ALMA2:
Atacama Large Millimeter/submillimeter Array in Exploration of the Origins of the Universe and Life

NAOJ ALMA Project

December 2024

国立天文台
NAOJ
National Astronomical Observatory of Japan

Notes

- Enhancing the capabilities of ALMA while continuing its science operations in line with the ALMA Development Roadmap is called the “ALMA2” project in Japan, which is supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) to promote large-scale academic frontiers.

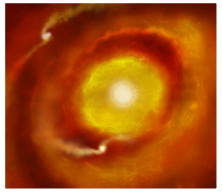
- ALMA2 discussion started as a bottom-up effort with the Japanese science community since 2011. Science goals and scientific objectives of ALMA2 are in line with those listed in the ALMA Development Roadmap, while not exactly same. ALMA2 science goals and scientific objectives are optimized for the Japanese science community.

- We notice that definition of items listed in the NAOJ Science Roadmap (SR) are slightly different from those used in the ALMA 2 documentation. For examples, “science goals” normally referred in the ALMA2 project correspond to “scientific objectives” in the NAOJ SR proposal. In this presentation file, we follow the definitions of the NAOJ SR.

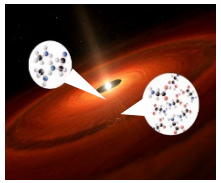
Summary of ALMA2

To achieve the three major objectives newly established for the next decade of scientific advancements, we will continue operating the ALMA telescope through international collaboration while undertaking a significant upgrade of its observational capabilities.

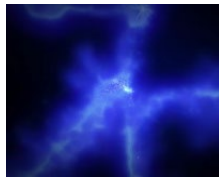
Major Scientific Objectives



Understanding Planet Formation on Terrestrial Orbital Scales



Understanding Building Blocks of Life in the Forming Process of Planetary Systems



Probing the Emergence of Heavy Elements in the Era of the First Galaxies

- (Instantaneous) Frequency bandwidth: 2x or more
- Sensitivity: approx. 2x
- Spatial resolution: 2x or more

Involving the significant upgrade of the system

Open-use for various science topics, not limited to the 3 scientific objectives.

Overview of ALMA

ALMA has a mission to search for our cosmic origins of life
in global partnership of 22 countries and regions

ALMA is an international project to construct and operate a large radio telescope in global partnership of East Asia, North America, and Member States of the European Southern Observatory (ESO)

22 countries and regions
- Japan: NINS + East Asia
- Europe: ESO (16 countries)
- United States: NSF + Canada

※ in corporation with Republic of Chile (host country)

East Asia partnership：
- Taiwan: ASIAA
- South Korea: KASI

23 Japanese universities and institutes have collaborated with NAOJ through the science operation collaboration agreements (21) and the development collaboration agreements (2).

In Japan, ALMA started with bottom-up discussion in the science community in the early 1980s: Large Millimeter Array (LMA) was proposed in 1983.
In 1987, idea of LMA evolved as Large Millimeter and Submillimeter Array (LMSA) taking submillimeter observations into consideration.
In 2001, NAOJ, NSF, and ESO signed resolution to form the ALMA.
In 2004, NAOJ officially joined the ALMA constructions, which is also the year "Atacama Large Millimeter/submillimeter Array (ALMA)" is named.

ALMA (past), ALMA2 (on going), and toward ALMA3 (future)

NAOJ contributions at the construction
- ACA (Morita Array) with 12x 7m antennas, 4x 12m antennas, ACA correlator
- Band 4, 8, and 10 receivers

US and Europe: 50x 12m antennas, the correlator for the 12-m Array, Band 3, 6, 7, 9 receivers, etc.

2011
Early science operations started with 16 antennas

2013
Full science operations started

2023
ALMA2 started in Japan **(-2032)**

2033
ALMA3(?)

Construction
2004-2013

Operation phase
2015: 30+ years of operations agreed among the executives
(Trilateral Agreement concerning Operations of ALMA signed in Tokyo)

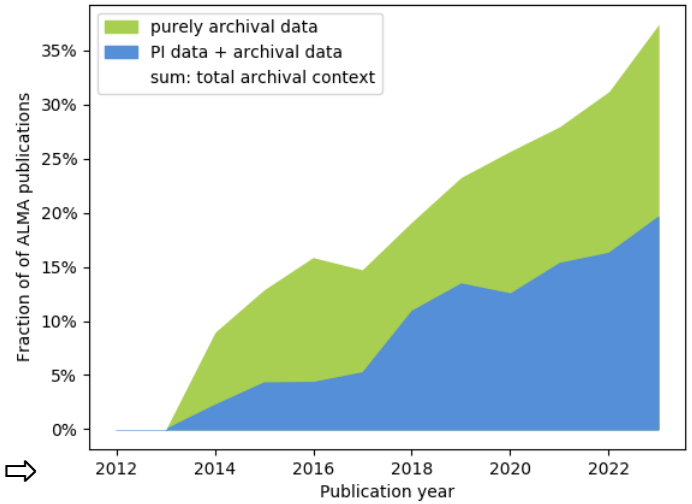
ALMA2
Significant system upgrade in parallel to science observing

ALMA3
New science goals and further enhancements of capabilities

Publications

- Total publication of **3,716** (as of March 2024) in ~13 years.
  - **545** papers by the 1st authors based in Japan, 2nd highest after US
- Approximately 90% of publication has been made through international collaborations
- Covering various science topics, growth of new fields: planet formation, AGN, astro-chemistry, redshift (z) beyond 10, etc.
- Published in high impact journals such as **Nature (102) and Science (22)**
  - 21.8% by 1st authors in East Asia, at the same level of the telescope time allocation

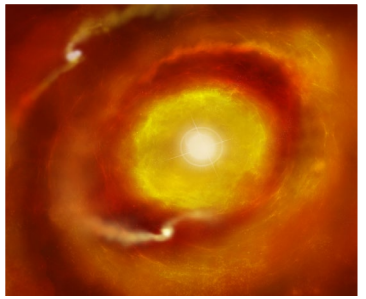
- Over one third of all ALMA publications now make use of data from the ALMA Science Archive
  - 37.7% of all ALMA publications (science verification data were excluded from the statistics) are from either purely archival data (green) or archival data combined with data associated with one of the authors (PI data, blue)



Reference: ALMA Science Protal News (February 16, 2024) ⇨

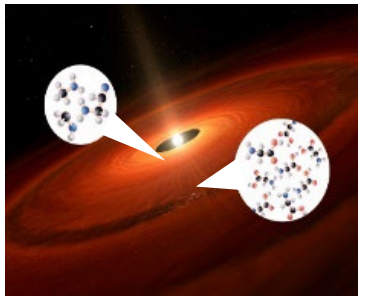
ALMA2 Science Goal:
What are the origins of the Universe and life?

Scientific Objective 1
Understanding Planet Formation
on Terrestrial Orbital Scales



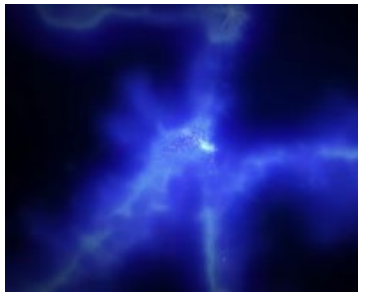
Terrestrial planet forming region (Artist's impression)

Scientific Objective 2
Understanding Building Blocks of Life
In the Forming Process of Planetary Systems



Distribution of organic molecules (Artist's impression)

Scientific Objective 3
Probing the Emergence of Heavy Elements
In the Era of the First Galaxies

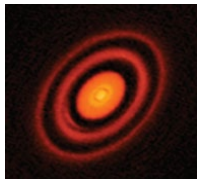


Galaxy formation at the birth of the Universe (Simulations)

Toward Science in the Next Decade

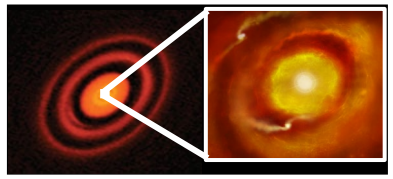
2011 2013 | 2023 2024 | 2033

Formation process of planetary systems



Achievements: Detailed structures of planet forming regions, with the significant diversity, have been revealed **at the radii greater than the Jupiter orbital scale.** ALMA results indicate that the standard theoretical model of planetary-system foramtion belived last 40 years should be updated.

Understanding planet formation on terrestrial orbital scales



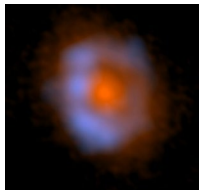
Left: Observations; Right: Artist's impression

Twice the angular resolution, 100 times the sample size

Goals: ALMA2 will enable imaging **structures with 1-au resolution,** capturing signs of planetary system formation not only for gas giants but also for rocky and icy planets, revealing initial environments where the planets form.

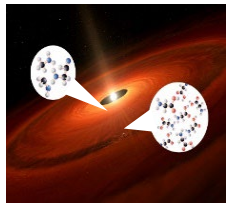
Exploring exoplanets, analyzing solar system materials, linking them and advancing our understanding of habitable environments

Chemical evolution in the expanding Universe



Achievements: A variety of molecules have been discovered in star-forming regions. **Various organic molecules, such as methanol and dimethyl ether, have been detected for the first time toward planet-forming regions.** ALMA results have opened a new window for discussions on the initial physical and chemical environments for young planets.

Understanding building blocks of life in the formation process of planetary systems

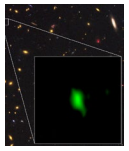


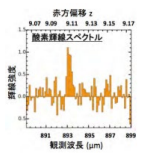
Artist's impression

Twice the sensitivity, double the instantaneous bandwidth, mapping diverse organic molecules

Goals: ALMA2 will enable us to **observe more than 100 star- and planet- forming regions with linear size scales down to 10-100 au.** Tracing the chemical evolution leading to large organic molecules and identify regions where building blocks of life form.

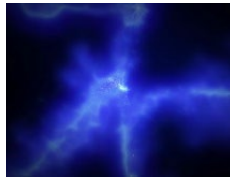
History of galaxy formation





Achievements: **There have been a series of discoveries of the most distant detection of oxygen and dust, including a galaxy 13.28 Gyr away**. The results suggest that the first stars are formed approximately 0.3 Gyr after the birth of the Universe.

Probing the emergence of heavy elements in the era of the first galaxies



Simulations

Direct observations of the first-generation stars with TMT

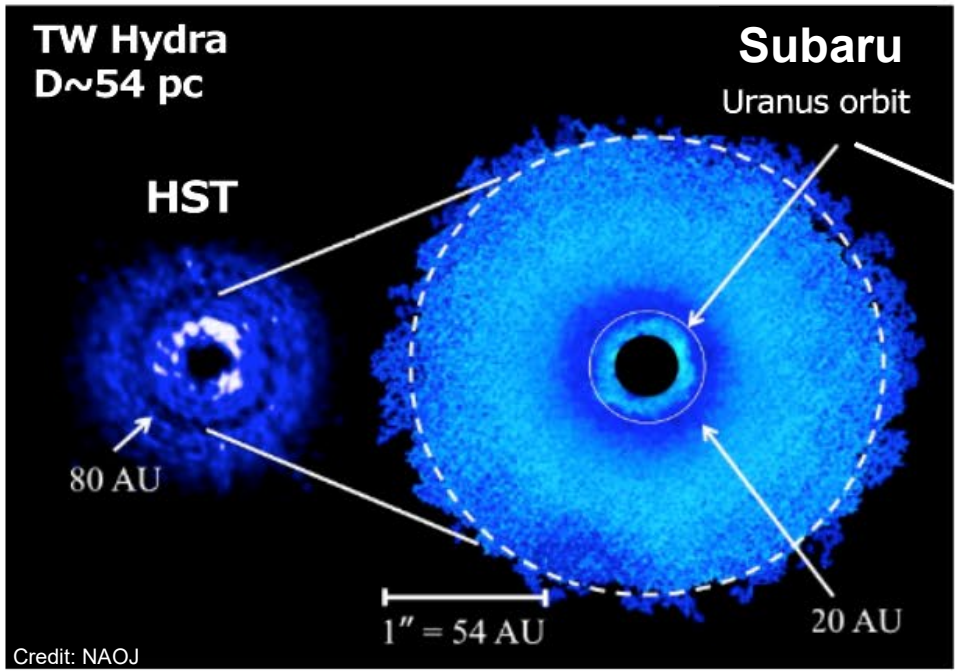
Twice the sensitivity, double the instantaneous bandwidth, reaching more distant galaxies with greater efficiency

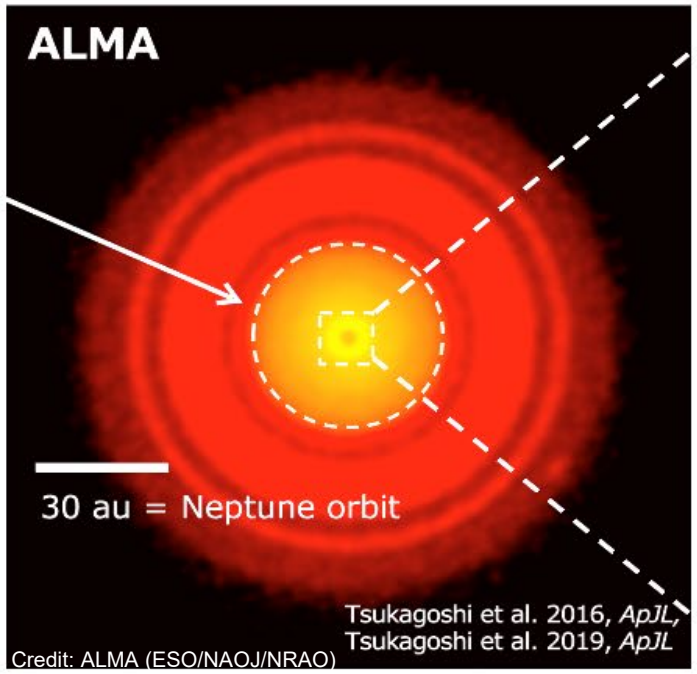
Goals: ALMA2 will probe the starting point of metal enrichment of the Universe by **directly detecting the oxygen emitted from the supernovae of the first-generation stars,** expected to have occurred at roughly 0.3 Gyr after the birth of the Universe.

