ADVANCED TECHNOLOGY CENTER

National Astronomical Observatory of Japan, National Institutes of Natural Science

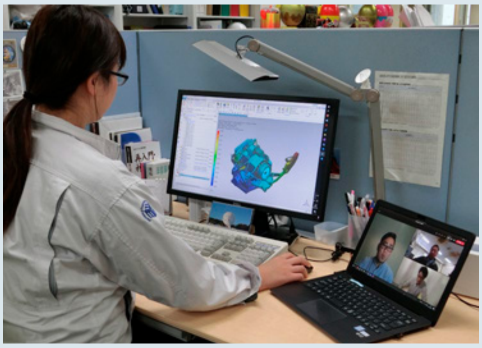
The Advanced Technology Center supports research activities at NAOJ by providing technology and support for instruments to observe the Universe. We conduct research and development for both basic and applied technologies to support the telescopes and instruments currently operated by NAOJ, as well as for technologies intended for future projects. We also promote joint development activities with other institutes and support their development of new instruments.

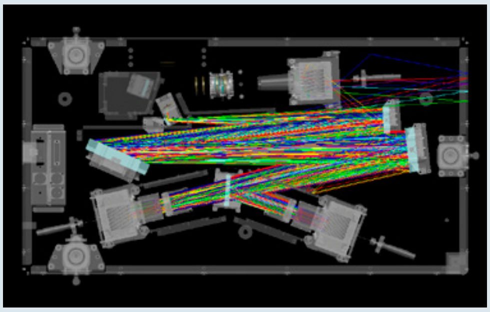
ATC
Advanced Technology Center

Integrated Production

Design

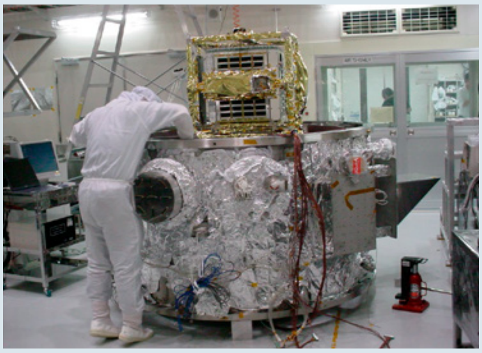
The optical design team executes optical design and analysis to achieve the ultimate optical performance. The mechanical design team designs structures and mechanisms to maintain the high precision and stability of the optics in extreme conditions such as cryogenic temperatures, ultra-high vacuum, and strong vibrations. These two teams work together for integrated optomechanical design.



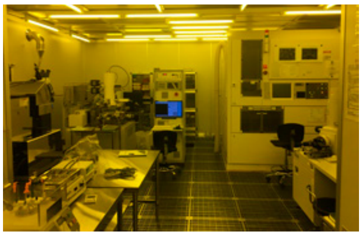


System Integration

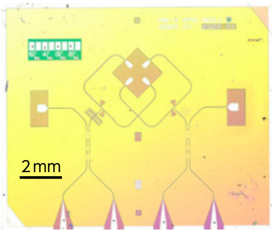
After assembling all the parts and devices into an instrument, integration tests are conducted to verify that the required performance criteria can be met under conditions which simulate the actual operational environments. Resilience to vibration caused by a launch or an earthquake, and operational and control testing under low-temperature and vacuum conditions are checked here.
Some tests use the large cleanroom or the large vacuum chamber of ATC to avoid contamination from materials and dust.



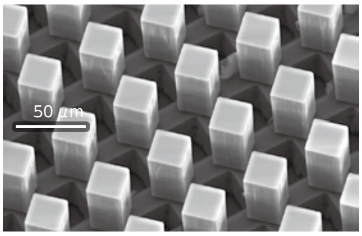
Ultra-sensitive superconducting detectors, necessary for radio astronomy observations, are developed in the cleanroom. State-of-the-art high-frequency circuits and optical elements for the terahertz band are fabricated on quartz and silicon substrates using microfabrication technologies such as photolithography.



Microfabrication cleanroom

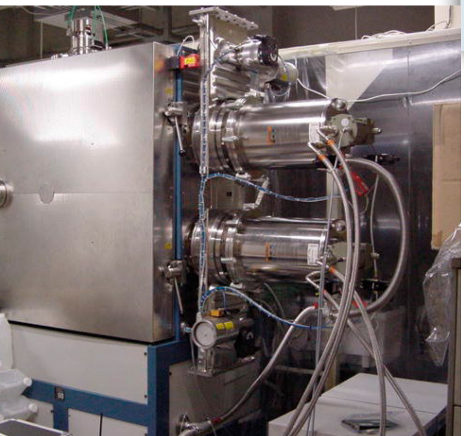


Silicon-based superconducting monolithic microwave integrated circuit (MMIC)



Silicon micromachined anti-reflection layers for silicon optical window

Ion-beam sputtering system



The manufacturing design group is in charge of production and inspection of mechanical components for experimental equipment and key components to be used in the observational instruments which are mounted on telescopes. This group not only manufactures based on detailed blueprints but also helps shape the designs based on ideas from clients. Along with conventional cutting techniques, the new technology additive manufacturing is included in the group mission to aid the development of advanced equipment.

