南半球にあるサブミリ波10m望遠鏡ASTEによるサブミリ波天文学の推進

Promotion of Submillimeter Astronomy with ASTE 10-m Submillimeter Telescope in Southern Hemisphere

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国立天文台 NAOJ National Astronomical Observatory of Japan

1. Summary of the Proposal

- Elucidating the formation and evolutionary process of diverse astronomical objects in cosmic history, especially the formation and evolution of stars, galaxies, and galaxy clusters, as well as the evolution of black holes.
- Perform CO and [CI] observations with the ASTE 10-m Submillimeter Telescope, and an ultra-wideband spectral imaging instrument, TIFUUN, will be developed and installed.
- By FY2027, we will overcome the technical issues, improve instruments and systems and make observations between FY2028 - FY2023.

2. Science Goals (and Key Questions)

- Elucidating the formation and evolutionary process of diverse astronomical objects in cosmic history, especially the formation and evolution of stars, galaxies, and galaxy clusters, as well as the evolution of black holes.
- Specific key questions for the proposed project are:
  - How does the formation process of high-density molecular gas, leading to star formation from diffuse interstellar medium, occur and what is the role of carbon in it?
  - What is the role of star formation obscured by dust through cosmic history? and what is the role of dark matter in it?
  - When and how were black holes formed in the universe?
  - What is the dynamic evolutionary process of galaxy clusters and their precise mass?
  - What kind of time-variable and transient objects exist in the submillimeter wavelengths?
- These are very significant challenges, and they will not be fully resolved by ASTE alone. The approach is to collaborate with others, such as ALMA, to tackle these difficult and fundamental questions.

3. Scientific Objectives

In this presentation, we will focus on 1-3, based on the existing A-project.

1. Clarification of the role of carbon in the evolution of interstellar matter based on wide-area spectroscopic mapping of CO and [CI] emission lines.
2. Exploration of floating stellar mass/intermediate-mass BH in the Milky Way based on submillimeter observations of high-velocity compact clouds, and clarification of their spatial and mass distribution.
3. Exploration of supermassive black holes that rapidly grow within heavily buried galaxies in the early universe.
4. Measurement of cosmic star formation history and dark matter power spectrum using [CII] emission line intensity mapping.
5. Clarification of the dynamic evolutionary process of spatially extended galaxy clusters based on component separation observations of the Sunyaev-Zeldovich effect (thermal, relativistic, and kinetic Sunyaev-Zeldovich effects, abbreviated as tSZ/rSZ/kSZ). Contribution to the refinement of cosmology through precision measurements of galaxy cluster mass.
6. Contribution to multi-messenger astronomy through immediate observations of transient objects, leveraging agility.

4. Science Investigation

Age of ASTE "Telescope" (Since 2000)	23	24	25	26	27	28	29	30	31	32	33
	第４期中期計画期間					第５期中期計画期間					
年次計画	2023 (R5)	2024 (R6)	2025 (R7)	2026 (R8)	2027 (R9)	2028 (R10)	2029 (R11)	2030 (R12)	2031 (R13)	2032 (R14)	2033 (R15)
ASTE望遠鏡の老朽化対策と改修											
・副鏡制御系の改修		副鏡制御系の改修									
・主鏡面精度の測定と改善			主鏡面の測定・調整								
ASTE望遠鏡の機能強化											
・新ヘテロダイン受信機の開発	開発			科学運用・共同利用観測							
・広帯域分光器DESHIMA 2.0	開発		科学運用								
・面分光観測装置TIFUUN			開発					科学運用			
ASTE望遠鏡による科学研究											
		(1) 星間物質の進化における炭素の役割									
		(2) 浮遊/中質量ブラックホールの探査									
			(3) 埋もれた大質量ブラックホールの探査								
						(4) 輝線強度マッピングによる観測的宇宙論					
			(5) 銀河団の動的な進化過程の解明								
			(6) 突発天体の即時観測								

4. Science Investigation

(1) Clarification of the role of carbon in the evolution of interstellar matter based on wide-area spectroscopic mapping of CO & [CI] emission lines

- We will also conduct an unbiased wide-area survey of the [CI] emission line in representative star-forming regions within the Milky Way, in giant molecular clouds (GMCs) existing at the outer Galaxy, as well as in GMCs in low metallicity environments such as LMC/SMC, NGC 6822, and others.
- To understand the feedback to the interstellar medium in the final stages of stellar evolution and the role of carbon therein, we will carry out wide-area spectroscopic mapping observations of several supernova remnants (SNRs) and the surrounding regions of late-type stars in the Milky Way.
- By further advancing such observations and research, significant insights can be provided for the interpretation of [CI] and CO emission lines in galaxies, especially for the interpretation of data in galaxies and high-redshift galaxies that cannot be spatially resolved adequately. This will enhance our understanding of star formation and the evolutionary process of galaxies.

4. Science Investigation

(1) Clarification of the role of carbon in the evolution of interstellar matter based on wide-area spectroscopic mapping of CO & [CI] emission lines