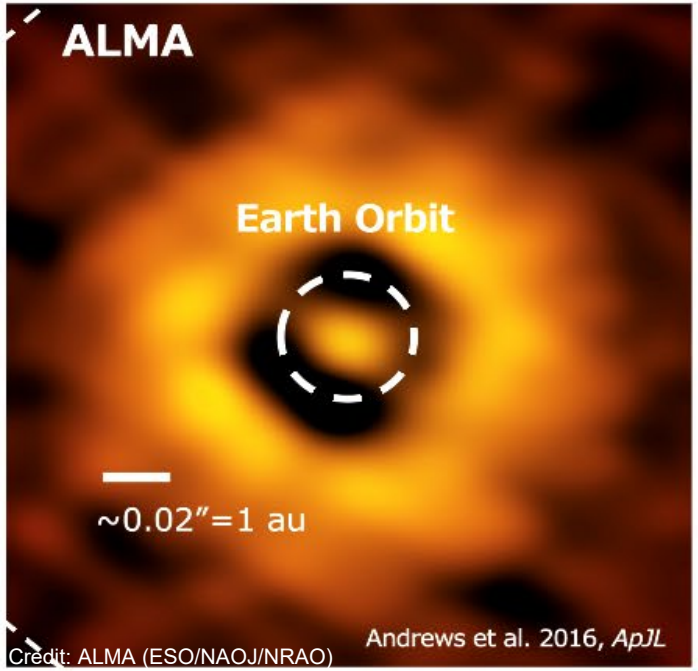
Previous Scientific Objective 1:
Formation Process of Planetary Systems

Outstanding spatial resolution

- Detailed structures of protoplanetary disks have been revealed. ALMA has brought about transformative changes in our understanding of planetary system formation
- ALMA has an advantage to image the most inner regions of protoplanetary disks
  → ALMA imaged a planetary system on a terrestrial orbital scale (but for very few sources)





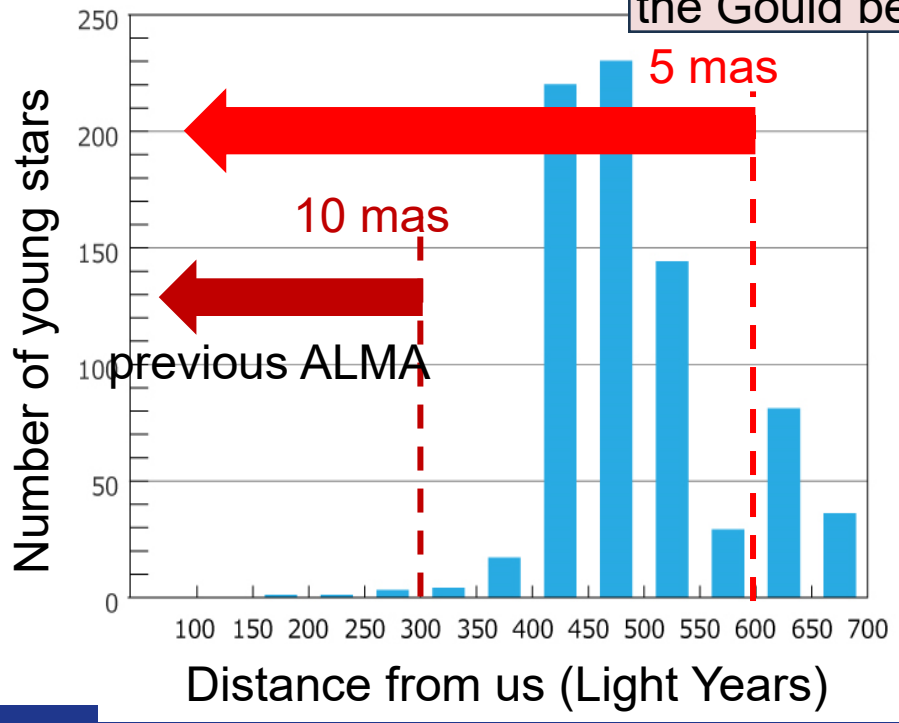


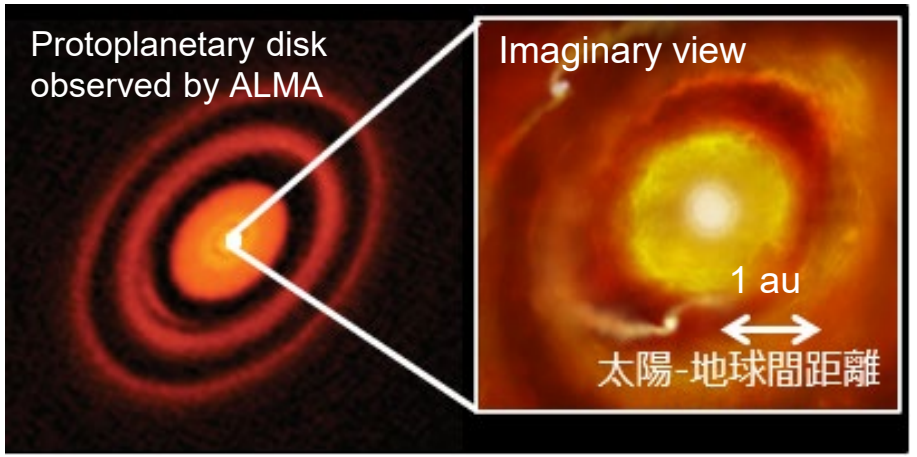
ALMA2 Scientific Objective 1:
Understanding Planet Formation on Terrestrial Orbital Scales

Expanding the sample size by a factor of 100 to explore planet forming disks at ~1-au scale

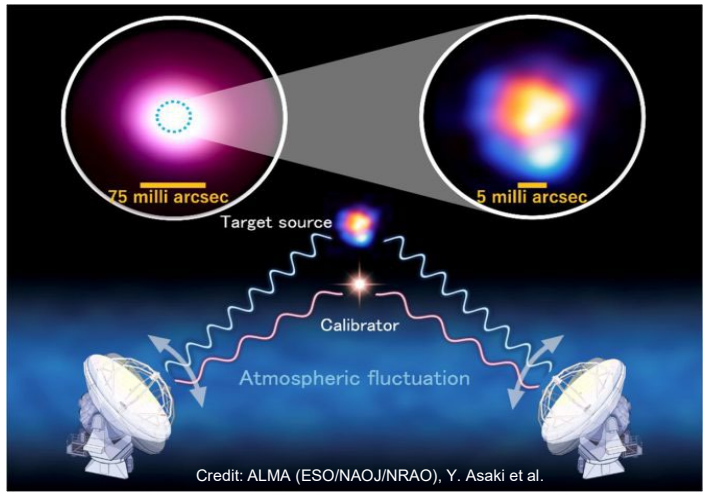
Imaging structures at 1-au, capturing signs of rocky and icy planets, revealing initial environments where the planets form

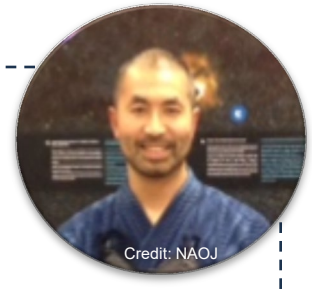
Young stars located inside the Gould belt (~200 pc)





Credit: (left) ALMA (ESO/NAOJ/NRAO), S. Andrews et al.; NRAO/AUI/NSF, S. Dagnello, (right) NAOJ



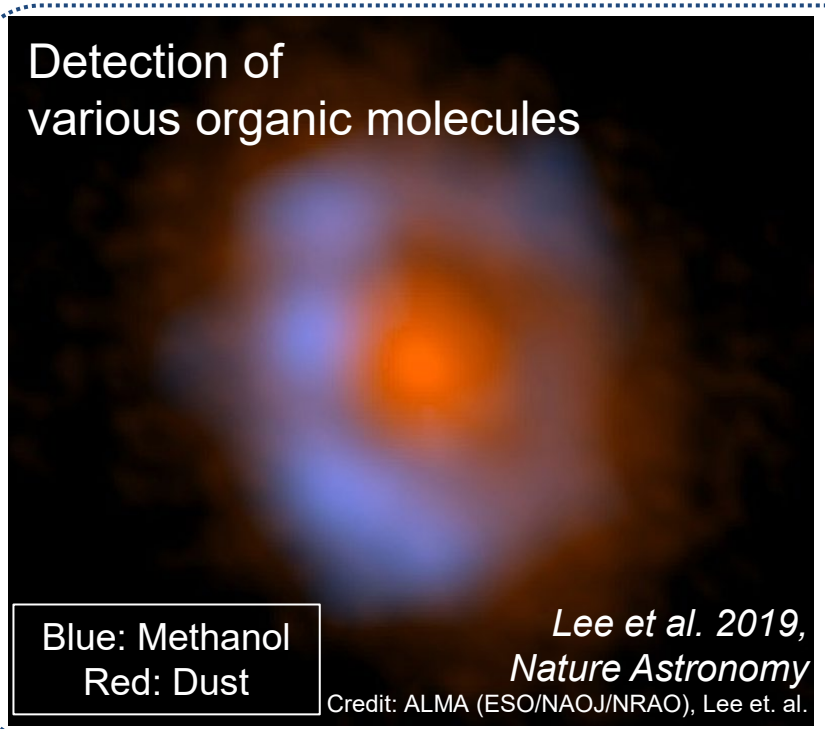


Commissioning team led by Yoshiharu Asaki(JAO/NAOJ) demonstrated **~5 mas angular resolution in Band 10** using the band-to-band observing technique.

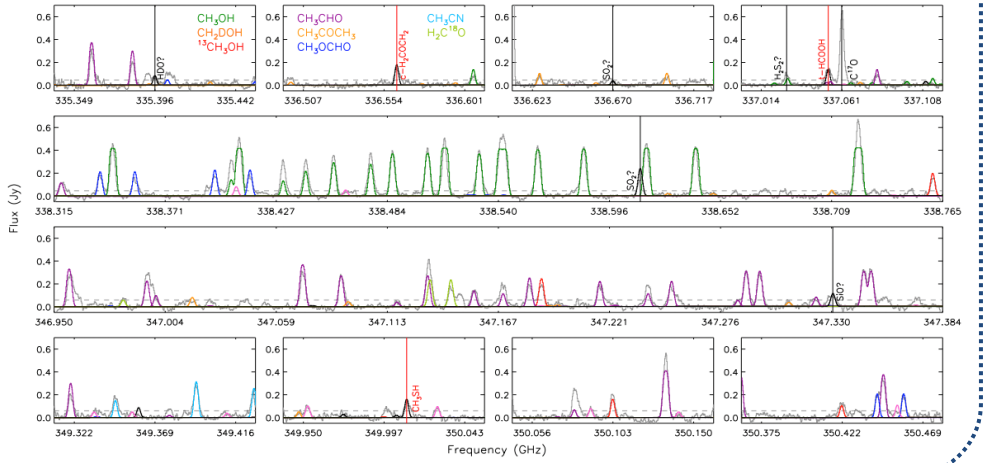
Previous Scientific Objective 2:
Chemical Evolution in the Expanding Universe

Outstanding spectroscopic capability

- A simple form of sugar in the star forming region, first detection of methanol in a protoplanetary disk… → Detection of organic molecules are becoming common
- ALMA revealed chemical compositions in various regions



