NAOJ Future Planning Symposium 2024:
Science Roadmap of NAOJ
December 3-6, 2024 @NAOJ

Study of the formation of astronomical objects and structures using wide-area/wide-band observations with the Atacama Submillimeter Telescope Experiment (ASTE)

DAY3 December 5th (Thursday), 9:45-10:15 (20 min talk + 10 min for Q&A)

K. Kohno (U. Tokyo), T. Minamidani (NAOJ), NAOJ-ASTE team,
A. Endo (TU Delft), Y. Tamura (Nagoya Univ.),
T. Oka (Keio Univ.), T. Tosaki (Joetsu Univ. Edu.), H. Sano (Gifu Univ.)

国立天文台 NAOJ National Astronomical Observatory of Japan

1. Summary of the Proposal

- Science goal: Elucidating the formation and evolutionary processes of diverse astronomical objects in cosmic history, particularly the formation and evolution of stars, galaxies, galaxy clusters, and black holes.
- (one of the) Science objectives: Unveil **the cosmic metal enrichment history** (threshold science) and extract information of the underlying large-scale structures of dark matter (stretch goal)
- (one of the) Science investigations: Conduct **submm-wave line intensity mapping** using the [CII] 158 μm line to constrain the bright end of the [CII] luminosity function and the [CII] power spectrum at z~6.
- (one of the) Instruments and Data to be Returned: 3D Imaging spectrograph **TIFUUN** based on the integrated superconducting spectrometer (ISS) technology. 3D cube over ~1 deg^2 covering two frequency bands with R~500
- Observations (including surveys) using **CAT8W** based on ALMA receiver technology + **XFFTS** will also be conducted
- Cost estimate: nominal operation ~72 MJPY/year (10 months, FY2024) ➔ a part of the operation cost + development of new observing instruments will be covered by external funds including JSPS KAKENHI grants
- Community-wide discussion for the future will be made during ALMA/45m/ASTE UM (2024.12.18-20) & ASTE workshop (2024.12.27) → will be incorporated into the final proposal. (due date: 2025.1.31)

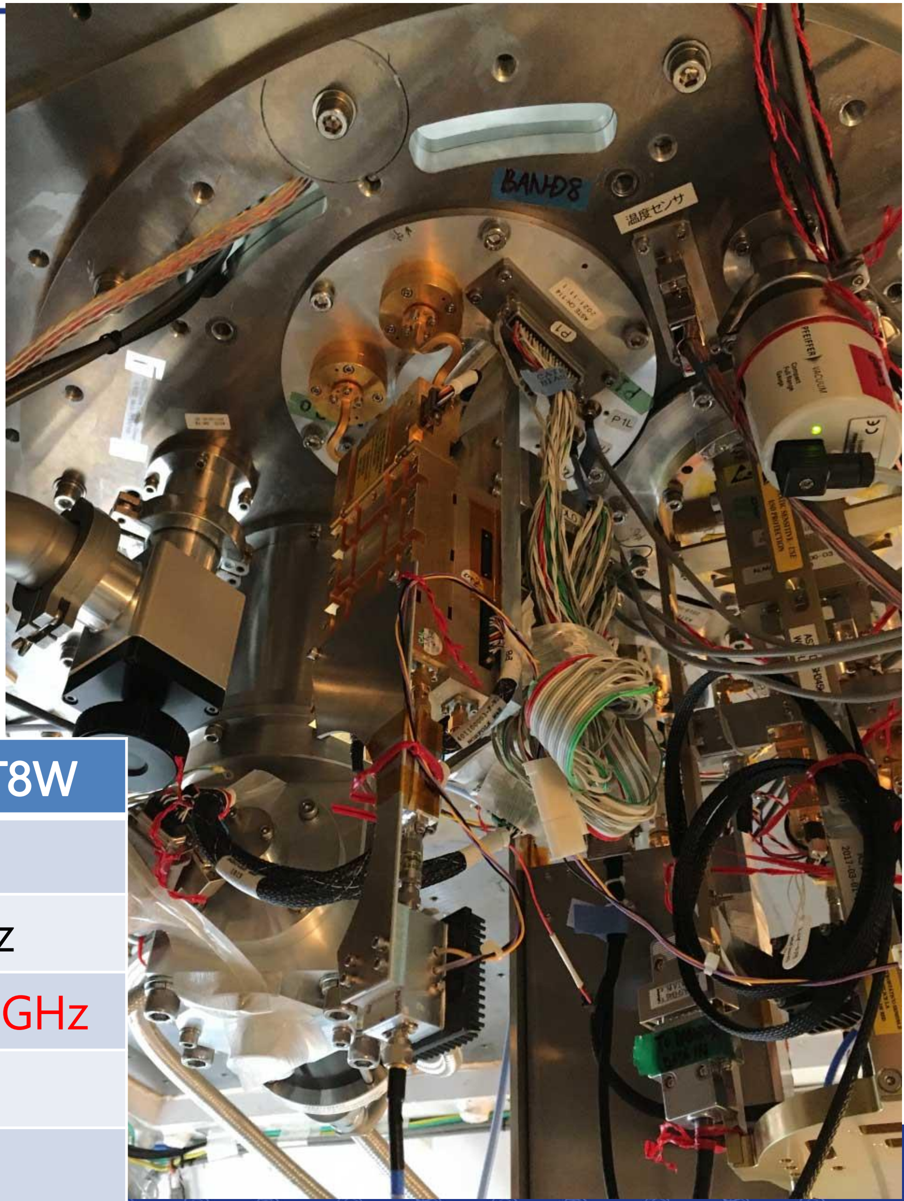
Fiscal Year		2024 (R6)	2025 (R7)	2026 (R8)	2027 (R9)	2028 (R10)	2029 (R11)	2030 (R12)	2031 (R13)	2032 (R14)	2033 (R15)
4th mid-term											
5th mid-term											
JSPS Grants		Kiban-A→				SPR→	ILR→				
ERC Grants				Consolidator Grants (TIFUUN)→		特別推進	国際先導				
ASTE project promotion											
WP1	Telescope upgrades										
	subreflector driving system		replace								
	Surface accuracy improvement	measurements	(panel adjustment?)								
WP2	FPI upgrades										
	CAT8W, XFFTS, etc.		science operation								
	multi-beam receivers	(development?)		(operatioin?)		(development?)			(science operation?)		
	DESHIMA 2.0	science operation									
	TIFUUN	development			science operation						
WP3	Science investigation										
WP4	Decommission study										study

➔ Leveraging ASTE for the next generation large submm telescope LST/AtLAST (see next talk)

7. Current status – ASTE has been back online!

- FY2023: Successfull science operation using CAT8W, a new receiver for 400 GHz band, which has been developed based on JSPS grant (Kiban-A, PI: T. Oka, Keio Univ.), and XFFTS new digital spectrometer based on another JSPS grant (Kiban-A, PI: T. Tosaki, Joetsu Univ. of Education).
  - International external evaluation was done (kick-off on Nov. 21st 2023; meeting on March 25th and 26th, 2024). The review report is public through the NAOJ web.
    - Quality-controlled data access via JVO
    - The re-organization and increase of the manpower in engineering and science operation
    - The use of ASTE as a testbench for instrumentation of future facilities
- FY2024: Focus on DESHIMA 2.0 commissioning and science verification (CSV) w/ >50 persons in universities/institutes in Japan, the Netherlands, and Sweden
  - Many of them are graduate students and postdocs, with some undergraduate students
  - Despite some technical issues (e.g., the telescope site blackout, sub-reflector drive troubles, etc.), the team successfully handled, and a large amount of CSV data has been taken.
  - We appreciated great efforts by the NAOJ-ASTE team.
  - Now intensive and careful data analysis is in progress.
  - Demonstrating these new developments attract and inspire talented students and PDs!
- FY2025: The focus is planned to be on heterodyne receivers + XFFTS

CAT8W: Wide-IF-bandwidth Band8 receiver



- Supported by KAKENHI Kiban-A (P.I. T. Oka; Keio U.)
- The current Band8 receiver cartridge was upgraded with SIS mixers employing high-*Jc* junctions developed by NAOJ ATC ➔ excellent demonstration for ALMA-WSU
- Same RF range, but IF bandwidth is expanded
  4-8 GHz → 4-18 GHz

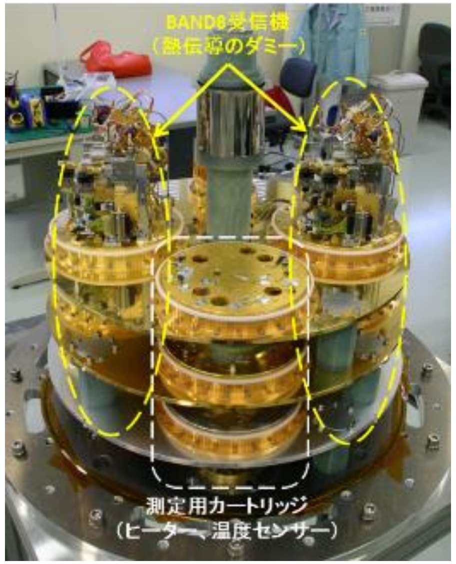
  Simultaneous observations of CO(J=4-3) and [CI]($^3P_1$-$^3P_0$) in Band 8 become available.
  - Receiver Temperature T(RX) ~150-250 K
  - Image Rejection Ratio (IRR) ~10-15 dB at Lab. (Mitaka)
- Tsys ~ 600 – 1000 K (492 GHz)
- Issue on one Pol. channel (DSB)
  - inspection & repair → done!
    almost ready for shipping back to Chile

Receiver	Band8	CAT8W
Beam	1	
RF range	387-498 GHz	
IF range	4-8 GHz	4-18 GHz
Sideband	USB, LSB	
Polarizations	X, Y	

ASTE Instruments – Heterodyne Frontend

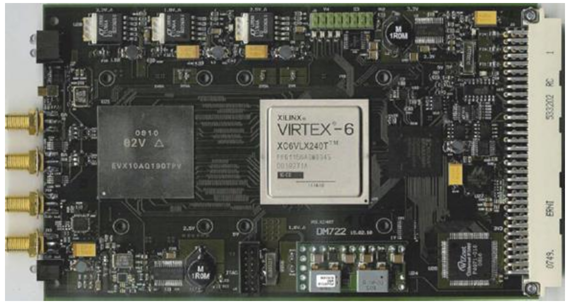
	Freq. (GHz)	HPBW (arcsec.)	Npix	Npol.		IF Freq. (GHz)	Trx (K)	Tsys (K) in SSB	Status	
DASH345	321 - 376	22	1	2	2SB	4 - 8	100 - 120	~250	Available	2015 -
CAT8W	387 - 498	17	1	2	2SB	4 - 18	150 - 250	600 - 1000	Available	2021 -
CAT10	787 - 950	8	1	2	DSB	4 - 12	200- 350	1500 – 4000	Available	2019 -

- Three cartridge-type receivers are operated simultaneously.



Digital Spectrometer and IF Down Converter

- **RPG eXtended bandwidth FFT Spectrometer (XFFTS)**
  - Supported by the KAKENHI project (P.I. Tosaki; JUEN)
  - 2.5 GHz BW / 32K channels [/Spw]
    - Δv=0.047 km/s, velo. width ~1500 km/s@492 GHz
  - 10-bit ADC, 5Gsps
    - Good linearity

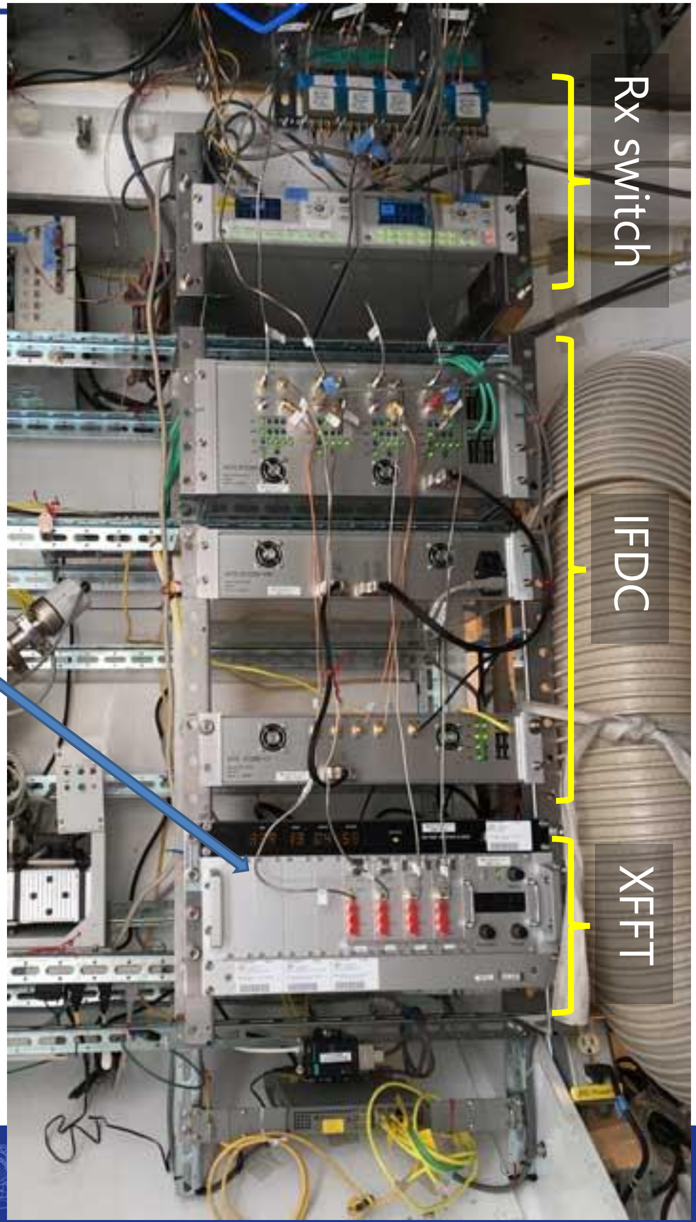


x4

- **IF Down Converter (IFDC)**
  - 4 spectral windows (2.5 GHz BW) from 4 IF signals of a receiver
  - Support of IF BW = 4-8GHz (**DASH345**, **CAT10**) and 4-18 GHz (**CAT8W**)