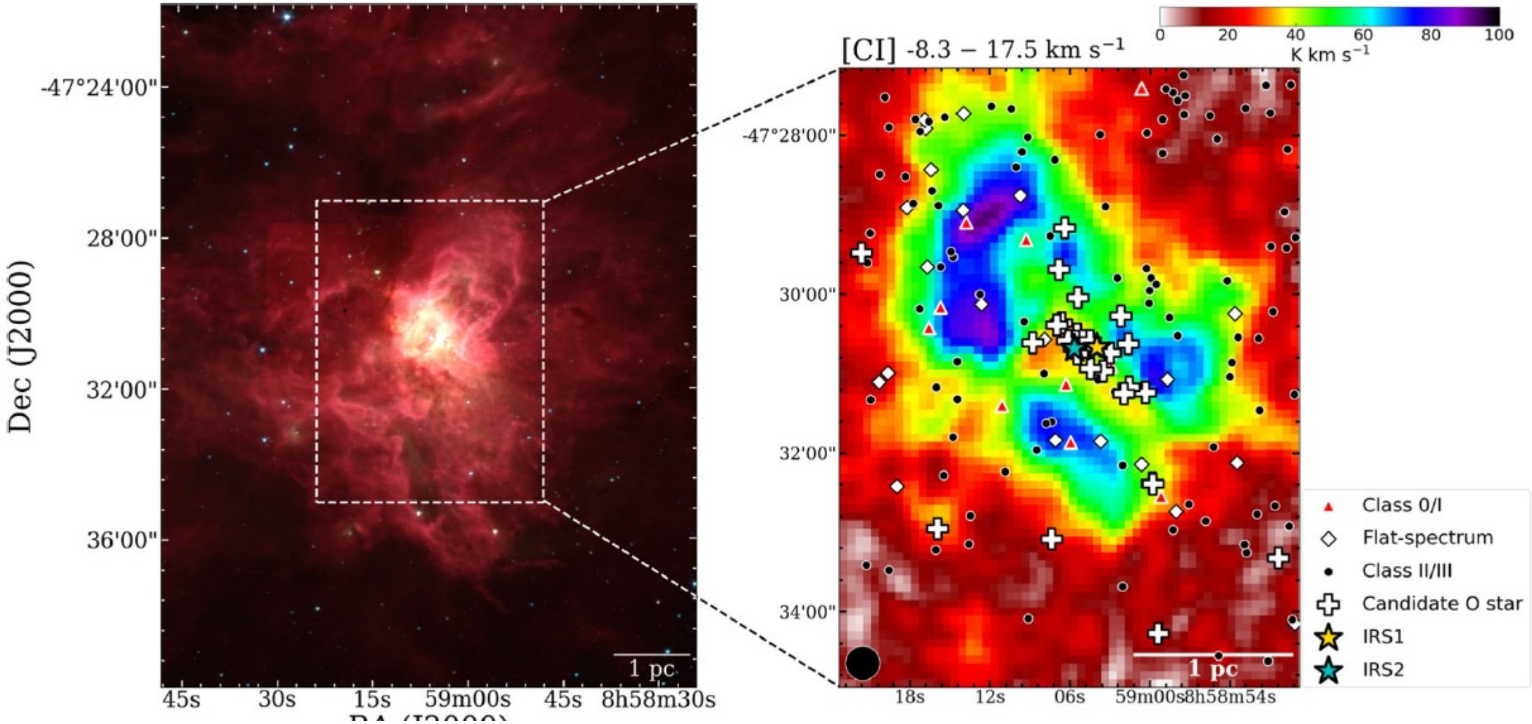


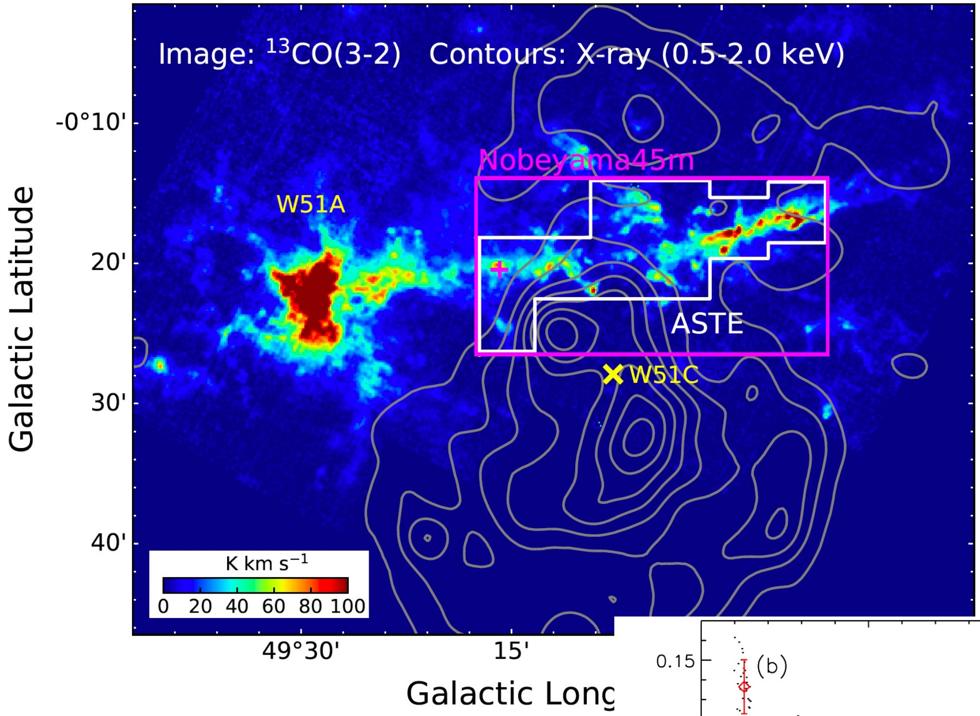
Figure 1. [CI]($^3P_1$-$^3P_0$) image of the star-forming region RCW38 using ASTE equipped with ALMA Band-8 QM.

Izumi Natsuko et al., 2021, PASJ, 73, 174

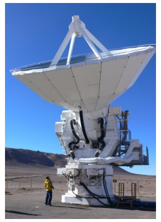
- In the [CI] emission line observations of the massive star-forming region RCW 38 (Figure 1), a high [CI]/CO column density ratio was observed even in regions with very high extinction (reaching Av ~100 mag). This cannot be interpreted by the classical PDR (Photo-Dissociation Region) depiction (plane-parallel PDR model), suggesting a clumped ISM distribution on sub-parsec scales.

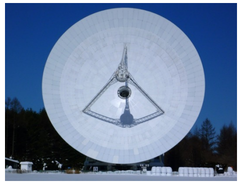
4. Science Investigation

(1) Clarification of the role of carbon in the evolution of interstellar matter based on wide-area spectroscopic mapping of CO & [CI] emission lines

