ADVANCED TECHNOLOGY CENTER
National Astronomical Observatory of Japan
National Institutes of Natural Sciences
**Advanced Technology Center (ATC)**

**The Mission and the Strategy**

The Advanced Technology Center (ATC) is the research center for advanced instrumentation and technology development for both ground-based and space astronomy with wavelengths ranging from radio through ultra-violet. Needless to say, advances in astronomy are made possible only through state-of-the-art instrumentation. NAOJ's advanced projects require development of the most modern technologies that are not readily available elsewhere in the world. ATC designs, develops, manufactures, and tests critical components vital for advanced instrumentation as well as instrument systems. We are determined to overcome the limitation imposed by conventional technology with technical innovation and breakthrough.

Our advanced products in the past 20 years include the ALMA Bands 4, 8 and 10 receivers (on-going), the Hyper Suprime-Cam, a prime focus camera of the Subaru Telescope, the solar optical telescope and X-ray CCD camera aboard the ISAS/JAXA Hinode spacecraft, two solar instruments for the ISAS sub-orbital program, and the first-generation adaptive optics and focal plane instruments for Subaru. Basic development of key technologies is also critically important for our future. Our ongoing work includes development of a focal plane camera for radio astronomy with MKID technology, and a Lyman-alpha polarimeter for NAOJ-ISAS-NASA sounding rocket experiments.

ATC also provides a platform to meet the current and future technology needs in astronomy for scientists and engineers inside and outside NAOJ. ATC owns world-class equipment such as high-quality clean rooms for the ALMA SIS mixer and space-astronomy instruments, space chambers, optical methodology instruments, ion-beam sputtering machine for thin-film coating, and precision machinery.

ATC consists of approximately 50 staff scientists, engineers and technicians including contract-based personnel as well as graduate students working with a wide range of instrument developments. Staff scientists are encouraged to perform astrophysics research as well with the instruments that they develop.

We are committed to the successful development of the TMT (Thirty Meter Telescope) focal plane instruments, and to contributing the development of the KAGRA gravitational wave telescope led by the Institute of Cosmic Ray Research, the University of Tokyo as well as various basic development programs vital for future ground-based and space astronomy. NAOJ ATC is a unique world-class center of astronomy instrumentation in Japan. We are grateful for your support and feedback that enables us to better serve the world astronomy community.

Director  Saku Tsuneta
Brief History
ATC was founded in 1993 to provide the platform much needed for the development of the focal plane and first-generation adaptive optics instruments for the Subaru Telescope. This is followed by the successful development of the solar optical telescope aboard Hinode satellite (with Mitsubishi Electric Corporation). The need to restructure the ATC into a state-of-the-art research center had been recognized by people inside and outside ATC as well as senior NAOJ management personnel. A new ATC was inaugurated in 2005 with a declared mission statement to pursue advanced instrument development. A major decision associated with this restructuring is that the new ATC is joined by excellent staff scientists from the ALMA receiver development group. The reorganization is essentially driven by the needs to reform the ATC from a passive platform into an active organization for the most advanced instrumentation in response to rapid growth in astronomy.

Priority Projects

We have prioritized the projects in terms of ATC resources. The Hyper Suprime-Cam, the prime-focus camera of the Subaru Telescope, and the ALMA bands 4, 8 and 10 receivers have been the ATC priority projects. With the successful completion of the Hyper Suprime-cam, we have chosen the TMT project and the KAGRA gravitational wave detection project as the next priority project (with ALMA receivers).

ATC has been responsible for the ultra-low noise large scale analog/digital circuitry and the structure of the large detector sub-system for the Hyper Suprime-Cam, and has supported the development of the large-format deep-depletion CCDs.

ALMA SIS receivers from millimeter-wave to terahertz have been designed and developed at ATC, and 73 receiver systems will eventually be deployed at the ALMA site in South America. The most important component of the ALMA receivers is the superconducting mixers, which have been fabricated in the ATC SIS clean room/Micro-fabrication unit. Other critical components such as cryogenic optics have also been fabricated by the mechanical engineering shop in ATC.