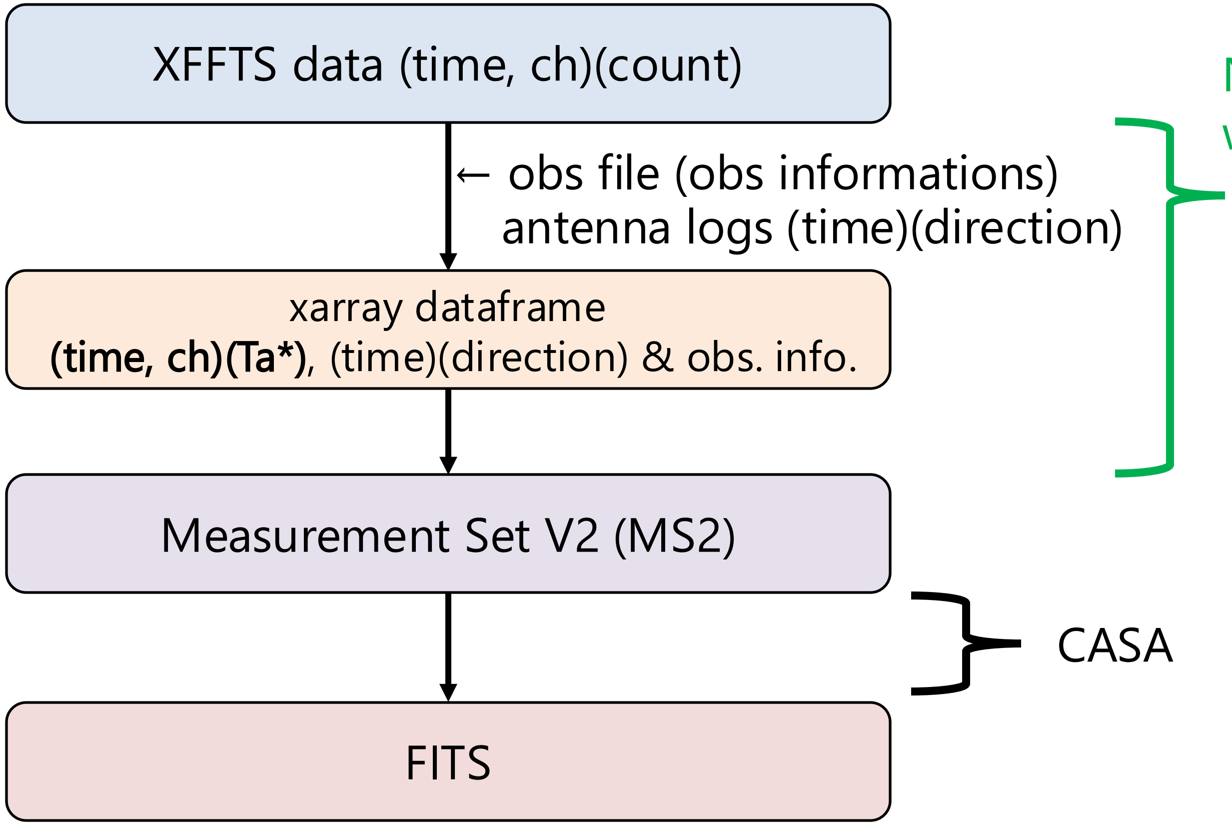
Spectrometer	WHSF ⇒	XFFTS
IF bandwidth	2 / 4 GHz	2.5 GHz
# of channels	2,048 *1	32,768
# of IFs	4 / 2	4

*1 NEWSTAR/NOSTAR limit



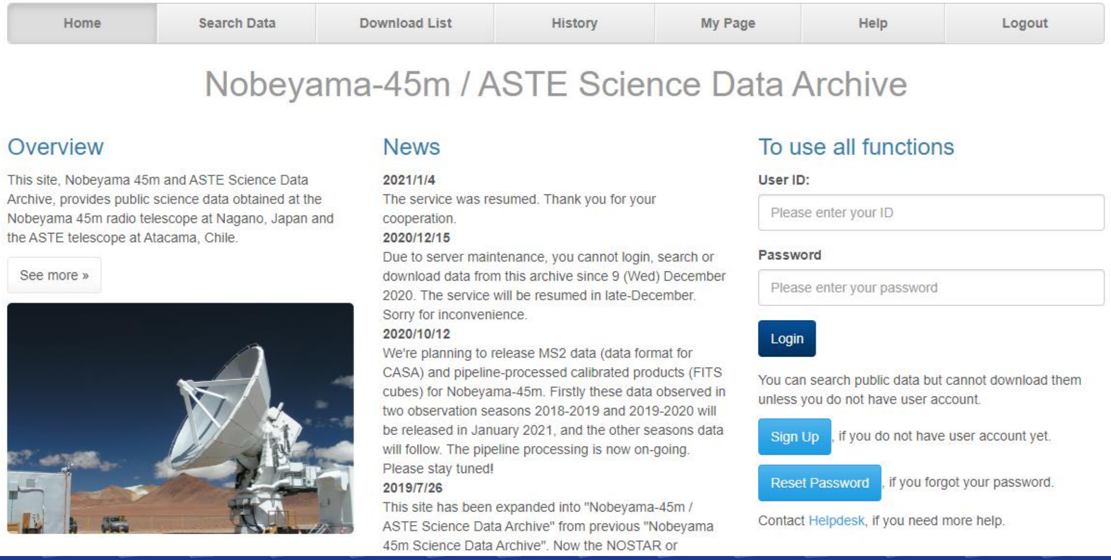
Data Reduction with CASA

- XFFTS data are reduced with CASA
  - No plan to update NEWSTAR and NOSTAR to support XFFTS data.
  - MSv2 data generator (aka MERGE2) for WHSF and MAC is also being tested.



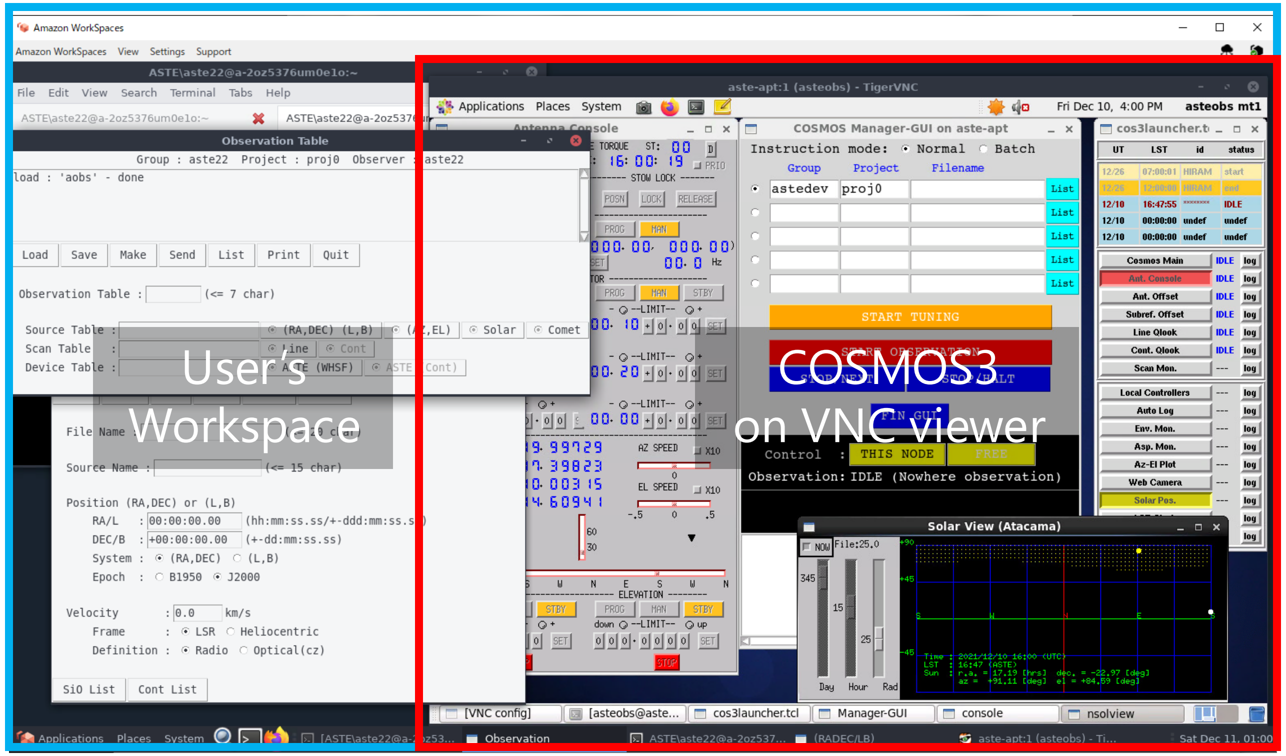
Newly developed Python reduction software, which converts XFFTS data to MS2 (Fujita & Kamazaki)

These CASA MSv2 format data will be delivered and distributed through Nobeyama-45m/ASTE Science Data Archive (https://nobeyama-archive.nao.ac.jp/)



User’s Workspace, Remote Control Terminal

- **Amazon Workspaces – Virtual Desktop Infrastructure**
  - A workspace is provided for a user
    - Observation preparation
    - VNC viewer to access the remote-control Virtual PC (on Amazon Web Services)
  - A user can connect its own workspace using AWS client (Win, Mac, Linux, …) from EA (even from Chile if network is stable)



DESHIMA: 1st integrated superconducting spectrometer

DESHIMA = DEep Spectroscopic HIgh-redshift MApper

Akira Endo
(PI, TU Delft)

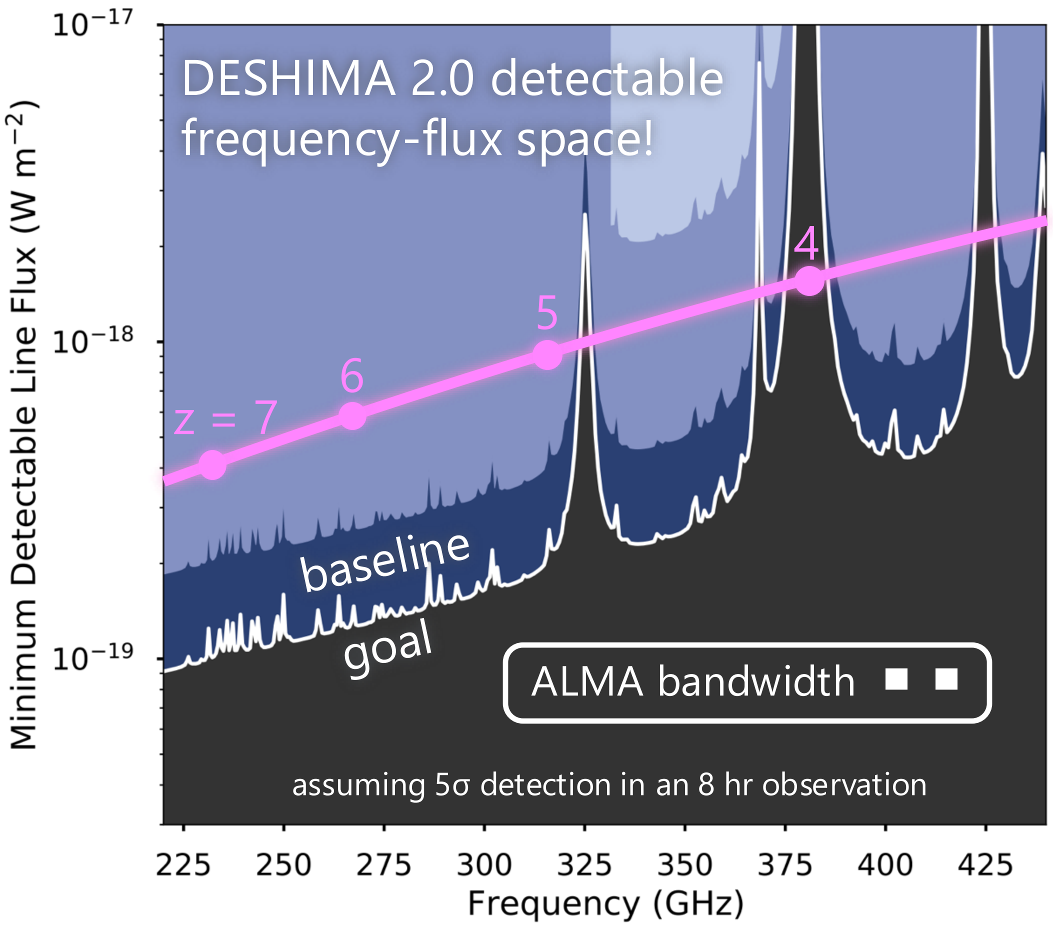
出島

Dejima/Deshima

DESHIMA 2.0 Executive Board:
Akira Endo (PI), Yoichi Tamura (co-PI), Jochem Baselmans, Kotaro Kohno, Paul van der Werf

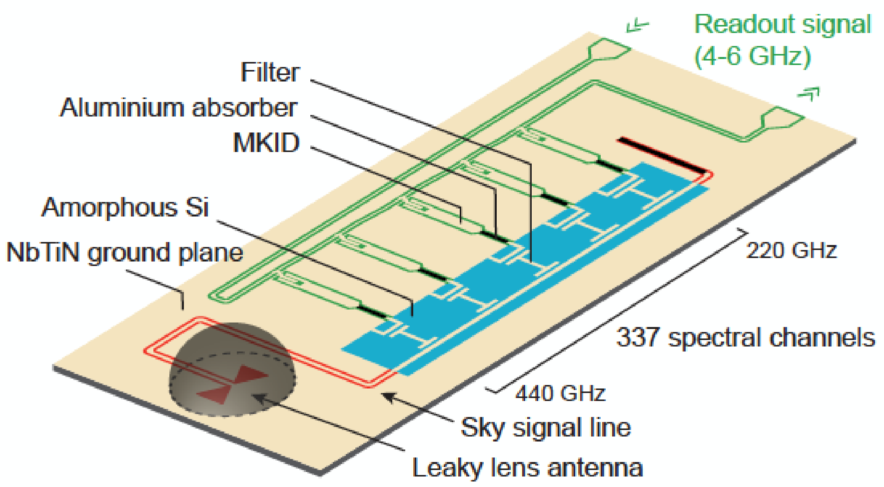
- **Hardware:** Jochem Baselmans (PM)
  - WP1 DESHIMA 1.0 results: Akira Endo
  - WP2 Optics Design: Nuria Llombart
  - WP3 Hardware: Robert Huiting
  - WP4 On-chip Spectrometer: Jochem Baselmans
  - WP5 Lab Demonstrator: Kenichi Karatsu
- **Software & Calibration:** Tatsuya Takekoshi (PM)
  - WP1 Data Formats: Akio Taniguchi
  - WP2 Data Analysis Software: Akio Taniguchi
  - WP3 Calibration: Tatsuya Takekoshi
  - WP4 CSV Plan: Akira Endo
  - WP5 Qlook System: Tatsuya Takekoshi
- **Commissioning & Science Verification:** Akira Endo (PM)
  - High-z galaxies: Tom Bakx, Matús Rybak
  - SZ effect: Kenichi Karatsu