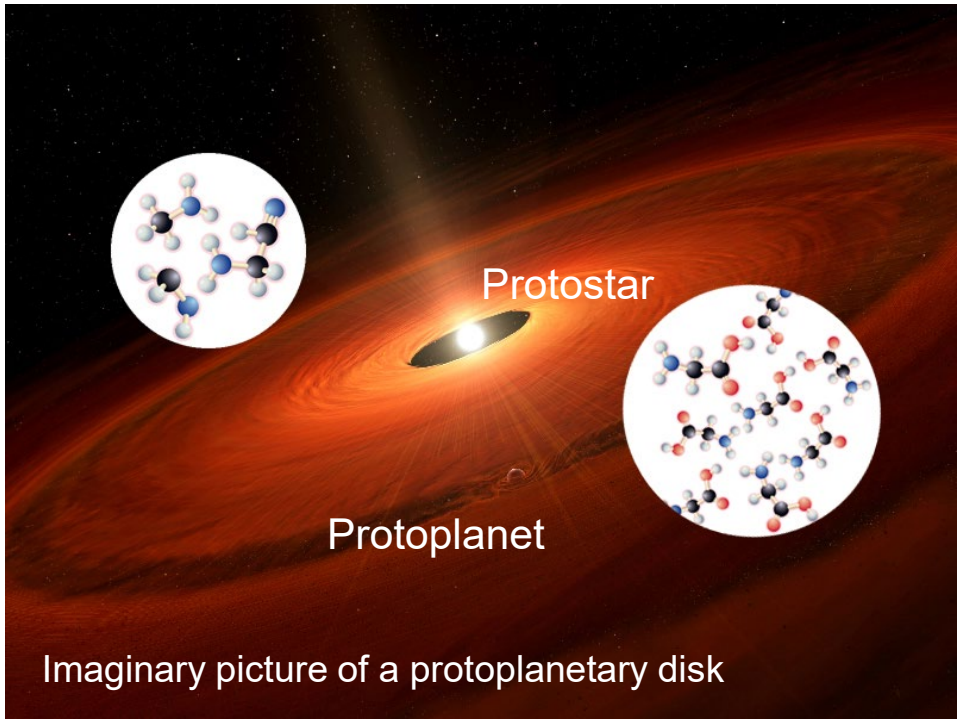
Combination of high sensitivity and high spatial resolution only achieved with ALMA made this type of study possible



ALMA2 Scientific Objective 2: Understanding Building Blocks of Life in the Forming Process of Planetary Systems

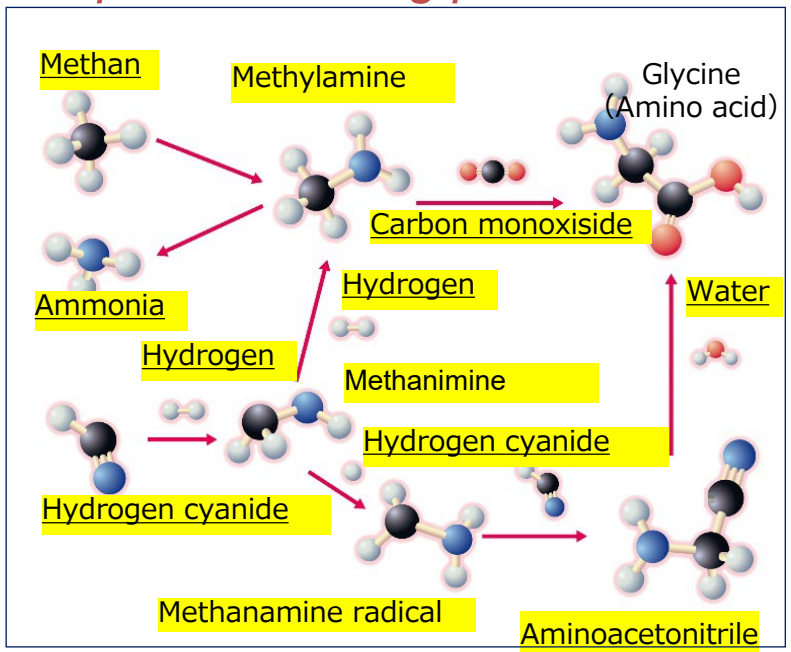
Tracing the chemical evolution of organic molecules and identify regions where building blocks of life form

Enabling us to observe more than 100 star and planet forming regions at spatial resolution down to 10-100 au



https://alma-telescope.jp/news/alma2-project-202202.html

What are the paths to amino acids in the planet-forming process?



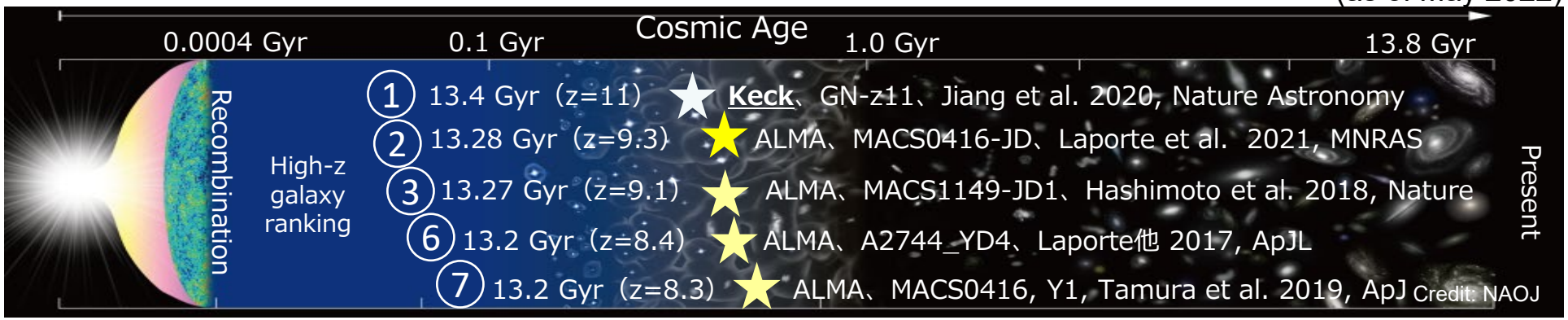
Previous Scientific Objective 3:

History of Galaxy Formation

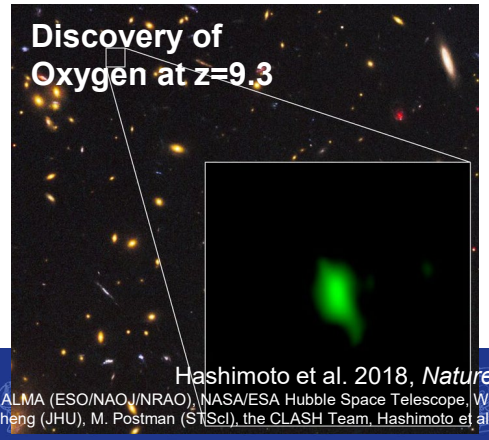
Outstanding sensitivity

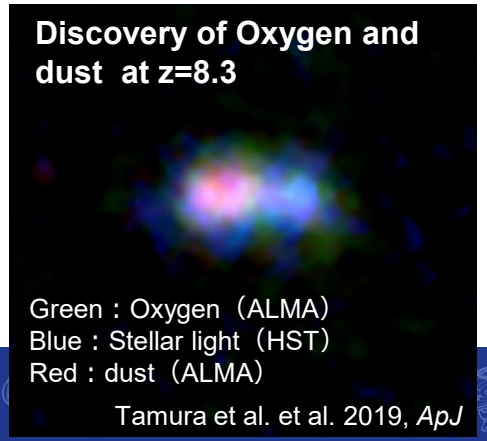
- Discovery of emission from oxygen in distant galaxies, including a galaxy 13.28 Gyr away
- A number of galaxies seem to be matured much earlier than theoretically expected

(as of May 2022)

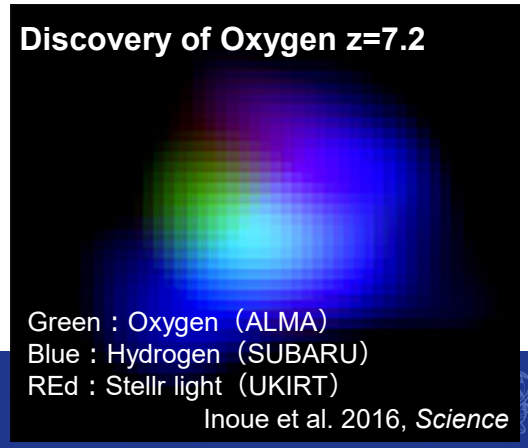


Candidates of more distant galaxies have been reported with JWST. Still, follow up observations with ALMA play a critical role to determine the nature of detected galaxies.



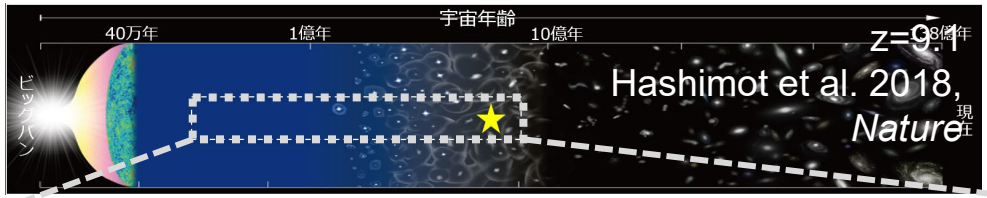


Detection of oxygen started from the idea and observations led by Japanese researchers



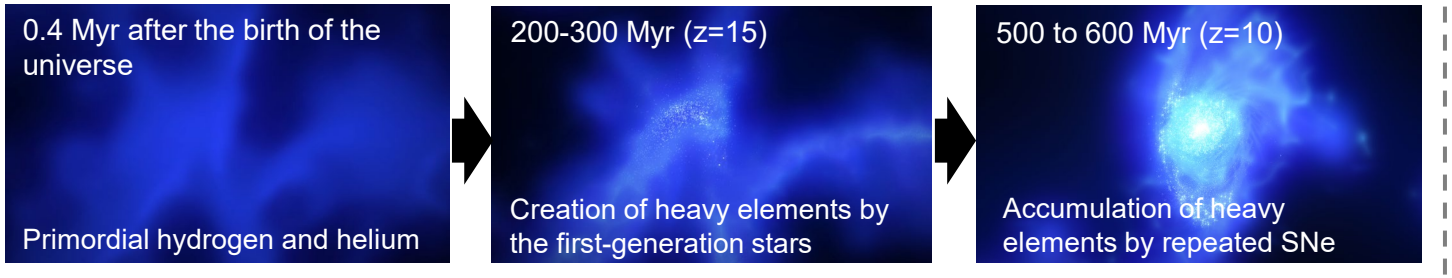
ALMA2 Scientific Objective 3:
Probing the Emergence of Heavy Elements in the Era of the First Galaxies

Probing the starting point of metal enrichment of the universe though direct detection of oxygen emitted from the supernovae of the first-generation stars, expected to have occurred at ~300 Myr after the birth of the universe.



Observing efficiency for distant galaxies by a factor of 10 or more

- Sensitivity 2x
- Instantaneous bandwidth 2x or more



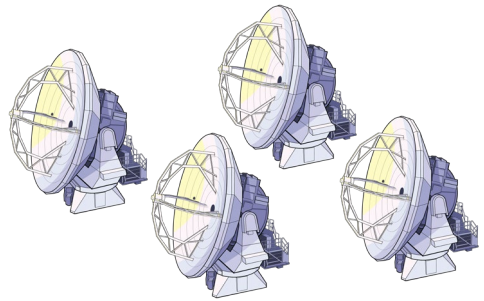
← Simulations
Credit: ALMA (ESO/NAOJ/NRAO)
https://alma-telescope.jp/en/news/press/oxygen-201803.html

Formation of the first galaxies

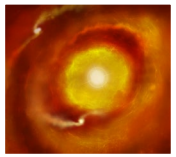
Star formation at z ~ 15?