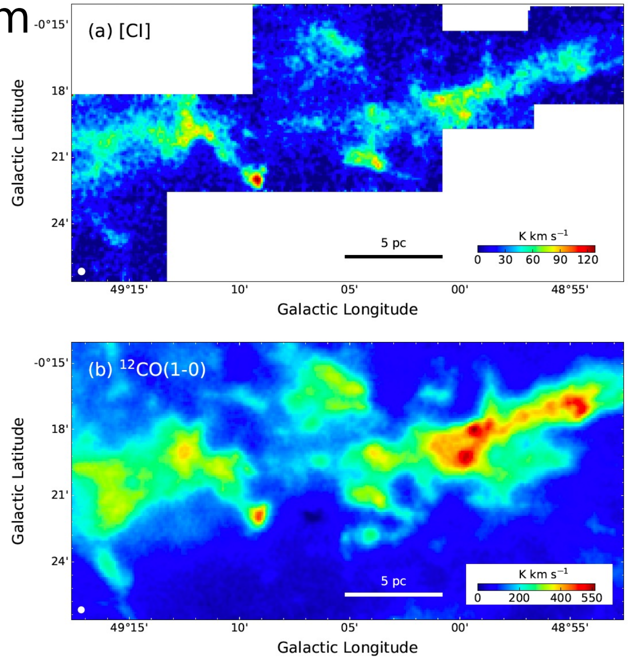


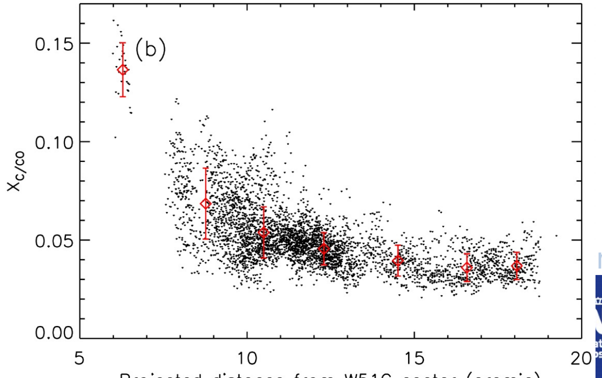
ASTE 10m

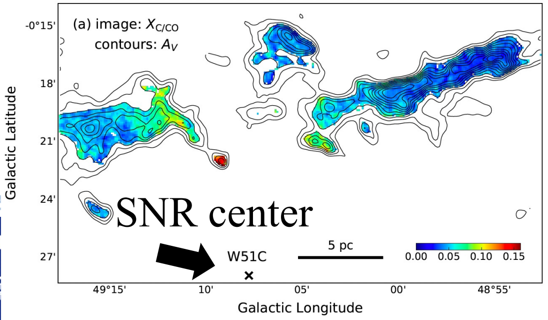




NRO 45m





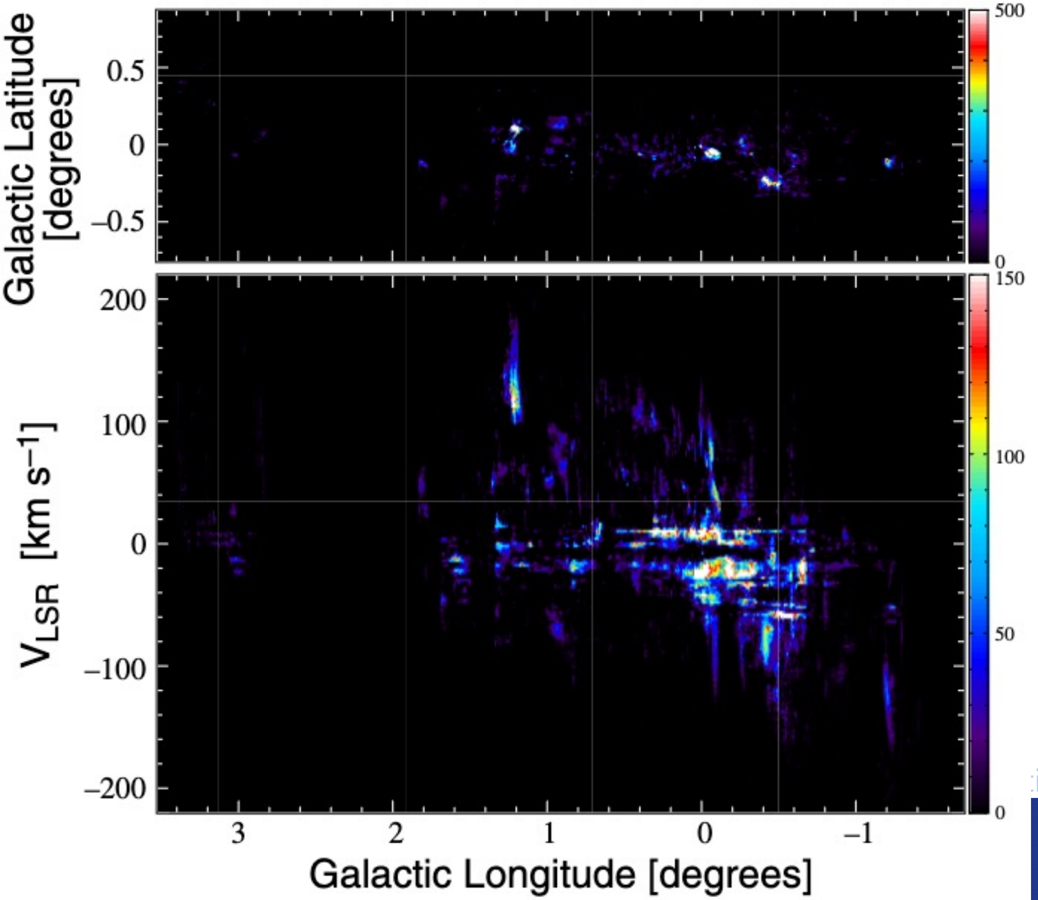


Yamagishi, M., et al. 2023, PASJ, 75, 883

- In the wide-area [CI] line observations of the molecular cloud adjacent to the supernova remnant W51C, a systematic change in the C/CO abundance ratio is clearly captured as a function of distance from the center of the SNR.
- ➔ The dissociation of CO due to cosmic rays and the consequent increase in neutral carbon.

4. Science Investigation

(2) Exploration of floating stellar mass/intermediate-mass BH in the Milky Way based on submillimeter observations of high-velocity compact clouds, and clarification of their spatial and mass distribution.



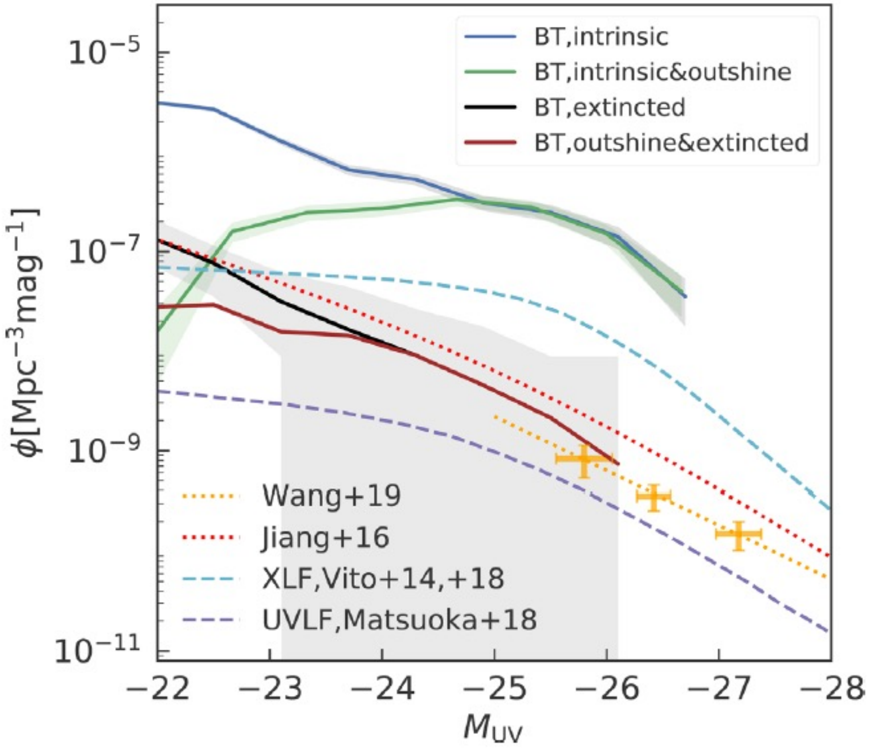
- Based on wide-area mapping observations (as seen in Figure 4), we will explore molecular clouds within the Milky Way that exhibit unique behaviors, leading to detailed investigations of their internal structures by ALMA and the identification of intermediate-mass black holes.