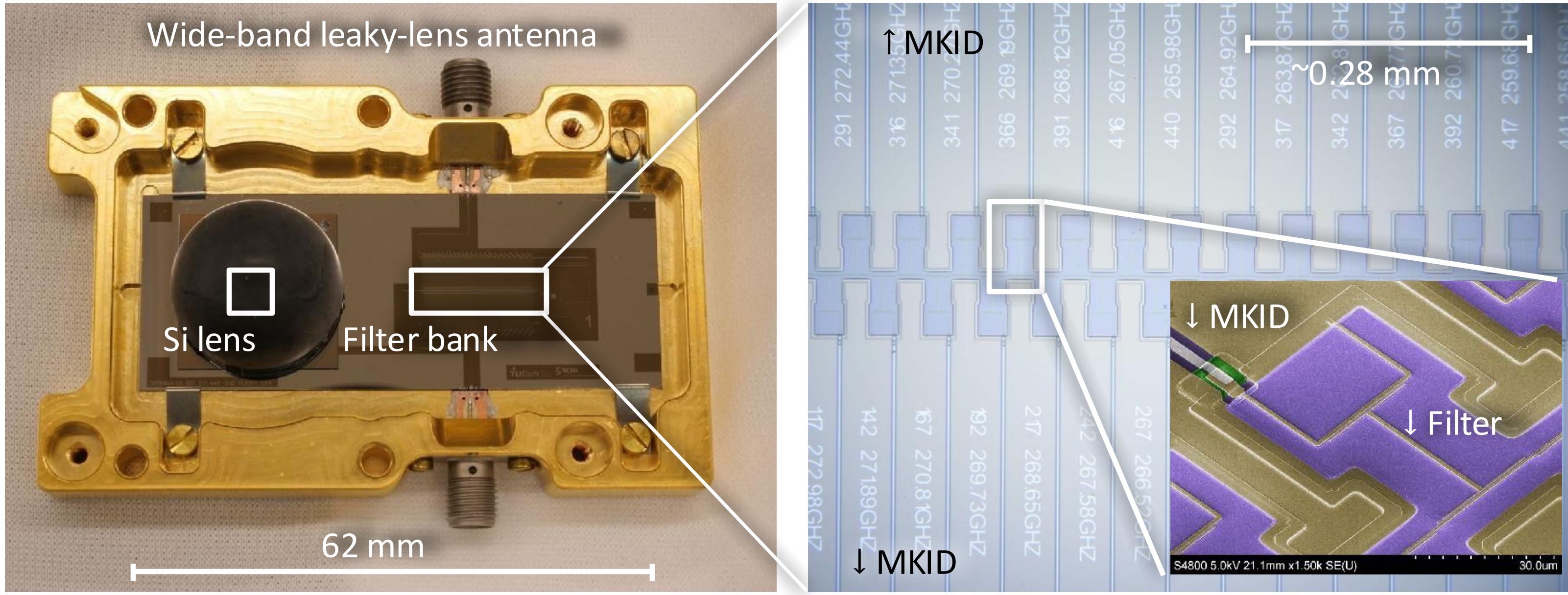
DESHIMA 2.0



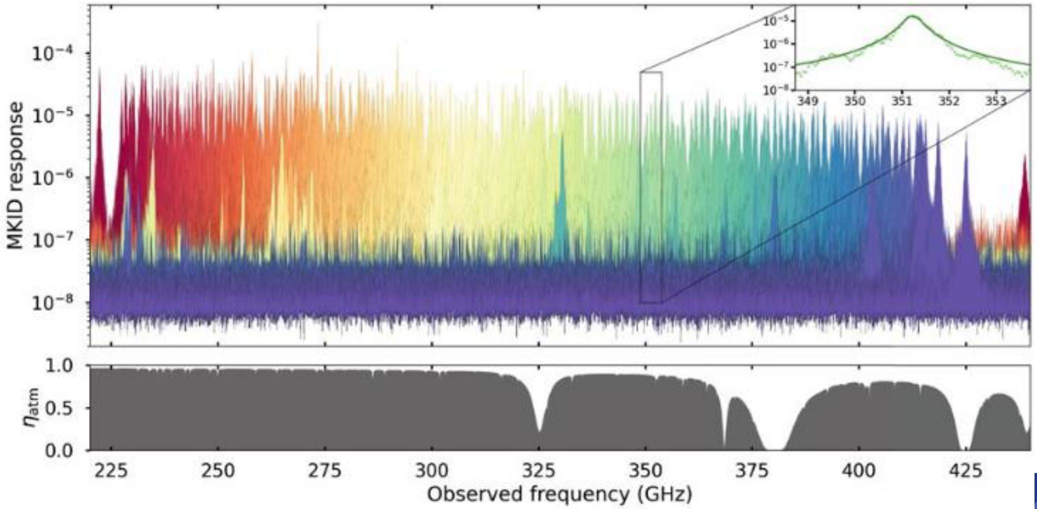
- Ready to observe the ionized/atomic carbon and CO lines from ultra-bright high-z galaxies

Integrated superconducting spectrometer (ISS) technology DESHIMA2.0 with wide-band chip and quasi-optical designs





Spectral resolution f/Δf ~500



Fabrication of a telescope chip with 220-420 GHz coverage

- Scatter of center frequency and Q-factor requires optimization
- Sufficient telescope-to-chip optical coupling by a novel wide-band antenna
- Aperture efficiency of η > 55% over the entire frequency range (Dabironezare, Ph.D thesis)

Taniguchi, A., Endo, A., Tamura, Y., Takekoshi, T., KK, et al. 2022, J. Low Temp. Phys., 209, pp. 278

Akira Endo (TU Delft)

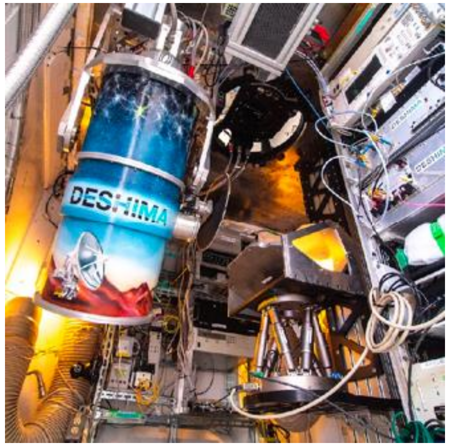
DESHIMA 2.0 on ASTE 2023

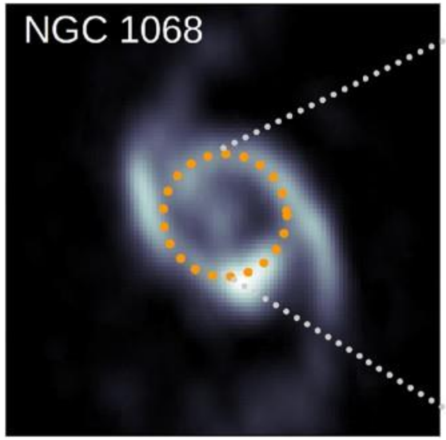
Sep	Oct	Nov	Dec

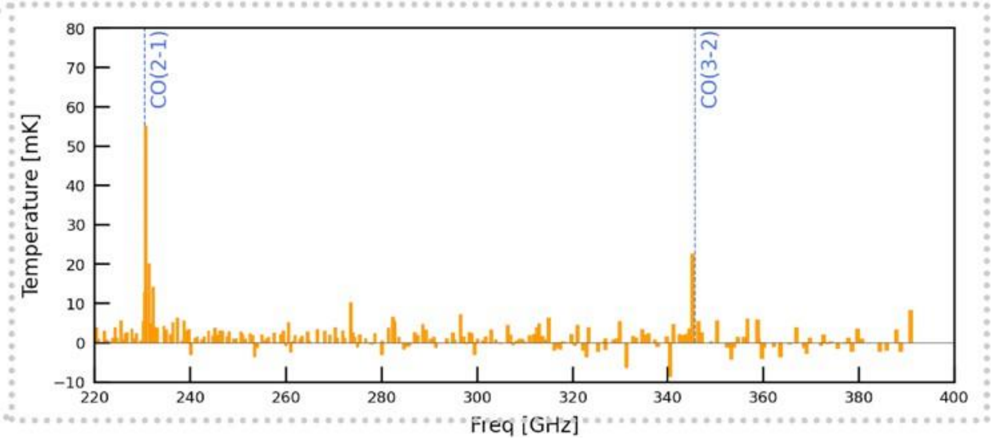
Days in Chile: 1, 16, 38, 50, 63, 76, 85

Logistics | Installation | Start up | Observation | Analysis | Shutdown

- Cryostat Lift
- 1st light
- M3M4 aligned
- Subref broke

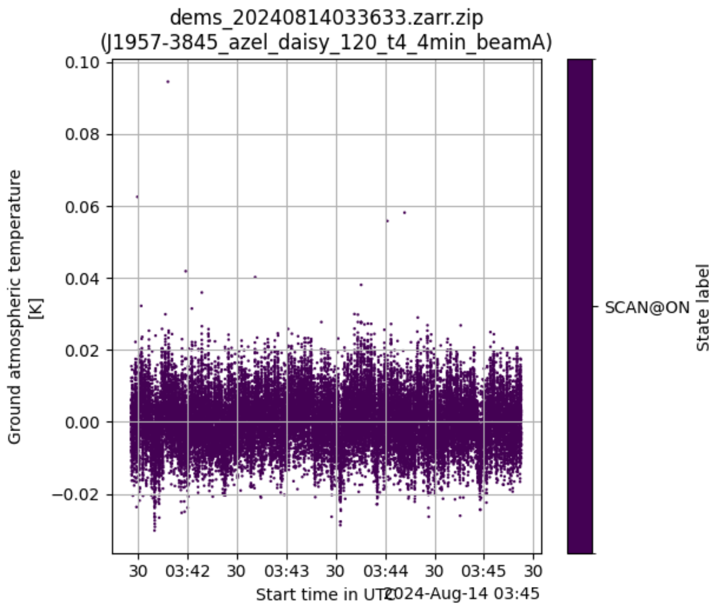


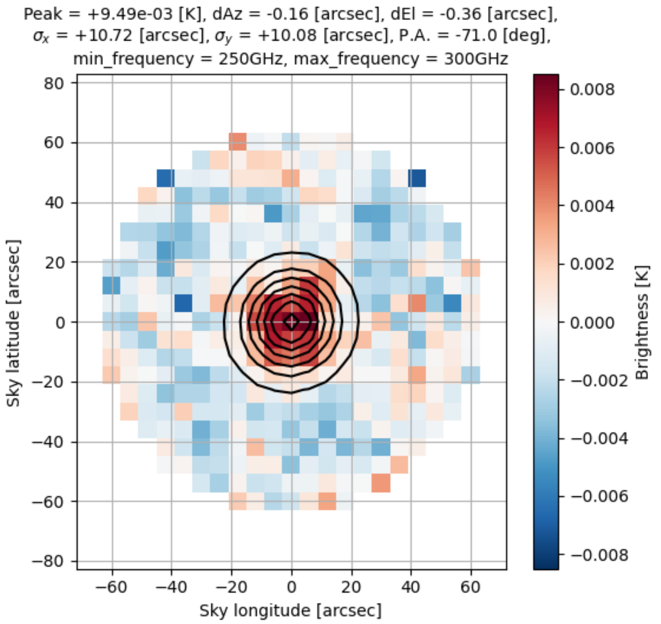


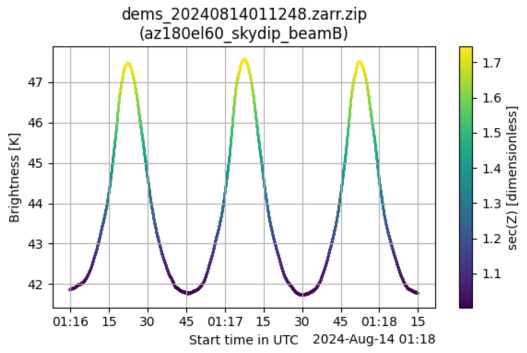


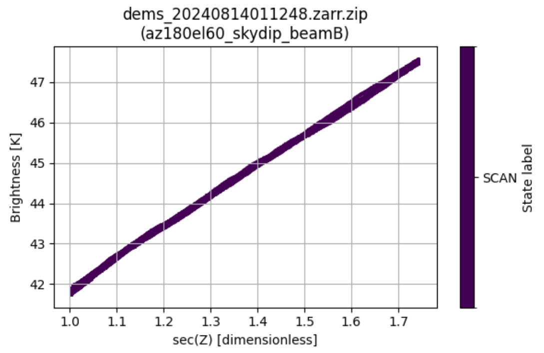
180 GHz

DESHIMA 2.0 on ASTE 2024 (June – December)