Detected oxygen at z=9

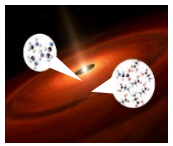
Direct detection of oxygen at z~15



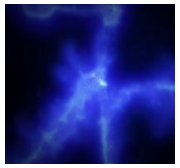
New Science Objectives and Capabilities



Scientific Objective 1: Understanding Planet Formation on Terrestrial Orbital Scales



Scientific Objective 2: Understanding Building Blocks of Life in the Forming Process of Planetary Systems



Scientific Objective 3: Probing the Emergence of Heavy Elements in the Era of the First Galaxies

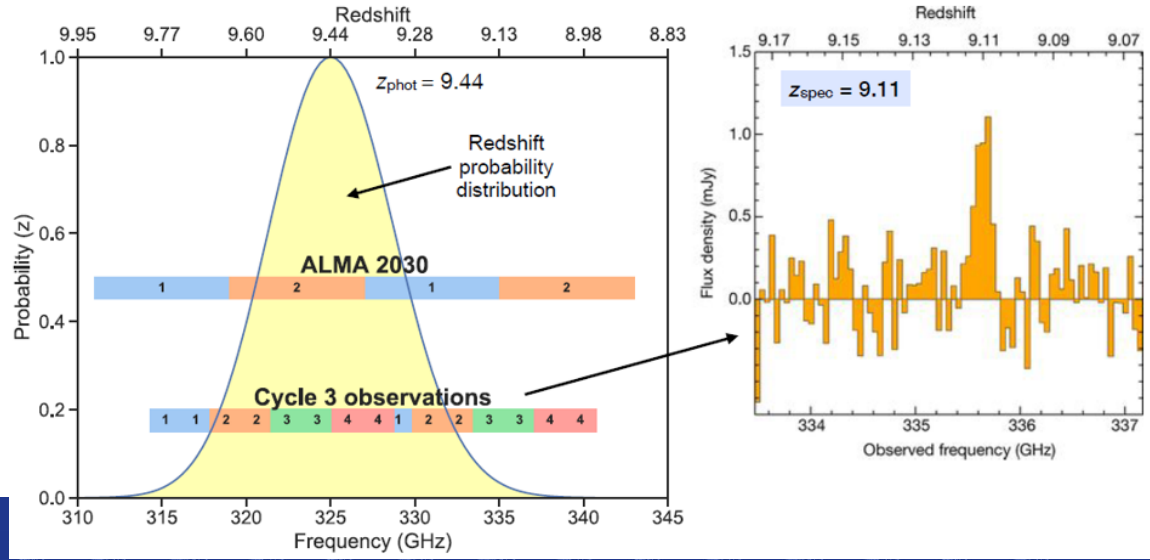
→ Improve angular resolution

→ Improve sensitivity and widen the instantaneous bandwidth

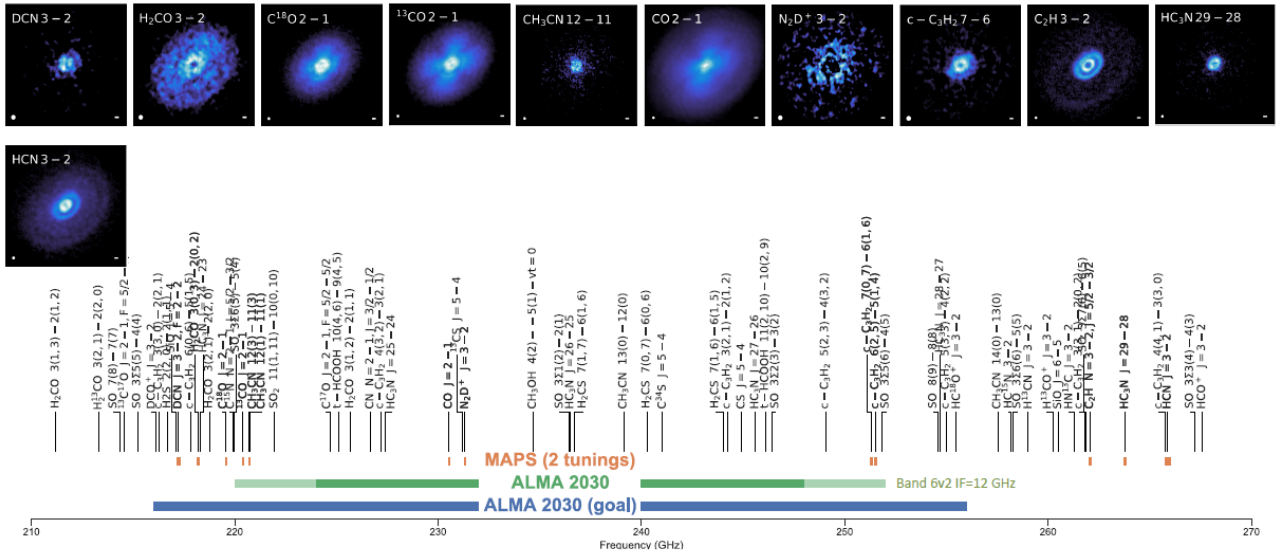
ALMA Wideband Sensitivity Upgrade:
https://arxiv.org/pdf/2211.00195

Example science cases

Spectral scan search for oxygen at high z



Search for various molecular lines in a protoplanetary disk



Hashimoto et al. (2018), Öberge et al. (2021), Carpenter et al. (2022)

Upgrades of WSU components

- Wideband Sensitivity Upgrade (WSU): Significant upgrade of the ALMA observing system
- Responsibilities of deliverables are shared by the partners. At the initial phase, East Asia is responsible for:
  - Upgrades of Band 8 (460 GHz)
  - Data Transmission System (DTS)
  - Total power GPU spectrometer (TPGS)
  - Computing infrastructure together with NA and EU

East Asia

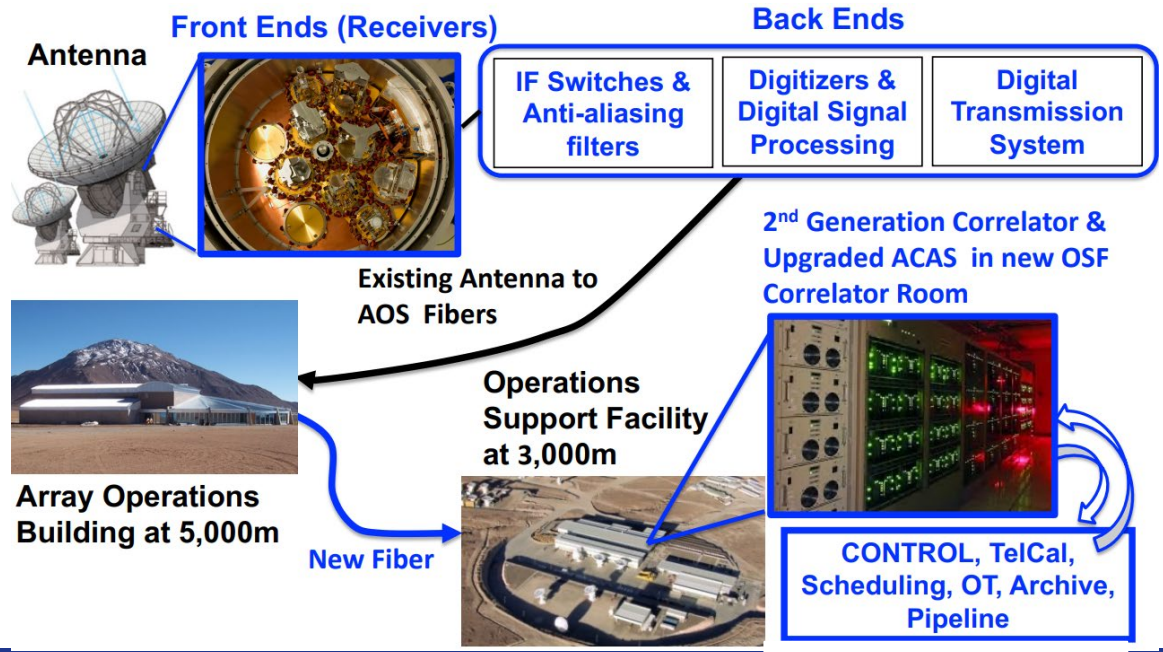
(1) Frontend
Band 8v2 (Japan)
(Band 10v2 (Japan))

(2) Backend
DTS (Japan)
TPGS (Korea, Japan)
Computing System (Japan)

North America and Europe

(1) Frontend
Band 2 (EU)
Band 6v2 (NA)

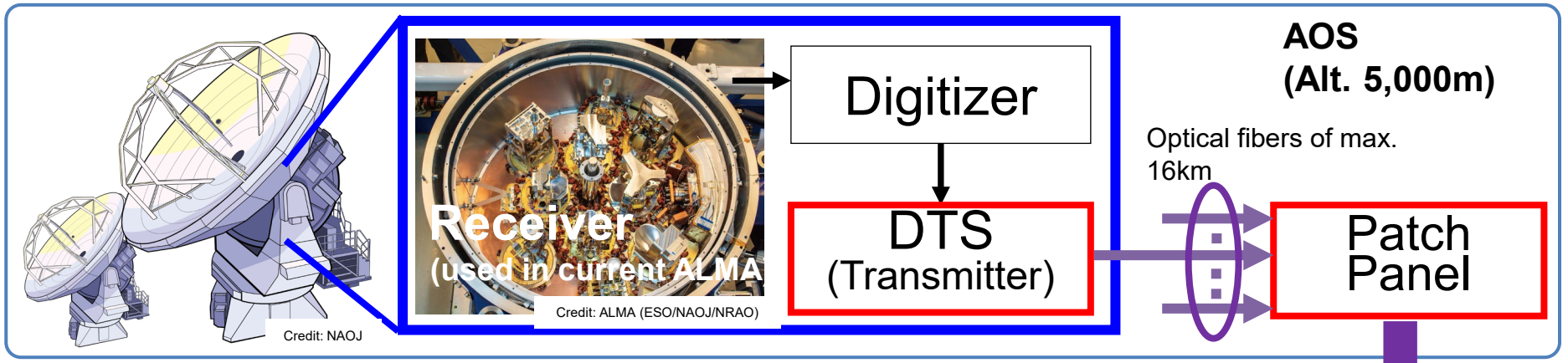
(2) Backend
Digitizer (EU)
Correlator (NA)
Computing System (NA / EU)

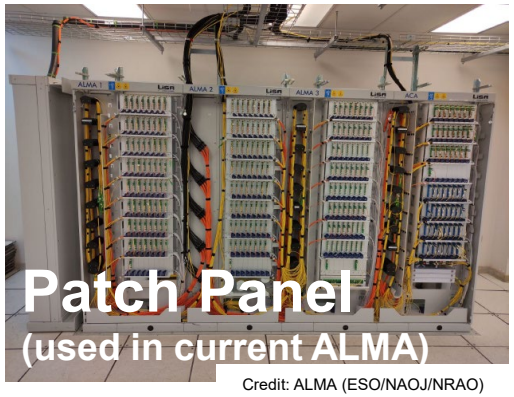


Carpenter et al. (2022)

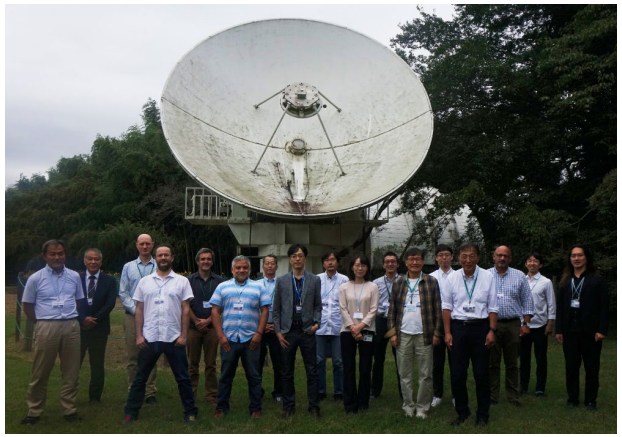
Upgrade of Data Transmission System

- Data rates will increase by ~10 times, the maximum of 1.2 Tbps
- It passed the preliminary design review in October 2024