Figure 4. CO(J=3-2) position-to-velocity map of the Galactic Center region taken with wide-area ASTE observations.

Oka et al., 2012, ApJS, 201, 14

4. Science Investigation

(3) Exploration of supermassive black holes that rapidly grow within heavily buried galaxies in the early universe.



- Recent successive discoveries of high-redshift (z = 6 – 7) quasars hosting SMBHs exceeding a billion times the mass of the sun. ➔ Their formation mechanism remains a significant unresolved issue in modern astronomy.
- ALMA observations have revealed that these quasars are accompanied by dust-enchrouded starburst.
- Theoretically, it has been pointed out that SMBHs may undergo a rapid growth phase deeply buried in dust.
- We aim to explore and identify the “precursors” to these quasars, that is, galaxies with SMBHs that grow so deeply buried in dust that they can't be recognized as quasars in visible or near-infrared light.

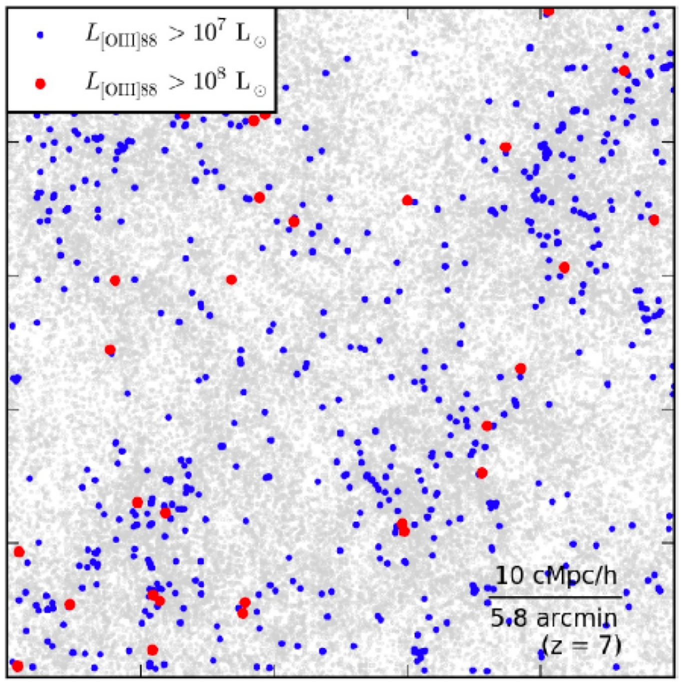
Figure. Comparison of the predicted, intrinsic ultra-violet (UV)-band luminosity of quasars from the BLUETIDES simulations at z = 7.0 and observed luminosity functions (UV, hard X-ray LFs). Dust-extincted UV-LF is about 1.5 dex lower than the intrinsic LF, implying that more than 99 % of the z = 7 AGNs are heavily dust extincted and therefore would be missed by the rest-UV observations. 🡐 in line with recent JWST findings of “red dots”

4. Science Investigation

(4) Measurement of cosmic star formation history and dark matter power spectrum using [CII] emission line intensity mapping.

0.5 deg = **50h-1 cMpc**

ALMA Band-7 FoV ➔



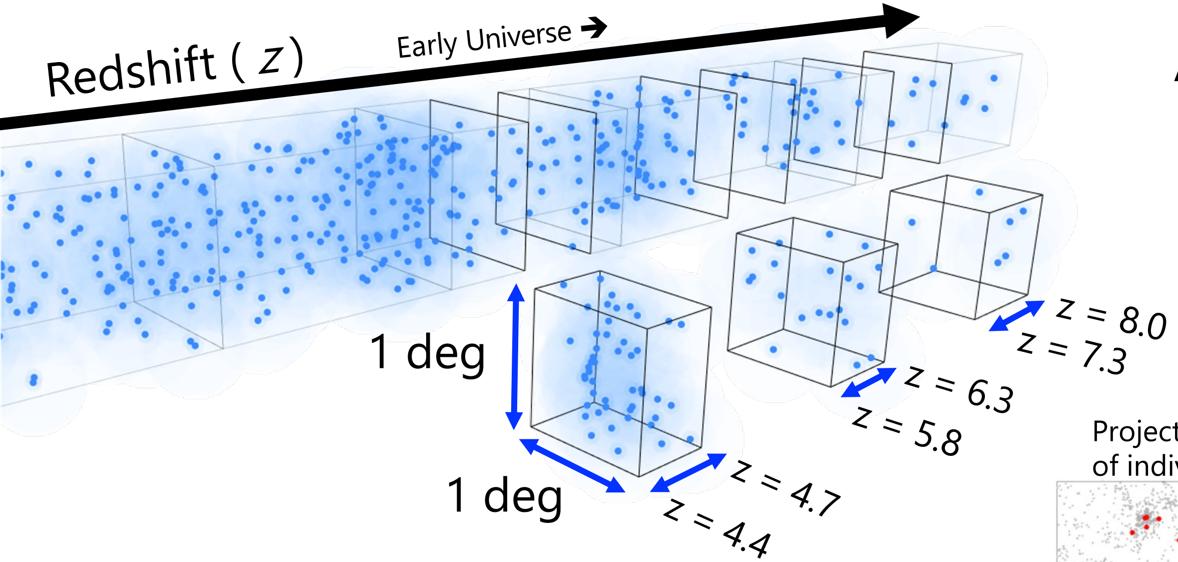
Moriwaki, K., et al. (2018) MNRAS, 481, L84

- Now rest-frame far-infrared fine structure lines including [CII] 158 um and [OIII] 88 um lines during the epoch of reionization (EoR) have been routinely observed using ALMA.
- But we actually focus on brightest sources in these epoch (unless it is gravitationally lensed); see Fig. 6.
- It means that we are missing the majority of galaxies emitting these FIR lines.
- And ALMA is not designed to observe regions on a ~deg^2 to capture the structures of these galaxies.