Development of the TMT focal plane package is on the horizon, and ATC is committed to being involved in the development of IRIS with our international partners and domestic universities.

Vision for the Future

Our vision for the next 20 years entails strategic planning for future ground-based and space astronomy. For example, the ATC radio astronomy group has been developing a superconducting radio camera with MKID technology. The device is fabricated in the SIS clean room facility/micro-fabrication unit. The detector with 10 k pixels is expected to revolutionize millimeter-wave and far infrared astronomy.

Shared Use of Facilities

ATC has various shops and units including a mechanical engineering shop, optical shop, detector laboratory, special coating unit, space chamber shop, and a facility support unit for clean rooms (see the organization chart). These shops and units possess expertise, dedicated personnel and facilities. These facilities include a superconducting device fabrication facility, a large 3-D coordinate measurement machine, precision machines, large and high-quality clean rooms, various optical equipment, and ion-beam sputtering (IBS) coating machine among others. These shops and units are widely used by researchers and engineers associated with universities and research institutes.
The Atacama Large Millimeter/submillimeter Array (ALMA), an international partnership of Europe, North America and East Asia in cooperation with the Republic of Chile, is the largest astronomical project in existence. ALMA will be a single telescope of revolutionary design, composed initially of 66 high precision antennas located on the Chajnantor plateau, 5000 meters altitude in northern Chile. A weak signal from distant galaxies is mixed with the reference signal by low-noise superconducting (SIS) mixers at 4 K (-269°C) and its microwave output is amplified for further processing. These receivers detect two orthogonal polarizations to reveal magnetic field structure in the universe with the state-of-the-art performance.

*AThese receiver bands will not be available at the beginning of full operation in 2013.

### ALMA Frequency bands

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency [GHz]</th>
<th>Sideband</th>
<th>Institute</th>
<th>Country</th>
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<td>787</td>
<td>950</td>
<td>SSB</td>
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</tr>
</tbody>
</table>

**Millimeter wave:**

- **Band 4**
- **Band 8**
- **Band 10**

**SIS mixers from millimeter-wave to terahertz-wave**

The heart of the receiver is made of a superconducting device used to convert the received submillimeter waves to low-frequency microwaves (4 – 12 GHz). The SIS (superconductor-insulator-superconductor) mixer is required to have low noise and a wide band. The SIS mixers for ALMA bands 4, 8 and 10 are developed and fabricated in a clean room at ATC by the SIS group.
The SIS devices are fabricated on a quartz wafer in the ultra clean environment shown on the left and diced into chips to be mounted in a mixer block as shown by photographs in the center. The magnified cross-section of a SIS junction and its electronic characteristics with an extremely sharp nonlinearity are presented on the right.

ATC has designed and developed ALMA cartridge-type receivers from millimeter-wave to Terahertz and produces $73 \times 3 = 219$ receivers in house. The performance of these receivers is the best currently available worldwide. The height of these receivers is around 50 cm and the diameter is around 17 cm.

**SIS device production and micro-fabrication unit**

The SIS devices are fabricated on a quartz wafer in the ultra clean environment shown on the left and diced into chips to be mounted in a mixer block as shown by photographs in the center. The magnified cross-section of a SIS junction and its electronic characteristics with an extremely sharp nonlinearity are presented on the right.

