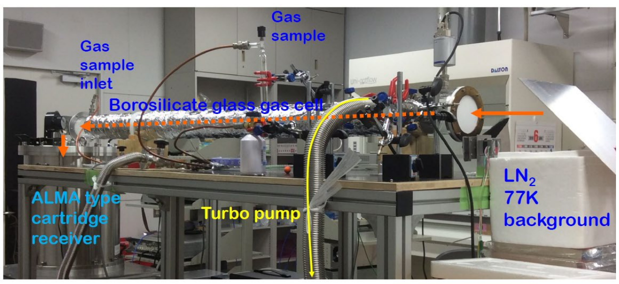
Figure 5. Cosmic web filaments. Extended Lyman- α emission are shown across the panel (0.9x1.3Mpc at z=3.1 in size). Background image is the 1.1~mm map taken with ALMA. SMGs ubiquitously distribute along the filaments, which suggests that cosmic web fuels such active galaxy growth.

B-3 An Episodic Wide-angle Outflow in HH 46/47 (Ref. paper 7, led by Yichen Zhang)

During the star formation, the accretion disk drives fast MHD winds which usually contain two components, a collimated jet and a radially distributed wide-angle wind. These winds further entrain the ambient gas into a secondary outflow which is traced by molecules. Our ALMA cycle 3 observation of the HH 46/47 molecular outflow revealed multiple wide-angle outflowing shell structures in both blue and red-shifted component. These shells are highly coherent in position–position–velocity space, extending to >40–50 km s^{-1} in velocity and 10^4 au in space, with well-defined morphology and kinematics. With simple model fitting, we suggest each of these outflowing shells is resultant from entrainment of ambient gas by an outburst event in the wide-angle wind. While episodic outbursts in collimated jet has been seen before, this is rare evidence that the wide-angle wind, same as the collimated jet, experiences episodicity, as expected by theories of episodic accretion and wind launching. The coherent shell structure further implies that the wide-angle wind should be launched from a relatively narrow region on the disk, which put constraints on the theory of wind launching.

Highlights of Project C: ***SUMIRE (Akemi Tamanai, Yoshimasa Watanabe, collaboration with NAOJ and UEC)***

ALMA has provided numerous innovative findings successively up to now. Specifically, observed emission and absorption lines give us plenty of details on gas kinematics, physical properties, and chemical compositions of both gas molecules as well as dust grains. Commonly, theoretically calculated and/or experimentally measured absorption/extinction spectra are applied for interpreting the observed spectra accurately. It is preferable to measure the spectrum of the same substance in a wide frequency range under the same measurement conditions in laboratory works. Although spectroscopic measurements of various molecules have been carried out, the number of measurement data from experiments in the high-frequency region is not sufficient to identify and interpret the molecules in astronomical environments. For that, we have developed the emission type molecular spectroscopy for astronomically relevant materials in ALMA band 6 up to 10. The Extended bandwidth fast Fourier Transform Spectrometer is coupled to a Superconductor-Insulator-Superconductor (SIS) mixer for 230 GHz (ALMA band 6) or a Superconducting Hot Electron Bolometer (HEB) mixer for ~0.9 THz band mounted on the ALMA-type cartridge receiver as a heterodyne apparatus (SUMIRE). This FY, we have started full scale operation. We have started to measure various isotopic species of CH_3OH as the first step. (From Sep.-Jan. SUMIRE is stopped due to maintenance works of the facility)



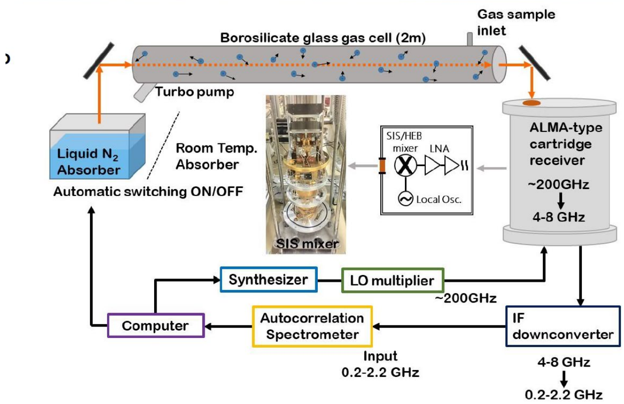
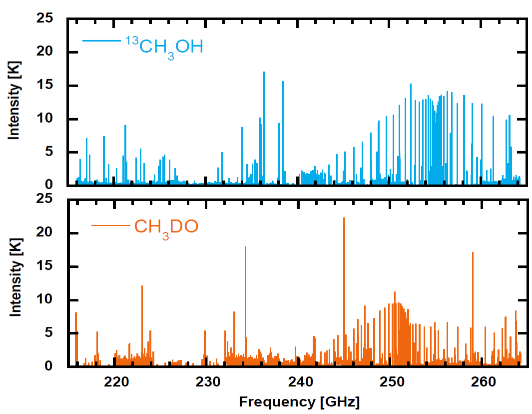