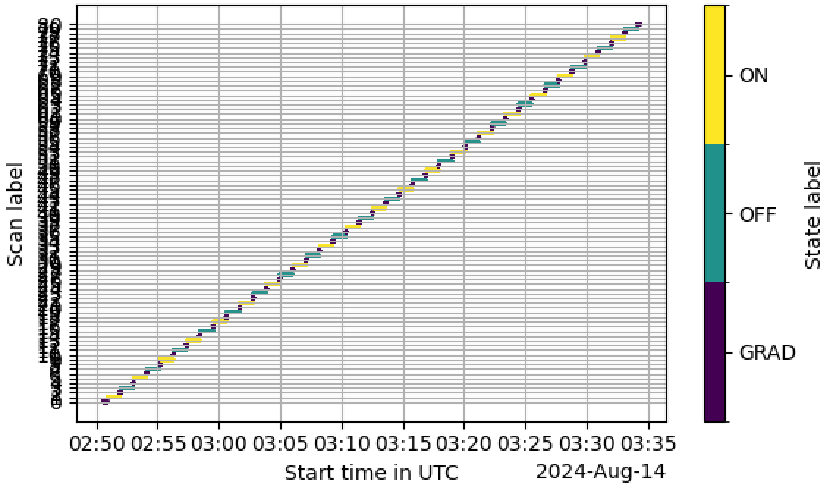


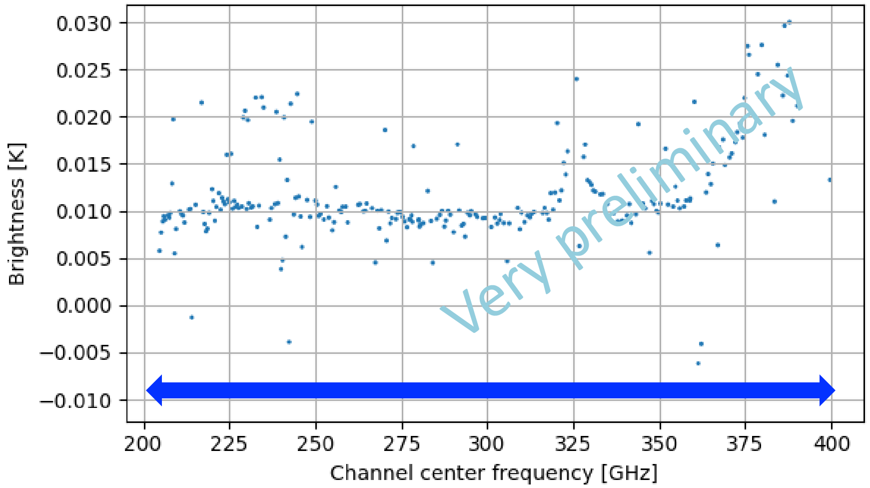




A few Jy point source can be easily detected as pointing and flux calibrators

Skydip observations behave quite well under good weathers





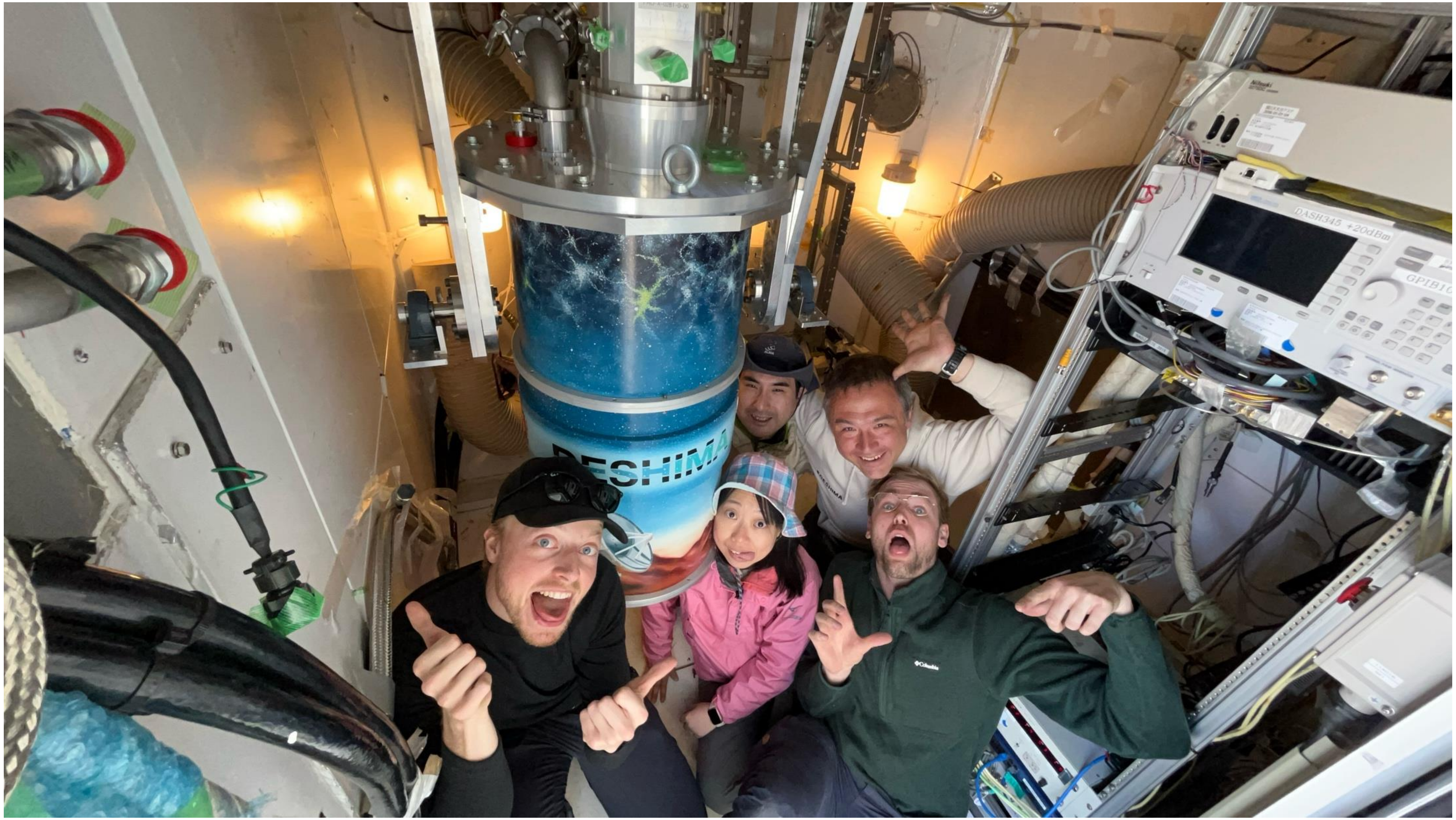
A high-redshift dusty galaxy
200 – 400 GHz
(z = 3.8 – 8.5 for [CII] 158μm)
spectrum in one shot
(just for your eyes)

Public demonstration of DESHIMA 2.0 on ASTE observations

@Mitaka

@TU Delft

Uninstall just completed safely after successful ~6 month run



Dec. 4th 2024

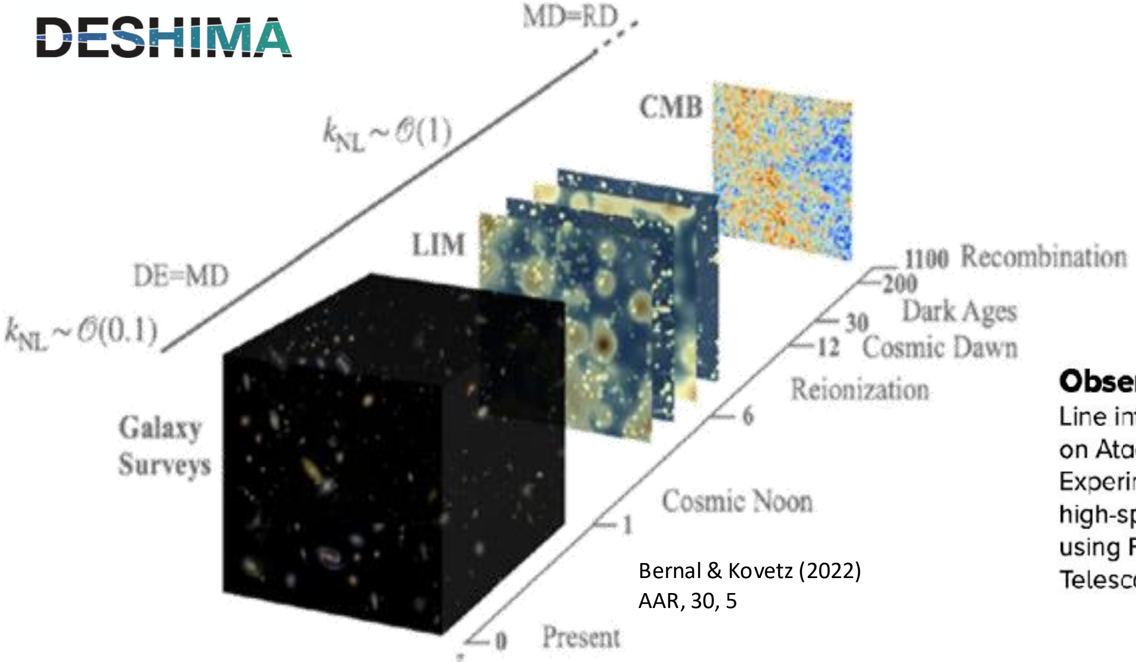
TIFUUN for Submillimeter-wave Line Intensity Mapping

https://sites.google.com/view/sublime-tifuun/home

A. Endo J. Baselmans K. Karatsu A. Monfardini K. Kohno N. Yoshida K. Moriwaki S. Ikeda T. Takekoshi Y. Tamura

S. Fujita Y. Nishimura E. Ogata A. Taniguchi E. Garaldi

DESHIMA



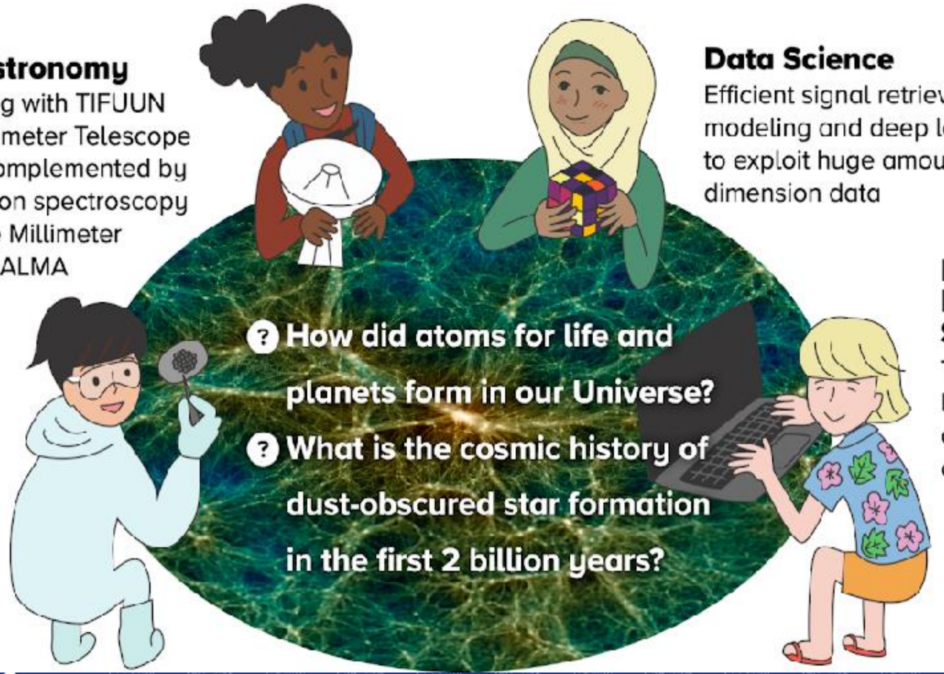
Bernal & Kovetz (2022) AAR, 30, 5

Cosmology with Superconducting Nanotechnology

TIFUUN

Observational Astronomy
Line intensity mapping with TIFUUN on Atacama Sub-millimeter Telescope Experiment (ASTE), complemented by high-spectral resolution spectroscopy using FINER on Large Millimeter Telescope (LMT) and ALMA

Data Science
Efficient signal retrieval with sparse modeling and deep learning to exploit huge amount of multi-dimension data



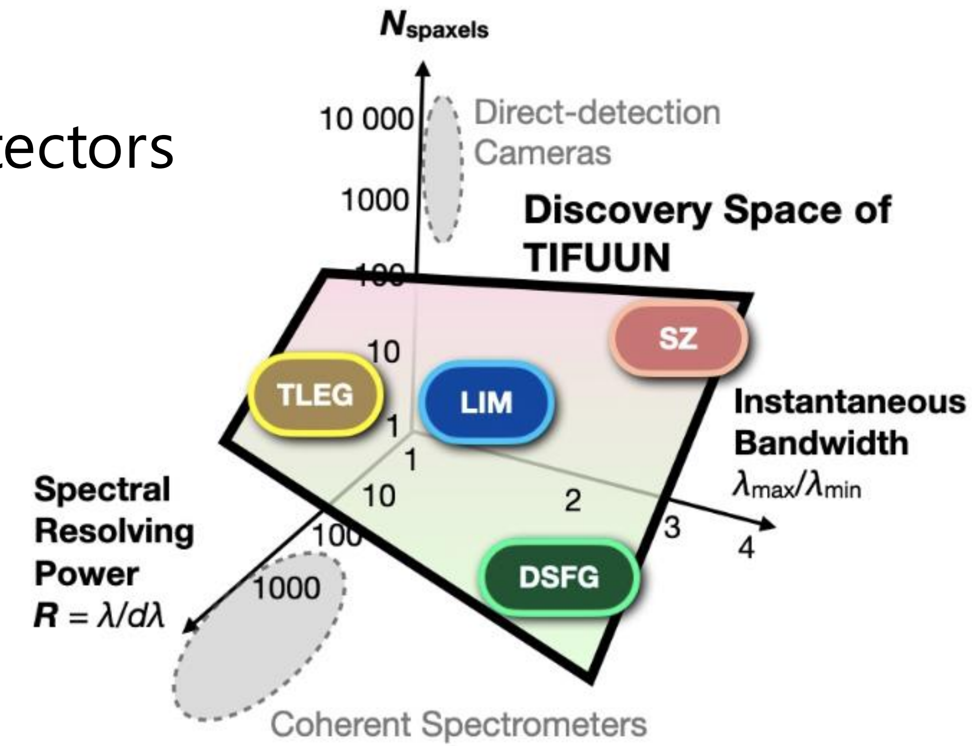
Large Scale Numerical Simulations
Theoretical prediction of line intensity signals and comparing to cosmological models

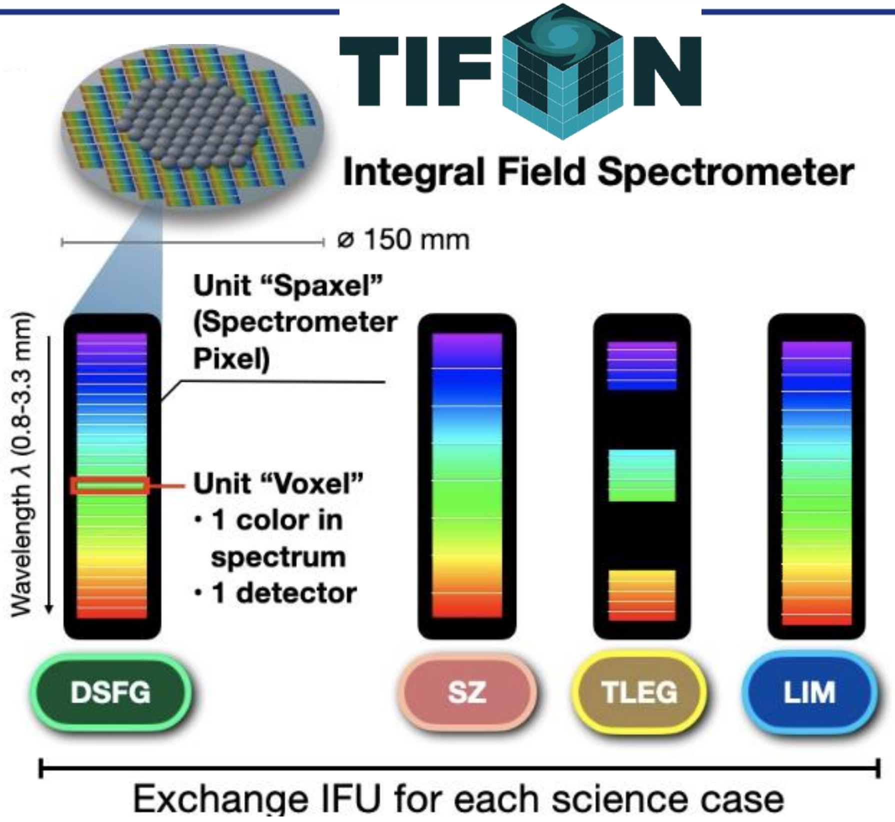
Superconducting Nanoelectronics
Development of novel Integrated Imaging Spectrograph TIFUUN

- **JSPS grants** (International Leading Research 国際先導研究 FY2023-2029 + Specially Promoted Research 特別推進研究 FY2024-2028 ~ €6M, PI: K. Kohno)
- **ERC Consolidate grant** (2022-2027 €3.4M, PI: A. Endo) awarded to TIFUUN/ASTE (and FINER/LMT)