Top: Clean-room facility for SIS device production at ATC
Left: Sub-micron mesa pattern fabricated photolithographically

Top: SIS device chip
Bottom: Quartz wafer (38 mm dia.) on which the SIS devices are fabricated

Top: SEM image of a SIS device
Middle: Magnified view of cross section of a SIS junction
Bottom: dc I-V curve of the SIS device
Hyper Suprime-Cam (HSC) is an 870 Mega pixel prime focus camera for the 8.2 m Subaru Telescope. The wide field corrector delivers sharp images of 0.25 arcsecond FWHM in r-band over the entire 1.5 degree (in diameter) field of view. The collimation of the camera with respect to the optical axis of the primary mirror is realized by hexapod actuators whose mechanical accuracy is a few μm. As a result, we expect to have seeing-limited images most of the time. Expected median seeing is 0.67 arcsecond FWHM in i-band. The sensor is a p-channel fully depleted CCD of 200 μm thickness (2048 x 4096 15 μm square pixel) and we employ 116 of them to pave the 50 cm focal plane. Minimum interval between exposures is roughly 30 seconds including reading out arrays, transferring data to the control computer and saving them to the hard drive. HSC uniquely features the combination of a large primary mirror, wide field of view, sharp image and high sensitivity, especially in red. This enables accurate shape measurement of faint galaxies which is critical for planned weak lensing surveys to probe the nature of dark energy. The system is being assembled now and will see the first light in August 2012.

Filter Exchanger

The Filter Exchange Unit (FEU) stores 6 filters in total, transfers and positions one of them in the optical path. FEU consists of two parts; the alignment mechanism of the filter in the optical path and a jukebox of the filters. The alignment mechanism can guarantee 10μm position stability with respect to the focal plane CCDs. On the exchange sequence, a motorized cart grabs and pushes the filter from the jukebox. Each jukebox has 3 slots and we have two identical jukeboxes. The operation is fully automated and the entire exchange sequence takes 14 minutes. FEU has been developed by international collaboration between Taiwan and Japan.
The focal plane of the HSC camera is covered with CCDs of 2k x 4k pixels of 15 μm pixel. The CCDs are fully depleted back-illuminated. The CCD has been developed by the Hamamatsu Photonics K.K. and the ATC. It has quantum efficiency (QE) of as high as 40% at wide wavelength ranging from visible to infrared. The QE of the newly developed CCD at 1μm is 4 times as high as the ordinary CCDs and is the highest in the world as of 2012.

The CCD dewar is the key component of HSC. The role of the CCD dewar is to maintain the CCDs tiled on the ~600mm cold plate aligned to the focus of the wide-field corrector with an accuracy of ~10μm against any changes of attitude of the telescope while keeping the CCDs cooled down to -100°C. The positional accuracy is attained by the careful mechanical design and the high precision mechanical fabrication which were carried out at ATC. The CCDs are cooled by two pulse tube coolers with the cooling power of 100W in total at -100°C.

The shutter determines the photometric accuracy of the data. We developed the two screen focal plane shutter with 1,030 mm diameter envelope and 60 mm thickness while having 600 mm aperture. The shutter consists of two independent drive units which drive ball screws and rollers to extend and wind the screens alternately. We achieved 0.01 sec p-p exposure accuracy and 1% p-p exposure uniformity at 1 sec exposure time.

 Backend electronics (BEE) and Frontend Electronics (FEE) perform science CCD readout. HSC has 116 CCDs with 464 signal outputs in total. FEE controls them, and reads the data precisely with ~5 electrons readout noise. BEE acquires image data with a data size of ~2 GB per image. BEE is capable of processing this in 10 sec continuously. The electronics system in the pictures was all designed in ATC in collaboration with the University of Tokyo and the High Energy Accelerator Research Organization (KEK) based on our previous experience of the developments for Subaru Telescope instruments.
The TMT (Thirty Meter Telescope) project is a plan to build an extremely large telescope with a primary mirror 30 meters in aperture size. The project is a collaborative effort between Japan and other countries and institutions including University of California, Caltech, Association of Canadian Universities for Research in Astronomy, China, and India.

Power of TMT

In comparison to the 8 meter class telescopes, TMT will perform with approximately 4 times the spatial resolution and 200 times the sensitivity when adaptive optics is in use.