Figure 6. The system structures and sample spectra



Publications (Refereed papers)

1) Shogo Tachibana, Takafumi Kamizuka, Tomoya Hirota, Nami Sakai, Yoko Oya, Aki Takigawa, Satoshi Yamamoto, "Spatial Distribution of AlO in a High-mass Protostar Candidate Orion Source I", Astrophys. J. Lett., 875, L29 (4 pp), Apr. 2019

2) Yoshimasa Watanabe, Yuri Nishimura, Kazuo Sorai, Nami Sakai, Nario Kuno, Satoshi Yamamoto, "A 3 mm Spectral Line Survey toward the Barred Spiral Galaxy NGC 3627", Astrophys. J. Suppl. Ser., 242, 26 (21 pp), Jun. 2019

3) E. Artur de la Villarmois, J. K. Jorgensen, L. E. Kristensen, E. A. Bergin, D. Harsono, N. Sakai, E. F. van Dishoeck, S. Yamamoto, "Physical and chemical fingerprint of protostellar disc formation", Astron. Astrophys., 626, A71 (19 pp), Jun. 2019

4) Natsuki H. Hayatsu, R. J. Ivison, Paola Andreani, Hideki Umehata, Yuichi Matsuda, Naoki Yoshida, Kotaro Kohno, Bunyo Hatsukade, Akio K. Inoue, Yoichi Tamura, Tutomu T. Takeuchi, Seiji Fujimoto, Minju M. Lee, Tohru Nagao, and Yiping Ao, "ADF22: Blind Detections of [C II] Line Emitters Shown to be Spurious", RNAAS, 3, 97, Jul. 2019

5) Yoko Oya, Ana Lopez-Sepulcre, Nami Sakai, Yoshimasa Watanabe, Aya E. Higuchi, Tomoya Hirota, Yuri Aikawa, Takeshi Sakai, Cecilia Ceccarelli, Bertrand Lefloch, Emmanuel Caux, Charl, "Sulfur-bearing Species Tracing the Disk/Envelope System in the Class I Protostellar Source Elias 29", Astrophys. J., 881, 112 (16 pp), Aug. 2019

6) Takuya Hashimoto, Akio K. Inoue, Ken Mawatari, Yoichi Tamura, Hiroshi Matsuo, Hisanori Furusawa, Yuichi Harikane, Takatoshi Shibuya, Kirsten K. Knudsen, Kotaro Kohno, Yoshiaki Ono, Erik Zackrisson, Takashi Okamoto, Nobunari Kashikawa, Pascal A. Oesch, Masami Ouchi, Kazuaki Ota, Ikkoh Shimizu, Yoshiaki Taniguchi, Hideki Umehata and Darach Watson, "Big Three Dragons: A z = 7.15 Lyman-break galaxy detected in [O III] 88 µm, [C II] 158 µm, and dust continuum with ALMA", PASJ, 71, 71, Aug. 2019

7) Yichen Zhang, Héctor G. Arce, Diego Mardones, Sylvie Cabrit, Michael M. Dunham, Guido Garay,Alberto Noriega-Crespo, Stella S. R. Offner, Alejandro C. Raga, and Stuartt A. Corder, "An Episodic Wide-angle Outflow in HH 46/47", Astrophys. J. 883, 1 (11 pp), Sept. 2019

8) Riouhei Nakatani, Naoki Yoshida, "Photoevaporation of Molecular Gas Clumps Illuminated by External Massive Stars: Clump Lifetimes and Metallicity Dependence", Astrophys. J., 883, 127 (16 pp), Oct. 2019,