TIFUUN provides flexible configurations tailored to your science cases

20k detectors in total

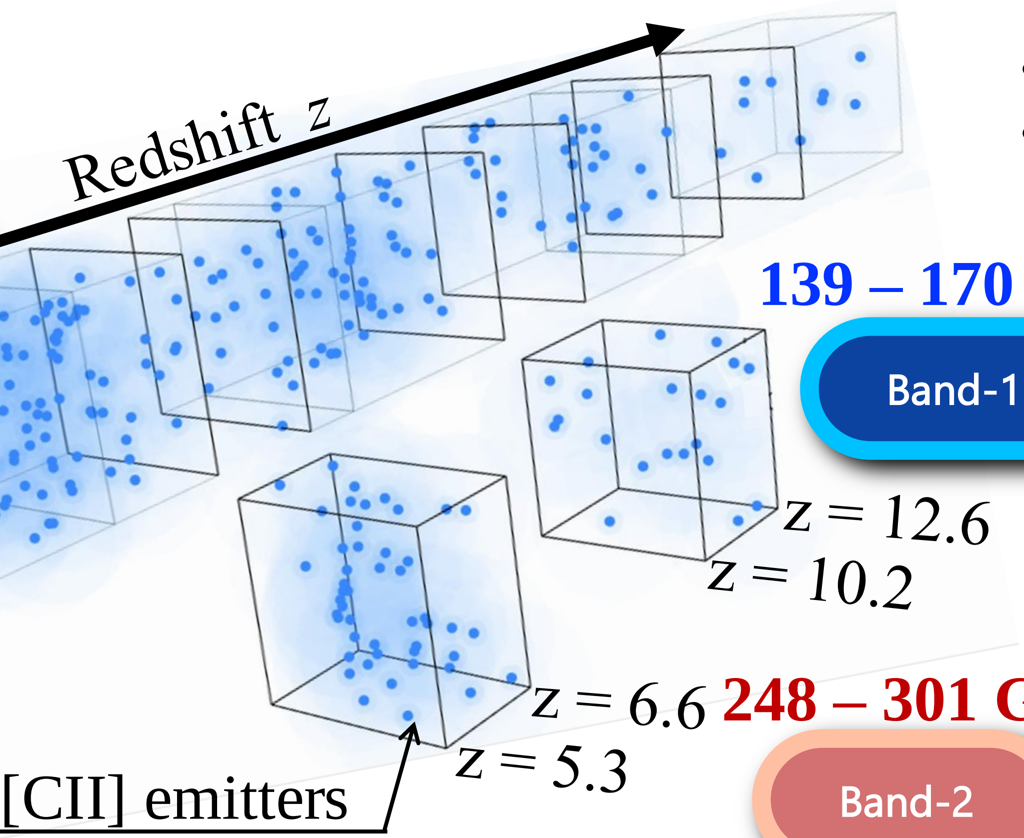




Science case	Spaxels	Total bandwidth	Spectral resolution
"Redshift machine" of dusty star-forming galaxies (DSFGs)	1 - a few	as wide as possible	moderate
Sunyaev-Zel'dovich (SZ) effect of galaxy clusters	~100	wide	low
Line intensity mapping (LIM) of two lines at a common redshift range	~100/band	distinct two frequency ranges	low - moderate

Dual-band line intensity mapping using TIFUUN

- 100 spaxels x 100 colors (R~500) x 2 bands = 20,000 voxels in total
- Simultaneous observations of line pairs at the same redshift range
  ➔ cross-correlation to mitigate contaminations & systematics



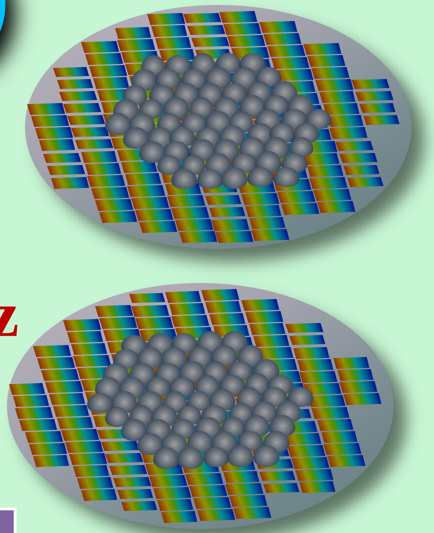
139 – 170 GHz

Band-1

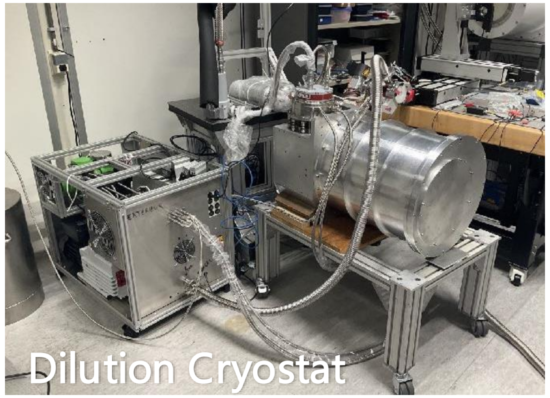
248 – 301 GHz

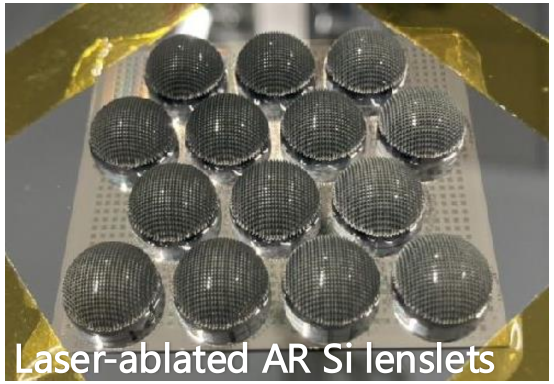
Band-2

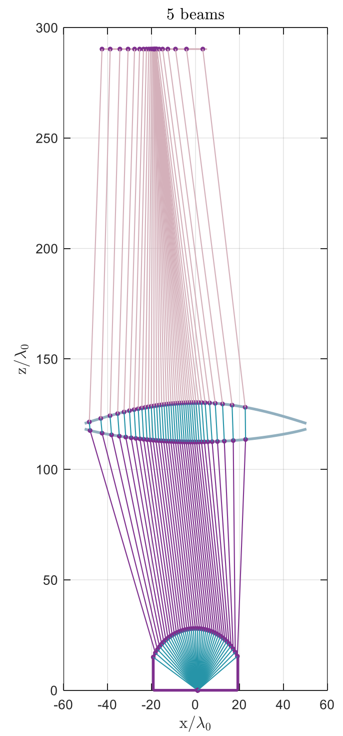
Integral Field Units



Field of view (@ASTE)
~8 arcmin (Band-1)
~5 arcmin (Band-2)



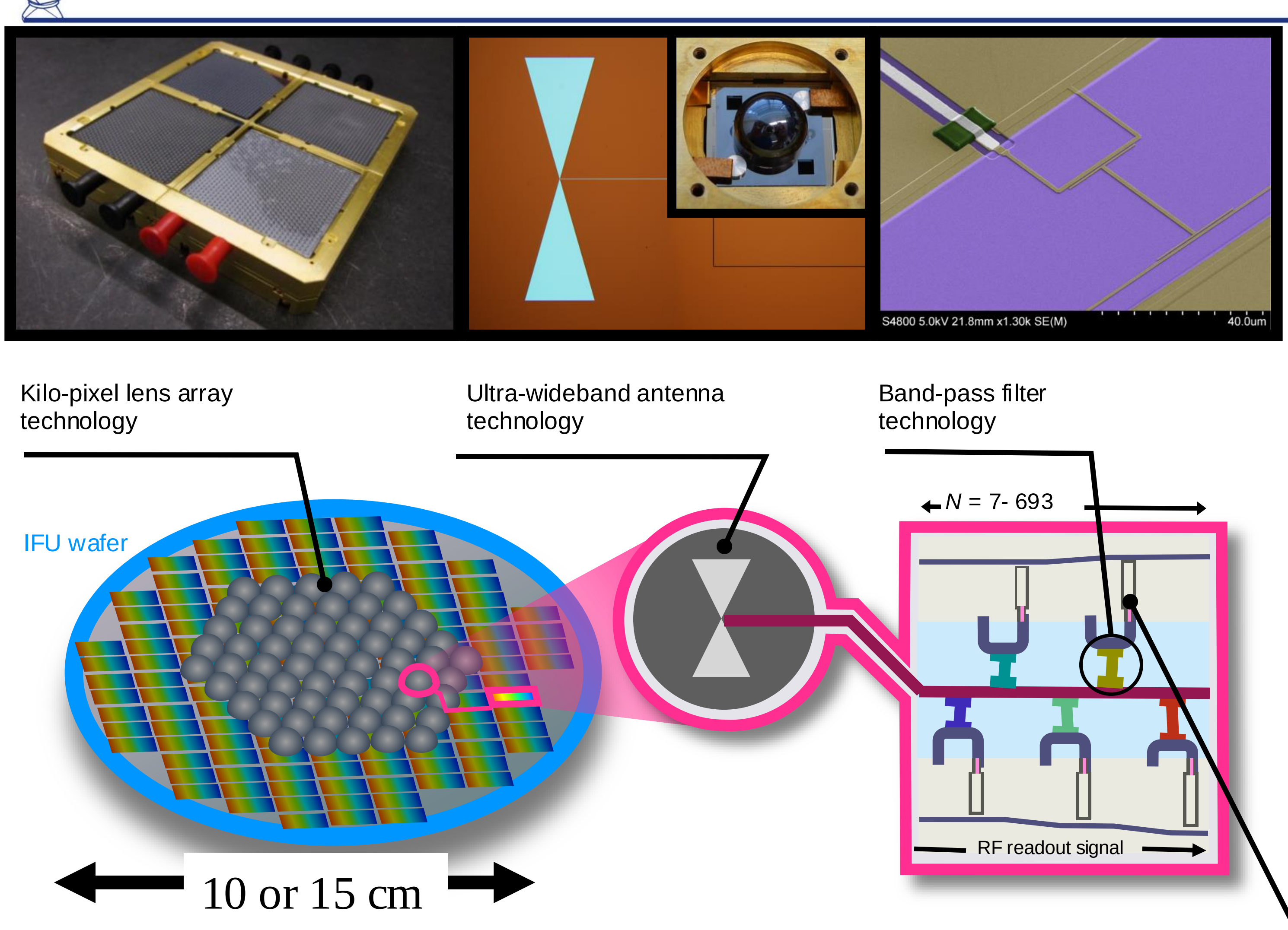


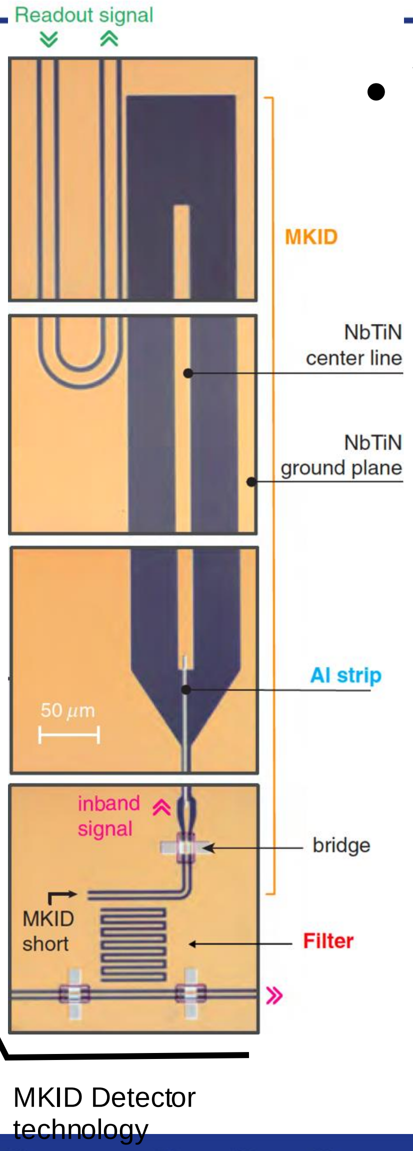


Wideband & Wide FoV optics

Redshift range	Band-1	Band-2
z = 10.2 – 12.6	[CII] 158 μm	[OIII] 88 μm
z = 1.9 – 2.2	CO(4-3), [CI](1-0)	CO(7-6), [CI](2-1)

Key technologies for TIFUUN implementation





Endo, A., Karatsu, K., Baselmans, J. J. A. et al. JATIS, 5, 035004 (2019)

- We have already successfully demonstrated all these key technologies, including:
  - (a) kilo-pixel lens array technology,
  - (b) ultra-wideband antenna technology,
  - (c) on-chip band-pass filters,
  - (d) based on MKIDs.

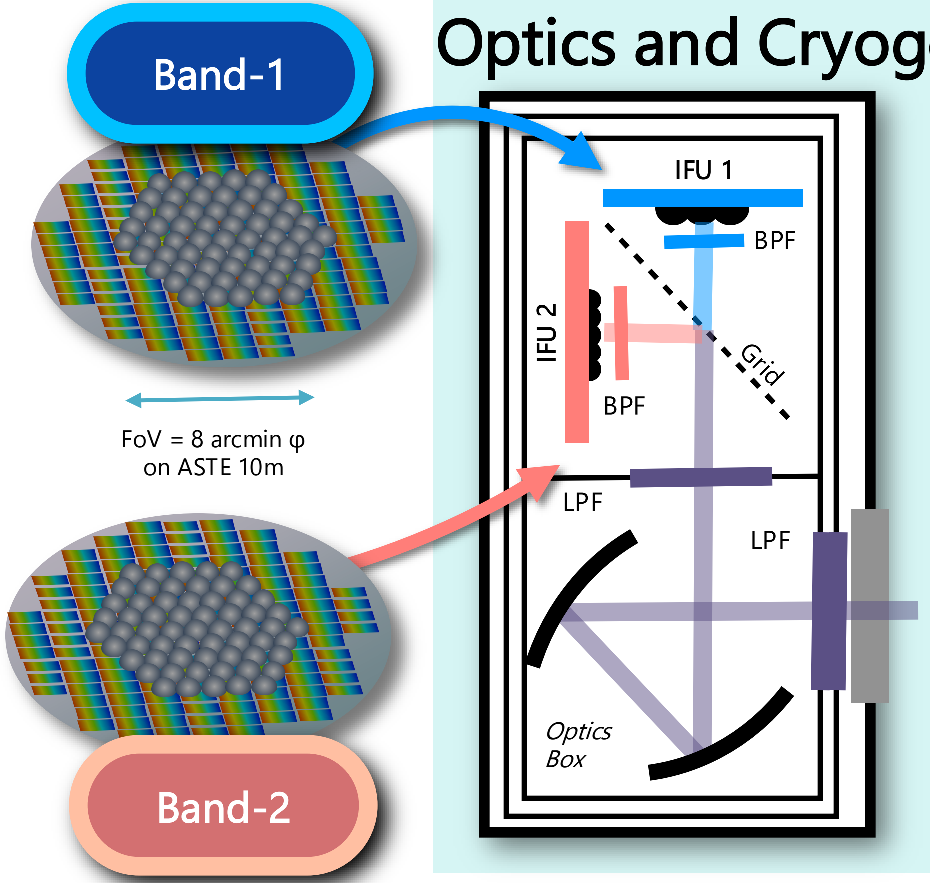
100-nm-thick NbTiN film deposited on the c-plane sapphire substrate, using reactive magnetron sputtering.
This film has a critical temperature Tc = 15 K ➔ F_gap = 3.5 k_b Tc/h = 1.1 THz

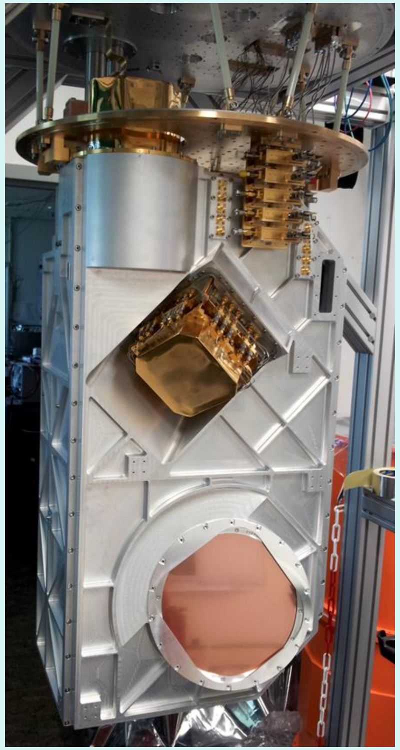
Dual-band line intensity mapping using TIFUUN

	DESHIMA 1.0	DESHIMA 2.0	TIFUUN for line intensity mapping	
Frequency range	332 – 377 GHz	220 – 440 GHz	**Band-1** 139-170 GHz	**Band-2** 248-301 GHz
Band-width	45 GHz	220 GHz	31 GHz	53 GHz
Number of spaxels	1	1	~100	~100
Number of spectral channels	49	347	100	100
Spectral resolution	~380	~500	~500	~500
Number of KIDs (voxels)	49	347	10,000	10,000
Deployment	2017	2023-2024	2027-2029	

139 – 170 GHz

Optics and Cryogenics





248 – 301 GHz

The total number of detectors (voxels) including both Band-1 and 2 will reach ~20,000.
The maximum data rate shall be ~100 MB/sec (128 bit, 160 Hz sampling).