Preliminary Design Review at NAOJ in October 2024

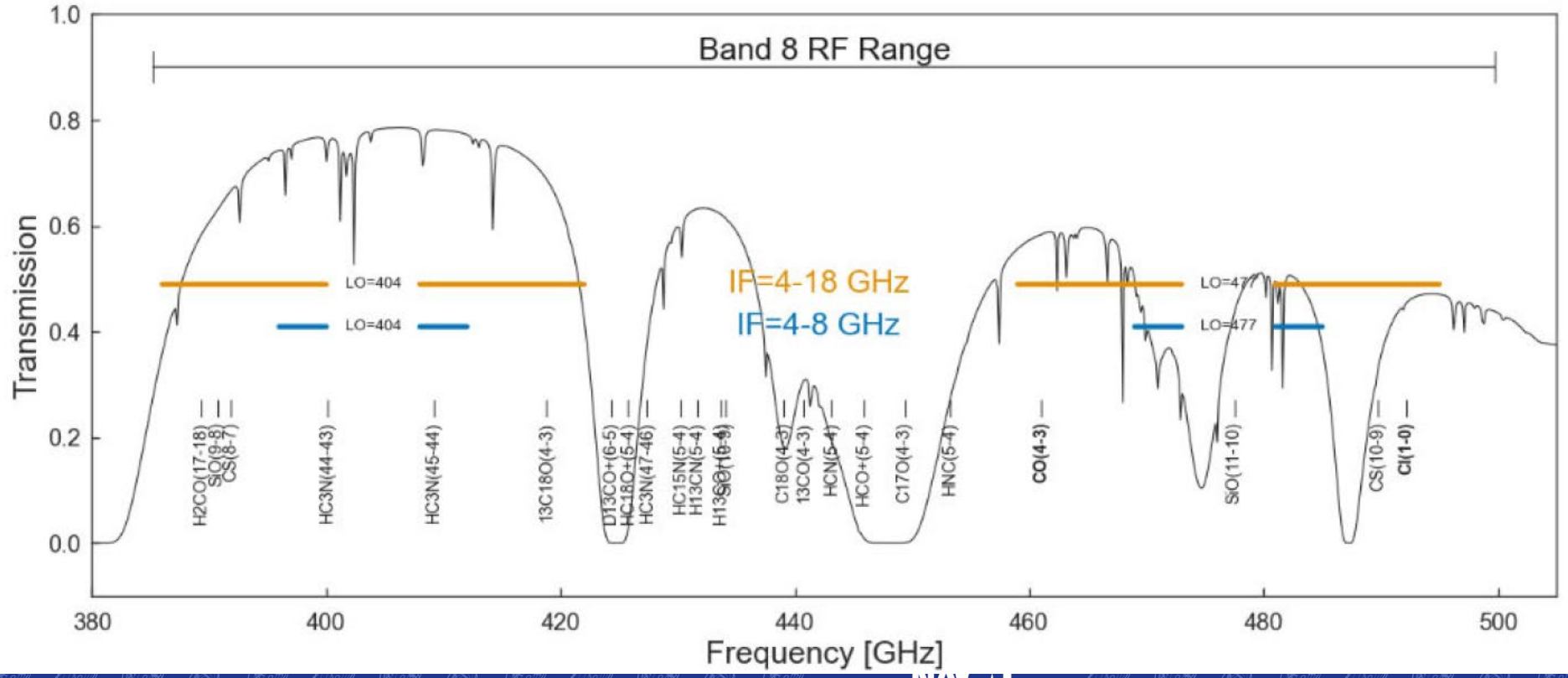


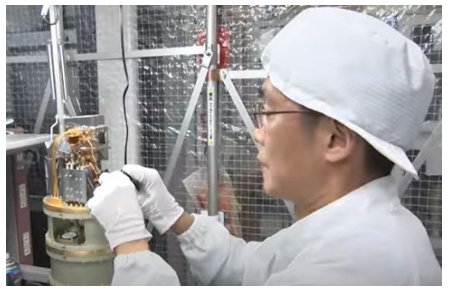
Credit: NAOJ

Upgrade of Band 8 Receivers

Receivers are manufactured in house at ATC

- Building on years of development study to widen the IF bandwidth
- Improvements to the sensitivity and spectral coverage for Band 8
  (a) Increase in IF bandwidth to 14 GHz (4-18 GHz) (goal: to 16 GHz)
  (b) Improvement in the receiver noise over the full IF range

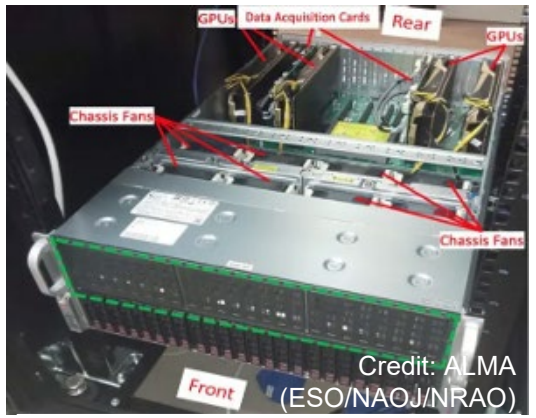




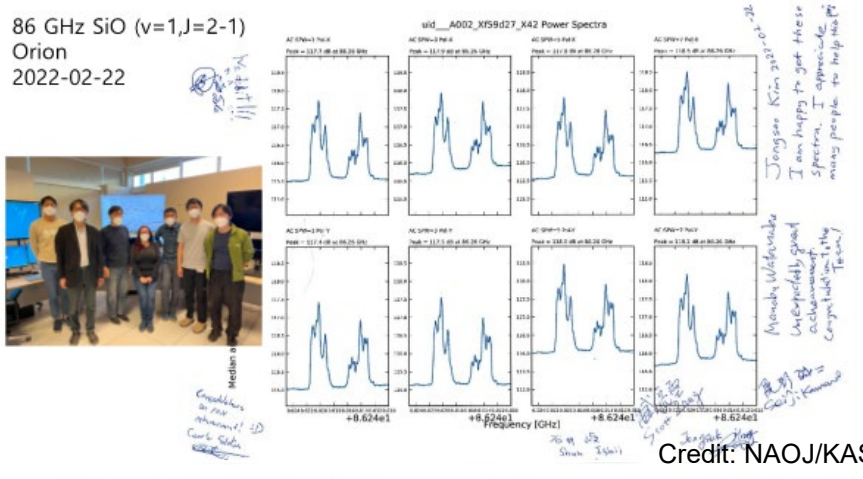
Credit: NAOJ

Total Power GPU Spectrometer (TPGS)

- Building on successful collaboration with KASI for the development of the ACA spectrometer (used for the science operations since 2023)
- Achieving 32 GHz per polarization per antenna
- Using GPUs to process 3.84 Tbps data stream in real-time

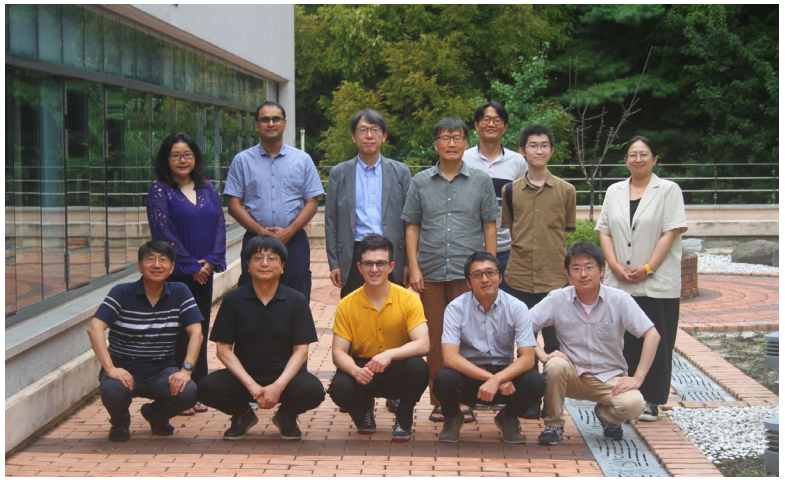


ACA Spectrometer Modules



Credit: NAOJ/KASI

First light of ACA spectrometer (2022)



Credit: NAOJ

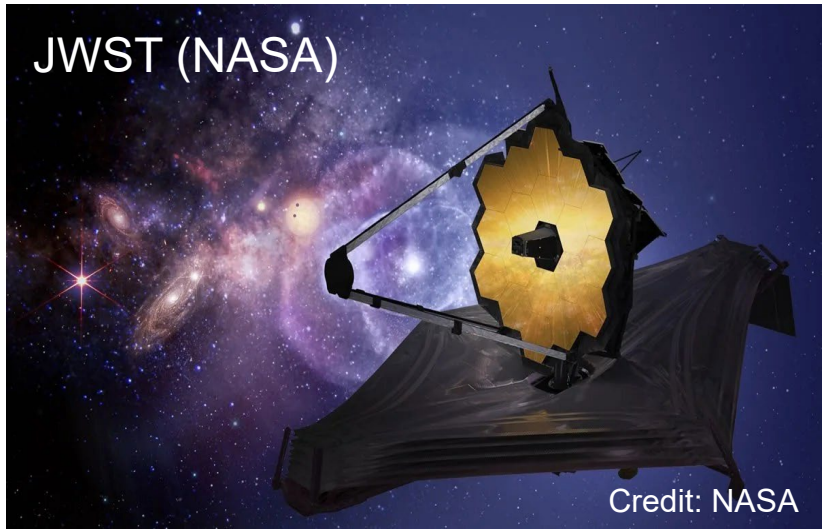
Development team of TPGS (2024)

Joint Proposal agreements between ALMA and JWST, VLA, VLT

ALMA is the international project operating the highest performance mm/submm radio telescope, and hence no competing projects in the same wavelength regime

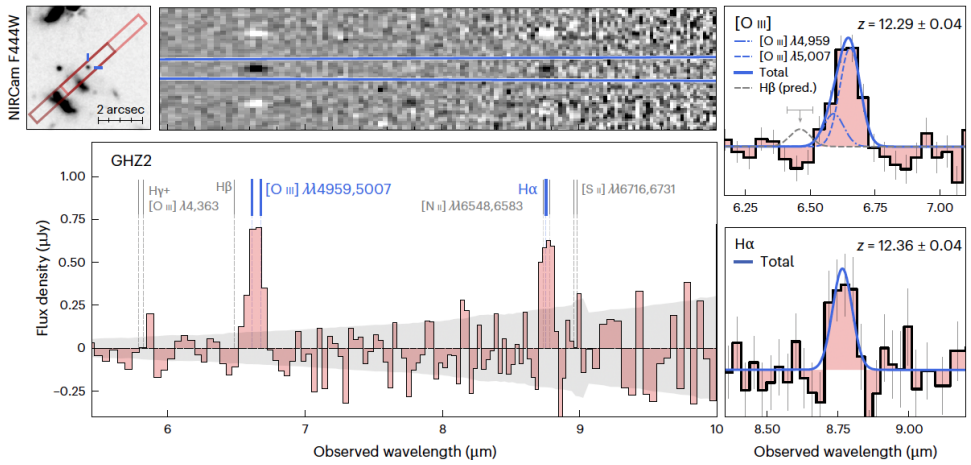
To enhance scientific impacts together with other world-leading facilities, the joint proposal framework started in Cycle 10 (proposal deadline was in April 2023)

- ALMA allocates up to 115hours of JWST time, up to 50 hours on VLT, and up to 5% of the available time on the VLA. Similarly, JWST allocates up to 115hours of ALMA time per cycle, and the VLA and VLT allocate up to 50 hours of ALMA time per year



Synergy between JWST and ALMA

1) Discovery of oxygen and Hα at z=12

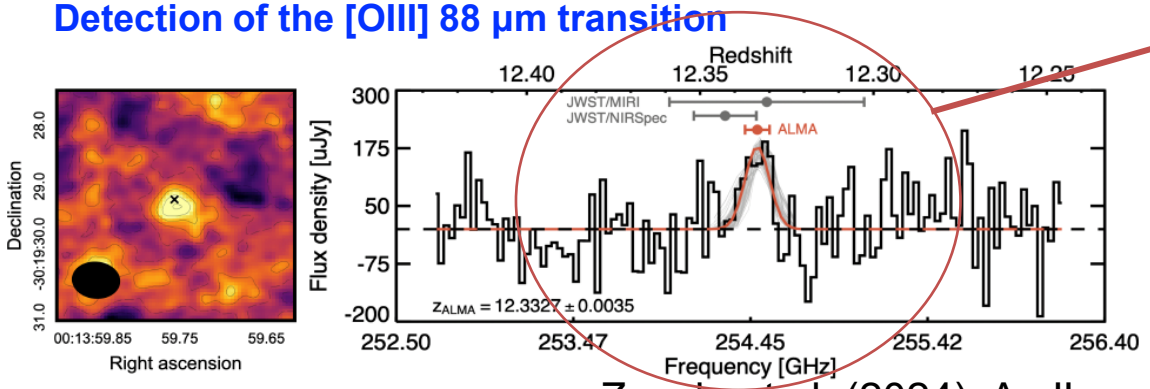


Zavala et al. (2024), Nature Ast.