9) Hideki Umehata, M. Fumagalli, I. Smail, Y Matsuda, A. M. Swinbank, S. Cantalupo, C. Sykes, R. J. Ivison, C. C. Steidel, A. E. Shapley, J. Vernet, T. Yamada, Y. Tamura, M. Kubo, K. Nakanishi, M. Kajisawa, B. Hatsukade, K. Kohno, "Gas filaments of the cosmic web located around active galaxies in a protocluster", Science, 366, pp. 97-100, Oct. 2019

10) Yuichi Harikane, Masami Ouchi, Yoshiaki Ono, Seiji Fujimoto, Darko Donevski, Takatoshi Shibuya, Andreas L. Faisst, Tomotsugu Goto, Bunyo Hatsukade, Nobunari Kashikawa, Kotaro Kohno, Takuya Hashimoto, Ryo Higuchi, Akio K. Inoue, Yen-Ting Lin, Crystal L. Martin, Roderik Overzier, Ian Smail, Jun Toshikawa, Hideki Umehata, Yiping Ao, Scott Chapman, David L. Clements, Myungshin Im, Yipeng Jing, Toshihiro Kawaguchi, Chien-Hsiu Lee, Minju M. Lee, Lihwai Lin, Yoshiki Matsuoka, Murilo Marinello, Tohru Nagao, Masato Onodera, Sune Toft and Wei-Hao Wang, "SILVERRUSH. VIII. Spectroscopic Identifications of Early Large-scale Structures with Protoclusters over 200 Mpc at z ~ 6–7: Strong Associations of Dusty Star-forming Galaxies", Astrophys. J., 883, 142 (16 pp), Oct. 2019

11) Aya E. Higuchi, Kazuya Saigo, Hiroshi Kobayashi, Kazunari Iwasaki, Munetake Momose, Kang Lou Soon, Nami Sakai, Masanobu Kunitomo, Daisuke Ishihara, Satoshi Yamamoto, "First Subarcsecond Submillimeter-wave [C i] Image of 49 Ceti with ALMA", Astrophys. J., 883, 180 (8 pp), Oct, 2019

12) Minju M. Lee, Tohru Nagao, Carlos De Breuck, Stefano Carniani, Giovanni Cresci, Bunyo Hatsukade, Ryohei Kawabe, Kotaro Kohno, Roberto Maiolino, Filippo Mannucci, Alessandro Marconi, Kouichiro Nakanishi, Toshiki Saito, Yoichi Tamura, Paulina Troncoso, Hideki Umehata and Min Yun, "First [N ii]122 µm Line Detection in a QSO-SMG Pair BRI 1202−0725 at z = 4.69", Astrophys. J. Lett., 883, L29 (7 pp), Oct. 2019

13) Yichen Zhang, Kei E.I.Tanaka, Viviana Rosero, Jonathan C. Tan, Joshua Marvil, Yu Cheng, Mengyao Liu, Maria T. Beltran and Guido Garay, "Discovery of a Photoionized Bipolar Outflow toward the Massive Protostar G45.47+0.05", Astrophys. J. Lett., 886, L4 (13 pp), Nov. 2019

14) Satoshi Ohashi, Akimasa Kataoka, "Radial Variations in Grain Sizes and Dust Scale Heights in the Protoplanetary Disk around HD 163296 Revealed by ALMA Polarization Observations", Astrophys. J., 886, 103 (19 pp), Nov. 2019

15) Kento Yoshida, Nami Sakai, Yuri Nishimura, Tomoya Tokudome, Yoshimasa Watanabe, Takeshi Sakai, Shuro Takano, and Satoshi Yamamoto, "An unbiased spectral line survey observation toward the low-mass star-forming region L1527", PASJ, 71, S18, Dec. 2019

16) Takuma Izumi, Masafusa Onoue, Yoshiki Matsuoka, Tohru Nagao, Michael A. Strauss, Masatoshi Imanishi, Nobunari Kashikawa, Seiji Fujimoto, Kotaro Kohno, Yoshiki Toba, Hideki Umehata, Tomotsugu Goto, Yoshihiro Ueda, Hikari Shirakata, John D. Silverman, Jenny E. Greene, Yuichi Harikane, Yasuhiro Hashimoto, Soh Ikarashi, Daisuke Iono, Kazushi Iwasawa, Chien-Hsiu Lee, Takeo Minezaki, Kouichiro Nakanishi, Yoichi Tamura, Ji-Jia Tang, Akio