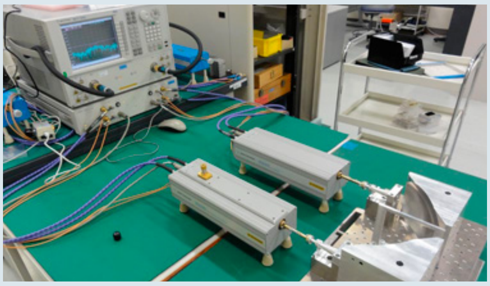
Fabrication

Astronomical instrument development is divided into four categories:

(1) instrument design to meet the requirements for observations,
(2) fabrication of parts and components,
(3) evaluation and verification, and
(4) system integration tests conducted under conditions simulating operational environments.

Successful development requires a long-term perspective about these activities.

Evaluation

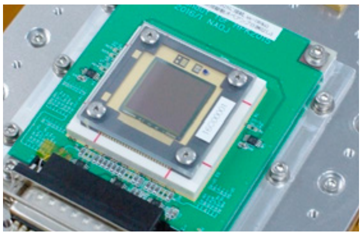


Material characterization system at millimeter-wave

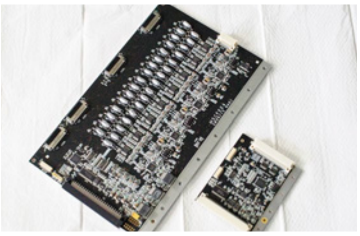
Durability test of a worm gear

Various specifications, such as dimensions, weight, mechanical characteristics, optical properties, and durability, must be met for an instrument, including its subsystems and components. If it is unclear whether the required specifications are met at the design phase, a prototype is produced for evaluation and we conduct checks and examine the feasibility of the requirements. ATC has various devices and apparatus for measurement and evaluation, and we develop new measurement equipment ourselves as needed.

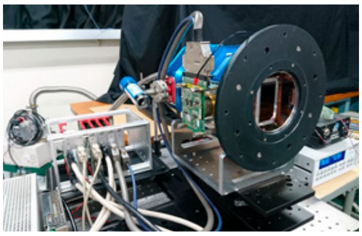
In collaboration with industry, we are developing CCD and CMOS sensors and near-infrared array detectors, which are necessary for visible and infrared astronomy observations. Development of the control electronics and evaluation of each detector is done in-house, leading to flexible and rapid development of new instruments. We also provide control electronics to other organizations and support for installing detectors in instruments.