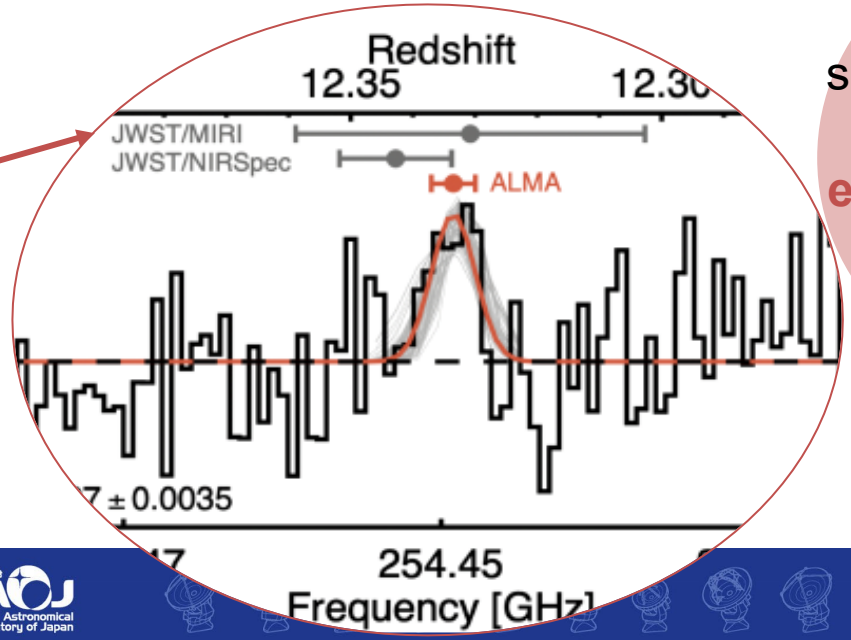
- JWST (NIR-Spec, MIRI) has become workhouses to find and study the highest redshift galaxies
- ALMA's high spectral resolution capability is critical to follow up those JWST discovered source to determine more accurate redshifts and physical properties

2) More accurate *z* determination of GHZ2/GLASS-z12

Detection of the [OIII] 88 μm transition

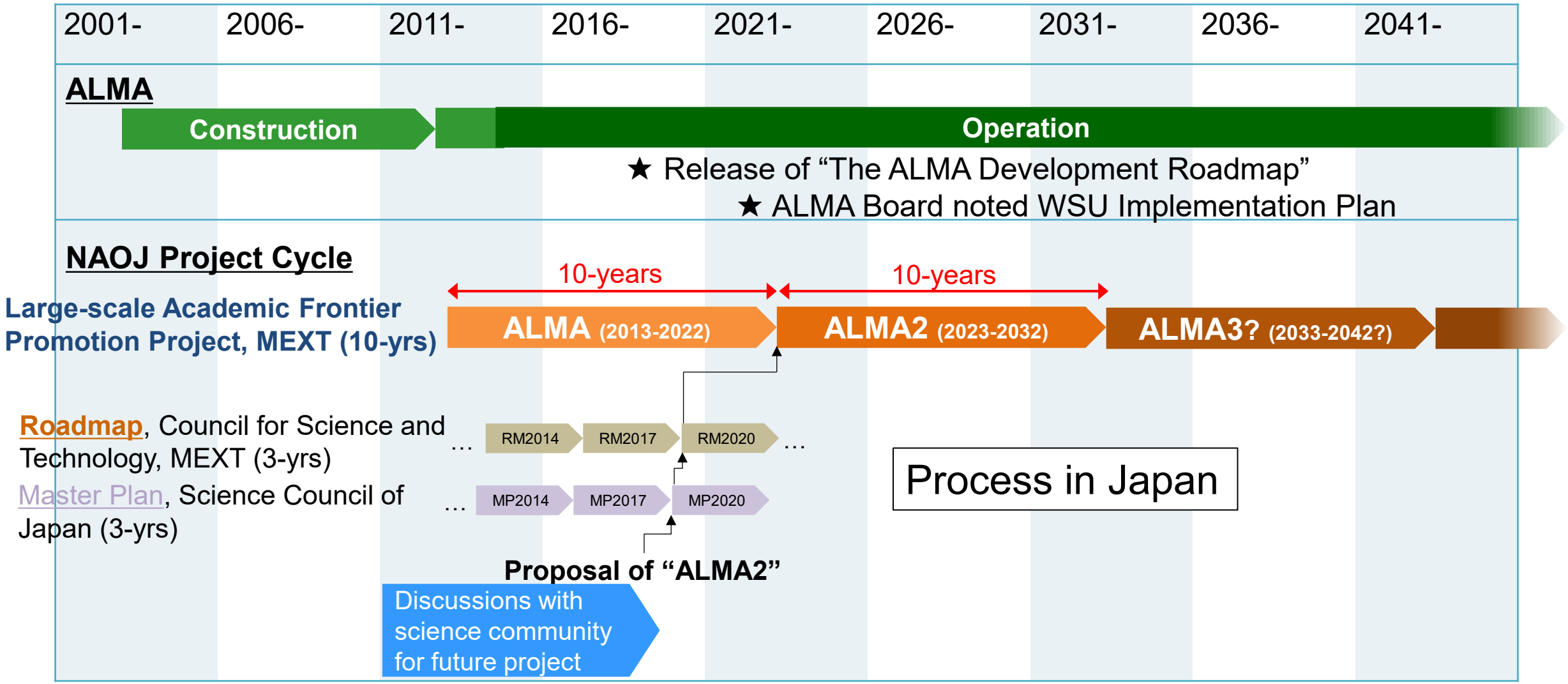


Zavala et al. (2024), ApJL



ALMA2 will significantly **improve observing efficiency** to explore these high-z systems

"ALMA2" Project (past, current, and future)



“ALMA2” Project (past, current, and future)

2001- 2006- 2011- 2016- 2021- 2026- 2031- 2036- 2041-

10-years 10-years

Large-scale Academic Frontier Promotion Project, MEXT (10-yrs)

ALMA (2013-2022) → ALMA2 (2023-2032) → ALMA3? (2033-2042?)

Roadmap, Council for Science and Technology, MEXT (3-yrs)

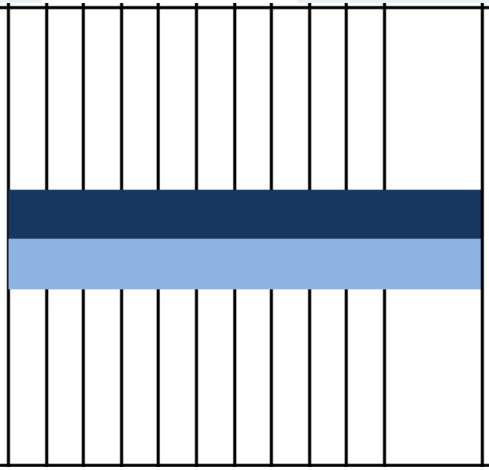
… RM2014 RM2017 RM2020 …

Master Plan, Science Council of Japan (3-yrs)

… MP2014 MP2017 MP2020

Proposal of “ALMA2”

This upgrade project, known as "ALMA2" in Japan, was recommended as the highest priority project by the Japan Radio Astronomy Forum in 2018.

物理学	大型施設計画	宇宙と生命の起源を探究する大型ミリ波サブミリ波望遠鏡アルマ2計画	日米欧共同で南米チリのアタカマ高地に設置したアルマ望遠鏡の機能を格段に向上させ、比類なき電波観測性能を国際学術コミュニティに供し、惑星の誕生の現場そして生命素材を含む宇宙での物質の進化の解明に迫る。	自然科学研究機構　国立天文台	米国国立科学財団、米国国立電波天文台、欧州南天天文台	総額：132,000 （日本分担分：30,000） 施設・設備費：18,000 （日本分担分：1,500） 人件費：16,000 （日本分担分：4,000） 運営費：98,000 （日本分担分：24,500） その他：0	【建設・初期投資、機能強化等期間】 1-12年目：アルマ望遠鏡の段階的な機能強化 【運転・運用期間】 1-12年目：アルマ望遠鏡の運用・成果創出		a	a

Outcome of Roadmap 2020 by MEXT

https://www.mext.go.jp/content/20200930-mxt_gakkikan1388523_1.pdf

Planning of ALMA2

- Japan led the discussion on future capabilities with the science community since 2011.
- These discussions were shared with the international Working Group and the ALMA Science Advisory Committee, who discussed and agreed on scientific goals, development items, and priorities. This was released as “the ALMA Development Roadmap”.

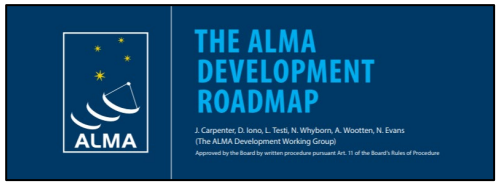
East Asia ALMA Development WS

International ALMA Development WS

ALMA Long Baseline Workshop held in Kyoto in October 2017. Researchers and engineers from around the world joined together for discussions that led directly to the preparation of “The ALMA Development Roadmap".

https://researchers.alma-telescope.jp/e/event/2017/alma_long_baseline_workshop.html

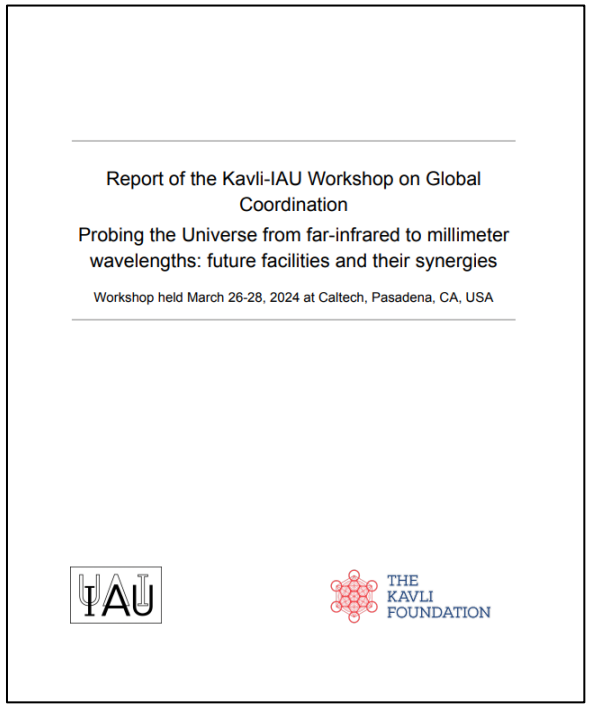
The ALMA Development Roadmap (2018) was signed by the ALMA Director and Prof. Toshikazu Onishi of Osaka Prefecture University, Chair of the ALMA Board.



https://www.almaobservatory.org/en/publications/the-alma-development-roadmap/

Toward ALMA3: IAU-Kavli Workshop

- "Proving the Universe from far-infrared to millimetre wavelengths: future facilities and their synergies" was held in March 2024 at Pasadena, organized by the Kavli foundation.
- Outcome from the conference was reported in the IAU general assembly in August 2024 in South Africa and summarized as a report (*https://arxiv.org/abs/2409.07570*).
  - The recommendations include the need for ALMA to develop an ALMA2040 vision.


Report of the Kavli-IAU Workshop on Global Coordination

Probing the Universe from far-infrared to millimeter wavelengths: future facilities and their synergies

Workshop held March 26-28, 2024 at Caltech, Pasadena, CA, USA

IAU

THE KAVLI FOUNDATION

Toward ALMA3: Development Workshop in Japan

- Development Workshop 2024: "Prospects for Radio Interferometery in the 2040s" in October 2024
- 17 invited speakers and more than 100 participants discussed the prospects of interferometer for the 2040 from both scientific and technological perspectives
- Scientific demands (frequently mentioned): increased line sensitivity, (simultaneous) multi-band observations, improved imaging fidelity
- The specifics of these requests should be discussed quantitatively, and the discussion needs to be continued in future workshops.

https://www2.nao.ac.jp/~eaarc/Meetings/ALMADW2024/

International Collaboration

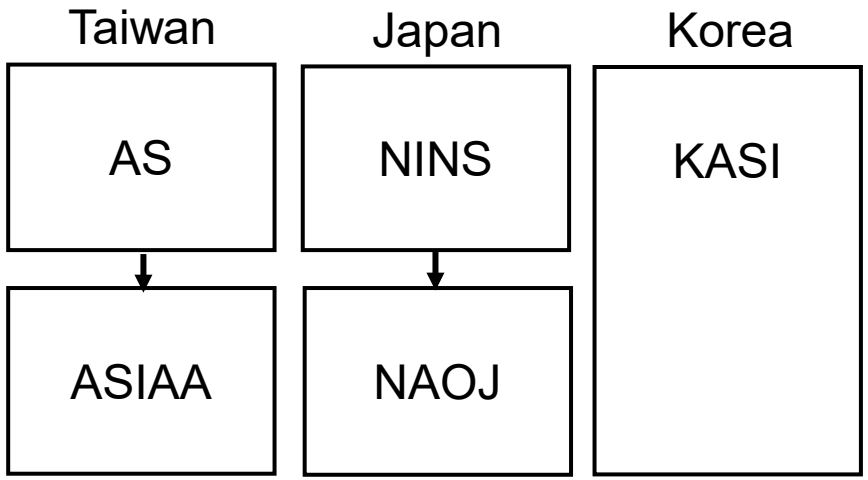
	East Asia	North America	Europe
ALMA Trilateral Agreement	NINS	NSF	ESO
ALMA Board	NAOJ	AUI / NRAO	
Joint ALMA Observatory (in Chile)	EA ALMA Support Center	NA ALMA Support Center	EU ALMA Support Center
Budget	25%	37.5%	37.5%
Observation Time Open Sky 5% Chile 9.5%	21.4%	32.1%	32.1%

Credit: ALMA (ESO/NAOJ/NRAO)

ALMA Trilateral Agreement
December 15, 2015.

Established the framework to continue the international collaborative operation of ALMA for 30+ years.