Taniguchi, “Subaru High-z Exploration of Low-Luminosity Quasars (SHELLQs). VIII. A less biased view of the early co-evolution of black holes and host galaxies”, PASJ, 71, 111, Dec. 2019
17) Ken-ichi Tadaki, Daisuke Iono, Min S. Yun, Itziar Aretxaga, Bunyo Hatsukade, Minju M. Lee, Tomonari Michiyama, Kouichiro Nakanishi, Toshiki Saito, Junko Ueda, Hideki Umehata, “A Noncorotating Gas Component in an Extreme Starburst at z = 4.3”, Astrophys. J., 889, 141, Feb. 2020
18) Yao-Lun Yang, Neal J. Evans II, Aaron Smith, Jeong-Eun Lee, John J. Tobin, Susan Terebey, Hannah Calcutt, Jes K. Jorgensen, Joel D. Green, Tyler L. Bourke, “Constraining the Infalling Envelope Models of Embedded Protostars: BHR 71 and Its Hot Corino”, Astrophys. J., 891, 61, Mar. 2020
19) Takashi Shimonishi, Ankan Das, Nami Sakai, Kei E. I. Tanaka, Yuri Aikawa, Takeshi Onaka, Yoshimasa Watanabe, Yuri Nishimura, “Chemistry and Physics of a Low-metallicity Hot Core in the Large Magellanic Cloud”, Astrophys. J., 891, 164, Mar. 2020

Oral Presentation (Invited)
1) Aya Higuchi, “Observations of gaseous debris disks”, NEW QUESTS IN STELLAR ASTROPHYSICS IV / ASTROCHEMISTRY, ASTROBIOLOGY AND THE ORIGIN OF LIFE, Puerto Vallarta, Mexico, 2 Apr. 2019
2) Nami Sakai, “Disk Formation and Evolution toward Protoplanetary Disks”, From Stars to Planets II, Gothemburg, Sweden, 17-20 Jun. 2019
3) Nami Sakai, “Toward understanding chemical evolution along protoplanetary disk formation”, International Symposium on Molecular Spectroscopy, Urbana, Illinois, US, 17-21 Jun. 2019
4) Satoshi Ohashi, “Observations for protoplanetary disks: From ALMA to ngVLA”, next generation VLA workshop, NAOJ, Mitaka, Japan, 17-20 Sept. 2019
5) Nami Sakai, “Chemical Diversity and Evolution toward Protoplanetary Disks”, ALMA2019: Science Results and Cross-Facility Synergies, Cagliari, Italy, 14-18 Oct. 2019
6) Nami Sakai, “Observational Challenges to Understand Molecular Evolution along Star Formaion”, DYMCOM : DYnamical Methods for COld Molecules, Pascal Institute, Paris-Saclay, France, Nov. 2019
7) Yao-Lun Yang, “Star Formation in Action: Tracing the Kinematics and Chemistry of Embedded Protostars with ALMA”, Star Formation Mini-workshop, Kyung Hee University, Suwon, Korea, 5 Dec. 2019