The TMT Construction Site: Mauna Kea, Hawaii

The summit of Mauna Kea on the island of Hawaii is the home to large telescopes from around the world. TMT is scheduled for construction right next to the Subaru Telescope. Detailed TMT observation of faint and distant galaxies discovered by the Subaru Telescope and its wide-field observation capability is a powerful synergy anticipated between TMT and Subaru Telescope.

The optics of TMT consists of 492 hexagonal mirror segments 1.44m in size that comprise the primary mirror, the 3.1m secondary mirror, and the 2.5x3.5m tertiary mirror. Light is guided to the instruments located on the two Nasmyth floors.
InfraRed Imaging Spectrograph (IRIS)
is one of the three first light instruments that will be available when TMT construction is completed. IRIS is an infrared imager with an integral field unit that snaps diffraction-limited images and spectra in the wavelength range of 0.84 to 2.4 10µm. IRIS combined with TMT will enable it to attain 4 times the resolution and 200 times the sensitivity of the Subaru Telescope, revealing a whole new universe with unprecedented precision.

IRIS development at ATC

The development of IRIS will be a collaborative effort of the United States, Japan, and Canada. The Advanced Technology Center will play a central role in the design, construction, and performance evaluation of the IRIS imaging system. The imaging system of IRIS is 2.3 meters in length and the interior of its entire vacuum enclosure is cooled to the temperature of liquid nitrogen. To guarantee the longevity of its performance, the system must be built to be maintenance free for at least 10 years. As stable operation of such a large cooled optics system is a challenging issue, the design and development of prototypes is currently underway utilizing the experience acquired in the developments of HSC and the focal plane instruments aboard the Subaru Telescope in the Advanced Technology Center.

Future Technology for TMT MOBIE/WFOS

IFU of FOCAS on Subaru Telescope

IFU Development at ATC

An integral field unit (IFU) is a powerful tool in studying extended objects such as galaxies as it allows us to obtain three dimensional data (2 spatial and 1 wavelength dimensions) simultaneously. IFU for the existing optical spectrograph, FOCAS, on the Subaru Telescope is being developed at ATC as a prototype aiming at future installation in the optical spectrograph, MOBIE/WFOS, on TMT.
Gravitational-wave astronomy will open a new window to the Universe.

In the beginning of the 20th century, A. Einstein proposed a new paradigm, today known as the general theory of relativity. According to his theory, gravitation is a consequence of a warp of spacetime. He also predicted that moving matter disturb the spacetime around it, and generates tiny ripples of spacetime, called gravitational waves.

Gravitational waves are so tiny that we cannot usually recognize them. If we can use gravitational waves as an astronomical tool, the heart of violent astrophysical phenomena including supernovae, births of black holes, or coalescence of binaries, into which electromagnetic observations cannot reach, will be observable. That will bring us a new insight into the nature of the Universe.

Gravitational-wave astronomy will open a new window to the Universe.
Developing various optics for KAGRA

ATC is in charge of developing various optical components for KAGRA. Designing high quality optical baffles with a vibration isolation system is one of the main responsibilities of ATC. The laser power builds up over 200 kW in the KAGRA arm cavities, and even a fraction of scattered photons from them obscures the signal photons by gravitational waves. In order to scrape such unwanted photons, the baffles are indispensable. Moreover, the baffles installed near input test masses and end test masses will be cooled along with them, and thus the baffles should be capable of enduring such a temperature change. Another of ATC’s responsibilities is to design an optical system for monitoring transmission laser beam though the end test mass. This monitor optics is a precise reference of each 3-km long optical path even during the observation mode, and thus it is indispensable for KAGRA to maintain the best quality sensitivity for observation periods as long as a year or more.

Research and Development for the advanced detectors

Resonant Sideband Extraction prototype interferometer

Resonant Sideband Extraction prototype interferometer is a room-size prototype system for KAGRA. It demonstrates the signal extraction scheme and the controllability of all the main mirrors’ degrees of freedom. The signal extraction and control scheme developed here will be adopted in KAGRA.