International Collaboration in East Asia

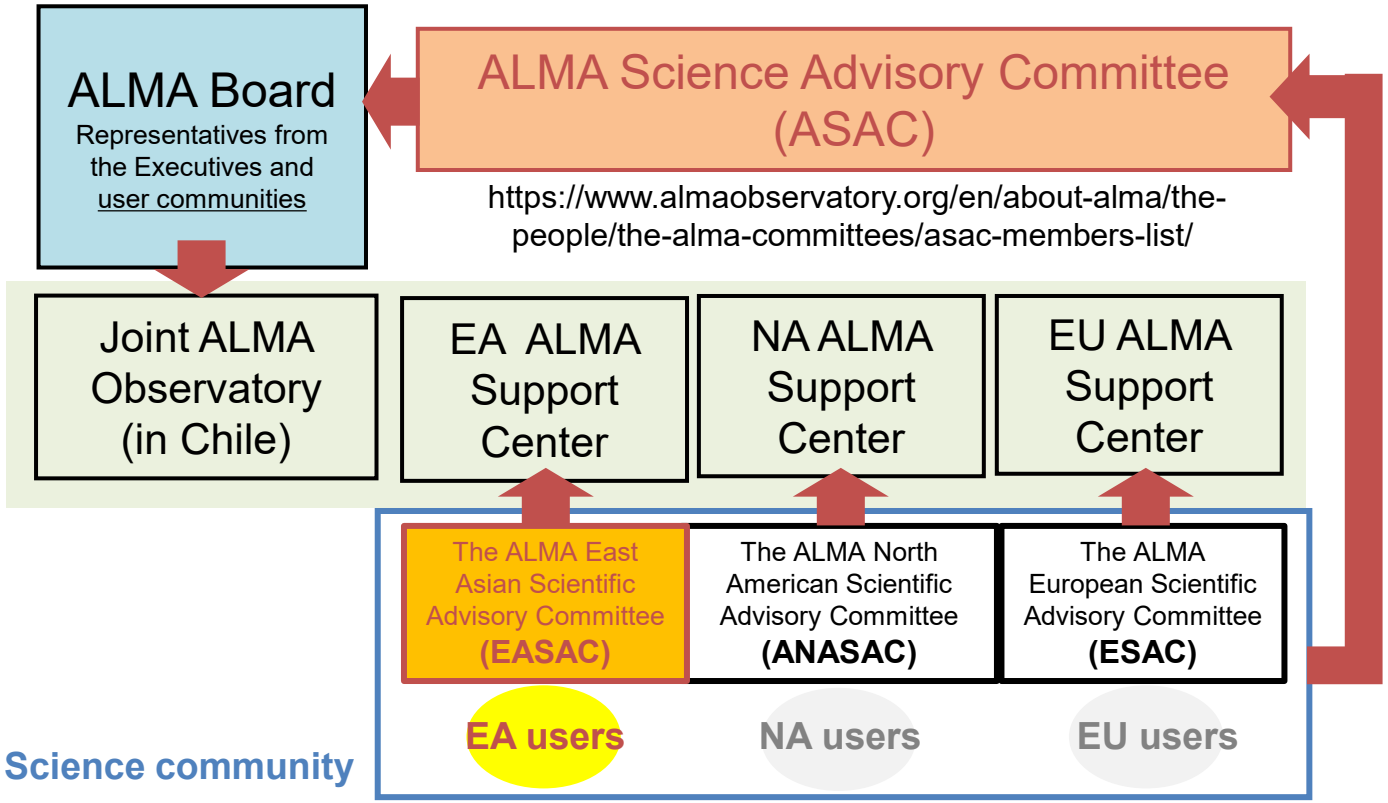


- NAOJ has a main responsibility to operate and manage the East Asia ALMA under the ASIAA's and KASI's contributions for the operations and development.
- East Asia ALMA shall perform the interface between the East Asian user communities (Japan, Taiwan, and Korea), including user support services and public outreach and education activities.

Science Advisory Committees

Independent advisory bodies to receive inputs/feedback from users

- ALMA Science Advisory Committee
  - Composed of representatives of the Chilean, East Asian, European and North American astronomical communities
  - Working on the charges by the Board, to make recommendations and advice to the Board on various issues including improvements in operations, future science capabilities, etc.
- Regional Science Advisory Committees
  - In addition to above, dealing with regional aspects related to the specific circumstances of the respective executives



Member of Japanese SAC /EA SAC:
https://alma-telescope.jp/en/structure/

Basic Concept of ALMA Operations and JAO

Joint ALMA Observatory (JAO)

Effective array operations: Execution of programs under suitable conditions

High availability of the array for science: Repairs, Preventive maintenance

Science operations in ALMA Regional Centers (ARCs)

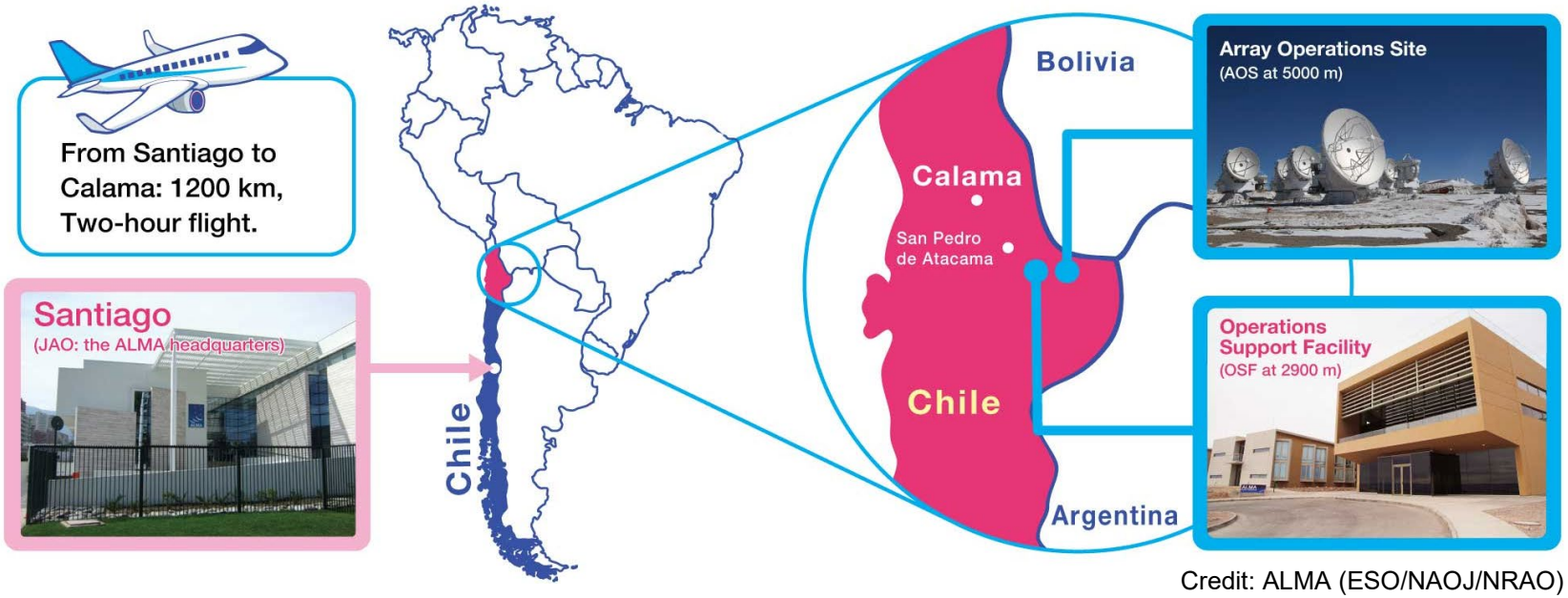
with **functions agreed in EA, EU, and NA, in close coordination with JAO**

EA ARC	NA ARC	EU ARC
East Asia ALMA users	North America ALMA users	Europe ALMA users

ARC provides support for users in the respective regions so that they can concentrate on observation proposals and data analysis.

Joint ALMA Observatory (JAO)

NAOJ staff are actively working at JAO to operate the telescope system, to solve problems in observations, and to implement new functions.



Credit: ALMA (ESO/NAOJ/NRAO)

Credit: ALMA (ESO/NAOJ/NRAO), O. Mendez (NAOJ)

Array Operations Site (at 5,000m)

Credit: JAO

Norikazu Mizuno
Deputy Director of Operations

Credit: ALMA (ESO/NAOJ/NRAO)

Credit: ALMA (ESO/NAOJ/NRAO)

Santiago (JAO: the ALMA headquarters)

Credit: JAO

Credit: ALMA (ESO/NAOJ/NRAO)

Credit: ALMA (ESO/NAOJ/NRAO)

Credit: NAOJ

Operations Support Facility (at 2,900m)

East Asia ALMA Support Center (EA ASC)

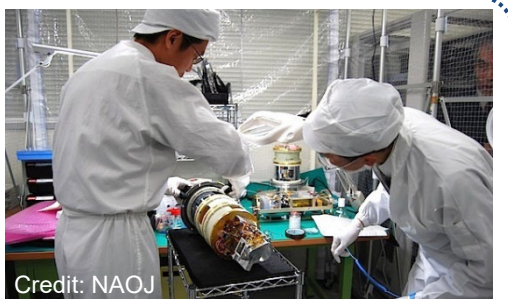
- Development and maintenance for the East Asia deliverables
- Support of users to maximize scientific return through wide range of tasks

Project Manager
Misato Fukagawa

Engineering Manager	Development Manager	Computing Manager	Project Scientist	Science Ops. Manager
Seiichi Sakamoto	Shun Ishii	Kanako Sugimoto	Bunyo Hatsukade	Takuma Izumi

Archive,software

Local user support



Development and maintenance

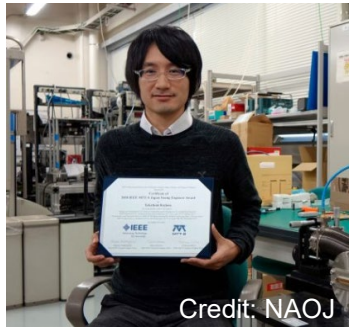
Two ARC nodes in Taiwan and Korea

Central office is at NAOJ Mitaka:
- Core functions: Agreed internationally
  - User documentation, User support, Helpdesk, Contact scientist, P2G, Archive research support, AoD, QA2
- Enhanced functions: Flexibly planned and executed in each ARC
  - Native language support
  - Friendly user support taking advantage of local experts

Human Resource Development

- Majority of researchers who worked at NAOJ-ALMA as the project- assistant professor, associate professor, and postdocs further proceed their academic career.
  - Many of them obtained tenure (track) position at the University, Institute, or Observatory.
    (Data obtained between April 2013 and September 2024)
    - e.g., ASIAA, KASI, JAO, ESA, SKA, NAOJ, Shizuoka, University, Kyushu Sangyo University, Tokyo University, Hokkaido University, Fukui University of Technology, Hokkai-Gakuen University, Kougakuin University, Kagoshima University, Nagoya University, Japan Science and Technolgy agency, Chalmers University of technology, Shanghai Astronomical Observatory, Purple Mountain Observatory, and others

- Young people who had oppotunities to be involved in ALMA development and science currently play key roles for ALMA2



Takafumi Kojima
- Associate professor at ATC, the lead of WSU receivers
- Multiple awards

Sho Masui
- Assistant professor at ATC
- Electronics society student award

Takuma Izumi
- EA-ARC manager
- NAOJ Young Scientist award, 2024 commendation for Science and Technology by MEXT

Development of Global Human Resources for the Large International Projects

Science

Engineering

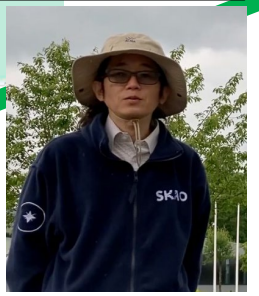
Management


Credit: Chalmers


Credit: ASIAA

ALMA world wide brain circulation: Rsearchers used to work for ALMA/NAOJ have positions at other ARC-nodes supporting their local users. **Daniel Tafoya** (left) works for the Onsala Space Observatory. **Yu-Ting Wu** (right) works for the EA-ARC node in Taiwan/ASIAA.

Brain circulation: A former colleague of ALMA/NAOJ, **Shin'ichiro Asayama** works for the system scientist at SKA in UK.




Credit: N. Lira – ALMA (ESO/NAOJ/NRAO)

Initiative at JAO in Chile, leading the science operations and commission tasks:
Akihiko Hirota together with other staff member at JAO received a medal from the Senate of the Republic of Chile in recognition of their achievement for the first direct imaging of the black hole. He also received the break through prize in fundamental physics together with other EHT members.

Brain circulation:
Masahiro Sugimoto, who used work as a system engineer at JAO in Chile, is currently leading developments of another international project, TMT led by NAOJ.


Credit: NAOJ


Credit: NAOJ

ALMA worldwide brain circulation: **Kanako Sugimoto** hired by NRAO based on her performance, then she returned to NAOJ to manage the EA ALMA computing team.


Credit: NAOJ


Credit: NAOJ

Various management experiences: **Masao Saito,** who led the science operations at JAO in ALMA Cycle 0, plays various key roles in NAOJ: Director at the NRO, TMT-telescope group leader, then vice Director General at NAOJ.


Credit: NAOJ

Project management: **Misato Fukagawa** serves as the East Asia Operations Manager of ALMA, has been named as one of the "Women in Tech 30" in 2024.

ALMA worldwide brain circulation: **Álvaro González,** a former EA project manager, serves as the Deputy Director of Development at JAO leading efforts for the world wide ALMA upgrades.