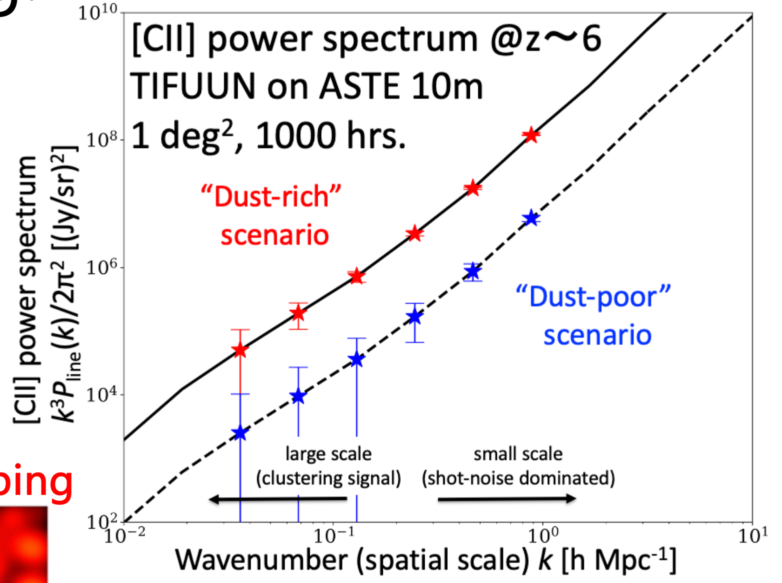
Figure 6. Projected distributions of [OIII] 88 um line emitting galaxies at z = 7 in a cubic volume of comoving 50 h^{-1} Mpc (~0.5 deg) on a side. Grey points are all galaxies in this volume, whereas the blue and red points represents galaxies with L_[OIII]88um > 10^7 L_sun and >10^8 L_sun, respectively.

4. Science Investigation

(4) Measurement of cosmic star formation history and dark matter power spectrum using [CII] emission line intensity mapping.

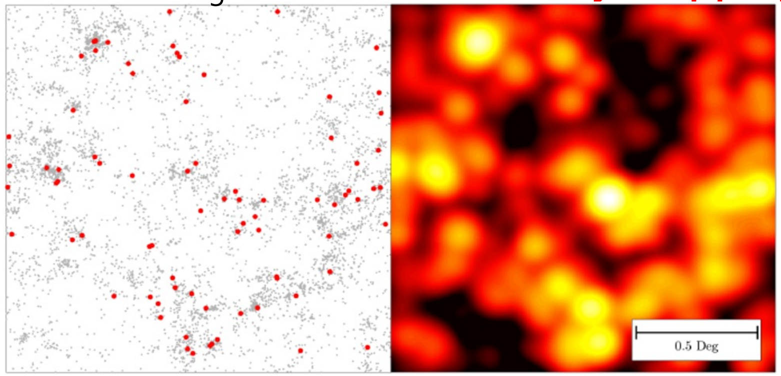


An anticipated game-changer in obtaining information on dimmer and more numerous galaxies is line intensity mapping (LIM)



Projected distribution of individual galaxies

Line Intensity Mapping



- In contrast to ALMA, which spatially and spectrally resolve individual galaxies, LIM observes summed signals from emission lines of numerous galaxies through low spatial and spectral resolution spectroscopic imaging. See Figs ➔

- The emission line power spectrum reflects the large-scale structure of galaxies.
- ➔ Constraints on dark matter distribution (power spectrum).

5. Instruments and Data to be Returned

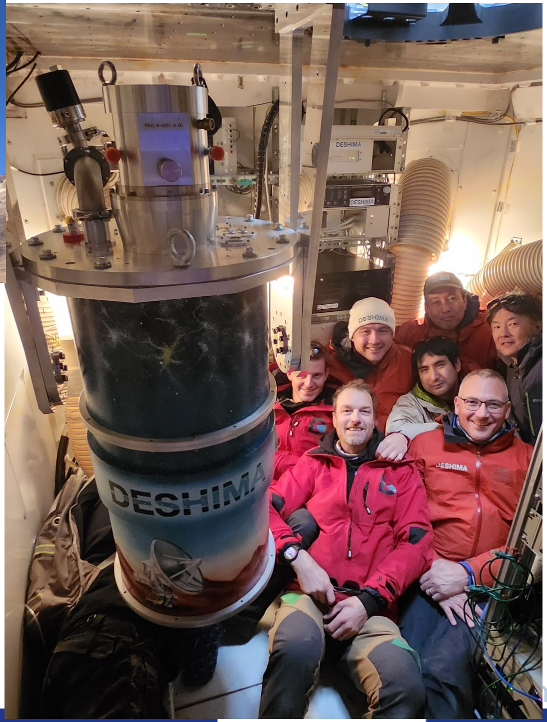
- In the research (1) and (2), Band 7+8 Multi-beam receiver, Band 10 receiver, and spectrometer (multi-beam compatible) will be set up and utilized.
- NAOJ is responsible for the ALMA Band 8 and Band 10 receivers.
- It is expected that the development of receivers leveraging advancements in the ongoing developments for ALMA2 (wider bandwidth and higher sensitivity) can be realized.
- The specifications to the final data products: TBD

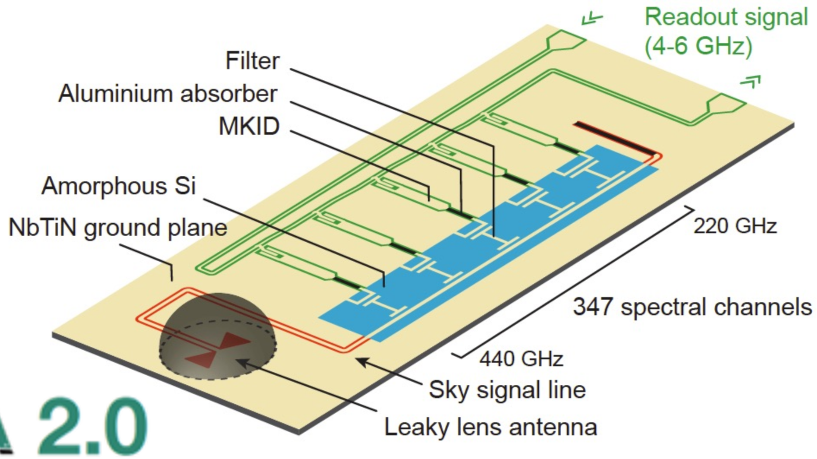
5. Instruments and Data to be Returned

- In the research (3) and (5), the ultra-wideband integrated superconducting spectrometer DESHIMA2.0 will be used. Additionally, for (4) and (5), the ultra-wideband imaging spectrograph TIFUUN will be developed and utilized.
- The data to be acquired will be spectra in the 220 GHz – 420 GHz band for bright submillimeter galaxies, targeting approximately 100 objects.
- The required quality assumes the typical $L_{[CII]}/L_{IR}$ ratio expected in bright submillimeter galaxies with an infrared luminosity of 10^{13} Lsun. This should allow the detection of [CII] emission lines with velocity widths ranging from about 100 km/s to 1000 km/s, at noise levels and baseline stability that make this feasible.
- It is anticipated that this quality of data can be obtained by observing each object over two nights.