Near-infrared detector under testing

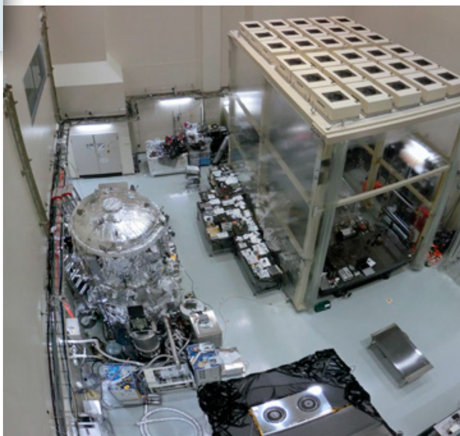


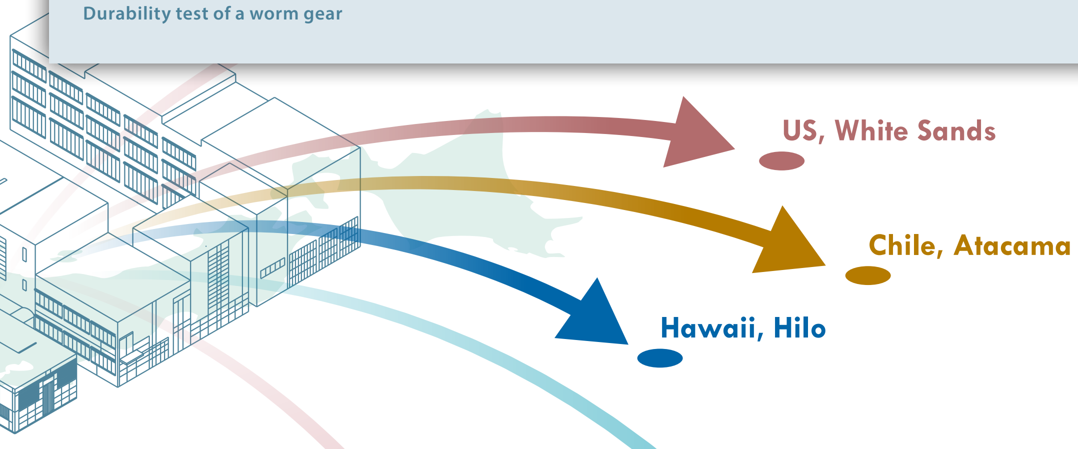
Dedicated electronics for detectors



CCD evaluation system

Overhead view of the large clean room





Gravitational Wave Observations

Gravitational-wave astronomy observes the Universe through extremely weak gravitational waves. It aims to discover new aspects of the Universe that are unobservable by conventional methods. While gravitational-wave astronomy is a new frontier, it is already proving its latent capabilities. ATC is in charge of designing and developing key components (optical equipment, vibration isolation system, etc.) necessary for KAGRA (Japan's large-scale cryogenic gravitational-wave telescope).

KAGRA

Located under Mt. Ikenoyama, Kamioka-cho, Hida city, Gifu Prefecture, KAGRA is Japan's first full-scale large gravitational wave telescope. Its first observation run began in the spring of 2020. Unlike the conventional image suggested by the word "telescope," this is a large-scale Michelson interferometer having two 3-km arms installed within a group of vacuum vessels, in an L-shape tunnel excavated under the mountain.

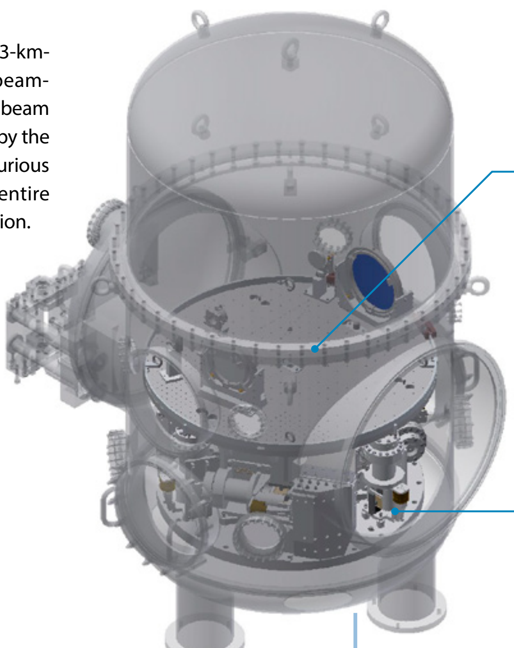
Gravitational waves are propagating periodic weak space–time distortions. To achieve sufficient sensitivity to such tiny signals, the optics in the interferometer should be isolated from noise of all kinds. For this reason, we have constructed the interferometer at a stable site with low ground vibration (less than one-100th that of Tokyo) and have suspended the mirrors from vibration isolators made of multi-stage pendulums. The most important mirrors are cooled to nearly -250°C to suppress thermal noise.

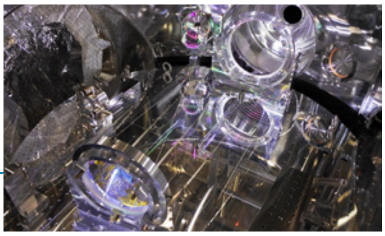
ATC applied technological capabilities accumulated during the development of other types of telescopes and detectors to the design, production, and installation of most of the various components that enabled the KAGRA interferometer to become what it is today. This includes equipment integrating the optical and mechanical systems such as beam monitors for the 3-km laser optical axes and stray light countermeasures as well as the vibration isolators. We also contribute to the development of new sapphire mirrors, which will be necessary for KAGRA's next goal of improving performance.

Optical equipment and vibration isolators

Transmitted light monitoring systems

Systems to detect misalignment in the optical axes of the 3-km-long optical cavities. The system is a combination of a beam-reducing telescope and a vibration-isolation stage. The laser beam diffuses as it propagates over a long distance so it is focused by the telescope to 1/10th size while the stage is used to avoid a spurious signal for optical axis misalignment. ATC supported the entire process from design to assembly, testing, and onsite installation.

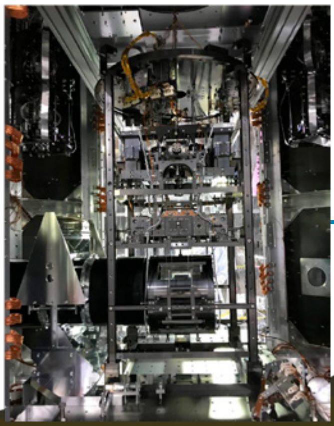


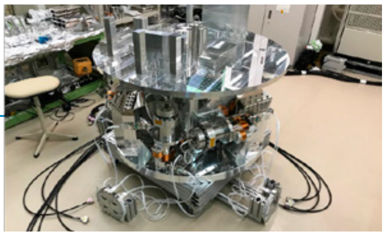


Optical components
A reflecting telescope with a reduction ratio of 10. The optical axis is folded to fit in a 1-m diameter vacuum vessel. The glass material selection was important to make the optical system compact.