Quantum non-demolition measurements

Laser power in KAGRA’s arm cavity will reach over 100 kW. In this situation, the radiation pressures of such high power photons to the mirrors impact the sensitivity of KAGRA at the lower frequency. We investigate how to recover the sensitivity by the ponderomotive squeezing (a quantum optical technique) with this tabletop experiment, where we use a tiny, lightweight (20 mg) mirror for each arm cavity instead of using the high power laser.

Synchronous recycling Interferometer

KAGRA has little sensitivity to the gravitational waves at very high frequencies. The synchronous recycling interferometer can enhance the sensitivity at a designed frequency. We prepare two units of this 75-cm baseline interferometer (suitable for 100 MHz gravitational waves), and experimentally improve the upper limit on the amount of the stochastic background of gravitational waves at around 100 MHz.
Superconducting array detectors are a promising technology for radio astronomy. Existing radio receivers such as ALMA were a single pixel device. Development of CCD (charge coupled device) image sensors has revolutionized optical and infrared astronomy. Likewise, a CCD-like millimeter camera is required for future radio astronomy. Indeed, intensity peaks are located from the millimeter-wave to far-infrared (terahertz) region for thermal emission of the low temperature dust in the galaxies, redshifted dust radiation of distance galaxies and the 2.7 K blackbody radiation from cosmic microwave background. Wide-field observations of these objects are needless to say extremely important. This kind of millimeter to terahertz camera is essential not only for photometry but for spectroscopy with Fourier spectrometer or superconducting filter bank circuits. The microwave kinetic inductance detector (MKID) is an attractive detector technology. The surface impedance of a superconductor changes as incoming photons breaks Cooper pairs. This change is sensed by superconducting microwave resonators, which are capable of frequency domain multiplexing.

A millimeter-wave camera has been developed to detect B-mode polarization of Cosmic Microwave Background (CMB) in collaboration with KEK, RIKEN, and Saitama University. LiteBIRD led by KEK is a satellite for future studies of B-mode polarization and inflation from CMB. A terahertz camera has been developed for the Antarctica terahertz telescope planned by University of Tsukuba, which enables us to observe distant cluster of galaxies and high-z galaxies.
Advanced technology development

Space optics

ATC has been developing instruments for various space missions (spacecraft and sub-orbital missions) in collaboration with the project offices inside NAOJ and ISAS/JAXA. Our uniqueness is the synergic approach from ground-based instrumentation to space instrumentation. We would like to employ state-of-the-art technologies developed for the ground-based astronomy in space. Only when the technology matures in the ground-based applications, it will be ready for space by combining it with the existing space technology. Our past missions include the optical telescope assembly of the solar optical telescope aboard Hinode (SOLAR-B) in collaboration with Mitsubishi Electric Corporation, X-ray CCD camera of the X-ray telescope aboard Hinode, and one sounding rocket and two balloon-borne instruments. Currently, a sounding rocket mission to detect chromospheric magnetic fields of the Sun (CLASP) is being developed in collaboration with NASA and other organizations. Other missions such as LiteBIRD, SOLAR-C, and WISH are on the horizon.

1 CLASP : Chromospheric Lyman-Alpha Spectro-Polarimeter for observing the magnetic field in the solar chromosphere
2 LiteBIRD : Lite (light) satellite for the studies of B-mode polarization and inflation from cosmic background Radiation Detection led by KEK (high energy accelerator research organization)
3 SOLAR-C : Space high-resolution solar observatory
4 WISH : Wide-field Imaging Surveyor for High-Redshift

Component test and calibration

Engineering-model and flight-model components are assembled here and are tested and calibrated under on-orbit conditions in ATC facilities.