2. Science Goals (and Key Questions)

Elucidating the formation and evolutionary processes of diverse astronomical objects in cosmic history, particularly the formation and evolution of stars, galaxies, galaxy clusters, and 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 sky?
- Some of the goals will be uniquely addressed by ASTE with its unique capabilities, but some of them will not be fully resolved by ASTE alone.
- The approach is to combine ASTE and ALMA to tackle these difficult and fundamental questions; e.g., a survey using ASTE → investigation with ALMA

3. Scientific Objectives (SO)

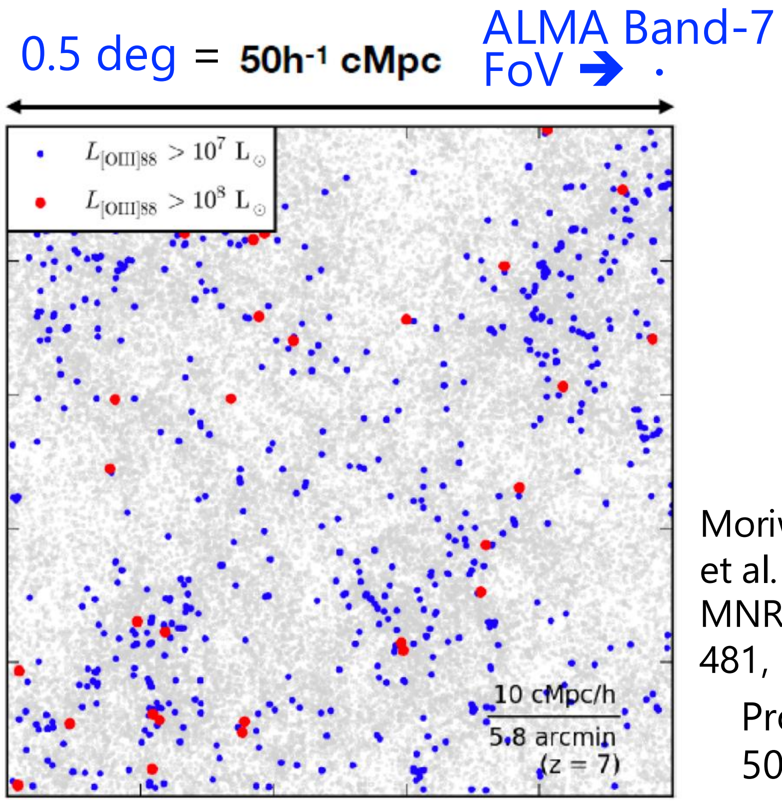
In this presentation, we will mainly focus on SO 1, which will be one of the major scientific objectives in the next mid-term (第五期中期計画)

1. Unveil **the cosmic metal enrichment history** (threshold science) and extract information of the underlying large-scale structures of dark matter (stretch goal)
2. Exploration of SMBHs that rapidly grow within heavily buried galaxies in the early universe.
3. Study of the dynamic evolutionary process of spatially extended galaxy clusters based on component separation observations of the Sunyaev-Zeldovich effect (thermal, relativistic, and kinetic SZE). Contribution to the refinement of cosmology through precision measurements of galaxy cluster mass.
4. Contribution to **time-domain** and multi-messenger astronomy through **immediate observations of transient objects**, leveraging agility.
5. Clarification of the role of carbon in the evolution of interstellar matter based on wide-area spectroscopic mapping of mid-J CO and [CI] emission lines.
6. 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.
7. Study of physical properties of cosmic-rays and ISM based on observations of mid-J CO and [CI] from molecular clouds associated with SNRs and massive star-forming regions.
8. Atmospheric and surface environments, as well as formation histories of solar system planets through high-precision spectroscopy.
9. Development of key technologies for next-generation large survey telescopes in the submillimeter wavelengths, with a focus on technology demonstration based on astronomical observations.

4. Science Investigation

In this presentation, we will mainly focus on SO 1, which will be one of the major scientific objectives in the next mid-term (第五期中期計画)

1. Conduct **submm-wave line intensity mapping** using the [CII] 158 µm line to constrain the bright end of the [CII] luminosity function and the [CII] power spectrum at z~6



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)
- 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.

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.

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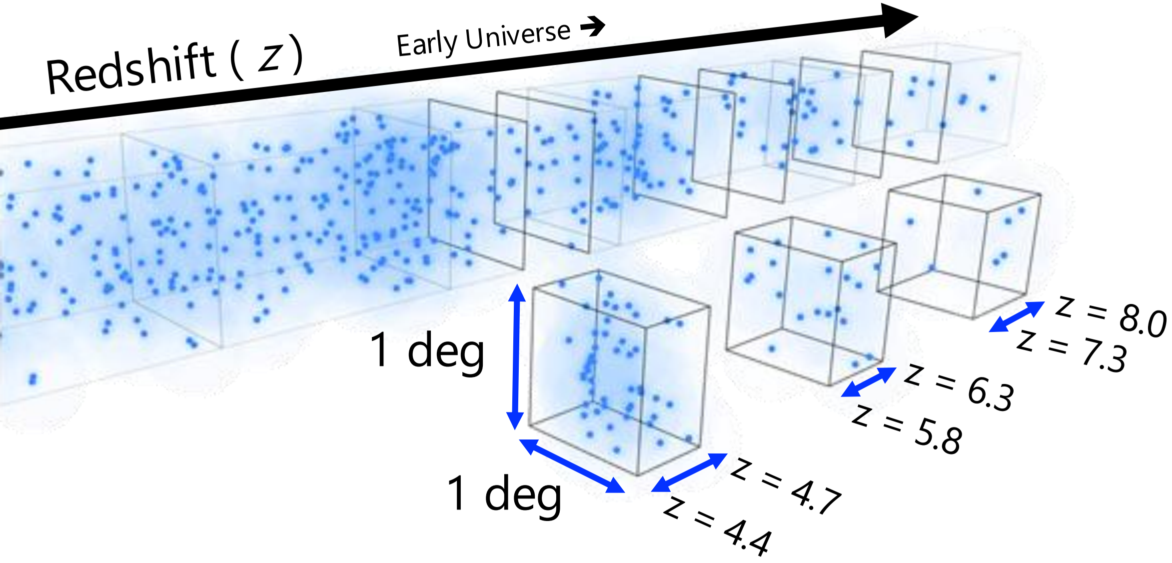

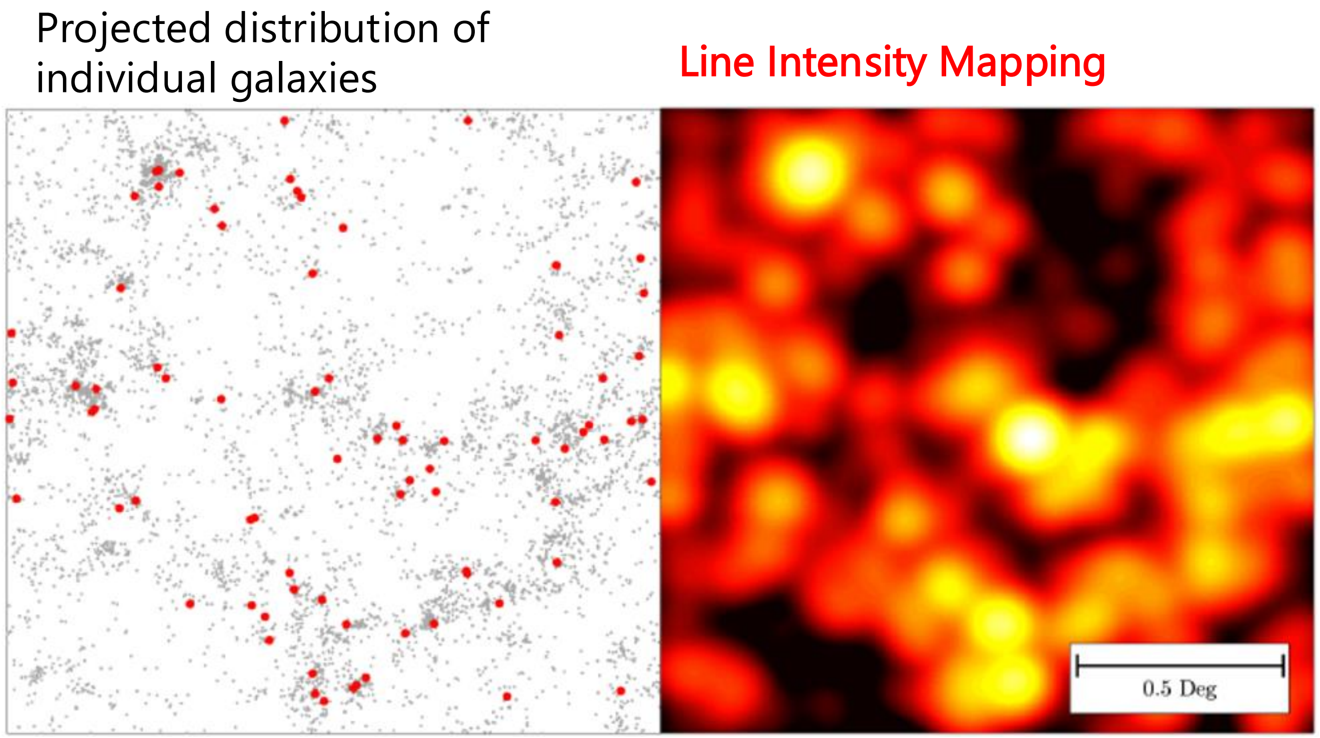

- In contrast to ALMA, which spatially and spectrally resolves individual galaxies, LIM observes summed signals from emission lines of numerous galaxies through low spatial and spectral resolution spectroscopic imaging.

4. Science Investigation

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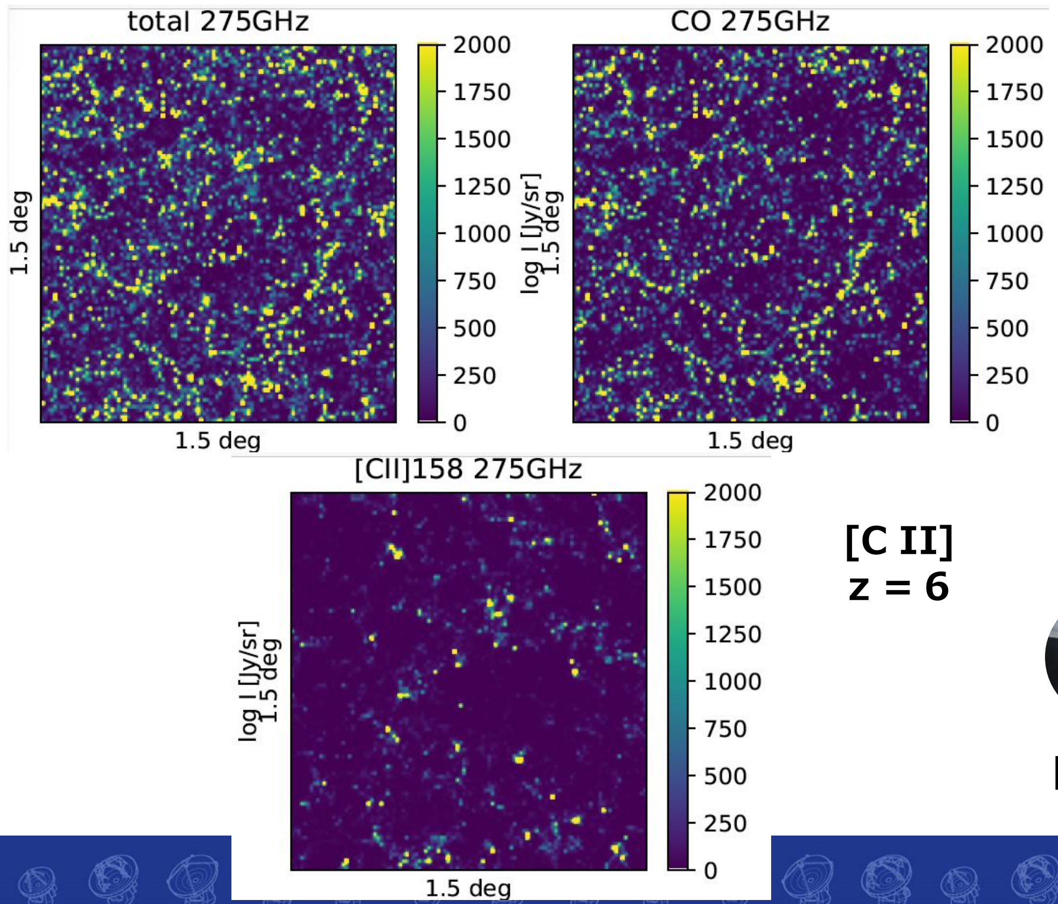
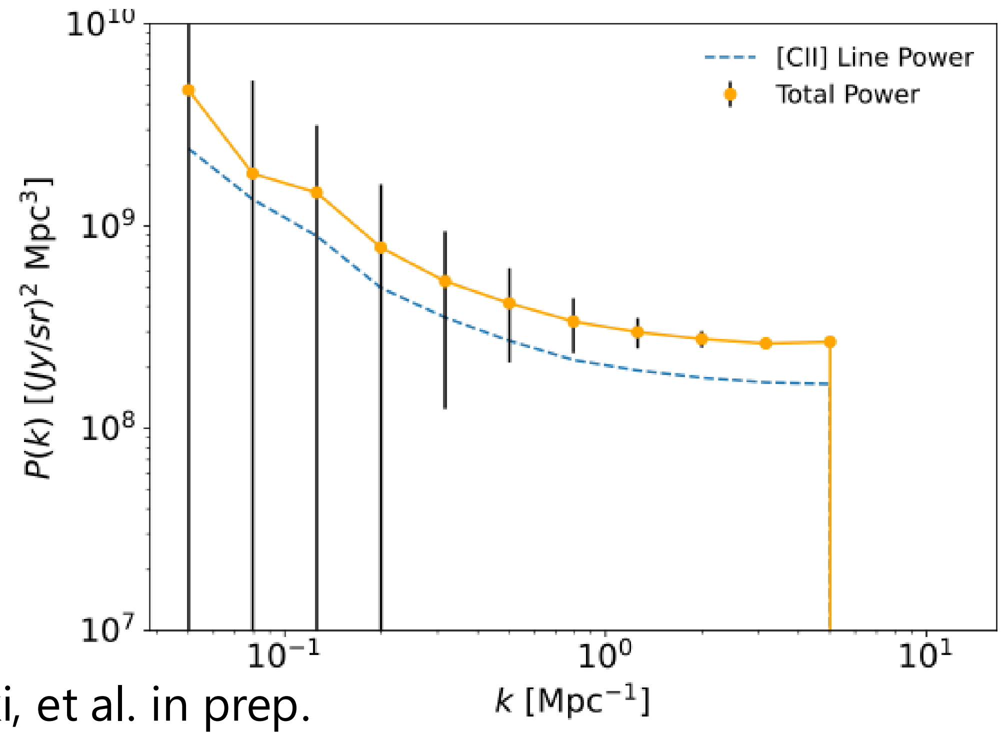
1. Conduct **submm-wave line intensity mapping** using the [CII] 158 μm line to constrain the bright end of the [CII] luminosity function and the [CII] power spectrum at z~6