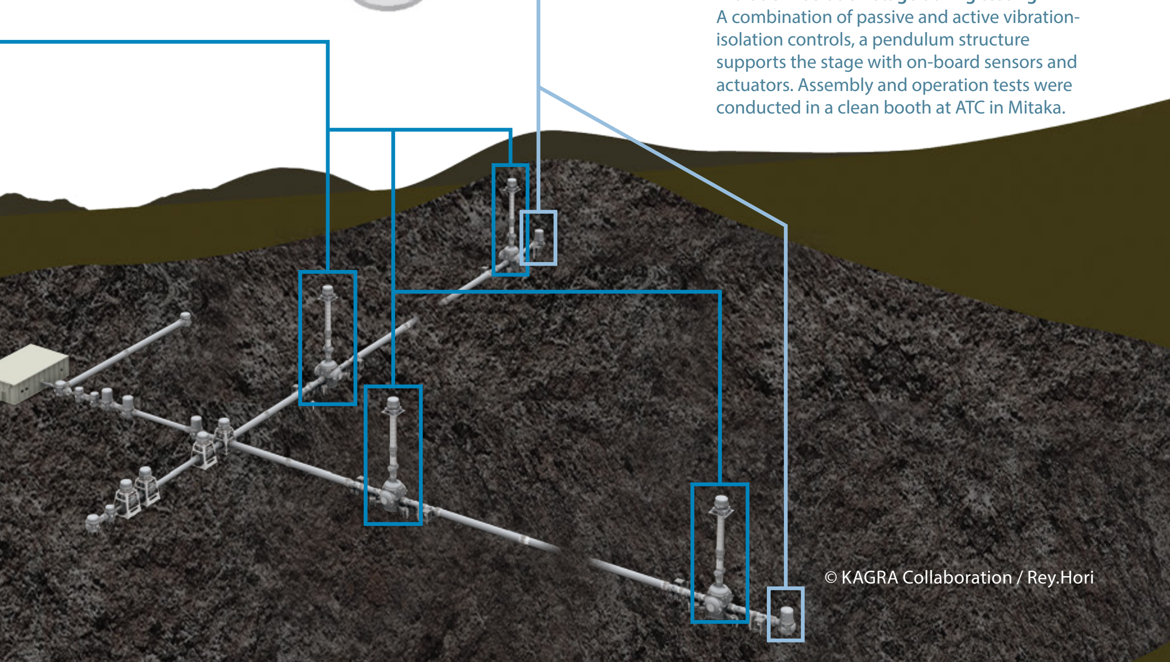
Main mirrors and optical baffles

The cryostat interior, housing the main mirror. The main mirror, which is cooled to about -250 °C, is suspended from a pendulum 14 m above for vibration isolation. The anti-vibration optical baffle developed by ATC is visible to the left of the main mirror.





Vibration-isolation stage during testing
A combination of passive and active vibration-isolation controls, a pendulum structure supports the stage with on-board sensors and actuators. Assembly and operation tests were conducted in a clean booth at ATC in Mitaka.



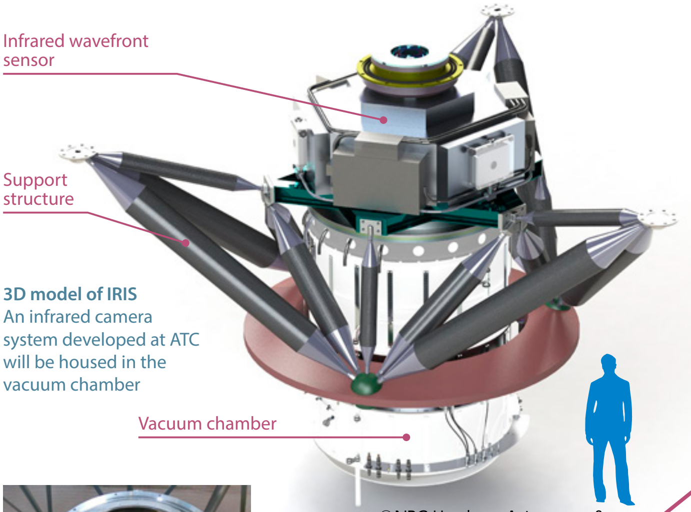
Optical and Infrared Observations

Optical and infrared astronomy is one of the major fields for exploring the Universe. ATC has been playing an important role in developing astronomical instruments for the Subaru Telescope, located at the summit of Mauna Kea in Hawaii, as well as for the Thirty Meter Telescope (TMT), which is a state-of-the-art telescope that is under construction.