Project management: **Norikazu Mizuno** serve as the Deputy Director of Operations at JAO. With his achievements in promoting academic exchange between Japan and Chile, he received Japan's Foreign Minister's Commendation in 2024.

Frameworks to Foster Next Generation Researchers

- Science operation collaboration agreements
  - Project assistant professor and project researcher positions to be stationed at the host universities and spend 100% of their time for the project with the host researcher.
  - So far, 21 universities and institutes have joined.

- Development collaboration agreements
  - Osaka Metropolitan University and University of Electro – Communications: Receiver developments, Utilization of AI, etc.

- Several graduate students from various universities received science awards based on research using the ALMA data (students highlighted with orange squares)


Credit: NAOJ

Credit: NAOJ


Credit: ICRR


Credit: NAOJ


Credit: NAOJ


Credit: NAOJ

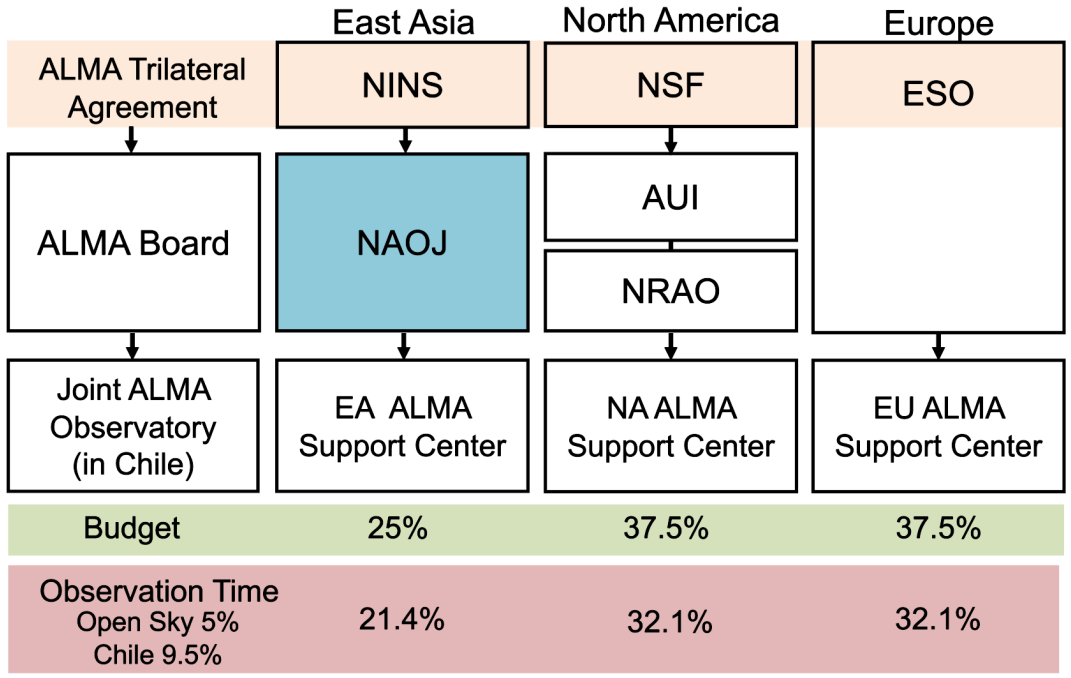
Credit: NAOJ


Credit: SOKENDAI

and
many more..

NAOJ: Operate and Manage the EA ALMA

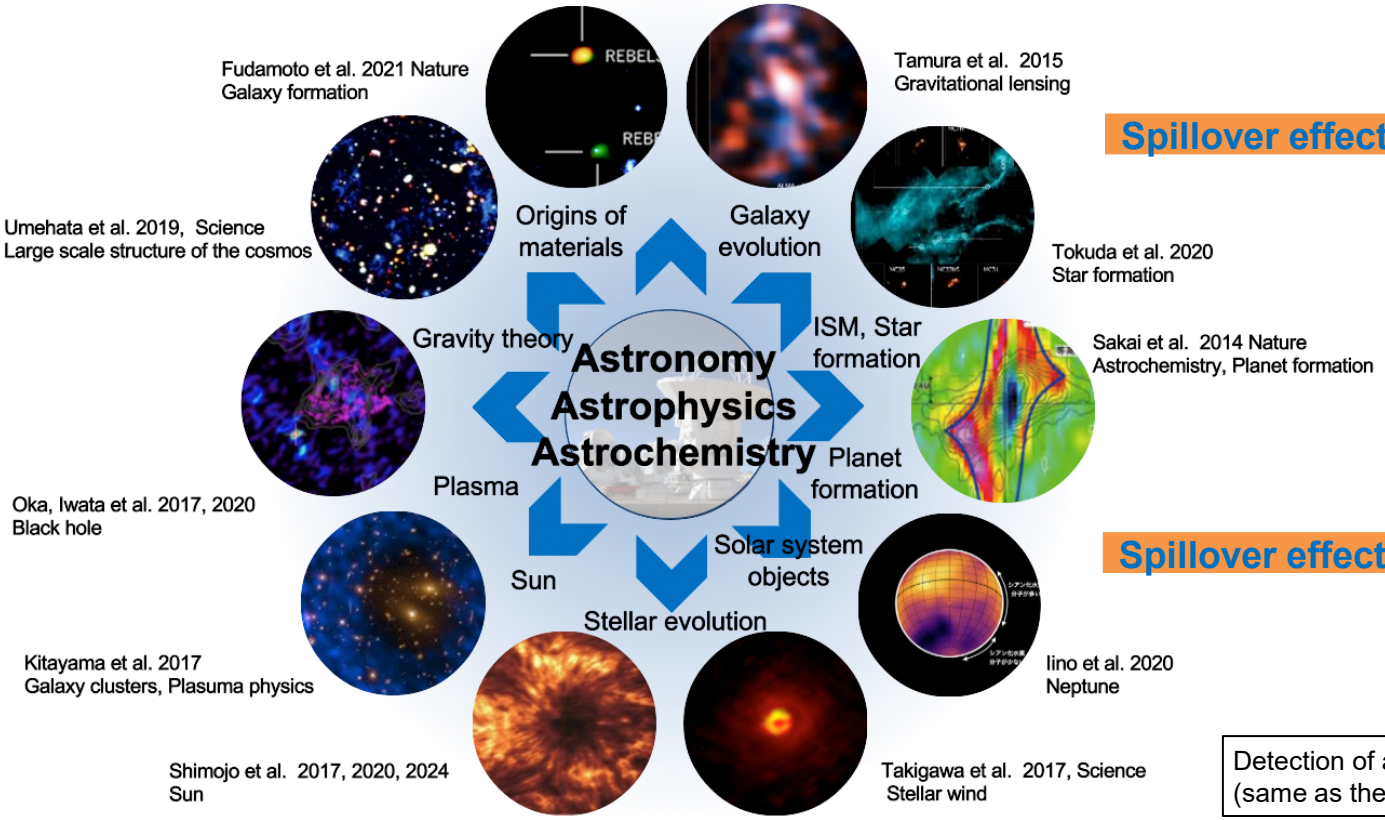
- ALMA is an international project to operate in global partnership of East Asia, North America, and Member States of the ESO.
- Partners signed the ALMA Trilateral Agreement on December 15, 2015, and established the framework to continue the international collaborative operation of ALMA for 30+ years.
- NAOJ has a main responsibility to operate and manage the East Asia ALMA under the ASIAA's and KASI's contributions for the operations and development.



Roots of ALMA can be traced back to the early 1980's. At that moment, NAOJ (Tokyo Observatory) had constructed the world's most advanced Nobeyama 45-m radio telescope and started discussions aiming for a next-generation very large radio telescope.

Impacts to Other Fields and Science Communities

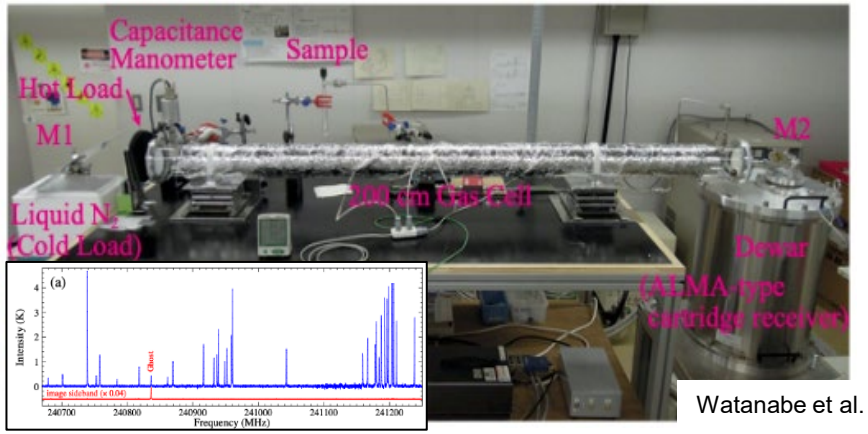
ALMA's open use policy enable us to reach wide range of science topics not only limited by the three main science goals



Spillover effect

Chemistry

Molecular spectroscopy experiments under the extreme condition

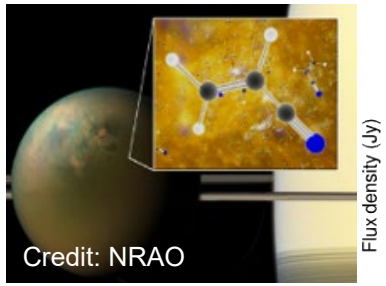


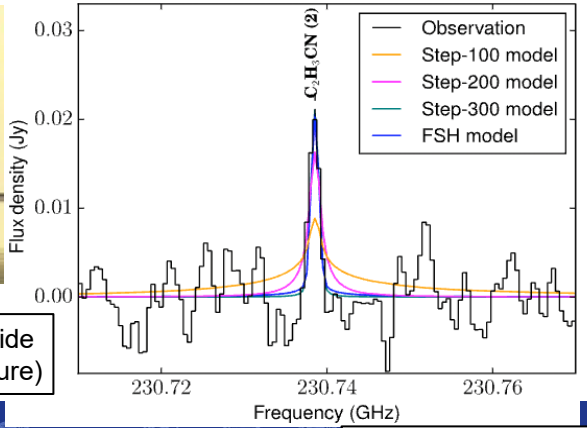
Watanabe et al. 2021, PASJ

Planetary Science

Study of solar system objects. Comprehensive study between ALMA and solar system explorations for understanding planet formation

Spillover effect





Detection of astrobiological potential of vinyl cyanide (same as the material consisting of cellular structure)

Palmar et al 2017, Science
Jupiter's moon Titan

Industry-Academia Collaborations

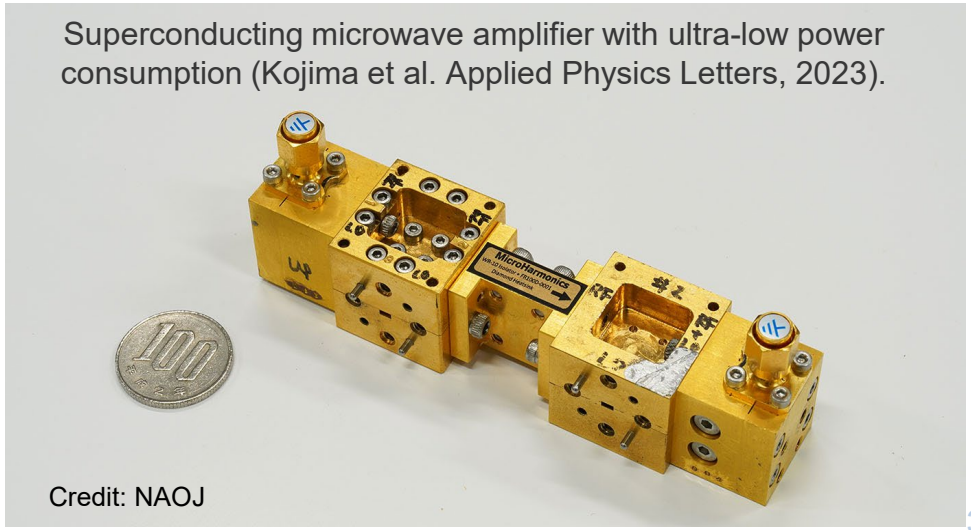
- Development of superconducting devices is necessary for the wideband and high-sensitivity receivers for ALMA.

- The technique can also be applied to
  - Next-generation information and communications (beyond 5G/6G)
  - Quantum computing (Moonshot research and development program)

    https://www8.cao.go.jp/cstp/english/moonshot/top.html
    - The technology for reading signals from superconducting receivers
    - Ultra-low power consumption microwave amplifiers
    - Significantly compact isolator using the two frequency mixers


Credit: NAOJ

Superconducting microwave amplifier with ultra-low power consumption (Kojima et al. Applied Physics Letters, 2023).



Credit: NAOJ

alma-telescope.jp

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