Total **Foreground CO**



[C II]
z = 6

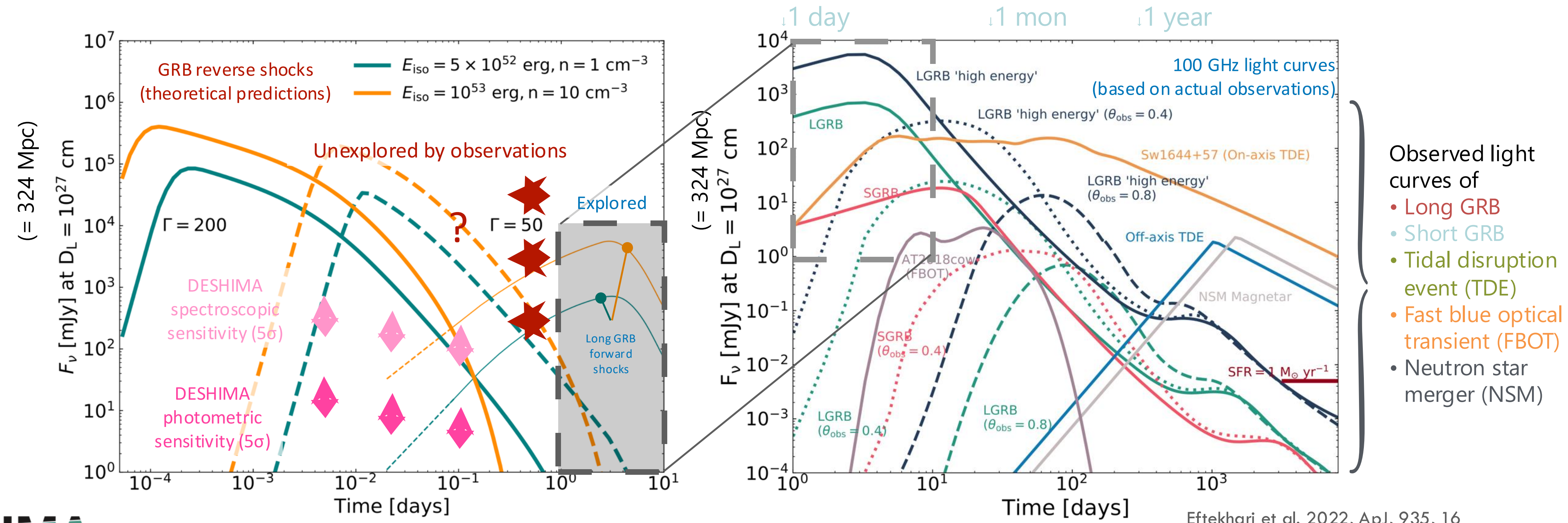
Mock observations using illustris TNG300 + emission line models

Narita, Moriwaki, et al. in prep.

Radio (mm/submm-wave) transient sky

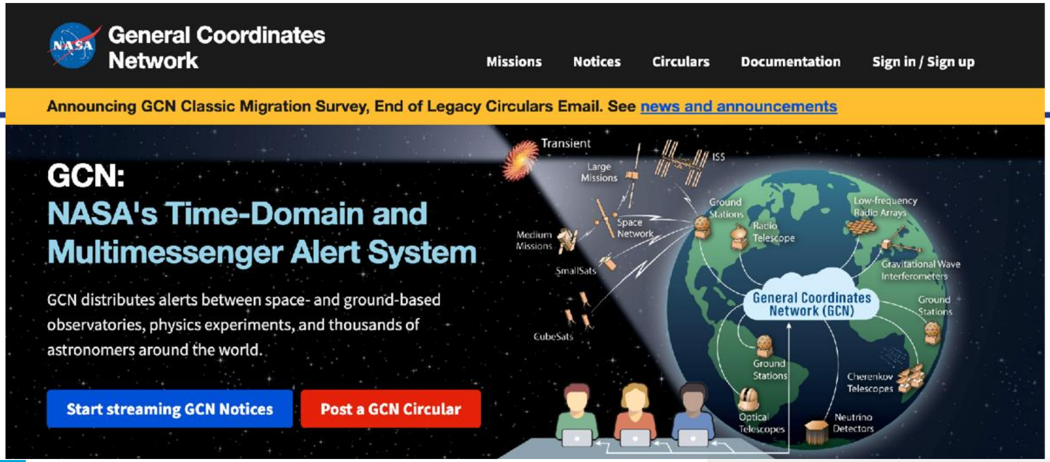
- Intraday (< 24 hr) sub/mm-wave events were unexplored. (but see also, Urata+2014)
- Afterglow from reverse shock of long GRBs should be bright ***even at redshift*** $z \gg 1$ (S. Inoue+2007)
- ***Physical properties*** (e.g., *B*, n_e) of a GRB jet can be imprinted in the sub/mm spectrum of synchrotron emission from GRB reverse shocks. ***No interstellar scintillation*** unlike low-freq radio.

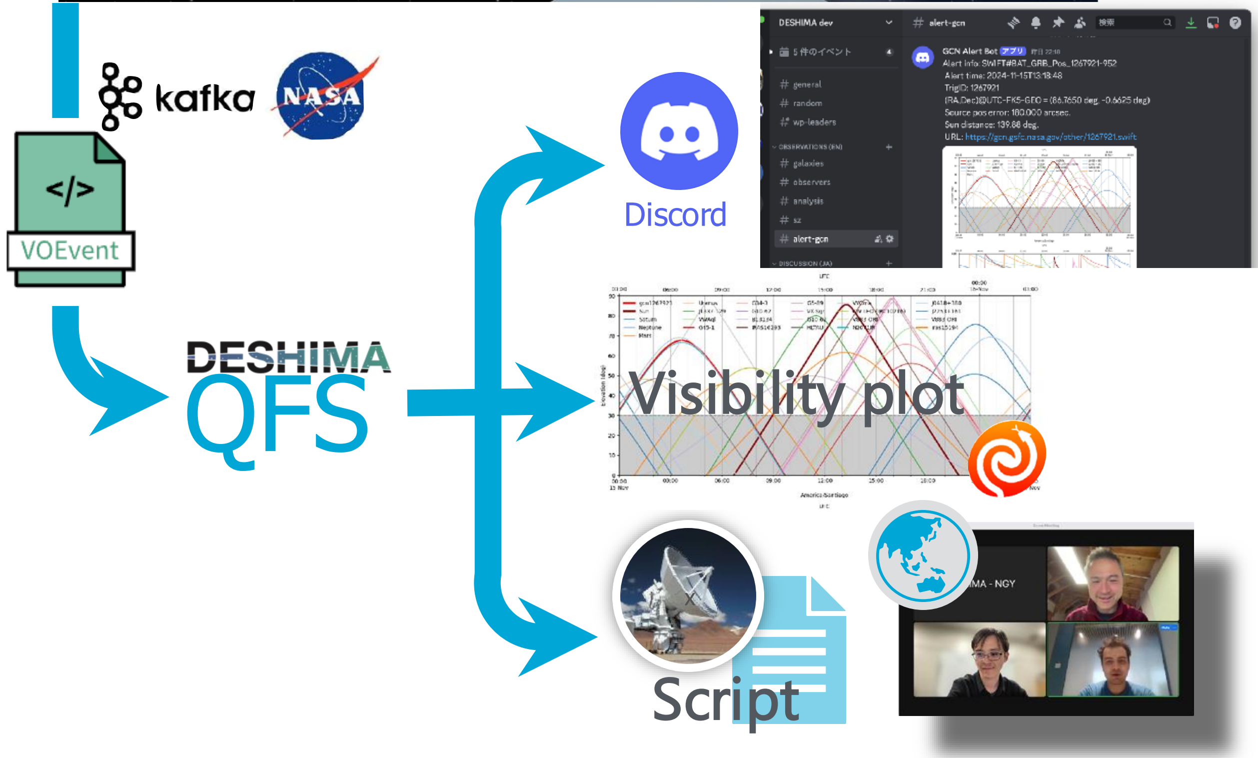


Eftekhari et al. 2022, ApJ, 935, 16

Quick follow-up system

- NASA's General Coordinate Network (GCN)
- DESHIMA/ASTE **autonomous** quick followup system (QFS)
  - Retrieves GCN/SWIFT alerts
  - Posts to Discord channel
  - Generates and posts visibility plots
  - Creates an observation script and sends it to ASTE system
- Actual telescope operation is done **manually** by an observer (human) in charge
  - Elevation must be > 30 deg, Sun separation must be > 25 deg → **60-70% of the sky in 24 hr**





GRBs we've observed so far

- List of *SWIFT* GRBs we observed in the past ~1.5 months.
- We can even go shorter if the burst is accessible immediately (EL > 30°).

Name	GCN #	Triger time (UTC)	Executed?	Start time (UTC)	Time after burst (hr)	*SWIFT* detect.
GRB241002	1257556	2024-10-02 00:50	No (north)	-	-	
GRB241006	1258721	2024-10-06 21:58	No (windy)	-	-	
GRB241010	1259578	2024-10-10 10:05	No (sun, windy)	-	-	
GRB241025	1262165	2024-10-25 01:36	No (north)	-	-	
GRB241026	1262764	2024-10-26 22:42	No (north)	-	-	
GRB241030A	1263718	2024-10-30 05:48	No (north)	-	-	
GRB241030B	**1263840**	**2024-10-30 18:34**	**Yes**	**2024-10-31 04:30**	**9.9 hr**	**BAT, XRT**
GRB241101	**1264304**	**2024-11-01 05:41**	**Yes**	**2024-11-01 13:46**	**6.1 hr**	**BAT only**
GRB241113	**1267501**	**2024-11-13 07:48**	**Yes** (cloudy)	**2024-11-14 22:21**	**39.3 hr**	**BAT, XRT**
GRB241115	1267921	2024-11-15 13:18	No (cloudy)	-	-	

5. Instruments and Data to be Returned

- The specifications to the final data products of TIFUUN (for science objectives no. 1)
  - The data to be acquired is the sub/millimeter imaging spectroscopy data (3D cubes) in an area of 1 deg^2 (nominal).
    - An area of >1.5 deg^2 (stretch), while the threshold will be set to 0.1 deg^2.
  - Frequency coverages will be 139-170 GHz (Band1) and 248-301 GHz (Band2).
  - A spectral resolution $R = \lambda/\Delta\lambda \sim 500$, an effective line mapping speed of around a few $arcmin^2\ mJy^{-2}\ hr^{-1}$
  - A typical noise level that decreases in accordance with long integrations extending up to ~1 hours and beyond (per imaging pixel).
  - Further considerations regarding the required quality will be conducted.

6. Originality and international competitiveness

Line Intensity Mapping (LIM) using TIFUUN

- LIM is not only a method for obtaining information about faint galaxy populations that are difficult to detect individually but is also an observational and theoretical approach that can provide new insights into structure formation and cosmology.
- Projects such as LIM using the optical Hα emission line with SPHEREx (NASA) and LIM with HI 21-cm emission line using SKA are planned. In submillimeter-wave LIM, insights into the history of heavy element formation, such as carbon and oxygen, can be gained, and synergistic effects, such as cross-correlation analysis with HI and other tracers, are also expected.
- While there are preceding projects like CONCERTO-APEX, **TIFUUN-ASTE**, which provides a leap of more than one order of magnitude in mapping speed, has a high level of competitiveness.
- Millimeter-wave CO emission line LIM using ALMA has also been attempted using ASPECS data, but due to the characteristics of interferometers, ALMA is only sensitive to "shot-noise" component. Information about "clustering term" that describes the spatially extended dark matter distribution can ***only*** be obtained ***through wide-field observations using a single-dish telescope***.

Time-domain astronomy using TIFUUN

- Although sensitivity is much worse than ALMA, **TIFUUN-ASTE** allows us to make an immediate response observations of transient objects, as demonstrated by our DESHIMA 2.0 on ASTE campaign.
- Another uniqueness is the ability to obtain simultaneous broad-band photometry including 2mm and 1mm. In case of ALMA, two independent observations are necessary using Band4 an Band6, for instance.
- Once we start LIM observations using TIFUUN-ASTE, it will need ~1,000 hours or more. It means that we will be always ready to accept any ToO observations.

6. Originality and international competitiveness

ASTE competitiveness

- ASTE offers advantages as a submm-wave observation site compared to the JCMT 15m telescope in Hawaii, including better visibility of key objects such as the Galactic Center CMZ and the LMC/SMC.
- Compared to the APEX 12m and FYST (CCAT-p) 6m telescope, also located in the Atacama, it has the strength of being able to dedicate observation time to specific instruments or scientific goals intensively.
- It is complementary to the Antarctic Terahertz Telescope (ATT) in terms of observed sky regions and primary frequency ranges.

TIFUUN competitiveness

- While other on-chip superconducting spectrometers, such as SuperSpec, have also been proposed, **DESHIMA/TIFUUN** is significantly ahead in areas like on-sky demonstration and characterization by observing astronomical sources, and the prototyping of imaging spectrograph (IFU).

8. 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
Human Resources		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.

8. Cost Assessments, Budget Line, and Status

- ASTE Baseline Operation Cost per Year: ~ 72 MJPY

FY2024, as of December 2024

Category	Amount (MJPY)	Notes
Antenna Maintenance		
Generator Operation Diesel Fuel Maintenance		10 months operation # partially covered by external funds
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 # partially covered by external funds
Human Resources		Only Contracted Staff (incl. Chile local)
Total	72	

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

8. 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 in Chile,
  - 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.
- Request for the next mid-term (第五期中期計画) :
  - Nomical operation cost 72 MJPY/year 7200 万円/年 (10 months, FY2024) ➔ a fraction of the operation cost + development of new observing instruments will be covered by external budgets including JSPS KAKENHI Grants
  - We may need to request an additional budget in the event of serious issues with the telescope, infrastructure, etc., although we will do our best to utilize external funding.
- The next question is whether there is a demand to develop a multi-beam receiver system, which would require another new grant.