TMT

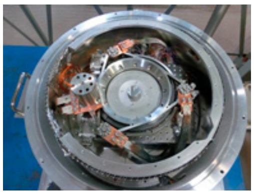
We are currently designing two astronomical instruments for TMT: the Infrared Imaging Spectrograph (IRIS) and the Wide Field Optical Spectrometer (WFOS). They will produce images and spectra of celestial objects, respectively using infrared light and optical light.

IRIS is being developed through international collaboration among institutes in Japan, the United States, and Canada. ATC is specifically responsible for delivering an infrared camera system. We are solving technical challenges such as a diffraction-limited optical system that functions at liquid nitrogen temperatures, cryogenic driving mechanisms that can operate for more than 20 years without maintenance, and a method to measure the positions of celestial objects with an accuracy of 1/100 millionths of a degree.

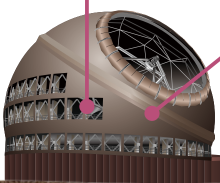


3D model of IRIS
An infrared camera system developed at ATC will be housed in the vacuum chamber

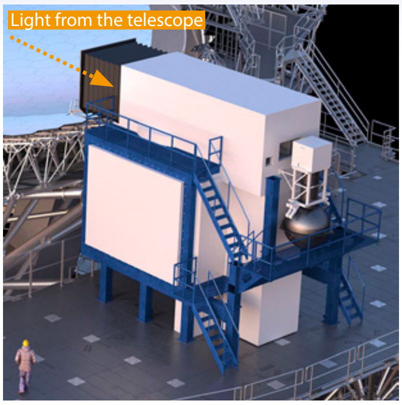
©NRC Herzberg Astronomy & Astrophysics／TMT-IRIS



A rotary stage, which functions reliably at liquid nitrogen temperatures

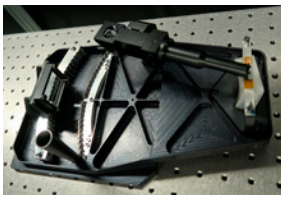


WFOS will uncover large-scale structures of gases in inter-galactic space. WFOS has been developed through international collaboration among institutes in Japan, the United States, and India. ATC is studying an integral field unit (IFU) providing us spectral information over entire field of view.

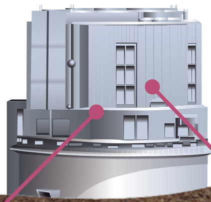


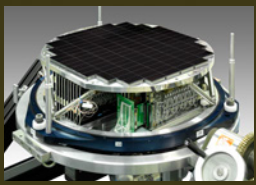
Overview of WFOS
(Courtesy TMT International Observatory)

IFU for the optical imaging spectrograph, FOCAS, on the Subaru Telescope. The IFU of WFOS is being developed based on our experience with FOCAS.



Subaru Telescope





116 CCDs tiled on the focal plane in the vacuum chamber

HSC is a wide-field digital camera, mounted on the prime focus of the Subaru Telescope. The camera system developed at ATC contains 116 CCDs with 870 million pixels in total. The CCDs are sealed in a vacuum chamber, cooled to -100°C, and operated by dedicated electronics, which were also developed at ATC. HSC demonstrates overwhelming performance for discovering new objects and phenomena in the Universe with its wide-field, high-resolution, and high-sensitivity capabilities. The instrument is also used to search for dark matter, by using the gravitational lensing effect.

HSC map http://hscmap.mtk.nao.ac.jp/

ULTIMATE employs Ground-Layer Adaptive Optics (GLAO) to compensate for atmospheric turbulence over a wide field of view and, in combination with the Wide-Field Infrared Imager (WFI), delivers wide-field, high-angular-resolution near-infrared observations. As a next-generation flagship instrument of the Subaru Telescope, the development is led by the ATC.

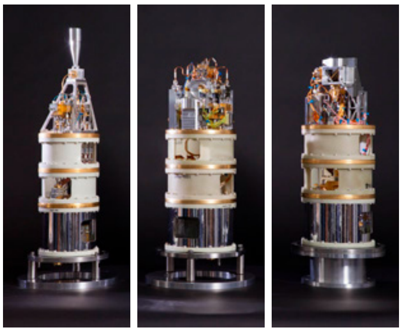
Radio Wave Observations

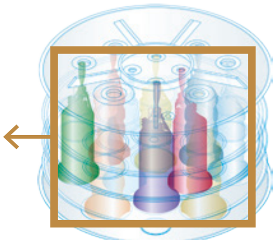
Radio astronomy studies the invisible Universe by detecting radio waves emitted by celestial objects. ATC develops instruments for the radio telescopes of NAOJ research facilities, including the Nobeyama Radio Observatory (NRO) in Nagano, Japan, and the Atacama Large Millimeter/submillimeter Array (ALMA), built in northern Chile, through an international collaboration among East Asia, North America, and Member States of the European Southern Observatory, with the support of the Republic of Chile. ATC also provides support for the development of radio astronomy instruments by universities and related institutes.