Top) Development of *VUV polarizer and VUV half wave plate
Bottom) Development of VUV grating
*VUV: Vacuum Ultra-Violet

Protomodel 30cm dia.
VUV primary mirror with its kinematic mounting for the CLASP sounding rocket mission

Mechanical endurance test for WISH filter exchanger at 100K in vacuum conditions

WISH filter exchanger
Shops and units (see below and page 2) have been established from the spin-off of research projects and have evolved with an accumulation of resources, knowledge, and personnel. ATC makes these workshops and units, measuring instruments and laboratory space available for researchers in universities and research institutes as a function of the inter-university institute. Announcements of opportunities for this program are issued twice (February and August) a year. The ATC steering committee consisting of chiefs of projects and shops selects about 50 proposals a year.

**Mechanical engineering (ME) shop**

Various mechanical components are designed and fabricated by skilled machinists with a machining center, a NC milling machine, a NC lathe, a wire electric-discharge machine. The ME shop also performs precision measurements of their products. This shop has much expertise in cryogenic and vacuum technology.

**Optical shop**

Makes available various measurement machines such as interferometric measurement systems, digital magnifiers, roughness measurement instrument, surface profiler, 3-D coordinate machines.

**Space chamber shop**

Owns large and small vacuum chambers some of which are equipped with LN$_2$ shrouds for various space environment tests. These are transferred from Hinode (Solar-B) satellite project.

**Facility support unit**

Maintains the ATC facility and laboratory including various clean rooms.

**Thin film coating unit (Ion Beam Sputtering machine)**

Designs and fabricates various thin film coating. Its products include flight IR-rejection filter for Hinode satellite, ultra-long focal-length mirror and high reflective mirror (99.97% at 1064nm) for gravitational wave detector.

**Optical / Infrared detector unit**

Develops optical CCD and IR detectors with associated low noise electrical systems. The latest achievement is a fully depleted back-illuminated CCD (2k x 4k) with high quantum efficiency near 1µm used for the Hyper Suprime-Cam of the Subaru Telescope.
Education in ATC

ATC provides an ideal environment for students who desire to acquire the experimental expertise and management skills for state-of-the-art instrumentation. Our approach is physics-based, and our uniqueness includes the synergy of radio vs optical/infrared astronomy and ground-based vs space astronomy. Students are directly involved in the most advanced instrument development for PhD theses, and are guided by science and technical staff who have recognized accomplishments in the advanced instrumentation. In addition to the students registered at ATC, students visiting for specific purposes are also welcome.

Graduate students

We have graduate students from various universities, which include the Department of Astronomical Sciences, Sokendai (The Graduate University for Advanced Studies), Department of Astronomy, University of Tokyo, Graduate School of Science, Toho University, Graduate School of Pure and Applied Sciences, University of Tsukuba, and School of Science, Osaka Prefecture University. Interested students belonging to Japanese and overseas universities are encouraged to contact ATC faculty members.

Recent PhD thesis

• Millimeter camera development (Univ. of Tokyo, 2012)
• Millimeter-wave noise source (Univ. of Tokyo, 2012)
• Balanced SIS mixers (Univ. of Tokyo, 2010)
• A low noise terahertz SIS mixer (Osaka Pref. Univ. 2010)
• Tunnel barrier of SIS mixers (Univ. of Tokyo, 2009)
• Submillimeter-wave Sideband separation mixers (Univ. of Tokyo, 2009)

Young/post-doc researchers

NAOJ has a postdoctoral fellow system, and yearly announcements of opportunities are issued usually in autumn-winter. ATC usually has a few postdoctoral fellows for instrument development.

Engineer and technical staff

One of the key elements in ATC’s success is the high quality and strong motivation of the engineering and technical staff including contract-based personnel. ATC provides technical staff with an environment full of stimulation and opportunities for on-the-job-training.
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URL: http://atc.mtk.nao.ac.jp/

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.11 bus stop
or Keio Bus (91) at the No.12 bus stop
and get off at “Tenmondai Mae” bus stop