Contributed (International)
1) Satoshi Ohashi, Akimasa Kataoka, “Radial variation of grain size in the HD 163296 protoplanetary disk revealed by ALMA polarization”, Workshop on Polarization in Protoplanetary Disks and Jets, Barcelona, Spain, 20-24 May, 2019
2) Yichen Zhang, Nami Sakai, Aya Higuchi, Ana Lopez-Sepulcre, Yoko Oya, Muneaki Imai, Takeshi Sakai, Yoshimasa Watanabe, Bertran Lefloch, Cecilia Ceccarelli, Satoshi Yamamoto, “Rotation in the NGC 1333 IIRAS 4C Outflow”, From Stars to Planets II, Gothenburg, Sweden, 17-19 Jun. 2019
3) Yichen Zhang, Jonathan Tan, Kei Tanaka, Vivianna Rosero, James De Buizer, Mengyao Liu, Maria Beltran, Kaitlin Kratter, Diego Mardones, Guido Garay, “Massive star formation in 0.03"resolution view of ALMA”, From Stars to Planets II, Gothenburg, Sweden, 17-19 Jun. 2019
4) Akemi Tamanai, “Lab-Based Dust Grain Investigation: Astromineralogy”, REMU 1st Symposium "Evolution of Matter in the Universe", RIKEN, Wako, Japan, 1-2 Aug. 2019
5) Riouhei Nakatani, Takashi Hosokawa, Naoki Yoshida, Hideko Nomura, Rolf Kuiper, “Radiation Hydrodynamics Simulations of Photoevaporating Protoplanetary Disks with Various Metallicities”, REMU 1st Symposium "Evolution of Matter in the Universe", RIKEN, Wako, Japan, 1-2 Aug. 2019
6) Yichen Zhang, “Probing kinematics of ionized gas around forming massive stars”, ngVLA workshop, NAOJ, Mitaka, Japan, 17-20 Sept. 2019
7) Hideki Umehata, “ngVLA and galaxy formation in proto-clusters”, ngVLA Workshop, NAOJ, Mitaka, Japan, 17-20 Sept. 2019
8) Satoshi Ohashi, Akimasa Kataoka, “Radial variations of grain sizes and dust scale heights on the protoplanetary disk of HD 163296”, ALMA2019: Science Results and Cross-Facility Synergies, Cagliari, Italy, 14-18 Oct. 2019
9) Satoshi Ohashi, “Understanding distributions of grain sizes and turbulence in protoplanetary disks”, Science with the Submillimeter Array: Present and Future, Taipei, Taiwan, 4-5 Nov. 2019
10) Akemi Tamanai, “Laboratory-Based Spectroscopy: From Astromineralogy to Astrochemistry”, Dynamical Methods for Cold Molecular Collisions, from laboratory to beyond the Earth (DYMCOM), Paris-Saclay, France, 4-8 Nov. 2019

11) Hideki Umehata, “Gas filaments connecting galaxies and supermassive black holes in a proto-cluster”, Subaru Telescope 20th Anniversary, Waikoloa, The Big Island of Hawaii, US, 17-22 Nov. 2019
12) Riouhei Nakatani, Takashi Hosokawa, Naoki Yoshida, Hideko Nomura, Rolf Kuiper, “Radiation Hydrodynamics Simulations of Photoevaporating Protoplanetary Disks: Implications to Metallicity Dependence of Disk Lifetimes”, Subaru Telescope 20th Anniversary, Waikoloa, The Big Island of Hawaii, US, 17-22 Nov. 2019
13) Satoshi Ohashi, Akimasa Kataoka, “Radial variations of grain sizes and dust scale heights of the protoplanetary disk around HD 163296 revealed by ALMA polarization observation”, Planet Formation Workshop 2019, NAOJ, Mitaka, Japan, 25-28 Nov. 2019
14) Riouhei Nakatani, Takashi Hosokawa, Naoki Yoshida, Hideko Nomura, Rolf Kuiper, “Photoevaporation of Protoplanetary Disks: Metallicity Dependence and Lifetimes”, Planet Formation Workshop 2019, NAOJ, Mitaka, Japan, 25-28 Nov. 2019
15) Yao-Lun Yang, “PEACHES: An Unbiased Survey of Carbon-chain Molecules and Complex Organic Molecules toward Embedded Protostars at the Perseus Star-forming Region”, Early Planet Formation in Embedded Disks, Tokyo University, Tokyo, Japan, 8-10 Dec. 2019
16) Yao-Lun Yang, “Directly Measuring the Progression of Infall from the Envelope to the Disk-forming Region of Embedded Protostars”, East Asian ALMA Development Workshop 2019, NAOJ, Mitaka, Japan, 10-11 Dec. 2019
17) Riouhei Nakatani, Hauyu Baobab Liu, Satoshi Ohashi, Yichen Zhang, Tomoyuki Hanawa, Claire Chandler, Yoko Oya, Nami Sakai, “Substructure Formation in a Protostellar Disk around a Class 0 Protostar”, Workshop for Protoplanetary Disks and Exoplanets, Taipei, Taiwan, 17-18 Dec. 2019
18) Satoshi Ohashi, Akimasa Kataoka, “Radial variations of grain size and turbulence in protoplanetary disks revealed by ALMA polarization”, East-Asian ALMA Science Workshop 2019, Taipei, Taiwan, 19-21 Feb. 2020

Seminar
1) 坂井南美, “21 世紀の天文学　構造形成学から物質科学へ”, 第 10 回 MACS コロキウム, 京都大学, 2019 年 11 月 15 日
2) Nami Sakai, “Astrochemical Approach to Star and Planet Formation”, ASIAA Colloquium, Taipei, Taiwan, 4 Dec. 2019
3) Yao-Lun Yang, “Tracing Kinematics and Complex Chemistry of Embedded Protostars with ALMA”, APEC Seminar (Astronomy - Particle Physics - Experimental Physics - Cosmology), Kavli Institute for the Physics and Mathematics of the Universe, Kashiwa, Japan, 19 Dec. 2019