5. Instruments and Data to be Returned

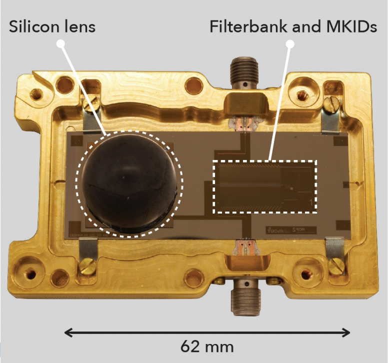
- Ultra-wideband submm-wave spectrometer DESHIMA2.0
  - Based on the successful demonstration of the integrated superconducting spectrometer (ISS) technology by DESHIMA1.0 (Endo, A., et al, 2019, Nature Astron., **3**, 989), we developed the science-grade spectrometer, DESHIMA2.0 for ASTE.
  - Its instantaneous bandwidth is ~200 GHz (covering 225 to 420 GHz), which is almost 27 times wider than that of ALMA. It functions as a powerful redshift machine for z = 3.3 - 7.6, utilizing the bright ionized car
  - Commissioning will continue until early December.

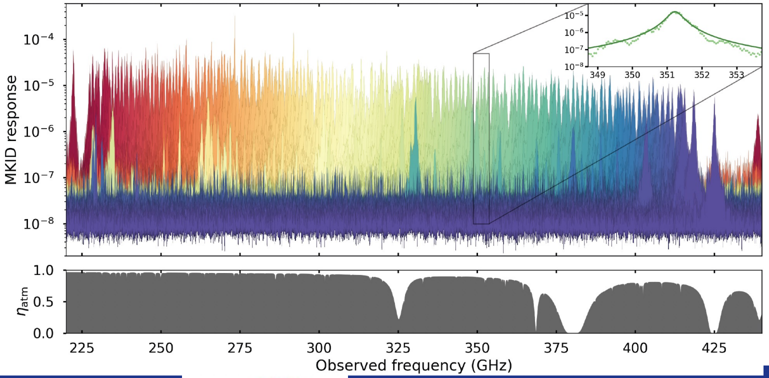




DESHIMA 2.0

225 - 420 GHz Spectroscopy in one shot





See:
- Taniguchi, A., et al. 2022, J. Low Temp. Phys., 209, 278
- Rybak, M., et al. 2022, J. Low Temp. Phys., 209, 766

DESHIMA2.0 installation
2023.10.5
@Atacama/Chile

5. Instruments and Data to be Returned

- Regarding the ultra-wideband imaging spectrograph TIFUUN, the Netherlands side has secured the ERC Consolidator Grant (2022-2027, 3.4 M€), and development has commenced with plans to mount it on ASTE.
- While TIFUUN aims to have a total of 30,000 elements, its most distinctive feature is the ability to freely adjust the distribution in both spatial and spectroscopic directions. Therefore, it is planned to determine the device specifications by distributing the imaging pixels and spectroscopic channels in accordance with the scientific objectives of (4) and (5).
- The specifications to the final data products:
  - The data to be acquired is the sub/millimeter imaging spectroscopy data (3D cubes) in an area of 1 square degree.
  - A spectral resolution $R = \lambda/\Delta\lambda$ of about 300, an effective line mapping speed of around a few $\mathrm{arcmin}^2\ \mathrm{mJy}^{-2}\ \mathrm{hr}^{-1}$, and a noise level that decreases in accordance with long integrations extending up to 1,000 hours.
  - Further considerations regarding the required quality will be conducted.

6. Operations

- To conduct observations efficiently, the followings will be implemented:
  - Observations will be conducted at night to avoid mirror deformation caused by sunlight and temperature fluctuations.
  - Observations in the submillimeter band, which are difficult to carry out from January to March, will be halted. Instead, during this period, maintenance, equipment replacement, and start-ups will be executed.
  - Remote observations from Japan (and other places) will continue.
  - A system that can accommodate time-domain astronomy will be developed and operated.
  - A certain amount of shared-use observation time will be secured, provided that there's an agreement on risk-sharing.

7. Rationale and Trade-off Studies

- Spectro-imaging observations of [CI] and CO emission lines using Band-8/10 are technically possible using ALMA's total power antenna. However, at present, observation proposals solely using the total power antenna for single dish observations are not accepted.
- Proposals using ACA for Band8/10 observations are possible just with ACA, but for the scientific aim of conducting wide-area observations of nearby molecular clouds or galaxies in the local group, with a moderate resolution (about 10” – 20”) where molecular clouds can be distinguished, there are issues with the ACA; the field of view is narrow and its resolution is already too high, making it inefficient.
- By equipping and operating a multi-beam receiver on ASTE, which has an angular resolution of 10" to 20" in the submillimeter band, wide-area mapping observations of molecular clouds complementary to ALMA can be effectively conducted.
- In addition to the scientific achievements solely from ASTE, it is anticipated that strong ALMA proposals can be made based on these results, and that one can more effectively approach scientific goals.