8. Cost Assessments, Budget Line, and Status

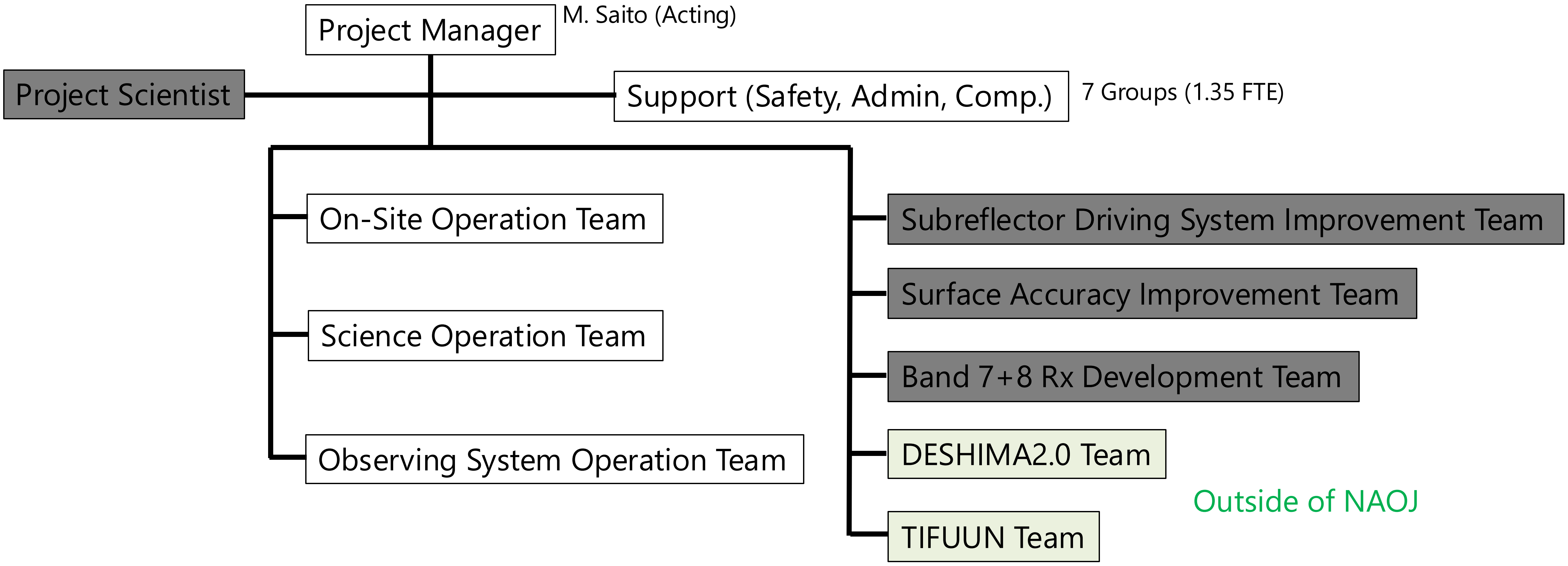
- Heterodyne receivers and digital spectrometers:
  - ASTE is equipped with three cartridge receivers developed under the JSPS Grant-in-Aid for Scientific Research (A) (led by Iono, D., FY2015-2019).
  - The prototype receiver for ALMA Band10 has been upgraded using an SIS mixer with High-Jc junctions, supported by the JSPS Grant-in-Aid for Scientific Research (A) (led by Asayama, S., FY2018-2022) and demonstrated on ASTE (Asayama et al. 2022, PASJ, 74, 678).
  - From the fiscal year 2020, two JSPS Grant-in-Aid for Scientific Research (A) programs have been selected and implemented. The ASTE Band8 receiver has been upgraded to a 4 – 18 GHz wideband IF SIS mixer for simultaneous observations of the CO(J = 4-3) and [CI](1-0) emission lines (PI: Oka, T., FY2020-2024). The new digital spectroscopy system for utilizing the wideband IF has been introduced with JSPS Kiban-A (PI: Tosaki, T., FY2020-2024).
- Integrated superconducting spectrometer DESHIMA2.0 & TIFUUN:
  - JSPS Grant-in-Aid for Scientific Research (S) (PI: Kohno, K., FY2017-2021), International Leading Research 国際先導研究 (PI: K. Kohno, FY2023-2029), and Specially Promoted Research 特別推進研究 (PI: Kohno, K. FY2024-2028), which also includes operation cost.
  - ERC Consolidator grant led by Delft University of Technology (PI: Akira Endo, TIFUUN, FY2022-2027, 3.5M€)

9. Project Organization

As of December 2024

Current

NAOJ:8 Persons (4.05 FTE) + 7 groups (1.35FTE)



10. Why NAOJ?

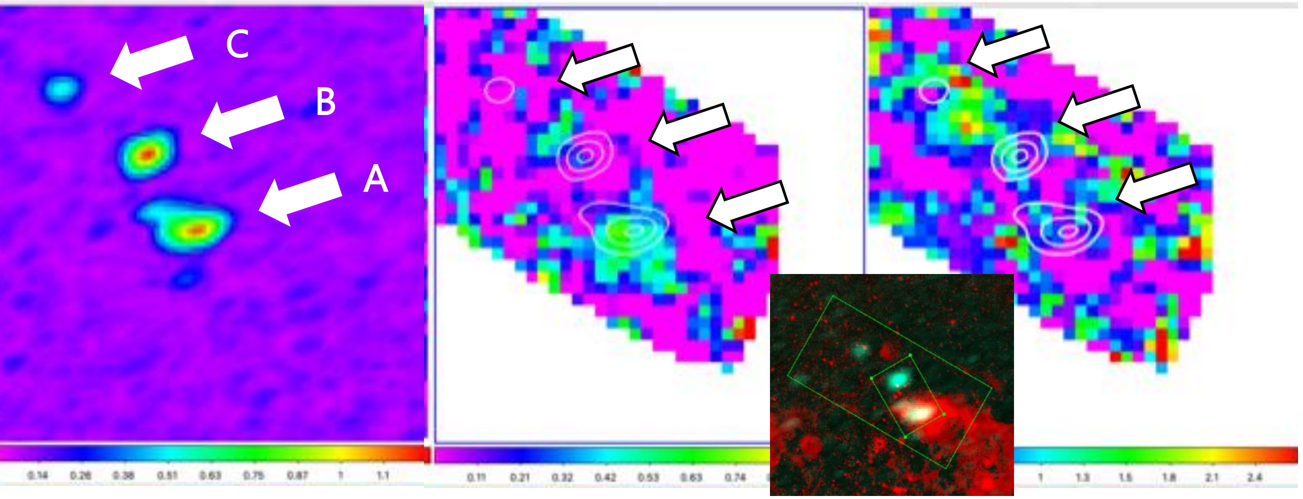
- Making full use of the technologies and expertise that NAOJ has developed and operated through its advancements from Nobeyama 45m, ASTE, and ALMA
- including large, high-precision radio telescopes, superconducting detectors, digital signal processing, signal transmission, and remote control
- We aim to enhance the scientific achievements of ALMA, one of NAOJ's flagship missions. Additionally, we will contribute to the exploration of new discovery spaces and the generation of groundbreaking scientific outcomes.
- What we would like to request to NAOJ:
  - Operation and maintenance of ASTE and its auxiliary facilities, as well as coordinated operations with other NAOJ facilities such as ALMA and the 45m telescope.
  - Development of instruments utilizing advanced technologies such as SIS receiver systems and direct detector array techniques at the Advanced Technology Center, along with the education and training of students and young researchers, supported by securing the necessary laboratory space.
  - Ensure the continuity of expertise in the operation, remote control, and signal transmission of telescopes, superconducting receivers, digital backends, and infrastructure, building on the knowledge accumulated so far.
  - Collaborative efforts with the Division of Science, as well as the management of data archives, will also be pursued.

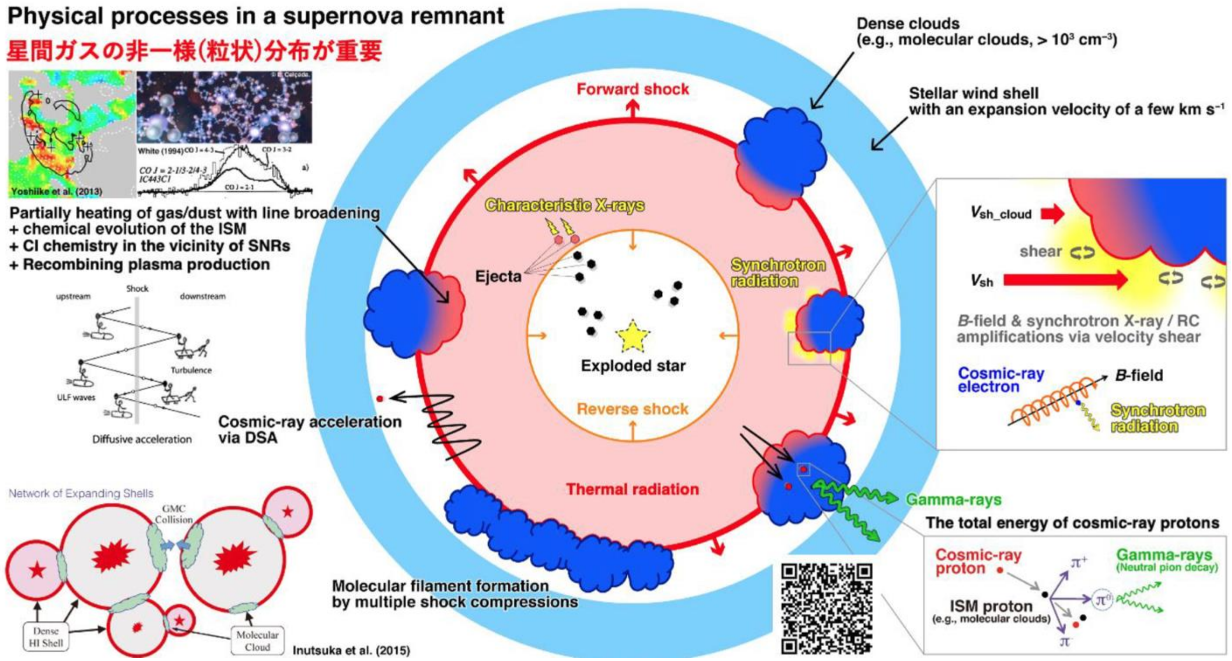
Supplemental slides

4. Science Investigation

5. Clarification of the role of carbon in the evolution of interstellar matter based on wide-area spectroscopic mapping of mid-J CO & [CI] emission lines
7. Study of physical properties of cosmic-rays and ISM based on observations of mid-J CO and [CI] from molecular clouds associated with SNRs and massive star-forming regions.

ACA CO(1-0) CO(4-3) [CI](1-0)

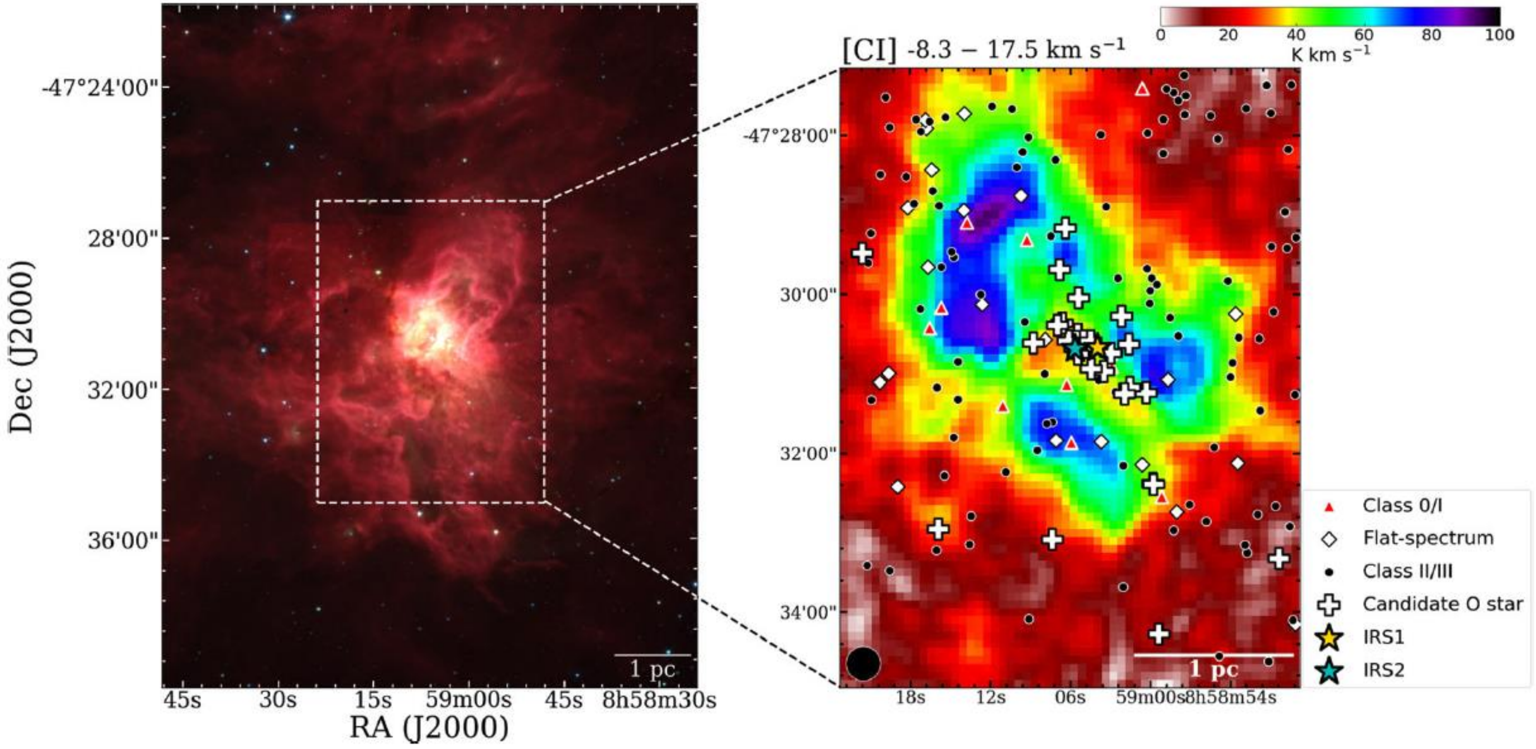




ASTE observations of Hubble V in NGC 6822. Fujita, Tosaki, et al. (in prep.)

H. Sano et al.

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



[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

- [CI] emission line observations of the massive star-forming region RCW 38
- 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 Photo-Dissociation Region (PDR) depiction (i.e., plane-parallel PDR model), suggesting a clumped ISM distribution on sub-parsec scales.

Wide-field submillimeter [CI] mapping using ASTE reveals Cosmic-ray-driven C/CO enhancement in the SNR W51C

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

- Wide-field [C I]($^3P_1 \rightarrow {^3P_0}$) observations reveal a striking enhancement of neutral carbon abundance with respect to CO ($X_{C/CO}$) depending on the distance from the SNR center.
  - The spatial extent of the enhanced $X_{C/CO}$ (~17 pc) is consistent with the CR diffusion distance (100 MeV).
  - The CR ionization rate is estimated to be 3×10^{-16} s^{-1} (30 times higher than the standard Galactic value).
- The neutral carbon [C I] line is a powerful probe to study the Cosmic-ray – ISM interaction.