Others (Domestic Meeting and Seminar, selected)
1) Yichen Zhang, Jonathan Tan, Kei Tanaka, James De Buizer, Mengyao Liu, Maria Beltrán, Kaitlin Kratter, Diego Mardones, Guido Garay, “Spiraling giants:　witnessing the birth of a massive binary star”, P138a, 日本天文学会 2019 年秋季年会, 熊本大学, 熊本市, 2019 年 9 月 11-13 日
2) 仲谷崚平, 吉田直紀, “大質量星近傍分子雲コアの紫外線光蒸発：輻射駆動爆縮とコア寿命の金属量依存性”, Z305a, 日本天文学会 2019 年秋季年会, 熊本大学, 熊本市, 2019 年 9 月 11-13 日
3) 梅畑豪紀, “gas filaments at z=3 revealed by MUSE”, 面分光研究会 2019, 国立天文台, 三鷹市, 2019 年 10 月 29-30 日
4) 梅畑豪紀, “赤方偏移３の宇宙網における銀河形成研究の現在地”, 12 月つくば宇宙フォーラム, 筑波大学　つくば市, 2019 年 12 月 11 日
5) 坂井南美, “星形成初期における円盤形成”, 第 32 回理論懇シンポジウム「天文学・宇宙物理学の変遷と新時代の幕開」, 国立天文台, 三鷹市, 2019 年 12 月 25-27 日(invited)
6) 梅畑豪紀, “Galaxy formation and evolution seen by ALMA and Subaru”, Z101r, 日本天文学会 2020 年春季年会、つくば市（online）

Posters
1) Riouhei Nakatani, Takashi Hosokawa, Naoki Yoshida, Hideko Nomura, Rolf Kuiper, “Radiation Hydrodynamics

Simulations of Photoevaporating Protoplanetary Disks: Metallicity Dependence", Planet2/RESCEU Symposium 2019, Okinawa, Japan, 14-18 Oct. 2019

2) Yichen Zhang, "Massive Star Formation in 0.03" Resolution View of ALMA: Two Case Studies", -ALMA 2019: Science Results and Cross-Facility Synergies, Cagliari, 14-18, Oct. 2019

3) Riouhei Nakatani, Takashi Hosokawa, Naoki Yoshida, Hideko Nomura, Rolf Kuiper, "Radiation Hydrodynamics Simulations of Photoevaporating Protoplanetary Disks with Various Metallicities", In the Spirit of Lyot 2019, Tokyo, Japan, 21-25 Oct. 2019

4) Akemi Tamanai, Yoshimasa Watanabe, Takeshi Sakai, Satoshi Yamamoto, Nami Sakai, "Experimental Molecular Emission Spectroscopy: Adopting an ALMA-Type Cartridge Receiver", Chemical Evolution of Cosmic Matter, Bad Honnef, Germany, 23-25 Oct. 2019

5) Akemi Tamanai, Yoshimasa Watanabe, Takeshi Sakai, Tatsuhiko Sato, Satoshi Yamamoto, Nami Sakai, "Experimental High Frequency Molecular Spectroscopy with an ALMA-Type Cartridge Receiver", East Asian ALMA Development Workshop 2019, NAOJ, Mitaka, Japan, 10-11 Dec. 2019

Books, proceedings and others

1) 野村英子，樋口あや，坂井南美，山本智，長沢真樹子，田中今日子，三浦均，中本泰史，田中秀和，山本哲生，Catherine Walsh, Tom J. Millar, "原始惑星系円盤の有機分子と硫黄系分子：モデルと ALMA 観測", 低温科学 第 78 巻 宇宙分子進化 p165-172, 2020 年 4 月

2) 坂井南美，"分子雲コアの有機分子：星なしコアと原始星エンベロープ"，低温科学 第 78 巻 宇宙分子進化 p219-227，2020 年 4 月

3) 渡邊祥正，酒井剛，坂井南美， "テラヘルツ受信機の ASTE 望遠鏡への搭載実験と実験室における分子分光実験", 低温科学 第 78 巻 宇宙分子進化 p241-251，2020 年 4 月