8. Scientific Traceability Matrix

Table: Science traceability matrix (Objectives 1-2)						
Science goals	Science objectives	Investigations		Instruments		Data requirements
		Physical parameters	Observables	Design Parameters	Requirement	
Elucidating the formation and evolutionary processes of diverse astronomical objects in cosmic history, especially the formation and evolution of stars, galaxies, and galaxy clusters, as well as the evolution of black holes.	To quantify the physical/chemical properties of the [CI] line	Column density	Intensity of [CI] line	Trx df f__width	< 150 K < 0.5 MHz > 0.2 GHz	Observation frequency: [CI] 492 GHz, ^{12}CO (J=4-3) 461 GHz Sensitivity: dTa* ~ 0.6 K for [CI] Spatial resolution: 16^{2} (39 pc) at 492 GHz Velocity resolution: 0.5 MHz (0.3 km s^{-1} at 492 GHz) Weather conditions: T_{SYS} < 1400 K at PWV < 1.0 mm (ALMA 3rd Octile)
	To search candidates for stellar mass BHs and IMBHs	Column density	Intensities of [CI] and CO(J=4-3) lines	Trx df f__width	< 150 K < 3 MHz > 0.1 GHz	Observation frequency: [CI] 492 GHz ^{12}CO (J=4-3) 461 GHz Sensitivity: ΔTa* ~ 0.1 K for [CI] ΔTa* ~ 0.5 K for ^{12}CO Spatial resolution: 16^{2} (0.6 pc) at 492 GHz Velocity resolution: 3,3 MHz (2 km s^{-1} at 492 GHz) T_{SYS} < 1400 K at PWV < 1.0 mm (ALMA 3rd Octile)

8. Scientific Traceability Matrix

Science traceability matrix (Objectives 3)

Science Objectives	Science Observables	Measurement Requirements	Technical Requirements	Mission Requirements
To understand the contributions to the brightest dust-enshrouded starburst galaxies to the cosmic star-formation and dust budget in the early Universe, beyond the peak epoch of cosmic star-formation history	To constrain the bright-end of [CII] luminosity functions at z~4-7	• Broad-band low-spectral resolution spectroscopy of • ~30 brightest FIR sources (HyLIRGs; L(IR) ~5 x 10^{13} $L_\odot$) • in a field of >100 deg^2 • to spectroscopically identify brightest starburst galaxies at z~4-7 • by detecting the redshifted [CII] 158 μm and • to measure the flux densities of identified galaxies	• Observing frequency range: 220 – 355 GHz • Spectral resolution: R = f/df = 500 • Spectral line sensitivity (5σ): (2 – 10) x 10^{-19} W/m^2 at PWV = 2 mm	• Observing time of 8 hr per source (including overheads) under the PWV = 2 mm weather x 50 nights • 400 hr in total (2 years)

9. Threshold Science

- Under investigation.

10. Key Technologies

- Accurate surface accuracy measurements and panel adjustment methods
- Multi-beam receiver with a physically compact size to fit the ASTE receiver cabin
- Software for data analysis acquired from the proposed multi-beam receiver

- Data-scientific methods for [CII] line intensity mapping based on e.g., sparse modeling for the separation of atmospheric emission from astronomical signals (e.g., Taniguchi, A., Tamura, Y., Ikeda, S., et al. 2021, AJ, 162, id. 111), signal separation and noise removal using conditional generative adversarial networks (cGAN) (e.g., Moriwaki, et al., 2020, MNRAS 496, L54; Moriwaki & Yoshida 2021, ApJ, 923, L7)

11. Technical Risk Identification and Major Risks

- The ASTE telescope began operations in Chile in 2002 and has already been in operation for over 20 years. Due to its age, certain malfunctions have occurred. For example, in November 2017, the gear of the Azimuth (Az) axis drive of the telescope broke down, and it took until March 2019 for the repairs to be completed. Subsequently, failures and replacements of both the secondary mirror drive computer and the drive motor for the secondary mirror were necessary. => Down Time, Recovery Cost
- The ASTE site has two generators installed to supply electricity. However, if one breaks down and takes a long time to be repaired, the site operates with only one generator. In this situation, every time there is a regular maintenance, which occurs approximately every two weeks, it's necessary to stop the power supply and restart the cooling process for the receivers. => Down Time
- Degradation of the surface accuracy, which is not the case now, would be a risk in the future. => Degradation of Sensitivity, Efficiency
- Improvement of observing scripts and data analysis system for bigger observing data sets in the future.

12. Risk Mitigation

- Antenna: replacement of control systems. Sharing relevant information on control system replancement in Subaru telescope. Suspend operations to solve the issues if necessary (as we did previously), which mitigates the cost impact.
- Surface accuracy: new measurement methods using e.g., photogrametry will be investigated from e.g., Nanten telescope, etc.
- Power generators: replacement, introduction of 3rd generator.
- Software development: sharing relevant information on software development in other observatories including Nobeyama and so on.

13. Technical Heritage, Technology Development Status and Plan

- For the development of heterodyne receivers, the superconducting receiver development led by NAOJ in ALMA and ALMA2 will be utilized as technical heritage.
- Multi-beam: Insights from the FOREST receiver developed for the Nobeyama 45m telescope and from 7BEE.
- Wideband: Learn from the Band 7+8 developed by KASI (Korea).
- Surface measurement: Learn from the photogrammetry used in NANTEN2.

14. Acquisition Surveillance: Make or Buy

- For the superconducting detector technology, independent development is necessary.
- As for the digital spectrometer technology, it can be procured from domestic and international manufacturers.
- For the analysis software of the multi-beam receiver, it is necessary to add custom development to the adaptation for the Nobeyama 45m telescope.

15. Cost Assessments, Budget Line, and Status

- ASTE Baseline Operation Cost per Year: ~ 67 MJPY

Category	Amount (MJPY)	Notes
Antenna Maintenance		
Generator Operation Diesel Fuel Maintenance		10 months operation
Network to the Site		
Car @ Site		10 months operation # partially covered by external funds
Travels to Site		10 months operation # partially covered by external funds
Base Facility @ SPdA		
Oxygen, AWS, etc.		10 months operation
HR		Only Contracted Staff (incl. Chile local)
Total	67	

Costs in Chile are very much influenced by the inflation in Chile and currency exchange rates between JPY and CLP.

15. Cost Assessments, Budget Line, and Status

- The expenses expected from NAOJ are for the maintenance and operation of the ASTE telescope, especially those parts where expenditure through external funding is challenging.
- Specifically, this includes
  - the employment costs of local staff,
  - maintenance costs for the telescope and generators, and
  - expenses for response and repairs when malfunctions occur.
  - Additionally, we anticipate NAOJ will cover expenses for open use, including open time for Chile.
- e.g.,: FY2023: NAOJ(運交金) ~ 53 MJPY + KAKENHI etc.