ALMA

ATC has developed and produced three types of ultra-sensitive superconducting receivers currently used in ALMA. After approximately 10 years of development and production, ATC completed the delivery of 219 receivers in February 2014. These receivers have been mounted on the antennas and have been used for observations by astronomers around the world. ATC provides maintenance and repair services for the ALMA receivers produced in Japan. In addition, ATC has continued to work to improve measuring systems to characterize the receiver performance.

In parallel with these activities, the "ALMA 2" project, also known as the Wideband Sensitivity Upgrade, is underway to enhance the capabilities of ALMA. With the goal of expanding simultaneous observing bandwidth to at least twice its current system, the next-generation Band 8 receiver and data transmission systems are being developed.





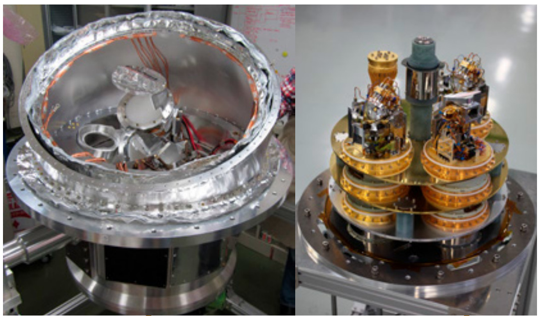
ALMA receivers developed at ATC
From Left to Right: Band 4 (125–163 GHz), Band 8 (385–500 GHz), and Band 10 (787–950 GHz)
Each of the 66 ALMA antennas can be equipped with receivers of ten different types.

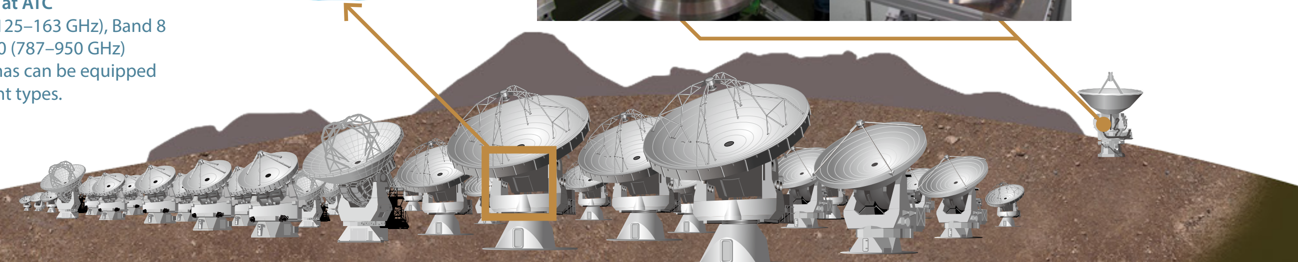
ASTE and 45-m Radio Telescope

The Atacama Submillimeter Telescope Experiment (ASTE) is a 10-m submillimeter telescope operated independently by NAOJ within the ALMA site. The largest millimeter-wave radio telescope in Japan is the 45-m telescope which has been operated at the NAOJ Nobeyama Radio Observatory for more than 40 years. ATC develops, improves, and provides maintenance and related support for the new cryostats and receivers of these telescopes in cooperation with domestic and overseas research institutes and universities.

(Left) Multicolor TES Bolometer Camera (under development)
This camera, using cryogenic superconducting devices cooled to almost absolute zero (−273 °C), will investigate numerous mysteries related to the birth of stars and galaxies.

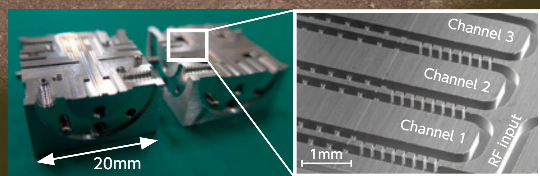
(Right) Interior of the cryostat for ASTE, which can be equipped with three cartridge-type receivers.
The cryostat used previously had one fixed-type port and one cartridge-type port. ATC developed the new cryostat to accommodate three cartridge-type receivers, enhancing the flexibility, and simplifying the installation and maintenance of receivers.



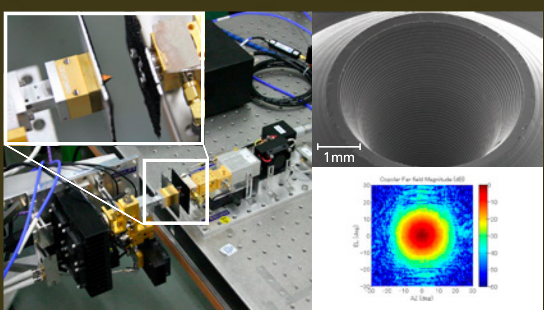


Development of New Technologies

ATC promotes the development of novel technologies and new receivers for observations at higher frequencies (>1 THz), over wider frequency ranges, and using multiple pixels. ATC aims to use the fruits of these developments in space and ground-based telescopes in Japan and overseas, including ALMA, ASTE, and the Nobeyama 45-m Radio Telescope.