Outreach

1) フロントランナー挑む 第 93 回 "惑星形成の謎を解き生命の起源に迫る:坂井南美", 日経サイエンス 2019 年 9 月号にて特集 http://www.nikkei-science.com/201909_010.html

1) 坂井南美, "次世代天文学 ～化学との融合～", 理化学研究所 科学講演会, 2019 年 11 月 3 日, 丸ビルホール

2) 坂井南美, "21 世紀の天文学：構造形成学から物質科学へ", 京都大学理学部 第 10 回 MACS コロキウム, 2019 年 11 月 15 日, 京都大学理学部 6 号館

3) ナショナルジオグラフィック「研究室」に行ってみた 掲載 2019 年 11 月 5 日-12 日連載
https://natgeo.nikkeibp.co.jp/atcl/web/19/102800012/

Press release

1) Hideki Umehata, Michele Fumagalli, Yuichi Matsuda, Yoichi Tamura, "初期宇宙で見つかった宇宙網－銀河とブラックホールに恵みをもたらす宇宙の清流－/Massive filaments fuel the growth of galaxies and supermassive black holes", 理研・東京大学大学院理学系研究科・英国ダーラム大学・国立天文台・名古屋大学共同研究, 4 Oct. 2019 https://www.riken.jp/press/2019/20191004_1/index.html

2) Shogo Tachibana, Takashi Kamitsuka, Tomoya Hirota, Nami Sakai, Yoko Oya, Akira Takigawa, and Satoshi Yamamoto, "Aluminum Oxide found a massive protostar candidate Orion KL Source I /巨大原始星の周りにアルミニウムを含む分子を発見－惑星材料の起源の理解へ－", 東京大学, 国立天文台, 理研共催, 25 Apr. 2019
https://www.riken.jp/press/2019/20190425_1/index.html

Award

1) 梅畑豪紀　理化学研究所・研究奨励賞(桜舞賞) 2019

Support from External Funds

1) 科学研究費補助金 [基盤 S] (分担)原始惑星系円盤形成領域の化学組成とその進化 2018-2022 (代表：山本智)

2) 科学研究費補助金 [基盤 C] 電波望遠鏡を用いた惑星系形成後期過程の観測的研究 2018-2020 (代表：樋口あや)

3) 科学研究費補助金 [若手研究(B)] 可視面分光とアルマ望遠鏡で探る銀河と銀河間物質の相互作用 2017-2019 (代表：梅畑豪紀)

4) 科学研究費補助金 [若手研究] 分子雲コアから星団形成へ、そして原始星円盤の角運動量の起源を探る 2018-2019 (代表：大橋聡史)

5) 科学研究費補助金 [若手研究] Understanding Accretion of Young Massive Protostars 2019-2021 (代表：Yichen Zhang)

6) 科学研究費補助金 [研究活動スタート支援] 輻射多流体計算を用いたより現実的な原始惑星系円盤内部進化モデルの構築 2019-2020 (代表：仲谷 崚平)

7) JSPS 外国人特別研究員(欧米短期・第 2 回) Aug. 2019- Jan. 2020 (Yao-lun Yang)

Group members list

Principal Investigator

Nami Sakai（坂井南美）- Chief Scientist

Members

Satoshi Ohashi（大橋聡史）- Research Scientist

Yichen Zhang - Special Postdoctoral Researcher (Fellow)

Hideki Umehata（梅畑豪紀）- Special Postdoctoral Researcher (Fellow)

Ryohei Nakatani（仲谷崚平）- Special Postdoctoral Researcher (Fellow)

Shota Notsu（野津翔太）- Special Postdoctoral Researcher (Fellow)

Yao-Lun Yang - JSPS Postdoctoral Fellow (Aug. 2019 – Jan. 2019)

Akemi Tamanai（玉内朱美）- Contract Researcher

Ziwei Zhang - Postdoctoral Researcher

Nadia Mariel Murillo Mejias - Postdoctoral Researcher

Shaoshan Zeng - Postdoctoral Researcher

(Kento Yoshida （吉田健人）- JSPS Student Fellow -Mar. 2019)

Ritsuko Matsumoto（松本律子）- Secretary (Part-timer)

Junko Nawata（縄田純子）- Secretary (Part-timer, Nov. 2019-)

Naoko Seiji（清治直子）- Secretary (Part-timer Apr. 2018-Oct.2019)