- On the other hand, for the observing instruments to be mounted on the telescope and used for scientific operations, the plan is primarily to secure external funding for development. (➔ see next)

15. Cost Assessments, Budget Line, and Status

- Heterodyne receivers:
  - ASTE is equipped with three cartridge receivers developed under the JSPS Grant-in-Aid for Scientific Research (A) (led by Iono, D., FY2015-2019).
  - The prototype receiver for ALMA Band 10 has been upgraded on ASTE using an SIS mixer with High-Jc junctions, supported by the JSPS Grant-in-Aid for Scientific Research (A) (led by Asayama, S., FY2018-2022) and has been installed.
  - From the fiscal year 2020, two JSPS Grant-in-Aid for Scientific Research (A) programs have been selected and implemented. The ASTE Band 8 receiver has been upgraded to a 4 – 18 GHz wideband IF SIS mixer for simultaneous observation of the CO(J = 4-3) and [CI] emission lines (led by Oka, T., FY2020-2024). The new digital spectroscopy system for utilizing the wideband IF has been introduced with the support (led by Tosaki, T., FY2020-2024).
- Integrated superconducting spectrometer DESHIMA2.0 & TIFUUN:
  - JSPS Grant-in-Aid for Scientific Research (S) (PI: Kotaro Kohno, FY2017-2021) and the ERC Consolidator grant led by Delft University of Technology (PI: Akira Endo, TIFUUN, FY2022-2027, 3.5M€)

16. Work Breakdown Structure (WBS)

Level 0	Level 1	Level 2	Level 3
ASTE Project			
	Project Management		
		Telescope Time Allocation	
	On-Site Operation		
		Telescope Site Operation	
			Maintain Generators and Fuel Tanks
			Coordination of Fuel Supply
			Safety Patrol
		Maintenance of Instruments	
		Base Facility Operation	
			Maintain Base Facility
			Safety Patrol
		Coordination of On-Site Crews	
		Arrangement of Rent-a-Car	

Level 0	Level 1	Level 2	Level 3
	Science Operation		
		Commissioning of Instruments	
		Handling Proposal	
		Observing Time Allocation	
		Support Observers/Users	
		Data Transfer and Distribution	
	Observing System Operation		
		Maintenance of Observing System	
	Instrument Development / Improvement		
		Subreflector driving system	
			Design
			Production
			Installation
		Improvement of surface accuracy	
		Band 7+8 Heterodyne Receiver	
		DESHIMA2.0	
		TIFUUN	

16. Work Breakdown Structure (WBS)

WBS for DESHIMA2.0 development

Executive board
A. Endo, J. Baselmans, Y. Tamura

Steering committee
K. Kohno, P. van der Werf

- *Hardware: NL*

PM: J. Baselmans

WP1
Lesson learned DESHIMA 1.0
A. Endo

WP2
Antenna & optics design
N. Llombart

WP3
HW development
R. Huiting

WP4
Chip development
J. Baselmans

WP5
Lab. demonstration
K. Karatsu

- *Software/Calibration: JPN*

PM: Y. Tamura

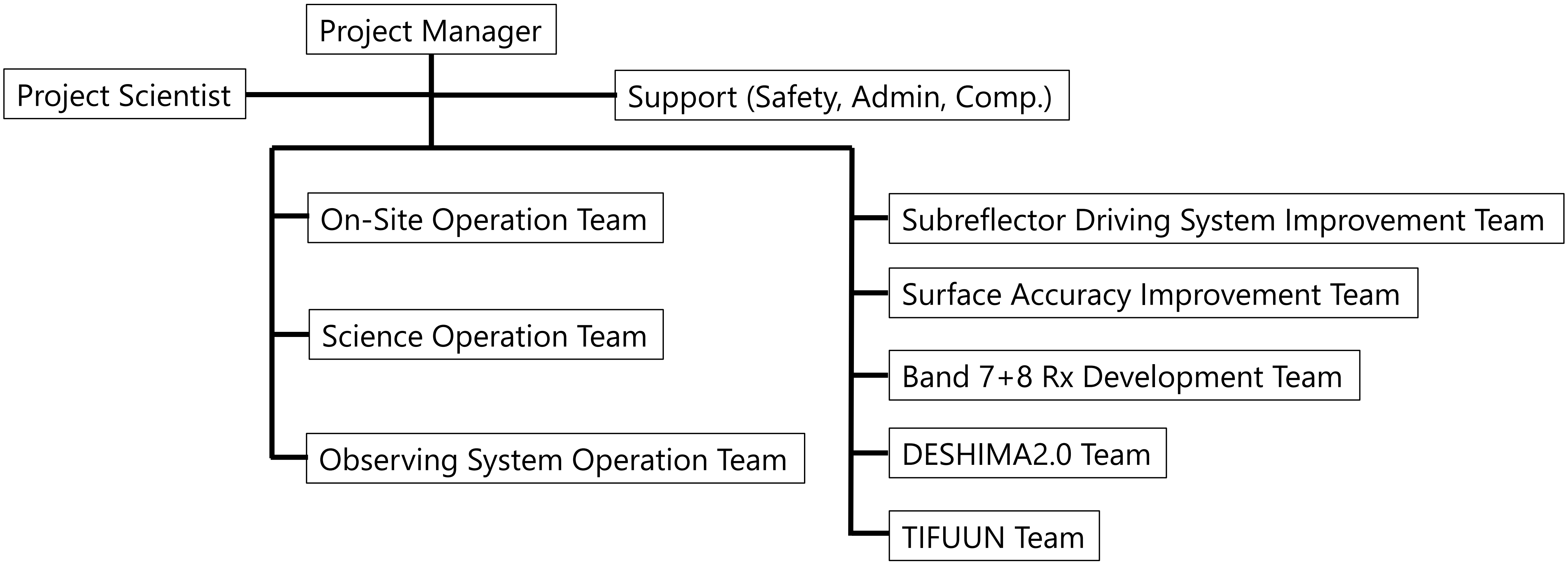
WP1
Data formats
A. Taniguchi

WP2
Data analysis software
A. Taniguchi

WP3
Calibration
T. Takekoshi

WP4
CSV mission
A. Endo

17. Project Organization



17. Project Organization

Current

NAOJ:13 Persons (3.9 FTE) + 3 groups (1.1FTE)

IoA: 1 Person (0.5 FTE)

Project Manager
T. Minamidani (0.4 FTE)

Project Scientist

Support (Safety, Admin, Comp.)
4 Staffs (0.25 FTE)
3 Groups (1.1 FTE)

On-Site Operation Team
Japan: 4 Staffs (1.95 FTE)
Chile: 2 Staffs (1 FTE)

Science Operation Team
NAOJ: 1.5 Staffs (0.7 FTE)
IoA: 1 Staff (0.5 FTE)

Observing System Operation Team
0.5 Staffs (0.1 FTE)

Subreflector Driving System Improvement Team

Surface Accuracy Improvement Team

Band 7+8 Rx Development Team

DESHIMA2.0 Team

TIFUUN Team

Outside of NAOJ

Summary

- Elucidating the formation and evolutionary process of diverse astronomical objects in cosmic history, especially the formation and evolution of stars, galaxies, and galaxy clusters, as well as the evolution of black holes.