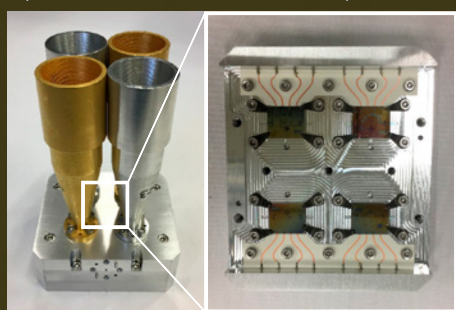
Waveguide filter circuit for wide instantaneous bandwidth observations



(Left) 1.25–1.5 THz band corrugated horn beam pattern measurement
(Top Right) Scanning electron microscope (SEM) image of the aperture of a THz corrugated horn
(Bottom Right) Beam pattern measurement result at 1.48 THz

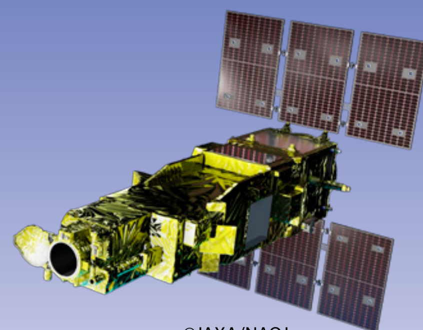
Microwave Kinetic Inductance Detectors (MKID)
When millimeter-wave photons break superconducting Cooper pairs, the kinetic inductance and resistance in the superconducting transmission lines change. Based on this effect, MKIDs can use superconducting microwave resonators to detect millimeter-wave radiation.

Multi-pixel MMIC-based superconductor-insulator-superconductor (SIS) receiver under development



Space-based Observations

From space, astronomical objects can be observed at any wavelength without being affected by the Earth's atmosphere. To conduct observations at the best locations possible, ATC combines mature technology for ground-based observations with space technology to develop observational instruments that can be mounted on sounding rockets, balloons, and satellites.



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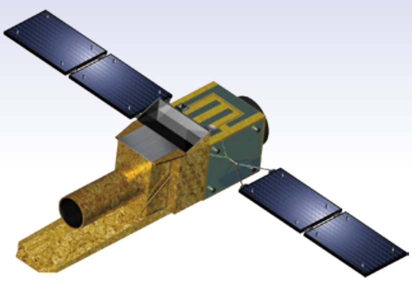
Solar-C (EUVST)

Solar-C（EUVST）is a next-generation solar-observing satellite planned for completion in the mid-2020s. With a high-resolution and high-sensitivity instrument, the EUVST will perform spectroscopic observations of the solar atmosphere seamlessly from the chromosphere at 10,000 degrees to the corona, which is heated to over several million degrees. We aim to elucidate the mechanisms of solar activity phenomena induced by the magnetic energy, through this advanced observation capturing the plasma and energy flow. The design study, assembly, and evaluation tests for the instrument are conducted using ATC's functions and facilities.



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JASMINE

JASMINE, the world's first infrared astrometry satellite, is targeting a launch in the early 2030s. It will measure stellar positions and motions with high precision of a few tens of micro-arcseconds in the central region of the Milky Way Galaxy, which is difficult to measure using visible light. Such measurements will reveal the evolution of the entire Milky Way Galaxy through exploration of the traces of the Galactic evolution hidden in the central region. JASMINE will also explore terrestrial planets in the habitable zone around stars smaller than the Sun.

CLASP

This program aims at direct measurement of magnetic fields in the chromosphere and transition region through observations of the polarization in the UV spectral lines emitted by the solar chromosphere and transition region (the thin layer between the chromosphere and corona) with high precision (<0.1%). Launched on NASA sounding rockets, CLASP (2015) and CLASP2 (2019, 2021) succeeded in the first spectro-polarimetric observations of the hydrogen Lyman-α line at 121.6 nm and of ionized magnesium at 280 nm, respectively, revealing the magnetic field in the chromosphere and the transition region. Integration and testing of these instruments were conducted at ATC.

(Image Credit: NAOJ, JAXA, and NASA/MSFC)

CLASP
High-precision Lyman-alpha spectropolarimeter

SUNRISE III

SUNRISE III is an international balloon project with a flight planned for 2022. The project observes the Sun from the stratosphere using a 1 m aperture optical telescope. Through high-resolution and high-precision near-infrared spectro-polarimetric observations, we will measure the three-dimensional structure of solar magnetic fields and investigate the transport and dissipation processes of magnetic energy in the solar atmosphere. In addition to opto-mechanical design and fabrication of the instrument to achieve high performance in the thermal-vacuum environment of the balloon flight, its performance was verified using the clean-room and thermal-vacuum test facilities at ATC.

SUNRISE balloon ready to fly
The SUNRISE balloon-borne telescope is launched from the ESRANGE in Kiruna, Sweden. The telescope continuously observes the Sun at an altitude higher than 35 km over the Atlantic Ocean, Greenland, and Canada.
©MPS

Testing the SUNRISE III near-infrared spectro-polarimeter
The high-precision opto-mechanical and polarimetric system were integrated and tested in the clean room.

Optical alignment in progress
Integration and testing of CLASP and CLASP2 were conducted in the large clean room.

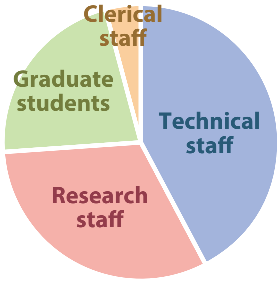
CLASP on the launch pad
Launched by a NASA sounding rocket in September 2015, CLASP conducted observations for only 5 minutes while it was flying outside the Earth's atmosphere.

Undergraduate and Graduate Student Education

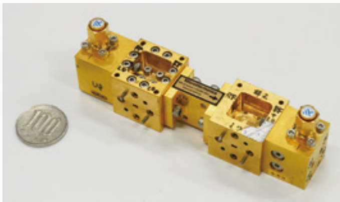
Through the Department of Astronomical Science, the Graduate University for Advanced Studies (SOKENDAI), ATC provides a graduate course, mainly aimed at obtaining a degree in astronomical instrumentation. Graduate students from other universities such as the University of Tokyo, Toho University, University of Tsukuba, and Osaka Prefecture University are also accepted to work on the development of astronomical instruments. They can take full advantage of opportunities to participate in state-of-the-art astronomical instrument programs, and to obtain know-how from researchers and engineers with broad experience in research and development. We also support undergraduates who are interested in the development of astronomical instruments through various opportunities such as summer student programs.

Members of ATC

Technical staff, research staff, administrative staff, and graduate students work in ATC. All research and development activities related to instrumentation, including concept creation, feasibility studies, design, fabrication, assembly, adjustment, and performance verification, are supported by many specialists with a variety of skills and expertise, as well as an administrative staff that manages the resources (budget, time, personnel, and facilities) necessary for daily work at ATC. We are seeking motivated persons for each of the above positions. If you are interested in joining ATC, please refer to the recruitment information posted from time to time on the NAOJ website.

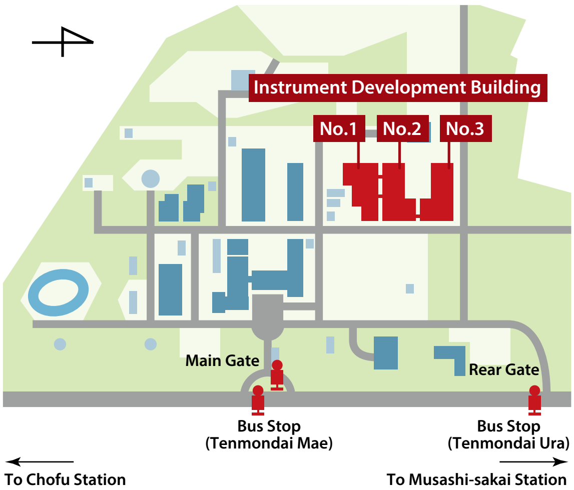


Industry Collaboration Initiatives



ATC works closely with the Industry Liaison Office to bring technologies originally developed for astronomical observation into wider use across society. Our projects include applying ultra-low-power microwave amplifiers—created for radio telescopes—to fault-tolerant quantum computers and adapting adaptive optics technology—developed to correct for atmospheric turbulence and achieve sharper images of astronomical objects—for use in optical instruments such as microscopes, as well as in advanced communication systems. To further accelerate these collaborative efforts, we have established the Social Implementation Program, strengthening our organizational framework to promote the practical deployment of our innovations. We also work with the Space Innovation Center to provide technical and engineering support for private-sector space development.

Access Map to ATC, Mitaka Campus, NAOJ



From the South Exit of Musashi-sakai station (JR Chuo Line)
Take Odakyu bus (91) at the No.3 bus stop and get off at "Tenmondai Mae" bus stop

From the North Exit of Chofu station (Keio Line)
Take Odakyu bus (91), (51) at the No.14 bus stop or Keio Bus (91) at the No.13 bus stop and get off at "Tenmondai Mae" bus stop

National Astronomical Observatory of Japan, National Institutes of Natural Science

Advanced Technology Center

2-21-1 Osawa, Mitaka, Tokyo, 181-8588 Japan
phone: +81-422-34-3865 fax: +81-422-34-3864
URL: http://atc.mtk.nao.ac.jp/en/index_e.html

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